Seminar at Departamento de Física Teórica, UAM

February 12, 2004

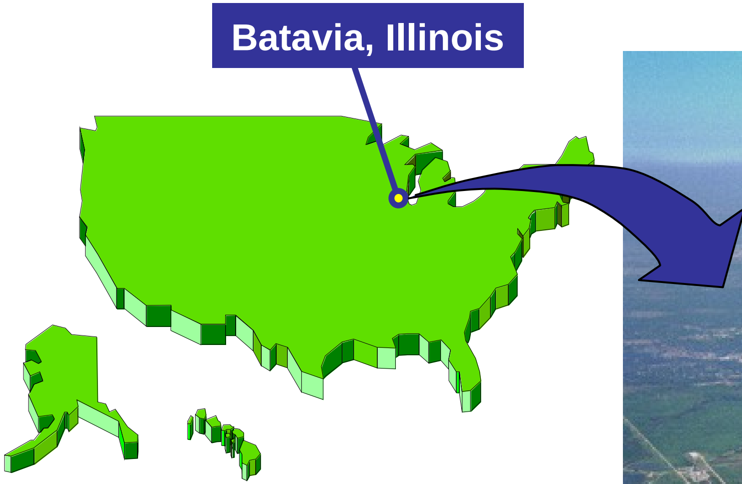
Protons in the praire:
Status of the DØ detector at Fermilab

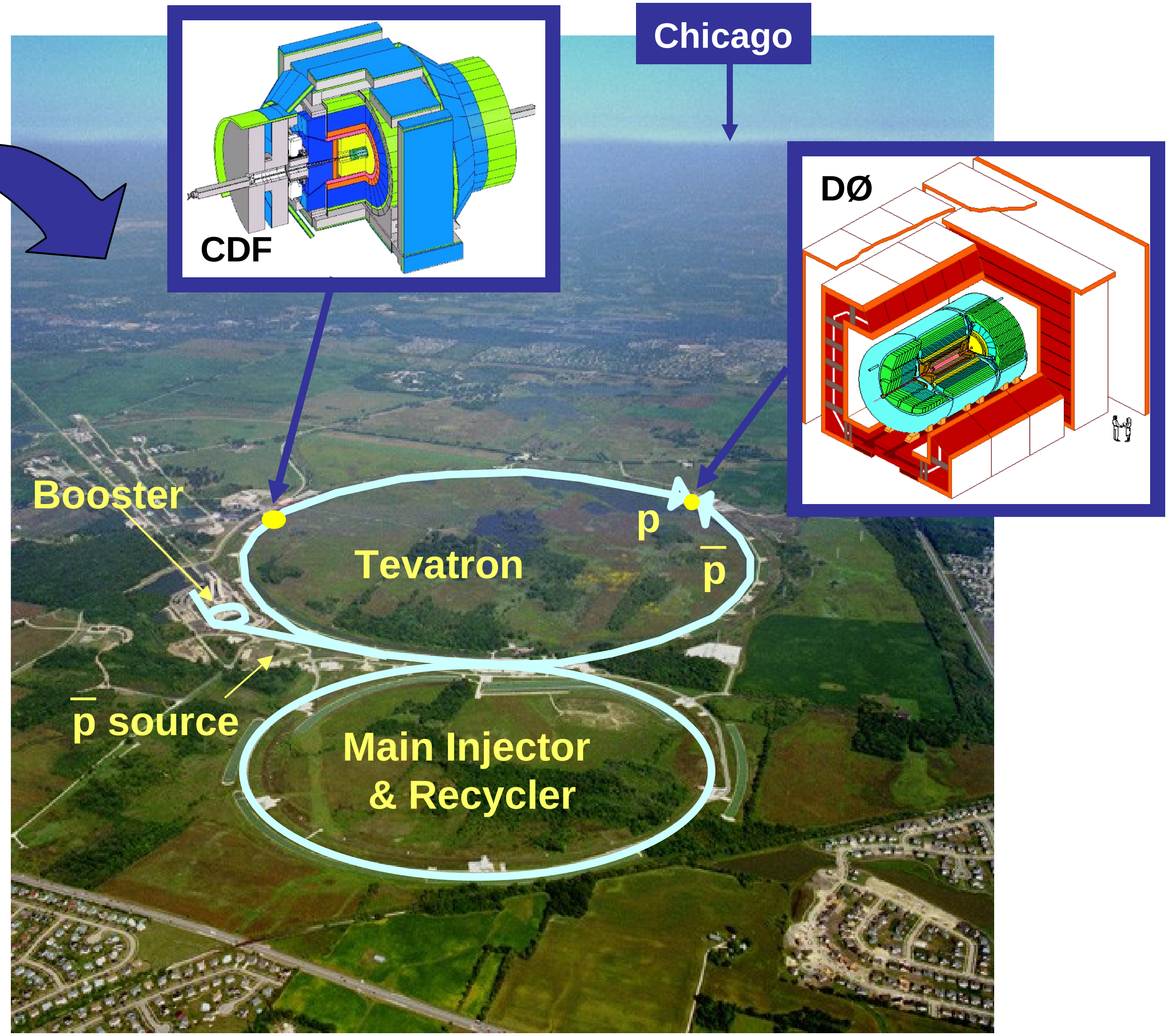
- The RunII detector. Operations. Upgrade
- Top physics
- New analysis of M_{top} with Run I data
- B-lifetimes and B_s mixing
- Higgs searches and sensitivity study
- New phenomena searches
- Expected results for the 2004 Winter Conferences

Arán García-Bellido

UNIVERSITY OF WASHINGTON

Tevatron at Fermilab





Run I 1992-95

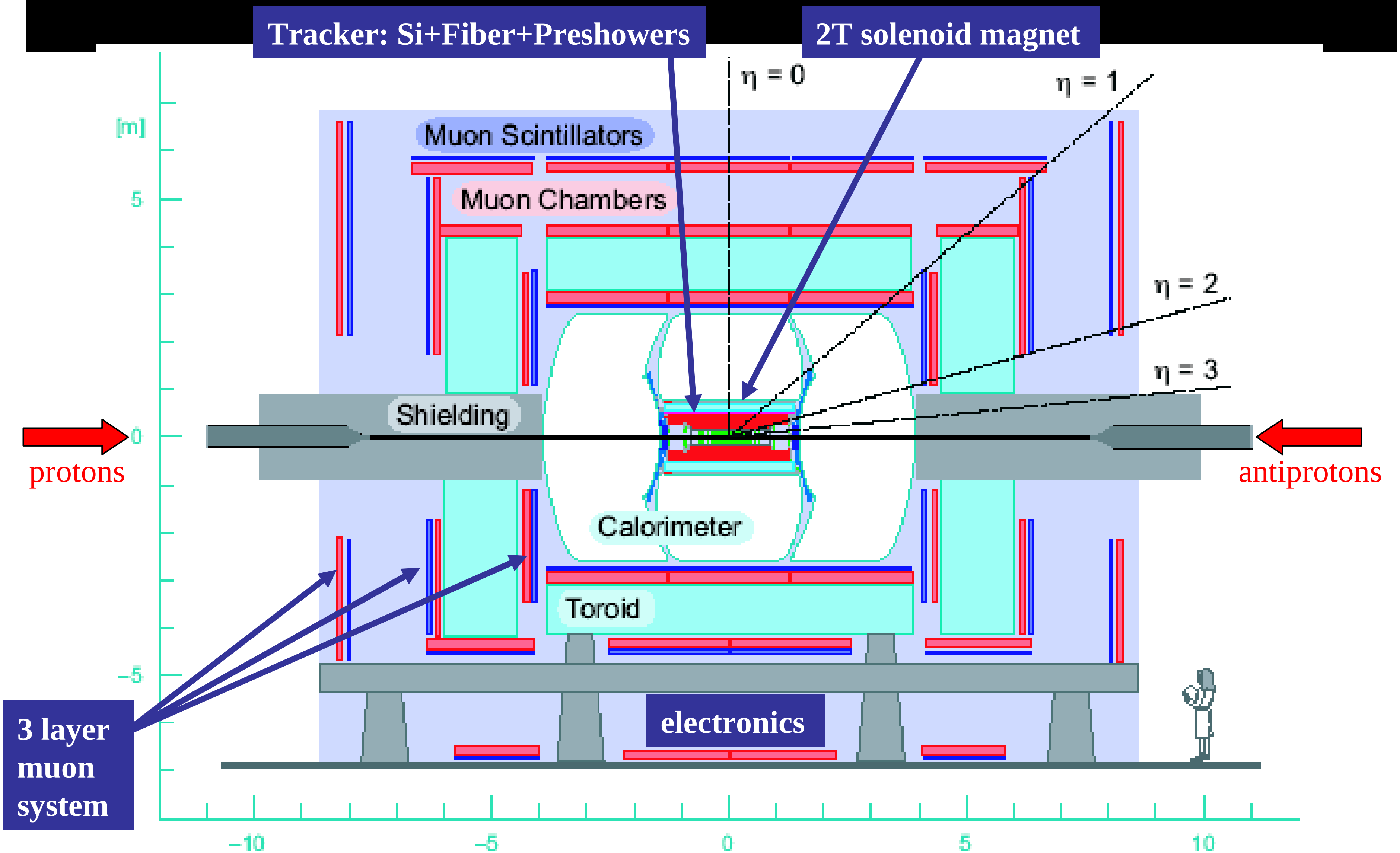
- **Top quark discovered!**

Run II 2001-09(?)

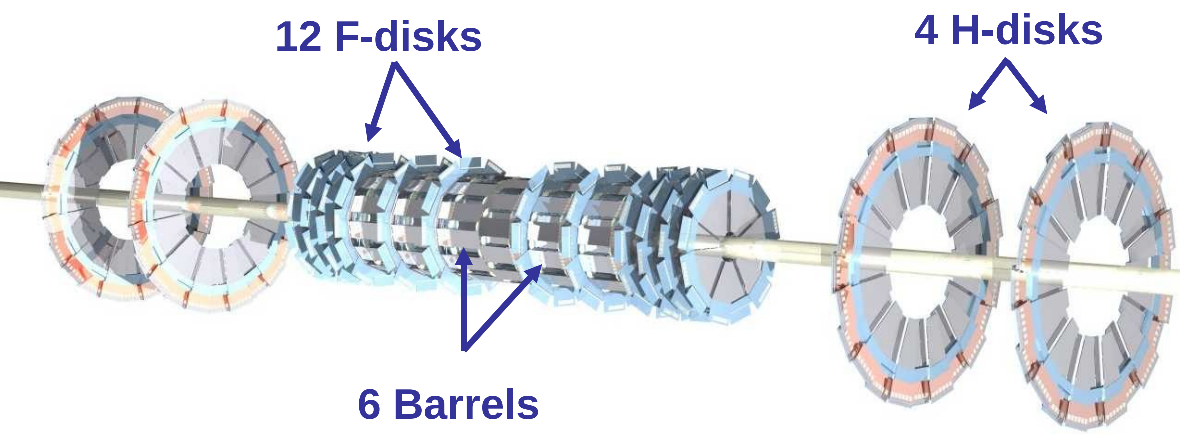
- **$\sqrt{s}$ =1.96 TeV**
- **Δt = 396 ns**
- **36x36 bunches**
- **Peak Lum 5×10^{31} $cm^{-2}s^{-1}$**
- **Delivered ~260 pb^{-1}**
- **(~ x2 previously collected)**

Unprecedented window into the nature of matter…

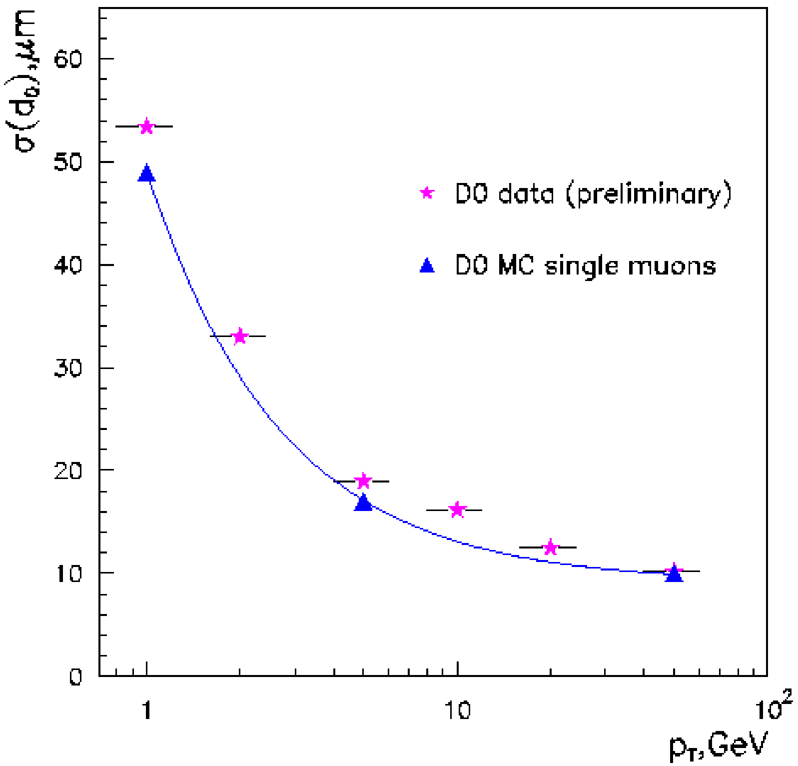
The Run II DØ detector

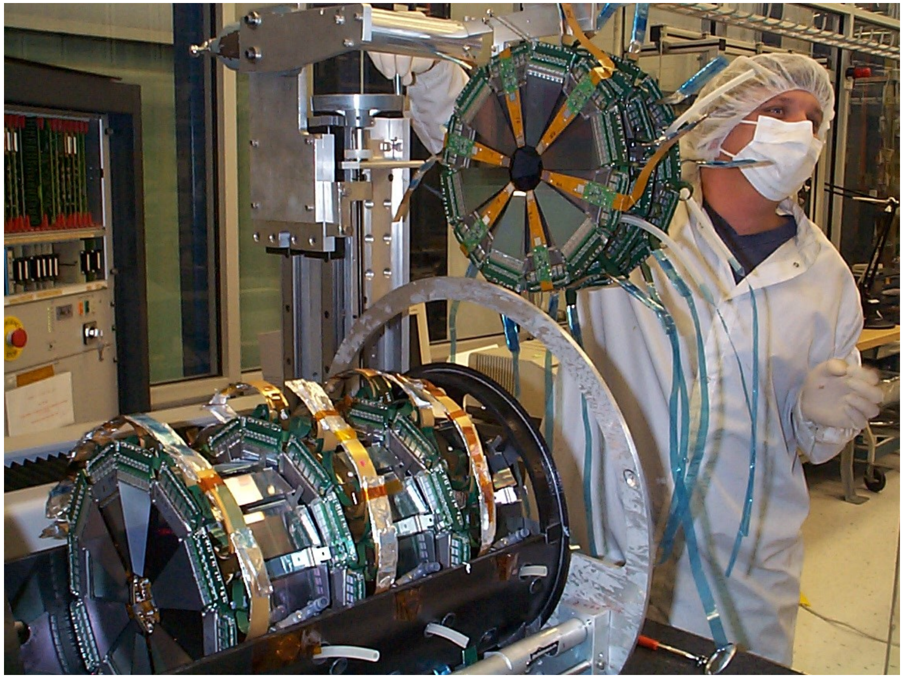


Silicon detector

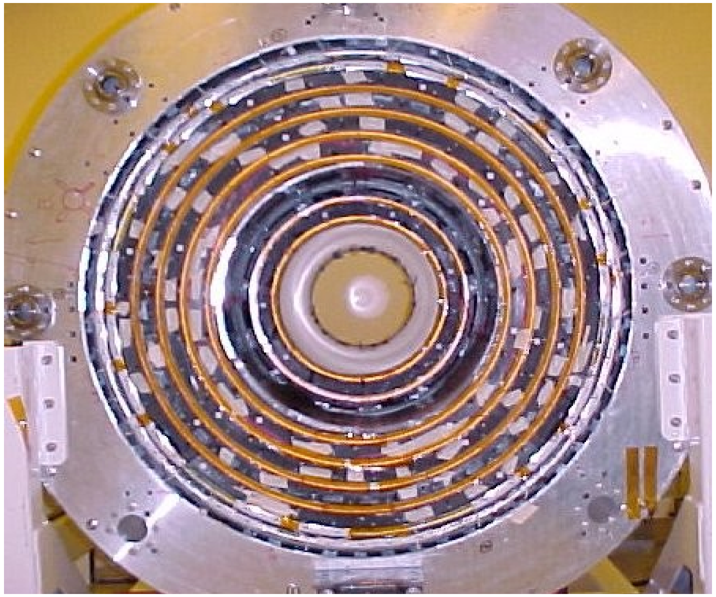


- $3m^2$ of silicon
- Active Channels: 91% of 800k
- S/N: > 10 all devices
- Cluster Efficiency: > 97%
- No fiducial loss

