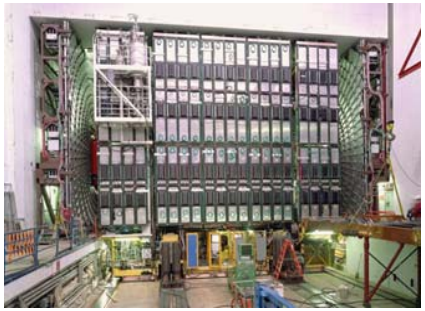
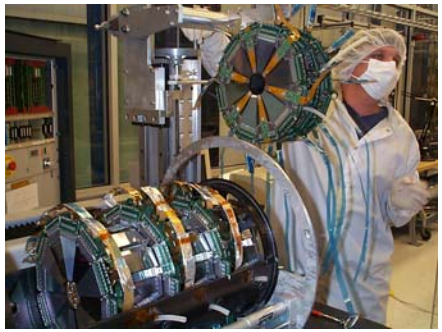
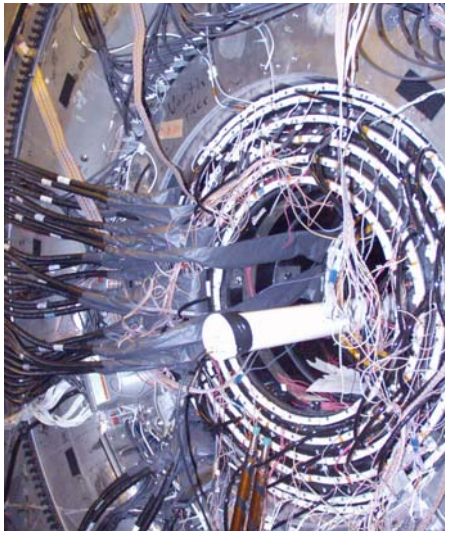
The DØ Research Program

Boaz Klima
Fermilab







DOE Program Review
May 24, 2005

Outline

- **The DØ Experiment**
  - Collaboration
  - Goals
  - Detectors
  - Operations
- **Physics Results**
  - Object Ids
  - Top
  - QCD
  - EW
  - B
  - NP
  - Higgs
  - Summary & Statistics
- **The FNAL Group at DØ**
  - General
  - Leadership
  - Physics Analysis
- **Conclusions**

The DØ Experiment

The DØ Collaboration

DØ is an international collaboration of ~ 670 physicists from 19 nations who have designed, built and has been operating a collider detector at the Tevatron in Fermilab

Institutions: 84 total, 35 US, 49 non-US

Collaborators:
~ 50% from non-US institutions
(note strong European involvement)
~ 100 postdocs, 140 graduate students

Physics Goals

Precision tests of the Standard Model

- **Weak bosons, top quark, QCD, B-physics**

Search for particles and forces beyond those known

- **Higgs, Supersymmetry, Extra Dimensions….**

Fundamental questions

Quarks sub-structure?

What is cosmic dark matter? SUSY?

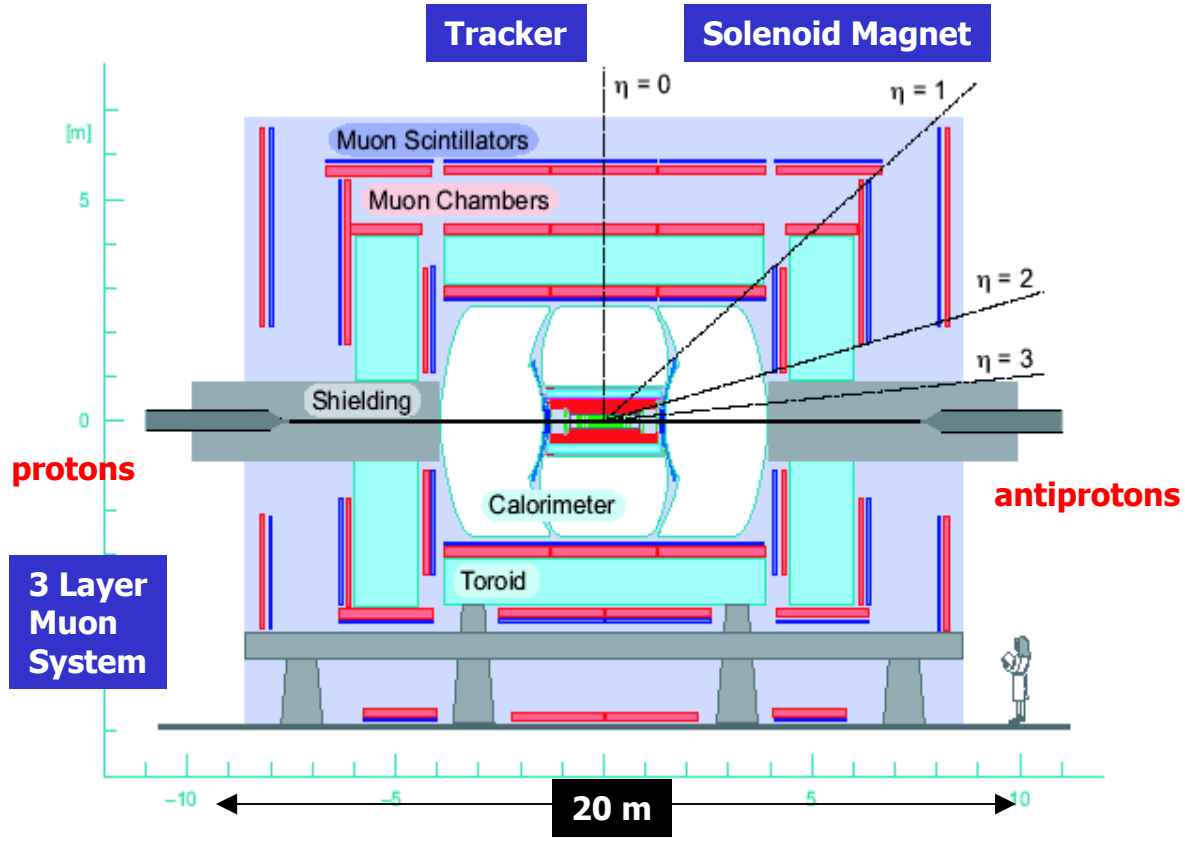
What is space-time structure? Extra dimensions?…

Driven by these goals, the detector emphasizes

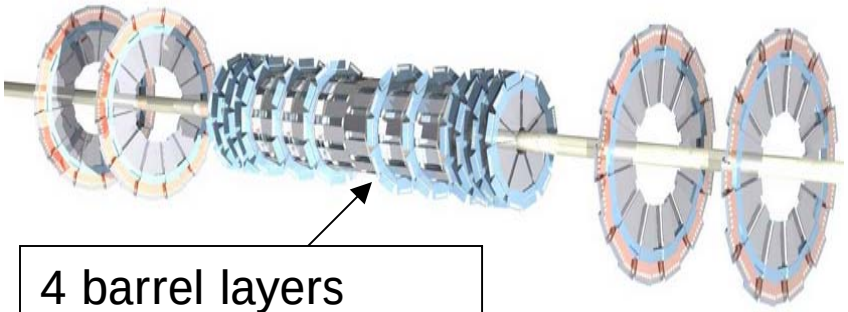
Electron, muon and **tau** identification

Jets and **missing transverse energy**

Flavor tagging through **displaced vertices** and **leptons**

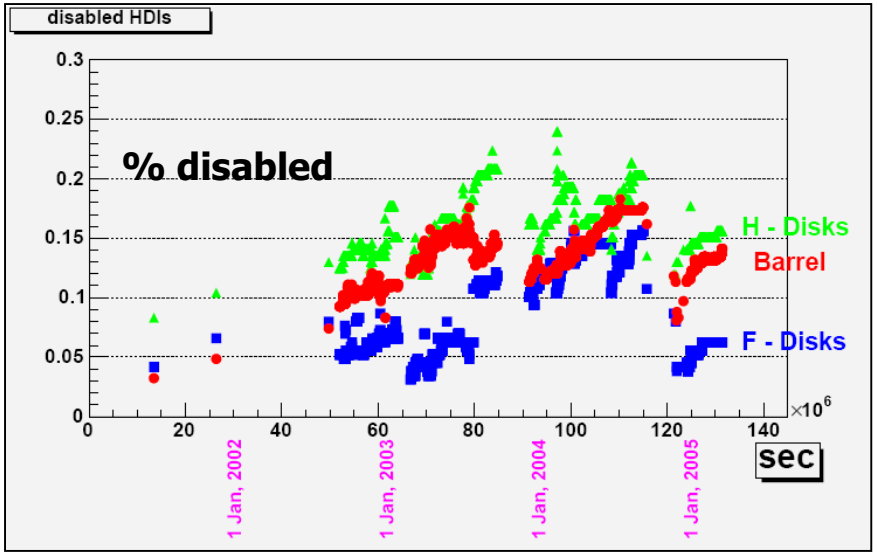


Silicon Microstrip Tracker

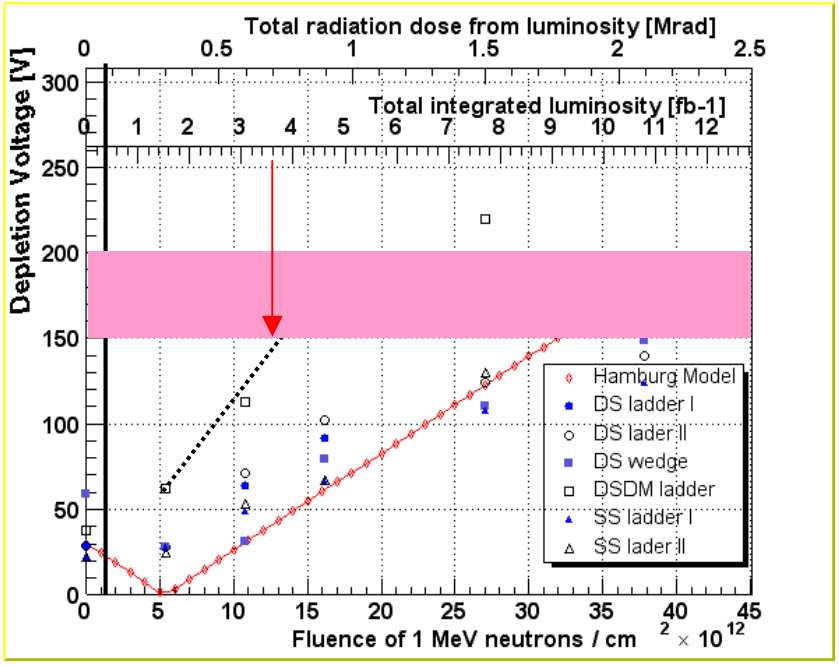


4 barrel layers
axial + stereo strips

All detectors are working very well



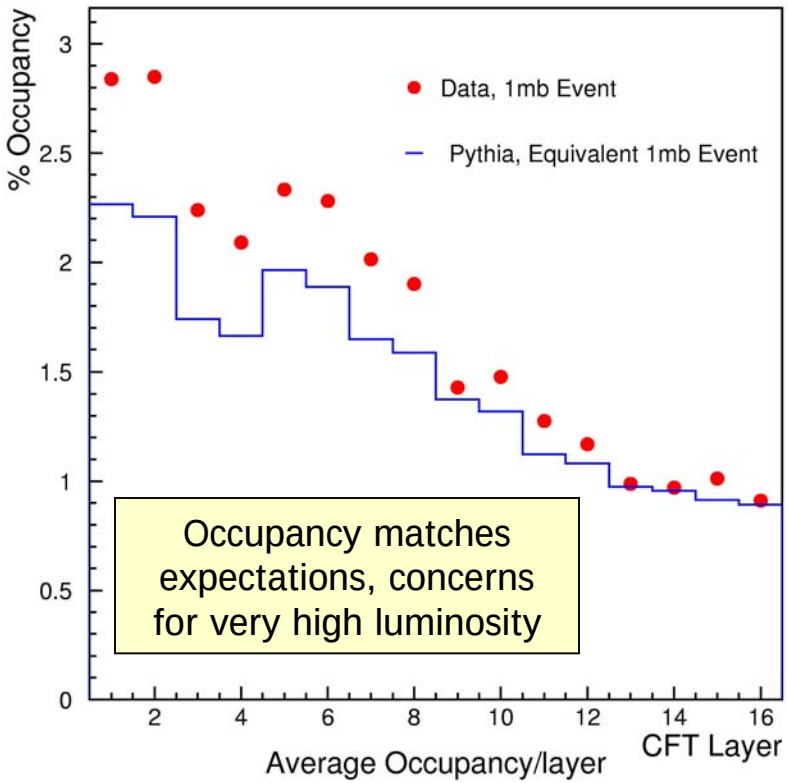
Mortality < 15% (not growing)



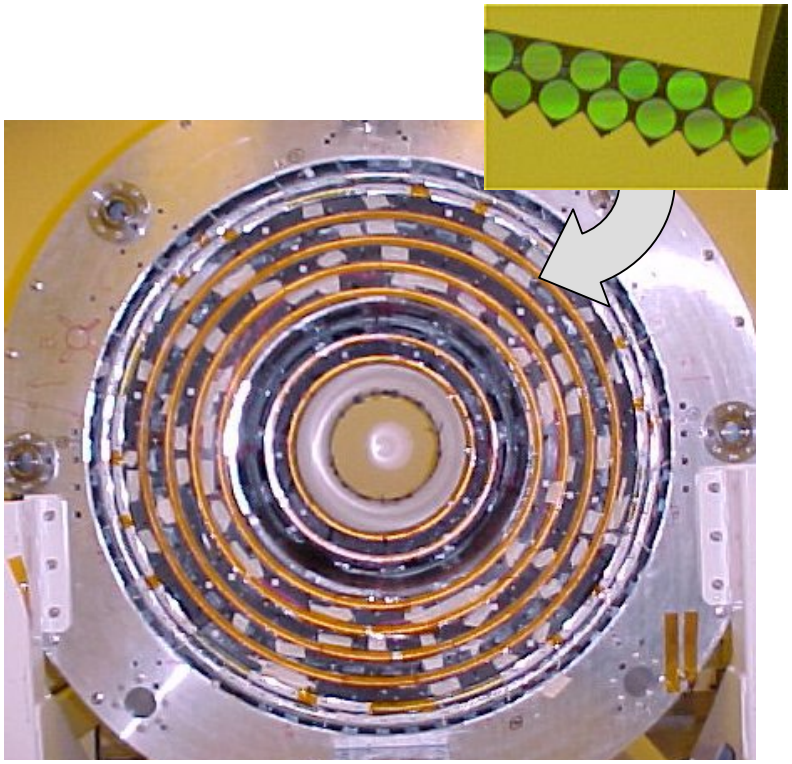
Radiation dose → no substantial changes in depletion voltage up to now

