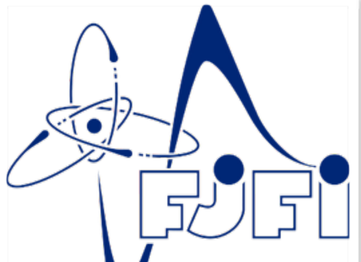
4th International Conference on the Initial Stages in High-Energy Nuclear Collisions

18-22 September 2017, Krakow, Poland

Coherent photoproduction of J/ψ vector mesons in peripheral and ultra-peripheral Pb-Pb collisions

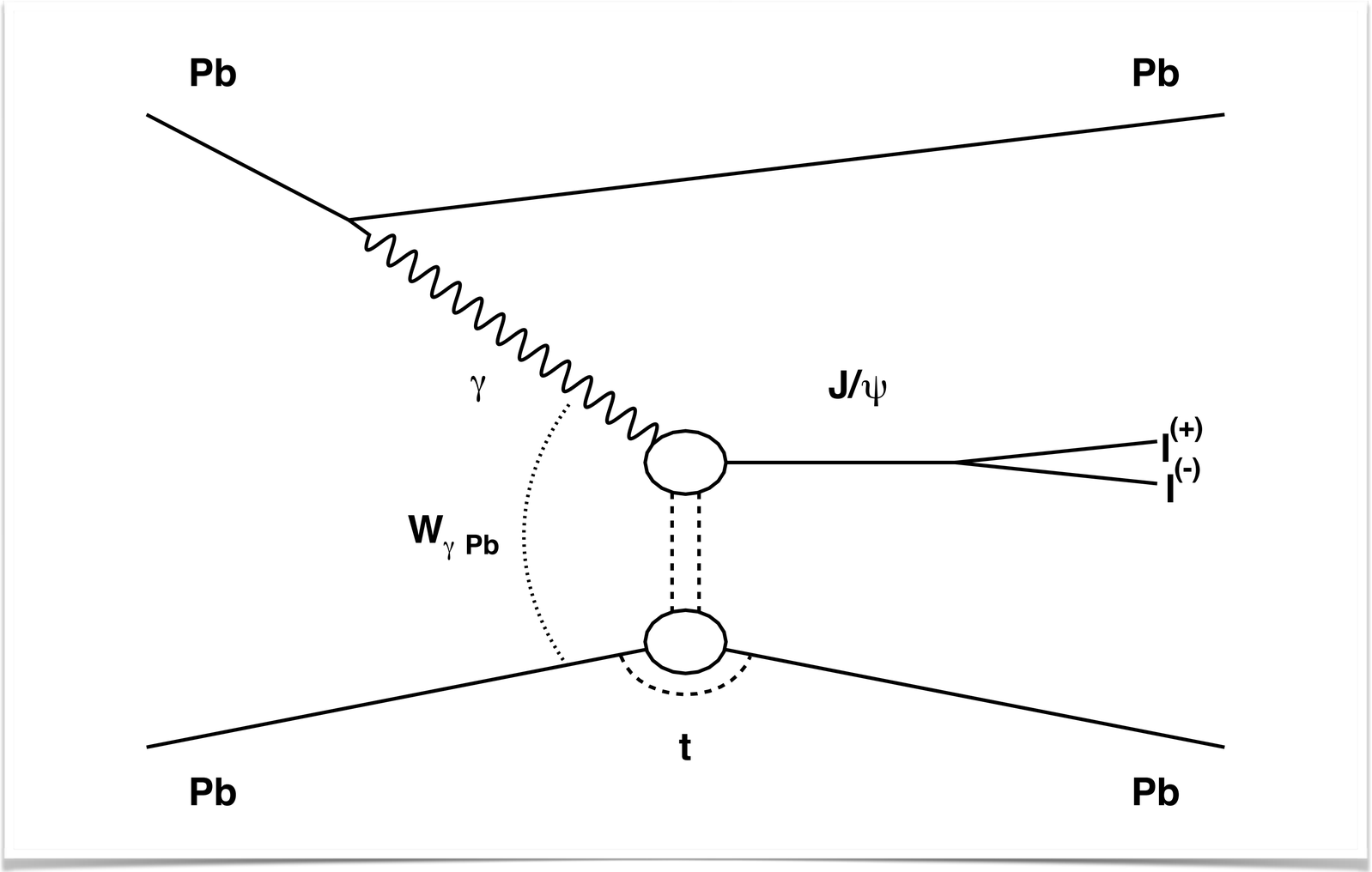


J. G. Contreras
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University

on behalf of the ALICE Collaboration

Introduction

The process we are interested in



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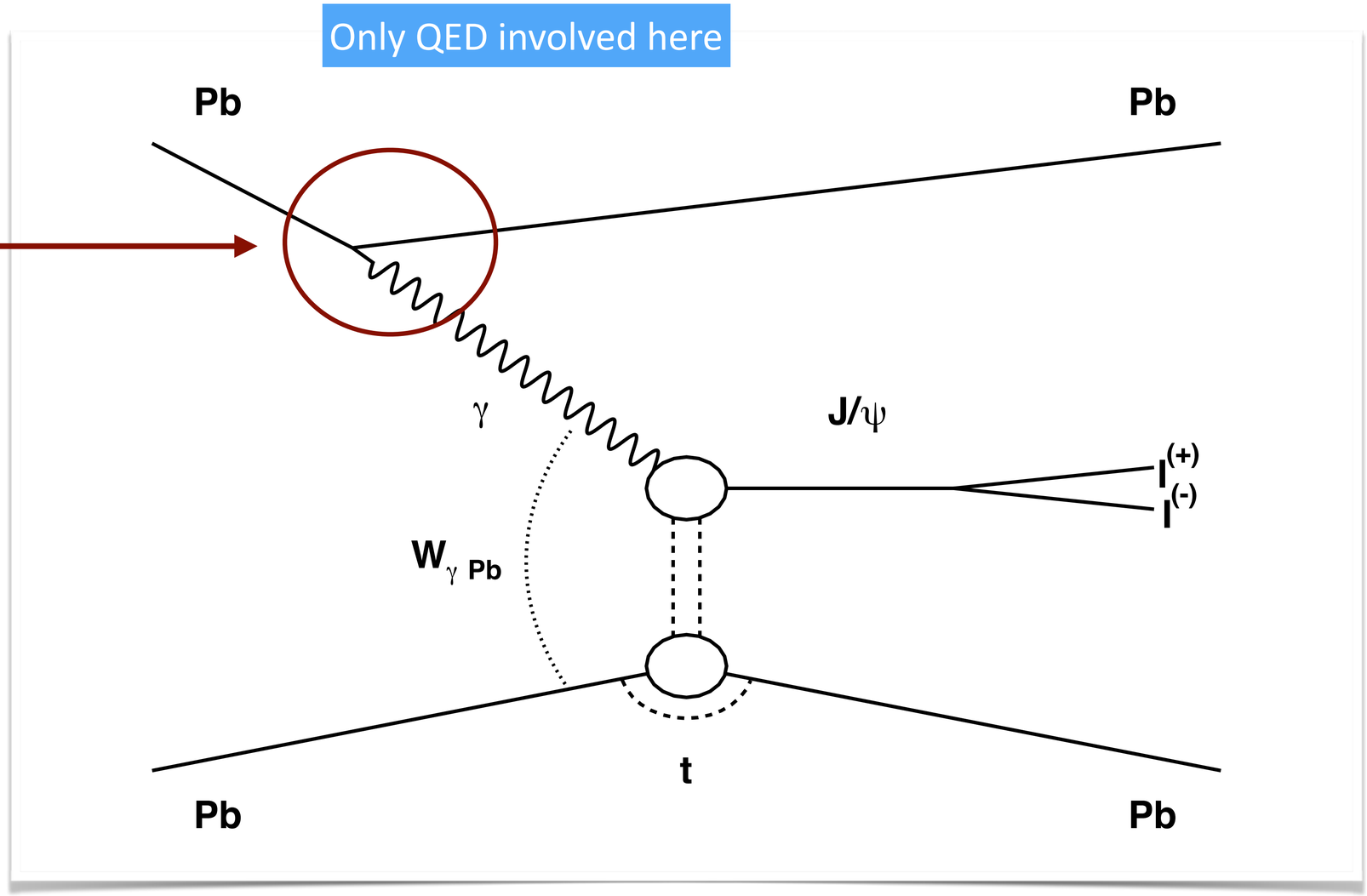

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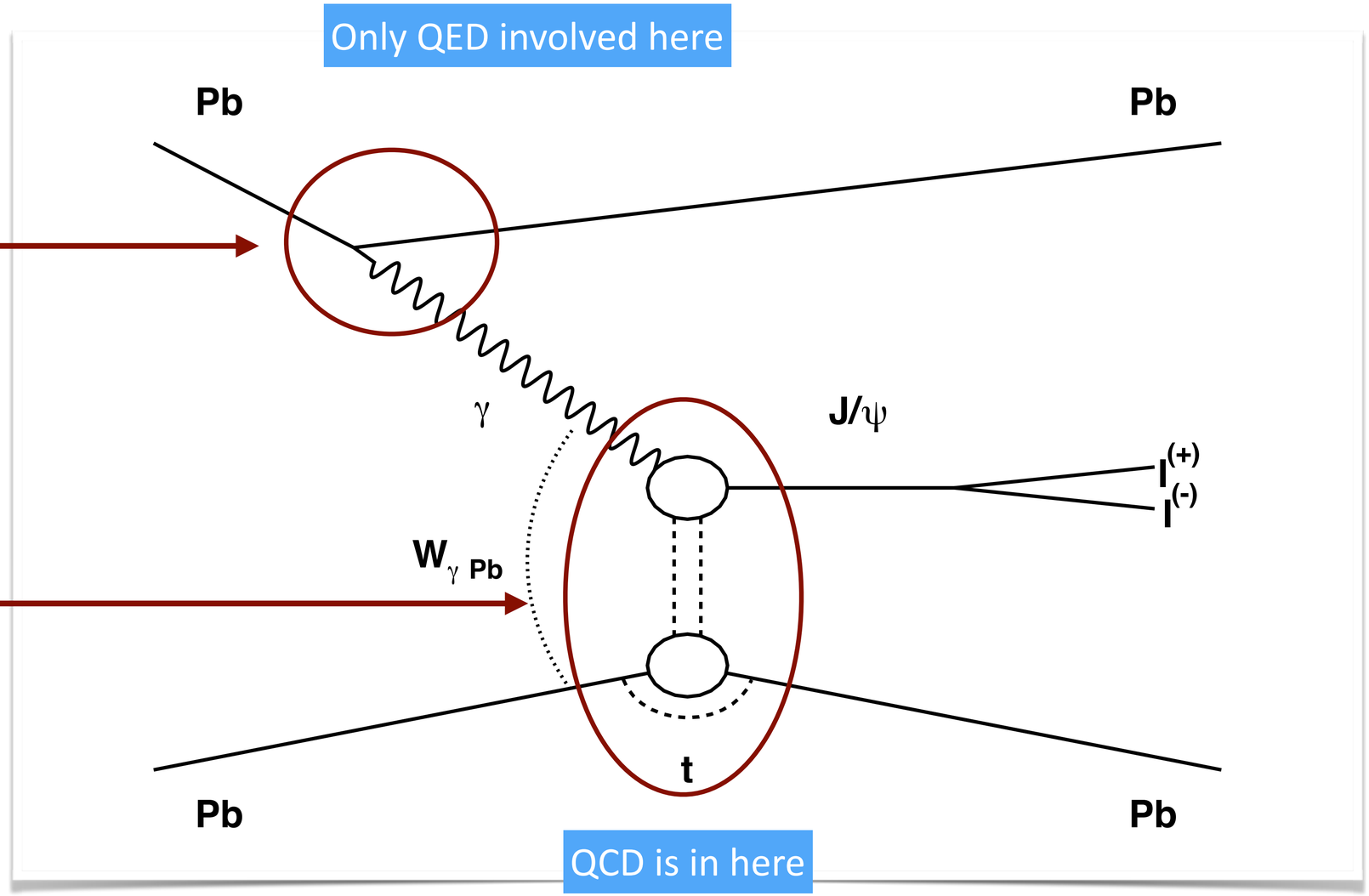
The process can be factorised in two parts:

- Emission of the photon.
- Interaction of the photon with the target.



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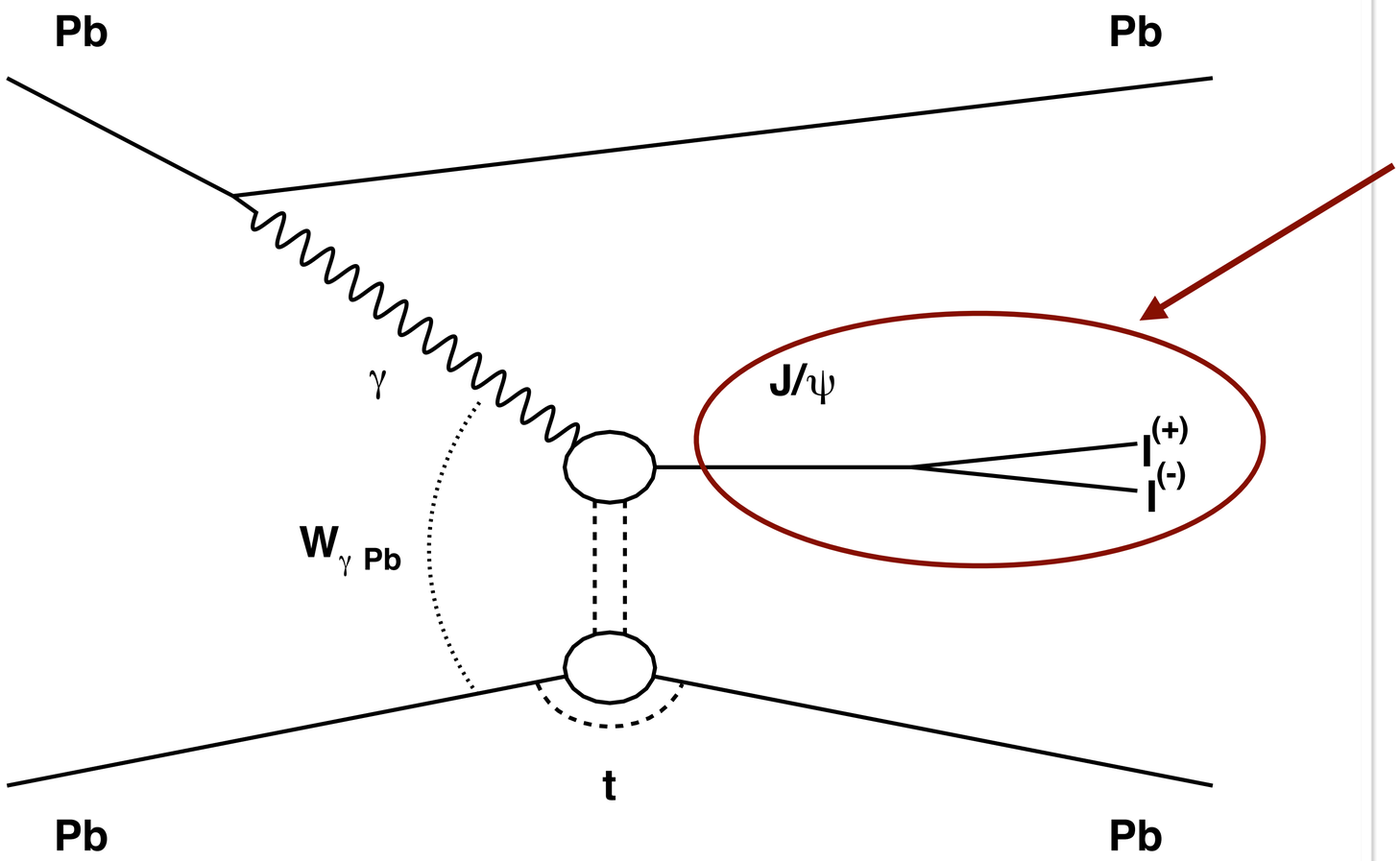
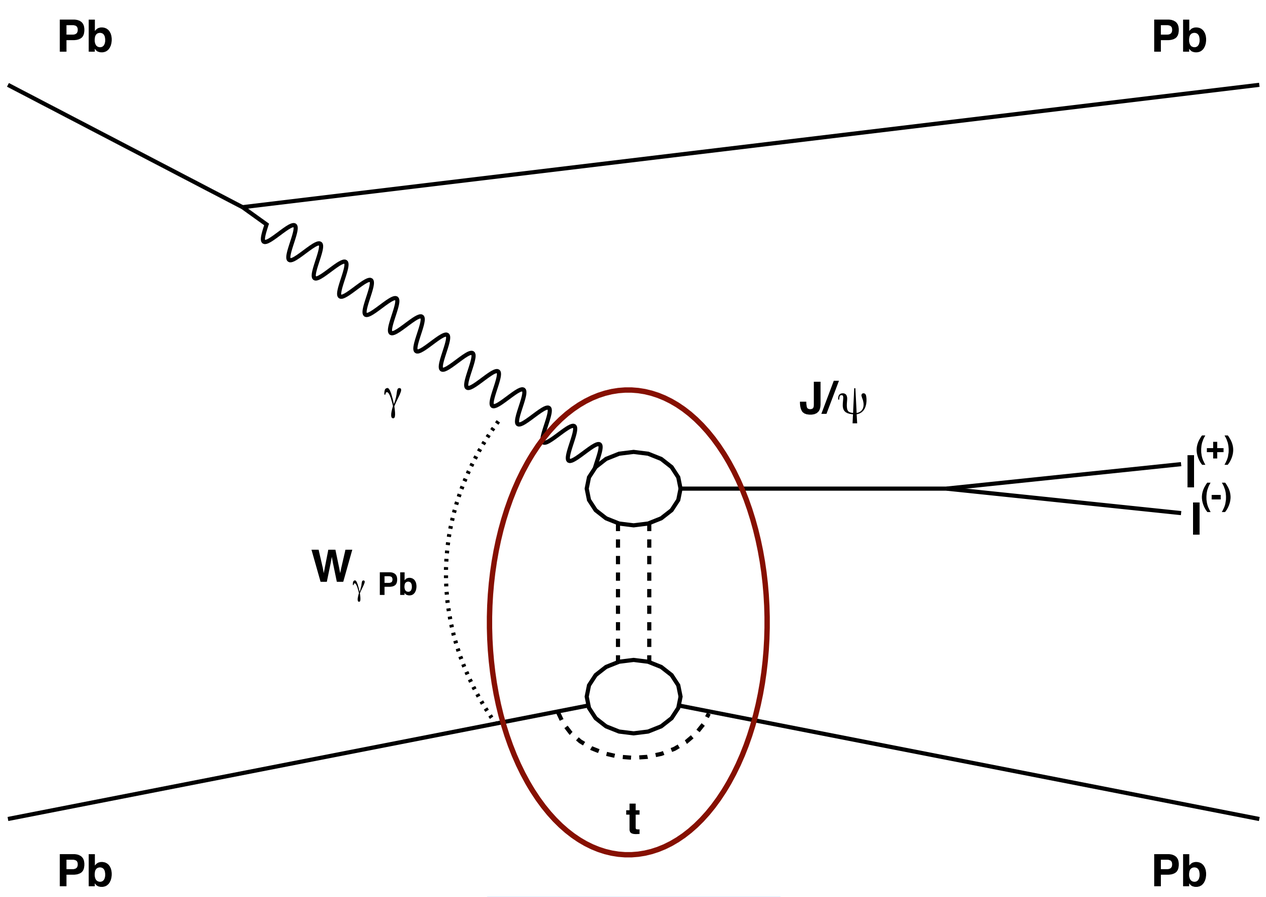


- J/ψ:
  - Large mass of the charm quark allows us to perform perturbative QCD calculations.
  - The small width of the J/ψ and leptonic decays with a sizeable branching ratio provide a clean experimental signal.

The process we are interested in



QCD is in here

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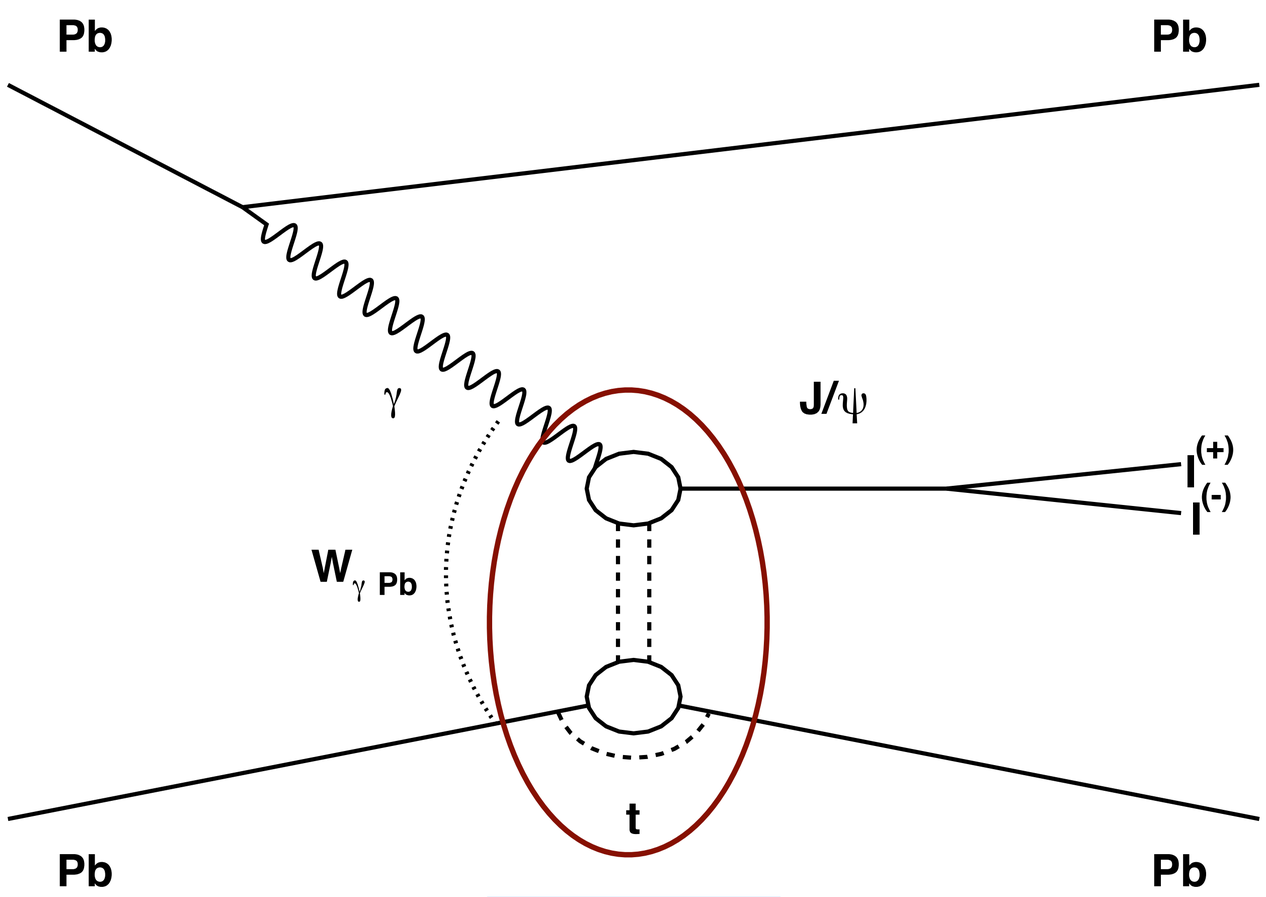

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- This process is particularly sensitive to the **gluon** content of the target.
- In the collinear approach, at LO it is proportional to the **square** of the gluon distribution:

$$\frac{d\sigma^T(\gamma p \to J/\Psi + p)}{dt} = \frac{|M|^2}{16\pi s^2}$$

$$= [F_N^{2G}(t)]^2 \frac{\alpha_s^2 \Gamma_{ee}^J m_J^3}{3\alpha_{em}} \pi^3$$

$$\times \left[\bar{x}G(\bar{x}, \bar{q}^2) \frac{2\bar{q}^2 - |q_t^J|^2}{(2\bar{q}^2)^3} \right]^2$$

Ryskin: Z. Phys. C 57, 89-92 (1993)

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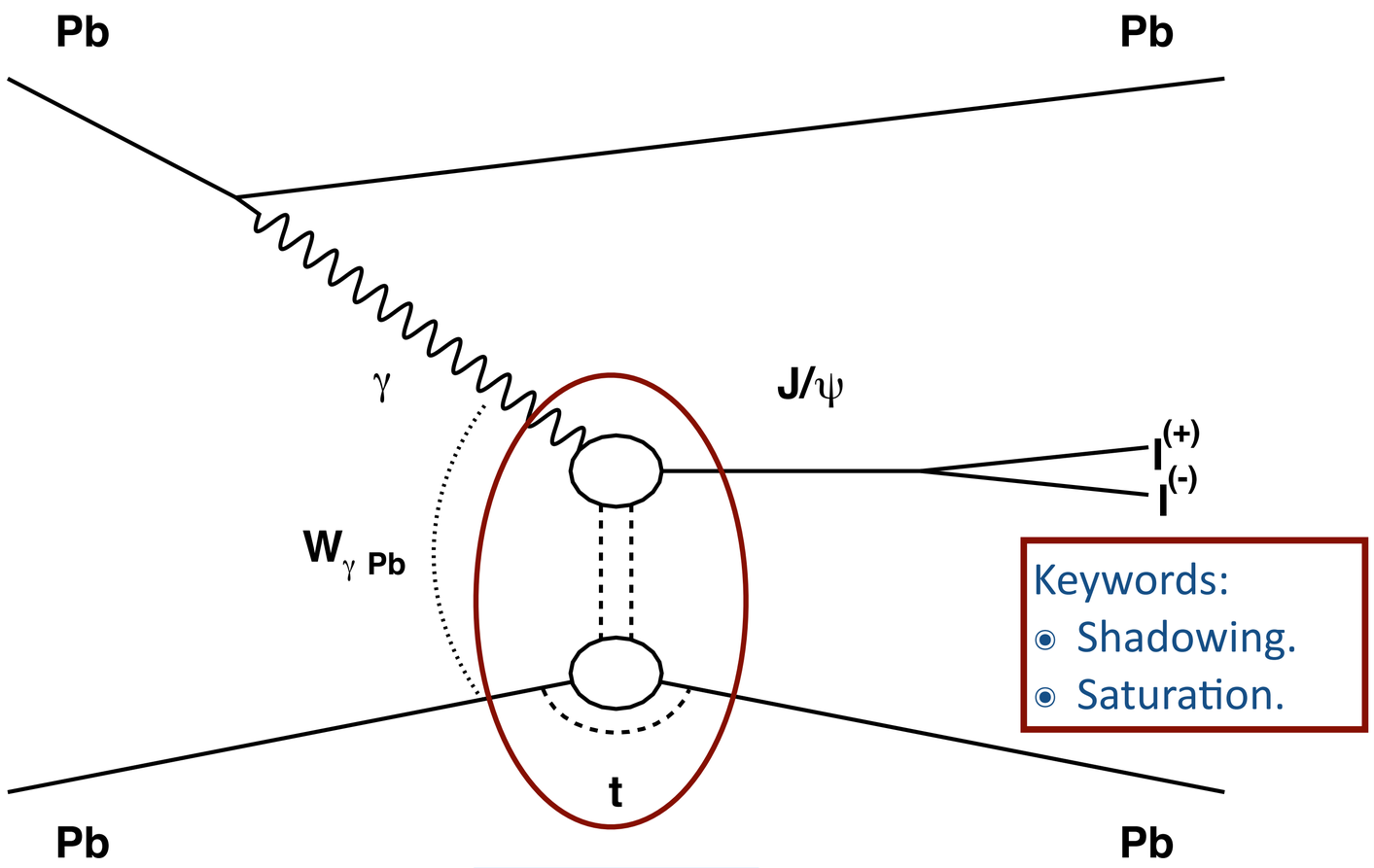

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Keywords:
- Shadowing.
- Saturation.

