Electroweak and Top Physics at the Tevatron Collider Run 2

On the Energy Frontier

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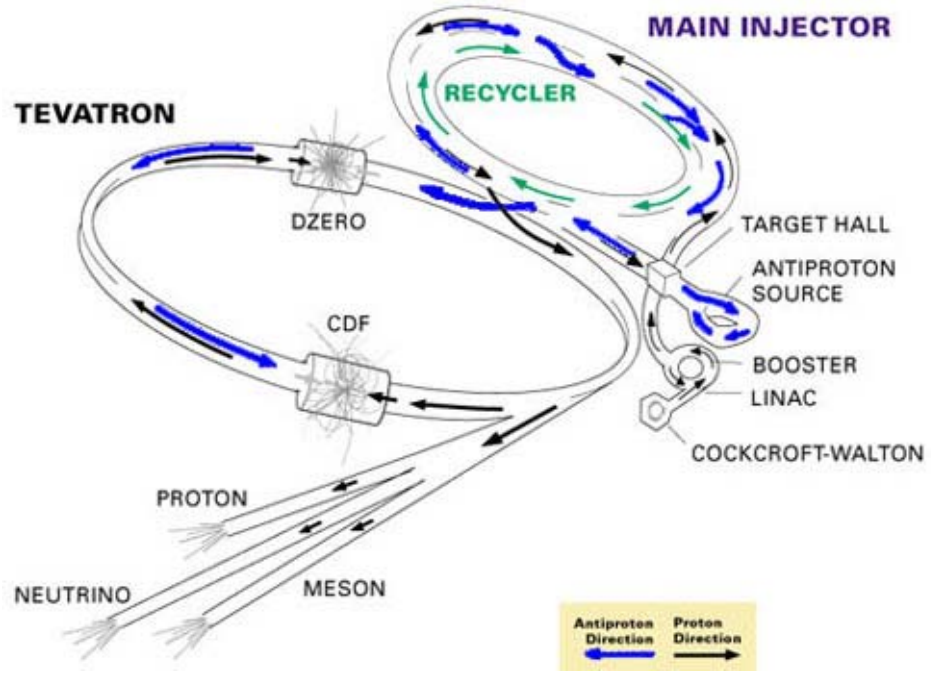
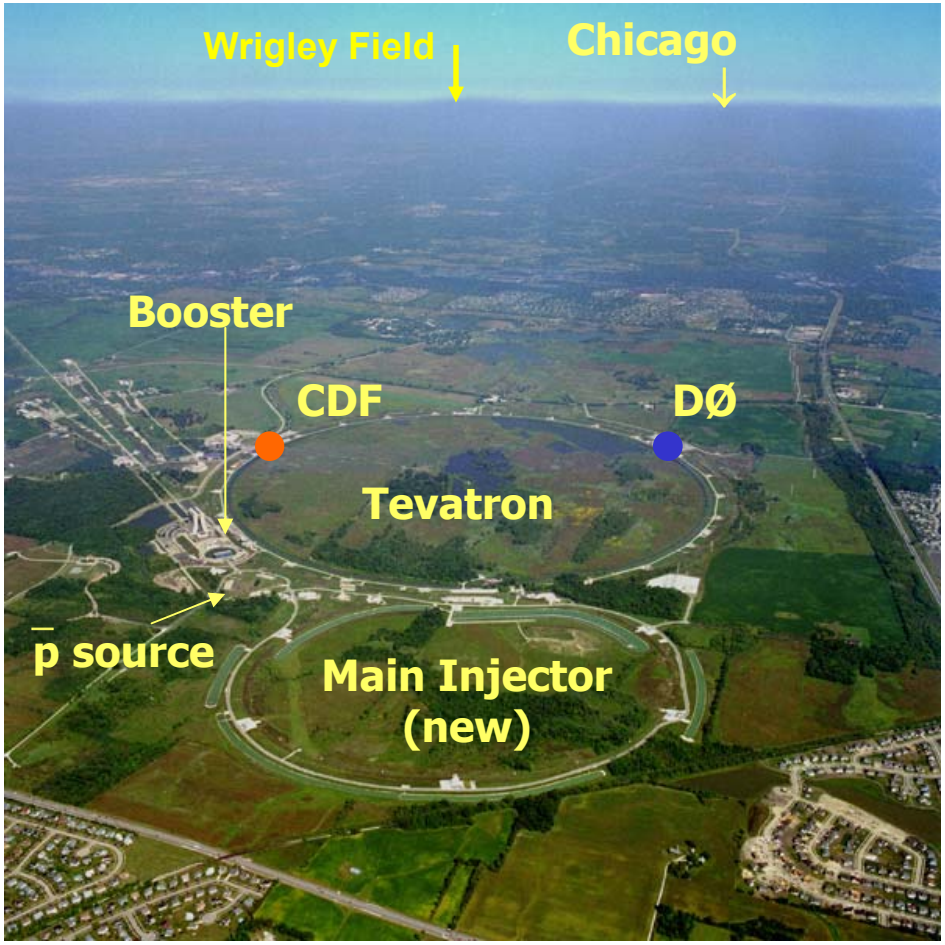
Status and Prospects for CDF and Dzero

Aspen Winter Conference on Particle Physics, January 2003

Fermilab Tevatron Upgrade





- **New Main Injector:**
  - Improve p-bar production
- **Recycler ring:**
  - Reuse p-bars

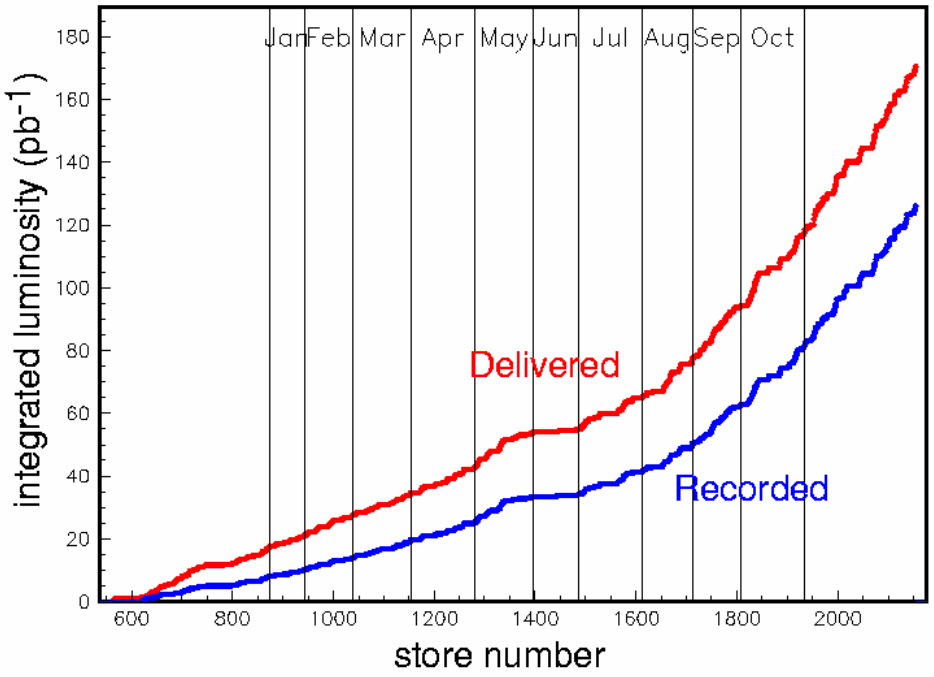
Tevatron Upgrade Goals

- **Run 1 ended 1995:**
  - Integrated 105 ± 4 pb^{-1}
  - Peak Lum ~ 2.4×10^{31} $cm^{-2}s^{-1}$
- **Run 2 began Mar '01:**
  - Record initial luminosity! $3.7 \times 10^{31} cm^{-2} s^{-1}$ in Nov.'02
  - Record integrated L: 7.1 pb^{-1} in one week

Jan shutdown- Apertures,…

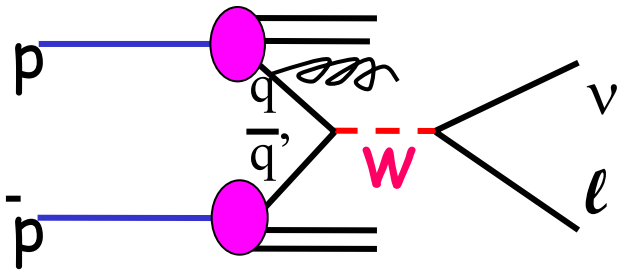
- **Physics Datasets:**
  - ~70-80 pb^{-1} for March '03 conferences!
  - 10-20 pb^{-1} used for ICHEP analyses & Aspen results

- $\sqrt{s}$ = 1.96 TeV !
  - $\sigma(W)$, $\sigma(Z)$ ~ 10% higher
  - $\sigma(t\bar{t})$ ~ 30% higher



Electroweak Physics Program

- **Run 1: Top discovery, precise M_W, Γ_W, and more**
- **Run 2: High statistics, precision W physics, precision top quark measurements, rare processes**



Run I: 105 pb^{-1}
Run IIa: 2 fb^{-1}

Event yields in per experiment

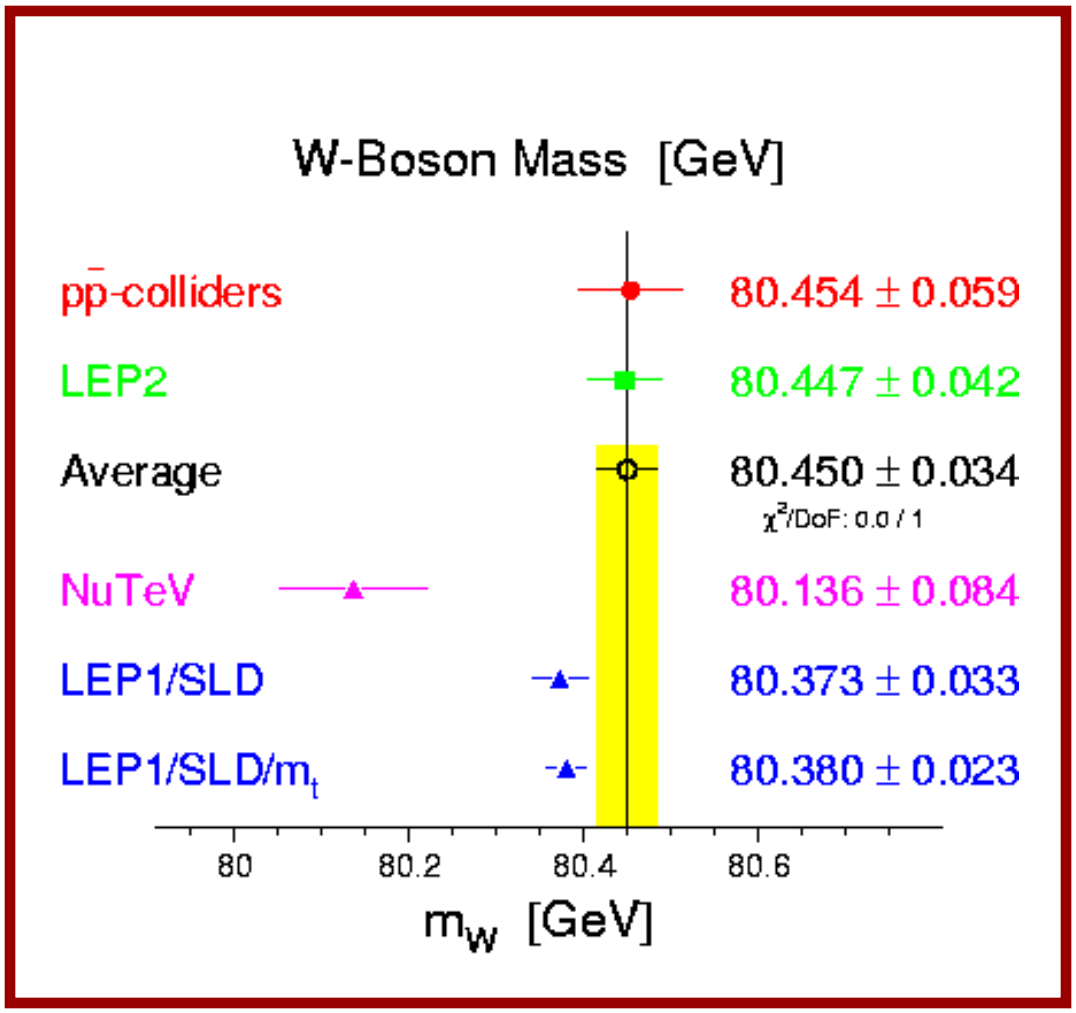
Sample	Run I	Run IIa
$W \to \ell\nu$	77k	2300k
$Z \to \ell\ell$	10k	202k
WV ($W \to \ell\nu$, V=W,γ,Z)	90	1800
ZV ($Z \to \ell\ell$, V=W,γ,Z)	30	500
tt (mass sample, ≥1 b-tag)	20	800

Precision W Physics

- The Tevatron will make a W mass measurement comparable to or better than that of LEP

- Run 2 combined CDF and D0 prospects for 2 (10) fb^{-1} :
  - δM_W = 30 (20) MeV/c^2
  - $\delta \Gamma_W$ ~ 40 MeV (direct)

- Searches for rare decay processes:
  - $W \rightarrow \pi + \gamma$, $D_s + \gamma$, …
  - ~250 million W bosons in 10 fb^{-1} of data



W Mass Measurement

CDF/D0 Combined

Statistics: 40 MeV

Systematics:

scale: 40 MeV +

recoil: 20 MeV +

modeling: 15 MeV *

other: 15 MeV +

Sys Total: 38 MeV

+ largely statistical in nature

* correlated among expts

From Run I

CDF: 80.433 ± 0.079 GeV

D0: 80.483 ± 0.084 GeV

Comb: 80.456 ± 0.059 GeV

After 2 fb^{-1} at Run II

$\Delta M_W = \pm 30$ MeV

ΔM_W (*World*) = ± 15-20 MeV

➔ Run II projections assume detectors will perform similarly to Run I, so that the mass uncertainty scales with statistics

➔ How will missing E_T resolution scale with inst. luminosity?

