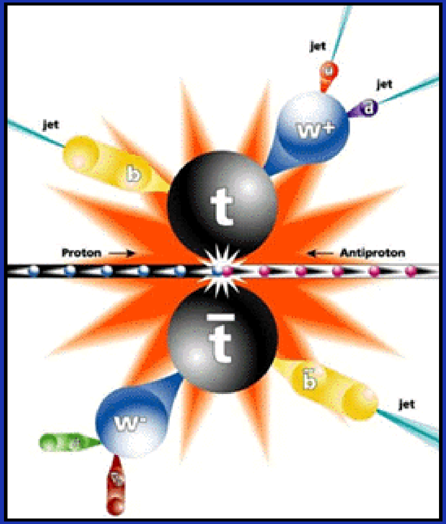
Top Quark Production and Properties at DØ



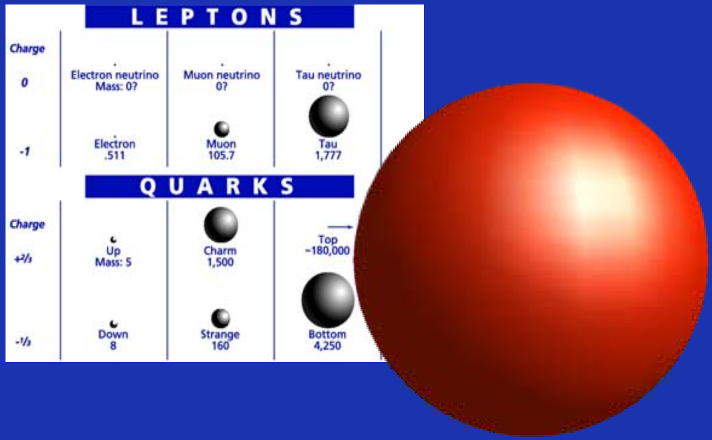
1. Introduction
2. Top quark production and decay
3. Top quark pair production cross section
4. Top quark production properties
   i. Top Branching Ratio
   ii. W-helicity
5. Conclusion and outlook

Gustavo Otero y Garzón, University of Illinois at Chicago
for the DØ experiment

The 2007 Europhysics Conference on High Energy Physics
July 19 – 25, 2007, Manchester, England

Top Quark CV

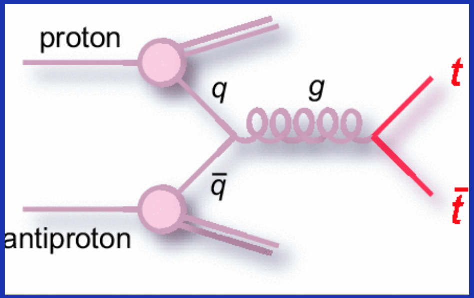
- **Discovered in 1995 by DØ and CDF after a 2 decades hunt**
- **Heaviest fundamental particle (m_t = 170.9 ± 1.8 GeV)**

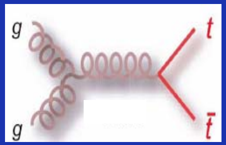


- **Strongest coupling to the Higgs (Yukawa coupling $\lambda_t \propto m_t \sim 1$)**
  - may help identify the EWSB mechanism and mass generation
  - may serve as a window to new physics related to EWSB that might couple preferentially to top
- **A unique laboratory: lifetime (5×10^{-25} s) shorter than the hadronization time makes it decay as a free quark**
- **We still have a lot to learn about this particle**
  - Indirect constraints from low energy data and statistically limited Tevatron data leave plenty of room for new physics
  - Even if the top is “just a normal quark”, precision top measurements are stringent tests of the SM

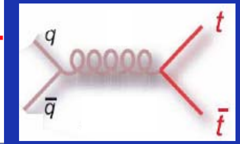
Top Quark Pair Production and Decay

- Top quarks are mainly produced in pairs (strong interactions) at Tevatron energies





15%

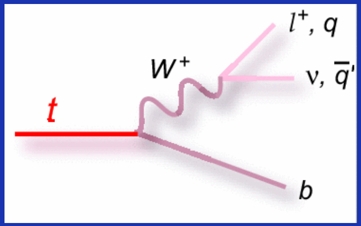


85%

$\sigma_{ttbar} / \sigma_{inel} \sim 10^{-10}$

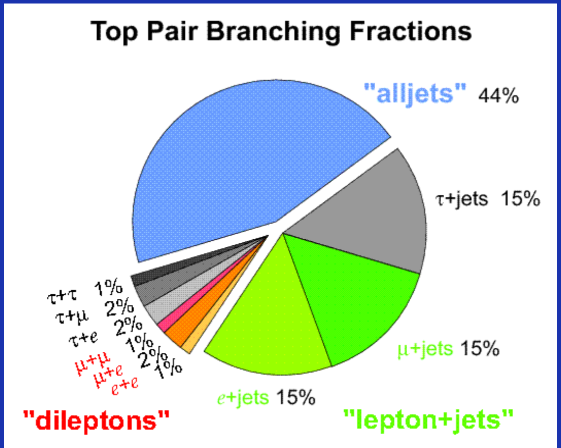
- High luminosity
- High efficiency

- No hadronic bound states due to short lifetime
- Electroweak decay



$|V_{tb}|$~1

- Final state determined by the decay of the *W* boson

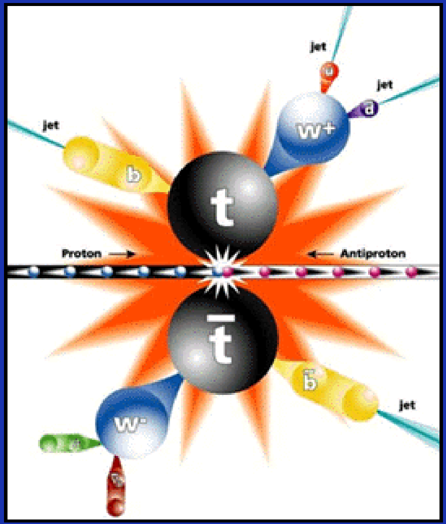


- dilepton channel (low bkg)
- lepton + jets channel (moderate bkg)
- all hadronic channel (huge bkg)

Lepton≡ e, μ from W or from τ from W

Top Quark Production Cross Section

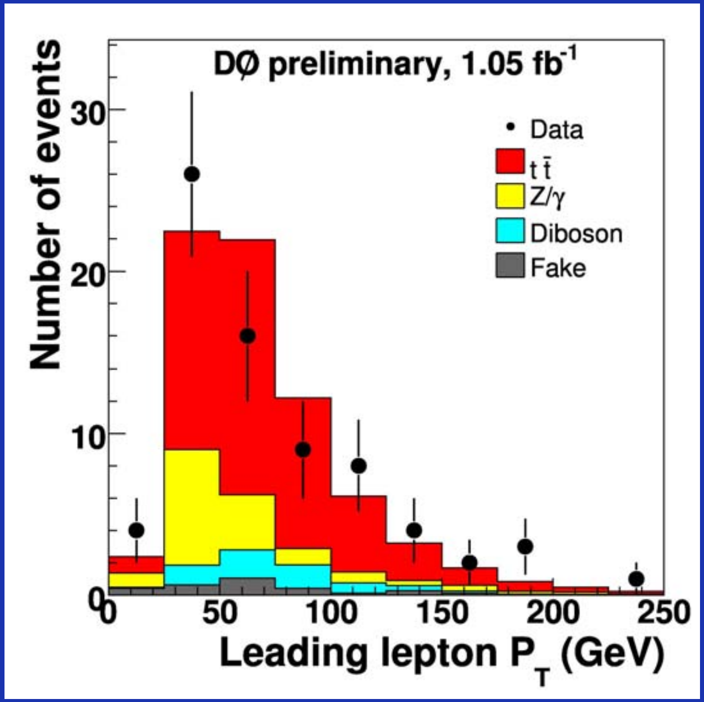
- Test of pQCD at high Q^2
- Sensitive to New Physics
  - Higher cross section → resonant state, anomalous couplings
  - Lower cross section → non SM decay modes

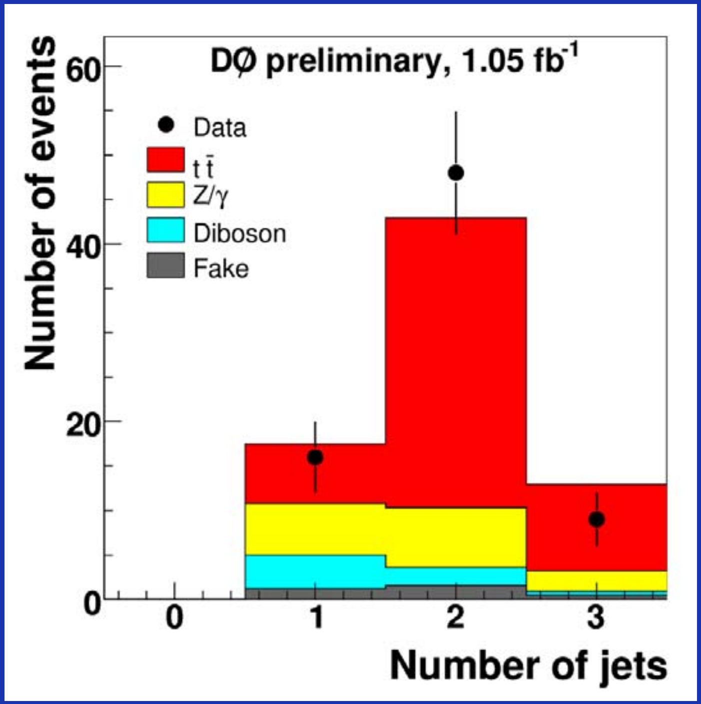


- Important to measure in different channels and with different techniques
- Provides sample composition for top properties measurements
- Gives input for searches for which top events are a dominant background

