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

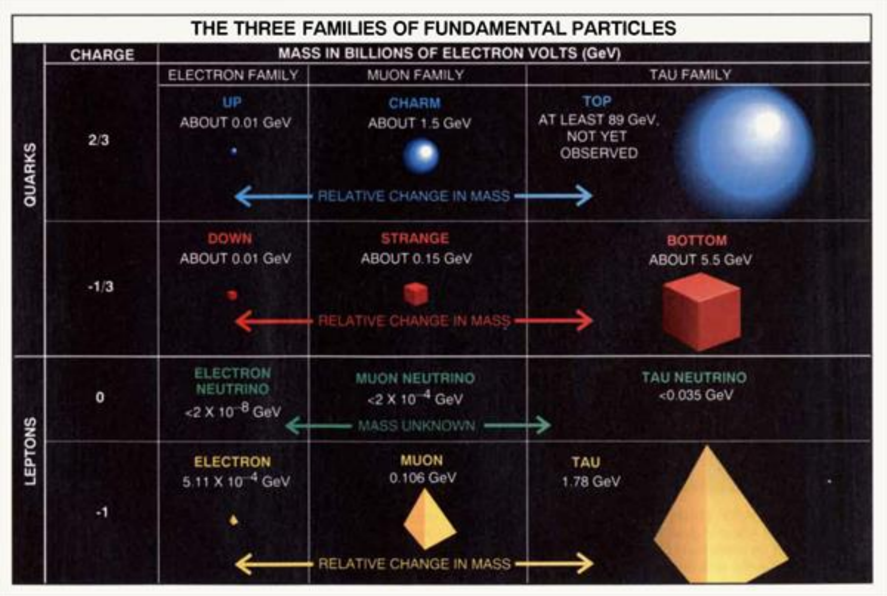
Prologue

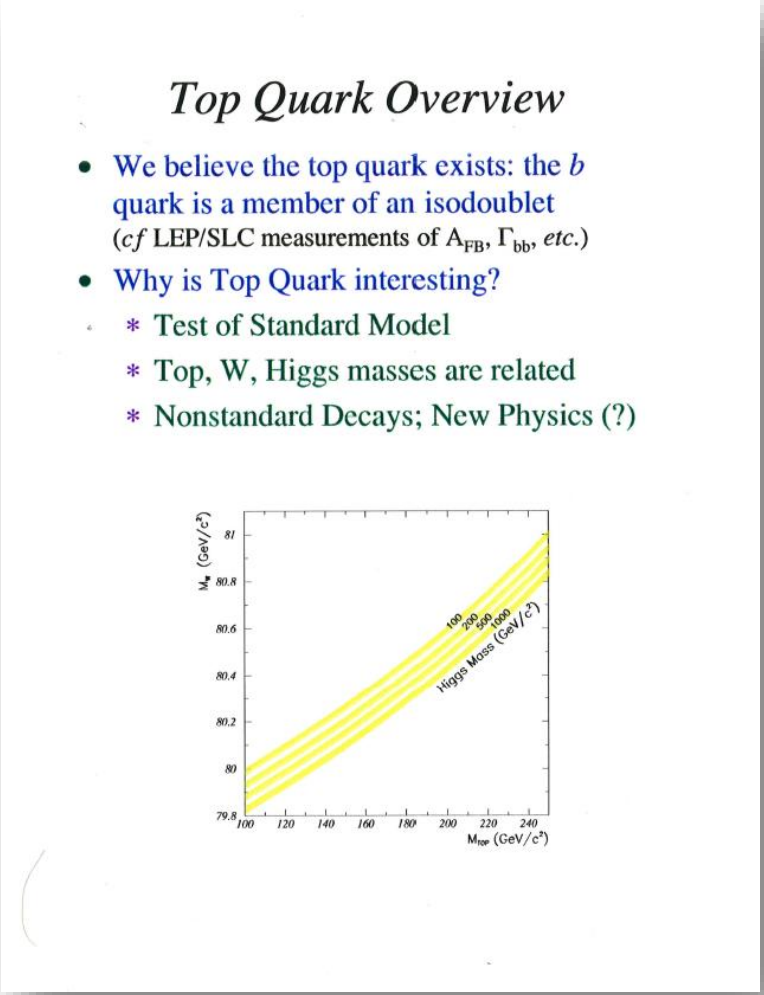
Top Mass – Predictions & Limits

- 1977 - since $M_b \approx 3xM_c \approx 9xM_s$, it seemed 'natural' to guess that the new Top quark would have $M_t \approx 3xM_b \approx 14$ GeV
- Variety of theoretical models & predictions followed, e.g. $M_t \approx 27$ GeV
- 1984 - PETRA e+e- collider @DESY, Germany, ruled out top quark with $M_t < 23.3$GeV
- 1984 - UA1 @ISR, CERN reported evidence for an excess of events at low $M_T(e\nu)$ 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; Mt > 30.2 GeV
- 1990 – LEP experiments excluded $M_t < 45.8$ GeV
- 1990 – UA2 @ISR set a limit on $W \rightarrow tb$ at $M_t > 69$ GeV, effectively closing the search channel $W \rightarrow$ Top (what if their masses are similar?)
- 1992 – CDF @Tevatron using Run 0 data excluded $M_t < 91$ 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 →





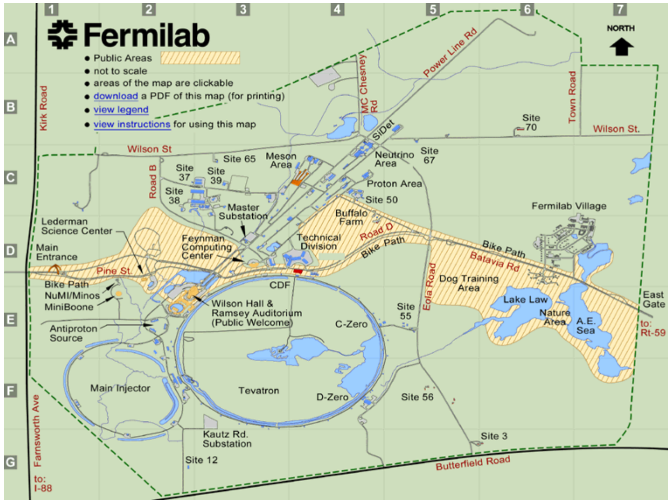
Top Quark Overview

- 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 DØ experiment recorded its very first antiproton-proton interaction on May 12, 1992 (“Run 1”)

