Photoproduction in Ultra-Peripheral Heavy-Ion Collisions

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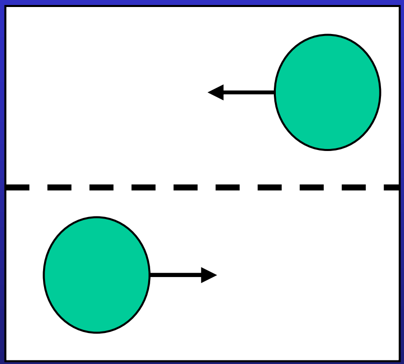
Ultra-Peripheral Collisions

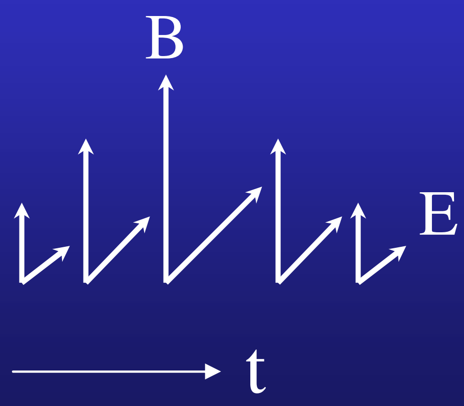


Collisions between two "hadrons" (protons, nuclei) in which no strong interactions occur. Implies impact parameters b > or >> 2R, typically in the range ~ 10 – 100 fm.

Talks on UPC at previous Photon NN Conferences

Photon 2005: V.G. Serbo, "Exclusive and inclusive muon pair production in collisions of relativistic nuclei".
Photon 2003: V.A. Khoze, "Multifaceted photon interactions at hadron colliders".
Photon 2001: F. Meissner, "Coherent photon-Pomeron and photon-photon interactions in ultra-peripheral collisions at RHIC"; V.G. Serbo, "Structure of the Coulomb and unitarity corrections in the e+e– pair production at relativistic nuclear collisions"; K. Piotrzkowski, "Tagging two-photon production at the LHC"
Photon 1999: K. Hencken et al., "Photon-photon and photon-hadron physics at relativistic heavy ion colliders"; V.G. Serbo, "Production of lepton pairs in free or bound states at relativistic heavy ion colliders".
Photon 1997: S.Klein and E. Scannapieco, "The gold flashlight: Coherent photons (and Pomerons) at RHIC".

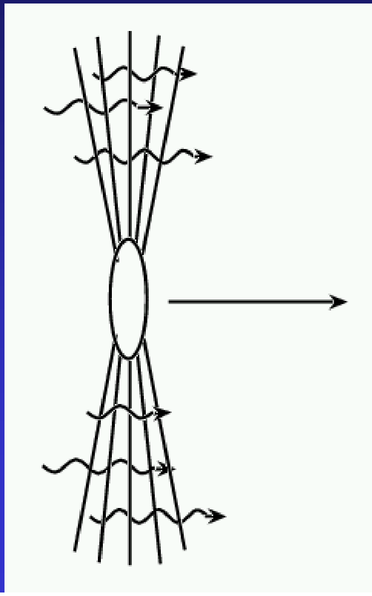
Electromagnetic Field of a Relativistic Charged Particle



An observer at a perpendicular distance b from the trajectory

1) $|E| \approx |B|$ 2) $(E \perp B)$ 3) $\Delta t \sim b/\gamma c$

Fermi 1924: The effect of the fields is equivalent to a flux of of photons with a continous energy spectrum. (hep-th/0205086)



Pulse width $b/\gamma c \leftrightarrow$ the spectrum contains photons w/ $\hbar\omega < \gamma\hbar c/b$

Quantum Mechanical derivation 1935 by Weizsäcker, Williams. $\Rightarrow$ *Weizsäcker-Williams method*

We can calculate $n(\omega)$ through a Fourier transform.

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

Traditionally, photon-induced interactions have been studied with electron beams:

Two-photon interactions at PEP, Petra, LEP.

Photon-proton interactions at HERA and in fixed target expts w/ electron beams.

Why study them at hadron colliders?

- Higher photon energies than at any existing accelerator (LHC).
- An opportunity to study strong electromagnetic fields (coupling $Z\sqrt{\alpha}$ rather than $\sqrt{\alpha}$ in heavy-ion collisions).
- Interference between the photon-emitter and target.
- An opportunity to search for the Odderon.

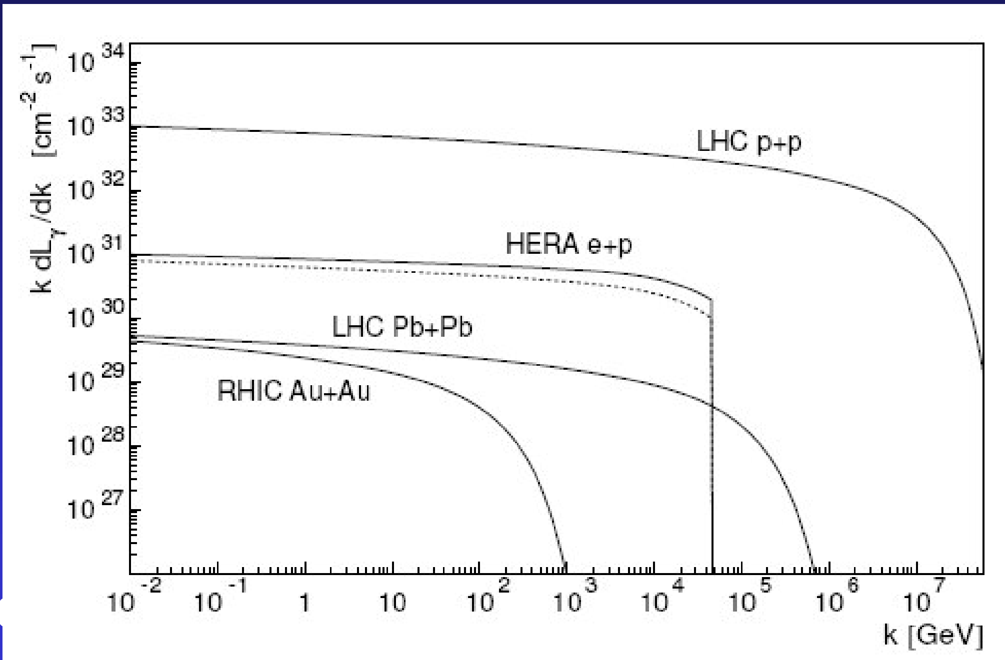
The Equivalent Photon Luminosity

The spectrum of photons with energy $E_\gamma = x \cdot E_{beam}$ and virtuality Q^2 is given by

$$x\frac{dn_\gamma}{dx\,dQ^2} = \frac{\alpha Z^2}{\pi}\left(1 - x + 1/2x^2\right)\frac{Q^2 - Q^2_{min}}{Q^4}$$

Q^2_{min} is constrained by x and the mass of the projectile. For hadron beams, the maximum of Q^2 is given by a form factor. In configuration space, this corresponds to $Q^2_{max} = (1/R)^2$.