Cross Section Results (dilepton)

- Combination of *ee*, $\mu\mu$ and $e\mu$ channels
  - Opposite sign leptons
  - Significant MET
  - ≥ 1 jet for $e\mu$, ≥ 2 jets for *ee* and $\mu\mu$





$$\sigma_{t\bar{t}} = 6.8^{+1.2}_{-1.1}(\mathrm{stat})^{+0.9}_{-0.8}(\mathrm{syst}) \pm 0.4(\mathrm{lumi})\,\mathrm{pb}$$

$\Delta\sigma/\sigma$ = 22%

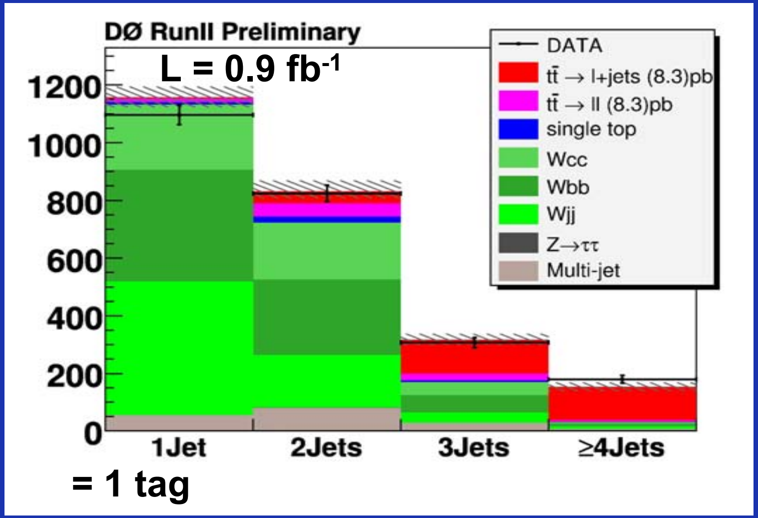
Improves from PLB **626**, 55 (2005)

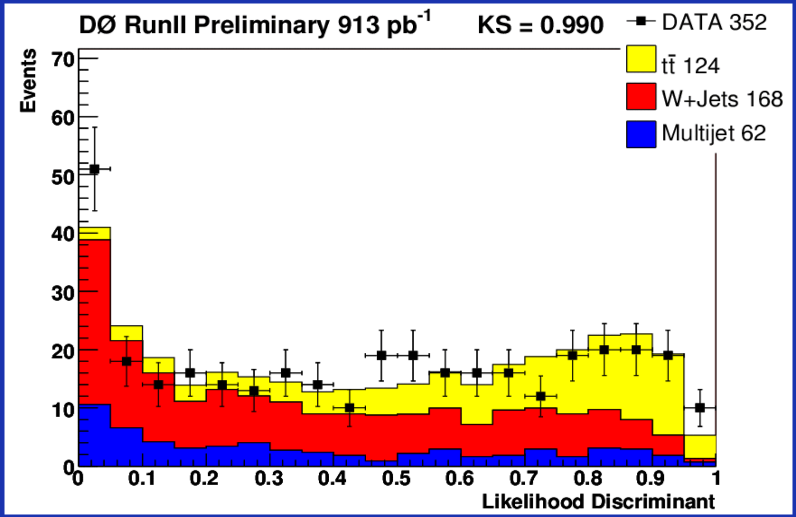
Cross Section Results (lepton + jets)

- 1 isolated lepton (e, μ)
- High MET
- b-tagged (≥ 3 jets), kinematic (≥ 4 jets

b-tagging

Kinematic

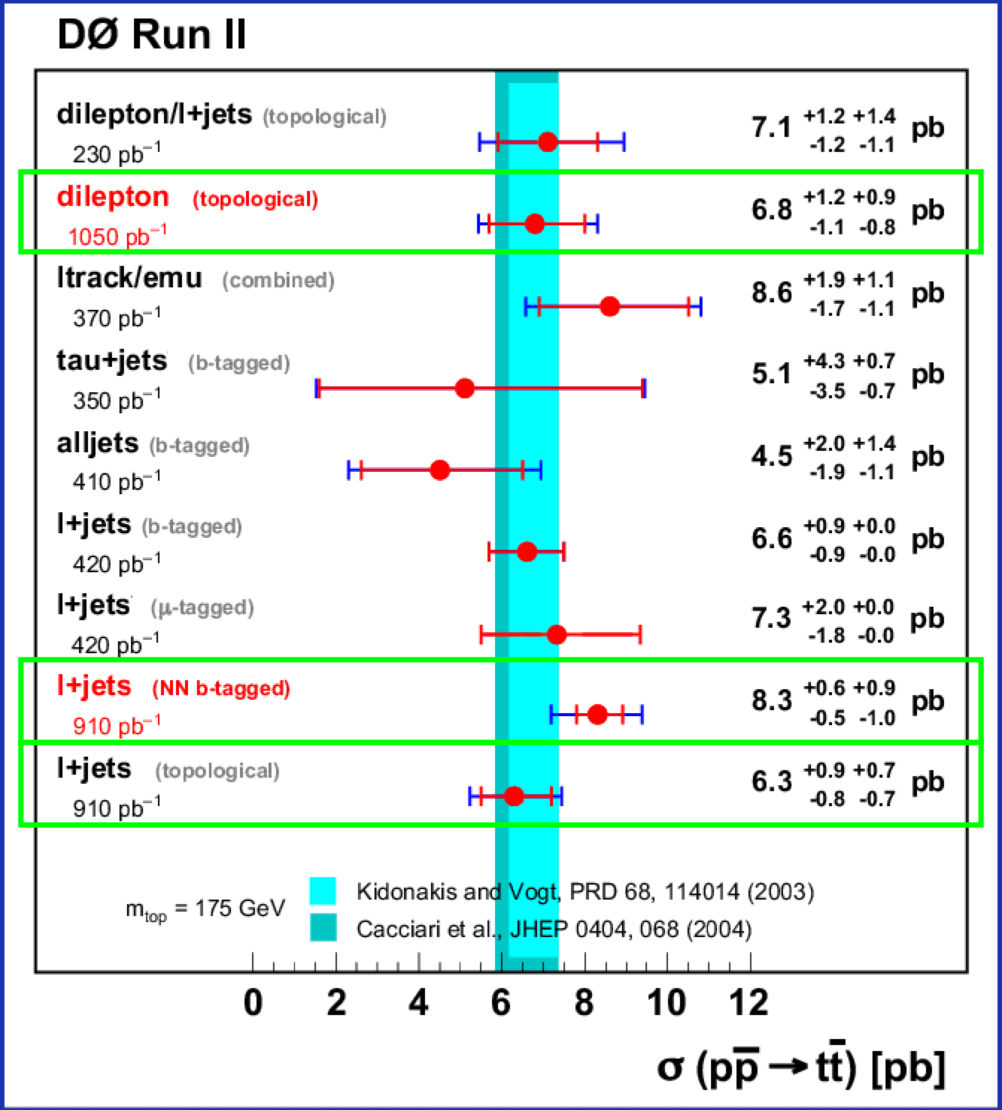




b-tag	$\sigma_{t\bar{t}} = 8.3^{+0.6}_{-0.5}\,(\text{stat})\,^{+0.9}_{-1.0}\,(\text{syst}) \pm 0.5(\text{lumi})\,\text{pb}$	Update of PRD **74**, 112004 (2006)
Kine.	$\sigma_{t\bar{t}} = 6.3^{+0.9}_{-0.8}\,(\text{stat}) \pm 0.7(\text{syst}) \pm 0.4(\text{lumi})\,\text{pb}$	Update of PLB **626**, 45 (2005)

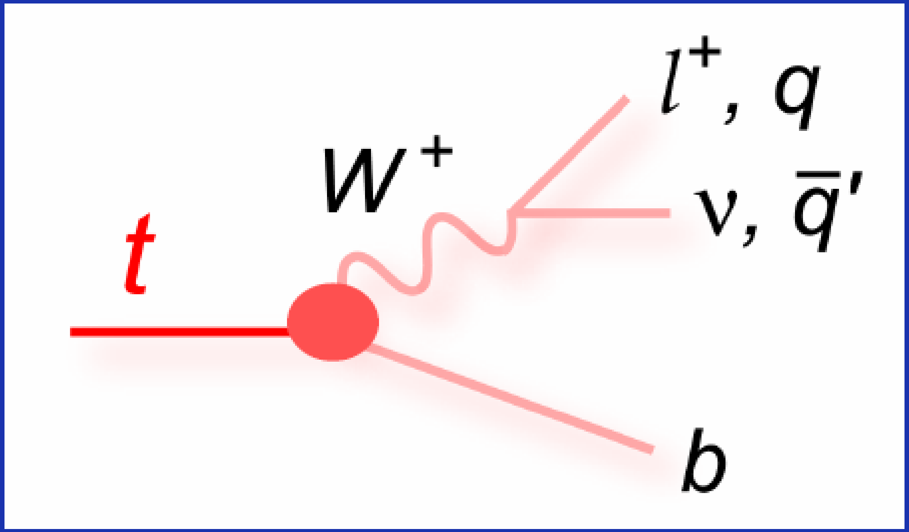
$\Delta\sigma/\sigma$ = 15% (a), 19%(b)

