Soft QCD Studies at CDF

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for the CDF collaboration

The Rockefeller University

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c. Minbias measurements at CDF
d. Hyperon Resonances

Part II

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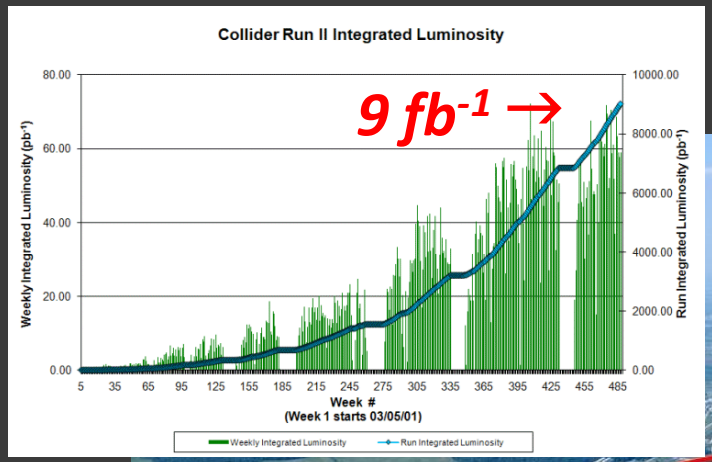
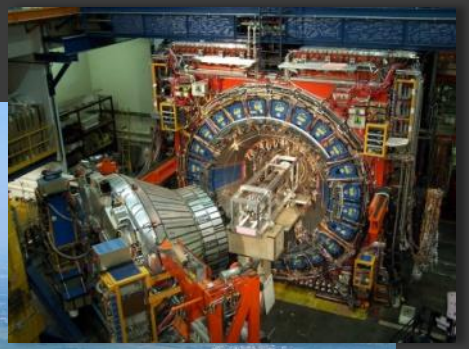
b. Single Diffractive measurements (W/Z production)
c. Double Diffraction (soft and hard processes)
d. Double Pomeron exchange and Exclusive processes

Collider Run II Integrated Luminosity





Tevatron ppbar Collider

Run I (1992-1996) $\sqrt{s}$=1.8 TeV (~120 pb^{-1})

Run II (2001-) $\sqrt{s}$= 1.96 TeV

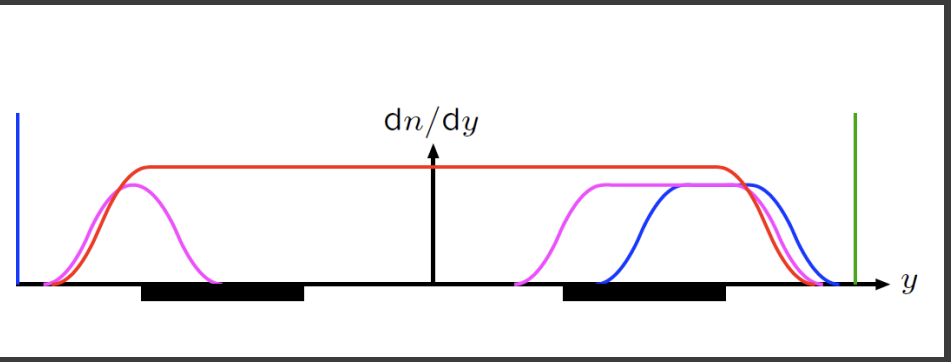
Definitions: MB and UE

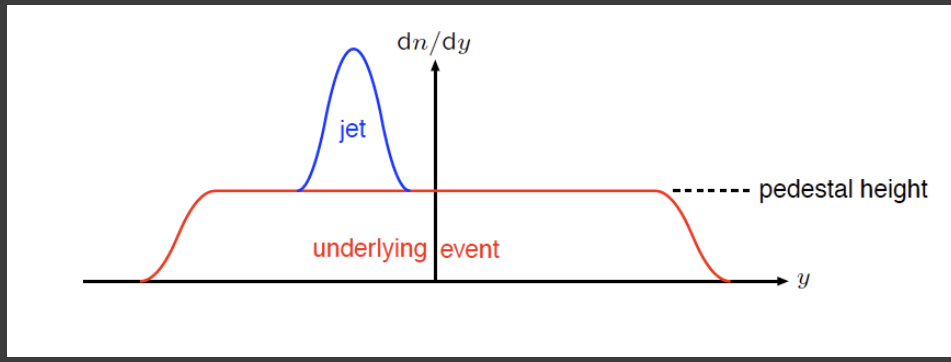
Minimum Bias (MB) – is the name of trigger

data sample is defined by trigger implementation

Underlying Event (UE) – is defined on event by event basis

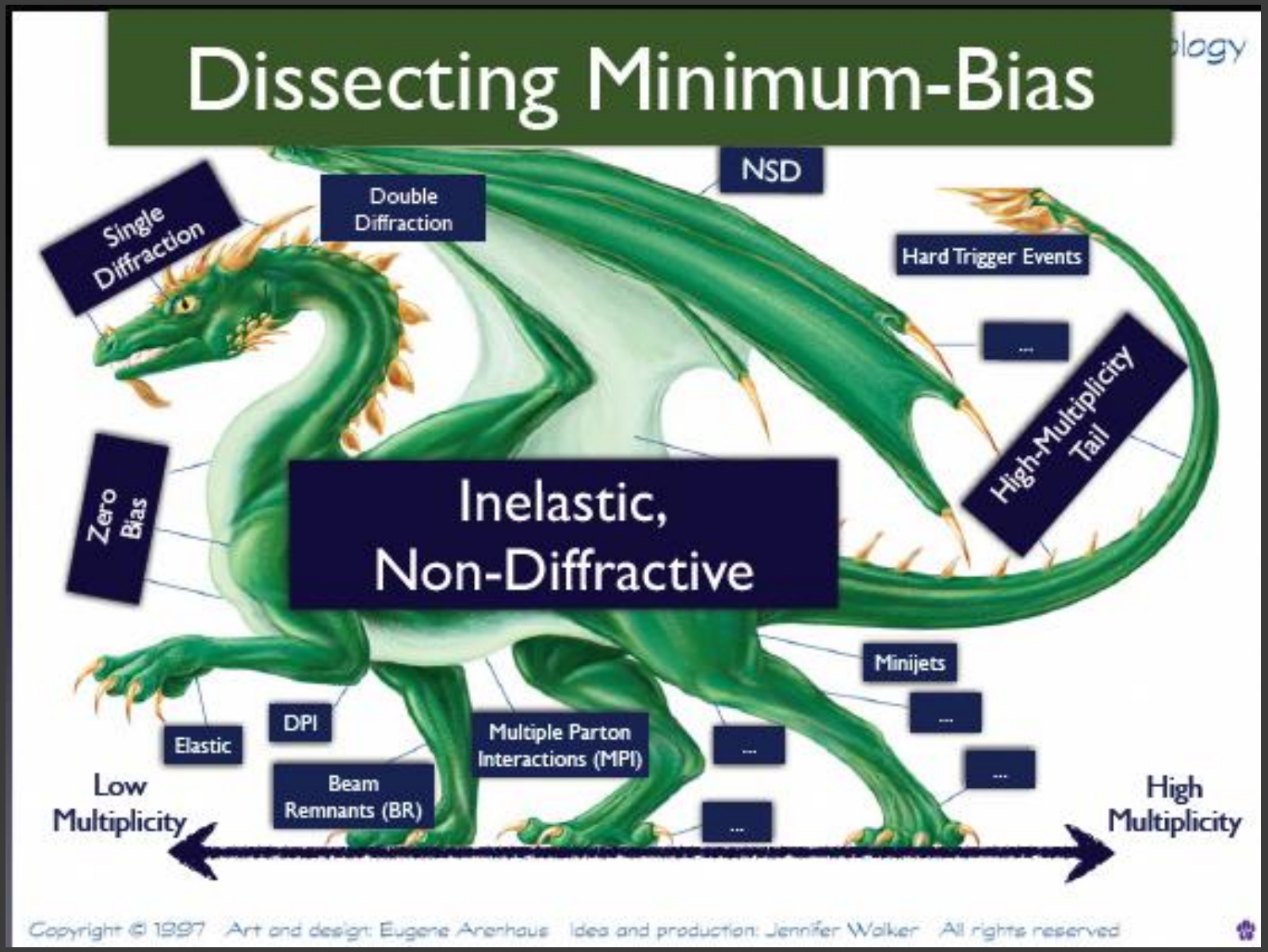
everything else except 2->2 hard scatter





