Diffractive and Exclusive Production at the Tevatron

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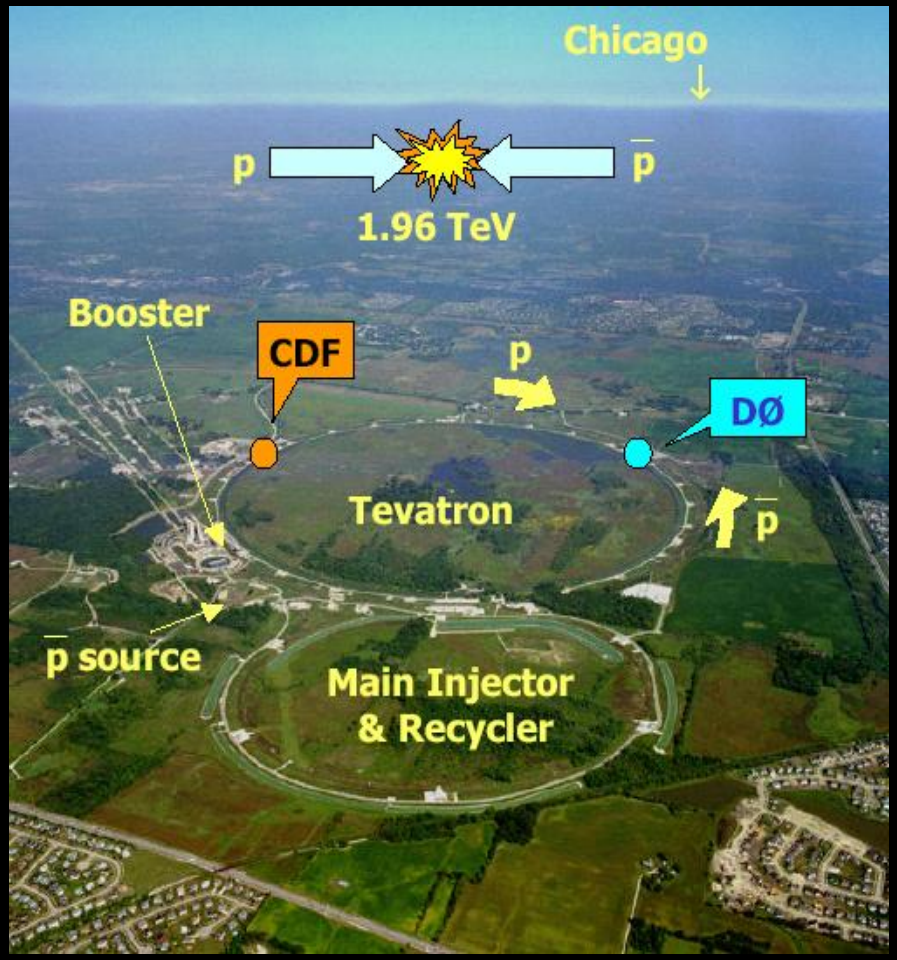
Outline

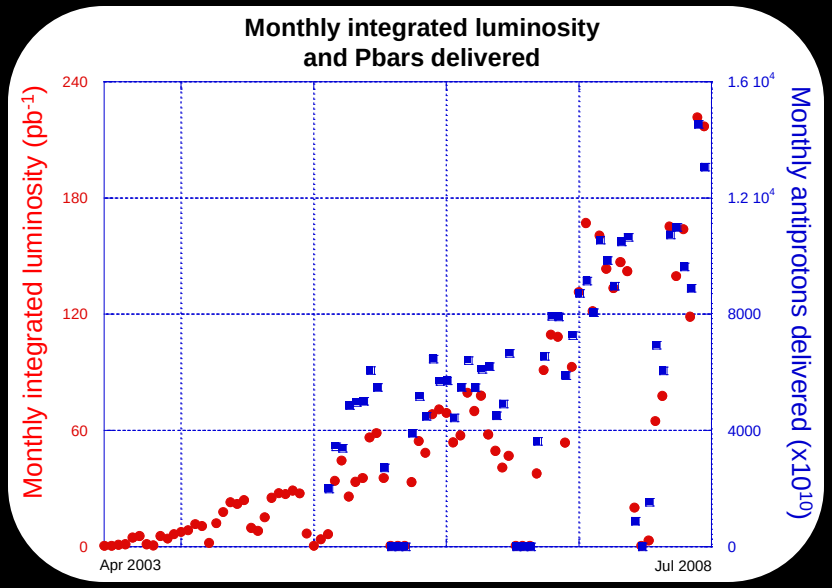
- Introduction
- Exclusive Production
  - Exclusive dijets
  - Exclusive ee, $\mu\mu$, $\gamma\gamma$
- Diffractive Production
  - Diffractive dijets
  - Diffractive W/Z
- Conclusions

The Fermilab Tevatron Collider Run II

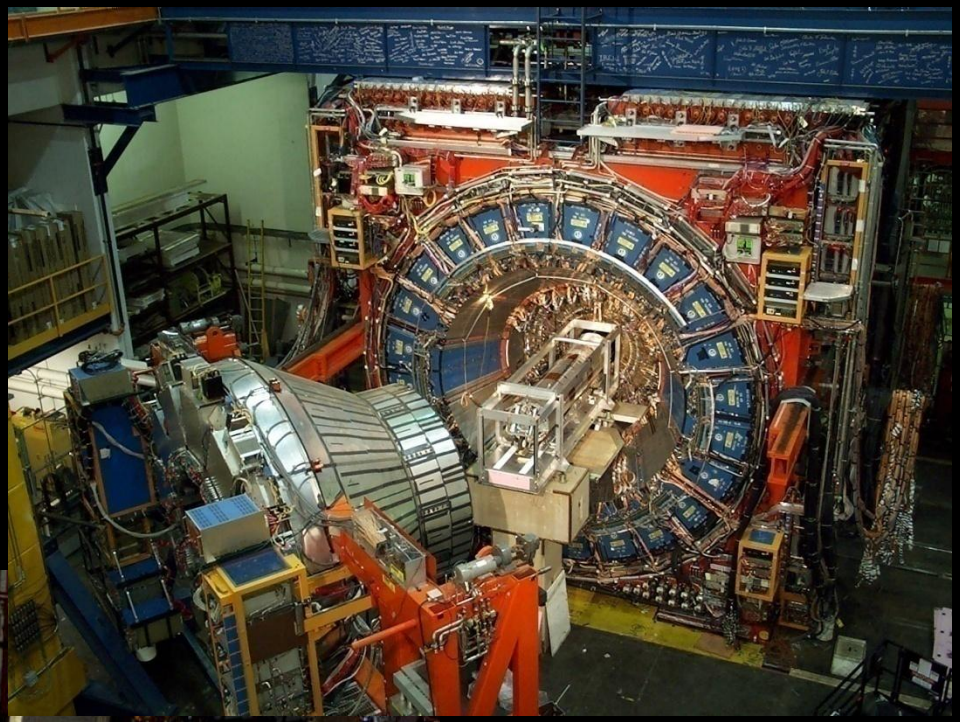
- Proton-antiproton collisions at √s=1.96 TeV

