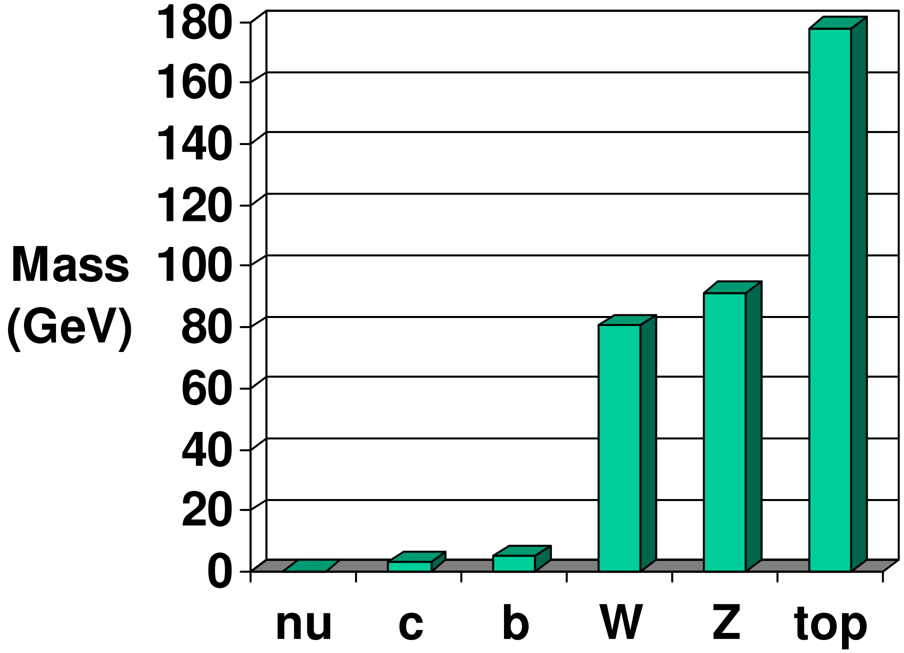
Top and Electroweak Physics

TeV4LHC

experiment & phenomenology & theory

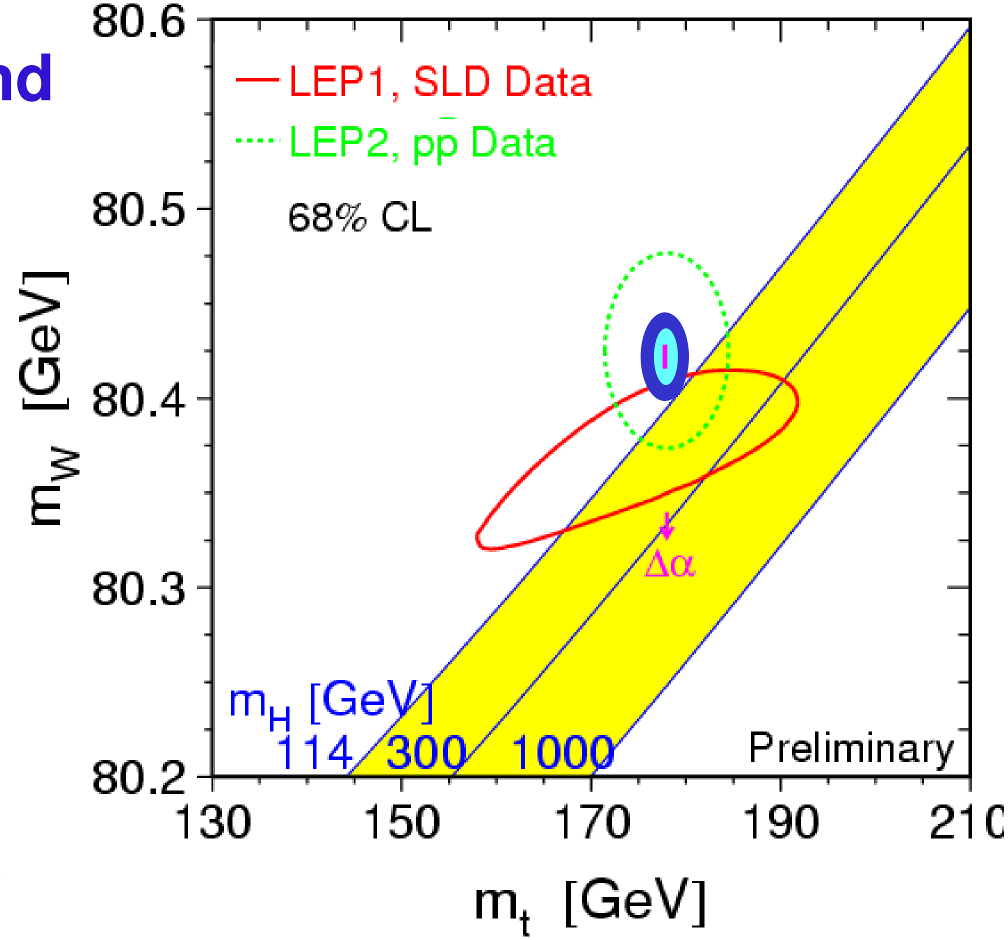


Evelyn J. Thomson
University of Pennsylvania
September 17 2004

Motivation

- **Fundamental parameters of Standard Model**
- **Sensitive to Higgs mass and new physics through radiative corrections**
  - **Precision measurements**
  - **Theory challenges**
- **Standard Candles for detector calibration**
  - **Lepton identification**
  - **Energy/Momentum scale**
  - **Luminosity**
- **Backgrounds to many new physics signals**

TeVatron Run II, LHC, ILC

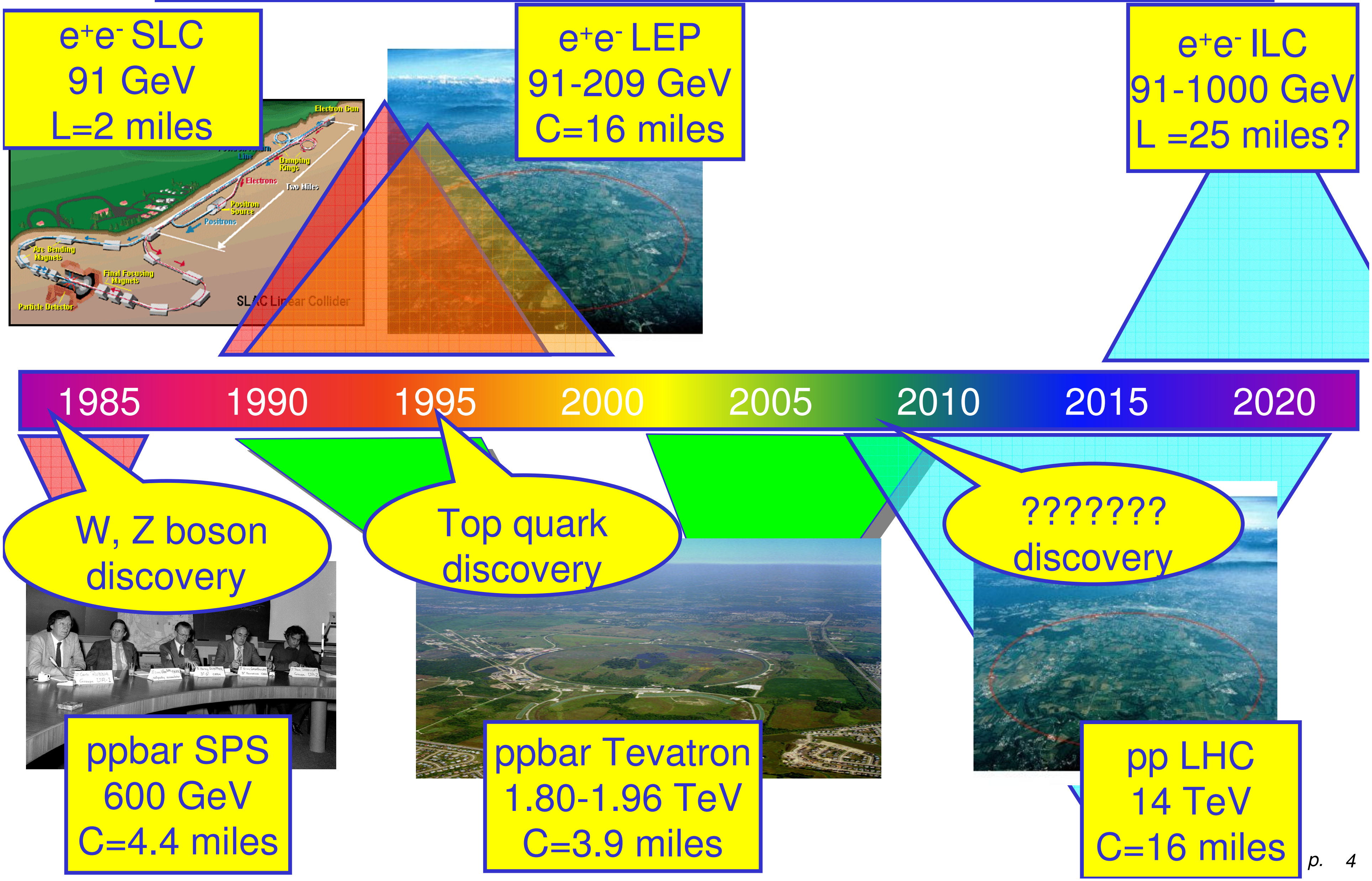


Outline

- Accelerators powerful enough to produce W, Z, top
  - Status
- W and Z physics
  - W and Z production cross-section
  - W charge asymmetry
  - W mass
- Top physics
  - Top production cross-section
  - Top decays
  - Top mass
- Standard Model (and beyond) global fit

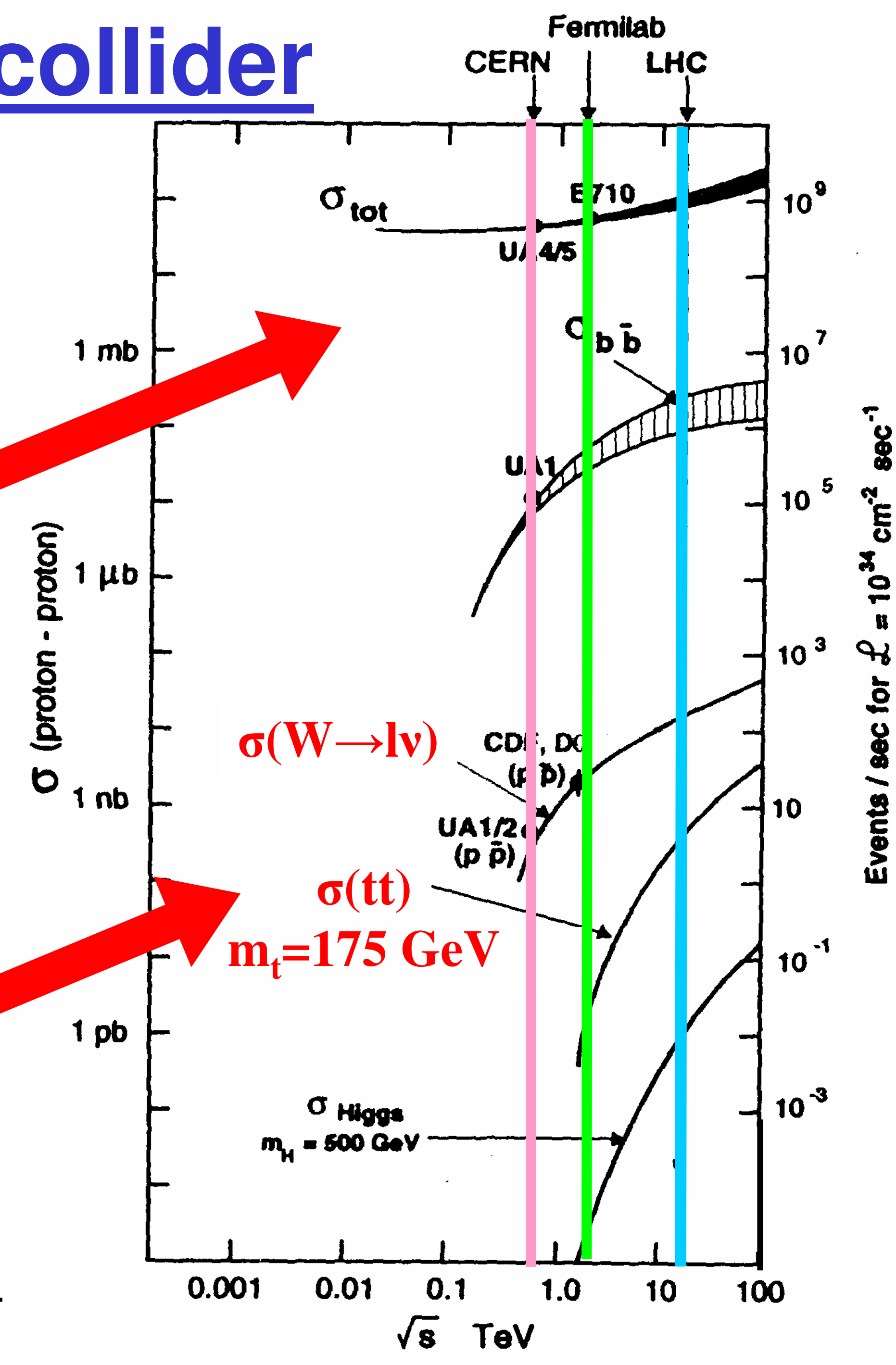
More details
P. Murat
A. Juste
Top/EWK Thursday

Accelerators:
The Decade of the Hadron Collider

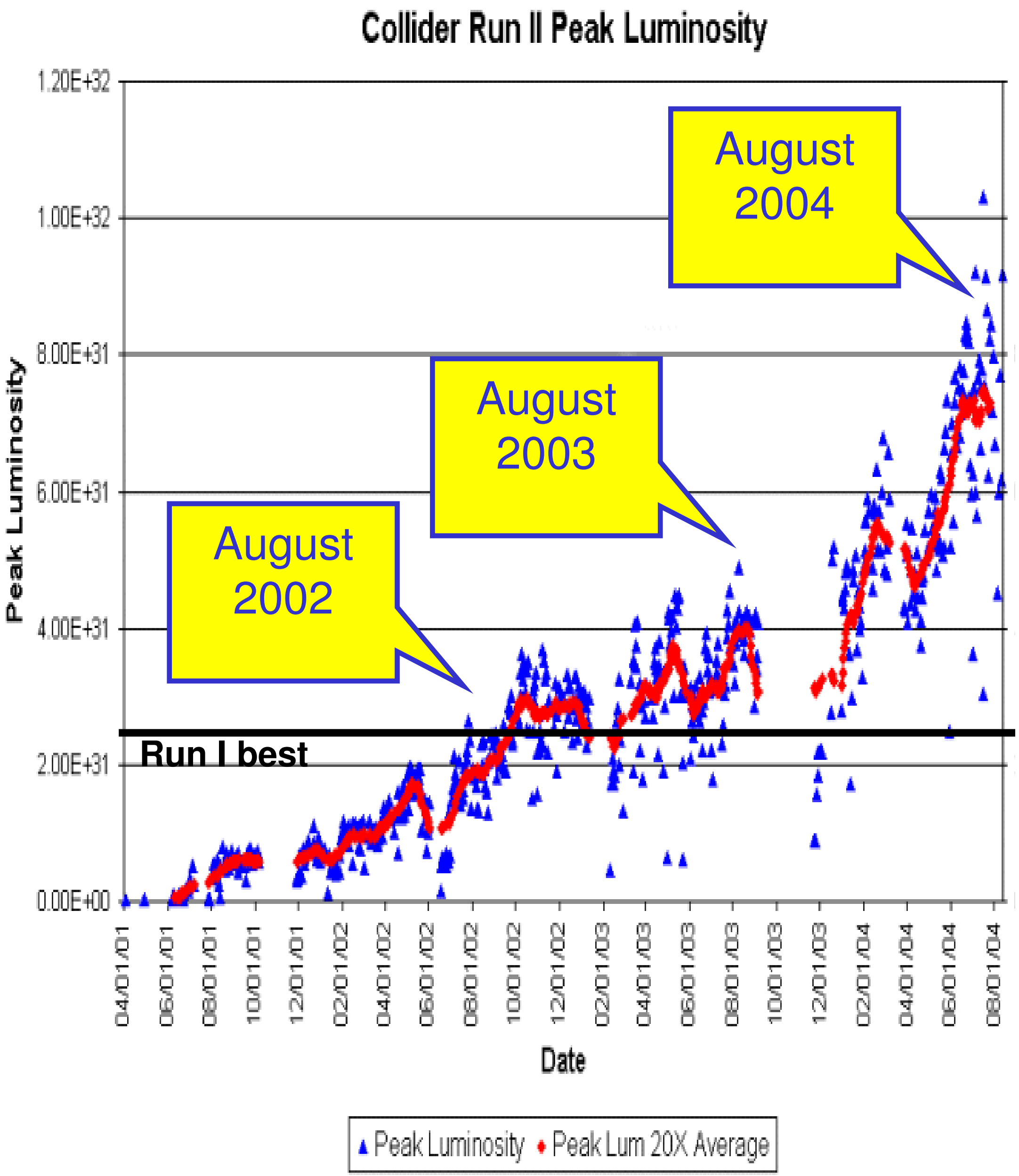


Physics at a hadron collider is like:

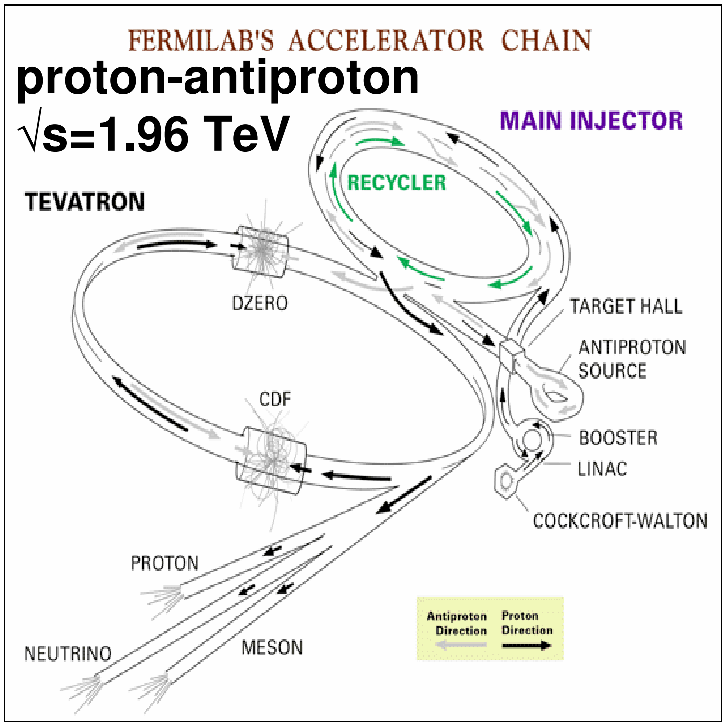
- Drinking from a firehose
  - Collision rate huge
    - Tevatron – every 396 ns
    - LHC – every 25 ns
  - Total cross section huge ~0.1b
    - 2-3 interactions per collision
      - Tevatron $L=10^{32}cm^{-2}s^{-1}$
      - LHC initial/low lumi $L=10^{33}cm^{-2}s^{-1}$
    - 20 interactions per collision
      - LHC design/high lumi $L=10^{34}cm^{-2}s^{-1}$
- Panning for gold
  - W, Z, top are relatively rare
    - Need high luminosity
    - Trigger is crucial
      - Distinguish using high p_T leptons



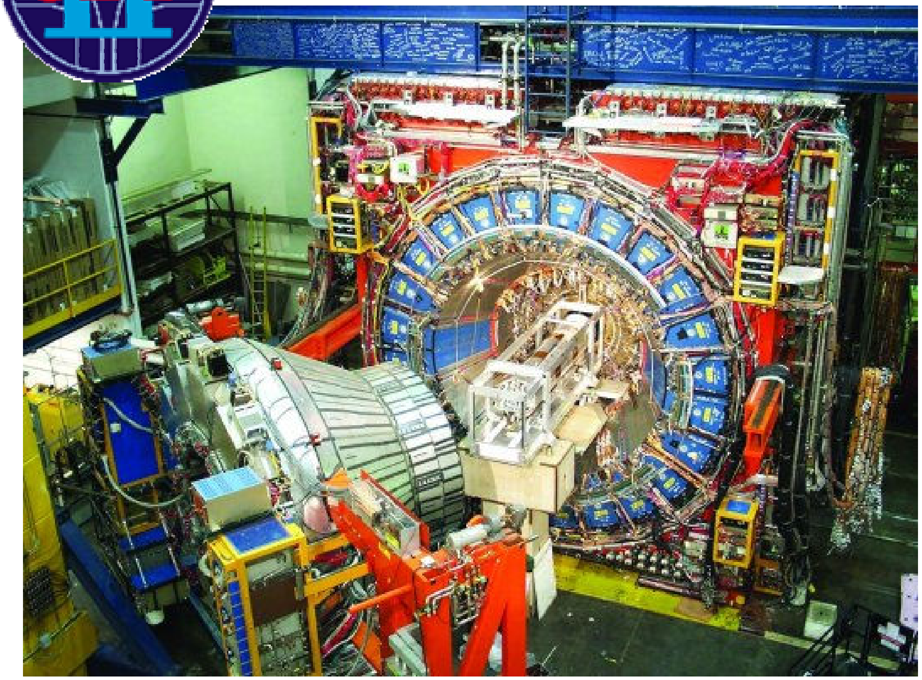
TeVatron Performance



- **Peak luminosity**
  - x2 increase since 2003
  - Reached $L=10^{32}cm^{-2}s^{-1}$
- **Future**
  - Run until 2009
  - Deliver 4-9 fb^{-1}



