



Top at Run II and LHC Prospects



APS/DPF 2006
April 23, 2006

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Top Quark Discovery



Discovered by CDF and DØ in 1995 during Run I of Tevatron

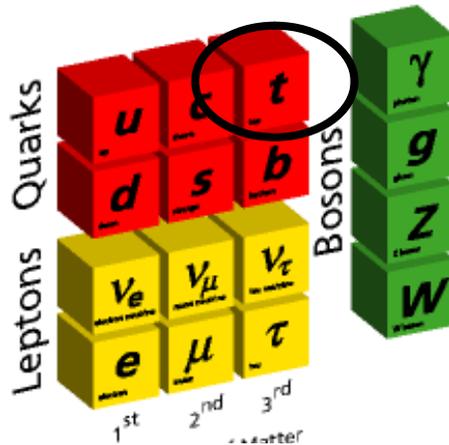
Top turned 10 years old!

Final Run I analyses $\sim 110\text{pb}^{-1}$
 ~ 30 events per experiment

“Precision Era” in Run II

Collected $> 1\text{fb}^{-1}$

$>$ factor of 10 more data!



Can only be studied at Tevatron until LHC turns on!
Want lots of top events to study its properties!

Why Is Top So Special?



Top is MASSIVE!

$$M_{\text{top}} = 172.5 \pm 2.3 \text{ GeV (TEWG hep-ex/0603039)}$$

Decays before hadronization!

$$\tau_{\text{top}} \sim 10^{-25} \text{ s}, \Gamma \sim 1.5 \text{ GeV} \gg \Lambda_{\text{QCD}} \sim 200 \text{ MeV}$$

Spin transferred to decay products

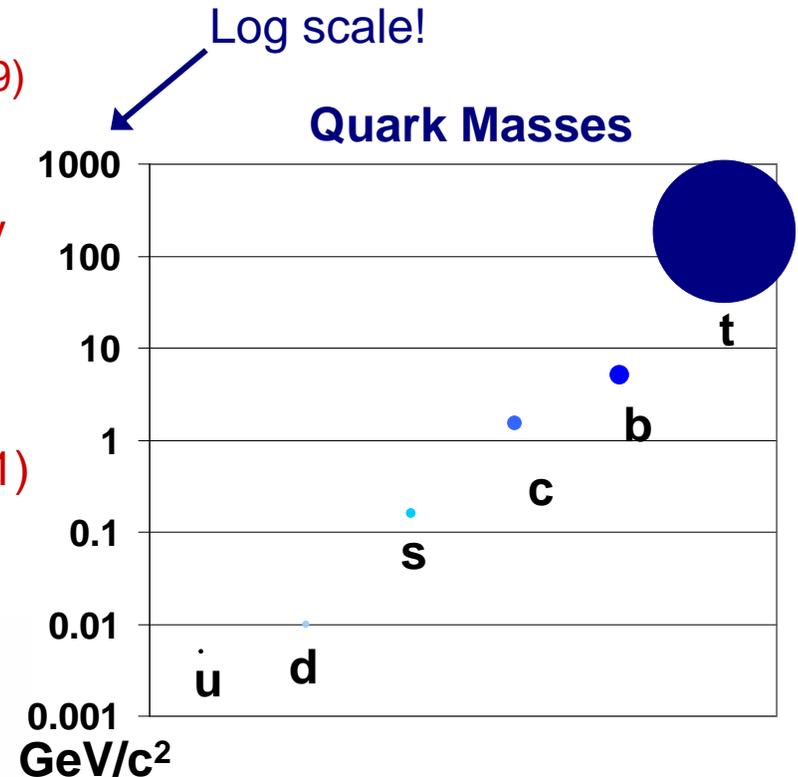
Special role in EWSB?

Top Yukawa coupling to Higgs is “natural” (~ 1)
 M_{top} together with M_W constrains M_{Higgs}

Probes physics at much higher energy scales than other known fermions



Is there anything beyond the SM????

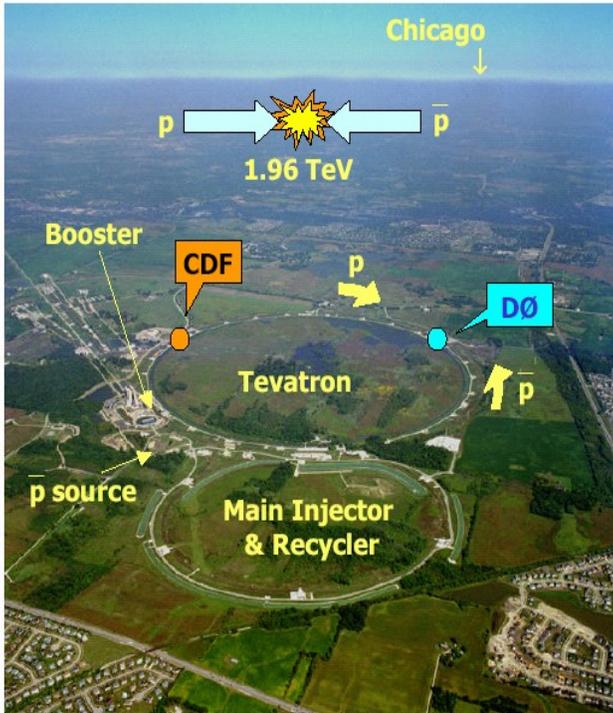


5 orders of magnitude between quark masses!

The Fermilab Tevatron



	<u>Run I</u>	<u>Run II</u>
\sqrt{s}	Ended 1996	2001-1.96 TeV
Peak L	1.8 TeV $2.4 \times 10^{31} \text{cm}^{-2}\text{s}^{-1}$	$1.7 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$

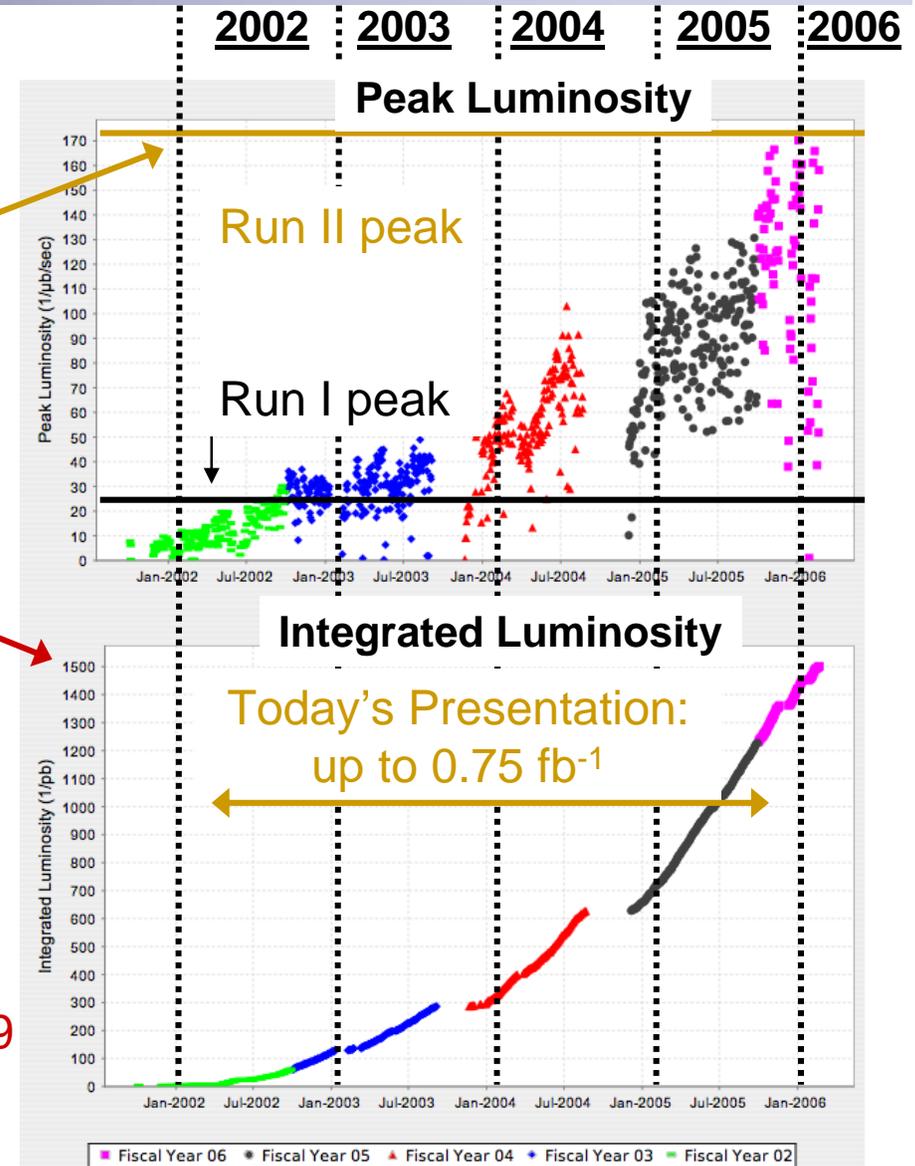


Record on Jan. 6, 2006!

Delivered:
 $1.5 \text{ fb}^{-1} / \text{exp}$

Recorded:
 $1.3 \text{ fb}^{-1} / \text{exp}$

Goal:
 2 fb^{-1} by 2006
 $4-8 \text{ fb}^{-1}$ by 2009



Large Hadron Collider (LHC)

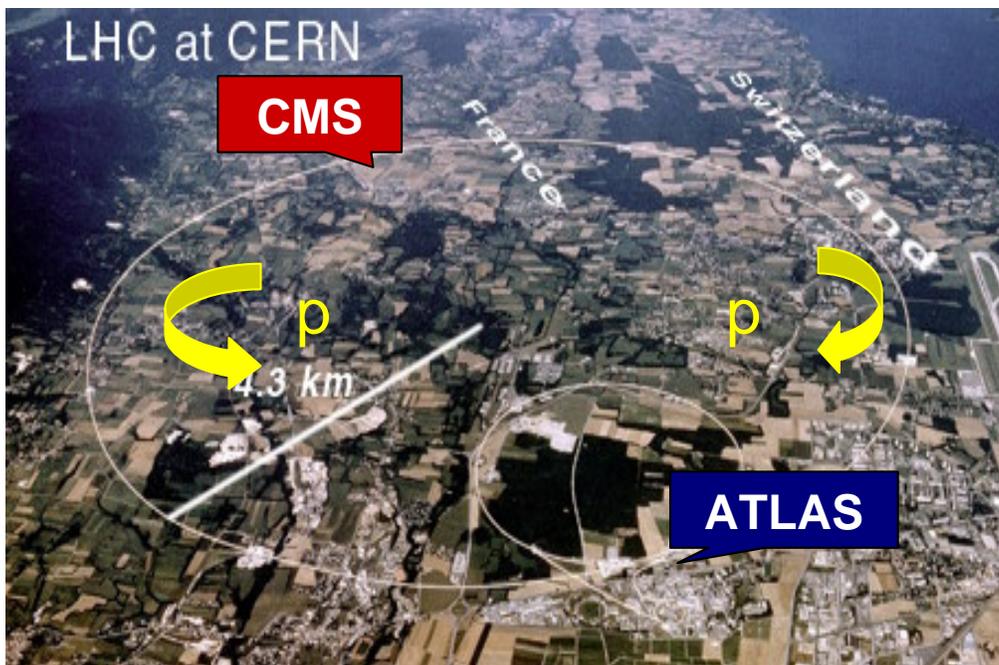


Designed to search for Higgs boson and other new discoveries.

Start in 2007!

proton-proton collisions

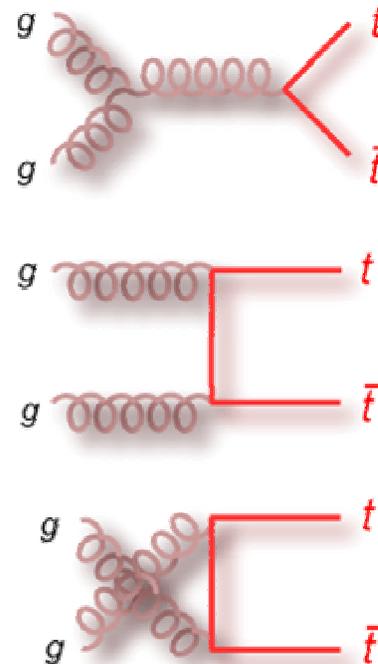
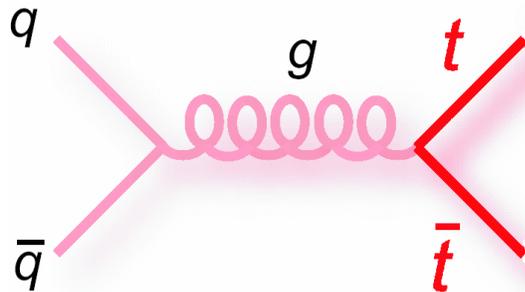
\sqrt{s}	14 TeV
Initial low L	$10^{33} \text{ cm}^{-2}\text{s}^{-1}$ 10 fb ⁻¹ /year
Design L	$10^{34} \text{ cm}^{-2}\text{s}^{-1}$ 100 fb ⁻¹ /year



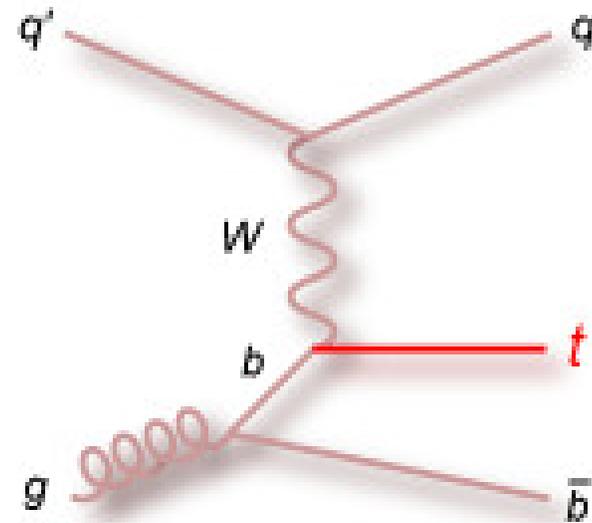
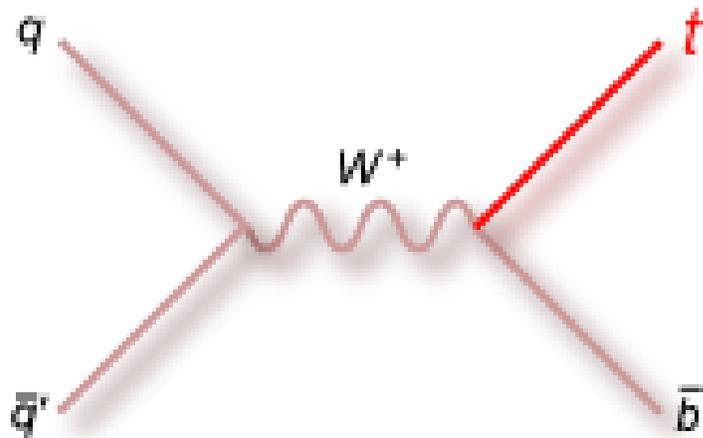
Top Quark Pair Production



	<u>Tevatron</u>	<u>LHC</u>
$\sigma(tt\bar{b}ar)$	~ 7 pb	~ 830 pb
qqbar	$\sim 85\%$	$\sim 10\%$
gg	$\sim 15\%$	$\sim 90\%$
evt./s	0.0007	0.8