Scintillating Fiber Tracker

- 8 axial, 8 stereo fibers double layers
- VLPC readout
- Performing well
  - good light yield of ~7 phe/mip
  - per layer ε > 98%



Occupancy matches expectations, concerns for very high luminosity



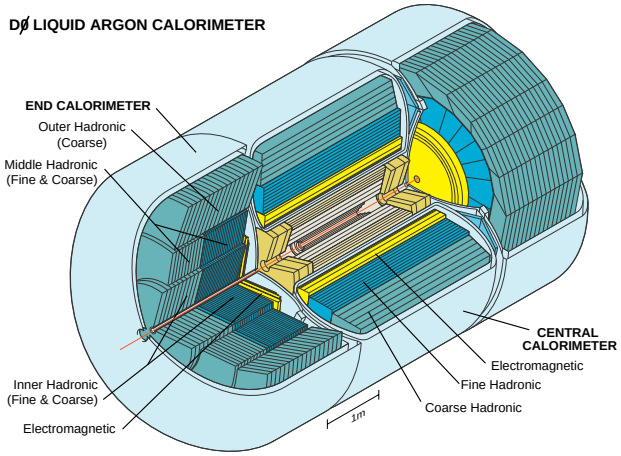
~2% of VLPC channels not functional since November '03 shutdown

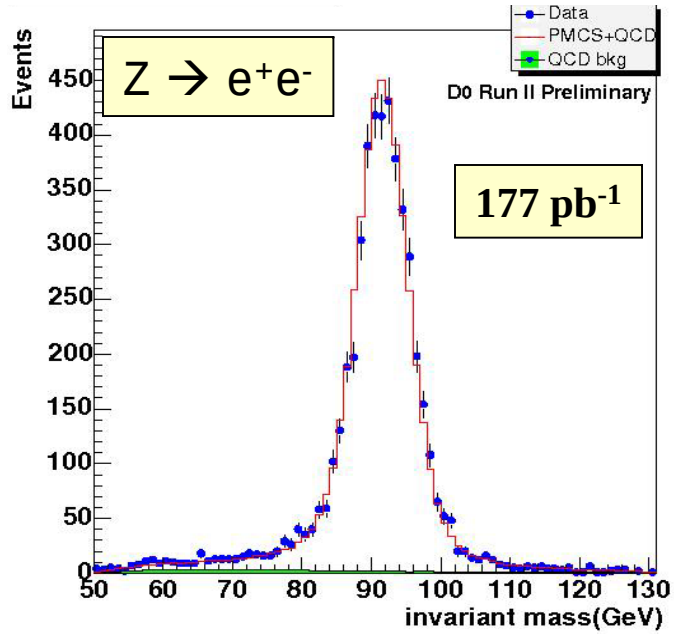
- Was 0.1% before
- Attributed to cryostat warm up/contamination

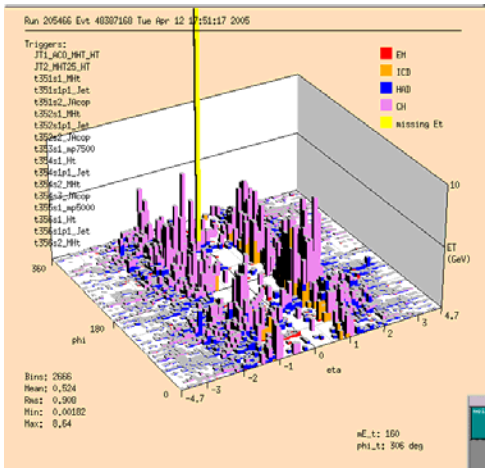
Attempted to fix problem in November '04

- ~2% not functional VLPCs? (different set of channels)
- Affecting mainly trigger rates

Calorimeter







April 12 2005

Stable and reliable operation

- less then 0.1% of non-working channels

Periodic problems with noise (~1% of data affected)

- **pickup from crane/welding**
- **muon toroids**
- **unknown**

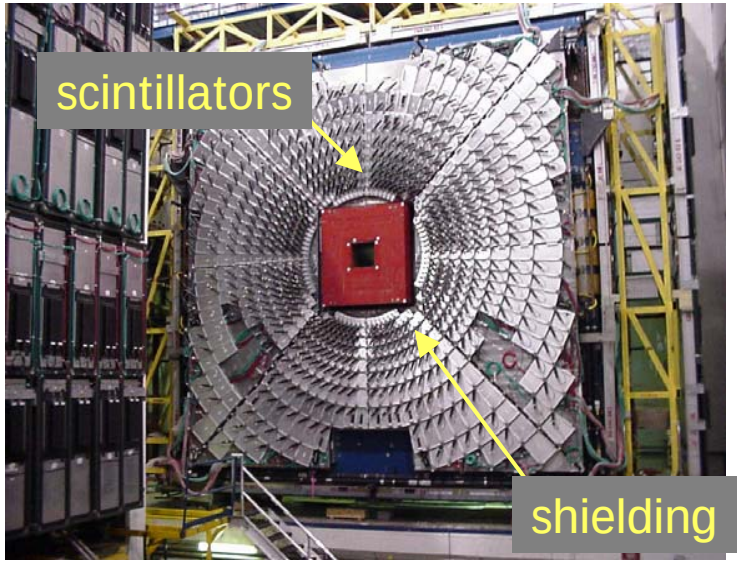
Better detector grounding during '04 shutdown

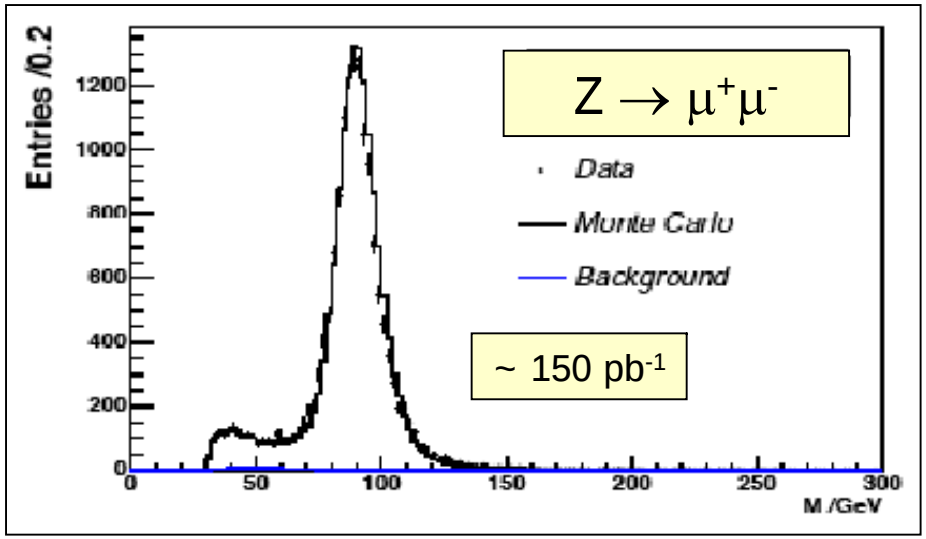
- **some sources of noise reduced**

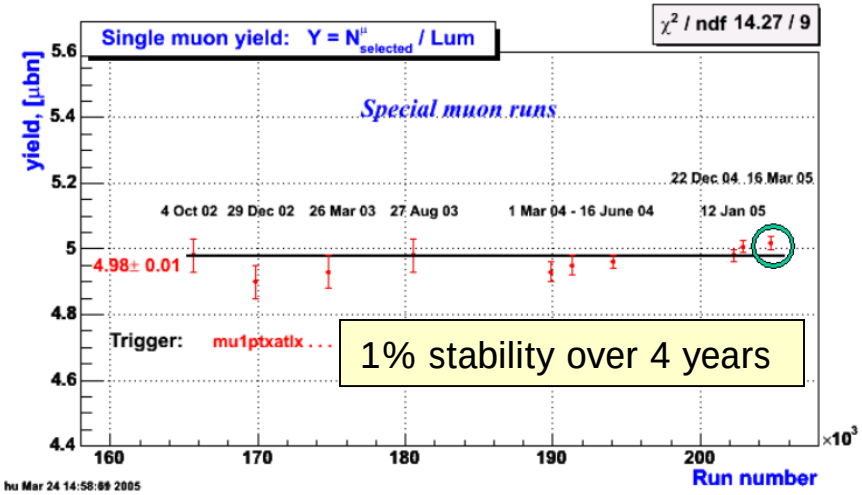
Calibration of detector with electron drift time above bunch spacing is a challenging task
Collected large data set for calibration

Muon System

Three layers of scintillator planes for triggering
Three layers of drift tubes for muon track reconstruction







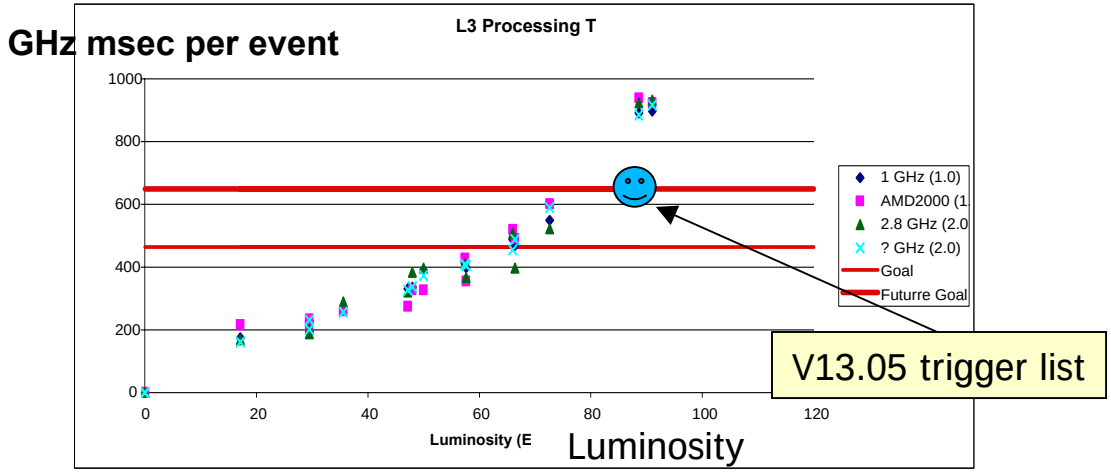
Works better than expectations!

Trigger System

Trigger system has to select 50Hz of events to write to tape out of 1.7MHz interactions rate:

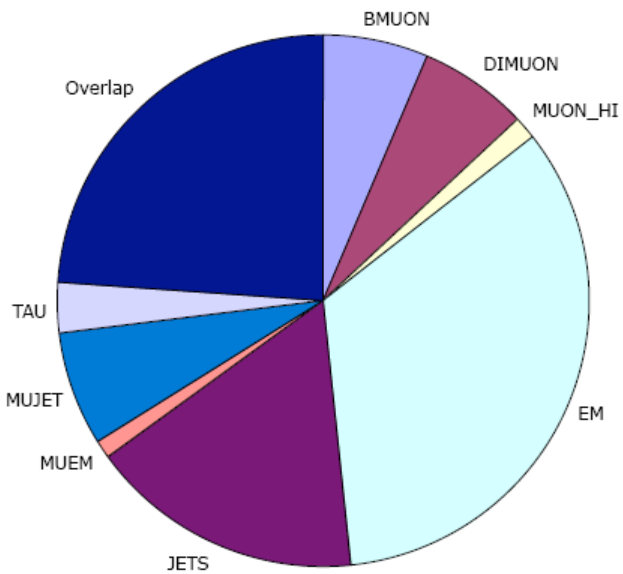
~ 10^5 rejection!

Rate=Lxσ → have to cut harder at high L

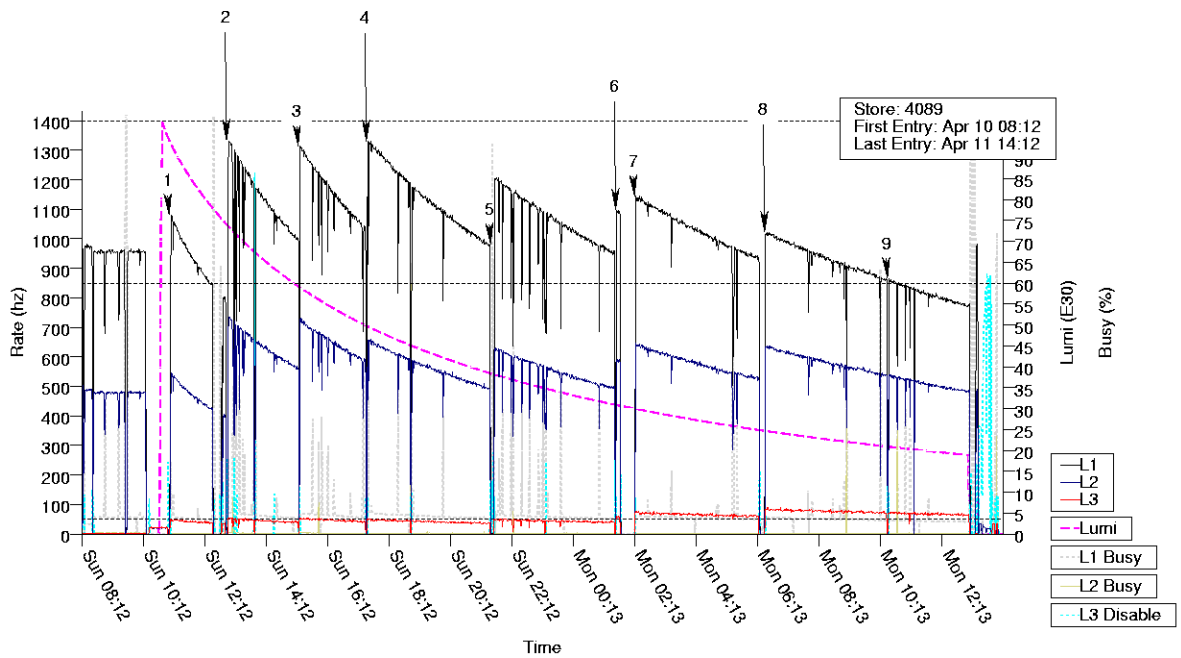


Current DØ capabilities:

Level 1 trigger ~2kHz
Level 2 trigger ~1kHz
Level 3 trigger ~50Hz



Level 1 triggers, %



Data Taking Performance

(An old timer view...)