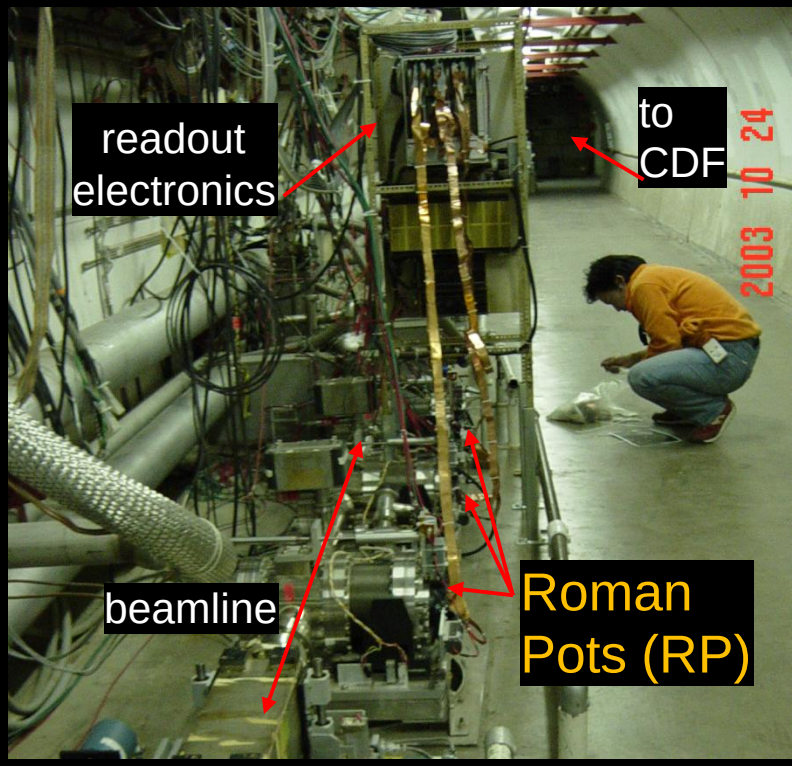


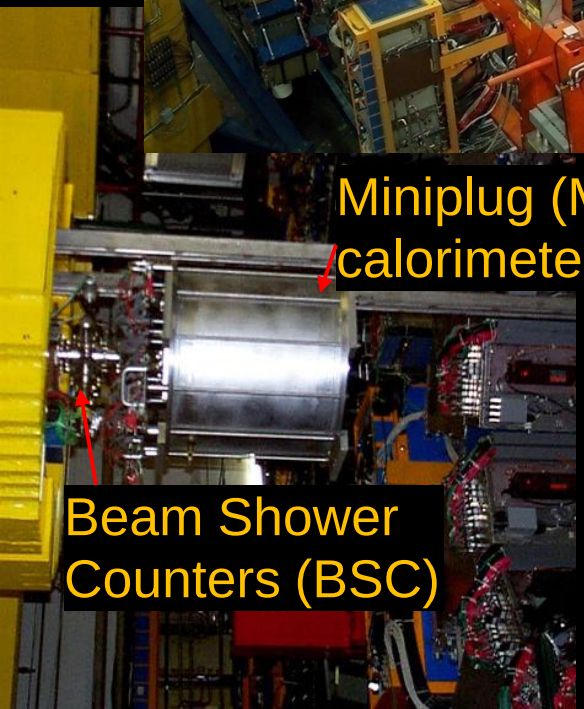
- Accelerator continuing to make significant improvements
  - Antiproton peak and average stacking rate continuing to climb
  - Initial luminosities and integrated luminosity/week improving even beyond gains from antiprotons

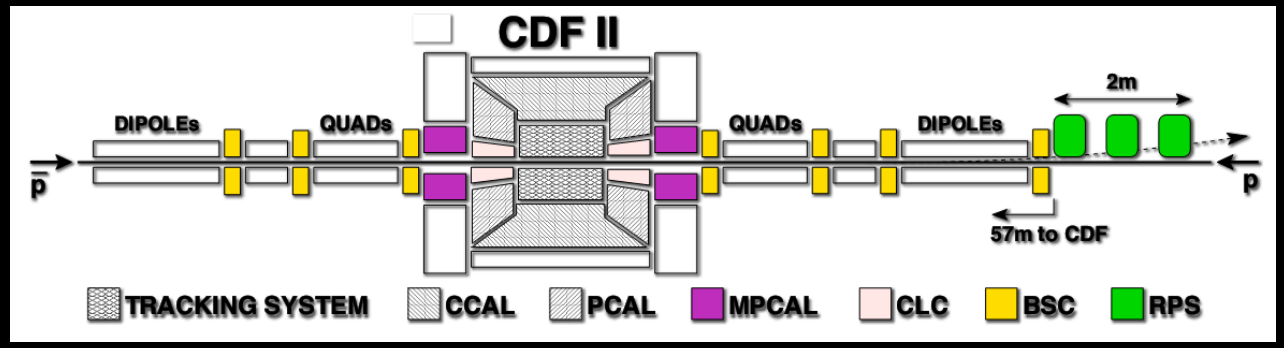


The CDF II Central and Forward Detectors



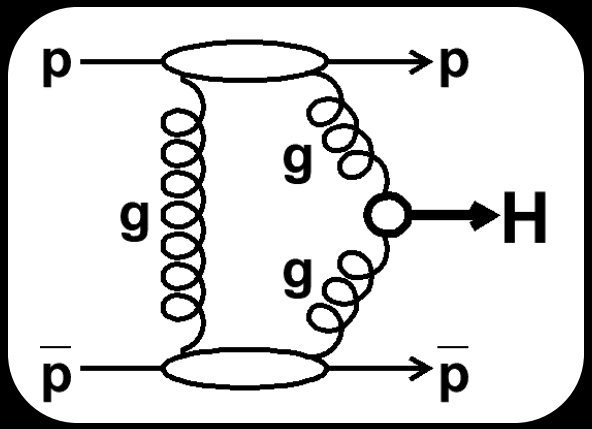






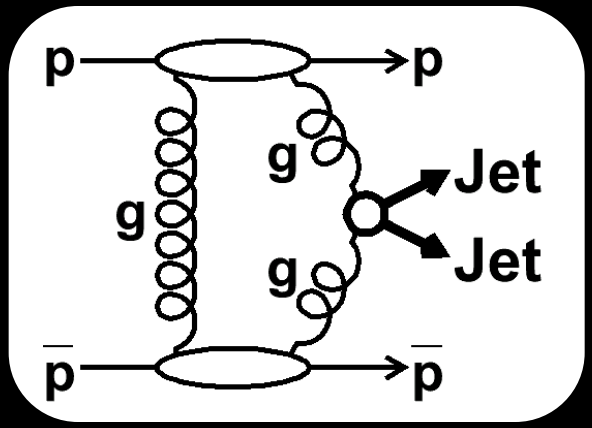
Exclusive Production

- Test and calibrate predictions for exclusive Higgs production at the LHC
  - Event consists of nothing but leading protons and Higgs



- CDF triggers use BSCs to veto on particles in the forward region (rapidity gap) on both proton and antiproton sides or hits in Roman pots (pbar) + gap (p) plus object being produced exclusively (jets, $\gamma\gamma$, ee…)

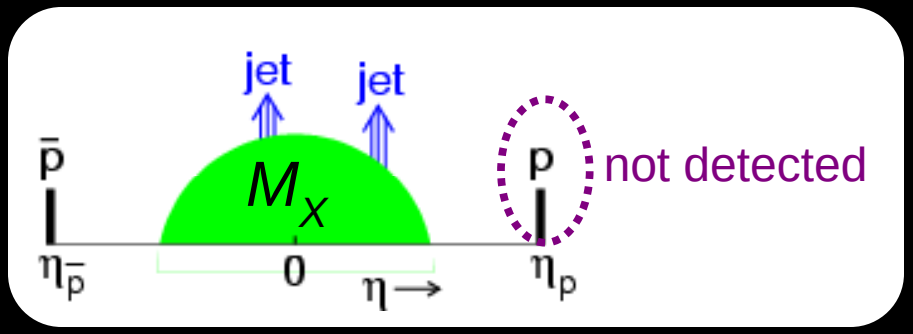
Exclusive Dijet Production



- Wide range of theoretical predictions
- Run I CDF limit of σ_{excl}<3.7 nb (95% CL)

- Run II search:
- Select inclusive Double Pomeron Exchange dijet events:

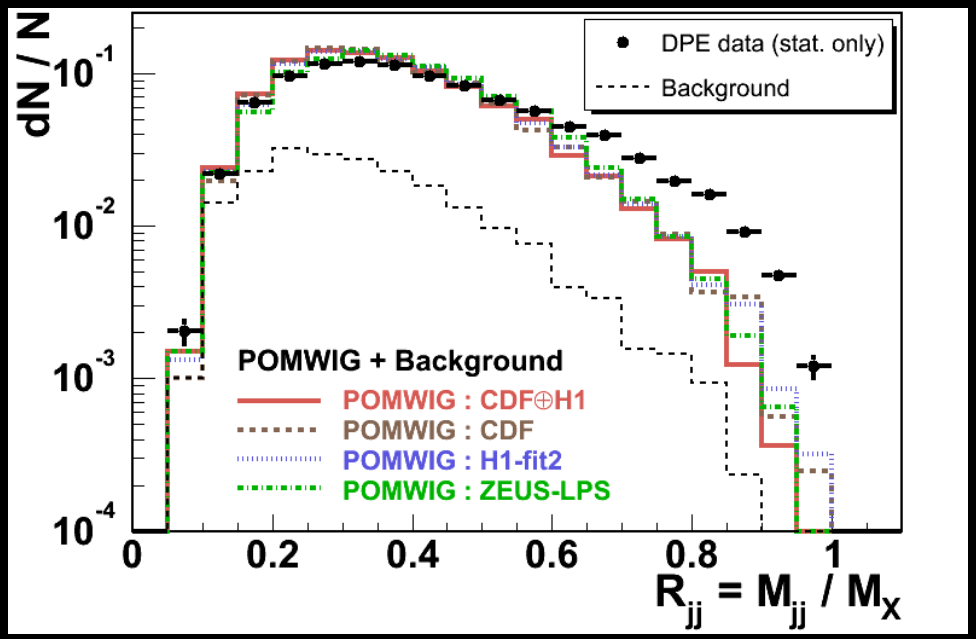
$$p + p \rightarrow IP\ IP \rightarrow p + X\ (\geq 2\ \text{jets}) + \text{gap}$$