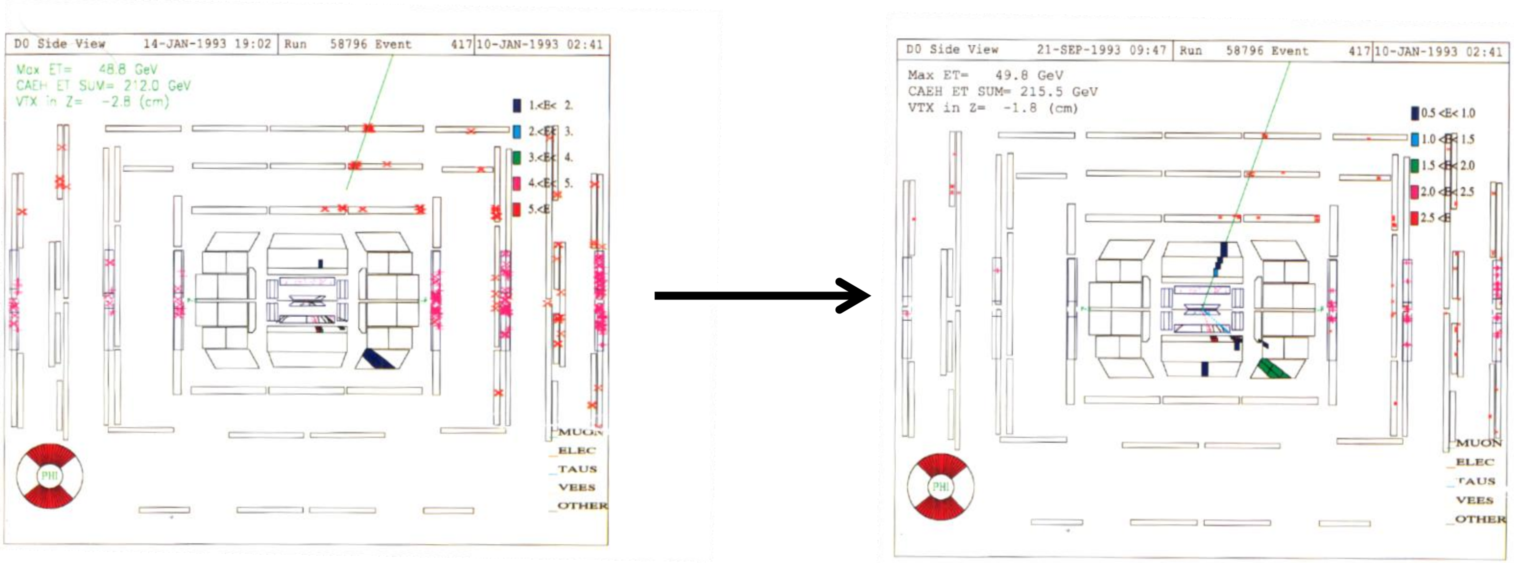


DØ Event 417 - Intro

- 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_T μ; 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^{μ} = 8 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

$$t\bar{t} \rightarrow e + \mu + 2\ \text{Jets} + \not{E}_T$$

(p_T^{μ}~195GeV; E_T^{e}=~99GeV, $\not{E}_T$~102GeV; E_T^{jets}~25, 22GeV)

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

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

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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 apologize 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 organize 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-FG02-91ER40685

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

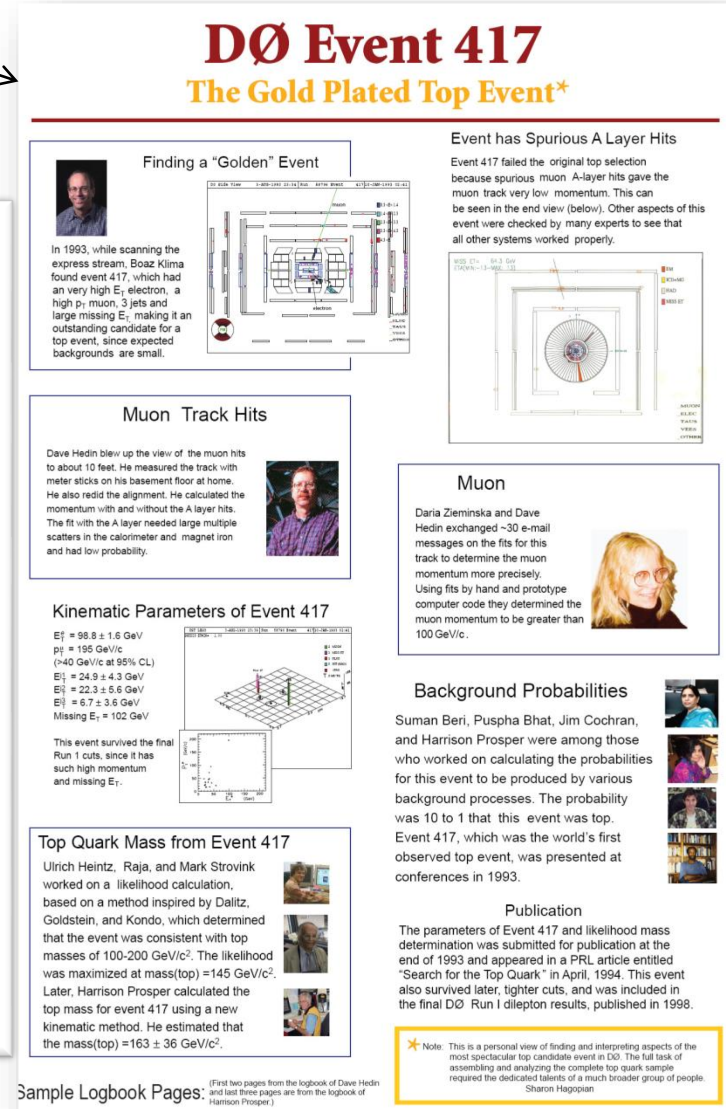
In contrast, I have a modern story about a paper on the D-Zero top event. An extraordinary μ-e event was found by Boaz Klima last winter, and I, for one, was immediately convinced that it was top. I did not need studies of backgrounds, of detector response, or of other factual matters, it was an open and shut case as far 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 Ω^- in K^+d 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 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!

We may have been a little too free-spirited in the days when Bogdan Maglic wrote in the Proceedings of the First Conference on Meson Spectroscopy that "to seek is nothing, to find is the thing", but it seems to me that we have now gone far too conservative. Too easily swayed from speaking out. So, I hope that we can recapture that entrepreneurial spirit that our field was known for, and give greater opportunity to our younger colleagues to risk, to fail and to learn.

I thank Derek Colley and the Organizers of "Bubbles-40" for providing me the opportunity of speaking at the meeting, and Paul Slattery for comments on this essay.

Tom Ferbel – Nucl. Phys. B

Sharon Hagopian – Top Turns Ten



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_T 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 Hedin 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 redid the alignment. He calculated the momentum with and without the A layer hits. The fit with the A layer needed large multiple scatters in the calorimeter and magnet iron and had low probability.

Muon

Daria Zieminska and Dave Hedin 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_T^e = 98.8 ± 1.6 GeV
p_T^μ = 195 GeV/c
(>40 GeV/c at 95% CL)
E_T^{j1} = 24.9 ± 4.3 GeV
E_T^{j2} = 22.3 ± 5.6 GeV
E_T^{j3} = 6.7 ± 3.6 GeV
Missing E_T = 102 GeV

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

Background Probabilities

Suman Beri, Puspha Bhat, Jim Cochran, and Harrison Prosper were among those who worked on calculating the probabilities for this event to be produced by various background processes. The probability was 10 to 1 that this event was top. Event 417, which was the world's first observed top event, was presented at conferences in 1993.

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.

Publication

The parameters of Event 417 and likelihood mass determination was submitted for publication at the end of 1993 and appeared in a PRL article entitled "Search for the Top Quark" in April, 1994. This event also survived later, tighter cuts, and was included in the final DØ Run I dilepton results, published in 1998.

