RECENT EXPERIMENTAL RESULT FROM ALICE AND PROSPECTS

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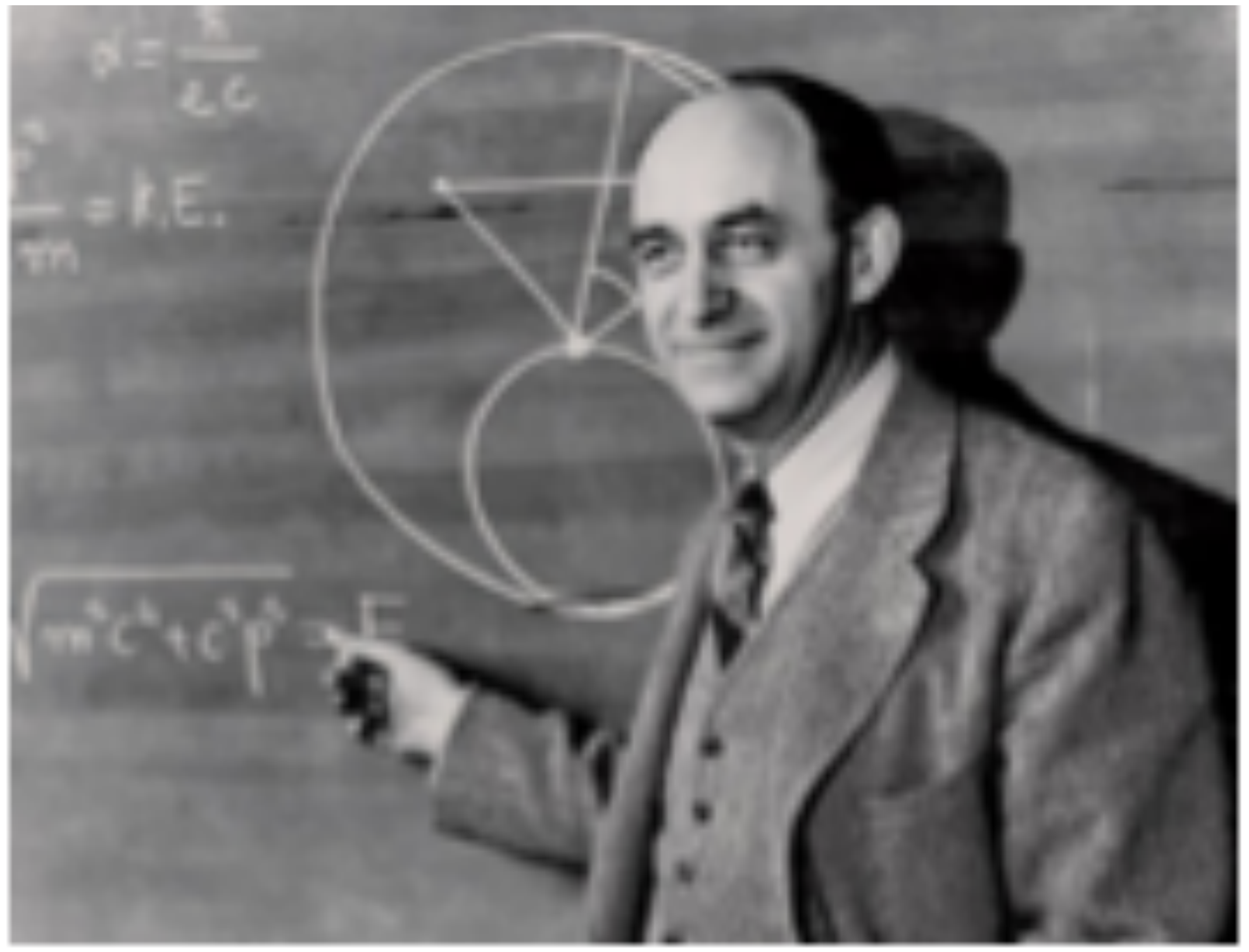
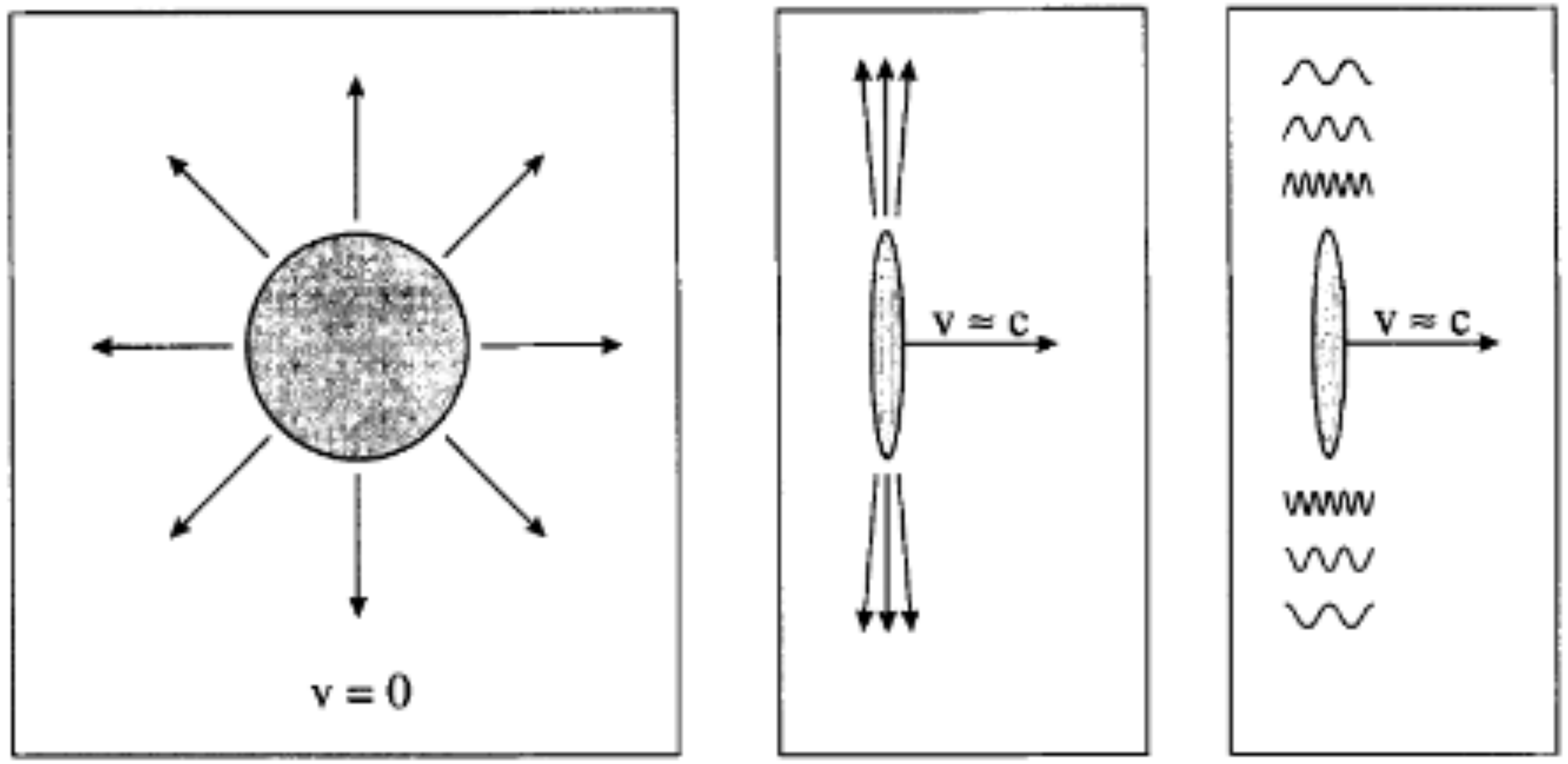
Using the LHC as γγ, γPb and γp collider

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

Equivalent photon approximation (EPA)



E.Fermi



Fast moving charged particles produce strong electromagnetic field [1]

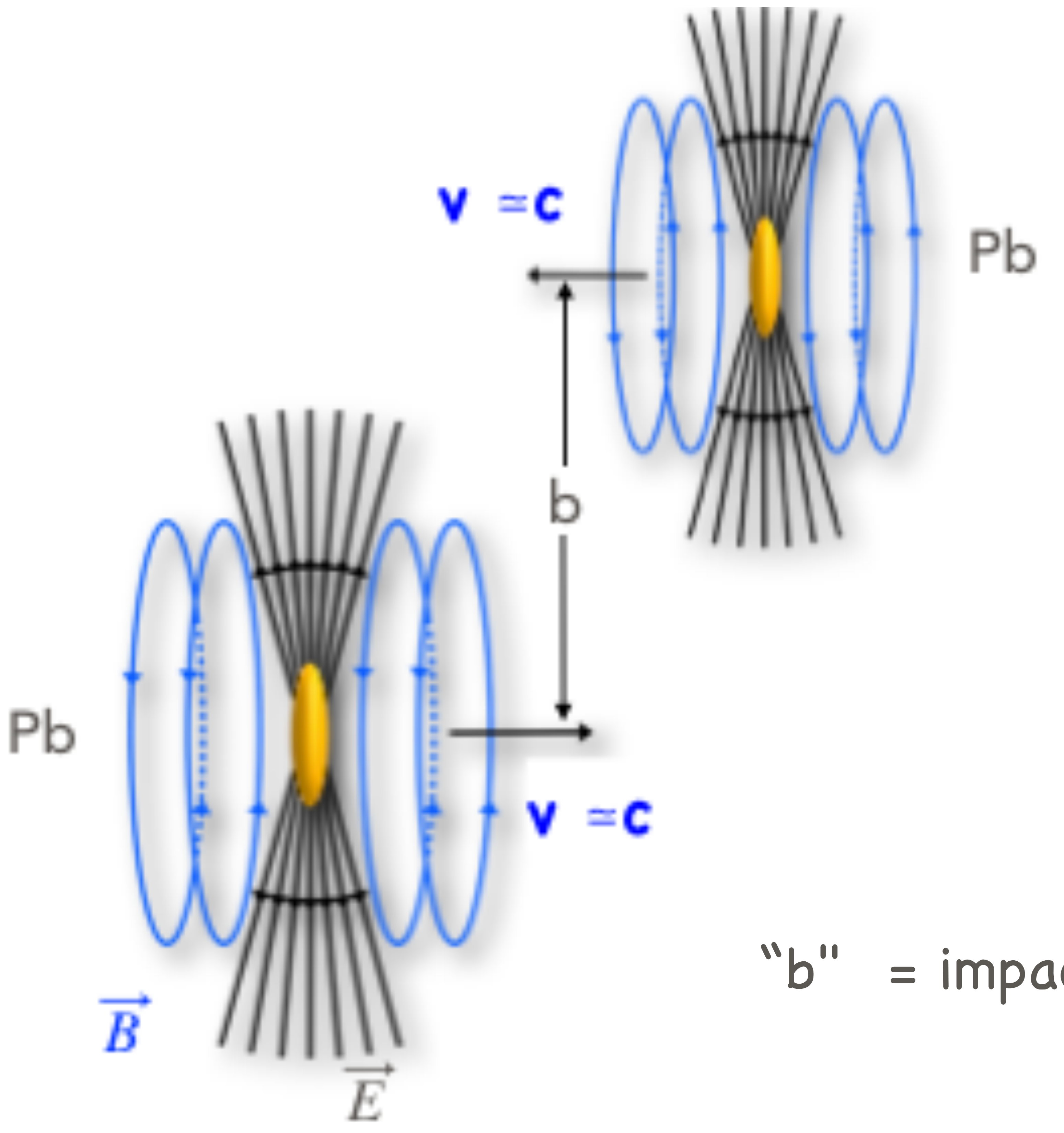
Electromagntic fileds ≈ photon fluxes

[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)]

Later, this method was extended to relativistic region($v \approx c$) by **Weizsacker-Williams , known as EPA Method** **[2.3]**

Equivalent photon approximation (EPA) in heavy-ion collisions

Relativistic heavy-ions are strong EM field emitters



"b" = impact parameter

Electromagnetic fields

In heavy-ion collisions (HIC) :

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

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

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

Magnetic field in other systems

Pulsar ~ 10^{11} T

Earth ~ 10^{-5} T

Strongest EM fields **in the Universe**

EM fields can be treated in terms of photon quanta or flux

Maximum photon energy

LHC ~ 80 GeV

RHIC ~ 3 GeV

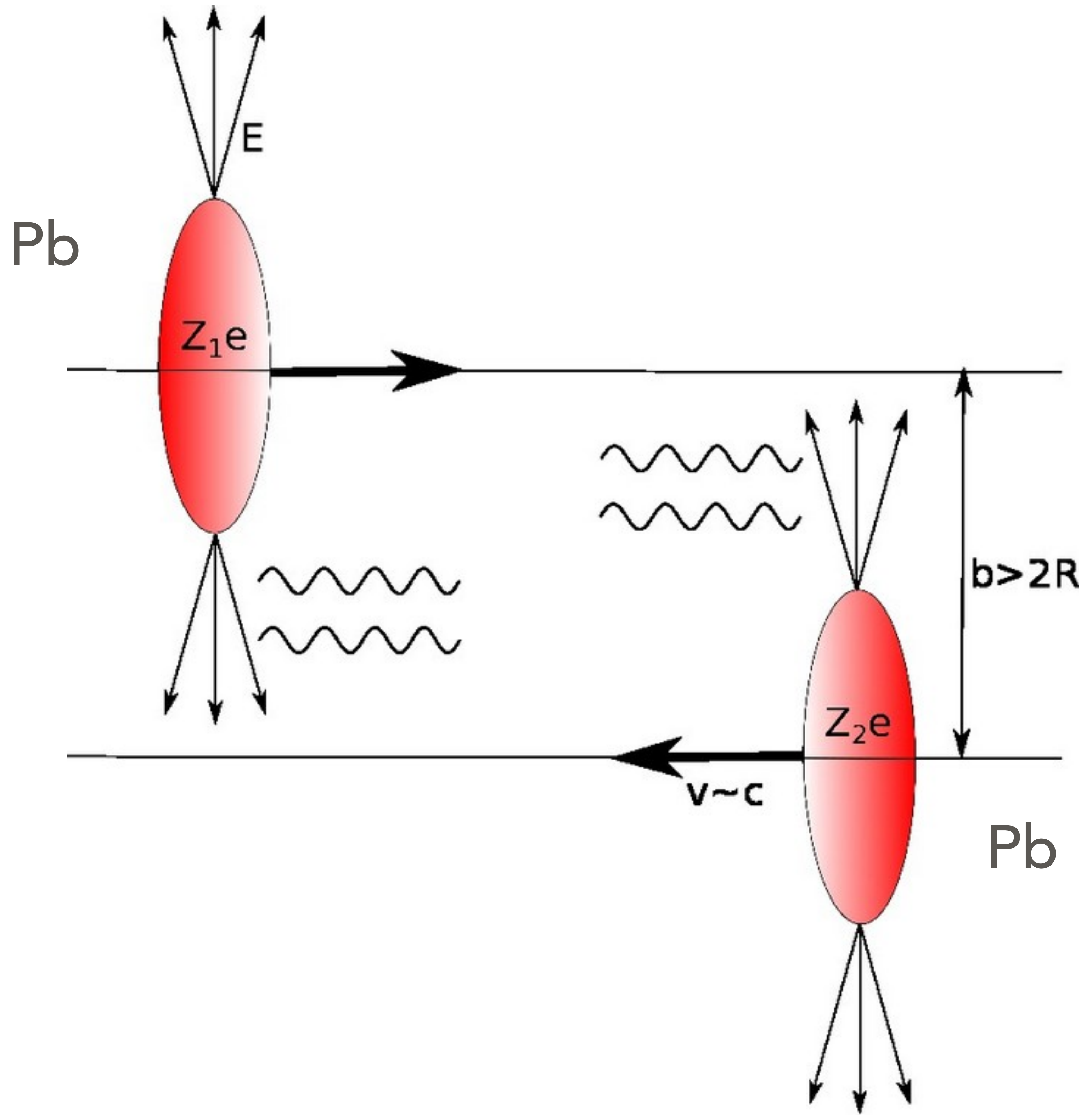
$E_{\gamma,\,max} \approx \gamma\hbar c/R$

γ = Lorentz factor

R = Radius of the nucleus

Photon-induced processes in heavy-ion collisions

UltraPeripheral Collisions (UPCs) : b > R_1+ R_2



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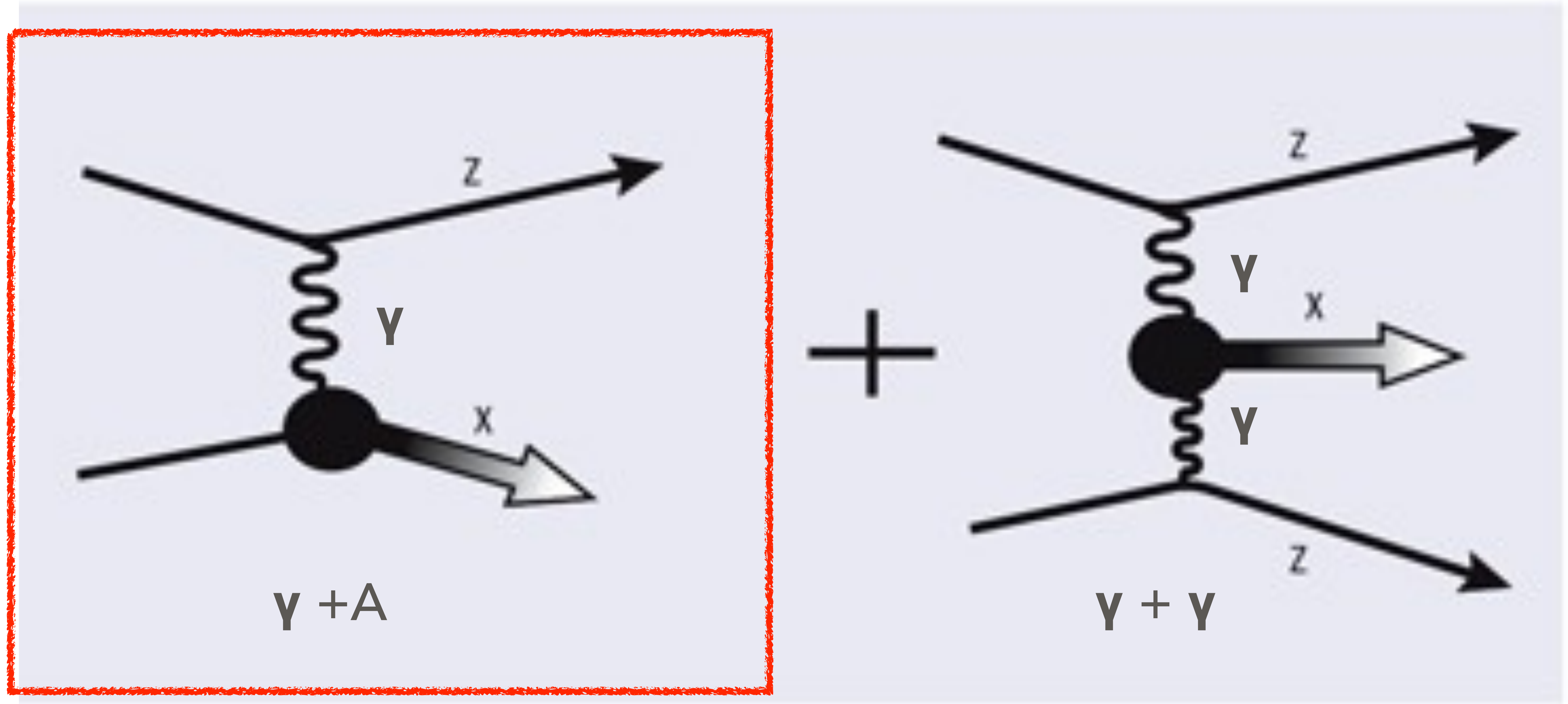
Types of interactions



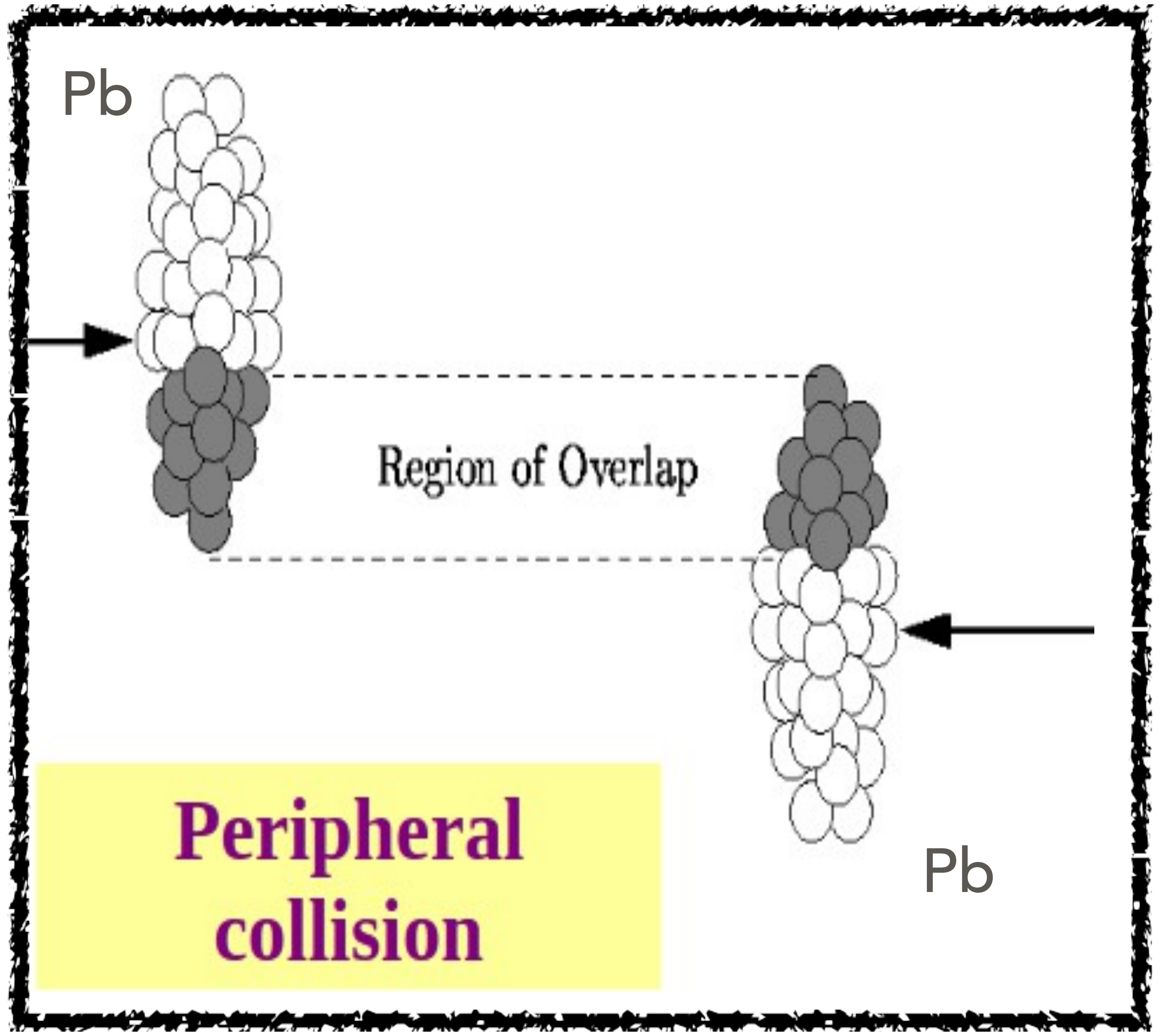
Photon flux density ∝ Z^2

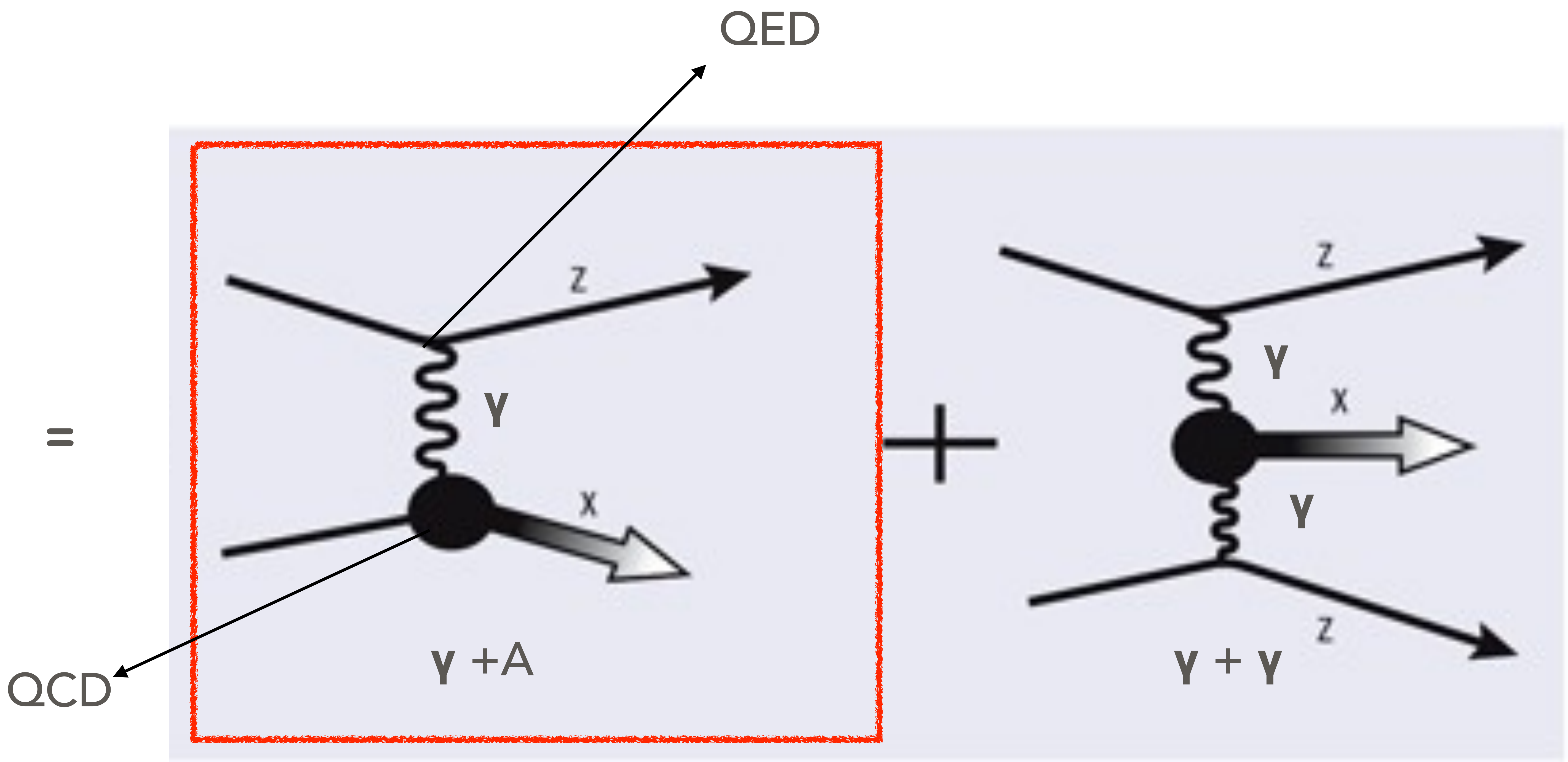
Electromagnetic interactions are dominant

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, (photon flux is expected to be modified from UPC to PC due to geometrical constraints on impact parameter and impact of nuclear overlap)