Cross Section Summary



Experimental results reaching theoretical precision of 12% (expect 10% with 2fb^{-1})

Probing the W-t-b vertex



- $t \to Wb$ / Wq
- W helicity fractions

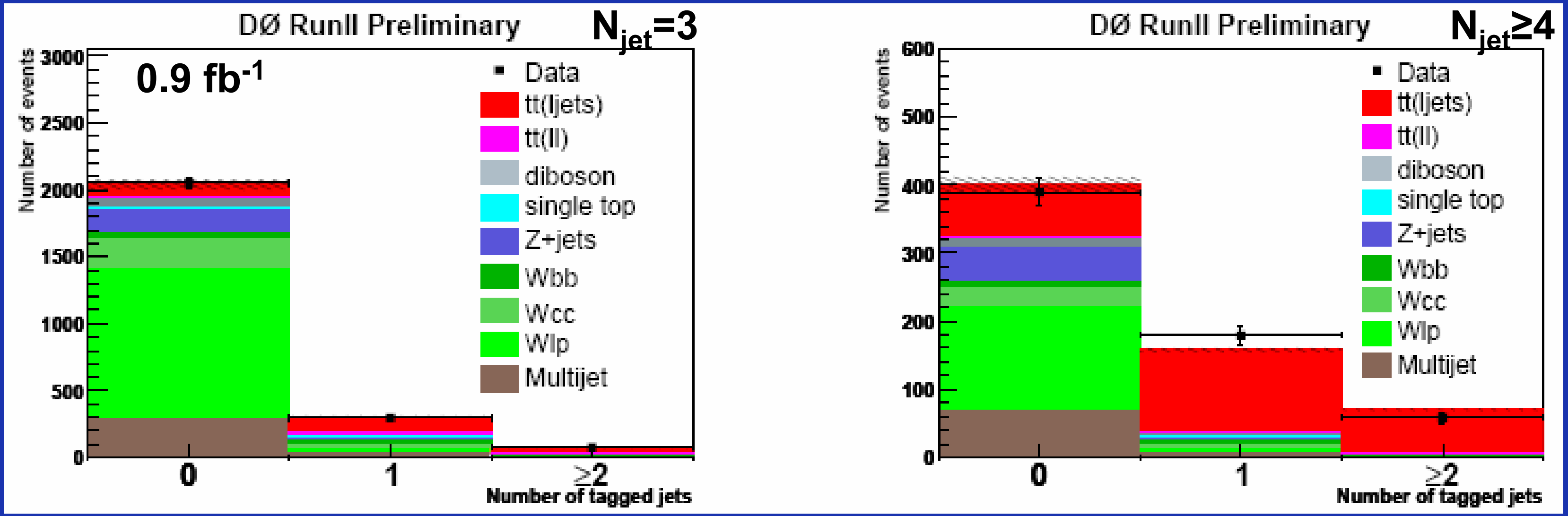
Top Branching Ratio

$$R = \frac{Br(t \to Wb)}{Br(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} = 0.9980 \text{ to } 0.9984$$

This is true at 90%CL if the CKM matrix is unitary and for 3 quark generations

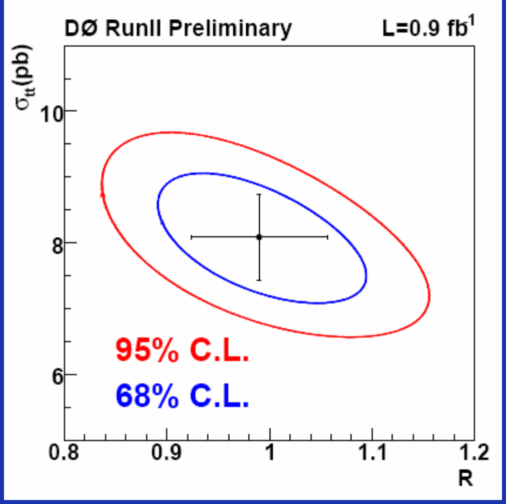
Measurement: count b-jets (strongly dependent on R and tagging efficiencies)

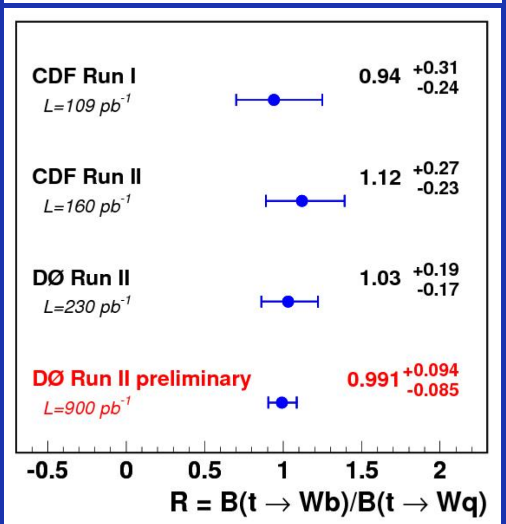
$$P_{t\bar{t}}^{n-tags} = P^{n-tags}(t\bar{t} \to bb) \times R^2 + P^{n-tags}(t\bar{t} \to qb) \times 2R(1-R) + P^{n-tags}(t\bar{t} \to qq) \times (1-R)^2$$

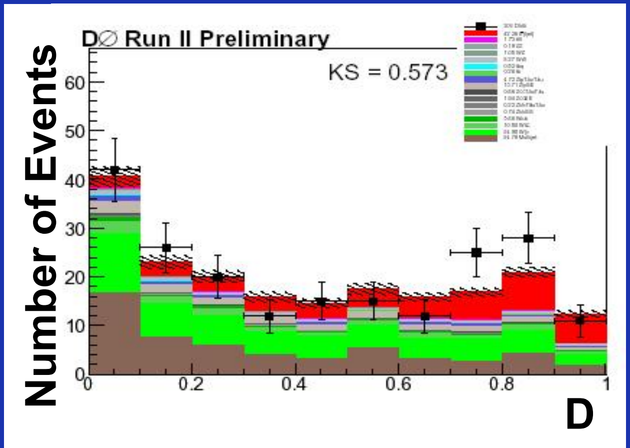


Top Branching Ratio (II)

- Result obtained from a binned likelihood fit to data for $N_{jet} = 3$ and $N_{jet} = 4$
- Simultaneous fit to R and σ_{tt}







$$R = \frac{Br(t \to Wb)}{Br(t \to Wq)} = 0.99 \pm 0.09(stat + syst)$$

Assuming CKM unitarity $|V_{tb}| > 0.81$ @ 95% CL

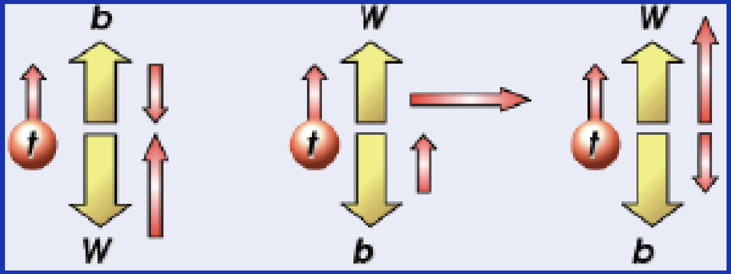
$$\sigma_{tt} Br^2(t \to Wq) = 8.1^{+0.9}_{-0.8}(stat + syst) \pm 0.5(lum)pb$$

$\Delta\sigma/\sigma$ = 12% !

Improves from PLB **639**, 616 (2006)

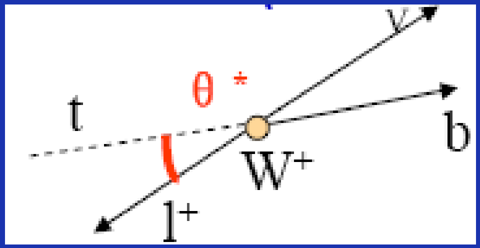
W Helicity

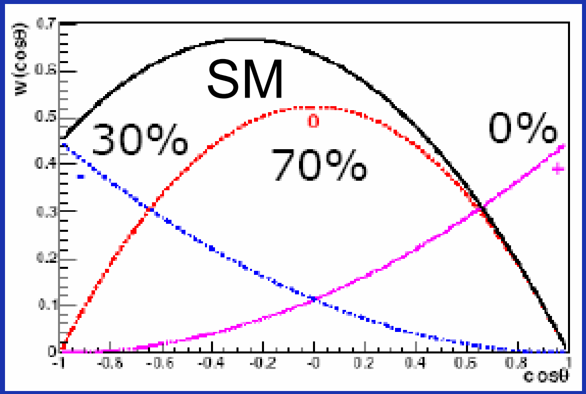
- Within the SM the top quark decays via the V-A charged current interaction
- W-helicity measurement probes new physics associated with V+A current interactions



left handed f_- | longitudinal f_0 | right handed f_+

Measure W-helicity through cos(θ*) distribution (l+jets and dilepton events)



