Top quark and electroweak results from Tevatron Run II

Presented on behalf of **CDF** and **DØ** by:

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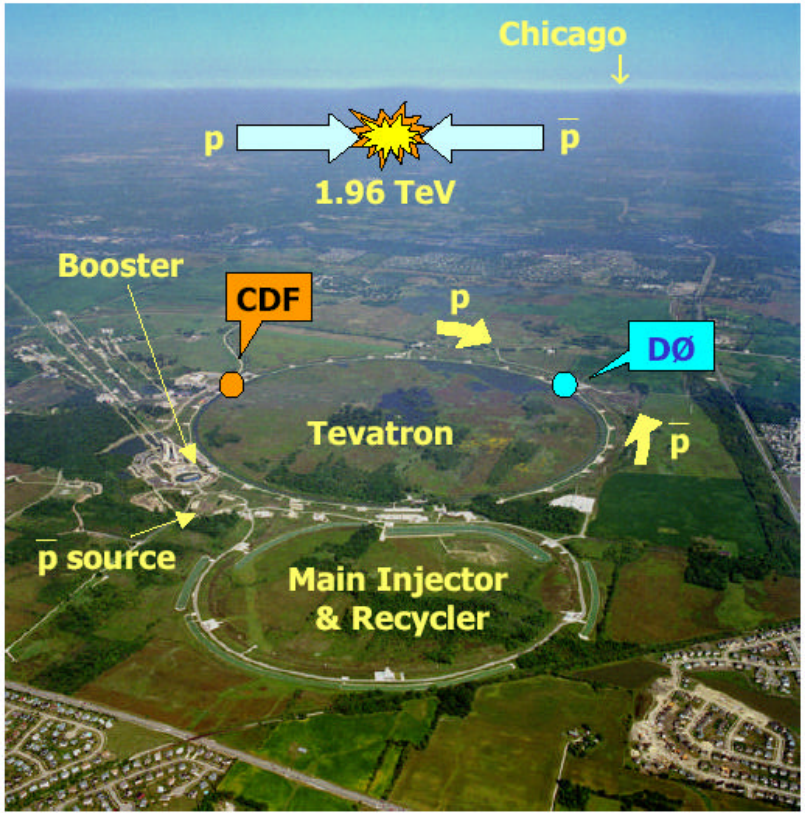
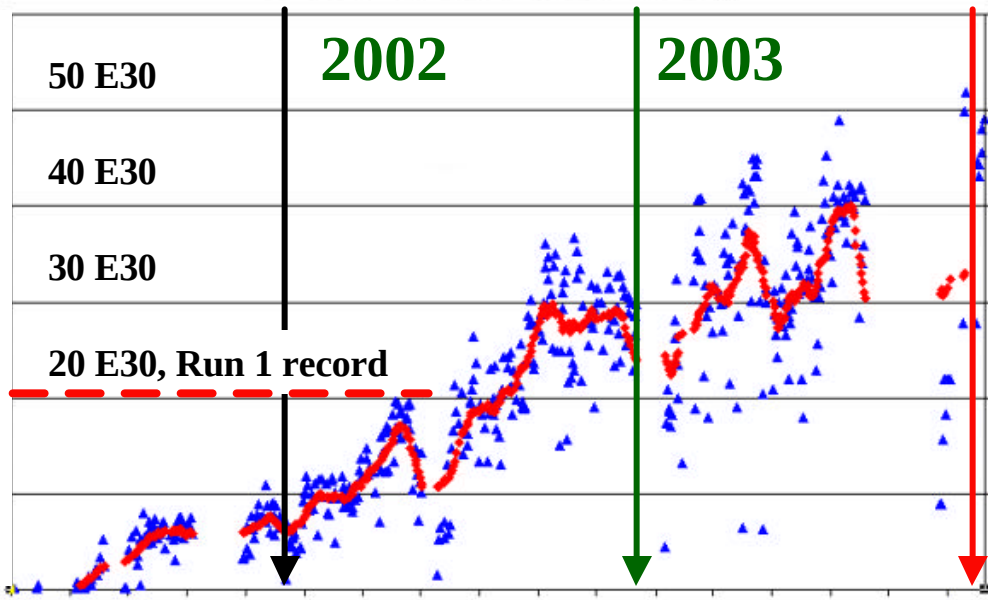
Tevatron Collider in Run II

- Tevatron is $p\bar{p}$ collider with $\sqrt{s} = \mathbf{1.96}$ TeV
- Increase of center of mass energy, crossing frequency, and bunch numbers



Collider Run II peak luminosity

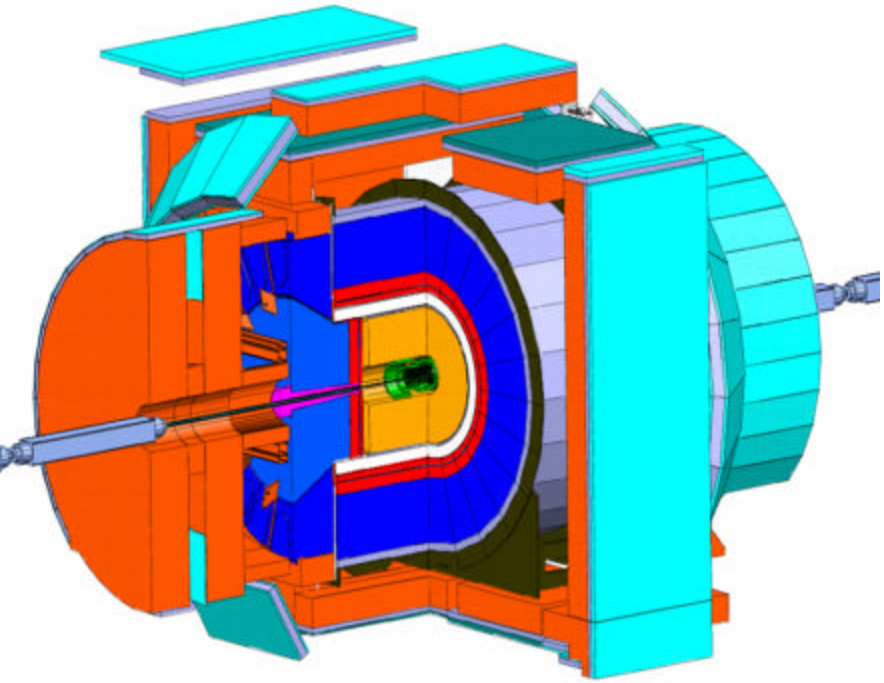


CDF and DØ Collaborations

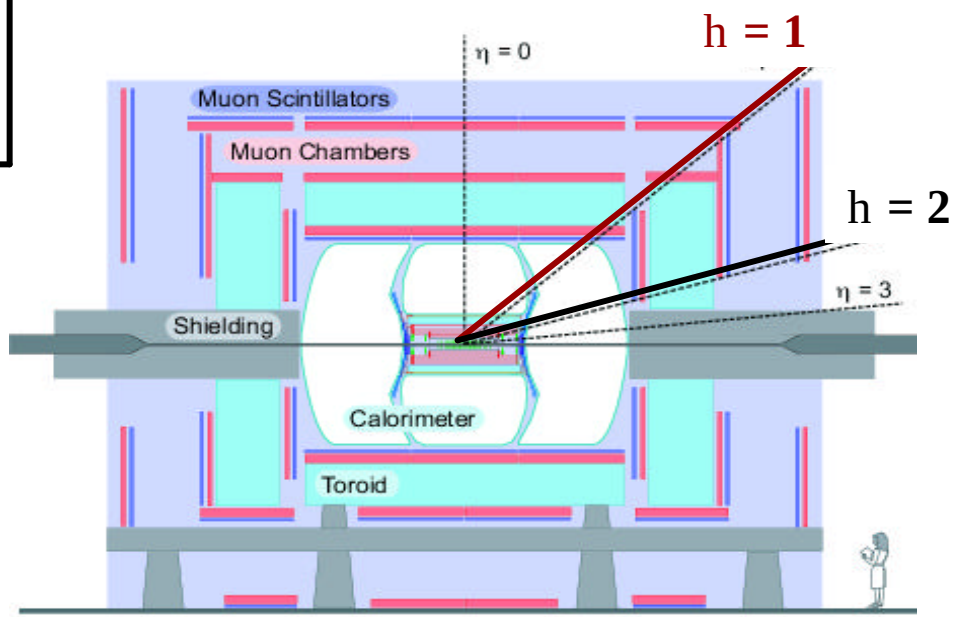
12 countries, 59 institutions
706 physicists

19 countries, 83 institutions
664 physicists

CDF and DØ Detectors

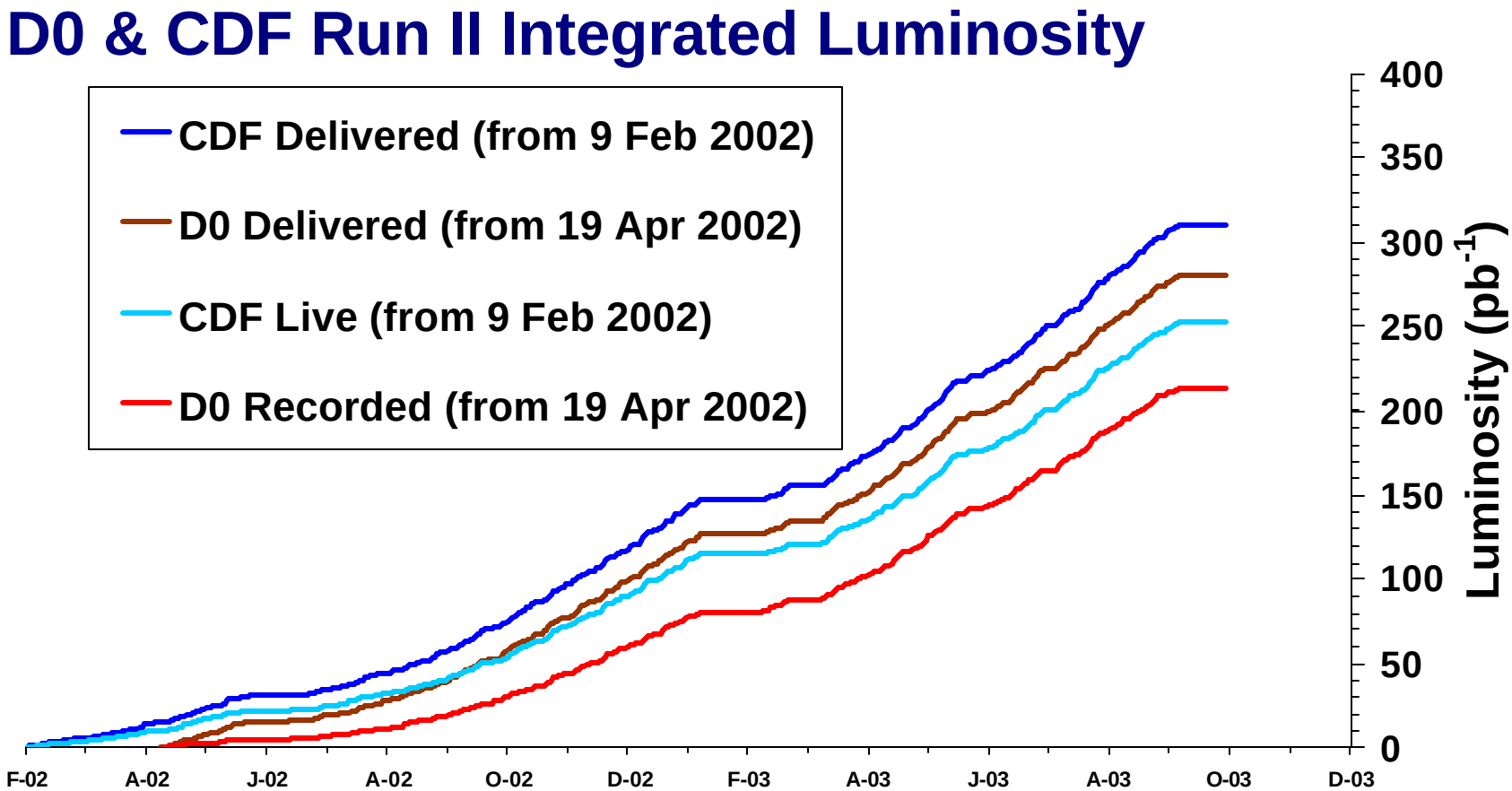


- New silicon and drift chamber
- Upgrade of calorimeter and muon system
- Upgrade of Trigger/DAQ



- New silicon and fiber tracker
- Solenoid (2 Tesla)
- Upgrade of muon system
- Upgrade of Trigger/DAQ

CDF and DØ performance



Extra **230-370 pb^{-1}** in FY 2004

The results presented in this talk are preliminary

- Use a subset of the data available

Electroweak and top physics

Run I:

top quark discovery, precision W mass and width measurements

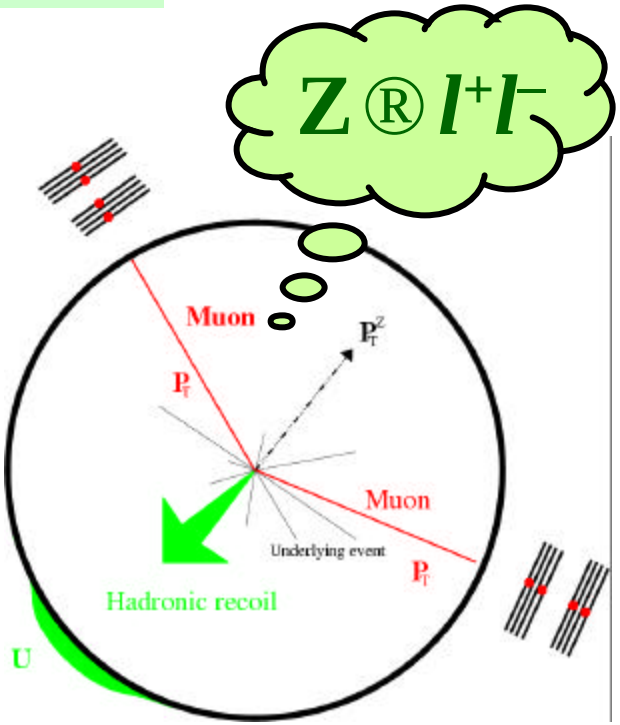
Run II:

precision electroweak and top quark measurements, analysis of rare processes

Sample	Run I	Run II (2 fb^{-1})
W ® *l*n	77k	**2300k**
Z ® l^+l^-	10k	**202k**
WV (V = W, Z, g)	90	**1800**
ZV	30	**500**
***tt* (mass sample, ³ 1 b-tag)**	20	**800**
Single top	4	**160**

