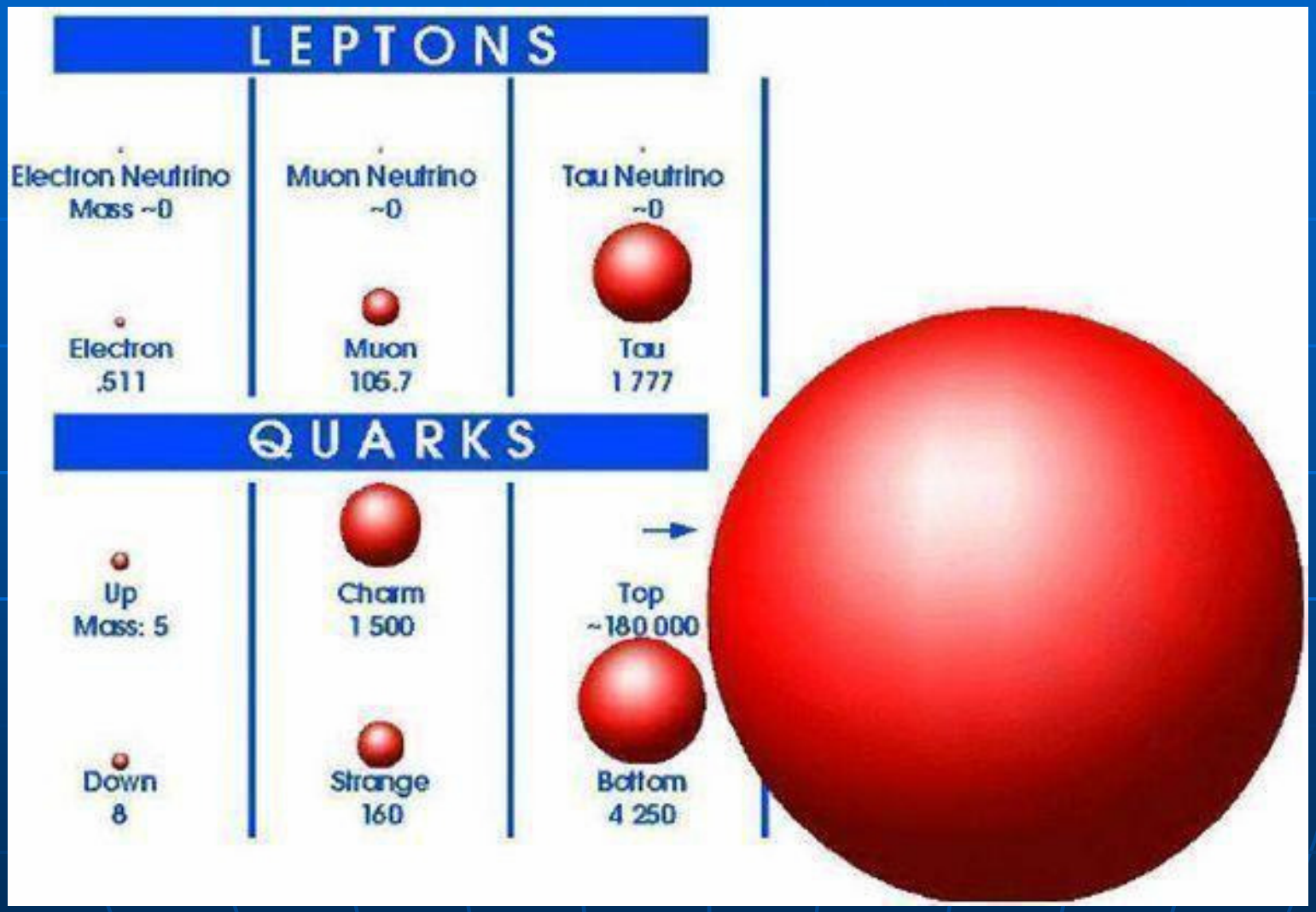
Top quark production and properties

from the Tevatron, where else ?

Michele Weber, Fermilab
For the D0 and CDF Collaborations

The top quark



TOP

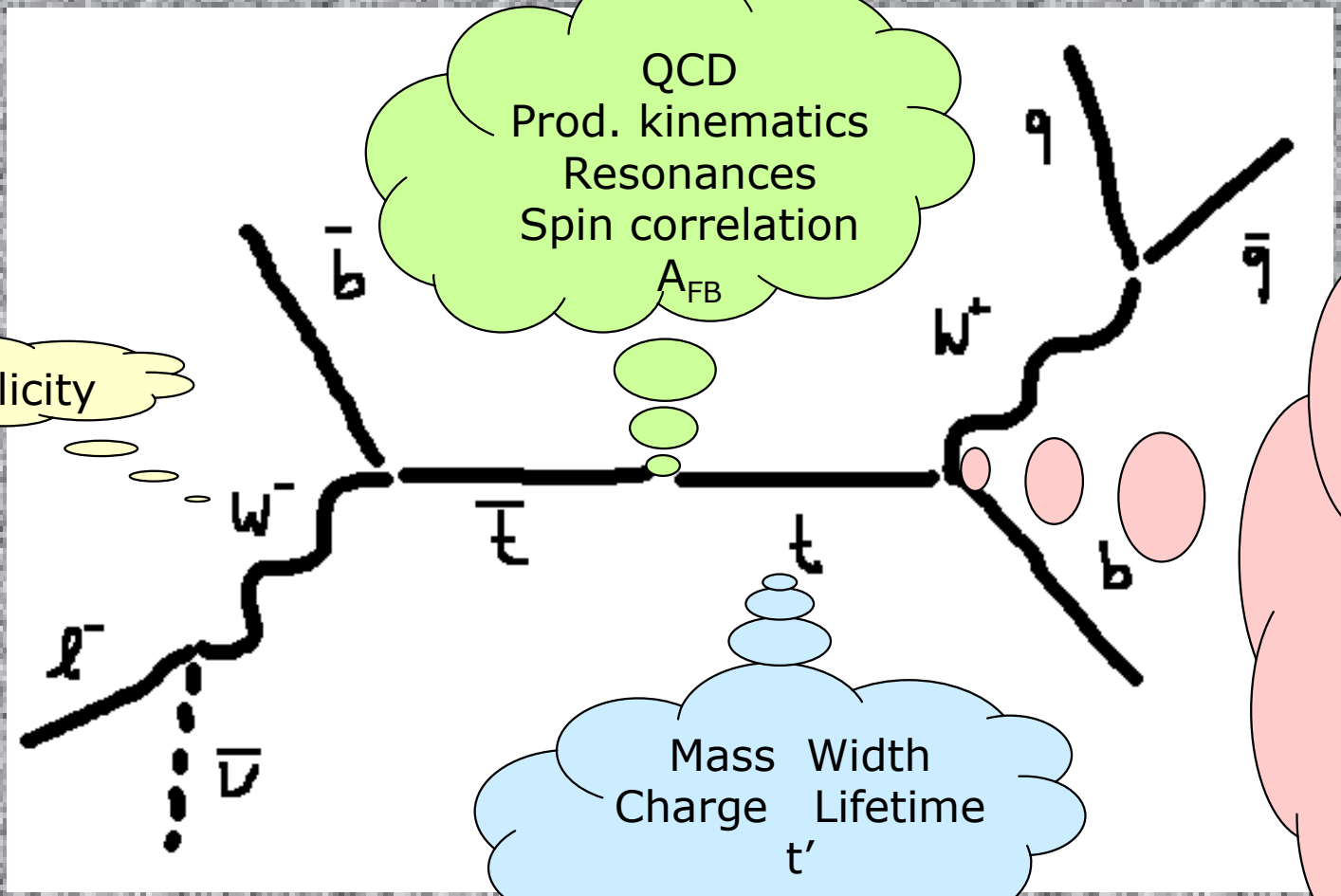
TURNS

~~TEN~~

~~ELEVEN~~

TWELVE

Top quarks exist, what do we do with them ?



QCD
Prod. kinematics
Resonances
Spin correlation
A_{FB}

W-helicity

Mass Width
Charge Lifetime
t'

$|V_{tb}|$

Branching ratios

Anomalous couplings

$t \rightarrow H^+b$

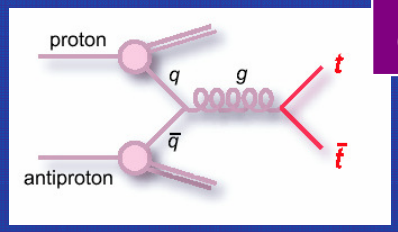
New Physics

Outline

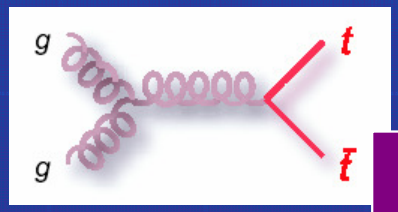
- Top quark production and identification
- Cross section measurements
- Properties of the top quark
- Wtb: branching ratio, W helicity
- Top and new physics

Top quark production

Top quark pair production via **strong** interaction



85%



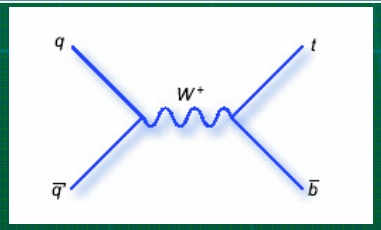
15%

6.7 pb (1.96 TeV, m_t=175GeV/c^2)

N. Kidonakis and R. Vogt, Phys. Rev. D68, 114014 (2003)

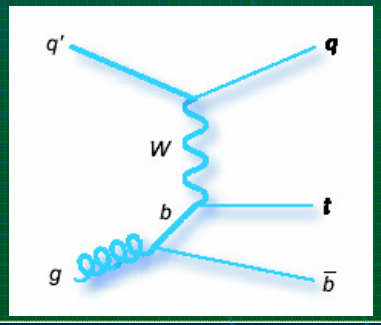
Cacciari etal, JHEP 0404, 068 (2004)

Single top quark production via **weak** interaction



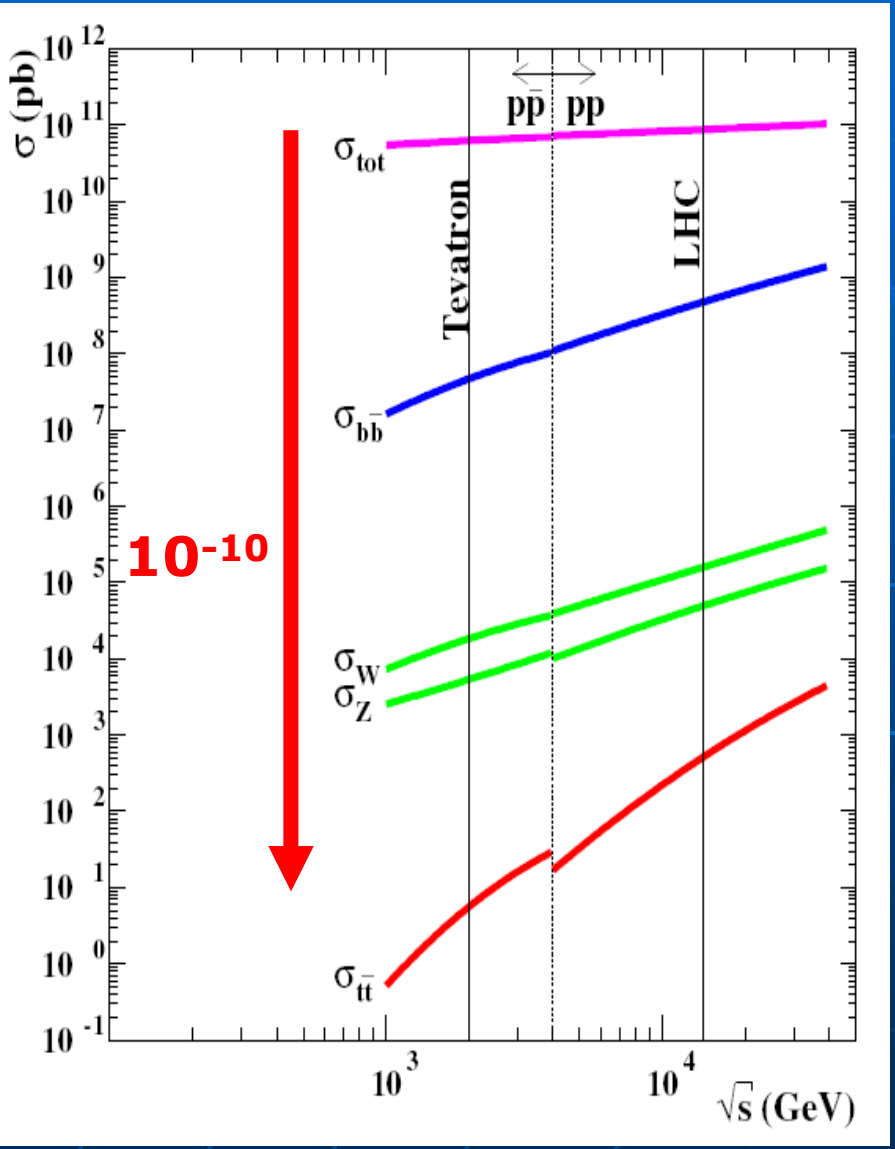
See talk by A.Juste

s-channel: 1.0 pb NNNLO, m_t=175 GeV

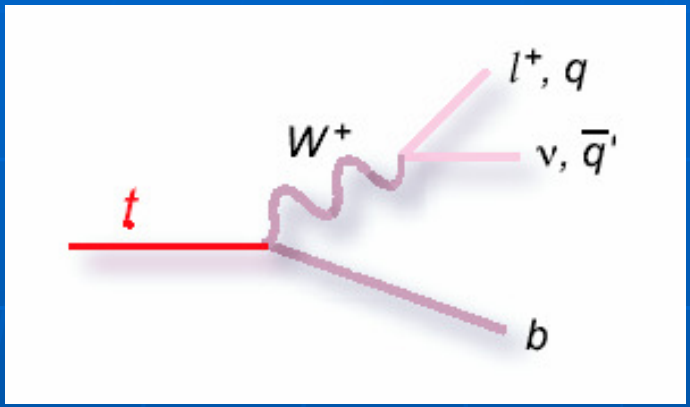


Kidonakis, Phys. Rev. D74, 114012 (2006)

