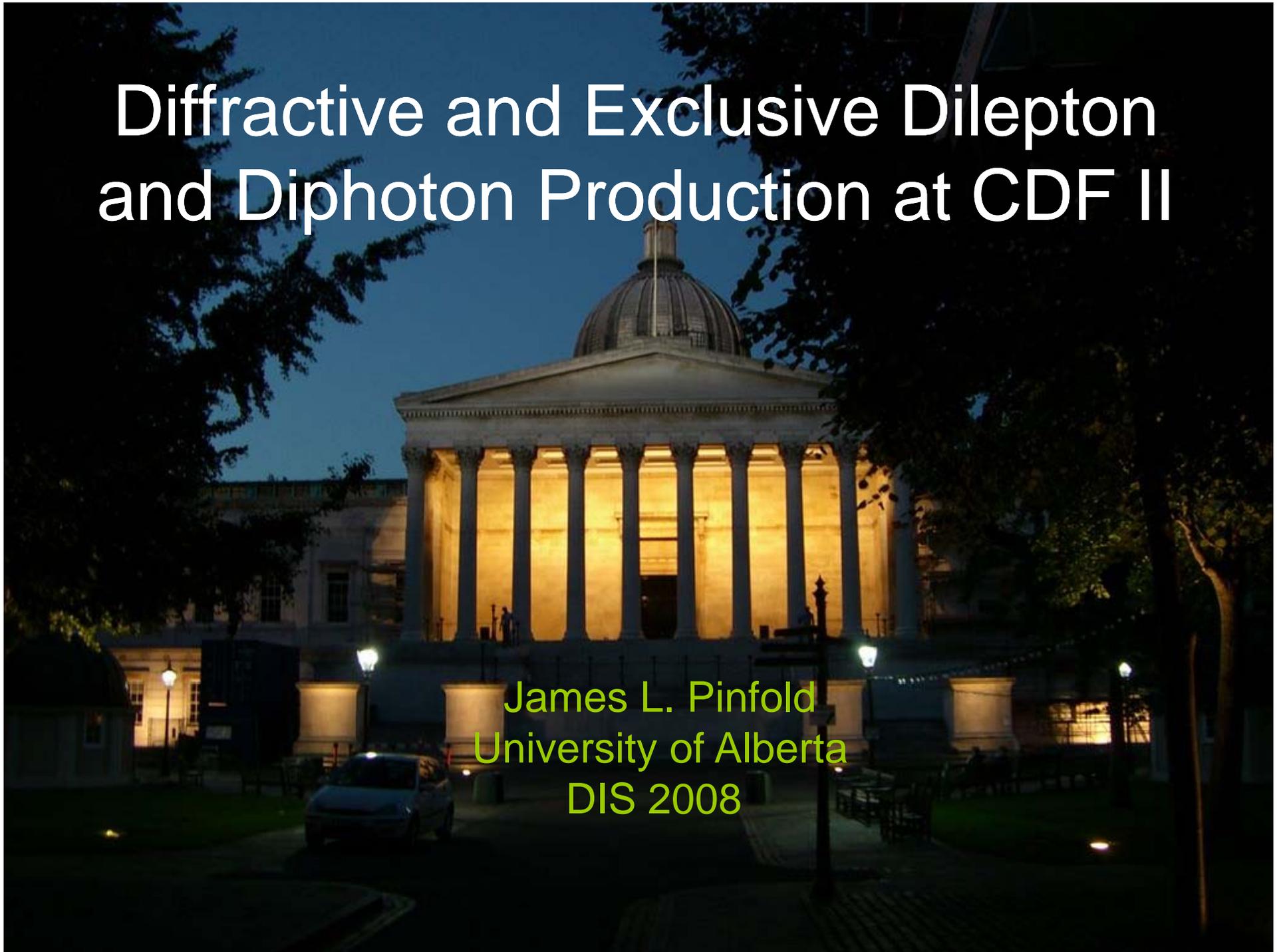


Diffractive and Exclusive Dilepton and Diphoton Production at CDF II

James L. Pinfold
University of Alberta
DIS 2008



Tevatron Performance



$p\bar{p}$ collisions @ $\sqrt{s} = 1.96 \text{ TeV}$

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

$\overline{\Delta t}_{\text{bunch}} = 580 \text{ ns}$ radius = 1 km
36 bunches

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

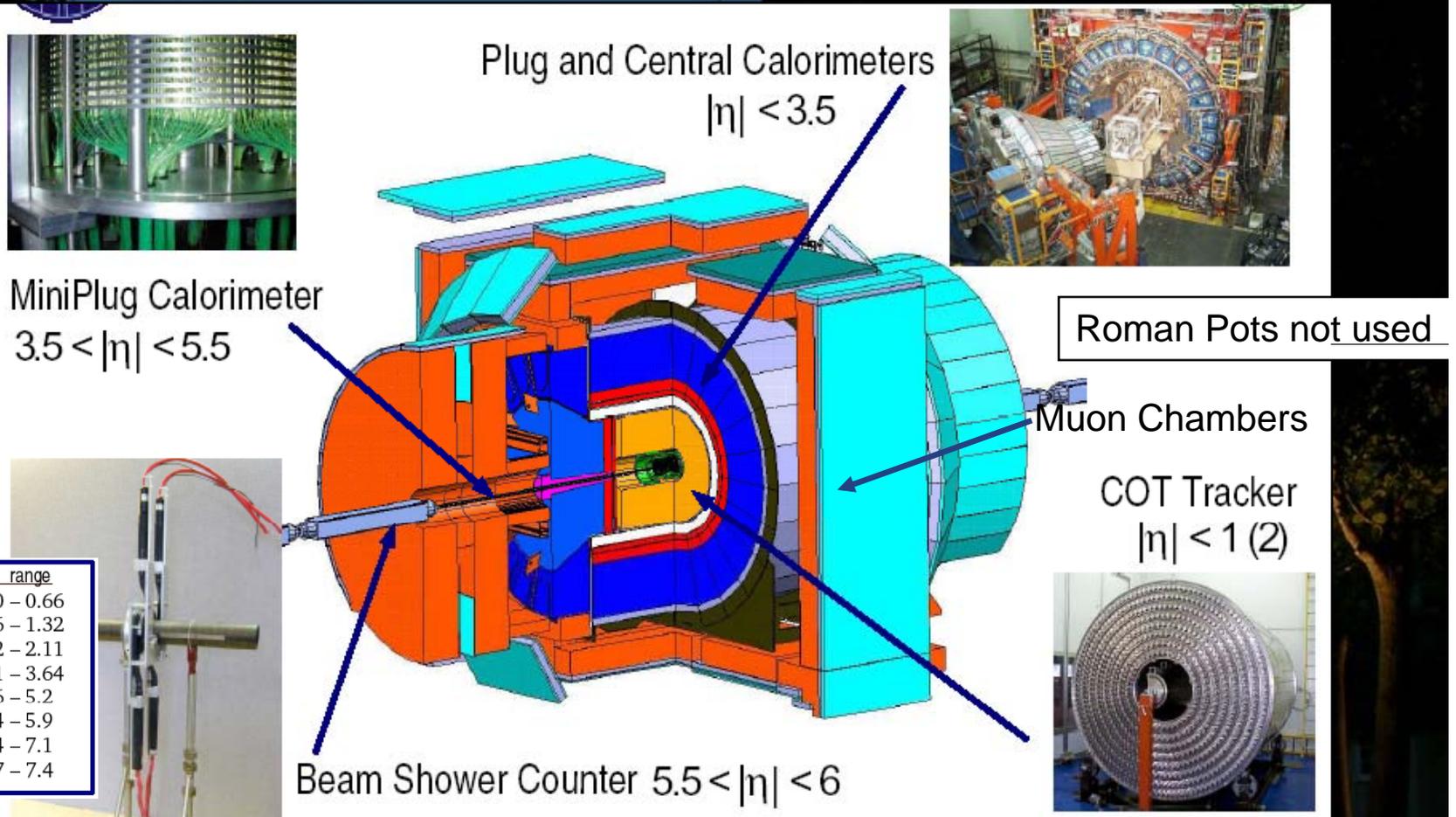
$\overline{n} = \sigma_{\text{inel}} \mathcal{L}_{\text{inst}} \overline{\Delta t}_{\text{bunch}}$