Integrating over all virtualities gives the following equivalent photon spectrum (energy in the rest frame of the target).



Probing the nuclear structure functions

For a final state with invariant mass m_{inv} , the equivalent photon-proton center-of-mass energy is

$$W_{\gamma p}^{\ 2} = 2 \cdot m_{inv} \cdot E_p$$

and the corresponding Bjorken x is

$$x = m_{inv}^{\ 2} / W_{\gamma p}^{\ 2}$$

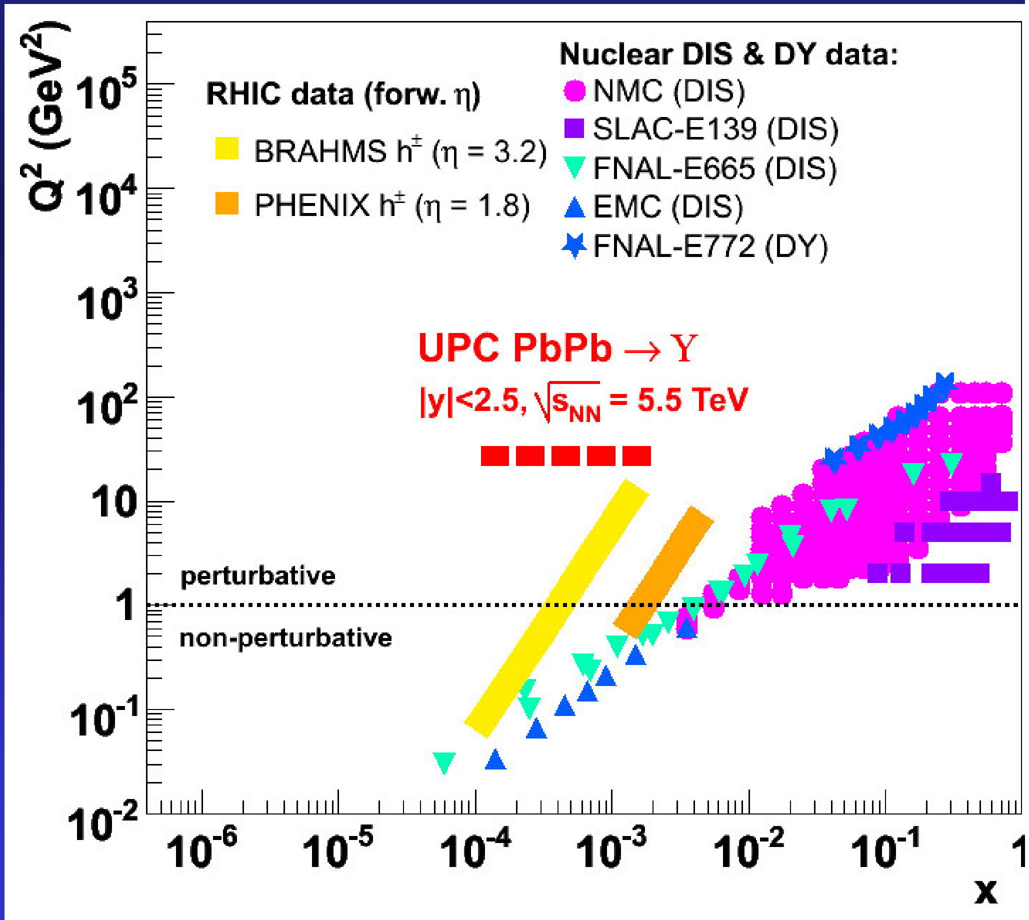
Examples of x–ranges probed at mid-rapidity at the LHC (exclusive vector meson production):

	J/ψ
LHC pp	$x \approx 2 \cdot 10^{-4}$
LHC PbPb	$x \approx 6 \cdot 10^{-4}$

	ϒ
LHC pp	$x \approx 6 \cdot 10^{-4}$
LHC PbPb	$x \approx 2 \cdot 10^{-3}$

For $y \neq 0$, $x = (m_{inv}^{\ 2}/W_{\gamma p}^{\ 2})\exp(\pm y)$

From D. d'Enterria, J. Phys. G 30 (2004)S767.



Example I: Production of Heavy Quarks

Consider the production of heavy quarks in a high-energy nucleus-nucleus collision. 3 production modes can be identified:

1. Hadronic production, dominated by $gg \rightarrow Q\overline{Q}$.
2. Photonuclear production, dominated by $\gamma g \rightarrow Q\overline{Q}$.
3. Electromagnetic production, $\gamma\gamma \rightarrow Q\overline{Q}$.

Estimated cross sections for these processes in Pb+Pb interactions at the LHC:

	hadroproduction $\sigma(Pb + Pb \rightarrow QQ + X)$	photoproduction $\sigma(Pb + Pb \rightarrow Pb + QQ + X)$	two-photon production $\sigma(Pb + Pb \rightarrow Pb + Pb + QQ)$
cc	252 b*	1.2 b	1.1 mb
bb	8.1 b*	4.9 mb	0.9 μb
	1	$\sim 10^{-3}$	$\sim 10^{-6}$

Hadroproduction dominates, but the cross sections for photoproduction and two-photon production are not small in absolute terms.

* Scaled pp cross sections from R.Vogt, Int. J. Mod. Phys. E 12 (2003) 211.
$> \sigma_{tot}$ because of production of multiple pairs in a single event.

Example II: Exclusive Production of di-lepton pairs

$A+A \rightarrow A+A + e^+e^- / \mu^+\mu^-$ or
$p+p \rightarrow p+p + e^+e^- / \mu^+\mu^-$ (the nuclei/protons remain intact).

