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Small x shadowing from data on coherent J/ψ photoproduction

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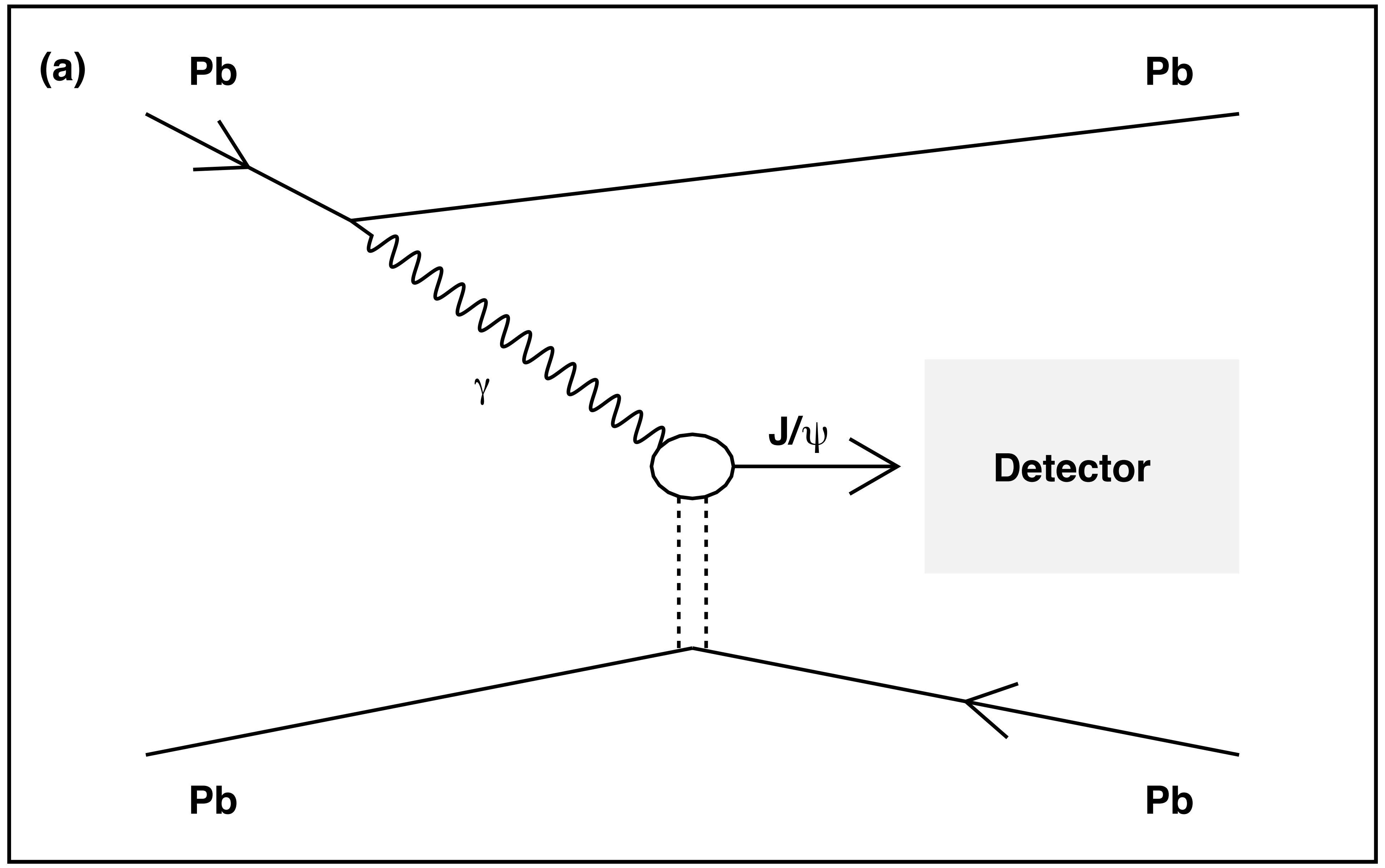
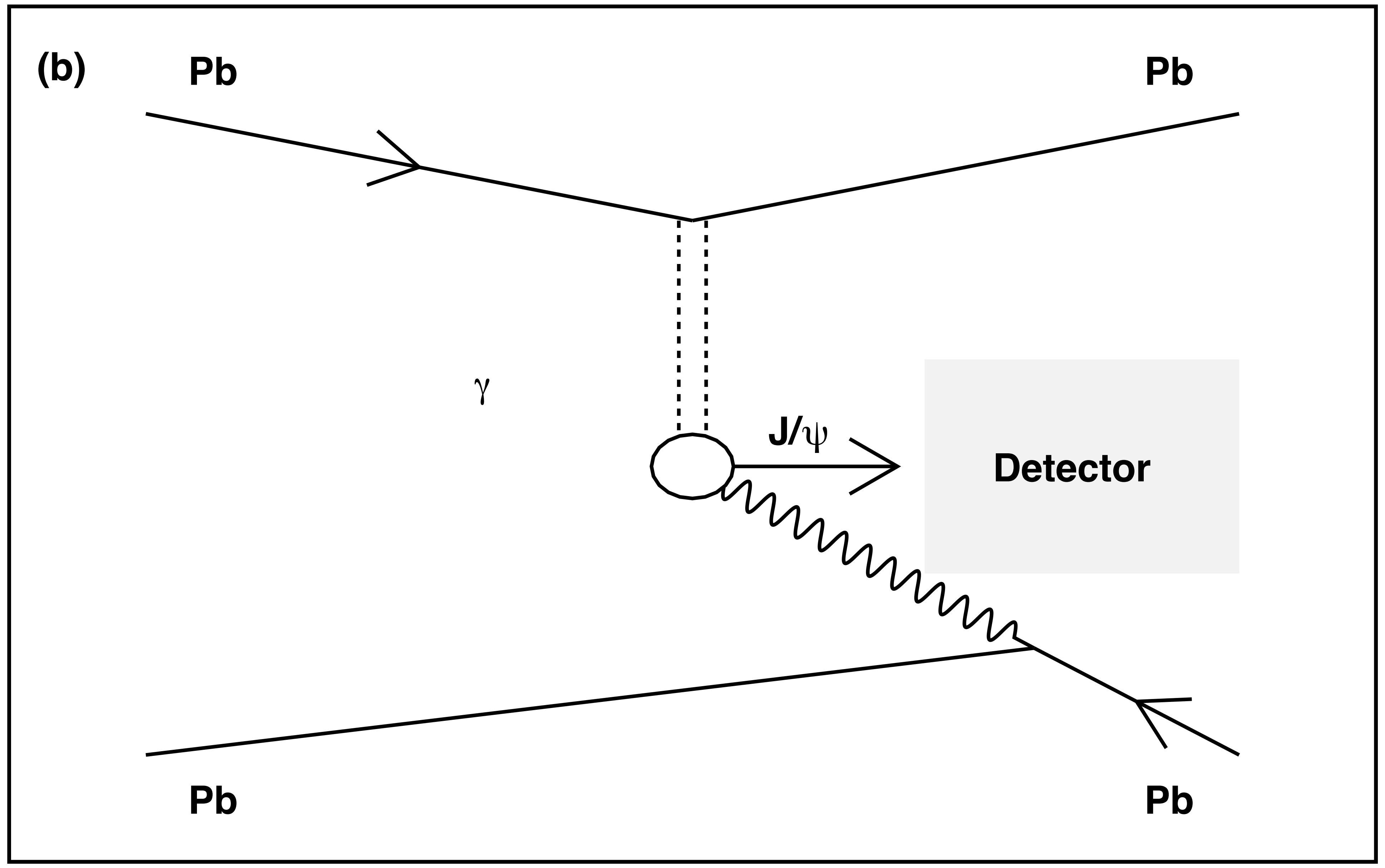
Cross section has two components





Source travels towards detector: photon has large energy

Source travels away from detector: photon has small energy

Coherent photoproduction of J/ψ in Pb-Pb collisions

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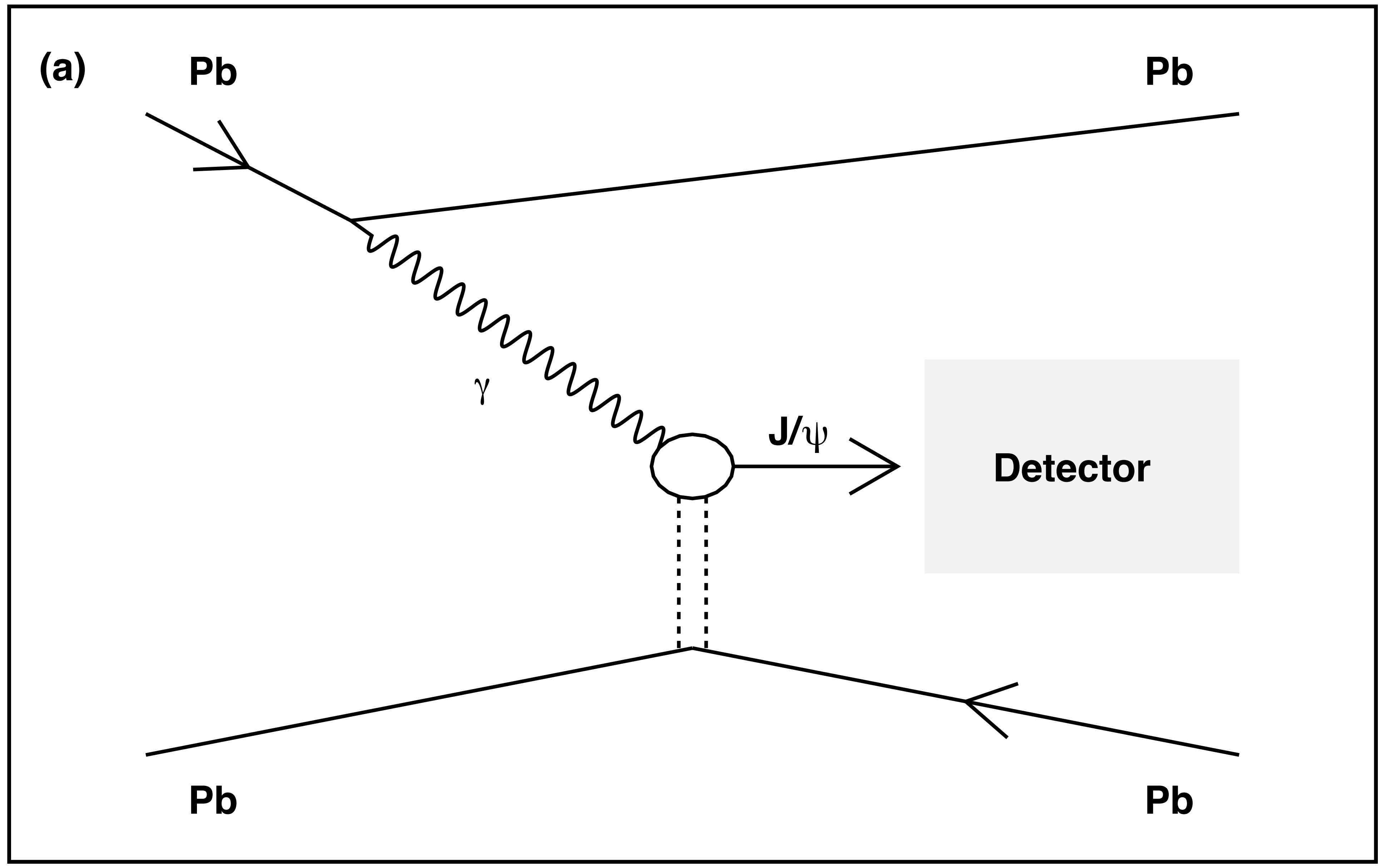

