Diffractive and Exclusive Dilepton and Diphoton Production at CDF II

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DIS 2008
Tevatron Performance

Collider Run II – anticipated 6\rightarrow 7 \text{fb}^{-1} by end FY09 with 2010 running 7\rightarrow 9 \text{fb}^{-1}

\text{pp collisions @ } \sqrt{s} = 1.96 \text{ TeV}

\mathcal{L}_{\text{inst}} = 20 \text{ to } 160 \times 10^{30} \text{ cm}^{-2} \text{s}^{-1}

\Delta t_{\text{bunch}} = 580 \text{ ns} \quad \text{radius} = 1 \text{ km}

36 \text{ bunches}

\sigma_{\text{inel}} = 60 \text{ mb}

\bar{n} = \sigma_{\text{inel}} \mathcal{L}_{\text{inst}} \Delta t_{\text{bunch}}

\sim 1 \text{ to } 6 \text{ interactions per crossing}

very important when searching for exclusive states without proton taggers
Luminosity delivered 3.7 fb\(^{-1}\) about 3 fb\(^{-1}\) of data to tape
Motivations to study exclusive lepton pair production:

- Potential to improve luminosity measurements at LHC since the cross section is known to better than ~5%.
- Can be used as a control sample for exclusive processes whose cross-sections are not well predicted ($\gamma\gamma$, $\chi_c$, Higgs, ...)
- For example, a place to search for $\chi_c$ and the odderon
- Can be used to calibrate forward proton spectrometers (FP420) at LHC (very important in the search for new physics and Higgs in exclusive channel)

Main motivation to study exclusive $pp \rightarrow p + \gamma\gamma + p$

- This process is a “standard candle” for exclusive Higgs production.
Central state produced via QED $\gamma\gamma \rightarrow e^+e^-$

Protons do not dissociate

Only $e^+e^-$ are produced $\Rightarrow$ nothing else

Process has never been observed before in hadron-hadron collisions
• Integrated luminosity $\rightarrow 532 \pm 32 \text{ pb}^{-1}$

• DIFF_DIPHOTON Trigger:
  – 2 EM clusters with $E_T>4\text{ GeV}$ plus a veto on BSC 1 ($E+W$)

• Exclusive $e^+e^-$ events are selected by:
  – Reconstructing the $e^+e^-$
  – Requiring that there is no other activity in $|\eta|<7.4$
  – Photons have $E_T>5\text{ GeV}$ and $|\eta|<2$
  – 16 $e^+e^-$ candidates selected

• Backgrounds $1.9 \pm 0.3$ events:
  – dijet fake (0.0 +0.1 -0.0)
  – cosmic (negligible)
  – inclusive distribution (0.3+/-0.1)
  – dissociation ($1.6 \pm 0.3$) (these are also $\gamma\gamma \rightarrow e^+e^-$ where one (or both) proton(s) dissociate)
• **Kinematics of 16 event candidate sample match the predictions of the LPAIR signal MC** (J.Vermaseren. Nucl. Phys., B229 347-371, 1983) - e^+e^- are collinear in \( \phi \) and have matching \( E_T \)

- Cross-section for \( \gamma \rightarrow e^+e^- \) LPAIR theory:
  \[
  \sigma_{\text{LPAIR}} = 1.71 \pm 0.01 \, \text{pb}
  \]
Exclusive $e^+e^-$ Production (4)

$$\sigma_{\text{MEASURED}} = 1.6^{+0.5}_{-0.3} \text{ (stat)} \pm 0.3 \text{ (sys)} \text{ pb}$$

- Agrees with LPAIR theory:
  $$\sigma_{\text{LPAIR}} = 1.71 \pm 0.01 \text{ pb}$$

- Probability of $1.9 \rightarrow \geq 16 = 1.3 \times 10^{-9}$ - corresponds to $5.5\sigma$ “observation”

- This is the first observation of exclusive two-photon produced $e^+e^-$ interactions in hadron-hadron collisions

- The LHC can rely on measuring such processes for luminosity measurement, etc.

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**We have found more candidates in later data with dedicated 2-EM shower trigger**

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**Tevatron**  
**CDF**  
**Motivation**  
**Exclusive $e^+e^-$**  
**Exclusive $\gamma\gamma$**  
**Exclusive $\mu^+\mu^-$**  
**Exclusive $\chi_c$**  
**Odderon**  
**Conclusions**

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• **Exclusive \( \gamma \gamma \) events:**
  - selected in the same way as \( e^+e^- \) (except tracking)

• **Selected in the same way as \( \gamma \gamma \rightarrow e^+e^- \) (except tracks)**
  agreement of \( \gamma \gamma \rightarrow e^+e^- \) cross section gives confidence in analysis methodology
• 3 candidate events are found in 532 pb-1 of Run II data.
• Background 0.09 ± 0.04 events (dominated by misid. of excl.)
• Good agreement on kinematics with ExHume MC (Monk & Pilkington. hep-ph/0502077)
• 0.8 +1.6 -0.5 events predicted from ExHuME MC -2 candidates are almost certainly γγ but the π0π0/ηη hypotheses cannot be excluded
Exclusive $\gamma\gamma$ Candidates

- The upper limit of the cross-section $pp \rightarrow p \gamma\gamma\bar{p}$ is set at 410 fb with 95% confidence level (taking into account the background + its uncertainty, signal selection efficiency, & $L_{\text{int}}$).

