# Top quark and electroweak results from Tevatron Run II

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

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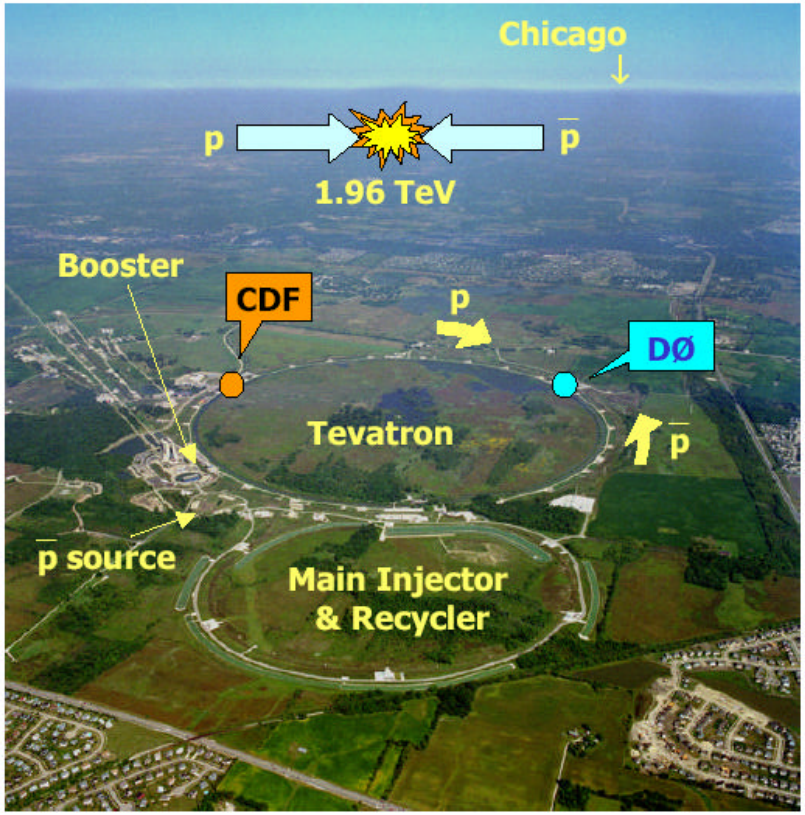
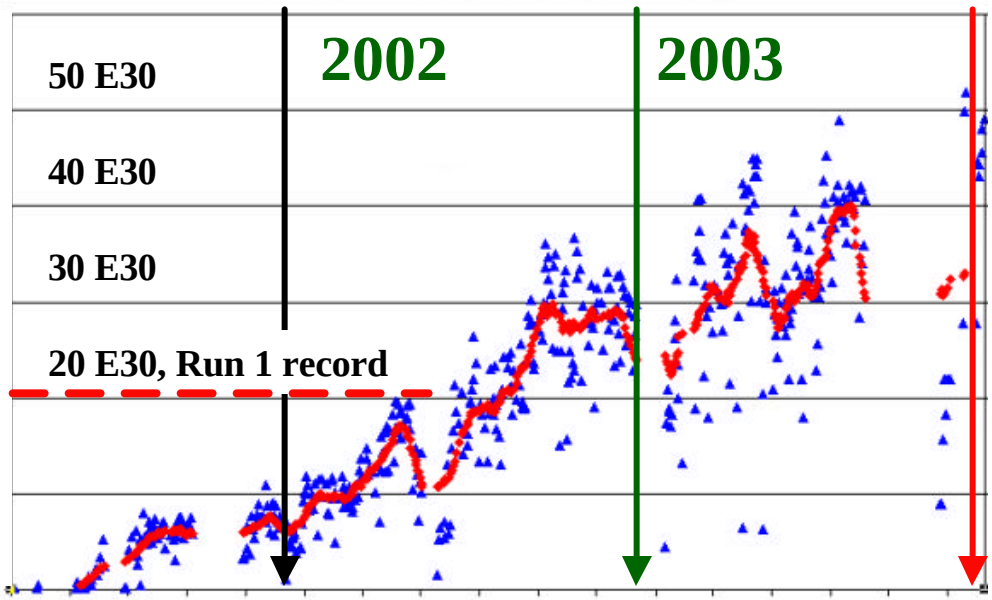
# Tevatron Collider in Run II

- 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

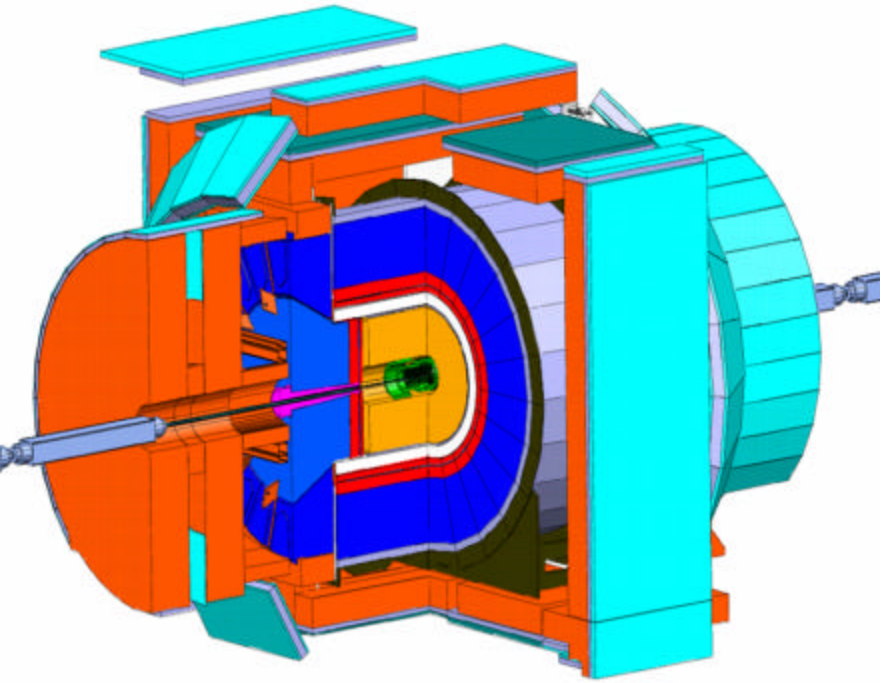


# CDF and DØ Collaborations

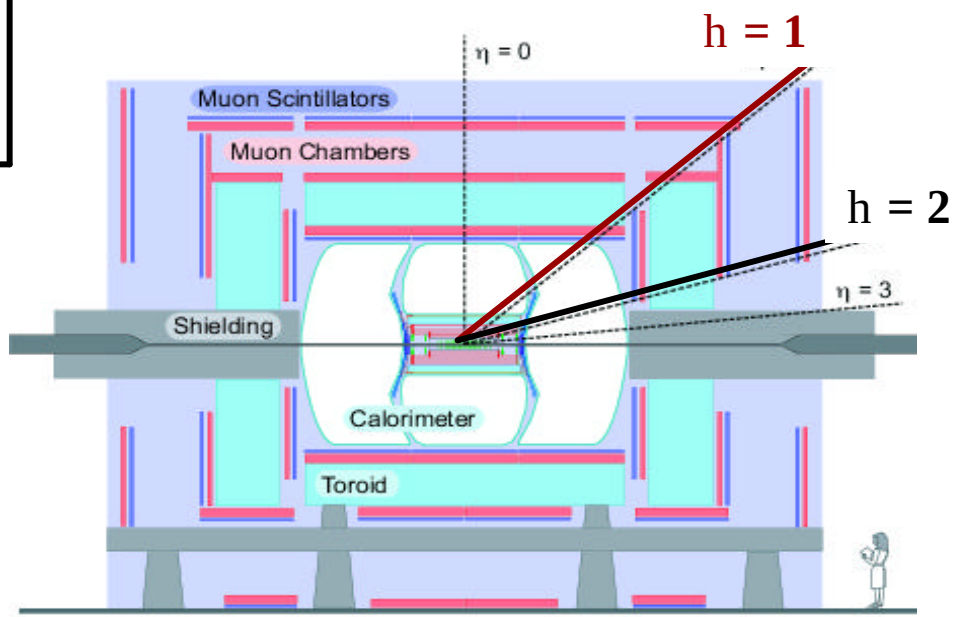
**12 countries, 59 institutions**
**706 physicists**

**19 countries, 83 institutions**
**664 physicists**

# CDF and DØ Detectors

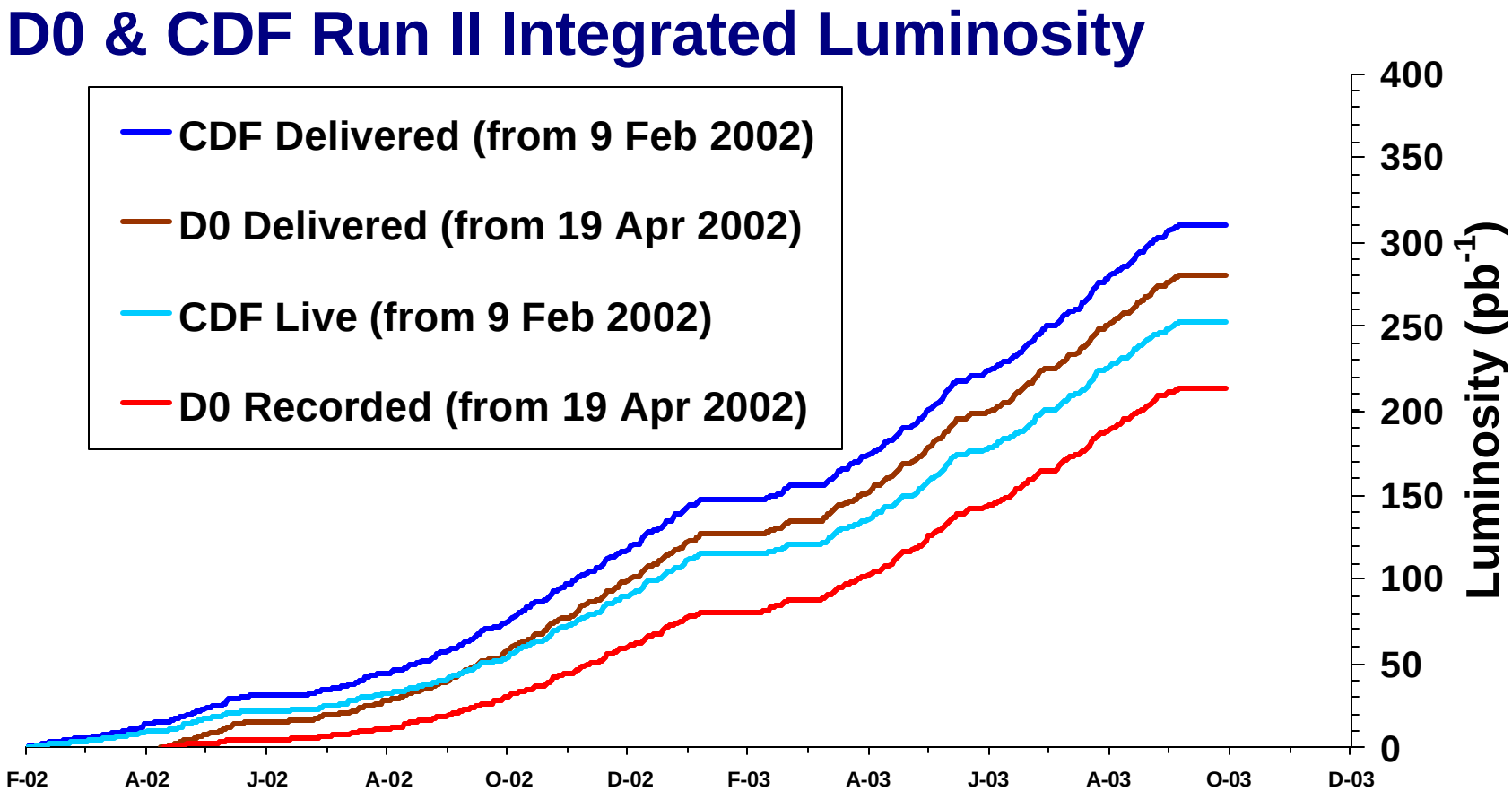


- New silicon and drift chamber
- Upgrade of calorimeter and muon system
- Upgrade of Trigger/DAQ