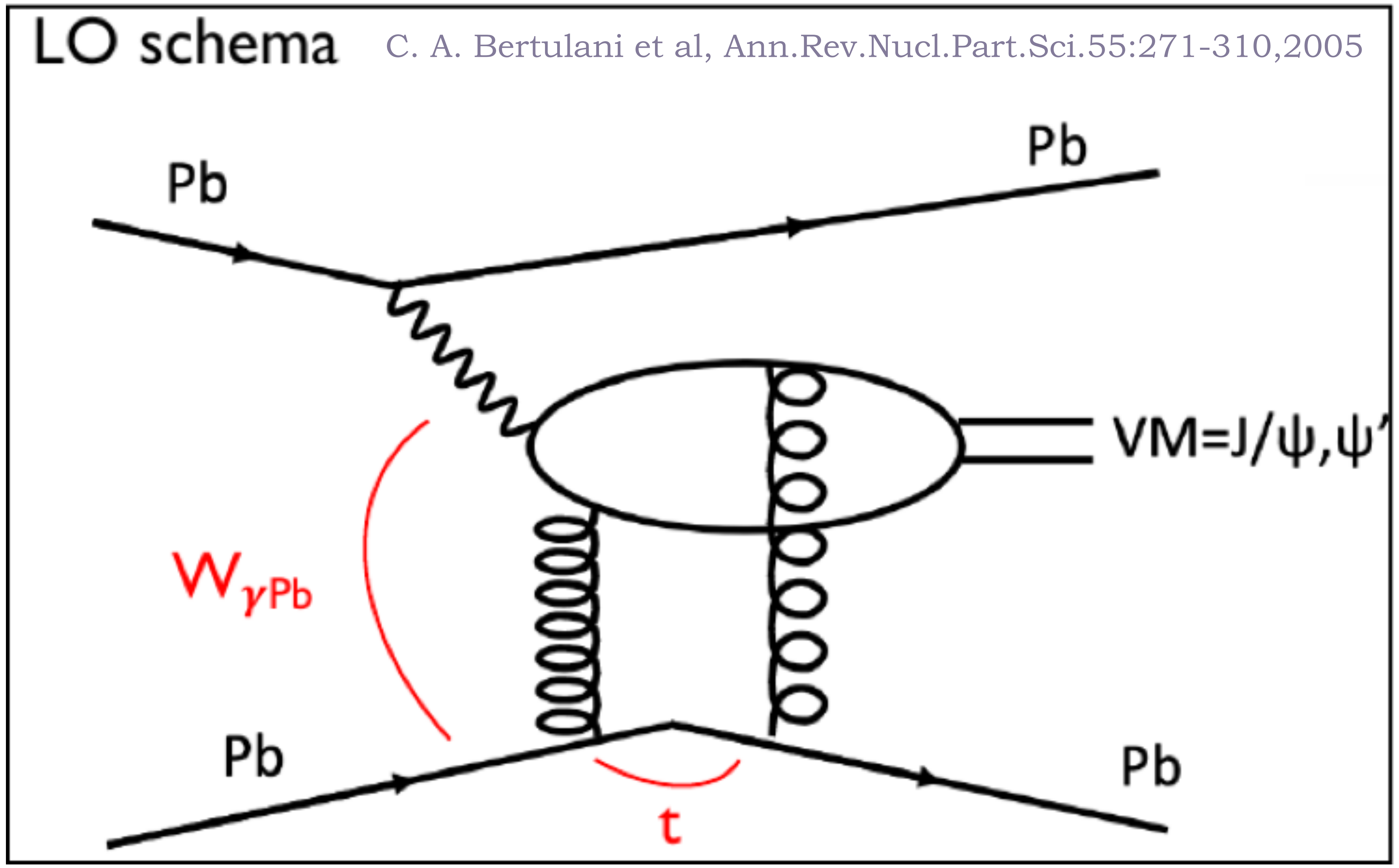
Hadronic interactions are dominant

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

Vector meson photoproduction in HICs



LO : Leading order

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

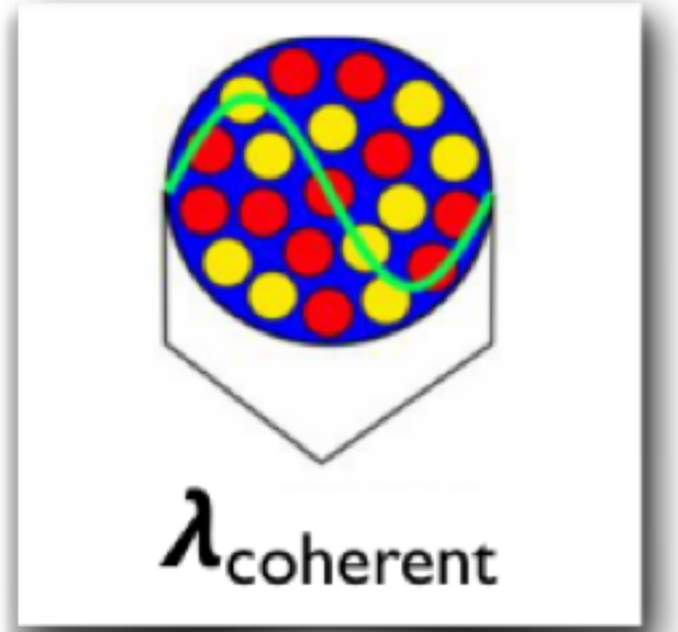
t: Mandelstam variable = - p_T^2

Coherent photo production

Photon (γ) couples coherently to all nucleons

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

Usually no breaking of target

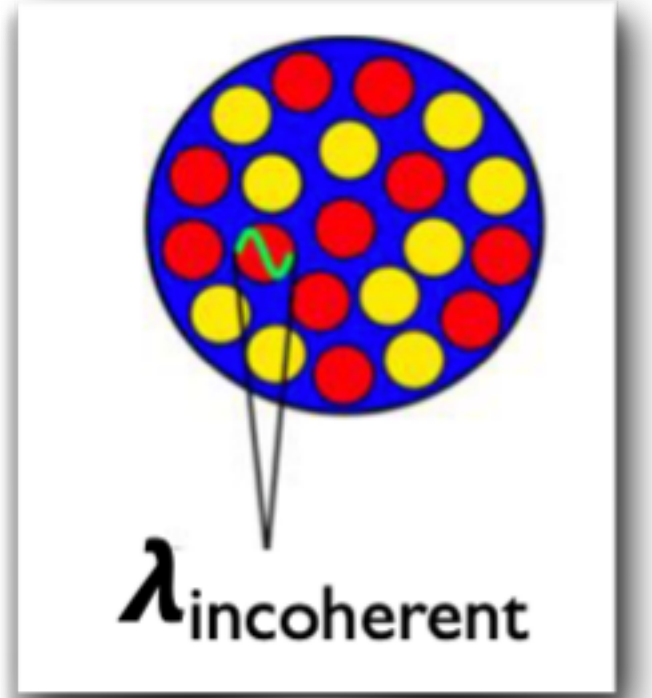


Incoherent photo production

Photon (γ) couples to single nucleon

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

Usually target nucleus breaks



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

Clean experimental signature and probing different photoproduction mechanisms

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

The ALICE Apparatus

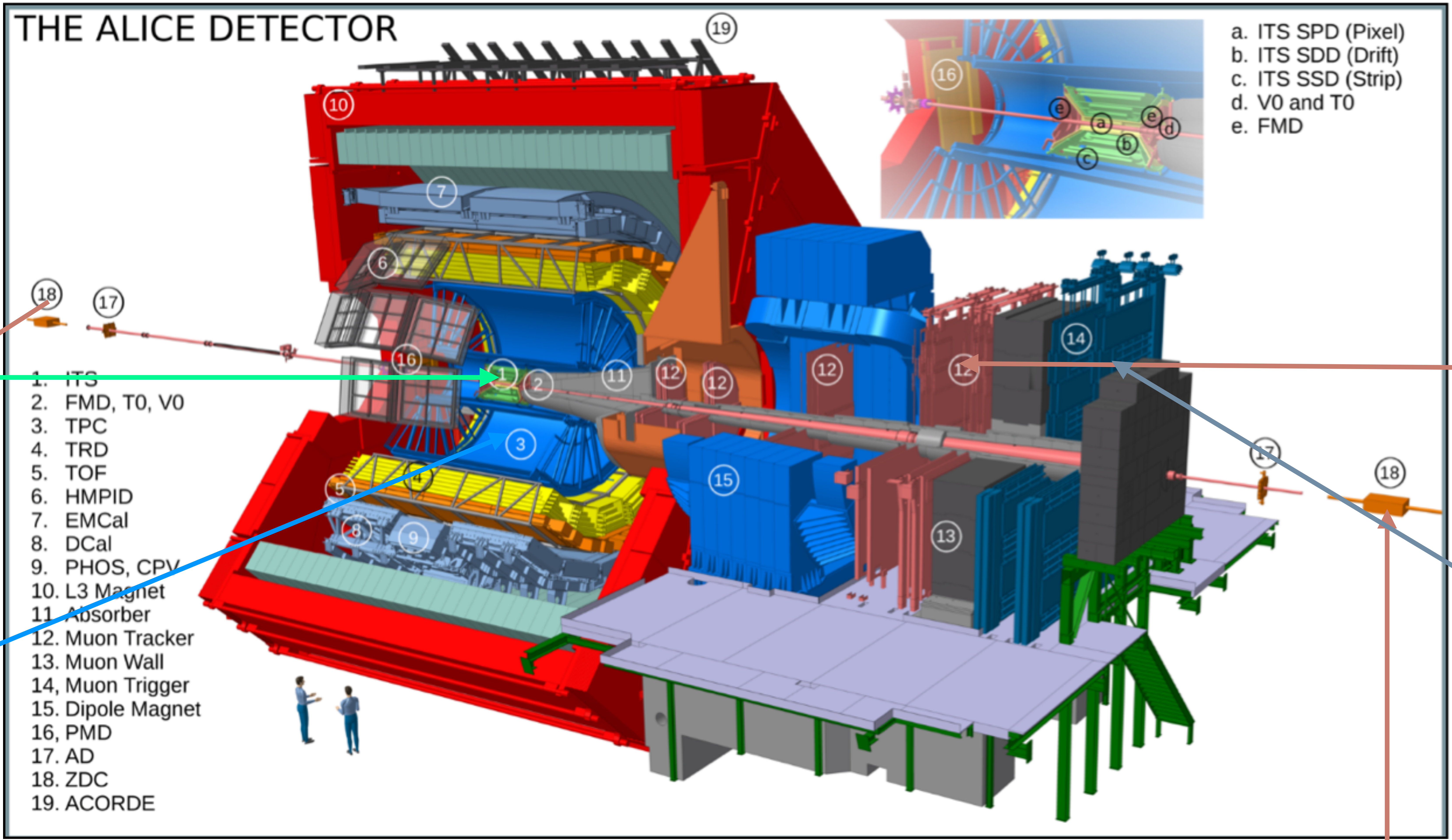
Data sample : 2015 + 2018 Pb—Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV (Run 2)

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

ITS : Tracking, vertex reconstruction

ZDC :Energy deposition

TPC : Tracking, Particle identification (PID)



Muon Spectrometer :
$2.5 < y < 4.0$
$J/\Psi \longrightarrow$ □+□-

Muon tracker : tracking

Muon trigger : triggering

V0 : triggering, centrality determination, background rejection

ZDC :Energy deposition

Experimental observation:

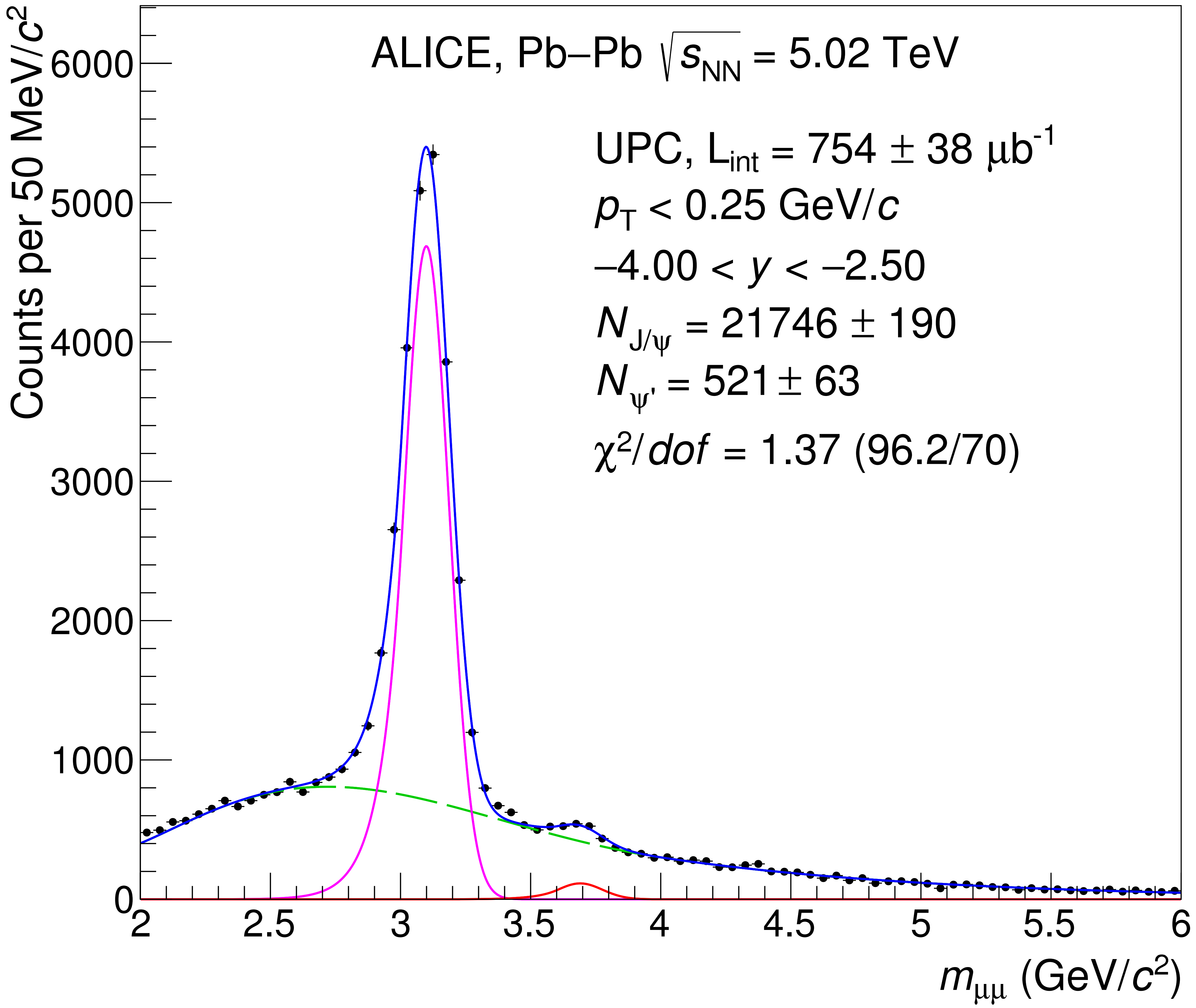
Coherent VM photo production in UPC

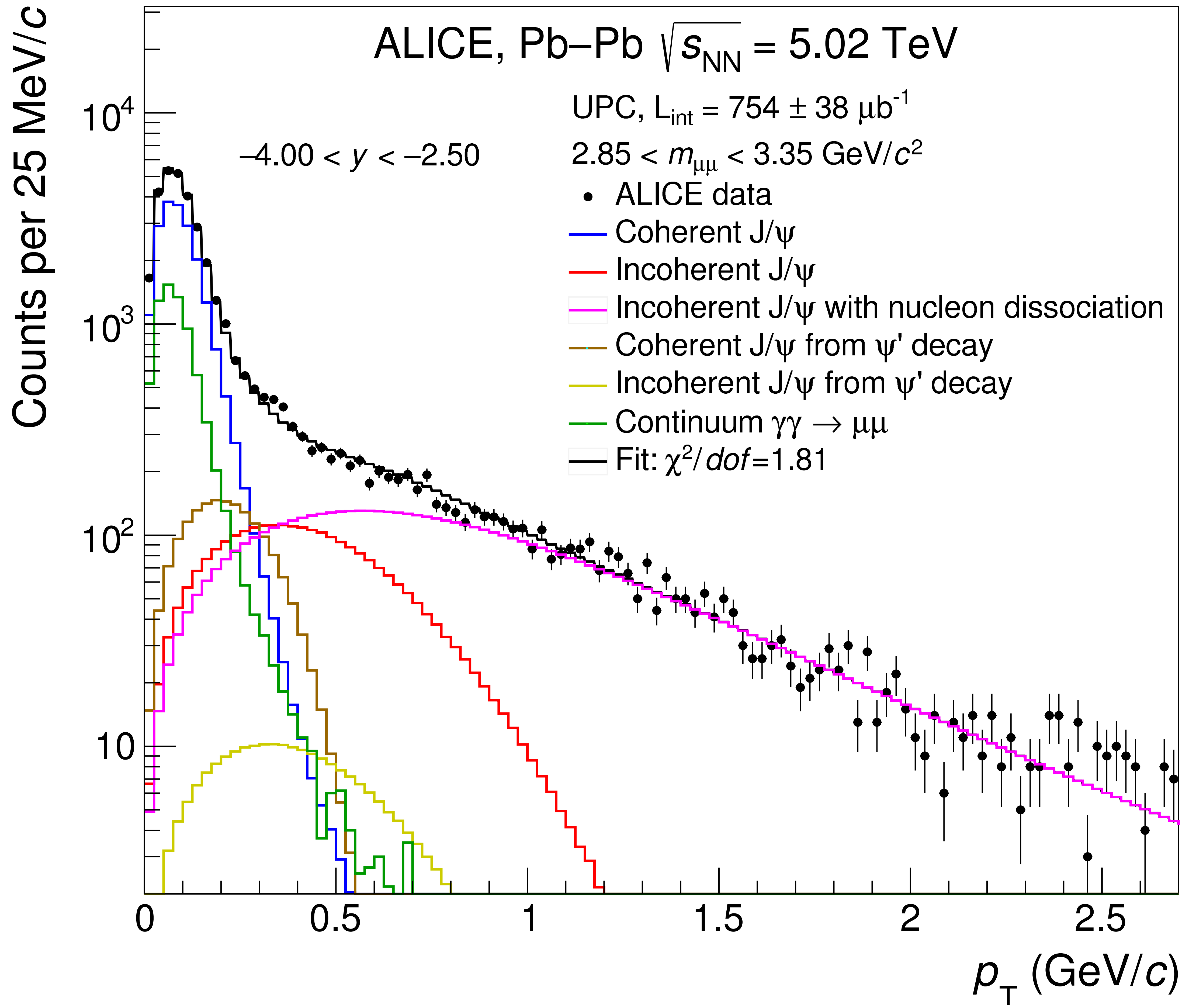
VM photoproduction : experimental observations in UPC

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

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

Phys. Lett. B798 (2019) 134926

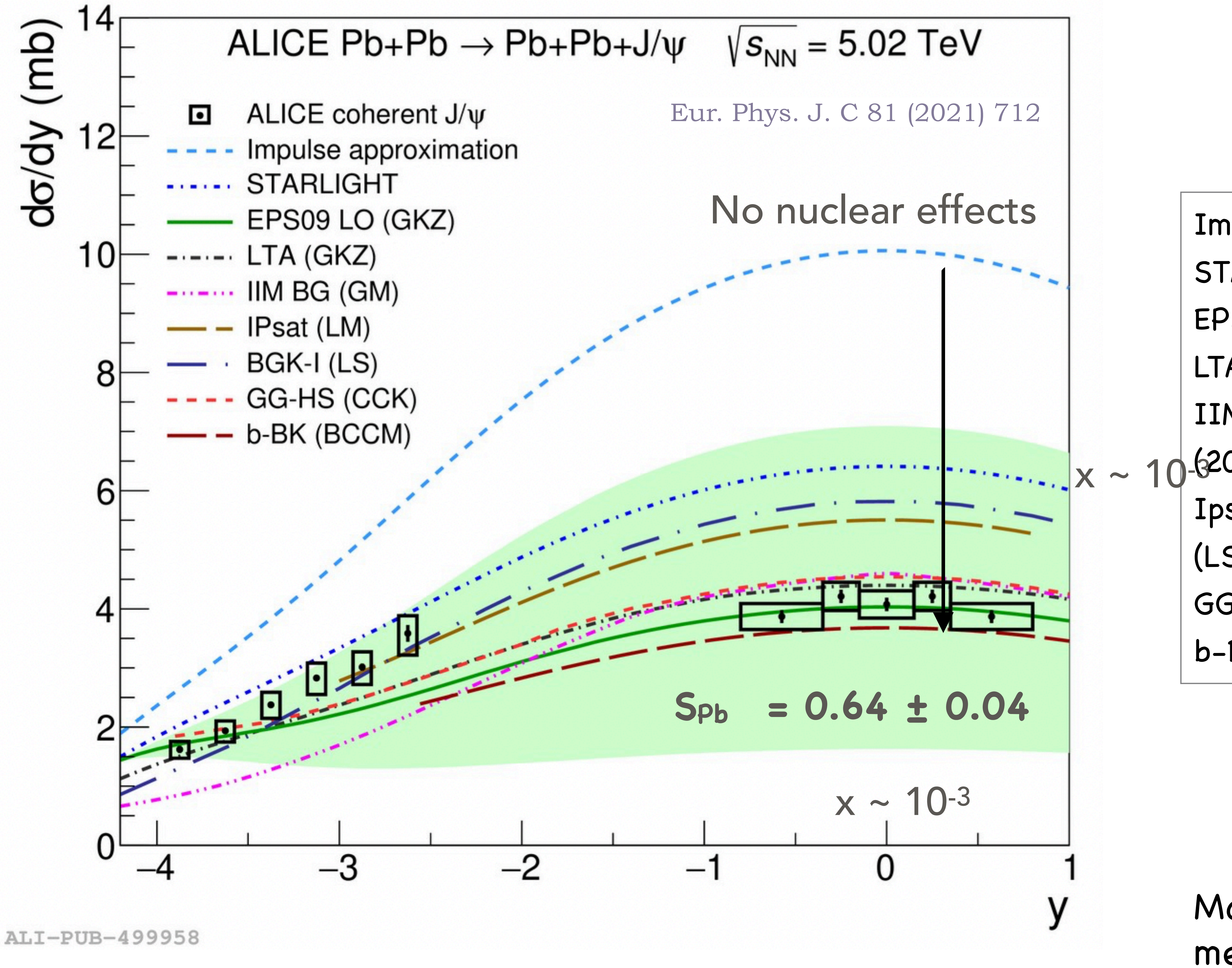




Coherent photo production process dominates at low p_T

VM photo production cross section vs. y in UPC

Coherent J/ψ photo production



Nuclear suppression factor (shadowing) =

$$S_{Pb}(y \sim 0) = \sqrt{\frac{d\sigma}{dy}_{data} \Big/ \frac{d\sigma}{dy}_{IA}} = 0.64 \pm 0.04$$

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)]

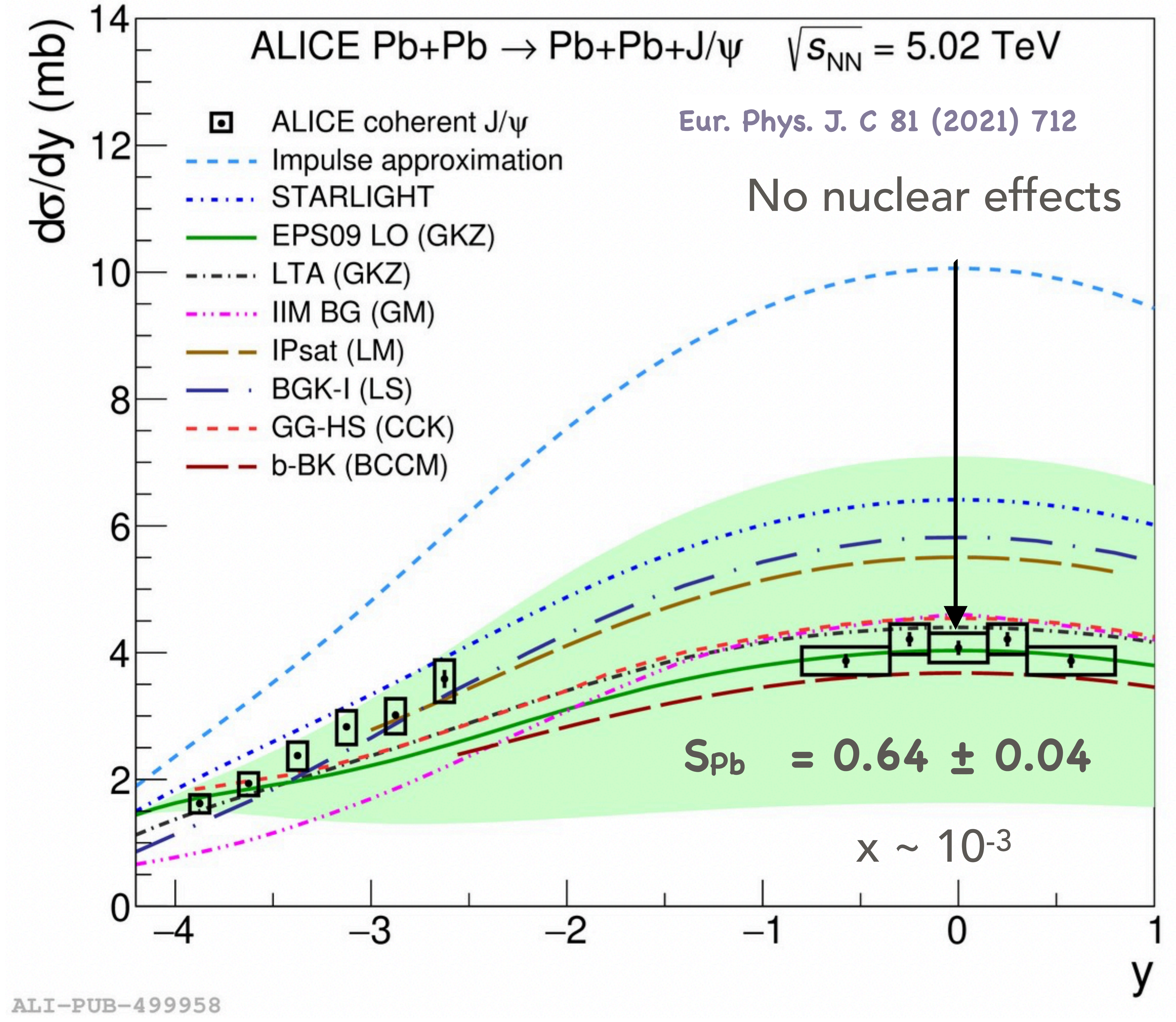
$$x = \frac{m_{J/\psi}}{\sqrt{s_{NN}}} \times \exp(\pm y)$$

Models including nuclear shadowing are in agreement with the measurement

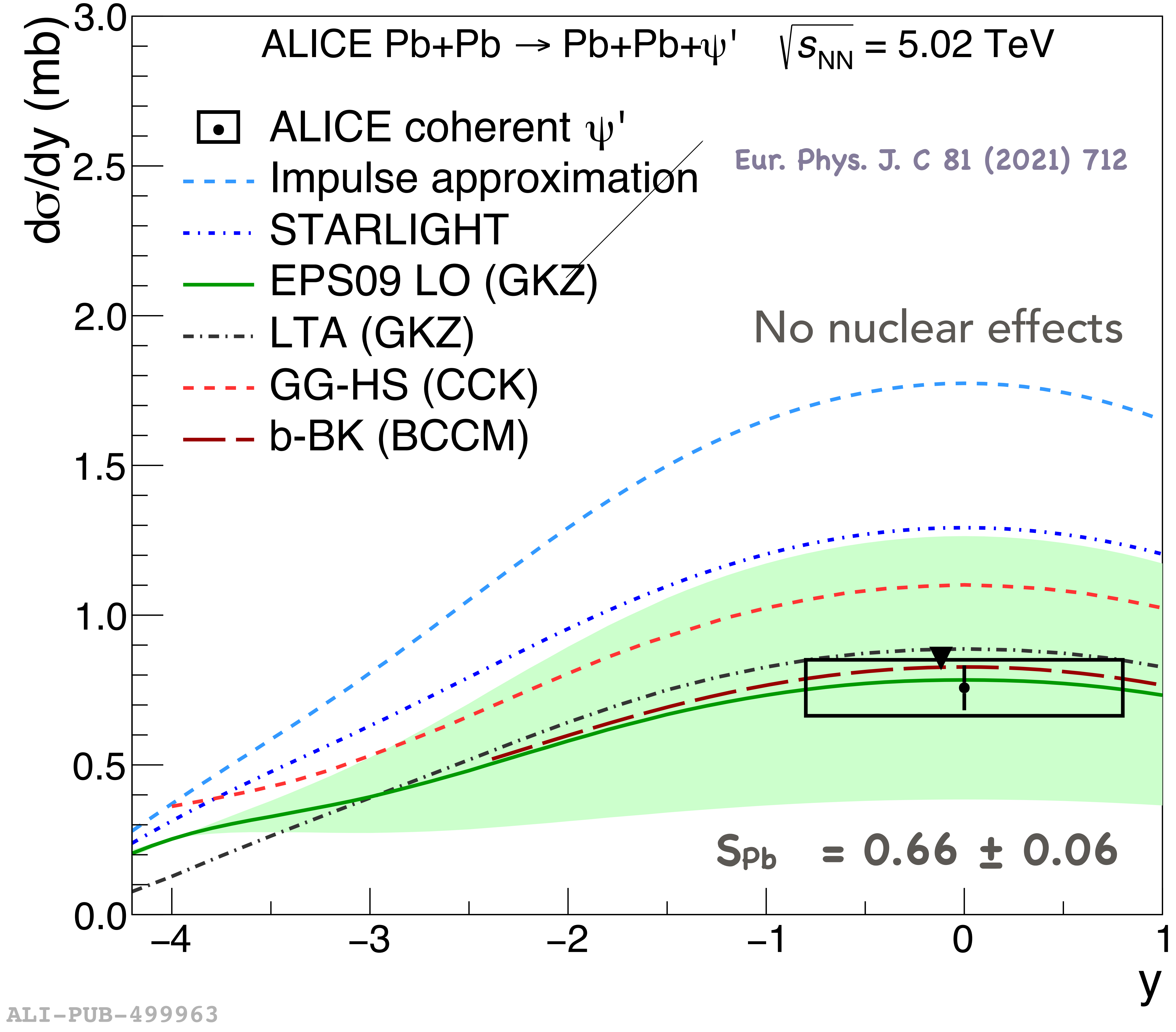
Models cannot describe at the same time the mid and forward rapidity cross section measurements