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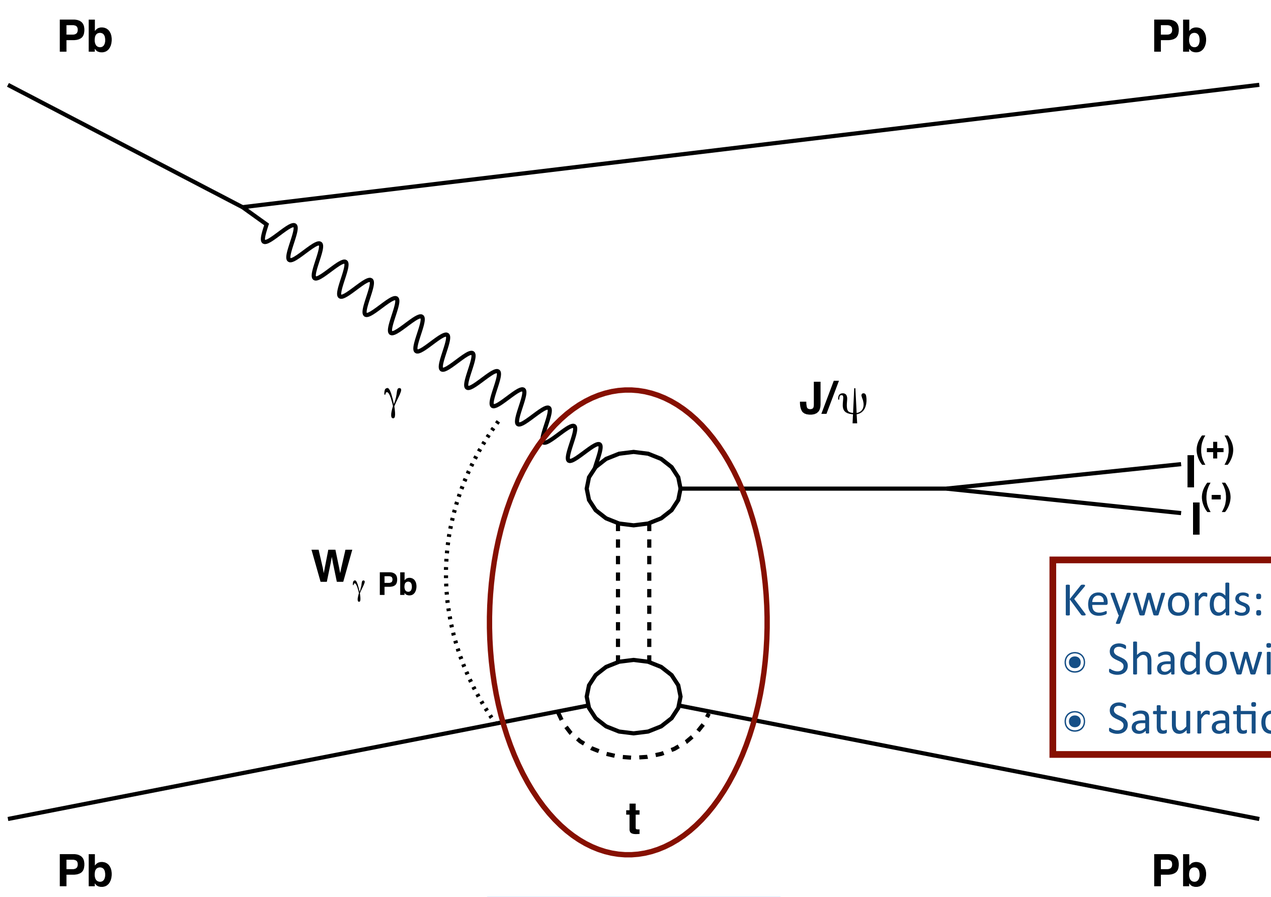

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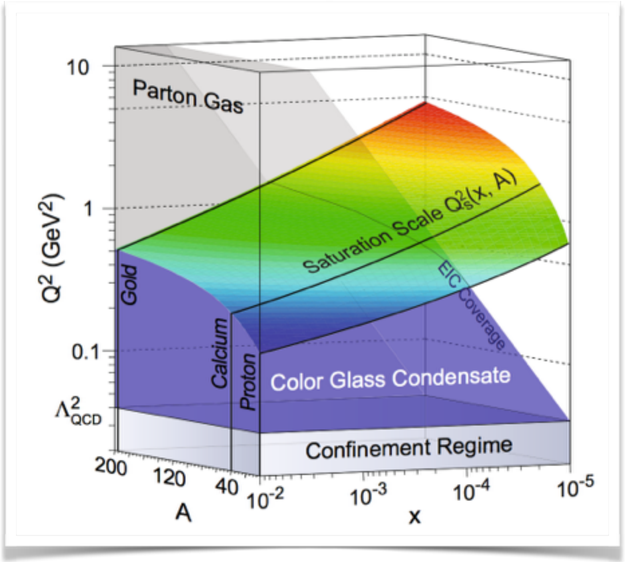


Accardi et al, EPJA 52 (2016) 268

Kinematics: energy and rapidity

Centre-of-mass energy of the photon-target system:

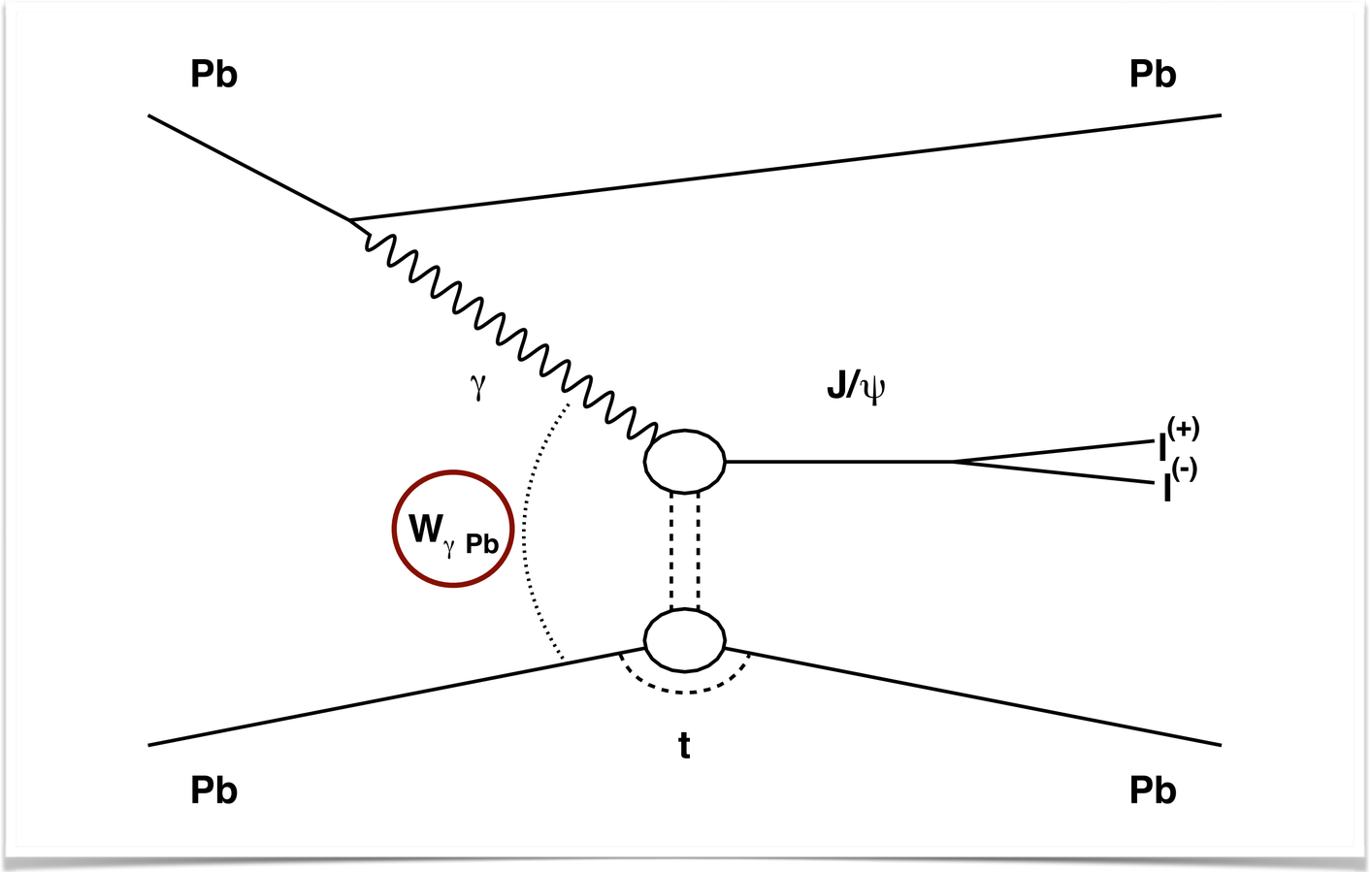
$$W_{\gamma \mathrm{Pb}} = \sqrt{2 E_{\mathrm{Pb}} M e^{-y}}$$

where

- E_{Pb} is the energy of the incoming beam,
- y is the rapidity of the vector meson measured in the laboratory frame **with respect to the direction of the target** and
- M is the mass of the vector meson.

This energy ($W_{\gamma Pb}$) is related to x-Bjorken:

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

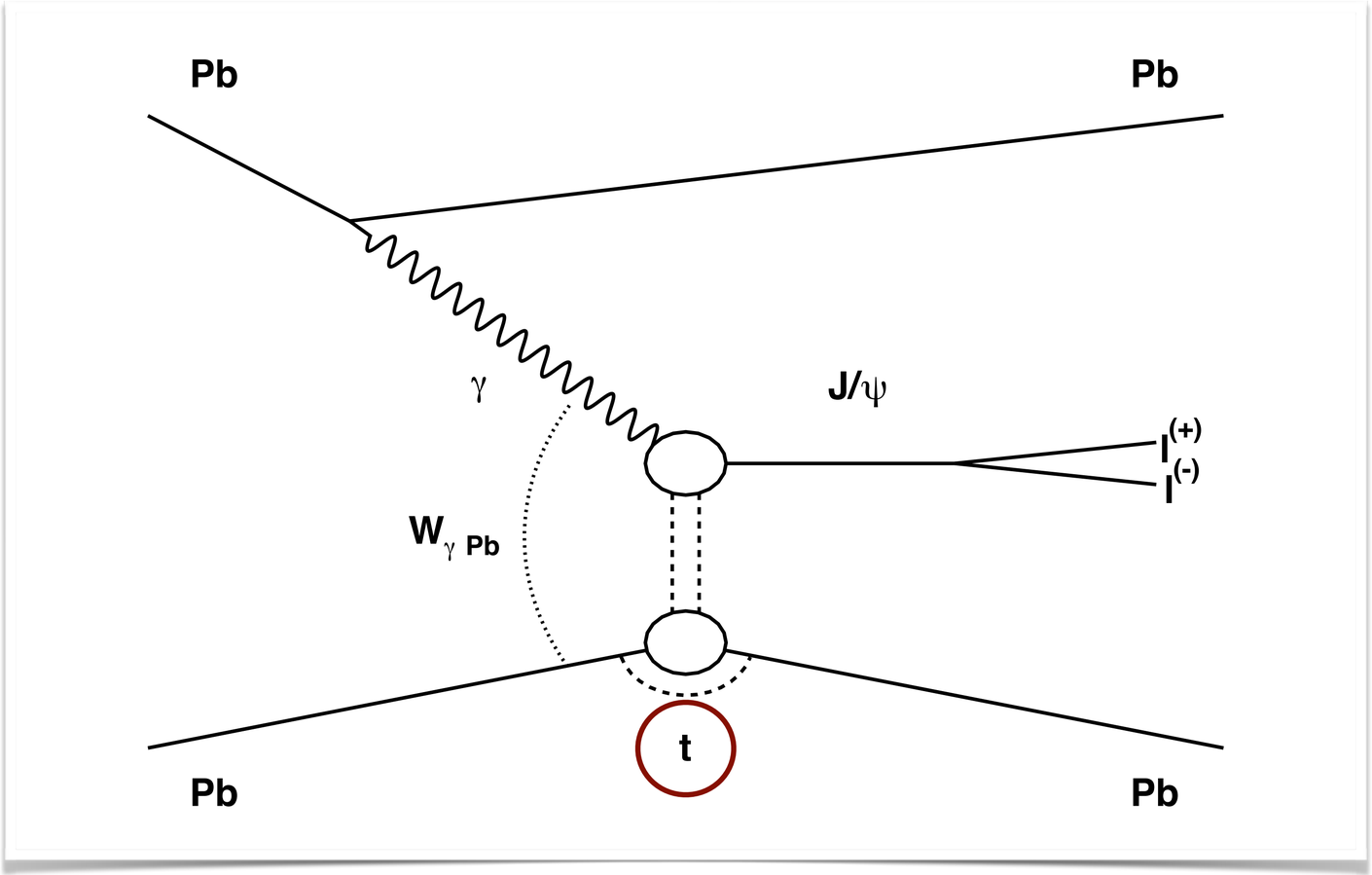


The rapidity of the vector meson determines the centre-of-mass energy (x-Bjorken) of the photon-target interaction

Kinematics: transverse momentum

The square of the momentum transferred in the lead vertex |t| is related to the transverse momentum of the J/ψ:

$$|t| \approx p_T^2$$



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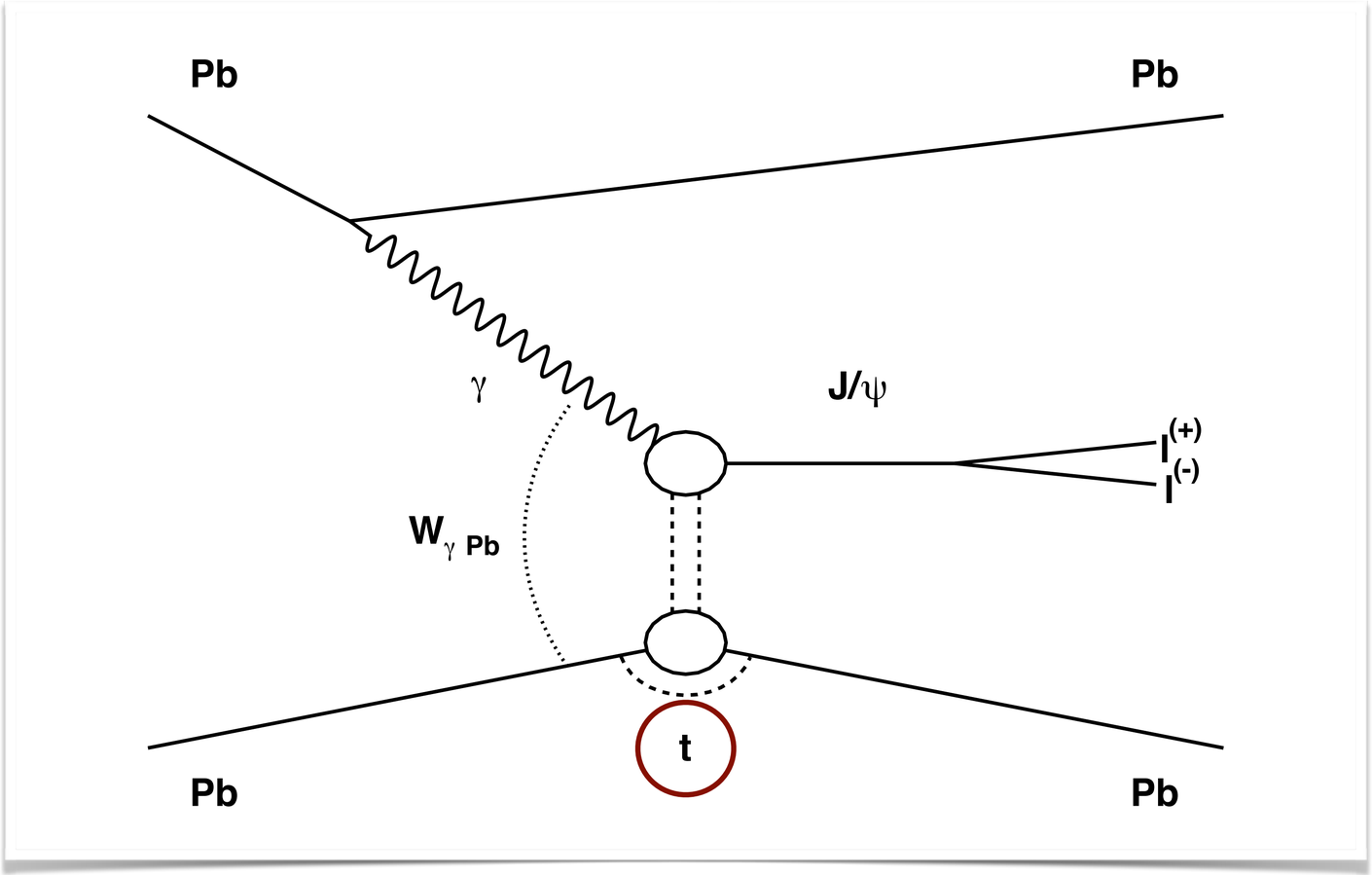
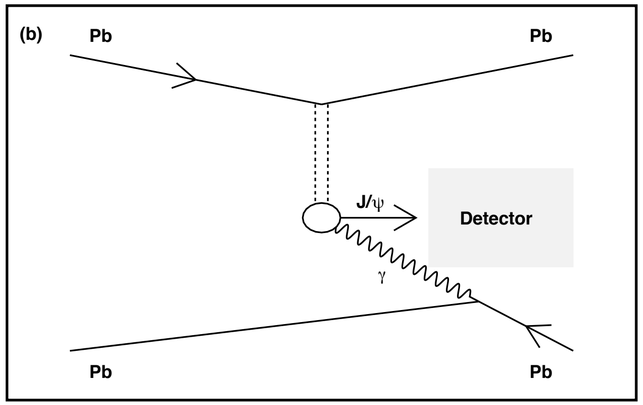
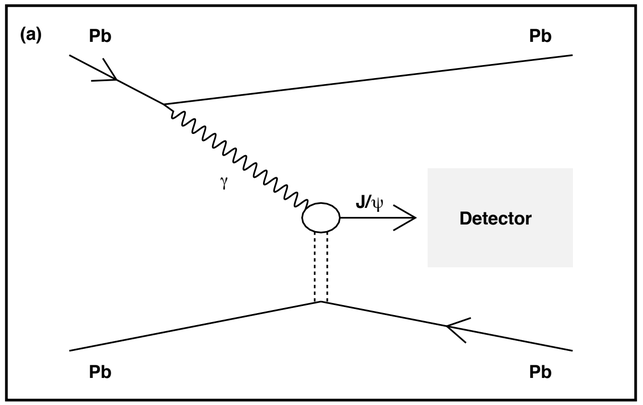
The t distribution is determined by the **nuclear form factor**, which gives, through a Fourier transform, the distribution of gluons in the transverse plane.



The t dependence of vector meson production determines the transverse distribution of matter in the target!

The cross section



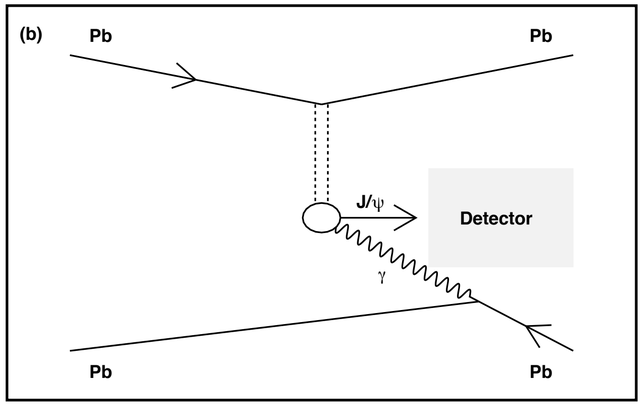


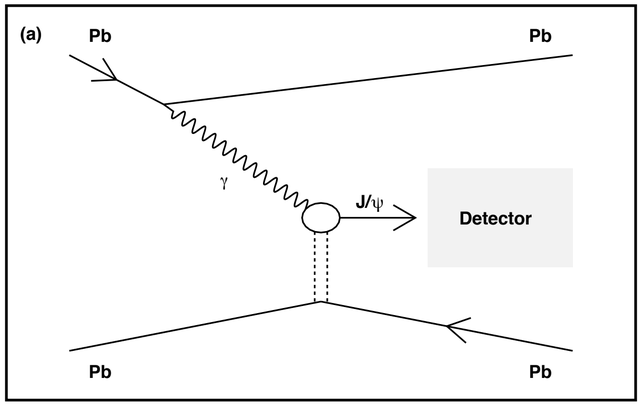
$$\frac{d\sigma_{\mathrm{PbPb}}}{dy} = n_\gamma(y; b_{1,2})\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y; b_{1,2})\sigma_{\gamma\mathrm{Pb}}(-y)$$

In general, there are two contributions. Each contribution is the product of:

- the photon flux and
- the photon-target cross section.