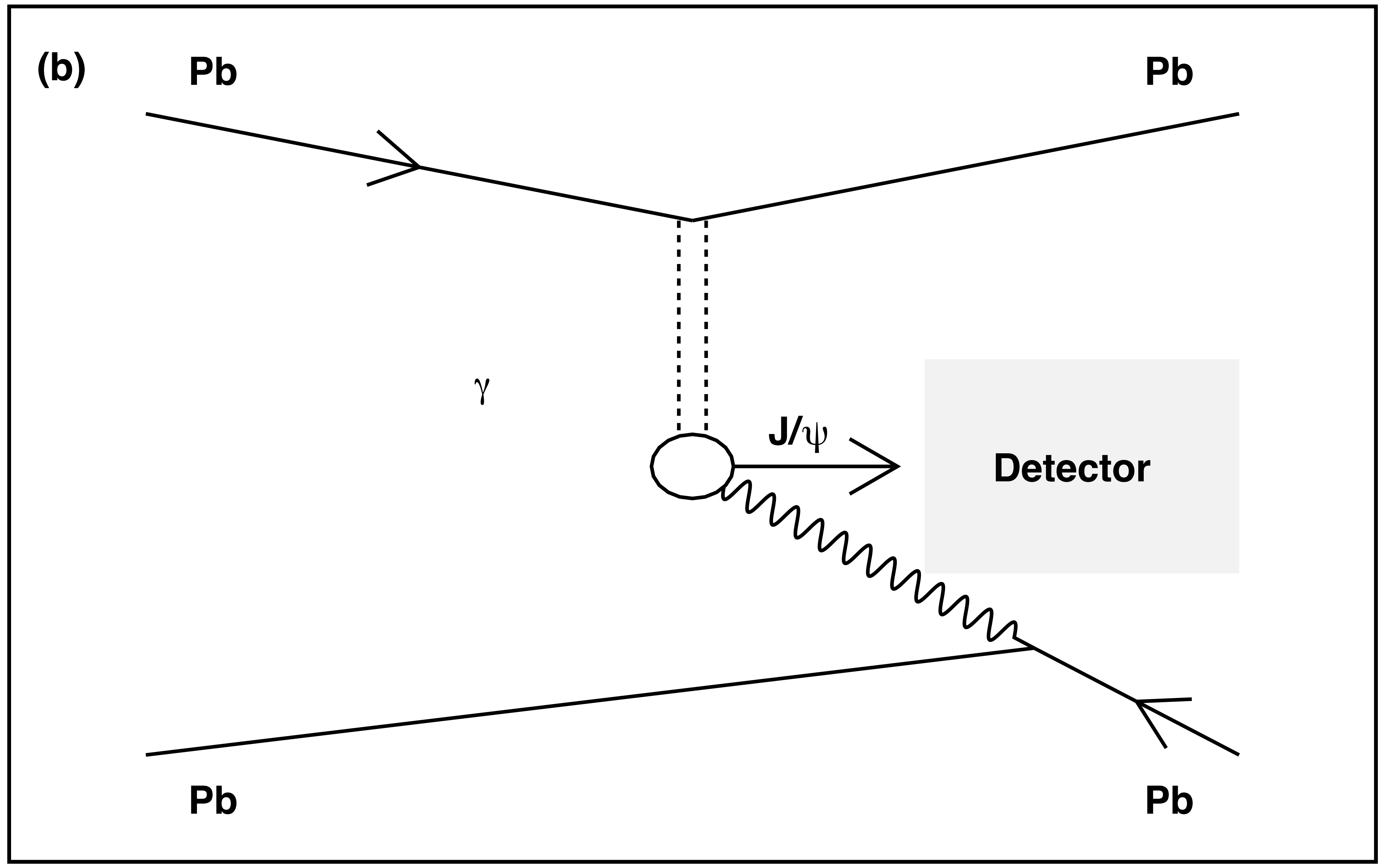

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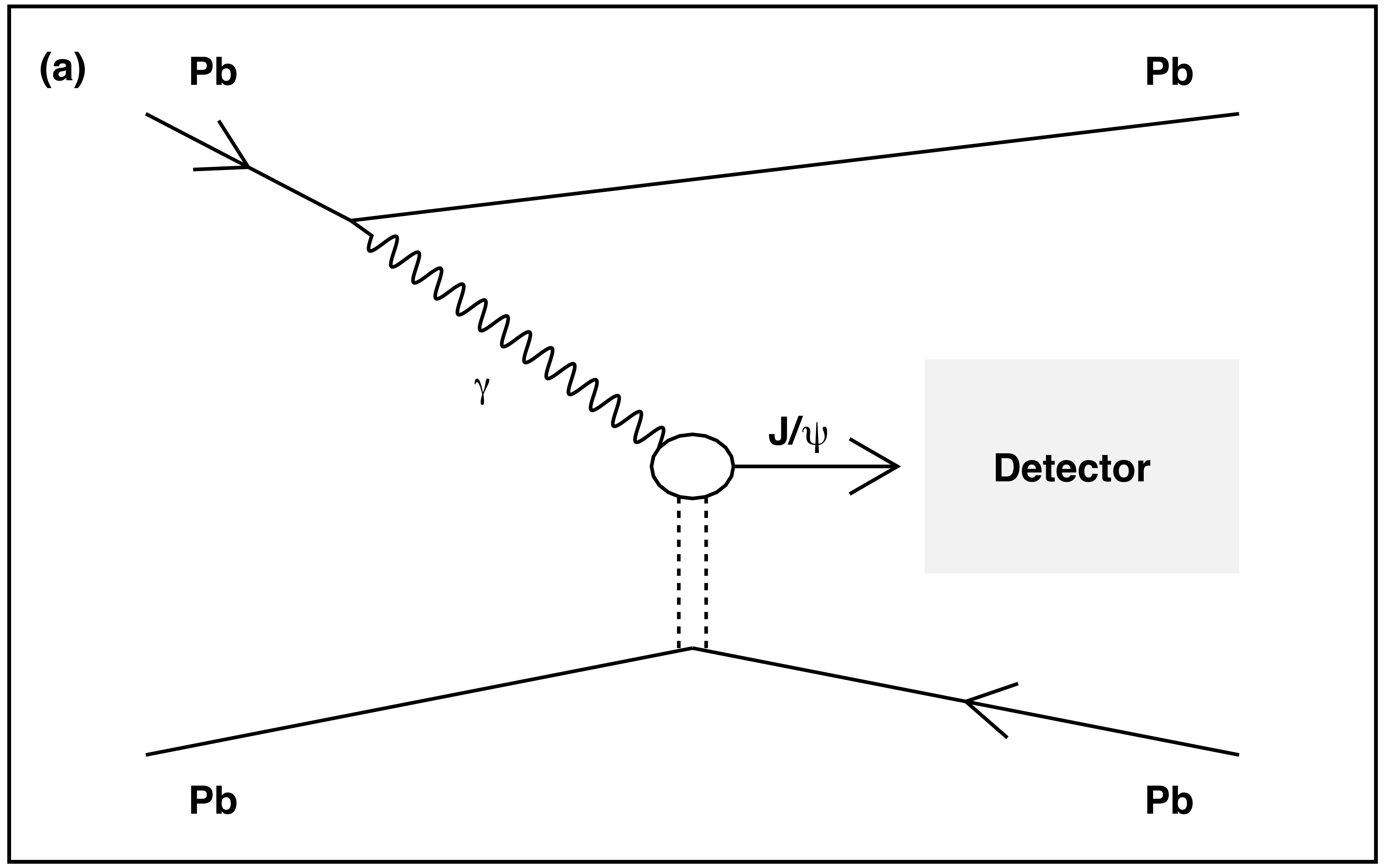

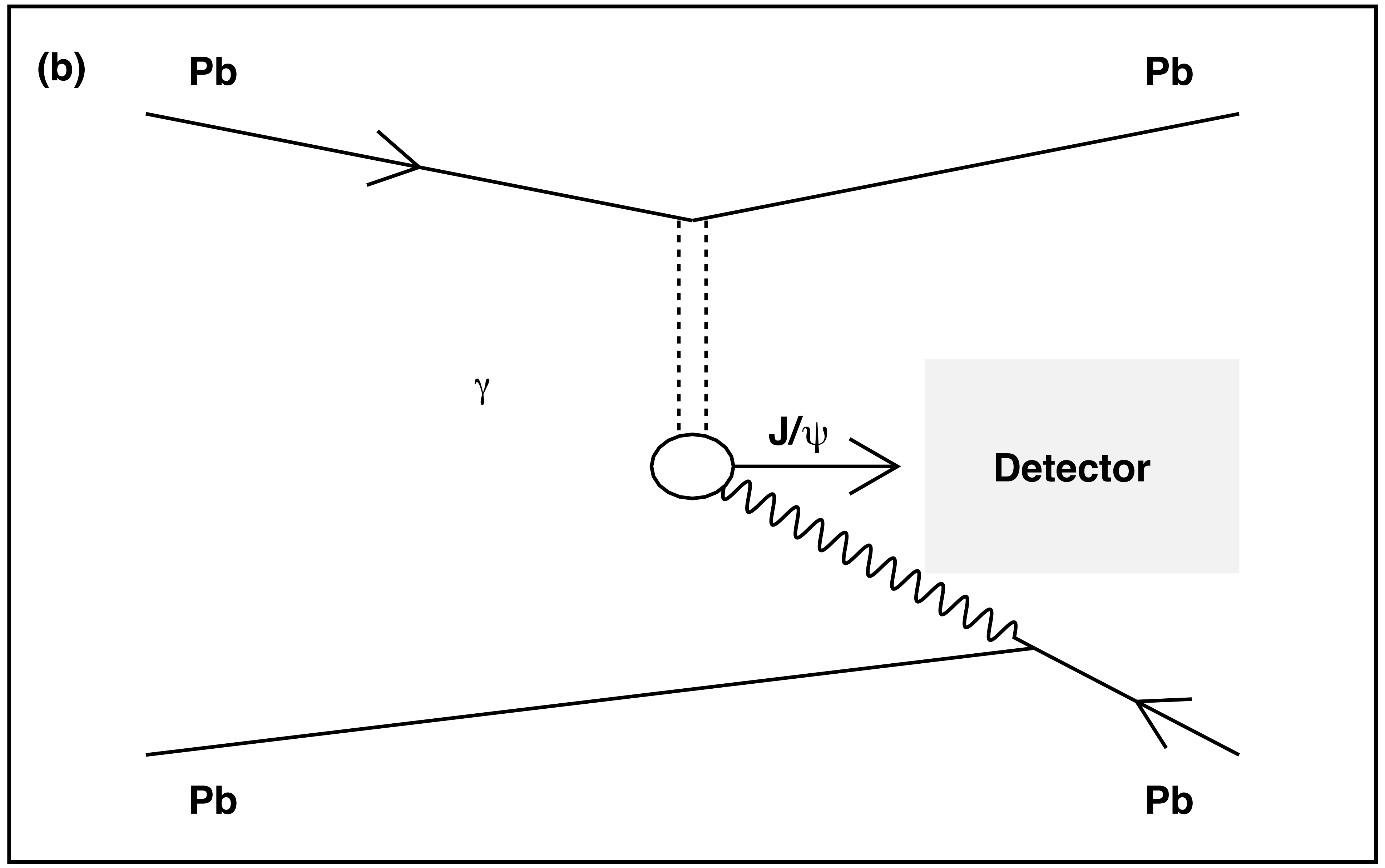

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For measurements at mid rapidity both components are equal

