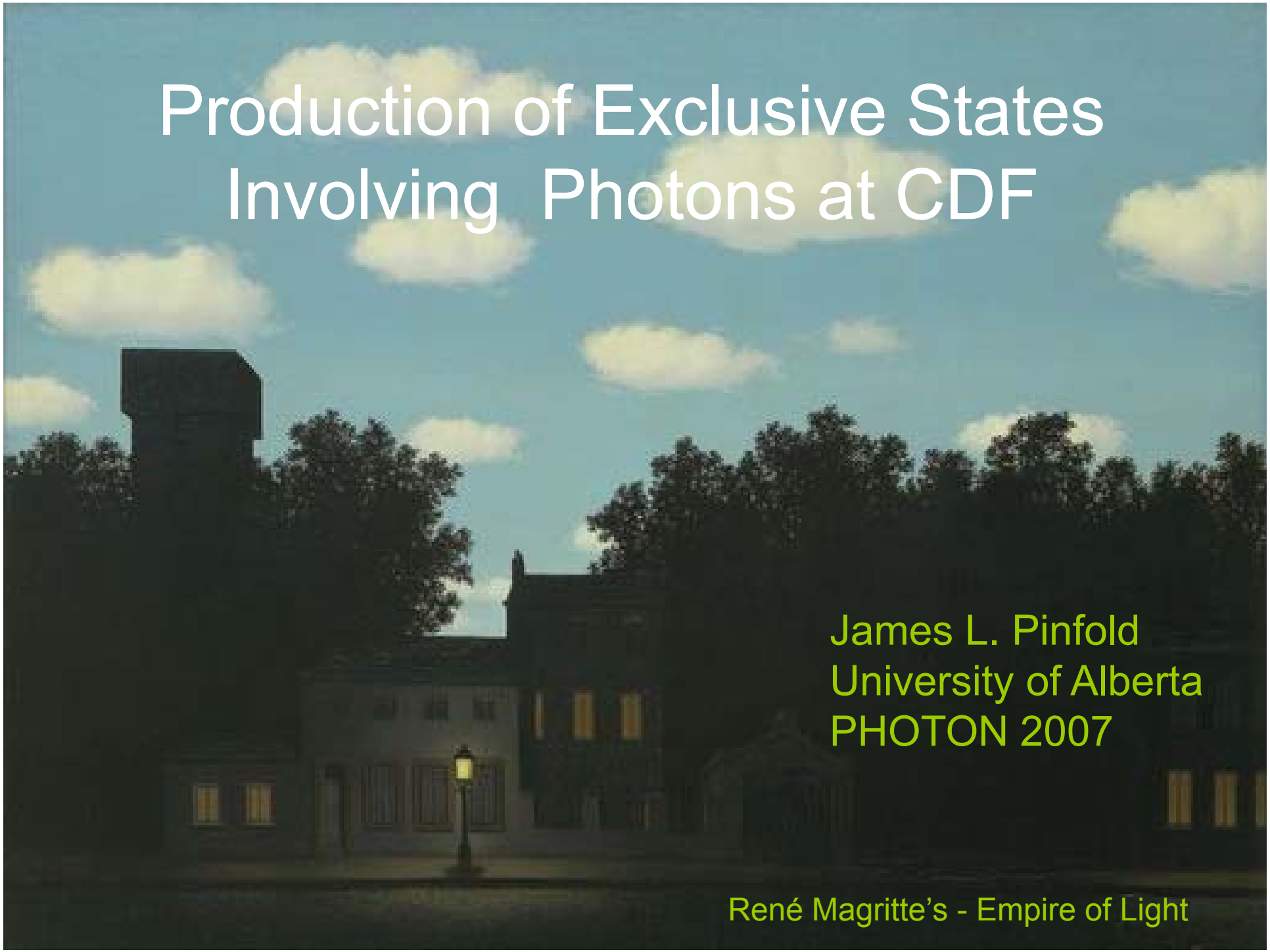
Production of Exclusive States Involving Photons at CDF