VM photo production cross section vs. y in UPC

Coherent J/ψ cross section



Coherent ψ' cross section



VM photo production cross section ratio vs. y in UPC

QM 2023,
https://indico.cern.ch/event/1139644/timetable/#20230906

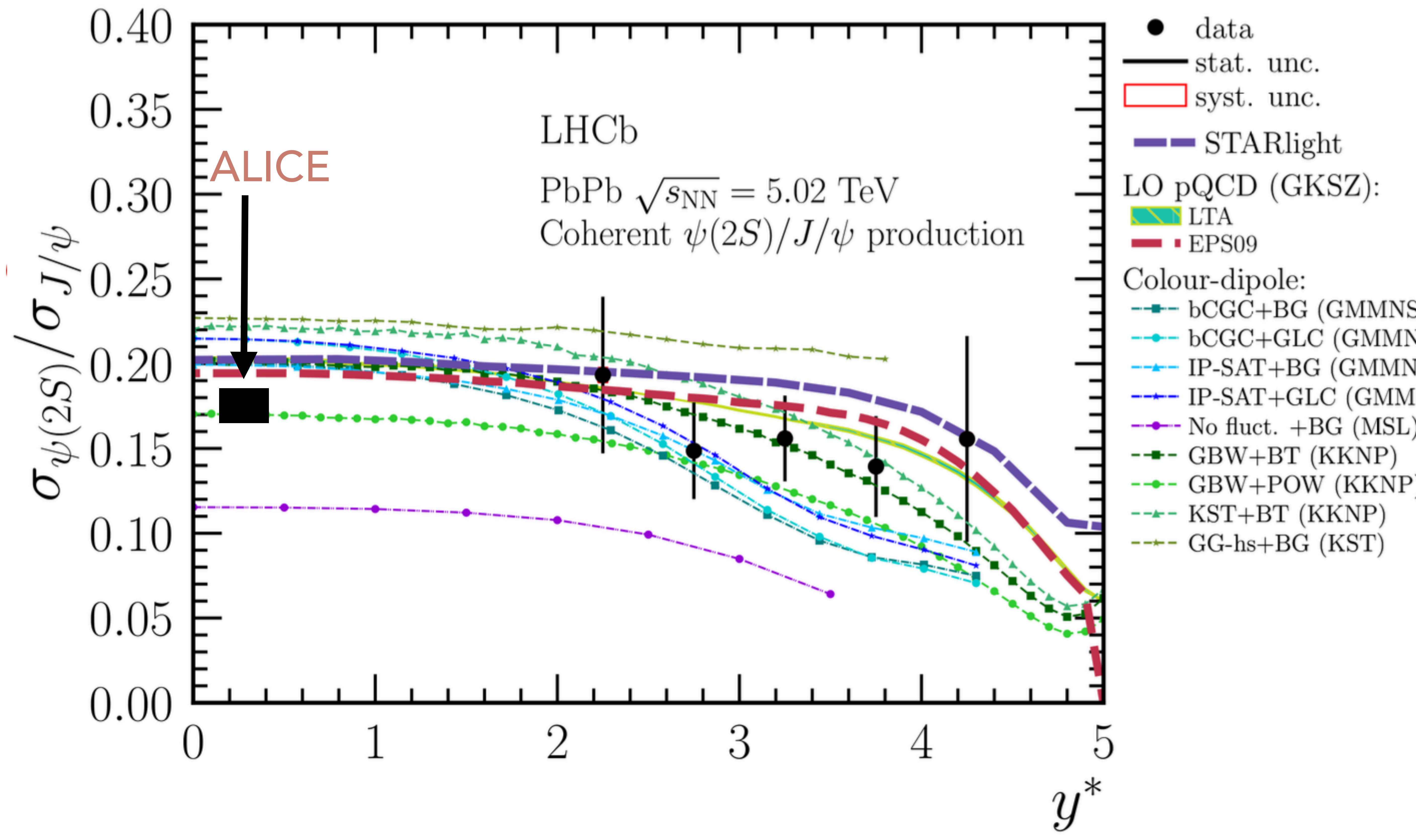
Eur. Phys. J. C 81 (2021) 712

ALICE : at mid-y

$\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$:

0.18 ± 0.0185(stat.) ± 0.028(syst.) ± 0.005(BR).

JHEP 06 (2023) 146



More details :
Recent experimental results in UPC collisions on coherent photoproduction at LHCb, Ronan Mcnulty, 12/10/2023

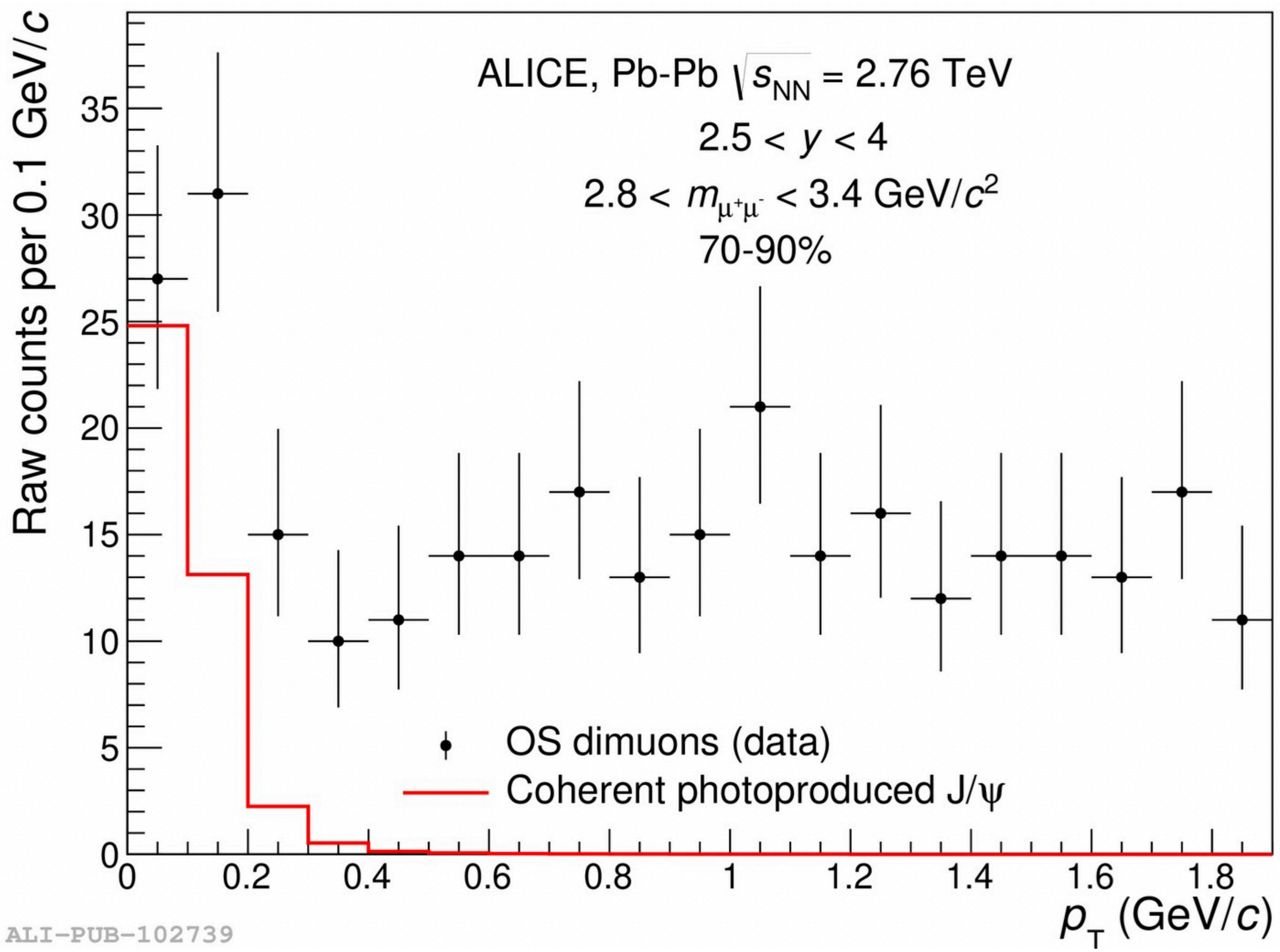
Experimental observation:

Coherent VM photo production in Peripheral Collisions

VM photoproduction in Pb-Pb collisions in PCs

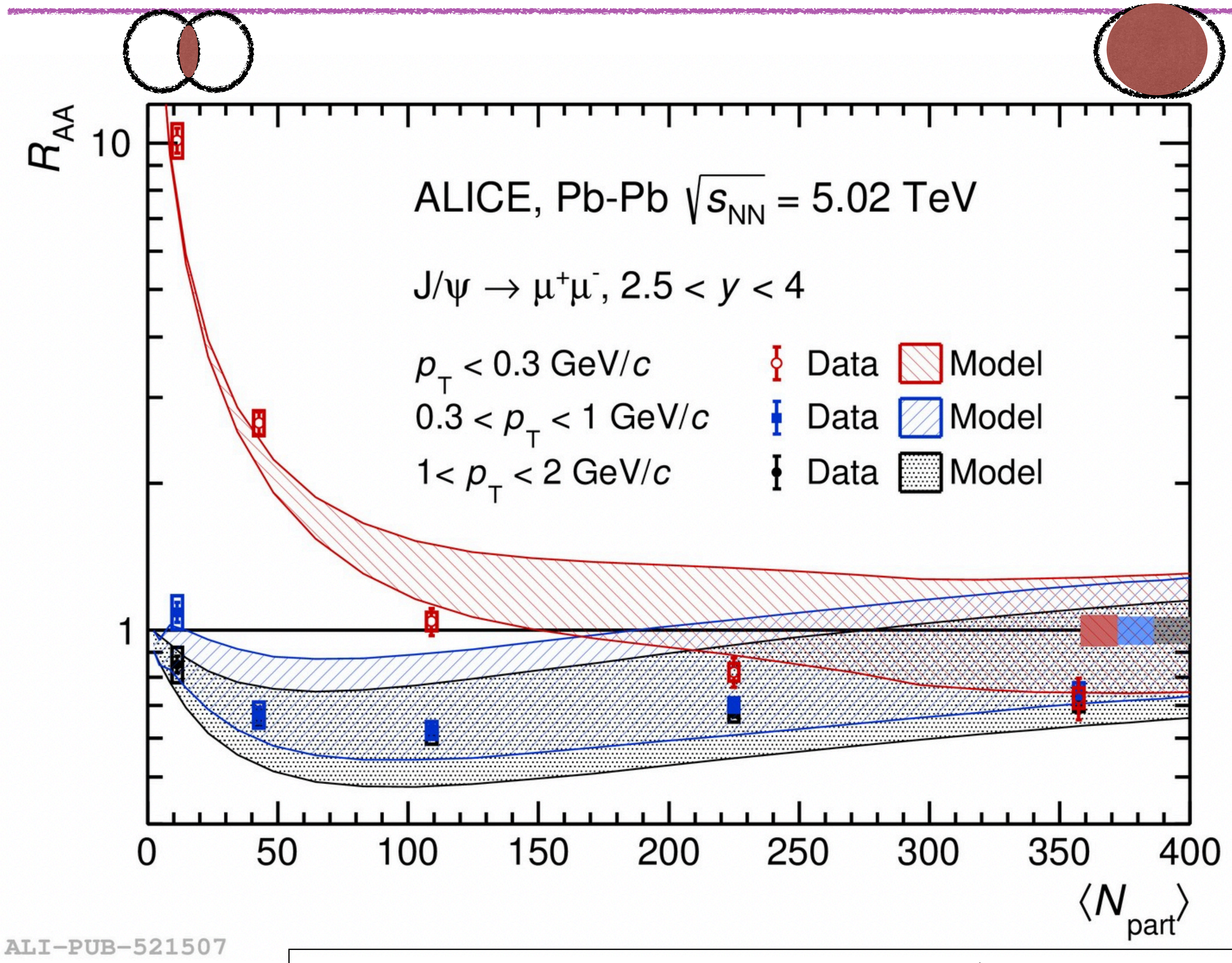
PRL 116, 222301(2016)
STARlight MC : Comp. Phys. Comm. 212 (2017) 258.

PCs = Peripheral collisions



First J/ψ excess for p_T < 0.3 GeV/c is observed in 70-90% Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV (PRL 116, 222301(2016)

Nuclear modification factor (R_{AA}) in Pb–Pb collisions



Associated with a dramatic increase of the R_{AA}

Phys. Lett. B 846 (2023) 137467

Model: W. Shi et al., Phys. Lett. B 777 (2018), 399-405

Including both cold and hot nuclear matter effects

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

Y^{Pb-Pb} = yield of J/ψ in Pb–Pb collisions
$<T_{AA}>$ = Nuclear thickness function
σ^{pp} = cross section of pp

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

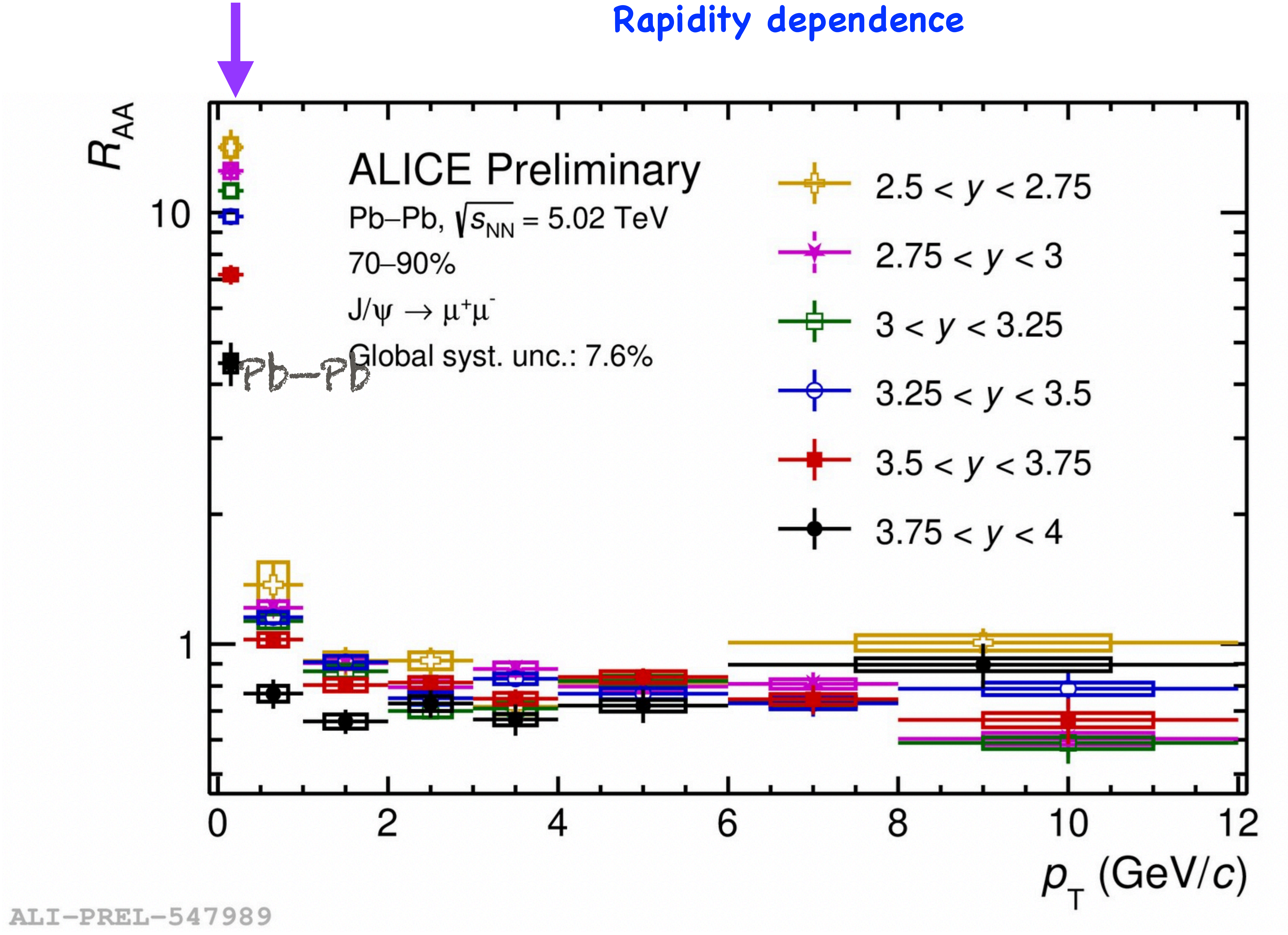
-> **Interprated dominant contribution from coherent photoproduction**

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

More details : For STAR and LHCb, Dr Daniel Kikoła 11/10/2023 and Ronan Mcnulty, 12/10/2023

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

Rapidity dependence

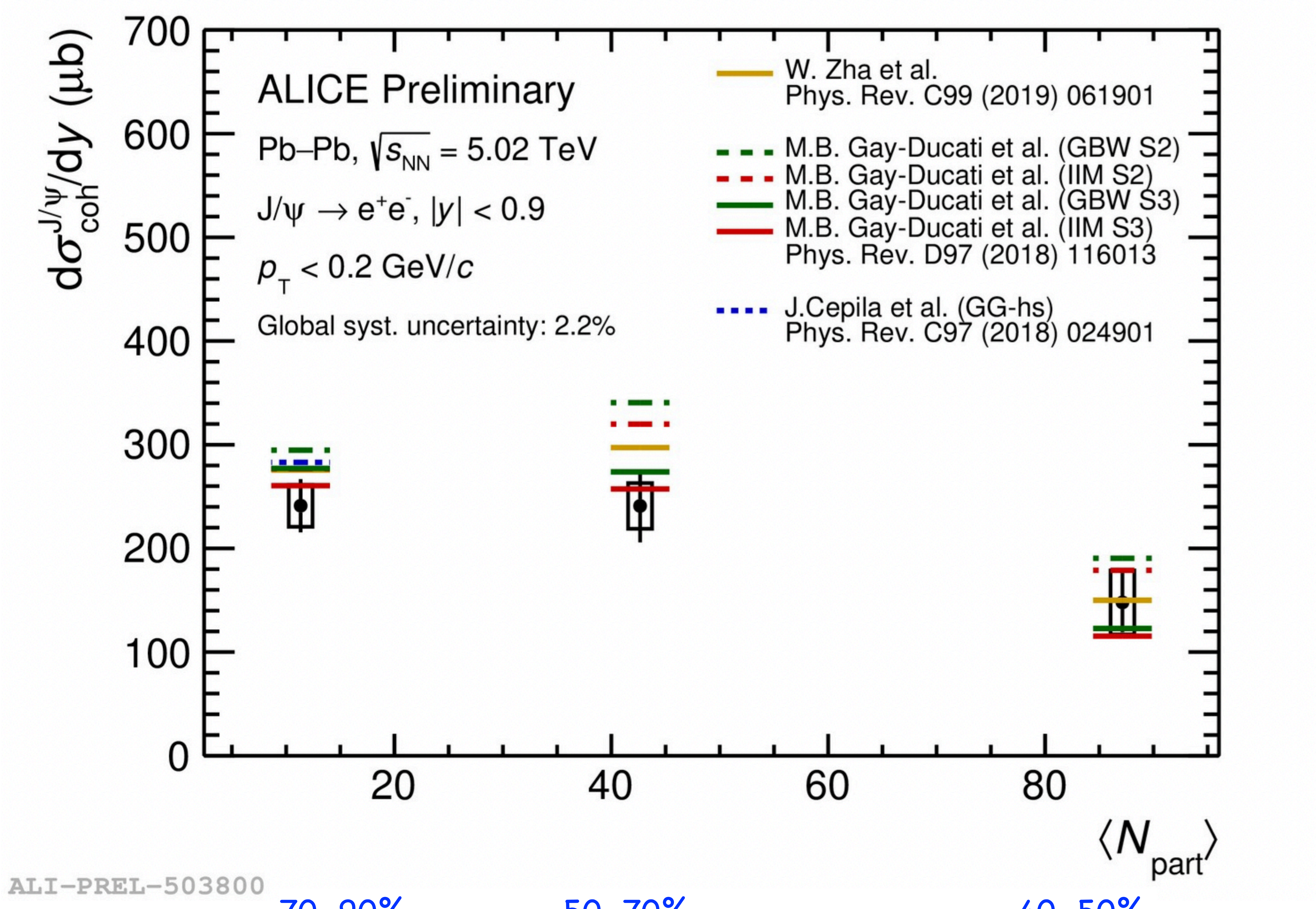


The J/ψ cross section in pp collisions and the J/ψ R_{AA} are used as inputs for modeling the expected hadronic J/ψ yield

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

Coherent J/ψ photoproduction : centrality dependence

mid rapidity



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

Measurements at mid rapidity doesn't show a significant centrality dependence

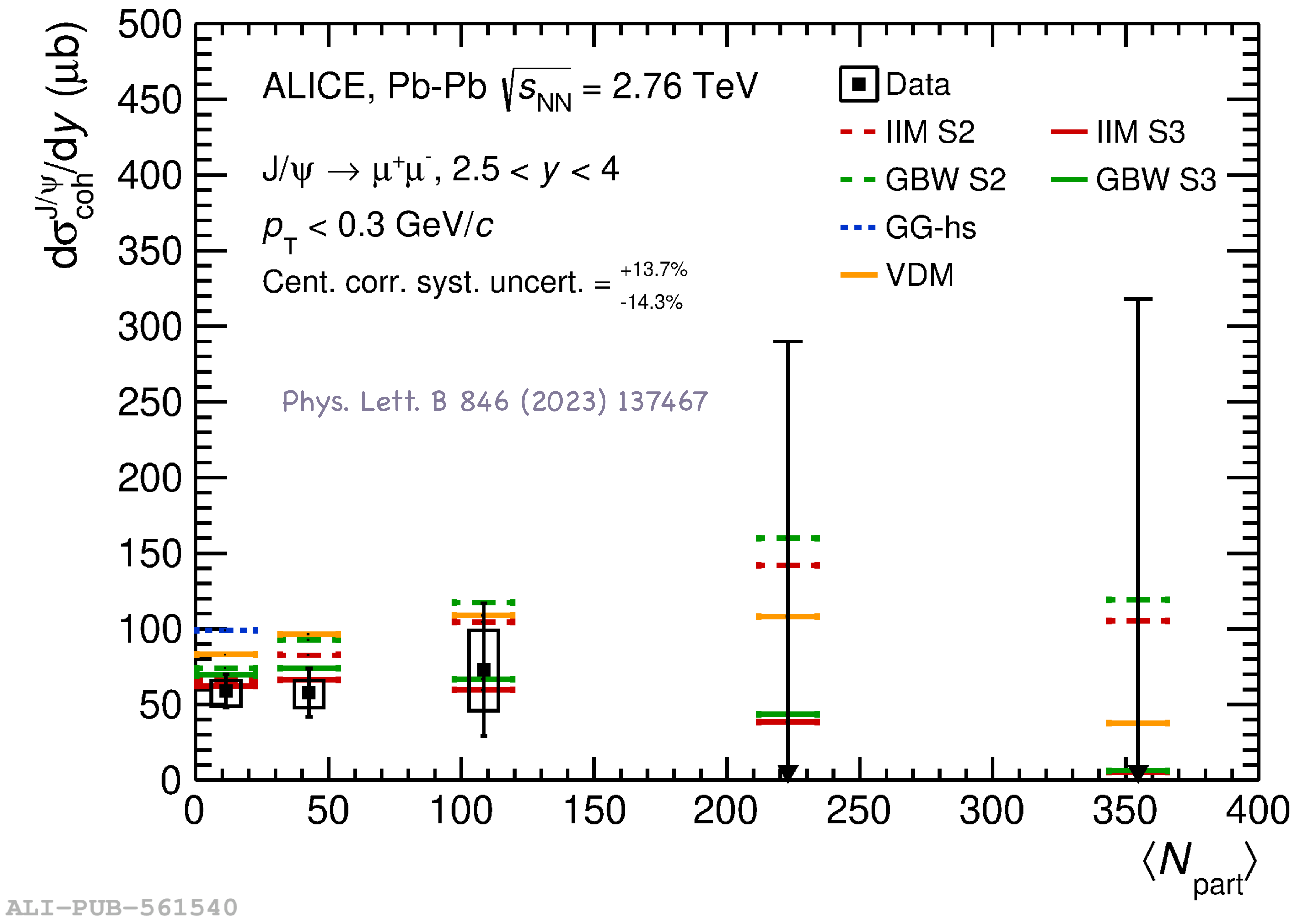
Measurements are **qualitatively described by a large number of models developed for UPC and extended to account for the nuclear overlap**

Coherent J/ψ photoproduction : centrality dependence

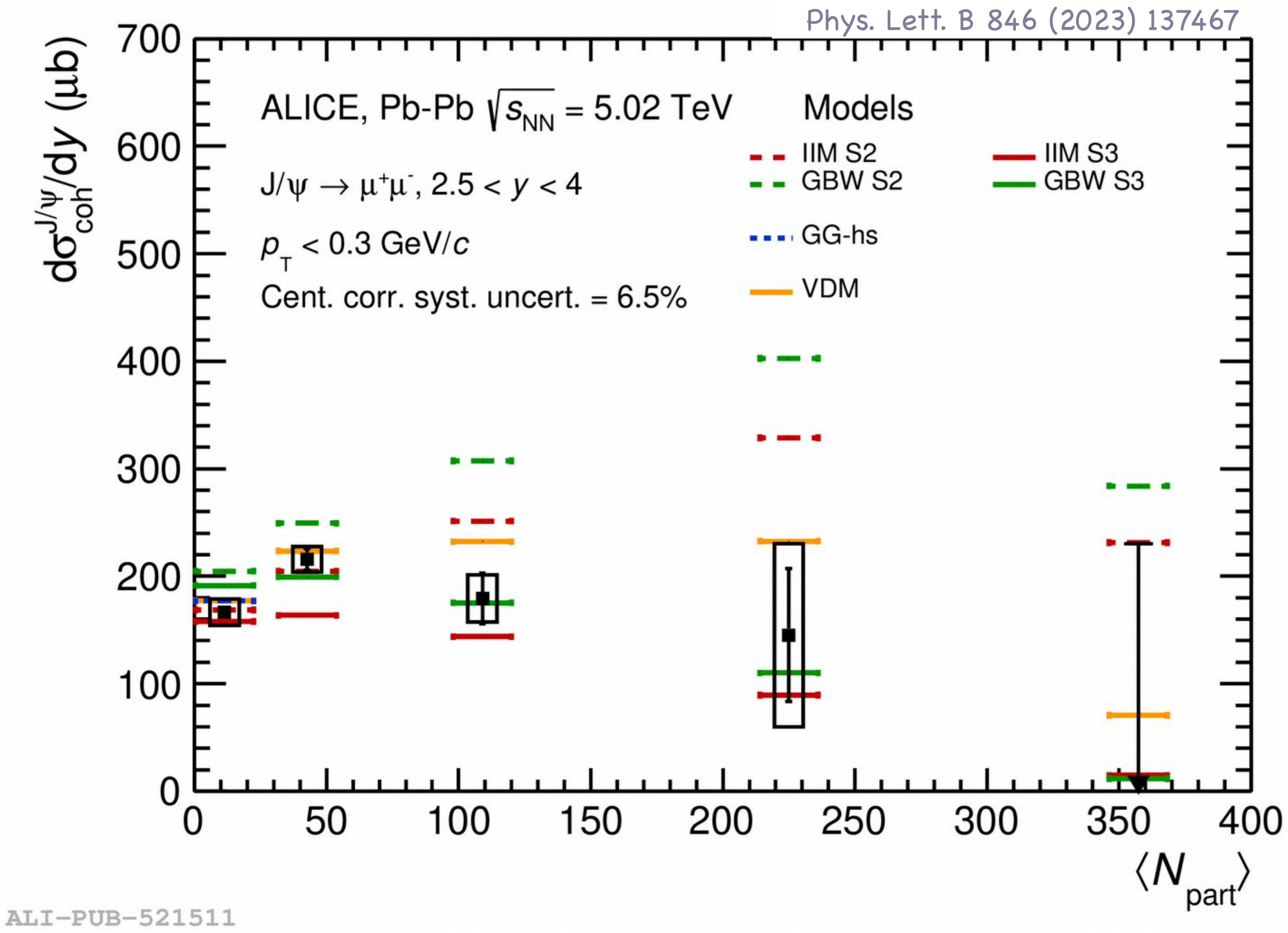
PCs.