Single Top Production

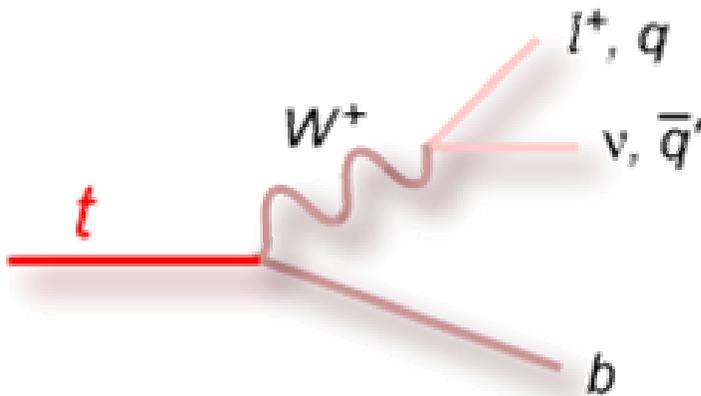


See next talk

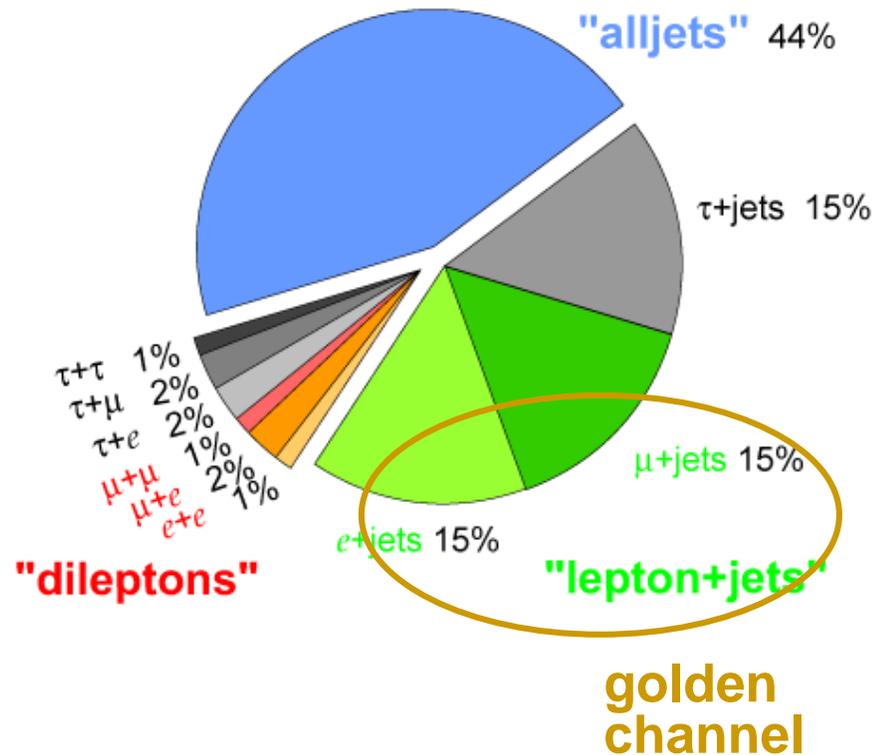
Top Quark Decay Modes



In Standard Model:
 $BR(t \rightarrow Wb) \sim 100\%$



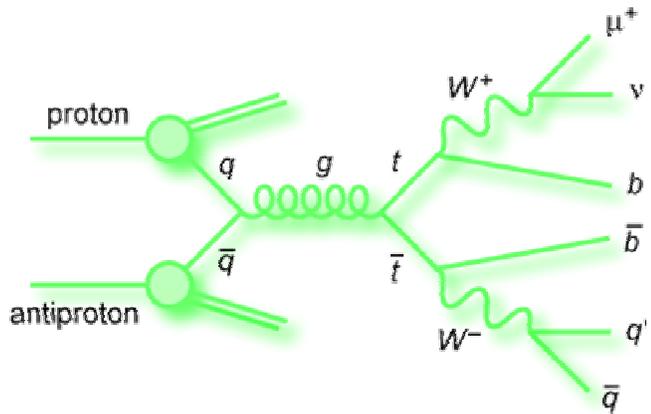
Top Pair Branching Fractions



Identifying Top

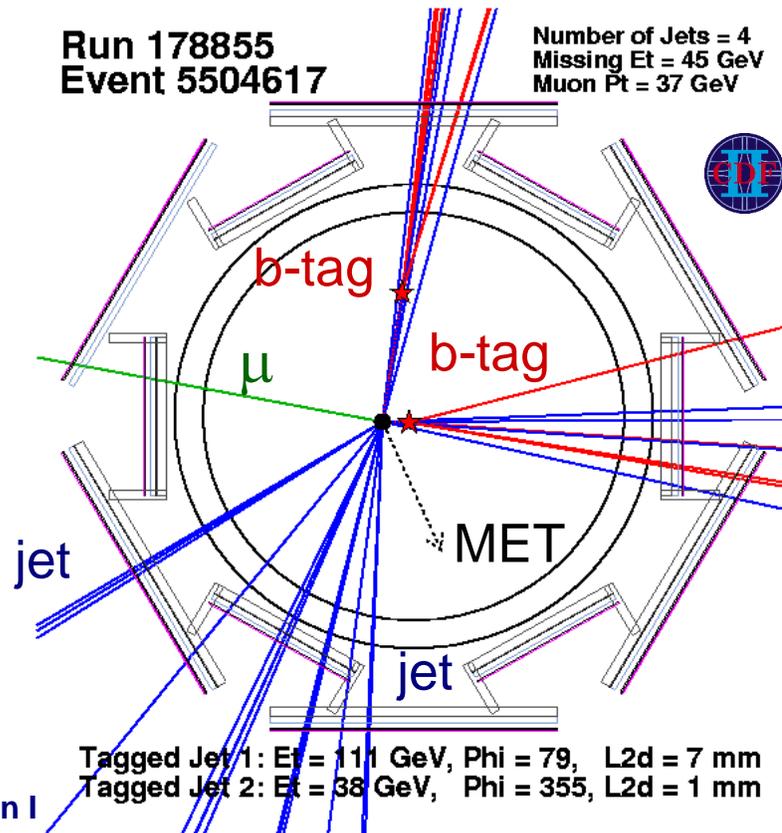


<p>leptons (e,μ) ν (missing E_T) quarks (jets) b-quarks ("b-tag" jet)</p>	}	$t\bar{t} \rightarrow l\nu l b b$	or
		$t\bar{t} \rightarrow l\nu q q b b$	or
		$t\bar{t} \rightarrow q q q q b b$	or



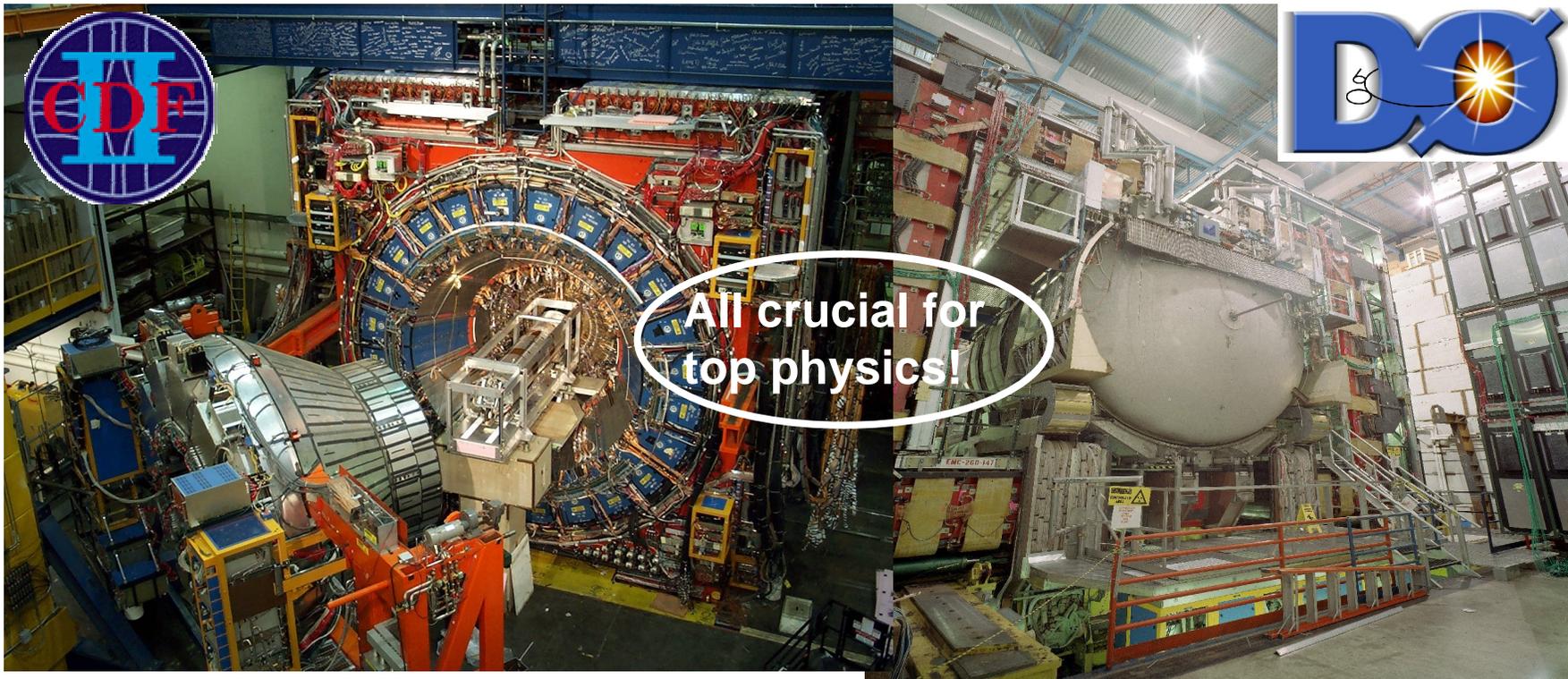
Run 178855
Event 5504617

Number of Jets = 4
Missing E_T = 45 GeV
Muon Pt = 37 GeV



Tagged Jet 1: E_T = 111 GeV, Phi = 79, L2d = 7 mm
Tagged Jet 2: E_T = 38 GeV, Phi = 355, L2d = 1 mm

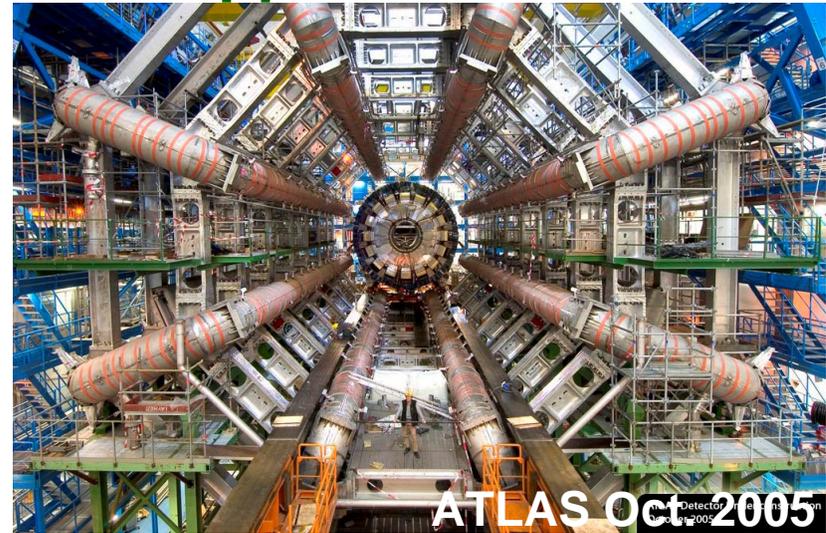
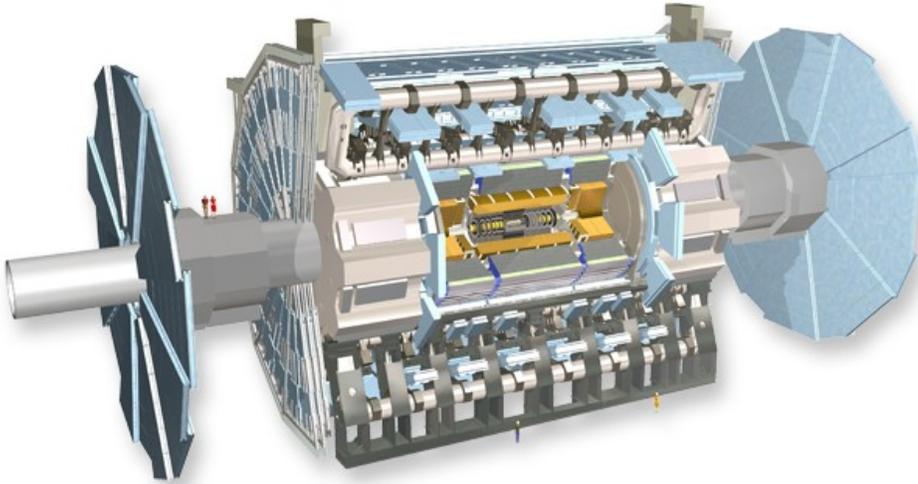
The CDF and DØ Detectors