For measurements at forward rapidities they differ

Coherent Pb-Pb cross section

Product of the photon flux and the photonuclear cross section

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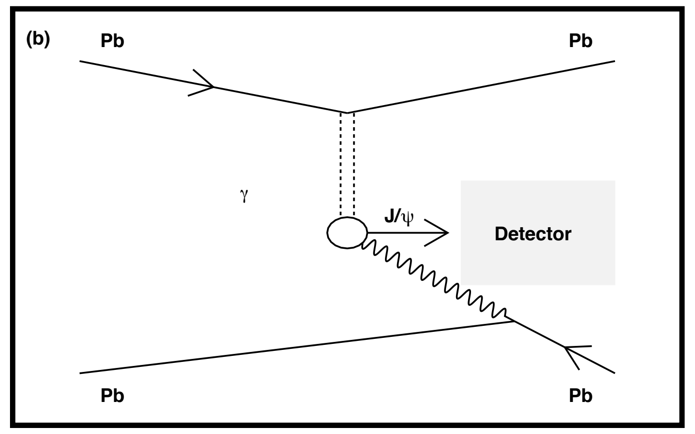

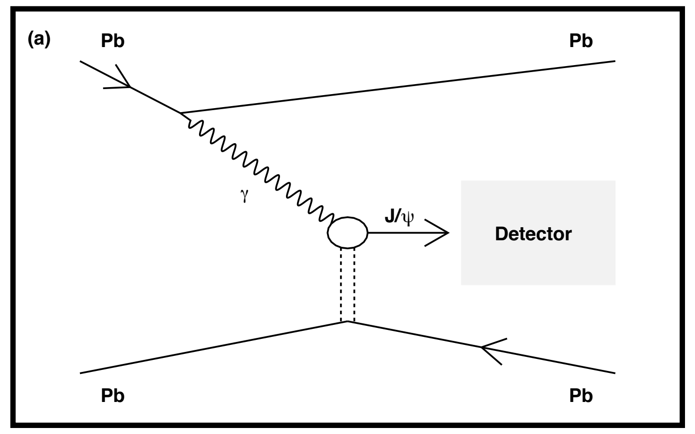

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Measured cross section from Pb-Pb collisions

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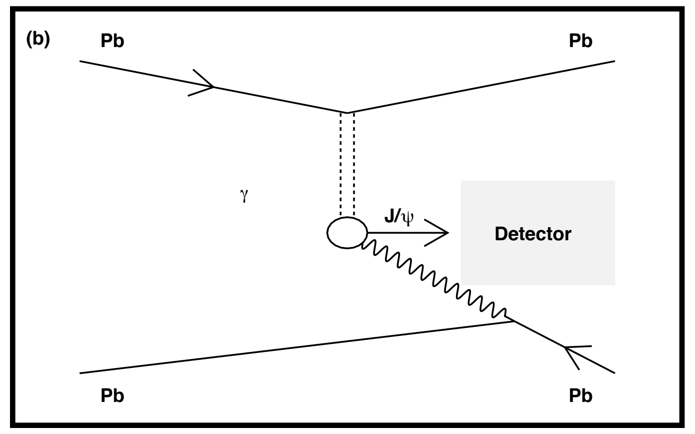

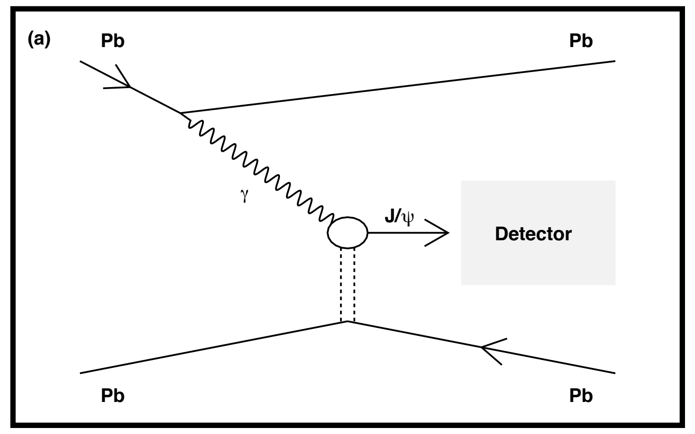

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[Calculable within standard EM]

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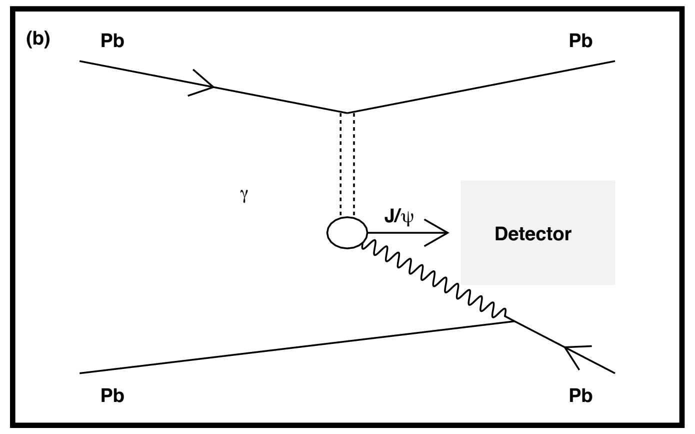

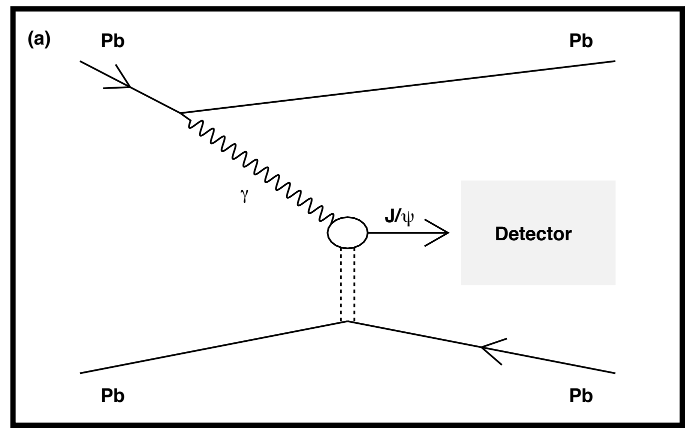

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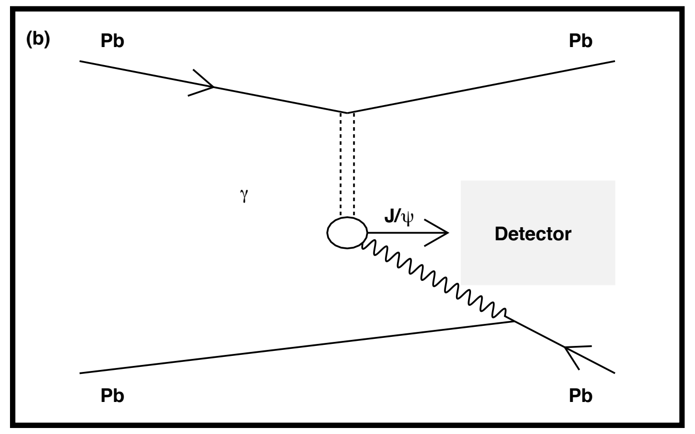

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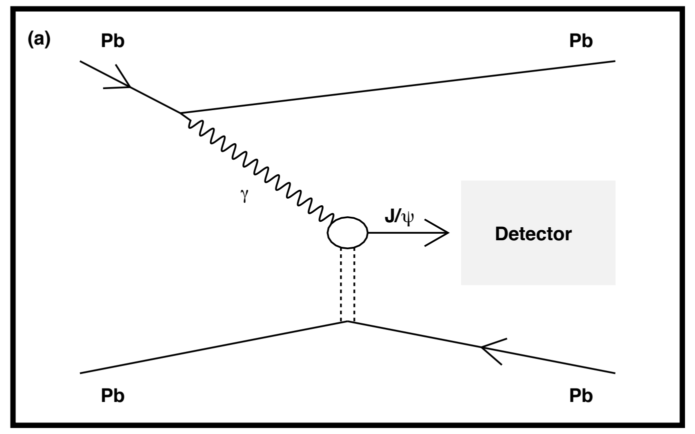

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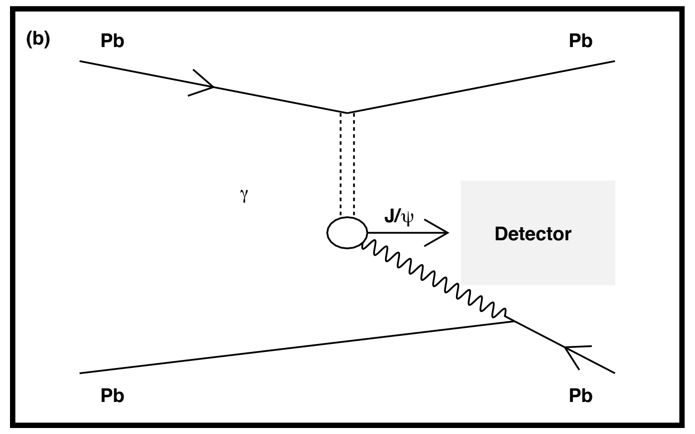

