

Double Pomeron Exchange and χ_c Production at CDF



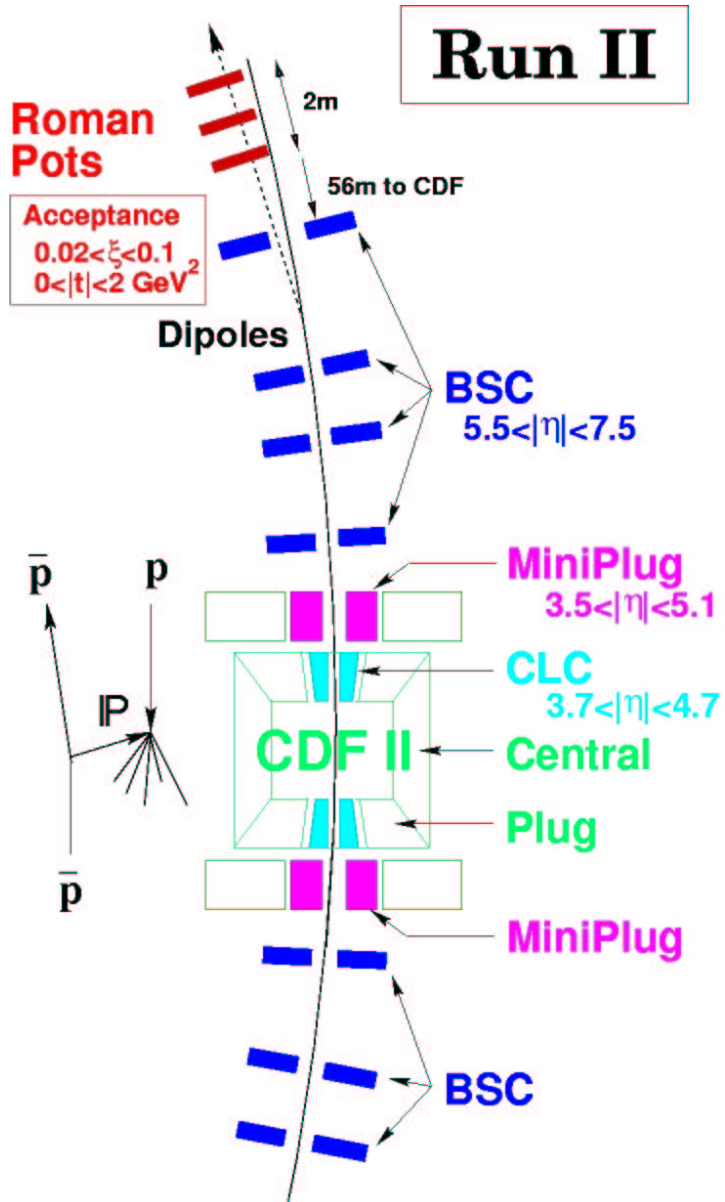
Angela Wyatt
University College London
for the CDF Collaboration

- **Diffraction in CDF Run II**
- **Double Pomeron Exchange Dijets**
- **Search for exclusive χ_c production**
- **Outlook & Summary**

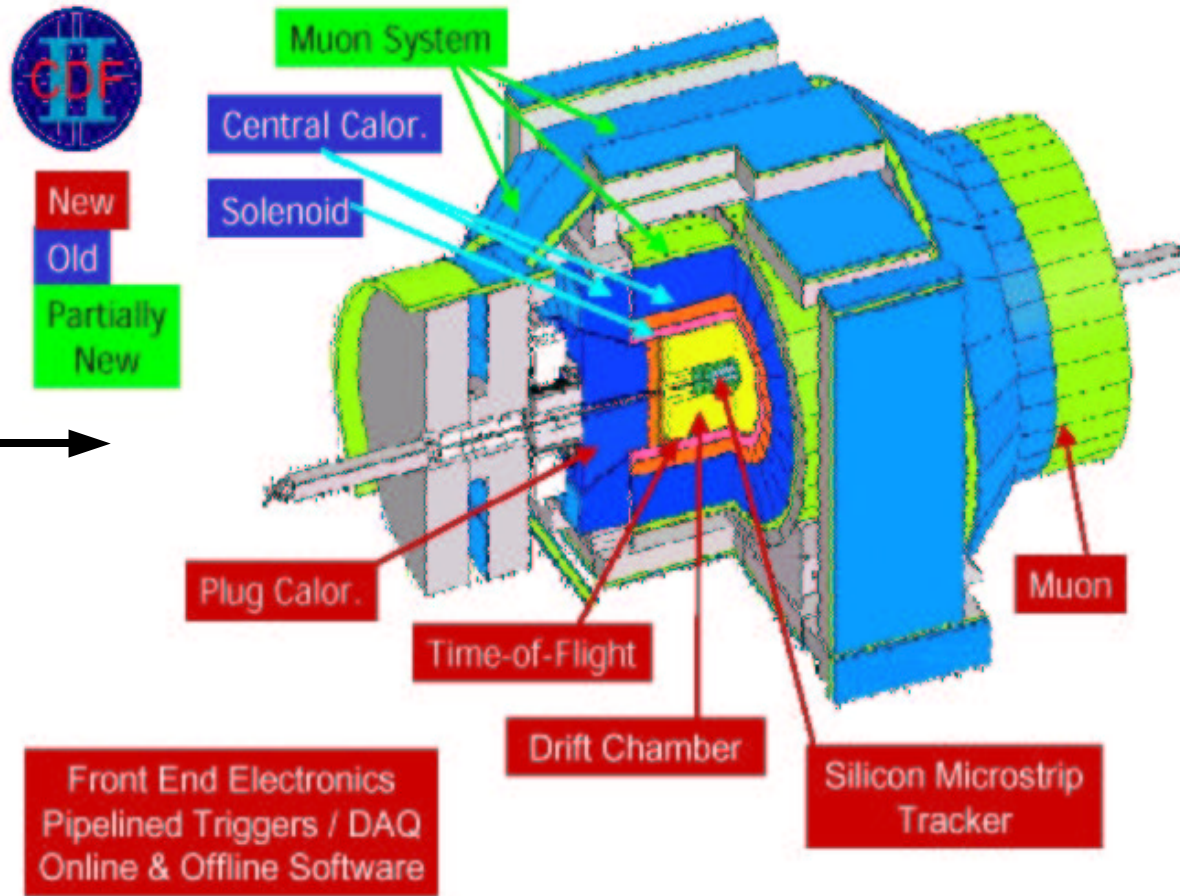


Improvements for run II

Run II

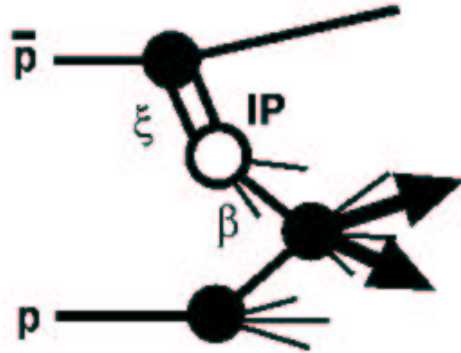


- Larger η coverage for rapidity gaps and forward jets: new BSC, miniplug.
- New plug calorimeter for jets/gaps.



Diffractive Dijets: structure function

Run II measurement.



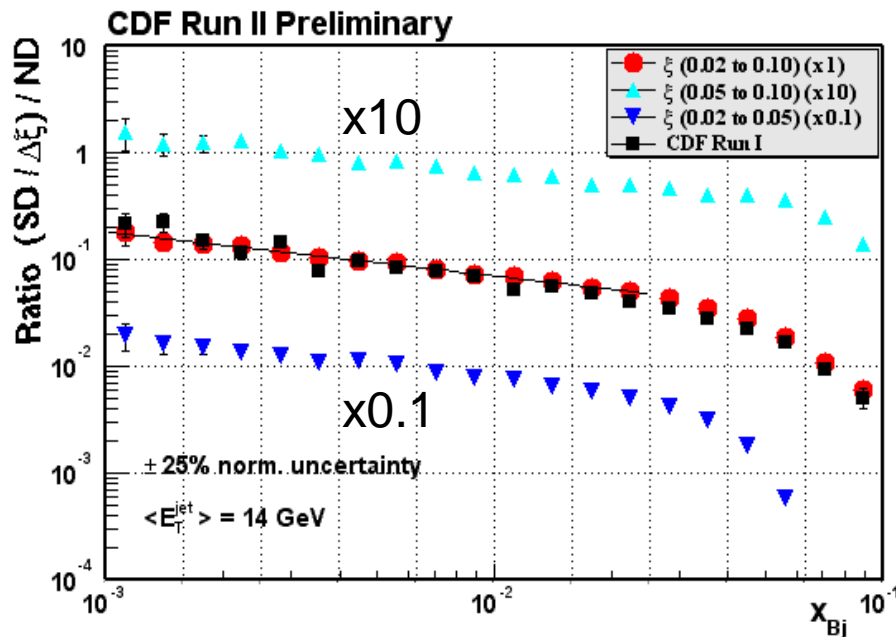
$$\text{LO QCD: } \frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} = \frac{F_{jj}^D(x)}{F_{jj}(x)}$$

Single diffractive (SD) dijets:

- Use roman pots to tag.
- Select 2+ jets:
corrected $E_{\uparrow} > 5\text{GeV}$, $|\eta_{1,2}| < 2.5$

Non diffractive (ND) dijets:

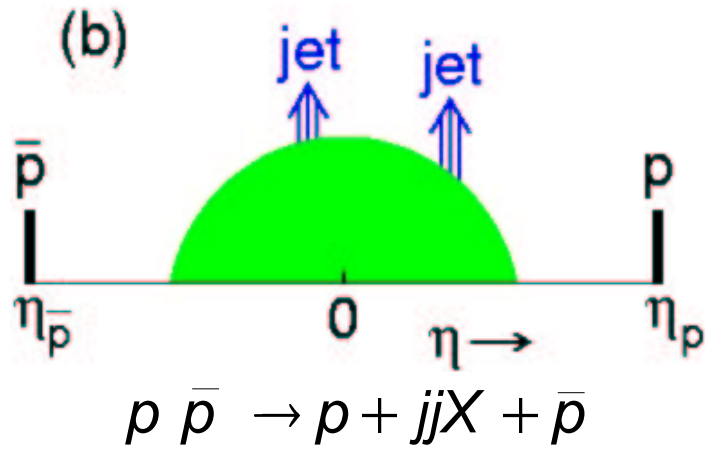
As above, no roman pot hit.



SD/ND dijets - different ξ ranges

- Good agreement with run I in normalisation and x_{Bj} dependence
- No ξ dependence observed
 $0.03 < \xi < 0.1$ (as in Run I)

Double Pomeron Exchange in run I

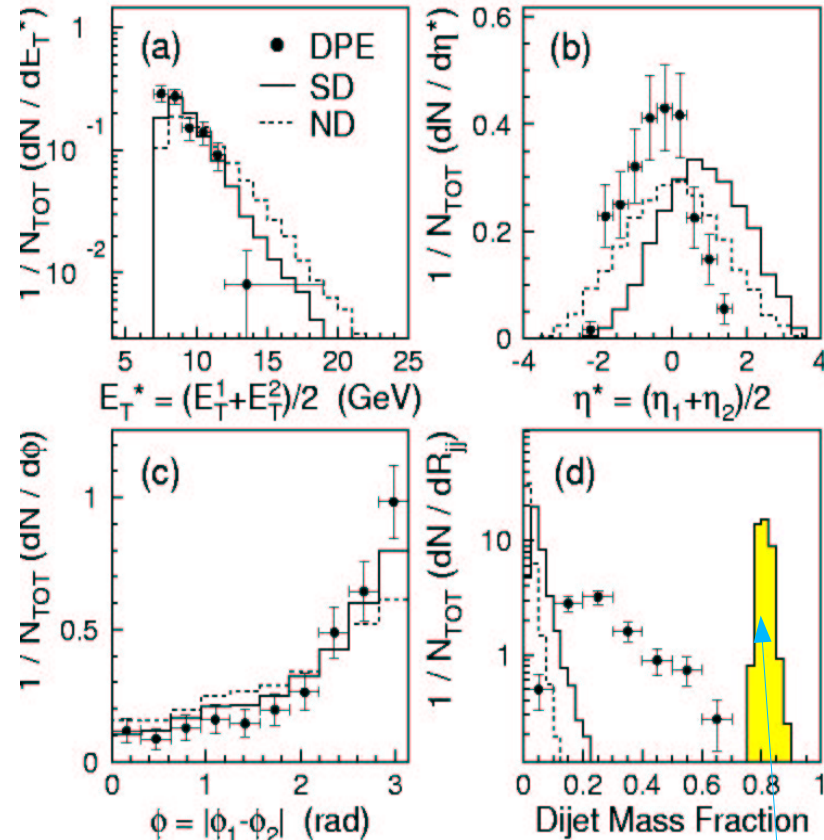


Tagged \bar{p} : $0.035 < \xi < 0.095$
 rapidity gap p side: $0.01 < \xi < 0.03$
 2 jets $E_T > 7$ GeV
 \Rightarrow 130 events

Mass Fraction:

$$R_{jj/X} = \frac{M_{jj}^{\text{cone}}}{M_x}$$

exclusive: $0.7 < R_{jj/X} < 0.9$



Inclusive $\sigma = 43.6 \pm 4.4$ (stat) ± 21.6 (syst) nb

Exclusive $\sigma < 3.7$ nb (95% C.L.)

