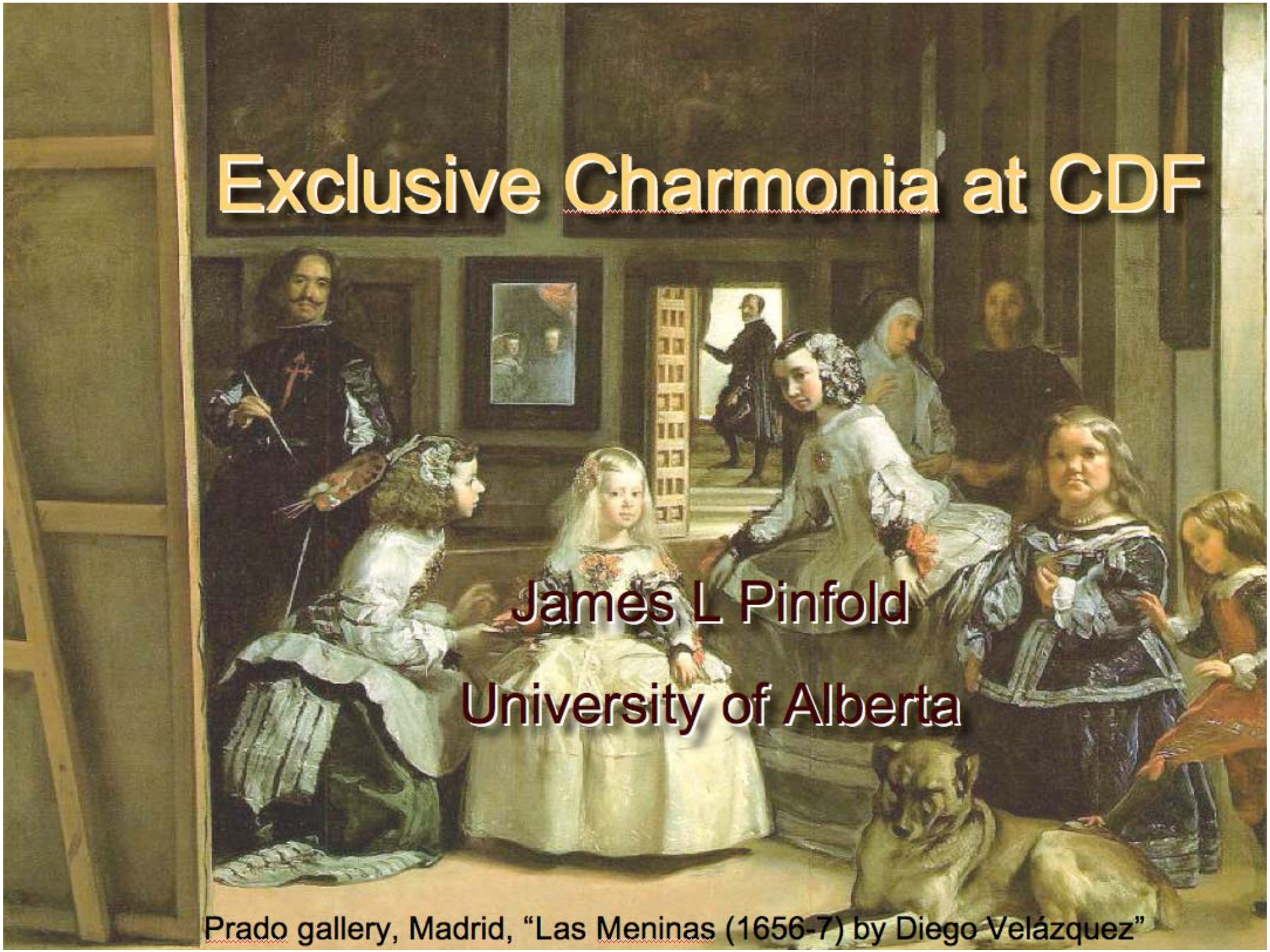
Exclusive Charmonia at CDF

James L Pinfold

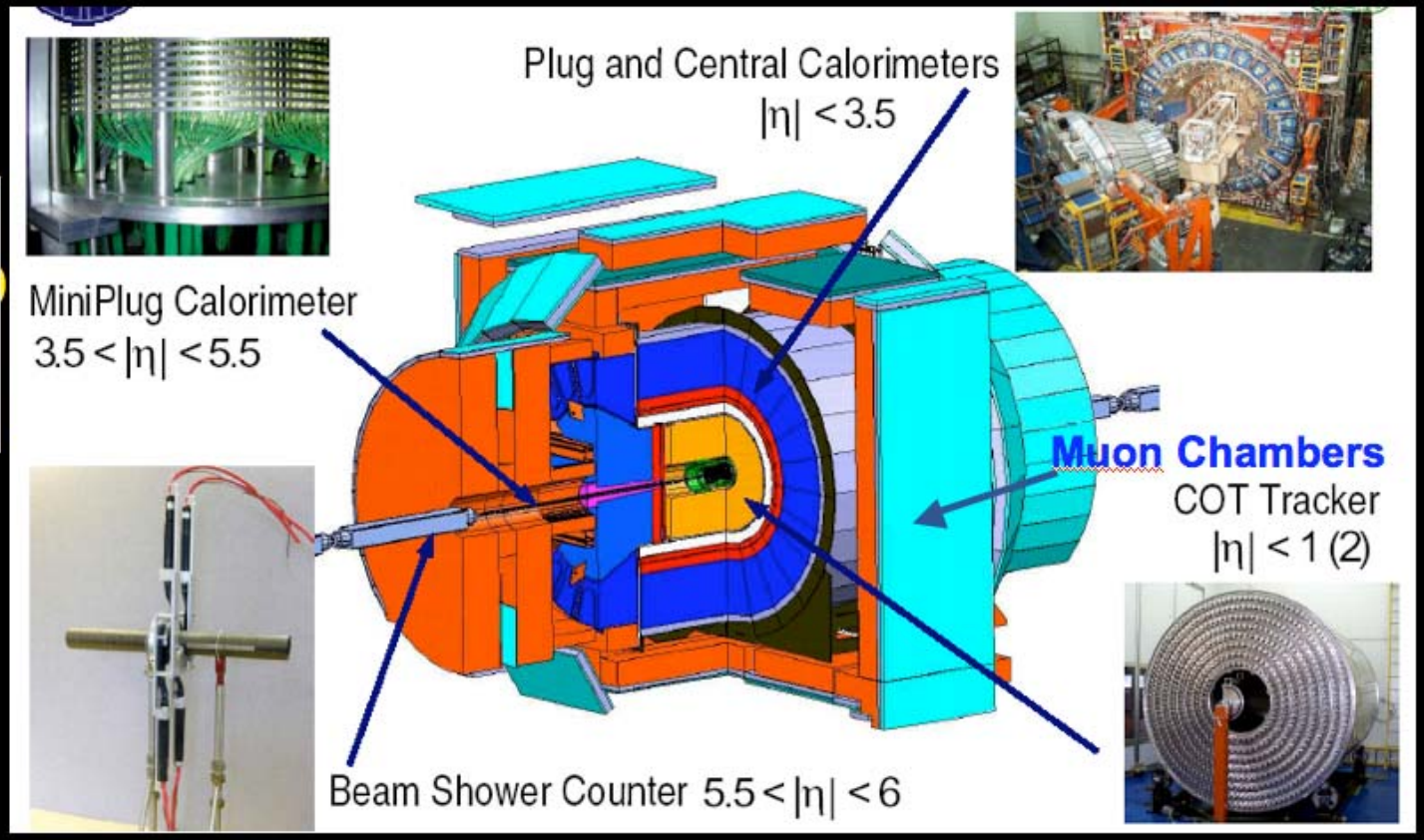
University of Alberta



Prado gallery, Madrid, “Las Meninas (1656-7) by Diego Velázquez”

