RECENT RESULTS ON COHERENT J/Ψ PHOTOPRODUCTION AND POLARIZATION IN HEAVY-ION COLLISIONS WITH ALICE

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Groupement de recherche
QCD Chromodynamique quantique

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Using the LHC as $\gamma\gamma$, γPb and γp collider

The most powerful collider not only for pp and Pb-Pb collisions, but also for photon-photon and photon-hadron interactions

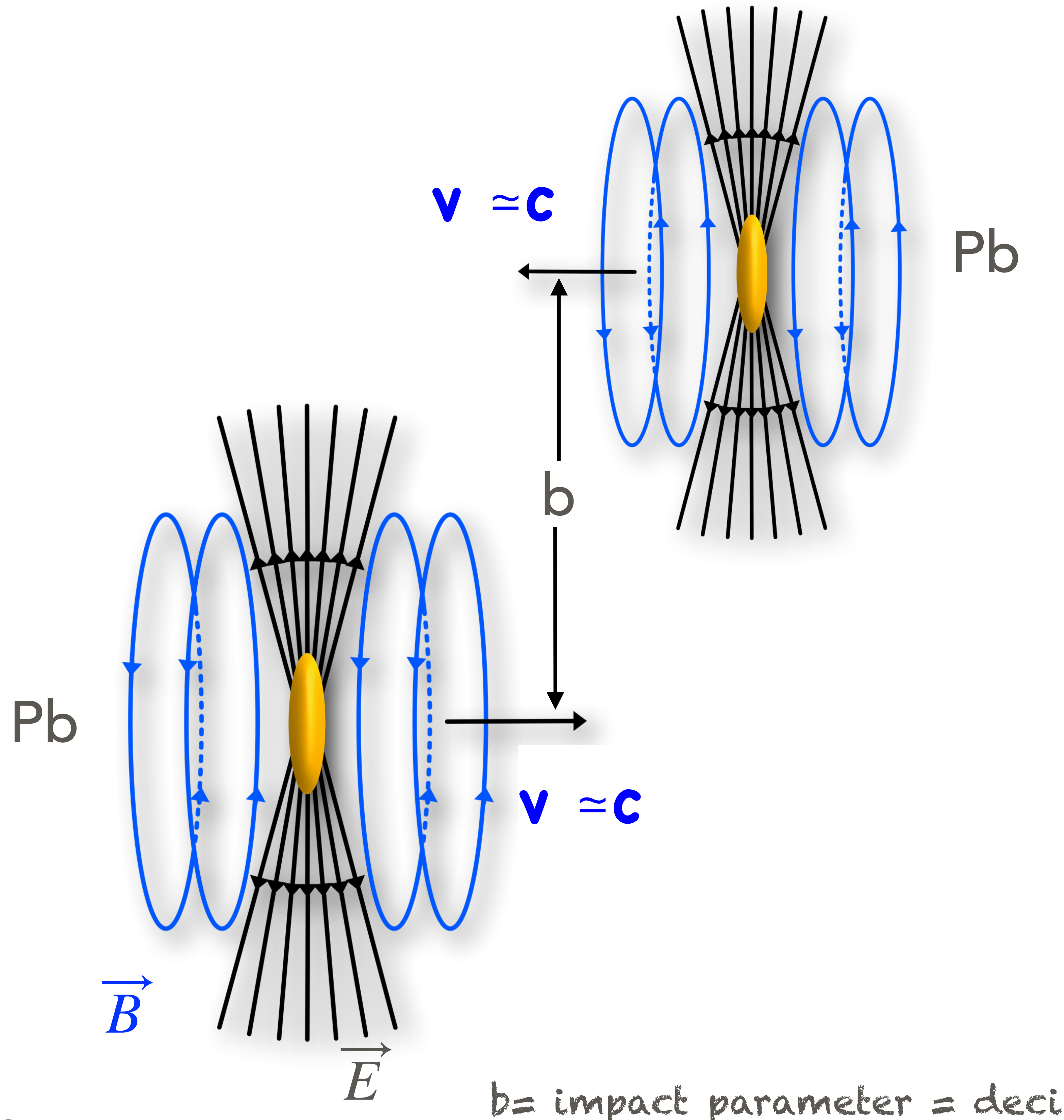
Equivalent photon approximation in heavy-ion collisions

Fast moving charged particle is equivalent to a **flux of quasi-real photons [1]**

Later, this method was extended to relativistic region known as **Weizsacker-Williams Method [2.3]**

[1] E. Fermi, Nuovo Cim.,2:143-158, arXiv:hep-th/0205086 (1925)
[2] C.F. von Weizsacker, Z. Phys. 88, 612 (1934)
[3] E. J. WILLIAM S, Kgl. Danske Videnskab. Selskab Mat.-Fys. Medd. 13, 4 (1935)]

Relativistic heavy ions are strong EM field emitters



b= impact parameter = decide the geometry of collisions

Strongest EM fields in the Universe

$|E| \sim 5\times10^{16} - 10^{18}$ V/cm

$|B| \sim 10^{14} - 10^{16}$ T

V. Skokov et al, *Int.J.Mod.Phys.A* 24 (2009) 5925-5932

Magnetic field (|B|) created in other systems

Pulsar ~ 10^{11} T

Earth ~ 10^{-5} T

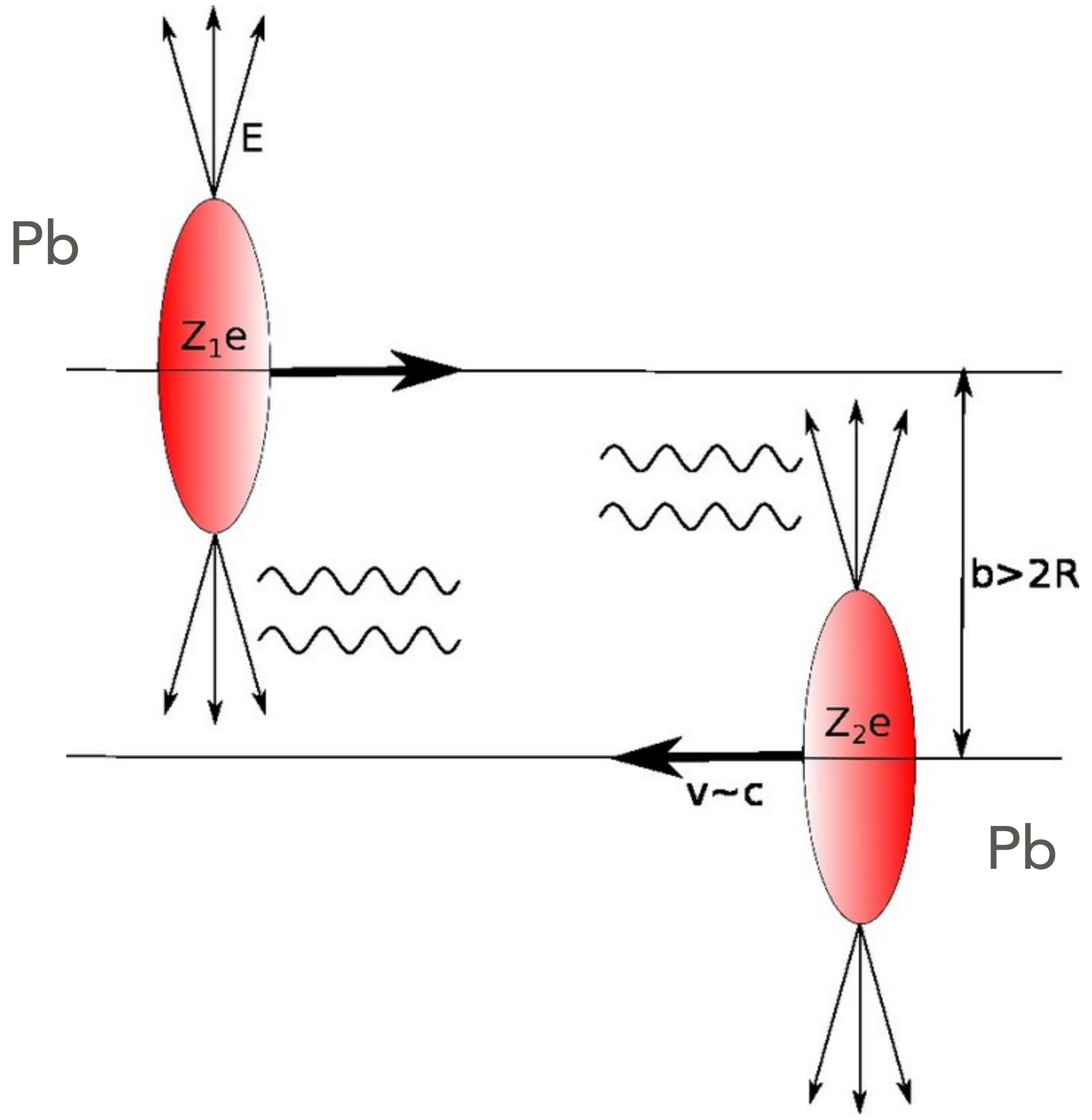
EM fields can be treated in terms of photon quanta

$$E_{\gamma,\max} \approx \gamma \hbar c / R$$

photon energy ~ 80 GeV @ LHC

Photon-induced processes in heavy-ion collisions

UltraPeripheral Collisions (UPCs) : b > $R_1 + R_2$



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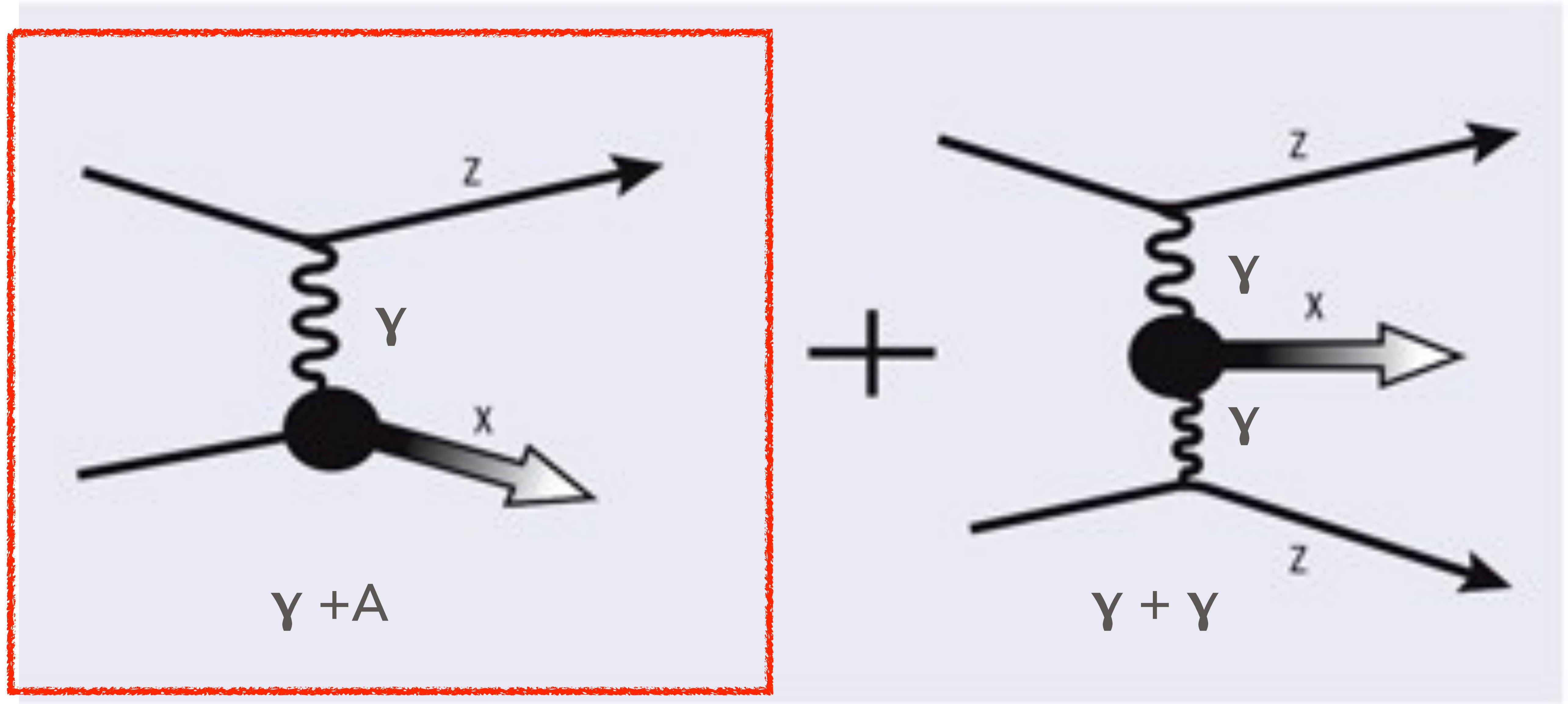
Types of interactions



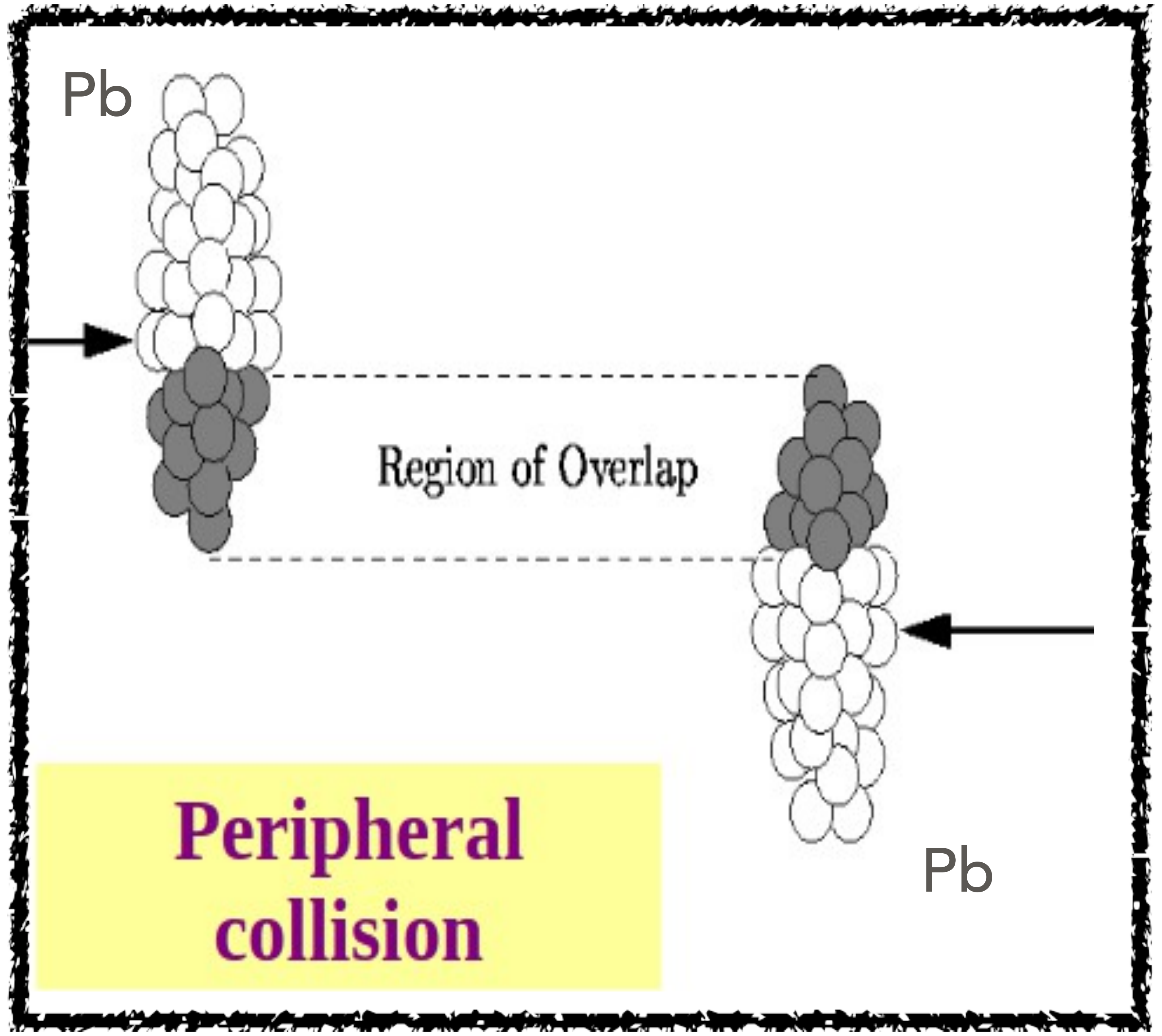
Photon flux density ∝ Z^2

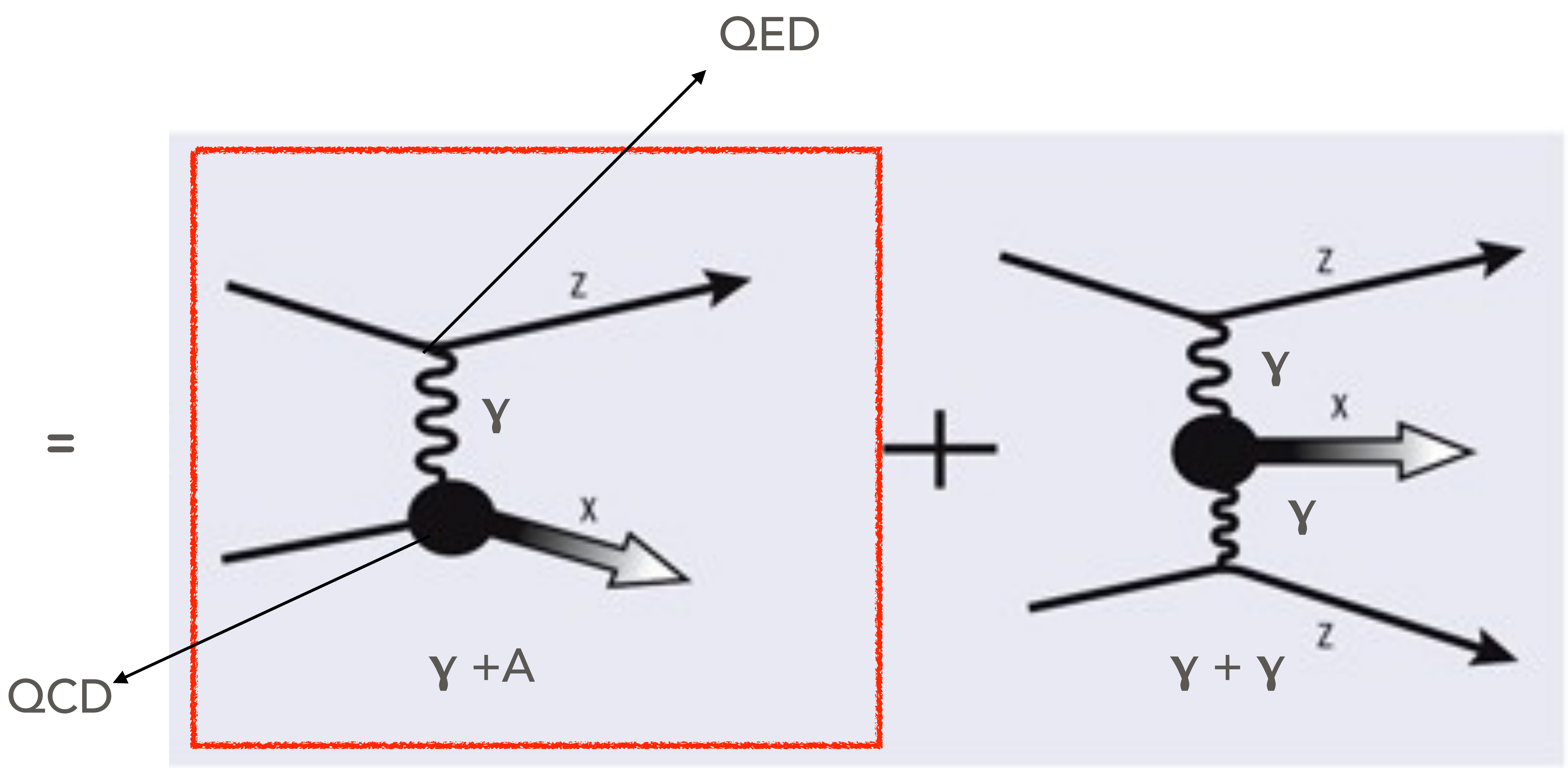
Electromagnetic interactions are dominant

Hadronic interactions are suppressed

Photon-induced processes in heavy-ion collisions

Peripheral Collisions (PC) : large b , $b \leq R_1 + R_2$





Photon flux density ∝ Z^2, (expected to modified of photon flux from UPC to PC as geometrical constraints on impact parameter, impact of nuclear overlap…)

Hadronic interactions are dominant

Electromagnetic interactions are observed

Photon-induced processes are present both in UPCs and PCs with nuclear overlap

-> Good probe to test QCD and QED phenomena

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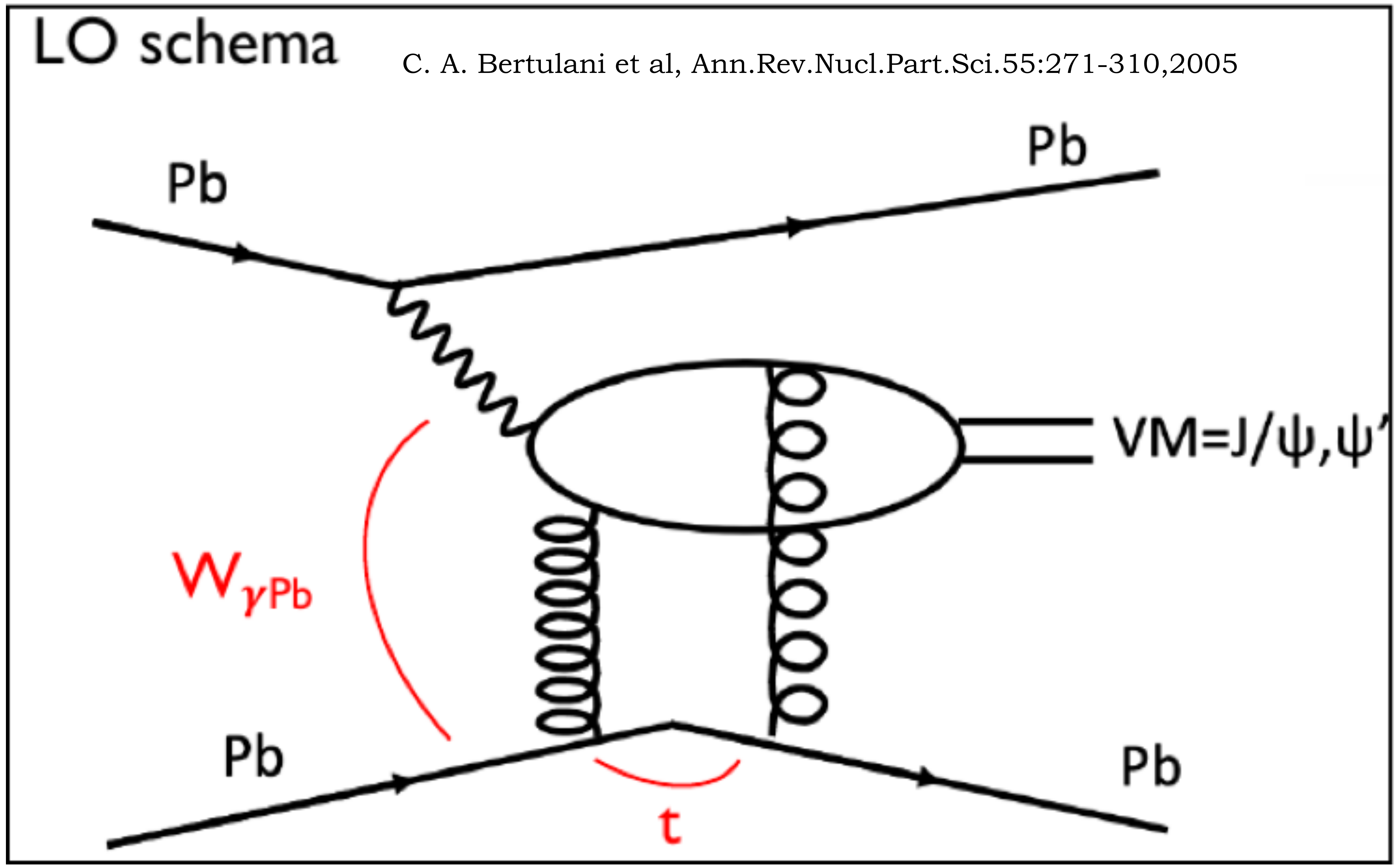
Vector meson photoproduction in HICs