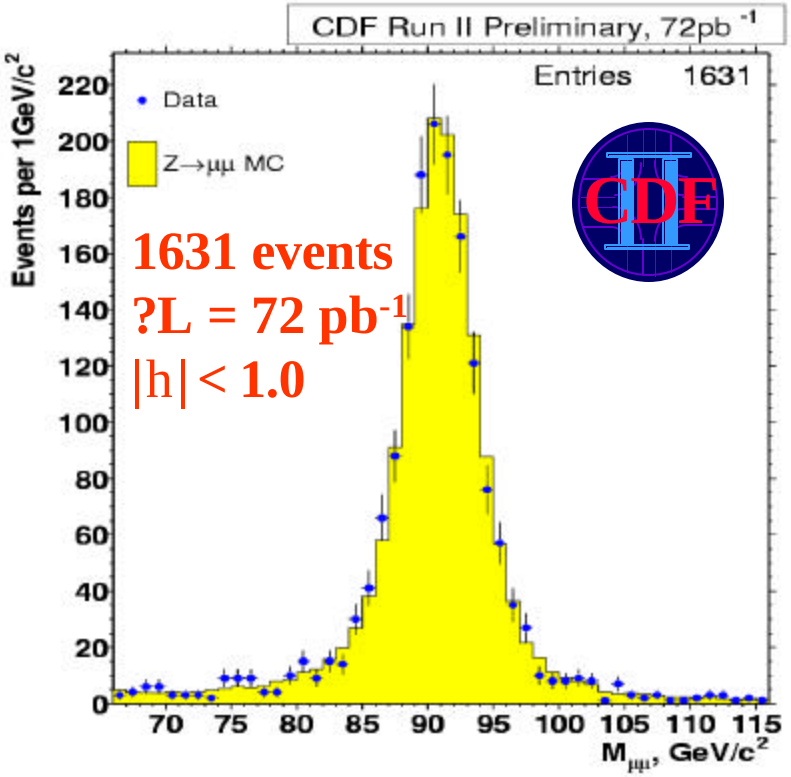
Electroweak program

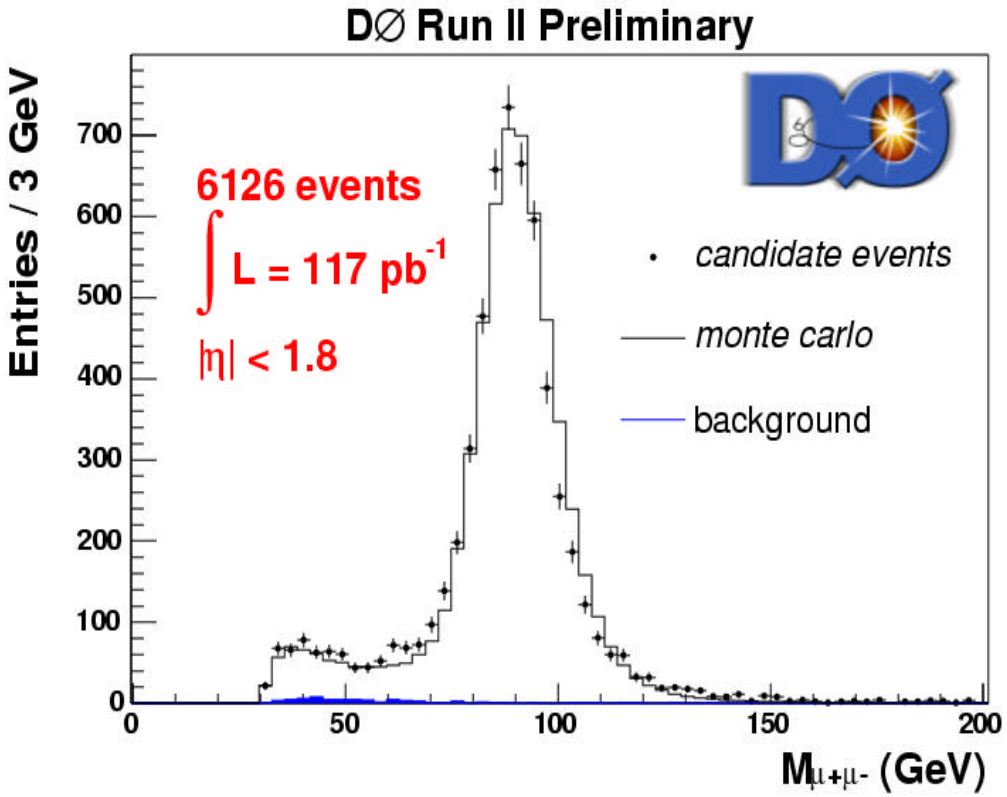
- Z, W cross section measurements
  - Detector commissioning and calibration
  - W width, lepton universality
  - Search for Z'/extra dimensions/…
- Z forward/backward asymmetry
- Di/triboson physics
- W charge asymmetry, differential W/Z cross sections
  - PDF constraints
- Use W and Z as a luminosity counter
- **W mass**



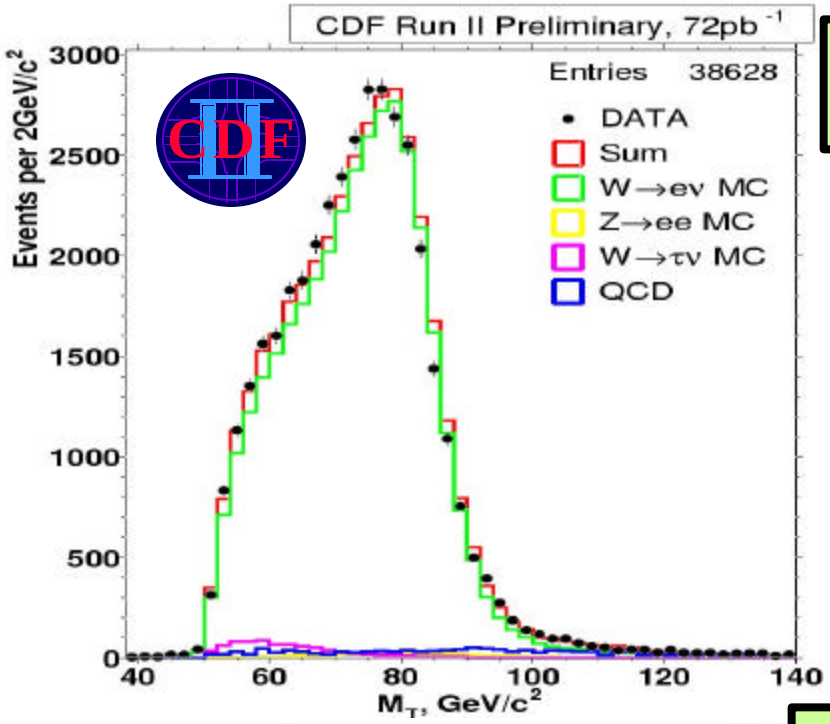
Cross-section measurements of $Z \rightarrow l^+ l^-$

Invariant mass of $\mathbf{Z} \rightarrow m^+ m^-$ candidate events:

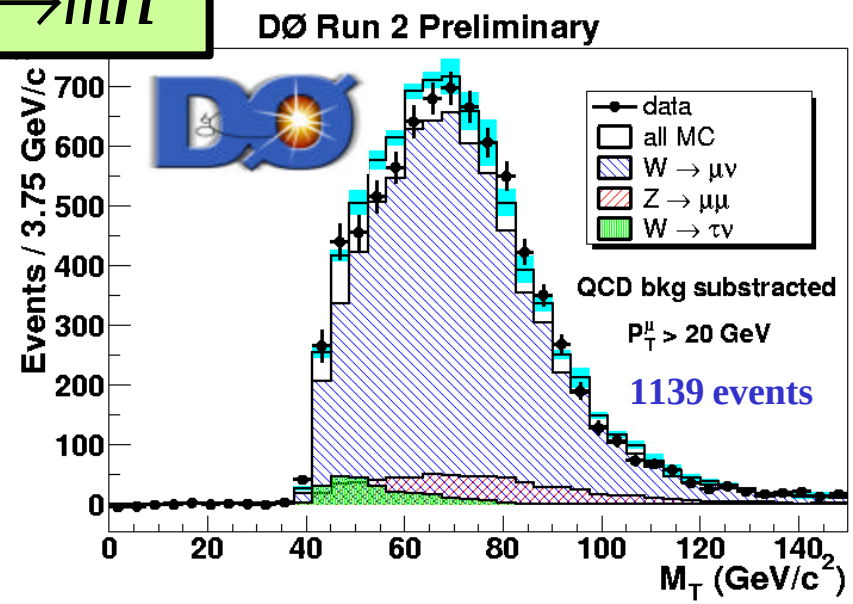


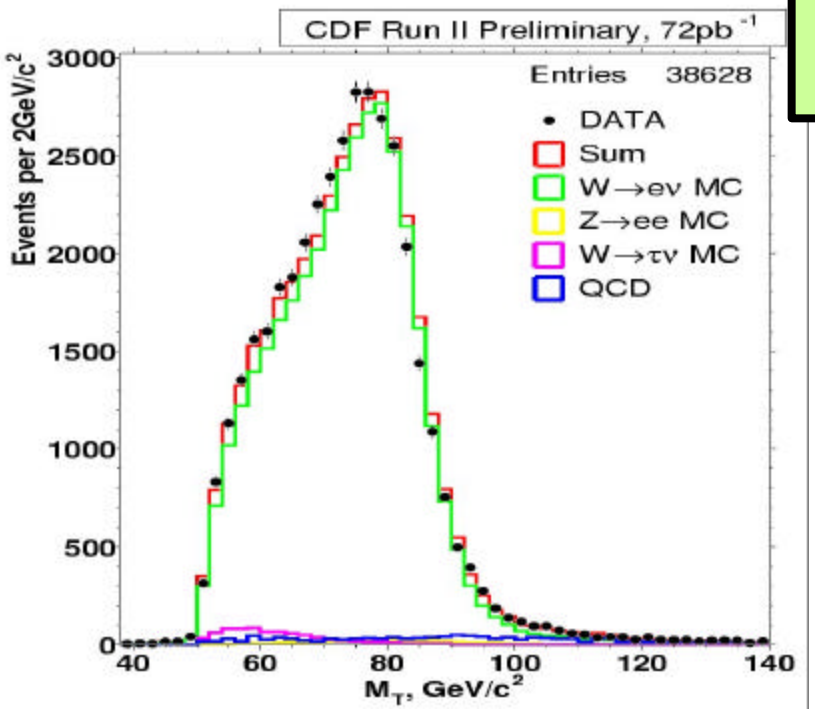


Good agreement between Monte Carlo simulation and data


CDF Run II Preliminary, 72pb^{-1}
Entries 38628
DATA
Sum
W→eν MC
Z→ee MC
W→τν MC
QCD
Events per 2GeV/c^2
M_T, GeV/c^2

W→*mn*


DØ Run 2 Preliminary
data
all MC
W → μν
Z → μμ
W → τν
QCD bkg substracted
P_T^μ > 20 GeV
1139 events
Events / 3.75 GeV/c
M_T (GeV/c^2)


CDF Run II Preliminary, 72pb^{-1}
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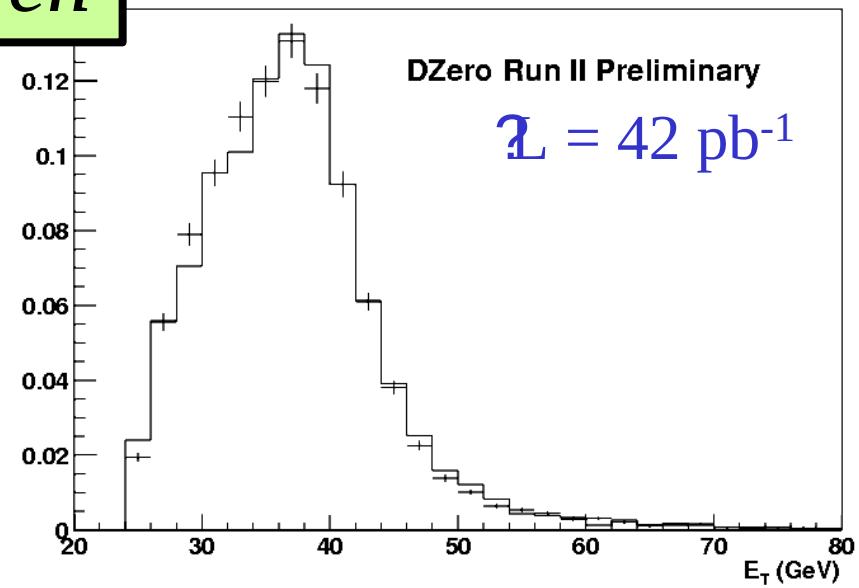
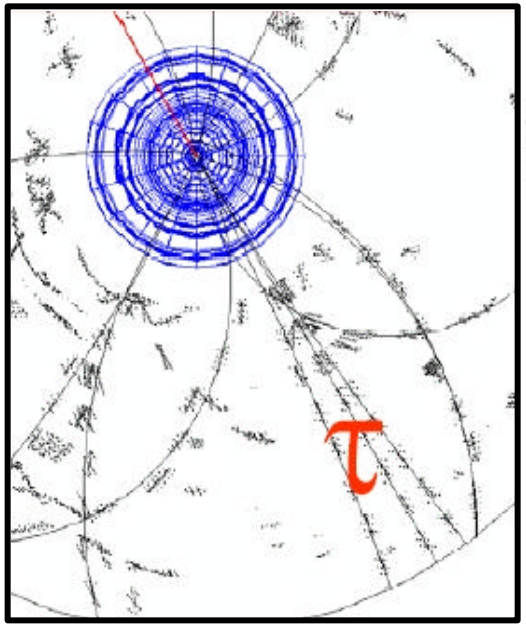
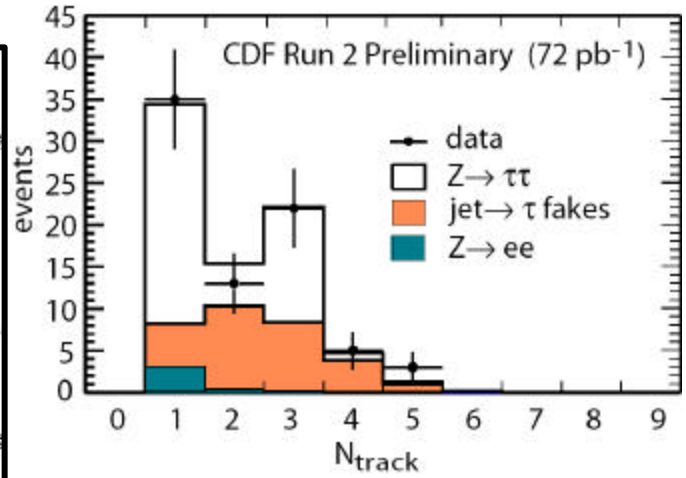
QCD
Events per 2GeV/c^2
M_T, GeV/c^2

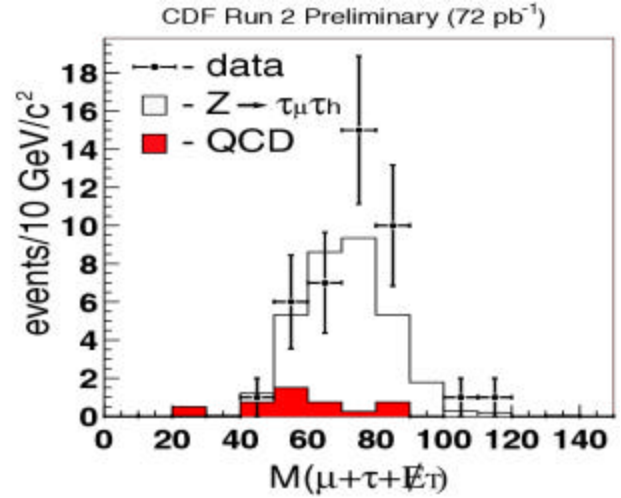
W→*en*

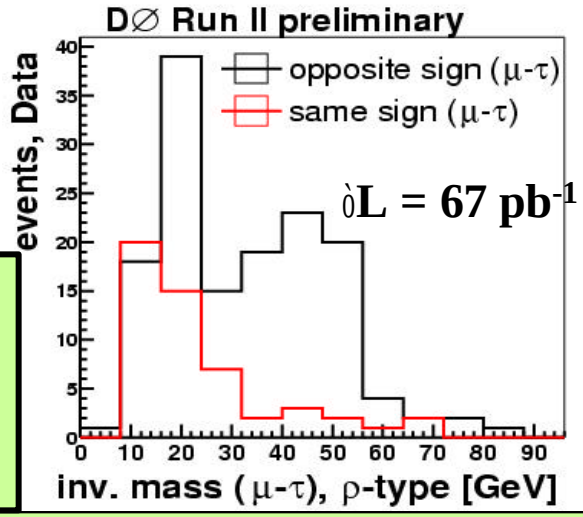

DZero Run II Preliminary
?L = 42 pb^{-1}
E_T (GeV)