Possible $\pi^0\pi^0/\eta\eta$ event

Search for Exclusive $\gamma\gamma$ Production in Hadron-Hadron Collisions


We have found additional candidates in later data with dedicated di-EM shower trigger

Tevatron CDF Motivation Exclusive $e^+e^-$ Exclusive $\gamma\gamma$ Exclusive $\mu^+\mu^-$ Exclusive $\chi_c$ Odderon Conclusions

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• **Trigger (DIFF_CHIC_CMU1.5_PT1.5_TRK):**
  - BSC Gap, east & west
  - muon + track ($p_t > 1.3; |\eta| < 1.2$)
  - $2.7 < M(\text{muon} + \text{track}) < 4.0$ GeVc$^2$

• **No other activity in the events (to an $|\eta|$ of 7.4)**

• **The existing sample corresponds to a luminosity 1.48 fb$^{-1}$**

• **Also higher mass muons have just been stripped, (trigs with $p_t(\mu) > 4$ GeV, 2 muons, no $\Delta\phi$ requirement).**

• **Should be very efficient for dimuons, with $M >\sim 9$ GeV, covering the Upsilon region and above.**
Example exclusive $\mu^+\mu^-$ event: Run 199559, Event 13120174
• **Integrated luminosity** – 1.48 fb$^{-1}$

• **Offline cuts**
  – Loose quality cuts
  – $P_T(\mu) > 1.4$ GeV/c & $|\eta(\mu)| < 0.6$
  – Cosmic ray cuts (abs (delta_TOF) < 3 ns)
  – Exclusivity cuts (same as for the $e^+e^-$ paper)

• **Analysis of cuts is underway**
  – Acceptance
  – Efficiency
  – Effective luminosity

• **STARLIGHT Monte Carlo simulation employed** (S. Klein & J. Nystrand)
Exclusive $\mu^+\mu^-$ Candidates (1)

Many candidate events have been found (CDF-II Preliminary)
We expect to increase the number of candidates after review of the cuts
Exclusive $\mu^+\mu^-$ Candidates (2)

The $\gamma\rightarrow\mu^+\mu^-$ continuum

- Good agreement on kinematics with STARLIGHT MC (Klein & Nystrand)

Tevatron CDF Motivation Exclusive $e^+e^-$ Exclusive $\gamma\gamma$ Exclusive $\mu^+\mu^-$ Exclusive $\chi_c$ Odderon Conclusions

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Exclusive $\chi_c$ Production Background

- Similar selection as $\mu^+\mu^-$ search with additional single isolated EM show requirement
- 10 candidates in 93 pb$^{-1}$ of data
- Many more candidates with new trigger
- New ChicMC (James Stirling)
- ExAnalysis in the doldrums after Angela Wyatt left for industry
- It is just now being actively worked on...watch this space
- Problem is - understanding low energy photon background

Candidate events (many more with new trigger but NB)
Exclusive Di-leptons – a Good Place to Search for the Odderon

- In perturbative QCD the lowest order prototype of the pomeron is the color neutral system of two gluons.
- The odderon is the C-odd partner of the pomeron - the hard odderon skeleton consists of three gluons in a color neutral state.
- Global fits of the available $hh$ and $h\bar{h}$ data seem to establish that high energy scattering dominated by exchange of the $C = P = +1$ Pomeron.
- If the Odderon exists it would contribute to the exclusive $J/\psi$ and $\psi'$ signal and be part of our signal.
- The Odderon would contribute to $J/\psi$ & $\psi'$ peaks unlike the $\chi_c$ background.
Conclusion

• The paper on the observation of exclusive \( p-\bar{p} \rightarrow p + e^+e^- + \bar{p} \) production has been published in PRL (March 2007)
  - Studies continue with new low \( E_T \) di-photon trigger

• The study of exclusive \( p-\bar{p} \rightarrow p + \gamma\gamma + \bar{p} \) production was published in PRL (December 2007)
  - Studies are continuing with a new low \( E_T \) di-photon trigger (\( E_T > 3 \text{ GeV} \))

• The study of \( p-\bar{p} \rightarrow p + \mu^+\mu^- + \bar{p}, J/\psi, J/\psi', \Upsilon, \)Upsilon, is underway

