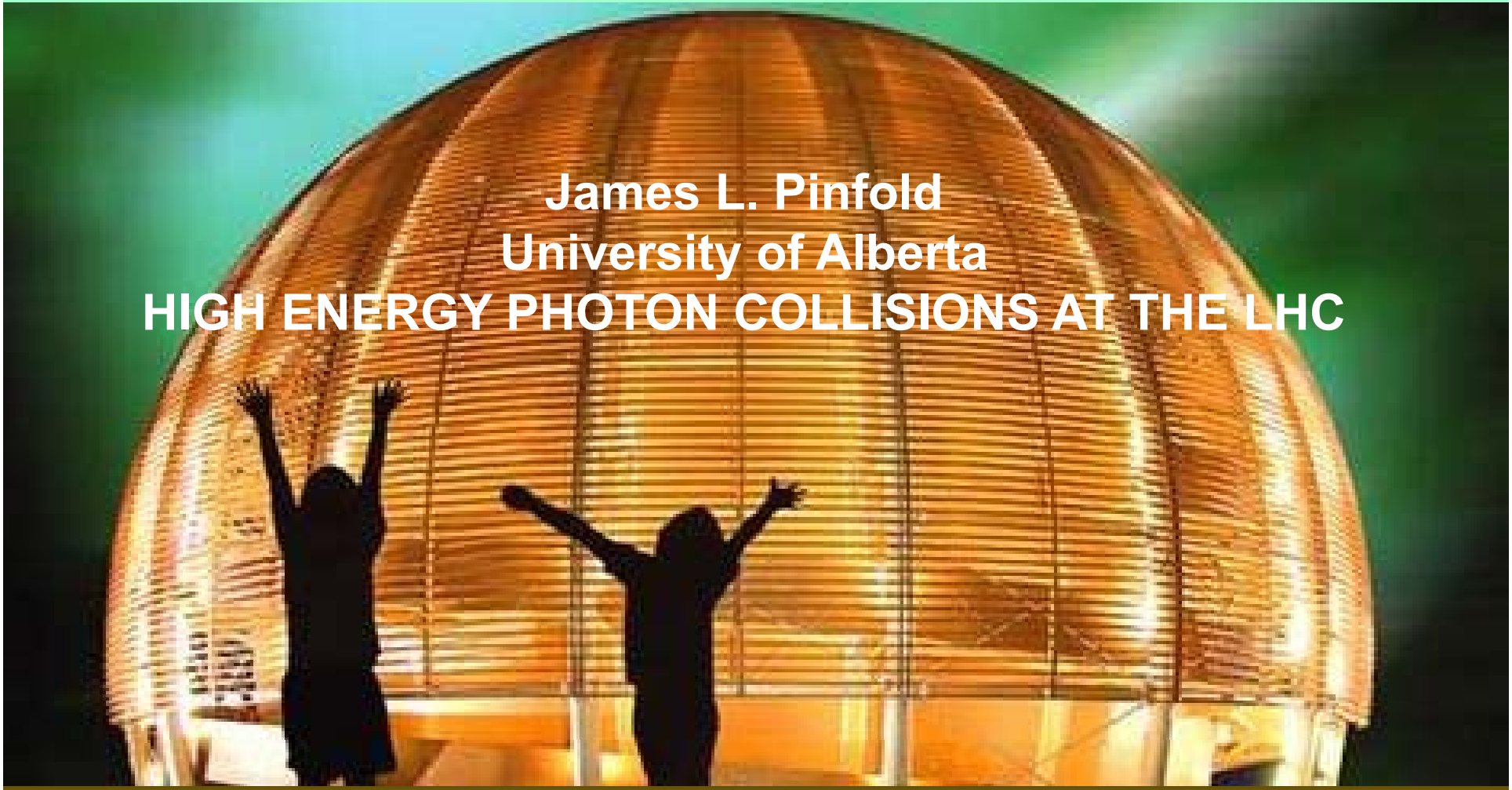
Exclusive Dilepton (e^+e^-,$\mu^+\mu^-$,J/Ψ, Ψ',Υ) and Diphoton Production at CDF II

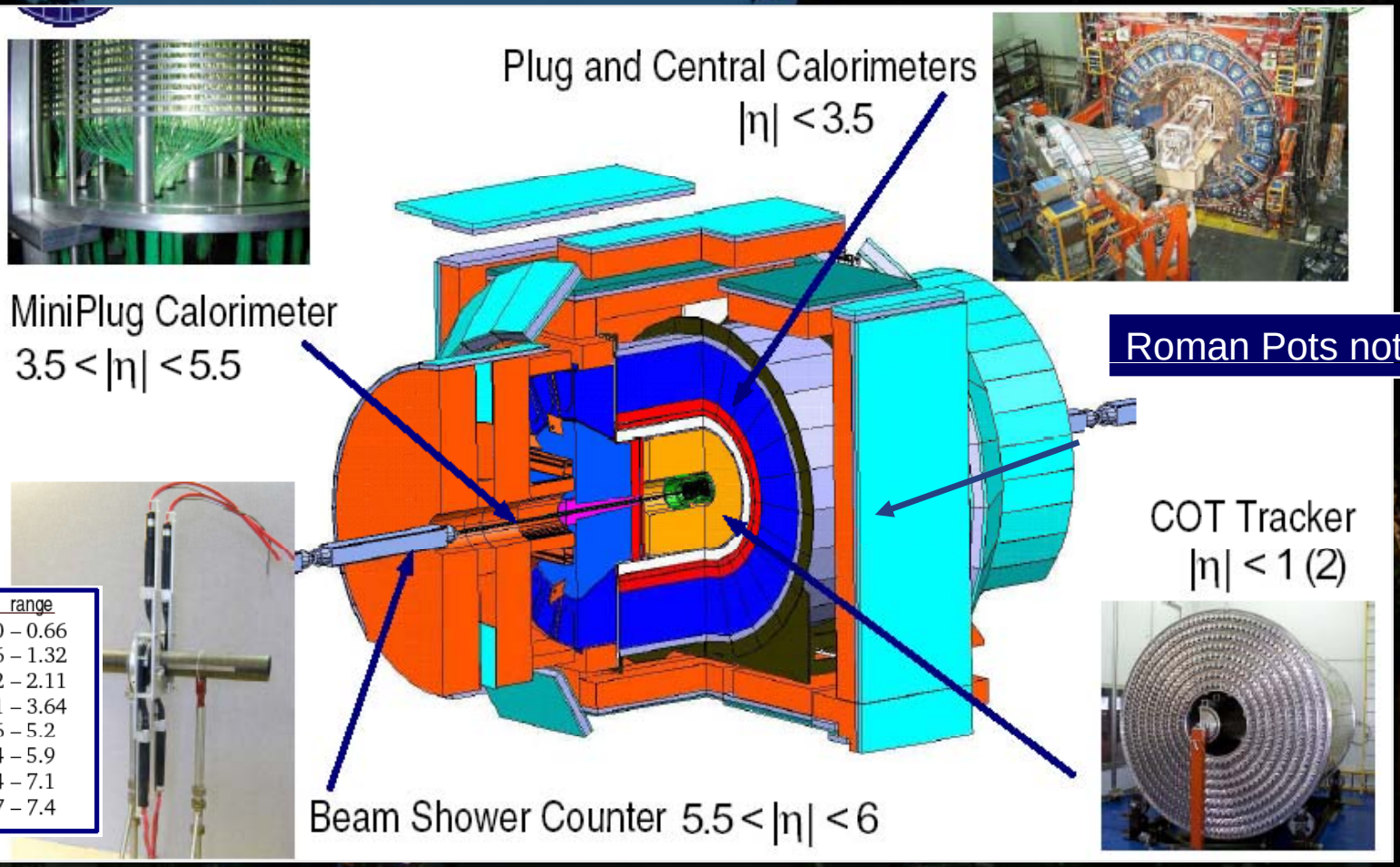


James L. Pinfold
University of Alberta

HIGH ENERGY PHOTON COLLISIONS AT THE LHC

MENU: CDF Motivation e^+e^- $\gamma\gamma$ $\mu^+\mu^-$,J/Ψ,Ψ',Υ χ_c Odderon Conclusions

