Photoproduction of Quarkonium

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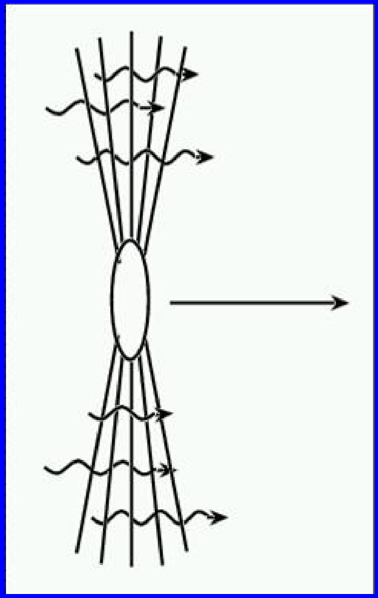
- Photonuclear interactions in ultra-peripheral collisions (b > 2R).
- Photonuclear interactions in collisions of intermediate centrality (10-15 fm).
- Comparison of hadroproduction and photoproduction in these collisions.

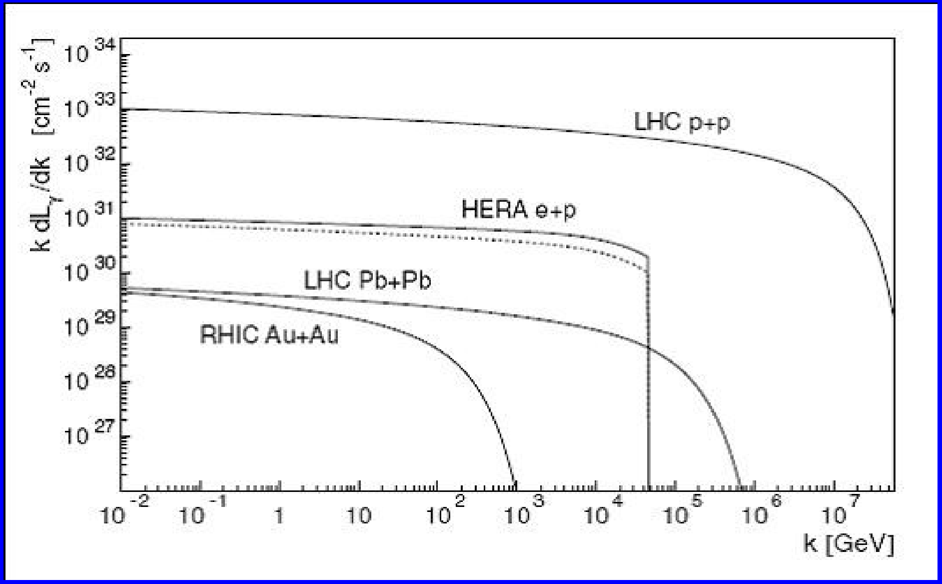
The Photon Spectrum at Heavy-Ion Colliders



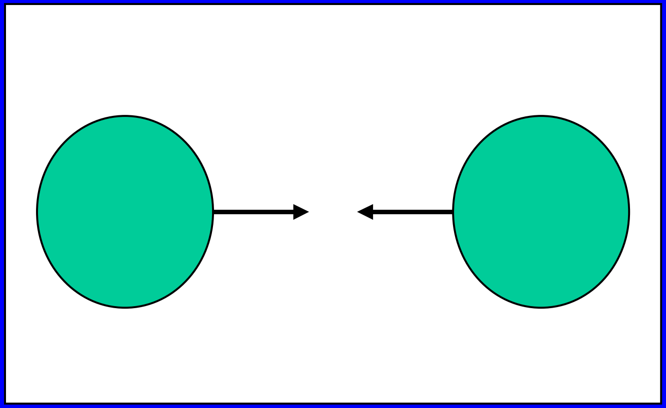
Electromagnetic field of a relativistiv charged particle ↔ An equivalent flux of photons (Weiszäcker-Williams)

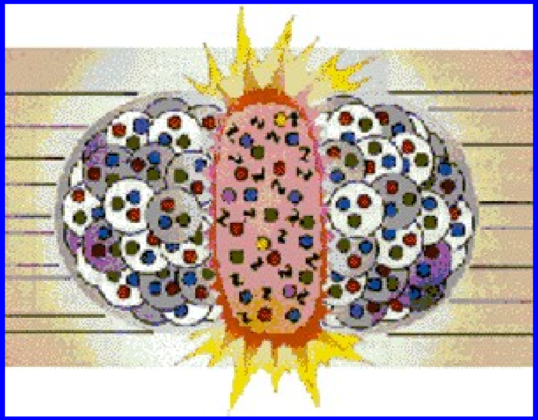
Number of photons in one beam $\propto Z^2$.

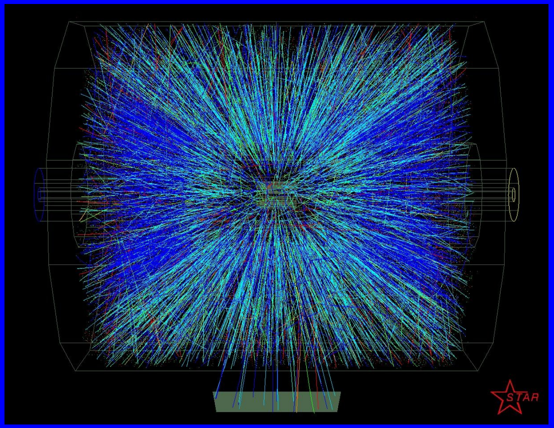
The spectrum extends to $\sim \gamma/R \leftrightarrow W_{\gamma p} \approx 1000$ Gev in Pb+Pb collisions ($Q^2 \approx 0$). Extends the energy range reached at HERA.