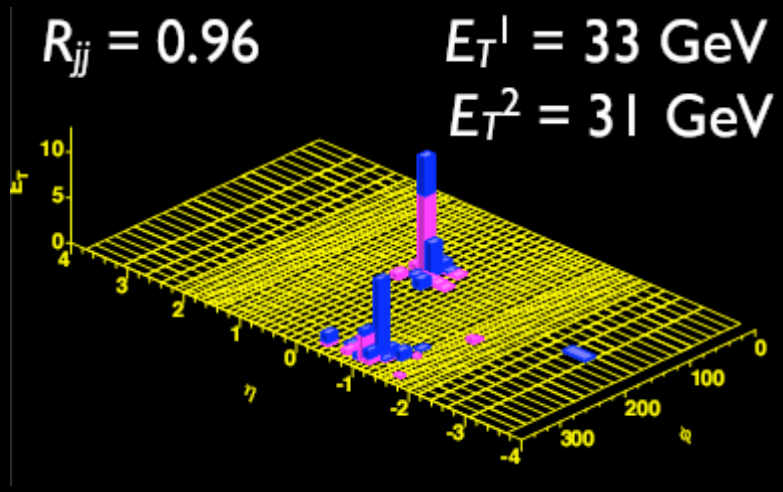


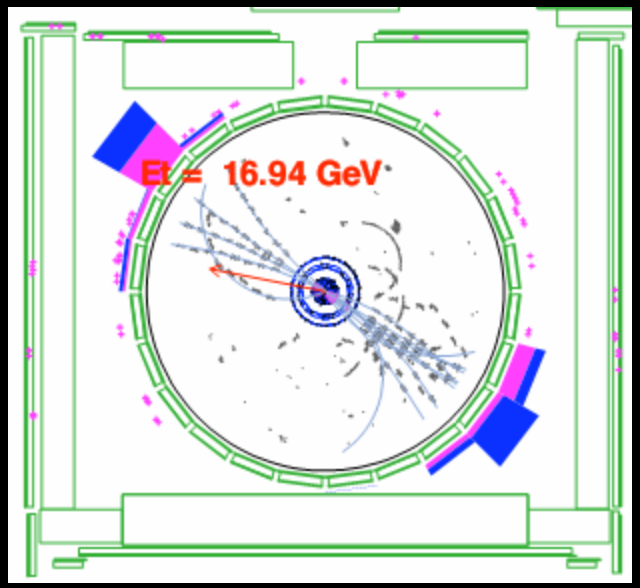
- Look for exclusive signal using dijet mass fraction
  - R_{jj} = ratio of dijet mass M_{jj} to system mass M_X

Observation of Exclusive Dijet Production

PRD 77, 052004 (2008)

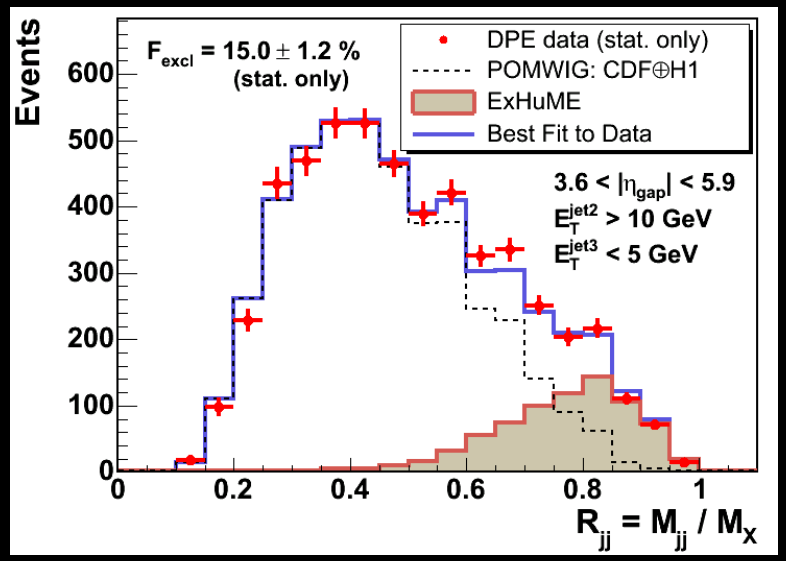


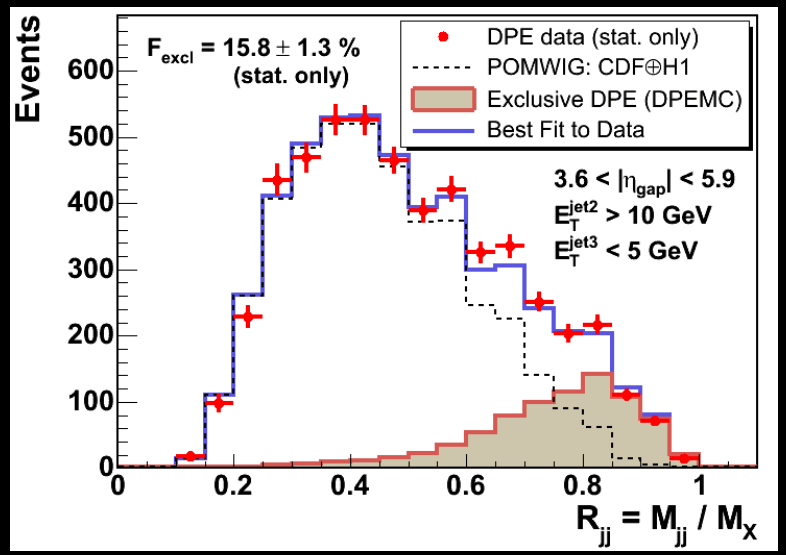




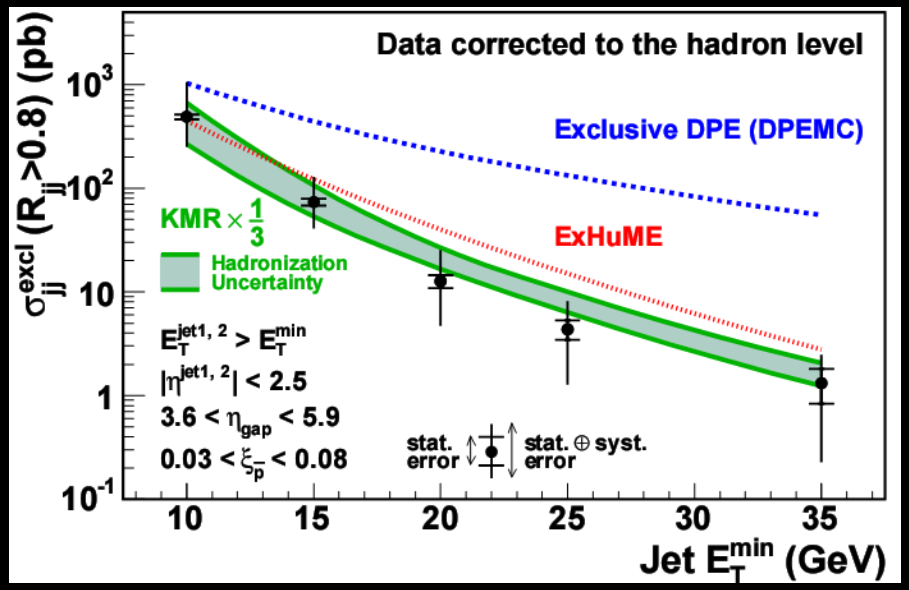
- Observe excess over inclusive DPE dijet MC's at high dijet mass fraction

