



New (QCD) Results from the Tevatron

Sarah Eno

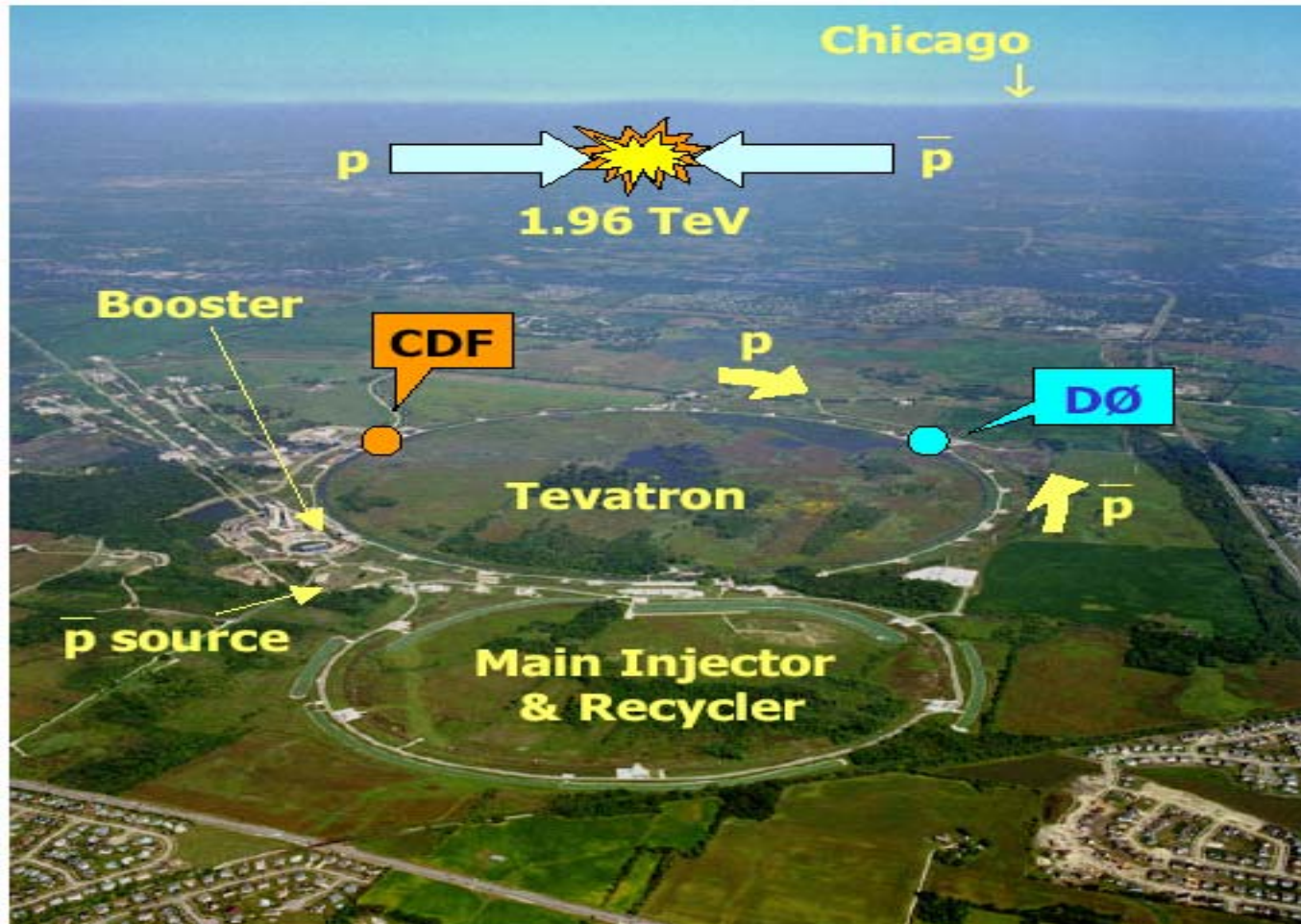
U. Maryland

For the D0 and CDF collaborations

14 Apr 2004



Tevatron



Run 0 '88/'89

20 pb⁻¹

Run I '92/'96

120 pb⁻¹

Upgraded 2000

1.8 TeV ⇒ 1.96 TeV

Goal:

20 pb⁻¹/week

10E31 cm⁻² s⁻¹

2 fb⁻¹

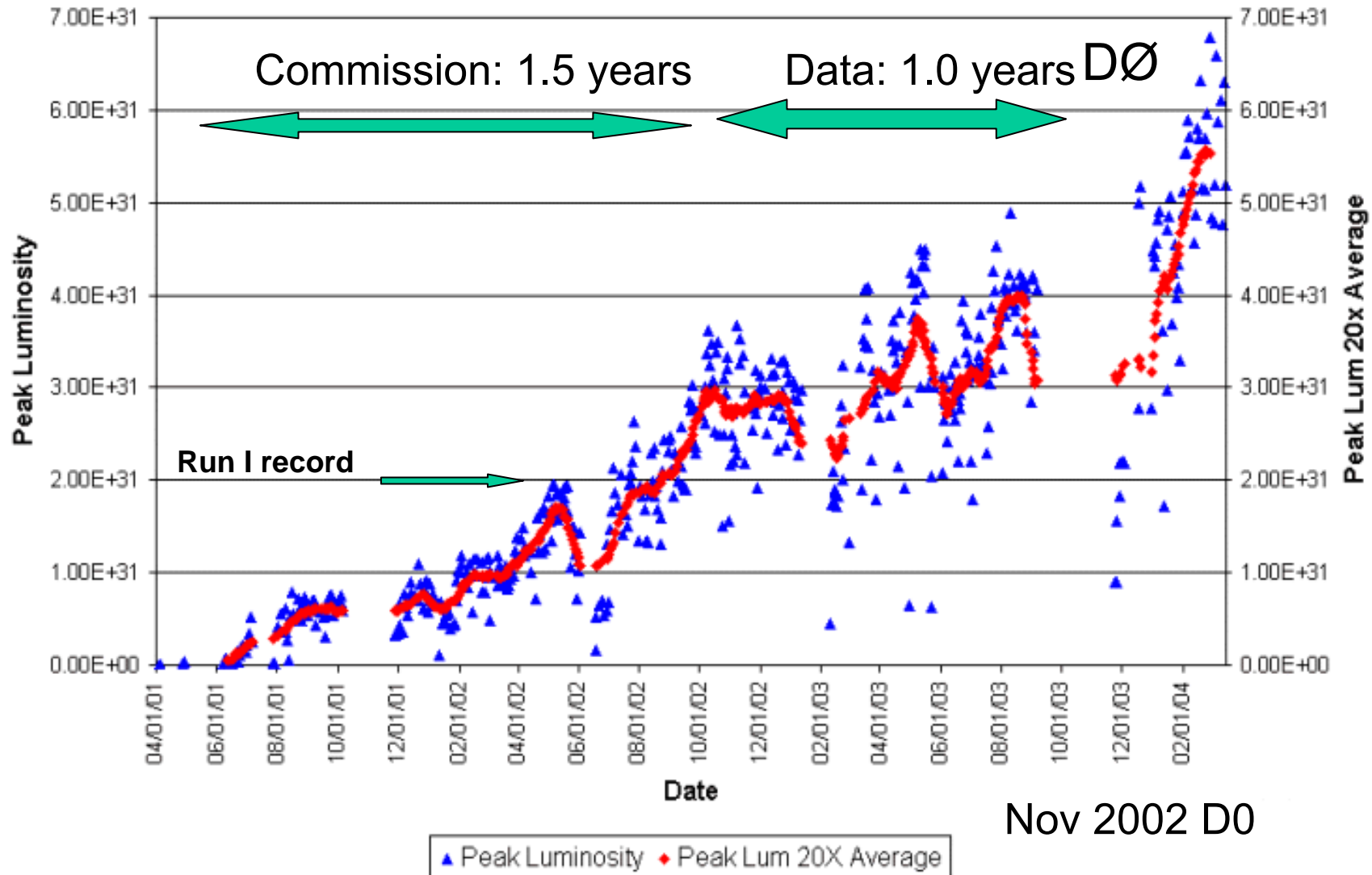
(from summary taped onto my office wall in '92)



Tevatron



Collider Run II Peak Luminosity



Nov 2002 DØ

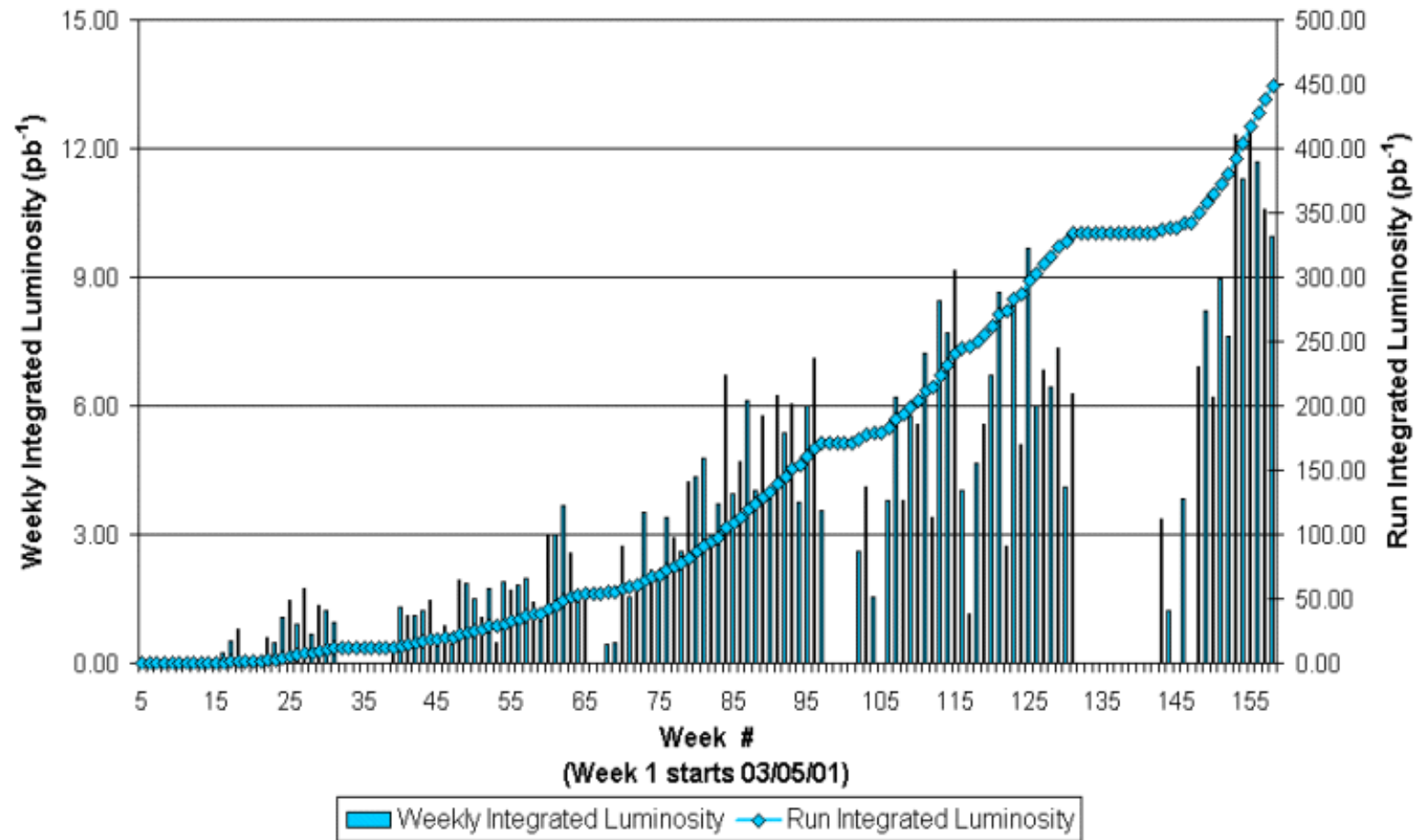
March 2002 CDF



Tevatron



Collider Run II Integrated Luminosity



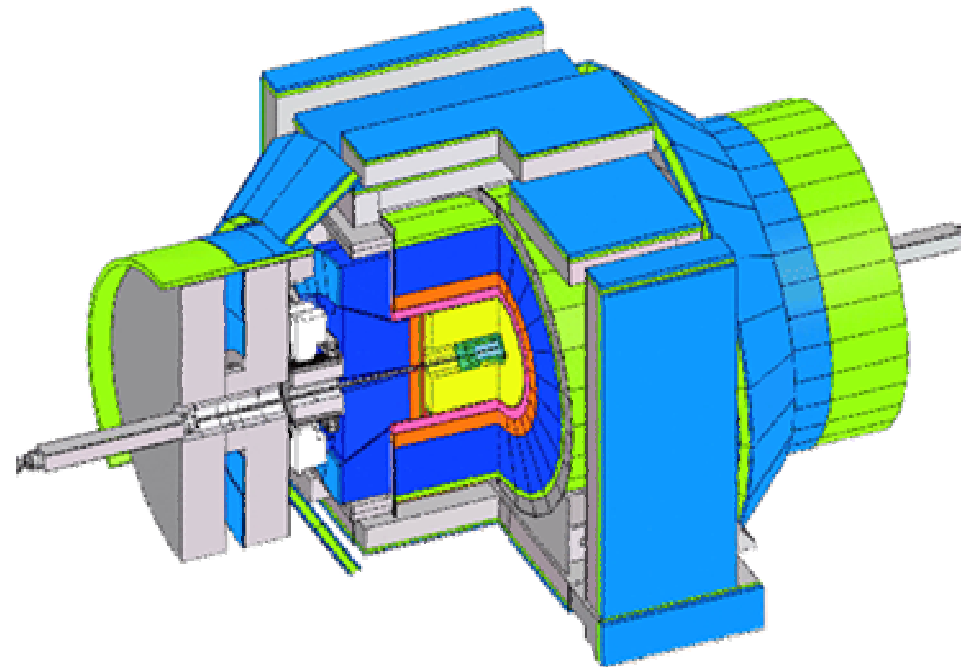
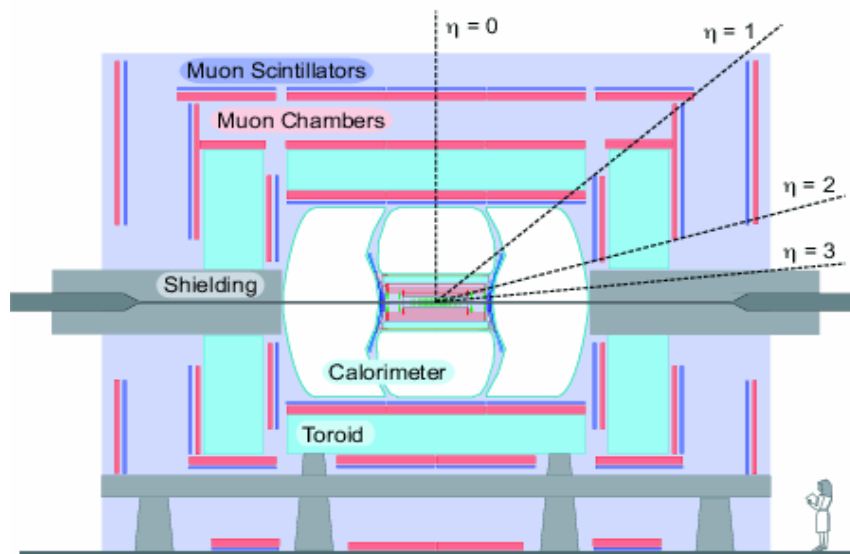


CDF and D0



DØ

CDF



Cal: Ur-liquid Ar

Cal: Pb-scintillator



QCD: Run0/Run I



84 papers! (+ lots of b/c papers)

- Rapidity Gaps/Diffractive Physics/Elastic Physics (10 papers)
- PDF's: double parton interactions (1 paper), W charge asymmetry (3 papers)
- Non-Perturbative QCD: jet shapes (4 papers), W/Z boson P_T spectra (8 papers), other (9 papers)
- Perturbative QCD, particle cross sections: W/Z bosons (9 papers), prompt photons (8 papers), jets (14 papers), top (6 papers), b/c quarks (lots of papers)
- Perturbative QCD with W/Z bosons (6 papers)
- Perturbative QCD with jets: α_s (1 paper), jet topologies (12 papers)

New results in all these areas for this winter's conferences.

It's not all top and electroweak physics!