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

* 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

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 Next Directory

Folder: TOP
From: D0SFT::KLIMA (Boaz Klima (708)840-2323)
Subject: New TOP Group Organization
Date: 29-MAR-1994 17:08
Expires: 28-MAY-1994 17:08

The TOP group has been very active for more than two years
leadership of Raja and Serban. The group produced exciting phy
resulted in the world's highest lower limit on the top quark m
GeV/c**2. These results were summarized in a paper which has bee
for publication in Physical Review Letters. We'd like to commen
Serban on the fine work they have done.

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

The new TOP group structure will be the following:

Convenors: Nick Hadley and Boaz Klima

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

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

7 subgroups:
===========

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 th
leaders. This is by no means everything that they will do, bu
some indication of where we are heading.

The subgroup leaders will be responsible for organizing thei
and for coordinating the activities in their subgroup with the
group effort. Dzero is likely to find top only through the combin
of all the subgroups, and it is important that each subgroup pe
analysis taking into account the efforts of the other groups.
large size of the TOP group, subgroup leaders are expected t
large fraction of their time to communicating with other subgrou
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 D0News. 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 D0FS 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:     D0SFT::KLIMA          ( Boaz Klima (708)840-2323 )
ubject:  TOP Group EMail Distribution List
ate:     29-MAR-1994 17:10
xpires:  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  D0News. We have received the TOP
roup mailing list  from the previous  convenors. We'd  like to make sure the
ist 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

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                    TOP GROUP MAILING LIST, 1-APR-1994
                    ----------------------------------

DECNET ADDRESS            NAME                      COMMENTS      STUDENT
--------------            ----                      --------      -------

 e-mu channel

NALD0::WIMPENNY           !Steve Wimpenny
NALD0::BHATNAGAR          !Vipin Bhatnagar                         X (1b)
NALD0::COCHRAN            !Jim Cochran
```

```
!
D0SFT::MEENA              !Meenakshi Narain
FNALD0::KEHOE             !Bob Kehoe                               X (1b)
FNALD0::BALAMURA          !V. Balamurali                           X (1a)
!
! mu-mu channel
!
FNALD0::BANTLY            !Jeffrey Bantly
FNALD0::TARAZI            !Jamal Tarazi                            X (1b)
FNALD0::RAYMOND           !Raymond Hall
!
! e-jets channel
!
FNALD0::PARTRIDGE         !Richard Partridge
FNALD0::CHOPRA            !Sailesh Chopra                          X (1b)
FNALD0::CHANG             !Ssu-Min Chang           b-tagging       X (1b)
FNALD0::TAMBURELLO        !Peter Tamburello                        X (1b)
FNALD0::DHIMAN            !Dhiman Chakraboty                       X (1a)
FNALD0::XU                !Haowei Xu               b-tagging       X (1a)
FNALD0::SNYDER            !Scott Snyder            b-tagging       X (1a)
FNALD0::PANG              !Myungun Pang                            X (1a)
BNLD01::SERBAN            !Serban Protopopescu
FNALD0::MIETTINEN         !Hannu Miettinen
FNALD0::COBAU             !Bill Cobau
UMDHEP::DREW              !Drew Baden
D0SFT::BHAT               !Pushpa Bhat
D0SFT::GREENLEE           !Herb Greenlee
D0SFT::JMBUTLER           !John Butler
!
! mu-jets channel
!
FNALD0::HOBBS             !John Hobbs
FNALD0::YOSHIKAWA         !Cary Yoshikawa                          X (1a)
FNALD0::JOEY              !Joey Thompson
UCRPHY::HEINSON           !Ann Heinson
!
! tau channels
!
FNALD0::QZLI              !Qizhong Li-Demarteau
FNALD0::KOTCHER           !Jon Kotcher
!
! all jets channel
!
D0SFT::STEWART            !Chip Stewart
FNALD0::CRETSINGER        !Cathy Cretsinger                        X (1b)
```

```
! We don't know yet!
!
!
BNLCL6::GORDONH           !Howard Gordon
BNLD01::GIBBARD           !Bruce Gibbard
CSA::STROVINK             !Mark Strovink
D0SFT::ABACHI             !Shariahr Abachi
D0SFT::FUESS              !Stu Fuess
D0SFT::KRZYW              !Stan Krzywdzinski
D0SFT::RAJA               !Rajendran Raja
FNALD0::BRAJESH           !Brajesh Chouhary
FNALD0::EPPLEY            !Geary Eppley
FNALD0::FATYGA            !Mirek Fatyga
FNALD0::HEDIN             !David Hedin
FNALD0::NGRAF             !Norman Graf
FNALD0::PLUQUET           !Alain Pluquet
FNALD0::TAKETANI          !Atushi Taketani
FNALD0::ULI               !Ulrich Heintz
FNALD0::AHN               !Seung Ahn
FNALD0::DIEHL             !Tom Diehl
FNALD0::YAMADA            !Ryuji Yamada
FNALV::GENSER             !Krzysztof Genser
FNALV::SLAVIK             !Slava Klyukhin
FSUHEP::HARRY             !Harrison Prosper
IND::DARIA                !Daria Zieminska
MSUHEP::ABOLINS           !Maris Abolins
SBHEP1::ALPINIST          !Chang Kee Jung
UHHEPG::MDJ               !Michael Jones
UHHEPB::MWP               !Mike Peters
!
! Ex officio
!
FNALV::PGRANNIS           !Paul Grannis
FNALV::MONT               !Hugh Montgomery
FNALV::HEFISK             !Gene Fisk
!
!
! Convenors
!
D0SFT::KLIMA              !Boaz Klima
UMDHEP::HADLEY            !Nick Hadley
!
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DØ Updated Top Mailing List

- Later on (in Nov. 1994) it was updated
  - More people (84) - ~20% of the entire collaboration
  - Better recognition of individual effort

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Previous     Next     Directory

Folder:    TOP
From:      D0SFT::KLIMA          ( Boaz Klima (708)840-2323 )
Subject:   Updated TOP Group EMail Distribution List
Date:      02-NOV-1994 14:13
Expires:   21-MAY-1995 14:13

