

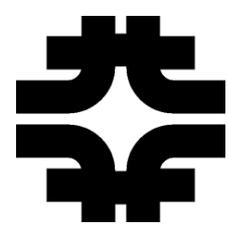
20 Years of Top: The Discovery Story

(one-person's account...)

Boaz Klima
Fermilab



HCPSS2015
July 3, 2015



This Talk



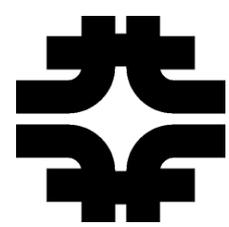
Alison described to you in great detail the latest and greatest in Top Quark Physics these days – I will not repeat it.

Instead, I'll take you 20+ years back in memory lane and tell you what happened during the Top Quark Discovery era (in $DØ$)
– stories, anecdotes, lessons, ...

Rather than being a formal historic account of official results, it'll hopefully be more interesting (educational? pedagogical?)

I'll obviously concentrate on what happened in my own collaboration; similar stories available from members of CDF

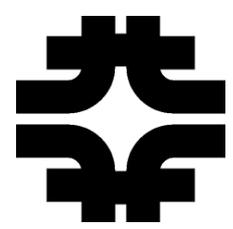
Disclaimer: my recollection, my biases, my material



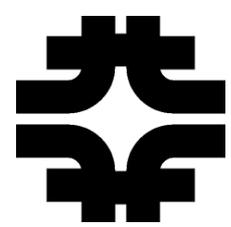
Outline



- Prologue
 - Intro – Top mass predictions & limits (<1992)
 - Run 1a @Tevatron (1992-1993) – limits, event 417, evidence
- The Road to Discovery
 - Top group re-organization and meetings, objectivity
 - Status as of summer 1994
- Discovery of the Top Quark
 - Strategy, first sighting, optimization
 - Marathon
 - Discovery – papers, meeting, announcement
- Epilogue
 - Media
 - Conferences
 - Top Turns Ten



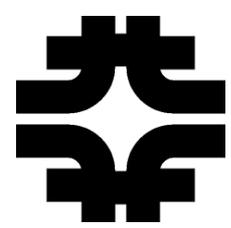
Prologue



Top Mass – Predictions & Limits



- 1977 - since $M_b \approx 3M_c \approx 9M_s$, it seemed 'natural' to guess that the new Top quark would have $M_t \approx 3M_b \approx 14 \text{ GeV}$
- Variety of theoretical models & predictions followed, e.g. $M_t \approx 27 \text{ GeV}$
- 1984 - PETRA e+e- collider @DESY, Germany, ruled out top quark with $M_t < 23.3 \text{ GeV}$
- 1984 - UA1 @ISR, CERN reported evidence for an excess of events at low $M_T(\text{ev})$ when jets were present, in agreement with 40 GeV Top (Arnison et al., PL B147 (1984) 493). In retrospect, the W+jets background was underestimated.
- 1988 - new e+e- collider, Tristan @KEK, Japan, with energy up to ~60 GeV, was built to find it - no discovery; $M_t > 30.2 \text{ GeV}$
- 1990 – LEP experiments excluded $M_t < 45.8 \text{ GeV}$
- 1990 – UA2 @ISR set a limit on $W \rightarrow tb$ at $M_t > 69 \text{ GeV}$, effectively closing the search channel $W \rightarrow \text{Top}$ (what if their masses are similar?)
- 1992 – CDF @Tevatron using Run 0 data excluded $M_t < 91 \text{ GeV}$
- All along theoretical predictions increasing steadily with new limits...



Top Quark Basics

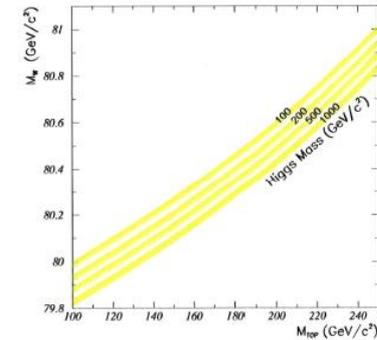


- In 1991 the world looked like this and the intro to every top search talk looked like that →

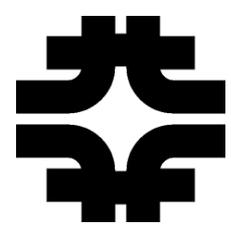
THE THREE FAMILIES OF FUNDAMENTAL PARTICLES				
		MASS IN BILLIONS OF ELECTRON VOLTS (GeV)		
		ELECTRON FAMILY	MUON FAMILY	TAU FAMILY
QUARKS	2/3	UP ABOUT 0.01 GeV	CHARM ABOUT 1.5 GeV	TOP AT LEAST 89 GeV, NOT YET OBSERVED
	← RELATIVE CHANGE IN MASS →			
	-1/3	DOWN ABOUT 0.01 GeV	STRANGE ABOUT 0.15 GeV	BOTTOM ABOUT 5.5 GeV
← RELATIVE CHANGE IN MASS →				
LEPTONS	0	ELECTRON NEUTRINO $< 2 \times 10^{-8}$ GeV	MUON NEUTRINO $< 2 \times 10^{-4}$ GeV	TAU NEUTRINO < 0.035 GeV
	← MASS UNKNOWN →			
	-1	ELECTRON 5.11×10^{-4} GeV	MUON 0.106 GeV	TAU 1.78 GeV
← RELATIVE CHANGE IN MASS →				

Top Quark Overview

- We believe the top quark exists: the b quark is a member of an isodoublet (cf LEP/SLC measurements of A_{FB} , Γ_{bb} , etc.)
- Why is Top Quark interesting?
 - * Test of Standard Model
 - * Top, W, Higgs masses are related
 - * Nonstandard Decays; New Physics (?)



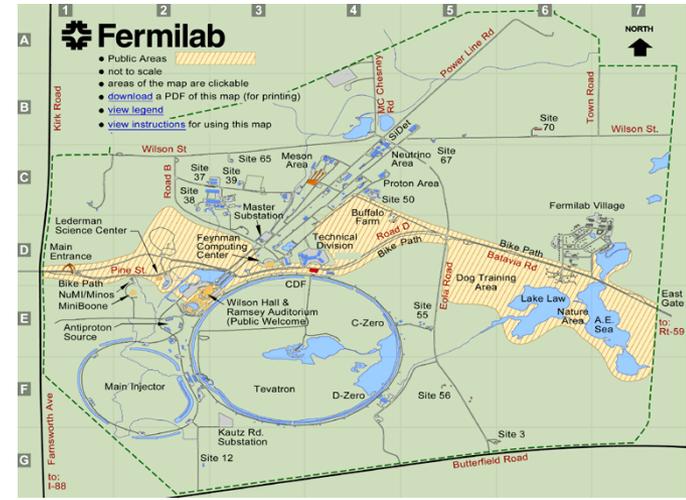
The dawn of PPT in HEP...



Tevatron Run 1a (1992/3)

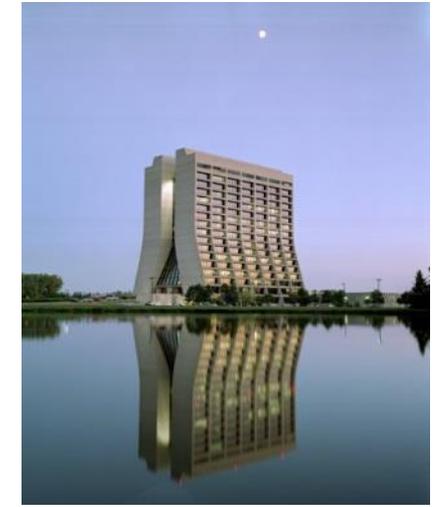


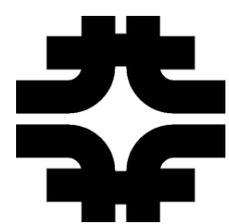
- The Tevatron $p\bar{p}$ accelerator worked well compared to its performance during Run 0 – significantly higher luminosity
- The $D\bar{0}$ experiment recorded its very first antiproton-proton interaction on May 12, 1992 (“Run 1”)



The $D\bar{0}$ Collaboration

 U. of Arizona U. of California, Berkeley U. of California, Davis U. of California, Irvine U. of California, Riverside Cal State U., Fresno Lawrence Berkeley Nat. Lab. Florida State U. U. of Hawaii Fermilab U. of Illinois, Chicago Northern Illinois U. Northwestern U. Indiana U. U. of Notre Dame Purdue U. Iowa State U. U. of Kansas Kansas State U. Louisiana Tech U. U. of Maryland Boston U. Northeastern U. U. of Michigan Michigan State U. U. of Nebraska Columbia U. New York U. U. of Rochester SUNY, Stony Brook Brookhaven Nat. Lab. Langston U. U. of Oklahoma U. of Pennsylvania Bowling Green U. U. of Texas, Arlington Texas A&M U. Rice U. U. of Washington	 U. de Buenos Aires	 LAFEX, CBPF, Rio de Janeiro State U. do Rio de Janeiro State U. Paulista, São Paulo	 IHEP, Beijing	 U. of Los Andes, Bogotá
 Academy of Sciences Charles U., Prague Czech Tech. U., Prague	 U. San Francisco de Quito	 IN2P3, CNRS CPM, IN2P3, Marseille LAL, IN2P3, Orsay LRIHE, IN2P3, Paris DAPNIA/SPP-CEA, Saclay	 Punjab U., Chandigarh Delhi U., Delhi Tata Institute, Mumbai	
 Seoul National U., Seoul Kyungsung U., Pusan Korea U., Seoul	 CINVESTAV, Mexico City	 FOM-NIKHEF, Amsterdam U. of Amsterdam/NIKHEF U. of Nijmegen/NIKHEF	 INP, Krakow	
 JINR, Dubna ITEP, Moscow Moscow State U. IHEP, Protvino PNPI, St Petersburg	 U. of Lund RIT, Stockholm U. of Stockholm U. of Uppsala	 Lancaster U. Imperial College, London U. of Manchester		

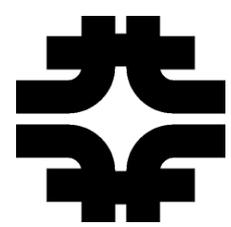




DØ Event 417 - Intro



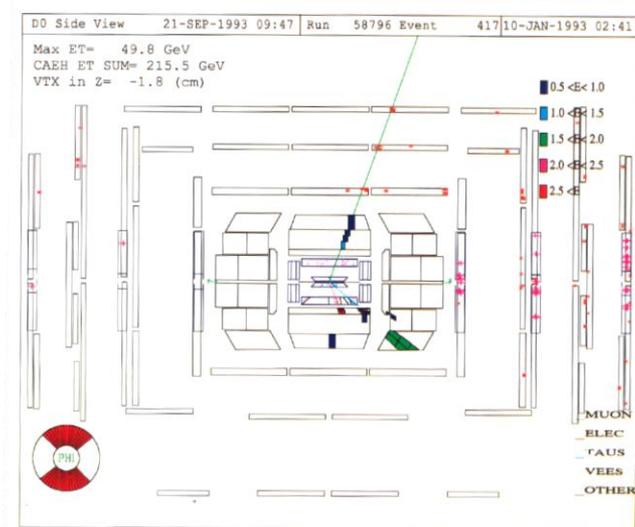
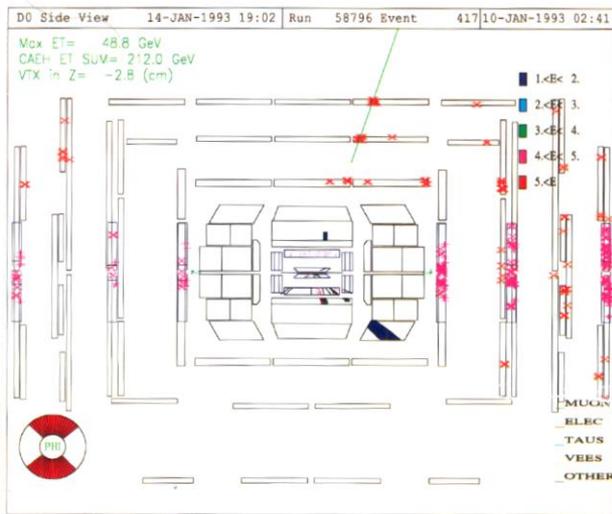
- In DØ we reconstructed ~10% of the data, high priority triggers and “garbage collectors” (for debugging), via the Express Line; it took some time to RECO the bulk of the data
- Top analyzers routinely went through the Express Line data to look for candidate events
- On Jan. 10, 1993 at 2:41am event 417 in Run 58796 was taken – it was rejected by the main e- μ analysis team (did not pass their selection cuts – low $P_{\tau \mu}$; no track in CDC)
- I conducted my own search (“sanity check”) with looser cuts since I did not believe that at that early stage we understood our data and reconstruction well enough
- I consistently checked event displays for “my” candidates to verify the quality of the data and the reconstruction reliability



DØ Event 417 - Details



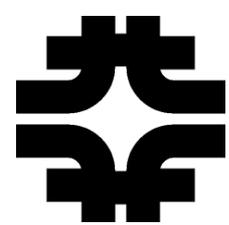
- The then-current (Jan. 10, 1993) reconstruction determined $P_T^\mu = 8 \text{ GeV}$
- I could see a much higher momentum Muon from the event display and a clear matching track in CDC – visual inspection early in the run is crucial!