- Use to test calculations or to normalise calculations of diffractive Higgs.

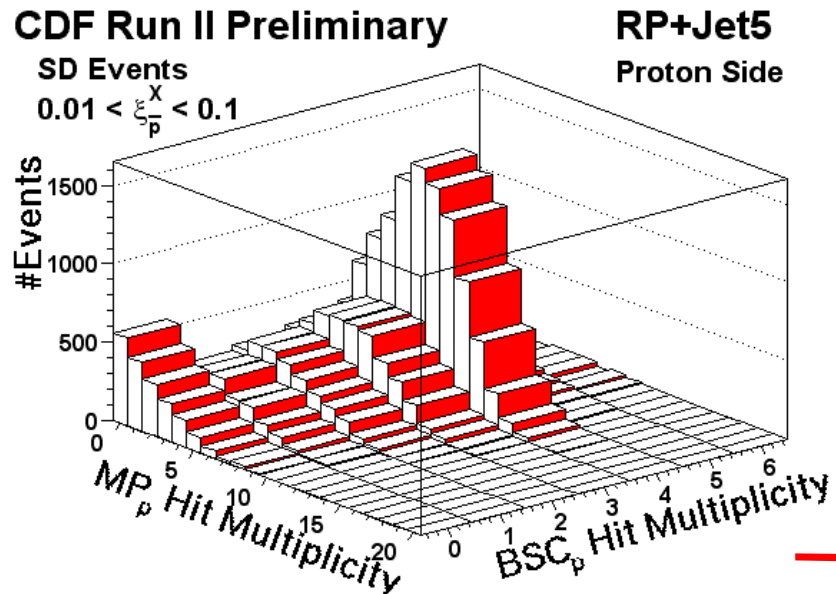
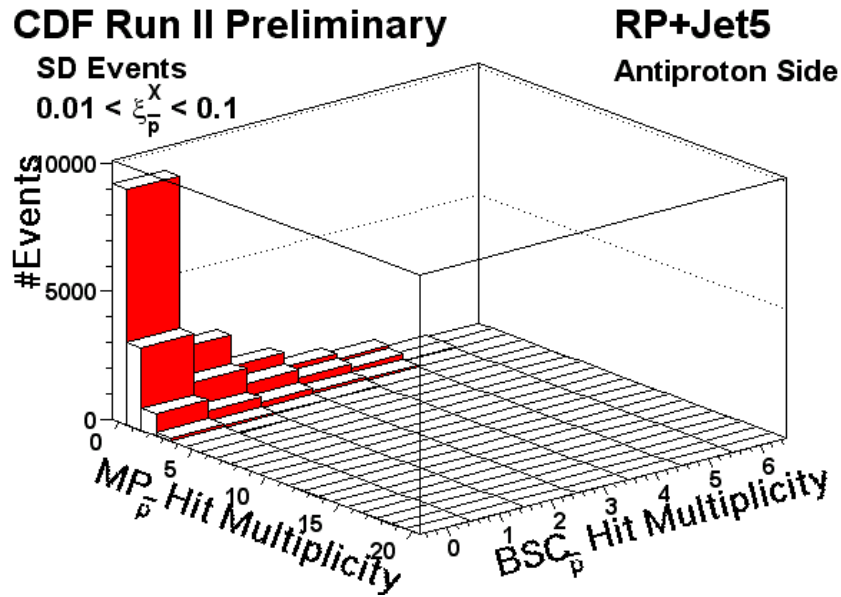
DPE Dijets: event selection

Trigger Requirement

- Tag \bar{p} in roman pots
- Gap on p -side in BSC ($5.5 < \eta < 7.5$)
- Cal tower $E_{\dagger} > 5$ GeV
- 26 pb^{-1} prescaled x5

Additional Event selection

- $0.03 < \xi_{\bar{p}} < 0.1$
- Gap in miniplug ($3.6 < \eta < 5.1$)
- $N(\text{good vertex}) \leq 1$
- No significant missing E_{\dagger}
- 2+ jets (cone 0.7) $E_{\dagger} > 10$ GeV (corrected E_{\dagger}), $|\eta_{1,2}| < 2.5$



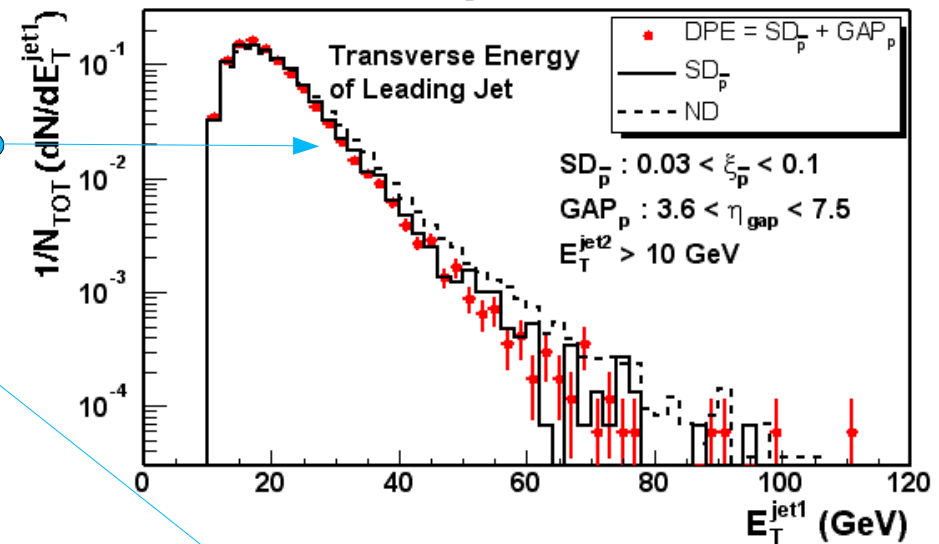
→ X200 improvement in stats on run I

DPE Dijets: kinematic properties

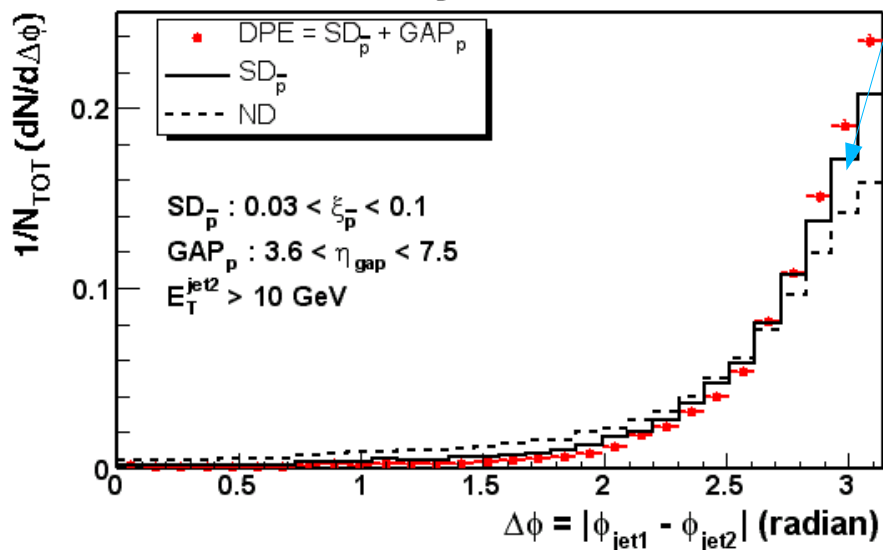
Jets in **DPE** compared to **SD**:

- Fairly **similar** E_T distribution
- Jets now almost **central** again
($\xi_p \sim \xi_{\bar{p}}$)
- Even more **back to back** in ϕ