~ 1 to 6 interactions per crossing

very important when searching for exclusive states without proton taggers

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

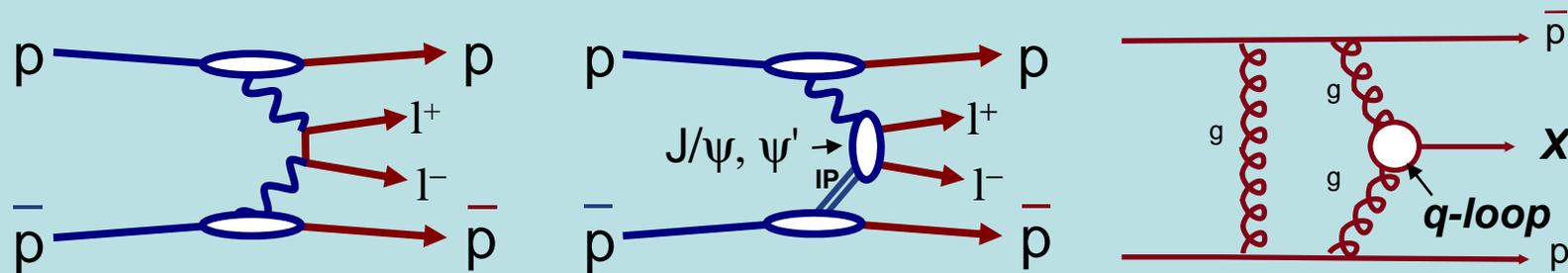
CDF Detector + Performance



Luminosity delivered 3.7 fb^{-1} about 3 fb^{-1} of data to tape

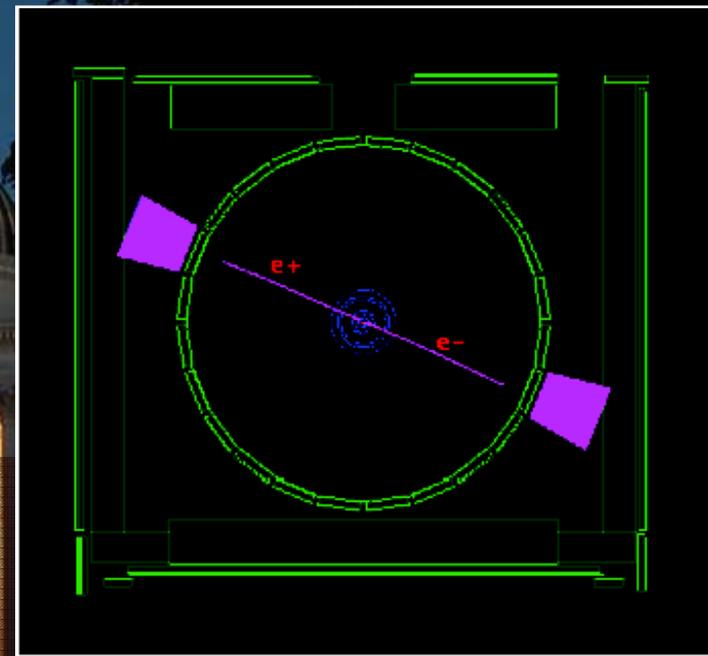
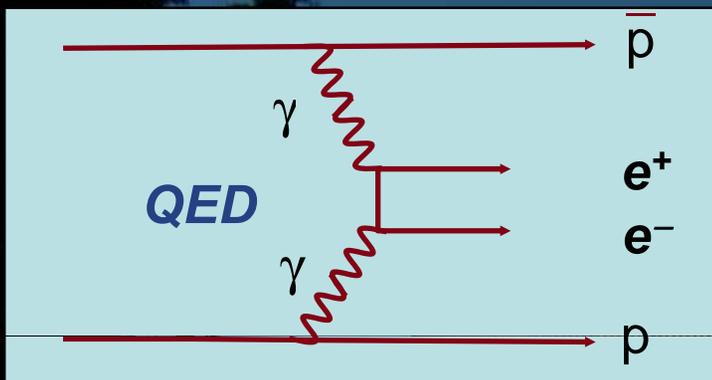
Tevatron CDF Motivation Exclusive e^+e^- Exclusive $\gamma\gamma$ Exclusive $\mu^+\mu^-$ Exclusive χ_c Odderon Conclusions

