Recent Results on Electroweak & Related Physics at DØ

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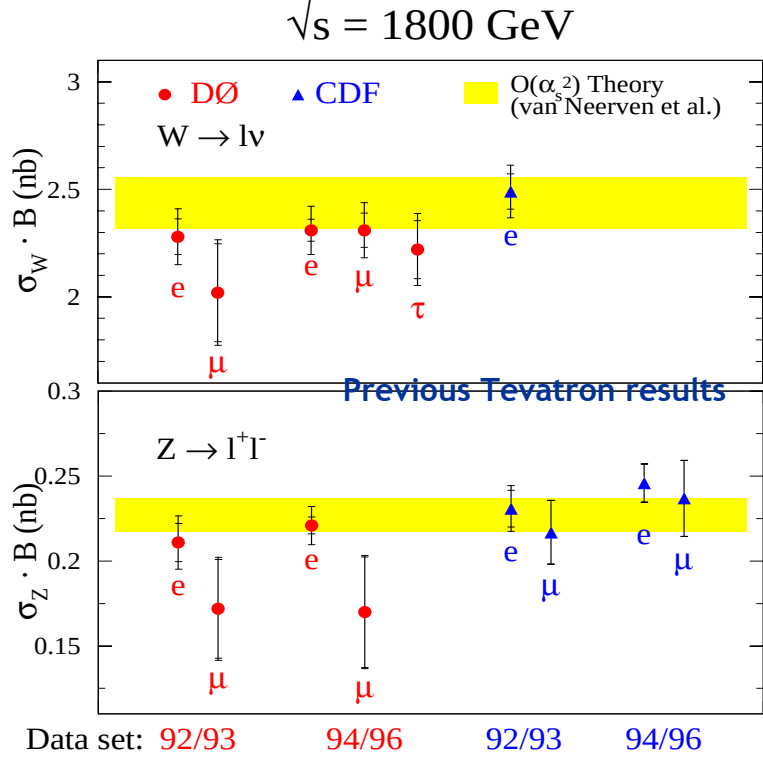
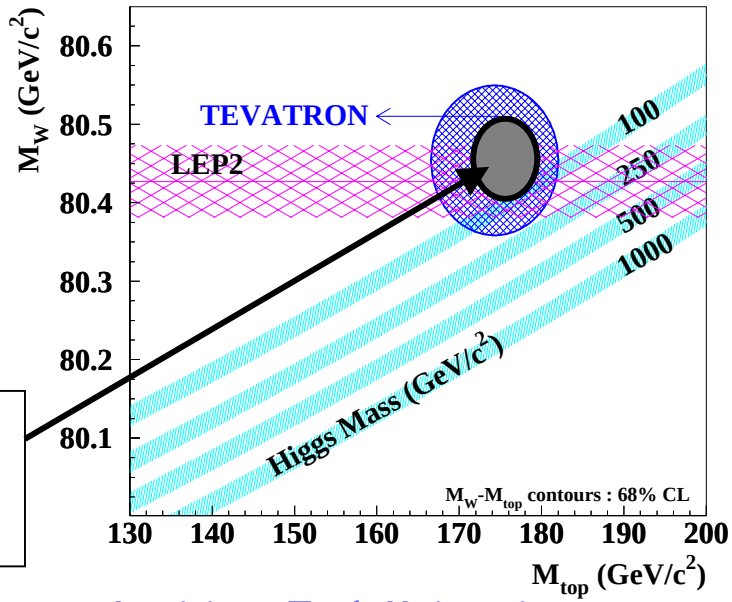
...on behalf of the DØ Collaboration

- Introduction & Motivation
- W/Z → muons
- W/Z → electrons
- Z' (ee) Search
- Top Quark Cross Section
- Conclusions

Motivation for Measuring W & Z Production

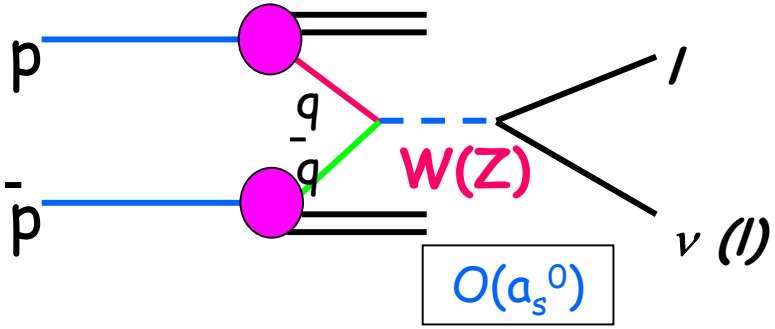
- Test of SM couplings
- Constrain proton PDFs
- Probe effects of NLO QCD corrections
- Better understanding of our Experiment
  - Efficiencies, Backgrounds, Luminosity
  - Use these signals to tune triggers & algorithms
- Improved luminosity measurement
  - With sufficiently small statistical & systematic uncertainties
  - Normalize to other measurements
- Preliminaries to other Run II goals
  - W boson mass
  - Precision EW measurements
  - Top Quark Studies
  - (W or Z) + Higgs





DØ Run IIa Prediction

W and Z Production Mechanics

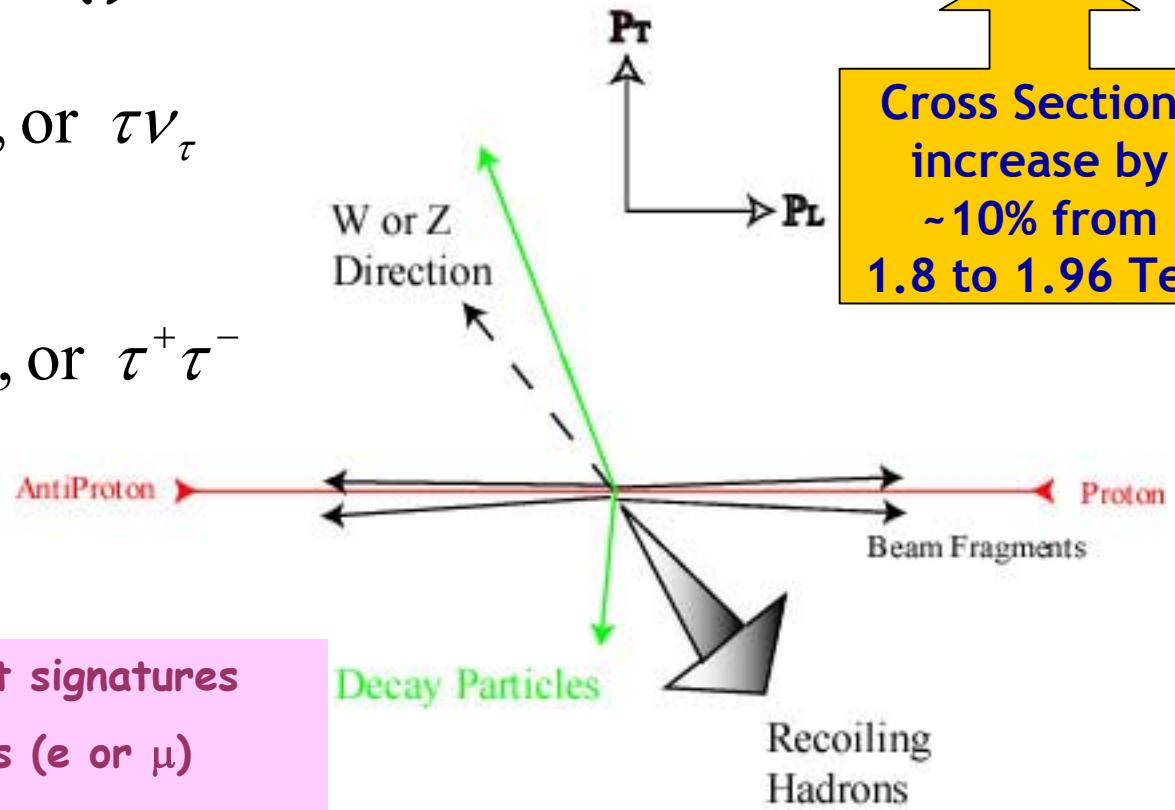


$O(\alpha_s^0)$

$$\sigma\left(p\bar{p} \to W + X \to \ell\nu + X\right) \approx 2\ \text{nb}$$
$$\sigma\left(p\bar{p} \to Z + X \to \ell\bar{\ell} + X\right) \approx 0.2\ \text{nb}$$

Cross Sections increase by ~10% from 1.8 to 1.96 TeV

$$W^{\pm} \xrightarrow{10.6\%} e\nu_e, \mu\nu_\mu, \text{or } \tau\nu_\tau$$
$$\xrightarrow{68.5\%} q\bar{q}'$$
$$Z^0 \xrightarrow{3.4\%} e^+e^-, \mu^+\mu^-, \text{or } \tau^+\tau^-$$
$$\xrightarrow{20.0\%} \nu\bar{\nu}$$
$$\xrightarrow{69.9\%} q\bar{q}$$



Distinctive lepton decay event signatures

- High P_T isolated leptons (e or μ)
- One high P_T lepton + Missing E_T (W)
- Two high P_T leptons (Z)

$W \to l\nu \Rightarrow$ ~1 Hz @ $L = 2\times10^{32}$

W & Z Cross Sections: A Counting Experiment

$$\sigma \cdot B = \frac{N_{obs} - N_{bkg}}{A\varepsilon \int Ldt}$$

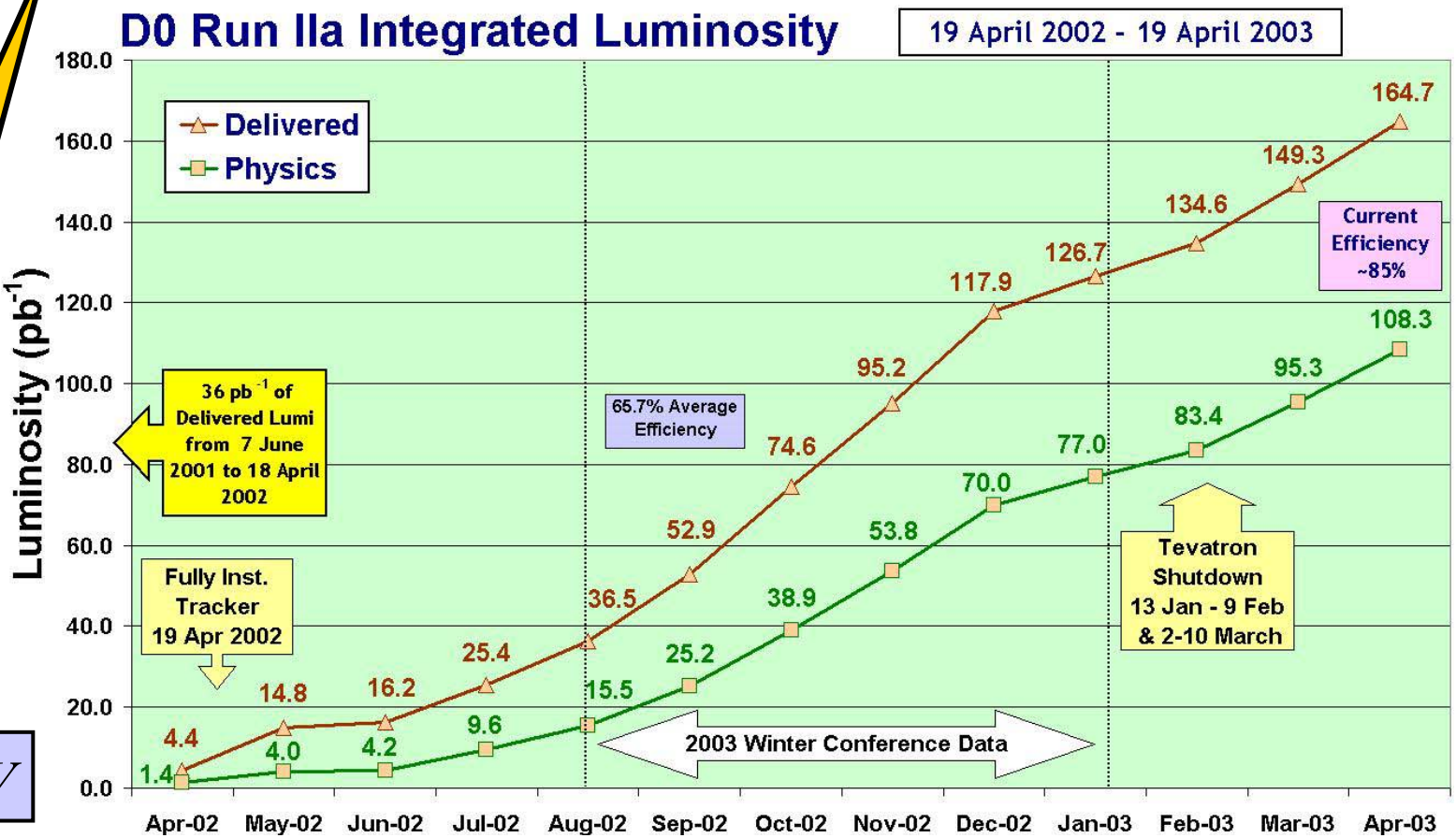
Backgrounds

Integrated Luminosity

Acceptance from Monte Carlo

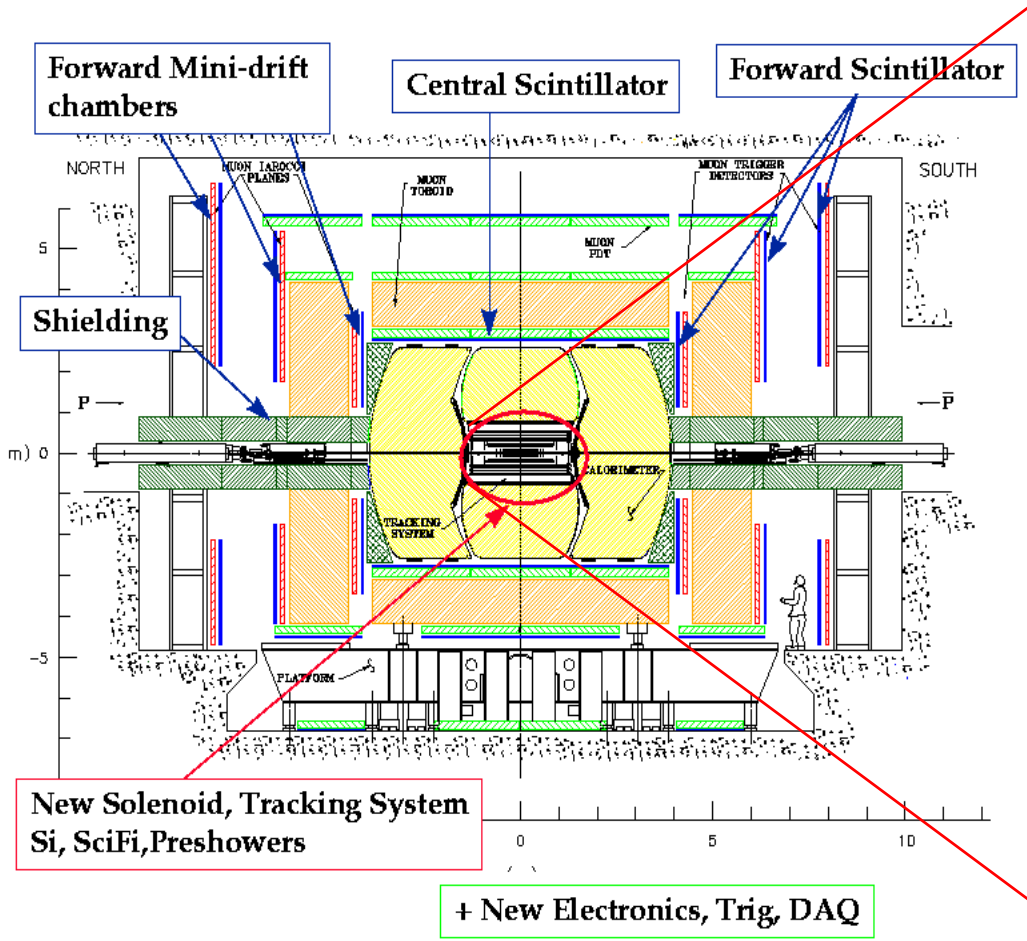
Efficiencies from data where possible

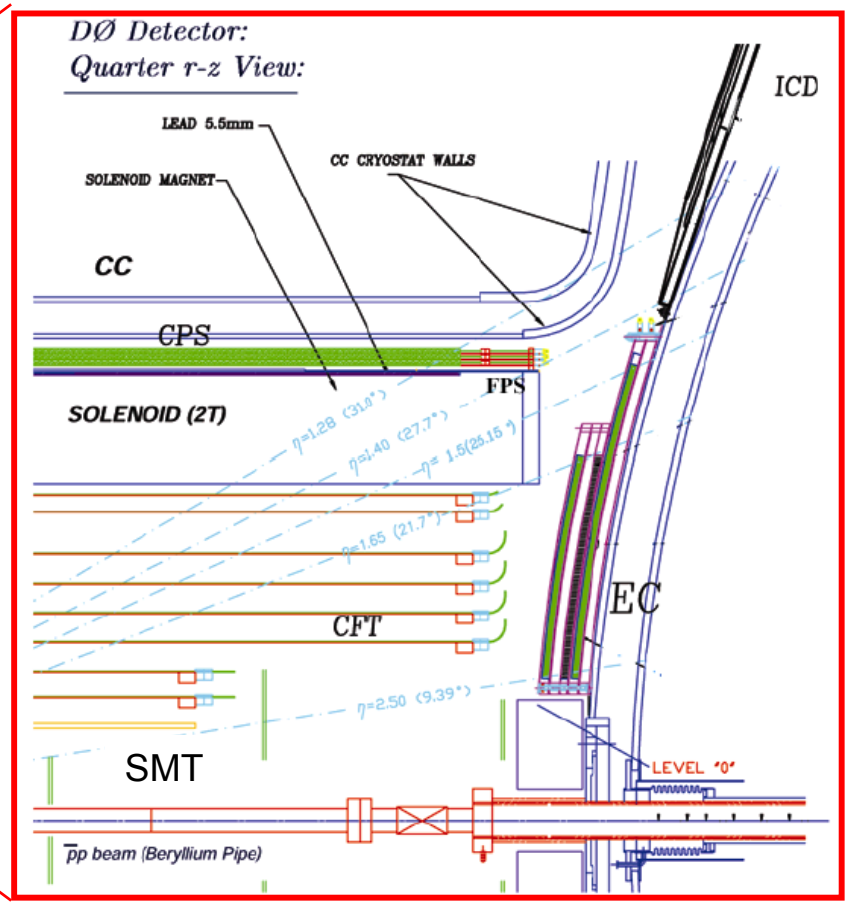
Measurements make use of data taken from mid-August '02 through mid-January '03