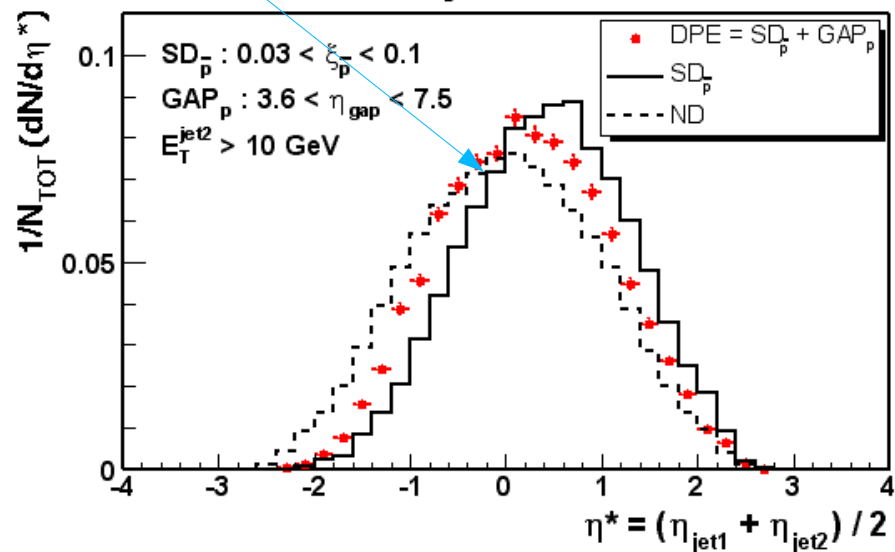
CDF Run II Preliminary



CDF Run II Preliminary

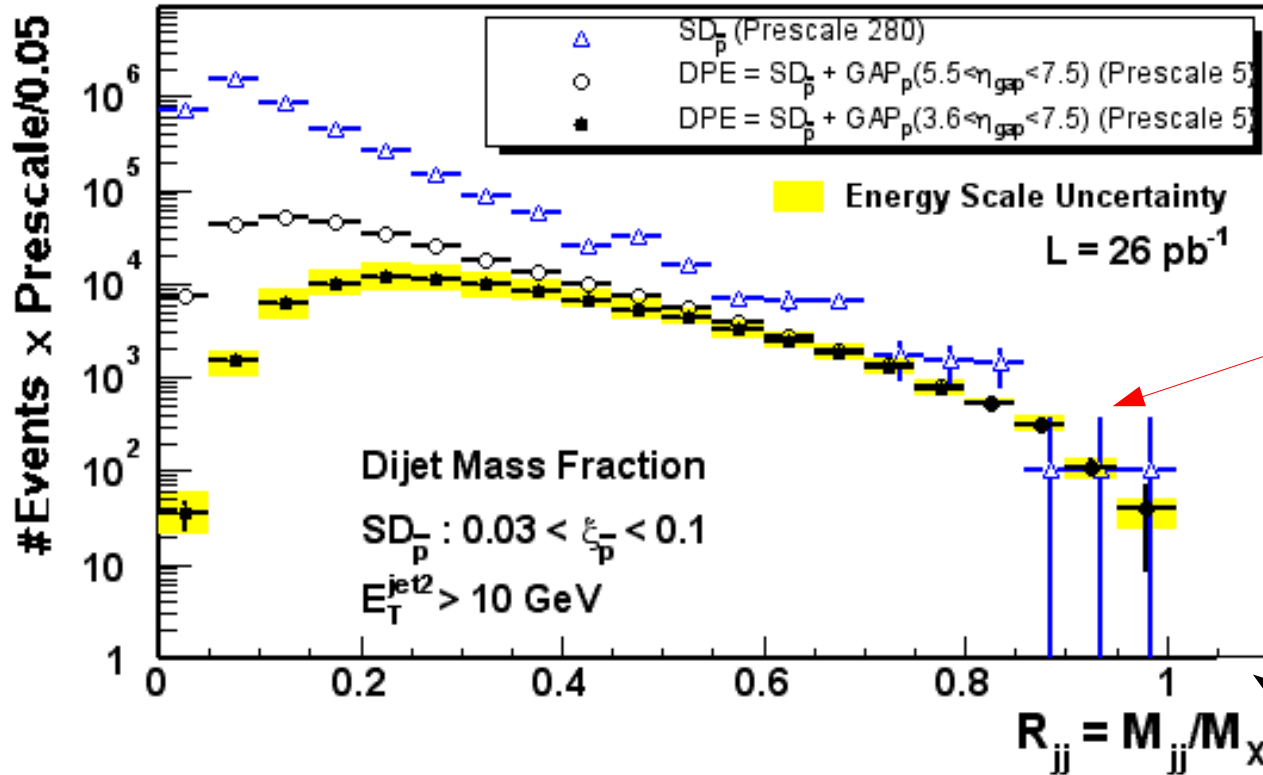


CDF Run II Preliminary



DPE Dijets: Mass Fraction

CDF Run II Preliminary



$$R_{jj} = \frac{\text{Dijet Mass}}{\text{Diffractive Mass}}$$

• R_{jj} will be large for exclusive events (but < 1 due to out of cone energy)
Smooth distribution

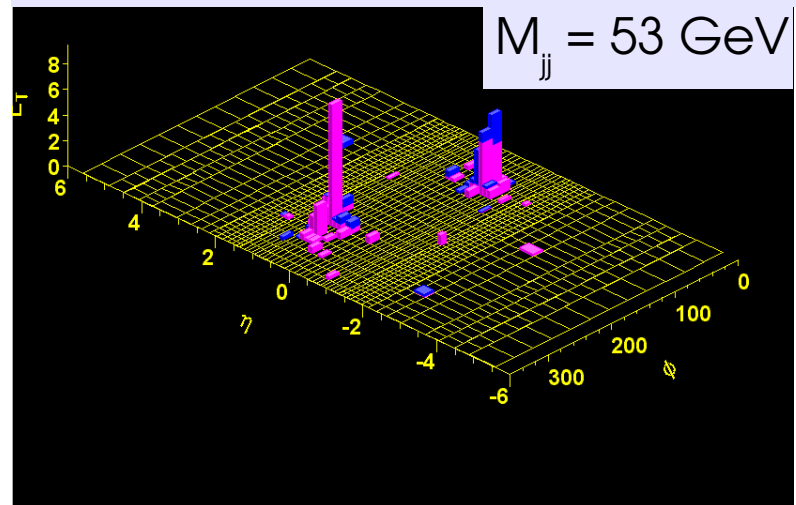
Note: •

Here corrections for underlying event or to get the parton energy are not applied in the calculation of M_{jj}

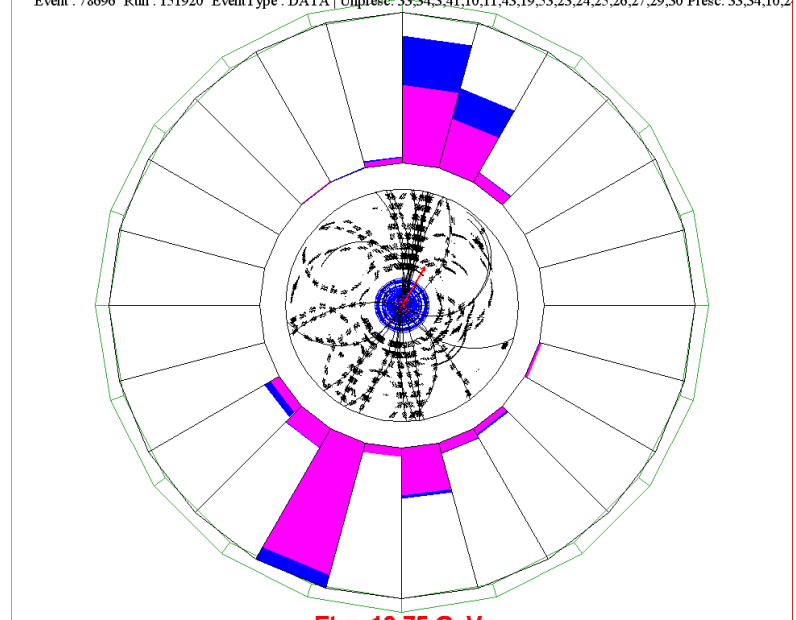
Min $E_t(\text{jet1})$	Cross Section ($R_{jj} > 0.8$)
10 GeV	970 ± 65 (stat) ± 272 (syst) pb
25 GeV	34 ± 5 (stat) ± 10 (syst) pb

DPE Dijets: event pictures

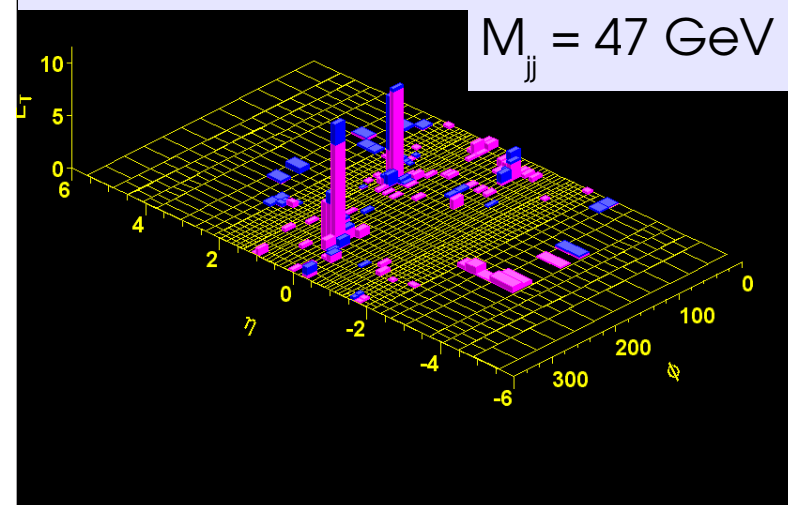
$R_{jj} = 0.81, E_{\uparrow} 1(2) 33.4 (31.5) \text{ GeV}$



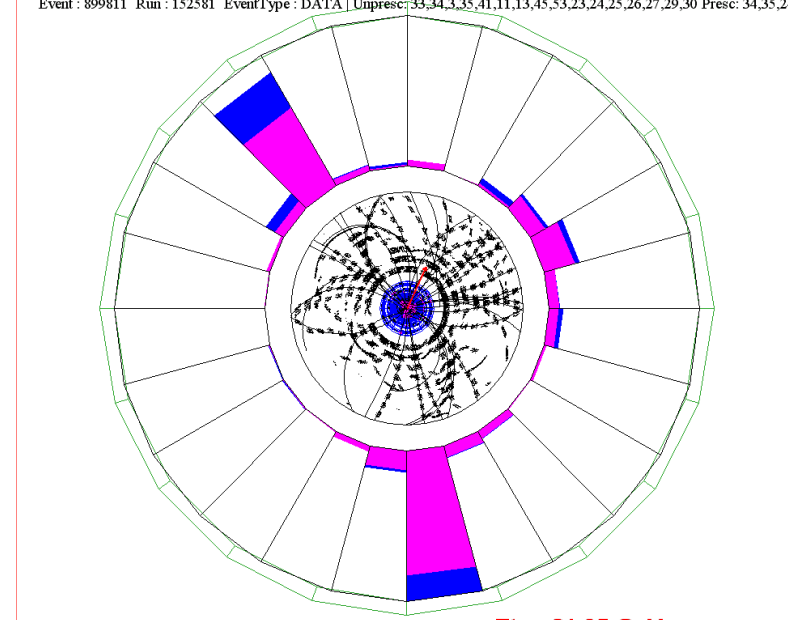
Event : 78696 Run : 151920 EventType : DATA | Unpresc: 33,34,3,41,10,11,43,19,53,23,24,25,26,27,29,30 Presc: 33,34,10,2



$R_{jj} = 0.36, E_{\uparrow} 1(2) 36.2 (33.3) \text{ GeV}$

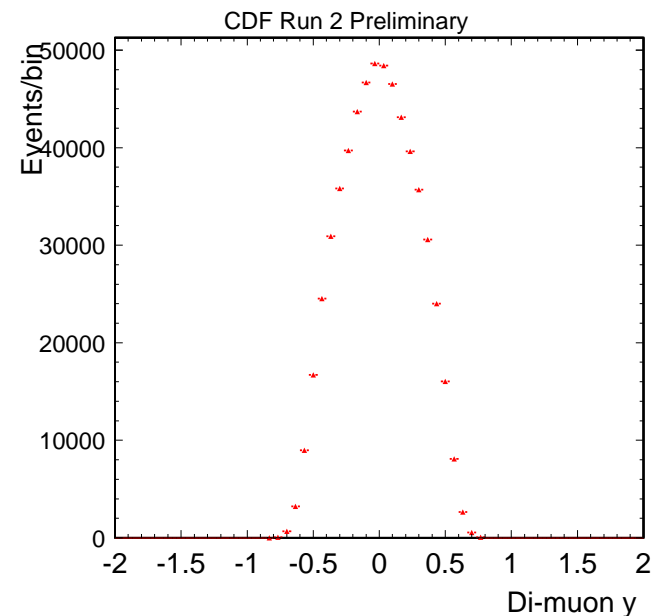
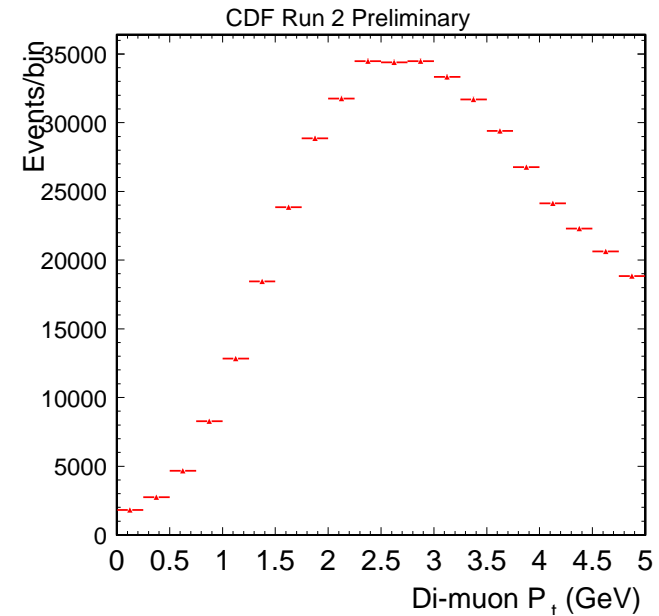
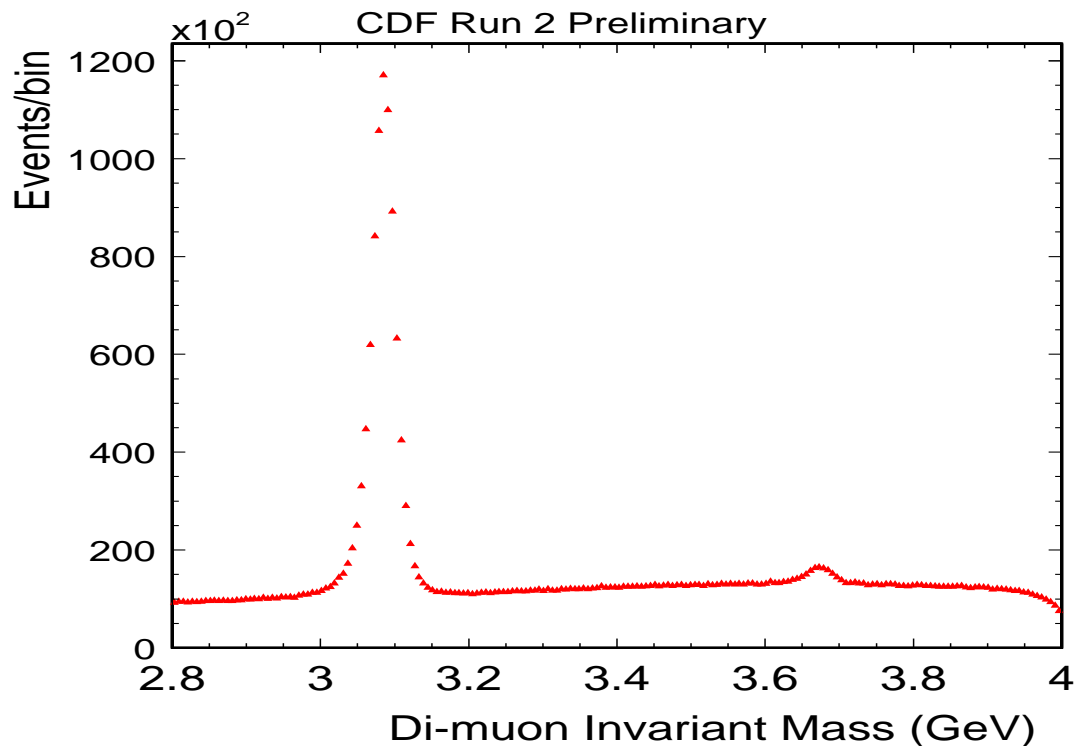