Motivation: for Exclusive Studies



- **Motivations to study exclusive lepton pair production:**
 - Potential to improve luminosity measurements at LHC since the cross section is known to better than $\sim 5\%$
 - Can be used as a control sample for exclusive processes whose cross-sections are not well predicted ($\gamma\gamma$, χ_c , Higgs, ...)
 - For example, a place to search for χ_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

Exclusive e^+e^- Production (1)



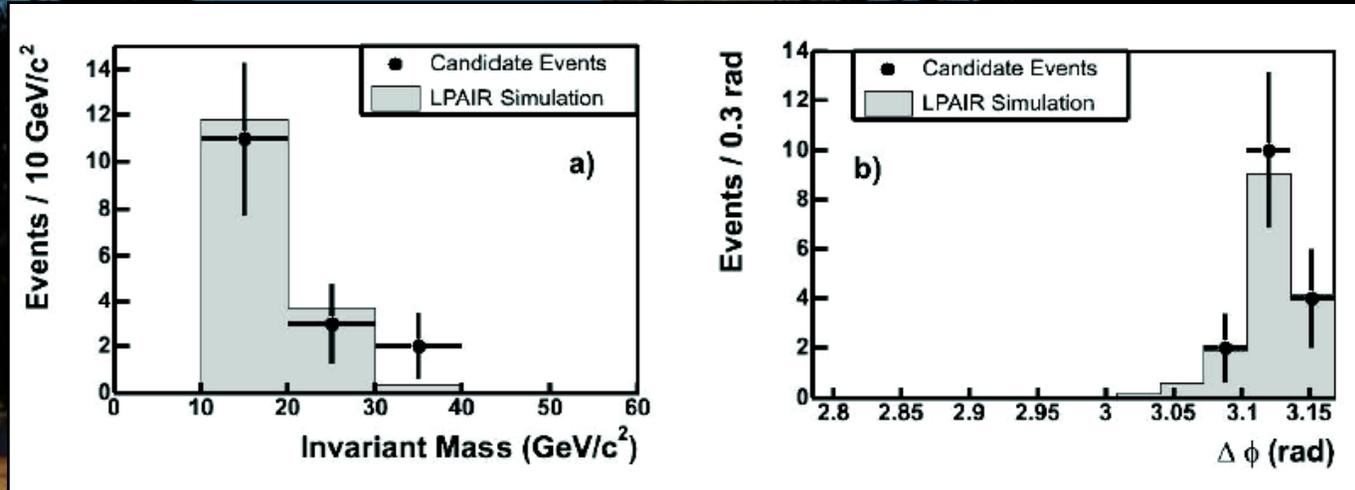
- *Central state produced via QED $\gamma\gamma \rightarrow e^+e^-$*
- *Protons do not dissociate*
- *Only e^+e^- are produced \rightarrow nothing else*
- *Process has never been observed before in hadron-hadron collisions*

Exclusive e^+e^- Production (2)

- **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 ± 0.3 events:**
 - dijet fake ($0.0 +0.1 -0.0$)
 - cosmic (negligible)
 - inclusive distribution (0.3 ± 0.1)
 - dissociation (1.6 ± 0.3) (these are also $\gamma\gamma \rightarrow e^+e^-$ where one (or both) proton(s) dissociate)

Exclusive e^+e^- Production (3)

- **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 ϕ and have matching E_T**



- **Cross-section for $\gamma\gamma \rightarrow e^+e^-$ LPAIR theory:**
 $\sigma_{\text{LPAIR}} = 1.71 \pm 0.01 \text{ pb}$

Exclusive e^+e^- Production (4)

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

- **Agrees with LPAIR theory:**
 $\sigma_{LPAIR} = 1.71 \pm 0.01 \text{ pb}$
- **Probability of $1.9 \rightarrow \geq 16 = 1.3 \times 10^{-9}$ - corresponds to 5.5σ "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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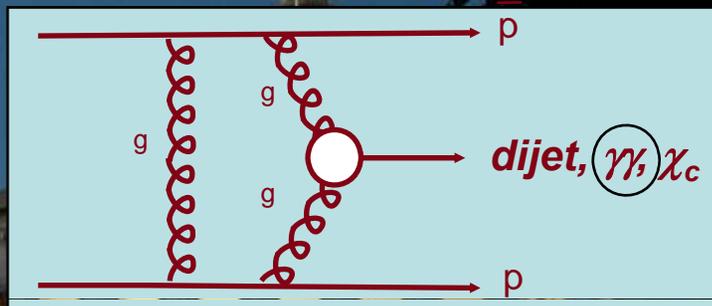
Observation of Exclusive Electron-Positron Production in Hadron-Hadron Collisions

A. Abulencia,²³ J. Adelman,¹³ T. Affolder,¹⁰ T. Akimoto,⁵⁵ M. G. Albrow,¹⁶ D. Ambrose,¹⁶ S. Amerio,⁴³ D. Amidei,³⁴
A. Anastassov,⁵² K. Anikeev,¹⁶ A. Annovi,¹⁸ J. Antos,¹ M. Aoki,⁵⁵ G. Apollinari,¹⁶ J.-F. Arguin,³³ T. Arisawa,⁵⁷