- 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

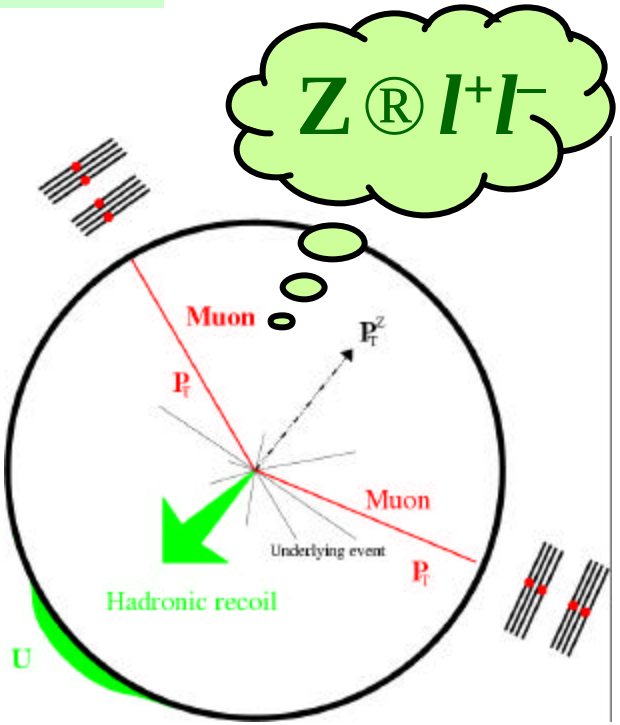
**Run II:**

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** |

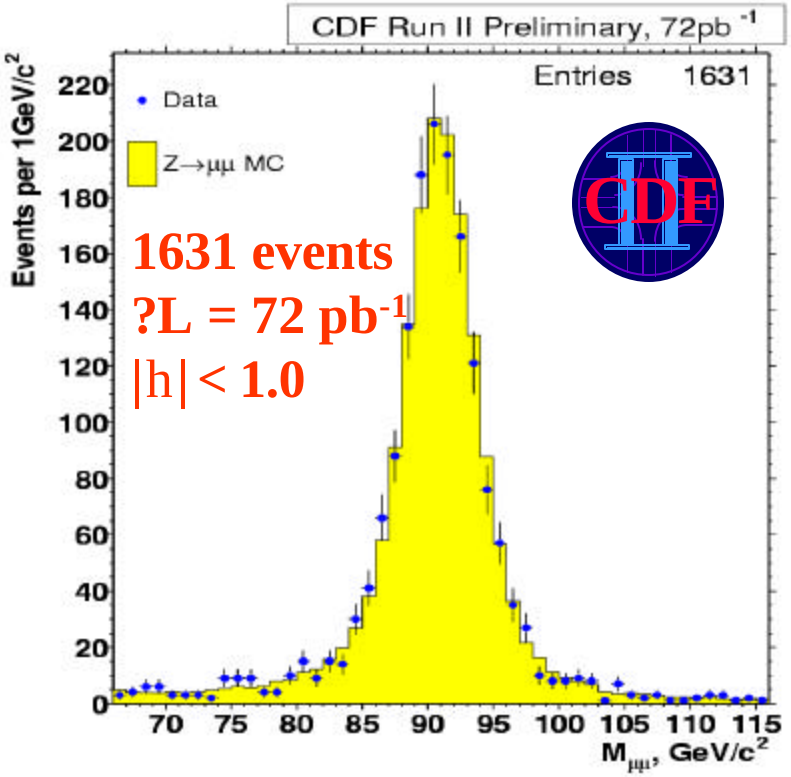
# Electroweak program

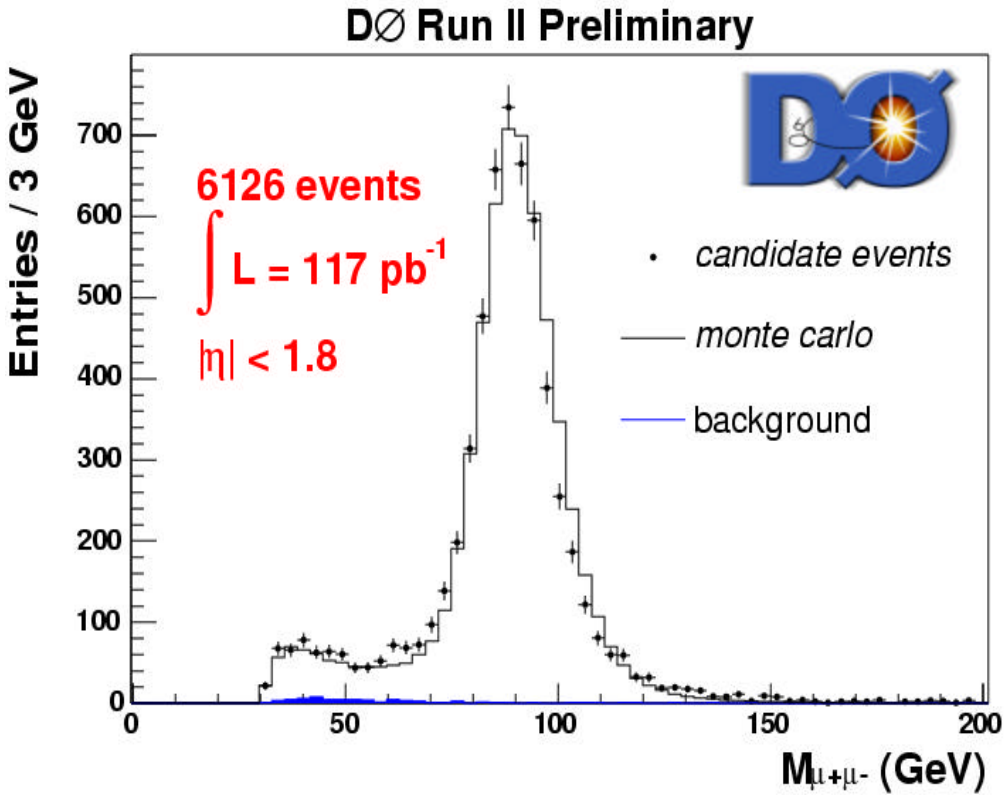
- Z, W cross section measurements
  - Detector commissioning and calibration
  - W width, lepton universality
  - Search for Z'/extra dimensions/…
- Z forward/backward asymmetry
- Di/triboson physics
- W charge asymmetry, differential W/Z cross sections
  - PDF constraints
- Use W and Z as a luminosity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



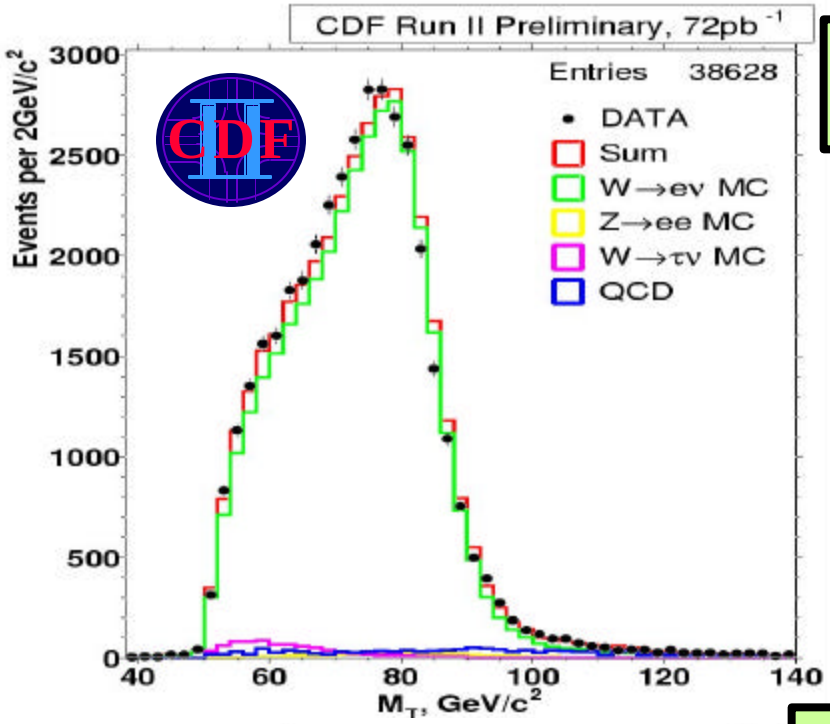
# Cross-section measurements of $Z \rightarrow l^+ l^-$

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

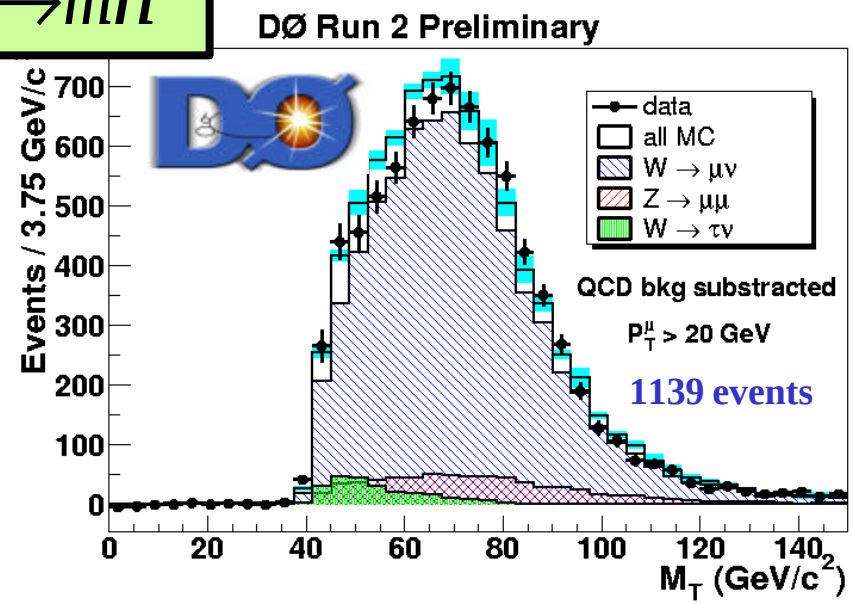


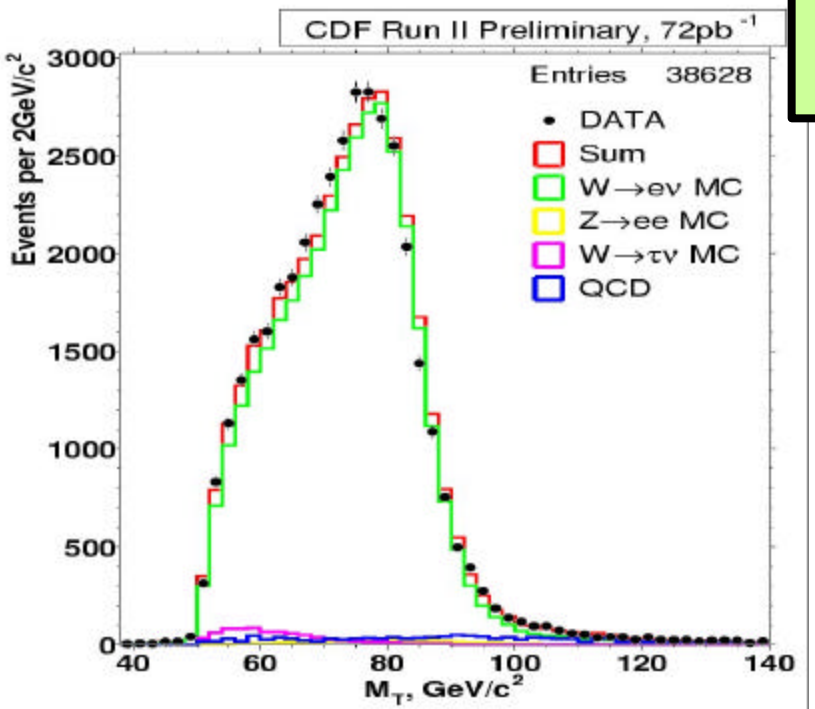




Good agreement between Monte Carlo simulation and data


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
$P_T^\mu$ > 20 GeV
1139 events
Events / 3.75 GeV/c
$M_T$ (GeV/c$^2$)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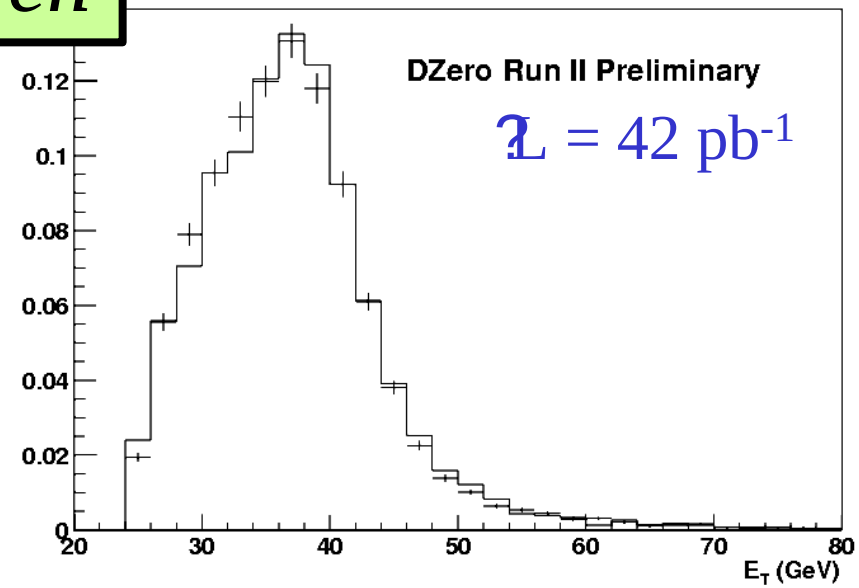
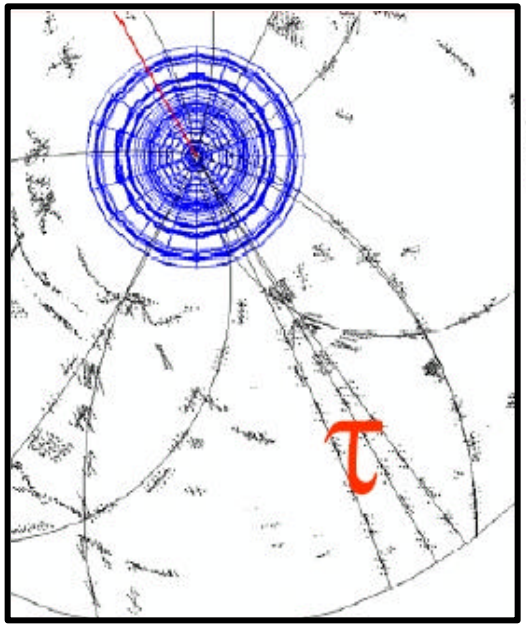
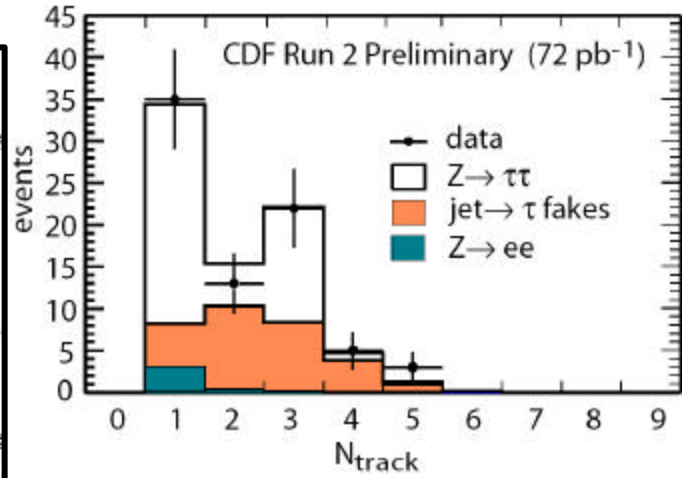
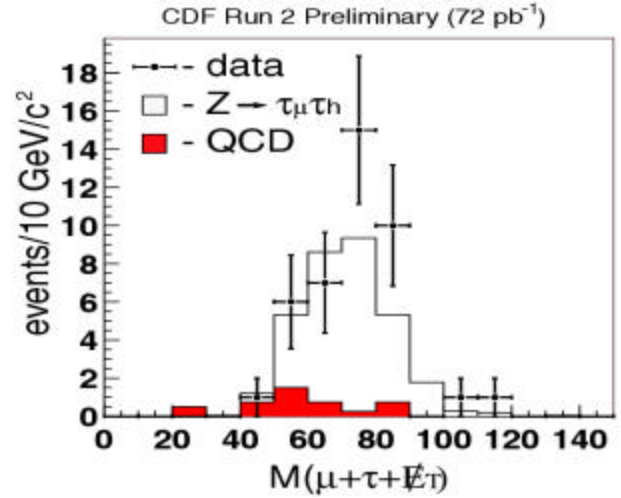
W→*en*