$$\sqrt{s} = 1.96\ TeV$$

The DØ Run II Detector

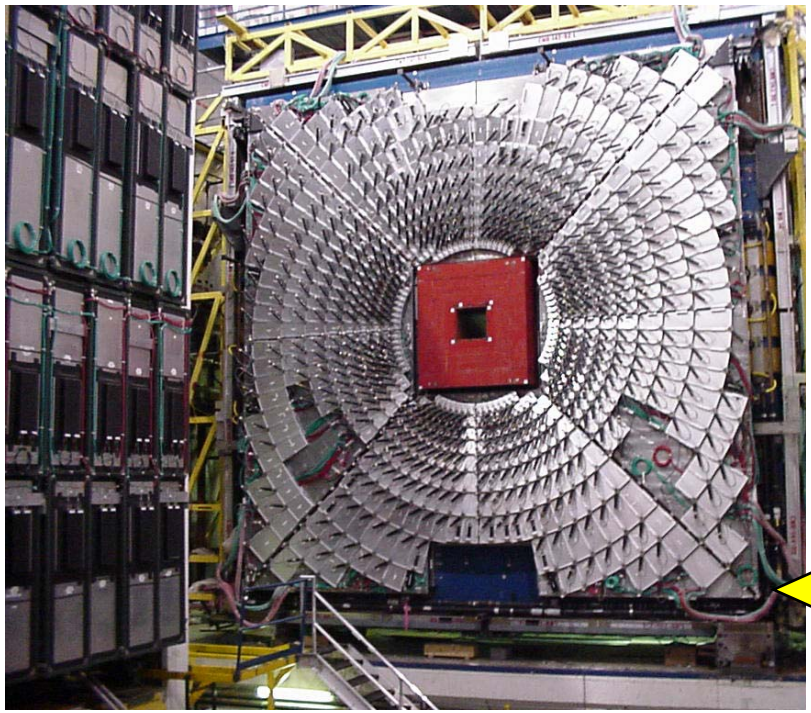


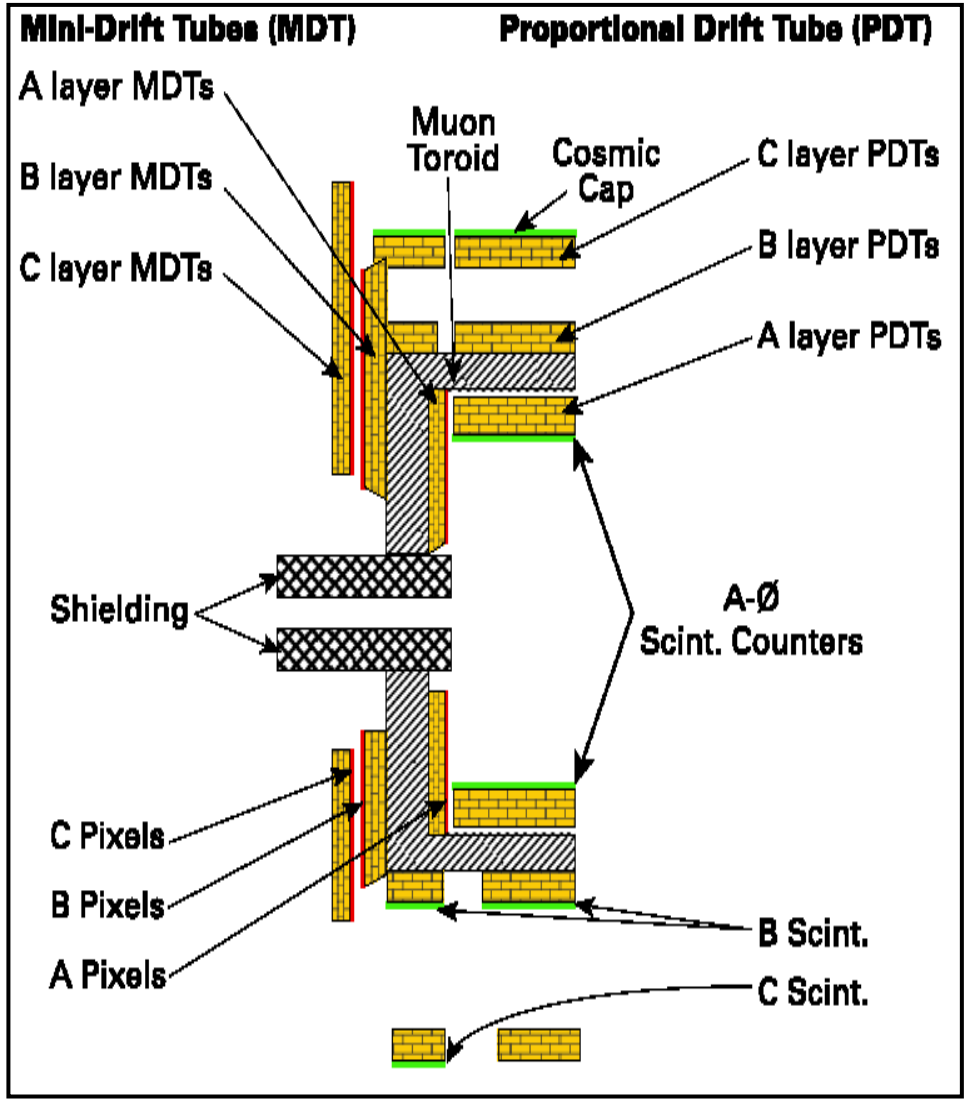


- Builds on the firm foundation of the Run I calorimeter & central muon system
- Added magnetic tracking, silicon, new forward muon system, new electronics
- Electroweak analyses make use of the full detector capabilities

The Muon Detector

- Two regions & Three layers of Scintillators and Drift Tubes
  - Central and Forward
  - A - inside toroid magnet
  - B & C - outside toroid magnet
- Muon rapidity coverage to ±2
- Shielding reduces backgrounds by 50-100x





Mini drift tube Plane and Pixels (10m × 10m)

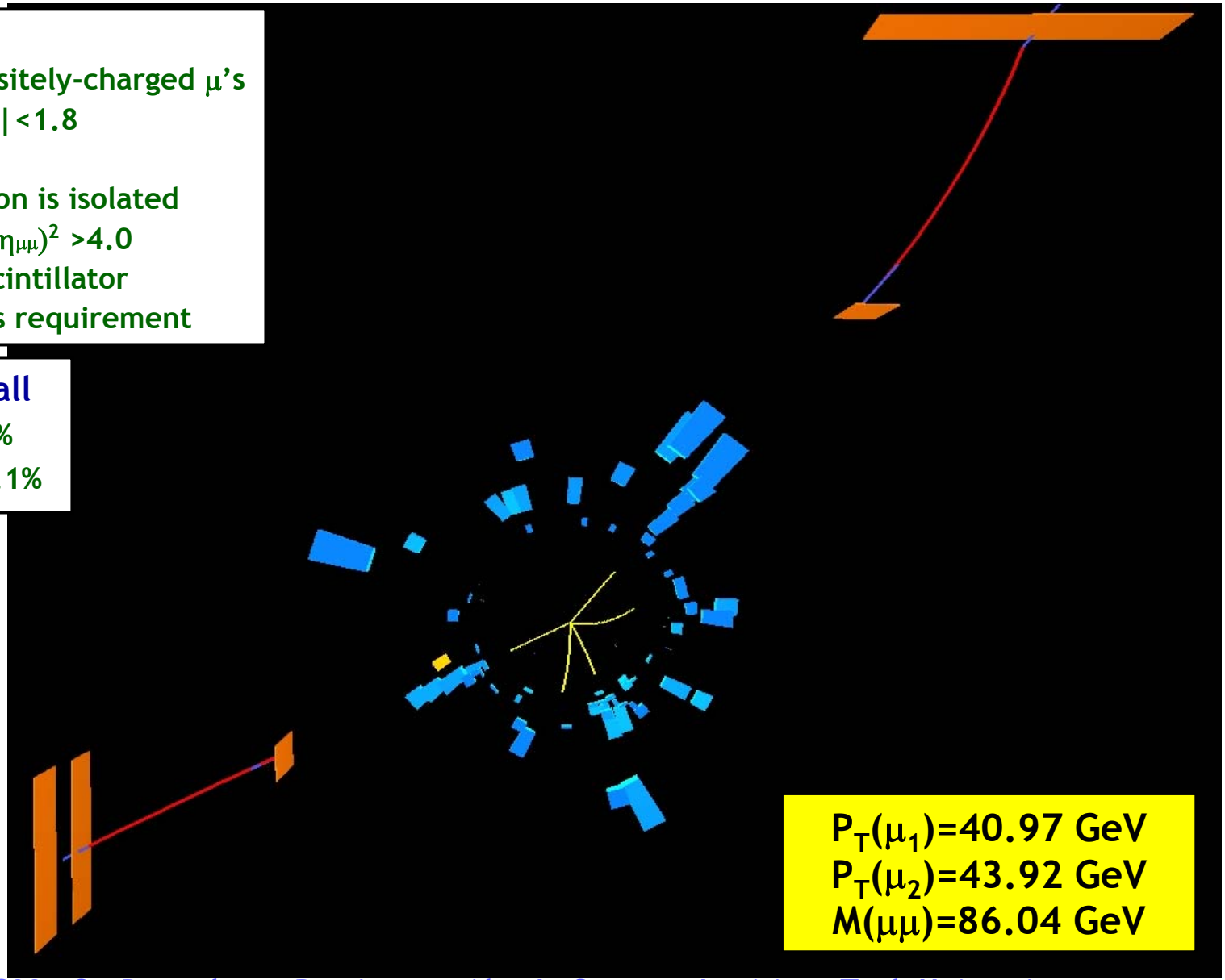
Z →μμ Event Selection

Event selection

- 2 tracked, oppositely-charged μ's
- p_T>15 GeV & $|\eta|$<1.8
- Di-muon trigger
- At least one muon is isolated
- $(\Delta R)^2=(\Delta\phi_{\mu\mu})^2+(\Delta\eta_{\mu\mu})^2$ >4.0
- $|\Delta t|$ < 9 ns in scintillator
- NO explicit mass requirement

Background is small

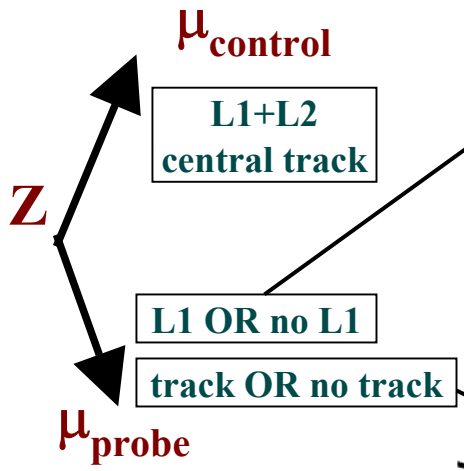
- Z→bbar is 1 ± 1%
- Z →ττ is 0.5 ± 0.1%

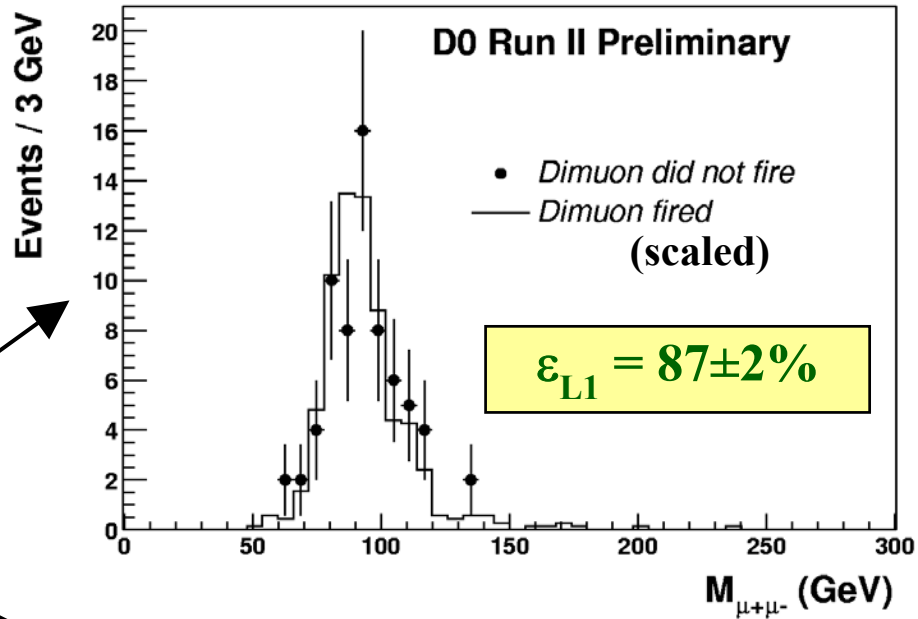


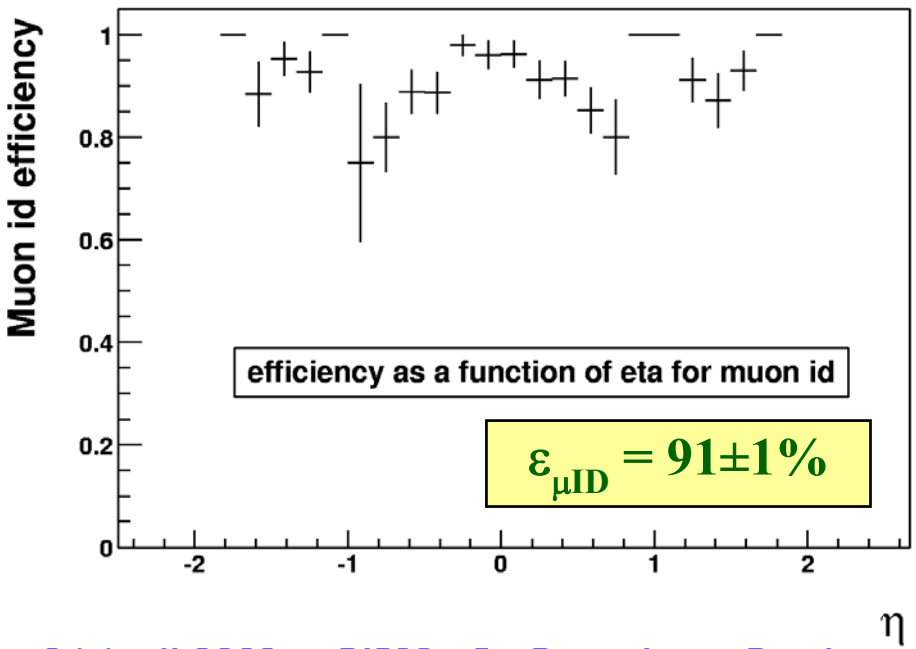
$P_T(\mu_1)$=40.97 GeV
$P_T(\mu_2)$=43.92 GeV
M(μμ)=86.04 GeV