Event : 899811 Run : 152581 EventType : DATA | Unpresc: 33,34,3,35,41,11,13,45,53,23,24,25,26,27,29,30 Presc: 34,35,24,



Selection of an inclusive J/ψ sample

- Events are triggered on by a **di-muon trigger**
- Muons have $P_t > 1.5$ GeV, $|\eta| < 0.6$
- **Reject cosmic rays** with time of flight info.
- Select events in J/ψ **mass window**.



Rapidity gap selection at CDF

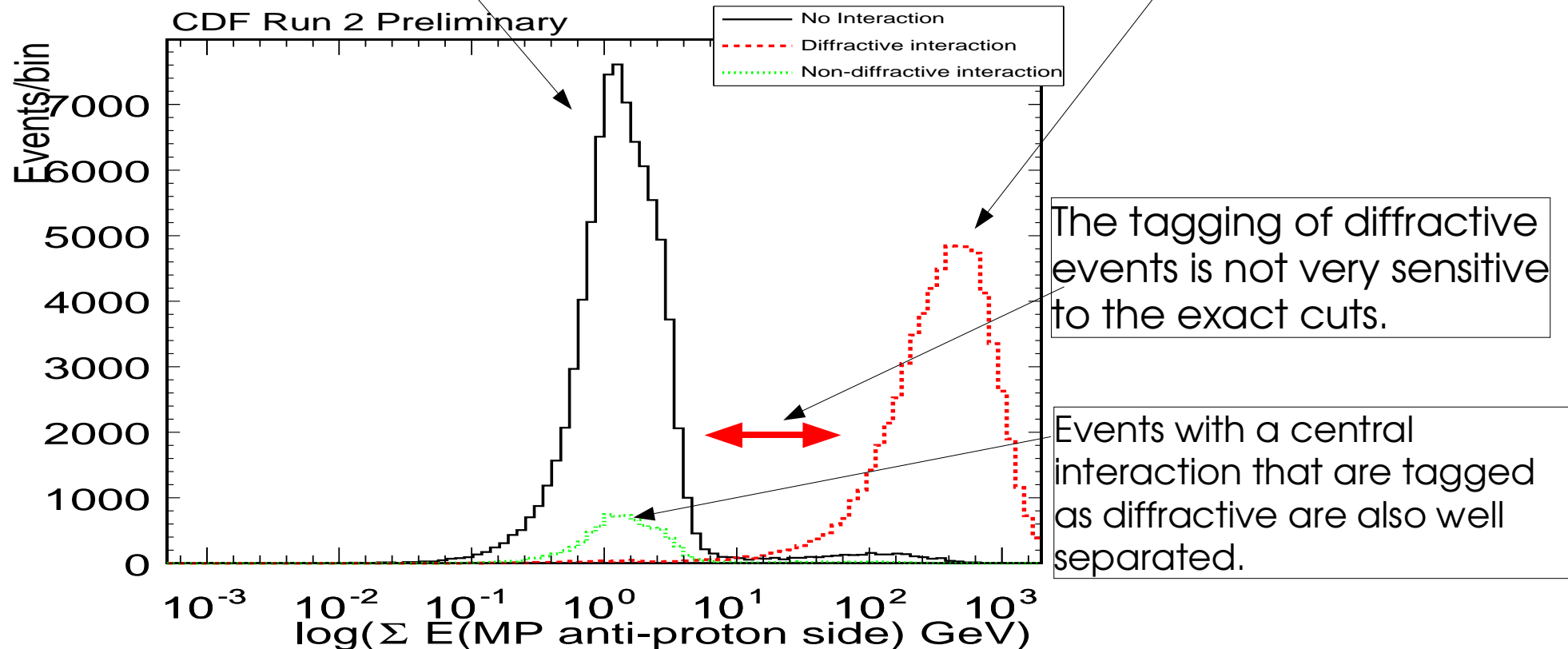
Beam/electronic noise means that exclusive isn't zero signal

⇒ define rapidity gap by a cut at low energy

Used trigger unbiased data to study this choice.

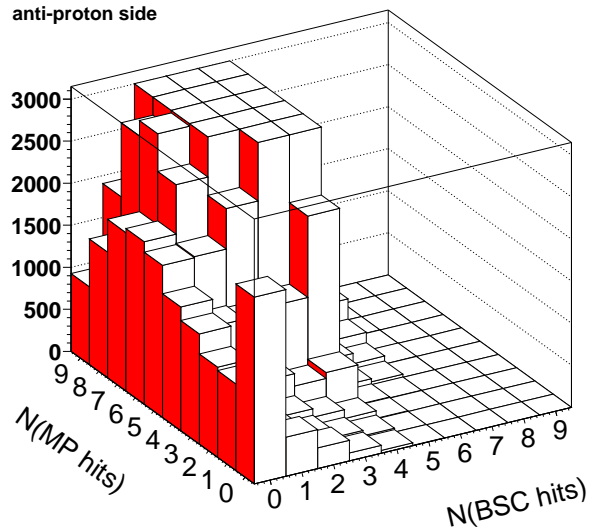
Events with no central interaction have little energy in the detector

Events with a central interaction typically have energy in the detector.