Detectors @ LHC



ATLAS: A Toroidal LHC ApparatuS

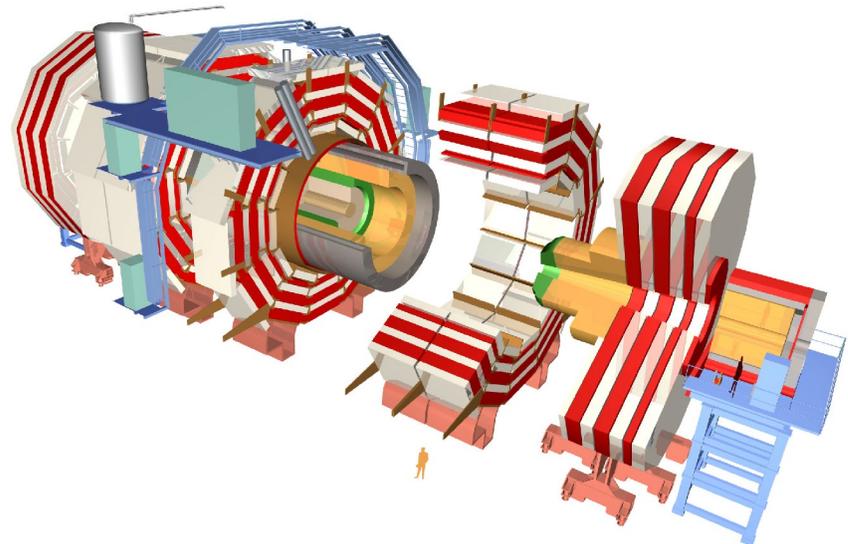


ATLAS Oct 2005

CMS: Compact Muon Solenoid



CMS Feb. 2006



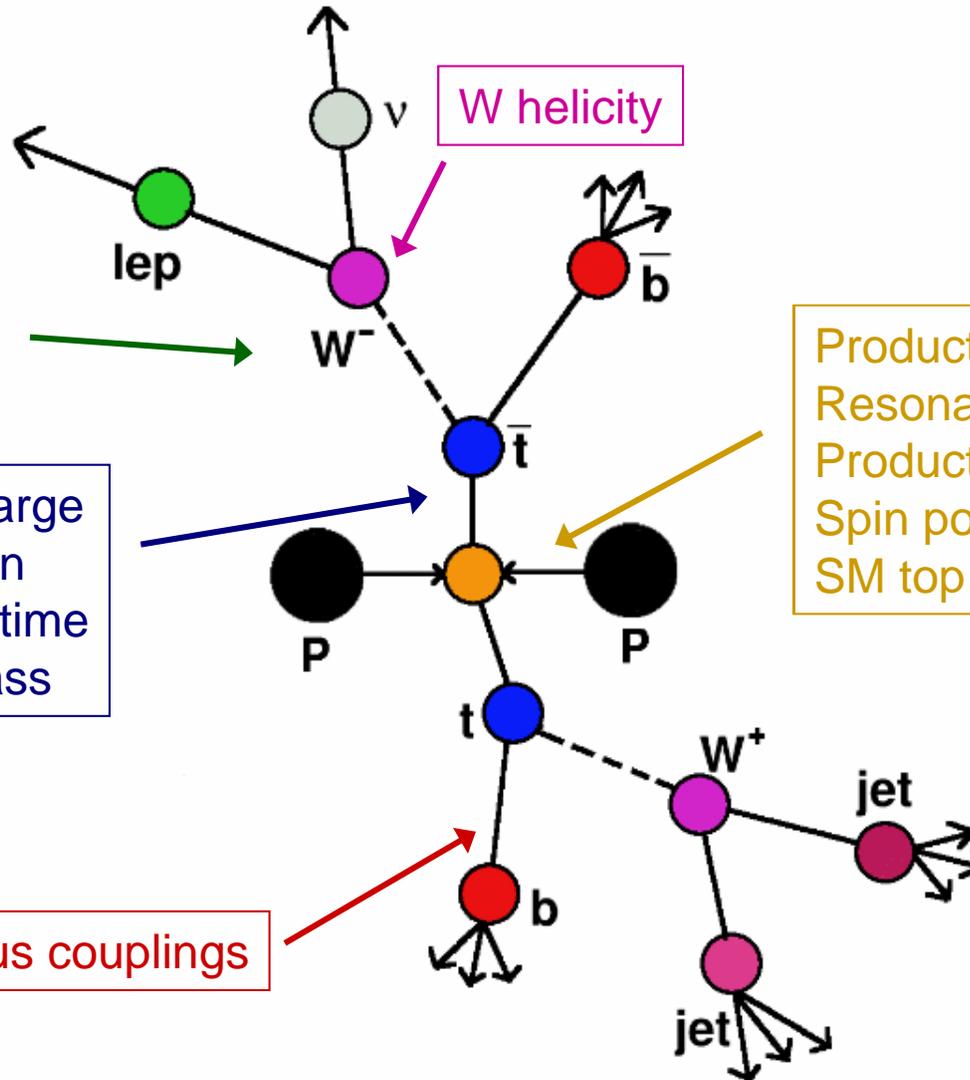
Physics With Top



Branching ratios
Rare decays
Non-SM decays
Decay kinematics
 $|V_{tb}|$

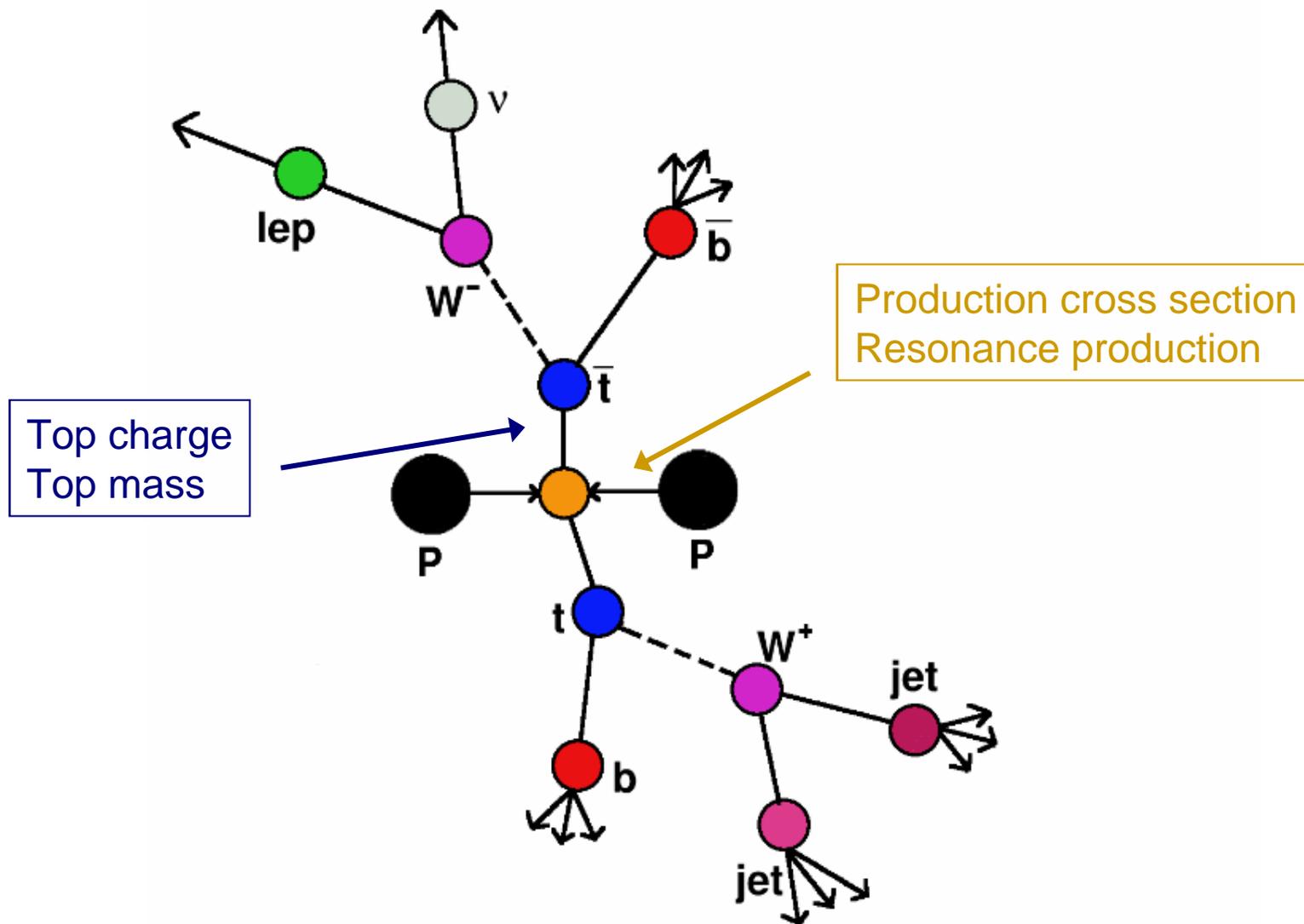
Top charge
Top spin
Top lifetime
Top mass

Anomalous couplings

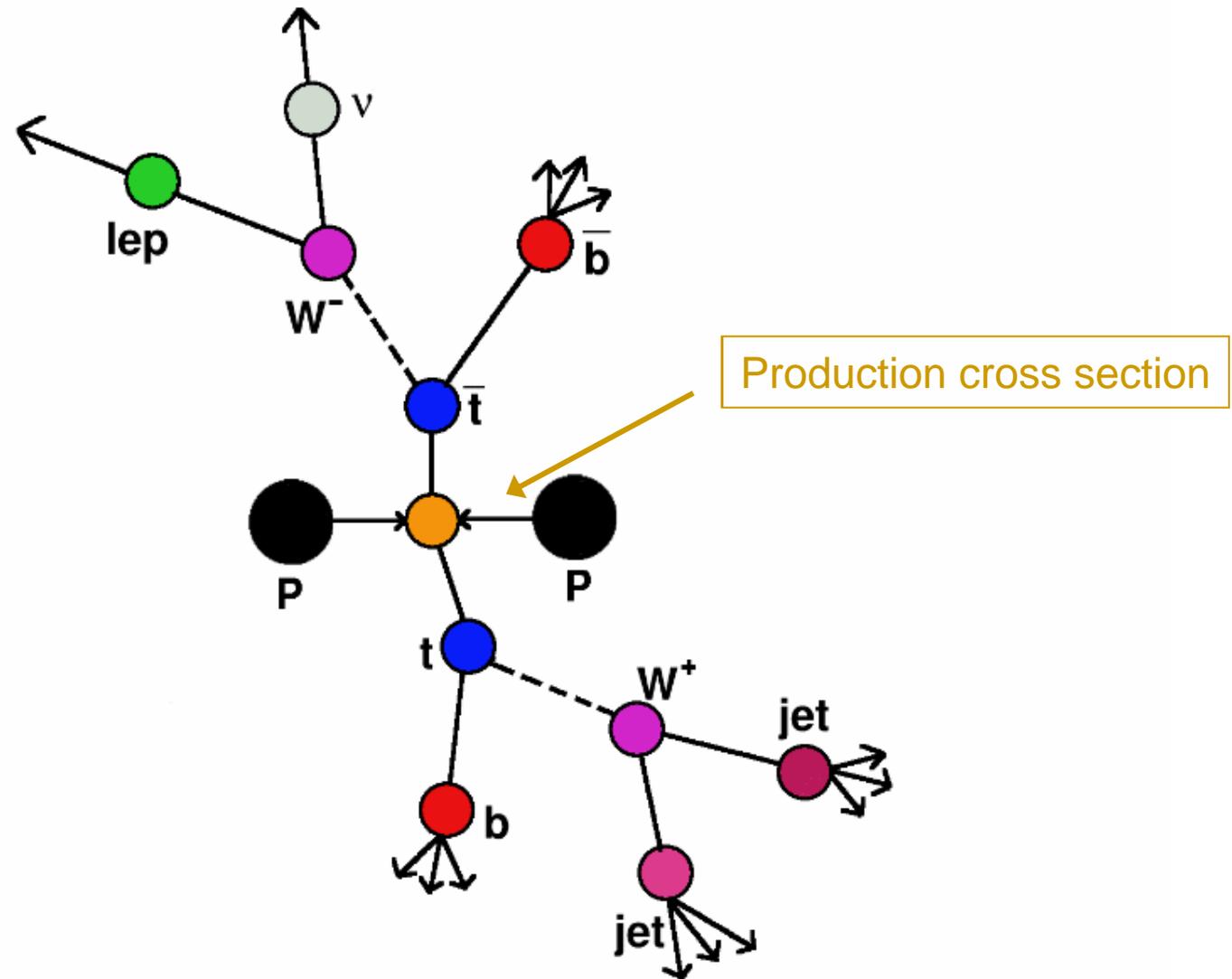


Production cross section
Resonance production
Production kinematics
Spin polarization
SM top production?

Physics With Top In Today's Talk



Top Pair Production Rate

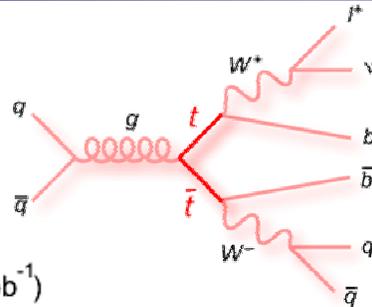


Lepton+Jets Cross Section

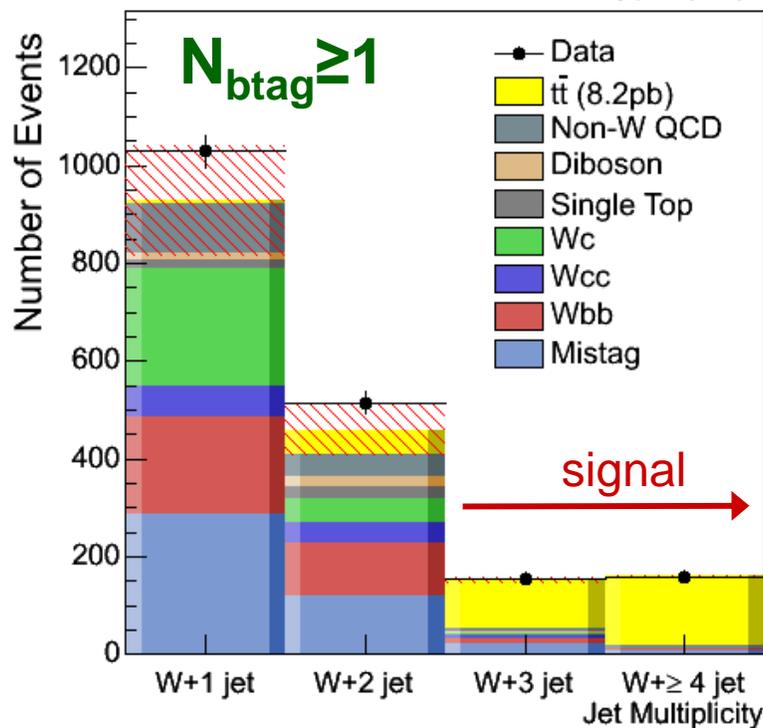


$L=695\text{pb}^{-1}$

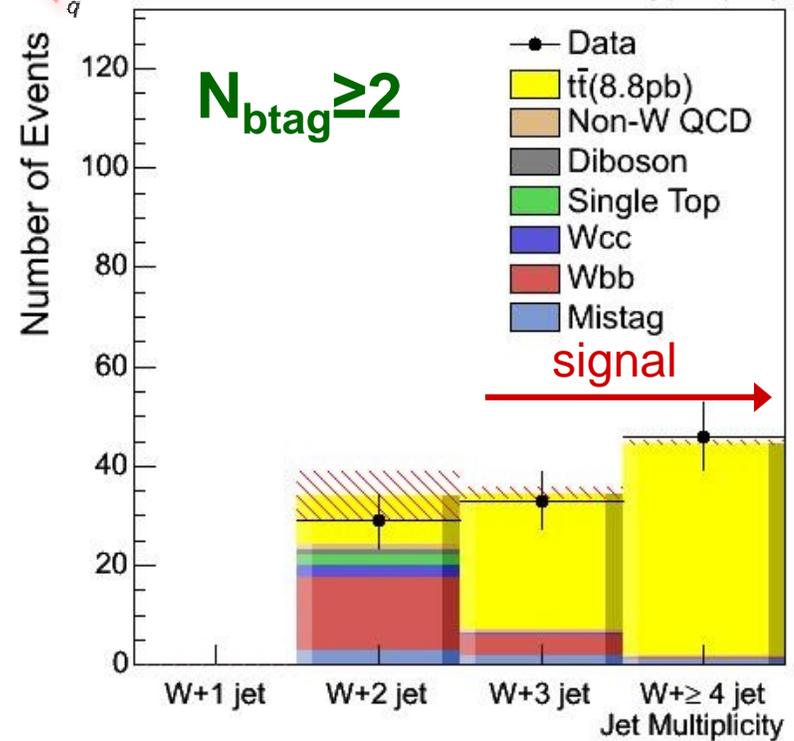
With b-tagging



CDF RUN II Preliminary(695pb⁻¹)



CDF Run II Preliminary(695pb⁻¹)



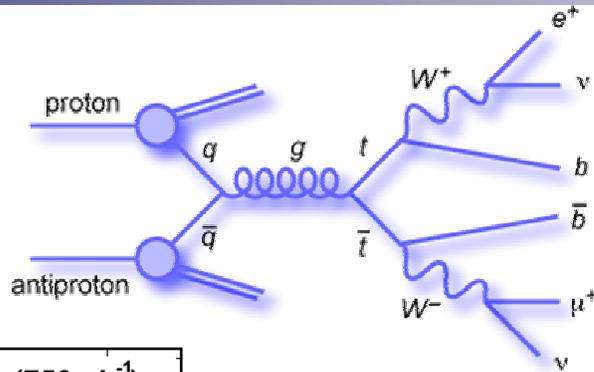
$$\sigma(\bar{t}t) = 8.2 \pm 0.6(\text{stat}) \pm 1.0(\text{syst})\text{pb}$$

$$\sigma(\bar{t}t) = 8.8^{+1.2}_{-1.1}(\text{stat})^{+2.0}_{-1.3}(\text{syst})\text{pb}$$

