Run II Physics at DØ

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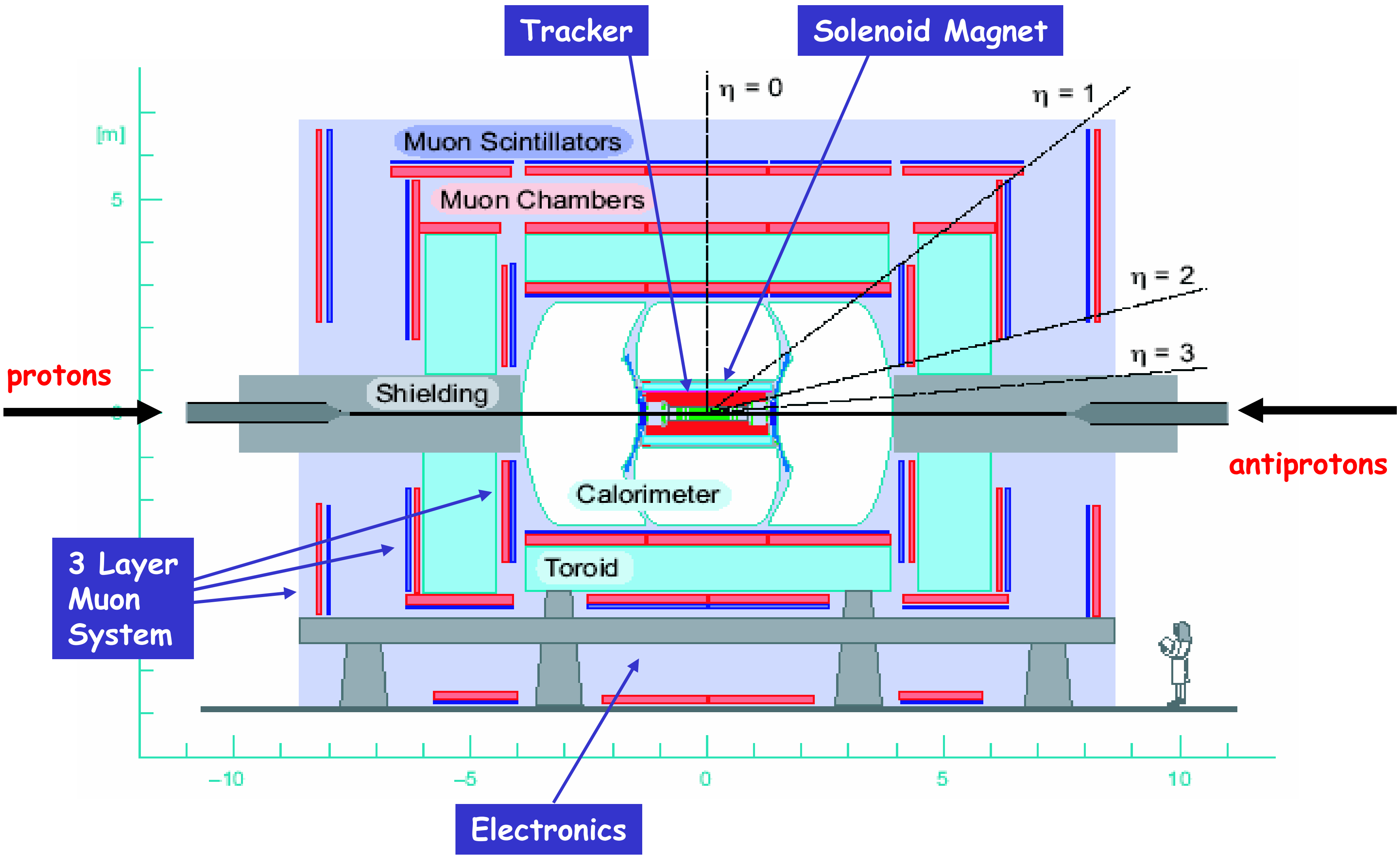
for the DØ Collaboration

Outline of talk

- A few facts about the DØ detector
- The Run II data set
- Results from the first ~100 pb^{-1} of Run II data
  - W's and Z's
  - Top
  - Jets
  - Heavy quarks
  - Searches
- Throughout, I will try to point out areas where we rely on current and future theoretical work to extract, understand, and interpret our results

Detector

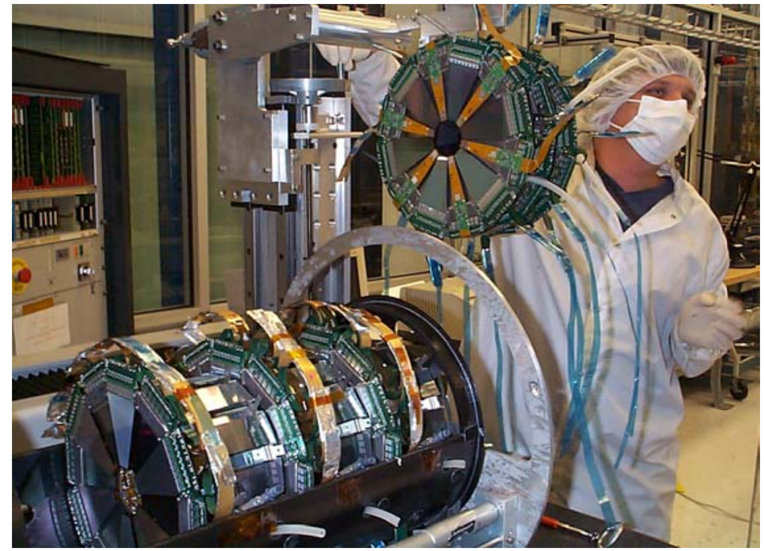


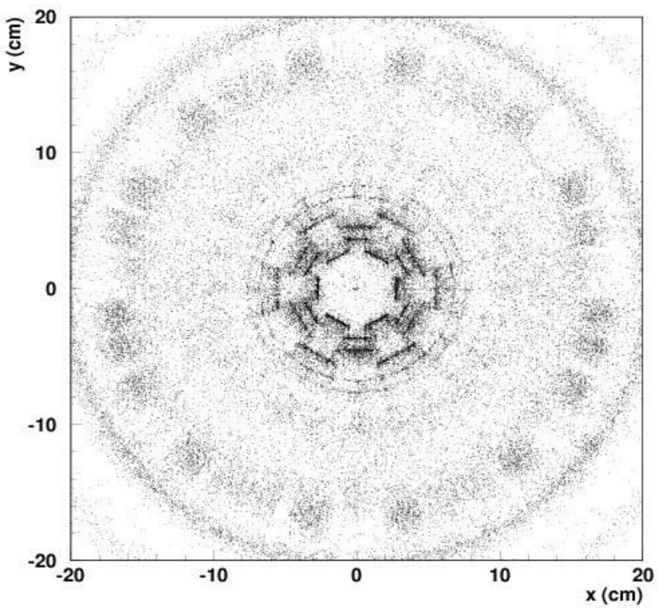
Tracker
Solenoid Magnet
η = 0
η = 1
η = 2
η = 3
[m]
5
Muon Scintillators
Muon Chambers
protons
Shielding
antiprotons
Calorimeter
Toroid
3 Layer Muon System
-10
-5
0
5
10
Electronics

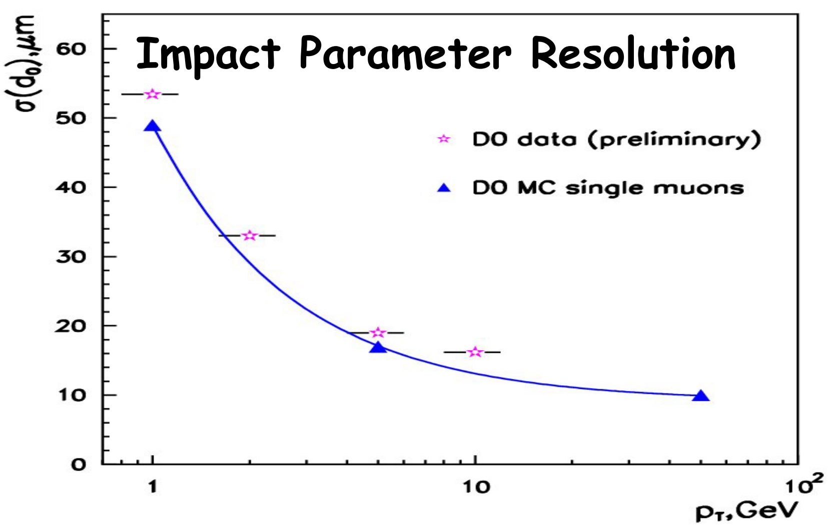
Silicon Detector

~ 90% channels live

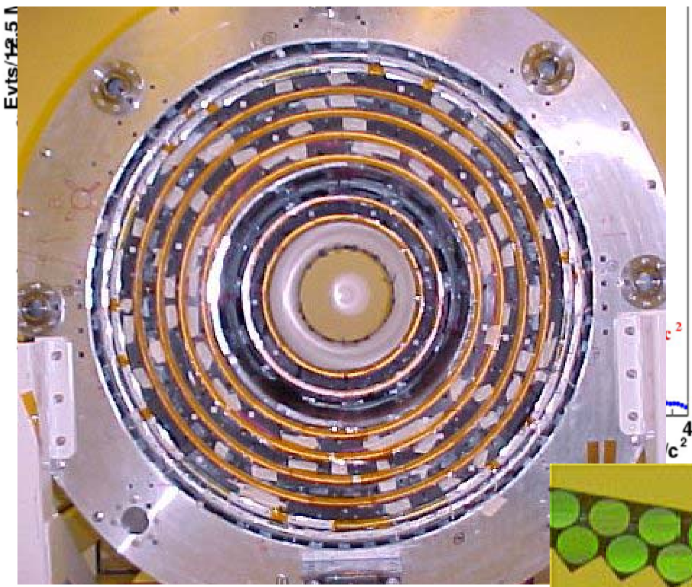
$\gamma \to e^+e^-$ vertex

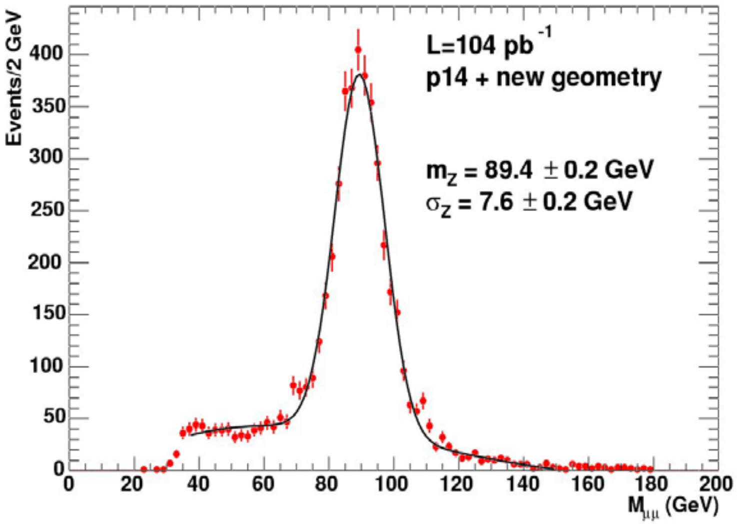






Fiber Tracker



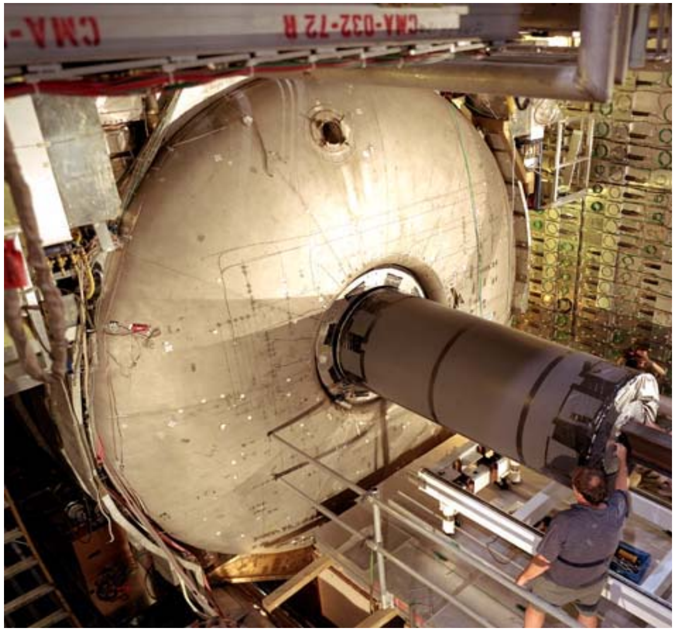


~ 99% channels live

8 super layers of scintillating fibers, each layer with one axial and one stereo doublet

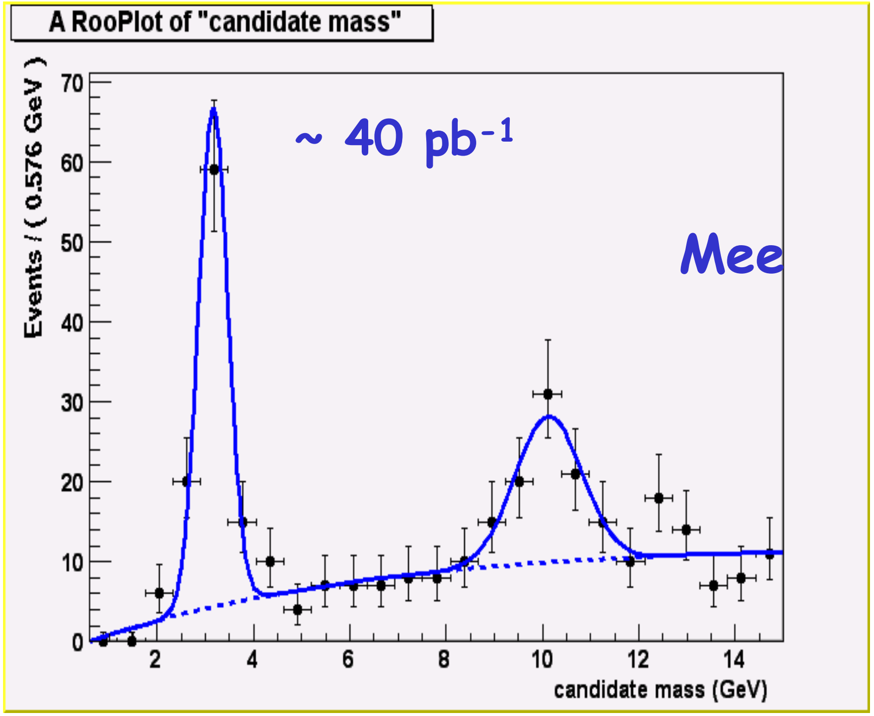
$$B\ell^2 \approx 0.5\mathrm{Tm}^2$$ ⇒ Compact