• Implications for the LHC
  - Use of \( \gamma\gamma \rightarrow \mu^+\mu^- / e^+e^- \) as a luminosity monitor
  - Study of \( \gamma\gamma \rightarrow \mu^+\mu^- g-p \rightarrow \Upsilon \rightarrow \mu^+\mu^- \) as a calibration for FP420 is underway
  - Exclusive study of \( p-\bar{p} \rightarrow J/\Psi, \Psi', \ldots \rightarrow \mu^+\mu^- \) is a good place to search for the odderon
  - The process \( p-\bar{p} \rightarrow \gamma\gamma/\chi_c \) is a standard candle for the exclusive Higgs
  - We are understanding how to use the LHC as a \( \gamma\gamma \) and a \( \gamma p \) collider
Motivation: for Exclusive Studies (1)

- We are looking at exclusive channels to study:
  - LHC as a $\gamma\gamma$ collider - exclusive production models for new and SM physics
  - Measurement of luminosity at the LHC &
  - Calibration of forward detectors (FP420) using $\gamma\gamma \rightarrow l^+l^-$
  - LHC as a $\gamma p$ collider higher energy reach & luminosity yield than for $\gamma\gamma$ case
  - Experimental techniques to select exclusive events at the LHC

- Advantages: reconstruct mass of central state (if protons tagged)

Related measurements:

- In pp Collisions:

- In ep Collisions:

In Heavy Ion Collisions:

- A. Belkacem et al., Phys. Rev. A 56, 2806 (1997);
- C. Vane et al., Phys. Rev. A 50, 2313 (1997);
Motivation: for Exclusive Studies (2)

**Standard Model:**
- $\gamma\gamma \rightarrow W^+W^-$
- $\gamma\gamma \rightarrow t\bar{t}$
- $\gamma\gamma \rightarrow H$

**Beyond SM:**
- $\gamma\gamma \rightarrow H^+H^-$
- $\gamma\gamma \rightarrow \chi\chi$
- $\gamma\gamma \rightarrow S^+S^-$

Number of Higgs events for single tags and assuming integrated luminosity of 30, 0.3 and 0.03 fb$^{-1}$ for $pp$, $pAr$ and $ArAr$ collisions, respectively.

~1% of $pp$ luminosity

Reconstruct central state using FP420

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Motivation: for Exclusive Studies (3)

- **Exclusive Diffraction:**
  - Where $X$ has $J^{PC} = 0^{++}$
  - Two significant advantages over inclusive case:
    - Mass of $X$ can be determined from outgoing protons
    - ‘Measures’ the quantum numbers of $X$
  - Exclusive channels we are looking at involving photons:
    - $\gamma\gamma$ - very ‘clean’ signature, but low cross section
    - This channel is a Standard Candle for exclusive DPE Higgs prod.

*(Calculations of V.Khoze et al., show that pomeron-pomeron cross-sections for Higgs production are a few times larger than for the $\gamma\gamma$ case)*
Exclusive $e^+e^-$ Study Results

- 4 backgrounds are considered:
  - Jet Fakes: $0.0^{+0.1}_{-0.0}$ events
  - Cosmics: negligible
  - Inclusive (QCD) events: $0.3 \pm 0.1$ events
  - Dissociation events: $1.6 \pm 0.3$ events

- Efficiency
  - Electron ID: $(26 \pm 3)\%$
  - Cosmic Rejection: $(93 \pm 3)\%$
  - Final State Radiation: $(79 \pm 5)\%$
  - Exclusive Cuts: $8.6\%$

$$\sigma_{\text{measured}} = 1.6(\text{stat})_{-0.3}(\text{sys})\text{pb}$$

Agrees with LPAIR theory: $\sigma_{\text{LPAIR}} = 1.71 \pm 0.01 \text{ pb}$

Tevatron CDF Motivation Exclusive $e^+e^-$ Exclusive $\gamma\gamma$ Exclusive $\mu^+\mu^-$ $\chi_c$ Outlook to LHC Conclusions

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The Odderon

- The color neutral gluon systems, exchanged at high energy scattering processes, can be classified with respect to their C parity. The most important one is C-even system with quantum numbers of vacuum i.e. the pomeron.
- In perturbative QCD the lowest order prototype of the pomeron is the color neutral system of two gluons.
- The odderon is the C-odd partner of the pomeron - the hard odderon skeleton consists of three gluons in a color neutral state.
- One would naively expect a suppression by a power of the coupling constant for the additional gluon. It is not clear, however, why the contribution of the odderon is so small that it has not been definitely observed by any experiment.
Limit on $\gamma\gamma$ Cross-section

- We therefore observe three exclusive candidate events with a background of $0.09 \pm 0.04$ events.
- The probability for three or more events to be observed when $0.09 \pm 0.04$ (assumed to be the mean and standard deviation of a gamma-distribution) are expected is $1.7 \times 10^{-4}$.
- We set an upper limit on the cross section for exclusive production, taking into account the background and its uncertainty, the signal selection efficiency, and the integrated luminosity.
- A Bayesian approach is used assuming a flat prior for the cross section and a gamma-distribution for the uncertainties. This gives a limit on the production cross section $410 \text{ fb}$.