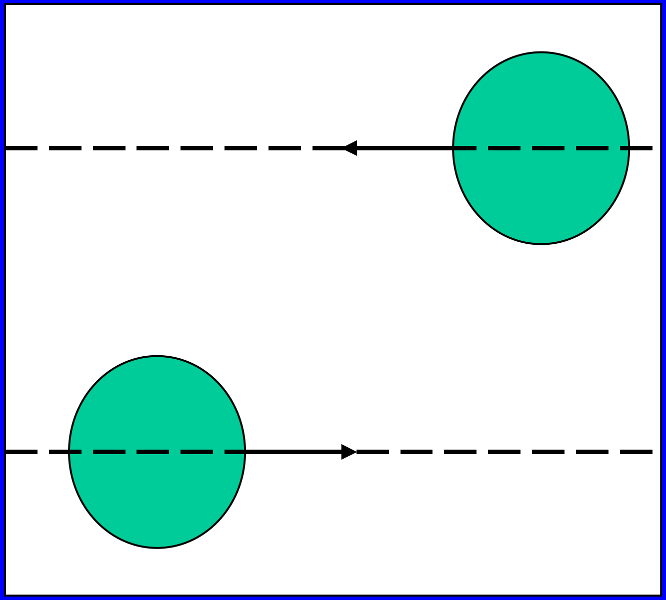
J/Ψ Production in Central vs. Ultra-peripheral Collisions







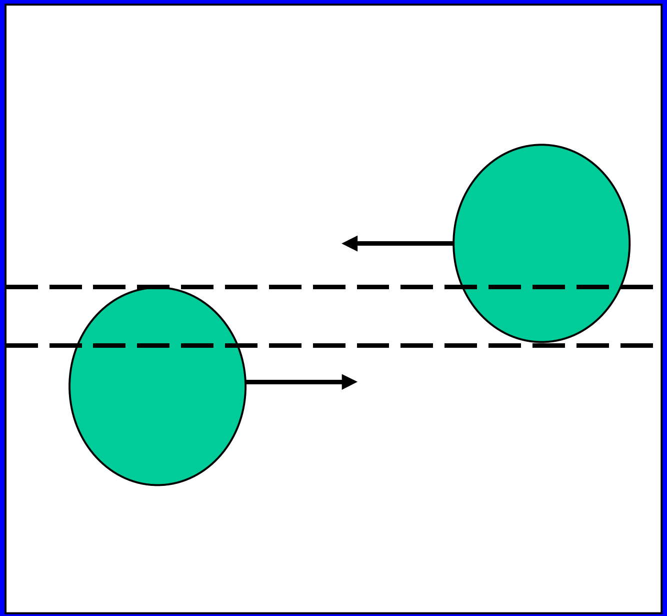
J/Ψs are produced in central collisions through the strong interaction, starting with $g + g \rightarrow c\bar{c}$ etc.



J/Ψs are also produced in ultra-peripheral collisions.

Vector Meson Dominance - The photon fluctuates to a J/Ψ which scatters off the target nucleus.

J/Ψ Production in Collisions of Intermediate Centrality



Collisions of intermediate centrality (b $\approx$ 10 - 15 fm in Pb+Pb collisions).

J/Ψs can be produced both hadronically and electro-magnetically.

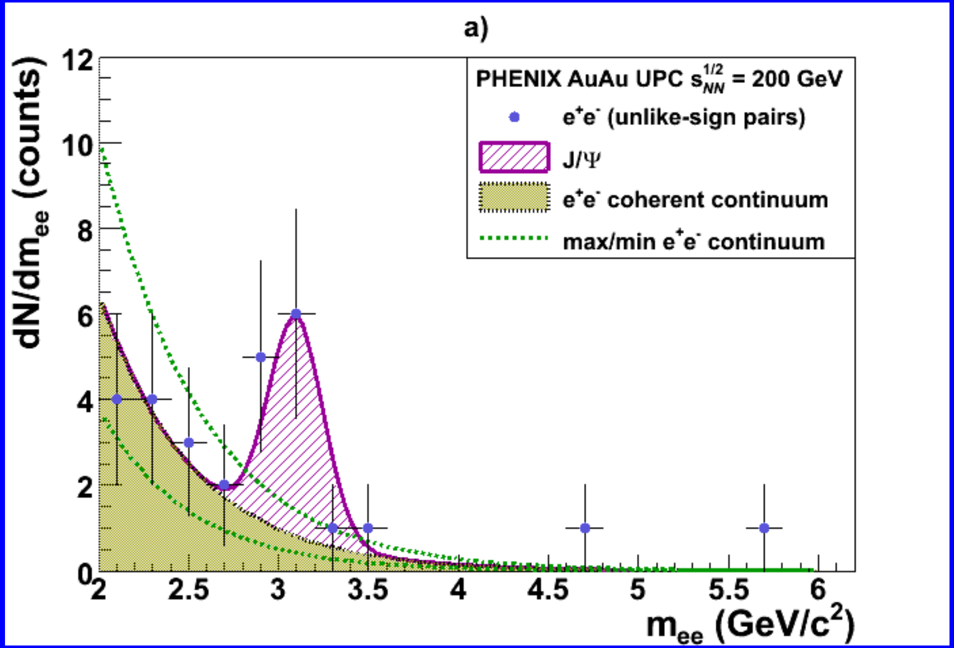
The spectator fragments act as photon-emitters and targets, like in an ultra-peripheral collision.

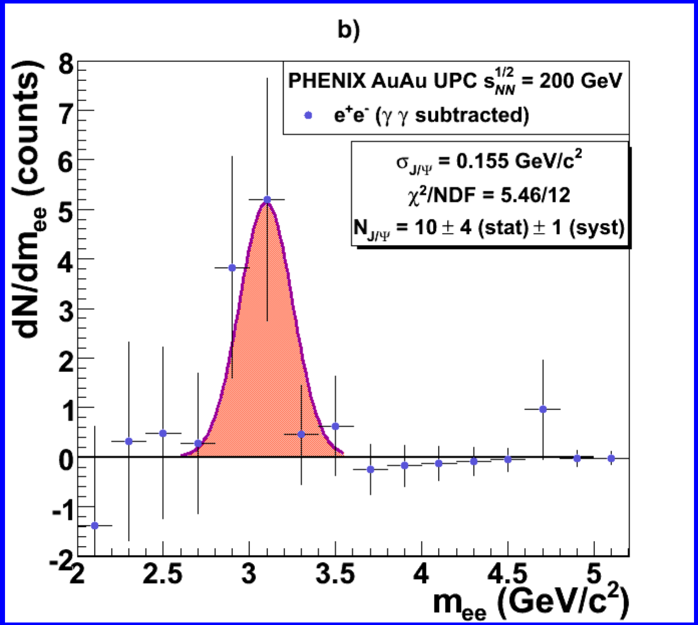
$\Rightarrow$ Try to estimate the photoproduction component in these events and compare with the hadroproduction.