CDF Detector + Performance



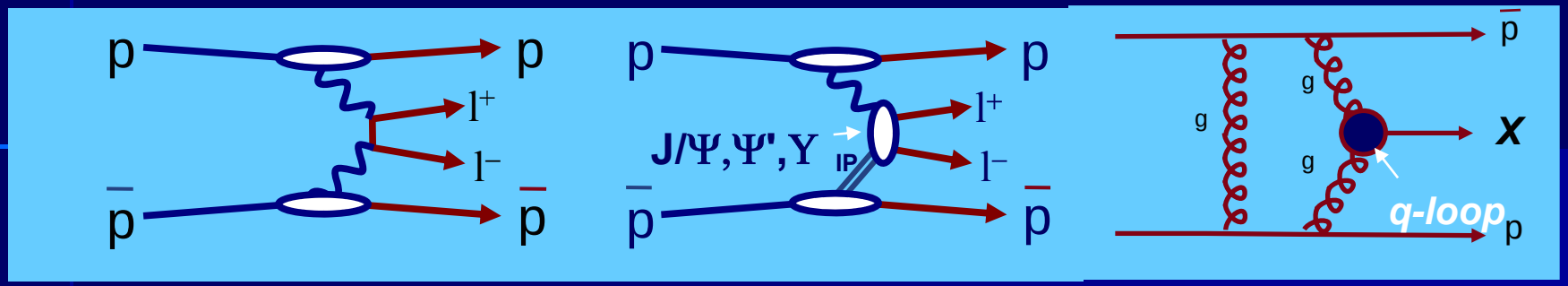
Region	η range
Central	0.00 – 0.66
End Wall	0.66 – 1.32
Mid Plug	1.32 – 2.11
Fwd Plug	2.11 – 3.64
Mini Plug	3.6 – 5.2
BSC 1	5.4 – 5.9
BSC 2	6.4 – 7.1
BSC 3	6.7 – 7.4

Roman Pots not used

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

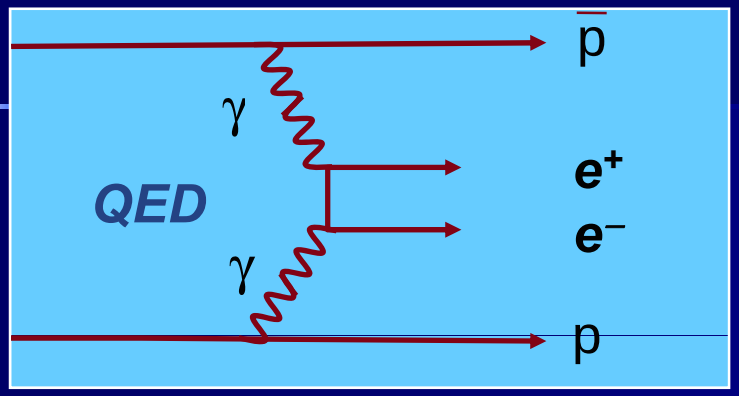
MENU: CDF Motivation e^+e^- $\gamma\gamma$ $\mu^+\mu^-$,J/Ψ,Ψ',Υ χ_c Odderon Conclusions

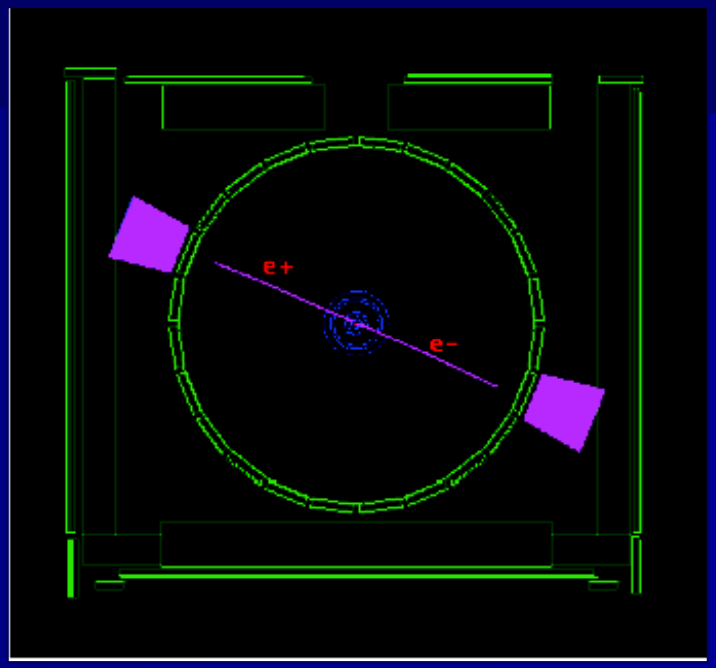
Motivation: for Exclusive Studies



- ***Motivations to study exclusive lepton pair production:***
  - *Potential to improve luminosity measurements at LHC since the cross section is known to better than ~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 (important in the search for new physics & Higgs in exclusive channel)*
- ***Main motivation to study exclusive pp→ p + $\gamma\gamma$ + p***
  - *This process is a "standard candle" for exclusive Higgs production*

Exclusive e^+e^- Production (1)





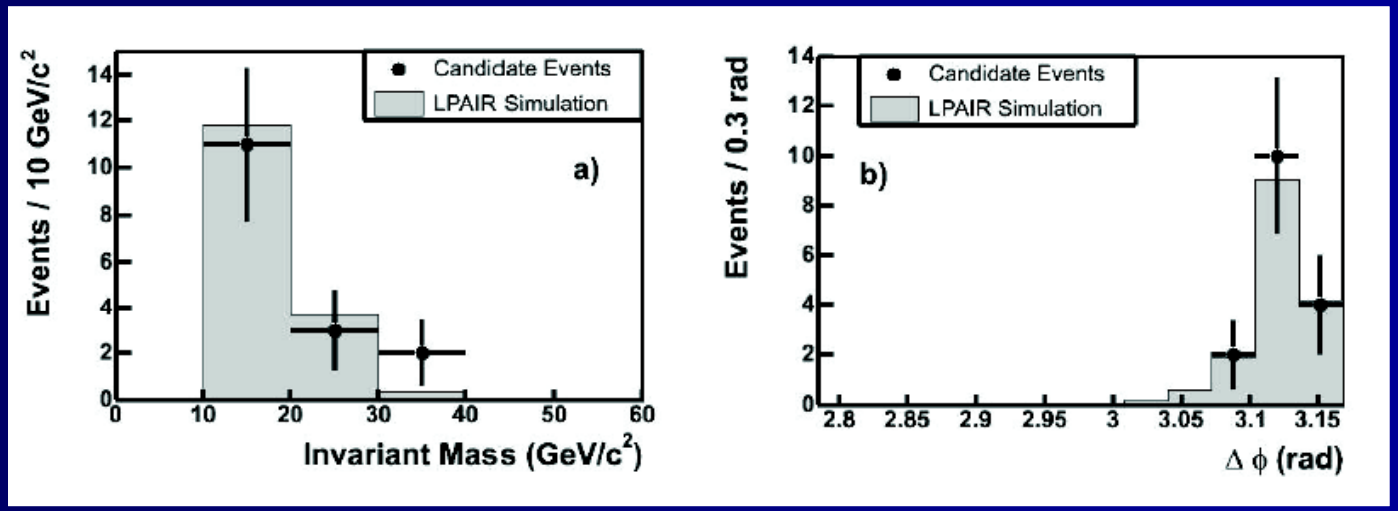
- *Central state produced via QED $\gamma\gamma \rightarrow e^+e^-$*
- *Protons do not dissociate*
- *Only e^+e^- are produced → nothing else*
- *Process has never been observed before in hadron-hadron collisions*