- Long Short – the Reco program was fixed (muon & tracking) – everybody wins (higher efficiency, less misses, more attention to special cases, ...)
- When asked in a DØ-wide meeting on Jan. 15, 1993, I commented that the most conservative interpretation of this event within the Standard Model was -

$$tt \rightarrow e + \mu + 2 \text{ Jets} + \cancel{E}_T$$

$$(p_T^\mu \sim 195 \text{ GeV}; E_T^e \sim 99 \text{ GeV}, \cancel{E}_T \sim 102 \text{ GeV}; E_T^{\text{jets}} \sim 25, 22 \text{ GeV})$$



DØ Event 417 – Impact



- It created a huge buzz in the collaboration...
 - “The “excitement” generated by this event was so high, that until Oct – Nov 1993, it subsumed almost every meeting and every person “associated” with the top group.” (TTT)
- Many people spent long hours verifying all aspects of it (hardware, alarms, software, triggers, ...), assessing the interpretation of this event (signal vs background), and finally measuring the Top quark mass (one event; 2 ν 's!!).
- Few typical comments from very senior colleagues
 - “The e/μ event is fantastic. It would be a shame to sit on it endlessly. We should send it in to PRL as a prime candidate (for Top). Draft a letter this week and send it in by Friday (Jan. 22, 1993).”
 - “We should publish this. It is obviously a gold-plated top candidate like there has not been at FNAL before. I wish the QCD group had something like this !!!!”
 - “Congratulations on your event. It has occupied many of my thoughts.”
- DØ chose the conservative way and published a new lower limit on the Top Quark mass (131 GeV) with this event flagged as a special clean Top candidate. The Top quark mass determined via this one (di-lepton; 2 ν 's) event was calculated to be in the range of 145 – 200 GeV.

DØ Event 417 – Later On

Sharon Hagopian
– Top Turns Ten

The Bubble Chamber: Era of the Young Particle-Physics Entrepreneur

T. Ferbel*
*Dept. of Physics
University of Rochester
Rochester, NY 14627 USA

Stan Wojcicki described for us today the levels of senility that we attain in our scientific careers, the penultimate being when you are asked to give an after dinner speech at a conference. Well, I got into this position when I recommended to Derek Colley that he ask some boisterous fellow to talk about the entrepreneurial aspects of the Bubble Chamber Era. Derek thought this a great idea, and, with Don Perkins far too busy at the United Nations, wondered whether I would like to comment on this phenomenon. He also advised me to tread lightly, because some time ago when the late Sir John Adams referred admiringly to Carlo Rubia's entrepreneurship, he subsequently had to apologise for that remark because it did not translate well into Italian.

In the business world, in order to produce something, someone has to decide what is marketable. Someone must take the initiative to plan, to bring together ideas, personnel and machines, assign jobs, and organise and direct operations. The individuals who perform such functions are termed entrepreneurs. They take risks by judging prospects, and stand responsible for the outcome of that judgment. Entrepreneurship therefore involves intuition and shrewdness, as much as raw brain power.

Skillful, energetic and imaginative entrepreneurs are recognized as the most valuable of all productive resources of the economy. Without them, all sorts of possibilities would not be realized. Economists claim that the easier it is to set up and operate an enterprise, the more effectively and rapidly can entrepreneurs mobilize resources for production. Of course, not every new idea turns out to be a good idea. Sometimes, expensive equipment is assembled that does not lead to

*supported by US D.O.E. grant DE-FG02-91ER40065

greater production later, etc. If and puts value on the financial investment society - protomistakes.

So, you can't be between physics. We, for our errors have become recall one of mottos that "which was run days of our streets. There's everything, pi ger biases (ce and so, if you find some

Looking back, especially in the U and out-of-the actively young as much to and dynamics

and more est not require interesting point, l a problem and

Even within the times independent. In fact, that counter/spark reflected more rather than the

overly-protective mechanisms of large collaborations. Sure we made some mistakes, but that's also what we learned to think independently.

In contrast, I have a modern story about a paper on the D-Zero top event. An extraordinary μ -e event was found by Boaz Klima last winter, and I, for one, was immediately convinced that it was top. I did not need studies of backgrounds, detector response, or of other factual matters, it was so open and shut case for me as I was concerned. A clean event like that could not be anything but top. Now, we would, of course, have to do some calculations to convince the rest of D-Zero and the physics community of the veracity of the result, but I was already certain, and would not be swayed by naysayers. In my mind, the event looked more convincing than, for example, Gerson Goldhaber's discovery of the $\bar{\nu}_\tau$ in K^0 interactions, and far more likely than the first Ω^- found by Nick Samios et al. I was, of course, younger and more belligerent in those days, and less of a believer, and that might account for the difference in my current response. Well, last March, Klima wrote a relatively conservative first draft of a paper on that beautiful event, but, as you know, it has not yet hit the streets. So, what happened to the paper? Was it just scientific conservatism that got it stalled? Certainly some of the delay can be attributed to that. However, I believe that another reason that the top candidate event has not as yet been published has to do with the change that our field has gone through. We have become far more political. Some of our colleagues imagine that the discovery of top may have implications on the funding of Fermilab's Main Injector or even possibly on the very existence of Fermilab. The reporting of a scientific result is no longer a matter of concern for just the individuals doing the science, but it has become a group and a political statement. After more than a half year of study, I still don't know what is holding up the publication of that lovely event. All I know is that Nick would never have allowed such delay!

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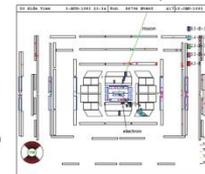
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DØ Event 417 The Gold Plated Top Event*



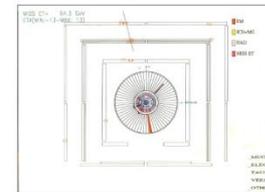
Finding a "Golden" Event

In 1993, while scanning the express stream, Boaz Klima found event 417, which had an very high E_e electron, a high p_T muon, 3 jets and large missing E_T , making it an outstanding candidate for a top event, since expected backgrounds are small.



Event has Spurious A Layer Hits

Event 417 failed the original top selection because spurious muon A-layer hits gave the muon track very low momentum. This can be seen in the end view (below). Other aspects of this event were checked by many experts to see that all other systems worked properly.



Muon Track Hits

Dave Hedlin blew up the view of the muon hits to about 10 feet. He measured the track with meter sticks on his basement floor at home. He also rectified the alignment. He calculated the momentum with and without the A layer hits. The fit with the layer needed large multiple scatters in the calorimeter and magnet iron and had low probability.



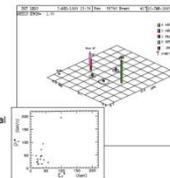
Muon

Daria Zieminska and Dave Hedlin exchanged ~30 e-mail messages on the fits for this track to determine the muon momentum more precisely. Using fits by hand and prototype computer code they determined the muon momentum to be greater than 100 GeV/c.



Kinematic Parameters of Event 417

$E_e^j = 98.8 \pm 1.6$ GeV
 $p_T^j = 195$ GeV/c
(≈ 40 GeV/c at 95% CL)
 $E_e^j = 24.9 \pm 4.3$ GeV
 $E_e^j = 22.3 \pm 5.5$ GeV
 $E_e^j = 6.7 \pm 3.5$ GeV
Missing $E_T = 102$ GeV



This event survived the final Run 1 cuts, since it has such high momentum and missing E_T .

Top Quark Mass from Event 417

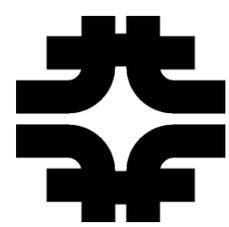
Ulrich Heintz, Raja, and Mark Strovink worked on a likelihood calculation, based on a method inspired by Dalitz, Goldstein, and Kondo, which determined that the event was consistent with top masses of 100-200 GeV/c². The likelihood was maximized at mass(top) = 145 GeV/c². Later, Harrison Prosper calculated the top mass for event 417 using a new kinematic method. He estimated that the mass(top) = 163 ± 36 GeV/c².



Tom Ferbel –
Nucl. Phys. B

*Note: This is a personal view of finding and interpreting aspects of the most spectacular top candidate event in DØ. The full task of assembling and analyzing the complete top quark sample required the dedicated talents of a much broader group of people. Sharon Hagopian

Sample Logbook Pages: (First two pages from the logbook of Dave Hedlin and last three pages are from the logbook of Harrison Prosper.)

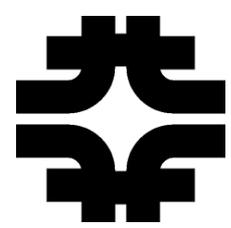


Lessons (1)

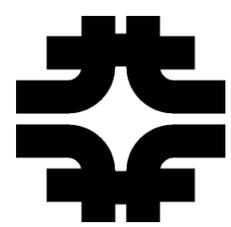


- Do not assume that you know more than you really know (that's probably a good strategy for life in general...)
 - Especially at the beginning of the Run
 - When you embark on a new topic/subject
- Trust the experts, but verify whenever possible
 - Challenge (politely!) the “common wisdom”
 - Don't hesitate to bring up new ideas/ways of looking at the data
- Look closely at the data, not just via statistical analysis
 - Event display are not just for the media!
 - ◆ Examine displays for “special” events
 - ◆ Learn to recognize “features” in the data

Be creative, be innovative – your (our!) future is in your hands



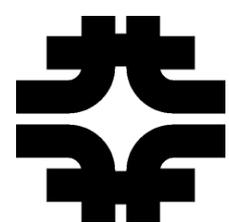
The Road to Discovery



DØ Top Group Organization



- Run 1a of the Tevatron lasted for 2 years (1992 – 1993)
- Run 1b started in 1994 (and lasted until early 1996)
- I was appointed Top Group convenor, together with Nick Hadley (Maryland), in early 1994. Our job was to take care of Run 1b analysis while the previous convenors were still in charge of Run 1a analysis.
- We recognized that the group was big and there was no time in the group meetings for exchanges of ideas as well as for technical presentations and discussion of any particular analysis – need for formal structure and responsibilities
- Moreover, the existing working groups had no clear leaders and hence no obvious accountability structure
- So, on Mar. 29, 1994 we announced...



DØ Top Group Re-Organization



- Formation of formal sub-groups, including leaders in charge with well-defined responsibilities and deliverables (and timeline...)

Previous messages by

Folder: TOP
From: DOSFT::KLIMA (Boaz Klima (708)840-2323)
Subject: New TOP Group Organization
Date: 29-MAR-1994 17:08
Expires: 28-MAY-1994 17:08

7 subgroups:
=====

The TOP group has been very active for more than two years leadership of Raja and Serban. The group produced exciting physics results in the world's highest lower limit on the top quark mass $m_{t^*} > 175$ GeV/c². These results were summarized in a paper which has been published in Physical Review Letters. We'd like to commend Serban on the fine work they have done.

We feel that the group has grown to become large enough that "discussions and bolts" cannot be dealt with in the large group meetings. We are forming working subgroups which will operate within the TOP group through their own meetings, and report back to the entire group. The chair of each subgroup will be both to lead their subgroup and to coordinate their subgroup activities with the larger TOP group effort. We have the best possible communication within the TOP group and the efforts of those doing top analyses as efficient and productive as possible. We would like to encourage new people to join the group regardless whether they are resident at Fermilab or at their institution.

The new TOP group structure will be the following:

Convenors: Nick Hadley and Boaz Klima

Trigger Board (TCB) Representative: Meena Narain (deputy: Jeff Bantly)

Offline Board (OCPB) Representative: Pushpa Bhat (deputy: Jim Cook)

Top to Leptons - Steve Wimpenny (deputy: Meena Narain)

1. emu - Steve Wimpenny
2. ee - Meena Narain
3. mu mu - Jeff Bantly

Top to Lepton + jets - Rich Partridge (deputy: John Hobbs)

4. e + jets: Rich Partridge
5. Mu + jets: John Hobbs

6. Top to Taus: Qizhong Li-Demarteau

7. Top to Jets: Chip Stewart

We have tried to come up with a more specific charge for the subgroup leaders. This is by no means everything that they will do, but it gives some indication of where we are heading.

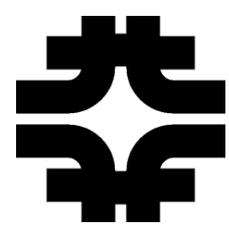
The subgroup leaders will be responsible for organizing their subgroups and for coordinating the activities in their subgroup with the rest of the TOP group effort. Dzero is likely to find top only through the combination of all the subgroups, and it is important that each subgroup leader take into account the efforts of the other groups. Because of the large size of the TOP group, subgroup leaders are expected to spend a large fraction of their time communicating with other subgroups and with the TOP group as a whole.