Run II, 2003 Winter Conferences



CDF

- inclusive jet cross section, central region
- dijet mass spectra
- jet shapes and energy flow in dijet events
- diffractive jets
- photon plus heavy quark

DØ

- inclusive jet cross section, central region
- dijet mass
- uncorrected dijet $\Delta\Phi$
- elastic scattering data



New Results for 2004



CDF

- **jet multiplicities in W+jet events (127 pb⁻¹)**
- **Underlying event in jet events/minbias data**
- **Di-photon Cross section (207 pb⁻¹)**
- **W/Z cross sections (72 pb⁻¹)**
- **top cross sections (126-200 pb⁻¹)**

DØ

- **inclusive jet cross section, forward region (143 pb⁻¹)**
- **dijet cross section (143 pb⁻¹)**
- **azimuthal decorrelation in dijet events (150 pb⁻¹)**
- **elastic scattering**
- **Z's with rapidity gaps (117 pb⁻¹)**
- **top cross sections (140-156 pb⁻¹)**

Channel-by-channel luminosity variations due to detector-specific good run selection

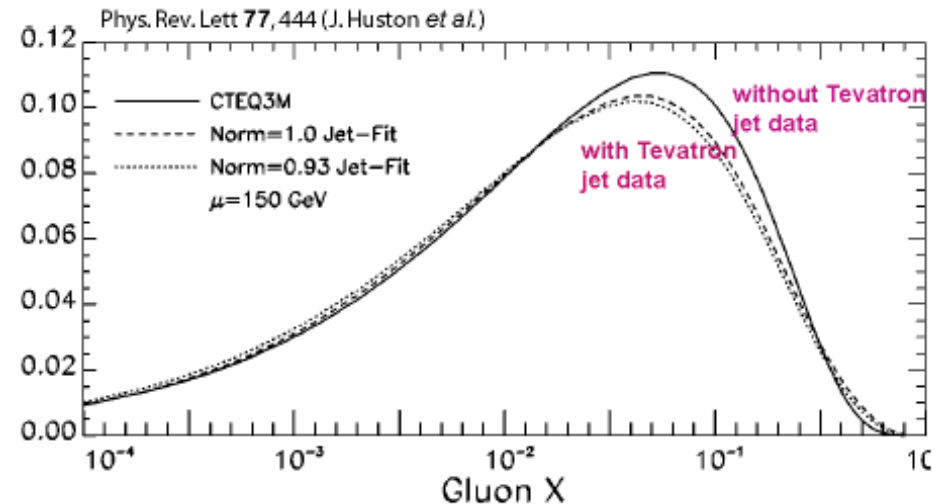
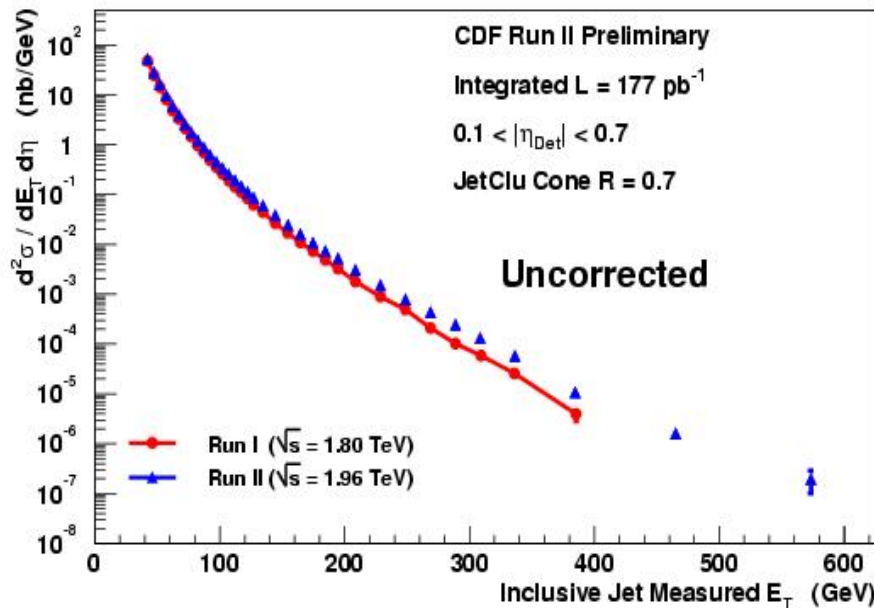
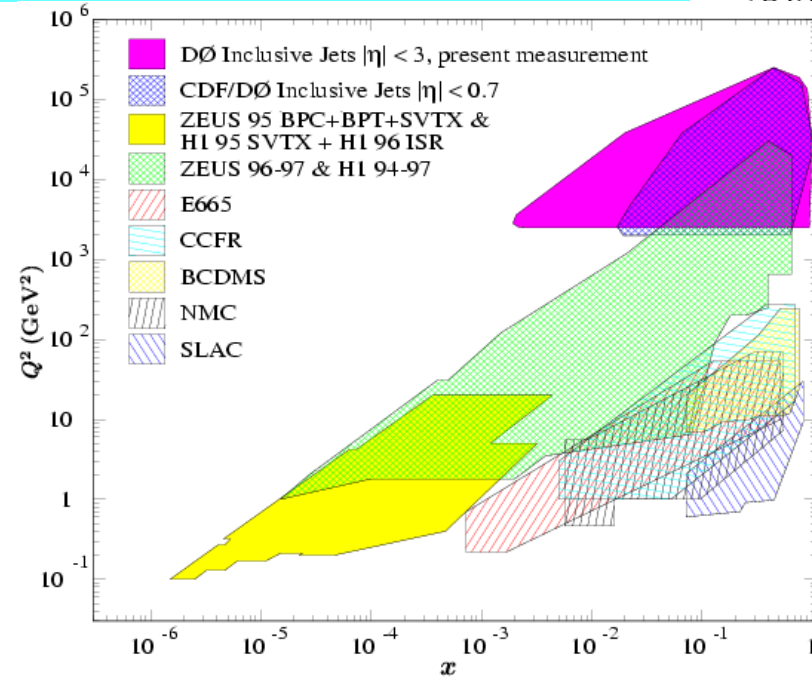
Harder analyses tend to freeze their data sample earlier, and thus have less luminosity



Jet Cross Section, Run I



High E_T jets probe large x PDF's, especially gluon PDF. Run II has extended reach in jet E_T





New Algorithm



- Use Run II cone algorithm
- Combine particles in a $R=0.7$ cone
- Use the four vector of every tower as a seed
- Rerun using the midpoints between pairs of jets as seeds
- Overlapping jets merged if the overlap area contains more than 50% of lower Pt jet, otherwise particles assigned to nearest jet.

Both groups now using same algorithm

Reduced sensitivity to soft radiation

E-scheme recombination

$$P^J = (E^J, \mathbf{p}^J) = \sum_{i \in J=C} (E^i, p_x^i, p_y^i, p_z^i)$$

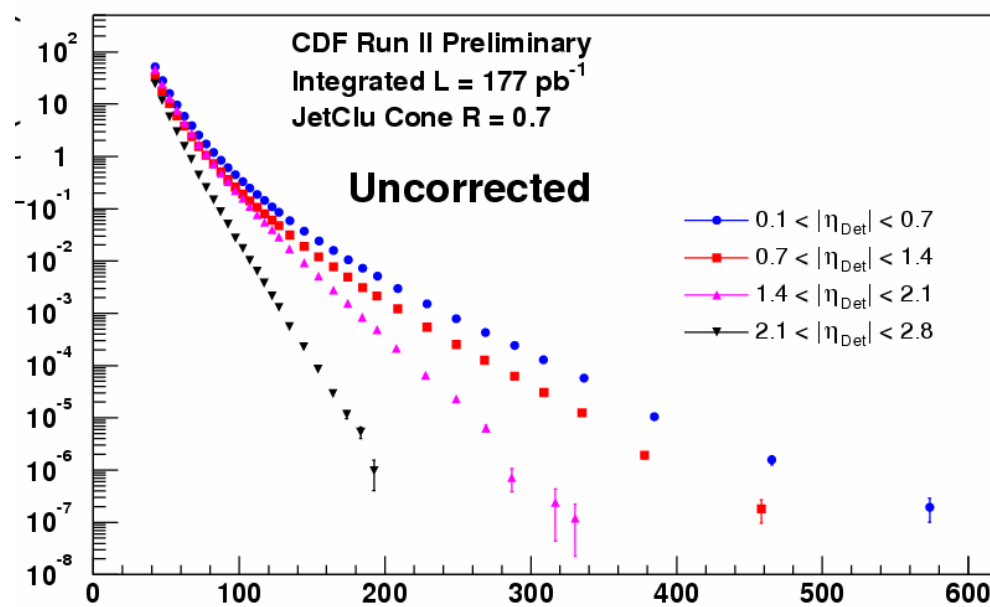
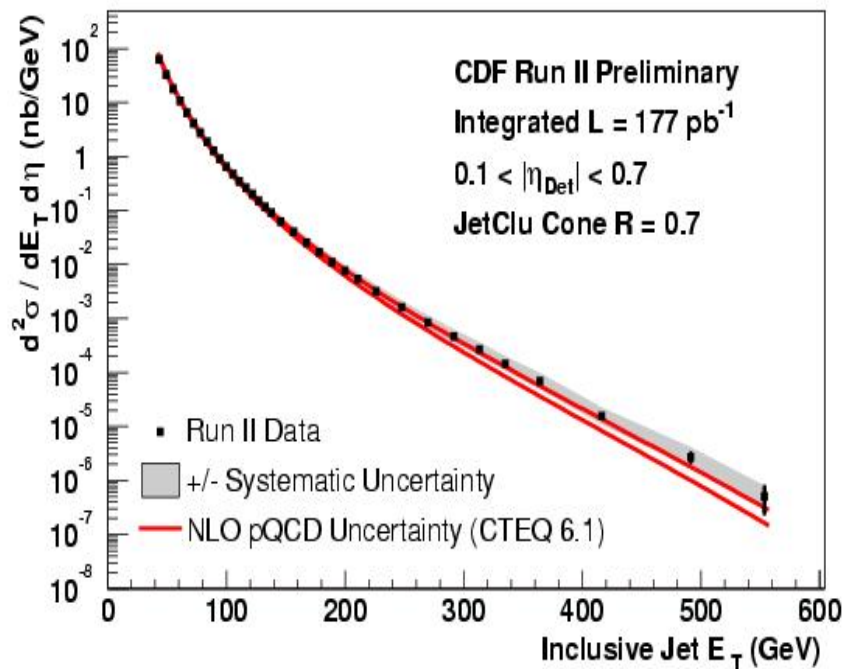
$$P_T^J = \sqrt{(p_x^J)^2 + (p_y^J)^2}$$

$$y^J = \frac{1}{2} \ln \frac{E^J + p_z^J}{E^J - p_z^J}$$

$$\phi^J = \tan^{-1} \frac{p_y^J}{p_x^J}$$



CDF Update

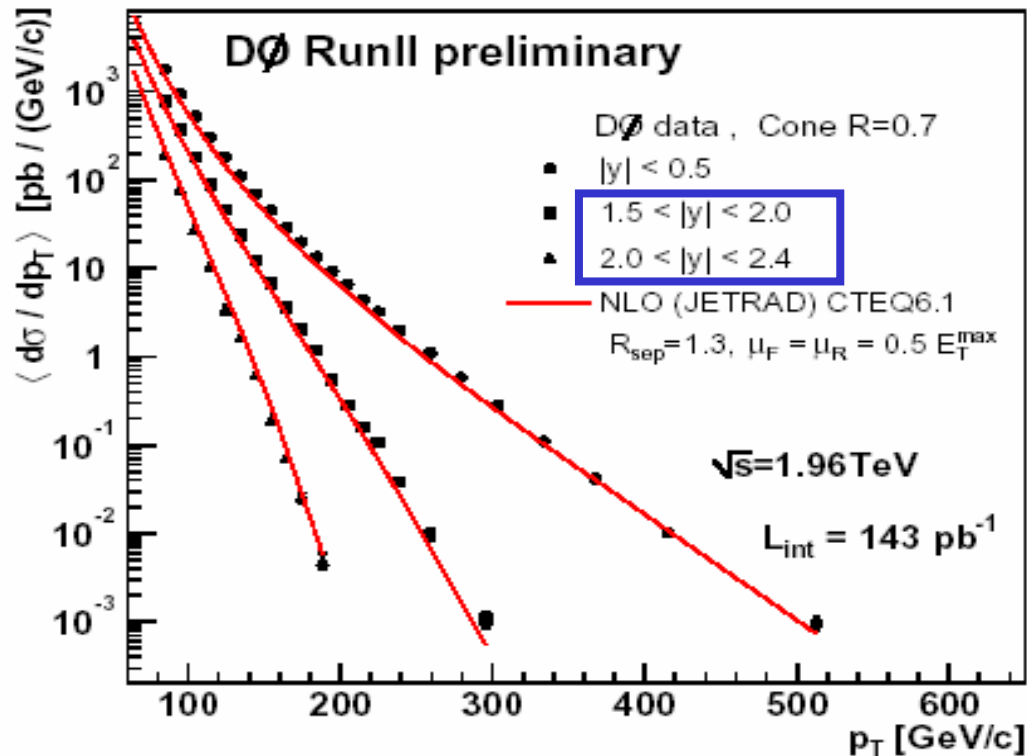


More luminosity since winter 2003

177 pb⁻¹



DØ Results

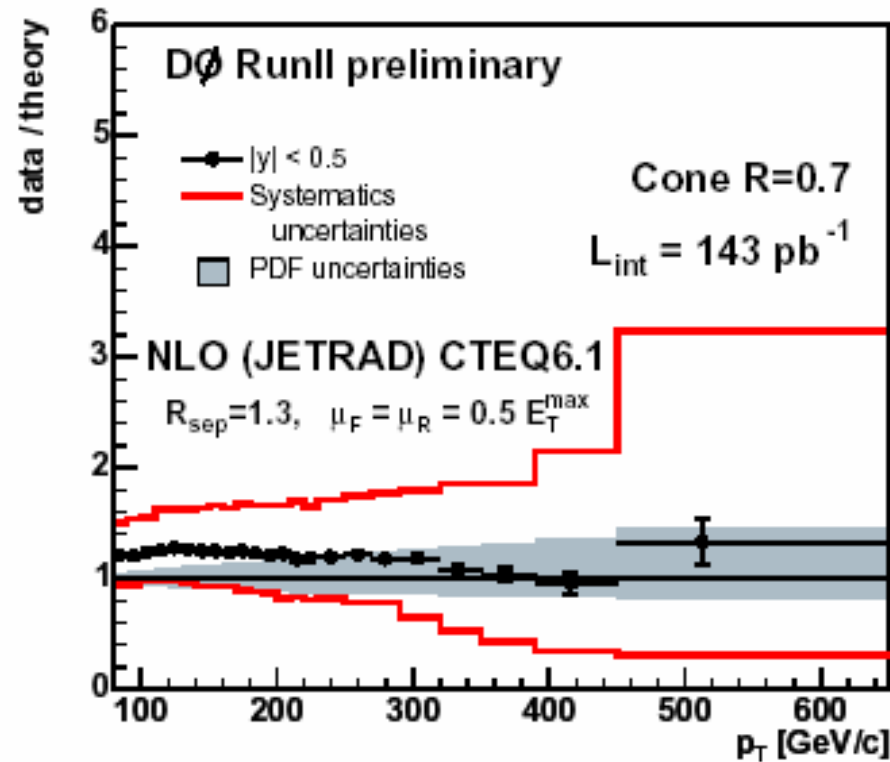
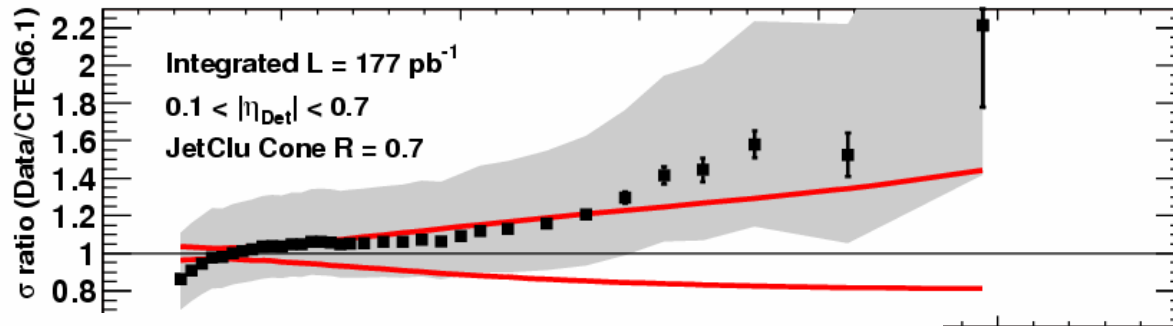