James L. Pinfold
University of Alberta
PHOTON 2007

René Magritte's - Empire of Light

Tevatron Performance

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

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

$\overline{\Delta t}_{bunch} = 580$ ns

radius = 1 km
36 bunches

$\sigma_{inel} = 60$ mb

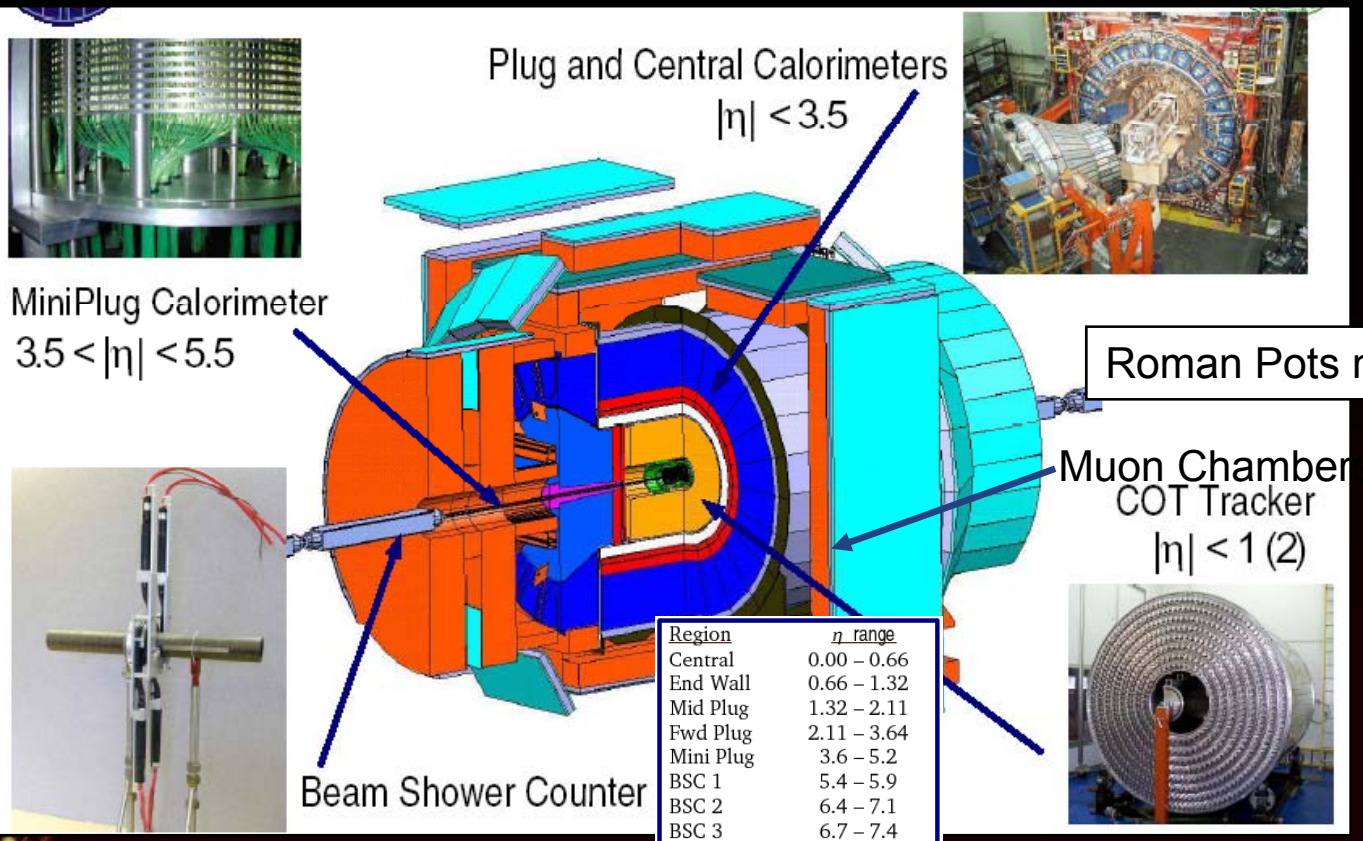
$\overline{n} = \sigma_{inel}\ \mathcal{L}_{inst}\ \overline{\Delta t}_{bunch}$

~ 1 to 6 interactions per crossing

very important when searching for exclusive states without proton taggers

Collider Run II - design Goal 8 fb^{-1} by end FY09
Approximately 3 fb^{-1} delivered so far

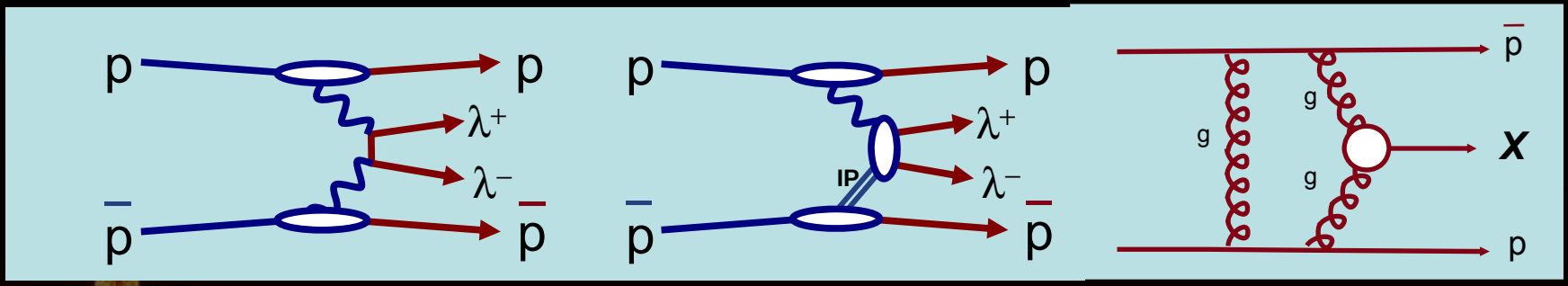
CDF - Performance



Around 2.5 fb^{-1} written to tape

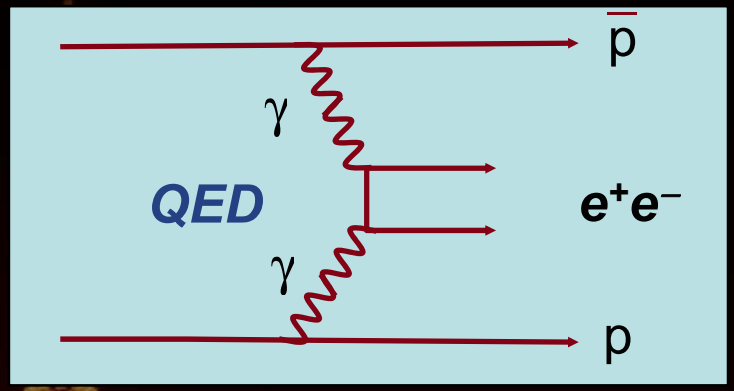
Anticipate around 3.5 fb^{-1} to tape by May 2008

