Measurement Opportunities at the Tevatron

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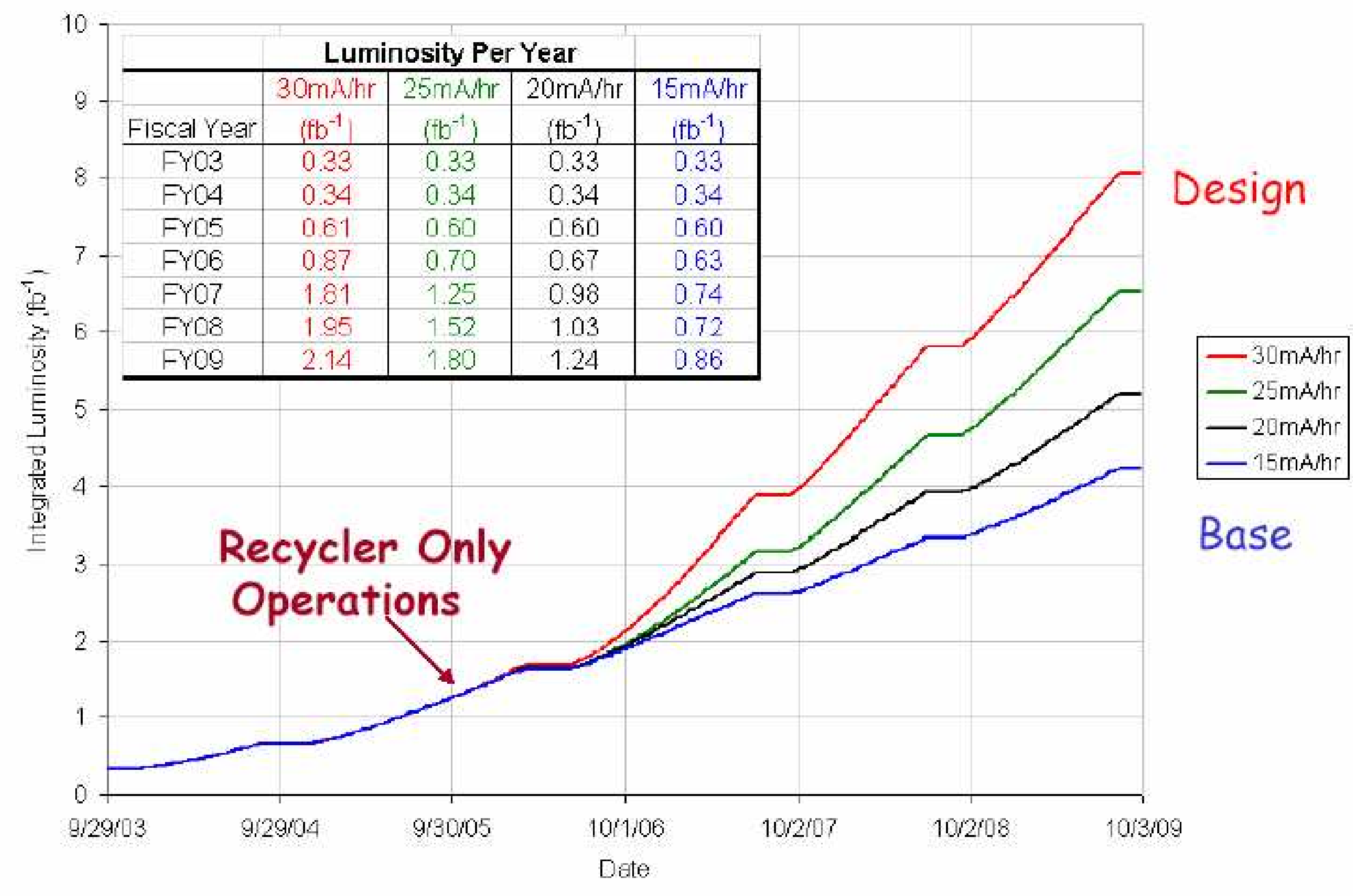
CDF Collaboration Meeting

Oct 28 2005, Fermilab

The Tevatron has delivered more that 1 fb^{-1} of data and is projected to deliver between 4 - 8 fb^{-1} by the end of 2009.



Fiscal Year	30mA/hr (fb^{-1})	25mA/hr (fb^{-1})	20mA/hr (fb^{-1})	15mA/hr (fb^{-1})
FY03	0.33	0.33	0.33	0.33
FY04	0.34	0.34	0.34	0.34
FY05	0.61	0.60	0.60	0.60
FY06	0.87	0.70	0.67	0.63
FY07	1.81	1.25	0.98	0.74
FY08	1.95	1.52	1.03	0.72
FY09	2.14	1.80	1.24	0.86

To put this in context, the LHC is expected to accumulate $\mathcal{O}(10)$ fb^{-1} of data by **2009**.

"What are the advantages of running the Tevatron until the end of 2008 (2009) and accumulating 6(8) fb^{-1} before the LHC has a comparable amount of data?"

A goal for Run II should be the establishment of a "complete" description of Standard Model backgrounds to new physics.

$\longrightarrow$ *To expand beyond our current knowledge, this means obtaining a good understanding of the single top and diboson production processes and an excellent understanding of the $t\bar{t}$ process.*

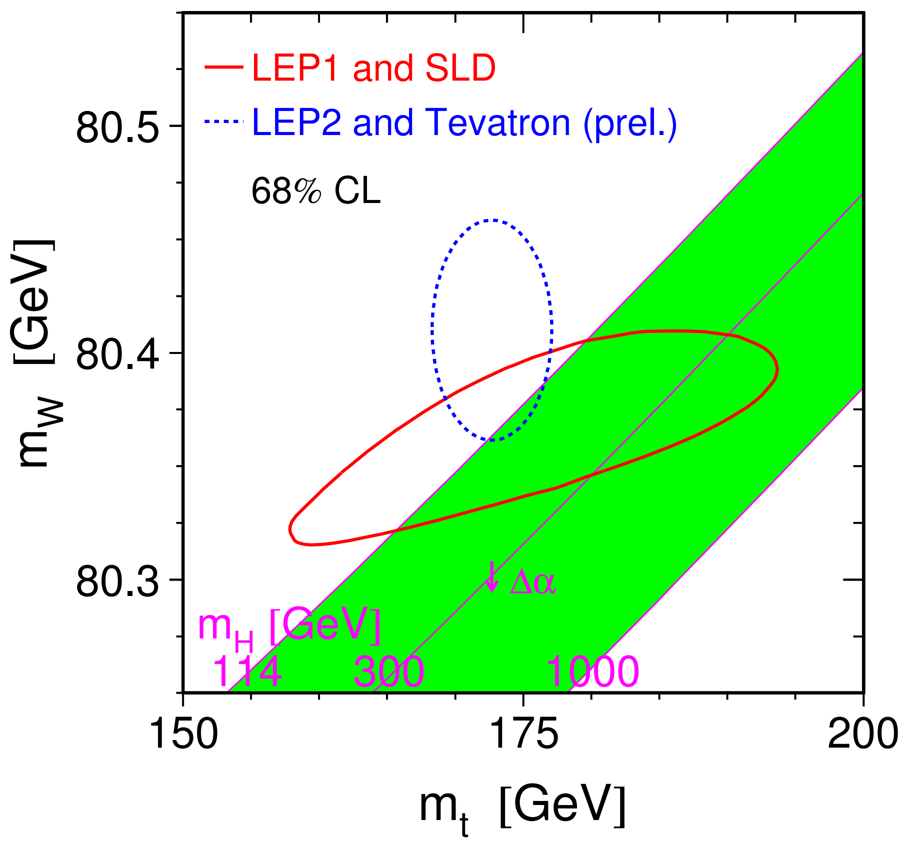
$\longrightarrow$ *Understand background processes to new physics*

$\longrightarrow$ *Extract as much information from the Tevatron as we can in order to reduce uncertainties on PDFs*

$\longrightarrow$ *Tune MC generators in preparation for LHC*

Precision Electroweak Measurements

A key test of the Standard Model, once we have a Higgs mass, is to look for consistency between the W, Top and Higgs mass.



In order to constrain the SM Higgs mass need to measure both m_W and m_t

With 8 fb^{-1} of data, the Tevatron can provide a competitive measurement of the top mass to what is expected from the LHC.