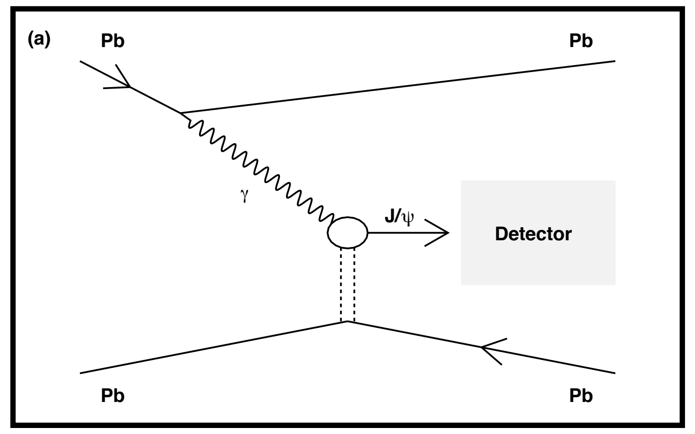

Photonuclear cross section

QCD is here

Coherent photonuclear production

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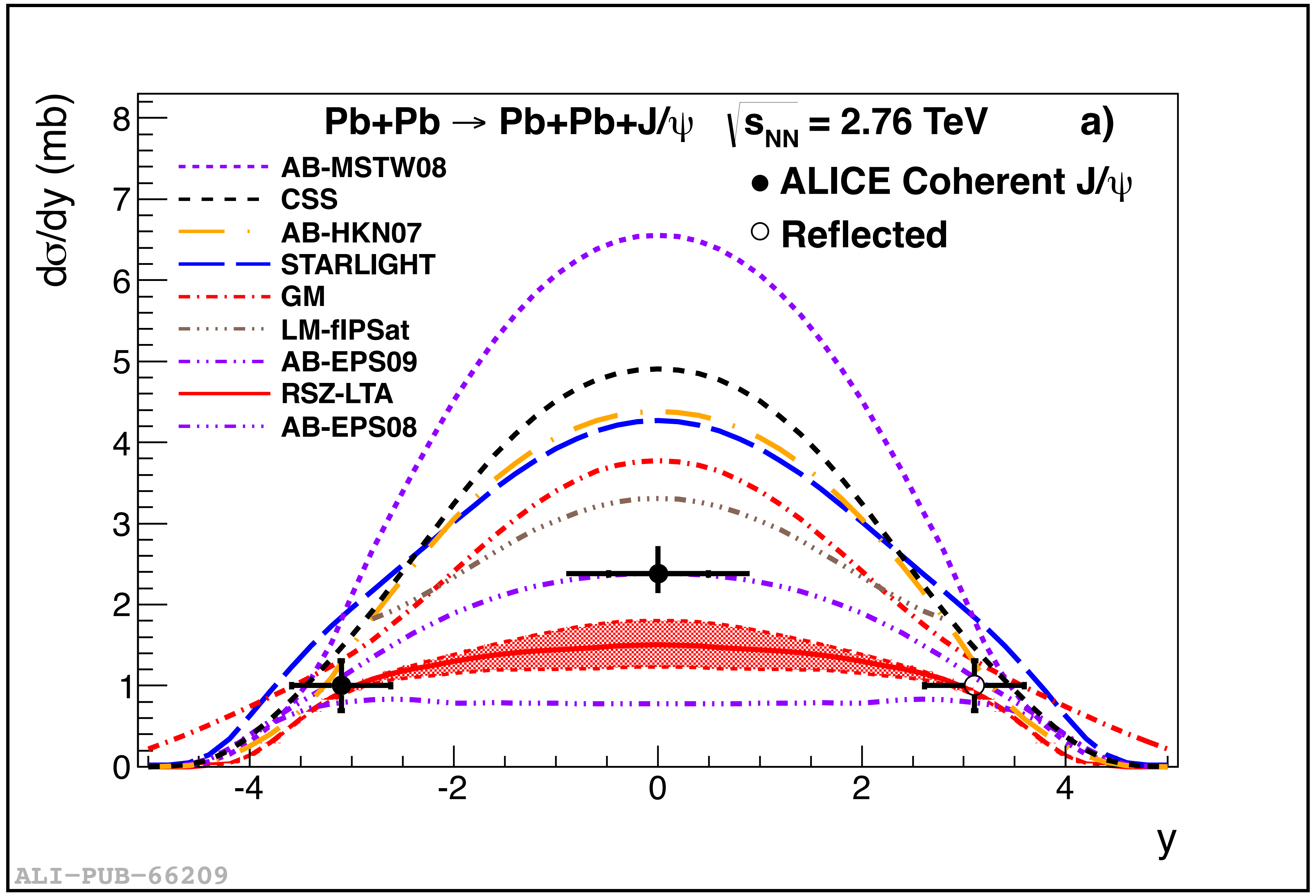
Use measurements in ultra-peripheral (U) and in peripheral (P) collisions by ALICE to test the method!

The available data

Measurements of coherent production of J/ψ in Pb-Pb collisions

ALICE: Phys.Lett. B718 (2013) 1273-1283 and Eur. Phys. J. C (2013) 73:2617



In UPC collisions:
Measurements at mid and forward rapidities

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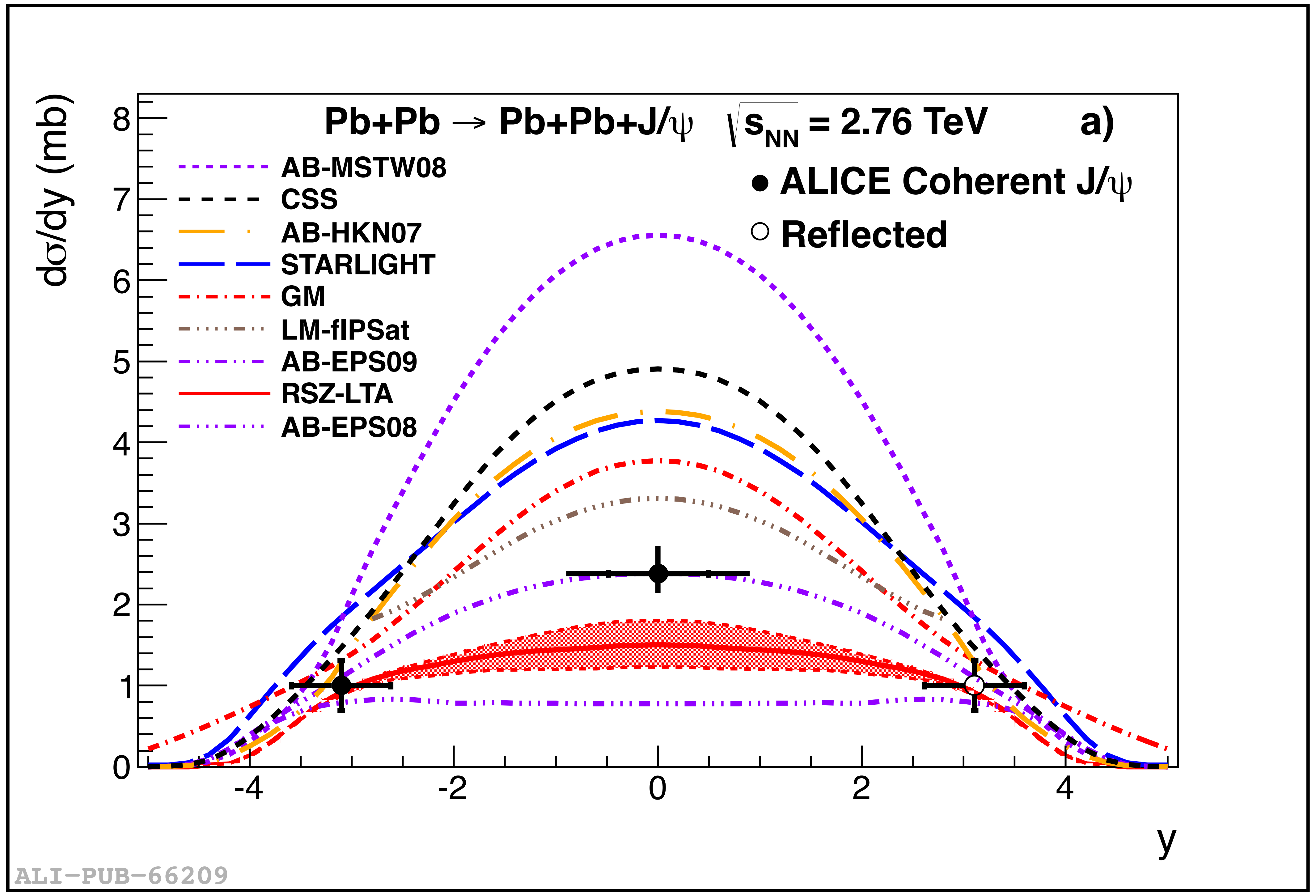
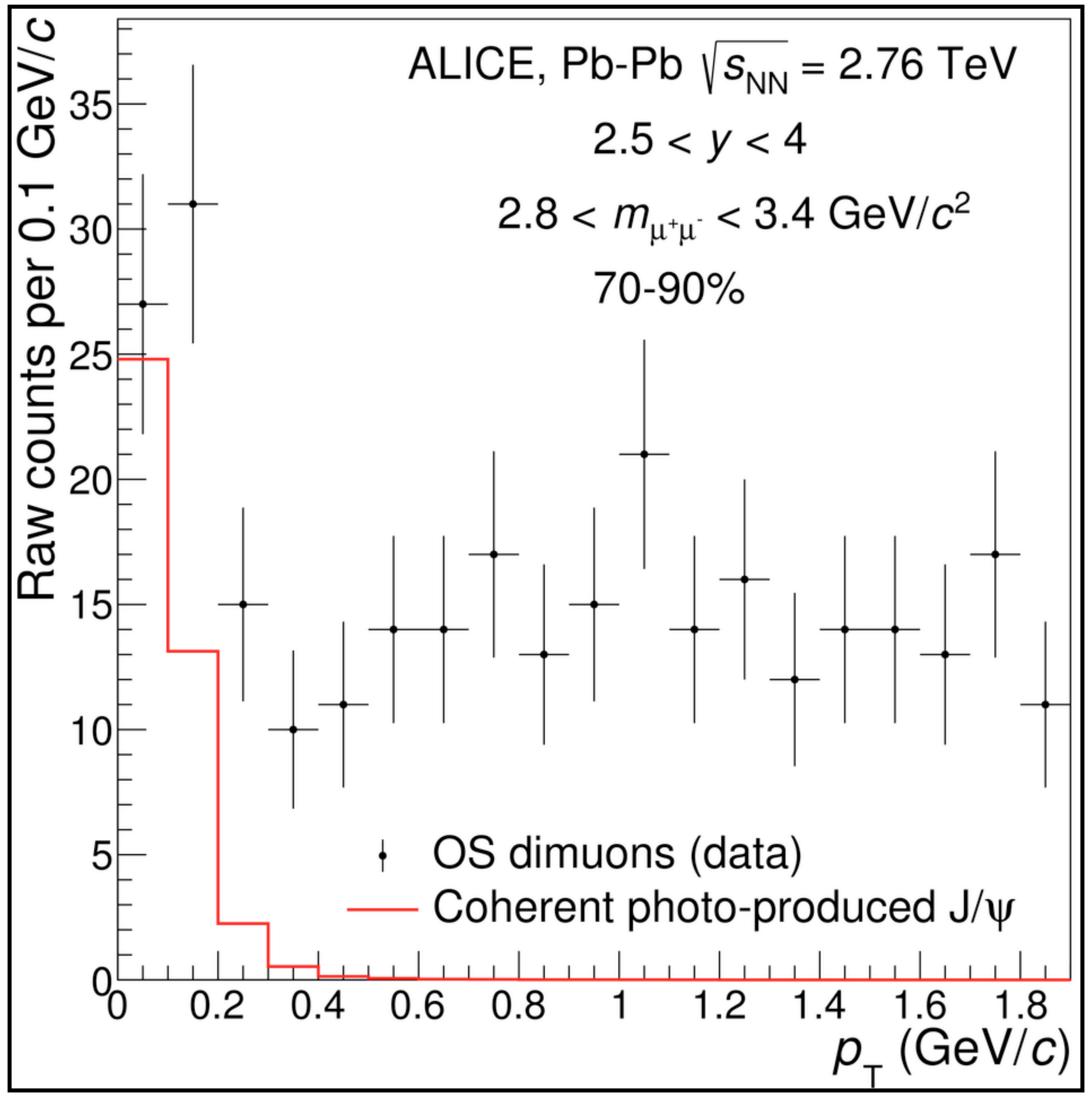