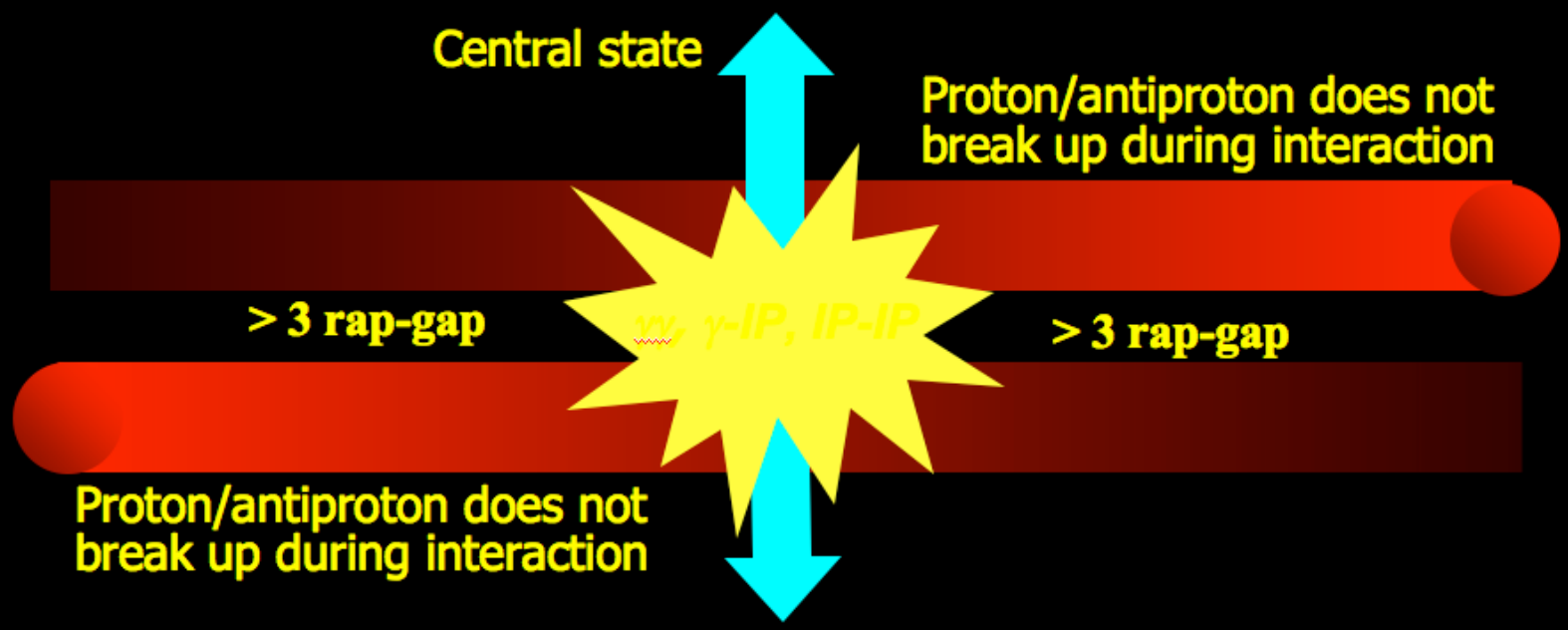
CDF Detector (2)

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



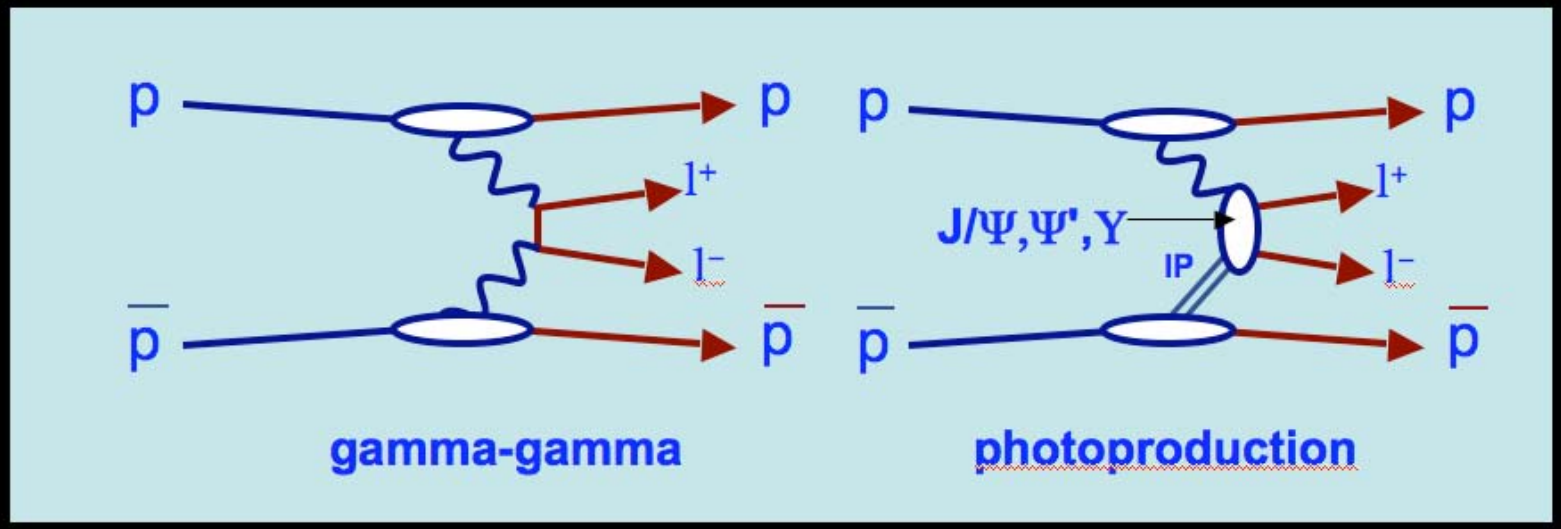
***A Roman Pot deployed detector** is placed on one side of CDF at at 60m from the IP. (RPS acceptance ~80% for 0.03 < x < 0.1 and |t| < 0.1)*