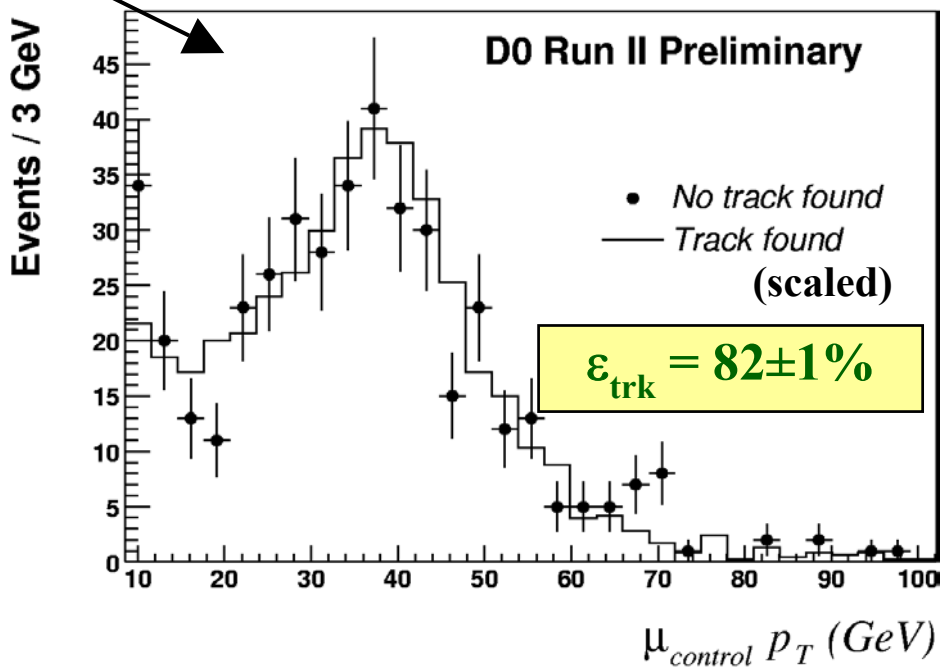
Z→μμ Efficiencies

- Acceptance from MC (40±1%)
- Efficiencies from data





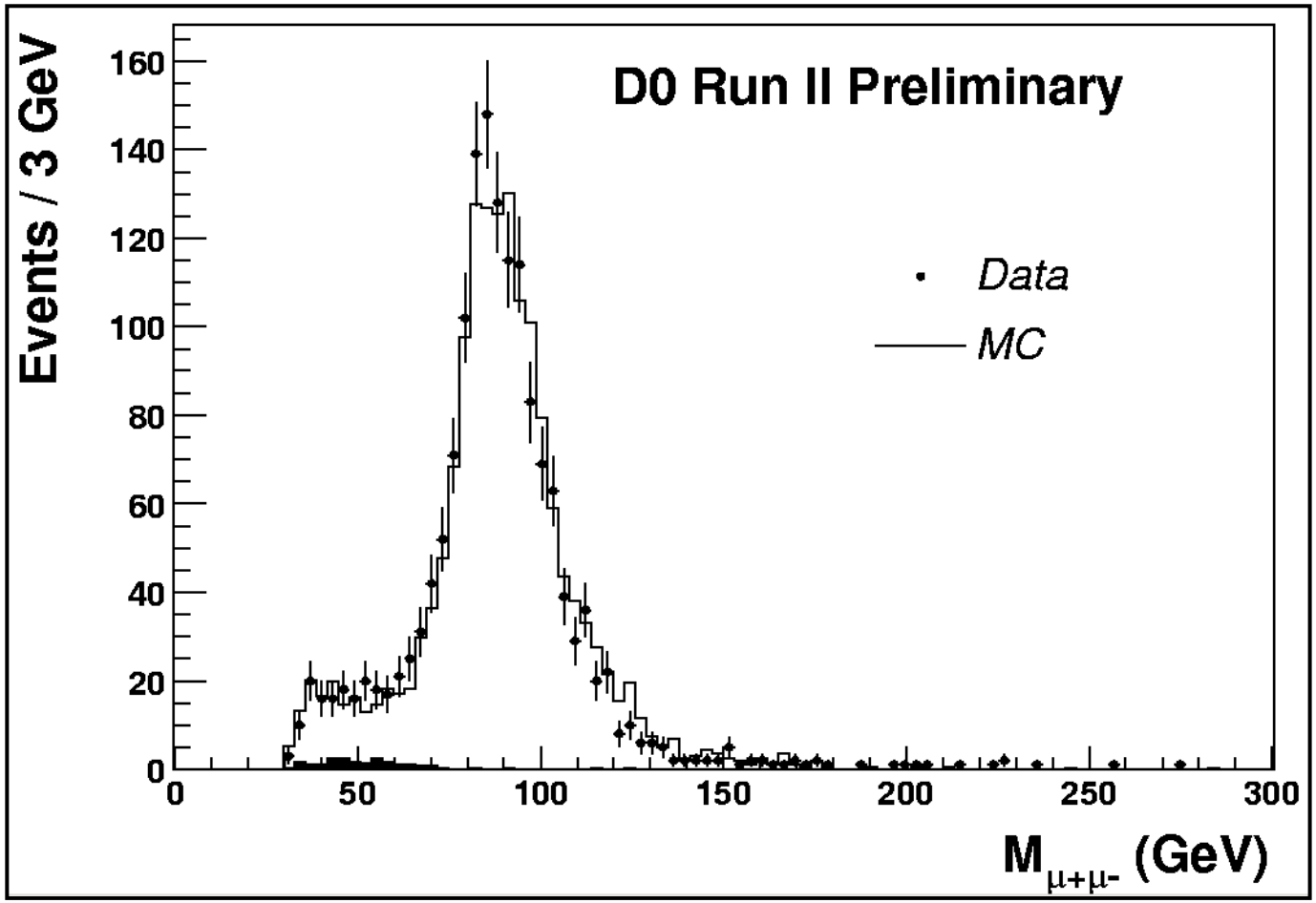




Z→μμ Cross Section

Drell-Yan Contribution

- Correct for 12±1% due to photon exchange and photon-Z interference determined from Pythia



1585 Candidates

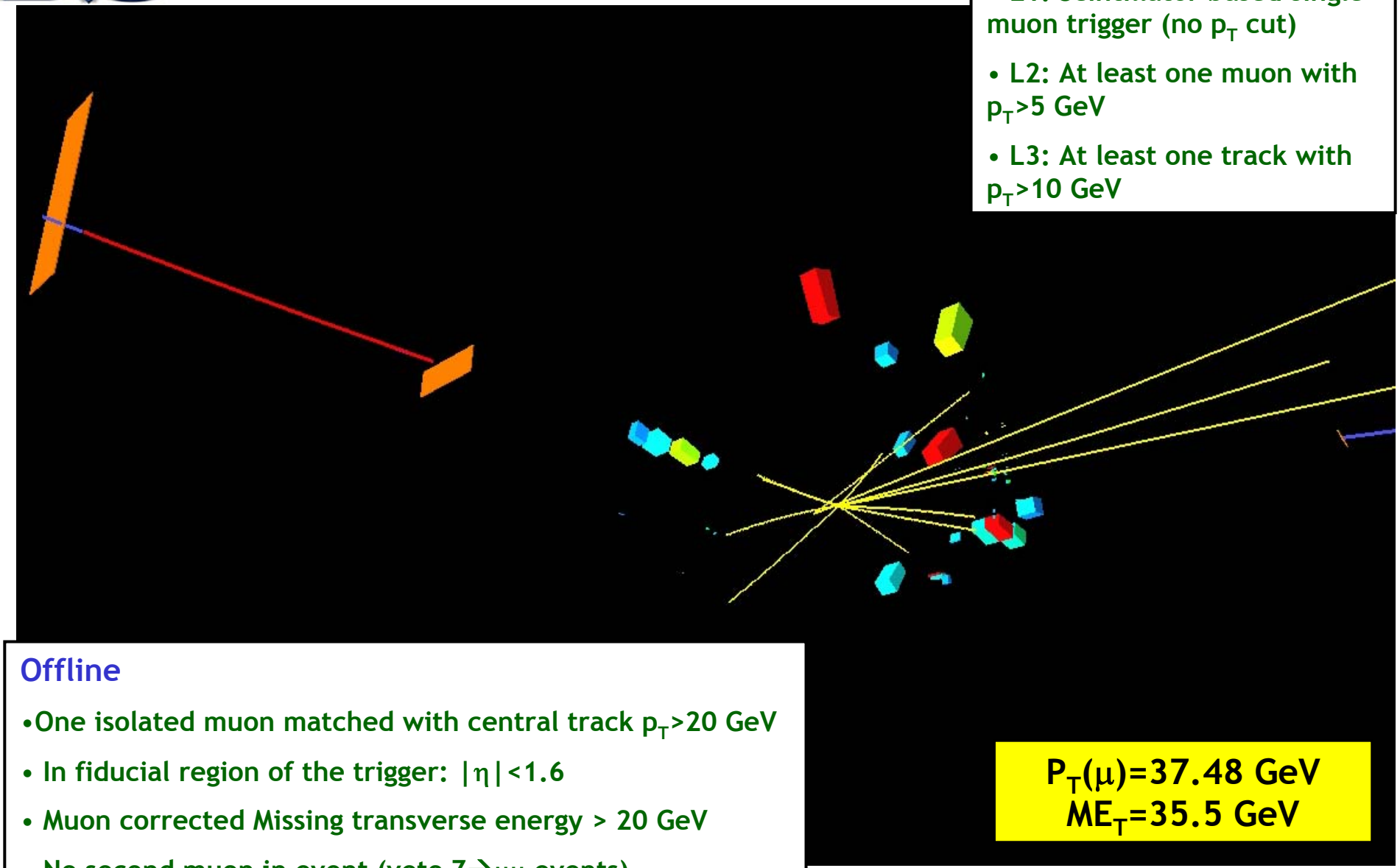
$\int Ldt = 32\ pb^{-1}$

$$\sigma(Z)\text{x B}(Z \to \mu\mu) = 264 \pm 7_{stat} \pm 17_{sys} \pm 26_{lum}\ pb$$

W→μν Event Selection

Trigger

- L1: Scintillator based single muon trigger (no p_T cut)
- L2: At least one muon with p_T>5 GeV
- L3: At least one track with p_T>10 GeV

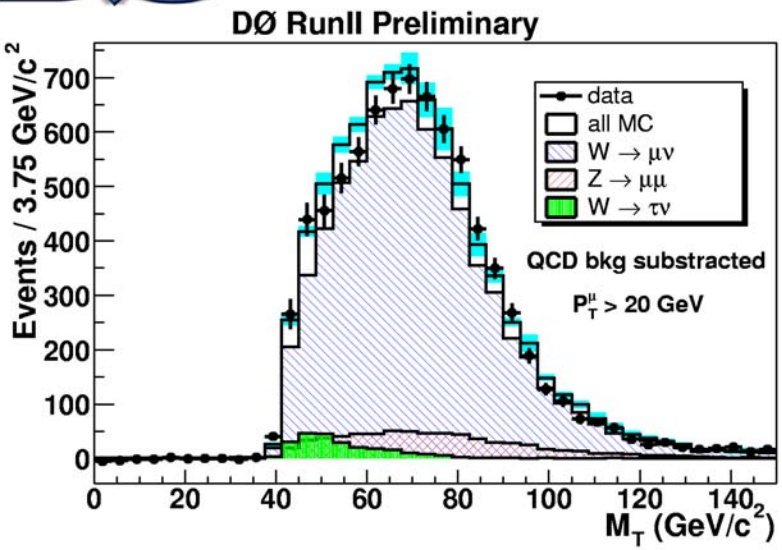


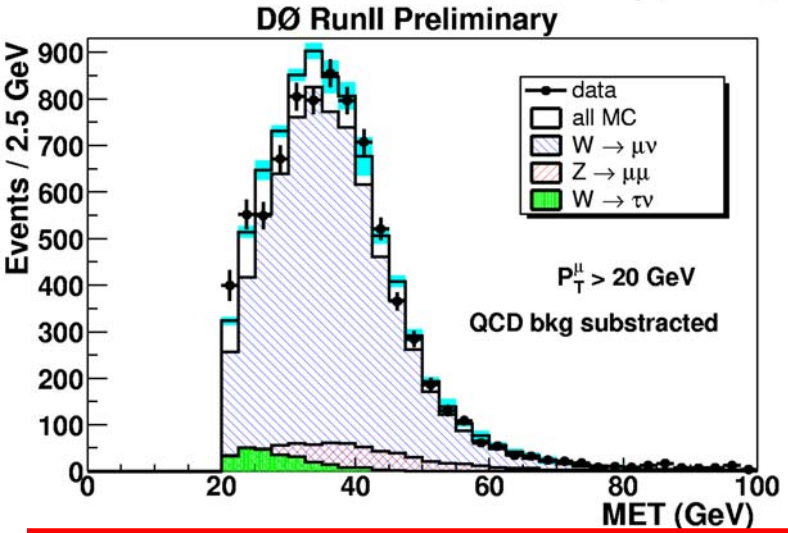
Offline

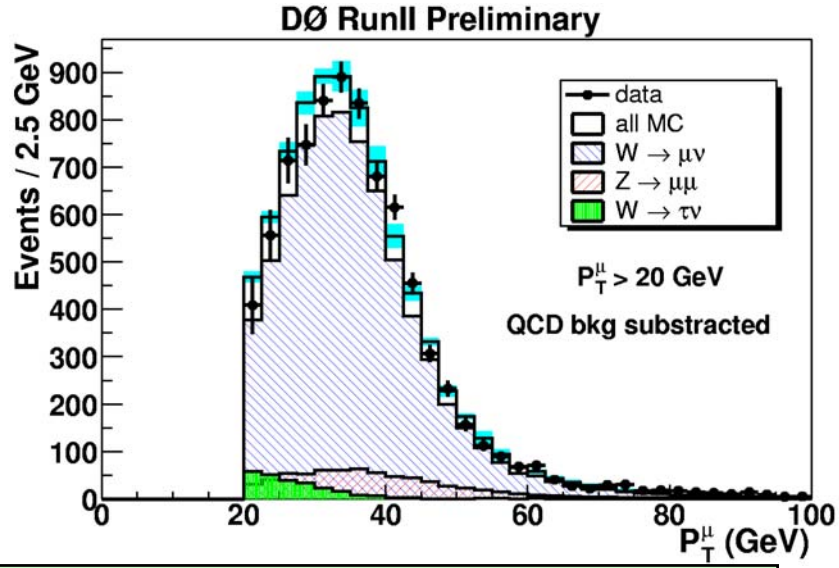
- One isolated muon matched with central track p_T>20 GeV
- In fiducial region of the trigger: $|\eta|$<1.6
- Muon corrected Missing transverse energy > 20 GeV
- No second muon in event (veto Z→μμ events)

$P_T(\mu)$=37.48 GeV
ME_T=35.5 GeV

W→μν Cross Section







Backgrounds

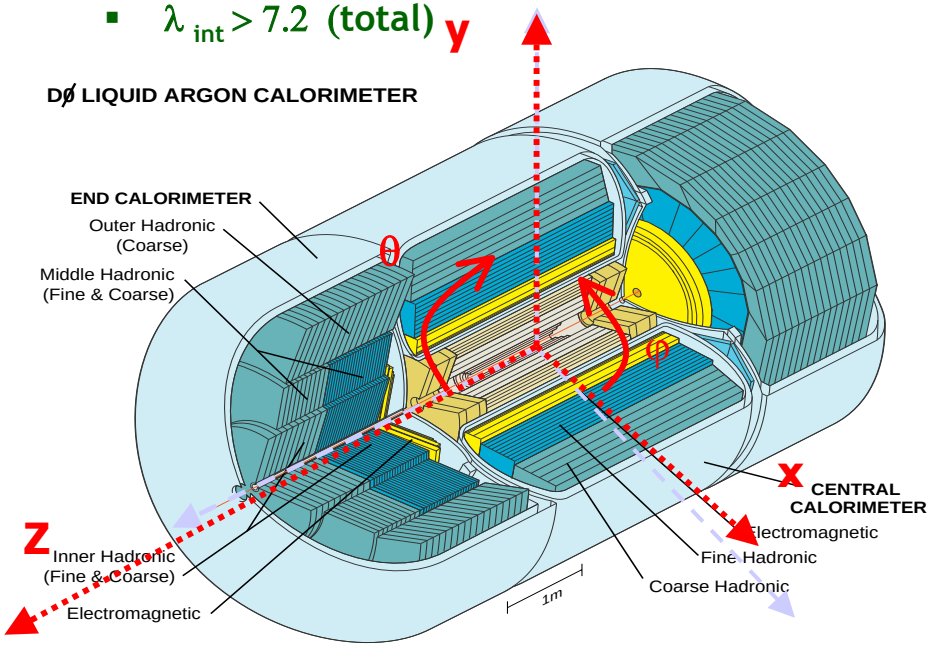
- Z→bb, b→μν where μ passes isolation cut
  - 5.8%, subtracted from above distributions
- Z→μμ: ~9%
- W→τν→μνν: 3.6%
- QCD estimated from data

7352 Candidates in $\int Ldt = 17\ pb^{-1}$

$$\sigma(W)\mathrm{x\ B}(W \to \mu\nu) = 3226 \pm 128_{stat} \pm 100_{sys} \pm 323_{lum}\ pb$$