A strong contribution from exclusively produced vector mesons (γ+Pomeron), followed by $V \rightarrow e^+e^- / \mu^+\mu^-$.

Reaction		Colliding system
$\gamma+\gamma$	$\rightarrow e^+e^- / \mu^+\mu^-$	ee, ep, pp/AA
γ+Pomeron	$\rightarrow V \rightarrow e^+e^- / \mu^+\mu^-$	ep, pp/AA
Odderon+Pomeron	$\rightarrow V \rightarrow e^+e^- / \mu^+\mu^-$	pp/AA

$\Rightarrow$ If the $\gamma+\gamma$ and γ+Pomeron contributions are well understood, pp (and AA) interactions can be used to search for the Odderon.
[A. Schäfer, L. Mankiewicz, O. Nachtmann, Phys. Lett. B 272 (1991) 419 and A. Bzdak, L. Motyka, L. Szymanowski, J.-R. Cudell hep-ph/0702134]

Trigger and Analysis Techniques

Although hadronic processes dominate, the cross sections for photon-induced interactions at hadron colliders are high. Special techniques are, however, required to separate the signal from "background". In addition to the low multiplicity, these are

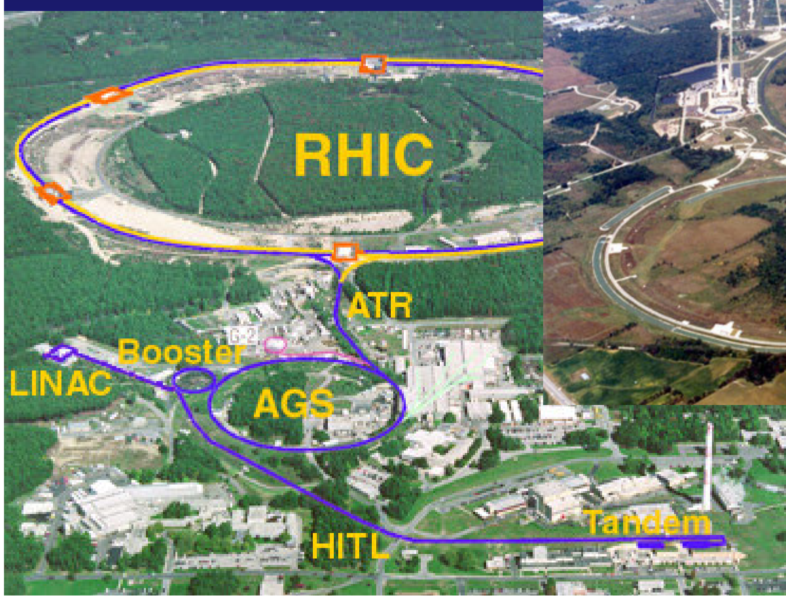
- Rapidity gap between photon-emitting nucleus and the produced particles, suppression for a gap Δy: $\exp(-\langle dn/dy \rangle \cdot \Delta y)$
With $\langle dn/dy \rangle \approx 2.5$-$3.5$ in pp at the LHC and $\Delta y=2 \Rightarrow \sim 10^{-2}$–$10^{-3}$ reduction.

- Coherence requirement for exclusive production in nucleus-nucleus collisions. If all produced particles are reconstructed, the total (summed) p_T is determined by the nuclear form factor, $p_T < \approx 50$ MeV/c, much smaller than the typical pT for hadronic events, ≈ 350 MeV/c.

Background sources: Cosmic rays (triggering), beam-gas, low-multiplicity hadronic events.

The Hadron Colliders RHIC, Tevatron and LHC

RHIC (1st collisions 2000):
Au+Au at $\sqrt{s_{nn}}$ = 200 GeV; p+p at $\sqrt{s}$ = 200 and 500 GeV.
Tevatron (1st collisions 1987):
p+$\bar{p}$ at $\sqrt{s}$ = 1.8 and 1.96 TeV
LHC (expected in 2008):
Pb+Pb at $\sqrt{s_{nn}}$ = 5.5 TeV; p+p at $\sqrt{s}$ = 14 TeV.



Ultra-Peripheral Collisions at RHIC

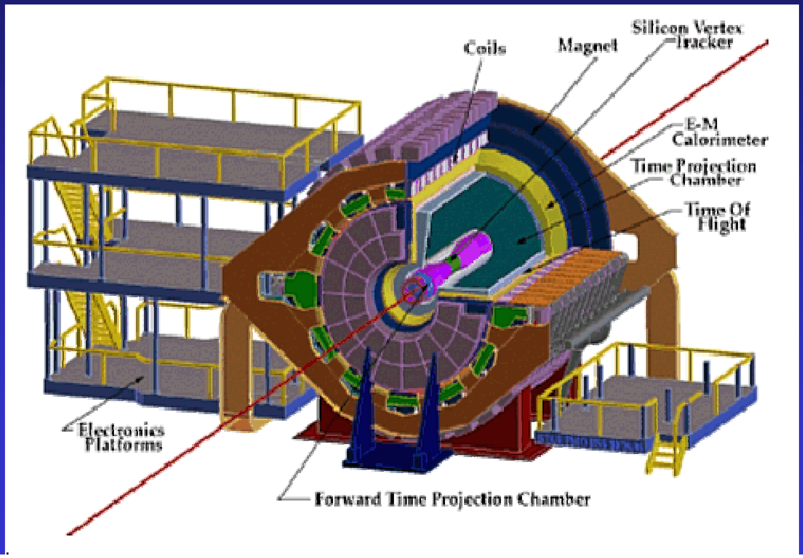
Experimental UPC results from RHIC so far:

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

Next talk by Janet Seger

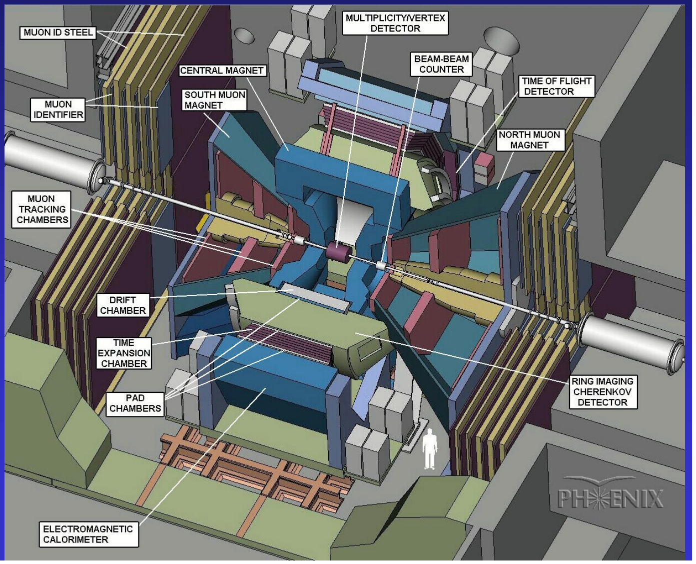
2) e^+e^--pair production, STAR Collaboration, (J.Adams et al., Phys.Rev. C70(2004)031902).