ALICE: Phys.Rev.Lett. 116 (2016) 222301



In UPC collisions:
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In peripheral collisions:
at forward rapiditities

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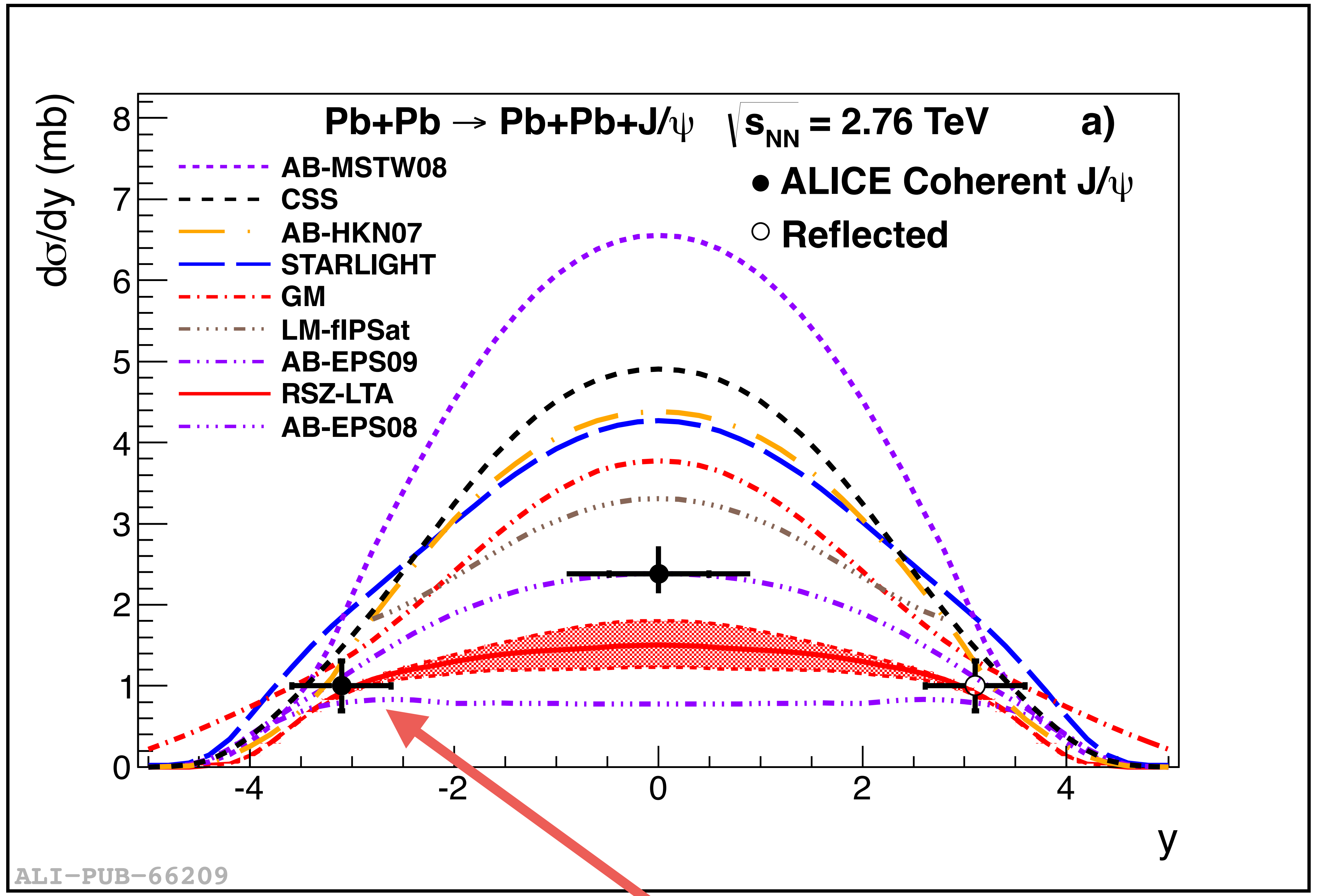

1.0±0.18(stat.)±0.25(syst.) mb

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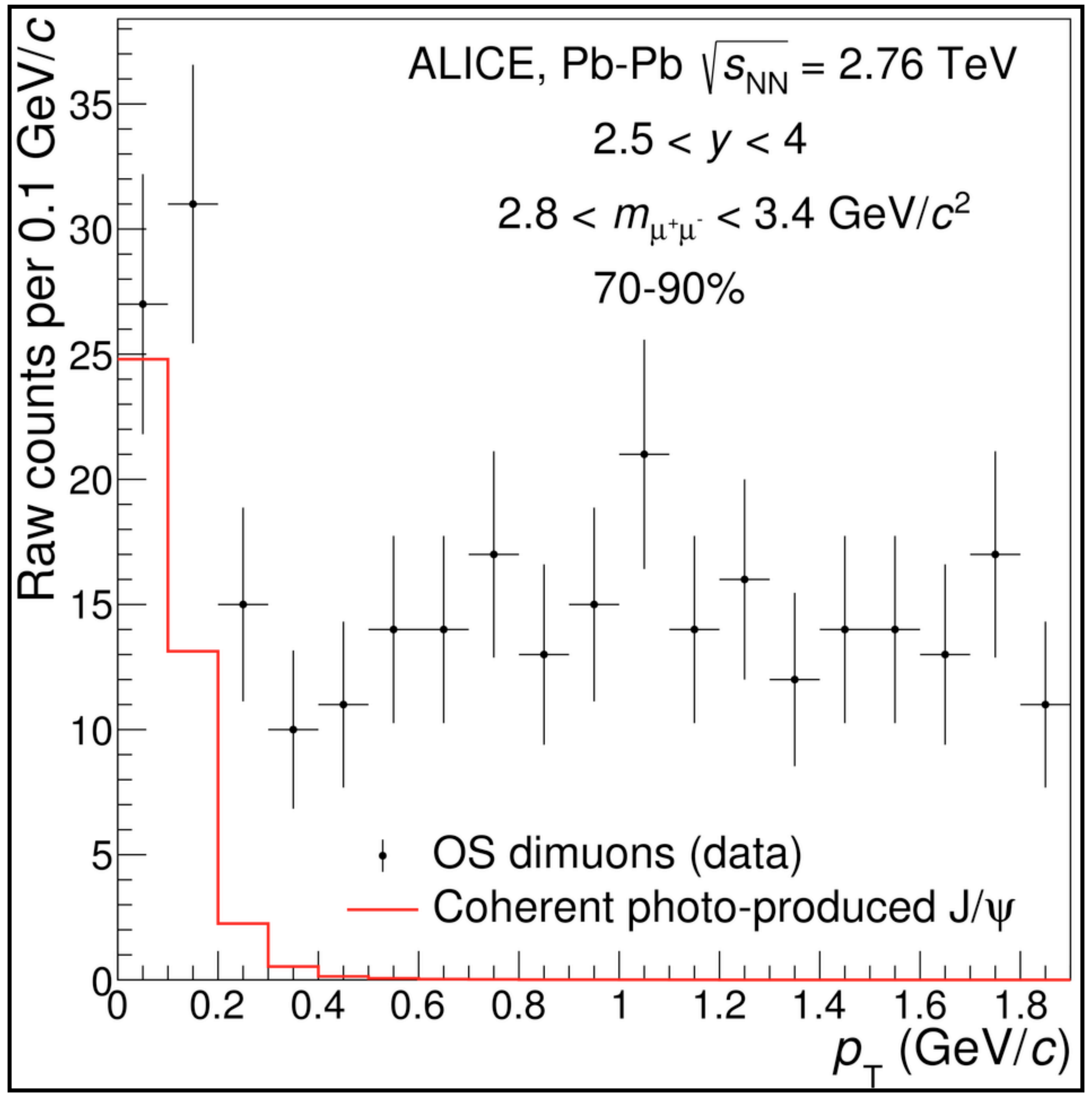

59±11(stat.)±12(syst.) μb

In peripheral collisions:
at forward rapiditities

Comments about the available data

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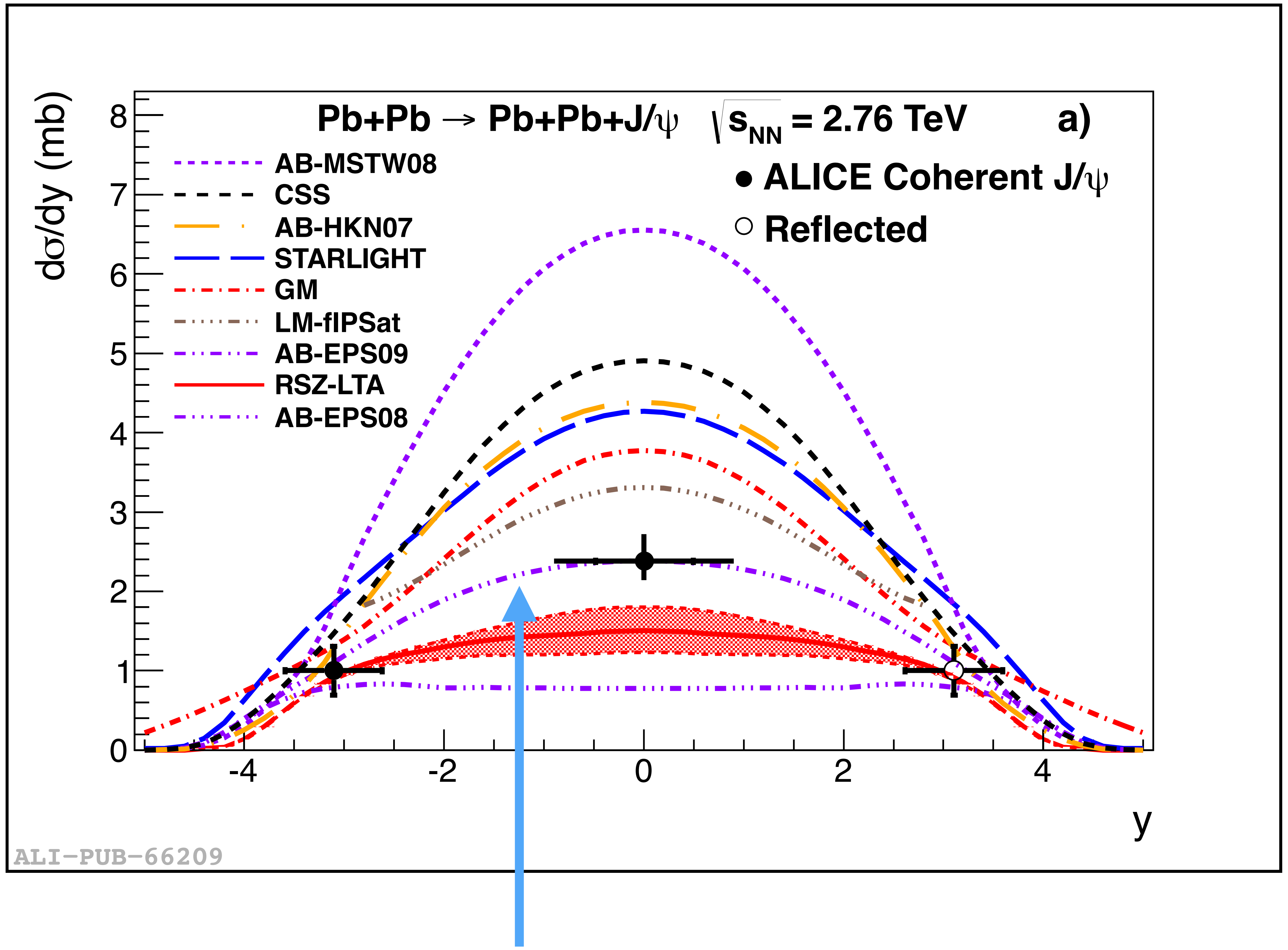

