New (QCD) Results from the Tevatron

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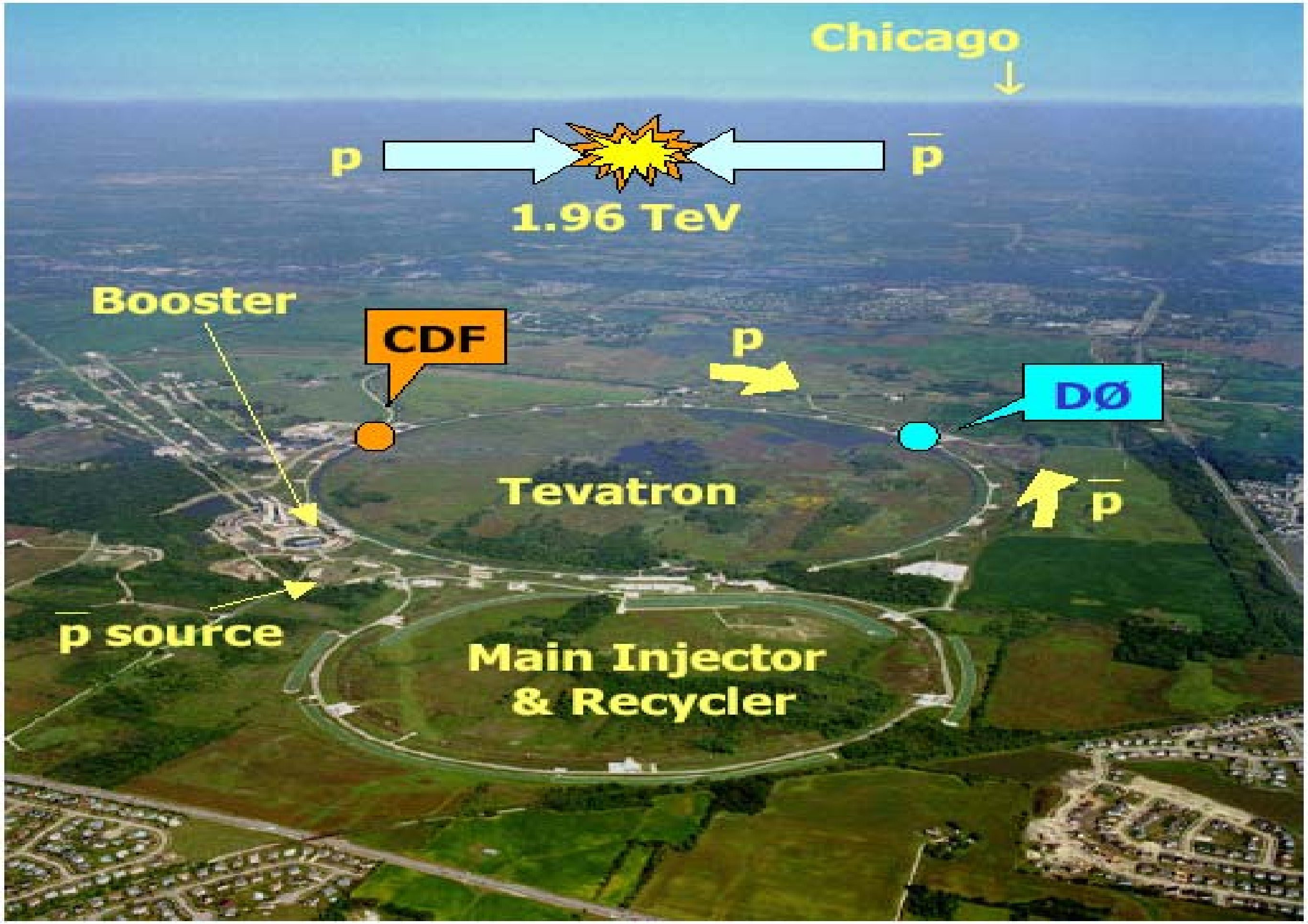
U. Maryland

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$\Rightarrow$1.96 TeV

Goal:

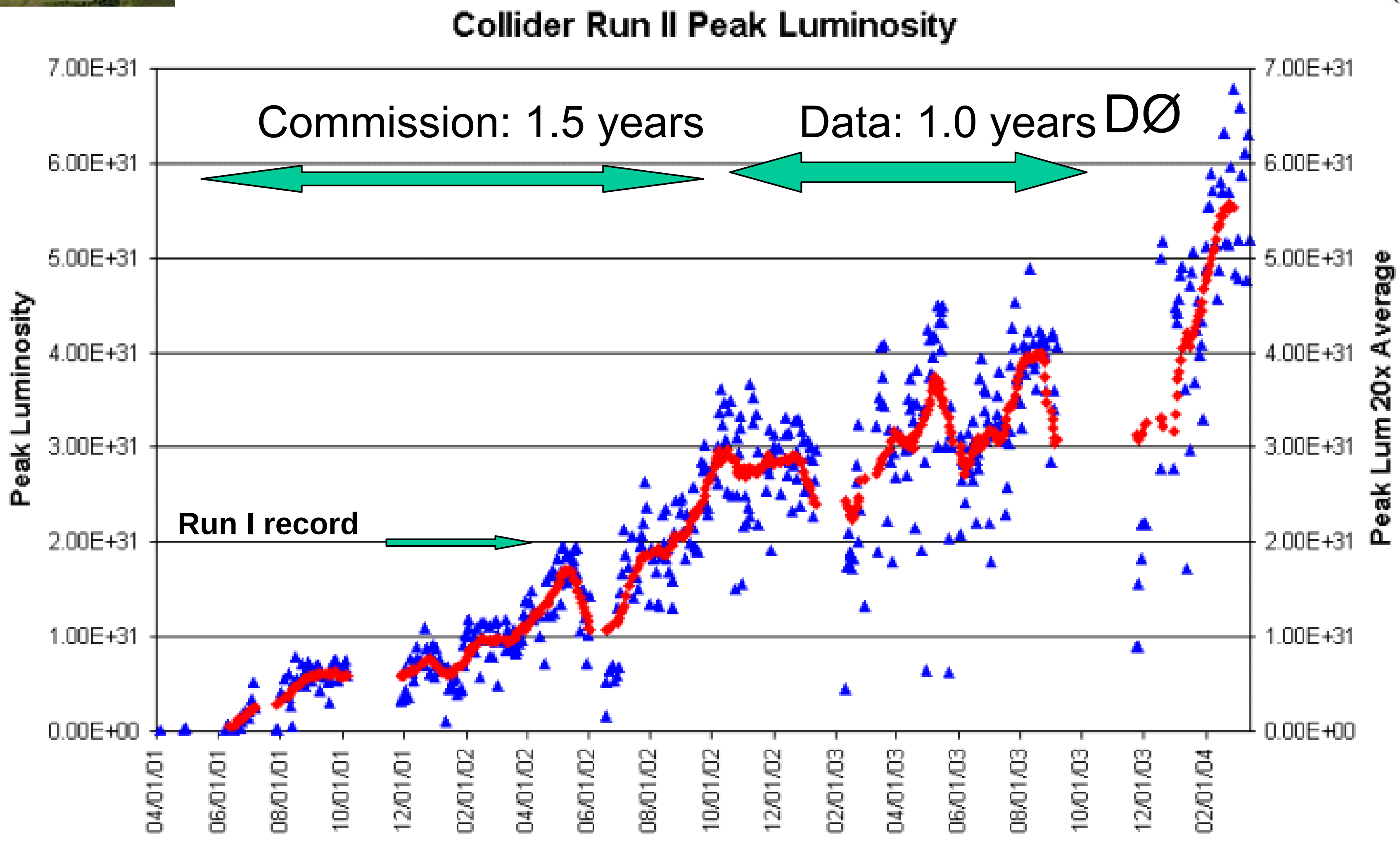
20 pb^{-1}/week

10E31 cm^{-2} s^{-1}

2 fb^{-1}

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

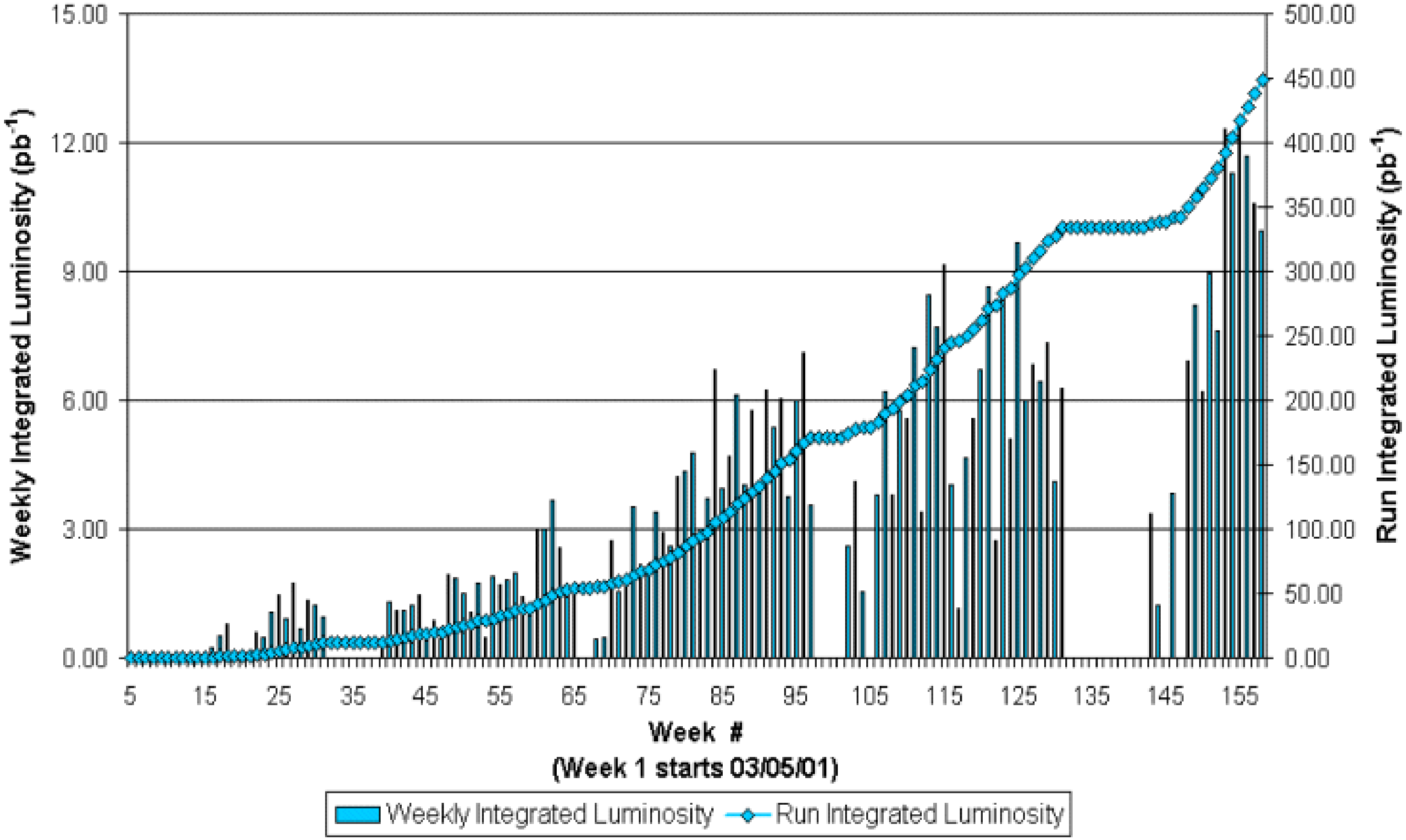
Tevatron



Nov 2002 D0

March 2002 CDF

Tevatron

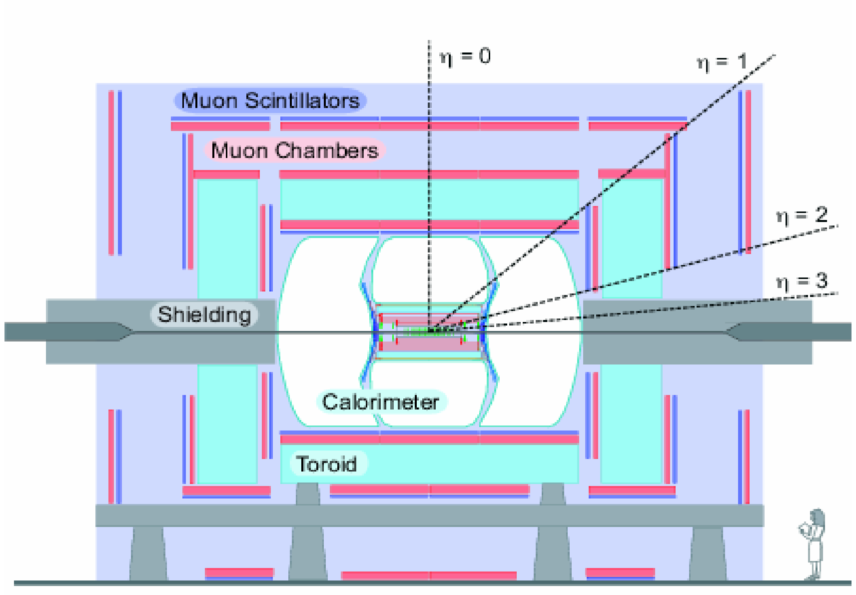


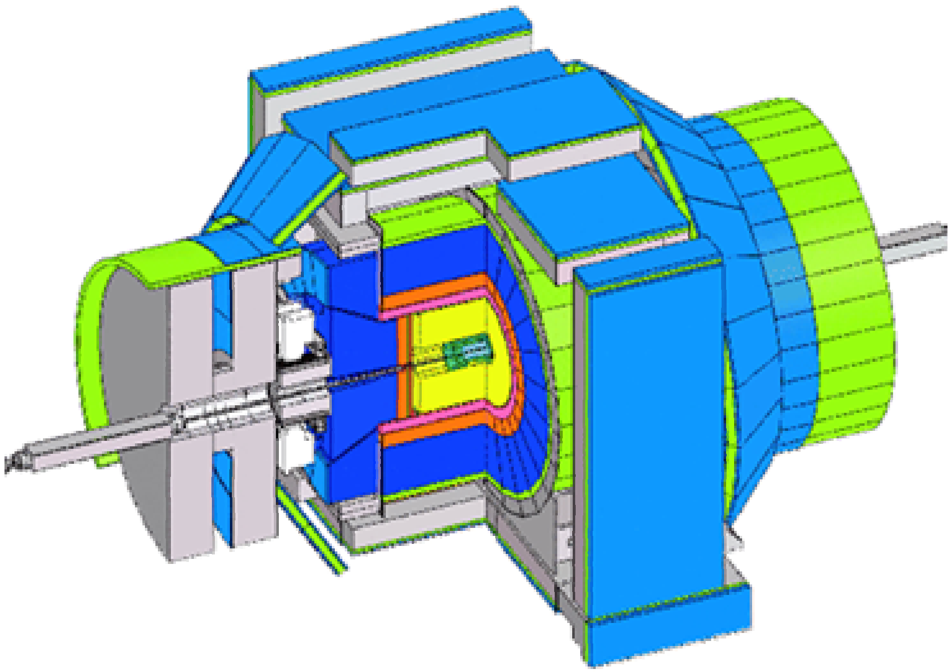
Collider Run II Integrated Luminosity
Weekly Integrated Luminosity (pb-1)
15.00
12.00
9.00
6.00
3.00
0.00
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Run Integrated Luminosity (pb-1)
5
15
25
35
45
55
65
75
85
95
105
115
125
135
145
155
Week #
(Week 1 starts 03/05/01)
Weekly Integrated Luminosity
Run 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 sctions: 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