Forward rapidity

2.76 TeV



5.02 TeV



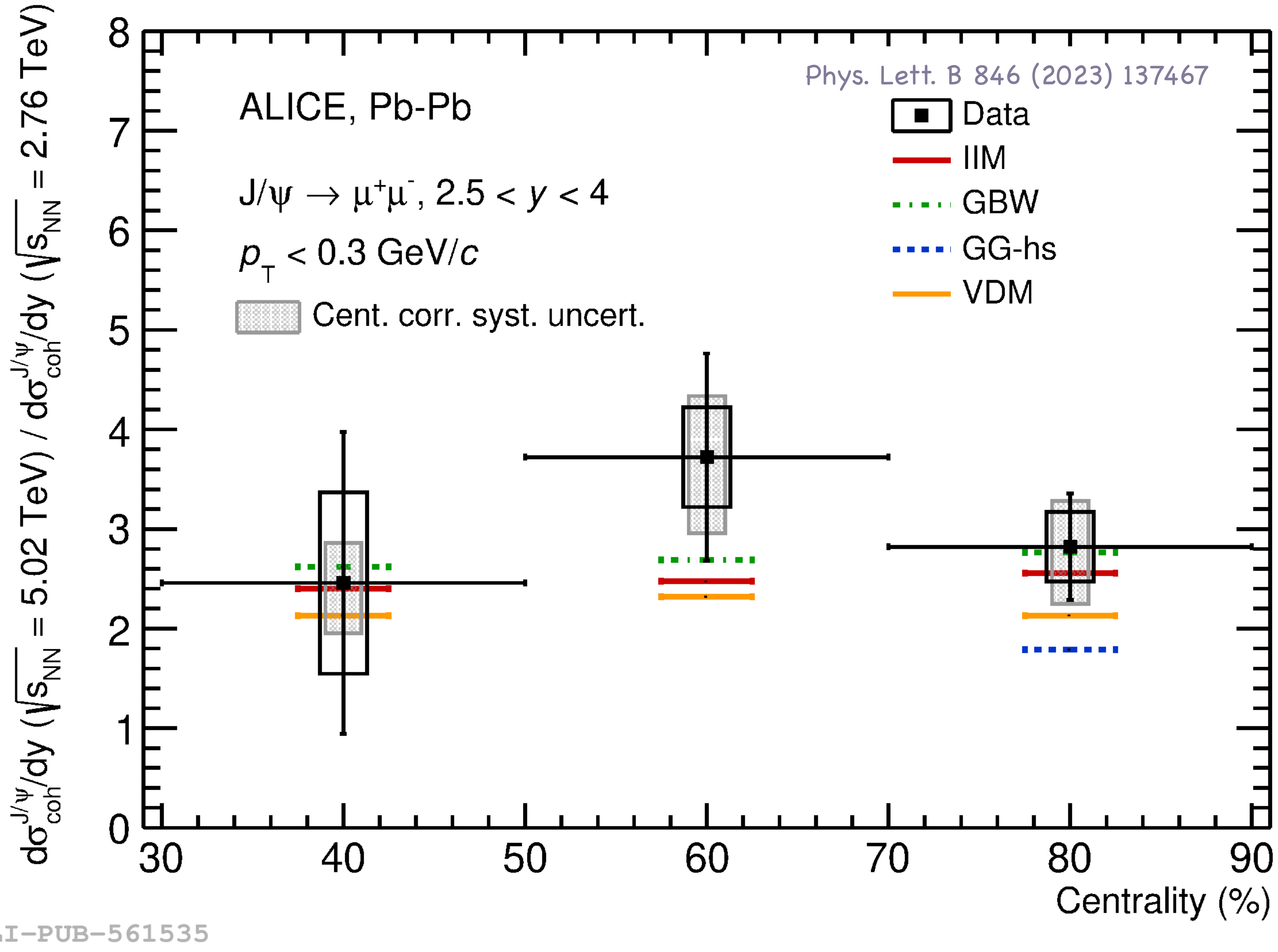
70-90% 50-70% 30-50%. 10-30%. 0-10%

* 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 : energy dependence

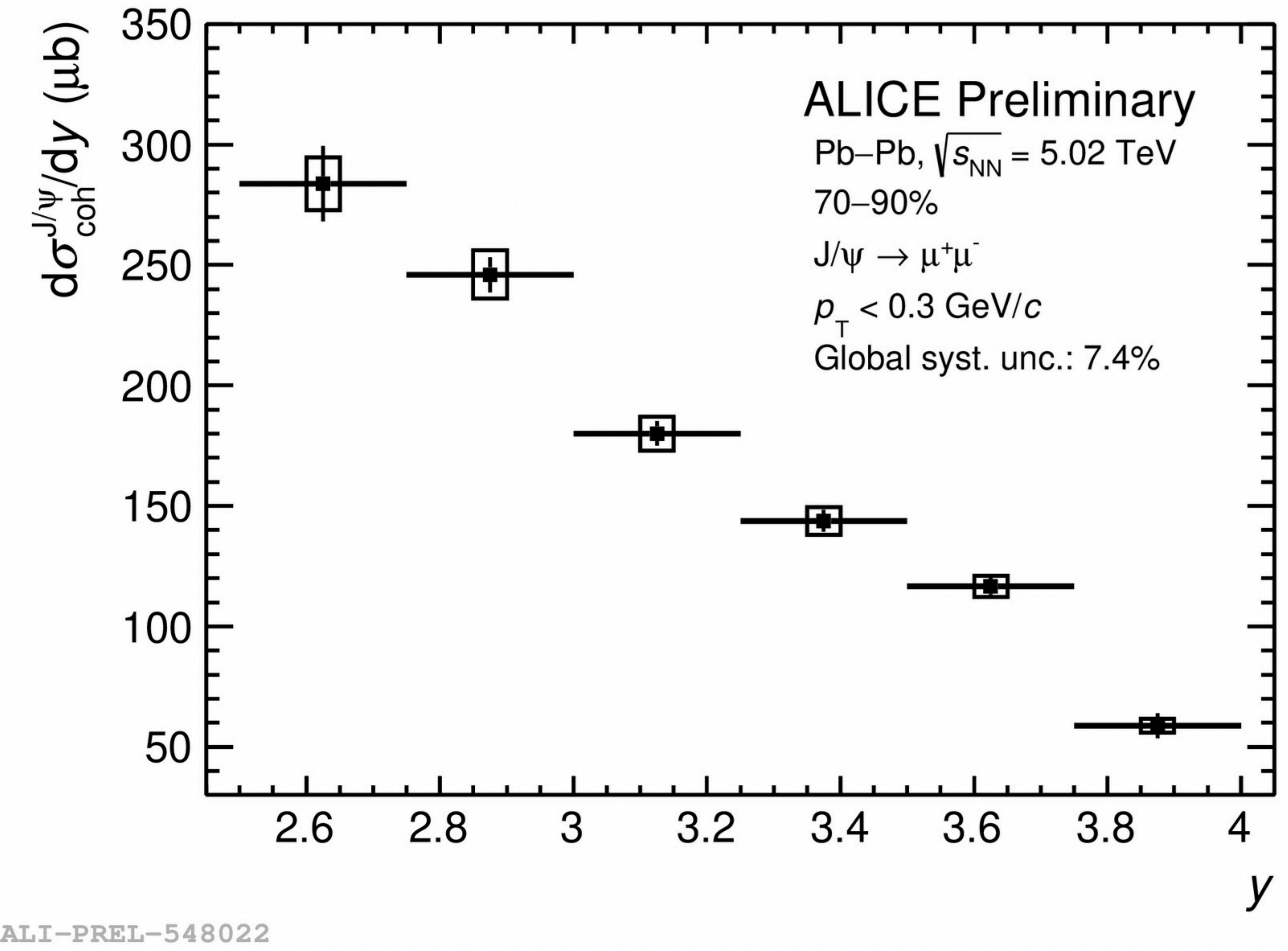
Forward rapidity, centrality and energy dependence



Measurements don't show a significant centrality/energy dependence

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

J/ψ photoproduction cross section vs. y in PCs

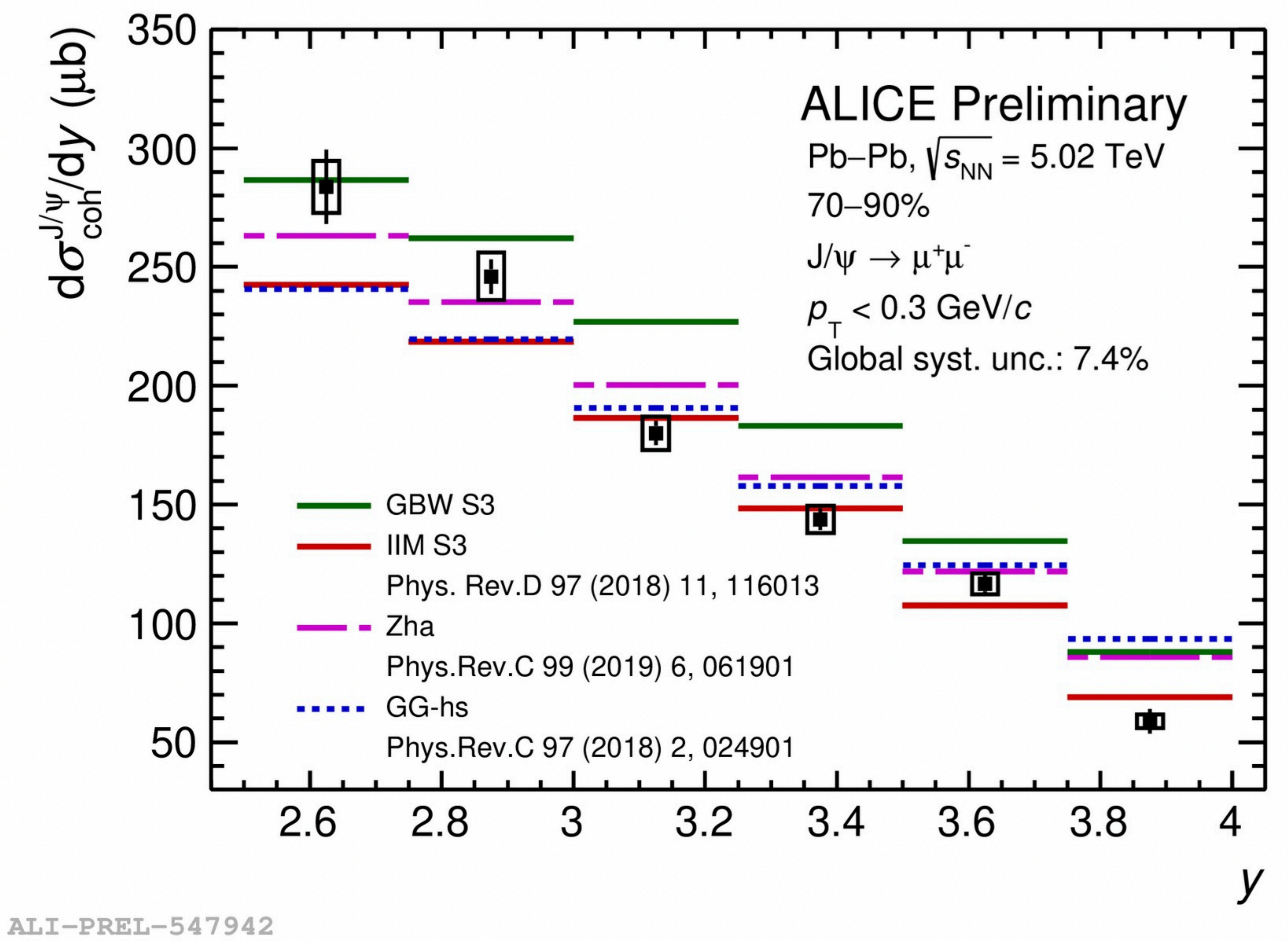


J/ψ excess yield = J/ψ raw yield – J/ψ hadronic yield

The coherent J/ψ yield is obtained by correcting the excess yield for the fraction of incoherent J/ψ (fI, 8.9%) and the fraction of coherent (fd, 6.6%) ψ(2S)→J/ψ evaluated in UPC. arXiv:2204.10684

A strong rapidity dependence is seen

J/ψ photoproduction cross section vs. y in PCs

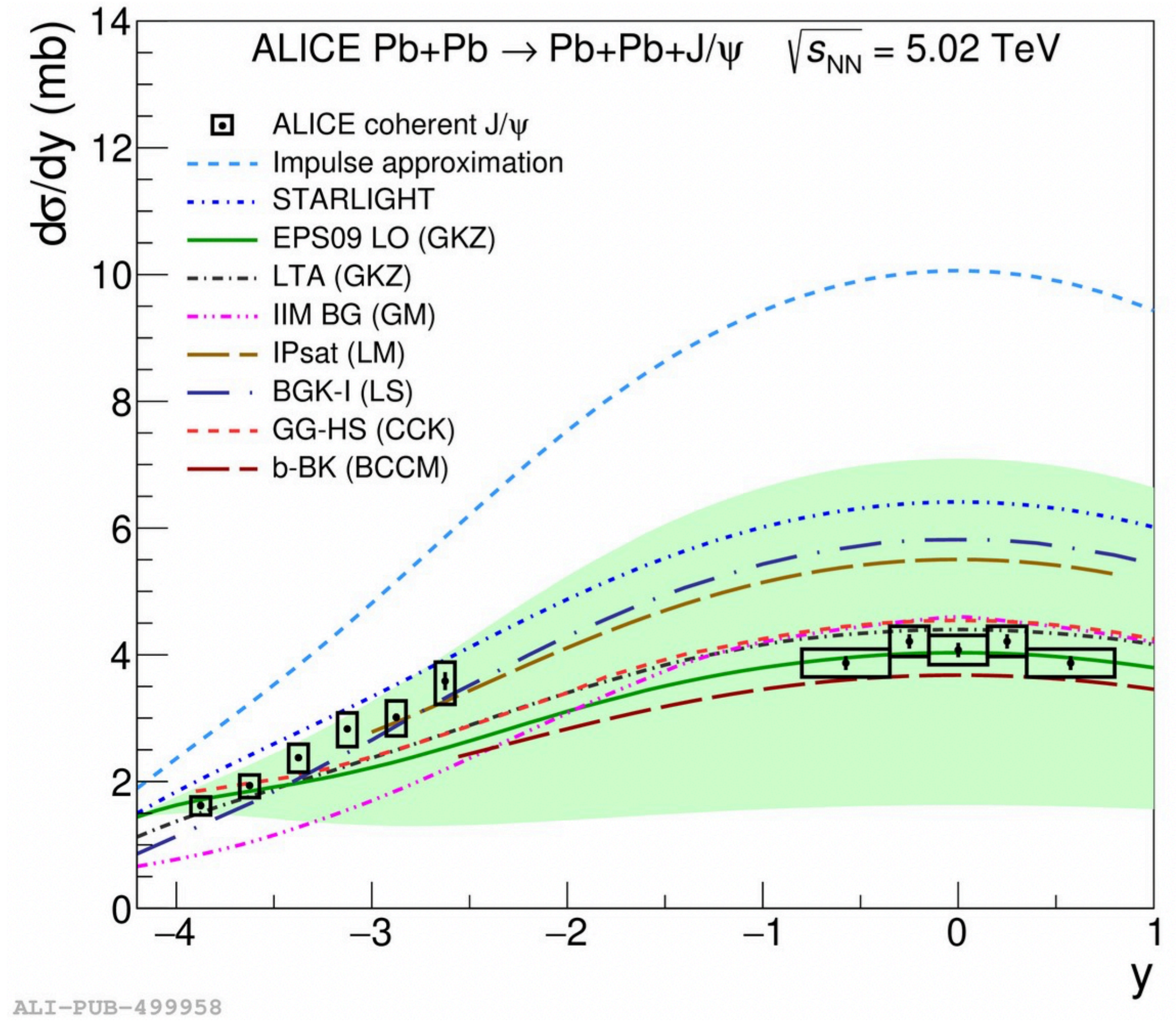


Models considerations:

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

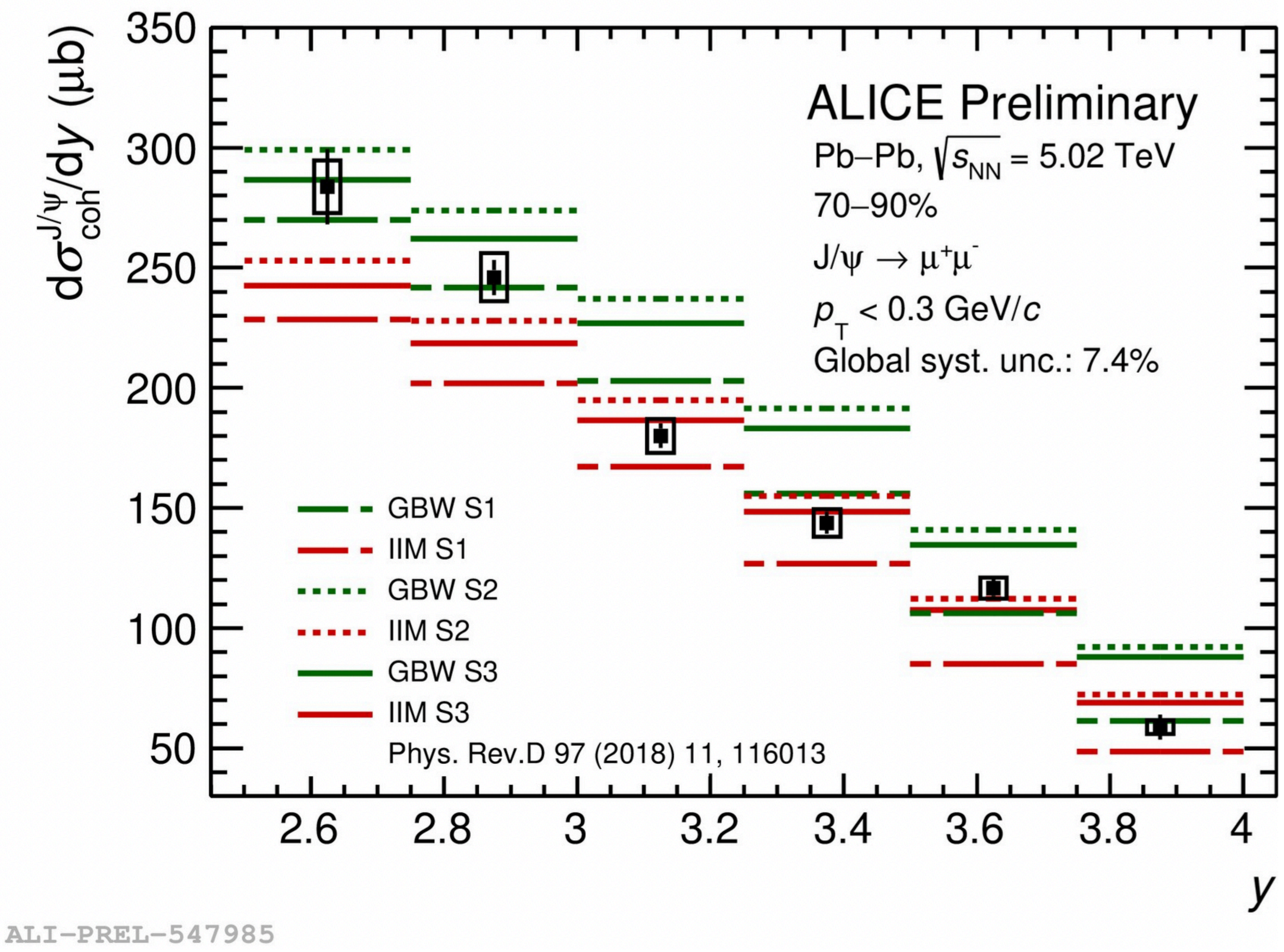
Zha : assumptions on photon-pomeron coupling (nucleus+spectator)

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



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 in PCs



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)

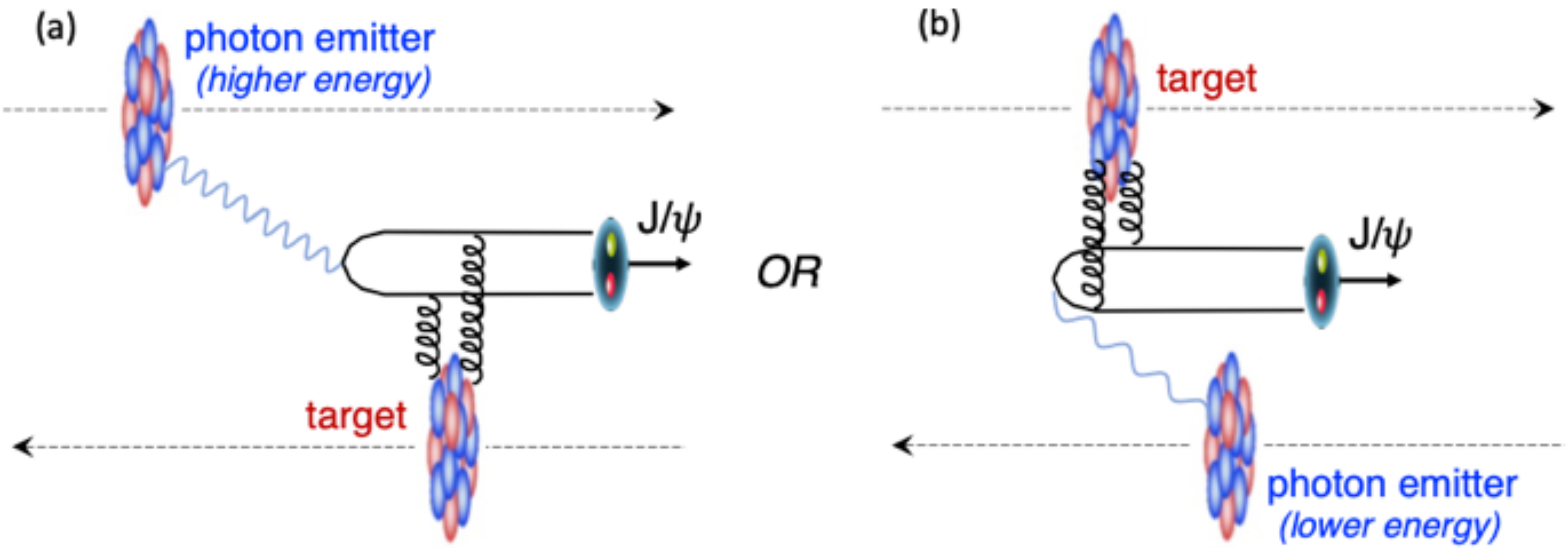
The three scenarios are qualitatively describing the cross section

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)



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

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

Photo-induced processes in symmetric collisions (Pb—Pb)

↓

Energies of photon emitted are different (corresponds to different Bjorken-x)

↓

Depends on which nucleus acts as source or target

↓

Due to direction (or sign in the rapidity) of photon emitter

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

Bjorken-x depends on center-of-mass energy of photon-Pb system ($W_{\gamma Pb}$) and rapidity of VM

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!

For midrapidity, y =0

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y} = 2n(\gamma)\sigma_{\gamma\mathrm{Pb}}$$

Goal is extracted : $\sigma_{\gamma\mathrm{Pb}}$ vs. $W_{\gamma\mathrm{Pb}}$ or x

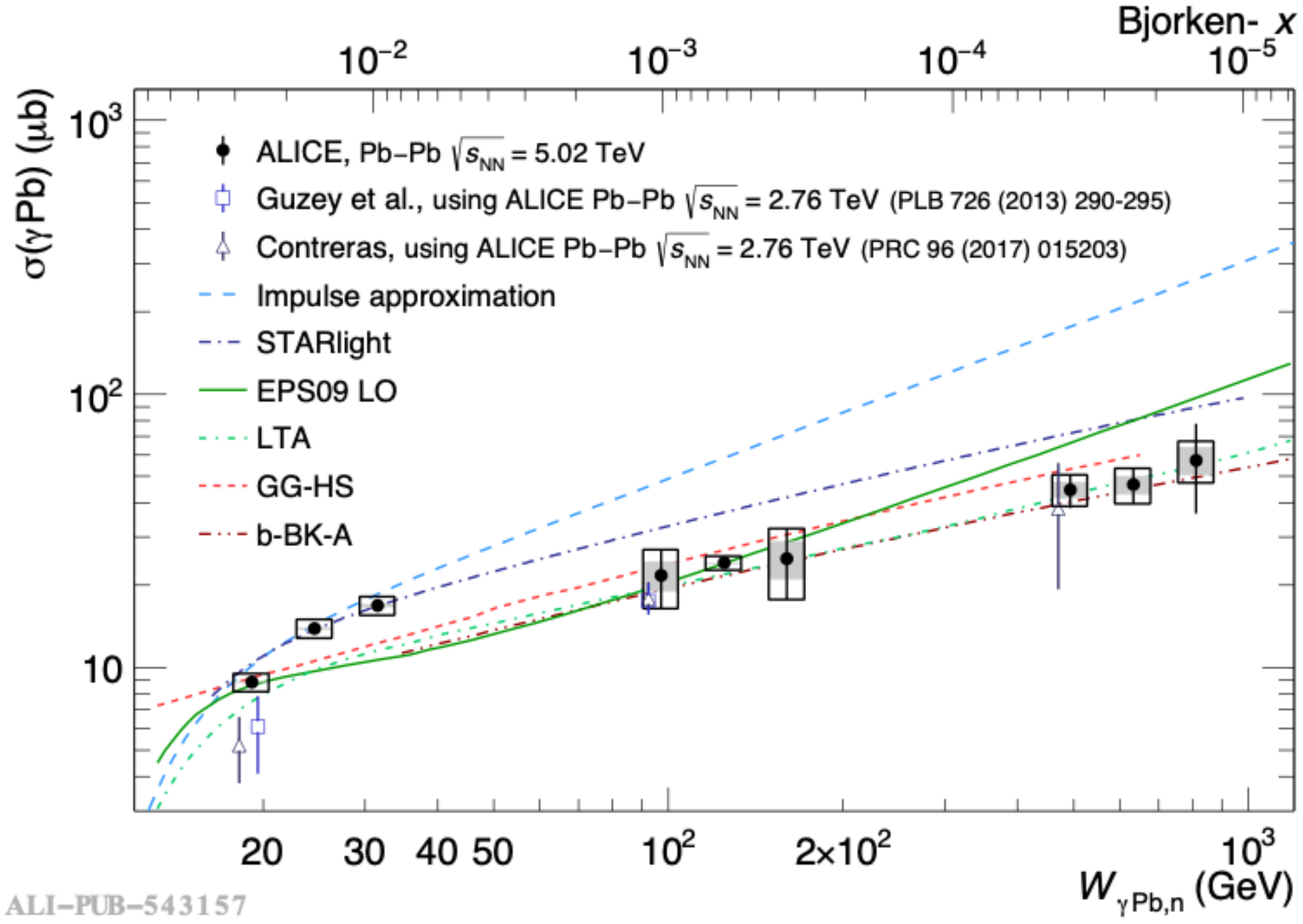
Proposed solution by Guzey et al., Eur.Phys.J.C 74 (2014) 7, 2942 and J. G. Contreras, PRC 96, 015203 (2017)

i) Electromagnetic dissociation of nuclei (EMD): Different neutron emission

ii) Measurement in UPCs and PCs (both integrated and differential y)