Exclusive Dijet Cross Section

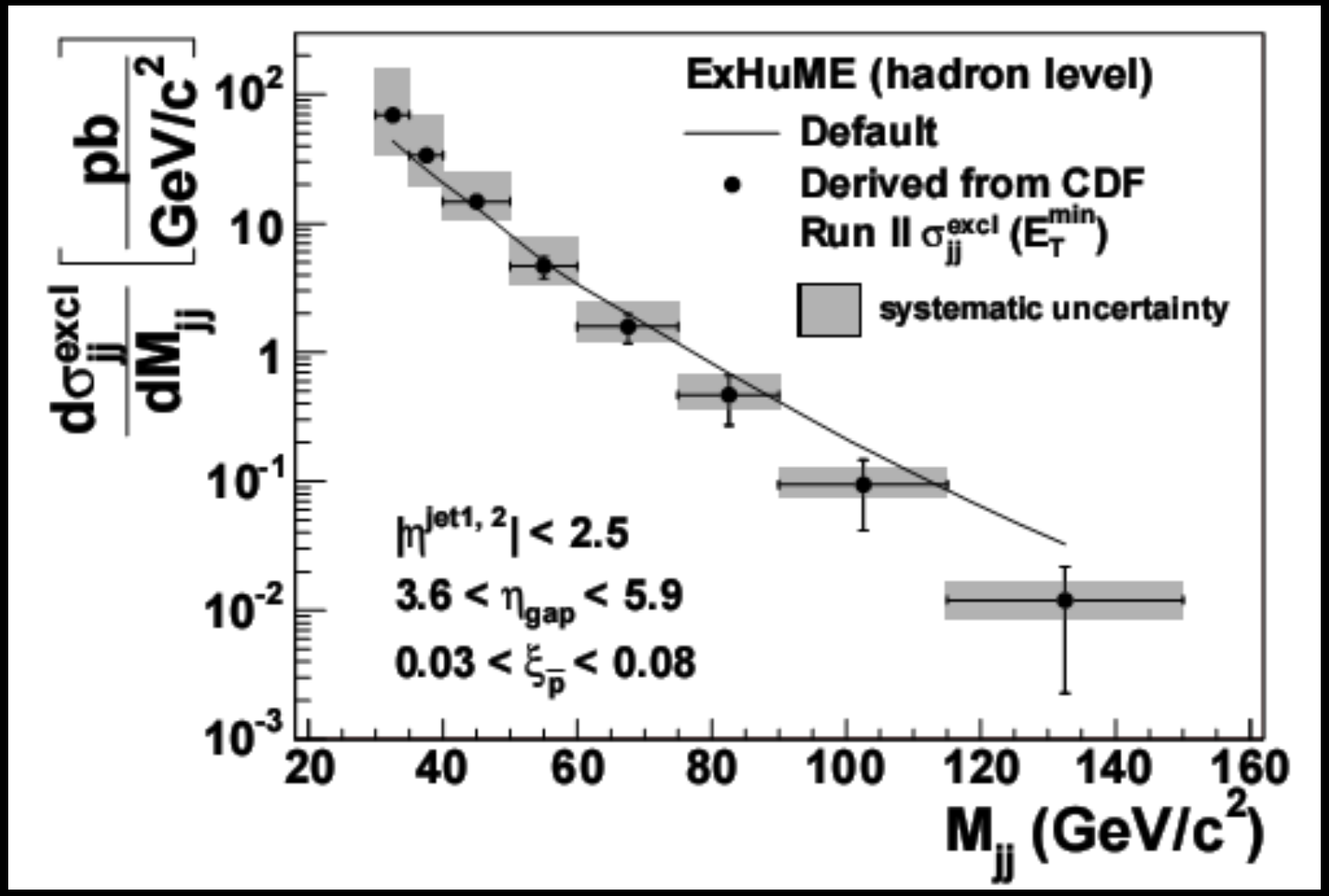




- Shape of excess described by exclusive dijet MC based on two models (ExHuME, DPEMC), but cross section disfavors DPEMC
- Calculation by Khoze, Martin, and Ryskin consistent within its factor of 3 uncertainty EurPhysJ C**14**, 525 (2000)

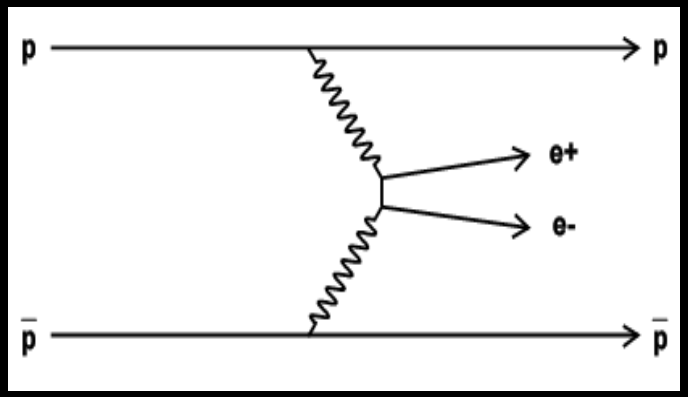


Exclusive Dijet Mass Reach

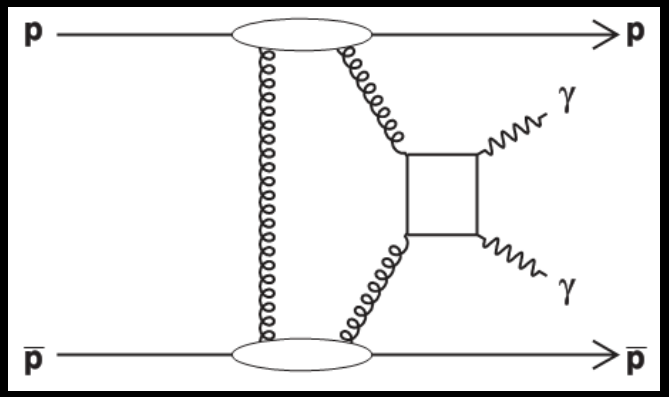


Exclusive e^+e^- and $\gamma\gamma$ Production

PRL 98,112001 (2007)



PRL 99, 242002 (2007)



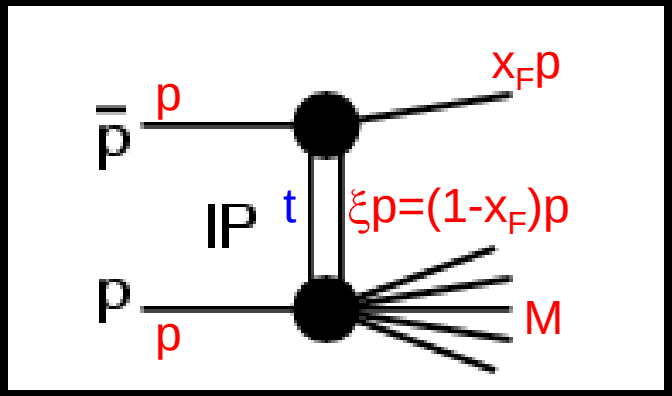
- 16 exclusive e^+e^- events observed (5.5σ) consistent w/ QED
  - First observation of an exclusive 2-photon process ($\gamma\gamma \rightarrow ee$) in hadron-hadron collisions
- Studies of exclusive $\mu\mu$ production also in progress
  - QED, also photo-production of vector mesons
- 3 candidate $\gamma\gamma$ events observed: 2 likely $\gamma\gamma$, 1 likely $\pi^0\pi^0$
  - $P(\geq 3) = 1.7\times10^{-4} \rightarrow$ upper limit on exclusive $\gamma\gamma$ of 410 fb (95% CL)
  - Prediction by Khoze, Martin, and Ryskin compatible EurPhysJ C**38**, 475 '05
  - Measurements used 0.5 fb^{-1} – planning to update with more data

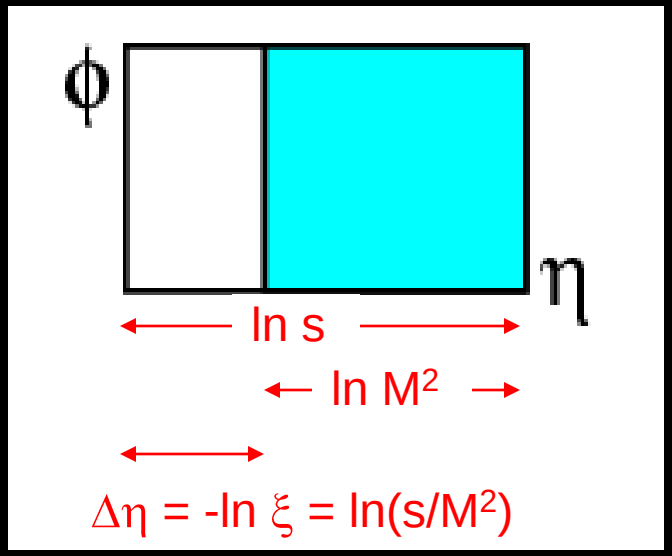
Single Diffraction

- Examine partonic structure of diffractive exchange using high-p_T probes (hard diffraction)

- Confirm and extend the kinematical reach of the Run I results allowed by larger dataset
  - Diffractive dijet production in ranges of Q^2
  - Diffractive structure function from diffractive W/Z production

Kinematics of a Diffractive Interaction





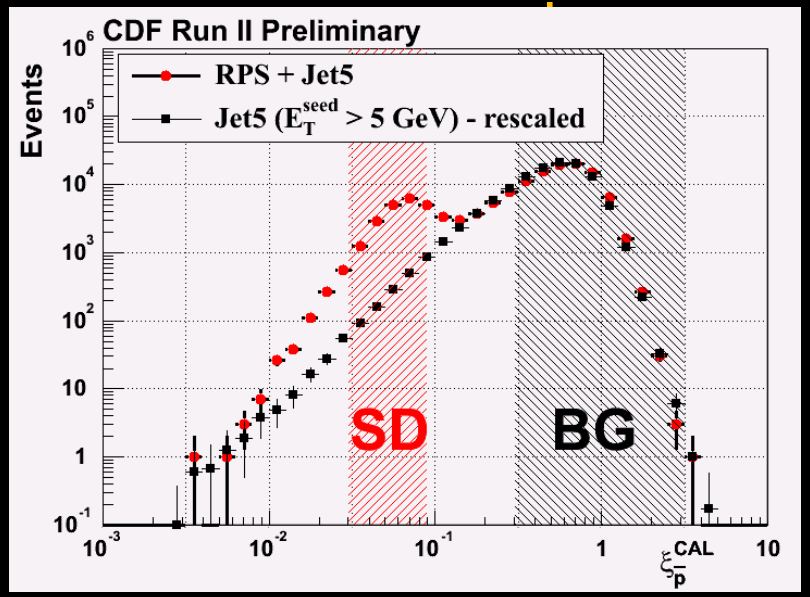
- ξ = fractional momentum loss of (anti)proton
- t = four-momentum transfer squared
- CDF Roman pot acceptance: ~ $0.03<\xi<0.10$, $0<|t|<1$
- The diffractive exchange is colorless (vacuum quantum numbers), creating a gap in rapidity space of width $\Delta\eta$ void of particles, referred to as a "rapidity gap"