Dilepton Cross Section

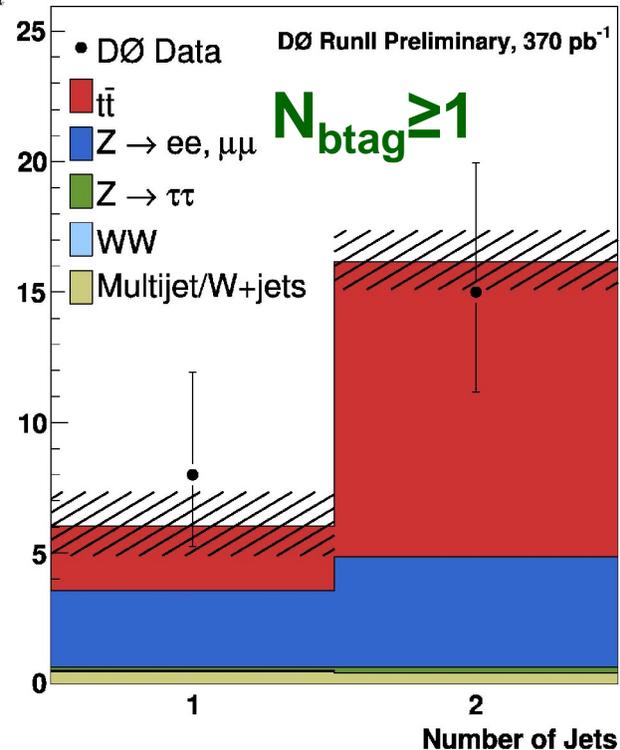
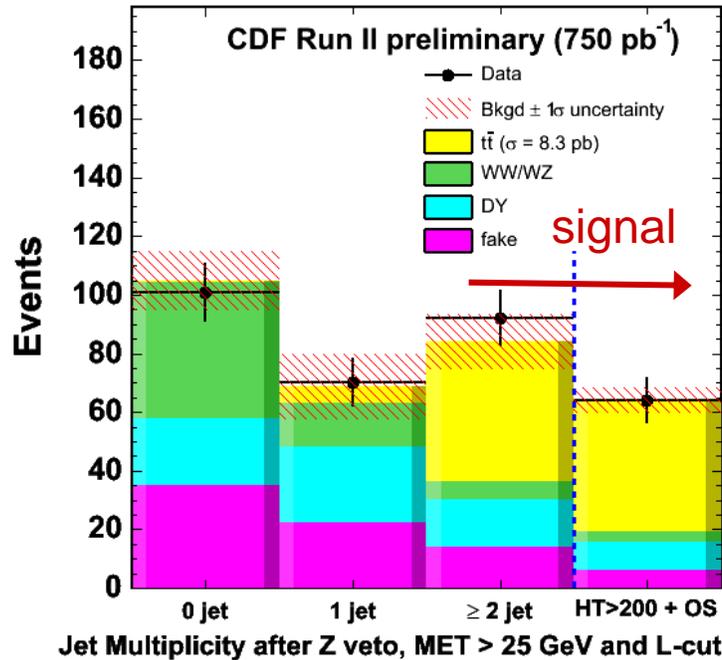


$L=750\text{pb}^{-1}$



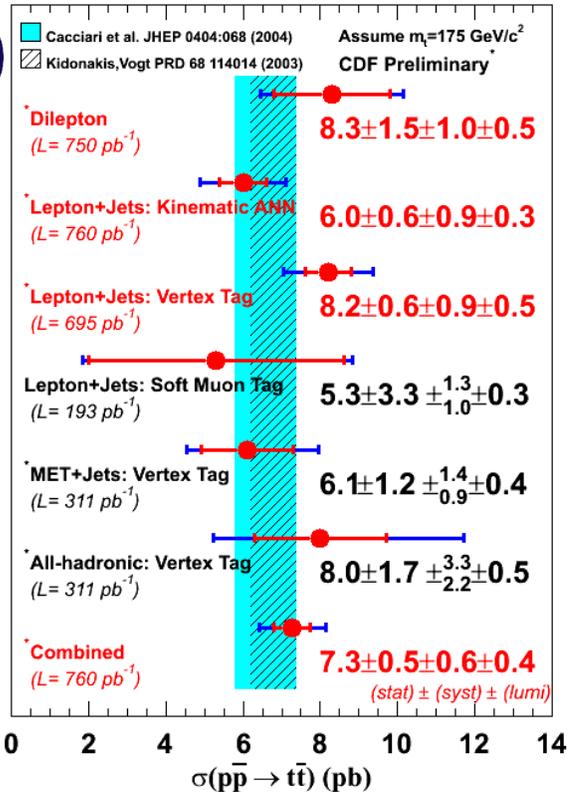
$L=370\text{pb}^{-1}$

With b-tagging!

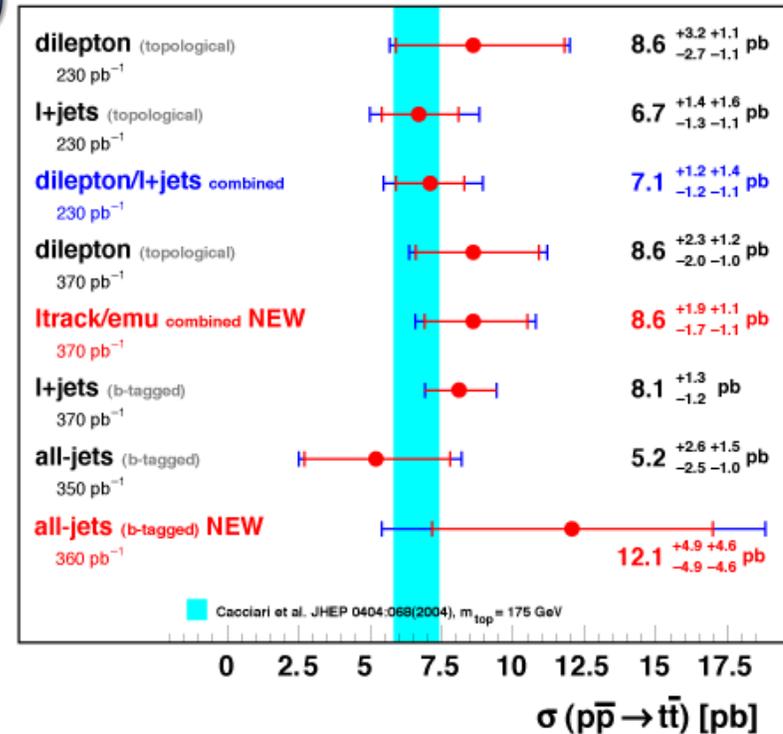


$$\sigma(t\bar{t}) = 8.3 \pm 1.5(\text{stat}) \pm 1.1(\text{syst})\text{pb} \quad \sigma(t\bar{t}) = 8.6_{-1.7}^{+1.9}(\text{stat}) \pm 1.3(\text{syst})\text{pb}$$

Summary Of Top Cross Sections



DØ Run II Preliminary



Measurements in *all channels* using different methods are found to be consistent.
 Ongoing effort to have a Tevatron combined average.

Most precise single measurement ~14%

Goals:

Tevatron: 10% uncertainty/experiment with 2fb^{-1} .

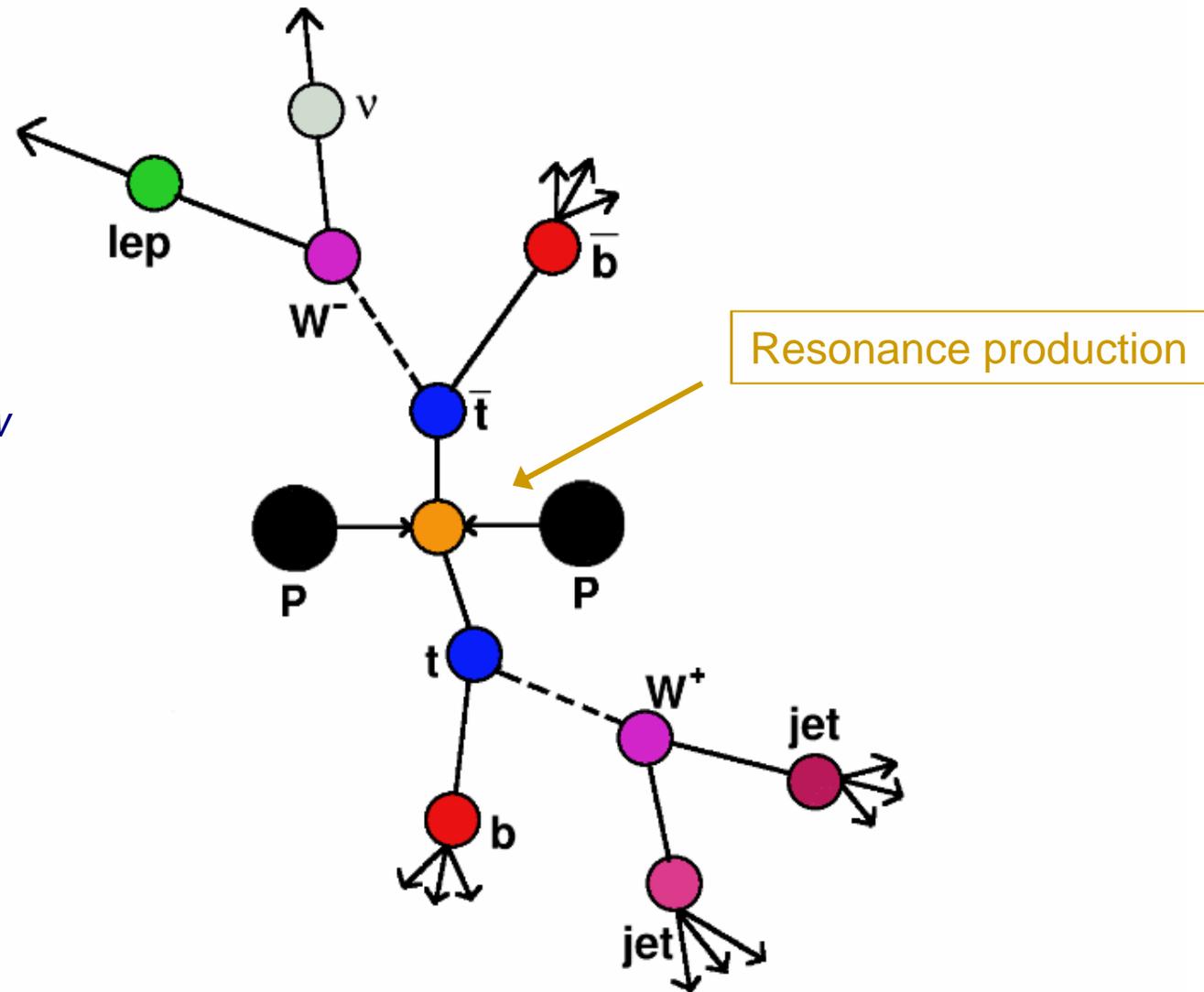
LHC: <10% with 10fb^{-1} and ultimately <5%.

Testing Top Pair Production



Does something *new*
produce top pairs?

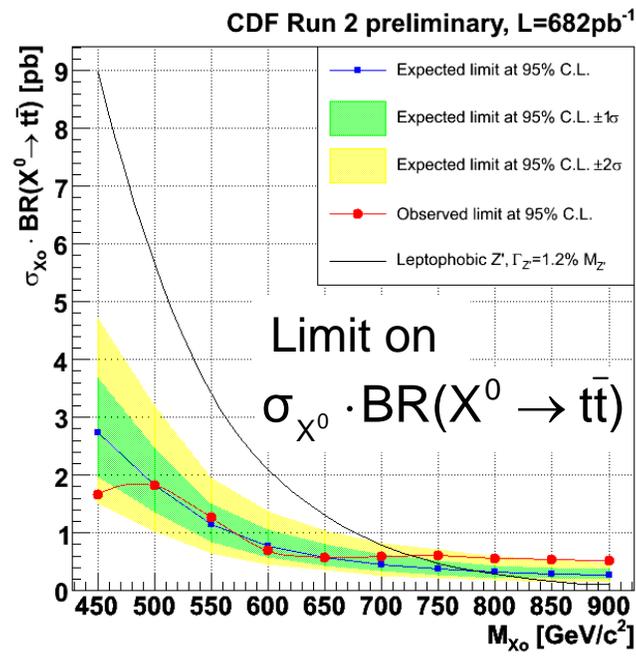
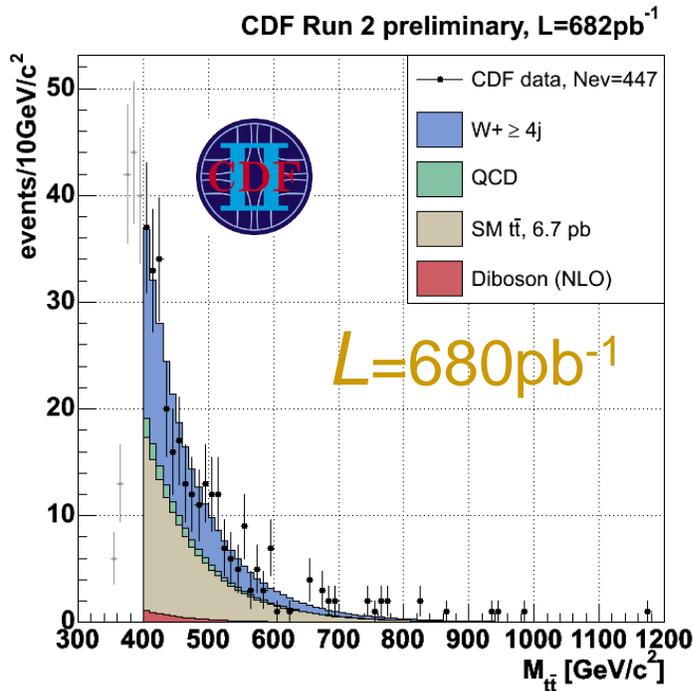
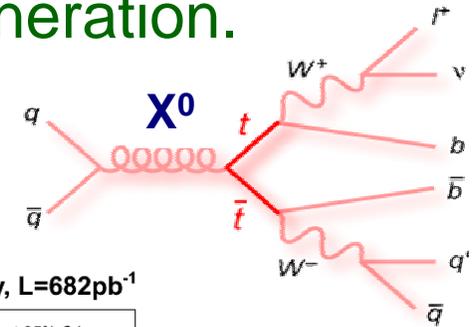
$X^0 \rightarrow t \bar{t}$?



