

Photoproduction of J/ψ and dileptons in events with nuclear overlap

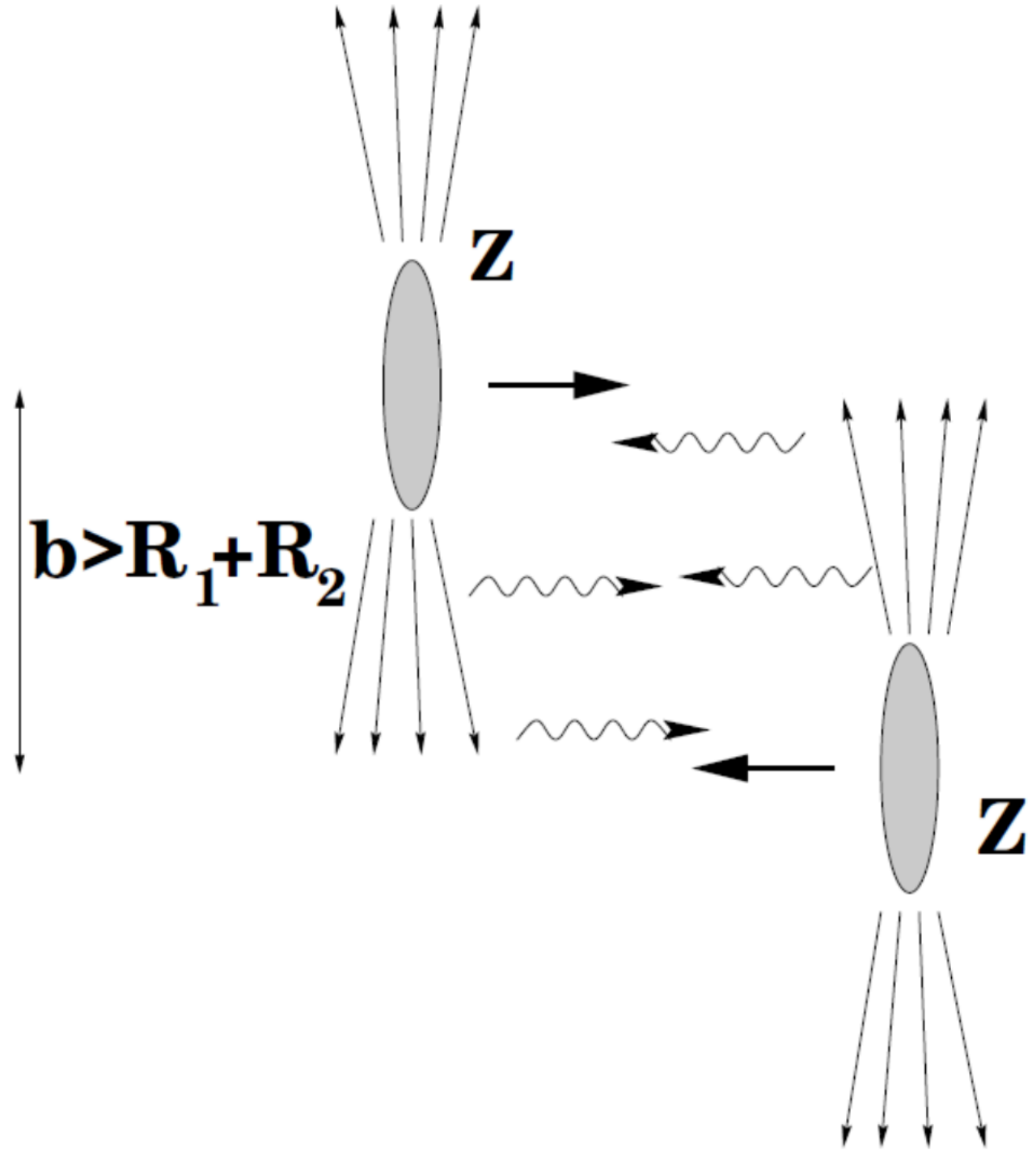
Nicolas Bizé, on behalf of the ALICE Collaboration

- Physics motivations and experimental apparatus
- Results
 - Dielectron photoproduction measurement at midrapidity
 - Coherently photoproduced J/ψ γ – differential cross section at forward rapidity
 - Inclusive J/ψ polarization at forward rapidity
- Summary and outlook

Photon induced processes in HICs

In Ultra-Peripheral Collisions (UPC)