The Calorimeter

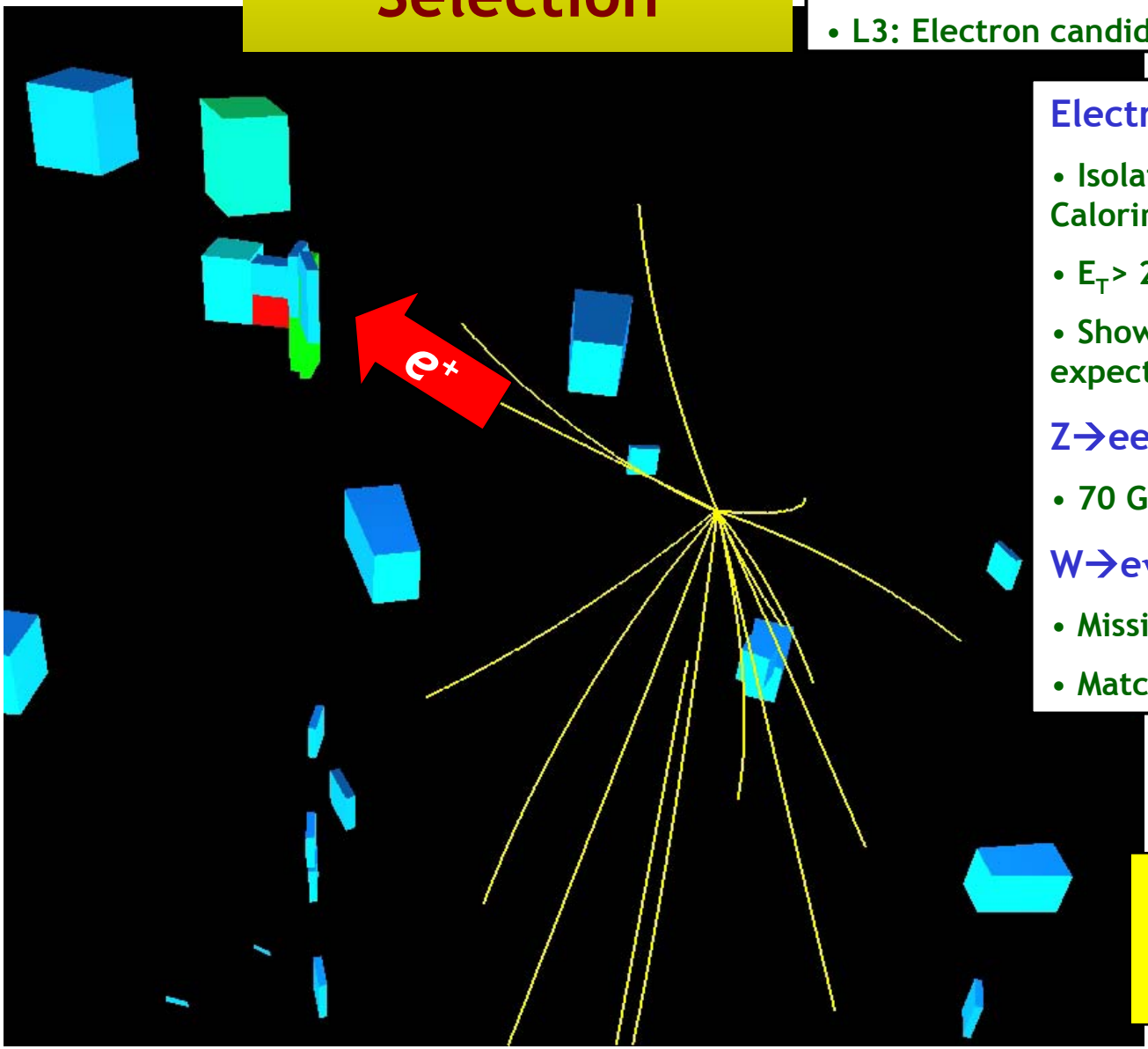
- Liquid argon sampling
  - Stable, uniform response, rad. hard
  - LAr purity important (< 0.7 ppm O_2 equivalent)
- Uranium absorber (Cu/Fe for coarse hadronic)
  - dense absorber hence can be compact
  - Nearly compensated EM and hadronic response
  - Linear response
- Hermetic with full coverage
  - $|\eta| < 4.2$ ($\theta \approx 2^o$)
  - $\lambda_{int} > 7.2$ (total)



W/Z→e Event Selection

Trigger:

- L1: 1 calorimeter tower > 10 GeV (or 2 > 5 GeV)
- L3: Electron candidate > 20 GeV, shower shape cut



Electrons

- Isolated EM Cluster in the Calorimeter
- E_T> 25 GeV with large EM fraction
- Shower shape consistent with MC expectation

Z→ee

- 70 GeV < m_{ee} < 110 GeV

W→eν

- Missing transverse energy > 25 GeV
- Matched with central tracks

$P_T(e)$=40.5 GeV
ME_T=43.2 GeV
$M_T(W)$=83.7 GeV

Z→ee Cross Section

Efficiencies per electron

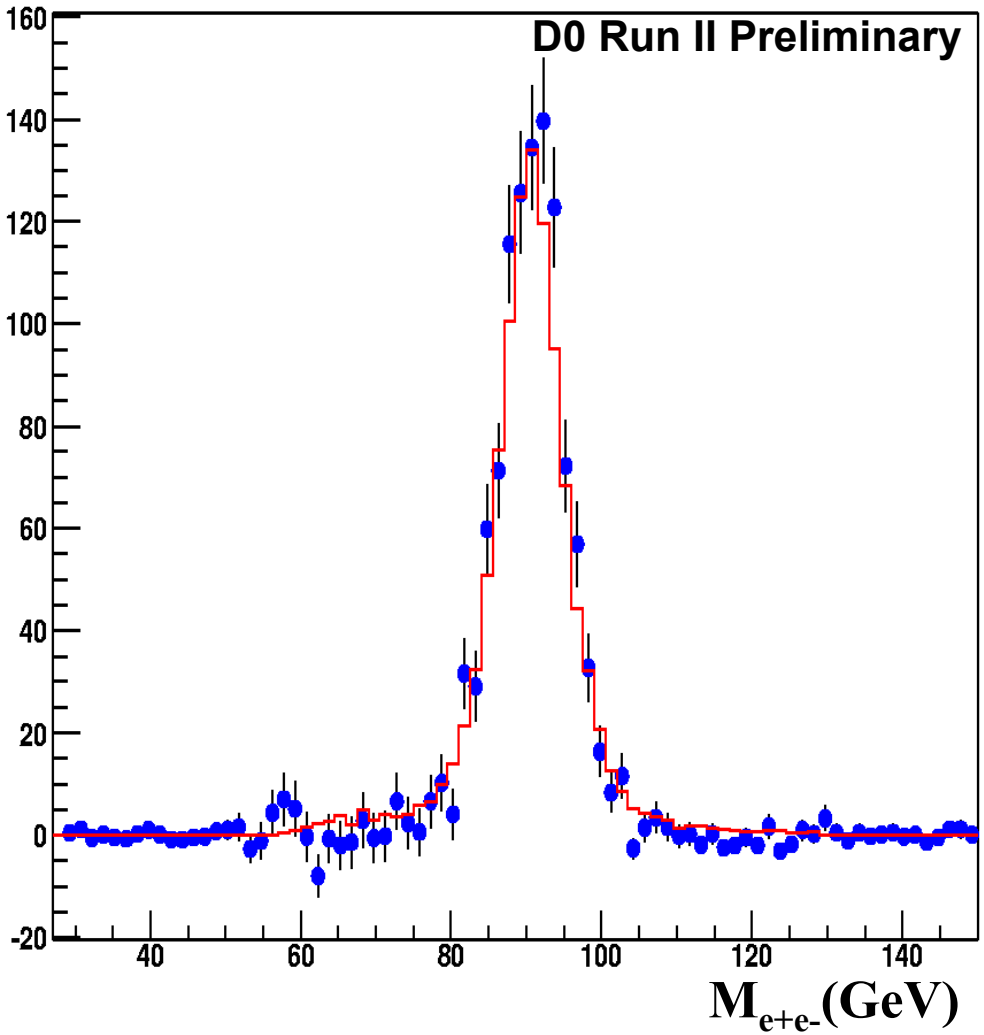
- Trigger: 98±2%
- EMF, isolation: ~100%
- Shower shape: 86±1%
- Track Matching: 73±2%

Drell-Yan Contribution

- Small effect (1.7%) in the mass window of $70 < m_{ee} < 110$ GeV

QCD Background

- Determined from data by fitting signal and background shape



1139 Candidates in $\int Ldt = 42\ pb^{-1}$

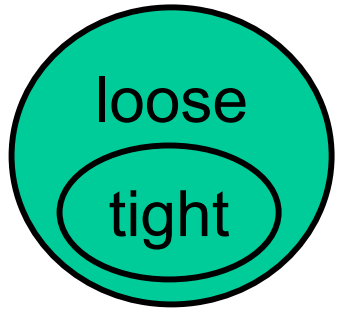
$$\sigma(Z)\mathrm{x\ B}(Z \to ee) = 294 \pm 11_{stat} \pm 8_{sys} \pm 29_{lum}\ pb$$

W→eν Backgrounds

- Dominant background from QCD multijet events
- Estimated from data

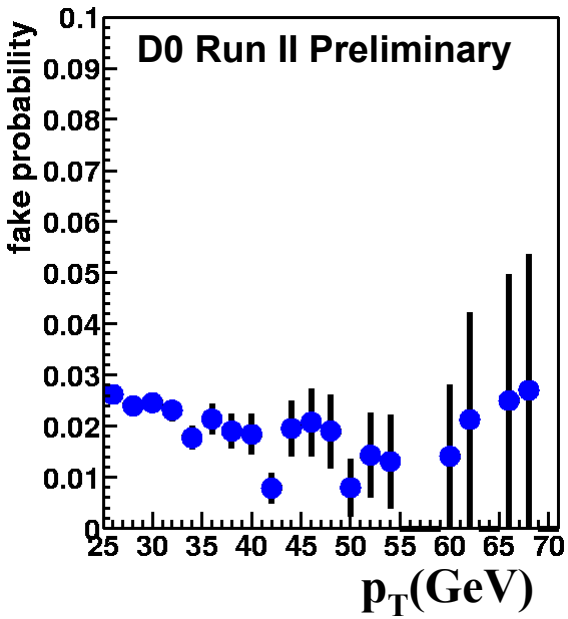
$$N_{loose} = N_W + N_b$$
$$N_{tight} = N_W\varepsilon_{trk} + N_b\varepsilon_f$$

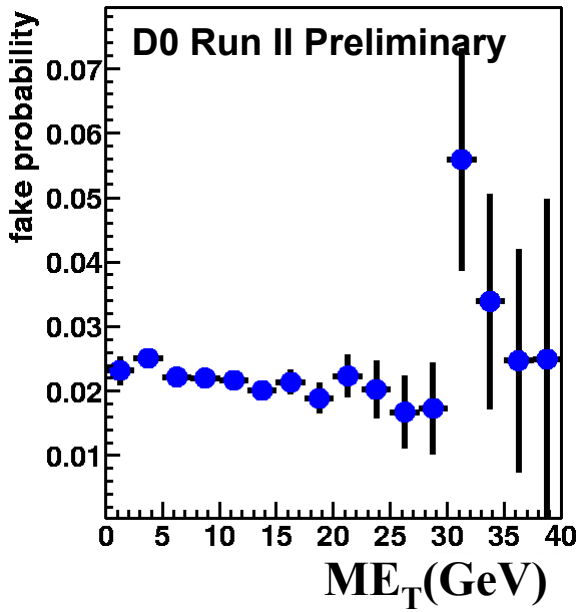
} Solve for N_W



tight = loose + track match

From QCD dijet sample



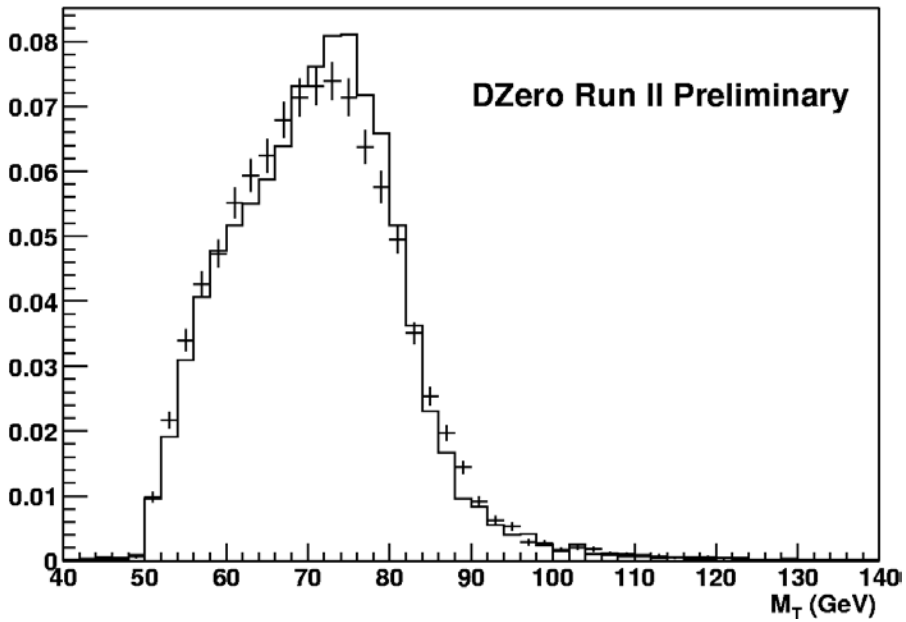


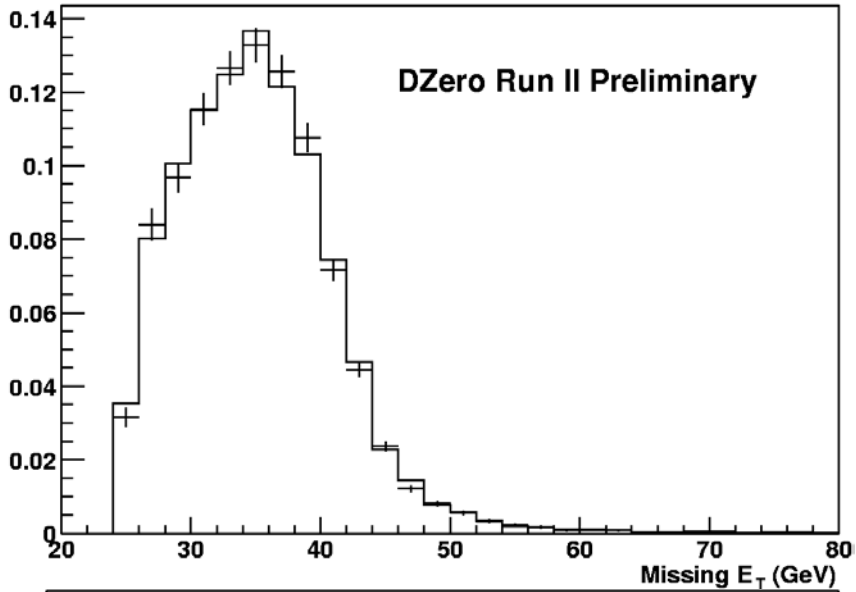
Other backgrounds:

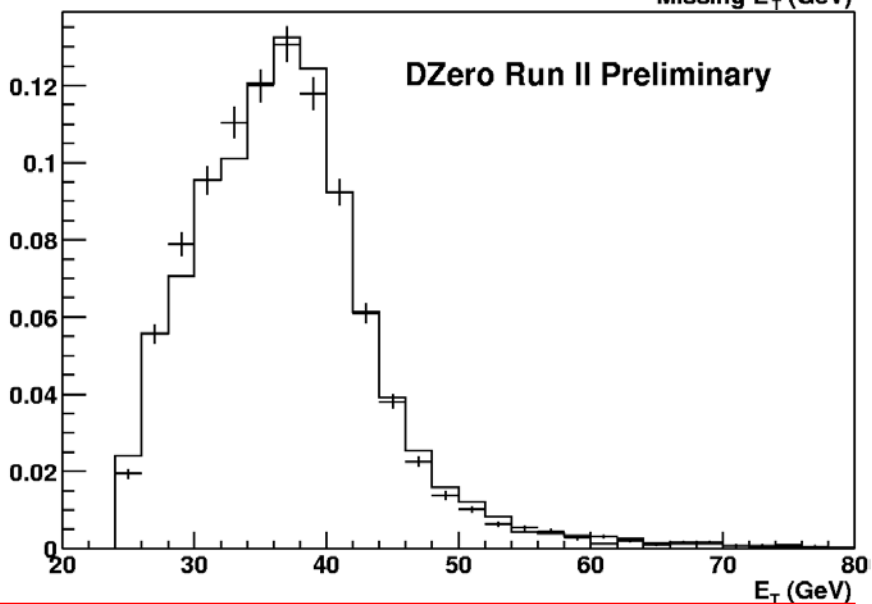
- W→τν→eνν (1.5 %, MC)
- Z→ee (very small)