Improved Tools for Precision Measurements

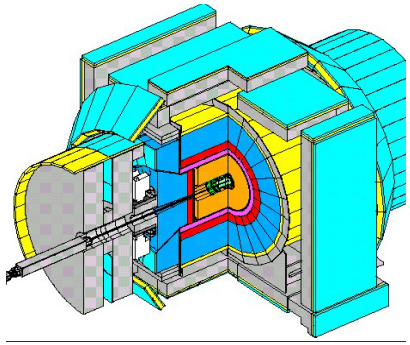
Detector upgrades for Run 2 have been extensive. Measuring detector resolutions and performances, and re-establishing Run 1 physics signals has been crucial.

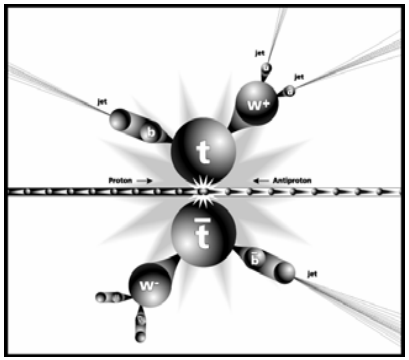
CDF:

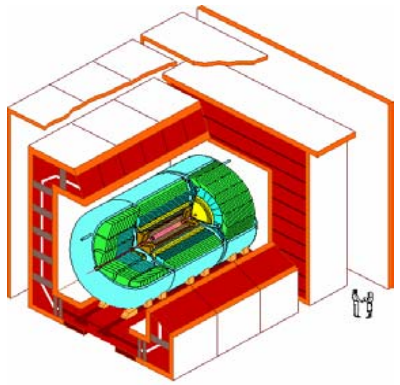
- 8 layers of silicon
- New drift chamber (COT)
- Extended lepton-ID: $|\eta| > 1$
- Displaced track trigger

D0:

- 4 layers + disks of silicon
- New fiber tracker (CFT)
- Solenoid (2 Tesla)
- Extended lepton-ID: $|\eta| > 1$

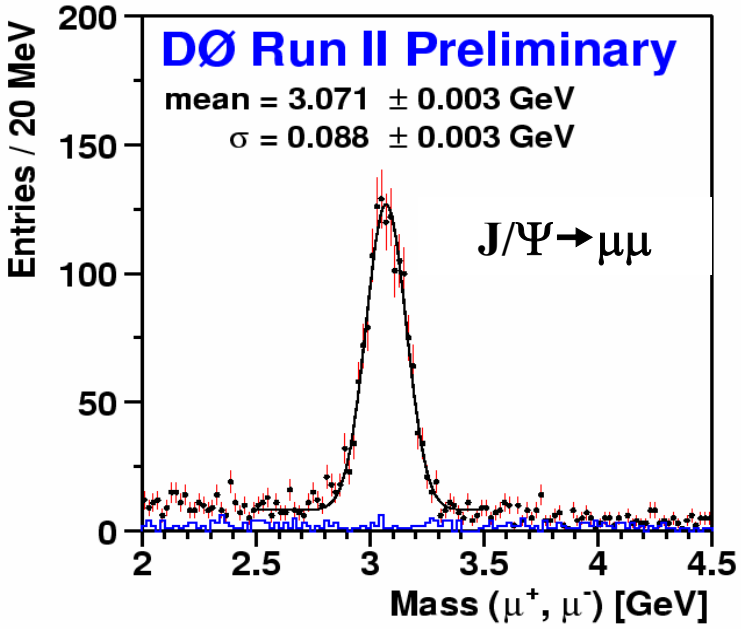




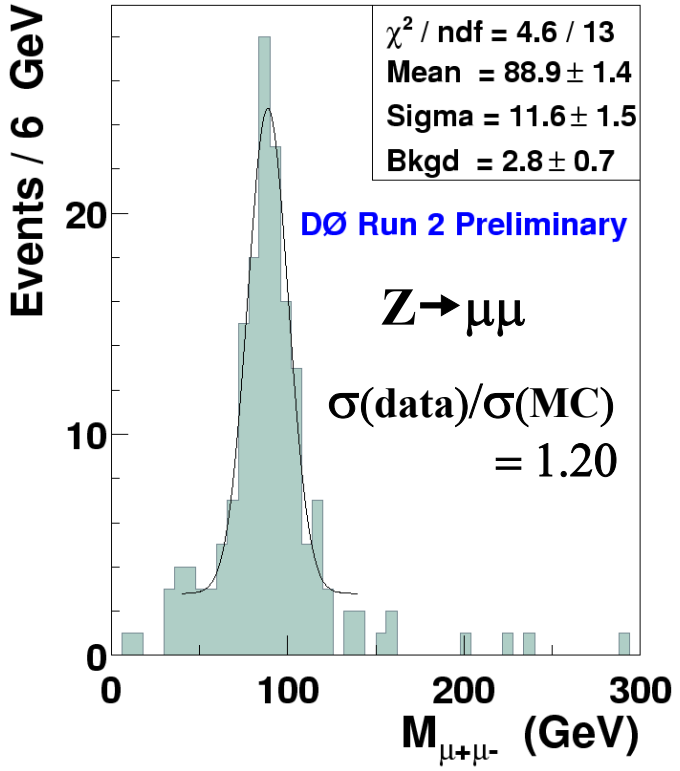


Momentum Scale/Resolution

Use low lying resonances to get P scale and resolution



Assuming "nominal" positioning:

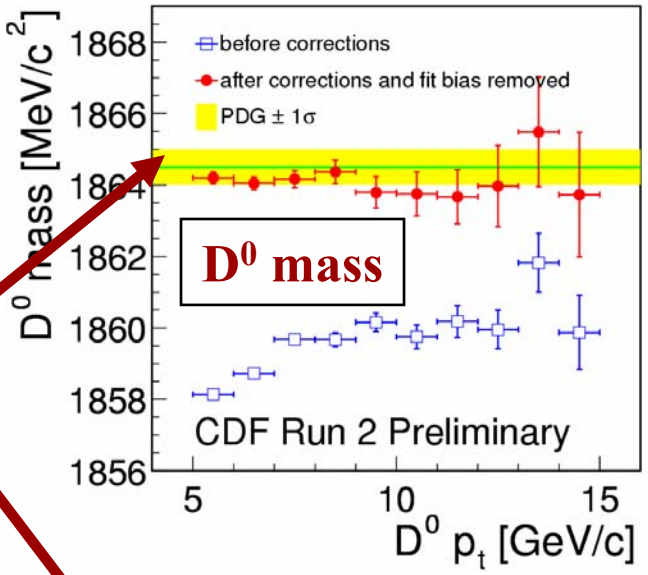


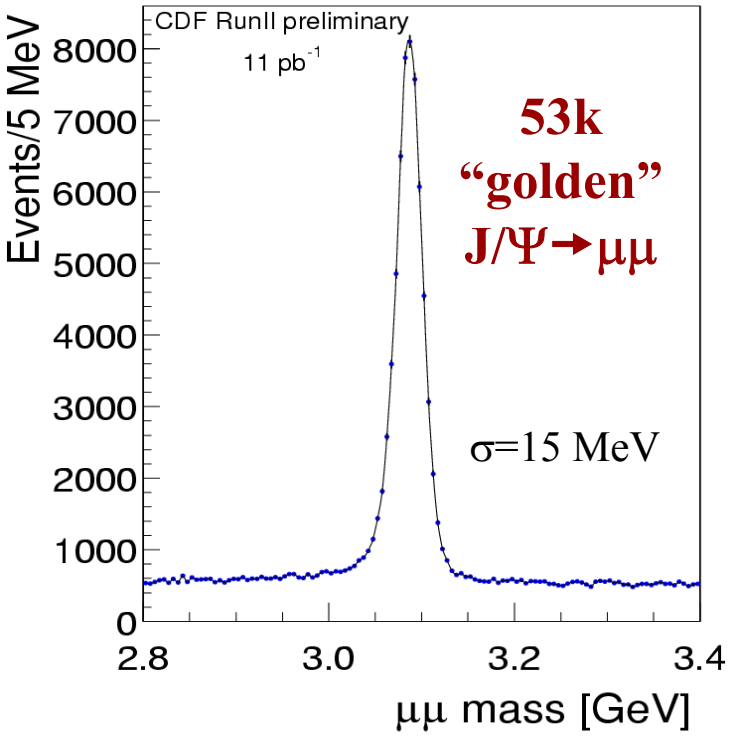
D0's New Central Fiber Tracker (CFT):

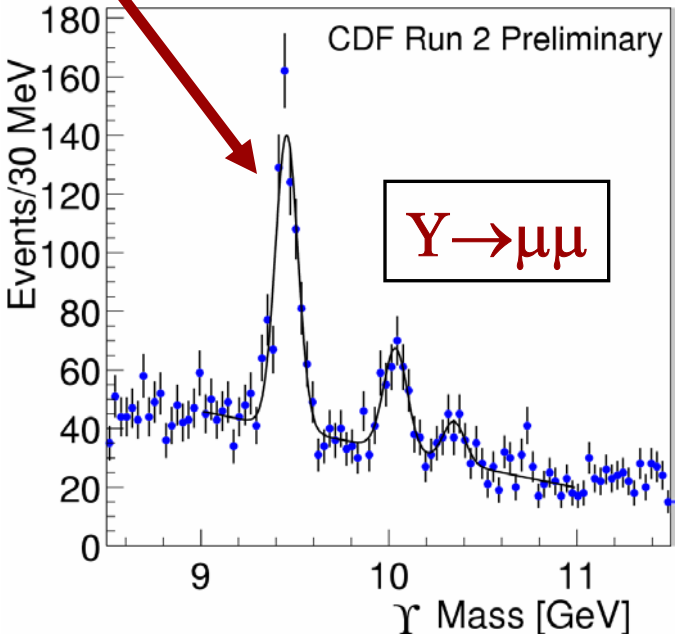
- 2 Tesla field, 8 axial/stereo layers each
- Expect high tracking efficiencies
- Alignment underway

Calibrations Using Low P_T muons

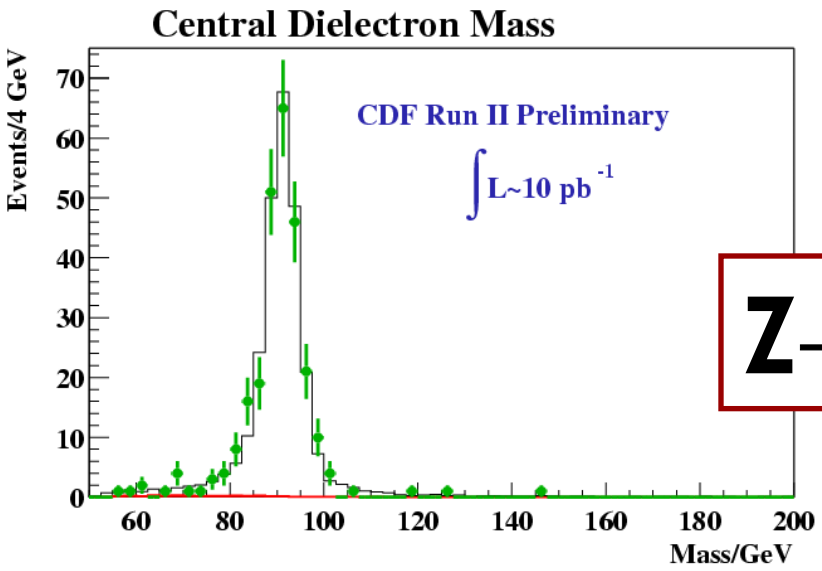
- CDF COT performance impressive
- ε (COT tracking) = 99.7±0.3% from W→eν evts
- Use ψ's to understand E-loss and B-field corrections: check with known signals