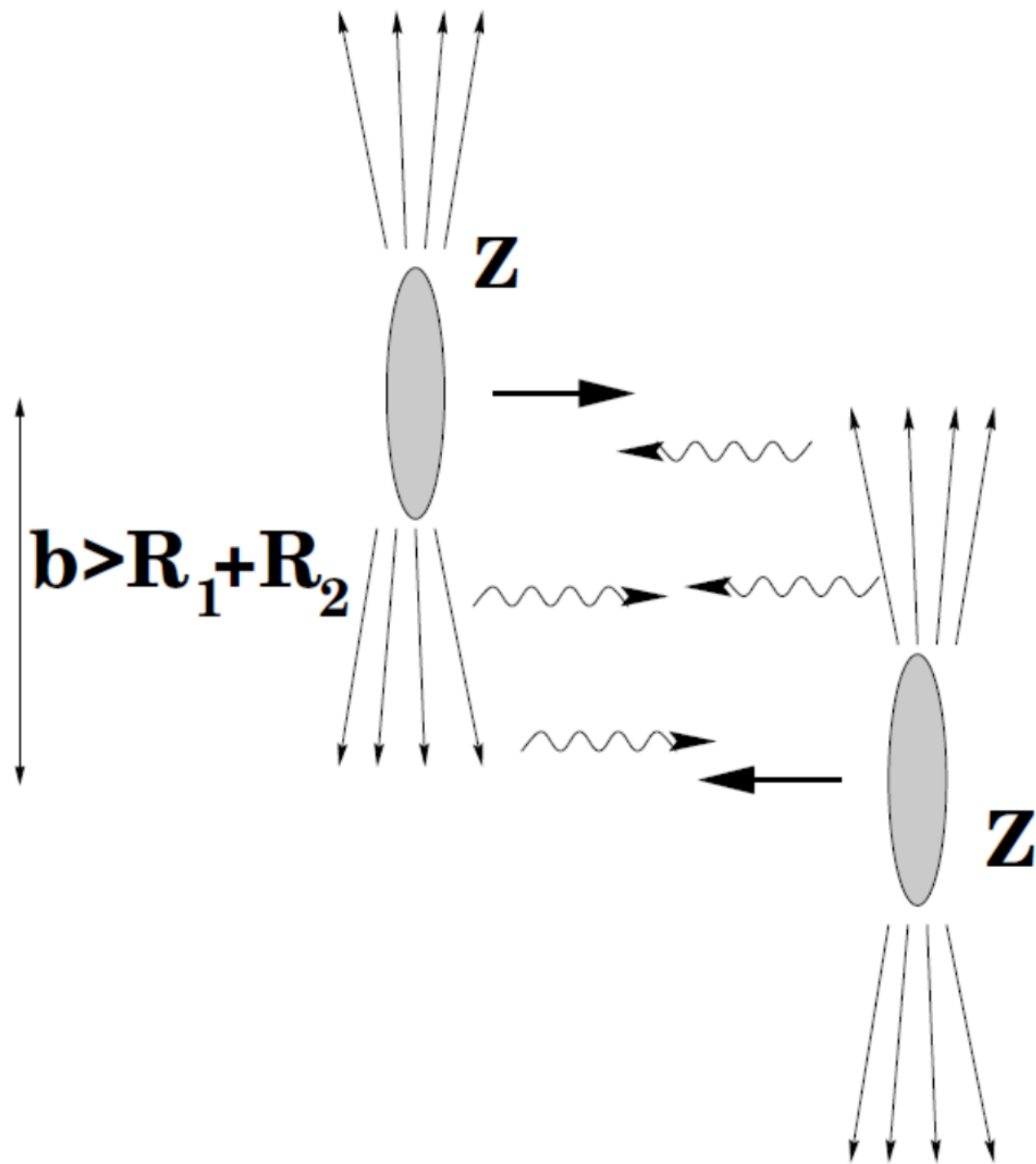
- Strong EM fields generated in ultra relativistic heavy-ion collisions can be treated as quasi-real photon flux $\propto Z^2$