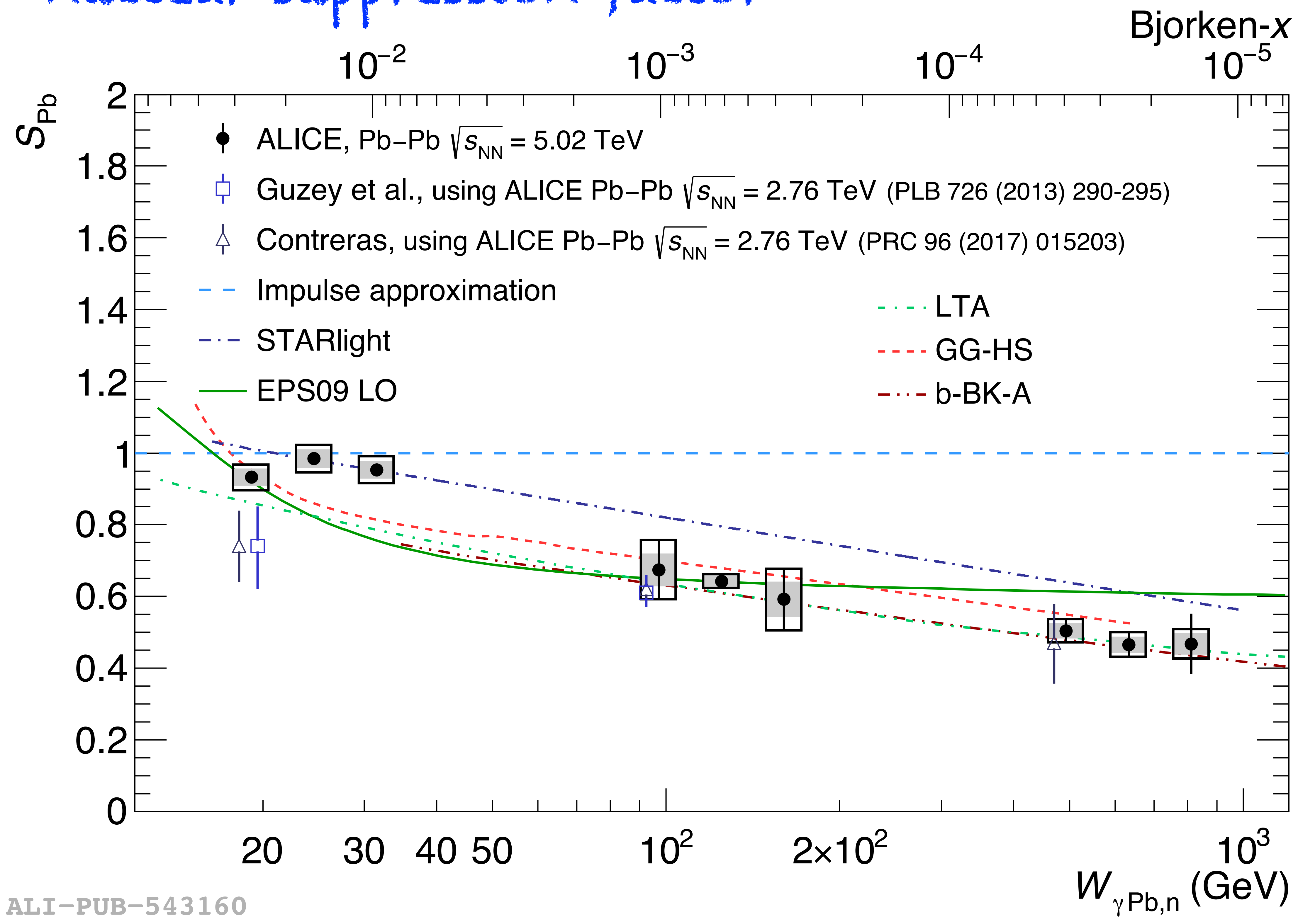
Coherent J/ψ with Neutron emission

Photonuclear cross section



nuclear suppression factor

ALICE, arXiv:2305.19060



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

At low-x data favors both saturation and shadowing models whereas at x (~ 10^{-2}) LTA and impulsive approximation describes the measurement

Photon energy ambiguity : simultaneously measurement

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

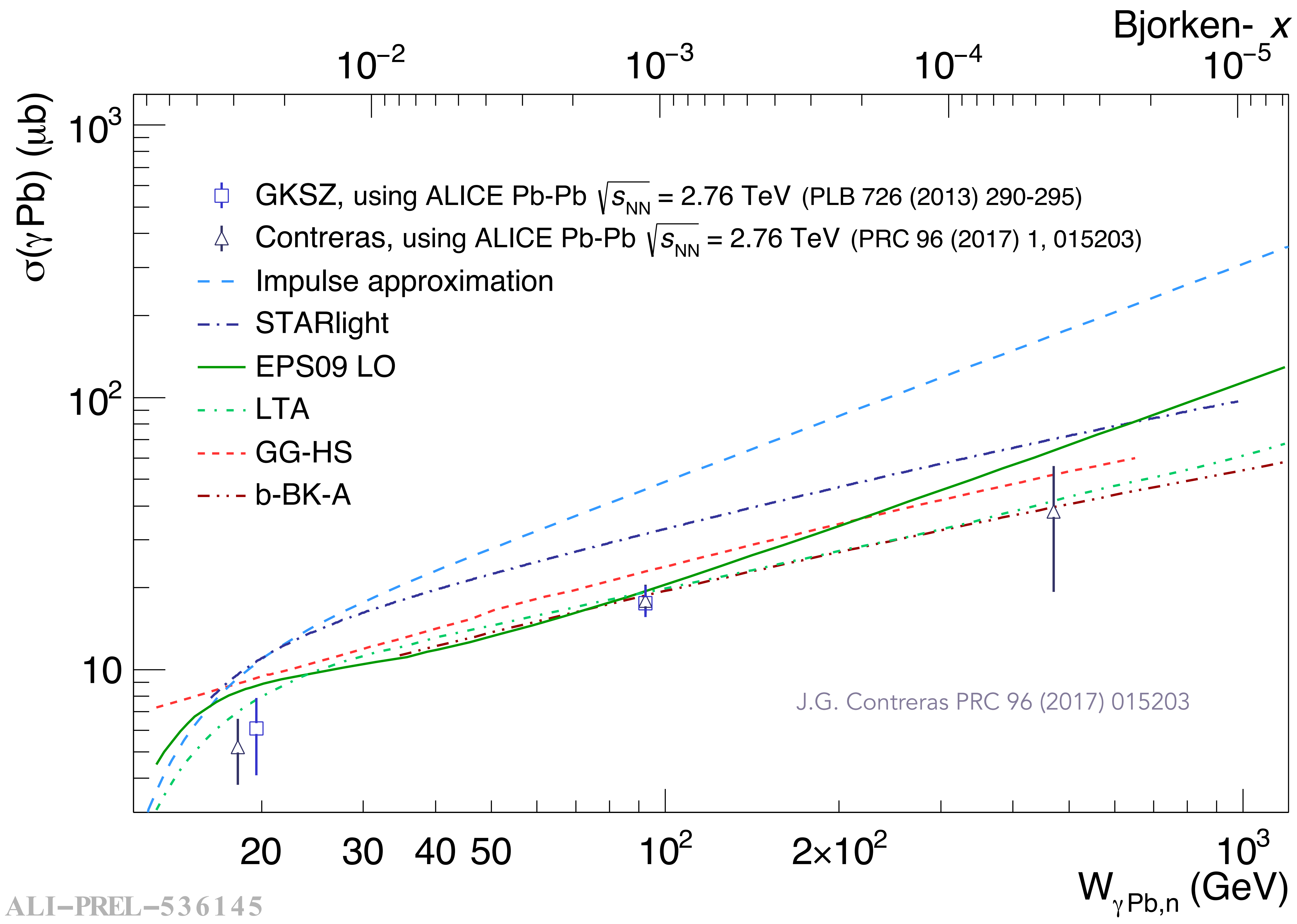
Goal is extracted :
$\sigma_{\gamma Pb}$ vs. $W_{\gamma Pb}$ or x

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

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

Photon energy ambiguity : simultaneously measurement

PEA



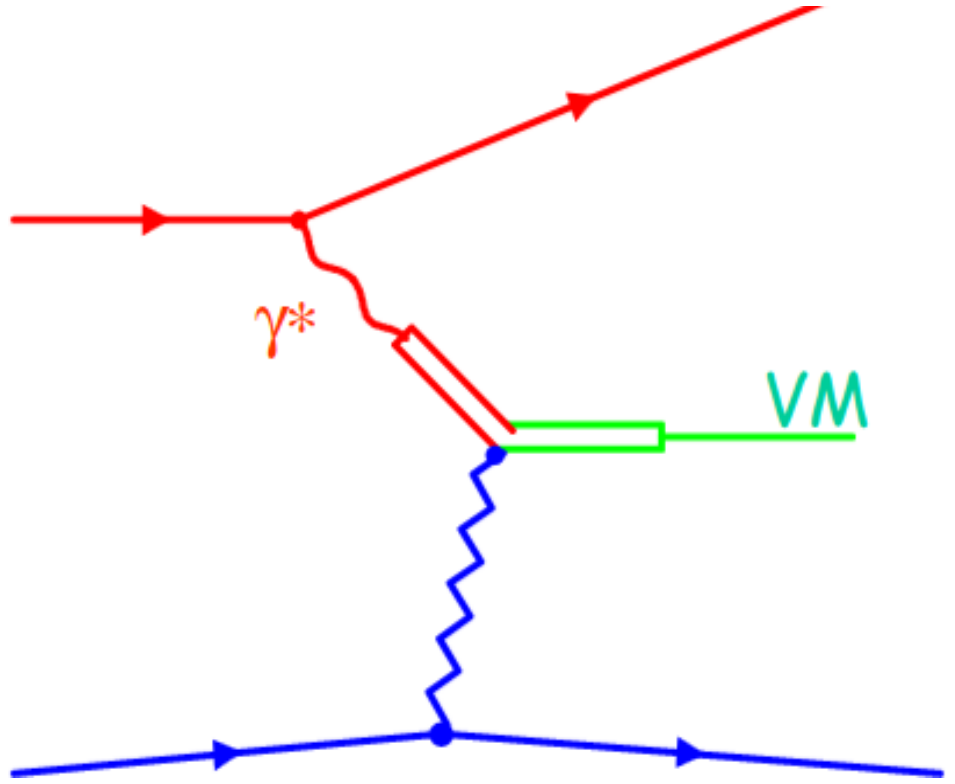
Caveat : this calculation considers the photon-nucleus cross sections in both PC and UPC to be the same.

Using new rapidity-dependent results provide further constraint on photonuclear cross section computations

Polarization:

Coherent VM photo production in UPCs and PCs

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)

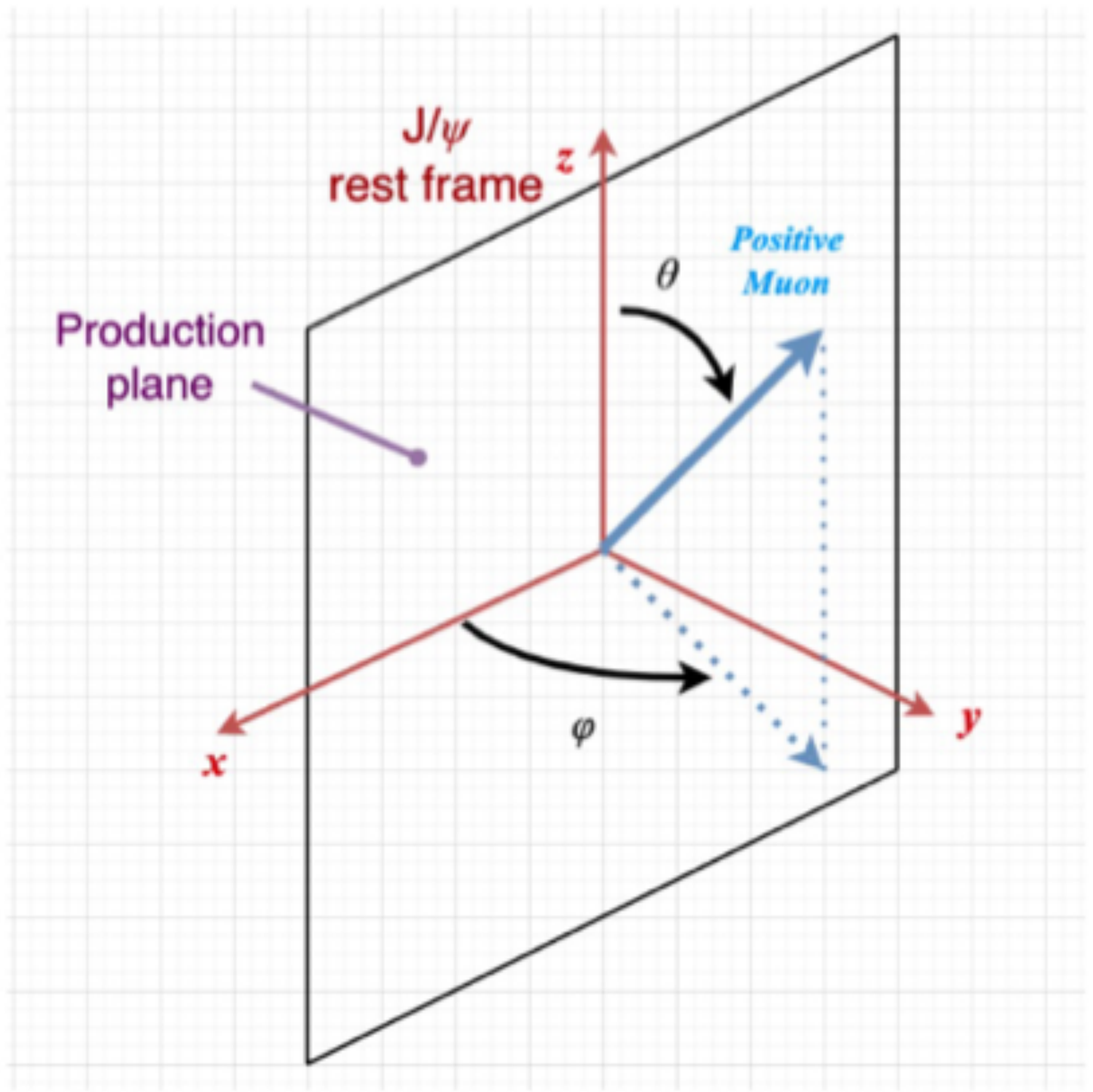
Vector meson (VM) has retained same helicity and polarization as that of the initial photon that interacted with the target

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

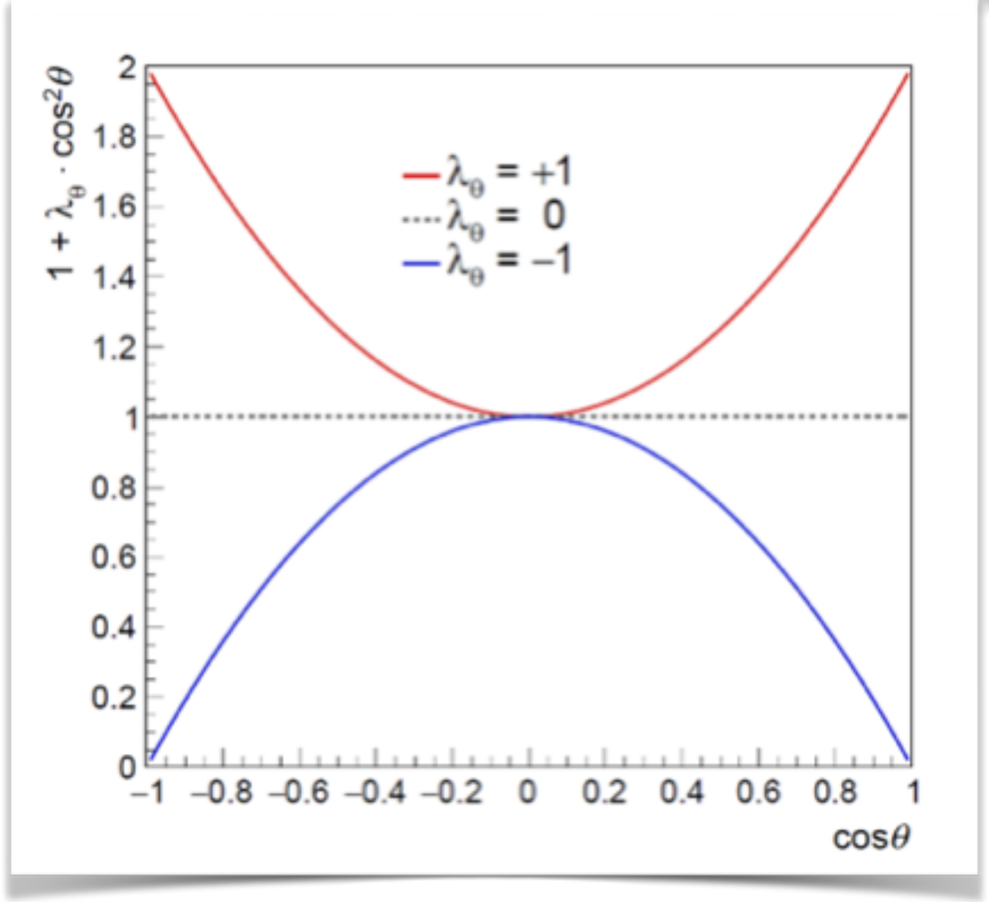


$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_\theta} \cdot (1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos2\phi + \lambda_{\theta\phi} \sin2\theta \cos\phi)$$

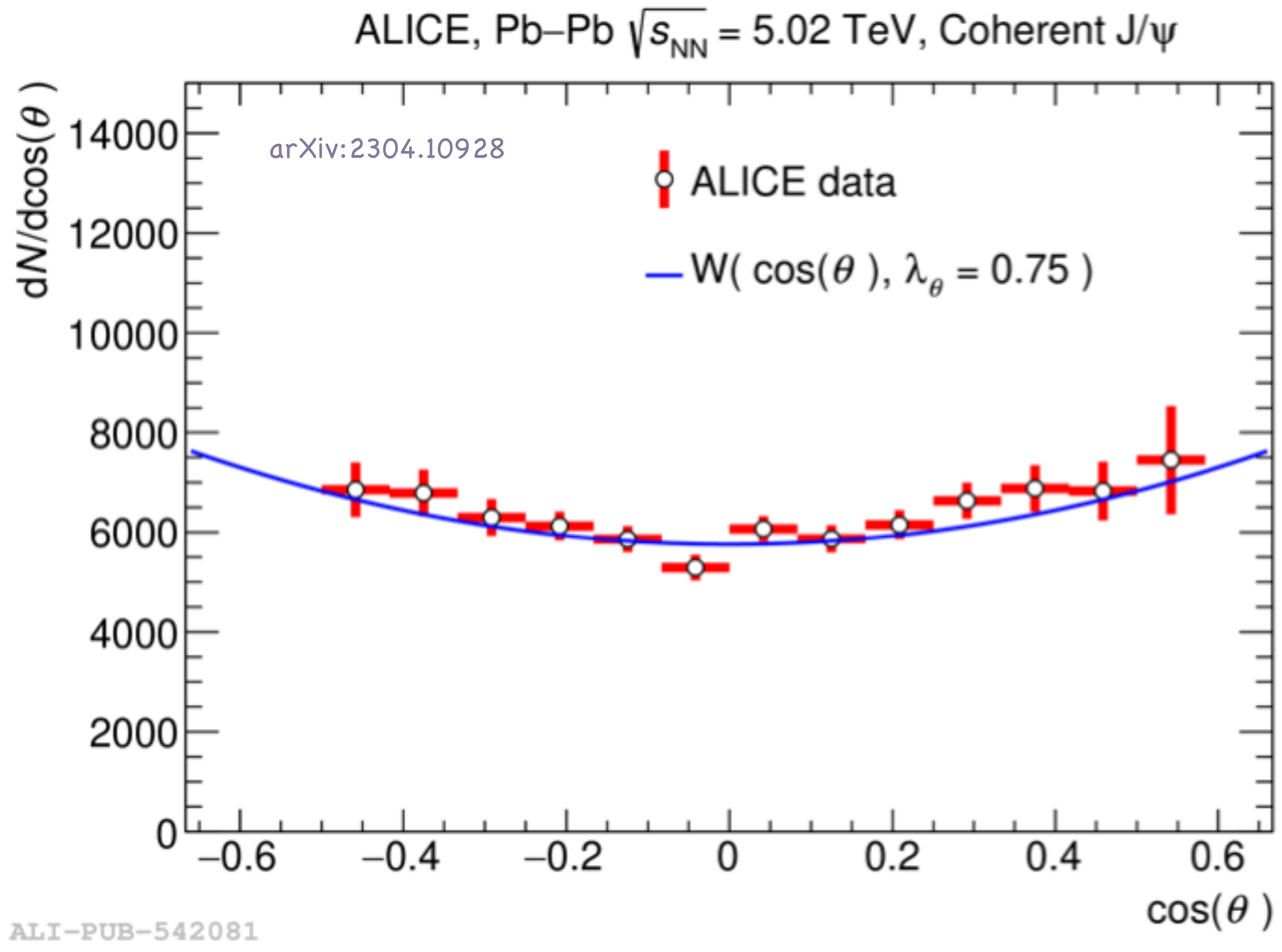
$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (0,0,0)$ ⟹ No polarization

$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (+1,0,0)$ ⟹ 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

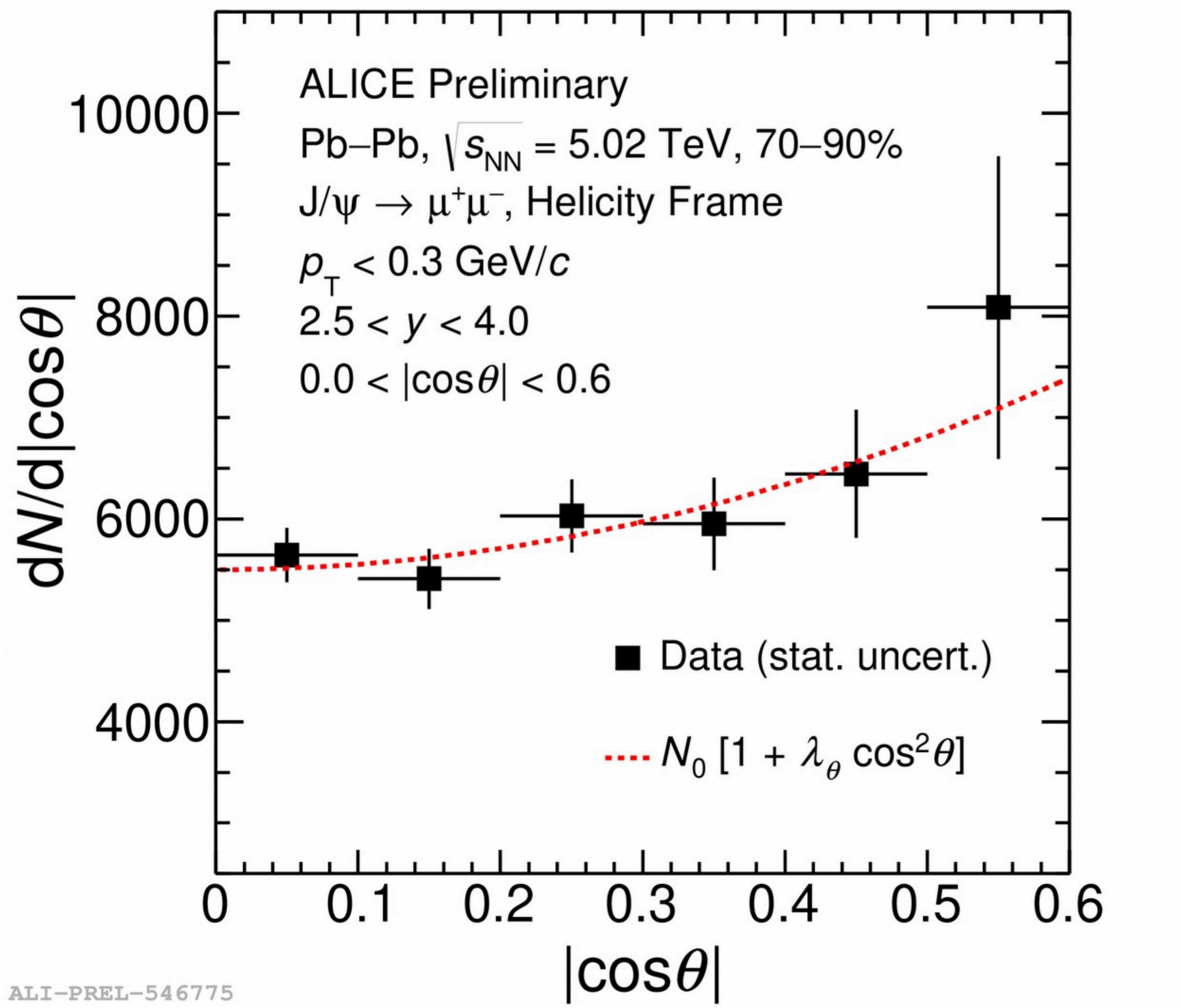
Transversely polarized

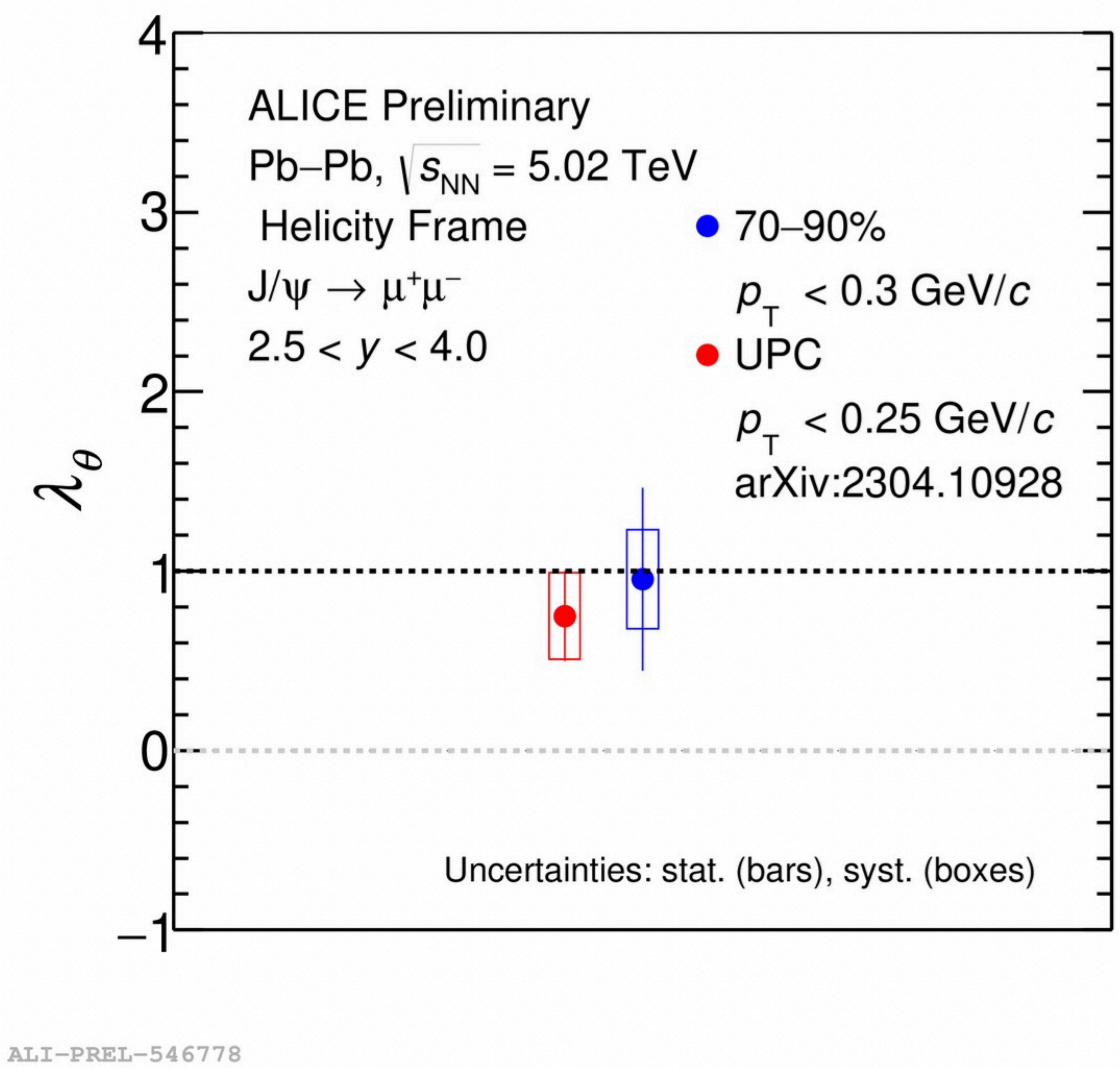
Consistent with SCHC hypothesis

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

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 (~ 78%) over the J/ψ hadronic production [arXiv:2204.10684]

Summary

Coherent photo production cross section measurements:

☑ No significant centrality/energy dependence are seen in coherent J/ψ photoproduction cross section

☑ First y-differential measurement of coherent J/ψ photoproduction cross section in peripheral Pb–Pb collisions (PC) 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

Photoproduction cross section

- 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 and new MFT results:**
  - 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)