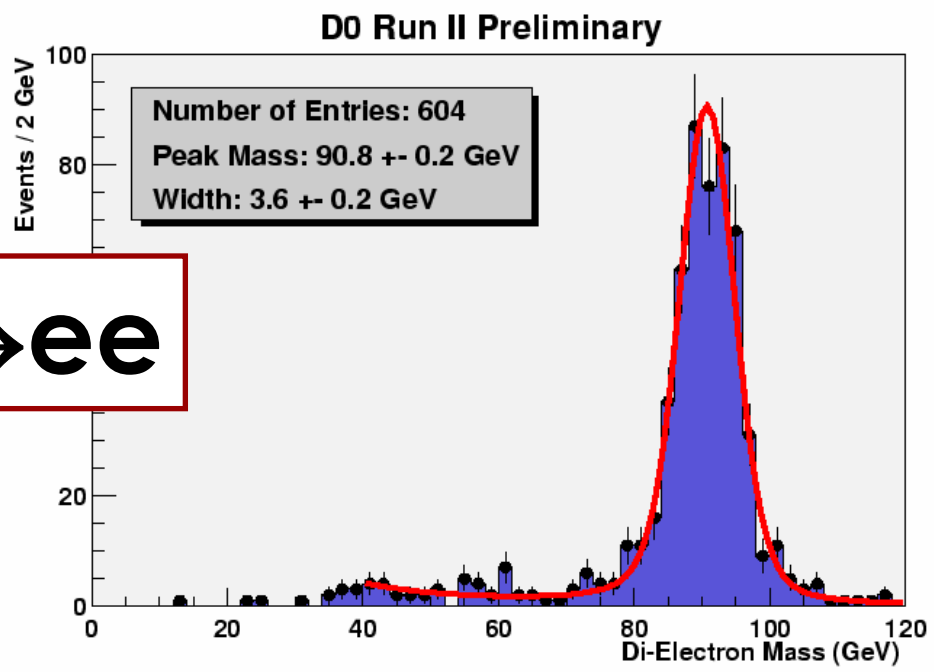




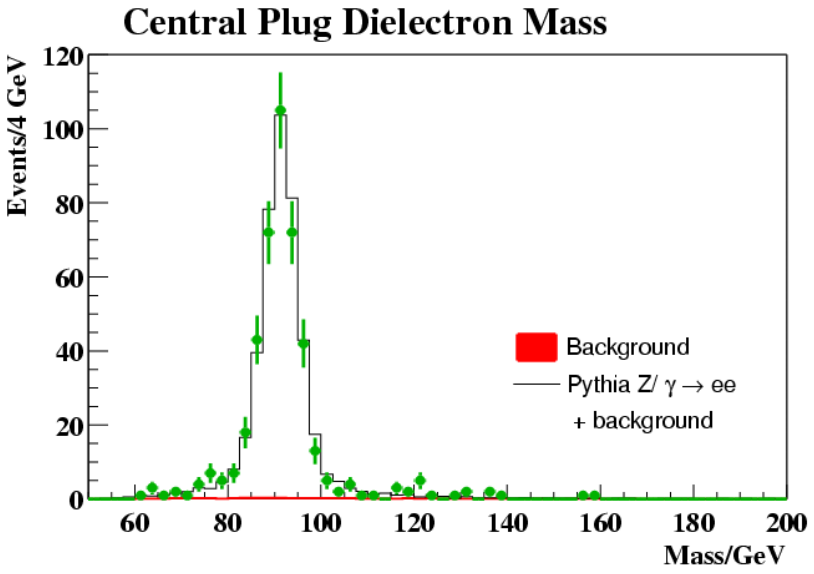


Energy Scales in Run 2





Z→ee



- **D0:** central + forward electrons with only partial corrections. Resolution will meet expectations.
- **CDF:** central & fwd electrons with dominant corrections included. resolution as expected.

CDF W Cross Section Analysis

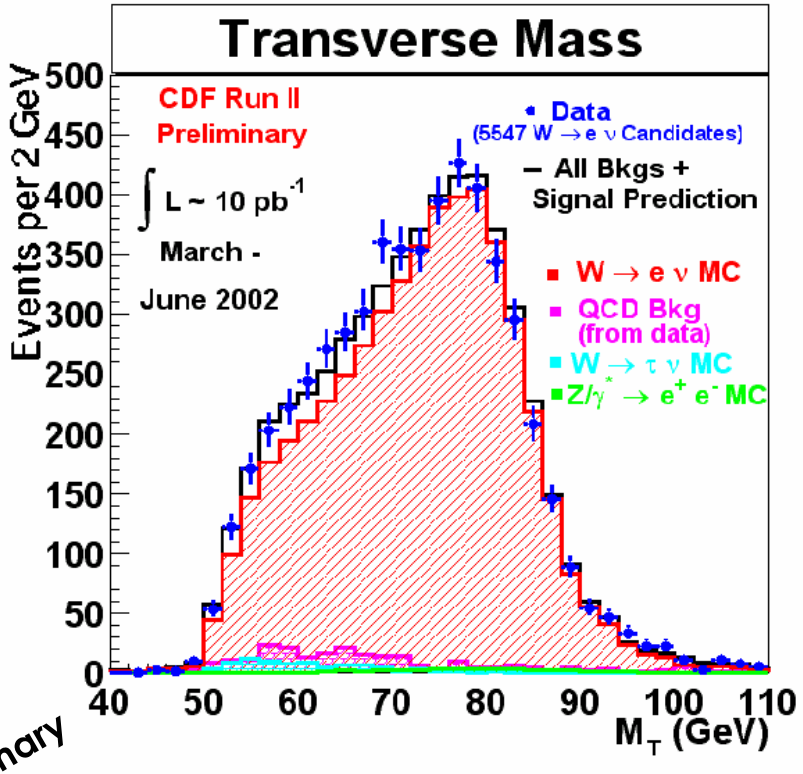
W→eν cross section:

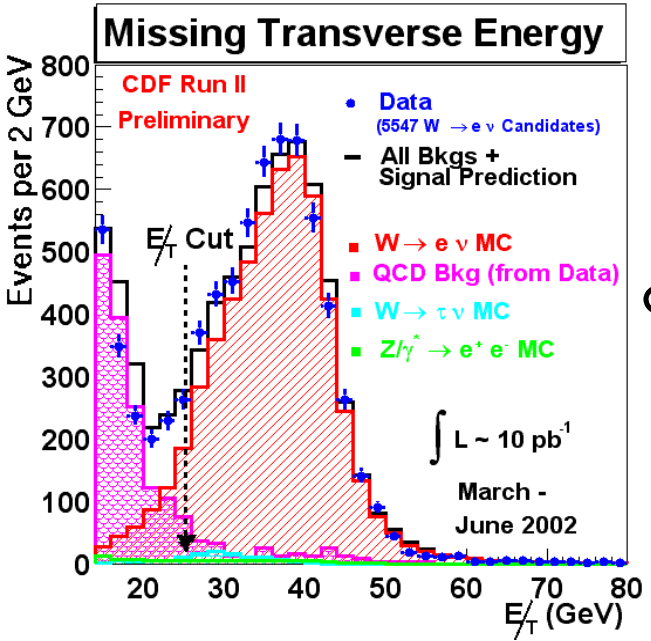
Number of Candidates:

- **5547 in 10 pb^{-1}**

Background (8%):

- QCD: 260 ±34±78
- Z →ee: 54 ± 2 ± 3
- W→τν: 95 ± 6 ± 1



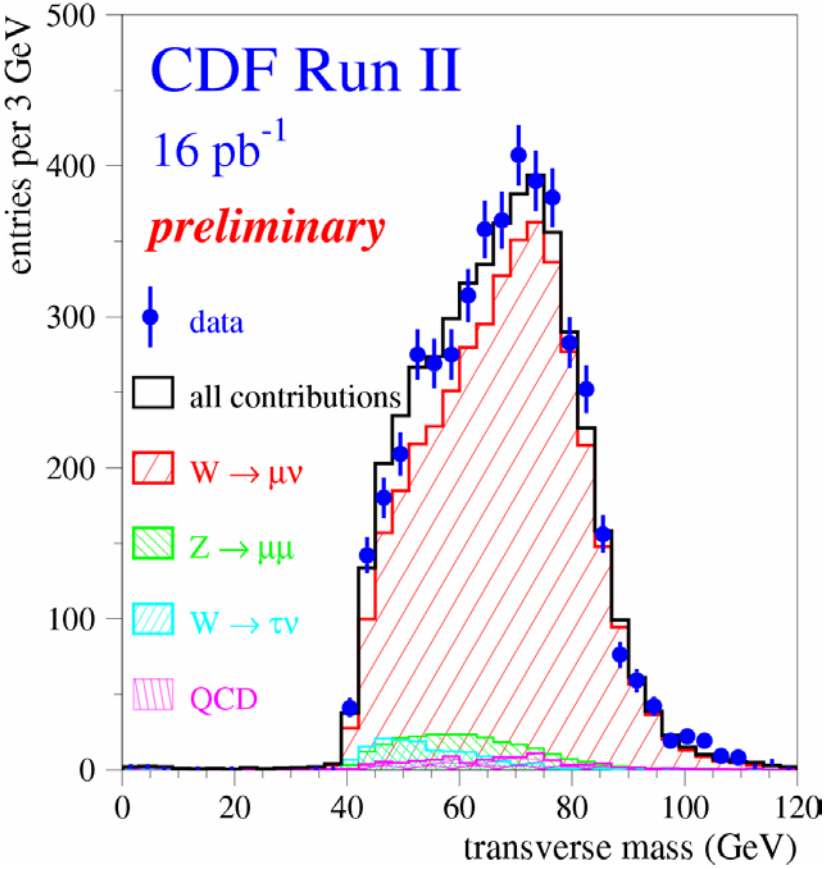


CDF Run 2 Preliminary

σ_W*BR(W→eν) =

2.60 ± 0.03$_{stat}$ ± 0.13$_{syst}$ ± 0.26$_{lum}$

CDF W→μν Cross Section

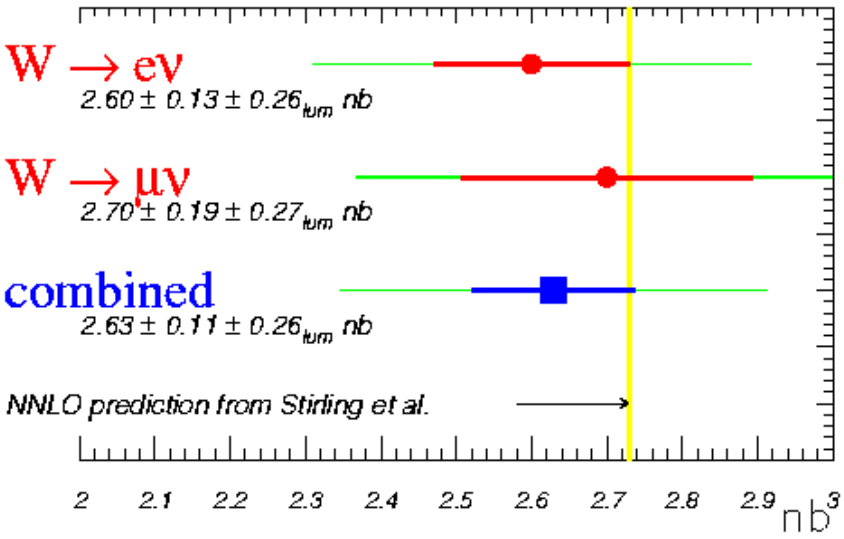


Number of Candidates:

- **4561 in 16 pb^{-1}**

Background (12.5%) :

- **QCD: 104 ± 53**
- **cosmics: 73 ± 30**
- **Z →μμ: 247 ± 13**
- **W→τν: 145 ± 10**



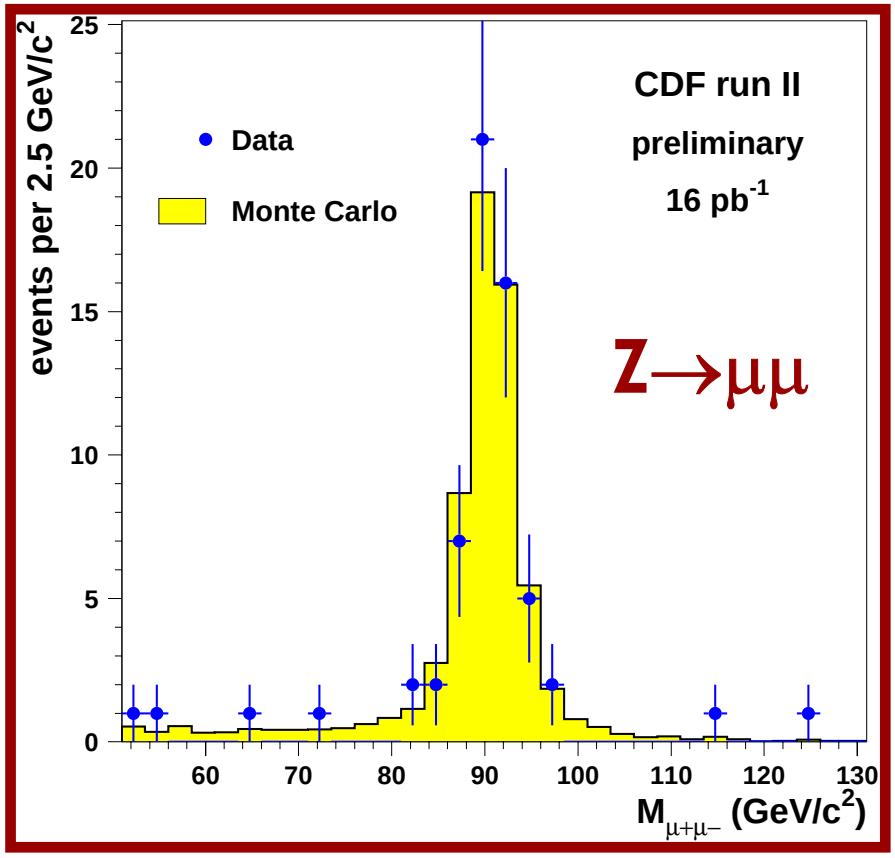
$$\sigma_W * BR(W \to \mu\nu) = 2.70 \pm 0.04_{stat} \pm 0.19_{syst} \pm 0.27_{lum}$$

CDF Run 2 Preliminary

CDF Measurement of R_μ and $\Gamma(W)$

$$R_\ell = \frac{\sigma(pp\to W)\,\Gamma(Z)\,\Gamma(W\to \ell\nu)}{\sigma(pp\to Z)\,\Gamma(Z\to \ell\ell)\,\Gamma(W)} = \frac{N_W \varepsilon_z A_z}{N_Z \varepsilon_W A_W}$$

- Measure $N_W\varepsilon_Z A_Z / N_Z\varepsilon_W A_W$
- Use LEP $\Gamma(Z)/\Gamma(Z\to ee)$
- Use PQCD and SM EWK
- Extract $\Gamma(W)$