First corrected
run II jet cross
section for
forward jets

Important PDF
information is in
the cross section
versus rapidity



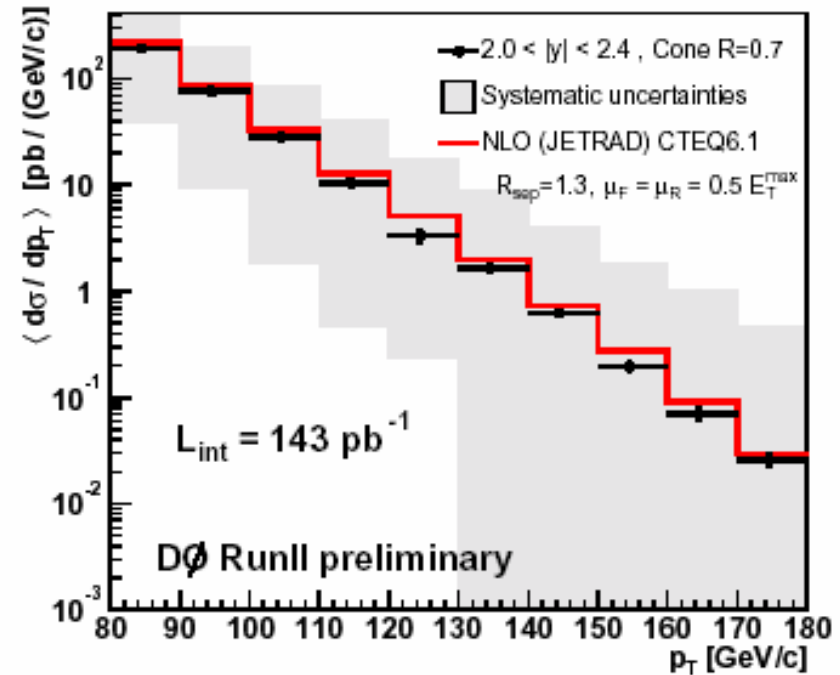
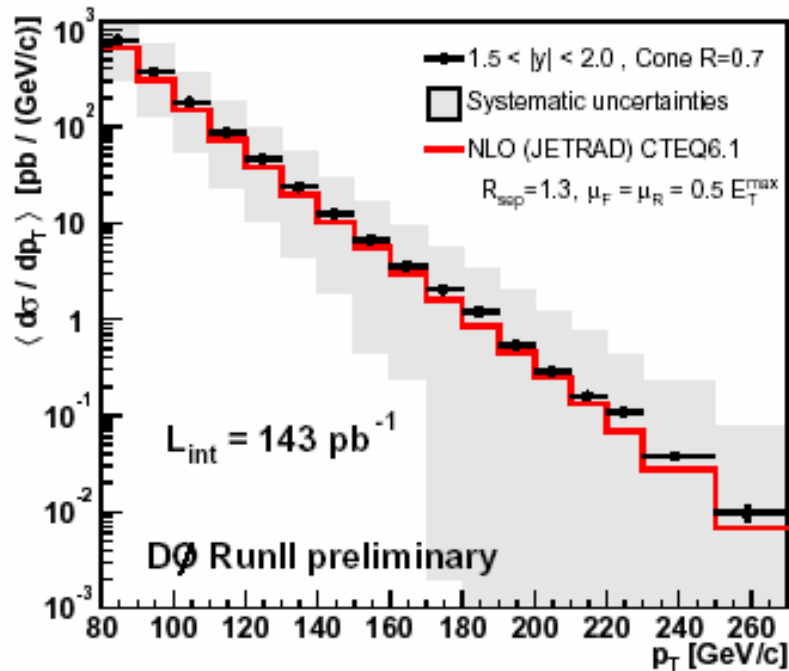
Uncertainties, Central Jets



Uncertainties dominated by jet energy scale. Jet energy scale is systematics dominated in central.



Uncertainties, Forward Jets



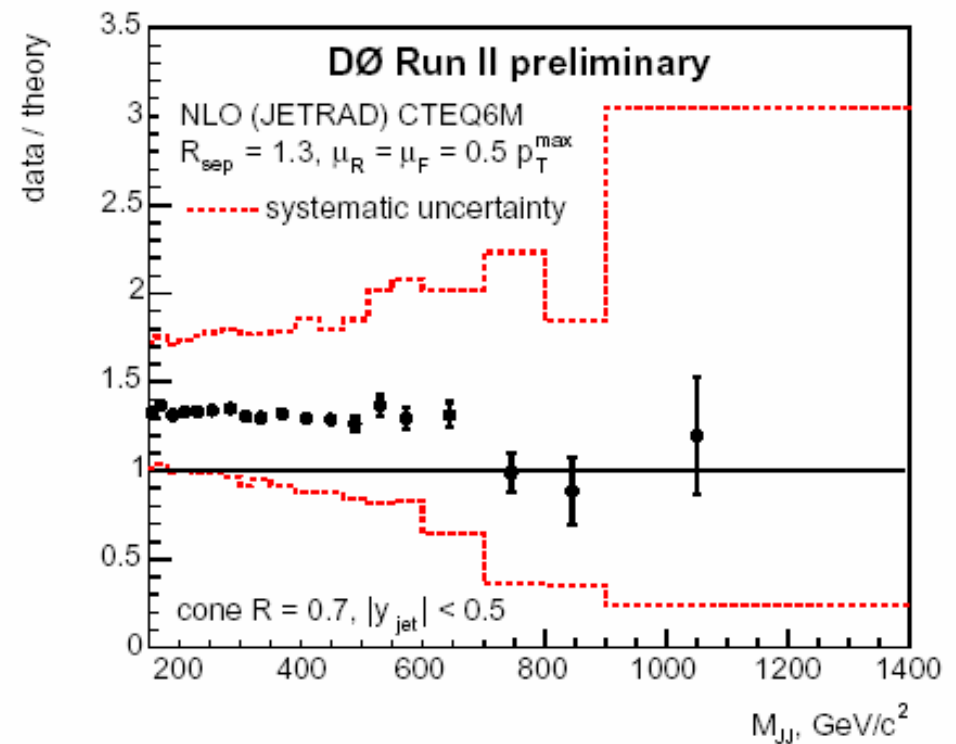
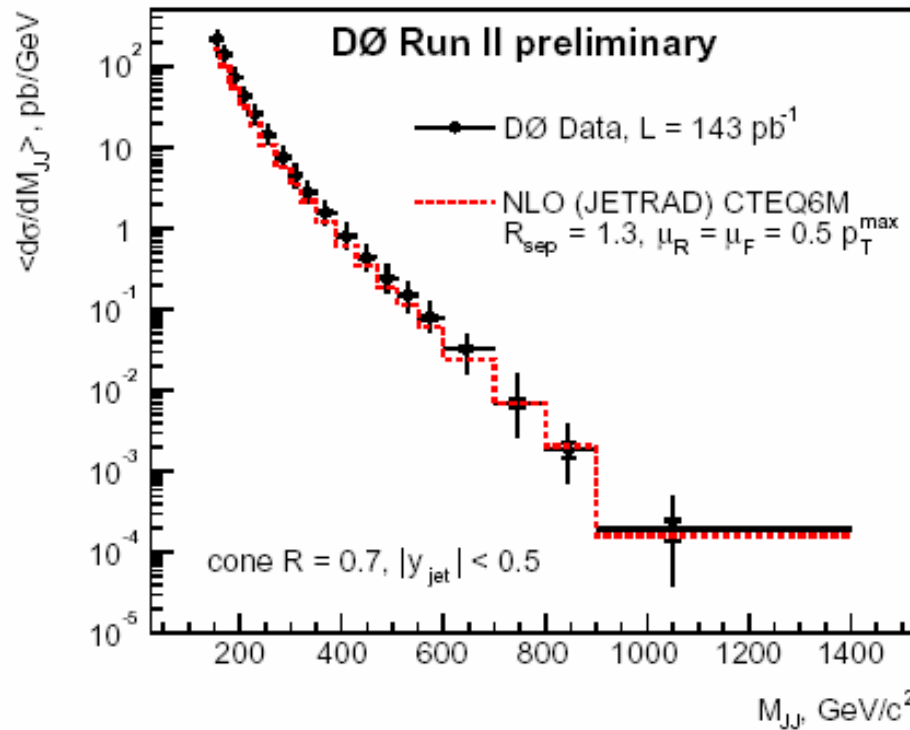
Energy scale error large. Systematics dominated.
Expect improvement soon.



DØ DiJet Cross Section



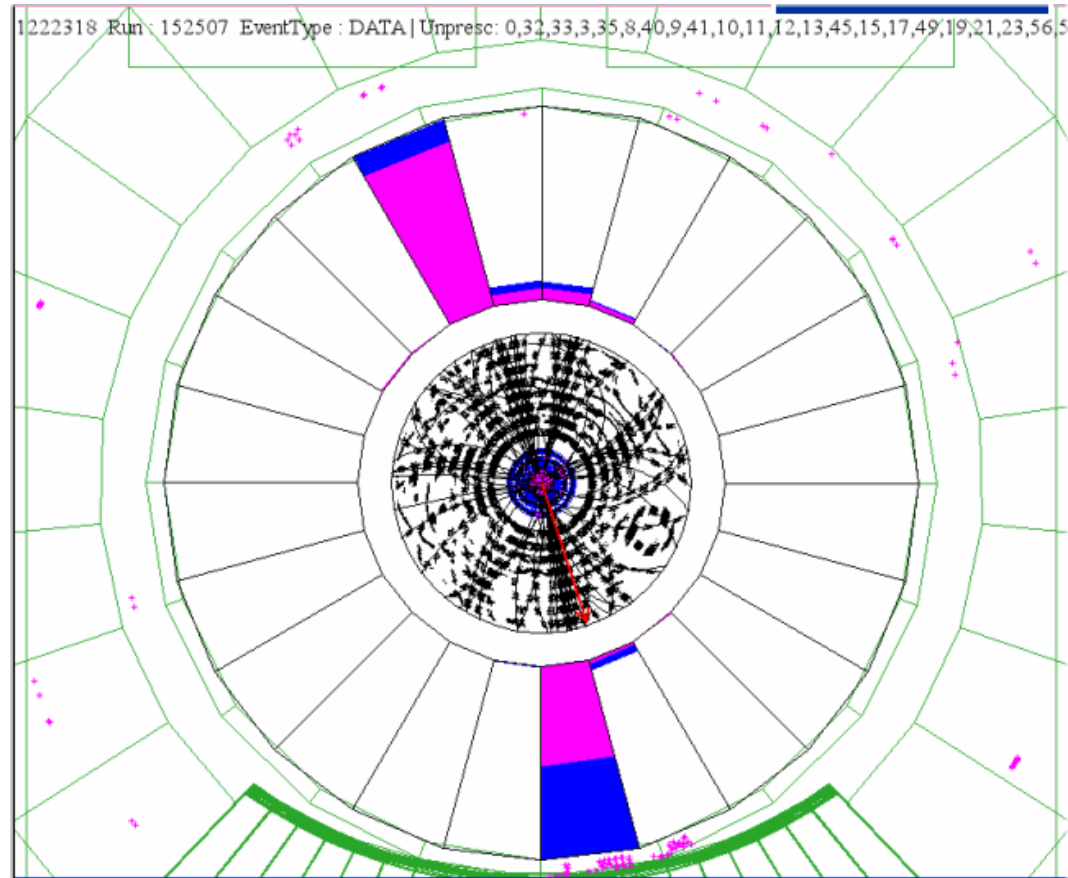
Uncertainty dominated by jet energy scale



Often used to search for new resonances



CDF, Dijet Mass



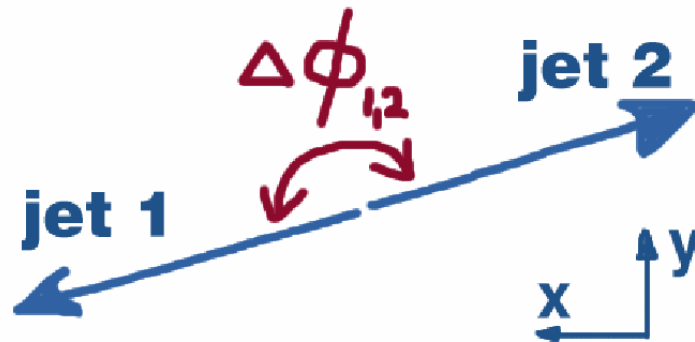
CDF's highest mass dijet event $M=1364$ GeV, E_T 's=633,666



$D\phi$, Φ Decorrelation



Leading Order pQCD

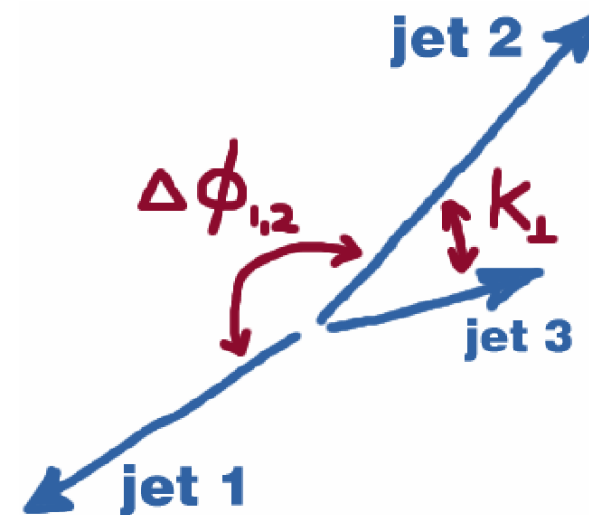


Jets are back-to-back

$$\Delta\phi_{12} = \pi$$

$\Delta\phi_{12}$ is sensitive to jet formation without having to measure 3rd jet directly!

3 jets in pQCD



$$\Delta\phi_{12} < \pi$$

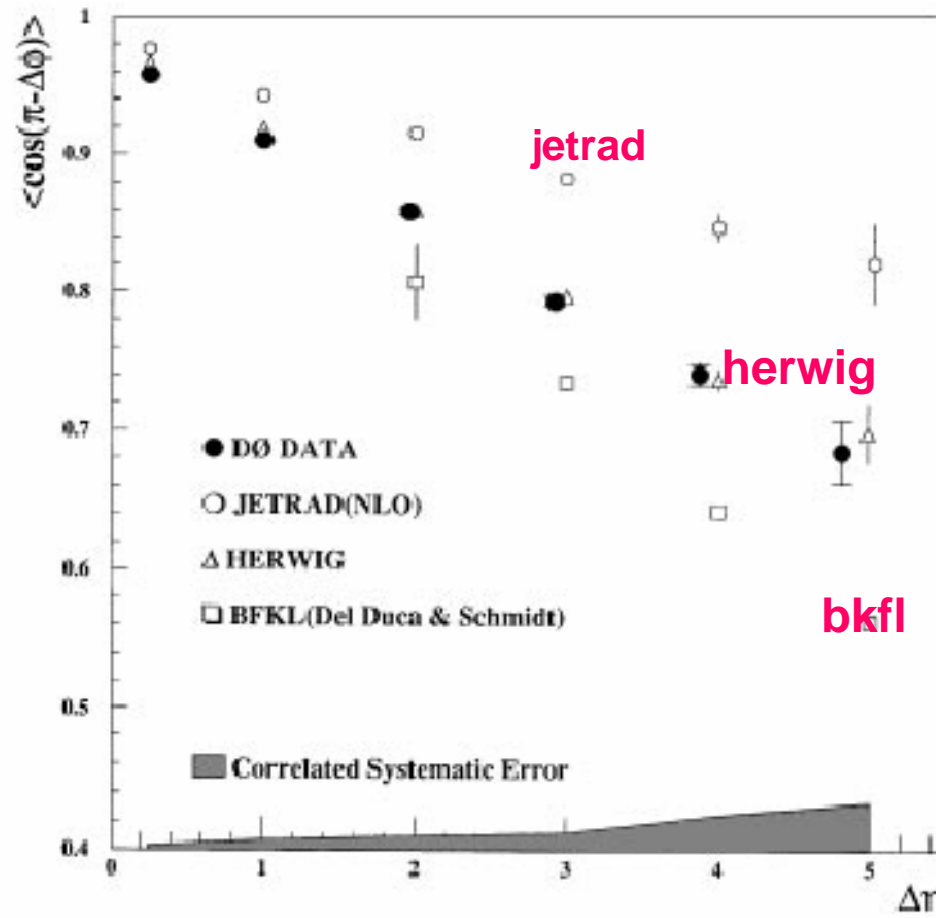
$$\lim_{p_{T3} \rightarrow 0} \Delta\phi_{1,2} = \pi$$



Azimuthal Decorrelation



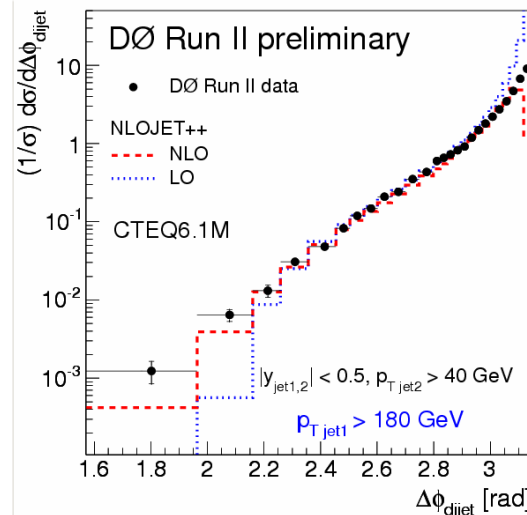
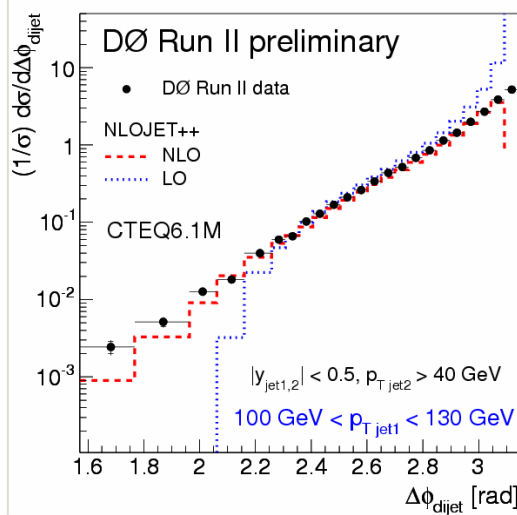
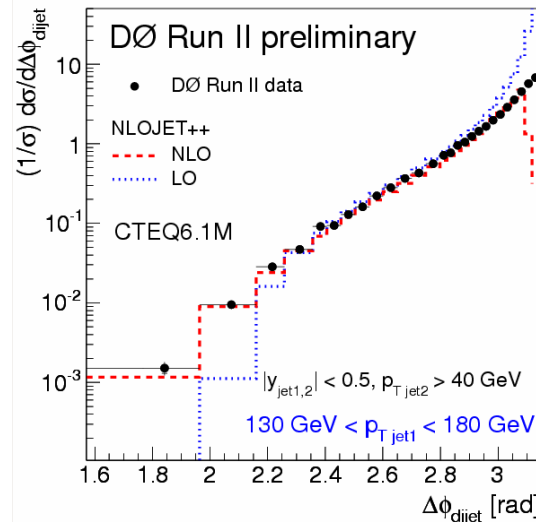
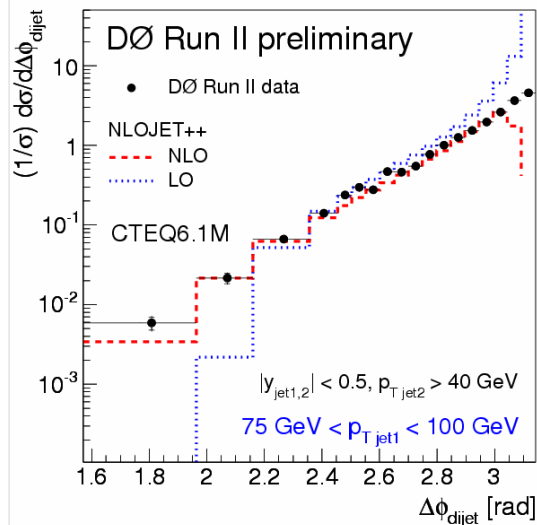
DØ, Run I



For small $\Delta\eta$, data agrees well with herwig and reasonably well with LO perturbative calculation (JETRAD)



Azimuthal Decorrelation



Run II. Differential measurement at small $\Delta\eta$.