MB is background to high luminosity pile-up events

UE is background to high p_T observables (jets etc…)

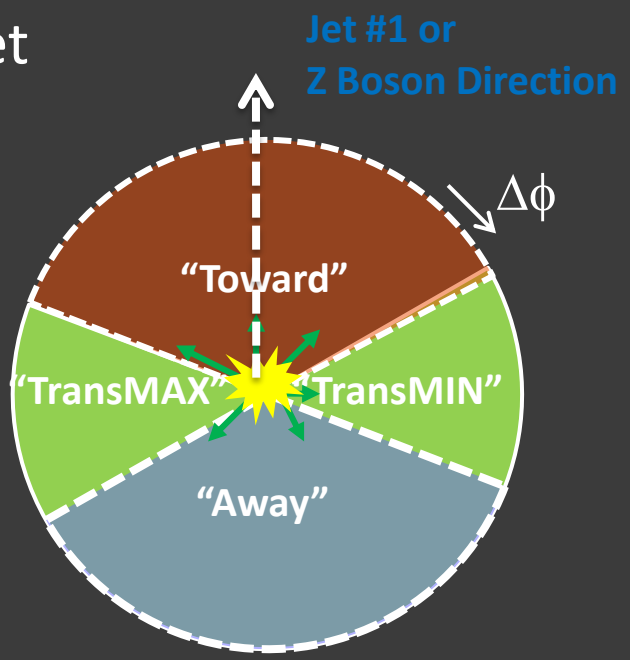


slide from talk by Peter Scands at "MB & UE Workshop" at CERN, March 2010

The Underlying Event

$\Delta\phi$ relative to the leading calorimeter jet (or the Z-boson)

- $|\Delta\phi| < 60^{o}$ as **Toward**
- $60^{o} < |\Delta\phi| < 120^{o}$ as **Transverse**
- $|\Delta\phi| > 120^{o}$ as **Away**
- TransMAX (MIN) - "Transverse" region with largest (smallest) number of charged particles



Underlying Event is
Beam Beam Remnants (BBR)
Final State Radiation (FSR)
Initial State Radiation (ISR)
Multi-Parton Interactions (MPI)

Data corrected to the particle level:
Tracks p_T>0.5 GeV/s
$|\eta|$<1
Jets with $|\eta|$<2

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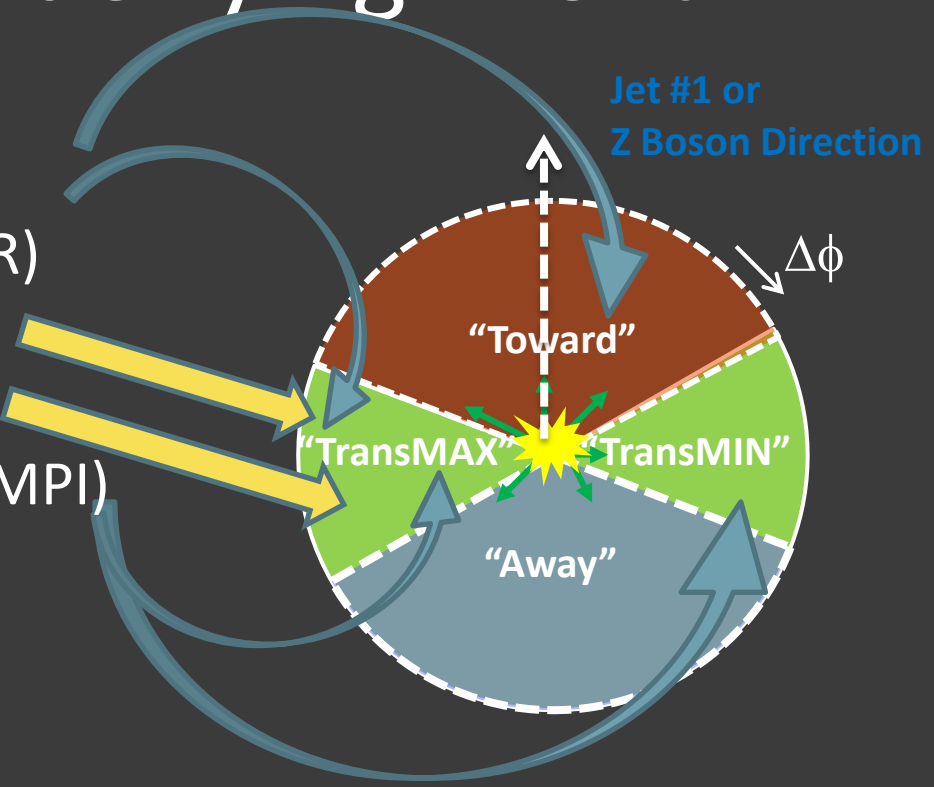


Different regions sensitive to different contributions:

TransMIN – BBR+MPI
TransMAX – BBR+MPI+ ISR+FSR

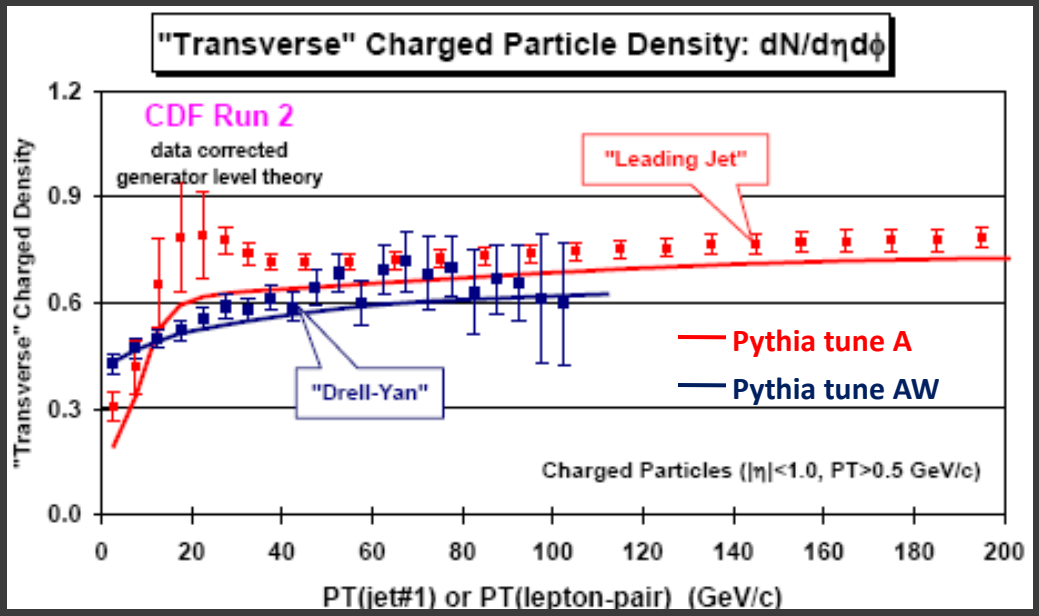
Data corrected to the particle level:
Tracks p_T>0.5 GeV/s
$|\eta|$<1
Jets with $|\eta|$<2

UE in Drell-Yan and incl. jet events

Event topologies:

- Leading Jet
- Drell-Yan

Transverse Region

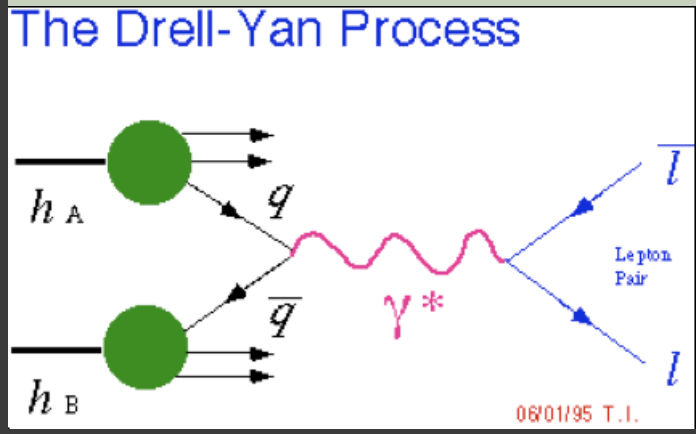


Drell-Yan:

less gluon radiation,
easier to reconstruct

ll = ee, μμ

p_T>20 GeV/c
|η|<1
70 GeV/c^2<M_{pair}<110 GeV/c^2
|η(pair)|<6

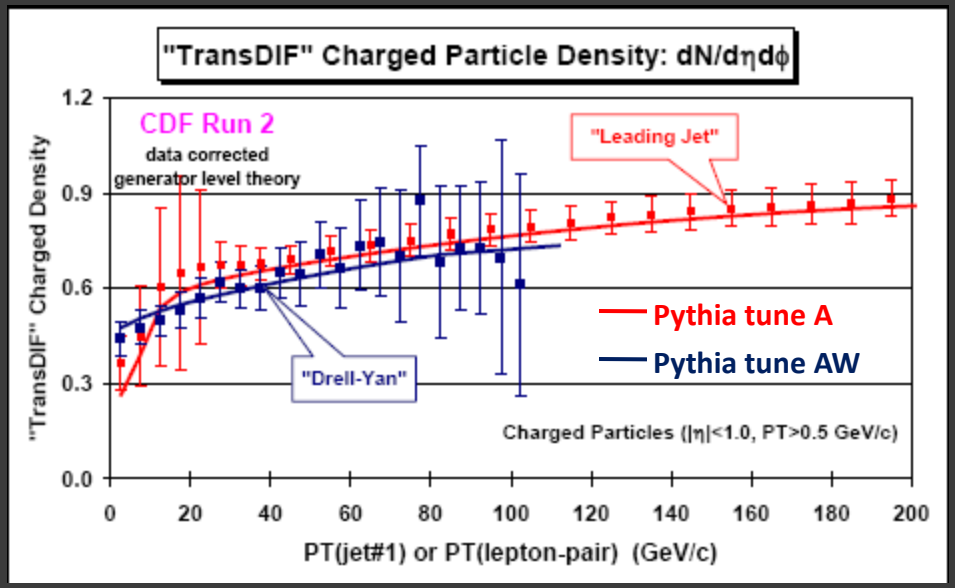


UE in Drell-Yan and incl. jet events

Event topologies:

- Leading Jet
- Drell-Yan

TransDIF Region = TransMAX-TransMIN
sensitive to hard ISR



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less gluon radiation,
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$ll = ee, \mu\mu$

$p_T > 20$ GeV/c
$|\eta| < 1$
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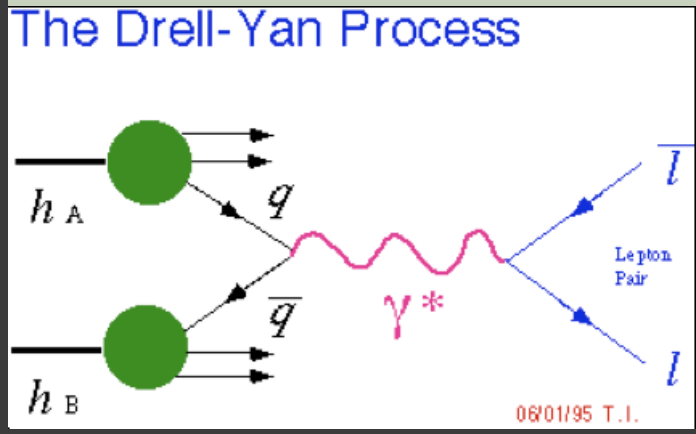
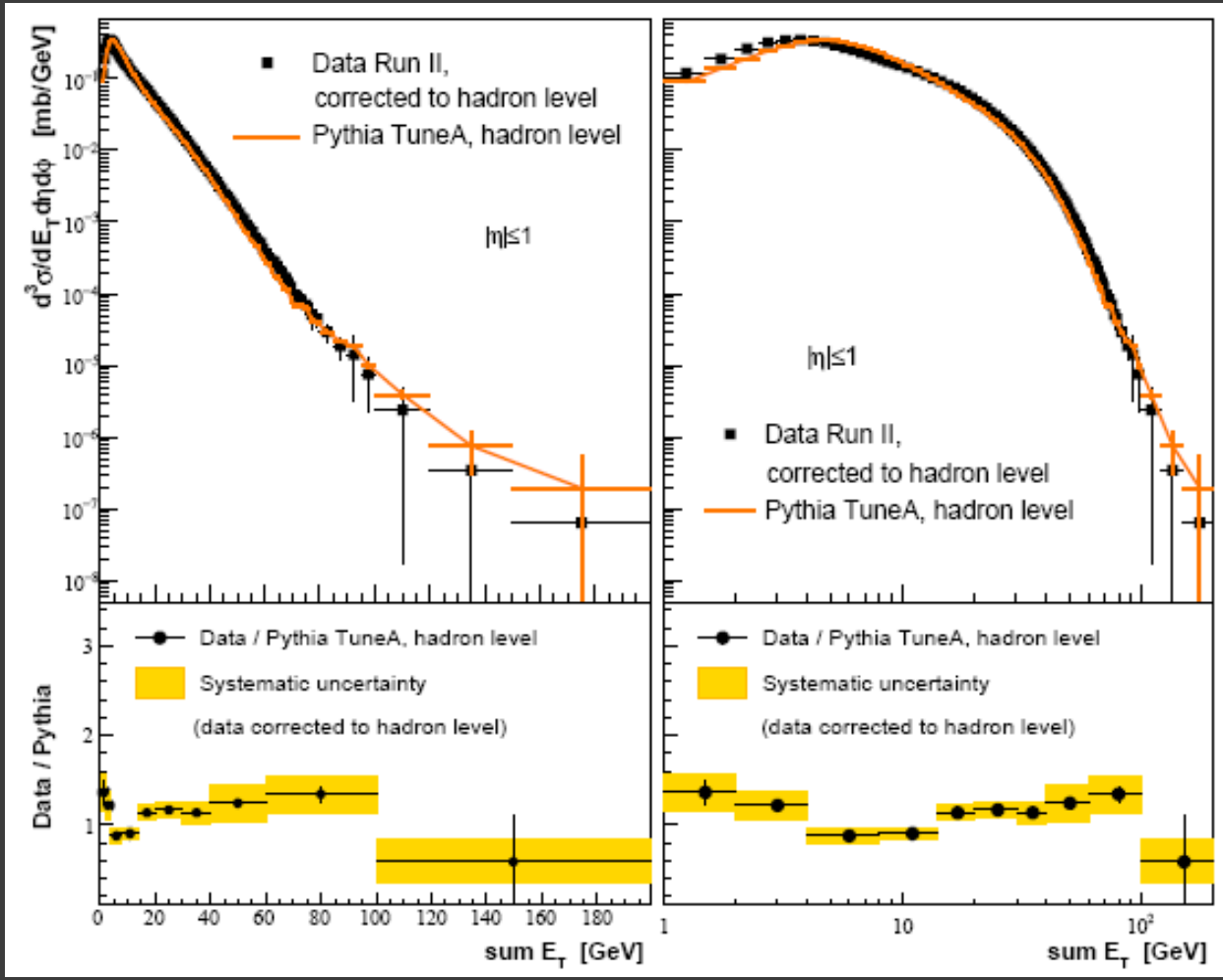
$|\eta(\text{pair})| < 6$