Central Exclusive Physics



… both protons coherently scattered. *Central state fully specified and measured, unlike "inclusive" production:*

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



Trigger (DIFF_CHIC_CMU1.5_PT1.5_TRK):

BSC Gap, east & west (BSC1 - $5.4 \leq |\eta| \leq 5.9$)

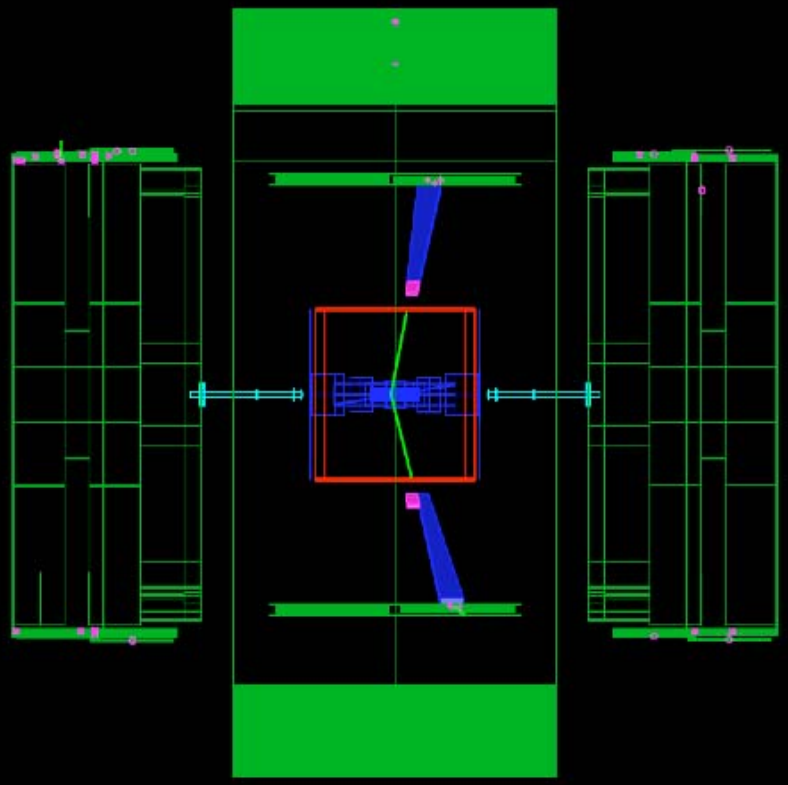
muon + track ($p_t > 1.3$; $|\eta| < 1.2$)

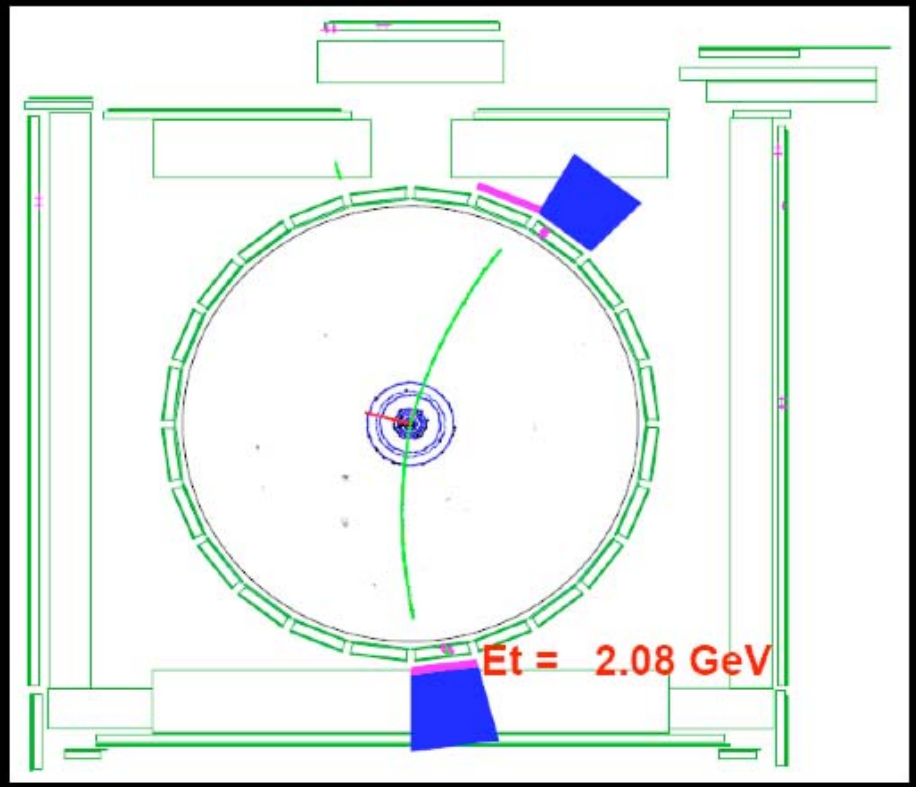
$2.7 < M(\text{muon} + \text{track}) < 4.0$ GeVc^2 (3rd level)

***The existing sample** corresponds to a lumi of 1.48 fb^{-1}*

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

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





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

Offline cuts:

Loose quality cuts

Two oppositely charged muon tracks

No other activity in the events (to an $|\eta|$ of 7.4)

$P_T(\mu) > 1.4$ GeV/c & $|\eta(\mu)| < 0.6$

Cosmic ray cuts (abs (delta_TOF) < 3 ns)

Exclusivity cuts:

No other particles in the event

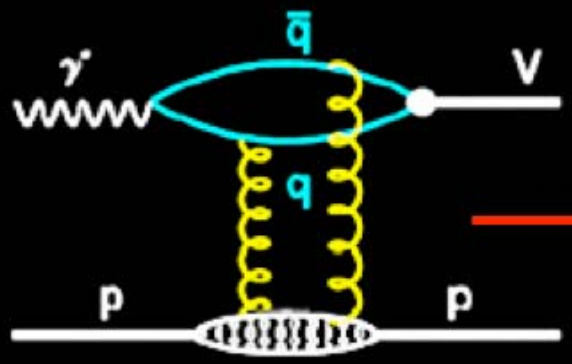
At most one EM shower with $E_T^{EM} > 80$ MeV and $|\eta| < 2.1$

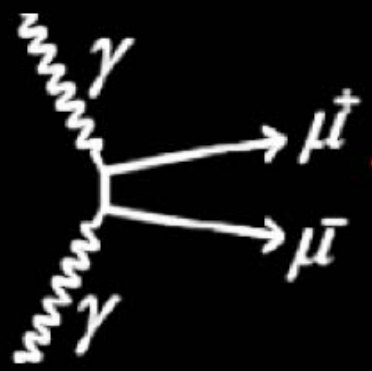
STARLIGHT Monte Carlo simulation employed (S. Klein & J. Nystrand) for photoproduction and QED channels

