



# Exclusive Photon-Pair Production in Hadron-Hadron Collisions

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Motivation CDF Run II



#### Motivation



- $p\bar{p} \rightarrow p + X + \bar{p}$ , + denote large rapidity gap.
- Hard process: gluon-gluon fusion.
- Screening gluon; Sudakov suppression; gap Survival factor S<sup>2</sup>; no soft hadronisation.

- ⇒ Rapidity gaps; no HADRONS produced.
- Earlier: 3 events found in 532 pb<sup>-1</sup>  $(E_{T,min} = 5 \text{ GeV}, |\eta| < 1.0)$  (Phys. Rev. Lett. **99** (2007) 242002).
- Durham (KMR): 0.8<sup>+1.6</sup><sub>-0.5</sub> events (Eur.Phys.J. C38 (2005) 475).
- Now: new trigger with lower *E<sub>T</sub>* threshold; more data.
- Counting experiment:

 $\sigma = \frac{\text{Signal} - \text{Background}}{\text{Efficiencies} \times \mathcal{L}_{\text{eff}}}$ 





Motivation CDF Run II



#### Collider Detector at Fermilab Run II



- Tevatron: pp̄ collisions at 1.96 TeV.
- Multipurpose solenoidal detector.
- Azimuthal and forward-backward symmetry.
- Precise tracking, projective calorimetry, muon detection.
- Wire chamber detector at shower max within EM calorimeter (CES).



Motivation CDF Run II



## **CDF** Forward Coverage



We make use of:

• Miniplug (liquid scintillator)  $(3.6 < |\eta| < 5.2)$ 

+ CLC (Cherenkov luminosity counters)  $(3.7 < |\eta| < 4.7)$ 

• BSC-1/2/3 (beam shower counters) (scintillator + PMT) (5.4 <  $|\eta| <$  7.4)







# Trigger and Data

New trigger, "DIFFDIPHOTON2":

- L1: BSC-1 veto; EM shower > 2 GeV; Had/Em < 0.125</li>
- + L2: 2 EM showers within  $|\eta| <$  2.6 + Had/Em
- L3: Isolation cut,  $\chi^2$  cut on shower shape



- 1.11 fb<sup>-1</sup> data available
- Taken from June 06 till Aug 07.
- Trigger rate peaks at  $40 \times 10^{30} \text{cm}^{-2} \text{s}^{-1}$
- Falling due to pile-up
- Avoiding trigger threshold inefficiency by cutting at  $E_T = 2.5$  GeV.



Introduction	
Trigger & Data	
$\gamma\gamma$ Analysis	
Conclusions	

Selection QED  $e^+e^-$ QCD  $\gamma\gamma$ Background





- We look for photon/electron pairs plus nothing (anti/protons not detectable)
- Select events with 2 ElectroMagnetic Objects (EMO) in calorimeter for |η| < 1.0 each with E<sub>T</sub> > 2.5 GeV.
- Filter for exclusivity (rapidity gap selection).
- Quality cuts.
- Tracking cut (separate for  $\gamma\gamma$ ,  $e^+e^-$ )
- 3 samples:
  - **1** 2 EMO with good tracks  $\Rightarrow$  34  $e^+e^-$  candidates.
  - **2** EMO without any tracks  $\Rightarrow$  43  $\gamma\gamma$  candidates.
  - **3** 2 EMO mixed  $\Rightarrow$  5 events.



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 $\begin{array}{c} \text{Selection} \\ \text{QED} \ e^+ \ e^- \\ \text{QCD} \ \gamma \ \gamma \\ \text{Background} \end{array}$ 



#### Exclusivity

- Selection of rapidity gap events
  - Using Calorimetry + BSC's + CLC ( $|\eta| <$  7.4).
  - Defining detector noise level.
  - Skipping events above noise except signal.





- Efficiency estimation using zero-bias data.
- $\Rightarrow$  6.8%±0.4% (price for no pile-up)
- Exponential fit: Intercept=  $0.98 \pm 0.2$ , slope= $\hat{6}7 \pm 6$  mb (consistent with  $\sigma_{inel}$ )



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#### e<sup>+</sup>e<sup>-</sup> Control Study

- 1 quality track per EMO (p<sub>T</sub> > 1 GeV/c).
- No Bremsstrahlung
- Good agreement with prediction (LPAIR MC, Nucl. Phys. B229 347 (1983))

Exclusive e <sup>+</sup> e <sup>-</sup>	
Events	34
$\mathcal{L}_{int}$	$1.11 \pm 0.07~{ m fb}^{-1}$
Electron eff.	0.33±0.01(stat)±0.02 (syst)
Exclusive eff.	0.0680±0.004 (syst)
Radiative accept.	0.42±0.08 (syst)
Dissoc. B/G (events)	3.8±0.4 (stat)±0.9 (syst)

 $\sigma_{e^+e^-,\text{exclusive}}^{|\eta|<1, E_T(\gamma)>2.5\text{GeV}} = 2.88 \pm 0.59(\text{stat}) \pm 0.62(\text{syst}) \text{ pb,}$ compared to 3.25±0.07 pb (QED).