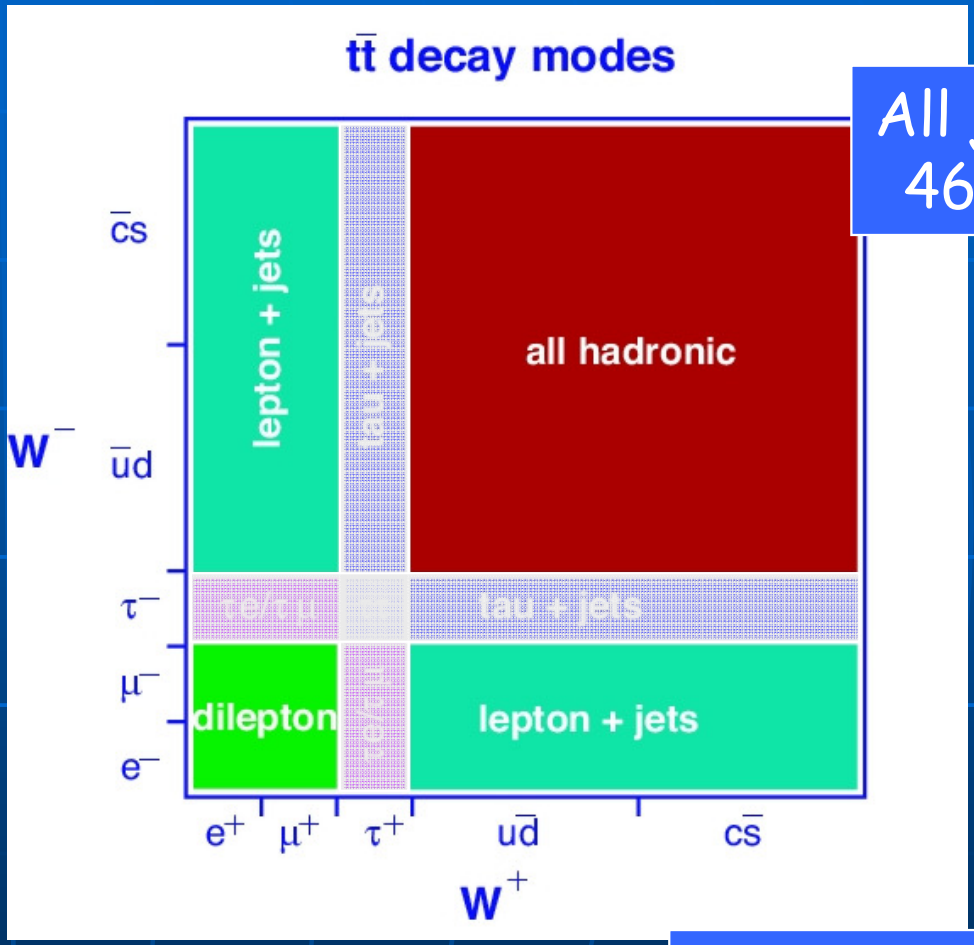
t-channel: 2.2 pb



Top quark decay & identification



$t \rightarrow Wb \cong 100\%$



All jet 46%

dilepton (e/μ) 4.5%

e/mu + jets 29%

Need to reconstruct and identify Electrons, muons, jets, b-jets and missing transverse energy

decay products have:

- good angular separation in the lab frame
- high transverse momentum

Production cross section

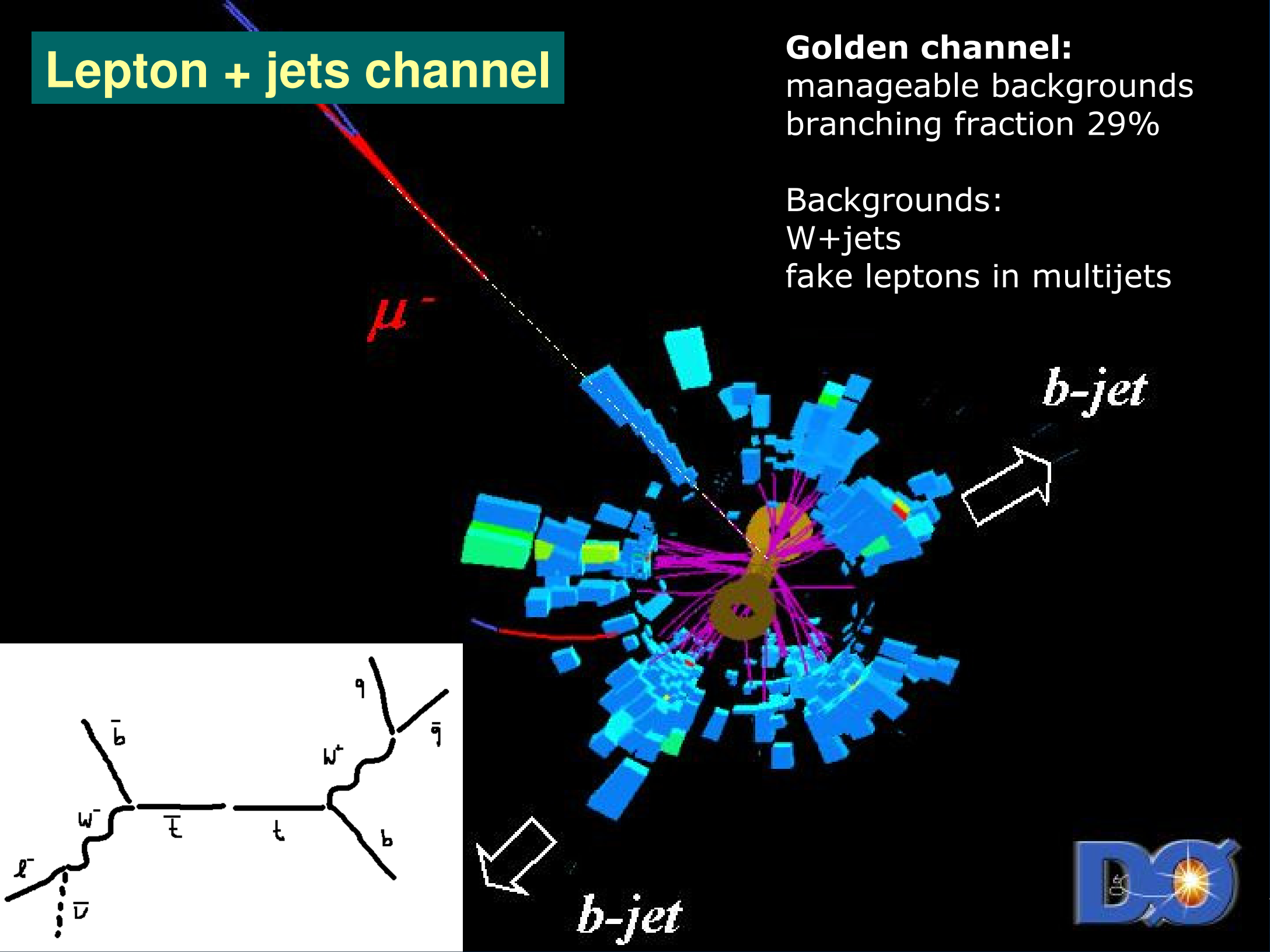
$$\sigma = \frac{N_{events} - N_{background}}{Luminosity * \varepsilon}$$

- Test of QCD at high Q^2
- Higher cross section than predicted could be a sign of new physics: resonant state $X \rightarrow tt$ OR anomalous couplings in QCD?
- Lower cross section could also mean new physics: we make assumptions on the expected decay mode
- Important to measure all decay channels and topologies: different sensitivities to new physics possibilities
- Provides samples for properties measurements

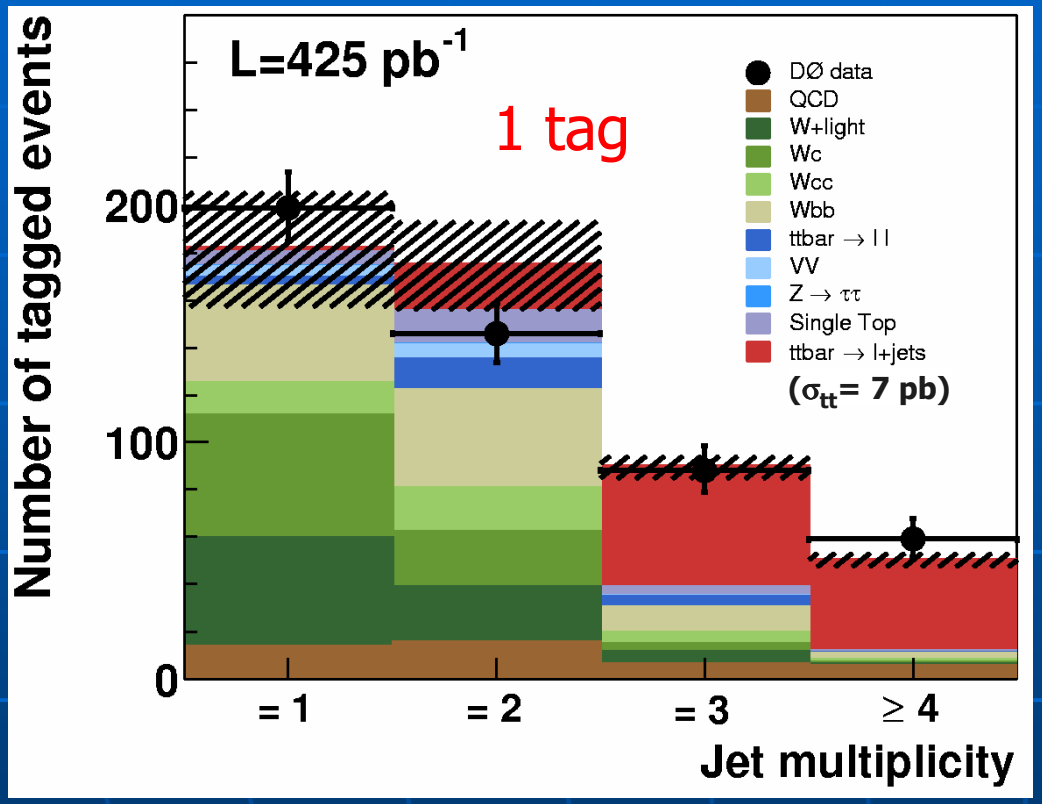
Lepton + jets channel

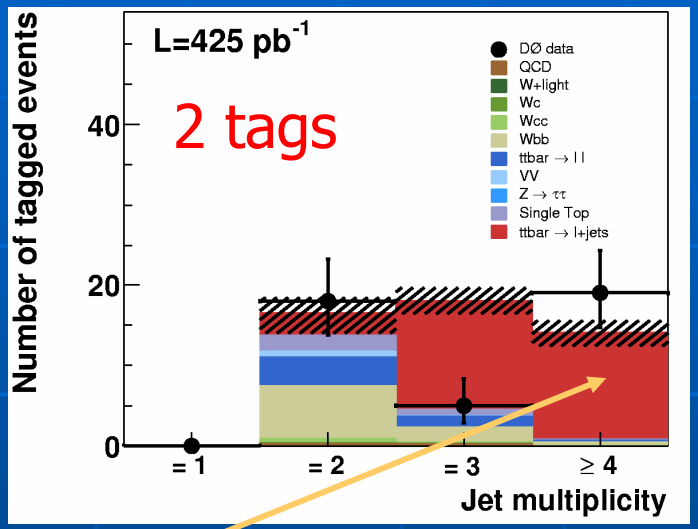
Golden channel:
manageable backgrounds
branching fraction 29%

Backgrounds:
W+jets
fake leptons in multijets



Lepton+jets cross section





Ultra pure top sample:
≥4 jets, 2tags
0.6±0.4±0.1 BG expected
19 observed

Combining 1,2tags; 3,>4 jets; e,μ:

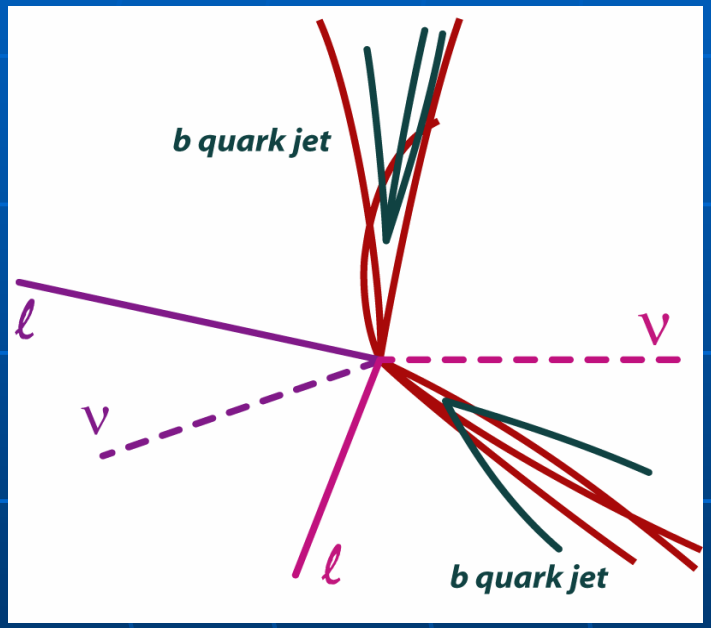
$$\sigma_{t\bar{t}} = 6.6 \pm 0.9(\text{stat} + \text{syst}) \pm 0.4(\text{lumi})\text{pb}$$

@ m_t=175 GeV

PRD 74, 112004 (2006)

Dilepton cross section

low BG, but also
low branching fraction (4.5%)



Increase efficiency by requiring one fully reconstructed lepton, and require an additional track

370pb^{-1}

$$\sigma_{tt} = 8.6^{+1.9}_{-1.7}(\text{stat})^{+1.1}_{-1.1}(\text{syst})\text{pb}$$