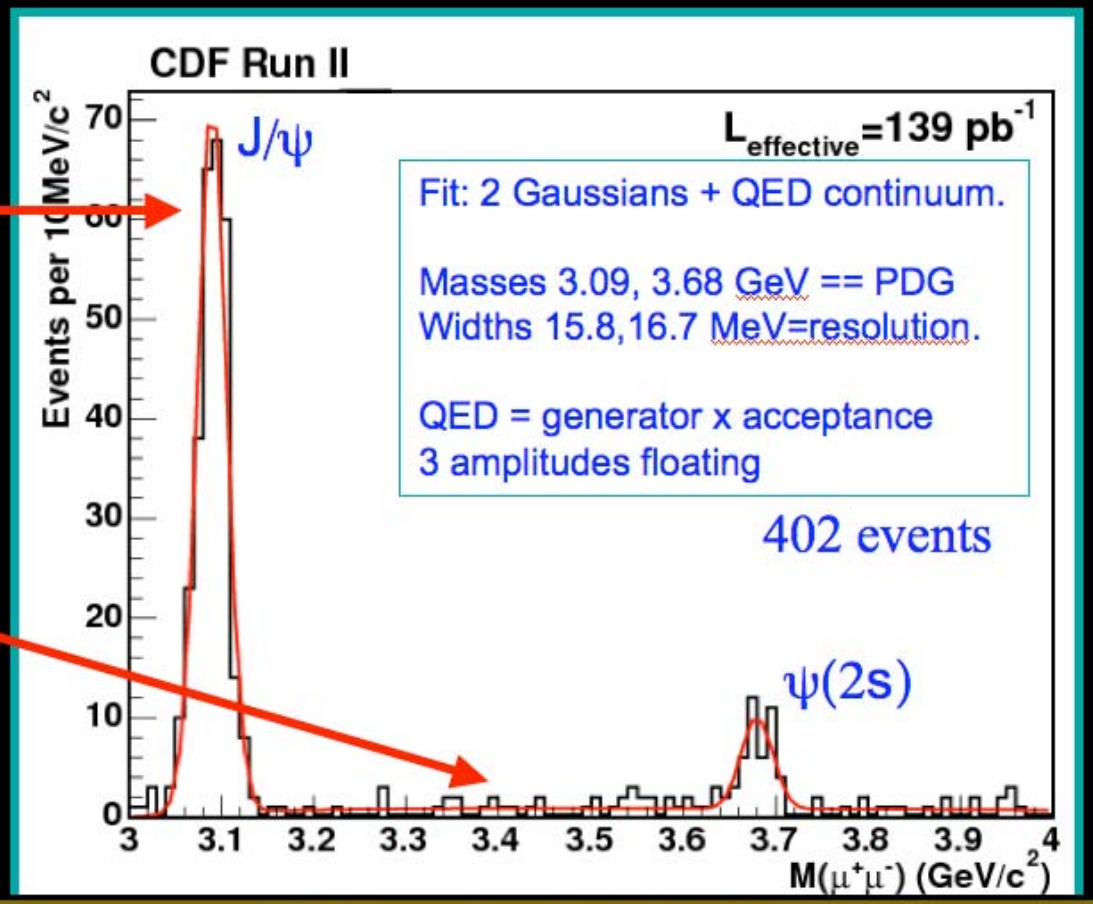
ChiC-MC (James Stirling) employed for DPE χ_c channel