Calorimeter and Multiple Interactions

- Determine ξ using RP tracking
- Can also determine ξ from E_T in calorimeters

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

  – Important that we have miniplugs $3.5<|\eta|<5$

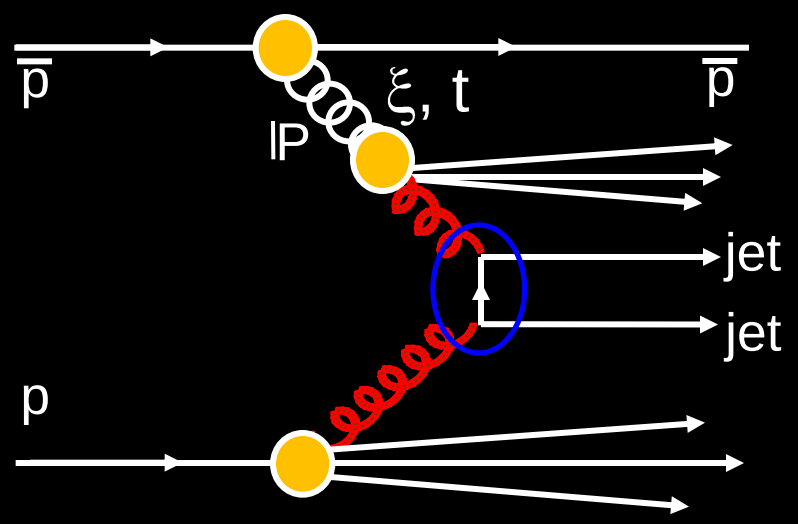


- Use to reject overlap events (require $\xi^{cal}<0.1$) and estimate remaining overlap bkgrd
  – e.g. non-diffractive dijet + soft diffractive interaction

Diffractive Dijet Production

PRD draft in preparation

- Use high p_T jets as a probe to determine the partonic structure of the diffractive exchange



- Diffractive dijet cross section:

$$\sigma(\bar{p}p \to \bar{p}X) \approx F_{jj} \otimes F_{jj}^{D} \otimes \hat{\sigma}(\to jj)$$

$$F_{jj}^{D} = F_{jj}^{D}(\xi, t, x_{Bj}, Q^2)$$

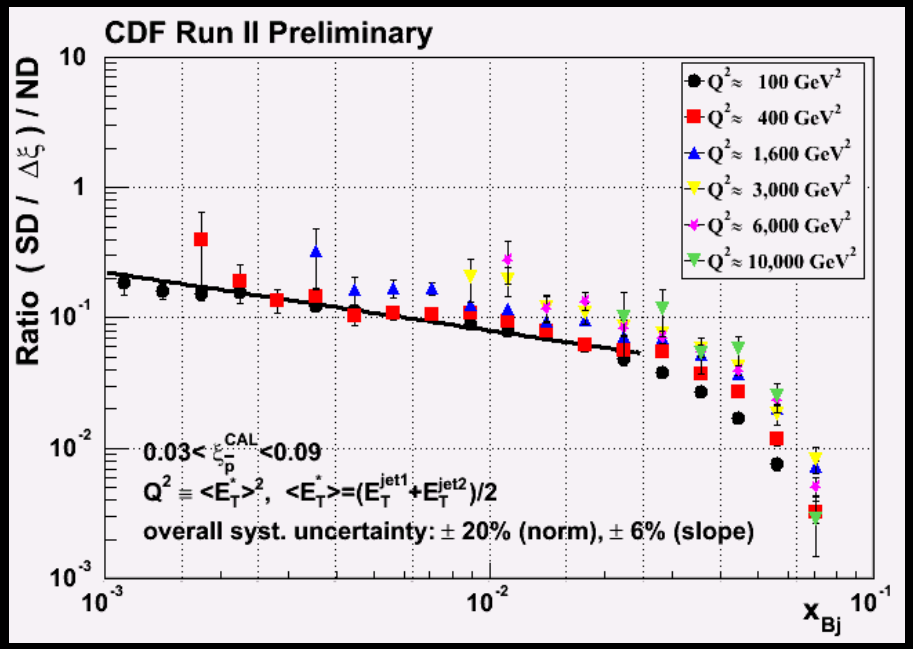
  - Experimentally determine the diffractive structure function F_{jj}^{D} :

$$R(x_{Bj}) = \frac{\sigma_{jj}(SD)}{\sigma_{jj}(ND)} \approx \frac{F_{jj}^{D}(x_{Bj}, Q^2)}{F_{jj}(x_{Bj}, Q^2)}$$

measure ratio

known proton structure function

Ratio of Diffractive to Non-Diffractive Structure Function



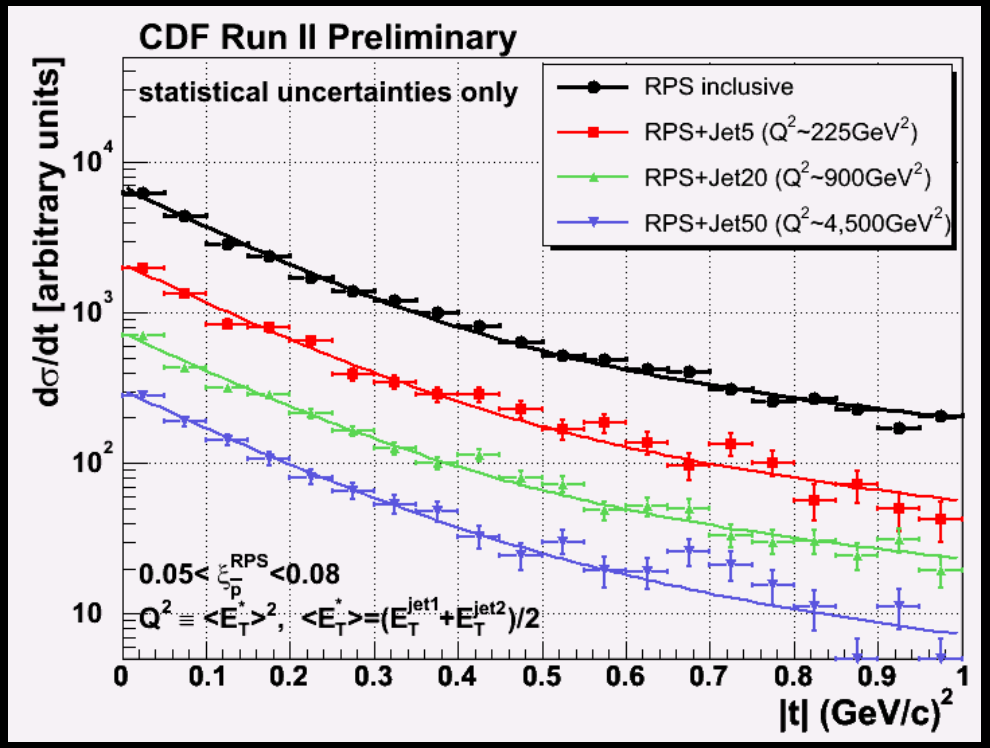
$$R_{\frac{SD}{ND}}(x_{Bj}) = R_0 x_{Bj}^{-r}, \quad r \approx 0.45$$