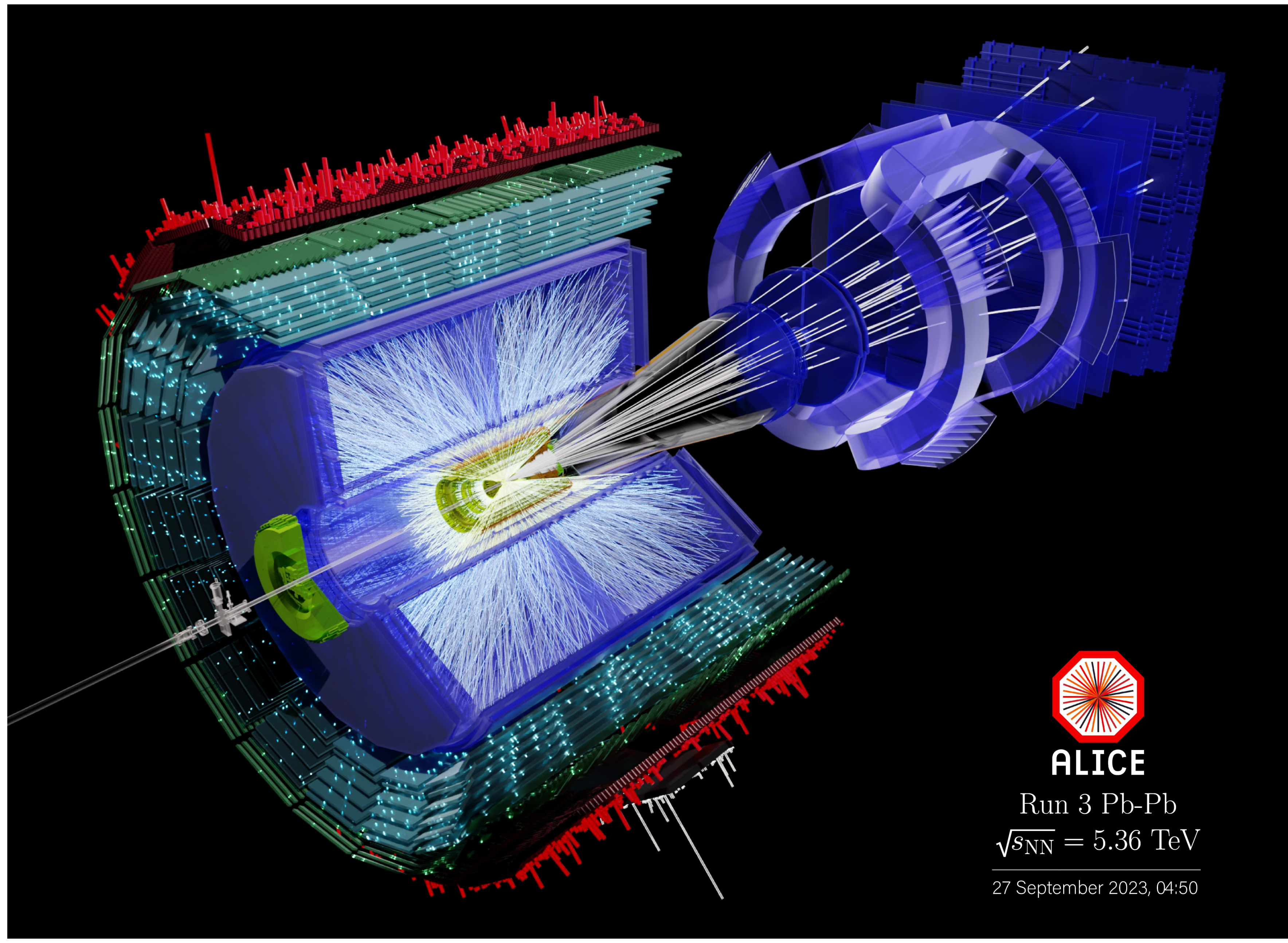
    -> **precision and more differential measurements**

- Look at **heavier vector mesons** could become also possible to pin down possible **QGP effects** on the measured probes
- Look at ratios of coherent ψ(2S)/J/ψ(1S) : centrality and rapidity

Polarization :

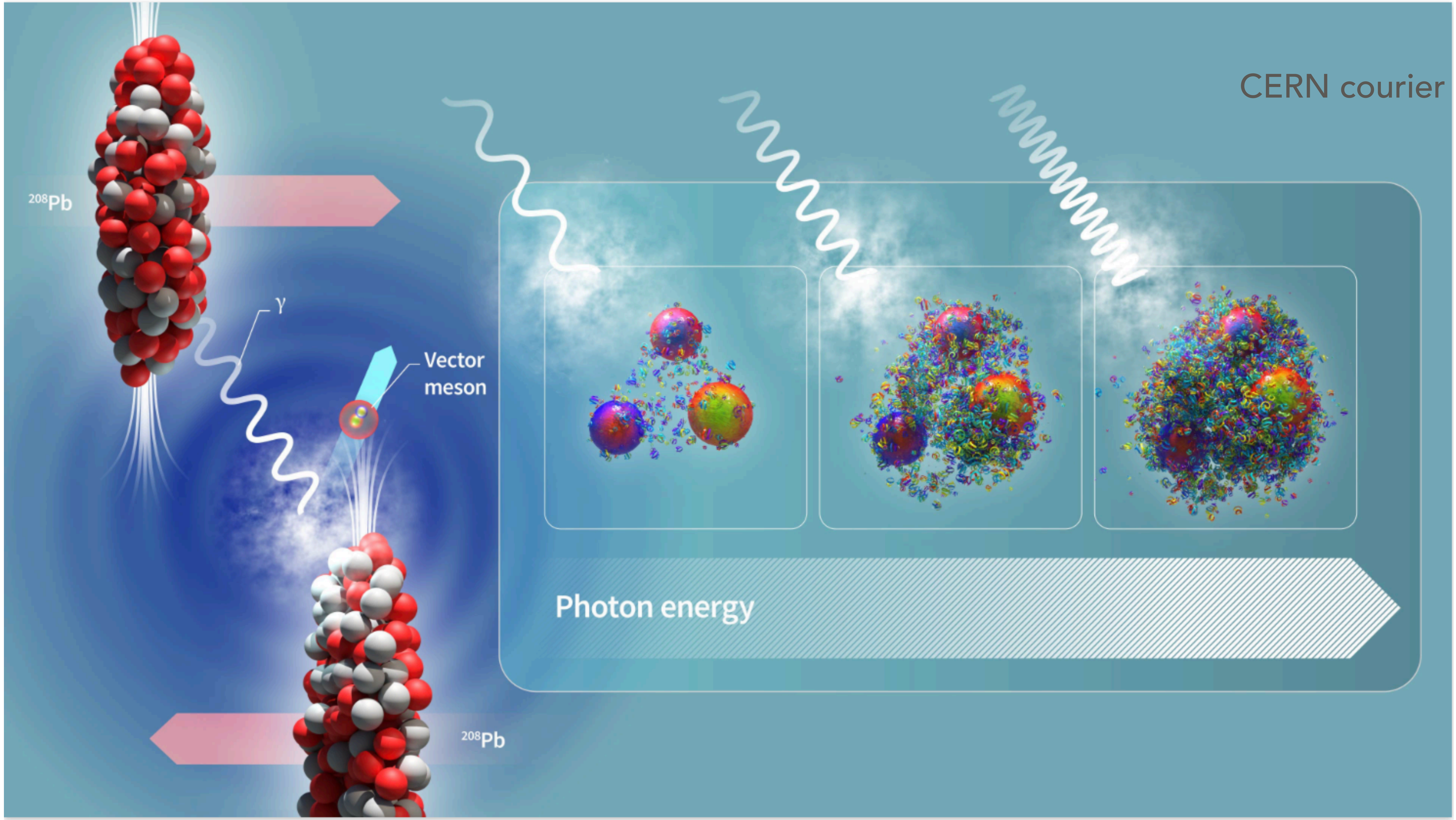
- **Precision measurement** in J/ψ and other VMs (i.e ψ (2S), Υ(nS) etc.)

- Will explore **interference and entanglement phenomena** of VMs



Back up

ALICE shines light into the nucleus to probe its structure

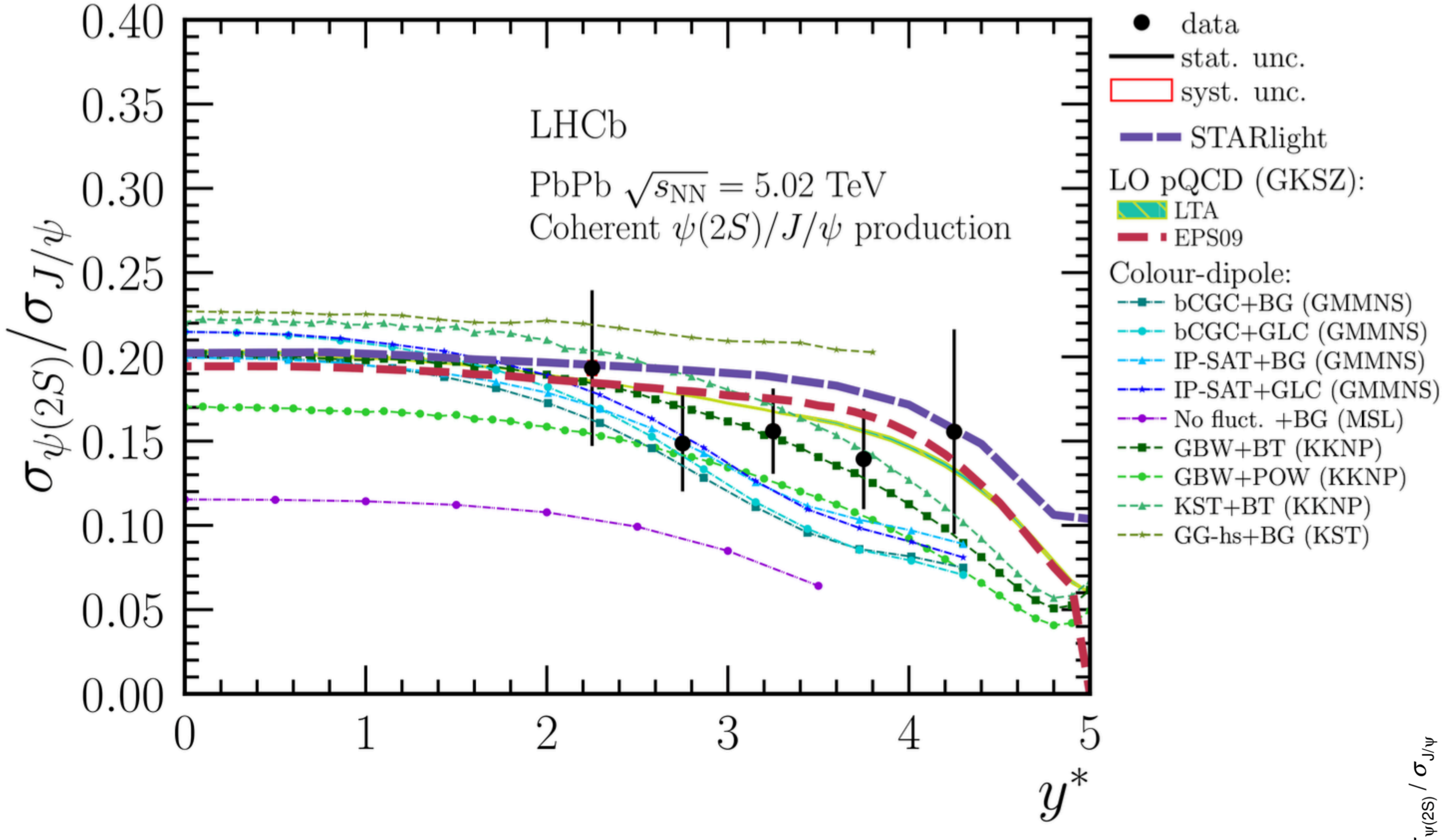


The structure of the gluonic matter in the nucleus gets further exposed when probed by higher energy photons

https://home.cern/news/news/physics/alice-shines-light-nucleus-probe-its-structure

VM photo production cross section ratio vs. y in UPC

JHEP 06 (2023) 146



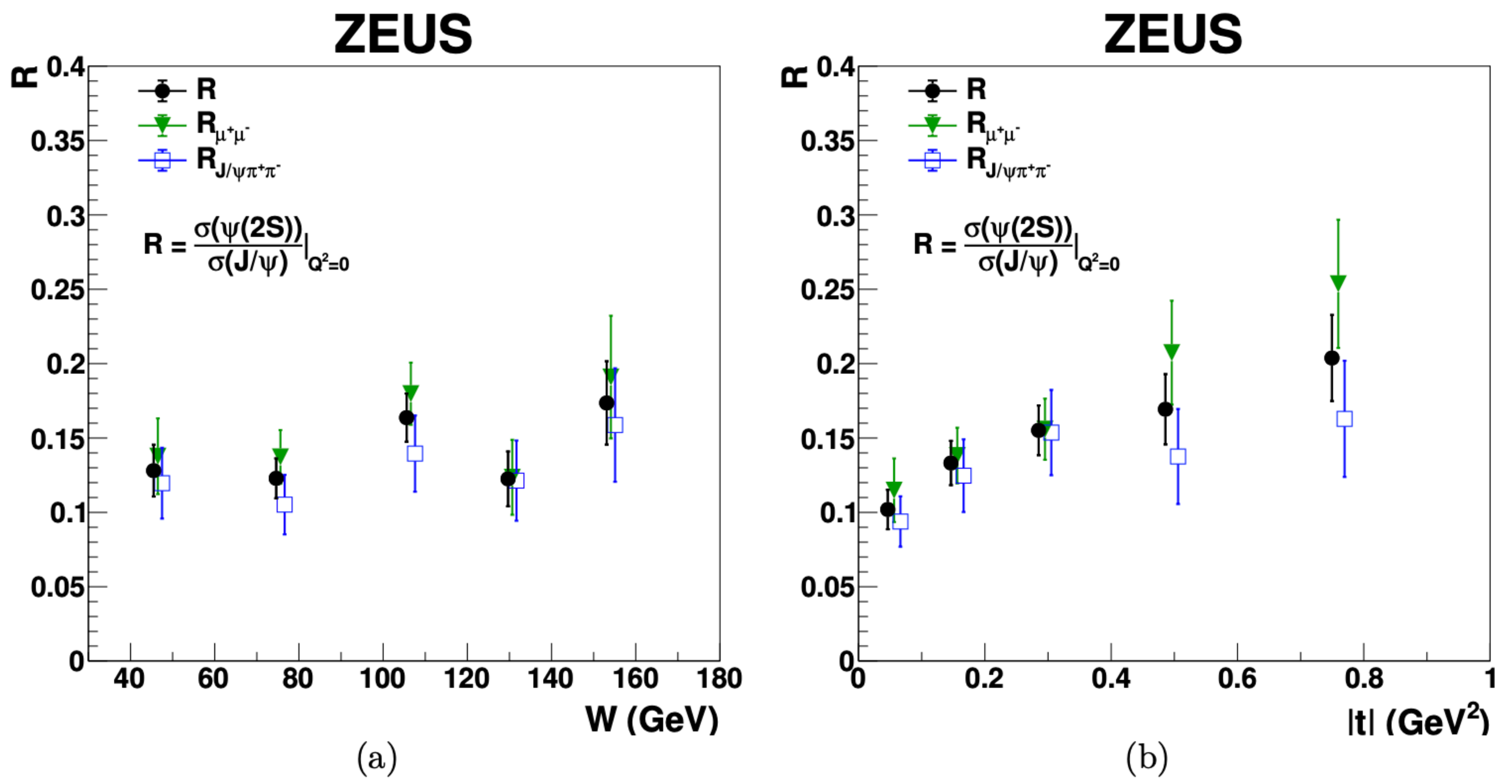
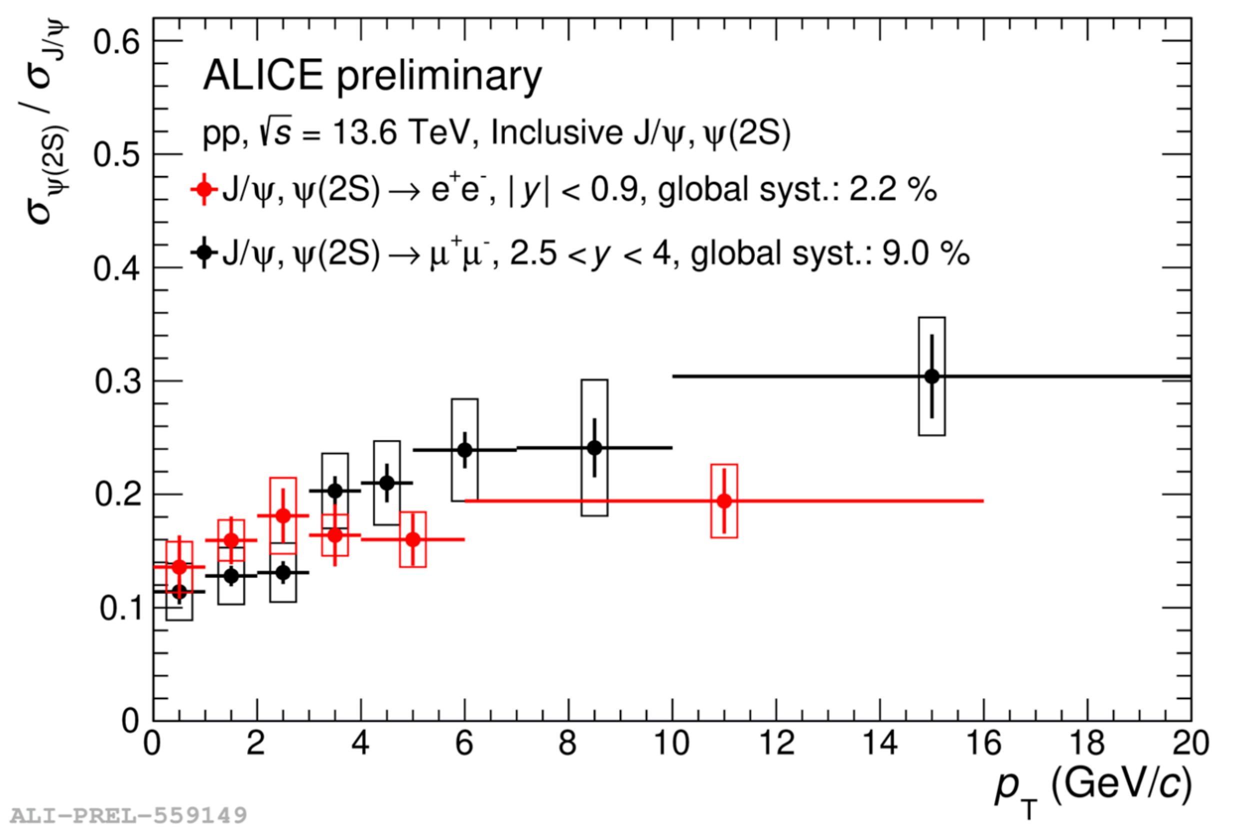


Figure 7. Cross-section ratio $R = \sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ in photoproduction as a function of (a) W and (b) $|t|$ for the two decay channels, $R_{\mu\mu}$ for $\psi(2S) \to \mu^+\mu^-$ (triangles) and $R_{J/\psi\,\pi\pi}$ for $\psi(2S) \to J/\psi(1S)\,\pi^+\pi^-$ (squares), and the combination of the two decay modes (solid circles). The error bars show the statistical uncertainties only. The points for R are shown at the mean W and $|t|$ values for each bin as determined for the $J/\psi(1S)$ data (see table 1). The points for $R_{\mu\mu}$ and $R_{J/\psi\,\pi\pi}$ are displaced horizontally for better visibility.

ALICE : at mid-y

coh.$\sigma_{\psi(2S)}$/coh.$\sigma_{J/\psi(1S)}$

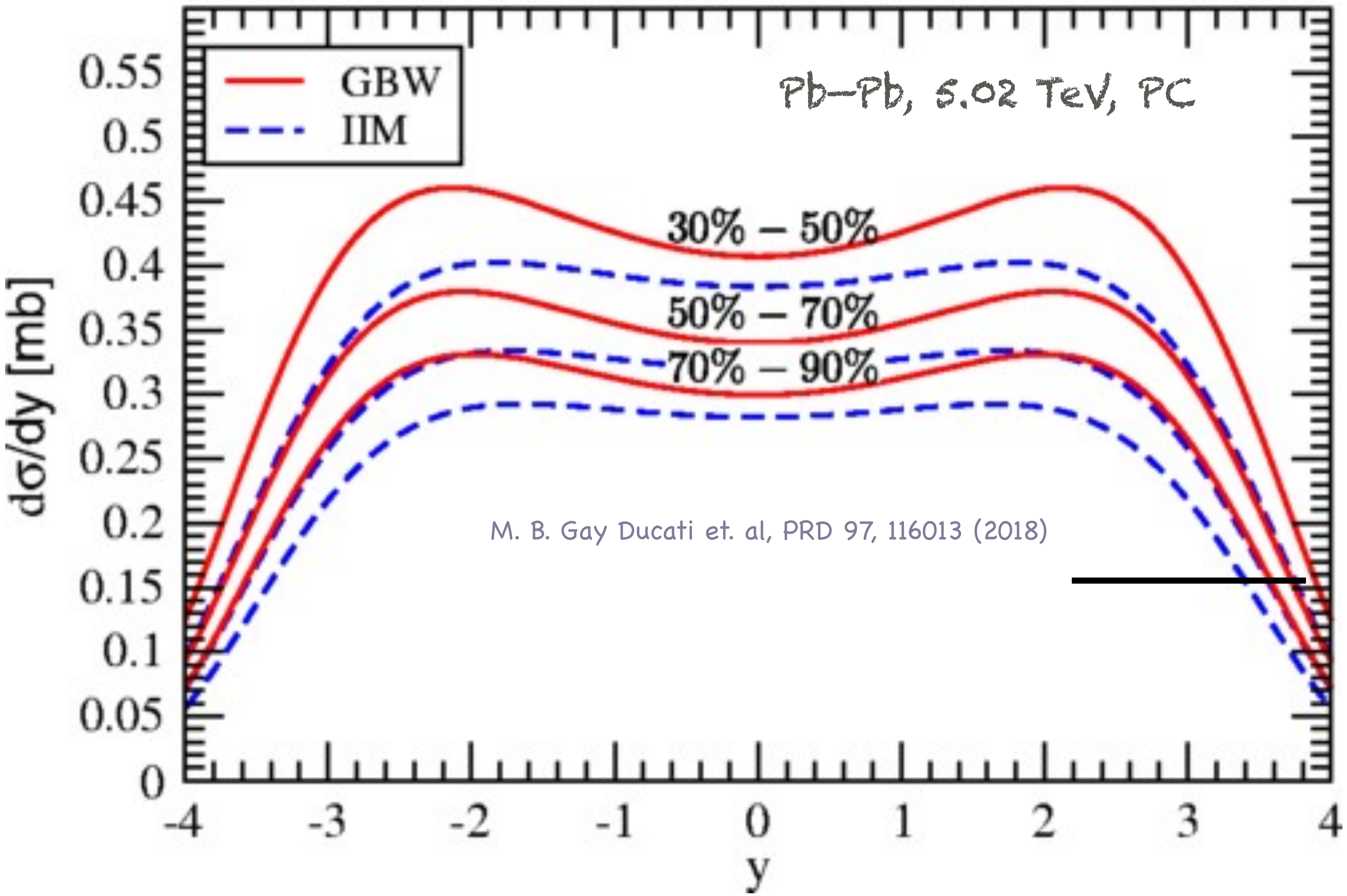
0.18 ± 0.0185(stat.) ± 0.028(syst.) ± 0.005(BR).



Ratio of ψ(2S) to J/ψ in LHC Run 3 proton-proton collisions as a function of transverse momentum, showing ALICE's capability for measurements of the excited and ground charmonium states in the central (red points) and forward (black points) region. (Image: ALICE)

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)



PCs = Peripheral collisions

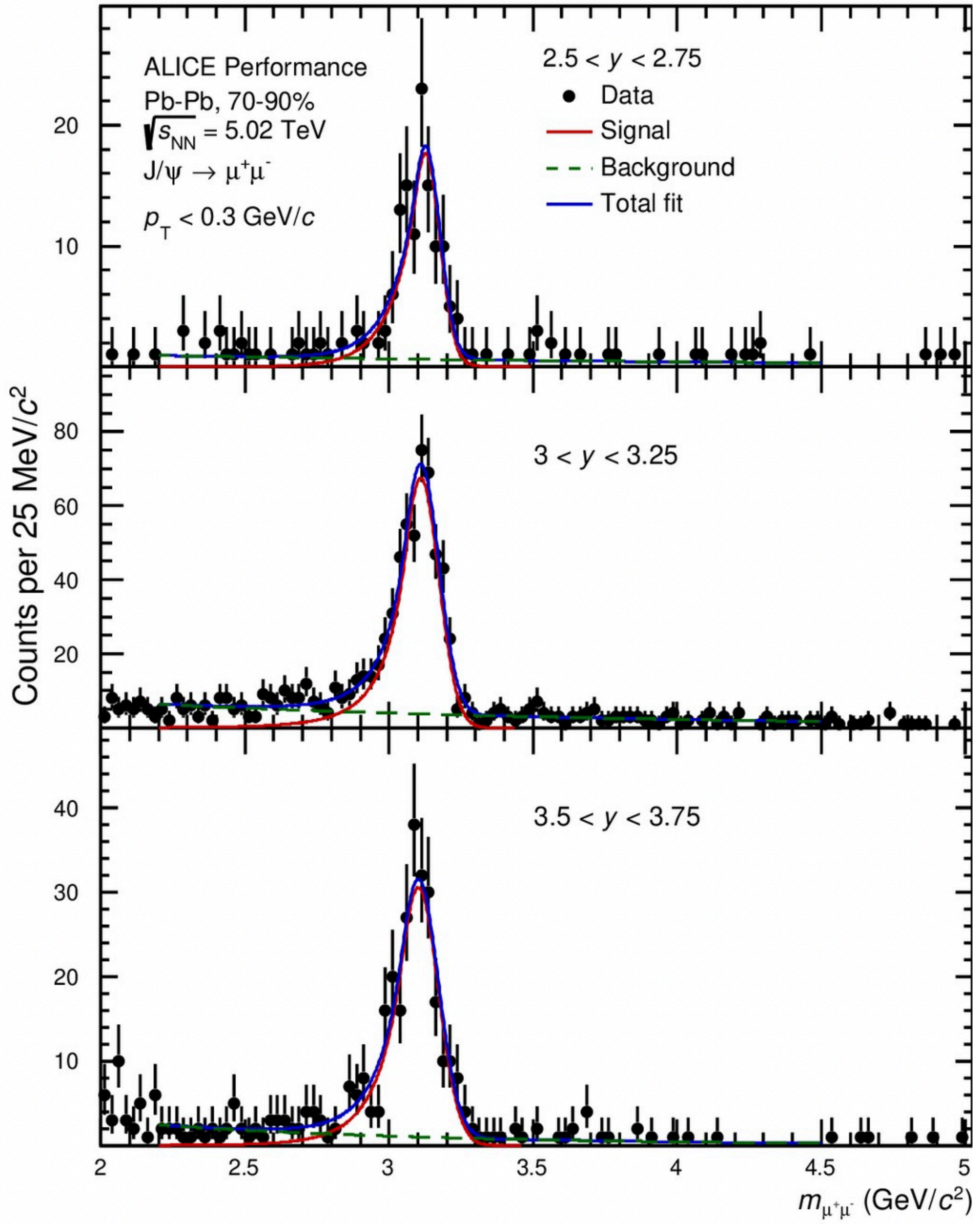
Additional differential measurements are needed to better constrain models, as done in UPC

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

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

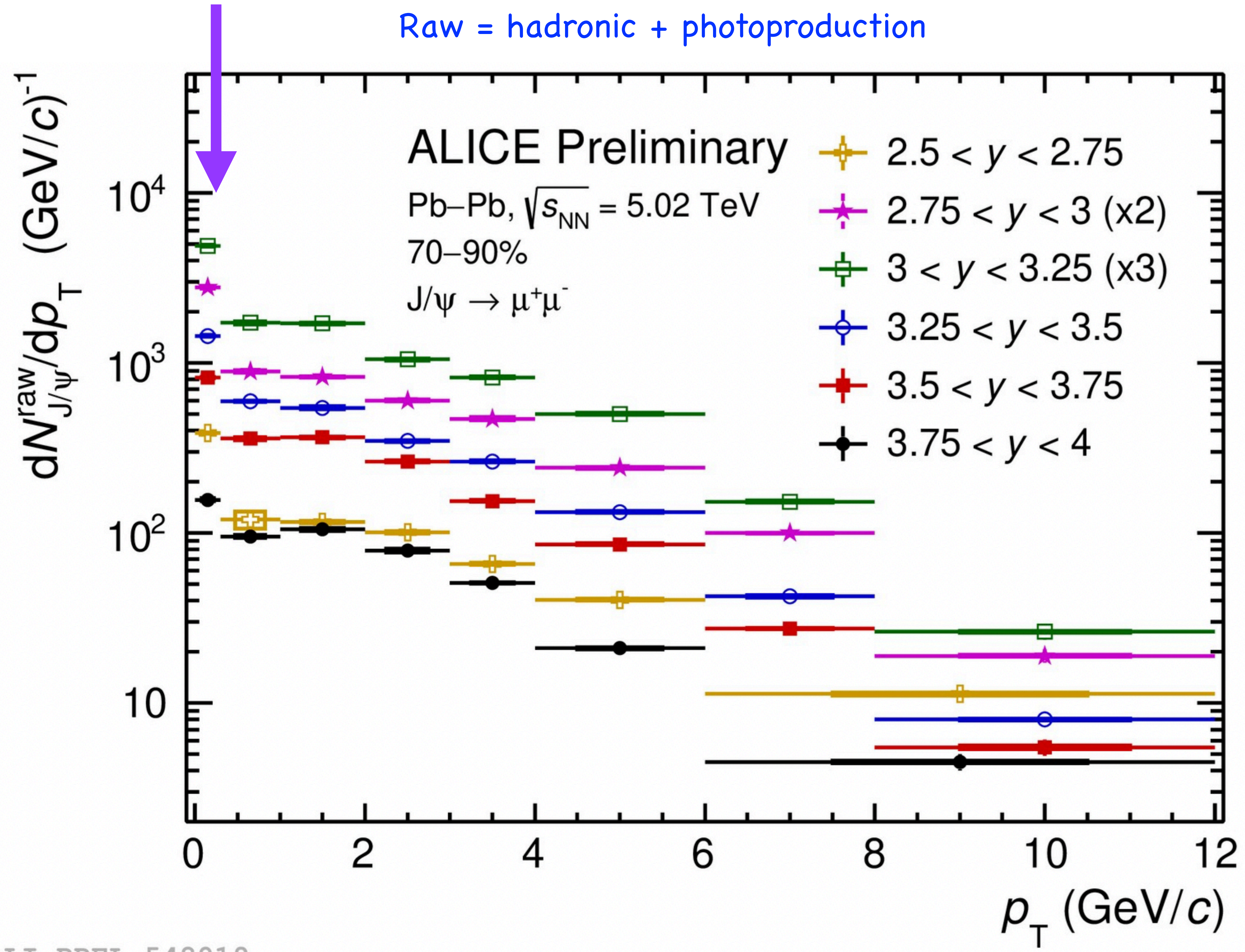
J/ψ signal extraction from the invariant-mass distribution of the decay daughters