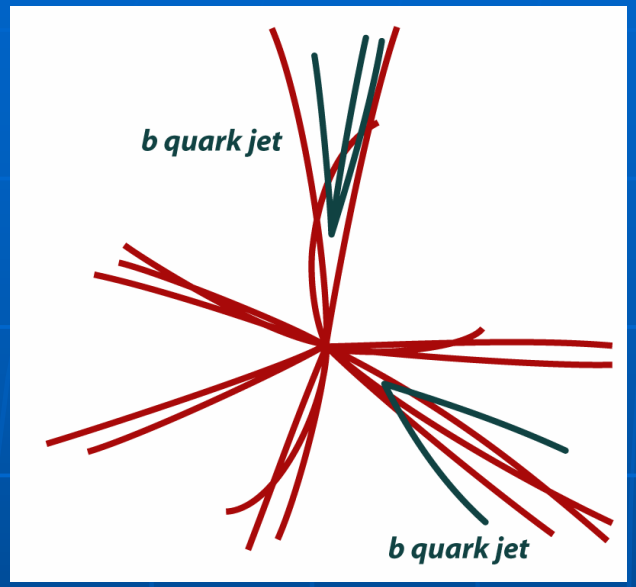
Combined with e-μ
(which has both leptons fully reconstructed)

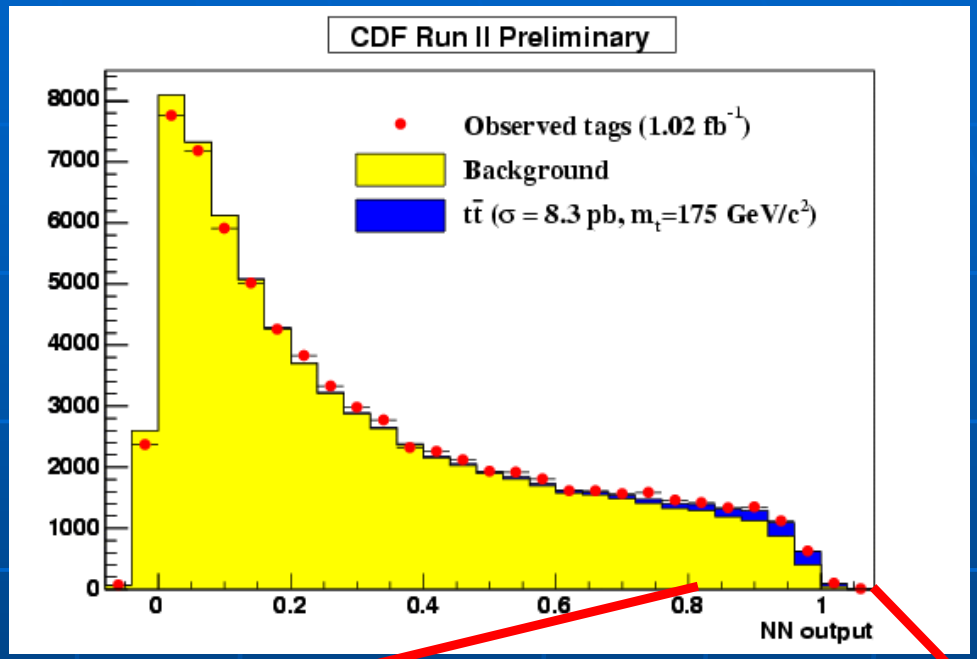
Backgrounds:
- WW/WZ, $Z/\gamma^* \to \tau\tau \to ll$
- fake MET in DY or
- fake leptons in multijet

$$\sigma_{tt} = 9.0 \pm 1.3(\text{stat}) \pm 0.5(\text{syst})\text{pb}$$

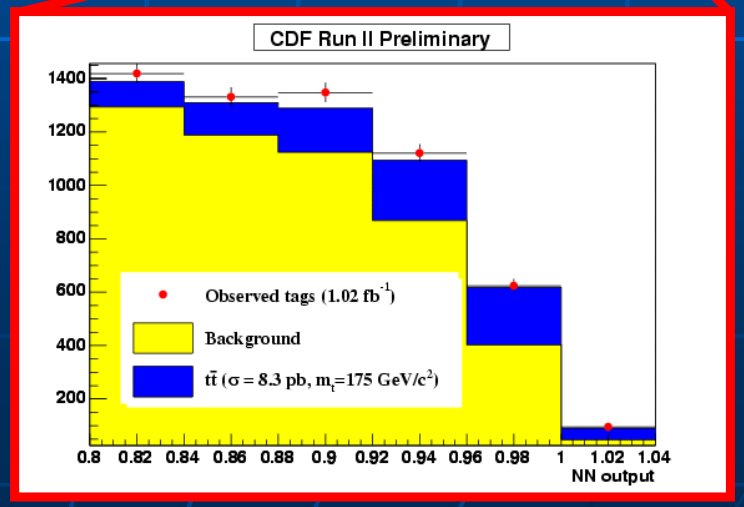
March 5 2007, 1.1fb^{-1}

All-hadronic cross section





- Large branching fraction (46%)
- Huge multijet background (S/B~1/300)
- Need b-jet tagging

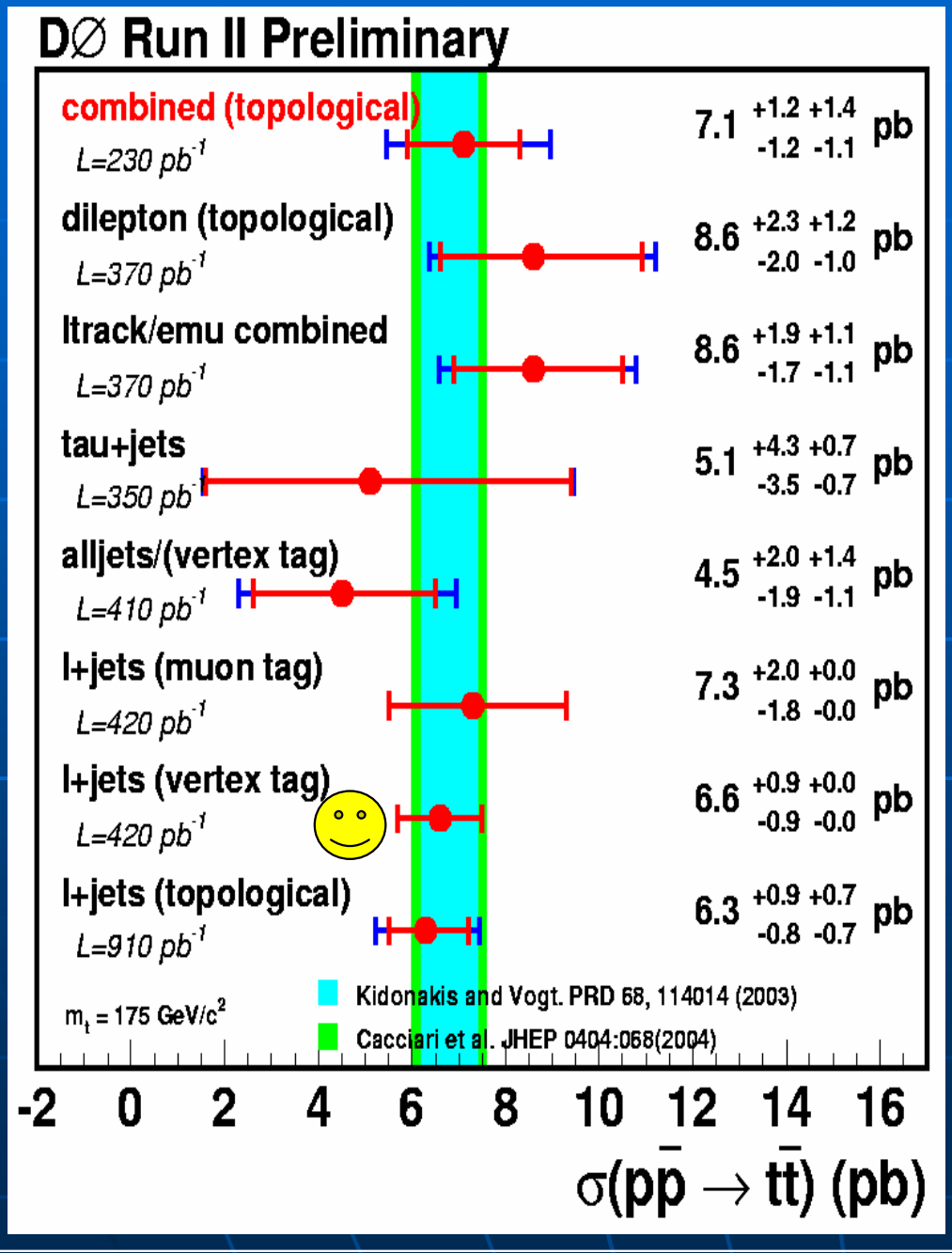


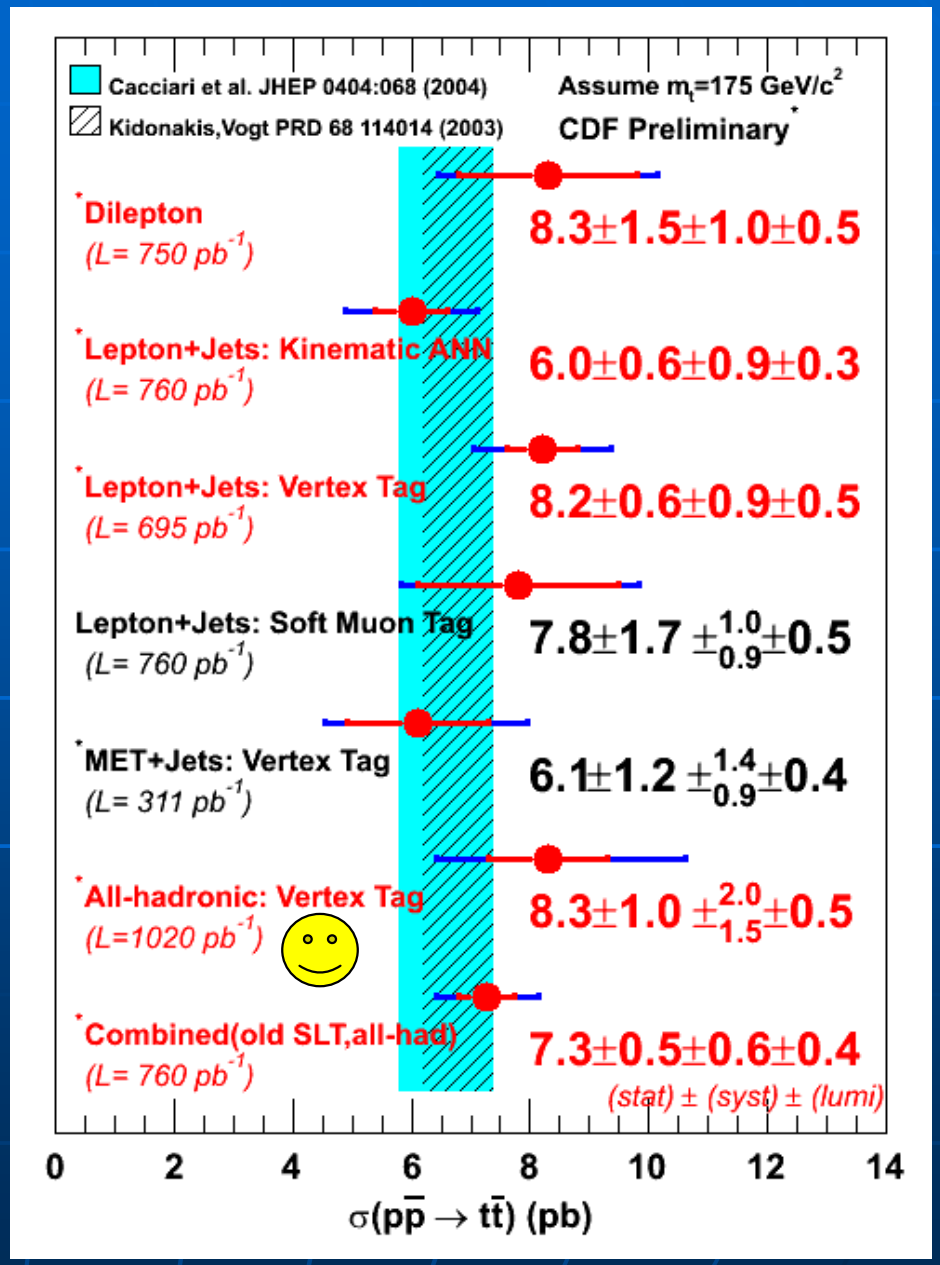
NN-based analysis

$$\sigma_{t\bar{t}} = 8.3 \pm 1.0(\text{stat})^{+2.0}_{-1.5}(\text{syst}) \pm 0.5(\text{lumi})\ \text{pb}$$