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- No tracks in event.
- No conversion allowed.
- SuperCHIC signal MC (KMR, Harland-Lang, Eur.Phys.J. C69 (2010) 179).

Selection QED  $e^+e^-$ QCD  $\gamma\gamma$ Background



 $\gamma\gamma$  Study

Exclusive $\gamma\gamma$	Value
Events	43
$\mathcal{L}_{int}$	$1.11 \pm 0.07~{ m fb}^{-1}$
Photon eff.	0.40±0.02 (stat)±0.03 (syst)
Exclusive eff.	0.0680±0.004 (syst)
Conversion accept.	0.57±0.06 (syst)
$\pi^0 \pi^0$ B/G (events)	0.0, <35% (95% C.L.)
Dissoc. B/G (events)	0.14 ±0.14 (syst)



Note: Normalized to data. No overflow! Could be  $\gamma\gamma$  or  $\pi^0\pi^0$ ,  $\gamma\pi^0$  forbidden.

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## Background

Main background: exclusive  $\pi^0\pi^0$  and inelastic  $\gamma\gamma$ 

- $\pi^0 \rightarrow \gamma \gamma; \Delta \phi_{\min} = 3.1^{\deg}$  for  $p(\pi^0) = 5 \text{ GeV}$
- Reconstructing of showers in wire chambers at shower max.
- Scaled  $\gamma\gamma$  and  $\pi^0\pi^0$  MC.



- Signal to hypothesis test with composition of Signal and B/G MC.
- Using Pearson's  $\chi^2$  methods.
- Most likely B/G fraction = 0; <35% (95% C.L.).
- Durham: π<sup>0</sup>π<sup>0</sup> B/G < 1% ((KMR, Harland-Lang, arXiv:1105.1626 [hep-ph].)







EVI



# Conclusions & Outlook

Exclusive Photon-Pair Production		
Theoretical	$\sigma_{ m SuperCHIC}^{ \eta <1,{ m E_T}>2.5{ m GeV}}=0.35^{ imes3}_{\div3}{ m pb}$ (MRST99)	
	$\sigma_{ ext{SuperCHIC}}^{ \eta <1,  ext{E}_{T}>2.5  ext{GeV}} = 1.42 \substack{ imes 3 \  imes 3}{ imes 3}  ext{pb}$ (MSTW08LO)	
Measured	$\sigma_{\gamma\gamma m excl.}^{ \eta <1, E_{ m T}>2.5 { m GeV}} = 2.48\pm0.42({ m stat})\pm0.51({ m sys}){ m pb}$	



- Measurement of the cross section of the exclusive production of two high-E<sub>T</sub> photons in hadron hadron collisions.
- This corresponds to 1 in 25 billion inelastic collisions.
- Constraint on central exclusive Higgs if existing (produced by same mechanism).
- Possible upper limit on exclusive neutral pion pair production (working on).



EVD



#### Typical $\gamma\gamma$ Event





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- Photon 1:
  - $E_T = 2.7 \,\mathrm{GeV}$ 
    - $\phi = 0.3 \, \mathrm{rad}$
  - $\eta = -0.1$
- Photon 2:
  - $E_T = 2.6 \, \text{GeV}$  $\phi = 3.3 \, \text{rad}$
  - $\eta = 0.7$



EVD



# **Additional Material**

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EVD



## **Exclusive Cuts**

Exclusive	Filter	Cuts
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Detector Part	max. Signal	$ \eta $ coverage
Central EM Calorimeter ( $E_T$ ):	80 MeV	0 - 0.66
Central HAD Calorimeter ( $E_T$ ):	200 MeV	0 - 0.66
End Wall EM Calorimeter ( $E_T$ ):	80 MeV	0.66 - 1.32
End Wall HAD Calorimeter ( $E_T$ ):	200 MeV	0.66 - 1.32
Mid Plug Calorimeter ( $E_T$ ):	80 MeV	1.32 - 2.11
Forward Plug Calorimeter ( $E_T$ ):	30 MeV	2.11 - 3.64
Mini Plug Calorimeter ( $E_T$ ):	5 MeV	3.6 - 5.2
BSC-1 (ADC):	400 counts	5.4 - 5.9
BSC-2 (ADC):	300 counts	6.4 - 7.1
BSC-3 (ADC):	400 counts	6.7 - 7.4
CLC (Sum of West and East) (ADC):	6300	3.7 - 4.7



EVD



#### **Event Numbers**

#### Number of events after exclusive cuts

Trigger:	200,143,239
Presel: (2EMO > 2 GeV, $ \eta  <$ 1.8):	93,976,483
Empty BSC counters (all):	39,099,062
Empty Miniplug and CLC:	136,914
Empty Forward Plug Calorimeter:	13,974
Empty Mid Plug:	5,254
Empty Low Plug:	1,359
Empty Central Calorimeter:	421
2 EMO, Central $ \eta  <$ 1.0:	180
2 EMO, Central $ \eta $ < 1.0, E <sub>T,min</sub> = 2.5 GeV:	82



EVD





Note: Normalized to data. No overflow!

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