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



ALI-PERF-538924

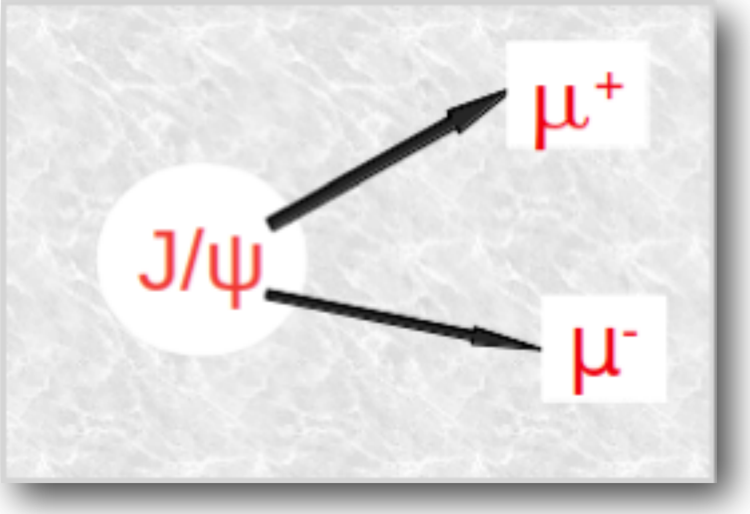
Raw = hadronic + photoproduction



ALI-PREL-548019

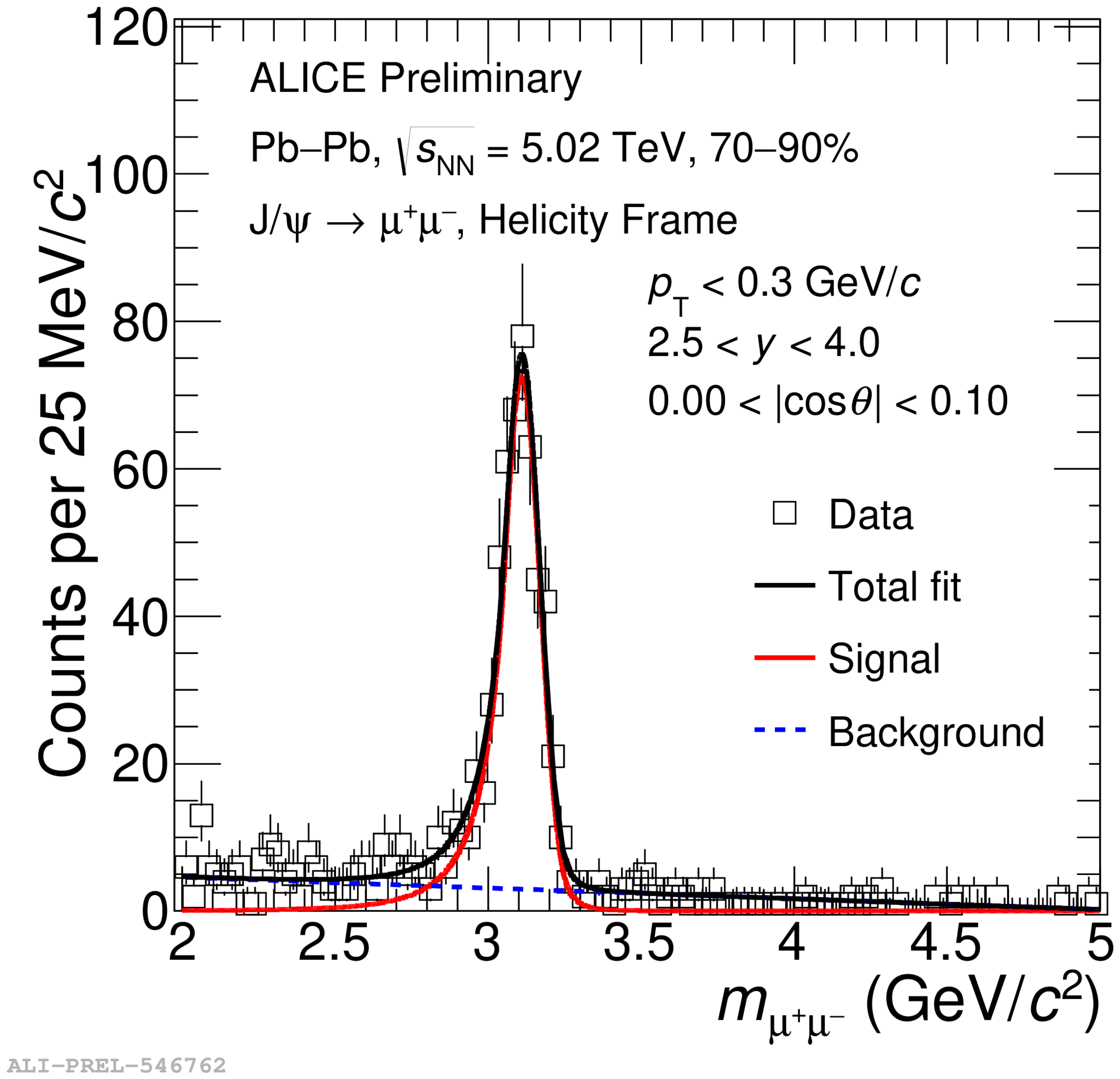
Raw yield excess is observed for $p_T < 0.3$ GeV/c for all y

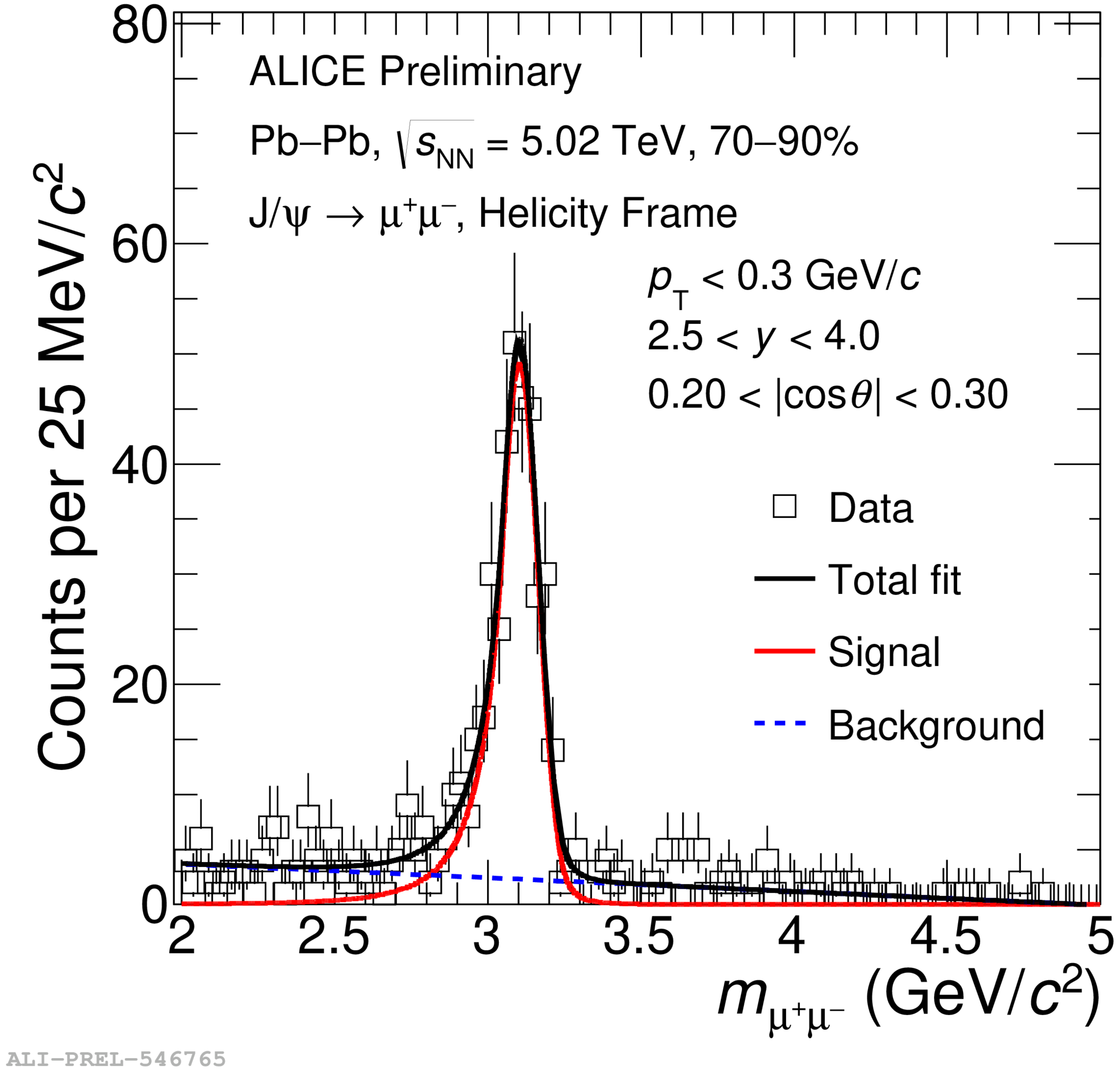
J/ψ signal extraction in angular intervals for p_T < 0.3 GeV/c



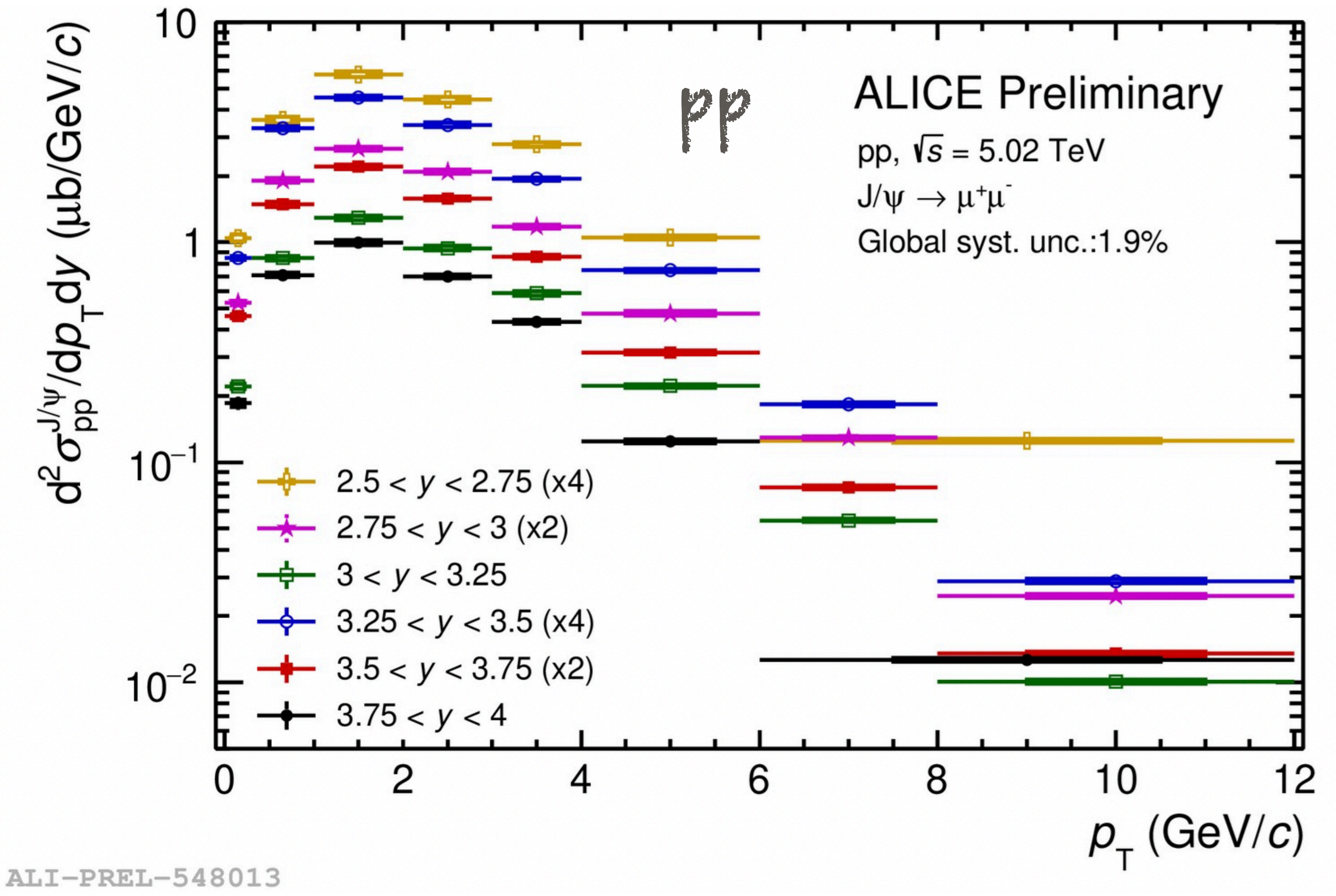
$J/\psi \to \mu^+\mu^-$, 70–90%, 2.5 < y < 4, p_T < 0.3 GeV/c

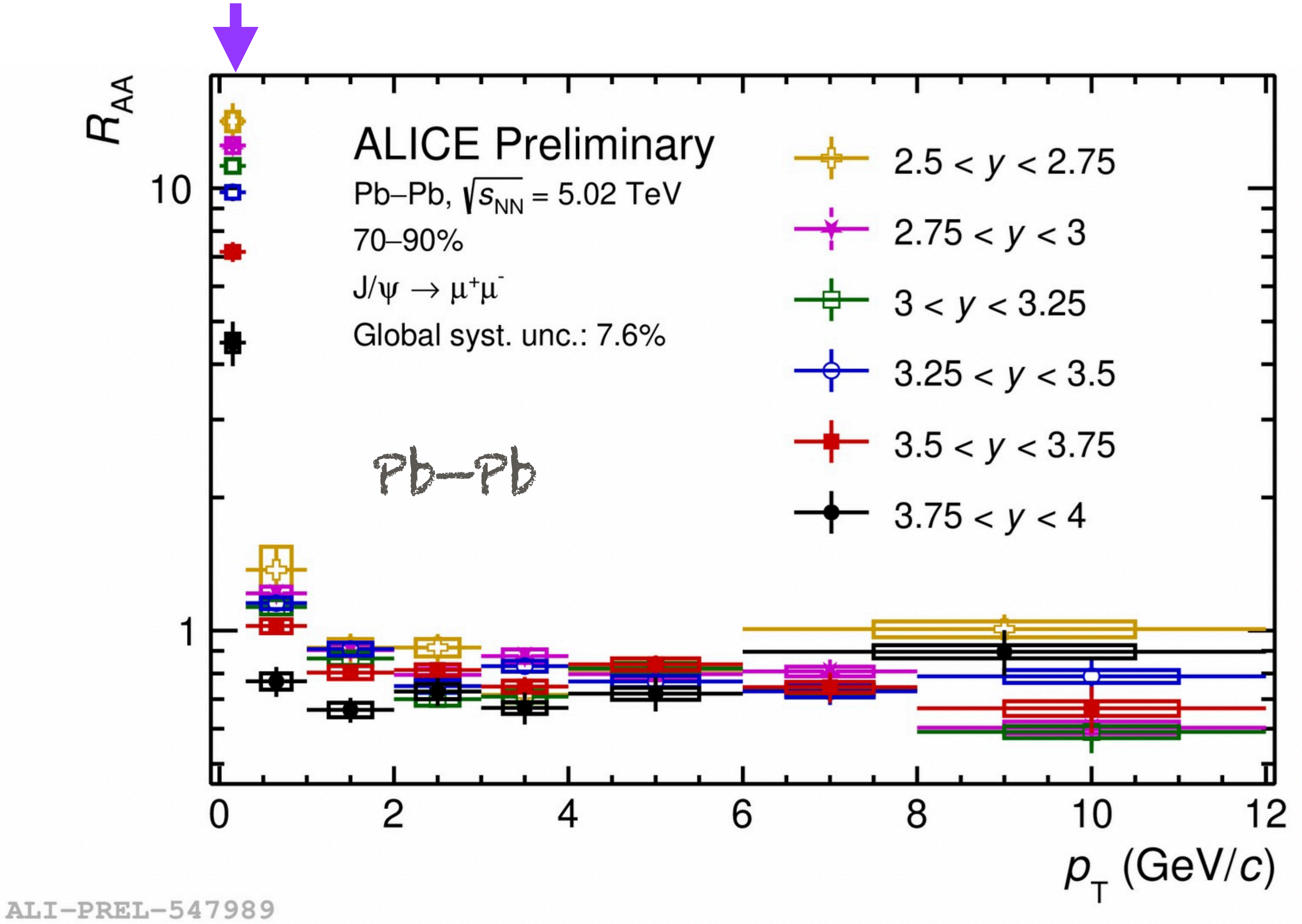
J/ψ signal is extracted in six cosθ intervals using the dimuon invariant mass distribution





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

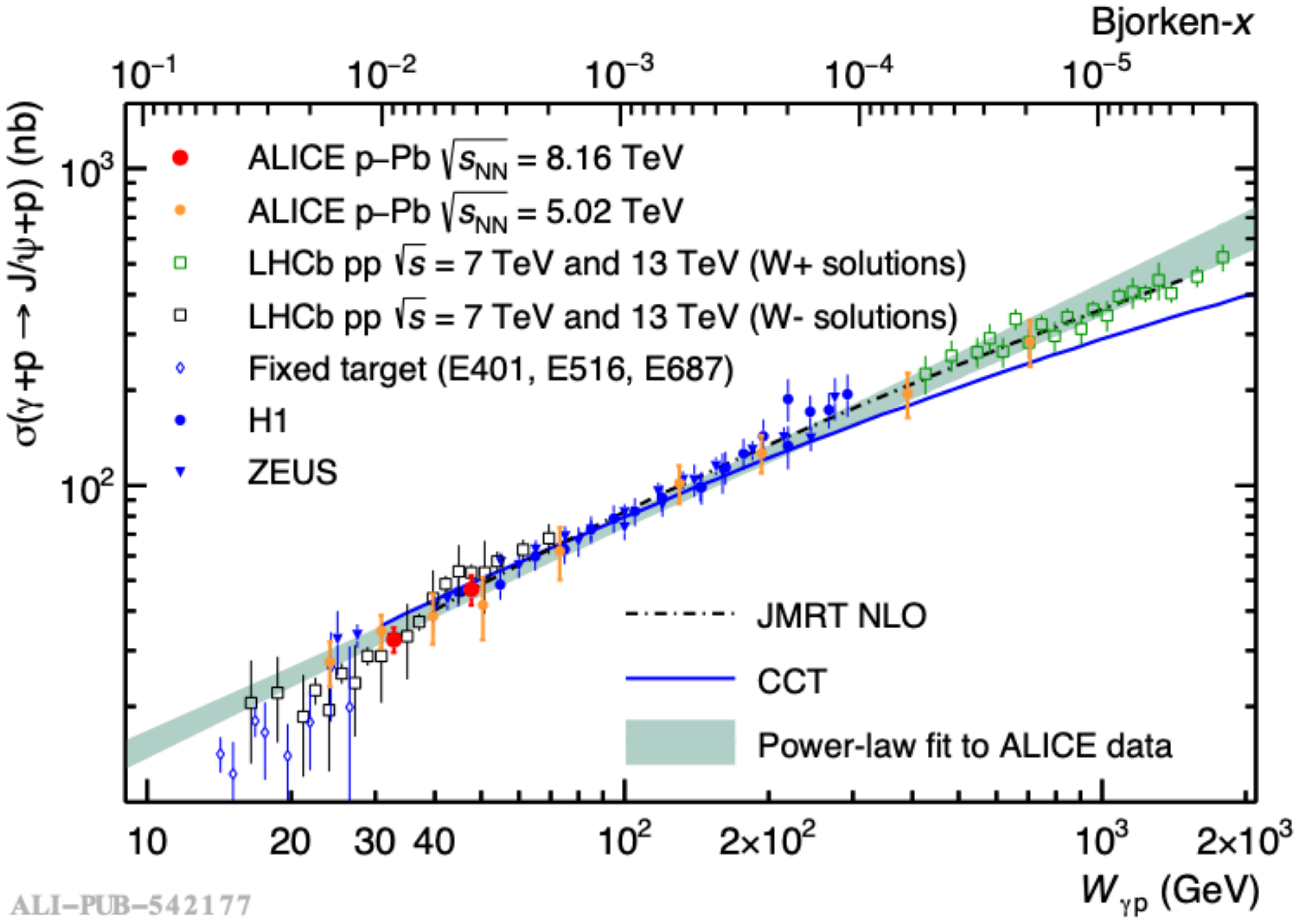




The J/ψ cross section in pp collisions and the J/ψ R_{AA} are used as inputs for modeling the expected hadronic J/ψ yield

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

Exclusive J/ψ in p-Pb UPC



ALICE, arXiv:2304.12403

$x = e^{\pm y} M_{J/\psi}/2E_p$

ALICE data probe Bjorken-$x \sim 10^{-5}$

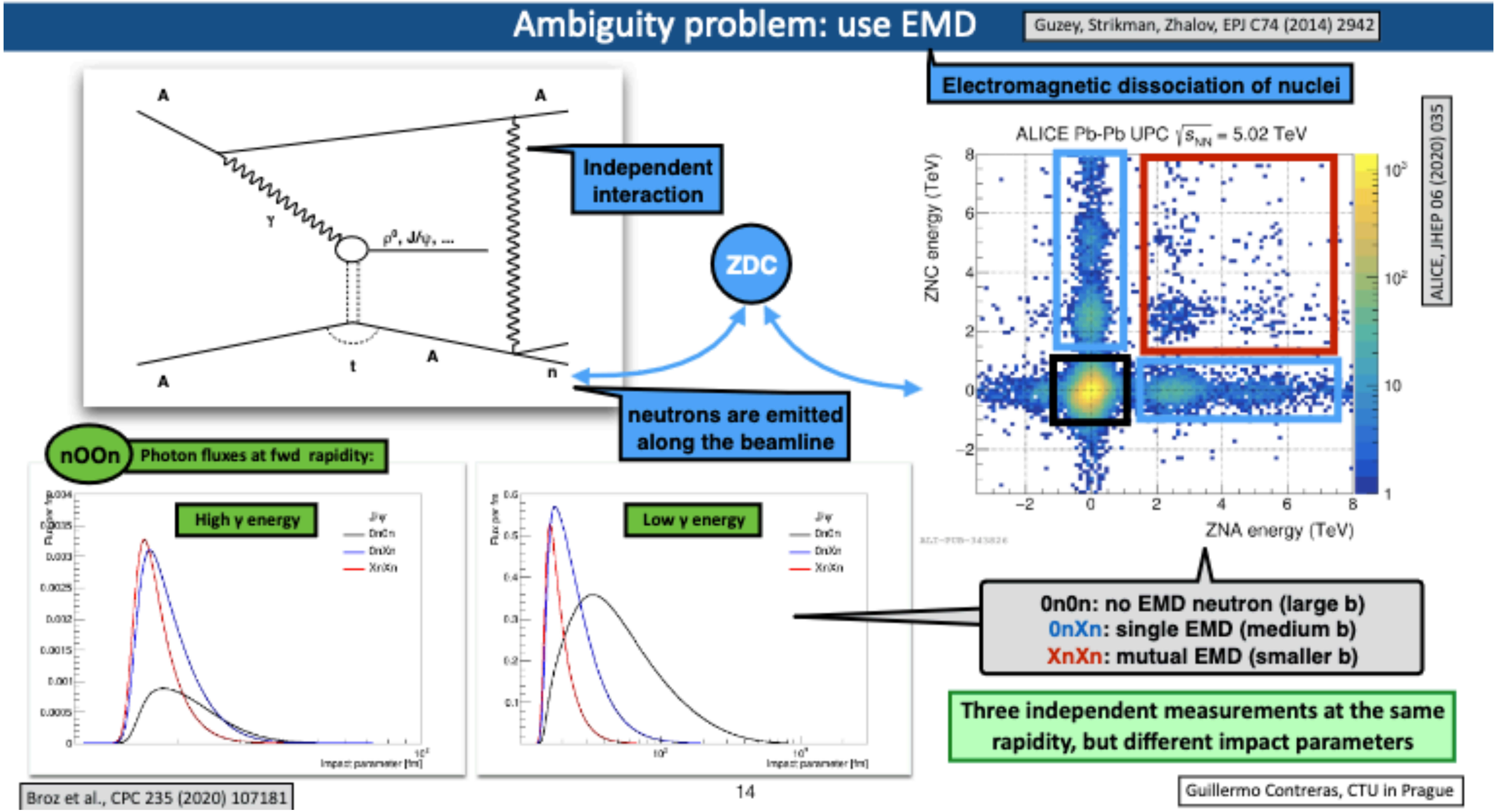
Power-law growth of cross sections observed

-> No change in the behaviour of the gluon PDF

in the proton between HERA and LHC energies

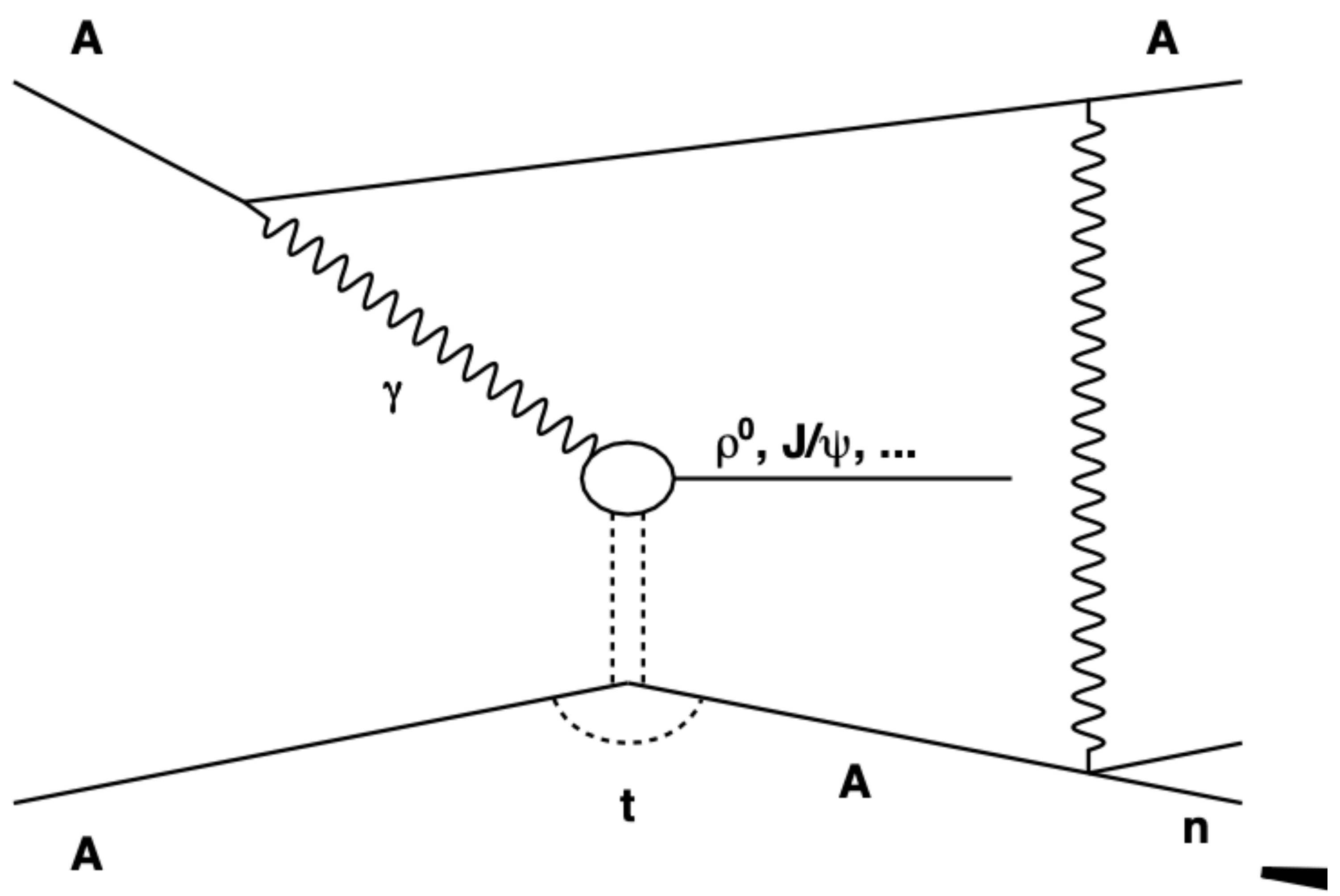
Eur. Phys. J. C (2019) 79: 402 (ALICE midrapidity and semiforward)
Phys. Rev. Lett. 113 no. 23, (2014) 232504 (ALICE forward)