!
!                 TOP Group Mailing List, 02-NOV-1994
!                 ===================================
!
!                    ( Total number - 81+3 people )
!
!
!DECNET ADDRESS            NAME                 COMMENTS          STUDENT
!--------------            ----                 --------          -------
!
! e-mu channel (6)
!
SMTP%"WIMPENNY@UCRPH0.UCR.EDU" !Steve Wimpenny   subgroup leader
FNALD0::BHATNAGAR          !Vipin Bhatnagar                       X (1b)
D0SFT::ABACHI              !Shahriar Abachi
FNALD0::COCHRAN            !Jim Cochran
FNALD0::SUMAN              !Suman Beri
FNALD0::YAMADA             !Ryuji Yamada
!
! e-e channel (3)
!
D0SFT::MEENA               !Meenakshi Narain    subgroup leader
FNALD0::KEHOE              !Bob Kehoe                             X (1b)
FNALD0::BALAMURA           !V. Balamurali                         X (1a)
!
! mu-mu channel (2)
!
FNALD0::BANTLY             !Jeffrey Bantly      subgroup leader
FNALD0::RAYMOND            !Raymond Hall
!
! e-jets channel (25)
!
FNALD0::PARTRIDGE          !Richard Partridge   subgroup leader
FNALD0::CHOPRA             !Sailesh Chopra                        X (1b)
FNALD0::CHANG              !Ssu-Min Chang                         X (1b)
FNALD0::TAMBURELLO         !Peter Tamburello                      X (1b)
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FNALD0::VIRADOR            !Patrick Virador                       X (1b)
FNALD0::DHIMAN             !Dhiman Chakraboty                     X (1a)
FNALD0::XU                 !Haowei Xu                             X (1a)
FNALD0::SNYDER             !Scott Snyder                          X (1a)
FNALD0::PANG               !Myungun Pang                          X (1a)
BNLD01::SERBAN             !Serban Protopopescu
D0SFT::BHAT                !Pushpa Bhat
D0SFT::GREENLEE            !Herb Greenlee
D0SFT::JMBUTLER            !John Butler
D0SFT::RAJA                !Rajendran Raja
FNALD0::COBAU              !Bill Cobau
FNALD0::EPPLEY             !Geary Eppley
FNALD0::MIETTINEN          !Hannu Miettinen
FNALD0::QIANJ              !Jianming Qian
FNALV::MELANSON            !Harry Melanson
FNALV::SLAVIK              !Slava Klyukhin
ISUMMA::HAUPTMAN           !John Hauptman
SBHEP::MOHAMMADI           !Mohammad Mohammadi
UMDHEP::DREW               !Drew Baden
!
! mu-jets channel (9)
!
FNALD0::HOBBS              !John Hobbs          subgroup leader
D0SFT::AMIDI               !Erfan Amidi                           X (1b)
FNALD0::HUIZHU             !Hui Zhu                               X (1b)
FNALD0::ROCKWELL           !Tom Rockwell                          X (1b)
FNALD0::YOSHIKAWA          !Cary Yoshikawa                        X (1a)
FNALD0::JOEY               !Joey Thompson
SMTP%"HEINSON@UCRPH1.UCR.EDU" !Ann Heinson
UHHEPG::MDJ                !Michael Jones
MSUHEP::ABOLINS            !Maris Abolins
!
! tau channels (3)
!
FNALD0::QZLI               !Qizhong Li-Demarteau subgroup leader
FNALD0::GRIFFIN            !Greg Griffin                          X (1b)
FNALD0::KOTCHER            !Jon Kotcher
!
! all jets channel (8)
!
D0SFT::STEWART             !Chip Stewart        subgroup leader
FNALD0::CRETSINGER         !Cathy Cretsinger                      X (1b)
D0UMI1::AMOS               !Norm Amos
FNALD0::AHN                !Seung Ahn
FNALD0::FEHERS             !Sandor Feher
FNALD0::MAREK              !Marek Zielinski
```
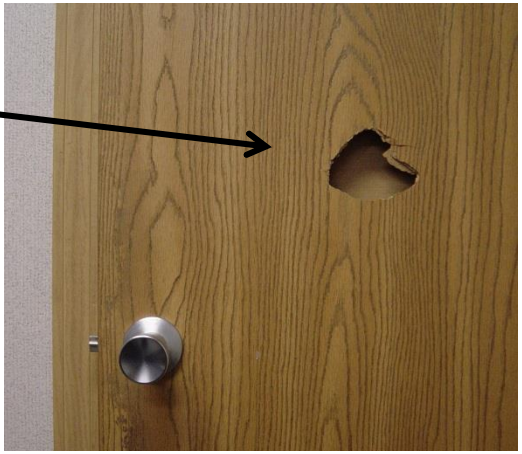