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 and |h| < 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 gg →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*



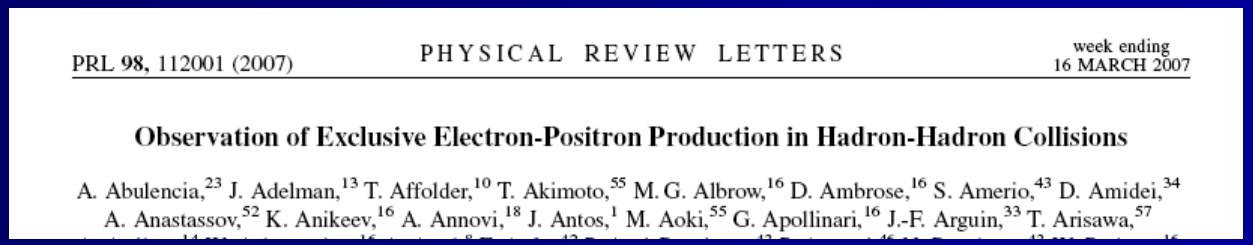
- ***Cross-section for $\gamma\gamma \rightarrow e^+e^-$ LPAIR theory:***

σ = 1.71 ± 0.01 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 produced e^+e^- interactions in hadron-hadron collisions***
- *The LHC can rely on measuring such processes for luminosity measurement, etc.*



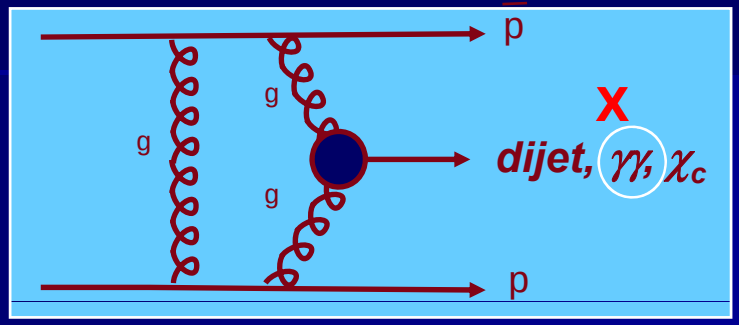
PRL 98, 112001 (2007) PHYSICAL REVIEW LETTERS week ending 16 MARCH 2007

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

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 many more candidates in new data with dedicated 2-EM shower trigger

Exclusive $\gamma\gamma$ Study (1)

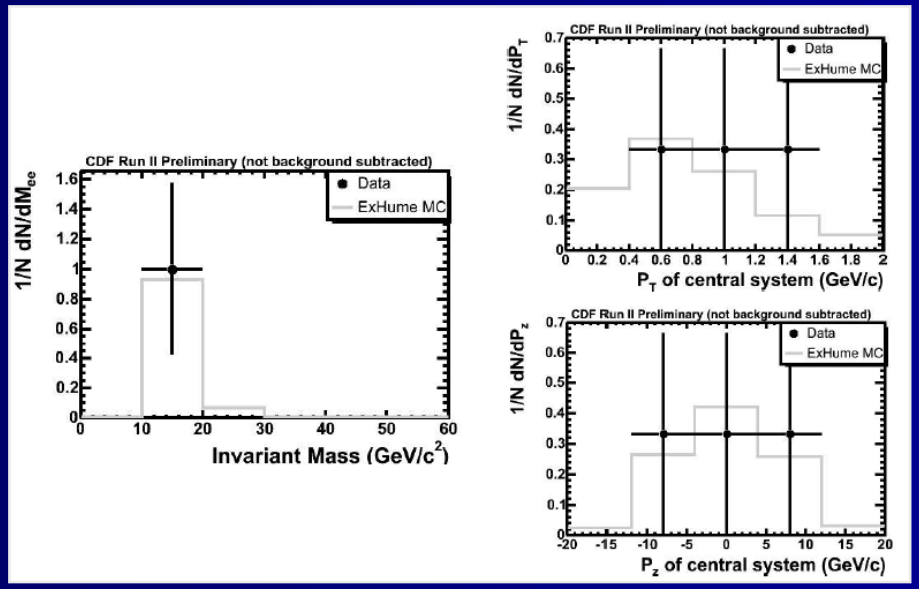


where X has $J^{PC} = 0^{++}$

- ***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*

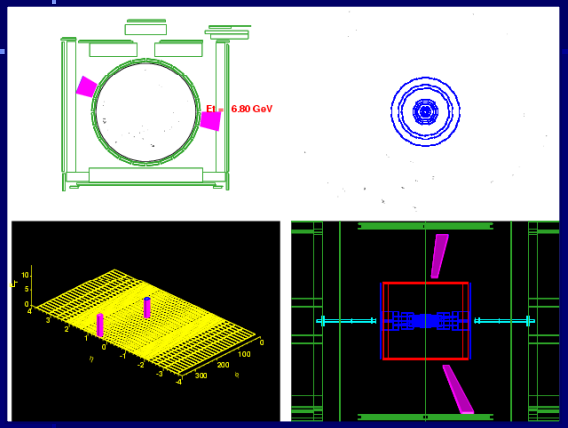
Exclusive $\gamma\gamma$ Study (2)

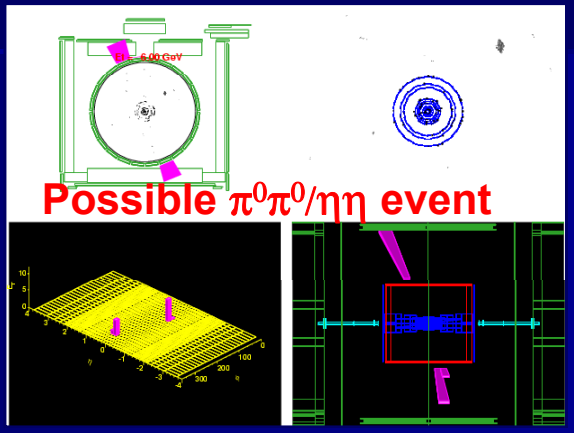
- ***3 candidate events are found in 532 pb-1 of Run II data.***
- ***Background 0.09 ± 0.04 events (dominated by misid. of excl.)***
- ***Good agreement on kinematics with ExHume MC*** *(Monk & Pilkington. hep-ph/0502077)*
- ***$0.8\ ^{+1.6}_{-0.5}$ events predicted from ExHuME MC*** *-2 candidates are almost certainly $\gamma\gamma$ but the $\pi^0\pi^0/\eta\eta$ hypotheses cannot be excluded*



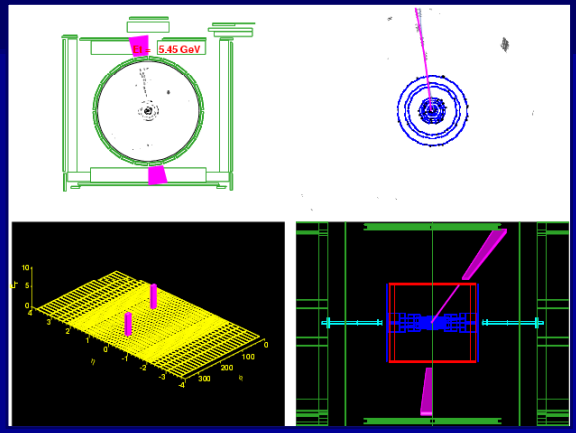
MENU: CDF Motivation e^+e^- $\gamma\gamma$ $\mu^+\mu^-$,J/Ψ,Ψ',Υ χ_c Odderon Conclusions

Exclusive $\gamma\gamma$ Candidates (1)





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



PRL 99, 242002 (2007) PHYSICAL REVIEW LETTERS week ending 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]

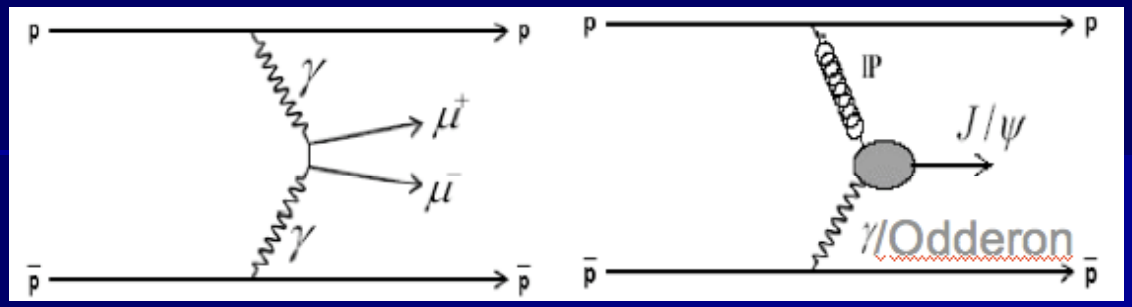
We have found >10 more candidates in new data with new di-EM shower trig.

