Ultra-Peripheral Collisions at RHIC

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- Brief Introduction to "Ultra-Peripheral Collisions".
- Experimental results from RHIC (and Tevatron).
- Conclusions and outlook for the LHC.

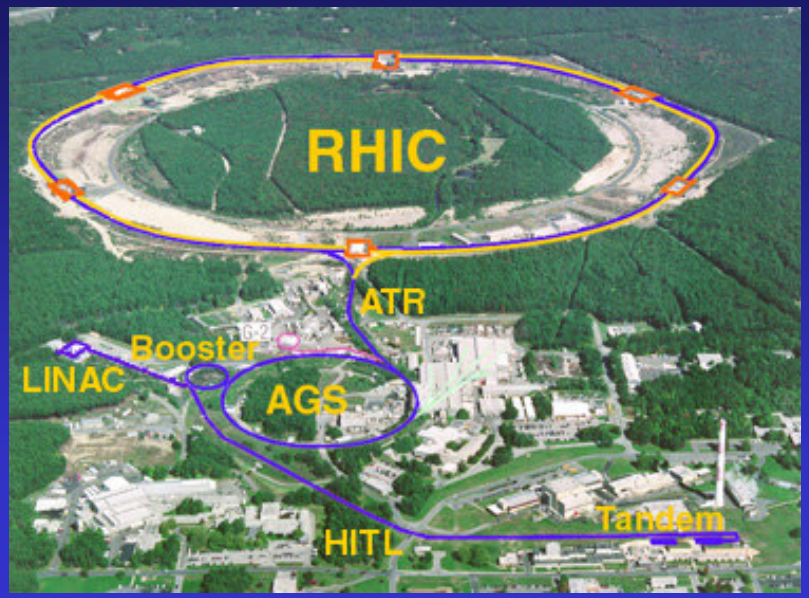
Heavy-Ion Collisions at RHIC and the LHC

Ultra-Relativistic Heavy-ion collisions

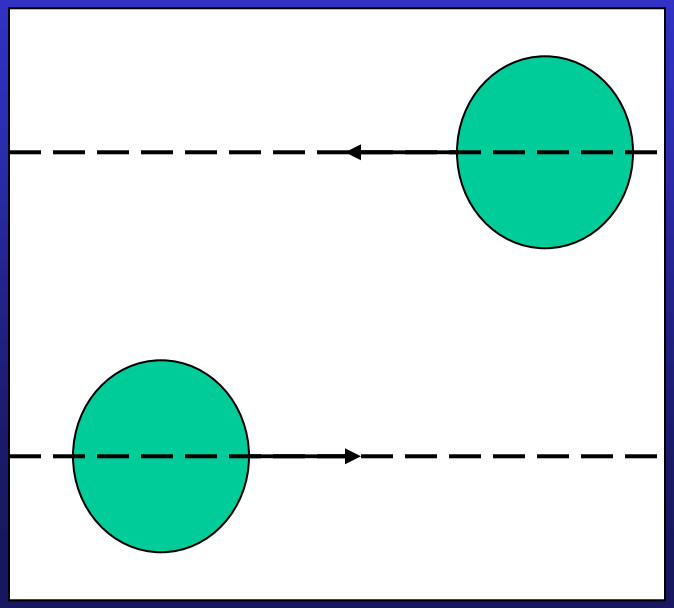
- at the Brookhaven AGS (14 A GeV) and CERN SPS (200 A GeV) since 1986;
- fixed target experiments.

Heavy-ion colliders

- RHIC since 2000 (Au+Au at 100+100 A GeV);
- LHC, expected in 2008(?) (Pb+Pb at 2.75+2.75 A TeV).



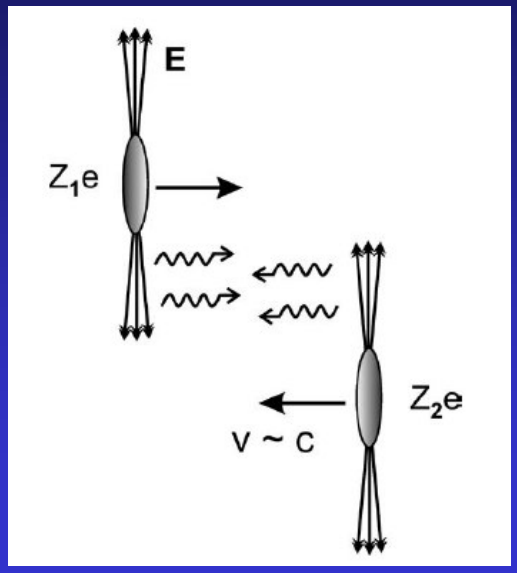
Ultra-Peripheral Collisions



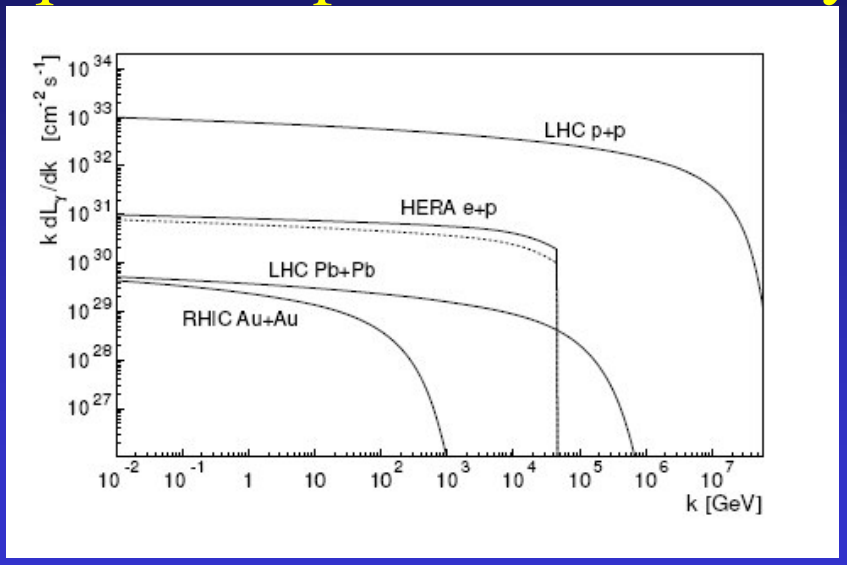
- The goal is to utilize the strong electromagnetic fields in inter-actions without overlap, $n_\gamma \propto Z^2$.

- b > or >> 2R

- Photonuclear and photon-proton interactions at unprecedented energies (at the LHC)!