```
!
! We don't know yet! (23)
!
FNALD0::HSIEH              !Frank Hsieh
BNLCL6::GORDONH            !Howard Gordon
BNLD01::GIBBARD            !Bruce Gibbard
CSA::STROVINK              !Mark Strovink
DPHVX2::AZYLBER            !Armand Zylberstejn
D0SFT::FUESS               !Stu Fuess
D0SFT::KRZYW               !Stan Krzywdzinski
FNALD0::BRAJESH            !Brajesh Chouhary
FNALD0::FATYGA             !Mirek Fatyga
FNALD0::HEDIN              !David Hedin
FNALD0::NGRAF              !Norman Graf
FNALD0::PLUQUET            !Alain Pluquet
FNALD0::ULI                !Ulrich Heintz
FNALD0::DIEHL              !Tom Diehl
FNALV::GENSER              !Krzysztof Genser
FSUHEP::HARRY              !Harrison Prosper
IND::DARIA                 !Daria Zieminska
SBHEP1::ALPINIST           !Chang Kee Jung
UHHEPB::MWP                !Mike Peters
CSA::MADARAS               !Ron Madaras
UMDHEP::ENO                !Sarah Eno
CSA6::AIHARA               !Hiro Aihara
MICH::NEAL                 !Homer Neal
!
! Ex officio (3)
!
FNALV::PGRANNIS            !Paul Grannis
FNALV::MONT                !Hugh Montgomery
FNALV::HEFISK              !Gene Fisk
!
! Convenors (2)
!
D0SFT::KLIMA               !Boaz Klima
UMDHEP::HADLEY             !Nick Hadley
!
```

- These were the main people driving the Top search in DØ

DØ Top Group Objectivity

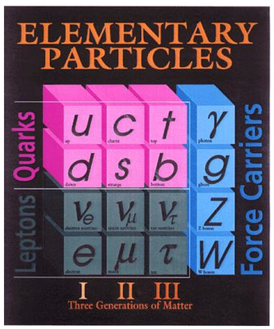
- Trivial statement – we were all eager to discover the Top quark unless it was not there…
- To guard against unconscious bias, we introduced (from above!) particle ID definitions that all analyzers had to follow. Later on in the life of DØ we called them “certified object ID”, but back then that was 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

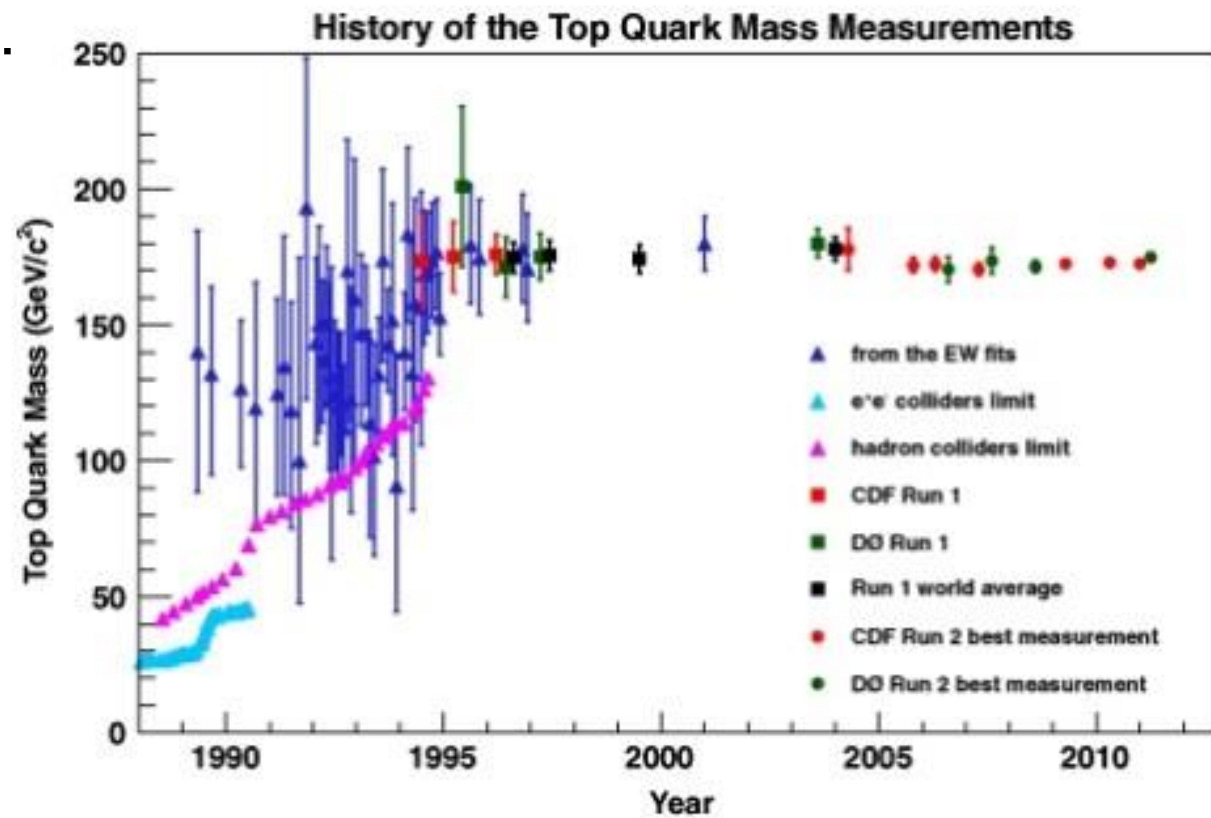


- As a side remark, if one does not pay attention to these potential biases, in an analysis with numerous channels the overall impact may be large/significant

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: D0SFT::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: D0SFT::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; ~sqrt(N)), I proposed a change in strategy

From: KLIMA
To: SBHEP::GRANNIS; FNALV::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 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

New Strategy for Discovery

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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 suspecious.