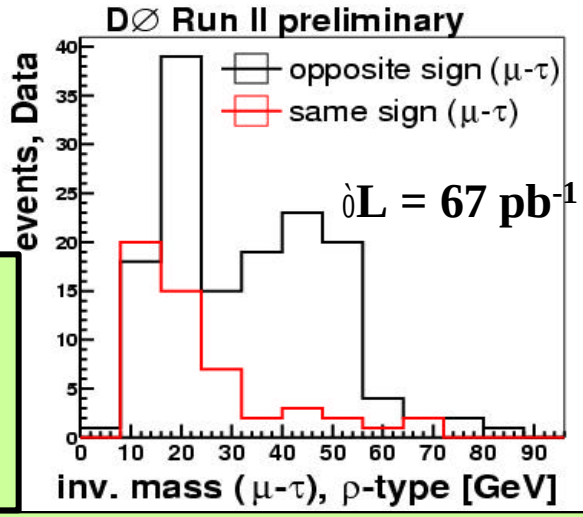

DZero Run II Preliminary
?L = 42 pb$^{-1}$
$E_T$ (GeV)

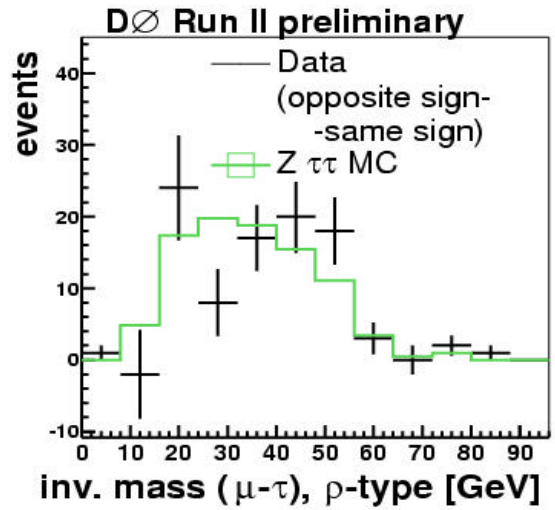
# $Z \to \tau\tau$



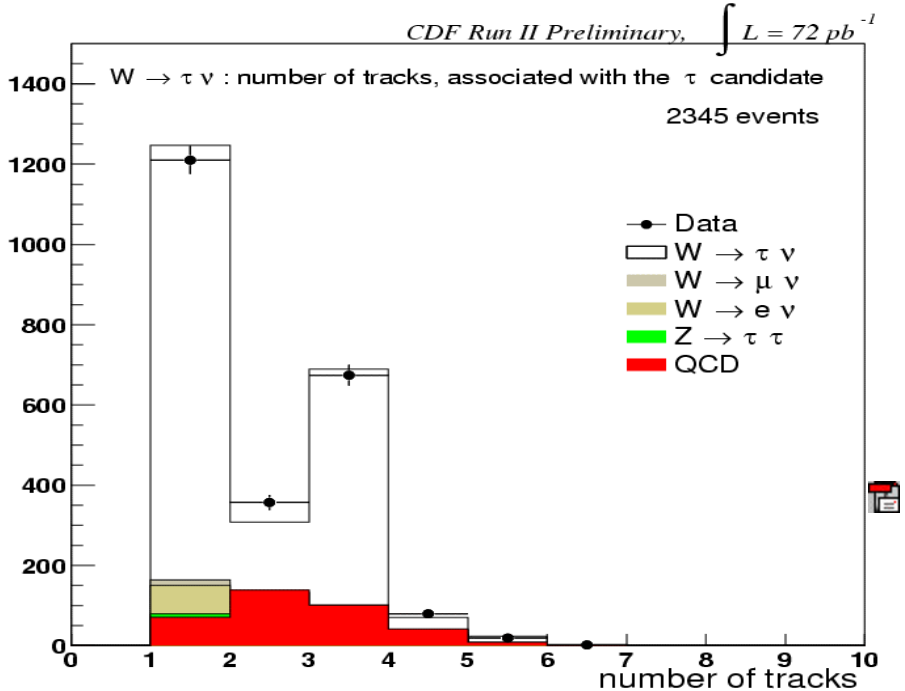



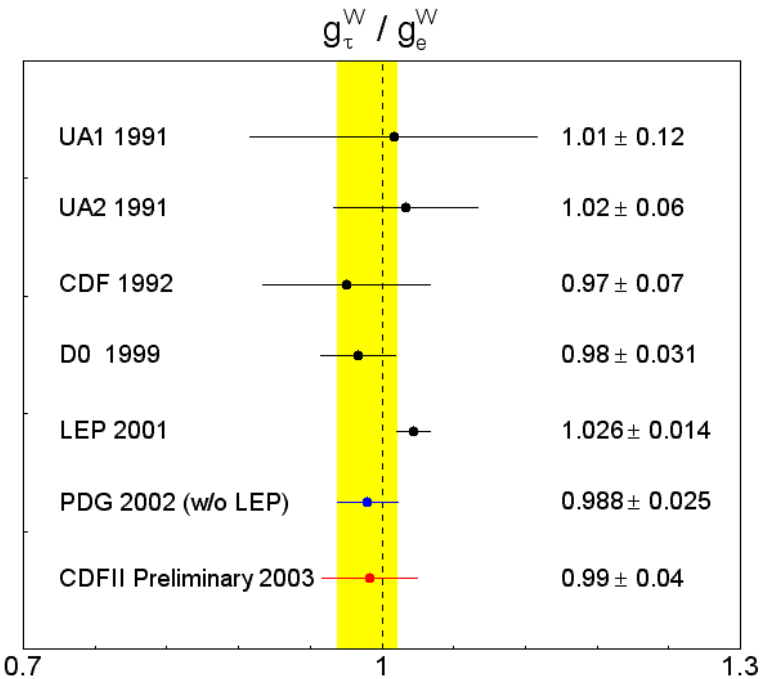

Run II preliminary:
First measurement at hadron collider

**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…

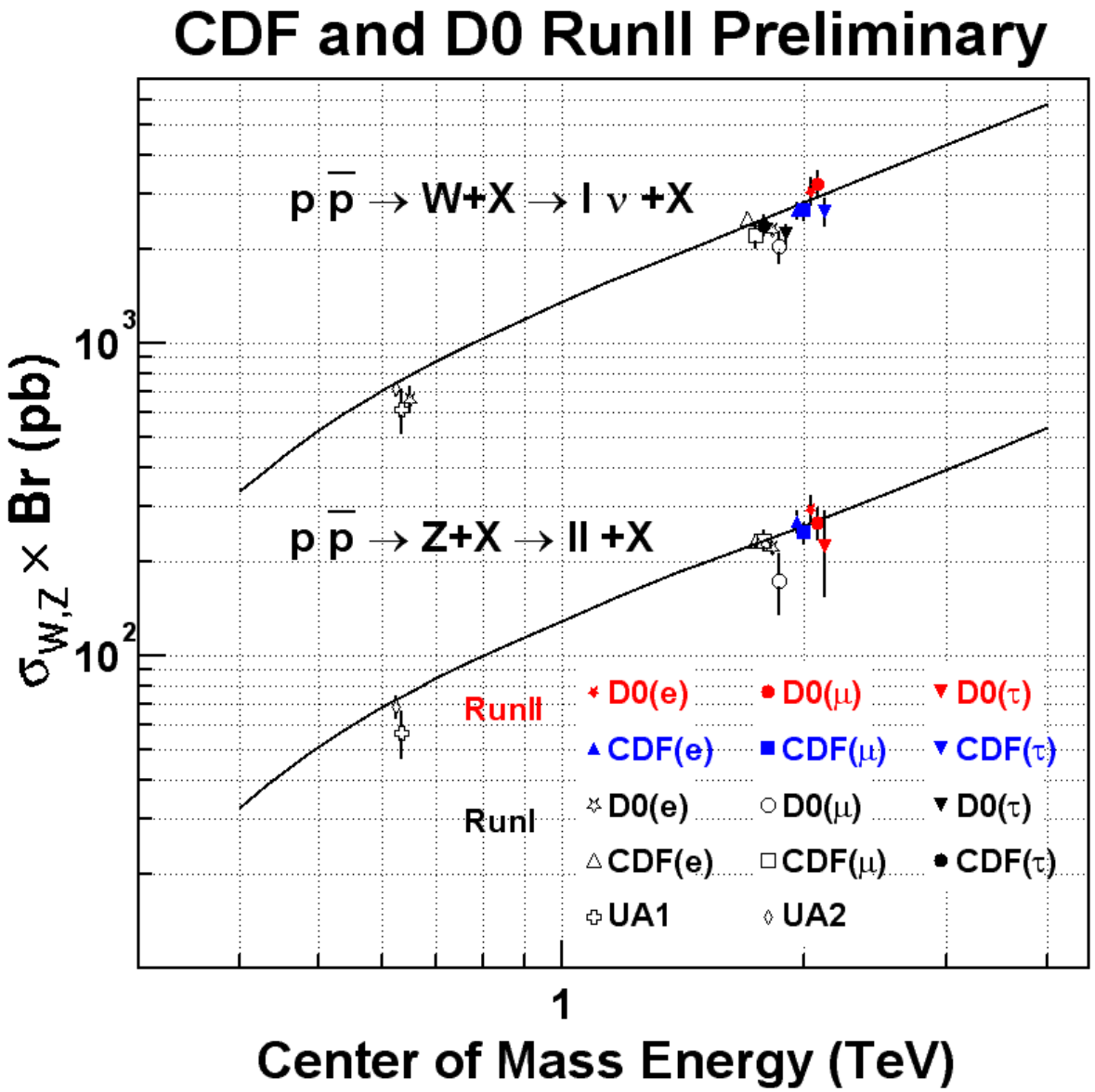
Run II preliminary

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.

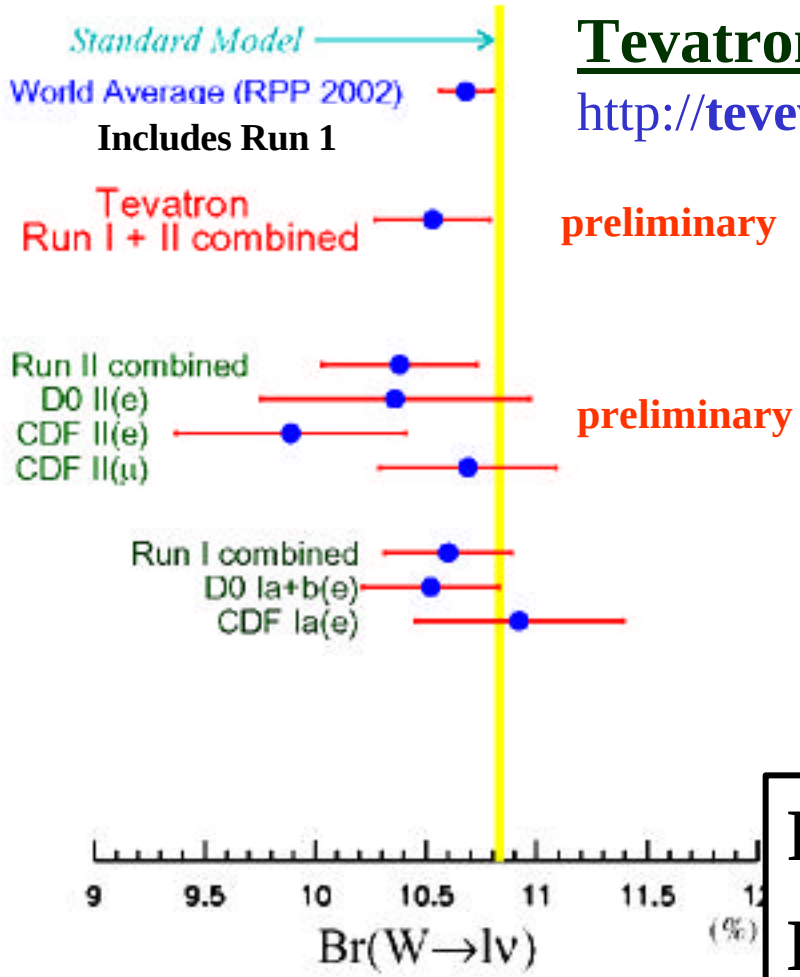
# W and Z cross section measurements




## 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

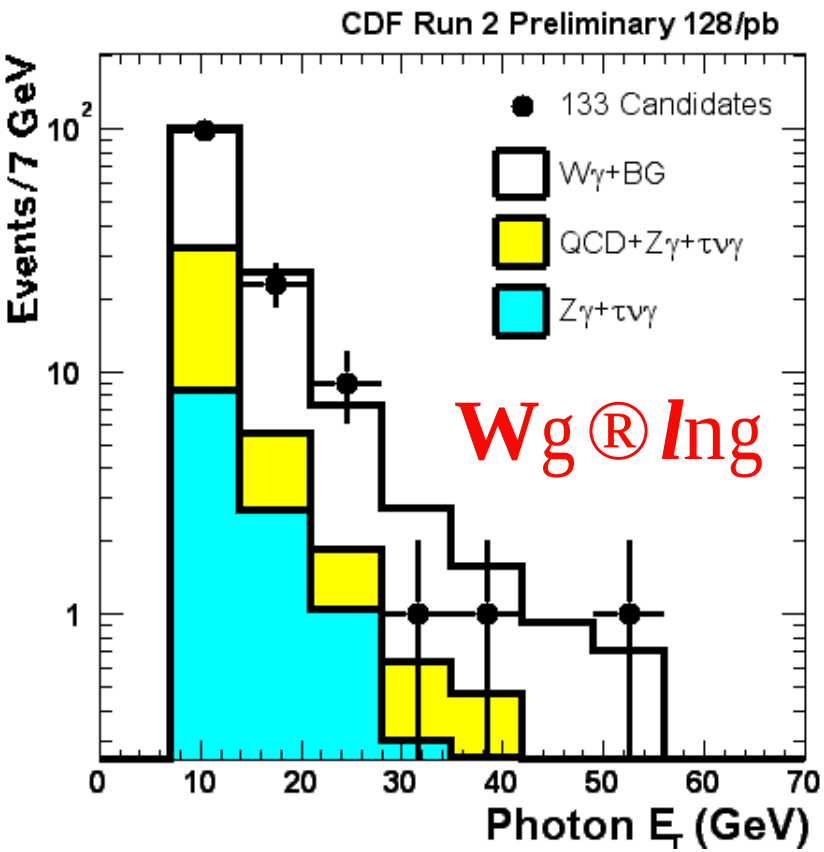
**R = 10.36 ± 0.31**

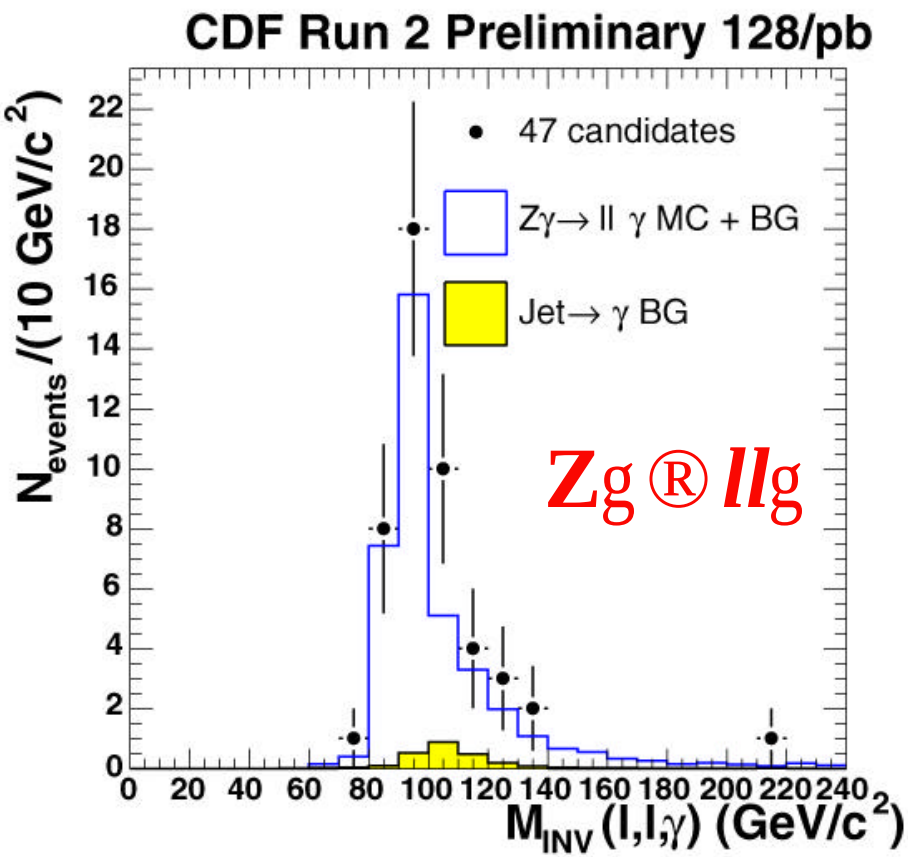
**Br(W ® *l*n) = (10.38 ± 0.35)%**

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$\to l\nu$)

