QCD challenges in pp, pA and AA collisions at high energies

Trento, February 27 - March 3, 2017

Small x shadowing from data on coherent J/ψ photoproduction

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Czech Technical University
February 28, 2017

arXiv: 1610.03350

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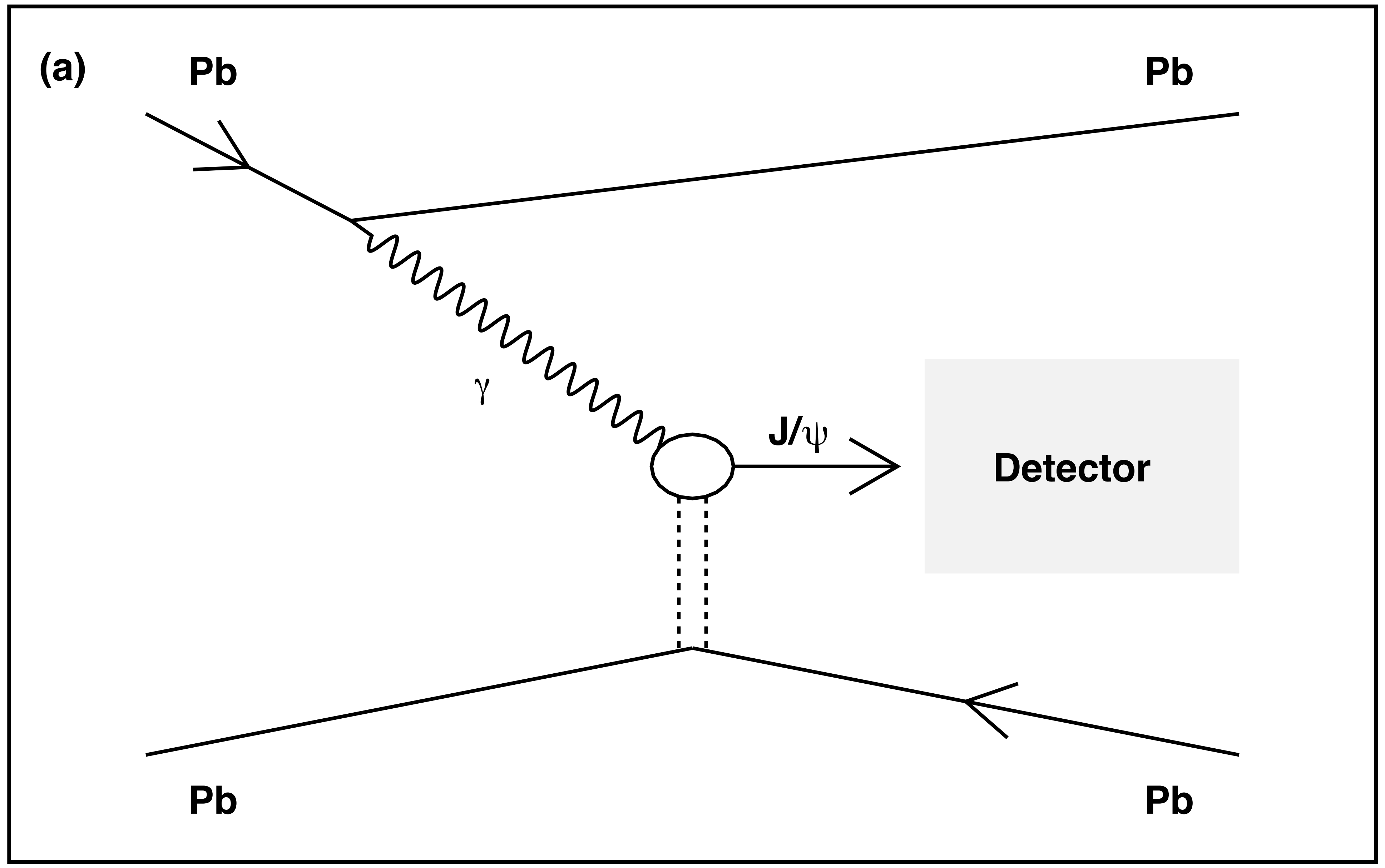
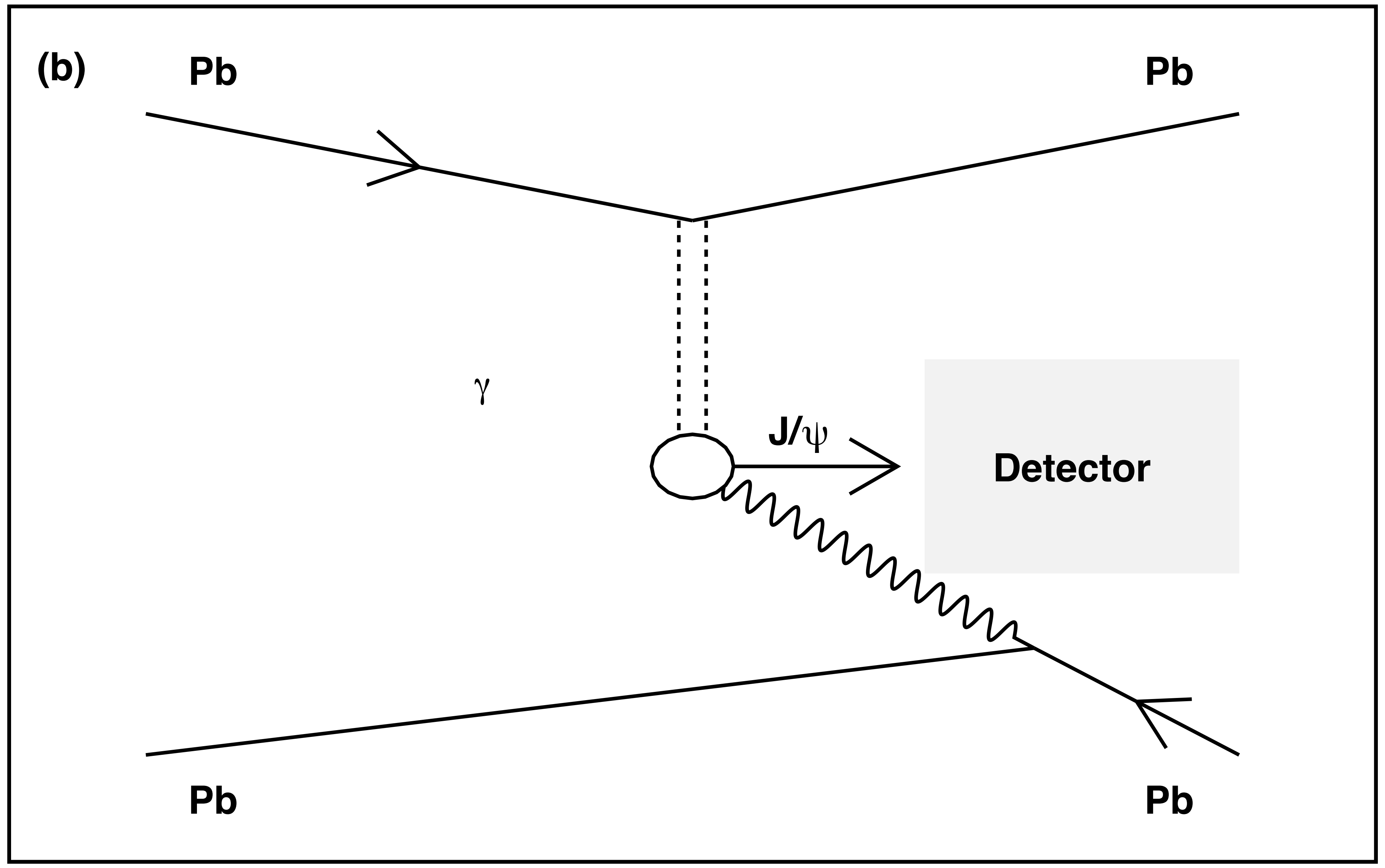
From Pb-Pb to γPb