LEP EW WG web pages

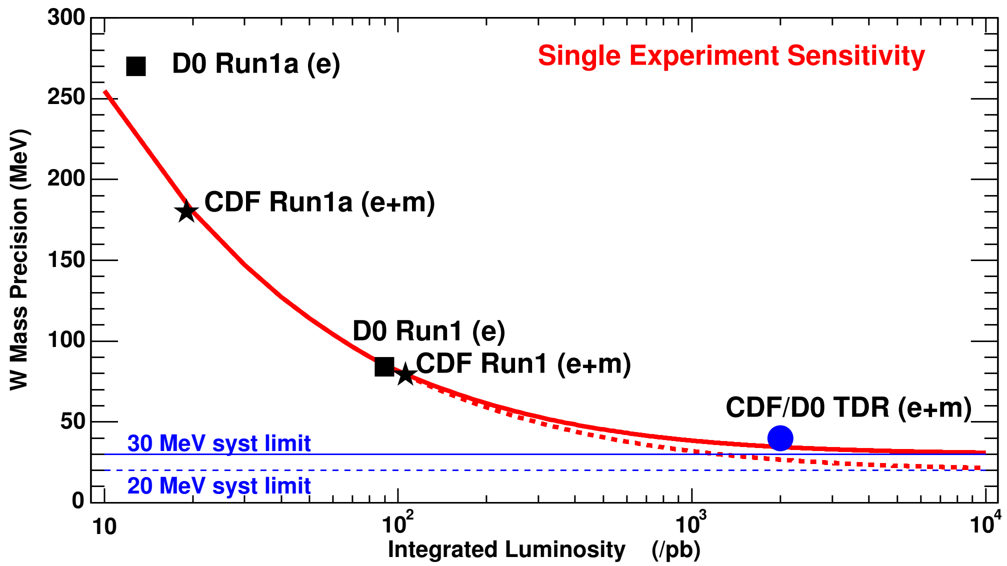
W mass measurement: $\delta m_W \sim 20 - 30$ MeV

Uncertainties assumed to scale with luminosity

- Statistical uncertainties
- Systematic uncertainties such as: Energy and momentum scale and Hadron Recoil against W

Uncertainties assumed not to scale with luminosity

- W production and decay: PDFs, $d(\sigma_W)/d(p_T)$, higher order QCD/QED effects (Assumed to be between 20 - 30 MeV)



LHC expectations are:

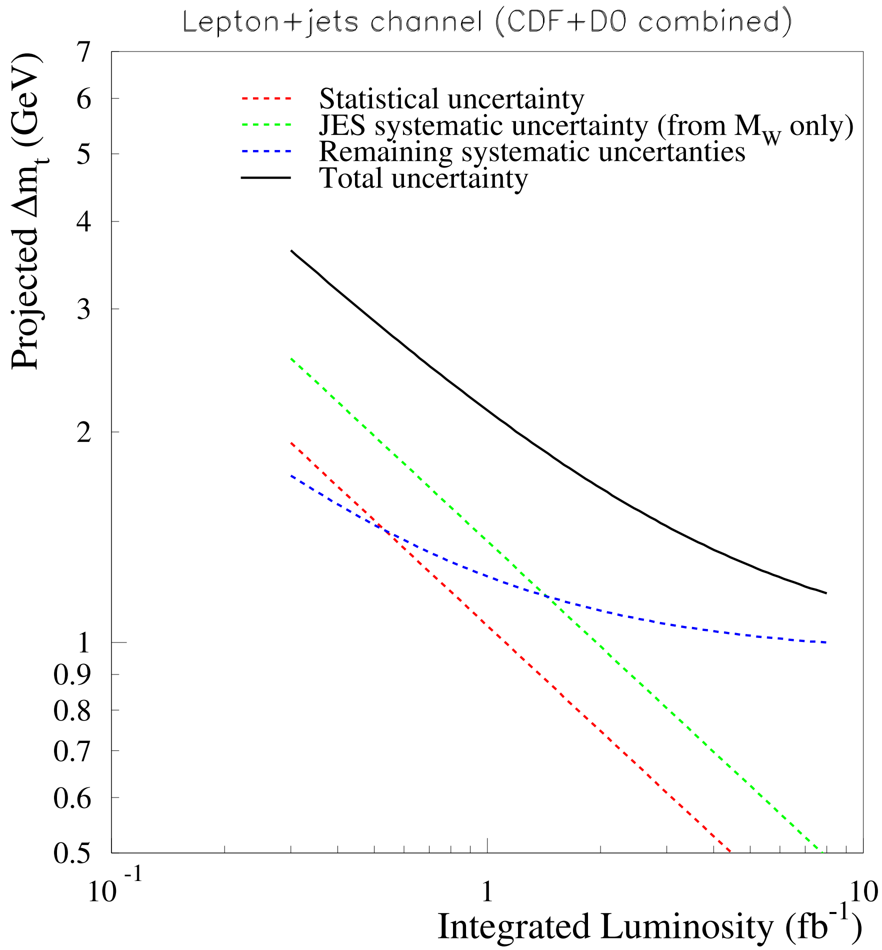
$\delta m_W \sim 10 - 20$ MeV

Requires:

→ *low luminosity running*

→ *good understanding of the detector*

Top Mass Measurement: $\delta m_t \sim 1.5$ GeV



Similar to the uncertainty on the top mass using the basic analysis at the LHC

$4\ \text{fb}^{-1} : \delta m_t = 1.4$ GeV

$8\ \text{fb}^{-1} : \delta m_t = 1.2$ GeV

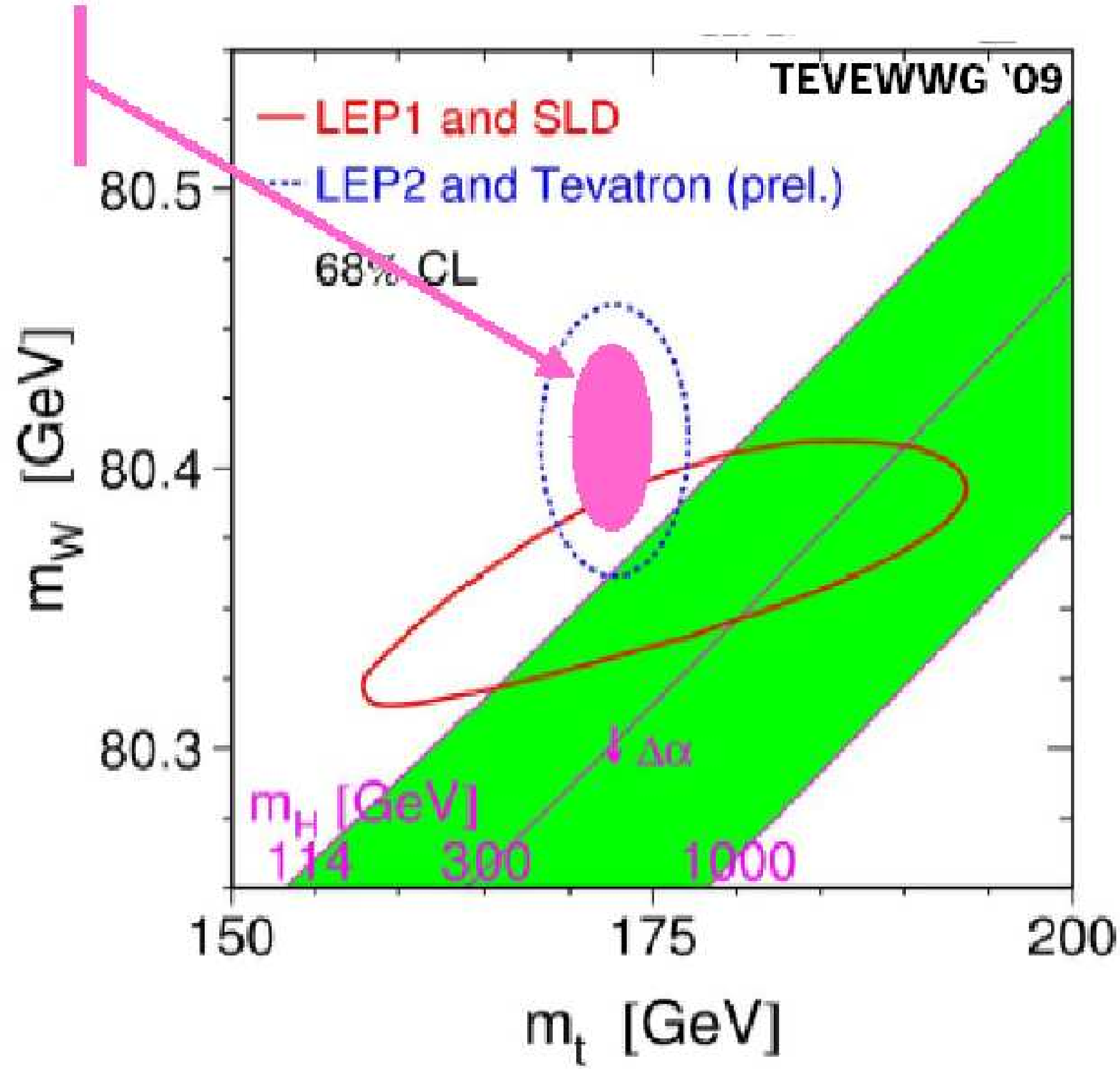
LHC predicts 1.5 GeV (hep-ph/0412214)

Perhaps as good as 1.0 GeV (hep-ex/0403021)

Expect to take several years to commission and fully understand the new LHC detectors and to process the data before precision measurements will be available...