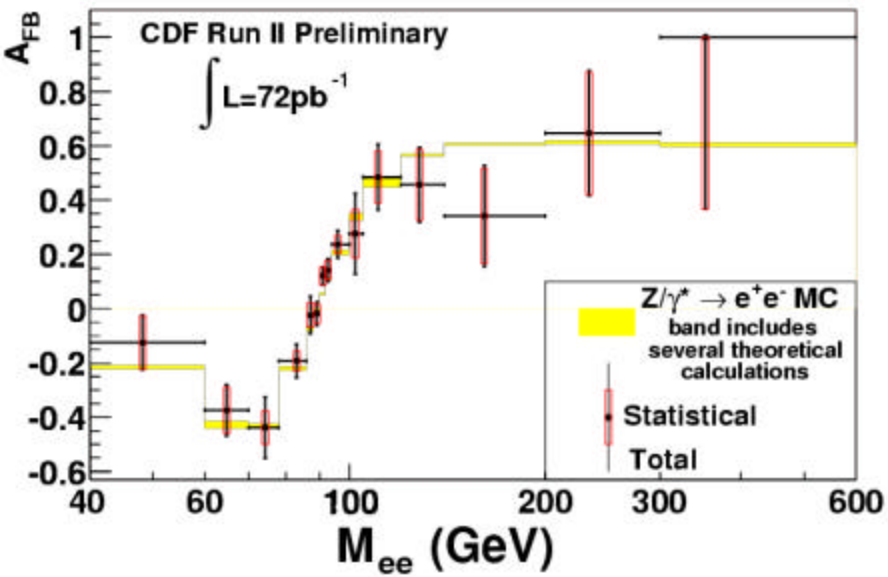
$$s(\mathrm{WW}) = 5.1^{+5.4}_{-3.6} \pm 1.3 \pm 0.3\ \mathrm{pb}$$

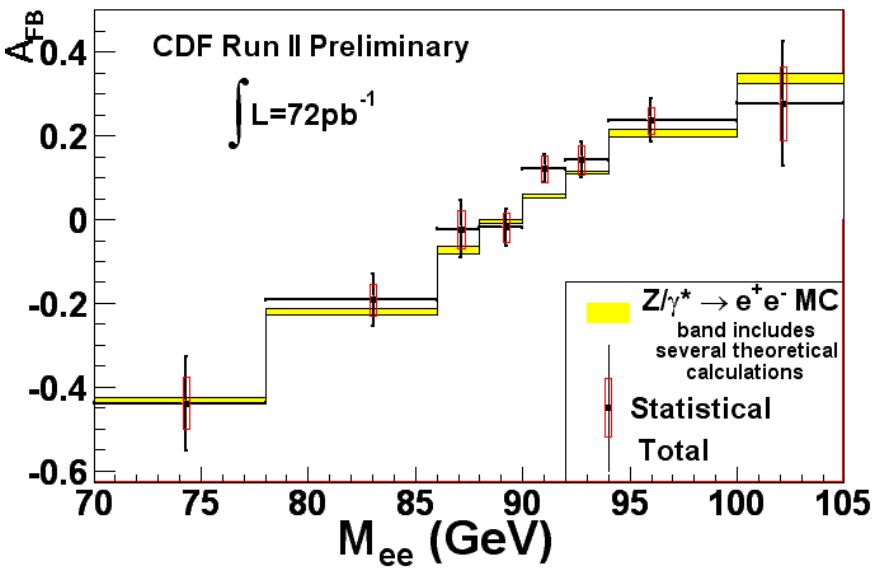
# Other measurements…

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



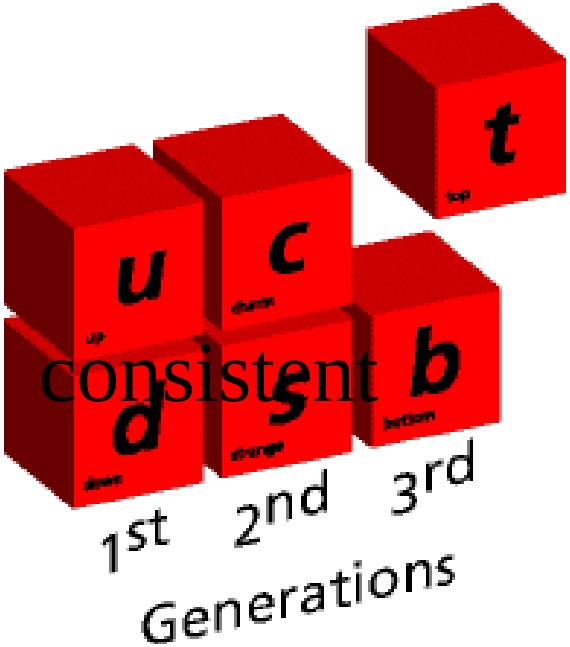

- Results agree with SM predictions

# 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

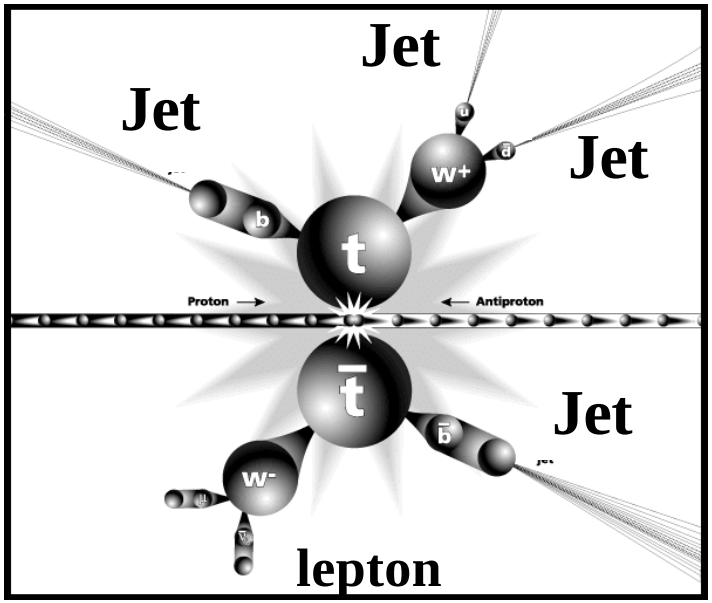
- Discovered by CDF and DØ collaborations in 1995
- Run I top physics results are consistent with SM
  - Statistics dominated errors

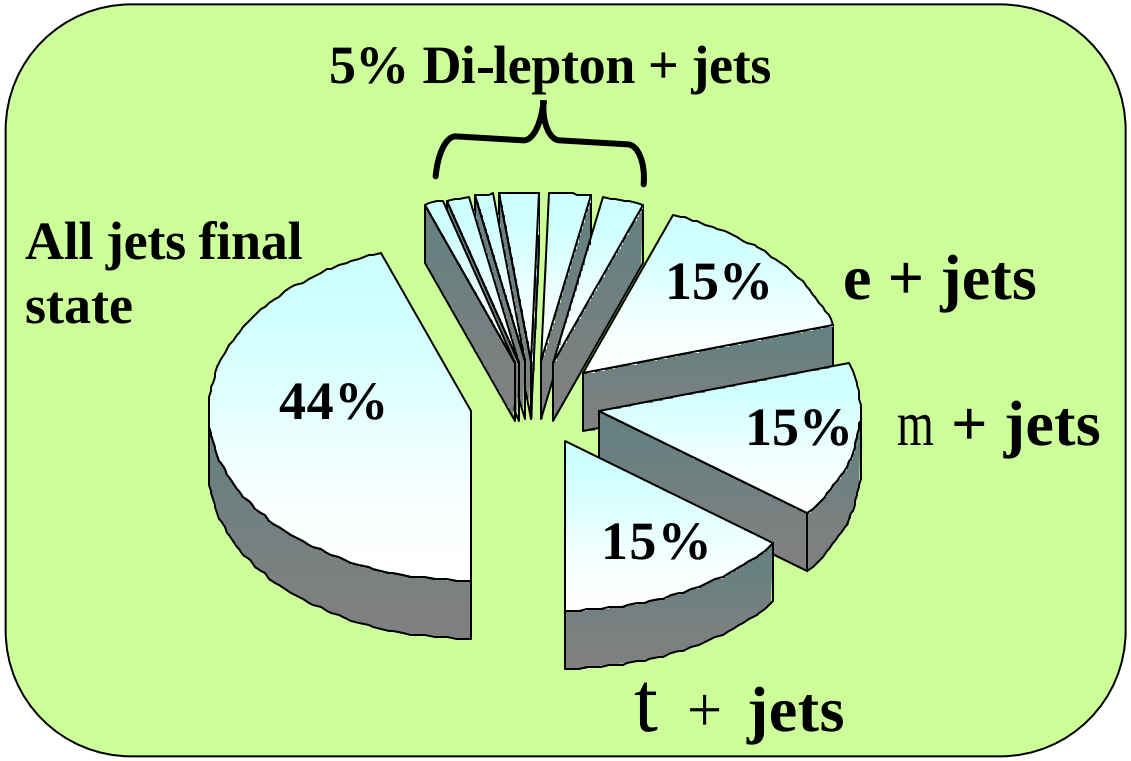



- Run II top physics program will take full advantage of higher statistics
  - Better precision
  - Search for deviations from SM expectations