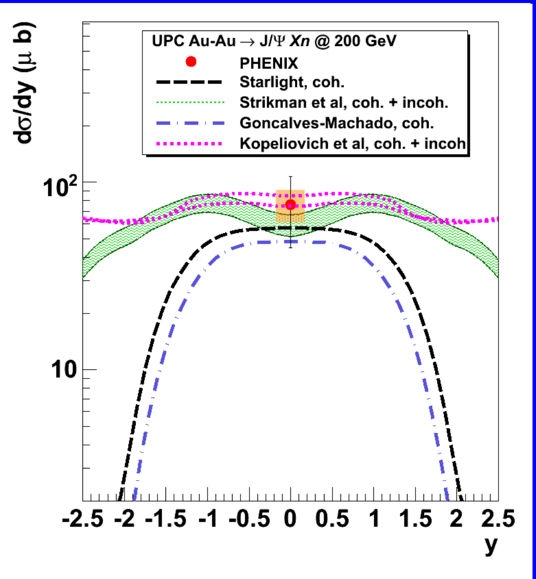
Photoproduction of J/Ψ in ultra-peripheral collisions

- Has been observed at RHIC (Au+Au) and at the Tevatron (p+$\overline{\text{p}}$).

Results from PHENIX (PLB 679 (2009) 321):



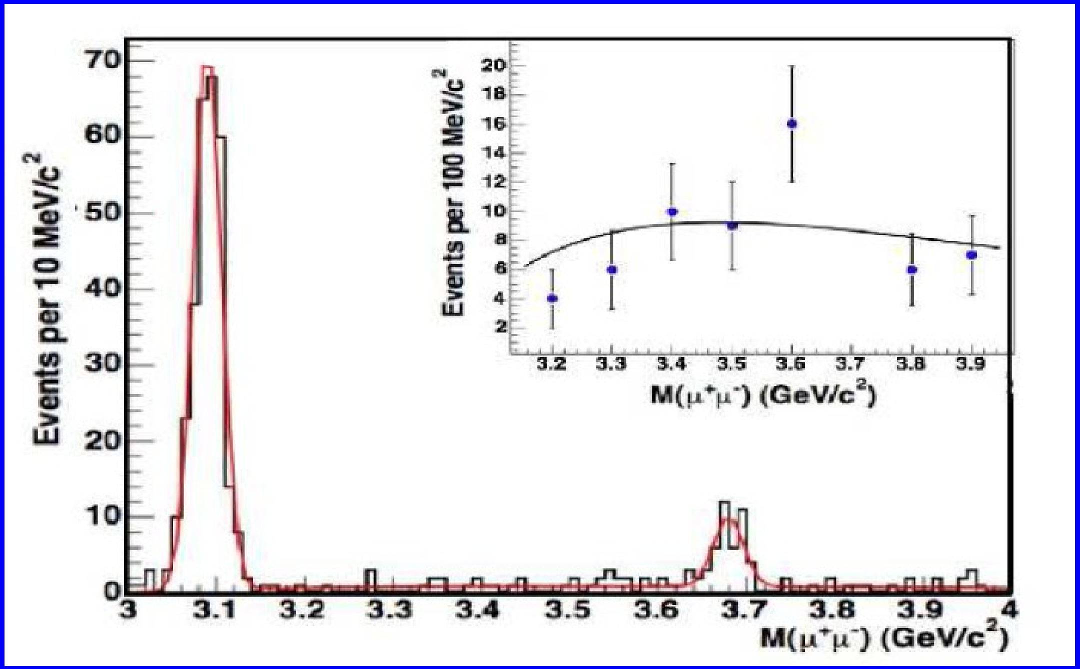




- Generally good agreement with STARLIGHT calculations, based on S.R. Klein and J. Nystrand, Phys. Rev. C 60 (1999) 014903, and with calculations by other groups.

Photoproduction of J/Ψ in ultra-peripheral collisions

Results from CDF (PRL 102 (2009) 242001, arXiv:0902.1271):



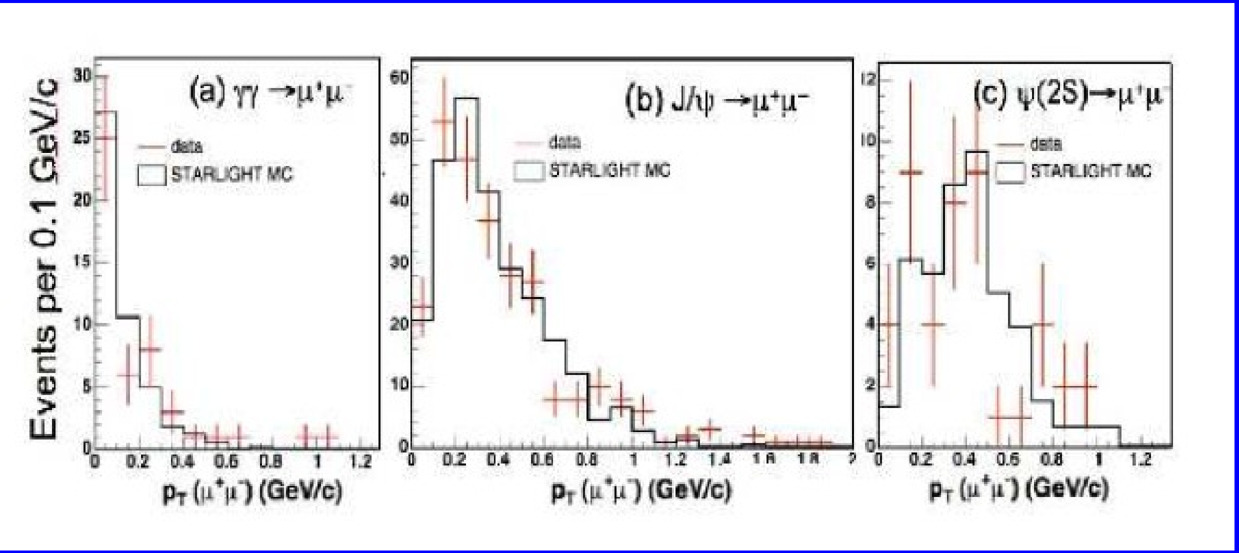
Two reconstructed muons in $|\eta|<0.6$ in an otherwise empty detector ($|\eta|<7.4$).

402 signal events in a nearly background-free sample.

Contributions from $J/\Psi \rightarrow \mu^+\mu^-$, $\Psi' \rightarrow \mu^+\mu^-$, $\gamma\gamma \rightarrow \mu^+\mu^-$.