LO : Leading order

$W_{\gamma Pb}$: Center-of-mass energy of photon-lead system

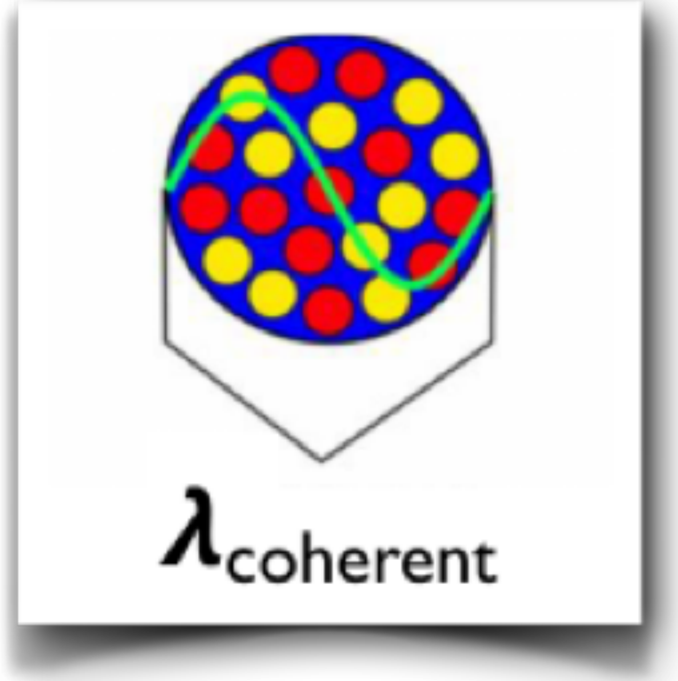
t: Mandelstam variable = - p_T^2

Coherent photo production

Photon (γ) couples coherently to all nucleons

$\langle p_T \rangle_{J/\Psi}$ ~ 1/R ~ 60 MeV/c

Usually no breaking of target

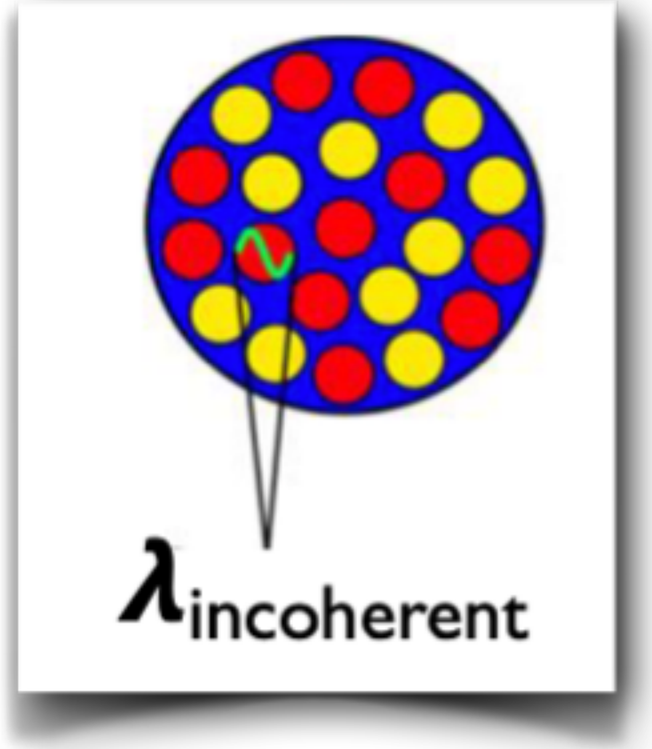


Incoherent photo production

Photon (γ) couples to single nucleon

$\langle p_T \rangle_{J/\Psi}$ ~ 500 MeV/c

Usually target nucleus breaks



$$x = \frac{m_{J/\psi}}{\sqrt{s_{\rm NN}}} \times \exp(\pm y)$$

Clean experimental signature and probing different photoproduction mechanisms

Imaging of nuclear gluon distributions in nuclei at low Bjorken-x

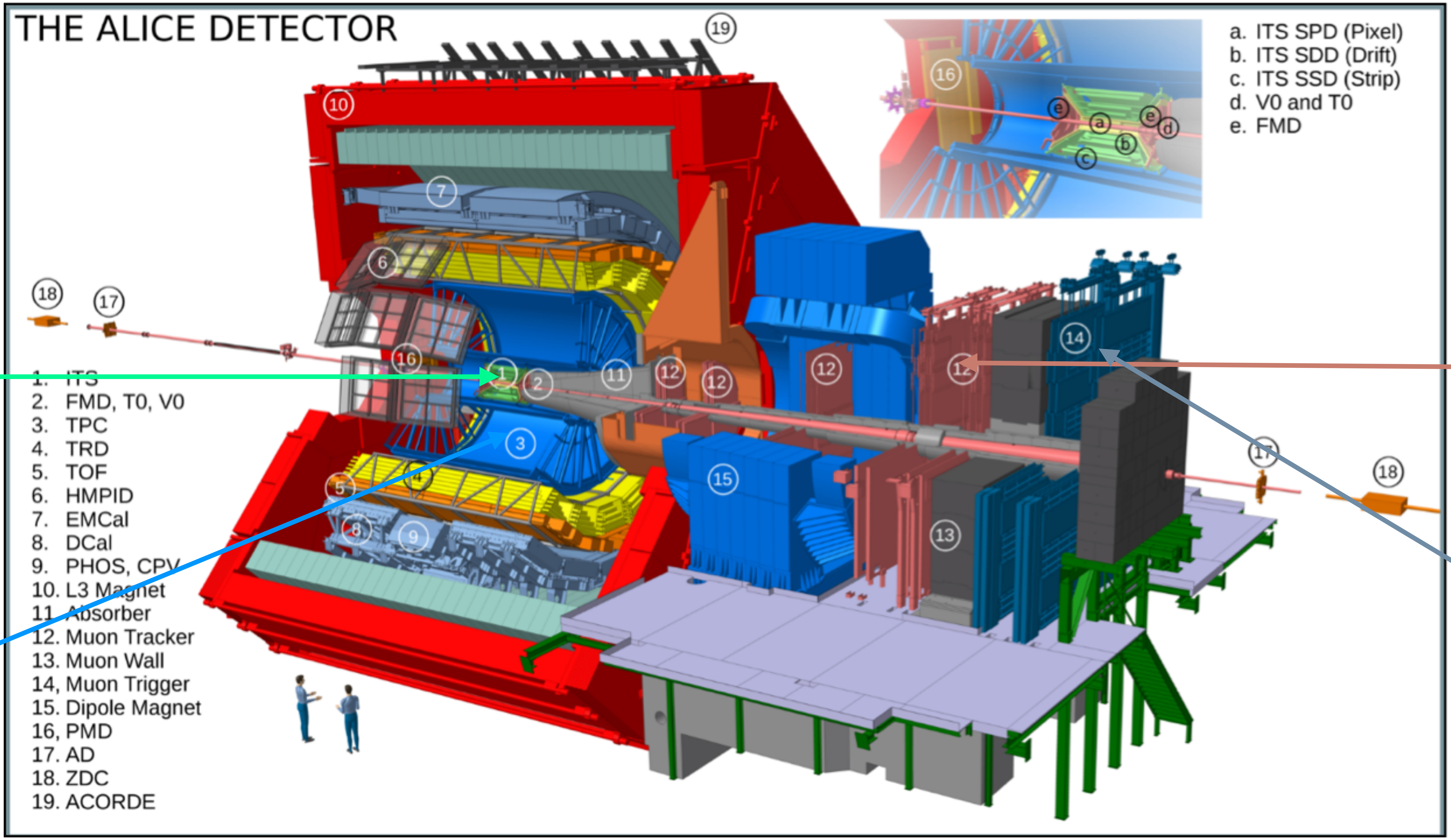
The ALICE Apparatus

Data sample : 2015 + 2018 Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV (Run 2)

Central barrel:
$|y| < 0.9$
$J/\Psi \longrightarrow e^{+}e^{-}$

ITS : Tracking, vertex reconstruction

TPC : Tracking, Particle identification (PID)



Muon Spectrometer :
$2.5 < y < 4.0$
$J/\Psi \longrightarrow \mu^{+}\mu^{-}$

Muon tracker : tracking

Muon trigger : triggering

V0 : triggering, centrality determination, background rejection

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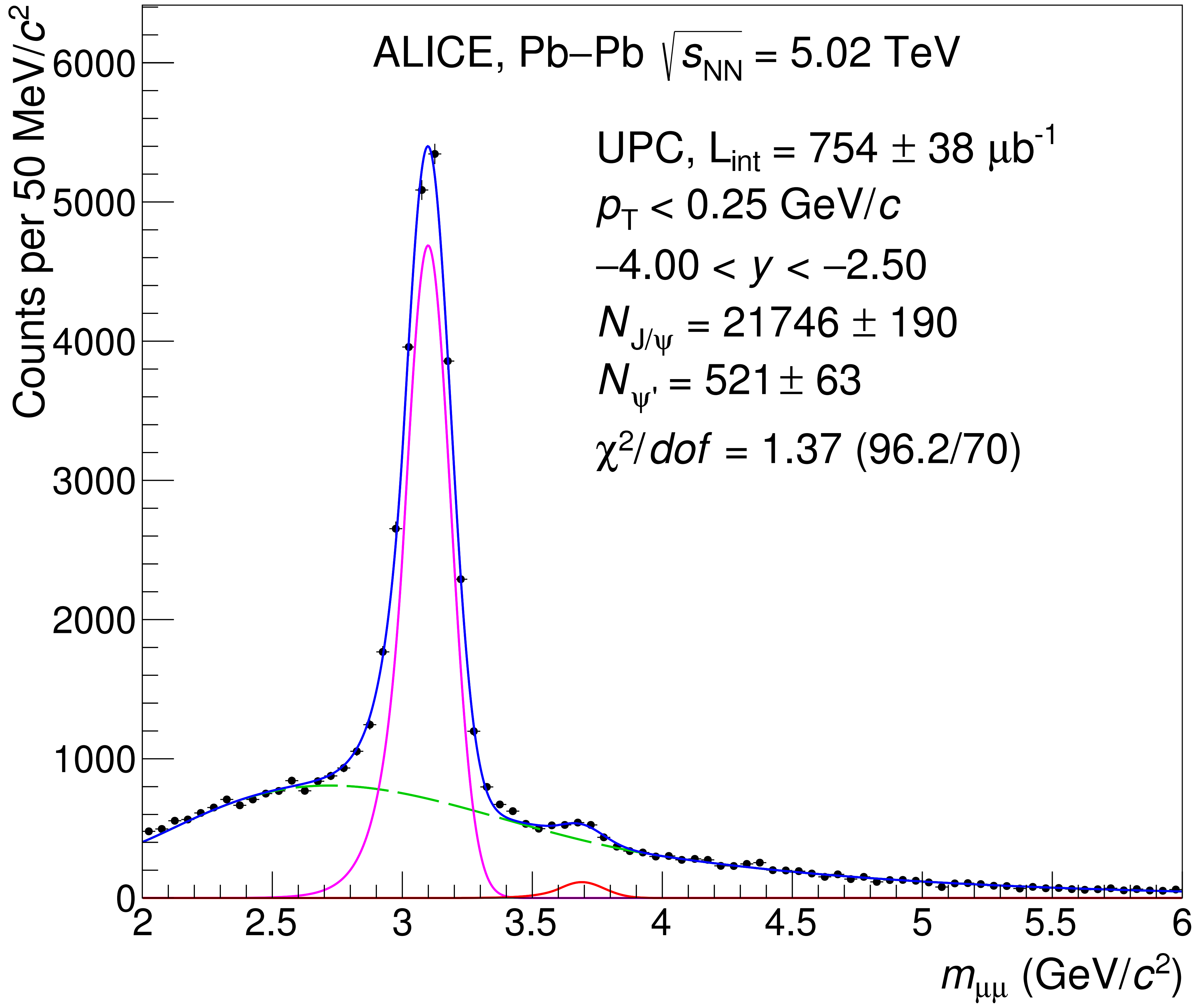
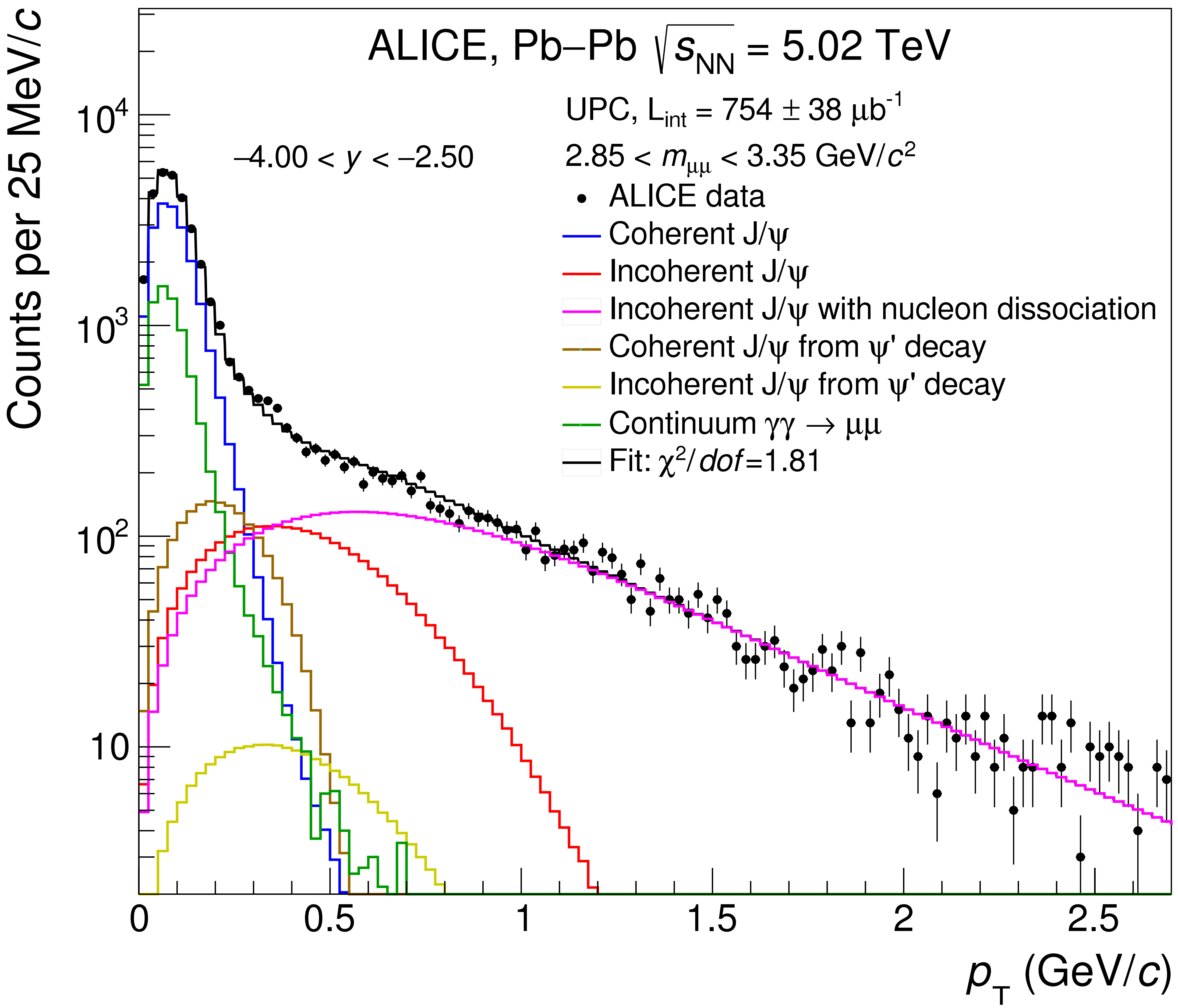
VM photoproduction : experimental observations in UPC

STARlight MC : Comp. Phys. Comm. 212 (2017) 258.

Phys. Lett. B798 (2019) 134926





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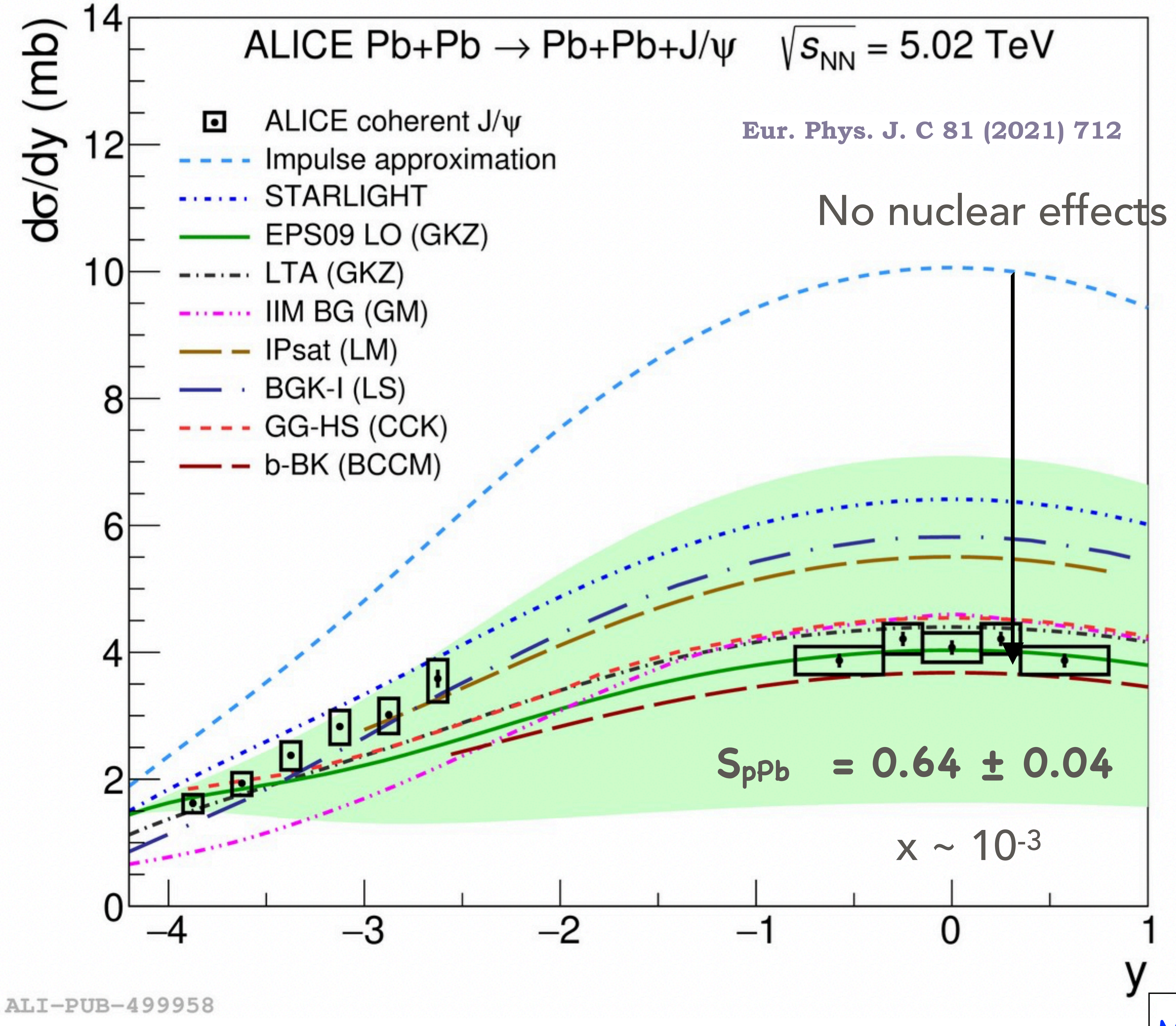
VM photoproduction : experimental observations in UPC

Cross section vs. rapidity (y)



Eur. Phys. J. C 81 (2021) 712

No nuclear effects

S_{pPb} = 0.64 ± 0.04

x ~ 10^{-3}

ALI-PUB-499958

Nuclear suppression factor (shadowing) = $S_{\text{pPb}} = \sqrt{\frac{\sigma_{\gamma Pb}}{\sigma_{\gamma Pb}^{IA}}}$

Impulse approximation: [PRC88, 014910 (2013)]

STARLIGHT: [Comp. Phys. Comm. 212 (2017) 258]

EPS09 LO (GKZ): [PRC. 93(5), 055206 (2016)]

LTA (GKZ): [Phys. Rep.512, 255-393 (2012)]

IIM BG (GM): [P.RC 90, 015203 (2014)] and [J. Phys.G 42(10), 105001 (2015)]

Ipsat (LM) : [PRC. 83,065202 (2011)] and [PRC. 87, 032201 (2013)] BGK-I (LS): [PRC. 99(4), 044905 (2019)]

GG-HS (CCK): [PRC. 97(2), 024901 (2018)], and [PLB 766, 186-191 (2017)]

b-BK (BCCM): [PLB 817, 136306 (2021)]

$$x = \frac{m_{J/\psi}}{\sqrt{s_{\text{NN}}}} \times \exp(\pm y)$$

Models including **nuclear shadowing are in agreement** with the measurement, but cannot describe at the same time the **mid and forward rapidity cross section**

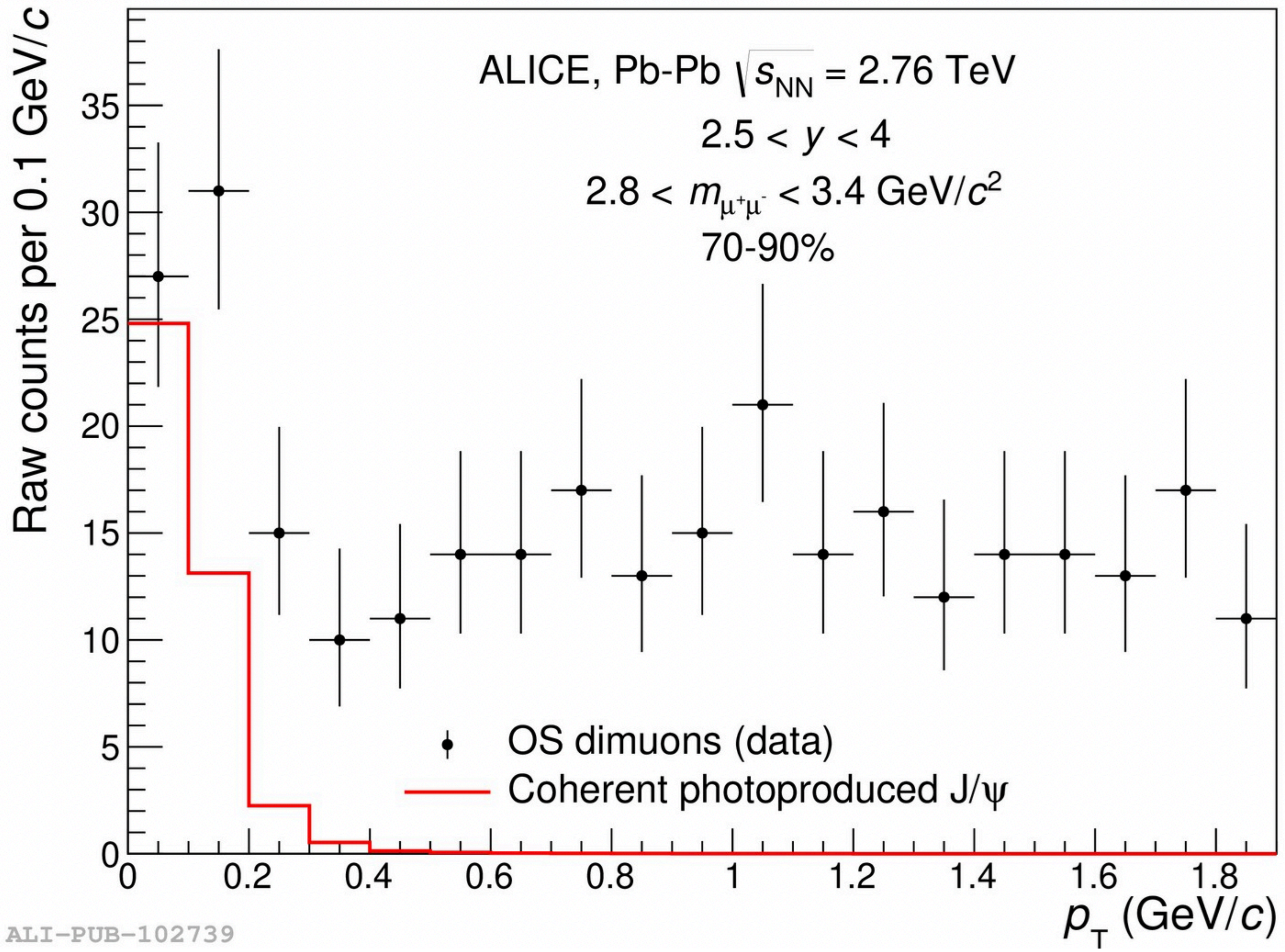
VM photoproduction in Pb–Pb collisions in PCs

PRL 116, 222301(2016)

STARlight MC : Comp. Phys. Comm. 212 (2017) 258.