1.02 fb^{-1}

☺ =shown in previous slides



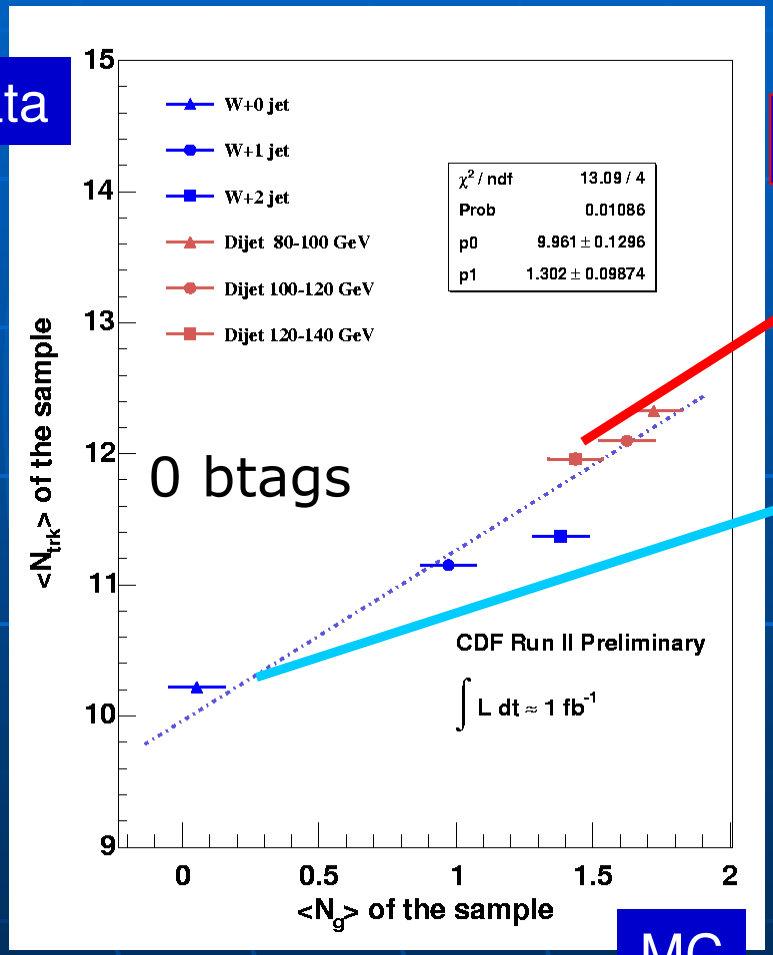


☺ lepton+track in the plot by next week…

Production mechanism (gg→tt)/(pp→tt)

The number of low-pt tracks (0.3-3.0 GeV) scales with the gluon content of the sample

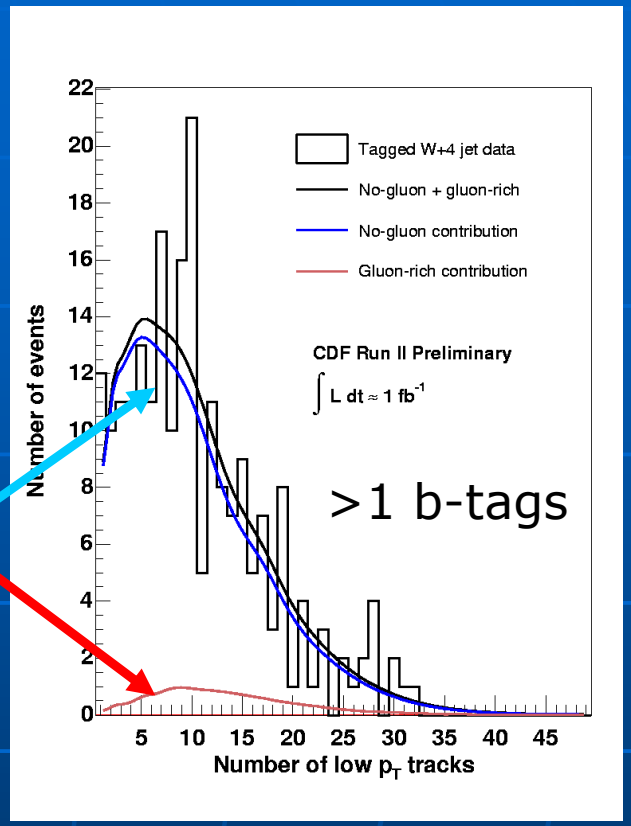
Data



MC

M(jj) 80-100 GeV ≅ gg

W+0jets ≅ qq

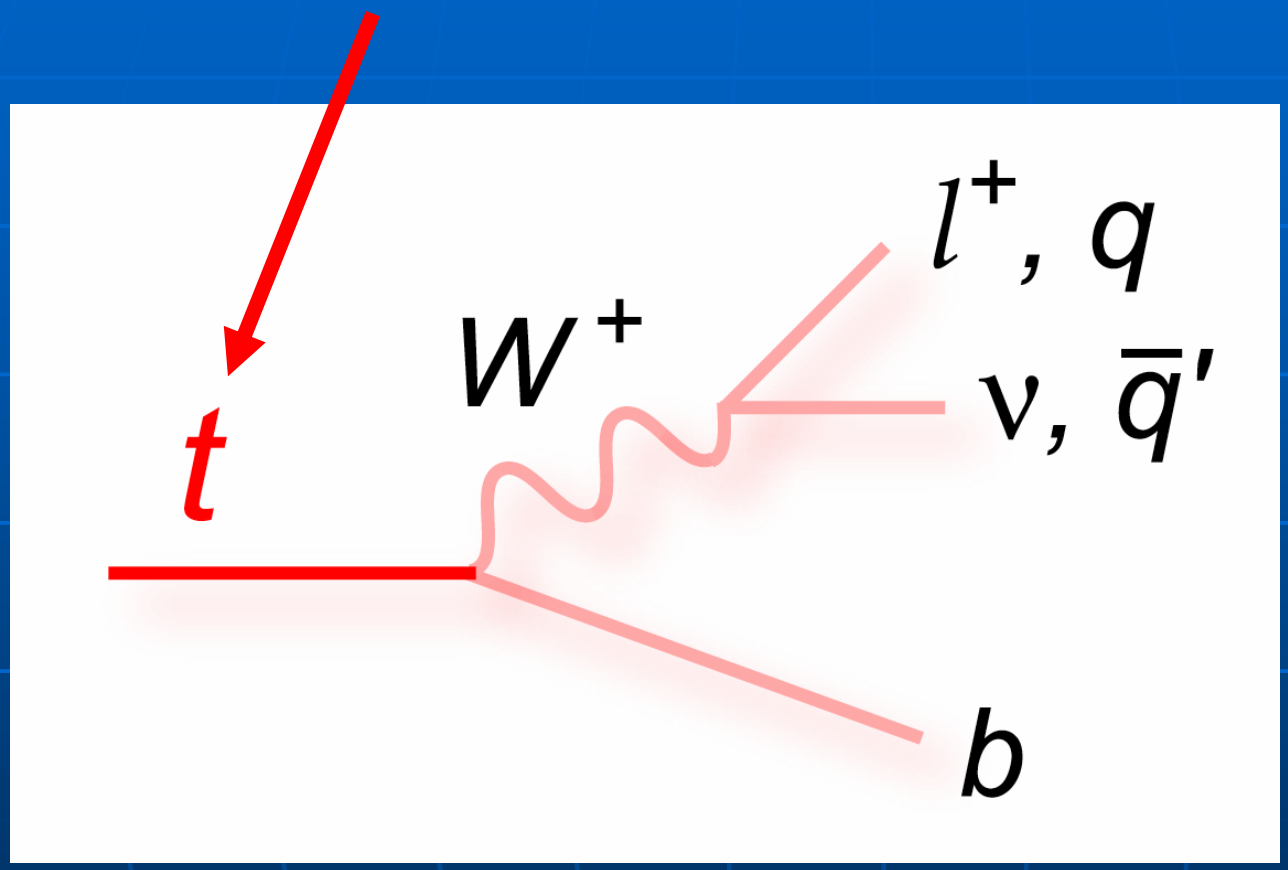


$$\frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})} = 0.01 \pm 0.16(\text{stat}) \pm 0.07(\text{syst})$$

March 5, 2007 !

Consistent with SM expectation of 0.18

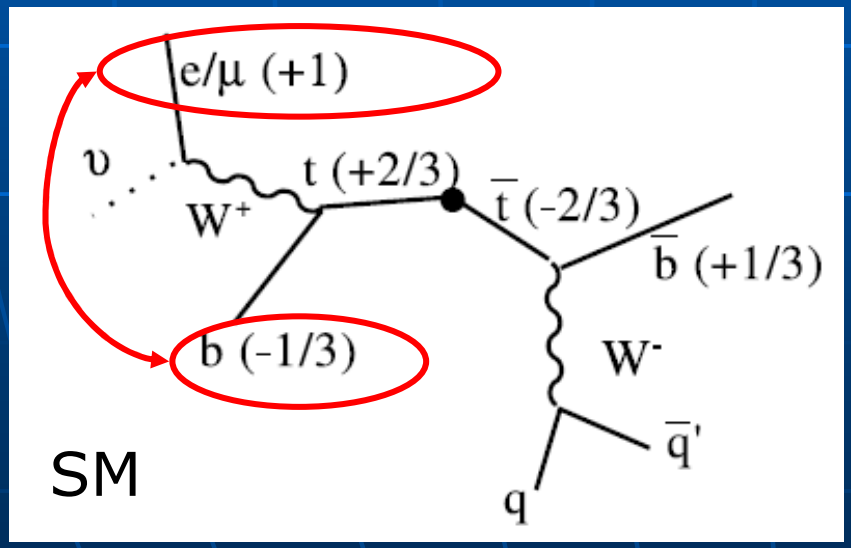
Is the ‘top’ the SM top ?

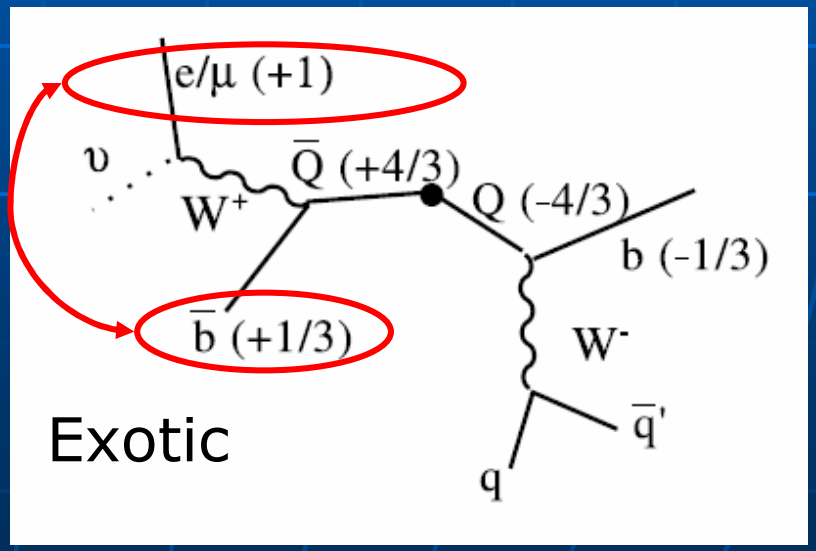


- charge
- lifetime

Top charge

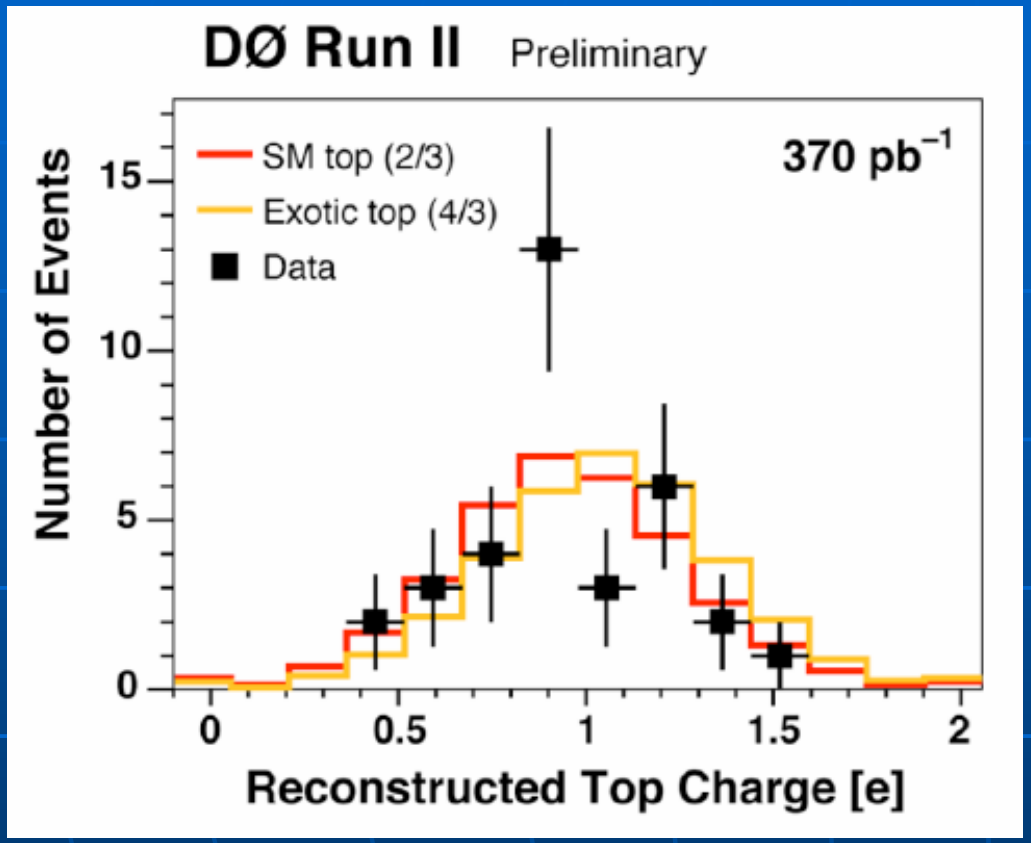
- A most fundamental quantity characterizing a particle
- Possible alternative to +2/3e (D.Chang etal PRD59, 091503 (1999))
  - Introduce an exotic 4th family $(Q_1,Q_4)_R$, with charge (-1/3,-4/3)
  - Q_4 is the "discovered top quark"
  - True top quark has a mass of ~270 GeV and escaped detection