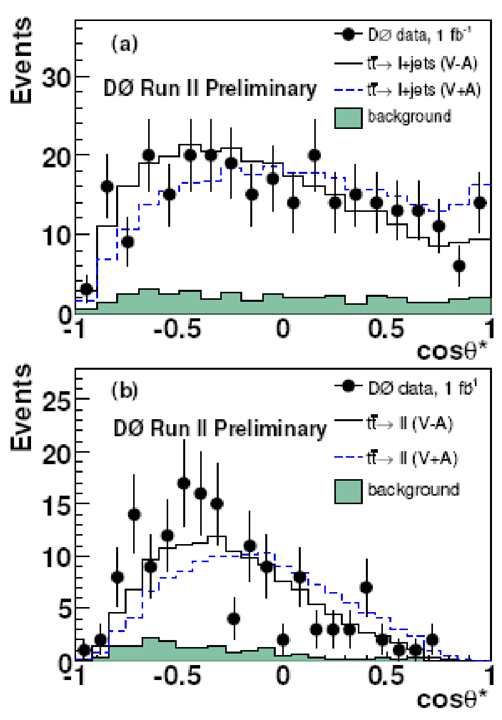


In the SM f_0=0.7 and f_+~10^{-4}

Fix f_0 to the SM prediction an look for f_+ deviations

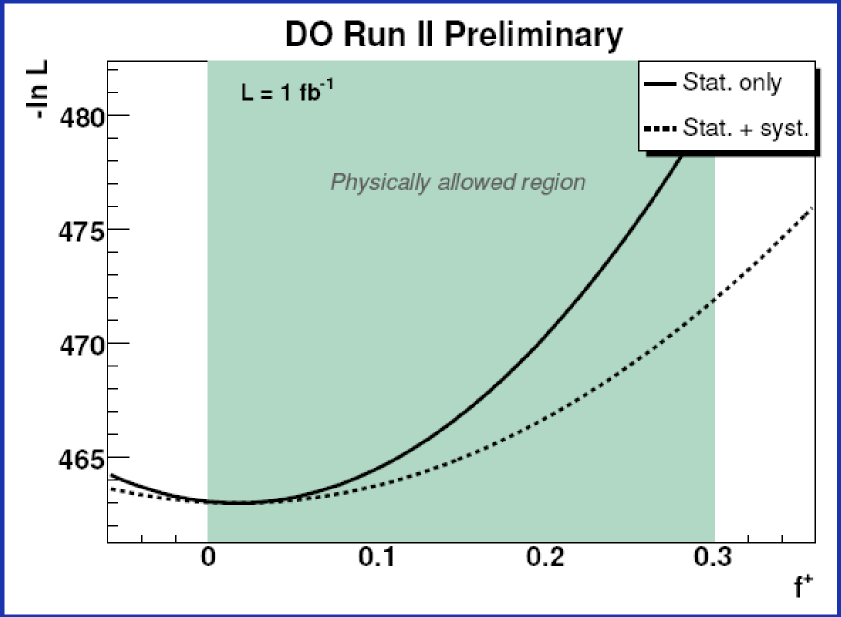
W Helicity (II)

- Reconstruct top quark and W boson four vectors
- Compare the cos(θ*) distribution in data to models with different f_+
- Compute a likelihood $L(f_+)$ for the data to be consitent with S+B templates at 7 chosen f_+ values



l +jets

dileptons



$f_+ = 0.017 \pm 0.048(\text{stat}) \pm 0.047(\text{syst})$

$f_+ < 0.14$ @ 95%CL when $f_0 = 0.7$

Improves from PRD **75**, 031102 (R) (2007)

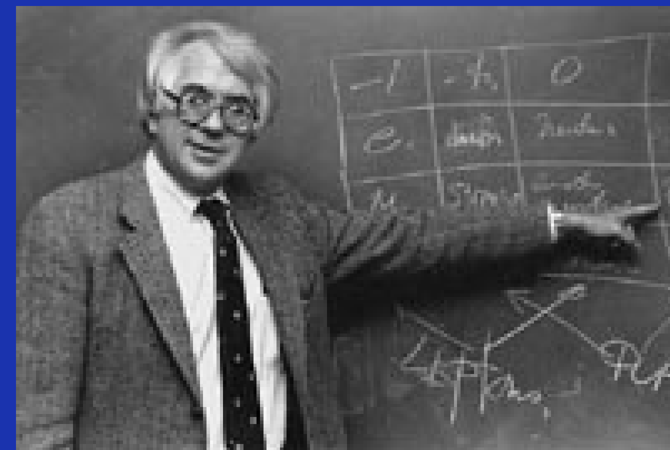
Conclusions and Outlook

- The Tevatron is still the only top quark factory
  - Comprehensive program on top quark measurements is underway
- Entering an era of top precision measurements
  - Cross section measurements reaching theoretical precision
  - Agreement among channels and with different methods
- Walking through the largely unexplored territory of top quark properties
  - Measurements are consistent with the SM
  - Analyses based on larger datasets very close
  - Eager to see what the expected $4fb^{-1}$ of data delivered by the end of the year will bring us!