Associated with a dramatic increase of the R_{AA} arXiv:2204.10684

Model: W. Shi et al., Phys. Lett. B 777 (2018)



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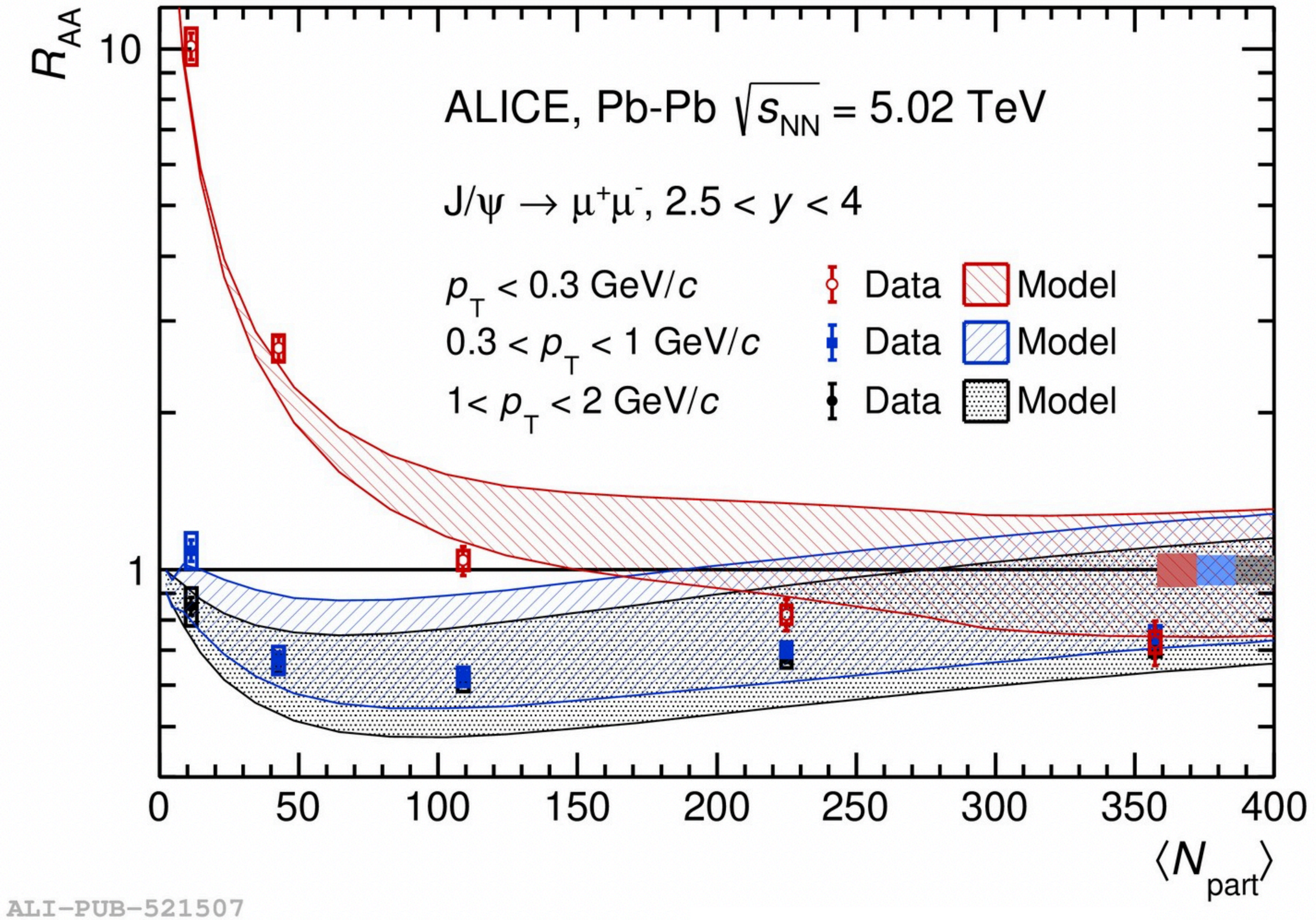


ALI-PUB-521507

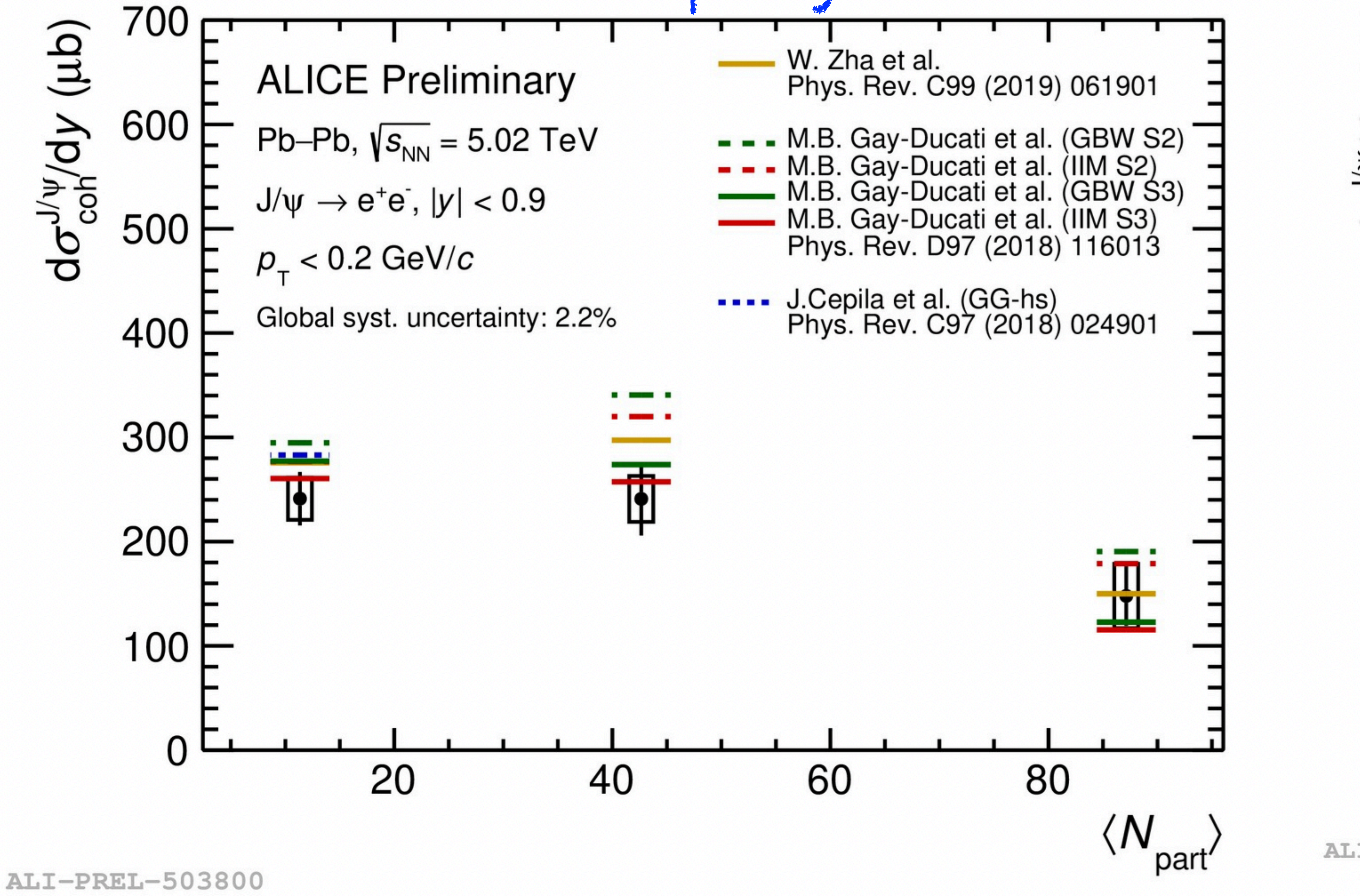
Significant J/ψ excess for p_T < 0.3 GeV/c in 70-90% Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV.

Observed also by STAR [PRL 123, 132302 (2019)] **and LHCb** [PRC. 105 (2022) L032201].

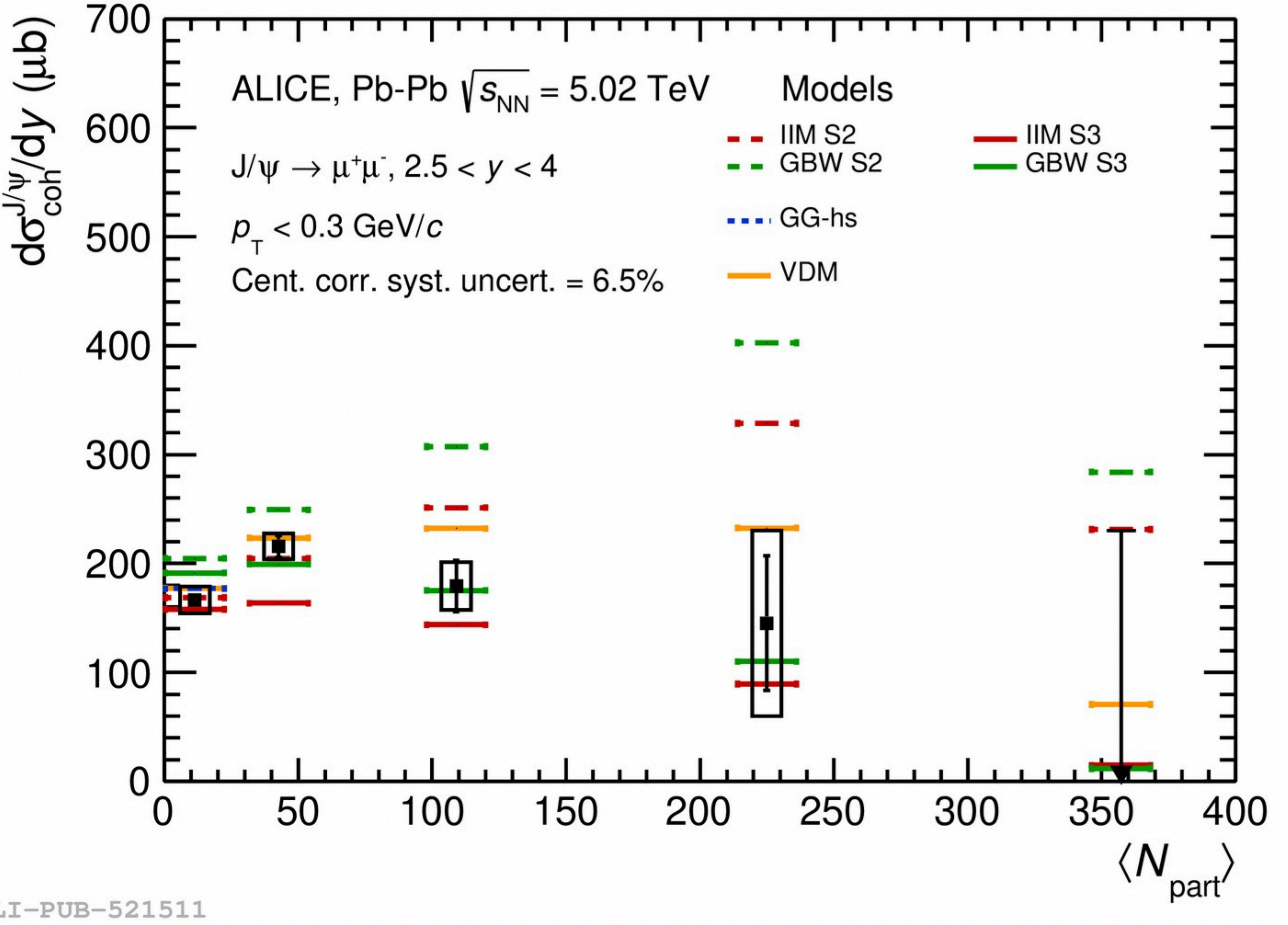
$$R_{AA} = \frac{Y^{Pb-Pb}_{J/\psi}}{< T_{AA} > \sigma^{pp}_{J/\psi}}$$

Coherent J/ψ photoproduction : centrality dependence

mid rapidity



Forward rapidity



70-90% 50-70% 40-50%

70-90% 50-70% 30-50%. 10-30%. 0-10%

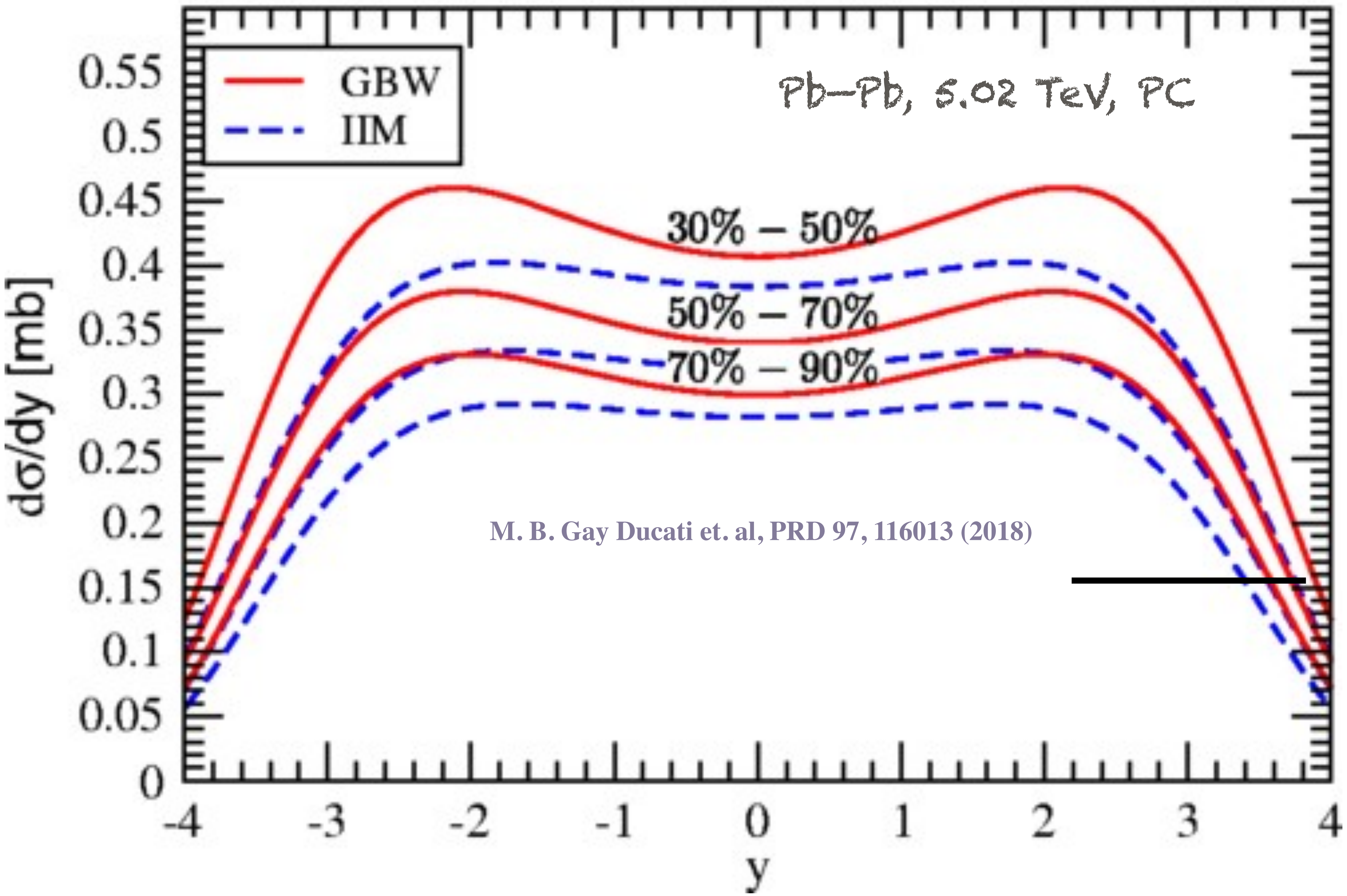
* The cross section is not normalized to the centrality interval width

Both measurements at **mid and forward rapidity don't show a significant centrality dependence**

Measurements are qualitatively described by a large number of models developed for UPC and extended to account for the nuclear overlap

Coherent J/ψ photoproduction : Rapidity (y) dependence

Models predict a strong y-dependence of the VM photoproduction cross section M. B. Gay Ducati et. al, PRD 97, 116013 (2018)



M. B. Gay Ducati et. al, PRD 97, 116013 (2018)

Additional differential measurements are needed to better constrain models, as done in UPC

A new measurement is performed as a function of rapidity in Pb–Pb collisions with nuclear overlap

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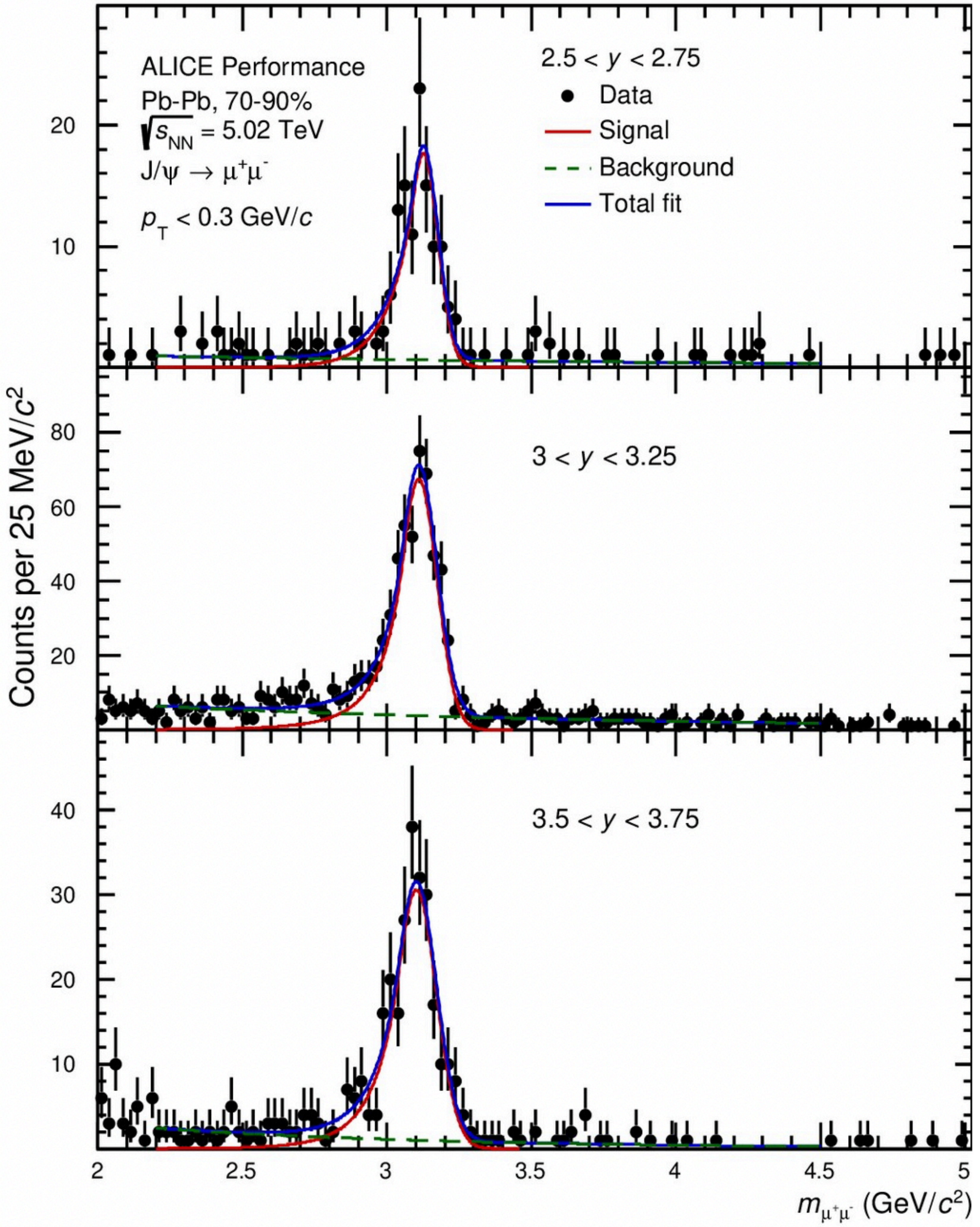
The state of art: raw J/ψ yield in rapidity intervals

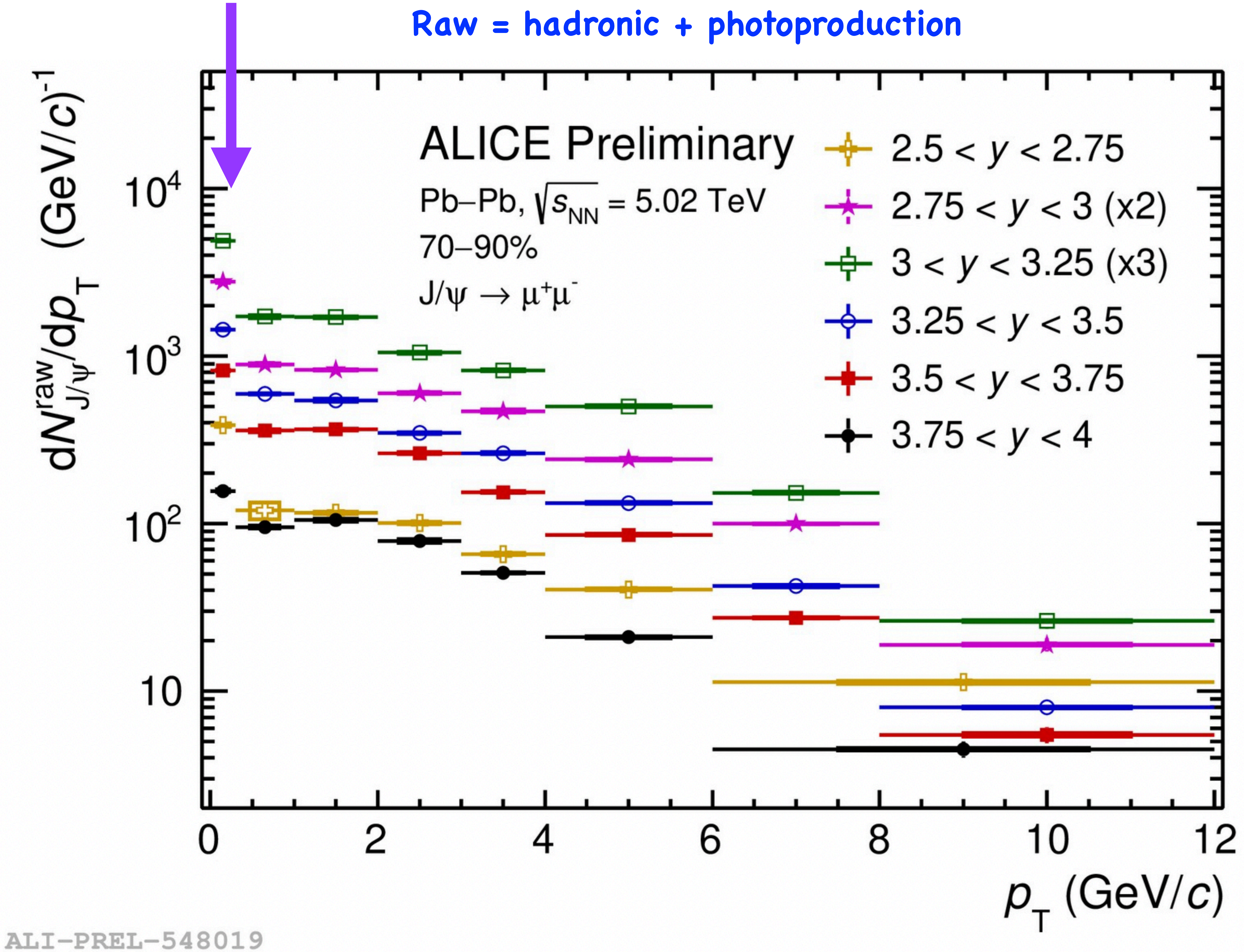
J/ψ signal extraction from the **invariant-mass distribution** of the decay daughters