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

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

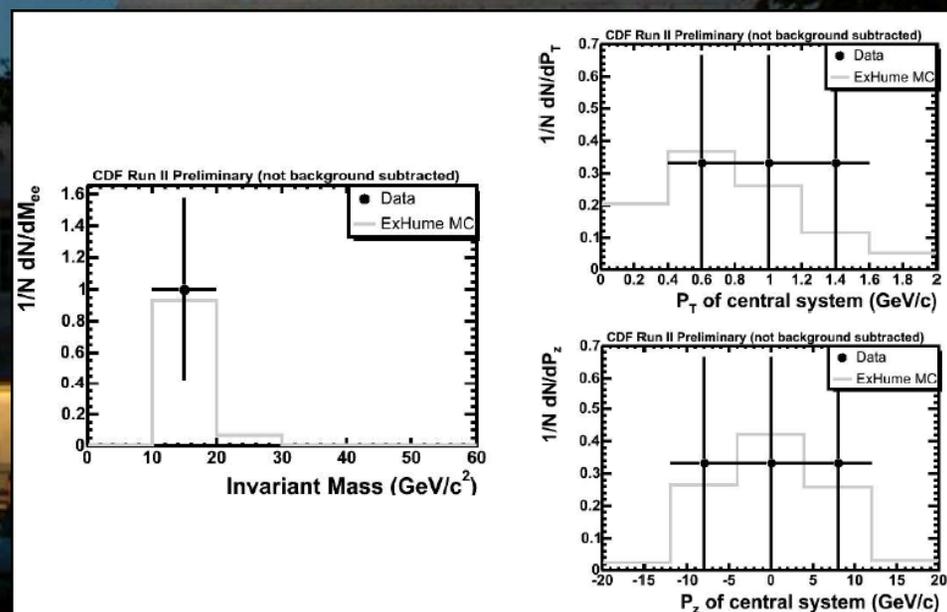
Exclusive $\gamma\gamma$ Study (1)



- **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

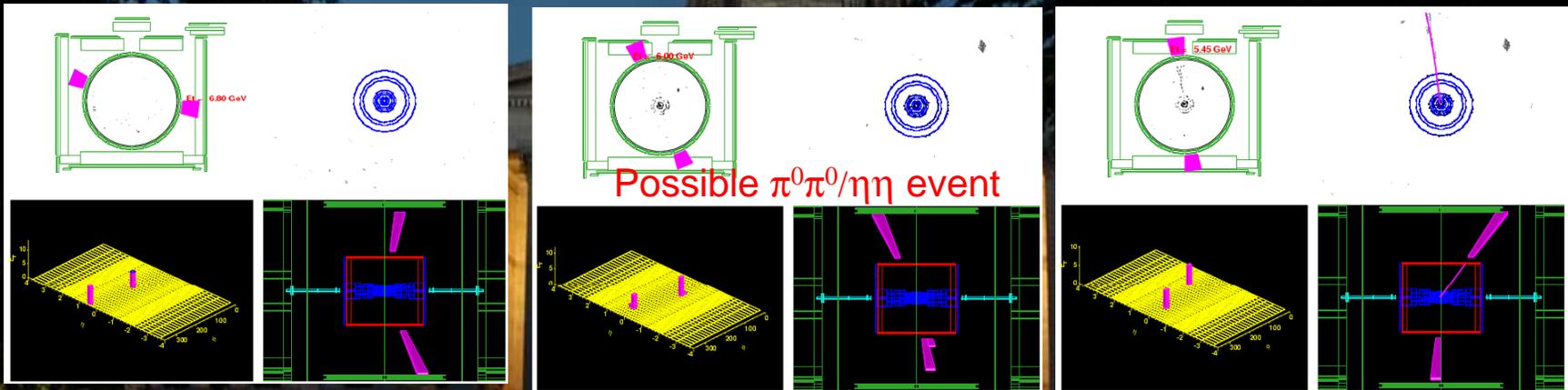
Exclusive $\gamma\gamma$ Study (2)

- 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 $\gamma\gamma$ but the $\pi^0\pi^0/\eta\eta$ hypotheses cannot be excluded



Exclusive $\gamma\gamma$ Candidates

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



PRL 99, 242002 (2007)

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14 DECEMBER 2007

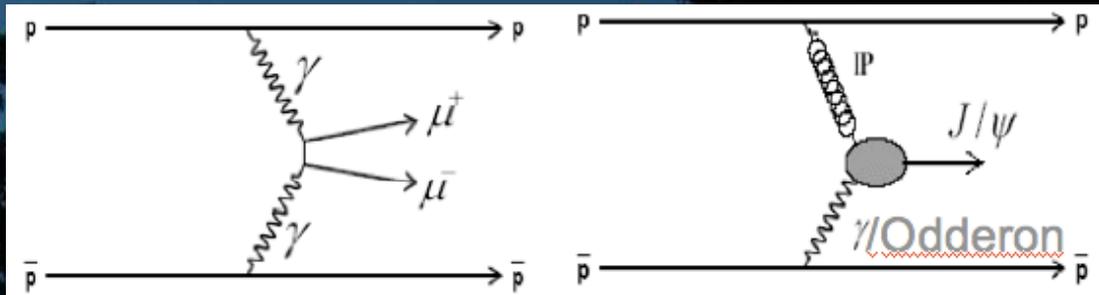
Search for Exclusive $\gamma\gamma$ Production in Hadron-Hadron Collisions

T. Aaltonen,²³ A. Abulencia,²⁴ J. Adelman,¹³ T. Affolder,¹⁰ T. Akimoto,⁵⁵ M. G. Albrow,¹⁷ S. Amerio,⁴³ D. Amidei,³⁵
A. Anastassov,⁵² K. Anikeev,¹⁷ A. Annovi,¹⁹ J. Antos,¹⁴ M. Aoki,⁵⁵ G. Apollinari,¹⁷ T. Arisawa,⁵⁷ A. Artikov,¹⁵