The cross section





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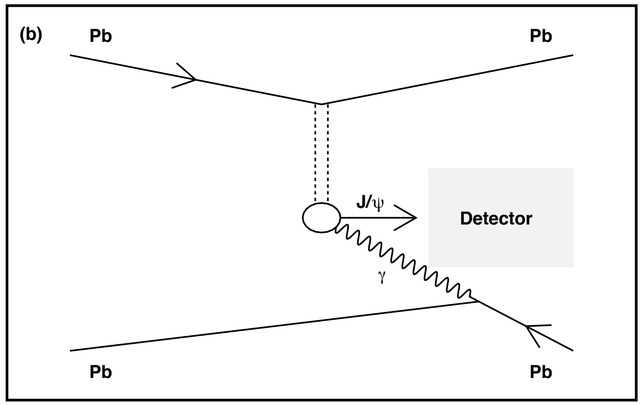

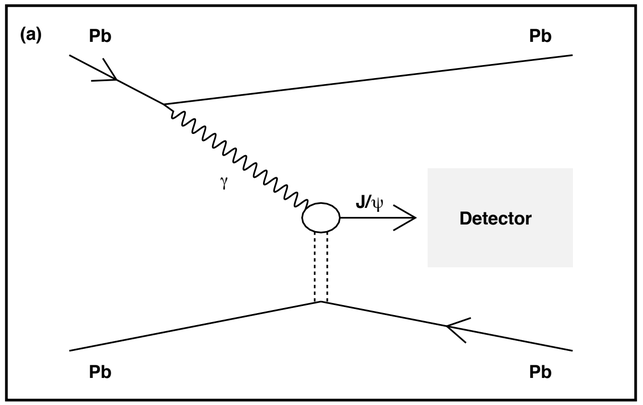

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This is what we measure

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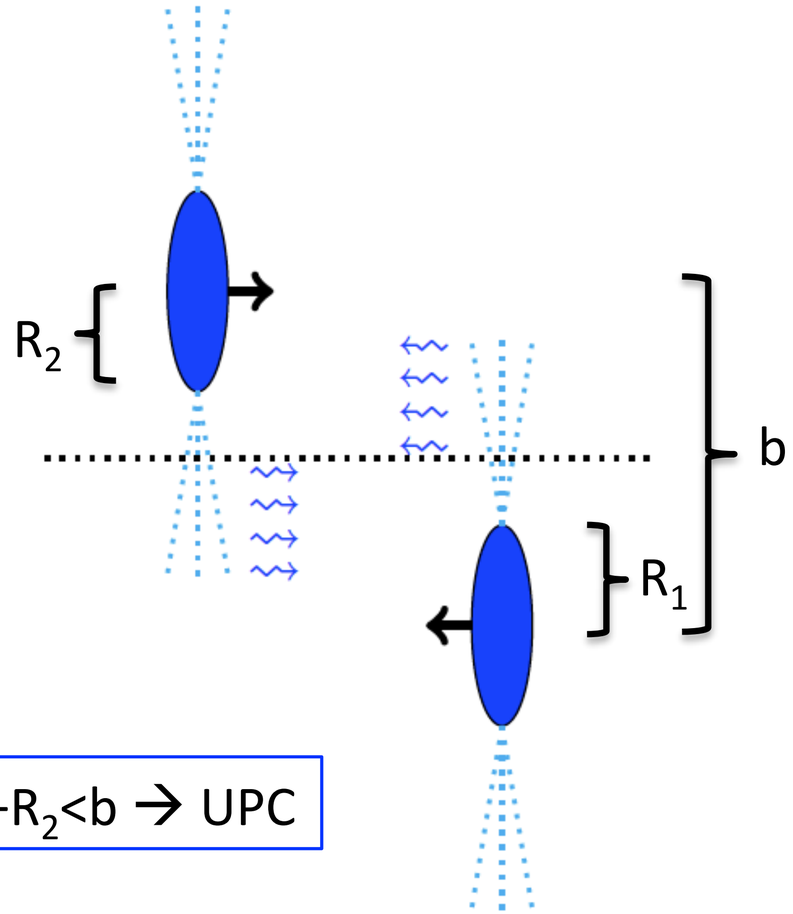
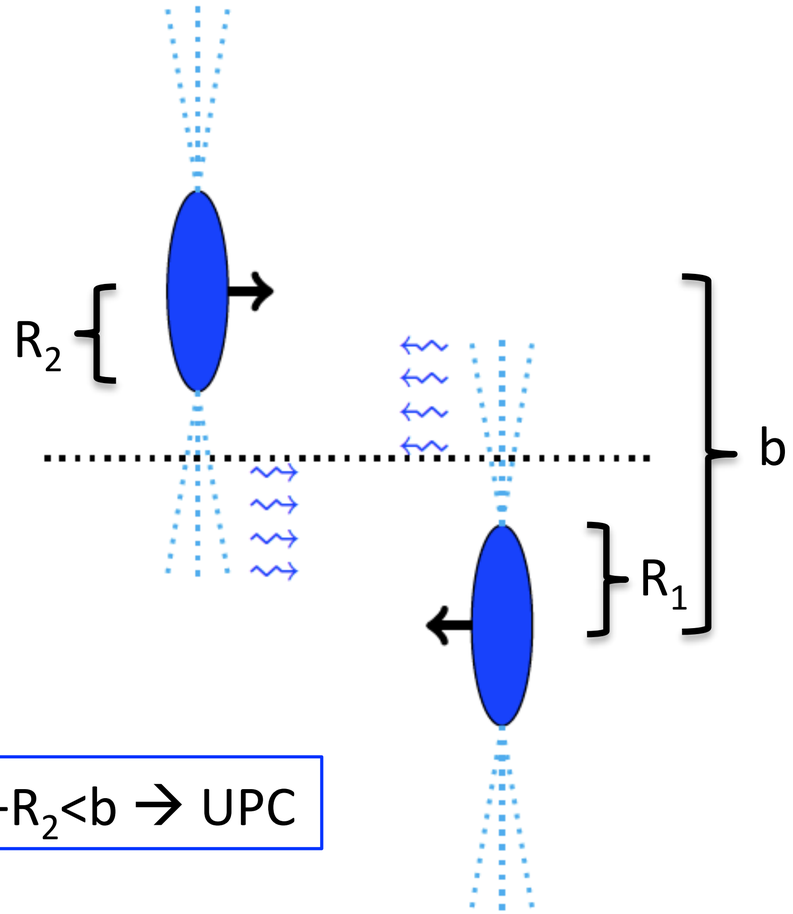
Ultra-peripheral collisions and photoproduction



- QCD is a short-range interaction.
- Interactions at an impact parameter (b) larger than the sum of radii of the incoming particles, are called **ultra-peripheral collisions** (UPC) and must involve at least one photon.

Ultra-peripheral collisions and photoproduction



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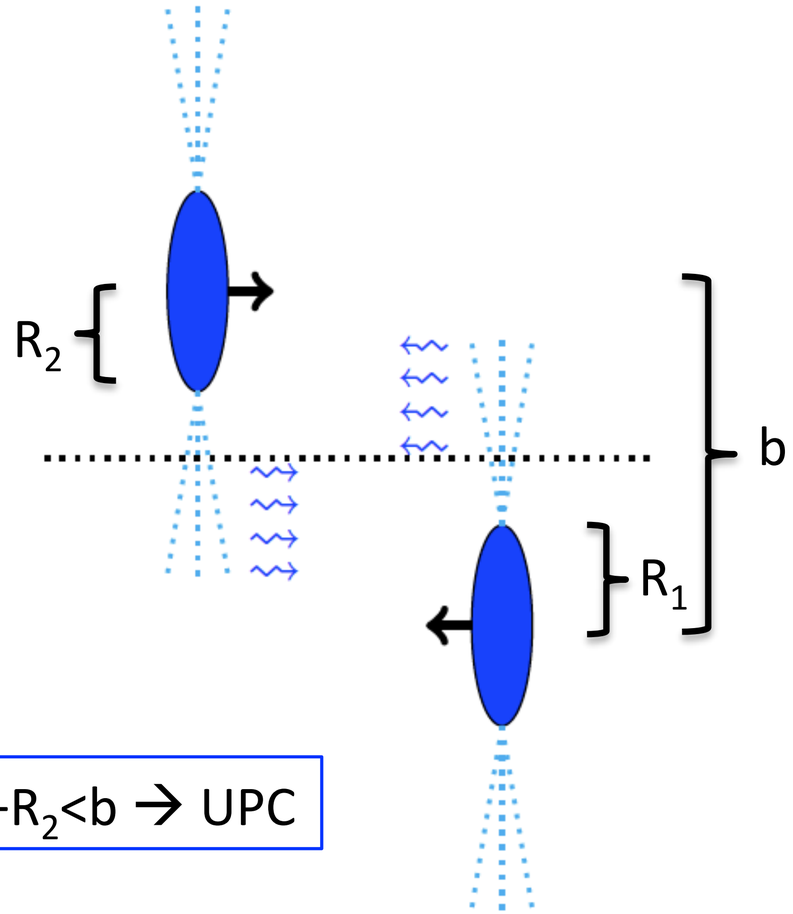

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- ALICE is very efficient to measure these neutrons.

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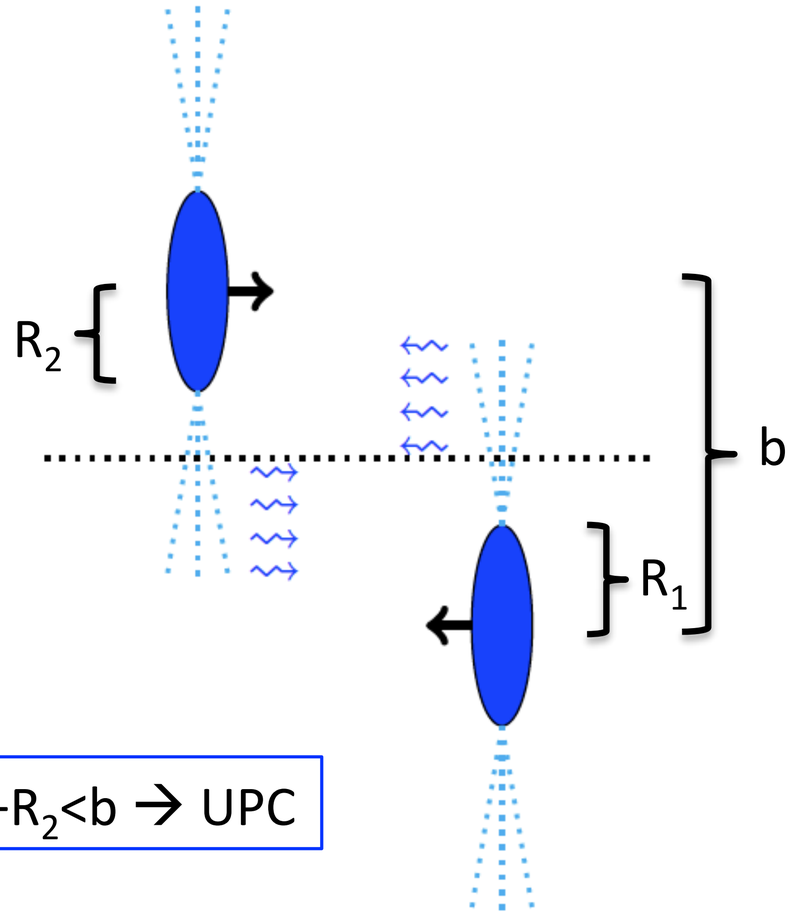

$R_1+R_2<b \rightarrow$ UPC

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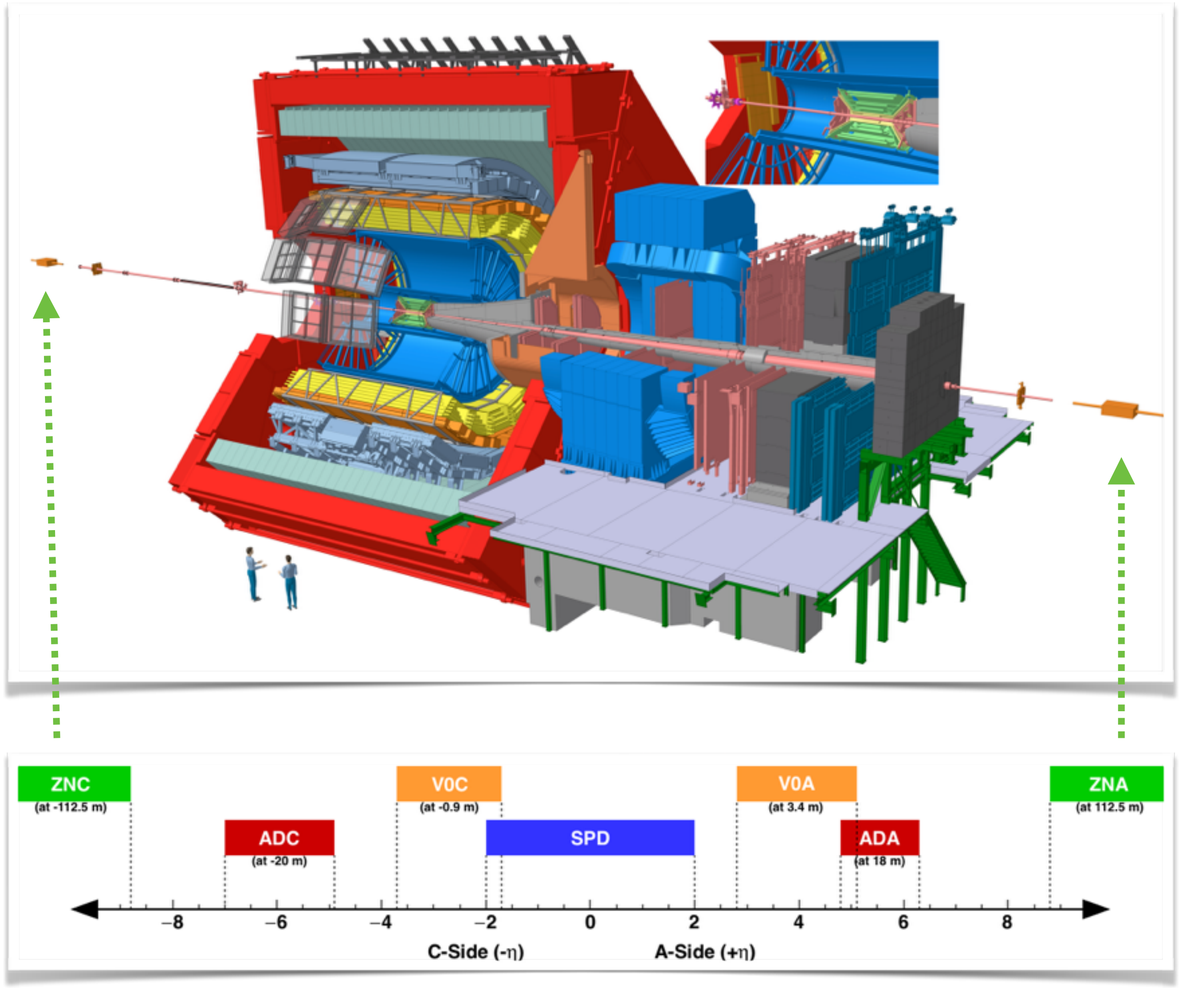
Search for events with a low-p_T J/ψ, large rapidity gaps and none (few) forward neutron(s)

ALICE

ALICE strategy for UPC and photoproduction



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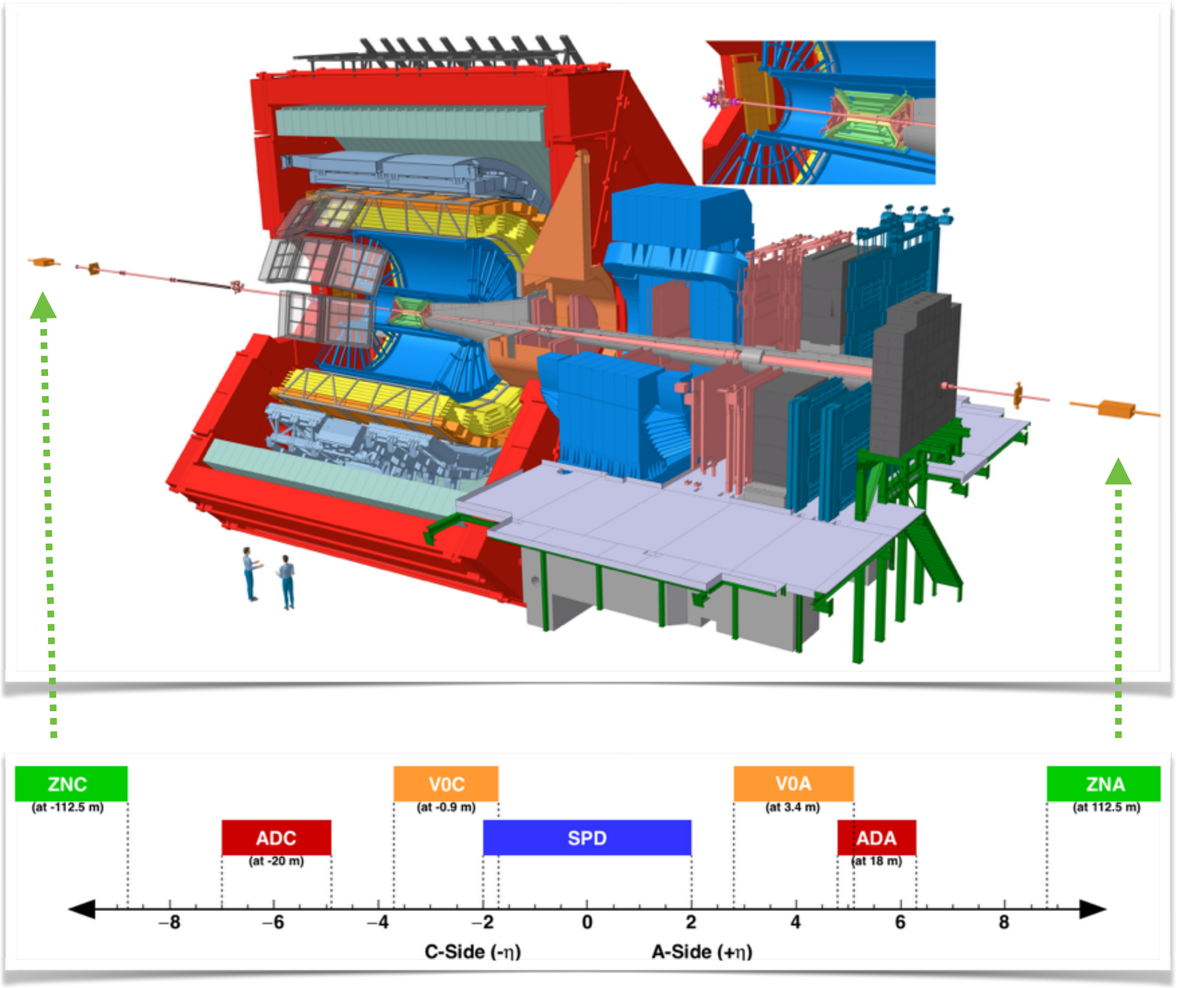

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- Measure the J/ψ via its leptonic decay:
  - e+e-, μ+μ- in the central detector, and
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  (see next page)

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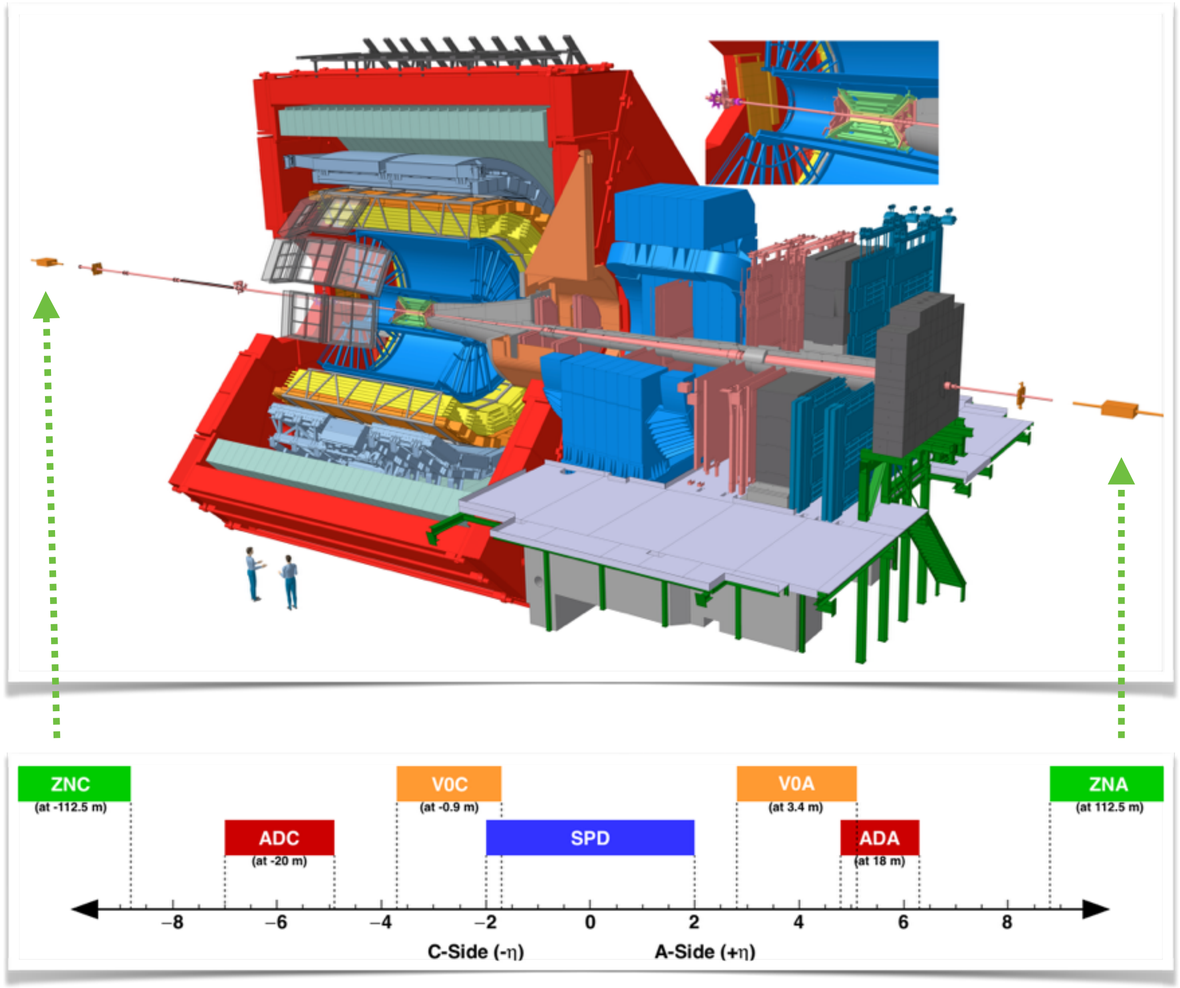