ALI-PERF-538924

$J/\psi \rightarrow \mu^+\mu^-$, 70–90%, 2.5 < y < 4, p_T < 0.3 GeV/c

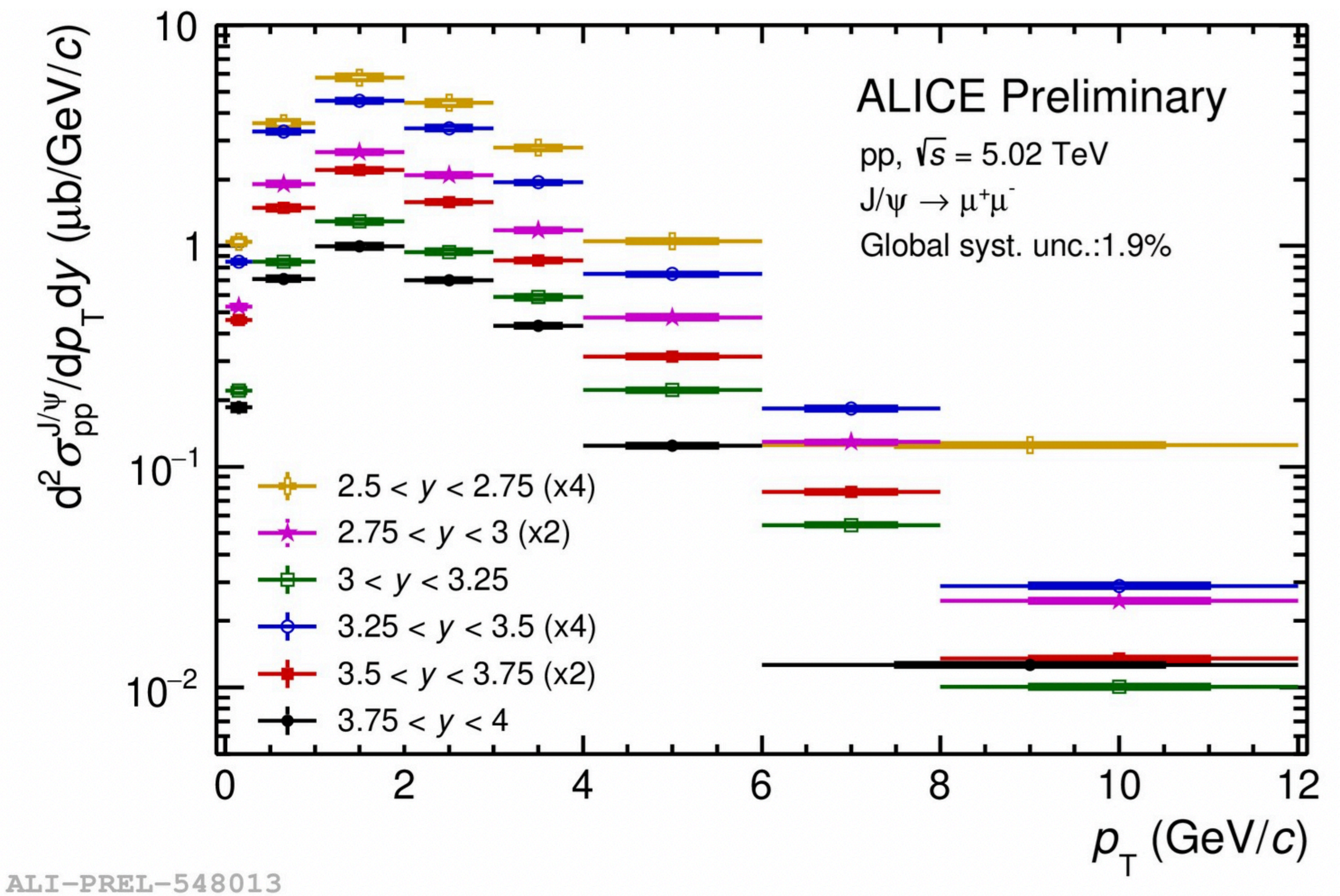
Raw = hadronic + photoproduction



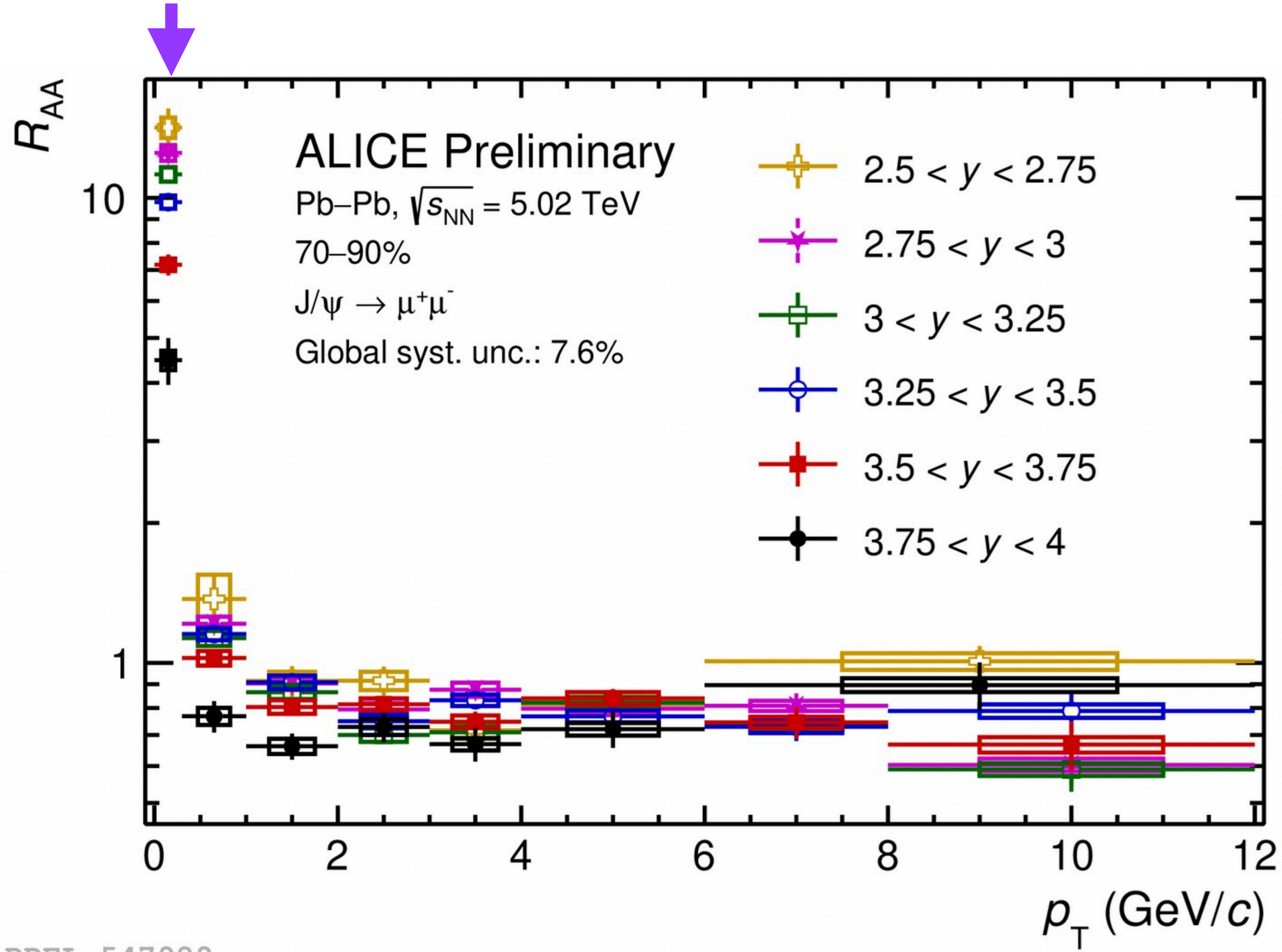
ALI-PREL-548019

Raw yield excess is observed for p_T < 0.3 GeV/c for all y

Modelization of hadronic J/ψ yield contribution for $p_T < 0.3$ GeV/c



ALI-PREL-548013



ALI-PREL-547989

The J/ψ cross section in pp collisions and the J/ψ R_{AA} are used as inputs for modeling the expected hadronic J/ψ yield

J/ψ excess yield = J/ψ raw yield – J/ψ hadronic yield

The coherent J/ψ yield is obtained by correcting the excess yield for the fraction of incoherent J/ψ and the fraction of coherent ψ(2S)→J/ψ evaluated in UPC.

The R_{AA} largely increases for $p_T < 0.3$ GeV/c and it has a hierarchy in y, the most forward R_{AA} is the least enhanced

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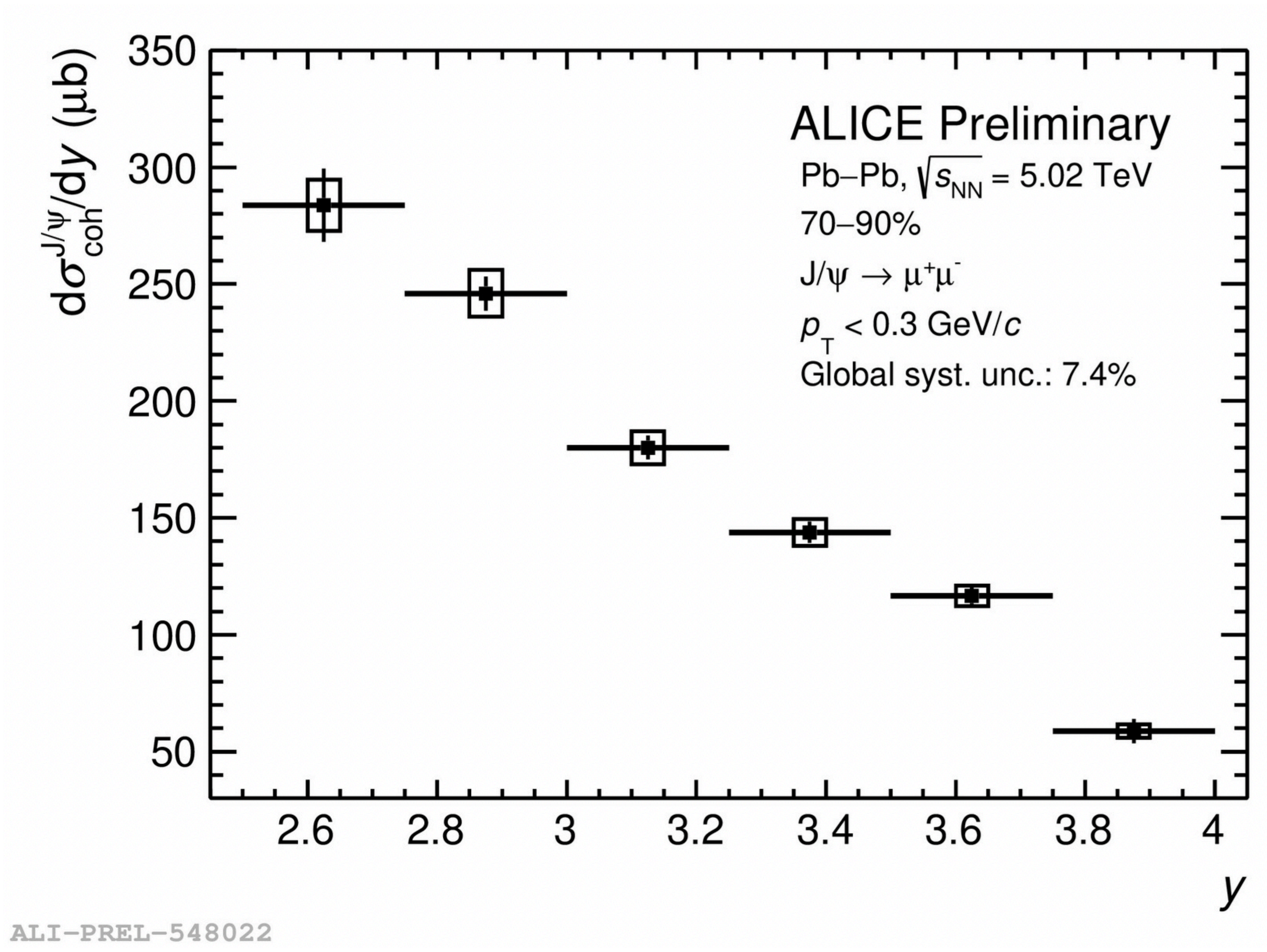
J/ψ photoproduction cross section vs. y



A strong rapidity dependence is seen

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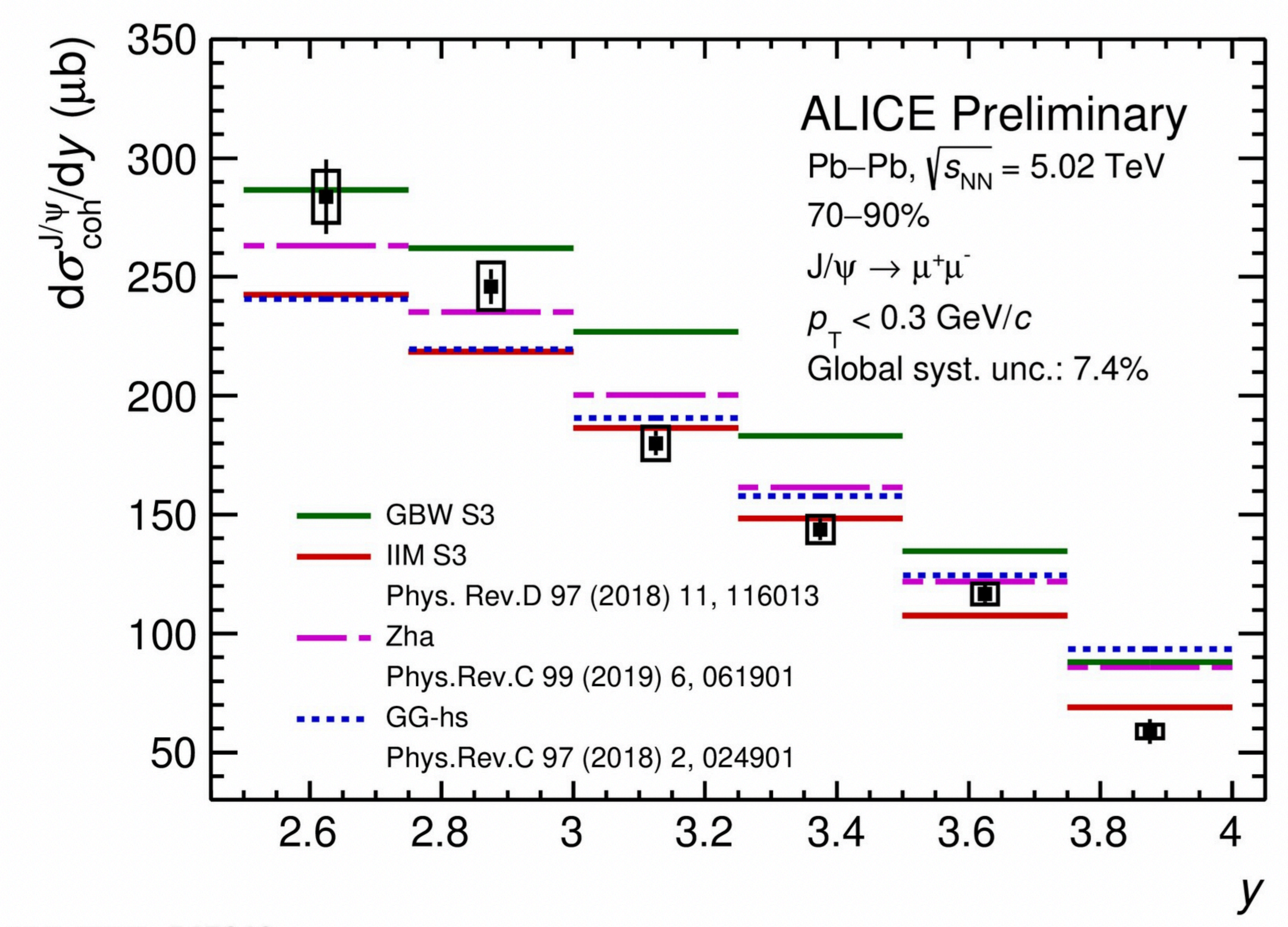
J/ψ photoproduction cross section vs. y



ALI-PREL-547942

Models considerations:

GG -hs : photon flux with constraints on impact parameter range

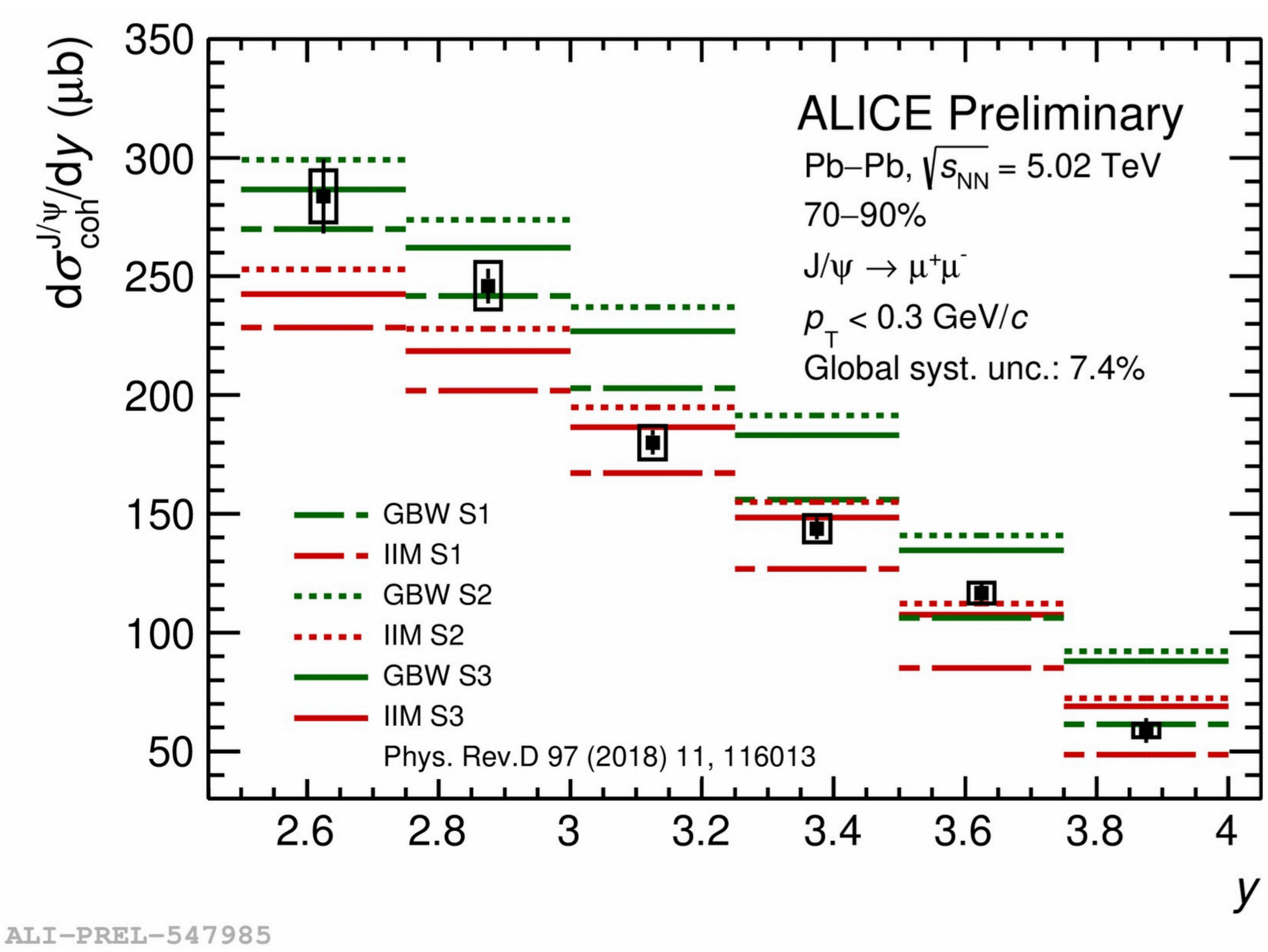
Zha : assumptions on photon-pomeron coupling (nucleus+spectator)

GBW/IIM S3 : effective photon flux and photonuclear cross section considered w.r.t UPC calculations (accounting for nuclear overlap)

A strong rapidity dependence is seen

Models initially developed for VM photoproduction in UPC and modified for PC are able **to describe qualitatively the magnitude of the cross section, but fail at reproducing the *y*-dependence,** similarly to UPC.