Coherent photoproduction of J/ψ in Pb-Pb collisions

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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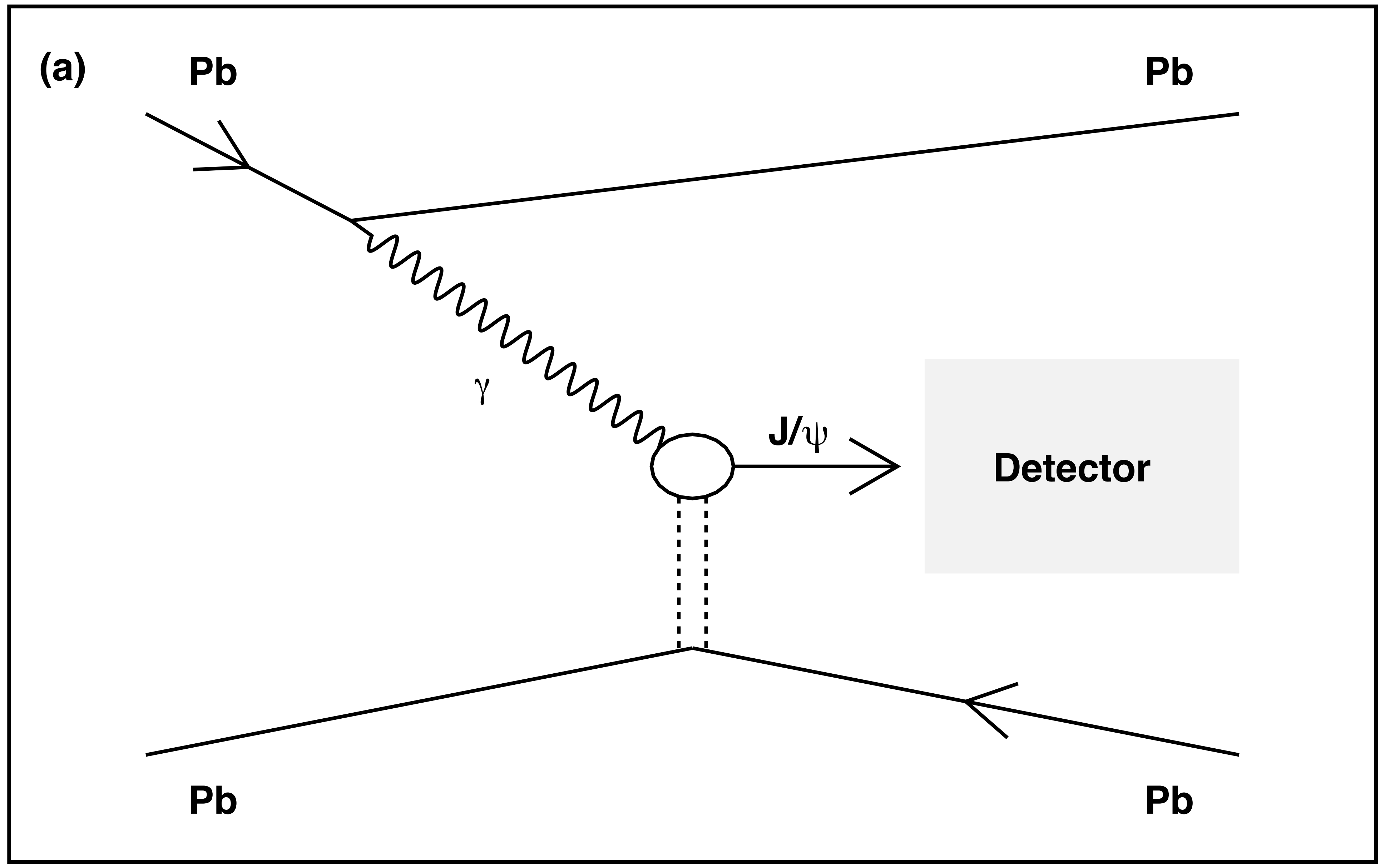

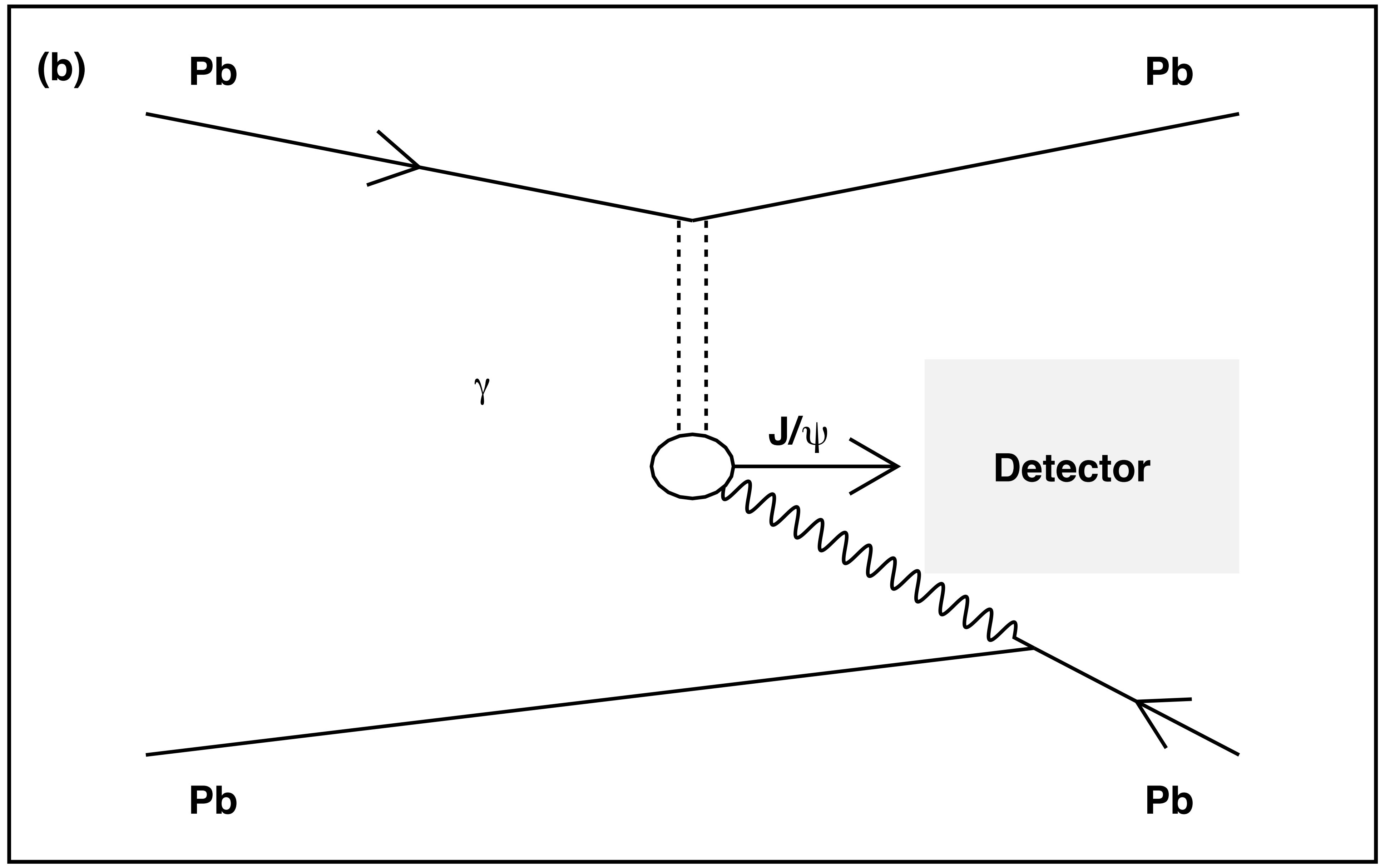

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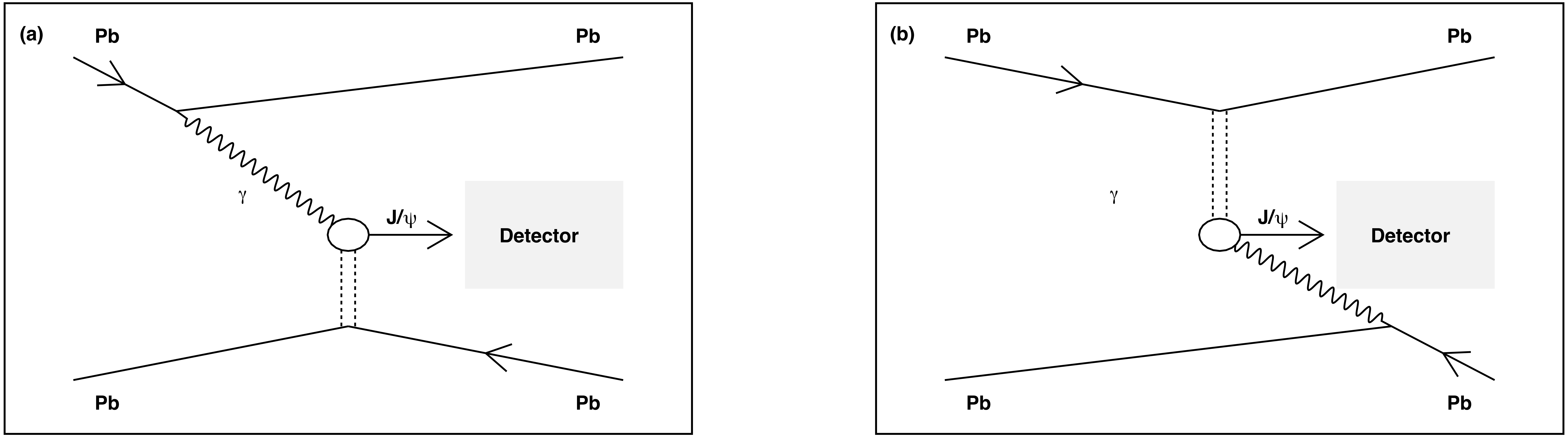