$R_\mu = \sigma(W\to\mu\nu)/\sigma(Z\to\mu\mu) =$
$13.66 \pm 1.94_{stat} \pm 1.12_{syst}$
CDF Run 2 Preliminary

Extracted $\Gamma(W)$ GeV =
$1.67 \pm 0.24_{stat} \pm 0.14_{syst} \pm 0.01_{th}$
CDF Run 2 Preliminary

$\Gamma(W)$ (theory) = 2.093±0.002 GeV (PDG 98)
Run1 CDF: $2.04 \pm 0.11_{stat} \pm 0.09_{syst}$ GeV

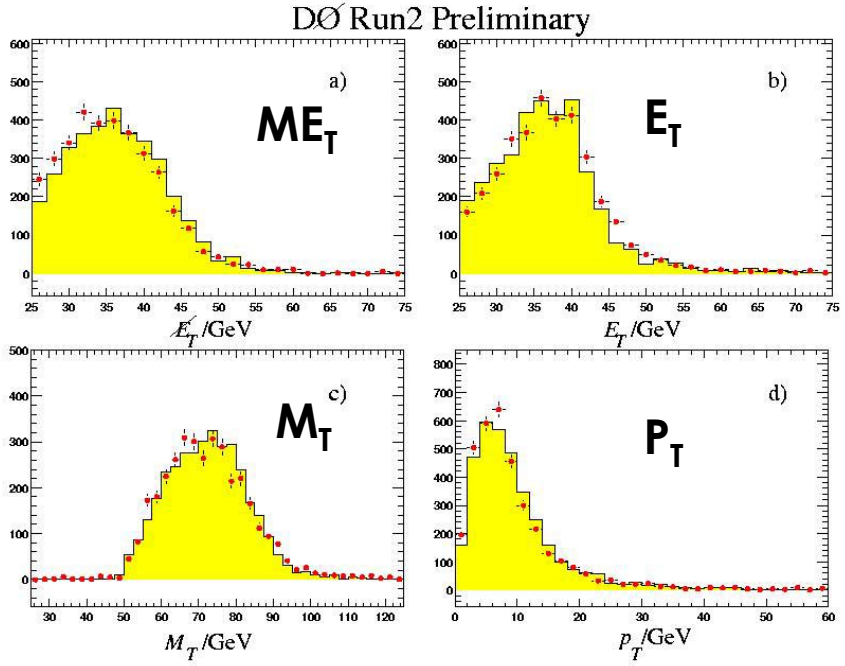
W →eν at Dzero

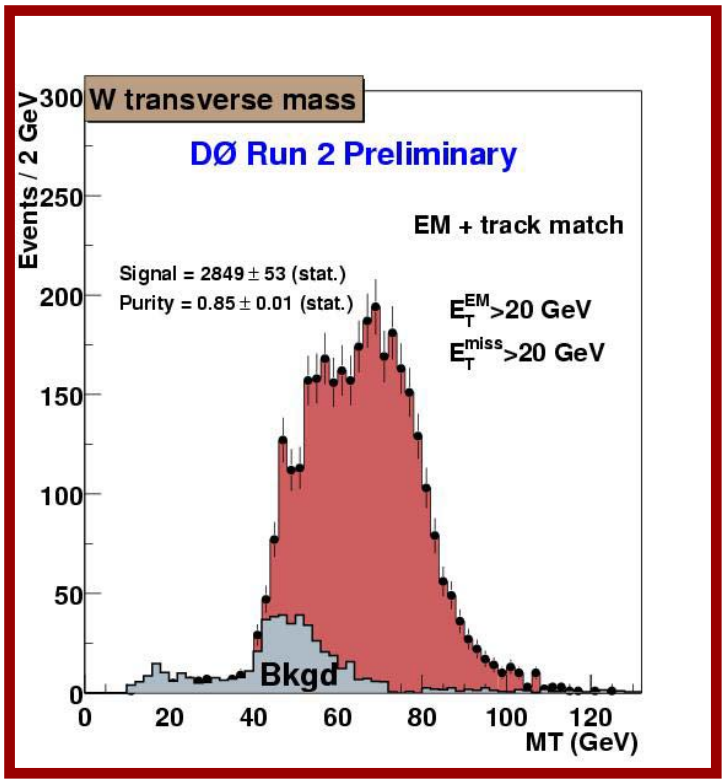
Number of Candidates:

- $N_w = 3493 \pm 75_{stat} \pm 357_{sys}$

Background:

- $N^{tot} = N_W + N_{QCD}$
- $N^{trk} = \varepsilon_{trk} N_W + f_{fake} N_{QCD}$





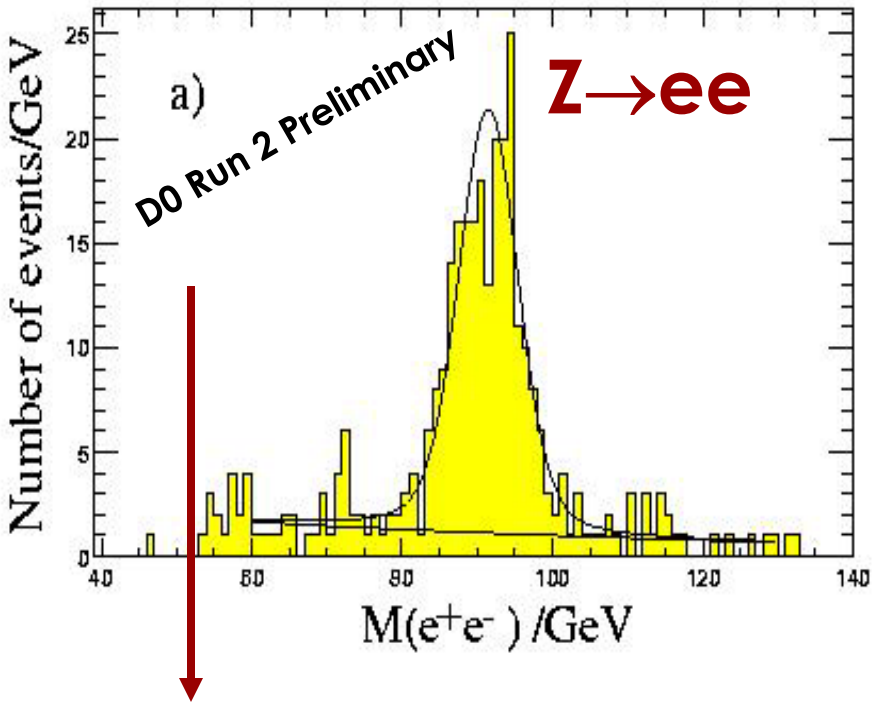
Dzero Run 2 Preliminary

$\sigma_W * BR(W \to e\nu) =$
$2.67 \pm 0.06_{stat} \pm 0.33_{syst} \pm 0.27_{lum}$

Measurement of R_e and $\Gamma(W)$ at D0

$$R_\ell = \frac{\sigma(pp\to W)\,\Gamma(Z)\,\Gamma(W\to\ell\nu)}{\sigma(pp\to Z)\,\Gamma(Z\to\ell\ell)\,\Gamma(W)} = \frac{\sigma(W\to\ell\nu)}{\sigma(Z\to\ell\nu)}$$

- Measure $\sigma(W\to e\nu)$ / $\sigma(Z\to ee)$
- Use LEP $\Gamma(Z)/\Gamma(Z\to ee)$
- Use PQCD and SM EWK
- Extract $\Gamma(W)$



$R_e = \sigma(W\to e\nu) / \sigma(Z\to ee) =$
$10.0 \pm 0.8_{stat} \pm 1.3_{syst}$
D0 Run 2 Preliminary

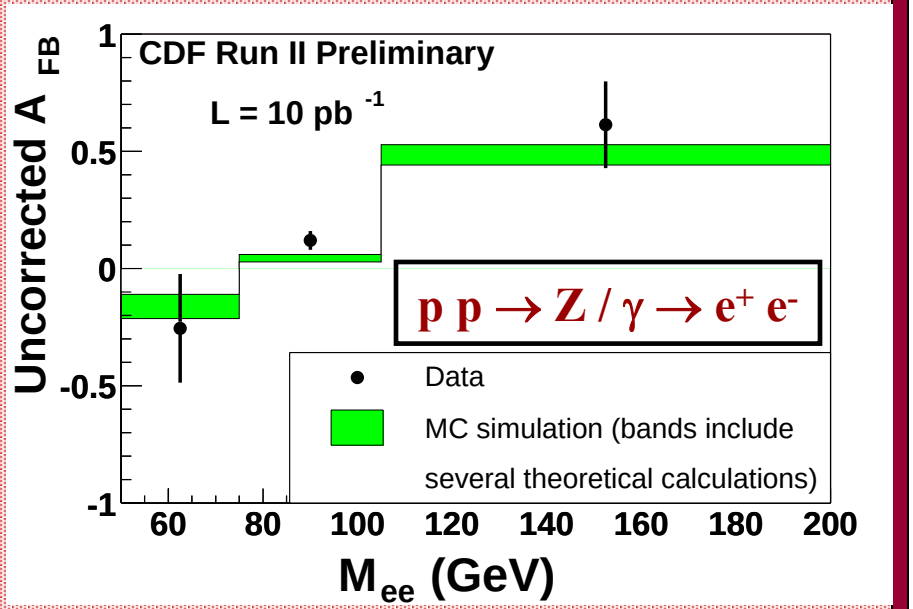
Extracted $\Gamma(W)$ =
$2.26 \pm 0.18_{stat} \pm 2.9_{syst} \pm 0.04_{th}$
D0 Run 2 Preliminary

$\sigma_Z \times BR(nb) = 2.66 \pm 0.20_{stat} \pm 0.20_{sys} \pm 0.27_{lum}$
D0 Run 2 Preliminary

$\Gamma(W)$ (theory) = 2.093 ± 0.008 GeV
Run1 D0: $2.23 \pm 0.15_{stat} \pm 0.01_{syst}$ GeV

EWK Physics To Come

- W cross sections strengthened: systematic errors on and P scale and resolution decrease with increased *L*.
- W mass: Resolution limited by multiple interactions.
- W width, both direct and indirect.
- A_{FB} in Z: Probe of V,A couplings… off pole!
- Extract $\sin^2\theta_W^{eff}$ from A_{FB}.
- W charge asymmetry: constrains PDFs.
- Tri-linear couplings of W,Z,γ.
- QCD: W/Z+Jets; W angular distribution; $P_T(W)$, $P_T(Z)$.



Physics of the Top Quark

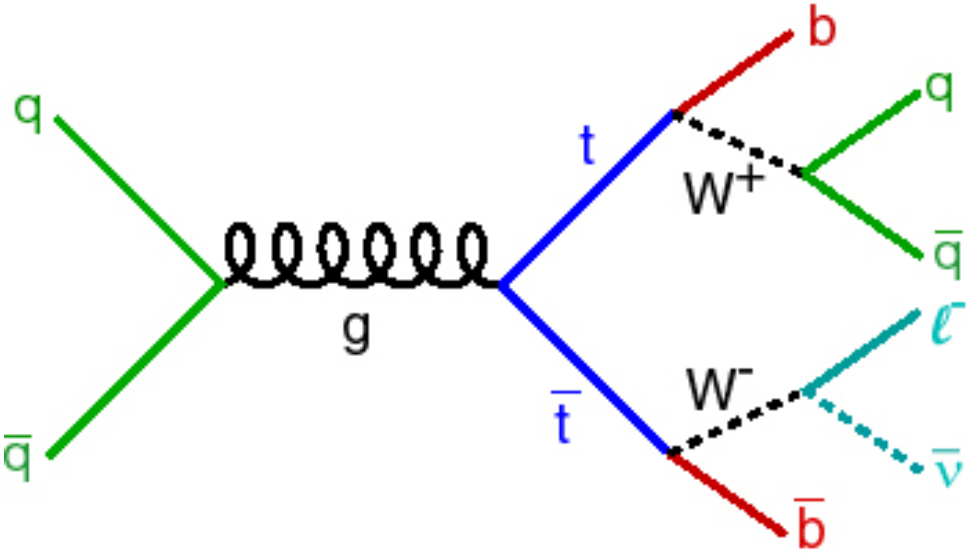
When Trish discovers Ned works exclusively with top quarks, she will be putty in his hands.