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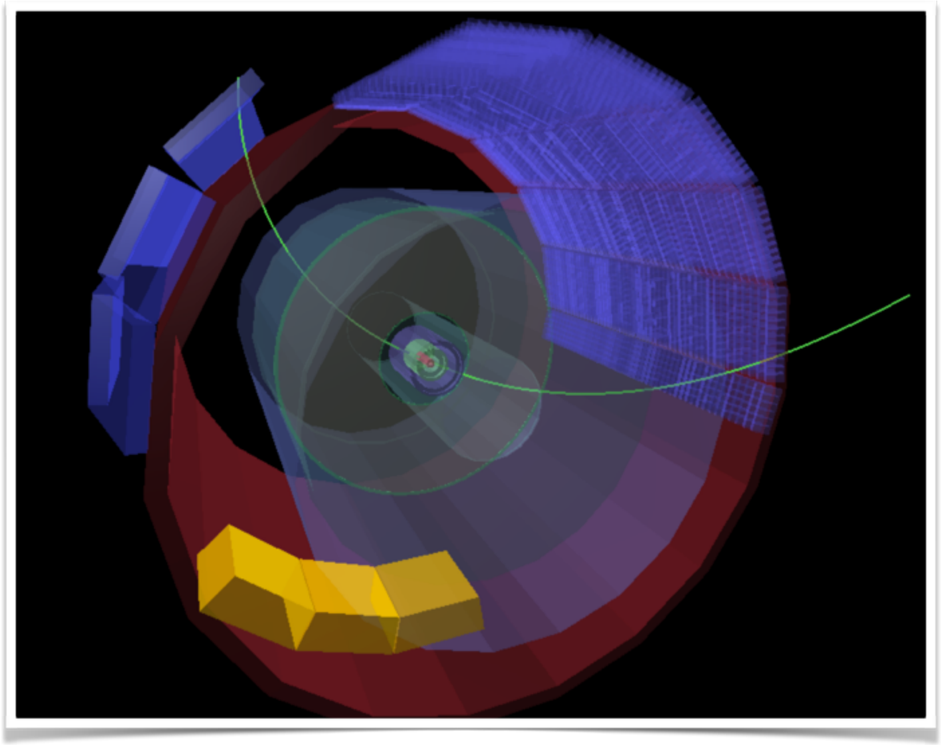
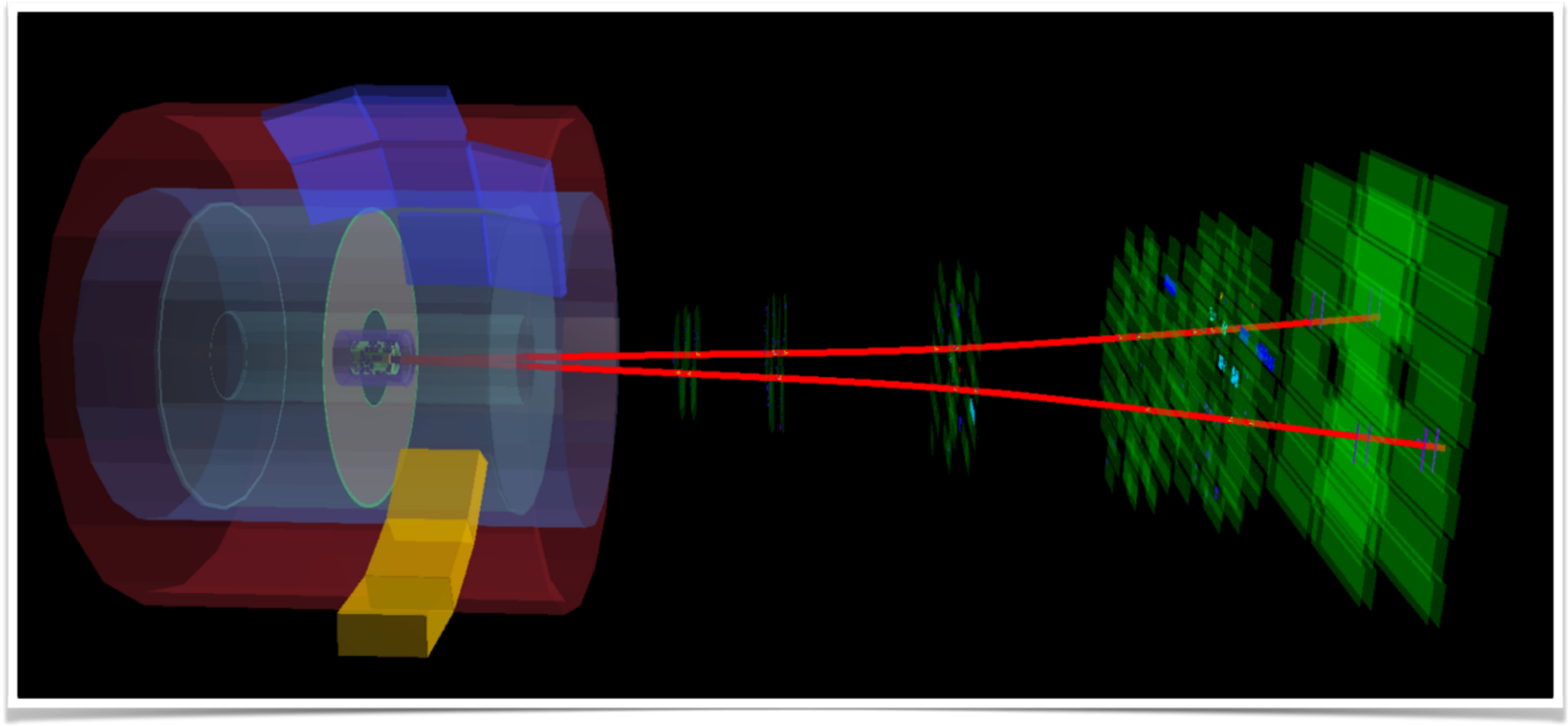
- Make sure there is nothing else in the detector, taking advantage of
  - the low pile-up conditions in ALICE,
  - the large rapidity coverage,
  - the low material budget, and
  - the low detector thresholds used in ALICE.

Photonucleear production of J/ψ in UPC as seen by ALICE

J/ψ measured in the Central Barrel



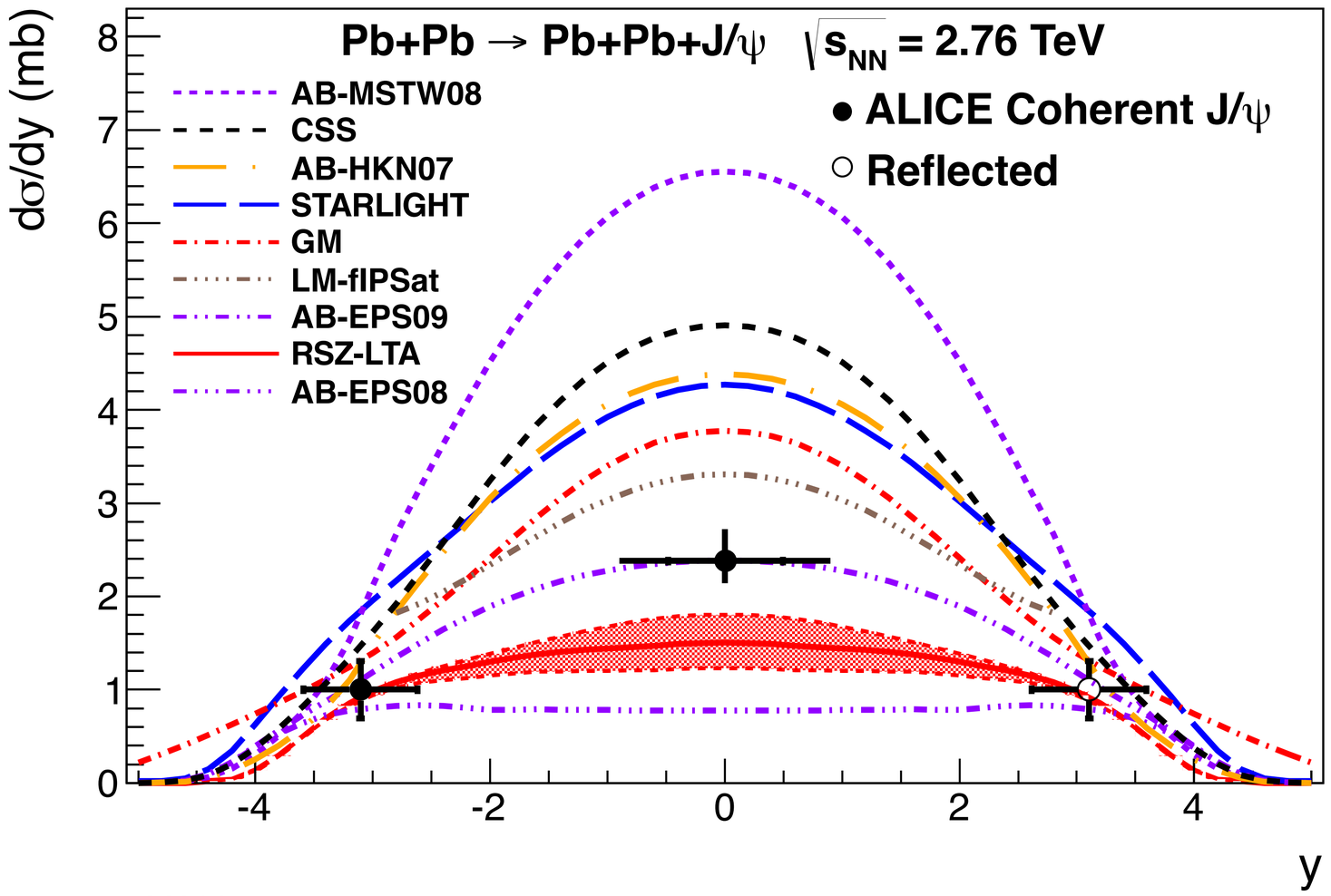


J/ψ measured with the forward muon spectrometer

ALICE results on coherent photoproduction from Run 1

Coherent photoproduction in UPC @ 2.76 TeV

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



- Models based on collinear approach with different amount of shadowing (AB), fit to HERA data (Starlight), kt-factorisation (CSS), colour dipole model with saturation (GM, LM) and leading twist approximation (RSZ).

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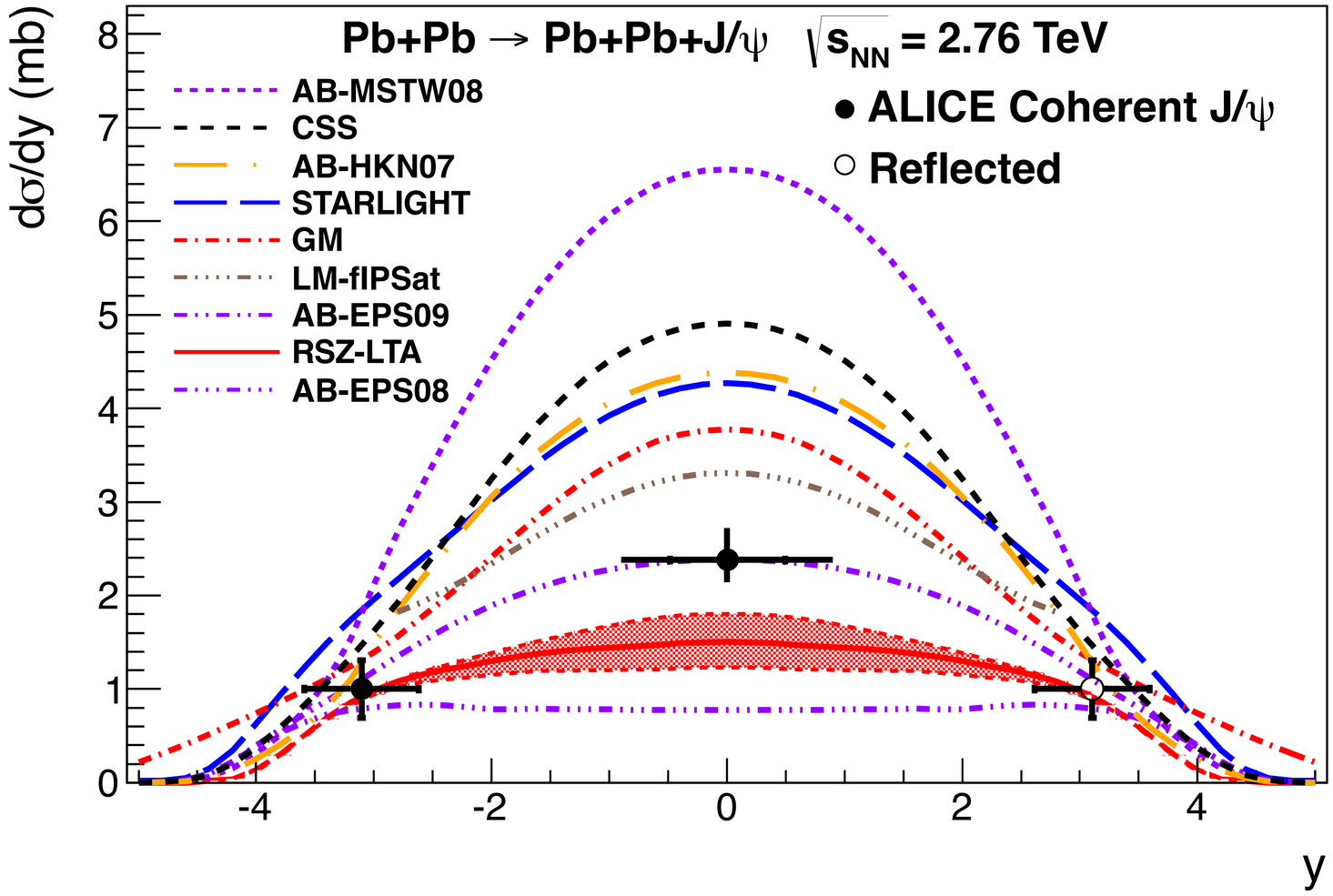

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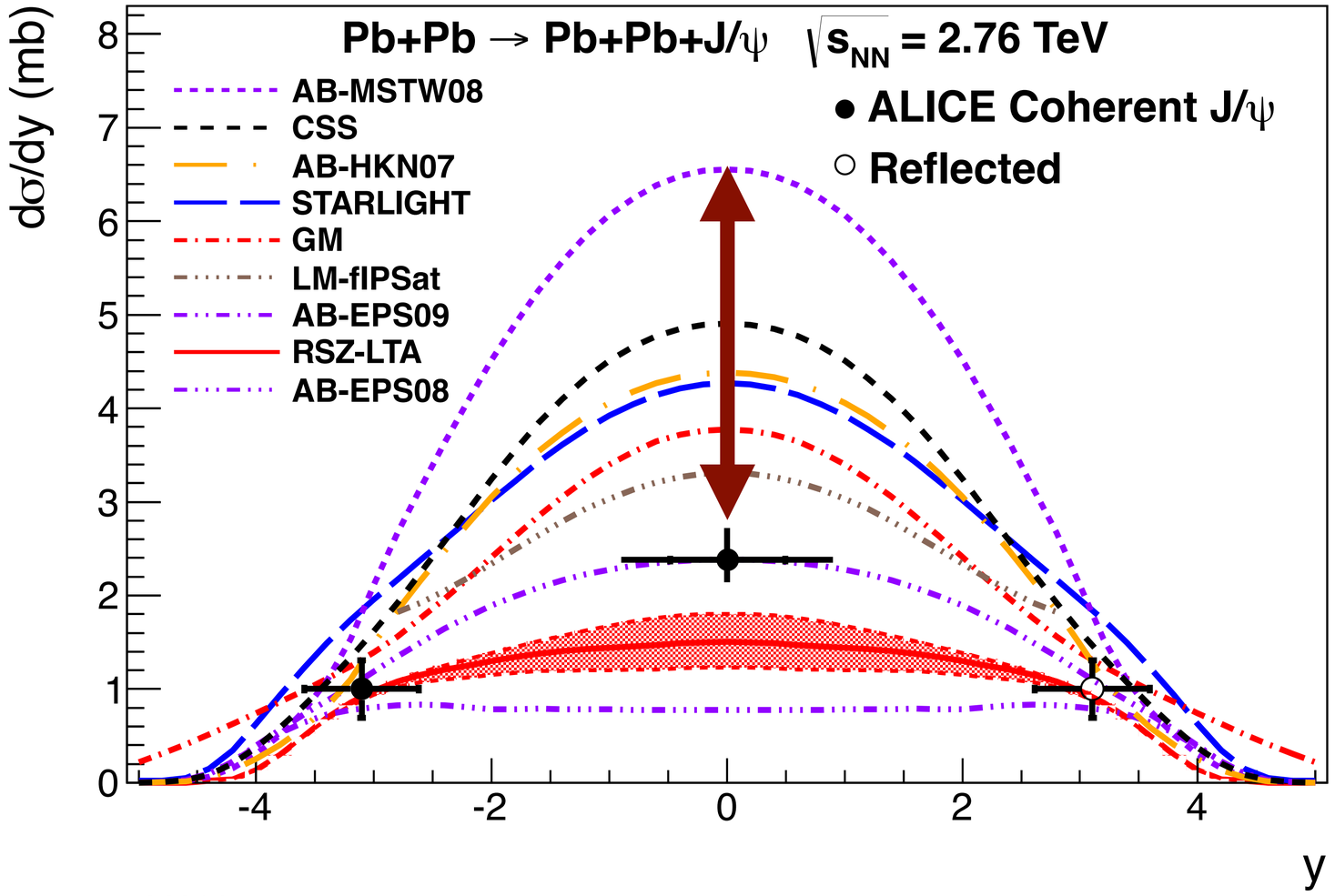

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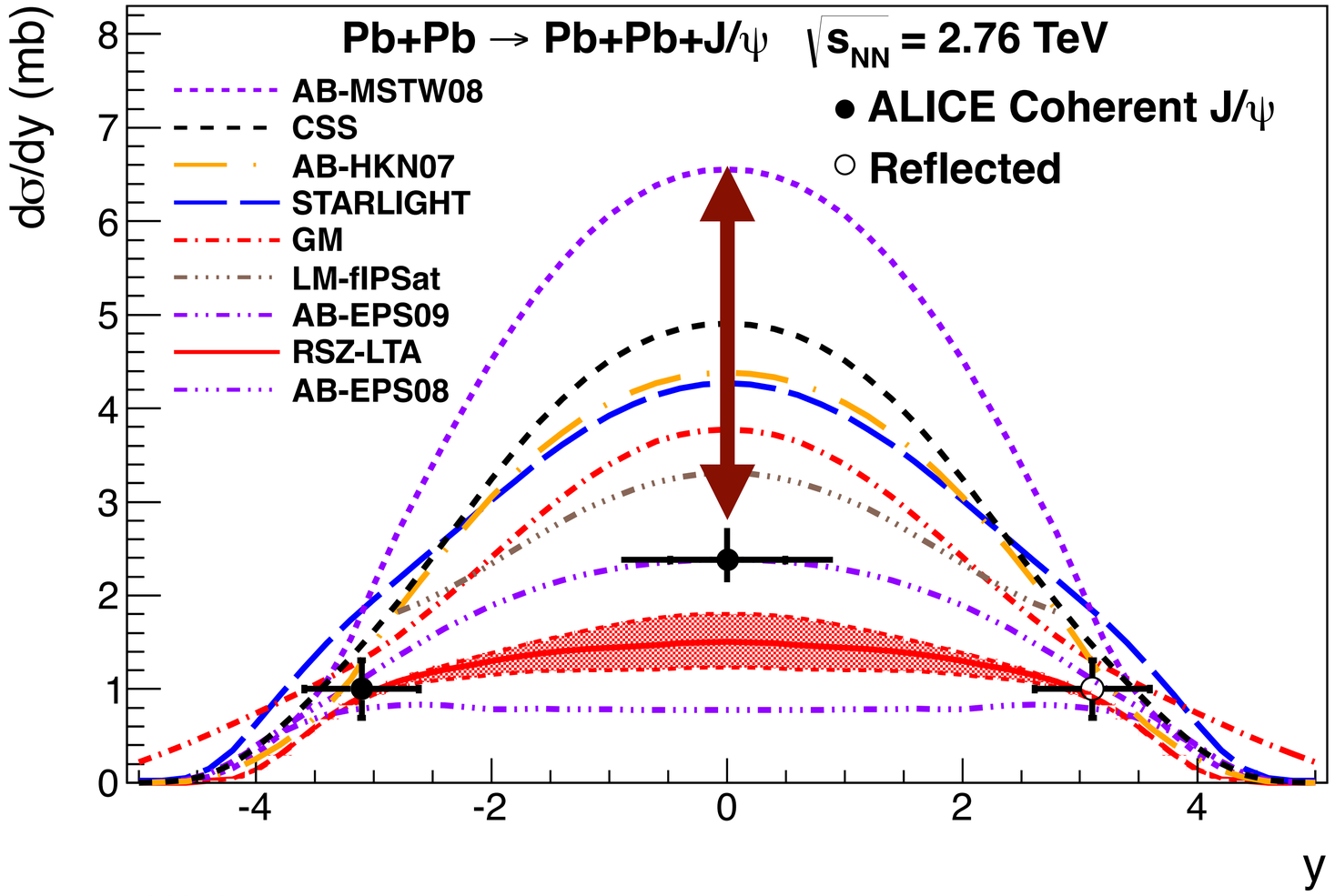

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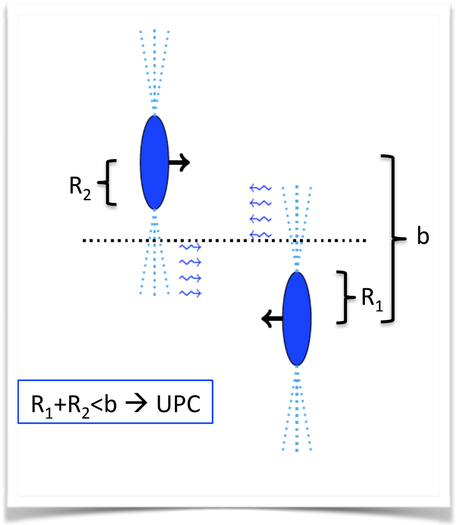
Direct evidence of moderate nuclear shadowing!

Coherent photoproduction in peripheral collisions @ 2.76 TeV



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- The EM fields will still be there ….
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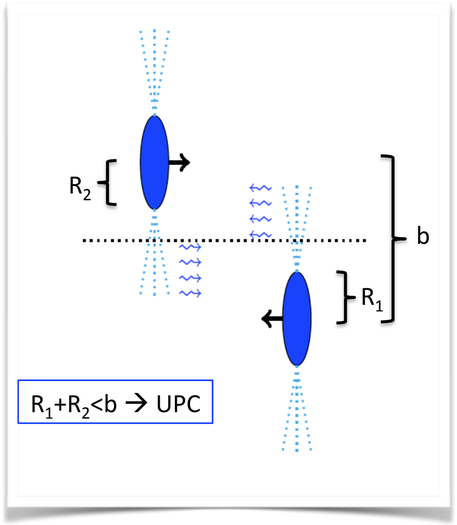

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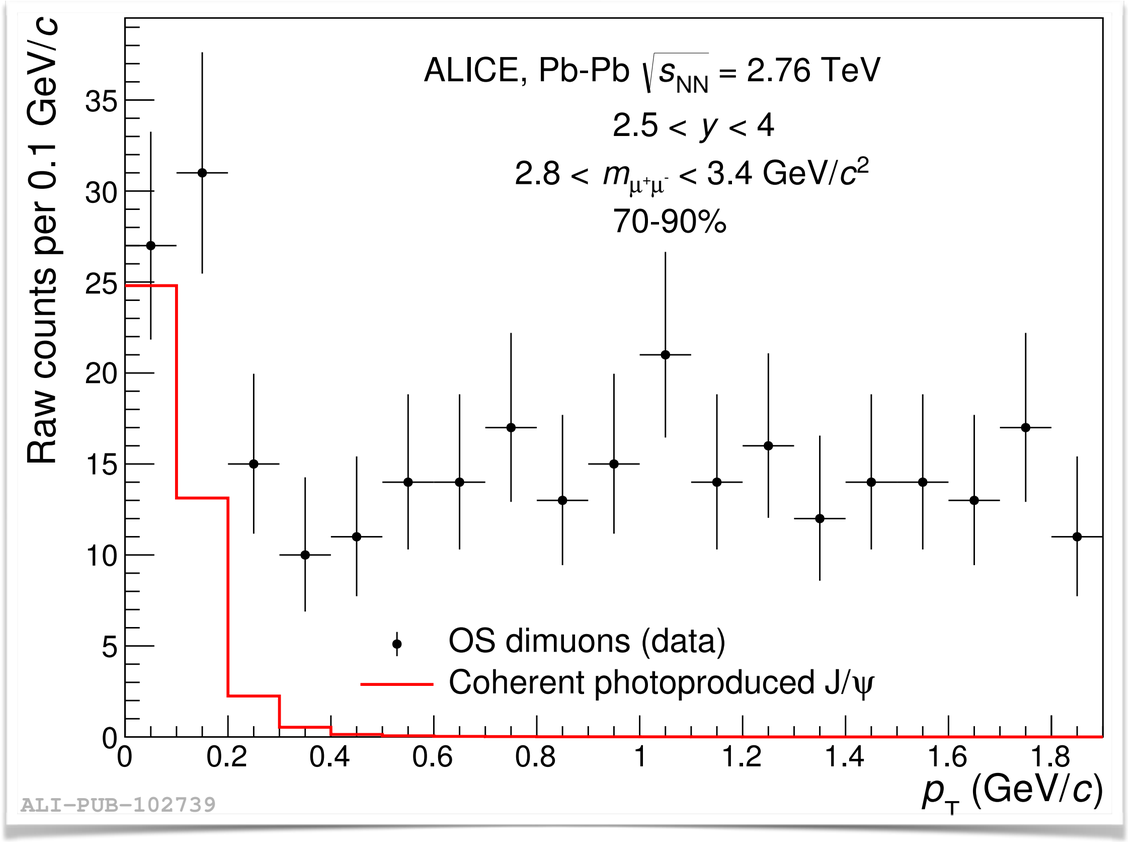