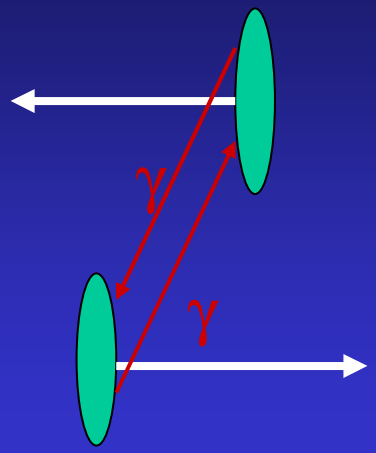


Equivalent photon luminosity



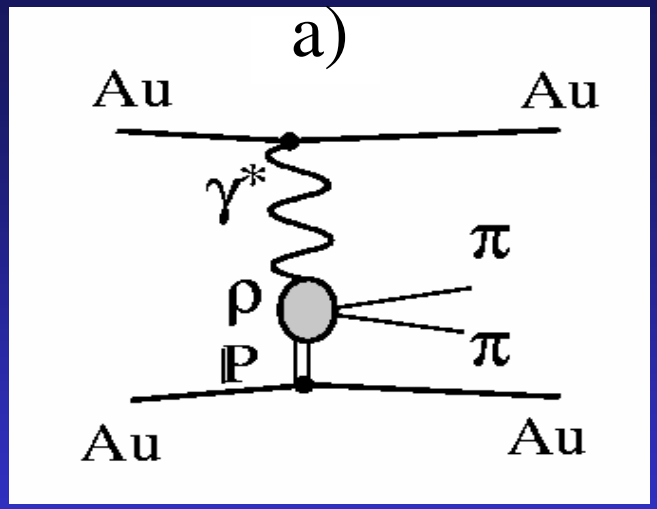
Electromagnetic Interactions in p+p and A+A vs. in e+p(A)

- Directional symmetry. Both beams (nuclei) and can act as photon emitter or target; away from y=0, the different photon emitter/ target combinations give different contributions.
- Strong fields lead to high probability for emission of multiple photons.
- The photoproduction signal must be separated from the hadroproduction background (multiplicity, rapidity gaps, …).
- Results so far on exclusive processes, e.g. $\gamma\gamma \rightarrow e^+e^-$ and $\gamma A \rightarrow VA$.

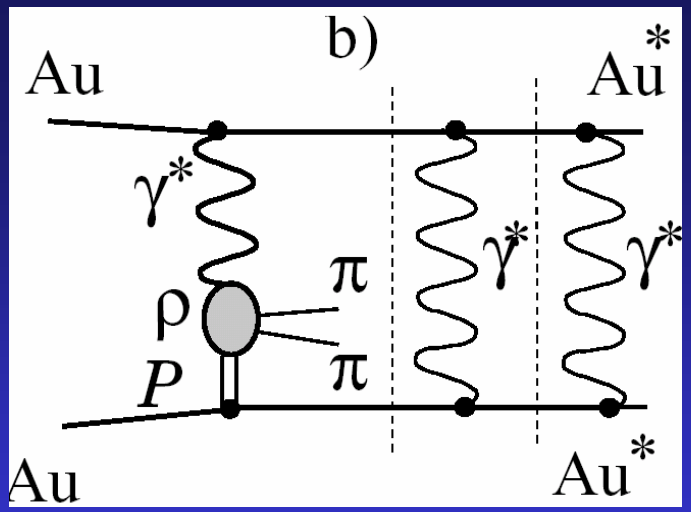


Particle Production and Coulomb break-up

- Very high probability for emitting one soft photon, which can excite the target to a Giant Dipole Resonance.
- P ≈ 35-50 % in grazing Au+Au/Pb+Pb collisions at RHIC-LHC.
- Excitation to GDR leads to emission of neutrons which can be detected in Zero Degree Calorimeters (ZDC). ⇒ Useful as trigger



vs.



σ = 370 mb

σ = 30 mb

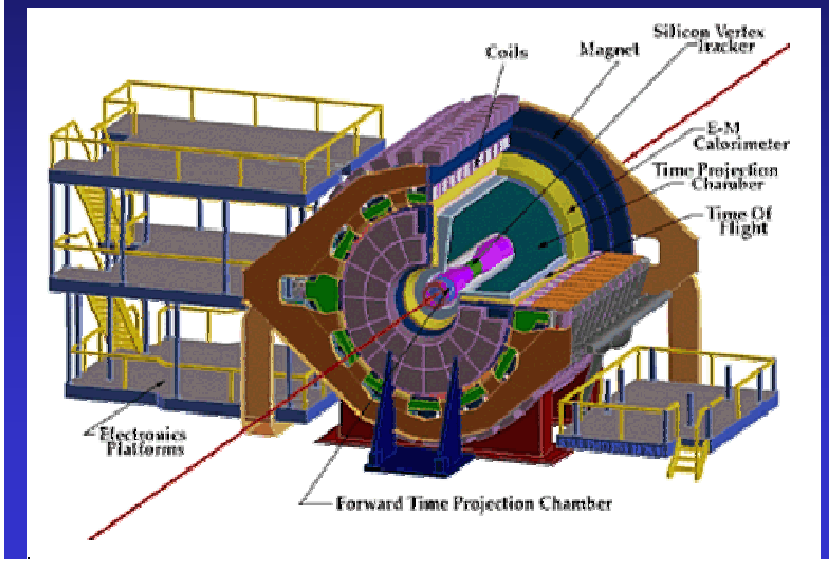
Ultra-Peripheral Collisions at RHIC

Experimental UPC results from RHIC so far:

1) ρ^0-production, Au+Au→Au+Au+ρ^0 STAR Collaboration (C. Adler et al. PRL 89(2002)272302).

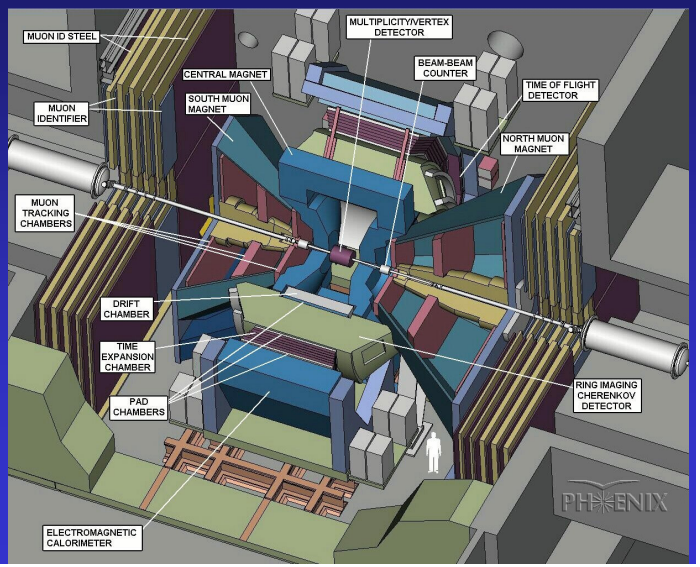
2) e^+e^--pair production, STAR Collaboration, (J.Adams et al., Phys.Rev. C70(2004)031902).

3) J/Ψ and high-mass e^+e^--pair production PHENIX Collaboration, nucl-ex/0601001.