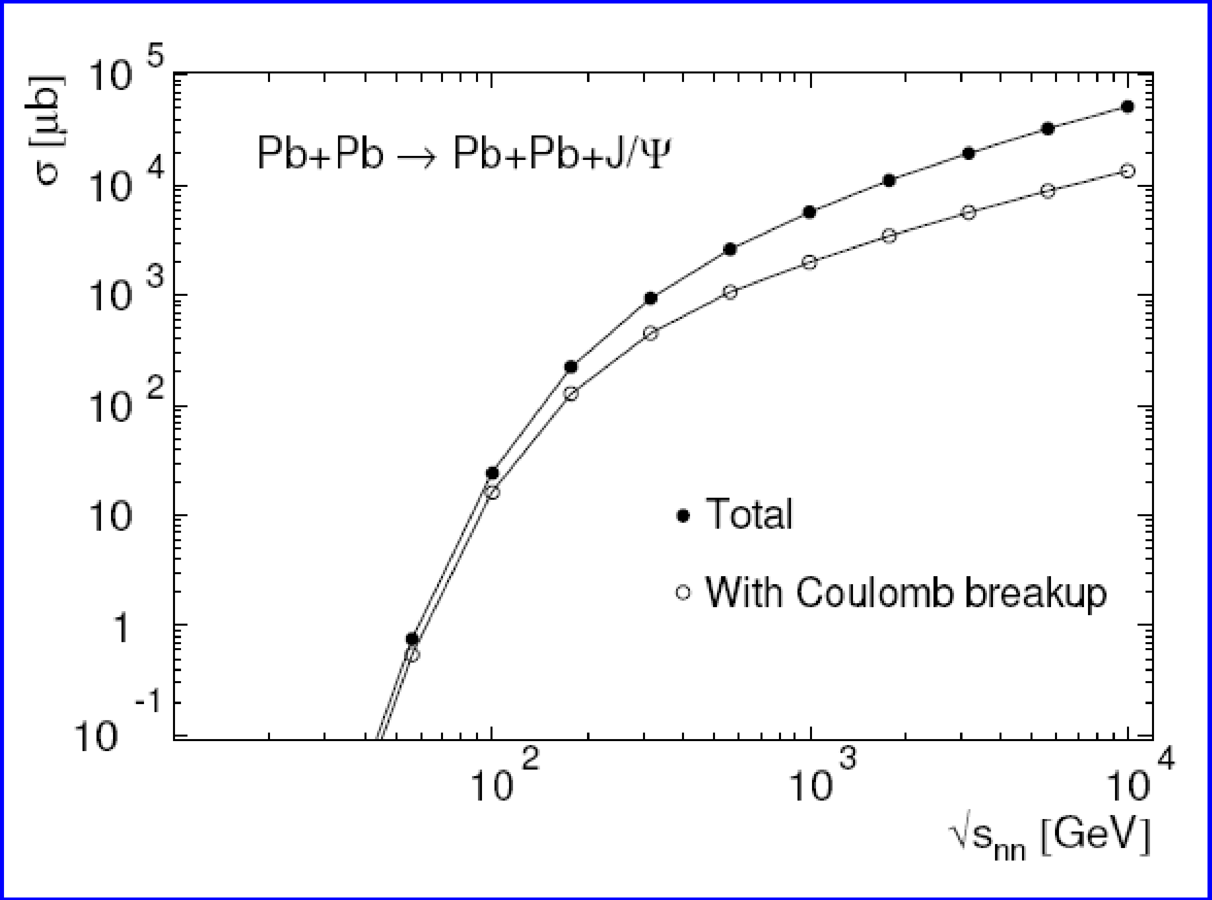
p_T distributions in agreement with expectations.

STARLIGHT: Based on S.R.Klein, J.Nystrand, PRL 92 (2004) 142003.



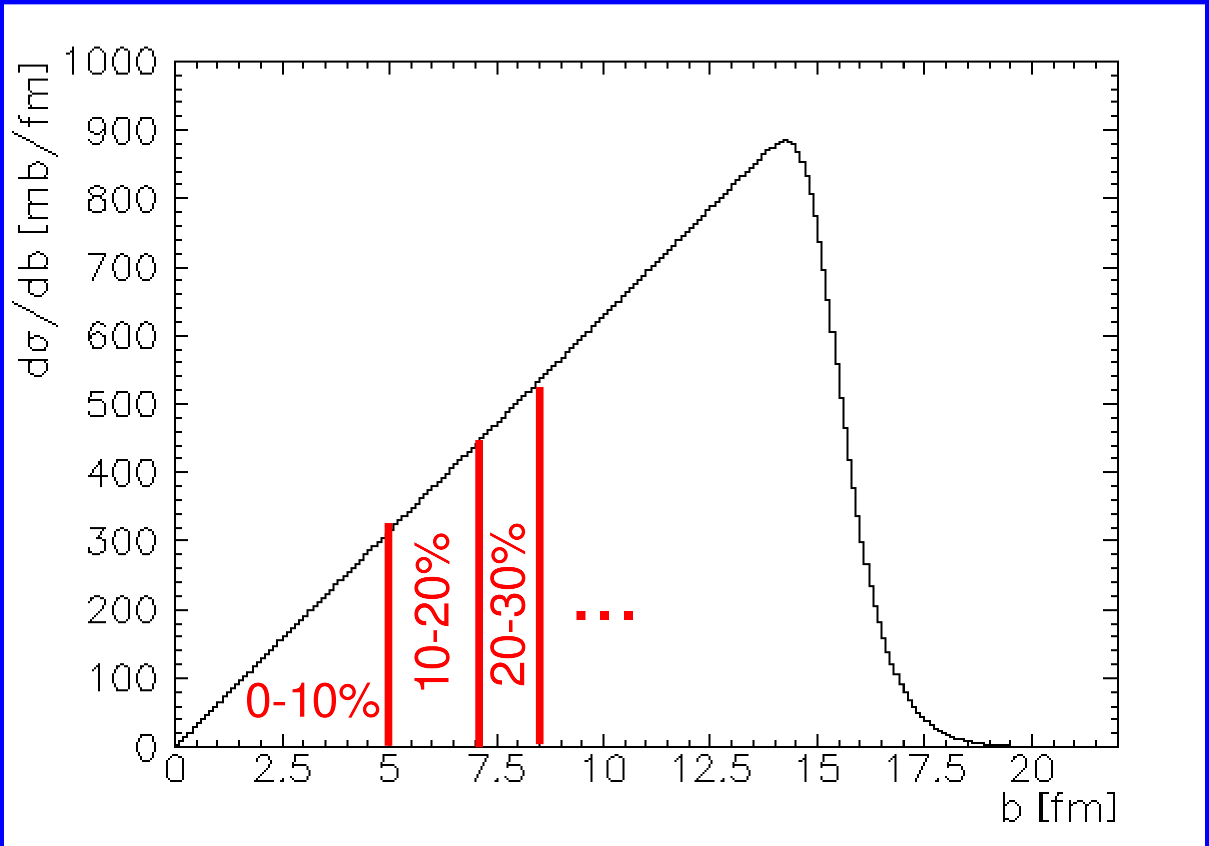
Photoproduction of J/Ψ in ultra-peripheral collisions