TeVatron Experiments



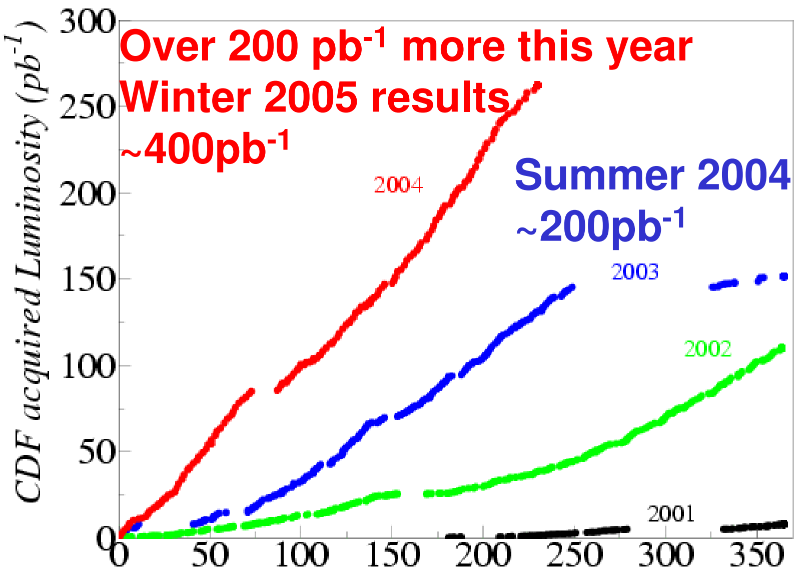
Top & Electroweak Physics need

Trigger

Electron/Muon/Tau identification

Tracking and b tagging

Calorimetry



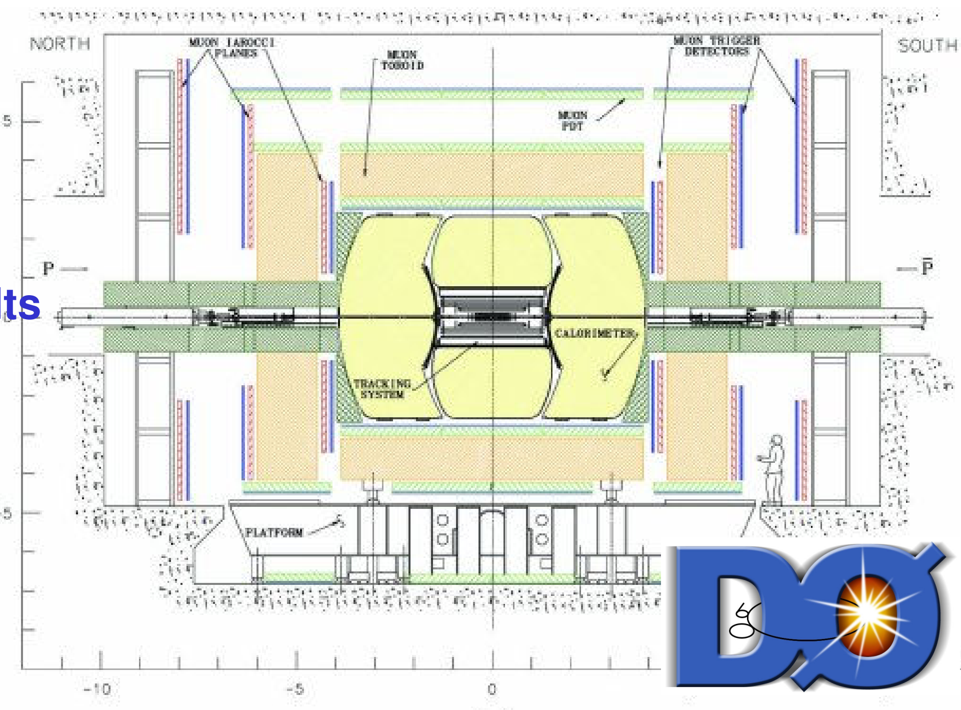
Over 200 pb^{-1} more this year

Winter 2005 results

~400pb^{-1}

Summer 2004 results

~200pb^{-1}



W and Z Physics

Standard Candles

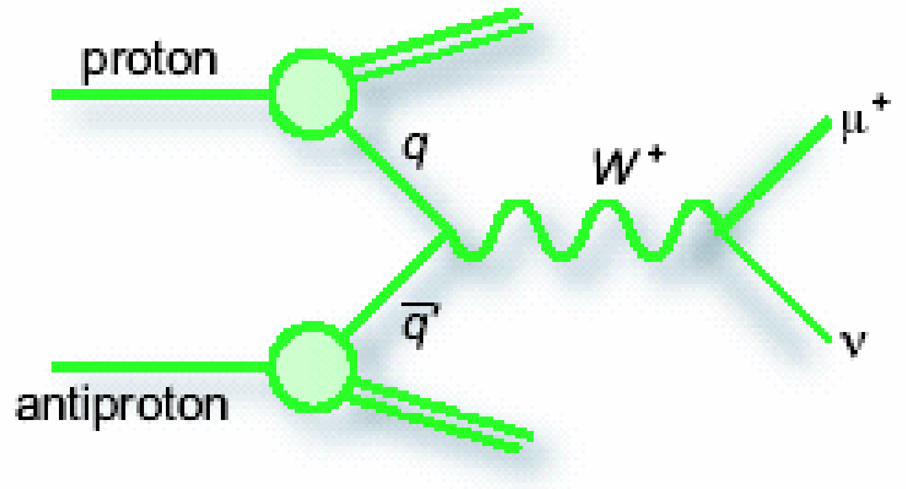
at Tevatron and LHC

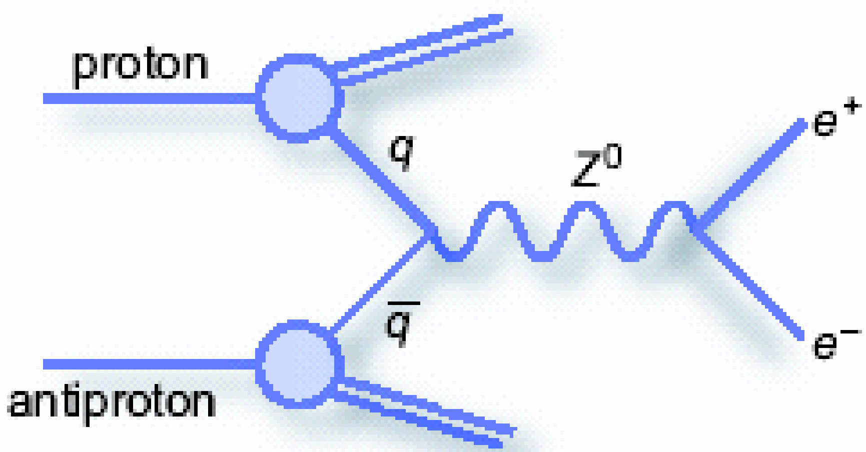
W/Z cross-sections → W width

W/Z asymmetries

W mass

WW, WZ, ZZ, Wγ, Zγ





Trigger on leptonic decays at Tevatron and LHC

Clean event signatures with low background

BR~11% per mode for W → $\ell\,\nu$
BR~3% per mode for Z→ $\ell^+\ell^-$

CDF(D0) W and Z Event Selection

$W \rightarrow e\nu$

1 electron E_T>25 GeV, $|\eta|$< 2.8(1.1)
High MET> 25 GeV

$Z^0 \rightarrow e^+e^-$

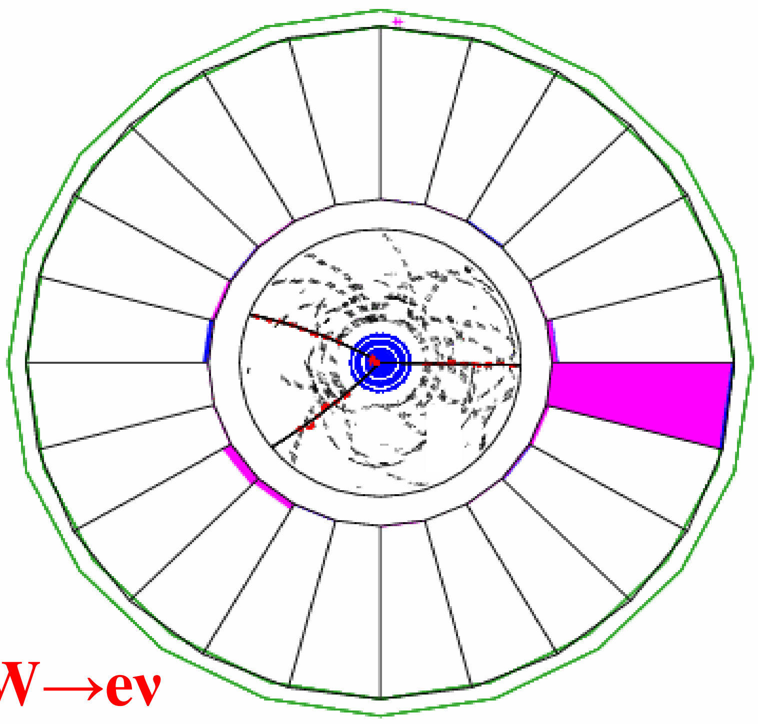
2 electrons E_T>20 GeV

$W \rightarrow \mu\nu$

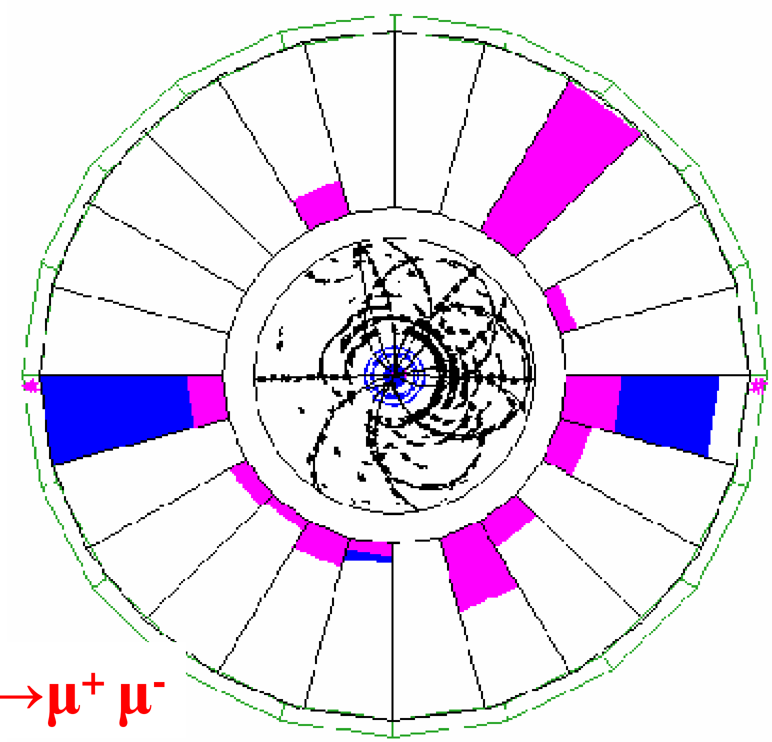
1 muon p_T>20 GeV, $|\eta|$< 1.0(1.5)
High MET>20 GeV

$Z^0 \rightarrow \mu^+ \mu^-$

2 muons p_T>20(15) GeV



$W \rightarrow e\nu$

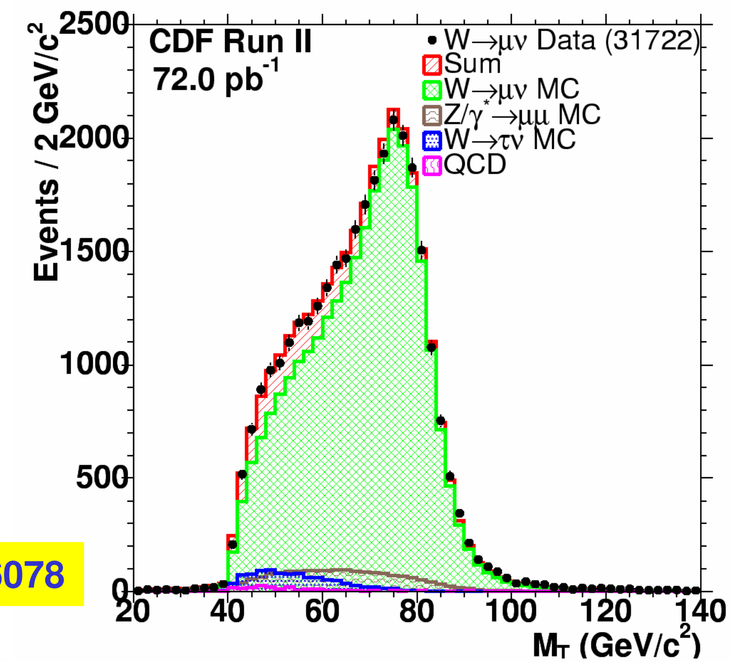


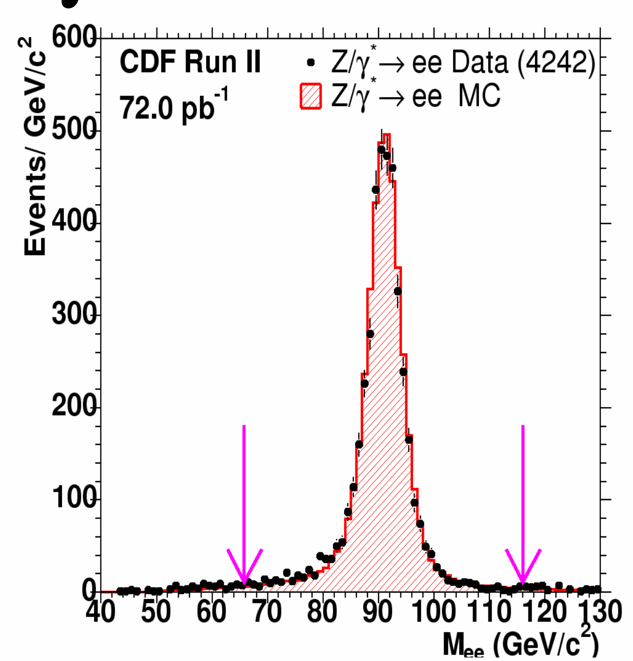
$Z^0 \rightarrow \mu^+ \mu^-$

W and Z production cross section

$$\sigma \cdot B = \frac{N_{obs} - N_{bkg}}{\mathcal{A} \cdot \mathcal{E} \cdot \int \mathcal{L}}$$

Uses $\sigma_{inelastic}$ = 60.7± 2.4 mb (CDF+E811)





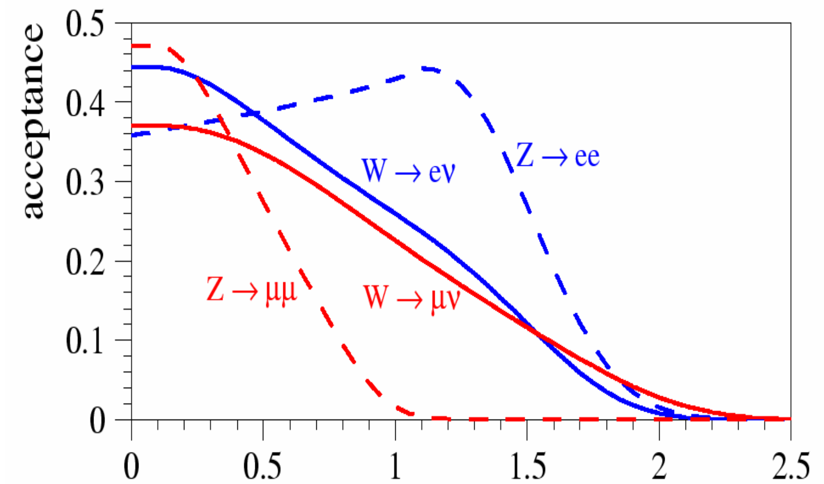
hep-ex/0406078

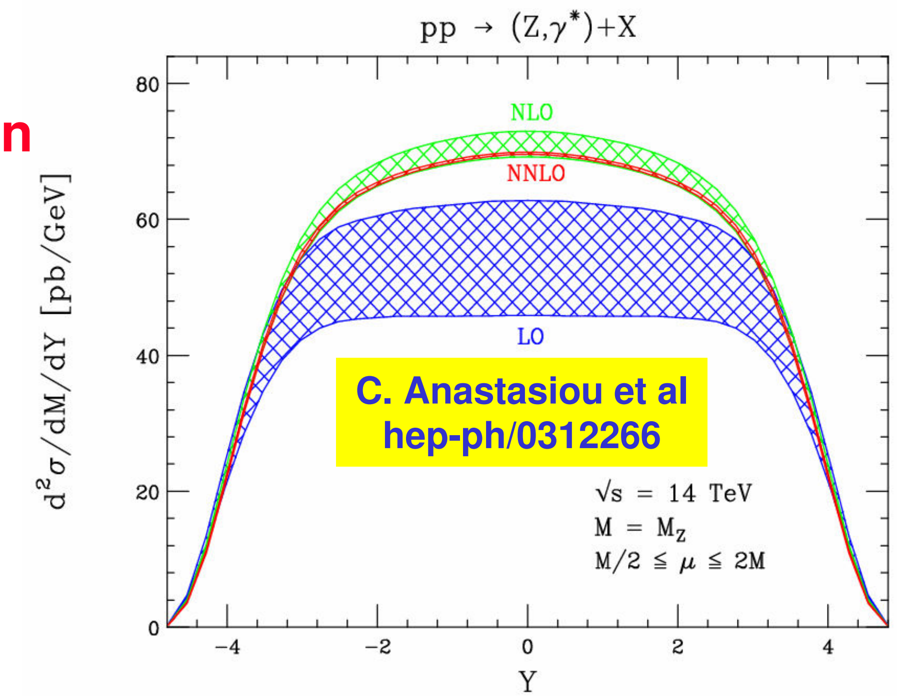
Precision	2.2%	2.4%	2.6%	3.9%
category	channel $W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
N candidates	37584	31722	4242	1785
acceptance	0.2397 ± 0.0036	0.1970 ± 0.0025	0.3182 ± 0.0040	0.1392 ± 0.0027
efficiency	0.749 ± 0.009	0.732 ± 0.013	0.713 ± 0.012	0.713 ± 0.015
background	1656 ± 300	2990 ± 140	62 ± 18	13 ± 13
cross section (pb)	$2780 \pm 14 \pm 60$	$2768 \pm 16 \pm 64$	$255.8 \pm 3.9 \pm 5.5$	$248.0 \pm 5.9 \pm 7.6$

Additional luminosity uncertainty of 6% is 166pb for W and 15pb for Z

$\mathcal{A}$: geometric and kinematic acceptance

- Key quantity is boson rapidity, y
- Calculate $\mathcal{A}$(y) from PYTHIA with GEANT detector simulation
  - Dominant systematics
    - E_T,P_T scale <0.4%
    - Detector material < 1%
- Convolve with NNLO differential cross-section
  - First complete NNLO computation of a differential quantity for high energy hadron collider physics
    - Powerful new calculation
    - Applicable to many observables
    - Important for LHC
- Dominant $\mathcal{A}$ systematic
  - PDFs CTEQ6M (0.7-2.1%)



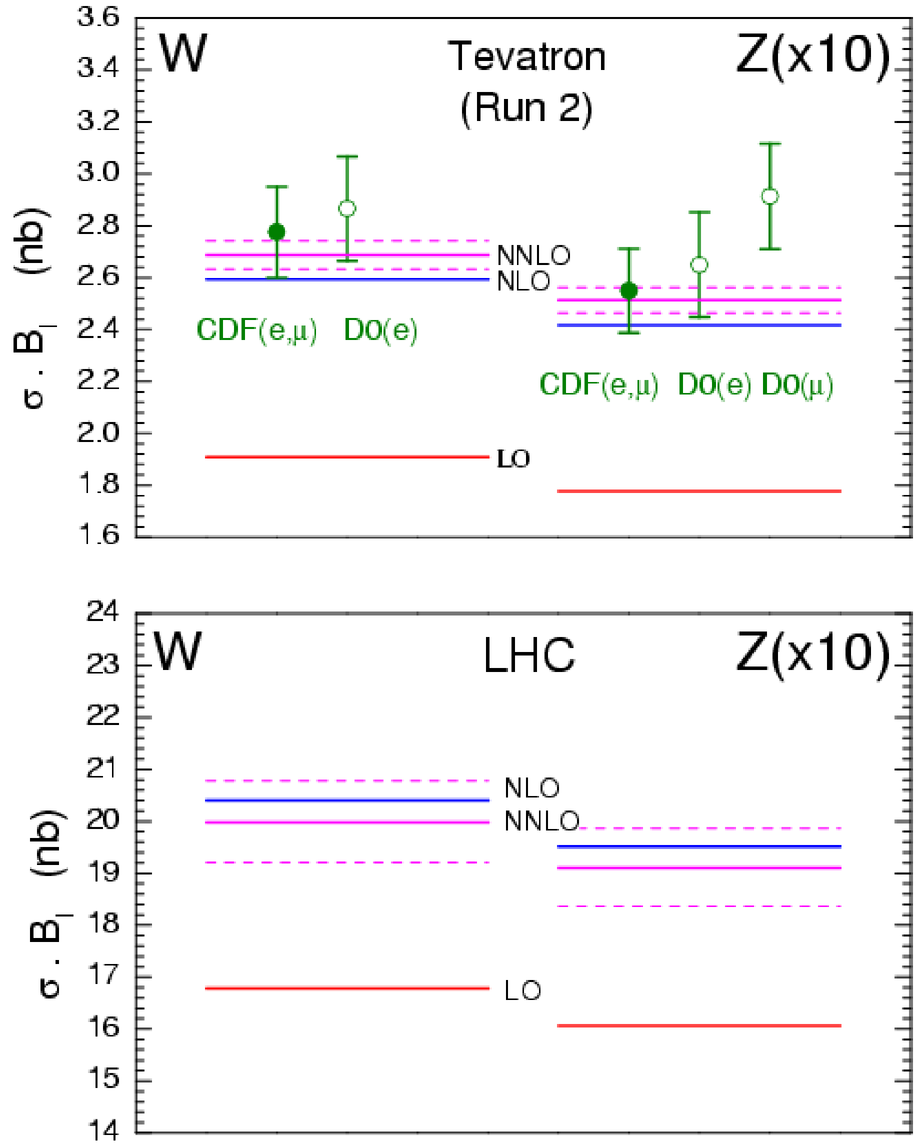


Boson rapidity

Experiment vs theory

- Precision measurements vs precision NNLO predictions
  - Theoretical uncertainty 2%
  - Experimental uncertainty 2%
  - Luminosity uncertainty 6%
- Future: instead use W and Z as a luminosity monitor at LHC

S. Frixione, M. Mangano
hep-ph/0405130

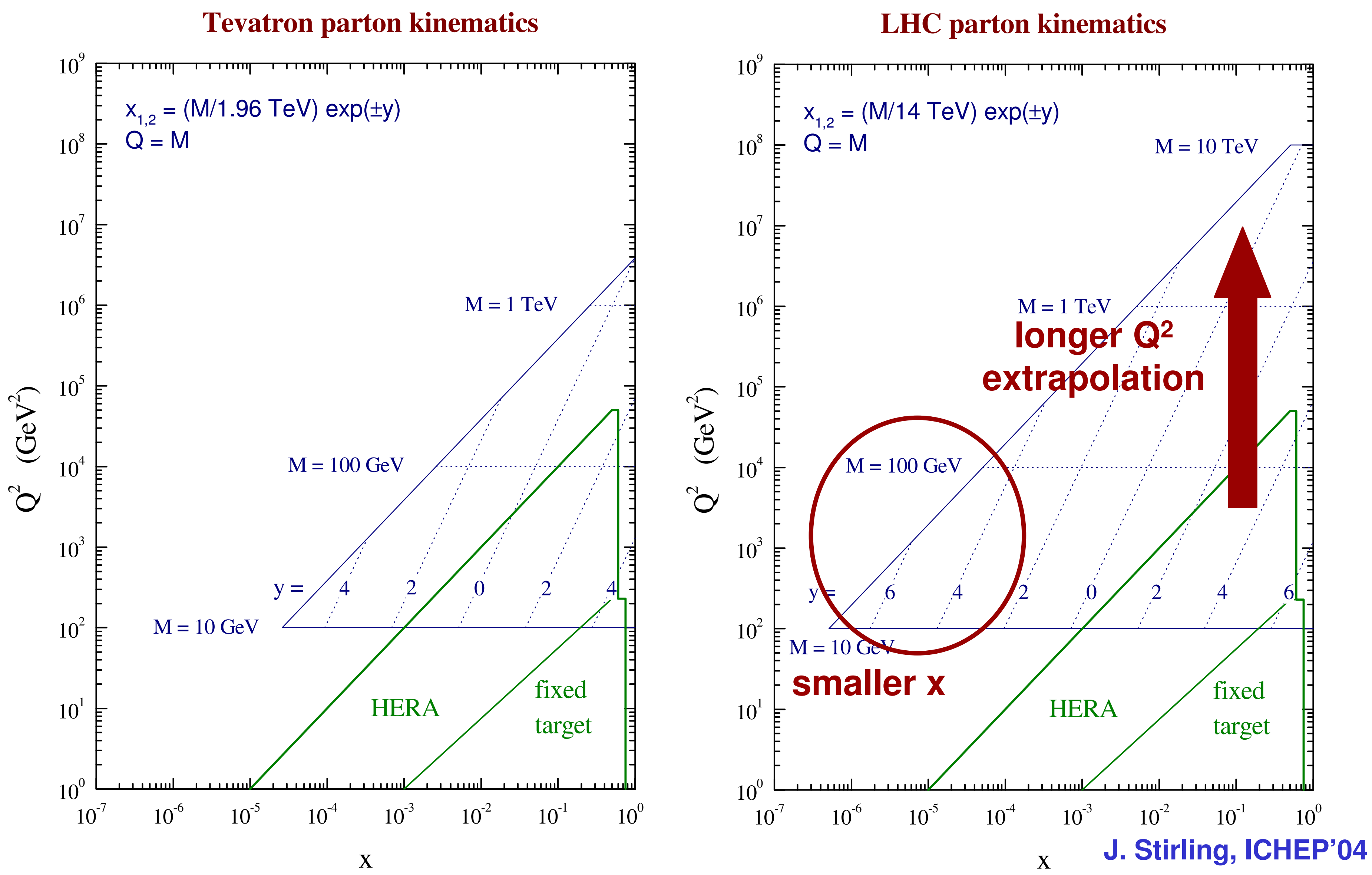


From W.J. Stirling

partons: MRST2002
NNLO evolution: Moch, Vermaseren, Vogt
NNLO W,Z corrections: van Neerven et al. with Harlander, Kilgore corrections