J/ψ photoproduction cross section vs. y



GBW/IIM: extending UPC models to PCs considering the overlap region

— - S1 : no relevant modifications w.r.t the UPC calculations

- - S2 : effective photon flux where only photons reaching the spectator region are considered

— S3: S2 + modification of the photonuclear cross section (exclusion of the overlap region)

The three scenarios are qualitatively describing the cross section

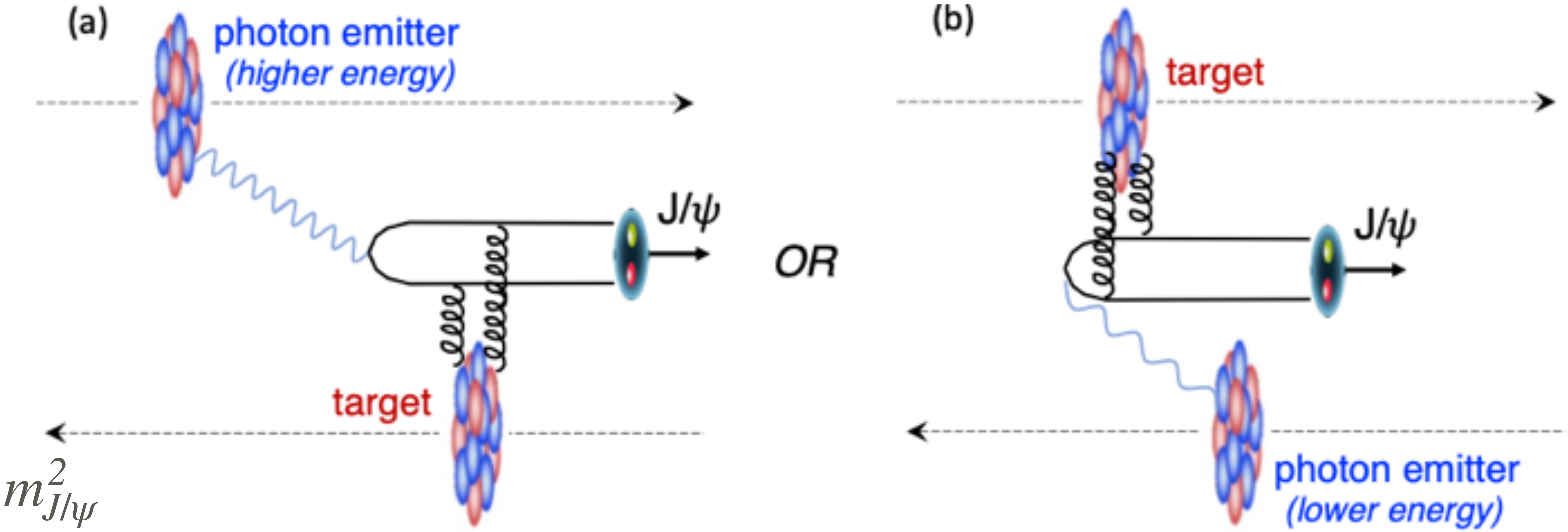
Any effect related to the nuclear overlap is expected to be small in the peripheral 70-90% centrality range

Understanding the impact of the nuclear overlap on the VM photoproduction cross section measurement is a theoretical challenge

Photon energy ambiguity

Each colliding nucleus could serve as a photon emitter, the other acts as a target (±y)

Ambiguity due to sign in the rapidity of the photon emitter



$$x = \frac{m^2_{J/\psi}}{W^2_{\gamma \mathrm{Pb}}}$$

Higher photon energy ($W_{\gamma \mathrm{Pb}}$) corresponds to lower Bjorken-x

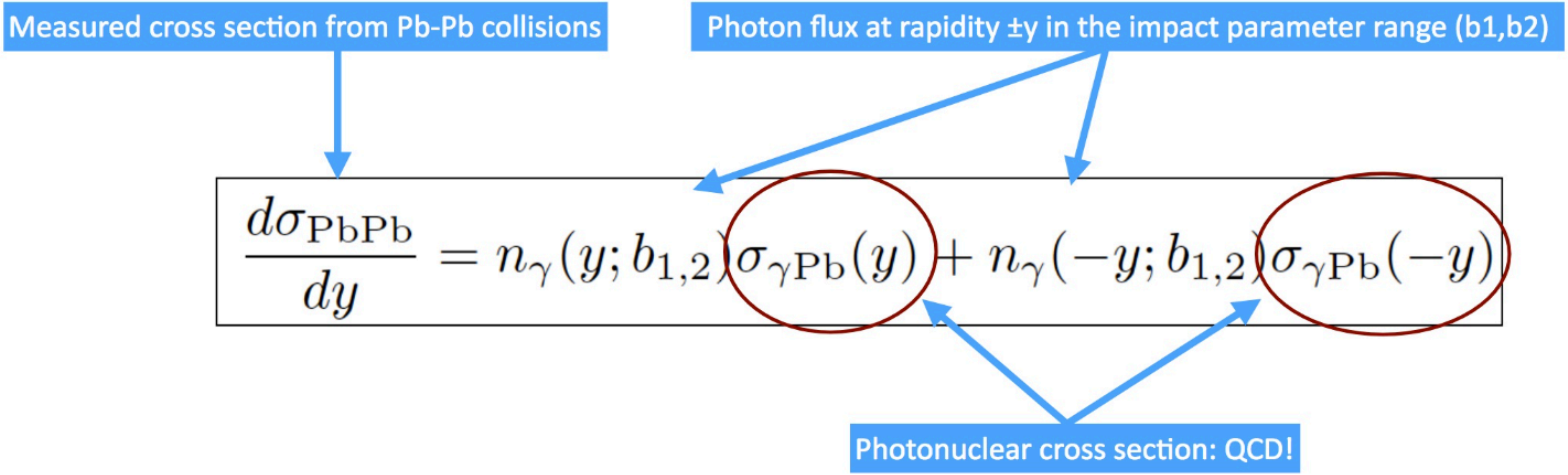
$$x = \frac{m_{J/\psi}}{\sqrt{s_{\mathrm{NN}}}} \times \exp(\pm y)$$

Different y corresponds to different Bjorken-x and photon energy (WγPb)

For a fixed mass ($m_{J/\psi}$) and center-of-mass energy ($\sqrt{s_{\mathrm{NN}}}$),

Distinguish different Bjorken-x regions depend on **photon energy (WγPb) and rapidity (y)**

Photon energy ambiguity



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!

Proposed solution by [J. G. Contreras, PRC 96, 015203 (2017)]

Measurement of cross section

i) **Electromagnetic dissociation nuclei (EMD): Different neutron emission (arxiv:2305.19060)**

ii) **Rapidity measurement in UPC and PCs (both integrated and differential measurement)**

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Photon energy ambiguity

Perform two independent measurements at the same rapidity, but different impact parameter, then solve the equations.

$$\left(\frac{d\sigma_{\mathrm{PbPb}}}{dy}\right)_A = n_\gamma(y;\{b\}_A)\sigma_{\gamma\mathrm{Pb}}(y)+n_\gamma(-y;\{b\}_A)\sigma_{\gamma\mathrm{Pb}}(-y)$$

A =UPC

$$\left(\frac{d\sigma_{\mathrm{PbPb}}}{dy}\right)_B = n_\gamma(y;\{b\}_B)\sigma_{\gamma\mathrm{Pb}}(y)+n_\gamma(-y;\{b\}_B)\sigma_{\gamma\mathrm{Pb}}(-y)$$

B= PC

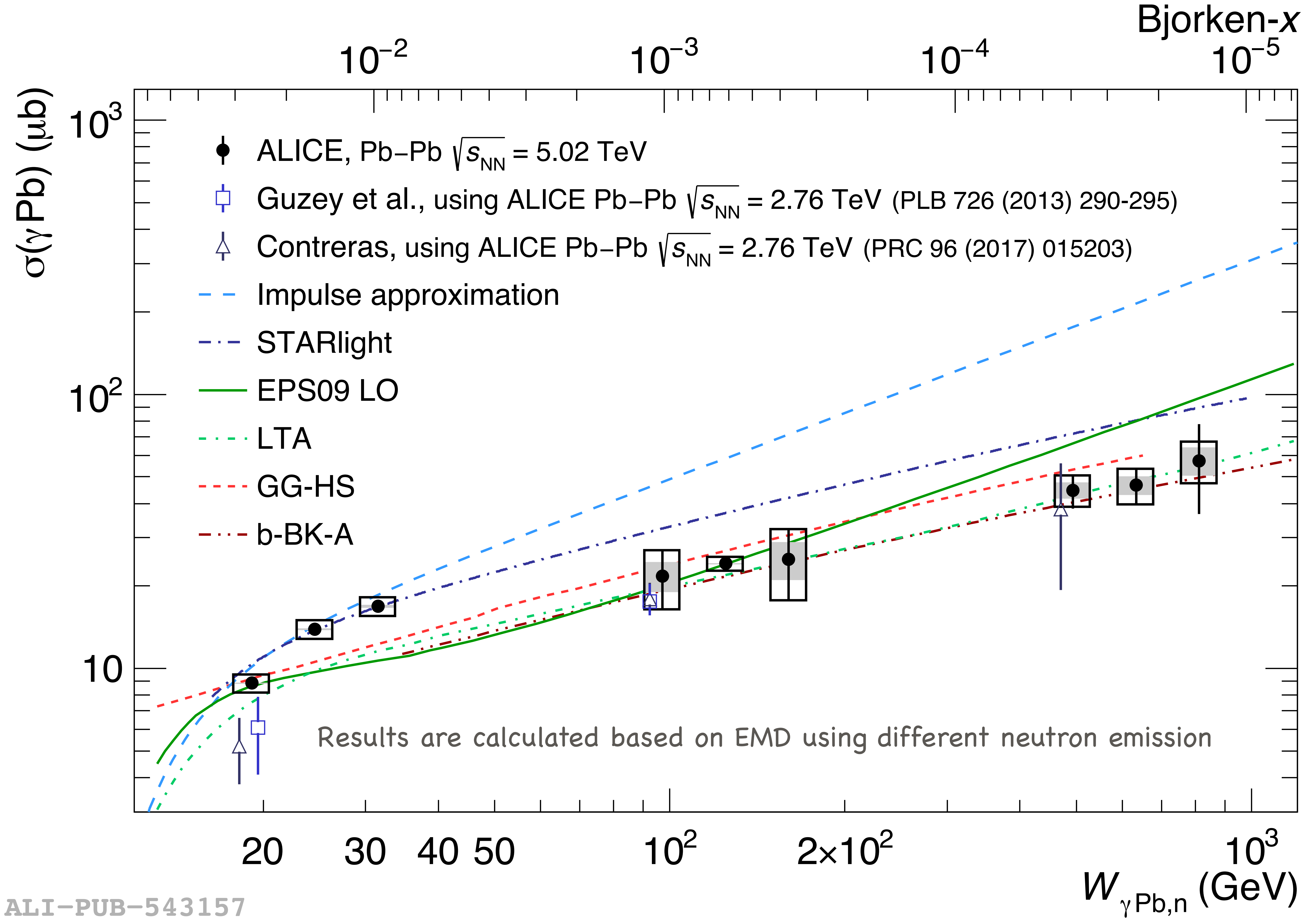
Observable :

$\sigma_{\gamma Pb}$ vs. $W_{\gamma Pb}$ or x

For example, use peripheral and ultra-peripheral collisions

JGC, PRC **96**, 015203 (2017)

Photo production of VM: $\sigma_{\gamma Pb}$ vs. $W_{\gamma Pb}$ or x



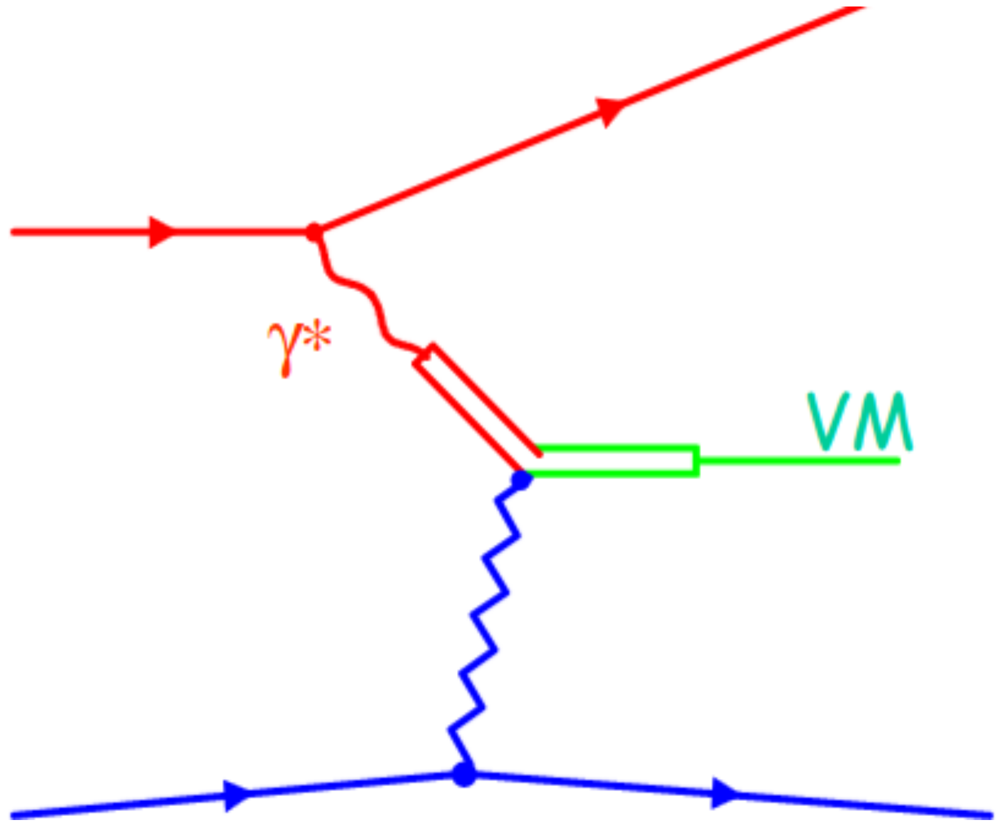
Recent measurement photo nuclear cross section ($\sigma_{\gamma Pb}$) access to go low-x (10^{-5})

At low -x data favors both saturation and shadowing models

Using new results rapidity dependence of PC and UPC, further understanding can be done on photo-nuclear cross section calculation

Further theoretical inputs are needed to understand from low-x to high-x regions

Polarization : Coherent vector meson photoproduction



Polarization refers to the particle spin alignment with respect to a chosen direction

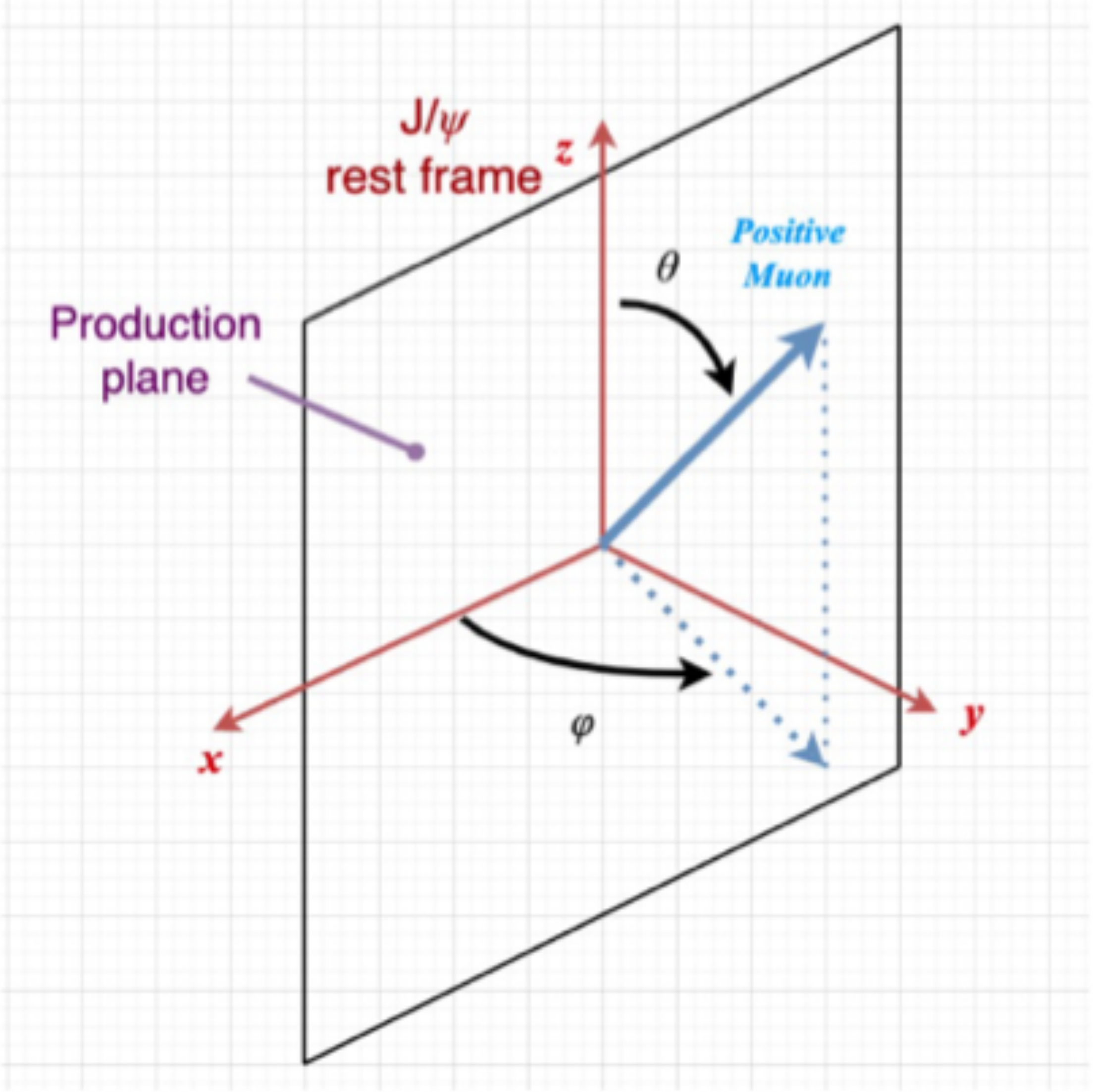
s-channel helicity conservation (SCHC): helicity or polarization of photon transferred to vector meson (J/ψ)

Vector meson (VM) has retained same helicity and polarization as that of the initial photon that interacted with the target

Phys. Lett. B 31 (1970) 387-390, JETP Lett. 68 (1998) 696-703

Helicity frame

z-axis (polarization axis): flight direction of the J/ψ in its rest frame



Dilepton decay angular distribution

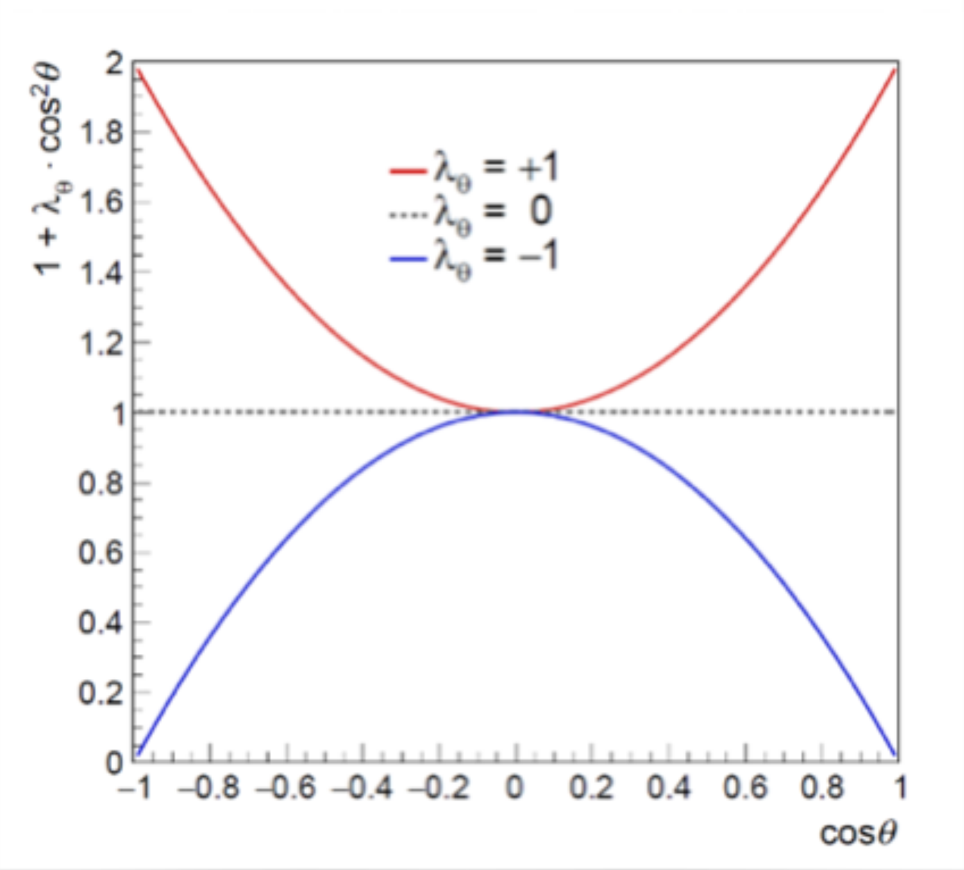
P. Faccioli et al., Eur.Phys.J.C69:657-673, 2010

$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_\theta} \cdot (1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi)$$

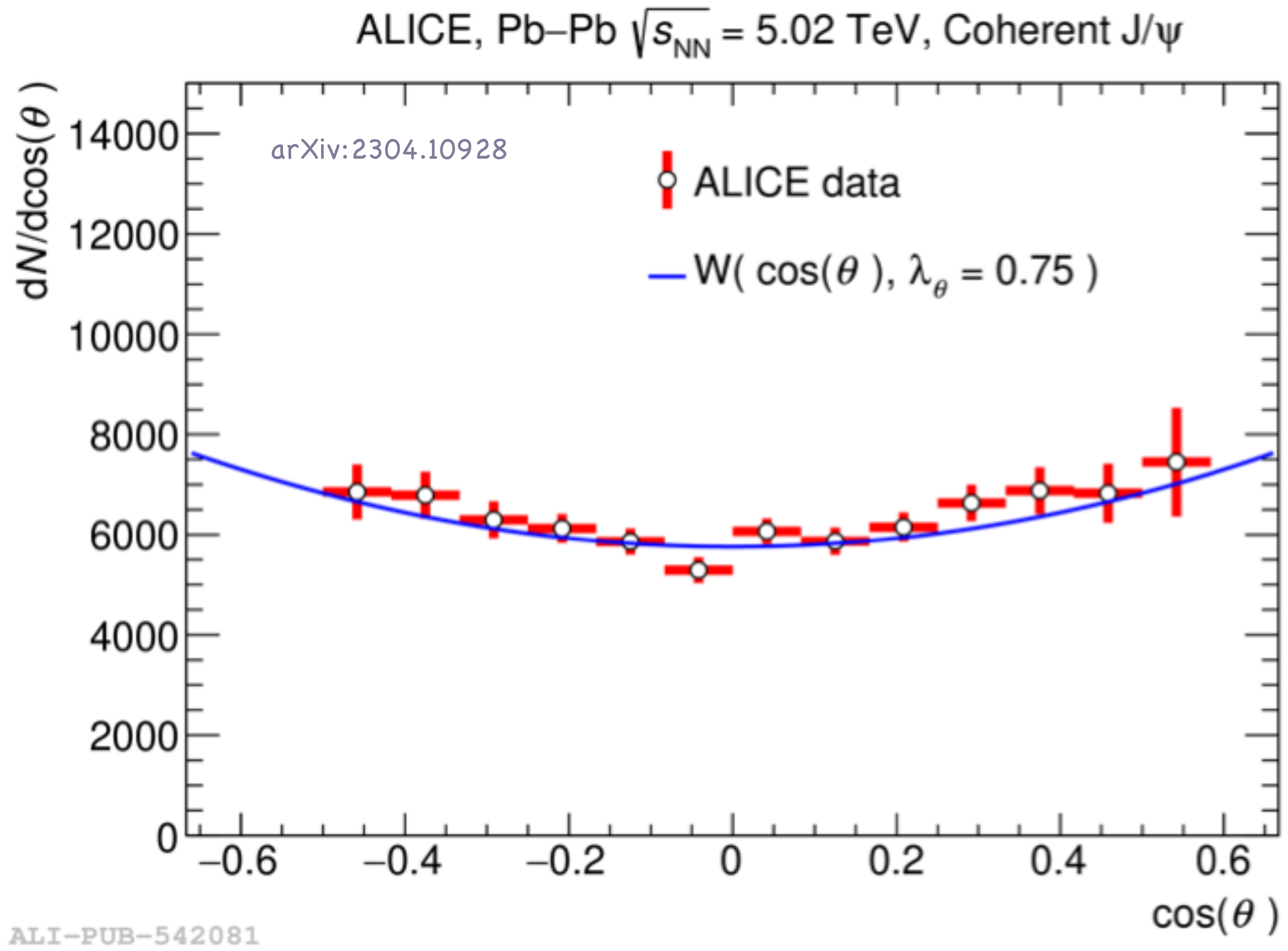
$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (0,0,0)$ ⇒ No polarization

$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (+1,0,0)$ ⇒ Transverse polarization

$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (-1,0,0)$ ⇒ Longitudinal polarization



Polarization : Coherent vector meson photo production in UPC



Coherently photoproduced J/ψ in UPCs at $\sqrt{s_{NN}}$ = 5.02 TeV

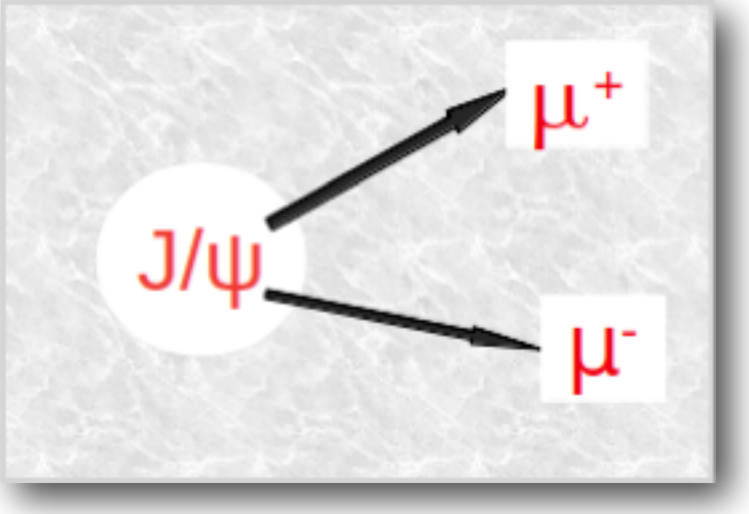
Transversely polarized

Consistent with SCHC hypothesis

Do we expect similar observation for J/ψ at low p_T (< 0.3 GeV/c) in Pb—Pb collisions with nuclear overlap (70-90 %)