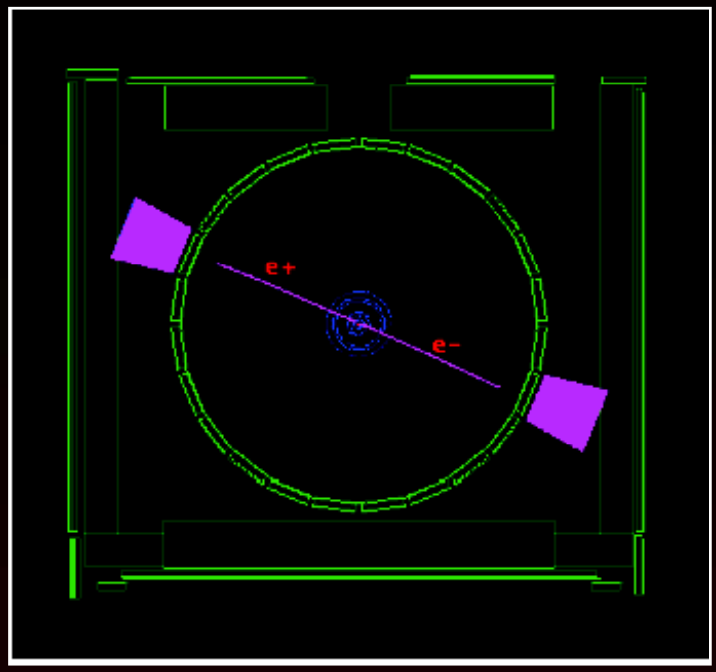
Motivation: for Exclusive Studies



- ***Motivations to study exclusive lepton pair production:***
  - *Potential to improve luminosity measurements at LHC since the cross section is known to better than ~0.1%*
  - *Can be used as a control sample for exclusive processes whose cross- sections are not well predicted ($\gamma\gamma$, χ_c, Higgs, ...)*
  - *Can be used to calibrate forward proton spectrometers (FP420) at LHC (very important in the search for new physics and Higgs in exclusive channels)*
- ***Main motivation to study exclusive pp→$\gamma\gamma$***
  - *This process is a "standard candle" for exclusive Higgs production*

Exclusive e^+e^- Production (1)





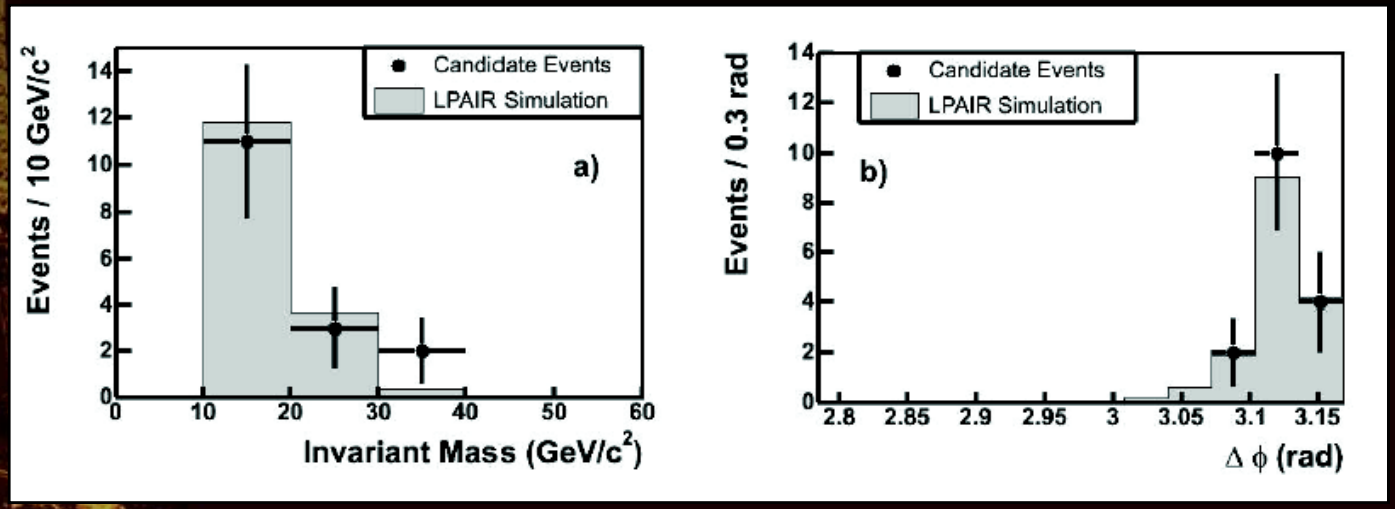
- *Central state produced via QED $\gamma\gamma \rightarrow e^+e^-$*
- *Protons do not dissociate*
- *Only e^+e^- are produced → nothing else*
- *Process has never been observed before in hadron-hadron collisions*

Exclusive e^+e^- Production (2)

- ***Integrated luminosity → 532 ± 32 pb^{-1}***
- ***DIFF_DIPHOTON Trigger:***
  - *2 EM clusters with E_T>4GeV 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 GeV*
  - *16 e^+e^- candidates selected*
- ***Backgrounds 1.9 ± 0.3 events:***
  - *dijet fake (0.0 +0.1 -0.0)*
  - *cosmic (neglible)*
  - *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:*

$$\sigma_{LPAIR} = 1.71 \pm 0.01 \text{ pb}$$

Exclusive e^+e^- Production (4)

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

- *Agrees with LPAIR theory:*
  $\sigma_{LPAIR} = 1.71 \pm 0.01$ *pb*
- *Probability of 1.9 → ≥16 = 1.3 × 10^{-9} - corresponds to 5.5σ "observation"*
- *This is the first observation of exclusive two-photon interactions in hadron-hadron collisions*
- *The LHC can rely on measuring such processes for luminosity measurement, etc.*