Prospects from reducing the errors on m_t and m_W

$\delta m_t = 1.2$ GeV
$\delta m_W = 24$ MeV

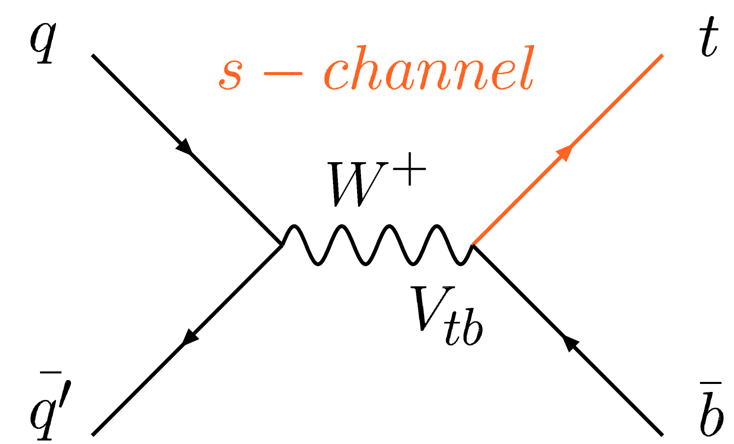


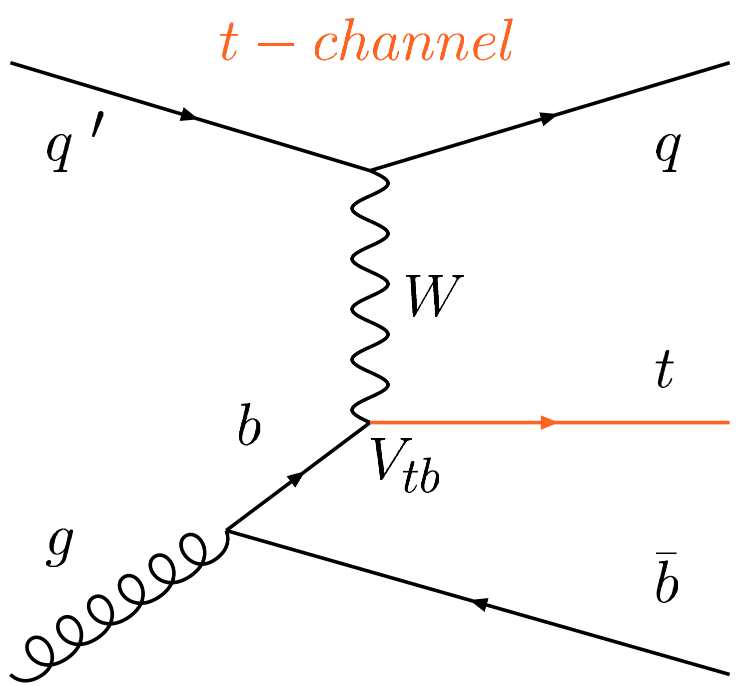
→ *Provides tighter constraints on the SM Higgs*

→ *Could be available near the start of LHC physics running*

J. Hobbs, presentation to P5

Single top production





→ *Tests the SM, search for new physics*

→ *Important to fully understand top production (probes V_{tb})*

→ *Important for Higgs searches*

→ *Probes the heavy flavor content of the proton*

SM Predictions:

$\sigma(\mathrm{s-channel}) = 0.88 \pm 0.14$ pb

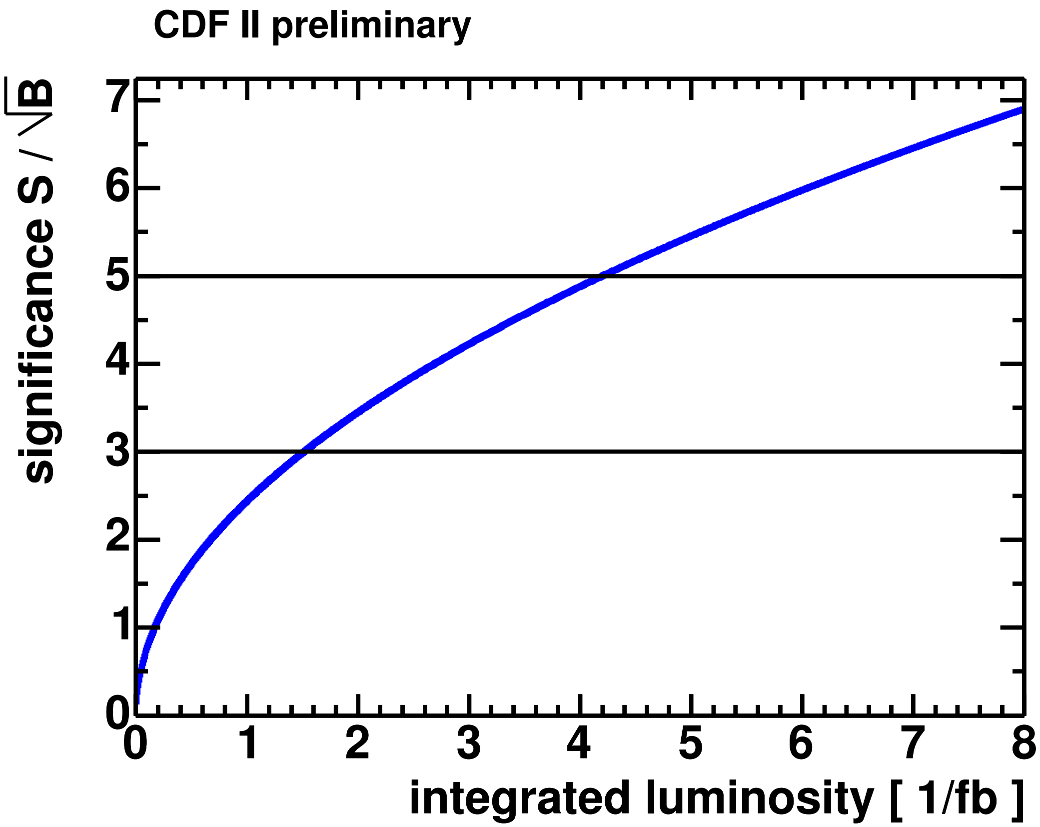
$\sigma(\mathrm{t-channel}) = 1.98 \pm 0.30$ pb

Currently published bounds:

s-channel: $\sigma < 6.4$pb

(DØ 230 pb^{-1})

t-channel: $\sigma < 5.0$pb



Combined channel likelihood for SM single top production.

With 4 fb^{-1} (2007/8?), we expect an event sample of about 75 events and should have a 5 σ signal to claim discovery.

A doubling or quadrupling of the data will allow for multi-variate fits, increasing our confidence that we are observing pure Standard Model single top production.

→ *The LHC is expected to have a significant sample of single top events by 2008.*

→ *Need to make sure that quality data gets on tape...*

Di-Boson Production

Di-Boson cross section measurements provides tests of the SM and probes boson self couplings.

ZZ/ZW production probes the triple guage boson couplings.