W→eν Cross Section

Background subtracted distributions compared to MC Pythia



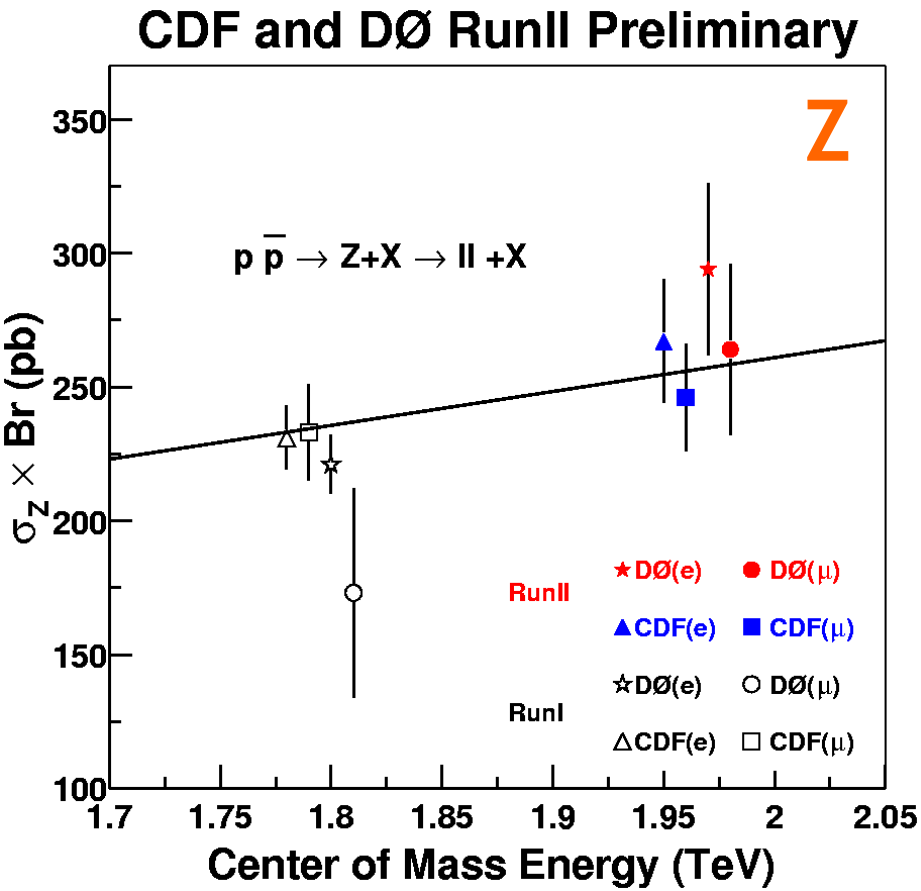


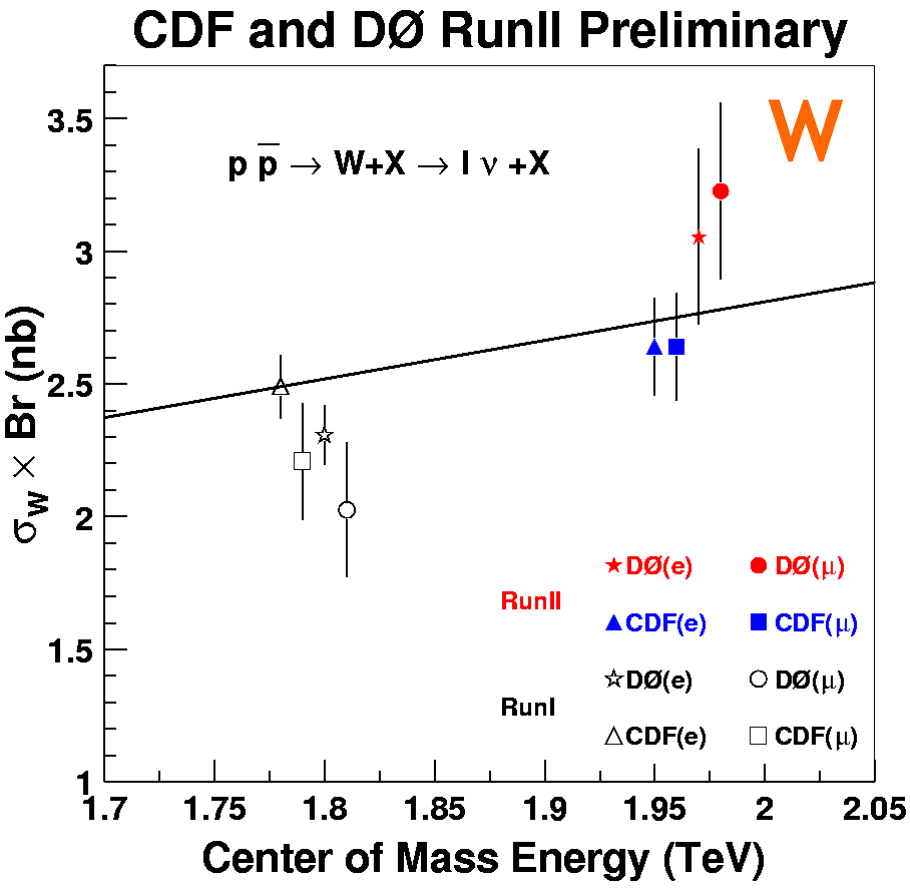


27370 Candidates in $\int Ldt = 42\ pb^{-1}$

$$\sigma(W)\mathrm{x\ B}(W \to e\nu) = 3054 \pm 100_{stat} \pm 86_{sys} \pm 305_{lum}\ pb$$

Results





C. R. Hamberg, W.L. van Neerven and T. Matsuura, Nucl. Phys. B359 (1991) 343

CTEQ4M PDF

Direct Search for Z'→ee

- Search for Non-SM heavy particles that decay to lepton pairs
  - Assumes Z' couples as Z
- Previous Tevatron Run I Limit
  - $M_{Z'}$>690 GeV
- Event Selection
  - 2 isolated EM objects
    - $|\eta|<1.1$ or $1.5<|\eta|<2.5$
    - E_T>25 GeV
  - No track requirement necessary

mass (GeV)	expected	observed
150-200	125 ± 11	103
200-250	56 ± 6	52
250-350	47 ± 6	47
350-450	9.0 ± 1.3	10
450-550	1.8 ± 0.26	1
550-750	0.54 ± 0.08	0
750-1000	0.01 ± 0.001	0

4585 Candidates in $\int Ldt = 50.0\ pb^{-1}$

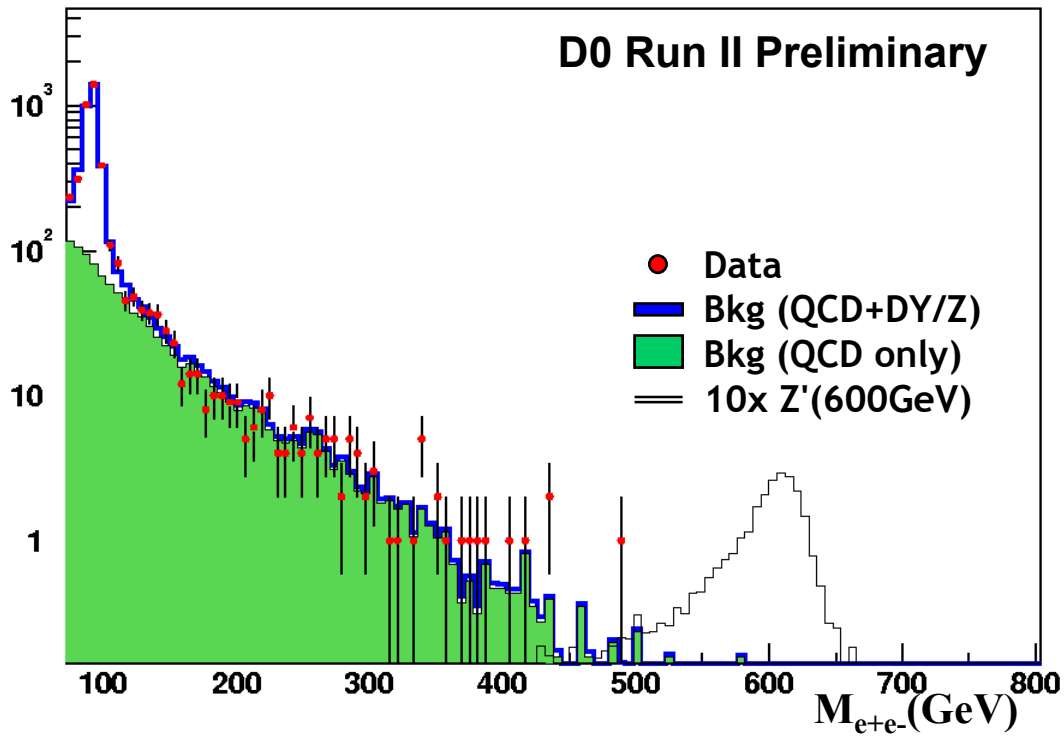
Backgrounds

Drell-Yan dominates M_{ee}<150 GeV

- Estimated from Pythia (CTEQ4L)

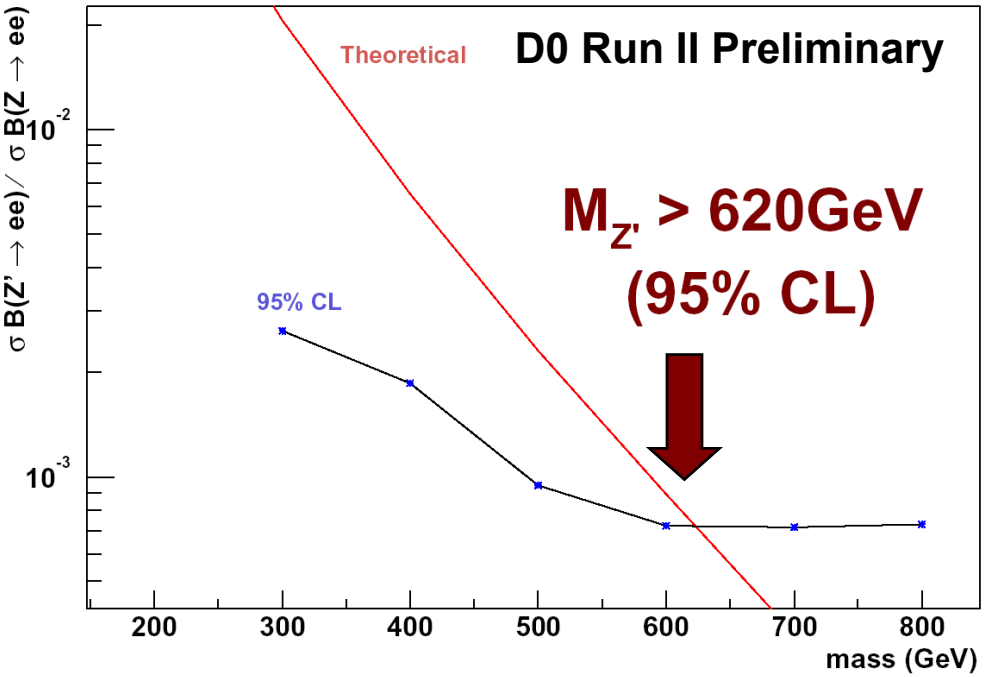
QCD dominates M_{ee}>150 GeV

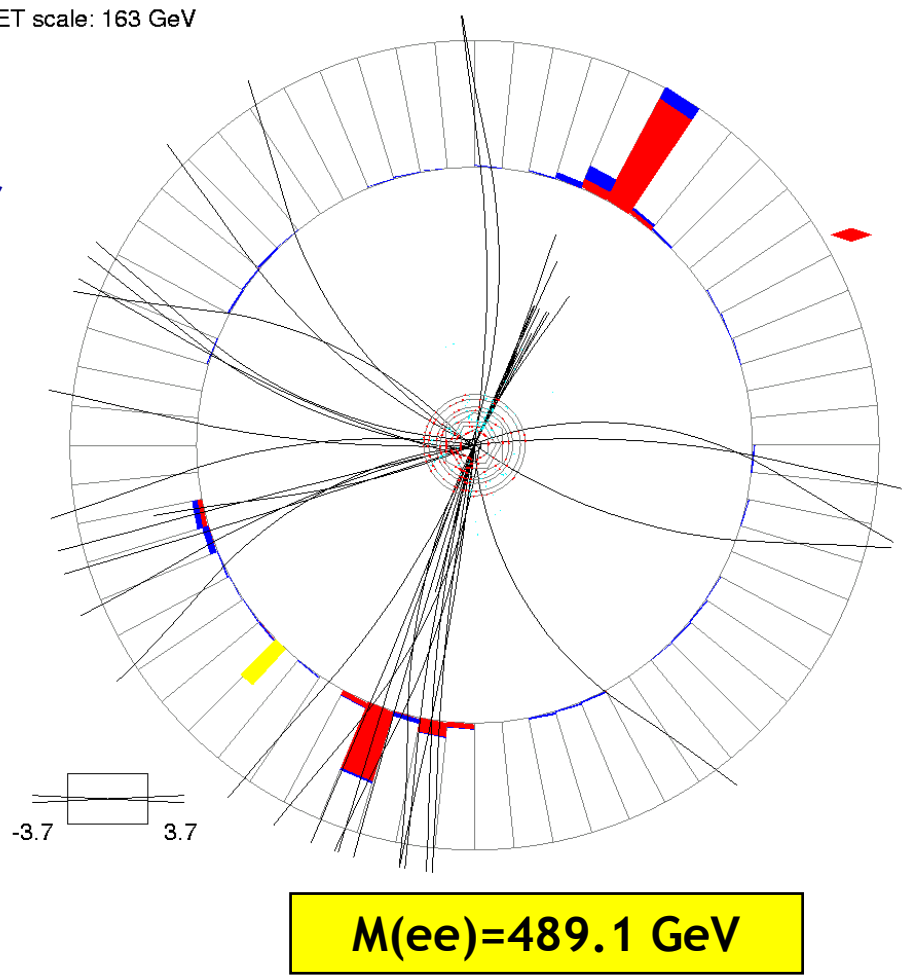
- Fake electrons from jets
- Real electrons from heavy flavor
- Estimated from data



Z' Search

- Form limit from the ratio of cross sections for $(\sigma B)_{Z'}/(\sigma B)_Z$ where many of the systematic errors in the efficiencies and luminosity measurements cancel
- Applied a binned likelihood approach with Poisson statistics
- Remaining Uncertainties
  - K-factor 5%
  - $A_{Z'}/A_Z$ & PDFs 2-3%





M(ee)=489.1 GeV

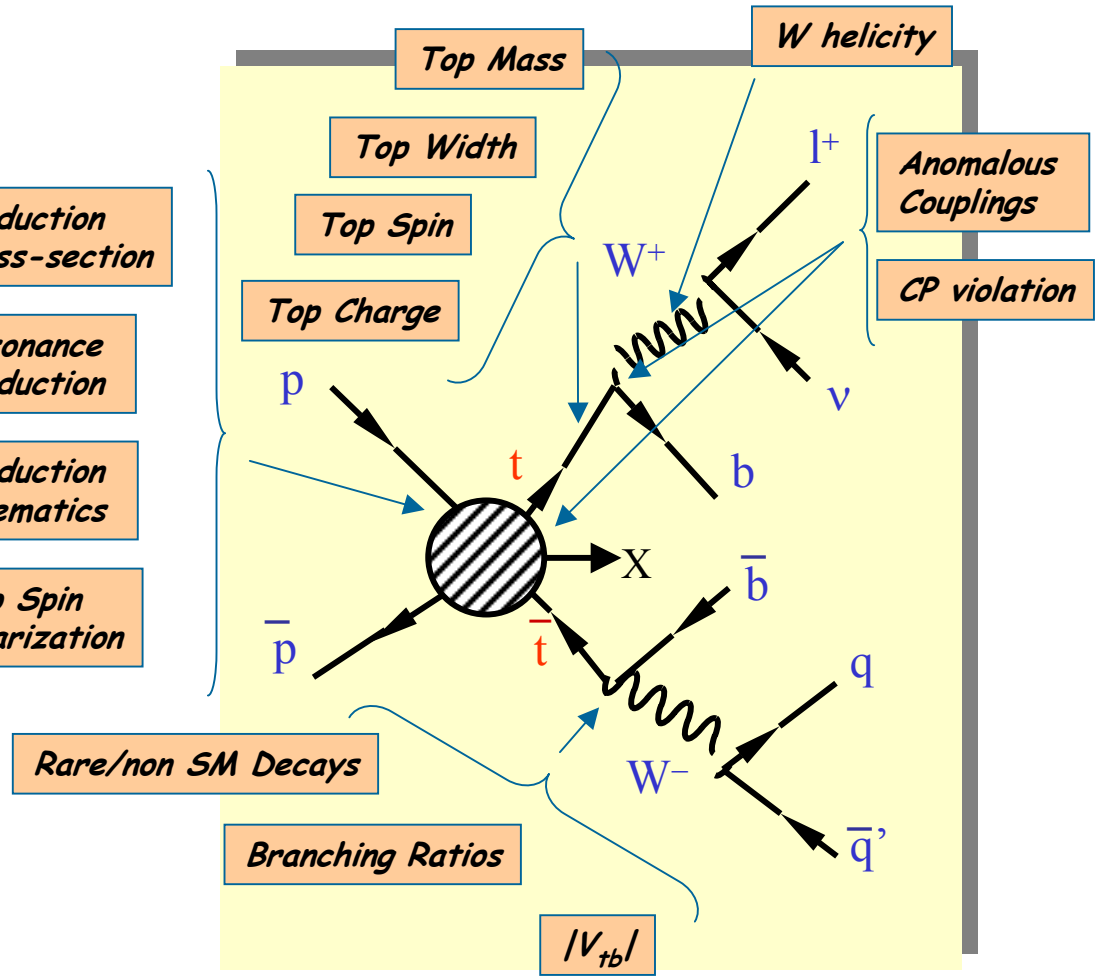
Motivation for Measuring Top Quark Production

Run I: Discovery

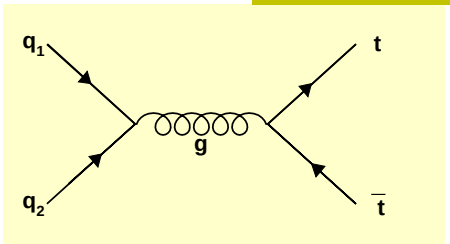
- σ_{tt}
- Top mass
- W helicity in top events
- tt spin correlations
- Top p_T
- Searches for new physics (X→ tt and top decay)

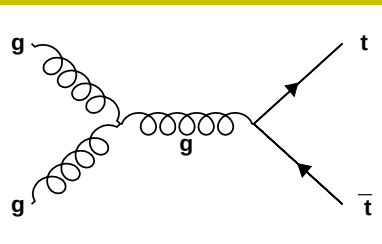
Run II: With high precision we hope to answer questions such as:

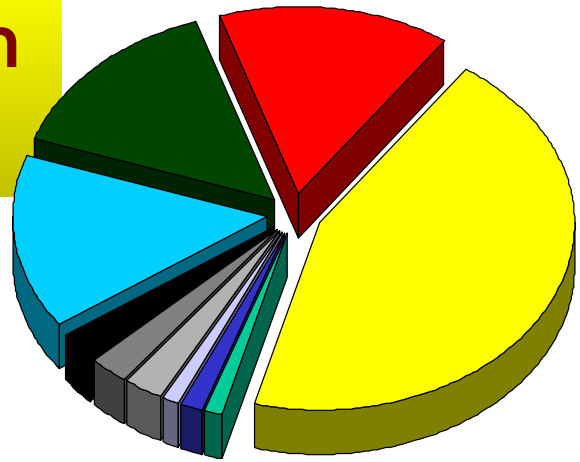
- Why is top so heavy?
- Is it or the third generation special?
- Is top involved with EWSB?
- Is it connected to new physics?