Exclusive $\gamma\gamma$ Candidates (2)

- ***The upper limit of the cross-section pp --> p $\gamma\gamma$ p is set at 410 fb with 95% confidence level*** *(taking into account the background + its uncertainty, signal selection efficiency, & L_{int})*
- *If 2 of the 3 candidates are $\gamma\gamma$ events we obtain a cross section:*

Durham Group Khoze, Martin, Ryskin & Stirling hep-ph/0507040 Eur.Phys.J C38 (2005) 475 : 38 fb with factor ~ 3 uncertainty

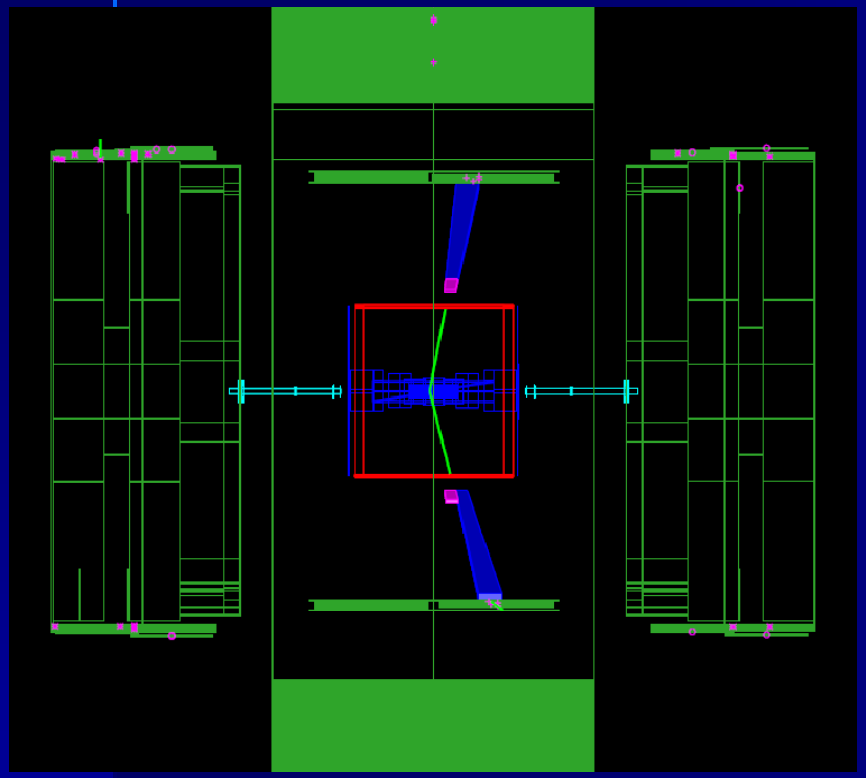
Exclusive $\mu^+\mu^-$ Production (1)

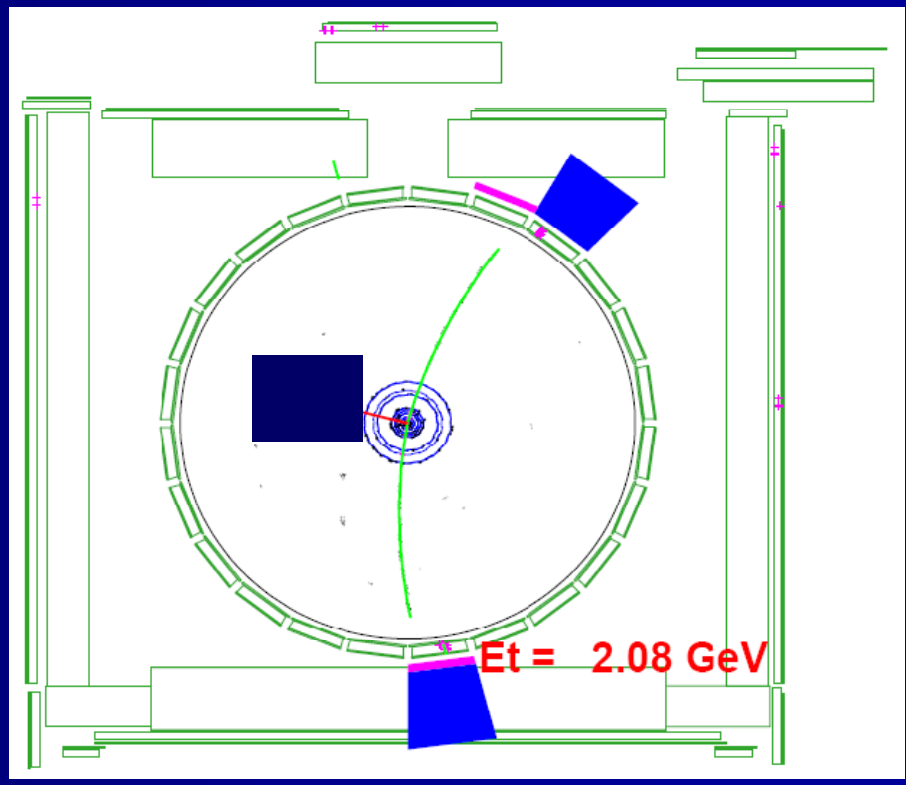


- ***Trigger (DIFF_CHIC_CMU1.5_PT1.5_TRK):***
  - *BSC Gap, east & west*
  - *muon + track (p_t > 1.3; $|\eta|$ < 1.2)*
  - *2.7 < M(muon + track) < 4.0 GeVc^2*
- *No other activity in the events (to an $|\eta|$ of 7.4)*
- *The existing sample corresponds to a luminosity 1.48 fb^{-1}*
- *Also higher mass muons have just been stripped, (trigs with $p_t(\mu)$ > 4 GeV, 2 muons, no Df 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