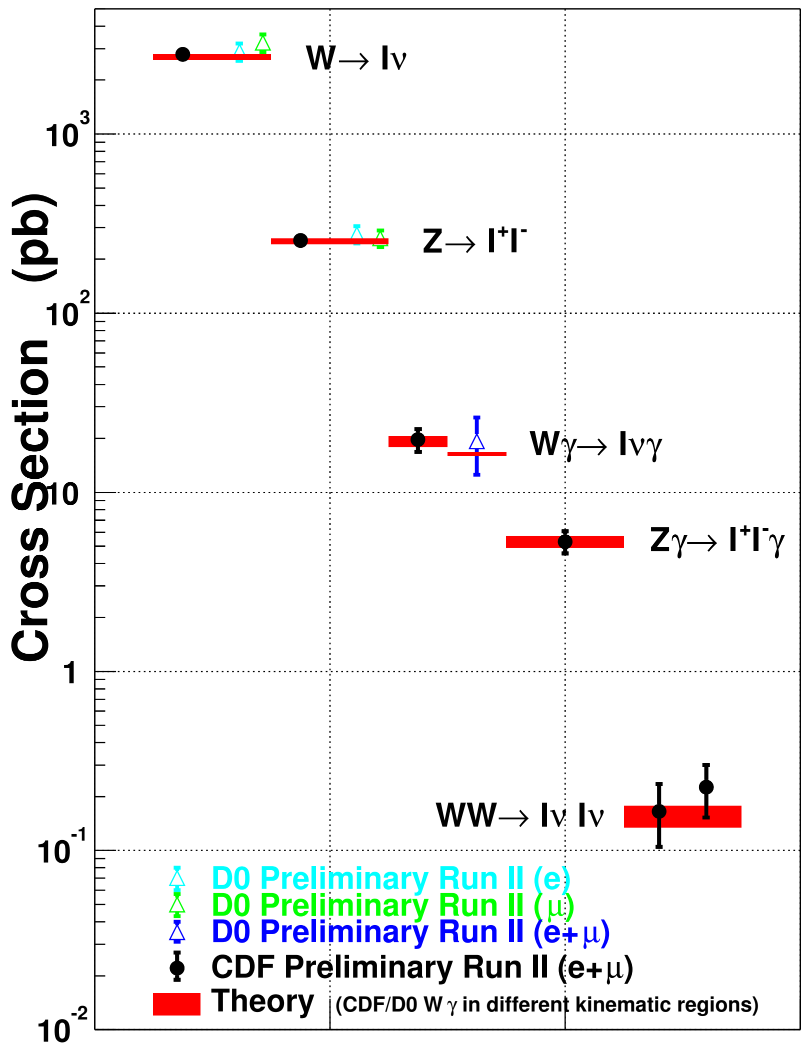
$\longrightarrow$ *The presence of unexpected neutral triple-guage-boson couplings (ZZZ and $ZZ\gamma$) can lead to enhanced ZZ production.*

$\longrightarrow$ *Anomalous WWZ coupling can increase the ZW production rate above the SM predictions.*

A good understanding of di-boson production is needed to estimate the background for other important physics.

$\longrightarrow$ *In $t\bar{t}$ events when the Ws decay leptonically signature is similar to WW production.*

$\longrightarrow$ *The production of WZ and ZZ boson pairs is a significant background in searches for the SM Higgs.*



Uncertainty on the cross section for the WW process is $6-7\times$ the theoretical uncertainty.

With 194 pb^{-1} of data CDF set a 95% confidence level upper limit of 15.2 pb on the cross section for ZZ plus ZW production, compared to the standard model prediction of 5.0 ± 0.4pb (hep-ex/0501021).

Similar footing as single top production, and needs comparable statistics for a good description.

hep-ex/0405026

With more data, Di-Boson measurements could soon become "precision measurements"...

Details of the Underlying Event

The underlying event (UE) is an unavoidable background to many measurements at the Tevatron and the LHC.

There is also interesting QCD physics in the UE which contains particles originating from initial and final state radiation, beam-beam remnants, and multiple parton interactions.

Don't think we have a satifactory description of the UE in MC

→ *PYTHIA has only a few parameters available to tune UE*

→ *PYTHIA 6.3 provides additional handles*

→ *No handles in HERWIG*

→ *Add JIMMY to HERWIG*

Can we find "universal tunes"... HERA → Tevatron → LHC

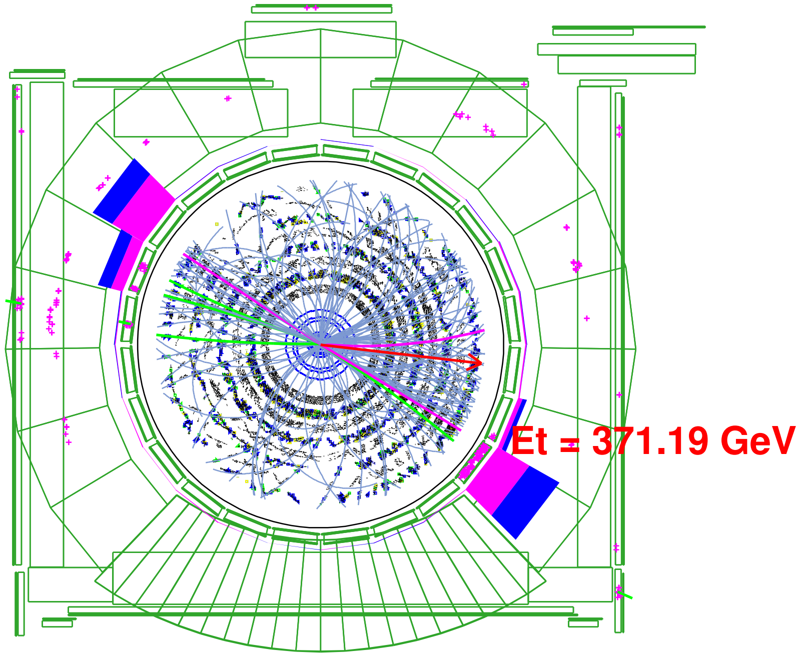
Do have the possibility to help tune the models...

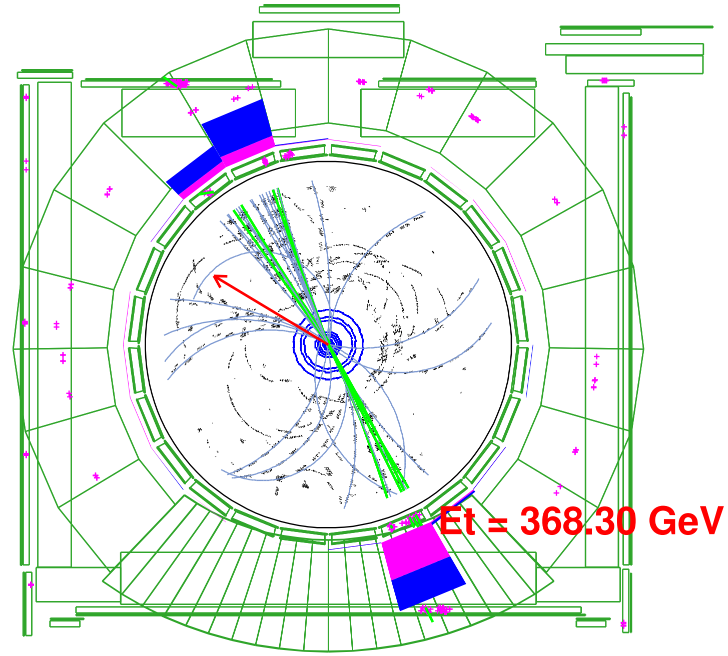
→ *Measure the cross-section for multiple-parton collisions and establish precisely how much it contributes to the UE in various processes.*

→ *Multiplicity distributions in W, Z, Drell Yan, WW, ZZ, and WZ*

→ *Study the UE in color singlet production (Z-boson and Drell Yan processes). Compare to the UE in high p_T jet production.*