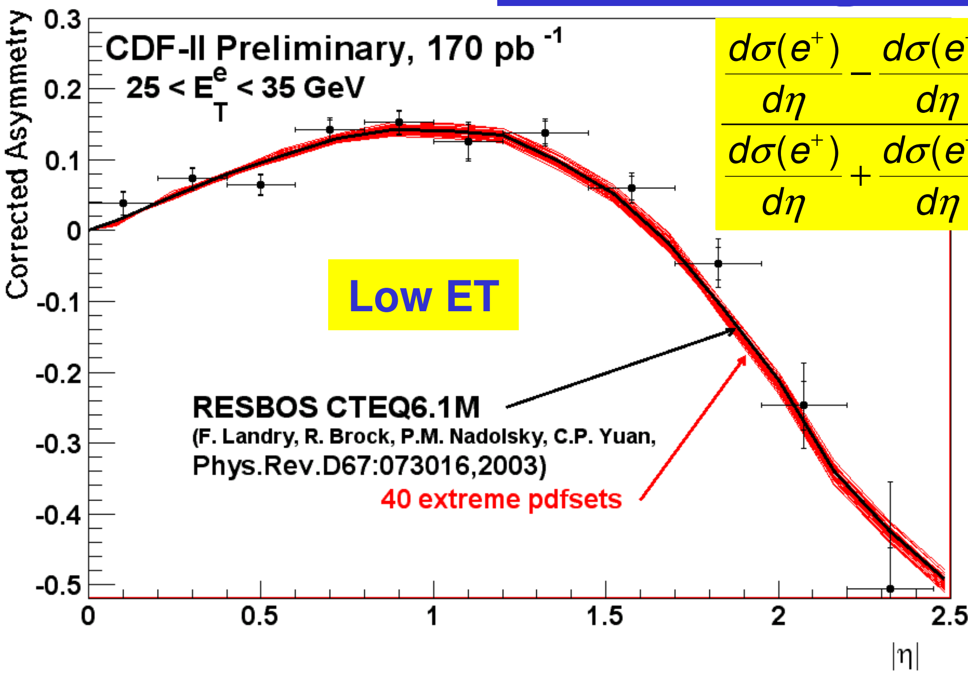
PDFs at LHC

LHC-HERA workshop on PDFs

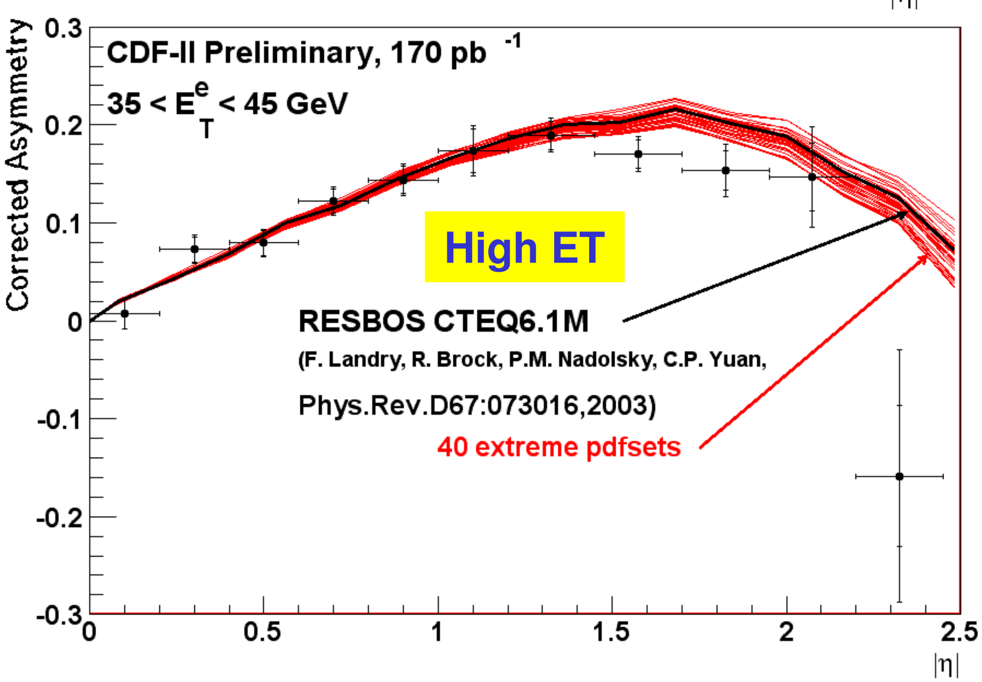


J. Stirling, ICHEP'04

W charge asymmetry



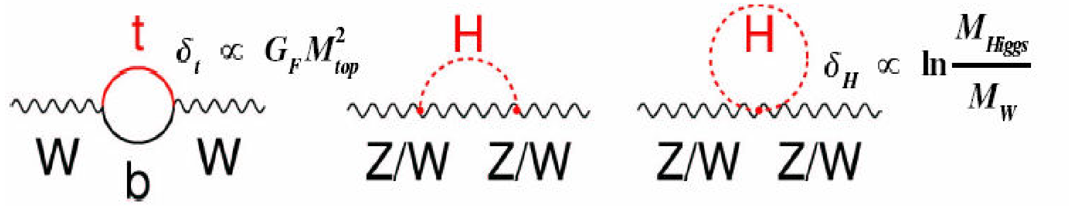
$$\frac{\frac{d\sigma(e^+)}{d\eta} - \frac{d\sigma(e^-)}{d\eta}}{\frac{d\sigma(e^+)}{d\eta} + \frac{d\sigma(e^-)}{d\eta}}$$



- Constrain PDFs at large x with Tevatron data
  - u quark carries more of proto momentum than d quark
    - W^+ boosted along proton beam direction
    - W^- boosted along anti-proton beam direction
  - W charge asymmetry sensitiv to u/d quark ratio at large x
    - Count e^+ and e^- vs η
    - High E_T sensitive to PDFs
    - Calorimeter- seeded Silicon tracking for electrons with $|\eta|>1$, charge mis-id < 2%
- At LHC? Total W^+ / W^- ratio probes (u dbar) / (ubar d) ratio

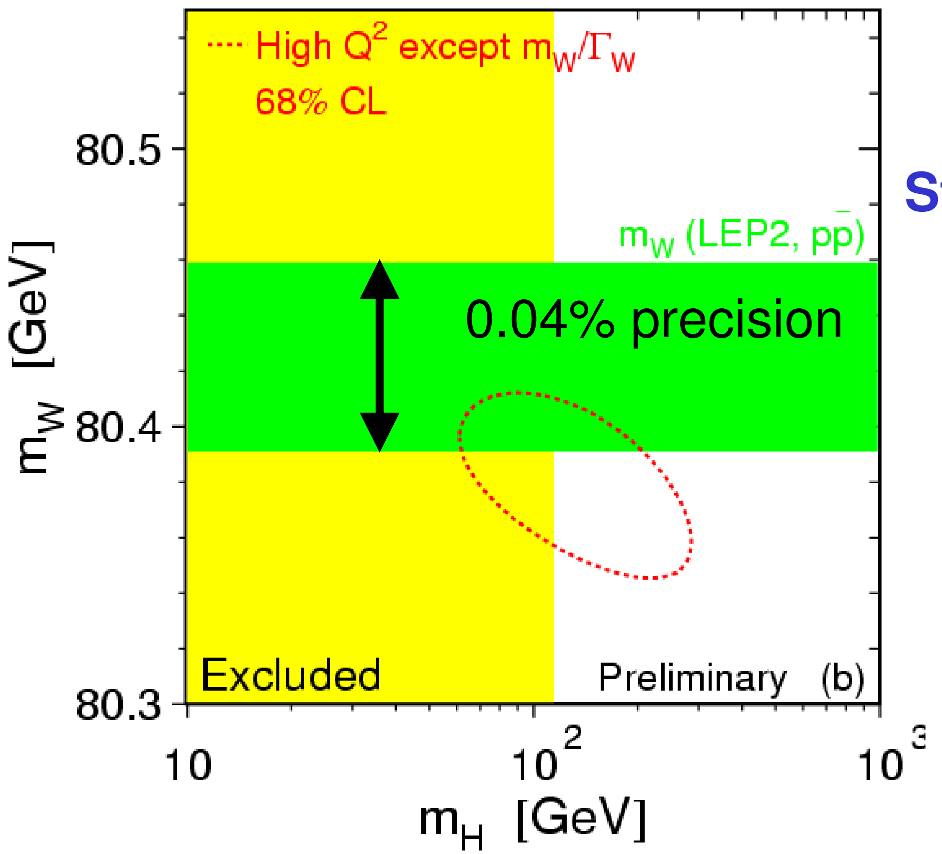
Standard Model prediction for W mass

Radiative corrections make W mass sensitive to top and Higgs mass



A. Freitas et al
hep-ph/0311148

Recent theoretical calculation of full two-loop electroweak corrections



$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r)$$

Standard Model prediction for W mass dominated by error on top mass

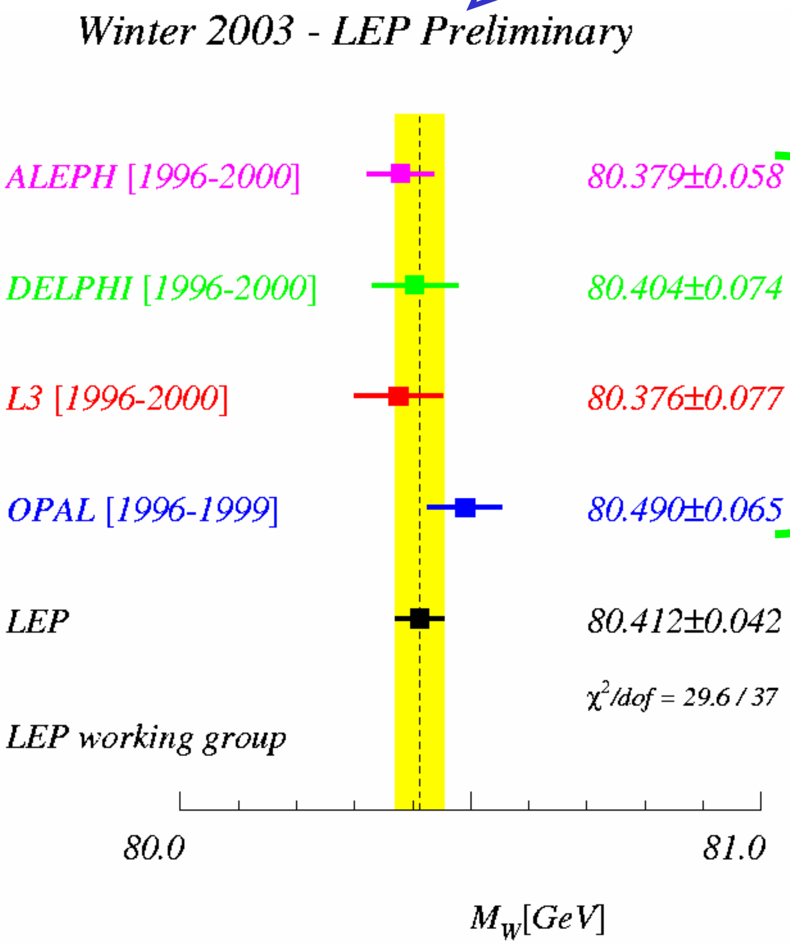
Contribution from error on top mass

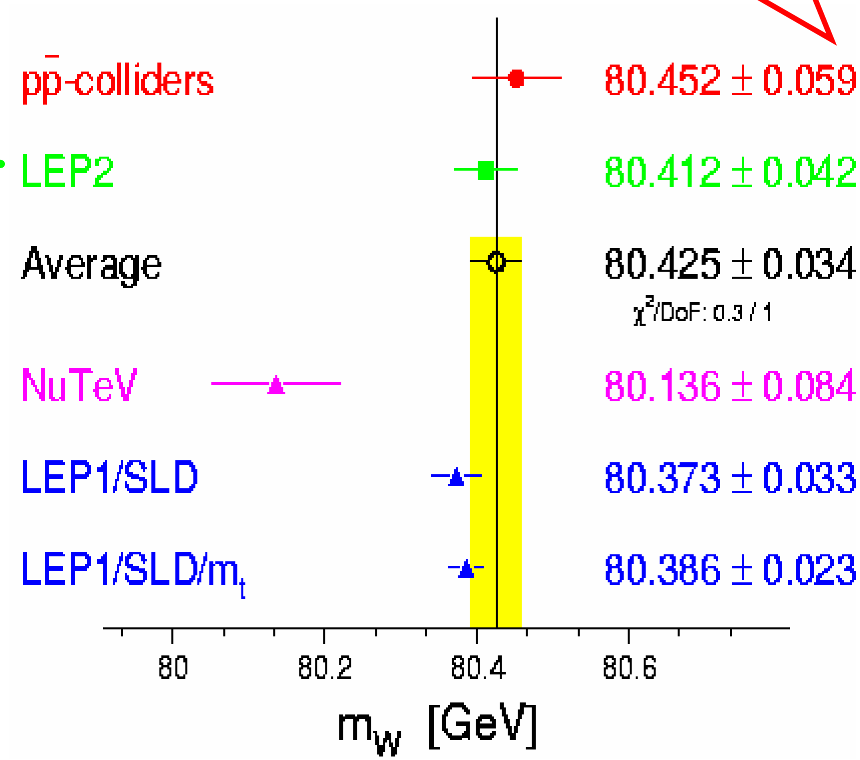
	Experiment δM_{top} (GeV)	Prediction δM_W (MeV)
Now	4.3	26
TeV	2.5	15
LHC	1.3	8
LC	0.1	-

Experimental measurements of W mass

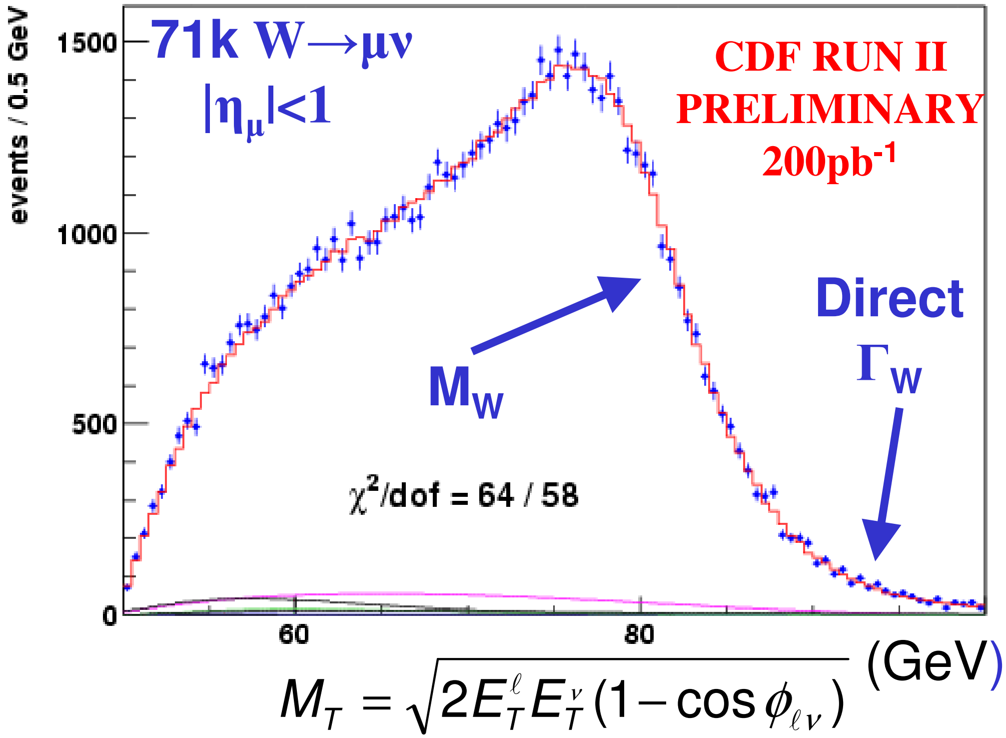
Limited by uncertainty from Final State Interactions in 4q

Final Run I hep-ex/0311039
First Run II soon!





Tevatron/LHC

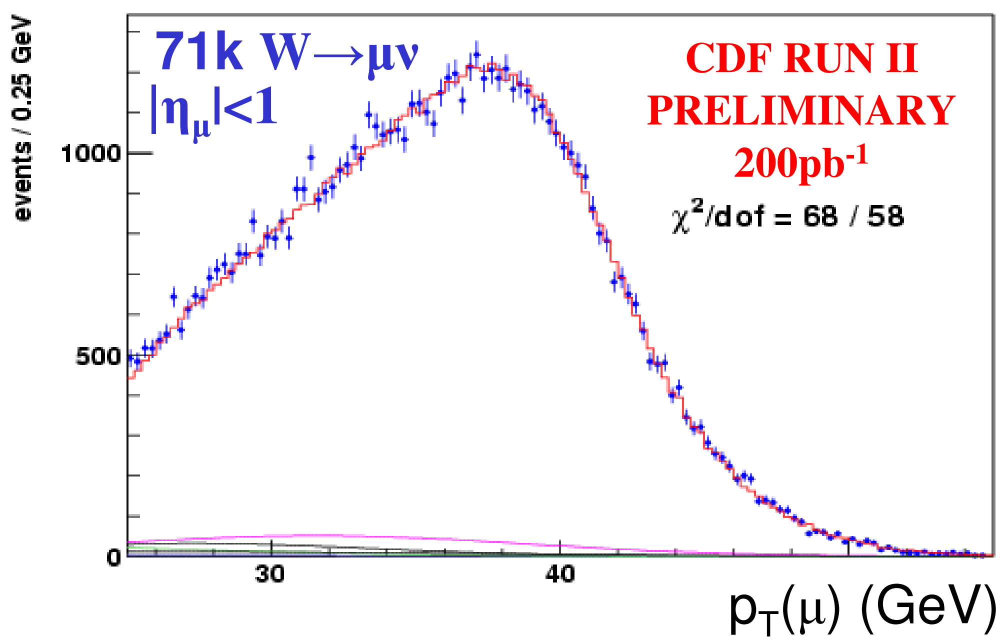


Measure W mass from fit to

- **W Transverse mass**
  - **Hadronic recoil model**
- **Muon P_T or electron E_T**
  - **W p_T model**

Run II fit results are still blinded!

- **Statistical error 50 MeV per channel**



Dominant systematic uncertainty from lepton energy/momentum scale and resolution

- **Most time and effort spent on detector calibration**
- **This is a very difficult and demanding measurement**

C. Hays Top/EWK Thursday

Run 1 W mass Systematic Uncertainties

Combined Run I uncertainty 59 MeV

How do we reach 40 MeV per channel per experiment in Run II?

And 15 MeV per experiment at LHC?

Most of the systematics are statistics-limited…get smarter with more data!

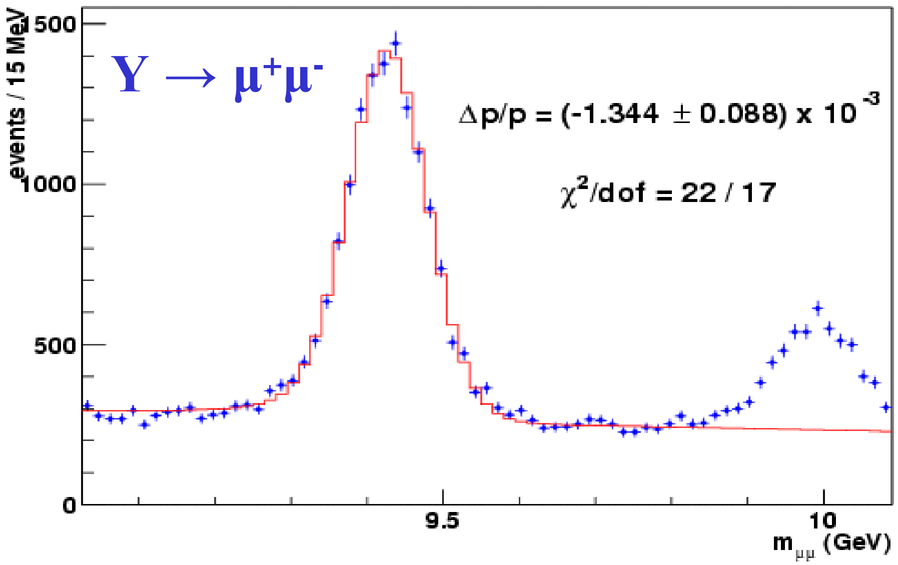
Theory uncertainties important above 1 fb^{-1}

TeVatron Run 1	CDF $W \to \mu\nu$	CDF $W \to e\nu$	D0 $W \to e\nu$
W statistics	100	65	60
Lepton Energy scale	85	75	56
Lepton resolution	20	25	19
Selection bias	18	-	12
Backgrounds	25	5	9
Recoil model	35	37	35
PT(W)	20	15	15
PDFs	15	15	8
QED corrections	11	11	12
Γ_W	10	10	10

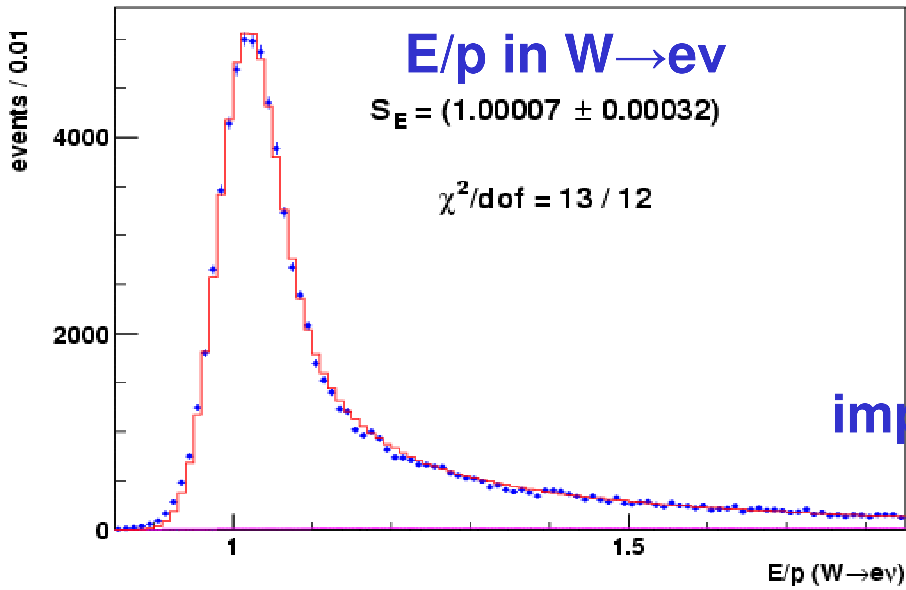
Correlated! (PDFs, QED corrections, Γ_W)

Lepton Energy scale

Some advantages to a hadron collider – many calibration samples!
And uncertainties decrease with higher statistics



Muon momentum scale/resolution
use J/ψ, Υ
cross-check with $Z \rightarrow \mu^+\mu^-$
Preliminary syst. 30 MeV !!! (87)



Electron energy scale/resolution
use E/p in W→eν
cross-check with Z→e+e-
Preliminary syst. 70 MeV (70)

Accurate model of detector material
important due to electron bremsstrahlung
Source of 55 MeV uncertainty
ATLAS/CMS take note!