More than Run 1a

All detectors are in and functioning well

Best Weeks (Recorded Luminosity)

- For the period of Monday through Sunday

Date	Delivered Lumi (/nb)	Recorded Lumi (/nb)	Efficiency	In Store (hrs)	Events (in k)
2005 Mar 21-27	18729	16881	90.1%	143.0	21606
2005 Jan 24-30	16262	14617	89.9%	122.7	16721
2005 Apr 4-10	16263	14148	87.0%	120.0	17757
2005 Mar 14-20	15937	13825	86.8%	113.2	13657
2005 Apr 18-24	16173	13814	85.4%	129.9	19110
2005 Mar 28-Apr 3	15105	13732	90.9%	122.9	17727
2004 Jun 21-27	16428	13598	82.8%	127.2	19443
2005 Feb 21-27	15920	13356	83.9%	127.4	17951

Integrated Luminosity of these 8 weeks is ~ the entire Run 1

Typical High Luminosity Store

Store 4116
Wed Apr 27 18:51 - Fri Apr 29 02:57
D0 Initial Luminosity = 110.88E30
CDF Initial Luminosity = 12[illegible]56E30 (D0/CDF = 0.9[illegible])
PBars: 154.6E10(A)+137.2E10(R) ([illegible]+122.0E10(R) used). Initial losses at D0: p=4.4k, ap=2.59k
Store end: Normal

Run	Shifter	Begin/End Lum[E30]	Prescale	Events	Start	Duration	Avg rate	Rec Lum
205961	Jun Guo	110.34 / 85.83	92-100E30	323440	18:54	1.98 h	45.41 Hz	637.8 nb-1
205962	Jun Guo	85.17 / 71.35	84-92E30	290821	20:56	1.96 h	41.53 Hz	503.6 nb-1
205963	Jun Guo	70.52 / 58.74	68-76E30	328851	23: 0	2.24 h	40.84 Hz	490.4 nb-1
205964	Joe Haley	58.80 / 50.94	55-60E30	299134	1:15	1.99 h	41.73 Hz	354.2 nb-1
205965	Joe Haley	50.90 / 40.59	45-50E30	586737	3:15	4.00 h	40.75 Hz	618.4 nb-1
205966	Joe Haley	40.34 / 32.91	40-45E30	549277	7:16	4.03 h	37.86 Hz	503.6 nb-1
205967	Ana Assis Jesus	32.93 / 27.57	30-35E30	666952	11:20	3.89 h	47.57 Hz	401.7 nb-1
205968	Ana Assis Jesus	27.56 / 23.25	25-30E30	639774	15:17	3.99 h	44.51 Hz	342.7 nb-1
205969	Jun Guo	23.33 / 21.92	20-25E30	262043	19:18	1.57 h	46.34 Hz	120.0 nb-1
205970	Jun Guo	21.90 / 19.96	20-25E30	406543	20:53	2.57 h	42.30 Hz	187.2 nb-1
205971	Jun Guo	19.76 / 17.51	15-20E30	585734	[illegible]:35	3.33 h	48.81 Hz	207.8 nb-1

Recorded Luminosity 4.37 pb-1 (delivered 4.76 pb-1, rec/del= 92%)

Best Days (Data Taking Efficiency)

- Efficiency = recorded / delivered luminosity
- At least 10 hours in store
- Complete detector in readout
- No major obvious online data quality issues

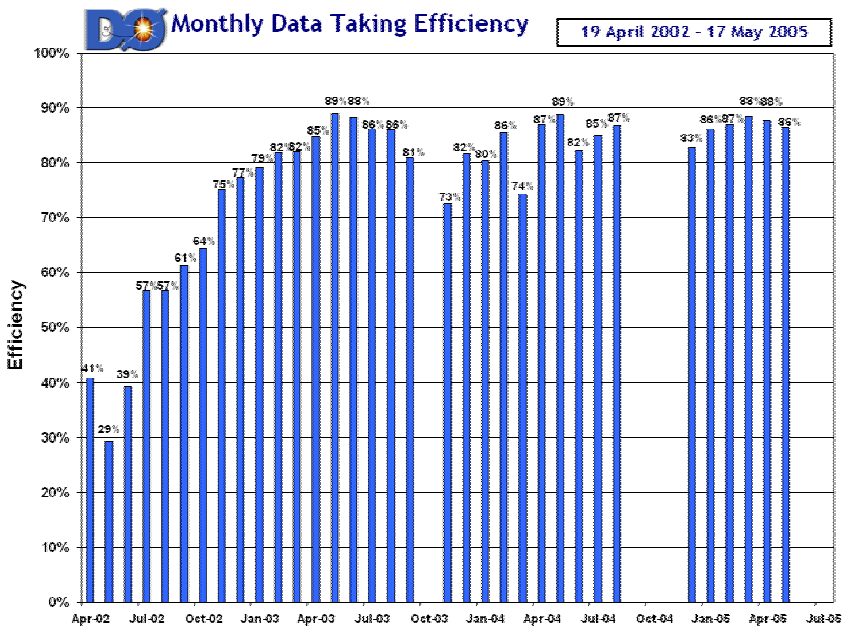
Date	Delivered Lumi (/nb)	Recorded Lumi (/nb)	Efficiency	In Store (hrs)	Events (in k)	DAQ Shifters
2004 Aug 3	782.83	753.49	96.3%	11.9	1598	Pieter Houben, Miruna Anastasoaie, Jessica Leveque
2005 Feb 15	552.19	526.40	95.3%	12.0	1570	Carsten Magass, Sabine Lammers, Stephen Robinson
2003 Jun 22	1073.93	1020.03	95.0%	17.2	2451	Mikhail Arov, James Heinmiller, Philipp Schiefer-decker
2003 Jun 9	908.95	861.57	94.8%	19.1	2311	Mike Clements, Arnd Meyer, Rick Jesik
2004 May 4	548.13	519.55	94.8%	11.0	1498	Mahsana Ahsan, Christian Autermann, Paul Telford
2003 Jun 4	598.25	566.61	94.7%	13.2	1571	Aran Garcia-Bellido, Mansoora Shamim, Maggie Geppert
2004 Jul 17	1704.14	1611.58	94.6%	20.9	3271	Miruna Anastasoaie, Jessica Leveque, Pieter Houben
2004 Aug 7	2083.35	1961.39	94.1%	20.5	2862	Pieter Houben, Miruna Anastasoaie, Joe Haley
2005 Mar 5	2496.72	2348.03	94.0%	22.0	3057	Mikko Voutilainen, Lei Wang, Suharyo Sumowidagdo

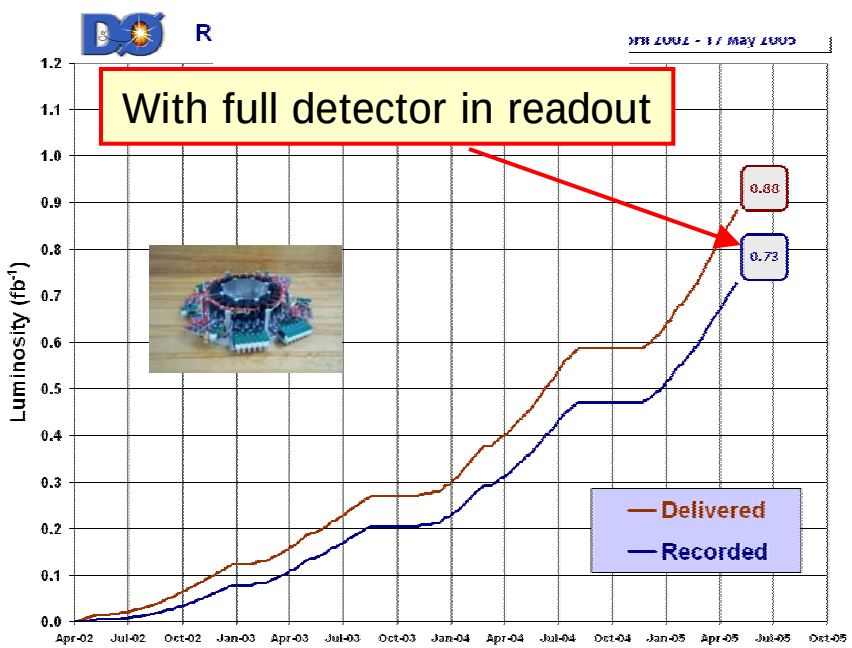
Integrated Luminosity written to tape at DØ over the last two full months (Mar. & Apr.) is

57.4 + 59.4 = 116.8 pb-1

~ the entire Run 1

Operations





- The experiment is operating well and recording physics quality data with close to 90% efficiency
  - Typical "good" day 2 pb^{-1}
  - Typical "good" week 14 pb^{-1}
    - Run I top quark discovery in 3-4 weeks!
- **90% data taking efficiency**
  - 5% are trigger system disables
  - 5% are begin/end stores, failures
- As of today DØ has >**0.7 fb^{-1}** on tape
  - **All detectors functioning well**
  - Most physics results are from data collected before end of 2004 shutdown

On-line data quality monitoring

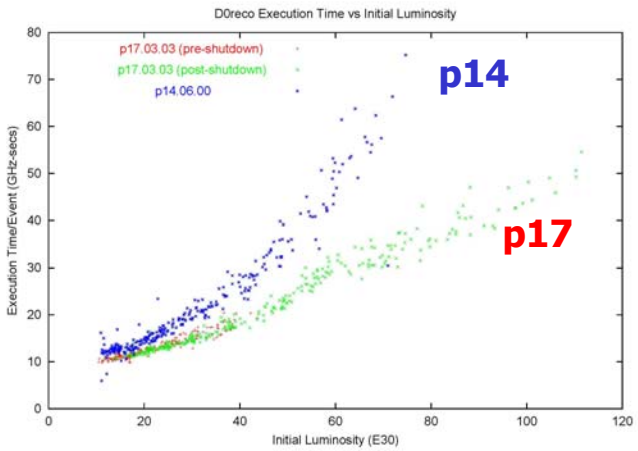
"remote" shifters from all over the World: Europe, Brazil, India, China...

Thanks to Accelerator Division for luminosity!

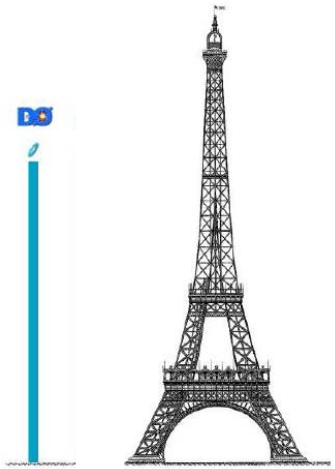
Events Reconstruction

- **DØ collected over 10^9 events!**
  - **Recently developed new reco program (version p17)**
    - **Faster**
    - **Better performance**

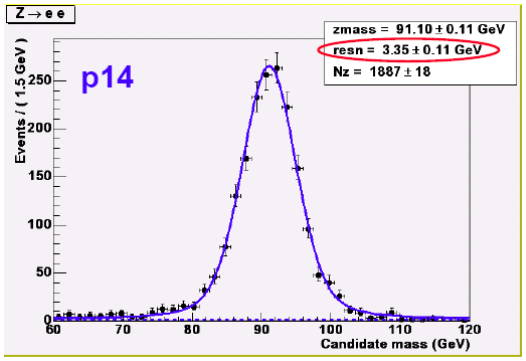
For uniform and better quality data set have to reprocess all data collected before Autumn 2004 shutdown

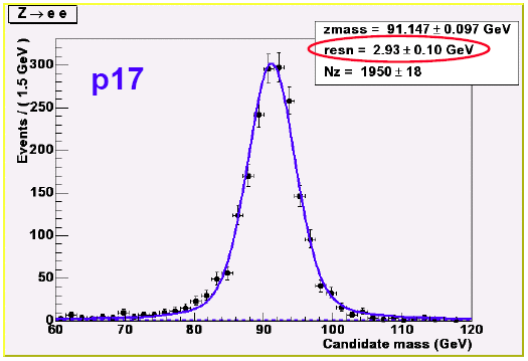


	p17 reprocessing
Luminosity	$470\,\mathrm{pb}^{-1}$
Events	1G
Rawdata 250kB/Event	250TB
DSTs 150kB/Event	150TB
TMBs 20kB/Event	20TB
Time 50s/Event	20,000months
(on 1GHz Pentium III)	3400CPUs for 6mths
Remote processing	100%