Subgroup leaders will:

Subgroup leaders will:

- 1) organize weekly or bi-weekly working meetings of their subgroup and keep minutes of these meetings so that all members of the TOP group will remain up to date on the activities of each subgroup. The meetings will be open and announced on DØNews. A copy of the minutes will be kept in the TOP drawer in Barbara Edmondson's office, and will be available electronically.
- 2) be responsible for ensuring that proper triggers exist for the relevant decay channels. Any problems with and/or modification required to the existing trigger list should be discussed in the subgroup meeting as well as with the TOP representative to the TCB. Once a modification is approved by the convenors, it will be submitted to the TCB by the TOP representative.
- 3) ensure that the necessary data is streamed and/or filtered and stored appropriately (on DØFS or on the TOP project disks). Any problems with and/or modification required to the existing streams/filters should be discussed in the subgroup meeting as well as with the TOP representative to the OCPB. Once a modification is approved by the convenors, it will be submitted to the OCPB by the TOP representative.
- 4) maintain in a public area a list of relevant data and Monte Carlo files (signal and background) and their locations as well as relevant information, e.g. generator info for Monte Carlo events, set of cuts/filters for data events etc.
- 5) maintain a documentation of all the relevant physics analyses, i.e. "standard", more sophisticated (Neural Network, H-matrix, PDE etc), mass analyses etc. A copy of this up to date documentation should be kept in the TOP drawer in Barbara Edmondson's office and should be available electronically as much as possible.
- 6) ensure a proper presentation of the status of their analysis in the TOP meetings as required by the TOP group convenors. The presentation will be done either by the leader or by a person in the group designated by the leader.
- 7) make sure that everything else that the convenors neglected to specify in this document but is essential for getting the physics results in a timely fashion is properly done (the legal department asked us to put this in...).

Boaz and Nick



DØ Top Group Mailing List



- We typically sent around messages on DØNEWS (“old” HyperNews). However, we envisioned time when we’ll want correspondence that would fit a more limited audience...
- So, we created a mailing list, consisting of 75 members, which was ordered by people’s activity/sub-group

```

older: TOP
rom: DOSFT:KLIMA ( Boaz Klima (700)840-2323 )
subject: TOP Group EMail Distribution List
ate: 29-MAR-1994 17:10
xpircs: 28-APR-1994 17:10

```

As most of you are aware of, at times we prefer to send messages directly o you via EMail rather than putting it on DØNews. We have received the TOP roup mailing list from the previous convensors. We'd like to make sure the list is up to date and to organize it by subgroup.

Please take a few minutes to:

- . Verify that your name is on the list, if you wish to get the direct TOP EMail.
- . Indicate to us which subgroup you'd like to be part of.
- . Let us know if you'd like your name to be removed from the list.
- . If you are a student, please tell us the name of your advisor.

Boaz and Nick

TOP GROUP MAILING LIST, 1-APR-1994

DECNET ADDRESS	NAME	COMMENTS	STUDENT
e-mu channel			
NALDO::WIMPENNY	!Steve Wimpenny		
NALDO::BHATNAGAR	!Vipin Bhatnagar		X (1b)
NALDO::COCHRAN	!Jim Cochran		

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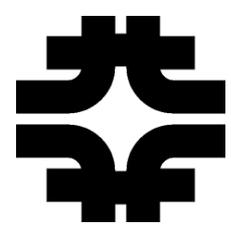
!
DOSFT::MEENA !Meenakshi Narain
FNALDO::KEHOE !Bob Kehoe X (1b)
FNALDO::BALAMORA !V. Balamurall X (1a)
!
! mu-mu channel
!
FNALDO::BANTLY !Jeffrey Bantly
FNALDO::TARAJI !Jamil Taraji X (1b)
FNALDO::RAYKOND !Raymond Hall
!
! e-jets channel
!
FNALDO::PARTRIDGE !Richard Partridge
FNALDO::CHOPRA !Sailash Chopra X (1b)
FNALDO::CHANG !Su-Min Chang b-tagging X (1b)
FNALDO::TAMBURELLO !Peter Tamburello X (1b)
FNALDO::SHIMAN !Shiman Chakraborty X (1a)
FNALDO::KU !Haowei Ku b-tagging X (1a)
FNALDO::SNYDER !Scott Snyder b-tagging X (1a)
FNALDO::FANG !Myungun Fang X (1a)
MNLDO1::SERBAN !Serban Protopoescu
FNALDO::MIETTINEN !Hannu Miettinen
FNALDO::COBAU !Bill Cobau
MNDHEP::DREW !Draw Baden
DOSFT::BHAT !Pushpa Bhat
DOSFT::GREENLEE !Herb Greenlee
DOSFT::JMRUTLER !John Butler
!
! mu-jets channel
!
FNALDO::HOBBS !John Hobbs
FNALDO::YOSHIKAWA !Cary Yoshikawa X (1a)
FNALDO::JOEY !Joey Thompson
JCRPHY::HEINSON !Ann Heinson
!
! tau channels
!
FNALDO::QZLI !Qizhong Li-Demarteau
FNALDO::KOTCHER !Jon Kotcher
!
! all jets channel
!
DOSFT::STEWART !Chip Stewart
FNALDO::CRETSINGER !Cathy Cretsinger X (1b)

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! We don't know yet!
!
MNLCLG::GORDONH !Howard Gordon
MNLDO1::GIBBARD !Bruce Gibbard
DJA::STROVINK !Mark Strovink
DOSFT::ABACHI !Shariahr Abachi
DOSFT::FUESS !Stu Fuess
DOSFT::KRZYW !Stan Krzywdzinski
DOSFT::RAJA !Rajendran Raja
FNALDO::BRAJESH !Brajesh Chouhary
FNALDO::EPPLEY !Geary Eppley
FNALDO::FATYGA !Mirek Fatyga
FNALDO::HEDIN !David Hedin
FNALDO::NGRAF !Norman Graf
FNALDO::PLUQUET !Alain Pluquet
FNALDO::TAKETANI !Atushi Taketani
FNALDO::ULI !Ulrich Heintz
FNALDO::AHN !Seung Ahn
FNALDO::DIEHL !Tom Diehl
FNALDO::YAMADA !Ryuji Yamada
FNALV::GENSER !Krzysztof Genser
FNALV::SLAVIKH !Slava Klyukhin
FSUHEP::HARRY !Harison Prosper
IND::DARIA !Daria Zieminska
4SUHEP::ABOLINS !Maris Abolins
SRHEP1::ALDINIST !Chang Kee Jung
JHHEPG::MDJ !Michael Jones
JHHEPG::MMP !Mike Peters
!
! Ex officio
!
FNALV::PGRANNIS !Paul Grannis
FNALV::MONT !Hugh Montgomery
FNALV::HEFISK !Gene Fisk
!
! Convensors
!
DOSFT::KLIMA !Boaz Klima
MNDHEP::HADLEY !Nick Hadley

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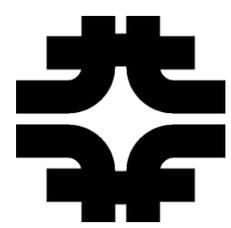



DØ Top Group Objectivity



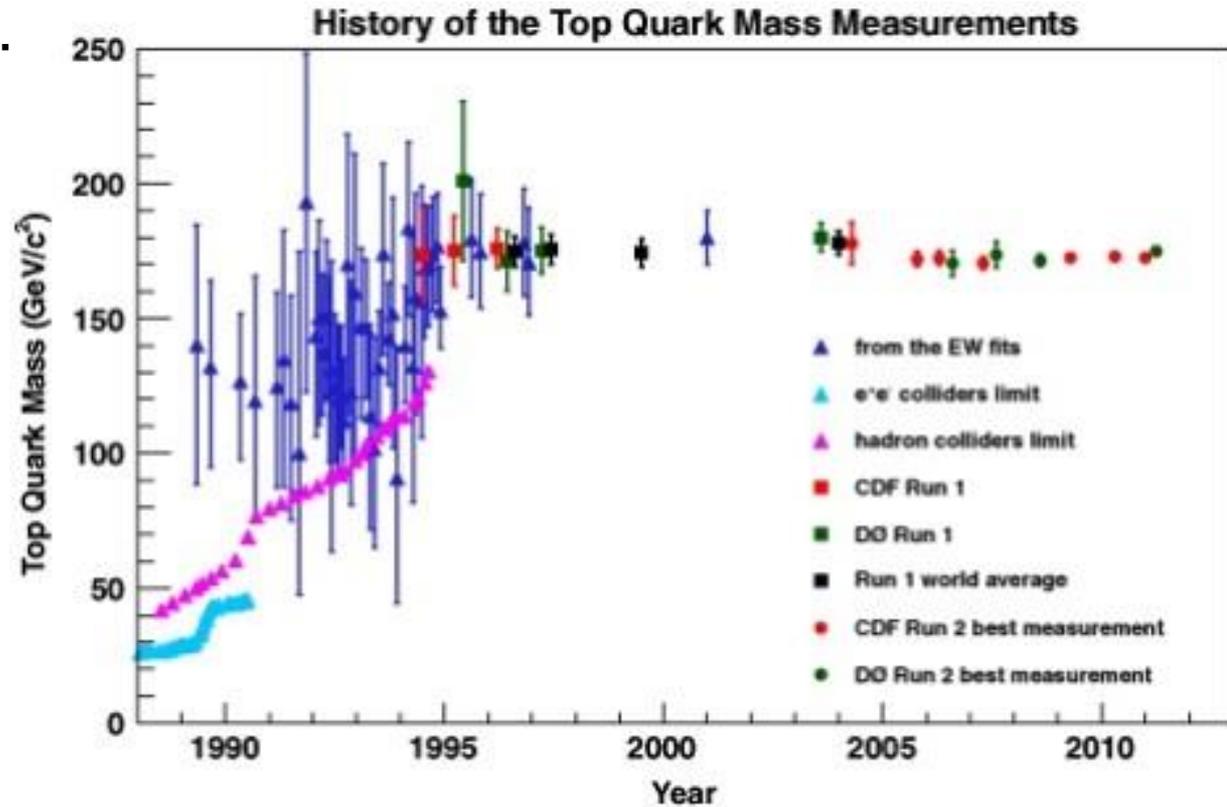
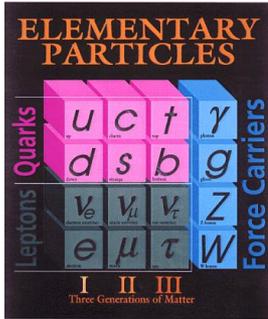
- Trivial statement – we were all eager to discover the Top quark unless it was not there...
- To guard against unconscious bias, we introduced (from above!) particle ID definitions that all analyzers had to follow. Later on in the life of DØ we called them “certified object ID”, but back then that was a very new concept and not very popular move (how can you tell the experts what to do?...)
- So much so that when one analyzer lost his sole top candidate, the result was
- As a side remark, if one does not pay attention to these potential biases, in an analysis with numerous channels the overall impact may be large/significant



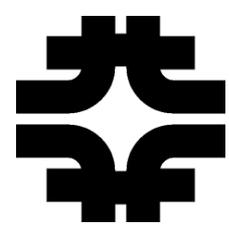


Summer 1994

- The search for the Top quark in experiments worldwide has been going on for at least the last 17 years
- Limits, limits, limits...



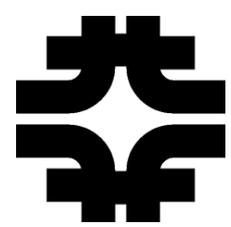
- SM fits increasing steadily with new limits...



Summer 1994



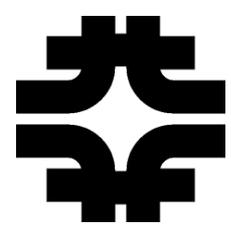
- At the Tevatron, the CDF and DØ collaborations finished analyzing their Run 1a data – both having similar (“expected”) sensitivity to Top pair production
- CDF published a paper claiming evidence (2.8σ) for Top quark production with a cross section that was twice as large as predicted by the Standard Model
- DØ’s result (1.9σ) was consistent both with CDF’s and with no signal – its “measured” $\sigma_{t\bar{t}}$ was consistent with SM
- Both experiments needed more data - Run 1b was well underway
- Each collaboration decided (independently!) to double the data sample while analyzing the new data (Run 1b) exactly as before – sanity/consistency check (signal or background?)