ALICE: Phys.Rev.Lett. 116 (2016) 222301

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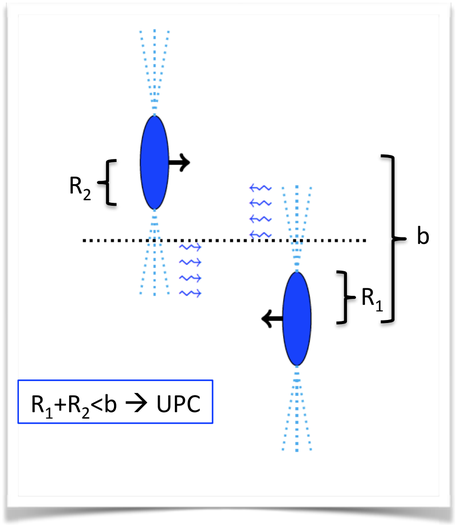
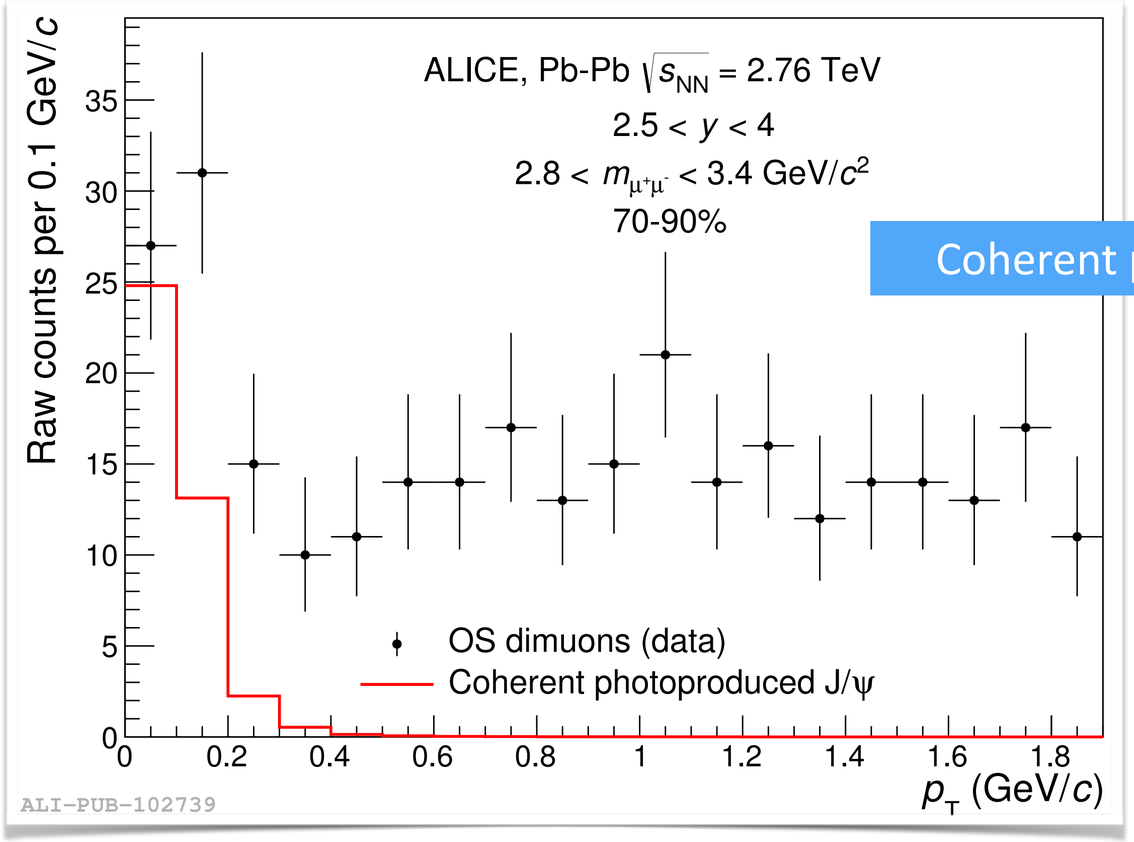


- What happens if **b** is slightly smaller than R_1+R_2?
- The EM fields will still be there ….
- … the incoming nuclei will break …



Coherent photoproduction in **peripheral** collisions!

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

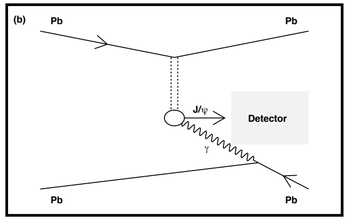
Cent. (%)	$d\sigma^{coh}_{J/\psi}/dy$ (μb)
0–10	< 318
10–30	< 290
30–50	$73 \pm 44^{+26}_{-27} \pm 10$
50–70	$58 \pm 16^{+8}_{-10} \pm 8$
70–90	$59 \pm 11^{+7}_{-10} \pm 8$

Accessing σ(γPb) at small x

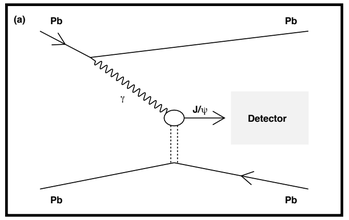
Measured cross section from Pb-Pb collisions

Photon flux at rapidity ±y in the impact parameter range (b1,b2)

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



Photonuclear cross section: QCD!



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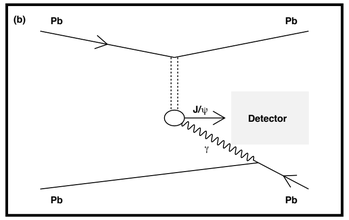

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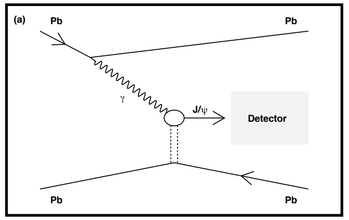
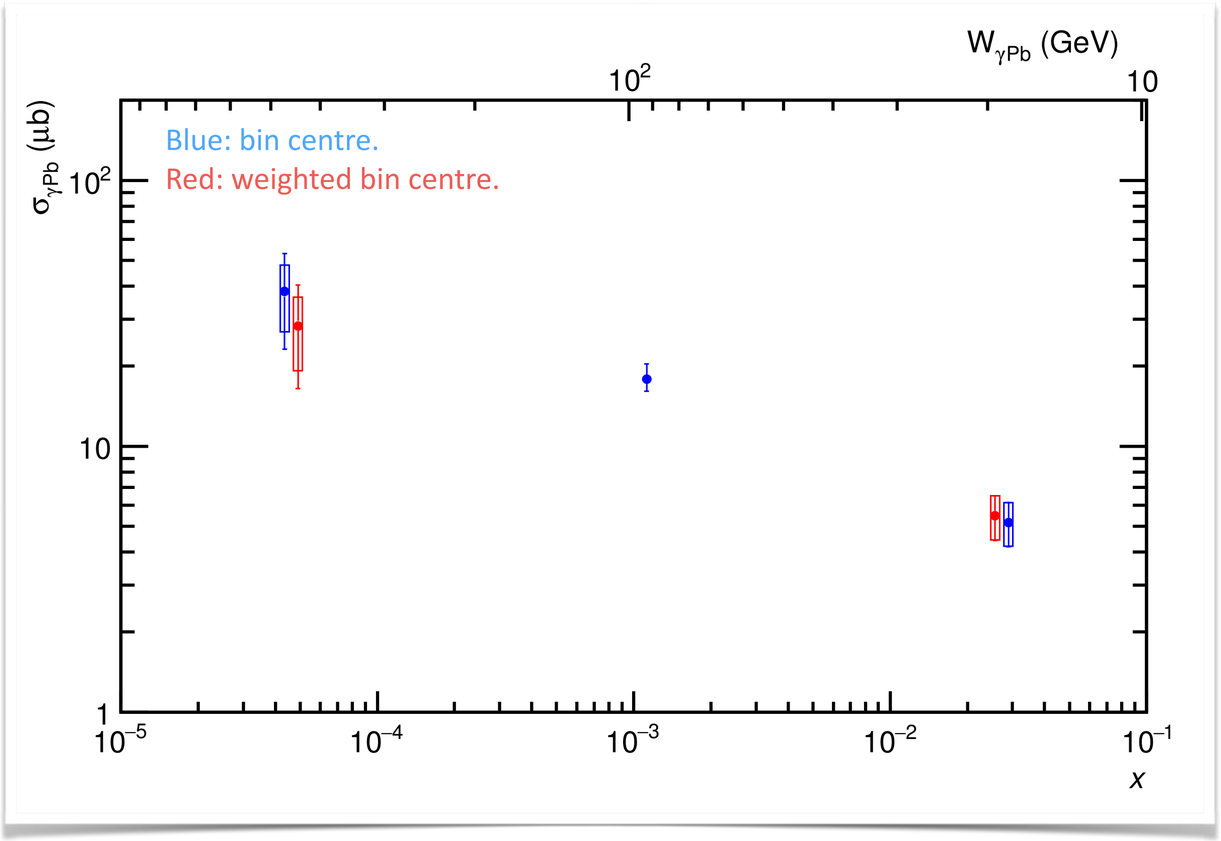


Use coherent J/ψ photoproduction measurements at same rapidity and different impact parameter range!

Impact parameter ranges:
70-90% (13 fm,15 fm).
UPC: (R_1+R_2,∞)

Photonuclear cross section extracted from ALICE data

Photonuclear cross section



JGC, Phys.Rev. C96 (2017) no.1, 015203

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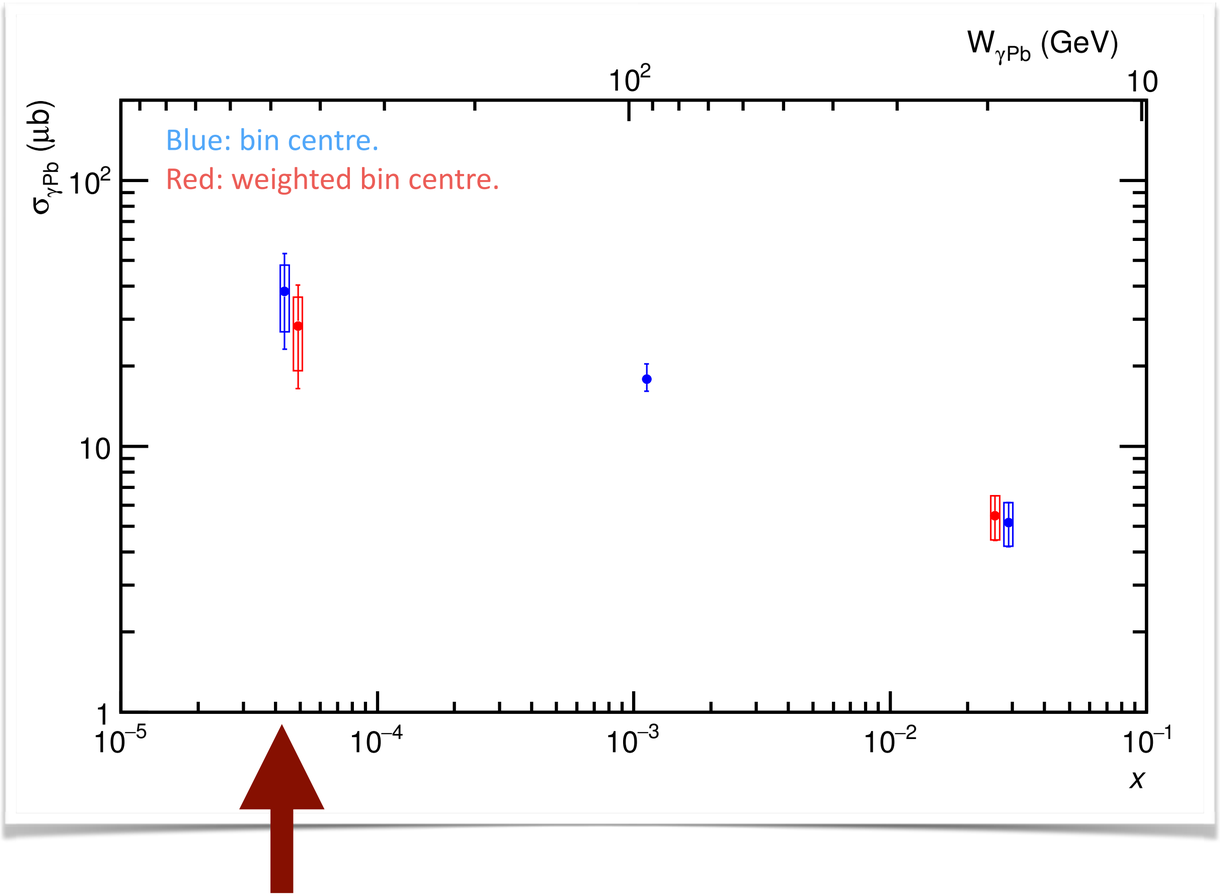

x down to 4×10^{-5} !

JGC, Phys.Rev. C96 (2017) no.1, 015203

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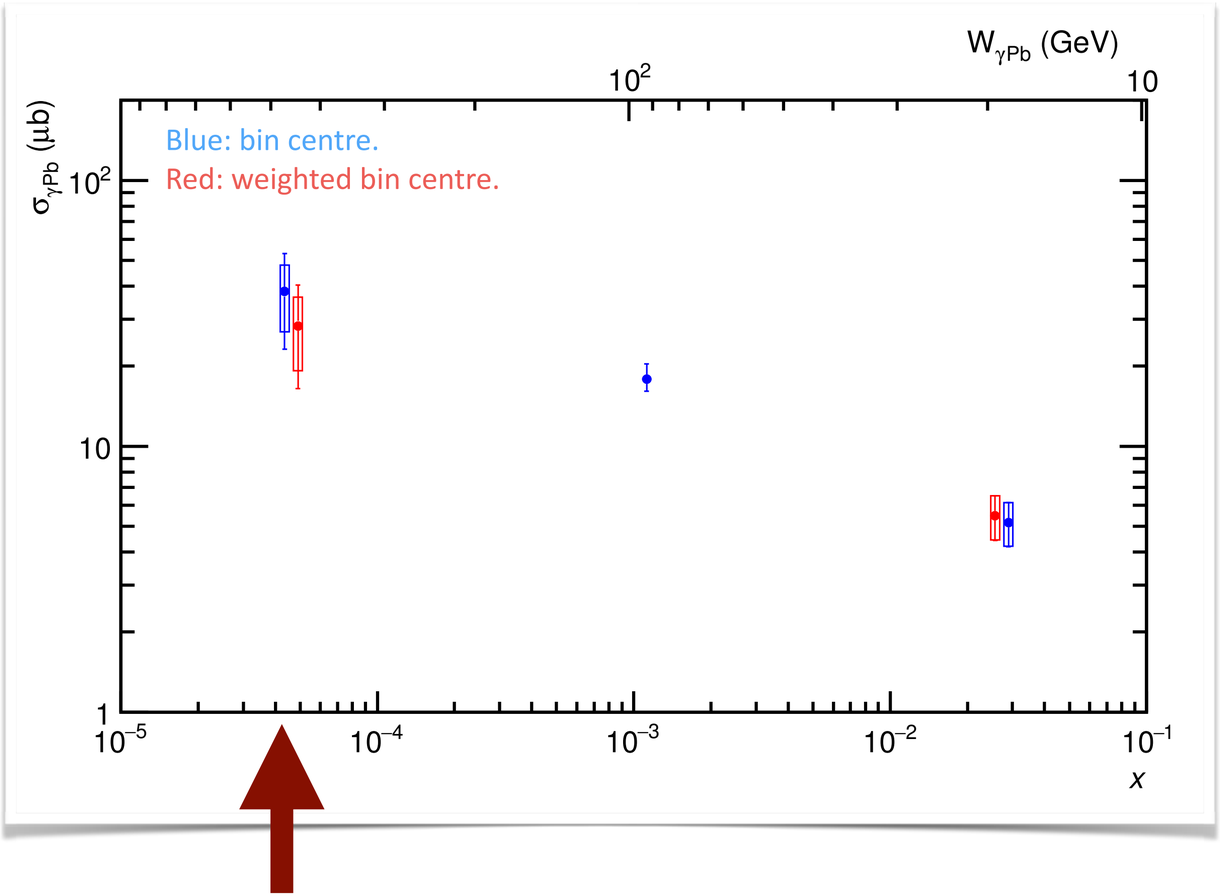

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Nuclear suppression factor

Impulse approximation

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

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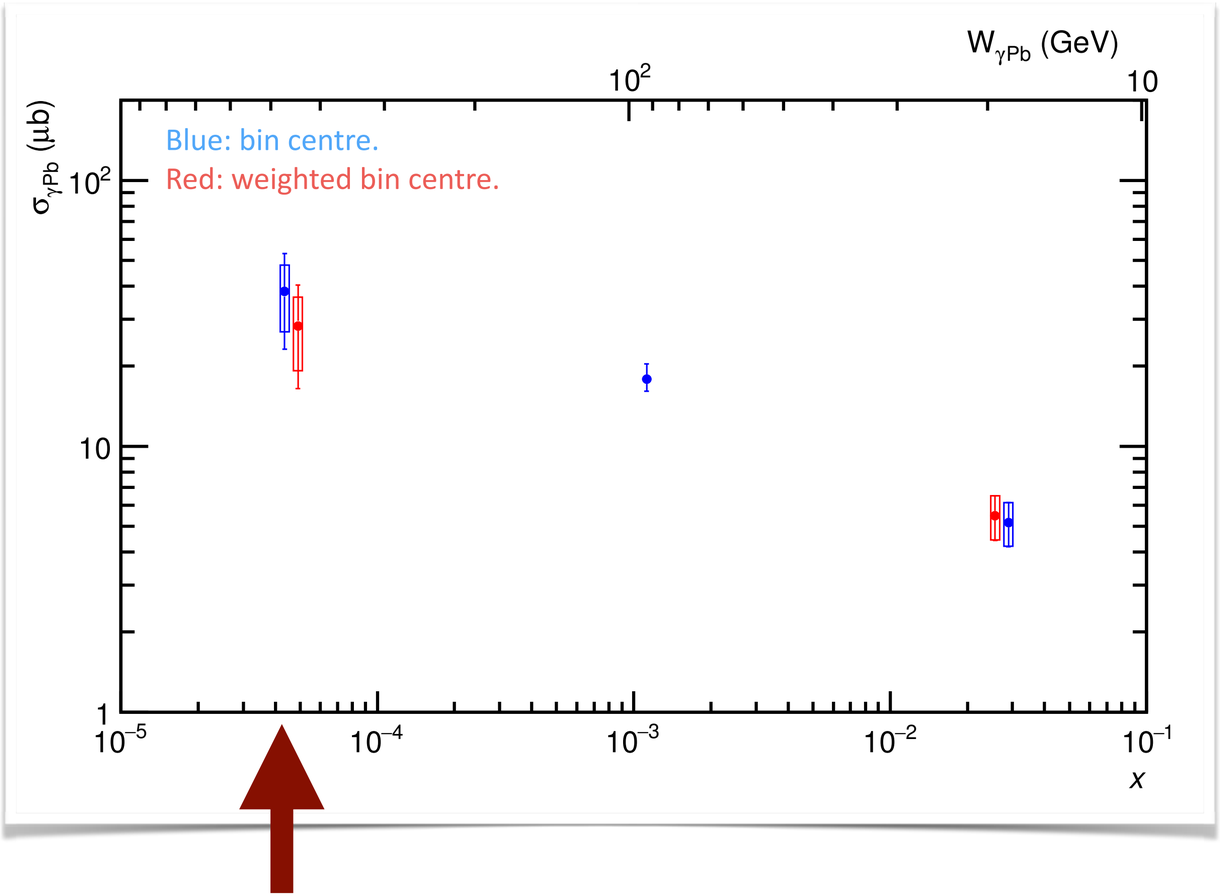

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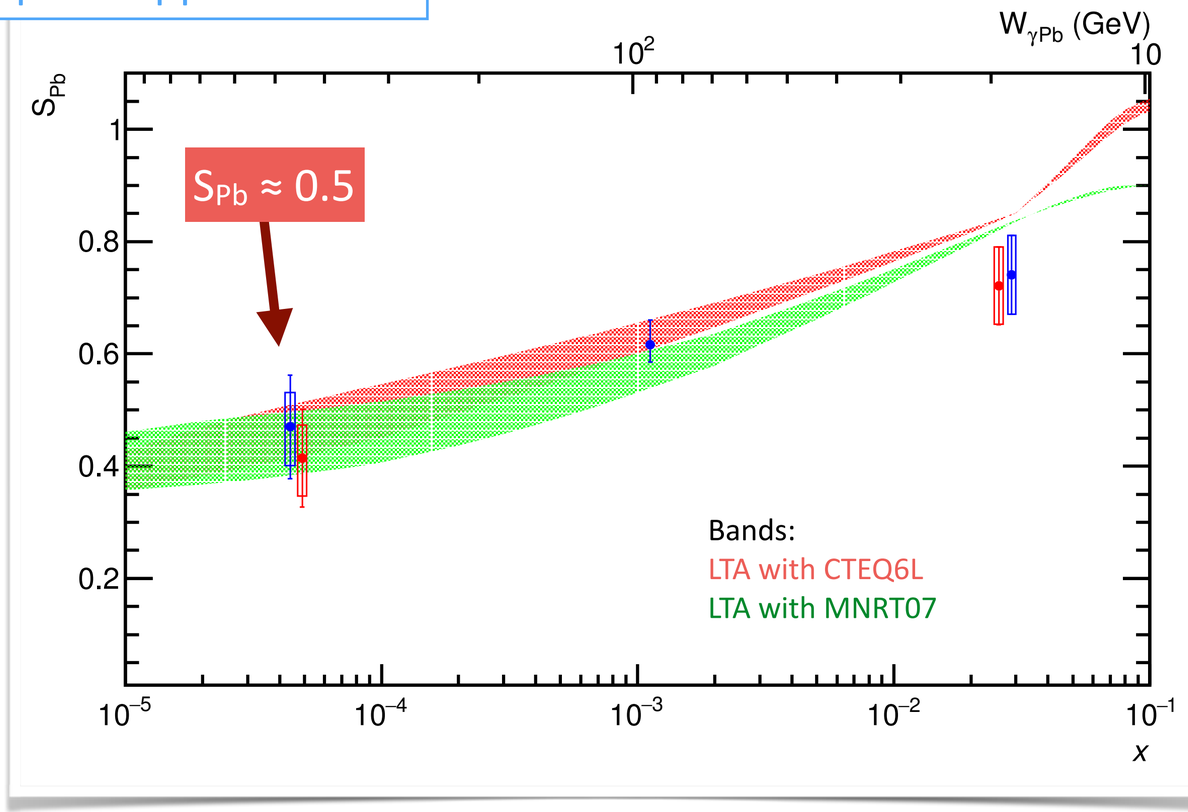
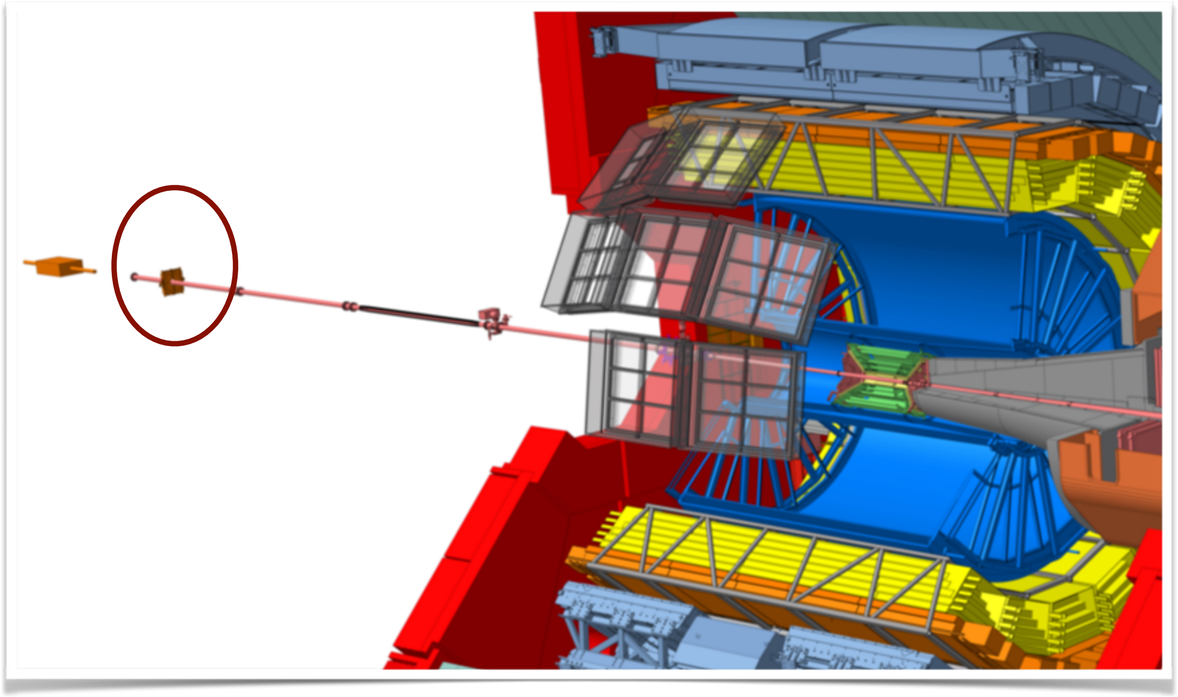
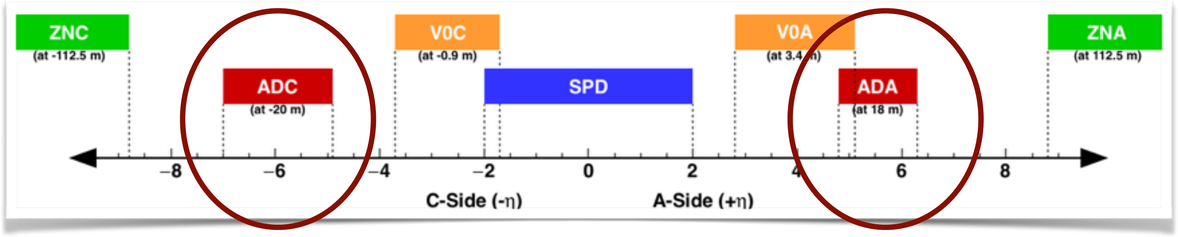


JGC, Phys.Rev. C96 (2017) no.1, 015203

ALICE news on coherent photoproduction from Run 2

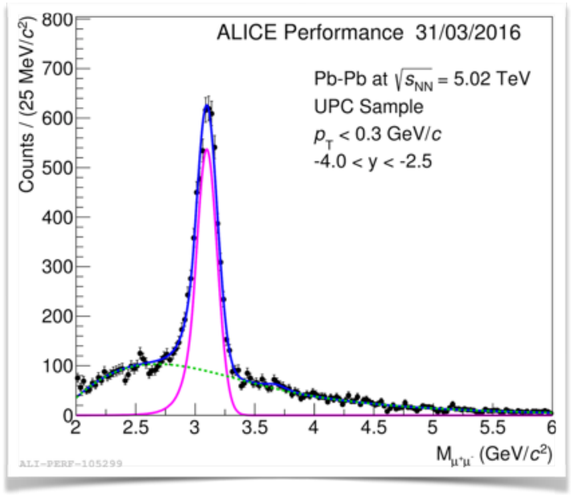
Run 2 addition: AD detector





- In Run2 ALICE added new detectors, the ALICE Diffractive (AD) detectors
  - Placed at both sides of the nominal interaction point and covering large rapidities.
  - These detectors give ALICE enhanced performance to veto extra activity in the events.