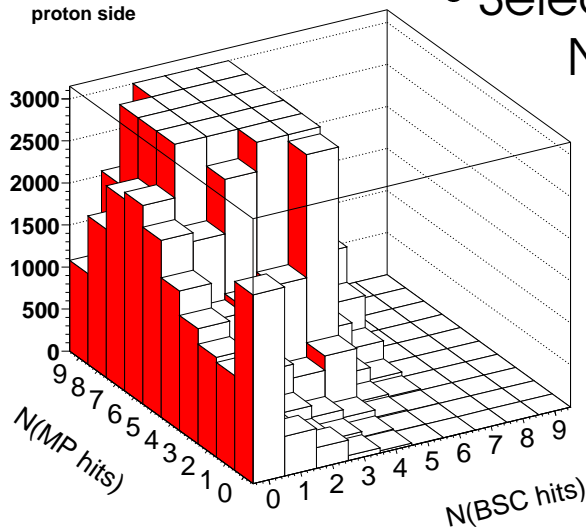


Selection of double pomeron exchange

CDF Run 2 Preliminary
anti-proton side

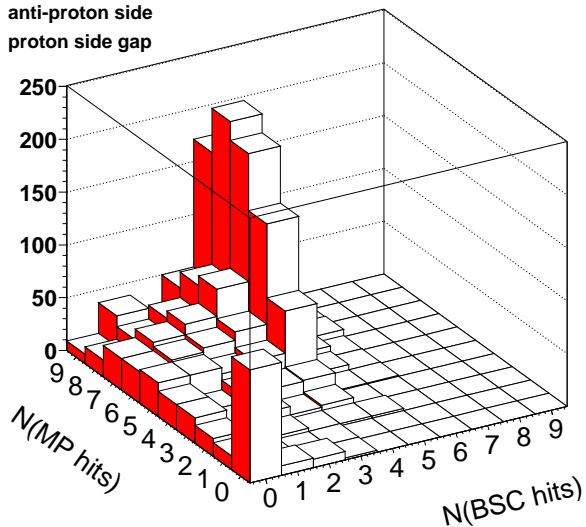


CDF Run 2 Preliminary
proton side

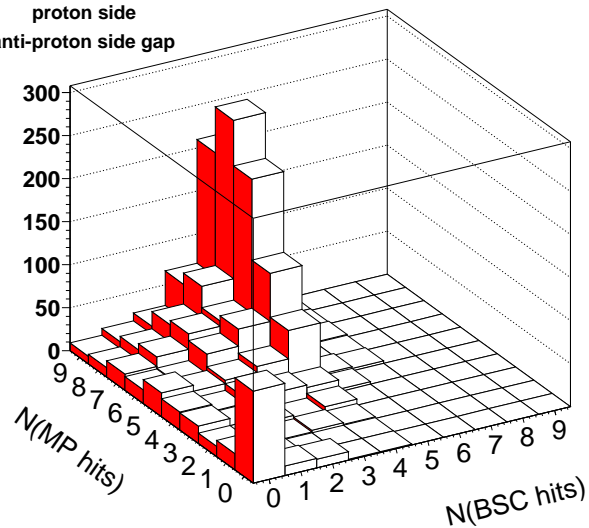


- Select single diffractive sample
 $N(\text{BSC hits}) = N(\text{MP hits}) = 0$

CDF Run 2 Preliminary
anti-proton side
proton side gap



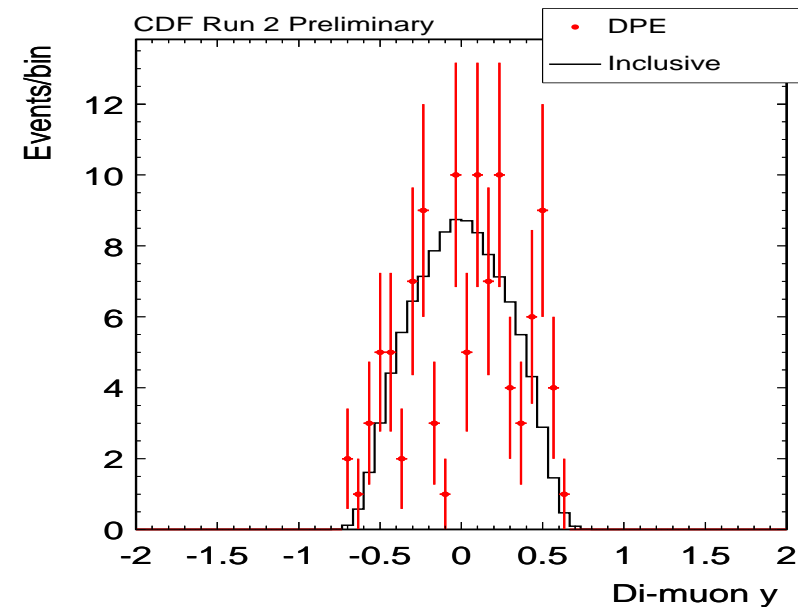
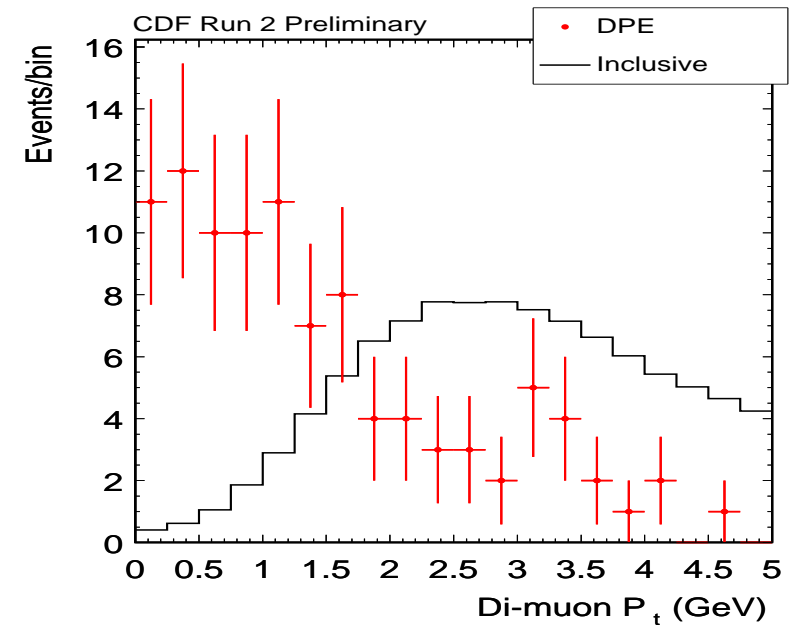
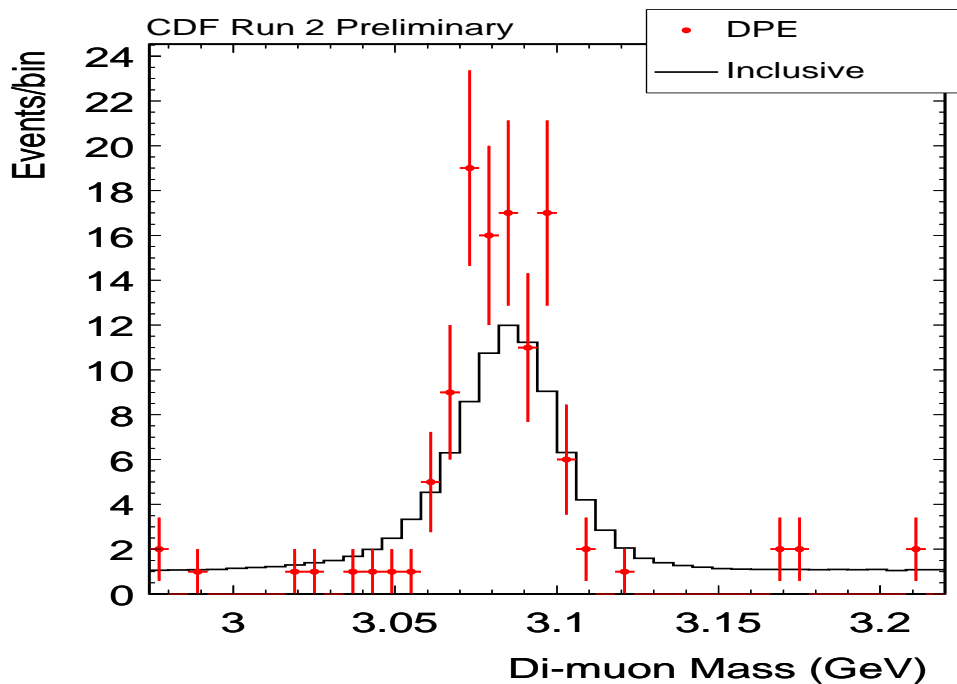
CDF Run 2 Preliminary
proton side
anti-proton side gap



- Select double pomeron exchange
 $N(\text{BSC } \bar{p}) = N(\text{MP } \bar{p}) =$
 $N(\text{BSC } p) = N(\text{MP } p) = 0$

Kinematics of the J/ψ in DPE

- Selected double pomeron exchange (DPE)
- DPE events have a lower $J/\psi P_t$
- Otherwise, very similar to inclusive sample.



Selection of exclusive events

- Start from the DPE sample.
- Ignore the tracks and calorimeter towers of the J/ψ .
- Define events as exclusive if they contain:
 - no muon stubs.
 - no towers $E_t > 0.1$ GeV
 - no tracks
- Allow 1 EM tower in the event.

Number of EM towers before cut:

From 107 DPE events:

13 events just J/ψ

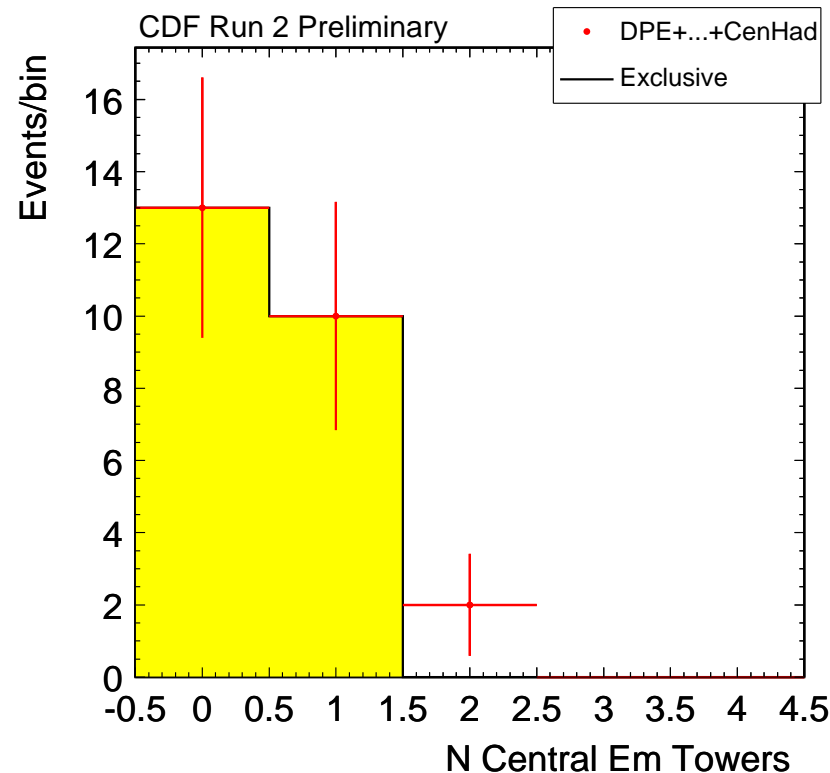
10 events just $J/\psi + \gamma$

and nothing else

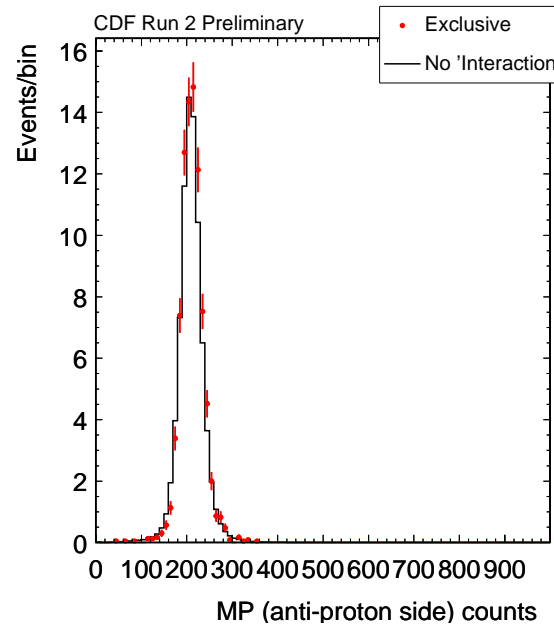
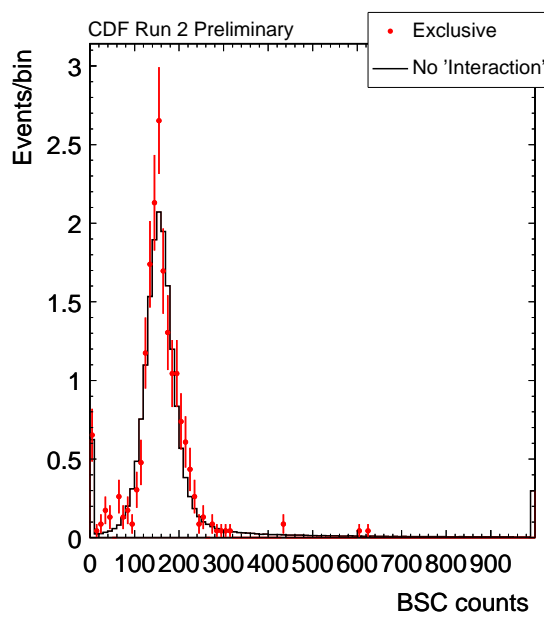
OBSERVABLE

These 23 events are **DEFINED**
as the exclusive sample.

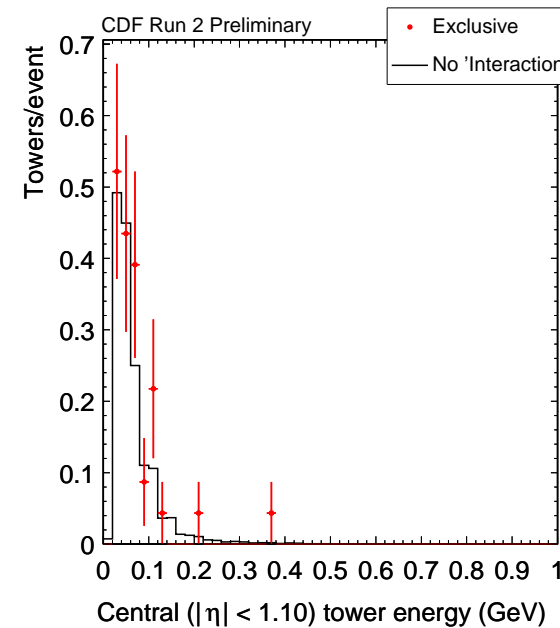
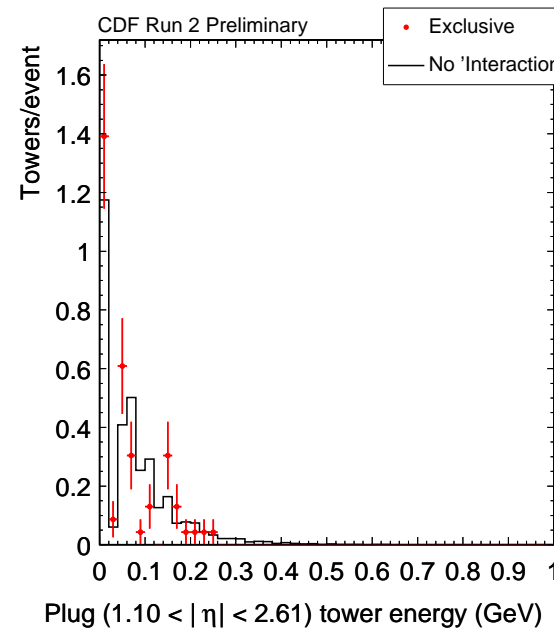
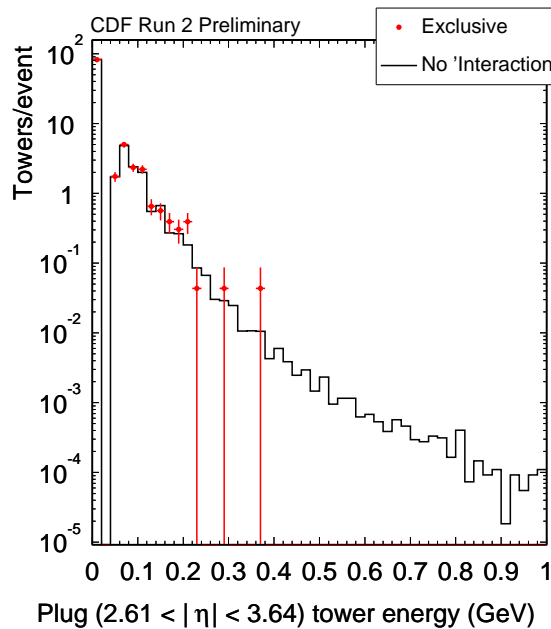
They may not all be truly exclusive.