Detour - DØ and Conferences



- The DØ collaboration had a Speakers Bureau (SB), headed by Sharon Hagopian (FSU), which assigned DØ talks at conferences and workshops
- As convenors of the Top Physics group at DØ, we regularly recommended to the SB on candidates from the Top group for talks at conferences; obviously never ourselves
- In November I received an unexpected invitation from Sharon to give a “standard” status of Top Search talk at Moriond 1995
- I hesitated since
 - There was nothing new yet from Run 1b
 - Just another “Search” talk...
 - I didn't ski
- I finally accepted since we had to send name to the organizers



DØ Top Group Meetings



- During 1994 the Top group had regular bi-weekly meetings
- Nick and I did not make presentations except news/updates
- When things started heating up, we changed the frequency to weekly meetings and... I made an exception early in January

```
News      263 in D0.TOP on node D0SFT                VaxNews 3.15

Newsgroups: D0.TOP
From: D0SPT::KLIMA      ( Boaz Klima (708)840-2323 )
Subject: Top Meeting Agenda - 1/13/95
Date: 11-JAN-1995 12:18:58.95
Expires: 26-JAN-1995 12:18:58.95
Path: d0sf21.fnal.gov:d0sf28.fnal.gov:vaxnews!KLIMA
Message-ID: <00011500_VAXNEWS@d0sf28.fnal.gov>

                                Fermilab, 11-JAN-1995

                                AGENDA

                                TOP Group Meeting
                                -----

                                Friday, 1-13-95, 1994
                                10:30 AM - 12:30 PM
                                The Ninth Circle

                                1. News, updates etc - N. Hadley/ B. Klima.
                                2. Update on PRD - R. Madaras.
                                3. Cuts, efficiencies etc - B. Klima.
                                4. The grid search - C. Yoshikawa.
                                5. More on mass analysis - S. Protopopescu.
```

```
News      267 in D0.TOP on node D0SFT                VaxNews 3.15

Newsgroups: D0.TOP
From: D0SPT::KLIMA      ( Boaz Klima (708)840-2323 )
Subject: Top Meeting Agenda - 1/20/95
Date: 18-JAN-1995 16:43:06.42
Expires: 2-FEB-1995 16:43:06.42
Path: d0sf21.fnal.gov:d0sf28.fnal.gov:vaxnews!KLIMA
Message-ID: <00011507_VAXNEWS@d0sf28.fnal.gov>

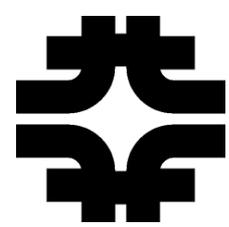
                                Fermilab, 18-JAN-1995

                                AGENDA

                                TOP Group Meeting
                                -----

                                Friday, 1-20-95, 1994
                                10:30 AM - 12:30 PM
                                The Ninth Circle

                                1. News, updates etc - N. Hadley/ B. Klima.
                                2. Report from the mass analysis - T. Ferbel.
                                3. Cuts, efficiencies etc - M. Narain.
                                4. More on mass analysis - S. Protopopescu.
                                5. Mt-mw studies - P. Grannis.
```

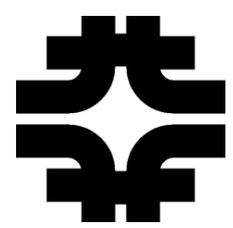


Lessons (2)

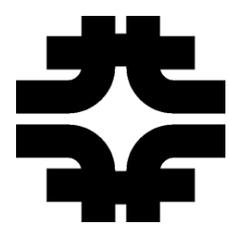


- As a leader of a group, do not assume that you know more than you really know (sounds familiar by now?)
 - Talk regularly to members of your group
 - Consult regularly with senior colleagues outside your group
- Don't hesitate to introduce new ideas
 - Organizationally – there will be resistance
 - Scientifically – there will be a lot of resistance
- Since you are in charge
 - make sure the overall effort of your group is well balanced and carefully planned (timing is everything)
 - don't be afraid to make bold moves!!

Be creative, be innovative – your (our!) future is in your hands



Discovery



New Strategy for Discovery



- In very early January 1995, after seeing that the significance when doubling the sample was going up as expected (2.4σ ; $\sim\sqrt{N}$), I proposed a change in strategy

From: KLIMA
To: SBHEP::GRANNIS; FVALY::MONT
Cc: KLIMA
Subject: Food for Thought

Sent: Tue 1/10/1995 10:32 AM

Fermilab, 10-JAN-1995

Paul and Mont,

I wrote a "document" stating a strategy for trying to find top in D0 now. This is probably one out of few strategies which one can think of at this time. It should serve as "food for thought", and hopefully it'll stimulate some discussion among experts and convince people to move fast towards achieving our main goal. Nick, the only one which I've shared this doc with so far, is happy with it. What do you think? I know that you're very busy these days with the review, but maybe you can find a few minutes for this as well.

Boaz

Jan. 9, 1995

A STRATEGY FOR FINDING TOP IN D0

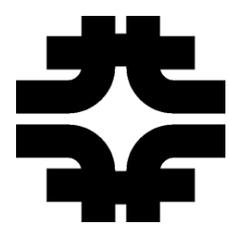
The current results of the top search are:

	Di-leptons	Lepton+jets	Lepton+jets+mu tag	All
Data	2	8	8	16
Bkg	2.0+/-0.2	3.9+/-1.6	2.3+/-0.4	8.2+/-1.7
TT(180)	1.1+/-0.1	3.6+/-0.6	2.1+/-0.4	6.8+/-1.0
TT(200)	0.6+/-0.1	2.2+/-0.4	1.3+/-0.2	4.0+/-0.6

The significance of our results in terms of probability for not having top in our data ("consistency with no top" hypothesis) is 0.7% (assuming gaussian likelihood - 2.4 sigma).

What should be the strategy (or why are we modifying our analysis)?

We know now that the top quark mass is much larger than the mass we used to determine our cuts during run 1a. At the beginning of run 1a we tuned our analyses cuts to have good efficiency for M_t of about 80-100GeV (just above M_w ; around the CDF limit). About one year ago after setting the 131GeV limit (during the so-called "operation heavy top"), we tuned our analyses cuts for M_t of about 120-140GeV (around our mass limit). Based on our current knowledge of the top mass, namely that M_t is about 200GeV, one can further optimize the analysis.



New Strategy for Discovery



Jan. 9, 1995

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The current results of the top search are:

	Di-leptons	Lepton+jets	Lepton+jets+mu tag	All
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The significance of our results in terms of probability for not having top in our data ("consistency with no top" hypothesis) is 0.7% (assuming gaussian likelihood - 2.4 sigma).

What should be the strategy (or why are we modifying our analysis)?

We know now that the top quark mass is much larger than the mass we used to determine our cuts during run 1a. At the beginning of run 1a we tuned our analyses cuts to have good efficiency for Mt of about 80-100GeV (just above Mw; around the CDF limit). About one year ago after setting the 131GeV limit (during the so-called "operation heavy top"), we tuned our analyses cuts for Mt of about 120-140GeV (around our mass limit). Based on our current knowledge of the top mass, namely that Mt is about 200GeV, one can further re-optimize the analysis.

In addition, one can argue that we understand our data better than we used to, we have higher statistics to better determine our cuts etc. However, if we make these kind of changes and find top, many people will be suspicious.

Which analysis to modify and how to tune its cuts?

I'd recommend to make as few modifications as possible. If we do that, it'll be easier both to justify the changes to ourselves and to explain/sell it to other people. I believe that a few well-justified changes have a good chance to be accepted by the collaboration in a short time.

Since we have just a little more than a handful of events, the strategy should be to reduce the background as much as we can while maintaining good efficiency for signal. We'll have to make sure that the efficiency loss will be relatively small.

What cuts are good candidates for modifications?

The Mt cut in the lepton+jets can go up from 140GeV to about 180-200GeV. By doing that we'll keep high efficiency for very heavy top whereas the background will be reduced by about a factor of 2 or so. One has to keep in mind that this kind of modification will also change the mass analysis. Both the total number of background events and the background mass distribution shape (move to "higher masses") will be different. The

significance of the mass analysis as a "direct top finder" may be reduced since top and its background will peak closer as the Ht cut increases.

The Ht cut, which was used only in the no tag lepton+jets channels, can be raised in the tagged analyses. A cut of about 150GeV (?) added to the lepton+jets+mu tag analyses should, in principal, keep similar efficiency for heavy top to the "old analysis" while reducing the background significantly (by a factor of 2?). One has to keep in mind that the tagged analysis requires only three jets, so the Ht cut can't be as high as in the no-tagged analysis where we require four jets.

The jet Et cut used across all channels in all channels (including the lepton+jets) can go up from 150GeV (to 200GeV?). Once again, the effect on heavy top should be minimal while the rejection for background might improve significantly.

What else? Any other obvious candidates??

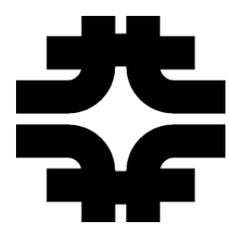
What are we aiming at?

The probability for not having top in our data (consistency with no top hypothesis) is 0.7% (assuming gaussian likelihood it's about 2.4 sigma). In order to get a feel for what needs to be done to be able to claim top with the data we have now, I estimated the significance for a few possible scenarios using Nick's probability calculation software, which agrees with Rich's code, at least for the current analysis.

The following table may serve as "food for thought":

	Data	Background	Probability
1. Current	18	8.2+/-1.7	0.71%
2. No dileptons	16	6.2+/-1.7	0.42%
3. No (mu,mu)	18	7.3+/-1.7	0.31%
4. Half Bkg 1	13	4.1+/-0.9	0.11% (about 3.3 sigma)
5. Half Bkg 2	18	4.1+/-0.9	0.014% (about 3.8 sigma)
6. Half Bkg 3	16	4.1+/-0.9	0.0047% (about 4 sigma)

Scenario 1 is obviously the current one. In scenarios 2 and 3 I eliminated one or all of the dilepton analyses. This does not require any change in our current analysis; just looking at a subset. In scenarios 4,5, and 6 I reduced the background by a factor of 2 while keeping different no. of data events since we don't know how many of them will eventually pass the "new" cuts.



First Sighting



- Following that change, we saw SIGNIFICANT signal

Jan. 12, 1995

Optimizing Top Analysis for Heavy Top - 1st Attempt

In the spirit of making a few well-justified changes wrt the current (Aspen) top search analysis, we have made the first attempt. As indicated earlier, the idea was to reduce the background as much as we could while maintaining good efficiency for signal. The first attempt contained the following modifications:

- Lepton+Jets: the Ht cut was increased from 140GeV to 180GeV.
- Lepton+Jets+mu tag: the Ht cut was introduced with a value of 150GeV.
- Dilepton: The Ht cut on the jets was increased from 150GeV to 200GeV.

In all channels the change in the cut caused an efficiency loss for 180GeV (about 10% and about a factor of 2 increase in the rejection against the main background. The exact numbers will have to be checked/verified later, at the rough estimate of the effect of changing the cuts has been done by the expert in each channel.

The current (=Aspen) results of the top search are:

	Di-leptons	Lepton+jets	Lepton+jets+mu tag	All
Data	2	8	0	10
Bkg	2.0+/-0.2	3.9+/-1.6	2.3+/-0.4	8.2+/-1.7
TT(180)	1.1+/-0.1	3.6+/-0.6	2.1+/-0.4	6.8+/-1.0

The significance of our results in terms of probability for not having top in our data ("consistency with no top" hypothesis) is 0.7% (assuming gaussian likelihood - 2.4 sigma).

The results with the optimized cuts are:

	Di-leptons	Lepton+jets	Lepton+jets+mu tag	All
Data	2	8	7	17
(Meena)		(Sailesh, Serban)	(Bill, John H.)	
Bkg	1.0+/-0.1	2.0+/-0.8	1.2+/-0.2	4.2+/-0.8
TT(180)	1.0+/-0.1	3.2+/-0.5	1.8+/-0.4	6.0+/-0.6

The significance of our results in terms of probability for not having top in our data ("consistency with no top" hypothesis) is 0.001% (assuming gaussian likelihood - 4.2 sigma).

Jan. 13, 1995

Optimizing Top Analysis for Heavy Top - 2nd Attempt

Two interesting questions were asked about my previous message:

Are we fooling ourselves, or in a polite way, are we biasing the results by choosing the "best" cuts? More specifically, can we change the cuts and see what happens? For example, Nick asked to change the Ht cut on lepton+jets to 200GeV (I had 180GeV in my first attempt).

Serban pointed out that VECBOS doesn't agree with the data very well at the tails. He suggested to make a correction based on M+3jets data as Strovink and Varnes. His conclusions are that we have to increase the background estimate for Ht>140(180)GeV by a factor of <1.2(1.6). I put the "<" sign since he believes that this is probably an overestimation. For Ht>200GeV he ran out of statistics in the data, so my guessimate will be a factor of 1.8.

The results in my previous message (1st attempt) were:

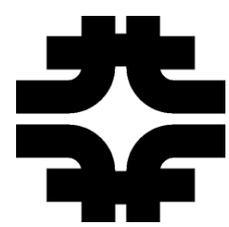
	Di-leptons	Lepton+jets	Lepton+jets+mu tag	All
Data	2	8	7	17
(Meena)		(Sailesh, Serban)	(Bill, John H.)	
Bkg	1.0+/-0.1	2.0+/-0.8	1.2+/-0.2	4.2+/-0.8
TT(180)	1.0+/-0.1	3.2+/-0.5	1.8+/-0.4	6.0+/-0.6

The significance of our results in terms of probability for not having top in our data ("consistency with no top" hypothesis) is 0.001% (assuming gaussian likelihood - 4.2 sigma).

The results with Ht>200GeV and VECBOS AS IS are:

	Di-leptons	Lepton+jets	Lepton+jets+mu tag	All
Data	2	6	7	15
(Meena)		(Sailesh, Serban)	(Bill, John H.)	
Bkg	1.0+/-0.1	1.5+/-0.6	1.2+/-0.2	3.7+/-0.6
TT(180)	1.0+/-0.1	2.9+/-0.5	1.8+/-0.4	5.7+/-0.6

The significance of our results in terms of probability for not having top in our data ("consistency with no top" hypothesis) is 0.002% (assuming gaussian likelihood - 4.1 sigma).