Photon induced processes in HICs

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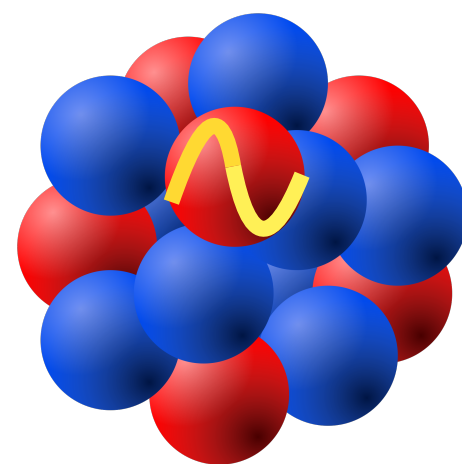
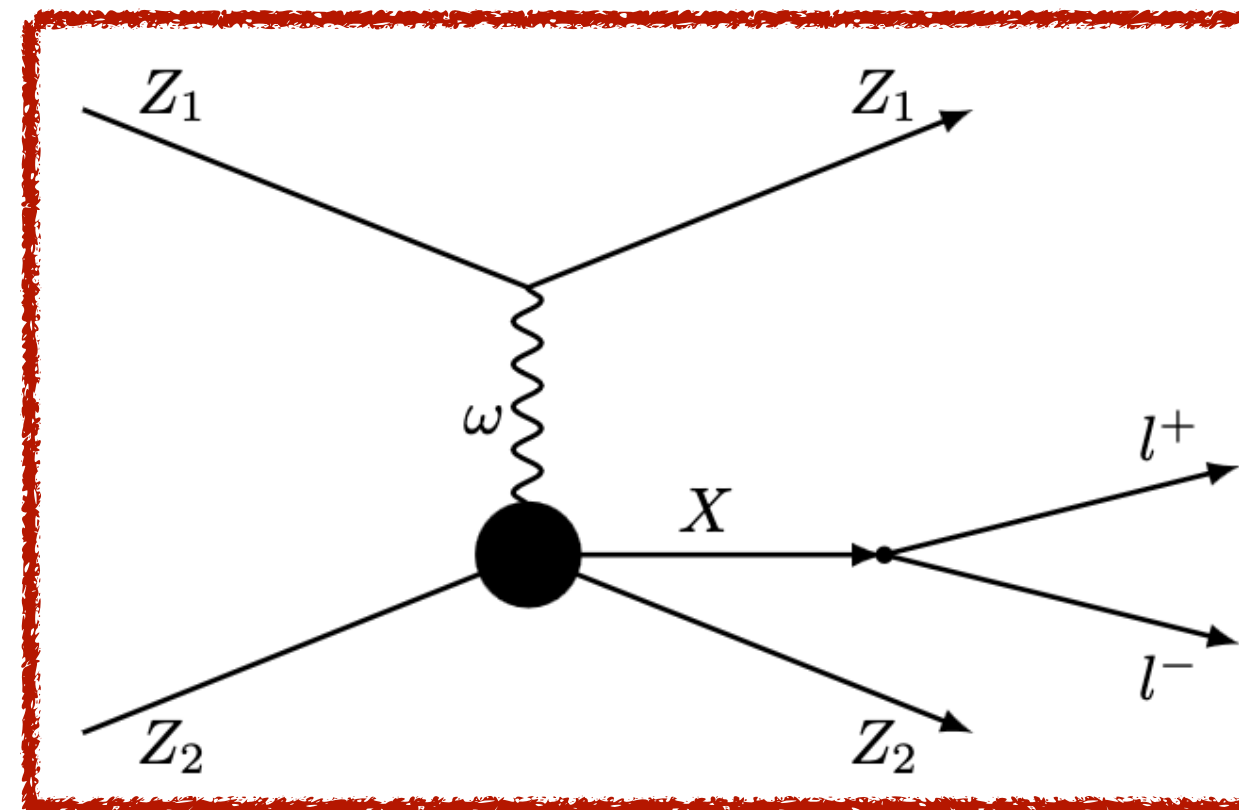
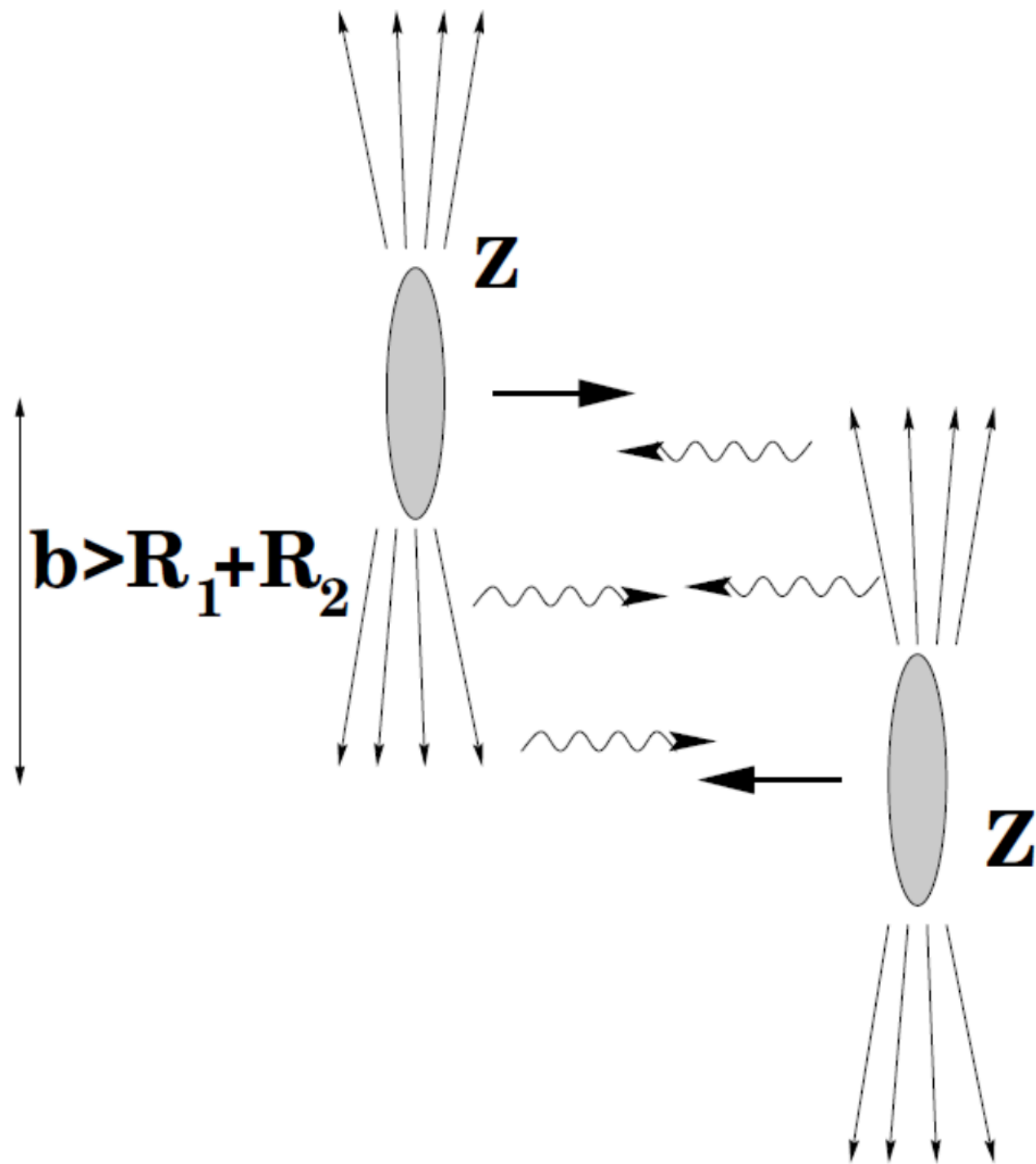
- Strong EM fields generated in ultra relativistic heavy-ion collisions can be treated as quasi-real photon flux $\propto Z^2$
- Ideal ground to study processes such as **vector meson** or **dilepton** photoproduction