← STAR

PHENIX →

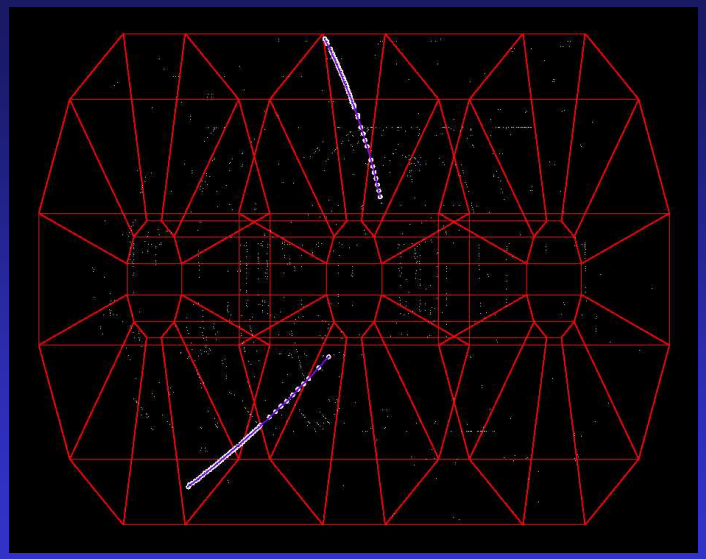


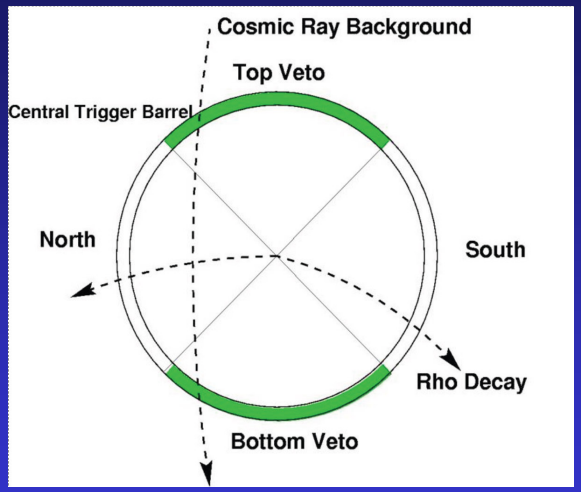
Ultra-Peripheral Collisions in STAR

Two UPC trigger classes:

1) Topology trigger: Based on hits in Central Trigger Barrel, with a "topology" cut to remove cosmic rays.

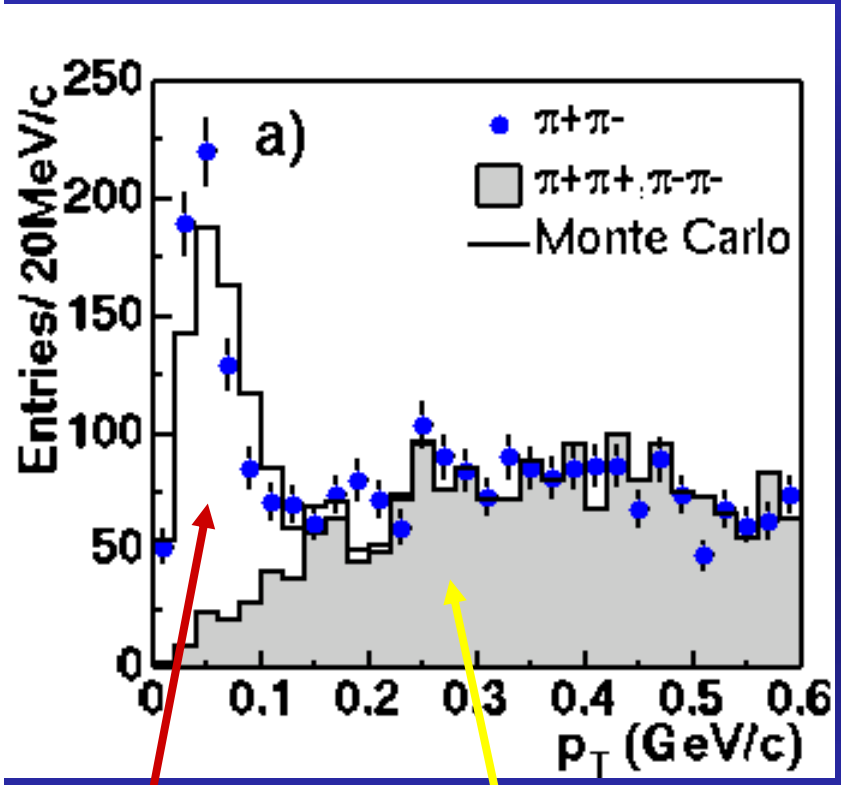
2) Min. Bias trigger: At least one neutron in each ZDC (Coulomb break-up). Low mult. in Central Trigger Barrel.





$Au+Au \rightarrow Au+Au+\rho^0$

STAR Collaboration (C. Adler et al. PRL 89(2002)272302)



background, like-sign pairs

Signal+background, unlike-sign pairs

Cross sections in agreement with Glauber model:

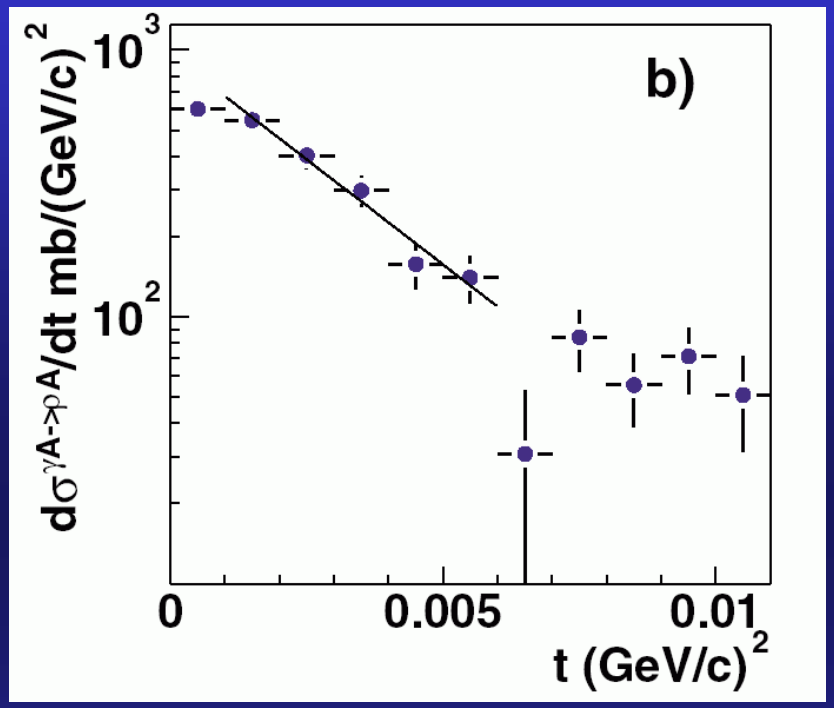
$\sigma(Au+Au \rightarrow Au+Au+\rho^0)$ [mb]

	STAR	Theory
Exclusive:	460±220±110	490*

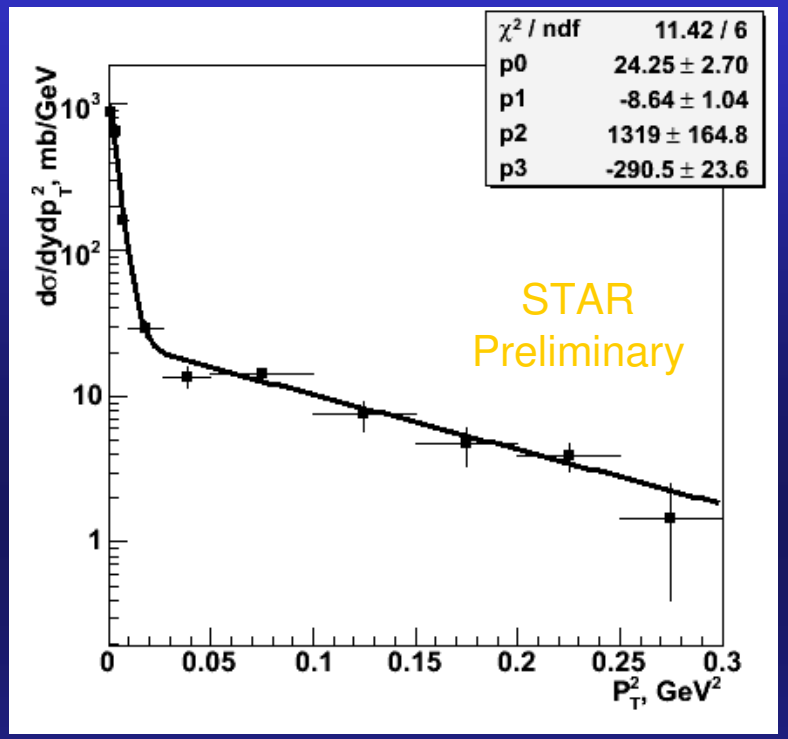
* Frankfurt, Strikman, Zhalov Phys. Lett. B 537 (2002) 51.