→ *Determine rate of vector boson fusion (VBF) and study rapidity gaps.*

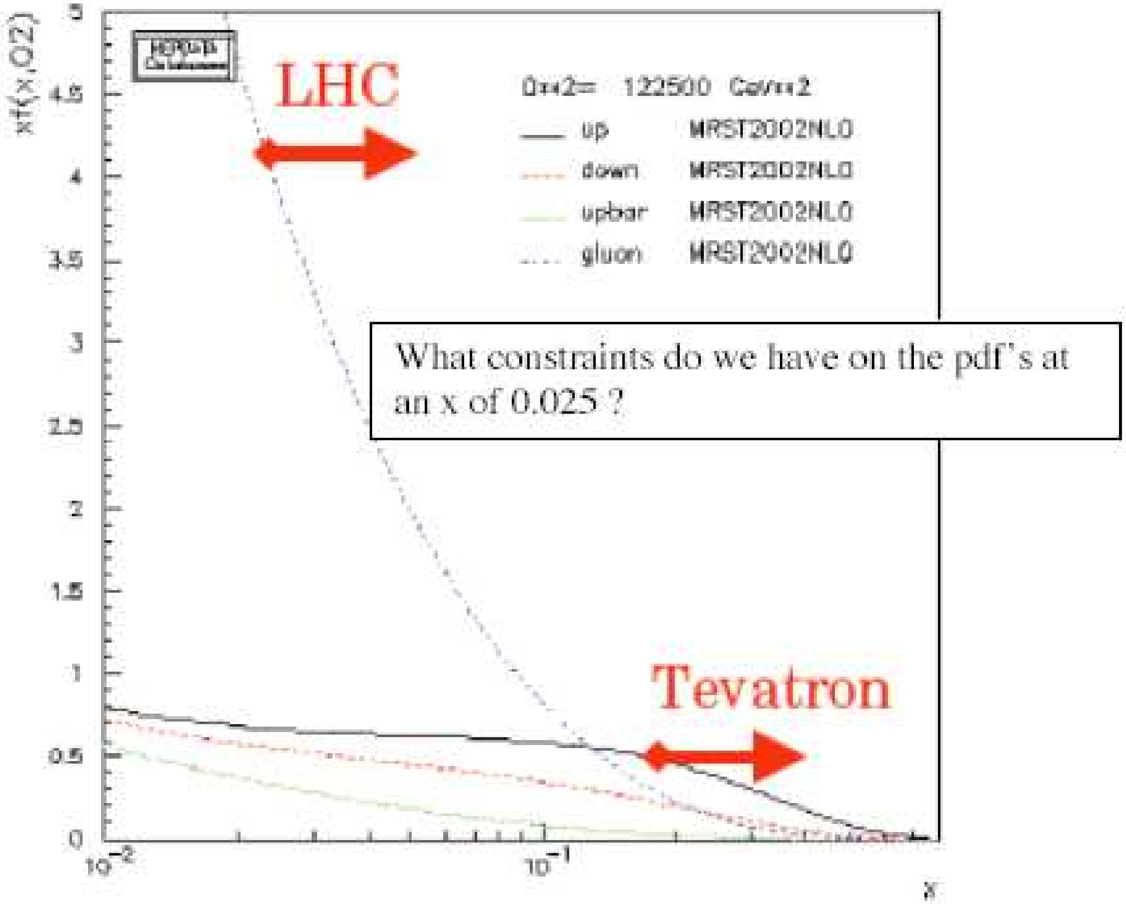




Understanding of the UE will be among the first things needed at the LHC. *Also probably one of the first things studied...*

Tevatron and LHC (will) access different kinematic regions

→ *Tevatron valence quark dominated*
→ *LHC sea quark dominated*



An important aspect of the Tevatron program is to provide data that can be used in new global QCD fits to produce refined sets of PDFs with reduced uncertainties.

PDF Uncertainties

Errors on PDFs can influence the measurement at several stages

$$\sigma_{\text{meas}} = \frac{\epsilon}{\mathcal{L}}(N_{\text{obs}} - N_{\text{bkg}})$$

Calculation of acceptance (ϵ), luminosity ($\mathcal{L}$), event selection (N_{obs}), background estimate (N_{bkg})

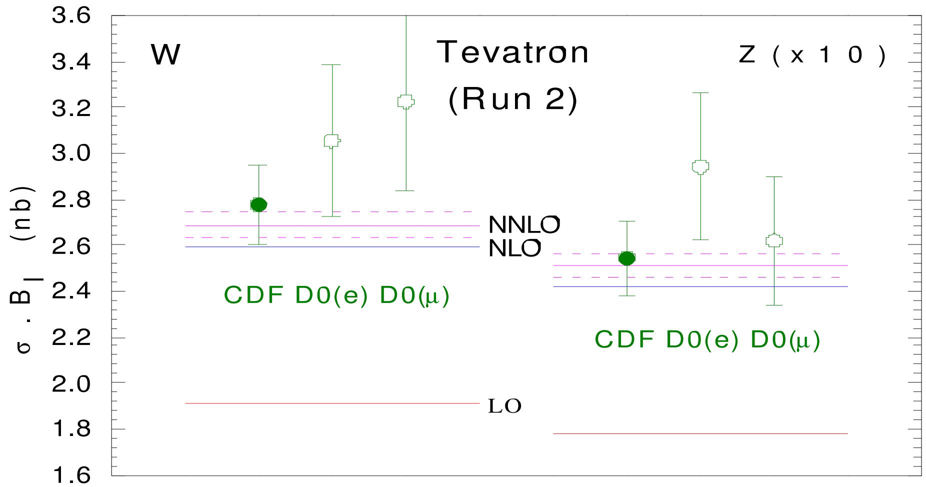
$$\sigma_{\text{theory}} = \text{PDF}(x_1, x_2, Q^2) \otimes \sigma_{\text{hard}}$$

Theory calculation includes:

- Experimental errors when fitting measured data
- Theoretical errors resulting from input parameters (flavor threshold, α_s...) uncertainties on the theoretical modeling (scale errors, nonperterbative effects, PDF parameterization...)

W/Z Cross Sections

"Standard Candle" process that can be used to determine the proton-proton luminosity at the LHC



$\sigma_{\text{NLO}}(W)$ at the LHC

MRST2002	$204 \pm 4\ (nb)$
CTEQ6	$205 \pm 8\ (nb)$
Alekhin02	$215 \pm 6\ (nb)$

$\rightarrow$ 2-4% uncertainty

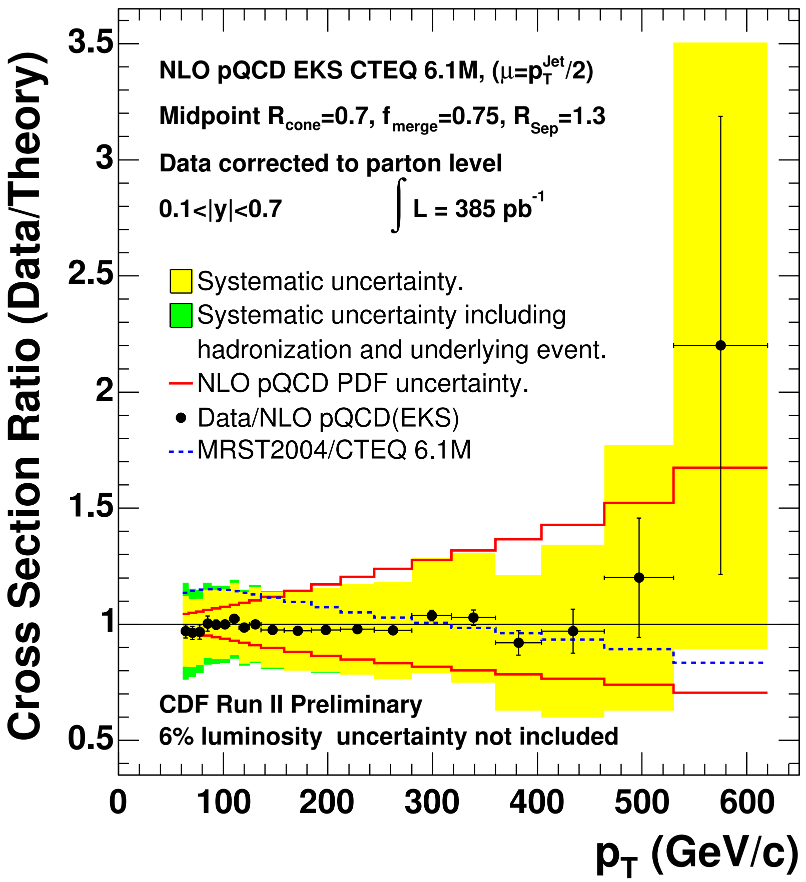
Different PDF sets lead to different predictions...
$\rightarrow$ *depends on the choice of data used in the fits...*

Choice of $\Delta\chi^2$ definition leads to different error on calculation...

Can use cross section ratios to reduce the uncertainty on the luminosity to $\sim$ 1% (Dittmar et al., hep-ex/9705004)

Would be interesting to see if we can use this as the Tevatron.