Source travels towards detector: photon has large energy

Source travels away from detector: photon has small energy

For measurements at mid rapidity both components are equal

For measurements at forward rapidities they differ

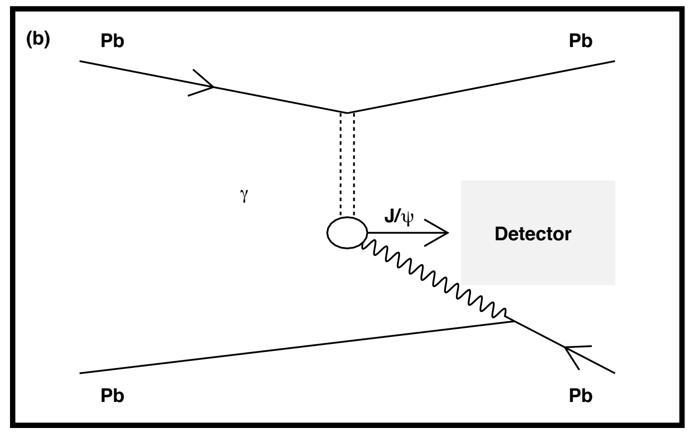
Coherent Pb-Pb cross section

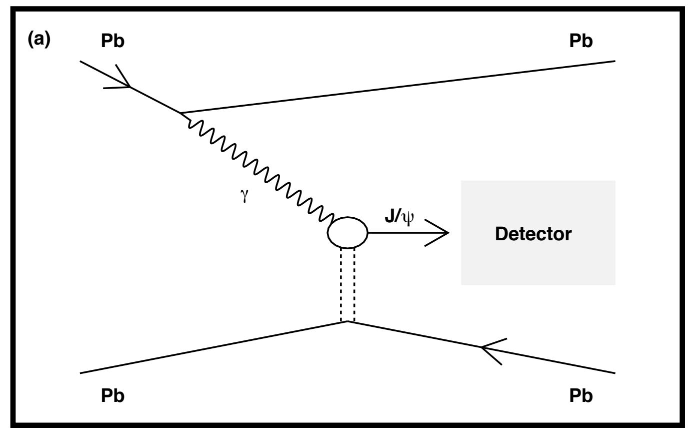
Convolution of the photon flux and the photonuclear cross section

Coherent Pb-Pb cross section

Convolution of the photon flux and the photonuclear cross section

$$\frac{d\sigma_{\mathrm{PbPb}}}{dy} = n_\gamma(y; b_{1,2})\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y; b_{1,2})\sigma_{\gamma\mathrm{Pb}}(-y)$$





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Convolution of the photon flux and the photonuclear cross section

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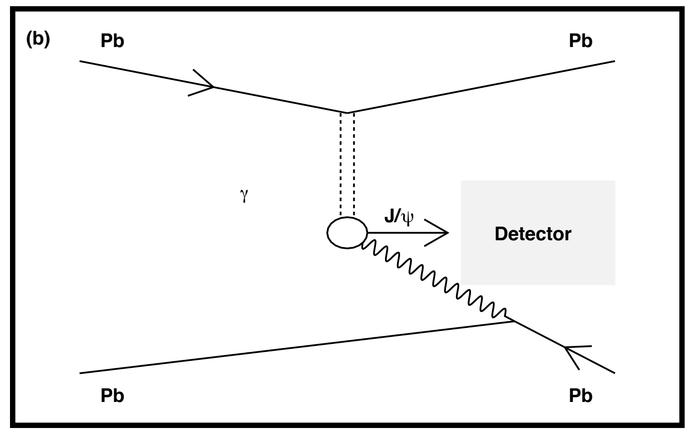

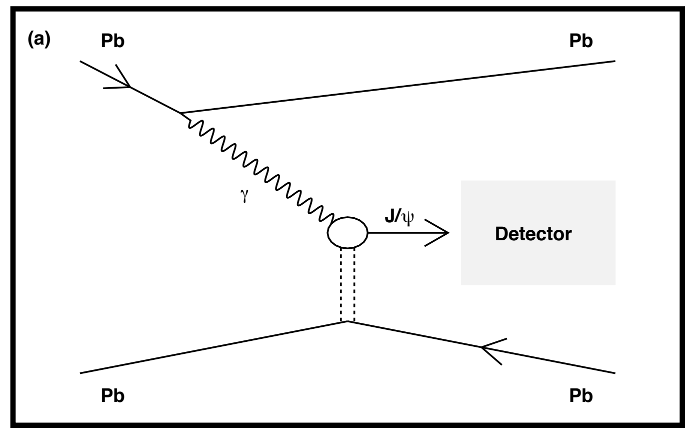

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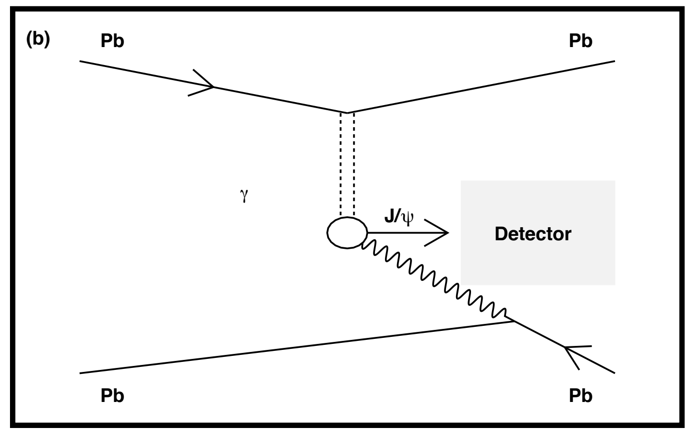

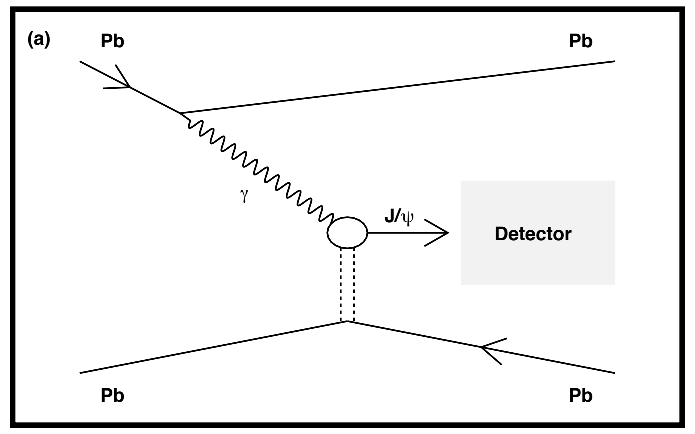

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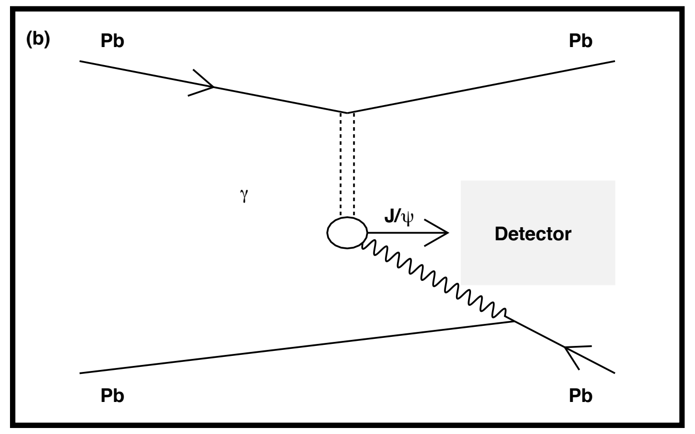

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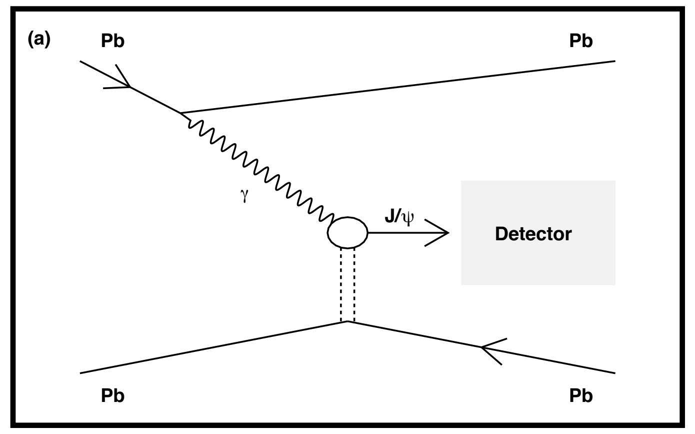