See also S.R. Klein, J. Nystrand PRC 60 (1999) 014903; Gonçalves, Machado, J. Phys. G 32 (2006) 295.

Coherent vs. Incoherent ρ^0 Production



Published: $\sqrt{s}$ = 130 GeV, low luminosity, $\approx$ 700 ρ^0



Preliminary: $\sqrt{s}$ = 200 GeV, Run-II intermediate luminosity, $\approx$ 16,000 ρ^0 (coherent and incoherent)

Au+Au → Au+Au+ρ^0

ρ^0 production cross sections measured by the STAR Collaboration

0n – no neutron in ZDC; 1n – one neutron in ZDC; Xn – ≥1 neutron in ZDC

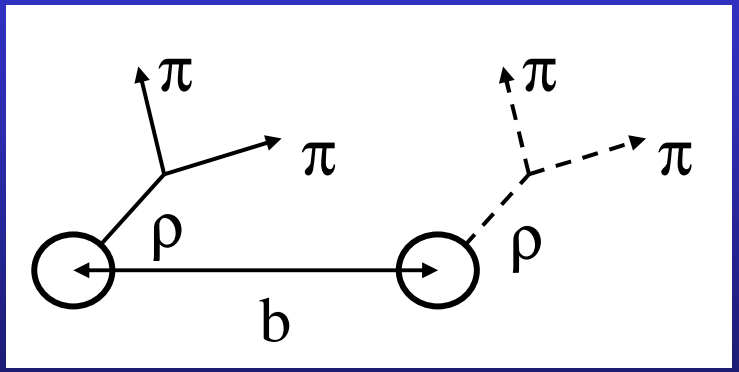
	STAR $\sqrt{s}$=200GeV, mb	STAR $\sqrt{s}$=130GeV, mb
σ_{xnxn}	30.26±1.1±6.35	26.2±1.8±5.8
σ_{0nxn}	108.74±9.08±22.83	90±55±20
σ_{1n1n}	1.63±0.18±0.34	2.5±0.4±0.6
σ_{0n0n}	370.19±33.26±77.74	285±145±70
σ_{total}	509.2±34.5±106.9	410±190±100

Y. Gorbunov, Workshop on Photoproduction at Collider Energies: From RHIC and HERA to the LHC, ECT* Trento, 15 – 19 January, 2007, http://www.ect.it/.

Interference in ρ^0 Production

The production amplitudes will interfer (at y=0 $|A_1|=|A_2|$),
$|A_1+A_2|^2 = 2\,|A_1|^2\,[1 - \cos(\mathbf{p}\cdot\mathbf{b})]$

The interference is destructive because of the (–) parity of the photon.



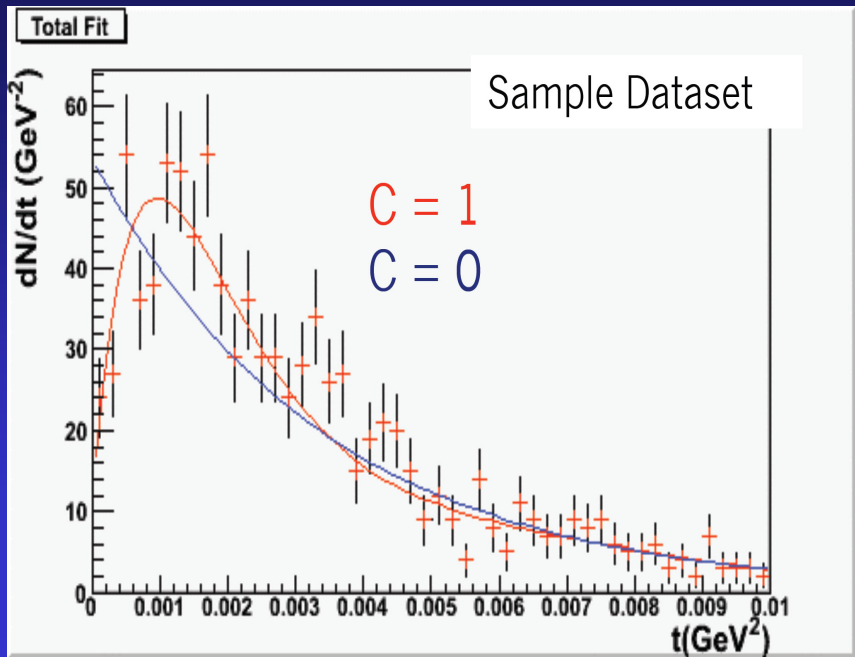
Transverse plane

See S.R. Klein, J. Nystrand PRL 84(2000)2330; PLA 308(2003)323.

Fit the observed t distribution (with $t=p_T^2$) to a function

$$\frac{dN}{dt} = Ae^{-kt}\left(1 + C\left[R(t) - 1\right]\right)$$

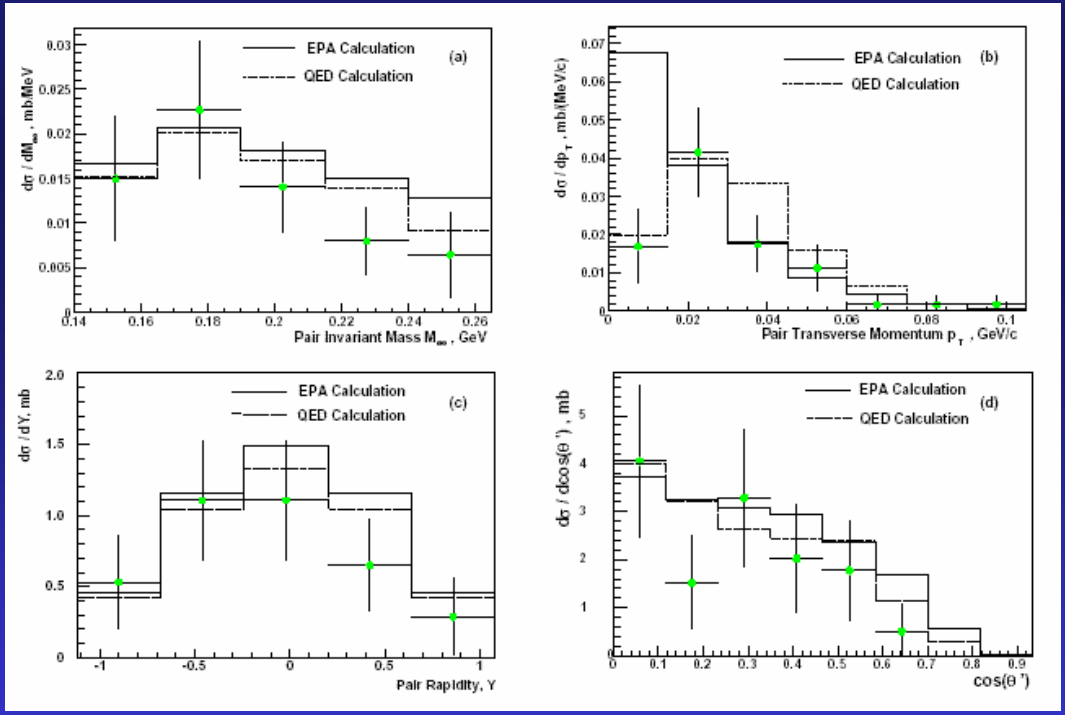
C = 0 ↔ no interference
C = 1 ↔ interference



STAR Results on Au+Au → Au*+Au*+e^+e^-

The total cross section is huge, 32 kb at RHIC!