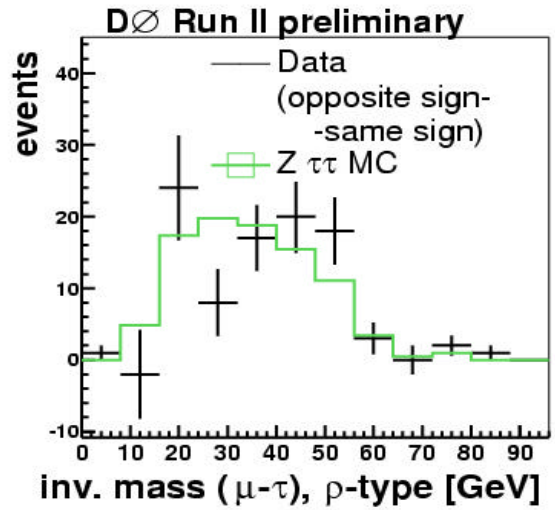
$Z \to \tau\tau$









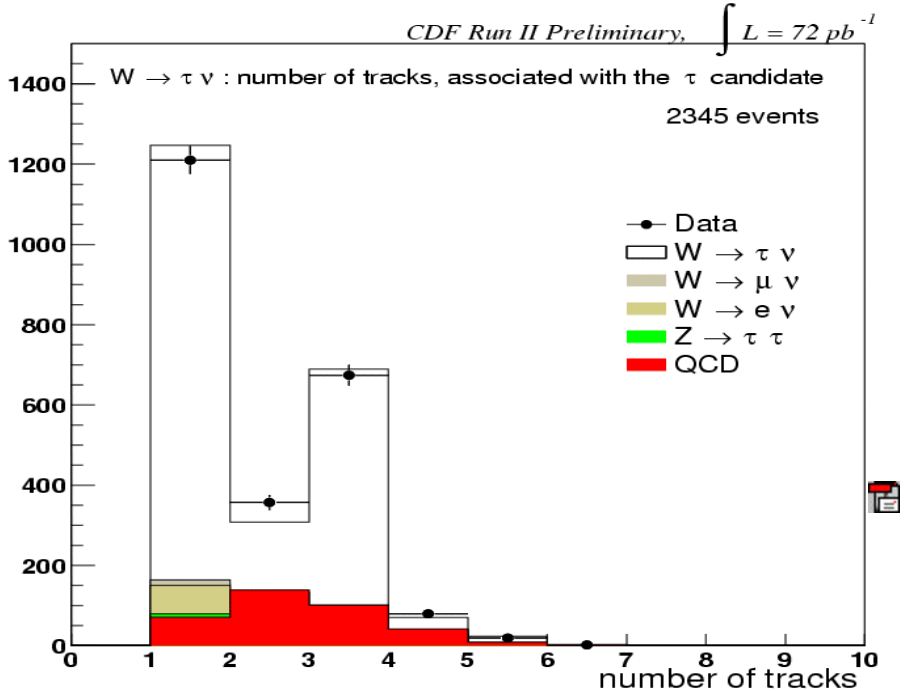


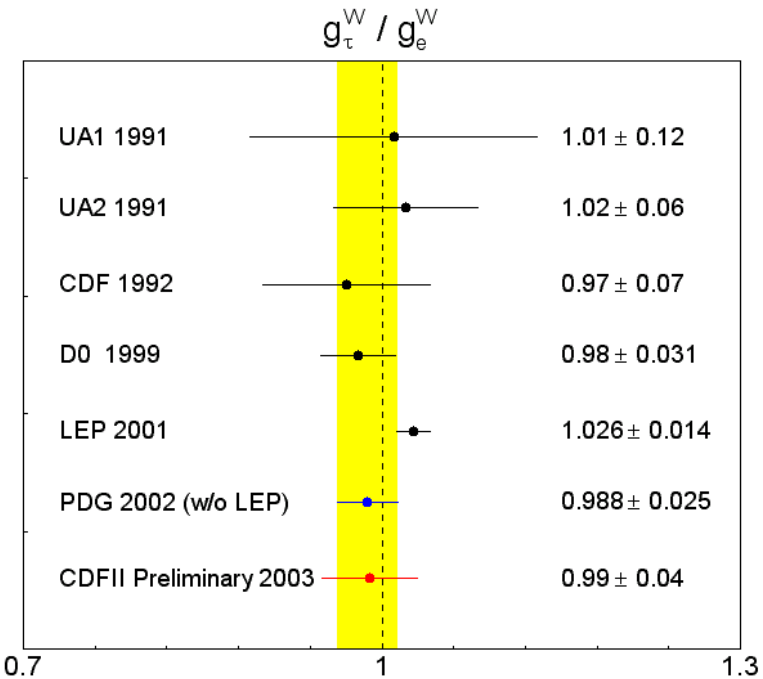
Run II preliminary:
First measurement at hadron collider

DØ: $\sigma_{Z^*}\mathrm{Br}(Z \to t\,t) = 222.1 \pm 32.8 \pm 56.8 \pm 22.2$ pb

Stat. Syst. Lumi.

W→τν (CDF)





Re-established W→τν signal – sensitive to new physics…

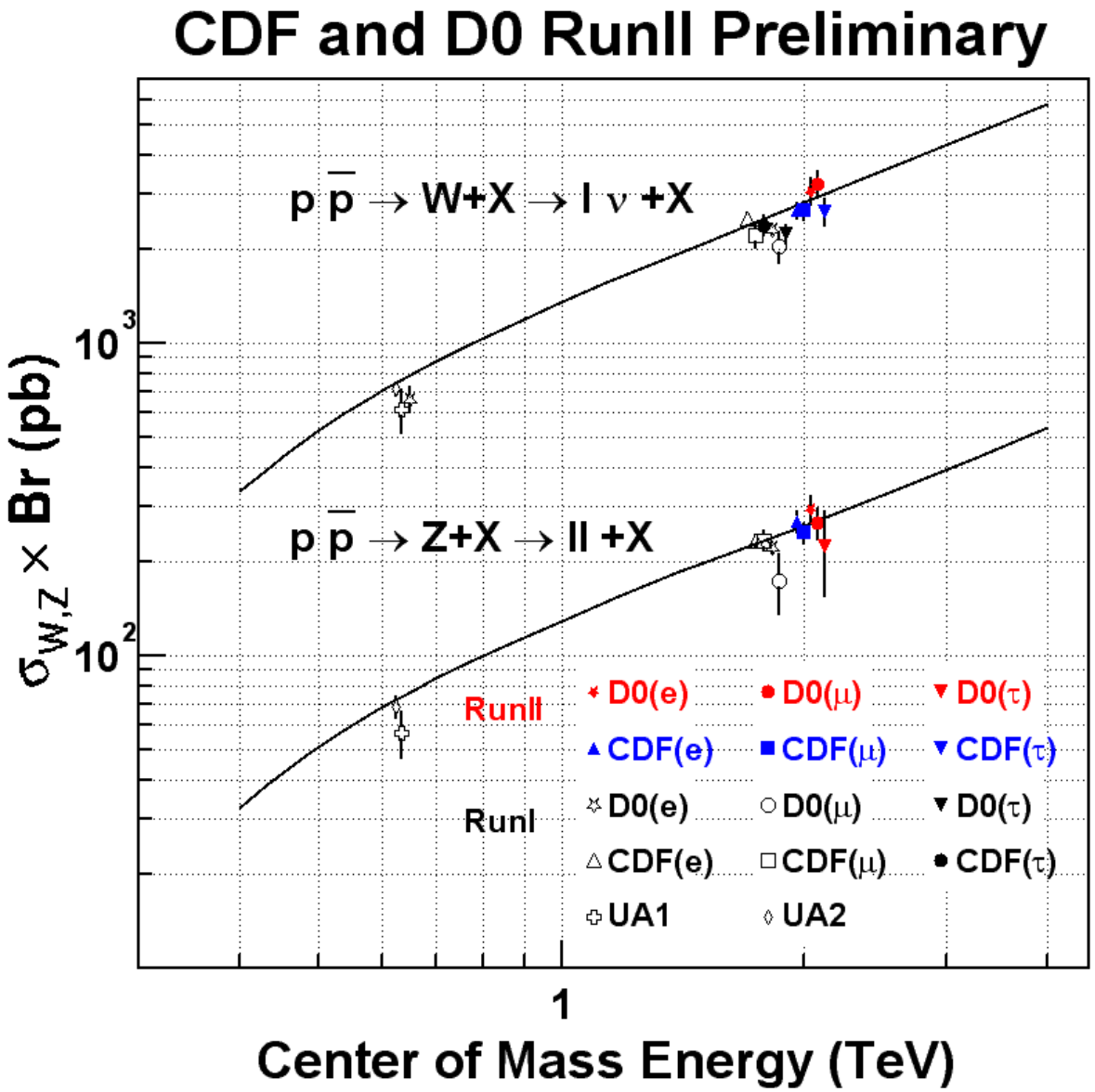
Run II preliminary

CDF: $\sigma_W * Br(W \to \tau\nu) = 2.62 \pm 0.07 \pm 0.21 \pm 0.16$ nb

$g(\tau)/g(e) = 0.99 \pm 0.02 \pm 0.04$

Stat. Syst. Lumi.

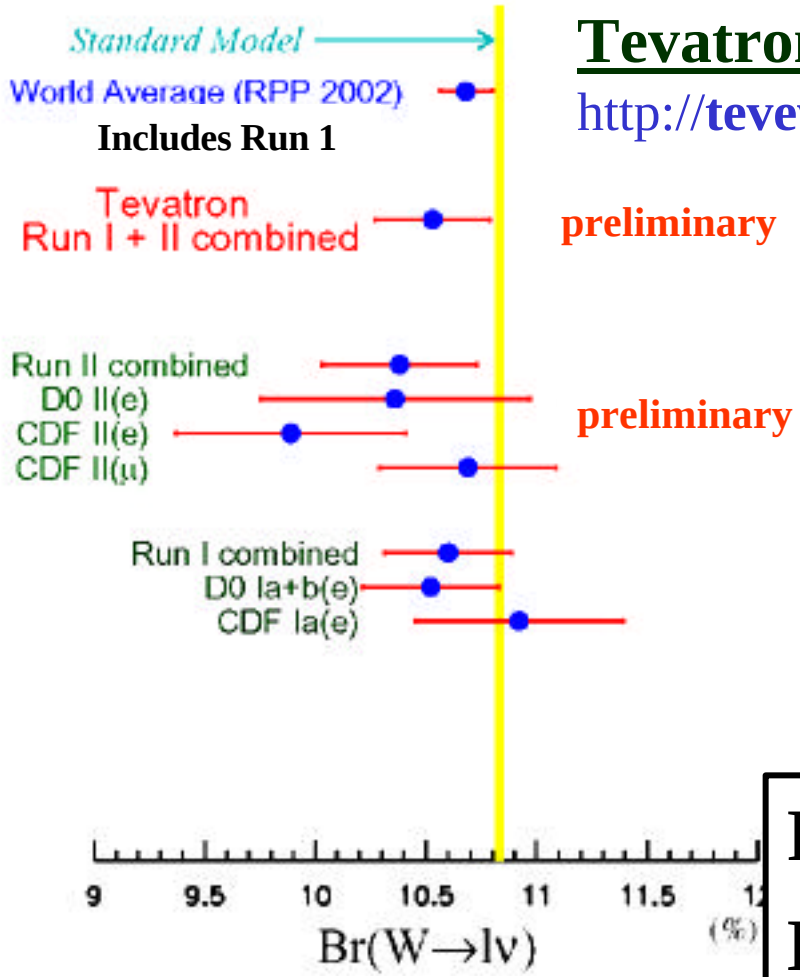
W and Z cross section measurements



Theory curves:

- Hamberg, Van Neerven, and Matsuura, Nucl. Phys. **B**359 (1991) 343

$R = \frac{\sigma_W * Br(W \to l\nu)}{\sigma_Z * Br(Z \to l^+l^-)}$, **Br**$(W \to l\nu)$, and $G(W)$



Tevatron Electroweak Working Group:

http://**tevewwg.fnal.gov**

preliminary

preliminary

$$R = \frac{\sigma_W}{\sigma_Z} \frac{Br(W? \ l\nu)}{Br(Z? \ l^+l^-)}$$

NNLO

LEP

SM

$$Br(W? \ l\nu) = \Gamma(W? \ l\nu)/\Gamma(W)$$

EWWG Run II preliminary

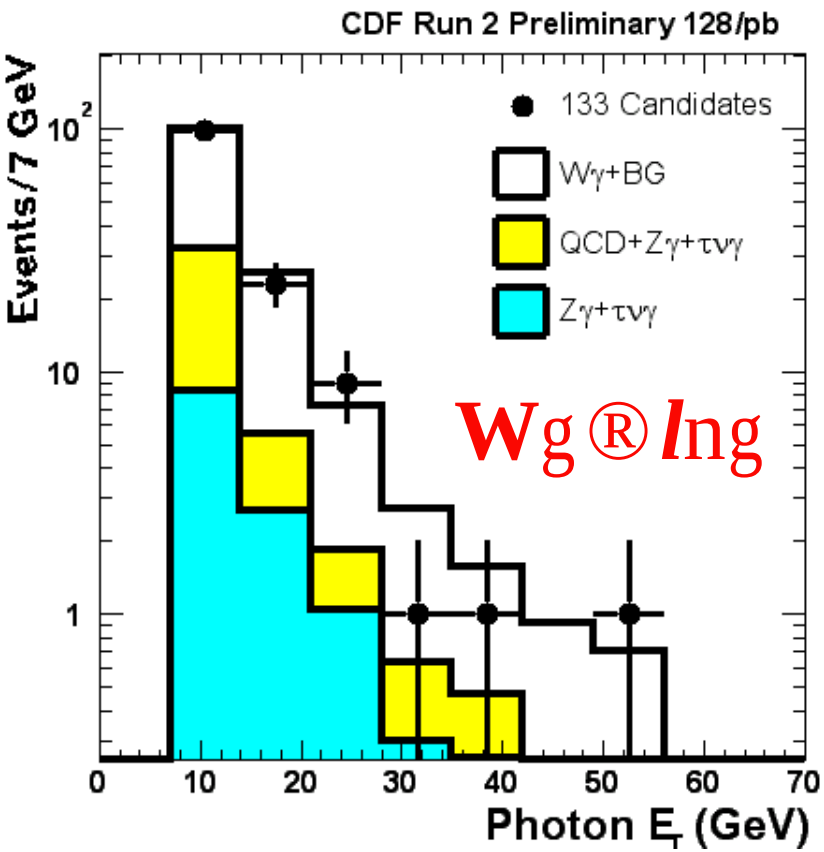
R = 10.36 ± 0.31

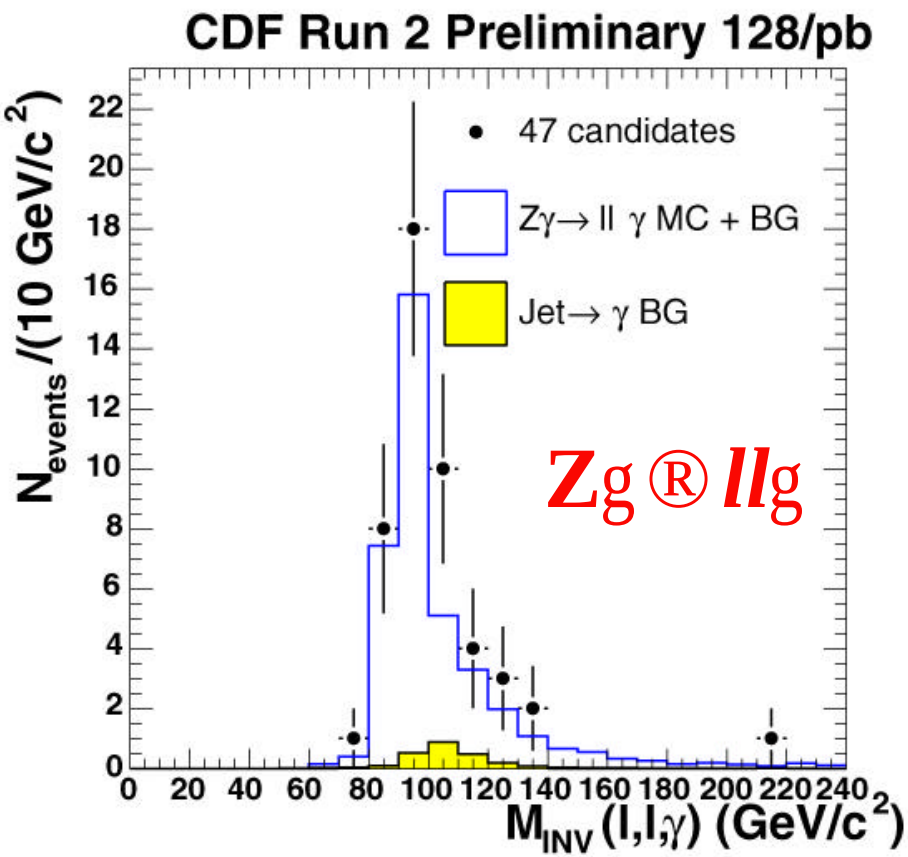
Br(W ® *l*n) = (10.38 ± 0.35)%

G**(W) = 2.181 ± 0.074 GeV**

Di- and tri-boson physics

- Important tests of SM
  - Search for anomalous couplings, radiation zero etc.
  - Crucial step towards discovery of Higgs