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



← STAR

PHENIX →



Ultra-Peripheral Collisions in PHENIX

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/.

The goal was to search for the process γ+Au $\rightarrow$ J/Ψ+Au in reactions Au+Au $\rightarrow$ Au + Au + e^+e^-. There was also a contribution from $\gamma+\gamma\rightarrow e^+e^-$.

The electrons were identified in the central tracking arm ($|\eta| \leq 0.35$, $\Delta\varphi = 2\times 90°$).

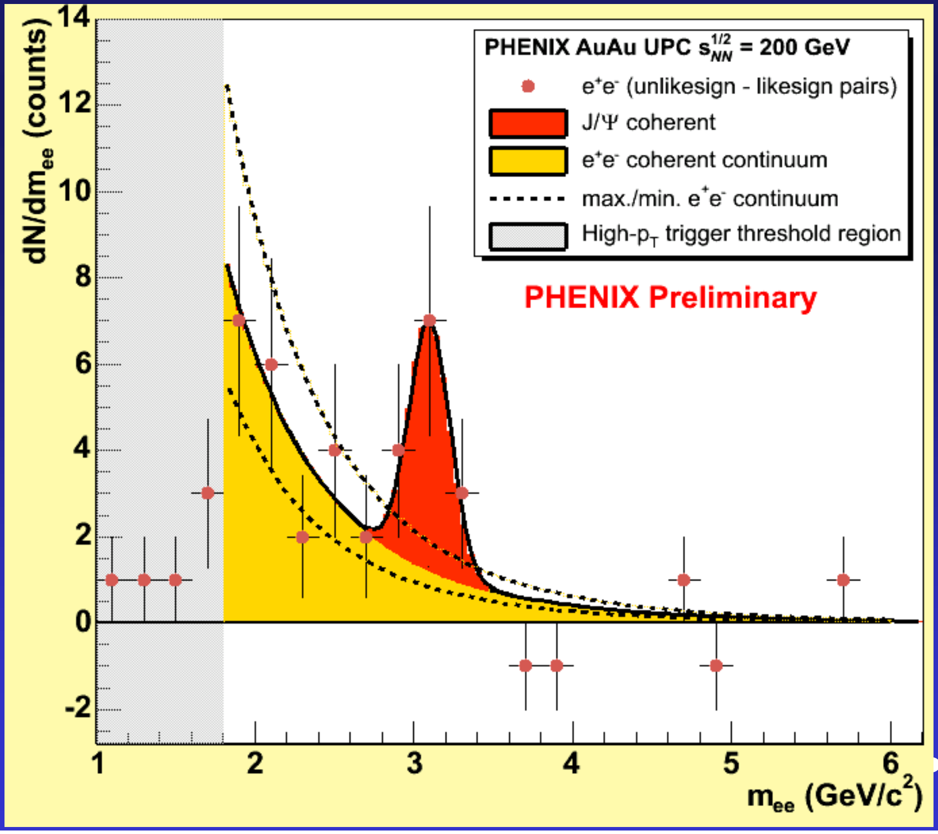
Level 1 Ultra-Peripheral Trigger:

- Veto on coincident BBC $|\eta| \sim 3 – 4$ (rapidity gap).
- Large Energy (E > 0.8 GeV) cluster in EmCal.
- Neutron(s) in at least one ZDC (E > 30 GeV) from Coulomb break up of one or both nuclei.

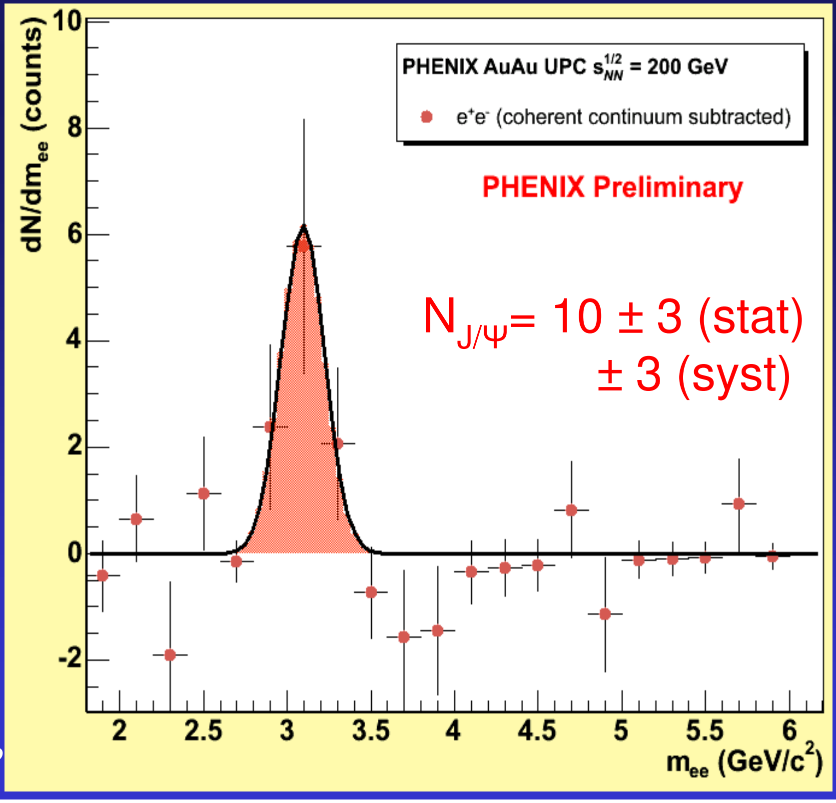
Ultra-Peripheral Collisions in PHENIX

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/.