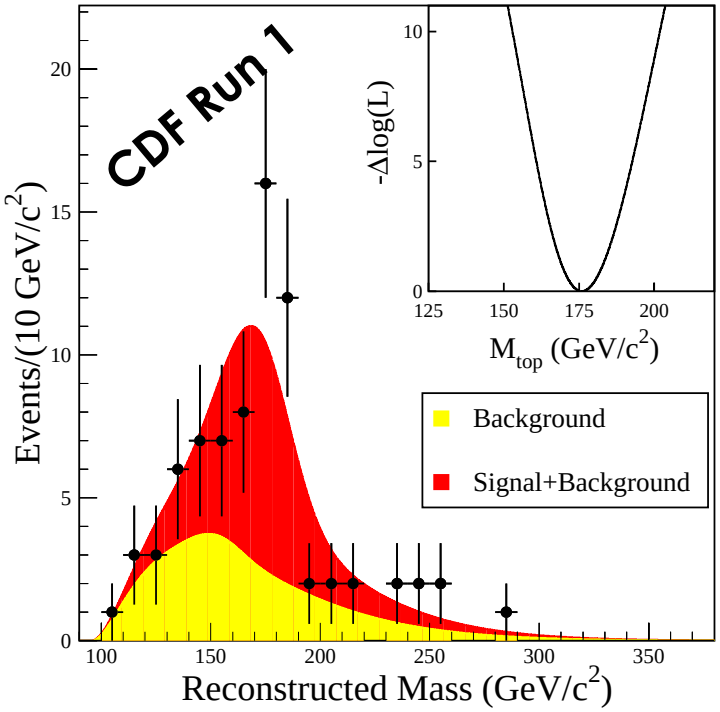
Top physics is one of the more sexy things to study at the Tevatron…

Top Physics at the Tevatron

- **Discovery in 1995**

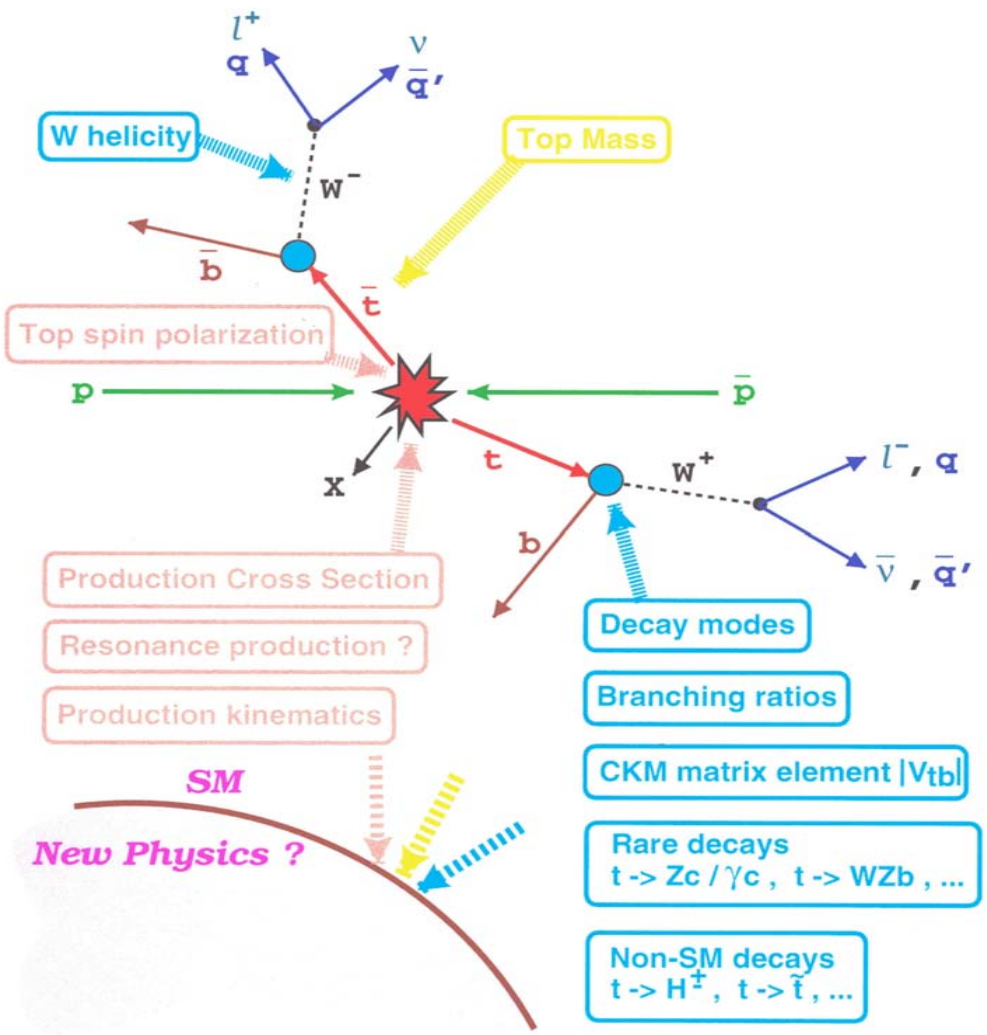
  CDF+D0 combined:
  m_t=174.3± 5.1 GeV/c^2





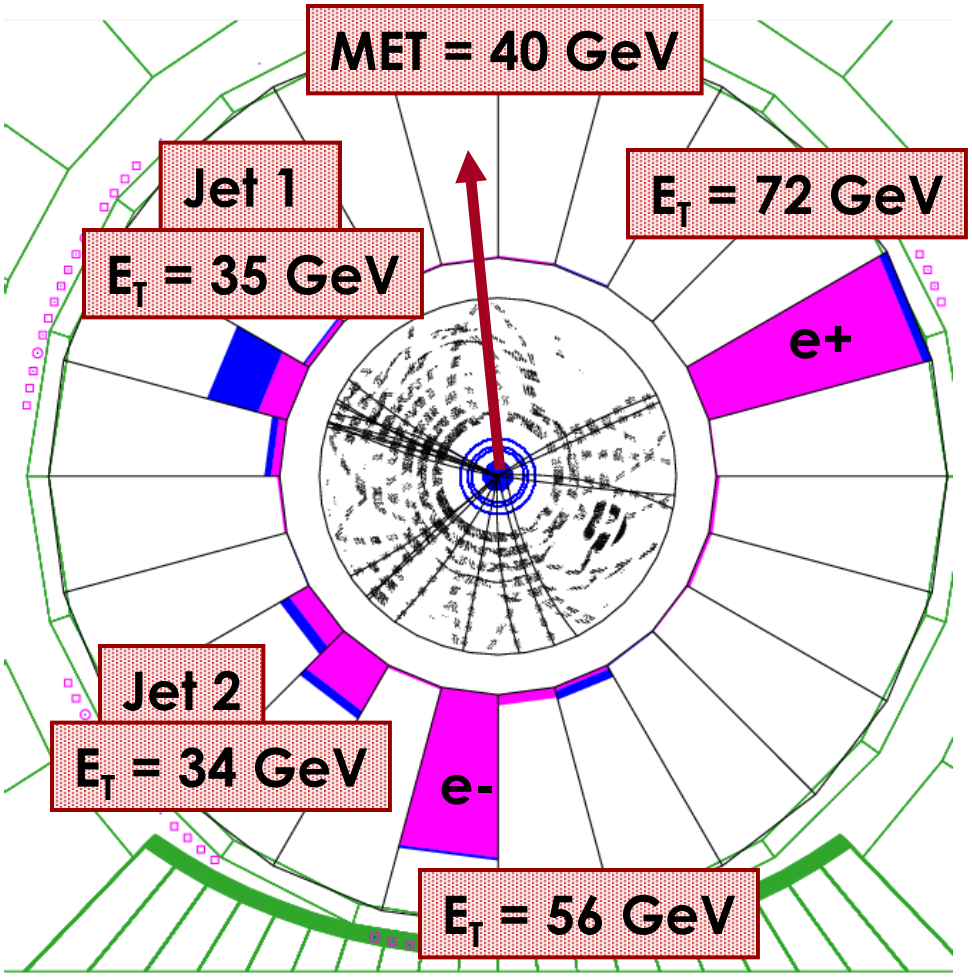
- **Main "usable" top event topologies:**
  - **$t\bar{t} \to \ell\nu\ell\nu bb$** **di-lepton** **5% e+μ**
  - **$t\bar{t} \to \ell\nu qqbb$** **lepton+jets** **30% e+μ**
  - **$t\bar{t} \to qqqqbb$** **all hadronic** **45%**

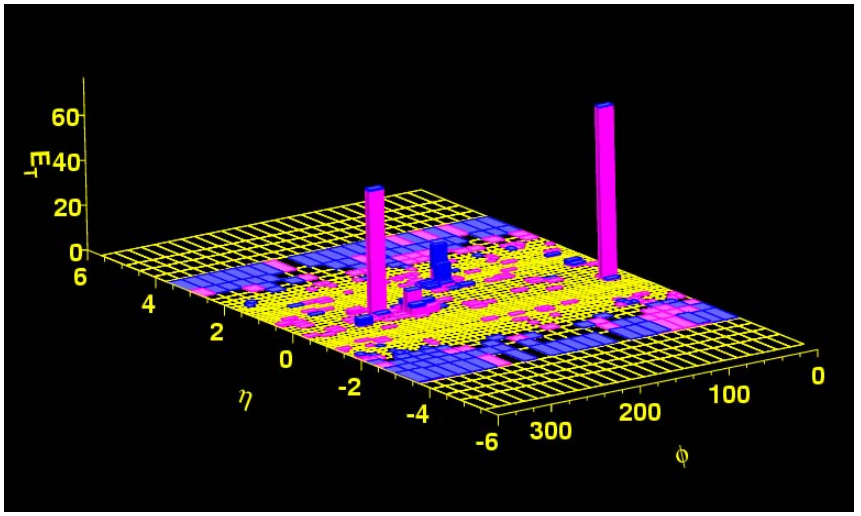
Top Quark Understanding



- **Top pairs: $\sigma(t\bar{t}) \sim 8$ pb**
  - W helicity in top events
  - t-tbar spin correlations
  - Top P_T
  - QCD tests
  - Top Drell-Yan via $d\sigma/dM$ of $t\bar{t}$
  - New physics in $X \rightarrow t\bar{t}$
  - Anomalous couplings, new particles
- **Single top: $\sigma(tb) \sim 3$ pb**
  - $|V_{tb}|$
  - QCD tests
  - New physics?

Toward a Top Dilepton Cross-Section





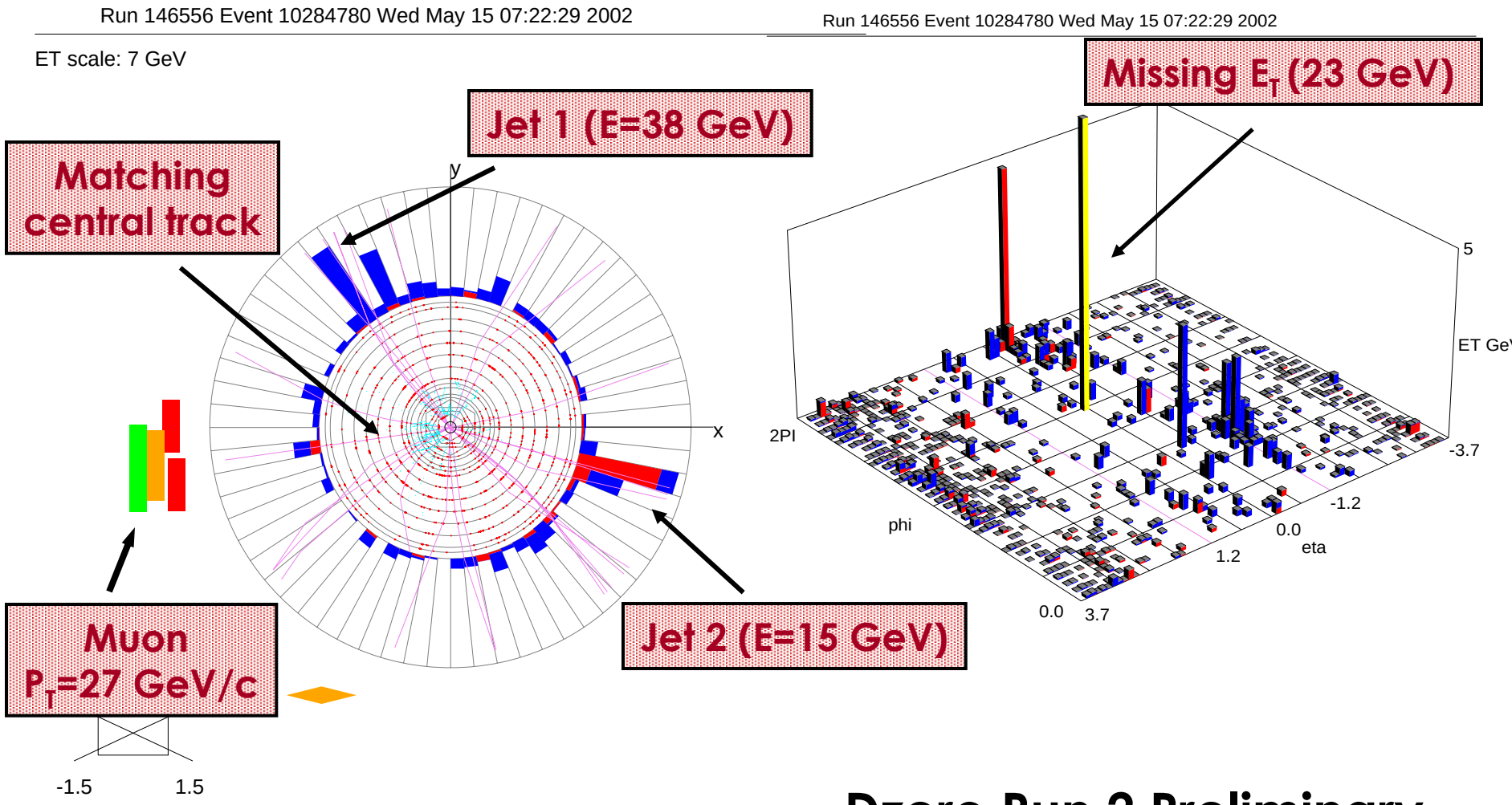
CDF Top Dilepton Candidate

CDF and Dzero both expect to measure the t-tbar cross section in the dilepton channel for winter conferences (March)