Top Quark Production Mechanics

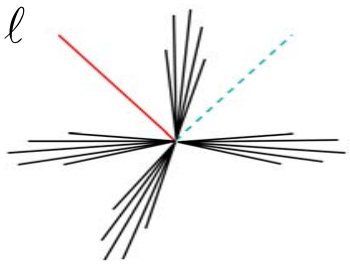






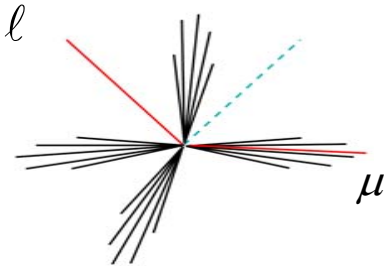
- At the Tevatron, top quarks are produced in pairs
  - Br(t→Wb)=100%

Lepton+jets (topological)



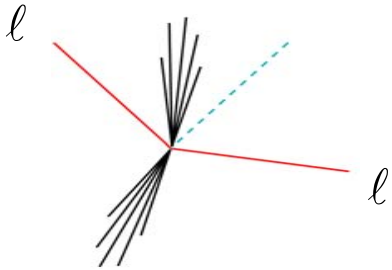
e+jets, μ+jets
Br = 14.7%
Efficient
Not very pure

Lepton+jets (soft muon tag)



e+jets/μ, μ+jets/μ
Br = 14.7%
Pure
Not very efficient

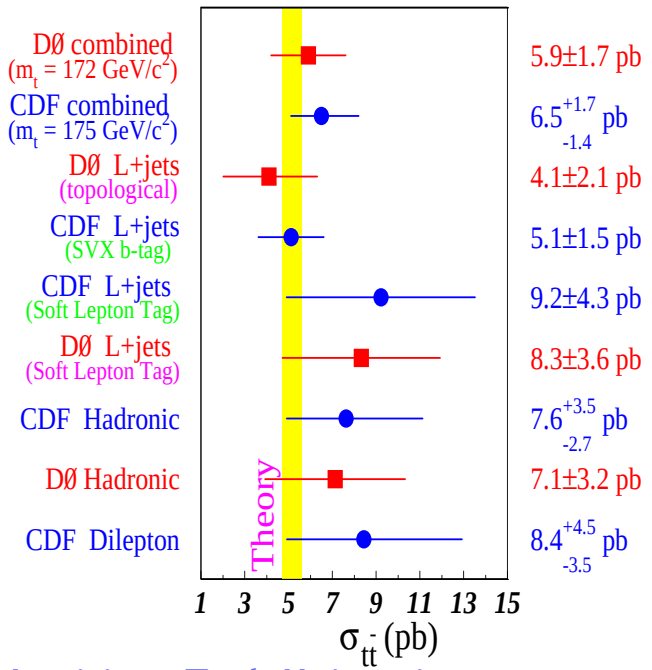
dileptons



ee, eμ, μμ
Br = 2.5 and 1.2%
Pure and efficient
Low branching

- Prediction of ~30% σ_{tt} cross section increase from Run I (1.8 TeV) to Run II (1.96 TeV)

Run I Results ~100 top events



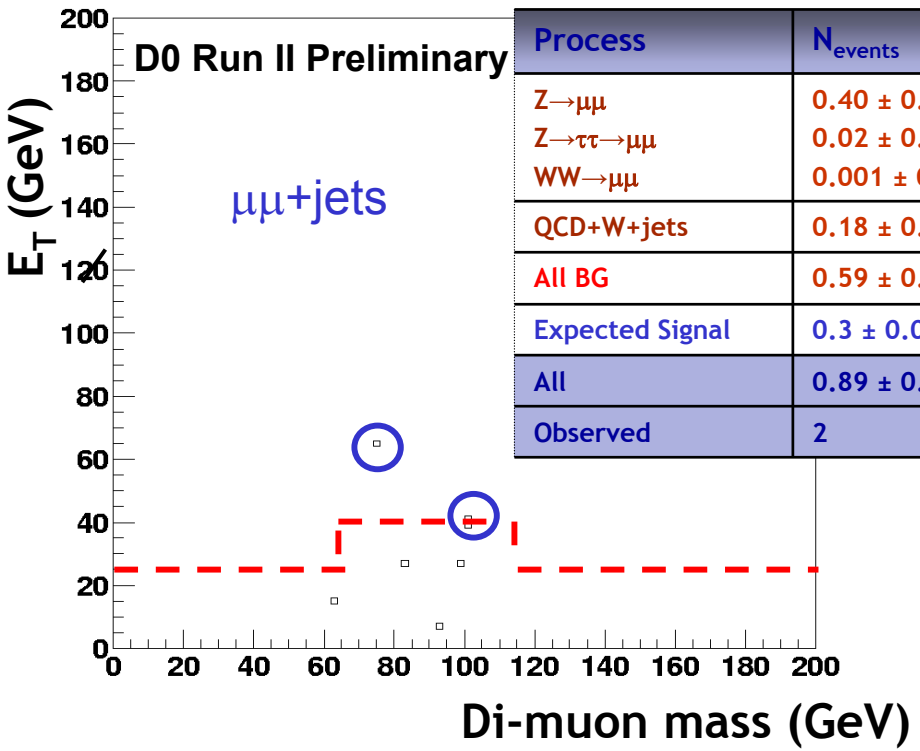
σ(tt→*ll*+jets) Event Selection

Event Selection

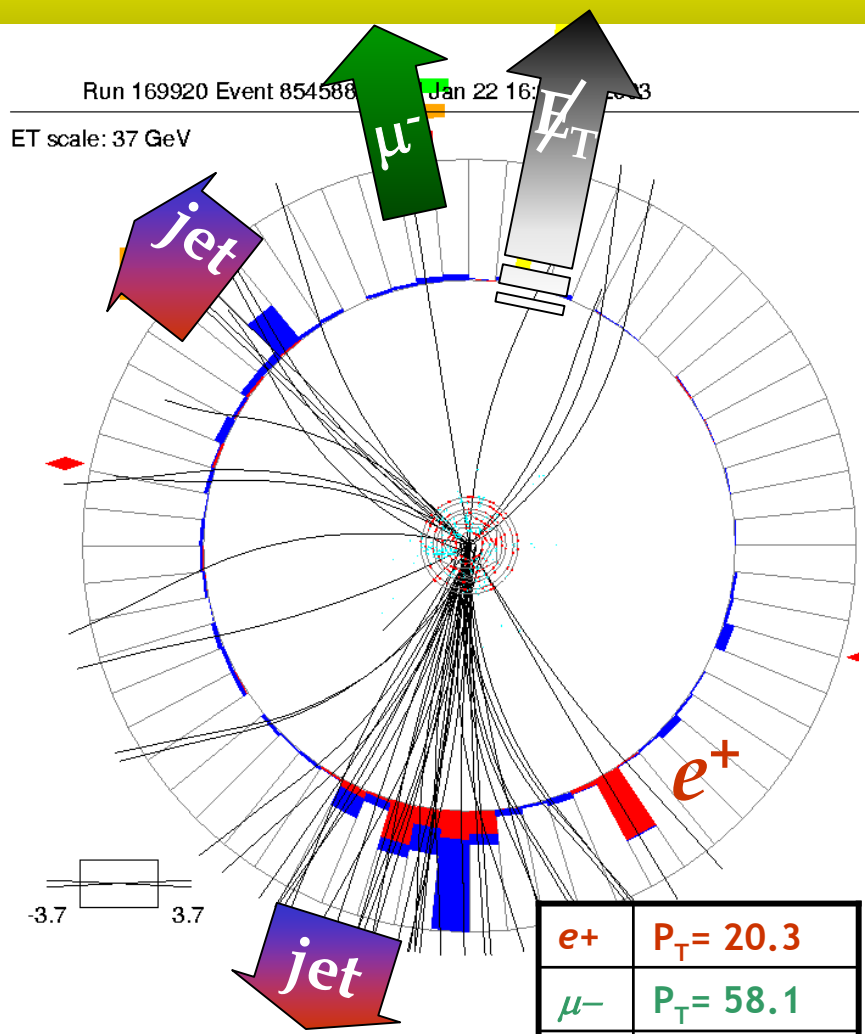
- Two high p_T isolated μ or e
- E_T (Z mass) cut
- ≥ 2 jets, E_T>20 GeV & |η| < 2.5
- $H_T = \Sigma(E^l_T, E^{jet}_T)$ cut

Backgrounds

- WW, Z→ tt determined with MC
- Z/g*, W+jets and QCD from data



Process	N_{events}
Z→μμ	0.40 ± 0.23
Z→ττ→μμ	0.02 ± 0.02
WW→μμ	0.001 ± 0.001
QCD+W+jets	0.18 ± 0.084
All BG	0.59 ± 0.30
Expected Signal	0.3 ± 0.02
All	0.89 ± 0.30
Observed	2

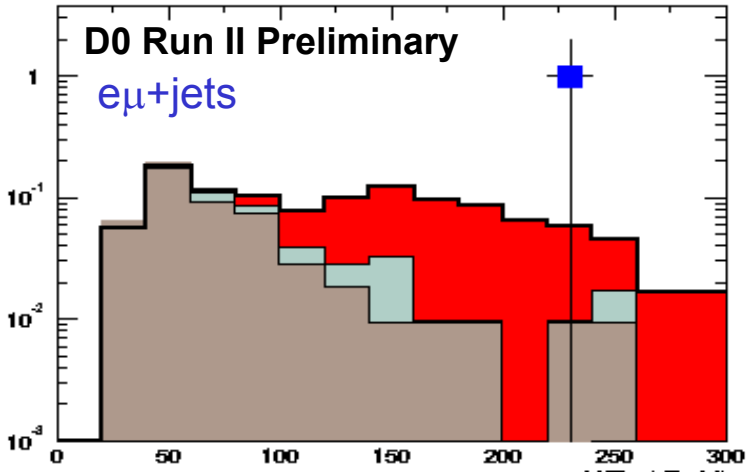


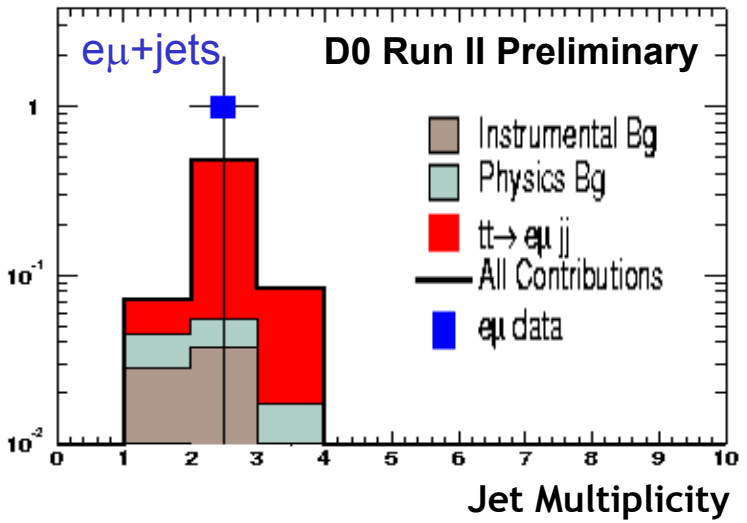
e+	P_T= 20.3
μ–	P_T= 58.1
j	P_T= 141.0
j	P_T= 55.2
$\not\!\!E_T$	91 GeV

σ(tt→*ll*+jets) Results

$\int Ldt = 33 - 48\ pb^{-1}$

	eμ	μμ	ee
Z→tt→ll WW→ll	0.02 ± 0.01 0.001± 0.001	0.02 ± 0.02 0.00 ± 0.00	0.02 ± 0.02 0.001 ± 0.001
Z→ll DY→ll QCD,W+jets	-- -- 0.05 ± 0.01	0.20 ± 0.12 0.20 ± 0.21 0.18 ± 0.18	0.98 ± 0.48
All BG	0.07 ± 0.01	0.60 ± 0.30	0.60 ± 0.30
Expected Signal	0.50 ±0.01	0.3 ± 0.04	0.25 ± 0.02
Observed	1	2	4





σ(tt→*l*+jets) Event Selection (no μ tag)

Procedure

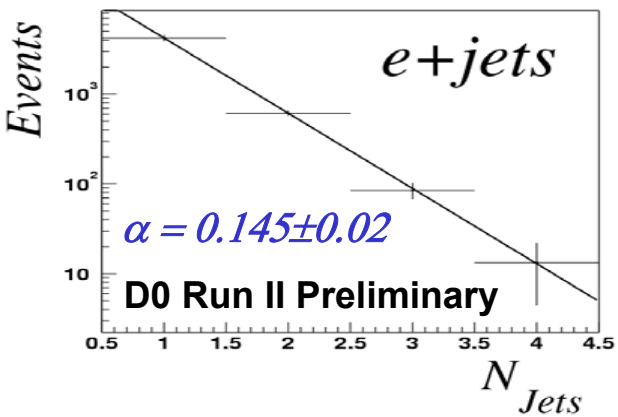
- Preselect a sample rich in W's
- Evaluate QCD multi-jet (as f [Njets])
- Estimate W+4 jets assuming Berends Scaling
- Apply topological selection

Event Selection

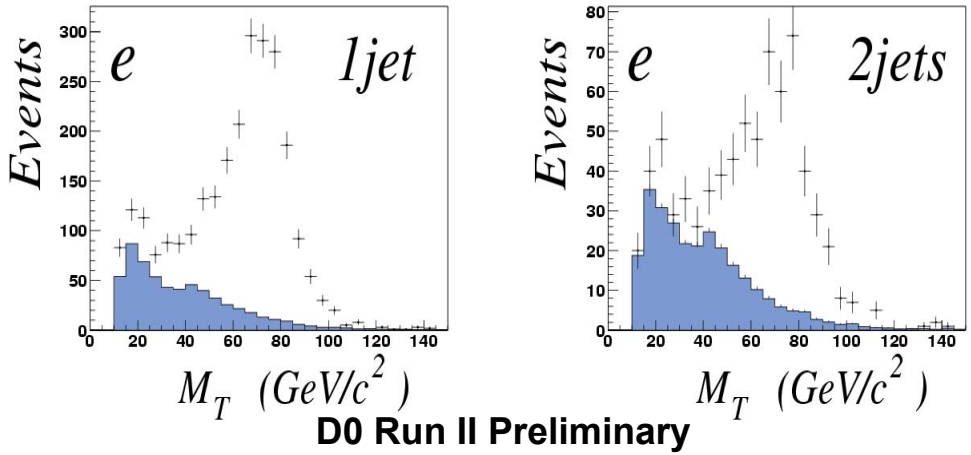
- Isolated lepton w/ P_T>20 GeV
- ME_T > 20 GeV
- 4+ jets with E_T>15 GeV & $|\eta|$<2.0 (2.5)
- Soft non-isolated muon tag veto

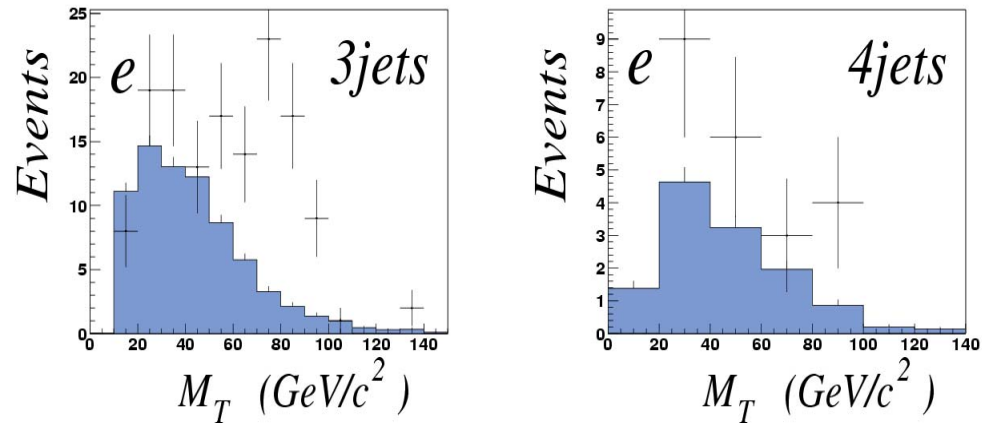
Backgrounds

- multijet evaluated from data vs. N_{jets}
  - e+jets: due to fake jets (real π^0 and γ)
  - μ+jets: due to heavy flavor decays
- Estimate real W+4 jets with scaling law