We use this mode, which describes data

Shifting the UPC measurement

This method implicitly assumes that the measurements have been performed at the same rapidity

This is not so for the case of ALICE results, where two different rapidity ranges were used:

UPC: $-3.6<y<-2.6$, peripheral $-4<y<-2.5$

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TABLE II. Ratios of the $d\sigma^{U}_{\mathrm{PbPb}}/dy$ at $|y| = 3.1$ to that at $|y| = 3.25$ for five different models.

Model	[13]	[15]	[16]	[17]	[18]
Ratio	1.10	1.12	1.12	1.17	1.09

Here, [13] = Starlight, [15] =RSZ, [16] = AB, [17] = CSS and [18] = GM

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This model describes best the measured data. It has been used to shift the UPC measurement and also to compute the weighted mean of rapidity in a range.

Photon flux

Photon flux from a fast particle

$$n(k,\vec{x}_\perp) = \frac{Z^2\alpha_{\mathrm{QED}}}{\pi^2 k}\left|\int_0^\infty dk_\perp k_\perp^2 \frac{F(k_\perp^2+(k/\gamma)^2)}{k_\perp^2+(k/\gamma)^2} J_1(x_\perp k_\perp)\right|^2$$

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Photon flux from a fast particle

Photon energy

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Distance from centre of particle to point of emission

Photon flux from a fast particle

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Charge of fast particle

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EM Form factor

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Distance from centre of particle to point of emission

Lorentz factor

Photon flux from a fast particle

Point charge

Convolution of Yukawa and hard sphere potentials

Fourier Bessel transform of Woods-Saxon distribution

EM Form factor

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Distance from centre of particle to point of emission

Lorentz factor

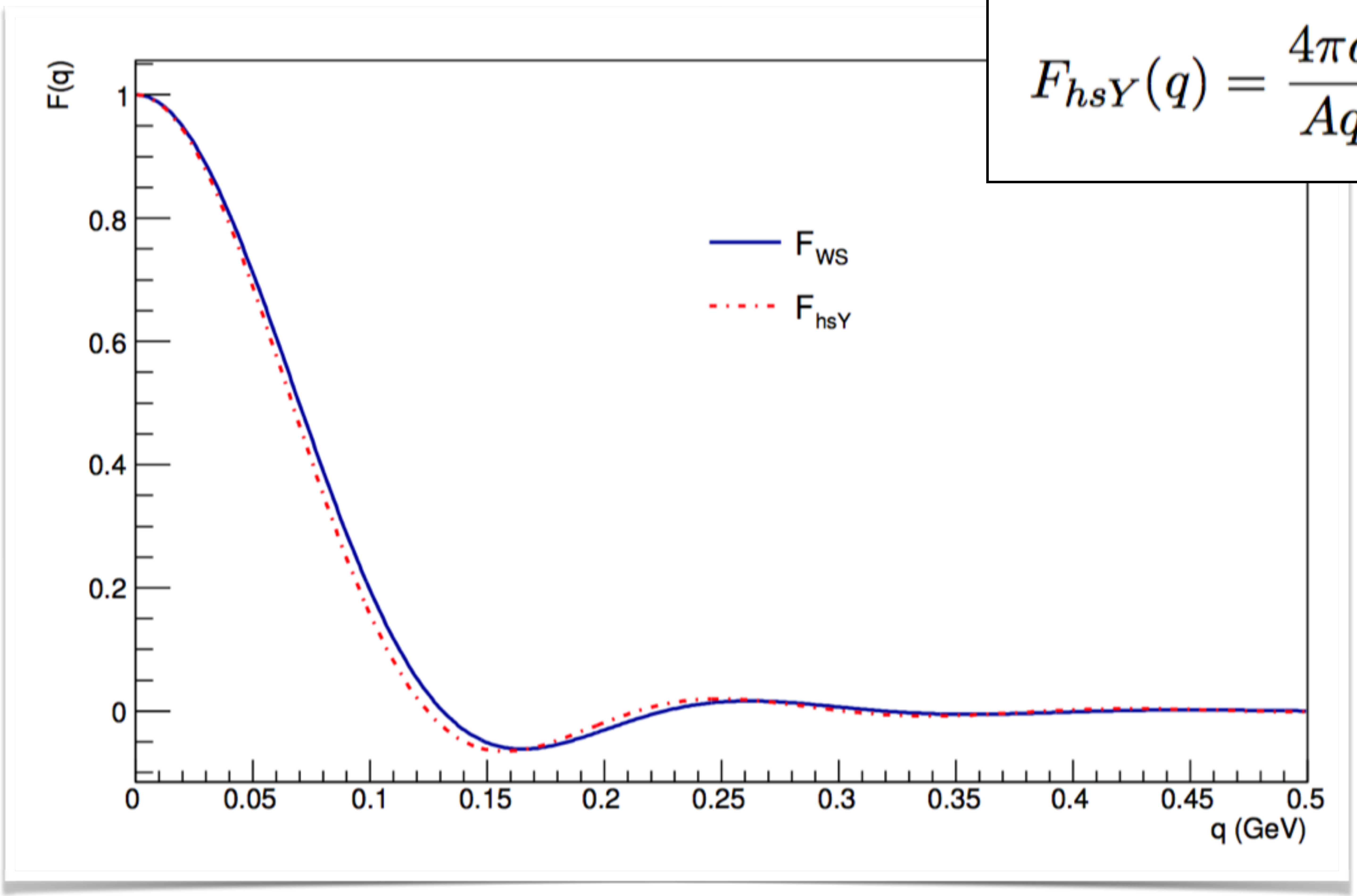
Form factor for a point charge

$$F_{pc}(q) = 1$$

integral can be done analytically

$$n_{pc}(k, \vec{x}_\perp) = \frac{Z^2 \alpha_{\rm QED} k}{\pi^2 \gamma^2} K_1^2(k x_\perp / \gamma)$$

Other form factors for Pb



$$F_{hsY}(q) = \frac{4\pi d_0}{Aq^3}[\sin(qR_A) - qR_A\cos(qR_A)]\left(\frac{1}{1+a^2q^2}\right)$$

$$F_{WS}(q) = \frac{4\pi}{qA}\int \rho(r)\sin(rq)rdr$$

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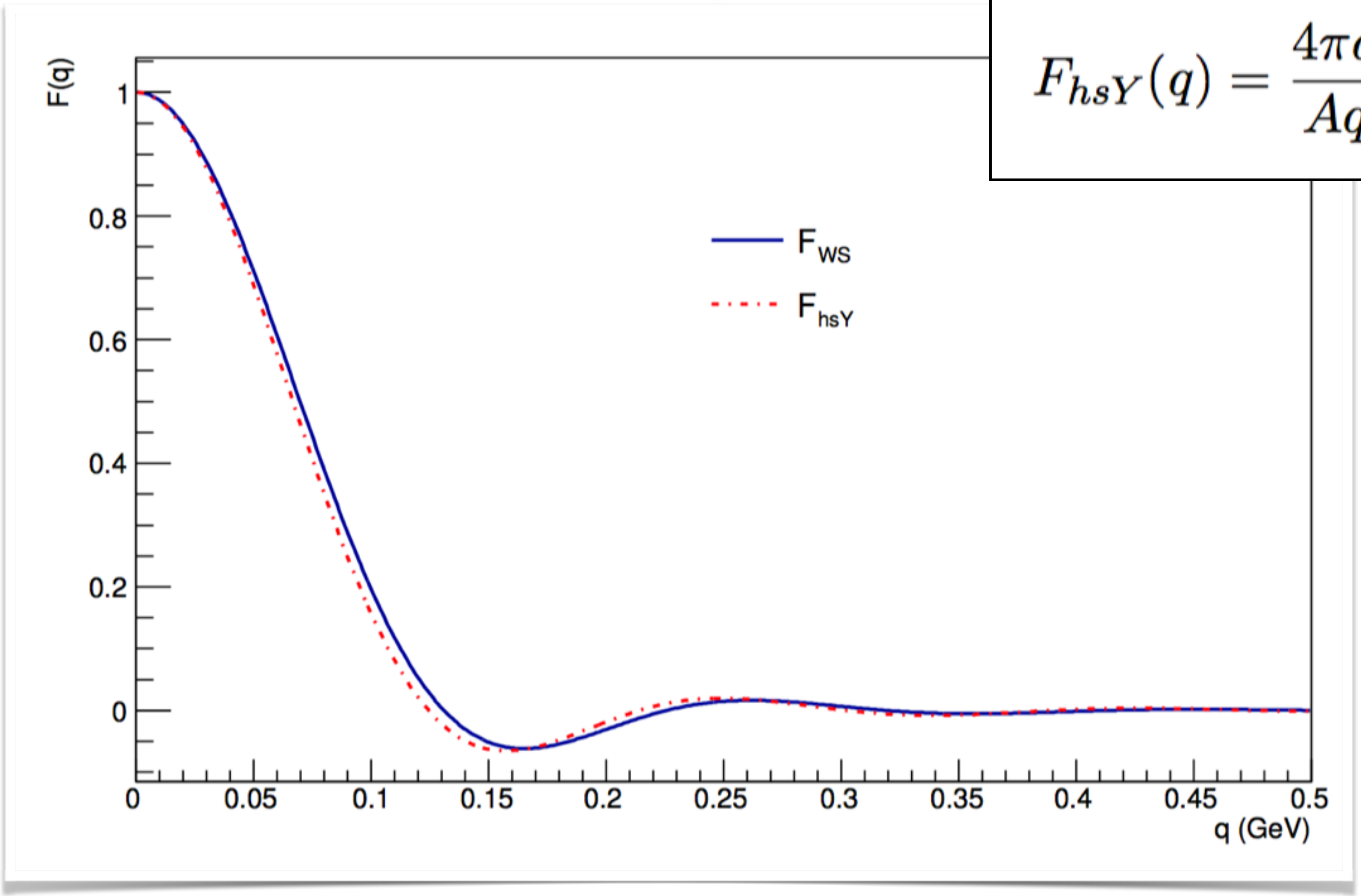