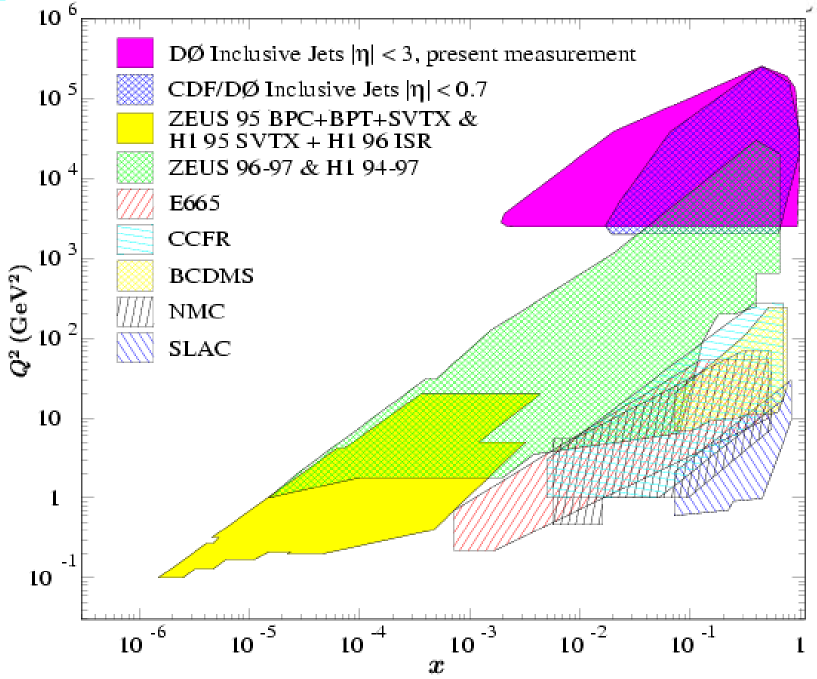
- **inclusive jet cross section, forward region (143 pb^{-1})**
- **dijet cross section (143 pb^{-1})**
- **azimuthal decorrelation in dijet events (150 pb^{-1})**
- **elastic scattering**
- **Z's with rapidity gaps (117 pb^{-1})**
- **top cross sections (140-156 pb^{-1})**

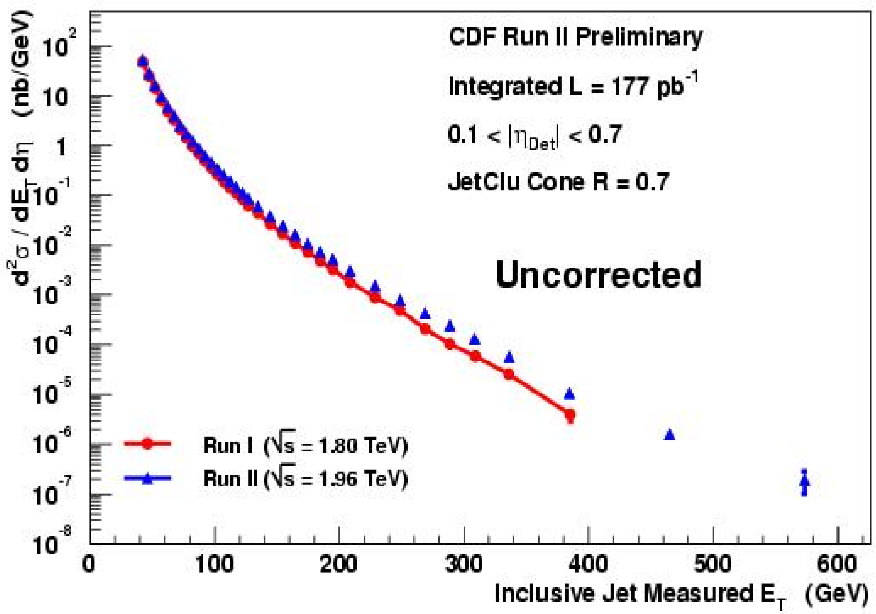
Channel-by-channel luminosity variations due to detector-specific good run selection

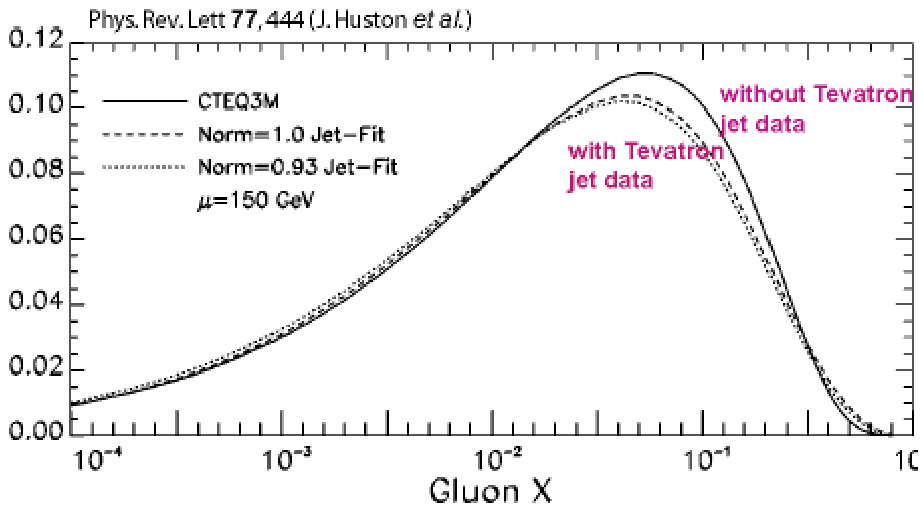
Harder analyses tend to freeze their data sample earlier, and thus have less luminosity

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

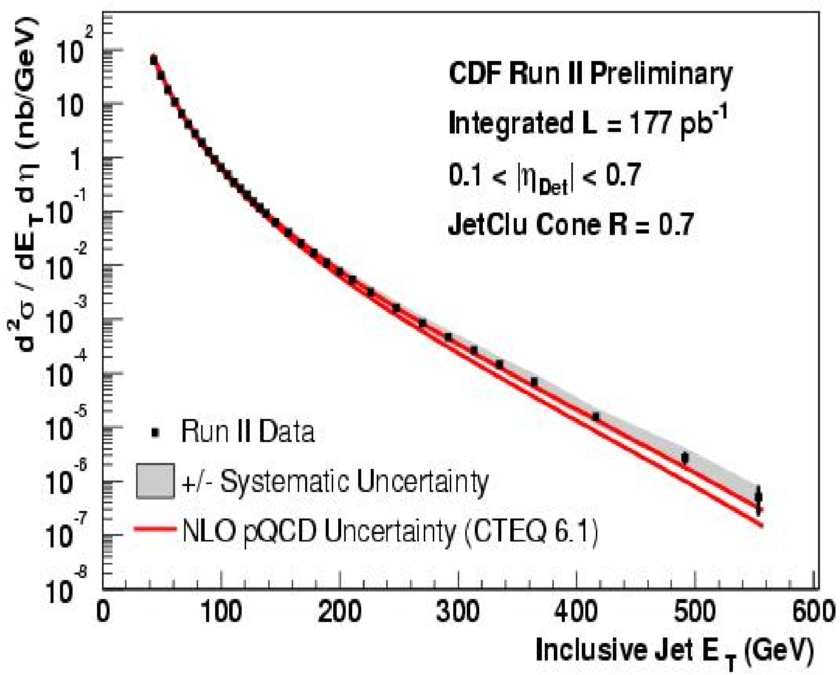
$$P^J = (E^J, \mathbf{p}^J) = \sum_{i \subset J = C} (E^i, p_x^i, p_y^i, p_z^i)$$

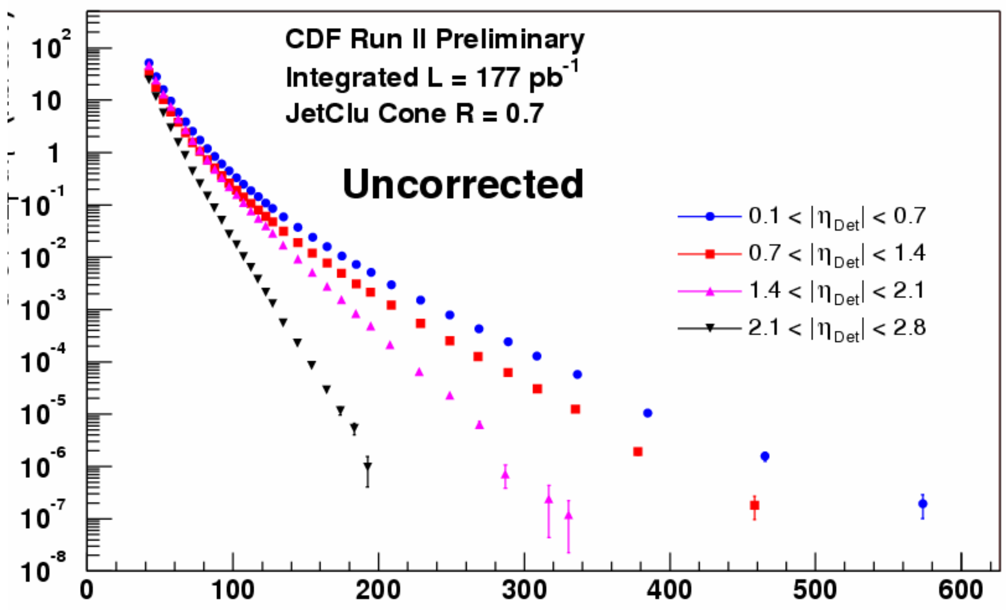
$$P_T^J = \sqrt{(p_x^J)^2 + (p_y^J)^2}$$

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

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

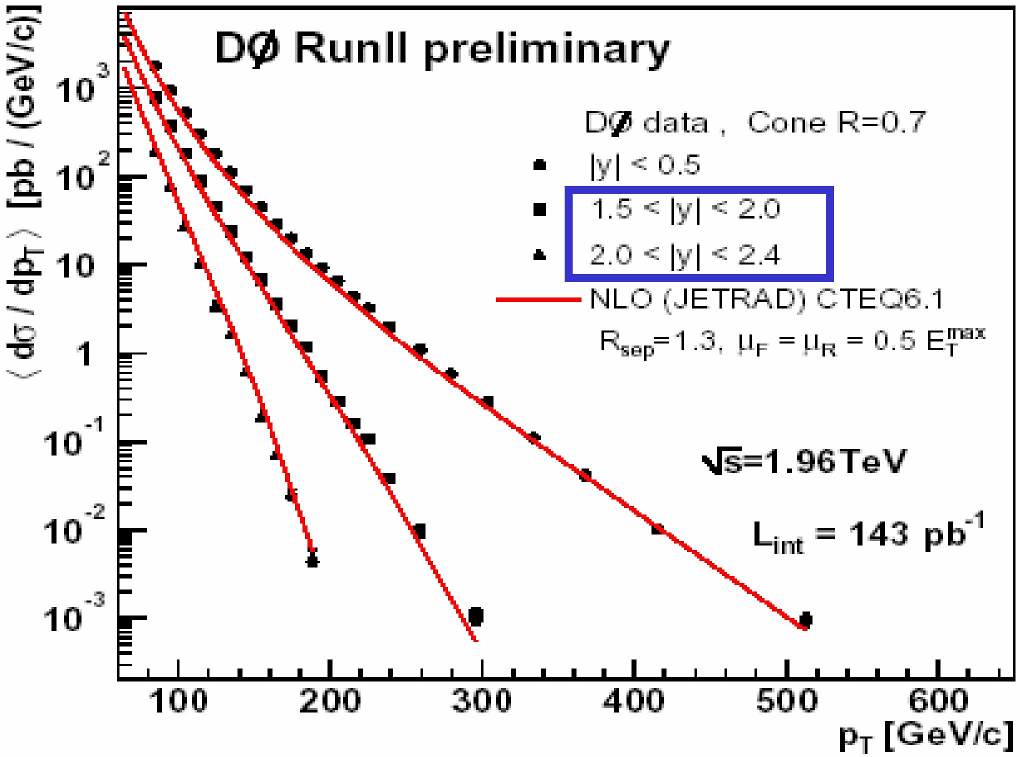
CDF Update





More luminosity since winter 2003 177 pb^{-1}

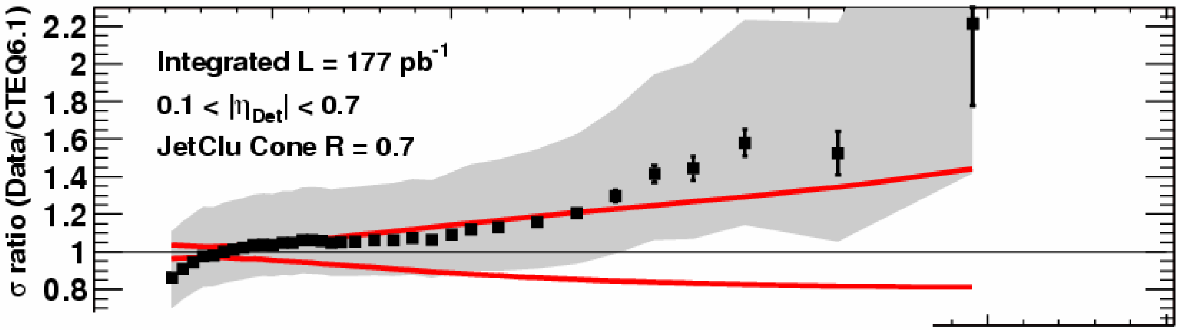
DØ Results

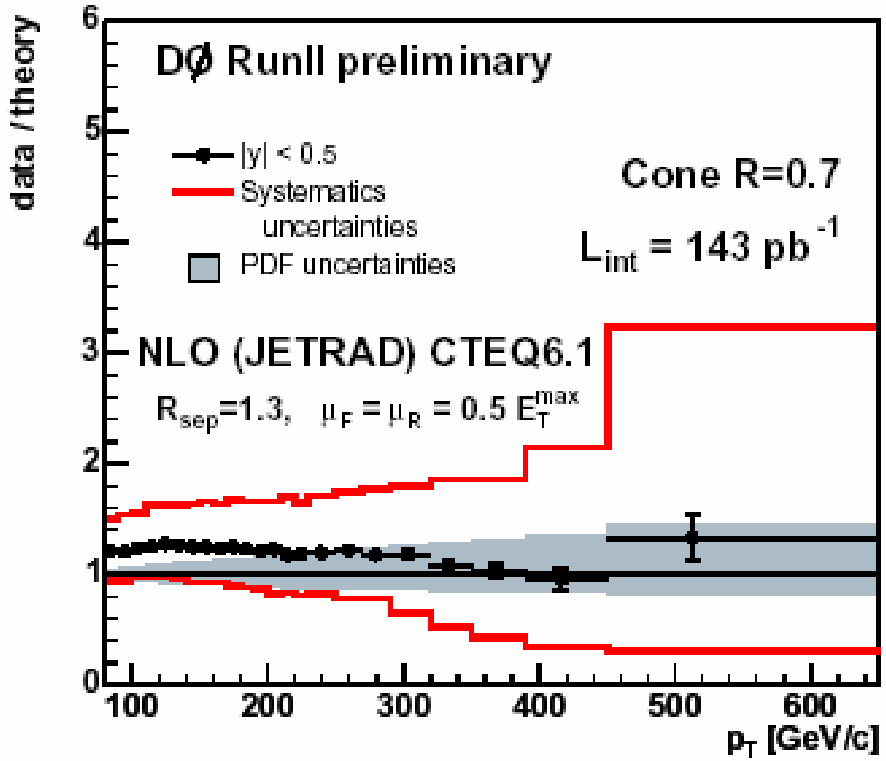


First corrected run II jet cross section for forward jets

Important PDF information is in the cross section versus rapidity

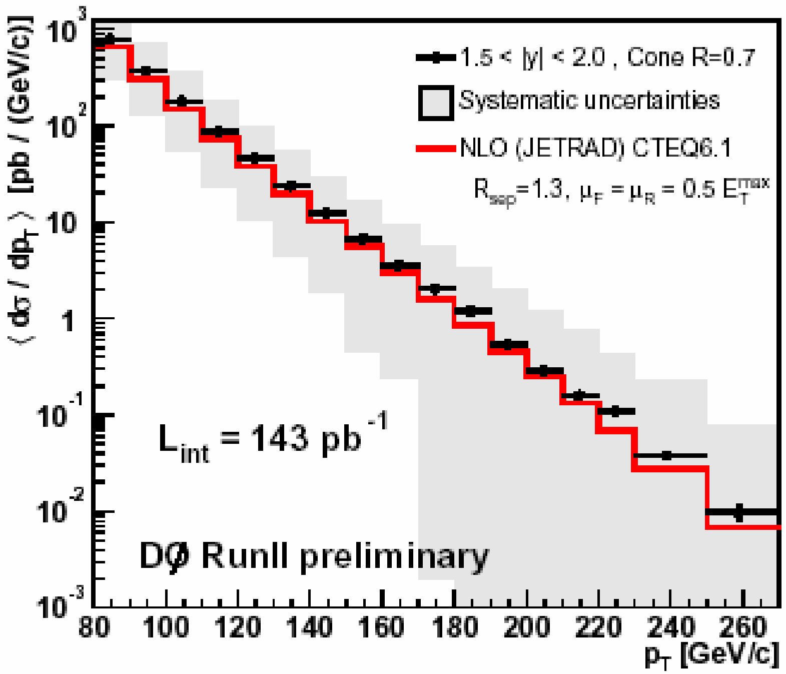
Uncertainties, Central Jets

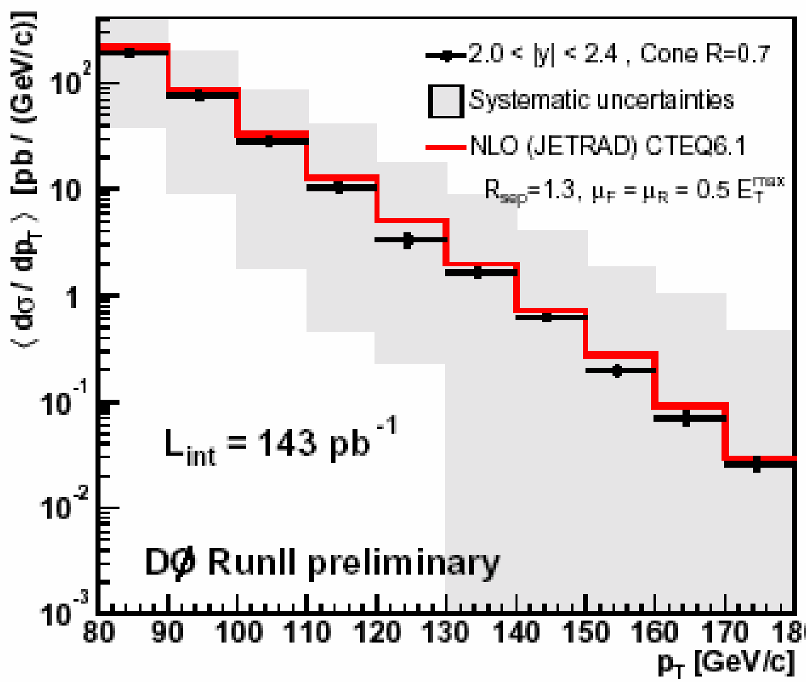




Uncertainties dominated by jet energy scale. Jet energy scale is systematics dominated in central.