MB: charged + neutral E_T



ΣE_T from calor. information

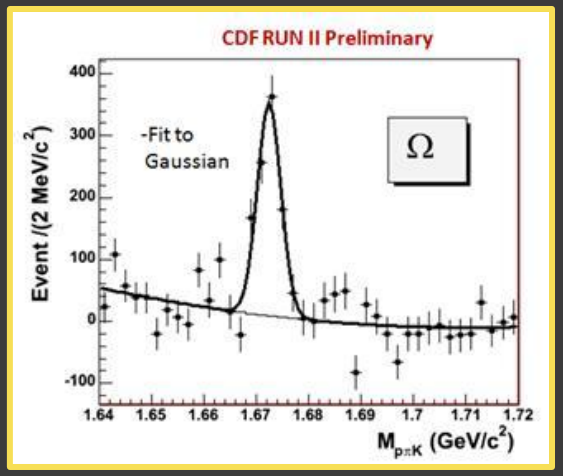
506 /pb of data

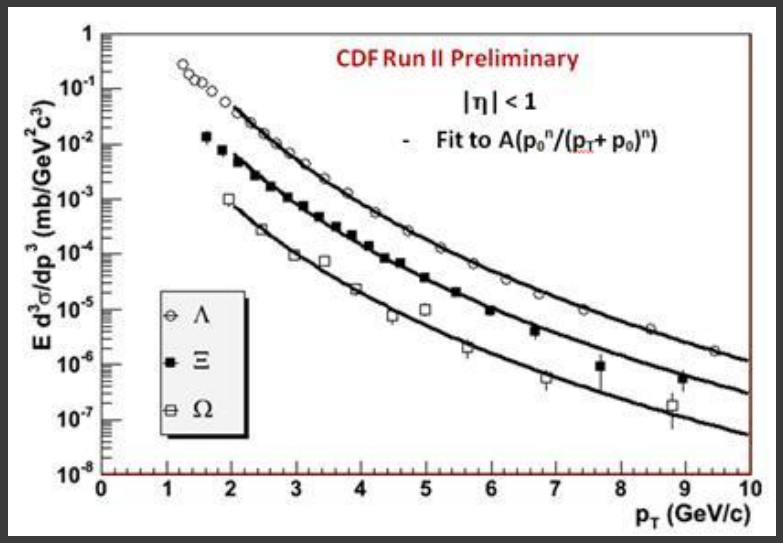
Pythia tune A agrees reasonably well

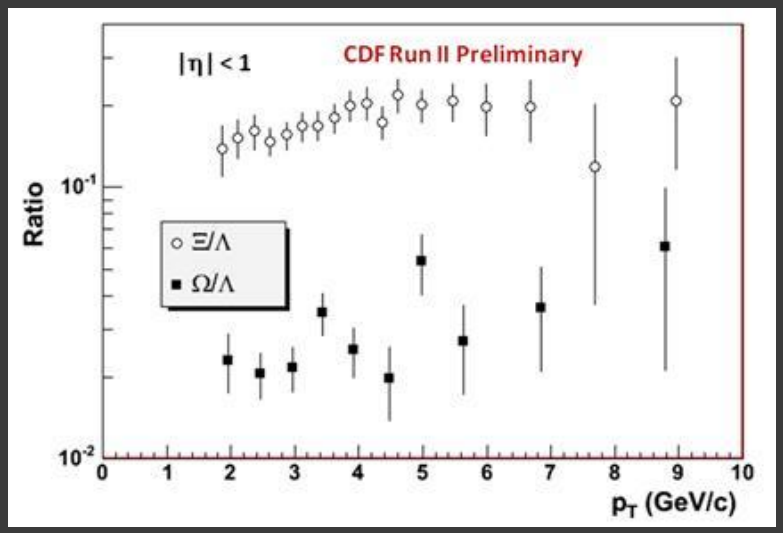
Hyperon Production

Previous studies of Λ and Ξ from colliders were limited in statistics and p_T range

10^8 MB events
$|\eta|<1.0$
p_T >0.3 GeV
$|z_{vtx}|<60$ cm



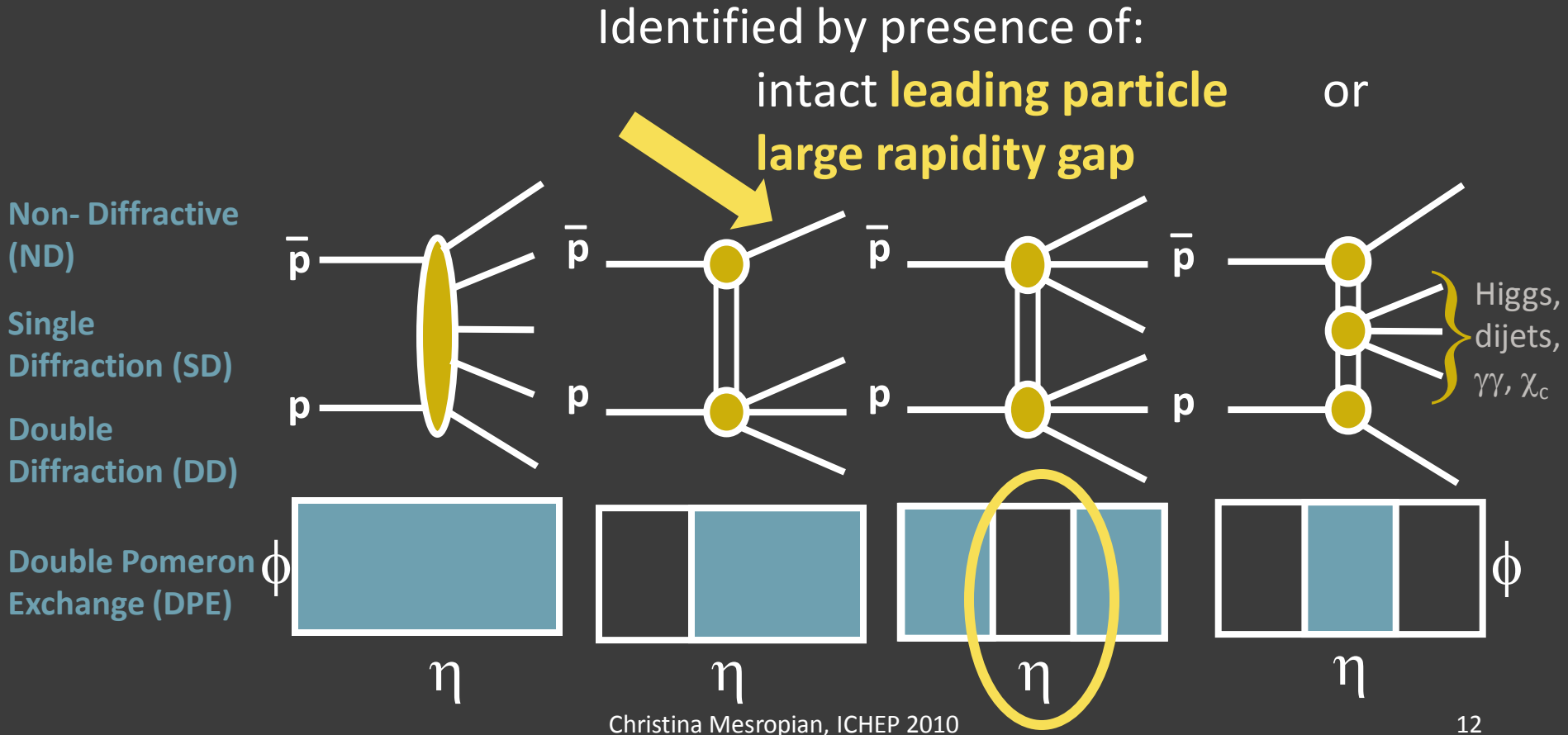




Production cross section drops by a factor of ~7 as the number of strange quarks increases by 1.