Unbiased (=MC) Optimization



- And then it was time for unbiased systematic optimization

Jan. 10, 1995

OPTIMIZING THE LEPTON+JETS ANALYSIS

1. "Simple/Obvious" - changing only the H_t cut from 140GeV to 200GeV (or to 180GeV) while keeping everything else (all id and analysis cuts) in the analysis unchanged.
2. "Same top efficiency" - changing the H_t and Aplanarity cuts from (140., .05) to (200., .03) while keeping everything else (all id and analysis cuts) in the analysis unchanged. The way I decided on this 2-dim point was by picking the 200GeV point for the H_t cut first and then looking in Sailesh's table for the corresponding A cut which gave similar efficiency for 200GeV top.
3. "Max rejection" - changing the H_t and Aplanarity cuts from (140., .05) to (200., .08) while keeping everything else (all id and analysis cuts) in the analysis unchanged. The way I decided on this 2-dim point was by picking the 200GeV point for the H_t cut first. Then looking at Sailesh's table I realized that, as a rule of thumb, for an increase of the A cut by .01 the background rejection improves by about 30%. My arbitrary choice was to have an additional rejection due to the change in A by a factor of 3. The numbers in my table below are just a guess since I don't have Sailesh's results yet.

*

The results for the current set of cuts and the three "new" sets are:

(H_t , A)	tt(200GeV)	Background	S/B	S/sqrt(B)
-----	-----	-----	---	-----
	# events	% loss wrt	# events	increased
	in 36pb-1	current	in 36pb-1	rejection
Current (140., .05)	2.2+/-0.4	0	3.9+/-1.6	0
Opt. 1 (200., .05)	1.8+/-0.3	20	1.5+/-0.6	2.6
Opt. 1 (180., .05)	2.0+/-0.3	10	2.0+/-0.8	1.9
Opt. 2 (200., .03)	2.3+/-0.4	0	2.4+/-1.0	1.6
Opt. 3 (200., .08)	1.1+/-0.2	50	0.5+/-0.2	5.0

** - Haven't checked the data yet; not relevant at this point!
 ** - A guess/extrapolation based on Sailesh's tables below



Jan. 16, 1995

Optimizing Top Analysis for Heavy Top - 3rd study

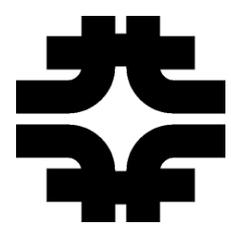
Following his presentation during the TOP group meeting on Friday, Nick and I asked Cary Yoshikawa to make a grid search with only one parameter, H_t (and everything else as in the "standard 1a" analysis). We asked him to plot two parameters as a function of H_t for different top masses:

1. The significance, $S/\sqrt{S+B}$.
2. The efficiency for top events.

He did the study on the Mu -jets channel (no tag), and his plots are with me (we don't have the ps files, and FNALD0 is still down...). We summarized his results, as we read them from his plots, below:

M_t (GeV)	140	160	180	200
Significance peaks at (GeV)	130	160	210	230
Efficiency loss wrt $H_t > 100$ GeV				
10%	130	140	170	200
20%	150	160	190	220
Efficiency loss wrt $H_t > 140$ GeV				
10%	150	160	180	200
20%	160	170	190	220

The conclusion from Cary's study using his optimization technique is that for top mass of 180-200 GeV the optimal cut on H_t is around 180-200 GeV. One could, in principal, think of going even higher based on the significance optimization, but the efficiency loss for top events would be too high. At this time, since the statistics is low, we'd advocate not to increase H_t beyond 200 GeV.



DØ Top Discovery Marathon



- Once we knew we had it in early January, we announced a 2-day marathon inviting the entire collaboration for
 - airing of all details about the analyses involved with the discovery
 - having plenty of time for questions and discussion
- The collaboration needed that to **understand** all the analyses and **bless** them – basically to **own the discovery!**

Top Marathon

Feb. 16-17, 1995

Welcome!

Many thanks to all the people who worked very hard during the last several weeks.

Boaz & Nick

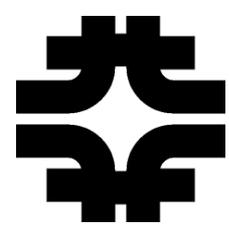
You don't get to be part of a team which discovers a new elementary particle more than once!

AGENDA
TOP Group Marathon

Thursday and Friday
Feb. 16-17, 1995
The Ninth Circle

Thursday, Feb. 16, 1995	
9:30 - 9:50	
* Introduction - N. Hadley/ B. Klima	20 min
9:50 - 10:55	Di-Lepton Channels
* The e-e channel - B. Kehoe	15 min
* The e-mu channel - J. Cochran	15 min
* The mu-mu channel - R. Hall	15 min
* Summary of dilepton channels - M. Narain	20 min
Coffee Break	
11:10 - 12:30	Lepton+Jets Channels
* The e-jets channel - S. Chopra	15 min
* The mu-jets channel - T. Rockwell	15 min
* The e-jets/mu channel - B. Cobau	15 min
* The mu-jets/mu channel - J. Hobbs	15 min
* Summary of lepton+jets channels - R. Partridge	20 min
Lunch Break	
1:30 - 3:00	X-section, significance and 2-d Analysis
* Cross section, significance - J. Bantly	30 min
* M(3j) vs M(2j) - S. Protopopescu	30 min
* Discussion - All	30 min
Coffee Break	
3:15 - 4:30	Mass analysis
* Mass analysis studies - S. Snyder	40 min
* Mass distribution fits - R. Partridge	20 min
* Discussion - All	15 min

Friday, Feb. 17, 1995	
9:00 - 10:15	Multivariate Analyses
* The Neural Network analysis - Prosper	30 min
* The PDE analysis - H. Miettinen	30 min
* The H matrix analysis - R. Raja	15 min
Coffee Break	
10:30 - 12:30	Summaries
* Dilepton channels - M. Narain	15 min
* Lepton+jets channels - R. Partridge	15 min
* Counting experiment - J. Bantly	15 min
* 2-d analysis - S. Protopopescu	15 min
* Mass analysis - S. Snyder	15 min
* Multivariate analysis - P. Bhat	15 min
* Conclusion - B. Klima/N. Hadley	30 min



Top Quark Discovery



- Both collaborations submitted simultaneously their **discovery papers to PRL on Feb. 24, 1995** at 11am CST (not that anybody is counting...)

Observation of Top Quark Production in $\bar{p}p$ Collisions

Abstract

We establish the existence of the top quark using a 67 pb^{-1} data sample of $\bar{p}p$ collisions at $\sqrt{s} = 1.8 \text{ TeV}$ collected with the Collider Detector at Fermilab (CDF). Employing techniques similar to those we previously published, we observe a signal consistent with $t\bar{t}$ decay to $WWb\bar{b}$, but inconsistent with the background prediction by 4.8σ . Additional evidence for the top quark is provided by a peak in the reconstructed mass distribution. We measure the top quark mass to be $176 \pm 8(\text{stat.}) \pm 10(\text{sys.}) \text{ GeV}/c^2$, and the $t\bar{t}$ production cross section to be $6.8^{+3.6}_{-2.4} \text{ pb}$.

VOLUME 74, NUMBER 14

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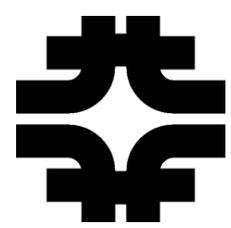
3 APRIL 1995

Observation of the Top Quark

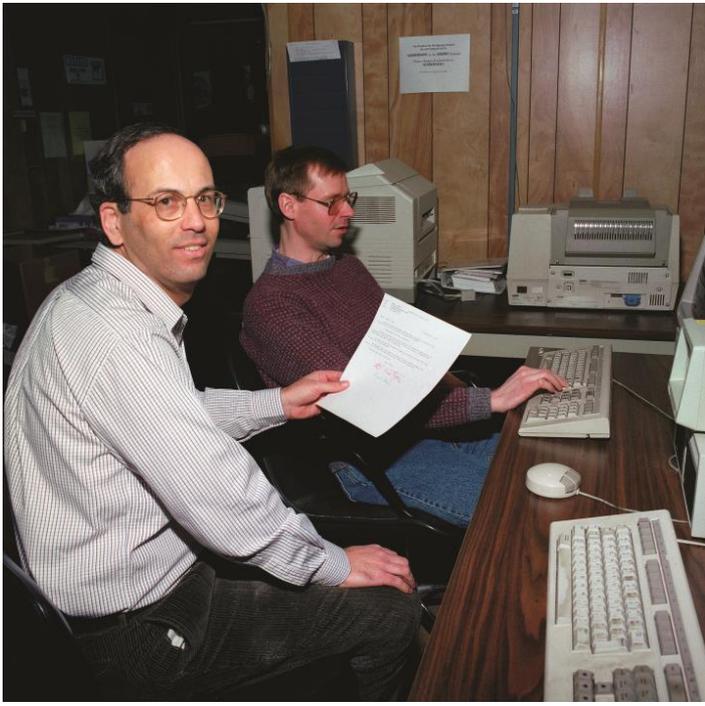
The D0 Collaboration reports on a search for the standard model top quark in $p\bar{p}$ collisions at $\sqrt{s} = 1.8 \text{ TeV}$ at the Fermilab Tevatron with an integrated luminosity of approximately 50 pb^{-1} . We have searched for $t\bar{t}$ production in the dilepton and single-lepton decay channels with and without tagging of b -quark jets. We observed 17 events with an expected background of 3.8 ± 0.6 events. The probability for an upward fluctuation of the background to produce the observed signal is 2×10^{-6} (equivalent to 4.6 standard deviations). The kinematic properties of the excess events are consistent with top quark decay. We conclude that we have observed the top quark and measured its mass to be $199^{+21}_{-19}(\text{stat}) \pm 22(\text{syst}) \text{ GeV}/c^2$ and its production cross section to be $6.4 \pm 2.2 \text{ pb}$.

PACS numbers: 14.65.Ha, 13.85.Qk, 13.85.Ni





Submission of Top Discovery Papers



Top Quark Discovery Paper



VOLUME 74, NUMBER 14 PHYSICAL REVIEW LETTERS 3 APRIL 1995

Observation of the Top Quark

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Kozlov,¹² E. A. Kozlovskiy,¹² M. R. Kridin,¹² S. Krzywdzinski,¹² S. Kuroki,¹² S. Lami,¹² G. Landsberg,¹² R. E. Lanoué,¹² F. H. Lehar,¹² L. Leo-Franzini,¹² A. Leflat,¹² H. Li,¹² J. Li,¹² Y. J. Li,¹² Q. Z. Li-Deuntau,¹² J. G. R. Lima,¹² D. Lincoln,¹² S. L. Lim,¹² J. Linemann,¹² R. Lipston,¹² Y. C. Liu,¹² P. Lohkovsky,¹² S. C. Loken,¹² S. Loken,¹² J. Loken,¹² A. K. A. Maciel,¹² R. J. Madars,¹² R. Madden,¹² I. V. Mandrichenko,¹² P. H. Manguerra,¹² S. Mant,¹² D. Mansour,¹² H. S. Mao,¹² S. Margolis,¹² R. Markeloff,¹² L. Markosky,¹² T. Marshall,¹² M. I. Martin,¹² M. Marx,¹² B. May,¹² A. A. Mayrow,¹² T. R. McCarthy,¹² T. McKibben,¹² J. McKinley,¹² H. I. Melancon,¹² J. R. T. de Mello Neto,¹² K. W. Merritt,¹² H. Miettinen,¹² A. Müller,¹² C. Müller,¹² A. Mincer,¹² J. M. de Miranda,¹² C. S. Mishra,¹² M. Mohammadi-Barmad,¹² N. Mekhov,¹² D. N. K. Mondal,¹² H. J. Montgomery,¹² P. Mooney,¹² M. C. Mudan,¹² C. Murphy,¹² C. T. Murphy,¹² J. Nam,¹² M. Naranjo,¹² V. S. Narasimhan,¹² A. Narayanan,¹² H. A. Neal,¹² J. P. Negret,¹² E. Neis,¹² P. Nemethy,¹² D. Nešić,¹² D. Norman,¹² L. Oesch,¹² V. Oguri,¹² E. Oltman,¹² N. Oshima,¹² D. Owen,¹² P. Palley,¹² M. Pang,¹² A. Para,¹² C. H. Park,¹² Y. Y. Park,¹² R. Partridge,¹² N. Parua,¹² M. Paterno,¹² J. Perkins,¹² A. Peryshkin,¹² M. Peters,¹² H. Pickard,¹² Y. Pichlakovich,¹² A. Pinquet,¹² V. M. Podstavny,¹² B. G. Pogre,¹² H. B. Prosper,¹² S. Protopopescu,¹² D. Priftić,¹² J. Qian,¹² P. Z. Qian,¹² R. Raja,¹² S. Rajagopalan,¹² O. Ramirez,¹² M. V. S. Rao,¹² P. A. Rapin,¹² L. E. Rossmoore,¹² A. L. Read,¹² S. Renfrew,¹² M. Ripstein,¹² P. R. Riedel,¹² N. A. Rice,¹² J. M. Riddell,¹² P. Rubinov,¹² R. Ruchti,¹² S. Ruzin,¹² J. Rutherford,¹² A. Santoro,¹² L. Sawyers,¹² R. D. Schamberger,¹² H. Scheltema,¹² D. Schmidt,¹² J. Scuderi,¹² P. Shatalina,¹² C. Shaffer,¹² H. C. Shankar,¹² R. K. Shivpuri,¹² M. Shupe,¹² J. B. Singh,¹² V. S. Sirotenko,¹² W. Soar,¹² A. Smith,¹² R. P. Smith,¹² R. S. Smithey,¹² G. R. Snow,¹² S. Snyder,¹² J. P. Soper,¹² M. Sosebec,¹² M. Sotz,¹² R. A. I. Spadoforo,¹² R. W. Stephens,¹² M. L. Stevenson,¹² D. Stewart,¹² F. Stocker,¹² D. A. Sritanovska,¹² D. Stoker,¹² K. Sreets,¹² M. Strovink,¹² A. Takanui,¹² P. Tamburello,¹² J. Tarazi,¹² M. Tangalia,¹² T. L. Taylor,¹² J. Tejer,¹² J. Thompson,¹² T. G. Tripp,¹² P. M. Tuzi,¹² N. Vaezian,¹² J. W. Varnes,¹² P. R. G. Vitairor,¹² D. Vitousek,¹² M. A. Wayne,¹² V. Volkov,¹² E. von Goeler,¹² P. P. Vorobiev,¹² H. D. Wahl,¹² J. Wang,¹² J. Wang,¹² J. Wang,¹² J. Warchol,¹² M. W. Warkentin,¹² H. Weerts,¹² W. A. Wenzel,¹² A. White,¹² J. T. White,¹² J. A. Wiglman,¹² J. Wilcox,¹² S. Willis,¹² S. J. Wimpenny,¹²