Uncertainties, Forward Jets

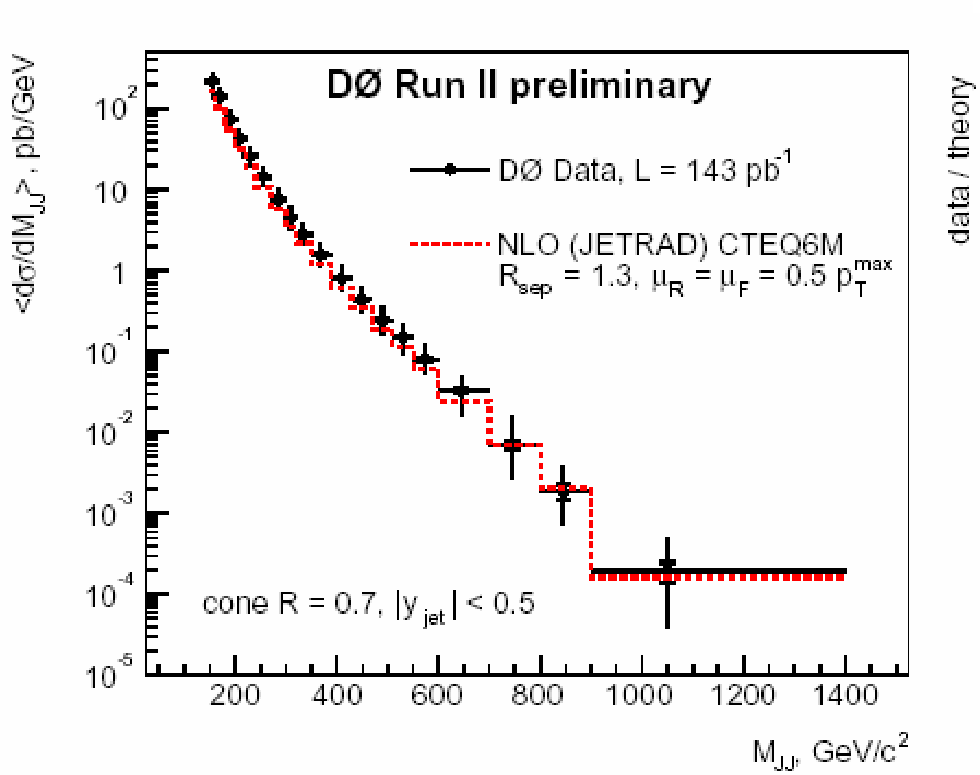


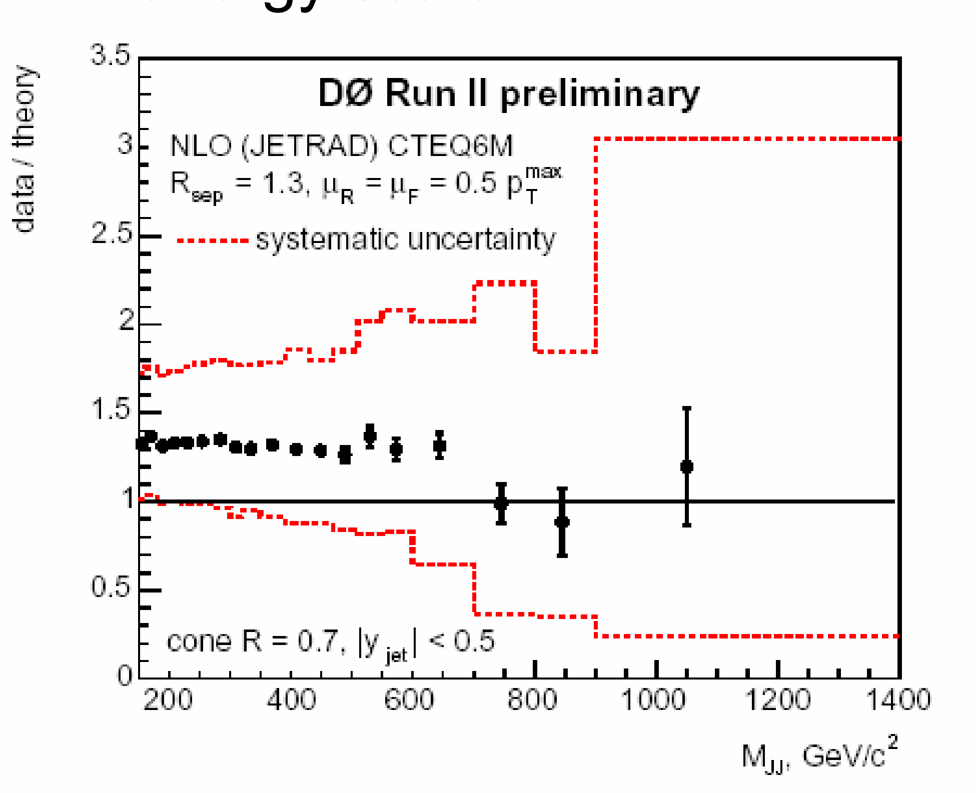


Energy scale error large. Systematics dominated.
Expect improvement soon.

DØ DiJet Cross Section

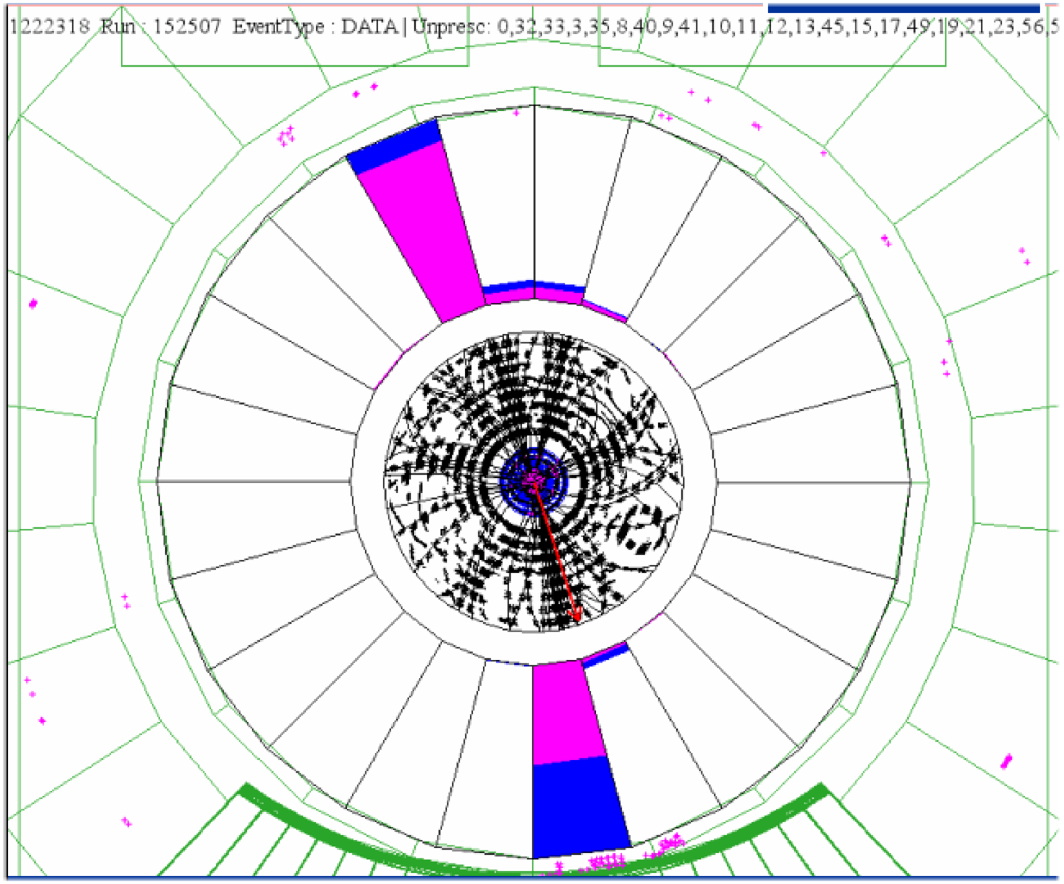
Uncertainty dominated by jet energy scale





Often used to search for new resonances

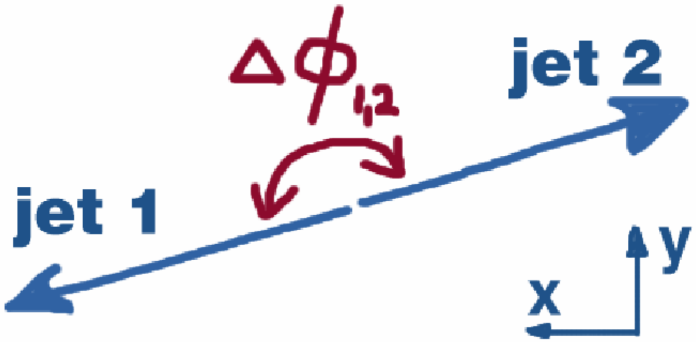
CDF, Dijet Mass



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

DØ, Φ Decorrelation

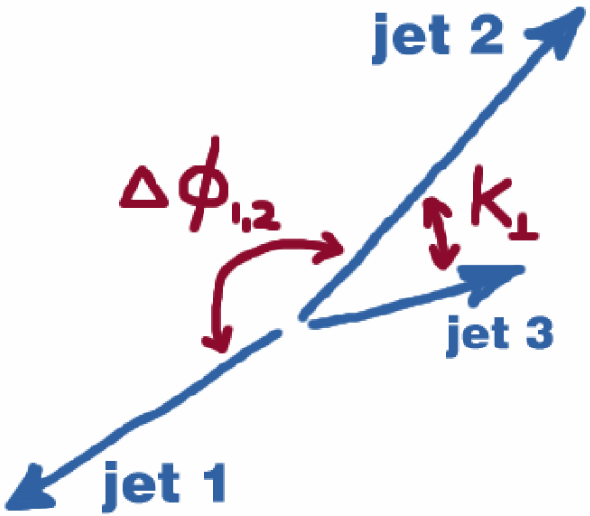
Leading Order pQCD



Jets are back-to-back

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

3 jets in pQCD



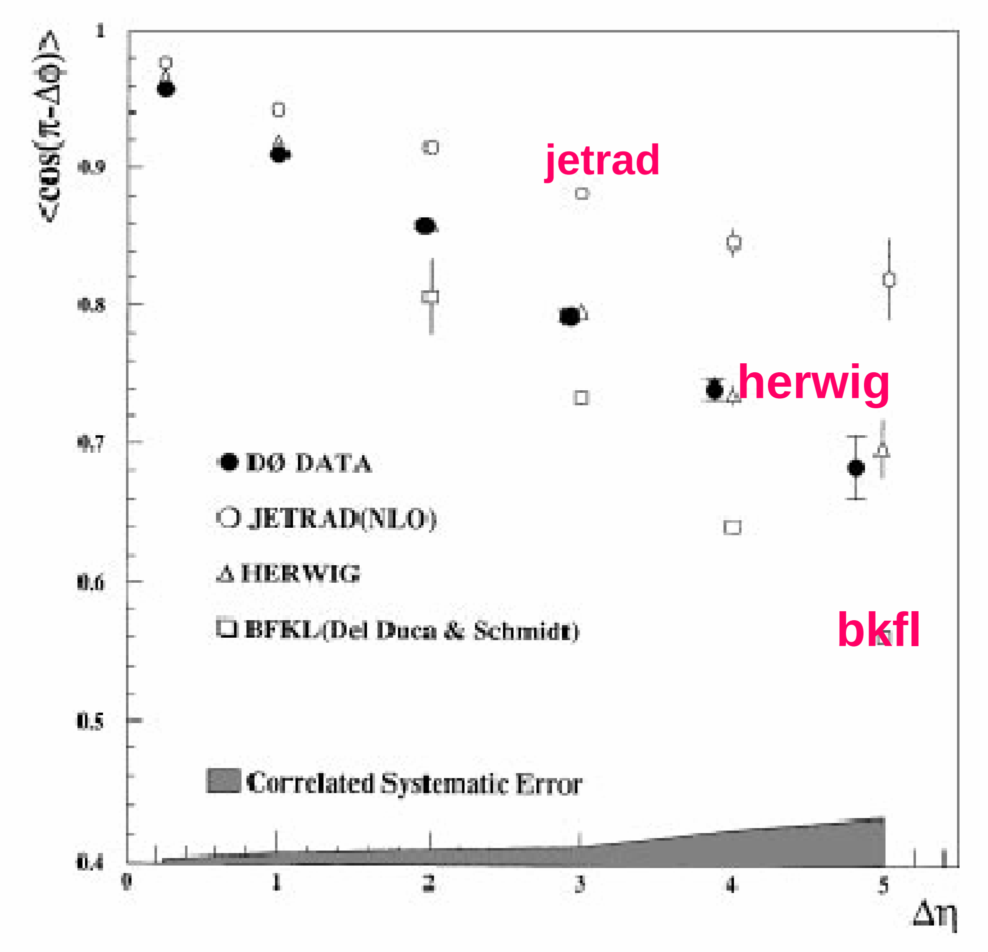
$\Delta\phi_{12} < \pi$

$$\lim_{p_{T_3}\to 0} \Delta\phi_{1,2} = \pi$$

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

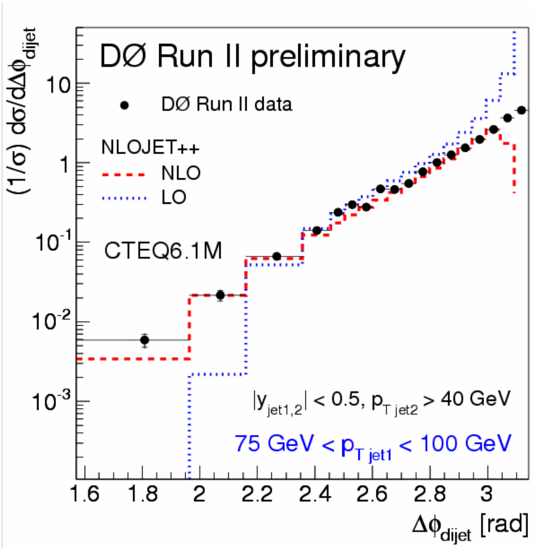
Azimuthal Decorrelation

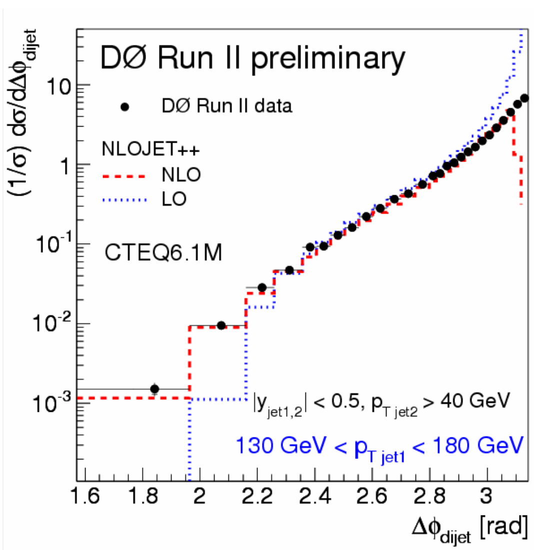
DØ, Run I

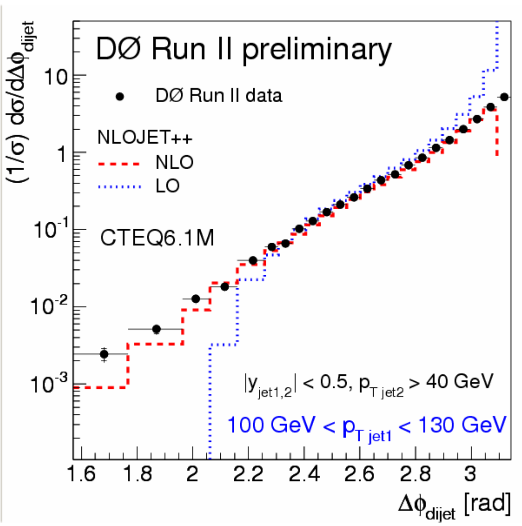


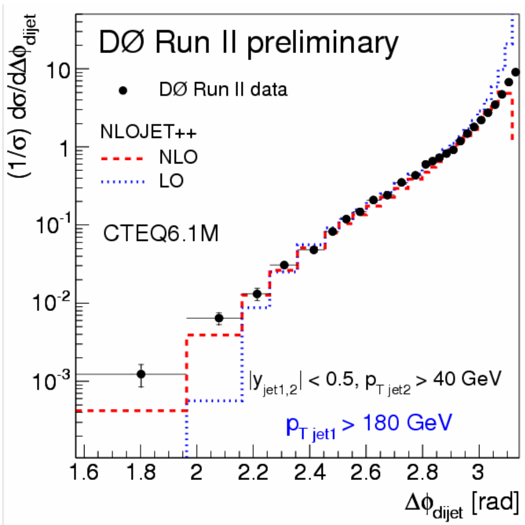
For small Δη, data agrees well with herwig and reasonably well with LO perturbative calculation (JETRAD)