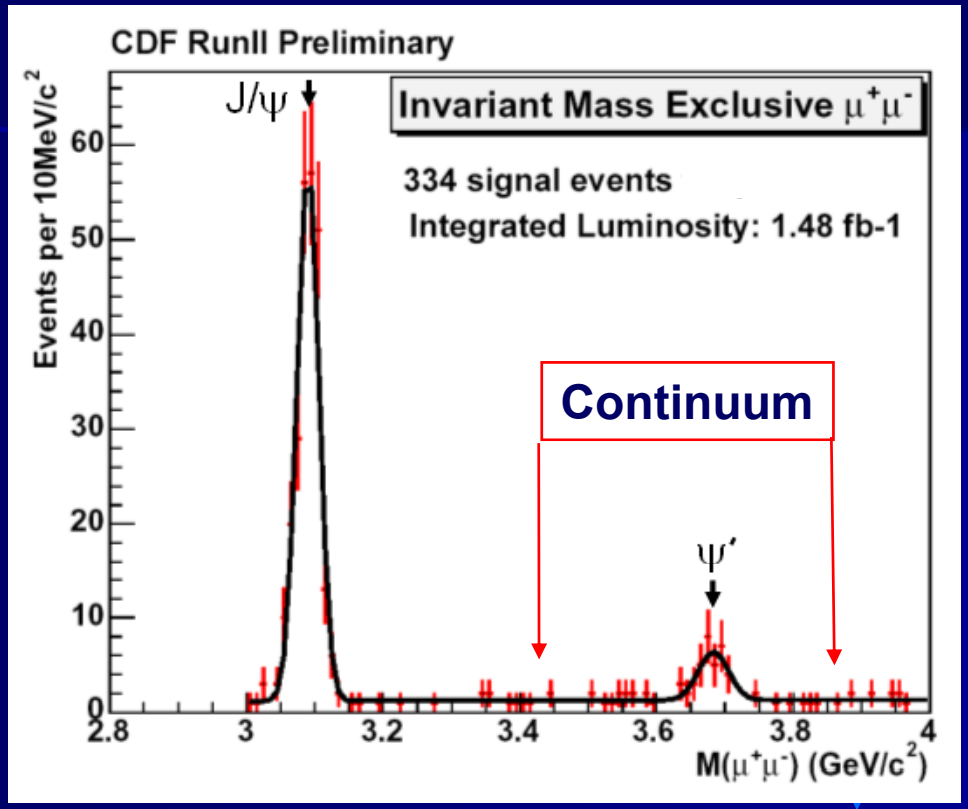




Exclusive $\mu^+\mu^-$ Production (3)

- ***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)

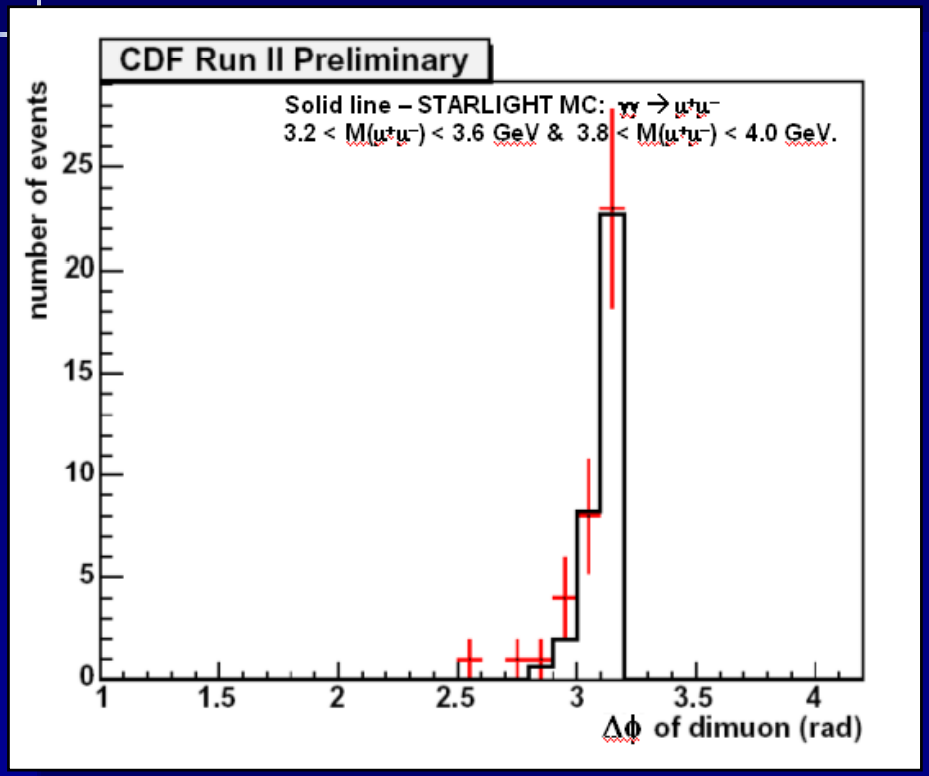


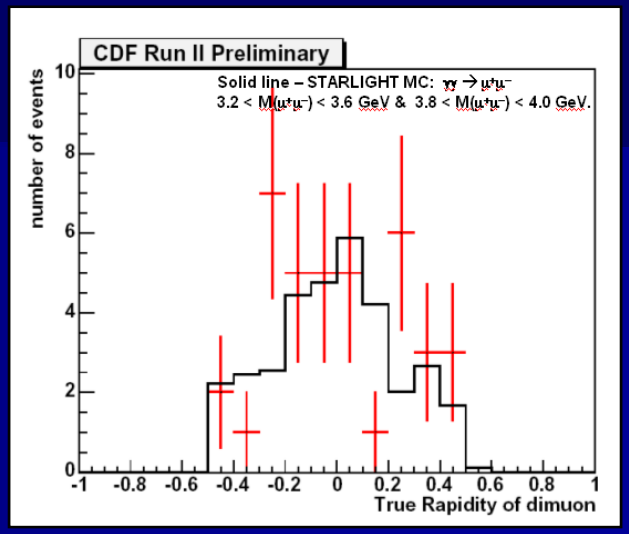
Many candidate events (334) have been found (CDF-II Preliminary)

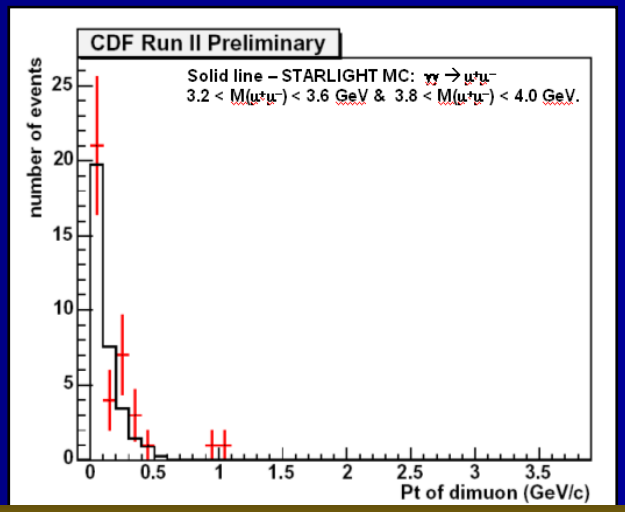
We expect to increase the number of candidates after review of the cuts

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

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



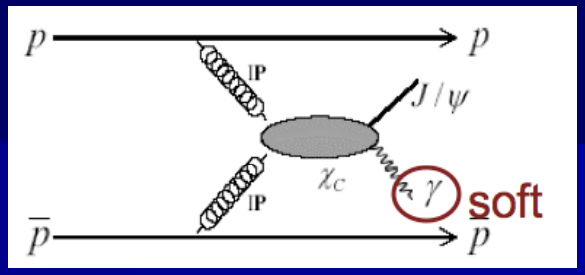


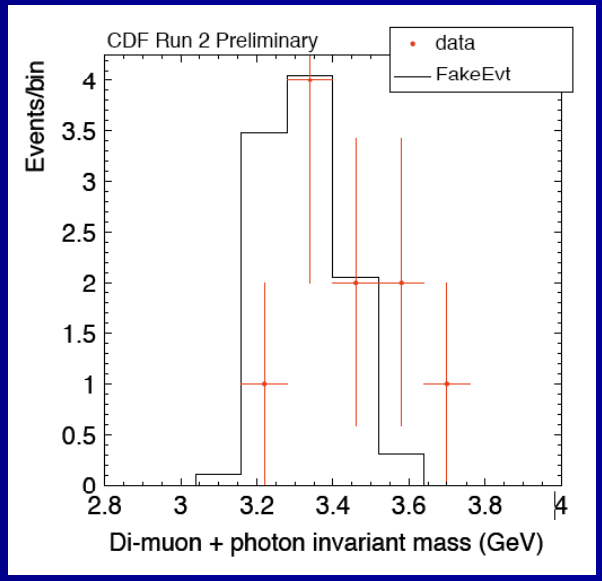


- *Good agreement on kinematics with STARLIGHT MC (Klein & Nystrand)*

Exclusive χ_c Production Background

- *Similar selection as $\mu^+\mu^-$ search with additional single isolated EM shower req.*
- *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*
- ***Many more events with new trigger***