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 χ_c Odderon Conclusions

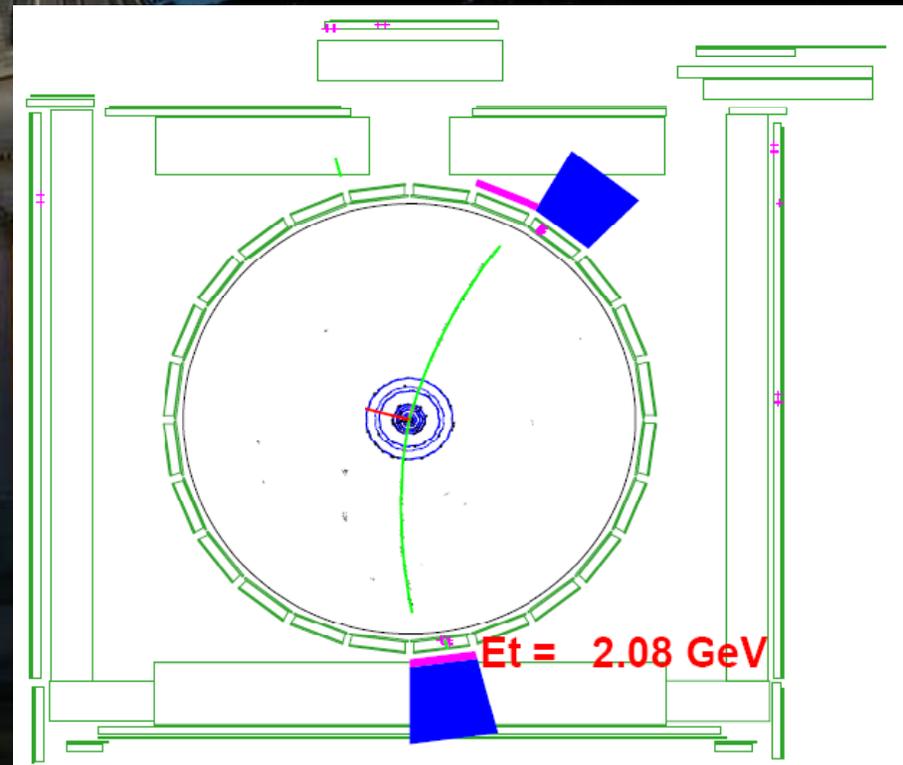
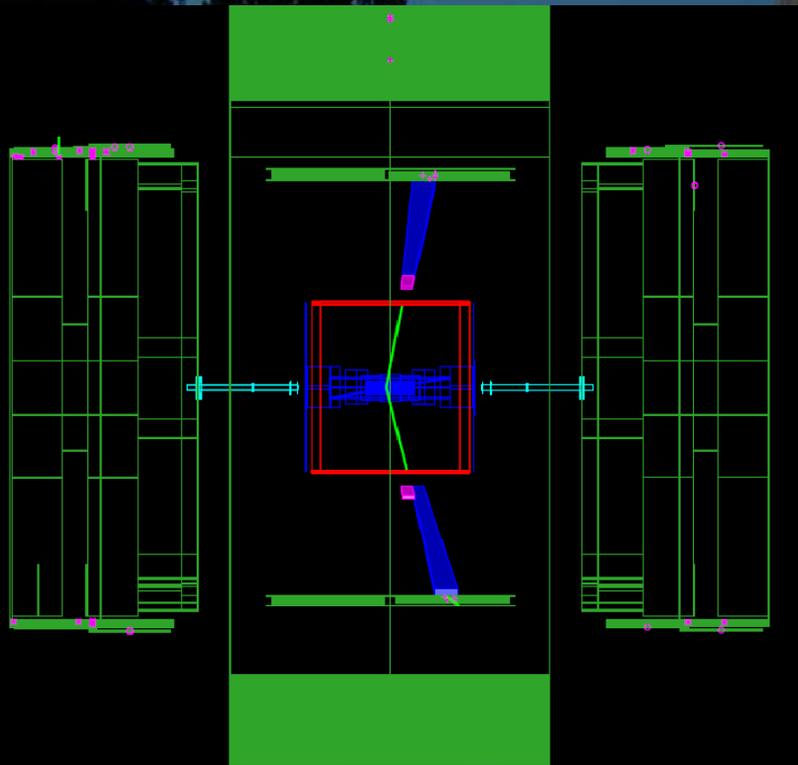
Exclusive $\mu^+\mu^-$ Production (1)



- **Trigger (DIFF_CHIC_CMU1.5_PT1.5_TRK):**
 - BSC Gap, east & west
 - muon + track ($p_t > 1.3$; $|\eta| < 1.2$)
 - $2.7 < M(\text{muon} + \text{track}) < 4.0 \text{ GeV}c^2$
- 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 $p_t(\mu) > 4 \text{ GeV}$, 2 muons, no $\Delta\phi$ requirement).
- Should be very efficient for dimuons, with $M > \sim 9 \text{ GeV}$, covering the Upsilon region and above.

Exclusive $\mu^+\mu^-$ Production (2)

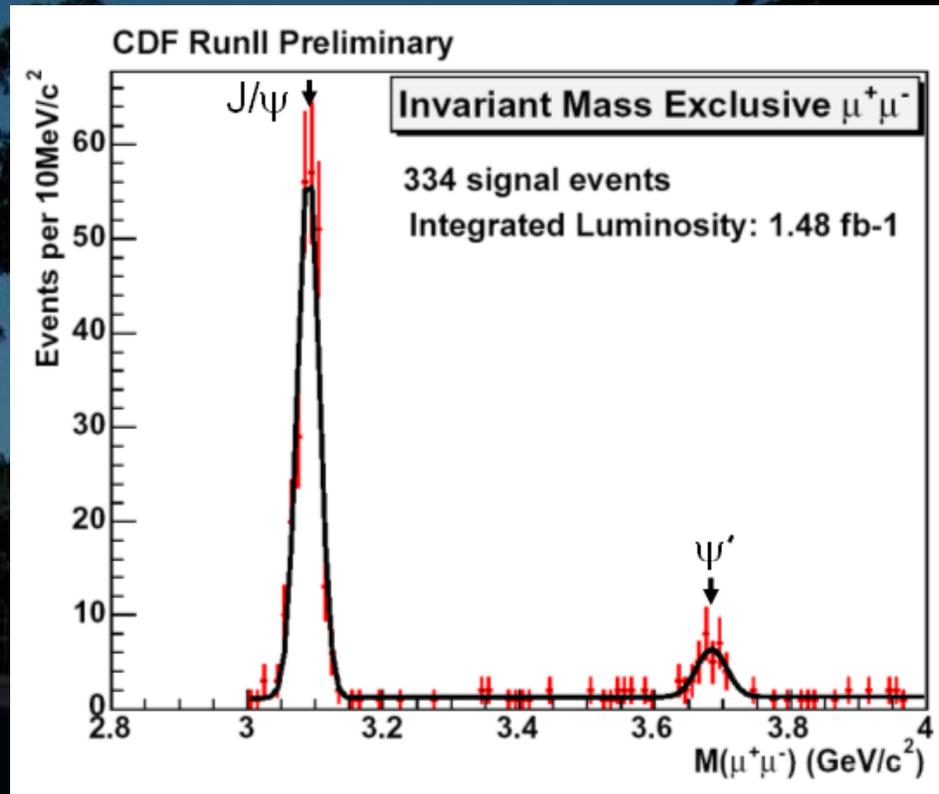
*Example exclusive $\mu^+\mu^-$ event:
Run 199559, Event 13120174*



