



Observation of Exclusive Photon-Pair Production in Hadron-Hadron Collisions

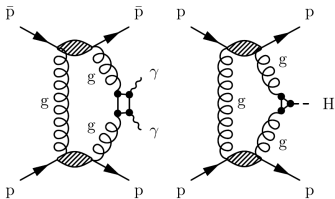
Erik Brücken

on behalf of the CDF Collaboration

University of Helsinki / Helsinki Institute of Physics, Finland

06.06.2011 Low x Meeting
Santiago de Compostela, Spain

Motivation

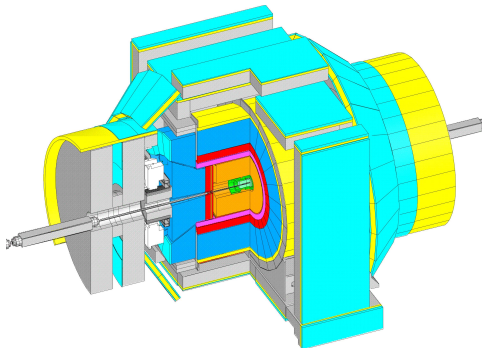


- $\mathbf{P} + \mathbf{P} \rightarrow \gamma + \gamma$
- Gluon-gluon fusion.
- Screening gluon; Sudakov.
- No soft hadronisation.
- Rapidity gaps; no HADRONS produced.

- Earlier: 3 events found in 532 pb^{-1} ($E_{T,min} = 5 \text{ GeV}$, $|\eta| < 1.0$).
- Phys. Rev. Lett. **99** (2007) 242002.
- Durham (KMR): $0.8_{-0.5}^{+1.6}$ events (Eur.Phys.J. C38 (2005) 475).
- Now: new trigger with lower E_T threshold; more data.
- Counting experiment:

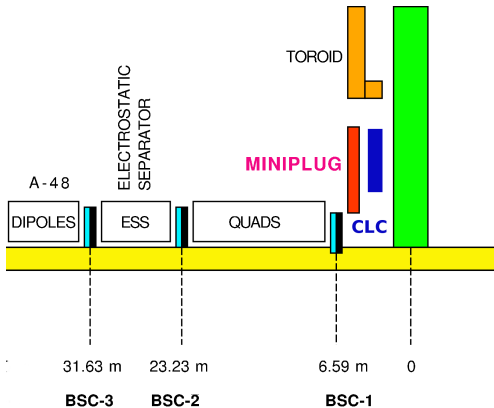
$$\sigma = \frac{\text{Signal} - \text{Background}}{\text{Efficiencies} \times \mathcal{L}_{\text{eff}}}$$

Collider Detector at Fermilab Run II



- Tevatron: $p\bar{p}$ 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).

CDF Forward Coverage



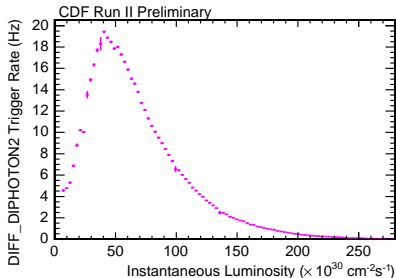
We make use of:

- 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
- L2: 2 EM showers within $|\eta| < 2.6 +$ Had/Em
- L3: Isolation cut, χ^2 cut on shower shape
- 1.11 fb $^{-1}$ 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.





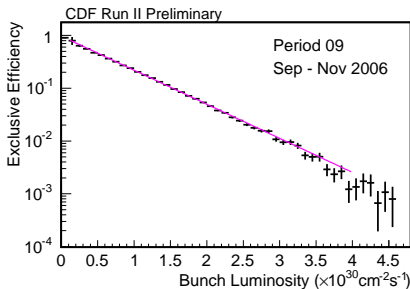
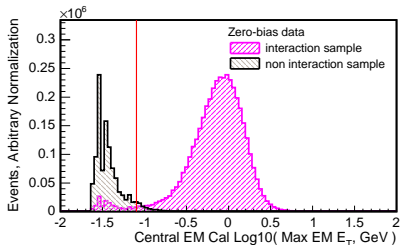
Selection

- We look for photon/electron pairs plus nothing (anti/protons not detectable)
- Select events with 2 ElectroMagnetic Objects (EMO) in calorimeter for $|\eta| < 1.0$ each with $E_T > 2.5$ 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 2 EMO without any tracks \Rightarrow 43 $\gamma\gamma$ candidates.
 - ③ 2 EMO mixed \Rightarrow 5 events.