Calorimeter



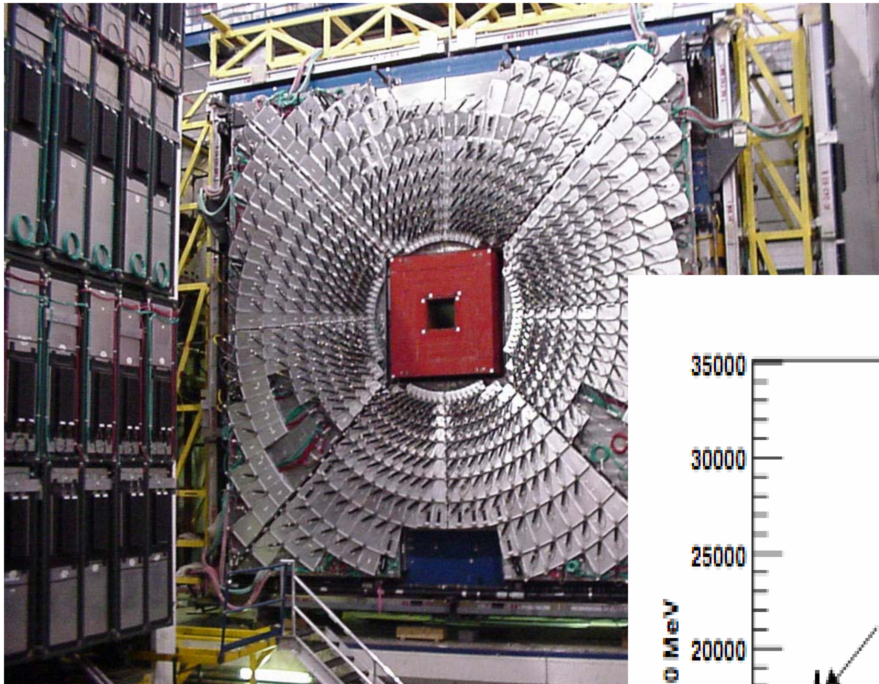
~99% channels live

Same detector, new electronics

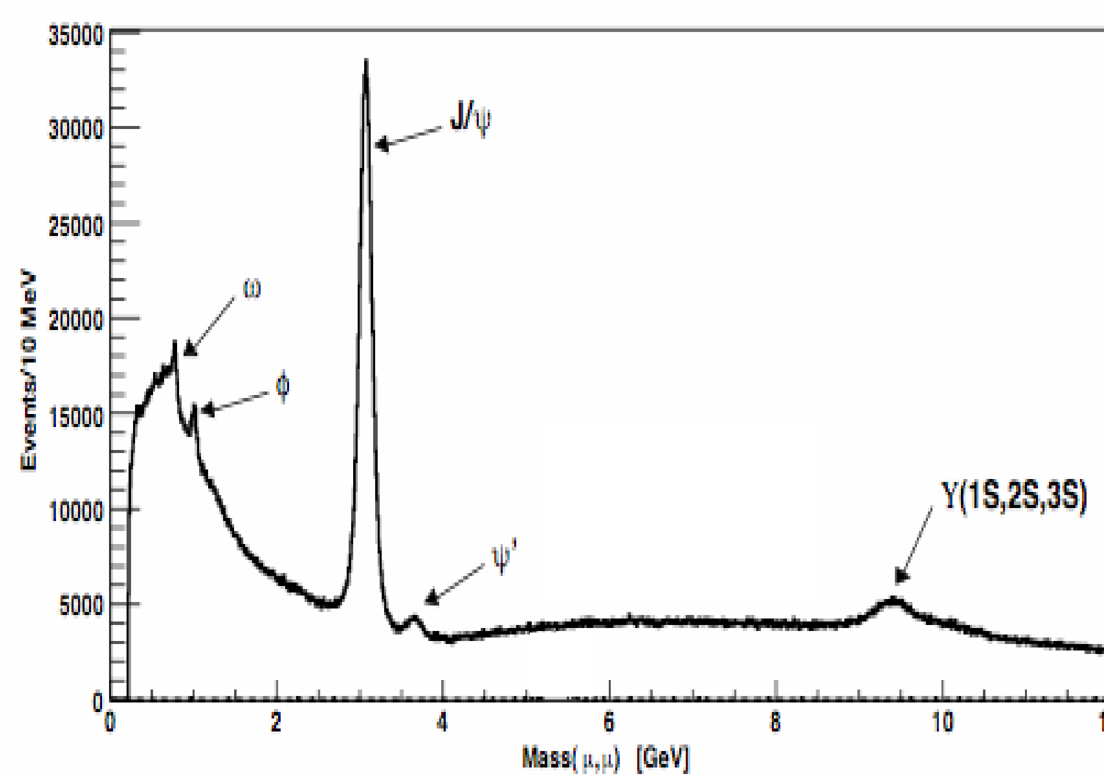


"Old" calorimeter with a new tracker
= new possibilities

Muon



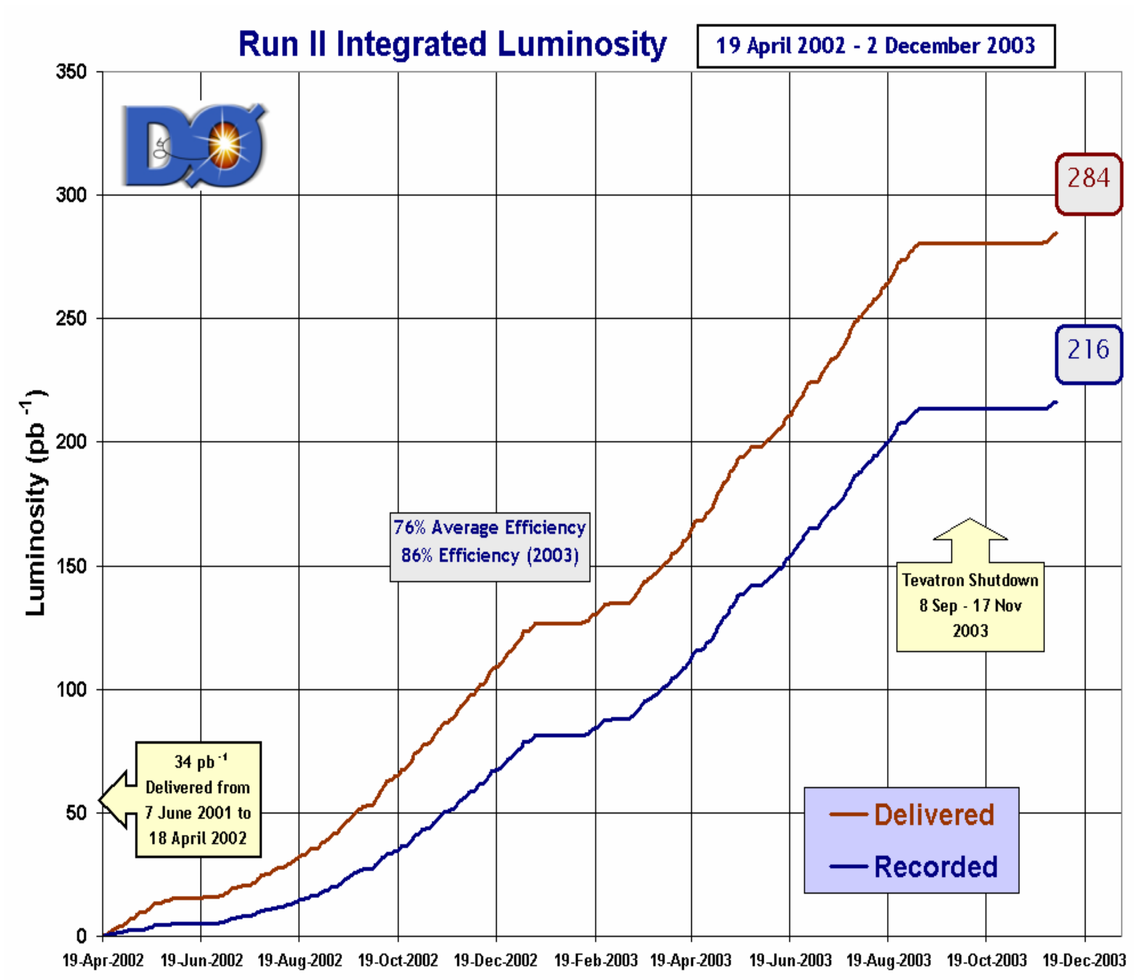
Run I central muon detector,
New forward muon detector
and many scintillator counters…



99+% channels live

A key upgrade
of DØ muon detection
is its magnetic central
tracker…

Integrated Luminosity



~216 pb^{-1} on tape w/ Silicon detector
⇒ an overall 76% efficiency since

First 8 days of 2004: 10.7 pb^{-1} recorded (86% efficiency).

Jan 8th was a Run II "best" with 1.75 pb^{-1}

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,
searches for single top quark production, …

QCD

inclusive jet cross section, dijet mass and angular distributions, diffraction, …

Heavy flavor

resonance reconstructions, masses, lifetimes,
branching fractions, rare decays, Bs mixing, …

New phenomena searches

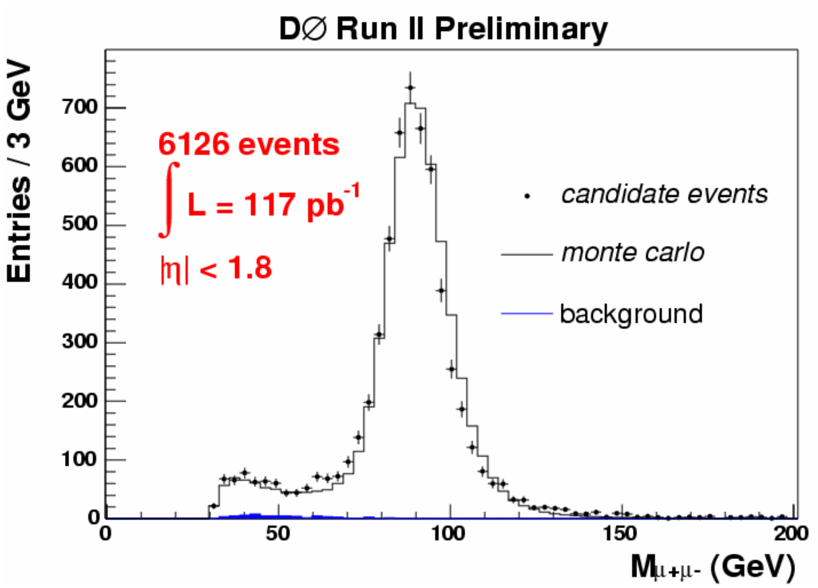
Higgs bosons, supersymmetry, leptoquark,
large extra dimensions, Z', …

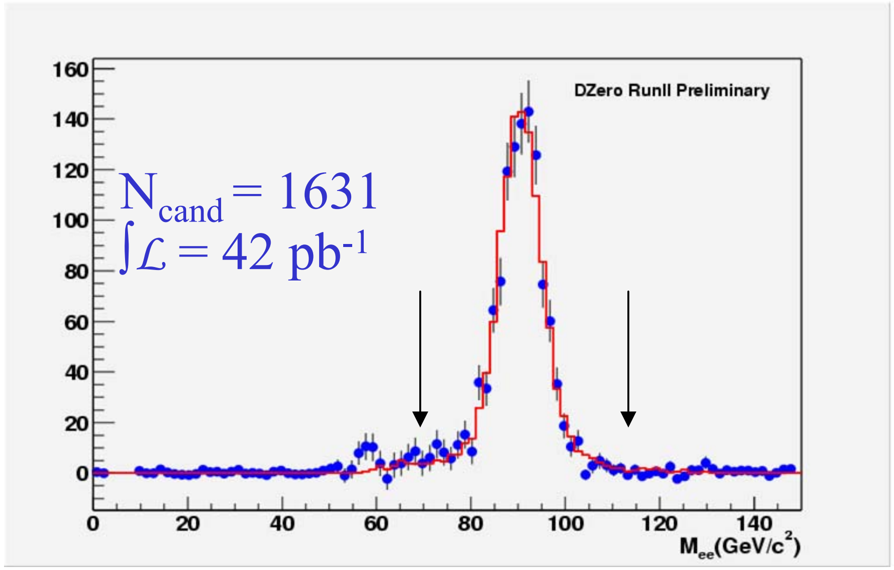
$Z \to \mu^+\mu^-$, $Z \to e^+e^-$

- Backgrounds:
  - QCD: (0.6 ± 0.3)%
  - $Z \to \tau^+\tau^-$: (0.5 ± 0.1)%
- ε_{total} = 19%
- Dominant systematics:
  - luminosity: 10%
  - efficiency measurements from $Z \to \mu^+\mu^-$ data: 3.3% (statistics limited)

$$\sigma_Z \cdot Br(Z \to \mu+\mu-) = 262 \pm 5 \pm 9 \pm 26 \text{ pb}$$
$$\sigma_Z \cdot Br(Z \to e+e-) = 275 \pm 9 \pm 9 \pm 28 \text{ pb}$$

stat sys lum





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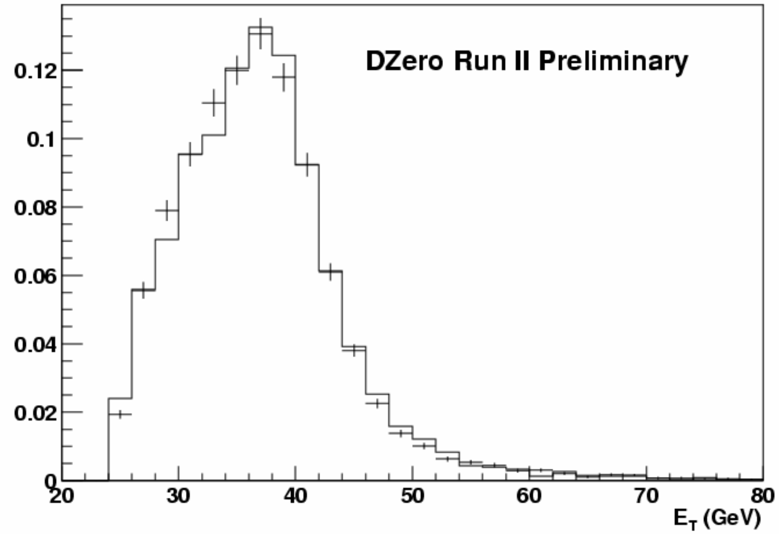
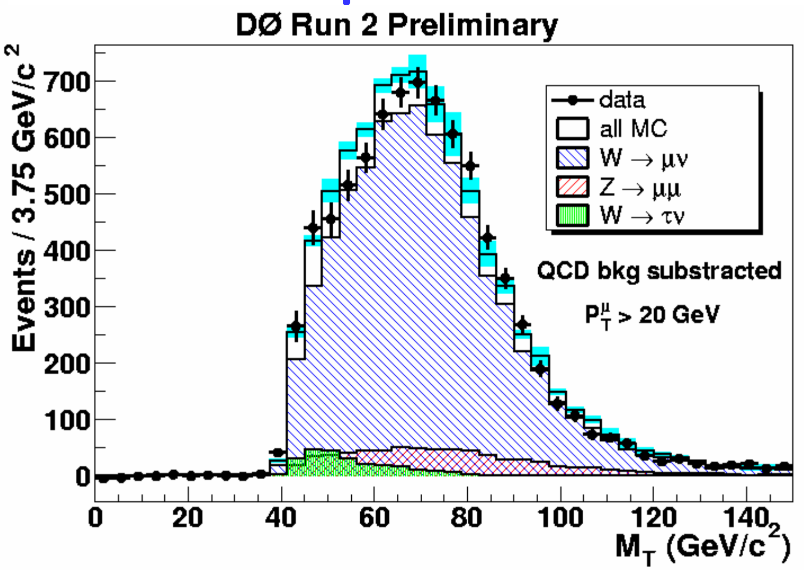
$W \to e\nu$ and $W \to \mu\nu$

- $p_T(e)$ > 25 GeV
- E_T^{miss} > 25 GeV
- N_{cand} = 27370
- $\int \mathcal{L}$ = 42 pb^{-1}

- $p_T(\mu)$ > 20 GeV
- E_T^{miss} > 20 GeV
- N_{cand} = 8302
- $\int \mathcal{L}$ = 17 pb^{-1}





$$\sigma_W \cdot Br(W \to e\nu) = 2.884 \pm 0.021 \pm 0.128 \pm 0.284 \text{ nb}$$
$$\sigma_W \cdot Br(W \to \mu\nu) = 3.226 \pm 0.128 \pm 0.100 \pm 0.322 \text{ nb}$$

stat. syst. lumi.

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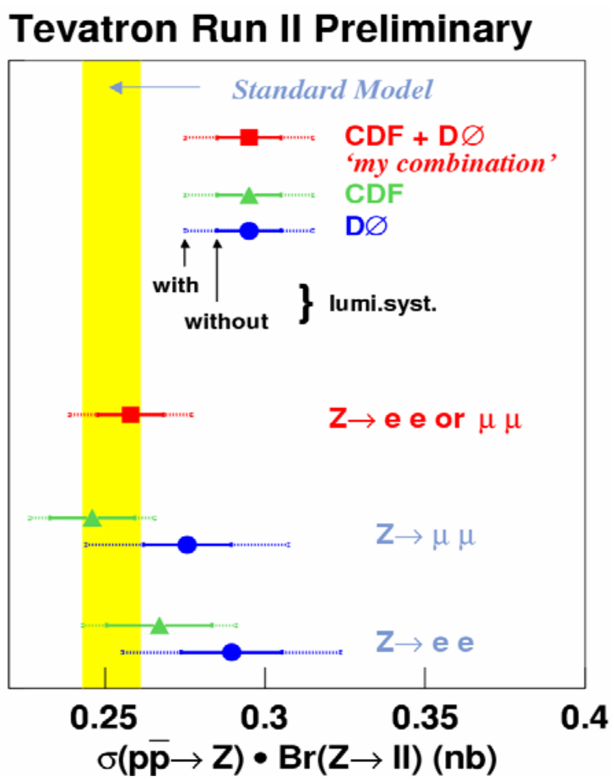
Comparison of W,Z cross sections with theory

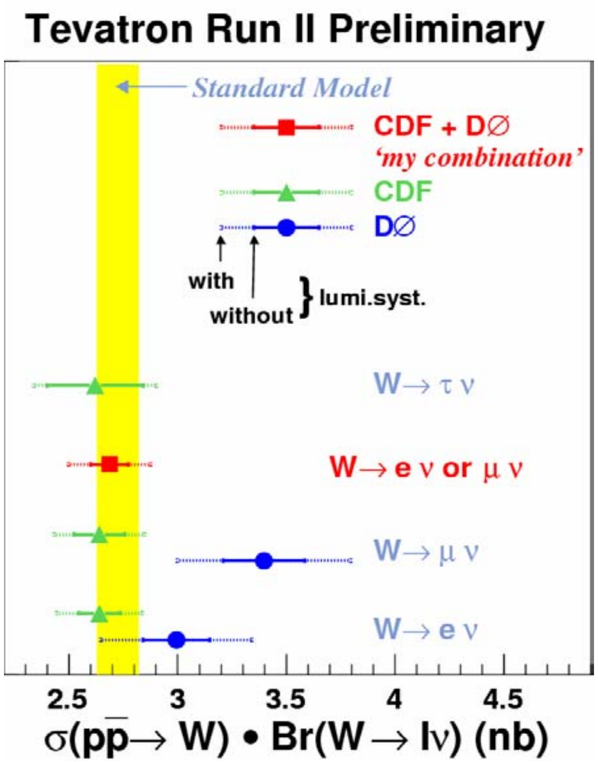
Standard Model:

- NNLO calculation
  [Nucl.Phys. B359 (1991) 343]
- NNLO MRST2002 PDFs
- 3.5% uncertainty assessed using CTEQ error PDFs

- LEP Br($Z \to l^+l^-$) = .03366 ± .00002
- SM Br($W \to l\nu$) = .1082 ± .0002

- CDF and DØ will use the same inelastic cross section to calculate our luminosities to avoid the Run I problem

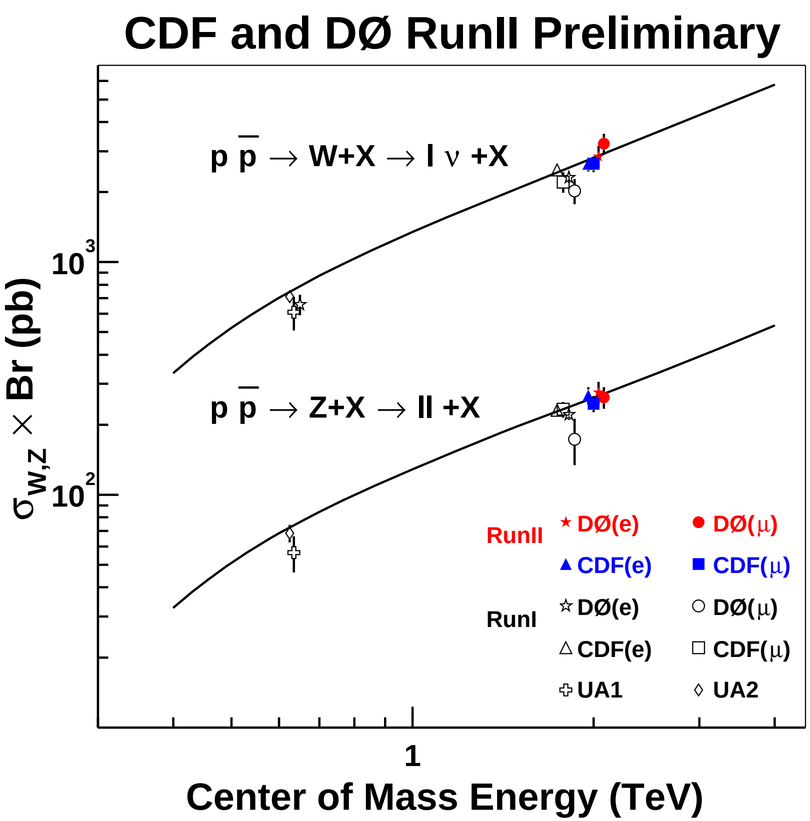


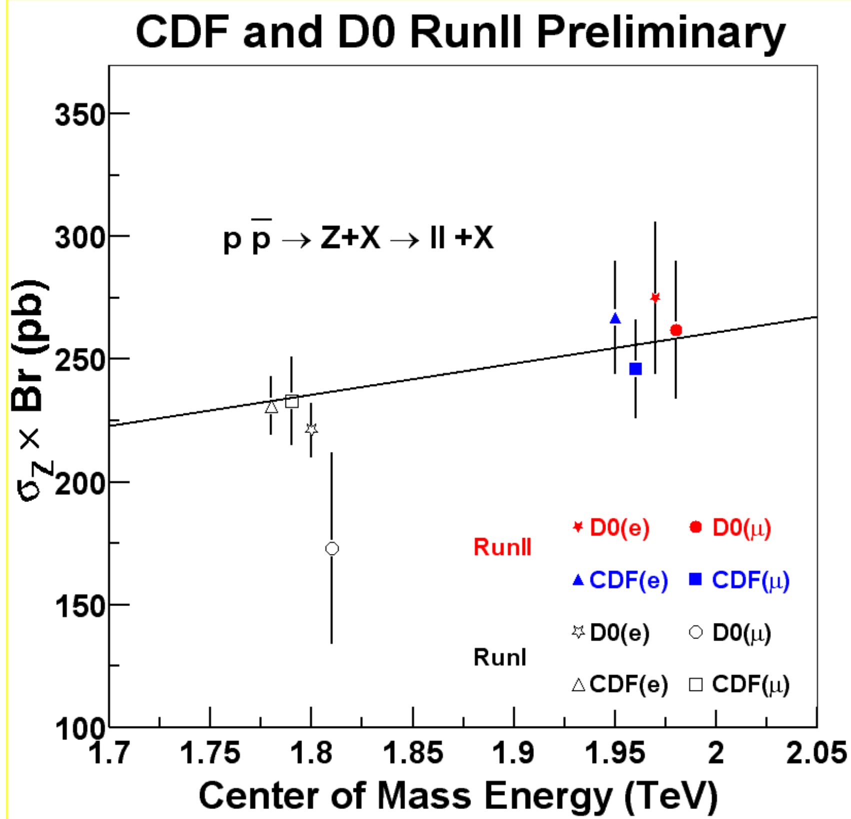


Combinations & plots from T. Wyatt, Lepton-Photon '03

W and Z Physics

Leptonic decays of W/Z are standard candles of hadron collider physics
- detector calibration
- understanding precision measurements
- luminosity (?)





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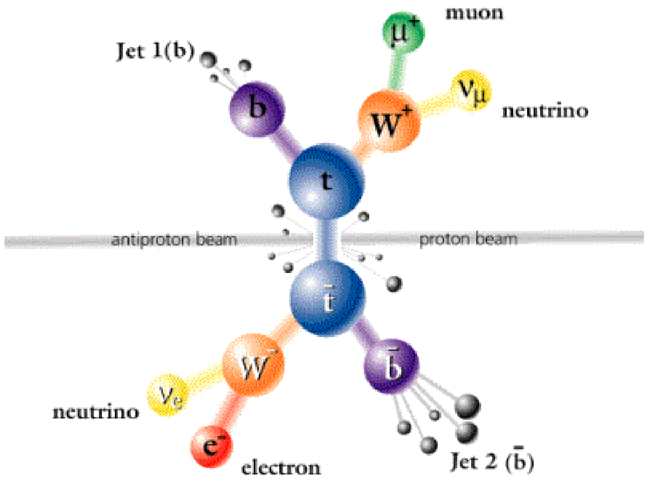
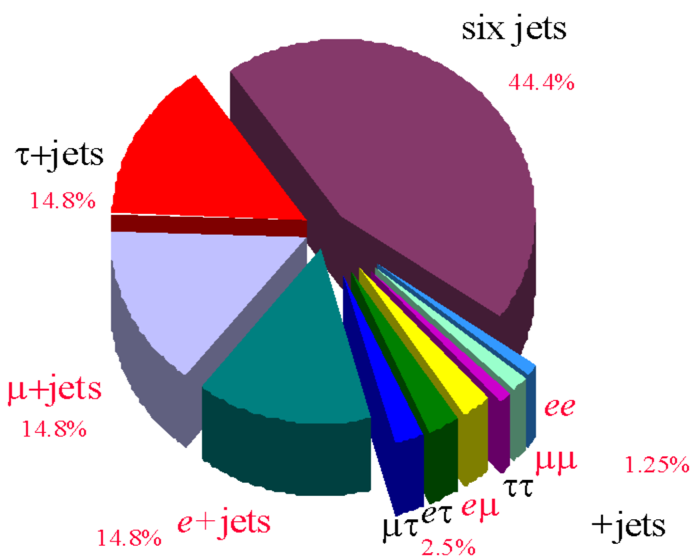
W and Z measurements: looking toward greater precision

- Luminosity from W, Z's
  - Note that experimental errors on cross sections are already lower than luminosity errors
  - Can use $\sigma \cdot B(Z)$ as the luminosity reference for the experiment
  - Precision then relies on theoretical prediction for $\sigma(p\bar{p} \rightarrow Z+X)$, including PDF uncertainties
- QED and QCD corrections to W, Z production
  - Calculations exist, should be fine for anticipated experimental precision
  - Look forward to a MC framework which unifies both
- Theoretical concerns for precision W mass
  - 2-photon radiative corrections: (1-photon ~100 MeV shift)
  - work underway

Top quark physics

- top-antitop production
  - mainly quark-antiquark annihilation
- W and b-quark decays specify final states
  - isolated high P_T leptons
  - soft leptons in jets
  - detached vertices in jets





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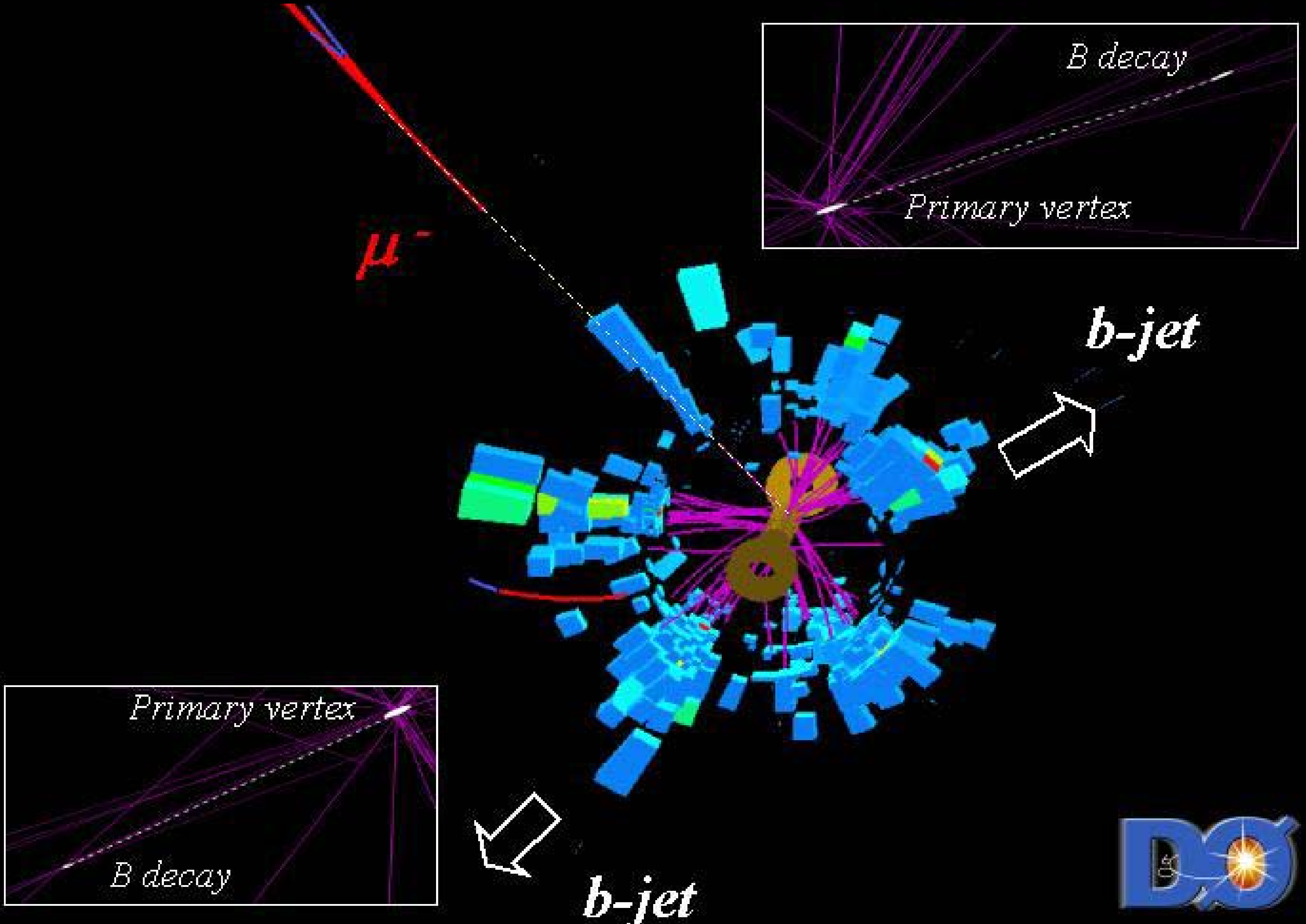
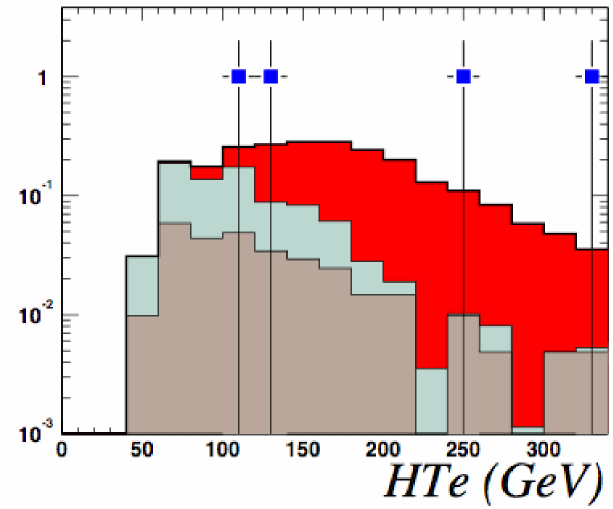
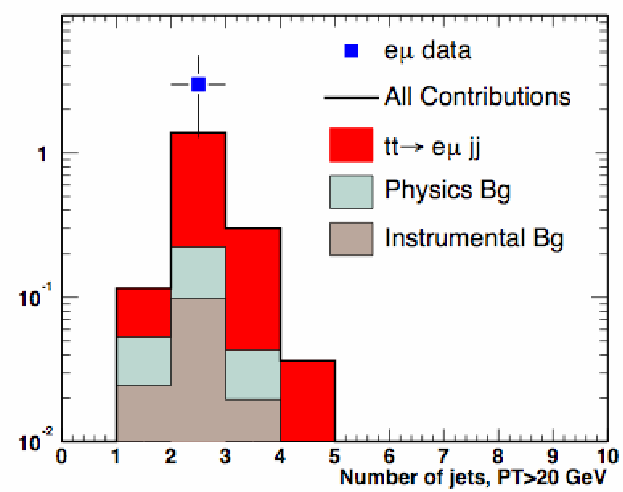
Run II top candidate



Dilepton Final States



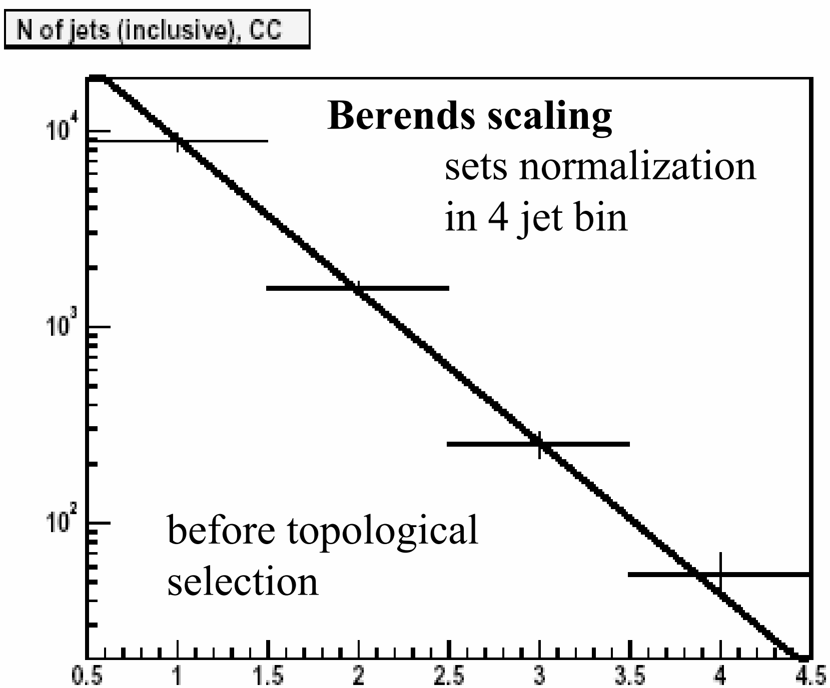


- *ee*: 107 pb^{-1}
  - backgrounds 0.6 ± 0.5 evt (Z/γ, WW, $Z\tau\tau$; W+jets, QCD fakes)
  - 2 events observed
- $\mu\mu$: 90 pb^{-1}
  - backgrounds 0.7 ± 0.2 evt (Z/γ, WW, $Z\tau\tau$; W+jets, bbbar)
  - 0 events observed
- $e\mu$: 98 pb^{-1}
  - backgrounds 0.6 ± 0.2 evt (WW, $Z\tau\tau$, W+jets, bbbar)
  - 3 events observed