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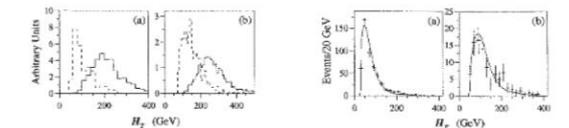


FIG. 1. Shape of H_T distributions expected for the principal backgrounds (dashed line) and 200 GeV/c^2 top quark (solid line) for (a) $ee + \text{jets}$ and (b) untagged single-lepton + jets.

lated by the virtual Monte Carlo program [7] and multijet events.

The acceptance for ij events was calculated using the BABER event generator [8] and a detector simulation based on the GRANAT program [9]. As a check, the acceptance was also calculated using the HERWIG event generator [10]. The difference between BABER and HERWIG was included in the systematic error.

From all seven channels, we observed 47 events with an expected background of 3.8 ± 0.6 events (see Table II). The probability of an upward fluctuation of the background to 4.6 standard deviations for a Gaussian probability distribution. Our measured cross section as a function of the top quark mass hypothesis is shown in Fig. 3. Assuming a top quark mass of 200 GeV/c^2 , the production cross section is 6.3 ± 2.2 pb. The error in the cross section includes an overall 12% uncertainty in the luminosity. The cross section determined from the loose selection criteria is in good agreement with this value, demonstrating that the backgrounds are well understood. We calculated the probability for our observed distribution of excess events among the seven channels and find that our results are consistent with top quark branching fractions at the 53% C.L. Thus,

TABLE II. Efficiency \times branching fraction ($\epsilon \times \mathcal{B}$) using standard event selection and the expected number of top quark events (N) in the seven channels, based on the central theoretical ij production cross section of Ref. [5], for four top masses. (a) given are the expected background, integrated luminosity, and the number of observed events in each channel.

m_t (GeV/c^2)	$ee + \text{jets}$	$ee + \text{jets}$	$e\mu + \text{jets}$	$e + \text{jets}$	$\mu + \text{jets}$	$e + \text{jets}/\mu + \text{jets}$	All
140 $e \times \mathcal{B}$ (%)	0.17 \pm 0.02	0.11 \pm 0.02	0.06 \pm 0.01	0.50 \pm 0.10	0.33 \pm 0.08	0.36 \pm 0.07	0.20 \pm 0.05
(N)	1.36 \pm 0.21	1.04 \pm 0.19	0.46 \pm 0.08	4.05 \pm 0.94	2.47 \pm 0.68	2.93 \pm 0.68	1.01 \pm 0.42
160 $e \times \mathcal{B}$ (%)	0.24 \pm 0.02	0.15 \pm 0.02	0.09 \pm 0.02	0.80 \pm 0.10	0.57 \pm 0.13	0.50 \pm 0.08	0.25 \pm 0.06
(N)	0.94 \pm 0.13	0.69 \pm 0.12	0.34 \pm 0.07	3.13 \pm 0.54	2.04 \pm 0.53	1.95 \pm 0.49	0.92 \pm 0.24
180 $e \times \mathcal{B}$ (%)	0.28 \pm 0.02	0.17 \pm 0.02	0.10 \pm 0.02	1.20 \pm 0.20	0.76 \pm 0.17	0.56 \pm 0.09	0.25 \pm 0.08
(N)	0.57 \pm 0.07	0.40 \pm 0.07	0.19 \pm 0.04	2.42 \pm 0.47	1.41 \pm 0.30	1.14 \pm 0.22	0.64 \pm 0.16
200 $e \times \mathcal{B}$ (%)	0.31 \pm 0.02	0.20 \pm 0.03	0.11 \pm 0.02	1.70 \pm 0.20	0.96 \pm 0.21	0.61 \pm 0.11	0.41 \pm 0.08
(N)	0.34 \pm 0.04	0.25 \pm 0.05	0.11 \pm 0.02	1.84 \pm 0.31	0.95 \pm 0.24	0.81 \pm 0.16	0.41 \pm 0.10
Background	0.12 \pm 0.03	0.28 \pm 0.14	0.25 \pm 0.04	1.22 \pm 0.42	0.71 \pm 0.25	0.85 \pm 0.14	0.36 \pm 0.08
$\int L dt$ (fb^{-1})	47.9 \pm 5.7	55.7 \pm 6.7	44.2 \pm 5.3	47.9 \pm 5.7	44.2 \pm 5.3	47.9 \pm 5.7	44.2 \pm 5.3
Data	2	0	3	5	3	3	17

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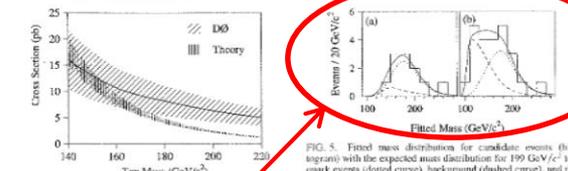


FIG. 2. Observed H_T distributions (points) compared to the distribution expected from background (line) for $H_T > 25$ GeV/c^2 and (a) $ee + \text{jets}$ and (b) $e + \text{jets}$.

only on the shapes of the distributions, the hypothesis that the data are a combination of ij quark and background events (40% C.L.) is favored over the pure background hypothesis (3% C.L.).

To measure the top quark mass, single-lepton + four-jet events were subjected to two-constraint kinematic fits to the hypothesis $ij \rightarrow W^+ W^- b\bar{b} \rightarrow l\nu qq\bar{q}\bar{q}$. Kinematic fits were performed on all permutations of the jet assignments of the four highest- E_T jets, with the provision that mono-top jets were always assigned to a b quark in the fit. A maximum of three permutations with $\chi^2 < 7$ (two degrees of freedom) were retained, and a single χ^2 -probability-weighted average mass ($\bar{M}_{\text{fitted mass}}$) was calculated for each event. Monte Carlo studies using the BABER and HERWIG event generators showed that the fitted mass was strongly correlated with the top quark mass. Gluon radiation, jet assignment combinations, and the event selection procedure introduced a shift in the fitted mass (approximately -20 GeV/c^2 for 200 GeV/c^2 top quark), which was taken into account in the final mass determination.

Events of the 14 single-lepton + jets candidate events selected using the standard cuts were fitted successfully. Figure 5(a) shows the fitted mass distribution. An unbiased likelihood fit to the ij quark and background distributions, with the top quark mass allowed to

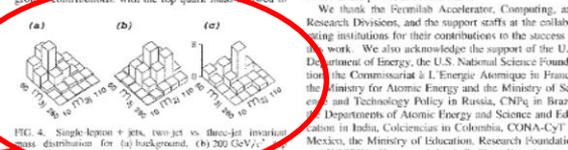


FIG. 3. D0 ij production cross section (solid line with one standard deviation error band) as a function of scanned top quark mass. Also shown is the theoretical cross section curve (dashed line) [5].

vary, was performed on the fitted mass distribution. The top quark contribution was modeled using BABER. The background contributions were constrained to be consistent with our background estimates. The likelihood fit yielded a top quark mass of 199^{+22}_{-21} (stat) GeV/c^2 and described the data well.

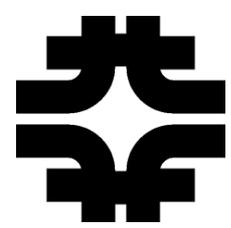
To increase the statistics available for the mass fit, and to remove any bias from the standard H_T requirement, we repeated the mass analysis on events selected using the loose requirements. Of 27 single-lepton + four-jet events, 24 were fitted successfully. The removal of the H_T requirement introduced a substantial background contribution at lower mass in addition to the top signal, as shown in Fig. 5(b). A likelihood fit to the mass distribution resulted in a top quark mass of 190^{+22}_{-21} (stat) GeV/c^2 , consistent with the result obtained from the standard event selection. The result of the likelihood fit did not depend significantly on whether the normalization of the background was constrained. Using HERWIG to model the top quark contribution resulted in a mass 4 GeV/c^2 below that found using BABER. This effect was included in the systematic error. The total systematic error in the top quark mass is 22 GeV/c^2 , which is dominated by the uncertainty in the jet energy scale (10%).

In conclusion, we report the observation of the top quark. We measure the top quark mass to be 199^{+22}_{-21} (stat) ± 22 (sys) GeV/c^2 and measure a production cross section of 6.4 ± 2.2 pb at our central mass.

We thank the Fermilab Accelerator, Computing, and Research Divisions, and the support staffs at the collaborating institutions for their contributions to the success of this work. We also acknowledge the support of the U.S. Department of Energy, the U.S. National Science Foundation, the Commissariat à l'Énergie Atomique in France, the Ministry for Atomic Energy and the Ministry of Science and Technology Policy in Russia, CNPq in Brazil, the Departments of Atomic Energy and Science and Education in India, Colciencias in Colombia, CONACyT in Mexico, the Ministry of Education, Research Foundation and KOSEF in Korea, and the A. P. Sloan Foundation.

• Very important contributions – M_t and (M_t vs M_W)