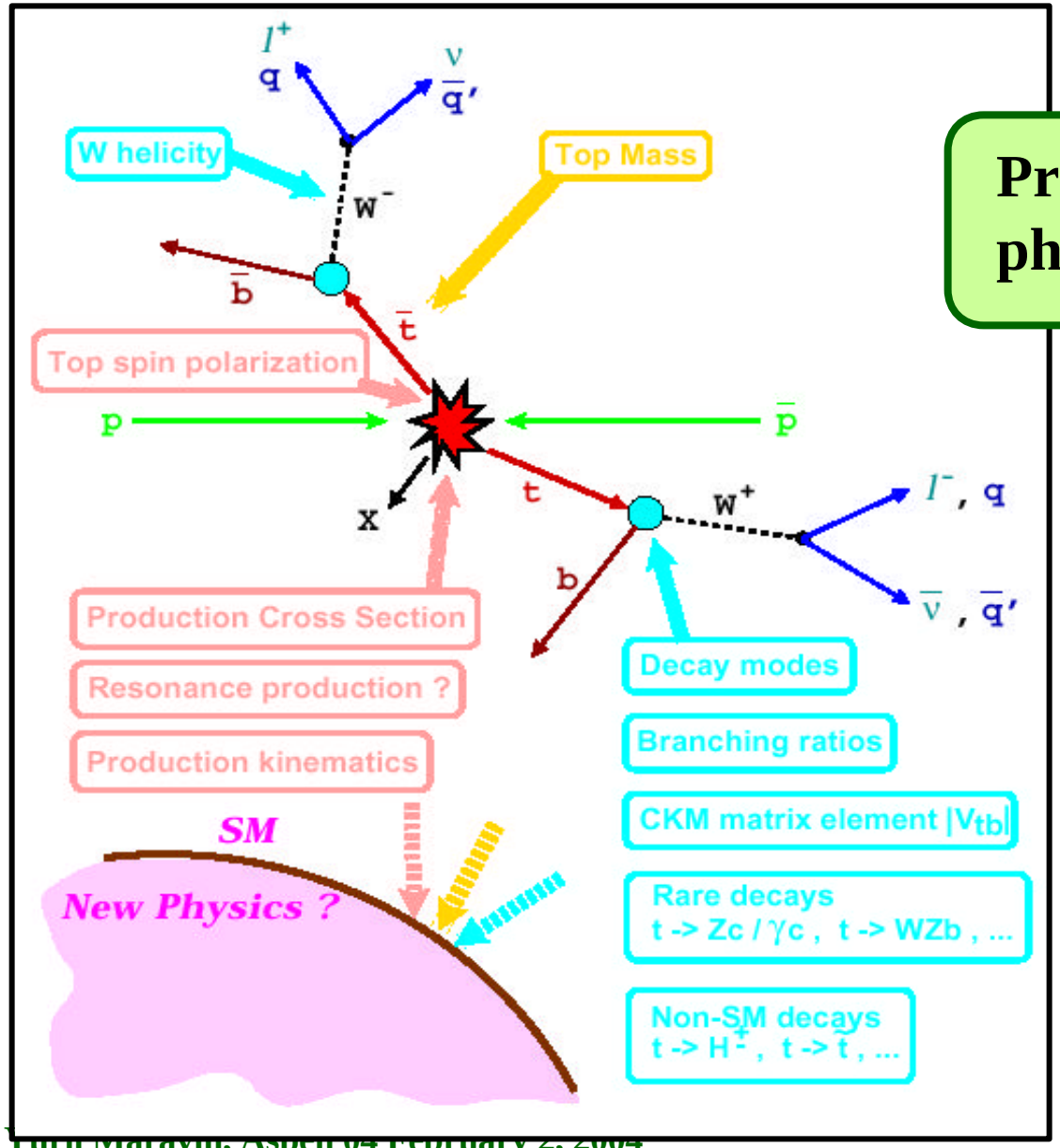
# Top production in Tevatron

- 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



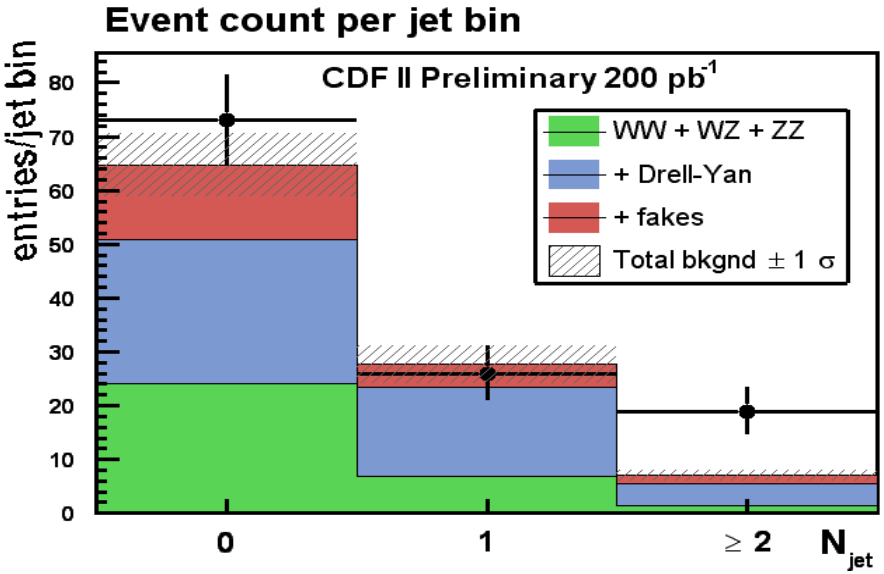

**Preliminary results on top physics at Tevatron:**

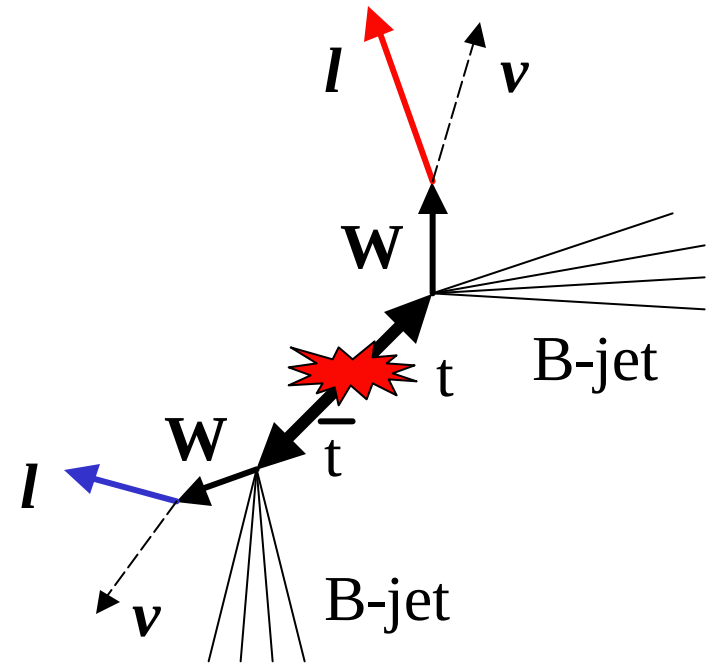
- $t\bar{t}$ cross-section
  - strong physics of top
- Single top production
  - electroweak physics
- Top mass
- **W** helicity

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

2 high-$p_T$ isolated leptons

Large missing $E_T$ | $\geq 2$ jets




Run II preliminary

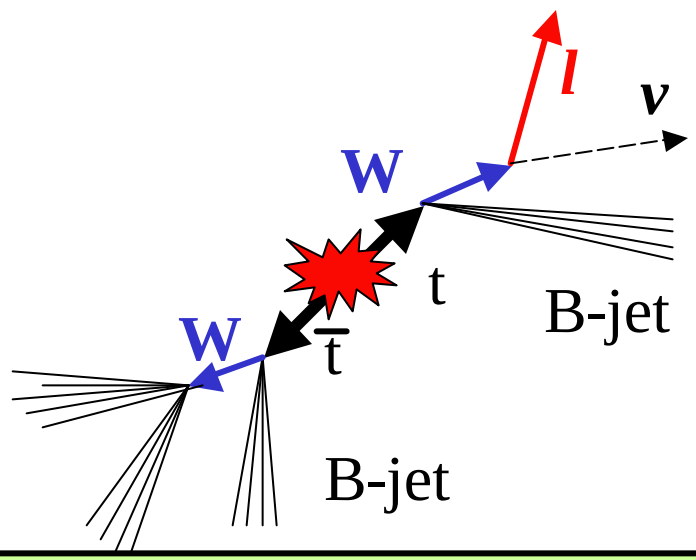
CDF (**200 pb$^{-1}$**): $s_{tt} = 6.9^{+2.7}_{-2.4}(\text{stat}) \pm 1.2(\text{syst}) \pm 0.4(\text{lumi})$ pb

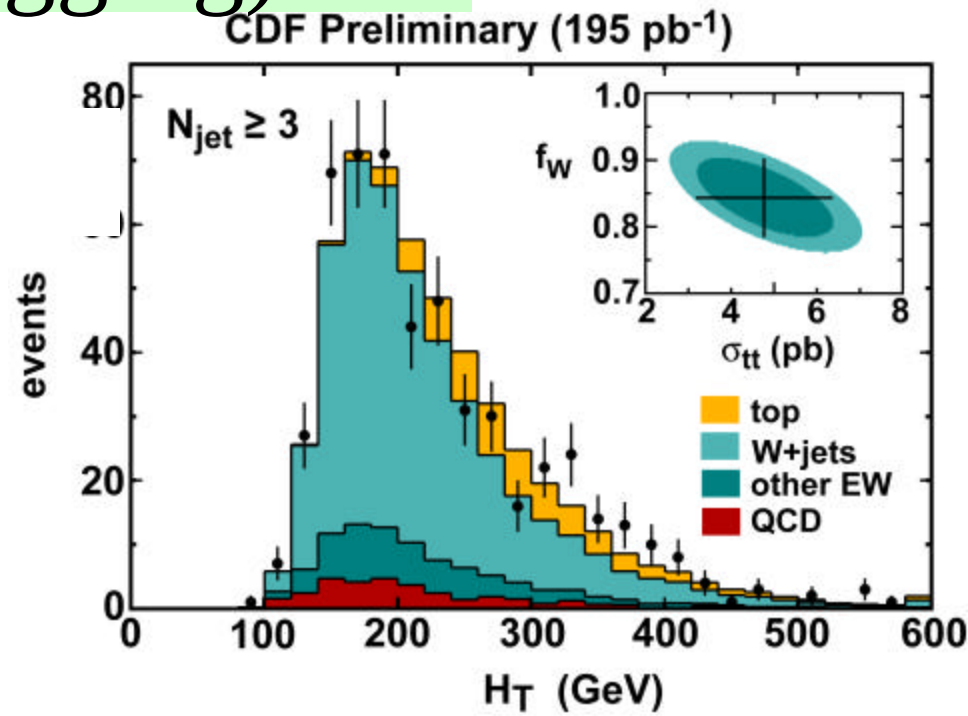
DØ (100 pb$^{-1}$) : $s_{tt} = 8.7^{+6.4}_{-4.7}(\text{stat})\ ^{+2.7}_{-2.0}(\text{syst}) \pm 0.9(\text{lumi})$ pb

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

Fermilab

| 1 high-$p_T$ isolated lepton | |
|---|---|
| Large missing $E_T$ | $\geq 3$ jets |