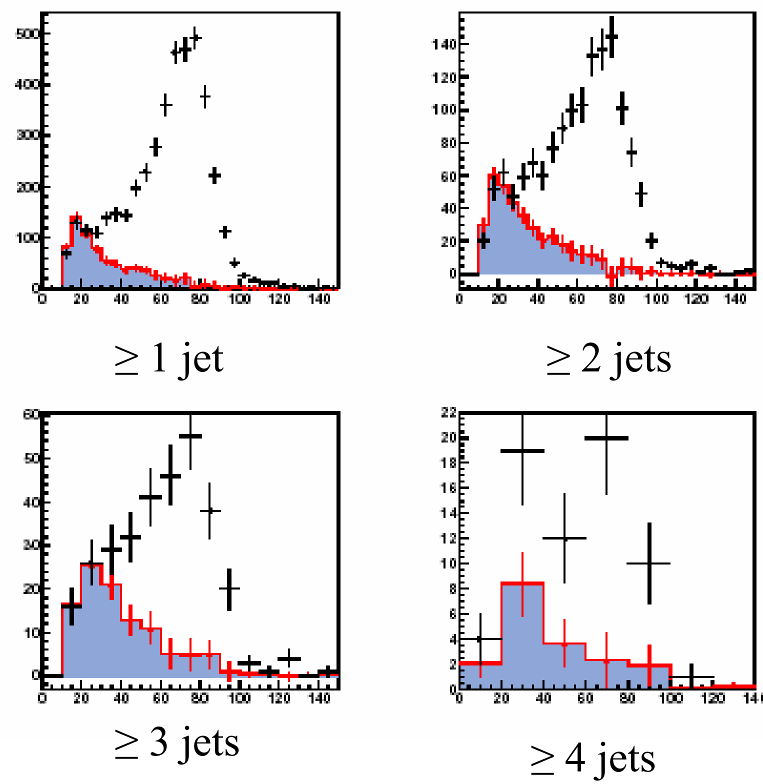
$$\sigma(p\bar{p} \to t\bar{t}) = 8.7^{+6.4}_{-4.7}(stat.)^{+2.7}_{-2.0}(sys.) \pm 0.9(lum.)\ pb$$

e+jets/topological

- use strategy of looking for events kinematically like top
  - veto on soft muons
- 92 pb^{-1}
- backgrounds
  - multijet with fake 'e' *(shown in blue), W+jets*



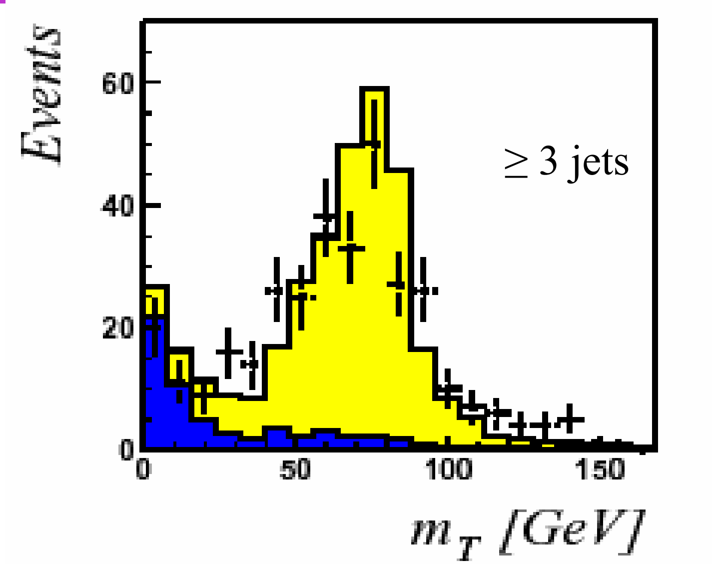
m_T (e,ν)
(QCD background in blue)

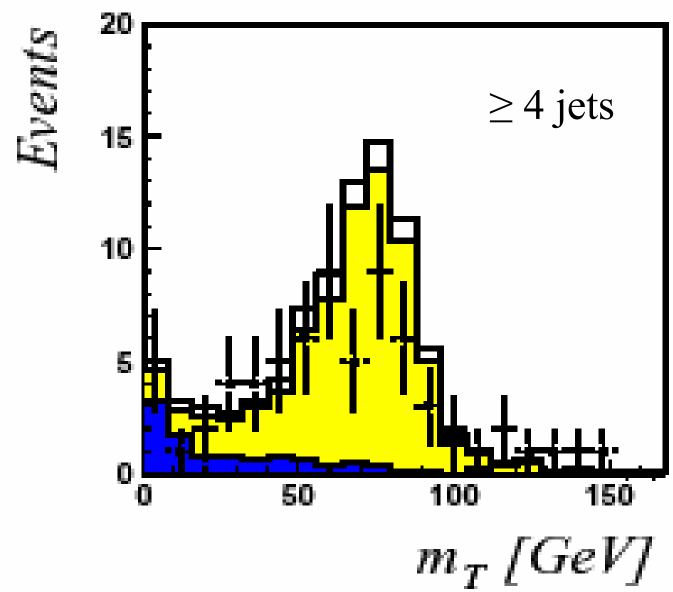


6.8 ± 1.6 evts background
12 events observed

μ+jets/topological

- 94 pb^{-1}
- background
  - W+jets, heavy flavor
  - 11.7 ± 1.9 evts background
- 14 events observed
- Plots
  - Before topological cuts (on H_T and aplanarity)
  - Blue: QCD background (heavy flavor semileptonic)
  - Yellow: W+jets, $t\bar{t}$



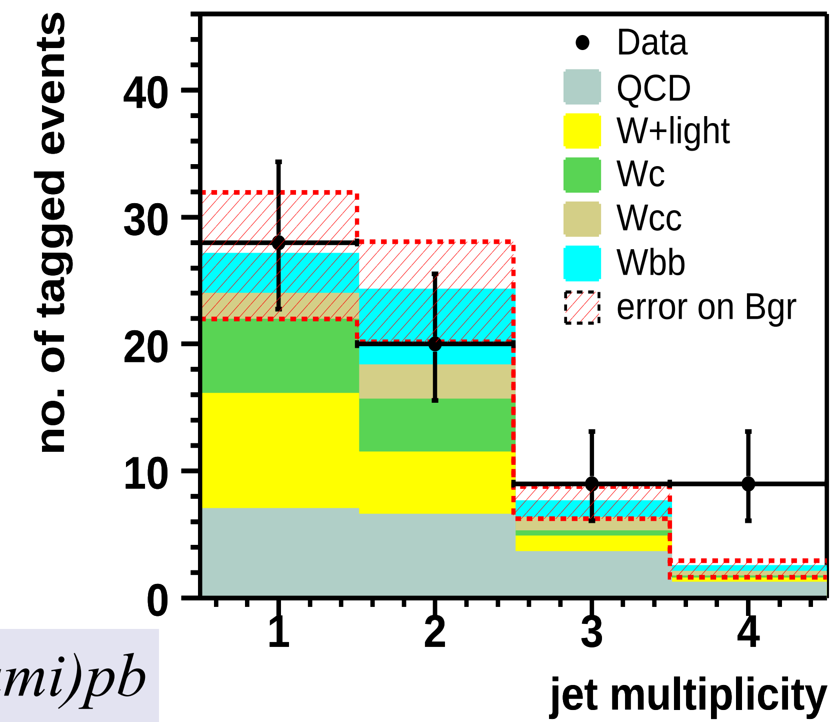


Lepton+Jets Using *b*-Tagging

- **soft lepton tag**
  - relax topological selection
  - require soft, non-isolated **muon within a jet**
  - $92\ pb^{-1}$

	All BG	Exp Sig	N_{obs}
e+jets	0.2±0.1	0.5	2
μ+jets	0.7±0.4	0.8	0

- **lifetime tag**
  - Relax topological selection
  - Require jet with signed **impact parameter** or **secondary vertex**
  - $45\ pb^{-1}$

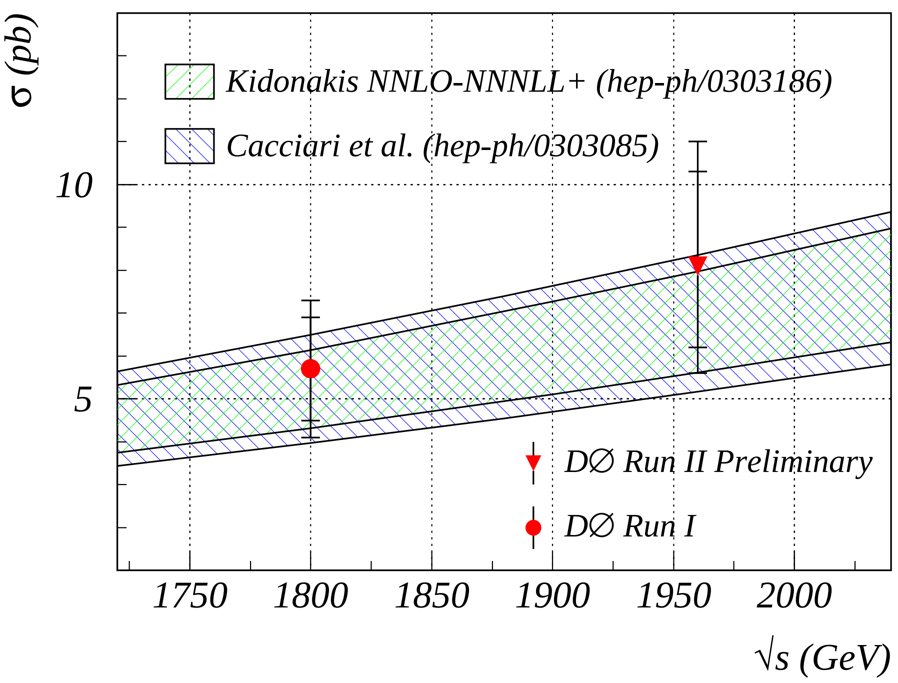


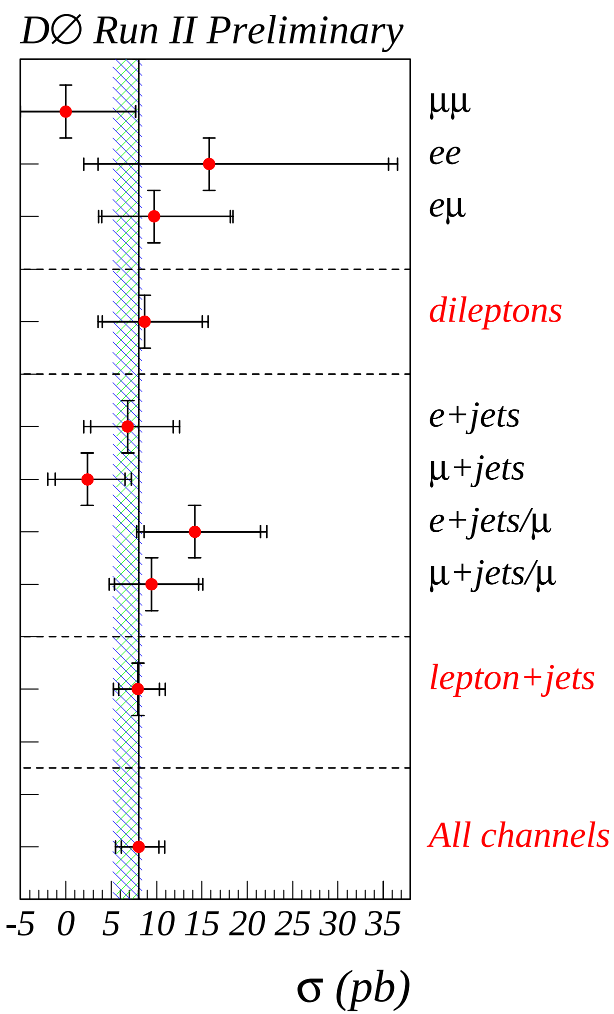
impact: $\sigma_{t\bar{t}} = 7.4^{+4.4}_{-3.6}(stat)^{+2.1}_{-1.8}(syst) \pm 0.7(lumi)pb$

vertex: $\sigma_{t\bar{t}} = 10.8^{+4.9}_{-4.0}(stat)^{+2.1}_{-2.0}(syst) \pm 1.1(lumi)\,pb$

$t\bar{t}$ cross sections

- check consistency among the channels
- Compare with NNLO-NNNLL calculations
- Look at dependence on center-of-mass energy

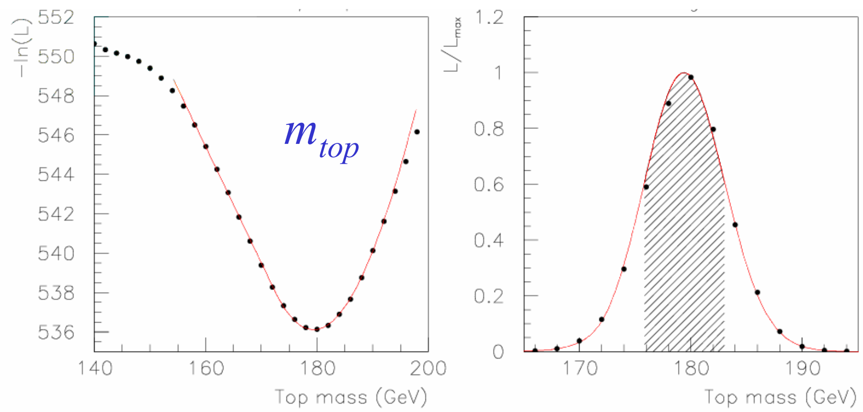




$$\sigma_{t\bar{t}} = 8.1^{+2.2}_{-2.0}(\text{stat})^{+1.6}_{-1.4}(\text{syst}) \pm 0.8(\text{lum})\ \text{pb}$$

Top mass

- We can look forward to improved precision on m_t in the near future
  - Expect ~ 500 b-tagged lepton+jets events per experiment per fb^{-1}
    - cf. World total at end of Run I ~ 50
- Improved techniques
  - e.g. new DØ Run I mass measurement extracts a likelihood curve for each event
  - equivalent to a factor 2.4 increase in statistics



m_{top} = 180.1 ± 5.4 GeV (DØ Run I, improved, prelim.)

cf 174.3 ± 5.1 GeV (all previous measurements combined)

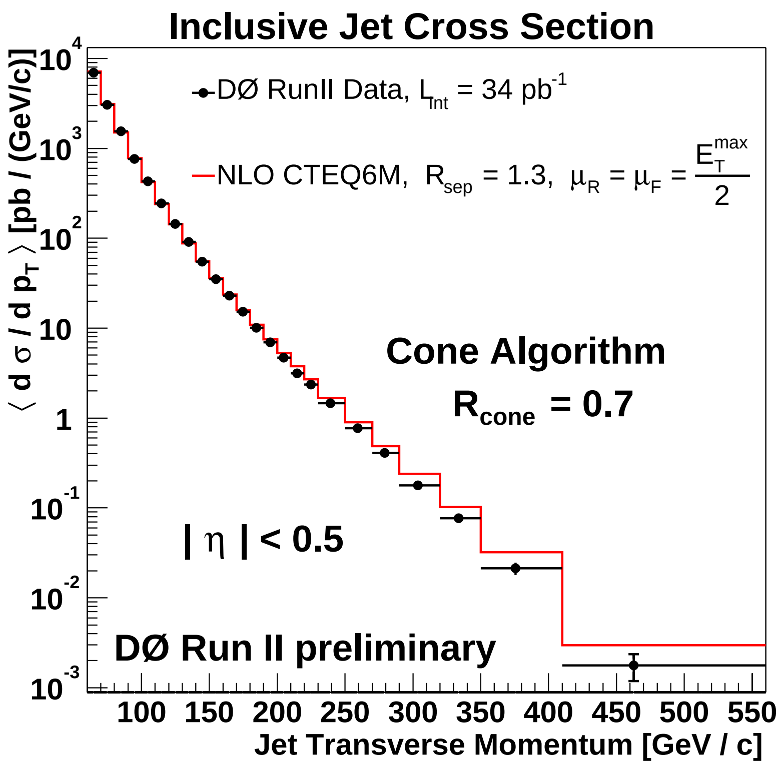
Top production & decay modeling

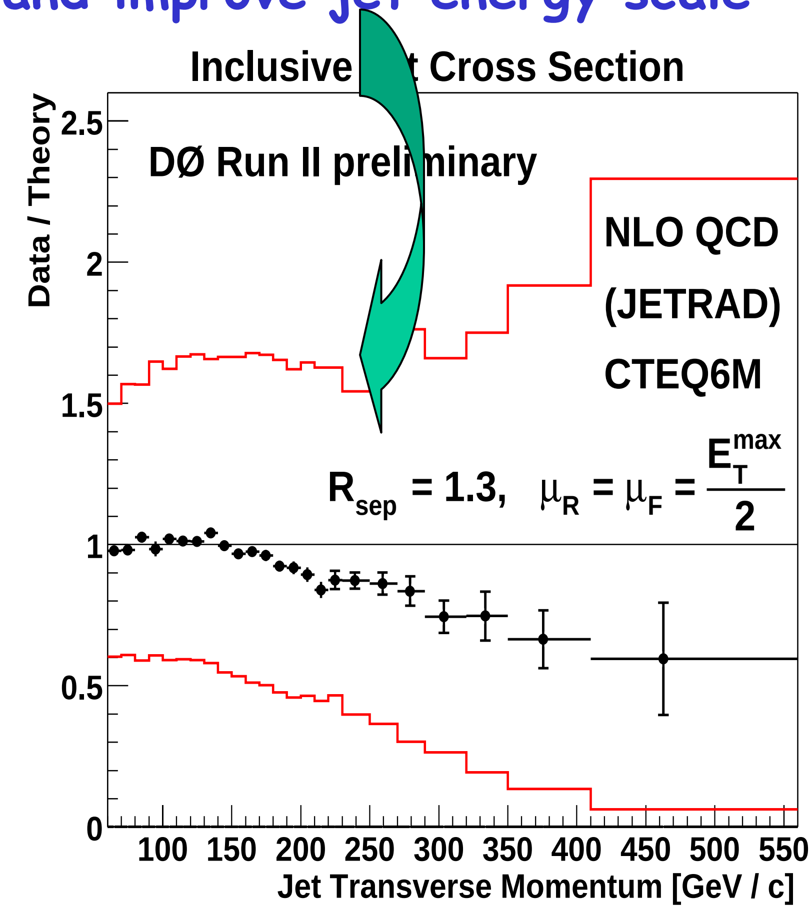
- NLO generator exist for 2→2 process ($p\bar{p} \rightarrow t\bar{t}+X$)
- Need at least a 2→4 generator ($p\bar{p} \rightarrow bW^{+}\bar{b}W^{-}$) to get correct description of initial and final state radiation with interference
- Also, want
  - spin correlations preserved
  - Possibility to add anomalous couplings