Expects a strong increase in the photoproduction cross section at the LHC



J/ψ RHIC 0.3 mb → LHC 32mb factor 100

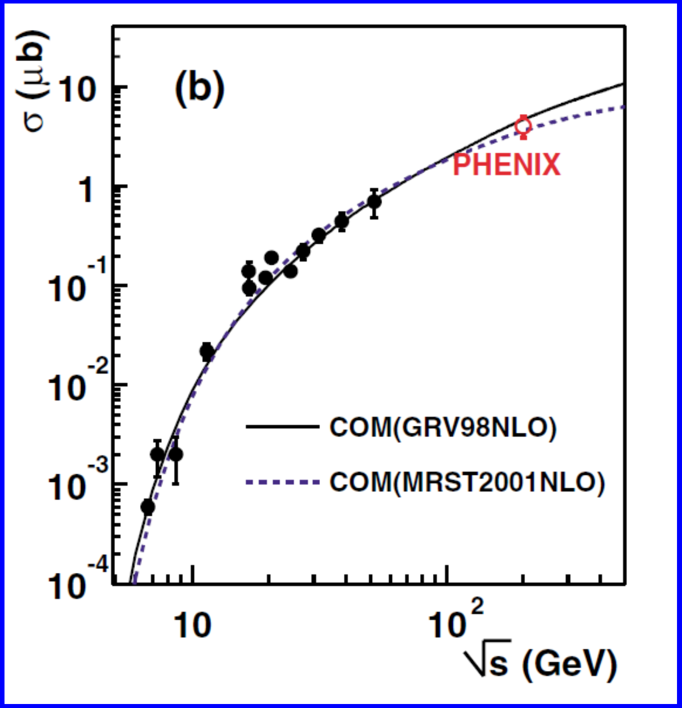
Distribution of impact parameters in Pb+Pb Collisions



- Glauber model calculation.
- Divide the total cross section in 10% centrality bins based on impact parameter...

Hadronic production of J/Ψ in pp collisions

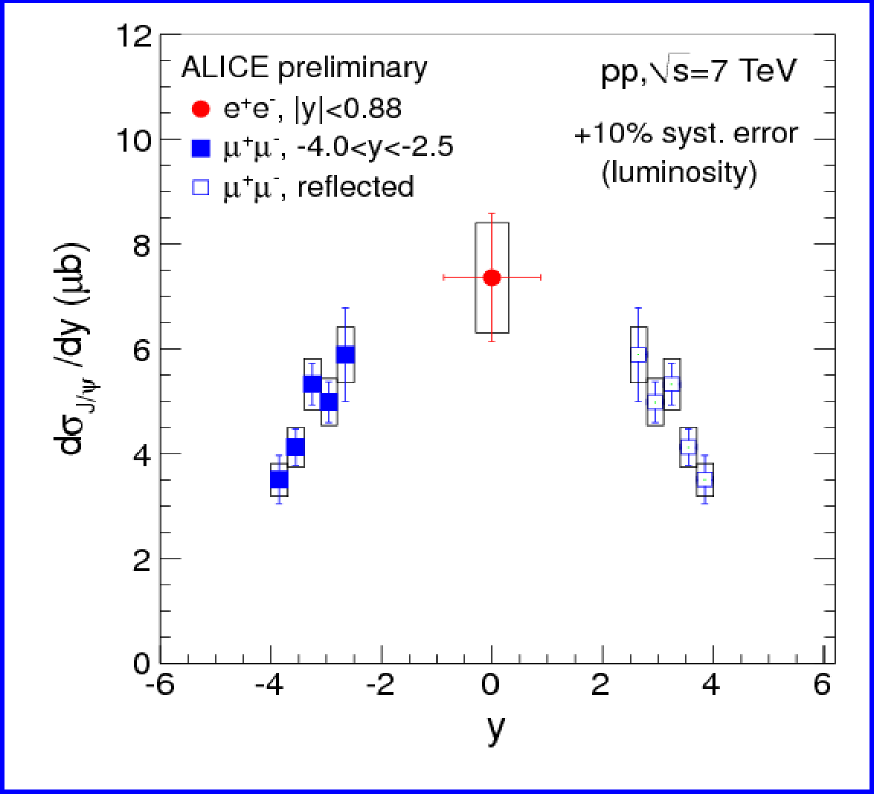
- Measurement of the total J/Ψ cross section by PHENIX at $\sqrt{s}$ = 200 GeV, $\sigma(pp \rightarrow J/\Psi + X)$ = 3.0 μb.
- Energy dependence reproduced by the Color Octet Model.



PHENIX Coll. Phys. Rev. Lett. 92 (2004) 051802; 98 (2007) 232002.

This is also being measured at the LHC at 7 TeV

From Ionut Arsene's talk Monday



Hadronic production of J/Ψ at the LHC

Calculations in the ALICE PPR Vol. I (J. Phys. G 30 (2004) 1517) at $\sqrt{s}$ = 5.5 TeV (including feed-down):

- Color Evaporation Model $\sigma(pp \to J/\Psi + X) = 30.5\ \mu b$
- NRQCD $\sigma(pp \to J/\Psi + X) = 83.1\ \mu b$