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

$$p + \bar{p} \rightarrow p + \mu^+\mu^- + \bar{p}$$

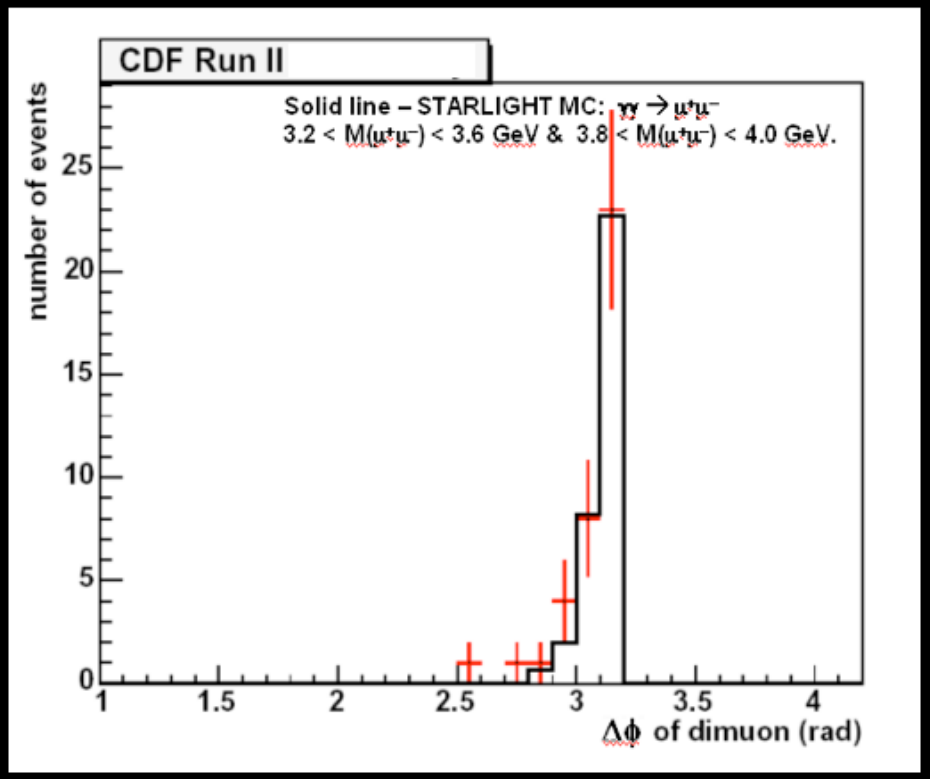


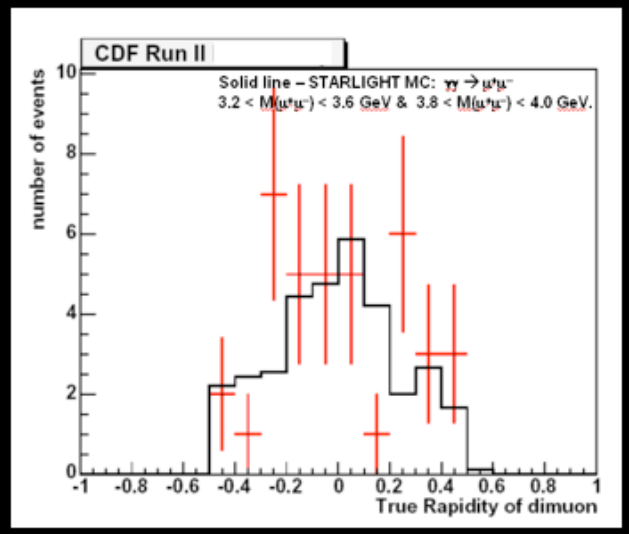


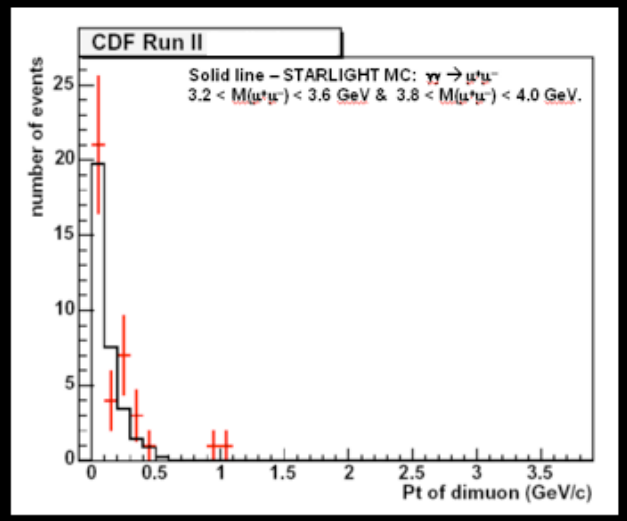


The $\mu^+\mu^-$ Continuum

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



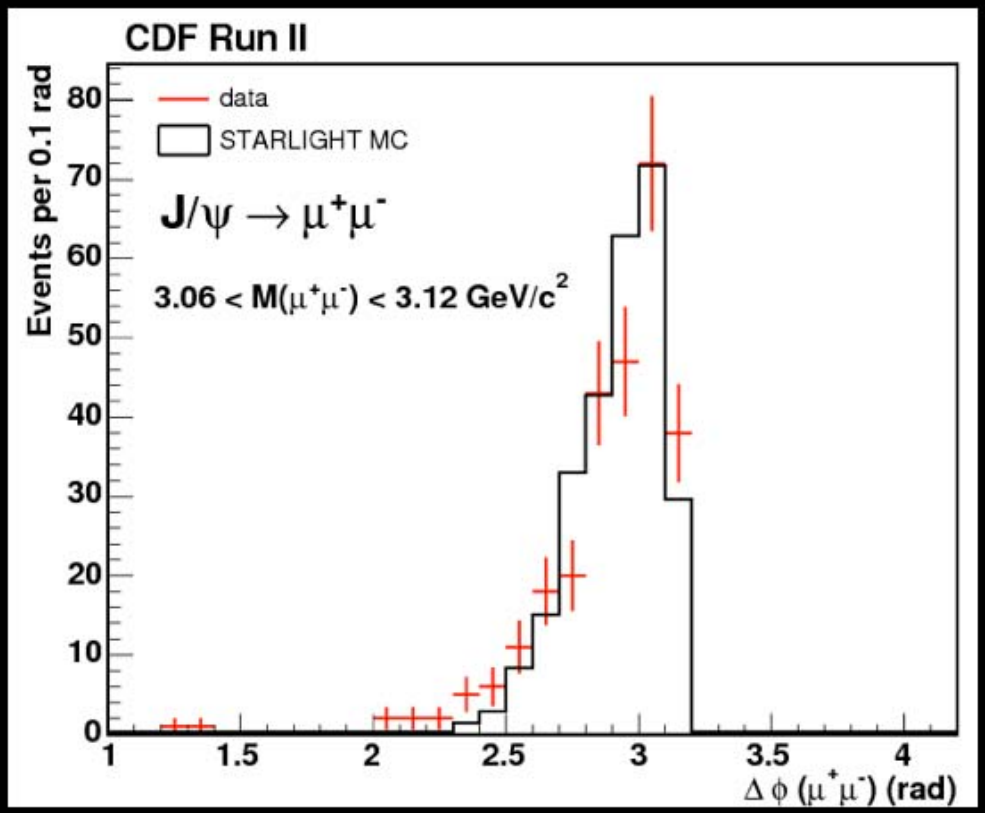


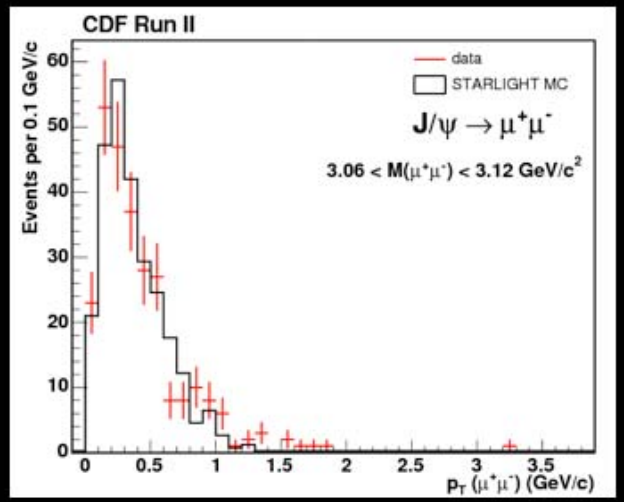


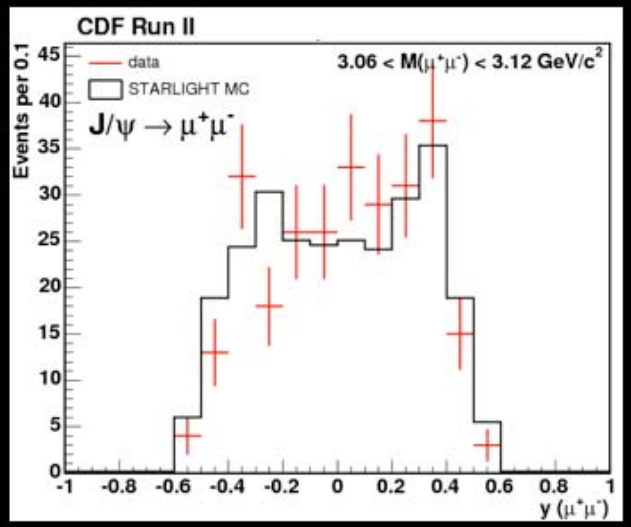
Good agreement on kinematics with STARLIGHT MC (Klein & Nystrand)