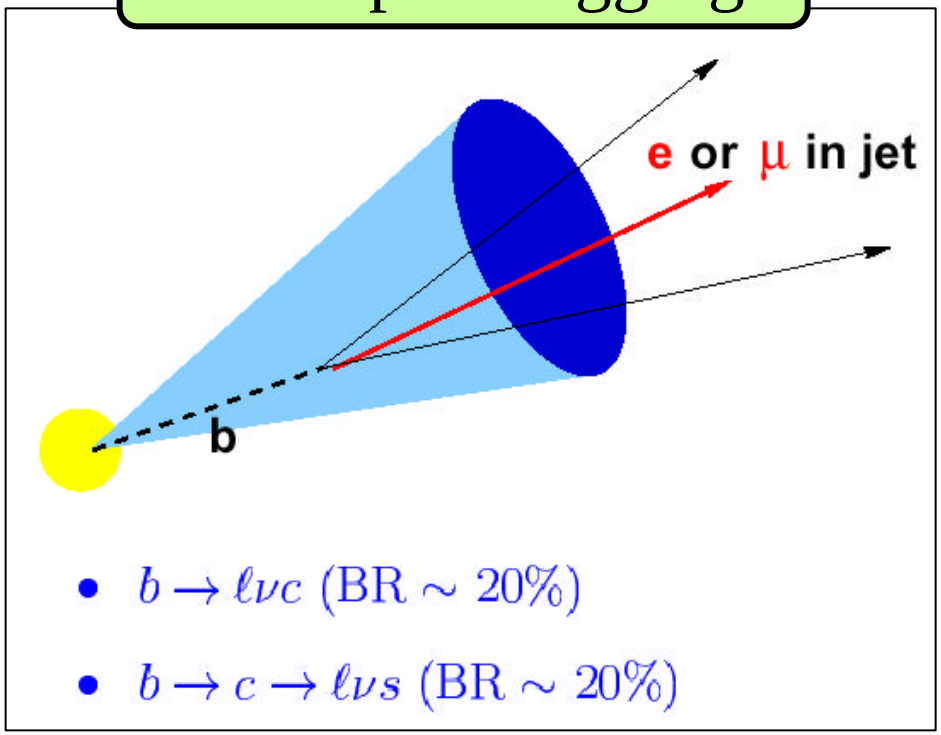

Run II preliminary

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

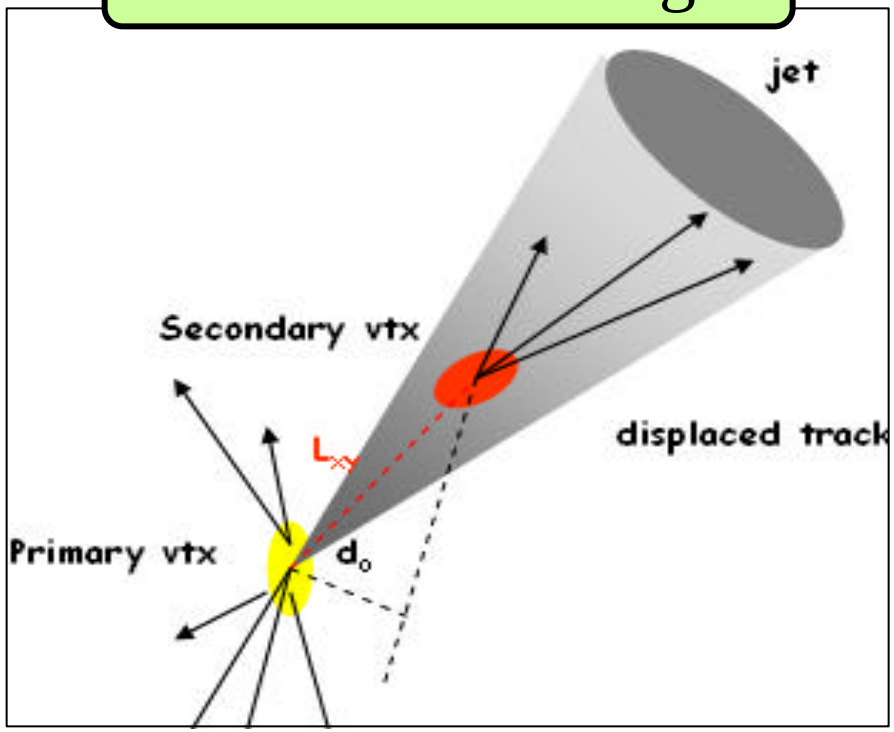
# Tagging a **b** quark

## Soft lepton tagging




Search for non-isolated soft lepton in a jet

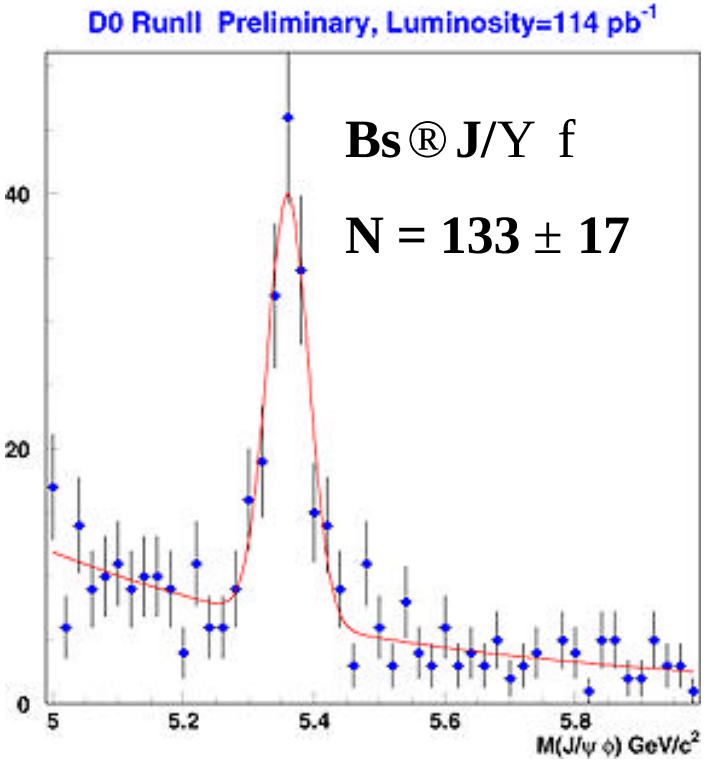
## Silicon Vertex tag




**B** meson travels ~ 3 mm before decaying:

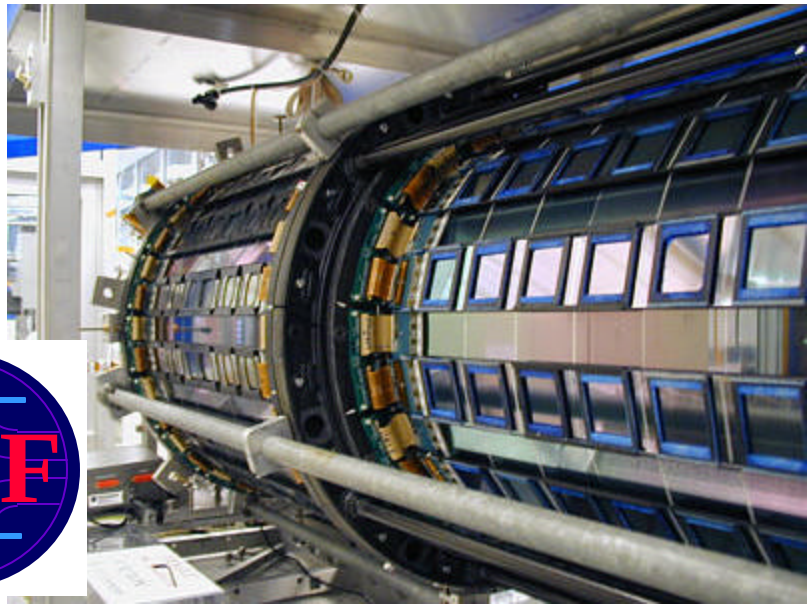
– Search for secondary vertex

# Silicon detectors




**Run II:** cover entire luminous region

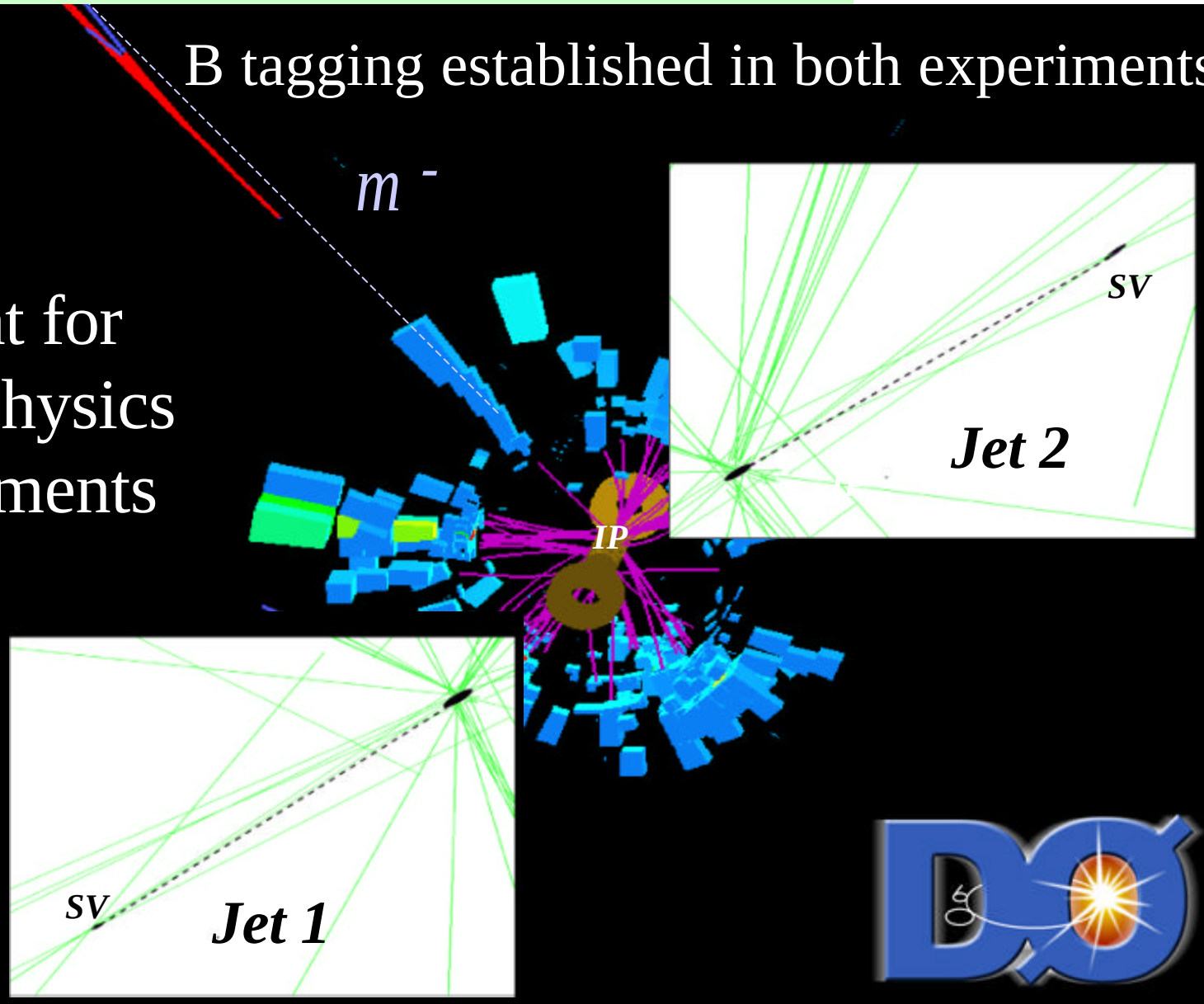
– **b**-tagging for all **$t\bar{t}$**!



# μ + jets double-tagged event

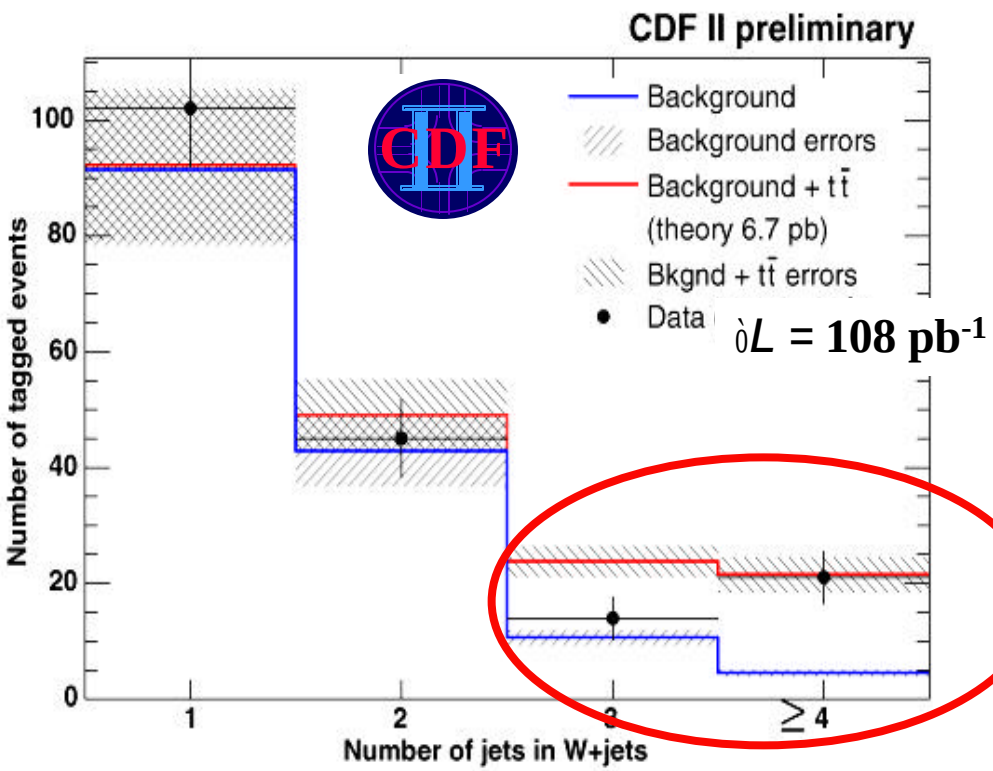
B tagging established in both experiments!

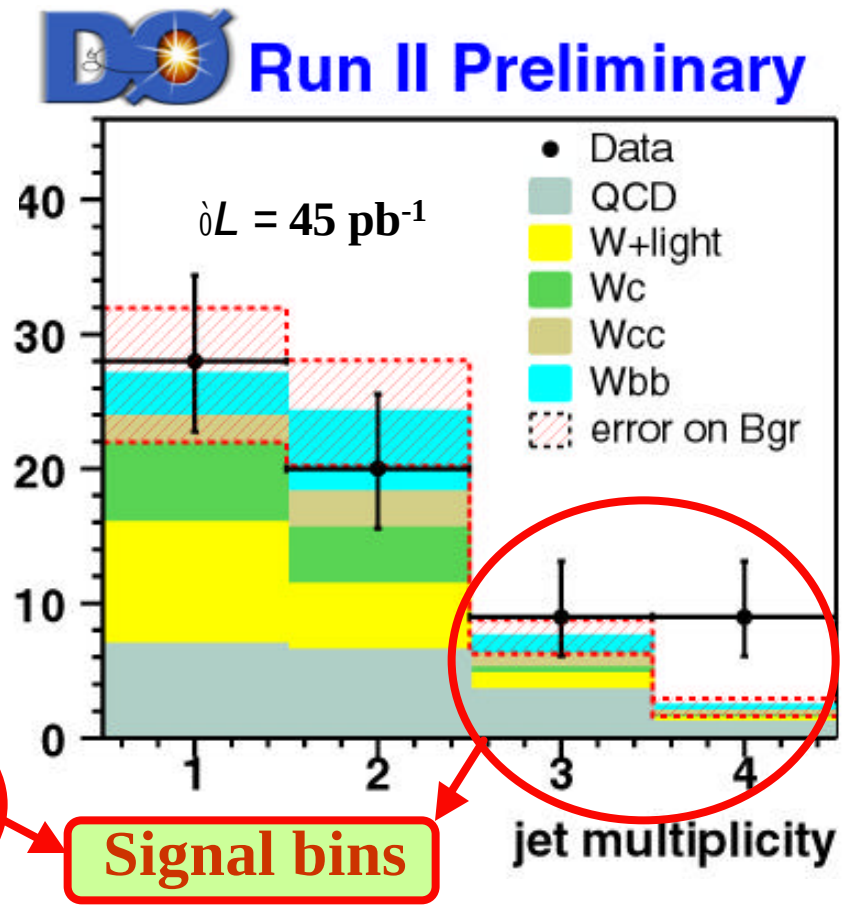
Important for the top physics measurements



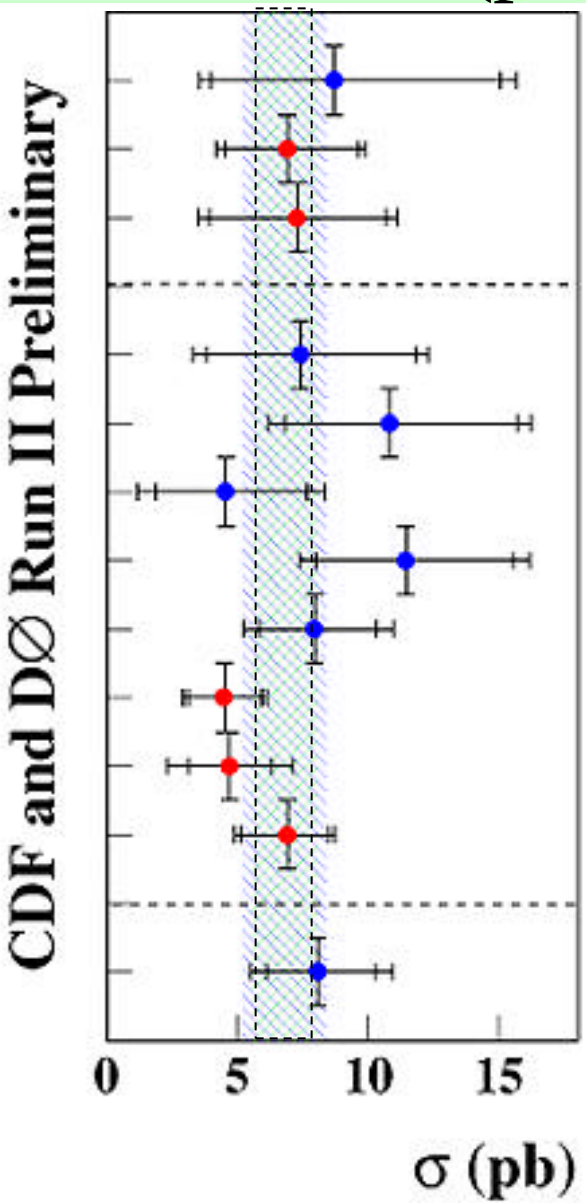
# $t\bar{t}$ cross section (lepton + jets) (silicon b-tag)

| | |
|---|---|
| 1 high-$p_T$ isolated lepton | |
| Large missing $E_T$ | $\geq 3$ jets |



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




| | |
|---|---|
| DØ Dileptons 90-107 $pb^{-1}$ | $8.7^{+6.4}_{-4.7}(stat)^{+2.7}_{-2.0}(syst) \pm 0.9(lum)$ |
| CDF Dileptons 200 $pb^{-1}$ | $6.9^{+2.7}_{-2.4}(stat) \pm 1.2(syst) \pm 0.4(lumi)$ |
| CDF L+Track 126 $pb^{-1}$ | $7.3 \pm 3.4(stat) \pm 1.7(syst)$ |
| DØ L+jets/CSIP 45 $pb^{-1}$ | $7.4^{+4.4}_{-3.6}(stat)^{+2.1}_{-1.8}(syst) \pm 0.7(lum)$ |
| DØ L+jets/SVT 45 $pb^{-1}$ | $10.8^{+4.9}_{-4.0}(stat)^{+2.1}_{-2.0}(syst) \pm 1.1(lum)$ |
| DØ L+jets/topo 92 $pb^{-1}$ | $4.6^{+3.1}_{-2.7}(stat)^{+2.1}_{-2.0}(syst) \pm 0.5(lum)$ |
| DØ L+jets/soft muon 92 $pb^{-1}$ | $11.4^{+4.1}_{-3.5}(stat)^{+2.0}_{-1.8}(syst) \pm 1.1(lum)$ |
| DØ L+jets combined 92 $pb^{-1}$ | $8.0^{+2.4}_{-2.1}(stat)^{+1.7}_{-1.5}(syst) \pm 0.8(lum)$ |
| CDF L+jets/SVX 108 $pb^{-1}$ | $4.5 \pm 1.4(stat) \pm 0.8(syst)$ |
| CDF L+jets/HT 195 $pb^{-1}$ | $4.7 \pm 1.6(stat) \pm 1.8(syst)$ |
| CDF L+jets/SVX/kine 108 $pb^{-1}$ | $6.9^{+1.6}_{-1.8}(stat) \pm 0.9(syst)$ |
| DØ Combined 90-107 $pb^{-1}$ | $8.1^{+2.2}_{-2.0}(stat)^{+1.6}_{-1.4}(syst) \pm 0.8(lum)$ |