Back up slides

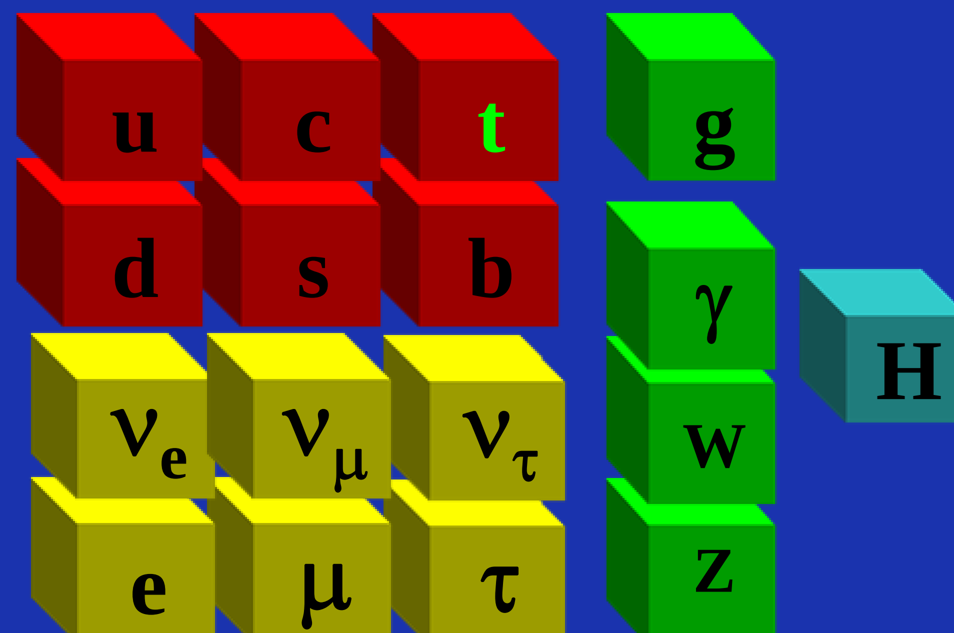
History of the Top quark

1961: Gell-Mann proposes the quark model to classify the hadron zoo

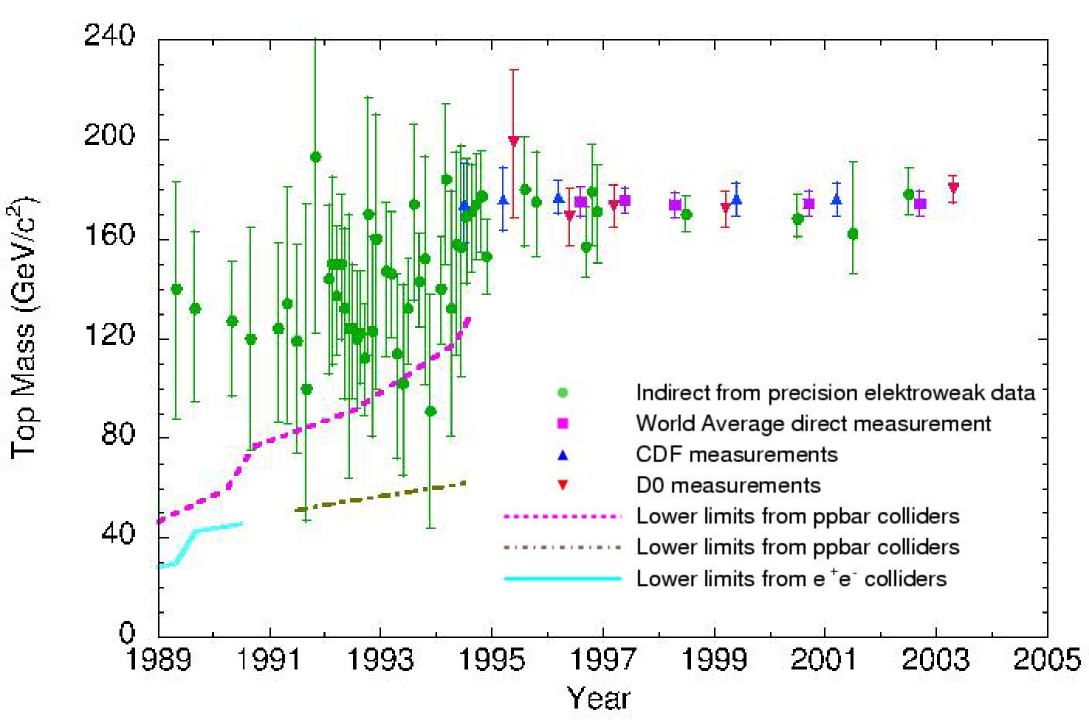


1973: Glashow predicts the Charm quark

1977: Lederman & Co. discover the Bottom quark



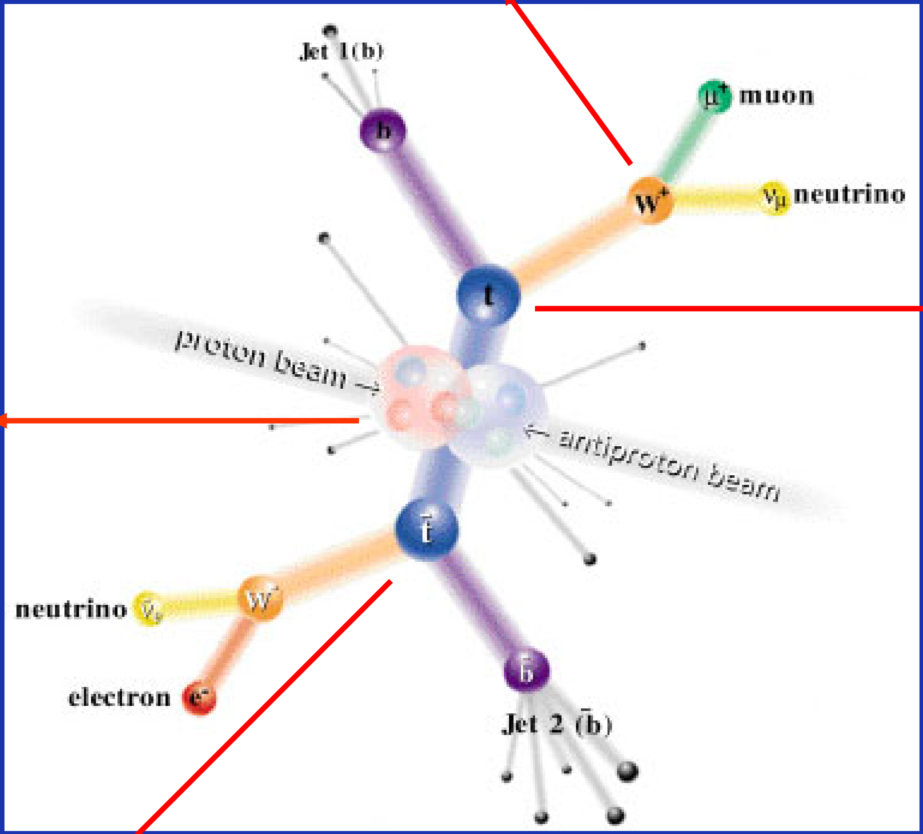
Top Quark Discovery



Fermilab's RunI started the experimental hunt of the top quark and a long fruitful program in top physics

Top Quark Physics

W Helicity



Production Cross Section

Top Spin Polarization

Resonance Production

Top Charge

Branching Ratios

Spin Correlation

Rare decays

Top Mass

$|V_{tb}|$

Still only available at the Tevatron

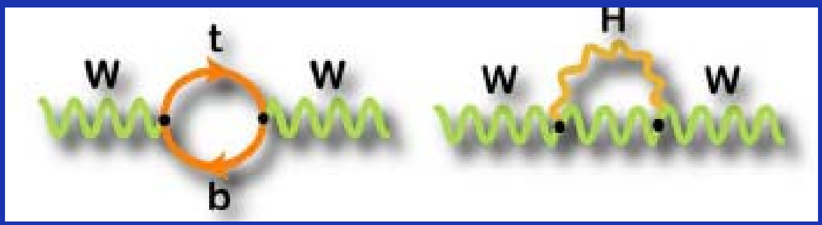
Precise measurements possible for the first time

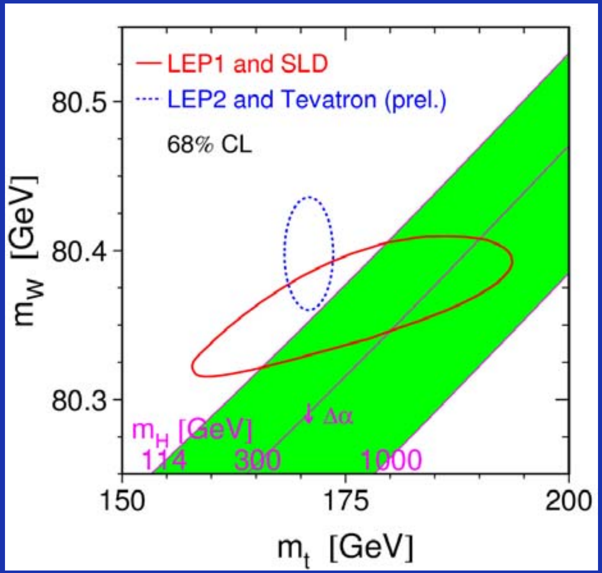
Are they really SM particles?

The top quark mass

Fundamental parameter of the Standard Model

- **Affects predictions of SM via radiative corrections**





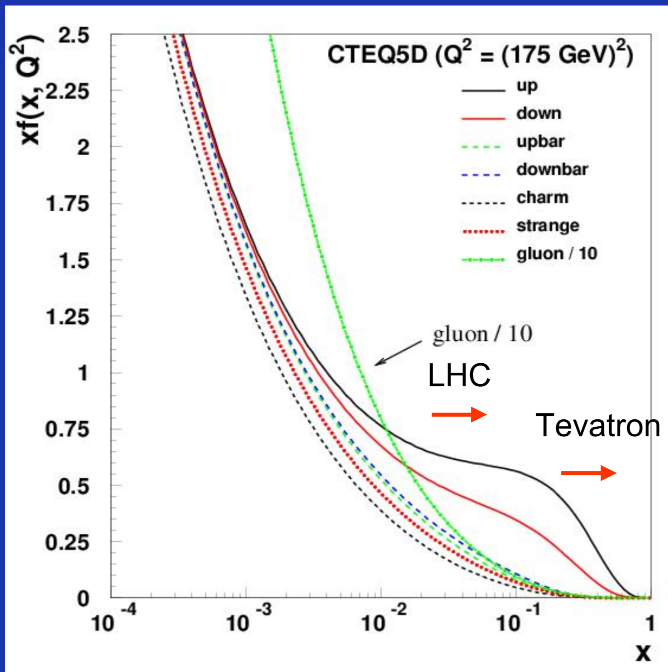
m_t can be related, with M_W, to the Higgs mass

$$\delta m_W \propto m_t^2, \ln(m_H)$$

Probing the EWSB mechanism (new physics?)

- **Precision measurement → 2 (8) fb^{-1} projection: δm_t ~ 1.5 (1) GeV**

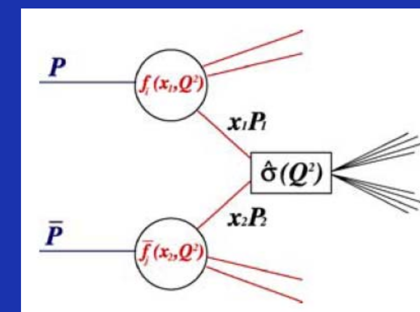
Top Quark Pair Production

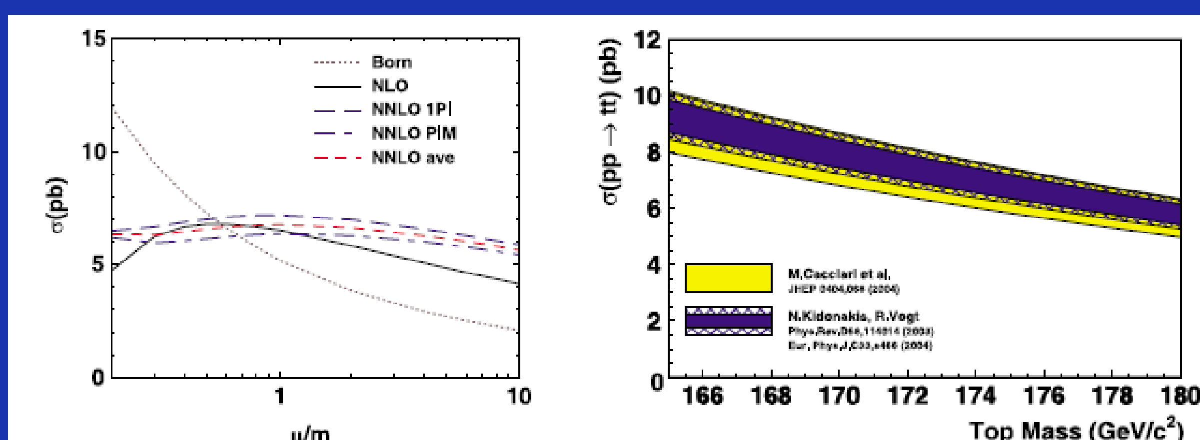


$$\sigma^{p\bar{p}\to t\bar{t}+X}(s, m_t) = \sum_{i,j=q,\bar{q},g} \int dx_i dx_j f_i(x_i, \mu^2) \bar{f}_j(x_j, \mu^2) \times \hat{\sigma}^{ij\to t\bar{t}}(\rho, m_t^2, \alpha_s(\mu^2), \mu^2).$$

$$x \approx \frac{2m_t}{\sqrt{s}}$$

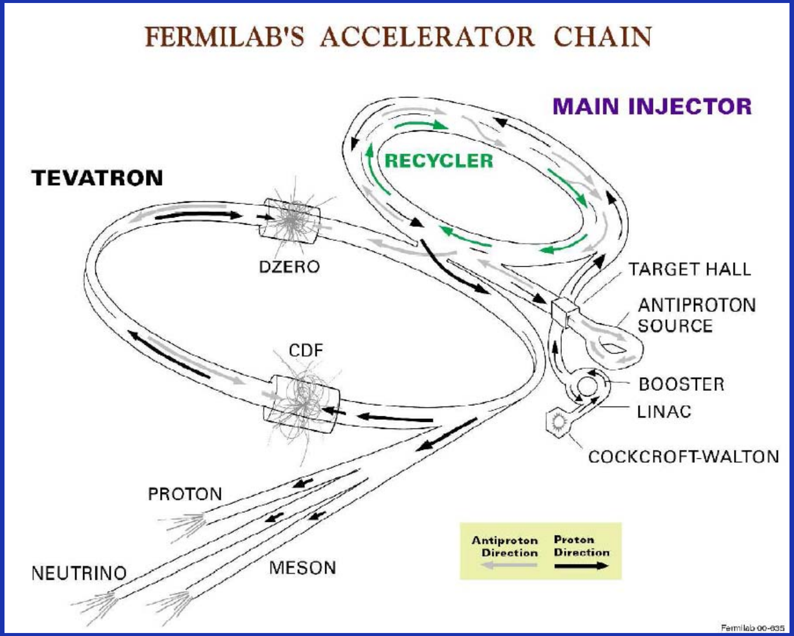
$= 0.19$	at the TEVATRON in Run I
$= 0.18$	at the TEVATRON in Run II
$= 0.025$	at the LHC