Azimuthal Decorrelation









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

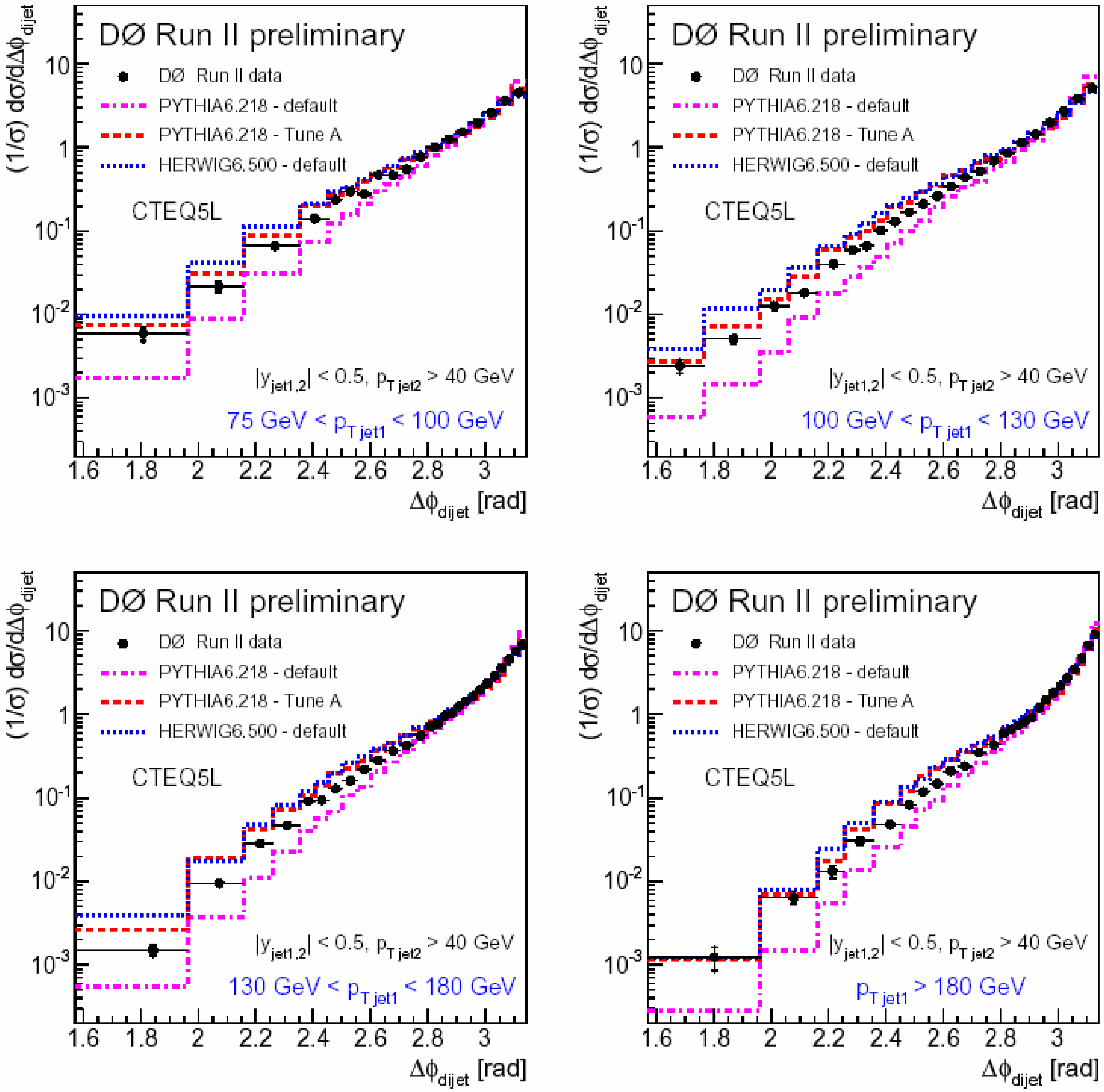
LO (in 3rd jet) perturbative calculation (JETRAD) does not agree.

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.

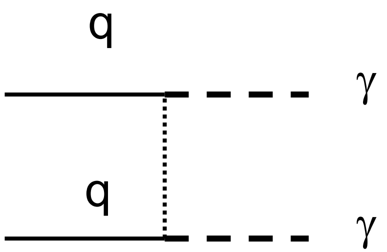
Pythia distribution sensitive to “maximum virtuality for the initial-state parton shower in terms of the hard matrix scale” (PARP(67)).

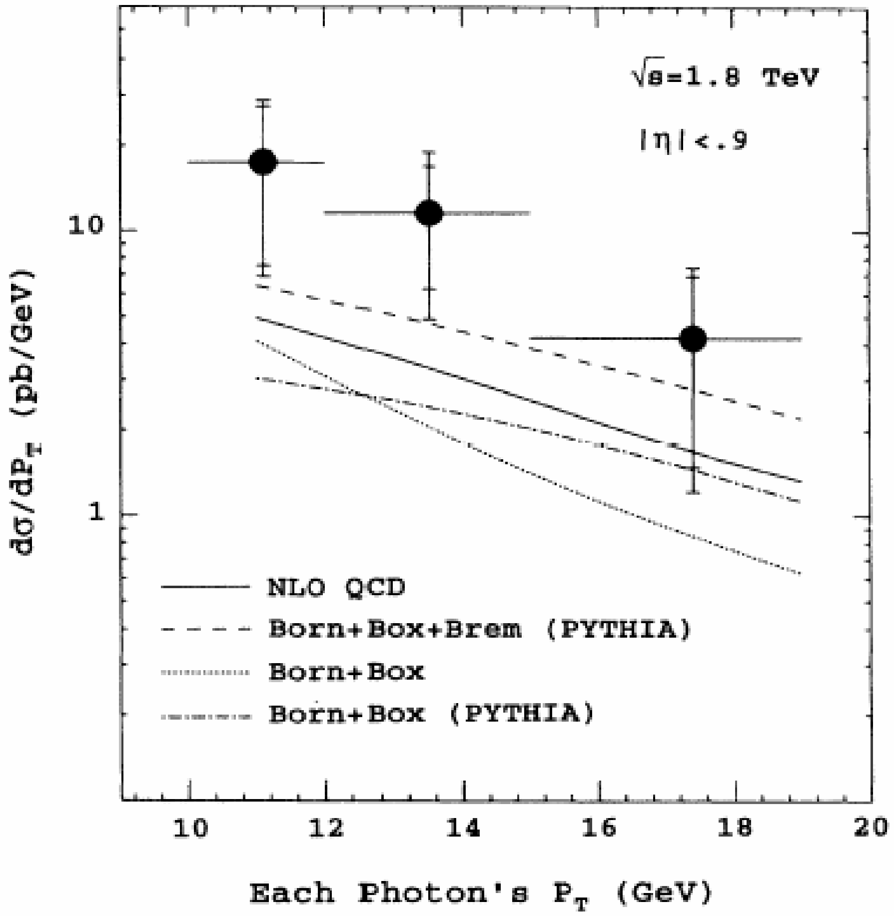
Tune “A” is the CDF UE tune discussed later.

CDF, Di-Photon

Two isolated and energetic high E_t photons in the central region

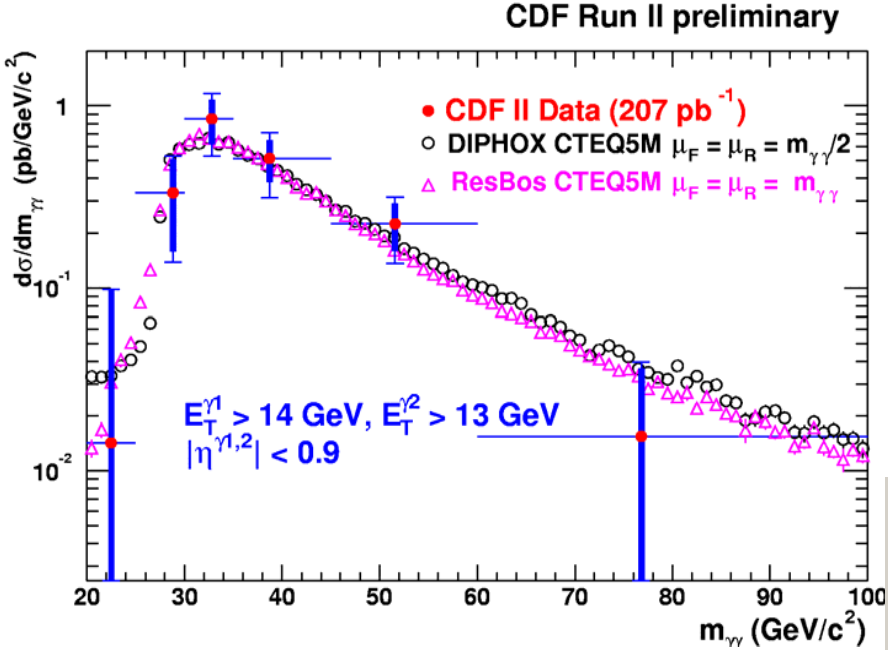
Correlations between the 2 photons can be used to test NLO QCD and study the transverse momentum of the initial partons (KT)



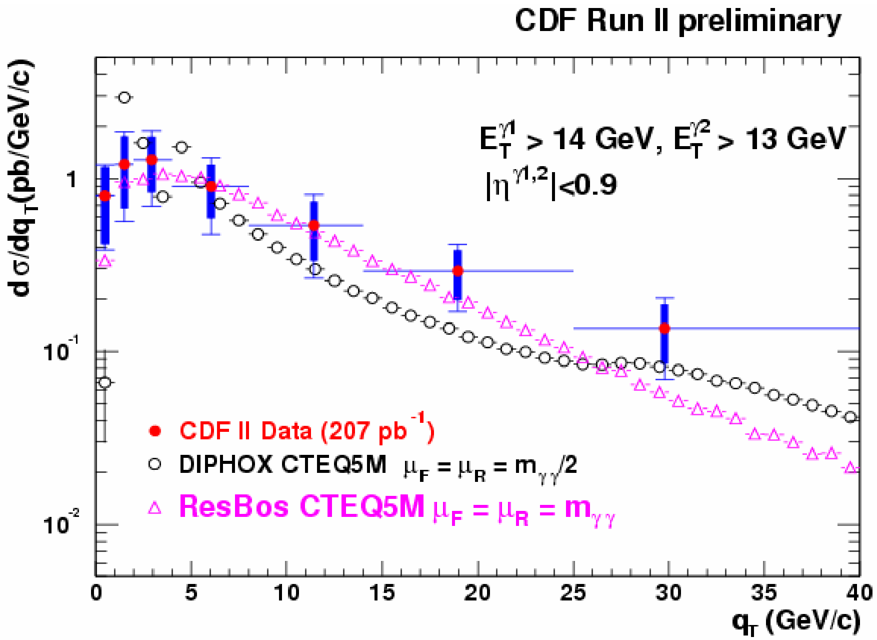


CDF Run I: cross section 3x prediction from NLO QCD (Bailey, Owens, Ohnemus, Phys. Rev. D 46, 2018 (1992)