QCD & QED corrections

U. Baur
P. Nadolsky
Top/EWK Thursday

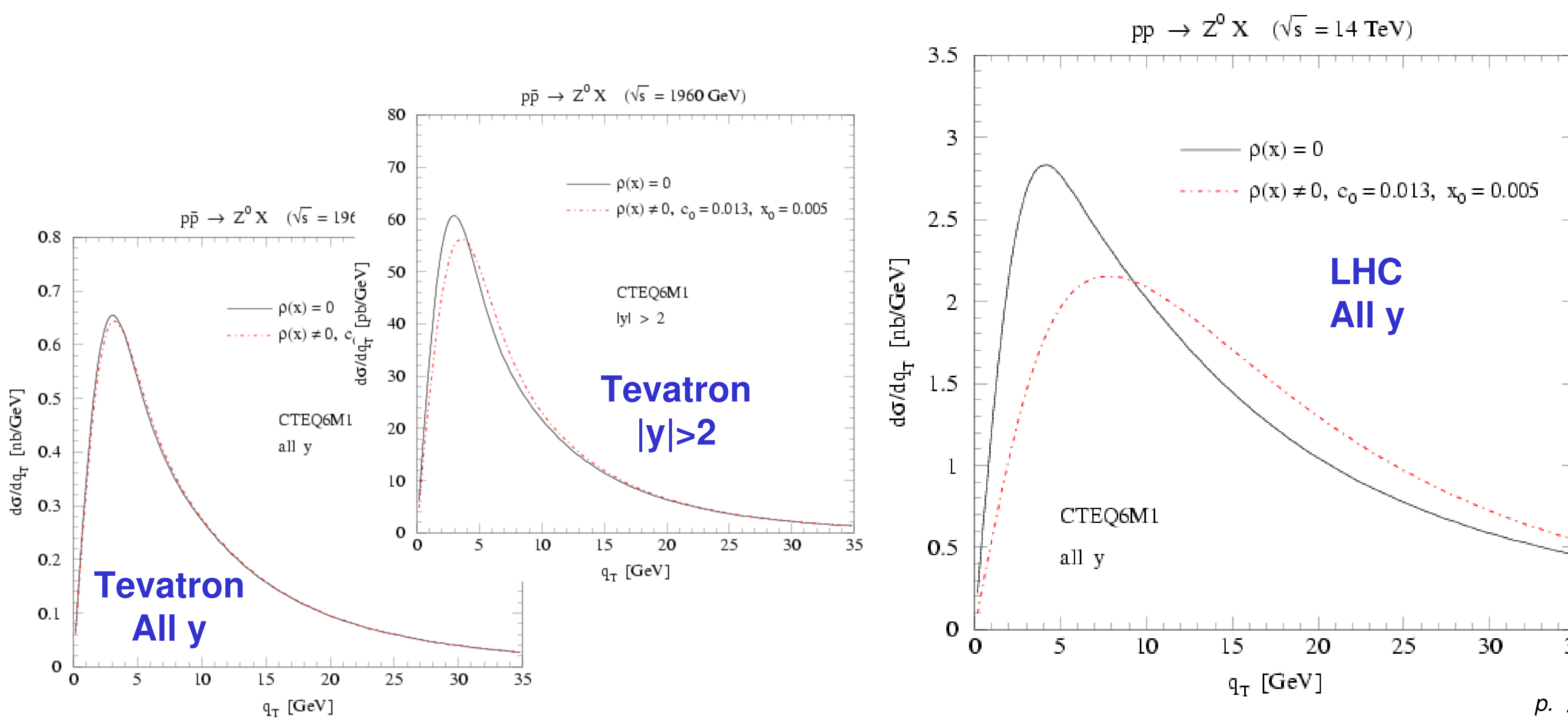
- QED radiative corrections
  - Multiple QED radiation
  - QCD+QED(FSR) in RESBOS-A

C. Calame et al hep-ph/0402235
W. Placzek, S Jadach Eur.Phys.J.C29:325-339,2003

Q. Cao, C.P.Yuan hep-ph/0401026

- Transverse momentum resummation at small-x?
  - TeVatron – may be visible at high rapidity
  - LHC important everywhere

S. Berge et al., hep-ph/0401128
DPF parallel session

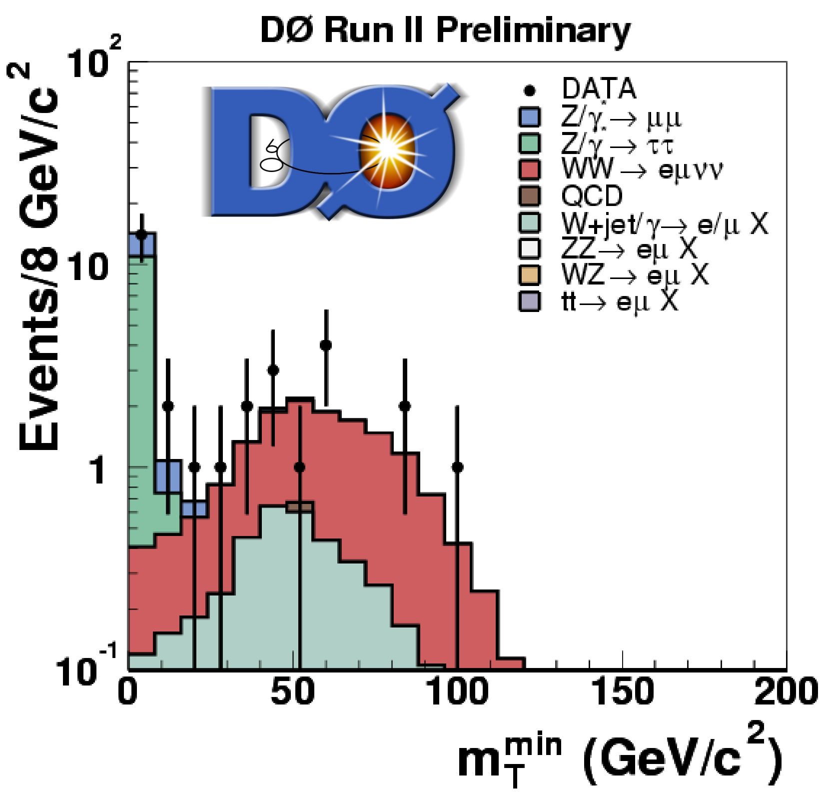


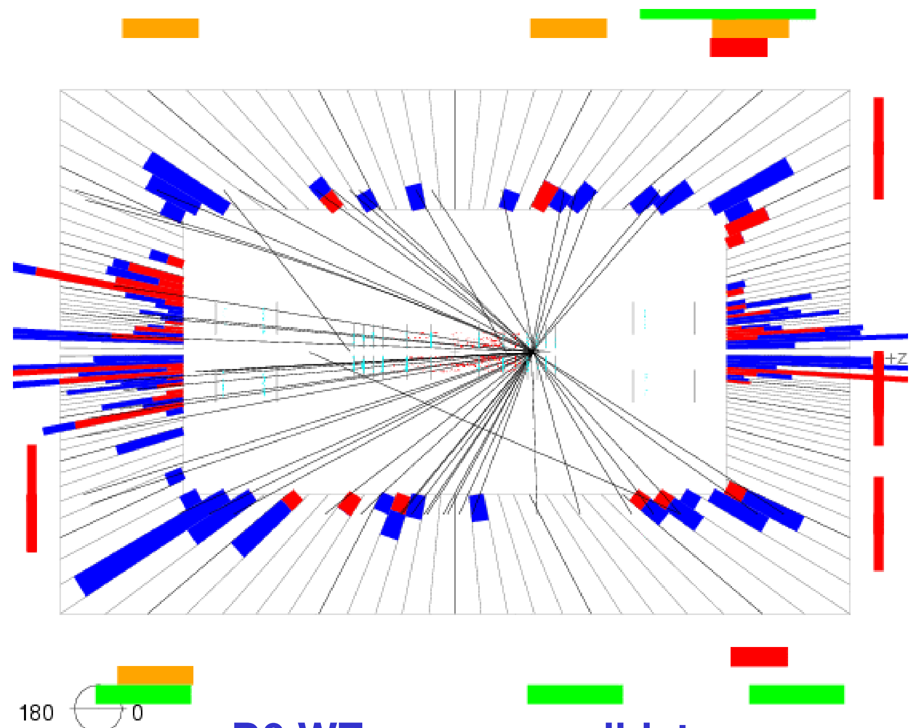
WW, WZ, ZZ production

- First observation of WW production at a hadron collider
- Still searching for WZ
  - TGC - Hard to beat LEP with 40k WW pairs
  - Important backgrounds to Higgs search!

CDF $\sigma(WW) = 14.3 \pm^{5.6}_{4.9} \pm^{1.8}_{1.8}\, pb$ $\qquad \sigma(WZ) < 13.9\, pb @ 95\%\ C.L.$

D0 $\sigma(WW) = 13.8 \pm^{4.3}_{3.8} \pm^{1.3}_{1.2}\, pb$ $\qquad \sigma(WZ) < 15.1\, pb @ 95\%\ C.L.$





D0 WZ→μνμμ candidate

Top Physics

Top discovered by CDF and D0 in 1995

Very heavy! Top mass = 178.0 ± 4.3 GeV

But only ~30 events per experiment

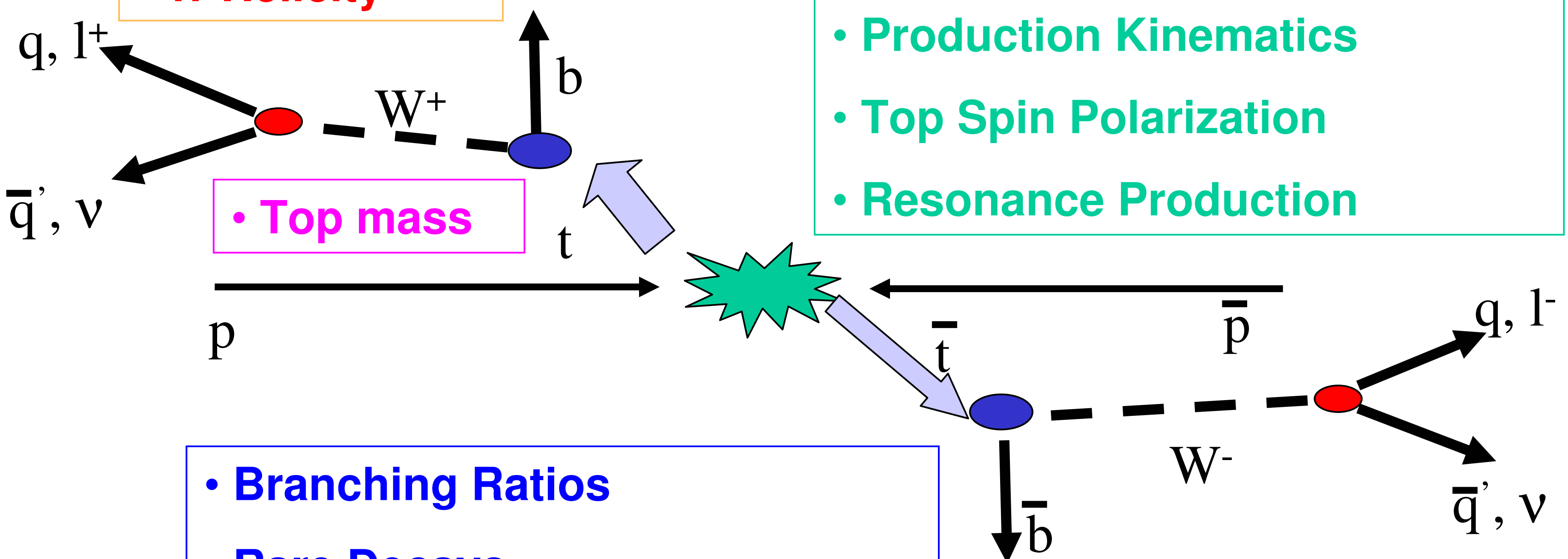
!!!Want more top events to study properties!!!

Run II σ 30% higher at $\sqrt{s}$=1.96 TeV

Similar mass to Gold atom! 35 times heavier than b quark

- **W Helicity**

- **Top mass**



- **Production Cross Section**
- **Production Kinematics**
- **Top Spin Polarization**
- **Resonance Production**

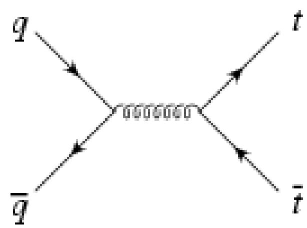
- **Branching Ratios**
- **Rare Decays**
- **Non-SM decay ($t \rightarrow H^+b$)**

Top Production

Top pairs via strong interaction

LHC √s=14 TeV
833 ± 100 pb

0.8 events per second at initial/low lumi LHC

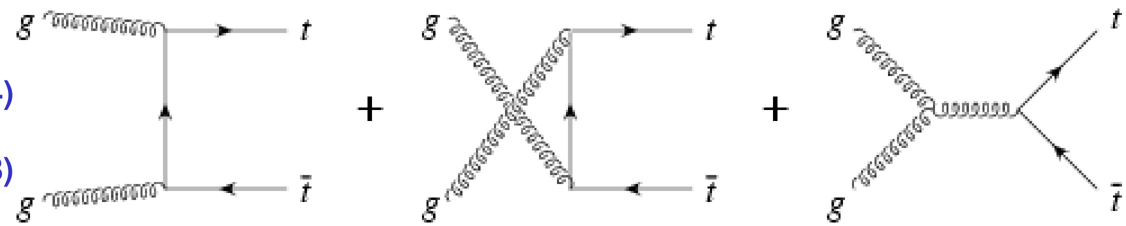


85% qq 15% gg
10% qq 90% gg

TeVatron √s=1.96 TeV

m_t (GeV)	- PDF	NLO σ(pb)	+PDF
170	6.8	7.8	8.7
175	5.8	6.7	7.4
180	5.0	5.7	6.3

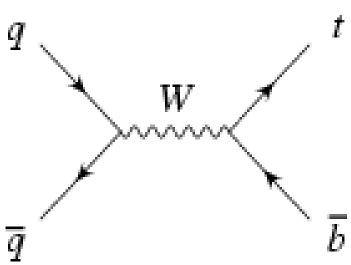
Cacciari et al
JHEP 0404:068 (2004)
Kidonakis et al
PRD 68 114014 (2003)

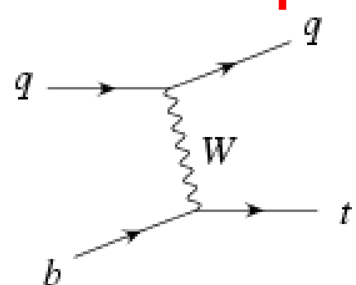


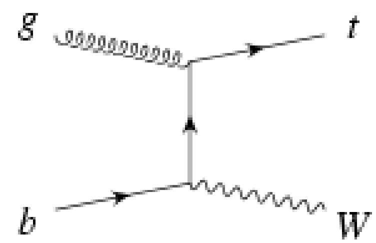
0.8 events per hour at recent lumi

Single top via weak interaction

0.88 ± 0.11 pb	1.98 ± 0.25 pb	<0.1 pb
10.6 ± 1.1 pb	246.6 ± 11.8 pb	62.0+16.6-3.6 pb





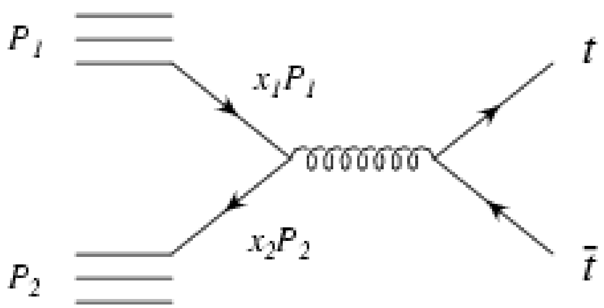


Harris, Laenen, Phaf, Sullivan, Weinzierl, PRD 66 (02) 054024
Sullivan hep-ph/0408049

Tait, PRD 61 (00) 034001
Belyaev, Boos, PRD 63 (01) 034012

Top pair production

- **Why is qq annihilation dominant at the TeVatron but gg fusion at LHC?**
- **Why does cross section increase by x100 for only x7 increase in √s?**

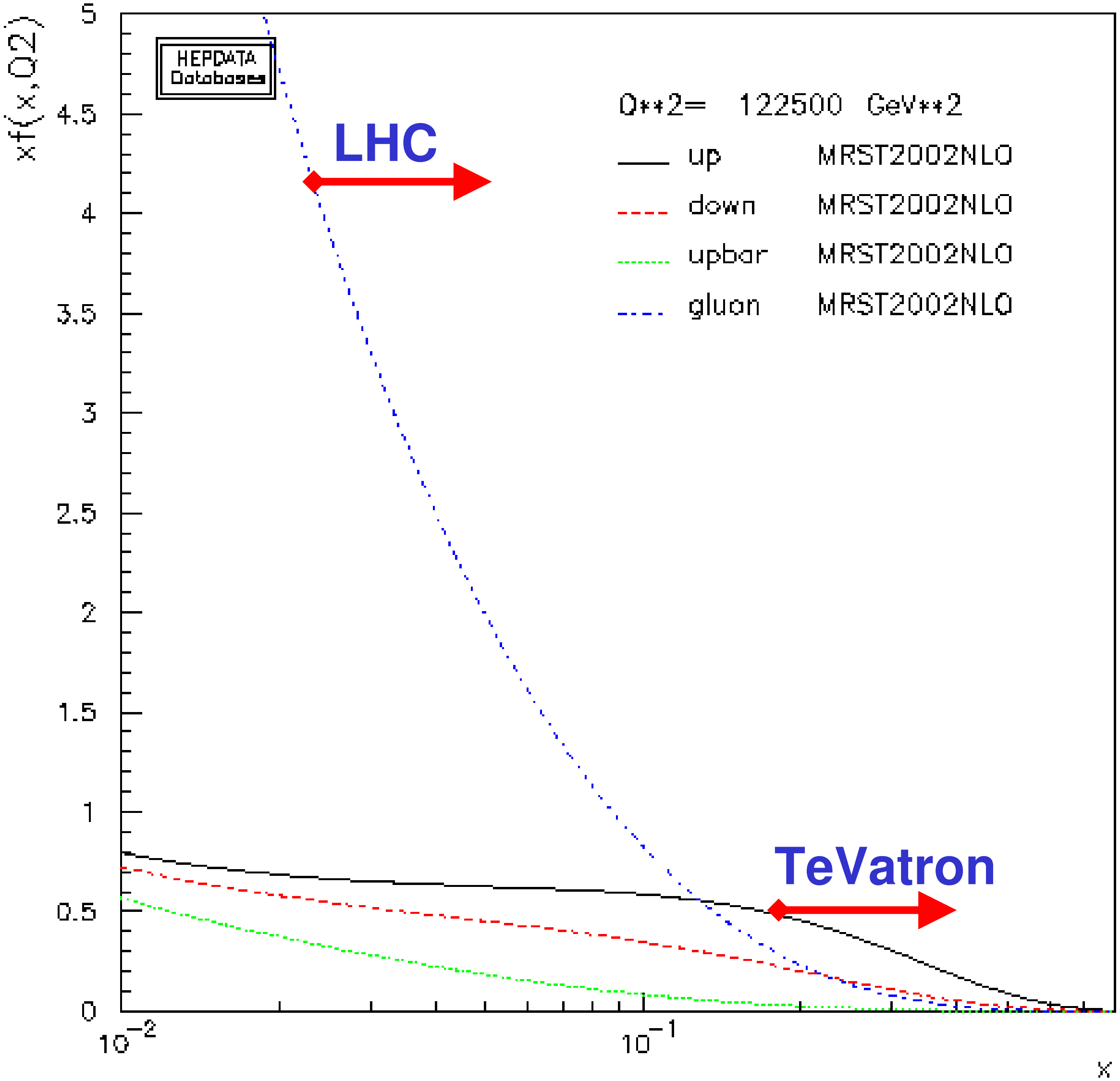


$$x \approx \frac{m_t}{\sqrt{s}/2}$$

$$\sqrt{s} = 1.96\,TeV \quad x \approx 0.18$$

$$\sqrt{s} = 14\,TeV \quad x \approx 0.025$$

http://durpdg.dur.ac.uk/hepdata/pdf3.html

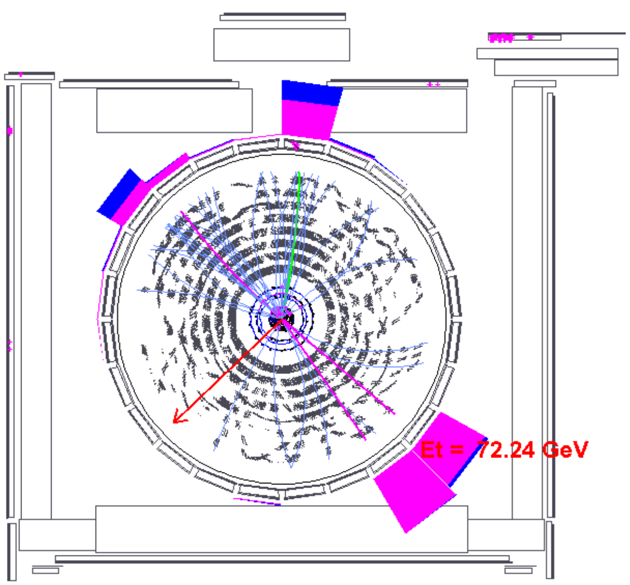


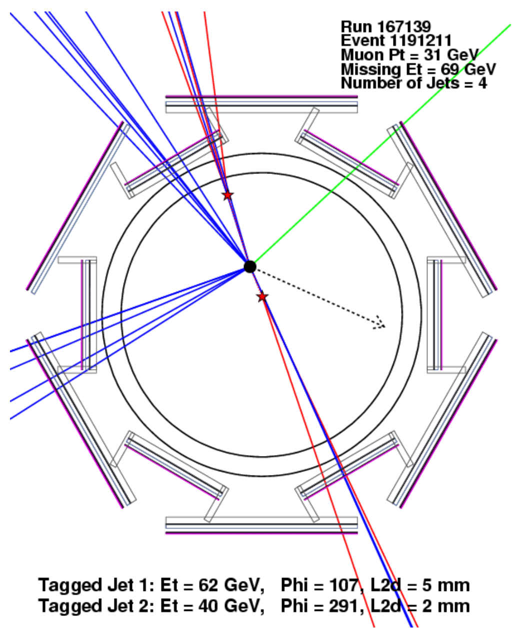
Top Decay

- **BR(t→Wb) ≈ 100% in Standard Model**
- **Top lifetime 10^{-25} s (Γ(t→Wb)=1.5 GeV)**
  - **No top mesons or baryons (Λ_{QCD}=0.1 GeV)**
  - **Top spin observable via decay products**

Final States in Top Pair Production

5% Dilepton	30% Lepton+Jets	46% All hadronic
Both W → lν (l=e or μ)	One W → lν (l=e or μ)	Both W → qq
2 leptons	1 lepton	
Missing ET	Missing ET	
2 b-jets	4 jets (2 b-jets)	6 jets (2 b-jets)





2 Lepton/isolated track p_T>20 GeV
MET>25 GeV
MET>40 GeV if m_{ll} [76,106] GeV
≥2 jets E_T>20 GeV

Dilepton

Observe 19 lepton/isolated track events in 200 pb^{-1}
Estimated background 6.9 ± 1.7 events
Observe 13 lepton/lepton events in 200pb-1
Estimated background 2.7 ±0.7 events

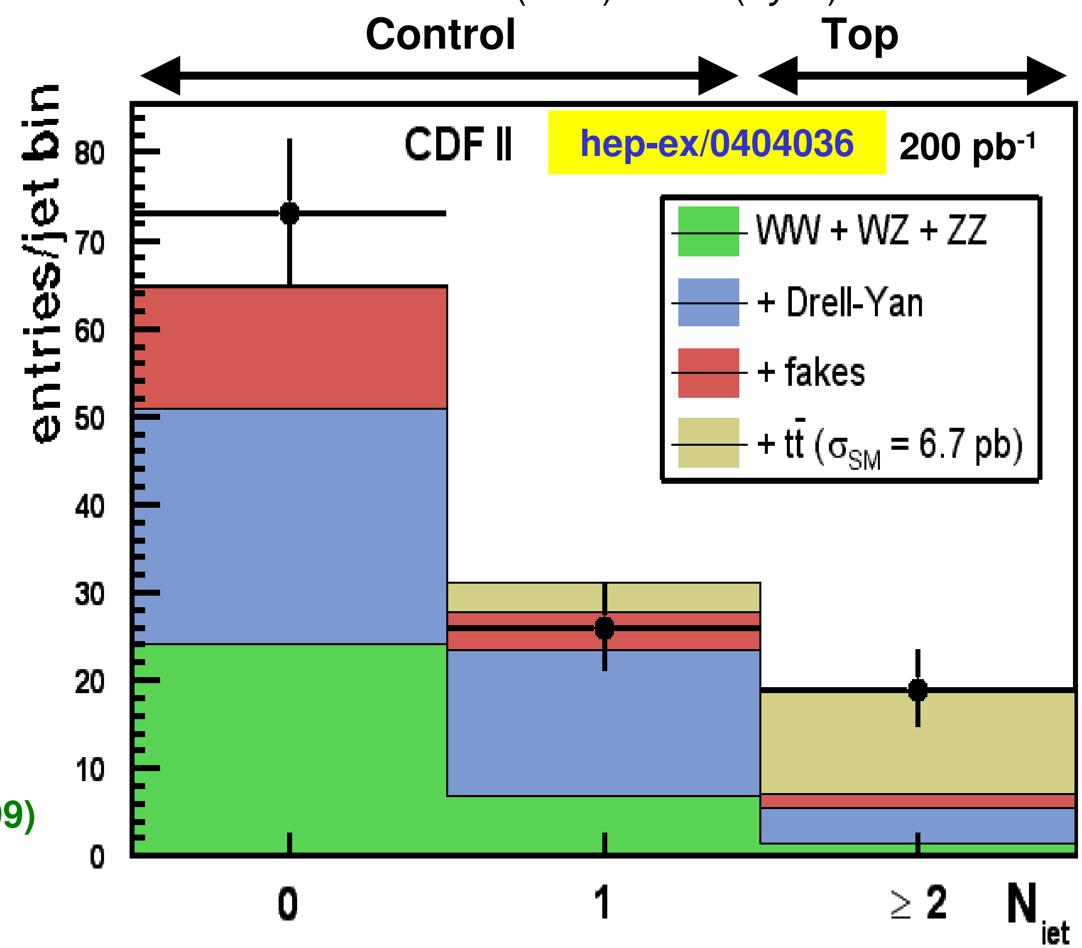
$$\sigma(t\bar{t}) = 7.0 \pm^{2.4}_{2.1(stat)} \pm^{1.6}_{1.2(syst)} \text{pb}$$

Background estimates

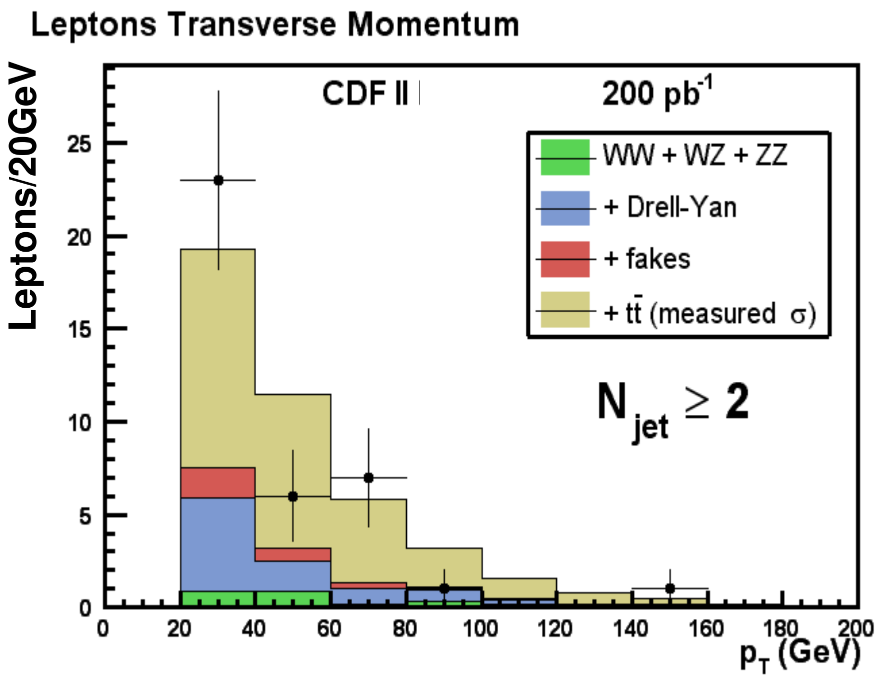
Data

Shape PYTHIA MC
Normalisation from data
Statistics-limited

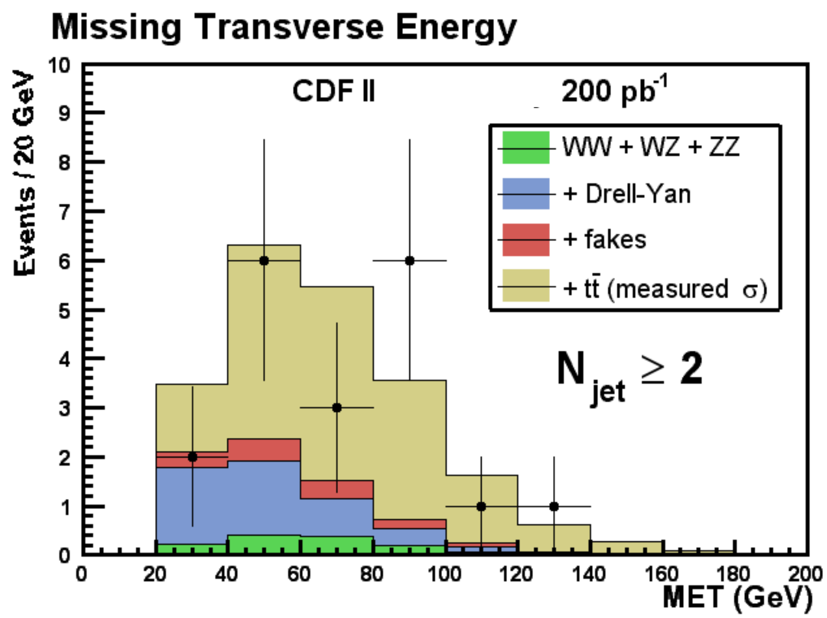
Shape PYTHIA MC
Normalisation from NLO
Campbell, Ellis
PRD60 113006 (1999)