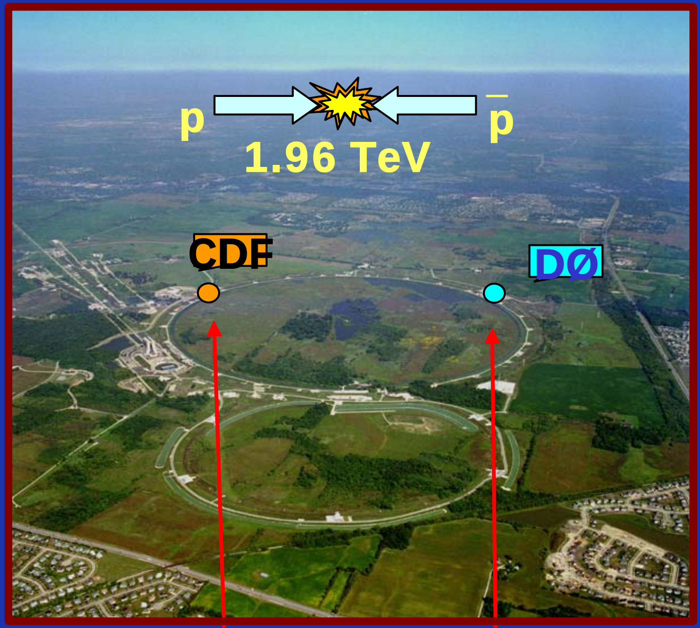


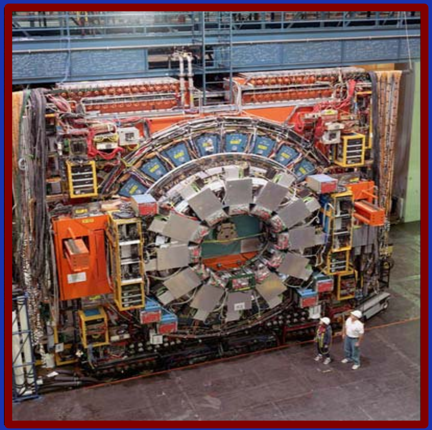


The Tevatron Collider

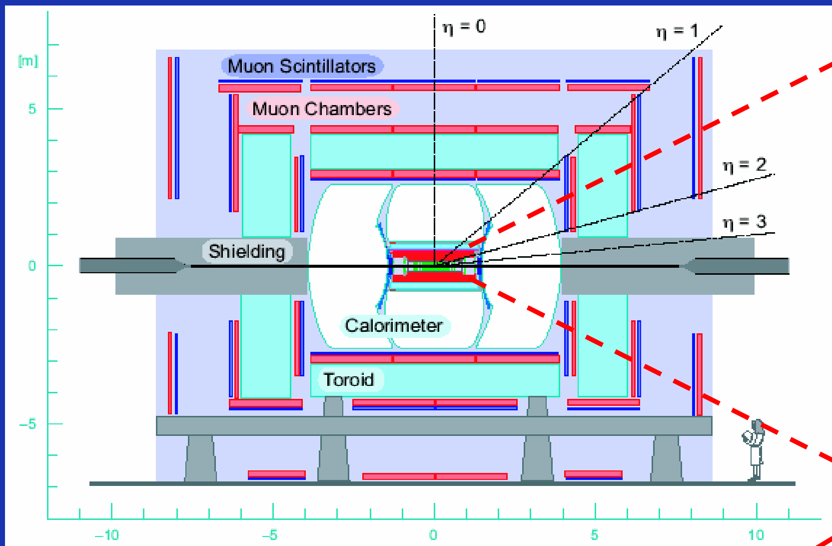
- Proton-antiproton collider with $\sqrt{s}$=1.96 TeV
- 36x36 bunches with 396ns between crossings
- 3 ~ collisions per bunch crossing
- $L_{inst} > 2 \times 10^{32} cm^{-2} s^{-1}$
- Expected 4-8 fb^{-1} integrated luminosity for RunII (0.11fb^{-1} in RunI)