Pythia 8.142 at $\sqrt{s}$ = 5.5 TeV gives

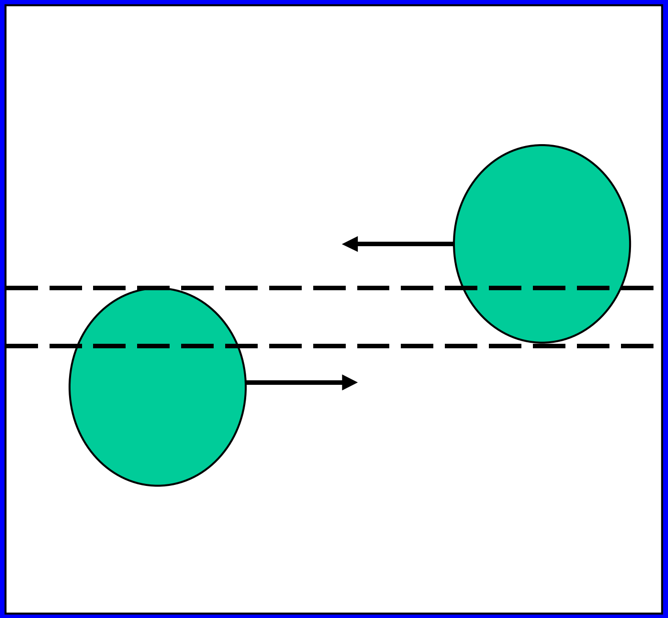
- $\sigma(pp \to J/\Psi + X) = 100\ \mu b$

Pythia 8.142 at $\sqrt{s}$ = 2.75 TeV gives

- $\sigma(pp \to J/\Psi + X) = 64\ \mu b$

$\Rightarrow$ Will use the 64 μb at 2.75 TeV for the rest of this talk.

Scaling of the cross section



The hadronic cross section for J/Ψ in the impact parameter range [b1,b2] is scaled from the pp cross section using the Glauber model:

$$\sigma = \int \sigma(pp \to J/\Psi + X)\ T_{AB}(\mathbf{b})\ d^2b$$

where

$$T_{AB}(\vec{b}) = \int T_A(\frac{\vec{b}}{2} - \vec{b}')T_B(\frac{\vec{b}}{2} + \vec{b}')d^2\vec{b}'$$

is the nuclear overlap function and $T_A(\mathbf{b})$ is the nuclear thickness function.

Scaling of the cross section

Centrality	b [fm]	$\langle T_{AB} \rangle$ [mb^{-1}]	$\langle N_{coll} \rangle$	$\sigma(J/\Psi)$ [mb]
0 - 10 %	0.0-5.0	23.8	1496.6	1179.8
10 - 20 %	5.0-7.0	14.4	905.4	713.6
20 - 30 %	7.0-8.6	8.52	536.5	422.9
30 -40 %	8.6-10.0	4.76	300.1	236.5
40 - 50 %	10.0-11.1	2.45	154.4	121.7
50 - 60 %	11.1-12.2	1.12	70.7	55.8
60 - 70 %	12.2-13.2	0.45	28.5	22.5
70 - 80 %	13.2-14.1	0.16	10.3	8.1
80 - 90 %	14.1-15.0	0.05	3.3	2.6
90 - 100 %	15.0-(25.0)	0.01	≈ 1	0.6

				2764.1 mb $\approx$ 63.8 μb $\cdot$ 208^2

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2764.1 mb $\approx$

63.8 μb · 208^2

Focus on these

Photoproduction in collisions of intermediate centrality

For each centrality class, define an effective A_{eff} and Z_{eff}

with

$$A_{eff} = (A - N_{part}/2)$$

and

$$Z_{eff} = (A_{eff}/A) \cdot Z$$

Calculate the photoproduction cross section over the relevant impact parameter range for a photon-emitter nucleus with charge Z_{eff} and a photon-target nucleus with A_{eff} nucleons.

Photoproduction in collisions of intermediate centrality

The photoproduction can be coherent or incoherent (quasi-elastic, γ+N $\rightarrow$J/Ψ+N). The scaling with Aeff in the two cases:

$$d\sigma(\gamma A)/dt\_t=0 = A^2\, d\sigma(\gamma p)/dt\_t=0 \qquad \text{Coherent}$$

$$\sigma(\gamma A) = A\, \sigma(\gamma p) \qquad \text{Incoherent}$$

Shadowing and absorption are not taken into account (as for hadronic production - we want a first estimate of the cross sections).

Photoproduction vs. hadronic cross sections

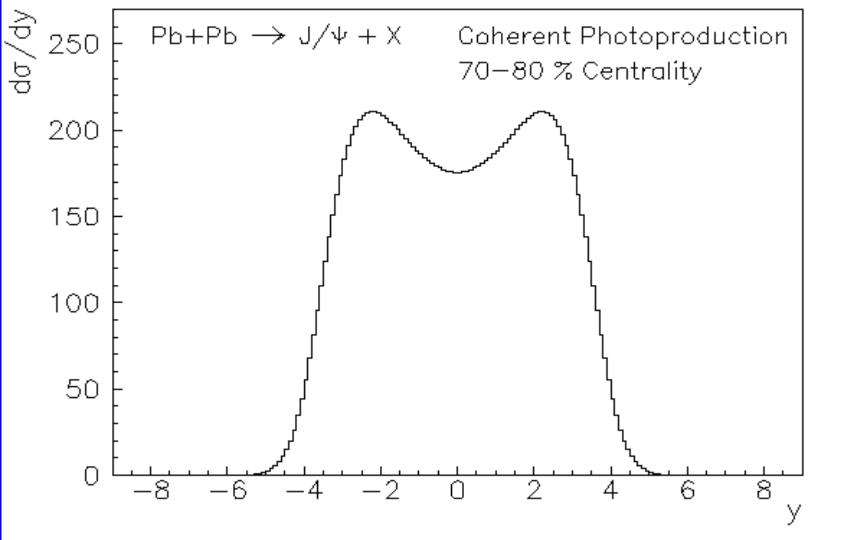
Centrality	$\sigma(J/\Psi)$ hadronic	$\sigma(J/\Psi)$ coh	$\sigma(J/\Psi)$ incoh [mb]
80 - 90 %	2.6	1.1	0.4
70 - 80 %	8.1	1.4	0.5
60 - 70 %	22.5	1.5	0.5
50 - 60 %	55.8	1.5	0.6
40 - 50 %	121.7	1.3	0.5