The observed cross section is a factor $5 \cdot 10^{-8}$ lower!
$\Rightarrow$ e^+,e^- emission angle $\theta \sim 1/\gamma \approx 1/100 \Rightarrow$ in beam-pipe.



Results in agreement with QED/equivalent photon calculations.

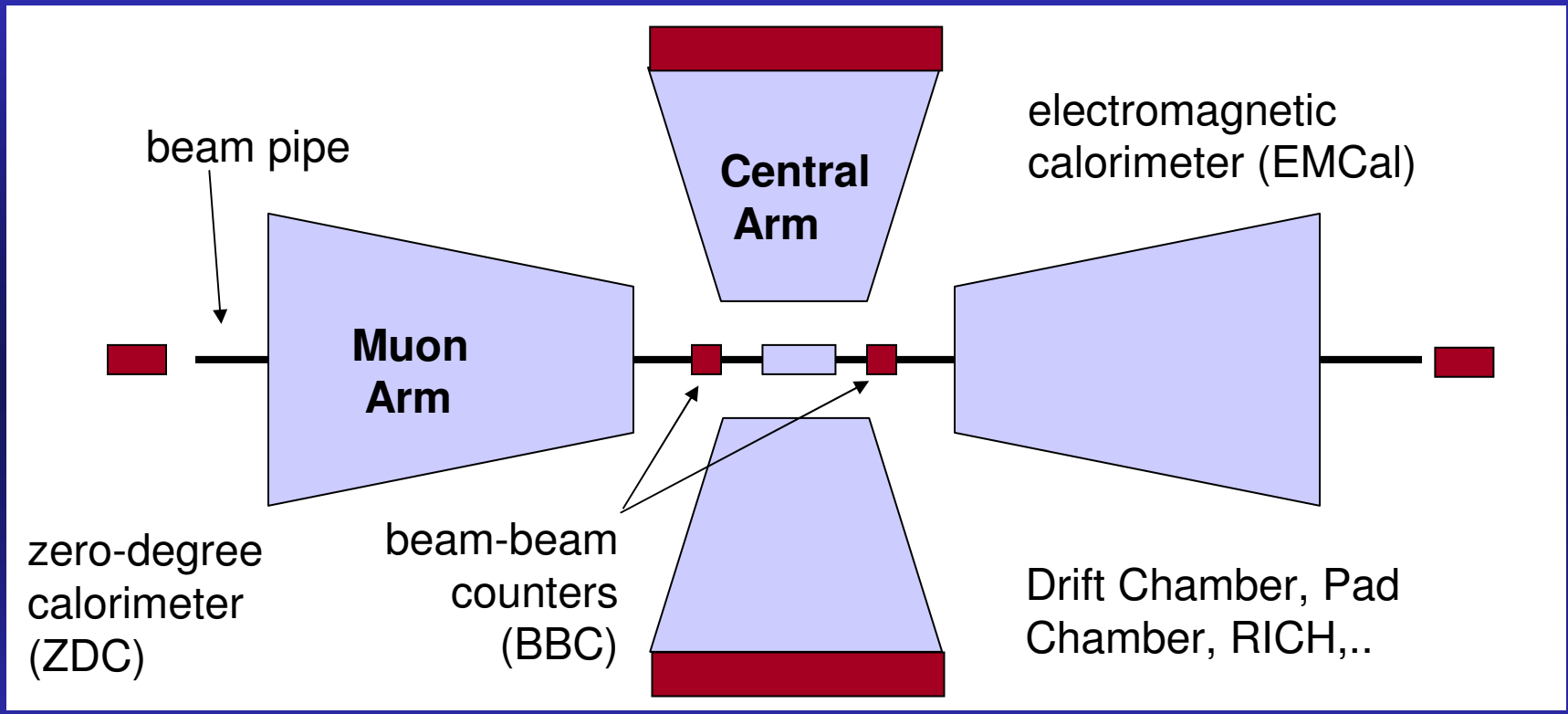
Low mass pairs,
$140 \leq m_{INV} \leq 260$ MeV

The photon virtuality important to describe the yield at low p_T.

STAR Collaboration, Phys.Rev. C70(2004)031902

Ultra-Peripheral Collisions in PHENIX

PHENIX (bird's eye view)

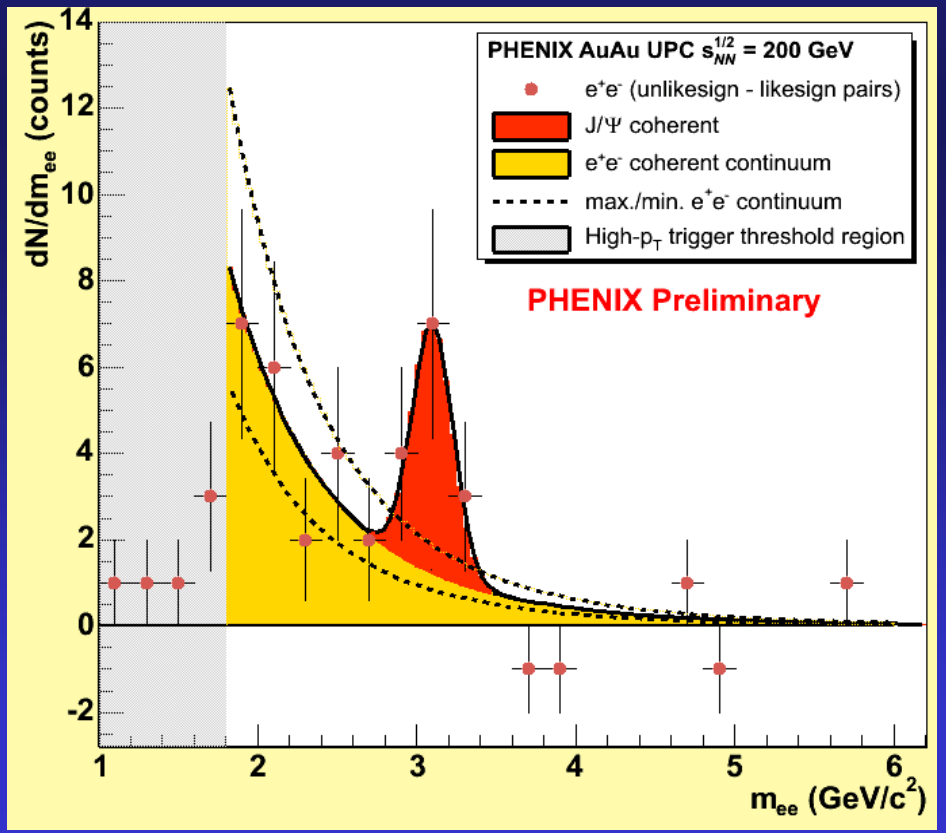


Level 1 Ultra-Peripheral Trigger: Veto on coincident BBC $|\eta| \sim 3 - 4$, Neutron(s) in at least on ZDC ($E > 30$ GeV), Large Energy ($E > 0.8$ GeV) cluster in EmCal.