M_{ee} = 118 GeV/c^2 and H_T = 255 GeV

CDF Run 2 Preliminary

Dzero W→μν + jets Candidate

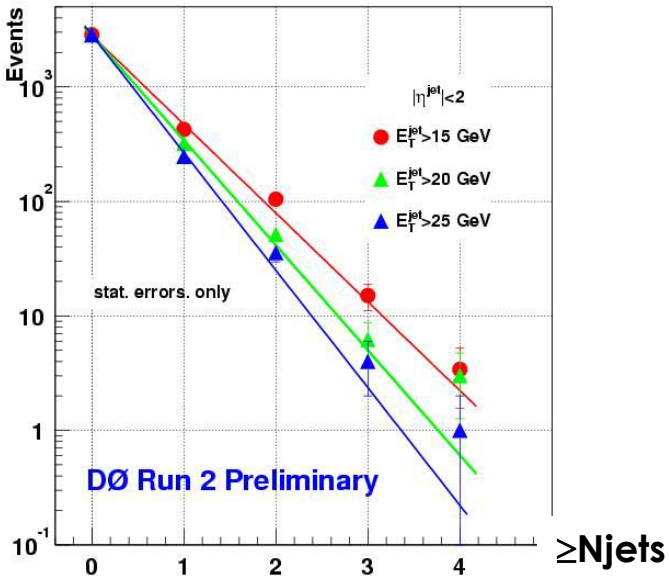


Dzero Run 2 Preliminary

Lepton+Jets Cross Section

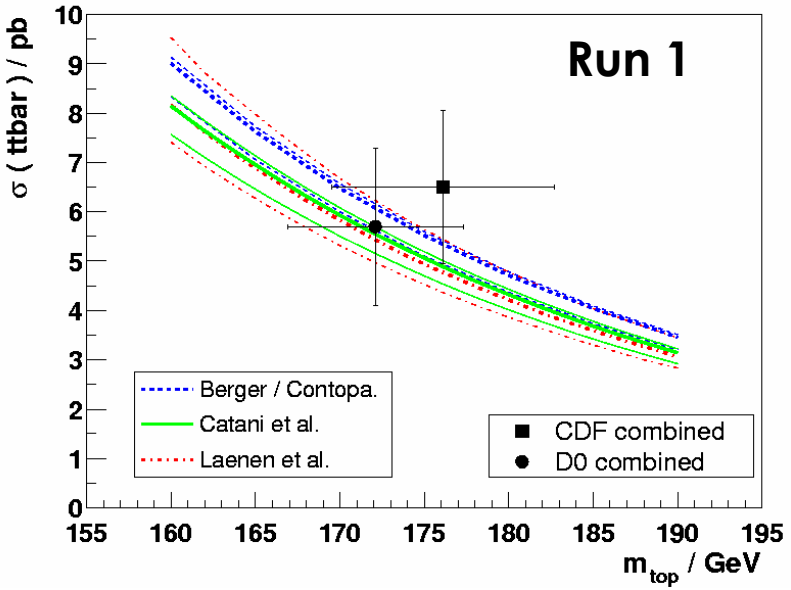
Separating Top from background:

- **Tagging b-jets**
  - **Displaced vertices**
  - **Soft lepton tagging (SLT)**
  - **Jet Probabilities**
- **Fitting to kinematical distributions using likelihood or neural network techniques**



D0 W→eν + jets candidates

Comparison with pQCD predictions

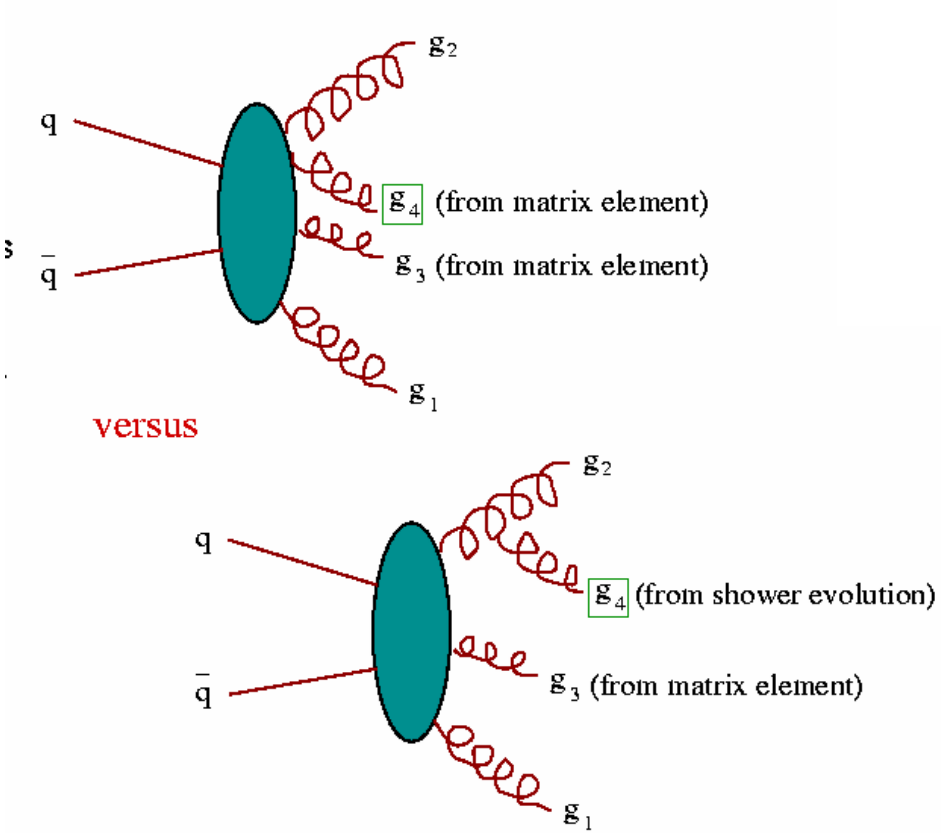


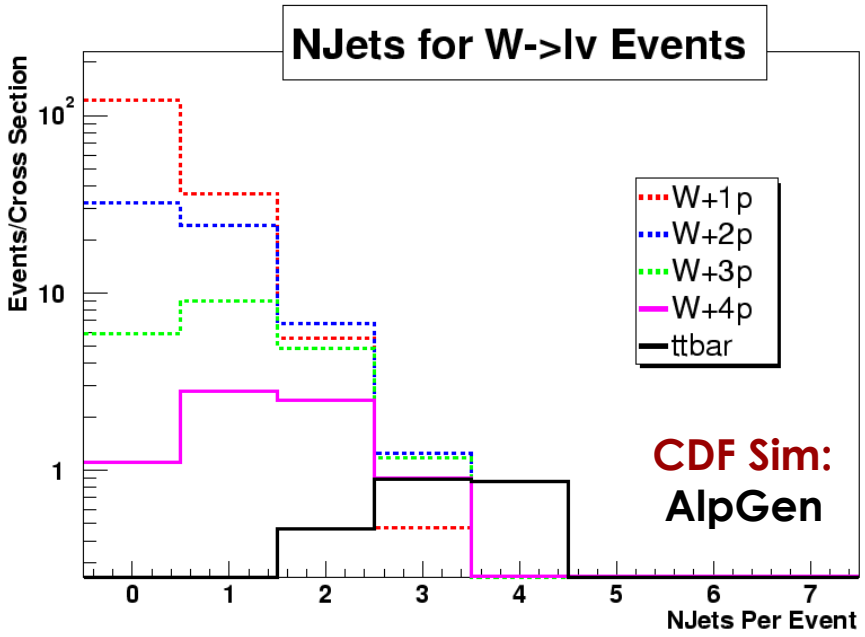
Run 2a: $\delta\sigma_{tt}/\sigma_{tt} < 7\%$
Run 1 : $\delta\sigma_{tt}/\sigma_{tt} \sim 26\%$

Both CDF and D0 plan to present ℓ+jets cross-section measurements in March

New ME/MC Generators

New tools have become available to generate background samples for top physics, including W+N partons and W+heavy flavor + N partons.



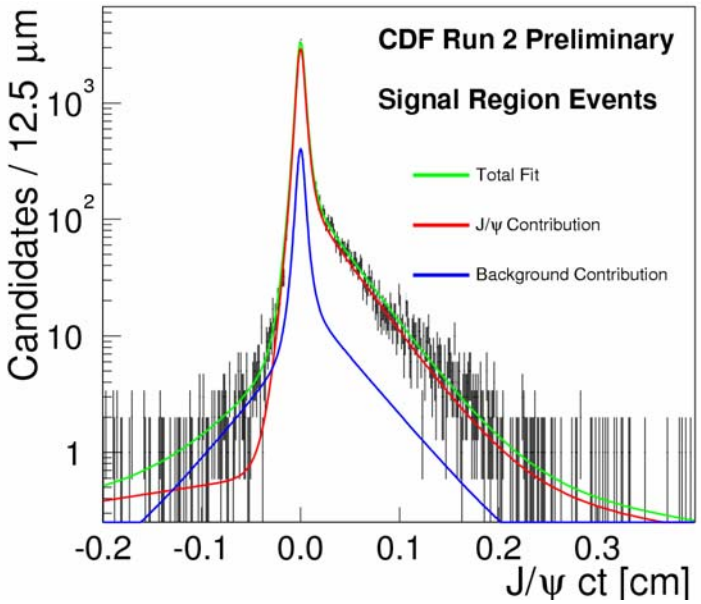


- **AlpGen, MadGraph, CompHep, GRAPPA, and MCFM are being studied and compared.**
- **Focusing on AlpGen: How to combine W+Np samples without double counting? What parton level cuts should be used?**

(M.L. Mangano, S. Tsuno, K. Ellis, J. Campbell, S. Mrenna, T. Stelzer, L. Dudko)

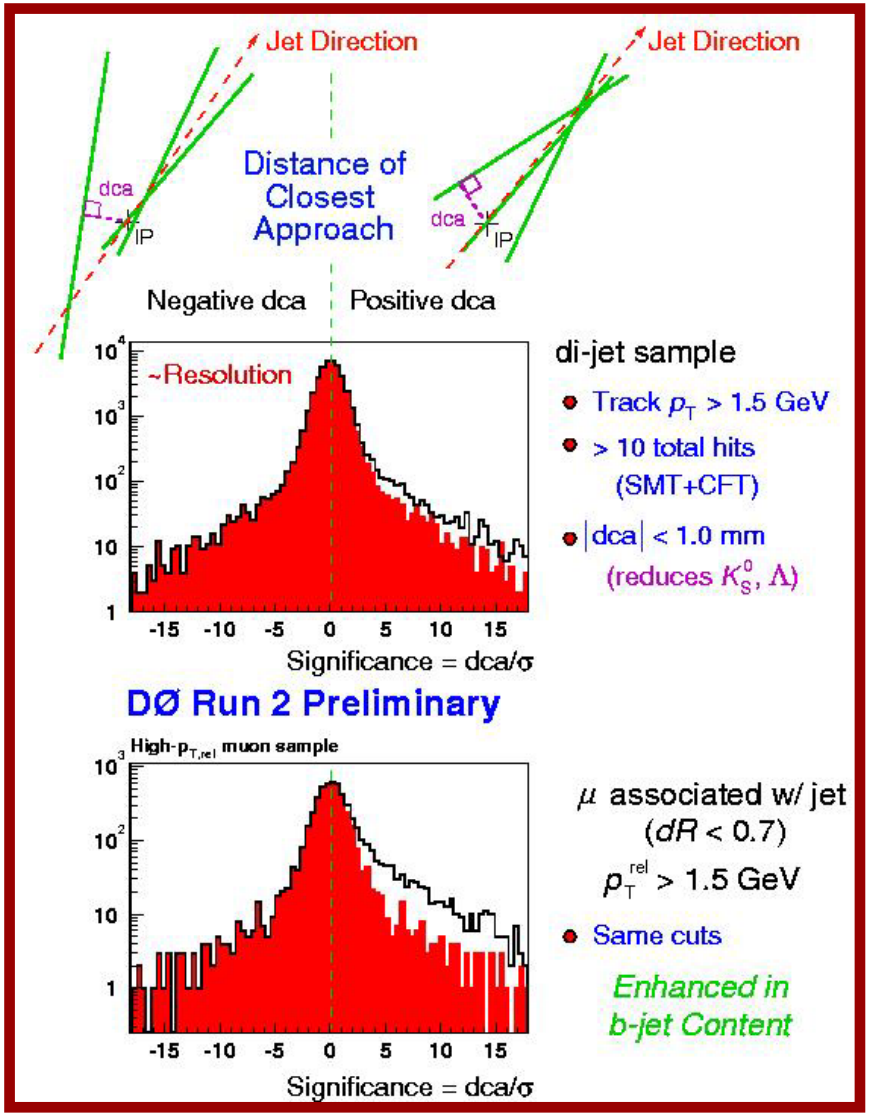
b-tagging in Run 2

Inclusive B lifetime from J/Ψ



- Run 2 silicon vertex detectors are performing well
- B-tagging studies underway
- Soft lepton tagging for b-jets is also being studied