A stack of CDs as high as the Eiffeltower

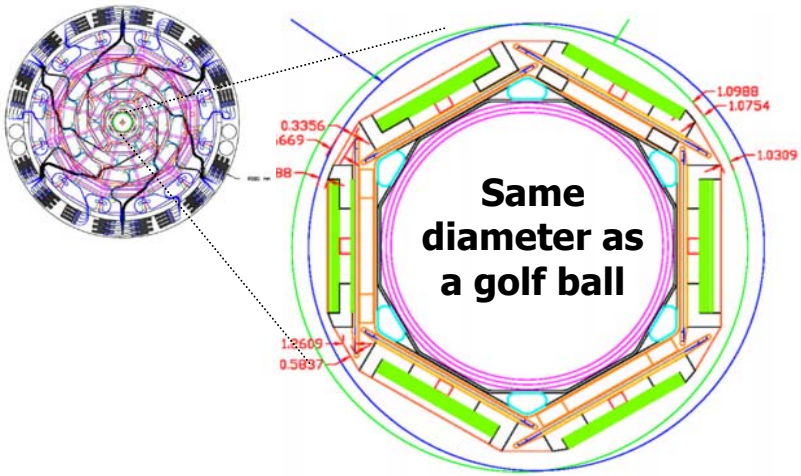


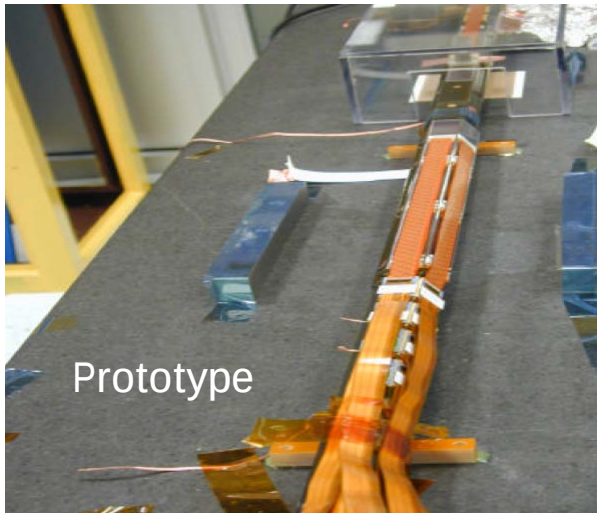


DØ has robust data-handling system (SAM)
fully integrated with GRID tools (SAMGRID/JIM)
All reprocessing is being done on remote farms worldwide and expected to be finished in 6 months
As of today ~15% done

Detector Upgrades

In order to mitigate concerns over silicon detector radiation damage and pattern recognition in DØ, we are constructing a new Silicon Layer Ø





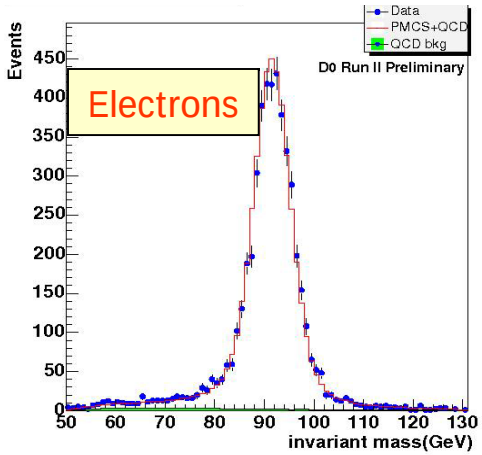
Calorimeter trigger upgrade is needed for managing trigger rates at high luminosity – in construction/commissioning stage
all 100 production Analog-Digital-Filter (ADF) cards have been tested successfully (2.5 months ahead of schedule...)

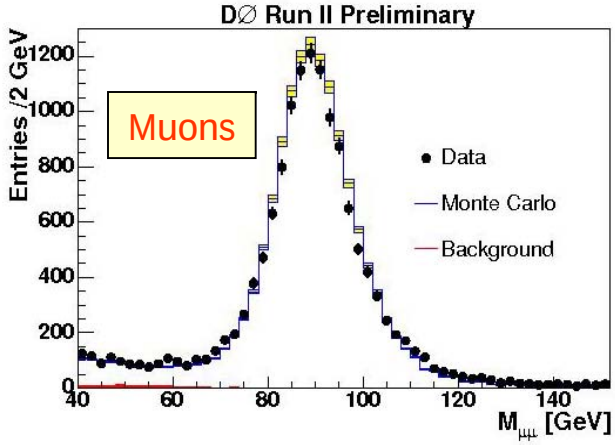
AFE II – new front-end electronics for fiber tracker
→ mitigate amplitude saturation at high counting rates

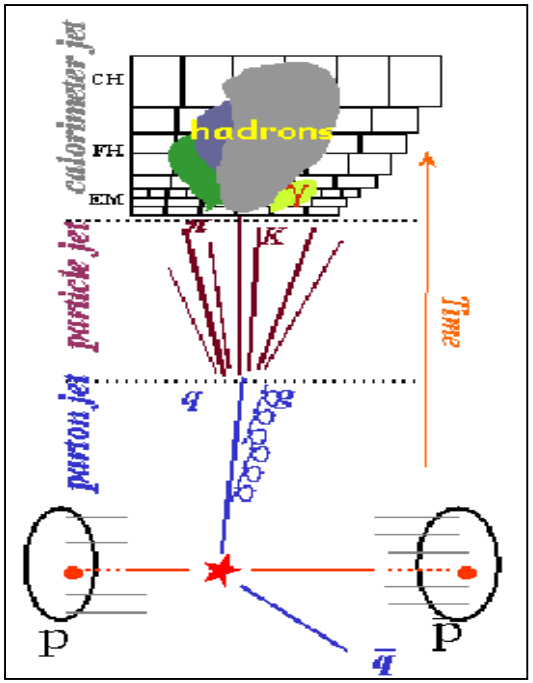
Plan to install Layer Ø and calorimeter trigger upgrades in Autumn 2005

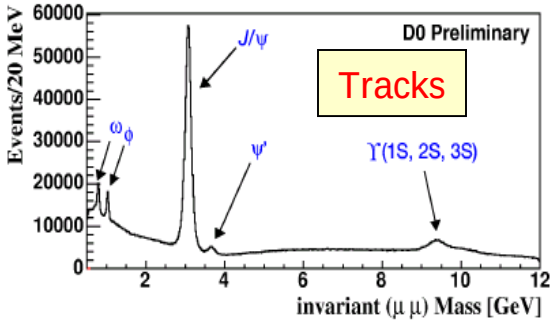
(A sample of)
Physics Results

Objects Identification



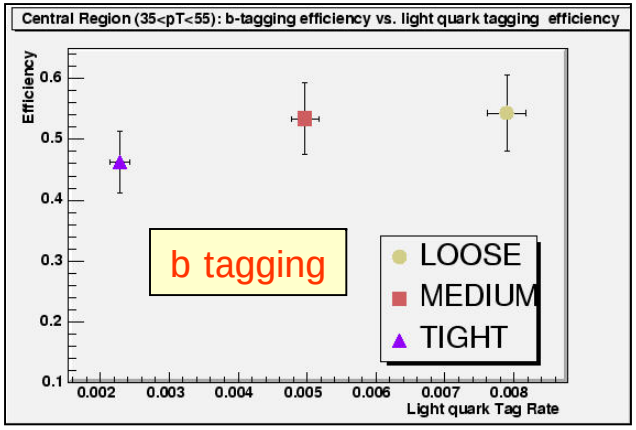


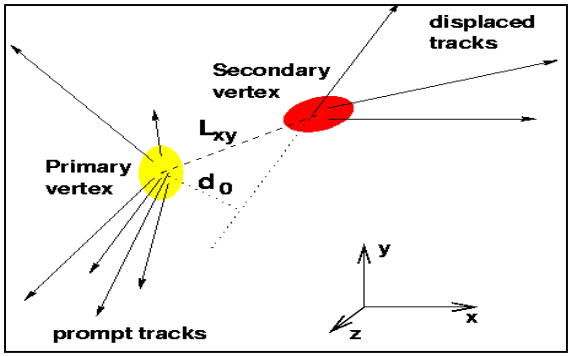


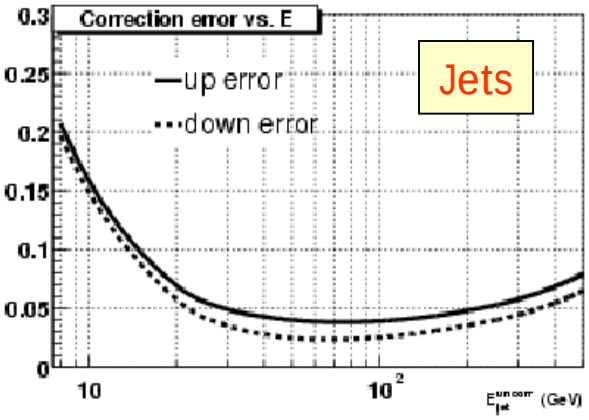


Final decay products are
- → electrons, photons
- → muons
- → jets (b)
- → missing E_t (ν)
- → charged tracks

Detection and MC optimization using known objects: Z/W, J/ψ, etc.





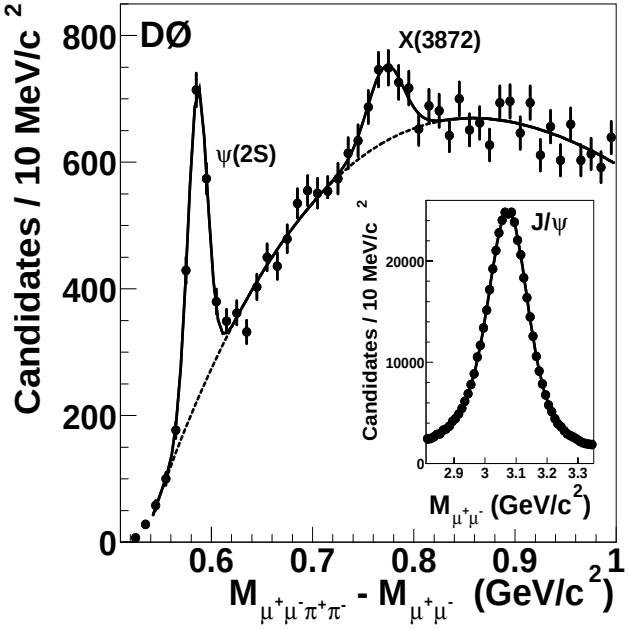


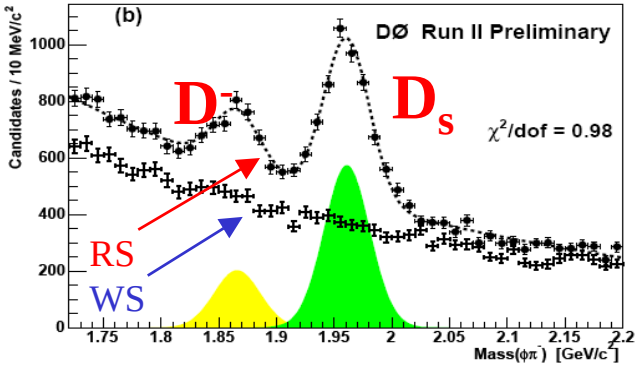
Heavy Flavors Masses and Lifetimes

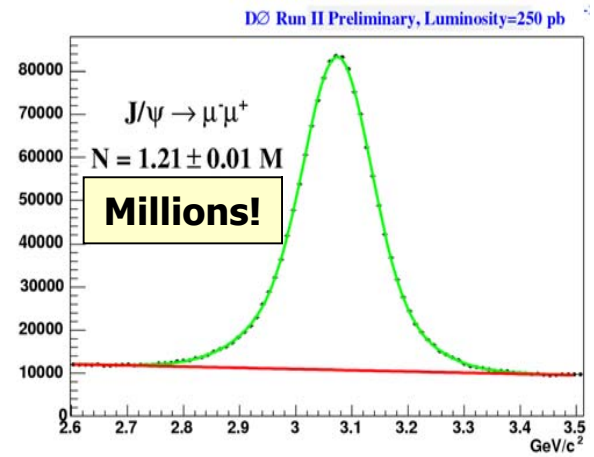
Measure particles production and decays properties
Confront the unitarity triangle in ways that complement measurements at the e^+e^- B-factories e.g. through the B^0_s system

DØ benefits greatly from large muon acceptance and forward tracking coverage

$X(3872) \rightarrow J/\psi\ \pi^+\pi^-$







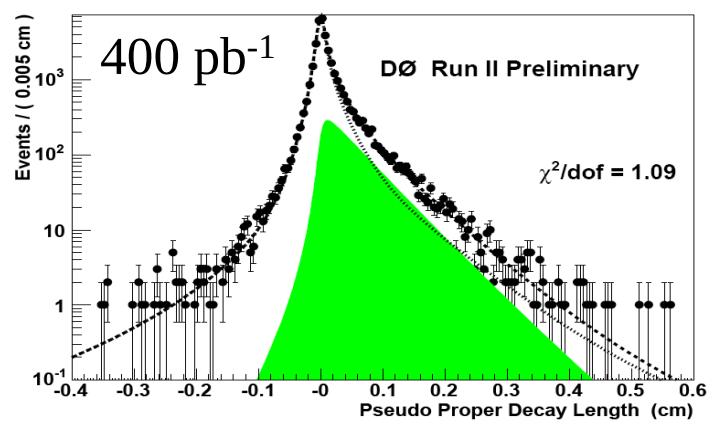
M(φπ)

B^0_s lifetime with $B_s \rightarrow l\nu D_s X$

Use $D_s \rightarrow \phi\pi$ decay

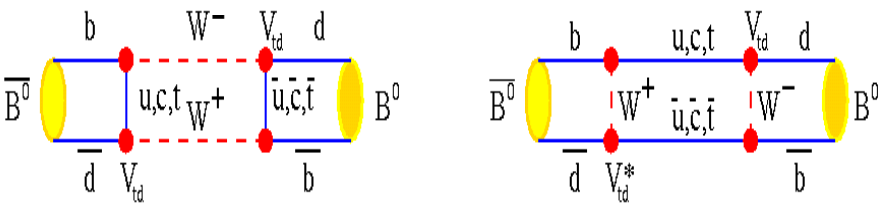
Currently World's best:

$\tau(B_s)$=1.420±0.043±0.057 ps

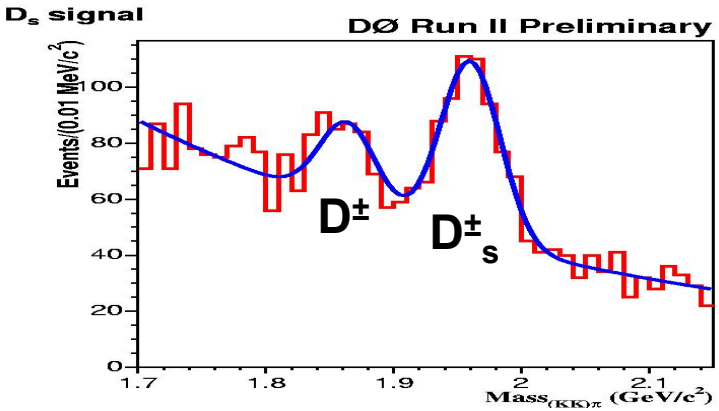


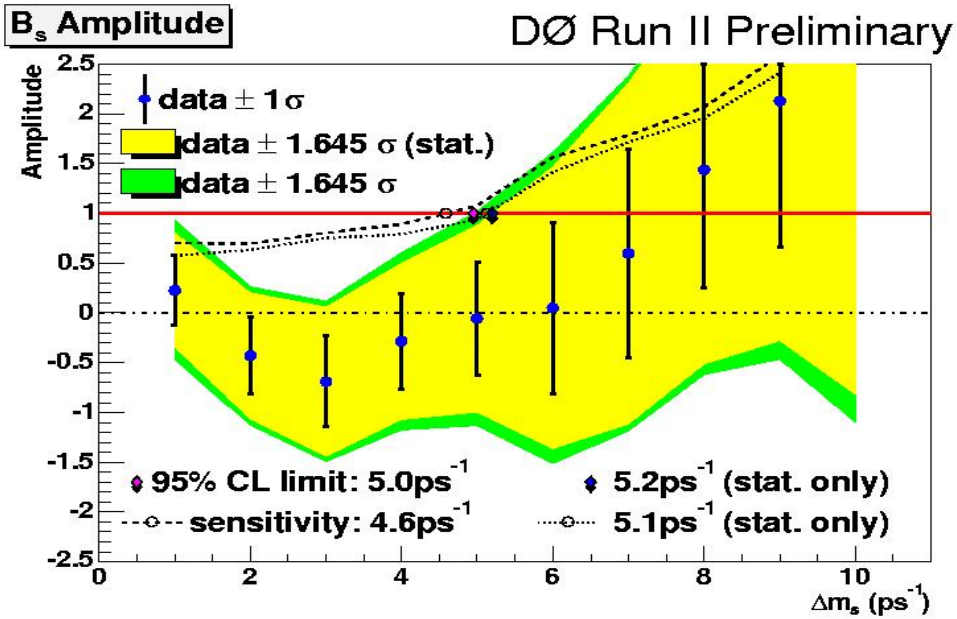
B_s Mixing

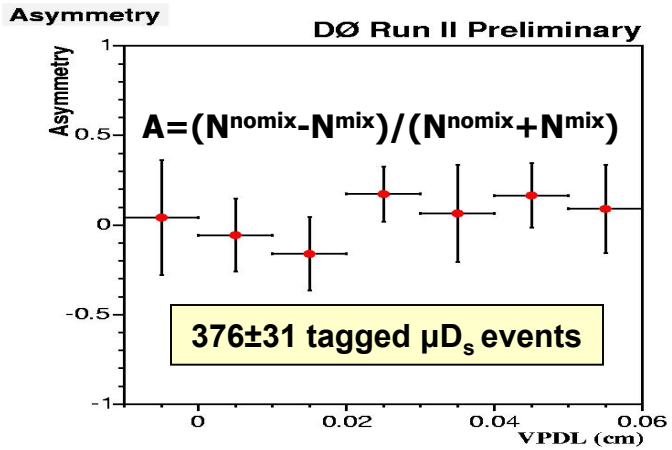
In SM B-mixing is explained by box diagrams
→ Constrains V_{td} and V_{ts} elements of CKM matrix
→ New physics → new particles in the box
→ $\Delta m_s/\Delta m_d$ is free from many theoretical uncertainties



Use semileptonic data sample μD_s (muon triggering helps)
Decay mode $D_s \to \Phi\pi$, $\Phi \to K^+K^-$
13,300 candidates in 460 pb^{-1}
Charge of the muon provides Final State Tag





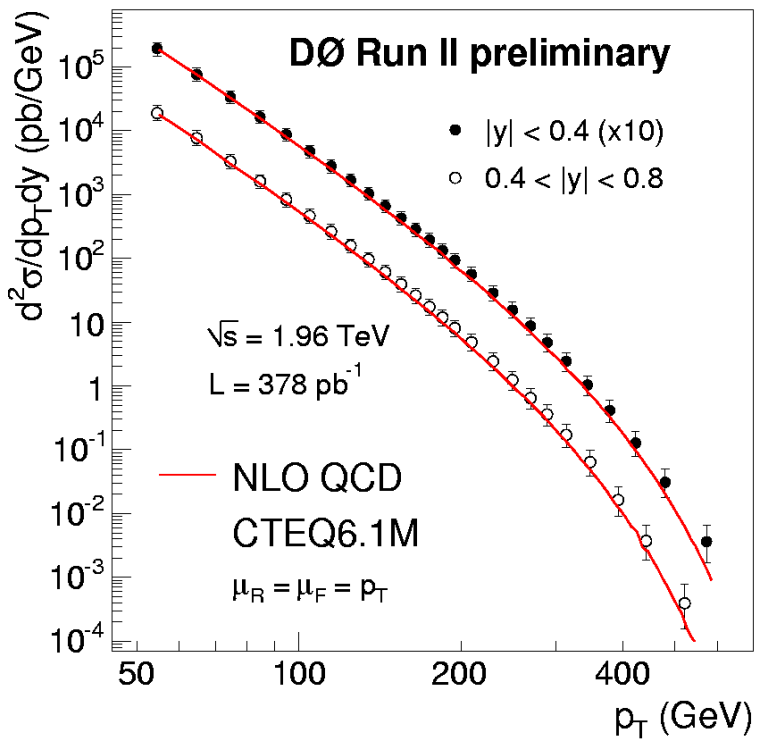


95% CL limit: $\Delta m_s > 5.0\ ps^{-1}$, statistically limited

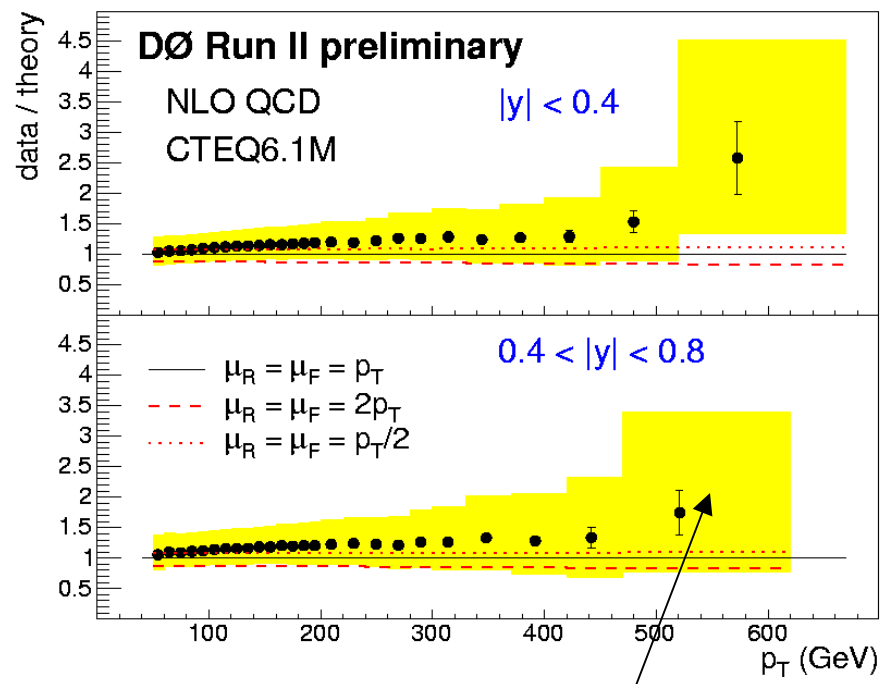
With anticipated DØ upgrades: $\Delta m_s > 20\ ps^{-1}$ with ~1 fb^{-1}

QCD Studies

Use well-understood processes to measure proton structure
→ quarks sub-structure?
Resolve some outstanding puzzles
→ e.g. heavy flavor production
Understand the backgrounds to physics beyond SM
Study diffractive production, new objects like X(3872)



8+ orders of magnitude σ changes

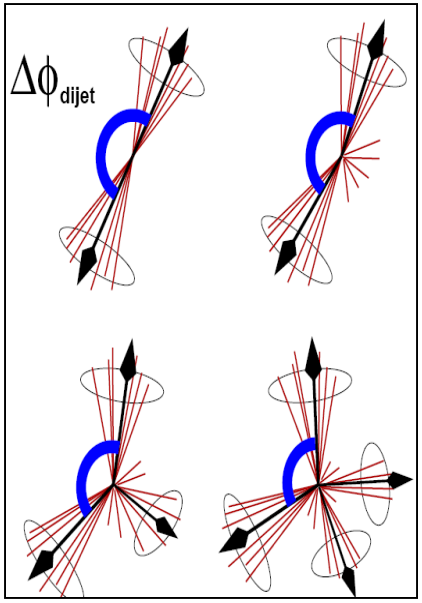


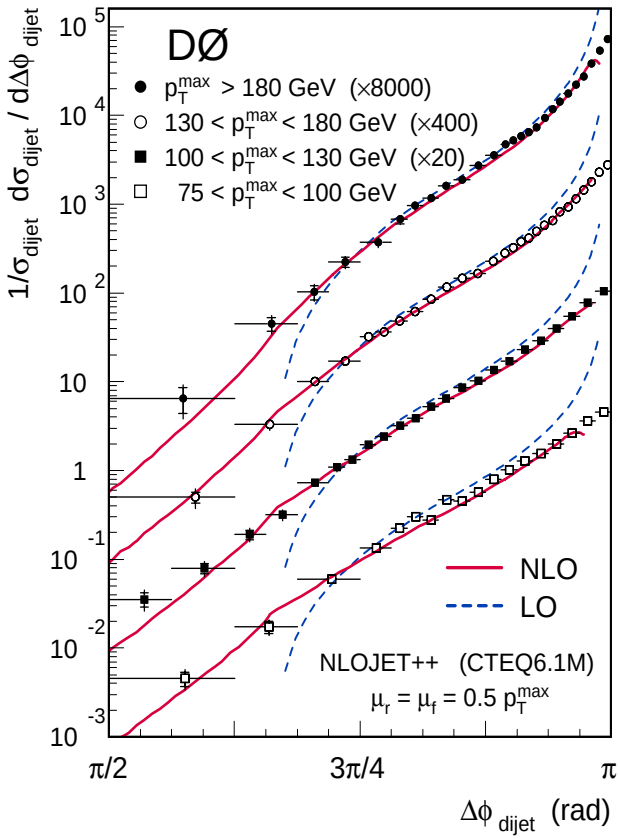
Dominant systematic uncertainty is currently jet energy scale

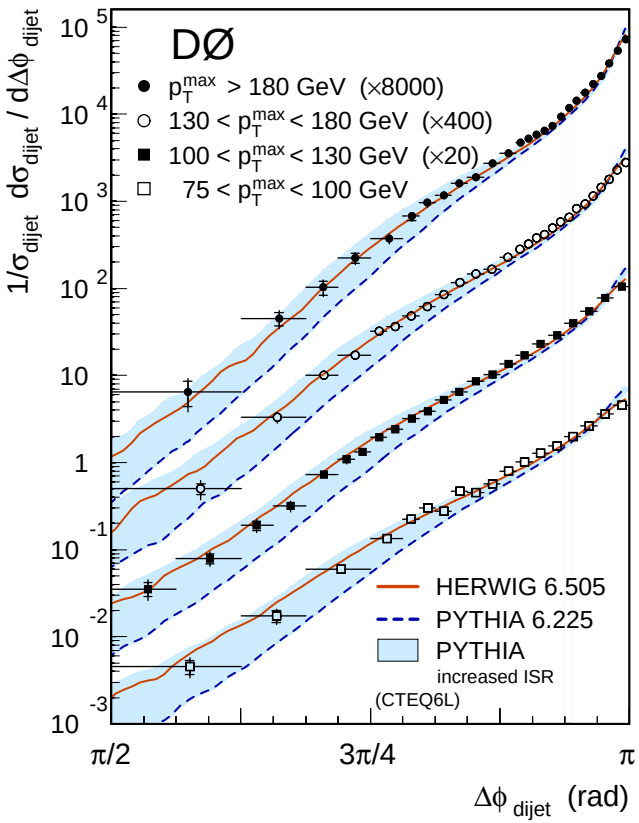
→ derived from p_T balance in photon + jet events

Dijet Angular Distributions

Clean and simple way to study QCD radiative processes
Reduced sensitivity to jet energy scale







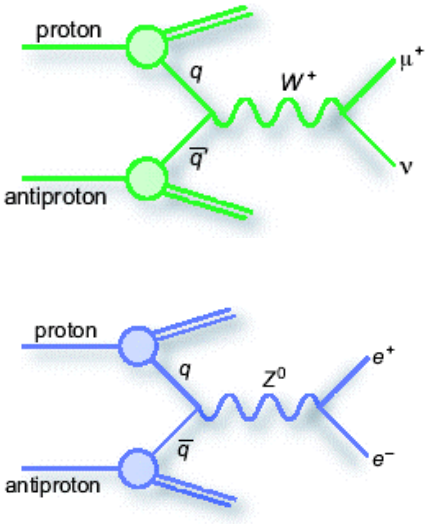
LO is not describing distributions
Agreement with NLO predictions