- Concern for getting eventually to 2 GeV on m_{top} uncertainty
  - Color reconnection?
- Single top
  - SM: Presently using NLO calculations, including spin correlations
    - Probably good enough for Tevatron studies
  - Non-SM
    - Anomalous FCNC
    - $W' \rightarrow t\bar{b}$

Inclusive Jet Production

Presented preliminary results for winter'03 conferences,
Current focus is to understand and improve jet energy scale





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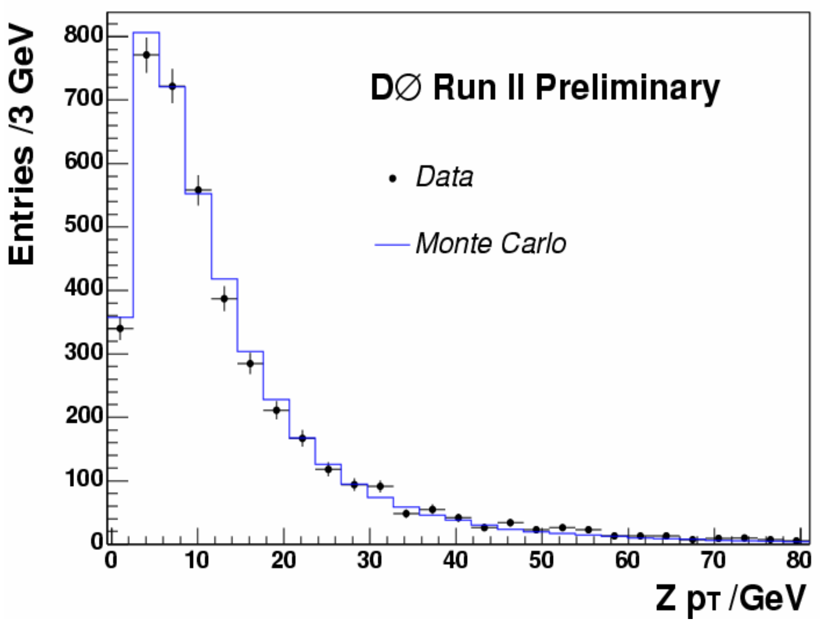
Jet Studies

- Can compare to NLO calculations for most of the basic observables
  - Inclusive jet xsec, dijet xsec, dijet mass, …
  - Higher order uncertainties smaller than experimental uncertainties
- Higher order calculations would still be useful
  - Verify that corrections are small
  - Especially at high-x where collider data could be used for gluon distribtution determination
- Still need and interface between NLO calculations and parton showering algorithms
  - Precise normalization of the NLO cross section
  - Precise modeling of final state

Studying QCD with W,Z Events

- Data/MC comparisons for $p_T(Z)$



$Z \rightarrow \mu^+\mu^-$

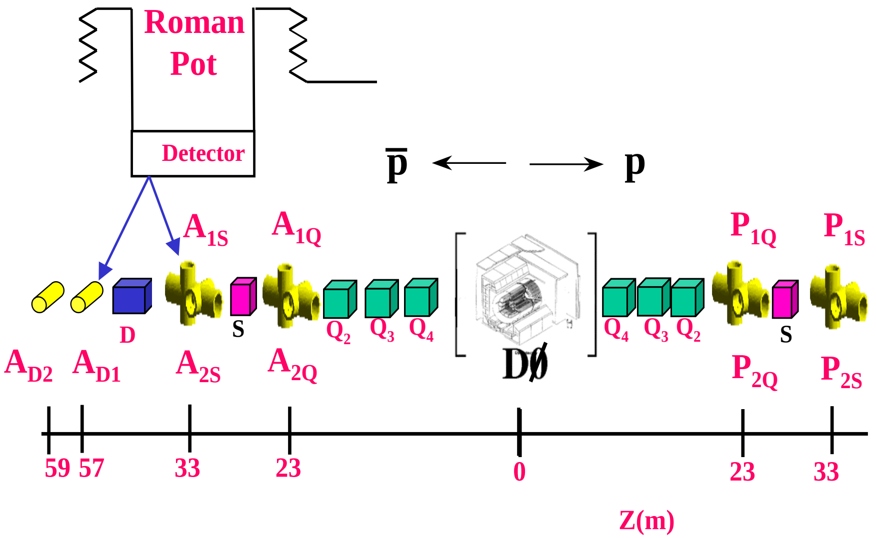
→ probe QCD phenomenolgy

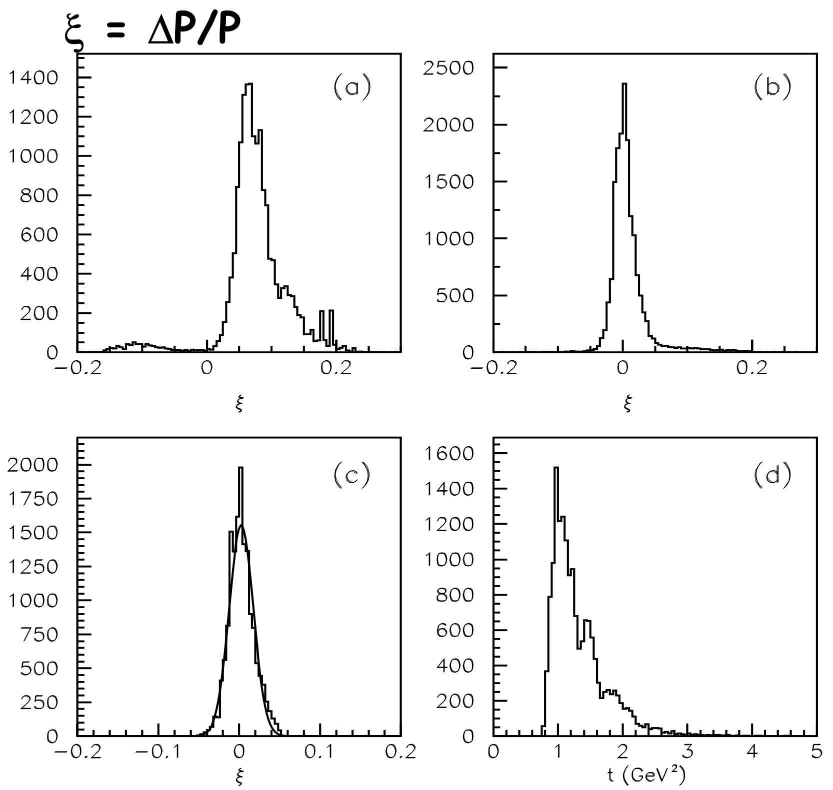
Many more such measurements to come:

e.g, W/Z rapidity → probe PDFs

Diffractive Physics

will significantly benefit from the newly installed forward proton detector.





18 Roman pots are installed and integration is underway.

Ongoing analyses:

- Elastic dN/dt measurements
- Diffractive and non-diffractive jet cross section ratio
- Diffractive W and Z production
- Double pomeron exchange using FPD

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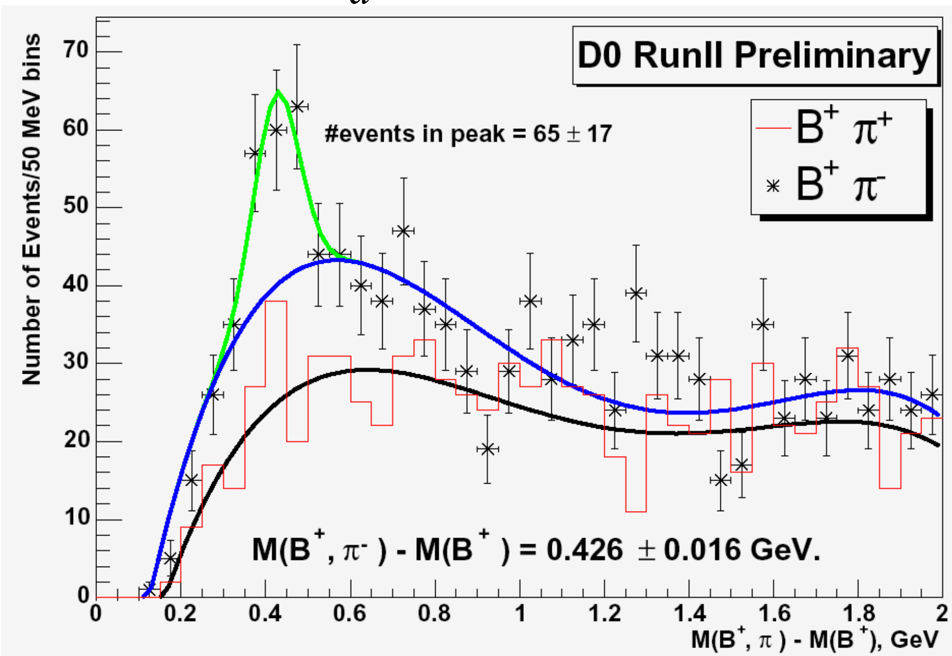
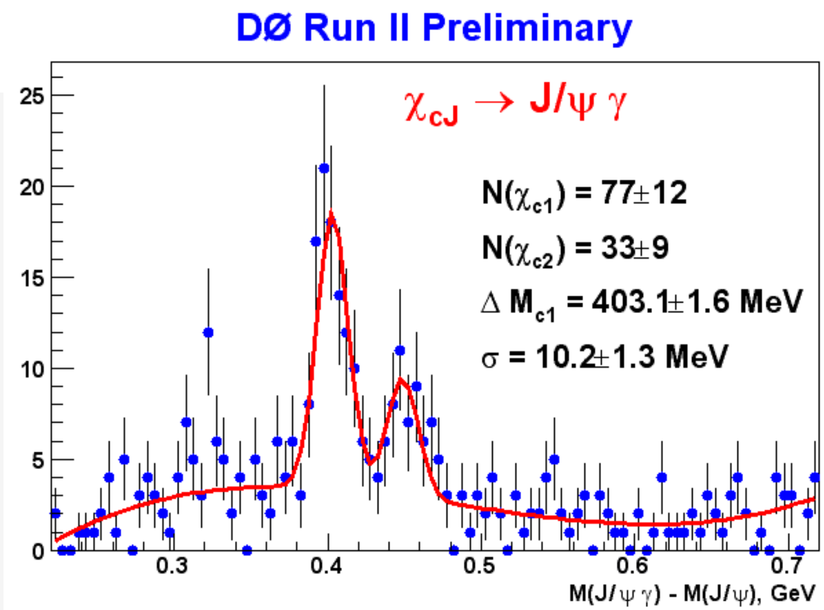
Heavy meson spectroscopy

$$B_d^{**} \to B^+ \pi$$

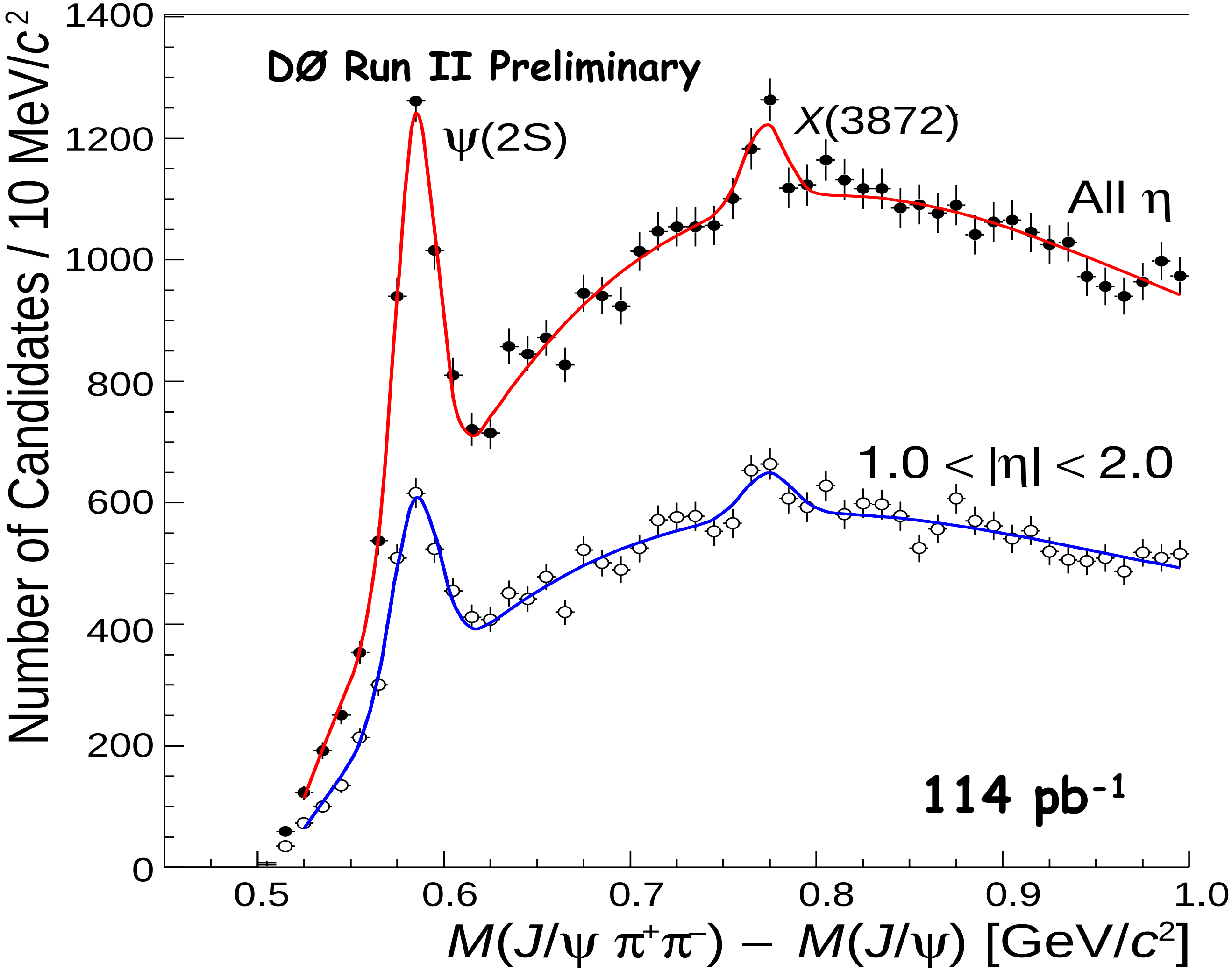




- fully reconstructed decays
- 114 pb-1
- **m = 5.71 ± 0.016 GeV**
- PDG: 5.698 ± 0.008 GeV
- 1st observation at Tevatron

- theo. production not understood
- resolve two mass peaks
  - χ_{c1} and χ_{c2}
  - given spins, don't expect equal production
- $N\chi_{c1}$ = 77 ± 12 evts; $N\chi_{c2}$ = 33 ± 9 evts

Observation of X(3872)



$\Delta M(\pi\pi)$>500 MeV
$\Delta R(X,\pi)$<0.6

Would be useful to have production predictions for different hypotheses

-Charmonium state

-Meson molecule

Production properties for given J^{PC} (once known)