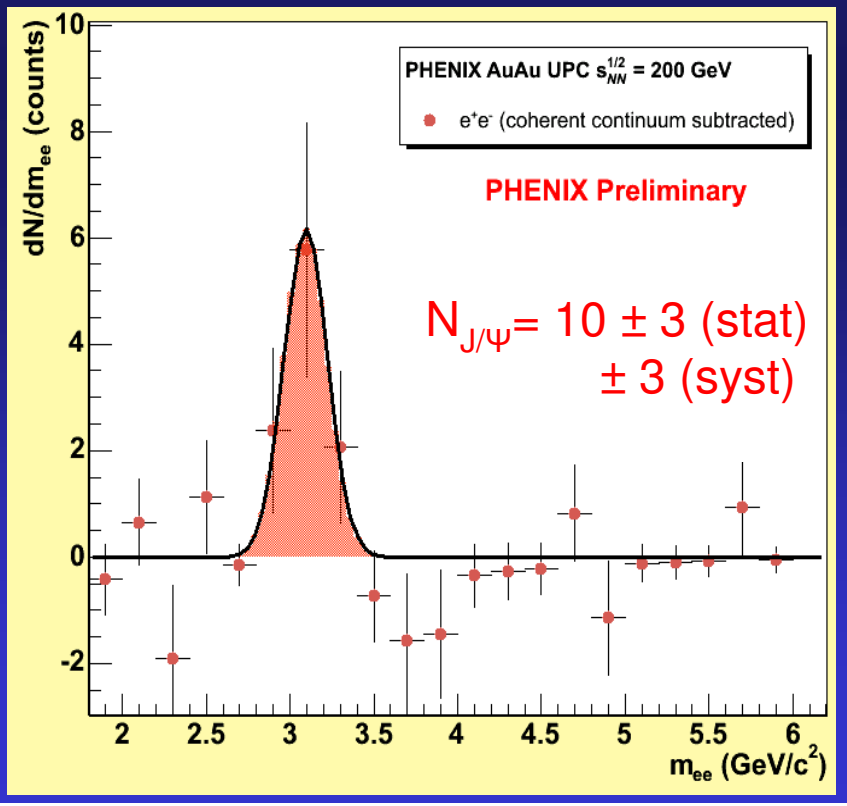
Ultra-Peripheral Collisions in PHENIX

The goal is to search for the process $\gamma+Au \rightarrow J/\Psi+Au$. There will also be a contribution from $\gamma+\gamma \rightarrow e^+e^-$.

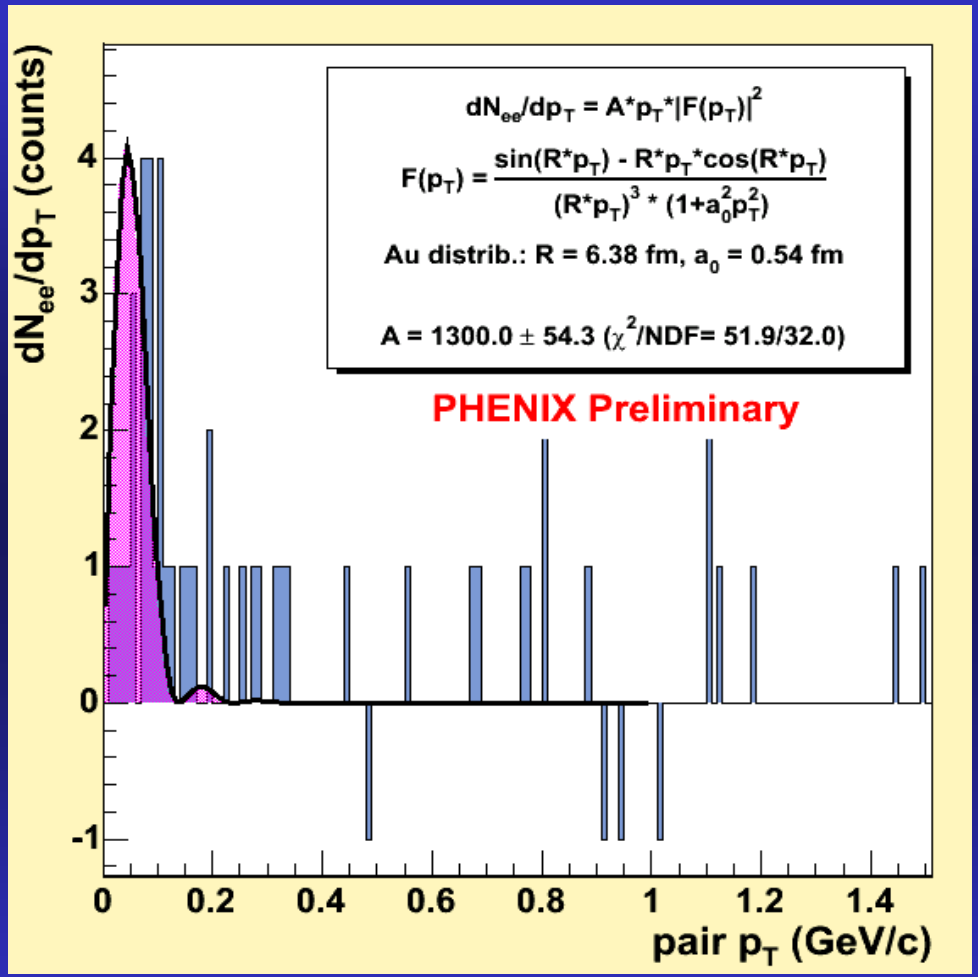
dN/dminv (backgd subtracted) & with 2 fits of expected e+e- continuum shape (normalized at m_{ee} = 1.8 – 2.2 GeV/c2)