Estimation of QCD Background

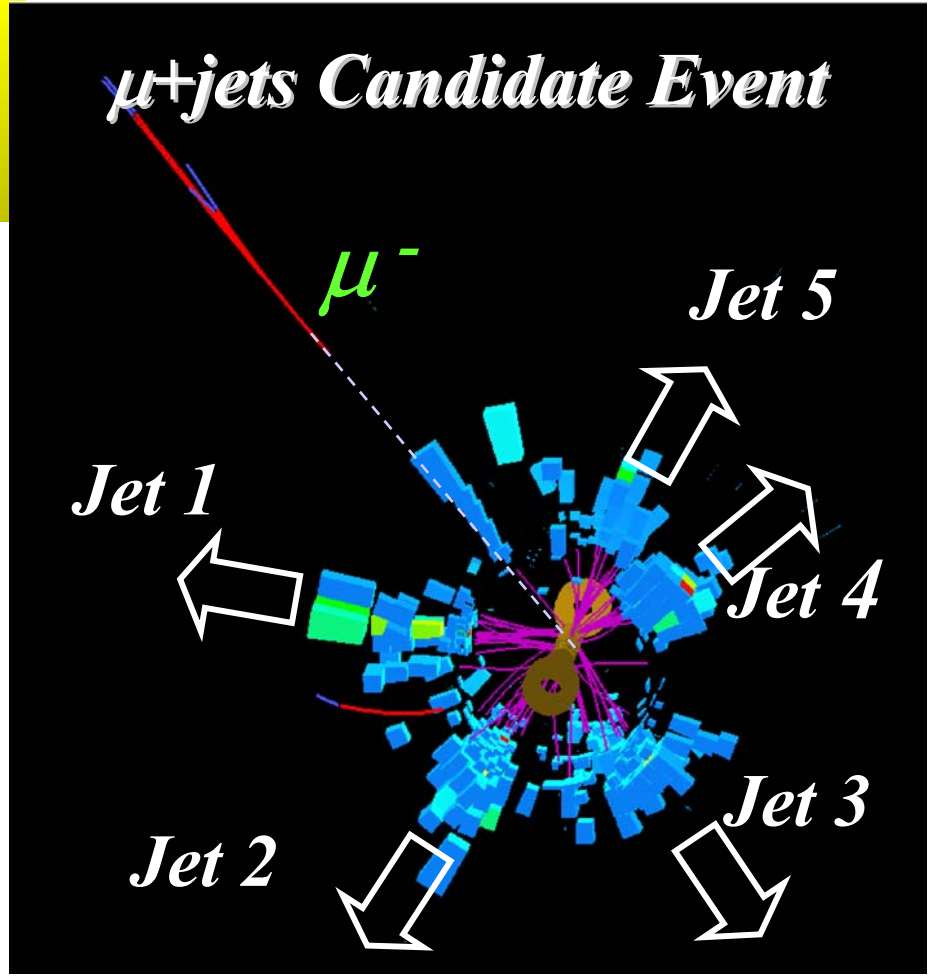




$$\alpha \equiv \frac{\sigma(W+(n+1)_{jets})}{\sigma(W+n_{jets})}$$

Scaling: # of W for $N_{jets} \geq 4$ jets

$\sigma(tt \rightarrow l+jets)$ Results (no μ tag)



Topological Selection

- 1+ jet with E_T>55 GeV
- ME_TCal>15 GeV
- $|\eta_W|$<2.0, E_{TW}>60 GeV
- H_T(jets & W)>220 GeV
- H_T>180 GeV
- Aplanarity(W-jets)>0.065

$$\int Ldt = 40 - 49.5\, pb^{-1}$$

Analysis	N_W	N_{QCD}	Bkg. Total	Exp Signal*	N_{obs}
e+jets	1.3±0.5	1.4±0.4	2.7±0.6	1.8	4
μ+jets	2.1±0.9	0.6±0.4	2.7±1.1	2.4	4

* For $\sigma = 7pb$

σ(tt→*l*+jets) Event Selection (soft μ tag)

Preselection criteria

- Same as leptons + jets except soft non-isolated muon is not vetoed
- 3+ jets with E_T>20 GeV & $|\eta|$<2.0
- Aplanarity > 0.04
- H_T>110 GeV

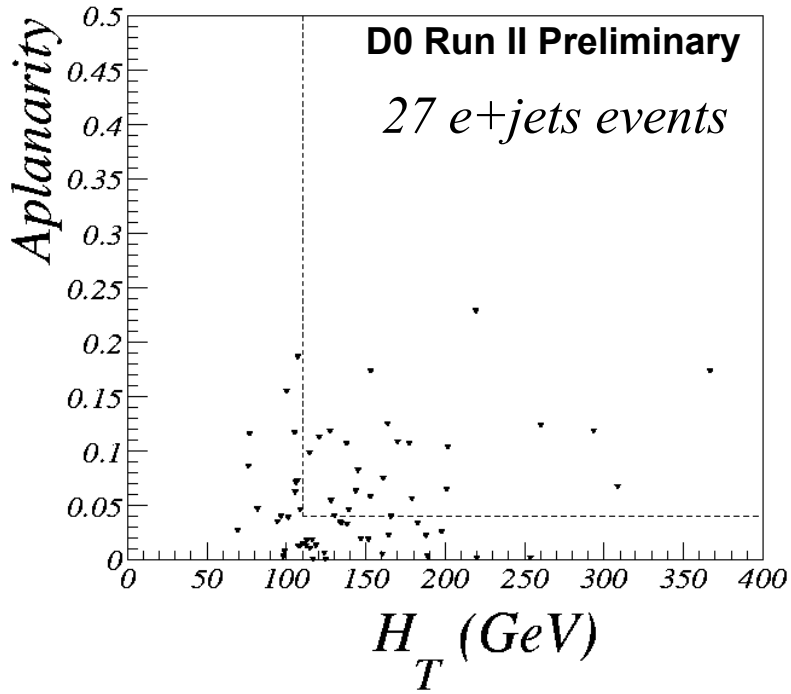
Soft Muon Tag

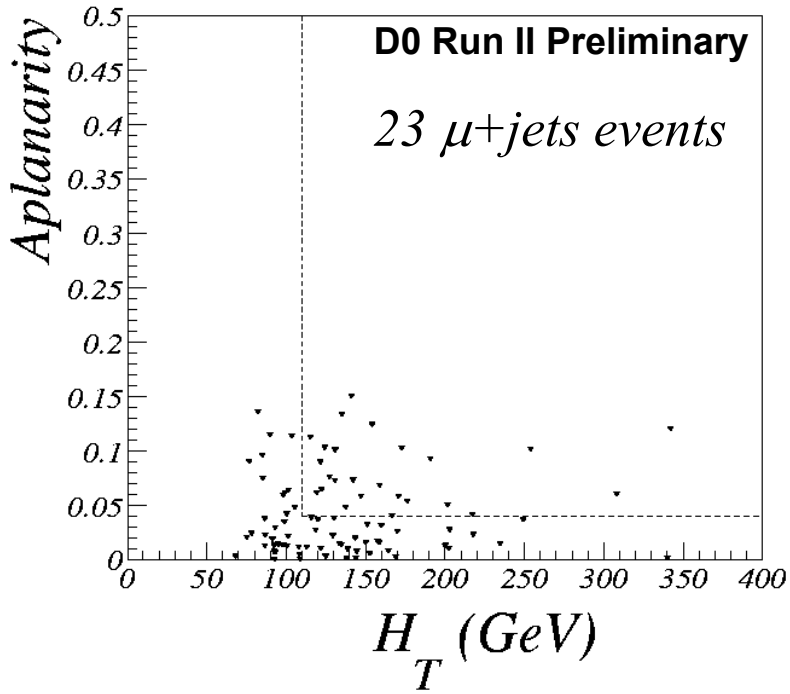
- $p_T(\mu)$>4 GeV within ΔR<0.5 of a jet

$$\int Ldt = 40 - 49.5\ pb^{-1}$$

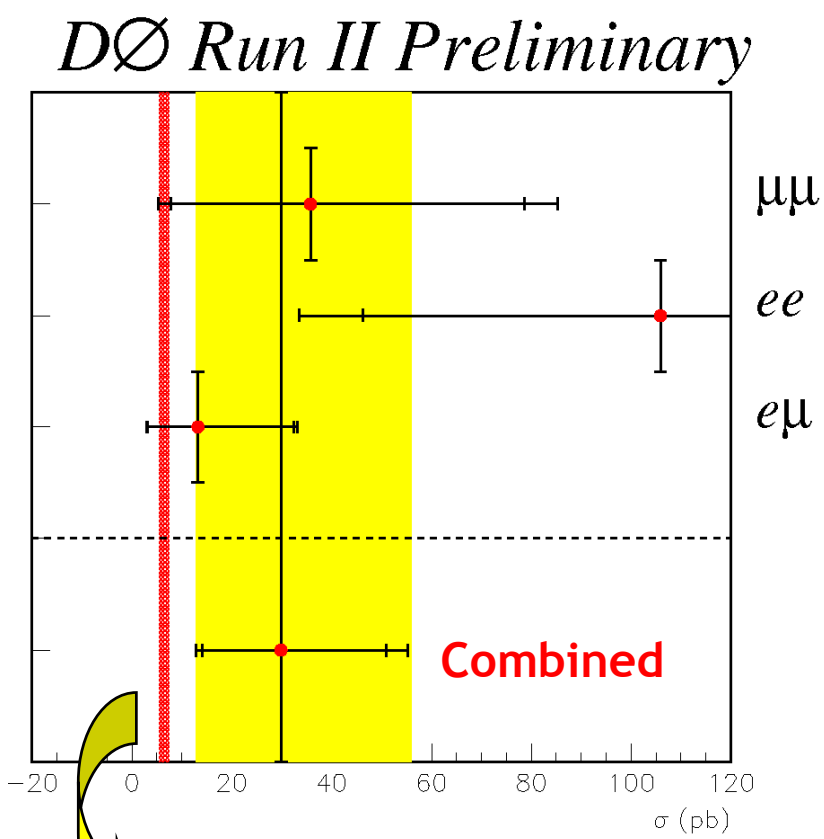
Analysis	Bkg. Tot.	Sig.*	N_{obs}
e+jets	0.2±0.1	0.5	2
μ+jets	0.6±0.3	0.4	0

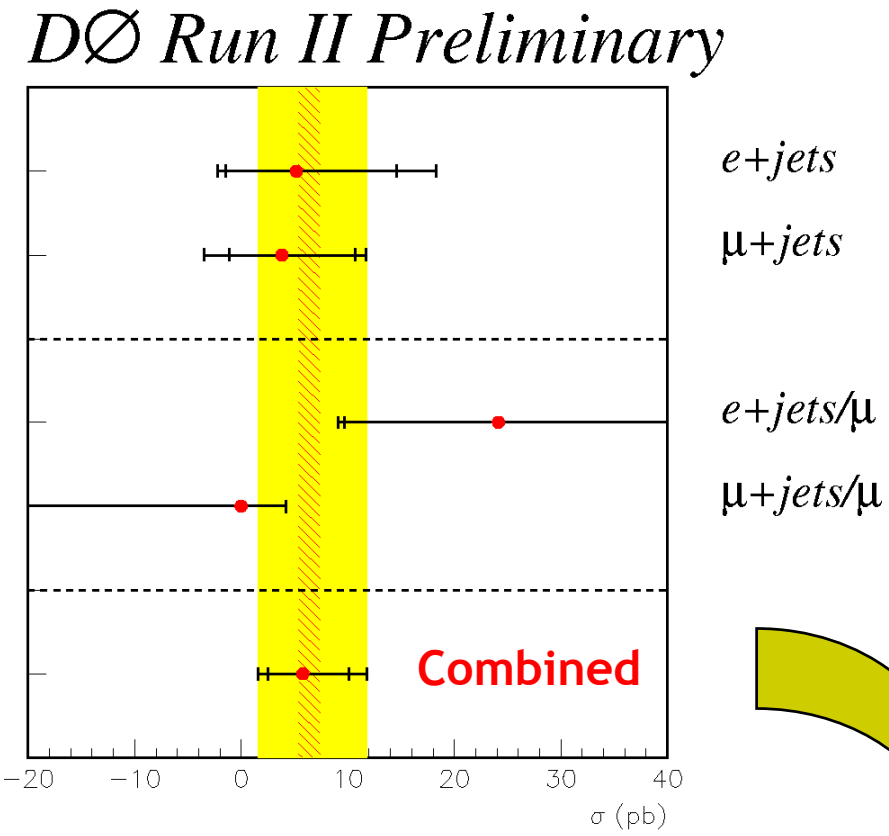
* *For* $\sigma = 7pb$





σ(tt→X) Cross Section





$$\sigma(t\bar{t}) = 29.9^{+21.0}_{-15.7}(\text{stat})^{+14.1}_{-6.1}(\text{sys}) \pm 3.0(\text{lum})\ \text{pb}$$

$$\sigma(t\bar{t}) = 5.8^{+4.3}_{-3.4}(\text{stat})^{+4.1}_{-2.6}(\text{sys}) \pm 0.6(\text{lum})\ \text{pb}$$

Conclusions

- Four new W & Z cross section measurements:

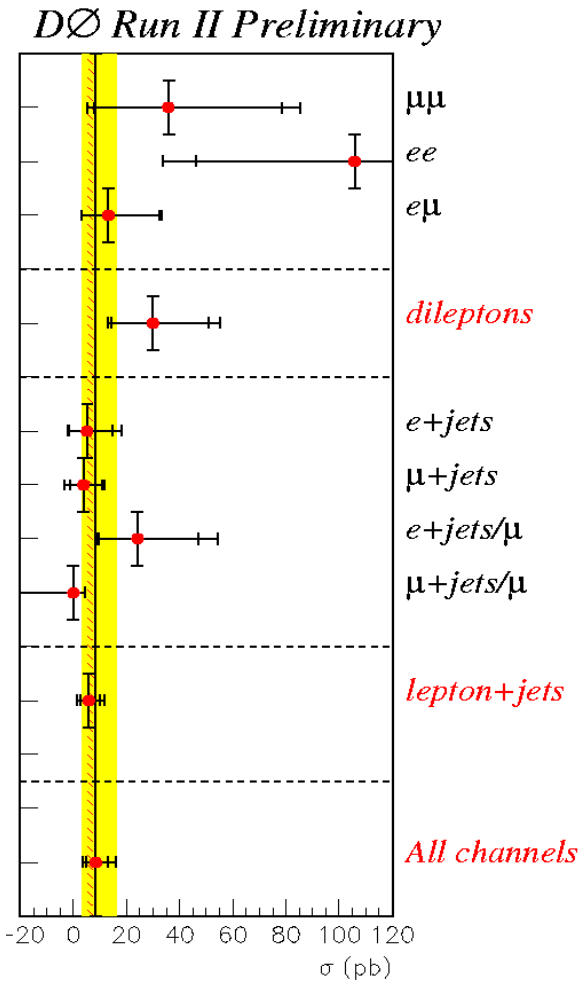
$$\sigma(Z)\times B(Z \to \mu\mu) = 264 \pm 7_{stat} \pm 17_{sys} \pm 26_{lum}\ pb$$

$$\sigma(W)\times B(W \to \mu\nu) = 3226 \pm 128_{stat} \pm 100_{sys} \pm 323_{lum}\ pb$$

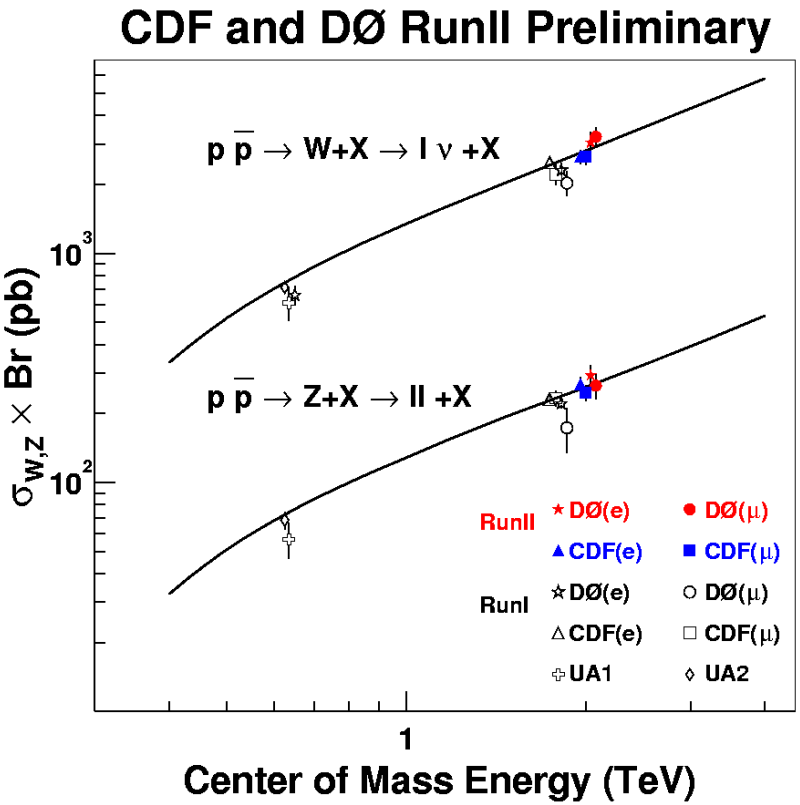
$$\sigma(Z)\times B(Z \to ee) = 294 \pm 11_{stat} \pm 8_{sys} \pm 29_{lum}\ pb$$

$$\sigma(W)\times B(W \to e\nu) = 3054 \pm 100_{stat} \pm 86_{sys} \pm 305_{lum}\ pb$$