Resonance Production



Search for new particles coupled to the 3rd generation.
 (e.g. Harris, Hill, Parke hep-ph/9911288)

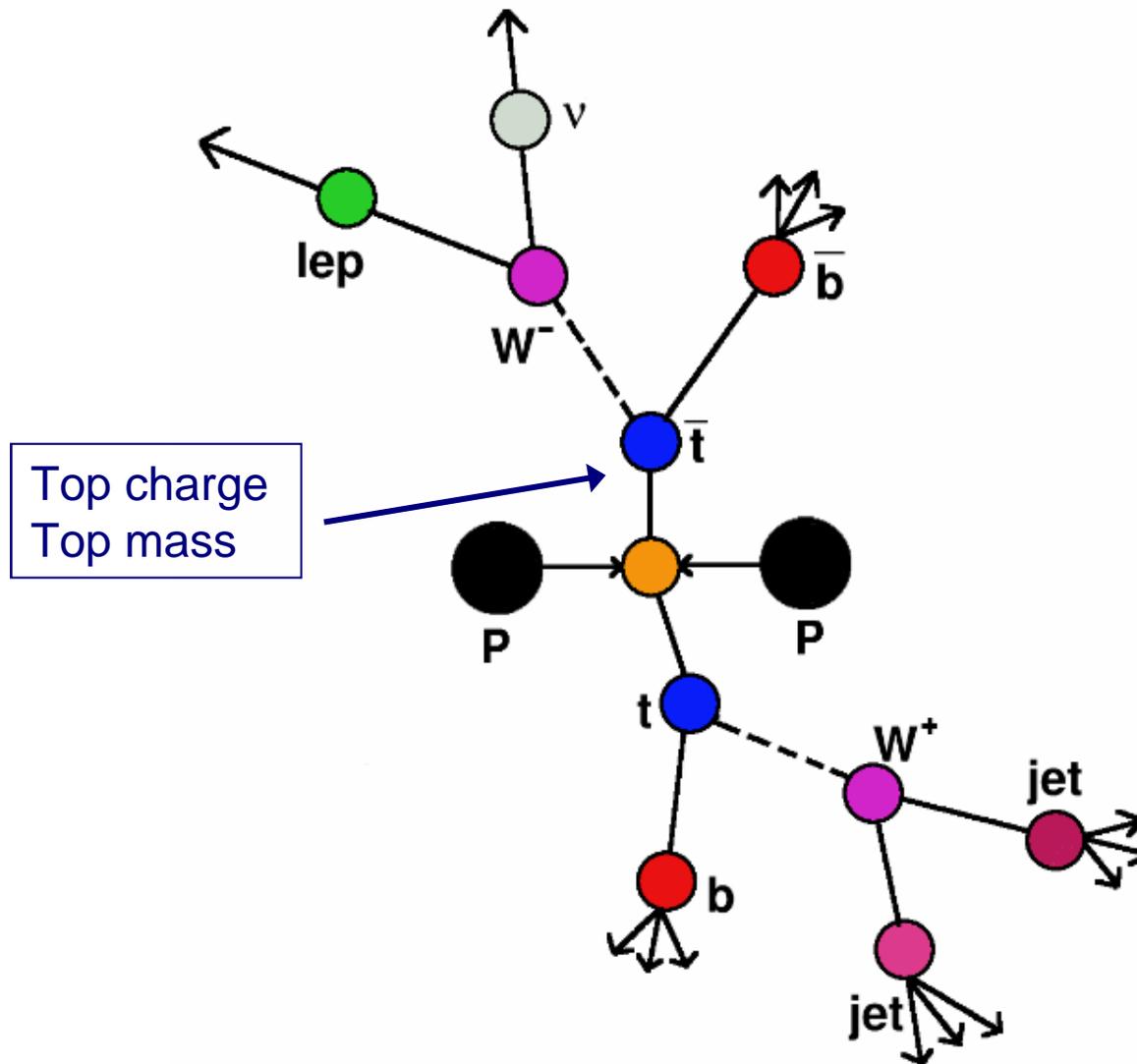


Exclude
 $M_{X^0} < 725 \text{ GeV}/c^2$
 @95%CL
 For model
 $\Gamma_X = 1.2\% M_X$

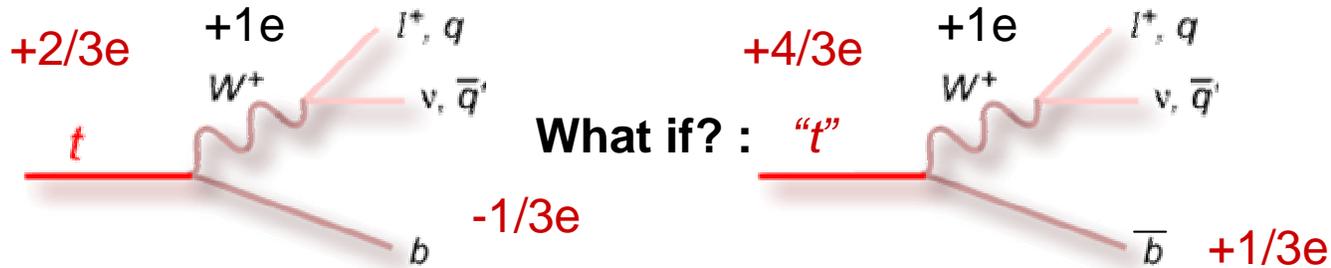
And at LHC?

With 30fb⁻¹ a 1TeV resonance could be discovered (5 σ)
 provided its $\sigma \cdot \text{BR}(X^0 \rightarrow t\bar{t})$ is at least 830 fb. (ATLAS TDR)

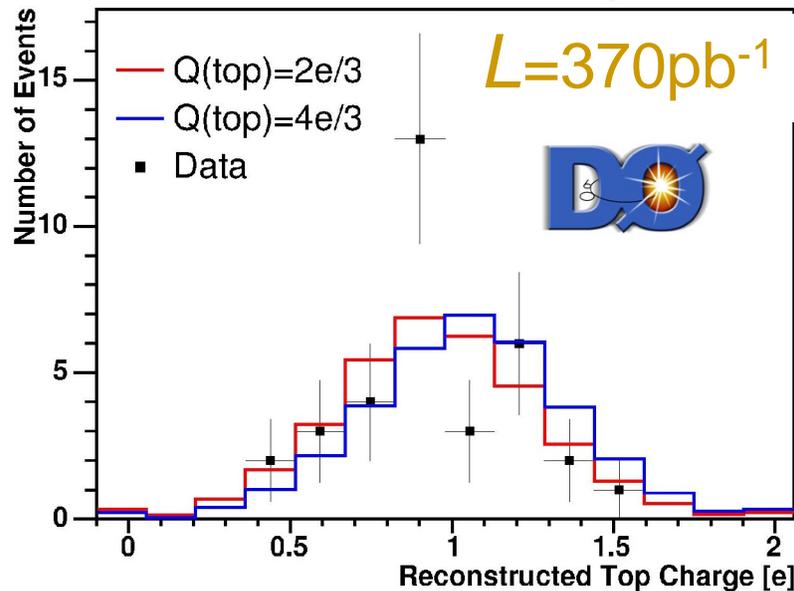
Testing Top Properties



Top Quark Charge



DØ Run II Preliminary



2 observables/event:

$$Q_1 = |q_l + q_{b,\text{lep}}|$$

$$Q_2 = |-q_l + q_{b,\text{had}}|$$

Discriminating
b from b-bar
is the key!

Exotic quark with charge $4/3e$
excluded @ 94% C. L.

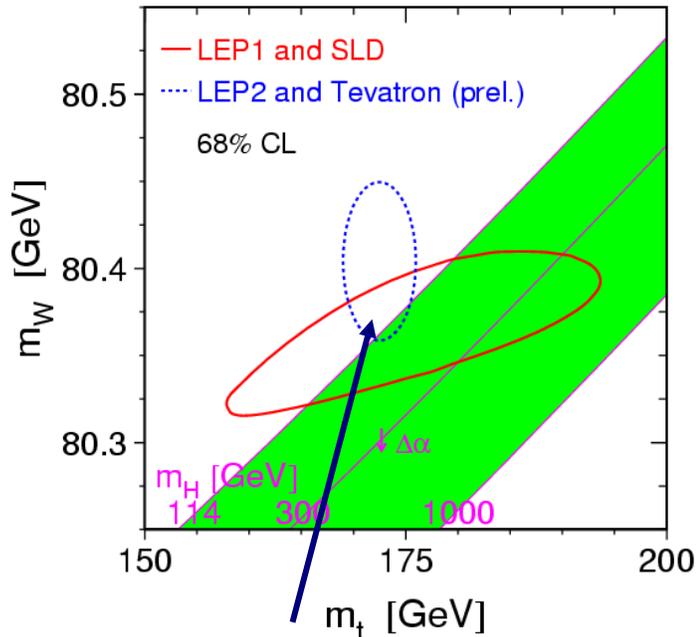
And at LHC?? (3rd speaker in this session is expert! hep-ph/0106341)

Directly measure top quark electromagnetic coupling through γ radiation:

$$pp \rightarrow t\bar{t}\gamma \quad pp \rightarrow t\bar{t}, t \rightarrow Wb\gamma$$

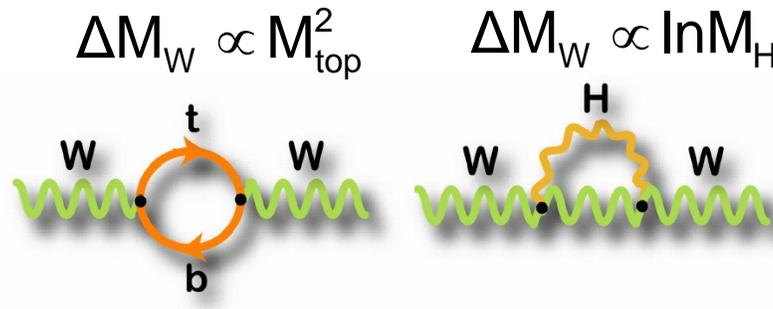
With 10fb^{-1} should be possible to measure Q_{top} with an accuracy of $\sim 10\%$.

Why Measure M_{top} ?



Higgs is “*giver*” of mass.

Its mass is tied to M_{top} and M_W .



New Tevatron WA result!

$$M_{\text{top}} = 172.5 \pm 2.3 \text{ GeV}/c^2$$

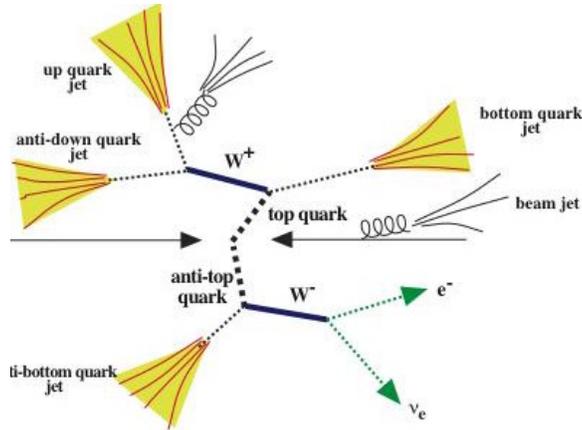
Recall Run I WA:

$$M_{\text{top}} = 178.0^{+4.3}_{-4.3} \text{ GeV}/c^2$$

Run II goal: $< 3 \text{ GeV}$ with 2 fb^{-1}
 \rightarrow Exceeded!

LHC goal: $< 1 \text{ GeV}$ with 10 fb^{-1}
 \rightarrow Will Tevatron get there first?

Measuring M_{top} is Challenging!



Combinatorics:

Experimental observations are not as *pretty* as Feynman diagrams!

Which jets go with which quarks?

Jet Energy Scale:

JES is dominant systematic for M_{top} !

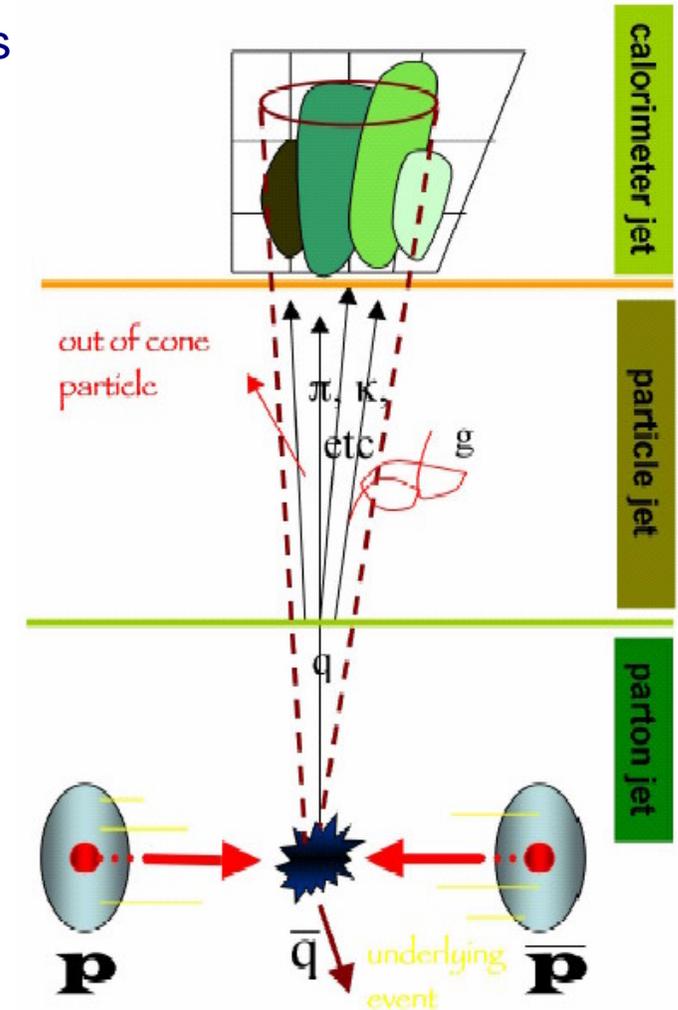
Handles:

In-situ JES calibration: use $W \rightarrow jj$ mass to measure JES uncertainty. Scales directly with statistics!

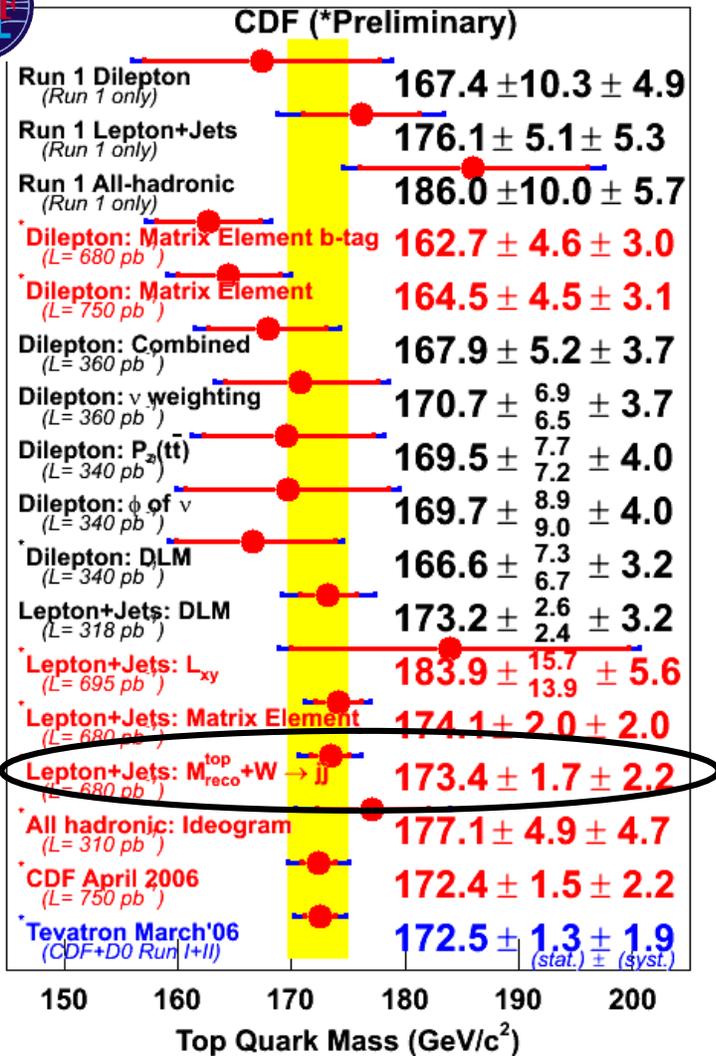
b-tagging: reduces combinatorial and physics bkg.

High statistics: top @ LHC.