Di-Photon



Plotted versus mass of 2 photons instead of photon P_T



DIPHOX hep-ph/9911340

Eur.Phys.J C16, 311

Additional "fragmentation" diagrams

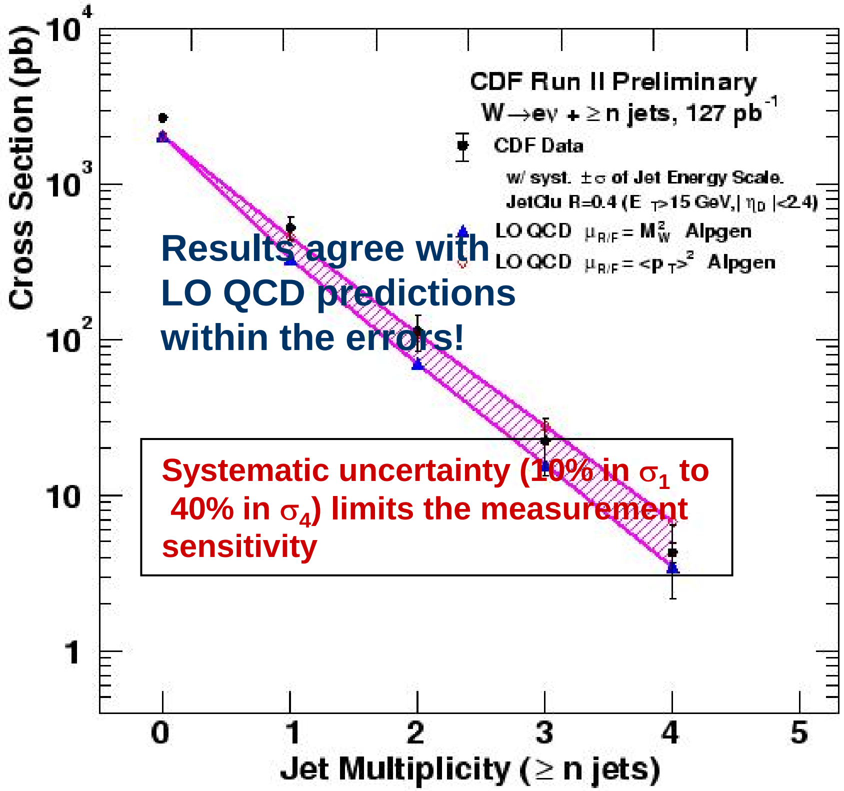
ResBos hep-ph/9712471

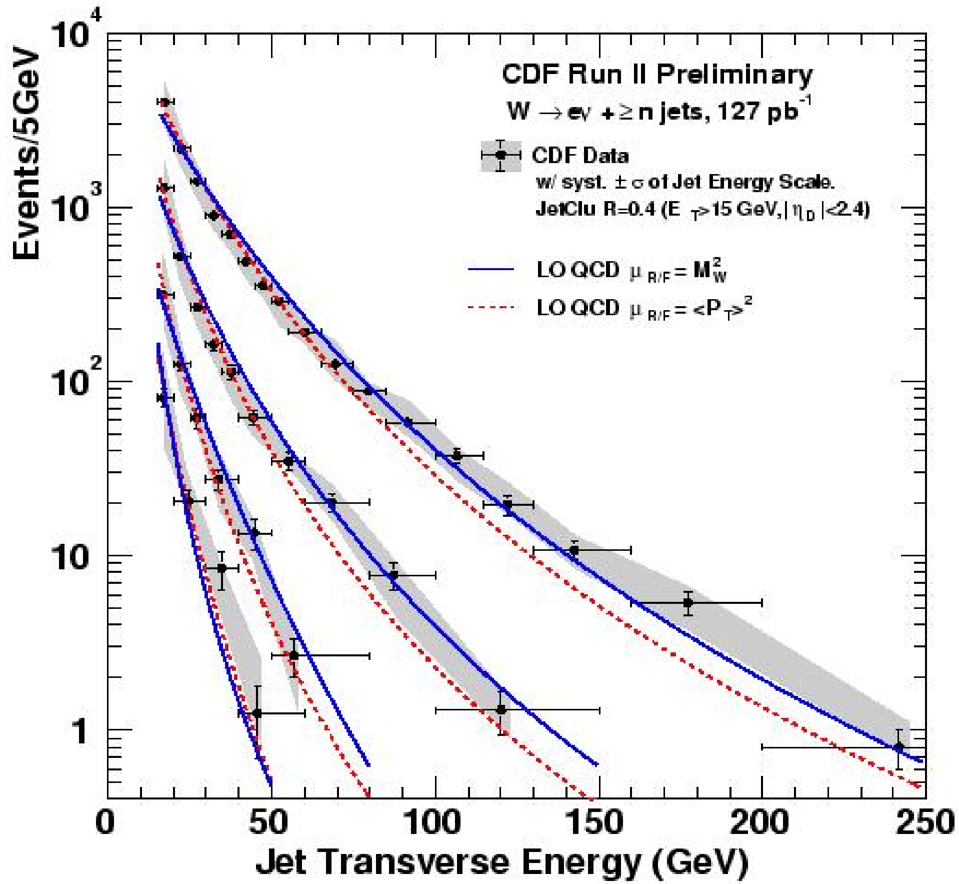
CDF W+Jets

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

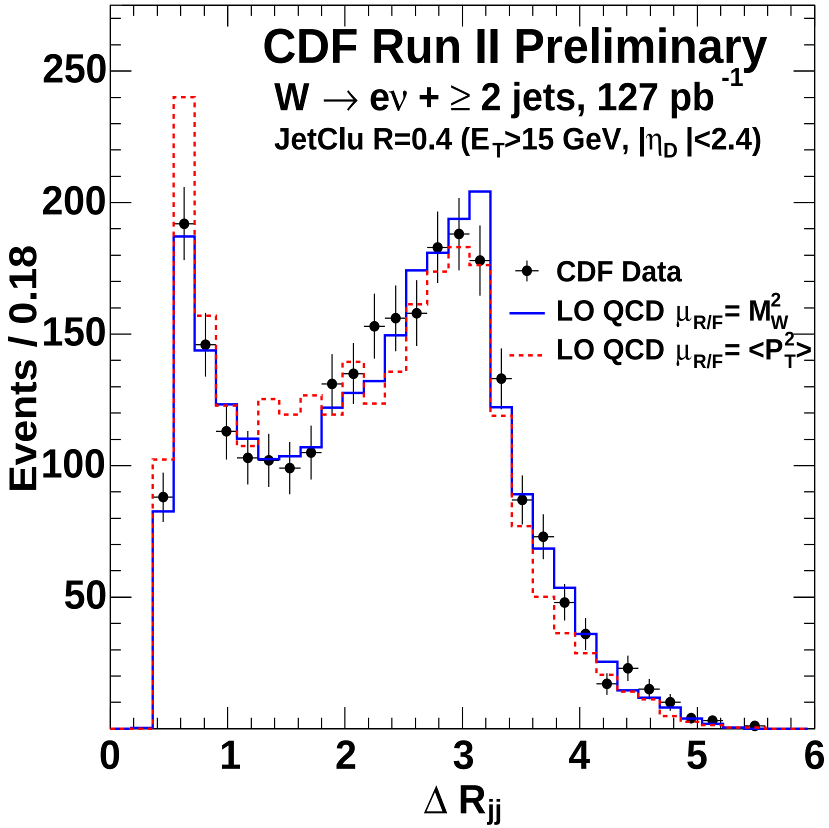
ALPGEN LO matrix element interfaced with HERWIG for parton shower

Not more than one parton associated with a reconstructed jet

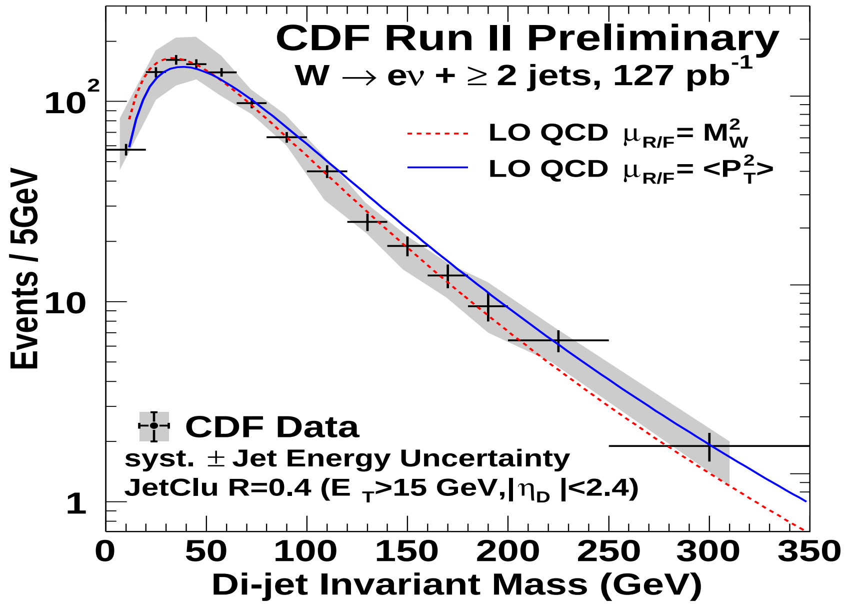




CDF W+jets

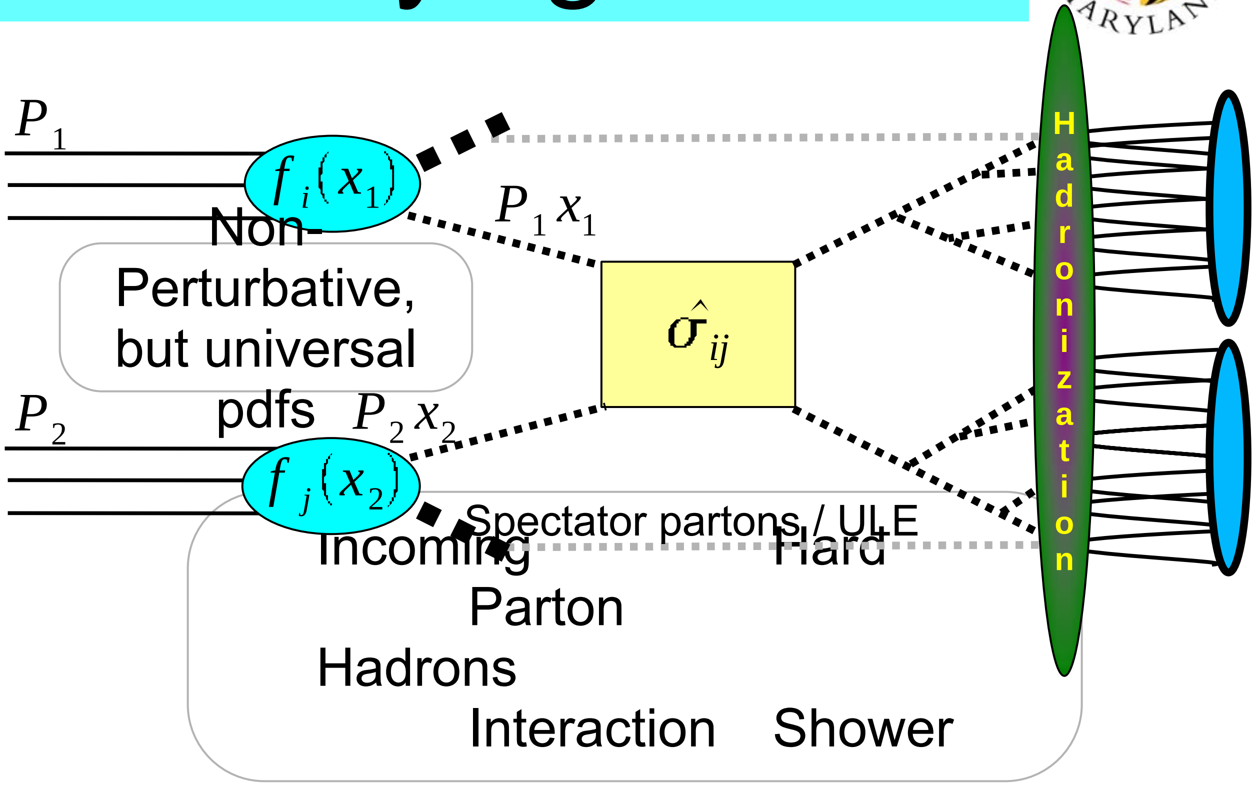


CDF Run II Preliminary
W → eν + ≥ 2 jets, 127 pb-1
JetClu R=0.4 (ET>15 GeV, |ηD |<2.4)
CDF Data
LO QCD μR/F= M2W
LO QCD μR/F= <P2T>
Events / 0.18
Δ Rjj



CDF Run II Preliminary
W → eν + ≥ 2 jets, 127 pb-1
LO QCD μR/F= M2W
LO QCD μR/F= <P2T>
CDF Data
syst. ± Jet Energy Uncertainty
JetClu R=0.4 (E T>15 GeV,|ηD |<2.4)
Events / 5GeV
Di-jet Invariant Mass (GeV)

CDF, Underlying Event



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

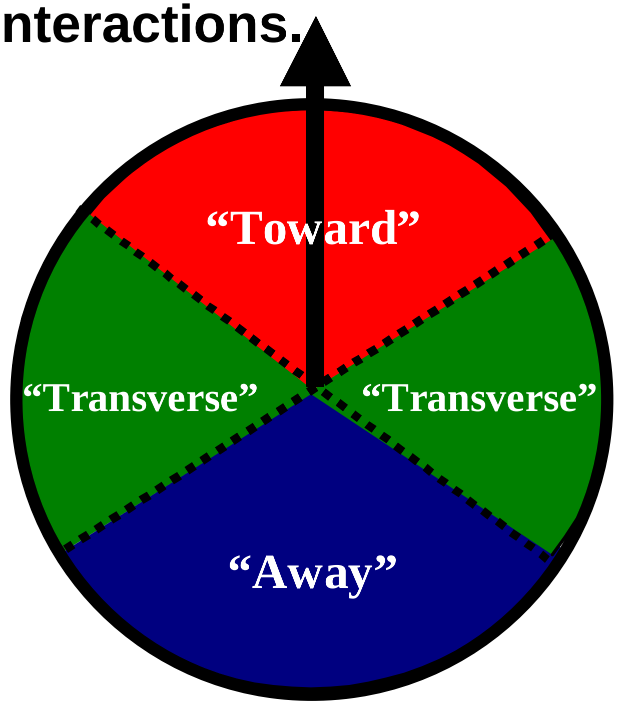
Studies of min bias events, Jet events in Run I produced "PYTHIA Tune A"

Run II:

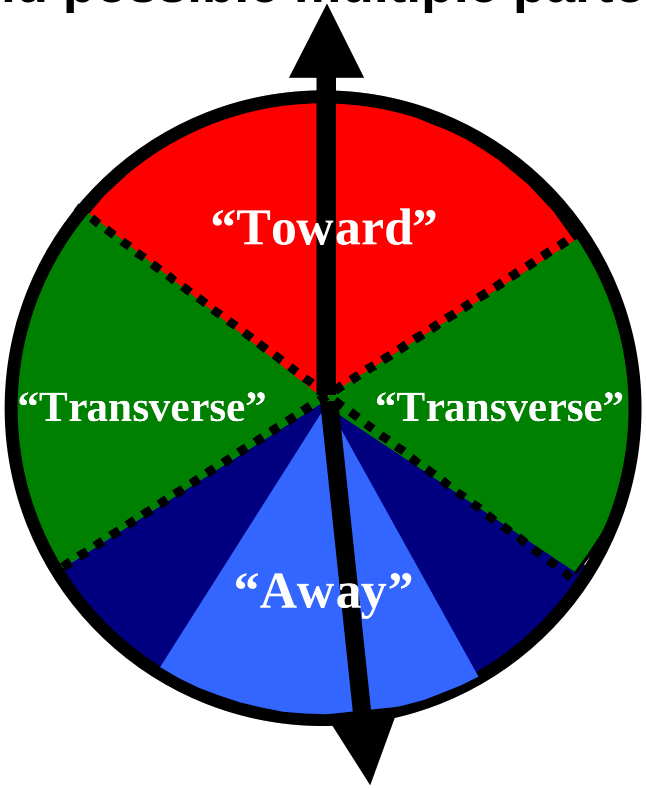
- **Look at distributions/correlations of charged particles with η<1, p_T>500 MeV**
- **Studies of mini-jets in min bias events**
- **Lots has work has been done, far too much to summarize here**

CDF, Underlying Event

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

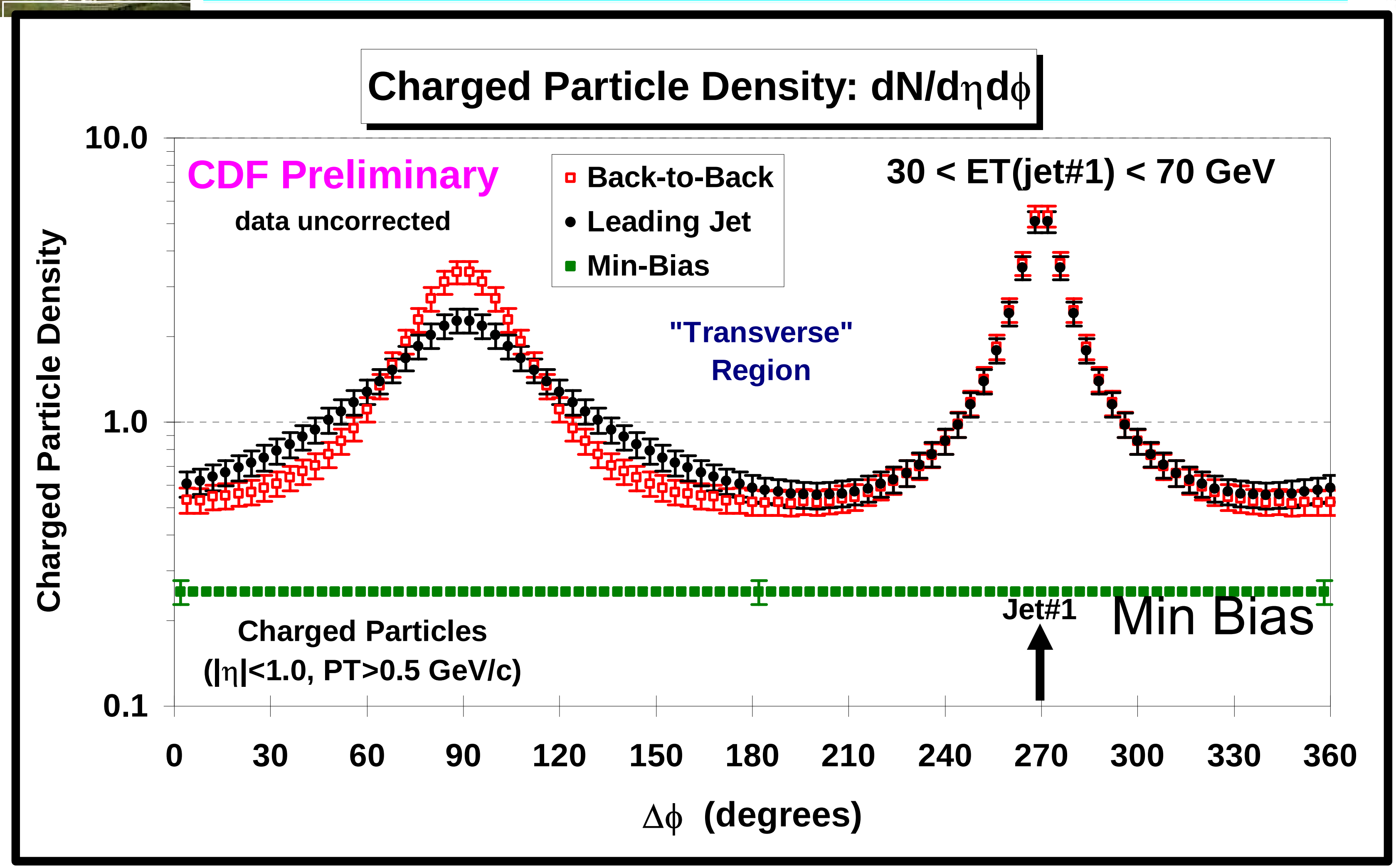


Transverse regions are sensitive to underlying event



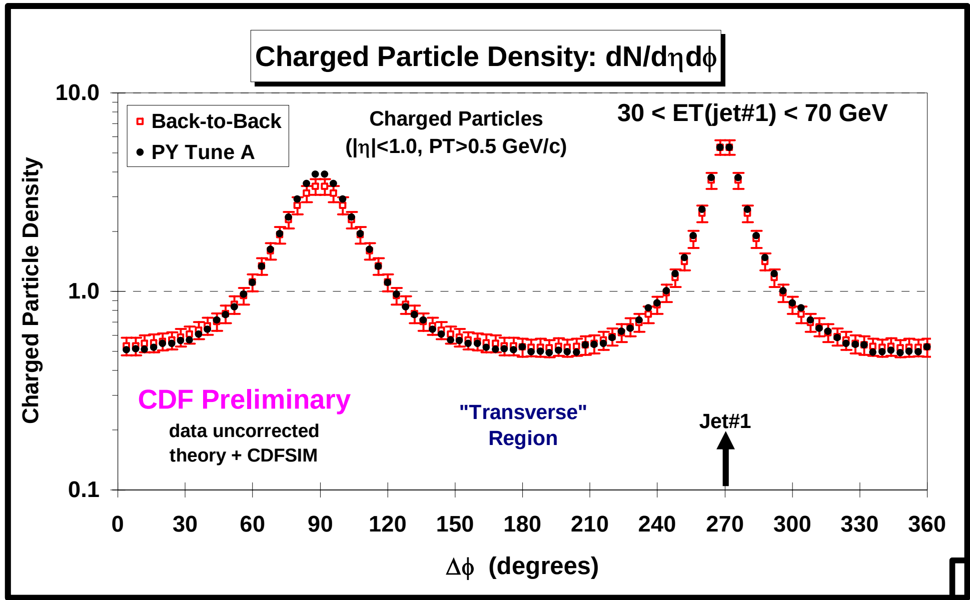
"Back-to-Back"
($\Delta\phi_{12}$>150^o,ETj_2/ETj^1>0.8)