- Confirms Run I results

- No appreciable Q^2 dependence in SD/ND ratio for $100 < Q^2 < 10000$ GeV^2

→ Pomeron evolves similarly to proton

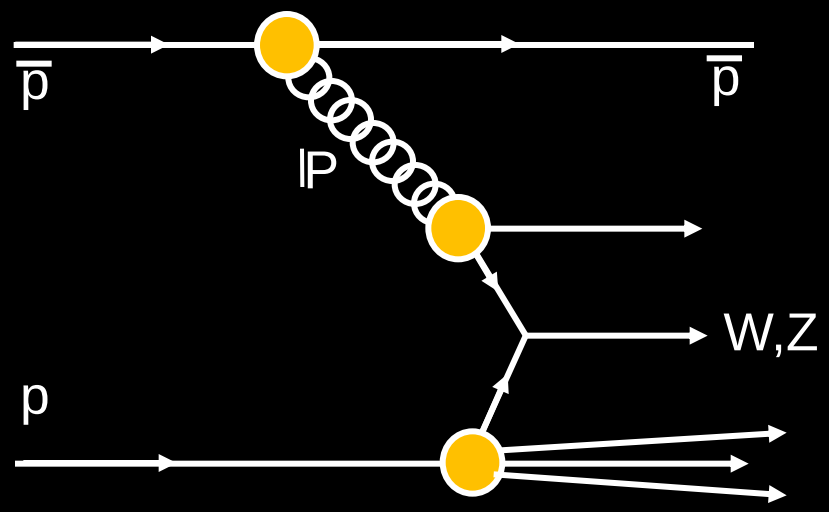
Diffractive *t* Distribution

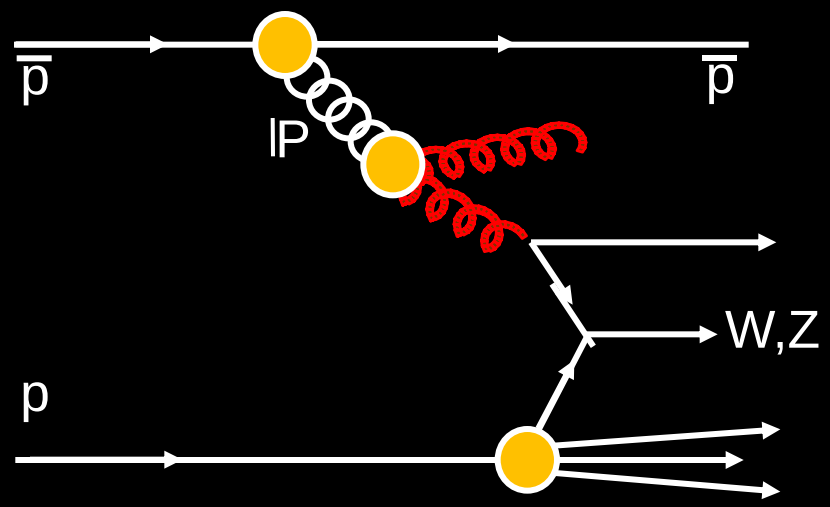


- First look at *t* distribution in diffractive dijet production at Tevatron energies
- Shape is independent of Q^2 for $0<Q^2<4500$ GeV^2
- Publication expected to include:
  - Absolute *t*-slope values
  - Larger |t| range
  - Data from special low luminosity running (~0.5×10^{30} cm^{-2}s^{-1})

Diffractive W/Z Production

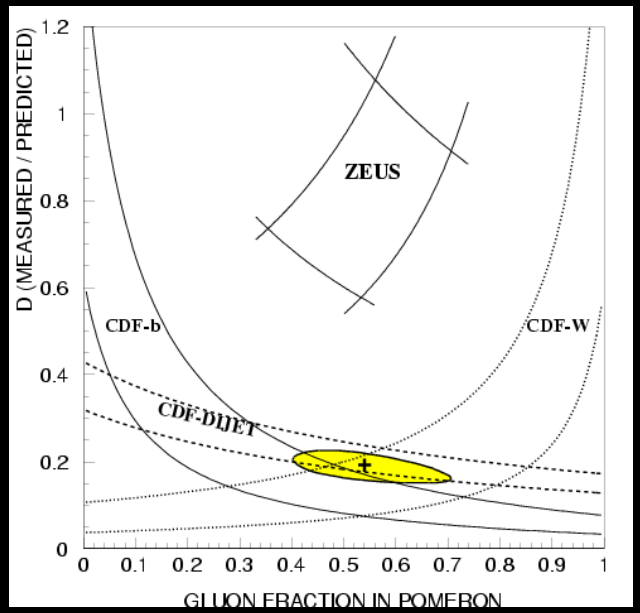
- The study of diffractive W/Z production helps to determine the quark content of the pomeron
  - To leading order, the W/Z is produced by a quark in the pomeron
  - Production by gluons is suppressed by a factor of α_S, and can be distinguished from quark production by an additional jet

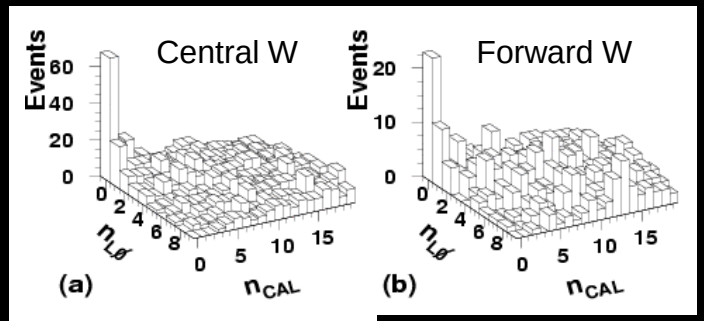


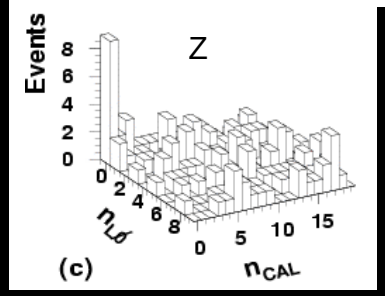


Diffractive W Production – Run I

- Run I studies used rapidity gaps instead of Roman-pots
- CDF Phys Rev Lett **78**, 2698 (1997)
  - Fraction of W events due to SD [1.15 ± 0.51(stat) ± 0.20(syst)]%
  - Observed fraction of events with a jet consistent with production via quarks
- DØ Phys Lett B **574**, 169 (2003)
  - Fraction of events with rap gap (uncorrected for gap survival)
  - W: $[0.89^{+0.19}_{-0.17}]\%$
  - Z: $[1.44^{+0.61}_{-0.52}]\%$