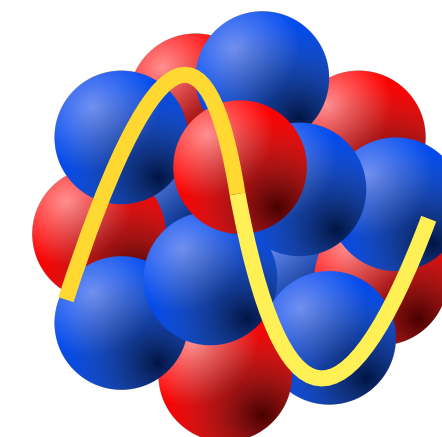
Photon induced processes in HICs

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Incoherent process

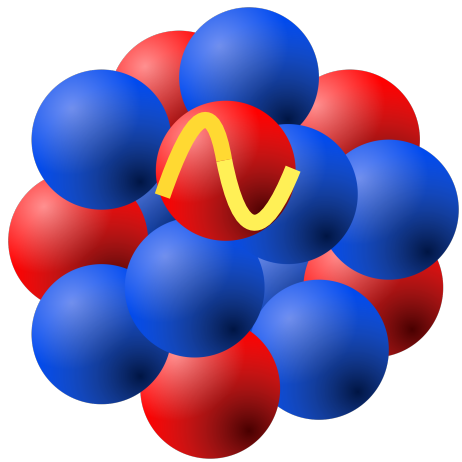
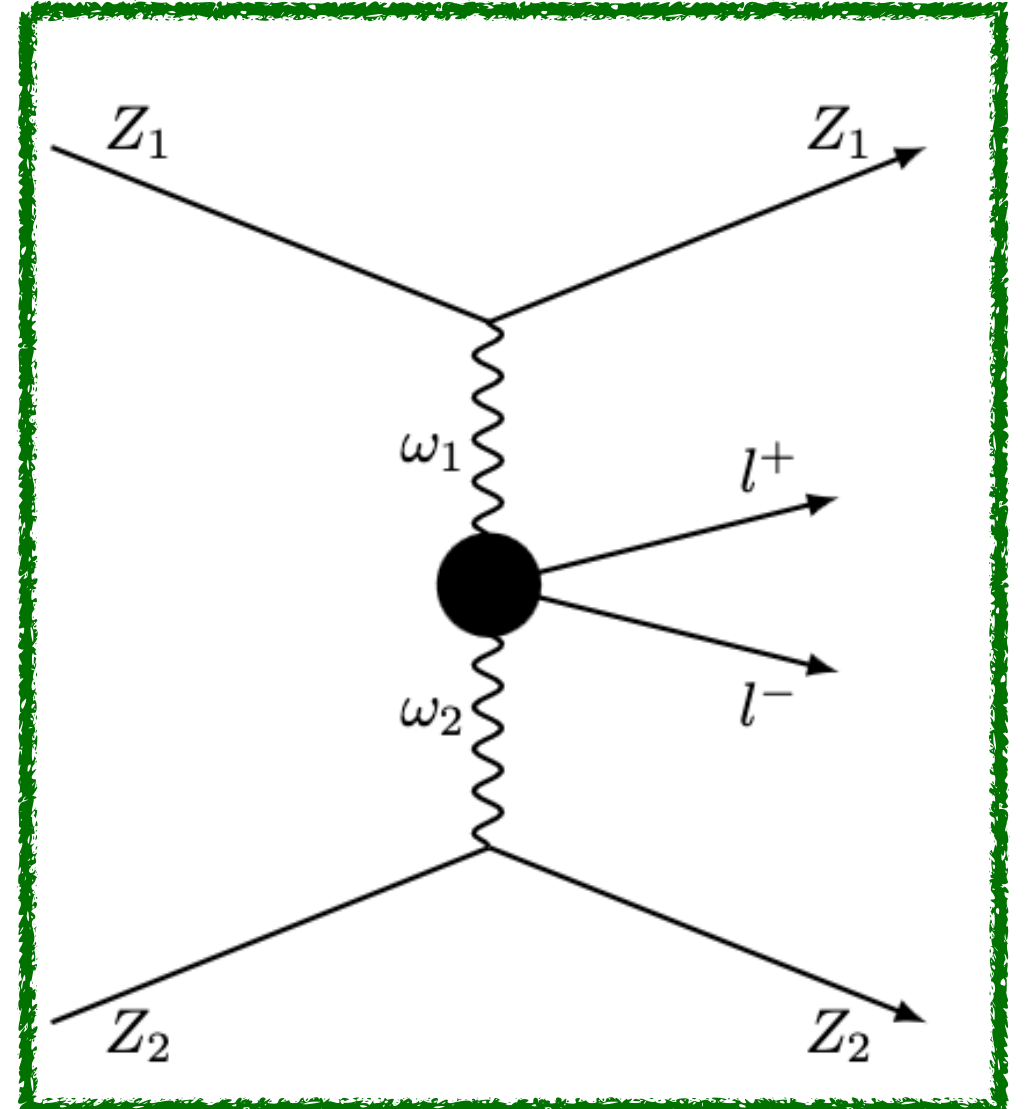
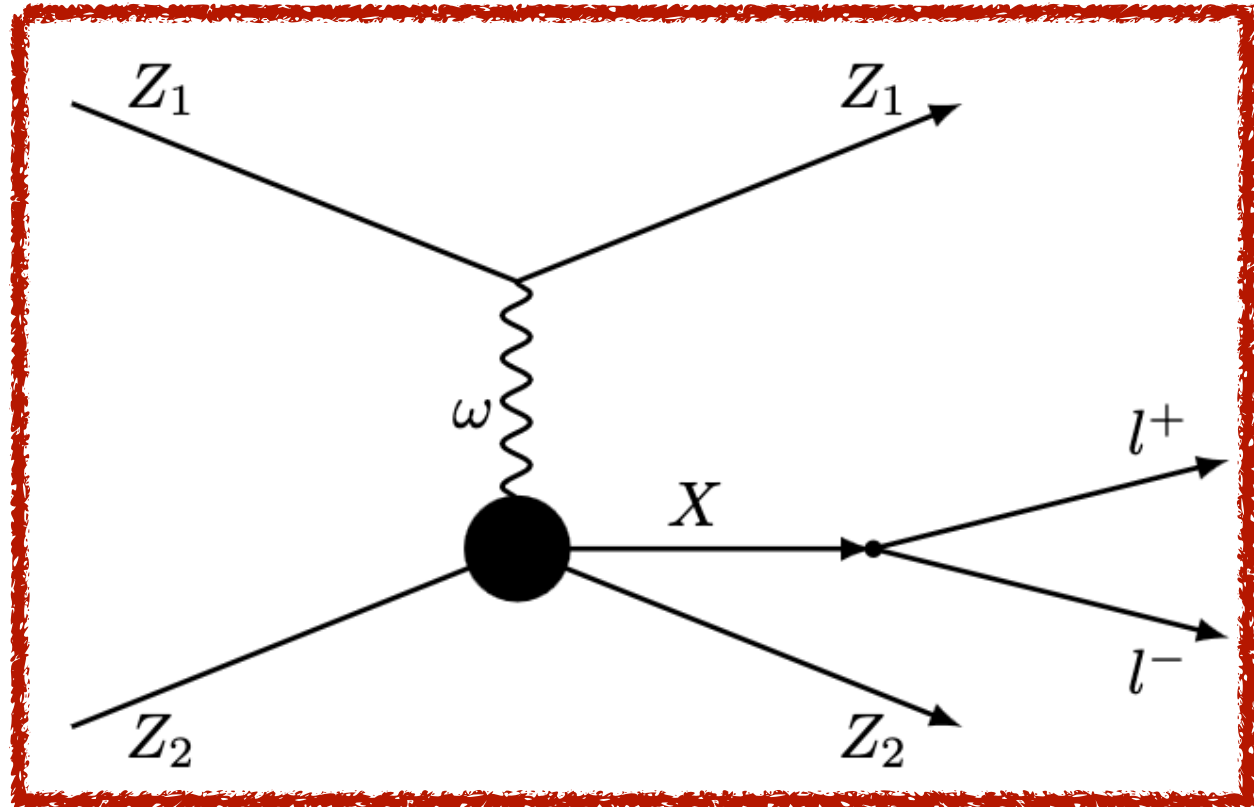
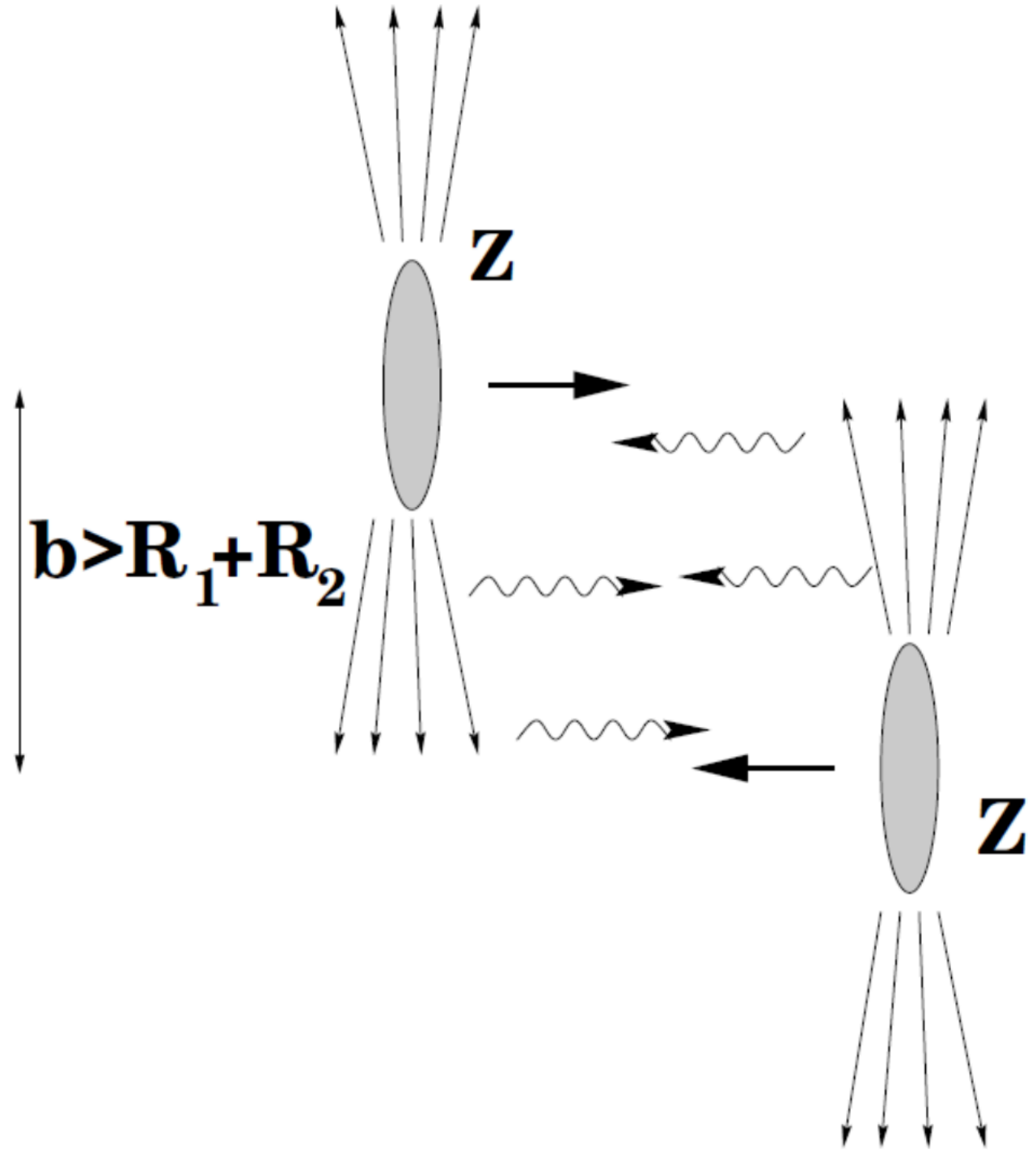