Additional challenge w.r.t UPC measurement : deal with a contamination from hadronic J/ψ

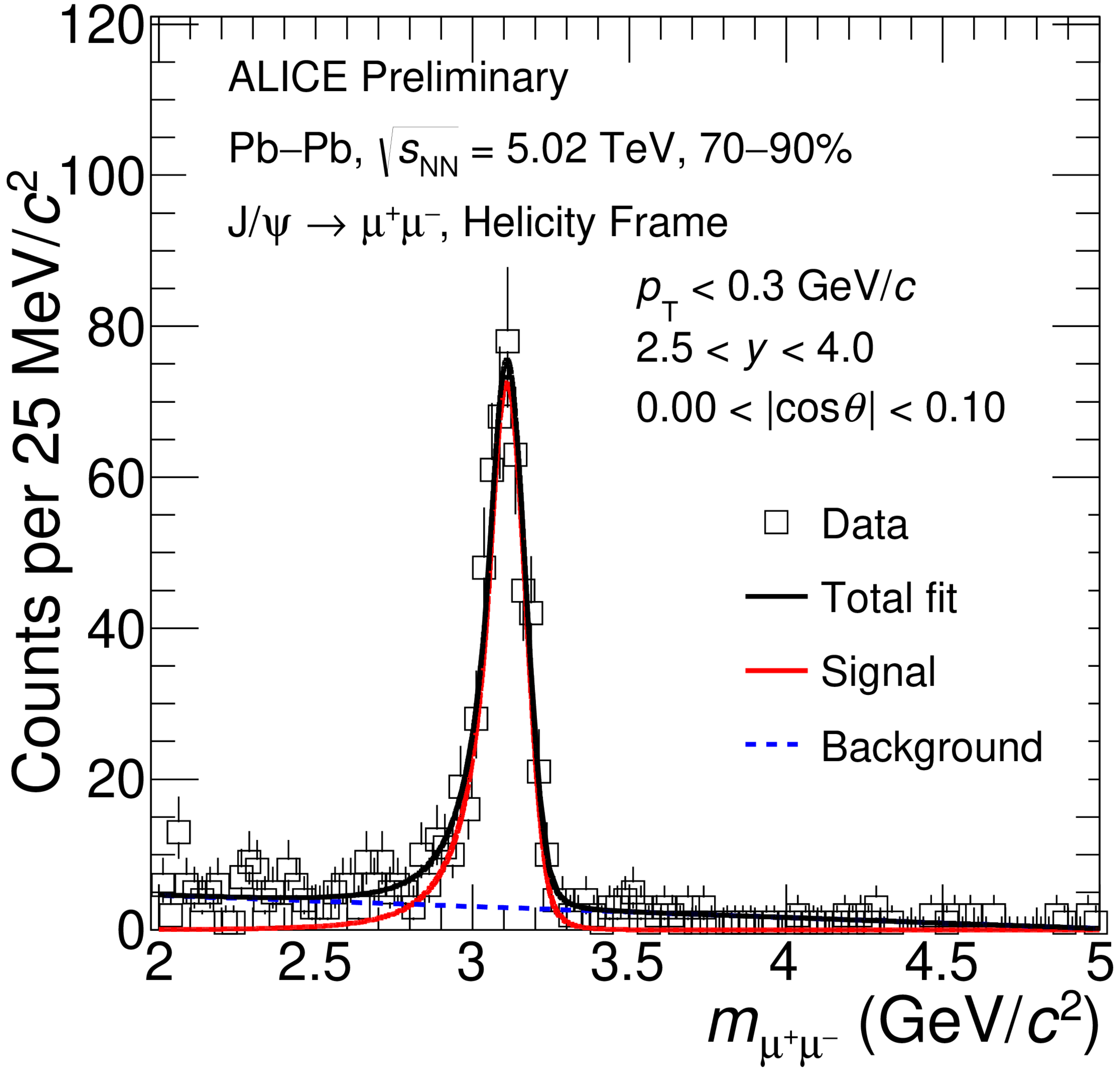
J/ψ signal extraction in angular intervals for $p_T < 0.3$ GeV/c



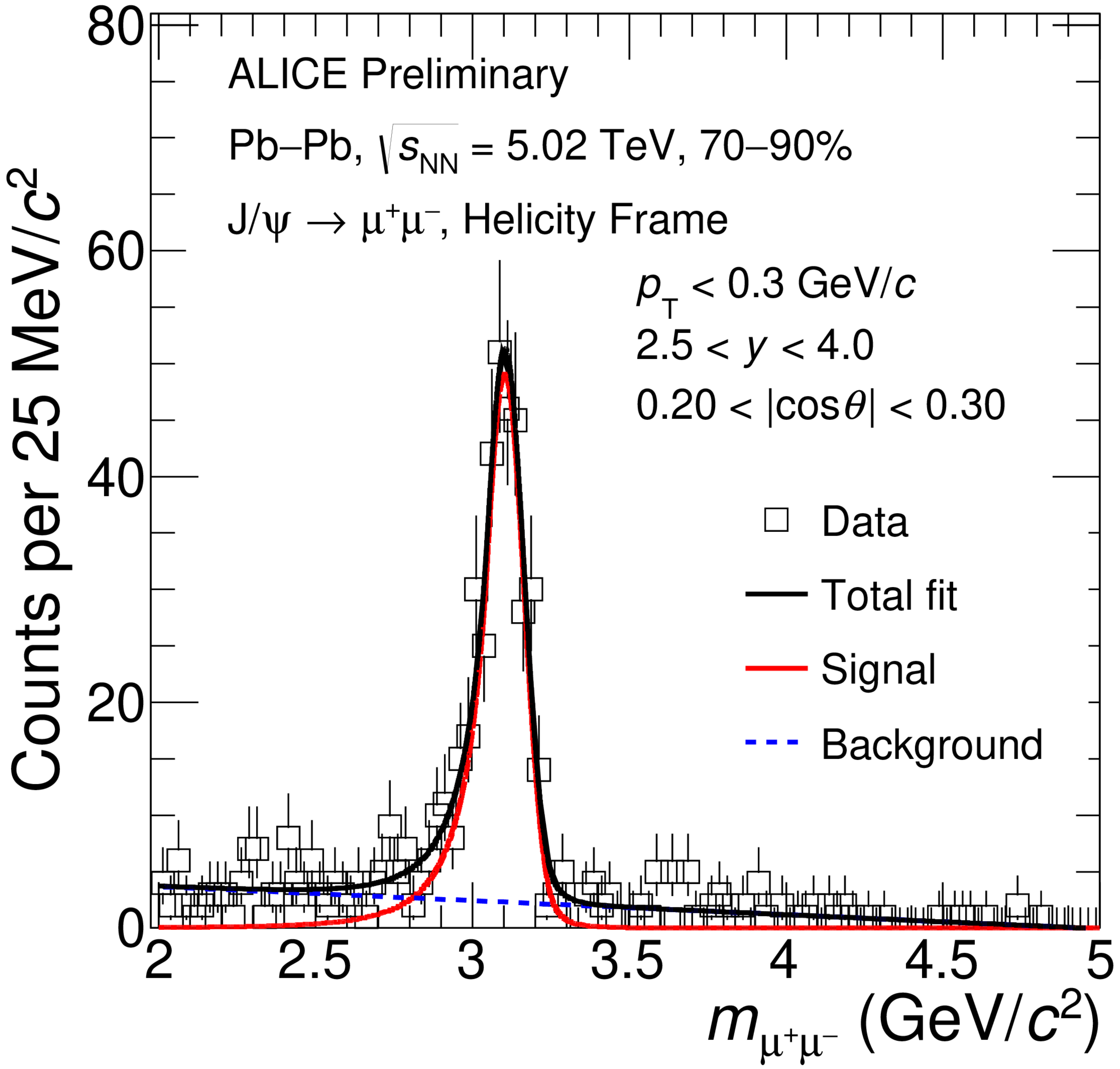
J/ψ → $\mu^+\mu^-$, 70-90%, 2.5 < y < 4, $p_T < 0.3$ GeV/c

$$m^2 = E^2 - \vec{p}^2 = (E_{\mu^+} + E_{\mu^-})^2 - (\vec{p_{\mu^+}} + \vec{p_{\mu^-}})^2$$

J/ψ signal is extracted in six cosθ intervals using the dimuon invariant mass distribution

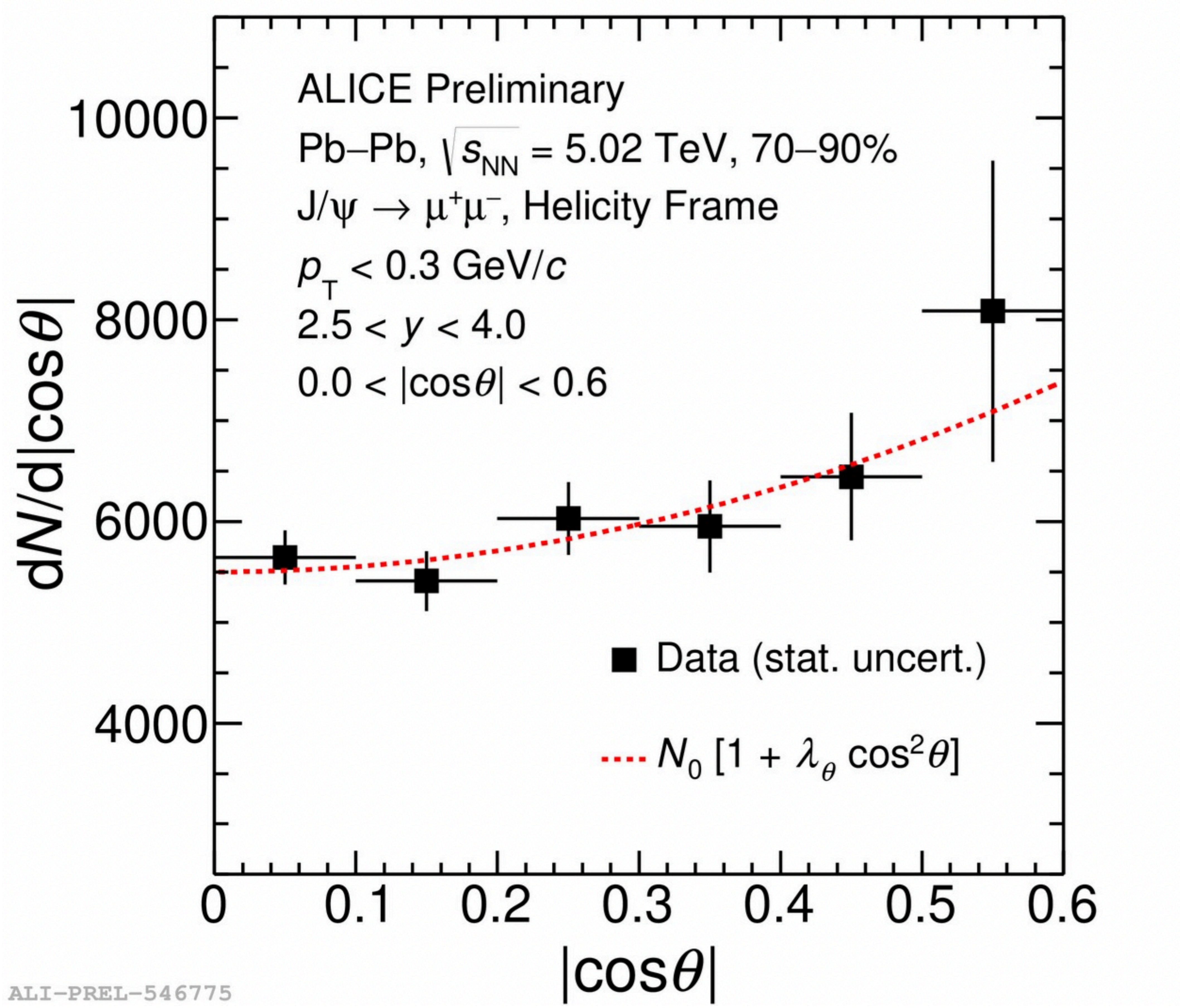


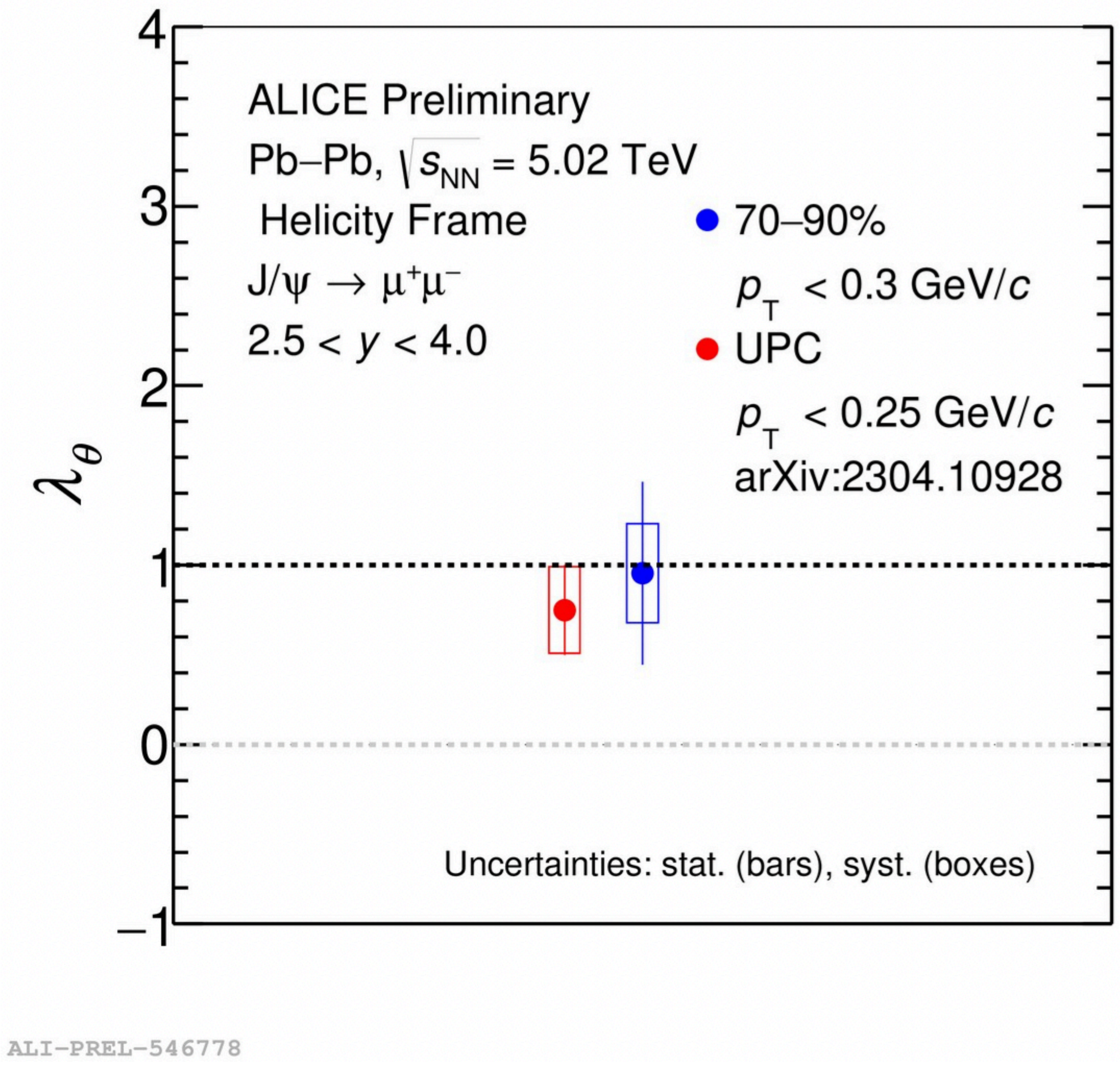
ALI-PREL-546762



ALI-PREL-546765

Inclusive J/ψ polarization in Pb-Pb collisions for $p_T < 0.3$ GeV/c





A hint for transverse polarization from cosθ angular distribution

The λ_θ parameter is **consistent with the UPC measurement for coherently photoproduced J/ψ within uncertainties**

➔ As expected in this kinematic region, where J/ψ coherent photoproduction dominates over the J/ψ hadronic production [arXiv:2204.10684]

Summary and Outlook

Rapidity dependence cross section measurement :

- ☑ **First y-differential measurement of coherent J/ψ photoproduction cross section** in peripheral Pb−Pb collisions (PC) with nuclear overlap at $\sqrt{s_{NN}}$ = 5.02 TeV for $p_T < 0.3$ GeV/c
- ☑ **Shows a strong y-dependence** similar to that observed in Ultraperipheral collisions (UPC).
- ☑ Measurements are **qualitatively described by a large number of vector meson photoproduction models** developed for UPC and extended to PC, but fail at reproducing the y-dependence (similarly to UPC)

Polarization measurement:

- ☑ **First inclusive J/ψ polarization measurement for $p_T < 0.3$ GeV/c** in peripheral Pb−Pb collisions with nuclear overlap at $\sqrt{s_{NN}}$ = 5.02 TeV
- ☑ In agreement with **the transverse polarization scenario (SCHC hypothesis) and consistent with a major contribution from a photoproduction** process in the region of study.

Outlook

- ☐ The coherent J/ψ photoproduction cross section measurement can be exploited to **extract photonuclear cross sections in two Bjorken-x regions** [J.G. Contreras, Phys. Rev. C 96, 015203 (2017)]

- ☐ **ALICE Run 3 will provide a large Pb–Pb data sample :**

will permit to study J/ψ photoproduction in the most central collisions, to better constrain models (especially the role of spectator nucleons in the coherence condition) -> **precision and more differential measurements**

- ☐ Look at **heavier vector mesons could become also possible to pin down possible QGP effects on the measured probes and precision polarization measurement of J/ψ other VMs**

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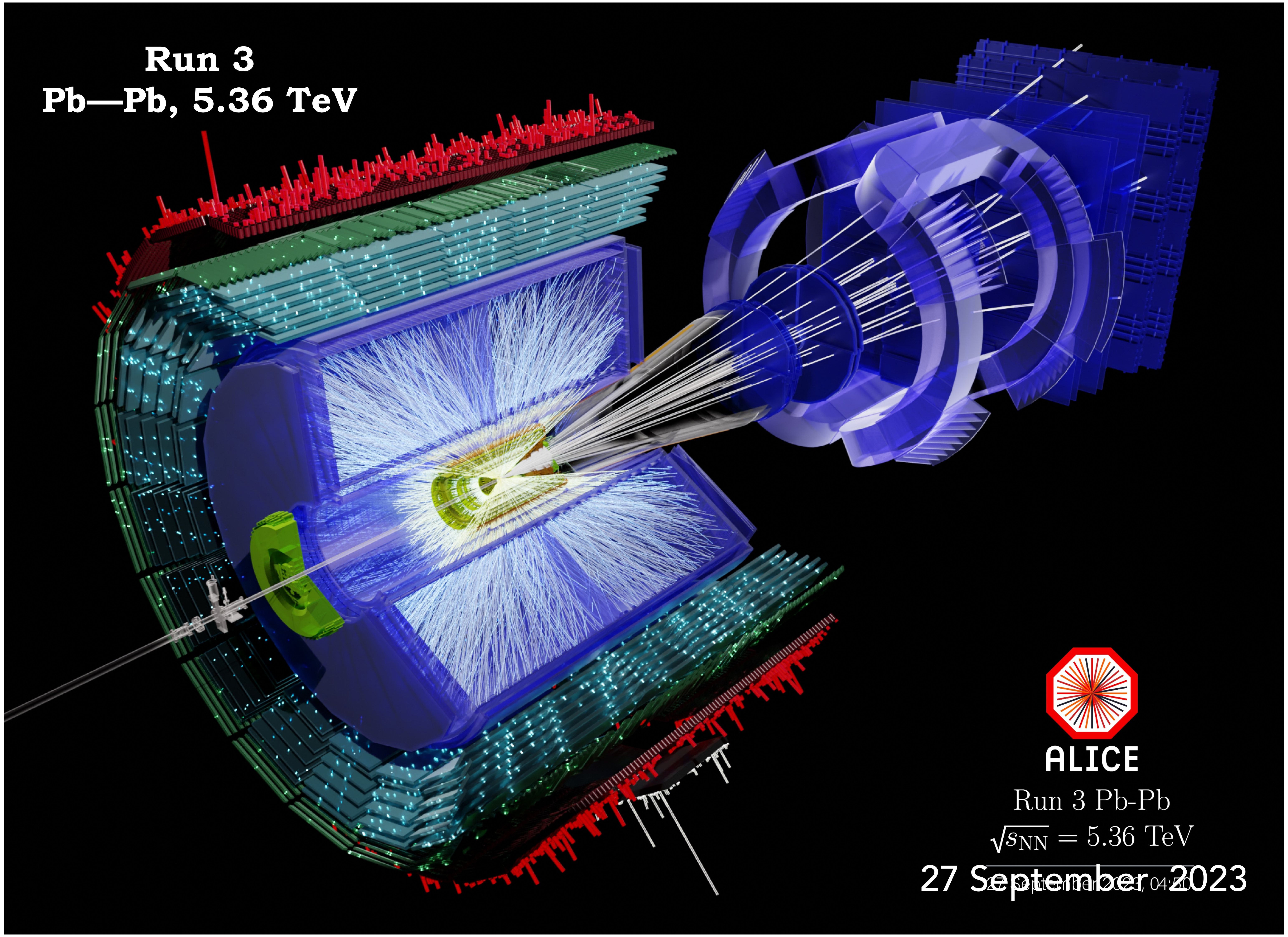
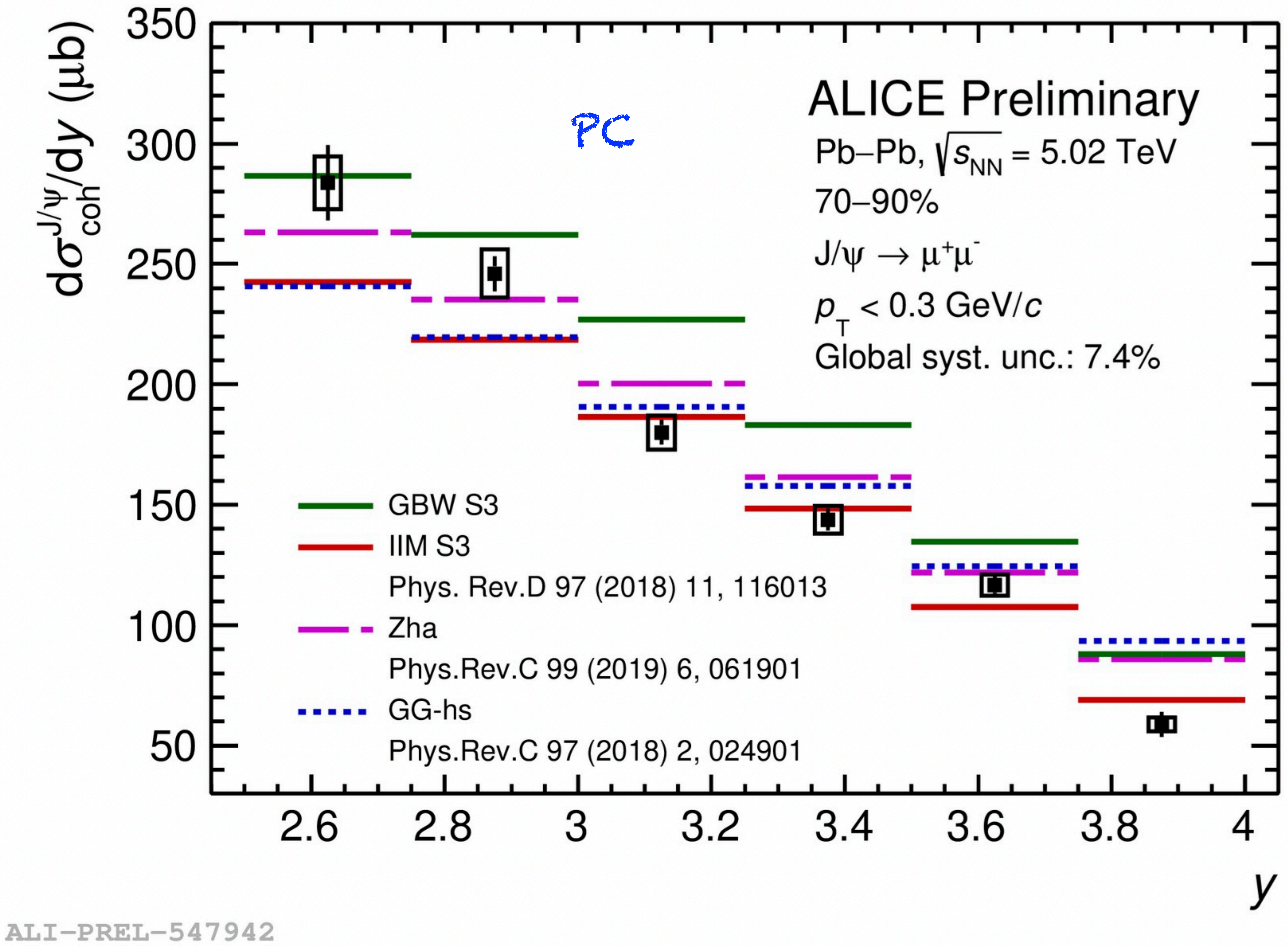
Event display : first Run 3 Pb-Pb collisions, 2023