Coherent production in UPC @ 5.02 TeV



- Much more data available for Run 2 analyses, w.r.t. Run 1.
- These data are at a higher Pb-Pb energy, allowing us to reach smaller values of x!

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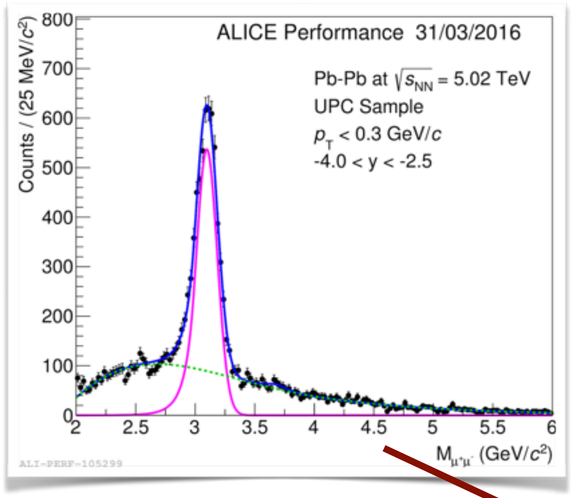

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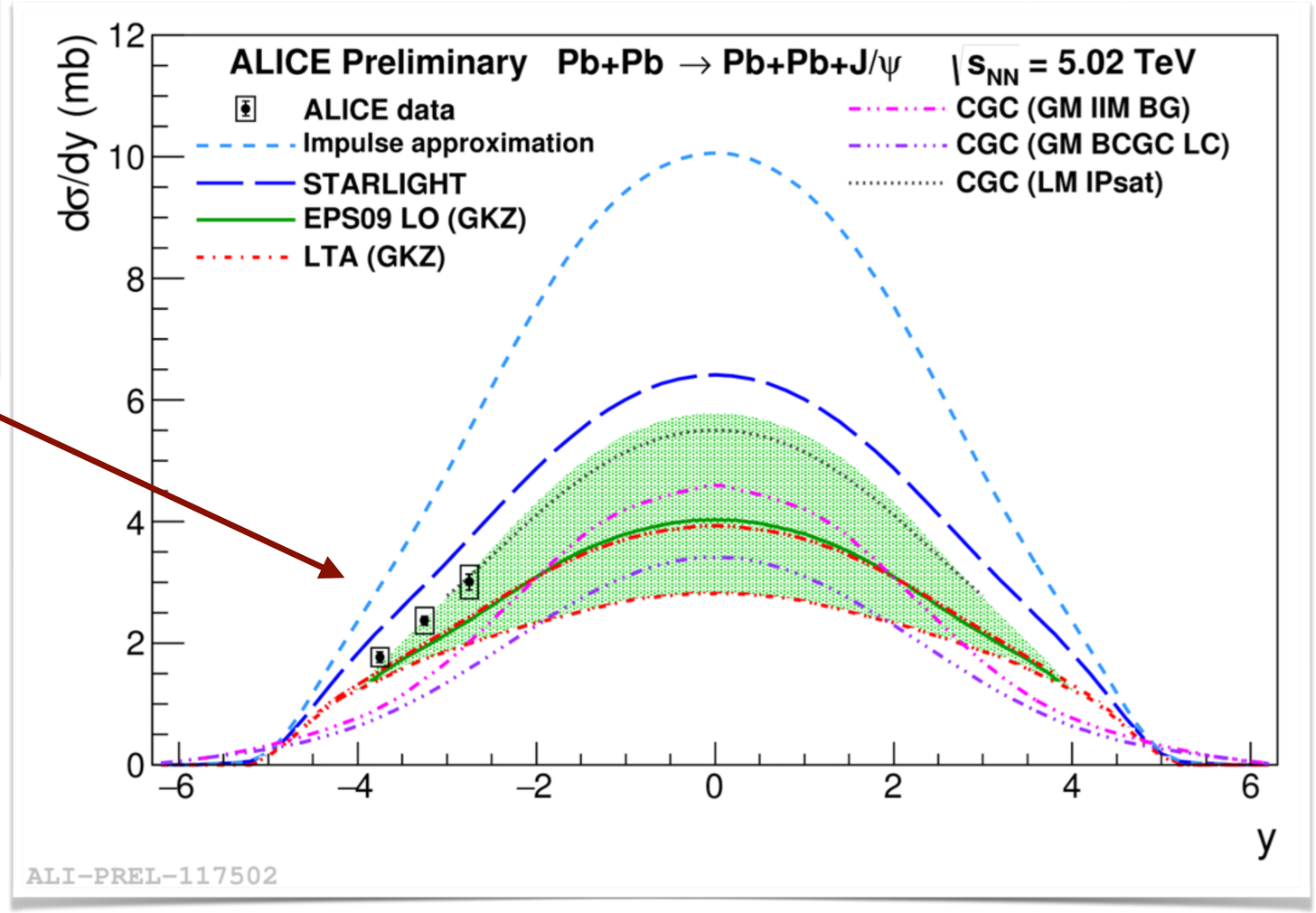

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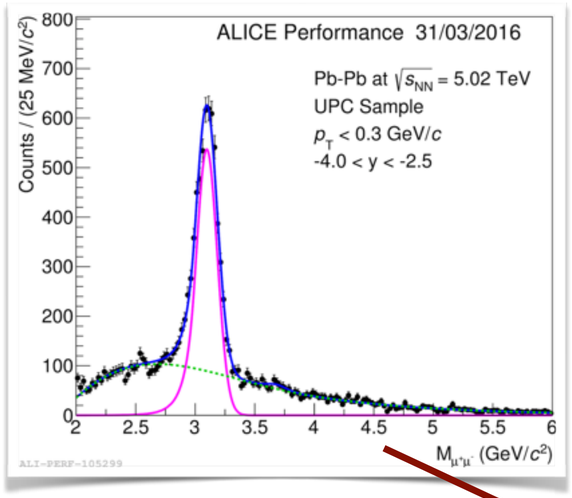

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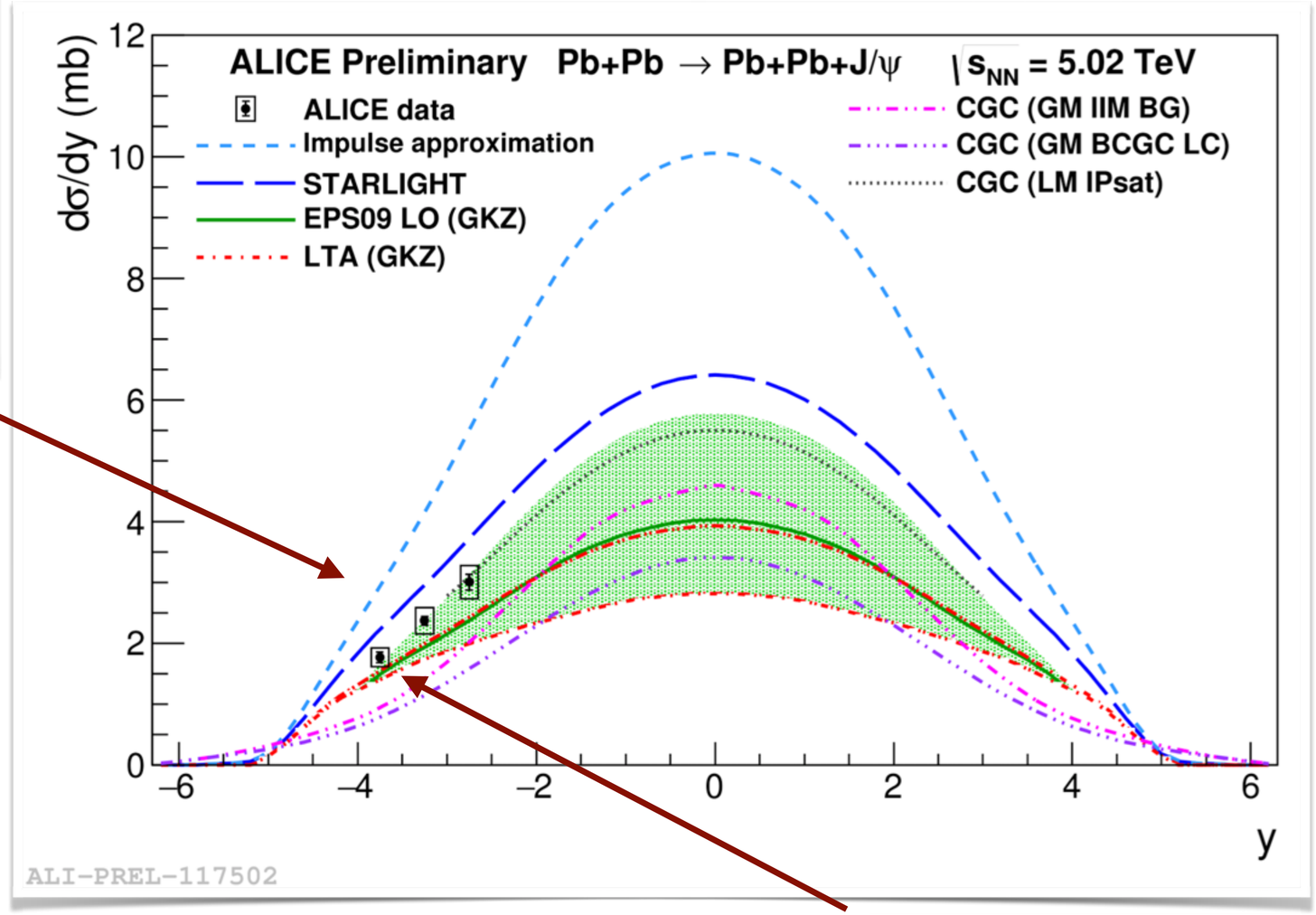

Sensitive to x ≈ 1.5x10^{-5}

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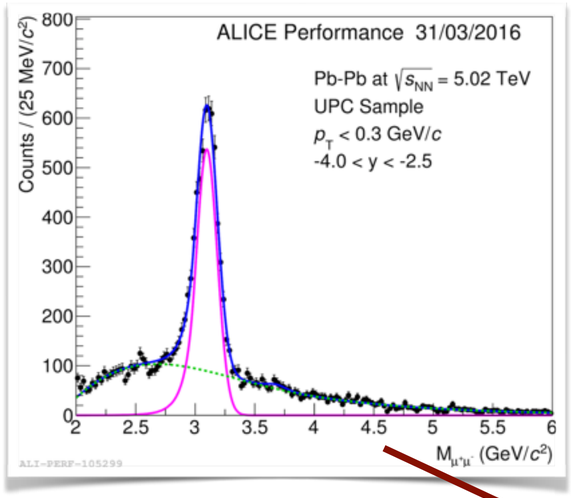

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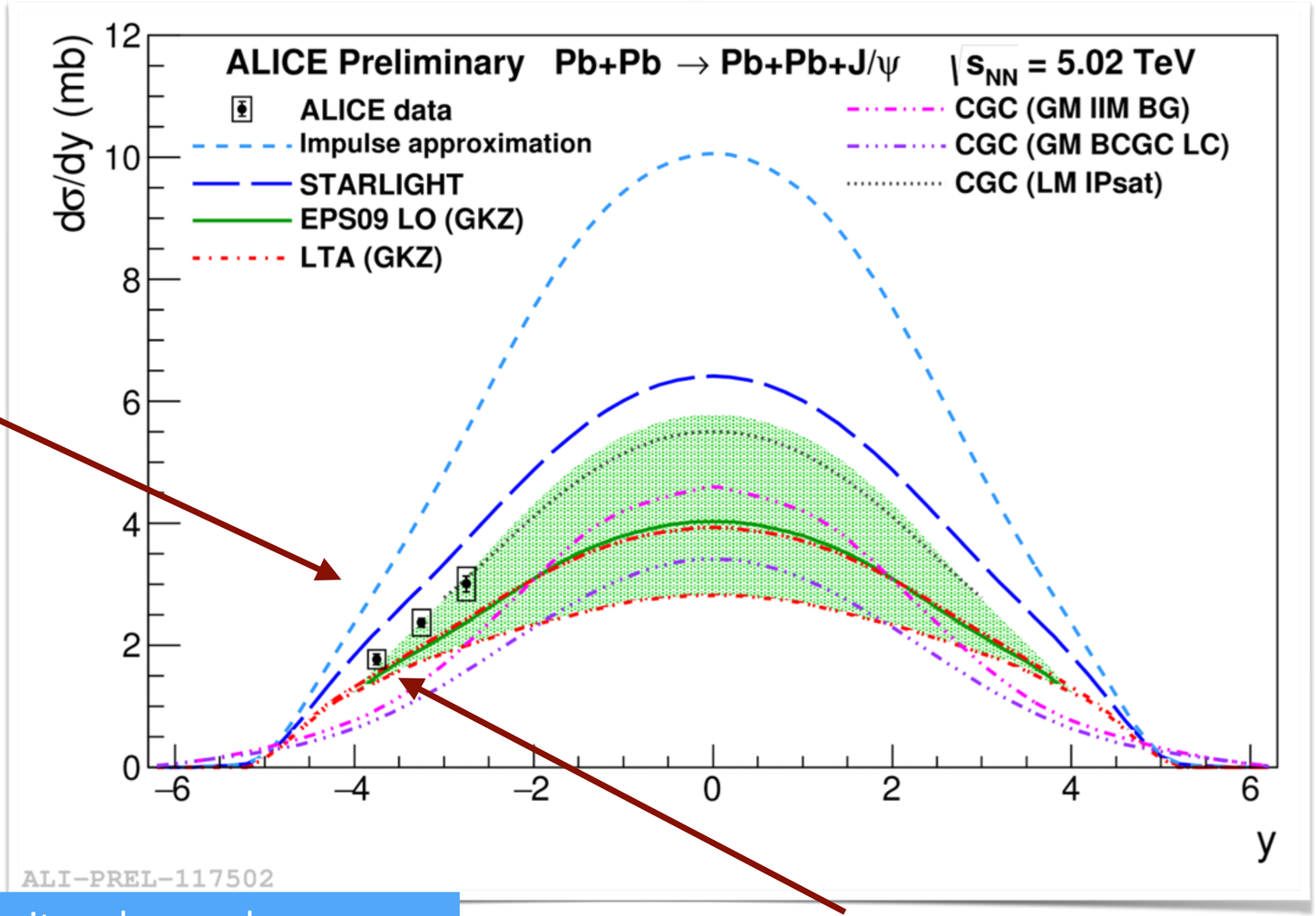

- The analysis is quite advanced.
- It confirms and improves Run 1 results!

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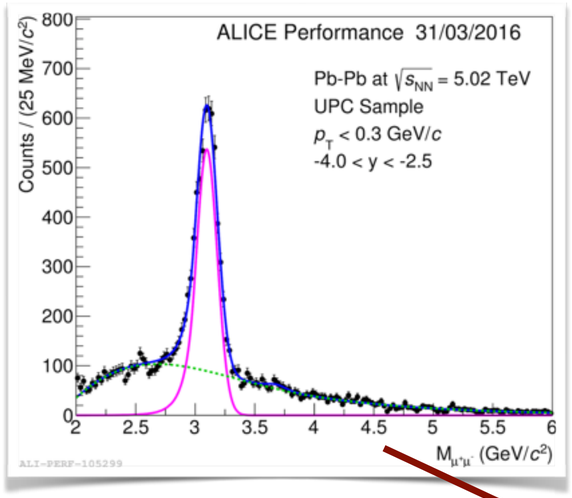

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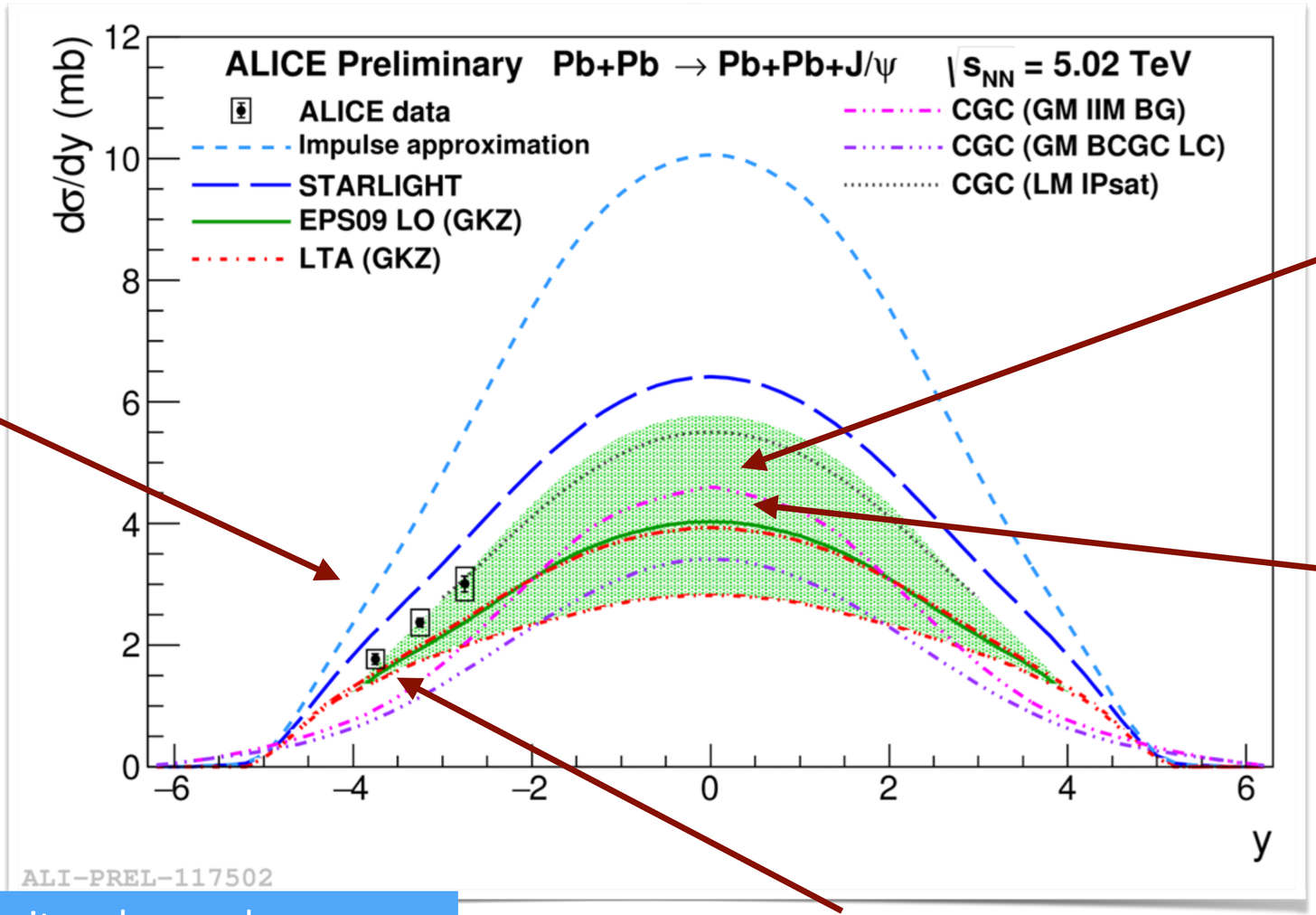
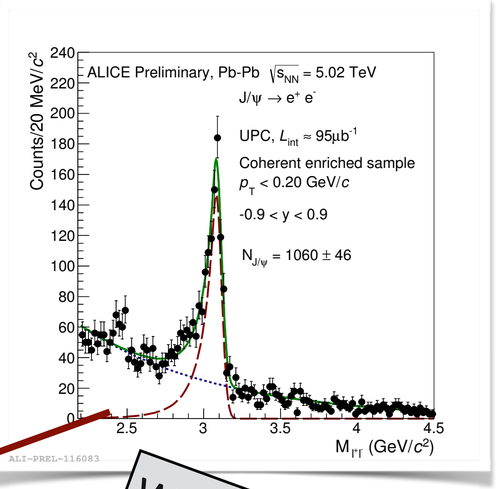
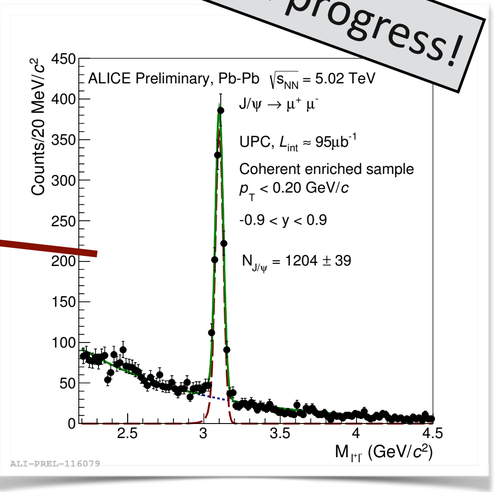




Work in progress!