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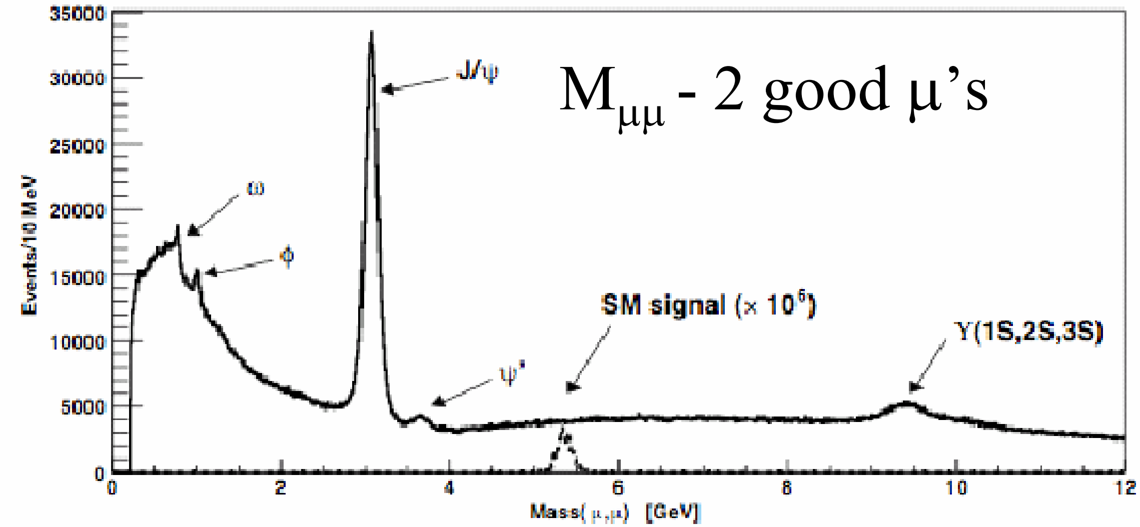
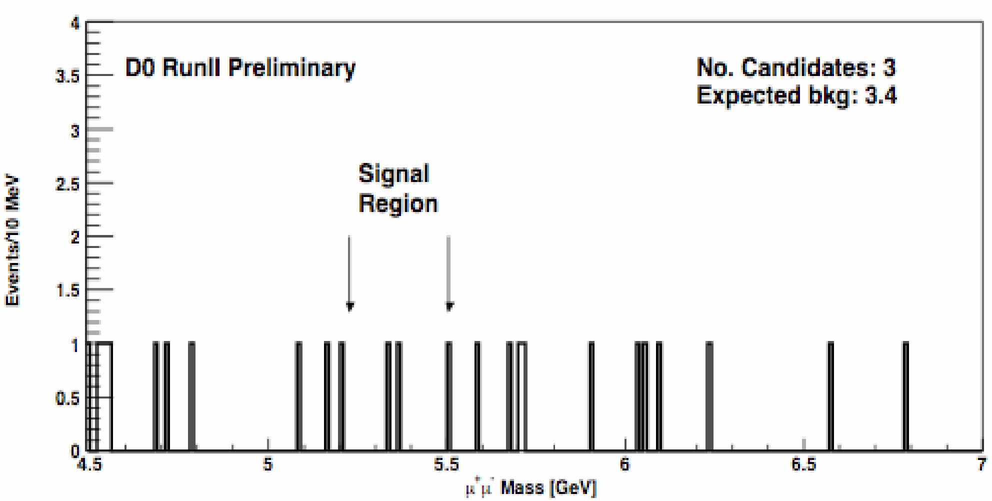
B-physics: rare decays

$$BR(B_s \to \mu^+\mu^-)$$

- SM predicts 3.7×10^{-9}, but
- light Higgs models BR up to 10^{-6}
- can probe SUSY at high $\tan(\beta)$





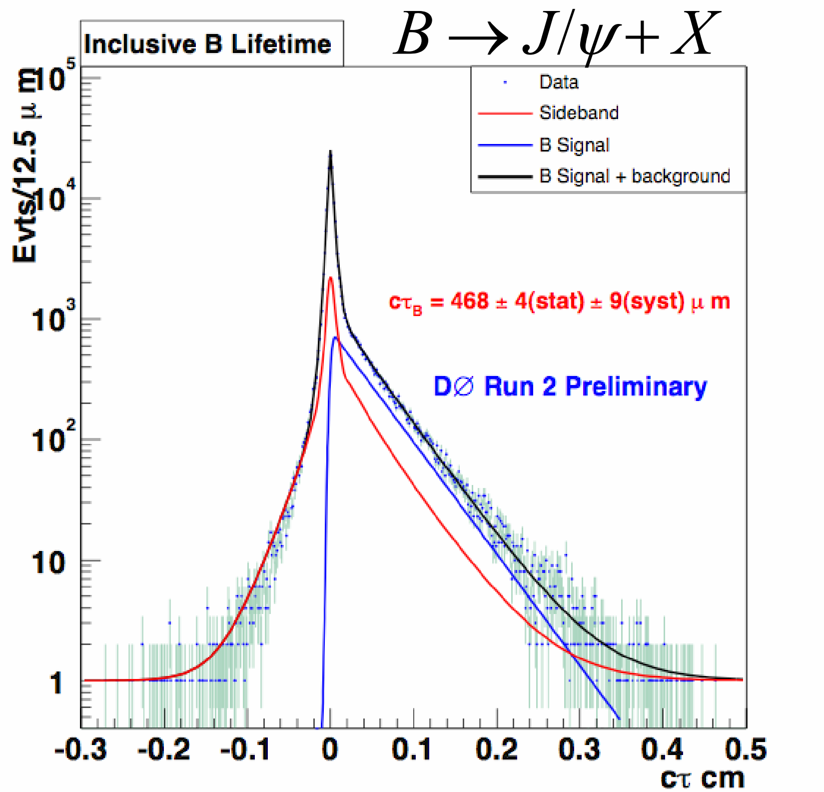
- data sample: 100 pb-1
- in signal region after all cuts
  - no peak
  - 3 candidates, 3.42 ± 0.79 evt BKG
- BR limit 1.6 x 10-6 @ 90% c.l.
  - < 2.0 x 10-6 @ 90% c.l. (PDG)

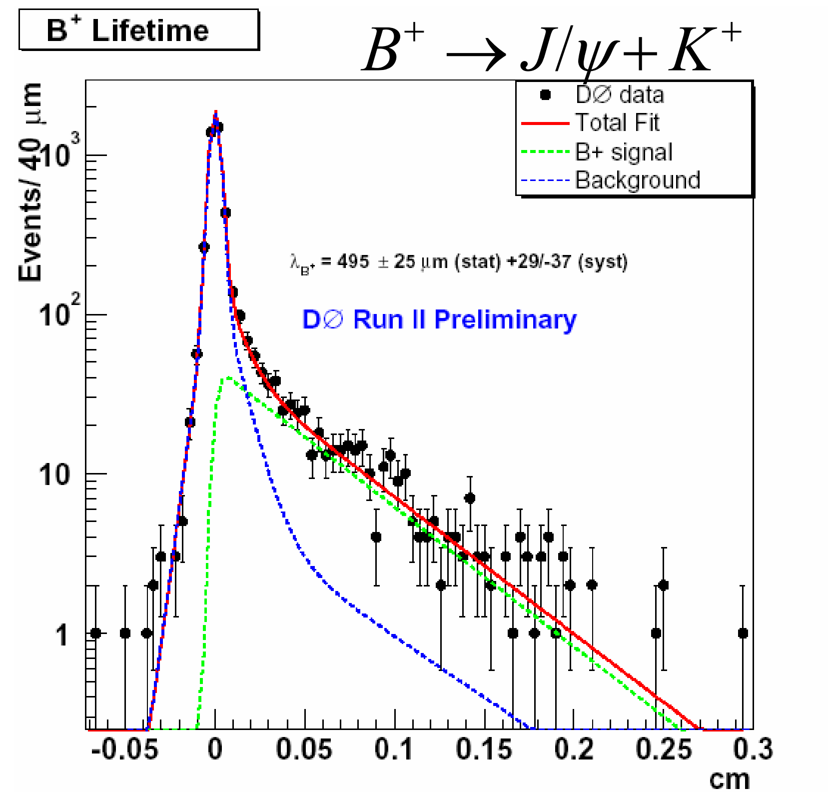
Lifetime Measurements

- **Inclusive lifetime**
  - 300k J/ψ's, 114 pb^{-1}

$$1.562 \pm 0.013(stat.) \pm 0.045(sys.)\text{ps}$$

▲ 1.564 ± 0.014 (PDG)





Charged B lifetime

$$1.65 \pm 0.08(stat.)^{+0.10}_{-0.12}(sys.)\text{ ps}$$

- 1.671 ± 0.018 ps (PDG)

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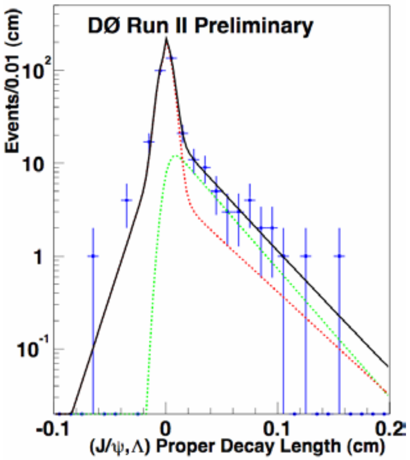
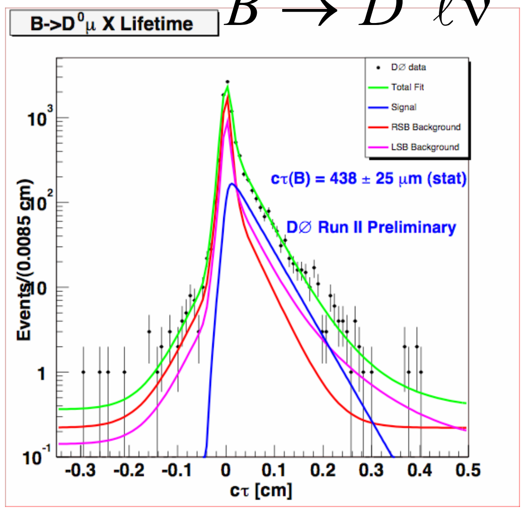
more lifetime measurements

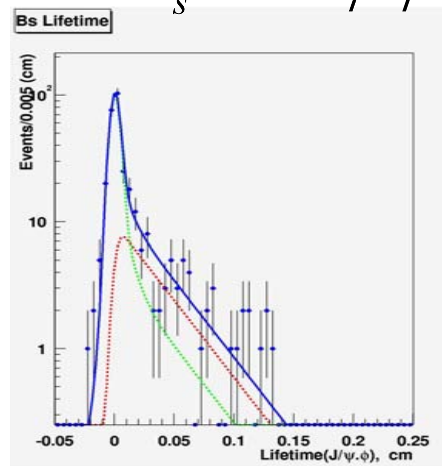
$B_s \to J/\psi\,\phi$



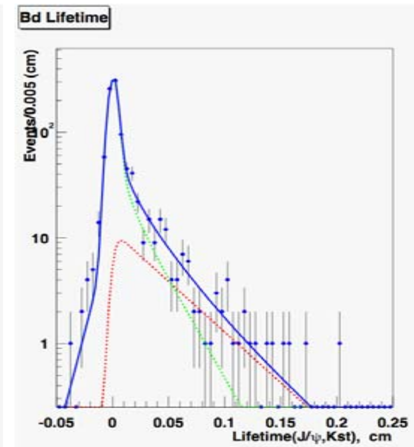
$B \to D^0 \ell \nu$



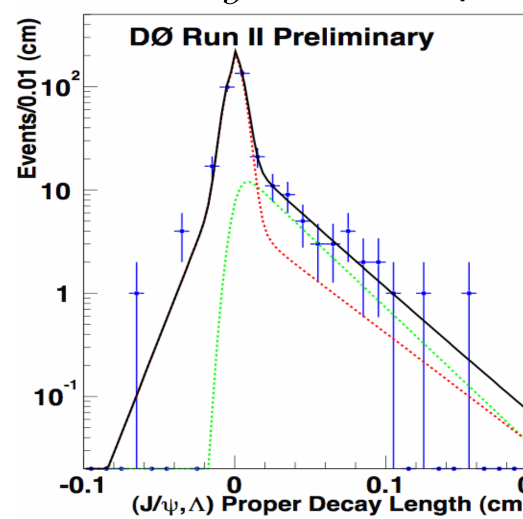
$B_s \to J/\psi\,\phi$



$B_d \to J/\psi\,K^*$



$\Lambda_b \to J/\psi\Lambda$



$\tau(B_d)$ = 1.52 +0.19-0.17 ps

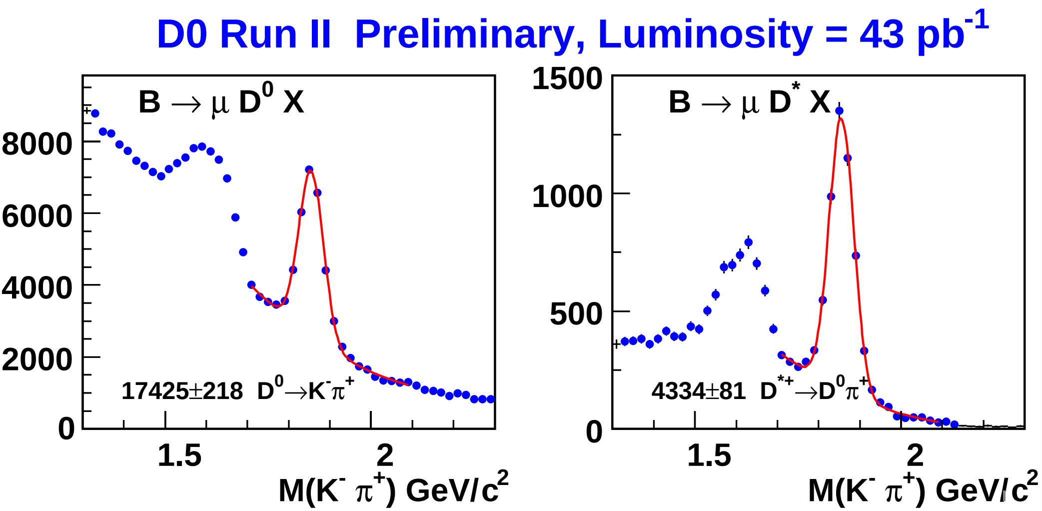
$\tau(B_s)$ = 1.19 +0.19-0.14 ps

$\tau(\Lambda_b)$ = 1.05 +0.21-0.18 ± 0.12 ps

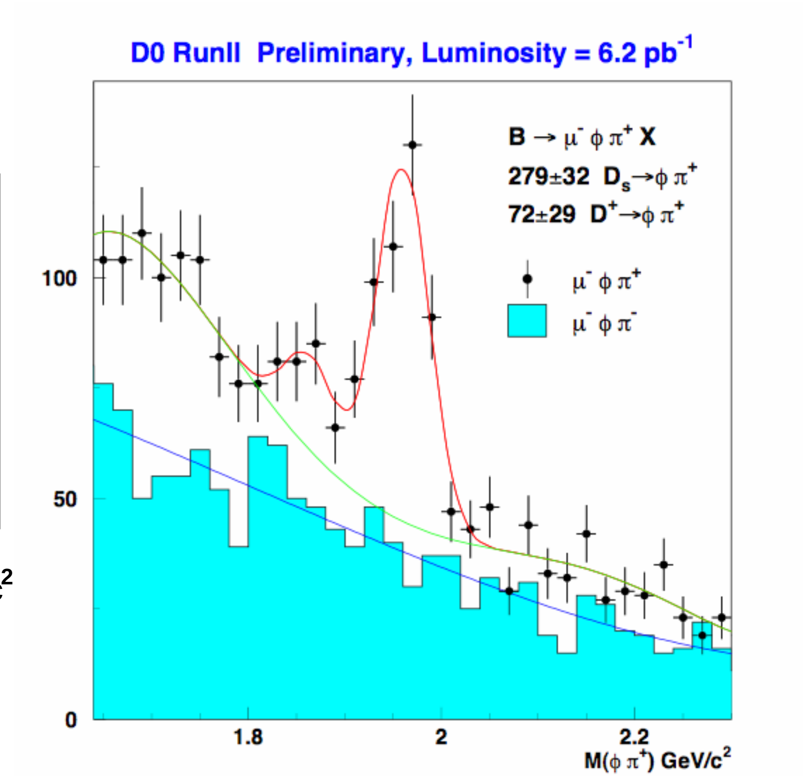
τ(B->Dμν) = 1.46 ± 0.08 ps

Toward B_s Mixing

Excellent B_d yield, ideal control sample for B_s mixing studies



$B_s \rightarrow \mu\ D_s\ x$



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

- Opposite side jet charge εD^2=3.3±1.8%
- Opposite side soft muon εD^2= 1.6±0.6%
- Same side track εD^2= 5±2%