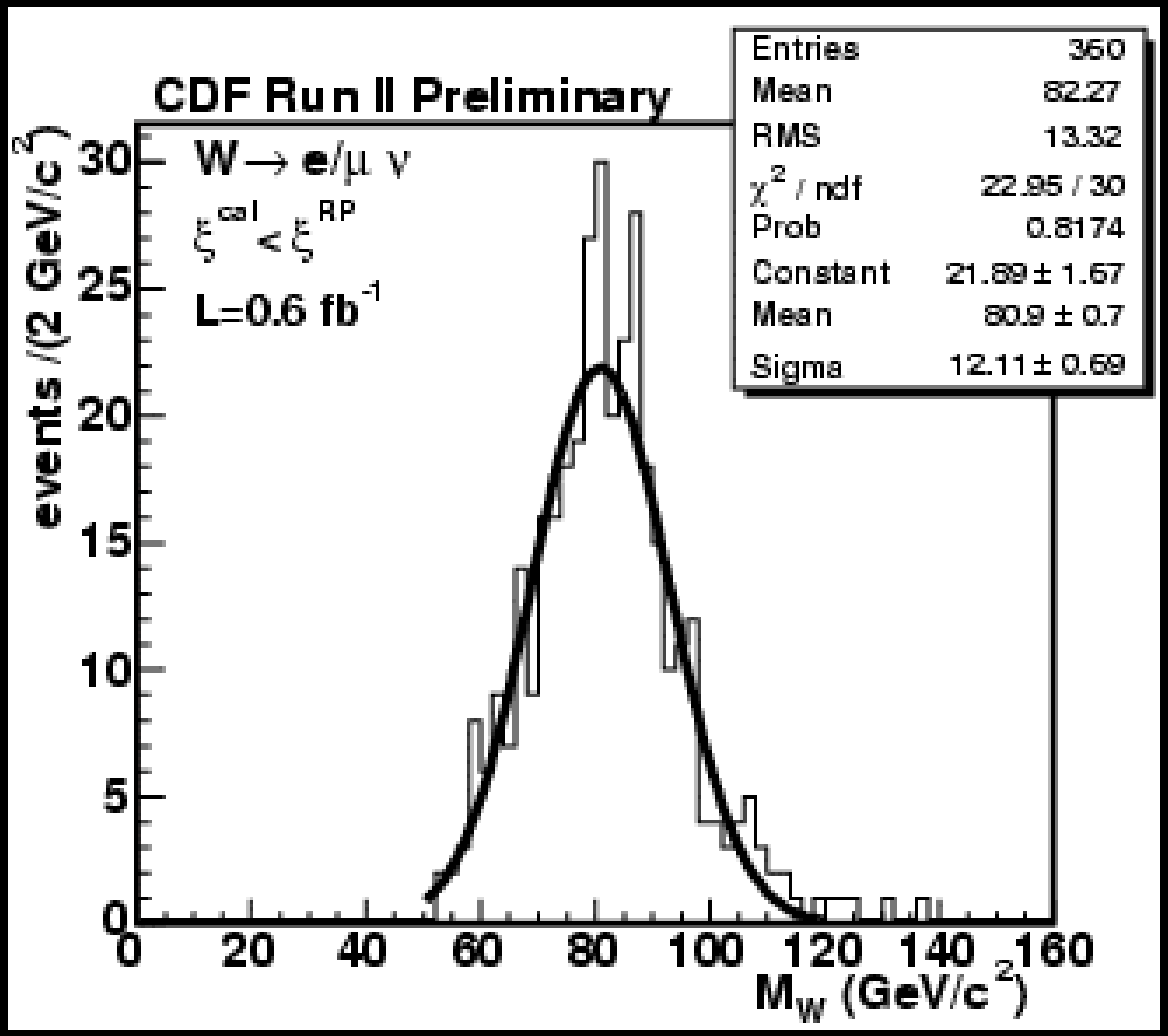




Diffractive W Production – Run II

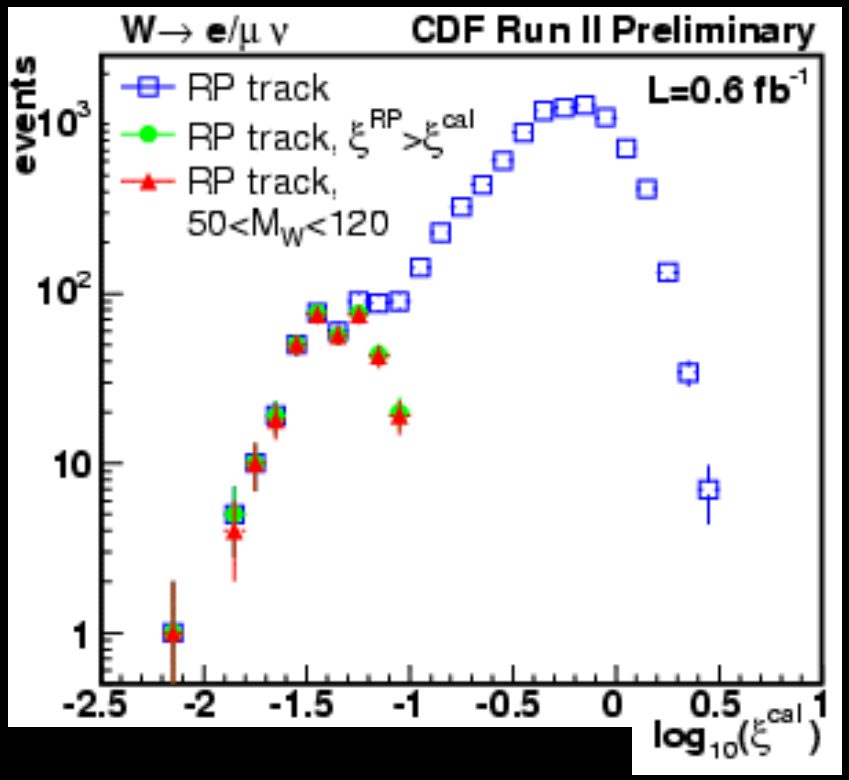
- Roman pots provide accurate ξ measurement
- As in diffractive dijet production, we can calculate ξ from the energy in the calorimeter $$\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$$
- In this case, the missing energy from the neutrino yields a difference compared to the true ξ determined from the RP track
- The difference between the calorimeter and RP ξ allows us to determine the neutrino kinematics, and therefore the W kinematics $$\xi^{RP} - \xi^{cal} = \frac{\not{E}_T}{\sqrt{s}} e^{-\eta_\nu}$$
- Hope to use to determine the structure function from diffractive W production

Reconstructed Diffractive W Mass



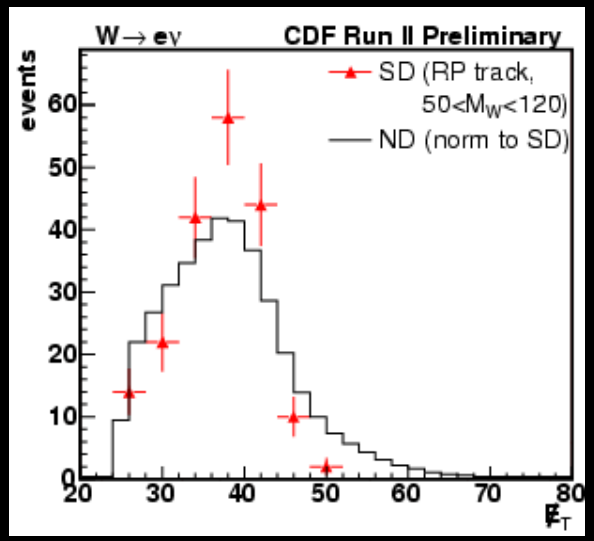
Diffractive W Production Measurement

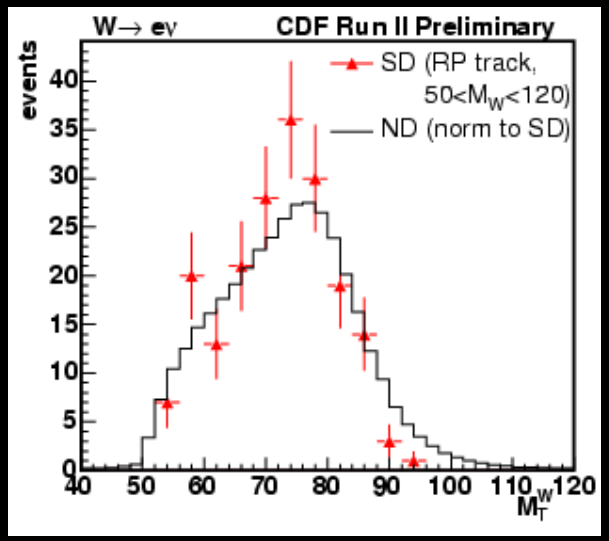
- Requiring $\xi^{cal}<\xi^{RP}$ removes most events with multiple pbar-p interactions
- Cutting on the reconstructed W mass $50<M_W<120$ GeV/c^2 cleans up possible misreconstructed events

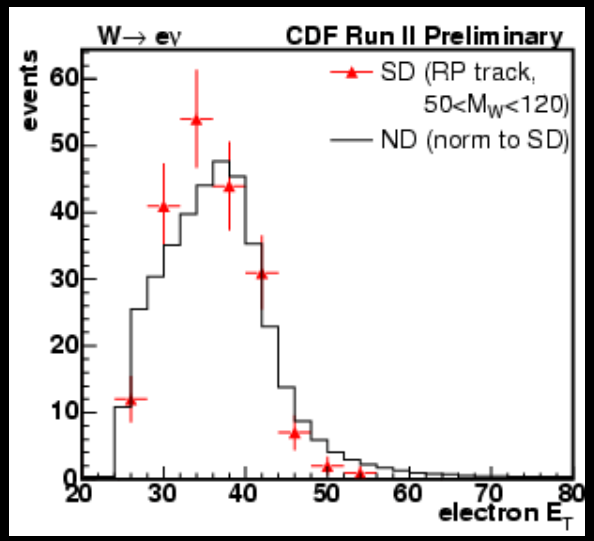


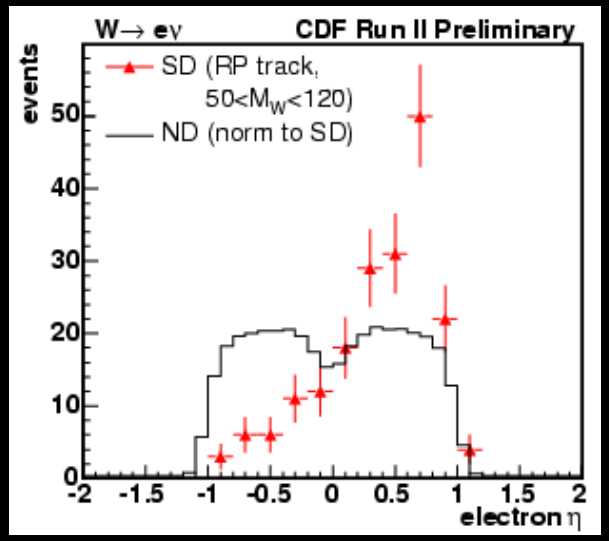
- Fraction of W's which are diffractive
- R_W $(0.03<\xi<0.10, |t|<1)$= [0.97 ± 0.05(stat) ± 0.11(syst)]%
- Consistent with Run I result which was extrapolated to all ξ