Input to PDF Fits



Inclusive jet cross section using the cone based MidPoint jet algorithm $\rightarrow$ *probes the high x gluon distribution*

Results based on 385 pb^{-1}

Extends Run I results by $\sim$ 150 GeV

New data will provide tighter constraints on PDFs, in particular the high x gluon distribution

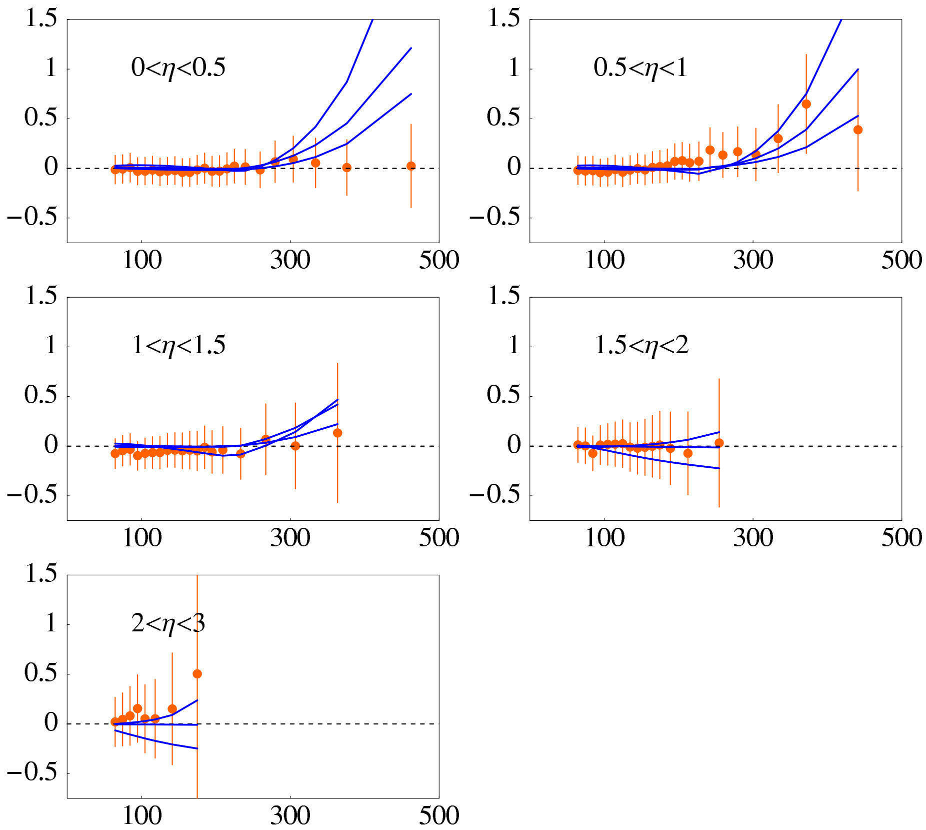
Energy scale is the dominant source of systematic error

$\rightarrow$ *May be able to reduce systematic uncertainties by measuring ratios (inclusive: forward/central, dijet: SS/OS...)*

New Physics could show up as a deviation from the SM predictions at high E_T in the inclusive jet cross section.

Flexibility in the PDF parameterizations could accommodate deviations in the central inclusive jet cross section at high E_T

Run I DØ data, inclusive jet cross section binned in rapidity (last bin $2 < |\eta| < 3$)

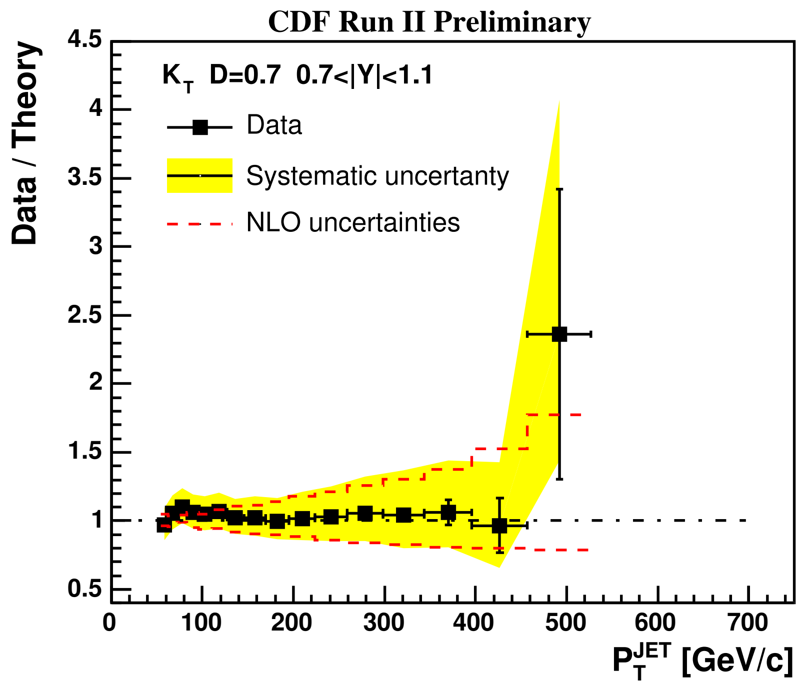


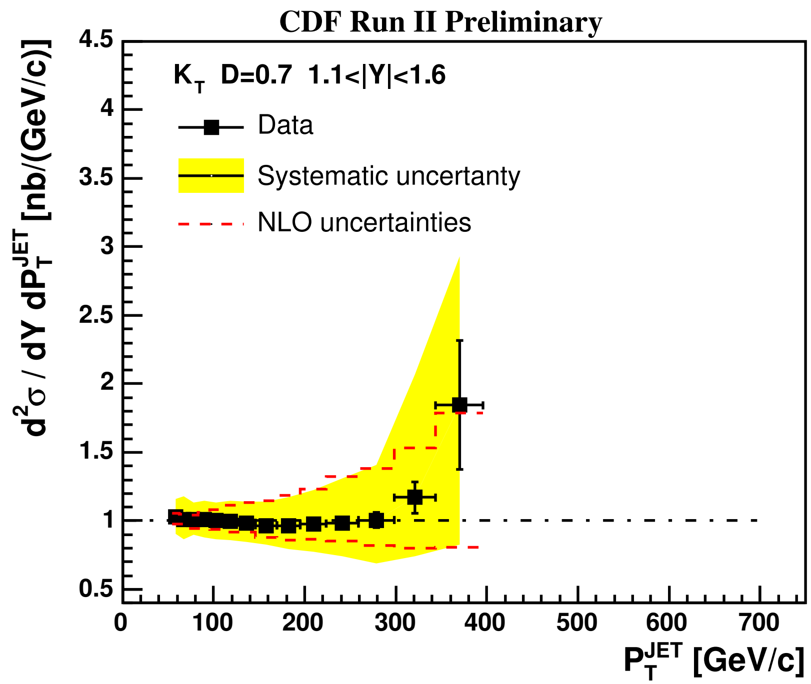
Usually look at the angular distribution between two leading jets

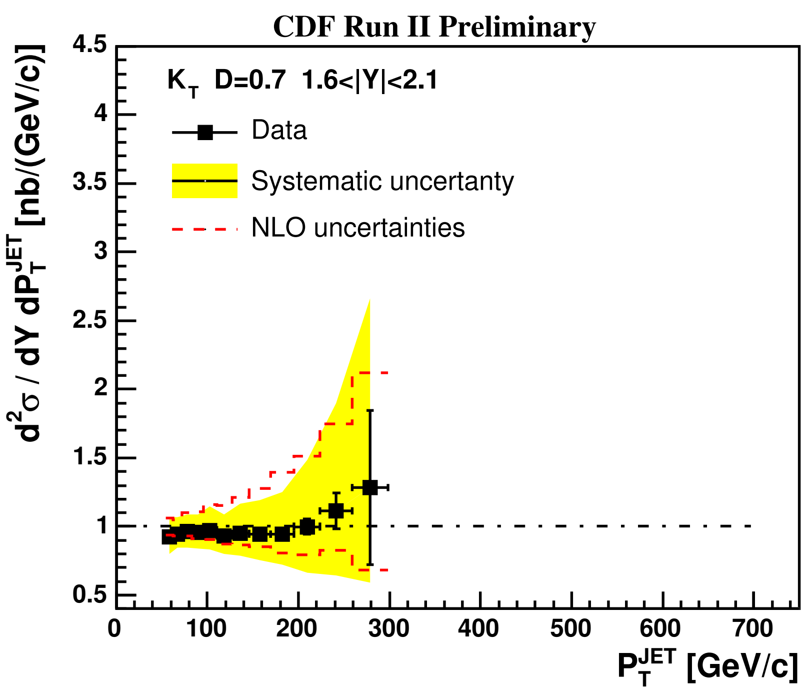
More general to include forward jets in the global fit