LO (in 3rd jet) perturbative calculation (JETRAD) does not agree.

Not too surprising...

- Calculation diverges at π

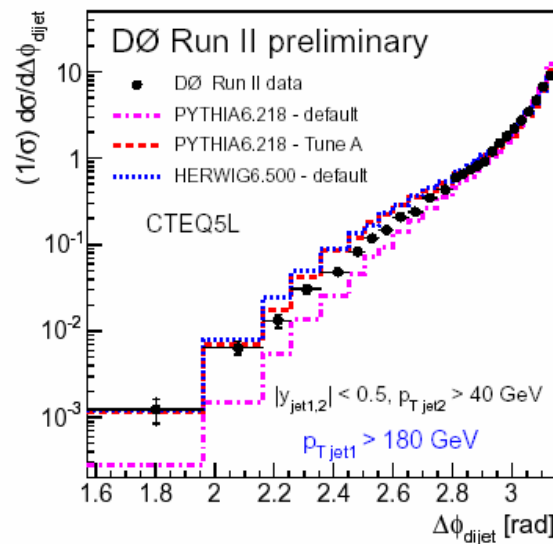
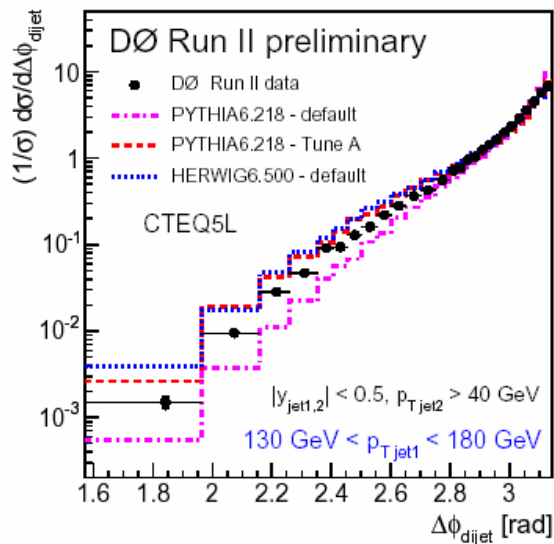
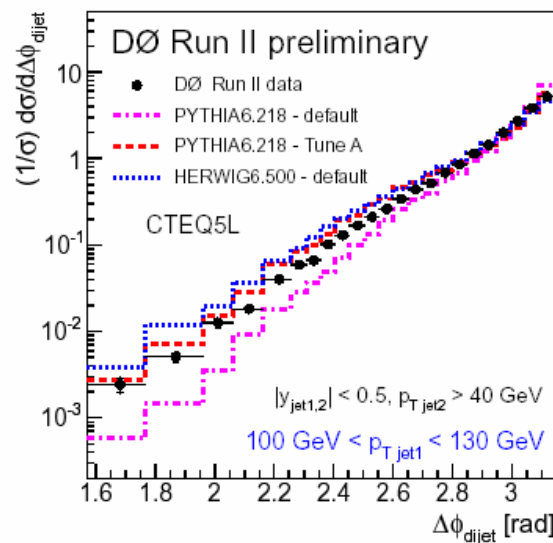
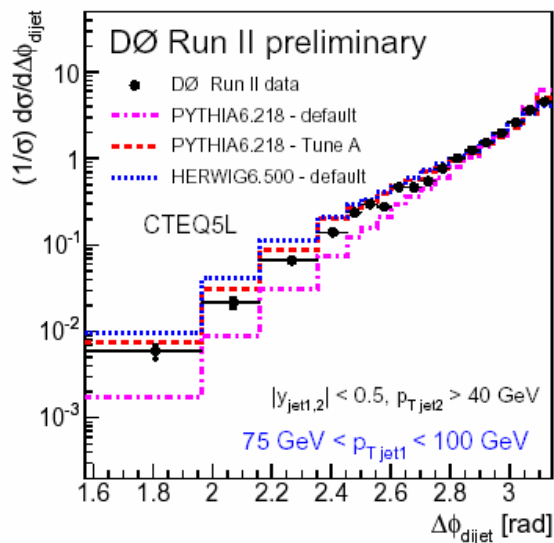
- no phase space beyond $2\pi/3$

- lots of 4 jet events at smaller $\Delta\Phi$.

NLO not so bad!



Azimuthal Decorrelation



okay agreement with herwig, pythia. Tuned pythia gives best agreement. NLO is better in intermediate region.

Pythia distribution sensitive to “maximum virtuality for the initial-state parton shower in terms of the hard matrix scale” (PARP(67)).

Tune “A” is the CDF UE tune discussed later.

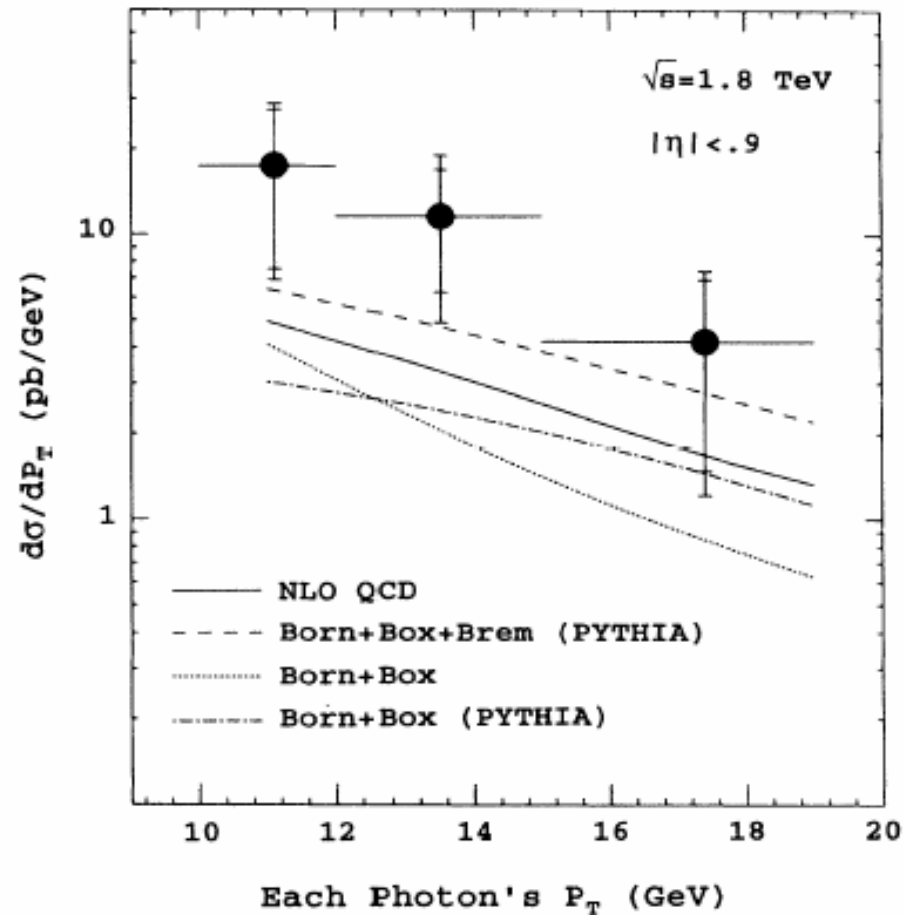
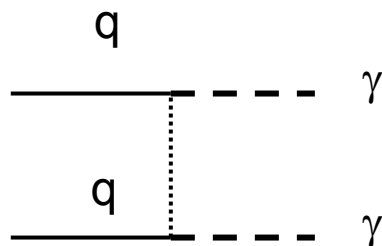


CDF, Di-Photon



Two isolated and energetic high E_t photons in the central region

Correlations between the 2 photons can be used to test NLO QCD and study the transverse momentum of the initial partons (KT)



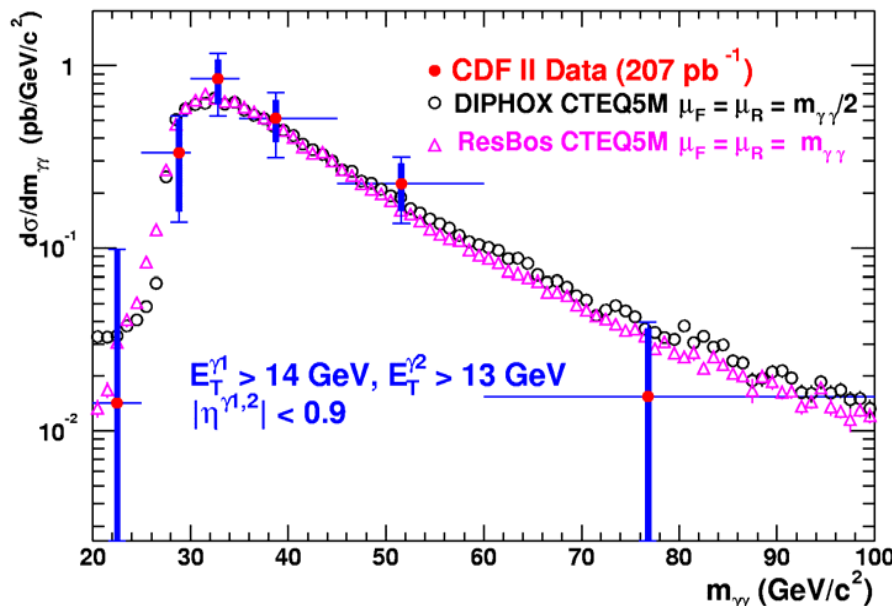
CDF Run I: cross section 3x prediction from NLO QCD (Bailey, Owens, Ohnemus, Phys. Rev. D 46, 2018 (1992))



Di-Photon

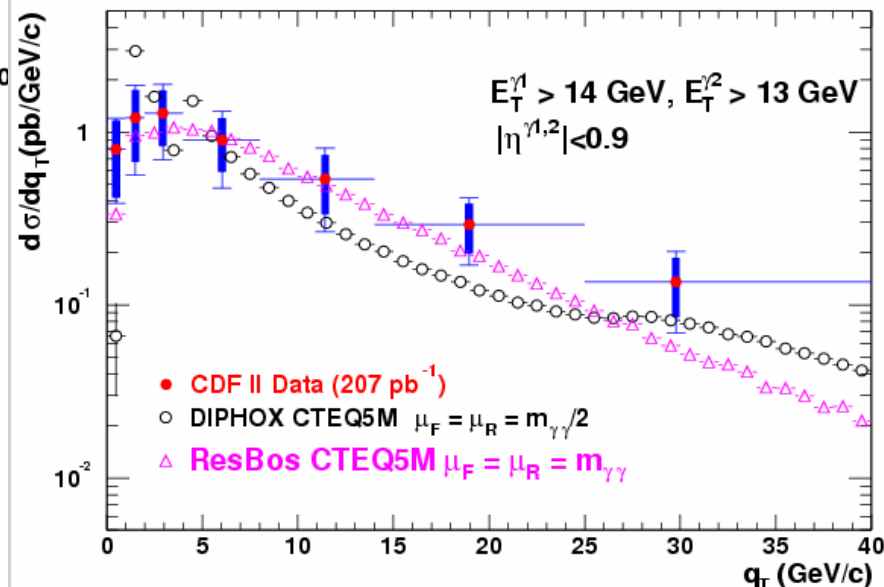


CDF Run II preliminary



Plotted versus
mass of 2
photons
instead of
photon P_T

CDF Run II preliminary



DIPHOX hep-ph/9911340

Eur.Phys.J C16, 311

Additional “fragmentation”
diagrams

ResBos hep-ph/9712471



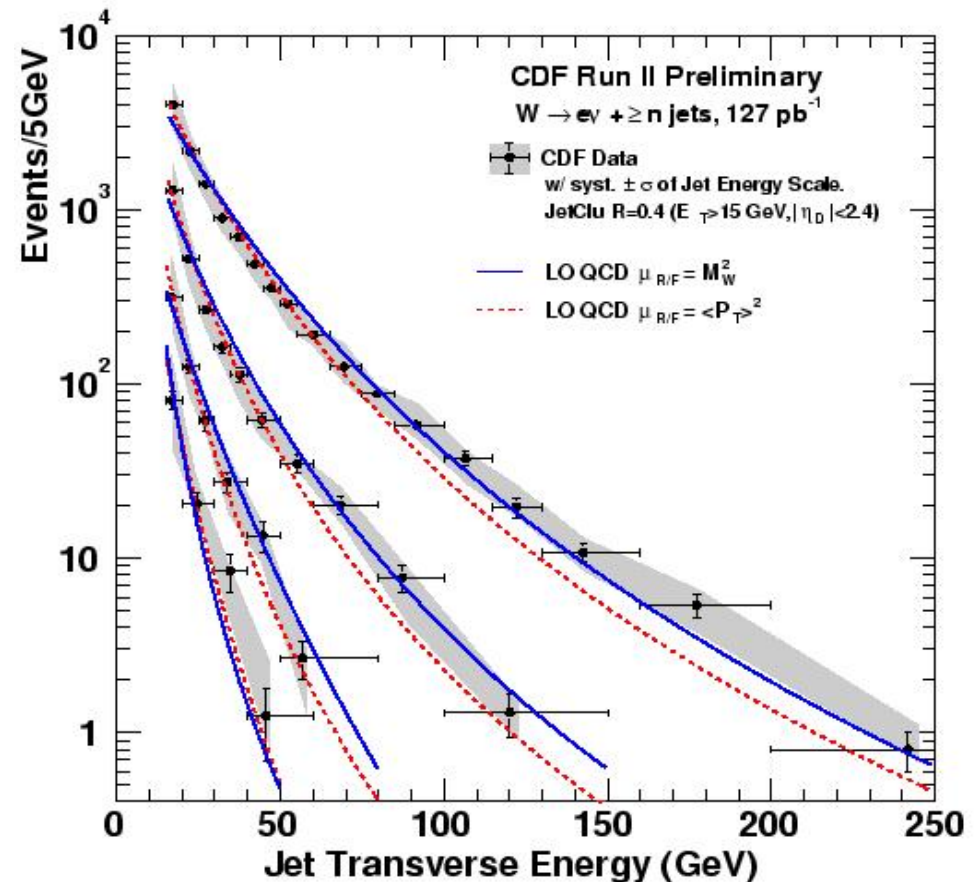
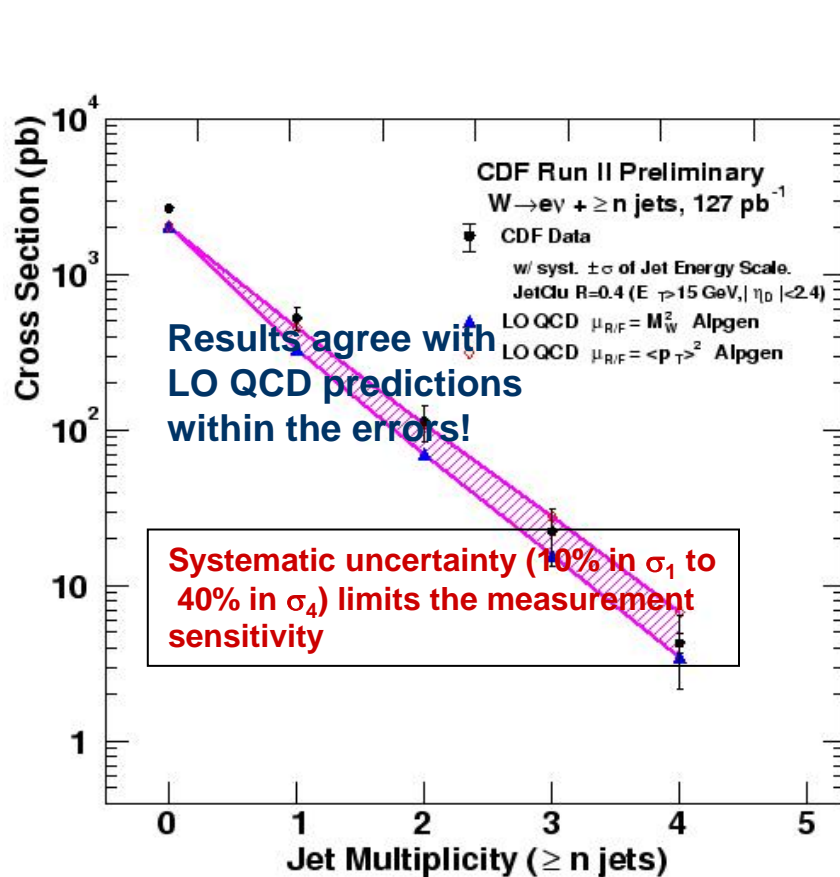
CDF W+Jets