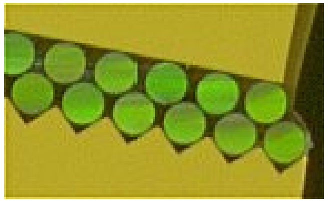


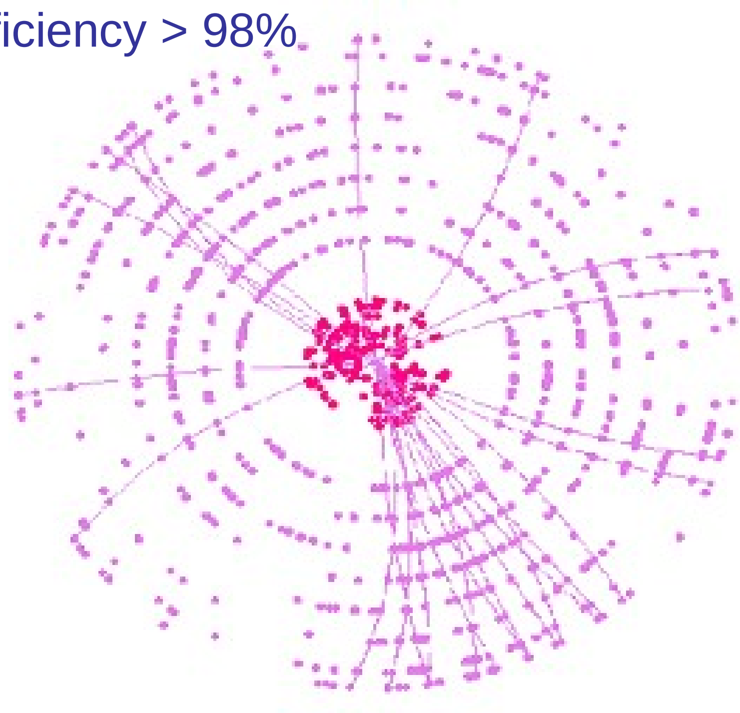


Central Fiber Tracker



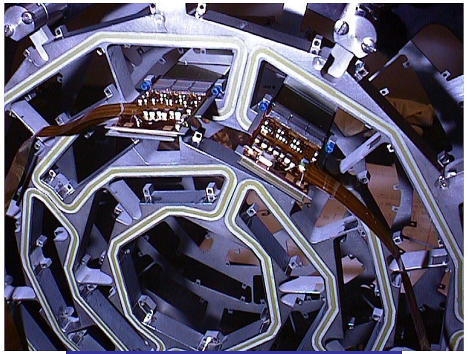
- First use of scintillating/VLPC in accelerator
- 8 layers scintillating fiber doublets
- 4 axial & 4 stereo
- Active Channels: 99% of 77k
- Excellent light yield
- Hit efficiency > 98%



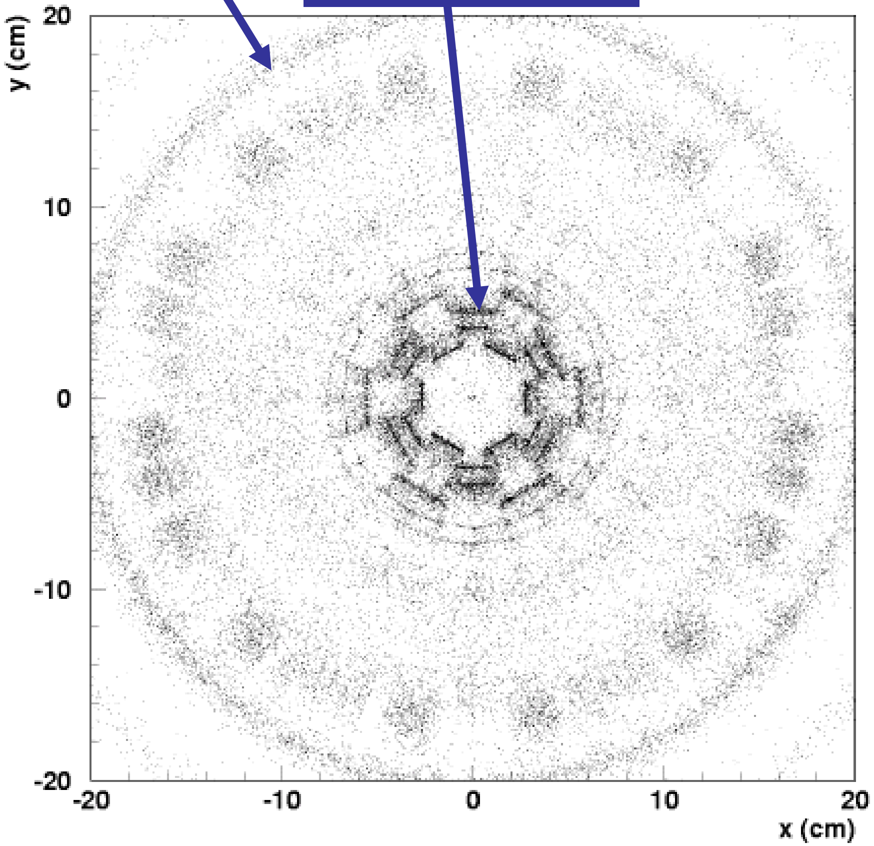


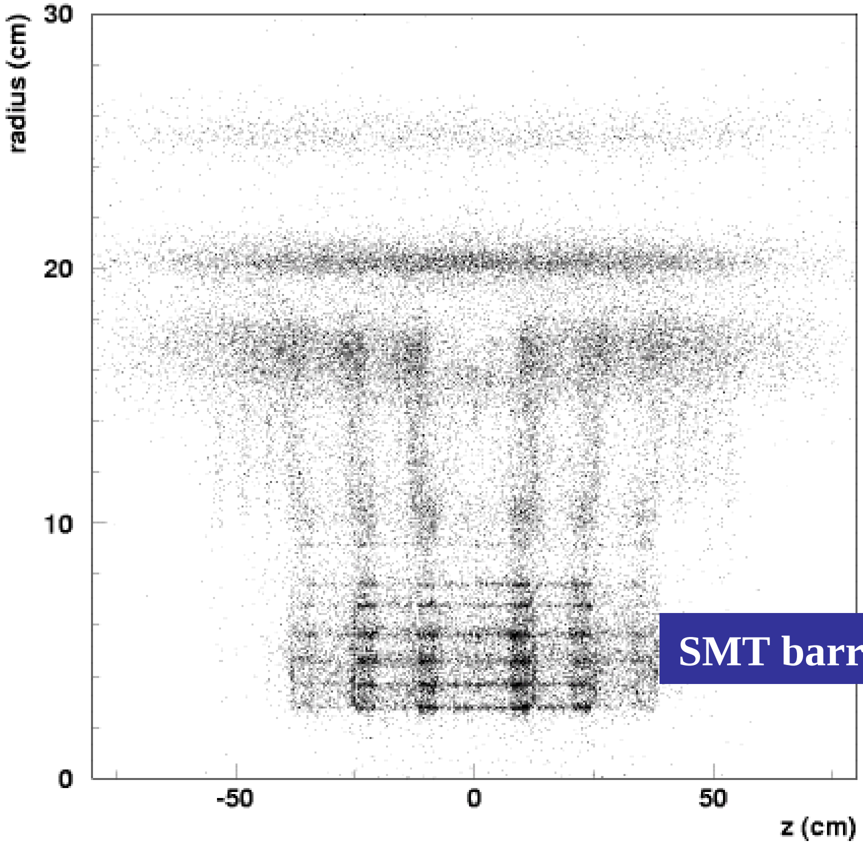
$\gamma \rightarrow e^+e^-$ tomography

Reconstruct conversion vertices
2.6 M vertices database
Understand material distribution
Source of well measured electrons→EMID



CFT
SMT bulkheads

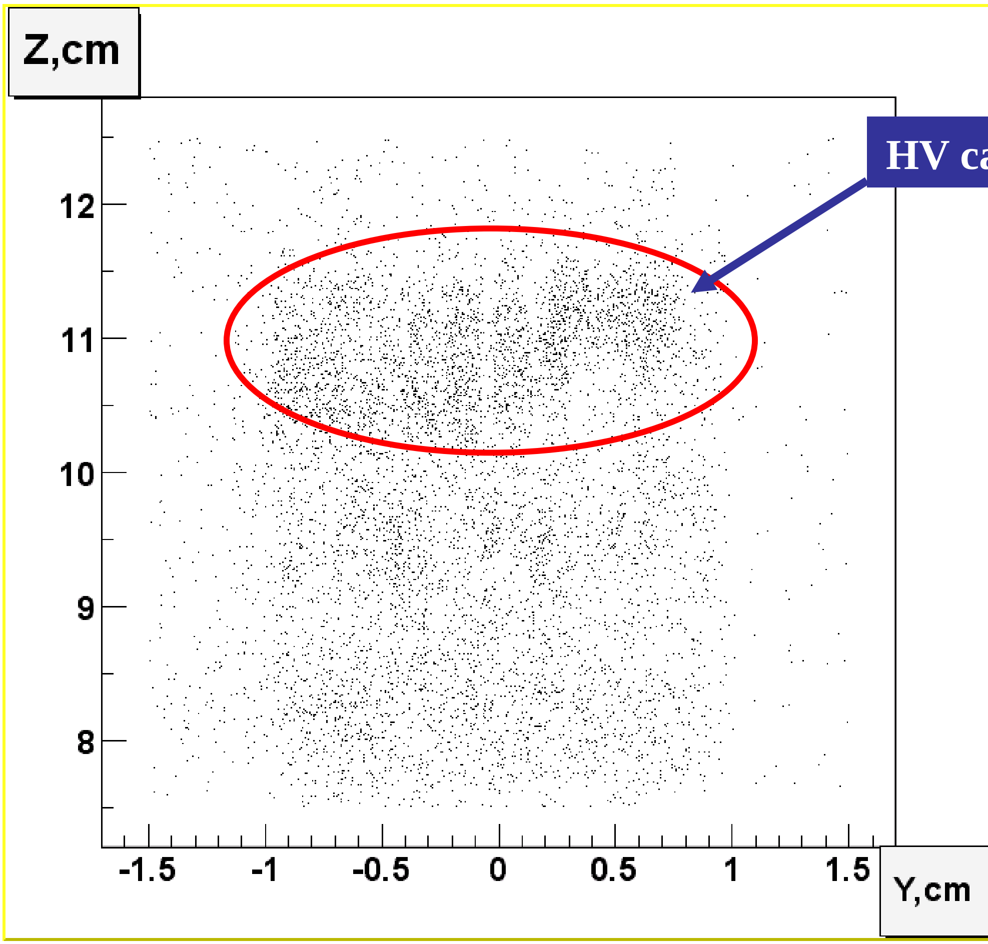


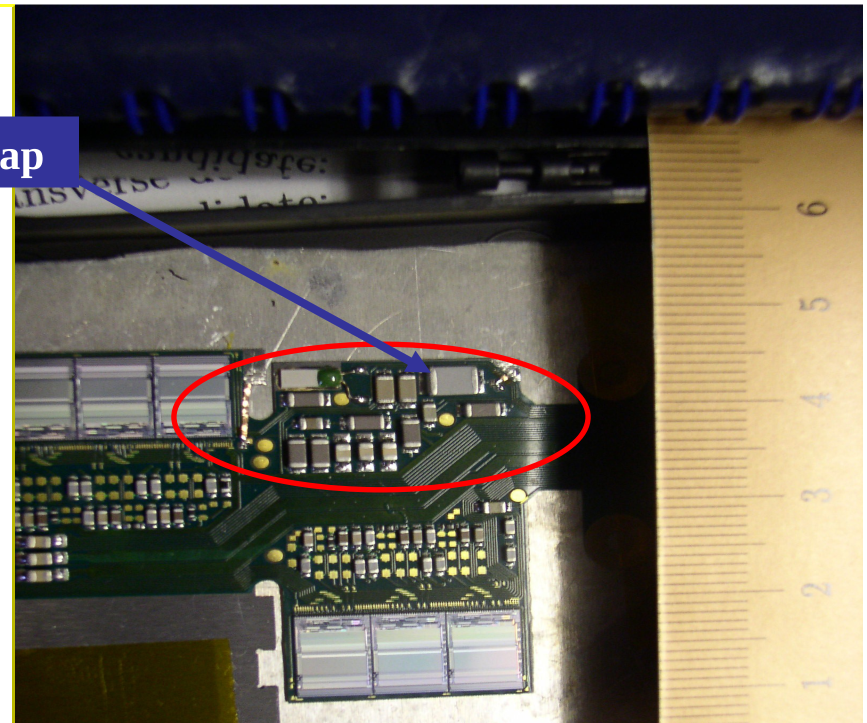


SMT barrel

γ→e^+e^- tomography

Fine structure of detector is seen and can be studied

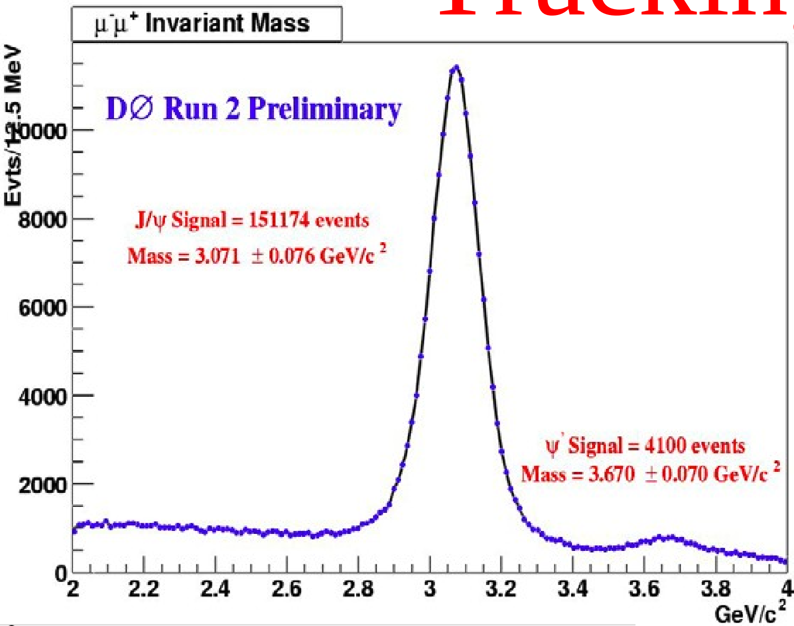


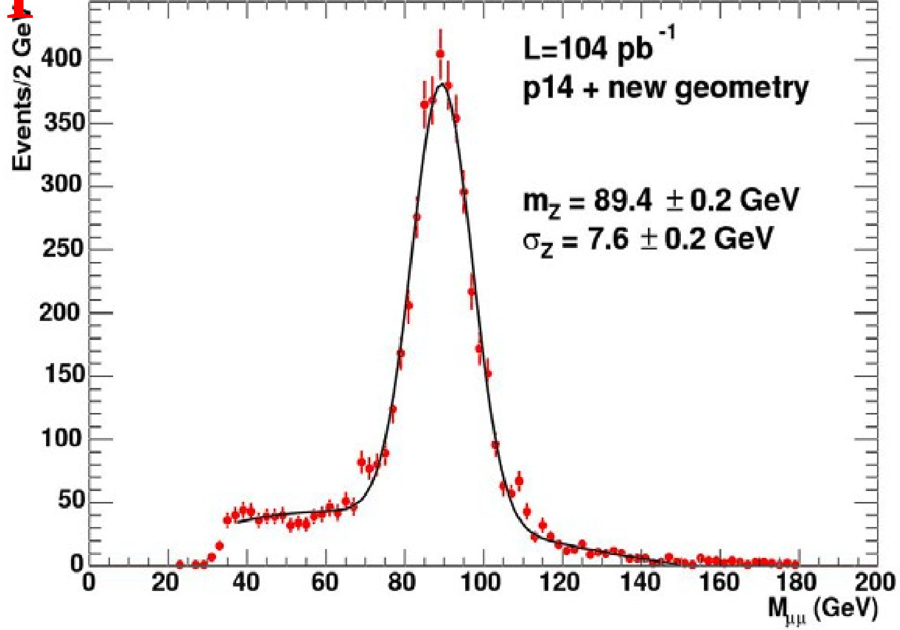


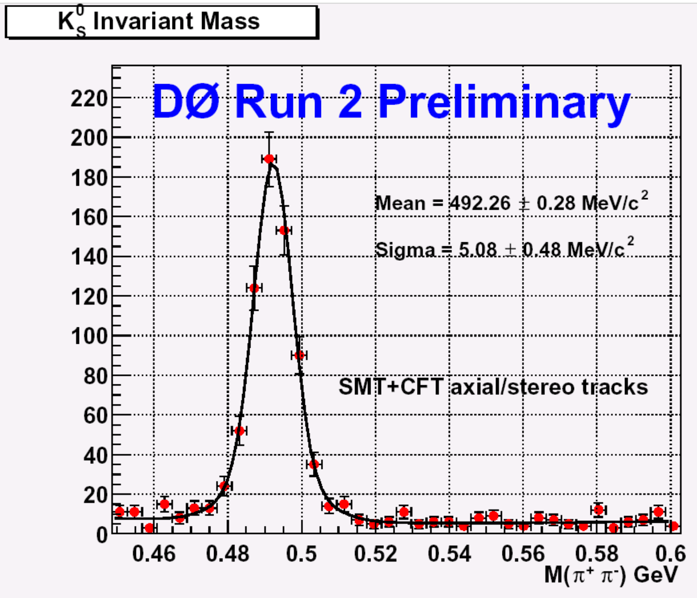
SMT HDI (High Density Interconnect)

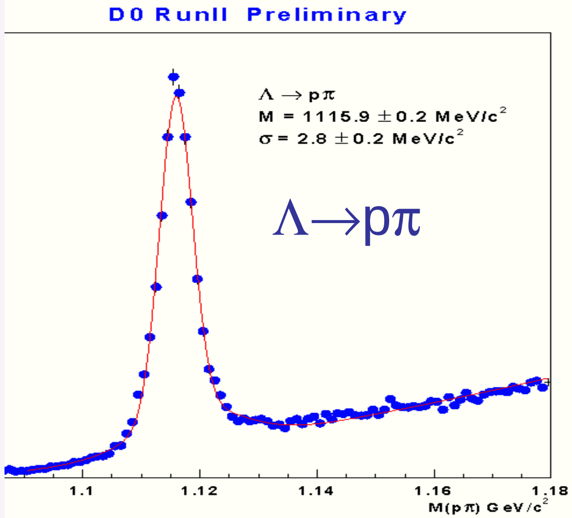
- Fe Readout electronics
- Laminated to Be plate
- Heavy metal content