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



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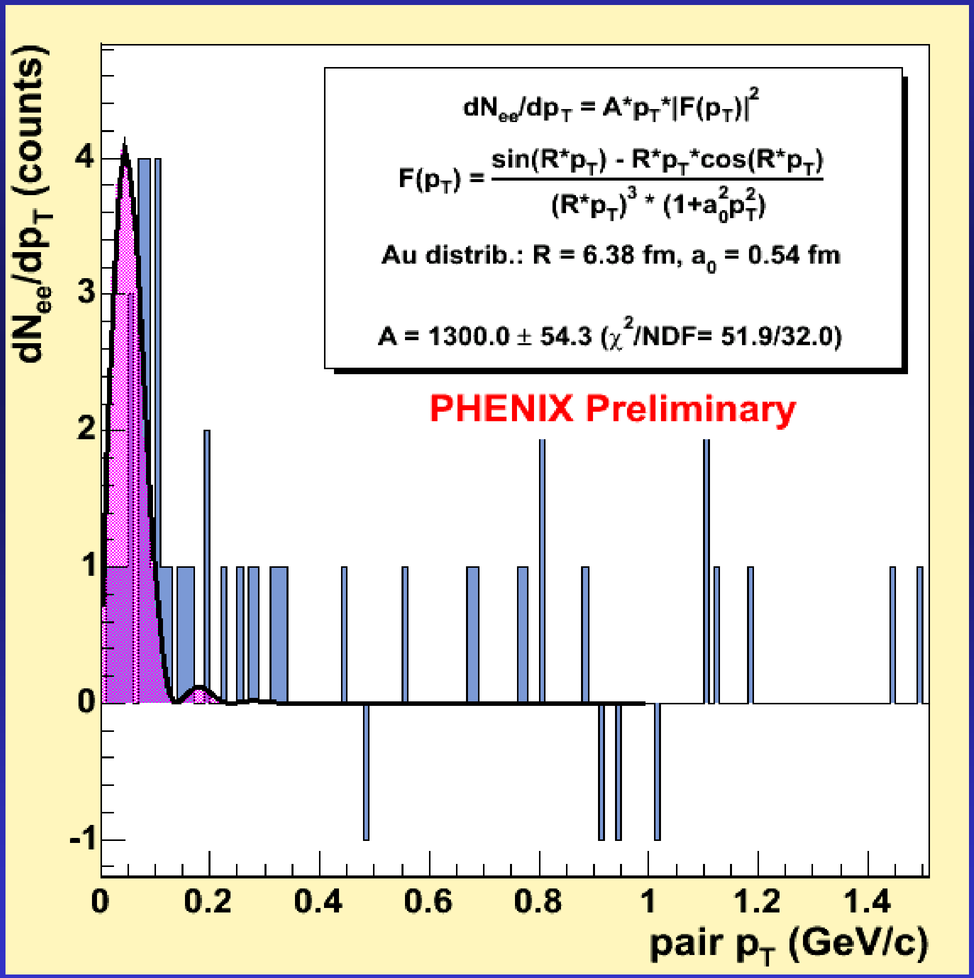


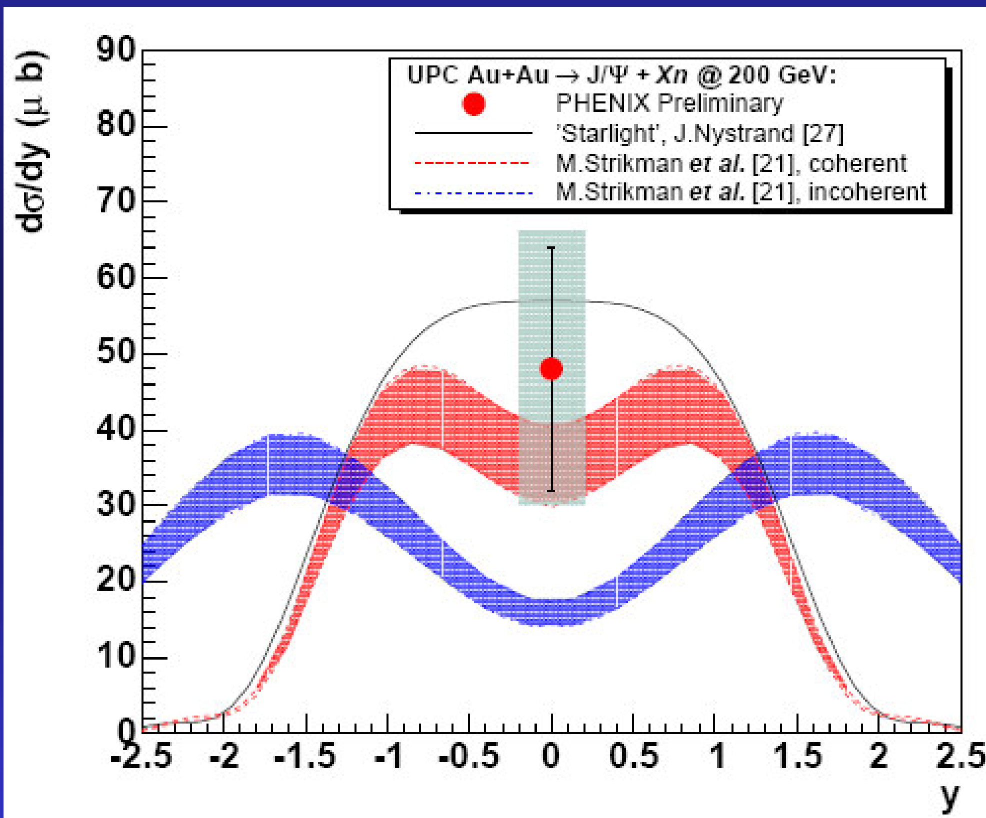
The coherent and incoherent contribution is separated based on the transverse momentum.