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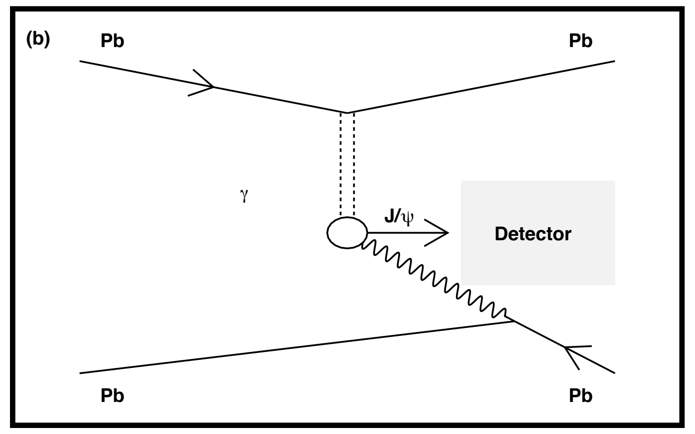

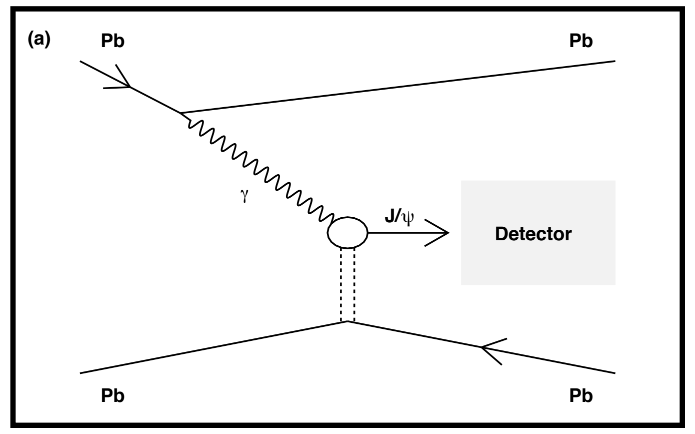

Photonuclear cross section

QCD is here

Coherent photonuclear production

When the photon flux is known, measuring the Pb-Pb cross section in two different impact parameter ranges at the same rapidity allows one to extract the photonuclear cross section at y and at -y simultaneously

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$$\sigma_{\gamma \mathrm{Pb}}(y) = \left(n_\gamma^U(-y) \frac{d\sigma_{\mathrm{PbPb}}^P}{dy} - n_\gamma^P(-y) \frac{d\sigma_{\mathrm{PbPb}}^U}{dy} \right) / F(y)$$

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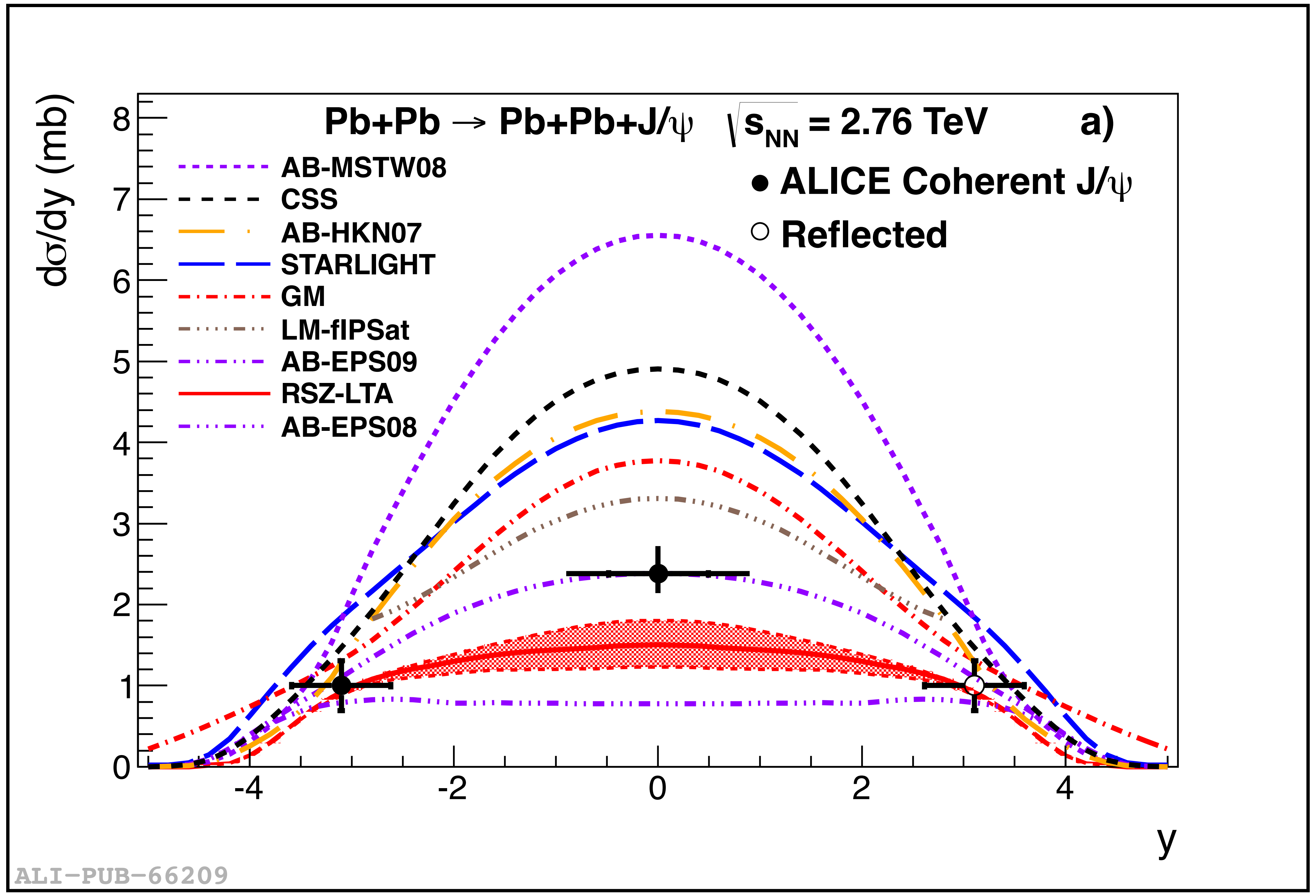
use measurements in ultra-peripheral (U) and in peripheral (P) collisions by ALICE