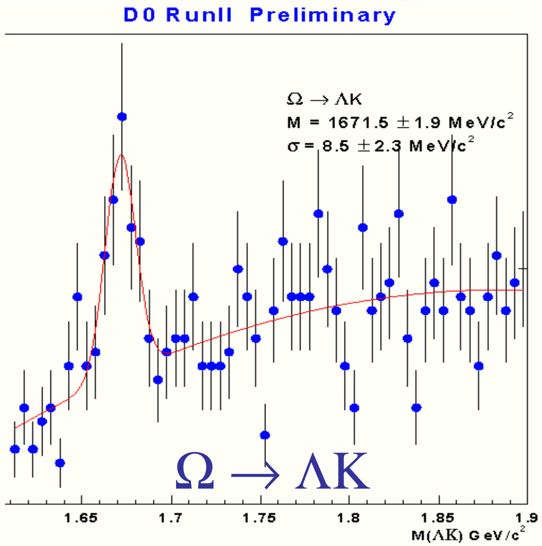
Tracking performance





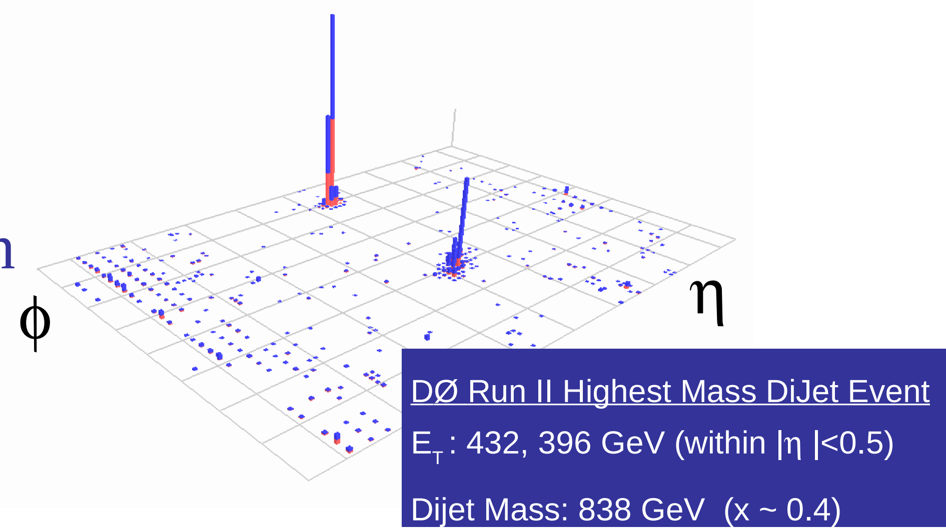


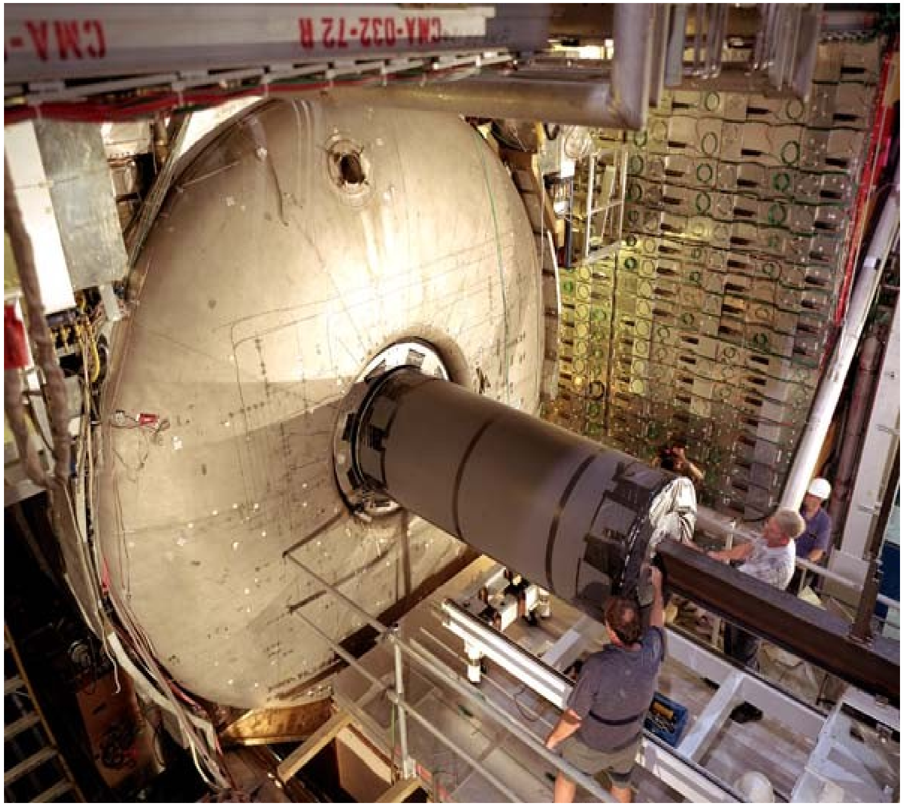


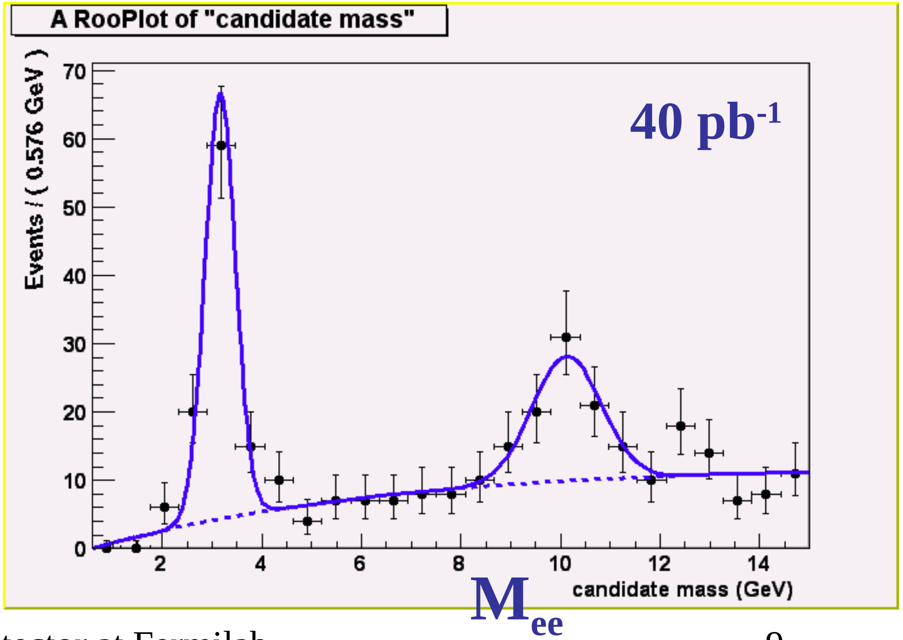


LAr Calorimeter with U absorber

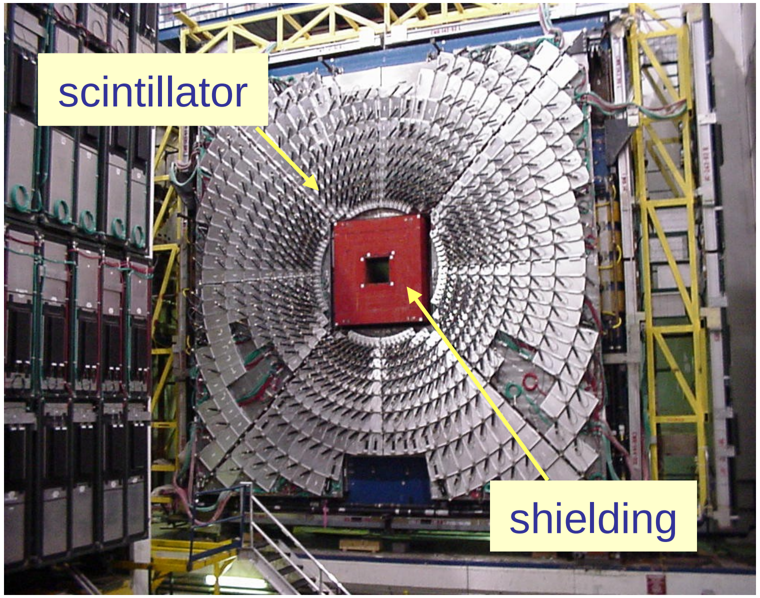
Same detector, new electronics
99% channels alive of 50k
Improved grounding and isolation during shutdown





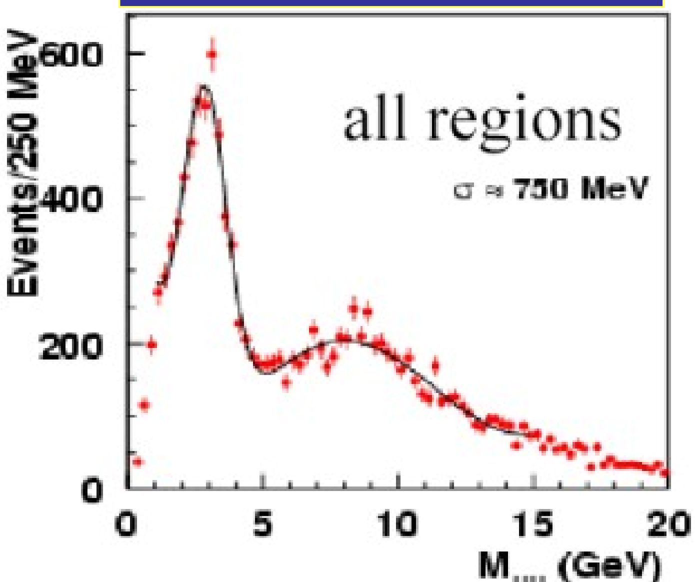


Muon system

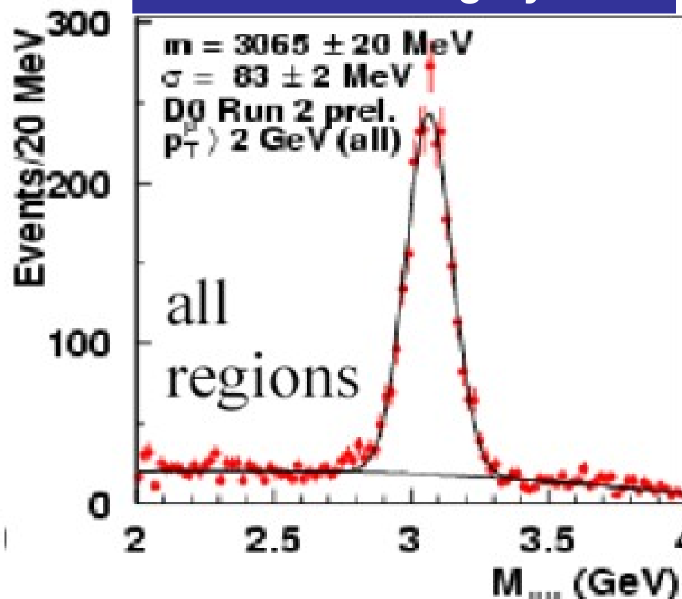


- New forward detector and shielding
- Coverage to $|\eta| < 2$
  - 3 layers of triggering scintillator planes: 99.9% active
  - 3 layers of precise tracking drift tubes: 99.5% active

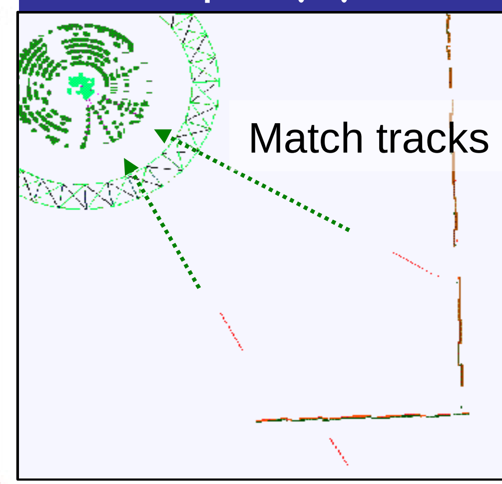
Muon System Only



Global Tracking System

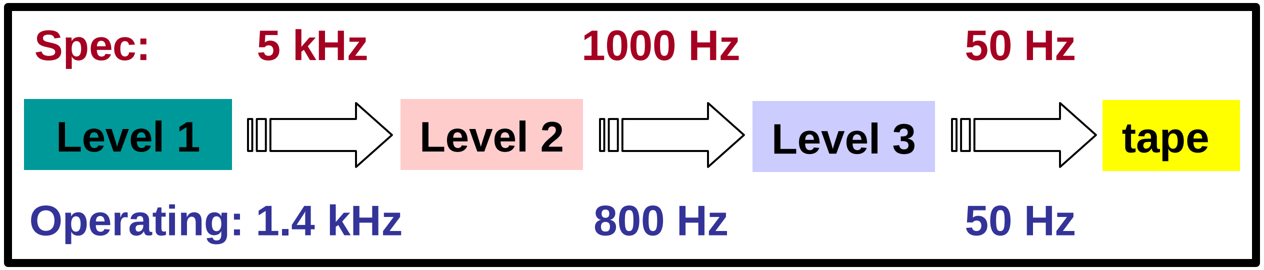


$J/\psi \rightarrow \mu^+\mu^-$



Trigger and DAQ system

Bunch crossing:
396 ns ⇒2.5 MHz



1M channels
~250KB/event

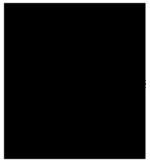
Runs comfortably up to 5x10^{31} cm^{-2}s^{-1} and will keep pace with luminosity growth as tracking triggers completed, CPUs added.

L1: >100 independent trigger bits
- Operating with Cal & Muon
- CTT & PS integration is testing

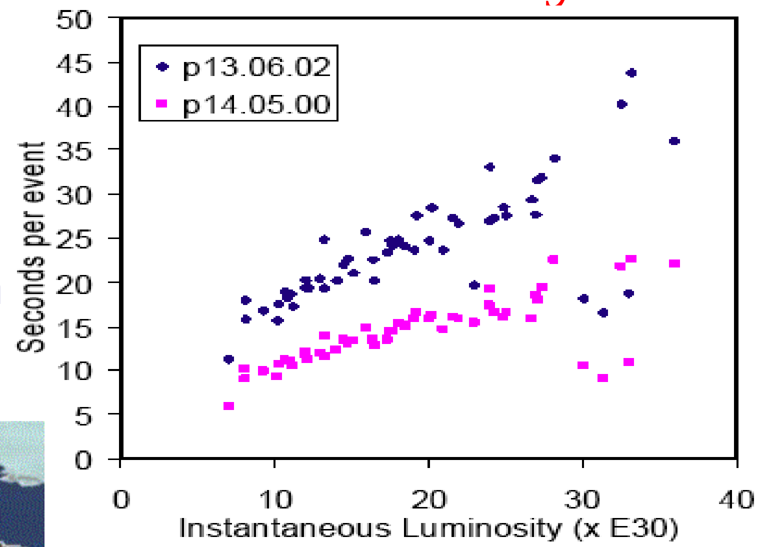
L2:
- Operating with Cal, Muon, Global
- CTT, STT is commissioning (taking data, not for physics)
- Input rate expansion w/ processor replacements

L3: Extensive suite of filters available

DAQ:
- Working to reduce Front End Busy rate (~4%, mostly tracking)
- All commodities solution easily meets 1 kHz L2 accept specification
- Can monitor from a cell phone!