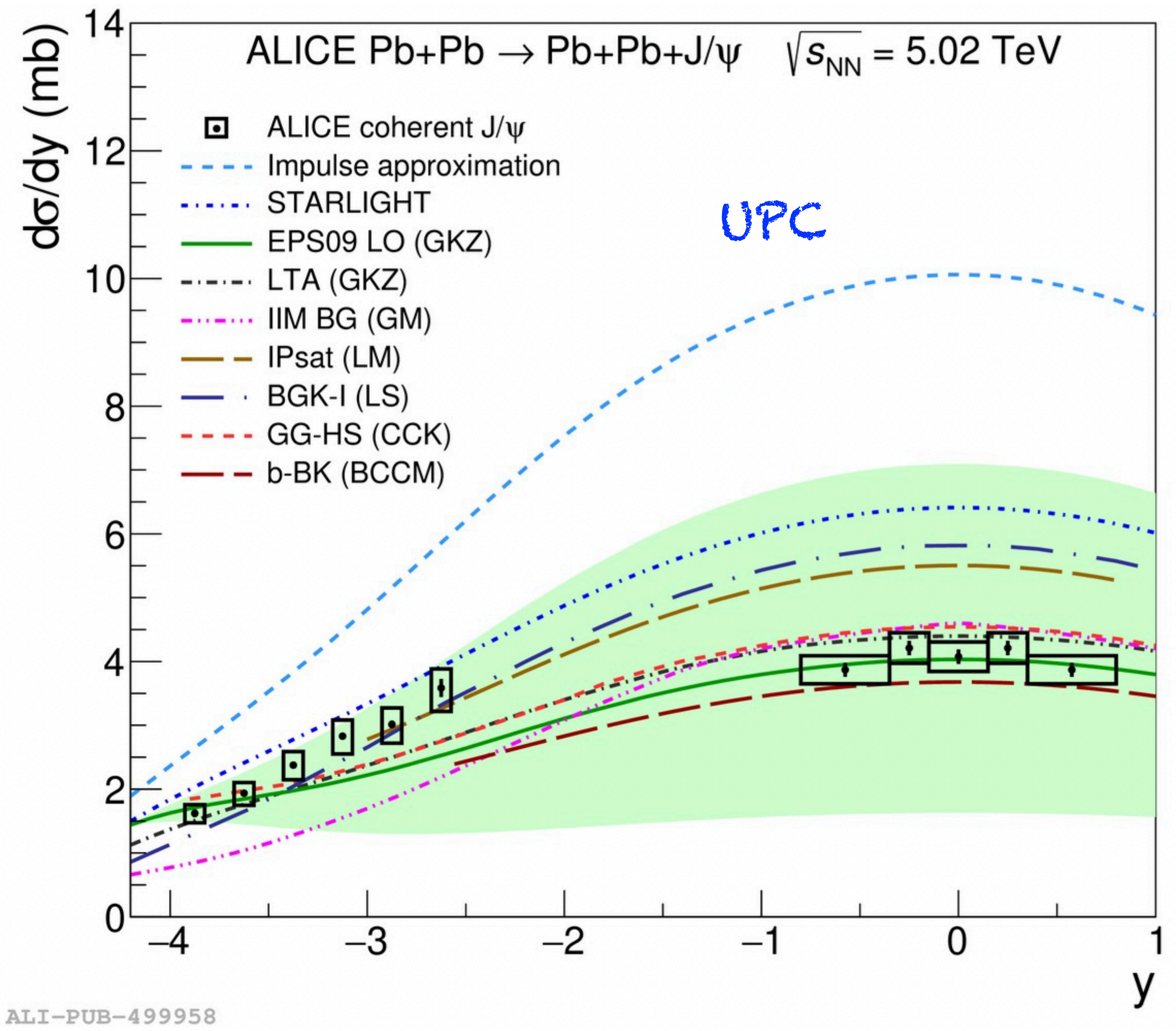
Stay tuned for more to come !

Thank you for your kind attention !

J/ψ photoproduction cross section vs. y



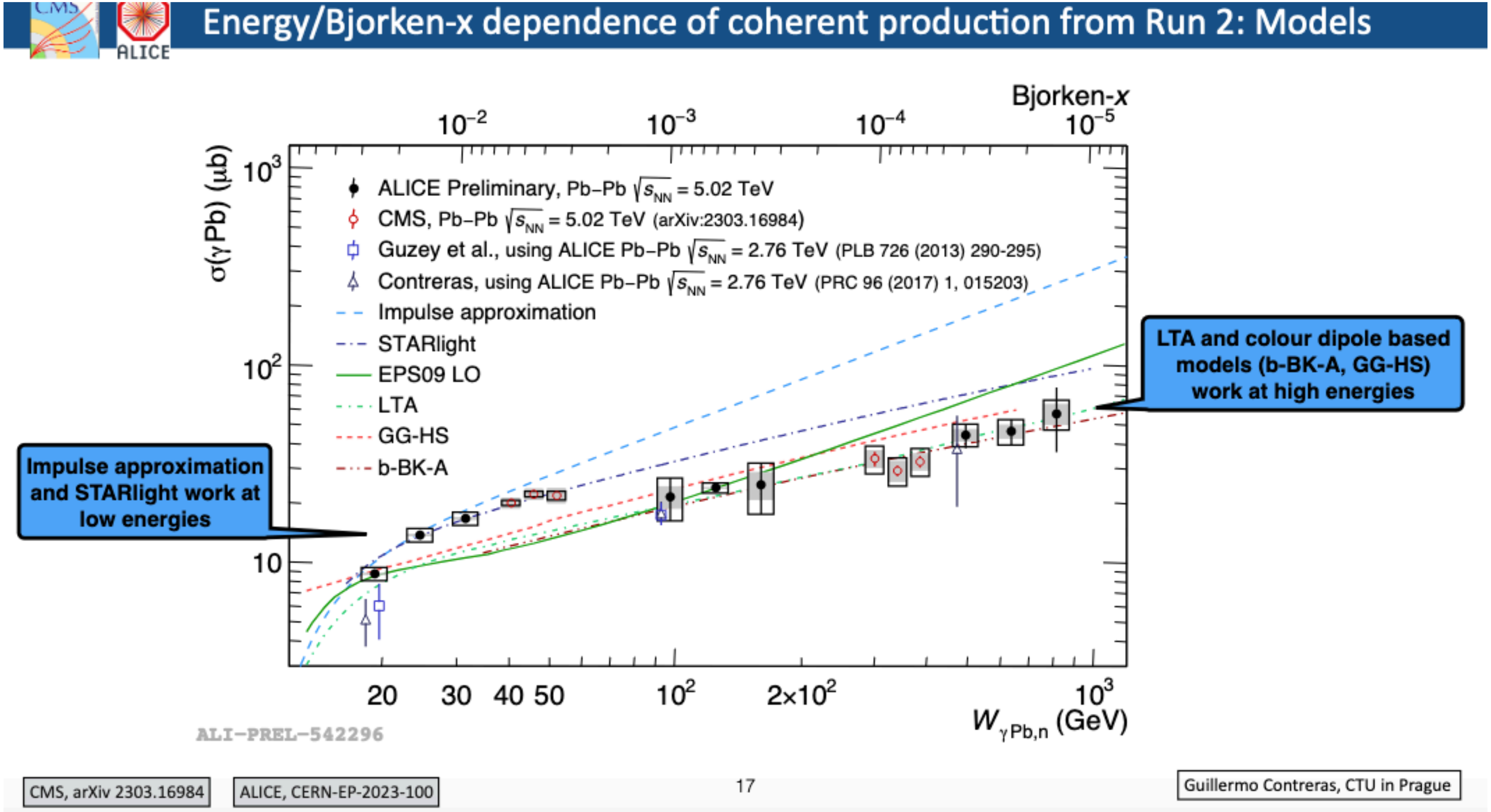
Phys. Lett. B798 (2019) 134926



A strong rapidity dependence is seen

Models initially developed for VM photoproduction in UPC and modified for PC are able **to describe qualitatively the magnitude of the cross section, but fail at reproducing the *y*-dependence,** similarly to UPC.

photo nuclear cross section



Energy/Bjorken-x dependence of coherent production from Run 2: Models

Impulse approximation and STARlight work at low energies

LTA and colour dipole based models (b-BK-A, GG-HS) work at high energies

CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

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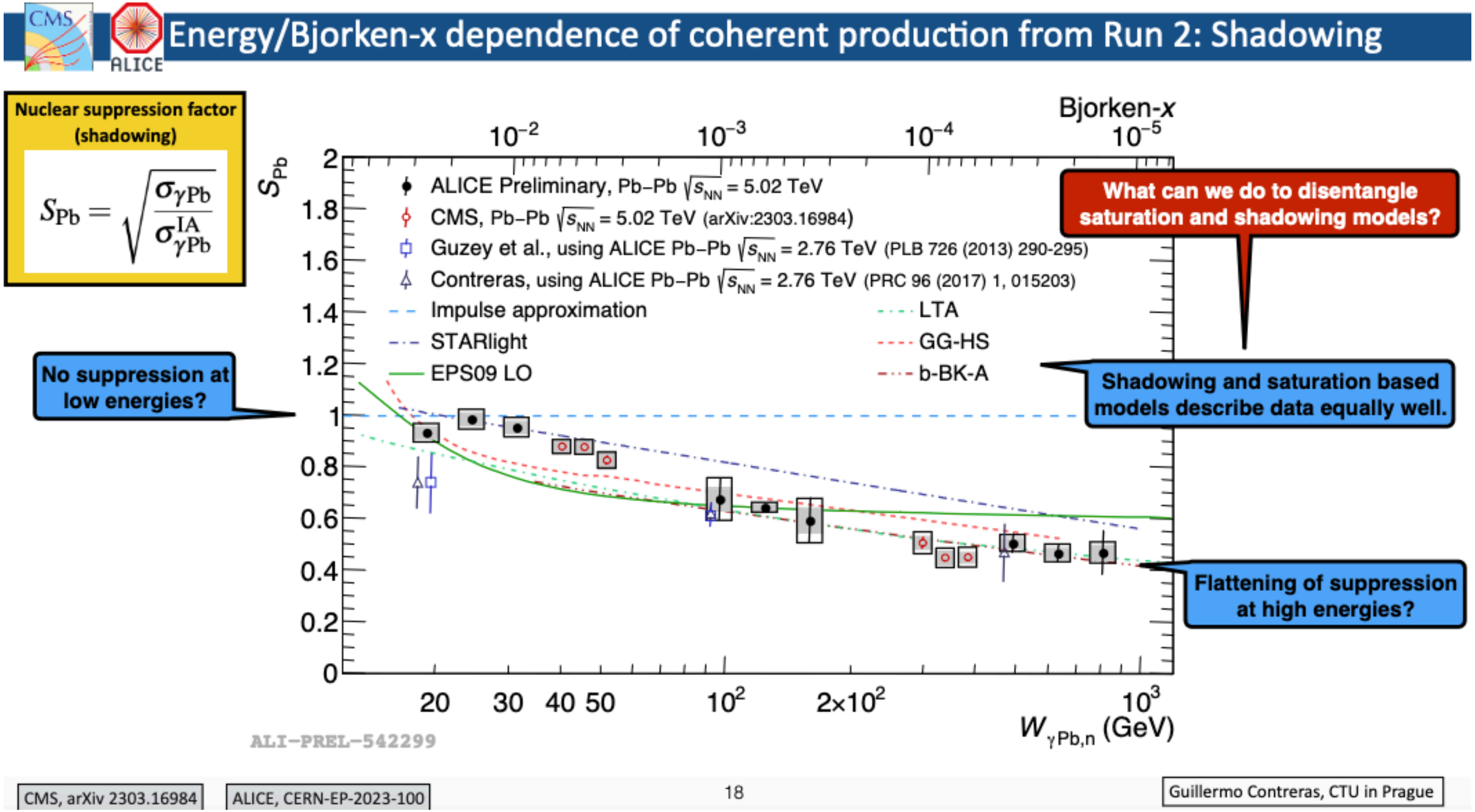
Guillermo Contreras, CTU in Prague

Nuclear shadowing



Energy/Bjorken-x dependence of coherent production from Run 2: Shadowing

Nuclear suppression factor (shadowing)

$$S_{Pb} = \sqrt{\frac{\sigma_{\gamma Pb}}{\sigma^{IA}_{\gamma Pb}}}$$

No suppression at low energies?

What can we do to disentangle saturation and shadowing models?

Shadowing and saturation based models describe data equally well.

Flattening of suppression at high energies?

CMS, arXiv 2303.16984

ALICE, CERN-EP-2023-100

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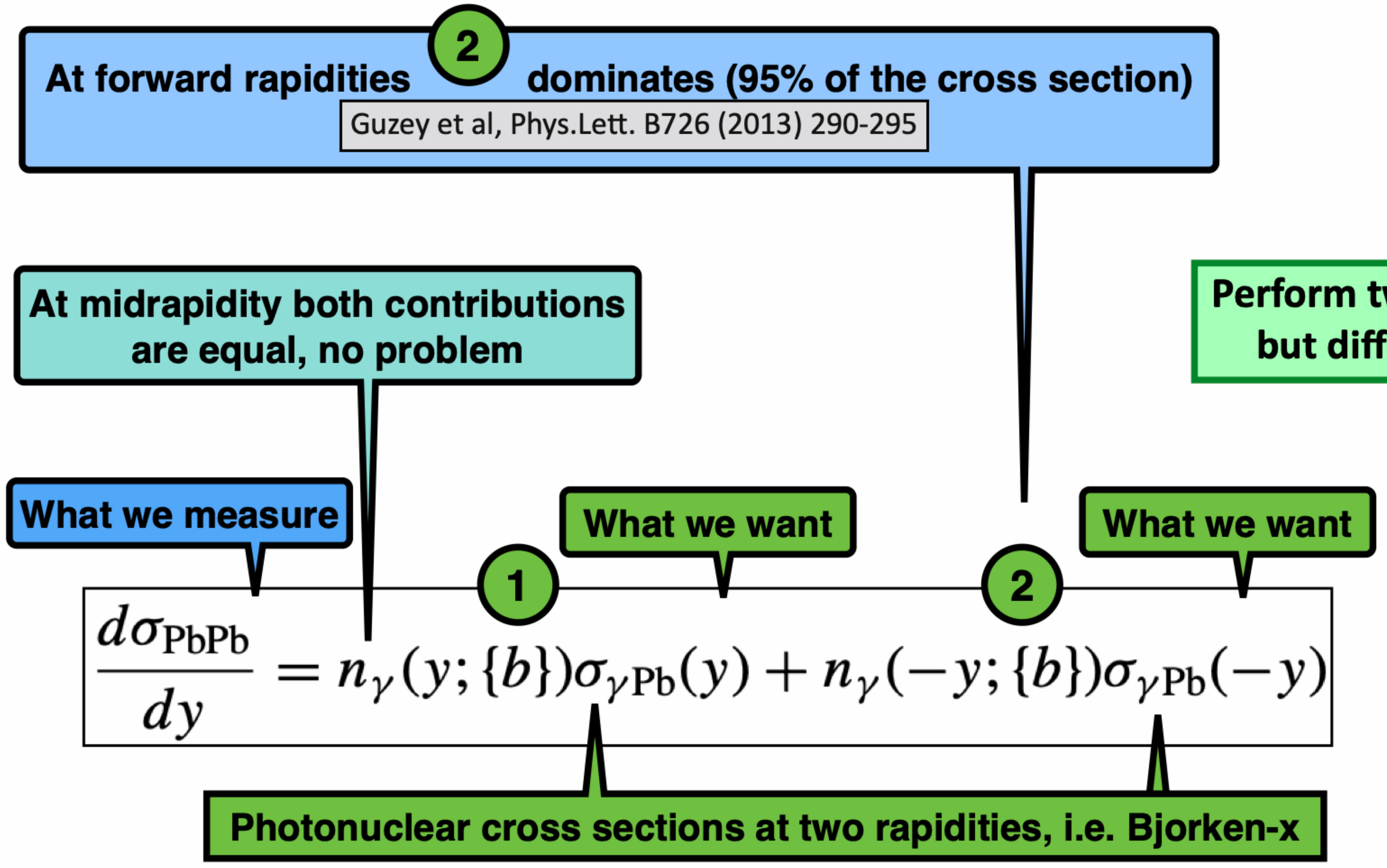
Photon energy ambiguity : Experimentally



At forward rapidities ② dominates (95% of the cross section)
Guzey et al, Phys.Lett. B726 (2013) 290-295

At midrapidity both contributions are equal, no problem

What we measure

What we want

What we want

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

Photonuclear cross sections at two rapidities, i.e. Bjorken-x

How to extract the photonuclear cross section if the photon fluxes are known?

$$x_B = (m_{J/\psi}/\sqrt{s_{\mathrm{NN}}}) \times \exp(\pm y)$$

Perform two independent measurements at the same rapidity, but different impact parameter, then solve the equations.

$$\left(\frac{d\sigma_{\mathrm{PbPb}}}{dy}\right)_A = n_\gamma(y;\{b\}_A)\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;\{b\}_A)\sigma_{\gamma\mathrm{Pb}}(-y)$$

$$\left(\frac{d\sigma_{\mathrm{PbPb}}}{dy}\right)_B = n_\gamma(y;\{b\}_B)\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;\{b\}_B)\sigma_{\gamma\mathrm{Pb}}(-y)$$

For example, use peripheral and ultra-peripheral collisions
JGC, PRC **96**, 015203 (2017)

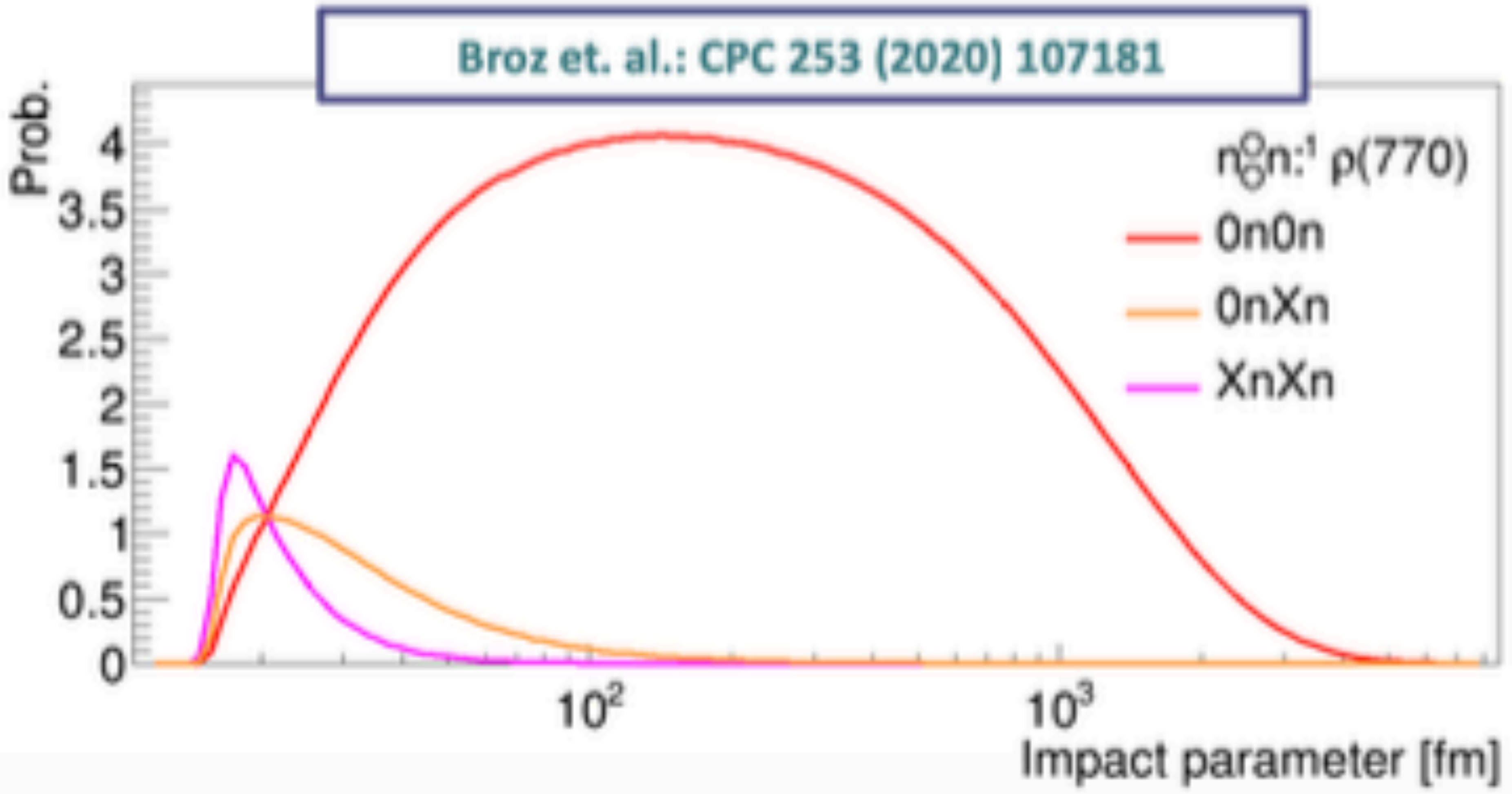
use PC measurement with the previous UPC measurement to disentangle the contribution from the low and high energy photon-nucleus interaction.

Caveat: this suggestion considers the photon-nucleus cross sections in both PC and UPC to be the same.