Diboson physics

CDF Run II preliminary $\int L \approx 126\ \mathrm{pb}^{-1}$

- **W**g cross-section

$$s(\mathrm{W}g) * \mathrm{Br}(\mathrm{W} \to en) = 18.0 \pm 3.3 \pm 2.5 \pm 1.2\ \mathrm{pb}$$
$$s(\mathrm{W}g) * \mathrm{Br}(\mathrm{W} \to mn) = 16.1 \pm 3.4 \pm 1.7 \pm 1.1\ \mathrm{pb}$$

- **Z**g cross-section (combined)

$$s(\mathrm{Z}g) * \mathrm{Br}(\mathrm{Z} \to l^+ l^-) = 5.8 \pm 1.0 \pm 0.4 \pm 0.4\ \mathrm{pb}$$

- **WW** cross-section (W$\to l\nu$)

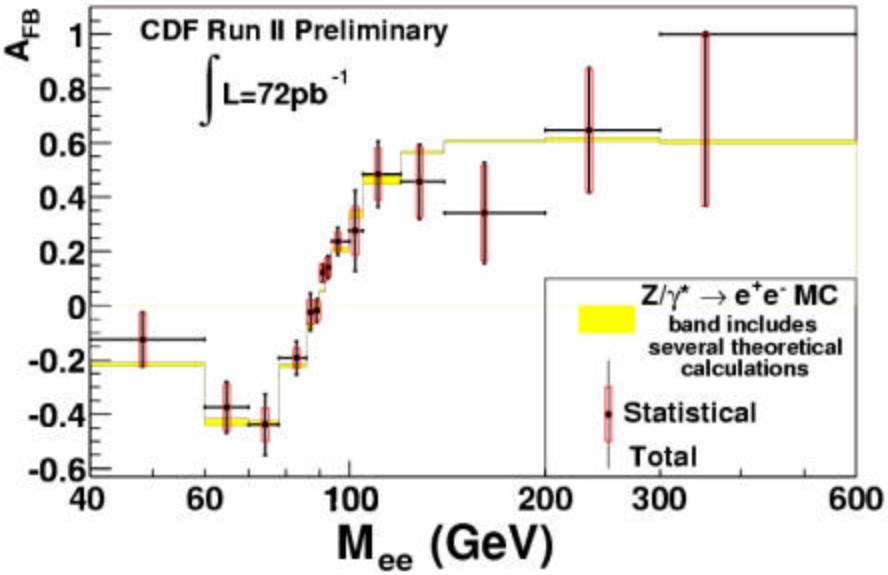
$$s(\mathrm{WW}) = 5.1^{+5.4}_{-3.6} \pm 1.3 \pm 0.3\ \mathrm{pb}$$

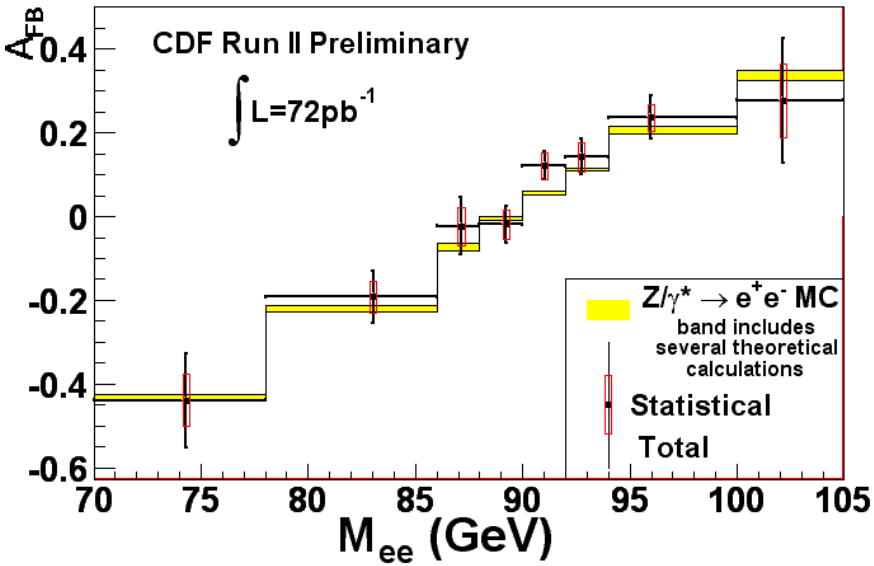
Other measurements…

- Forward-backward **Z** asymmetry

$$A_{FB} \equiv \frac{s(\cos q > 0) - s(\cos q < 0)}{s(\cos q > 0) + s(\cos q < 0)}$$

  – Direct probe of couplings over the range of Q^2
    - No measurements with Q^2 > 200 GeV – surprises might await there…





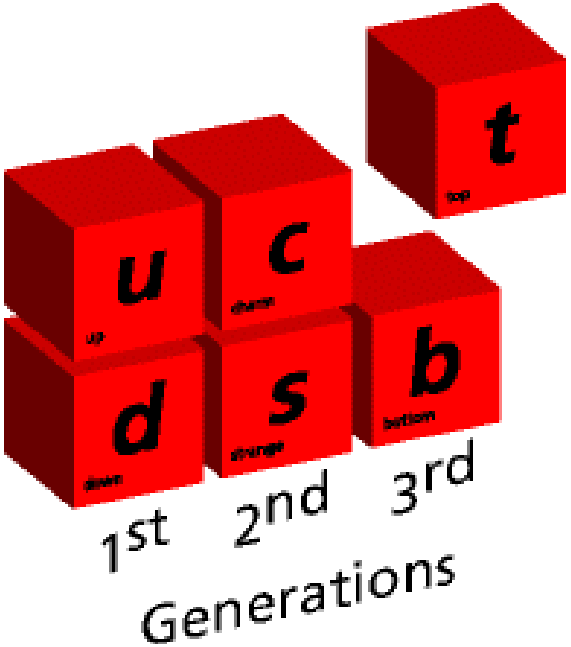
- Results agree with SM predictions

- Search for **Z'** – see Jane Nachtman talk later today…

Summary of EWK results

- Baseline signals are established
- Extensive work is going to understand detector, triggering, and simulation
  - Essential for precision measurement

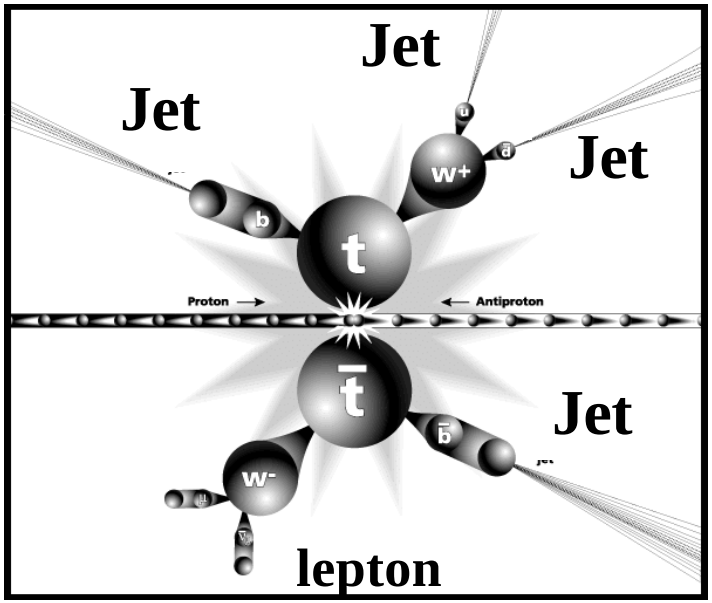
Top physics introduction

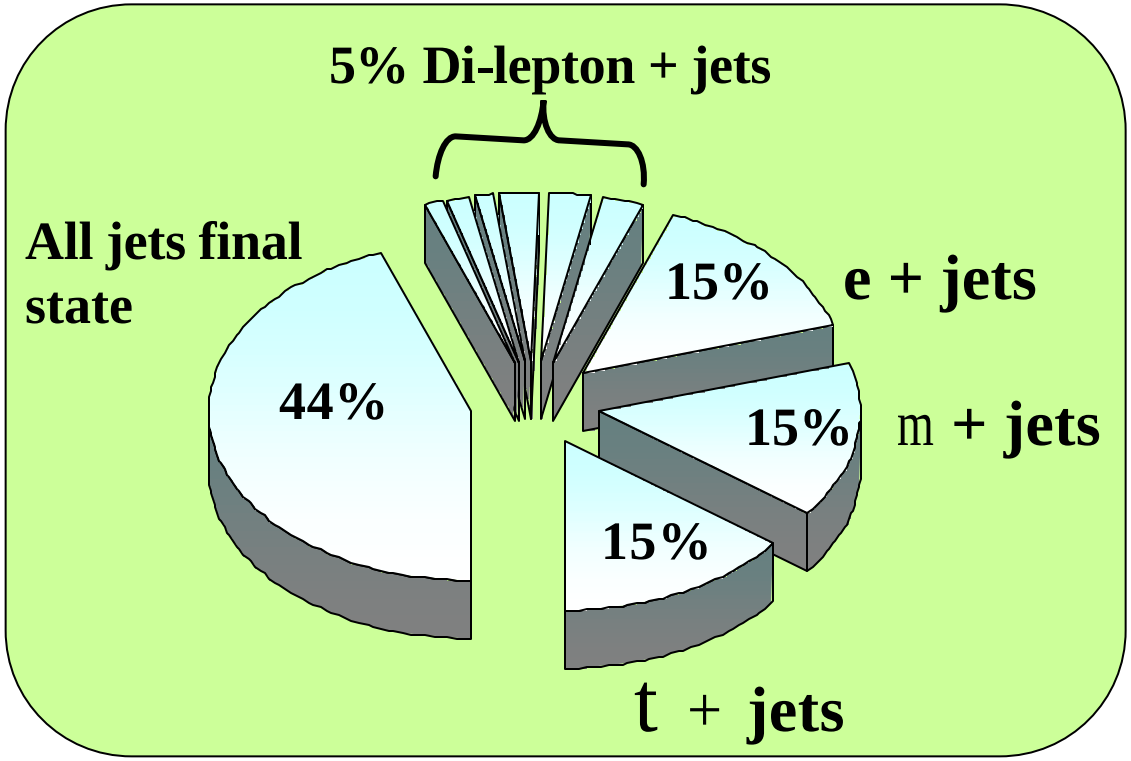


- Discovered by CDF and DØ collaborations in 1995
- Run I top physics results are consistent with SM
  - Statistics dominated errors
- Run II top physics program will take full advantage of higher statistics
  - Better precision
  - Search for deviations from SM expectations

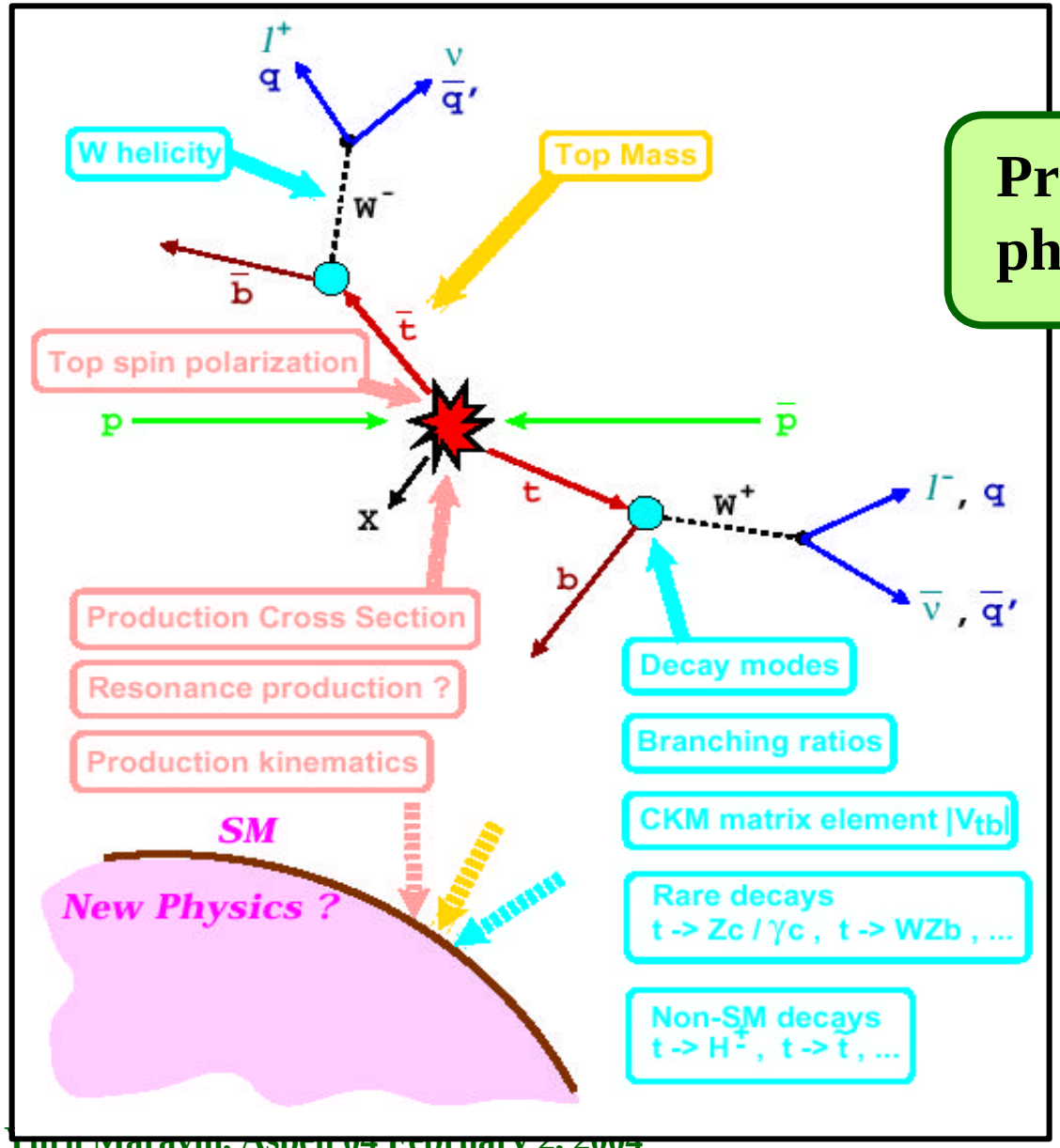
Top production in Tevatron

- Top pairs produced by $\mathbf{q\bar{q}}$ annihilation in 85%
- top decays to **Wb** in ~100%
  - Use **W** decay mode to classify final state