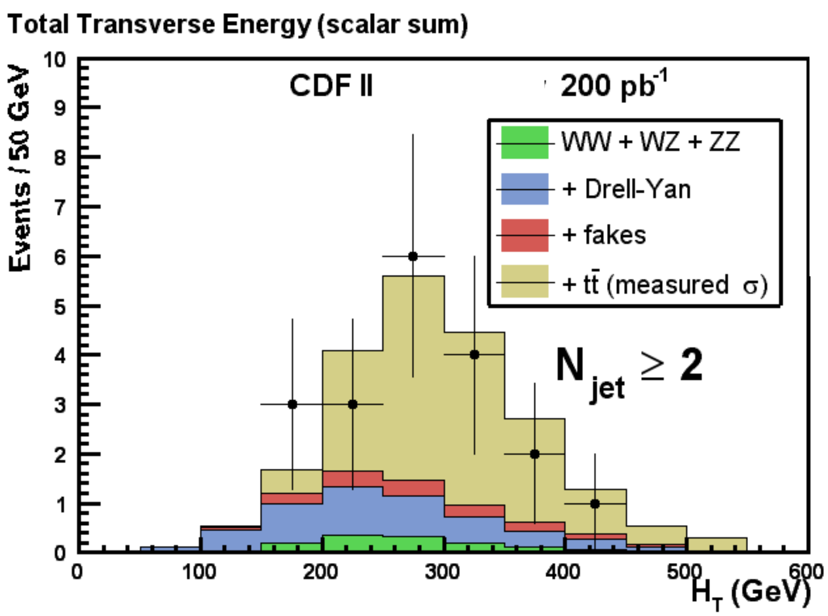


Dilepton kinematics



Kinematics consistent
with Standard Model so far

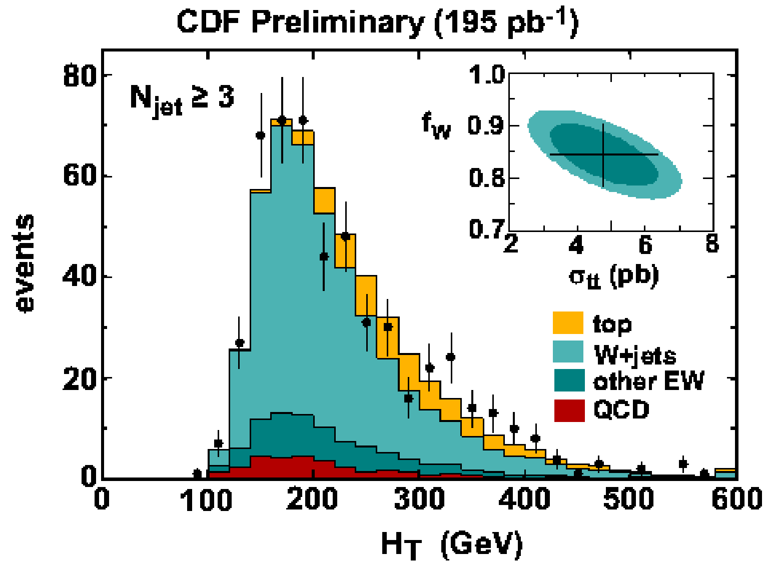


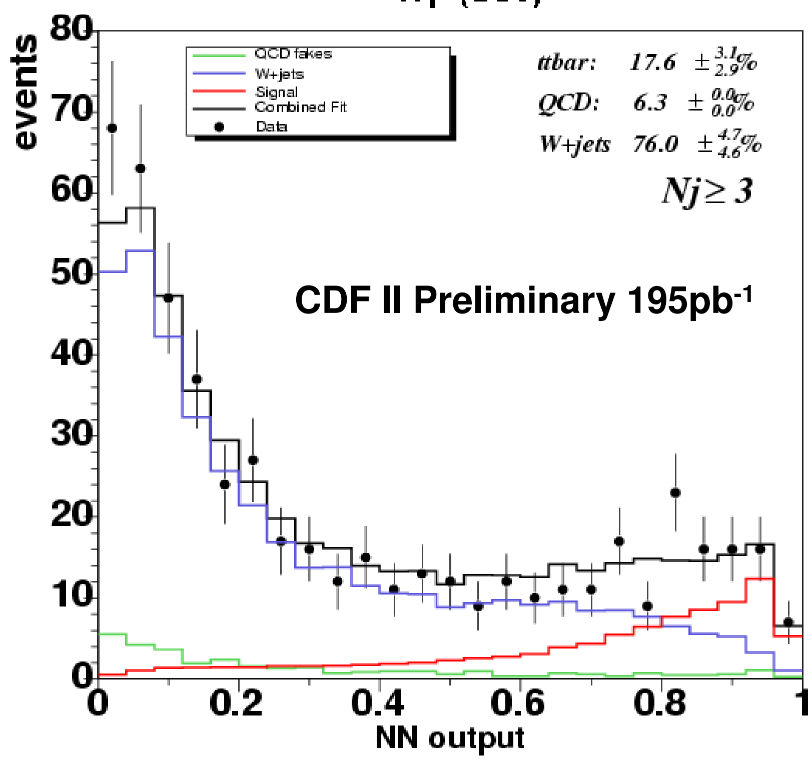


H_T is scalar sum of transverse energies
of jets, leptons and MET

1 Lepton p_T>20 GeV
MET>20 GeV
≥3 jets E_T>15 GeV, |η|<2.0

Lepton+Jets





Dominant background from W+jets

Go beyond single variable like H_T
Combine seven kinematic variables in a 7-7-1 neural network to improve discrimination

Top shape from PYTHIA

W+jets background shape from ALPGEN+HERWIG MC

Observe 519 events
Fit result 91.3 ± $15.6_{(stat)}$ top events

$$\sigma(t\bar{t}) = 6.7 \pm 1.1_{(stat)} \pm 1.6_{(syst)}\,\mathbf{pb}$$

Dominant systematics are
(1) Jet energy scale uncertainty
(2) Q^2 scale for W+jets MC since no well-defined scale for W+jets

b-Tagging: Vertices and Soft Muons

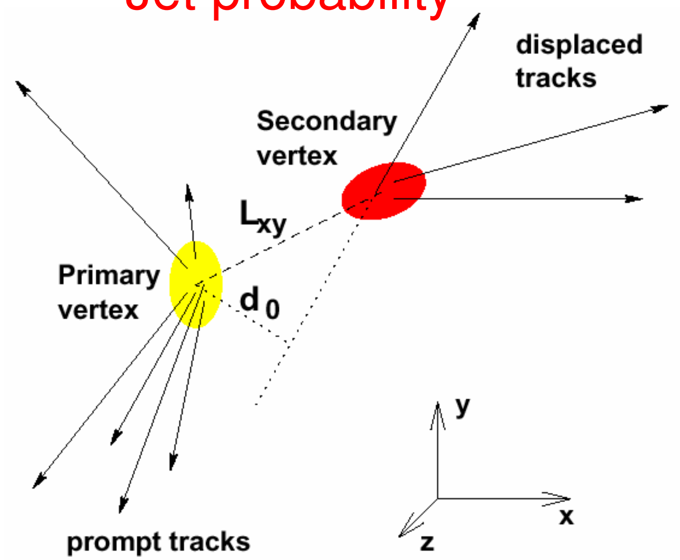
Recall Standard Model $t \to Wb$ branching ratio is ~100%

- **Every top signal event contains 2 B hadrons**
- **Only 1-2% of dominant W+jets background contains heavy flavor**

Improve S:B by exploiting knowledge that B hadrons

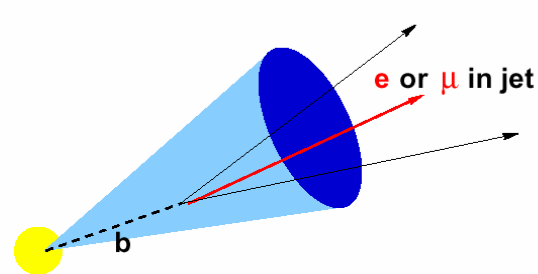
are long-lived and massive

Vertex displaced tracks
Jet probability



may decay semileptonically

Identify low-p_T muon



- $b \to \ell \nu c$ (BR ~ 20%)
- $b \to c \to \ell \nu s$ (BR ~ 20%)

F. Rizatdinova
Top/EWK/QCD Friday

Vertices		Soft muons
55%	Top Event Tag Efficiency	15%
0.5%	False Tag Rate (QCD jets)	3.6%

Lepton+Jets: Single vs Double b-tags

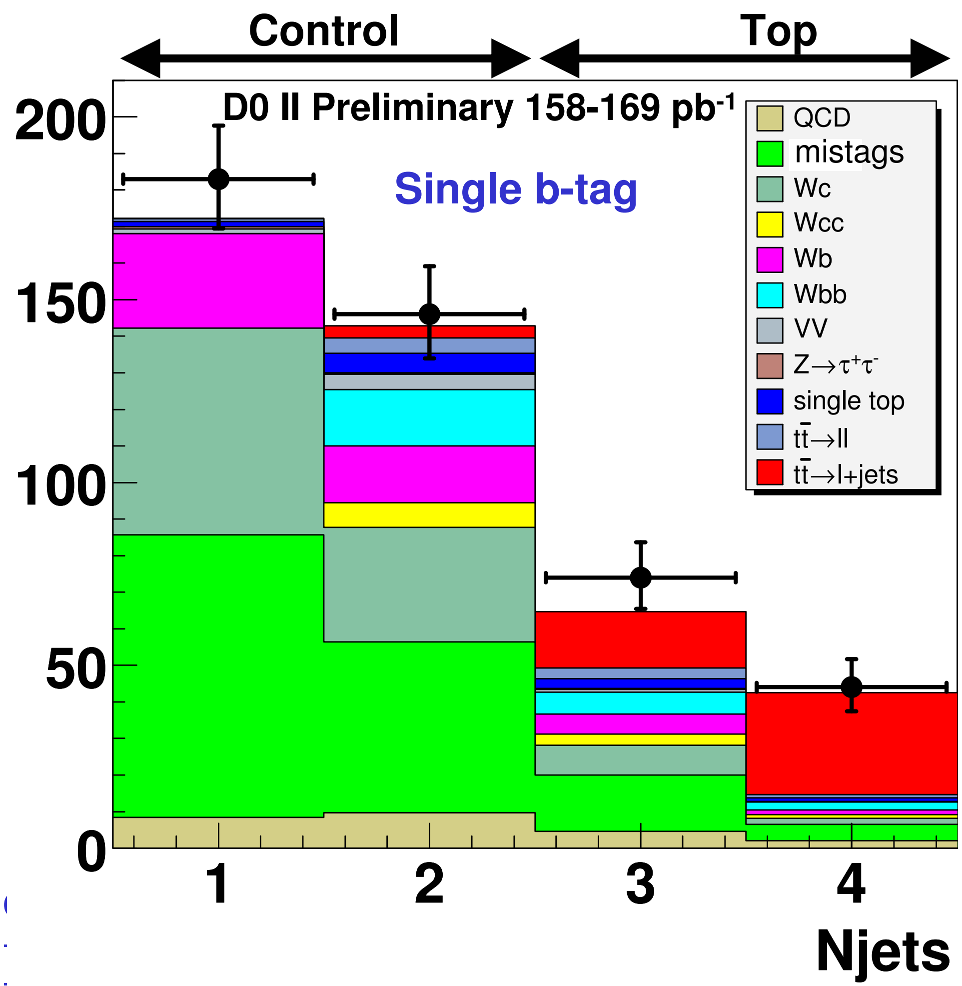
Double-tagged events – cleanest sample of top quarks!

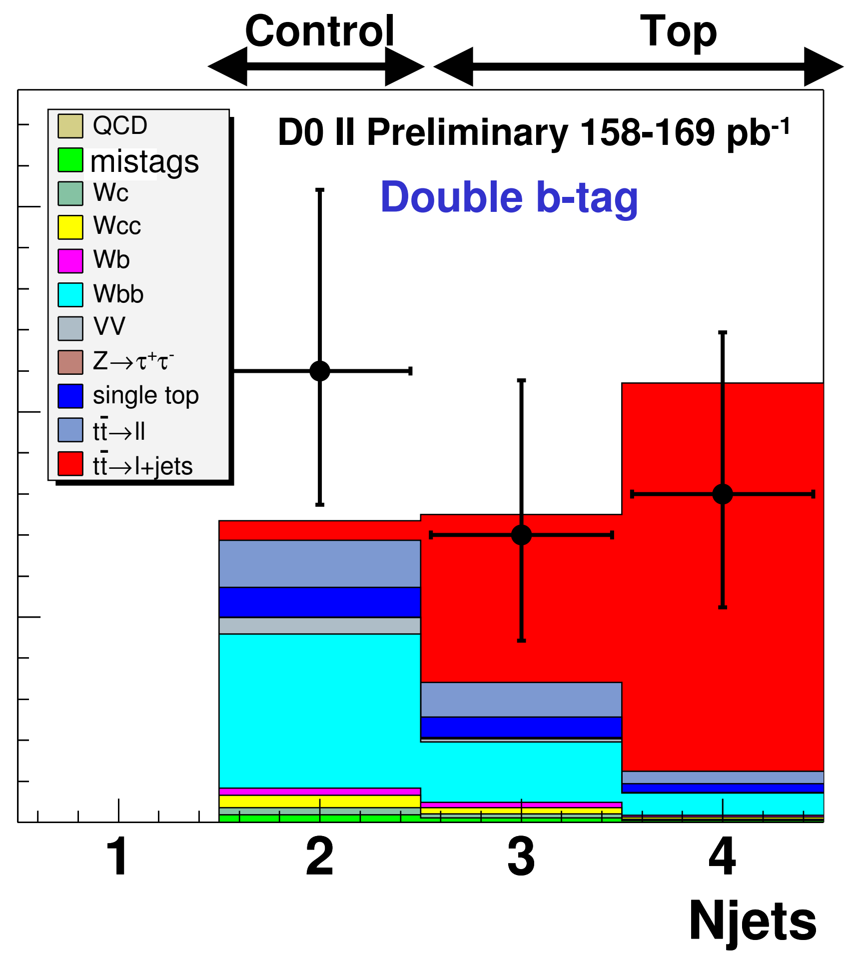
Separate into 8 subsamples – single or double tag, 3 or ≥4 jets, e or μ

F. Rizatdinova
Top/EWK/QCD Friday

$$\sigma(t\bar{t}) = 7.2 \pm^{1.3}_{1.2(stat)} \pm^{1.9}_{1.4(syst)} pb$$

Background estimate
b-tag efficiency



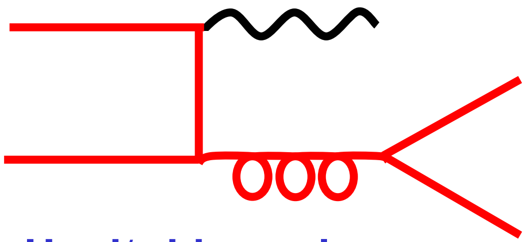


MC issue #1: How to use LO ME?

Leading Order Matrix Element
ALPGEN W,Z+≤6 jets
MADGRAPH W+≤9 jets

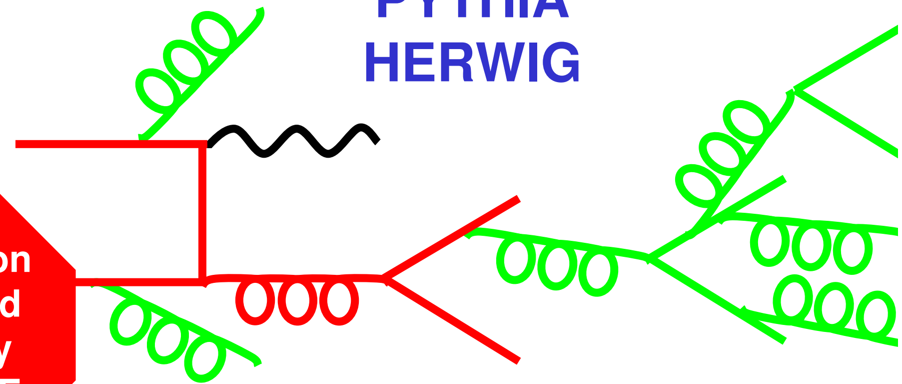
+

Parton Shower MC
PYTHIA
HERWIG



Good: Hard/wide-angle
Bad: Soft/collinear (ME diverges)

STOP!
Hard gluon
described
better by
W+3p ME



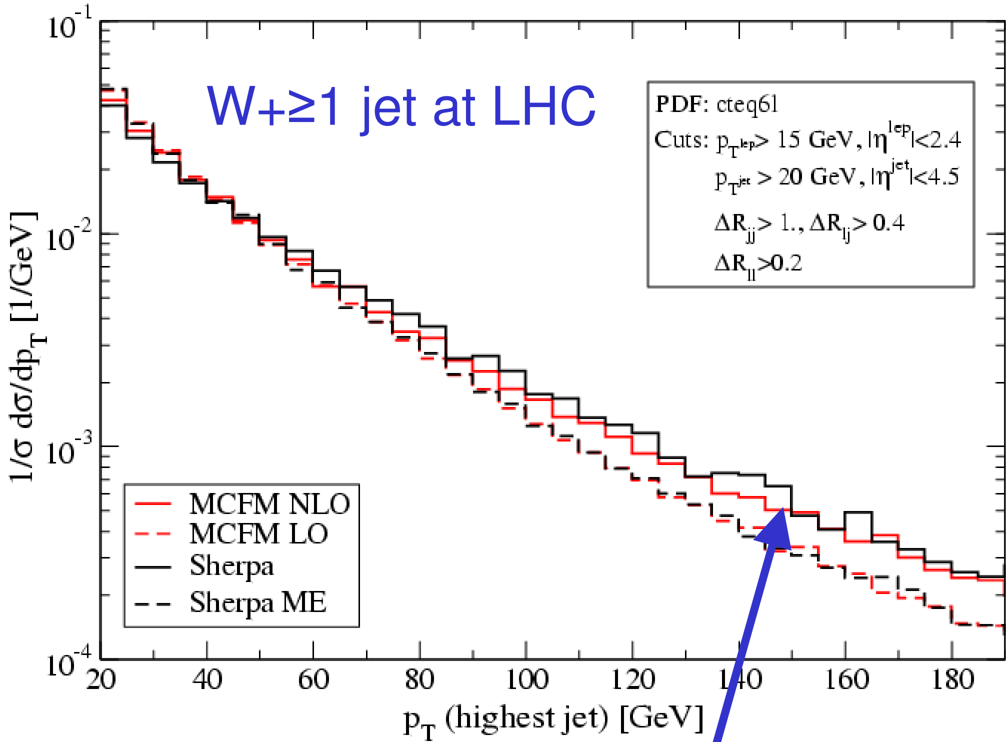
Bad: Hard/wide-angle
Good: Soft/collinear

Interpolation needed!
"matching"
Veto hard emissions in Parton Shower
that are already accounted for by Matrix Element
"avoid double-counting"

CKKW for e+e- hep-ph/0109231
Adapted to hadron collider
PYTHIA/HERWIG S. Mrenna, P. Richardson hep-ph/0312274
SHERPA F. Krauss hep-ph/0407365
Alternative approach from M. Mangano

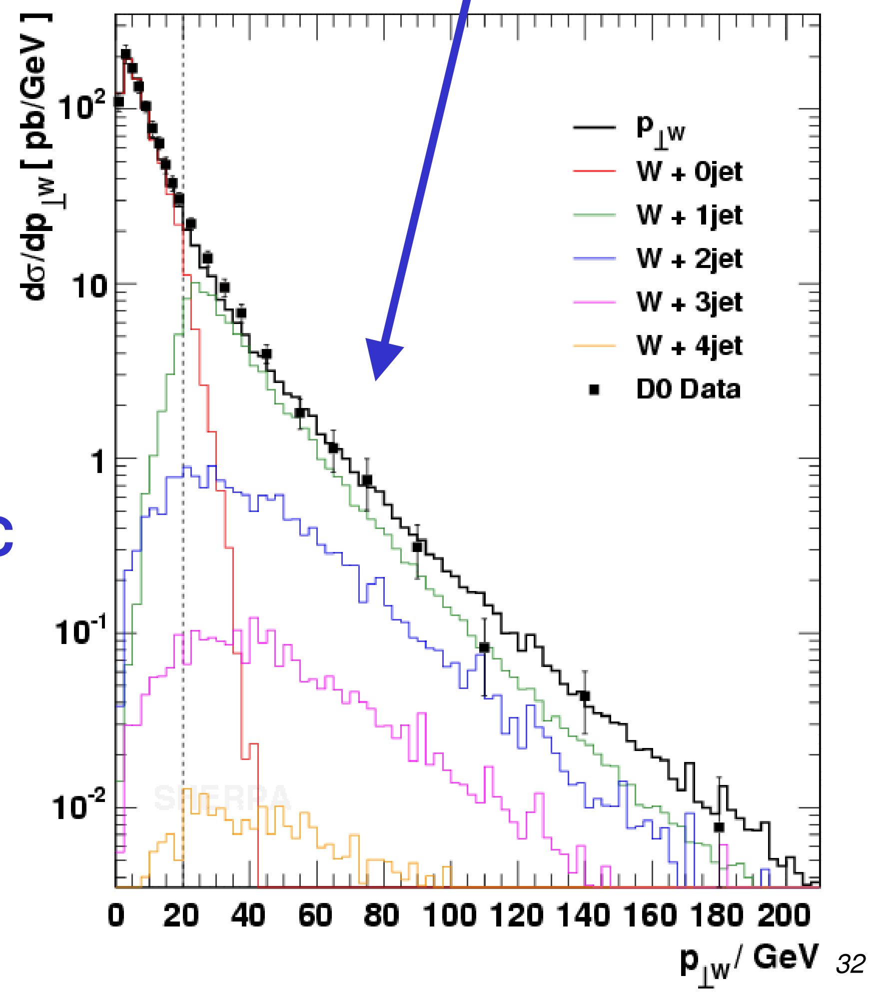
F. Krauss
B. Cooper
Top/EWK/QCD Friday

MC issue #1: how to use LO ME?



SHERPA F. Krauss hep-ph/0407365

Add matched LO Matrix Element MC from 0 to n partons to obtain inclusive W+jet model!



Leading jet pT in W+≥1 jet
Shape of Matched LO Matrix Element MC agrees with NLO prediction
Total rate still needs scale-factor

Important for modeling of kinematics at TeVatron and LHC
W+jets for top is like ttbar+jets for VBF

MC issue #2: how to use NLO?

NLO theory up to W+2jets and Wbb

MCFM J. Campbell, R.K. Ellis http://mcfm.fnal.gov

Calculations still needed

W+3jets (a distant goal)

Nagy & Soper, hep-ph/0308127
Giele & Glover, hep-ph/0402152

Inclusion of b mass effects in Wbb

W. Beenaker et al., hep-ph/0211352
S. Dawson et al., hep-ph/0311216

	Good	Bad	Users
NLO NNLO	Hard emissions Total rates W+jets Heavy flavour fraction at NLO J. Huston, J. Campbell hep-ph/0405276	Soft&collinear emissions Hadronisation No events	Theorists
MC	Soft&collinear emissions Hadronisation Outputs events	Hard emissions Total rates For example, W+4jets is $O(\alpha_s^4)$ Scale uncertainty of 10% leads to 40% uncertainty on total rate	Experimentalists

MC ∩ NLO = Ø ?

(From S. Frixione, HCP'04)

MC issue #2: how to use NLO?