Photon energy ambiguity : Neutron emission

Neutron emission:

- $x = \frac{M_{\mathrm{VM}}}{\sqrt{s_{\mathrm{NN}}}} \cdot e^{\pm y}$
- Ambiguity due to sign in the rapidity of the photon emitter → $10^{-2}, 10^{-5}$
- Additional photon exchanges may lead to neutron emission


Broz et. al.: CPC 253 (2020) 107181

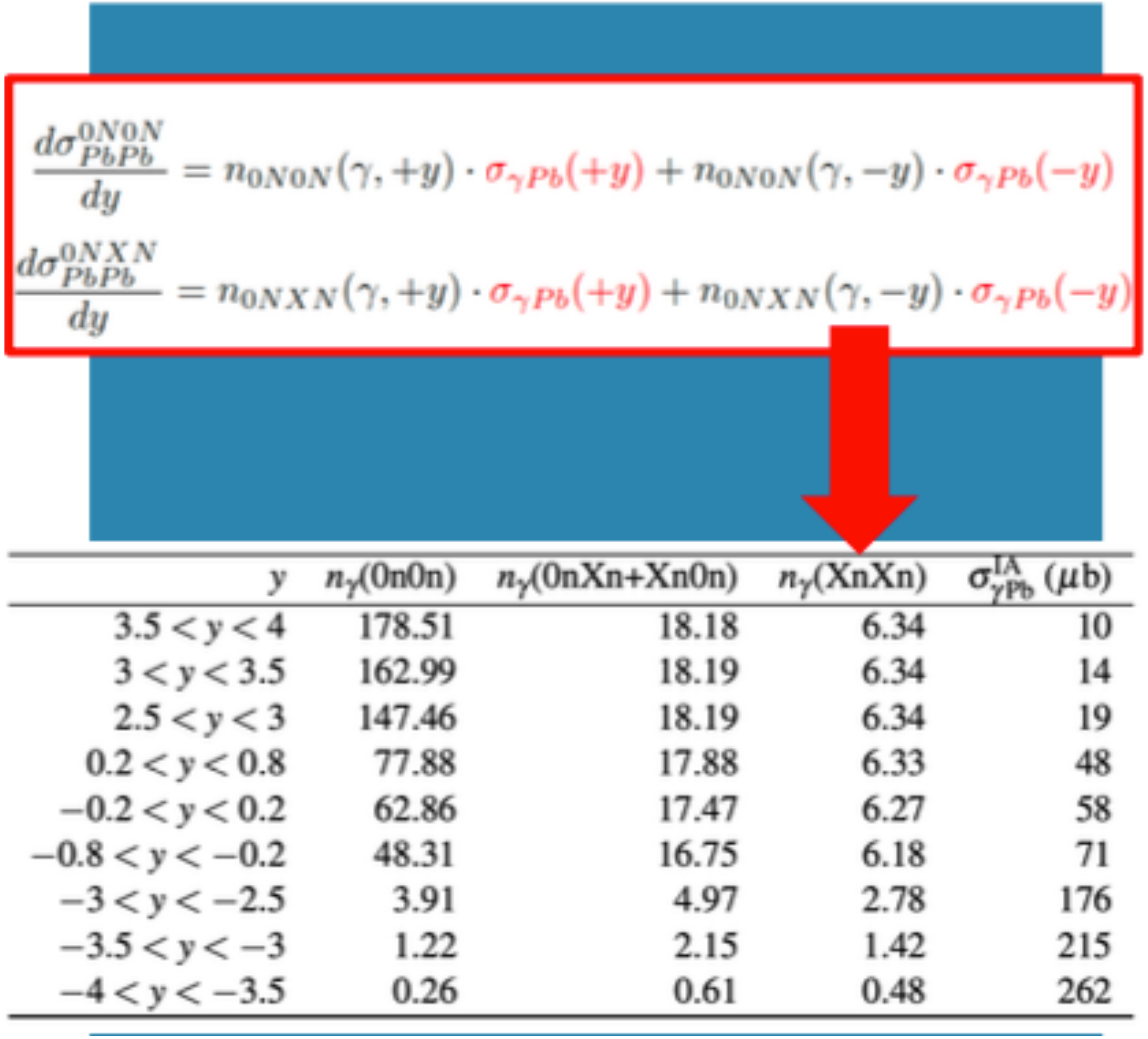
$$\frac{d\sigma^{0N0N}_{PbPb}}{dy} = n_{0N0N}(\gamma, +y) \cdot \sigma_{\gamma Pb}(+y) + n_{0N0N}(\gamma, -y) \cdot \sigma_{\gamma Pb}(-y)$$

$$\frac{d\sigma^{0NXN}_{PbPb}}{dy} = n_{0NXN}(\gamma, +y) \cdot \sigma_{\gamma Pb}(+y) + n_{0NXN}(\gamma, -y) \cdot \sigma_{\gamma Pb}(-y)$$

Guzey et al.,
Eur.Phys.J.C 74 (2014) 7, 2942

- Using the neutron ZDCs on the A and C side to detect the neutrons!
- E.g. 0N0N: no neutrons on either ZDCs
- E.g. 0NXN: neutrons only on one side
- Effectively leveraging on the impact parameter

Photon energy ambiguity : Neutron emission

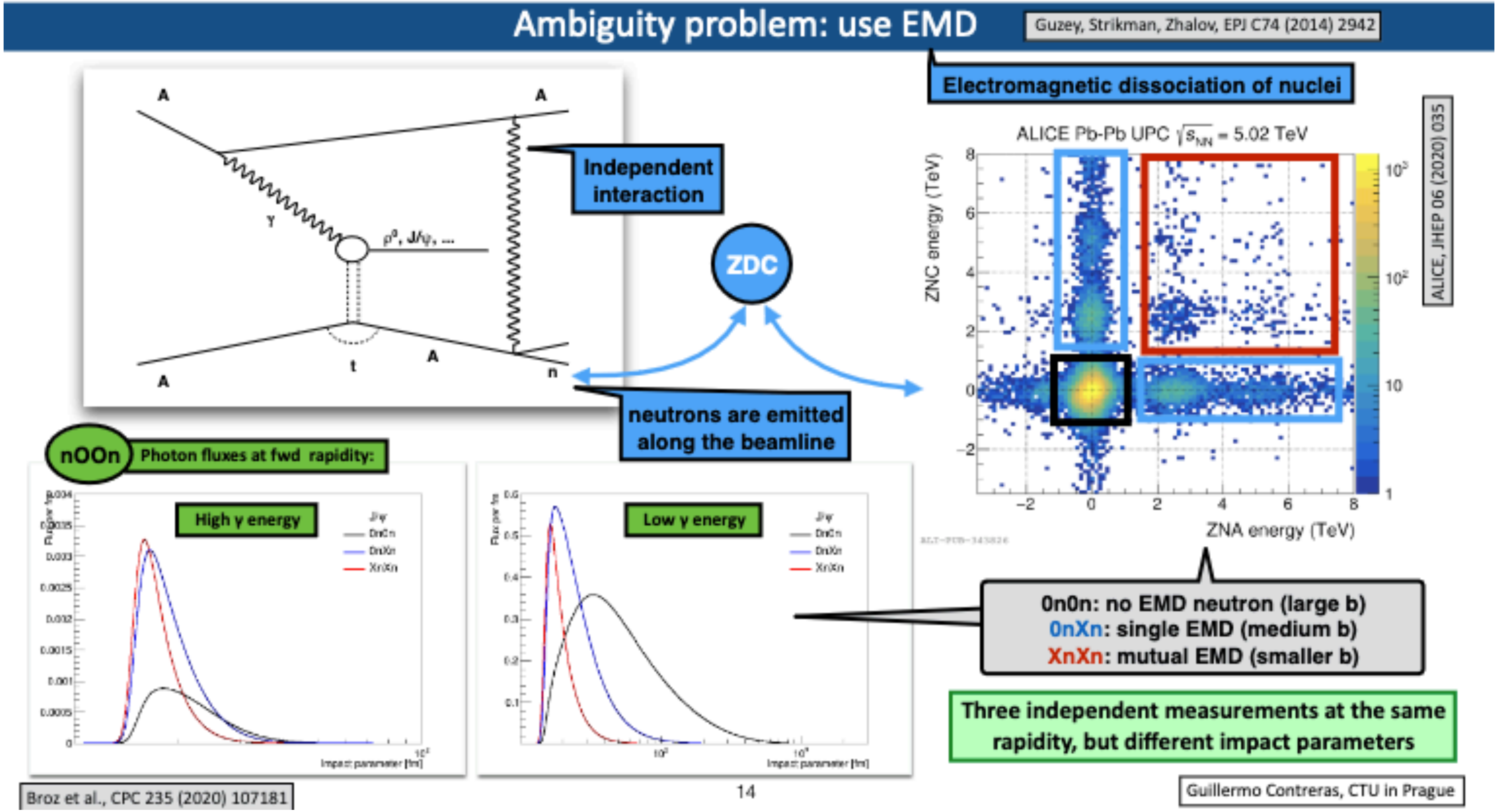


$$\frac{d\sigma^{0N0N}_{PbPb}}{dy} = n_{0N0N}(\gamma,+y)\cdot\sigma_{\gamma Pb}(+y) + n_{0N0N}(\gamma,-y)\cdot\sigma_{\gamma Pb}(-y)$$

$$\frac{d\sigma^{0NXN}_{PbPb}}{dy} = n_{0NXN}(\gamma,+y)\cdot\sigma_{\gamma Pb}(+y) + n_{0NXN}(\gamma,-y)\cdot\sigma_{\gamma Pb}(-y)$$

y	n_γ(0n0n)	n_γ(0nXn+Xn0n)	n_γ(XnXn)	$\sigma^{IA}_{\gamma Pb}$ (μb)
$3.5 < y < 4$	178.51	18.18	6.34	10
$3 < y < 3.5$	162.99	18.19	6.34	14
$2.5 < y < 3$	147.46	18.19	6.34	19
$0.2 < y < 0.8$	77.88	17.88	6.33	48
$-0.2 < y < 0.2$	62.86	17.47	6.27	58
$-0.8 < y < -0.2$	48.31	16.75	6.18	71
$-3 < y < -2.5$	3.91	4.97	2.78	176
$-3.5 < y < -3$	1.22	2.15	1.42	215
$-4 < y < -3.5$	0.26	0.61	0.48	262

Photon energy ambiguity : Neutron emission



Ambiguity problem: use EMD

Guzey, Strikman, Zhalov, EPJ C74 (2014) 2942

Electromagnetic dissociation of nuclei

Independent interaction

neutrons are emitted along the beamline

ALICE, JHEP 06 (2020) 035

nOOn **Photon fluxes at fwd rapidity:**

High γ energy

Low γ energy

0n0n: no EMD neutron (large b)
0nXn: single EMD (medium b)
XnXn: mutual EMD (smaller b)

Three independent measurements at the same rapidity, but different impact parameters

Broz et al., CPC 235 (2020) 107181

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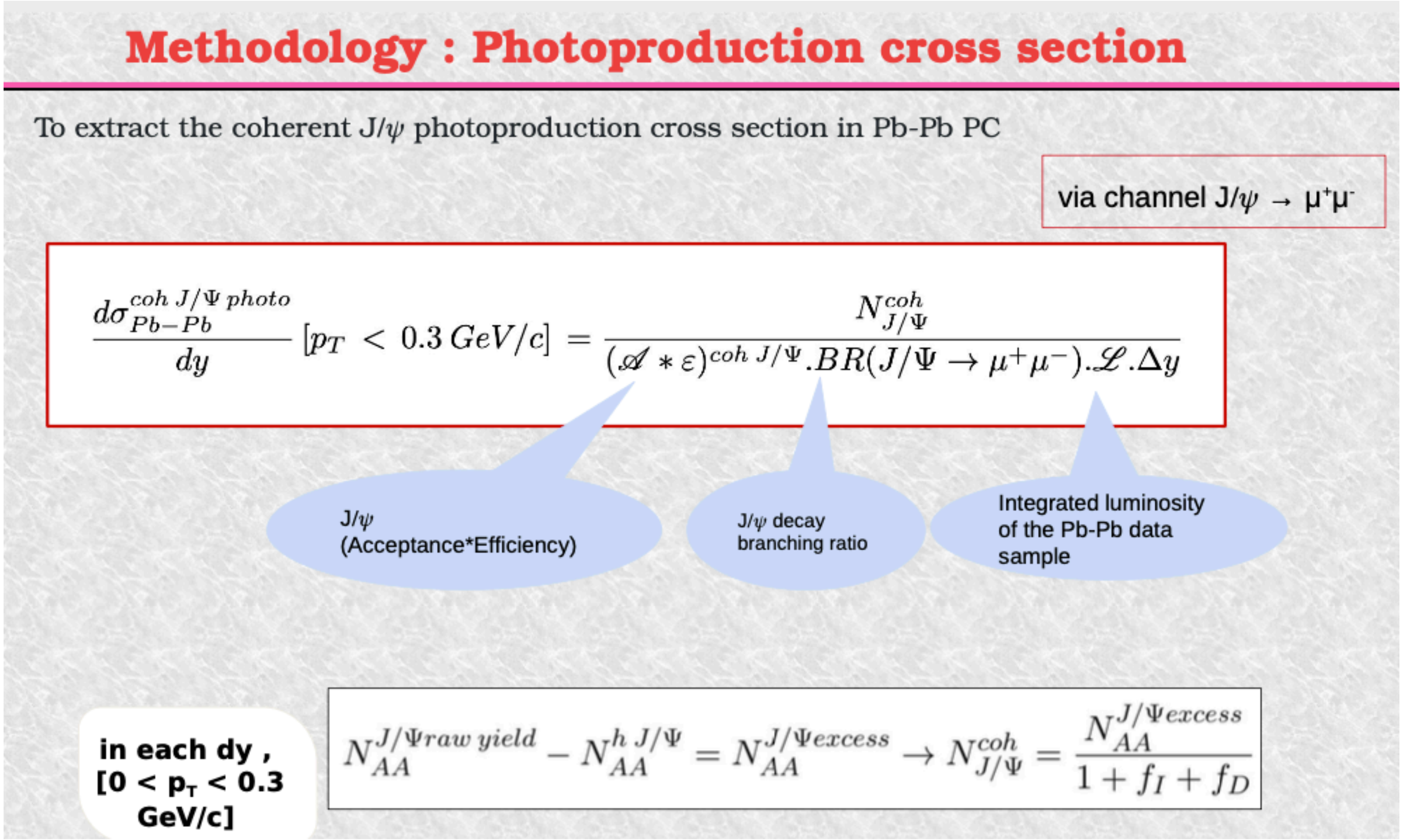
R_{AA} modelization for estimate photoproduction contribution



Methodology : Photoproduction cross section

To extract the coherent J/ψ photoproduction cross section in Pb-Pb PC

via channel J/ψ → $\mu^+\mu^-$

$$\frac{d\sigma^{coh\,J/\Psi\,photo}_{Pb-Pb}}{dy}[p_T < 0.3\,GeV/c] = \frac{N^{coh}_{J/\Psi}}{(\mathscr{A}*\varepsilon)^{coh\,J/\Psi}.BR(J/\Psi \to \mu^+\mu^-).\mathscr{L}.\Delta y}$$

J/ψ (Acceptance*Efficiency)

J/ψ decay branching ratio

Integrated luminosity of the Pb-Pb data sample

in each dy , [0 < p_T < 0.3 GeV/c]

$$N^{J/\Psi raw\,yield}_{AA} - N^{h\,J/\Psi}_{AA} = N^{J/\Psi excess}_{AA} \to N^{coh}_{J/\Psi} = \frac{N^{J/\Psi excess}_{AA}}{1+f_I+f_D}$$

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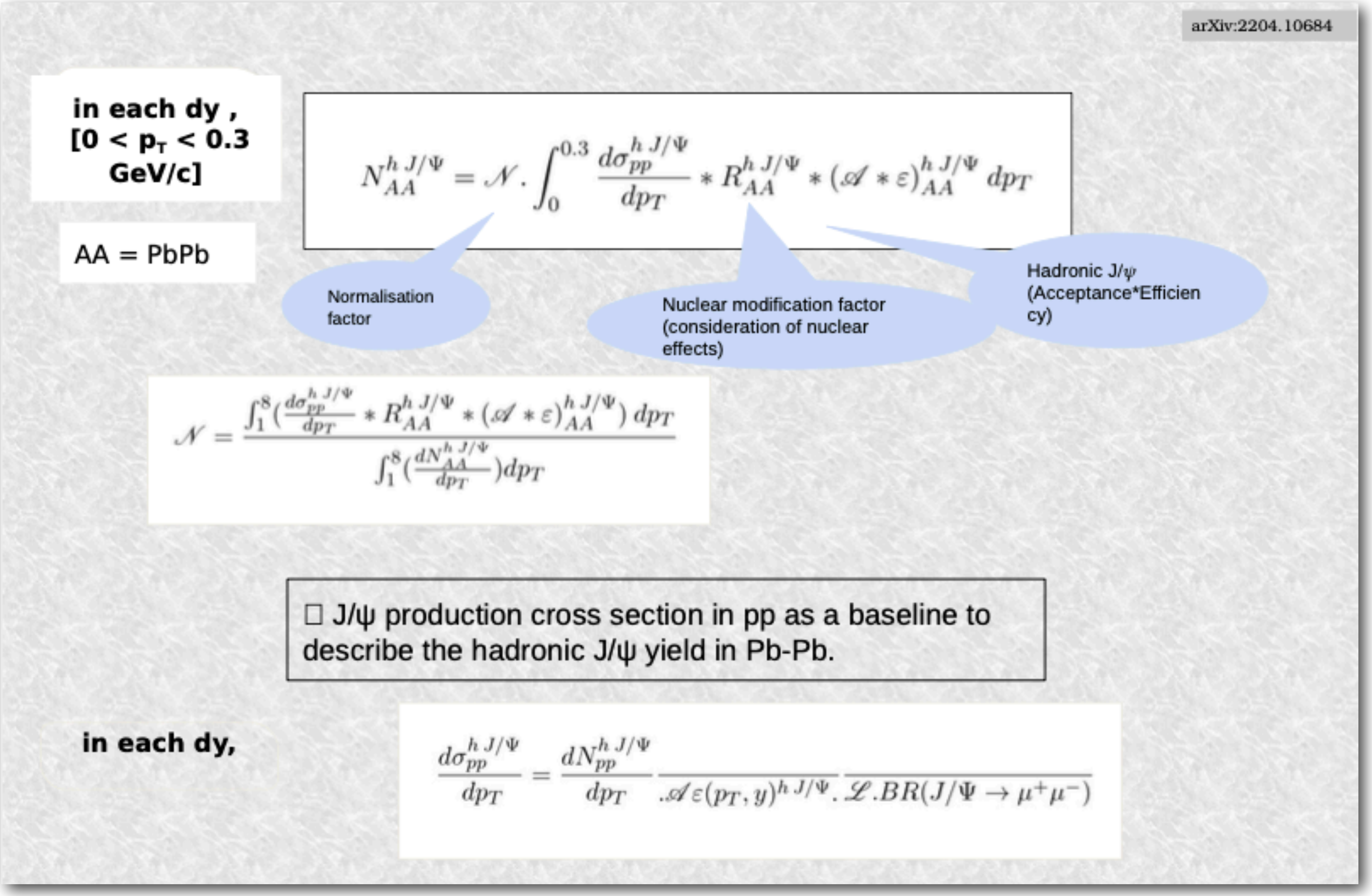
RAA modelization for estimate photoproduction contribution



arXiv:2204.10684

in each dy ,
[0 < p_T < 0.3 GeV/c]

AA = PbPb

$$N_{AA}^{h\,J/\Psi} = \mathscr{N}.\int_0^{0.3} \frac{d\sigma_{pp}^{h\,J/\Psi}}{dp_T} * R_{AA}^{h\,J/\Psi} * (\mathscr{A}*\varepsilon)_{AA}^{h\,J/\Psi}\, dp_T$$

Normalisation factor

Nuclear modification factor (consideration of nuclear effects)

Hadronic J/ψ (Acceptance*Efficiency)

$$\mathscr{N} = \frac{\int_1^8 (\frac{d\sigma_{pp}^{h\,J/\Psi}}{dp_T} * R_{AA}^{h\,J/\Psi} * (\mathscr{A}*\varepsilon)_{AA}^{h\,J/\Psi})\, dp_T}{\int_1^8 (\frac{dN_{AA}^{h\,J/\Psi}}{dp_T}) dp_T}$$

☐ J/ψ production cross section in pp as a baseline to describe the hadronic J/ψ yield in Pb-Pb.

in each dy,

$$\frac{d\sigma_{pp}^{h\,J/\Psi}}{dp_T} = \frac{dN_{pp}^{h\,J/\Psi}}{dp_T}\frac{\quad}{.\mathscr{A}\varepsilon(p_T,y)^{h\,J/\Psi}.}\frac{\quad}{\mathscr{L}.BR(J/\Psi\rightarrow\mu^+\mu^-)}$$

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Polarization : photoproduction of vector mesons

ρ^0 meson measurement : consistent with SCHC

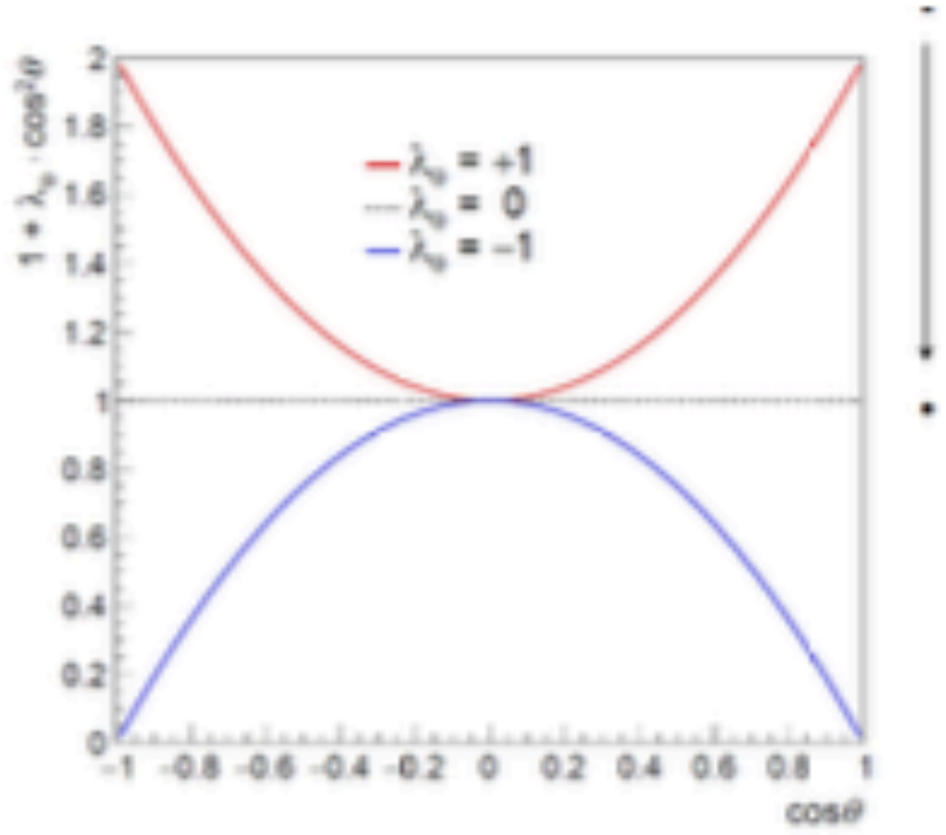
Phys. Rev. D 7, 3150, (1970) by SLAC Collaboration
Z. Phys. C 53, 581–594, (1992) by CERN SPS

ρ^0 [1] , ω[2] and φ [3] photoproduction by CLAS Collaboration : SCHC violation
[1] Eur. Phys. J. A 39, 5–31, (2009)
[2] Int. J. Mod. Phys. Conf. Ser. 26,1460063, (2014)
[3] Phys.Rev.C 90, 019901, (2014)

ρ0 photoproduction by STAR Collaboration : consistent with SCHC
Phys. Rev. C 77 (2008) 034910

Exclusive J/ψ photoproduction by H1 and ZEUS collaborations : consistent with SCHC
[1] Eur. Phys. J. C 46 , 585–603 (2006)

[2] Nucl. Phys. B 695, 3–37 (2004)



Do we see similar observation for J/ψ at low p_T (< 0.3 GeV/c) in Peripheral Pb-Pb collisions with nuclear overlap?

- ✓ Is the **J/ψ transversely polarized** and therefore obey **the SCHC hypothesis** ?
- ✓ Another way to test the **production mechanism** at the origin of the J/ψ **very low p_T excess**
- ✓ Also **complementary to the UPCs** measurement

$$r^{04}_{00} = \frac{1-\lambda_\theta}{3+\lambda_\theta}$$

$$r^{04}_{1,-1} = \frac{\lambda_\varphi}{2} \cdot (1+r^{04}_{00}) \,.$$

Observables : Extract angular variables and spin density matrix element