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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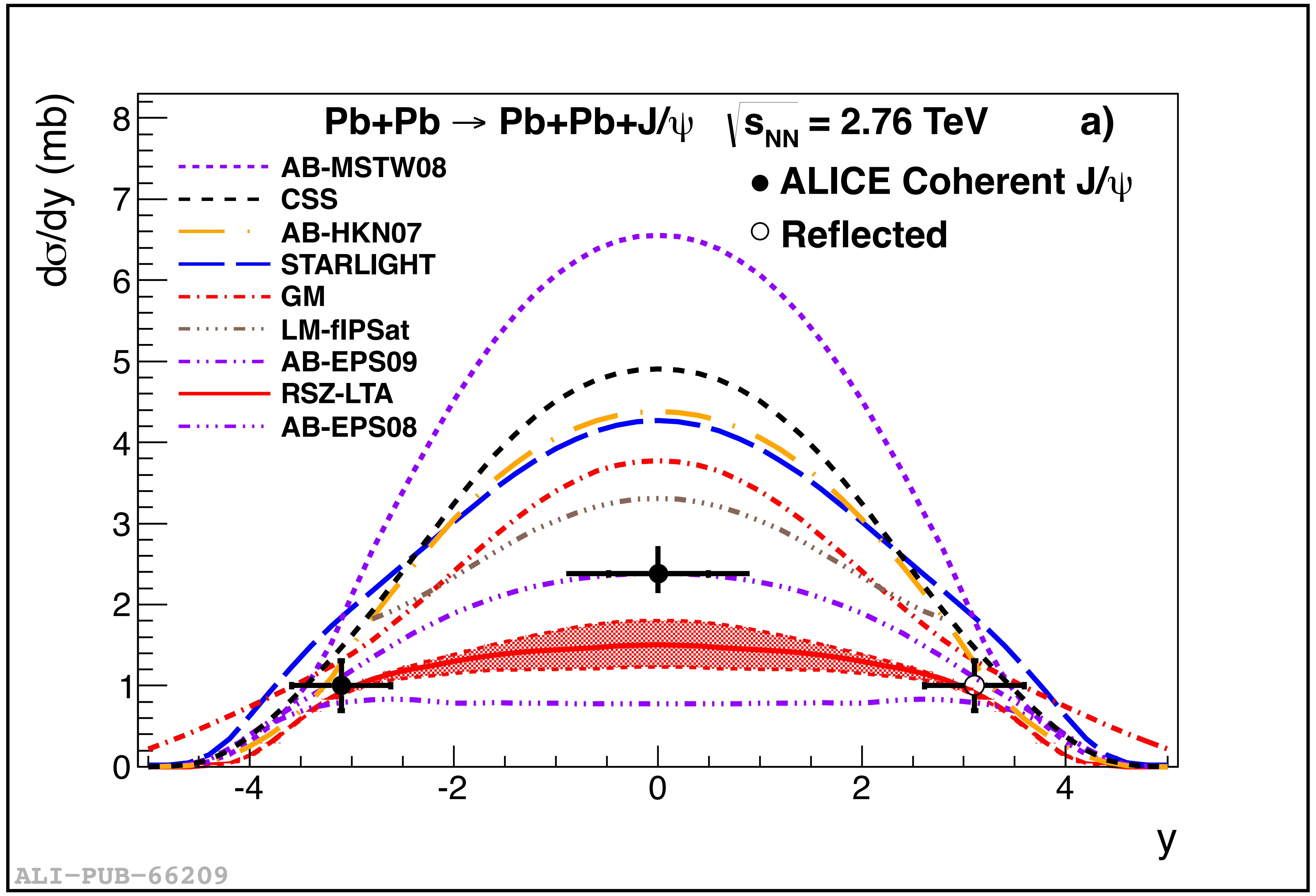
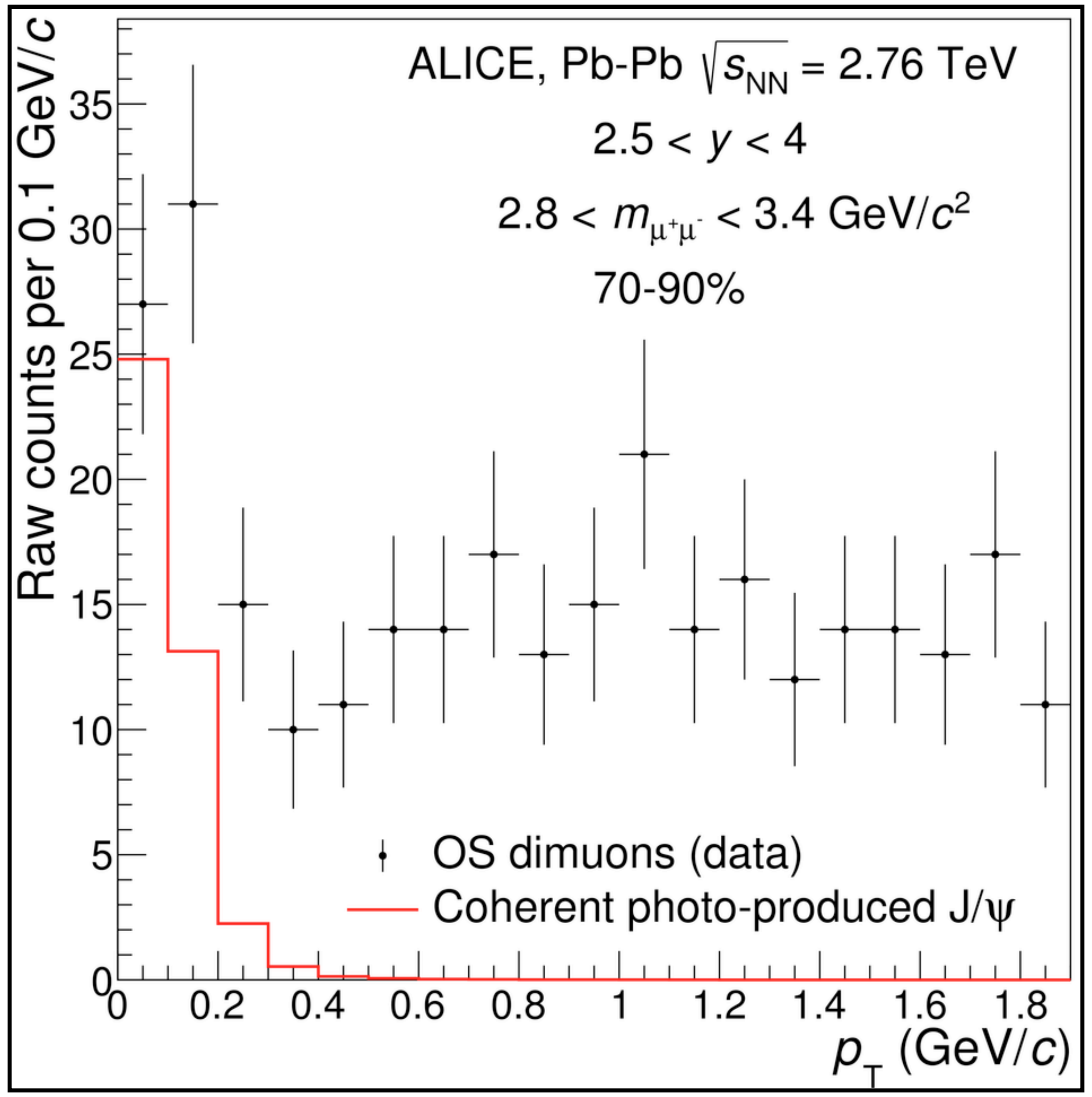


ALICE: Phys.Rev.Lett. 116 (2016) 222301



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In peripheral collisions:
at forward rapiditities

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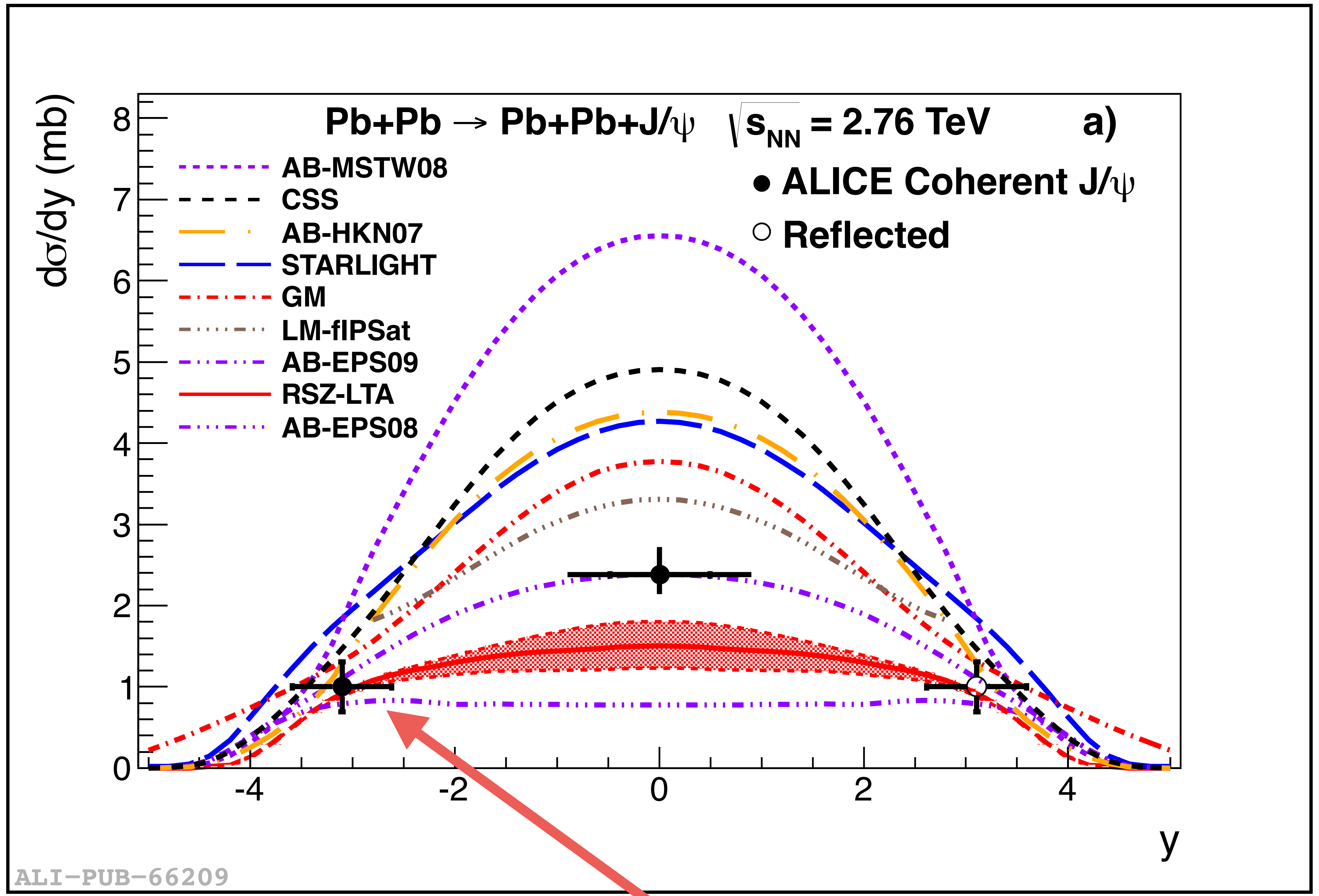