Inelastic $B(\chi_c \to J/\psi\gamma \to \mu^+\mu^-\gamma)$

$\times$ moderate trigger acceptance

$\times$ $\exp(-100\sin^2\theta)$

Exclusive $\mu^+\mu^-$ Candidates (High Mass) (1)

- *Find Exclusive events using*
  - *Number of associated tracks = 0*
  - *Kinematics: $\Delta\phi \approx 180^o$, $\Delta p_T \approx 0$, (or $\Sigma P_T \approx 0$)*
- *Trigger: 2 central muons with $p_T > 4$ GeV/c*
- *L = 890/pb^{-1} ~ 2.3 M events.*
- *Remove cosmic rays (timing + colinearity)*
- *Require on beam-line. Count additional (associated) tracks (n_ass) within 5 cm of $\mu^+\mu^-$ vertex.*
- *Cleanliness, backgrounds & acceptances being studied.*
- *Number of events "reasonable" for QED process & Lumi.*

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

Invariant Mass - Upsilon Region

$\Delta\phi > 120^\circ, m(\mu^+\mu^-) < 7\,GeV$

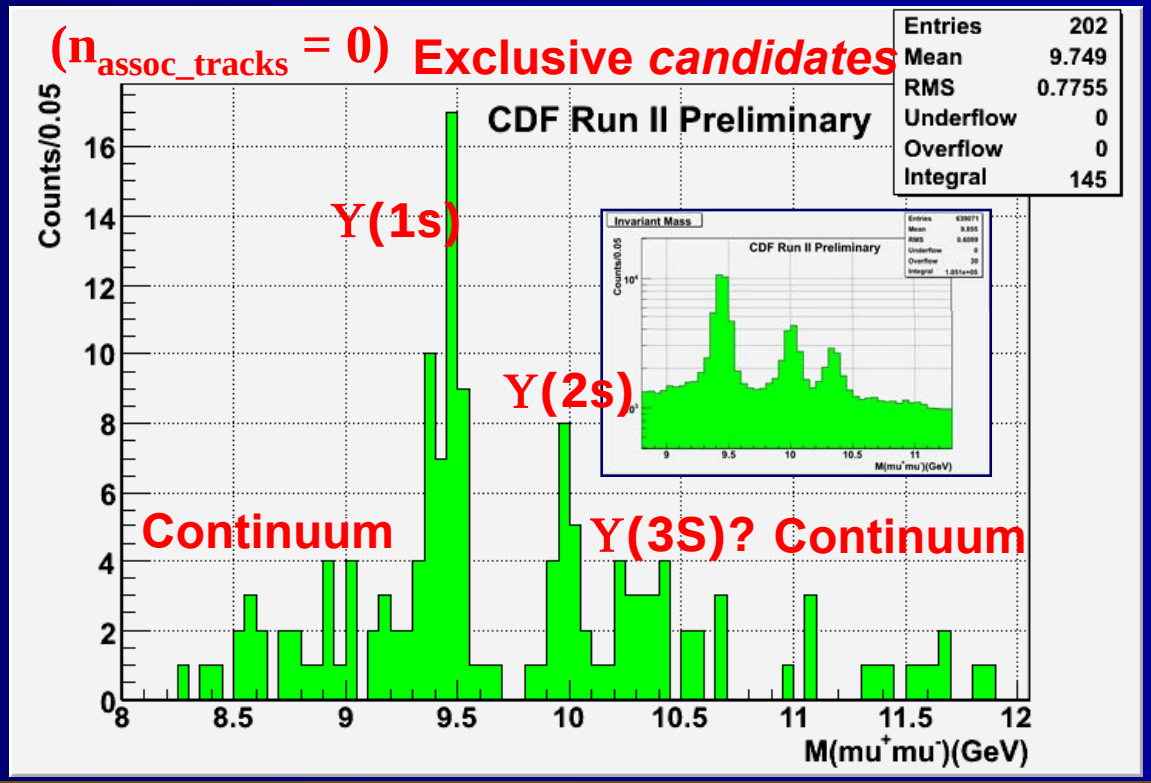
Branching ratios for μ+μ- channels:

Υ(1s)[9.46 GeV] : 2.5%

Υ(2s)[10.02 GeV] : 1.3%

Υ(3s)[10.36 GeV] : 1.8%

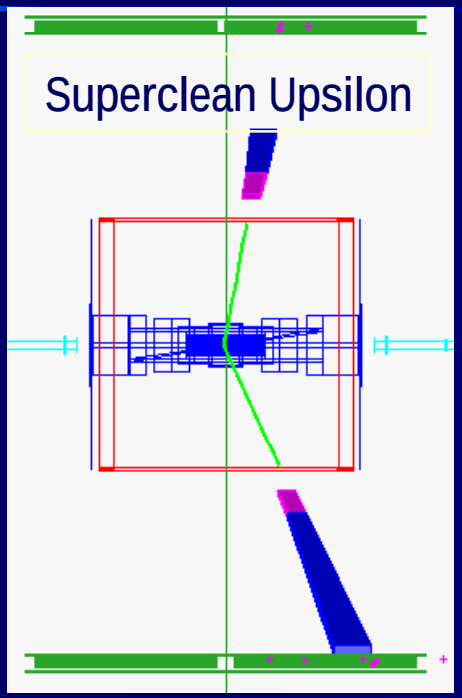
Clearly visible peaks Υ(1s) and Υ(2s), perhaps Υ(3S) too. + continuum

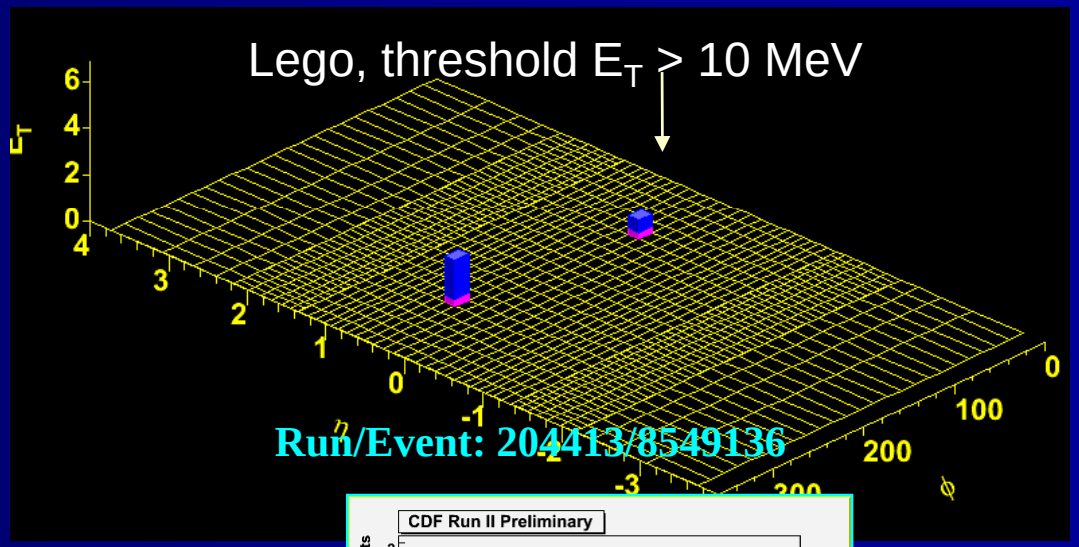


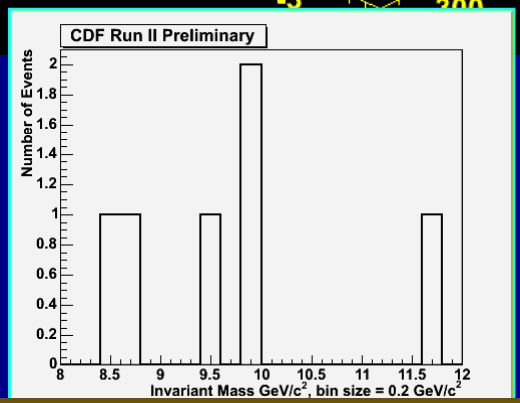
MENU: CDF Motivation e^+e^- $\gamma\gamma$ $\mu^+\mu^-$,J/Ψ,Ψ',Υ χ_c Odderon Conclusions