Exclusive $\mu^+\mu^-$ Production (3)

- **Integrated luminosity – 1.48 fb^{-1}**
- **Offline cuts**
 - Loose quality cuts
 - $P_T(\mu) > 1.4 \text{ GeV}/c$ & $|\eta(\mu)| < 0.6$
 - Cosmic ray cuts ($\text{abs}(\text{delta_TOF}) < 3 \text{ ns}$)
 - 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)

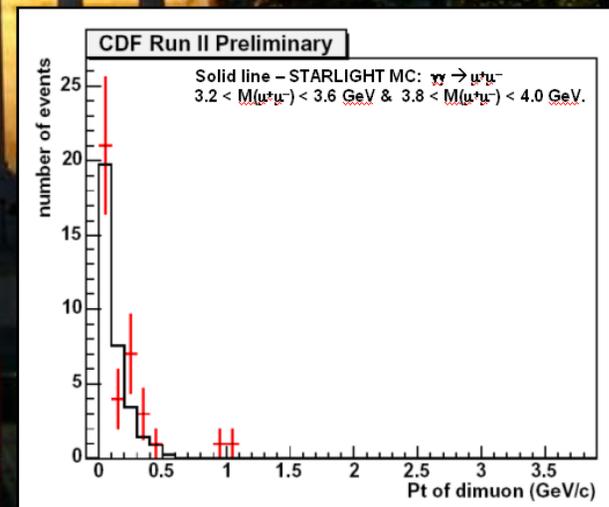
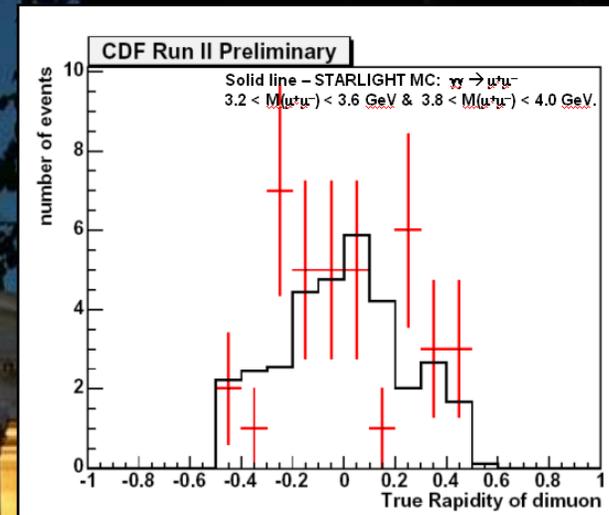
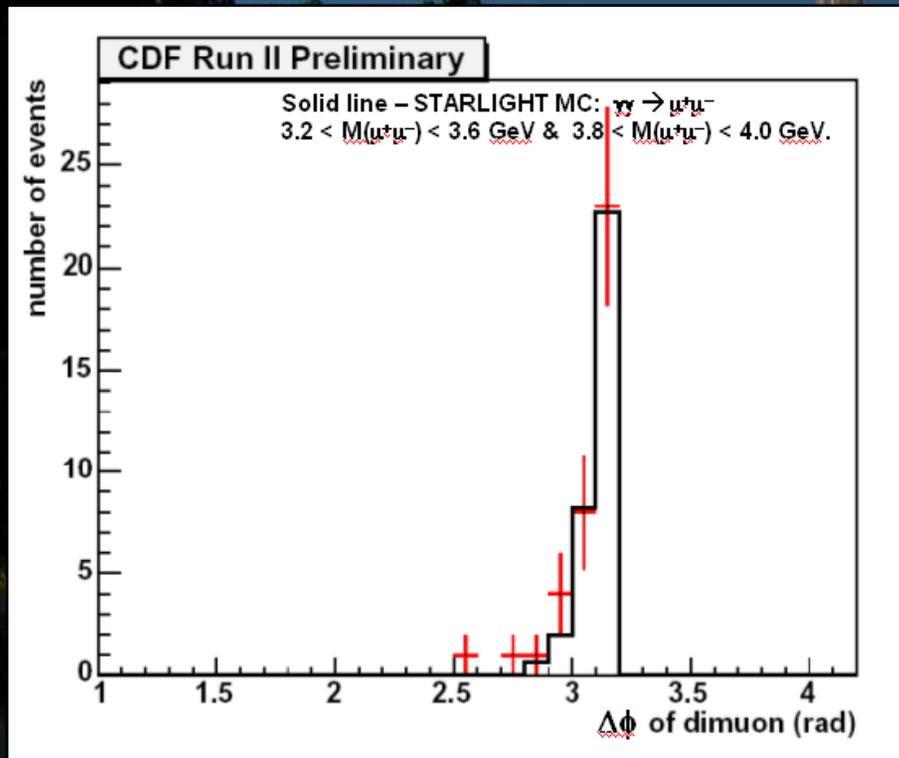


Many candidate events have been found (CDF-II Preliminary)

We expect to increase the number of candidates after review of the cuts

Exclusive $\mu^+\mu^-$ Candidates (2)

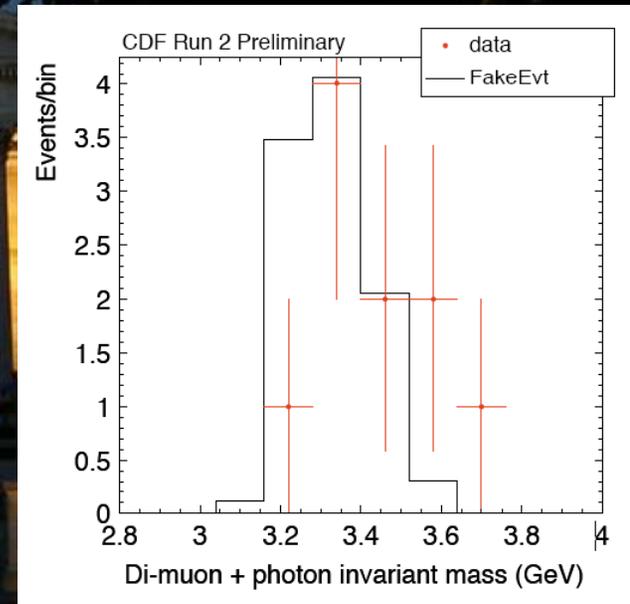
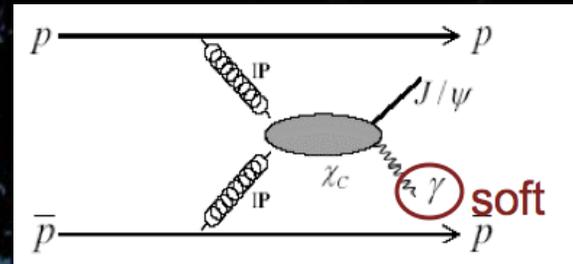
The $\gamma\gamma \rightarrow \mu^+\mu^-$ continuum