Definitions: Diffraction

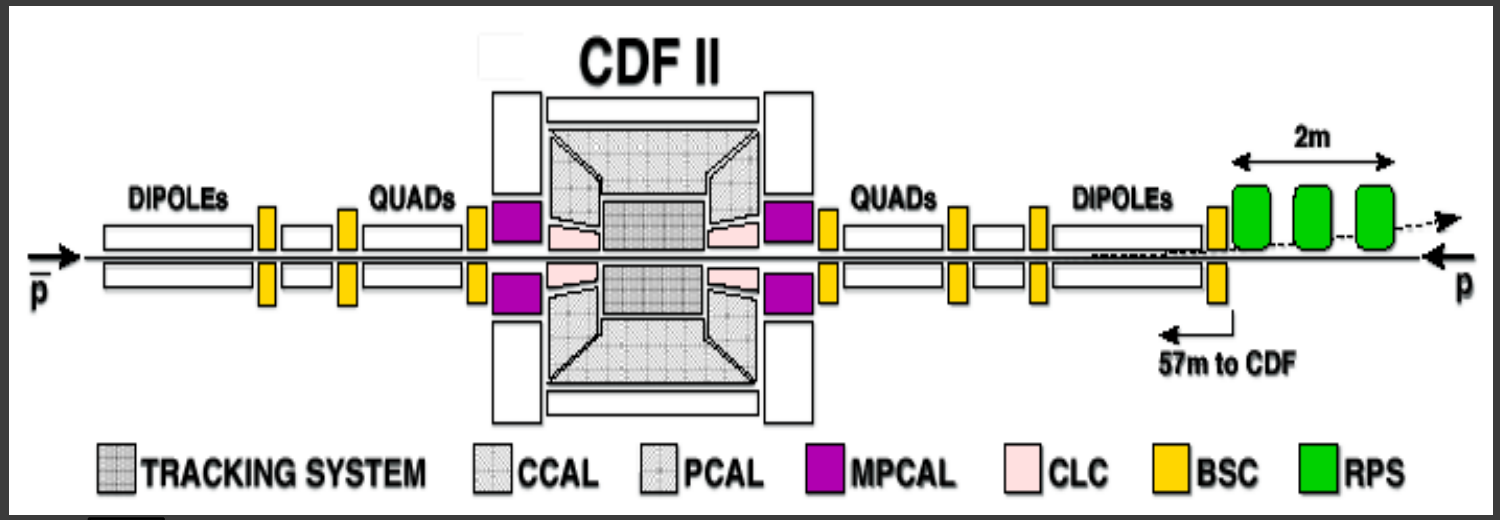
- **Diffractive reactions at hadron colliders are defined as reactions in *which no quantum numbers* are exchanged between colliding particles**



Definitions: Diffraction

Diffractive events at CDF are Identified by presence of:

intact **leading particle** or **large rapidity gap**



Tracking – Tracking Detectors $|\eta| < 2.0$

CCAL, PCAL – Calorimeters $|\eta| < 3.6$

RPS – Roman Pot Spectrometers

BSC – Beam Shower Counters $5.4 < |\eta| < 7.4$

MPCAL – MiniPlug Calorimeters $3.5 < |\eta| < 5.1$

Diffractive W/Z Production

Diffractive W/Z production probes the quark content of the Pomeron

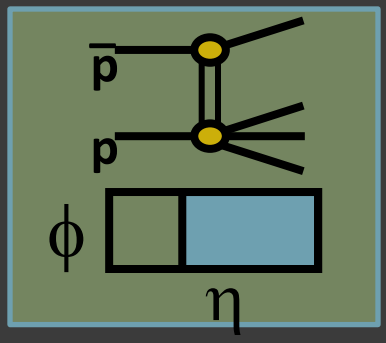
- to LO the W/Z are produced by a **quark** in the Pomeron
- production by gluons is suppressed by a factor of α_s and can be distinguished by an associated jet

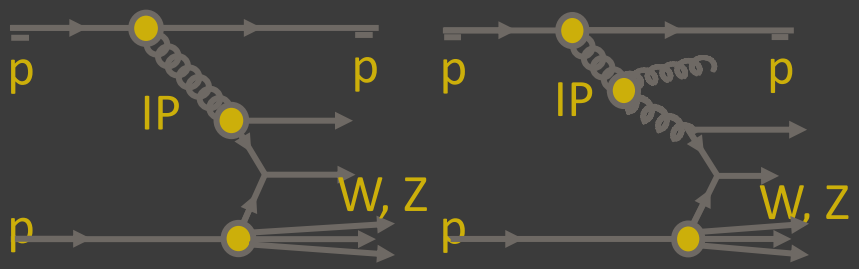
t - four-momentum transfer squared

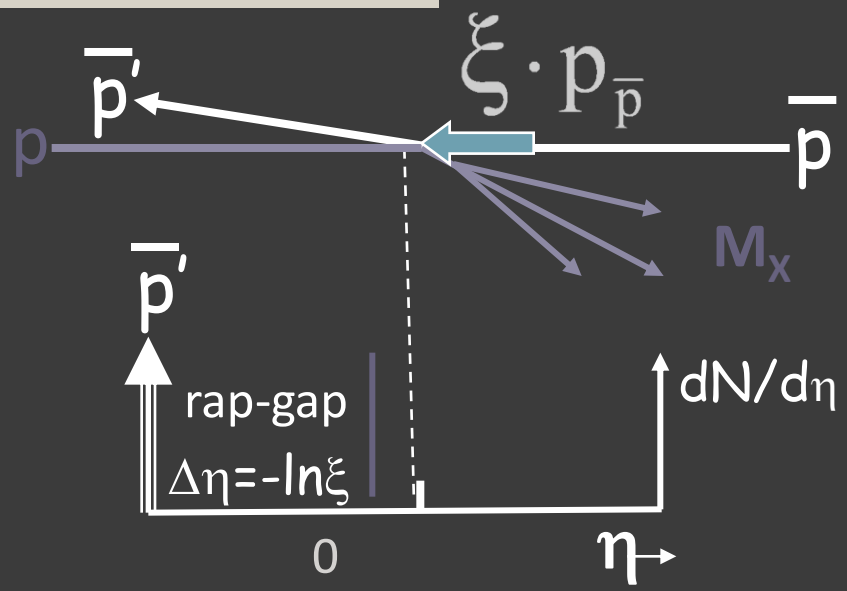
ξ- fractional momentum loss of pbar

M_X - mass of system X

$\xi = M_X^2/s$







- CDF Run I studies used rapidity gaps method PRL **78**, 2698 (1997)
  - Fraction of W events due to SD
  - **[1.15 0.51(stat) 0.20(syst)]%**

Diffractive W Production

Identify diffractive events using Roman Pots:

accurate event-by-event ξ measurement

no gap acceptance correction needed

can still calculate ξ^{cal}

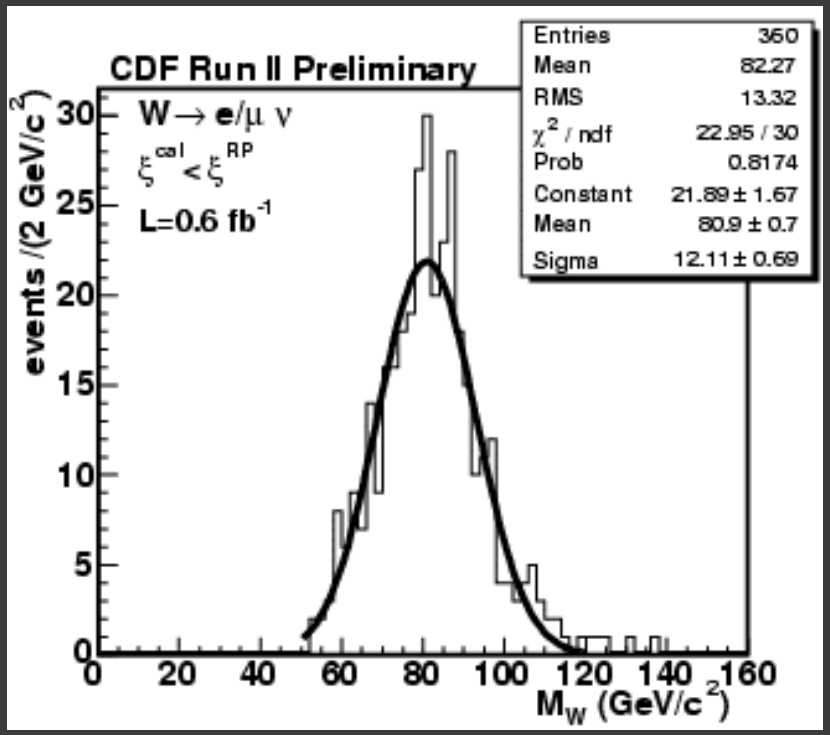
$$\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

In W production, the difference between ξ^{cal} and ξ^{RP} is related to missing E_T and η_ν

$$\xi^{RP} - \xi^{cal} = \frac{E_T}{\sqrt{s}} e^{-\eta_\nu}$$

allows to determine:

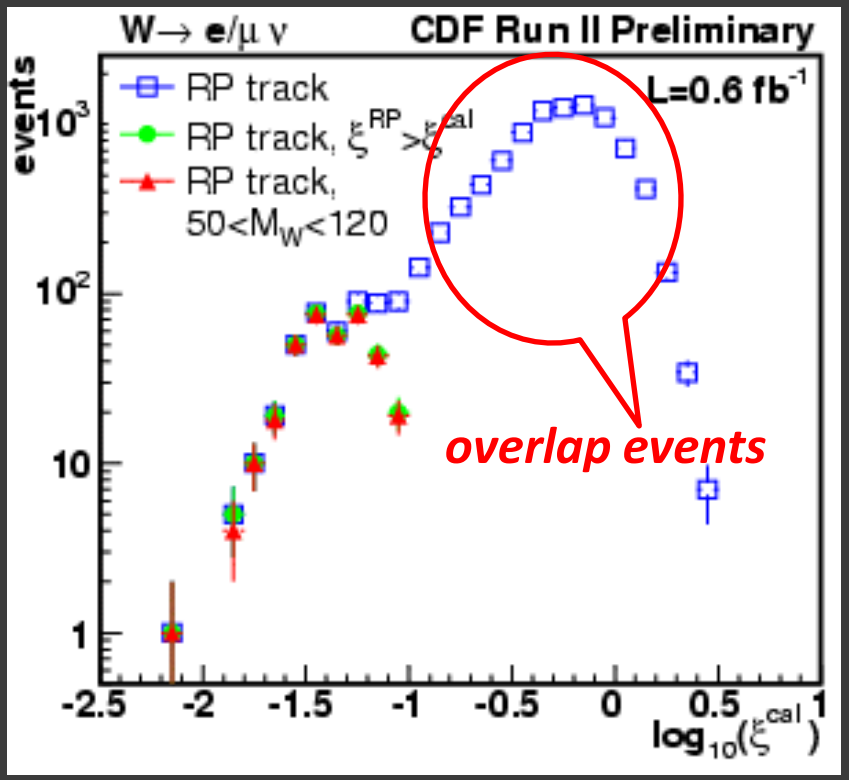
neutrino and W kinematics



reconstructed diffractive W mass

Diffractive W Production

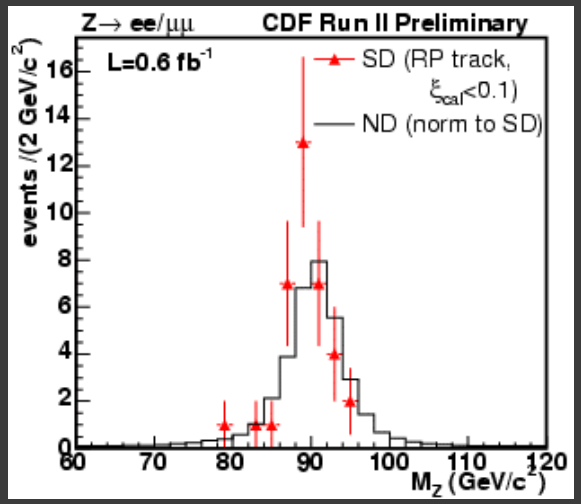
- $\xi^{cal} < \xi^{RP}$ requirement removes most events with multiple pbar-p interactions
- $50 < M_W < 120$ GeV/c^2 requirement on the reconstructed W mass cleans up possible mis-reconstructed events

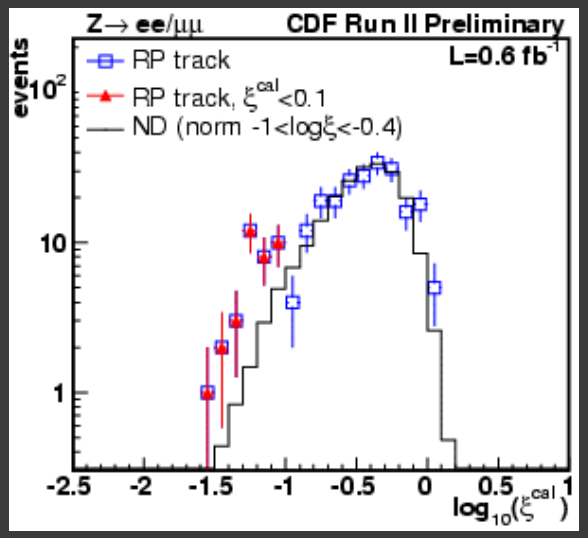


Fraction of diffractive W

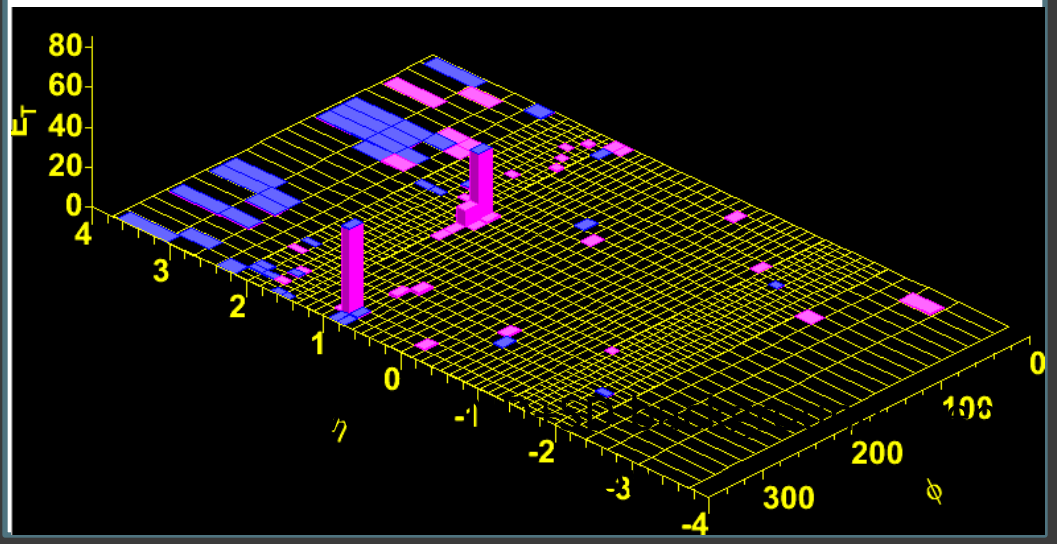
R_W (0.03<ξ<0.10, |t|<1)= [0.97 ±0.05(stat) ±0.10(syst)]%
consistent with Run I result, extrapolated to all ξ

Diffractive Z





37 diffractive Z→ ee/μμ candidates
(RP track, ξ^{cal}<0.1)

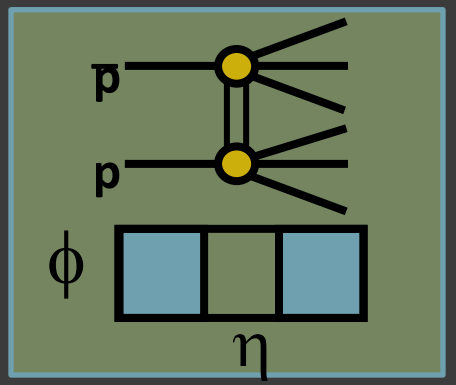


Fraction of diffractive Z

R_Z (0.03< ξ <0.10, |t|<1)= [0.85±0.20(stat) ±0.08(syst)]%

Double Diffraction

Diffractive signature:
large central rapidity gap – slightly different gap definitions

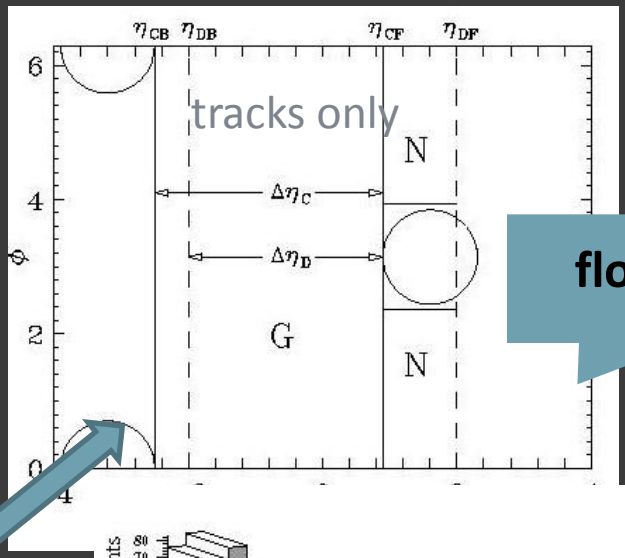


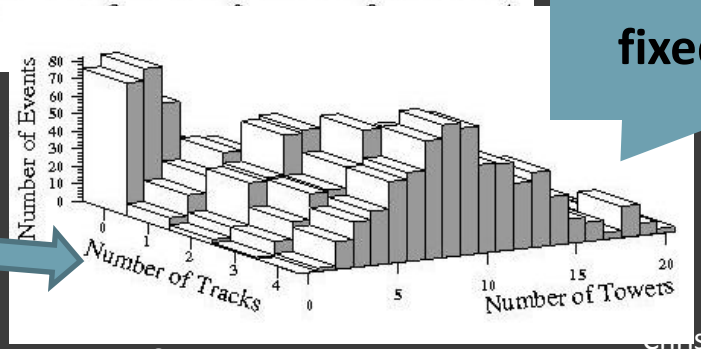
Soft Diffraction

Double Diffraction
PRL 87, 141802 (2001)