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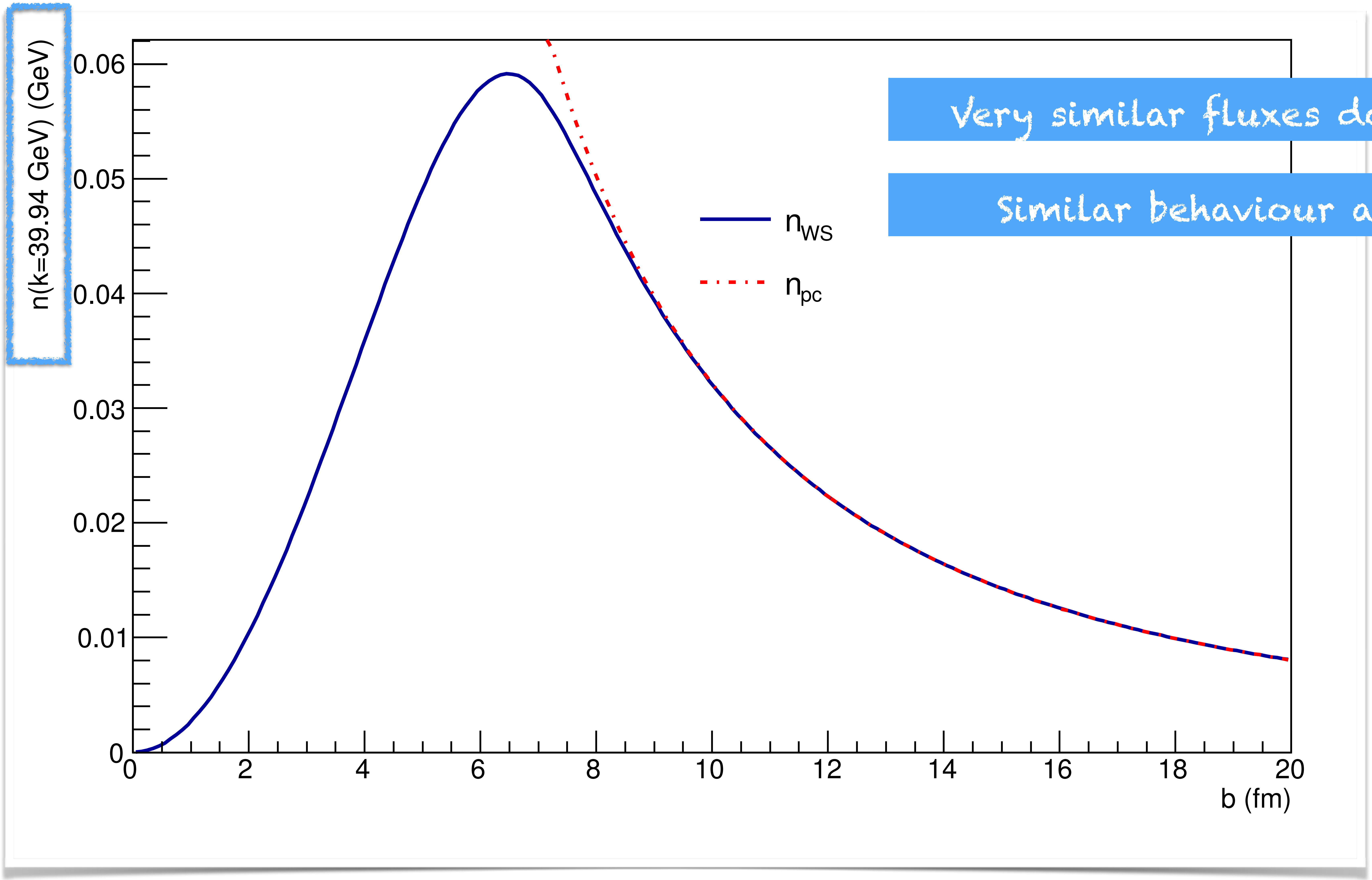
Very similar -> use convolution of hard sphere and Yukawa potential

Fluxes from Pb: point charge vs hsY form factors



Very similar fluxes down to about 9 fm

Similar behaviour at other energies

Flux in UPC collisions

$$n^U(y) = k\int_0^\infty db 2\pi b P_{NH}(b)\int_0^{r_A}\frac{rdr}{\pi r_A^2}\int_0^{2\pi} d\phi n(k, b + r\cos(\phi))$$

Flux in UPC collisions

the flux at a point

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the flux at a point

Probability of no hadronic interaction

Flux in UPC collisions

Nuclear thickness

$$T_A(\vec{r}) = \int dz \rho(\sqrt{|\vec{r}|^2 + z^2})$$

$$T_{AA}(|\vec{b}|) = \int d^2\vec{r}\, T_A(\vec{r}) T_A(\vec{r} - \vec{b})$$

Nuclear overlap

$$P_{NH}(b) = \exp(-T_{AA}\sigma_{NN})$$

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Probability of no hadronic interaction

Average over target surface

Flux in peripheral collisions

Integration limits given by centrality class

$$n^P(y) = k \int_{b_{\min}}^{b_{\max}} db 2\pi b (1 - P_{NH}(b)) \int_0^{r_A} \frac{r dr}{\pi r_A^2} \int_0^{2\pi} d\phi n(k, b + r\cos(\phi))$$

Probability of hadronic interaction

Extracted γPb cross section

Coherent photonuclear cross section

Using the procedure outlined previously, when using the bin centre as the representative rapidity:

$$\sigma_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}} = 18.2\ \mathrm{GeV}) = 5.2 \pm 1.0\ (\mathrm{stat.})\ \pm 1.0\ (\mathrm{syst.})\ \mu\mathrm{b},$$

$$\sigma_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}} = 92.4\ \mathrm{GeV}) = 17.9^{+2.6}_{-1.8}\ (\mathrm{stat.} + \mathrm{syst.})\ \mu\mathrm{b},$$

$$\sigma_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}} = 469.5\ \mathrm{GeV}) = 38.1 \pm 15.0\ (\mathrm{stat.})\ ^{+9.9}_{-11.3}\ (\mathrm{syst.})\ \mu\mathrm{b}.$$

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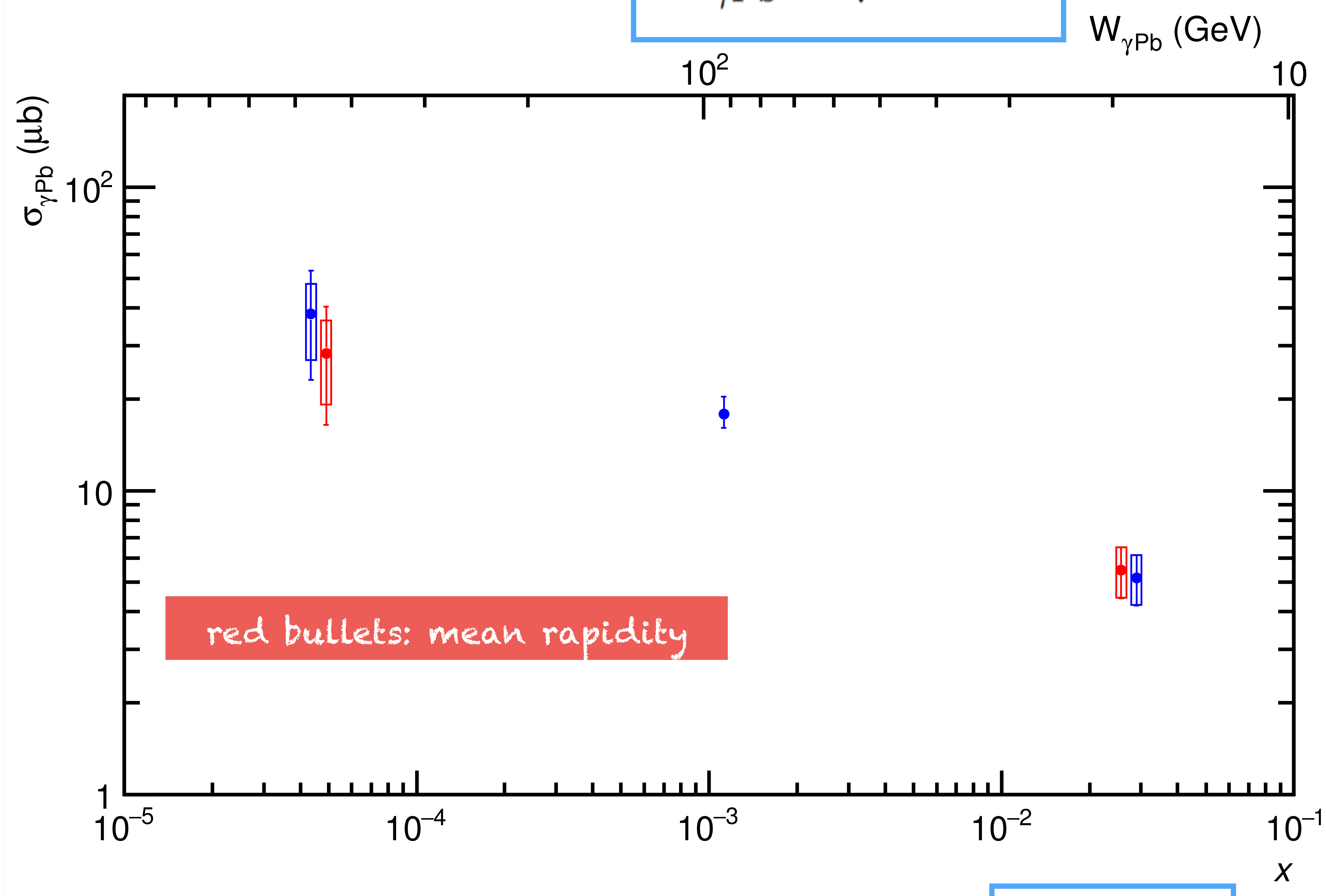
$$W^2_{\gamma\mathrm{Pb}} = \sqrt{s_{\mathrm{NN}}}Me^{y}$$