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 Ht 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 disrtibution 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 introduced 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 accross the board, namely in all channels (including di-leptons) can go up from 15GeV (to 20GeV?). 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	15	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 anlyses. This does not require any change in our current anlysis; 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 arlier, the idea was to reduce the background as much as we could while aintaining good efficiency for signal. The first attempt contained the ollowing 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 Et cut on the jets was increased from 15GeV to 20GeV.

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

ne significance of our results in terms of probability for not having top in ur data ("consistency with no top" hypothesis) is 0.7% (assuming gaussian ikelihood - 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

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

Jan. 13, 1995

Optimizing Top Analysis for Heavy Top - 2nd Attempt
==

Two interesting question 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 W+3jets data a la 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 guesstimate 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

e significance of our results in terms of probability for not having top in r data ("consistency with no top" hypothesis) is 0.001% (assuming gaussian kelihood - 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

e significance of our results in terms of probability for not having top in r data ("consistency with no top" hypothesis) is 0.002% (assuming gaussian kelihood - 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 Ht cut from 140GeV to 200GeV (or to 180GeV) while keeing everything else (all id and analysis cuts) in the analysis unchanged.

2. "Same top efficiency" - changing the Ht 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 Ht 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 Ht 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 Ht 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: *

	(Ht,A)	tt(200GeV)		Background		S/B	S/sqrt(B)
		# events in 36pb-1	% loss wrt current	# events in 36pb-1	increased rejection		
Current	(140,.05)	2.2+/-0.4	0	3.9+/-1.6	0	.56	1.11
Opt. 1	(200,.05)	1.8+/-0.3	20	1.5+/-0.6	2.6	1.2	1.47
Opt. 1	(180,.05)	2.0+/-0.3	10	2.0+/-0.8	1.9	1.0	1.41
Opt. 2	(200,.03)	2.3+/-0.4	0	2.4+/-1.0	1.6	.96	1.48
Opt. 3 **	(200,.08)	1.1+/-0.2	50	0.5+/-0.2	5.0	2.2	1.56