PRL 98, 112001 (2007) PHYSICAL REVIEW LETTERS week ending 16 MARCH 2007

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

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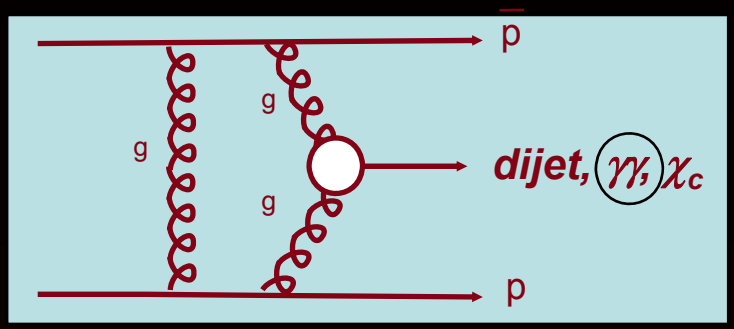
We have found additional candidates in later data with dedicated di-γ trigger

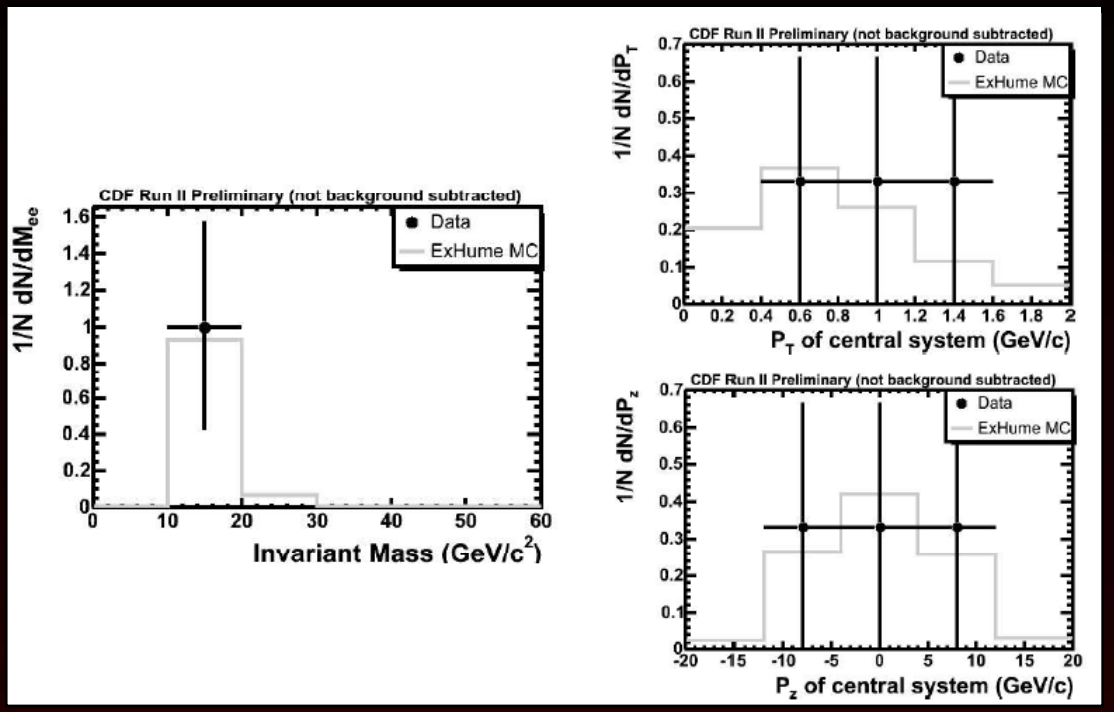
Exclusive $\gamma\gamma$ Study (1)



- ***Exclusive $\gamma\gamma$ events:***
  - *selected in the same way as e^+e^- (except tracking)*
  - *agreement of exclusive e^+e^- cross section gives confidence in analysis methodology*

Exclusive $\gamma\gamma$ Study (2)

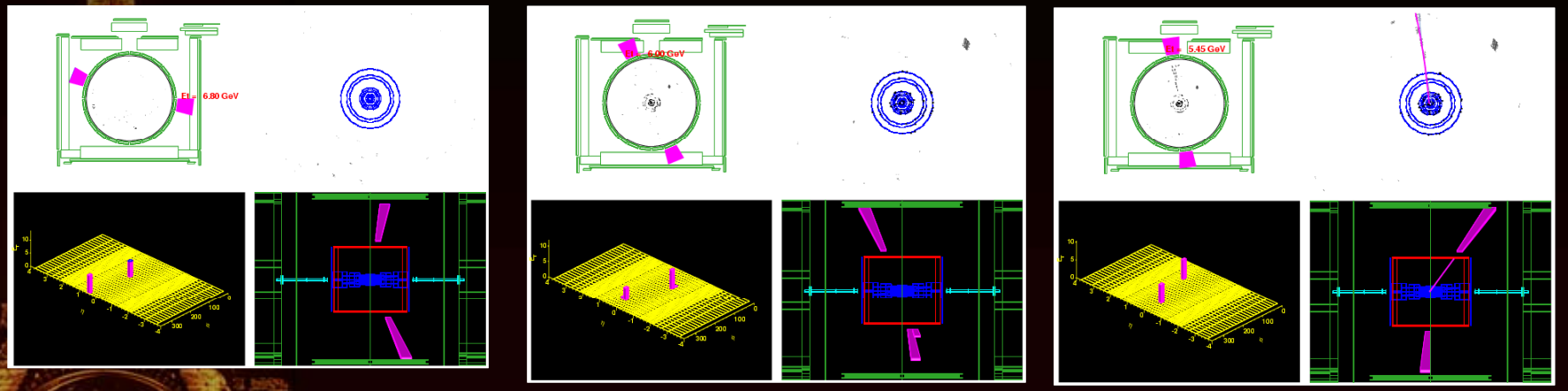
- *Good agreement on kinematics with ExHume MC (Monk & Pilkington. hep-ph/0502077)*
- *1^{+3}_{-1} events predicted from ExHuME MC. Two candidates are almost certainly $\gamma\gamma$ but the $\pi^0\pi^0/\eta\eta$ hypotheses cannot be excluded*



Exclusive $\gamma\gamma$ Candidates

3 candidate events are found in 532 pb^{-1} of Run II data.