Crucial to be able to calculate/understand this for top/higgs physics

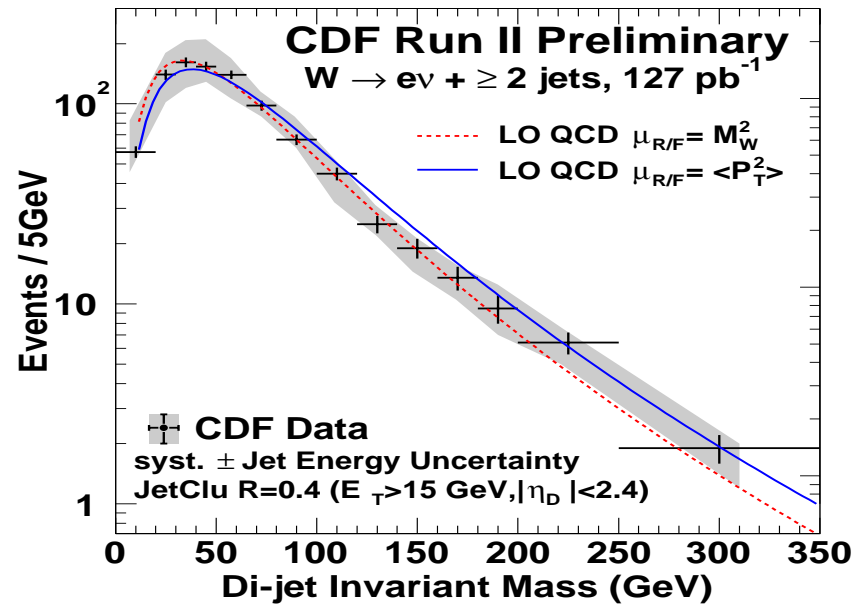
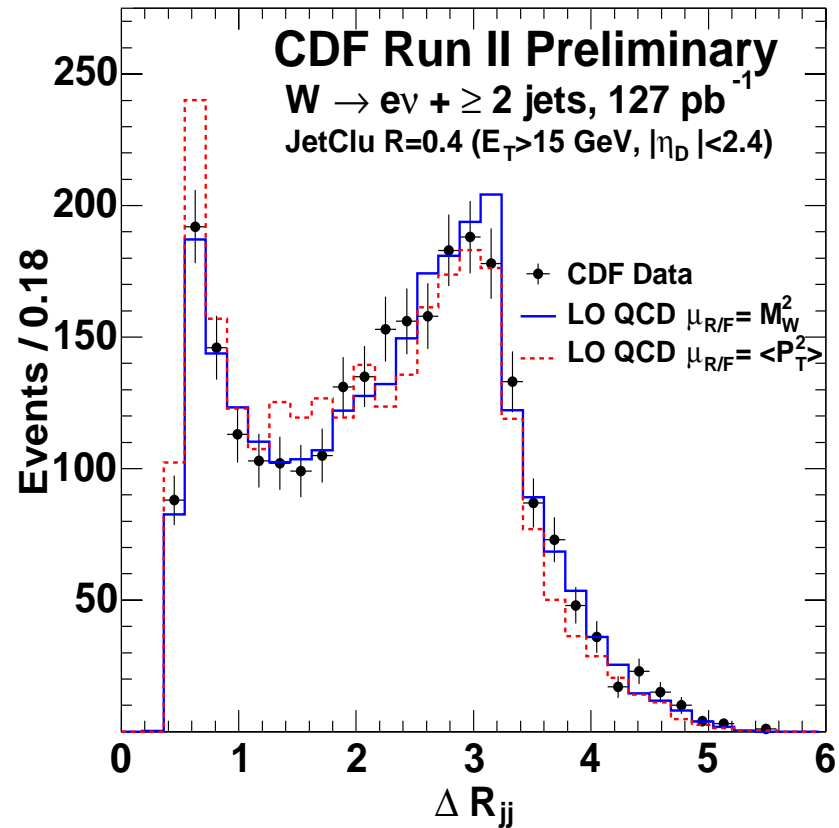
ALPGEN LO matrix element interfaced with HERWIG for parton shower

Not more than one parton associated with a reconstructed jet





CDF W+jets

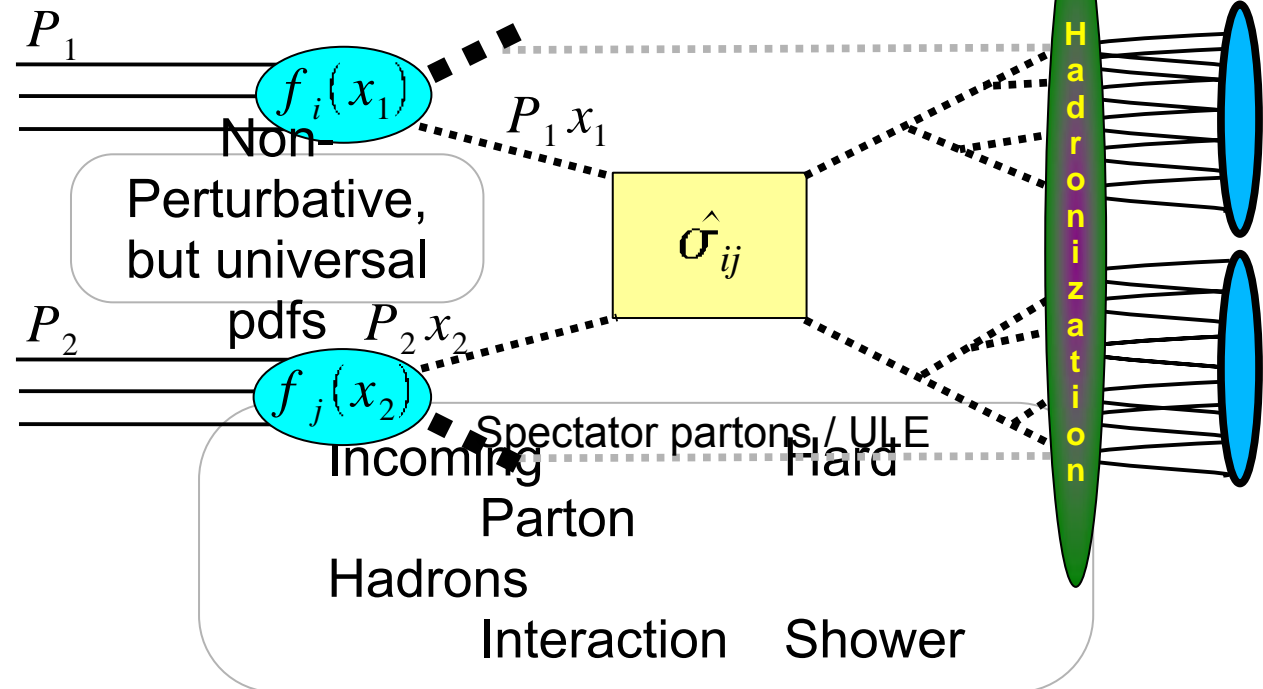




CDF, Underlying Event



The “underlying event” consists of hard initial & final-state radiation plus the “beam-beam remnants” and possible multiple parton interactions.



Studies of min bias events, Jet events in Run I produced “PYTHIA Tune A”

Run II:

Look at distributions/correlations of charged particles with $\eta < 1$, $p_T > 500$ MeV

Studies of mini-jets in min bias events

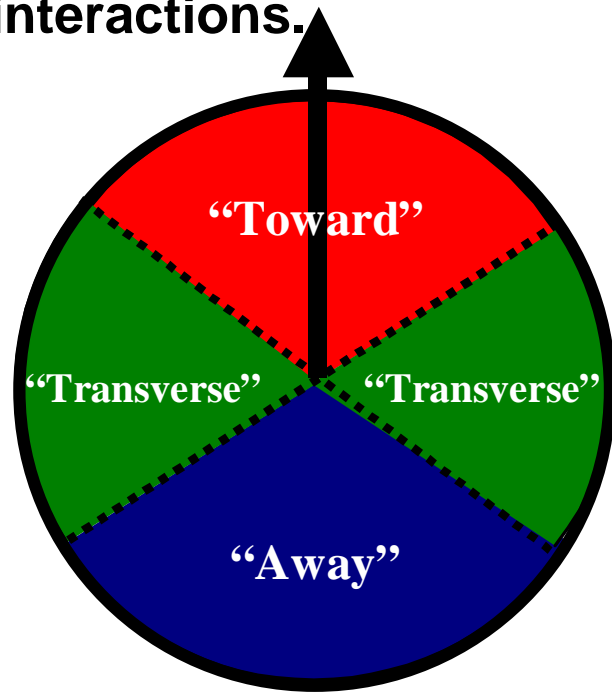
Lots has work has been done, far too much to summarize here



CDF, Underlying Event

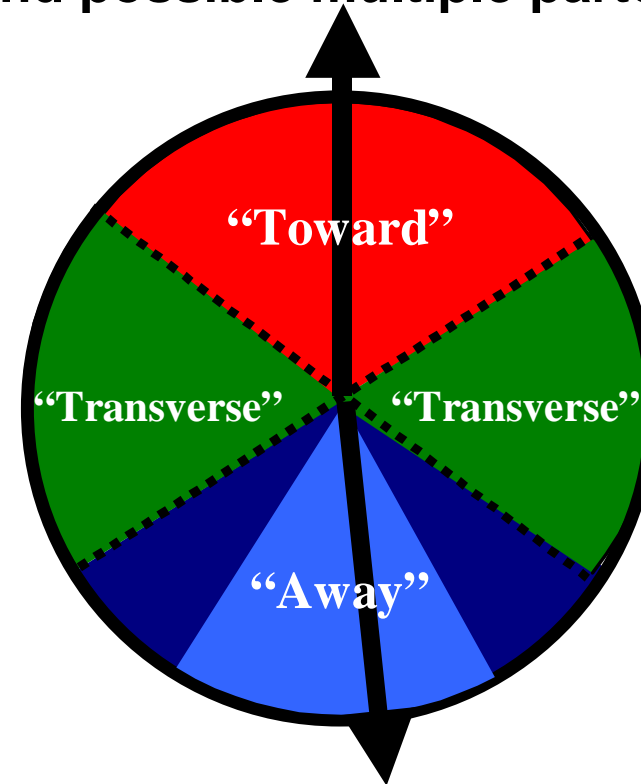


The “**underlying event**” consists of hard initial & final-state radiation plus the “beam-beam remnants” and possible multiple parton interactions.



Transverse regions are sensitive to underlying event

14 Apr 2004



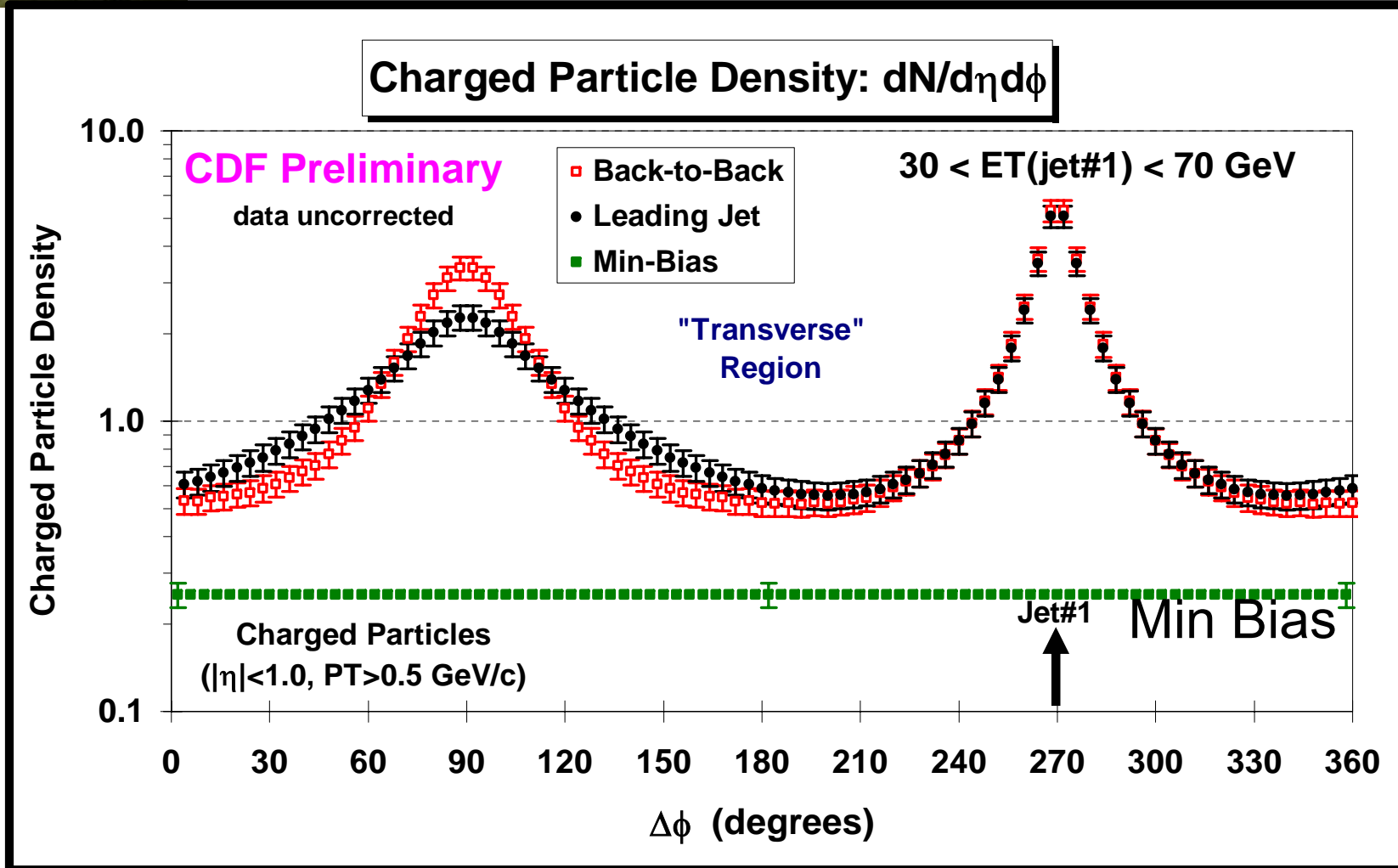
“Back-to-Back”
($\Delta\phi_{12} > 150^\circ, ET_{j_2}/ET_{j_1} > 0.8$)