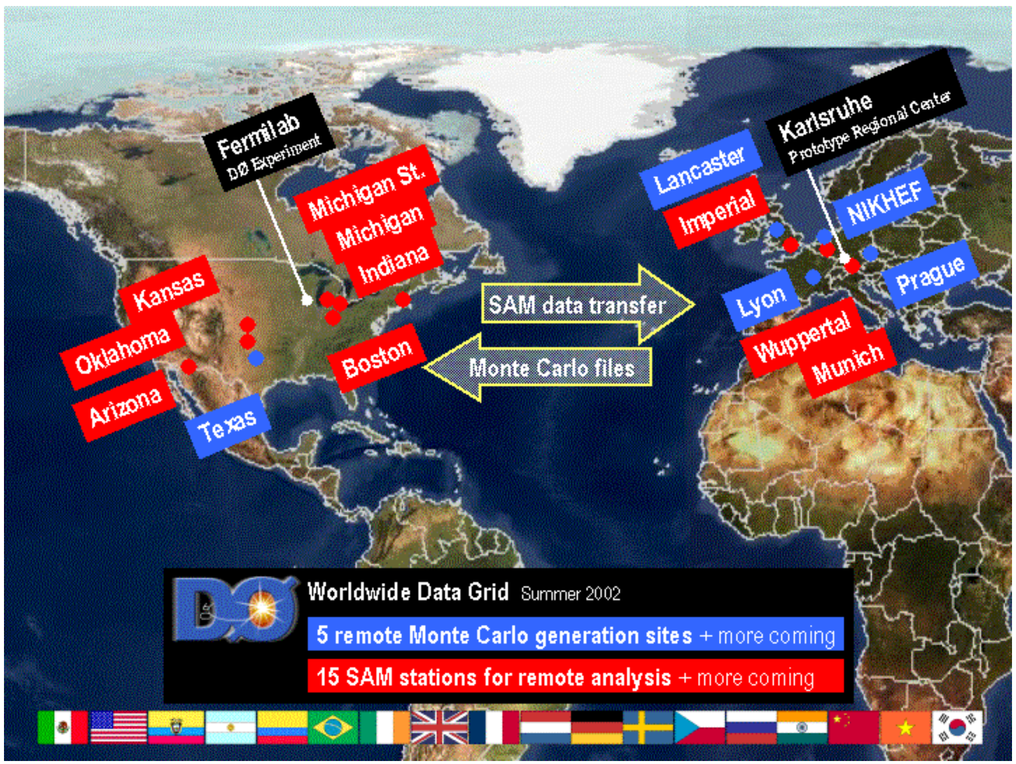


Offline event reconstruction and analysis



DØ Reconstruction Farm

- 240 1.8 GHz dual CPU machines
- 20M event/week capacity
- events processed within days of collection
- 400M events processed in Run II so far



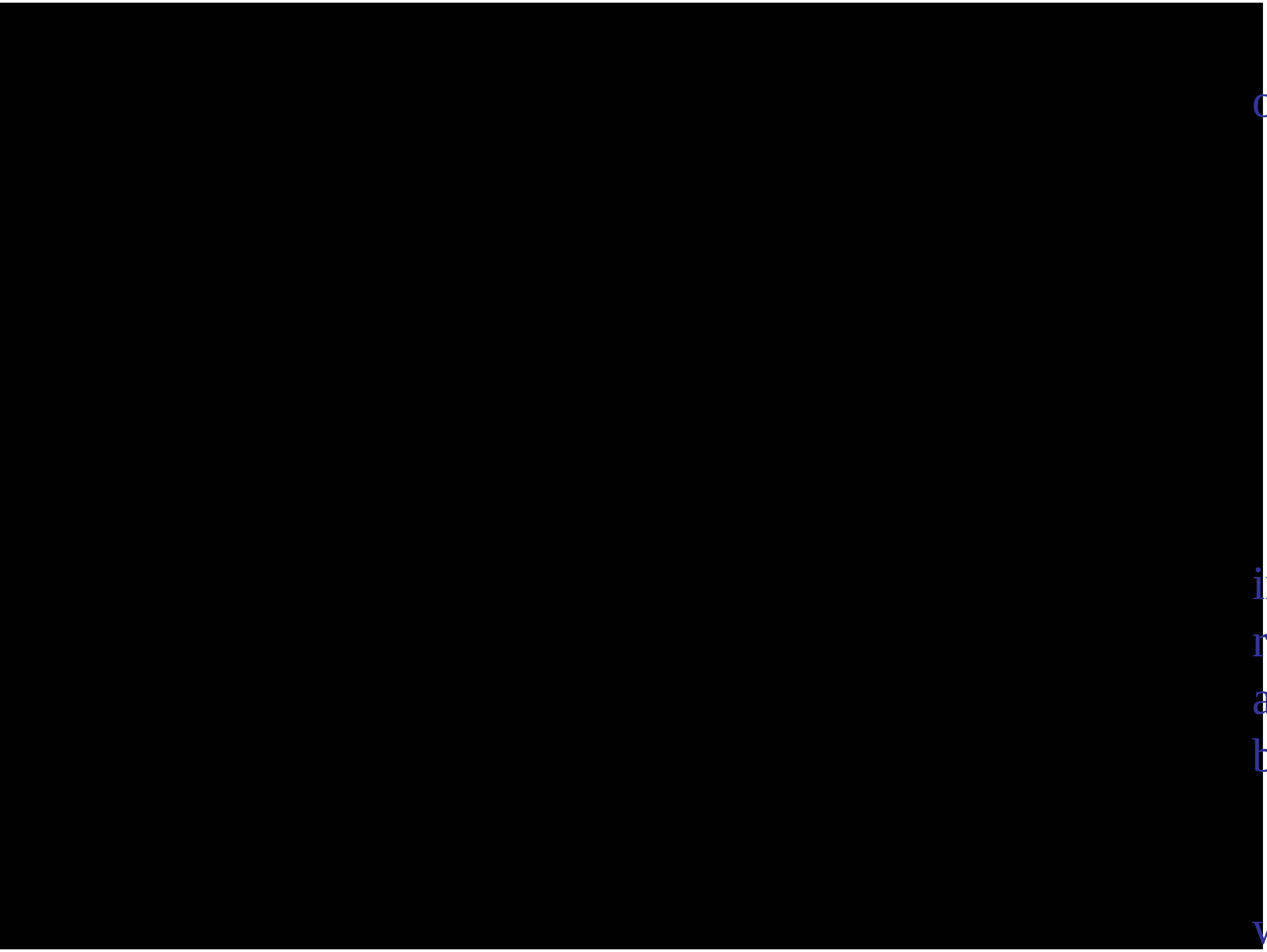
Globally Distributed Resources

6 remote Monte Carlo Farms

- 0.6M event/week capacity
- Running full GEANT, DØ reconstruction and trigger simulation

15 SAM stations for remote analysis

Integrated Luminosity



~260 pb^{-1} on tape: an overall 77% efficiency

Inefficiency due to:

- ~ 5% FEB
- ~ 5% losses in store & run transitions
- ~ 5% “incidentals”

DAQ steadily improved during the run and routinely run at 85% efficiency before the shutdown

Average 8 pb^{-1} per week after shutdown

Tevatron progress

We just had a major shutdown:

- Realignment ⇒ new beam position detectors installed
- Recycler ⇒ much better pbars now!

Tevatron recovered slowly but effectively from shutdown

Record peak luminosities almost every day since!

Latest record: $5.6 \times 10^{31}\ cm^{-2}s^{-1}$

Stores last around 20h

Ongoing analyses

Electroweak

- W/Z cross sections, dibosons and anomalous couplings, charge and rapidity asymmetry, …

Top Quark

- Top quark pair production cross section measurements, top quark mass and decay properties, search for single top quark production, …

New phenomena searches

- Higgs bosons, supersymmetry, leptoquarks, large extra dimensions, Z' ,…

Heavy flavor

- Resonance reconstructions, masses, lifetimes, branching fractions, rare decays, B_s mixing, …

QCD

- Inclusive jet cross section, dijet mass and angular distributions, diffraction, …

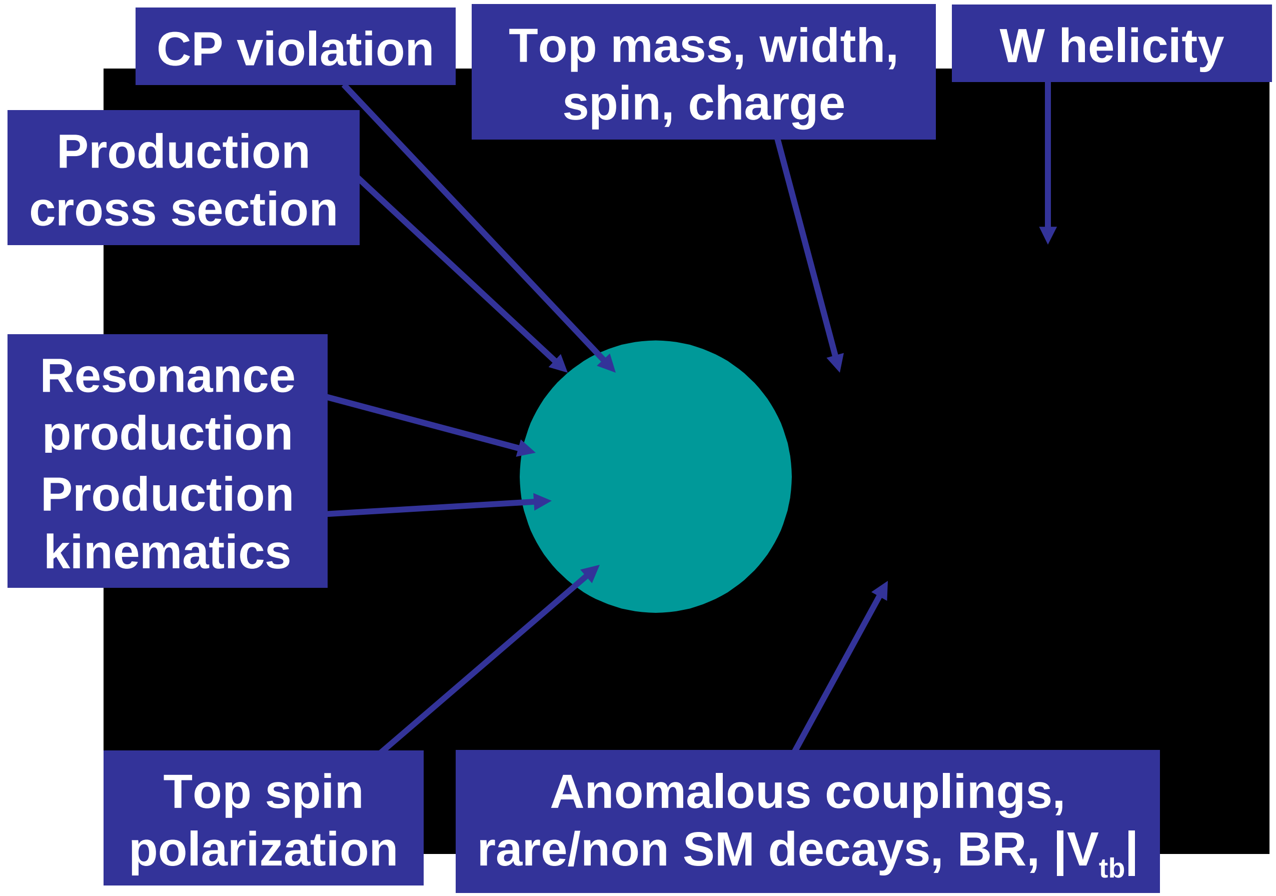
Top quark physics in Run II

The Tevatron is the world's only source of top quarks!

Top quark has a special place in the SM: $M_t \sim v/\sqrt{2}$

Run I:
Identified ~100 top events

Run II:
with high precision we hope to answer questions such as:



Why is top so heavy?
Is it or the third generation special?
Is top involved with EWSB?
Is it connected to new physics?

Top quark Production

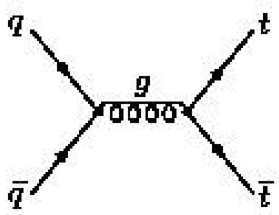
Pair production through strong interaction
σ(tt) ~ 7.5 pb at **1.96TeV** (NNLO CTEQ5M, Kidonakis et al.)

Main production mode at Tevatron
30% higher σ(tt) than in Run I
Run I result with ~100 tops/experiment:

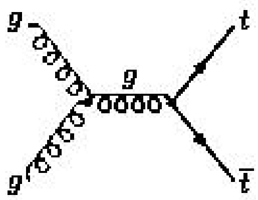
CDF | DØ

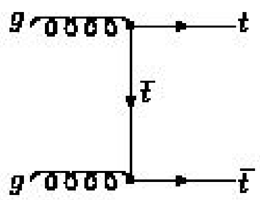
$$\sigma(t\bar{t}) = 6.5^{+1.7}_{-1.4}\ pb$$

M_t = 174.3±5.1 GeV



~90% of σ(tt)

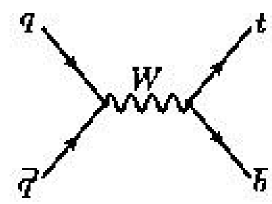




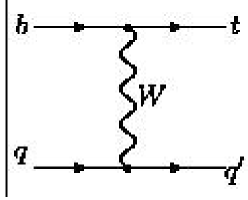
~10% of σ(tt)

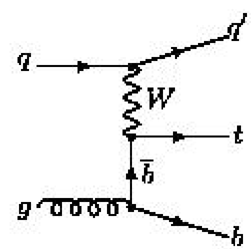
Single top production via EW interaction
σ(t) ~ 2.86 pb at **1.96TeV** (NLO, Sullivan et al.)

Flagship measurement at Run II
Discovery is possible with ~ 0.5 fb^{-1}
Dominant bkgs: Wjj, tt, QCD
Measure s- and t-channel cross sections separately (diff. topologies)
First direct probe of $|V_{tb}|$
(measure to 15% with $2fb^{-1}$)



~30% of σ(t)





~70% of σ(t)

Top decays

In the SM: BR(t→Wb)~100%, classify topologies according to W decays from ttbar:

dilepton: 2 high p_T leptons, 2 *b*-jets, large E_t^{mis}

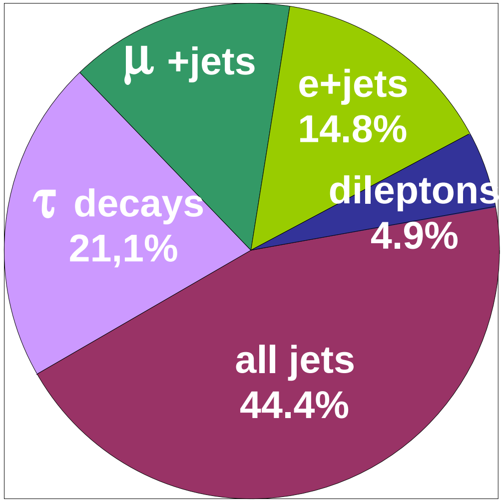
Small BR, but cleaner signal and small systematics. No *b*-tagging
Physics bkgs: WW/WZ (determined from MC); DY (from data)
Instrumental: fake leptons in W+jets and QCD and fake E_t^{miss} (from data)

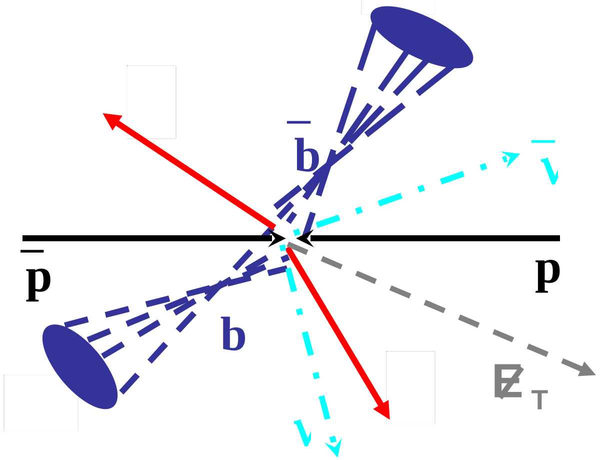
lepton+jets: 1 high p_T lepton, 4 jets (2 *b*'s), large E_t^{mis}

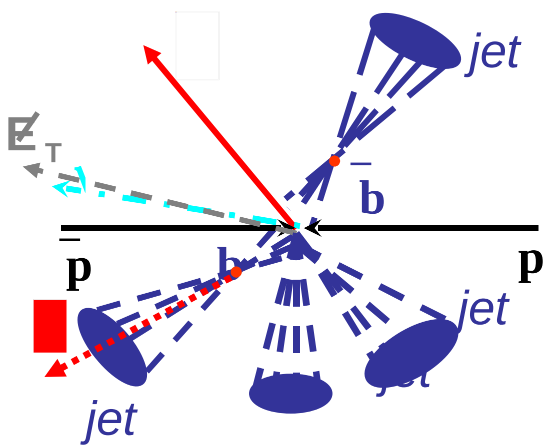
Larger yield, larger bkg⇒Use event topology, *b*-tagging (and SLT)
Backgrounds: W+jets and fake leptons in QCD

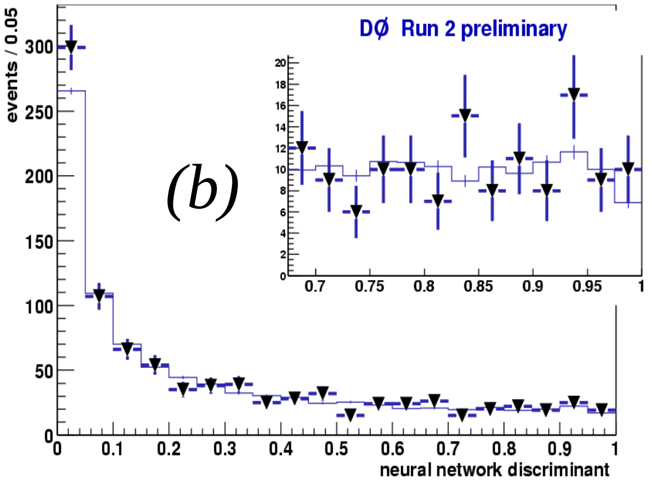
all jets: 6 jets (2 *b*'s)