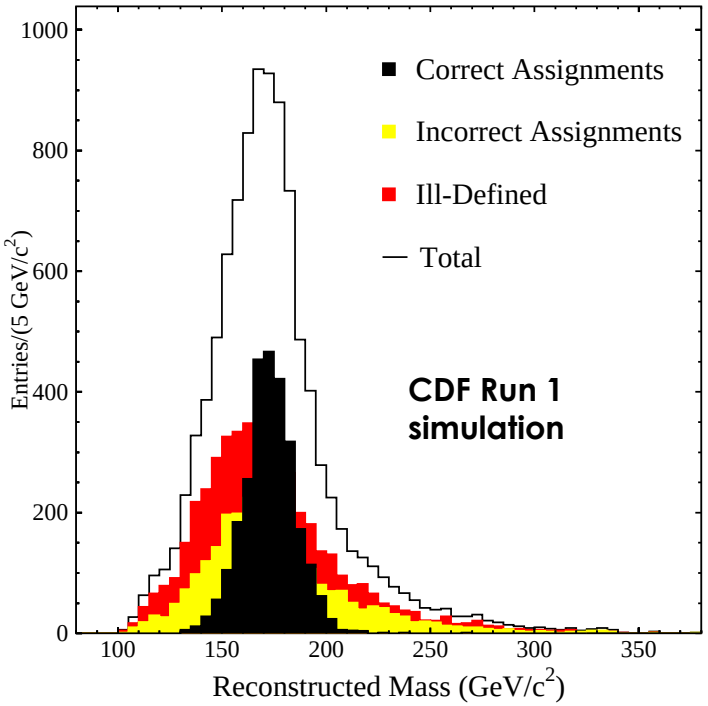
Tagging via Impact Parameter



Measuring the Top Mass

Lep+Jets & dilepton channels

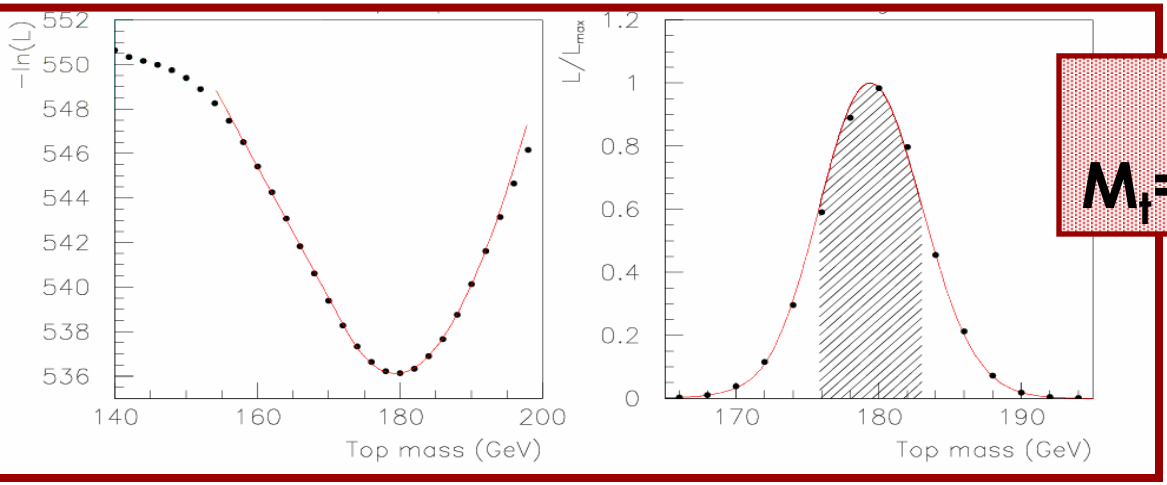
- **Improvements to ΔM_{top}:**
  - Statistics:
    - Increased b-tag acceptance
    - More events with b-tag reduces combinatorics
    - Choose best measured events
  - Jet Energy Scale
    - Use control samples ($Z \rightarrow bb$, $W \rightarrow qq$) to reduce systematics
    - Jet energy flow techniques
- **Run 2a Expectations:**
  - $\Delta M_{top} = \pm 2\text{-}3$ GeV per expt



Source	Value (GeV/c^2)
Jet Energy Scale	4.4
Initial State Rad.	1.3
Final State Rad.	2.2
Bckg Spectrum	1.3
b-tag bias	0.4
PDF	0.3
MC Generator	0.1
Total	5.3

New Run 1 Analysis of M_{top}

- Method similar to Dalitz, et. al., and dilepton M_t measurement by DØ - PRD 60 52001 (1999).
- For each event, S & B probabilities are added, then multiplied by the other event probabilities.
  - Probability is calculated using the matrix element for production/decay
  - Each event has its own probability distribution
  - The probability depends on (almost) all measured kinematical quantities
  - Each event's contribution depends on how well it is measured

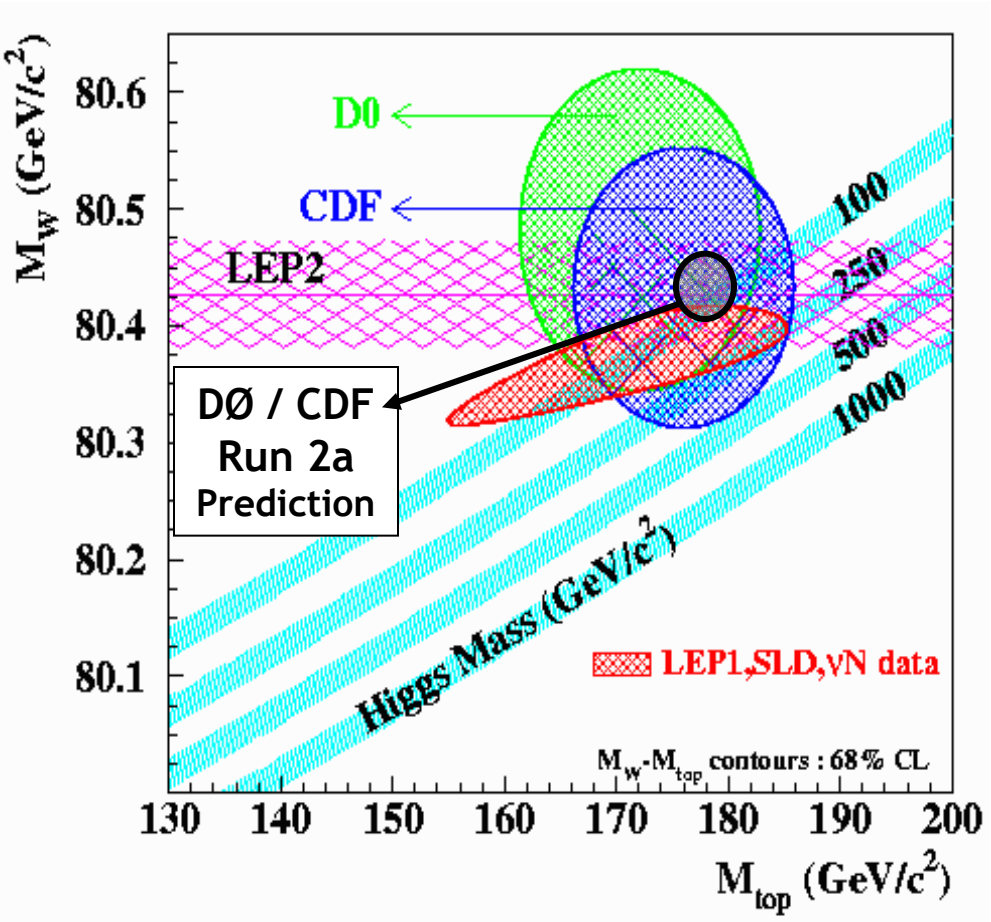


D0 Run 1 Preliminary:
M_t= 179.9±3.6±6.0 GeV

Compare D0 Run 1:
M_t=174.0 ±5.6 ± 5.5 GeV

- Improved stat. error equivalent to ~2.4 times # events.

EWSB Constraints



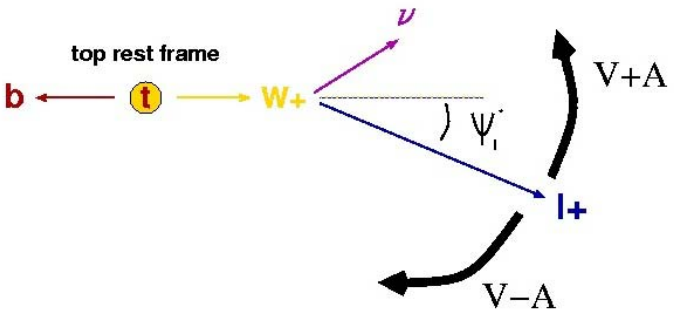
Precision measurements of top and W masses constrain the mass of the Standard Model Higgs

- M_W : CDF ⊕ DØ
  - σ_M ~ 30 MeV (2 fb^{-1})
  - σ_M ~ 20 MeV (10 fb^{-1})
- M_t : CDF or DØ
  - σ_M < 4 GeV (2 fb^{-1})
  - σ_M < 2 GeV (10 fb^{-1})

With only 2 fb^{-1} we may find a contradiction with the Standard Model Higgs direct search limit

V+A in the Top Sector

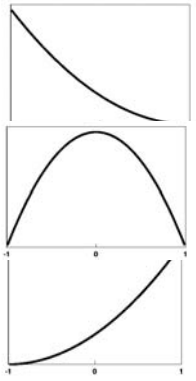
W helicity and $M^2_{\ell b}$ distributions

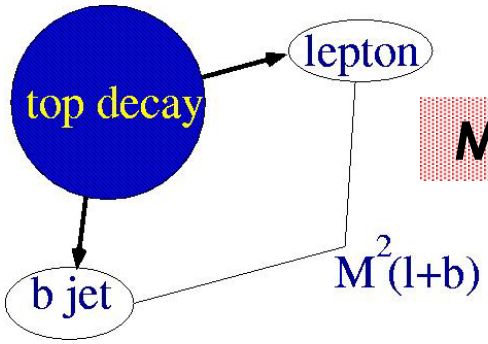


SM V-A Theory:

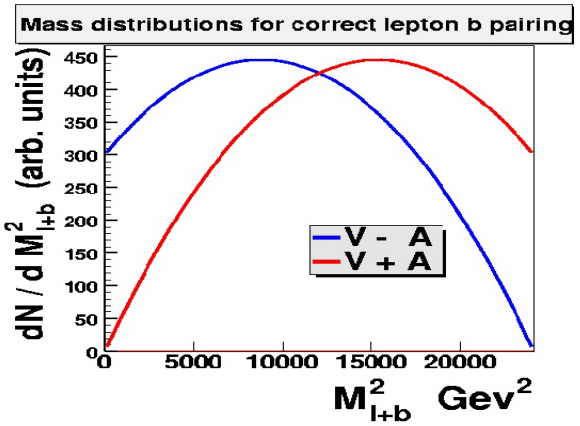
30%	F_-
70%	F_0
<0.04%	F_+ (M_b)

$$H_W = \bar{J} \cdot \hat{P} \begin{cases} \text{-1 Left handed} & F_-(\cos\Psi^*_\ell) \sim (1 - \cos\Psi^*_\ell)^2 \\ \text{0 Longitudinal} & F_0(\cos\Psi^*_\ell) \sim (1 - \cos\Psi^{*2}_\ell) \\ \text{+1 Right handed} & F_+(\cos\Psi^*_\ell) \sim (1 + \cos\Psi^*_\ell)^2 \end{cases}$$





$$M^2_{\ell b} = \tfrac{1}{2}(M^2_T - M^2_W)(1 + \cos\Psi^*_\ell)$$



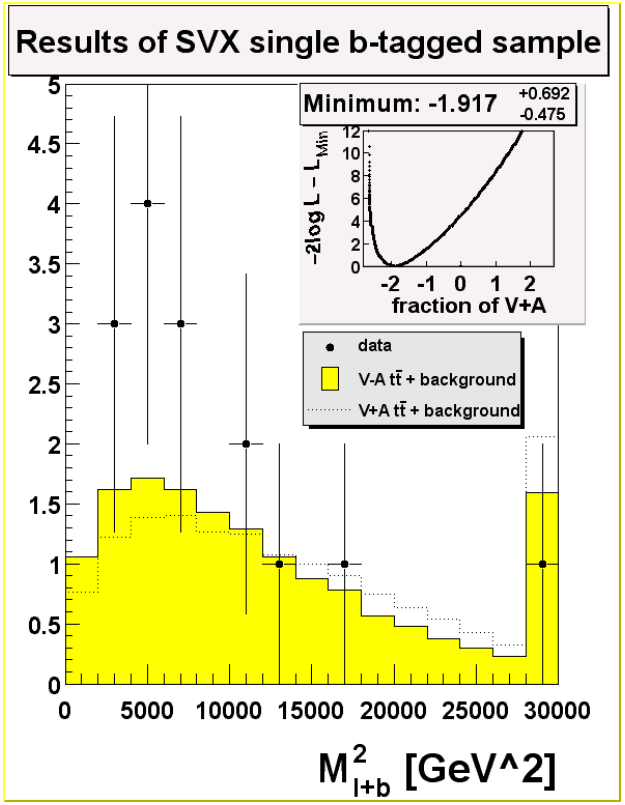
CDF Run 2 Preliminary

Sensitivity to V+A in Top

New CDF Run I Result:

(Using ttbar dilepton, and lepton+jets events with 1 and 2 SVX b-tagged jets)

$$f_{V+A} = -0.21\ ^{+0.42}_{-0.25} \pm 0.21$$



f_{V+A} :

0: corresponds to all V-A, (0 % right-handed W's)

1: corresponds to all V+A (30% right-handed W's)

Run 2 Expected sensitivity:

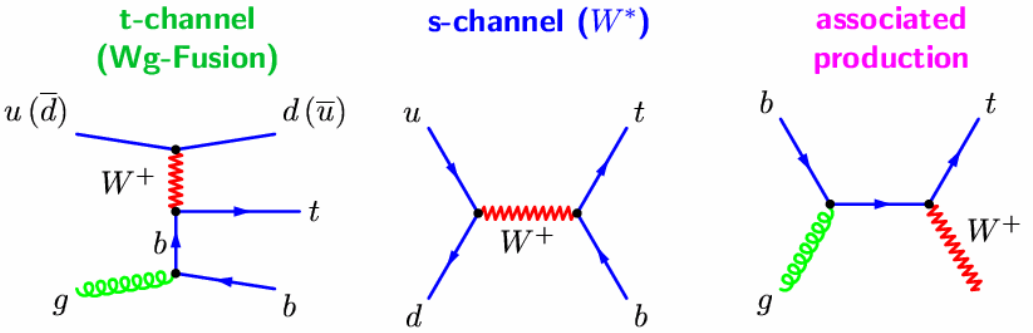
Luminosity	Stat Error	Syst Error
109 pb^{-1} (run I)	0.59	0.21
500 pb^{-1}	0.19	0.11 (2000 pb^{-1})
1000 pb^{-1}	0.14	
2000 pb^{-1}	0.10	

Ben Kilminster

Search for Single Top

- CDF and D0 have performed searches for s and t channels separately in Run 1.
- CDF has also searched for combined process:
  $\sigma(t) < 14$ pb at 95% C.L.