Kidonakis **hep-ph/0303086**

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

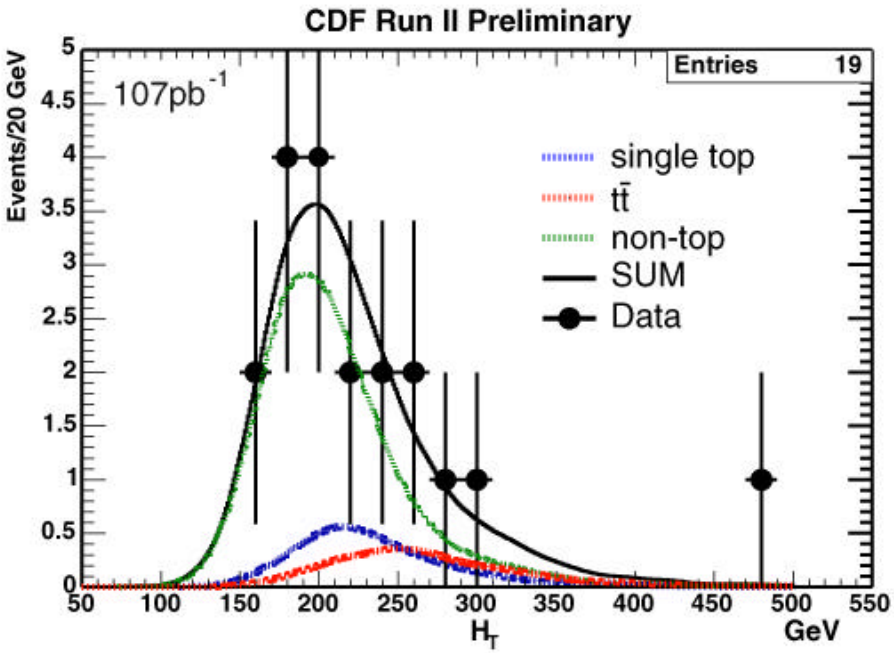
# Search for single top production

- 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:

- DØ $\sigma_t < 58$ pb, $\sigma_s < 39$ pb
- CDF $\sigma_t < 13.5$ pb, $\sigma_s < 12.9$ pb

CDF Run II preliminary

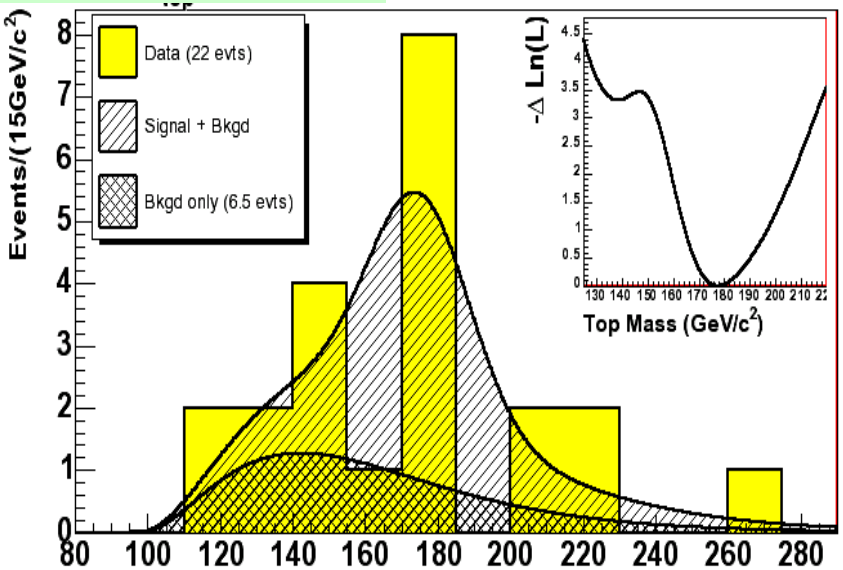
**$s_t$(combined) < 17.5 pb @95% C.L.**

# 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 (tt) hypothesis
  - Several combinations per event
  - Choose the one with best $\chi^2$ combination lepton+jets sample:

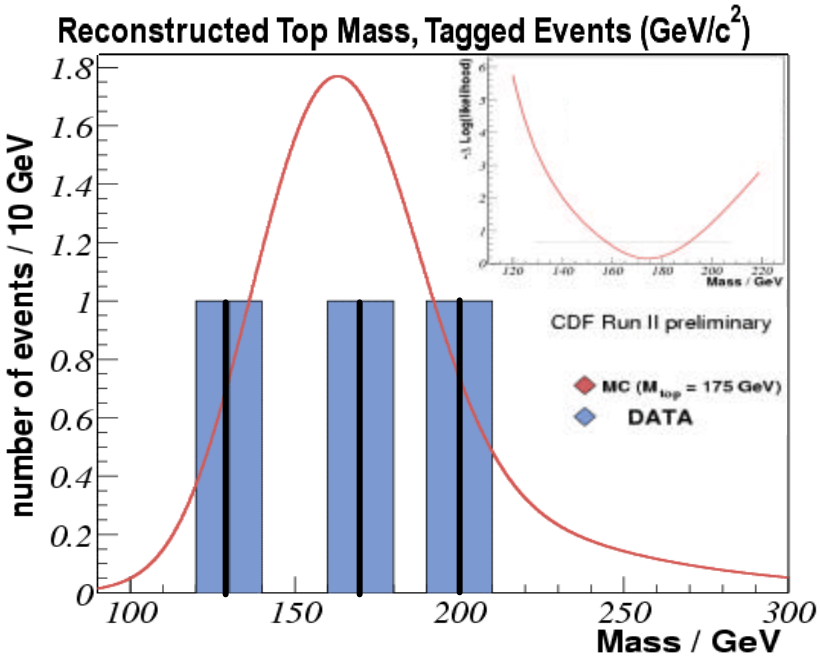



- lepton+jets sample: $\partial L$ = 108 pb$^{-1}$

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

- dilepton sample: $\partial L$ = 124 pb$^{-1}$

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



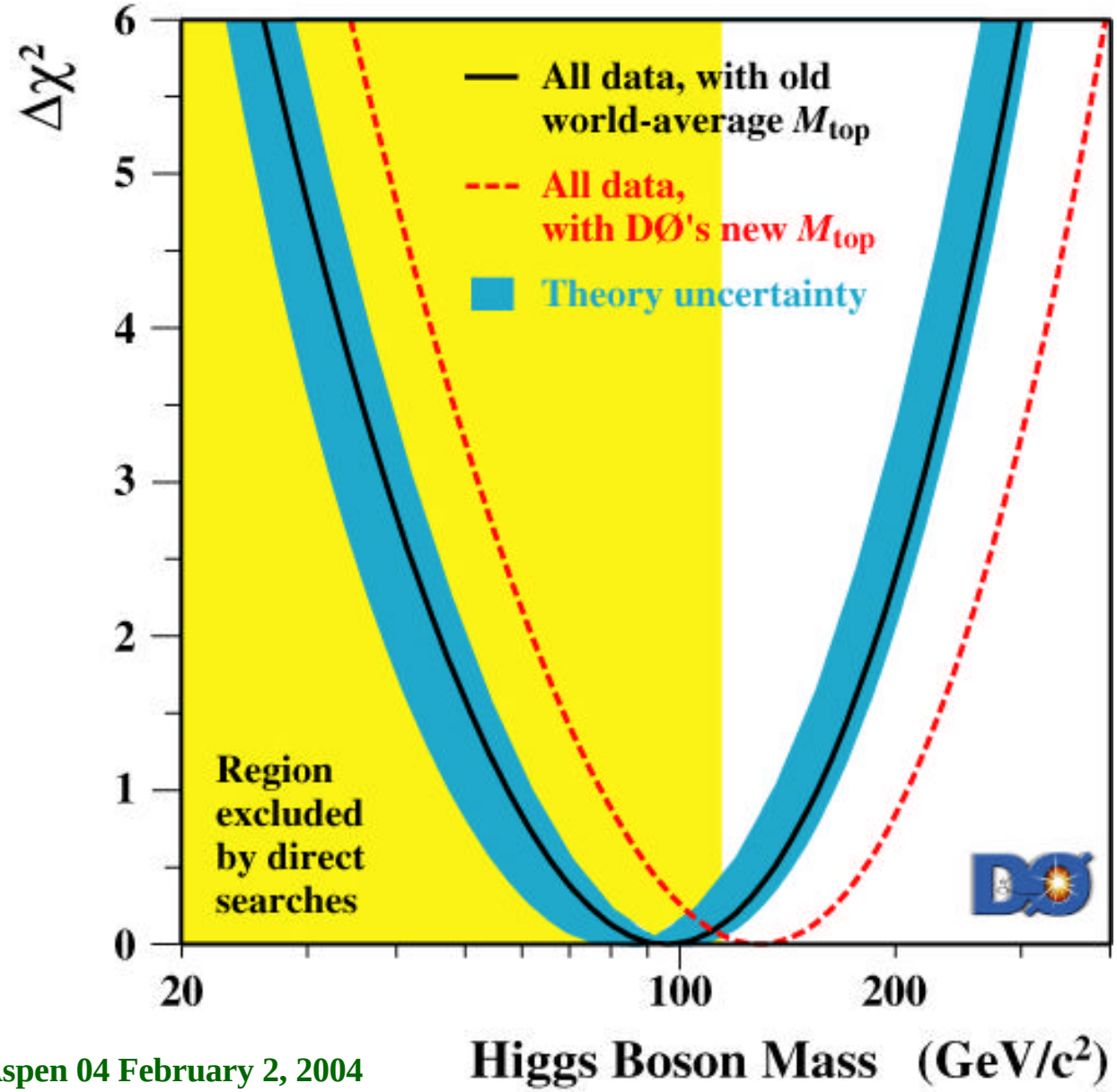
# Top mass measurement (Run I DØ)

- 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: $M_{top} = 180.1 \pm 3.6\ (stat) \pm 4.0\ (syst)\ GeV/c^2$

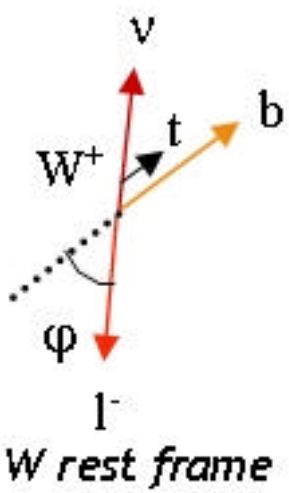
# New Higgs mass prediction
(preliminary)

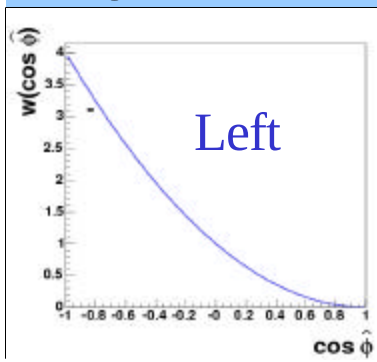


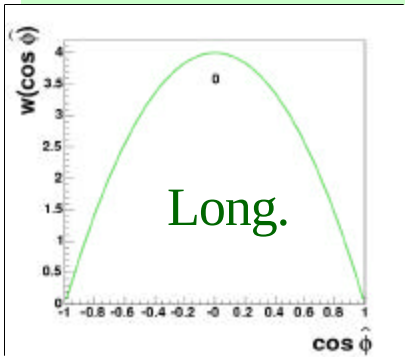
# W helicity in top decay (DØ)

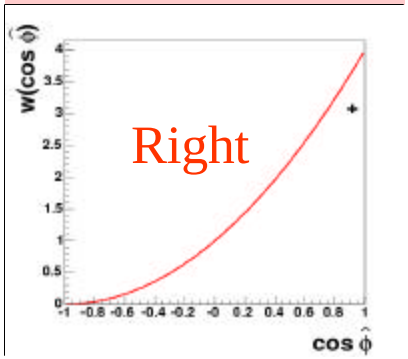
- Top quark decays before it can hadronize:
  - Unique opportunities to study bare quark with the mass of natural electroweak scale
- Angular dependence of the top quark decay:

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




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

**Preliminary DØ Run I result**

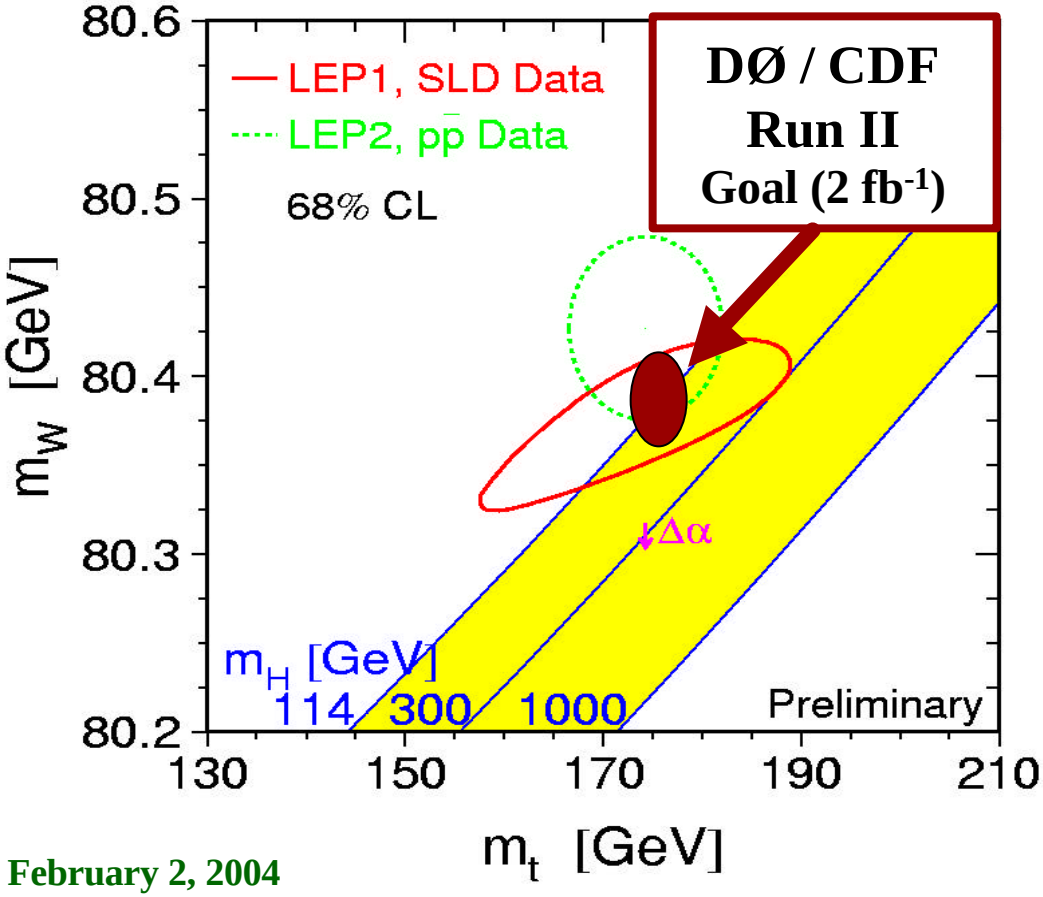
**$F_0 = 0.56 \pm 0.31$ (stat)$\pm 0.04$ (syst)**