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

Going further in heavy flavor physics: interaction with theory

- More theoretical input needed on bb, cc producution
  - Not just as a function of p_T, but including angular correlations
  - Separate direct, flavor excitation, gluon splitting …
- "fuzzy" boundary between QCD and observables
  - Match real generators to heavy flavor data
  - Fragmentation: how to use hadronic collision data to learn more
- Lattice QCD calculations for
  - BR and kinematics of semilep. $B \rightarrow D^{**}$, D^*, etc.
  - Reduction in errors on heavy-light decay constants
- Quarkonium production models for hadronic collisions
  - Beyond color octect and color evaporation
  - Prospects for NRQCD?
  - Alternative models for quarkonium polarization
- Polarization of heavy baryons in hadronic collsions
  - can this be predicted?
  - More insight into lighter baryon polarization
- More guidance on where to look for possible exotic mesons
  - Particularly in modes well-suited for hadron collider (e.g., no particle ID)

Searches: Higgs

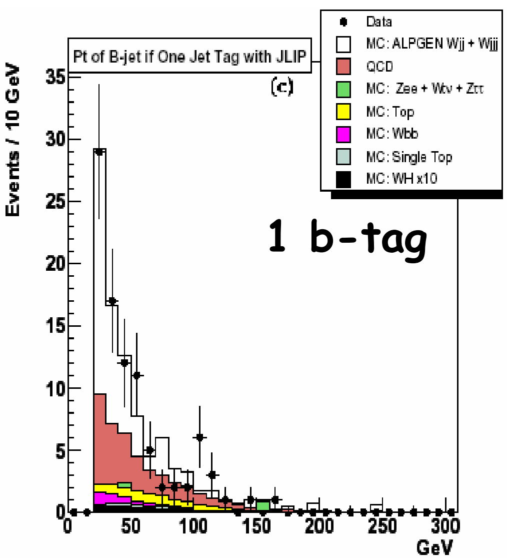
Look for unexpected, understand our data and develop tools

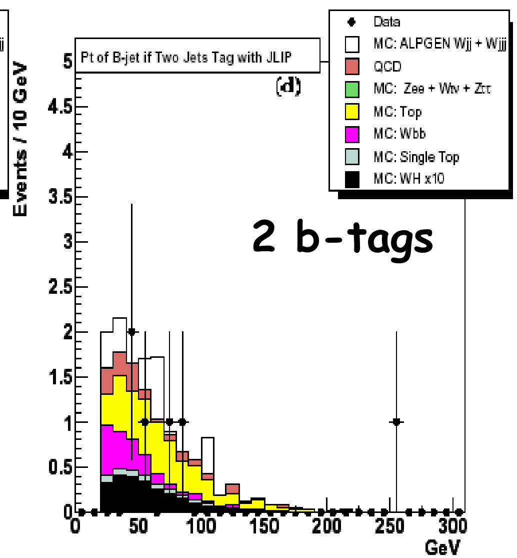
- Within the SM: WH and ZH with $H \to bb$; $gg \to H \to WW^*$
- Supersymmetry: $Hb \to bbb$, $Hbb \to bbbb$ (enhanced at large $\tan\beta$)
- More exotic: $H^{++} \to \mu\mu$, $H \to \gamma\gamma$

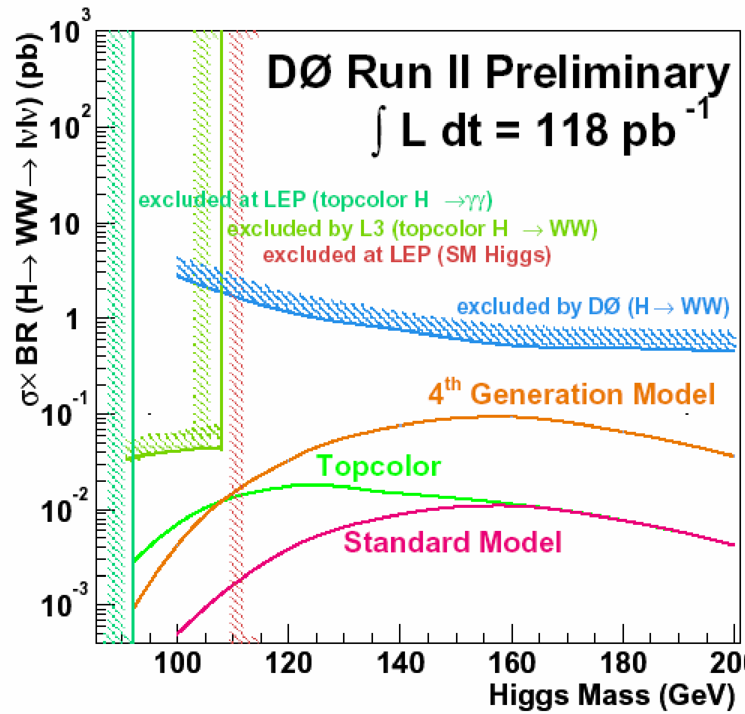
$$H \to WW^* \to \ell\ell'$$

$WH \to ebb$:

so far focused on understanding Wbb production







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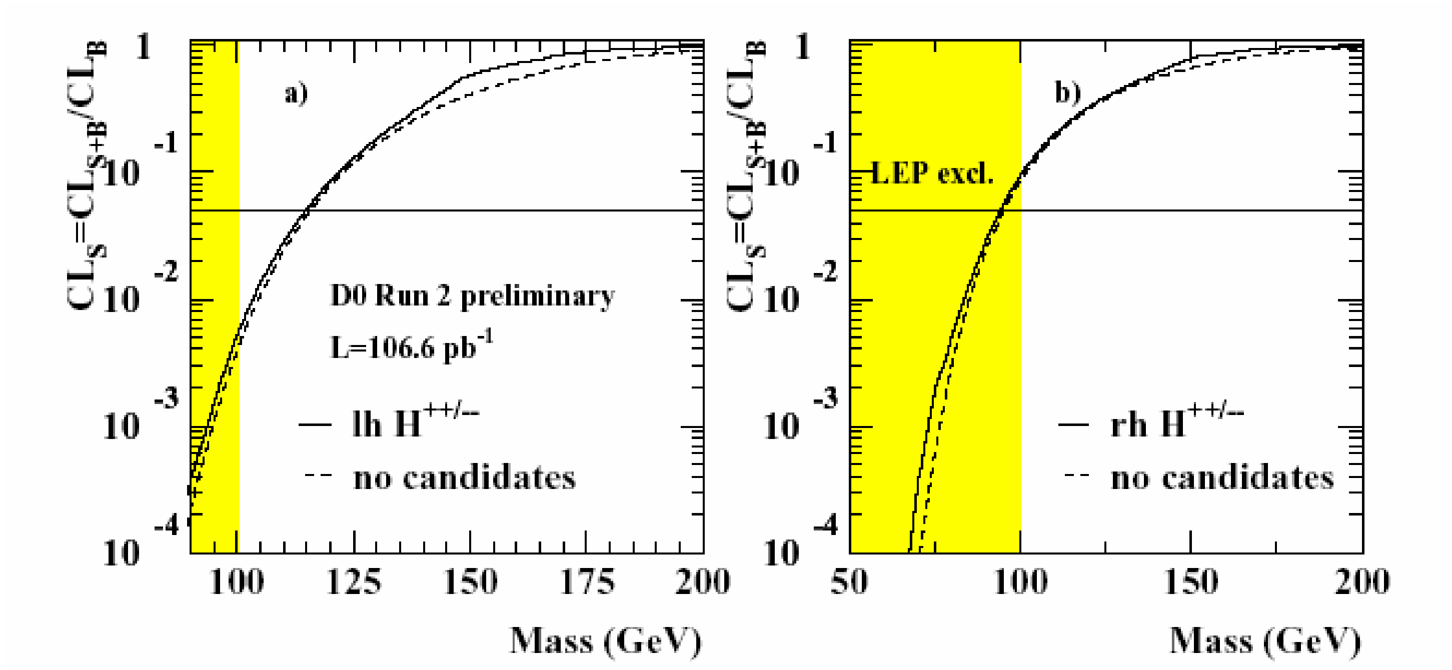
$p\bar{p} \rightarrow H^{++}H^{--} \rightarrow \mu^+\mu^+\mu^-\mu^-$

- appear in left-right symmetric models
  - for $M(H^{\pm\pm})$ < 160 GeV, dilepton decay modes dominant
- 107 pb^{-1}
- $M(H^{\pm\pm})$ > 95 GeV @ 95% c.l. (right-handed)
- $M(H^{\pm\pm})$ > 115 GeV @ 95% c.l. (left-handed)
  - world's best limit



Supersymmetry

A large number of analyses searching for supersymmetry

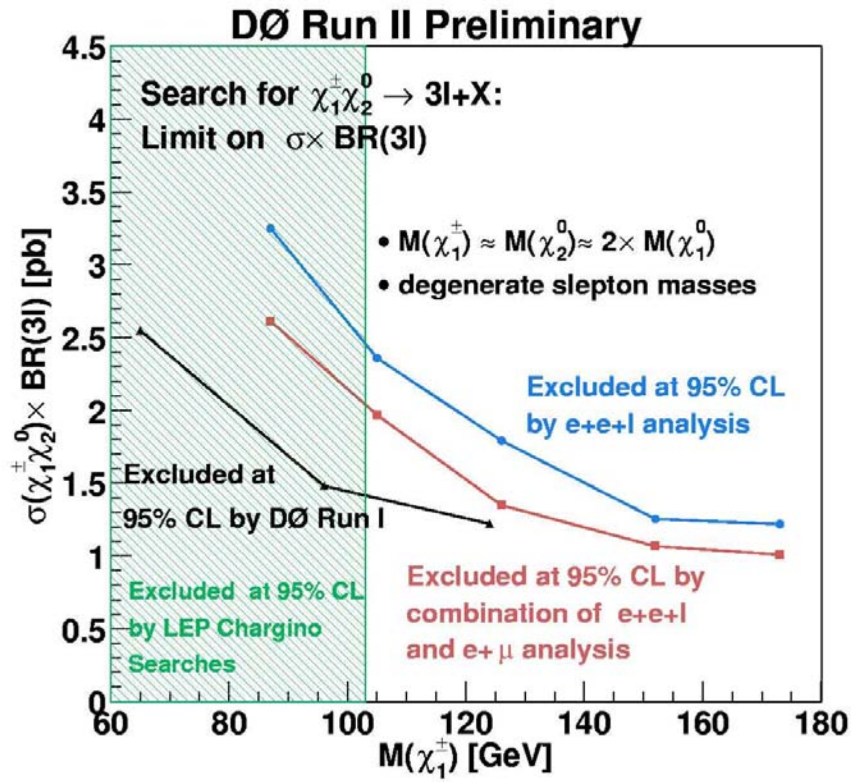
Experimentally (covering most conceivable topologies)

- di and tri-leptons,
- diphoton,
- tau,
- jets w/o b-tagging

Theoretically

- R-parity conservation
- R-parity violation
- gravity-mediation
- gauge-mediation
- different LSPs

Many analyses have reached or exceeded Run I sensitivities

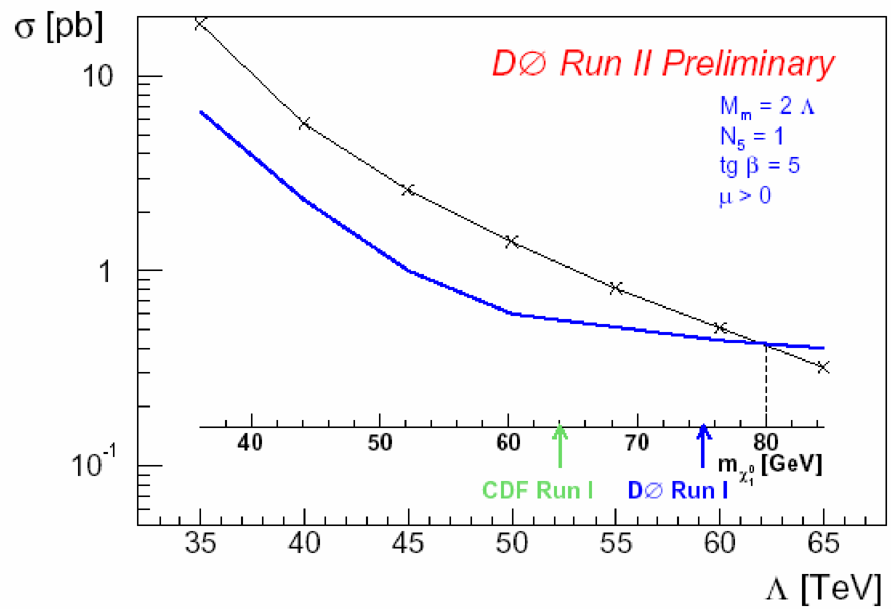


Dielectron chargino searches
120 pb^{-1}

$\sigma < 1.95$ pb @ 95% c.l.

More Supersymmetry

- $\gamma\gamma$+met
  - gauge mediated SUSY breaking
  - backgrounds
    - DY, QCD
  - $m(\chi_0^1)$ > 80 GeV @ 95% c.l.
    - limits better than Run I
    - best Tevatron limit to date
- R-parity Violating SUSY in trielectrons
  - should be 4 charged leptons in final state
    - allow for loss of one electron
  - 118 pb-1
  - 3 evts obs, 2.8 ± 1.4 expected BG
  - $m_{1/2}$ > 150 GeV



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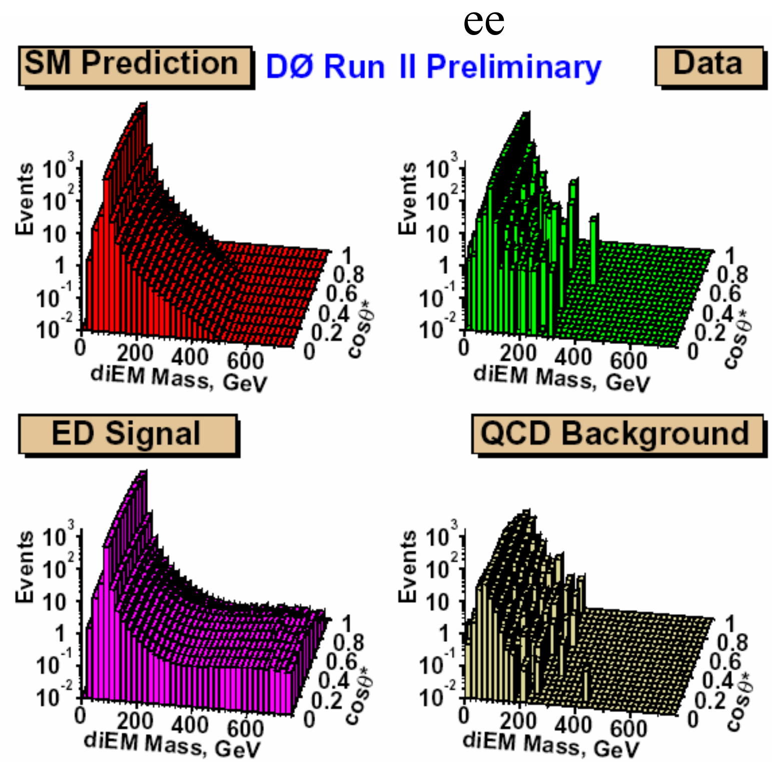
Large Extra Dimensions

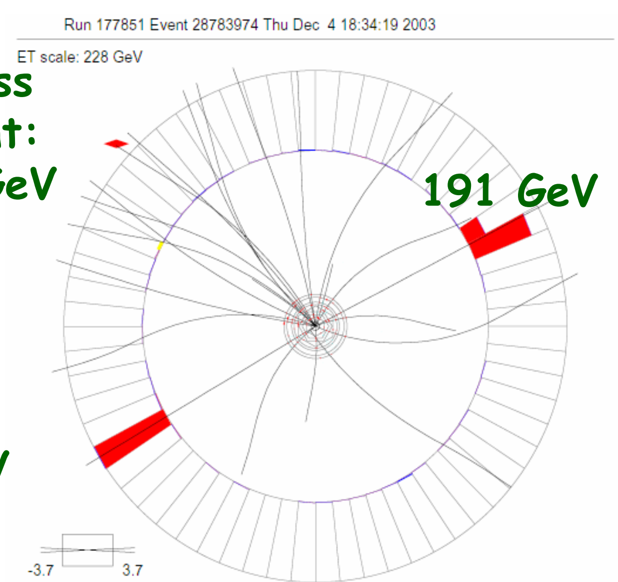
The mediation by the Kaluza-Klein gravitons will lead to modification of both dilepton and diphoton event topology

$$\frac{d^2\sigma}{dMd\cos\theta^*} = f_{SM}(M,\cos\theta^*) + f_{\text{int}}(M,\cos\theta^*)\eta + f_{KK}(M,\cos\theta^*)\eta^2$$

where $\eta = \dfrac{F}{M_S^4}$

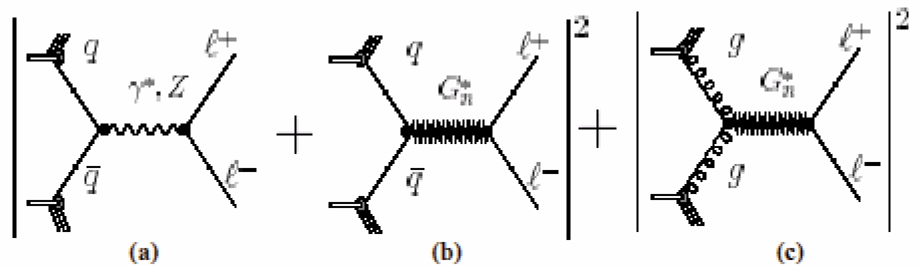


highest mass DY ee event: Mee=466 GeV



191 GeV

234 GeV



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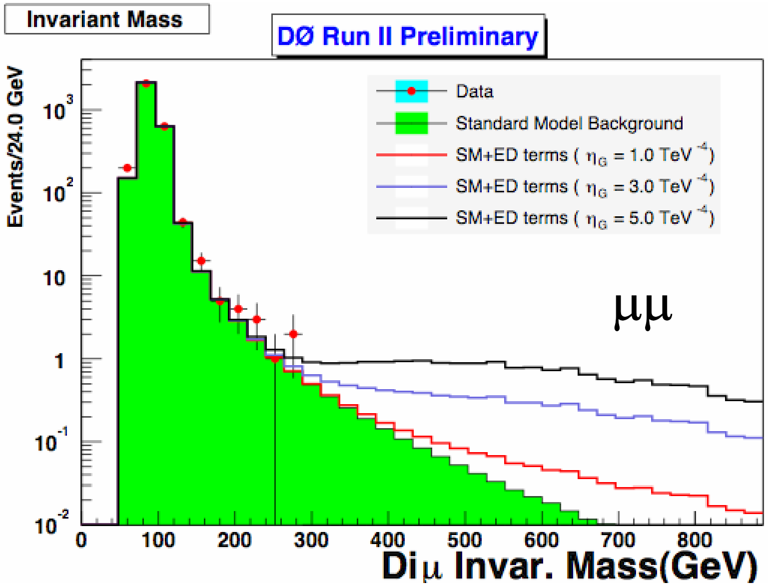
Large Extra Dimensions