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

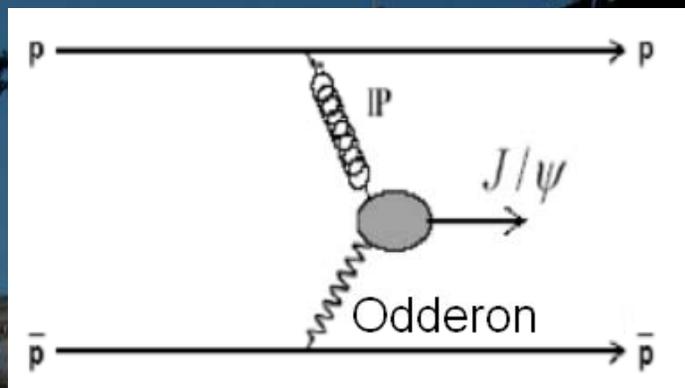
Exclusive χ_c Production Background

- *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/ψ and ψ' signal and be part of our signal*
- *The Odderon would contribute to J/ψ & ψ' peaks unlike the χ_c background*

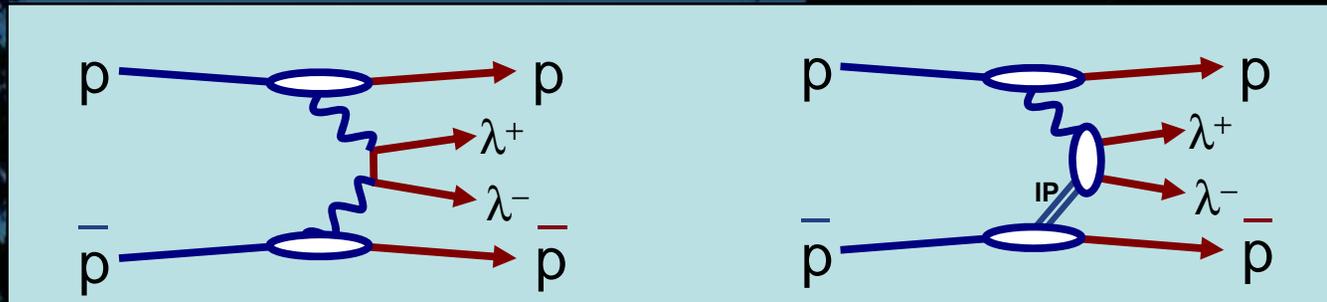
Conclusion

- *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/ψ , J/ψ' , 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 $p\bar{p} \rightarrow J/\Psi, \Psi', \dots \rightarrow \mu^+\mu^-$ 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 γp collider*

Extra Slides



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 γp collider higher energy reach & luminosity yield than for @@ case
 - Experimental techniques to select exclusive events at the LHC
- *Advantages:* reconstruct mass of central state (if protons tagged)

Related measurements:

In pp Collisions:
D. Antreasyan et al., CERN-EP/80-82 (1980).

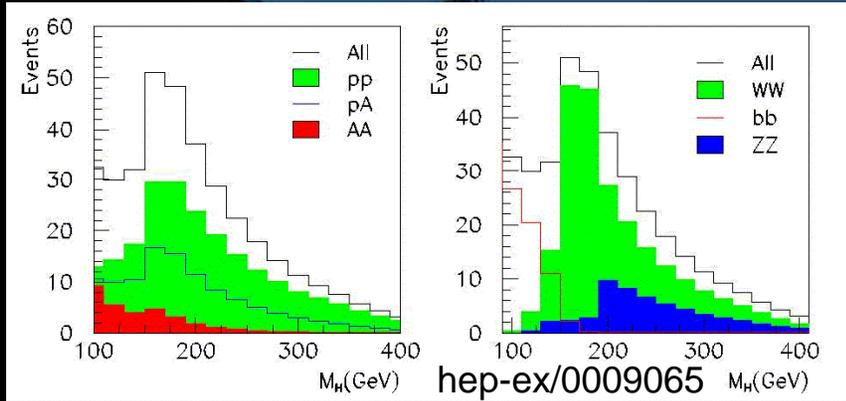
In ep Collisions:

In Heavy Ion Collisions:

A. Belkacem et al., Phys. Rev. A 56, 2806 (1997);
C. Vane et al., Phys. Rev. A 50, 2313 (1997);
R. Baur et al., Phys. Lett. B 332, 471 (1994);
J. Adams et al., Phys. Rev. C 70, 031902 (2004).