Underlying Event



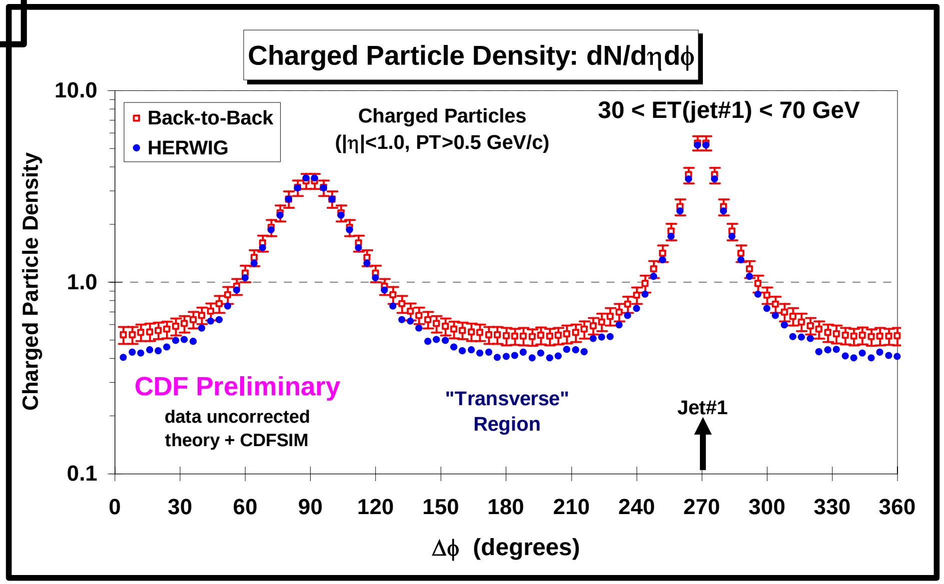
With and without requiring the 2nd jet back-to-back with leading jet

Underlying Event



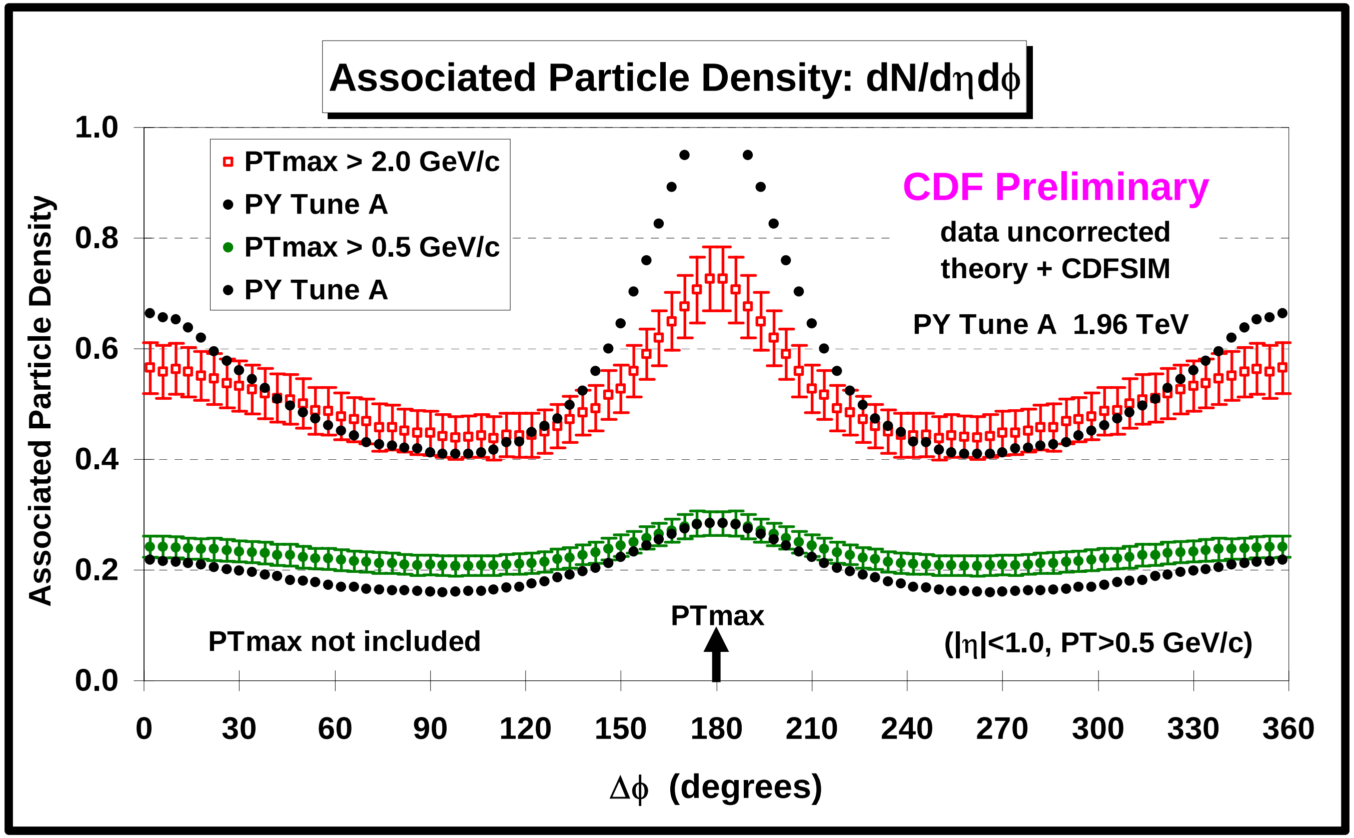
Compared to pythia Tune A

Compared to untuned herwig



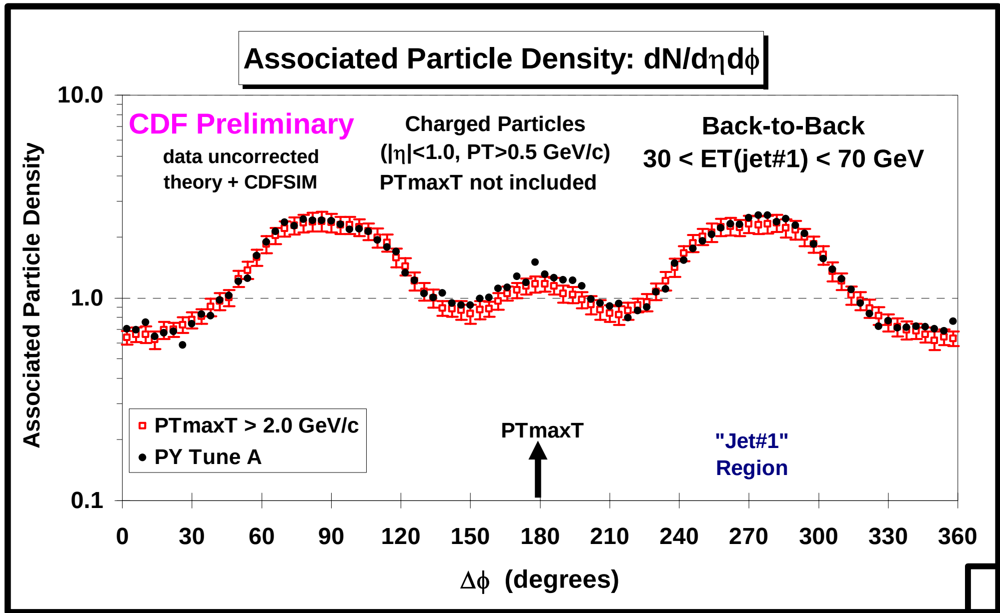
Pythia tuned using Run I data can describe data better than (untuned) Herwig

Min Bias Data



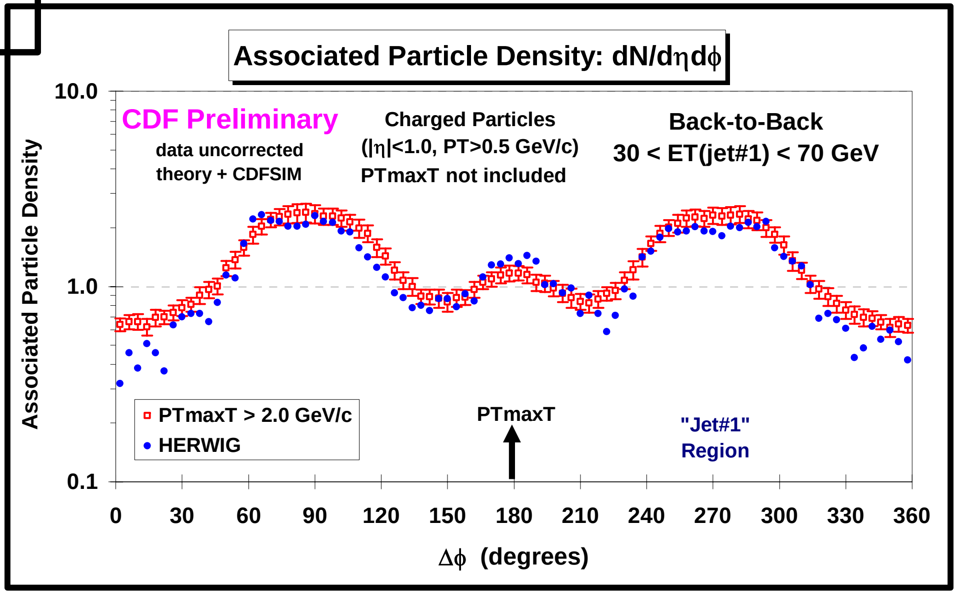
Look for min bias events with a track over a threshold. Look at distribution of charged P_T in Φ relative to that track. Compare to Tune A

3rd Jet



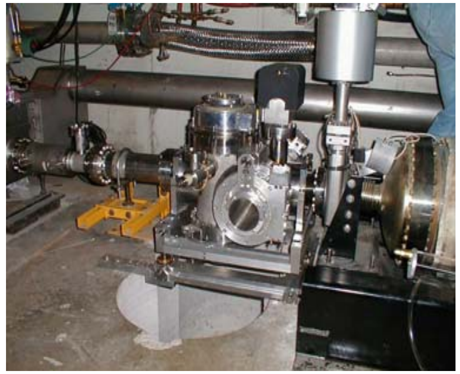
Tune A

Herwig



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

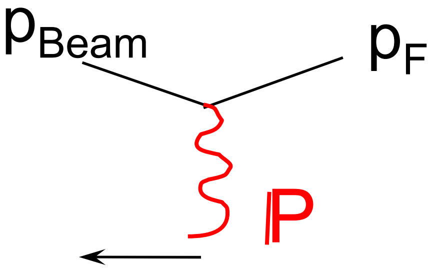
DØ, Elastic Scattering



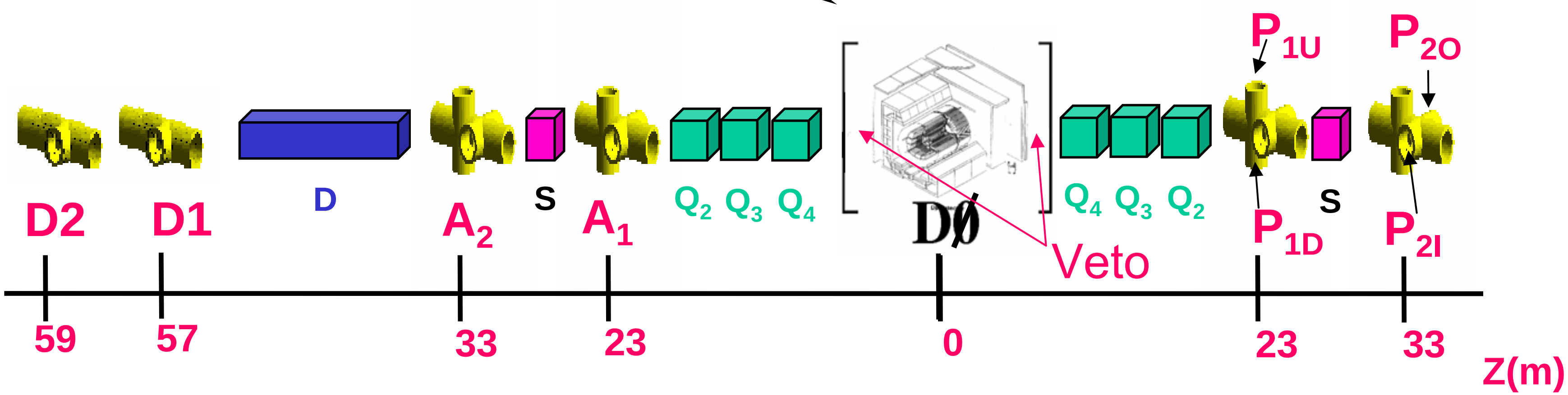
Pomeron, Odderon Exchange: intact proton,antiproton