Top physics program



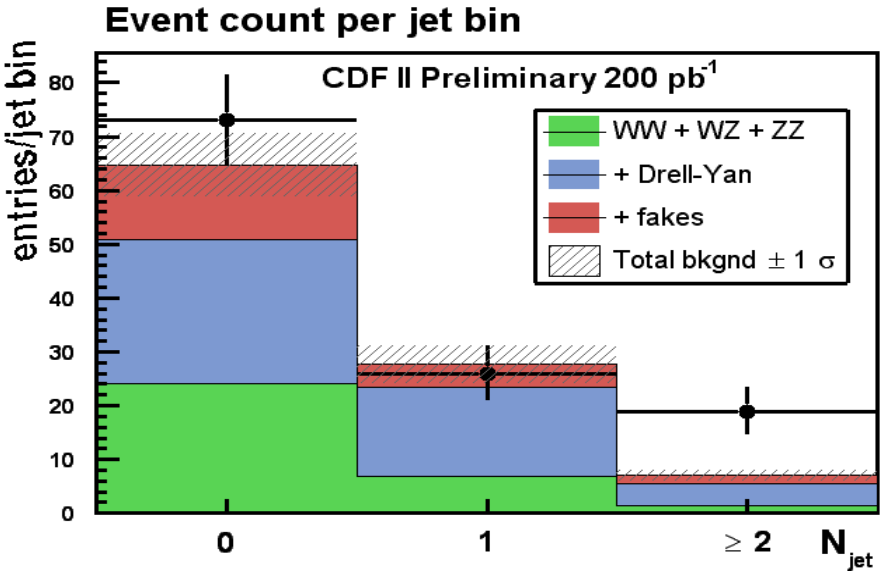
Preliminary results on top physics at Tevatron:

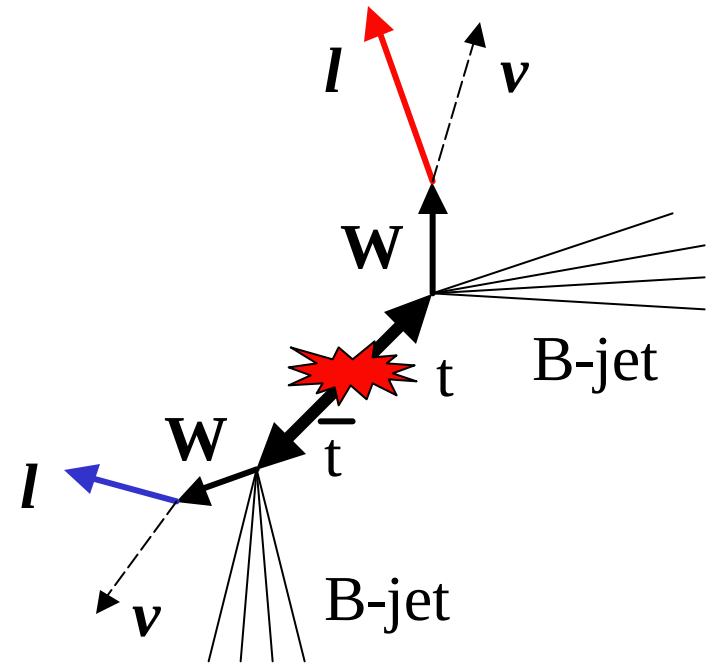
- $t\bar{t}$ cross-section
  - strong physics of top
- Single top production
  - electroweak physics
- Top mass
- **W** helicity

$t\bar{t}$ cross section (dilepton)

2 high-p_T isolated leptons

Large missing E_T | ≥ 2 jets





Run II preliminary

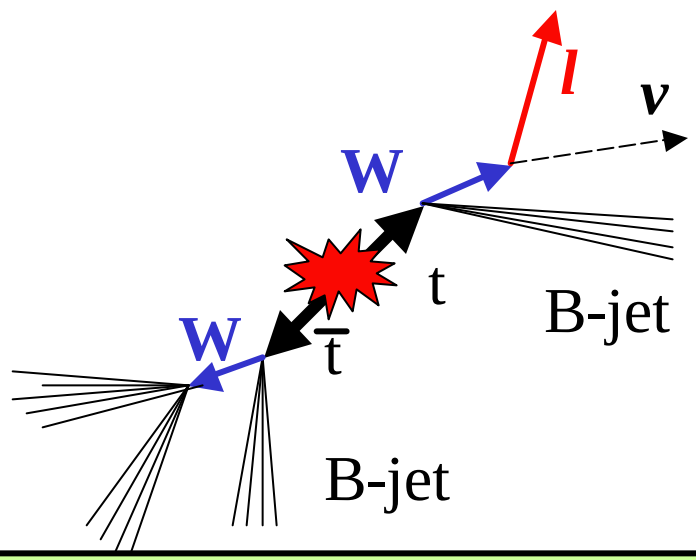
CDF (**200 pb^{-1}**): $s_{tt} = 6.9^{+2.7}_{-2.4}(\text{stat}) \pm 1.2(\text{syst}) \pm 0.4(\text{lumi})$ pb

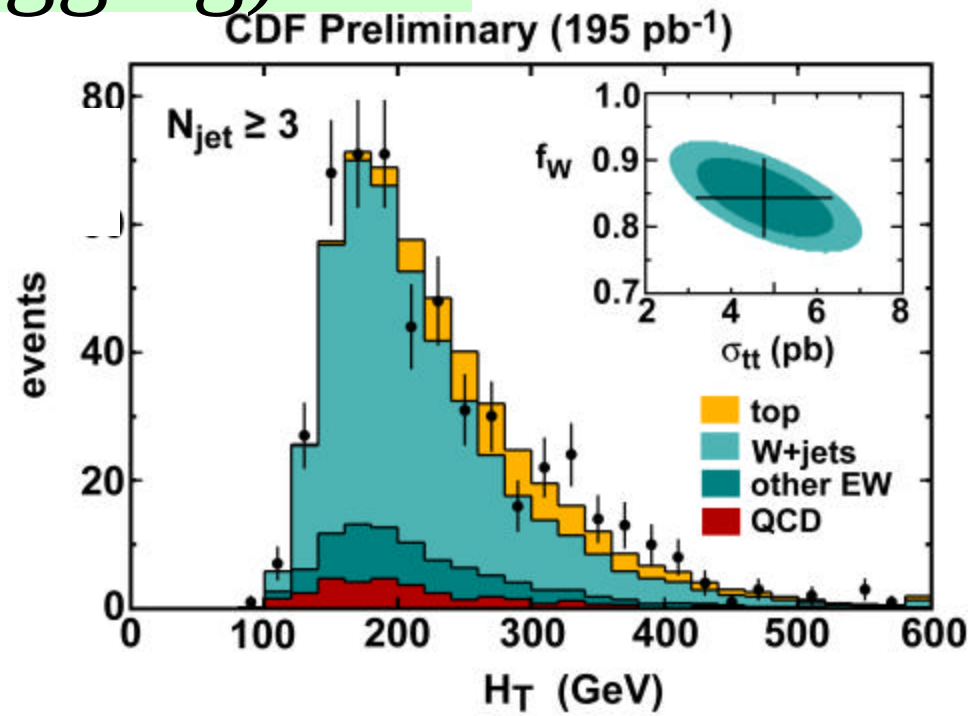
DØ (100 pb^{-1}) : $s_{tt} = 8.7^{+6.4}_{-4.7}(\text{stat})\ ^{+2.7}_{-2.0}(\text{syst}) \pm 0.9(\text{lumi})$ pb

$t\bar{t}$ cross section (lepton + jets) (topology, no b-tagging)

Fermilab

1 high-p_T isolated lepton	
Large missing E_T	≥ 3 jets





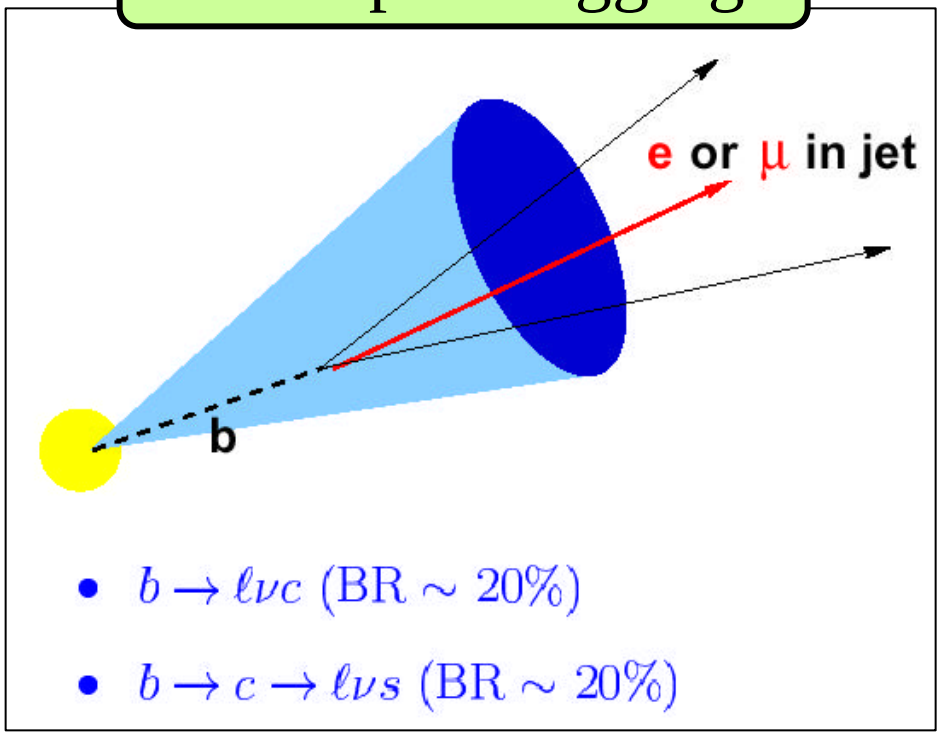
Run II preliminary

CDF (**195 pb^{-1}**): $s_{tt} = 4.7 \pm 1.6(\text{stat}) \pm 1.8(\text{syst})$ pb

DØ (97 pb^{-1}) : $s_{tt} = 4.6^{+3.1}_{-2.7}(\text{stat})\ ^{+2.1}_{-2.0}(\text{syst}) \pm 0.5(\text{lumi})$ pb

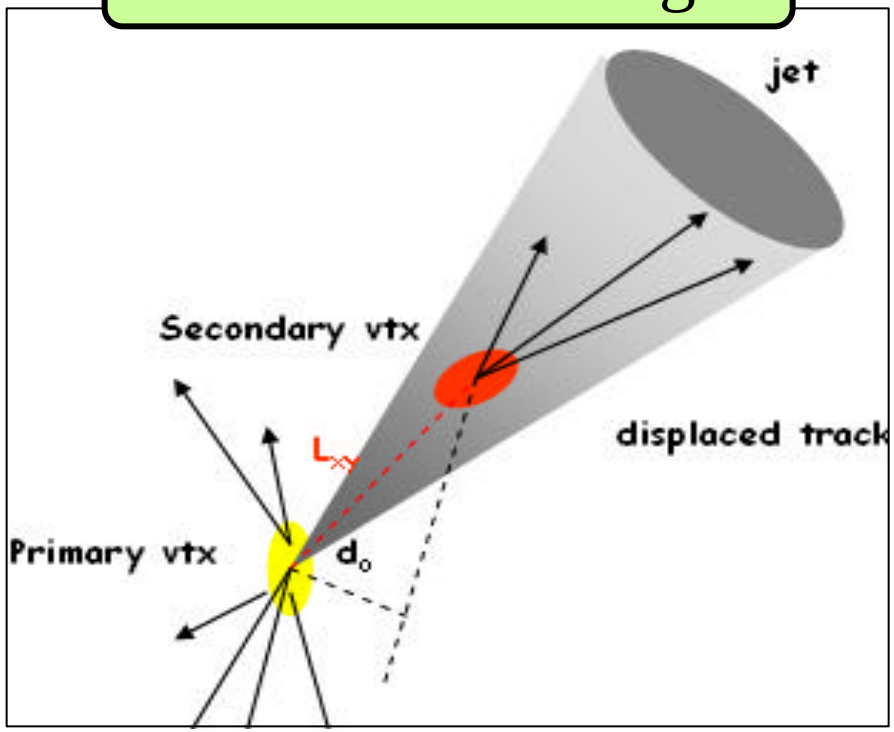
Tagging a **b** quark

Soft lepton tagging



Search for non-isolated soft lepton in a jet

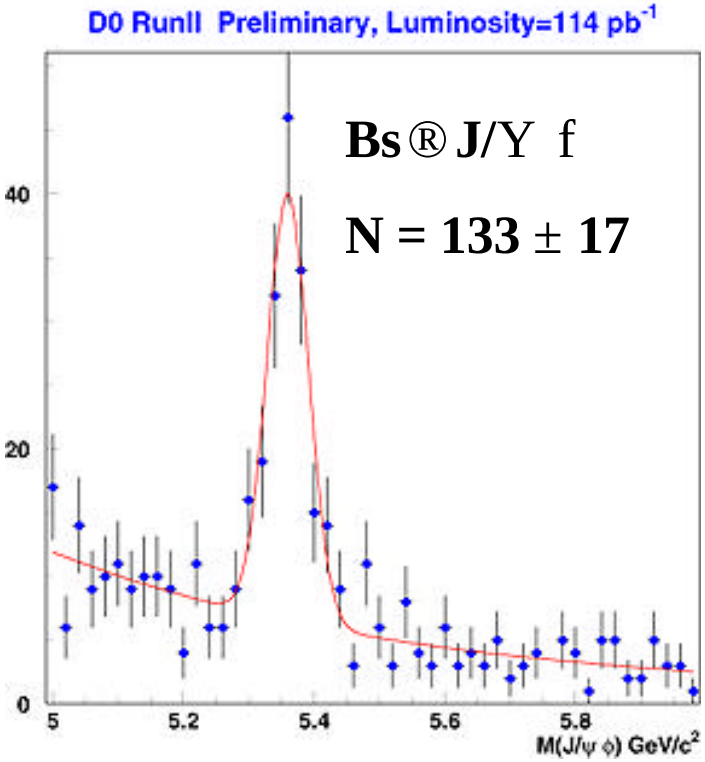
Silicon Vertex tag



B meson travels ~ 3 mm before decaying:

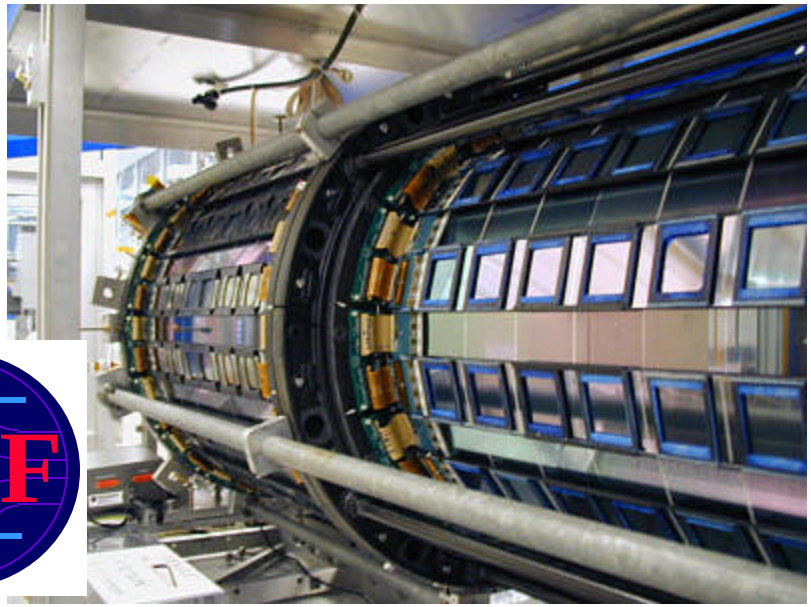
– Search for secondary vertex

Silicon detectors



Run II: cover entire luminous region

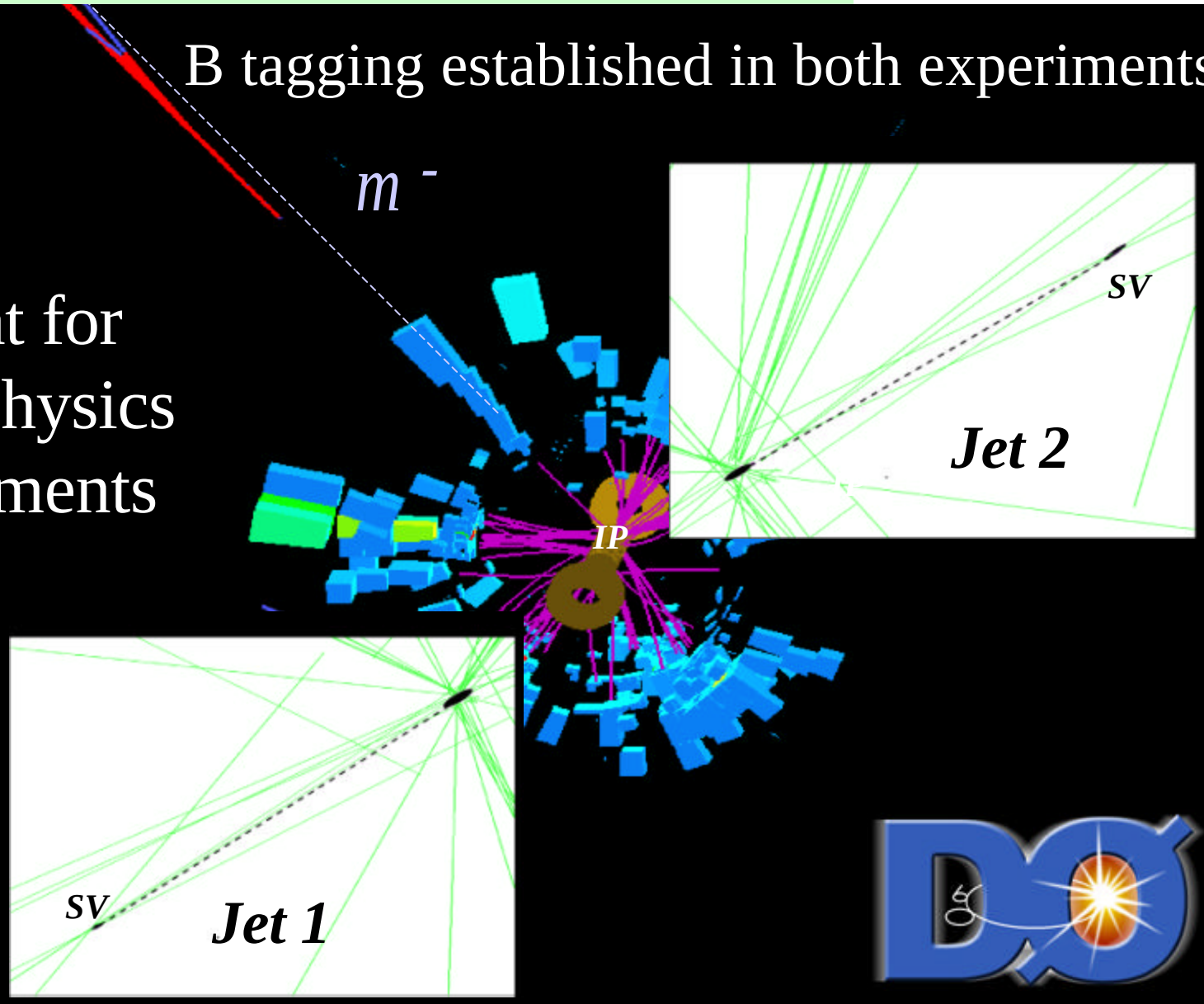
– **b**-tagging for all **$t\bar{t}$**!



μ + jets double-tagged event

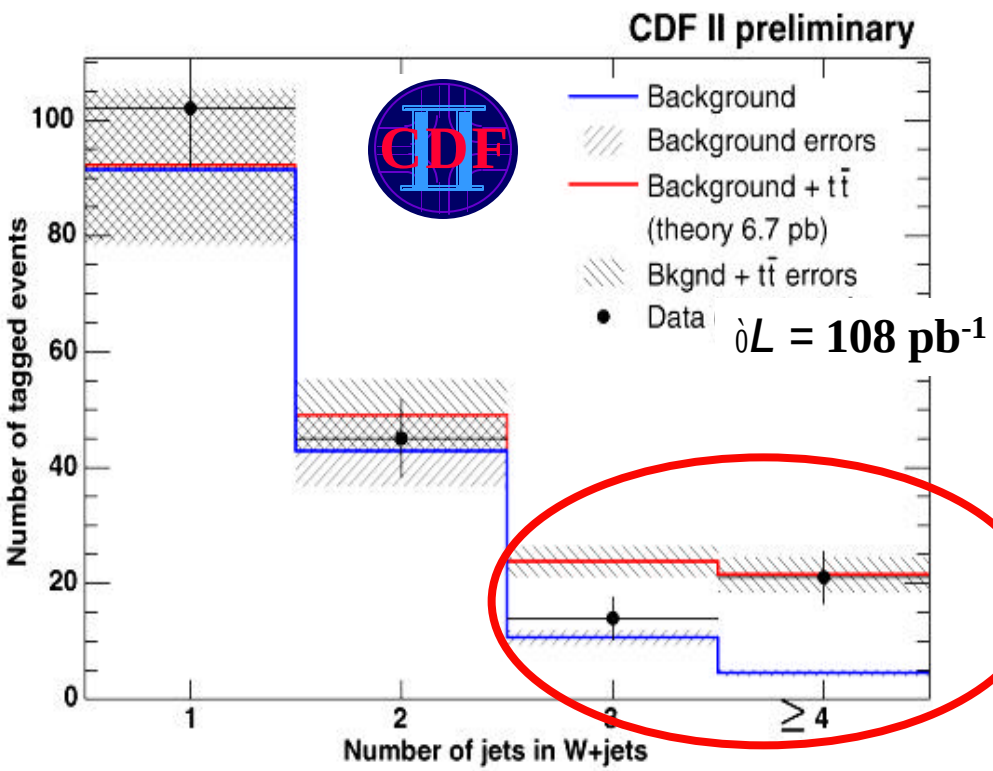
B tagging established in both experiments!

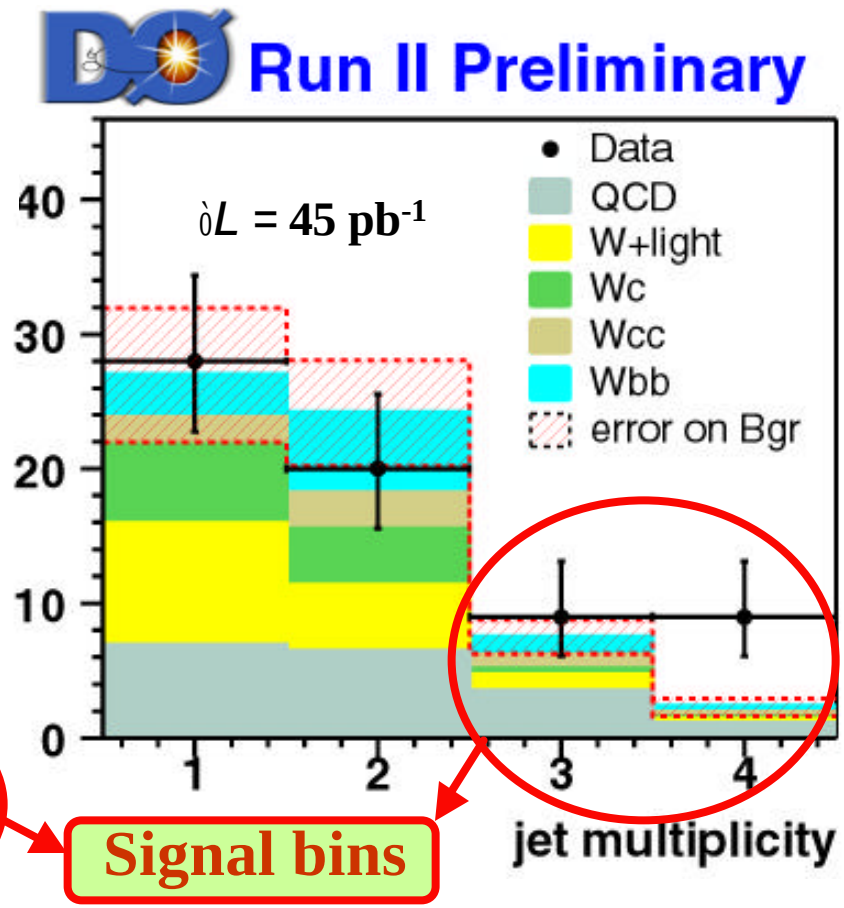
Important for the top physics measurements



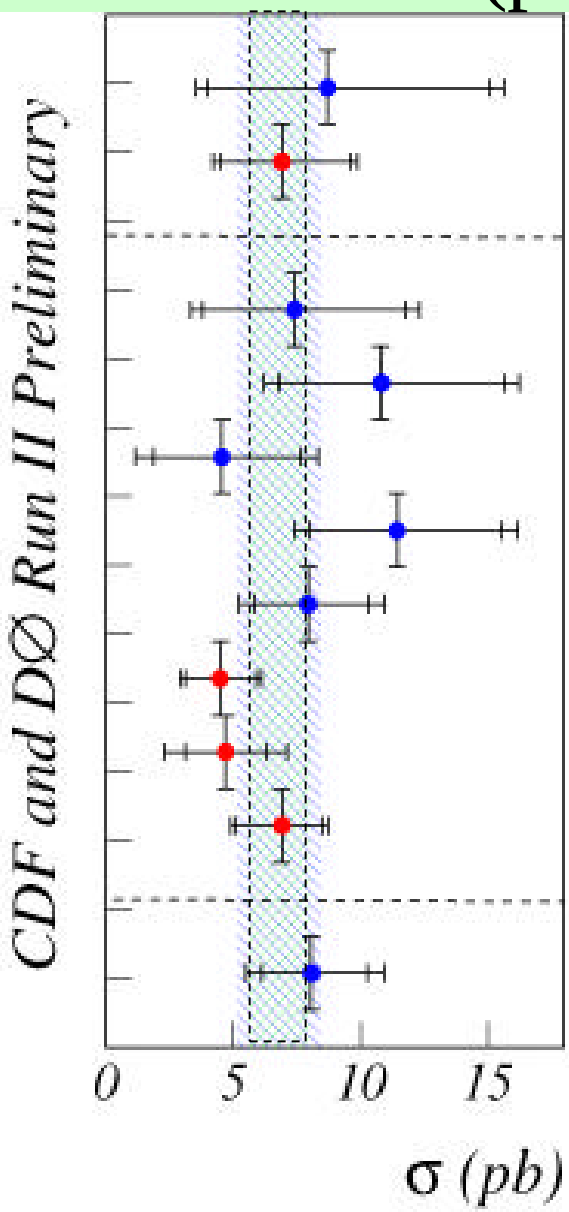
$t\bar{t}$ cross section (lepton + jets) (silicon b-tag)

1 high-p_T isolated lepton	
Large missing E_T	≥ 3 jets





$t\bar{t}$ cross section summary (preliminary)



DØ Dileptons 90-107 pb^{-1}	$8.7^{+6.4}_{-4.7}(\text{stat})^{+2.7}_{-2.0}(\text{syst}) \pm 0.9(\text{lum})$
CDF Dileptons 200 pb^{-1}	$6.9^{+2.7}_{-2.4}(\text{stat}) \pm 1.2(\text{syst}) \pm 0.4(\text{lumi})$
DØ L+jets/CSIP 45 pb^{-1}	$7.4^{+4.4}_{-3.6}(\text{stat})^{+2.1}_{-1.8}(\text{syst}) \pm 0.7(\text{lum})$
DØ L+jets/SVT 45 pb^{-1}	$10.8^{+4.9}_{-4.0}(\text{stat})^{+2.1}_{-2.0}(\text{syst}) \pm 1.1(\text{lum})$
DØ L+jets/topo 92 pb^{-1}	$4.6^{+3.1}_{-2.7}(\text{stat})^{+2.1}_{-2.0}(\text{syst}) \pm 0.5(\text{lum})$
DØ L+jets/soft muon 92 pb^{-1}	$11.4^{+4.1}_{-3.5}(\text{stat})^{+2.0}_{-1.8}(\text{syst}) \pm 1.1(\text{lum})$
DØ L+jets combined 92 pb^{-1}	$8.0^{+2.4}_{-2.1}(\text{stat})^{+1.7}_{-1.5}(\text{syst}) \pm 0.8(\text{lum})$
CDF L+jets/SVX 108 pb^{-1}	$4.5 \pm 1.4(\text{stat}) \pm 0.8(\text{syst})$
CDF L+jets/HT 195 pb^{-1}	$4.7 \pm 1.6(\text{stat}) \pm 1.8(\text{syst})$
CDF L+jets/SVX/kine 108 pb^{-1}	$6.9^{+1.6}_{-1.8}(\text{stat}) \pm 0.9(\text{syst})$
DØ Combined 90-107 pb^{-1}	$8.1^{+2.2}_{-2.0}(\text{stat})^{+1.6}_{-1.4}(\text{syst}) \pm 0.8(\text{lum})$