Swamped by bkg, very challenging, but impossible at LHC! Use NN





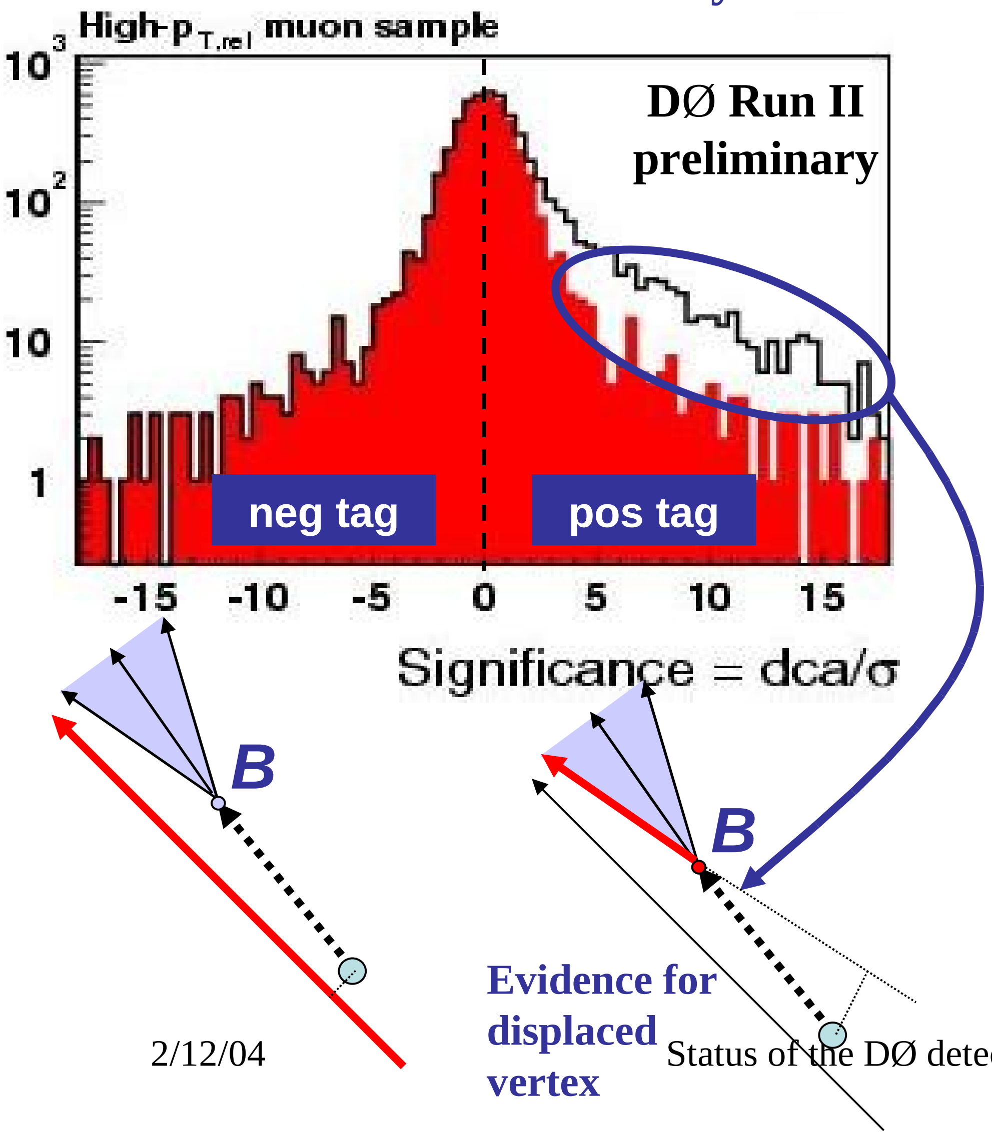


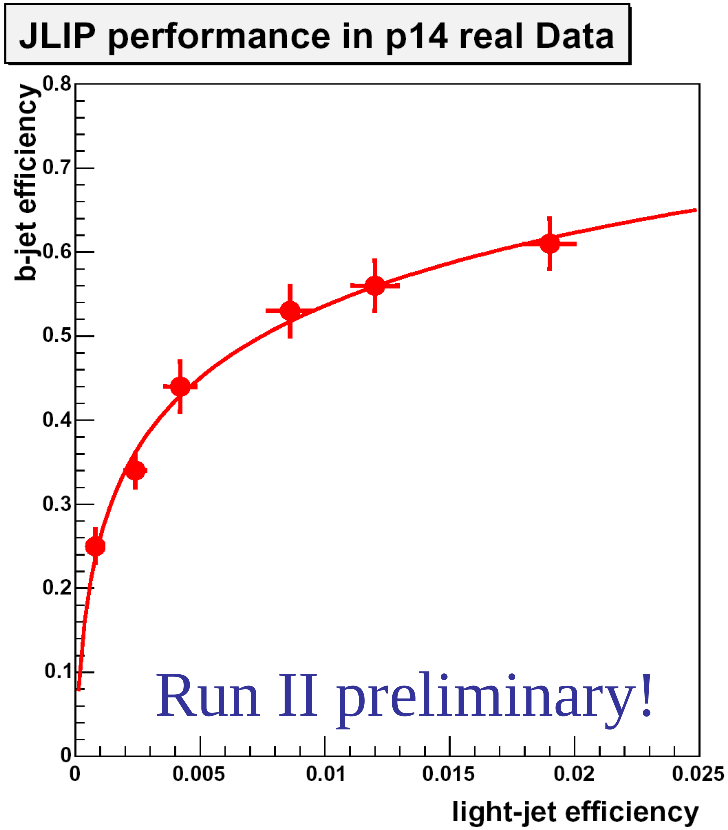


Lifetime *b*-tagging

Three different algorithms:

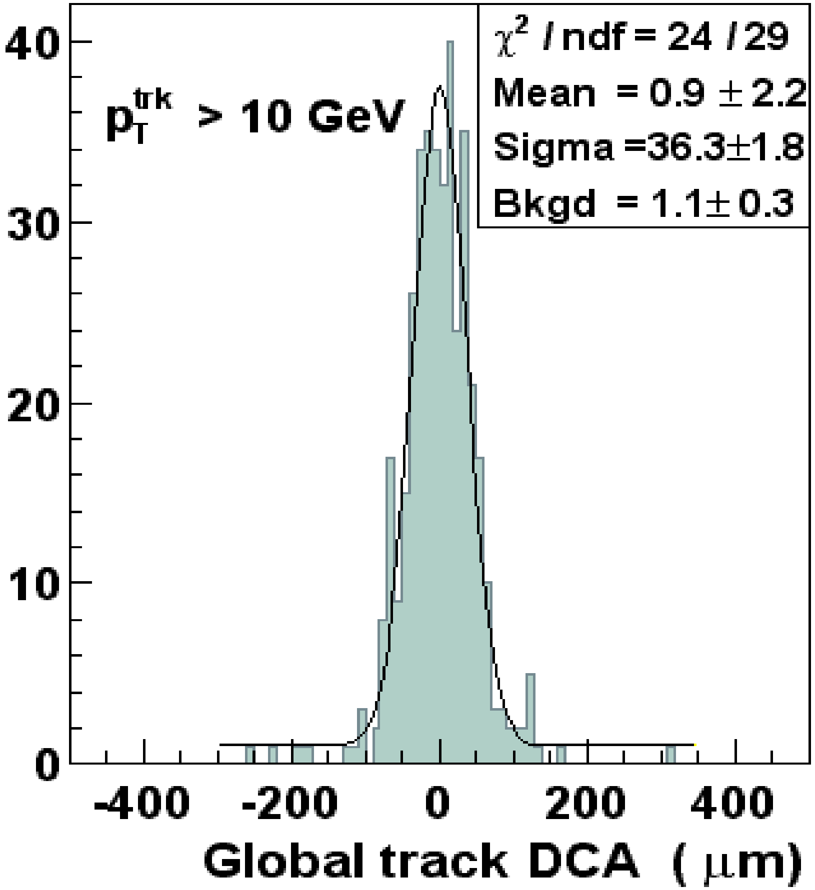
- **Two based on tracks with large IPs**
- **One based on secondary vertices**





~ 50% *b*-tagging eff at a fake rate of 1%, to be compared with ~60% for MC ⇒ Improvements to be made by tuning the algorithms

b-tagging performance

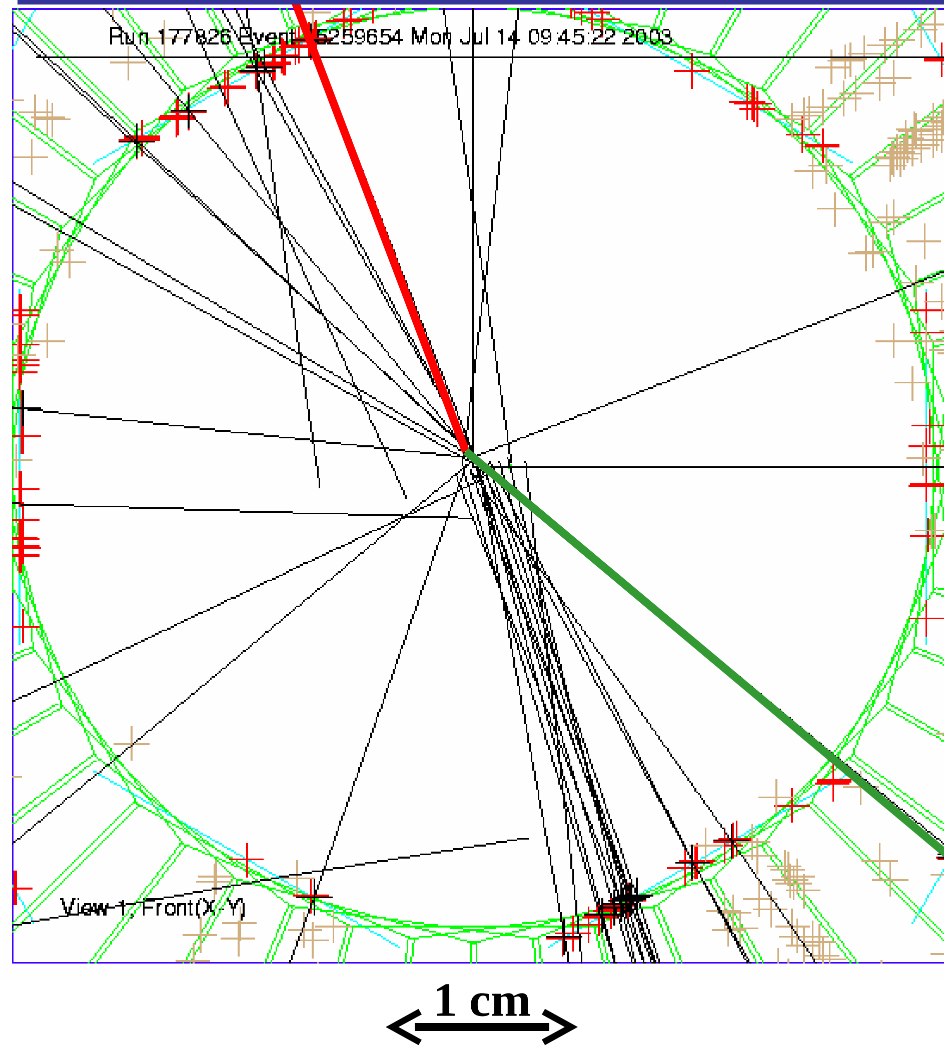


Width = 36.3 ± 1.8 μm

Beam ~ 30 μm

⇒ IP resolution ~ 10μm

CSIP tagged eμ top candidate

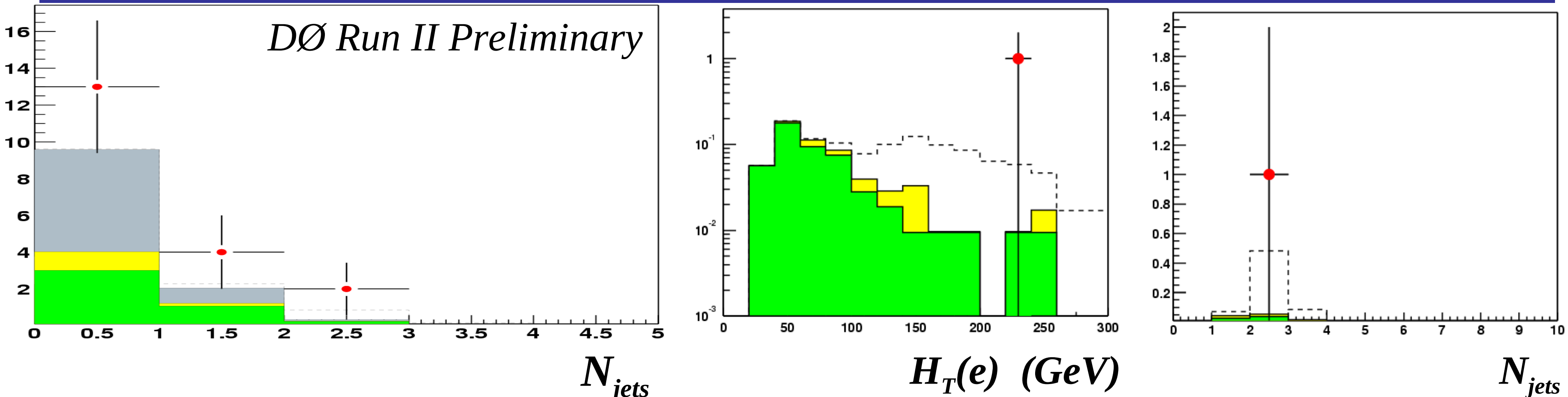


Top cross section- dilepton channel

Selection criteria:

2 isolated high-p_T leptons, MET_{CAL}, $H_T = \sum E_T$ and more than 2 jets

eμ channel after MET cuts and all cuts



Channel	Lum (pb^{-1})	Expected Background	Expected Signal	Obs.
ee	49	1.00+/-0.48	0.25+/-0.02	4
μμ	43	0.60+/-0.30	0.30+/-0.04	2
eμ	33	0.07+/-0.01	0.50+/-0.01	1

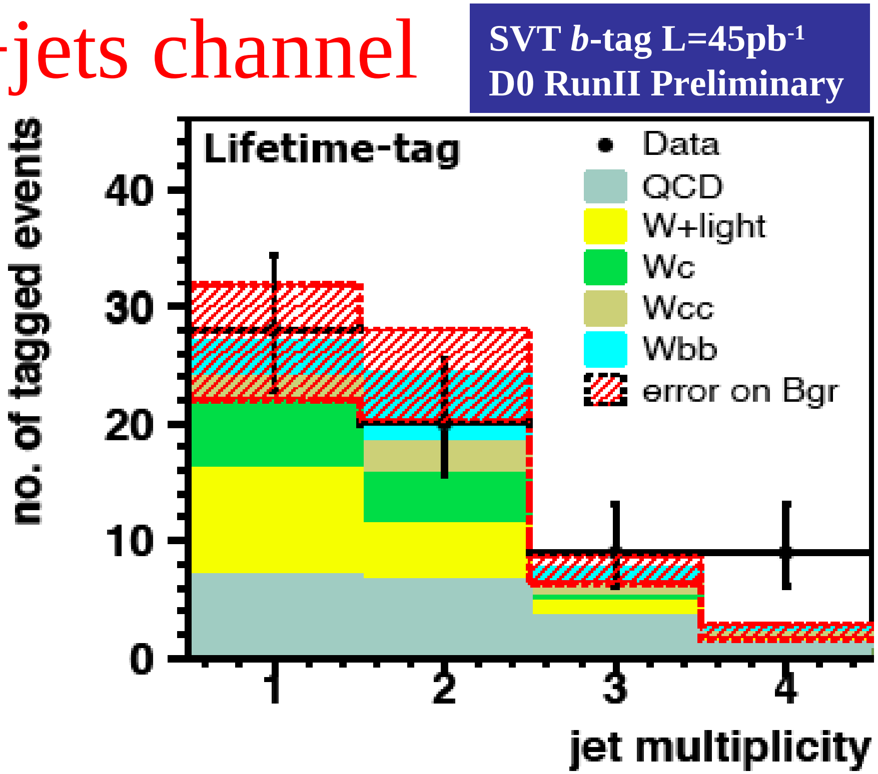
Top cross section- l+jets channel

Method:

- Preselect a sample enriched in W events
- Evaluate QCD multi-jet (as a function of N_{jets})
- Estimate W+4jets assuming Berends scaling
- Apply topological selection

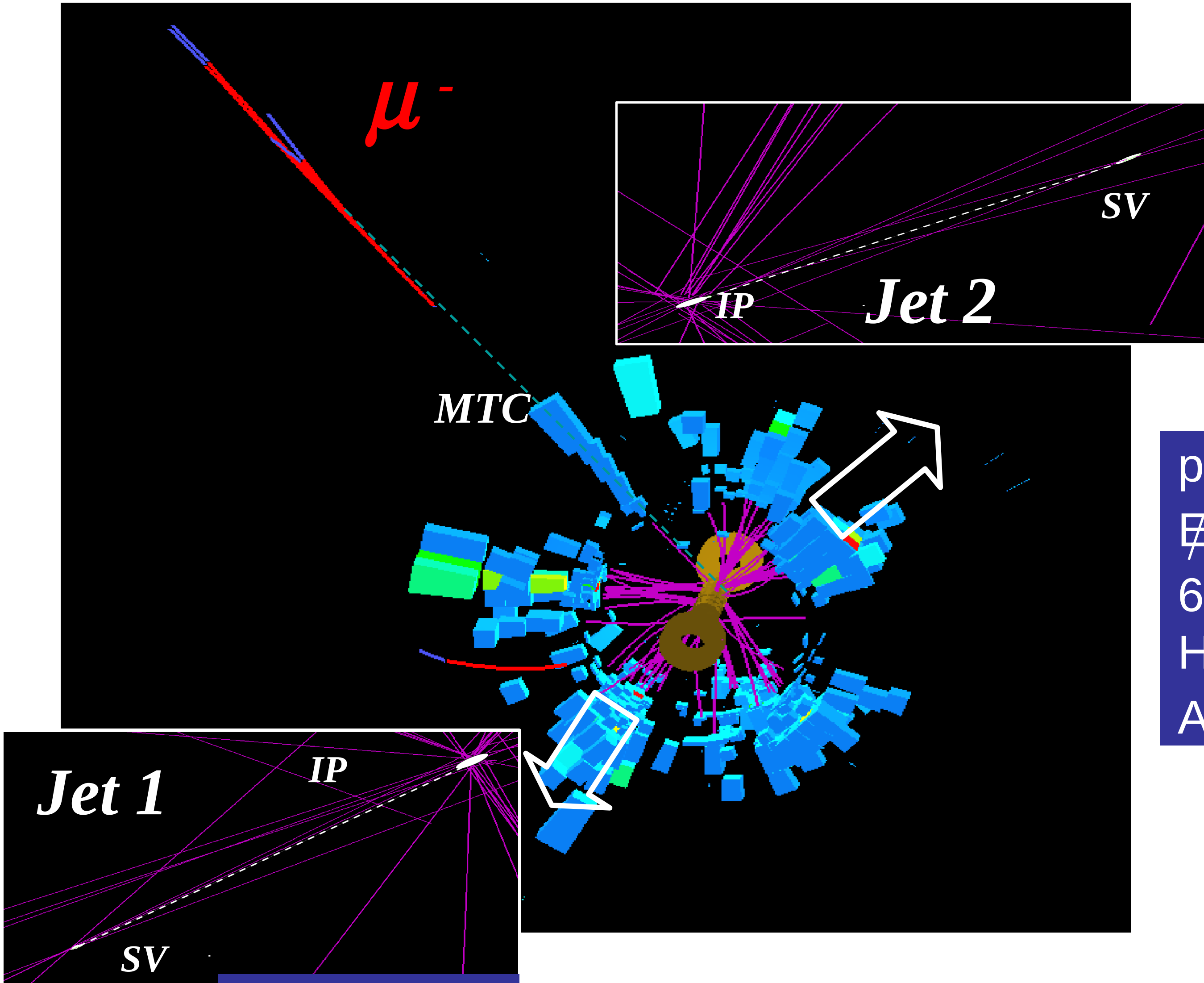
Require:

- 1 EM object or muon, MET, soft muon veto
- +Topological analysis: n ≥4 jets
- +Tag *b*-jets with soft lepton tag (SLT):
  - ≥3 jets, ≥1 SLT, H_T>110 GeV, E_T(W)> 60 GeV, A>0.04
- +Tag *b*-jets with *b*-lifetime tag (SVT or IP):
  - ≥3 jets, ≥1 *b*-tag



Channel	Lum (pb^{-1})	Expected Background	Expected Signal	Obs.
e+jet	50	2.7+/-0.6	1.8	4
μ+jet	40	2.7+/-1.1	2.4	4
e+jet/μ	50	0.2+/-0.1	0.5	2
μ+jet/μ	40	0.6+/-0.3	0.4	0
l+jet/CSIP	90	2.5+/-0.7	4.0	6

Double-tagged μ+jets candidate event



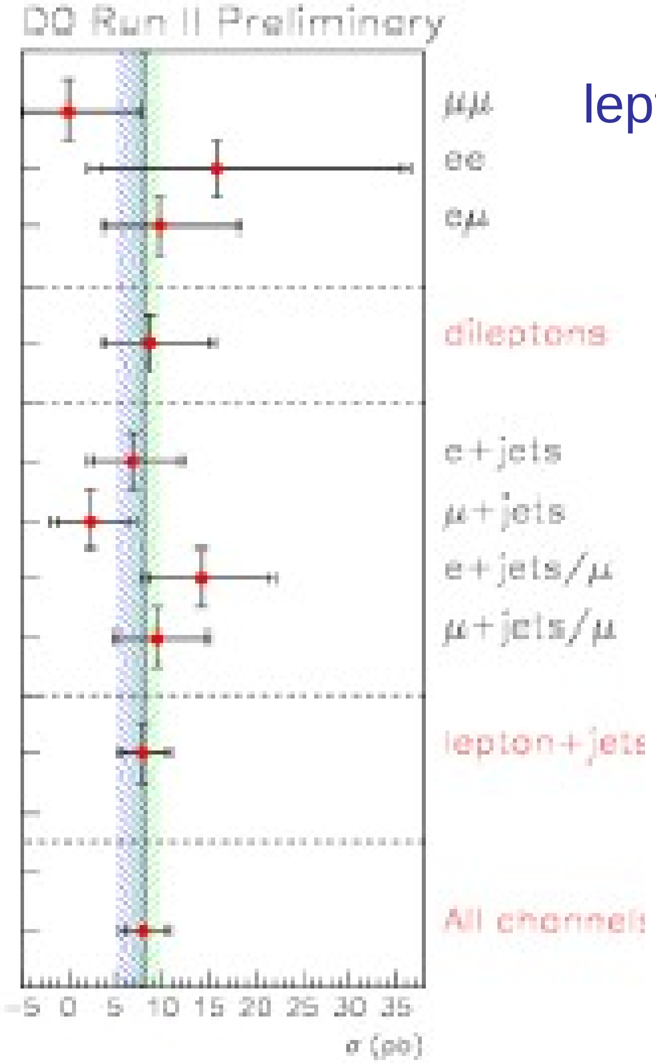
IP=0.53 cm
IP/ σ(IP)=14.9

$p_T(\mu)$ = 47.9 GeV
$\not{E}_T$= 55.1 GeV
6 jets
H_T = 482 GeV
A = 0.16

IP=0.44 cm
IP/ σ(IP)=32.1

Top cross section $\sigma(t\bar{t}) = \frac{N_{obs} - N_{bkg}}{A \int L}$

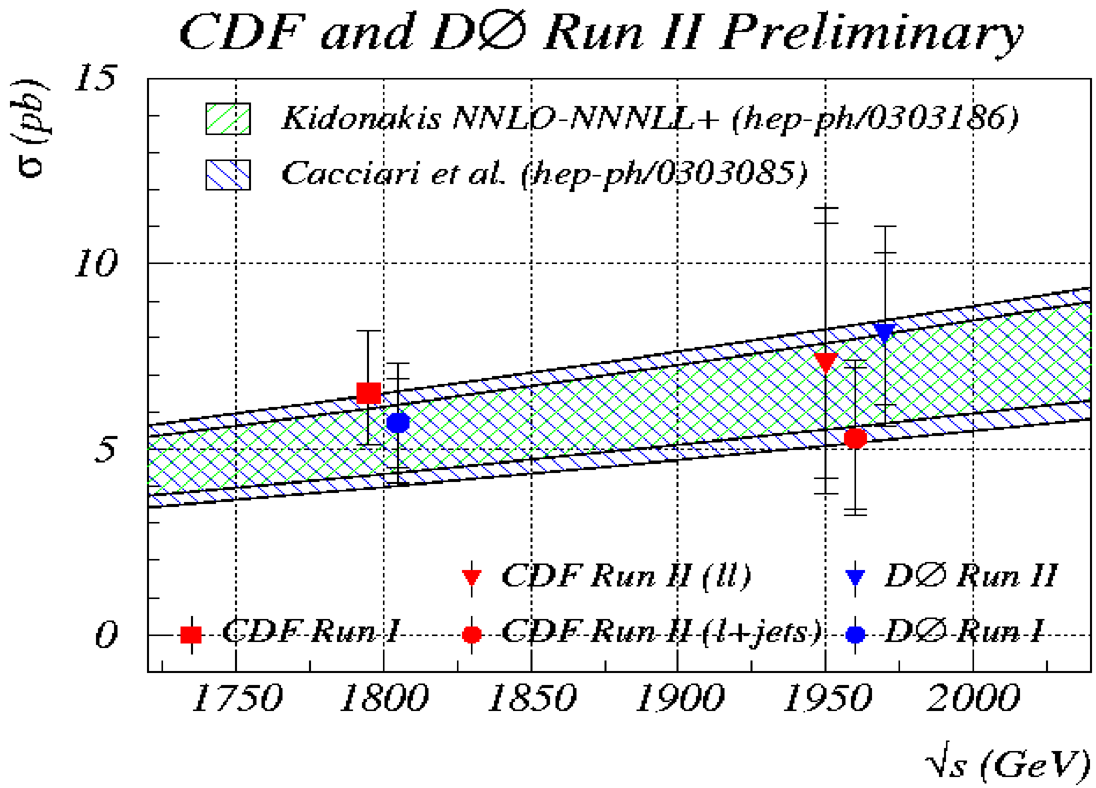
Summer conferences results:



dilepton channels only:

lepton+jets channels only:

all combined:



New M_t analysis with Run I data

Likelihood method using individual event probability and better combinatorial accounting

Construct signal and background probability:

x: reconstructed objects in the event (leptons, jets)

α: parameter to estimate(=M_t)

folding object resolutions

y: parton variables

$$\bar{P}(x;\alpha) = \underbrace{Acc(x)}_{\text{Acceptance}} \times \frac{1}{\sigma} \int \underbrace{d^n\sigma(y;\alpha)}_{\text{Matrix element}}\, dq_1\, dq_2\, \underbrace{f(q_1)\, f(q_2)}_{\text{PDF's}}\, \underbrace{W(x,y)}_{\text{Transfer Functions}}$$

Uses DØ Run I statistics (125 pb^{-1}) and selection → 91 events

+ require 4 jets exclusively (LO ME) → 71 events

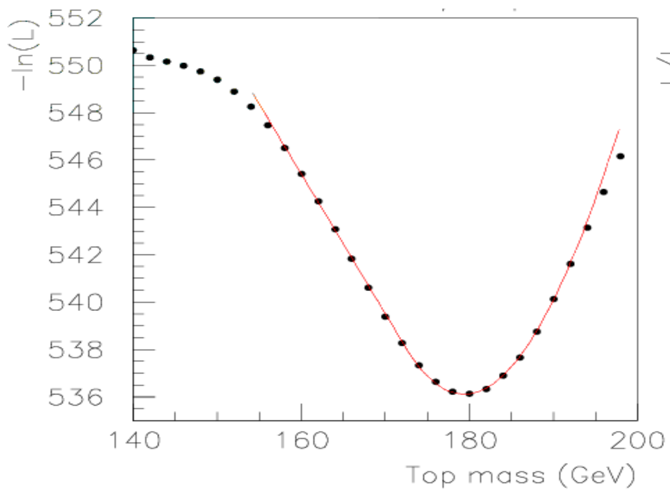
+ cut on bkg prob to improve purity → 22 events

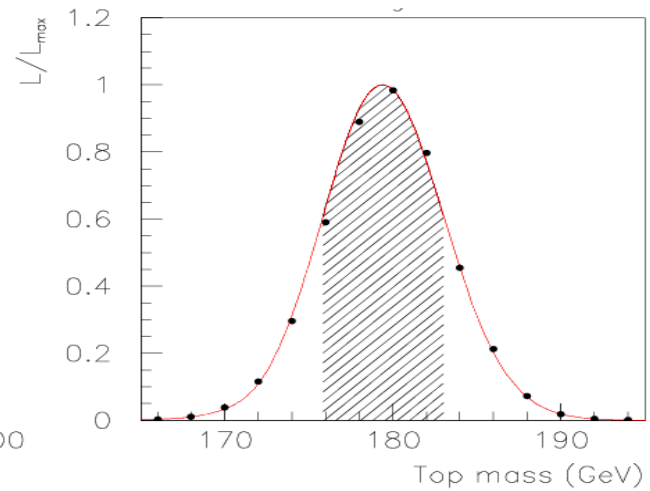
$$-\ln L(M_t) = -\sum_{i=1}^{N} \{ \ln[\, c_1 P_{t\bar{t}}(x_i; M_t) + c_2 P_{bkg}(x_i)\,] \}$$

$$+ N \int A(x)\, [\, c_1 P_{t\bar{t}}(x; M_t) + c_2 P_{bkg}(x)\,]\, dx$$

Minimize likelihood and estimate signal and bkg fractions (c_1 and c_2) and M_t

New M_t analysis with Run I data: results





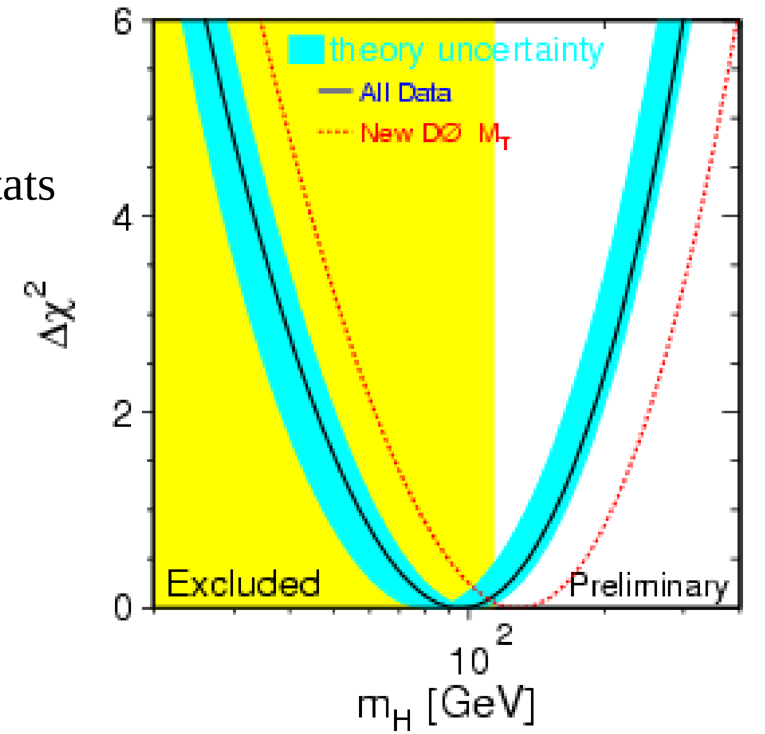
$$M_t = 180.1 \pm 3.6(stat) \ \pm 3.9(sys) \ GeV/c^2$$

Large improvement in the statistical uncertainty: ~2.4x stats

Combining with previous dilepton DØ measurement:

$$M_t = 179.0 \pm 5.2 \ GeV/c^2$$ *(cfr. PDG: 174.3 ±5.1 GeV)*

Shifts by 30% the expected m_H

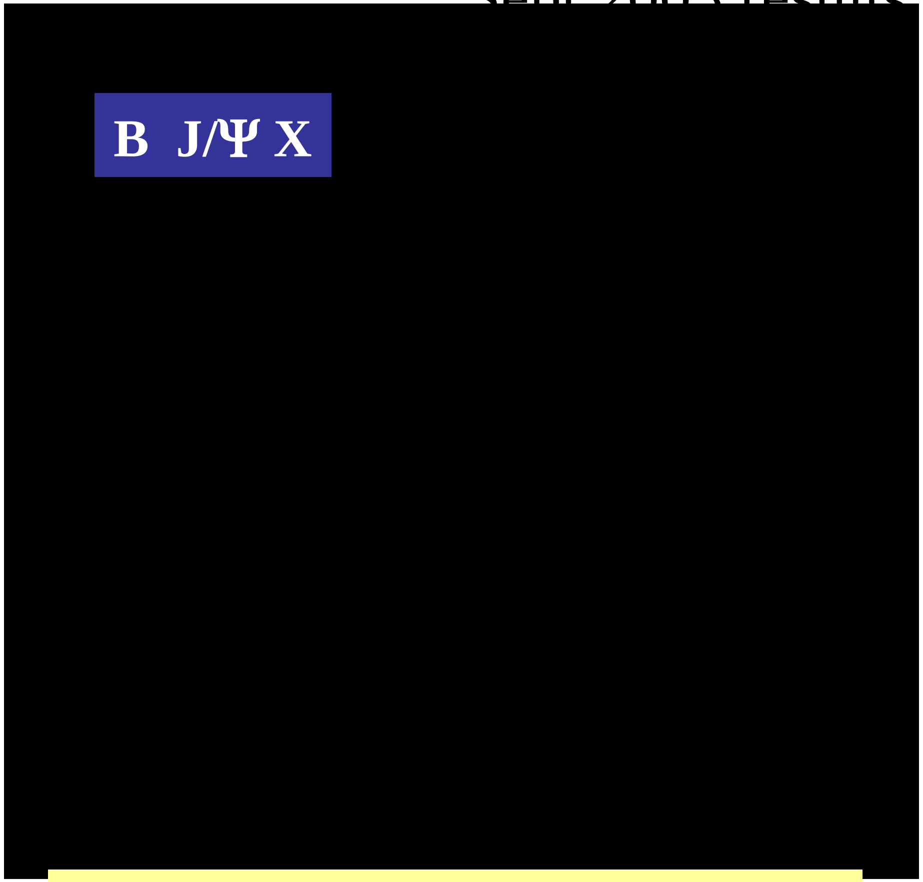


B-physics: average B lifetime

$$ct = \frac{L_{xy}}{bg} = \frac{L_{xy} m_B}{p_T^B}$$

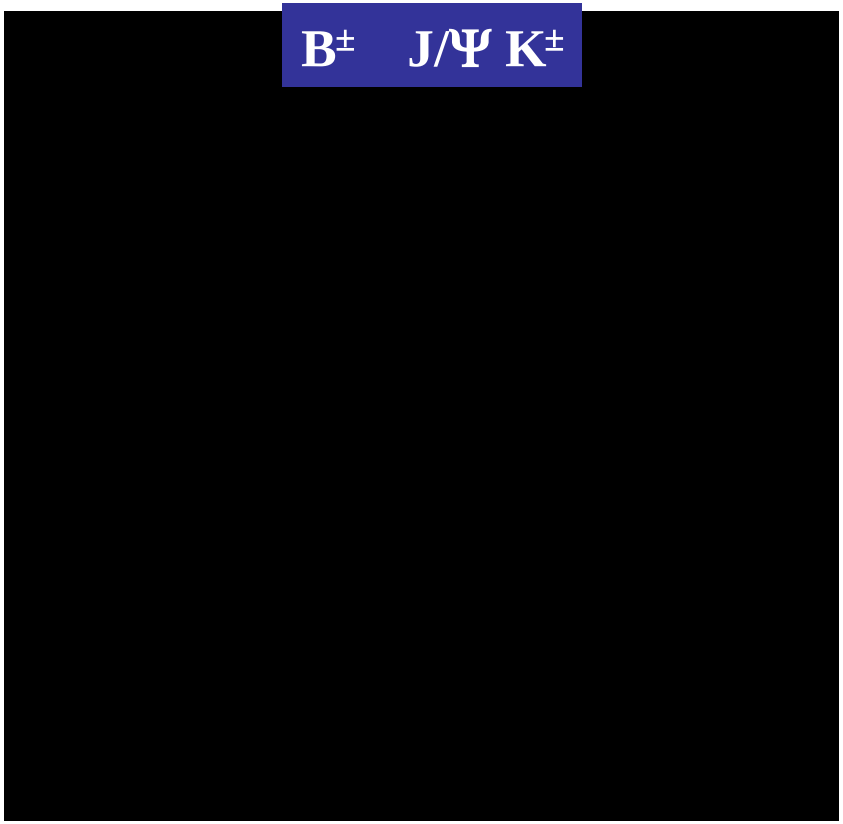
Tevatron can contribute to B_s, B_c and other lifetimes