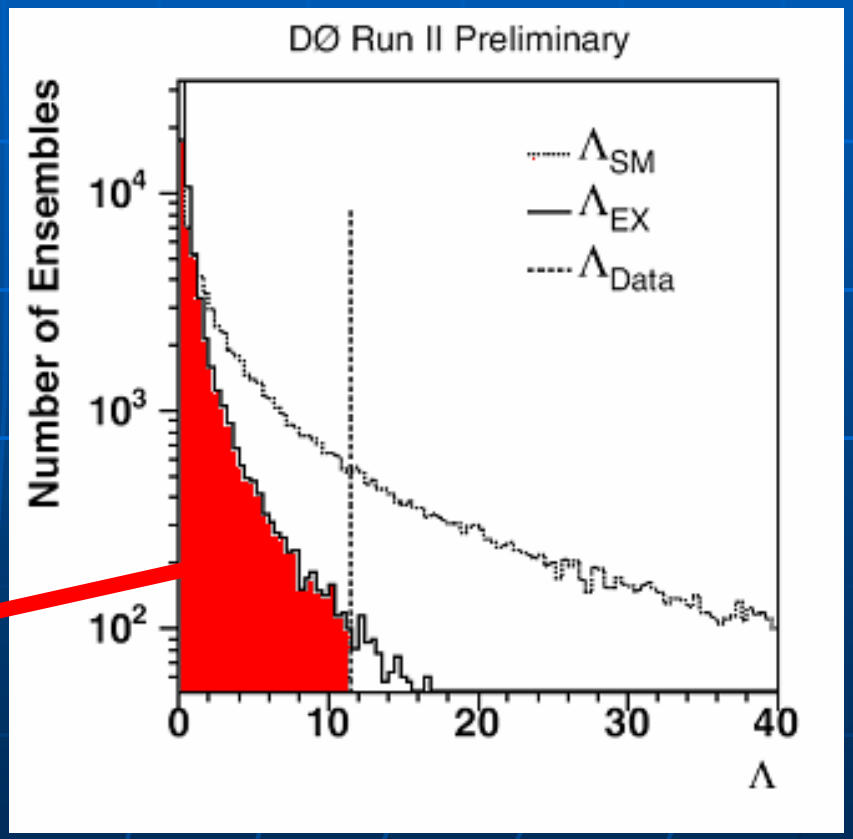


Top charge

Use a likelihood ratio method



$$\Lambda = \frac{\prod_i p^{\mathrm{sm}}(q_i)}{\prod_i p^{\mathrm{ex}}(q_i)}$$



92% $\Lambda_{EX} < \Lambda_{data}$

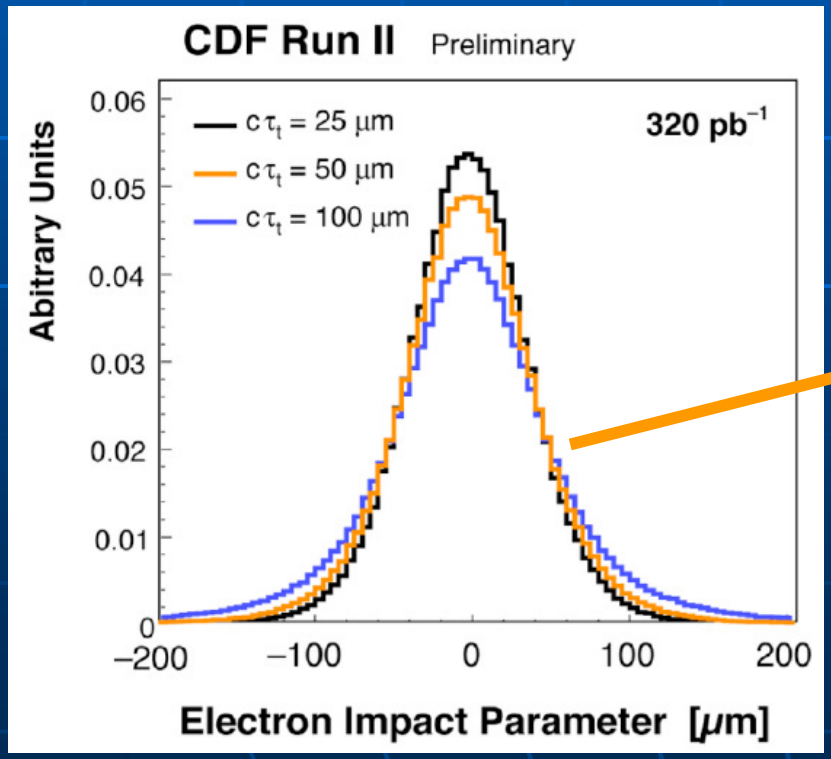
Exclude exotic 4/3e top at 92% C.L.

PRL 98, 041801 (2007)

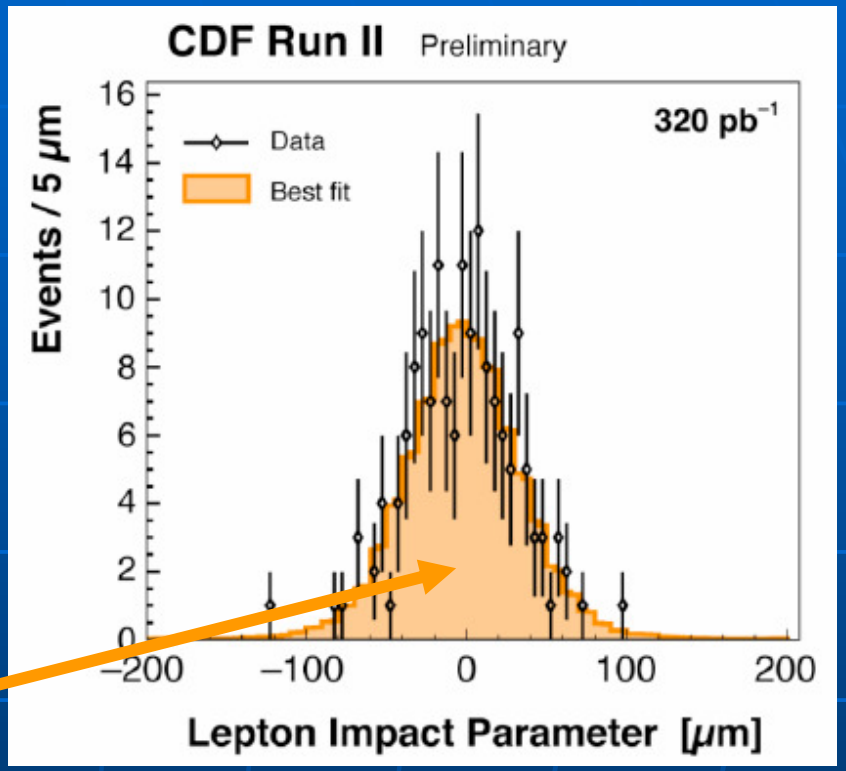
top lifetime

Lepton + jets channel with one b tagged jet

- Primary Vertex constrained by jets
- Measure the lepton impact parameter



Likelihood fit

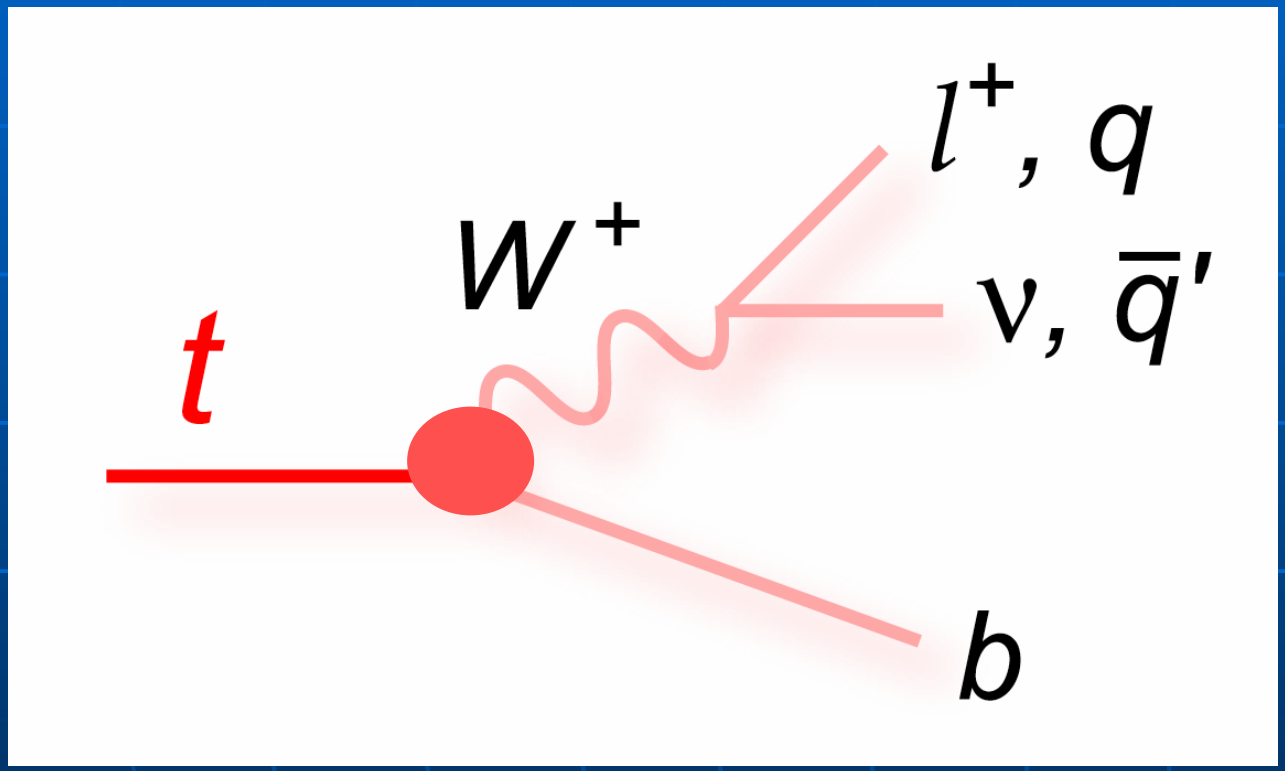


Maximum likelihood for $c\tau_{top}$=0 μm

$$c\tau_{top} < 52.5\mu m \quad \text{at } 95\% \text{ CL}$$

SM: 3x10^{-10}μm

Probing the Wtb vertex



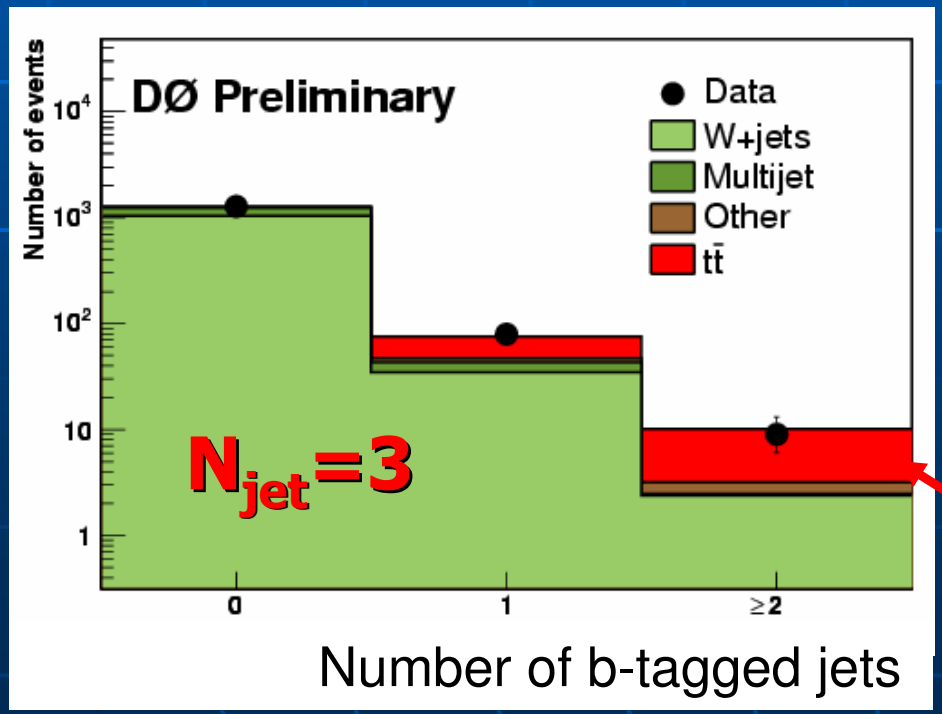
- t→Wb / t→Wq
- W helicity in top events

Probing the assumption t→Wb

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

(True in SM with three quark generations)

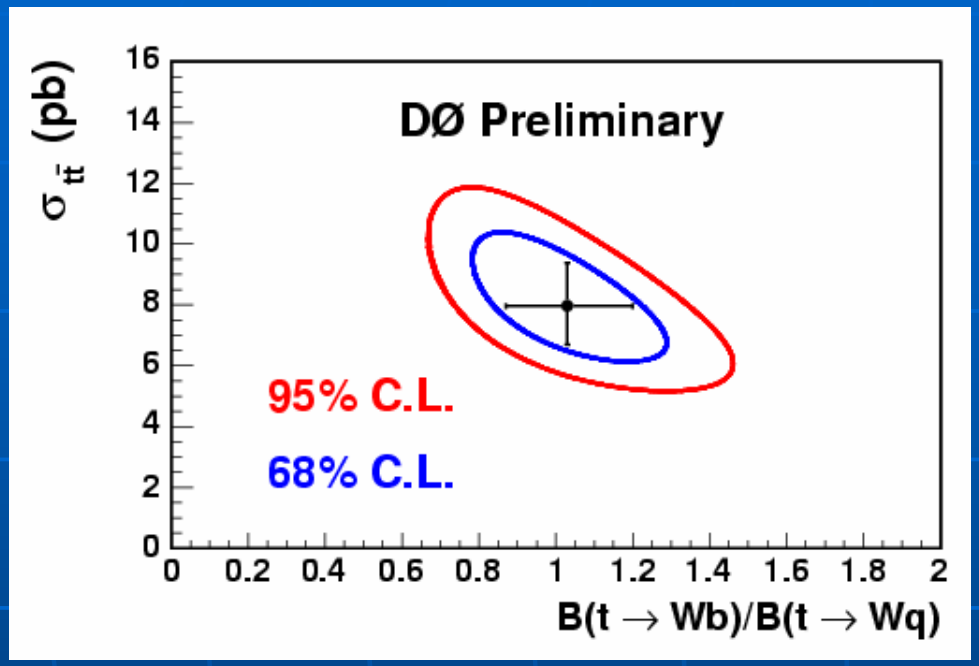
Measurement: count b-jets.
The number of b-jets depends strongly on R and the tagging efficiency.