Kidonakis **hep-ph/0303086**

Cacciari *et al.* **hep/ph-0303085**

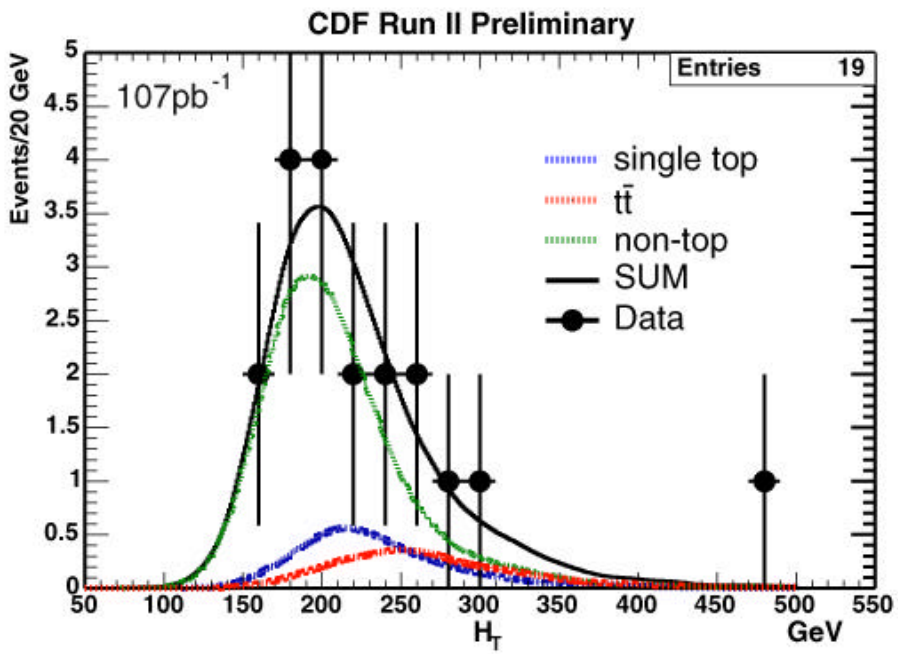
Search for single top production

- Very difficult analysis:
  - Requires a good knowledge of detector at large $|\eta|$
- Very interesting analysis:
  - Measure V_{tb} directly!
  - Probe for new physics

Z. Sullivan, NLO CTEQ5M1

$\sigma(t)_{t\text{-channel}} = 1.98 \pm 0.13$ pb

$\sigma(t)_{s\text{-channel}} = 0.88 \pm 0.09$ pb



Run I 95% C.L. limits:

- CDF $\sigma_t < 13.5$ pb, $\sigma_s < 12.9$ pb
- DØ $\sigma_t < 22$ pb, $\sigma_s < 17$ pb

CDF Run II preliminary

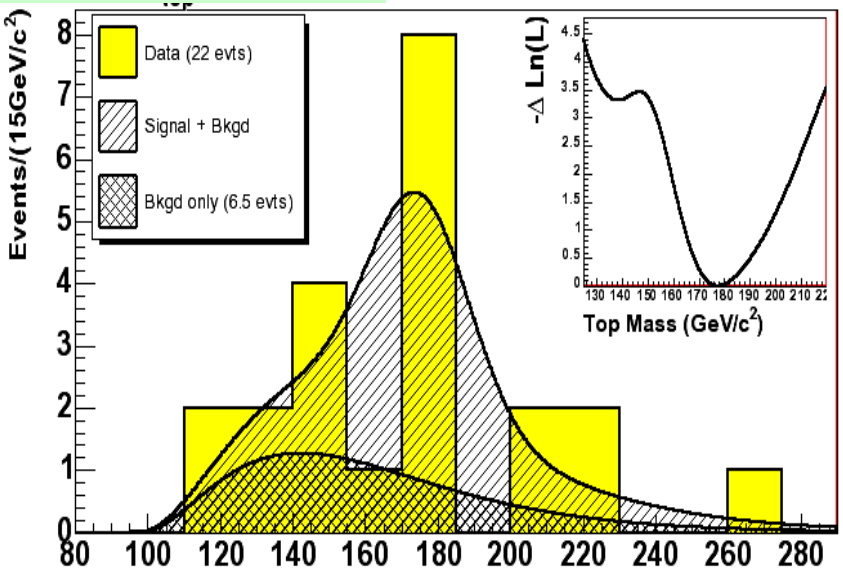
s_t(s+t channels) < 17.5 pb @95% C.L.

Top mass measurement

- Top mass is one of the SM parameters
  - Higgs mass constraint
- Run II goals ($\int L = 2\ \mathrm{fb}^{-1}$):
  - $\Delta M_t < 2.5$ GeV
- Important to use best analysis tools available to extract the top mass
- Will require help from theorists and phenomenologists to achieve this goal

Top mass measurement (CDF)
(preliminary)

- Template method of top mass calculation:
  - Kinematic fit under ($t\bar{t}$) hypothesis
  - Several combinations per event
  - Choose the one with best χ^2 combination lepton+jets sample:

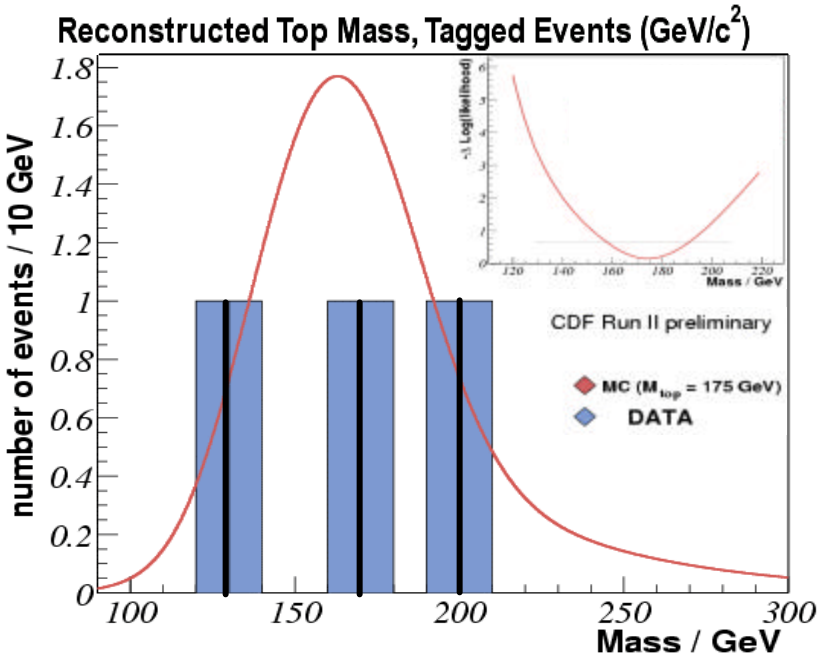


- lepton+jets sample: ∂L = 108 pb^{-1}

$$177.5^{+12.7}_{-9.4}\,(\text{stat}) \pm 7.1(\text{syst})\ \text{GeV/c}^2$$

- dilepton sample: ∂L = 124 pb^{-1}

$$175.0^{+17.4}_{-16.9}\,(\text{stat}) \pm 7.9(\text{syst})\ \text{GeV/c}^2$$



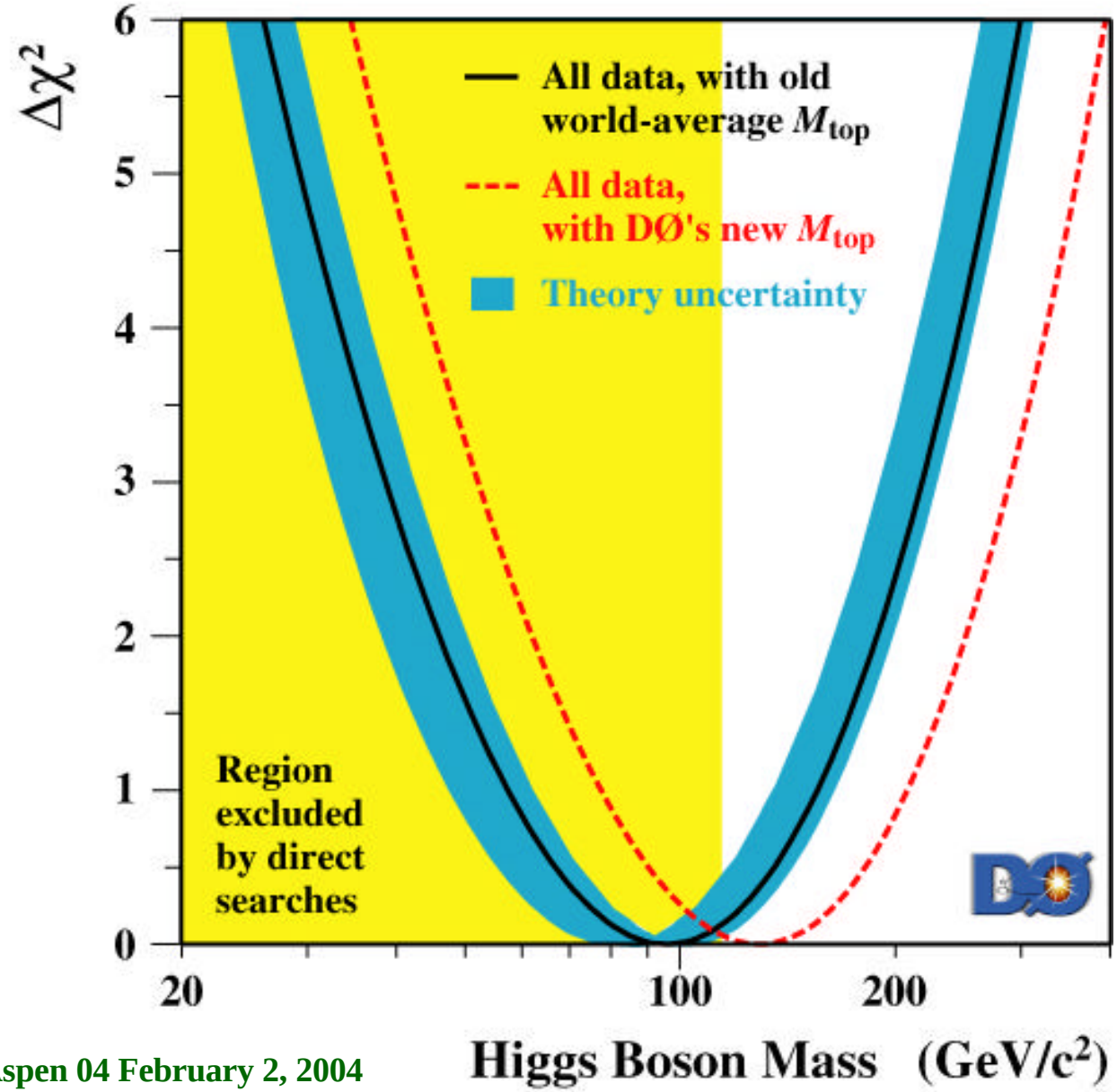
Top mass measurement (Run I DØ)

- While accumulating and analyzing new data from Run II, we use Run I data to develop new, more powerful techniques to measure the top mass:
- Matrix Element method:
  - All measured information are used in the fit
  - Well measured events contribute more to the fit
  - Each event has the probability distribution
- **Significant** improvement of the statistical error:
  - Equivalent to 2.4 more data in Run 1 sample

Preliminary

DØ Run I *l*+jets data: $M_{top} = 180.1 \pm 3.6\ (stat) \pm 4.0\ (syst)\ GeV/c^2$

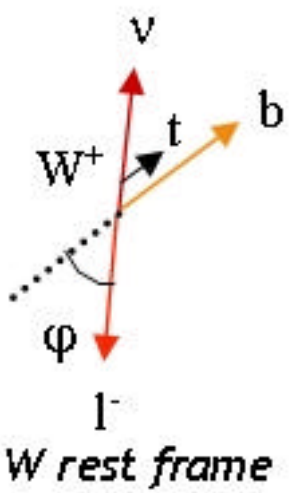
New Higgs mass prediction
(preliminary)

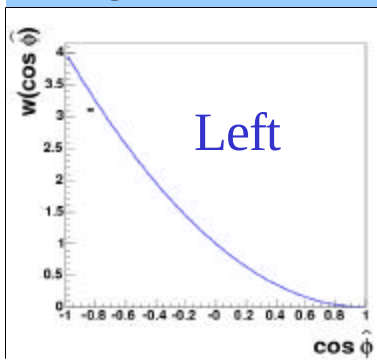


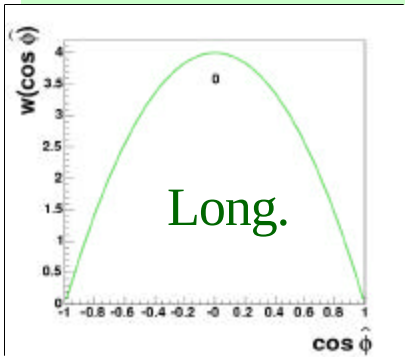
W helicity in top decay (DØ)

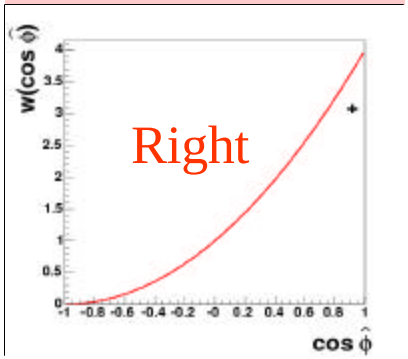
- Top quark decays before it can hadronize:
  - Unique opportunities to study bare quark with the mass of natural electroweak scale
- Angular dependence of the top quark decay:

$$w(\cos j_{l^-\bar{b}}) = F_- \cdot \frac{3}{8}(1-\cos j_{l^-b})^2 + F_0 \cdot \frac{3}{8}(1-\cos^2 j_{l^-b}) + F_+ \cdot \frac{3}{8}(1+\cos j_{l^-b})^2$$









Standard model prediction: **$F_- = 0.3$, $F_0 = 0.7$, $F_+ = 0$**

Preliminary DØ Run I result

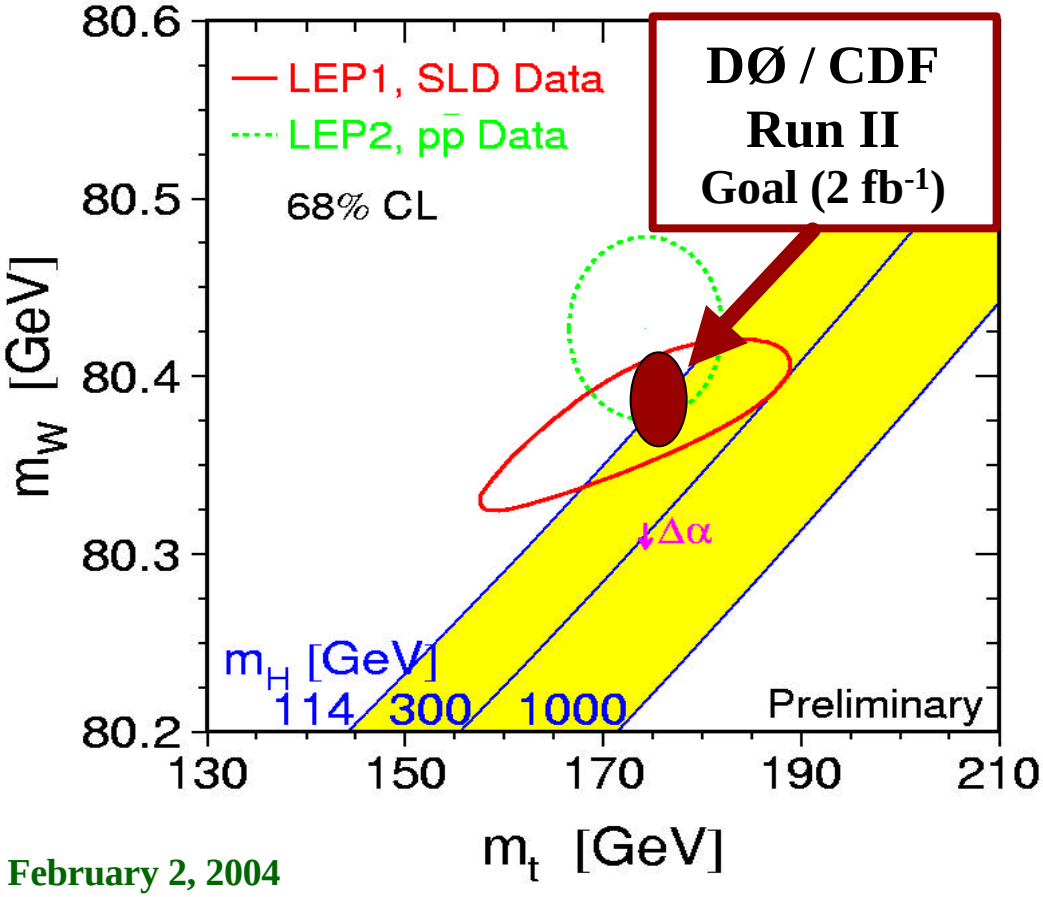
$F_0 = 0.56 \pm 0.31$ (stat)± 0.04 (syst)