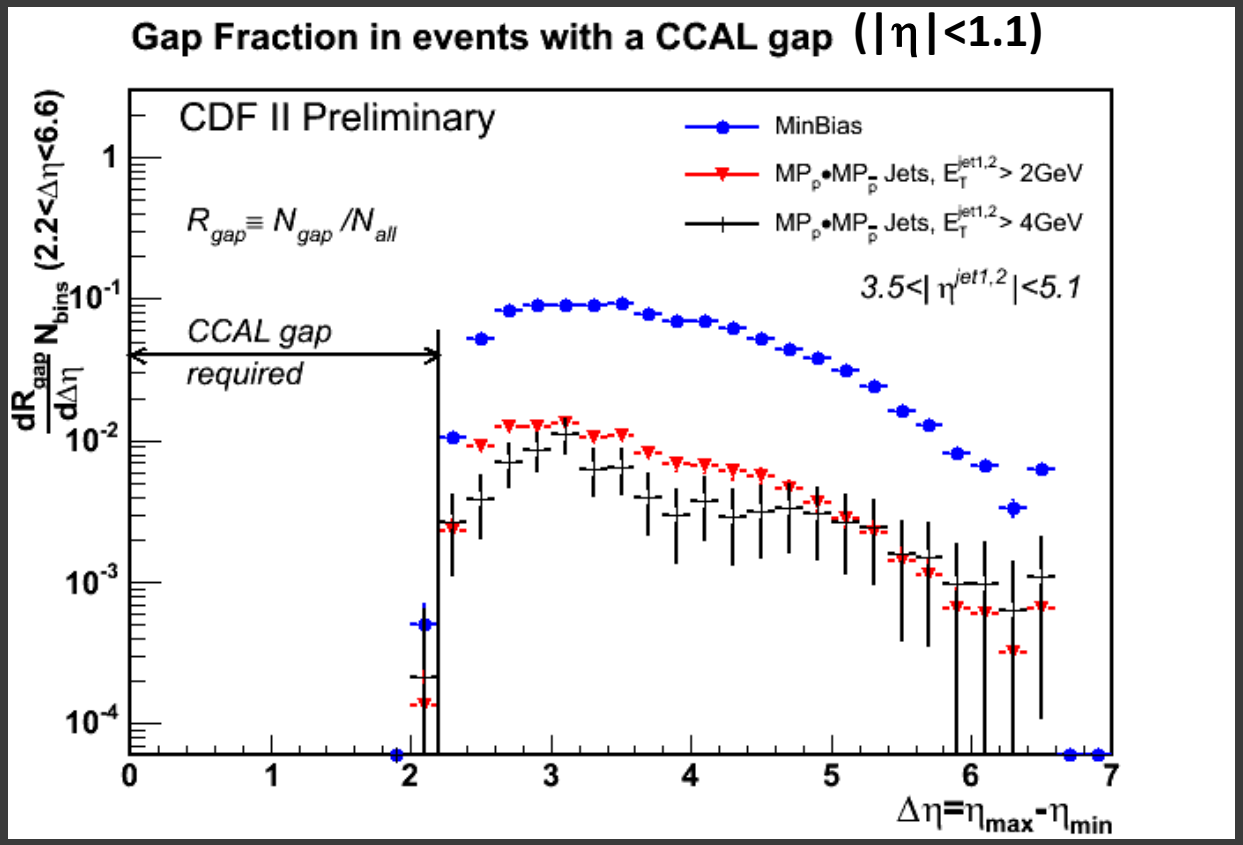
Hard Diffraction

Jet-Gap_Jet
1.8 TeV PRL 74, 855 (1995)
1.8 TeV PRL 80, 1156 (1998)
630 GeV PRL 81, 5278 (1998)

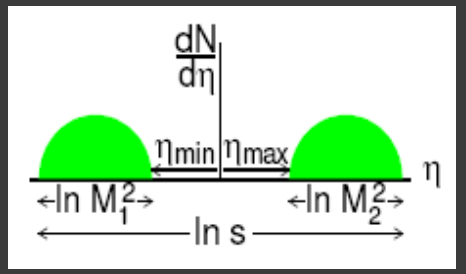




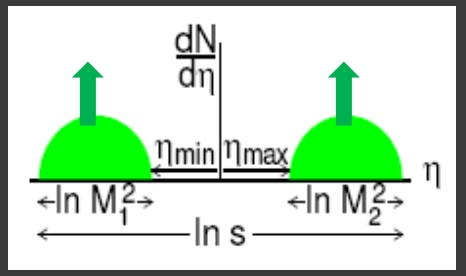
Central Gaps in Soft and Hard DD



soft DD



compare with



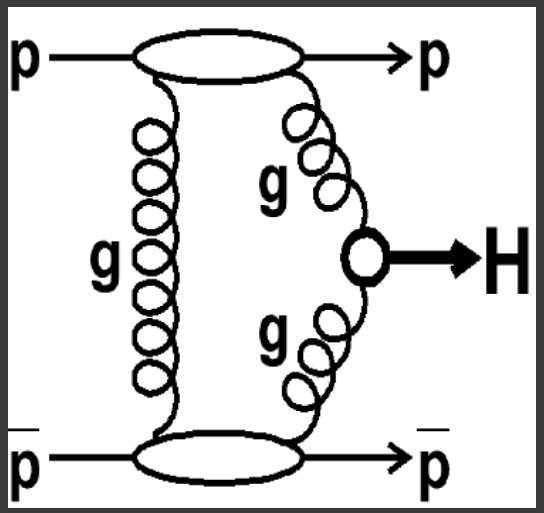
hard DD

Fraction of events with gaps:

~10% in soft DD events and ~1% in jet events

The distributions are similar in shape within the uncertainties

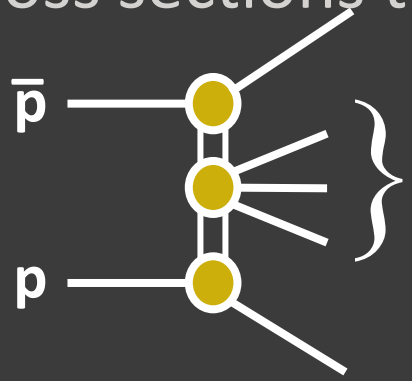
Exclusive Production



➔ suppression at LO of the background sub-processes (J_z=0 selection rule)

➔ "exclusive channel" → clean signal (no underlying event)

- At the Tevatron we use similar processes with larger cross sections to test and calibrate theor. predictions



Dijets, PRD 77, 052004 (2008)

$\gamma\gamma$, PRL 99, 242002 (2007)

χ_c, PRL102, 242001 (2009)

Exclusive Dimuon Production

Event Signature:

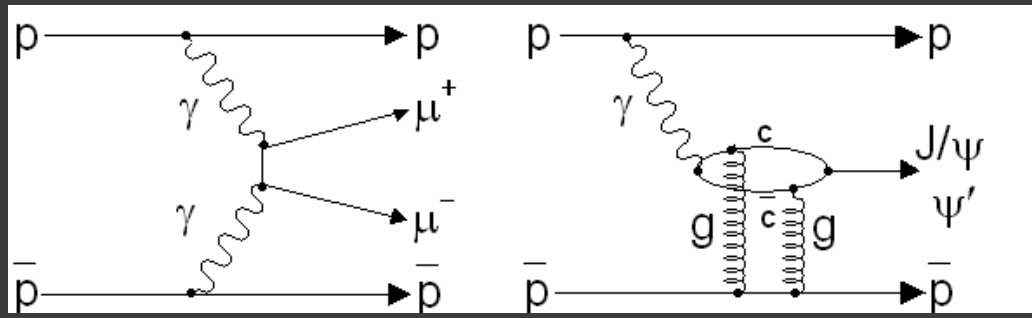
2 oppositely charged central muons +
no other particles (large rapidity gap)