Exclusive energy distributions

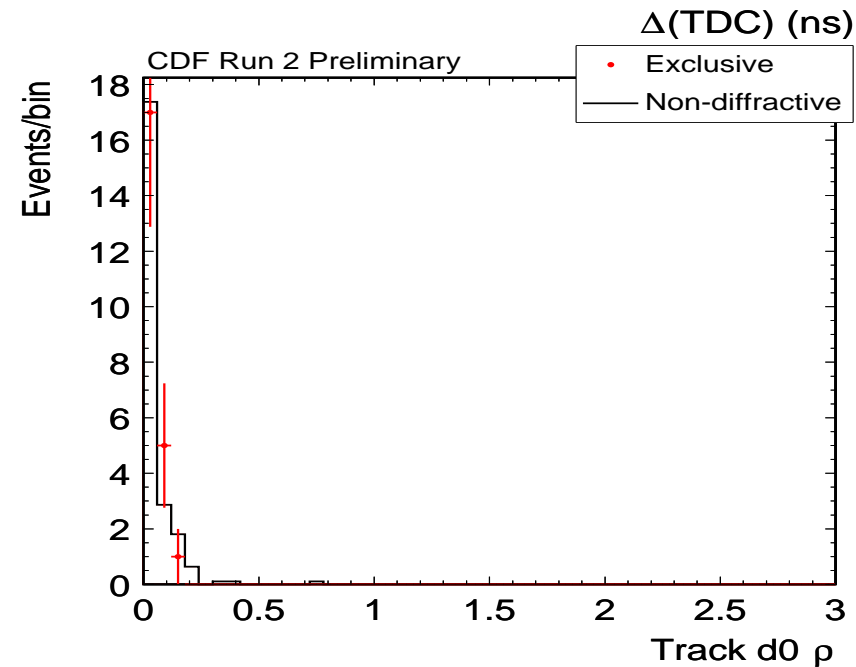
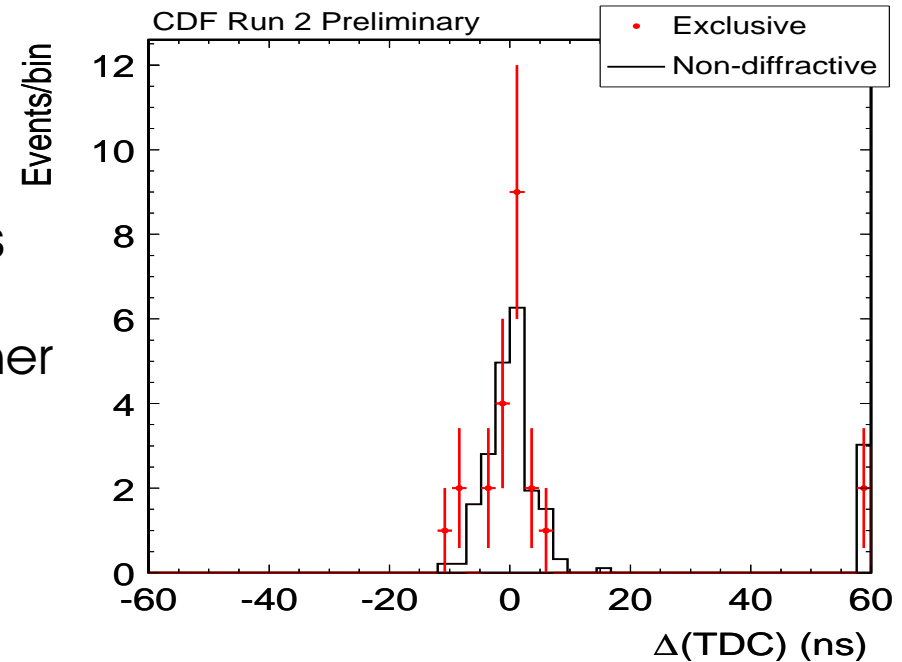
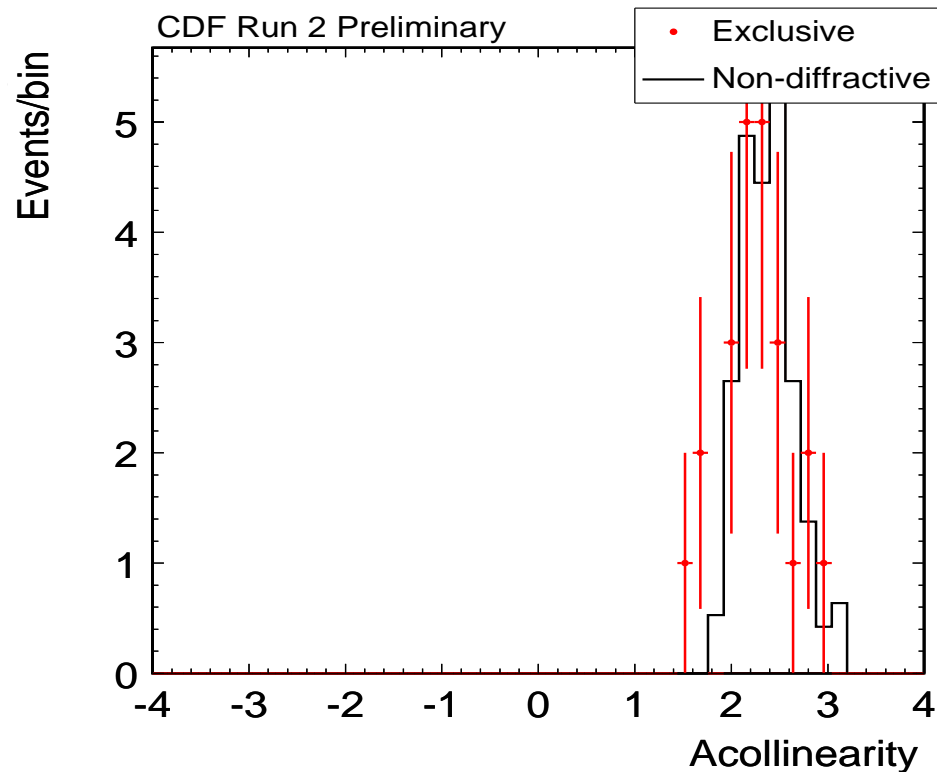


- Compare the 'signal' rejected by the noise cuts in exclusive events to non-interaction events in zero bias data
- good agreement.



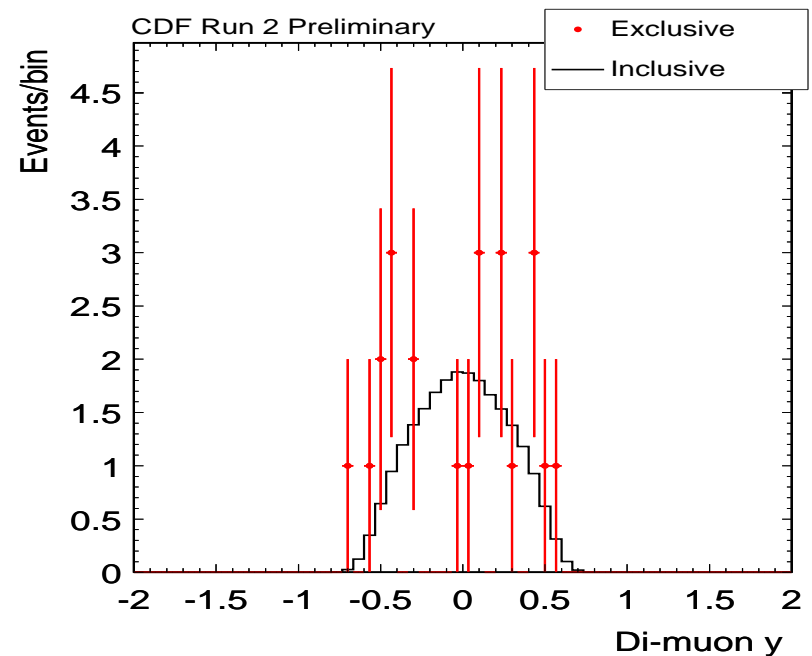
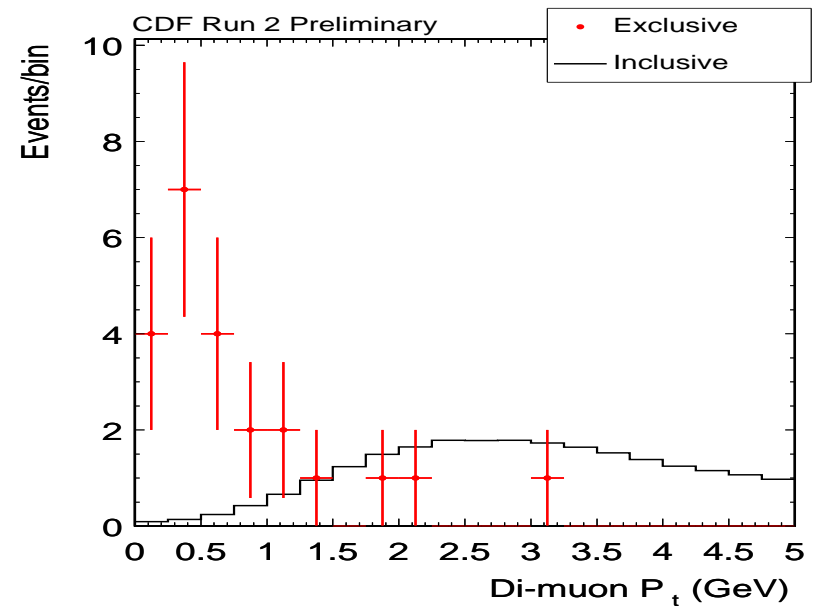
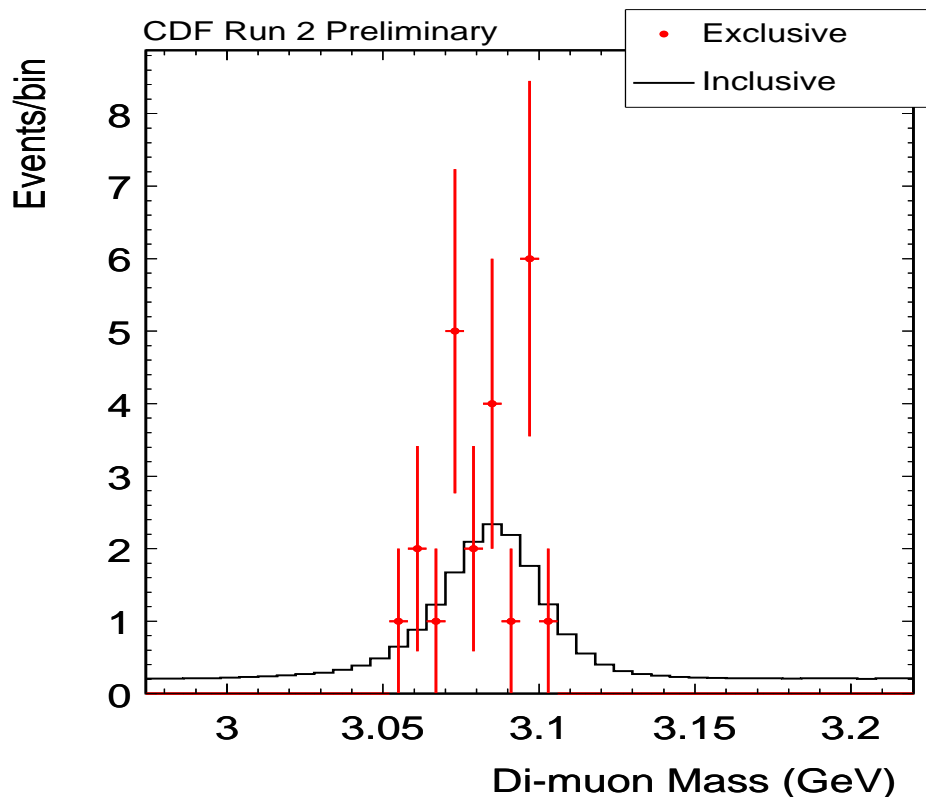
Cosmic background rejection

- Cosmic ray rejection was chosen to **reject 100% of cosmic rays**.
- Can be a significant background, so we **check many variables** that no event looks like a cosmic ray.
- Examples are: track opening angle, further timing information, track correlations.