dN/dm$_{inv}$ after e^+e^- continuum subtraction



Ultra-Peripheral Collisions in PHENIX

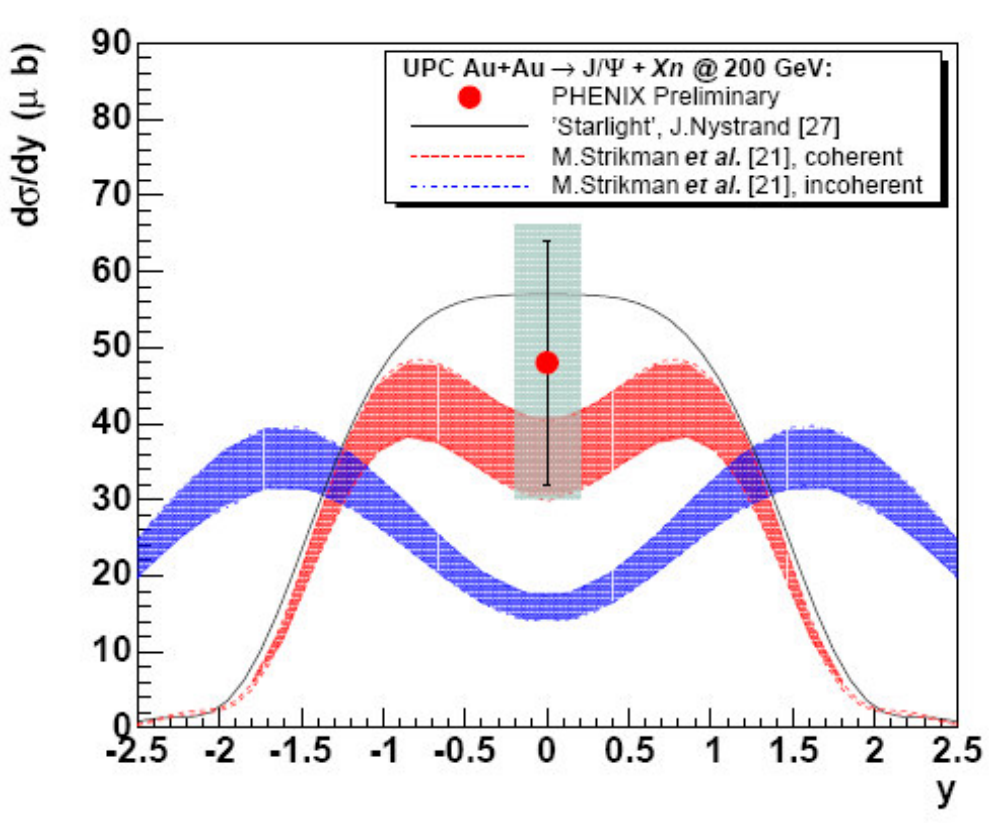


The coherent and incoherent contribution is separated based on the transverse momentum.

D. d'Enterria, Quark Matter 2005, nucl-ex/0601001;
D. Silvermyr, Workshop on Photoproduction at Collider Energies: ECT* Trento, 15 – 19 January, 2007, http://www.ect.it/.

Preliminary J/Ψ cross section

$$d\sigma_{J/\Psi}/dy|_{y=0} = 1/BR \times 1/(Acc|_{y=0}\cdot\varepsilon) \times 1/\varepsilon_{trig} \times 1/L_{int} \times N_{J/\Psi}/\Delta y =$$
$$= 1/(5.9\%)\times 1/(5.7\%\cdot 56.4\%)\times 1/(90\%)\times 1/120\ \mu b^{-1}\times(10 \pm 3 \pm 3) =$$
$$= 48. \pm 16.\ (stat) \pm 18.\ (syst)\ \mu b$$



- Measured J/Ψ yield at y=0 consistent w/ theoret. calcs. [1,2]
- Syst. uncertainty: coherent e^+e^- continuum under J/Ψ (*work in progress*).
- Reduction of stat. errors need larger luminosity.
- Current uncertainties preclude yet detailed study of crucial model ingredients:

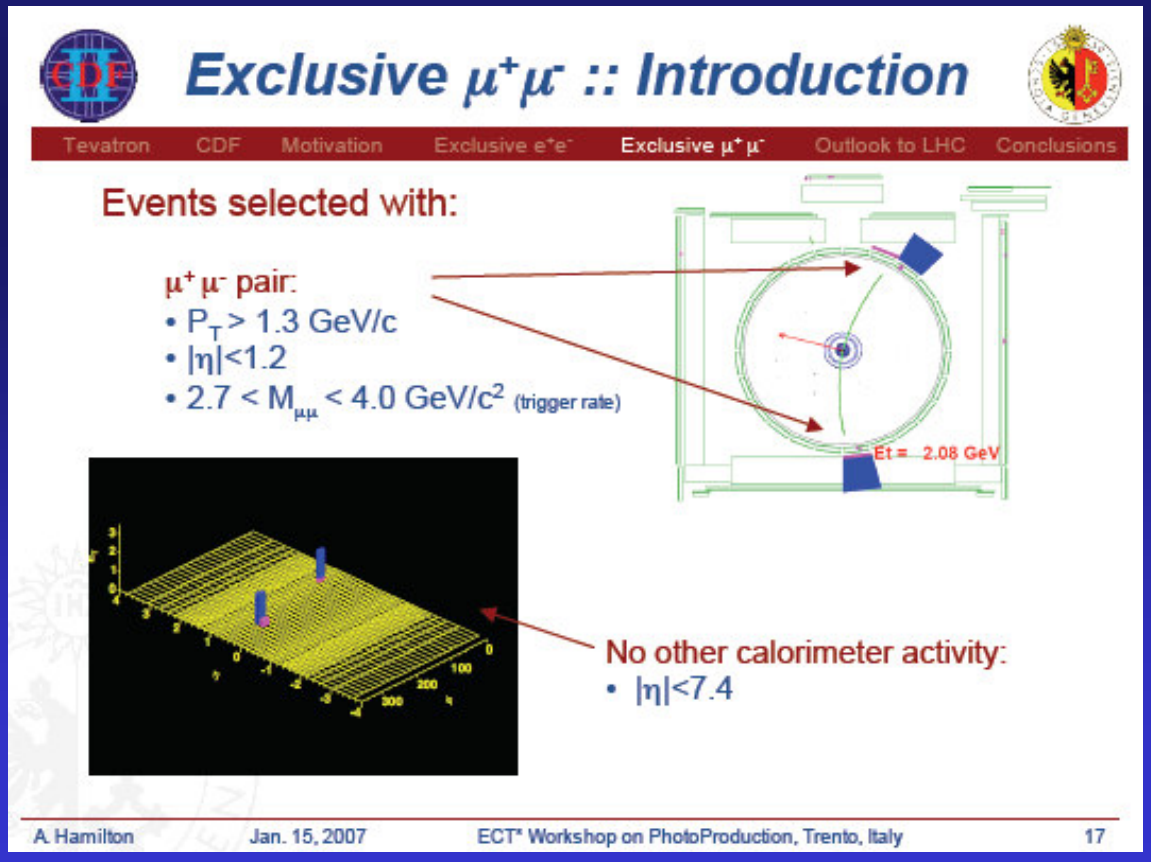
  $G_A(x,Q^2)$, σ(J/Ψ absorption).

[1] Starlight: S.R. Klein, J.Nystrand PRC 60(1999)014903, NPA 752(2005)470
[2] Strikman et al., PLB 626(2005)72.

”Ultra-peripheral” Collisions at the Tevatron

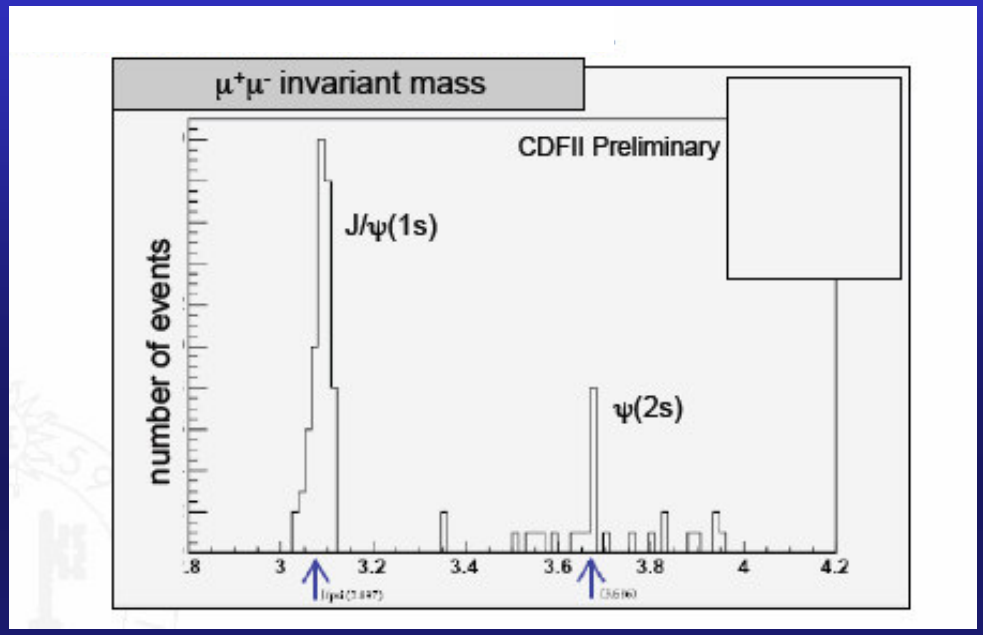
Recent results from CDF Collaboration on $p+p \rightarrow p+p+e^+e^-$ via $\gamma\gamma$:
A. Abulencia et al. PRL 98 (2007) 112001.