- $\mu\mu$: 100 pb^{-1}
  - 2D fit in $M_{//}$ vs. $\cos(\theta^*)$
  - M_S(GRW) > 0.88 TeV @ 95% c.l.
- ee/$\gamma\gamma$ 128 pb^{-1}
  - backgrounds
    - SM: DY, $\gamma\gamma$; fake '*e*': QCD and direct γ
  - M_S(GRW) > 1.28 TeV @ 95% c.l.
    - more stringent than Run1
  - combined with Run I: 1.37 TeV



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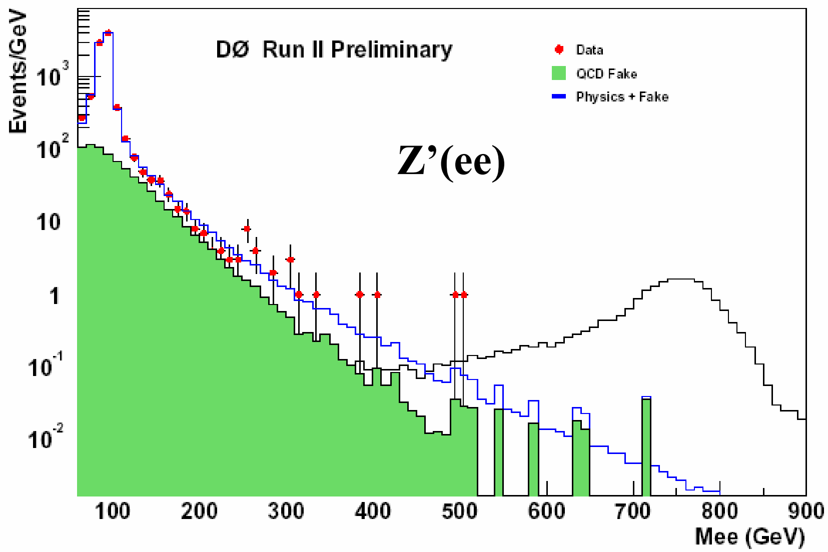
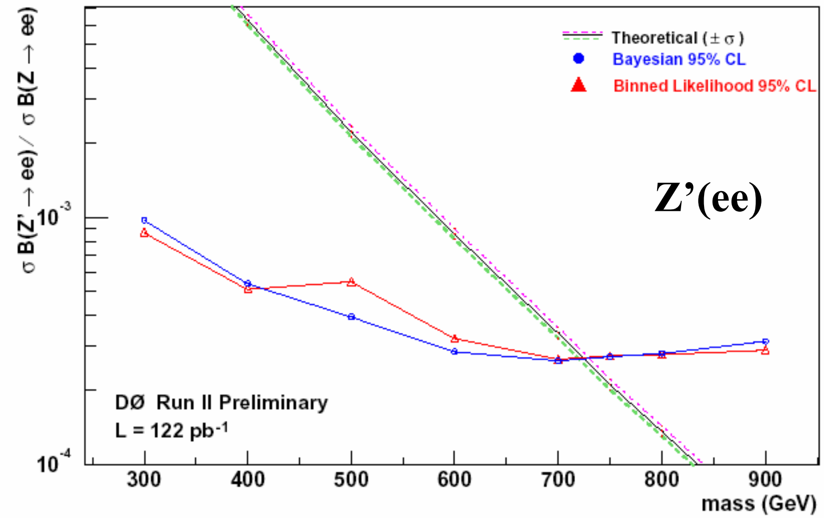
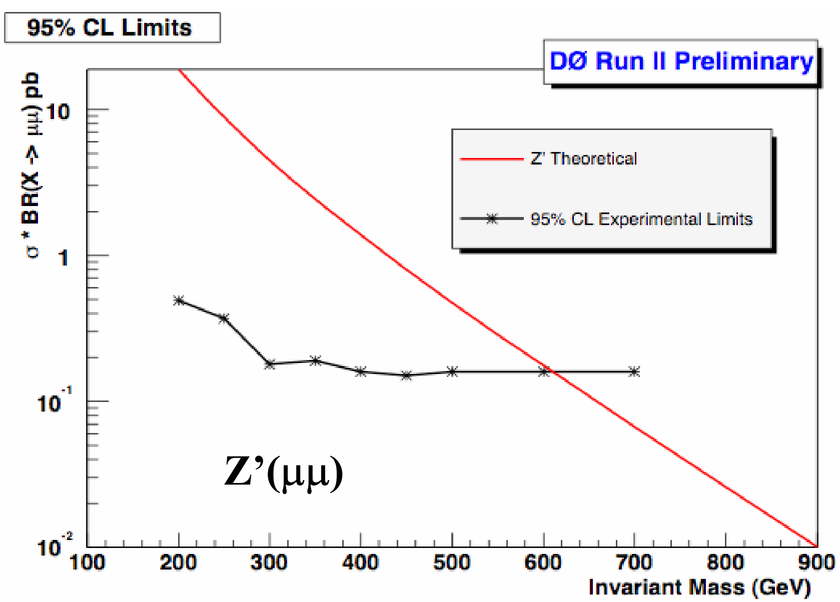
Z' Searches



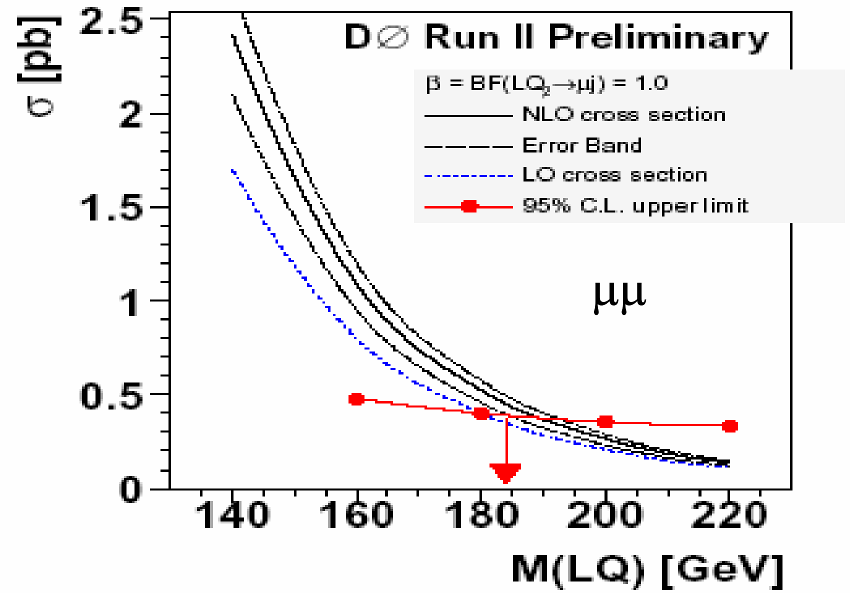


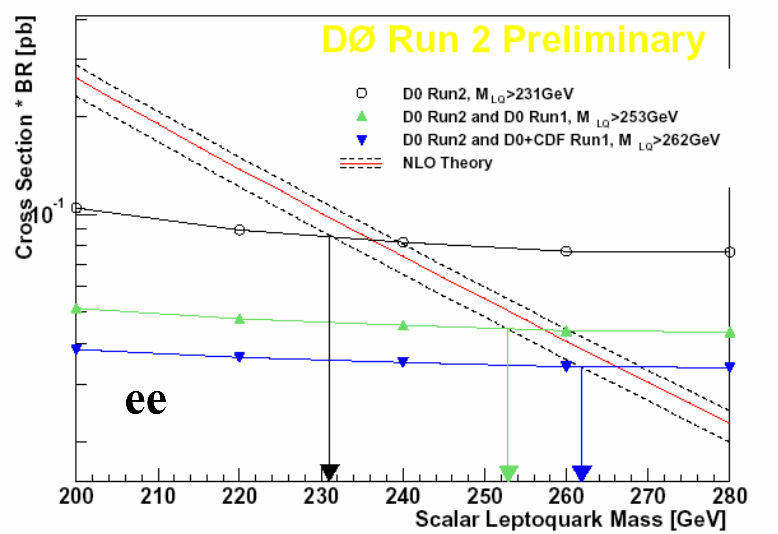


- $Z' \rightarrow ee$
  - $122\ pb^{-1}$
  - $M_{Z'} > 719$ GeV @ 95% c.l.
  - more sensitive than Run I
- $Z' \rightarrow \mu\mu$
  - $100\ pb^{-1}$
  - $M_{Z'} > 620$ GeV @ 95% c.l.

Leptoquark Searches

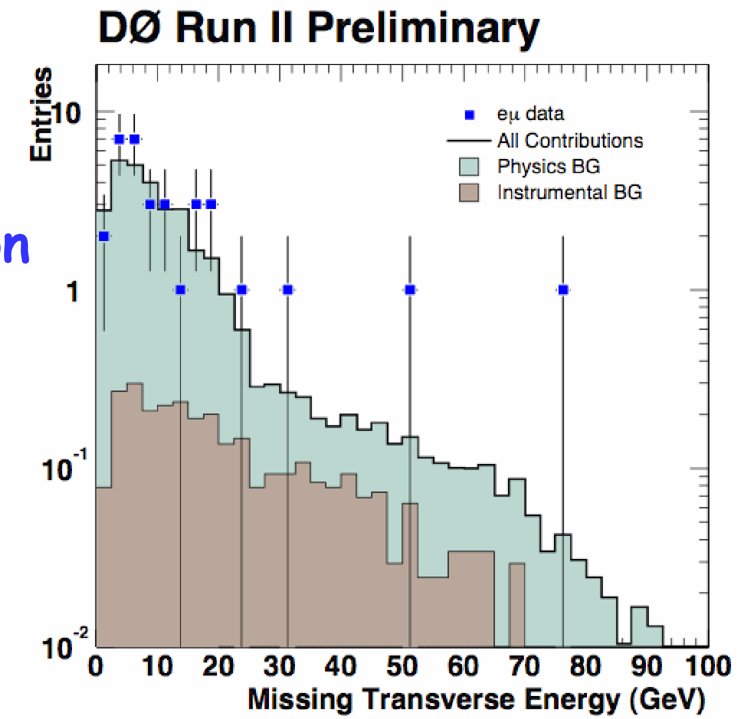
- $\mu^+ q\, \mu^- q'$ — 90 pb^{-1}
  - backgrounds DY, ttbar, WW
    - instrum. < 3% of high mass dimuon sample
  - $M_{LQ}(\beta=1)$ > 184 GeV
- $e\, q\, \nu\, q'$ — 121 pb^{-1}
  - backgrounds: W+2j, γ+2j, top
  - 3 events obs, 4.24 ± 1.0 expected
  - assume BR 0.5, M_{LQ} > 159 GeV
- $e^+ q\, e^- q'$ — 135 pb^{-1}
  - backgrounds DY, ttbar, QCD multijet with elec. fakes
  - cross section < 0.086 pb
    - $M_{LQ}(\beta=1)$ > 231 GeV
      - with Run1, get 253 GeV
      - most stringent limit to date

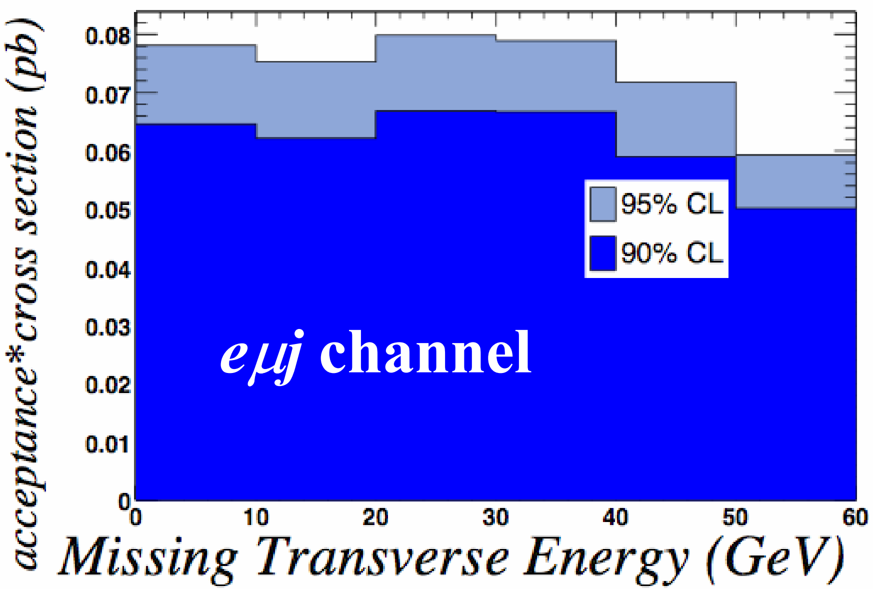


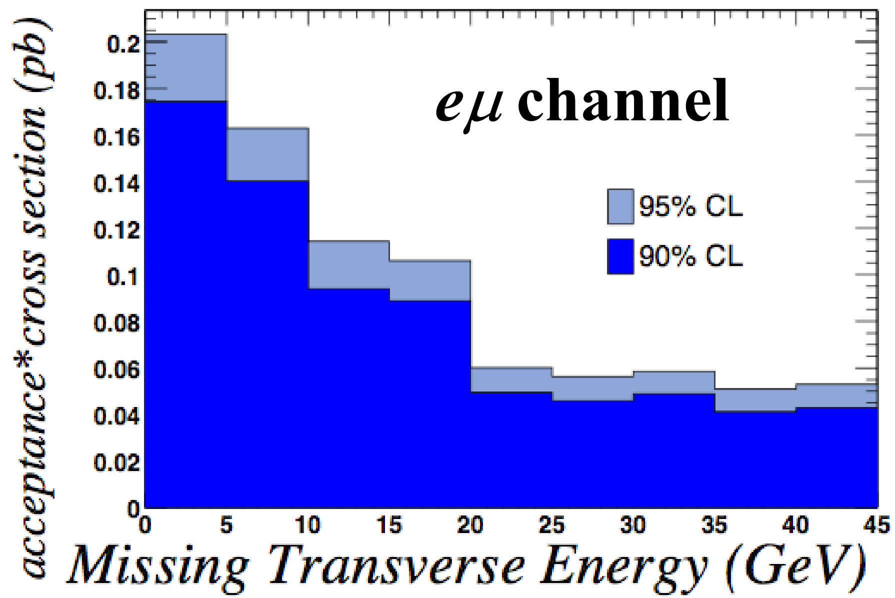


General $e\mu$ Search

- model independent limit on production of new physics (*a la* Sleuth)
- 98 pb^{-1}
- background
  - SM: $Z\tau\tau$, WW, ttbar, fake isolated leptons
  - $e\mu$: 1.8 ± 0.1 expected, 2 obs.
  - $e\mu j$: 0.1 evt expected, 0 obs.







Summary

- DØ has accumulated and is analyzing samples of ~200 pb^{-1} of data in Run II
- Preliminary results were shown on ~100 pb^{-1} representing studies in EW, top, QCD, heavy flavors, and searches
- We have exceeded or are exceeding the precision of Run 1
  - This trend, of course, will get much stronger in the next year
- We are able to use and test much theoretical work, but anticipate need for more theoretical contributions in several error
- We look forward with excitement to the next few years of new results and collaboration with our theoretical colleagues