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

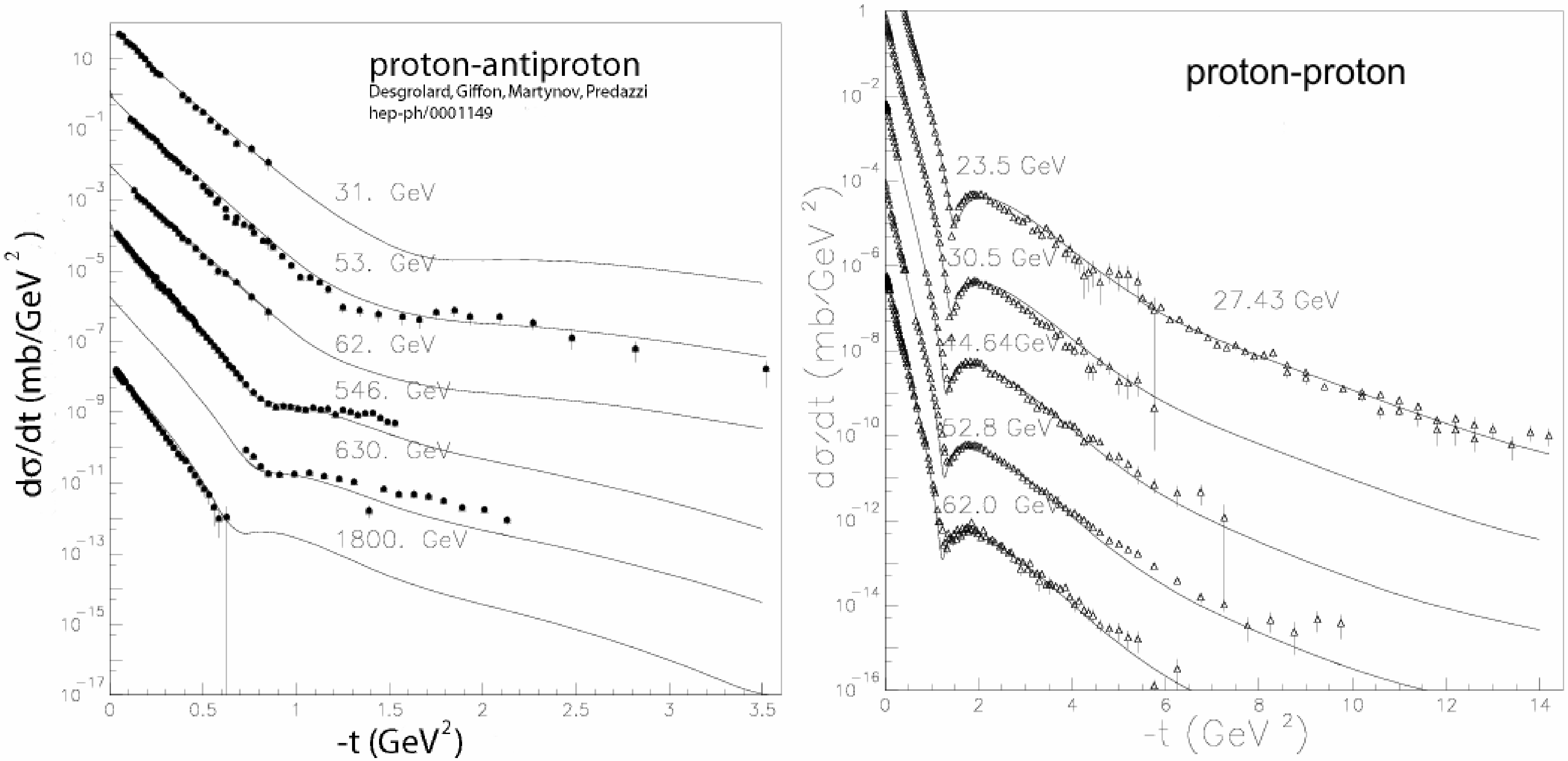
$$\xi = 1 - x_p = \frac{\Delta P}{P}$$



t ~ θ^2, where θ is scattering angle

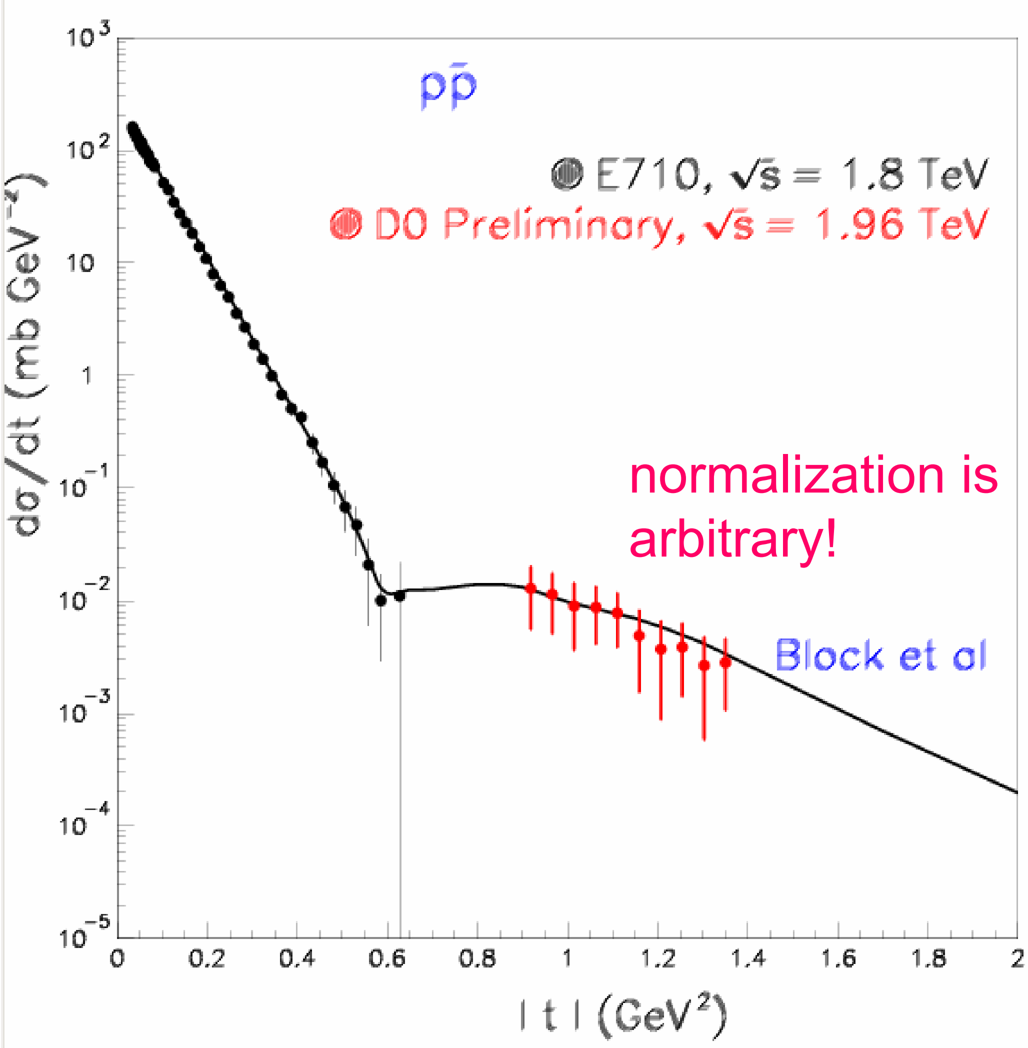


Elastic Scattering



ISR and E710 data

Elastic Results

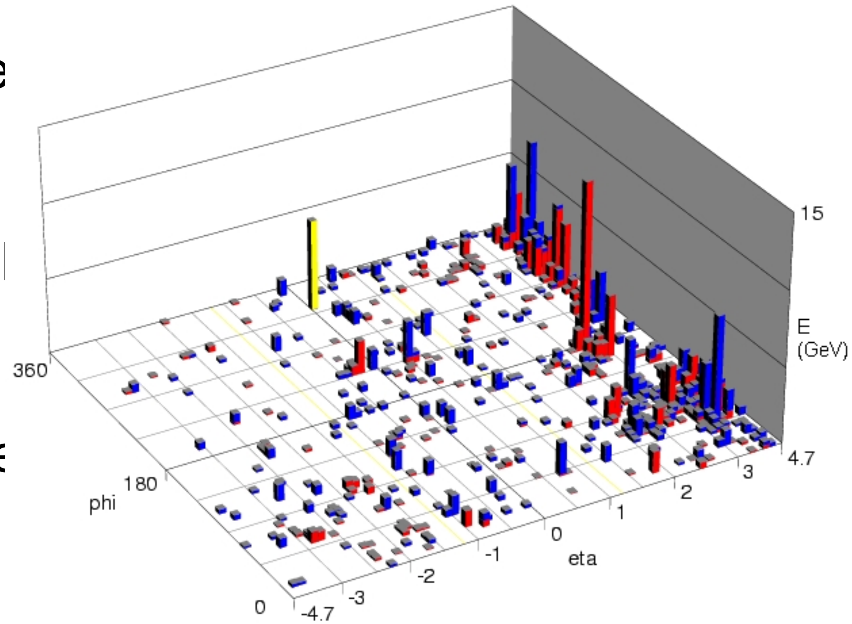


Diffractive Z's

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. SCI 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

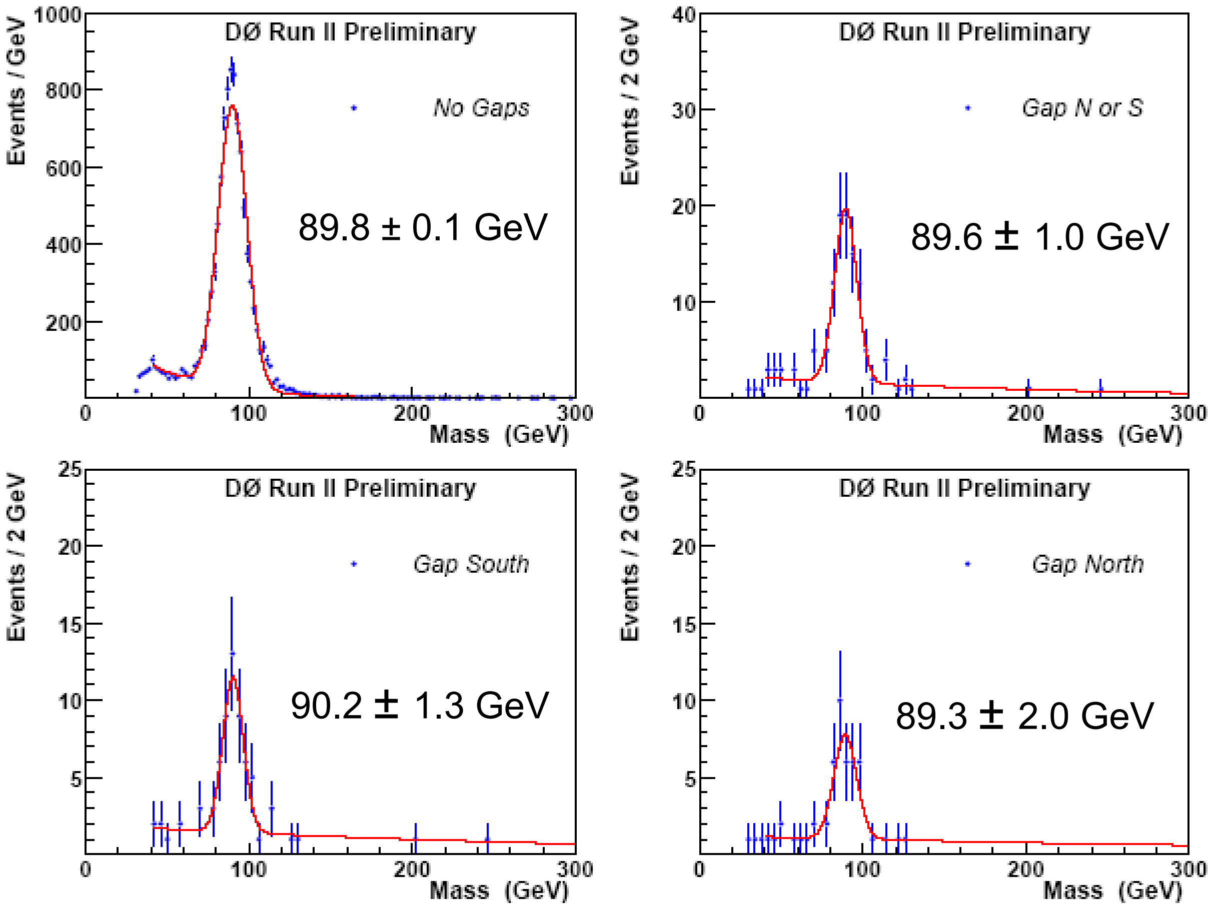
CDF: 8246 $W \rightarrow e\nu$'s with a gap fraction of 1.15+-0.6. Jet distribution consistent with quark-like pomeron from the jet fraction, gluon-like for the absolute rate.

DØ: 12622 $W \rightarrow e\nu$'s with gap fraction of 0.89 +-0.2%, 811 $Z \rightarrow ee$'s with gap fraction of 1.44+-0.6%. Event characteristics of diffracive 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)

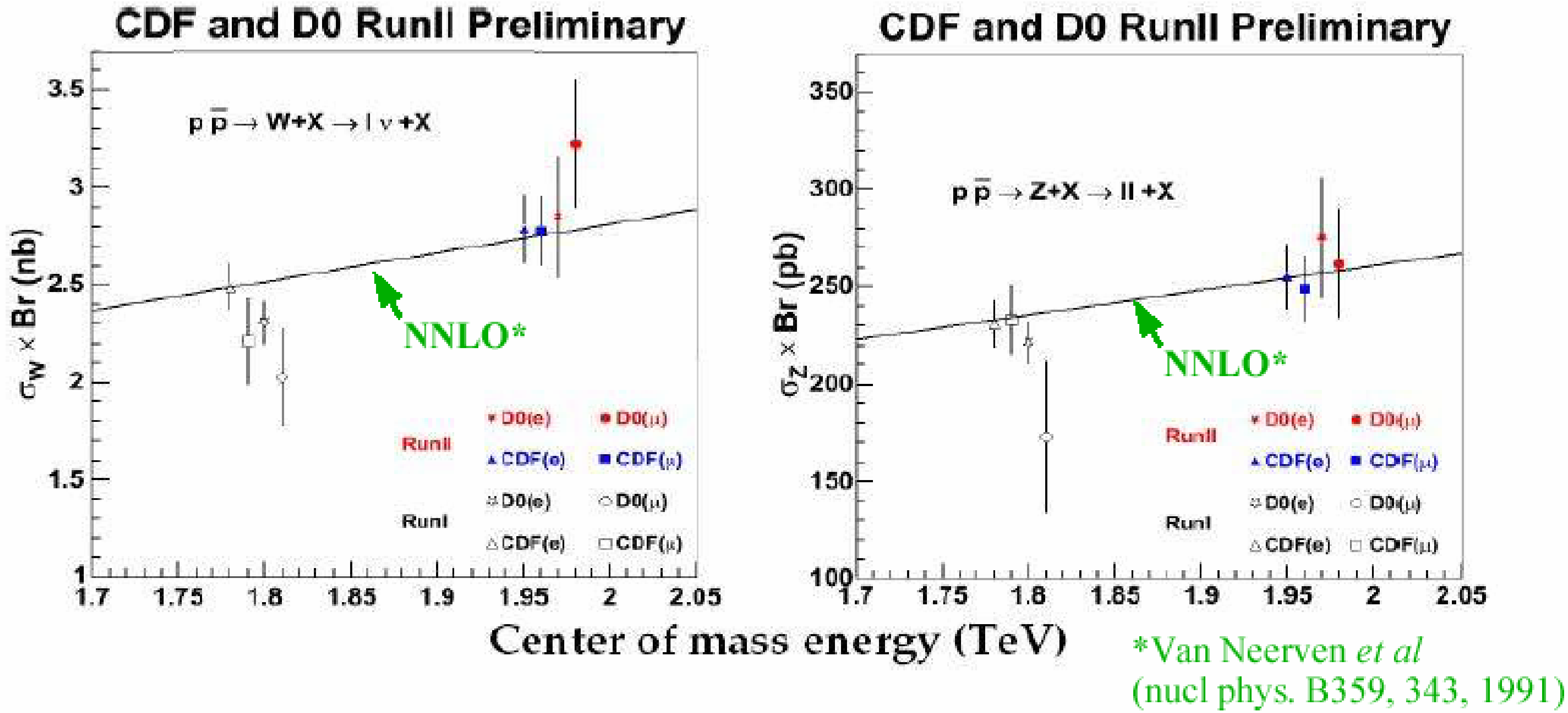
Run II

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



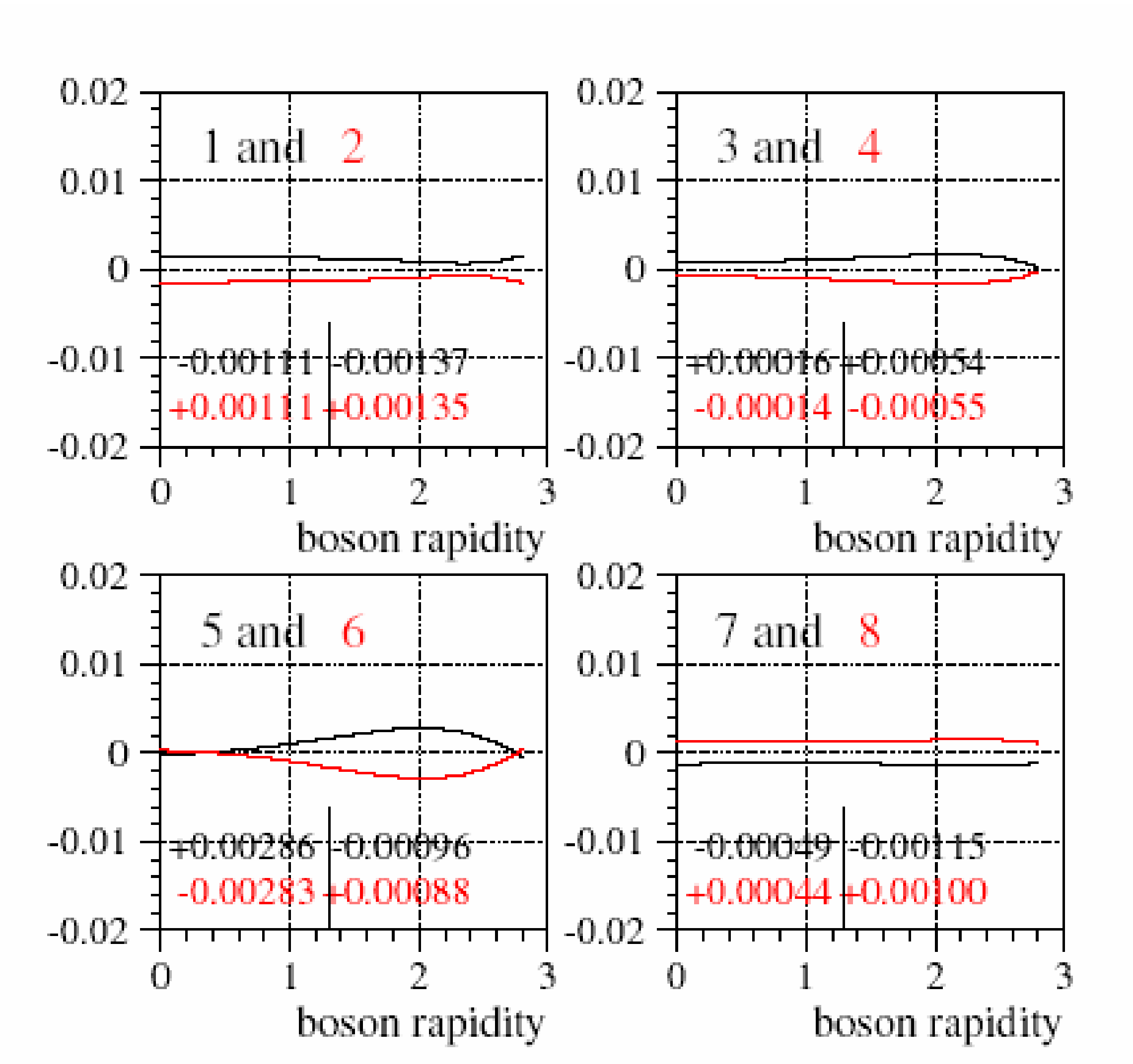
W/Z Cross Section

New results from CDF for winter 2004 in all channels.