Photoproduction vs. hadronic cross sections

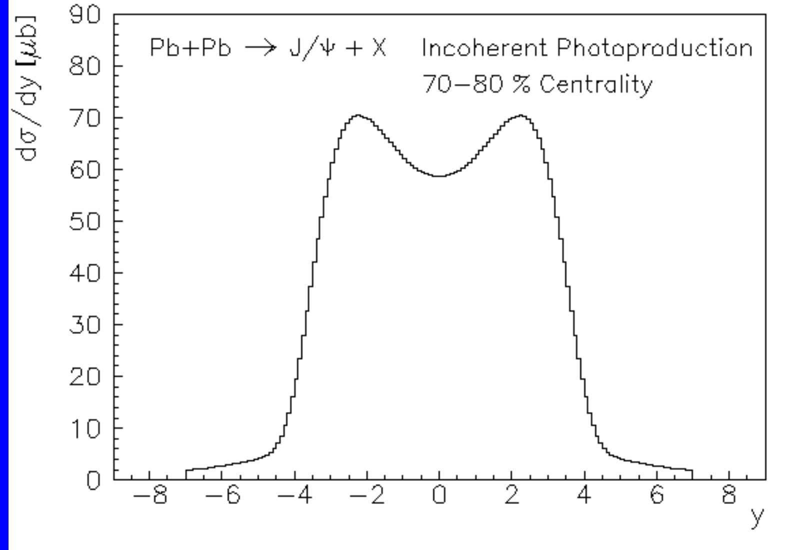
Centrality	fraction photoproduced J/Ψ
80 - 90 %	37%
70 - 80 %	19%
60 - 70 %	8%
50 - 60 %	4%
40 - 50 %	1.4%