1.0±0.18(stat.)±0.25(syst.) mb

In UPC collisions:
Measurements at mid and forward rapidities

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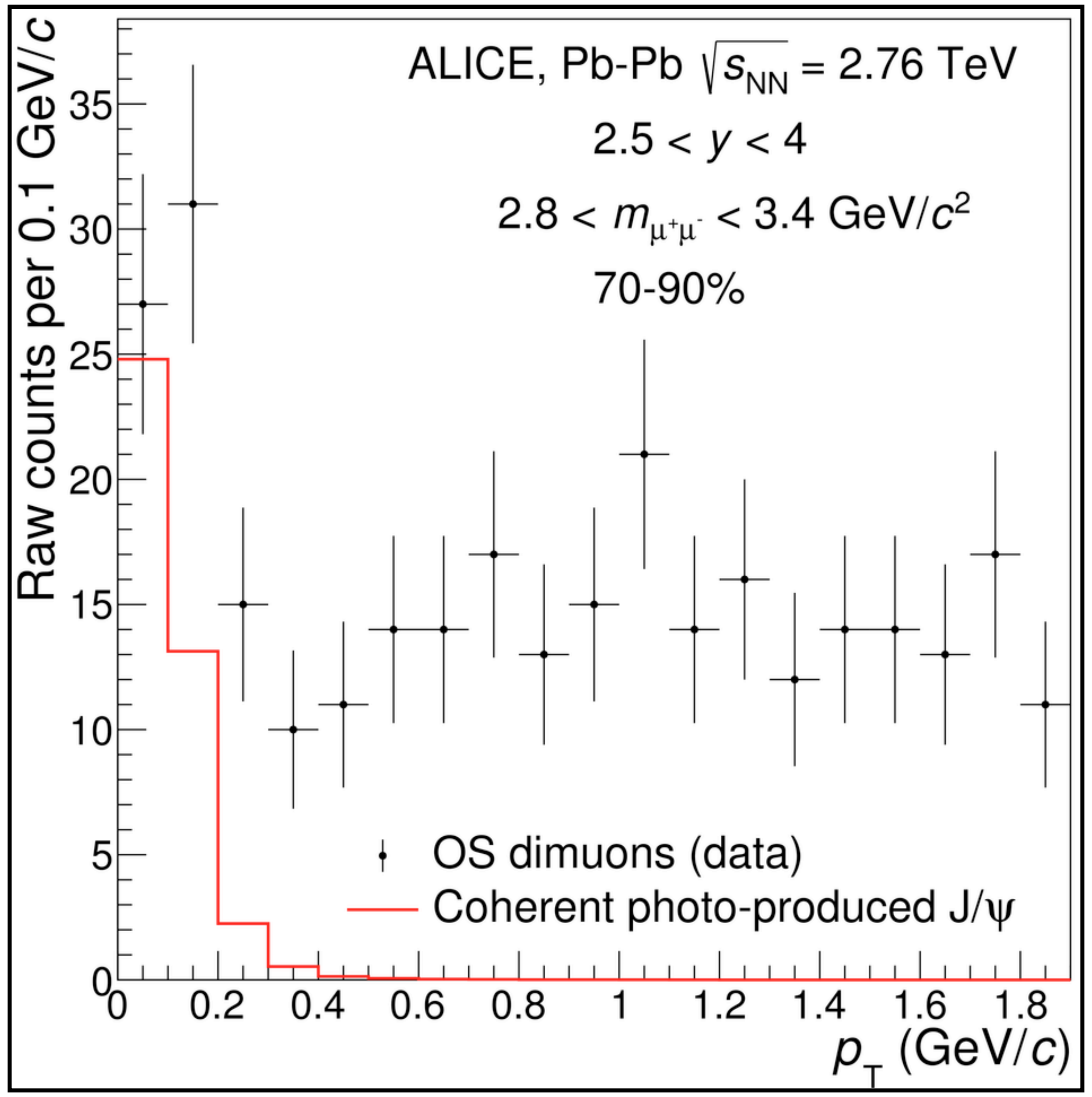

59±11(stat.)±12(syst.) μb

In peripheral collisions:
at forward rapiditities

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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Models have been used to shift the UPC measurement to the peripheral range

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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Photon flux

Photon flux from a fast particle

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

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Distance from centre of particle to point of emission

Photon flux from a fast particle

Photon energy

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EM Form factor

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- Flux of photons
- Photon energy
- Charge of fast particle
- EM Form factor
  - Point charge
  - Convolution of Yukawa and hard sphere potentials
  - Fourier Bessel transform of Woods-Saxon distribution
- Distance from centre of particle to point of emission
- Lorentz factor