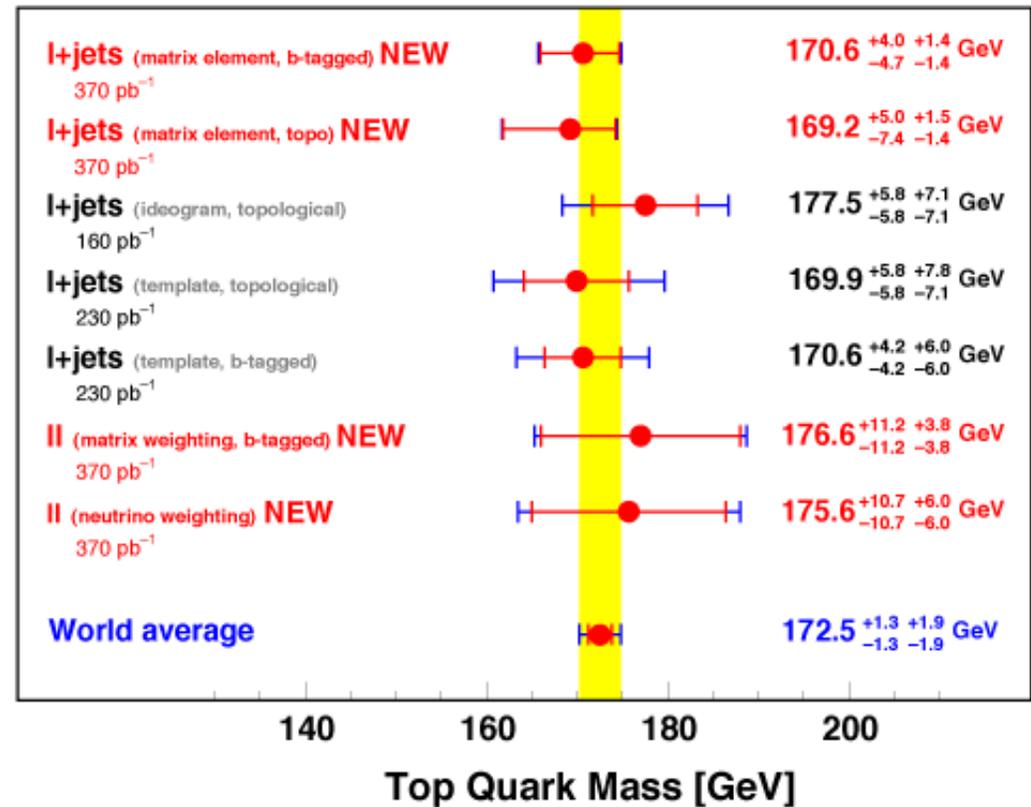
Determine true “parton” energy from measured jet energy in a cone



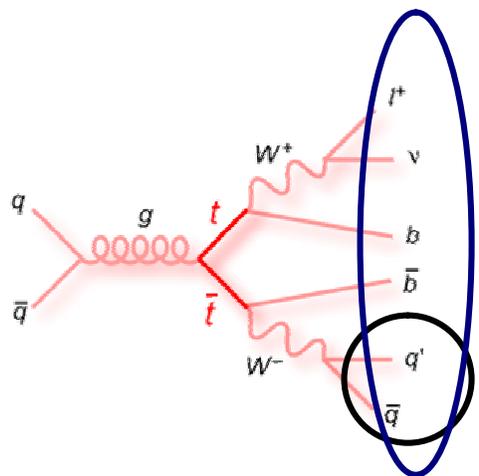
M_{top} Measurements At The Tevatron



D0 Run II Preliminary



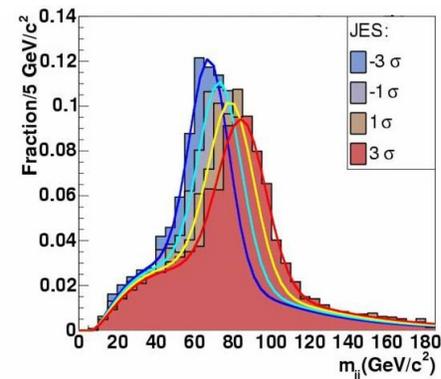
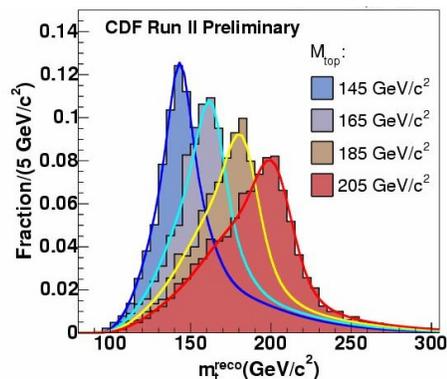
M_{top} with ℓ +jets Template Method



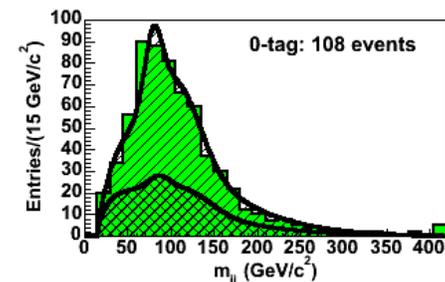
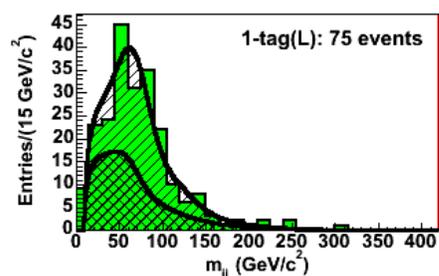
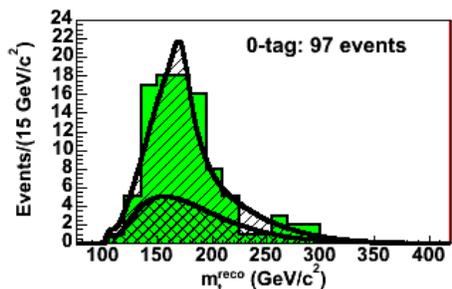
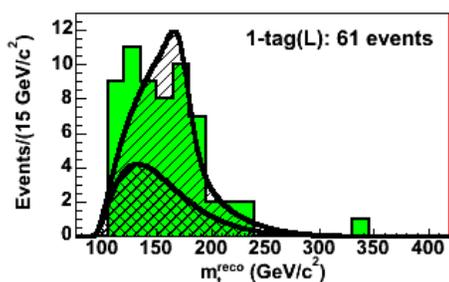
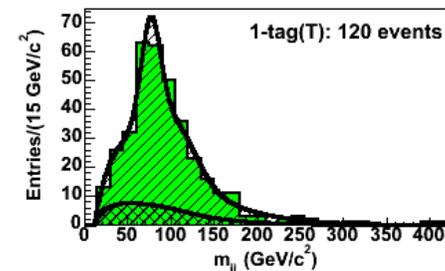
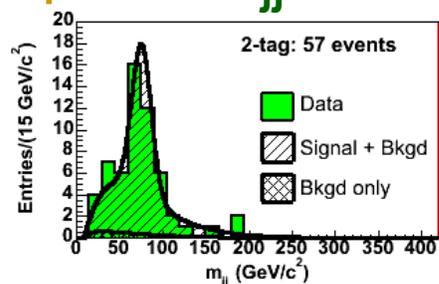
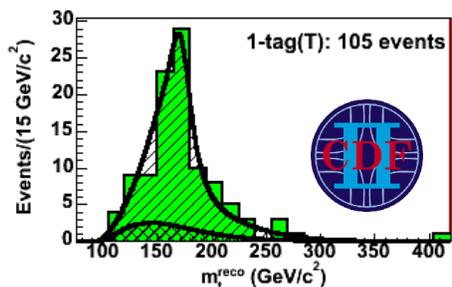
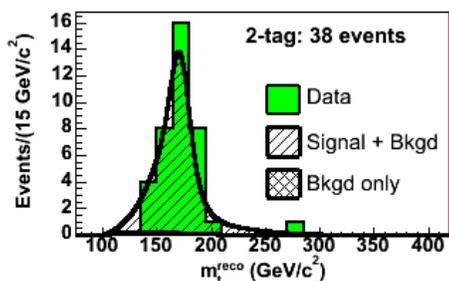
Kinematic fit
to get $M_{\text{top}}^{\text{reco}}$

M_{jj}

Use signal and background templates for varying M_{top} and JES.



$M_{\text{top}}^{\text{reco}}$ with fit overlaid $L=680\text{pb}^{-1}$ M_{jj} with fit overlaid

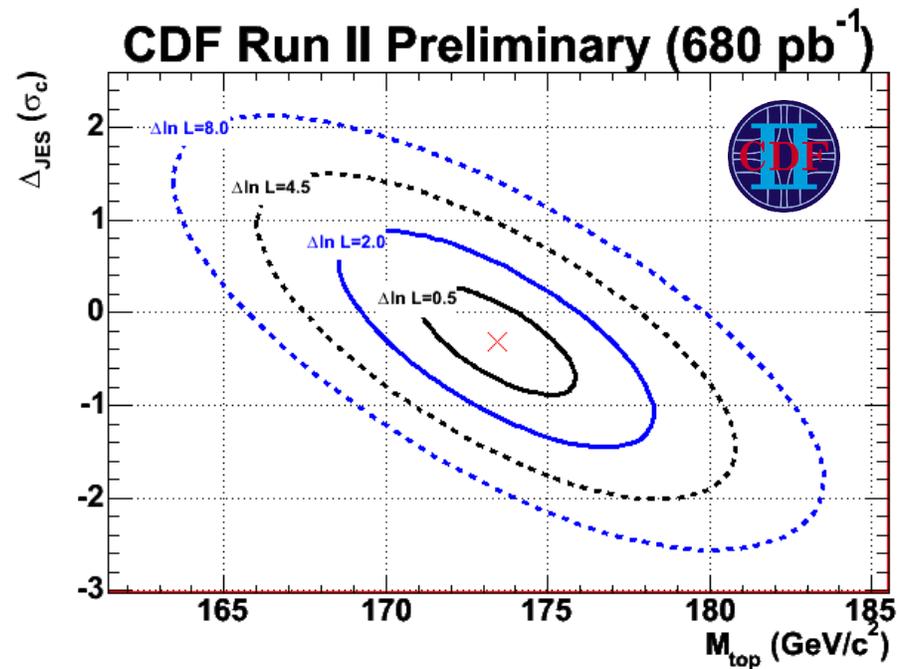


M_{top} with ℓ +jets Template Method

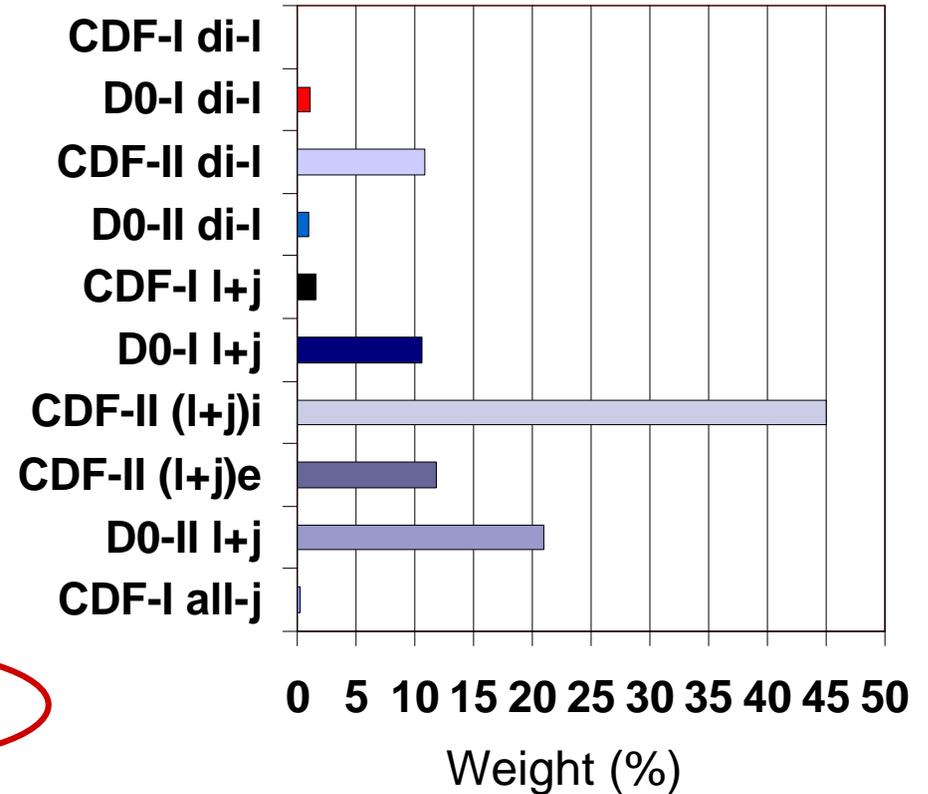
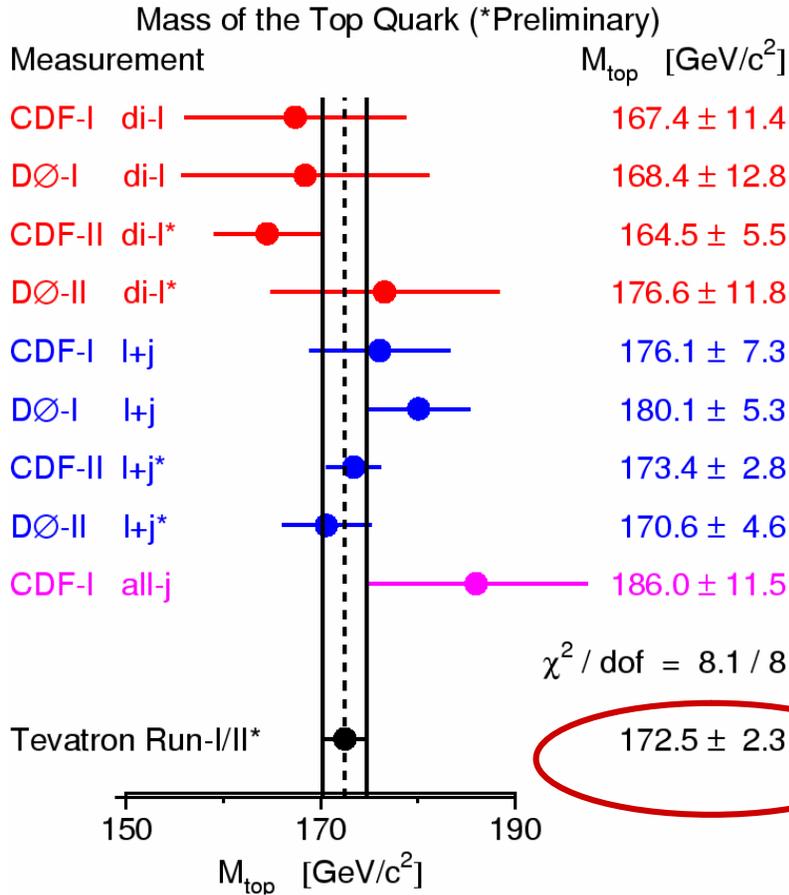


$M_{\text{top}} = 173.4 \pm 2.5(\text{stat.} + \text{JES}) \pm 1.3(\text{syst.}) \text{ GeV}/c^2$
Best single top mass measurement in the world!

Using in-situ JES calibration results
in 40% improvement on JES!