CDF's paper is available at PRL 74 (1995) 2626



DØ Top Meeting – Feb. 24, 1995



- We announced regular meeting to be held on Feb. 24, 1995
- The agenda was as boring as they come; looked believable

```
News      280 in D0.TOP on node D0SFT          VaxNews 3.15

Newsgroups: D0.TOP
From: D0SFT:KLIMA      ( Boaz Klima (708)840-2323 )
Subject: Top Meeting Agenda - 2/24/95
Date: 23-FEB-1995 16:13:53.42
Expires: 10-MAR-1995 16:13:53.42
Path: d0sf22.fnal.gov!d0sf28.fnal.gov!vaxnews!KLIMA
Message-ID: <00011592_VAXNEWS@d0sf28.fnal.gov>

                                Fermilab, 23-FEB-1995

                                AGENDA
                                -----
                                TOP Group Meeting
                                -----

                                Friday, 2-24-95
                                10:30 AM - 12:30 PM
                                The Ninth Circle

                                1. News, updates etc - N. Hadley/ B. Klima.
                                2. Status of the mass analysis - S. Snyder.
                                3. Background studies - M. Narain.
                                4. 2-d analysis - S. Protopopescu.
                                5. Optimization - R. Partridge.
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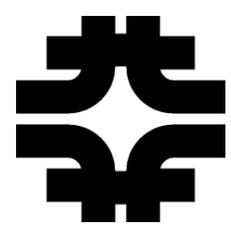


- ...and the party began...
- But the world had to wait...



March 2, 1995 at Fermilab Auditorium - Joint CDF/DØ
Seminar Announcing the Top Quark Discovery





Top Discovery - Media at Fermilab



Public Information Office, P.O. Box 500, Batavia, IL 60510 Telephone: 708-840-3351
Facsimile: 708-840-8780

NEWS MEDIA CONTACTS:
Judy Jackson, 708/840-4112 (Fermilab)
Gary Pitchford, 708/252-2013 (DOE)
Jeff Sherwood, 202/586-5806 (DOE)

95-2
March 1, 1995

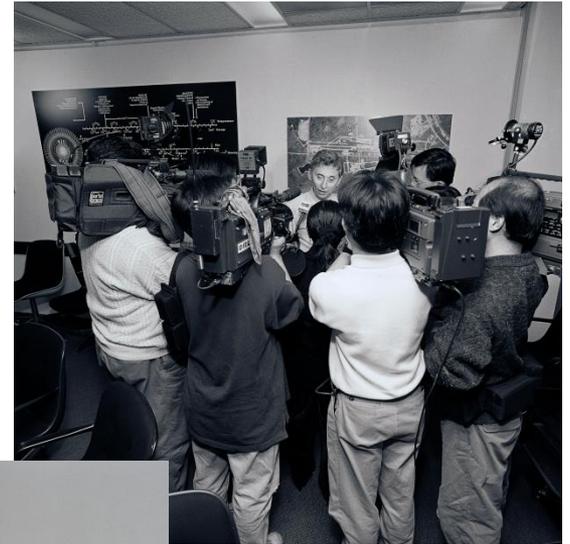
For release after 1:30 p.m. CST, Thursday, March 2

PHYSICISTS DISCOVER TOP QUARK

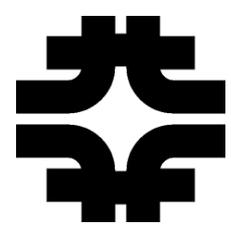
Batavia, IL—Physicists at the Department of Energy's Fermi National Accelerator Laboratory today (March 2) announced the discovery of the subatomic particle called the top quark, the last undiscovered quark of the six predicted to exist by current scientific theory. Scientists worldwide had sought the top quark since the discovery of the bottom quark at Fermilab in 1977. The discovery provides strong support for the quark theory of the structure of matter.

Two research papers, submitted on Friday, February 24, to Physical Review Letters by the CDF and DZero experiment collaborations respectively, describe the observation of top quarks produced in high-energy collisions between protons and antiprotons, their antimatter counterparts. The two experiments operate simultaneously using particle beams from Fermilab's Tevatron, world's highest energy particle accelerator. The collaborations, each with about 450 members, presented their results at seminars held at Fermilab on March 2.

Fermilab
Director



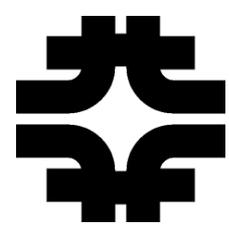
w/ Experiments'
Spokespersons



Top Discovery – Work of MANY



Work of hundreds of physicists over many years culminated in a discovery of a fundamental building block of nature – a triumph for science and for collaborative effort worldwide

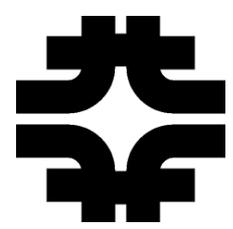


Lessons (3)

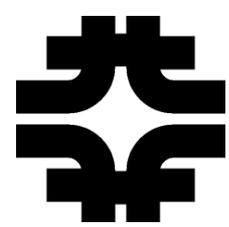


- As a leader of a group think big!
 - Re-think old strategies
 - Refine, if necessary
 - Change altogether if you are convinced that this is the way to go after understanding (well!)
 - ♦ the growth potential, the better route to success
 - ♦ the ramifications of the change (time delay, confusion, ...)
- Continue to be directly involved in all scientific aspects to understand well all relevant considerations
- Motivate members of your group regularly to ensure that everybody is on the same page
 - This is especially important when having many analyses that ought to converge at the same time

Be creative, be innovative – your (our!) future is in your hands



Epilogue



Top Quark Discovery - Media



- The Local and National media were enthusiastic about this major scientific accomplishment

news release
fermi national accelerator laboratory
Operated by Universities Research Association, Inc. for the U.S. Department of Energy
Public Information Office, P.O. Box 500, Batavia, IL 60510 • Telephone: 708-640-3351
Facsimile: 708-640-8780

NEWS MEDIA CONTACTS: 952
July Jackson, 708/640-4112 (Fermilab)
Gary Proffler, 708/252-2011 (DOE)
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Elusive Particle Found By Scientists in Illinois

Continued From Page A1

...we're so elated by the discovery of the top quark that we haven't yet begun to sift all the data," said Dr. Boaz Klima of Fermilab, one of the leaders of the successful search. "But this particle is so astonishingly heavy that its decay may give us hints of a lot of other things, perhaps even of supersymmetric particles."

...the top quark is the last of the six types of quarks predicted to exist by the Standard Model, the physics theory describing the particles that make up all matter. Along with electrons (like electrons) and force-carrying particles called photons, quarks are the building blocks of the universe.

THE STUFF OF ATOMS: The nuclei of ordinary matter, like the hydrogen atom below, contain protons and neutrons made up of two kinds of quarks, up and down.

THE BIG BANG: The other quarks, which are much heavier than the up and down quarks, can now be produced only with particle accelerators. The top quark, the most massive quark by far, was also the most elusive. Two teams now say they have found it, this great overlapping embrace of its mass.

Hydrogen Atom

The 6 Quarks
UP
DOWN
STRANGE
TOP
BOTTOM
CHARM

Forging a link between the physical and the metaphysical.

...the machine has at least 10 more years of useful life. The miles for the high-energy physics community are enormous, in terms of job security, the risks of failure and the promise of great prestige for leaders of successful experiments. Cooperation between physicists is often tenuous and sometimes bitter.

...the CDF and D0 detector collaborations have gone to great lengths to avoid even looking at each other's experiments—a policy that prevents even today analysis before their joint seminar begins.

...We know that some of the strongest physicists on both sides have been reexamining crated tapes of our reports, but we've tried to suppress such exchanges," one physicist said. "I've gotten there in 1995, but

New York Times Mar. 3, 1995

"We're so elated by the discovery of the top quark that we haven't yet begun to sift all the data," said Dr. Boaz Klima of Fermilab, one of the leaders of the successful search. "But this particle is so astonishingly heavy that its decay may give us hints of a lot of other things, perhaps even of supersymmetric particles."

Beware! You are not in control of your message in the media!!

Top Discovery in World Media



- ...and the exciting news went around the world...



Science has been with Ettore for 10 years and headed for the coast from '90 to '94. He also pioneered the use of scientific techniques that had already been discovered. The chase for the elusive top quark began with the discovery in 1977 of the bottom quark. The chase for the missing quark was tough and tortuous. Top quarks are produced during the collision of protons and antiprotons. Fermilab's Tevatron, the world's most powerful particle accelerator, accelerates protons and antiprotons in opposite directions in a giant underground ring which has a circumference of four miles. When they collide at the speed of light, they make a shower of particles.



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End of a Long Chase

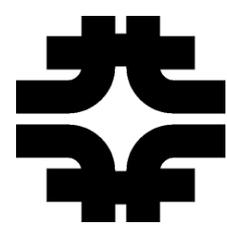
Indians share in the landmark discovery of the elusive top quark

by NANDINI BHARMA
Scores of physicists have been chasing it for almost two decades. But like a quarry which keeps giving its trackers the slip, it continued to elude them. Finally on March 2, scientists at the Fermilab National Accelerator Laboratory, 10 miles west of Chicago, announced the discovery of the top quark — a subatomic particle. Among those who were part of the effort were about 20 Indians. They are hardly surprised. We are a country which gave the world Ramanujan and Saha, Bhabha and Bose... The spirit of scientific enquiry is ingrained in our civilization... The discovery, considered as one of the most significant in high-energy physics, leaves the scientists at the lab ecstatic. "To my mind this is the discovery of a lifetime," says Dr. Subramanyam Raha, a fellow at Trinity College, Cambridge, who came to Fermilab in 1975 and stayed on because "the physics here was so exciting". "Not many people get to discover a particle in their lifetime. So, to be part of this discovery is really exciting," adds Dr. Merababiz Narain, a post-doc fellow at the lab. Most of the Indians were involved with DZero collaboration — one of the two competing teams at Fermilab that found the top quark using separate detection systems. DZero has collaborators from 12 countries including India. Three Indian institutions are part of the collaboration — the Tata Institute of Fundamental Research (TIFR), Panjab University and Indian Institute of Technology. The Indians, including the students, made a major contribution. I don't think that anybody has any doubts of that, says the head of DZero's top group, Dr. Suresh Kumar, Raha, for instance, leaves the scientists at the lab ecstatic.

The discovery of the top quark is as significant as the discovery of the electron.

The discovery of the top quark is as significant as the discovery of the electron.





After the celebrations...

- We (or I) learnt only later on that there was some cross talk...

RESEARCH NEWS

PHYSICS

With Quark Discovery, Truth Comes Out on Top—Twice

Last week's announcement by physicists at the Fermi National Accelerator Laboratory that they had finally discovered the top quark marked the end of one quest and the start of another. The 18-year search to find the sixth and final quark, a relative of the quarks that make up most of ordinary matter, was over after a last-minute sprint to the finish by groups working independently on Fermilab's mammoth accelerator, the Tevatron. In what might be called the moon shot of particle physics, two 450-person collaborations staffing detectors costing \$100 million each had collided trillions of particles and sifted tens of millions of collisions to corner the elusive particle.

But the 2 March announcement, which Energy Secretary Hazel O'Leary called "a crowning moment of success," doesn't close the book on the understanding of matter. Instead it marks the start of a new era in which, like naturalists poking and prodding an exotic new specimen, experimenters will be scrutinizing the top quark for clues to new physics. "Finding the top is much more than just filling in the blank in the table of quarks," says Fermilab collaborator John Huth of Harvard University. The top, after all, stands out from the crowd: With roughly the same mass as an entire gold atom, it is far and away the heaviest elementary particle and may hold clues to a major unsolved puzzle in physics—the origin of mass.

The top had been at large since the 1977 discovery of what turned out to be the fifth quark: the bottom, or beauty, quark. Physicists' standard picture of matter demanded a sixth: Beauty must have a mate. Fittingly, it was named truth, or top, and the search to find it was on. The top, like all but two of the other quarks, does not exist as part of ordinary, observable, matter and must be created by colliding high-energy streams of particles in an accelerator. In a tiny fraction of the collisions, physicists hoped, a top quark would materialize and live for 10^{-25} seconds before decaying into a characteristic shower of particles. But for 18 years, experiments designed to create the quark failed to muster enough energy.

Indeed, even the Tevatron—the world's most powerful accelerator at 1.8 trillion electron volts—was just barely able to probe the energy range where the top was thought to

hide. The first hints that the search might be ending came last April, when the CDF (Collider Detector at Fermilab) collaboration announced that their massive detector had recorded residue from 12 events that looked like top quark decays. It was "evidence" for the quark, but not enough to rule out the possibility that the events were due to background "noise" (Science, 29 April 1994, p. 658). Adding to the doubts, physicists at the other Tevatron detector, D0 (D-Zero), had seen no clear evidence. Since then, however, both groups continued to amass new data and reanalyze their earlier runs.

Rumors of strong results went back and forth between the two groups in January and February, each began to fear that the other would be the first to submit a report of the discovery, and the pace of the analysis sped up. Anxiety gripped the CDF group, for example, after an early February rumor that D0 had scheduled a seminar. At this "wine and cheese" event, some at CDF feared,