Exclusive $\mu^+\mu^-$ Candidates (High Mass) (3)

Now apply "super clean" exclusivity cuts as in low mass l-pair mass i.e. no pile-up, and only μ-pairs detected





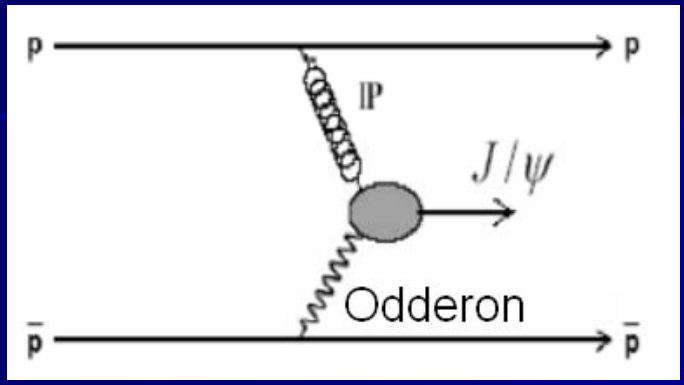


145 events in 8 – 12 GeV region

→6 events + 4 M($\mu+\mu-$) > 12 GeV.

(Most of reduction is killing pile-up)

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 hh-bar data seem to establish that HE 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', Υ peaks unlike the χ_c background*

Conclusion

- *The paper on the observation of exclusive p-p → p + e^+e^- + p production has been published in PRL (March 2007)*
  - *Studies continue with new low E_T di-photon trigger*
- *The study of exclusive p-$\bar{p}$ → 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>3GeV)*
- *The study of p-p → p + $\mu^+\mu^-$ + p, J/ψ, J/ψ ', Υ, is underway*
- *Implications for the LHC*
  - *Use of $\gamma\gamma \to \mu^+\mu^-$ /e^+e^- as a luminosity monitor*
  - *Study of $\gamma\gamma \to \mu^+\mu^-$ g-p → $\Upsilon \to \mu^+\mu^-$ as a calibration for FP420 is underway*
  - *Exclusive study of p-p → J/Ψ, Ψ',... → $\mu^+\mu^-$ is a good place to search for the odderon*
  - *The process p-p → $\gamma\gamma/\chi_c$ is a standard candle for the exclusive Higgs*
  - *We are understanding how to use the LHC as a $\gamma\gamma$, γ-p (γ– IP) & IP- IP collider*

MENU: CDF Motivation e^+e^- $\gamma\gamma$ $\mu^+\mu^-$,J/Ψ,Ψ',Υ χ_c Odderon Conclusions

Extra Slides

Tevatron Performance

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

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

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

radius = 1 km
36 bunches

$\sigma_{inel} = 60$ mb

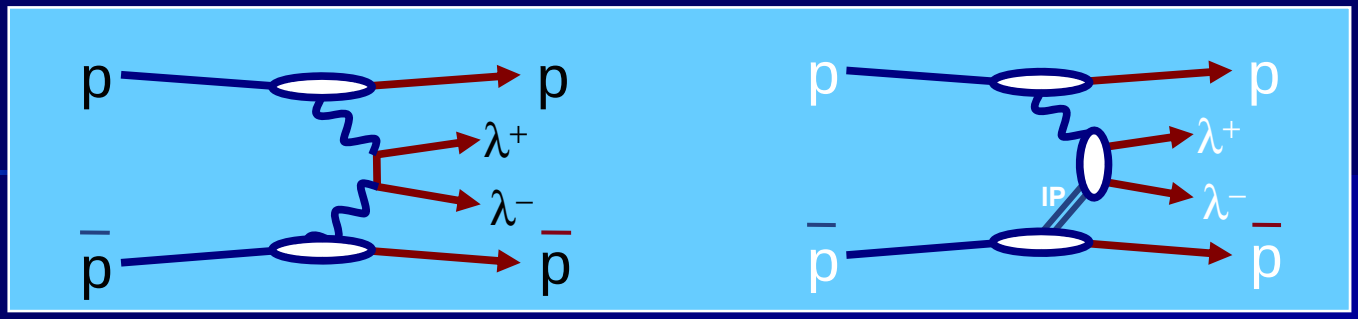
$\overline{n} = \sigma_{inel}\ \mathscr{L}_{inst}\ \overline{\Delta t}_{bunch}$

~ 1 to 6 interactions per crossing

very important when searching for exclusive states without proton taggers

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

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)*

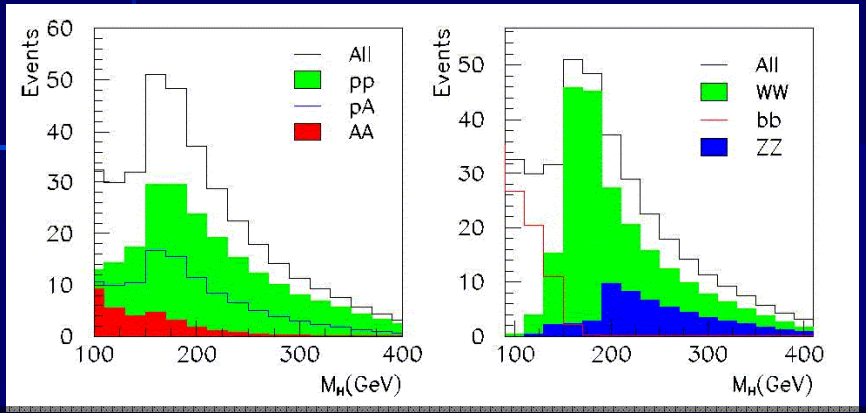
Related measurements:

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)

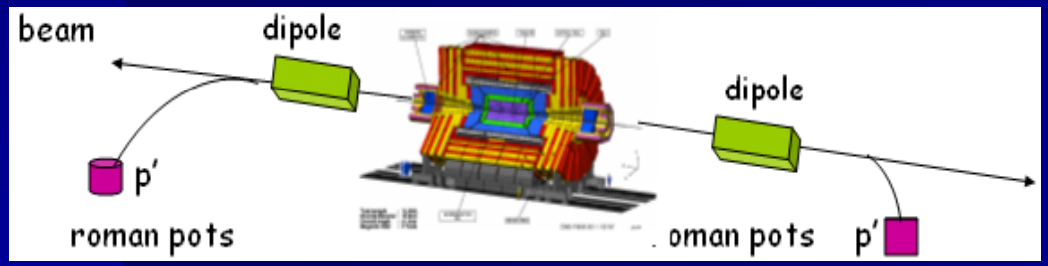


Number of Higgs events for single tags and assuming integrated luminosity of 30, 0.3 and 0.03 fb^{-1} for *pp*, *pAr* and *ArAr* collisions, respectively.