- Result is obtained from a binned maximum likelihood fit to data for $N_{jet}=3$ and $N_{jet}=4$
- Simultaneous fit to R and cross section

$Br(t \to Wb)=1$ and $\sigma_{tt}=7$ pb

Probing t→Wb



230 pb^{-1}

$$B = \frac{Br(t \to Wb)}{Br(t \to Wq)} = 1.03^{+0.19}_{-0.17}(\text{stat} + \text{syst})$$

PLB 639, 616 (2006)

Assuming CKM unitarity
$|V_{tb}|>0.78$ @ 95% CL

Direct $|V_{tb}|$ measurement with single top → see talk by Juste

Also allows for a model independent cross section measurement:

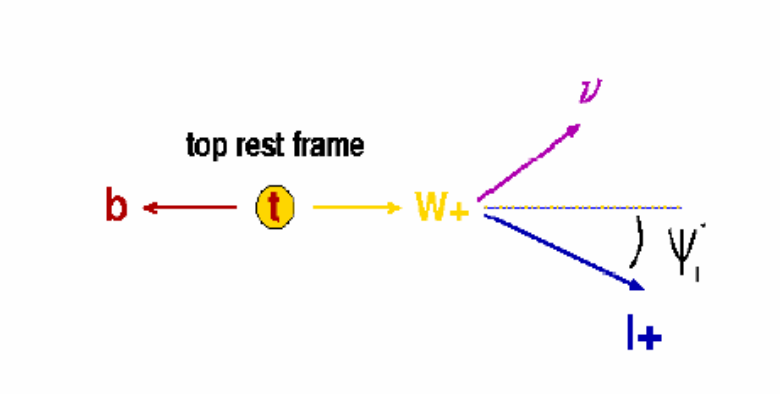
$$\sigma_{t\bar{t}} = 7.9^{+1.7}_{-1.5}(\text{stat}+\text{syst})\text{pb}$$

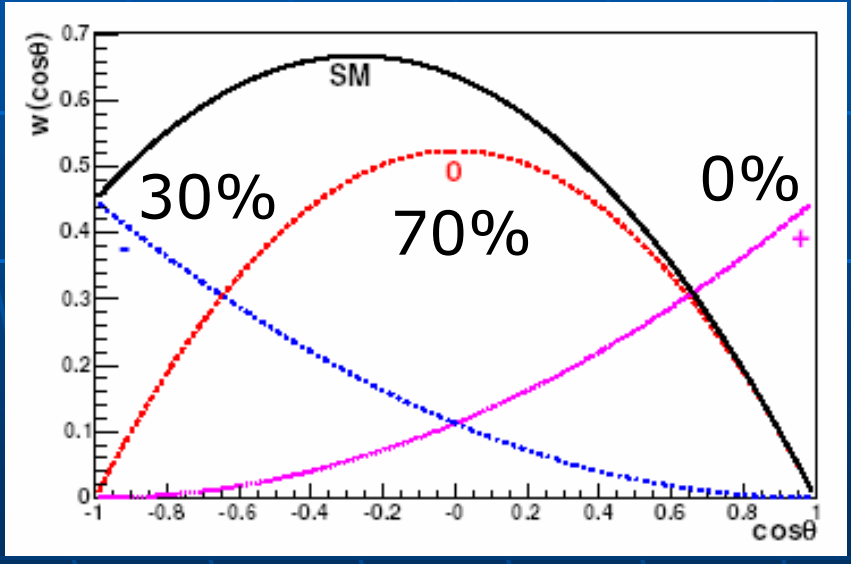
$$\frac{Br(t \to Wb)}{Br(t \to Wq)} = 1.12^{+0.21}_{-0.19}(\text{stat})\ ^{+0.17}_{-0.13}(\text{syst})$$

PRL 95, 102002 (2005)

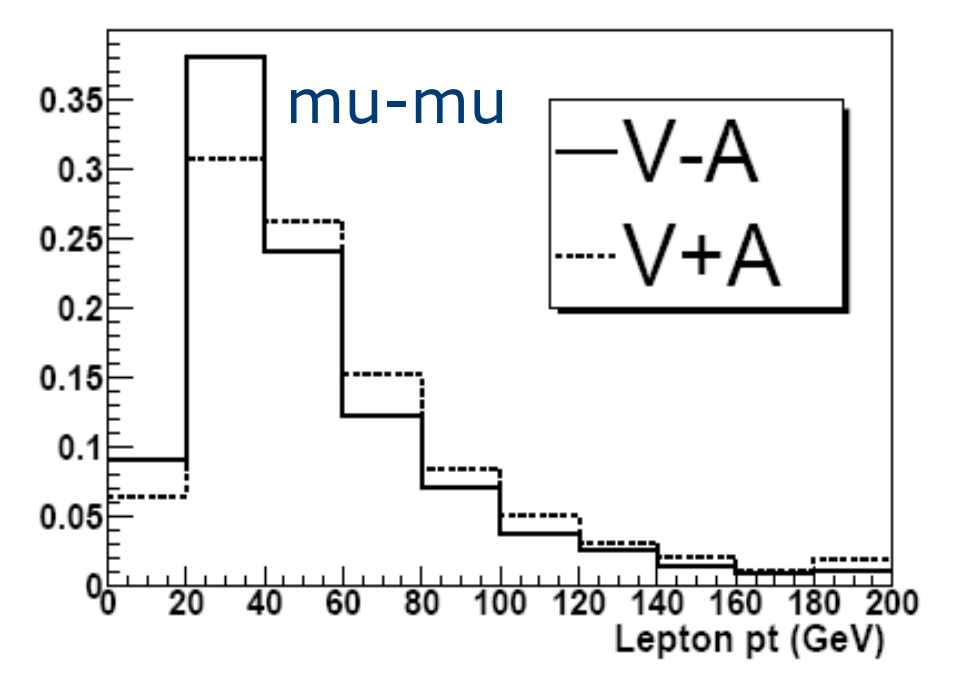
W Helicity from t→Wb Decays

- Examines the nature of the tWb vertex, probing the structure of weak interactions at energy scales near EWSB
- Stringent test of SM and its V-A type of interaction.
- Uses boosted W from top decays

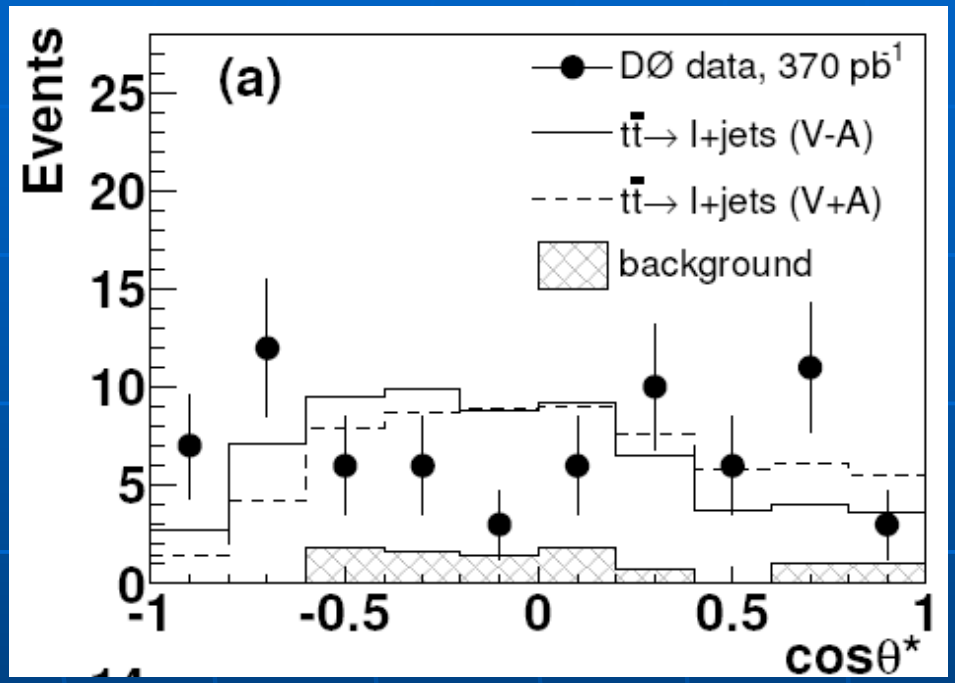


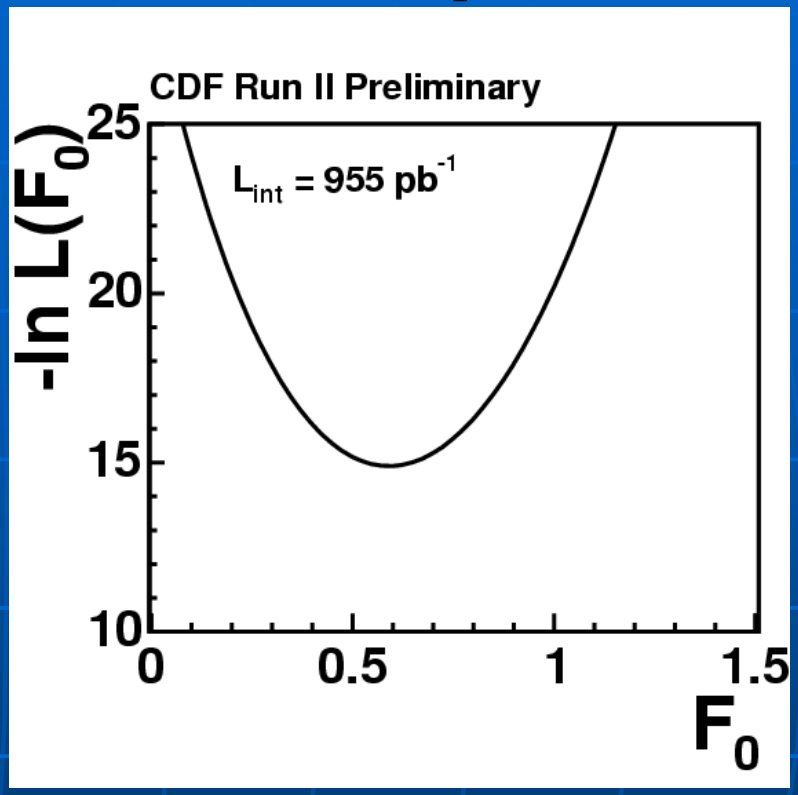


$$M^2_{l+b} = 1/2 \cdot (M^2_T - M^2_W)(1 + cos\psi^\star_l)$$



Results (2 selected)





lepton+jets and dilepton

F+ = 0.056 +- 0.080 (stat) +- 0.057 (syst)
F+ < 0.23 @ 95% C.L.

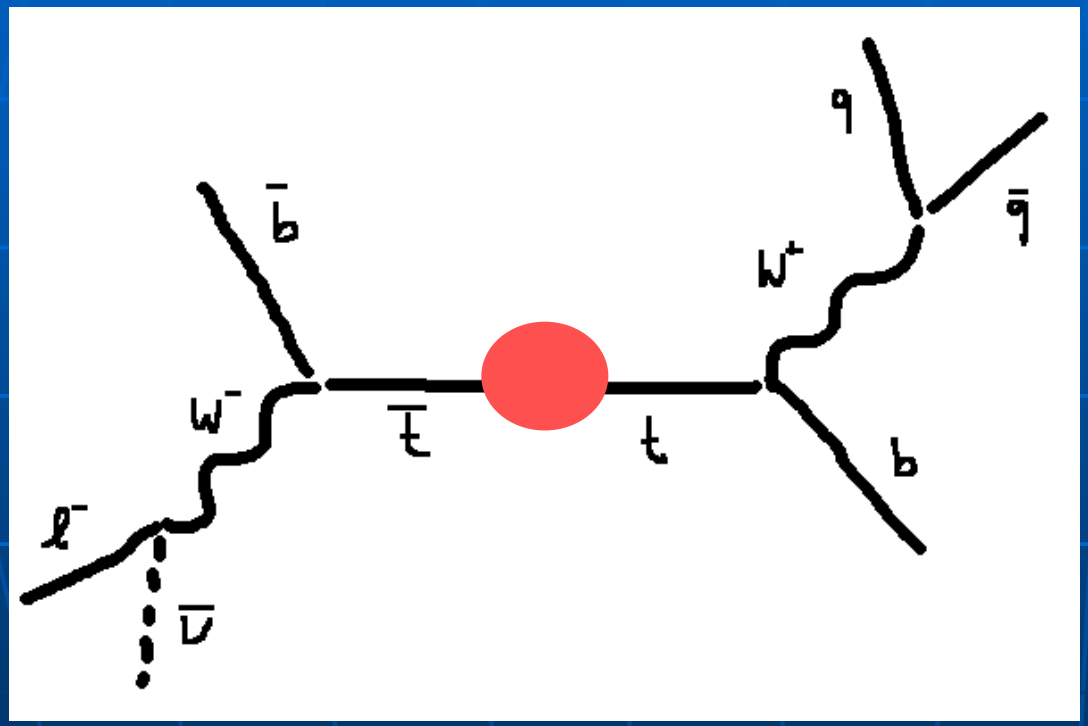
PRD 75, 031102(R) (2007)

lepton+jets

F0= 0.59 +-0.12(stat)+-0.07 (syst)
F+ < 0.10 @ 95% C.L.

(Earlier result with 0.7 fb^{-1}:
PRL 98, 072001 (2007))

Is there more than the top ?