Work in progress on $p+p \rightarrow p+p+\mu^+\mu^-$
(A. Hamilton, Workshop on Photoproduction at Collider Energies: ECT* Trento, 15 – 19 January, 2007, http://www.ect.it/.)

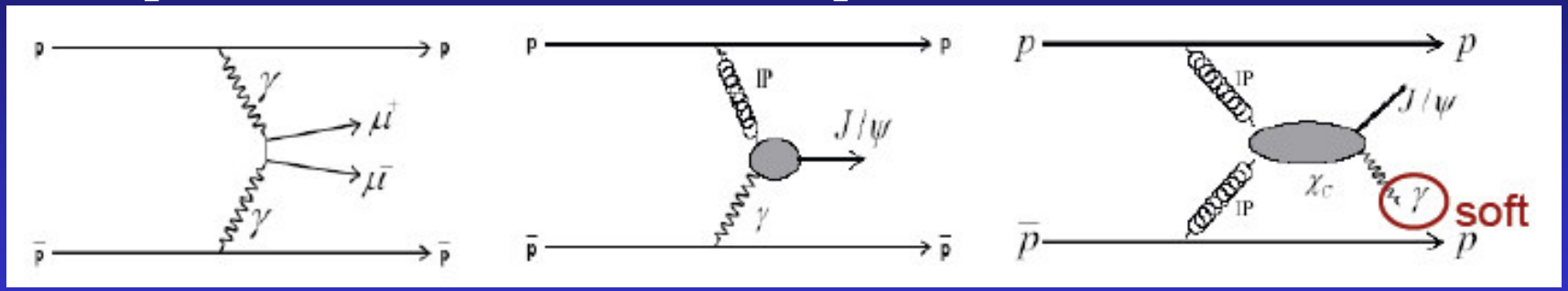


”Ultra-peripheral” Collisions at the Tevatron

Observed invariant mass distribution of the $\mu^+\mu^-$ pairs:



Three possible contributions to this process:

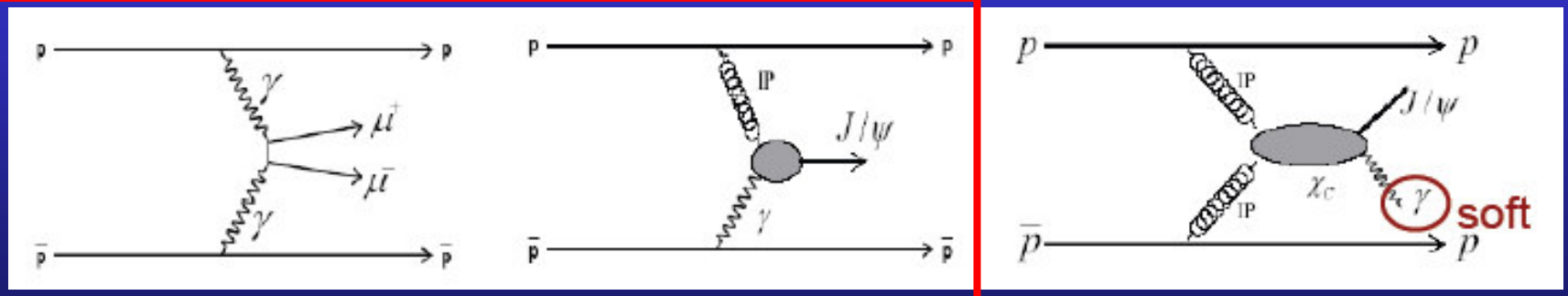


N.B. no feed down from χ_c to Ψ’.

A contribution from O+P also possible (see talk by L. Szymanowski)

”Ultra-peripheral” Collisions at the Tevatron

Calculations for the first two ($\gamma\gamma$ and γP):



$\sigma(pp \rightarrow pp+J/\Psi(1S))$: 15 nb $\quad\quad$ $\sigma \cdot Br(\mu\mu)$: 0.87 nb

$\sigma(pp \rightarrow pp+\Psi'(2S))$: 2.4 nb $\quad\quad$ $\sigma \cdot Br(\mu\mu)$: 18 pb

$\sigma(pp \rightarrow pp+\mu\mu)$: 2.4 nb ($m_{inv} > 1.5$ GeV/c^2)

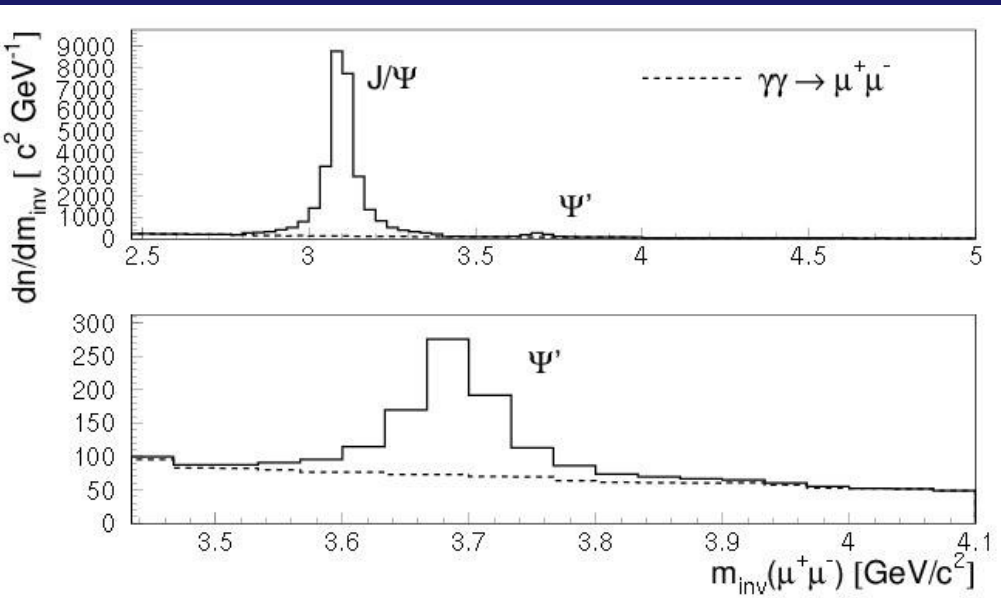
Applying cuts on the $\mu^+\mu^-$:

$p_T > 0.5$ GeV/c

$|\eta| < 2.0$ $\Rightarrow$

Yield(Ψ')/Yield(J/Ψ) ≈ 1:50

$\sigma(\gamma p \rightarrow Vp)$ parameterized from data. See S.R.Klein, J.Nystrand, PRL 92 (2004) 142003.



Conclusions and Outlook

- Several interesting results already obtained from RHIC and the Tevatron.
- The feasibility of studying electromagnetic interactions at hadron colliders has been proven.
- The prospects for the LHC are promising