Top physics summary

- Tevatron is the only place to study the top quark until first results from LHC are available…
- Measurements of $\mathbf{t\bar{t}}$ cross-section, as well as top mass are available and rapidly improving
- Already more than twice the Run I data:
  - Go beyond discovery stage: start to measure top quark properties…

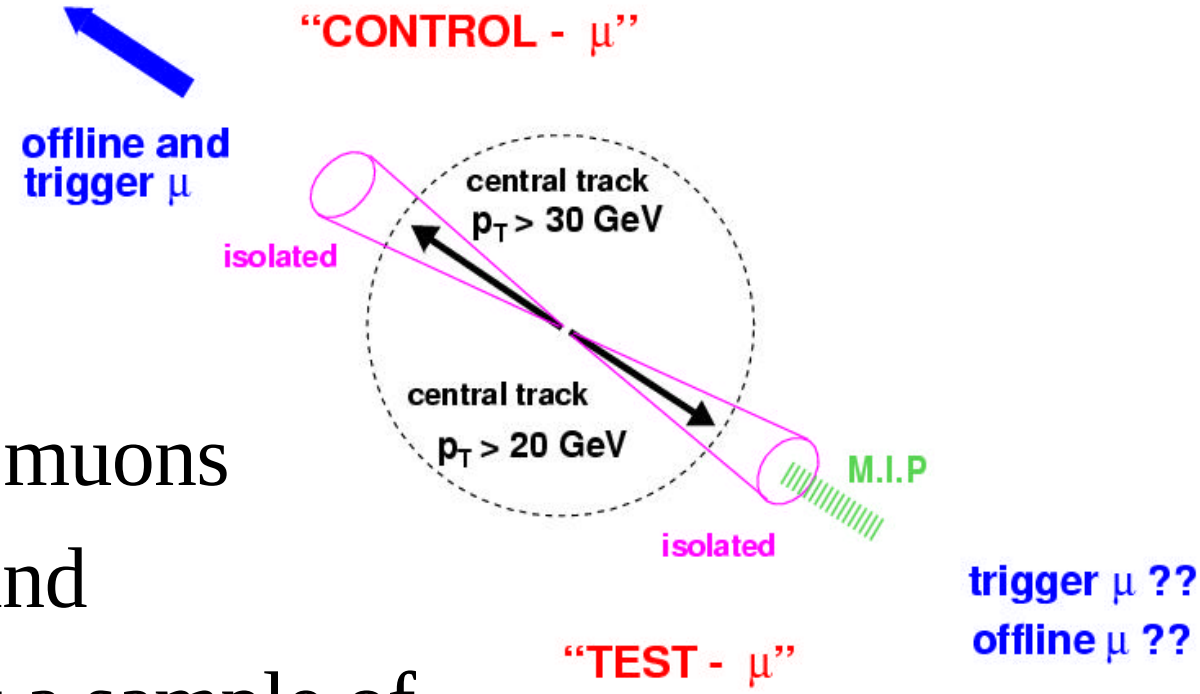
Conclusions

- CDF and DØ plan to make an **extensive** set of publications using the first 200 pb^{-1} of data
- Expect at least 30 times more data than in Run I by 2009

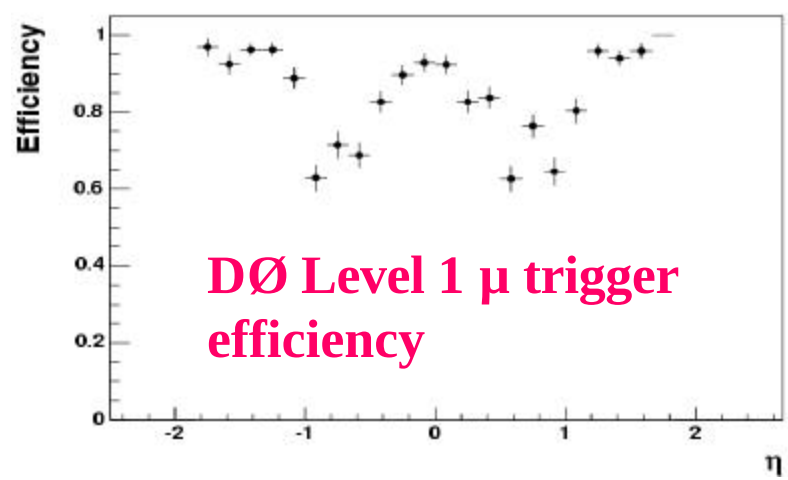


Additional slides

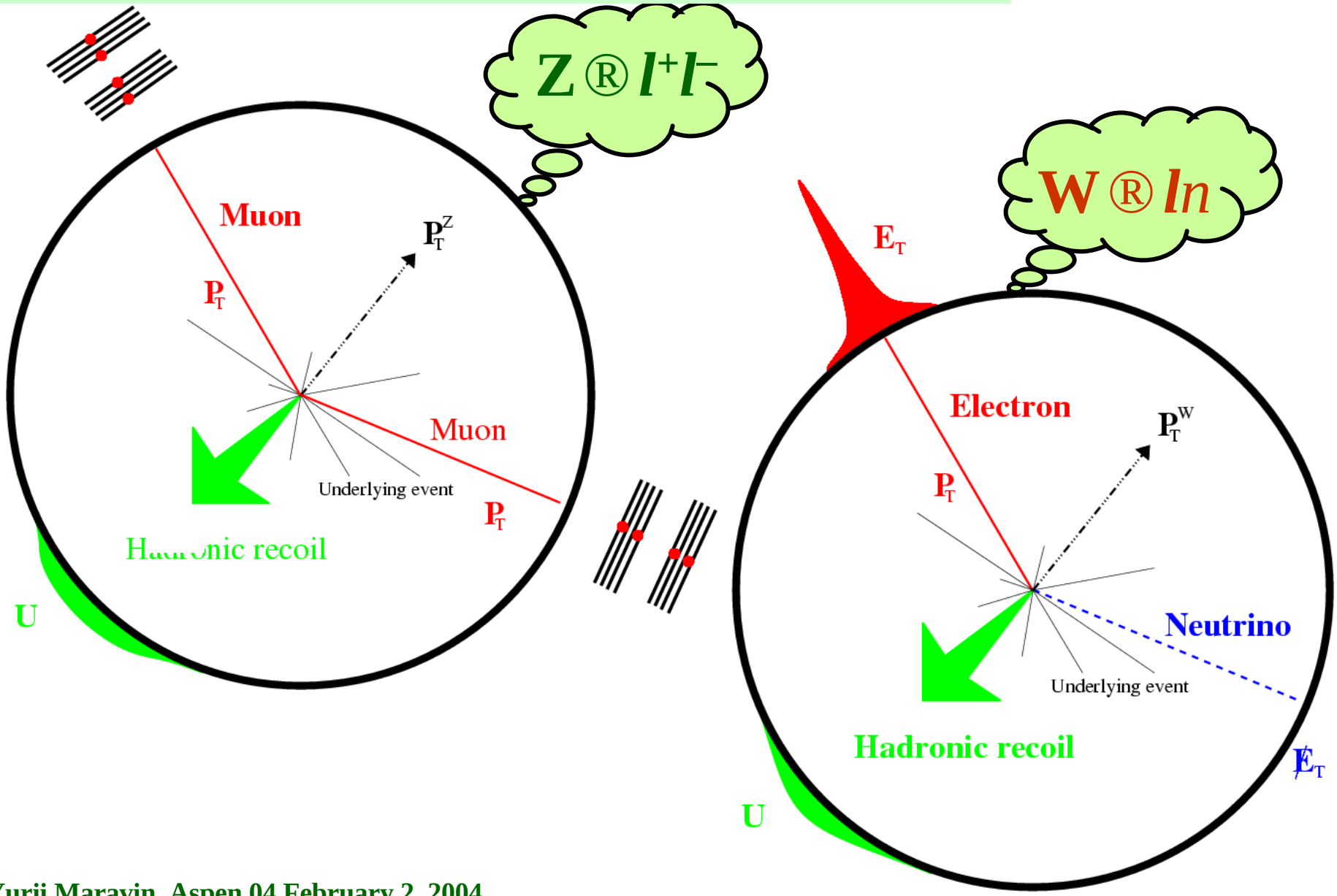
Measuring efficiency with $Z \rightarrow m^+m^-$



- There are two muons
- Low background
- One can select a sample of pure **Z** candidates with a very loose requirement on one of the muons



Signature of Z and W decays

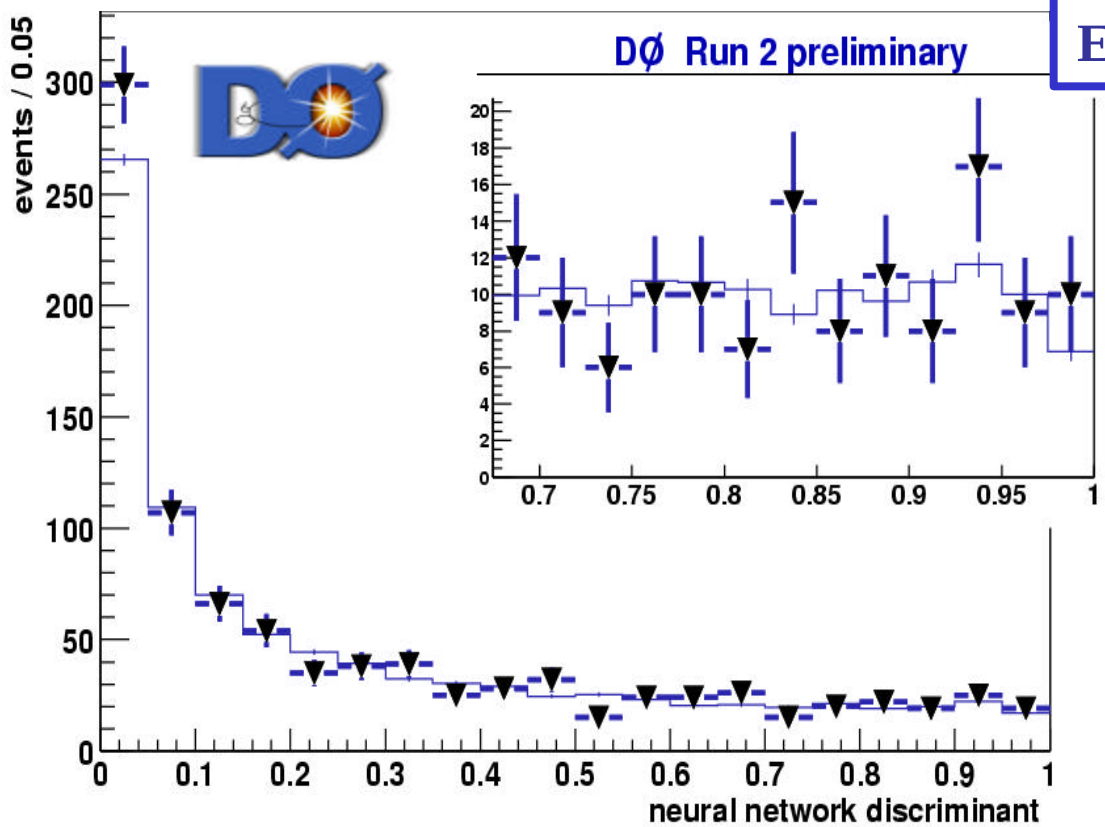


$t\bar{t}$ cross section (all jets)

no high-p_T isolated leptons	
no missing E_T	≥ 4 jets

Run 1 data

Luminosity 80.7 pb^{-1}
 # Selected events : 78
Expected Bkg. : 68.0±1.6

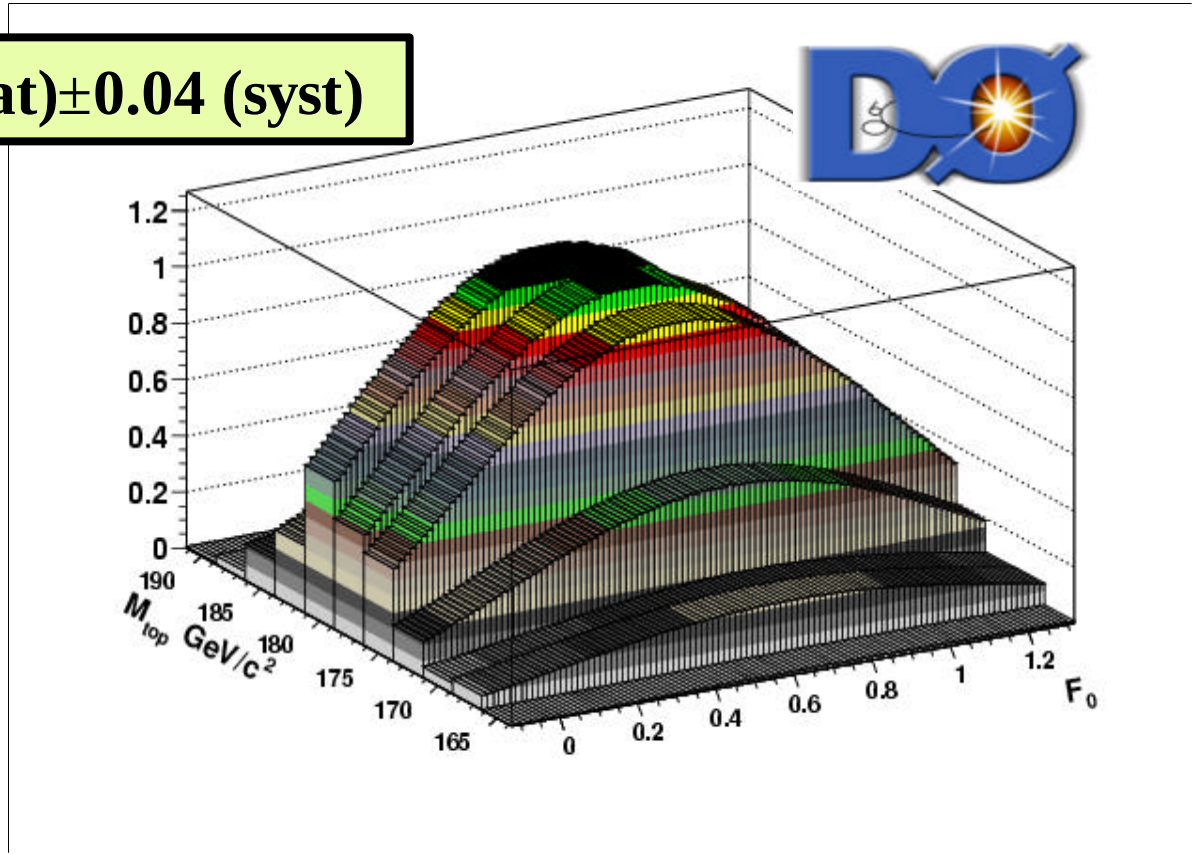


- Very difficult analysis
  - S/B is low
- Considered to be almost impossible in LHC

W helicity: test of SM

- Natural extension of the Matrix Element method developed for the top mass measurement
- Use Run 1 data:

F_0= 0.56 ± 0.31 (stat)±0.04 (syst)



- Ongoing work to apply the same method on Run 2 data sample