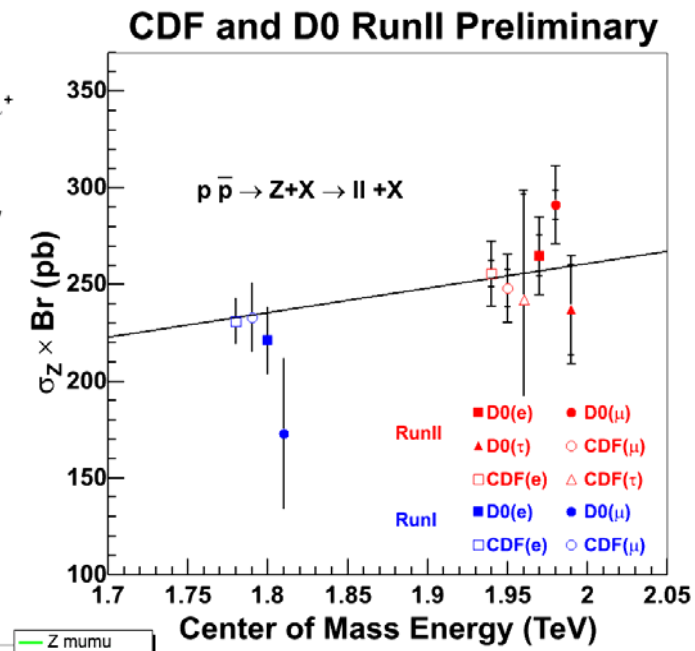
HERWIG describes data well

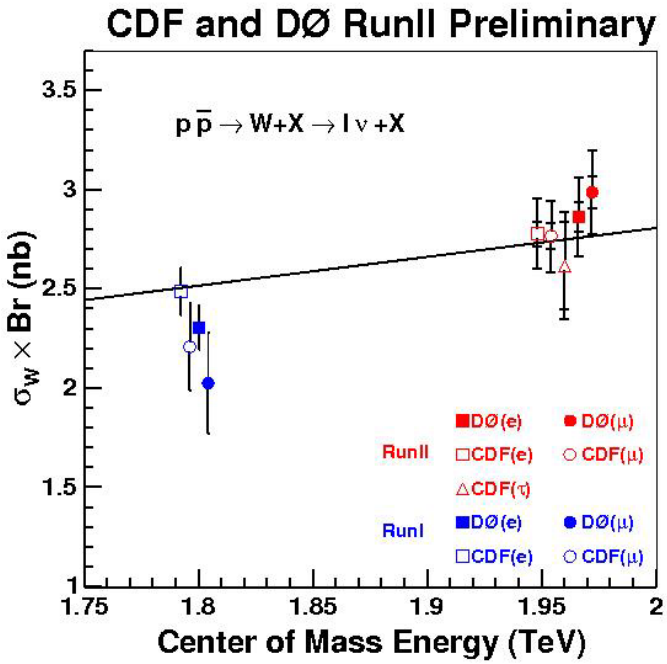
PYTHIA needs adjustments to its default parameters

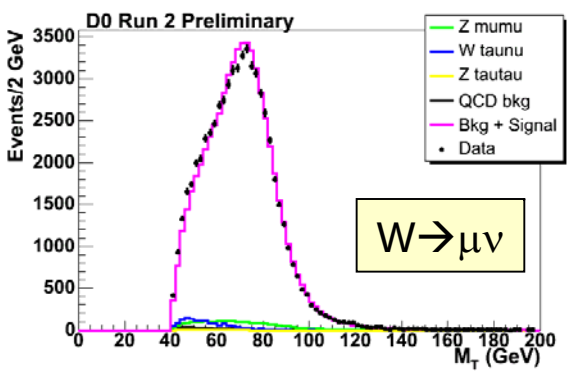
Electroweak Physics

Indirectly constrain new physics through precision measurements of electroweak parameters
Measure single and multiboson production, W production asymmetry, forward-backward asymmetry in Z production, …







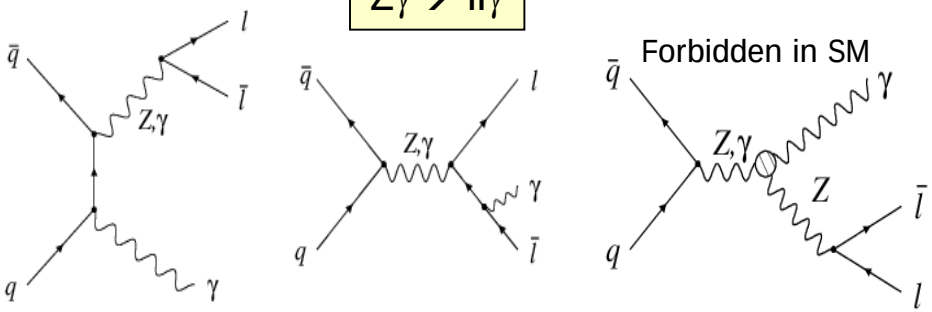


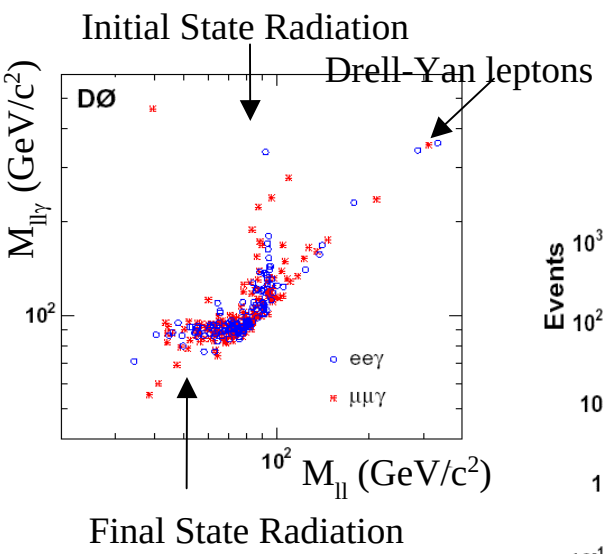
Clean, relatively high cross section and well known signals
Test of the Standard Model
Require a high level of understanding of the detectors
→ e, μ, τ and missing E_t
Can be used to cross check luminosity measurement

Diboson Production

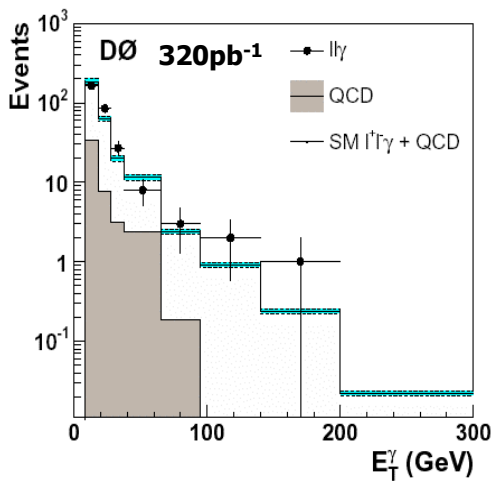
WW, WZ, ZZ, Wγ, Zγ production test SM and tell us about boson self-coupling
Background to many interesting searches, like H→WW

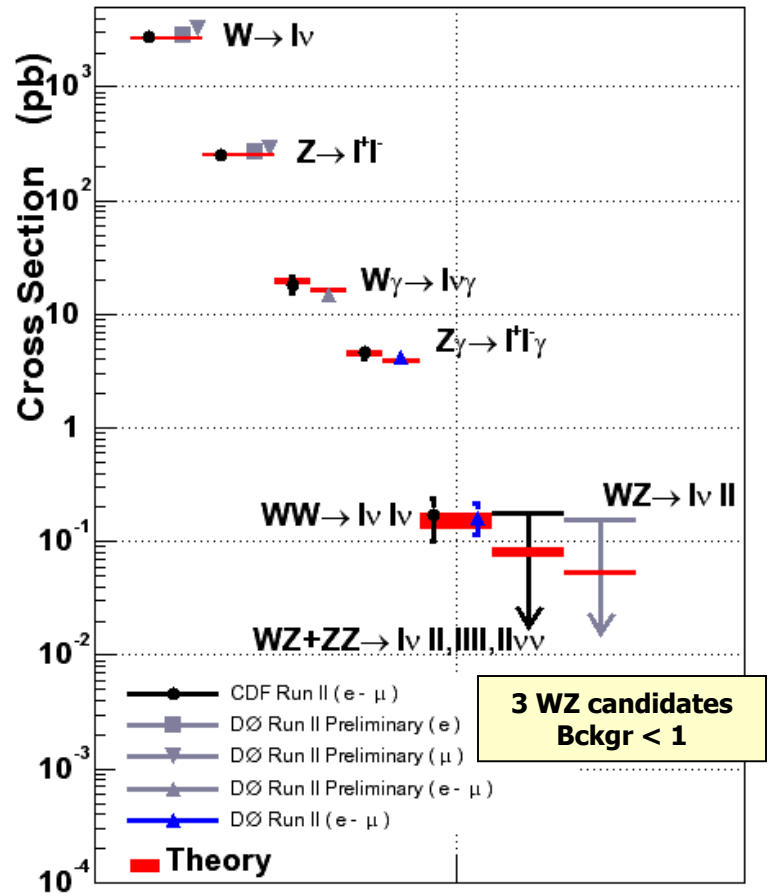
Zγ→ llγ





Limits on Anomalous Couplings set: world most stringent for WZ

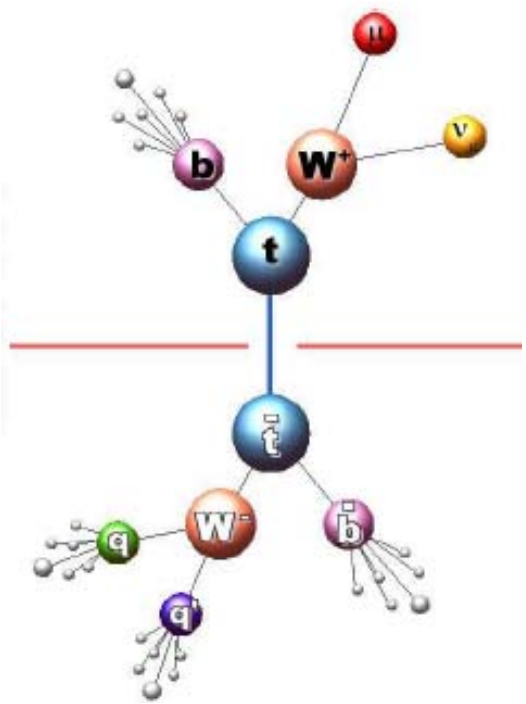




3 WZ candidates
Bckgr < 1

Cross sections are in good agreement with SM

Top Quark Production Cross Section



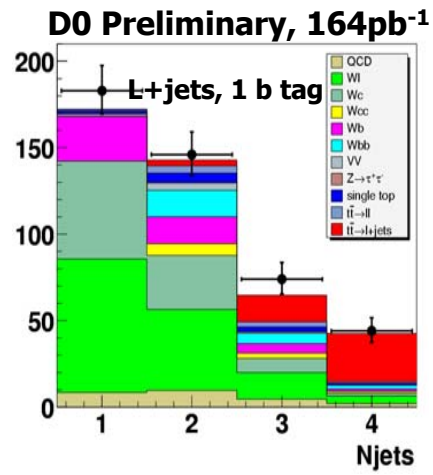
In triggering and analysis select events with

→ high P_t leptons

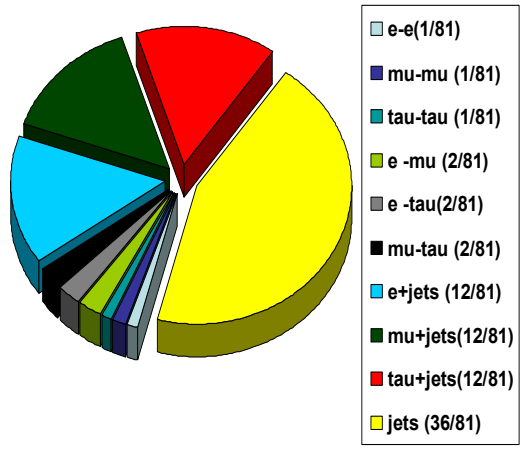
→ high E_t multiple jets

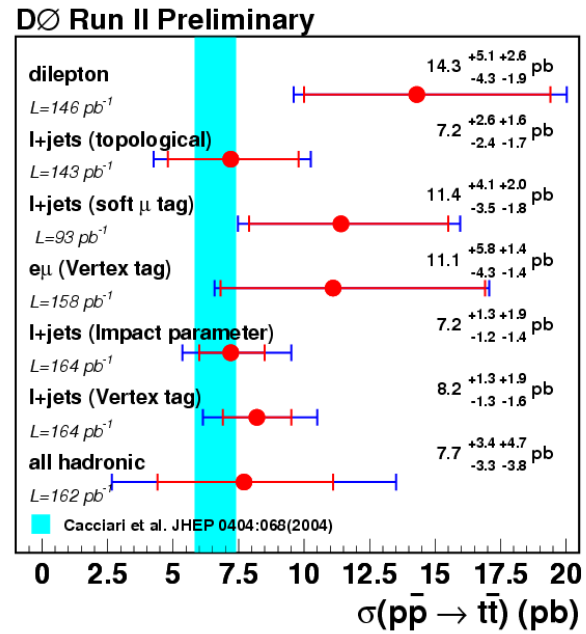
→ large missing E_t (ν)

→ displaced vertex for b jets



$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{Bkg}}{\epsilon \int Ldt}$$





"Di-lepton" mode has

→ low backgrounds: di-bosons, Drell-Yan, ...