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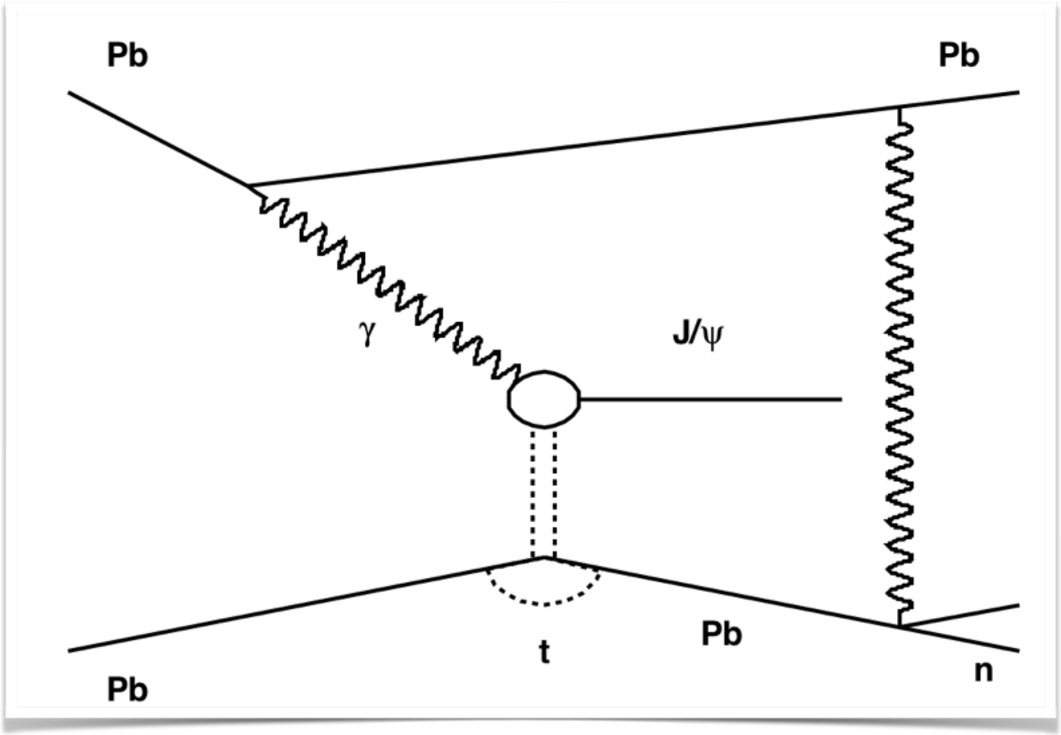
Coming soon: UPC with forward neutrons

Independent soft electromagnetic interactions between the outgoing nuclei excite the nuclei, which upon de-excitation **emit neutrons** in the forward direction



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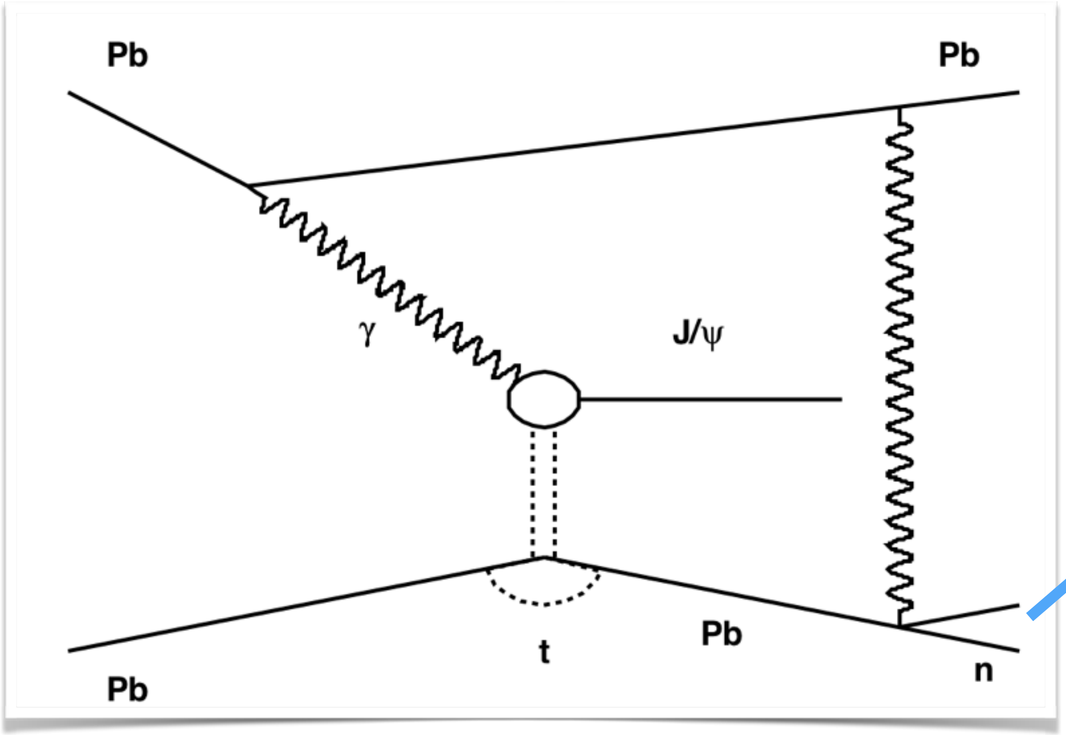

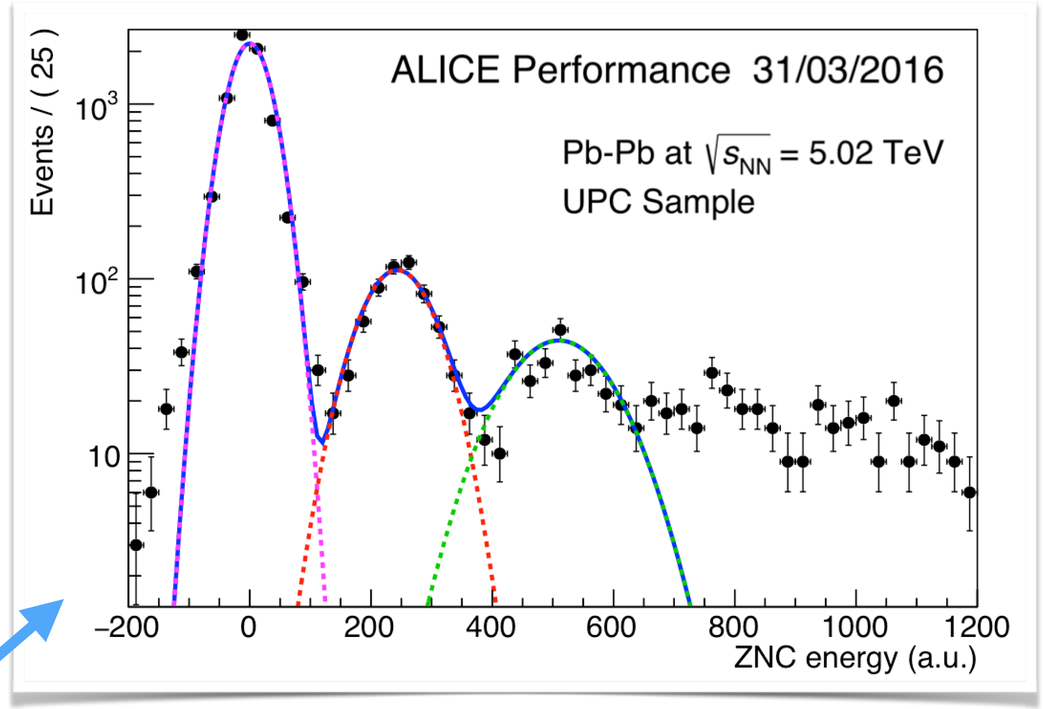

ALICE can measure these neutrons!

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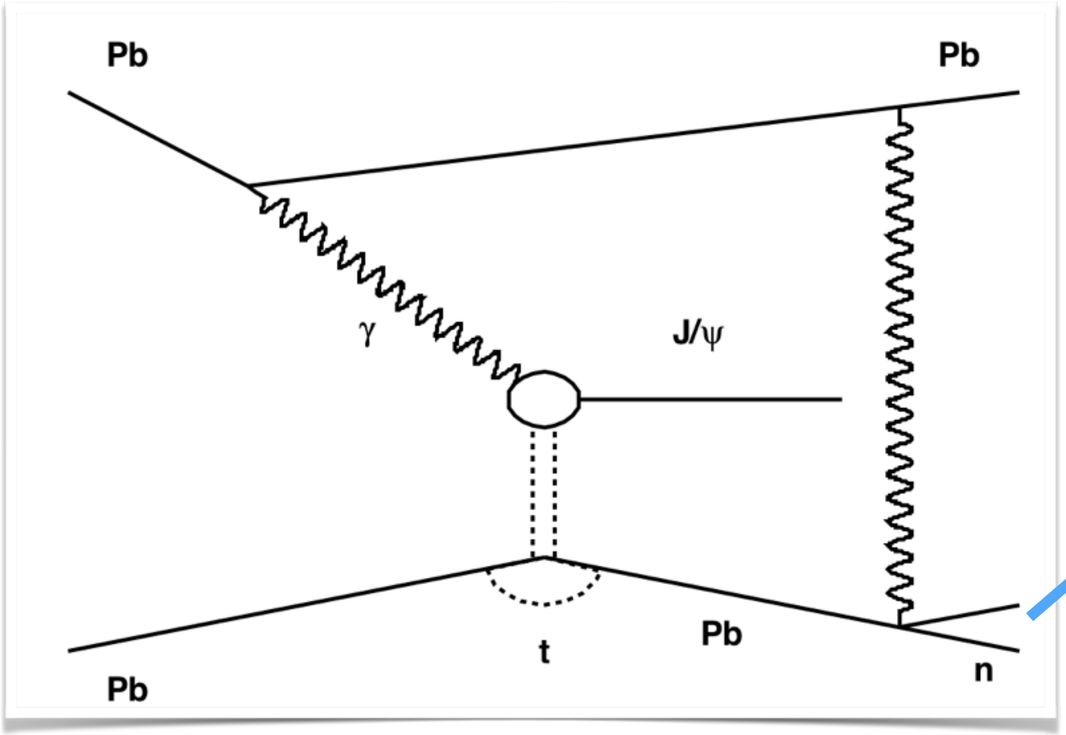

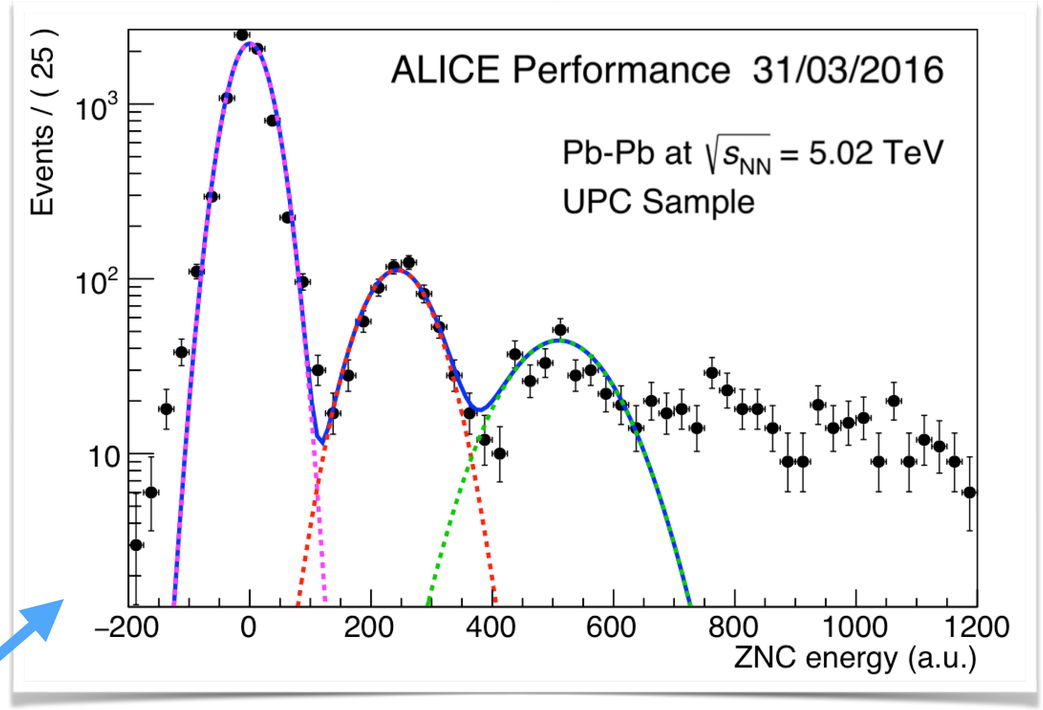

The emission of the neutrons changes the impact parameter dependence of the process and can be used to disentangle the high and low energy contributions!

ALICE can measure these neutrons!

Coming soon: peripheral production in Run 2

We also have new peripheral data at forward rapidities:

- at higher energies (smaller x values can be reached),
- and with around **7x more statistics** than in Run 1!

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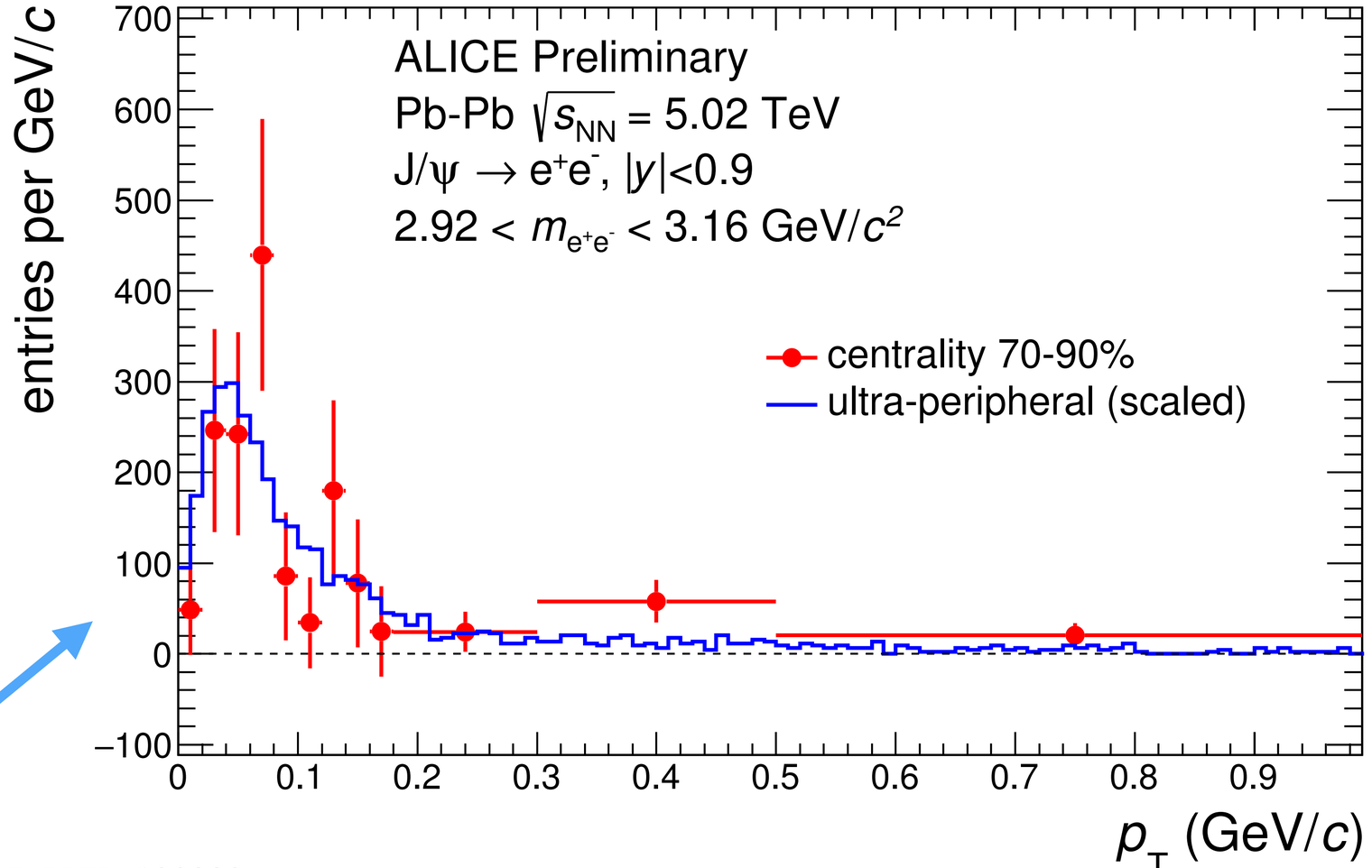
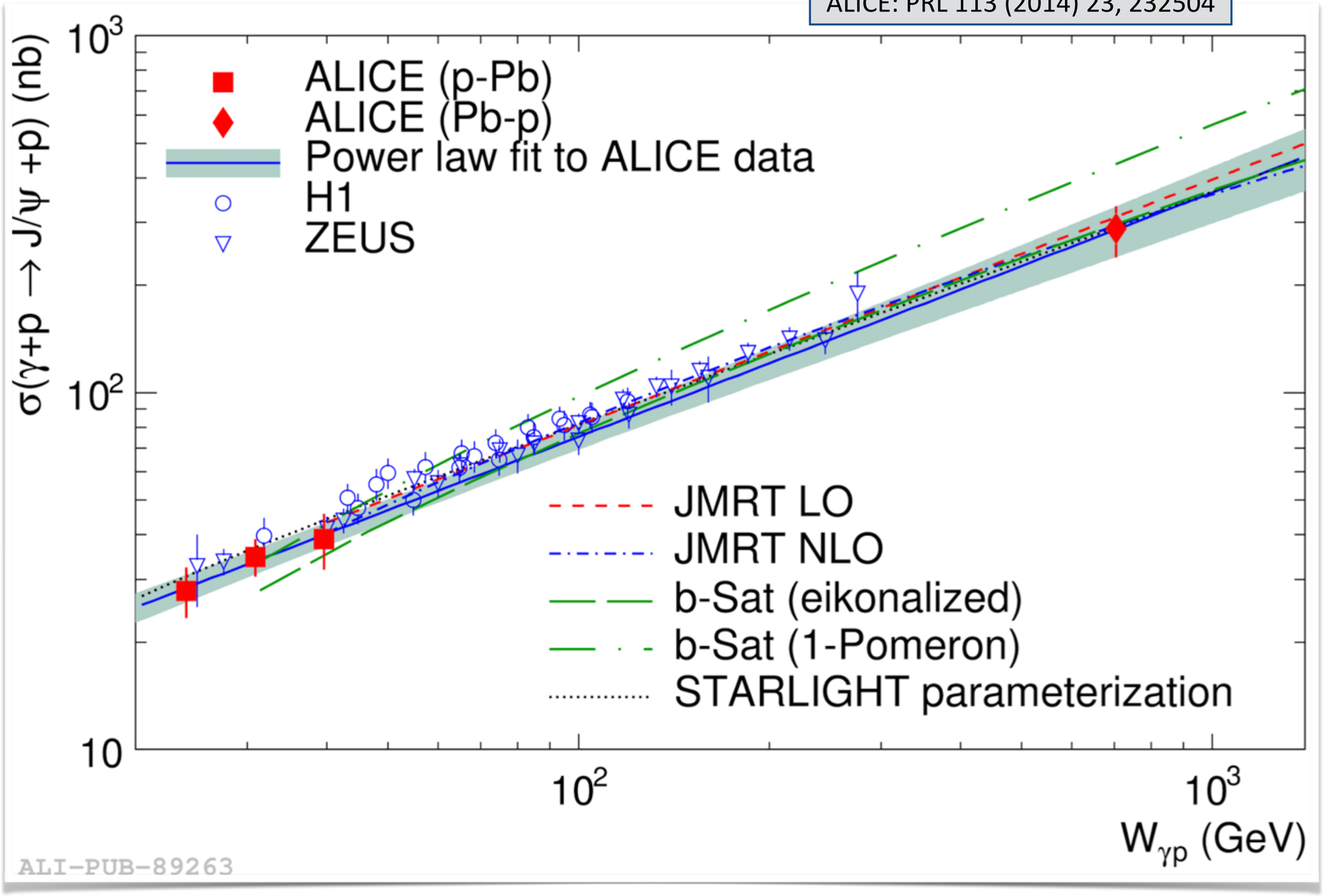


Now we also have peripheral photoproduction data at mid-rapidity!

ALICE news on exclusive photoproduction off protons in p-Pb collisions

Coming soon: Energy dependence of exclusive J/ψ photoproduction off protons

ALICE: PRL 113 (2014) 23, 232504



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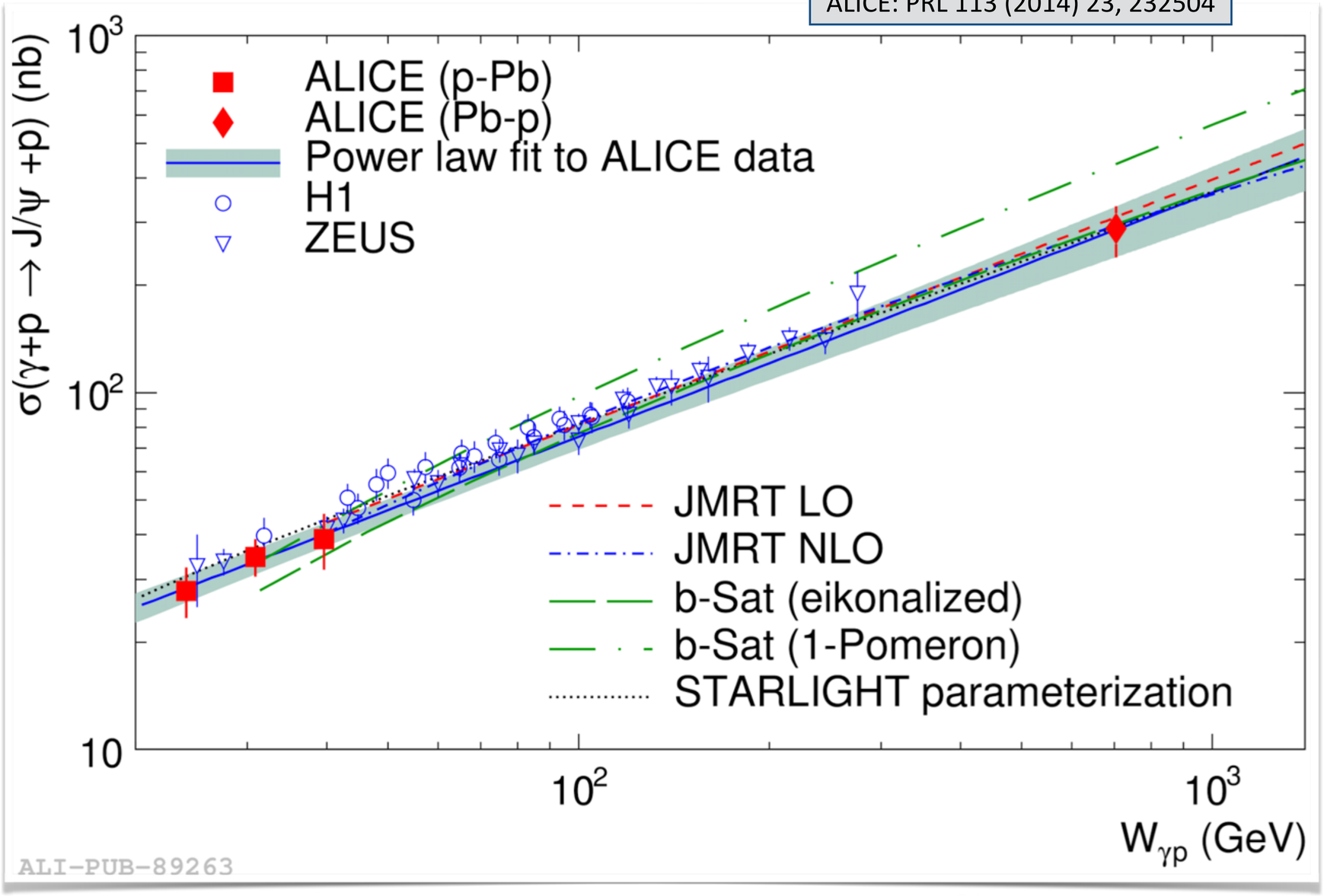