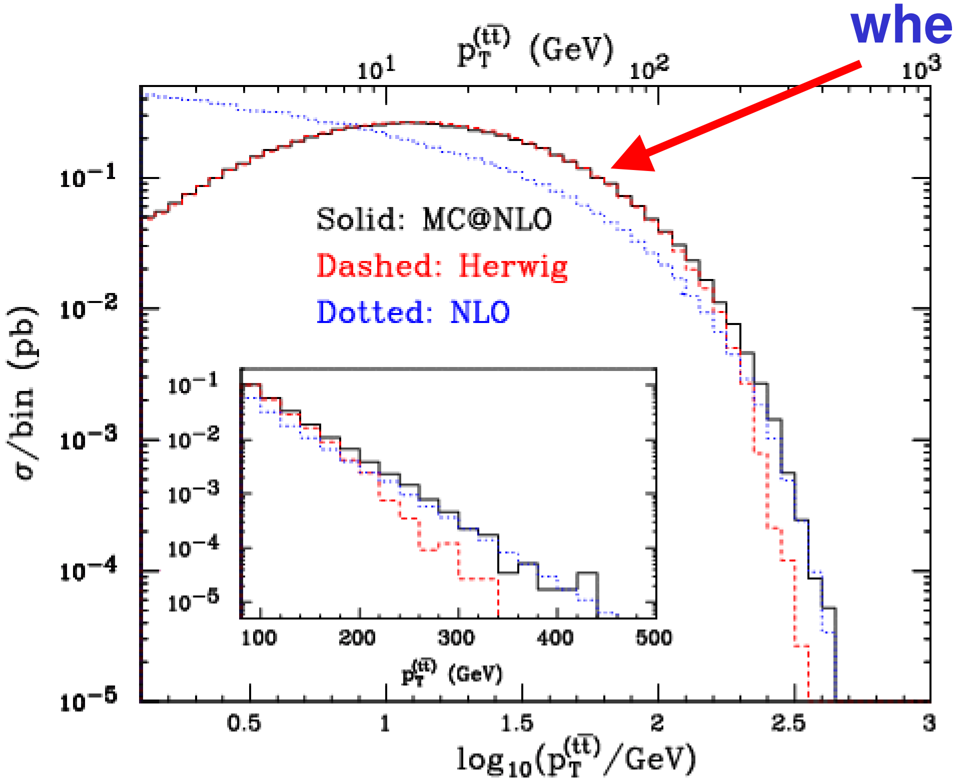
B. Webber
Top/EWK/QCD Friday

MC@NLO

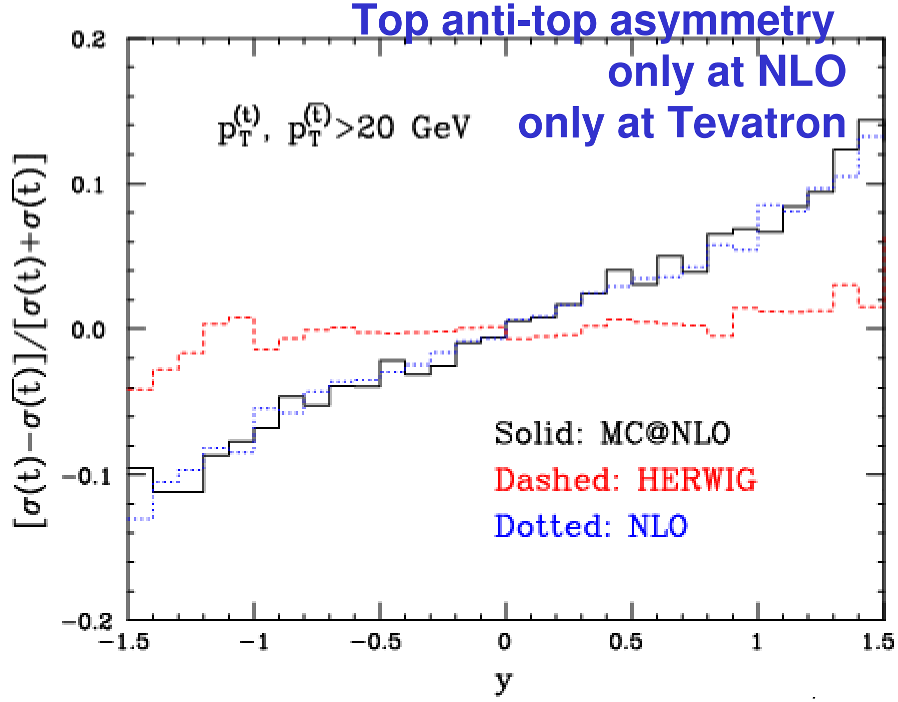
S. Frixione, P. Nason, B. Webber
hep-ph/0305252

Studies with realistic experimental cuts for these processes:
Single vector boson W, Z – no W/Z+jets yet!
Diboson WW, WZ, ZZ
Top pairs
Higgs
Lepton pairs

Top acceptance and kinematics at NLO
e.g. p_T of ttbar system at the Tevatron
MC@NLO rate= NLO rate
MC@NLO and MC predicted shapes are identical
where MC does a good job

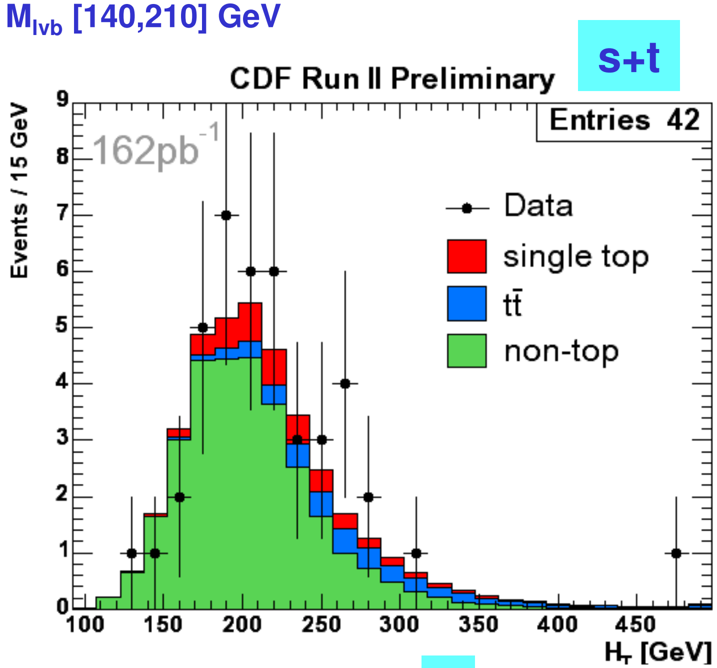


Top anti-top asymmetry
only at NLO
only at Tevatron



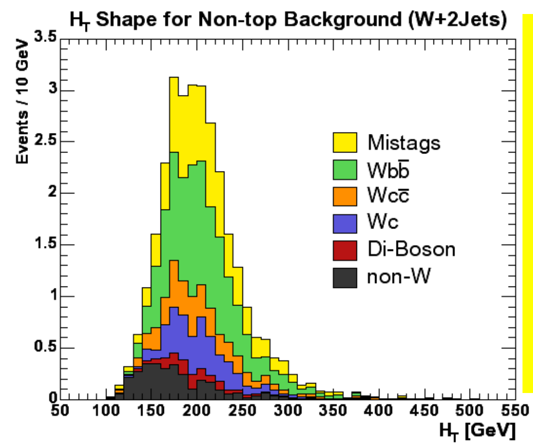
Search for Single Top

1 Lepton p_T>20 GeV
MET>20 GeV
Exactly 2 jets E_T>15 GeV $|\eta|$<2.8
≥ 1 b-tag
$M_{l\nu b}$ [140,210] GeV

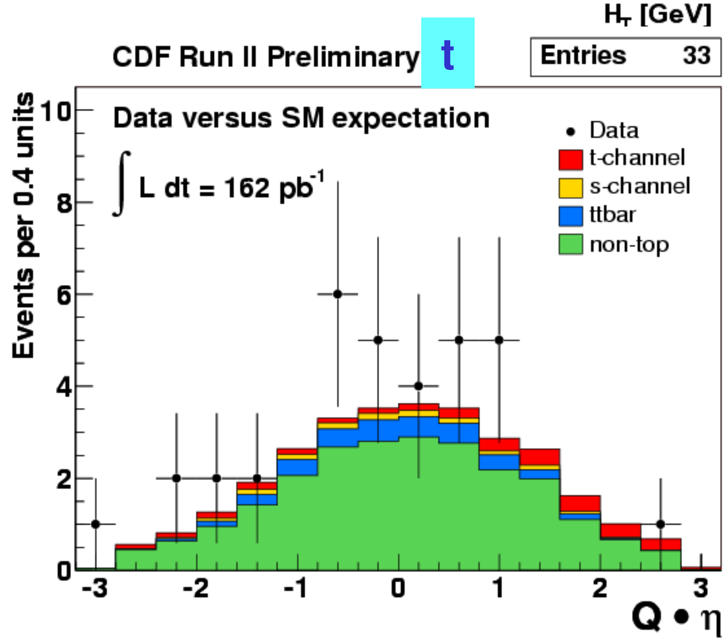


Single top is kinematically
between
W+jets and top pair production
NLO calculations for rate and shape
very important, especially at LHC

R.K. Ellis, J. Campbell hep-ph/0408158



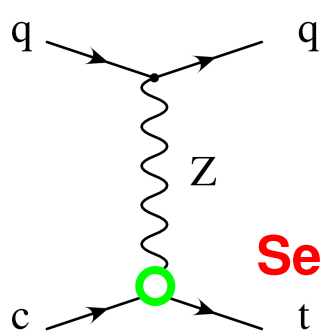
C.P. Yuan et al
hep-ph/0409040
hep-ph/0408180
Q. Cao
R. Schwienhorst
Top/EWK
Thursday



95% C.L. limits Observed (Expected)

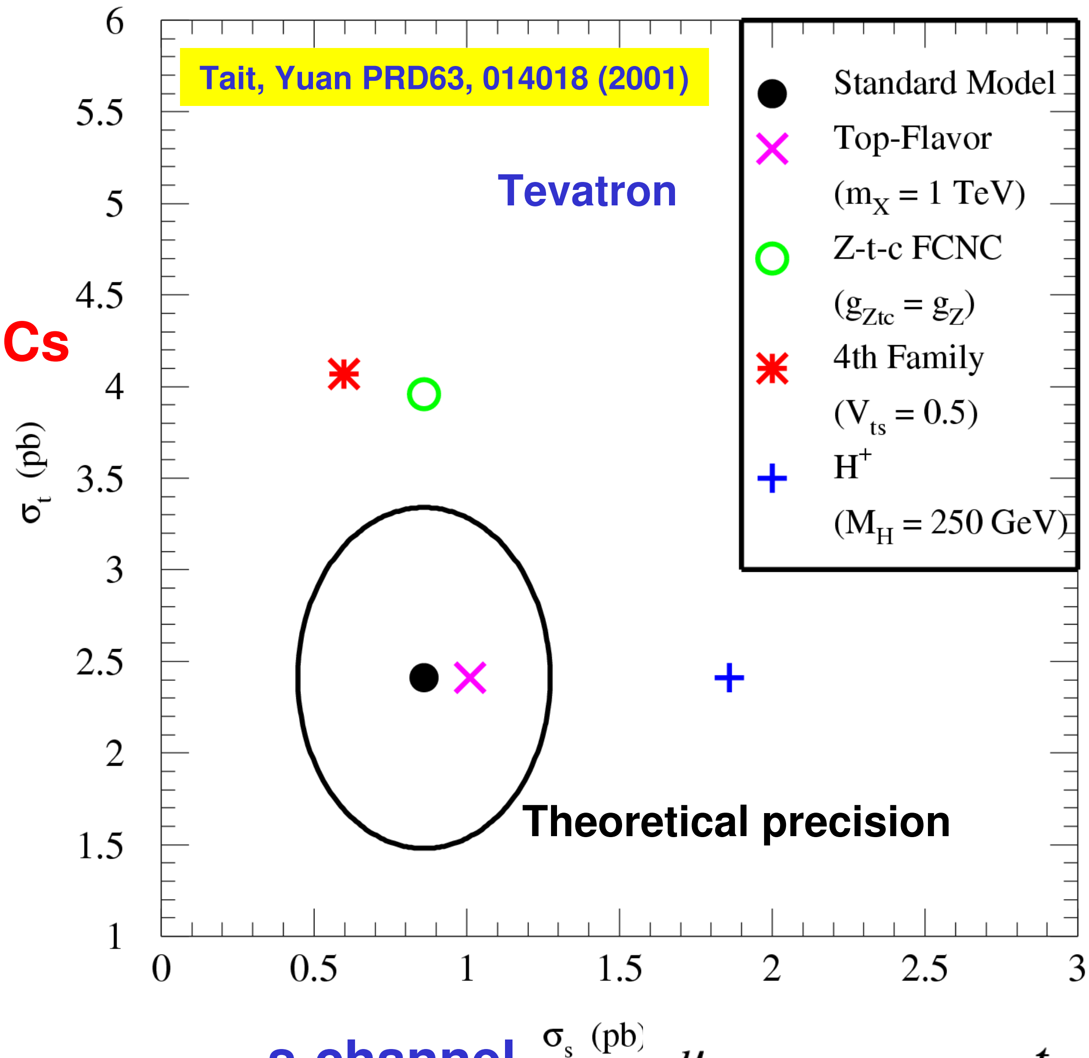
Channel	CDF (pb)	D0 (pb)
s+t	<17.8 (13.6)	<23 (20)
t	<10.1 (11.2)	<25 (23)
s	<13.6 (12.1)	<19 (16)

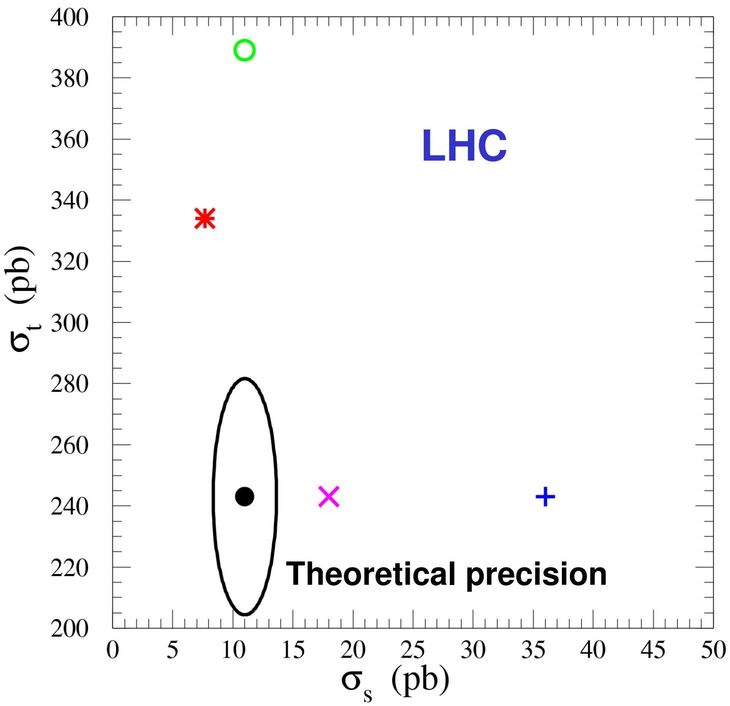
Why search for single top? New physics!



t-channel

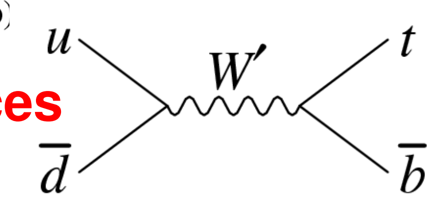
Sensitive to FCNCs



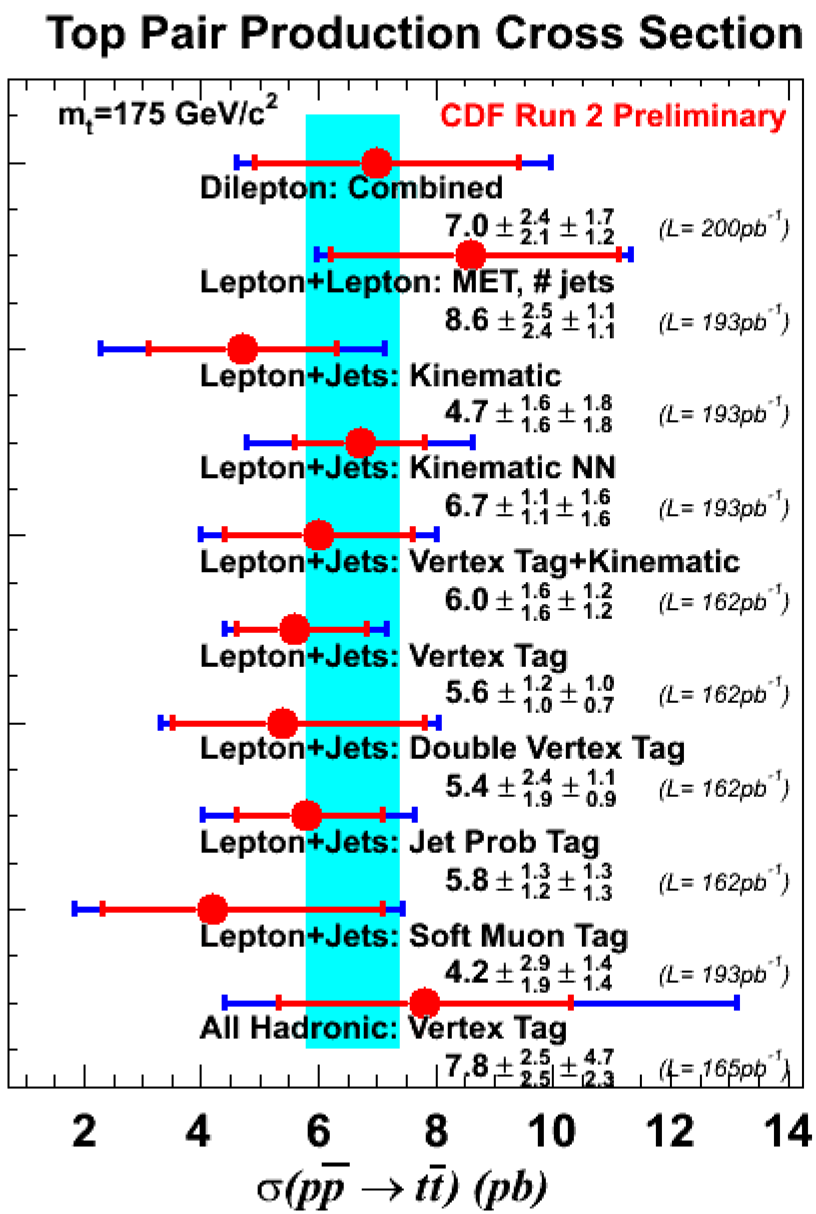


s-channel

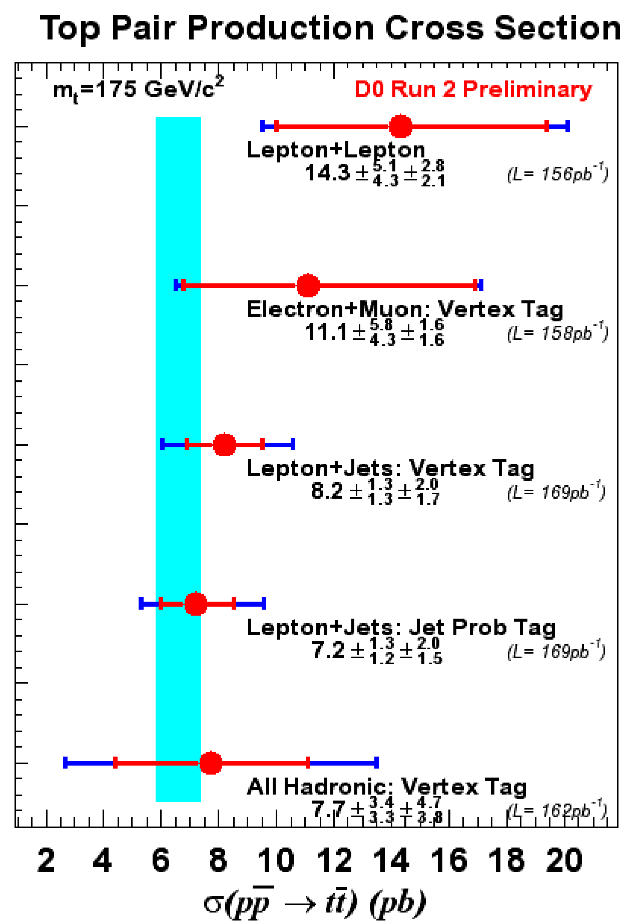
Sensitive to resonances



Top cross-sections: Summary

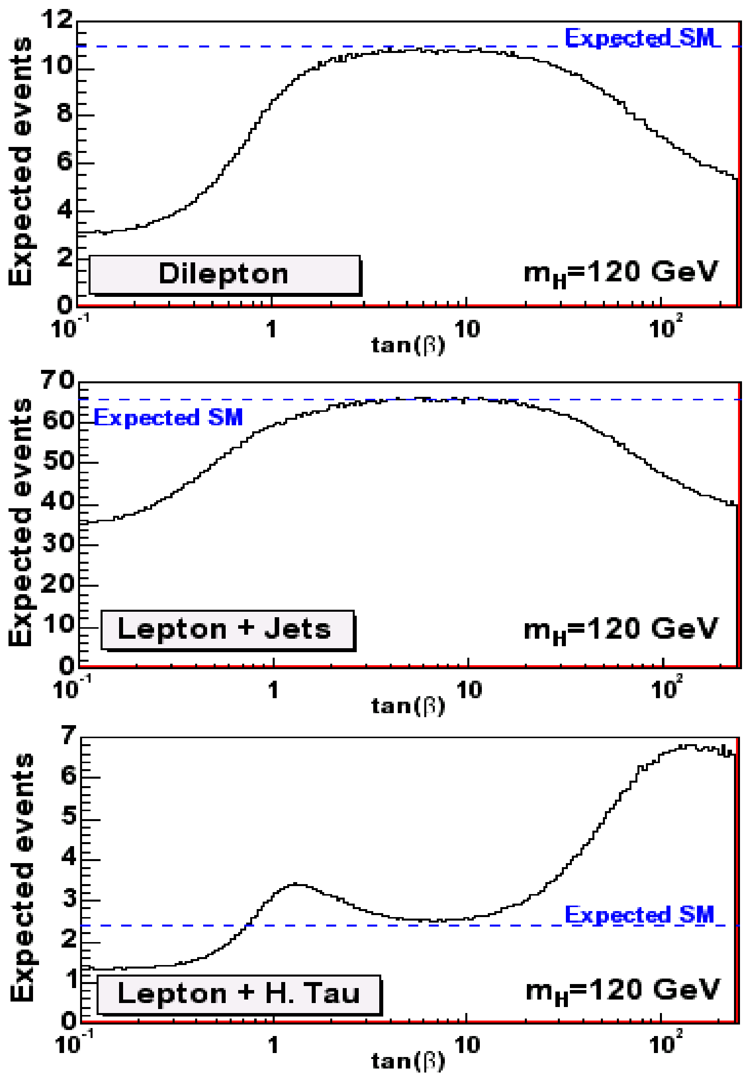


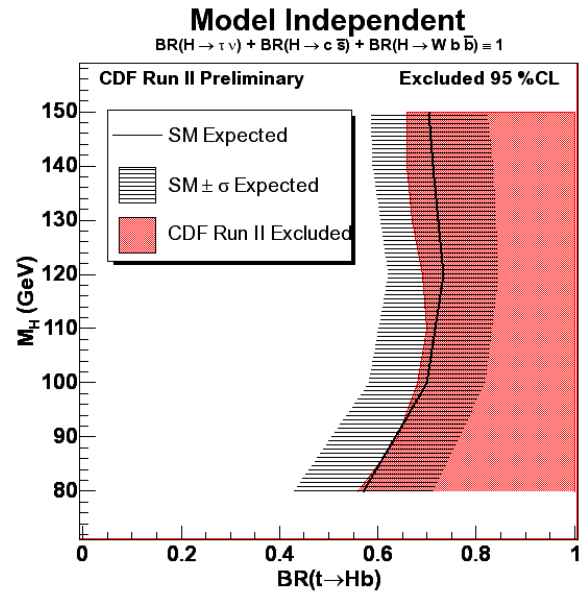
- **Many different measurements**
  - Test different assumptions
  - Compare to look for new physics
  - Combination ~20% precision
  - Currently statistics-limited

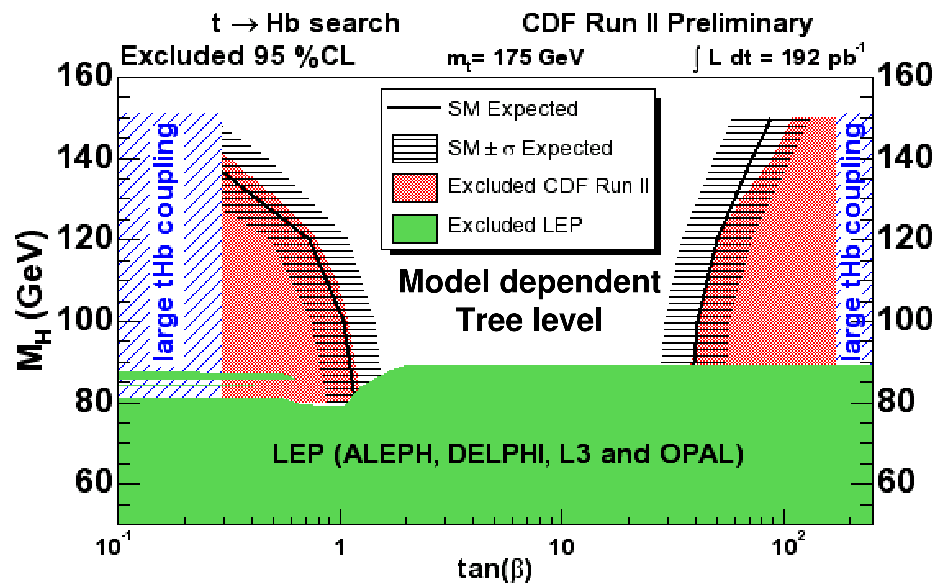


Top Decay: BR(t→H⁺b)?