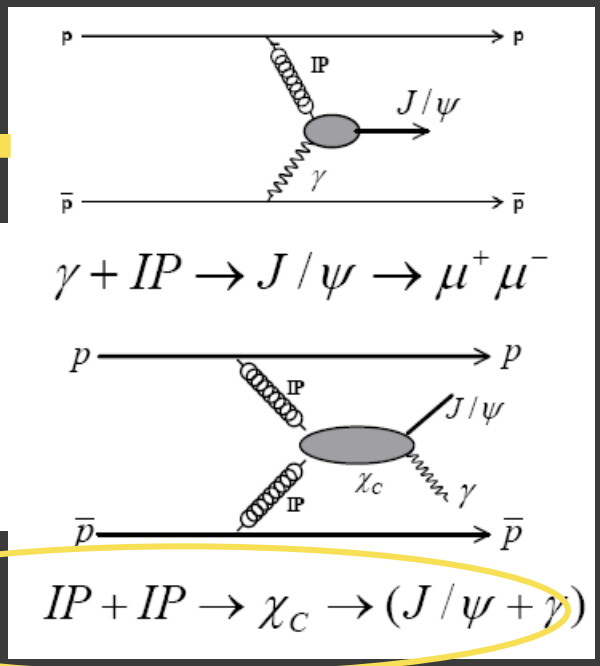
$$p + p \rightarrow p + \mu^+ \mu^- + p$$

$3\ \mathrm{GeV}/c^2 < M_{\mu\mu} < 4\ \mathrm{GeV}/c^2$

$|\eta| < 0.6$

Many Physics Processes in this data:





exclusive χ_c in DPE

Exclusive J/ψ and ψ(2s)

J/ψ production

243 ±21 events

$d\sigma/dy|_{y=0}$ = **3.92 ± 0.62 nb**

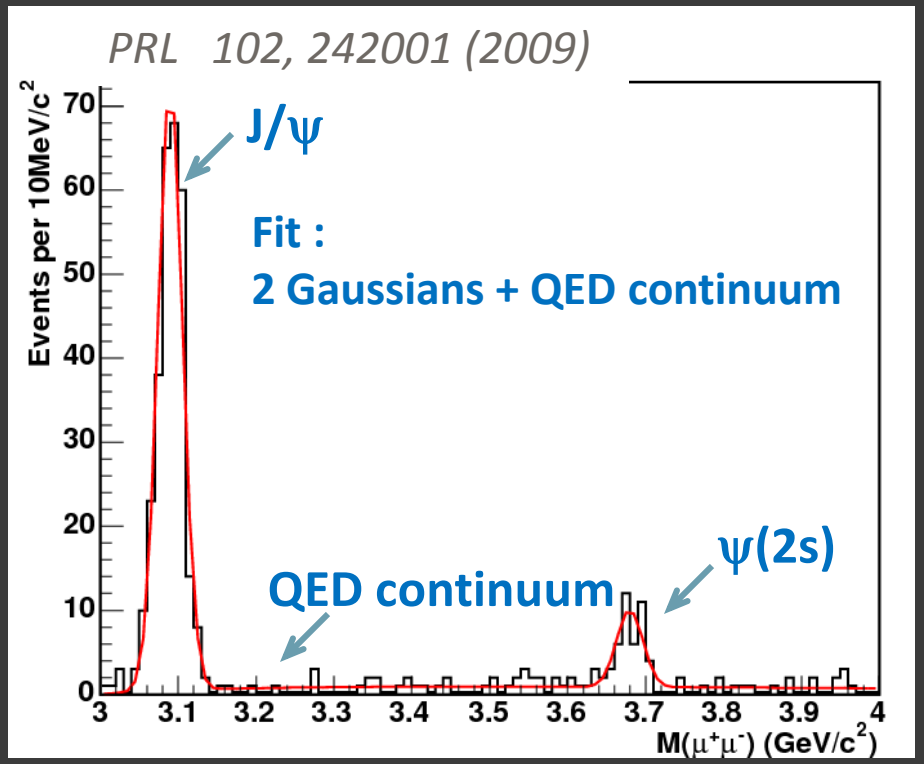
Theoretical Predictions

2.8 nb [Szczurek07,],

2.7 nb [Klein&Nystrand04],

3.0 nb [Conclaves&Machado05], and

3.4 nb [Motkya&Watt08].



Ψ(2s) production

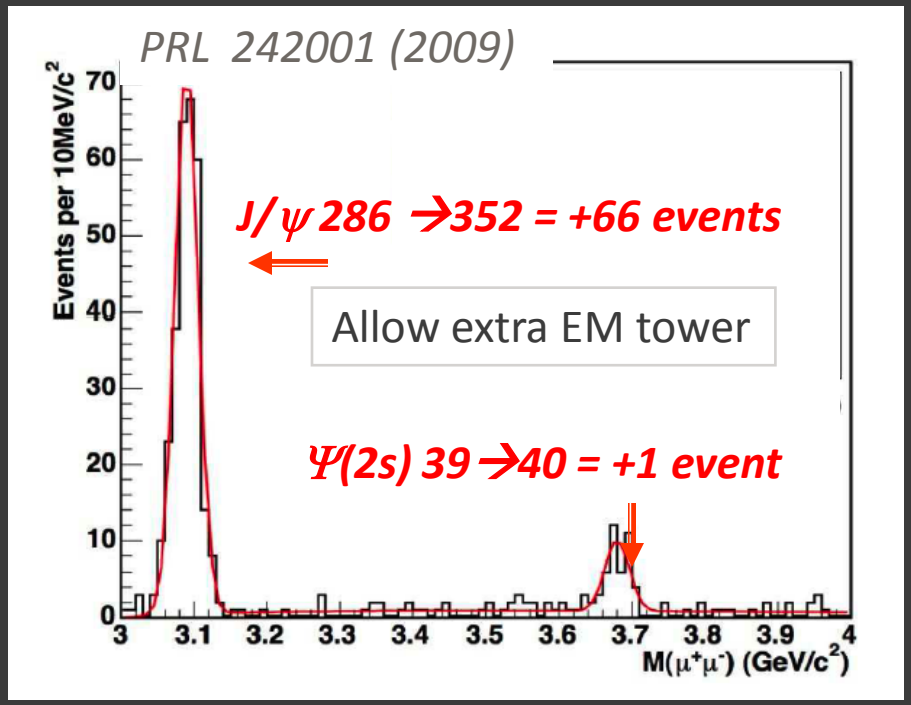
34±7 events

$d\sigma/dy|_{y=0}$ = **0.54 ± 0.15 nb**

R = ψ(2s)/J/ψ = 0.14 ± 0.05

In agreement with HERA: R = 0.166 ± 0.012 in a similar kinematic region

Exclusive $\chi_c \rightarrow J/\psi(\rightarrow \mu^+\mu^-)+\gamma$



➔ Allowing EM towers (E_T >80MeV)

large increase in the J/ψ peak

minor change in the ψ(2s) peak

↓

Evidence for

$\chi_c \rightarrow J/\psi+\gamma$ production

$d\sigma/dy|_{y=0}$ = 75 ± 14 nb,
compatible with theoretical predictions
160 nb (Yuan 01)
90 nb (KMR01)

Conclusions

- **CDF has very strong program of Soft QCD physics studies:**
  - complete and large set of measurements of MB & UE
    - important to extrapolate MC to LHC energies and to estimate backgrounds for high p_T processes
  - very extensive program of diffractive studies with rapidity gap and leading particle signatures for both soft and hard processes
  - new measurements of exclusive processes
    - validation of existing theoretical models

- More results are expected in final states correlations, heavy flavor MB, exclusive processes with forward gaps, and diffractive production with central gaps