DIS 2004

26



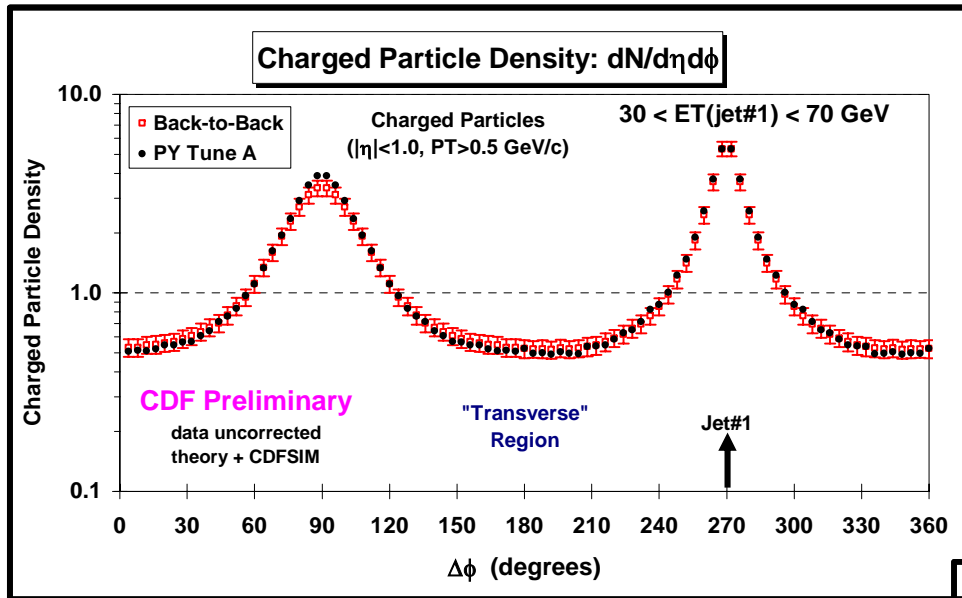
Underlying Event



With and without requiring the 2nd jet back-to-back with leading jet

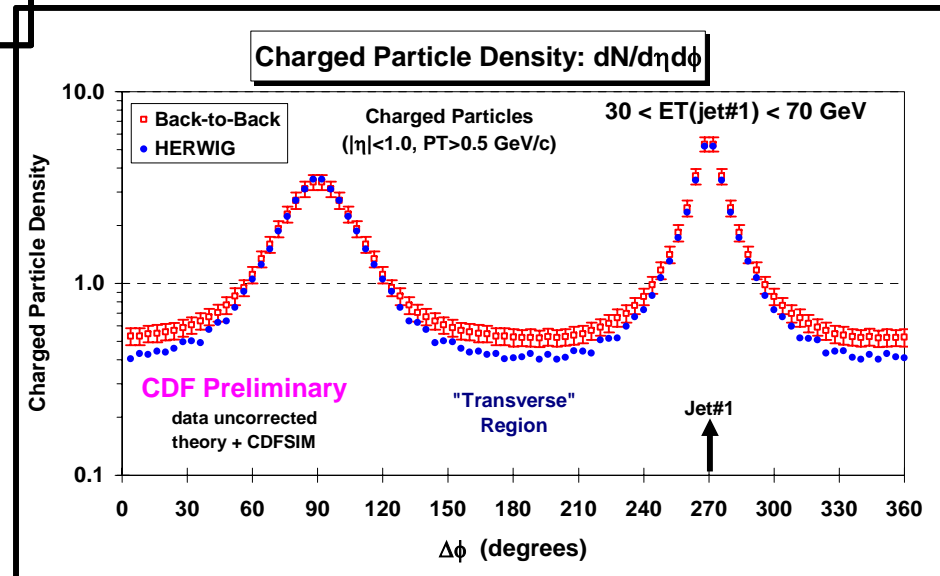


Underlying Event



← Compared to pythia Tune A

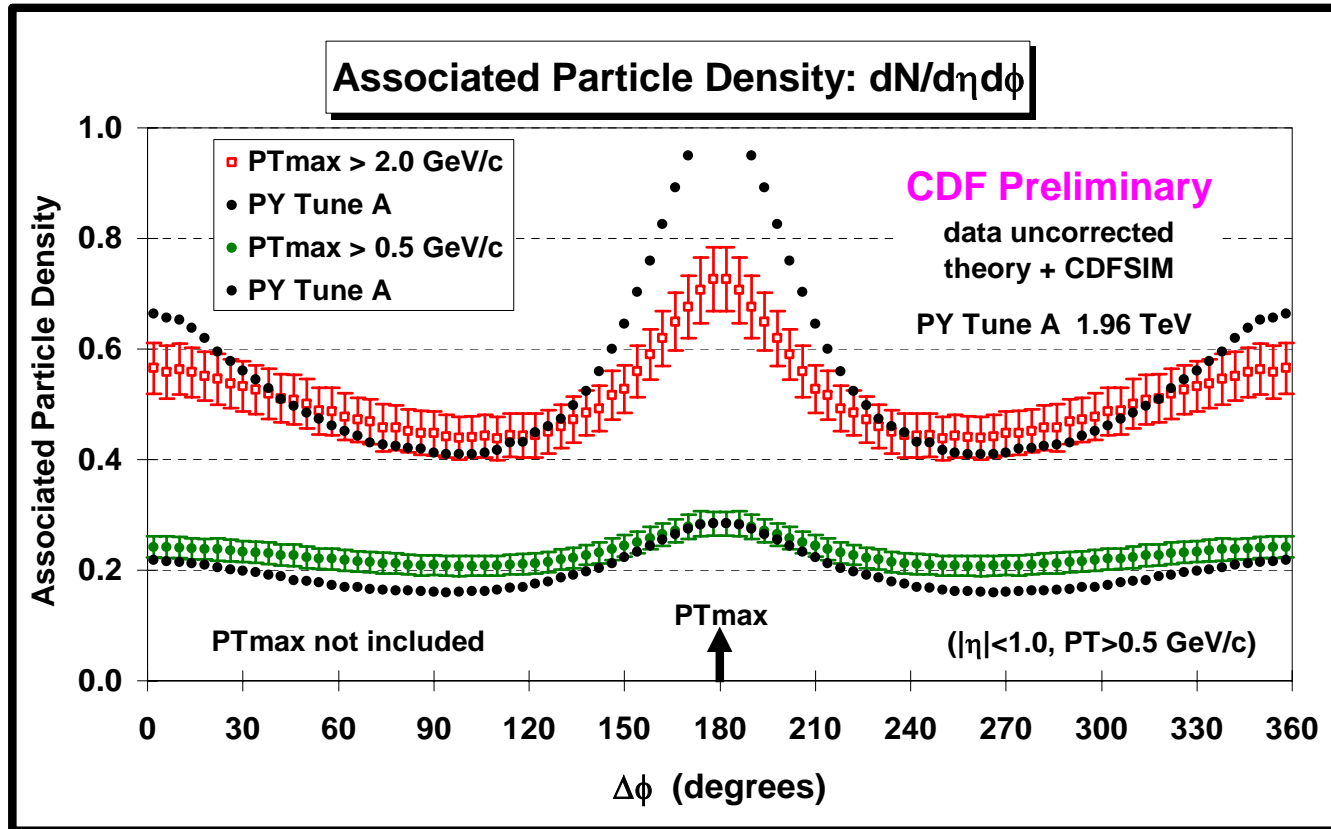
↓ Compared to untuned herwig



Pythia tuned using Run I data can describe data better than (untuned) Herwig



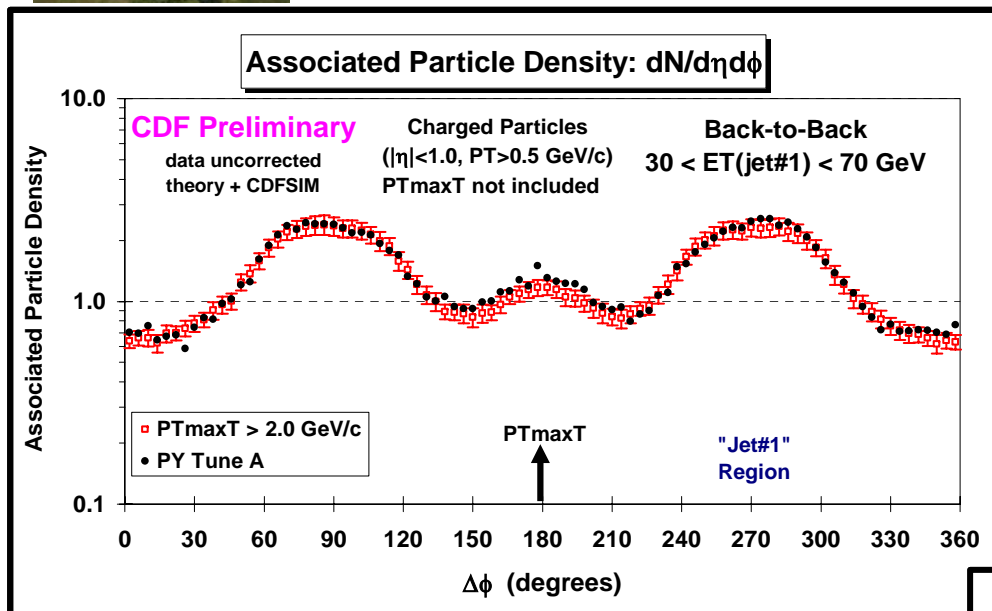
Min Bias Data



Look for min bias events with a track over a threshold.
Look at distribution of charged P_T in Φ relative to that track. Compare to Tune A



3rd Jet

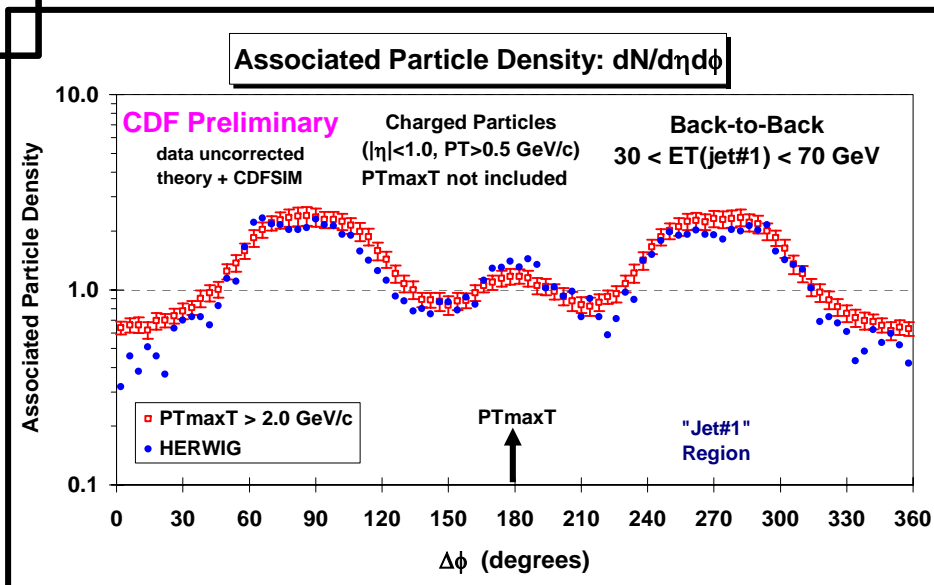


← Tune A

Herwig



Better job at predicting the emergence of the little jets in back-to-back dijet events than in Min Bias. Herwig also good





DØ, Elastic Scattering

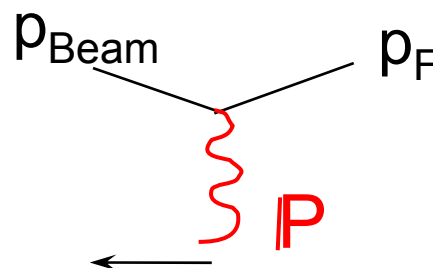


Pomeron, Odderon
Exchange: intact
proton, antiproton

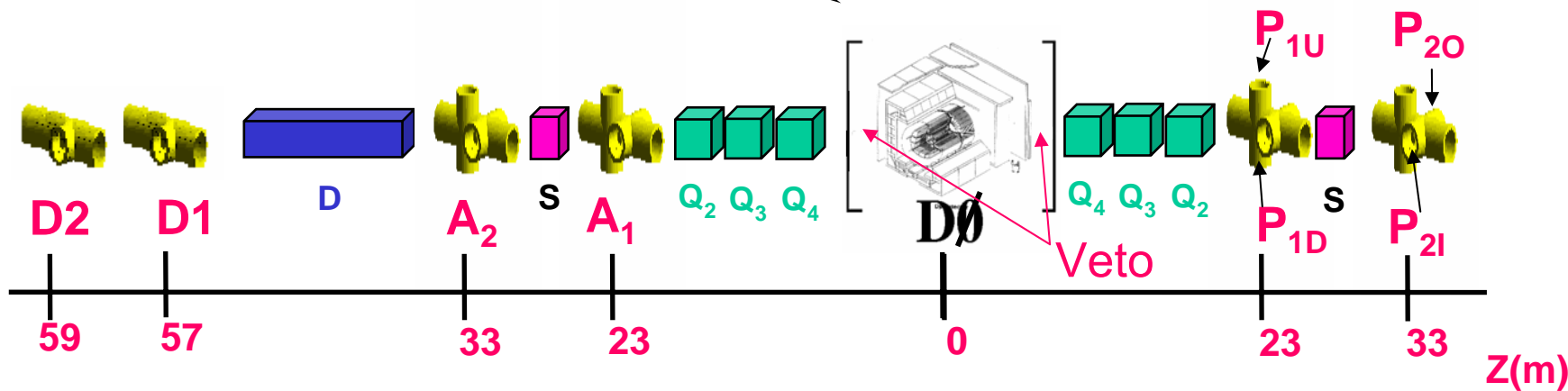


$$t = (P_{Beam} - P_F)^2$$

$$\xi = 1 - x_p = \frac{\Delta P}{P}$$

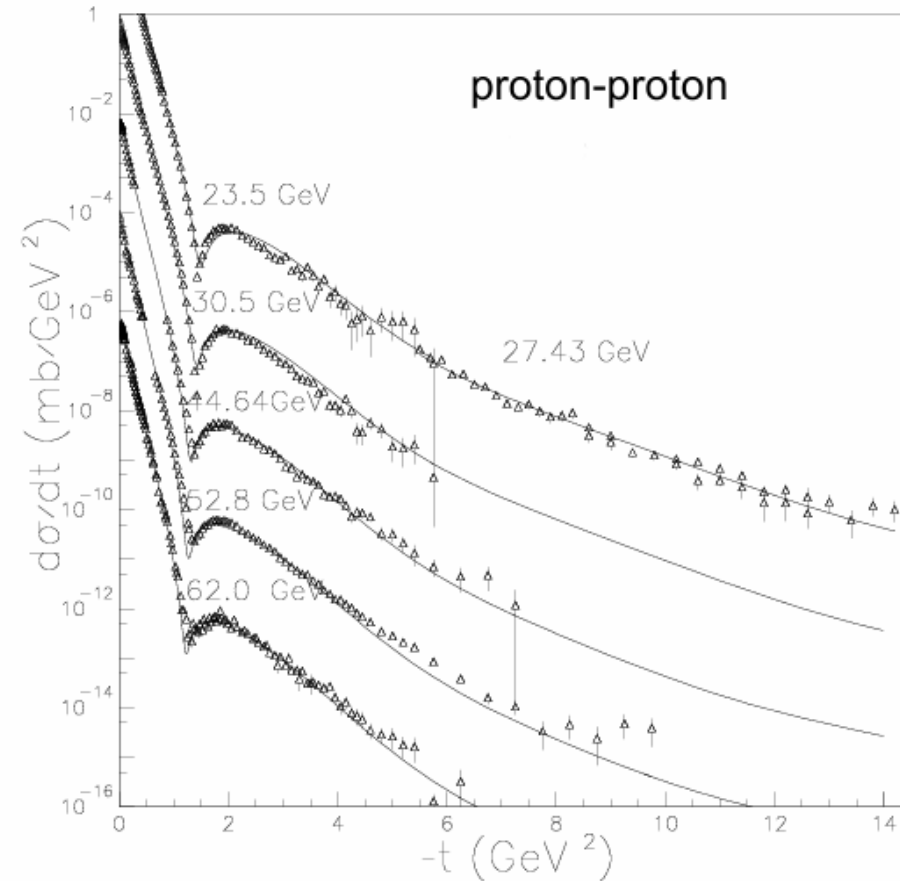
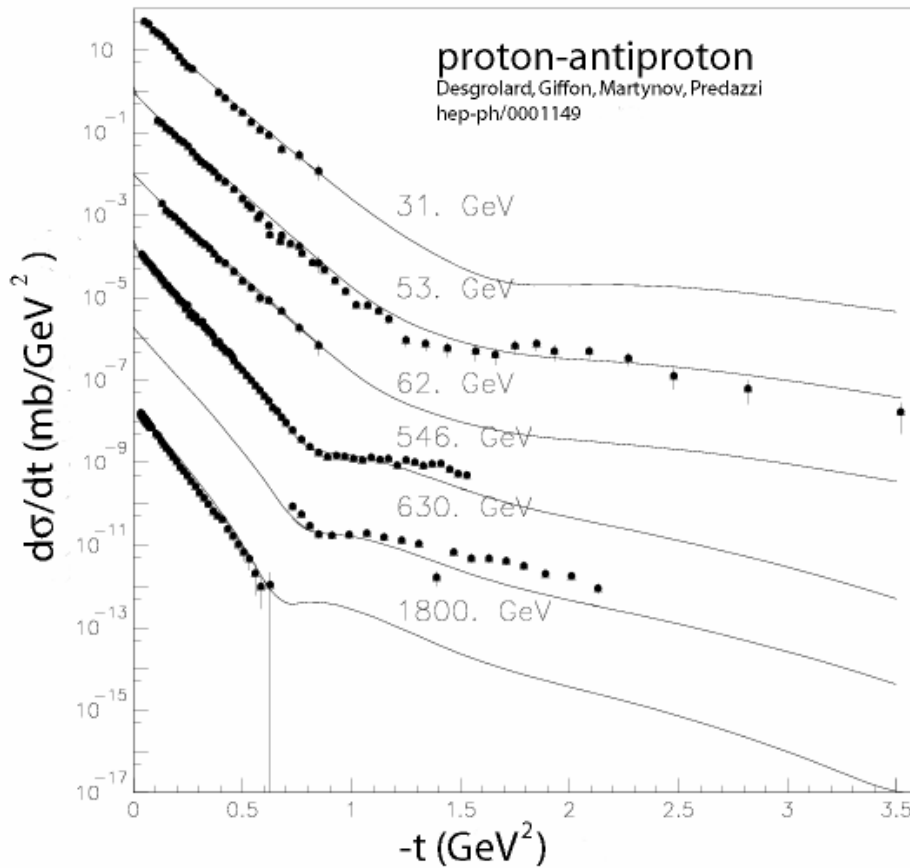