Does top decay to a charged Higgs instead of a W?
Compare observed number of events in 3 final states







All lower

Lepton+τ higher

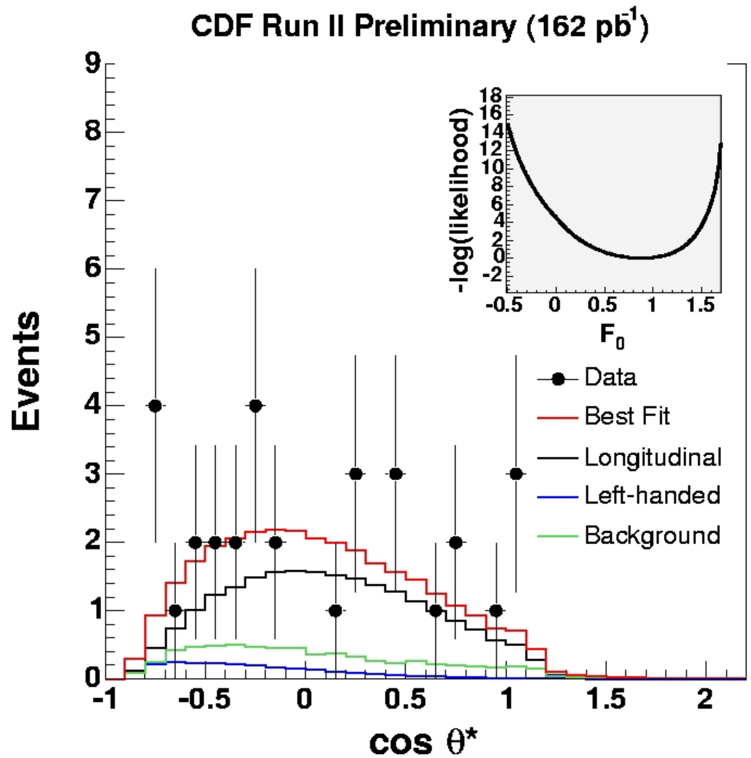
Helicity of W from top decays

Standard Model is V-A theory: predicts W from top are F_0=70% longitudinal, F_-=30% Left-handed

- **Assume F_+=0.0 (ie no V+A)**
  - **Measure F_0**

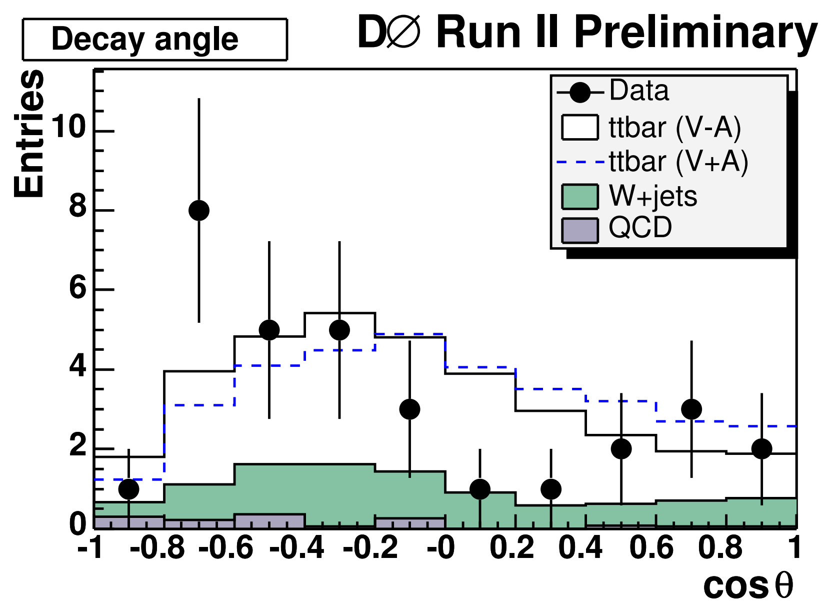
$$F_0 = 0.89 \pm^{0.30}_{0.34} \pm 0.17$$

  - **F_0>0.25 @ 95% C.L.**



"Who says it's a fermion?"
Top squark could mimic final state but W polarisation would be different

- **Assume F_0=70%**
  - **Set limit on V+A fraction**
  - **F_+<0.269 @ 90% C.L.**



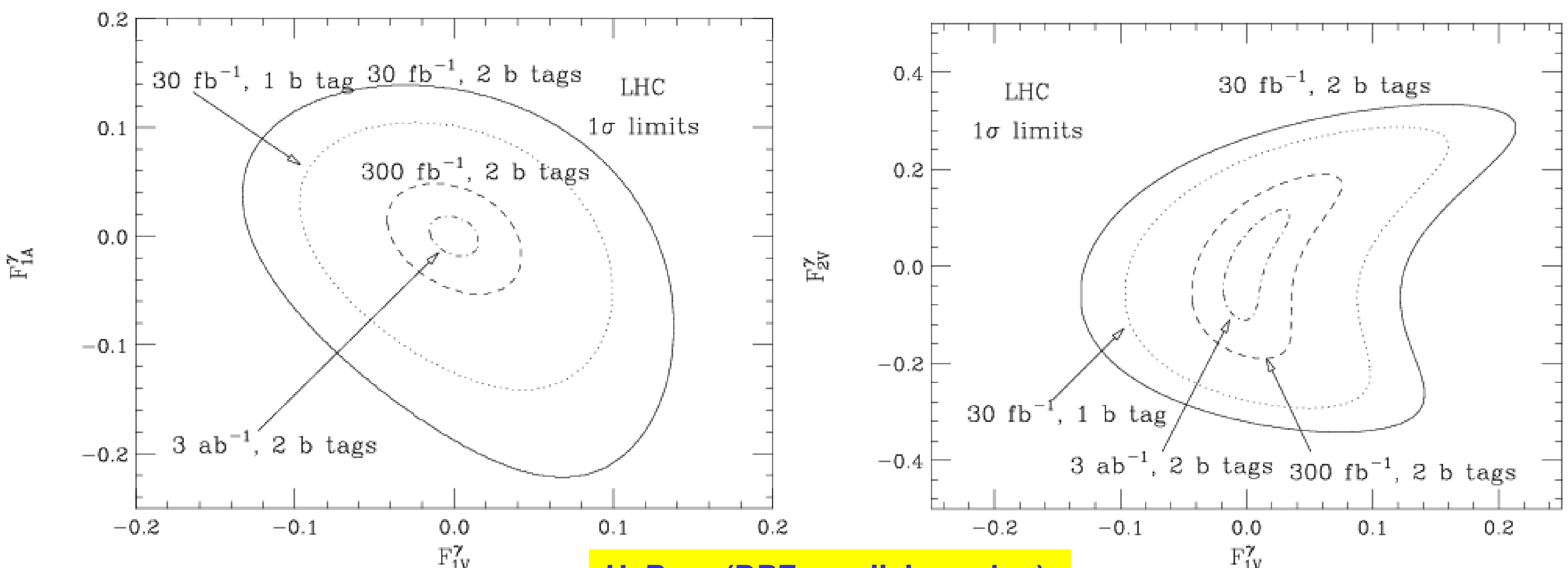
Top Charge and ttγ coupling

Standard Model top charge +2/3 implies t $\rightarrow W^{+}b$

Exotic top charge -4/3, then t$\rightarrow W^{-}b$ instead!

D. Chang et al
PRD59, 091503 (1999)

- Examine photon p_T and angular distributions
- Measure ttγ coupling at LHC to 3-10%
  - More difficult at Tevatron due to QED ISR from qq
  - Difficult at e^+e^- linear collider to disentangle ttγ and ttZ



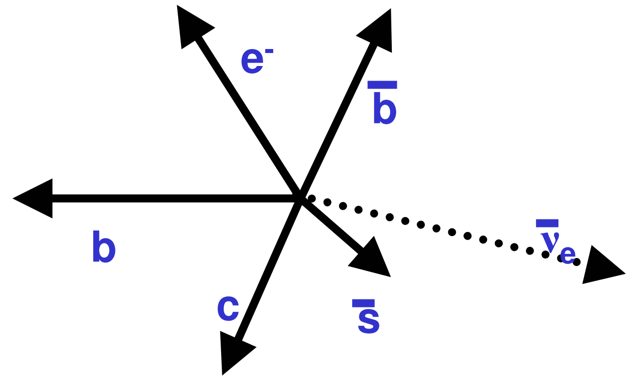
U. Baur (DPF parallel session)
A. Juste, L. Orr, D. Rainwater

Top Mass: Reconstruction

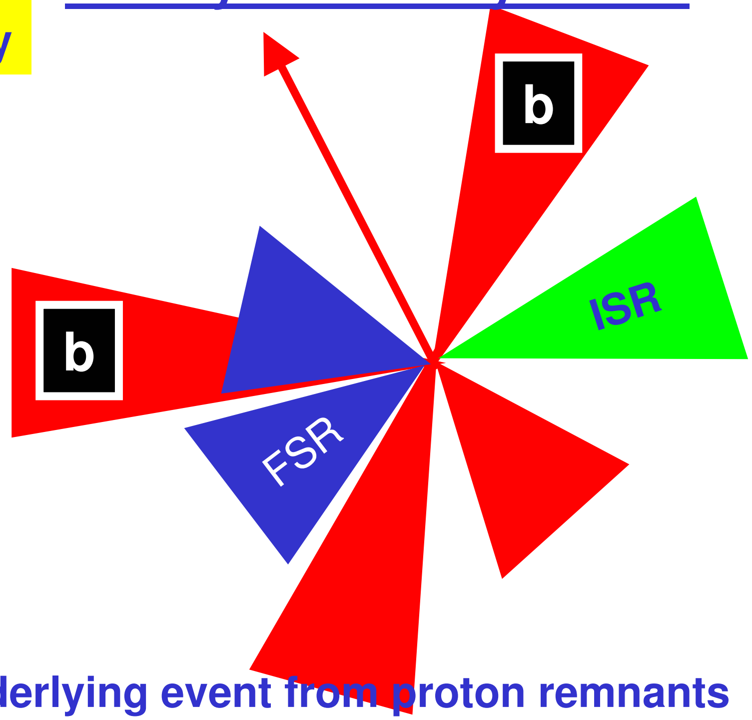
- Lepton+Jets
  - Neutrino undetected
    - P_x, P_y from energy conservation
    - 2 solutions for P_z from $M_{l\nu}=M_W$
  - Combinatorics of 4 highest E_T jets
    - 12 ways to assign jets to partons
    - 6 if 1 b-tag
    - 2 if 2 b-tags (beware of charm!)
  - ISR
    - Extra jets
    - 4 highest E_T jets not always from top decay
  - FSR
    - Poorer resolution if extra jet not included or jet clustering leaves no well-defined jet-parton match
- Dilepton
  - Lower statistics
  - Two undetected neutrinos
  - Fewer combinations – only 2 jets
  - ISR/FSR as above

U.K. Yang
Top/EWK/QCD Friday

Final state from LO matrix element



What you actually detect



+underlying event from proton remnants
+ multiple interactions!

1 Lepton p_T>20 GeV
MET>20 GeV
>3 jets E_T>15 GeV, $|\eta|$<2.0

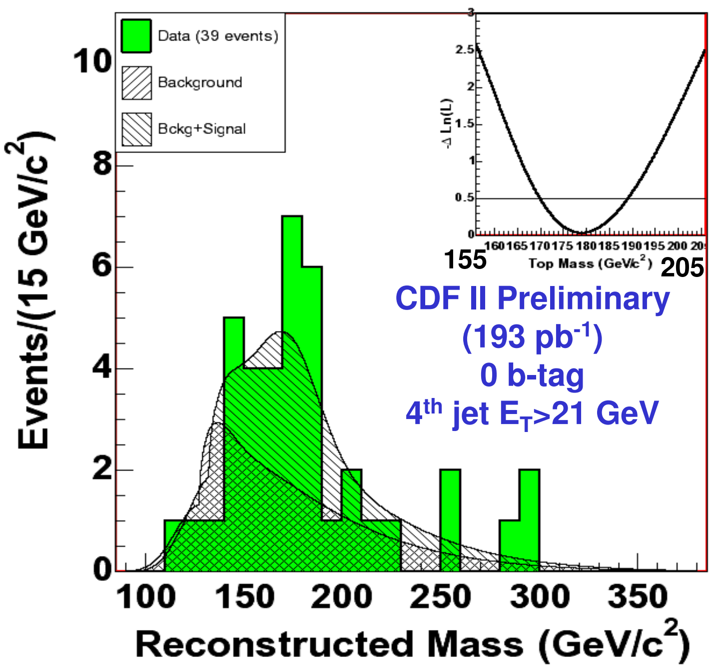
Top Mass: MC Template

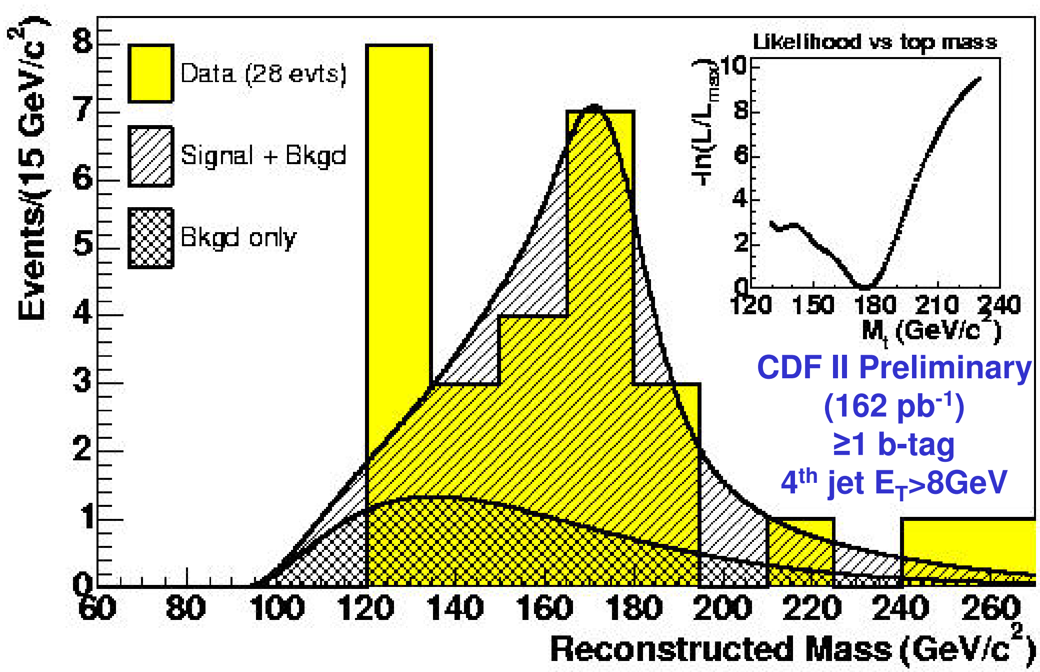
$$\mathcal{P}(\text{measurement}|\text{mtop}) = \mathcal{P}(\text{measurement}|\text{partons}) \otimes \mathcal{P}(\text{partons}|\text{mtop})$$

MC + GEANT detector simulation + reconstruction

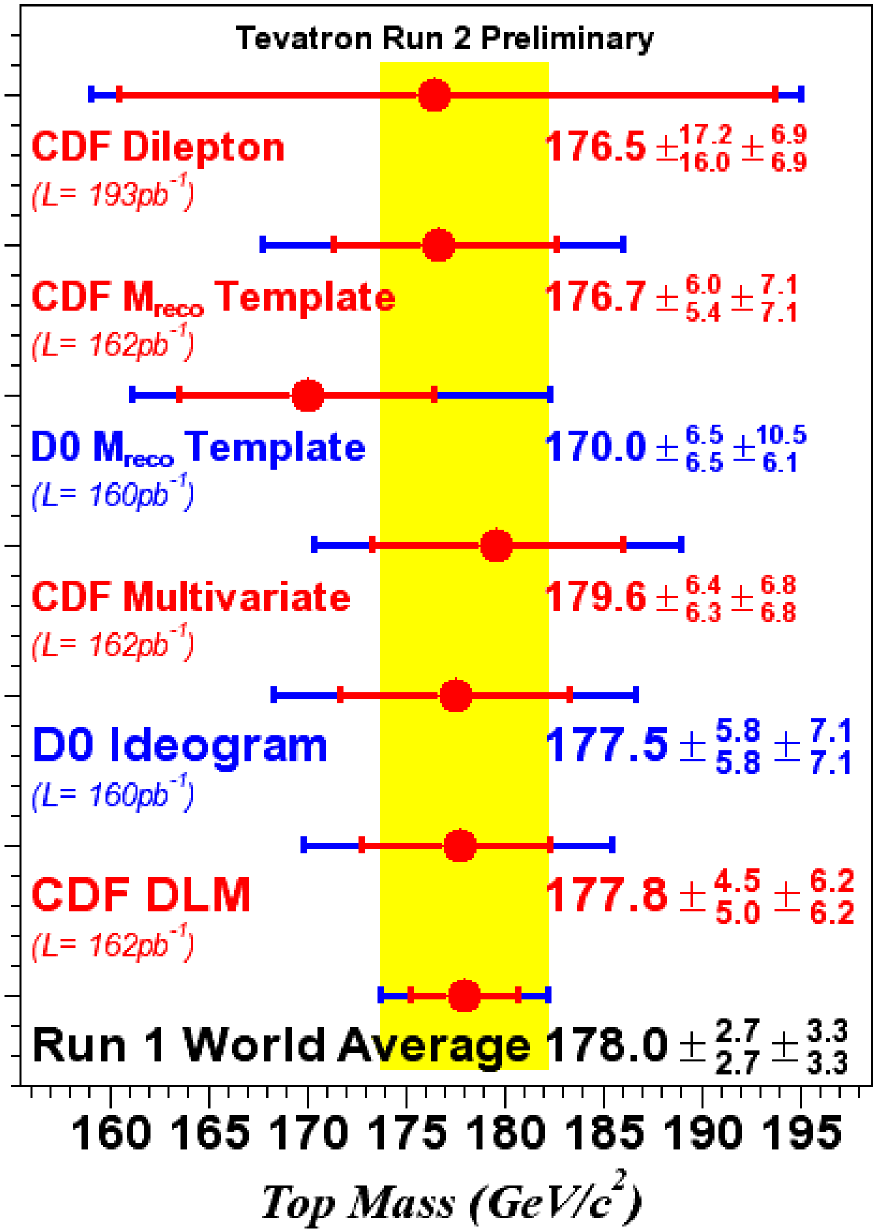
- Choose best combination and neutrino solution with a kinematic fit
- Parameterise reconstructed mass shape with MC
- Maximise Likelihood
- Dominant systematic from jet energy scale

$$m_{top} = 176.7 \pm^{6.0}_{5.4} \pm 7.1 \text{ GeV/c}^2$$





Top Mass: Tevatron Summary



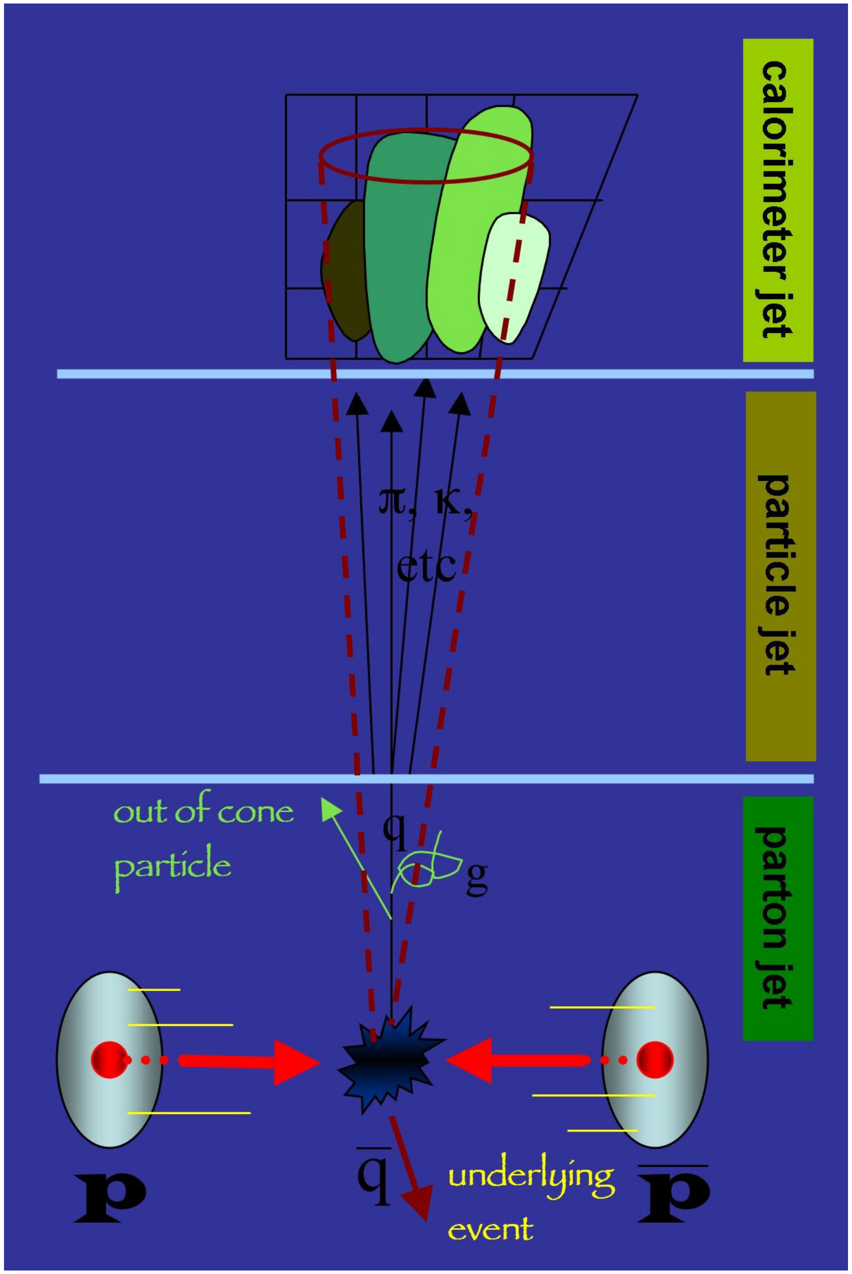
Run II goal is 2.5 GeV per experiment

Trying out many different techniques at this early stage

Dominant systematic from jet energy scale

None of the Run II preliminary measurements are in the world average

Jet Energy Scale



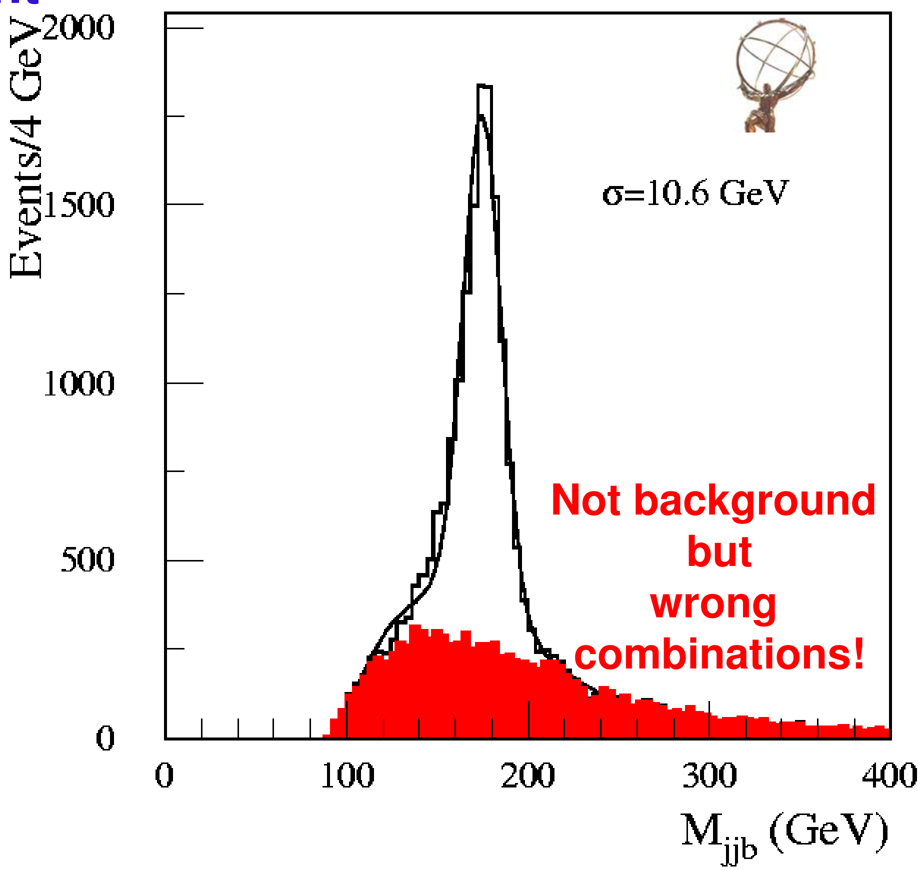
- Dominant systematic on current Tevatron top mass measurements. Will decrease soon as
  - Simulation improves
  - Get smarter with more statistics
- Absolute energy scale is the key!
  - No J/ψ for jets ☹
  - Mission impossible to trigger on Z→qq, though trying Z →bb
  - Must tune Calorimeter simulation at single particle level!!!
  - Accurate inner detector material description important
  - Data control samples
    - γ+jet
    - Z+jet
    - di-jet
    - Hadronic W in top events!