$J/\psi \rightarrow \mu^+\mu^-$

The $\gamma\gamma \rightarrow J/\psi \rightarrow \mu^+\mu^-$



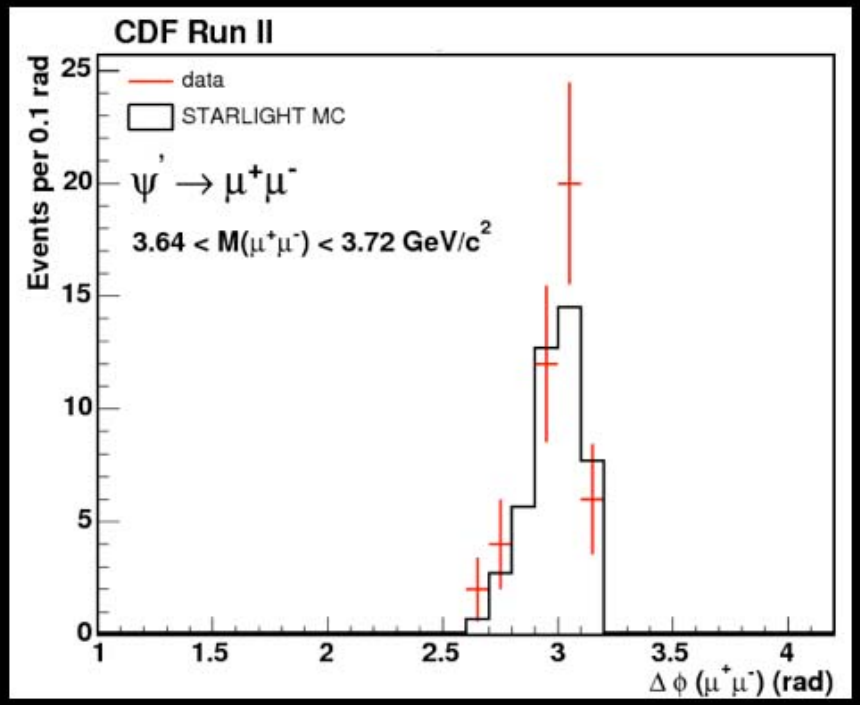


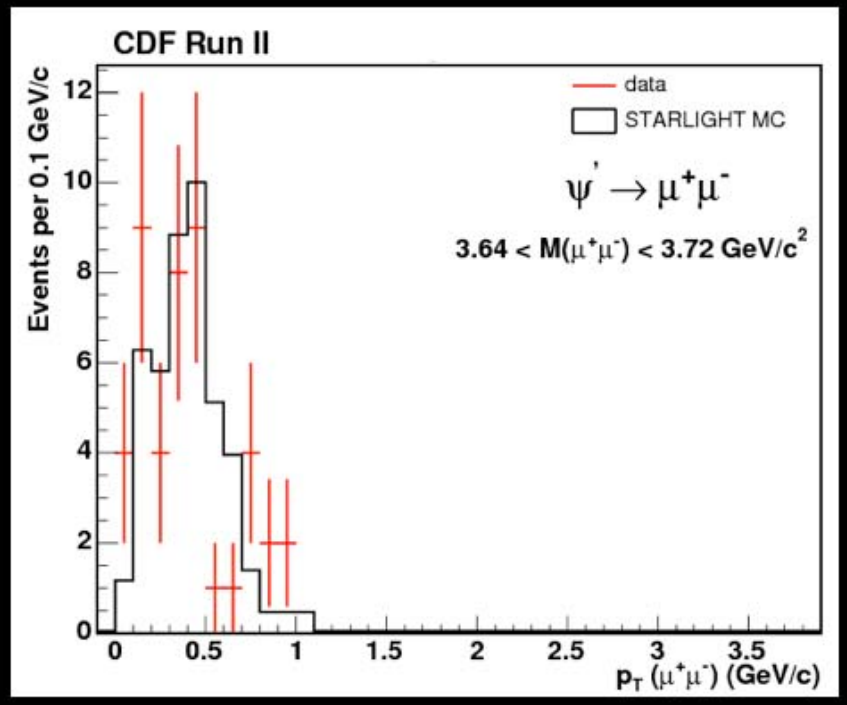


Good agreement on kinematics with STARLIGHT MC (Klein & Nystrand)

$\psi(2s) \rightarrow \mu^+\mu^-$

The $\gamma\gamma \rightarrow \psi(2s) \rightarrow \mu^+\mu^-$

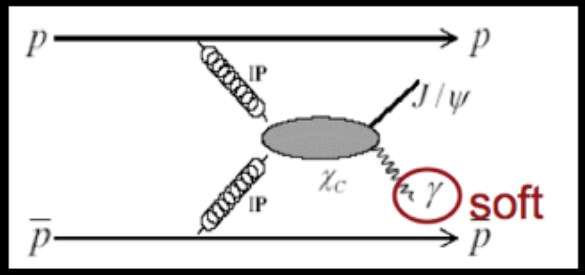




Good agreement on kinematics with STARLIGHT MC (Klein & Nystrand)

As with the J/ψ channel odderon exchange could contribute to this channel

$\chi_c \rightarrow J/\psi(\rightarrow\mu^+\mu^-) + \gamma(\text{soft})$



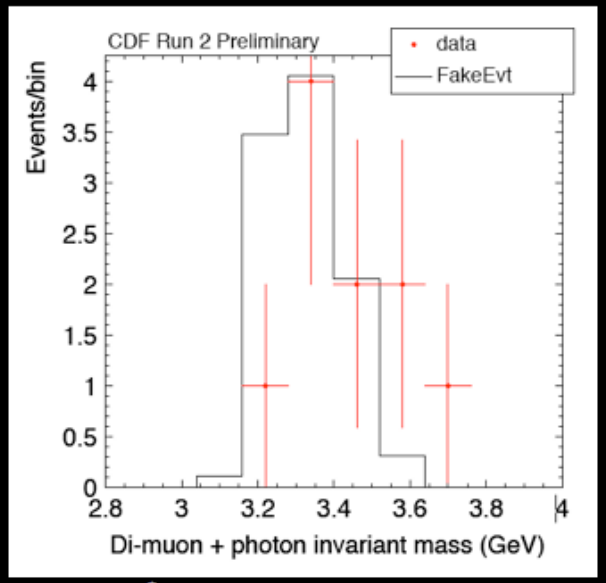
Similar selection as $\mu^+\mu^-$ search with additional isolated EM shower req.