M_{top} Tevatron Average



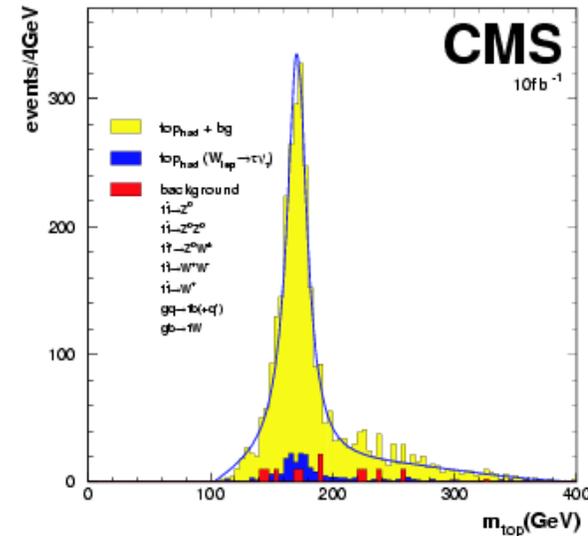
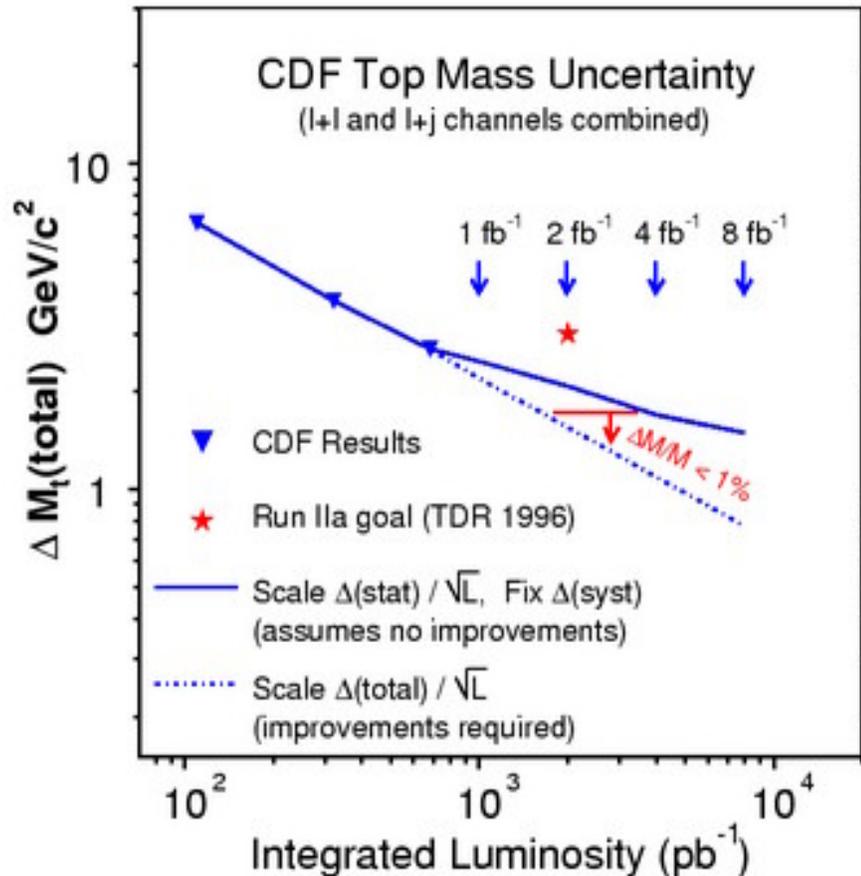
We combine published Run-I (1992- 1996) measurements with the most recent preliminary Run-II (2001- present) measurements using up to 750pb⁻¹ of data.

The Future of M_{top}



... @ the Tevatron

... @ the LHC



$L \sim 10 \text{ fb}^{-1}$ we expect per exp.:

stat $\sim 0.1\text{-}0.2 \text{ GeV}$

syst $\sim 1 \text{ GeV}$

M_{top} measured $< 1 \text{ GeV}$ should be achievable at CMS/ATLAS.

(hep-ex/0403021
hep-ph/0003033,
ALTAS TDR,
CMS 2001/001)

THE DATA MAKES US SMARTER!

Top: The New Standard Candle @LHC?

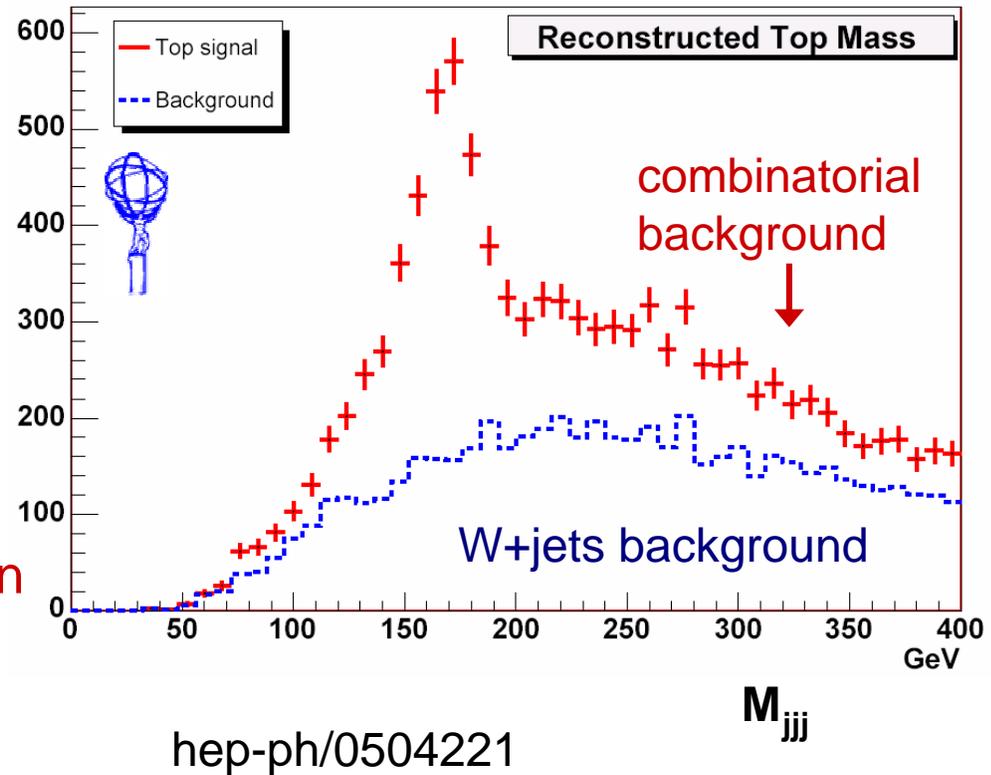
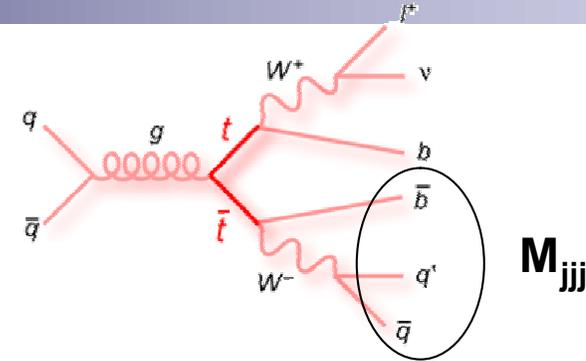


LHC study:
 ℓ +jets channel

Corresponds to $L \sim 150 \text{ pb}^{-1}$

<1 week of data taking
 at $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$!!

Early validation of detector
 performance, e.g.:
 Jet Energy Calibration
 B-tagging



MANY Topics I Didn't Have Time For



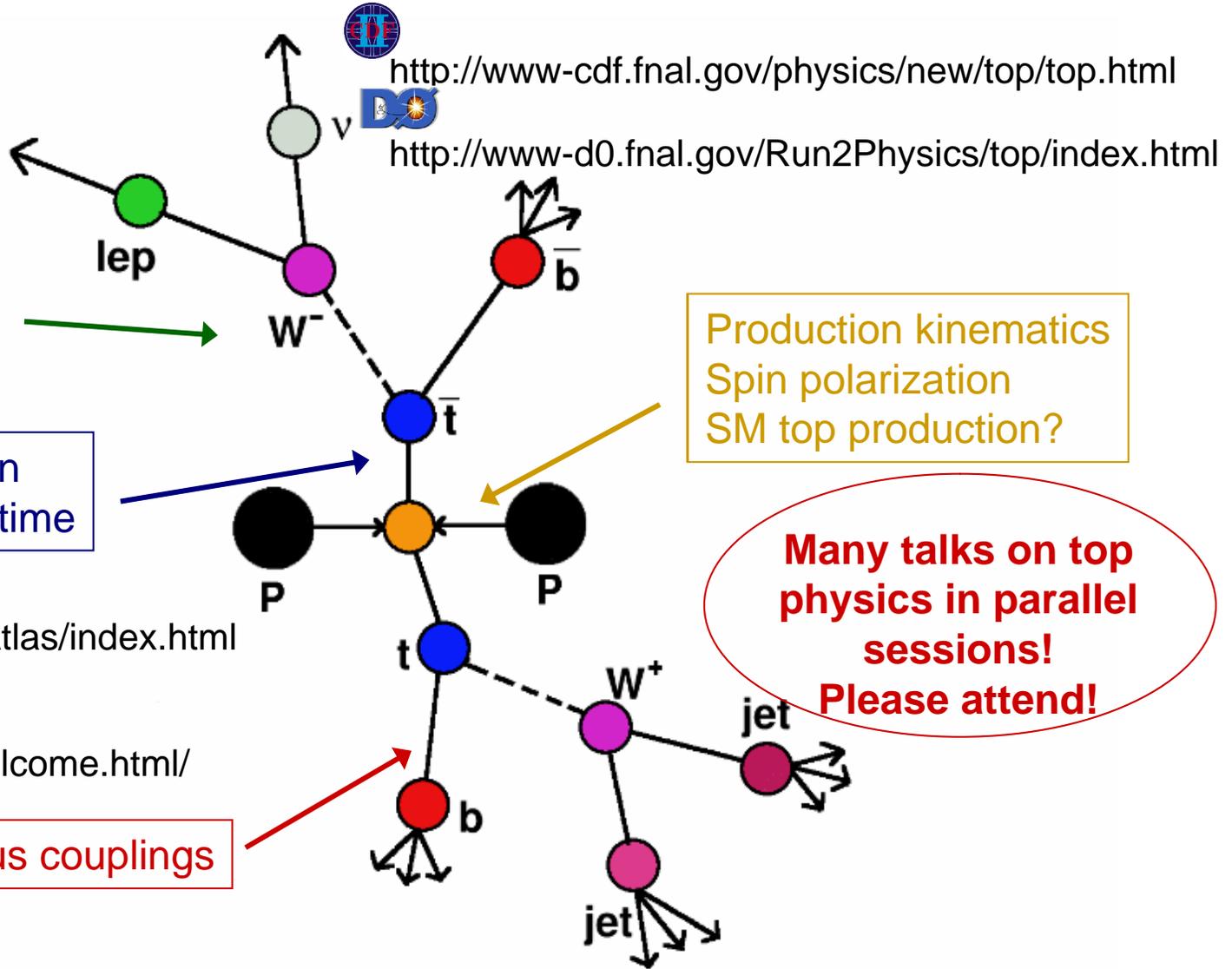
Branching ratios
Rare decays
Non-SM decays
Decay kinematics
 $|V_{tb}|$
W helicity

Top spin
Top lifetime

Production kinematics
Spin polarization
SM top production?

**Many talks on top physics in parallel sessions!
Please attend!**

Anomalous couplings



<http://www-cdf.fnal.gov/physics/new/top/top.html>
 <http://www-d0.fnal.gov/Run2Physics/top/index.html>

<http://atlas.web.cern.ch/Atlas/index.html>

<http://cmsinfo.cern.ch/Welcome.html/>

Summary



We've come a long way since the top quark discovery!
Entered precision era!

We are unraveling the true nature of the top quark and its role in EWSB.
Consistent with standard model, so far.

Best M_{top} measurement in the world @ Tevatron.
Surpassed our Run II goal.
Should reach 1% precision with full Run-II data set.

Understanding top at the Tevatron will also allow us to immediately distinguish new physics at the LHC.

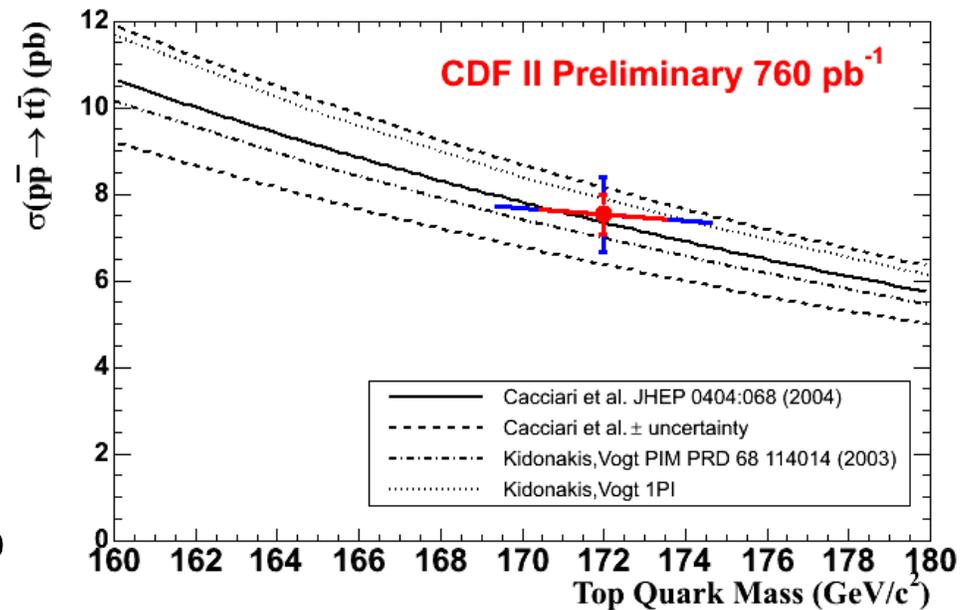
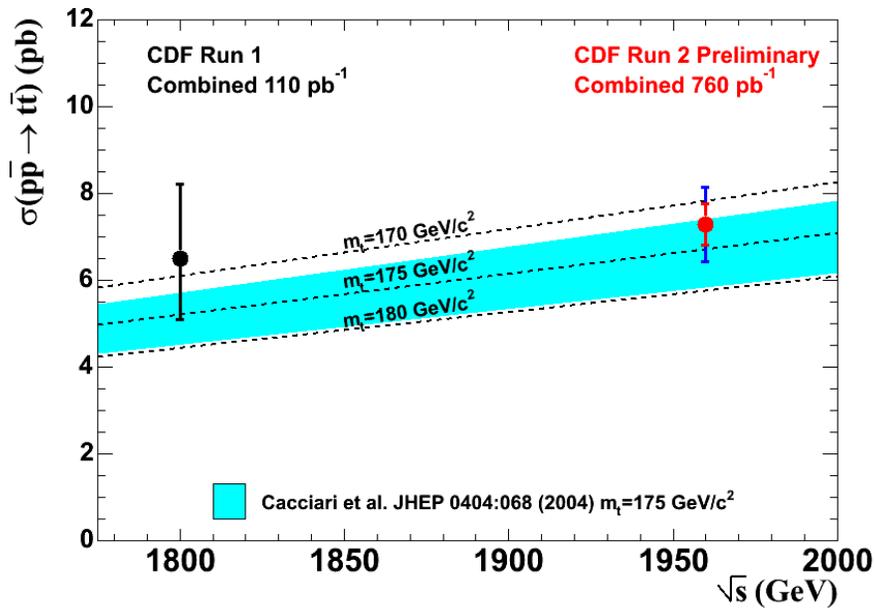
The top sector is a thriving field with an exciting future both at the Tevatron and at the LHC.

THE DATA MAKES US SMARTER!