Top mass @ LHC

1 Lepton p_T>20 GeV
MET>20 GeV
≥ 4 jets E_T>40 GeV, $|\eta|$<2.5
2 b-tags

- Much higher statistics…can reduce systematics
  - Double b-tags: reduce background and combinatorics
    - 87,000 top with S/B~78 with 10 fb^{-1}
  - Calibrate jet energy scale *in situ* using hadronic W decay!
  - b-jets – achieve 1% calibration with Z+b?
- Precision 1 GeV per experiment

Source of uncertainty	Hadronic δM_{top} (GeV)	Fitted δM_{top} (GeV)
Light jet scale	0.2	0.2
b-jet scale	0.7	0.7
b-quark fragmentation	0.1	0.1
ISR	0.1	0.1
FSR	1.0	0.5
Combinatorial bkg	0.1	0.1
Total	1.3	0.9
Stat	0.1	0.1



SN-ATLAS-2004-040

Global Standard Model Fit

Changes since Summer 2003

Only use high Q^2 measurements from LEP, SLC and Tevatron

Theory input

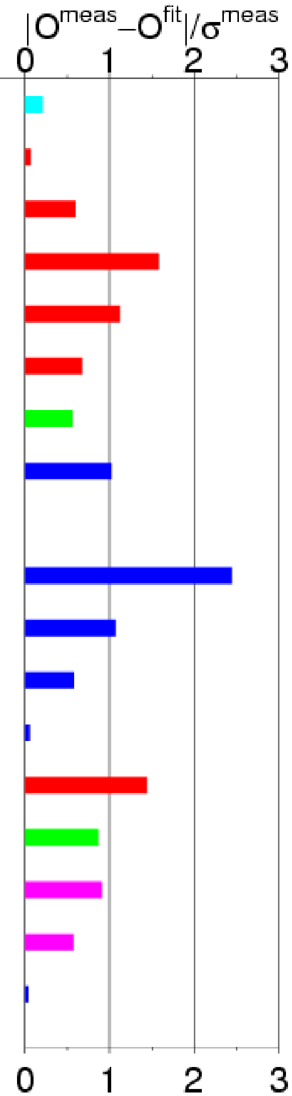
Complete two-loop for M_W
hep-ph/0311148
Fermionic two-loop for $\sin^2\theta^{eff}_{lept}$
hep-ph/0407317

Experimental input

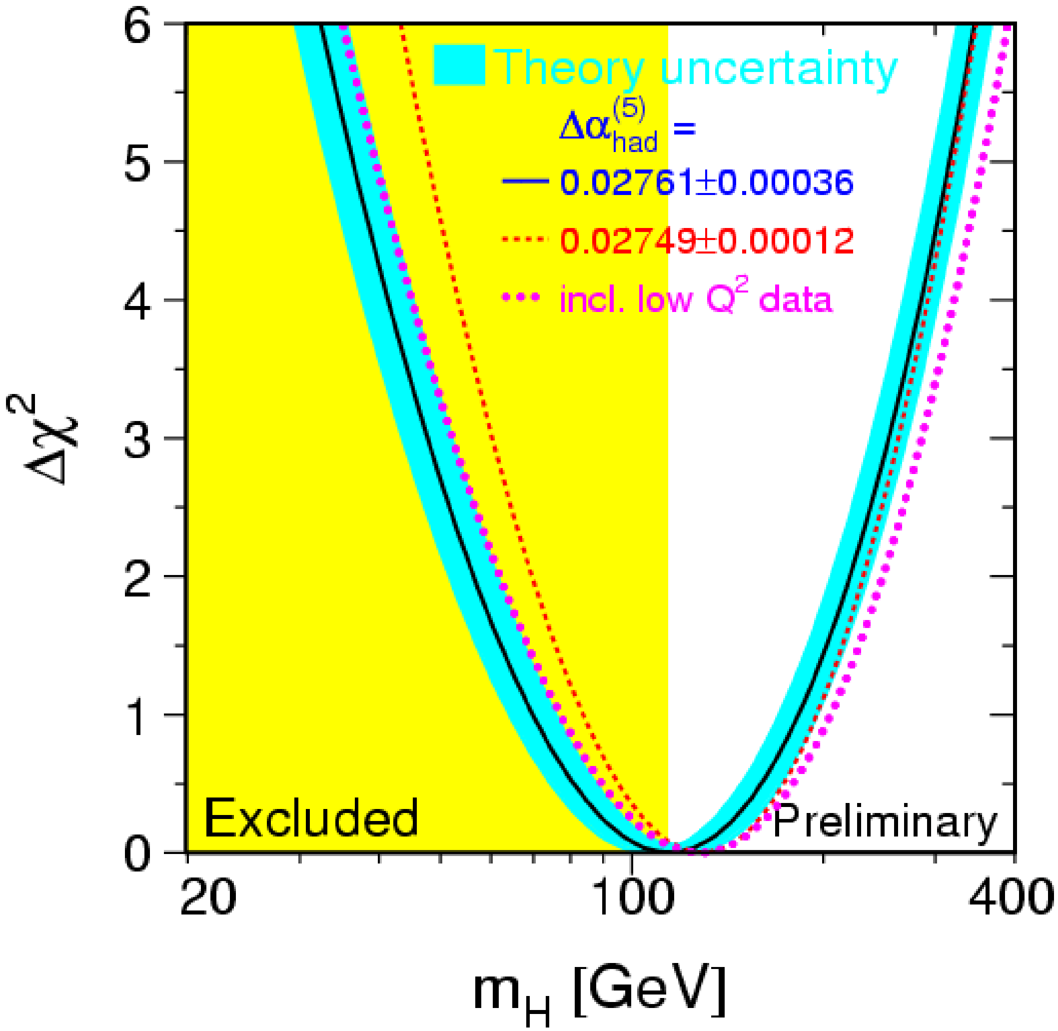
HF combination (LEP/SLC)
W mass combination (CDF/D0 Run I)
top mass (D0 Run I)

Summer 2004

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	0.02769
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4966
σ^0_{had} [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01650
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1483
R_b	0.21630 ± 0.00066	0.21562
R_c	0.1723 ± 0.0031	0.1723
$A^{0,b}_{fb}$	0.0998 ± 0.0017	0.1040
$A^{0,c}_{fb}$	0.0706 ± 0.0035	0.0744
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1483
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.394
Γ_W [GeV]	2.133 ± 0.069	2.093
m_t [GeV]	178.0 ± 4.3	178.2



SM constraint on Higgs boson mass



M_H=114 +69 –45 GeV

M_H<260 GeV @ 95% C.L.

Top mass and Higgs mass 70% correlated in SM

D0 run I updated result increased world average top mass by +3.7 GeV and increased 95% C.L. Higgs mass by +32 GeV

Vital to measure W and top mass well at TeVatron in next few years

Conclusions

Tevatron delivering high luminosities – expect 4-9 fb^{-1}
- More W bosons and top quarks than ever before
- Precision measurements of top properties – is it really top?

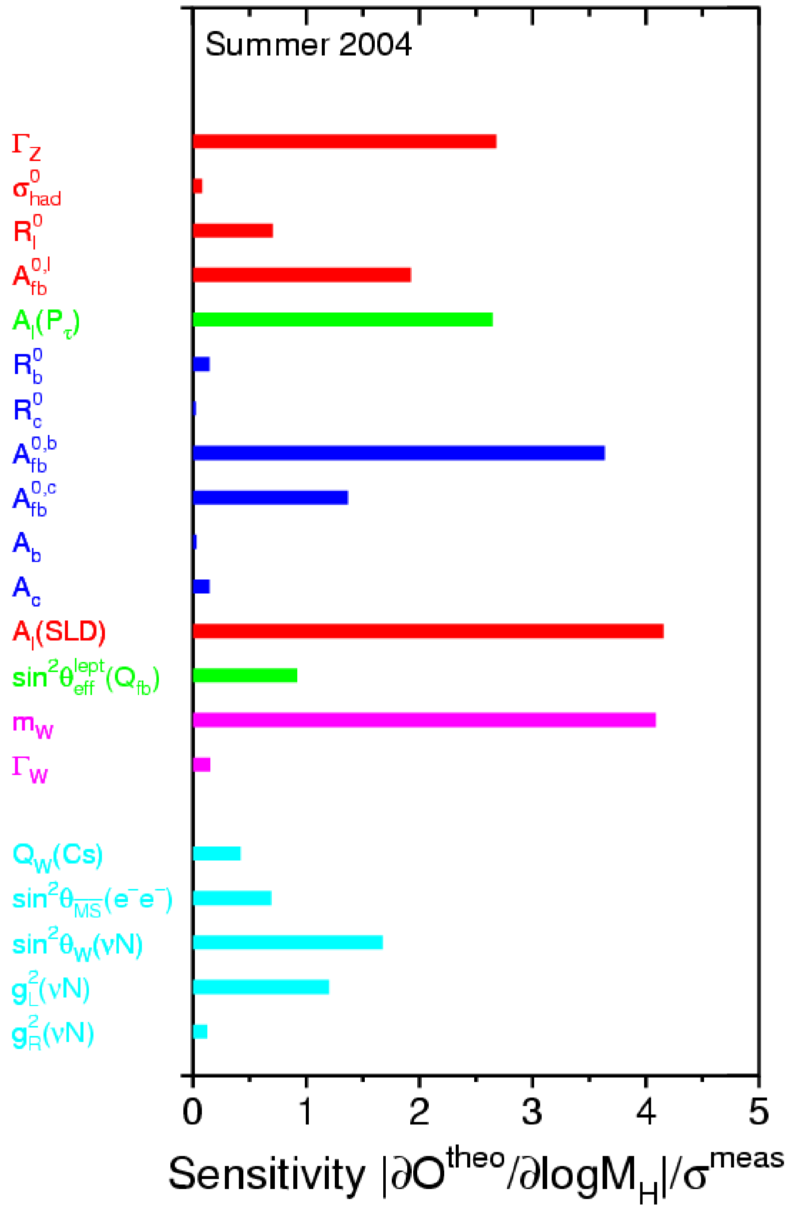
Interaction with theorists & experimentalists very important
- Modeling hadron collisions to required accuracy is hard!
- Tools/calculations from QCD needed
- Theorists need funding and jobs too!

LHC beam in 900 days
- Sharpen tools for ATLAS/CMS physics with experience/data at CDF/D0
- Funding agencies want to see transfer from Tevatron to LHC
- Graduate students & postdocs need data now to learn analysis skills

Let's get to work in the next year with Tev4LHC!

Photo Kevin J. Rice
http://www.justanyone.com/paris1.html

SM Higgs sensitivity



1 Lepton p_T>20 GeV
MET>20 GeV
==4 jets E_T>15 GeV, $|\eta|$<2.0
No b-tagging

Top Mass: Matrix Element

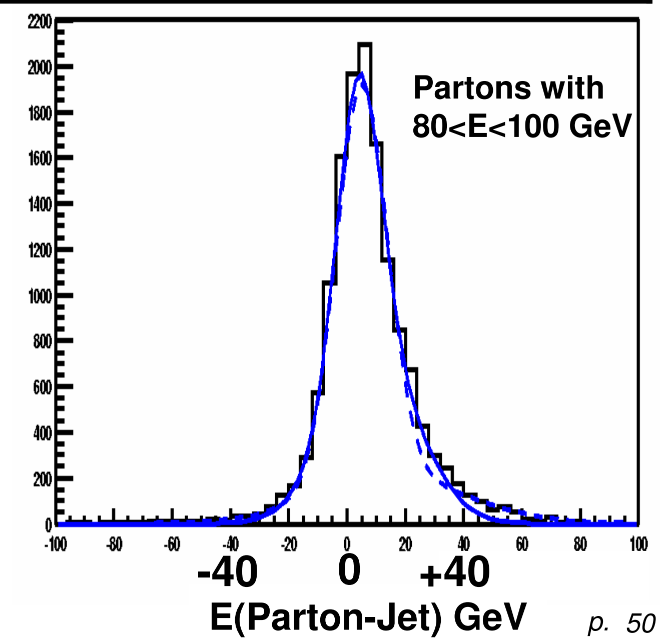
$$\mathcal{P}(\text{measurement}|\text{mtop}) = \underbrace{\mathcal{P}(\text{measurement}|\text{partons})}_{\text{GEANT detector simulation + reconstruction}} \propto \underbrace{\mathcal{P}(\text{partons}|\text{mtop})}_{\text{LO matrix element}}$$

$$P_{t\bar{t}} = \frac{1}{\sigma_{tot}} \int dp_{jet1} dm^2_{top1} dM^2_{w1} dm^2_{top2} dMw^2_2 \sum_{comb,\nu} W_{jet}(x,y) \frac{f(q_1)f(q_2)}{|q_1||q_2|} \phi_6 |M|^2$$

D0 91 events ≥4 jets	Events	(top, bkg)
Template χ^2 cut	77	(29,48)
ME ==4 jets	71	(16,55)
ME ==4 jets and $\mathcal{P}_{bkg}$	22	(12,10)

Updated D0 Run I measurement

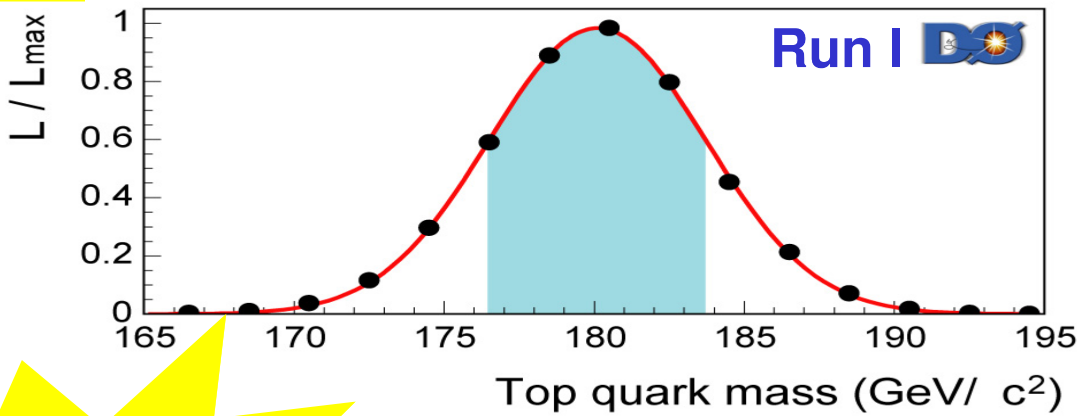
- Use LO matrix element…
  - Exactly 4-jets for final state
  - Background from W+jets VECBOS
- …but LO matrix element needs partons
  - 20 parameters to describe initial (2) and final state (18)
  - Measure lepton momentum (3) and jet angles (8)
  - Energy and momentum conservation (4)
  - Integrate over 5 unknowns
    - Choose W and top masses (4) and a jet momentum (1)
    - Relate poorly-measured jet energies to partons with transfer functions from MC
- Advantages
  - Use all 24 combinations – correct one always included
  - Well-measured events carry more weight
  - 2x statistical power!
  - Systematic from jet energy scale reduced by 40%



Top Mass: Matrix Element

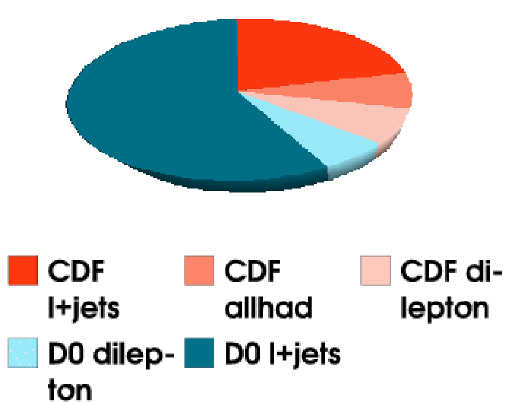
Nature 429 638-642
06/10/2004

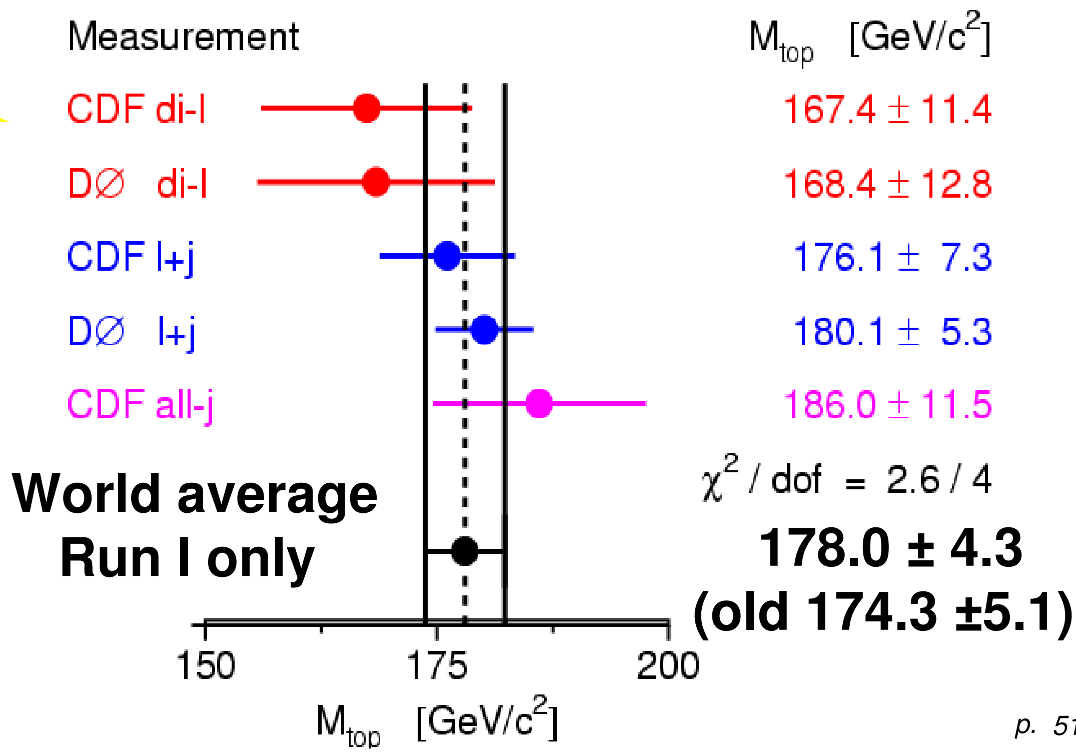
$$m_{top} = 180.1 \pm 3.6 \pm 3.9 \text{ GeV/c}^2$$



New world average
April 2004
hep-ex/0404010

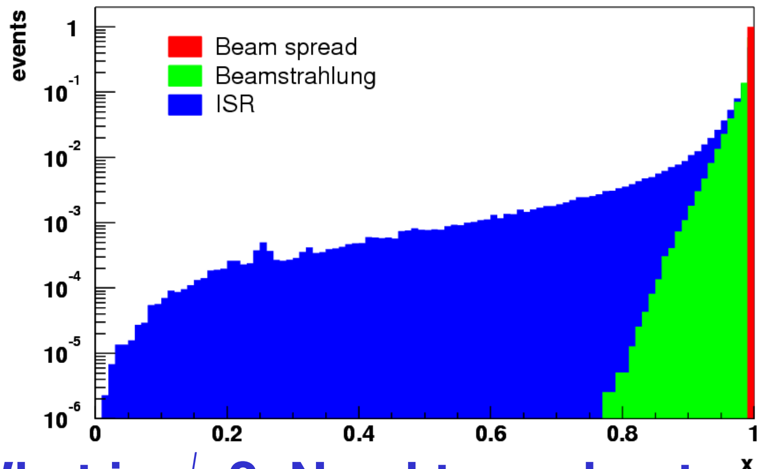
Relative weight in top mass average





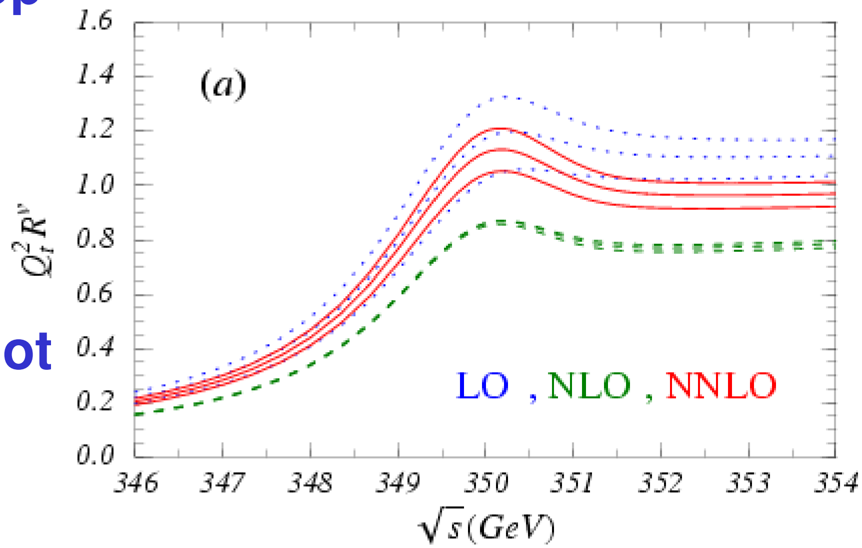
Top mass @ ILC

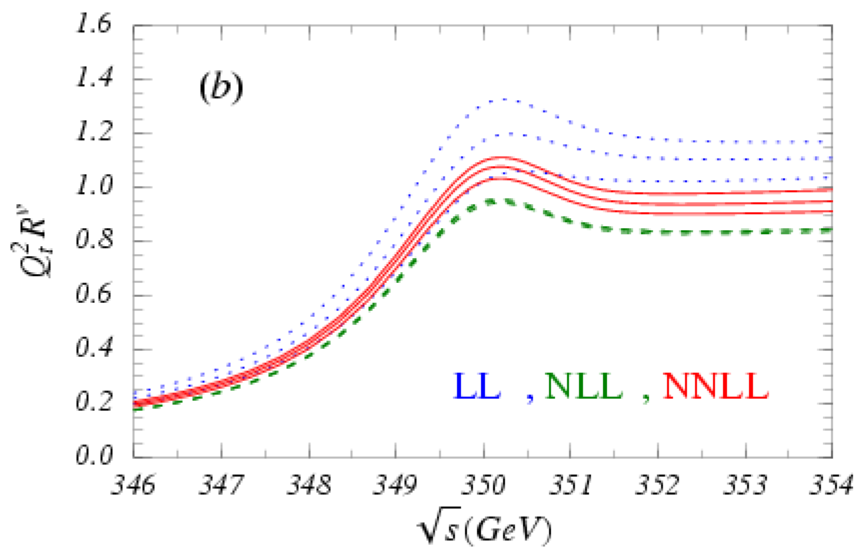
- Scan cross-section at threshold for top pair production
  - Theory calculation in good shape
  - Choose safe definition
- Ultimate limit of 100 MeV
  - Top carries colour charge, mass not well-defined below 100 MeV



- What is √s? Need to understand
  - Beam energy spread
  - Beamstrahlung
  - ISR

D. Miller, S. Boogert
http://www.linearcollider.ca/victoria04/





A. Hoang, hep-ph/0310301

K. Desch
M. Schumacher
hep-ph/0407159

Top Yukawa Coupling

SM prediction is $$g_{ttH} = \frac{\sqrt{2}m_{top}}{246\ GeV} = 1.02 \pm 0.02$$

- **Important to test coupling between Higgs and top quark**
- **Combine LHC and LC for model independent measurement**
  - **LHC: pp →ttH+X – measure σ(ttH)xBR(H→WW) to 20-50%**
  - **ILC: e^+e^-→ZH - measure BR(H→WW) to 2%**
    - **Can do with 500 GeV Linear Collider**

$$\sigma(ttH) \propto g_{ttH}^2$$