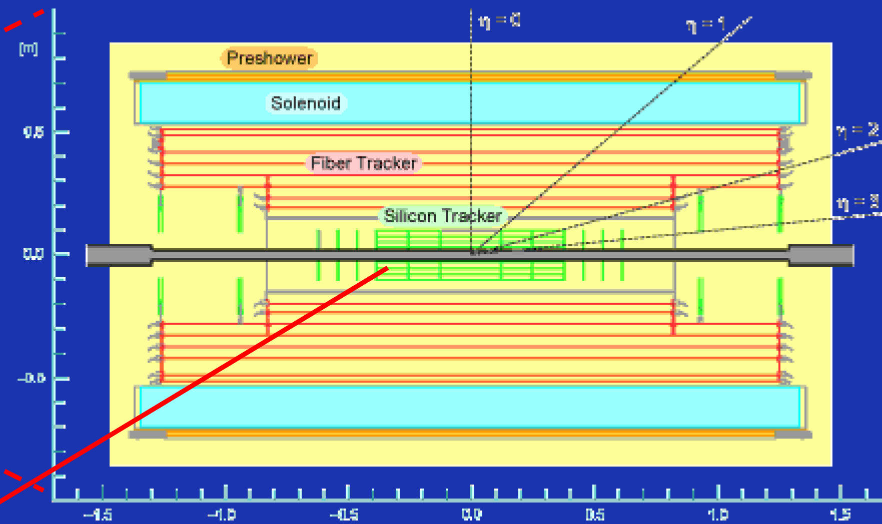


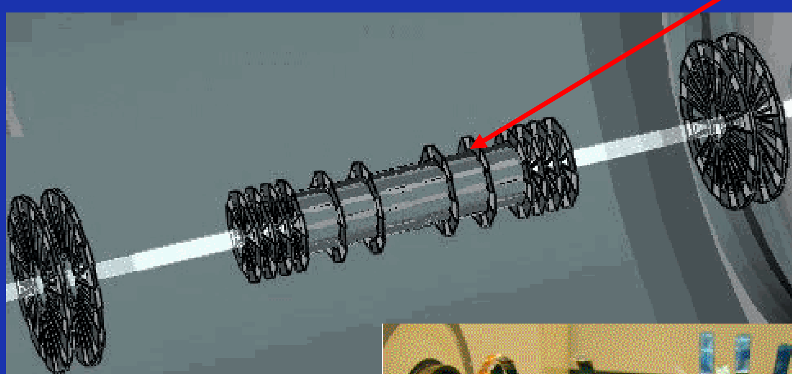




The DØ Detector



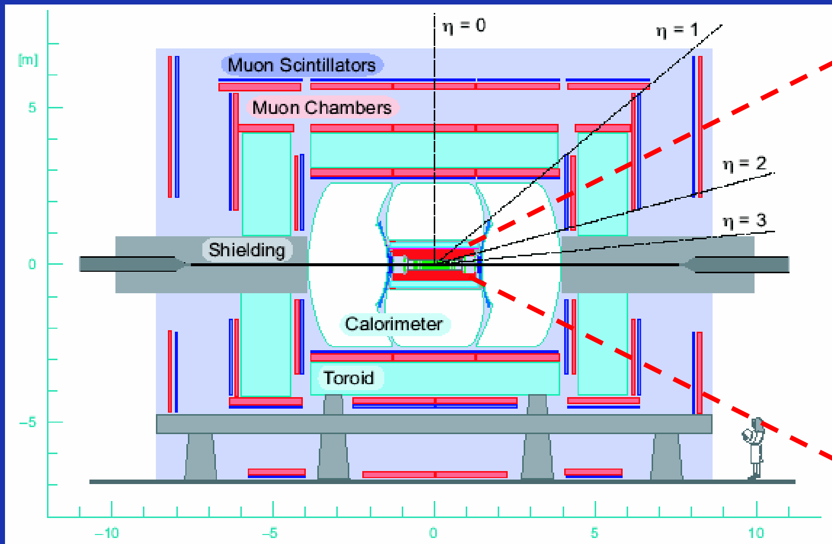


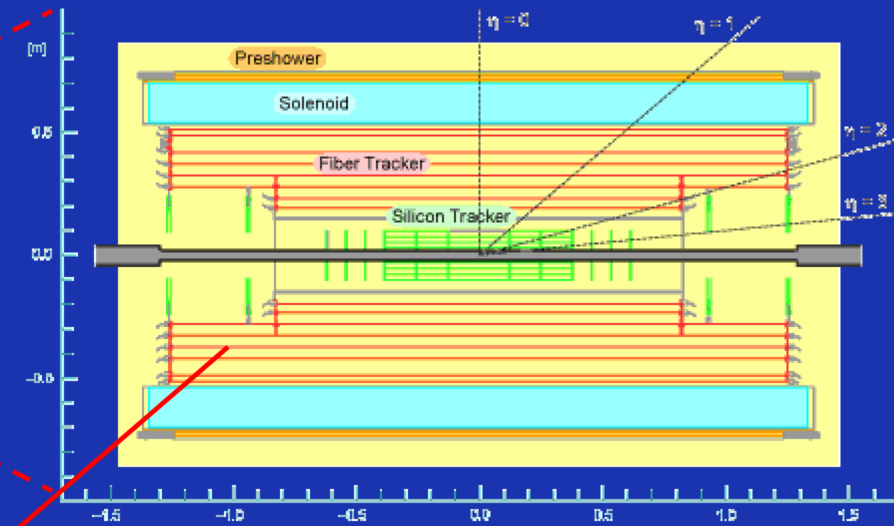


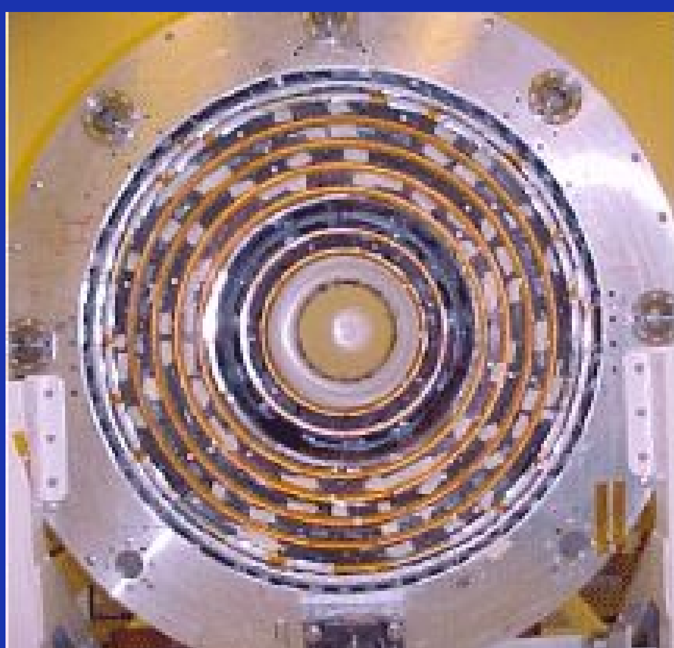
Silicon Microstrip Tracker

- Vertex measurement and tracking
- Crucial for b-tagging
- 6 barrels and 16 disks with 800000 channels
- 15 μm position resolution

The DØ Detector



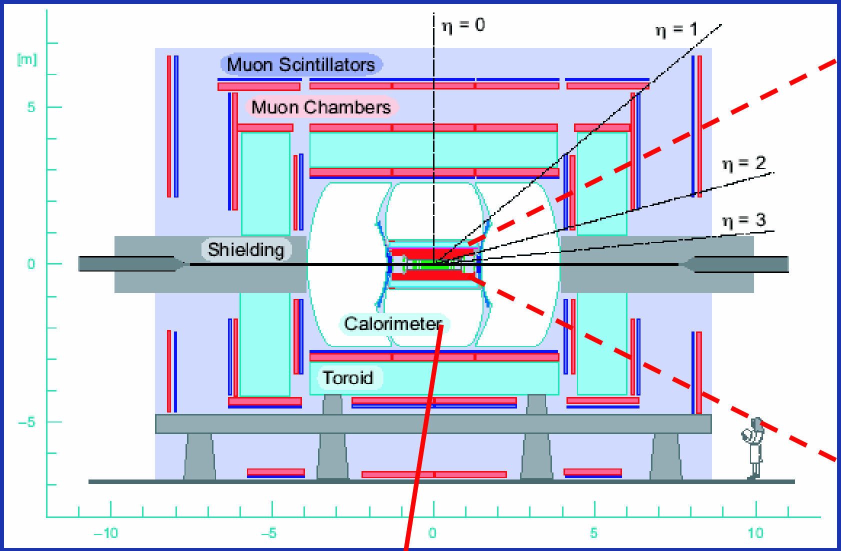


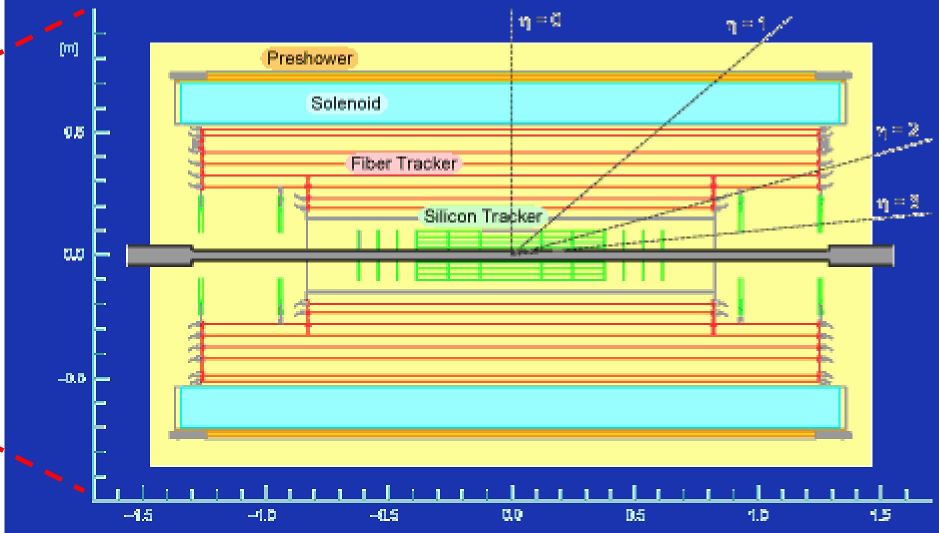


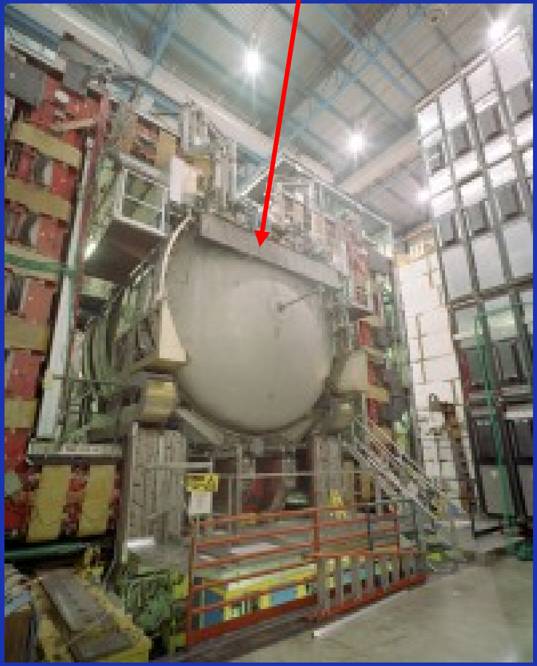
Central Fiber Tracker

- Charged particle tracking (momentum and charge)
- 8 concentric cylinders of scintillating fibers
  - Two layers per cylinder (axial & stereo)
- 80000 channels
- 100 μm position resolution