***10 candidates in 93 pb^{-1} of data** from an OLD analysis*

***New ChicMC** (James Stirling)*

***Problem is -** understanding low energy photon from the χ_c decay*

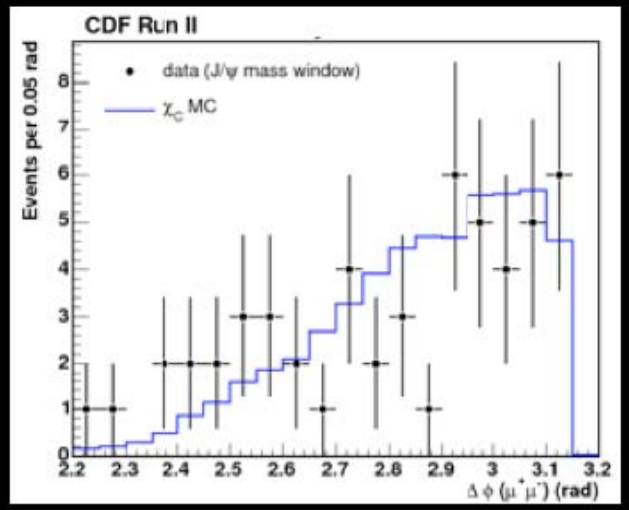
Many more events with new trigger

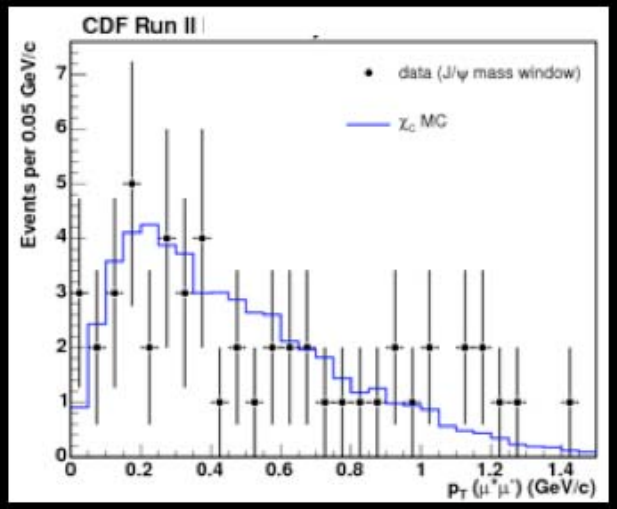


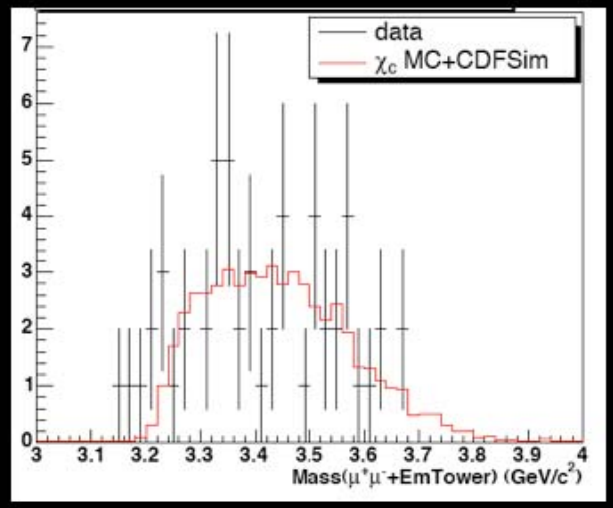
BR ($\chi_c^0 \rightarrow J/\psi + \gamma \rightarrow \mu^+\mu^-\gamma$

x no other interaction x acceptance (trig) ⇒ few pbs

$\chi_c \rightarrow J/\psi(\rightarrow\mu^+\mu^-) + \gamma(\text{soft})$



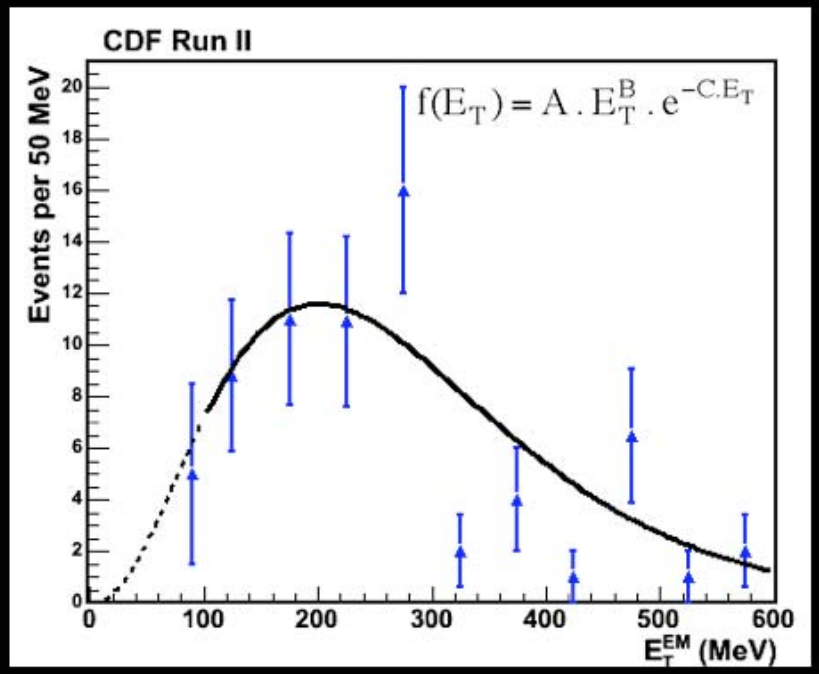




The ChiC-MC (James Stirling) is a good fit the data

Good fit to $\mu^+\mu^-$ kinematics from χ_c, if there is an EM shower in the event

Estimating the χ_c Contribution



- *Plot show fit of ET spectrum for events with:*
  - *E^{EM}_T tower > 100 MeV*
- *Total number of χ_c events: 68.2 ± 8.3*
- *65.4 χ_c events above the 80 MeV exclusivity cut*
- *$1.9^{+2.8}_{-1.9}$ χ_c event background to exclusive J/ψ signal*

	Events from fit	Data
Total number of events	68.2	
Number with E_T^{EM} > 80 MeV	65.2	65.4
Number below 80 MeV (extrapolated)	2.8	
Number 80-100 MeV	2.3	2
Number > 600 MeV	3.6	0

- *Addition γ inefficiency from:*
  - *Conversions - 7 ± 2%*
  - *Dead regions - 5.0 ± 2.5%*
  - *Total inefficiency - 17 ± 4%*
  - *Background to excl J/ψ - 4.0 ± 1.6%*

Backgrounds

Class	J/ψ	$\psi(2S)$	$\gamma\gamma \to \mu^+\mu^-$	$\chi_{c0}(1P)$
Backgrounds:				
Fragmention(%)	9±2	9±2	8±2	11±2
Non-excl.(%)	3±3	3±3	9±5	3±3
χ_{c0}(%)	4.0±1.6	-	-	-
Events-B/G	243±21	34±7	65±10	56±8

- *An important background is undetected proton fragmentation estimated using the LPAIR MC:*
  - *The proton frag. probability at the pγp(p*) vertex is estimated as 17%*
  - *The proton frag. probability at the pIPp (p*) vertex is estimated as 24%*
    - *From the ratio of single diffractive frag. To elastic scattering at the Tevatron*
  - *The probability that all proton fragmentation products have $|\eta|$ >7.4 is 14%*
  - *The probability that decay products may not be detected due to BSC inefficiency is 8%*

Charmonia Cross-sections

Class	J/ψ	$\psi(2S)$	$\gamma\gamma \to \mu^+\mu^-$	$\chi_{c0}(1P)$
$\mathcal{B}.\sigma_{FKR}$(pb)	28.4±4.5	1.02±0.26	2.7±0.5	8.0±1.3
$\mathcal{B} \to \mu^+\mu^-$(%)	5.93±0.06	0.75±0.08	-	0.076 ±0.007
$\frac{d\sigma}{dy}\|_{y=0}$(nb)	3.92±0.62	0.53±0.14	-	76±14