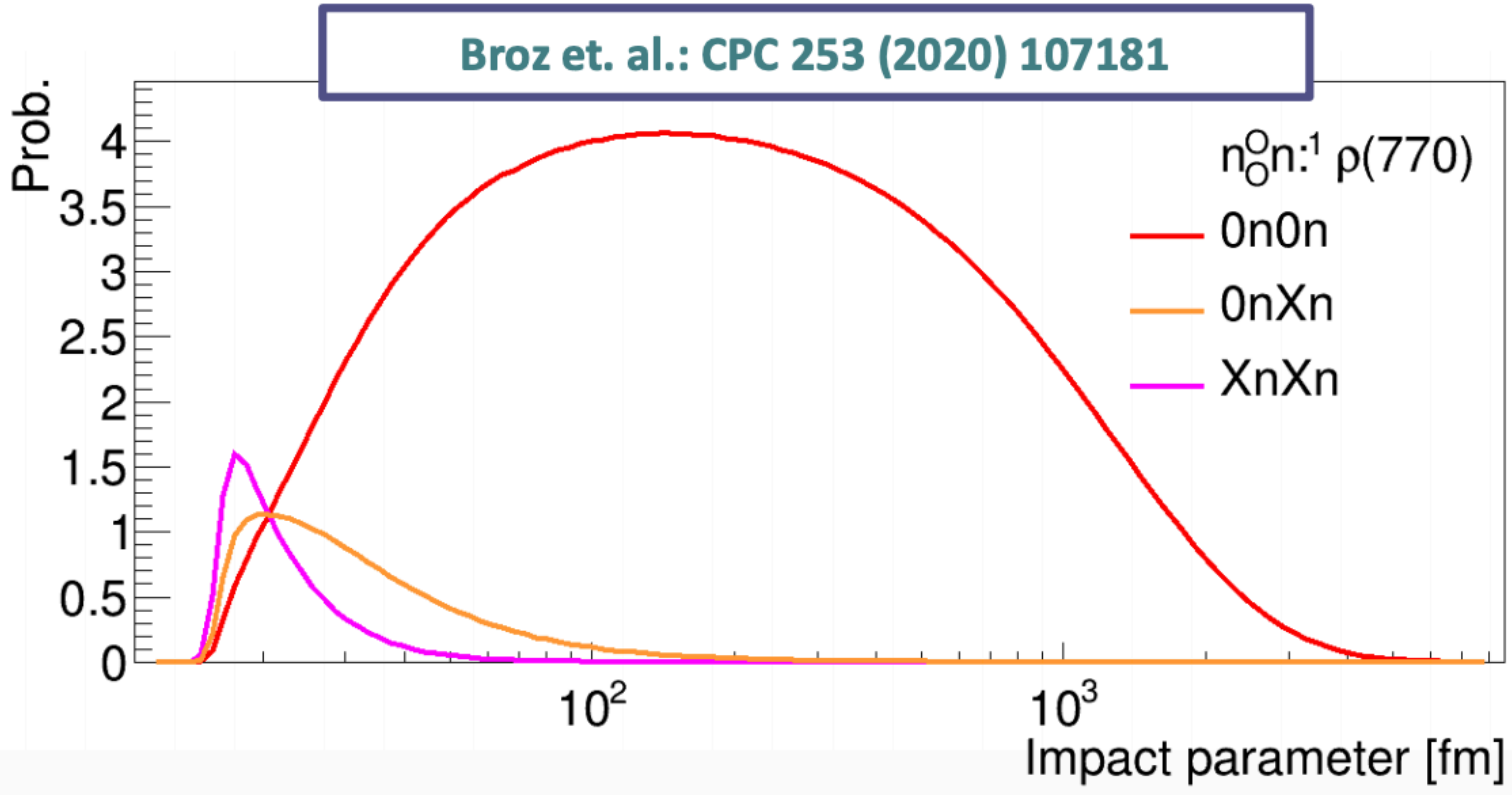
Photon energy ambiguity : Neutron emission



Coherent VM with Neutron emission

PEA, NE





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

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

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

Using the neutron ZDCs on the A and C side to detect the neutrons!

0N0N: no neutrons on either ZDCs

0NXN: neutrons only on one side

Coherent J/ψ with Neutron emission

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

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

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

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

ALICE, arXiv:2305.19060

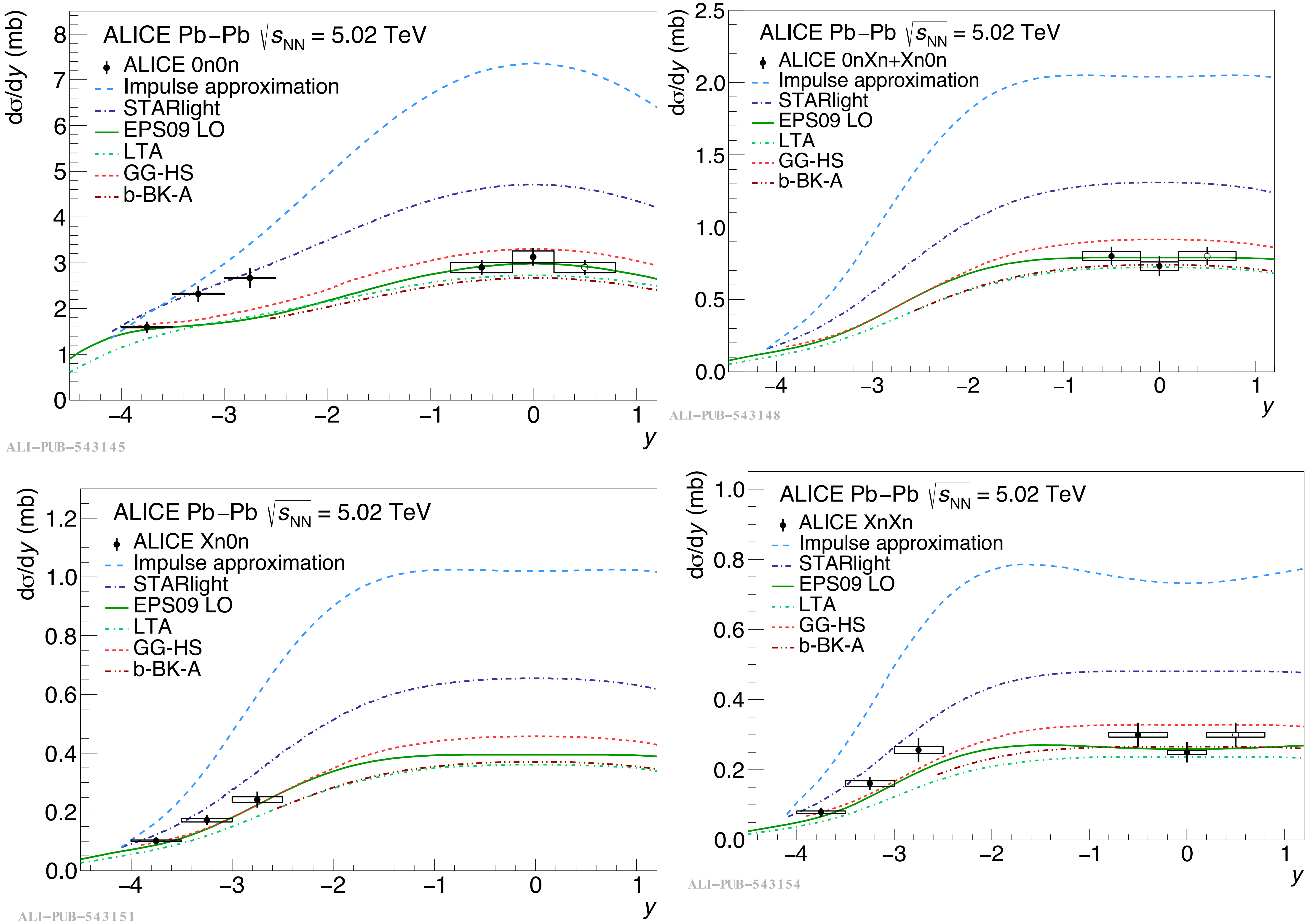
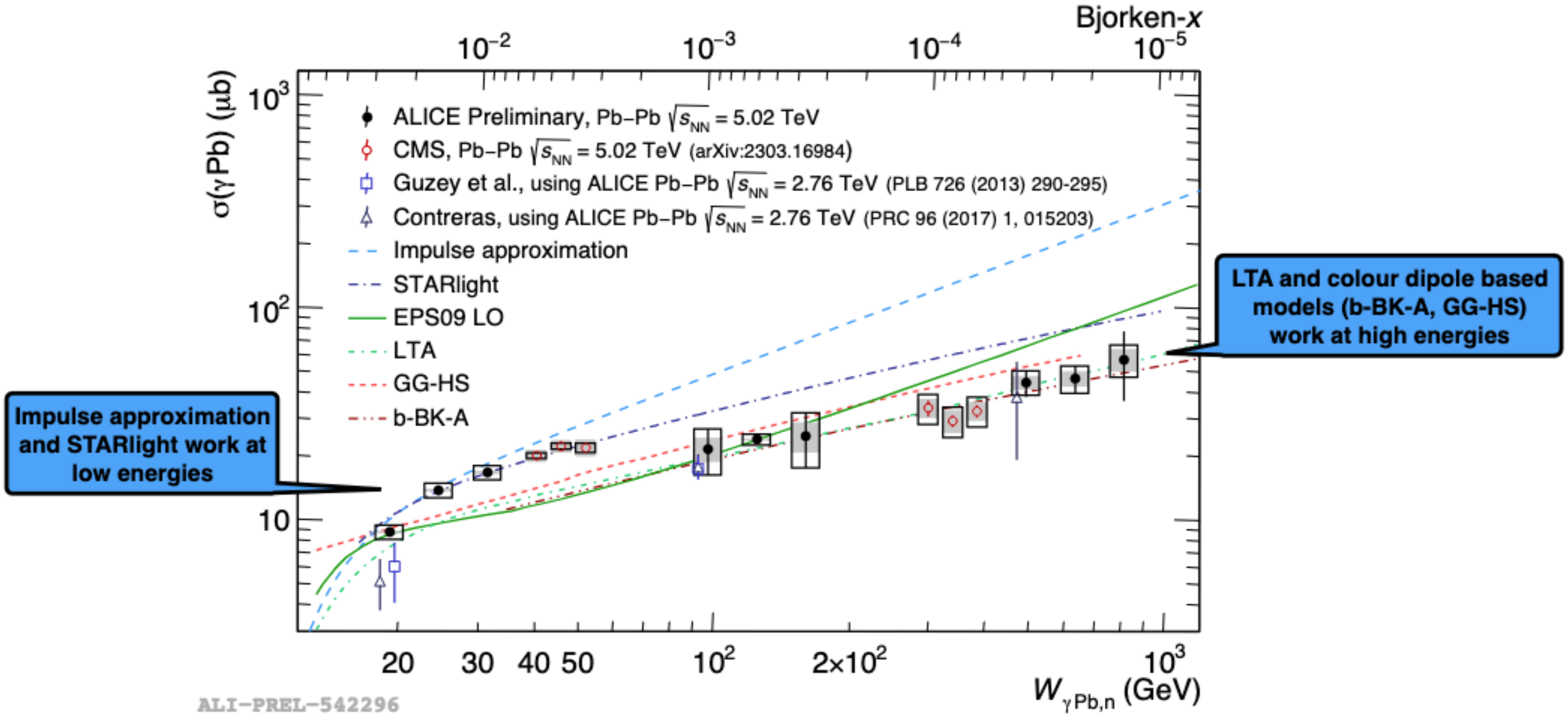


photo nuclear cross section

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



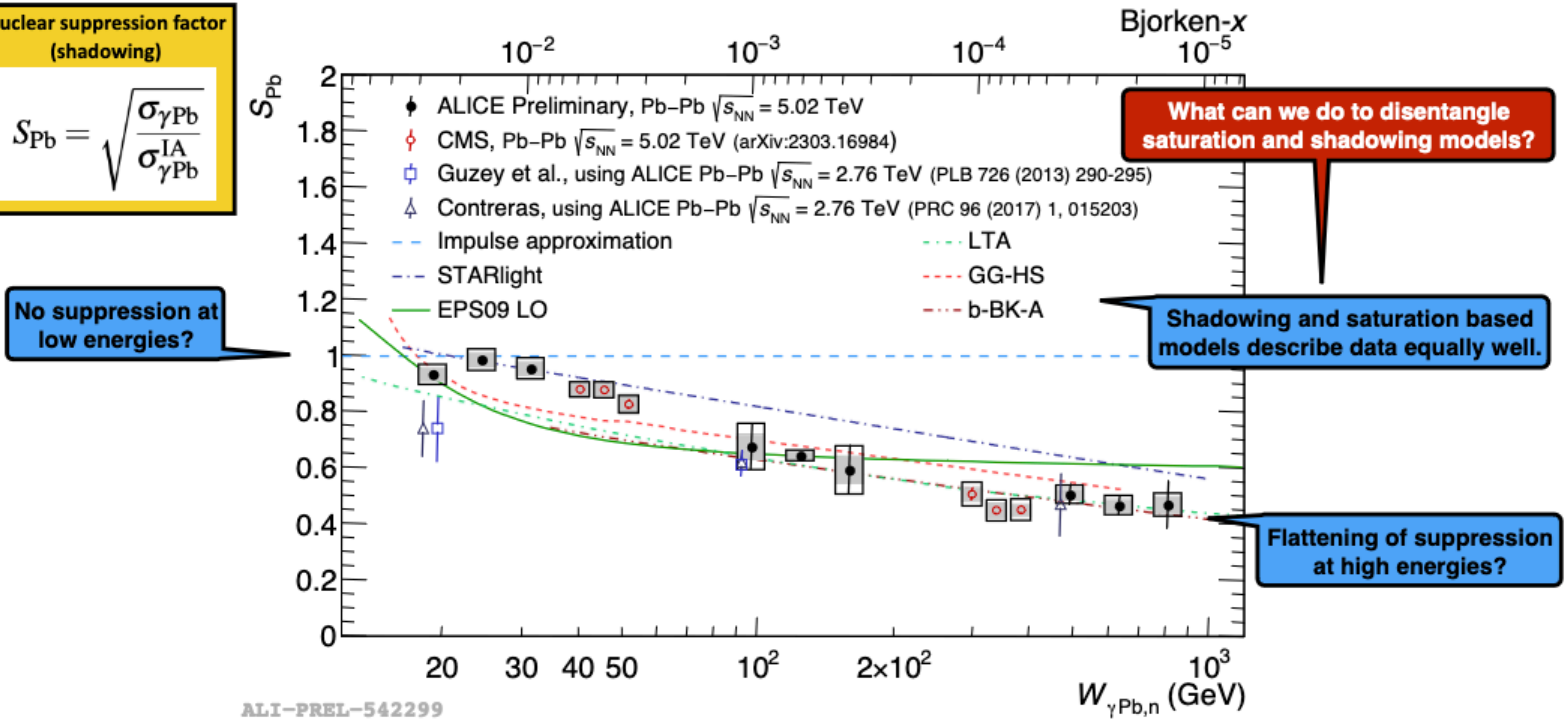
CMS, arXiv 2303.16984 | ALICE, CERN-EP-2023-100

Nuclear suppression factor : shadowing

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

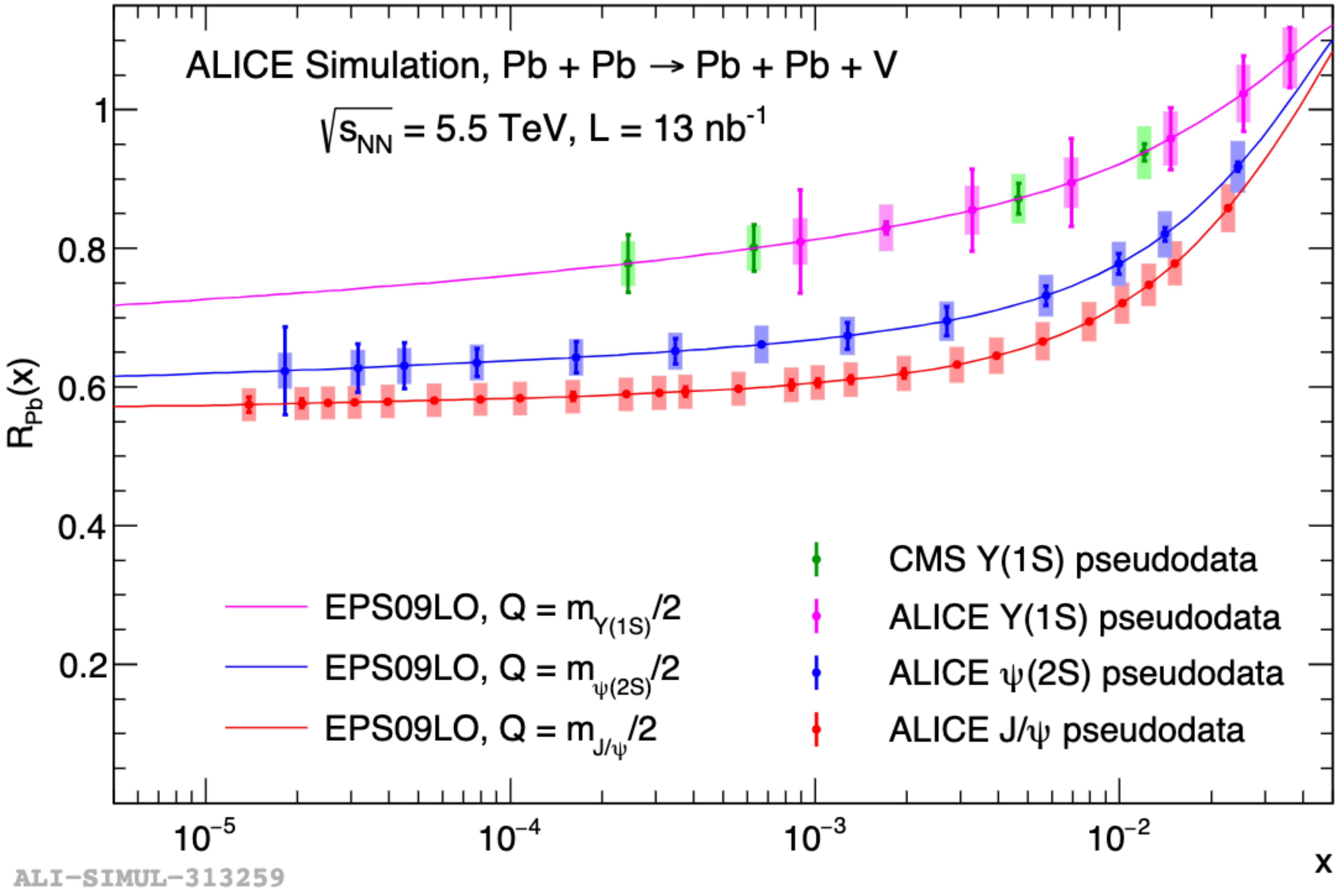
Nuclear suppression factor (shadowing)

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



CMS, arXiv 2303.16984 | ALICE, CERN-EP-2023-100 | 18 | Guillermo Contreras, CTU in Prague

Outlook : Run 3 and Run 4



		PbPb	
Meson	σ	Central 1 Total	Forward 1 Total 1
$\rho \to \pi^+\pi^-$	5.2b	5.5 B	4.9 B
$\rho' \to \pi^+\pi^-\pi^+\pi^-$	730 mb	210 M	190 M
$\phi \to K^+K^-$	0.22b	82 M	15 M
$J/\psi \to \mu^+\mu^-$	1.0 mb	1.1 M	600 K
$\psi(2S) \to \mu^+\mu^-$	30μb	35 K	19 K
$\Upsilon(1S) \to \mu^+\mu^-$	2.0 μb	2.8 K	880

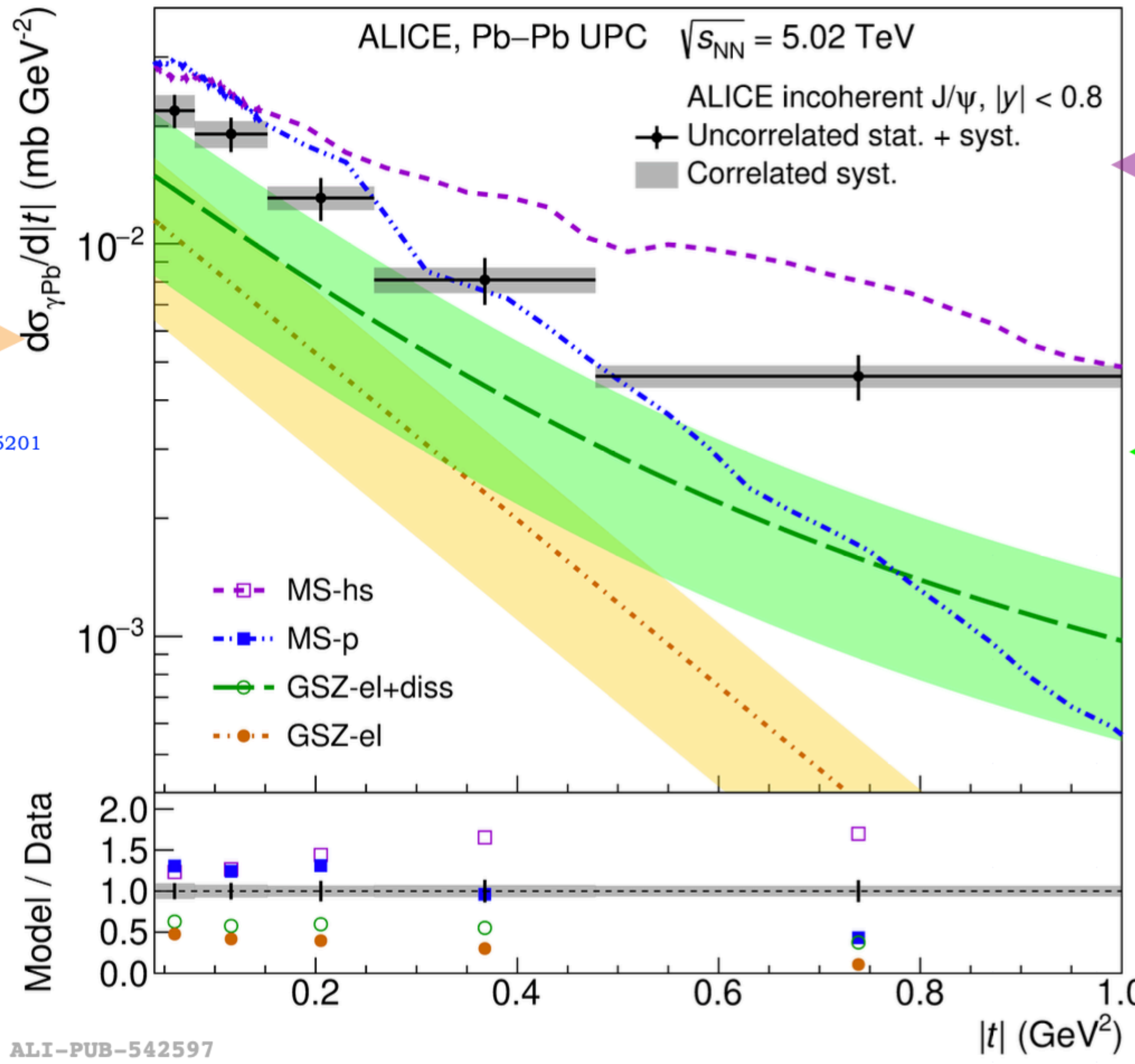
CERN Yellow Rep. Monogr. 7 (2019) 1159-1410, arXiv 1812.06772

t-dependence incoherent J/ψ photo production

arXiv:2305.06169

GSZ-el :production off nucleons elastic part (from HERA data) + Shadowing

V. Guzey et al., Phys. Rev. C 99 (2019) 015201



MS-hs: subnucleon fluctuations (hot spots fluctuating event by event) + saturation

H. Mäntysaari et al., Phys. Lett. B 772 (2017) 832–838

Saturation model : H. Kowalski et al. Phys. Rev. D 68 (2003) 114005

GSZ-el -diss: production off nucleons including dissociation (Shadowing+ elastic part from HERA data)

V. Guzey et al., Phys. Rev. C 99 (2019) 015201
Shadowing : N. Armesto, *J. Phys.* G 32 (2006) R367–R394

MS-p : subnucleon fluctuations not considered + saturation

H. Mäntysaari et al., Phys. Lett. B 772 (2017) 832–838

$|t| = p_{\perp}^2$ = related to the transverse size of the target

Models including fluctuations in subnucleon scale give reasonably good description of the measurement
—> suggests nuclear gluon density is not static at high energies

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 → $\mu^+\mu^-$

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

- 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]

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

R_{AA} 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)

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

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

in each dy,

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

Polarization : photoproduction of vector mesons

ρ^0 meson measurement : consistent with SCHC

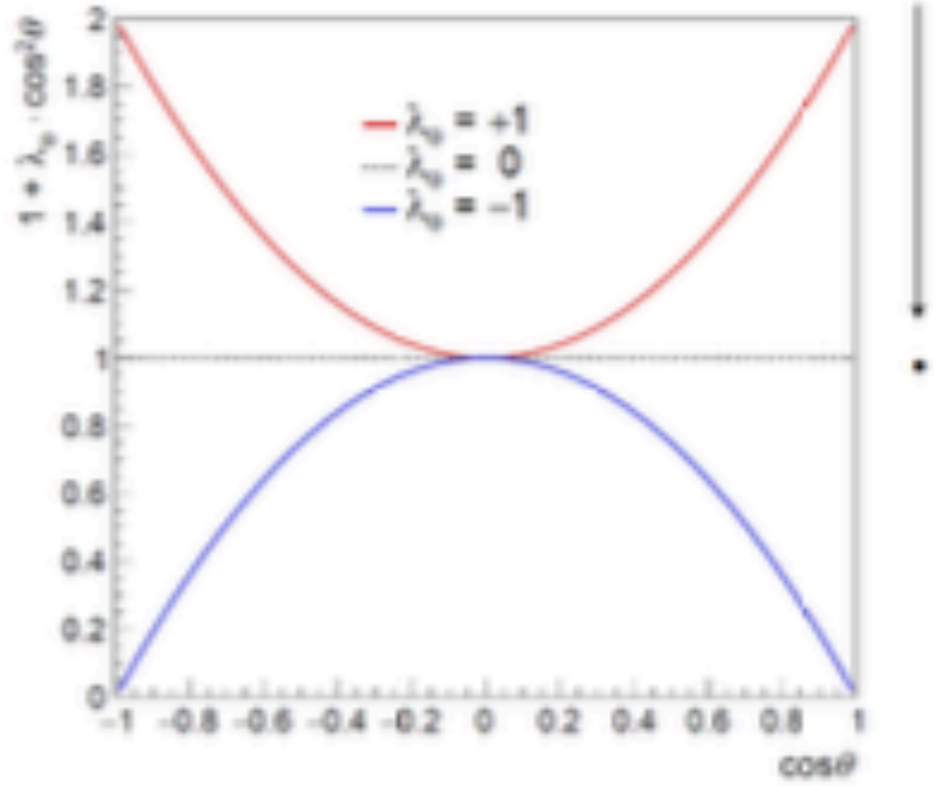
Phys. Rev. D 7, 3150, (1970) by SLAC Collaboration
Z. Phys. C 53, 581–594, (1992) by CERN SPS

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