Preliminary J/Ψ cross section

$d\sigma_{J/\psi}/dy|_{y=0} = 1/BR \times 1/(Acc|_{y=0}\cdot\varepsilon) \times 1/\varepsilon_{trig} \times 1/L_{int} \times N_{J/\psi}/\Delta y =$

$= 1/(5.9\%)\times 1/(5.7\%\cdot 56.4\%)\times 1/(90\%)\times 1/120\ \mu b^{-1}\times(10 \pm 3\pm 3) =$

$= 48. \pm 16.\ (stat) \pm 18.\ (syst)\ \mu b$



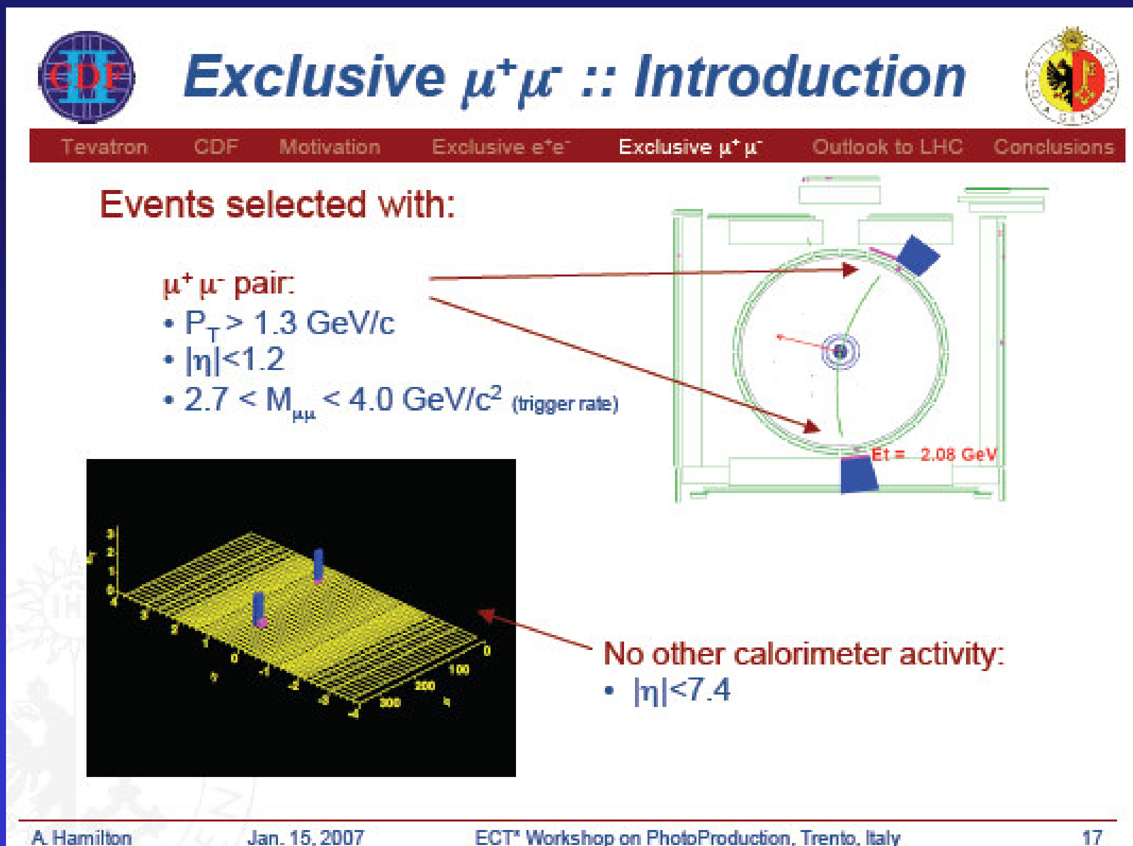
- Measured J/Ψ yield at y=0 consistent w/ theoret. calcs. [1,2]
- Syst. uncertainty: coherent e^+e^- continuum under J/Ψ (*work in progress*).
- Reduction of stat. errors need larger luminosity.
- Current uncertainties preclude yet detailed study of crucial model ingredients: $G_A(x,Q^2)$, σ(J/Ψ absorption).

[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 $p+\bar{p} \to p+\bar{p}+e^+e^-$ via $\gamma\gamma$:
A. Abulencia et al. PRL 98 (2007) 112001.

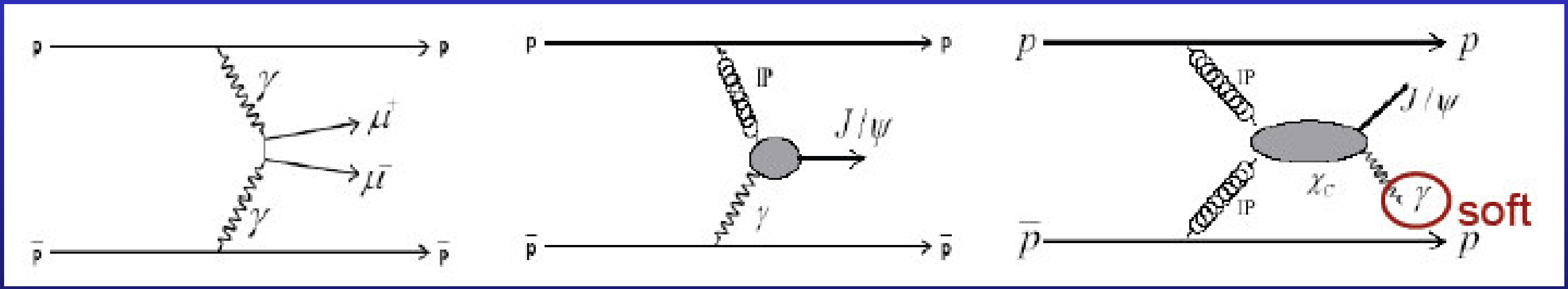
Work in progress on $p+\bar{p} \to p+\bar{p}+\mu^+\mu^-$
(A. Hamilton, Workshop on Photoproduction at Collider Energies: ECT* Trento, 15 – 19 January, 2007, http://www.ect.it/.)