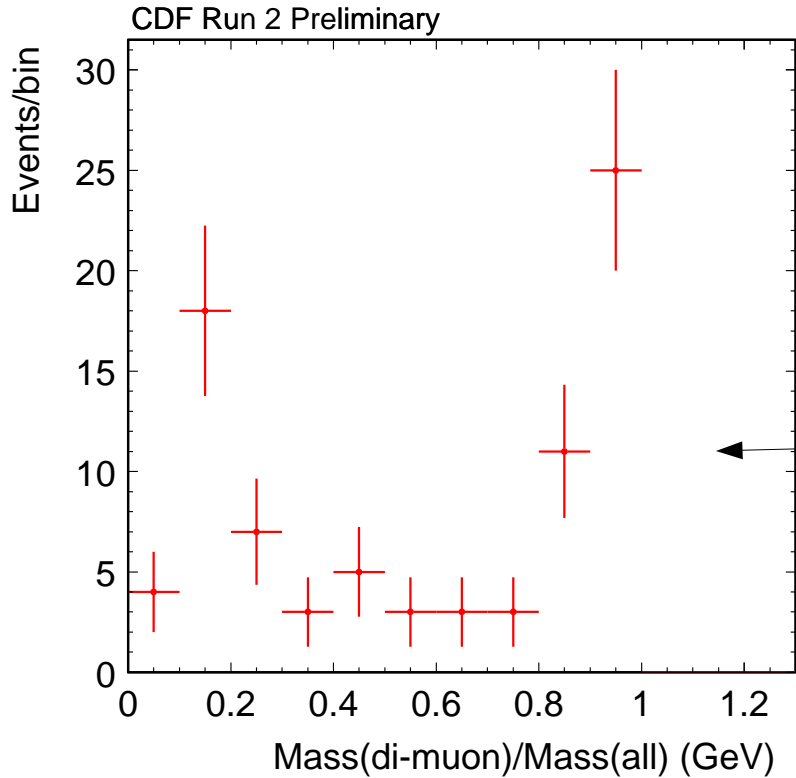


Kinematics of the J/ψ in exclusive events

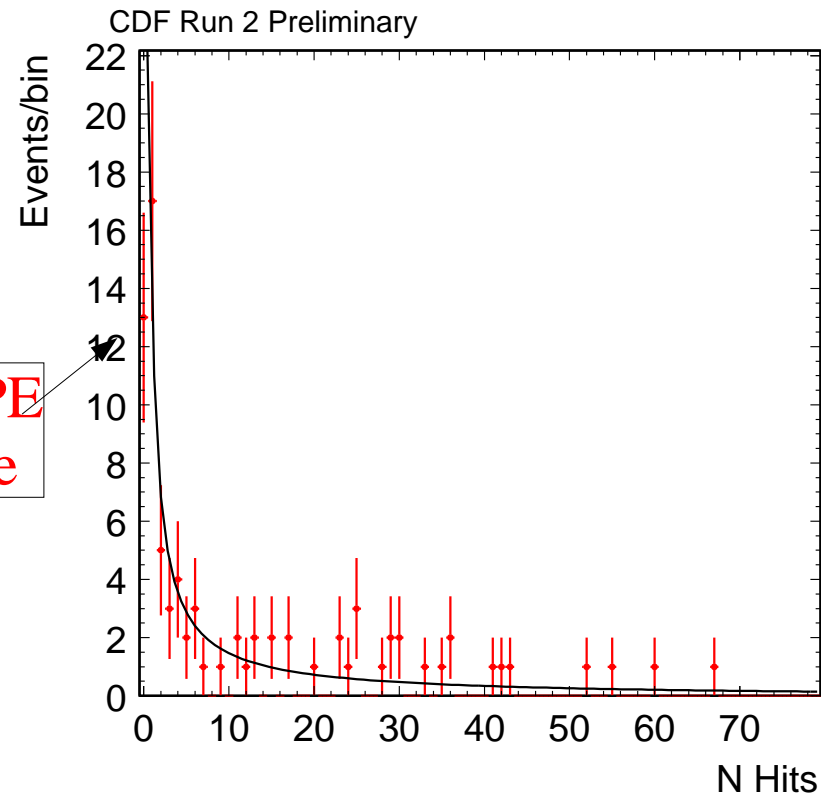
- **23 events**: J/ψ or $J/\psi + \gamma$
- The J/ψ has even **lower P_t** than in DPE, but not zero P_t - **recoils** against outgoing pp
- Again, the other variables look similar.
- Very little continuum background.



Are the events from exclusive production?



All DPE
Sample



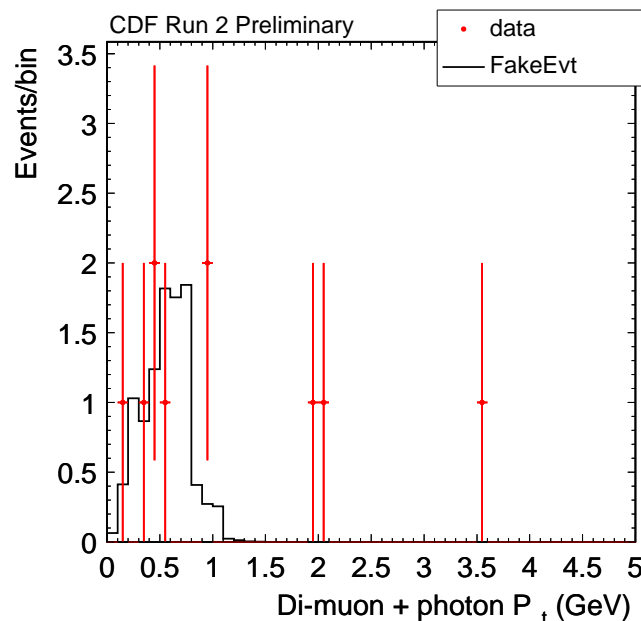
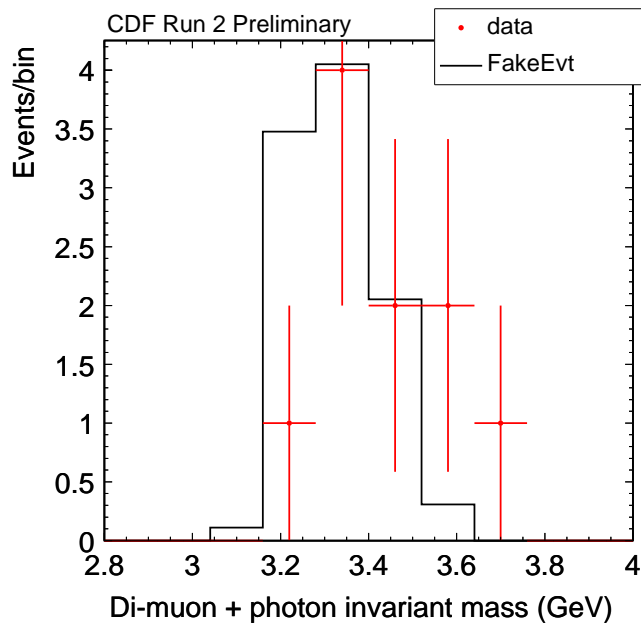
- Plot $M_{J/\psi}/M_x$

M_x = Mass of all tracks,towers

- You do see a peak, BUT, this mainly shows that the distribution has a low multiplicity.
- Plotting the multiplicity distribution may be less **mis-leading**.

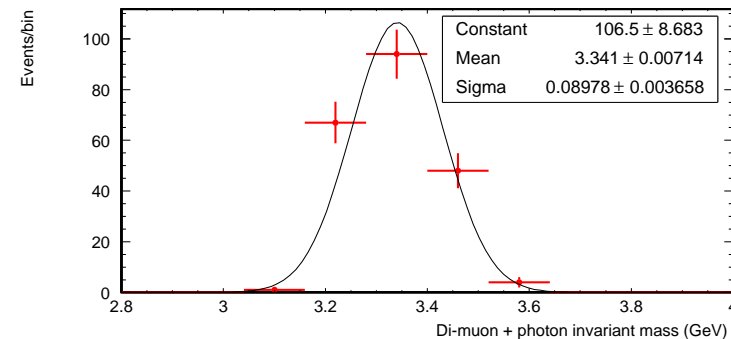
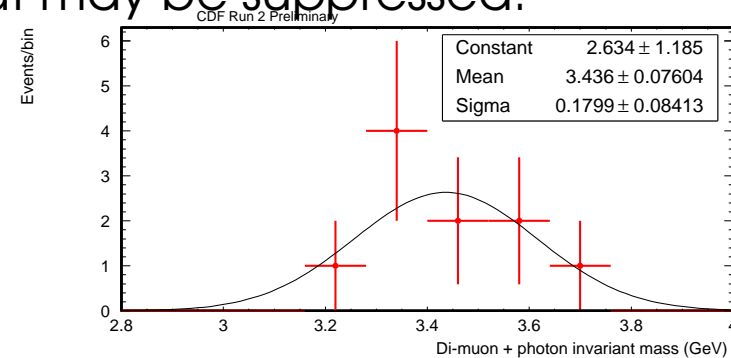
- **N Hits** is the total number of tracks+towers.
- **Not possible** to distinguish between
 - low multiplicity distribution
 - higher multiplicity distribution + additional exclusive events

Are the photons from χ_c decay?

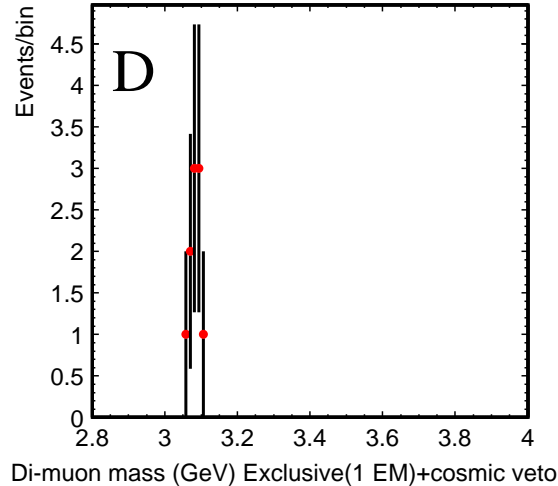
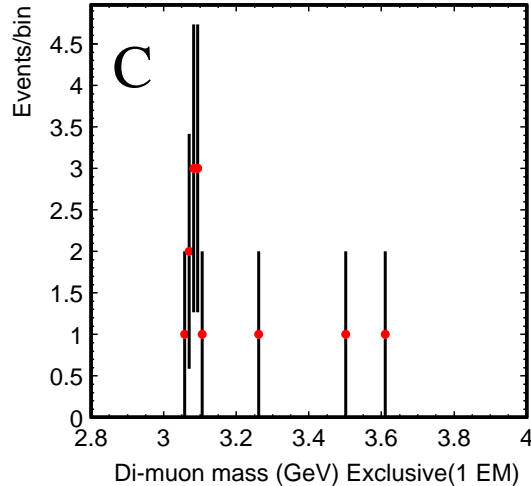
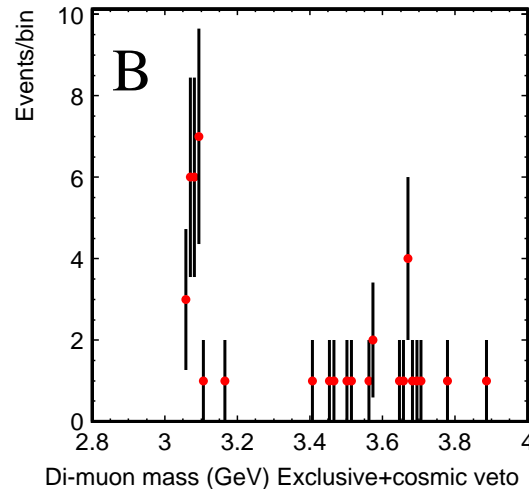
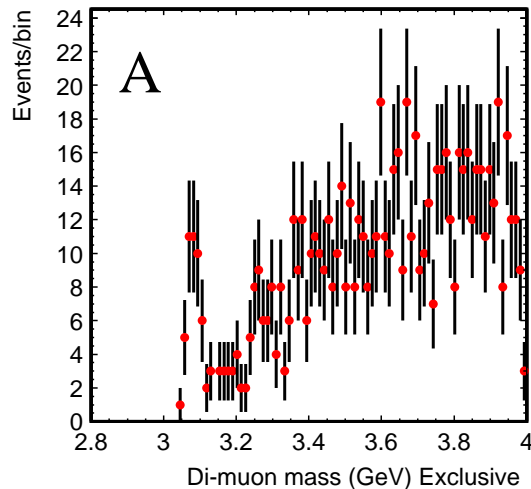


- This is very hard to tell.
- The photon E_t is so low in χ_c production that its distribution is **very similar** to the background.
- The data distribution is similar to that expected from χ_{c0} after detector simulation.
- With 10 events cannot tell the difference between a falling distribution and a mass peak.
- The mass resolution is worse in data. **Other χ_c** are possible, but may be suppressed.