Backup



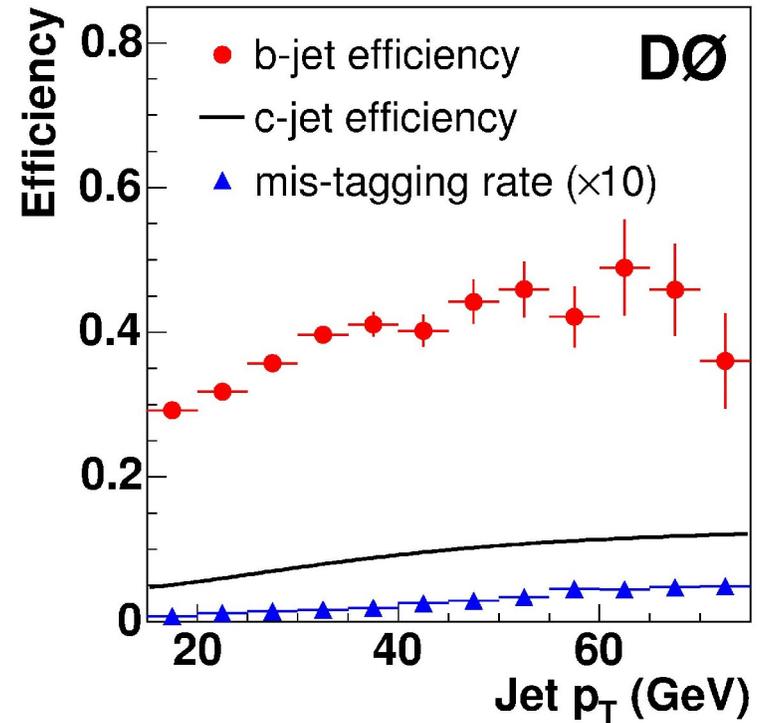
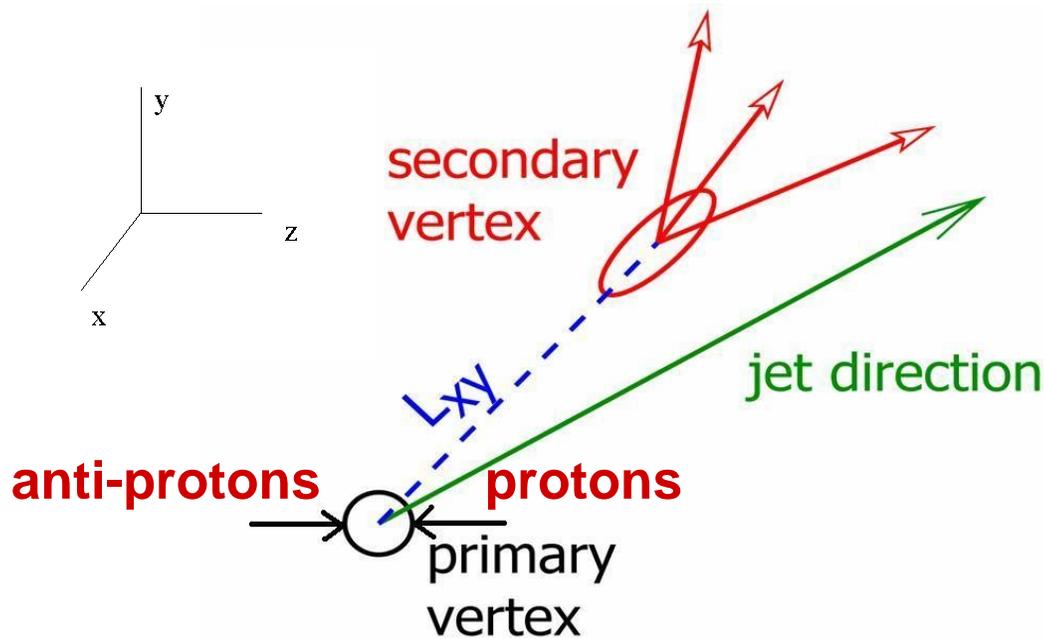
\sqrt{s} & M_{top} Dependence of $\sigma(\text{ttbar})$



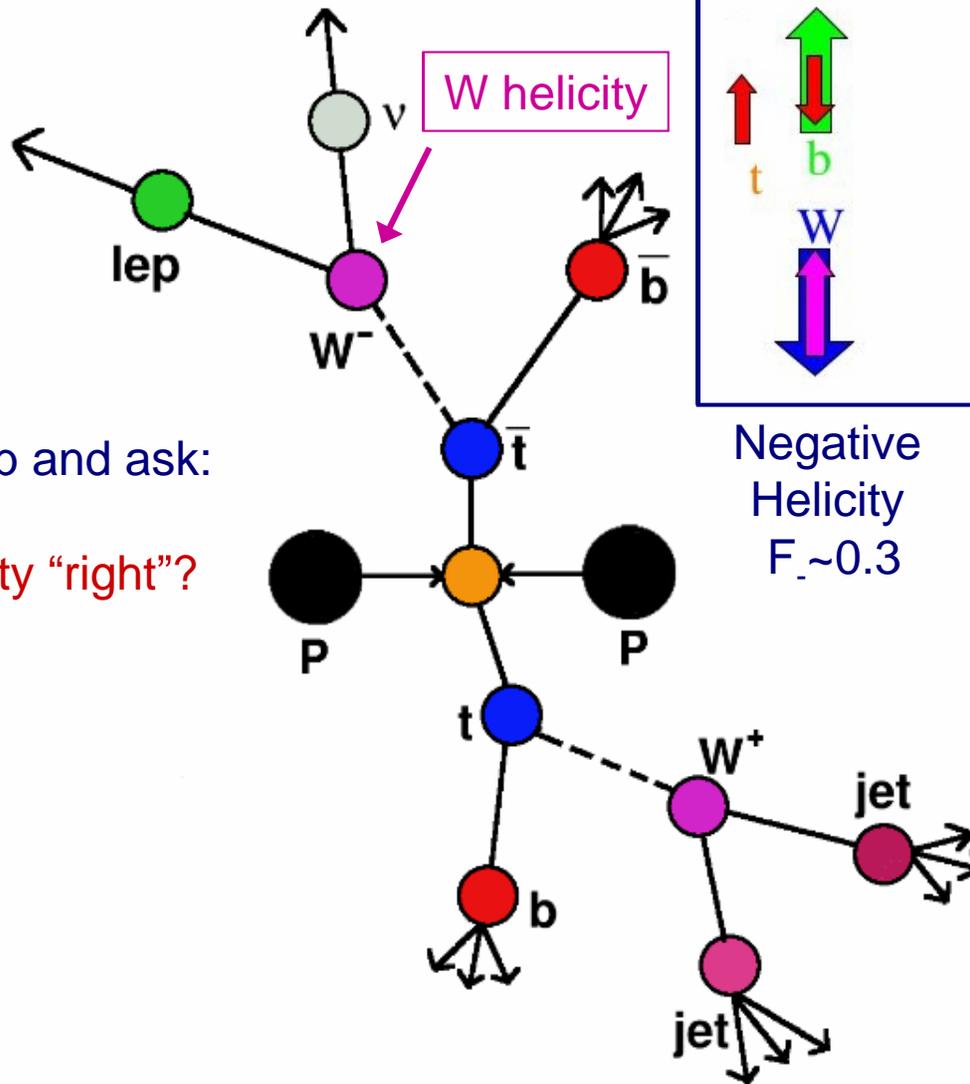
Tagging the b Quark



**B hadrons are long-lived and massive.
Signature of a b decay: displaced vertex.**

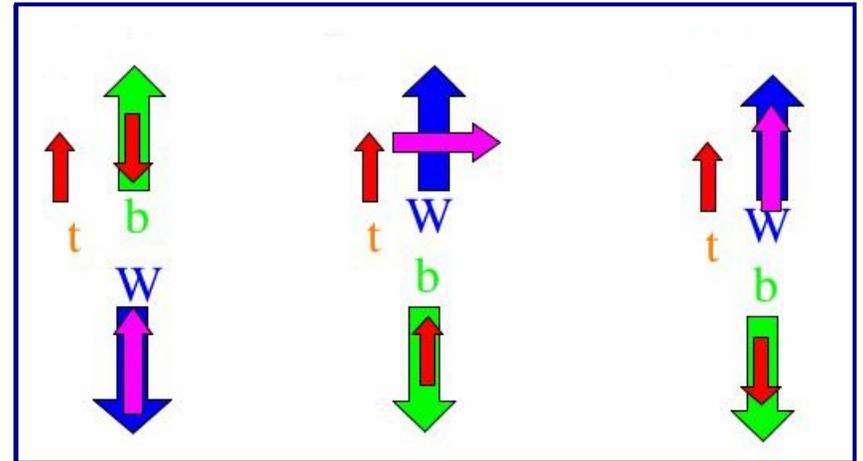


Testing Top Decay



Assume $t \rightarrow Wb$ and ask:

Is the W helicity "right"?

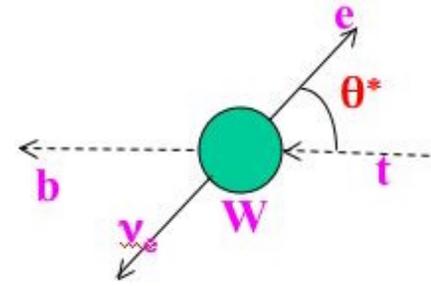
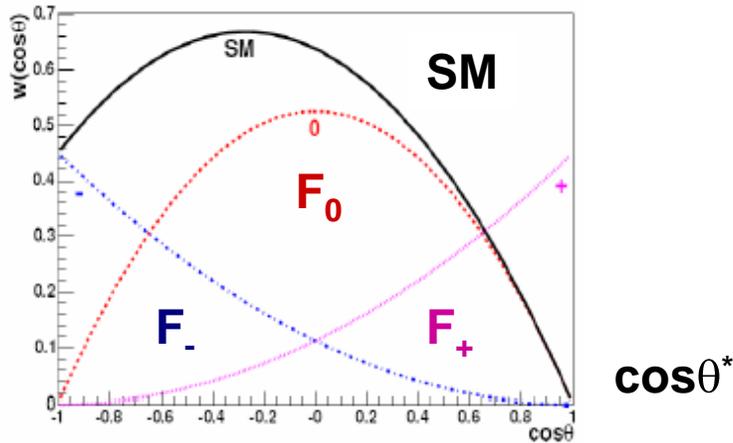


Negative Helicity
 $F_- \sim 0.3$

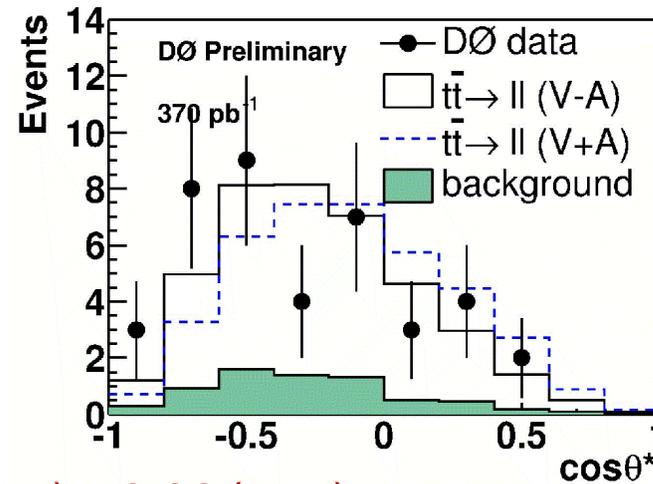
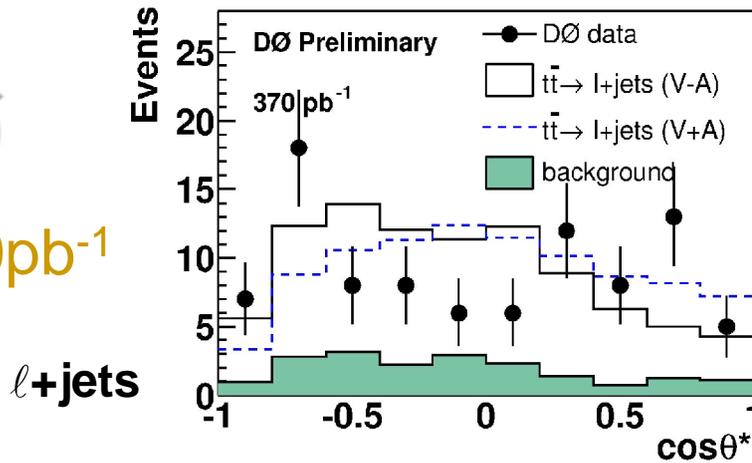
Longitudinal Helicity
 $F_0 \sim 0.7$

Positive Helicity
 $F_+ \sim 0$
V-A Suppressed

W Helicity in Top Decay



$L=370\text{pb}^{-1}$



$$F_+ = 0.08 \pm 0.08 \text{ (stat)} \pm 0.06 \text{ (syst)}$$

$$F_+ < 0.24 \text{ @ 95\%C.L.}$$

And at LHC??

hep-ex/0508061

Expect with 10fb^{-1} , l +jets and dileptons combined, $F_+ : \pm 0.003(\text{stat}) \pm 0.012(\text{syst})$.

Current M_{top} Avg. Impact on M_H Limit

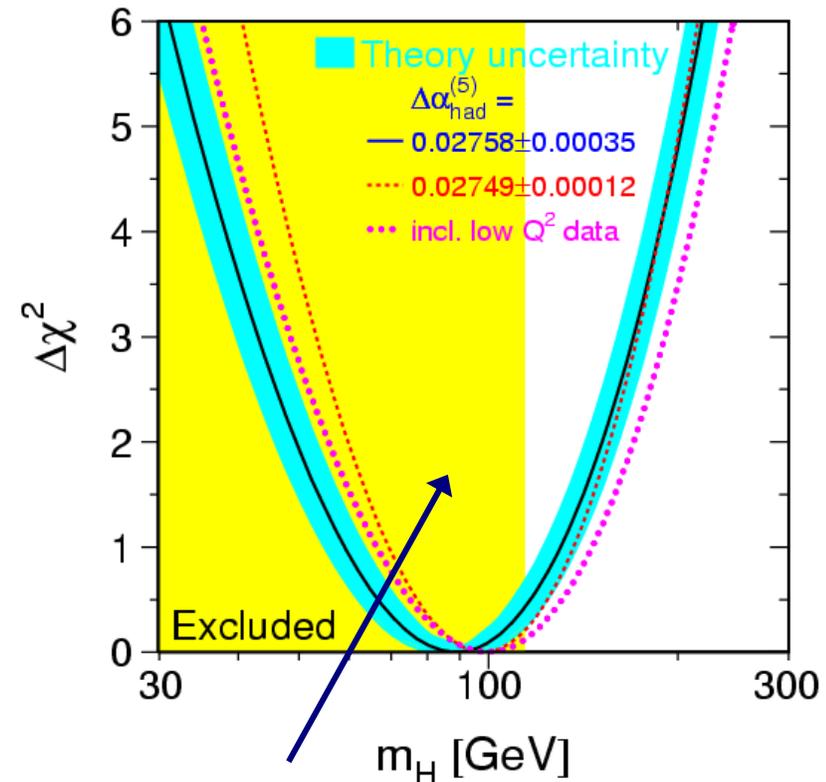


(Martin Grünewald, LEPEWWG, TEVEWWG)

EWK fit value
 $M_H = 89^{+42}_{-30} \text{ GeV}/c^2$

Fit limit including theory uncertainty:
 $M_H < 175 \text{ GeV}/c^2 @ 95\% \text{C.L.}$

If LEP direct search limit is included:
 $M_H < 207 \text{ GeV}/c^2 @ 95\% \text{C.L.}$



LEP direct search limit
 $M_H > 114 \text{ GeV}/c^2$
@ 95% C.L.

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