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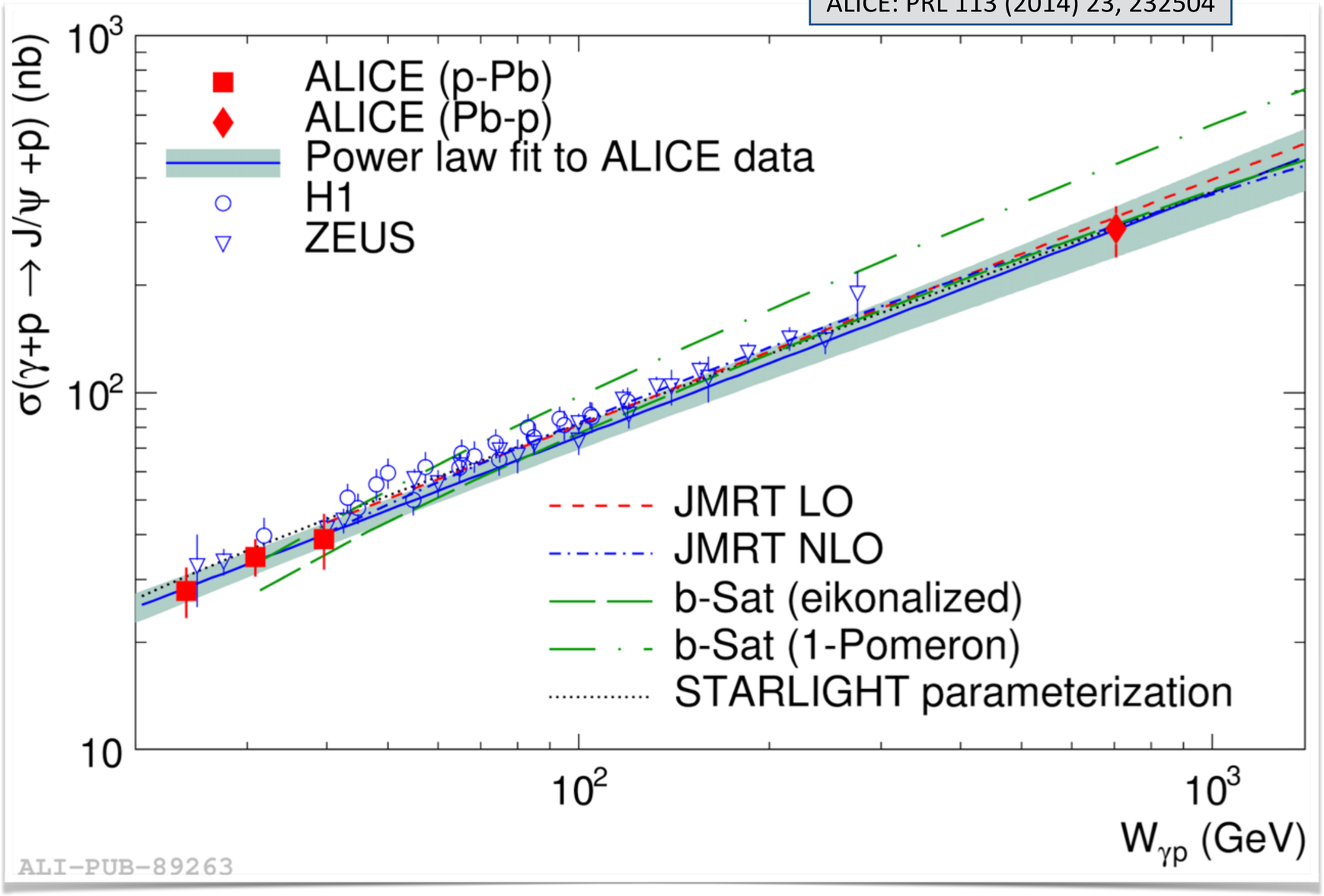

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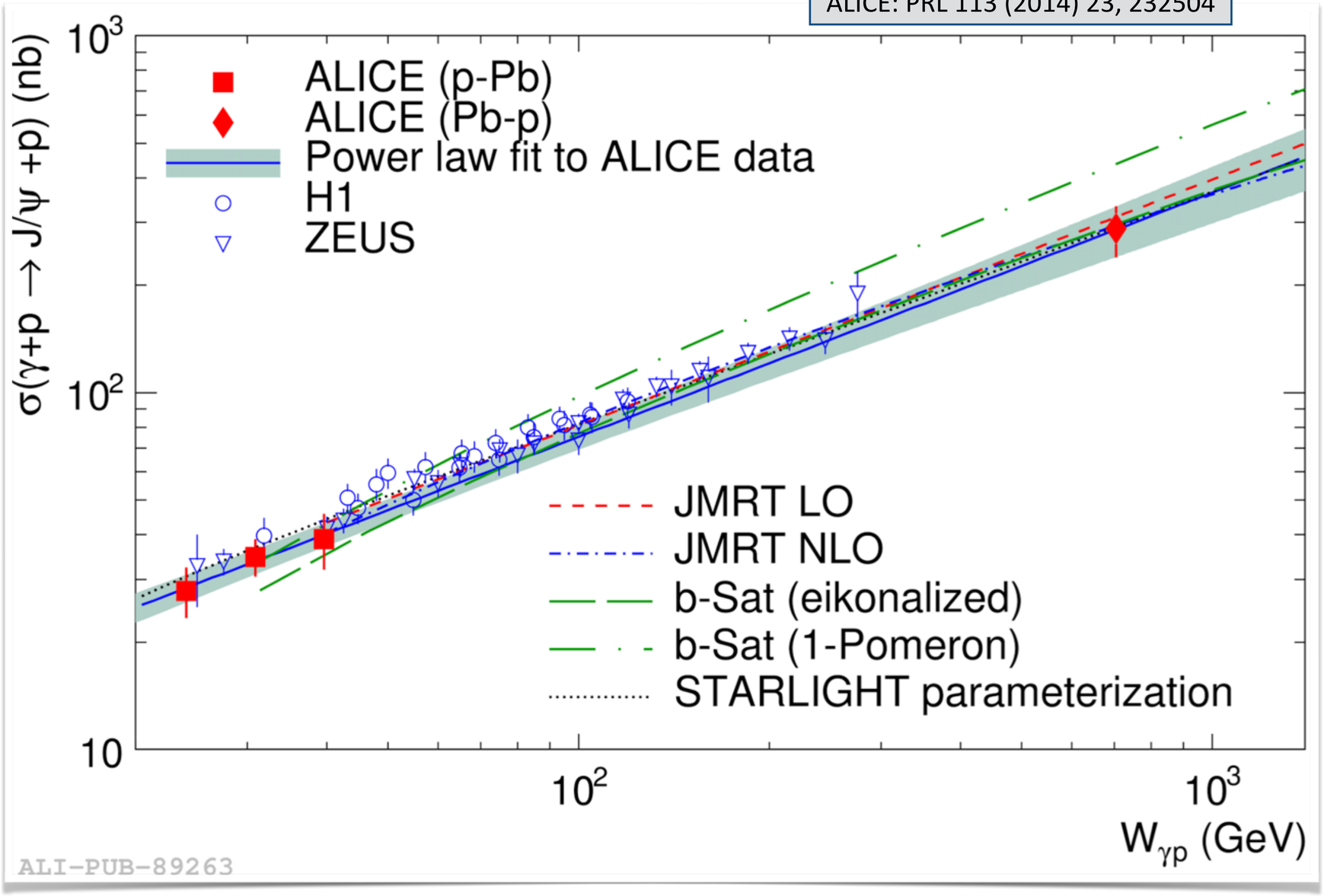

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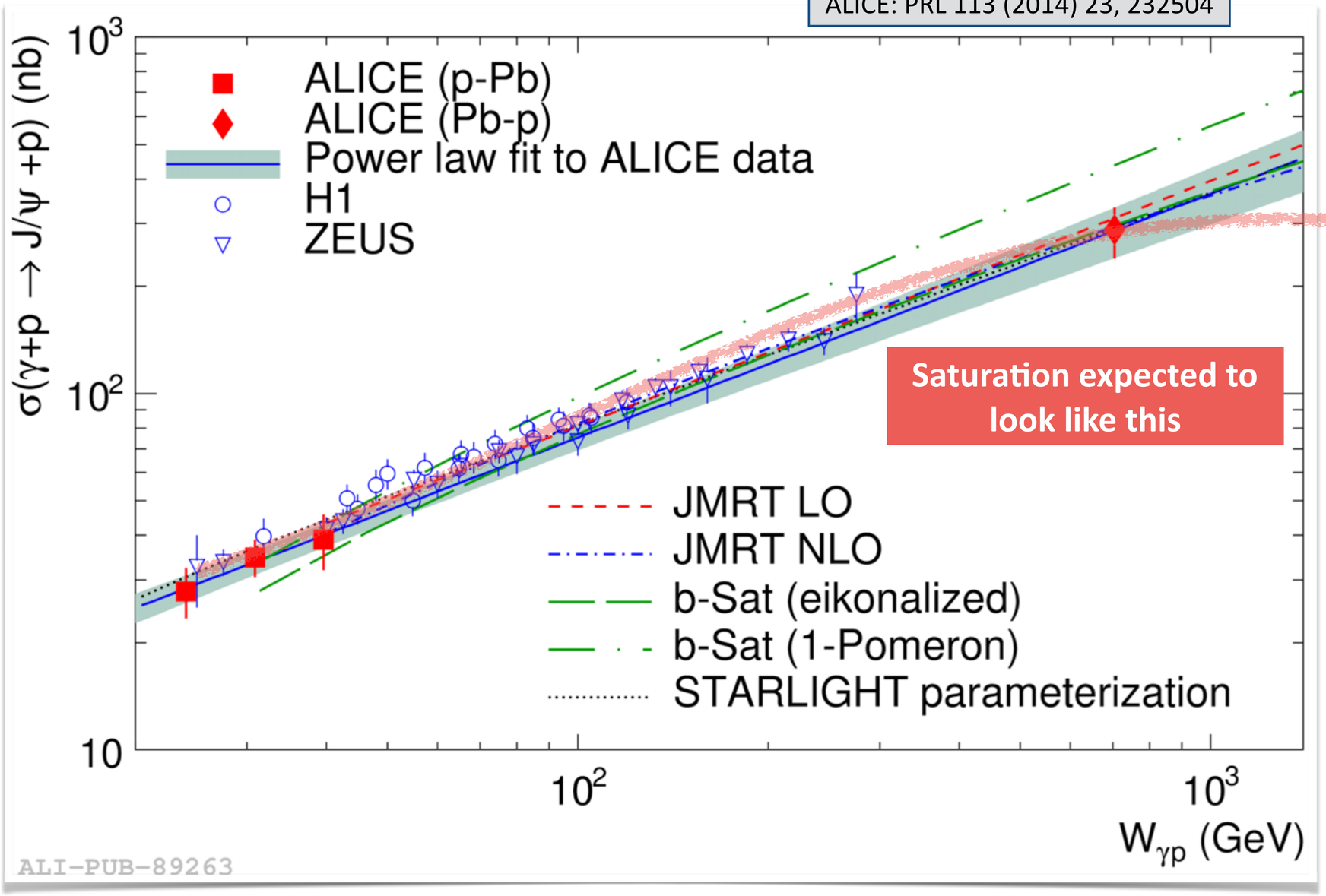

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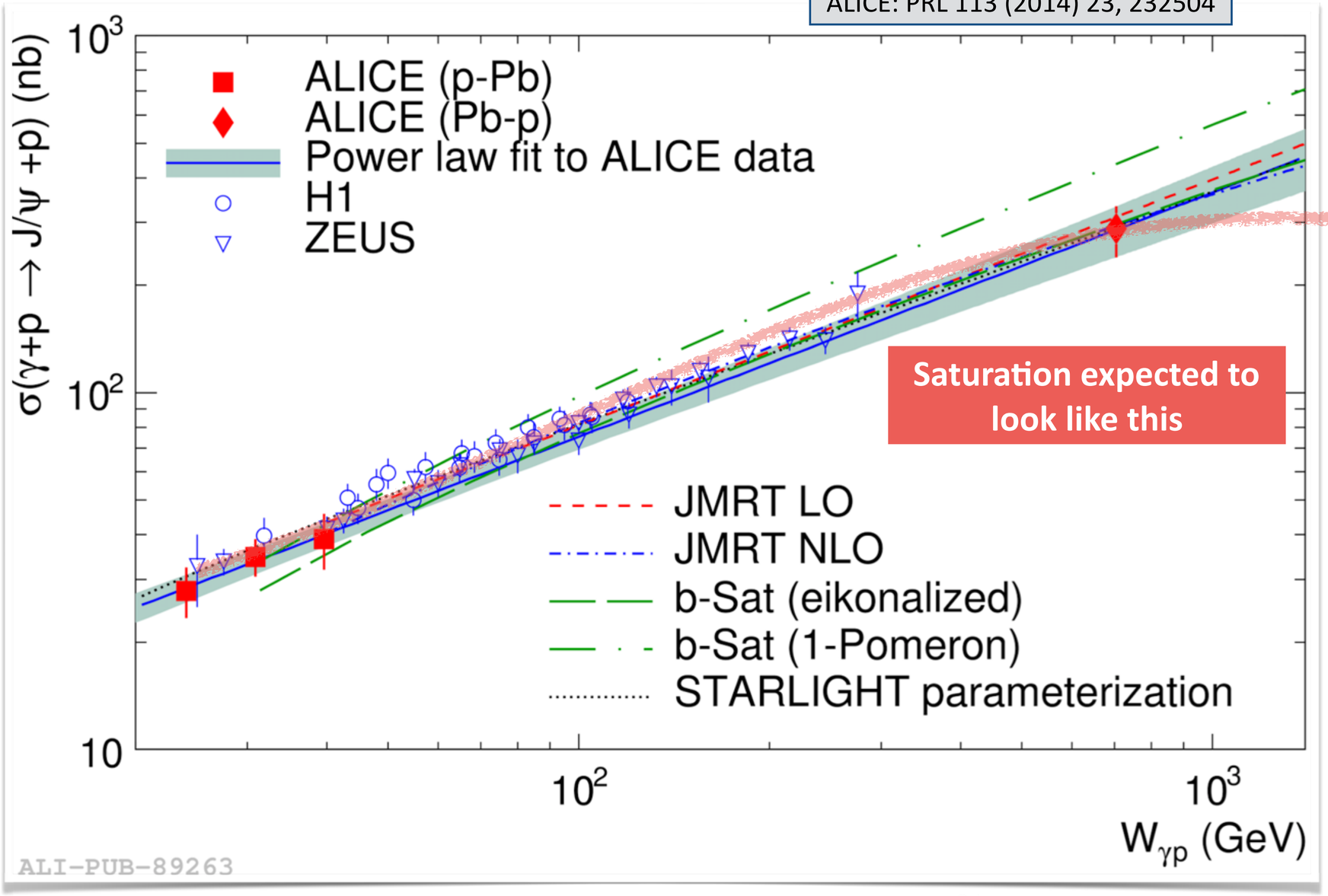

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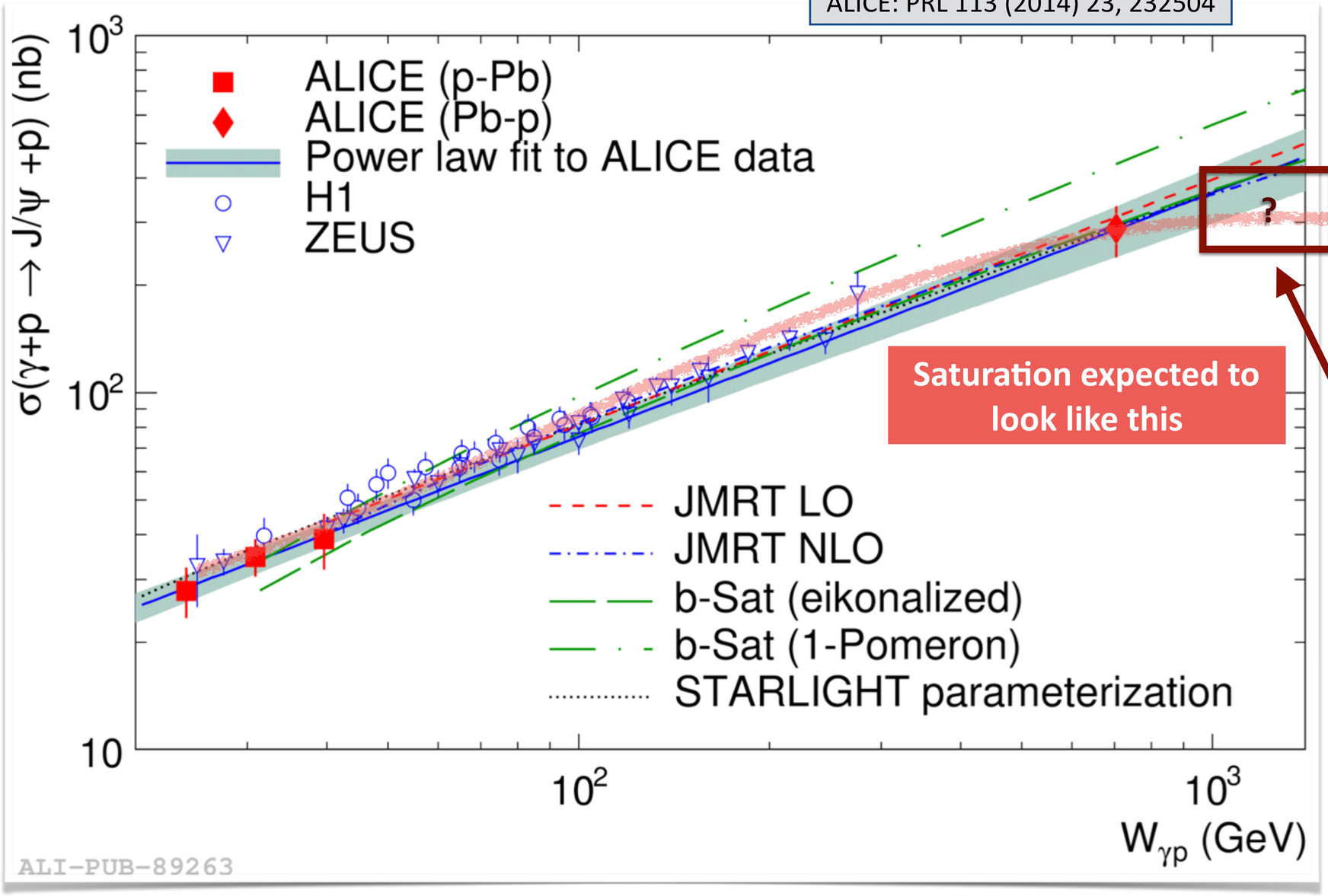

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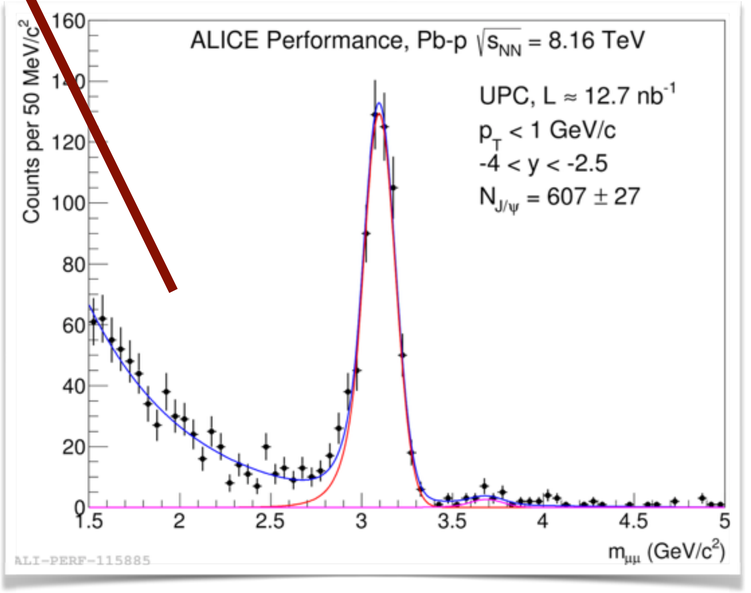

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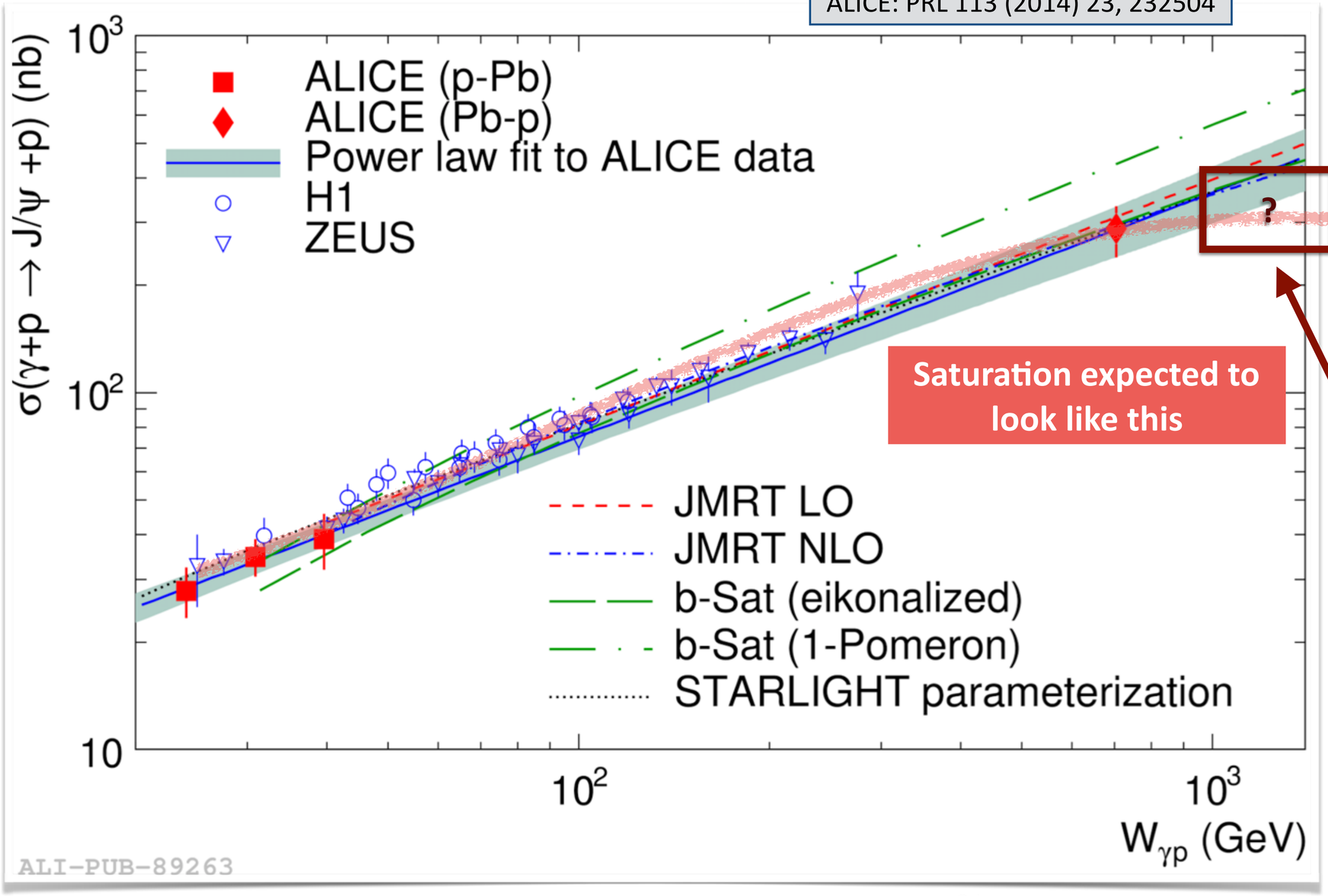

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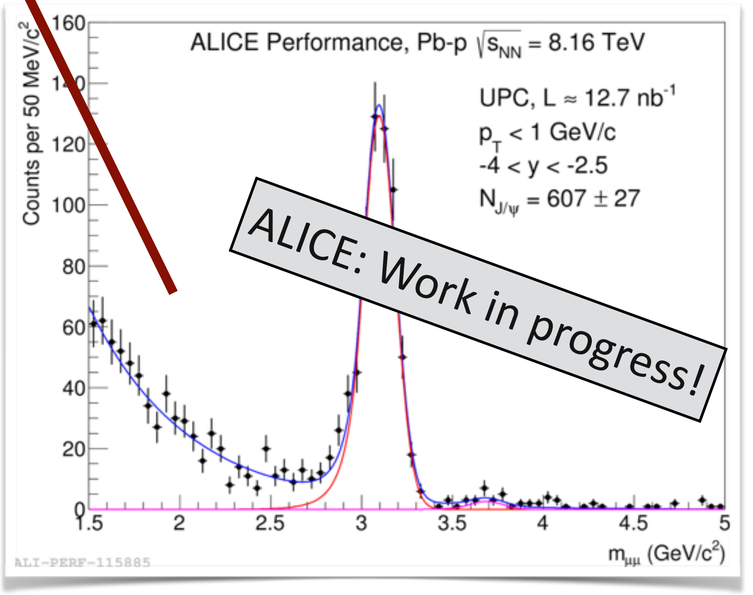

Summary and outlook

ALICE has new data on coherent J/ψ photoproduction from Pb-Pb collisions at 5.02 TeV from the LHC Run 2:

- Preliminary results confirm and improve our previous Run 1 results:
  Data is best described by models with moderate shadowing.
- We have more data, which is being currently analysed, for
  - UPC at mid rapidity;
  - UPC for different forward-neutron classes;
  - Photonuclear production in peripheral collisions, both at forward and mid-rapidities.
- **These data will allow phenomenological studies to extract gluon shadowing down to unprecedentedly low values of x-Bjorken.**

ALICE has also new data on exclusive J/ψ photoproduction off protons from p-Pb collisions at 8.16 TeV.

- **These data will allow us to search for saturation effects in a range well above 1 TeV in $W_{\gamma p}$!**