→ but low statistics: ~5% for e, μ decays

"Lepton+jets" very productive mode

→ 6 times more decays then di-lepton mode

→ main background W+jets

→ good purity after b tagging

"All jets" mode

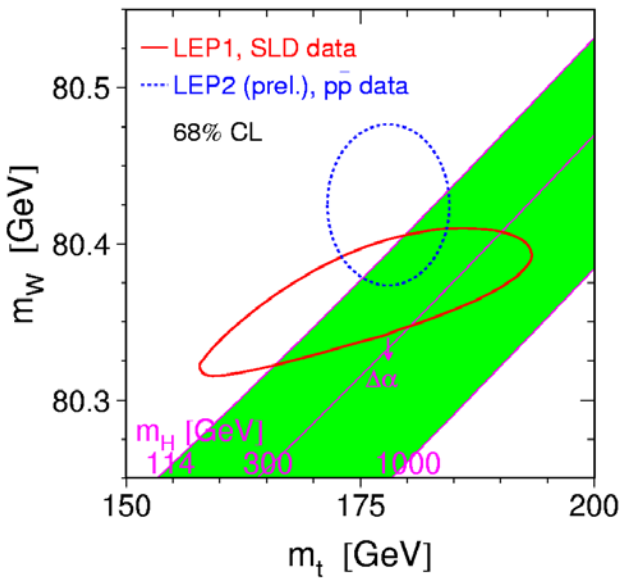
→ 44% branching

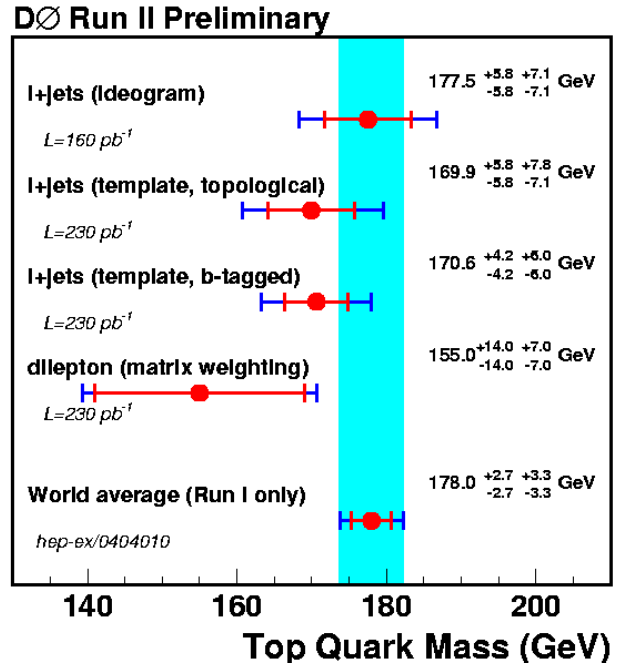
→ high QCD backgrounds, jets combinatoric

Results demonstrate success of multiple top quark detection techniques

Top Quark Mass

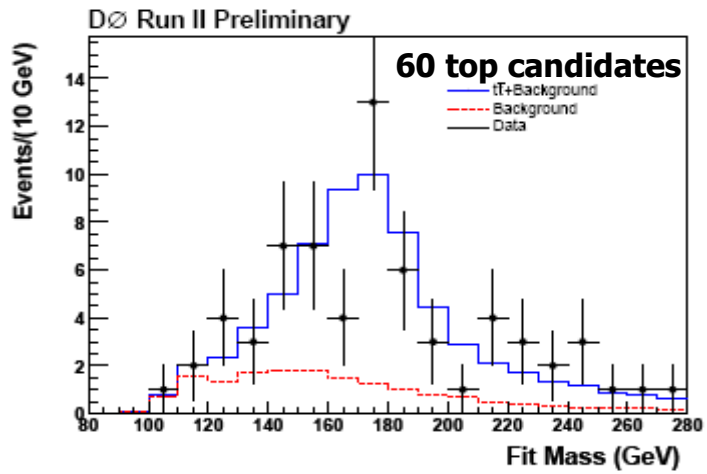
- Top quark mass is a fundamental parameter of the SM
- It provides constrain on Higgs mass





Different methods used
- "template"
- matrix element

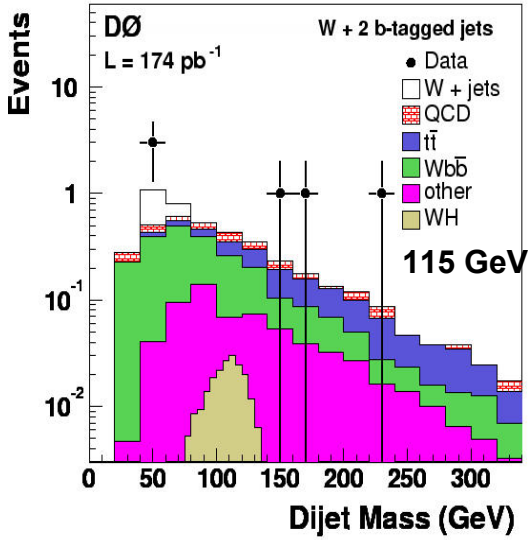
All results are consistent with Run I World average
- jet energy scale is the dominant systematic error



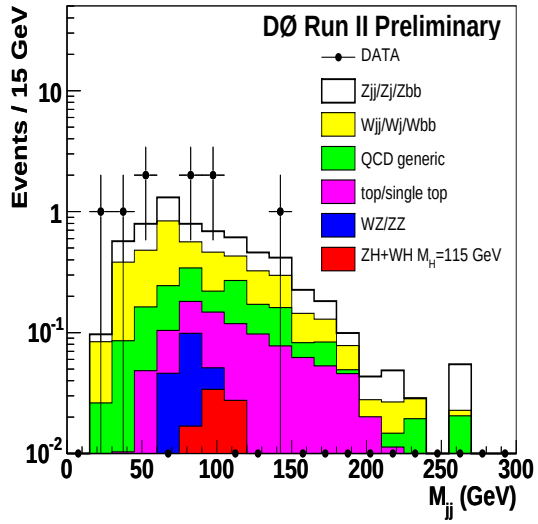
l+jets b-tagged template method, 230pb^{-1}

Standard Model Higgs Search

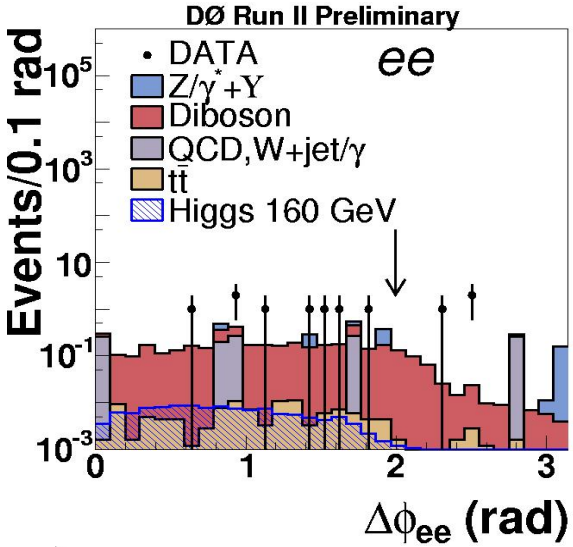
WH→eνbb

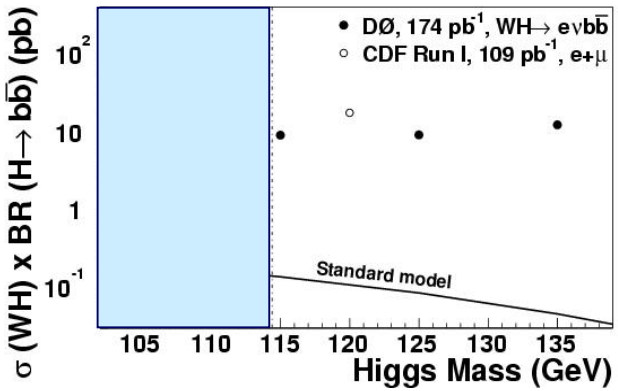


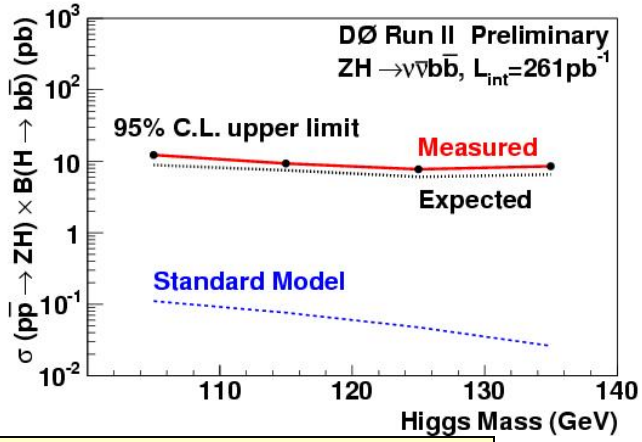
ZH → ννbb

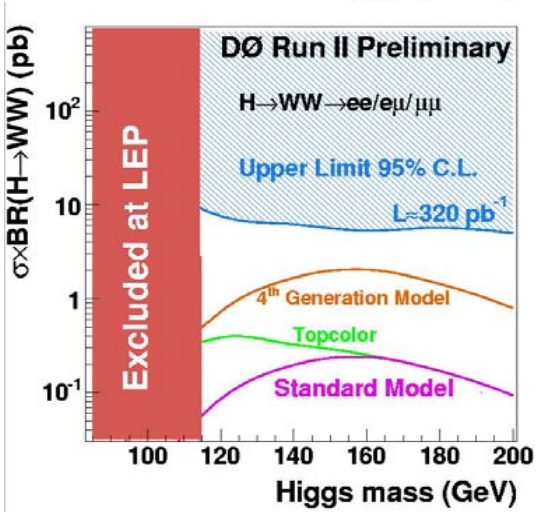


H → W⁺W⁻ → ℓ⁺ℓ⁻νν









Light Higgs observed sensitivity is close to expected

MSSM Higgs Search

MSSM predicts larger Higgs cross sections for some values of parameter space then SM

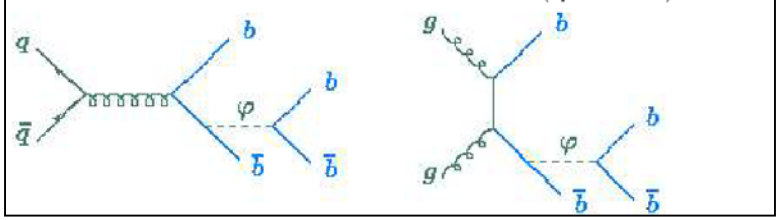
Using NLO cross section calculations and assuming no difference between A and h/H DØ performs search for MSSM Higgs

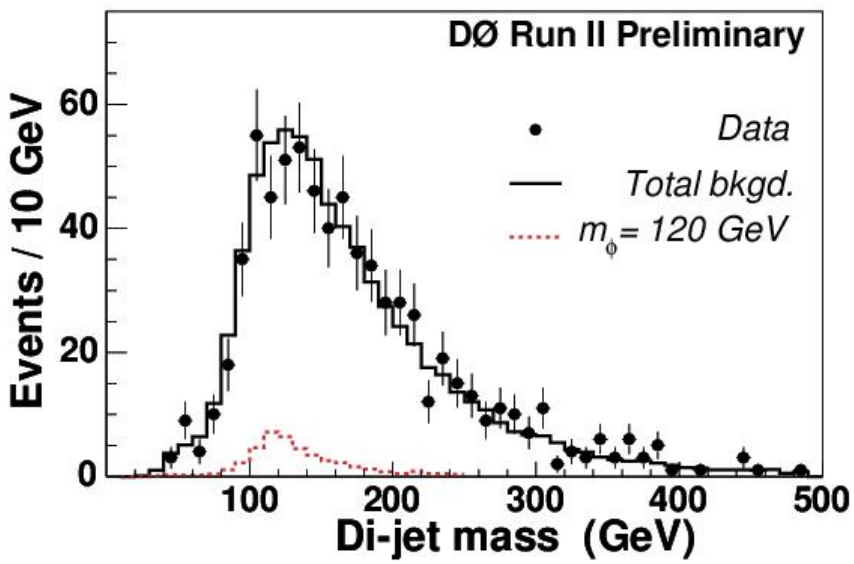
→ multi-jet high E_t sample

→3 or more jets b tagged

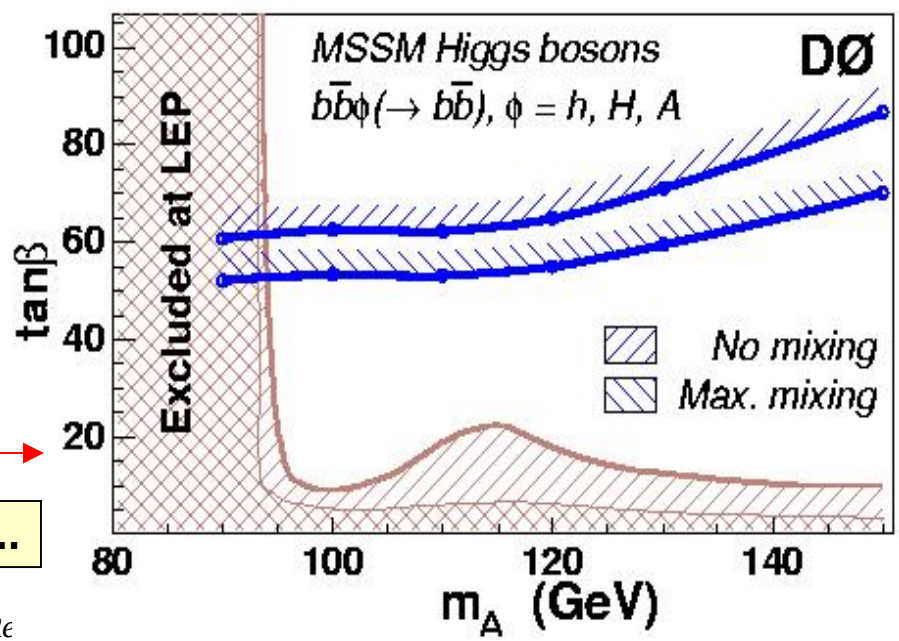
Two Higgs Doublets $\mathcal{H}_1$, $\mathcal{H}_2$ and 5 physical states

2 CP-even neutral Higgses	h^0, H^0	$m_h < m_H$
1 CP-odd neutral Higgs	A^0	
2 charged Higgses	$H^\pm$	
Free parameters:	$\tan\beta = v_2/v_1$	(VEV ratio)
	α	(mixing angle of h, H)
	μ	Higgs mass parameter
	A_0	common trilinear Higgs-sfermion coupling
tree level:	$m_h < m_Z < m_H$	
rad.corrected:	$m_h < 130$ GeV	$Br(\phi \to b\bar{b}) \sim 90\,\%$