# 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…

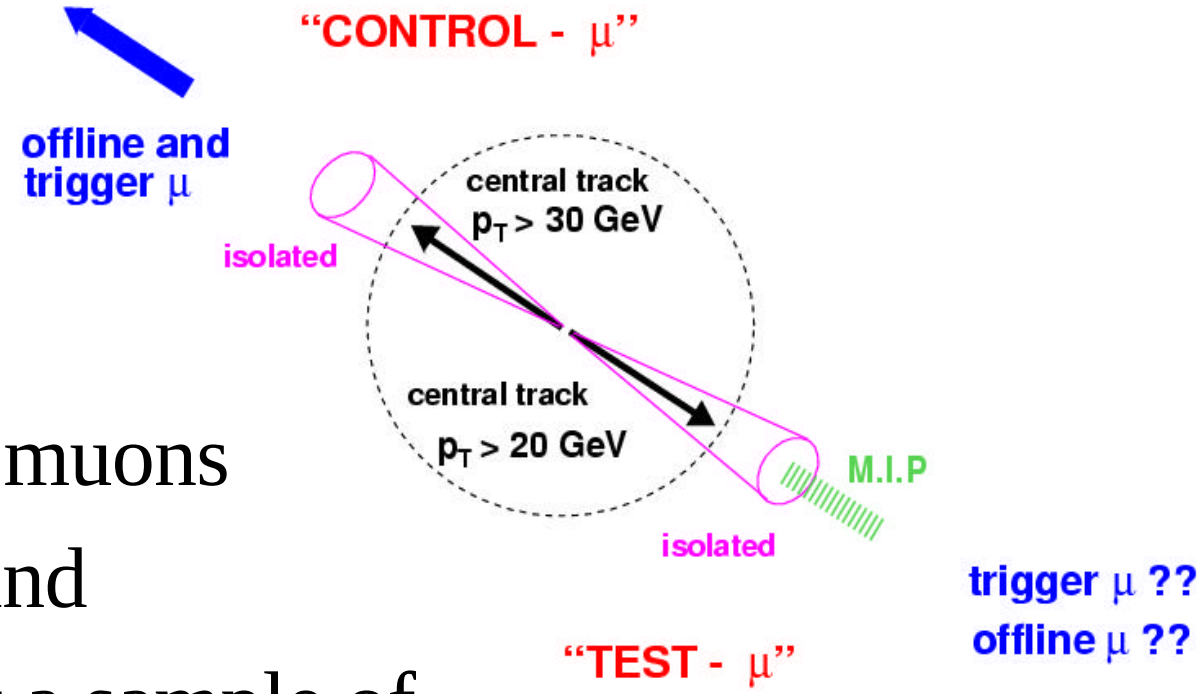
# Conclusions

- 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

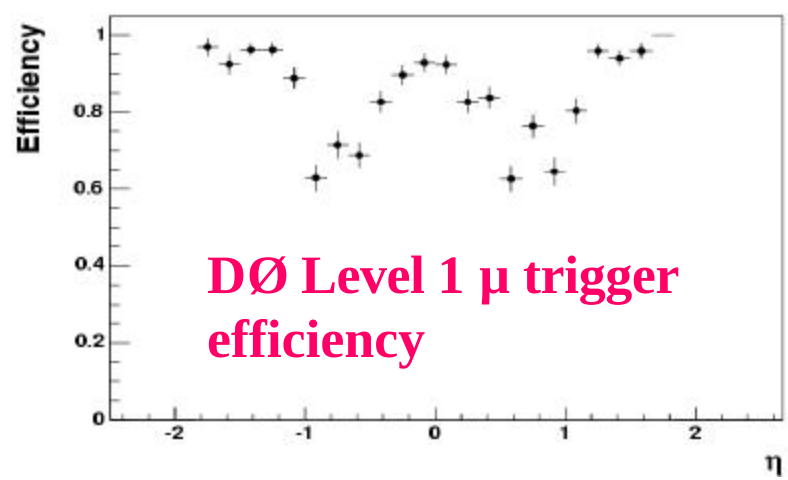


# Additional slides

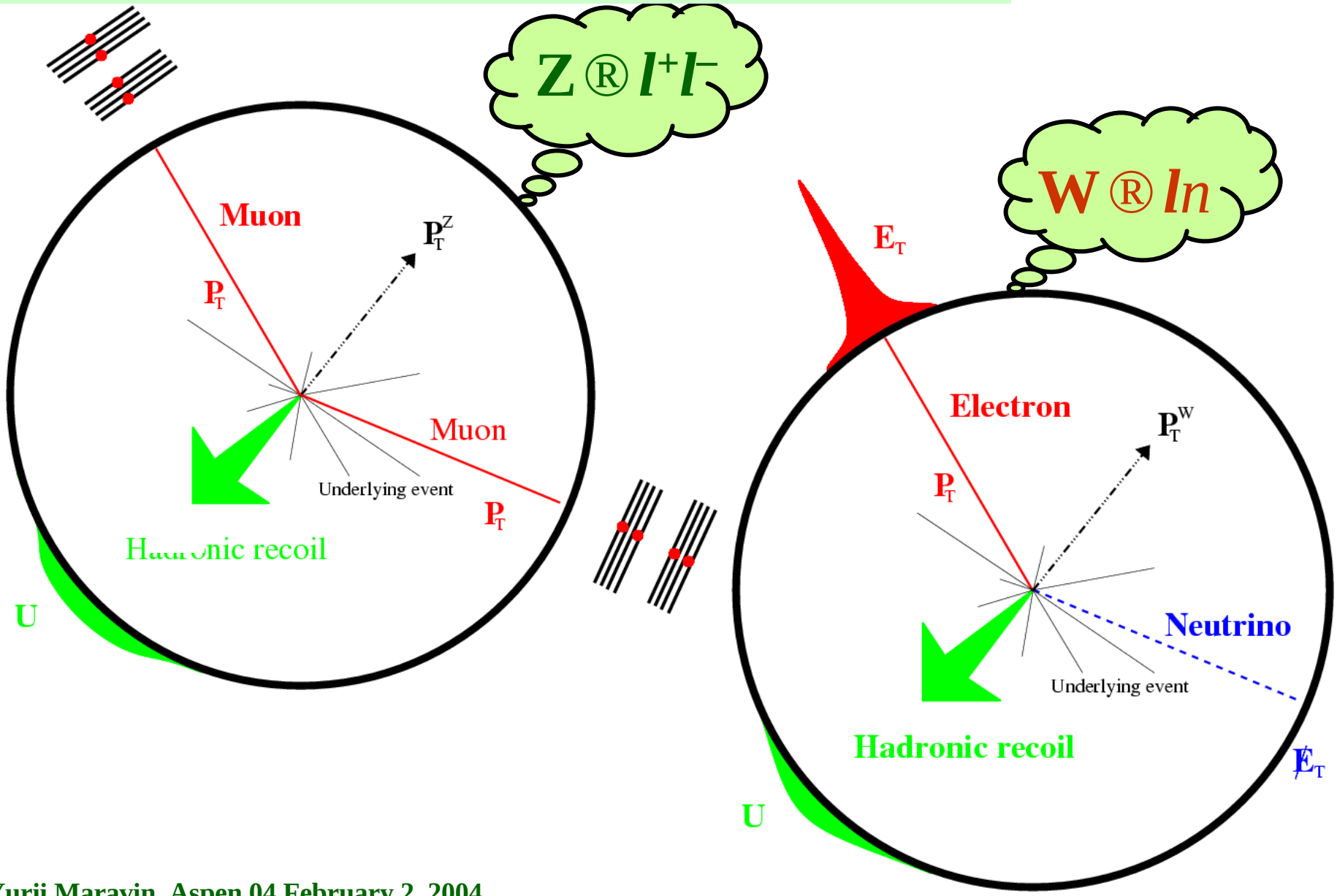
# Measuring efficiency with $Z \rightarrow m^+m^-$




- 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

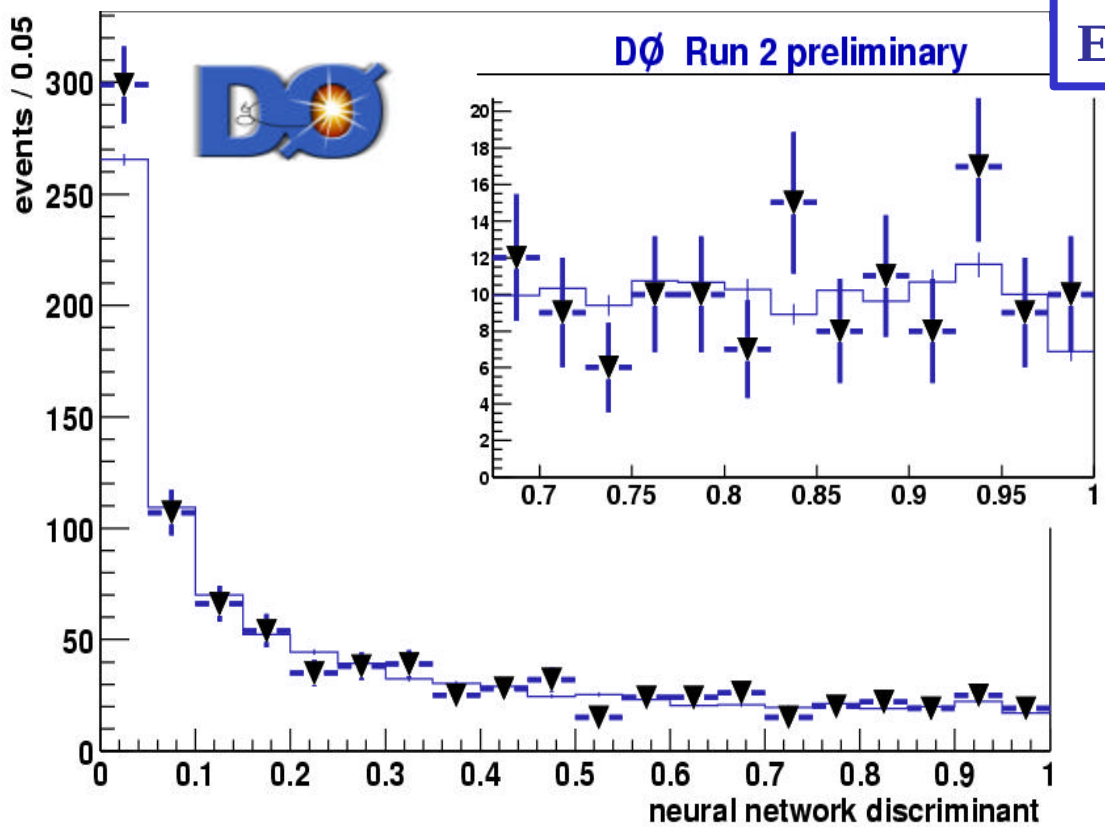


# $t\bar{t}$ cross section (all jets)

| | |
|---|---|
| no high-$p_T$ isolated leptons | |
| no missing $E_T$ | $\geq 4$ jets |

Run 1 data

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

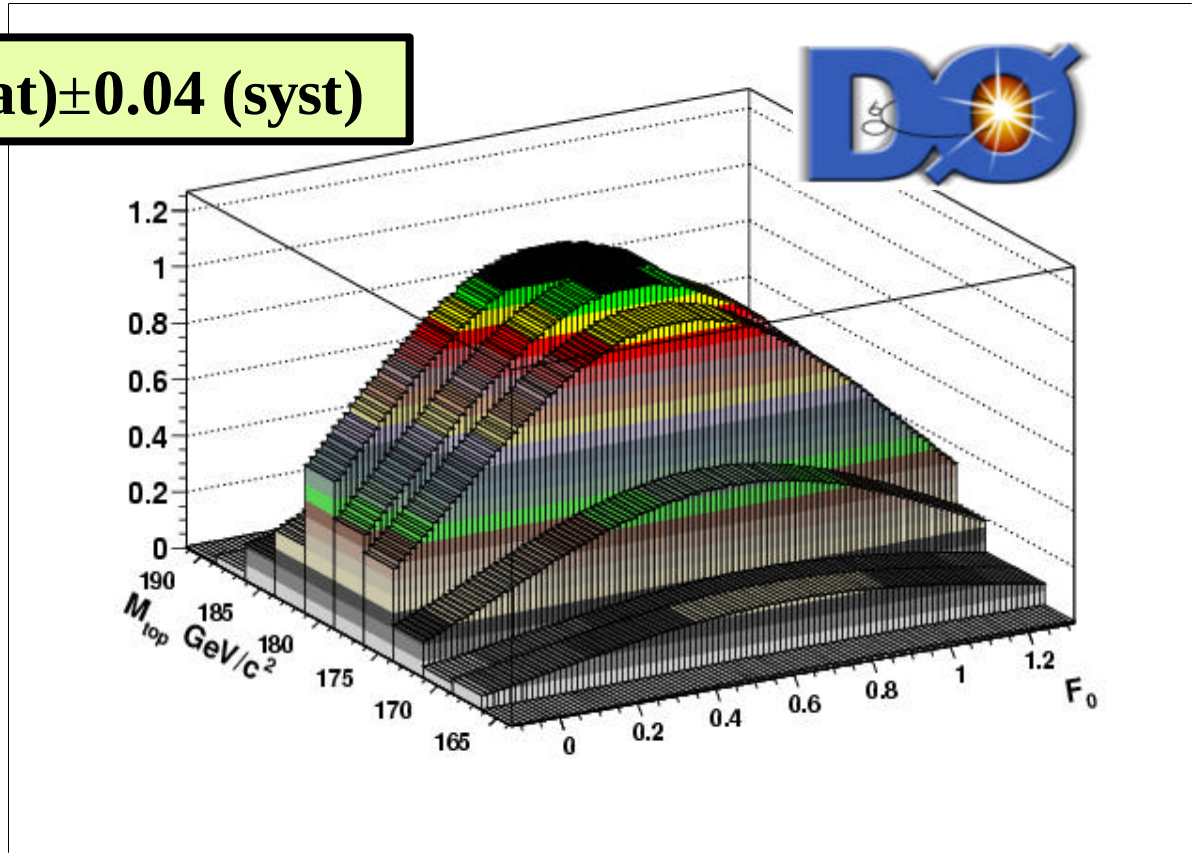



- Very difficult analysis
  - S/B is low
- Considered to be almost impossible in LHC

# **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