... Motivation

Motivation: for Exclusive Studies (2)



Standard Model:

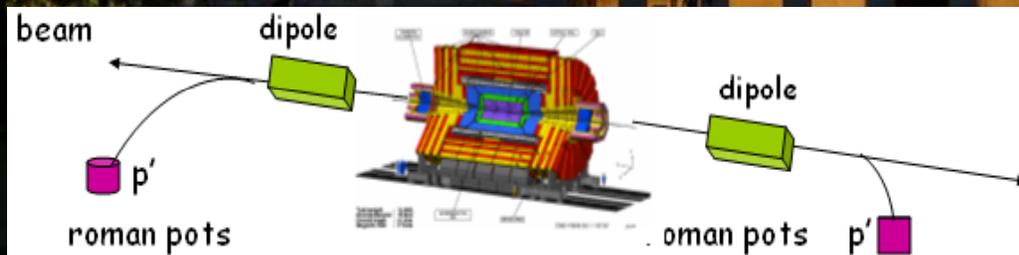
$$\begin{aligned} \gamma\gamma &\rightarrow W^+W^- \\ \gamma\gamma &\rightarrow tt \\ \gamma\gamma &\rightarrow H \end{aligned}$$

Beyond SM:

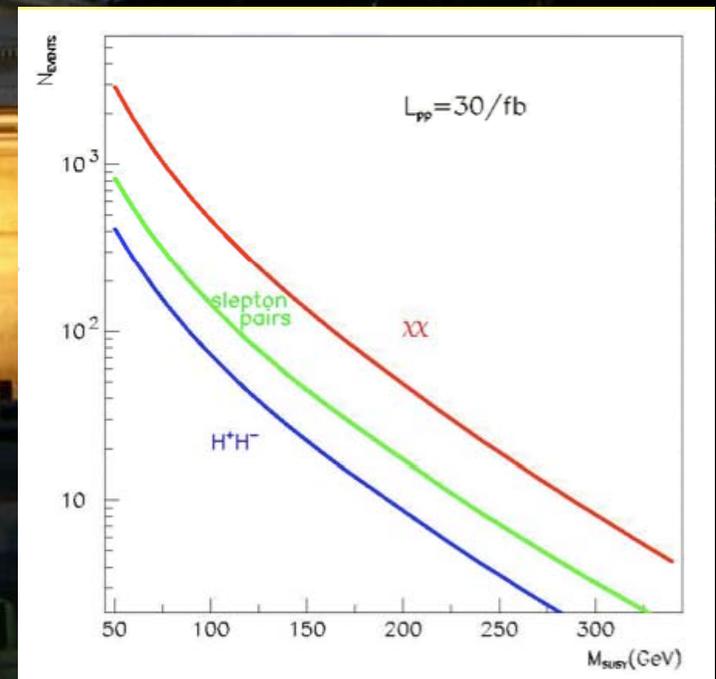
$$\begin{aligned} \gamma\gamma &\rightarrow H^+H^- \\ \gamma\gamma &\rightarrow \chi\chi \\ \gamma\gamma &\rightarrow S^+S^- \end{aligned}$$

Number of Higgs events for single tags and assuming integrated luminosity of 30, 0.3 and 0.03 fb⁻¹ for pp, pA and AA collisions, respectively.

~1% of pp luminosity



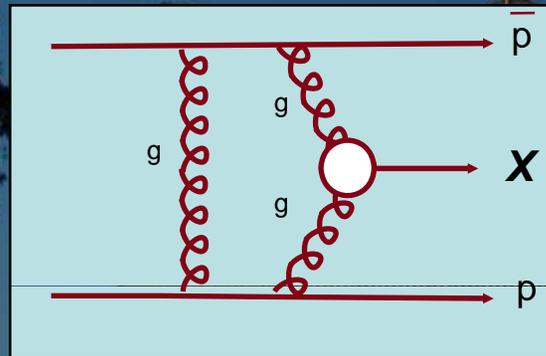
Reconstruct central state using FP420



Motivation

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 involve 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 ± 0.1 events
 - Dissociation events: 1.6 ± 0.3 events
- Efficiency
 - Electron ID: $(26 \pm 3) \%$
 - Cosmic Rejection: $(93 \pm 3) \%$
 - Final State Radiation: $(79 \pm 5) \%$
 - Exclusive Cuts: 8.6%

$\sigma_{measured} = 1.6(stat) \pm 0.3(sys) pb$ corresponds to 5.5σ observation"
Agrees with LPAIR theory: $\sigma_{LPAIR} = 1.71 \pm 0.01 pb$

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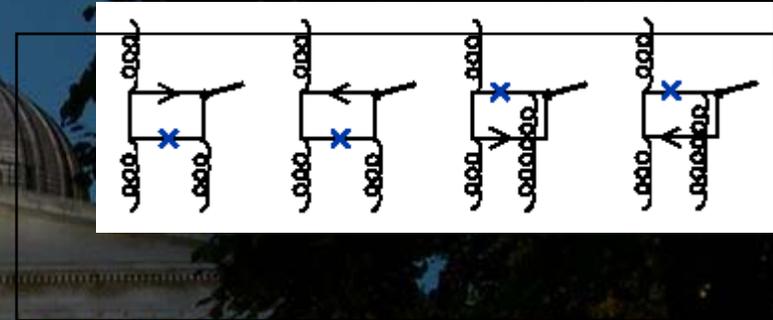
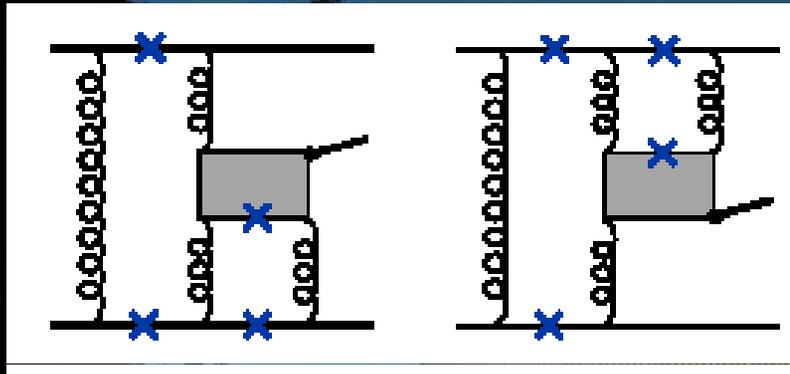
week ending
16 MARCH 2007

Observation of Exclusive Electron-Positron Production in Hadron-Hadron Collisions

A. Abulencia,²³ J. Adelman,¹³ T. Affolder,¹⁰ T. Akimoto,⁵⁵ M. G. Albrow,¹⁶ D. Ambrose,¹⁶ S. Amerio,⁴³ D. Amidei,³⁴
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Exclusive e^+e^-

The Odderon



- The color neutral gluon systems, exchanged at high energy scattering processes, can be classified wrt 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 s 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 ± 0.04 events.
- The probability for three or more events to be observed when 0.09 ± 0.04 (assumed to be the mean and standard deviation of a gammadistribution) are expected is 1.7×10^{-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 fb