World's most stringent limit

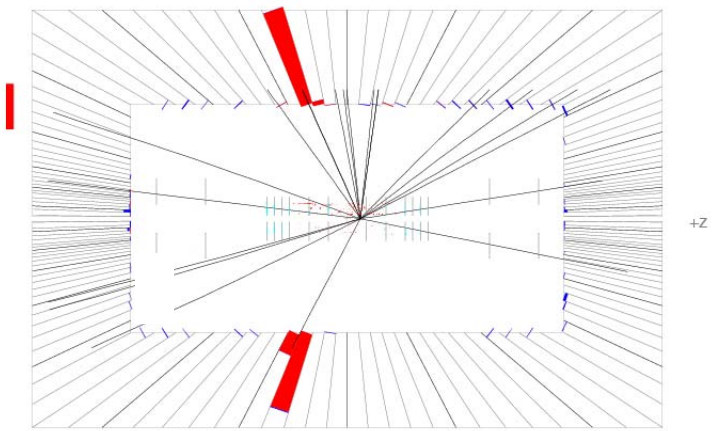


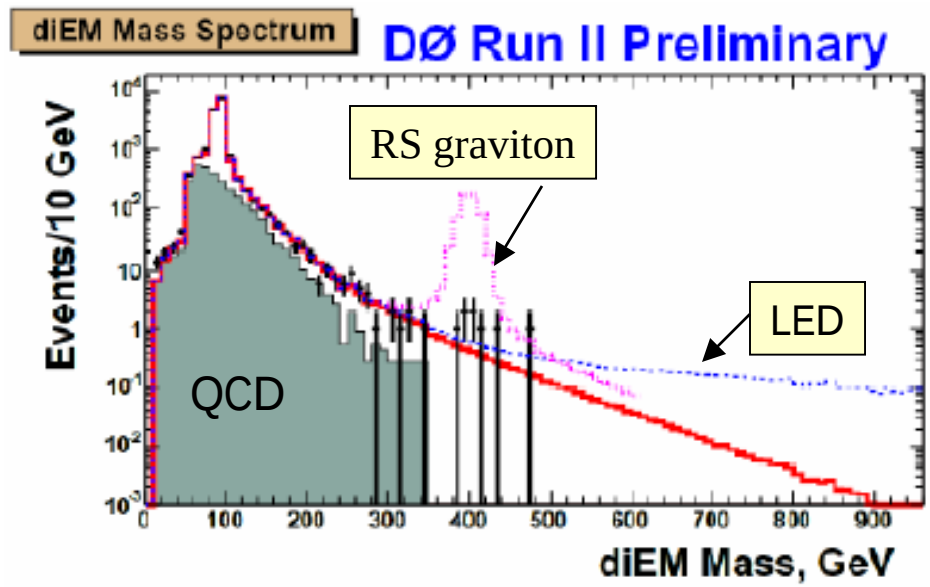
Also fermiophobic Higgs, doubly charged Higgs …

Searching for Extra Dimensions

Signal would be an excess of ee, $\mu\mu$, $\gamma\gamma$ events at large mass due to virtual graviton exchange

High-mass electron pair event
Mass=475 GeV





Latest DØ limit from $\bar{p}p \rightarrow$ ee, $\mu\mu$, $\gamma\gamma$ events

M_S(GRW) > 1.43 TeV (200 pb^{-1}, 95% CL)

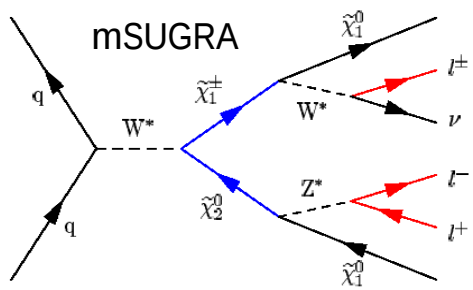
most stringent limit to date on Large Extra Dimensions

Same dataset places limits on TeV-scale extra dimensions, Z' ...

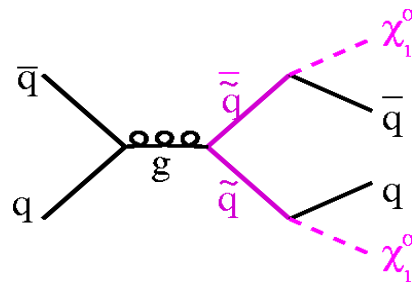
Search for SUSY

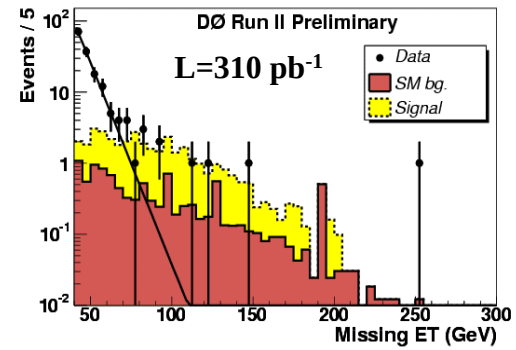
SUSY solves "Hierarchy Problem", provides Grand Unification at the 10^{16} GeV scale, and is a good Dark Matter Candidate (LSP)…

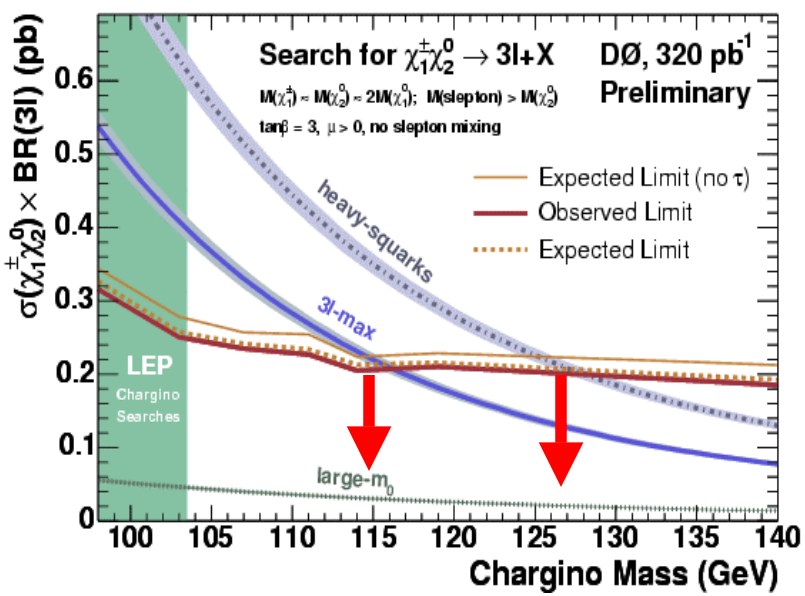
Chargino/Neutralino production in 3l+$\not{E}_T$

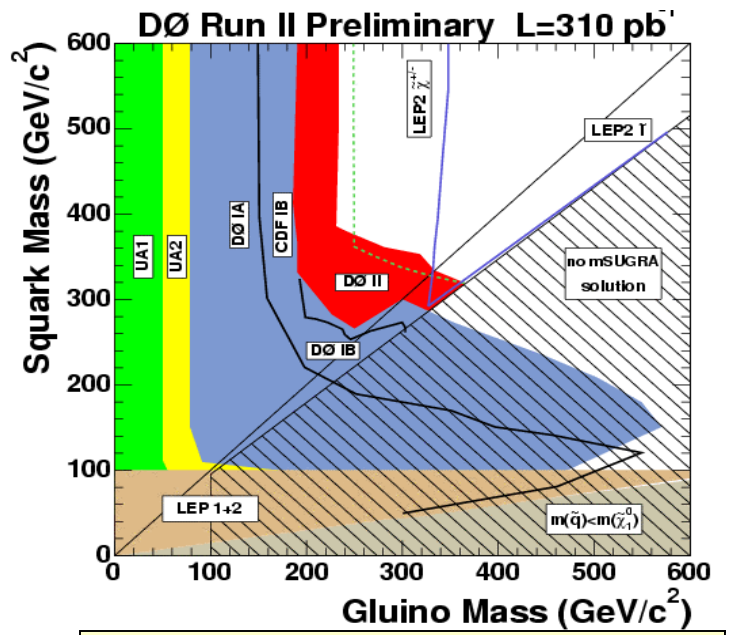


Squarks and Gluinos in jets+$\not{E}_T$









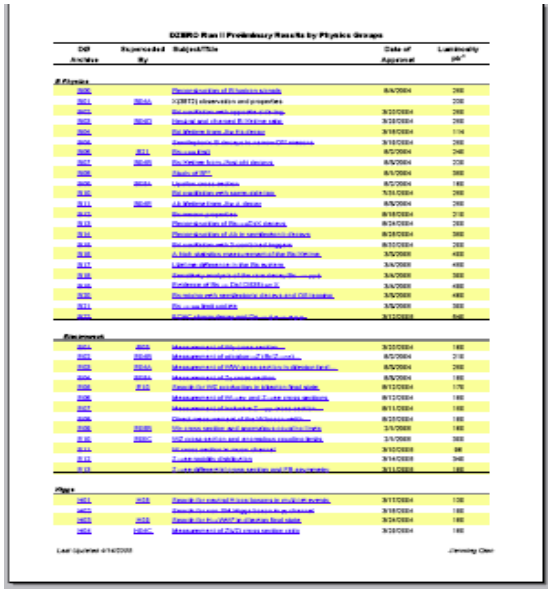
Much better then Run I limits of 1.6 pb

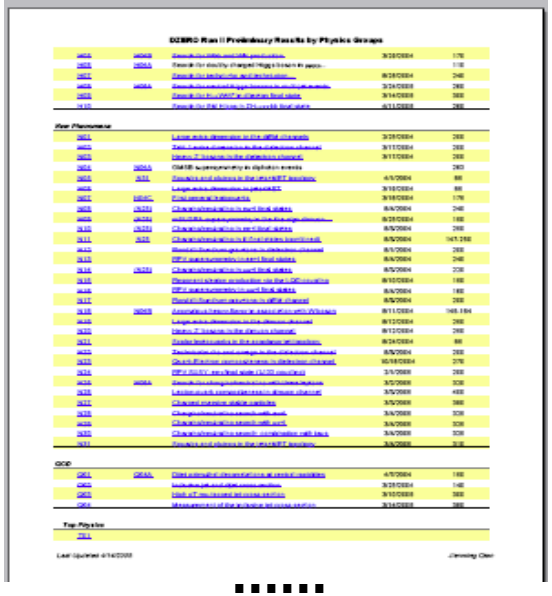
DØ extends LEP mSUGRA reach!

Summary of Results, Talks, Publications

Too many to fit on 3 pages...

- **25 publications over last year**
  - **Quantum leap from 2 by May 2004**
- **~60 new results approved for Conferences**
  - **Most will be published**
- **>250 invitations to Conferences per year**
  - **Invited talks at all major Conferences**
  - **e.g. Moriond/QCD – 9 (out of 50 Exp. HEP) talks**
- **Just submitted 58 abstracts to EPS05 (Lisbon)**





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For full list of DØ approved results and publications visit

http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

including plain-English summaries

Celebrating World Year of Physics!

The FNAL Group at DØ

FNAL/DØ - General

- All of the above would not be possible without the hard work of 100's of DØ Collaborators and Fermilab's/DØ physicists
- Fermilab's/DØ physicists "group" currently consists of 45 members
  - ~10% of the Collaboration – largest DØ group
- Fermilab physicists provide strong contributions to the experiment in a variety of areas, including
  - Items covered in the Operations Review, e.g.
    - Electrical and mechanical support of the experiment
    - Infrastructure support (buildings, computing, farms,…)
    - Safety of the personnel and equipment
  - Items covered under "DØ Upgrade"
  - Responsible for major detector parts
  - Software development
  - Active participation in all stages of physics analysis
- Our FY05 budget under this review is $3.3M
  - Dominated by SWF
  - Supports a fraction of ~30 physicists in PPD/DØ: Operating the experiment as well as extracting the physics

Strong Fermilab/DØ group is critical for the success of DØ operations and data analysis

FNAL/DØ - Leadership

- **Fermilab physicists currently help DØ in many key leadership positions**
  - **Operations – 10 of 25 group leaders (40%)**
  - **Software/algorithms – 2 of 13 group leaders (15%)**
  - **Computing – 7 of 14 group leaders (50%)**
  - **Physics analysis – 3 out of 12 conveners (25%)**
  - **Upgrade – 18 of 33 group leaders (55%)**
- **In the past 3 years the "group" provided leaders in most upper management positions, e.g. spokesperson, run coordinator, computing and core software leader, software algorithms leader, and physics coordinator**
- **In the past the group provided many physics group convenors**
- **Many senior members of the "group" provide leadership by example rather than by title…**

FNAL/DØ – Physics Analysis

- **Out of 45 members of the Fermilab's/DØ "group"**
  - **~20 are actively involved with current physics analysis (in all 6 physics analysis groups)**
  - **~30 are actively involved in reviewing current physics analysis (3 of those are chairs of Editorial Boards)**
- **Some of the more visible analyses our group is involved with are**
  - **B_S Oscillations**
  - **Higgs Search in**
    - **$Hb\bar{b}$ channel ($H \rightarrow bb$)**
    - **HZ channel ($Z \rightarrow \nu\nu$, $H \rightarrow b\bar{b}$)**
  - **WW Production**
  - **Top Measurements of**
    - **$t\bar{t}$ Production Cross Section**
    - **Top Quark Mass**
  - **Inclusive Jet Production**
  - **Leptoquark Search**

  …and there are many others…

Conclusions

Conclusions

- **The DØ detector is working well with high data taking efficiency**
  - **Currently >0.7fb^{-1} on tapes with full detector in readout**
- **Data processing is keeping pace**

Physics program is flourishing

Top Quark

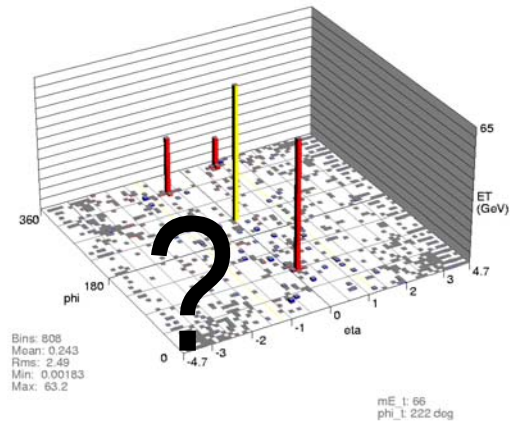
QCD

Electroweak

Heavy Flavor

Beyond SM searches

Higgs hunting



- **Many ongoing physics analyses**
- **Publishing with healthy rate**
- **The Collaboration is enthusiastic → 1 fb^{-1} of data in 2005**
- **There are challenges → technical, manpower**
- **Preparing for the future**

We entered unexplored energy frontier territory – stay tuned!