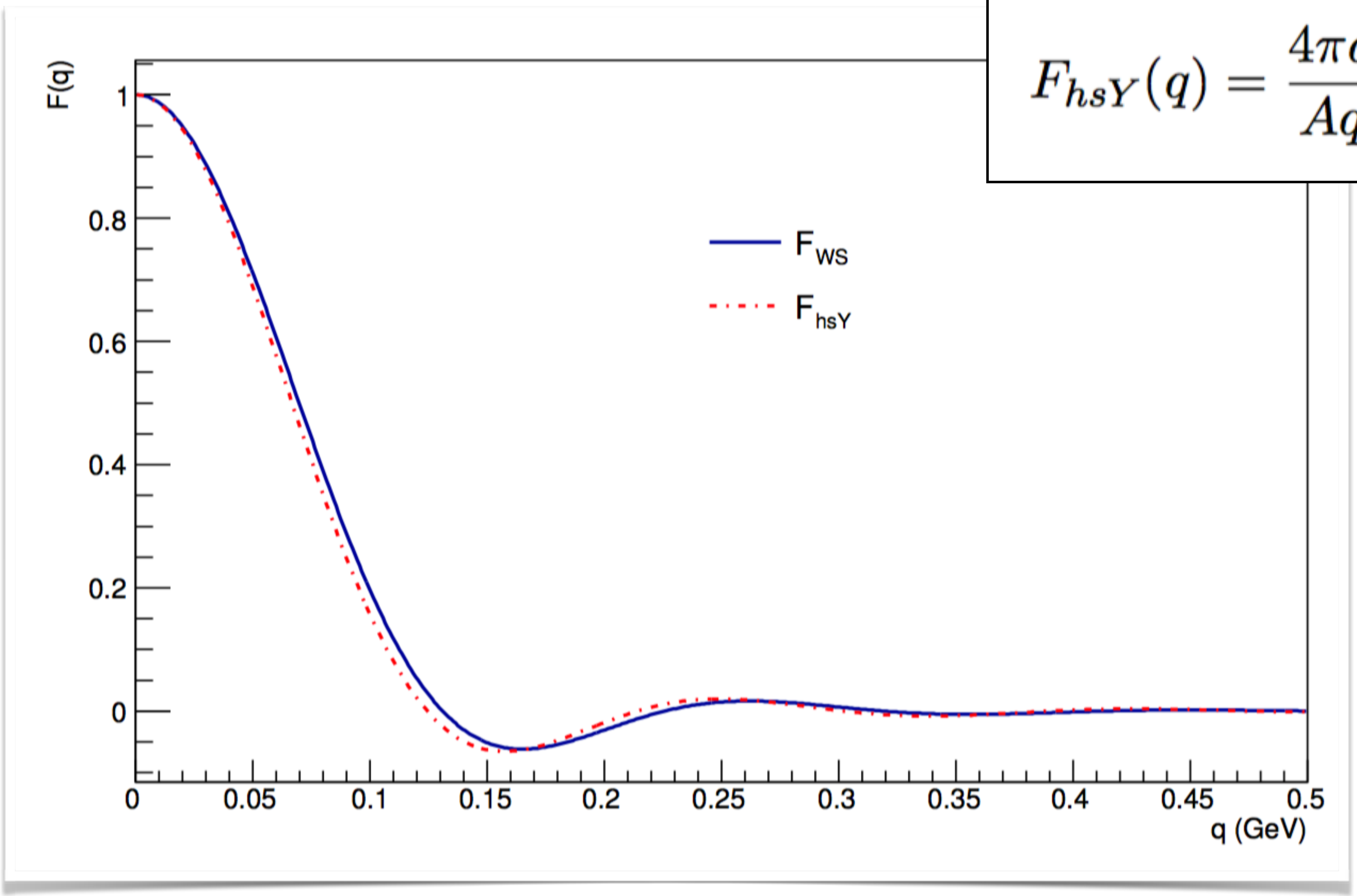
Form factor for a point charge

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

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



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

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

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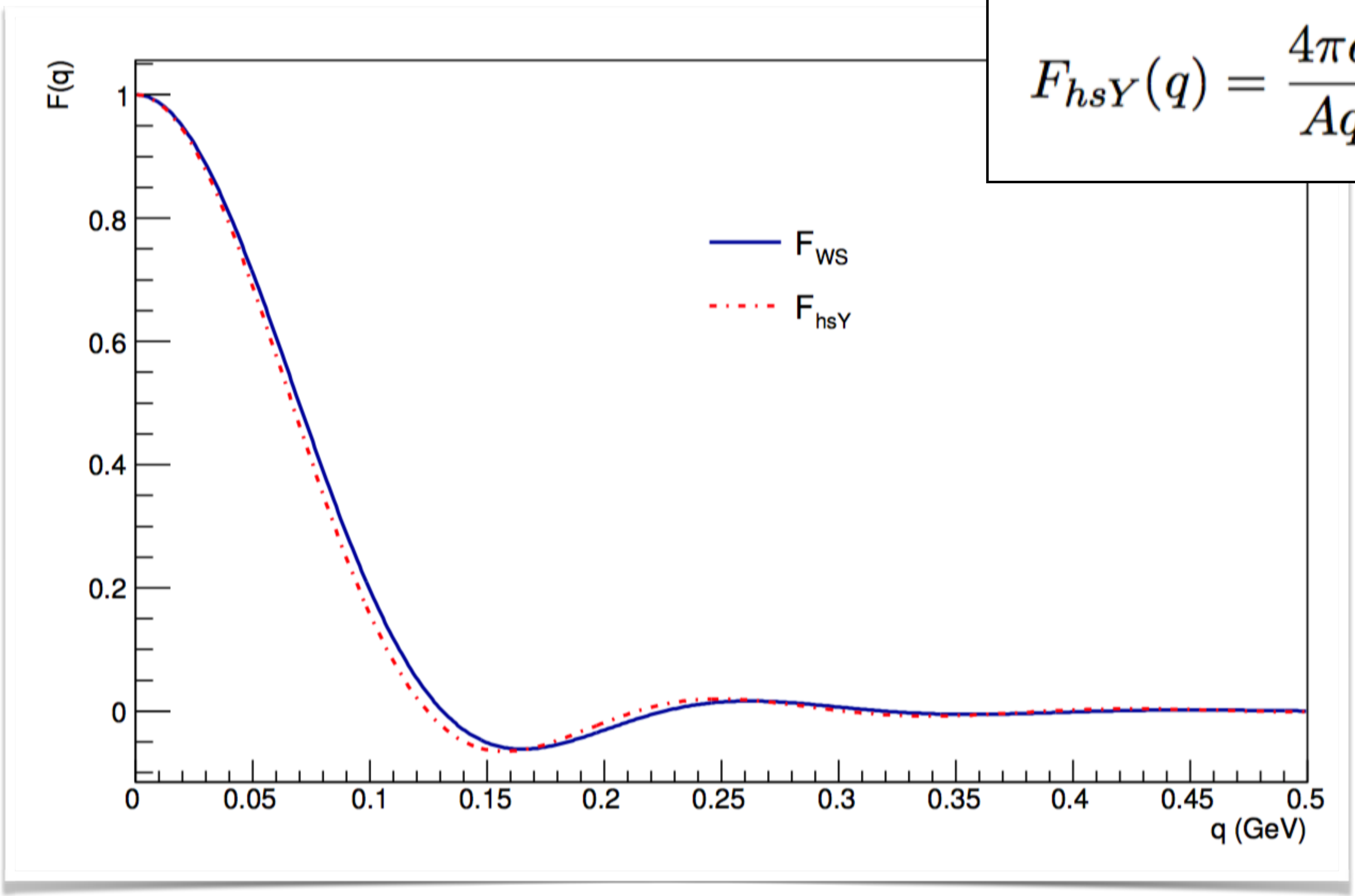

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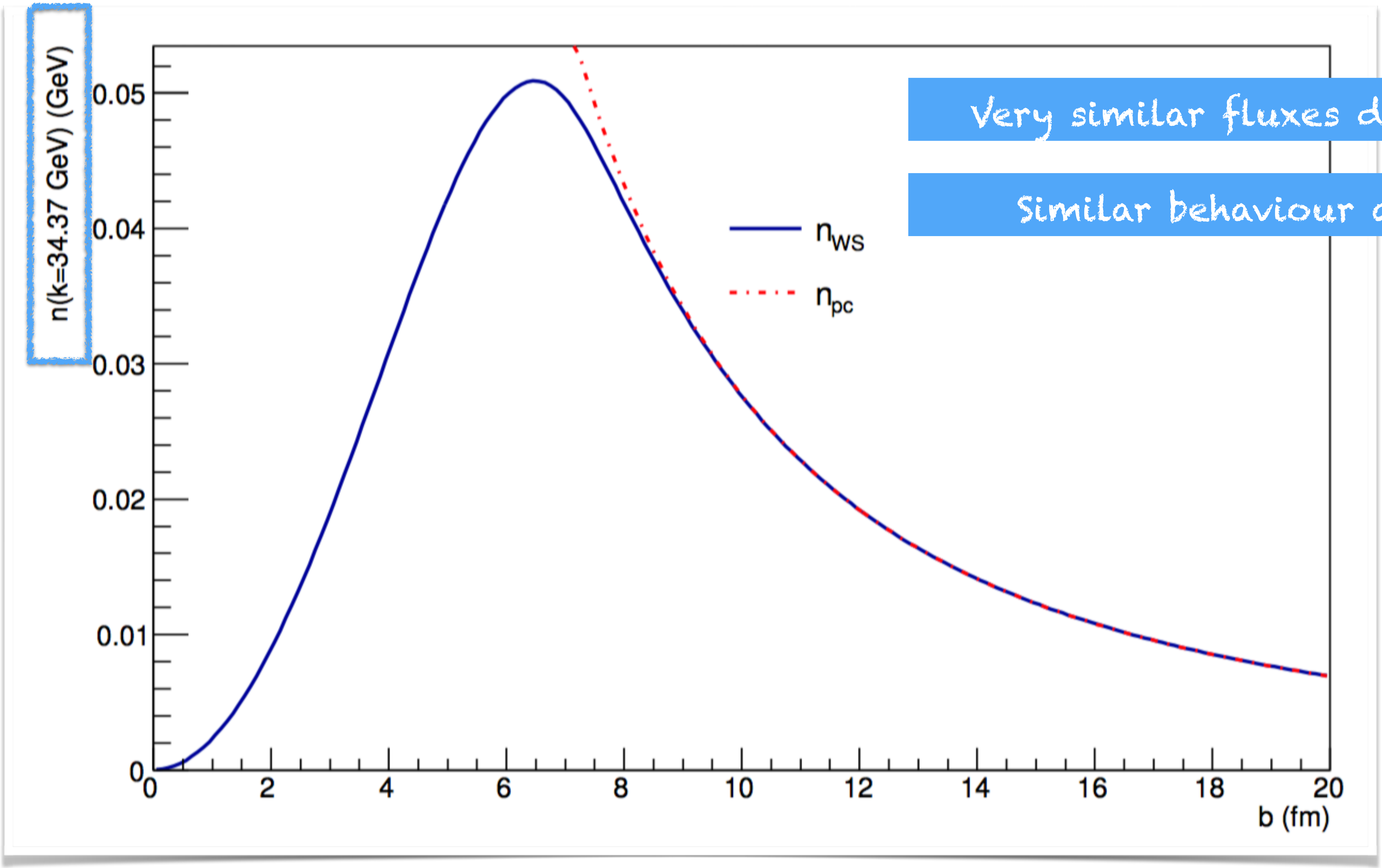
Very similar -> use convolution of hard sphere and Yukawa potential

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

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

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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