- *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*
- *The an upper limit of the cross-section $p\bar{p}$--> p $\gamma\gamma\bar{p}$ is set at 410 fb with 95% confidence level*



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]
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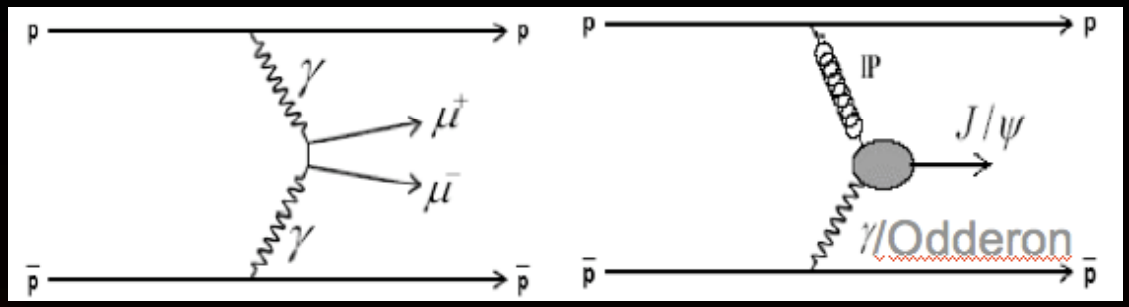
Submitted to PRL in July 2007

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

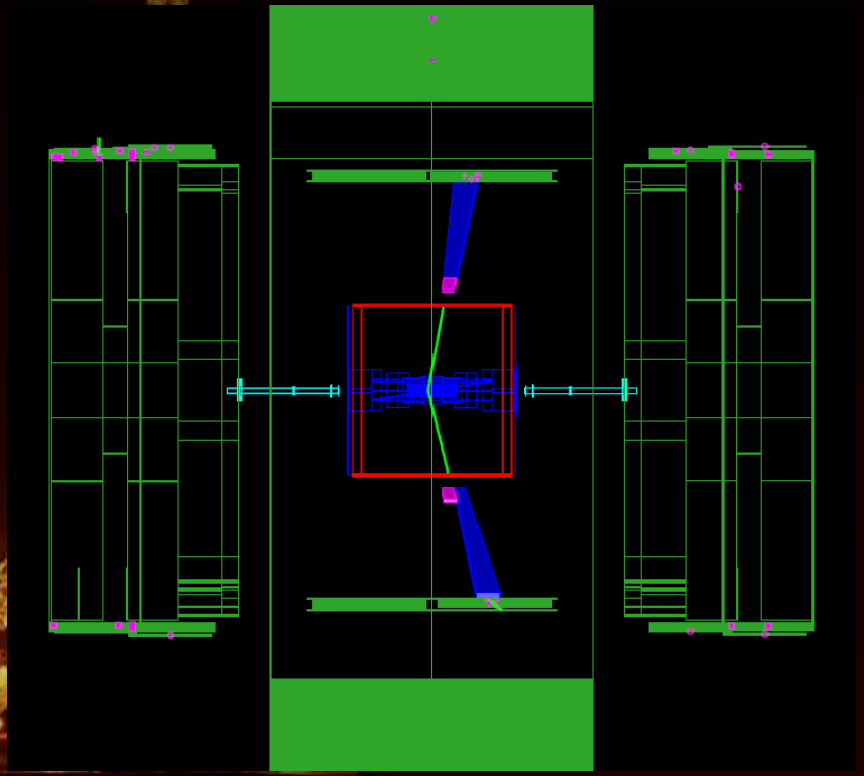
Exclusive $\mu^+\mu^-$ Production (1)