- Assuming same SM Z couplings to quarks and leptons, Z' is excluded at 95% CL at $m_{Z'}$<620 GeV



- Combining the observation of the top decay channels an excess of 3σ is observed, compatible with a signal expectation at the 35% CL

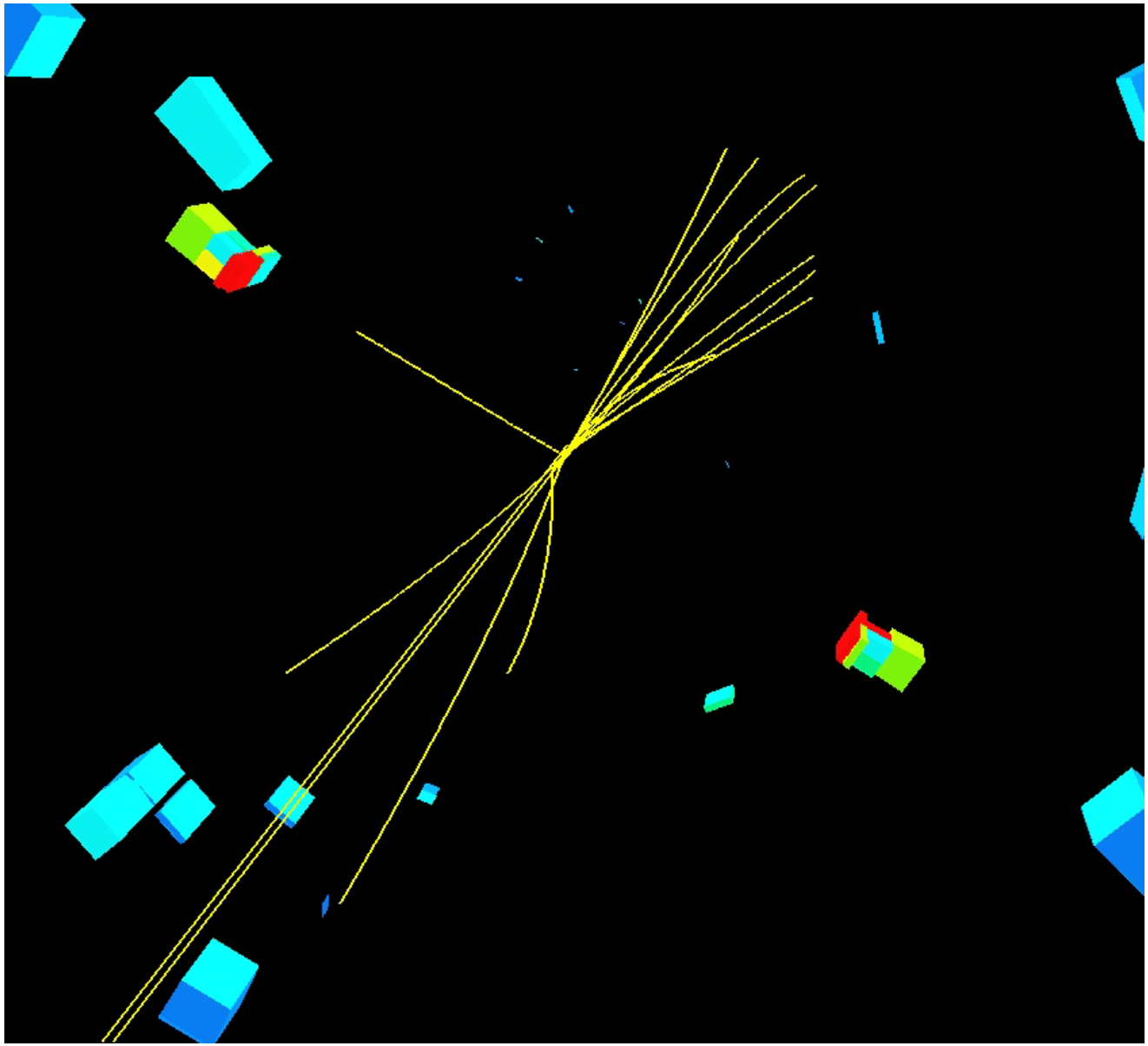


$$\sigma(t\bar{t}) = 8.5^{+4.5}_{-3.6}(stat)^{+6.3}_{-3.5}(sys) \pm 0.8(lum)\ pb$$

Backup Slides

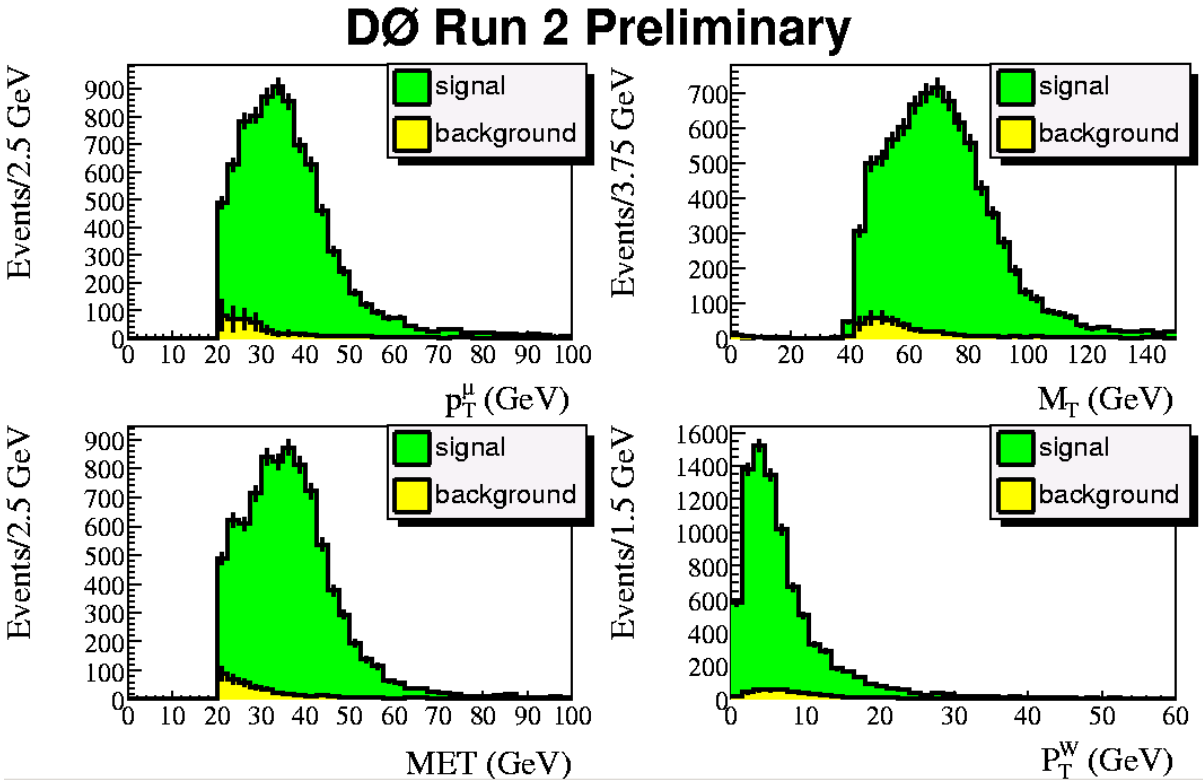
Z→ee Candidate

No centrally matched track to second electron



$P_T(e_1)$=45.1 GeV
$P_T(e_2)$=40.1 GeV
M(ee)=85.1 GeV

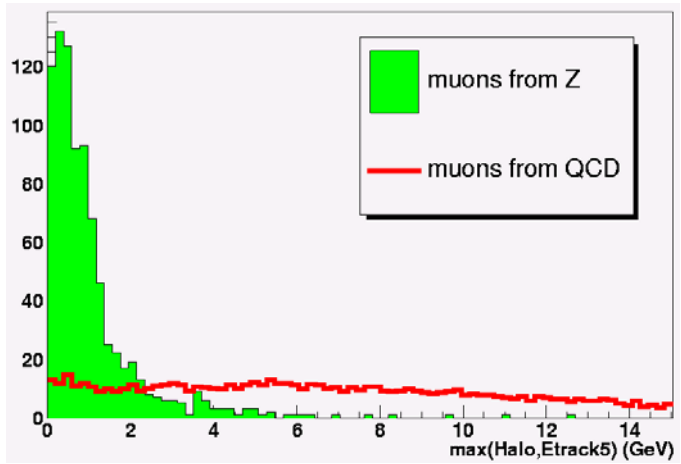
W→μν Backgrounds



Background estimated from data.

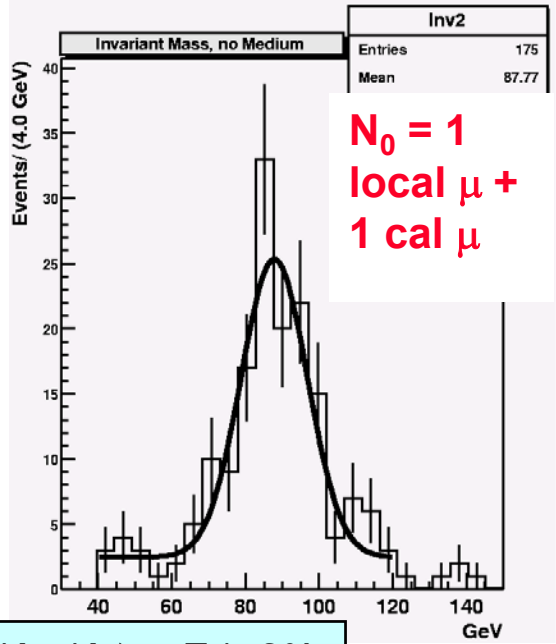
Dominant background:

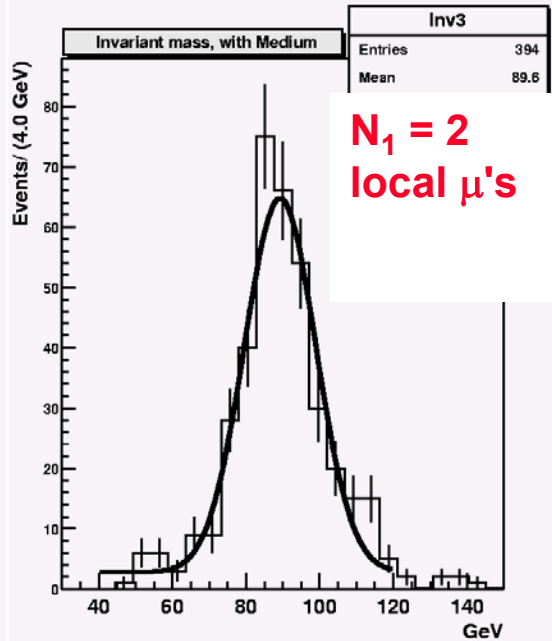
- bbar, b→μν events where the muon passes isolation cuts



W→μν Efficiencies

- Dimuon events
  - 1 μ w/central track match
  - 1 Calorimeter μ
- Determine fraction of Calorimeter muons that meet local muon criteria

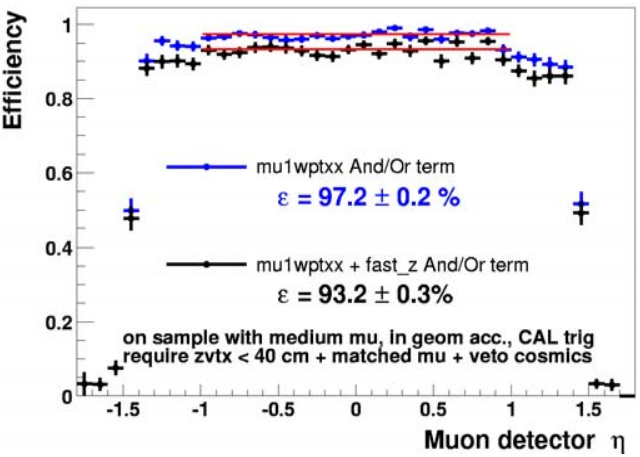




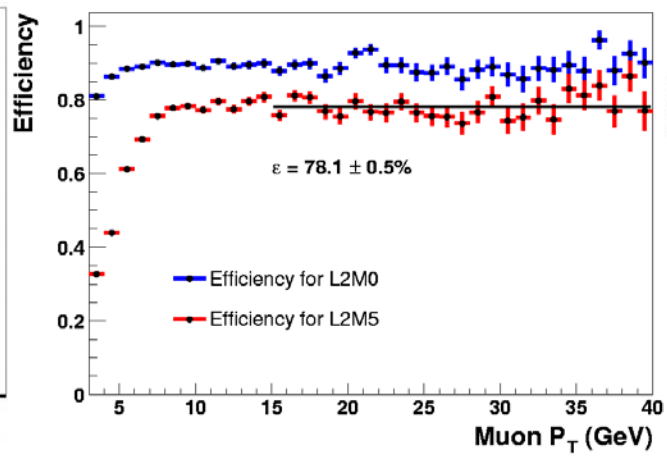
Muon reconstruction efficiency = $N_1/(N_0+N_1)$ = 74±2%

Trigger efficiencies

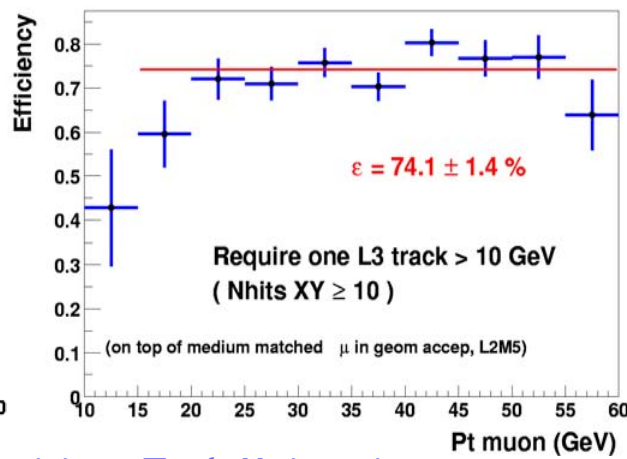
L1



L2



L3



Uncertainties

Z/W→e

	Value	Uncertainty
Trigger Efficiency	98%	2%
EMID Efficiency	85.6%	1%
Tracking Efficiency	73%	2%
Track Match Fake Probability	2.3%	1%
MC Acceptance: Ws	25.7%	0.4%
MC Acceptance: Zs	12.7%	0.2%
Number of Ws	27370	898
Number of Zs	1139	42
Luminosity	41.6 pb^{-1}	4.16 pb^{-1}

Z→μμ

Quantity	Value	Uncertainty	Contribution to fractional uncertainty on σ.Br
Monte Carlo, ϵ_{MC}	0.403	0.012	0.030
level 1 muon trigger, ϵ_{L1}	0.912	0.017	0.037
loose muon id., ϵ_{loose}	0.909	0.01	0.022
track efficiency, ϵ_{track}	0.822	0.014	0.034
Monte Carlo with efficiencies, ϵ^{eff}_{MC}	0.182	0.011	0.063
_fz trigger, ϵ_{fz}	0.955	0.005	0.005
level 2 muon trigger, ϵ_{L2}	0.861	0.007	0.002
opposite charge, $\epsilon_{opposite\_q}$	0.99	0.01	0.010
muon isolation, ϵ_{isol}	0.97	0.01	0.010
cosmic veto, ϵ_{cosmic}	0.995	0.005	0.005
total efficiency	0.163	0.011	0.065
$b\bar{b}$ backgrounds, f_{bb}	0.01	0.01	0.010
$\tau^+\tau^-$ backgrounds, $f_{\tau\tau}$	0.005	0.001	0.001
Drell-Yan correction, c_{DY}	0.875	0.01	0.011
integrated luminosity, $\int L$	31.8	3.18	0.100
number of candidates, N_{cand}	1585	39.8	0.025
σ.Br (pb)	263.8	32.2	0.122

W→μν

Luminosity for MU_W_L2M5_TRK10	$17.3 \pm 1.7\ pb^{-1}$
Efficiencies ±(stat) ±(sys) (in %)	
Timing cut	99 ± 0.5(stat)
Geometrical acceptance	63.1 ± 0.85(sys)
Pt cut	84 ± 0.2(sys)
medium ID	$74 \pm 2 \pm 1$
L1 trigger	84.7 ± 0.8(stat)
L2 trigger	78.1 ± 0.5(stat)
Tracking/Matching	81.5 ± 0.6(stat)
L3 trigger	74 ± 1(stat)
MET cut	95 ± 1.5(sys)
Veto cut	98.8 ± 0.3(stat)
Total without isolation cut	$14.5 \pm 0.5 \pm 0.4$
isolation cut efficiency	$90.6 \pm 1.4 \pm 0.5$
total efficiency	$13.2 \pm 0.5 \pm 0.3$