Sept 2003 results with L=114 pb^{-1}



τ =1.562±0.013(stat) ±0.045(sys) ps

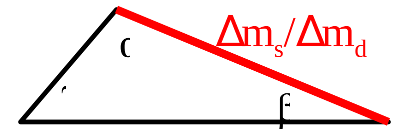
1.564±0.014 ps (PDG)

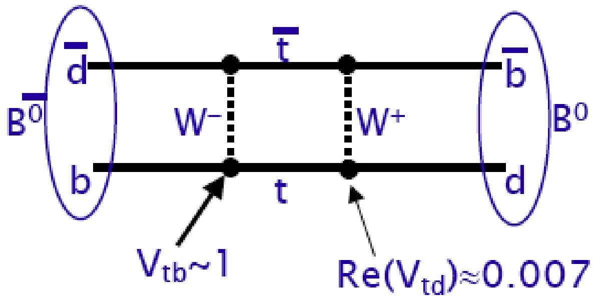


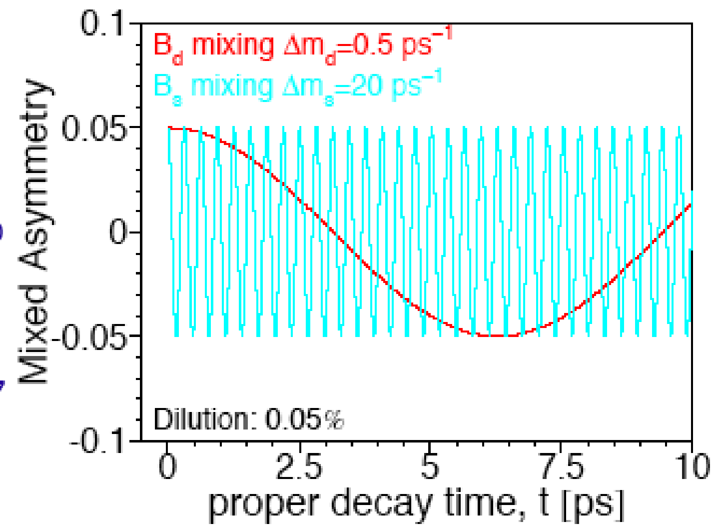
τ =1.65±0.08(stat)±0.12(sys) ps

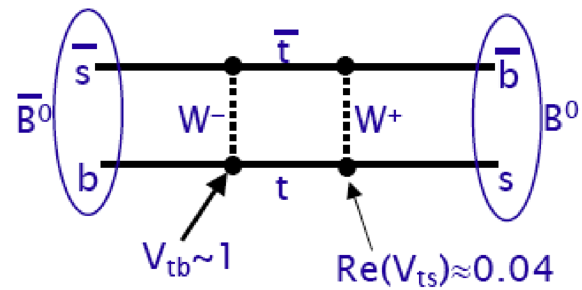
1.671±0.018 ps (PDG)

B-physics: B_s mixing









B_d fully mixes in about 4.1 lifetimes

$\Delta m_d = 0.502 \pm 0.006$ ps^{-1} (world comb.)

Measured with great precision by Belle & BaBar

B_s fully mixes in <0.15 lifetimes!!

$\Delta m_s > 14.4$ ps^{-1} 95%CL (world comb.)

Only at hadron colliders

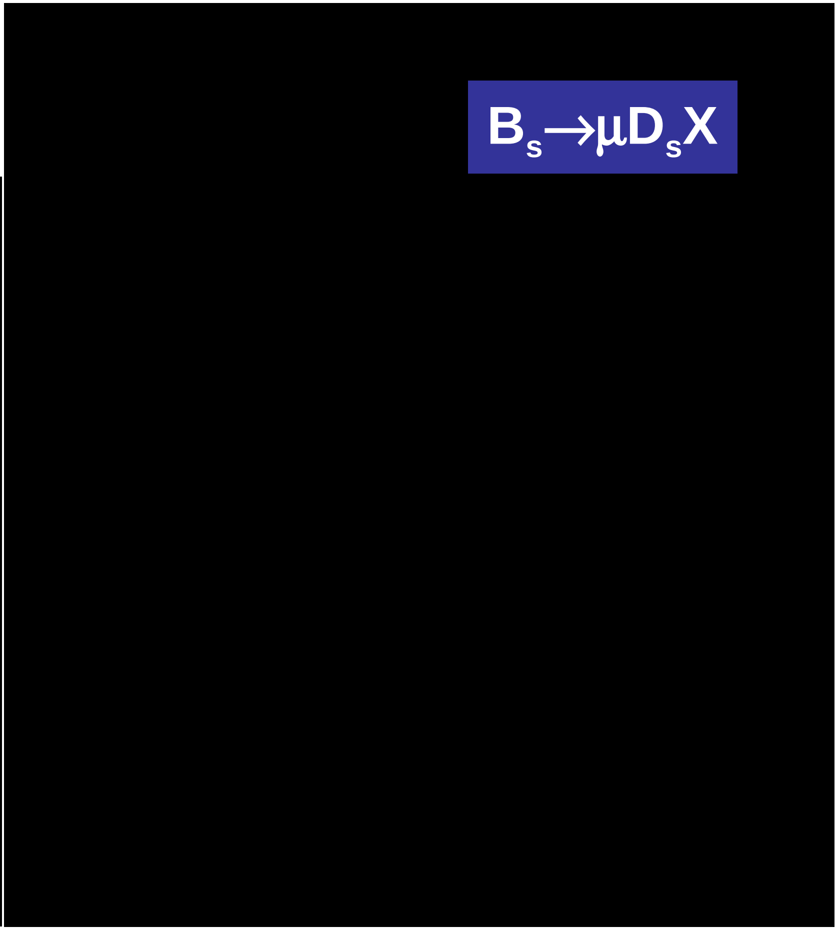
To measure B_s mixing, need:

- Tag initial state flavour (what was produced, a B or a Bbar?)
- Tag final state flavour (what decayed was a B or a Bbar?)
- Yield: as much decays as possible (flavour tagging is imperfect)
- Proper decay length: L_{xy} and $\beta\gamma = p_T/m_B$ (mix prob vs decay time)

Difficult measurement! It's doable, but will take time!

Towards B_s mixing

Excellent B_d yield, ideal control sample for B_s mixing studies



Tagging power estimated from $B^{\pm} \rightarrow J/\psi K^{\pm}$ data:

- Opposite side jet charge: $\varepsilon D^2 = 3.3 \pm 1.8\%$
- Opposite side soft muon: $\varepsilon D^2 = 1.6 \pm 0.6\%$
- Same side track: $\varepsilon D^2 = 5 \pm 2\%$

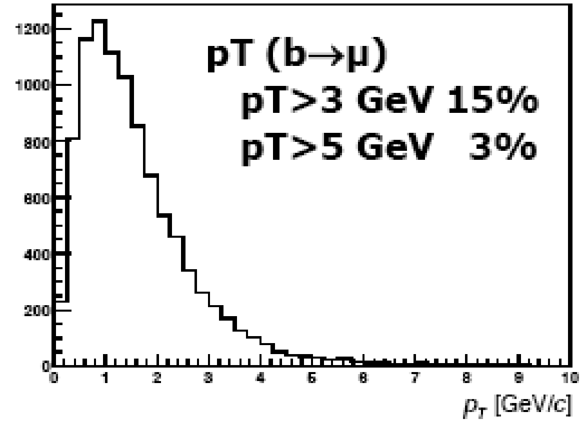
We have observed B_d signal and are working to optimize the analysis

Bandwidth Issues

Our heavy flavor physics program has shown great potential. However, its potential is currently limited by computing resources available.

We administratively limit the rate to tape at 50 Hz ⇒ low pT single muon triggers heavily prescaled and effectively turned off at luminosities above 40E30. Dimuon triggers are prescaled too.

Luminosity (cm-1 s-1)	Trigger Rate (prescale factor) pT > 5 GeV	pT > 3 GeV
20E30	8 Hz (2)	27 Hz
40E30	15 Hz (61)	52 Hz
60E30	23 Hz (off)	80 Hz



To fully explore the potential, we need to increase our rate to tape:

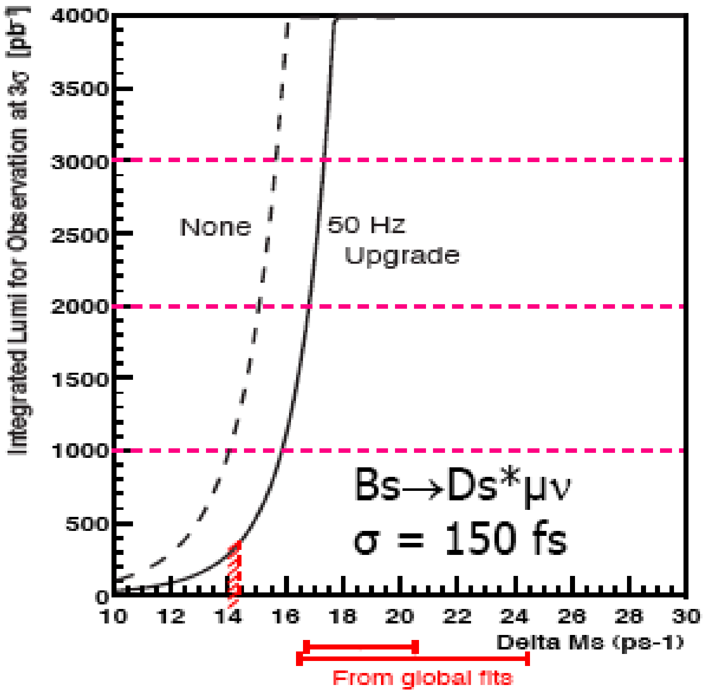
- Not a problem with the trigger system (prescale at Level 3).
- Planned Run IIb upgrade will enable our DAQ to run at 100 Hz.
- The problem: storage, drive, reconstruction and analysis CPUs.
- The solution: increase our capacity at Fermilab, expand offsite processing resources, speed up reconstruction program.

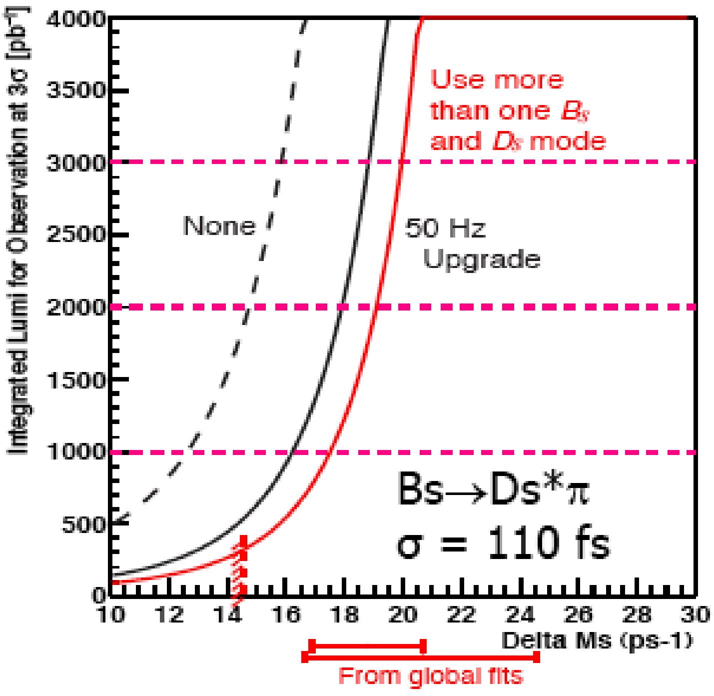
Reach in Bs Mixing

The upgrade will increase Bs yield by a factor of 3 at low luminosities to more than 5 at high luminosities. Thus it will extend the reach well into "interesting region" from the global fits.

$$Sig(\Delta m_s) = \sqrt{\frac{N\varepsilon D^2}{2}}\ Exp\{-\frac{(\Delta m_s \sigma_\tau)^2}{2}\}\ \sqrt{\frac{S}{S+B}}$$

Current knowledge:
$\Delta ms > 14.9\ ps^{-1}$





Observation of Belle's X(3872)

[redacted]

Decays:

$X \to J/\psi(\to \mu\mu)\pi^+\pi^-$

Cut:

$m(\pi\pi) > 520$MeV

$\Delta R(X, \pi) < 0.4$

Signal:

300±61 X (4.4 significance)

$\Delta M = 0.7684 \pm 0.0035 \pm 0.0039$ GeV

Properties:

Is it $c\bar{c}$ or more exotic?

[redacted]

Higgs searches

[redacted]

With current dataset we don't expect to see a SM Higgs signal

Looking for non-standard variants and developing tools:

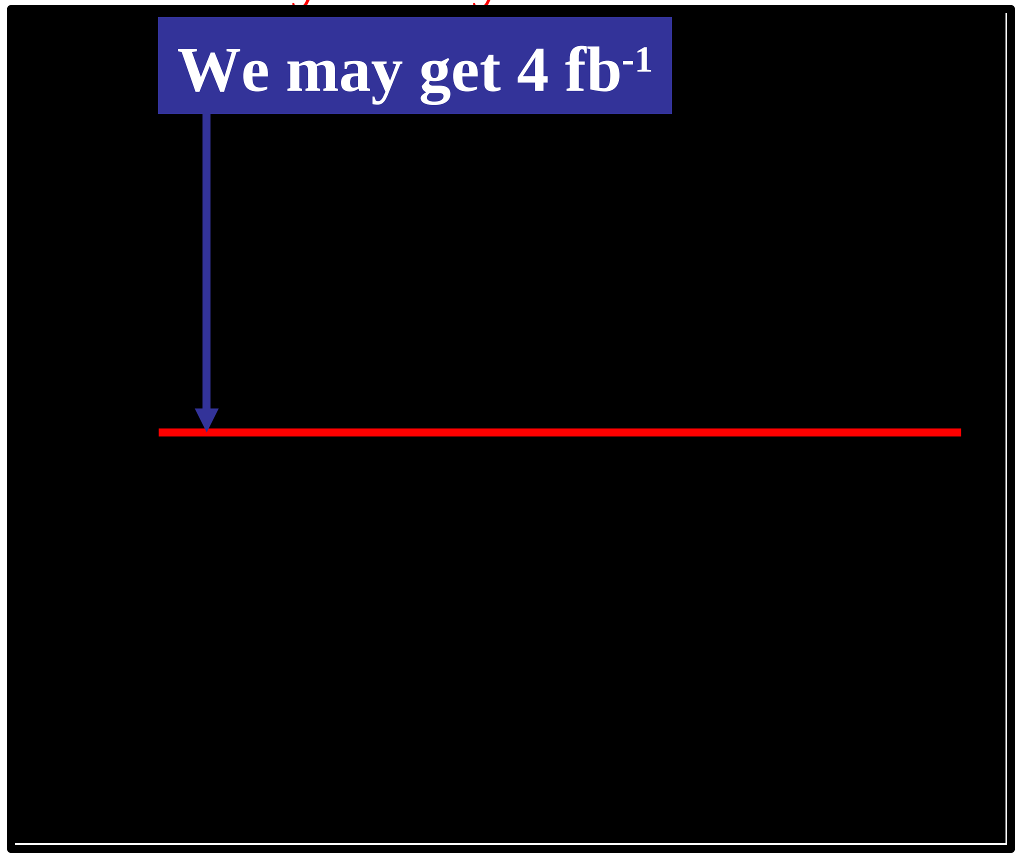
- Background understanding is critical
- Need high *b*-tag efficiency and low mistag rate
- Excellent dijet mass resolutions to disentangle H$\rightarrow$*bb* from multijet bkgs

[redacted]

Results on W($\rightarrow e\nu$)+jets with b-tagging, H$\rightarrow$WW* and H$^{++}\rightarrow\mu\mu$

[redacted]

New Higgs sensitivity study



- We now have tuned, hit-level simulations of our detectors
- Use current analysis techniques
- Event selections can now be based on actual top & EW analyses
- Concentrate on $115 < m_H < 140$ GeV
- Combine CDF: WH $\rightarrow l\nu bb$ and DØ: ZH$\rightarrow \nu\nu bb$

<u>Note</u>: no systematics + Si upgrade in!
Sadly, we now know we won't have RunIIb new silicon detectors

Findings:

- Despite some optimistic assumptions of the old study, its conclusions are supported
- There is room for more optimized analysis, better *b*-tagging (to large η)
- Fitting the mass distribution amounts to a gain of 20% in luminosity compared to counting in a mass window

New Phenomena Searches Summer 2003

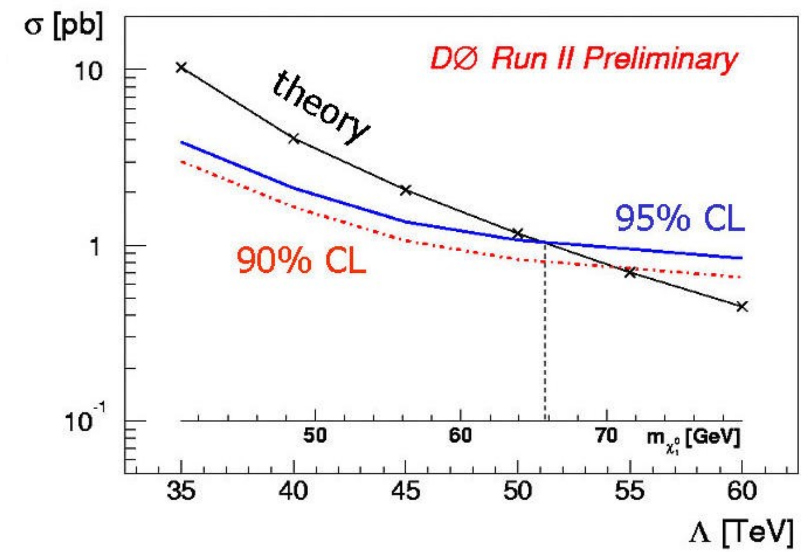
Seven analyses presented at the winter conferences.