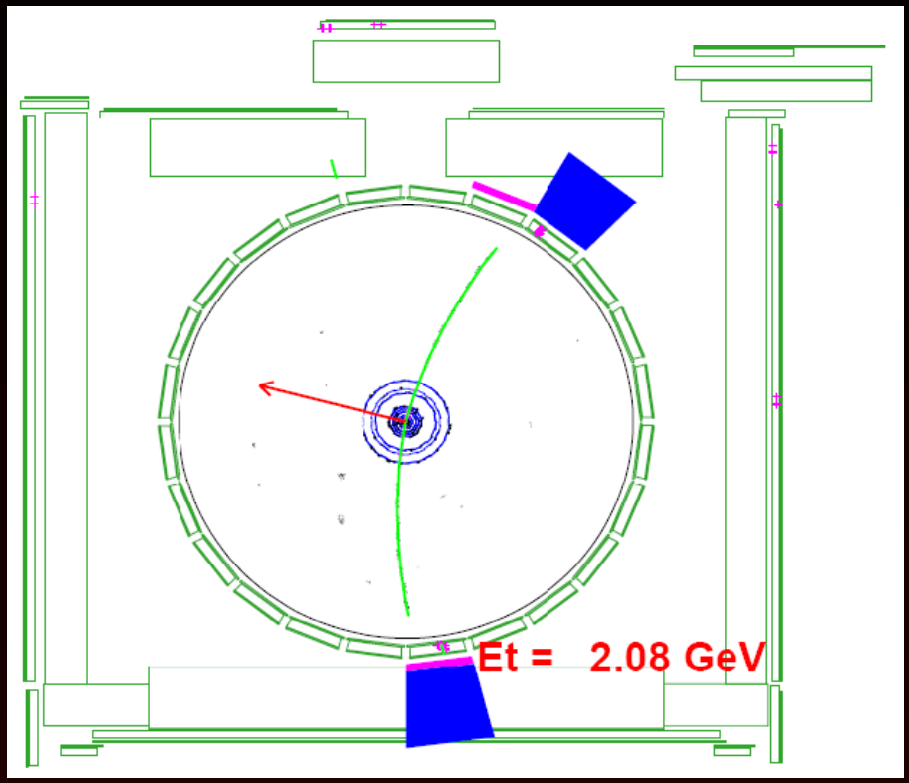


- ***Trigger (DIFF_CHIC_CMU1.5_PT1.5_TRK):***
  - *BSC Gap, east & west*
  - *muon + track (p_t > 1.3; $|\eta|$ < 1.2)*
  - *2.7 < M(muon + track) < 4.0 GeV*
- *No other activity in the events (to an $|\eta|$ of 7.4)*
- *The existing sample corresponds to a lumi 1298 pb^{-1}*
- *Also higher mass muons have just been stripped, (2 trigs with $p_t(\mu)$ > 4 GeV, 2 muons, no $\Delta\phi$ requirement).*
- *Should be very efficient for dimuons, with M >~ 9 GeV, covering the Upsilon region and above.*

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

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



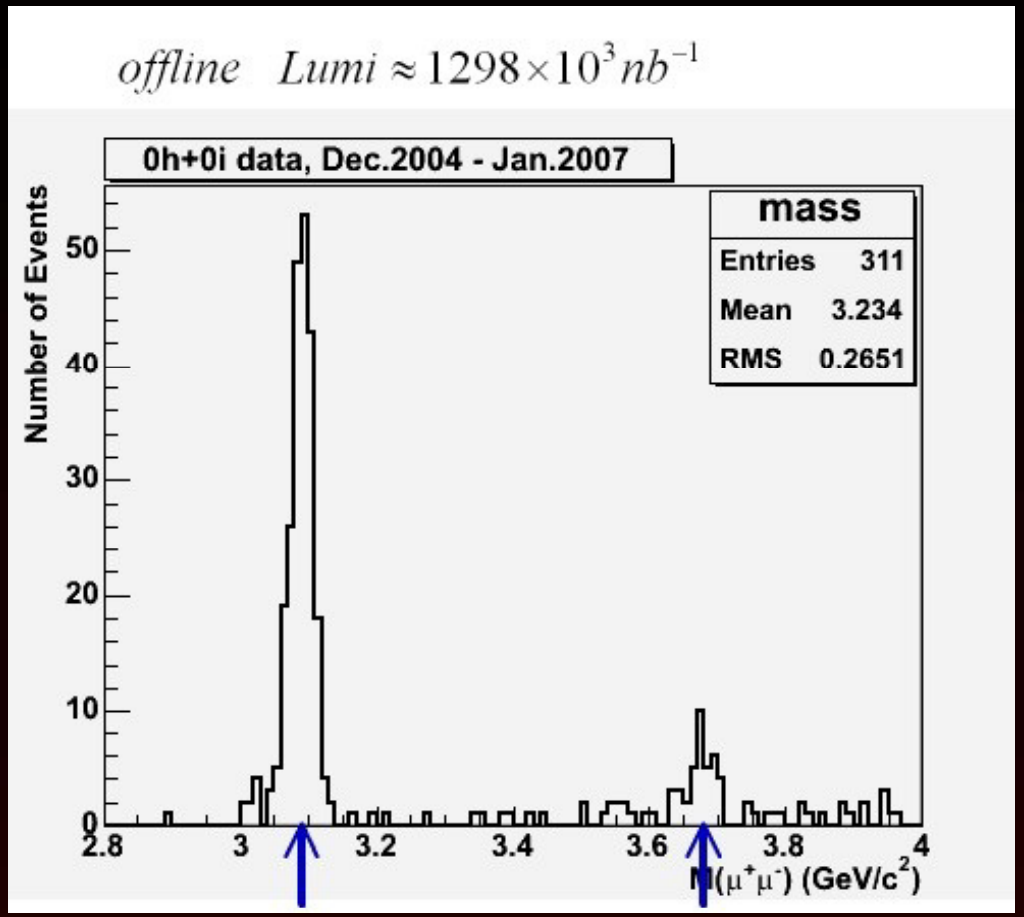


Exclusive $\mu^+\mu^-$ Production (3)

- ***Offline cuts***
  - *Loose quality cuts*
  - *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*

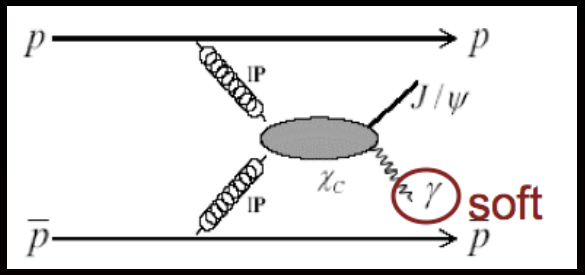
Exclusive $\mu^+\mu^-$ Candidates

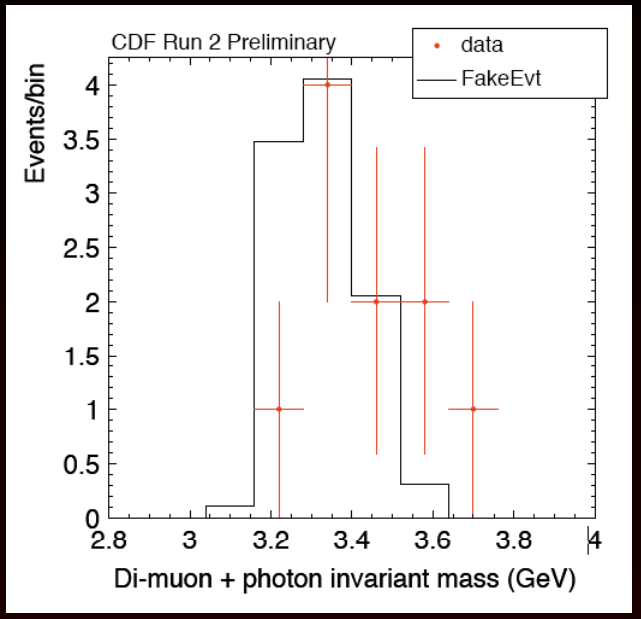
Many candidate events have been found (CDF-II Preliminary)