- ***The $\gamma\gamma \to \mu^+\mu^-$ results agree with the Starlight and LPAIR MCs***
- ***The J/ψ results (ds/dy\|y=0) agree with theoretical predictions:***
  - *S.Klein and J.Nystrand, Starlight, Phys. Rev. Lett. 92:142003 (2004).*
  - *L.Motyka and G.Watt, Phys. Rev. D78:014023 (2008).*
  - *W.Schafer and A.Szczurek, Phys. Rev. D 76, 094014(2007).*
  - V.P.Goncalves and M.V.T.Machado, Eur. Phys. J. C 40, 519 (2005).
- ***The ψ(2s) result consistent with the Starlight prediction***
- ***R = ψ(2s)/ψ(1s) = 0.14 ± 0.05 is in agreement with the HERA value***
  R = 0.166 ± 0.012 at similar √s(γp) (H.Jung, Acta. Phys. Polon. Supp.1, 531 (2008)

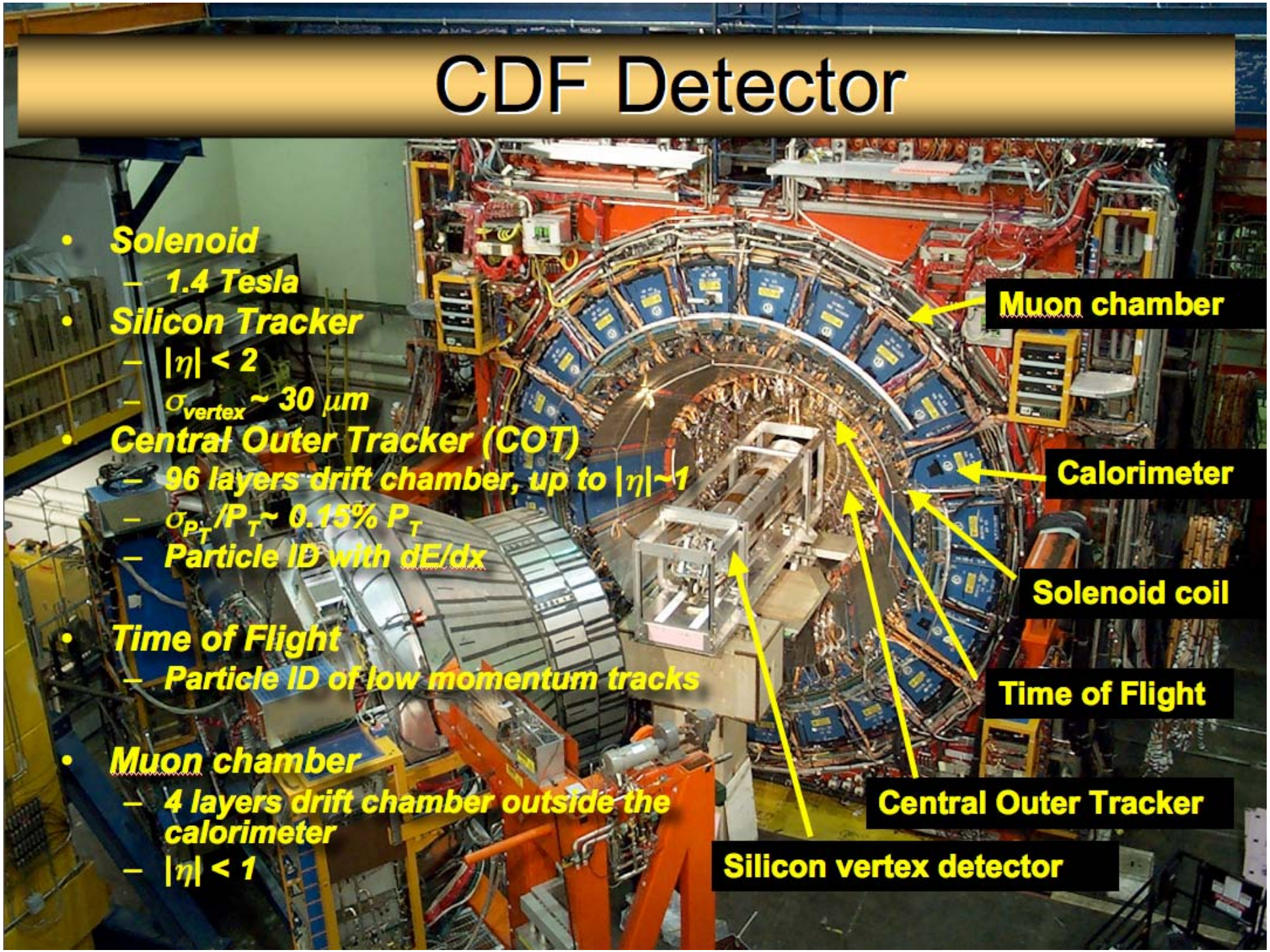
Summary & Conclusion

- *We have observed, for the first time in hadron-hadron collisions, exclusive photoproduction of J/ψ and $\psi(2S)$, exclusive double pomeron production of χ_c^0, and the QED process $\gamma\gamma \rightarrow \mu^+\mu^-$.*
  - *The results are in agreement with theoretical predictions*
- *Our observation of exclusive χ_c^0 production implies that exclusive Higgs boson production should occur at the LHC & imposes constraints on the $p + p \rightarrow p + H + p$ cross-section.*
- *PRL containing the analysis of these results has been submitted*

Extra Slides

CDF Detector

- **Solenoid**
  - 1.4 Tesla
- **Silicon Tracker**
  - $|\eta| < 2$
  - $\sigma_{vertex} \sim 30\ \mu m$
- **Central Outer Tracker (COT)**
  - 96 layers drift chamber, up to $|\eta| \sim 1$
  - $\sigma_{P_T}/P_T \sim 0.15\%\ P_T$
  - Particle ID with dE/dx
- **Time of Flight**
  - Particle ID of low momentum tracks
- **Muon chamber**
  - 4 layers drift chamber outside the calorimeter
  - $|\eta| < 1$



Class	J/ψ	$\psi(2S)$	$\gamma\gamma \to \mu^+\mu^-$	$\chi_{c0}(1P)$
Acceptances:				
Detector(%)	18.8±2.0	54±3	41.8±1.5	19±2
Efficiencies:				
μ-quality(%)	33.4±1.7	45±6	41.8±2.3	33±2
Photon(%)	-	-	-	83±4
Events(fit)	286±17	39±7	77±10	65±8
Backgrounds:				
Fragmention(%)	9±2	9±2	8±2	11±2
Non-excl.(%)	3±3	3±3	9±5	3±3
χ_{c0}(%)	4.0±1.6	-	-	-
Events-B/G	243±21	34±7	65±10	56±8
$\mathcal{B}.\sigma_{FKR}$(pb)	28.4±4.5	1.02±0.26	2.7±0.5	8.0±1.3
$\mathcal{B} \to \mu^+\mu^-$(%)	5.93±0.06	0.75±0.08	-	0.076 ±0.007
$\frac{d\sigma}{dy}\|_{y=0}$(nb)	3.92±0.62	0.53±0.14	-	76±14