$t \sim \theta^2$, where θ is
scattering angle





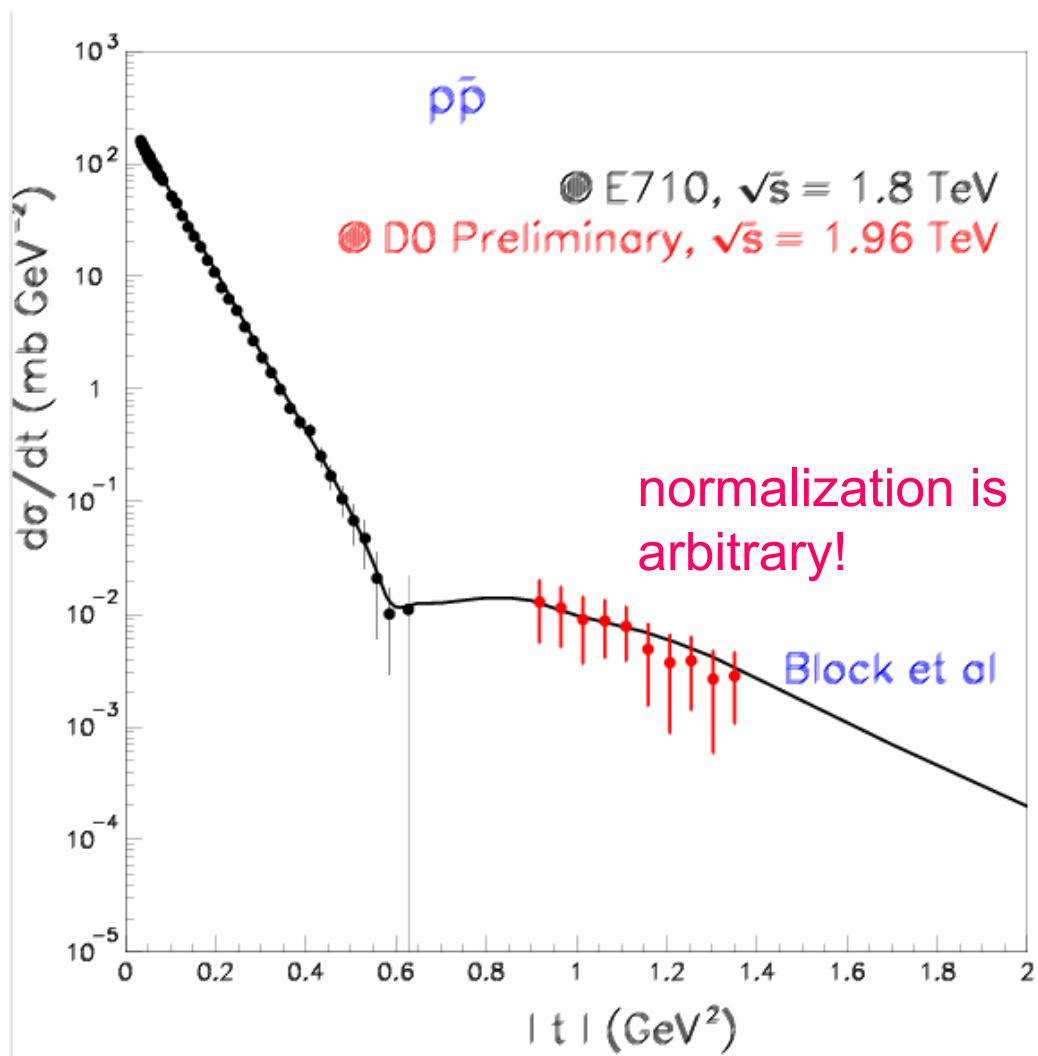
Elastic Scattering



ISR and E710 data



Elastic Results





Diffractive Z's

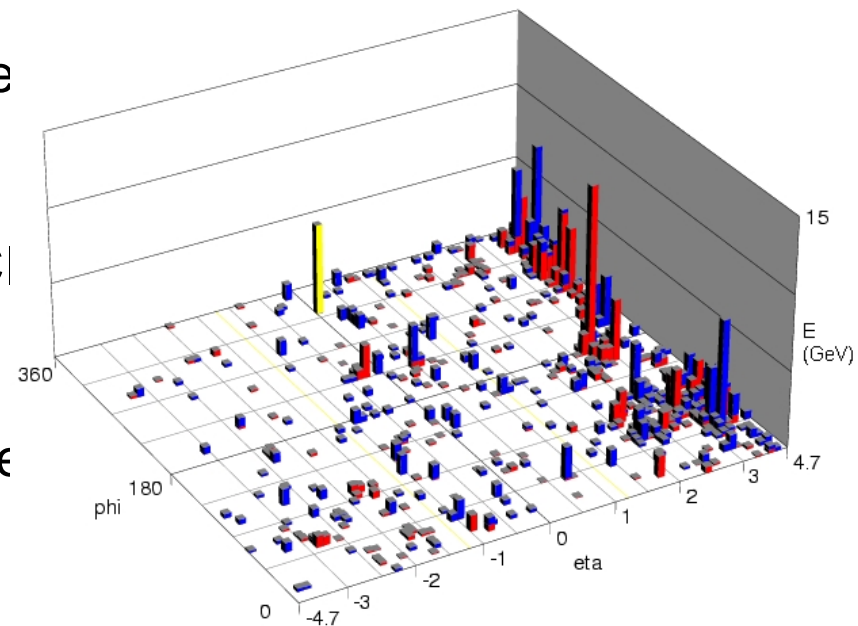


Collision between a “pomeron” and a proton or antiproton: intact p or pbar

Quark-like pomeron has larger event rate and larger fraction of events without jets than Gluon-like pomeron

Tevatron “gap” data from jet, b, J/Psi events favor hard-gluon pomeron, but rate is too high compared to extrapolation of DESY data. Tev data at 630 GeV further complicates the extrapolation picture. SC model (Edin, Ingelman, Rathsman, J. Phys. G22, 943 (1996) , which does not involve pomerons, may better describe the data.

Can we do at higher luminosity?



**Intact
proton**



Run I



CDF: 8246 $W \rightarrow e\nu$'s with a gap fraction of 1.15 ± 0.6 .
Jet distribution consistent with quark-like pomeron
from the jet fraction, gluon-like for the absolute rate.

DØ: 12622 $W \rightarrow e\nu$'s with gap fraction of $0.89 \pm 0.2\%$,
811 $Z \rightarrow ee$'s with gap fraction of $1.44 \pm 0.6\%$. Event
characteristics of diffractive and non-diffractive W 's
agree well. Unlike diffractive jet events, central W 's
have larger gap fraction than forward W 's

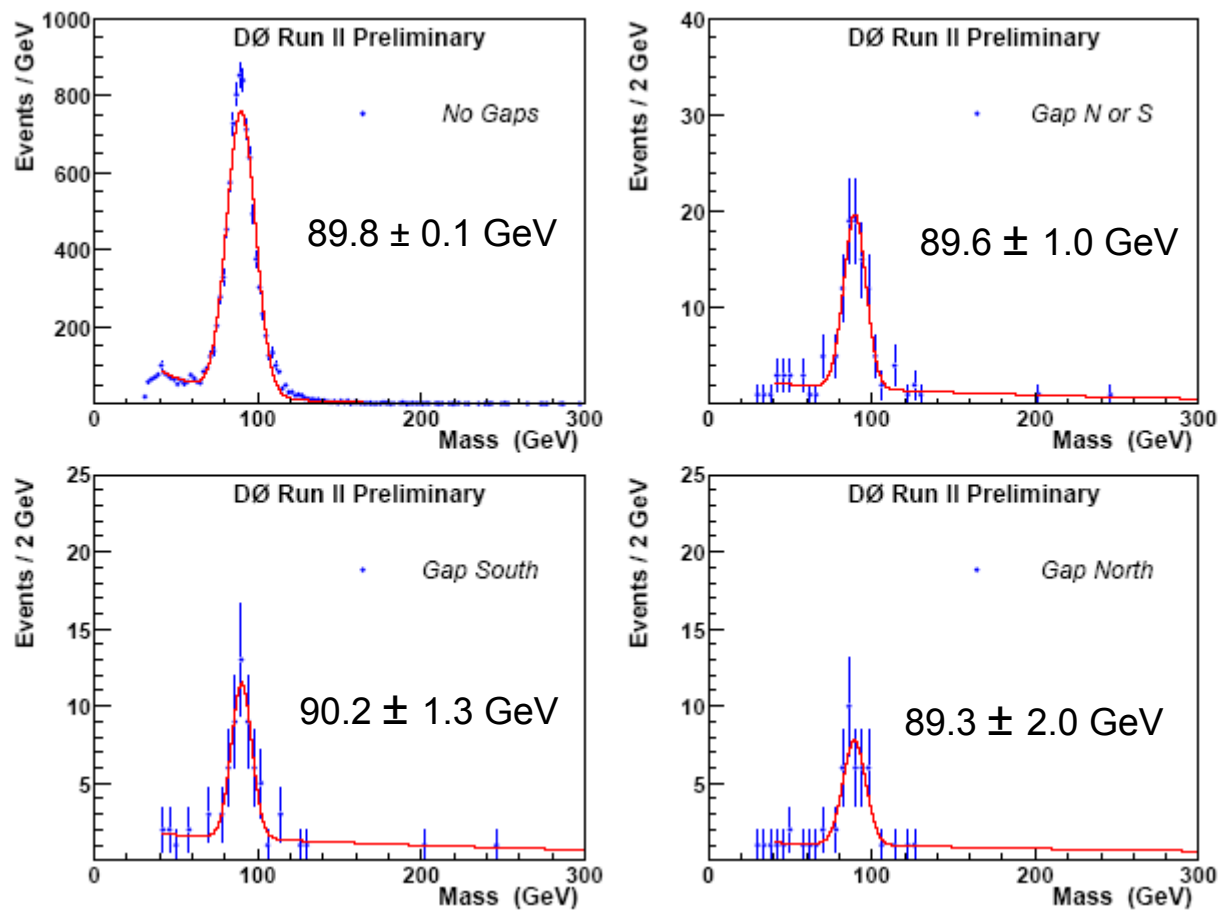
Some discussion regarding how to correct for the
fraction of diffractive events that do not contain a gap.
If this is done, the measurements are not in as good of
agreement as above implies (500% for DØ, 20% for
CDF for pomeron model)



Run II



Already same order as we had W's in Run I

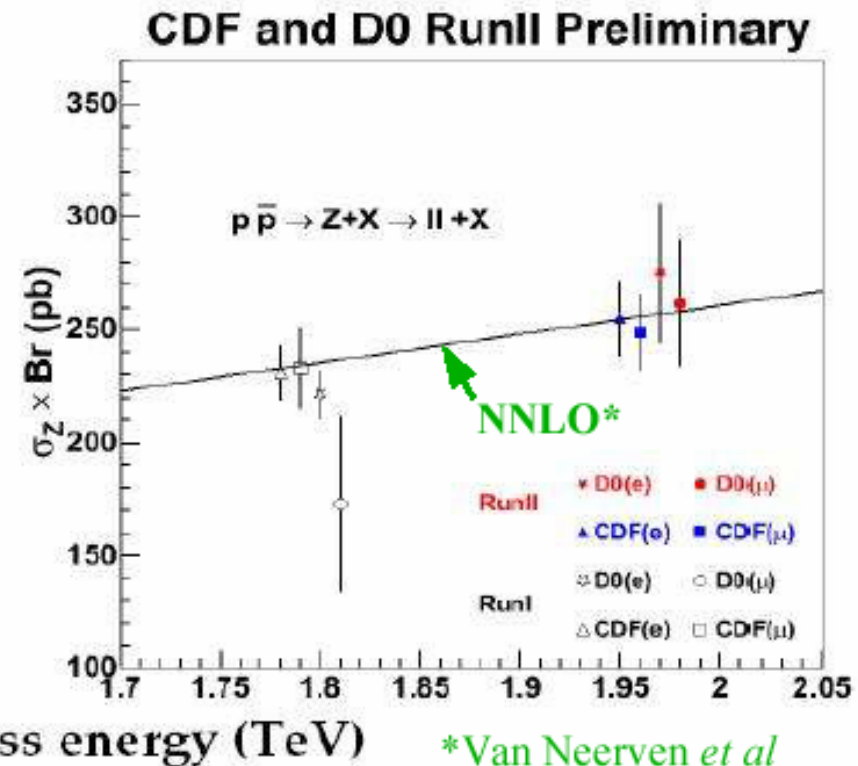
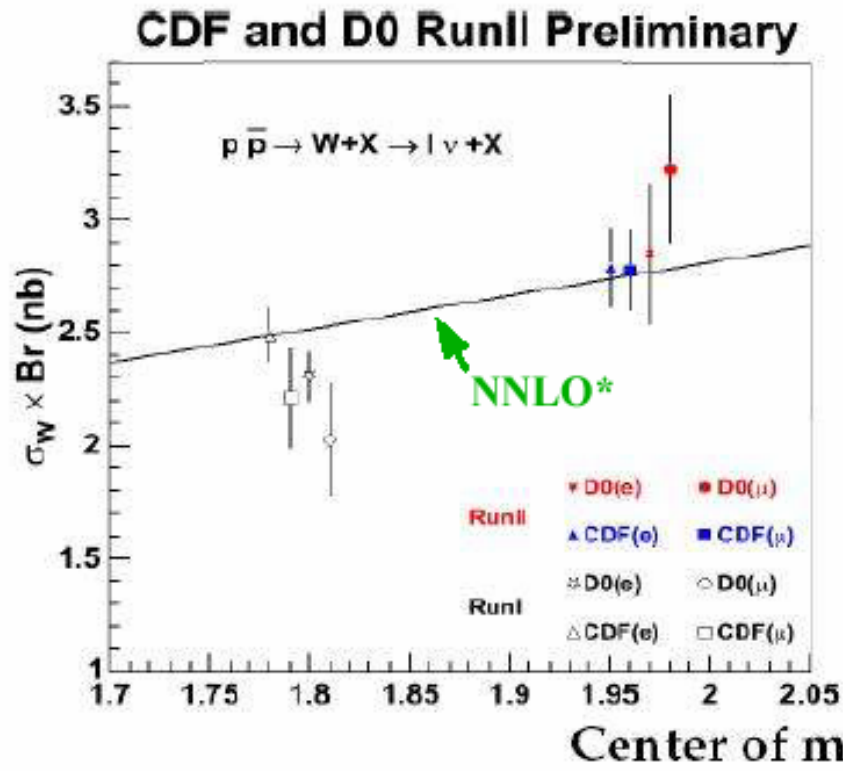




W/Z Cross Section



New results from CDF for winter 2004 in all channels.