Approaching Run I sensitivity.

Data samples: ~30-50 pb^{-1}

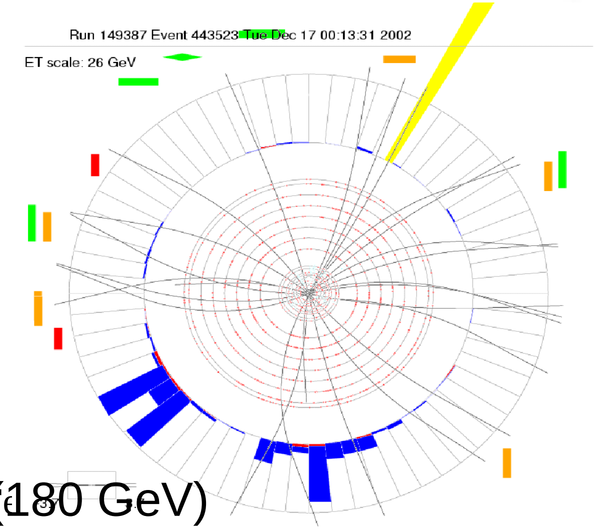
SUSY

GMSB SUSY LSP Search:
$2\gamma + ME_T$
m_{LSP} > 66 GeV @ 95% CL



mSUGRA Chargino/Neutralino
ee+lepton+ME_T (trilepton mode)
σxBR < 3.5 (2.2) pb @ 95% CL

Standard SUGRA ($\tilde{\chi}^0$ LSP)
2jets + ME_T
sets model independent cross-section limit vs ME_T



Highest MET event (180 GeV)

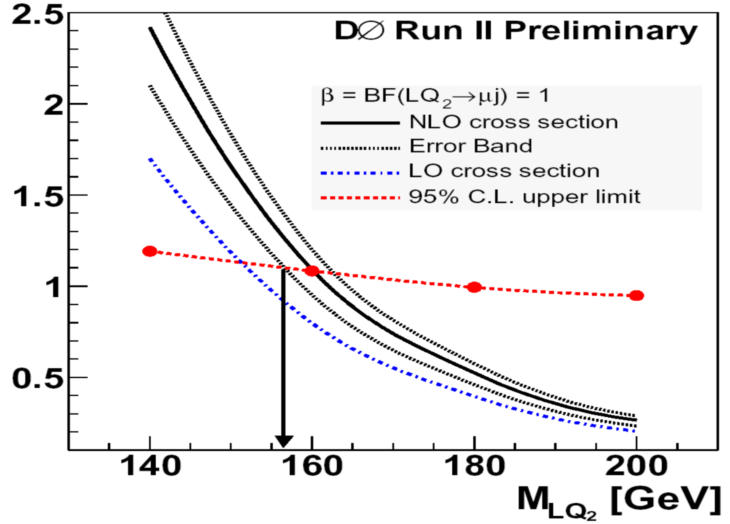
New Phenomena Searches Summer 2003

Non-SUSY

2nd Generation LQ

2μ + 2jets

m_{LQ} > 157 GeV @ 95% CL



Search for deviations from SM in e μ+X channel

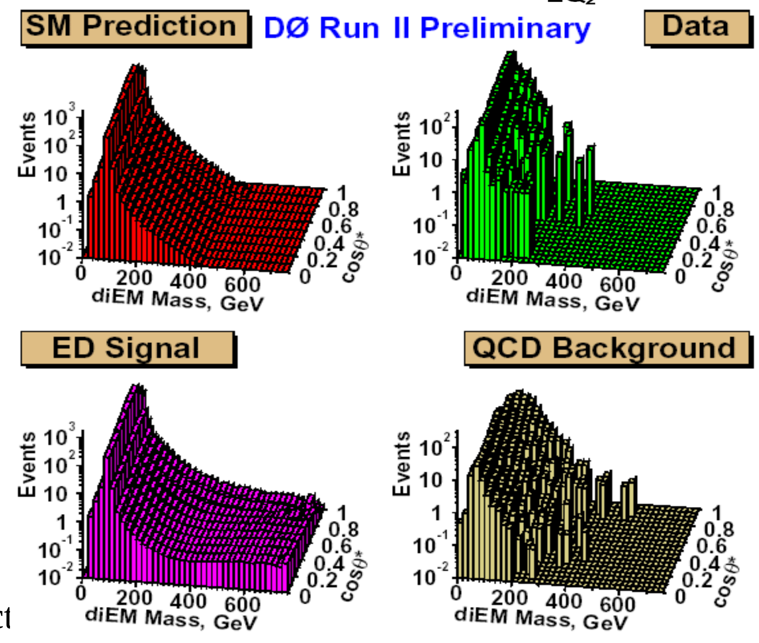
sets model independent cross-section limit vs ME_T

Search for large extra-dimensions in ee,$\gamma\gamma$ channel

Search for large extra-dimensions in $\mu\mu$ channel (**New!**)

Lower limits on Λ_S(TeV)

	GRW	HLZ for n: 2 7	Hewett $\lambda = +1$
διEM	1.12	1.16 0.89	1.00
διMY	0.79	0.68 0.63	0.71



New Phenomena Searches: τ Channel

The τ-lepton often plays a relevant role in models of Beyond the SM physics (trileptons in SUSY, 3rd generation LQs, Higgs decays).
addition of this channel considerably extends the physics reach

Need a SM channel for calibration: $Z\ \tau^+\tau^-$

Two searches at DØ are seeing evidence for the decay $Z\ \tau^+\tau^-$:

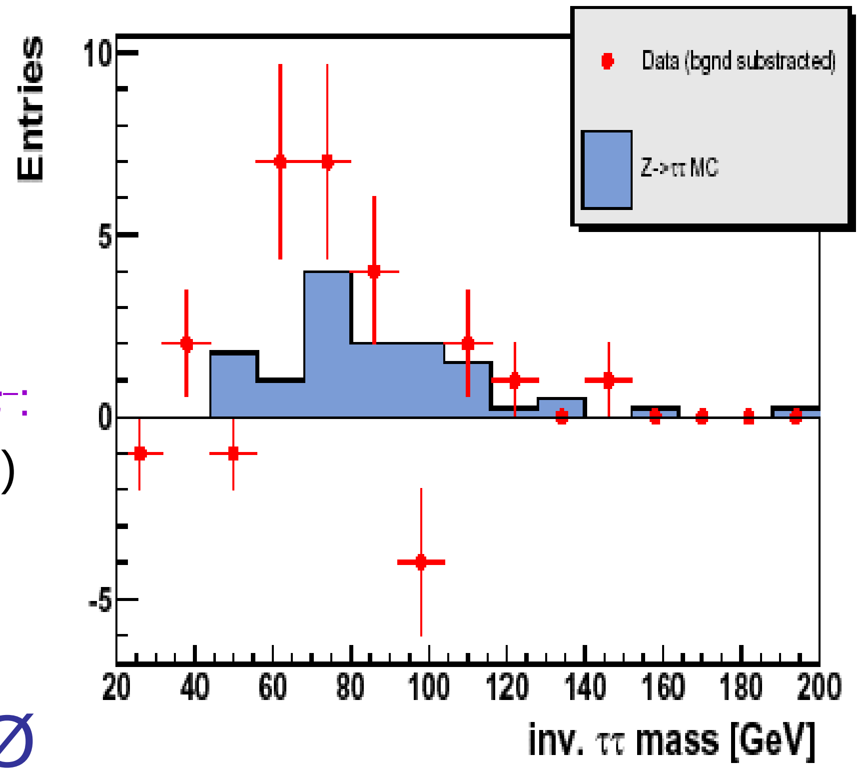
$Z\ \tau(\ e)\tau(\ 1,3$ prong)

$Z\ \tau(\ \mu)\tau(\ 1,3$ prong)

Comparison of opposite to like-sign gives an excess consistent with $Z\ \tau^+\tau^-$:

	Data	$Z\ \tau^+\tau^-$ (MC, 50 pb^{-1})
Opp sign	49	
Like sign	35	
Difference	14 ± 9	13± 4

$Z\ \tau(\ \mu)\tau(\ 1,2$ prong)



A new capability for DØ

DØ Results from summer 2003

I've shown just a fraction of our program

Masses, or scale limits

$M(B^{**}_d) = 5.71 \pm 0.016$ GeV

$m(\chi_0^1) > 80$ GeV

$m_{1/2} > 150$ GeV

$M_S(GRW) > 1.28$ TeV ($ee/\gamma\gamma$)

$M_S(GRW) > 0.88$ TeV ($\mu\mu$)

$M_{LQ}(\mu\mu) > 184$ GeV

$M_{LQ}(e\nu) > 159$ GeV

$M_{LQ}(ee) > 231$ GeV

$M_{Z'}(ee) > 719$ GeV

$M_{Z'}(\mu\mu) > 620$ GeV

$M(H^{\pm\pm}) > 115$ GeV

BR and R

$BR(B_s \to \mu\mu) < 1.6\times10^{-6}$

$R_{W/Z} = 10.34 \pm 0.35 \pm 0.48$

Lifetimes

$\tau(\text{incl. B}) = 1.562 \pm 0.013 \pm 0.045$ ps

$\tau(B^+) = 1.65 \pm 0.083\ ^{+0.096}_{-0.1233}$ ps

$\tau(B_d) = 1.52\ ^{+0.19}_{-0.17}$ ps

$\tau(B_s) = 1.19\ ^{+0.19}_{-0.14}$ ps

$\tau_{\Lambda b} = 1.05\ ^{+0.21}_{-0.18} \pm 0.12$ ps

$\tau(B \to Dl\nu) = 1.46 \pm 0.08$ ps

Cross sections, or limits

$\sigma(tt) = 8.1^{+2.2}_{-2.0}\ ^{+1.6}_{-1.4} \pm 0.8$ pb

$\sigma(Z\mu\mu) = 261.8 \pm 5.0 \pm 8.9 \pm 26.2$ pb

$\sigma(Z\tau\tau, \pi\text{–type}) = 235 \pm 137$ pb

$\sigma(Z\tau\tau, \rho\text{-type}) = 222 \pm 71$ pb

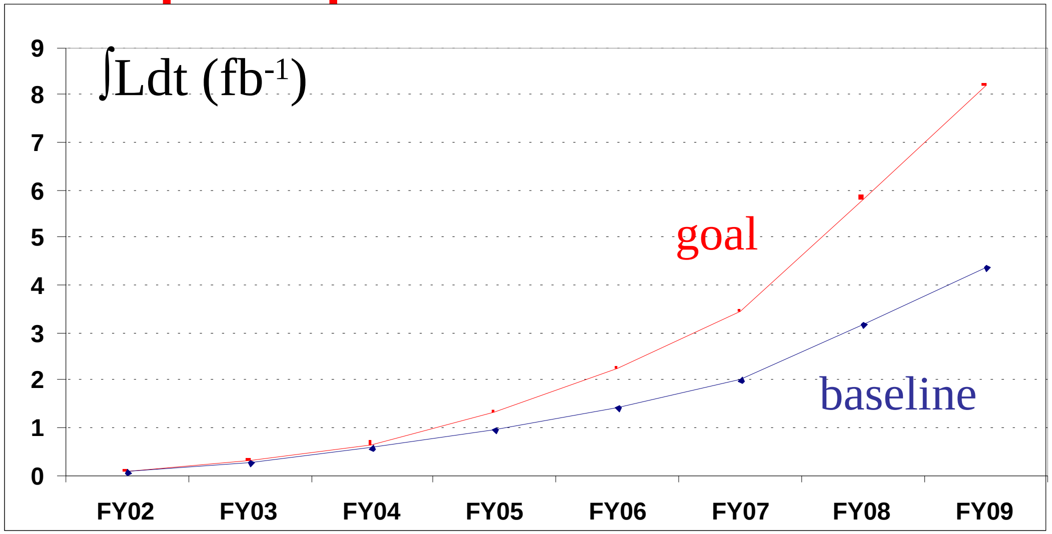
$\sigma(W+bb) < 33.4$ pb

$\sigma*BR(H \to WW \to ee/e\mu) < 0.45$ to 2.8 pb

$\sigma*BR(H \to WW \to \mu\mu) < 0.2$ to 0.7pb

Expect more for this winter conferences!

Tevatron prospects



300 pb^{-1}

- Improved m_t measurement
- High p_T jets constrain proton structure
- B Physics: lifetimes, BRs, …
- Searches beyond Run I sensitivity

2 fb^{-1}

- Measure m_t (M_W) to ±3 GeV (± 15 MeV)
- Explore top properties
- Directly exclude m_H = 115 GeV
- Significant SUSY and SUSY Higgs searches
- B-physics: constrain the CKM matrix

We have entered unexplored territory… who knows what we will find!

5 fb^{-1}

- 3σ Higgs signal @ m_H = 115 GeV
- exclude Higgs 115-125, 155-175 GeV
- exclude much of SUSY Higgs parameter space

Conclusions

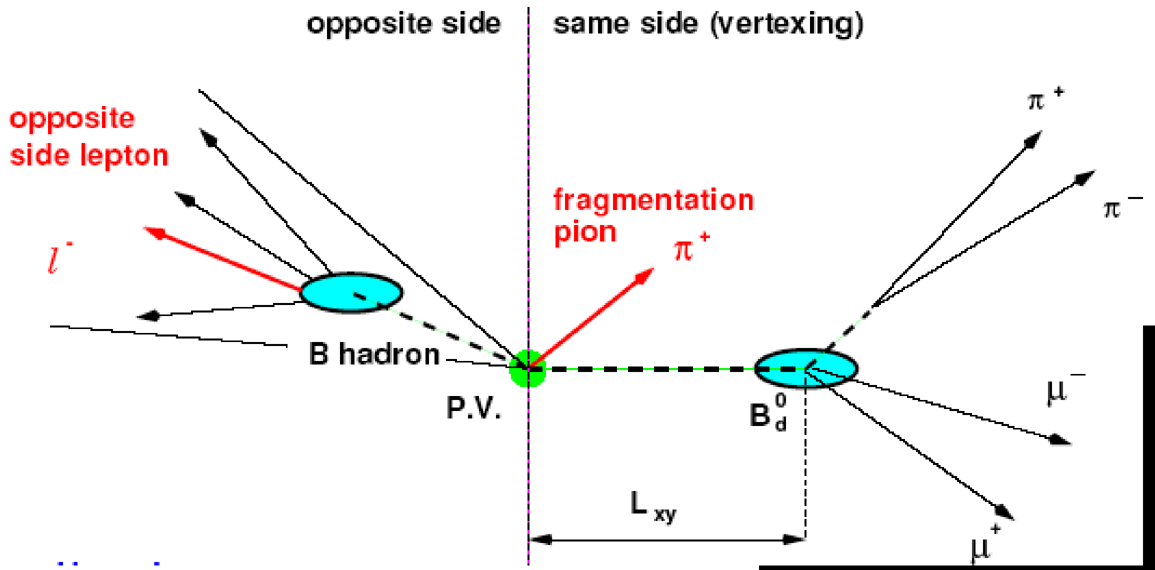
Detector is operating well and the performance keeps improving

- Just installed forward proton detector
- Making increasing use of tracking triggers
- Silicon track trigger is commissioning
- Intense work on reconstruction improvements: tracking efficiency, object identification, etc. Event reconstruction < 3 days

We have a large Run II dataset (x2 Run I) and exploiting upgraded detector

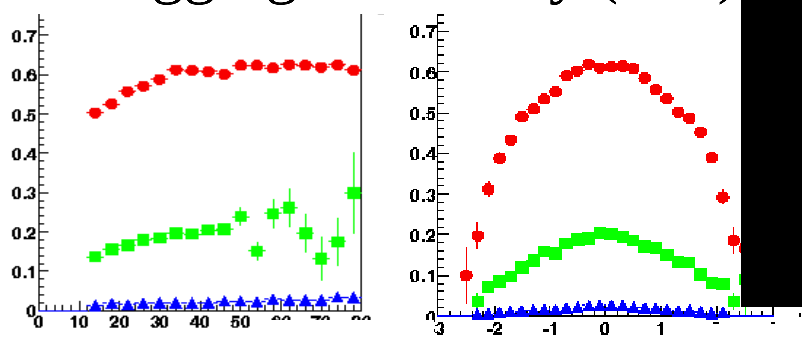
- Expect ~210 pb^{-1} for the summer updates
- Promising B-physics program but need new trigger capabilities
- Continue to explore the top quark and its properties: have progressed a lot! New algorithms, better understanding of the detector performance, object ID,…
- Searches for new phenomena are entering new sensitivity region
- And I haven’t even mentioned all the EW and QCD results…

Extras



[redacted]

b-tagging Efficiency (MC)



Jet p_T Jet η