* - 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 - 3nd 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, Ht (and everything else as in the "standard 1a" analysis). We asked him to plot two parameters as a function of Ht 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:

Mt (GeV)	140	160	180	200
Significance peaks at (GeV)	130	160	210	230
Efficiency loss wrt Ht>100 GeV				
10%	130	140	170	200
20%	150	160	190	220
Efficiency loss wrt Ht>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 Ht 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 Ht 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 $\sqrt{s} = 1.8$ 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 $176 \pm 8(\text{stat.}) \pm 10(\text{sys.})$ GeV/c^2, and the $t\bar{t}$ production cross section to be $6.8^{+3.6}_{-2.4}$ pb.

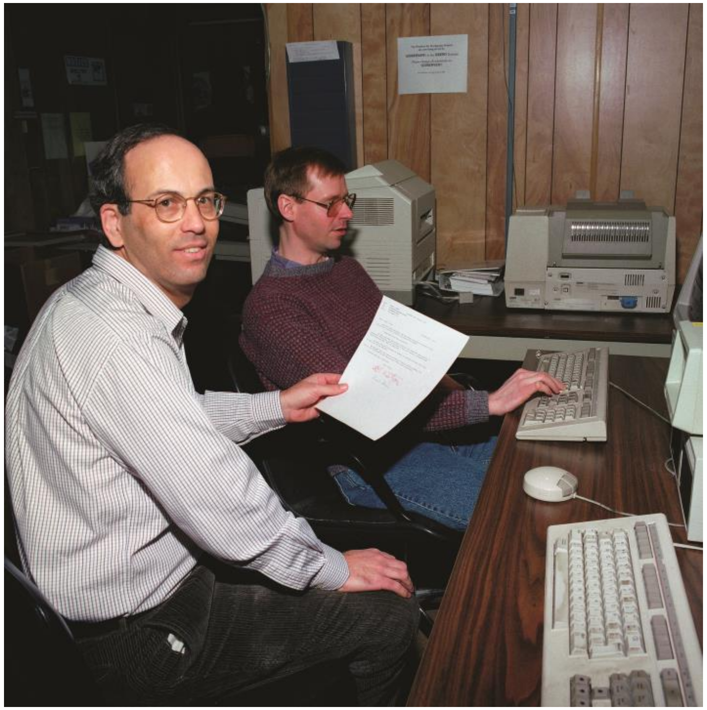
VOLUME 74, NUMBER 14 PHYSICAL REVIEW LETTERS 3 APRIL 1995

Observation of the Top Quark

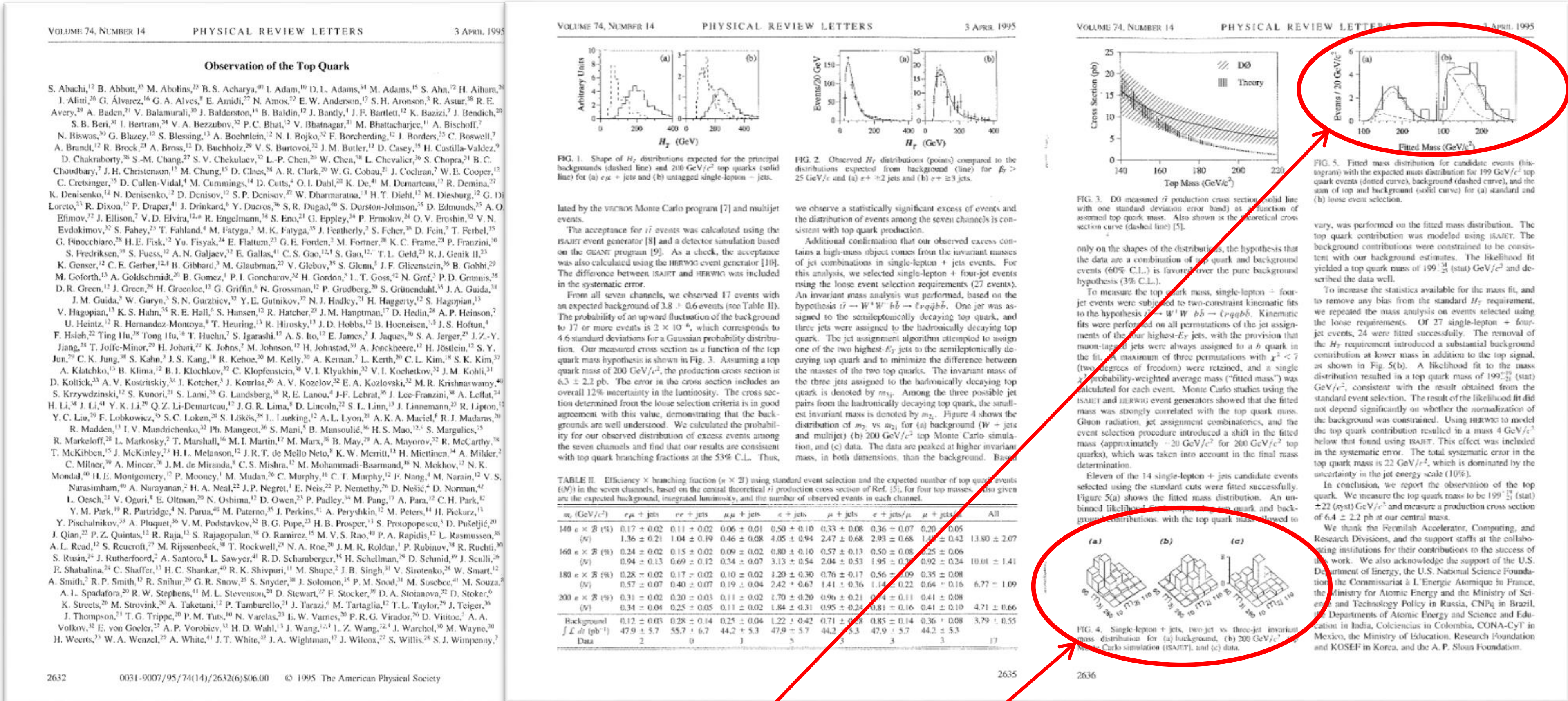
The D0 Collaboration reports on a search for the standard model top quark in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron with an integrated luminosity of approximately 50 pb^{-1}. We have searched for $t\bar{t}$ production in the dilepton and single-lepton decay channels with 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^{+19}_{-21} (stat) ± 22 (syst) GeV/c^2 and its production cross section to be 6.4 ± 2.2 pb.

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

Submission of Top Discovery Papers



DØ Top Quark Discovery Paper

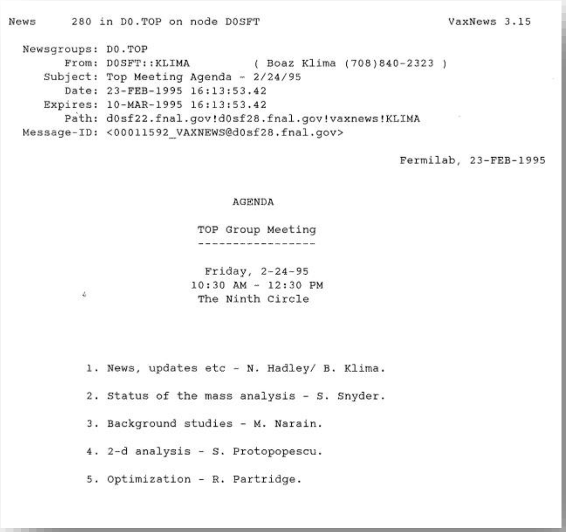


- Very important contributions – M_t and (M_t vs M_W)

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

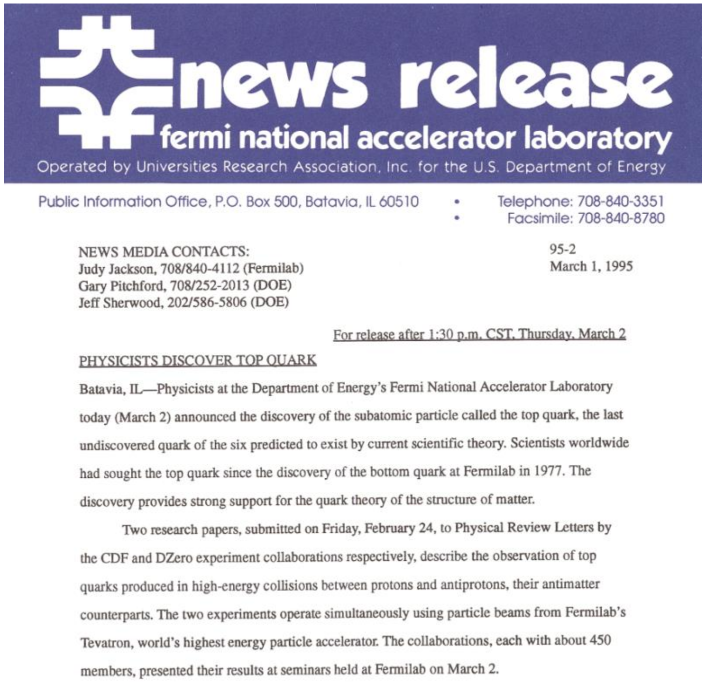
1. News, updates etc - N. Hadley/ B. Klima.
2. Status of the mass analysis - S. Snyder.
3. Background studies - M. Narain.
4. 2-d analysis - S. Protopopescu.
5. Optimization - R. Partridge.

→

- …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



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: 708-840-3351 • 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
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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…

After the celebrations…

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

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.

As rumors of strong results flew 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 protocol 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 preview 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 Hughes.

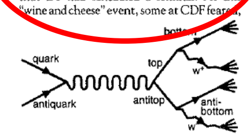