D0 might announce top quark results. "It was only human to imagine that," says Huth, a CDF member.

The meeting never took place, and in the end the announcement followed a program established 2 years ago by Fermilab Director John Peoples. If either group was ready to report significant results, it had to let the director know first and give the other collaboration a week to prepare and respond. In the end it was CDF that approached Peoples first, but at that point D0 was ready. Both groups submitted papers claiming "observation of the top quark" to Physical Review Letters on 24 February and agreed to publish their results in a joint seminar.

At the 2 March Fermilab seminar both collaborations reported detecting enough possible top quark events (see table) to reduce the odds that the signal arose by chance to around one in a million. The collaborations also presented data on what physicists call the "production cross section"—a measure of how, and how often, the top quark is produced—and on the quark's mass, determined from the energies of the decay products. "Everybody gets confidence from the fact that two collaborations that are pretty competitive with each other see the same result," says CDF physicist Richard Huth.

Now experimenters are looking ahead to the work to come. A Hughes puts it, "In a couple of months, no one will be asking you how sure you are the top exists; they will be asking you 'What is the mass?' A precise mass should provide insight into a theoretical mass-giving entity called the Higgs boson. "Particles are endowed with mass in proportion to their coupling with the Higgs field," explains William Bardeen, the acting head of Fermilab's theory group. "In that sense the more massive the particle, the closer you are to a place where the Higgs might reveal itself." Right now, he adds, "you can't get any closer than the top quark."

Besides its mass, physicists would like to test the new quark's spin, charge, and decay modes to see how well they match the predictions of standard theory. Serious gaps could serve as a window onto some new physics. Bardeen and his colleagues at Fermilab have theorized, for example, that certain energy states of the top quark may actually be the Higgs, or at least a part of it. Pursuing these questions, however, will mean creating top quarks in droves, says Bardeen. "You need a lot of events of all kinds to find the few events that will tell you the hint of the new physics," Fermilab's current schedule gives CDF and D0 another year to collect top quarks. That should be enough to improve measurements of the top's mass and cross section, but it won't satisfy physicists' craving for the particles.

After that, top quark enthusiasts will have to wait for two new machines. At Fermilab, the Tevatron is scheduled for a major upgrade, known as the main injector, slated to come on line in early 1999. "We are shooting for a factor of 10 and maybe 20 in total observable top quarks," says Peoples. Then the torch will pass to Europe's Large Hadron Collider, which will take the place of the Tevatron as the world's highest-energy accelerator sometime after the turn of the century.

—Antonio Regalado

	CDF	D0
Top events	43	17
Significance	4.8 σ	4.6 σ
Mass (billion electron volts)	176 \pm 13	199 \pm 30
Cross section (picobarns)	6.8 \pm 3.6	6.4 \pm 2.2

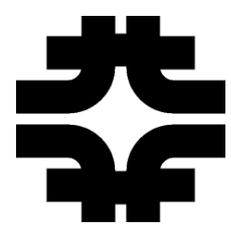
Two views of the top quark. In a rare high-energy collision, top quarks interact to produce top quarks, which decay into lighter particles.

SCIENCE • VOL. 267 • 10 MARCH 1995

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What actually happened...

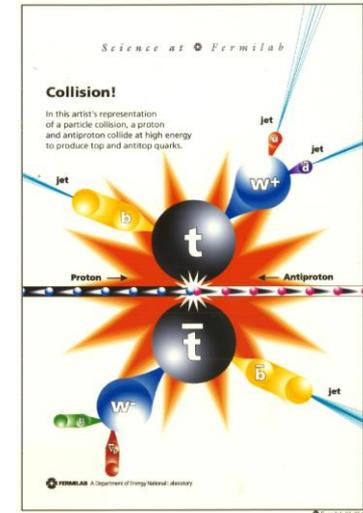
- Back in November we scheduled our regular show-at-the-lab-first seminar on the latest Top Results (search...) for Moriond
- Due to lack of time we temporarily put my name there as a placeholder (to be updated later)
- It was (mis-)interpreted by some at CDF as a potential ambush...



March 1995

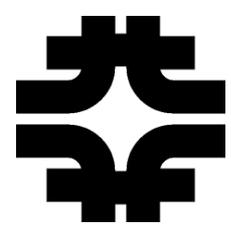


- A few more pics for the memories...



- ...and I was packing and heading to the airport – on my way to Moriond (if I'm not mistaken, that was Moriond30!; earlier this year we celebrated Moriond50...)
- My talk was scheduled as the very first of the conference...

Perfect Timing !!!

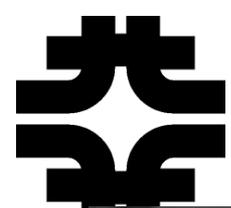


Moriond 1995



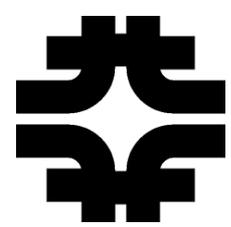
July 3, 2015

Boaz Klima - HCPSS2015



Moriond 1995

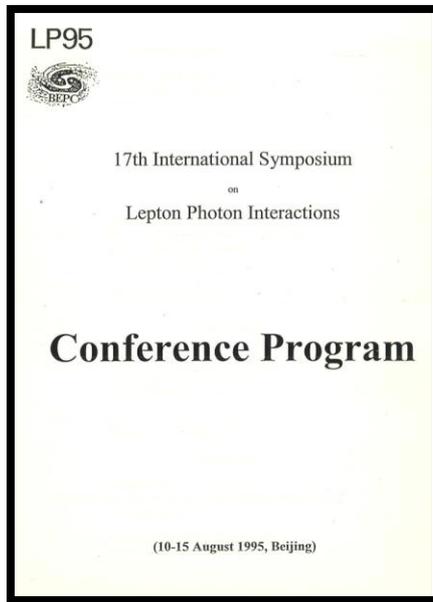




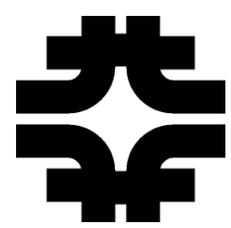
Top Results at LP95 (Beijing)



- Back in January I was also invited to give the “DØ Top Search” plenary talk at LP95



Thursday, August 10		Talk #
09:00-09:20	Chairman: Zhipeng Zheng (IHEP) Opening Speech - Guangzhao Zhou (CAS)	
09:20-09:50	Session chairman: Y. Yamaguchi (Tokyo) Top Physics in D0 - B. Klima (FNAL)	1a
09:50-10:20	Observation of Top Quark Production at Tevatron (CDF). Weiming Yao (LBL)	1b
	<i>Coffee break</i>	
11:00 -11:45	Session chairman: J. Sacton (Brussels) Review on Experimental Results on Precision Tests of Electroweak Theories. P.B.Renton (Oxford)	2
11:45-12:30	Implications of Precision Electroweak Data. Kaoru Hagiwara (KEK)	3
	<i>Lunch Break</i>	
14:00-14:45	Session chairman: Yuanben Dai (ITP, Beijing) Experimental Progress on Charmonium and Light Hadron Spectroscopy Jin Li (IHEP, Beijing)	4
14:45-15:30	Physics in Charm Energy Region Kuangta Chao (Peking Univ.)	5
	<i>Coffee Break</i>	
16:00-16:45	Session chairman: S. Yamada (Tokyo) Experimental Results from Polarized Beams at SLAC C. Prescott (SLAC)	6a
16:45-17:15	Nucleon Spin Structure Function From Muon Deep Inelastic Scattering V. Hughes (Yale)	6b
18:15-19:30	Welcome Reception	



Top Results at LP95 (Beijing)



- The first page of my talk was...

DØ 实验组顶夸克物理研究

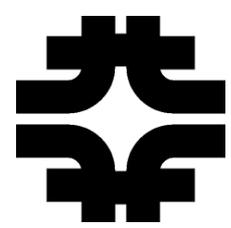
波阿兹·克立玛
费米国家实验室
代表DØ实验合作组

第十七届轻子光子相互作用国际学术会议
中华人民共和国 北京
一九九五年八月十日

Top Physics at DØ

Boaz Klima
Fermilab
for the DØ Collaboration

*17th International Symposium
on Lepton Photon Interactions
Beijing, People's Republic of China
10 August 1995*



Top Results at LP95 (Beijing)



- The second page looked like this...

The Title

- In January '95

Search for the Top Quark...

The Title

- In January '95

Search for the Top Quark...

- In February '95

*Observation of the Top Quark
at DØ*

The Title

- In January '95

Search for the Top Quark...

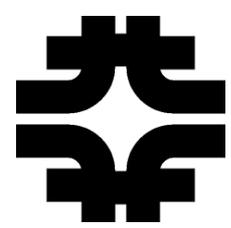
- In February '95

*Observation of the Top Quark
at DØ*

- In March '95

Top Physics at DØ

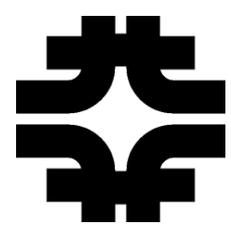
- In 3 months we went from search to discovery to studies...



Ten Years Later - Top Turns Ten



- ...we saw/heard variety of experiences/perspectives...



Top Turns Ten



- ...including on event 417...

The $e\mu$ Visits

As Run 1a progressed, I was occasionally visited by senior members of the collaboration (often with minions in tow) who had “discovered” $t\bar{t} \rightarrow e\mu$ events which I had apparently missed

Each time we dutifully staged the event(s) and looked it over with great care ...

... and each time the muon was obvious junk (and the other aspects of the events were unimpressive)

That is, until Boaz passed along the $e\mu$ event which he found (Jan 93)



The “muon” was not obvious junk! (although it did have some problems – reco gave $p_T^\mu \sim 8 \text{ GeV}/c$ & no CD track !)

And the other aspects of the event were truly spectacular!

a byproduct of the very loose default μ -id in reco

Event 417 – top discovery or not?
totally out of context e-mail quotes from 1993

Search for the Top Quark in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8 \text{ TeV}$

The mu's event is fantastic. It would be a shame to sit on it endlessly. I think that waiting for the collaboration meeting before going public would be too long a wait. If all the talent that has already thought about top cannot find a better explanation, we should then send it in to PRL as a prime candidate. Draft a letter this week, put all the good people on trying to tear it down, and if by Friday it still looks OK, fax it in.

Congratulations on your event. It has occupied many of my thoughts. Yes, I have fit the mass in a hopefully more model independent way than typically is done. With zero measurement errors the mass is above 147.5 and (with 68% confidence) less than about 162 GeV. The essential issue is reliable propagation of experimental measurement errors, which obviously will broaden these limits. I hope to make progress on this front in the next 24 hours.

We cannot ever assure ourselves of being right. However, I have always believed that, as scientists, we have the responsibility to tell what we know rather than hide behind obfuscation. We know that the $e\mu$ event is in a region of phase space that is not likely to be encumbered by background ...

once you have estimated the background ... and you find that all sources you can come up with give .03 events background (I have heard .01 event).... you have to publish the result. This should be done quickly, not because we are in a race with CDF BUT we have an obligation to do so as scientists after we were given the opportunity to build this detector. The conclusion of course is that within the minimal Standard Model the only source for such an event is the top quark.

Assuming ... there are no further surprises, because the event has been around for over a week now, I think we should publish this. By publish I mean not in the New York Times, but a seminar and a paper.

Philosophically, not being ex bubble chamber, what one can say about 1 event is not clear to me - the omega- was unambiguous - in D0 we do not have a unambiguous complete kinematic reconstruction.

No amount of hard work by the top group will change the fact that 417 is just one event, and one event will not find the top or limit the range of M_top.

It is obviously a gold plated top candidate like there has not been at FNAL before and I do not understand why we are not all scrambling over this event trying to find something wrong AND estimate the background (hard numbers).

"I, for one, was immediately convinced that it was top. I did not need studies of backgrounds, or of detector response, or of other factual matters... the event looked more convincing than, for example, Gerson Goldhaber's discovery of the Ω in $K^0 d$ interactions, and far more likely than the first Ω found by Nick Samios et al."

Many have urged publication of this event in some context as soon as possible. Opinion varies on how soon and with what slant. I consider three possible ways to publish:

1. publish the event and note that it looks like top, (going close to a claim)
2. publish the event as an interesting event with no spin on its physical origin.
3. publish a paper on the (negative) search for top with this event in the sample and discussed.

I believe the first two options are inappropriate. We cannot defend a single event as being top. We should not publish a paper that is a "gee whiz, isn't this one interesting" message - its not good physics. So:

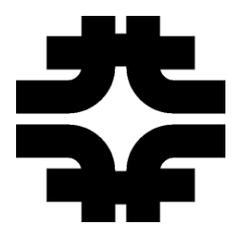
I propose we prepare a paper for publication which presents our best limit on the top quark mass. Both e-mu and e-e channels would be included in this paper...

Personally I'd rather be right than (infamous)

Event 417 is an unusual event and we might as well say so rather than play coy.

We have analyzed the surviving $e\mu$ event under the hypothesis that it is due to $t\bar{t} \rightarrow W(\mu)\bar{b}$ using an extension of the likelihood method based solely on the event topology as described in Ref. [13]. Our analysis [14] shows that this event is kinematically consistent with $t\bar{t}$ production over the mass range 100 to 200 GeV/c^2 . Using a likelihood function based upon the parton distribution functions, partonic cross sections, and decay leptonic distributions, we find that the peak likelihood for this event is near the median found in MC $e\mu$ samples. The likelihood distribution is maximized for a top mass of about 145 GeV/c^2 , but masses as high as 200 GeV/c^2 cannot be excluded. This result is consistent with, but independent of, our lower limit on m_t described above.

Congratulations!



Top Turns Ten

- ...and we even got the view of those who left the field...

Architecting Future Communications

From 3rd Generation of Quarks To 3rd Generation of Wireless

After Top Quark was found...



Building Next Generation Networks

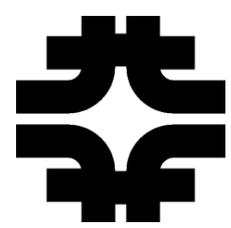
Homeland Security

Those who went on to search for TOP...dollar!

Quality Control & Verification

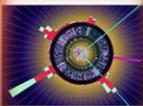
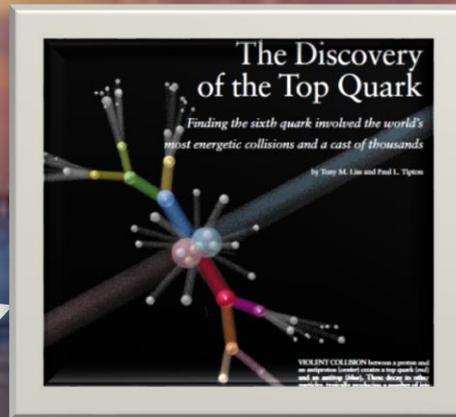
and still searching...

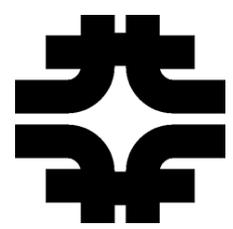
Patent Claims Worth Billions



To Sum It All Up

Following 2 decades of intense searches worldwide, the Top Quark was discovered at Fermilab by CDF and DØ in 1995, and then the HEP world turned to making intense studies of its production mechanism and fundamental properties – so far no surprises; stay tuned!





Thank you!