See talk by James L. Pinfold

"Ultra-peripheral" Collisions at the Tevatron

Three possible contributions to the process $p+\bar{p} \rightarrow p+\bar{p}+\mu^+\mu^-$:

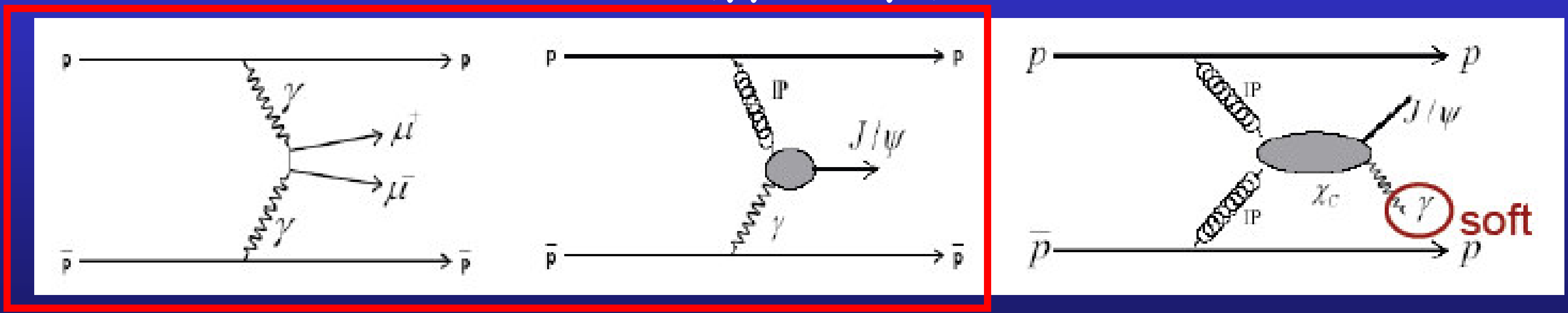


Note: no feed down from χ_c to Ψ'.

A contribution from Odderon+Pomeron also possible.

"Ultra-peripheral" Collisions at the Tevatron

Calculations for the first two (γγ and γP):



σ(pp→pp+J/Ψ(1S)): 15 nb σ·Br(μμ): 0.87 nb

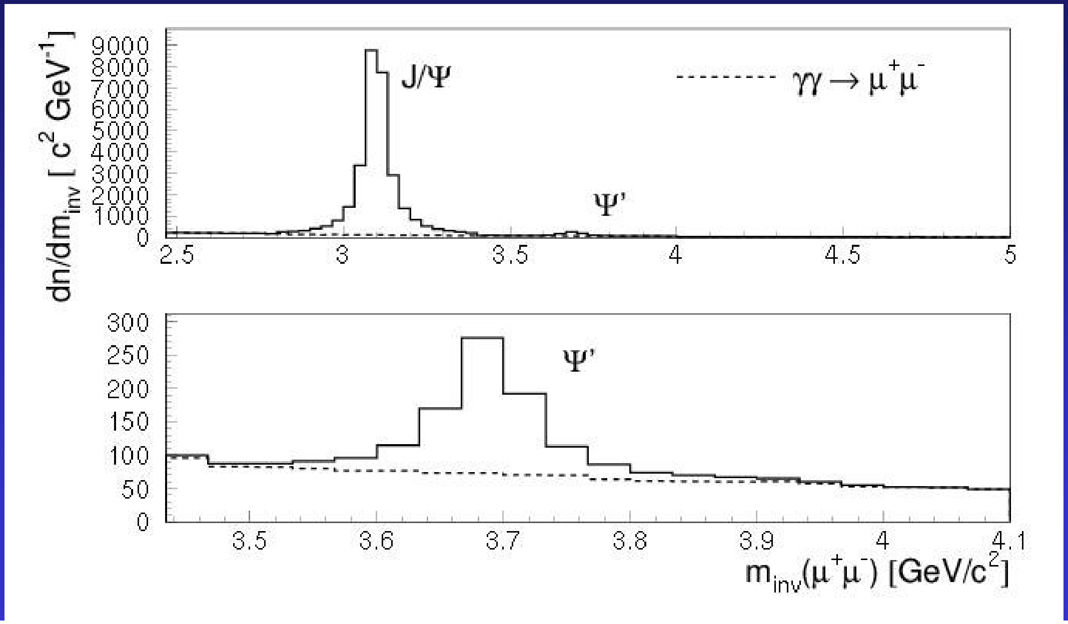
σ(pp→pp+Ψ'(2S)): 2.4 nb σ·Br(μμ): 18 pb

σ(pp→pp+μμ): 2.4 nb (m_{inv} > 1.5 GeV/c^2)

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

p_T > 0.5 GeV/c

|η| < 2.0 ⇒

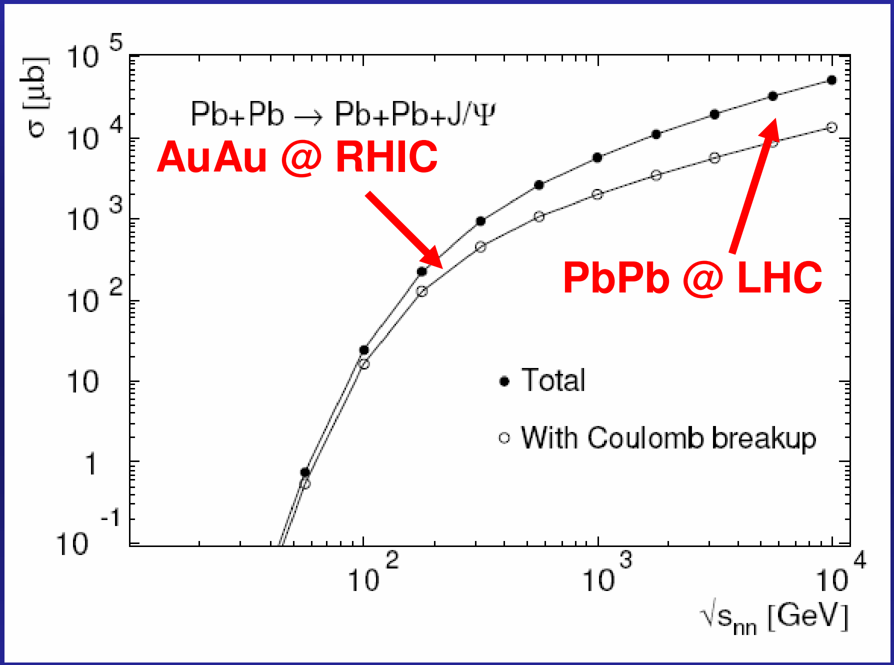


Yield(Ψ')/Yield(J/Ψ) ≈ 1:50

σ(γp→Vp) parameterized from data. See S.R.Klein, J.Nystrand, PRL 92 (2004) 142003.