10 events
 $J/\psi + \gamma$



Invariant mass of all 'exclusive' events



The cosmic background rate is **large**.

There are exclusive dimuon events that are not J/ψ .

- Compare A and C
 - photons occur more often in J/ψ events than cosmic events
 - not noise?

- Compare B and D
 - photons occur more often in J/ψ mass peak than continuum
 - some are really χ_c ??

A: No cosmic veto. B: Cosmic veto added
 C: Require 1 EM tower D: Cosmic veto+1 EM tower

Upper Limit on the Cross section

- If **ASSUME** 10 events are all exclusive $J/\psi + \gamma$ (no fake photons, DPE ...)

from

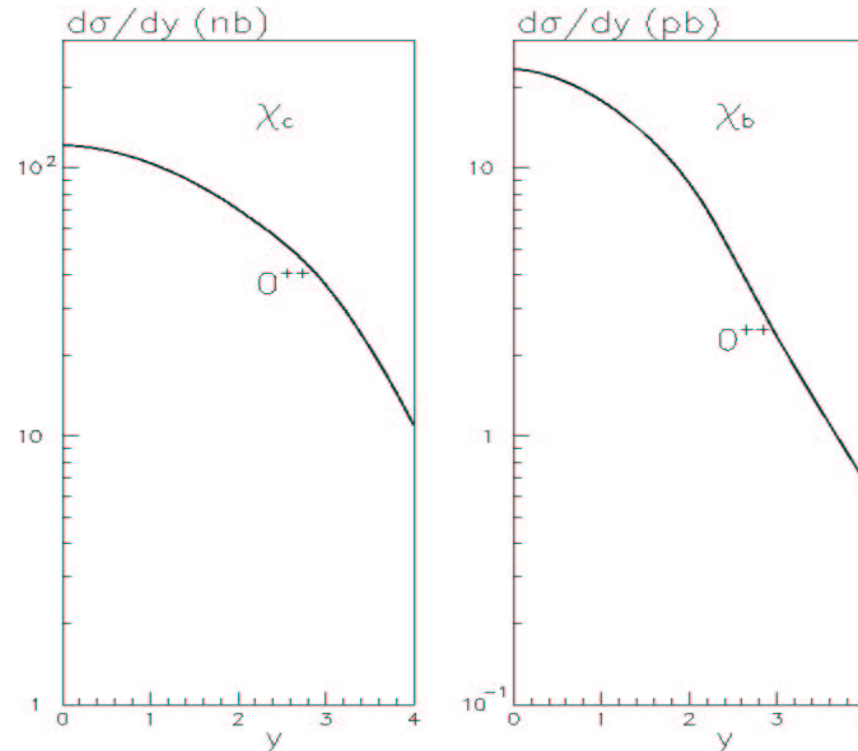
$$\sigma = \frac{N_{evt}}{(L \epsilon_S \epsilon_H A_{j/\psi} \epsilon_{j/\psi} A_\gamma \epsilon_{cosmic})}$$

$$\Rightarrow \sigma = (\text{BR}(J/\psi \Rightarrow \mu\mu) \times (49 \pm 18 \text{ (stat)} \pm 39 \text{ (syst)) pb})$$

$$= 0.8 \text{ nb} \pm 0.3 \text{ (stat)} \pm 0.7 \text{ (syst)} \text{ pb}$$

for exclusive $J/\psi + \gamma$ production, with $|y| < 0.6$.

- Estimate from Khoze, Martin, Ryskin Eur Phys J. C19, 477(2001)
 - $\sigma \approx 600 \text{ nb}$
 - (uncertainty factor 2-5)
 - $\sigma J/\psi + \gamma \approx 6 \text{ nb}$
 - $|y| < 0.6 \approx 1.2 \text{ nb}$
 - (all events are χ_c^0)

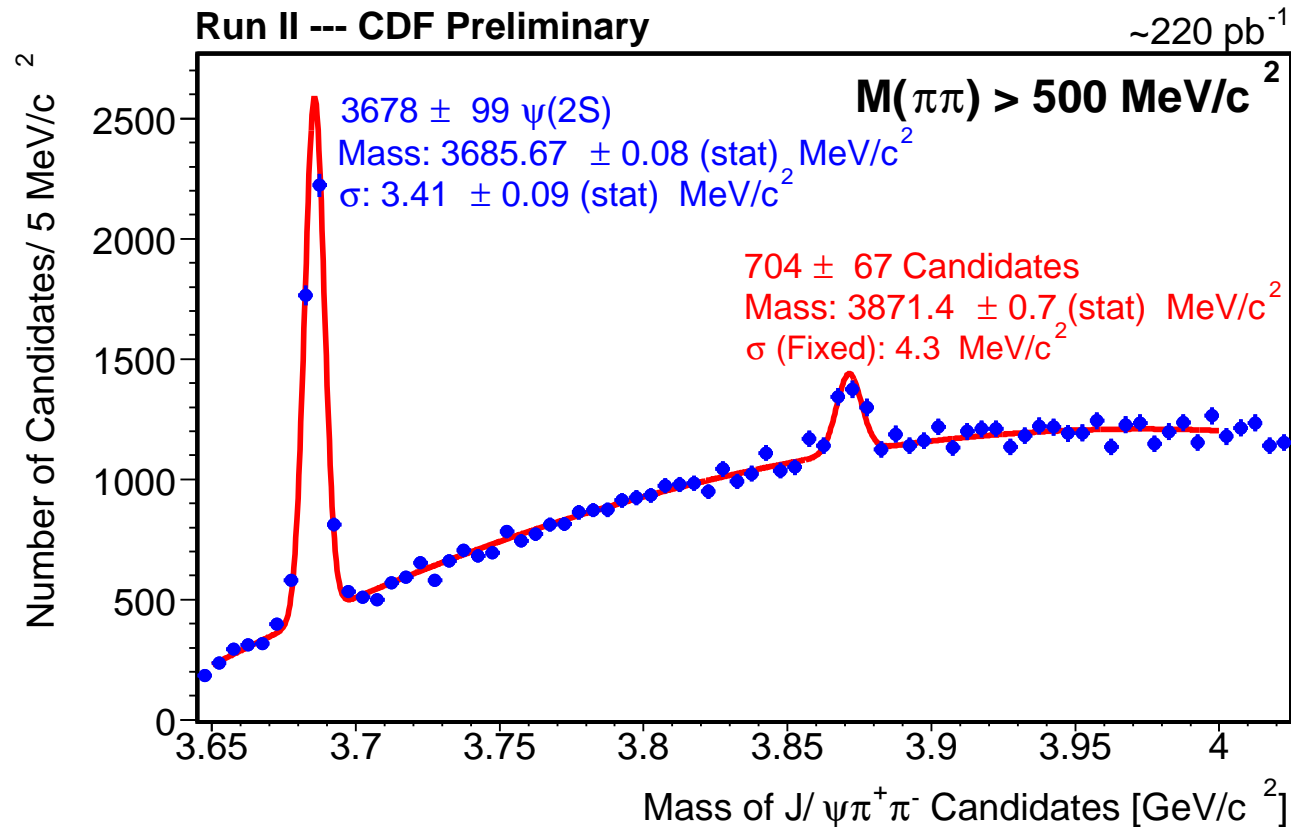


χ_c^0 summary

- We observe DPE events in which there is a J/ψ or a $J/\psi + \gamma$ and nothing else **OBSERVABLE** in the detector (defined as **exclusive events**).
- All of these events may be explained by **standard DPE** models, **IF** the multiplicity in DPE is low.
- Currently, the statistics/detector understanding don't allow us to make a serious estimate of the DPE contribution to the exclusive events (it could be 0-100%) or of the background contribution to the photons.
- There are 10 events which are compatible with exclusive χ_c production and we use these to give an **upper limit** and hope to improve this later when we have a better handle on the multiplicity and backgrounds.
- While the results are currently ambiguous, with more data and better understanding of the detector and Monte Carlo models we will be able to learn more.

Exclusive Production as a Spin-Parity selector

- CDF has also observed the $X(3872)$ state recently discovered at Belle.
- To work out what this is we need to know the C-parity.
- Observing the state in exclusive production would show $C +$.
- CDF would trigger on this process and could observe it
IF there was a large enough rate (would probably take a long time though)

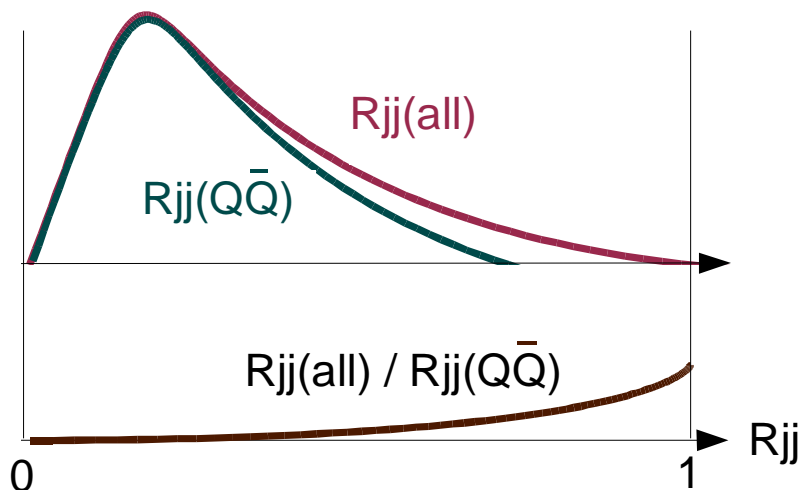


Future Exclusive Searches at CDF

Exclusive $\gamma\gamma$ Production

- Lower statistics but fewer uncertainties.
- CDF are currently developing a **diffractive di-photon trigger** with low E_{\dagger} threshold (analysis should be something like: $E_{\dagger} > 5 \text{ GeV}$, $\eta < 2$)
- Should be able to go down to low $M(\gamma\gamma)$ and maybe measure $R(\gamma\gamma/jj)$ to test cross sections

DPE Dijets: bb



Pros: many systematic effects cancel out

Cons: limited statistics

Khoze, Martin, Ryskin

Eur. Phys. J. C23, 311 (2001)

$$\sigma^{\text{excl}}(gg^{PP} \rightarrow qq)$$

$$\propto (m_q^2/M_{JJ}^2)(1 - 4m_q^2/M_{JJ}^2) \rightarrow 0$$

at $M_{JJ} \gg m_q$

*no such term for $\sigma^{\text{excl}}(gg^{PP} \rightarrow gg)$

- DPE b/c -jet production is interesting in itself
- Extract exclusive dijet:
 - normalize R_{jj} for all jets to R_{jj} for bb jets
 - look for excess as $R_{jj} \rightarrow 1$

Summary

- CDF detector working extremely well: BSC, mini-plug fully working, calibrated.
- Run II diffractive measurements consistent with Run I (detectors understood)
- **New Results:**
 - Single Diffractive dijets studies.
 - Huge increase (x200) in double pomeron exchange dijets sample
 - Dijets seen in exclusive region, but smooth distribution.
 - Observation of exclusive $J/\psi + \gamma$ candidates.
- Working on improved/new measurements, e.g.:
 - Higher statistics di-jets, $J/\psi + \gamma$
 - Di-photon and bb
- Should be able to:
 - make a range of measurements to test exclusive predictions
 - reduce experimental uncertainties
- Need input to understand whether we really see exclusive events or if they can be explained by DPE - are these low multiplicity?