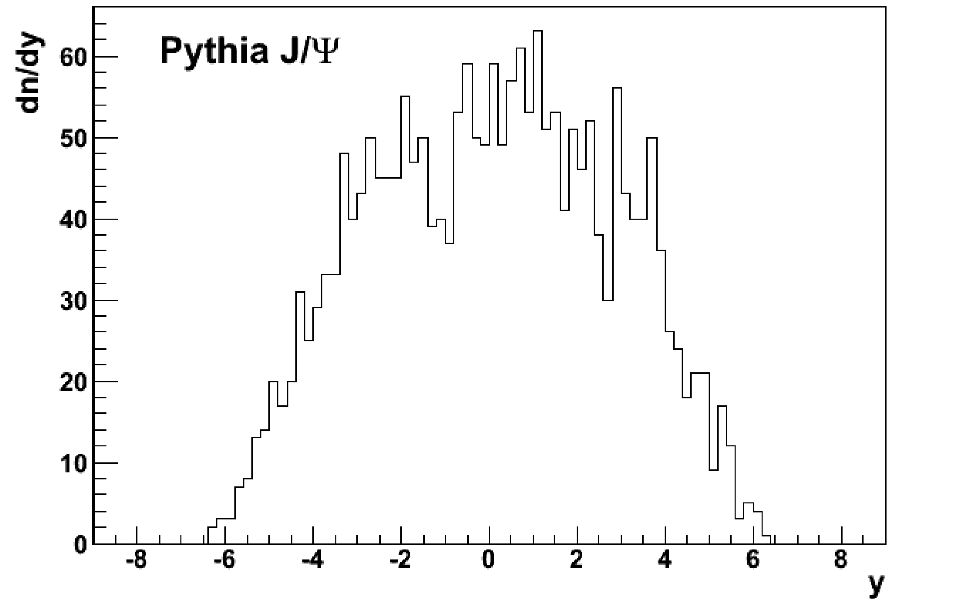
Rapidity distributions

Coherent Photopoduction

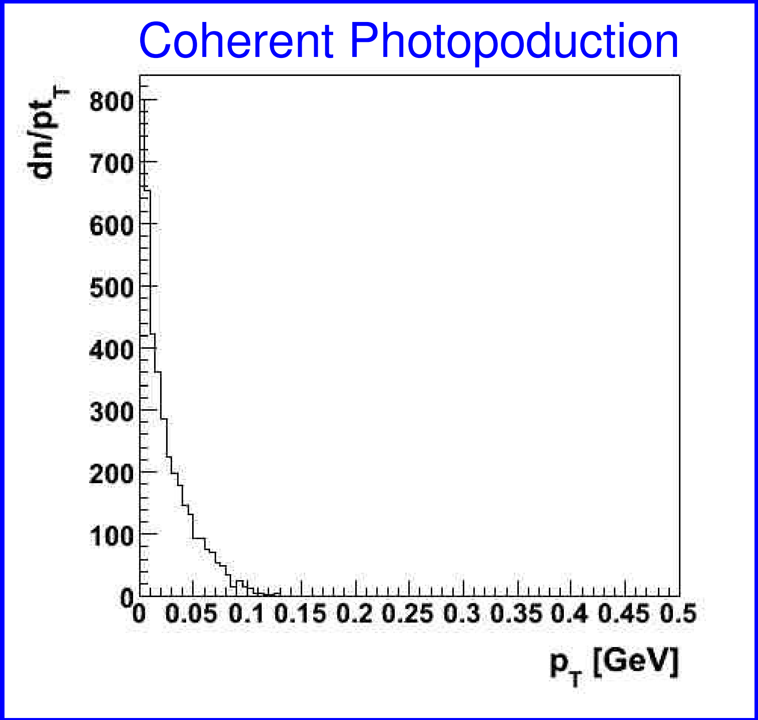


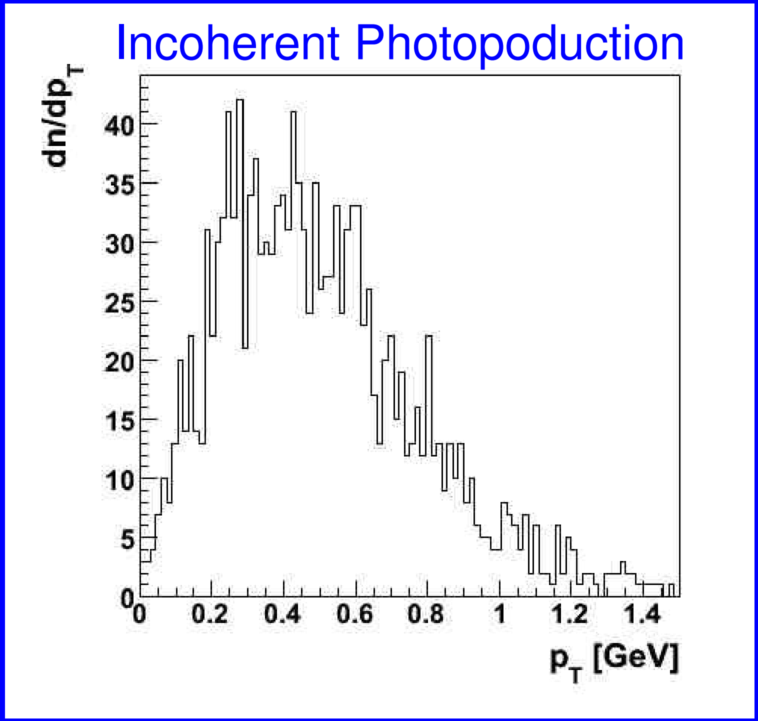
Incoherent Photopoduction

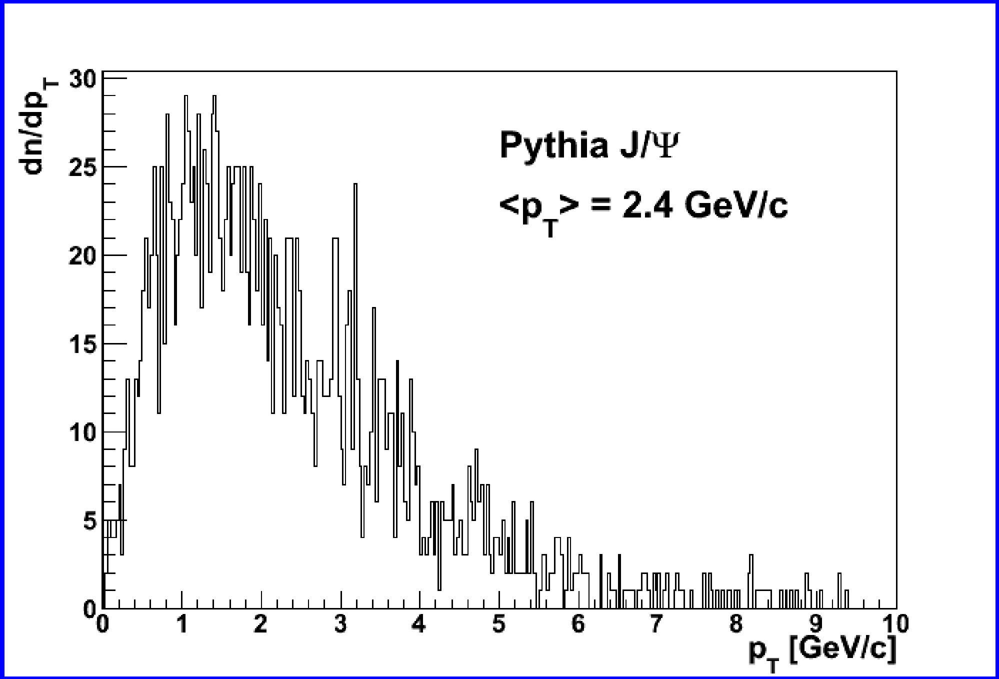




Transverse momentum distributions







Polarization

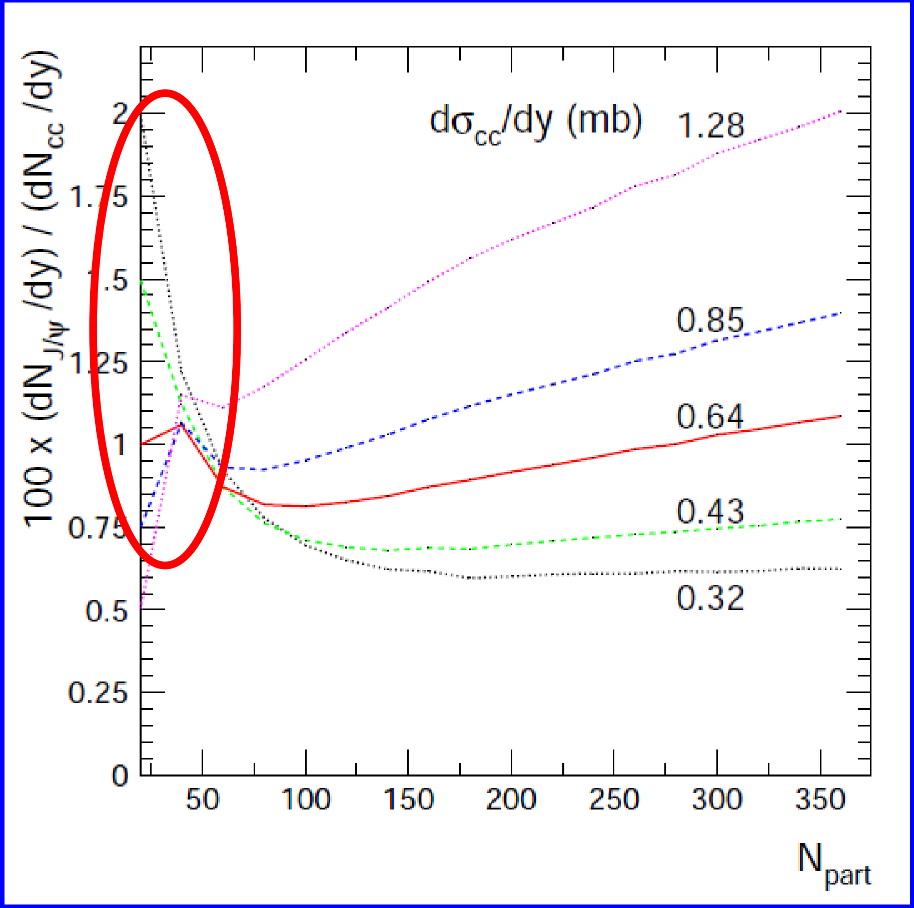
The photoproduced J/Ψs (coherent and incoherent) will be transversly polarized

- measured at HERA in γ+p $\rightarrow$ J/Ψ+p
- measured by STAR in Au+Au $\rightarrow$ Au+Au+ρ^0

The polarization of the hadroproduced J/Ψs is not known.

Centrality dependence of J/Ψ production at the LHC

Photoproduction will affect the centrality dependence of J/Ψ production in the impact parameter range 10-15 fm $\Leftrightarrow$ Npart $\approx$ 0-50.



From Anton Andronic's talk Tuesday

Conclusions

- Vector Mesons are copiously produced in ultra-peripheral heavy-ion interactions at the LHC.

- In semi-central heavy-ion interactions with impact parameters in the range 12-15 fm some 10-40% of the J/Ψs will be photoproduced.

- The photoproduced J/Ψs have roughly the same rapidity distributions as hadroproduced J/Ψs, but have lower transverse momenta and are transversly polarized.