$$x = \frac{M^2}{W^2_{\gamma\mathrm{Pb}}}$$

Coherent photonuclear cross section

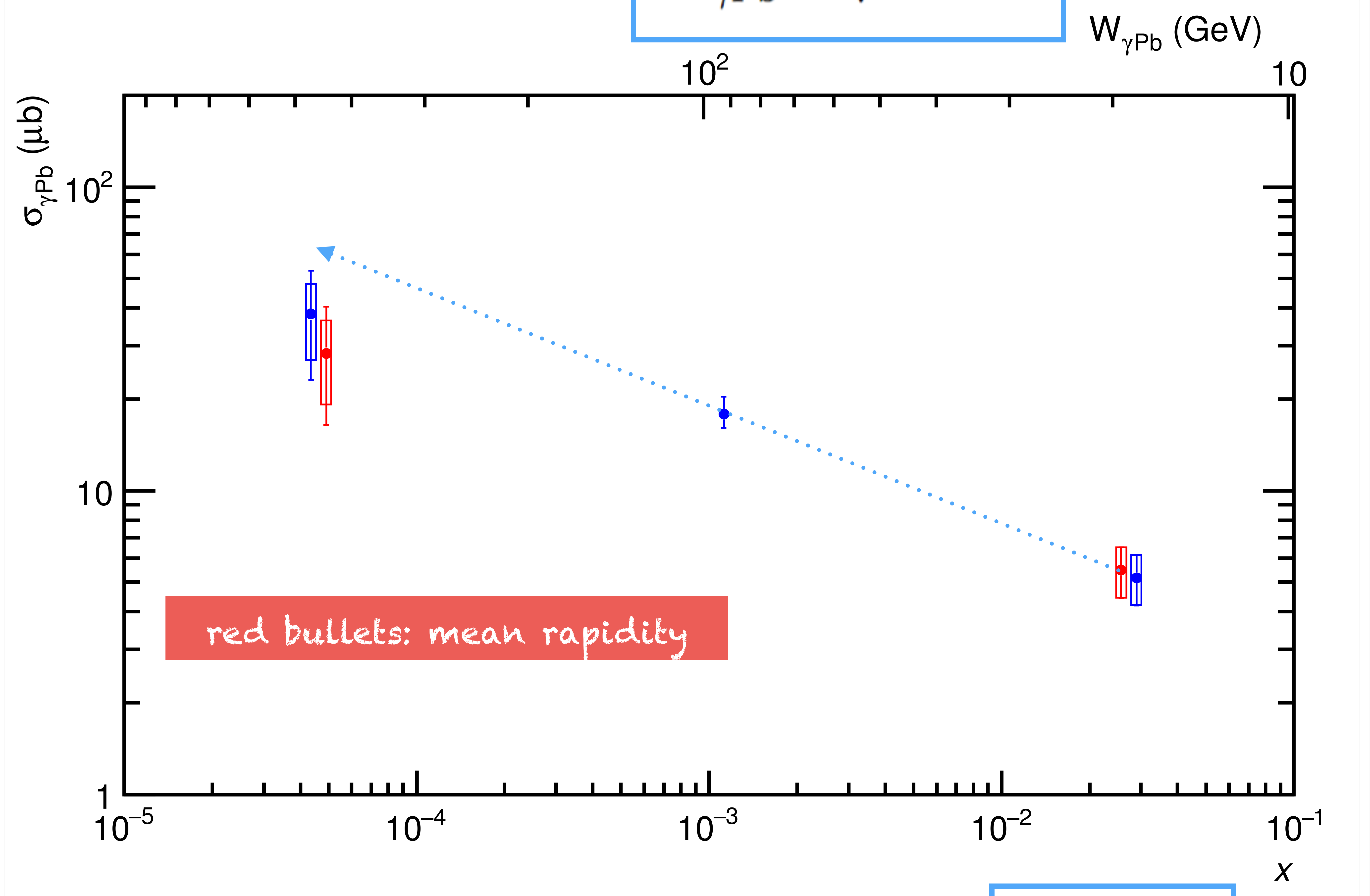
Using the procedure outlined previously, when using the bin centre as the representative rapidity:

$$\sigma_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}} = 18.2\ \mathrm{GeV}) = 5.2 \pm 1.0\ (\mathrm{stat.})\ \pm 1.0\ (\mathrm{syst.})\ \mu\mathrm{b},$$

$$\sigma_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}} = 92.4\ \mathrm{GeV}) = 17.9^{+2.6}_{-1.8}\ (\mathrm{stat.} + \mathrm{syst.})\ \mu\mathrm{b},$$

$$\sigma_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}} = 469.5\ \mathrm{GeV}) = 38.1 \pm 15.0\ (\mathrm{stat.})\ ^{+9.9}_{-11.3}\ (\mathrm{syst.})\ \mu\mathrm{b}.$$

$$W^2_{\gamma\mathrm{Pb}} = \sqrt{s_{\mathrm{NN}}} M e^{y}$$



$$x = \frac{M^2}{W^2_{\gamma\mathrm{Pb}}}$$

Suppression factor

Extracting the nuclear suppression factor

Nuclear suppression factor

$$S_{\mathrm{Pb}}(W_{\gamma\mathrm{Pb}}) = \left(\frac{\sigma^{\mathrm{data}}_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}})}{\sigma^{\mathrm{IA}}_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}})} \right)^{1/2}$$

Extracting the nuclear suppression factor

Data from the procedure just described

Nuclear suppression factor

$$S_{\mathrm{Pb}}(W_{\gamma \mathrm{Pb}}) = \left(\frac{\sigma^{\mathrm{data}}_{\gamma \mathrm{Pb}}(W_{\gamma \mathrm{Pb}})}{\sigma^{\mathrm{IA}}_{\gamma \mathrm{Pb}}(W_{\gamma \mathrm{Pb}})} \right)^{1/2}$$

Extracting the nuclear suppression factor

Data from the procedure just described

Nuclear suppression factor

$$S_{\mathrm{Pb}}(W_{\gamma\mathrm{Pb}}) = \left(\frac{\sigma^{\mathrm{data}}_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}})}{\sigma^{\mathrm{IA}}_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}})} \right)^{1/2}$$

Impulse approximation

$$\sigma^{\mathrm{IA}}_{\gamma\mathrm{Pb}}(W_{\gamma\mathrm{Pb}}) = \frac{d\sigma_{\gamma\mathrm{p}}(W_{\gamma\mathrm{p}} = W_{\gamma\mathrm{Pb}}, t = 0)}{dt} \Phi_{\mathrm{Pb}}(|t|_{\mathrm{min}}).$$

From HERA data

$$\Phi_{\mathrm{Pb}}(|t|_{\mathrm{min}}) = \int_{|t|_{\mathrm{min}}}^{\infty} d|t| \, |F_{WS}(t)|^2$$

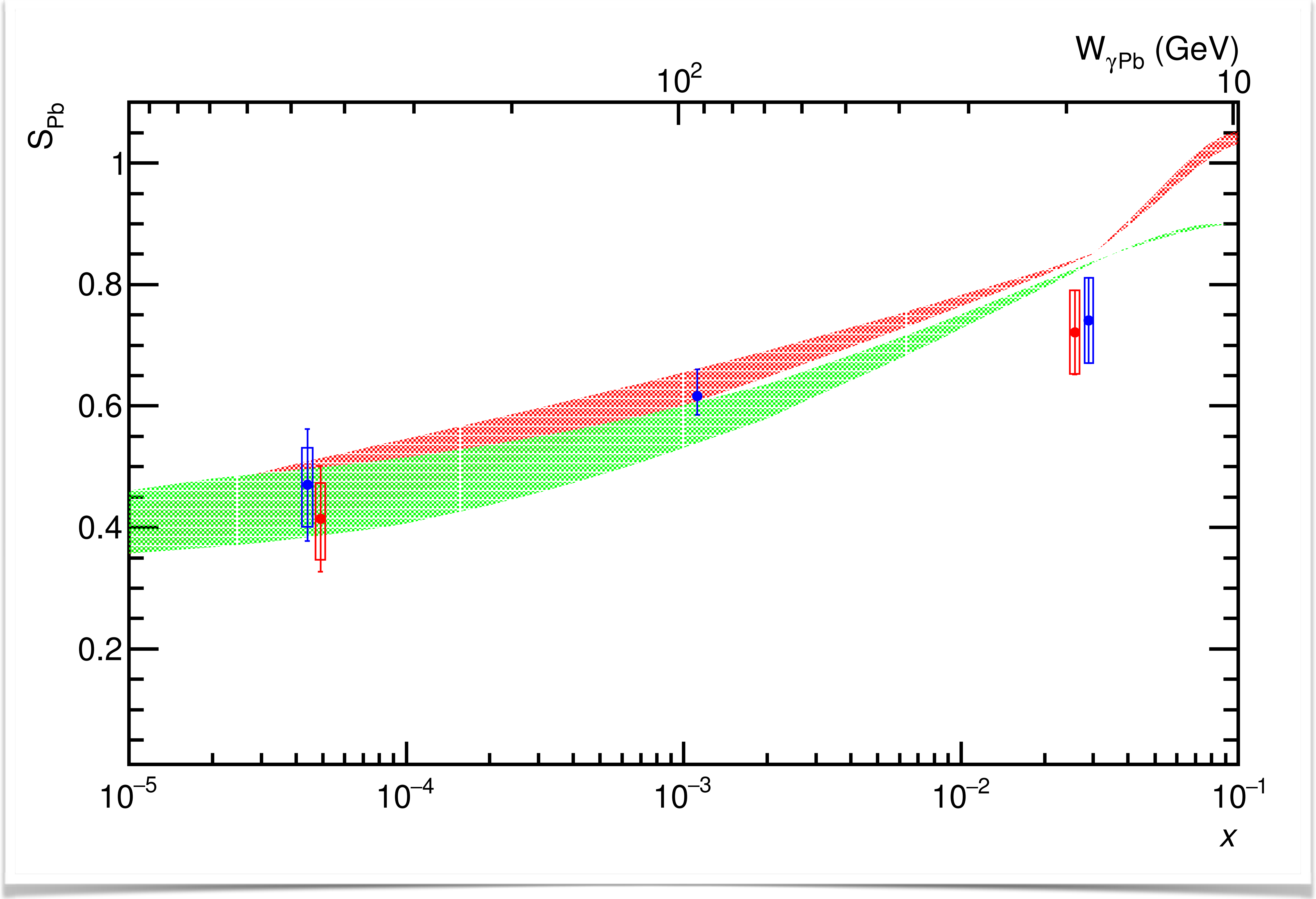
The nuclear suppression factor

Using the previous formulas

$$S_{\mathrm{Pb}}(W_{\gamma\mathrm{Pb}} = 18.2\ \mathrm{GeV}) = 0.74 \pm 0.07\ (\mathrm{stat.}) \pm 0.07\ (\mathrm{syst.}),$$

$$S_{\mathrm{Pb}}(W_{\gamma\mathrm{Pb}} = 92.4\ \mathrm{GeV}) = 0.62^{+0.04}_{-0.03}\ (\mathrm{stat.} + \mathrm{syst.})$$

$$S_{\mathrm{Pb}}(W_{\gamma\mathrm{Pb}} = 469.5\ \mathrm{GeV}) = 0.47 \pm 0.09\ (\mathrm{stat.})\ ^{+0.06}_{-0.07}\ (\mathrm{syst.}).$$



LTA from: V. Guzey, M. Zhalov, JHEP 10 (2013) 207

Thanks to Vadim for the LTA curves

Summary and outlook

- Using peripheral and ultra-peripheral data it is possible to extract the photonuclear coherent cross section at different rapidities/centre-of-mass energies/Bjorken-x values
- The main assumption is that one can use the standard formalism for the photon fluxes This is justified, for the current somehow large experimental errors, because
  - The shape of the pt distribution for j/psi in the centrality class 70-90 is compatible with the distribution obtained for UPC
  - The number of participants in this centrality class is small
- Using the extracted cross sections one can construct a nuclear suppression factor to allow a directer evaluation of nuclear shadowing and an easy comparison to different models.