DØ and CDF have agreed on a common luminosity normalisation.
Next round of plots will use this common scheme. **http://tevewwg.fnal.gov/**

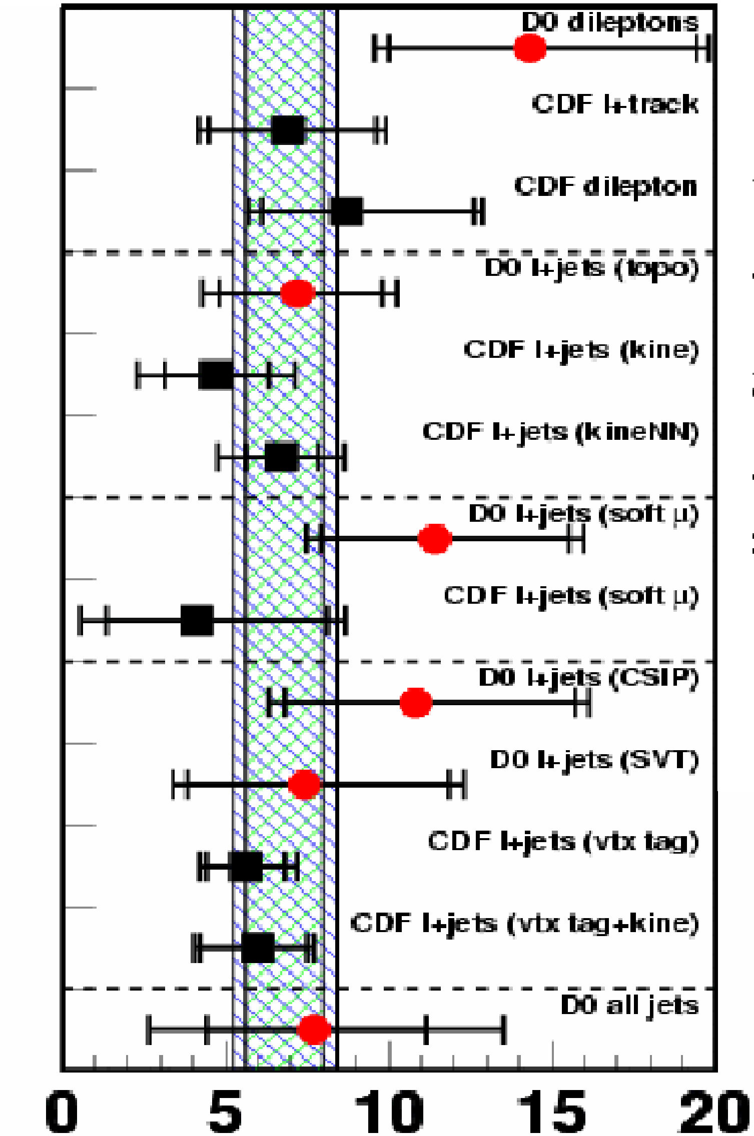
PDF Uncertainty

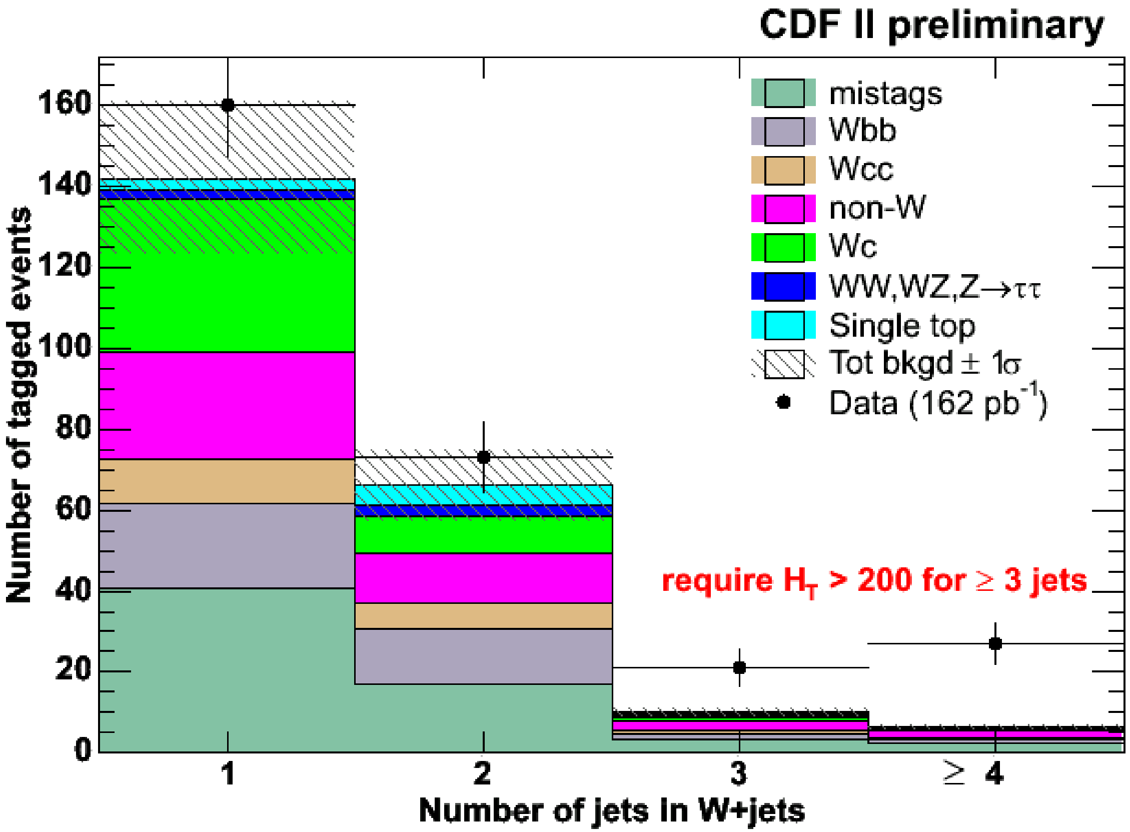


Uncertainty on ratio of acceptances using CTEQ6 SF, LO calculation of the cross section, and a parameterization of the acceptance versus boson rapidity. CTEQ6 has a nominal PDF and 40 error PDF's, corresponding displacing each of the X parameters by +/- 1 sigma.

Michael Schmitt, Northwestern U, CDF

Top Cross Section





Theory cross sections

Kidonakis NNLO-NNNLL hep-ph/0303185

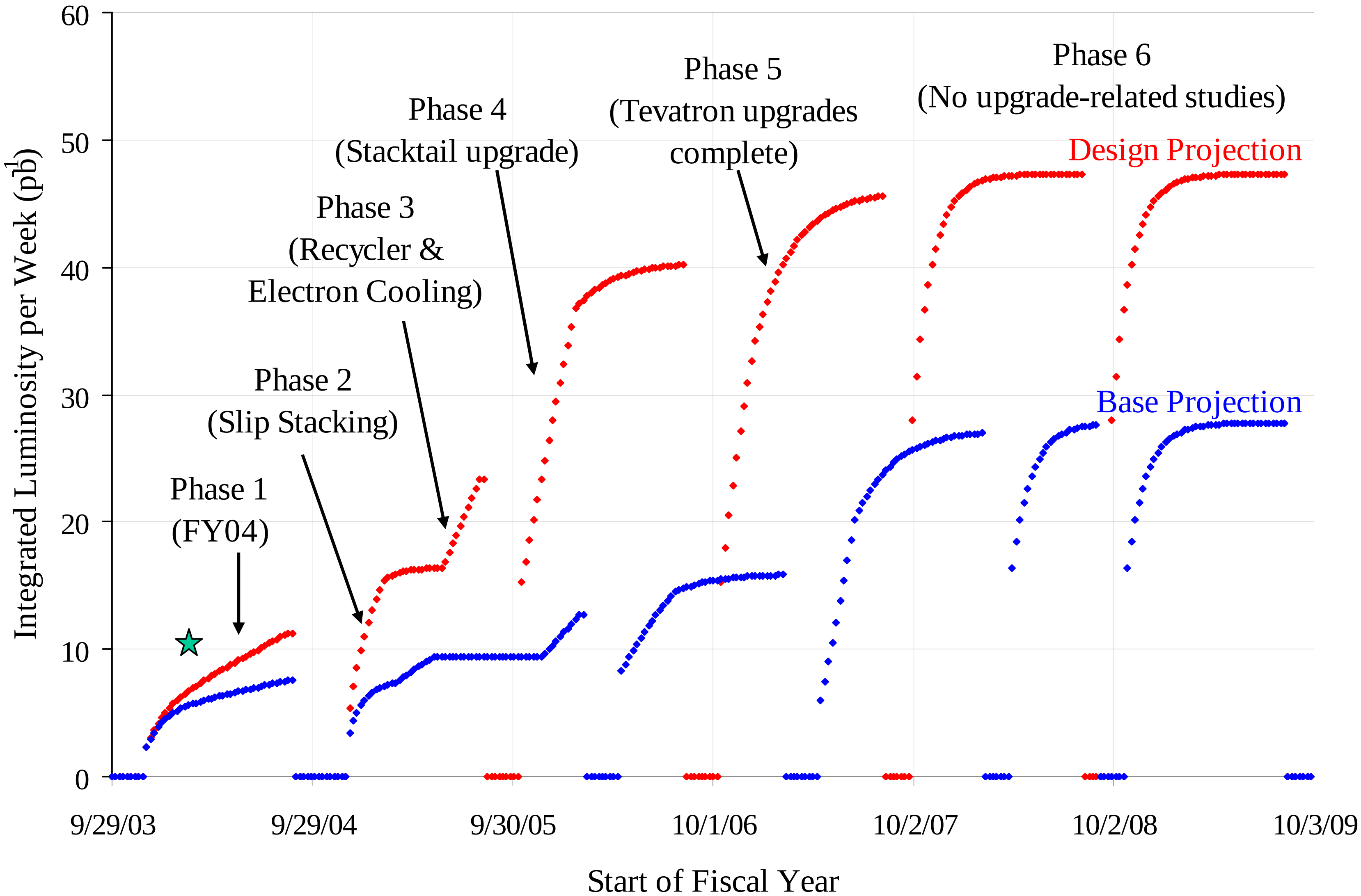
Cacciari et al hep-ph/0303085

Uncertainty dominated by large-x gluon pdf and α_s

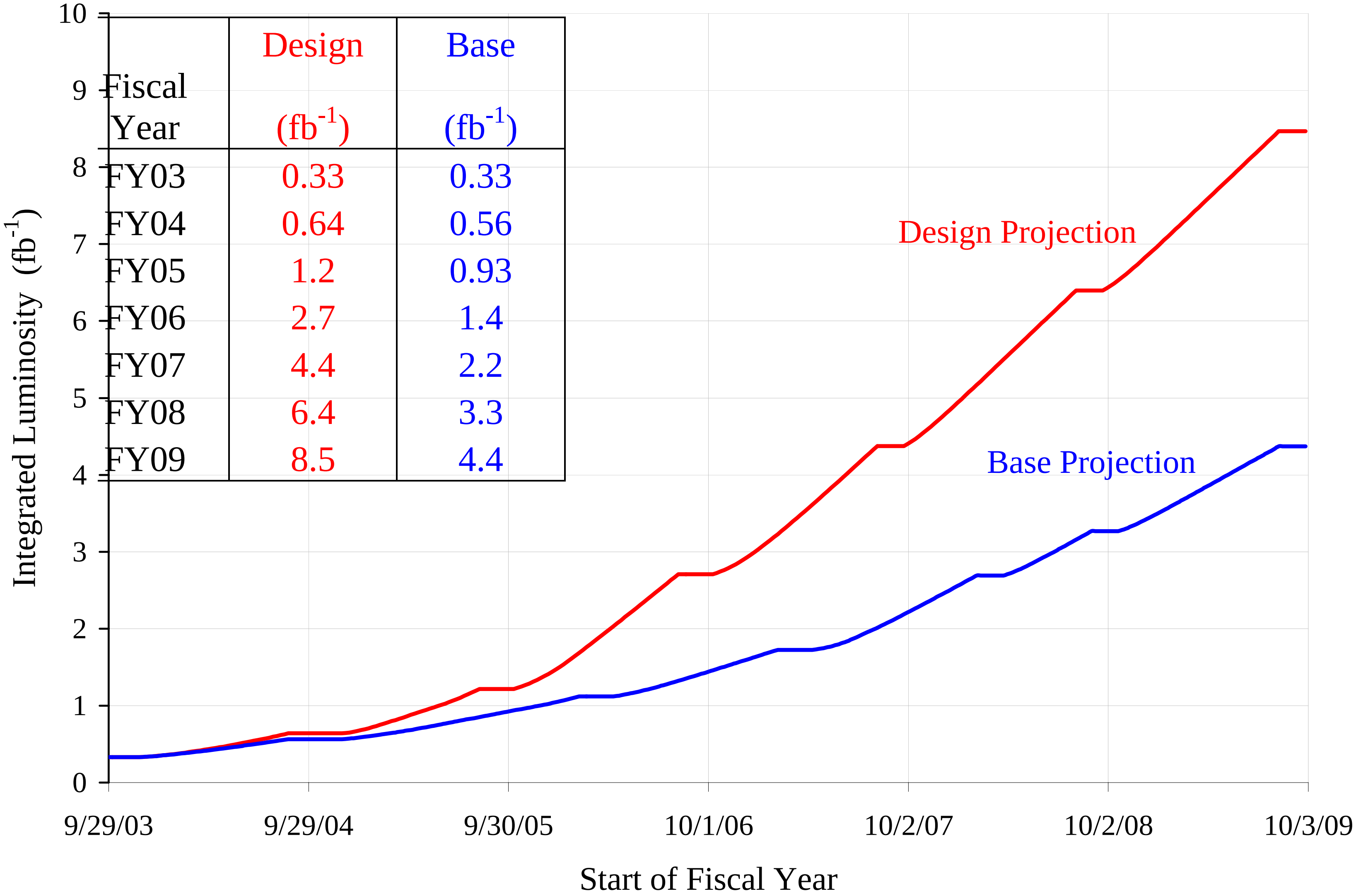
Prospects

Both Collaborations expect many publications before summer.

Prospects


Integrated Luminosity per Week (pb^{-1})
Start of Fiscal Year
0
10
20
30
40
50
60
9/29/03
9/29/04
9/30/05
10/1/06
10/2/07
10/2/08
10/3/09
Phase 1
(FY04)
Phase 2
(Slip Stacking)
Phase 3
(Recycler &
Electron Cooling)
Phase 4
(Stacktail upgrade)
Phase 5
(Tevatron upgrades
complete)
Phase 6
(No upgrade-related studies)
Design Projection
Base Projection

Prospects



Fiscal Year	Design (fb^{-1})	Base (fb^{-1})
FY03	0.33	0.33
FY04	0.64	0.56
FY05	1.2	0.93
FY06	2.7	1.4
FY07	4.4	2.2
FY08	6.4	3.3
FY09	8.5	4.4

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 searchs: Arnold Pompos
- Higgs Physics – Stephanie Beauceron