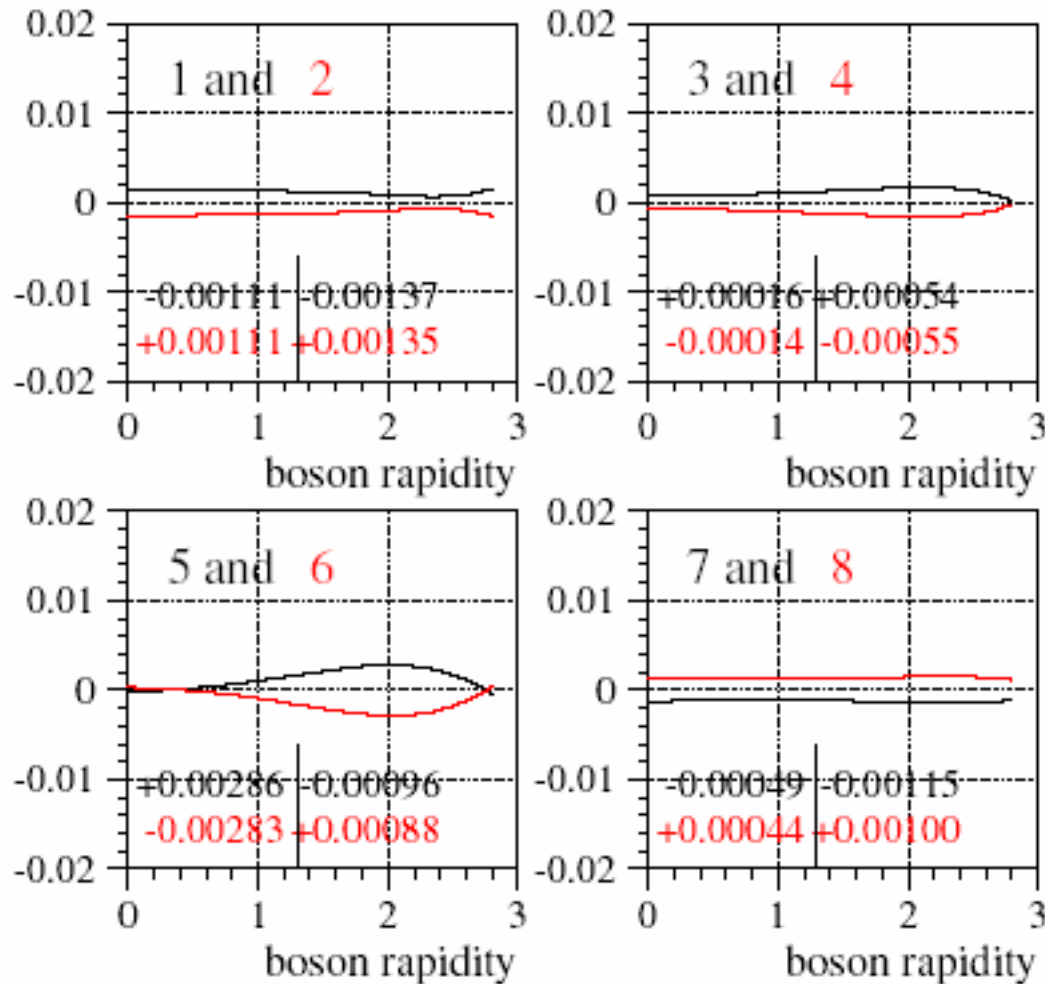
*Van Neerven *et al*
(nucl phys. B359, 343, 1991)

DØ and CDF have agreed on a common luminosity normalisation.

Next round of plots will use this common scheme. <http://tevewwg.fnal.gov/>



PDF Uncertainty

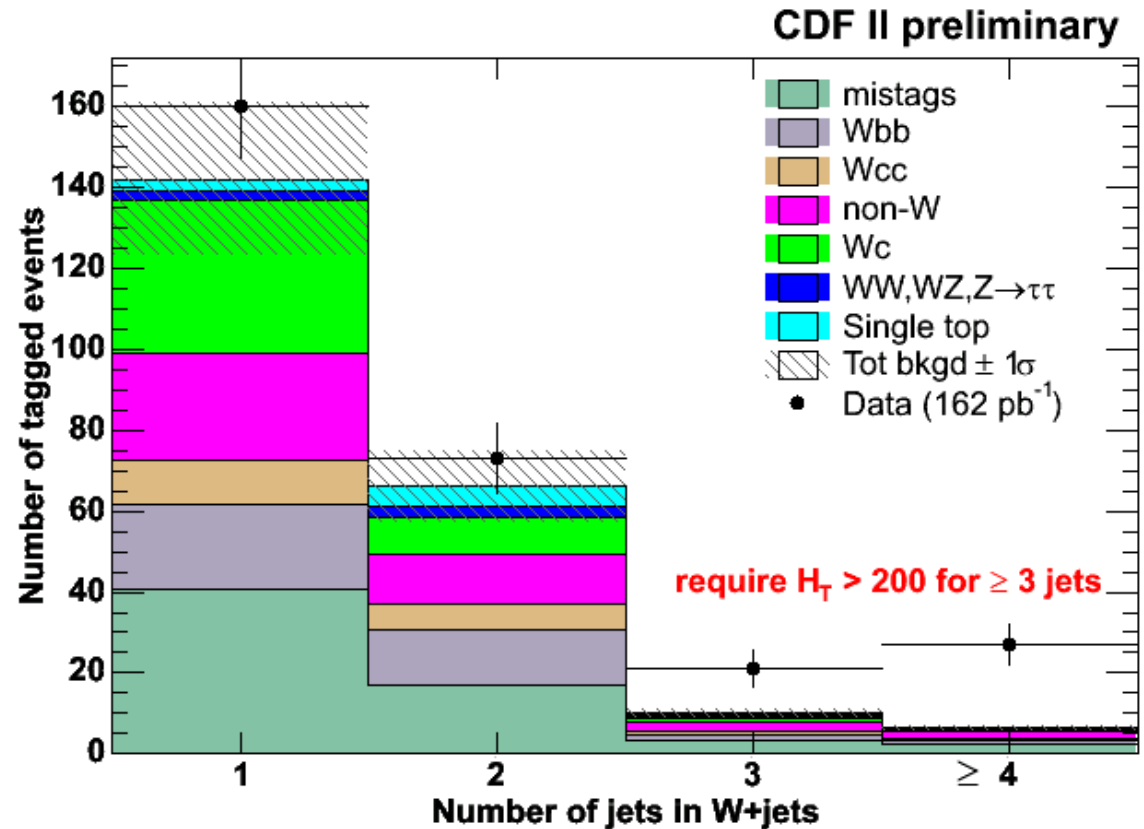
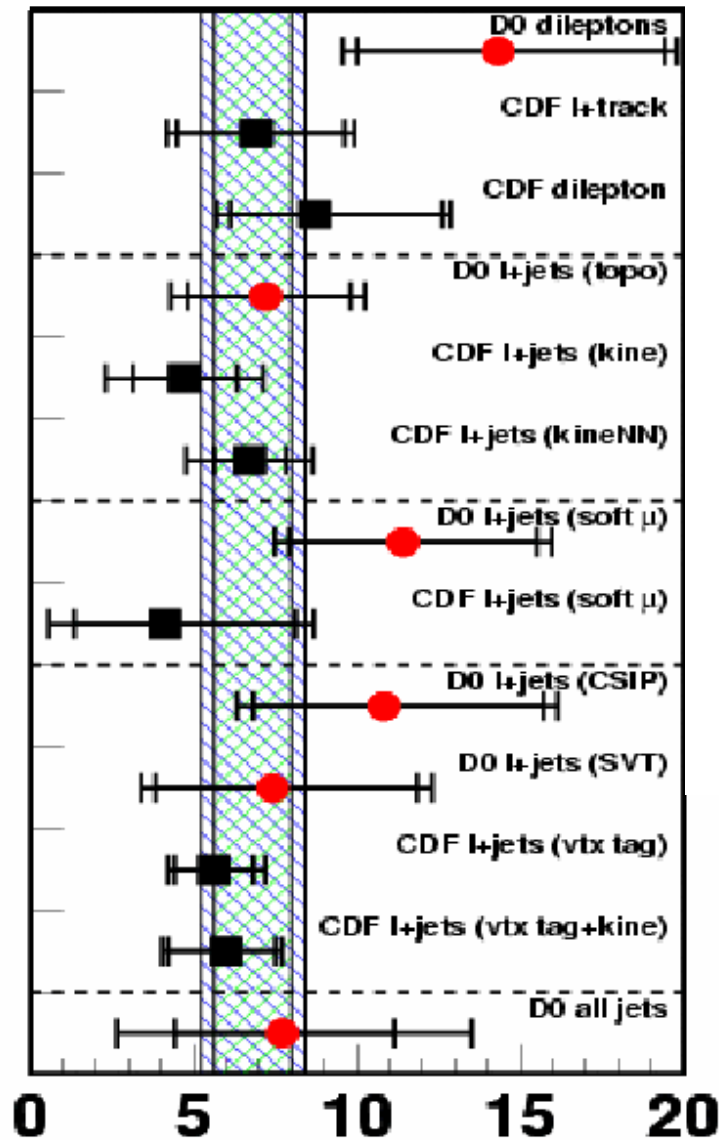


Uncertainty on ratio of acceptances using CTEQ6 SF, LO calculation of the cross section, and a parameterization of the acceptance versus boson rapidity. CTEQ6 has a nominal PDF and 40 error PDF's, corresponding displacing each of the X parameters by +/- 1 sigma.

Michael Schmitt,
Northwestern U,
CDF



Top Cross Section



Theory cross sections

Kidonakis NNLO-NNLL hep-ph/0303185

Cacciari et al hep-ph/0303085

Uncertainty dominated by large-x gluon pdf and α_s



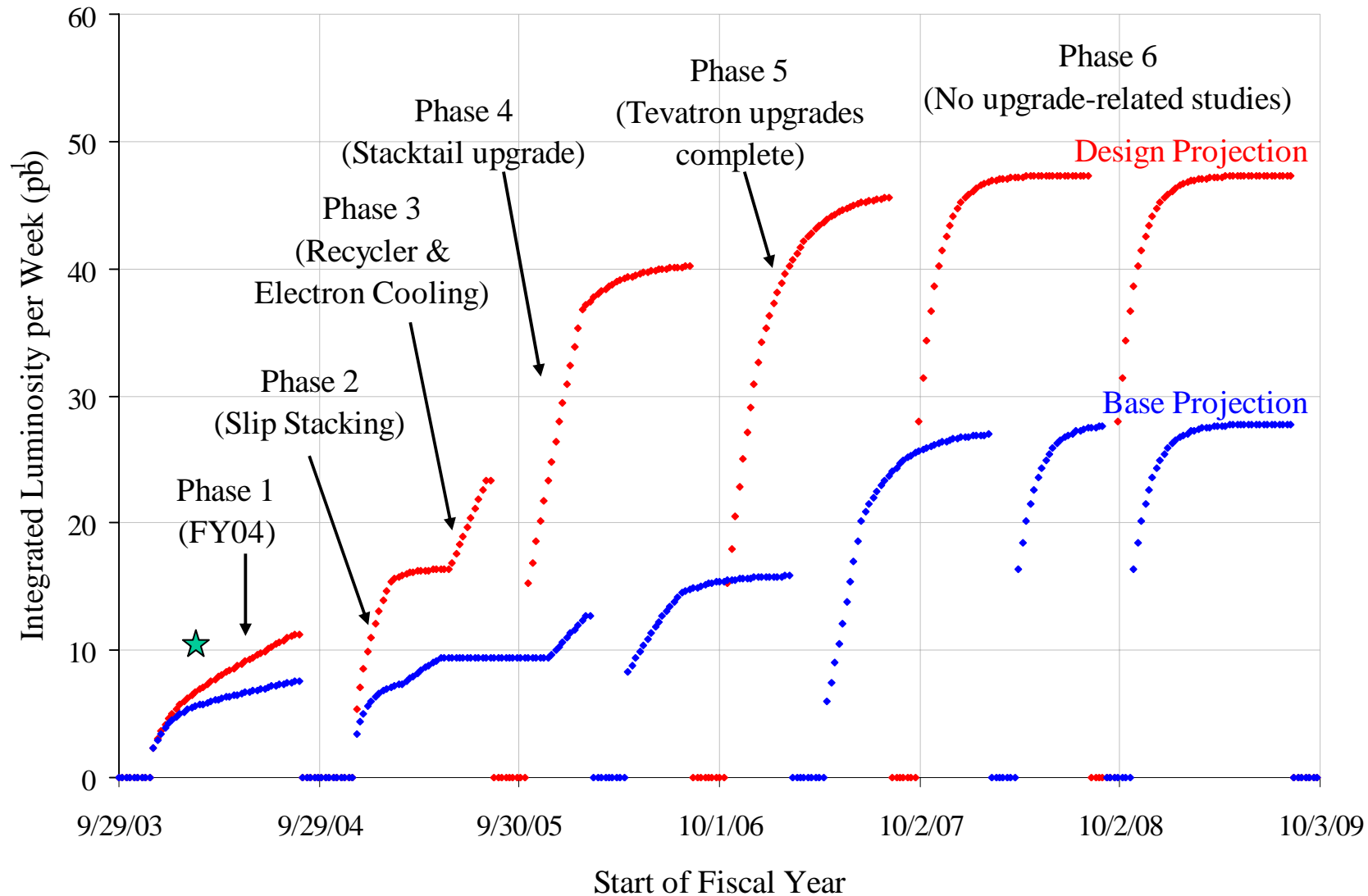
Prospects



Both Collaborations expect many publications before summer.

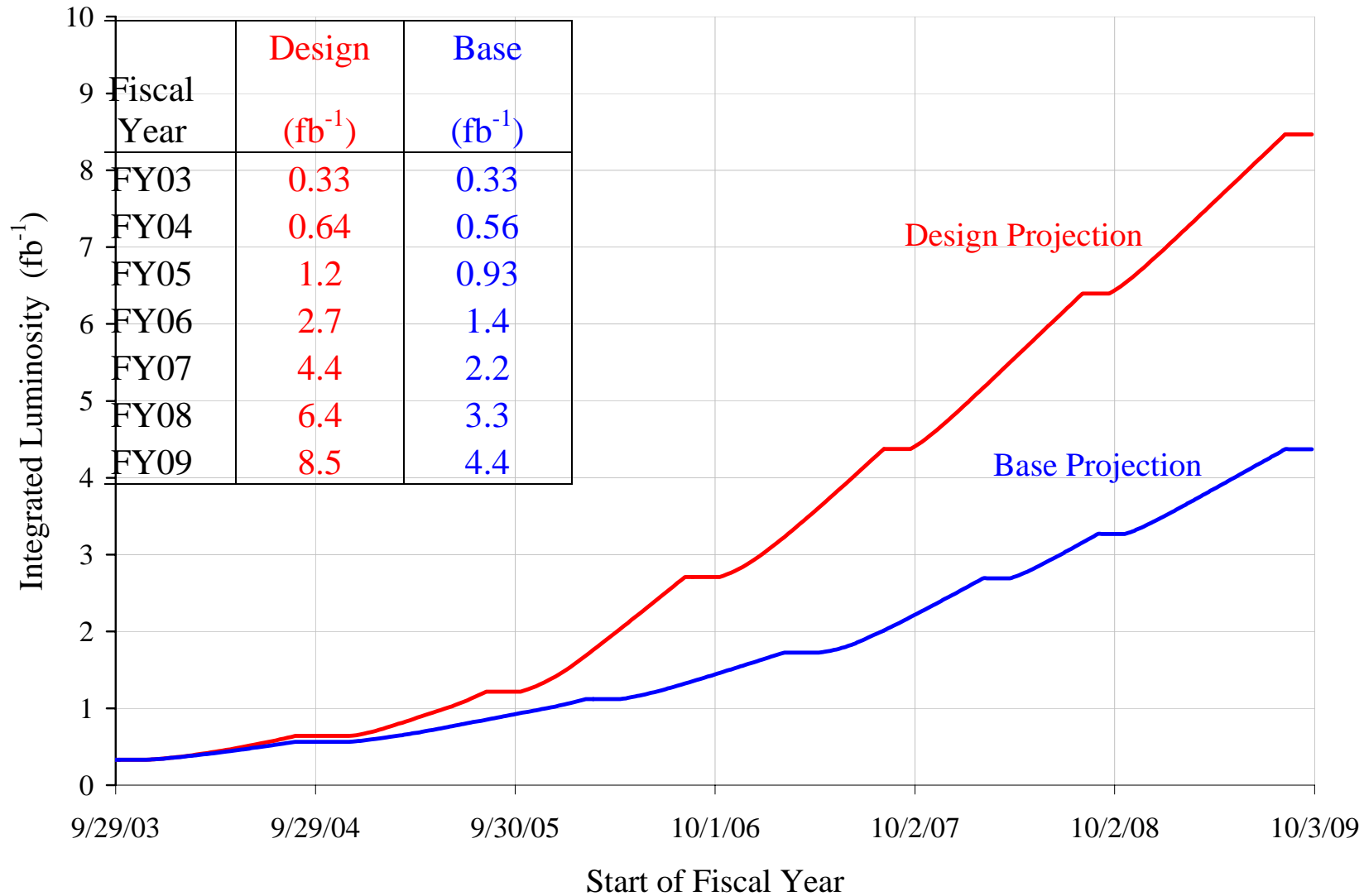


Prospects





Prospects





Talks in Working Groups



- Jets – Alexei Safonov
- Dijet Mass - Pavel Demine
- Inclusive Jet Cross Section – Miroslav Kopal
- Underlying Event: Niccolo Moggi
- Diffraction – Koji Terashi
- Diffractive Z production/elastic results - Tamsin Edwards
- Pentaquarks: Igor Gorelov
- bottom and charm: Peter Bussey
- Upsilon and X – Franck Lehner
- B physics – Tulika Bose
- EWK: Susana Cabrera
- Top Physics – Sebastien Greder
- Top: Roman Lysak
- SUSY Searches – Tibor Kurca
- B decays: Simone Donati
- Leptoquarks: Dan Ryan
- Other searches: Arnold Pompos
- Higgs Physics – Stephanie Beauceron