Now experimenters are looking ahead to the work to come. As Hughes puts it, "In a couple of months no one will be asking you how sure you are the top exists; they will be asking you 'What is the mass?' " A precise mass should provide insight into a theoretical mass-giving entity called the Higgs boson. "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	4.8σ	4.6σ
Mass (billion electron volts)	176 ±13	199 ±30
Cross section (picobarns)	$6.8^{+3.6}_{-2.4}$	6.4 ± 2.2

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

SOURCE: FERMILAB

As rumors of strong results flew 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,

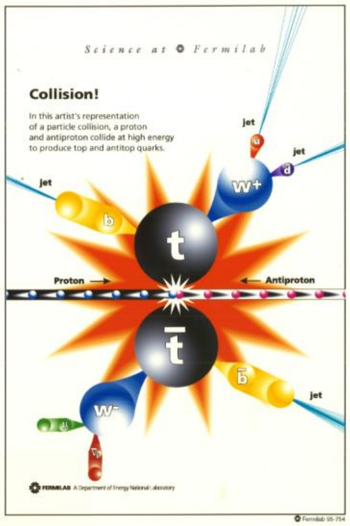
D0 might announce top quark results. "It was only human to imagine that," says Huth, a CDF member.

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…

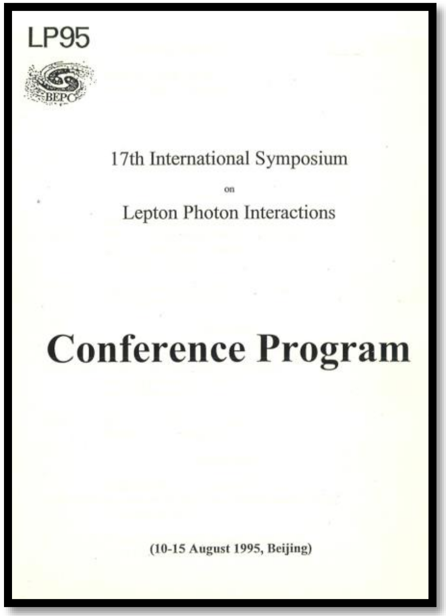
Perfect Timing !!!

Moriond 1995

Moriond 1995

Top Results at LP95 (Beijing)

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



LP95

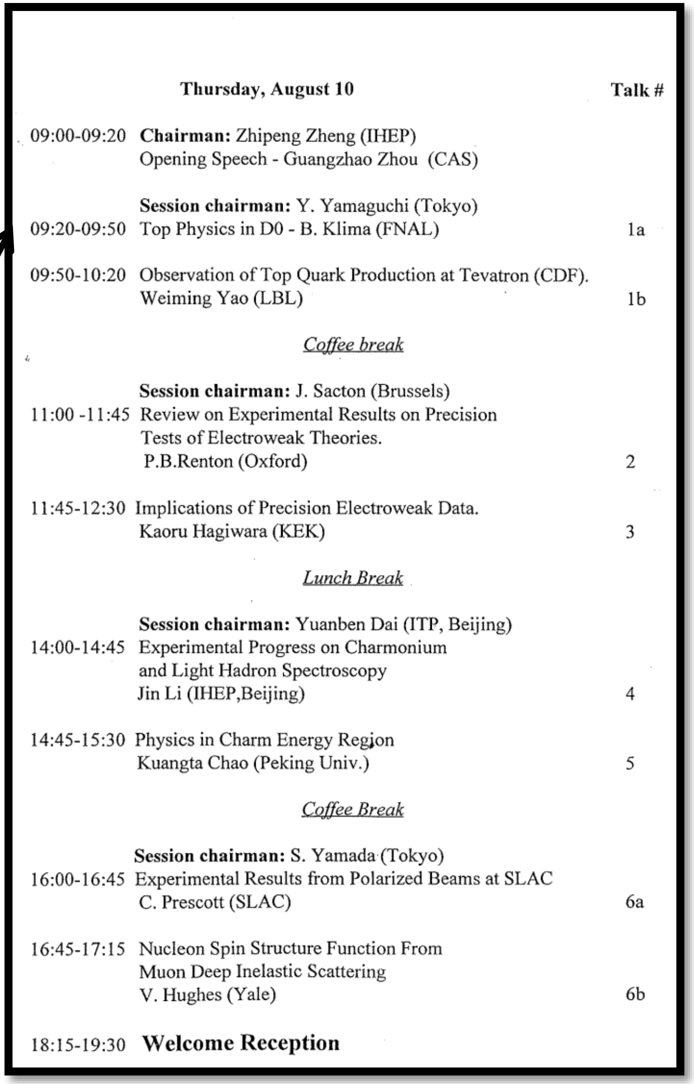
17th International Symposium

on

Lepton Photon Interactions

Conference Program

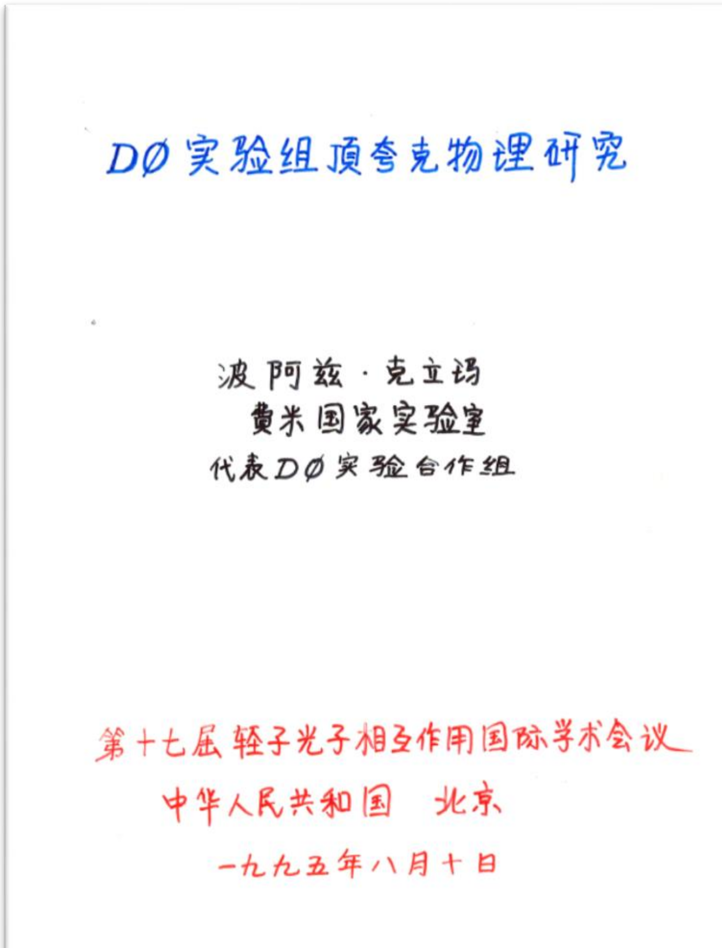
(10-15 August 1995, Beijing)



Thursday, August 10		Talk #
09:00-09:20	**Chairman:** Zhipeng Zheng (IHEP) Opening Speech - Guangzhao Zhou (CAS)	
	Session chairman: Y. Yamaguchi (Tokyo)	
09:20-09:50	Top Physics in D0 - B. Klima (FNAL)	1a
09:50-10:20	Observation of Top Quark Production at Tevatron (CDF). Weiming Yao (LBL)	1b
	Coffee break	
	Session chairman: J. Sacton (Brussels)	
11:00 -11:45	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
	Lunch Break	
	Session chairman: Yuanben Dai (ITP, Beijing)	
14:00-14:45	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
	Coffee Break	
	Session chairman: S. Yamada (Tokyo)	
16:00-16:45	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**	

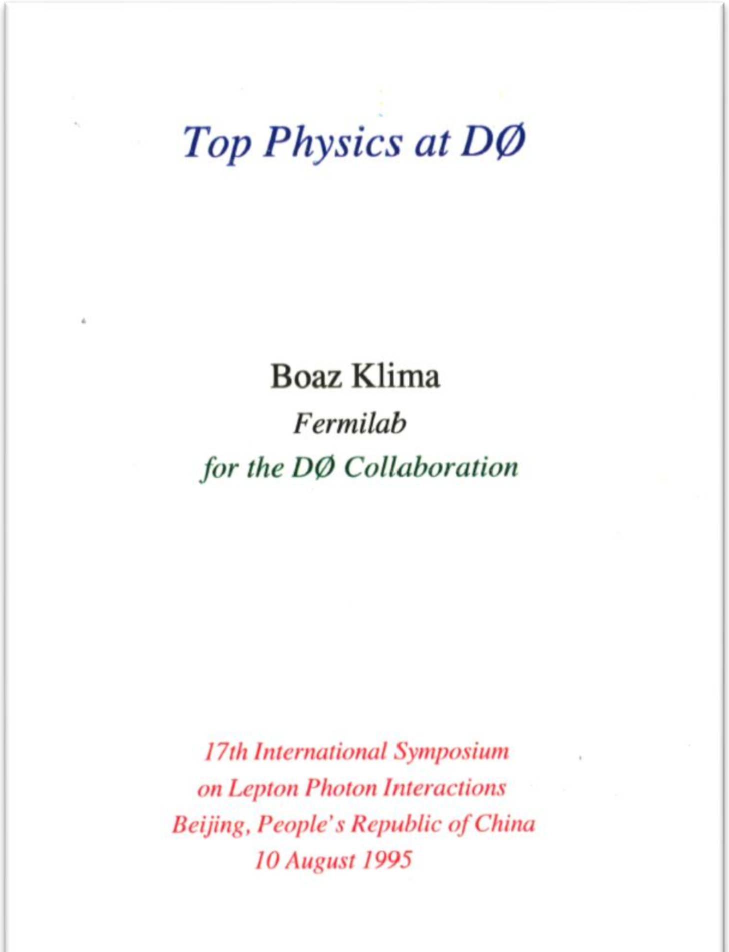
Top Results at LP95 (Beijing)

- 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

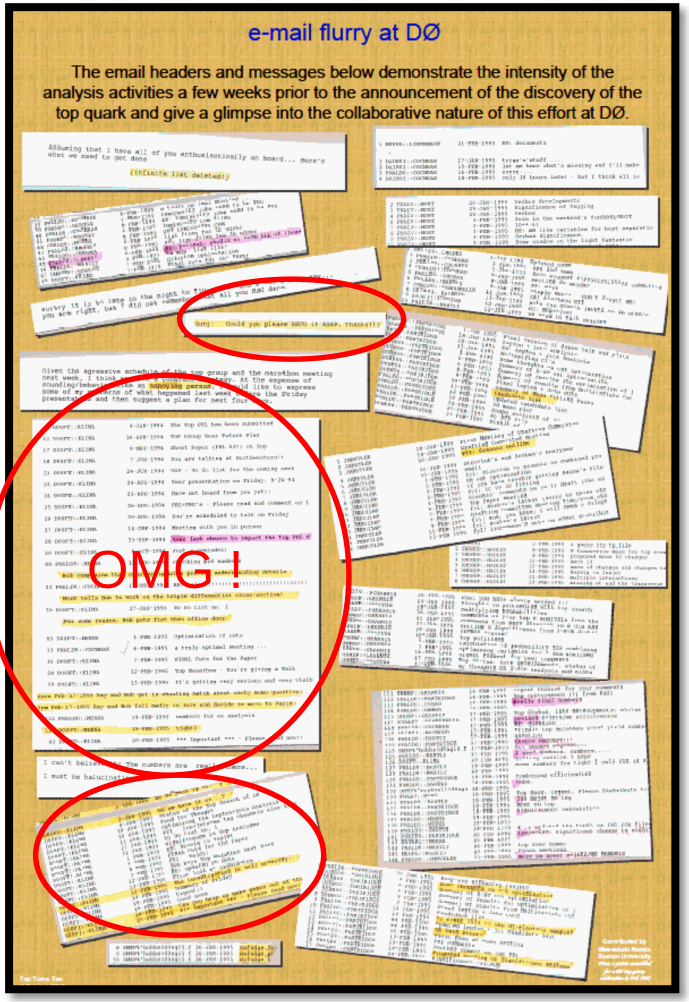
- In March '95

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 eμ 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)

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

That is, until Boaz passed along the eμ event which he found (Jan 93)

The "muon" was not obvious junk!

(although it did have some problems – reco gave $p_T^{\mu} \sim 8$ GeV/c & no CD track !)

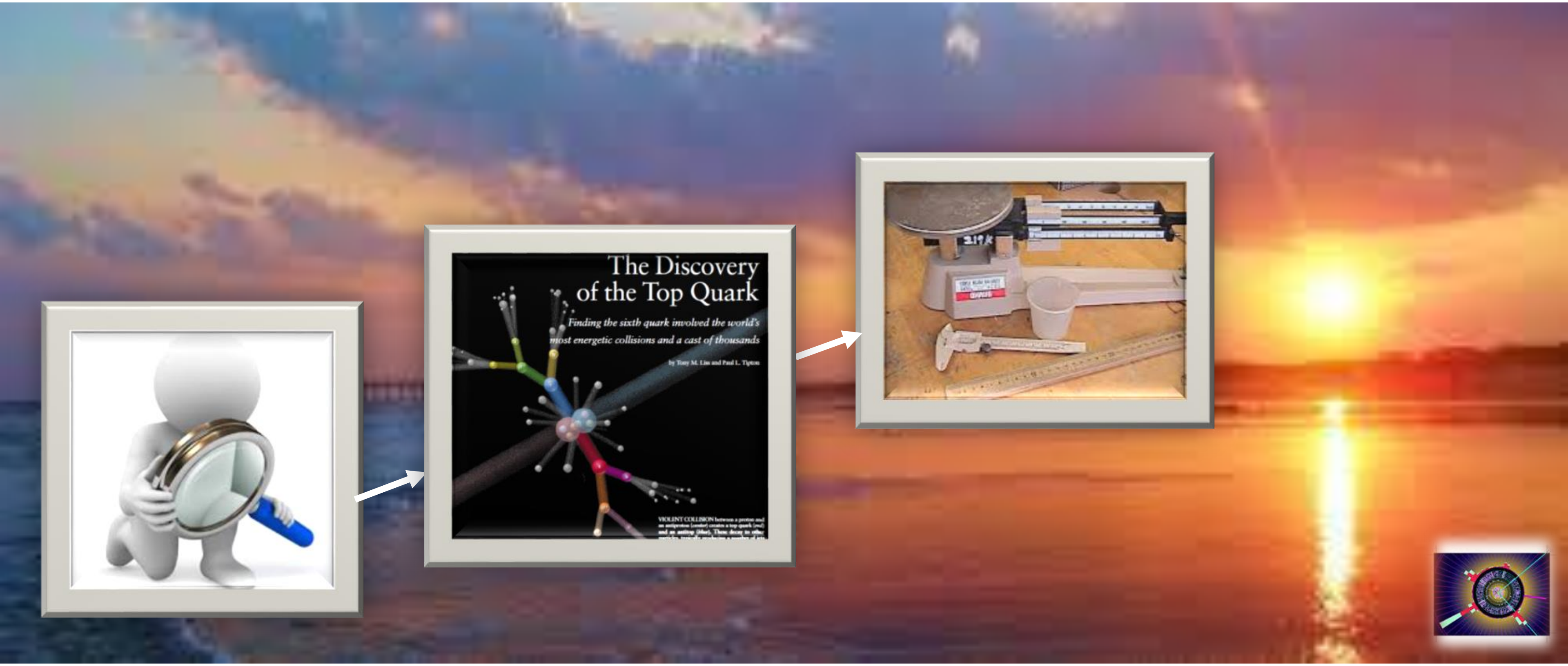
And the other aspects of the event were truly spectacular!

Top Turns Ten

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

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!