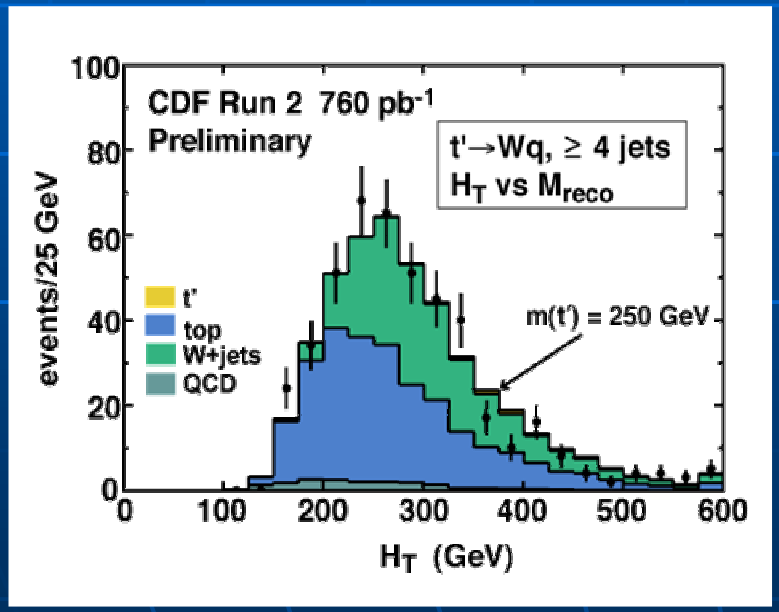


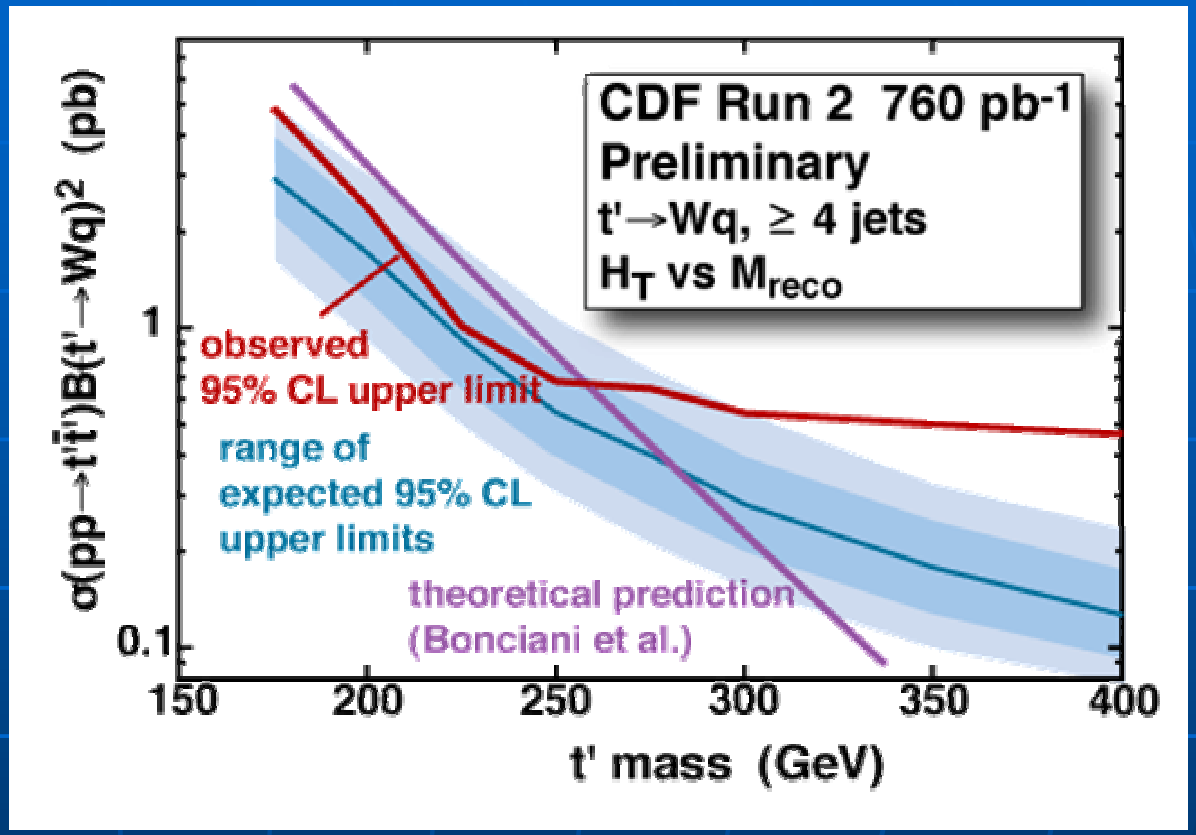
- t-prime
- Resonant top production

Search for a t' → Wb

Search for a heavy
4th generation quark
(He etal. Hep-ph/0102144)

Template fit in (H_T, M_T)



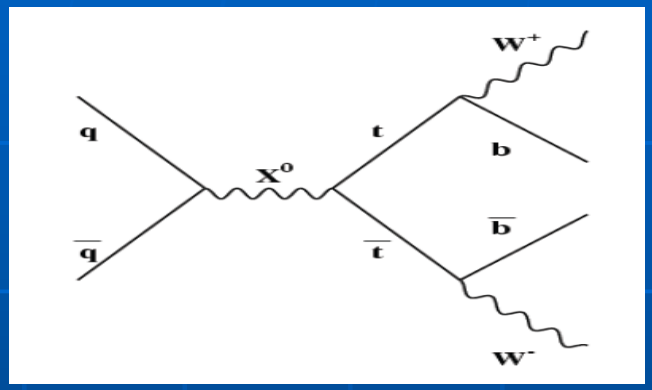


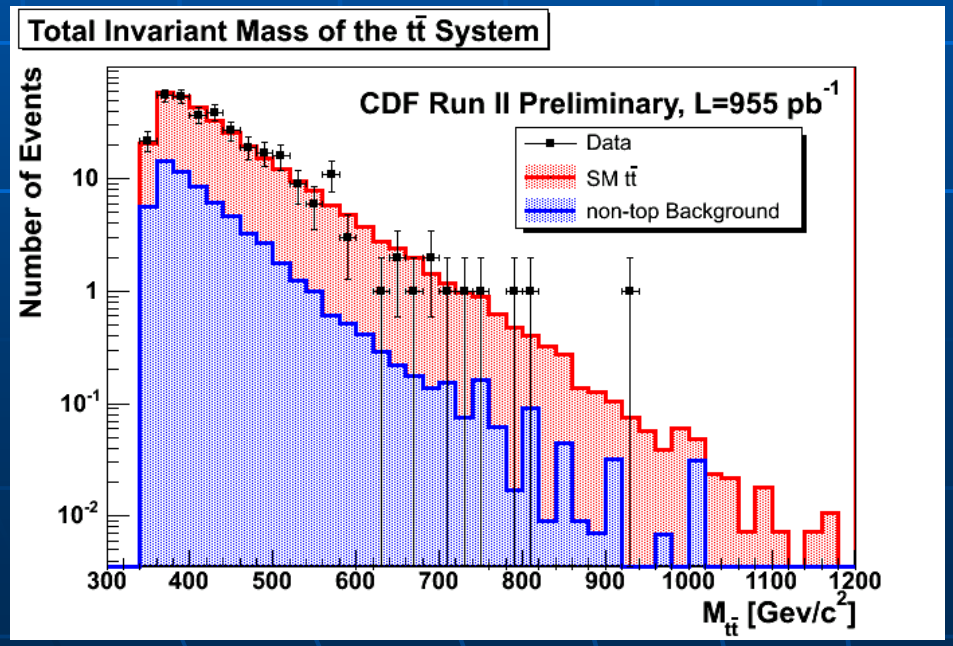
Lower limit on the t' mass of 258GeV/c^2 at 95% C.L.

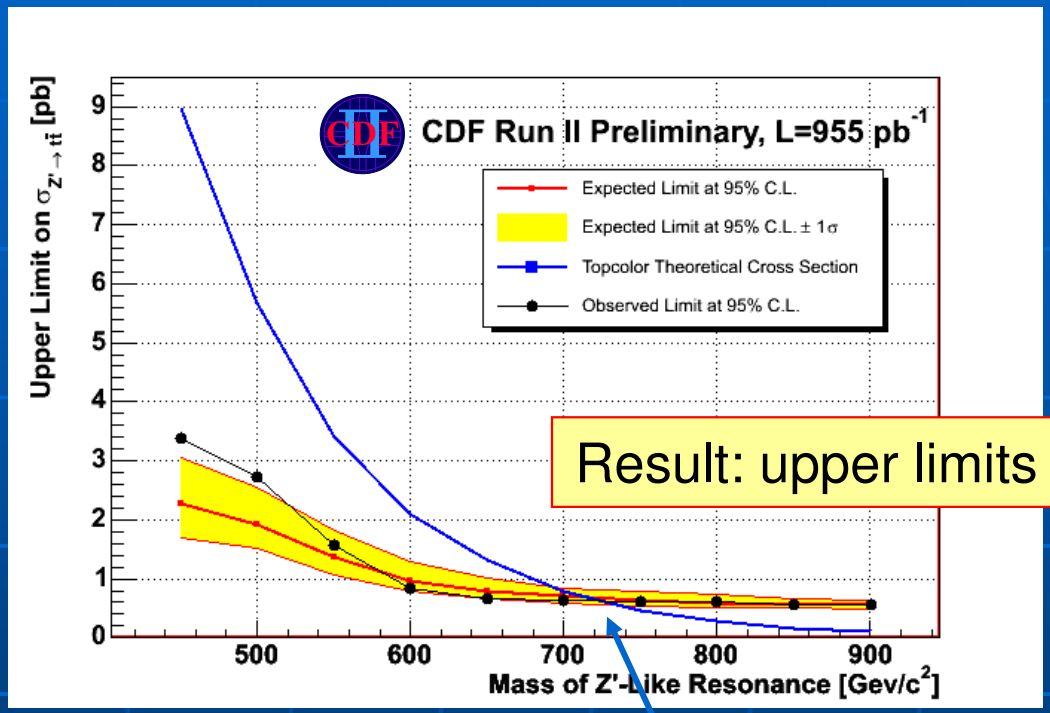
Expect m(t')>300 GeV/c^2 with 2 fb^{-1}, unless…

t-tbar resonances in *l+jets*

Search for a resonance in the
t-tbar invariant mass spectrum







Result: upper limits

Model exclusion:
narrow leptophobic Z' Γ=1.2%$M_{Z'}$

- CDF: exclude M(Z')<725 GeV/c^2
- D0: exclude M(Z')<680 GeV/c^2

Conclusions

- Top production and properties are consistent with the standard model expectation
- There is still space for new physics
- A lot of physics from the papers on top

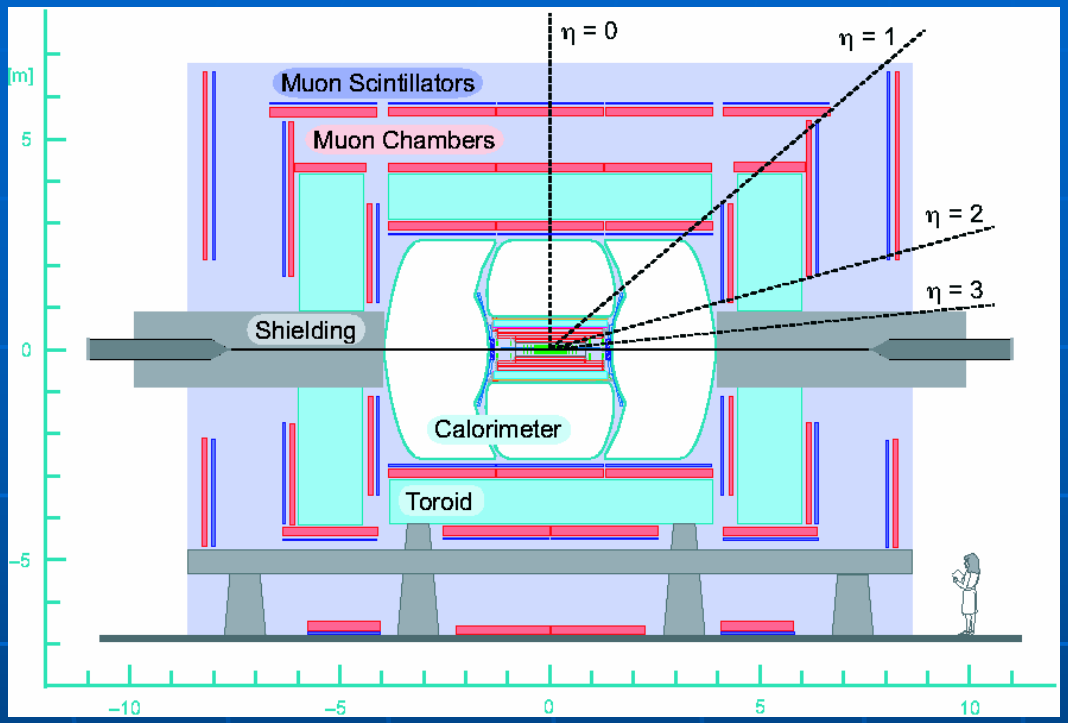
	Measured	SM
Cross section (CDF combination)	7.3±0.9 pb	6.7±0.8 pb
$\sigma(gg\rightarrow tt)/\sigma(pp\rightarrow tt)$	0.01±0.17	0.18
Mass	Next talk !	
Charge	Not 4/3e 92% C.L.	2/3e
$c\,\tau_{top}$	<53.5 μm 95% C.L.	10^{-10} μm
V_{tb}	>0.78 95% C.L.	0.998
Fraction of right-handed W	<0.09 95% C.L.	0
Heavy t'	Excluded $m_{t'}$<258 GeV	-
Production through narrow Z' resonance	Excluded $m_{t'}$<725 GeV	-

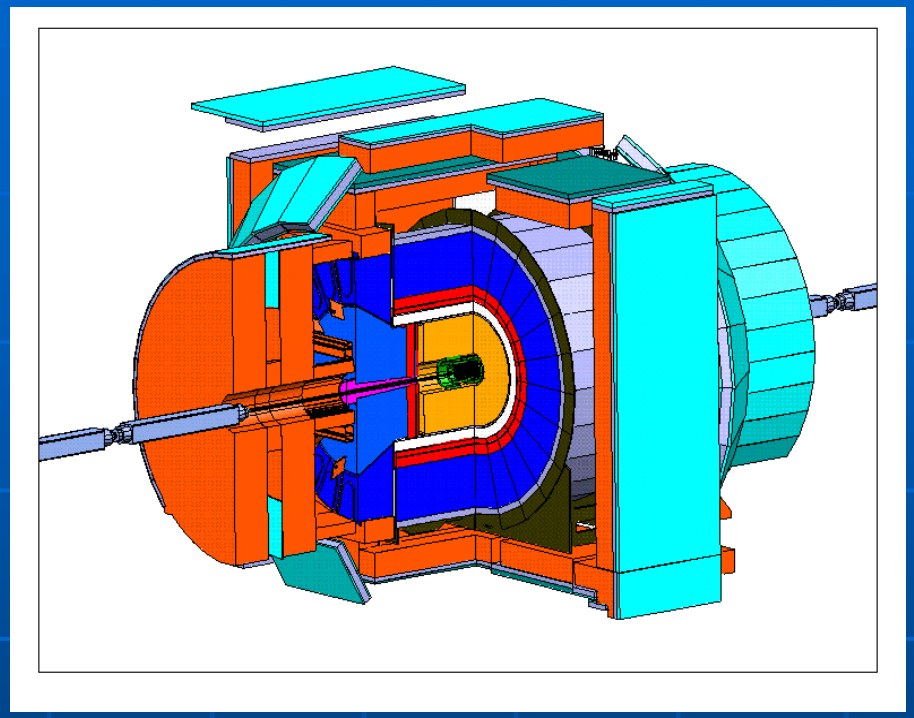
Understanding top quark production and properties will be crucial for success at LHC. What we learn at the Tevatron, both physics and analysis tools, extends directly to LHC!