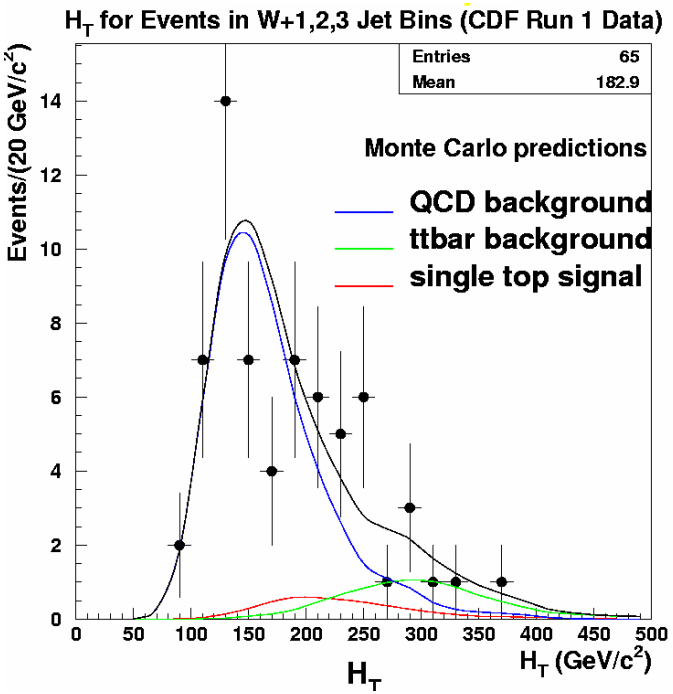
Electroweak Wtb Vertex



2.44 ± 0.12 pb
Steltzer, et al. '98

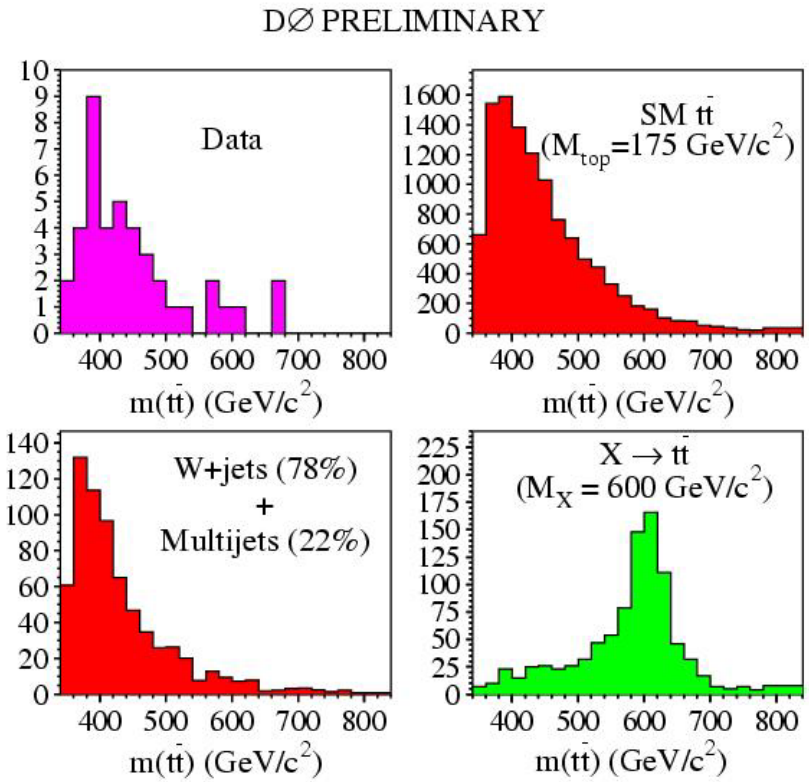
0.88 ± 0.12 pb
Smith/Willenbrock '96

σ<0.1 pb
Tait '99

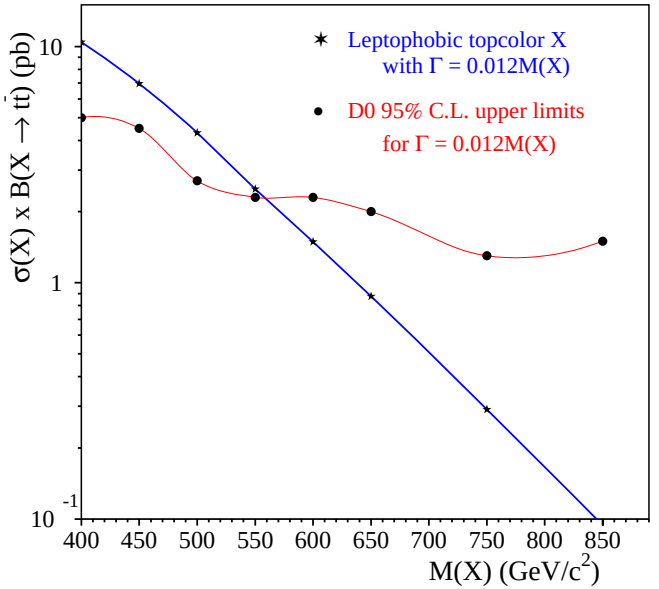


- Expect about 100-150 events in 2 fb^{-1}
- If SM is correct, observation in Run 2a
- Measure $|V_{tb}|$ with 10-15% precision

Search for t-tbar Resonances



Investigate models that dynamically break EW symmetry, such as topcolor-assisted technicolor



Search for narrow model-independent X→tt resonances in ℓ+jets

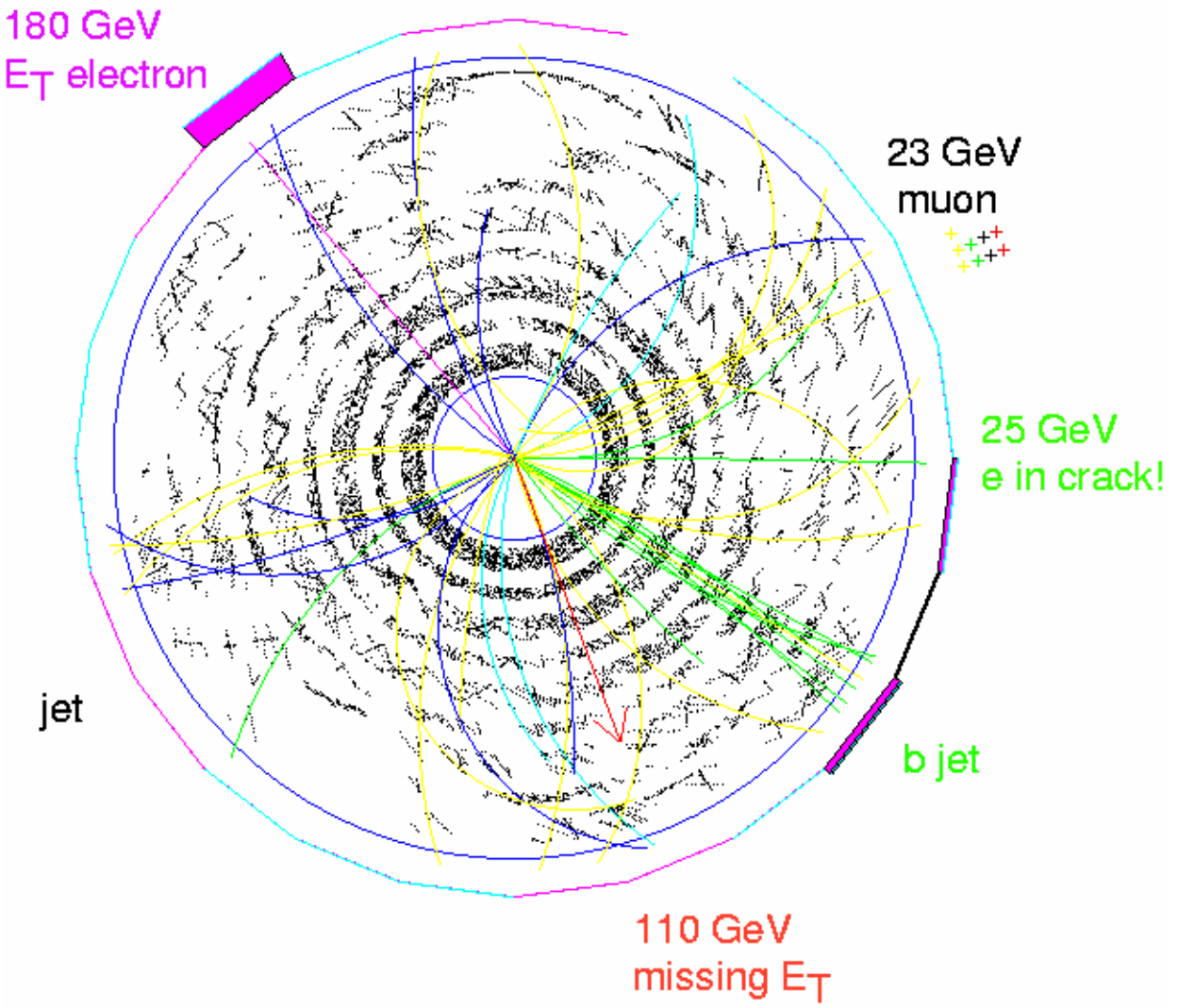
Exclude a narrow, leptophobic X boson with $m_X < 560$ GeV/c^2

…

Anomalies in the Top Sample?

- found in dilepton sample
- electron in crack called jet!
- 180 GeV E_T electron!
- 110 GeV missing E_T !

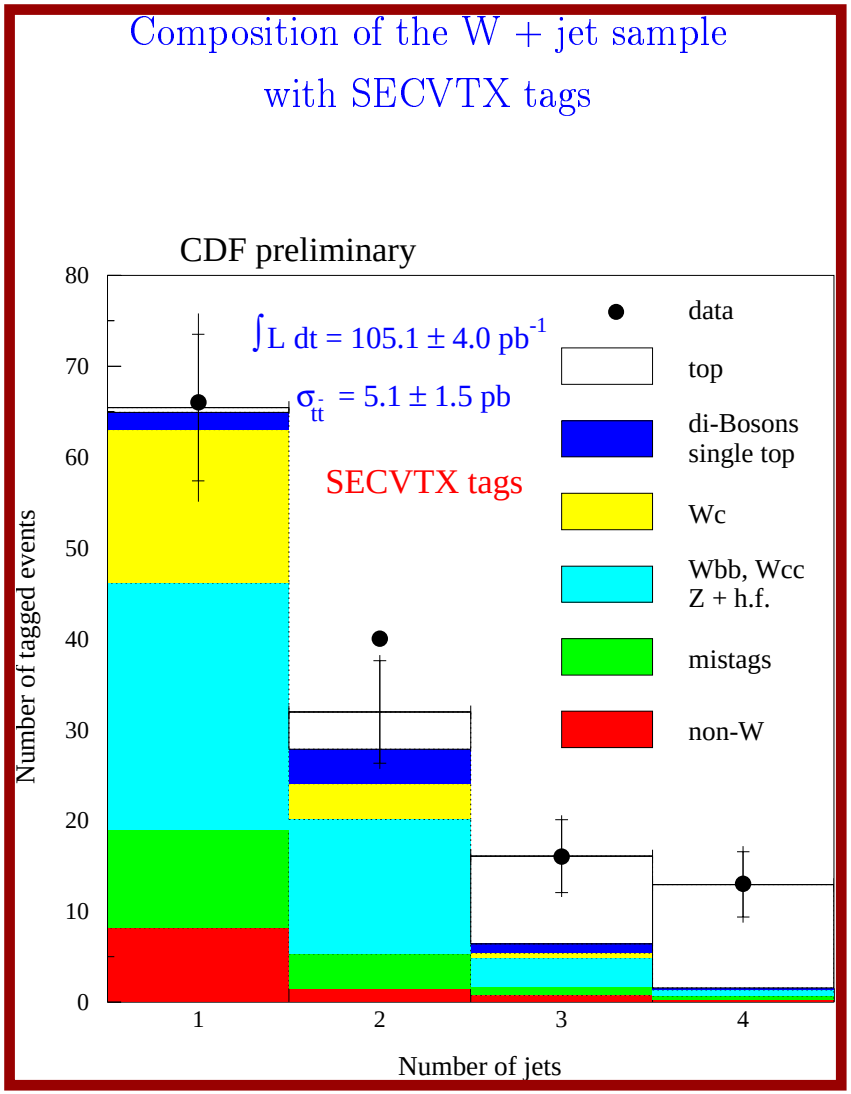
CDF Run 1 Trilepton Event



W + 2Jet Excess?

- Observed excess of b-tags in the 2 jet bin
- Too many SVX double tags (more than one b-tagged jet/event)
- Too many multiple tags (more than one b-tag/jet)

→ A lot of speculation, but nothing solid.



Summary

- Run I physics signals are being re-established
- Electroweak measurements from CDF and D0 are already being announced
- Top physics results are right around the corner
- Stay tuned for exciting results from the Tevatron!

John
The
Baptist

-da Vinci

Run 2 Luminosity Delivered