Exclusive χ_c Production

- *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*
- *Problems is understanding low energy photon background*





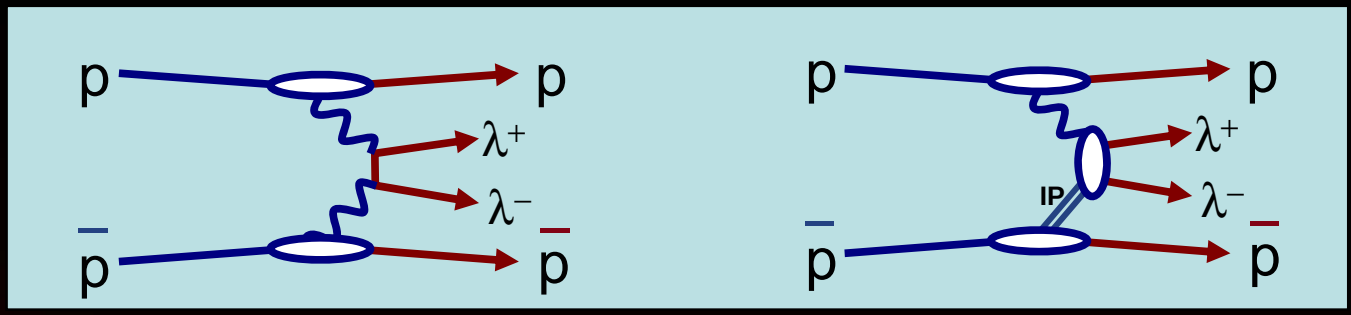
Candidate events (many more with new trigger but NB)

Conclusion

- *The paper on the observation of exclusive $p\text{-}\bar{p} \rightarrow p + e^+e^- + \bar{p}$ production has been published in PRL (March 2007)*
  - *Studies continue with new low E_T di-photon trigger*
- *The study of exclusive $p\text{-}\bar{p} \rightarrow p + \gamma\gamma + \bar{p}$ production has just been submitted to PRL (July 2007)*
  - *Studies continue with a new low E_T di-photon trigger*
- *The study of $p\text{-}\bar{p} \rightarrow p + \mu^+\mu^- + \bar{p}$, J/Ψ, J/Ψ', Upsilon, is underway*
- *The study of exclusive $p\text{-}\bar{p} \rightarrow p + \gamma\gamma + \bar{p}$ production is restarted*
- *Implications for the LHC*
  - *Use of $\gamma\gamma \rightarrow \mu^+\mu^-$ /e^+e^- as a luminosity monitor*
  - *Study of $\gamma\gamma \rightarrow \mu^+\mu^-$ as a calibration for FP420 is underway*
  - *The process $p\text{-}\bar{p} \rightarrow \gamma\gamma/\chi_c$ is a standard candle for the exclusive Higgs*
  - *We are understanding how to use the LHC as a $\gamma\gamma$ and a γ-p 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 $\gamma\gamma \to l^+l^-$
  - 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)*

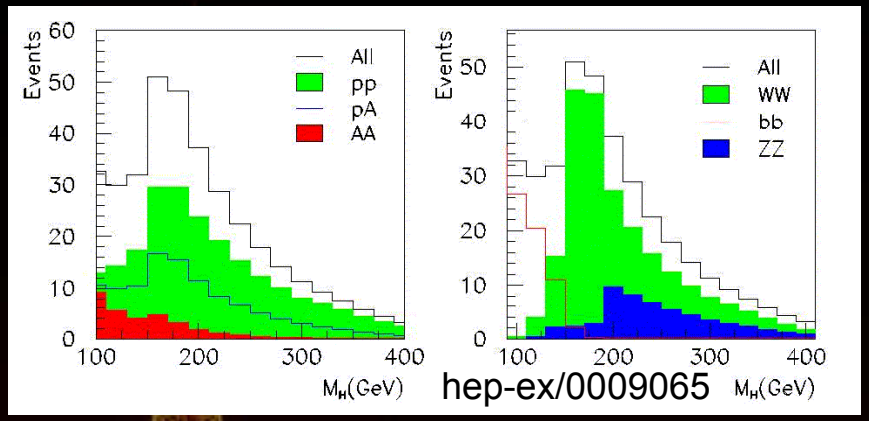
Related measurements:

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: for Exclusive Studies (2)



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.

Standard Model:

$\gamma\gamma \rightarrow W^+W^-$

$\gamma\gamma \rightarrow tt$

$\gamma\gamma \rightarrow H$

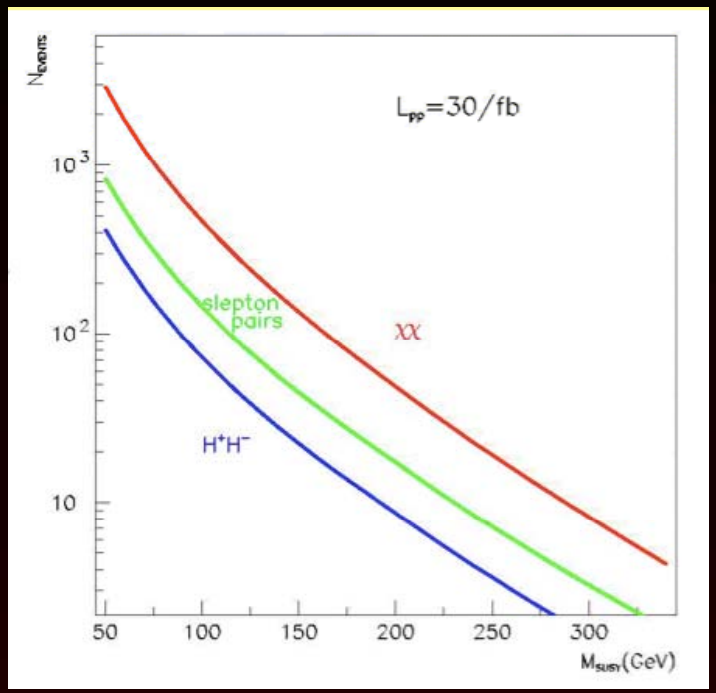
Beyond SM:

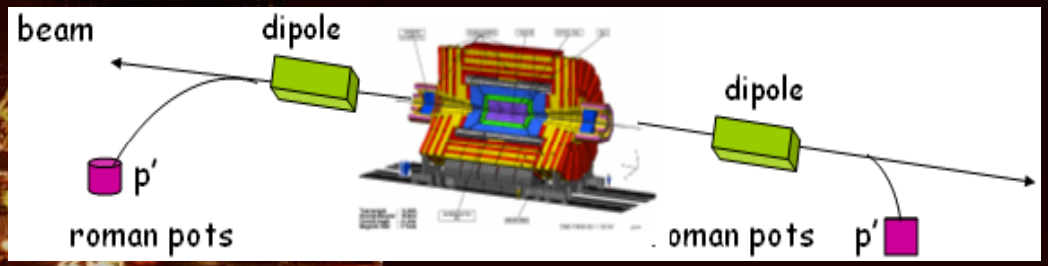
$\gamma\gamma \rightarrow H^+H^-$

$\gamma\gamma \rightarrow \chi\chi$

$\gamma\gamma \rightarrow S^+S^-$

~1% of pp luminosity

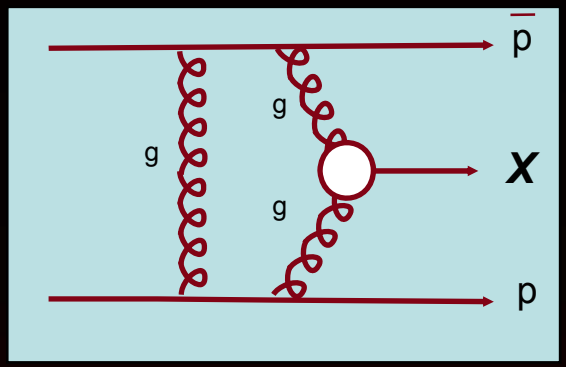




Reconstruct central state using FP420

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.

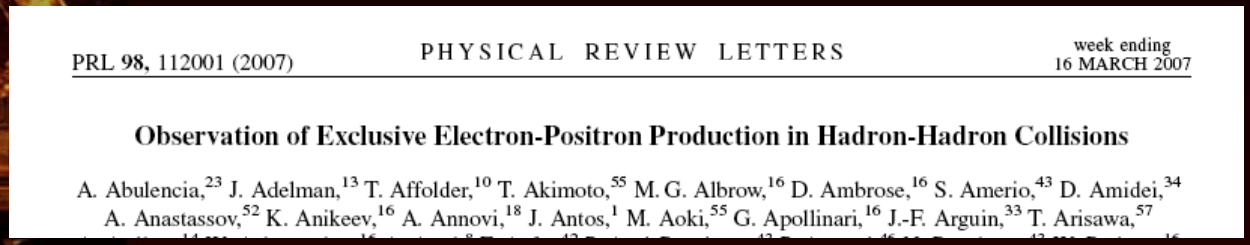
(Calculations of V.Khoze et al., show that pomeron-pomeron cross-sections for Higgs production are a few times larger than for the $\gamma\gamma$ case)

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 ± 3) %
  - Cosmic Rejection: (93 ± 3) %
  - Final State Radiation: (79 ± 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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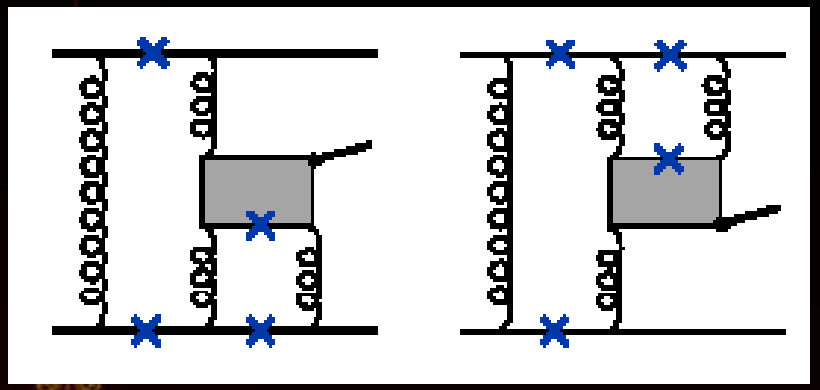
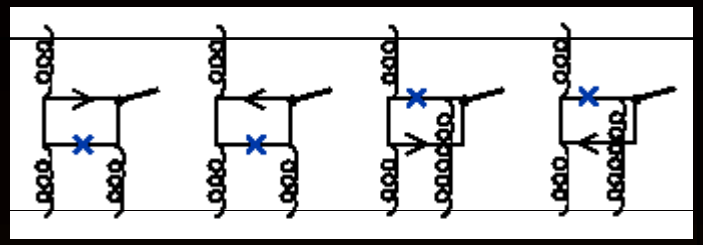
The Odderon





- *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.*