Curves show the result of a global fit including a contact interaction in theory with $\Lambda = 1.6, 2.0, 2.4$ TeV

Stump et al., hep-ph/0303013





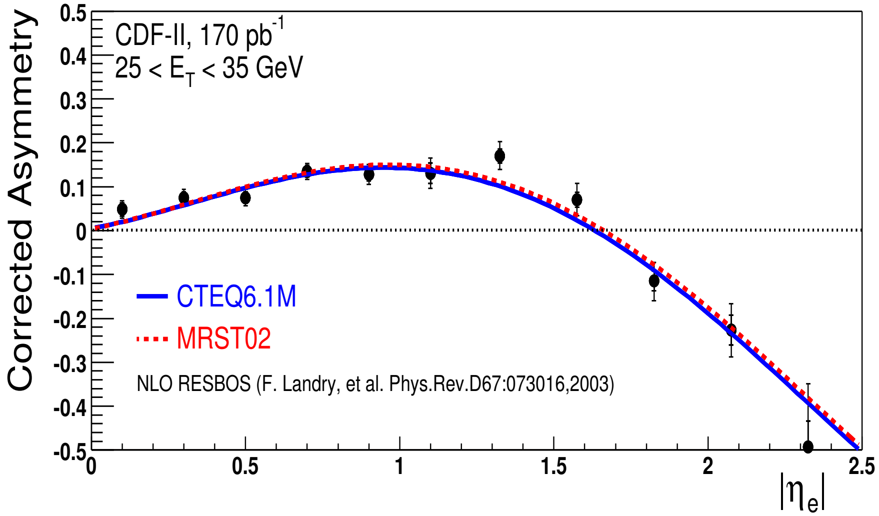


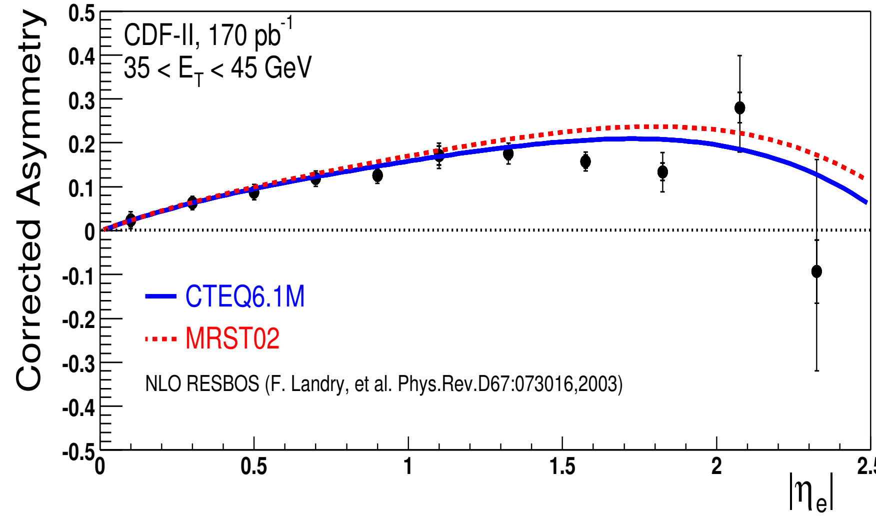
CDF Run II Preliminary results based on 385 pb^{-1} of data.

Forward ($|y| < 2.1$) Jet Data using the k_T Clustering algorithm

→ *With more data we will be able to use finner rapidity bins and better study the cross section shape*

W Charge Asymmetry: $A_{ch}(\eta) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta} \sim \frac{d(x,M_W)}{u(x,M_W)}$



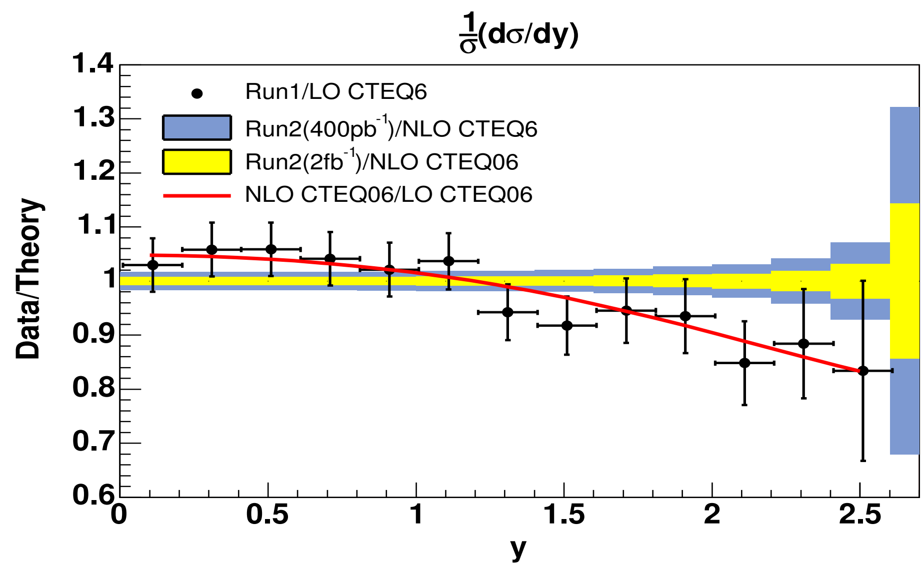


→ *In general for global QCD fits it is better to have more bins in η, E_T^e*

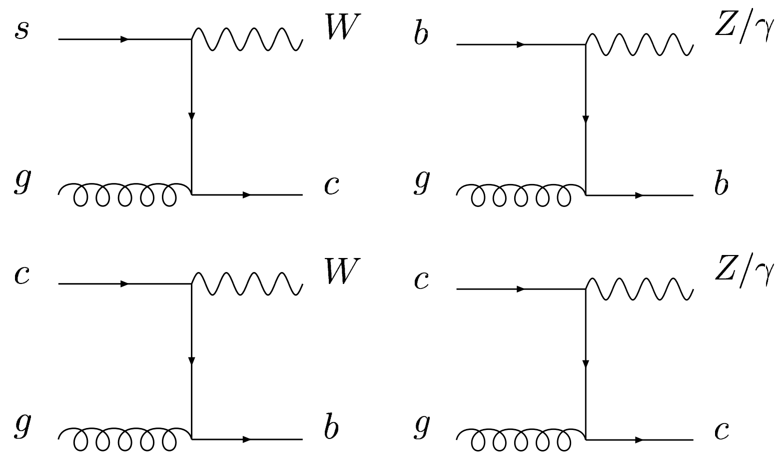
Z Rapidity Distributions

The shaded bands show the expected reduction in the statistical error for 400pb^{-1} and for 2fb^{-1}

Currently not being used in fits... but may be promising



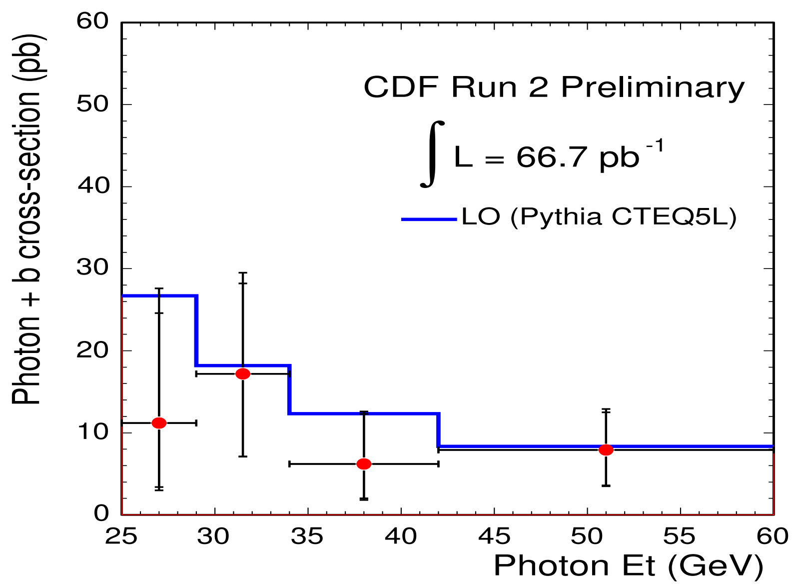
Intrinsic Heavy Quarks



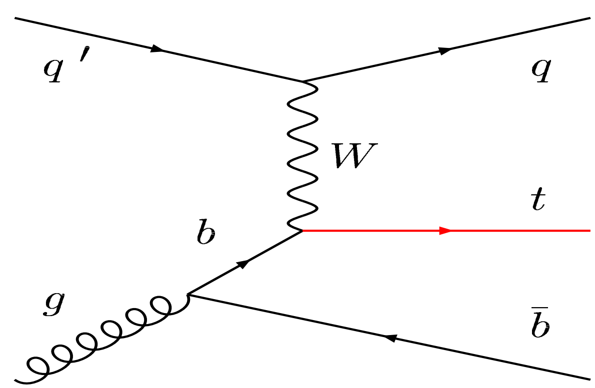
Very little direct experimental input
→ *all c and b distributions in existing PDF sets are radiatively generated*