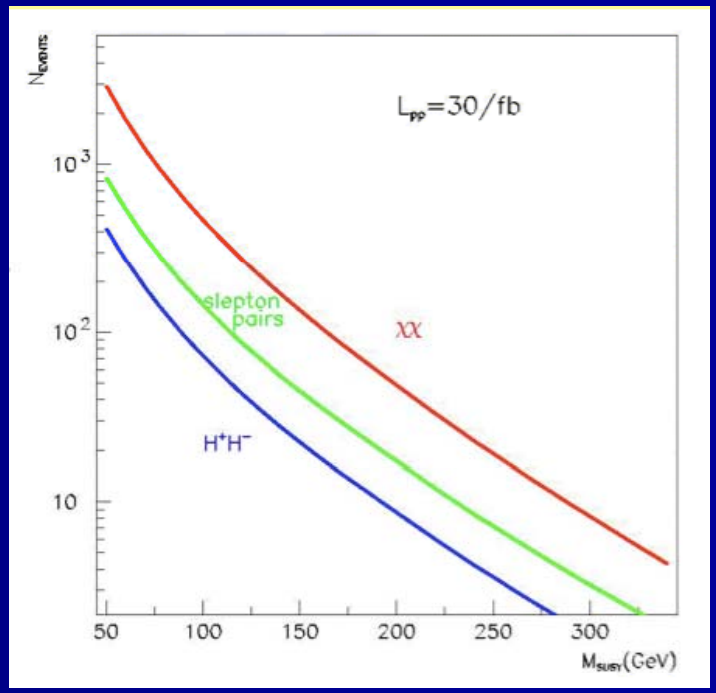
$\gamma\gamma \to tt$
$\gamma\gamma \to H$

$\gamma\gamma \to \chi\chi$
$\gamma\gamma \to S^+S^-$

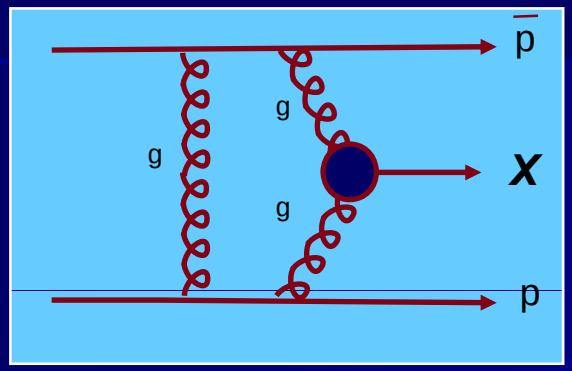
~1% of pp luminosity



Reconstruct central state using FP420



Motivation: for Exclusive Studies (3)



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:*

  $\forall\ \gamma\gamma$ *- 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)*

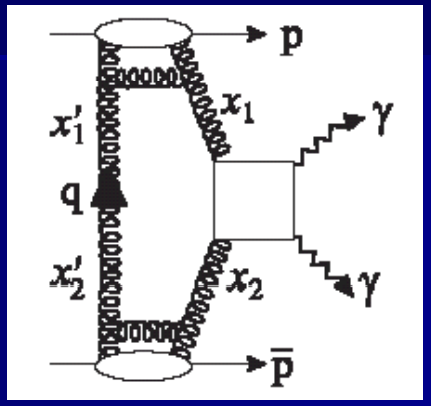
Central Exclusive 2-Photon Production

Cleanest test of p+H+p theory

MGA et al. (2001) hep-ex/0511057

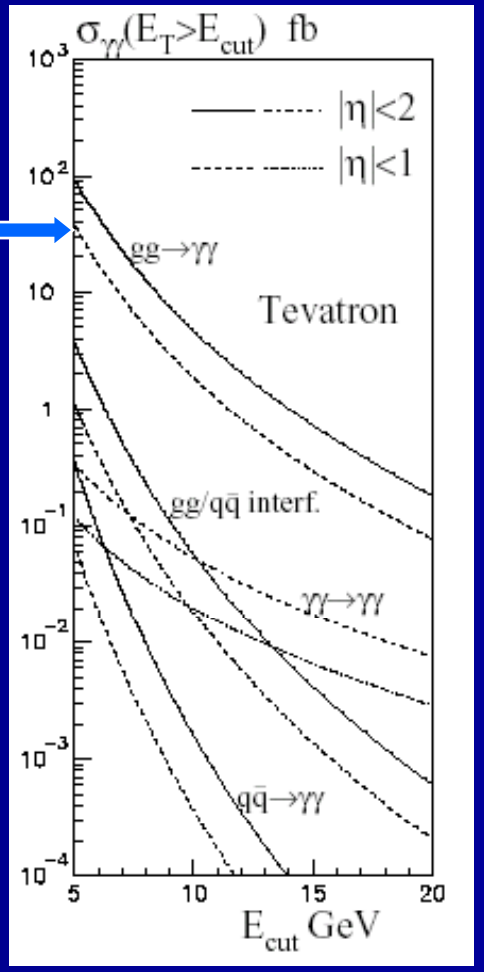
Khoze, Martin and Ryskin, hep-ph/0111078, Eur.Phys.J. C23: 311 (2002)
KMR+Stirling hep-ph/0409037

QCD diagram identical to pHp



Tevatron

38 fb



Claim factor ~ 4 uncertainty

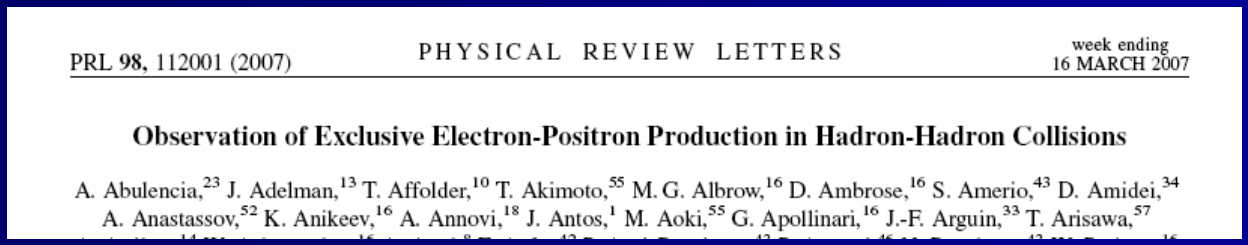
Exclusive e^+e^- Study Results

- 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

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

$\sigma_{measured} = 1.6(stat)\pm0.3(sys)pb$ *corresponds to 5.5σ observation"*

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

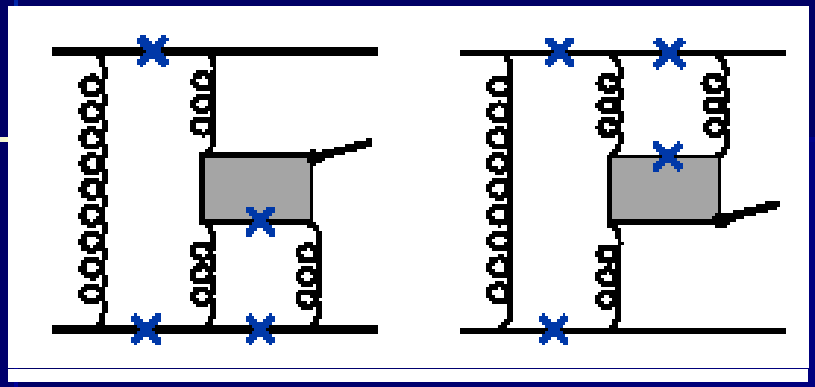


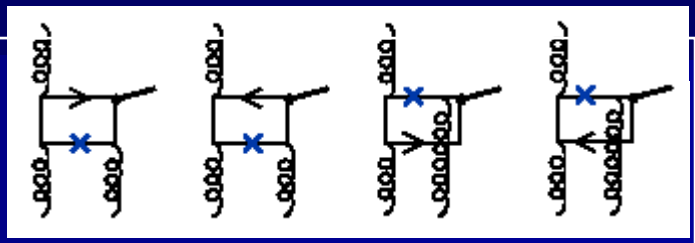
PRL 98, 112001 (2007) PHYSICAL REVIEW LETTERS week ending 16 MARCH 2007

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] 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]

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.*