Exclusivity

Selection of rapidity gap events

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



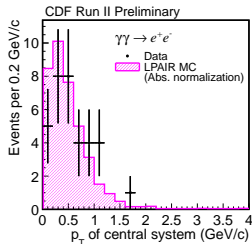
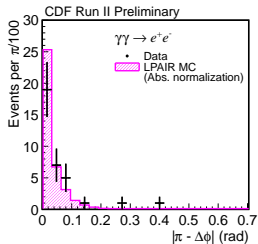
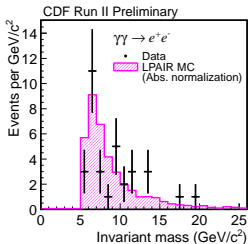
- Efficiency estimation using zero-bias data.
- $\Rightarrow 6.8\% \pm 0.4\%$ (price for no pile-up)
- Exponential fit: Intercept = 0.98 ± 0.2 , slope $\hat{=} 67 \pm 6 \text{ mb}$ (consistent with σ_{inel})

e^+e^- Control Study

- 1 quality track per EMO ($p_T > 1 \text{ GeV}/c$).
- No Bremsstrahlung
- Good agreement with prediction (LPAIR MC, Nucl. Phys. **B229** 347 (1983))

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

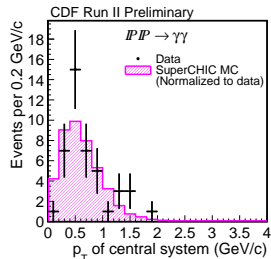
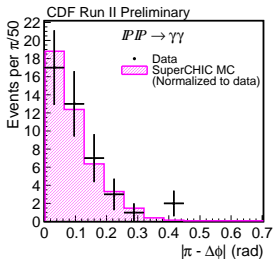
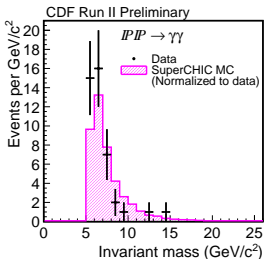
$\sigma_{e^+e^-, \text{exclusive}}^{|\eta| < 1, E_T(\gamma) > 2.5 \text{ GeV}} = 2.88 \pm 0.59(\text{stat}) \pm 0.62(\text{syst}) \text{ pb}$,
 compared to $3.25 \pm 0.07 \text{ pb}$ (QED).



$\gamma\gamma$ Study

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

Exclusive $\gamma\gamma$	Value
Events	43
\mathcal{L}_{int}	$1.11 \pm 0.07 \text{ fb}^{-1}$
Photon eff.	$0.40 \pm 0.02 \text{ (stat)} \pm 0.03 \text{ (syst)}$
Exclusive eff.	$0.0680 \pm 0.004 \text{ (syst)}$
Conversion accept.	$0.57 \pm 0.06 \text{ (syst)}$
$\pi^0\pi^0$ B/G (events)	$0.0, < 16\% \text{ (95\% C.L.)}$
Dissoc. B/G (events)	$0.14 \pm 0.14 \text{ (syst)}$

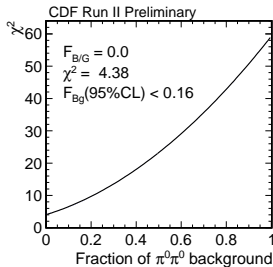
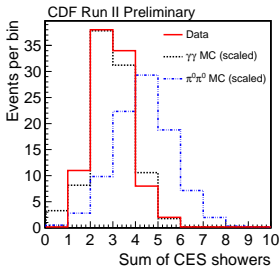


Note: Normalized to data. No overflow! Could be $\gamma\gamma$ or $\pi^0\pi^0$, $\gamma\pi^0$ forbidden.