++++++++

20 nations
92 institutions
~700 physicists

12 nations
60 institutions
~800 physicists

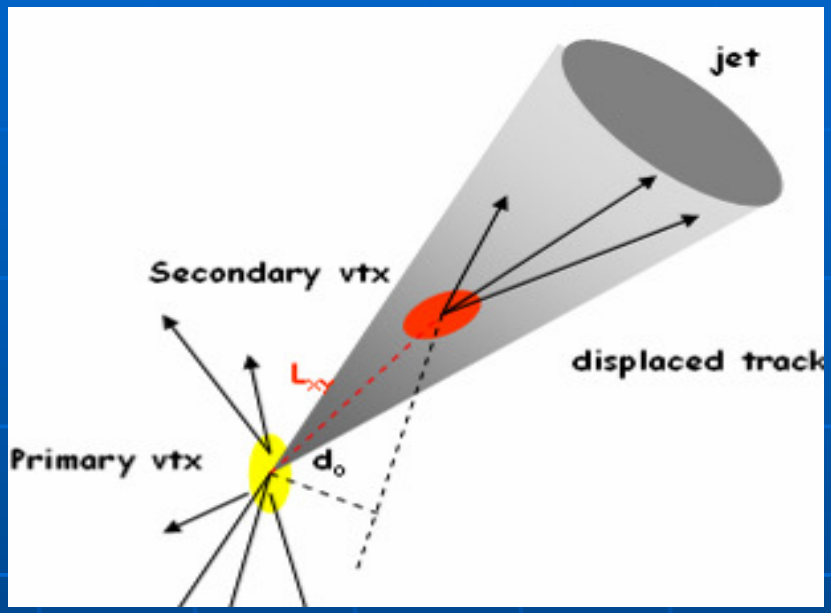




- **8 layer silicon**
- **16 layers scintillating fibers**
- **2T Solenoid**
- **Calorimeter: Cental + EndCap**
- **1.8T Toroid**
- **3 layers muon scintillator + drift tubes**

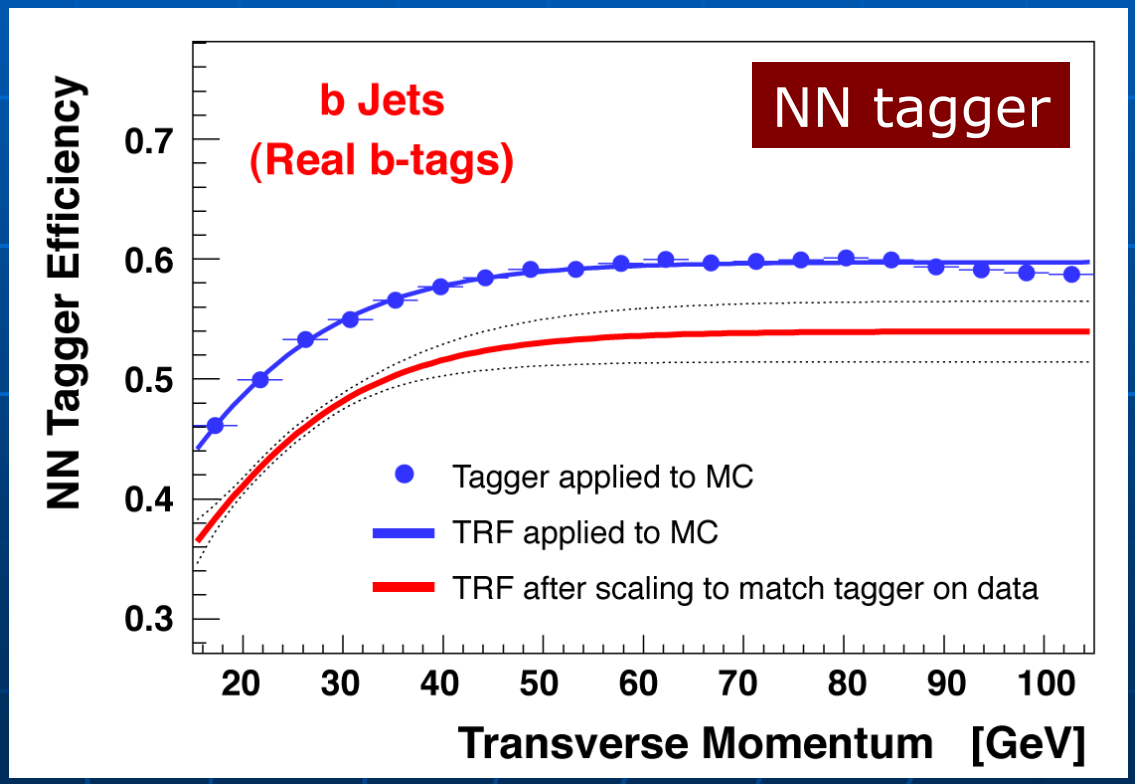
- **Silicon detector**
- **COT: drift chamber**
- **Solenoid**
- **Calorimeters: Central, wall, plug**
- **Muon: scintillator + chamber**

b-jet tagging



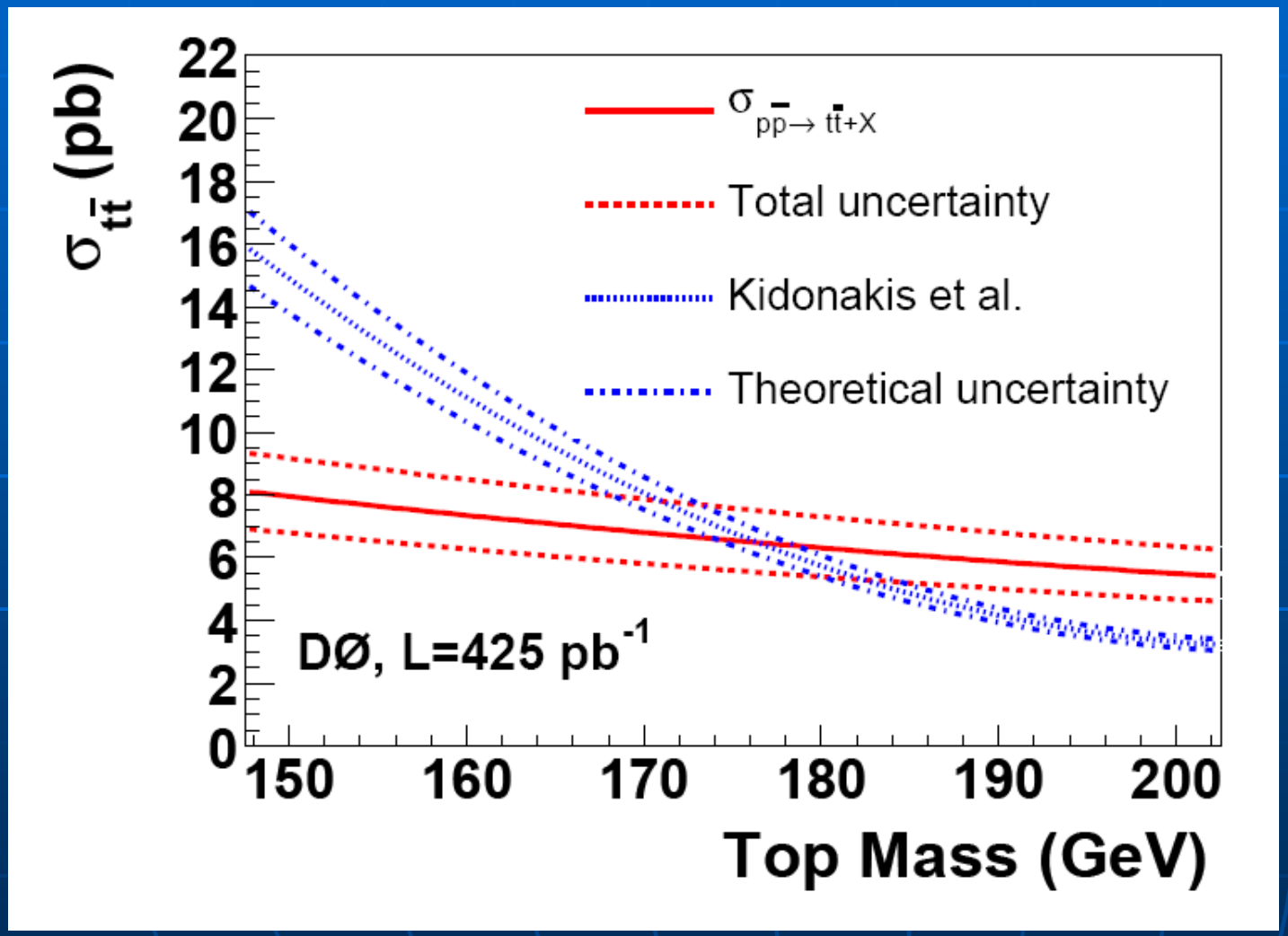
Secondary Vertex b-tagging algorithm

Separates b jets from light quark and gluon jets

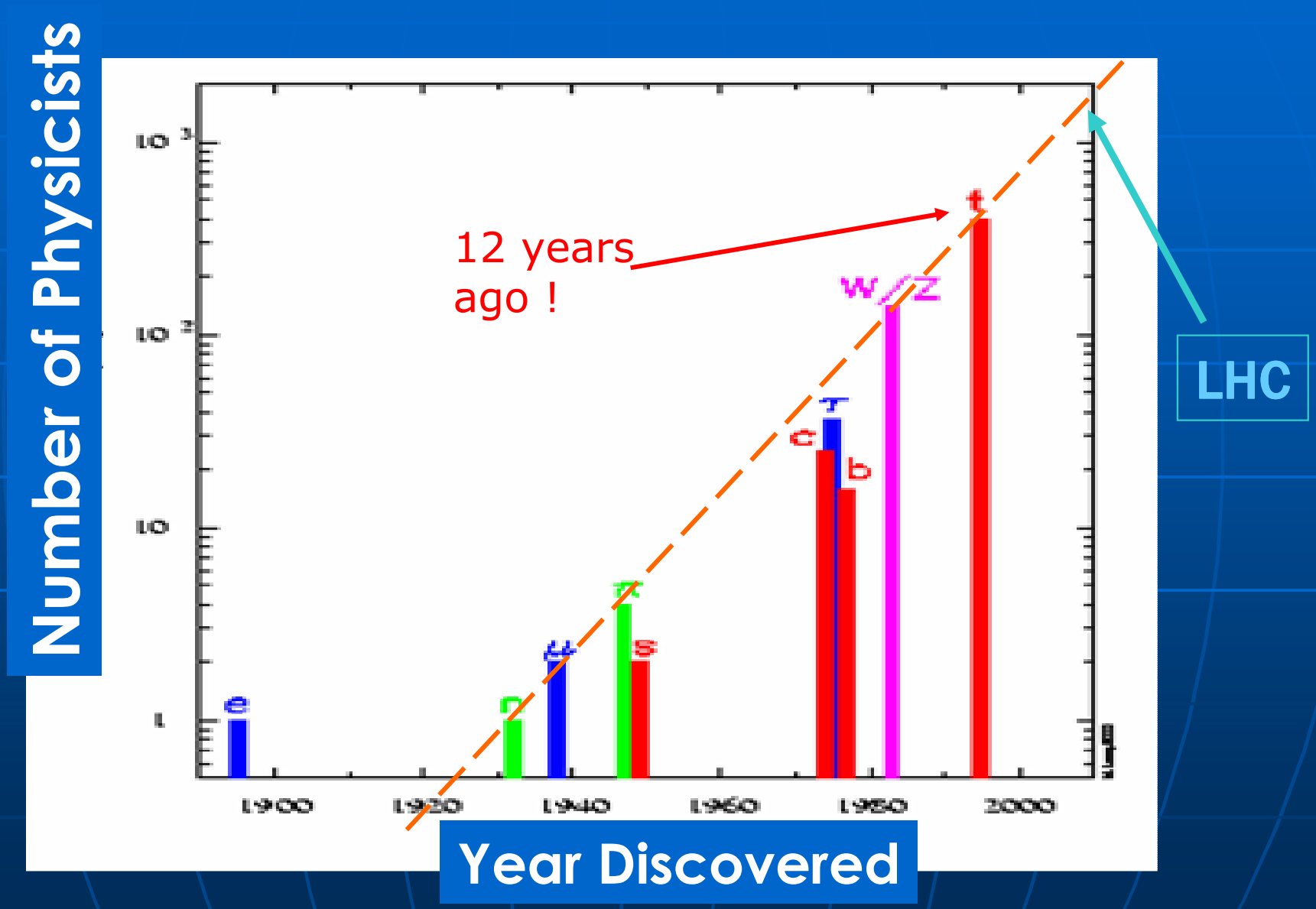


→ B hadrons travel ~3 mm before decay

Mass dependence



All cross sections are measured at mt=175 GeV

Dependence on mass is studied both for measurement (detection) and theory (production)

Discoveries…