Probe sea quark distributions with tagged final states $W/Z/\gamma + c/b$

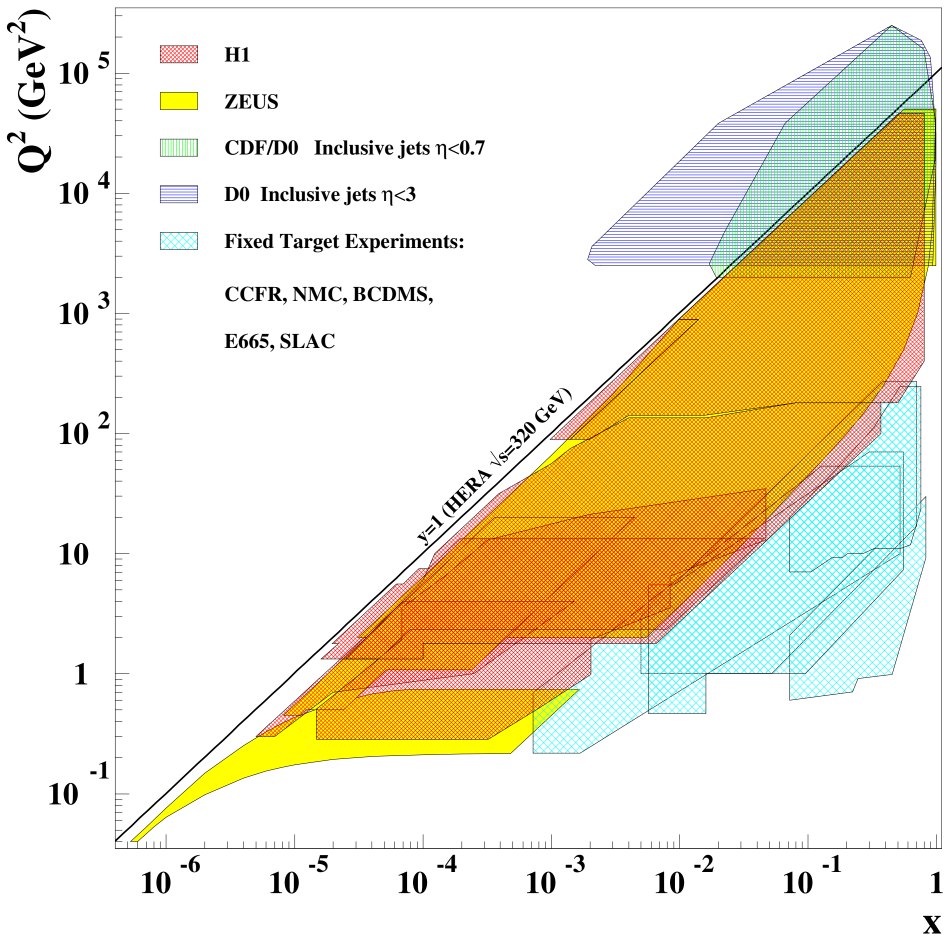
γ plus Tagged Heavy Flavor



Single top production also probes b quarks at high x



PDFs are Universal



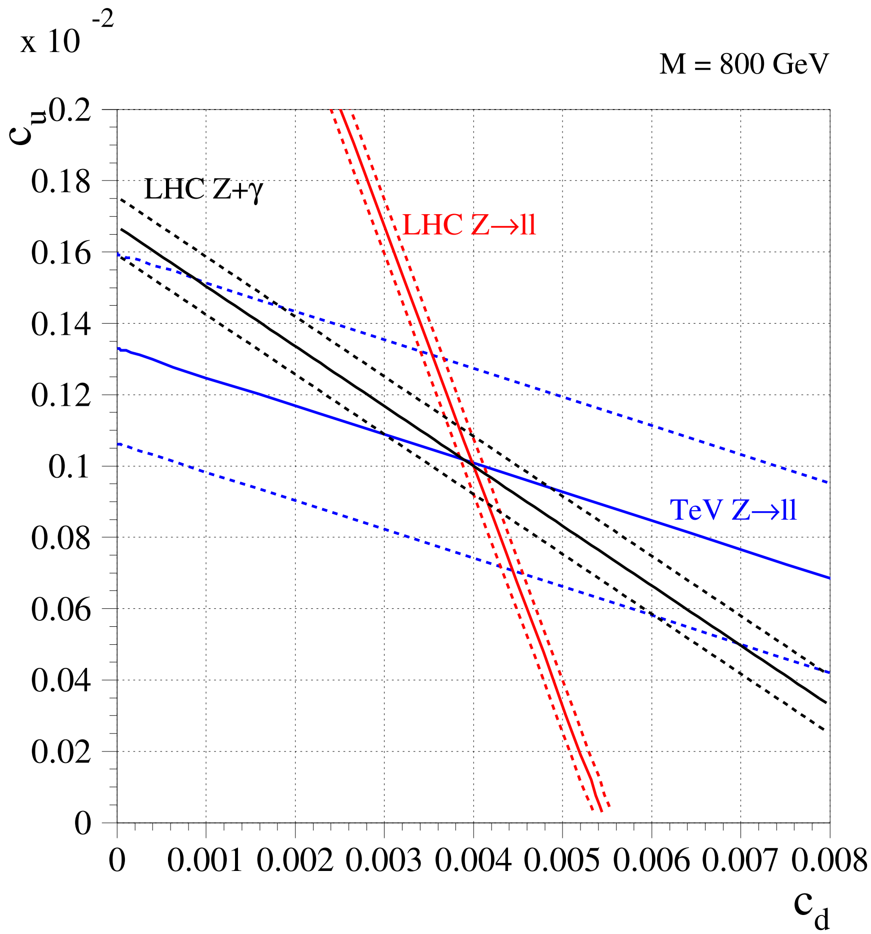
PDFs can lead to different predictions depending on parameterizations and on datasets used in the fits

→ *Should include as much data in the global fit as possible*

→ *Try to span the kinematic phase space*

The challenge is to demonstrate consistency between measurements in different regions of phase space as well as between different processes

Preserve the Data



M. Schmitt, "Z′ at the Tevatron..."
TeV4LHC Workshop

An upper limit on $\sigma(Z')$ directly translates into limits on the charge factors c_u and c_d.

The Tevatron and LHC are sensative to different contours and the complimentary measuremens can be used to more tightly contrain models.

$\rightarrow$ *Could imagine wanting to go back to the Tevatron data in order to test/constrain models that may gain interest at the LHC...*

Almost Finished...

Need to take full advantage of the Tevatron and extract as much as we can. $\rightarrow$ *Probably will never have another $p\bar{p}$ collider*

In addition to the usual arguments

- Searches for new physics
- Precision electron weak measurements (m_t, m_W)
- Single top production
- B_s mixing
- $\Delta\Gamma_s/\Gamma_s$

There are other basic measurements that we should not ignore

- Better understanding of $t\bar{t}$ production
- Di-Boson production
- Heavy flavor PDFs
- Heavy flavor splitting probability
- Jet reconstruction at high rapidity
- b tagging efficiencies
- τ reconstruction efficiencies

- Studies of rapidity gaps
- Details of the underlying event
- Transition between perterbative and nonperterbative QCD
- Improved PDFs
- Vector boson production and tests of QCD
- W charge asymmetry
- Jet fragmentation
- ISR/FSR
- ...

Motivated by the recent P5 meetings:

"...for the Tevatron collider, what factors or considerations might lead to stopping operations one year, or two years earlier than now planned? What might lead to running longer than now planned?"

As part of the write up for the Tev4LHC workshop we plan to highlight some of these measurements.