"Ultra-peripheral" Collisions at the LHC

The increased energy is particularly advantageous for heavy final states. Example: Exclusive J/Ψ production



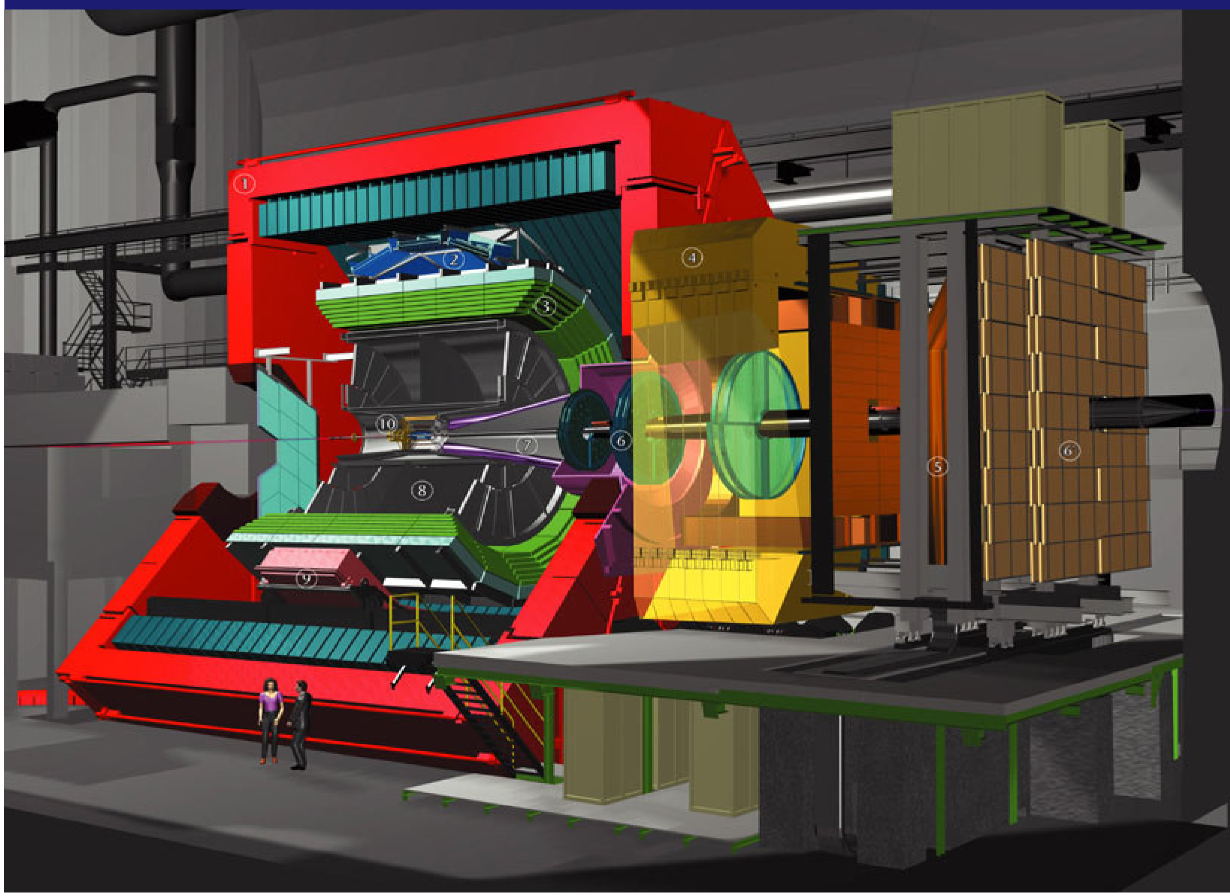
ρ:	RHIC 590mb	→ LHC 5200mb	factor 9
J/ψ	RHIC 0.3 mb	→ LHC 32mb	factor 100

See talks by David d'Enterria (CMS) and Valeri Pozdnyakov (ATLAS)

”Ultra-peripheral” Collisions in ALICE

(from the ALICE PPR, B. Alessandro et al., J. Phys. G 32 (2006) 1295)

ALICE (= A Large Ion Collider Experiment) –
The dedicated Heavy-Ion Experiment at the LHC
Located at IP 2 (former L3) and uses the L3 Magnet



Joakim Nystrand

”Ultra-peripheral” Collisions in ALICE

(from the ALICE PPR, B. Alessandro et al., J. Phys. G 32 (2006) 1295)

Ideas to study exclusive vector meson production, in particular J/Ψ and ϒ.

Mid-rapidity $V \rightarrow e^+e^-$.
Trigger: Level 0 multiplicity from SiPixel, ToF in anti-coincidence w/ t0 and v0 detectors ($\approx 2 < |\eta| < 5$).
Electron Id: Transition Radiation Detector (also in Level 1 Trigger).

Forward region ($2.2 \leq \eta \leq 4.0$) $V \rightarrow \mu^+\mu^-$.
Trigger: Muon arm trigger in anti-coincidence w/ central arm detectors (SiPixel, ToF).

”Ultra-peripheral” Collisions in ALICE

(from the ALICE PPR, B. Alessandro et al., J. Phys. G 32 (2006) 1295)

Expected rates (mid-rapidity; *Geo Acc: $|\eta|<0.9$, $p_T>0.15$ GeV/c)

	Prod. Rate	Decay	Br.Ratio	Geo Acc.*	Detection Rate
ρ	$2.6\cdot10^9$	$\pi\pi$	100%	0.079	$2.0\cdot10^8$
J/ψ	$1.6\cdot10^7$	e^+e^-	5.93%	0.164	$1.5\cdot10^5$
Υ	$\sim1\cdot10^5$	e^+e^-	2.38%	0.236	≈ 600

Expected rates (muon arm, $2.2 \leq \eta \leq 4.0$)

	Prod. Rate	Decay	Br.Ratio	Geo Acc.	Detection Rate
J/ψ	$1.6\cdot10^7$	$\mu^+\mu^-$	5.88%	0.061	$5.7\cdot10^4$
$\Upsilon(1S)$	$\sim1\cdot10^5$	$\mu^+\mu^-$	2.48%	0.016	≈ 40

Note: The rates are for a standard ALICE Pb+Pb month (10^6 s) with $<L> = 5\cdot10^{26}$ $cm^{-2}s^{-1}$. The calculations are done without shadowing (impulse approximation). Shadowing could reduce the rates by factors of ≈1-5.

Conclusions and Outlook

- Although it is not the main goal, studying photon-induced interactions at hadron colliders is an opportunity that should not be missed.
- The feasibility has been proven at RHIC and the Tevatron.
- A stronger commitment (and more manpower) from the collaborations would be desirable, but several interesting results have already obtained from RHIC and the Tevatron. (See the following talks this afternoon!)
- The prospects for the LHC are good.