The DØ Detector



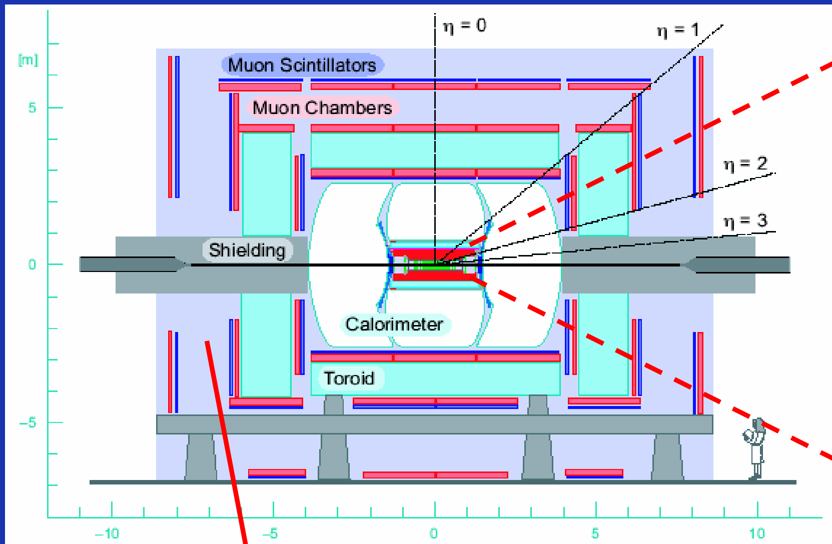


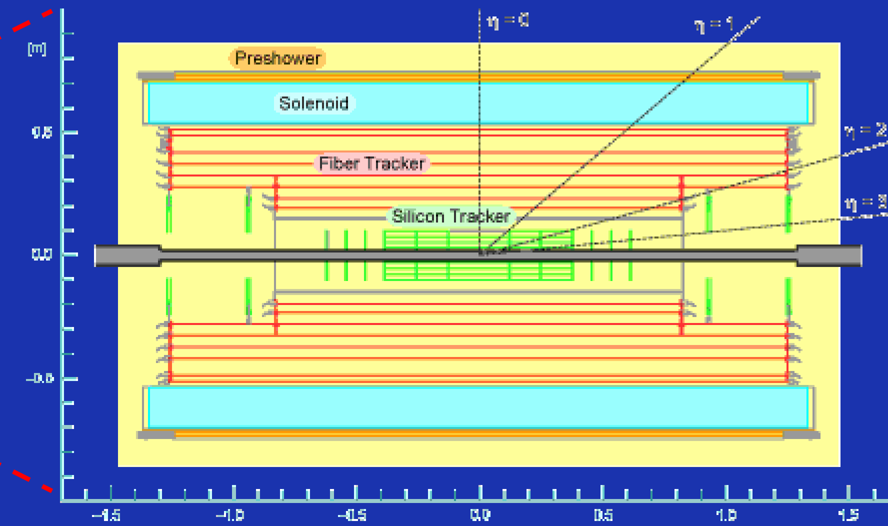


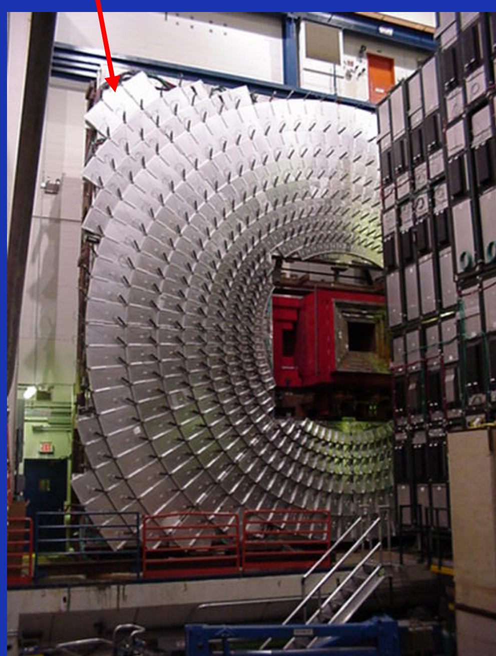
EM and hadronic calorimeter

- Energy measurement and ID of electrons, photons, taus, jets and MET
- 3 cryostats with EM, FH and CH sections with ICD
- Energy resolutions of 5-7% for 20 GeV electrons and 30% for 20 GeV jets

The DØ Detector



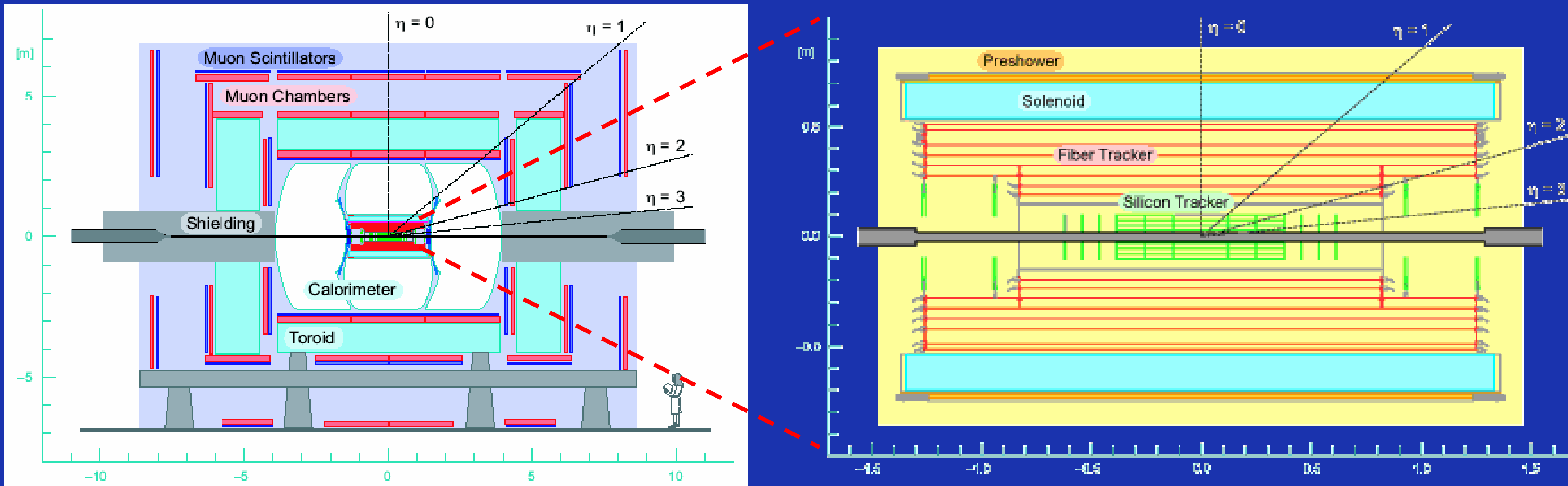




Muon spectrometer

- Muon position and tracking
- 3 layers of wire chambers (position) and 3 layers of scintillation counters (timing)
- 1.8T toroid outside inermost layer
- 1mm position resolution and 20% momentum resolution for < 40GeV forward muons

The DØ Detector



Other components

- 2T solenoid
- Luminosity monitor
- Preshower detectors
- Forward proton detectors

D0 Triggering

p → 2 MHz crossing frequency ← $\bar{p}$

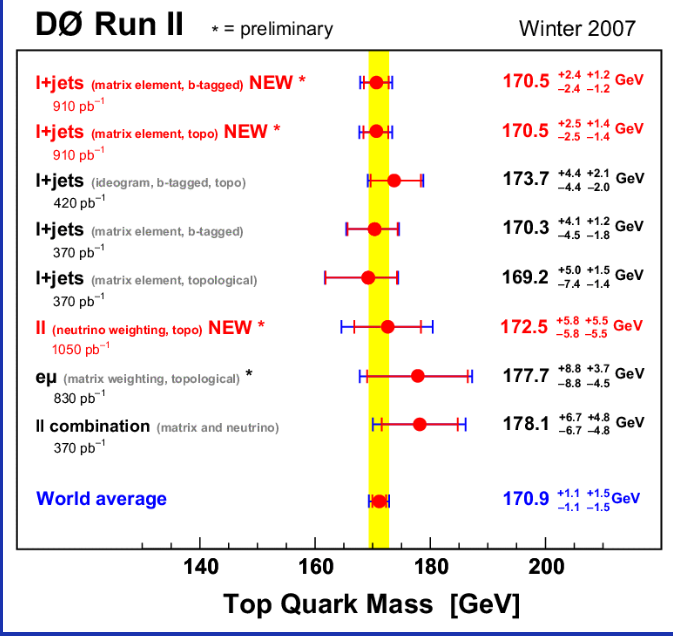
Data acquisition limited to 100Hz and not enough resources to store all these events ⇒ 3 tiered trigger system used to select rare and interesting events.

L1: Hardware based triggers with inputs from different detector subsystems

L2: DSP based triggers

L3: Online event reconstruction

Top Mass Measurements



M_{top} = 170.5 ± 2.4 (stat + JES) $^{+1.2}_{-1.1}$ (syst) GeV

MATRIX ELEMENT METHOD (0.9 fb^{-1})
DØ's most precise measurement

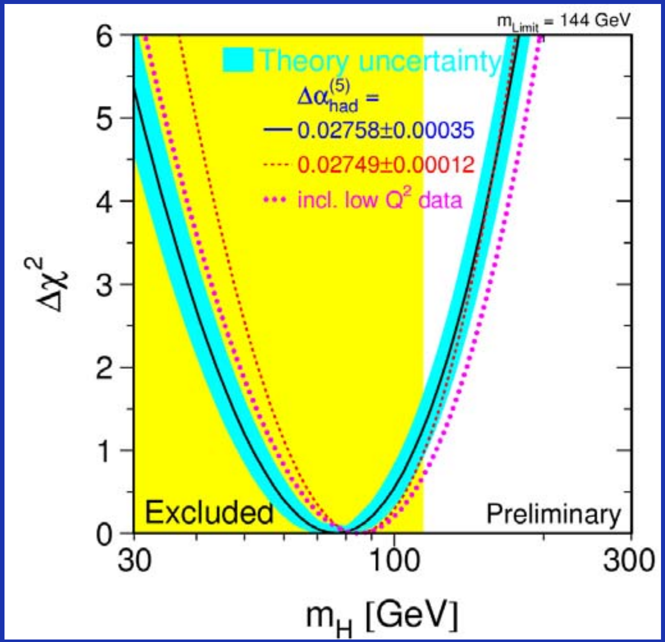
M_{top} = 173.7 ± 4.4 (stat + JES) $^{+2.1}_{-2.0}$ (syst) GeV

IDEOGRAM METHOD (0.42 fb^{-1})
hep-ex/0702018 (accepted for publication in PRD)

Top Mass

- **Improved measurements allows us to reach a 1.1% precision (DØ and CDF combined)**
  - **aim at < 1% with 8 fb^{-1}**

- **The precise measurement of the top mass helps constrain the mass of the SM Higgs and it is one of the most important measurements at the Tevatron**



$M_H = 76^{+33}_{-24}$ GeV, M_H < 144 @95%CL