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

Probability of hadronic interaction

Extracted γPb cross section

Coherent photonuclear cross section

Using the procedure outlined previously:

$$\sigma(y = -3.25) = 5.2 \pm 1.0 \ \mu\text{b},$$
$$\sigma(y = 0) = 15.0 \pm 2.7 \ \mu\text{b},$$
$$\sigma(y = 3.25) = 38 \pm 15 \ \mu\text{b},$$

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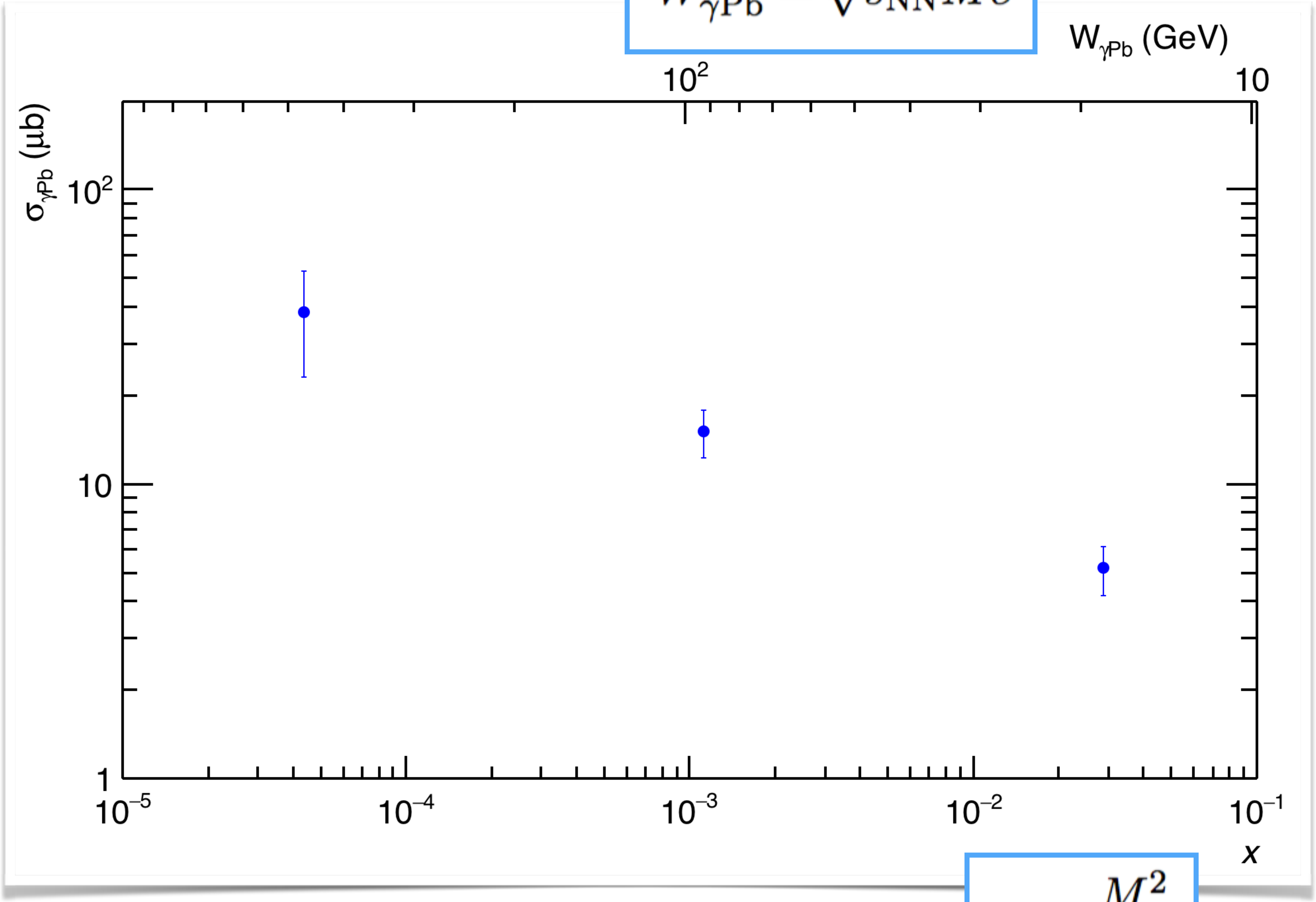
$$W^2_{\gamma\text{Pb}} = \sqrt{s_{\text{NN}}}Me^{y}$$



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

Suppression factor

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

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

$$\Phi_A(t_{\mathrm{min}}) = \int_{t_{\mathrm{min}}}^{\infty} dt\, |F_{WS}(t)|^2$$

The nuclear suppression factor

Using the previous formulas

$$S(W_{\gamma\mathrm{Pb}} = 18.2\ \mathrm{GeV}) = 0.74 \pm 0.10,$$
$$S(W_{\gamma\mathrm{Pb}} = 92.4\ \mathrm{GeV}) = 0.57 \pm 0.06,$$
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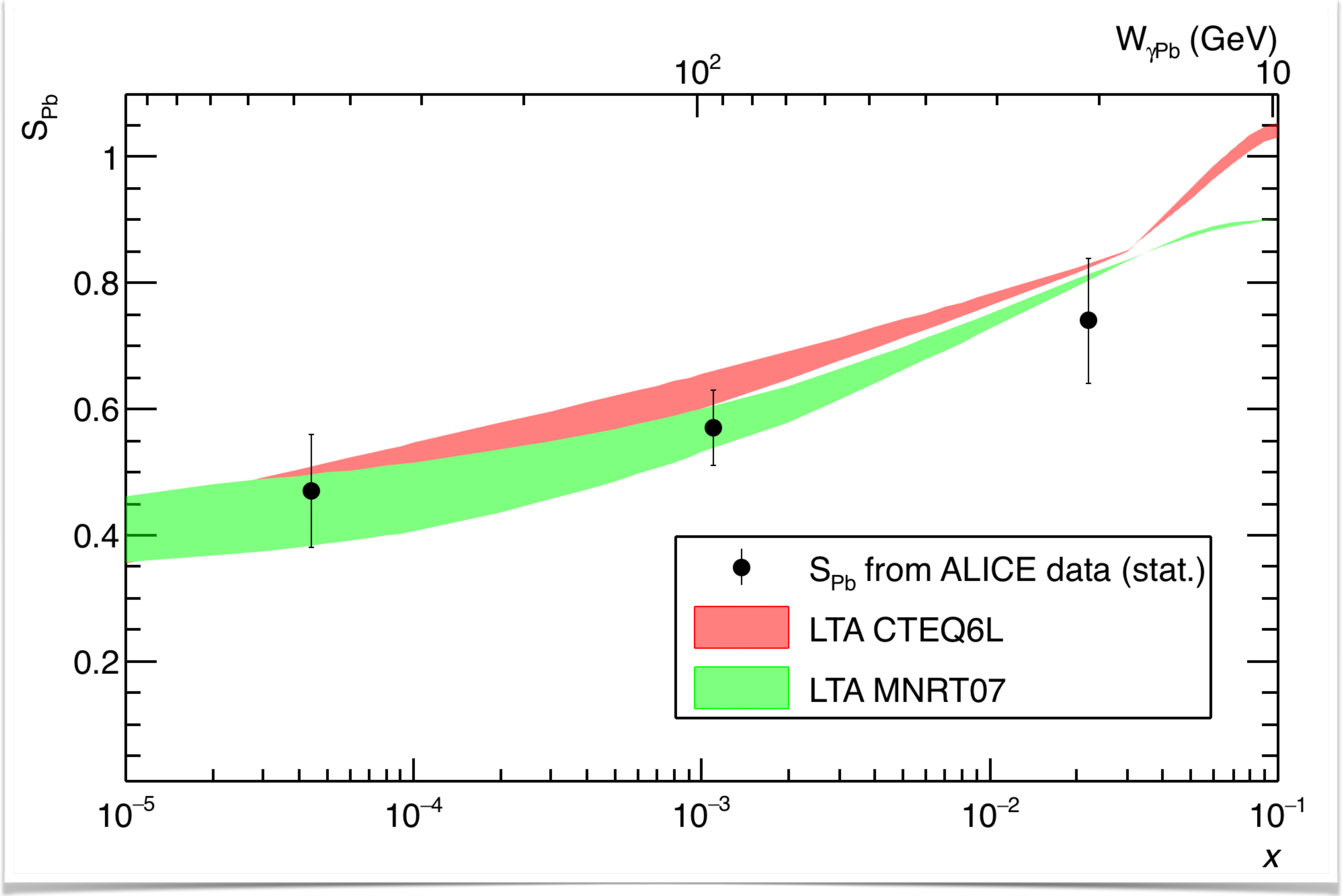

Thanks to Vadim for the LTA curves

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

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 easy comparison to different models.