W → eν Kinematics





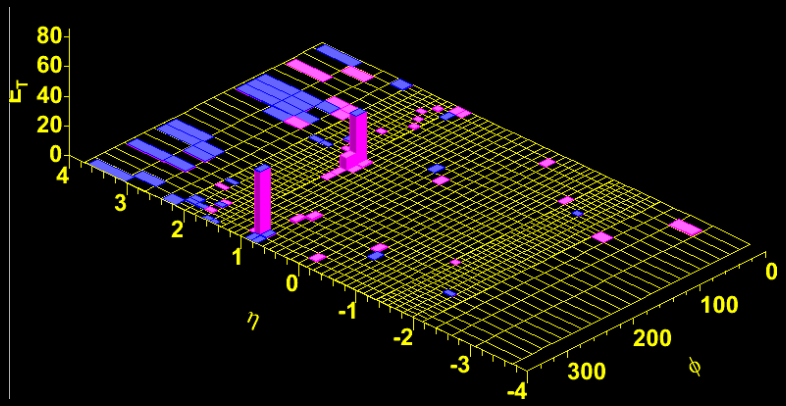




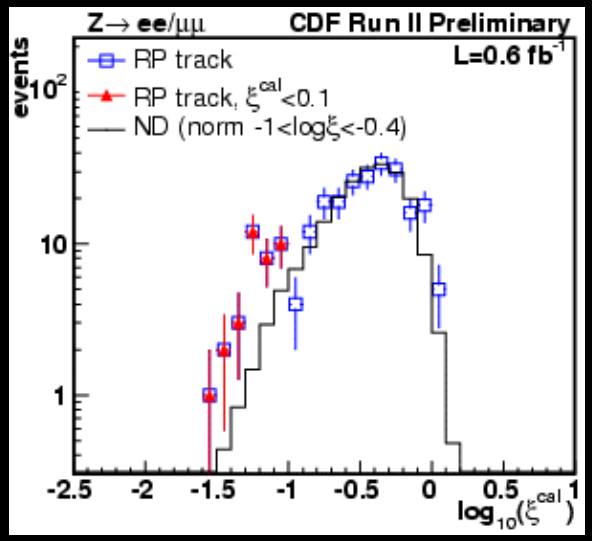
- Diffractive and non-diffractive missing E_T, W transverse mass, electron E_T similar
- Electrons boosted away from antiproton in diffractive events

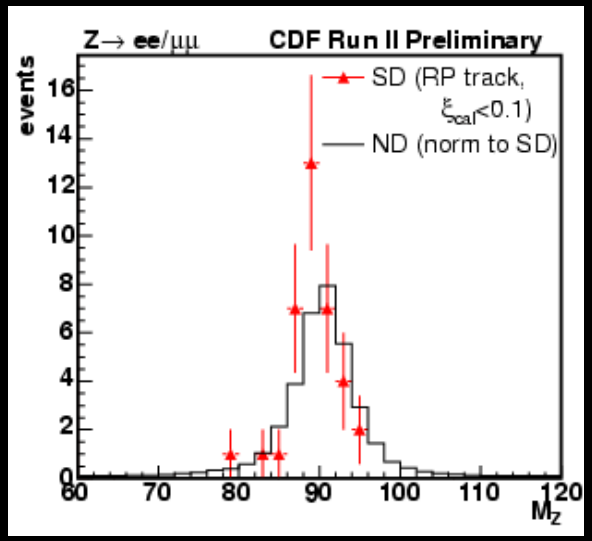
Diffractive Z

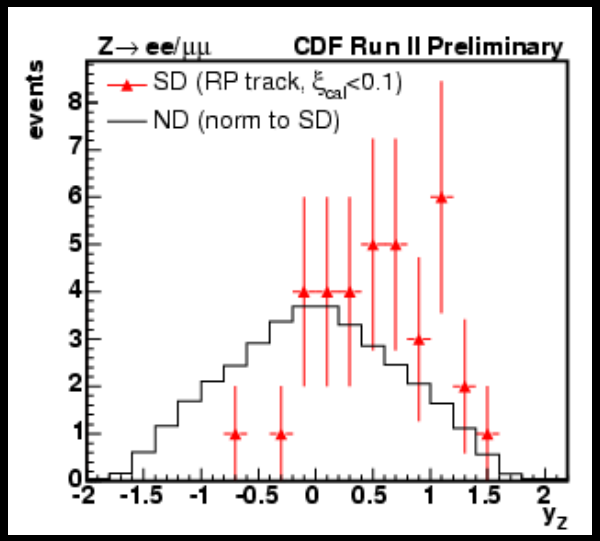
- 37 diffractive $Z \rightarrow ee/\mu\mu$ candidates (RP track, $\xi^{cal}<0.1$)
  - Estimate 11 overlap ND+SD background events based on ND ξ^{cal} distribution



- Fraction of Z's which are diffractive
- $R_Z(0.03<\xi<0.10, |t|<1)$= [0.85 ± 0.20(stat) ± 0.11(syst)]%





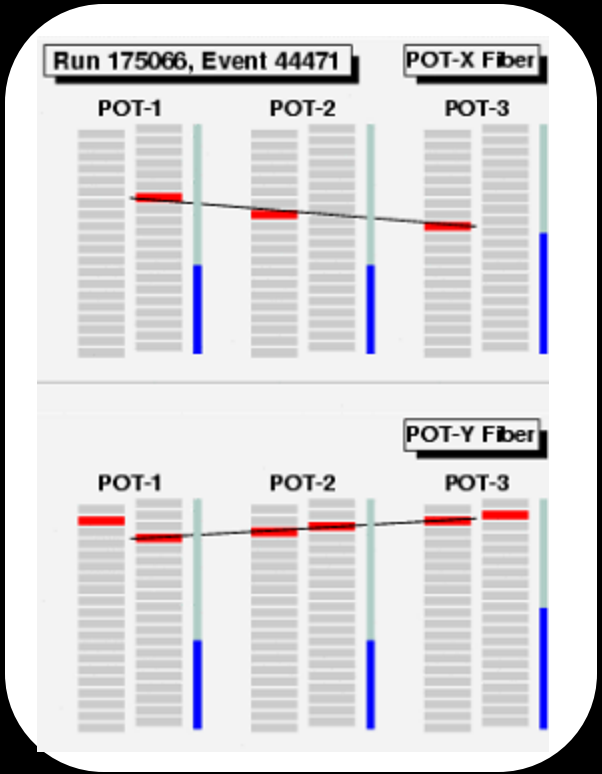


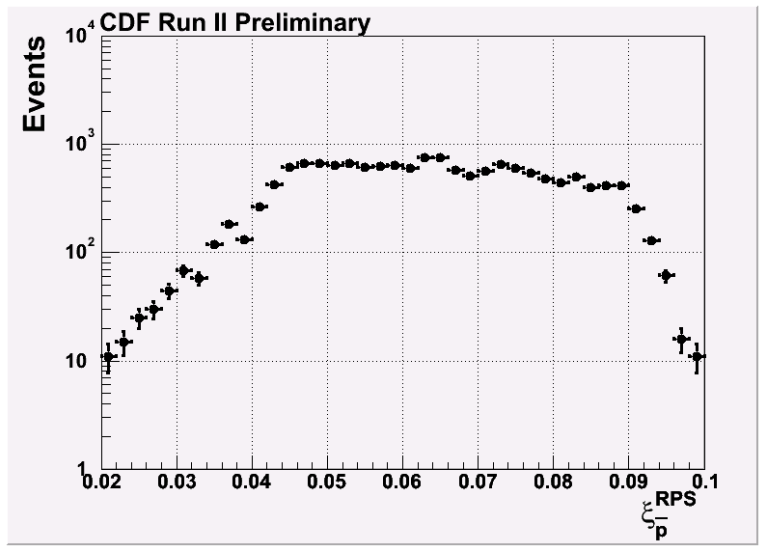
Conclusions

- Measurements of exclusive production at CDF have been essential for calibrating predictions for exclusive Higgs production at the LHC
  - Observation of exclusive dijet and limits on exclusive diphoton production
- The long-standing diffractive program at CDF continues to improve our understanding of the diffractive process
  - Extension of Run I diffractive dijet measurement to ranges in Q^2
  - First measurement of *t* distribution in diffractive dijet production at Tevatron energies
  - Measurement of diffractive W/Z production using Roman pots confirms CDF Run I rapidity gap result

backup

Roman-Pot Track Kinematics





- Reconstruct kinematics of the diffractive antiproton ξ, t :
  - antiproton track position and angle in RP detectors
  - beam position and angle at the interaction point
  - Tevatron optics between the interaction point and RPs

Diffractive W/Z Event Selection

- Standard W, Z selection from central ($|\eta|<1.1$), high-p_T electrons or muons, require Roman-pot track
- Data sample with Roman pots 0.6 fb^{-1}
- 300k $W\rightarrow e\nu$, 250k $W\rightarrow \mu\nu$, 30k $Z\rightarrow ee$, 15k $Z\rightarrow \mu\mu$
  - 2nd e for Z can be forward
- 5k $W\rightarrow e\nu$, 4k $W\rightarrow \mu\nu$, 500 $Z\rightarrow ee$, 250 $Z\rightarrow \mu\mu$ w/ RP track
  - 352 diffractive W with single-interaction
  - 37 diffractive Z single-interaction candidates w/ ~11 background due to overlap of SD and ND