Background

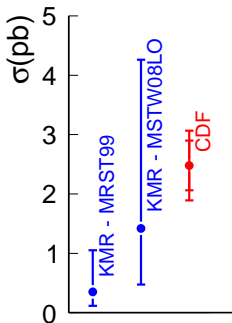
Main background: exclusive $\pi^0\pi^0$ and inelastic $\gamma\gamma$

- $\pi^0\pi^0 \rightarrow \gamma\gamma$; $\Delta\phi_{\min} = 3.1^{\text{deg}}$ 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 χ^2 methods.
- Most likely B/G fraction = 0; <16% (95% C.L.).



Conclusions & Outlook

Exclusive Photon-Pair Production	
Theoretical	$\sigma_{\text{SuperCHIC}}^{ \eta < 1, E_T > 2.5 \text{ GeV}} = 0.35 \times_{-3}^{+3} \text{ pb (MRST99)}$
	$\sigma_{\text{SuperCHIC}}^{ \eta < 1, E_T > 2.5 \text{ GeV}} = 1.42 \times_{-3}^{+3} \text{ pb (MSTW08LO)}$
Measured	$\sigma_{\gamma\gamma \text{ excl.}}^{ \eta < 1, E_T > 2.5 \text{ GeV}} = 2.48 \pm 0.42(\text{stat}) \pm 0.41(\text{sys}) \text{ pb}$



$$\sigma(p+\bar{p} \rightarrow p+\gamma\gamma+\bar{p})$$

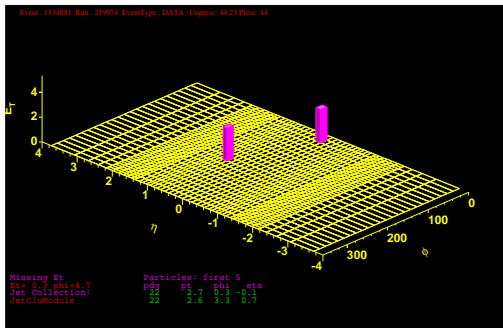
$$|\eta(\gamma)| < 1.0$$

$$E_T > 2.5 \text{ GeV}$$

$$\sqrt{s} = 1960 \text{ GeV}$$

- First observation of the exclusive production of two high- E_T 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).

Typical $\gamma\gamma$ Event



- Low invariant mass
- Photon 1:

$$E_T = 2.7 \text{ GeV}$$

$$\phi = 0.3 \text{ rad}$$

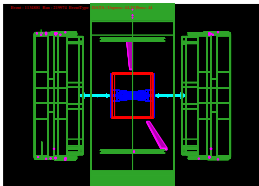
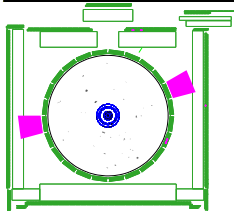
$$\eta = -0.1$$

- Photon 2:

$$E_T = 2.6 \text{ GeV}$$

$$\phi = 3.3 \text{ rad}$$

$$\eta = 0.7$$





Additional material



Exclusive Cuts

Exclusive Filter Cuts

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

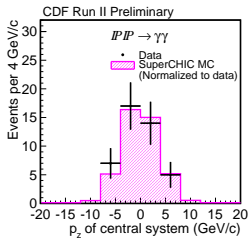
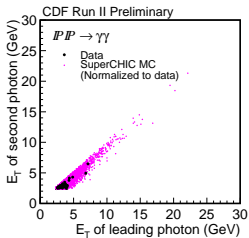
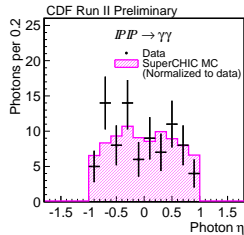
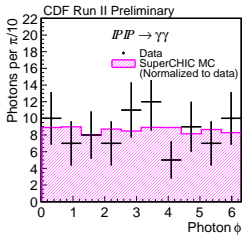
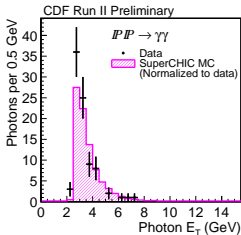


Event Numbers

Number of events after exclusive cuts

Trigger:	200,143,239
Presel: ($2\text{EMO} > 2 \text{ GeV}$, $ \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$, $E_{T,\min} = 2.5 \text{ GeV}$:	82

More $\gamma\gamma$ Plots



Note: Normalized to data. No overflow!