Coherent process

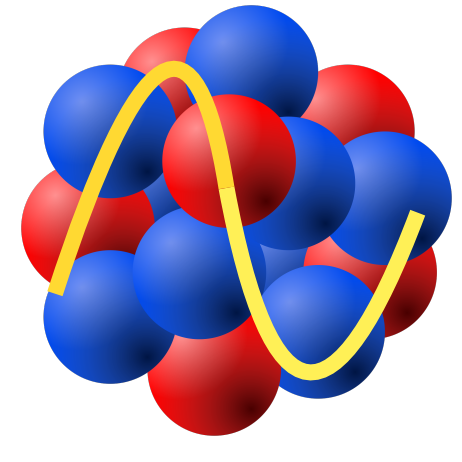
Photon induced processes in HICs

In Ultra-Peripheral Collisions (UPC)

- Strong EM fields generated in ultra relativistic heavy-ion collisions can be treated as quasi-real photon flux $\propto Z^2$
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Incoherent process

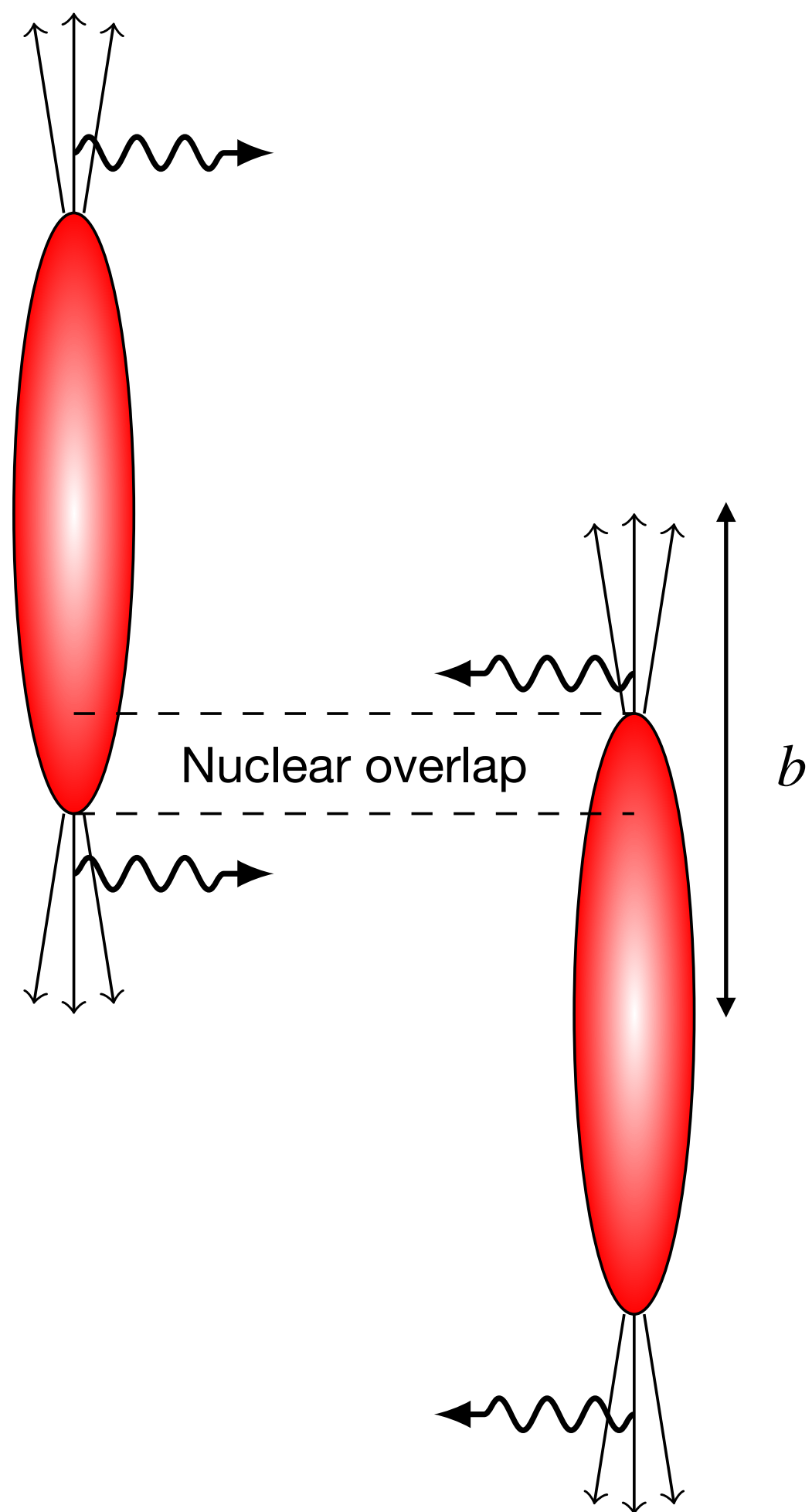


Coherent process

Photon induced processes in HICs

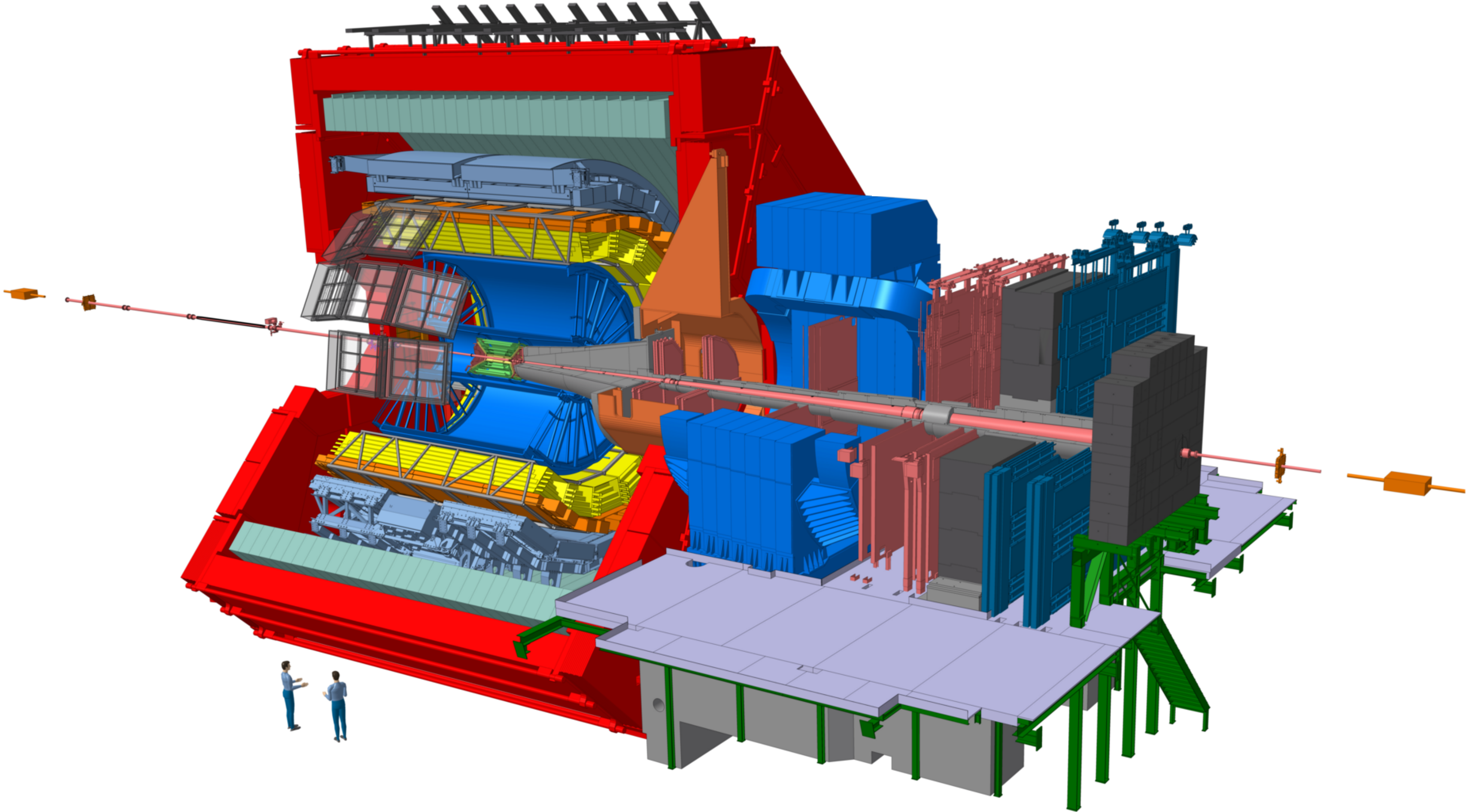
In events with nuclear overlap

Hadronic interactions become dominant

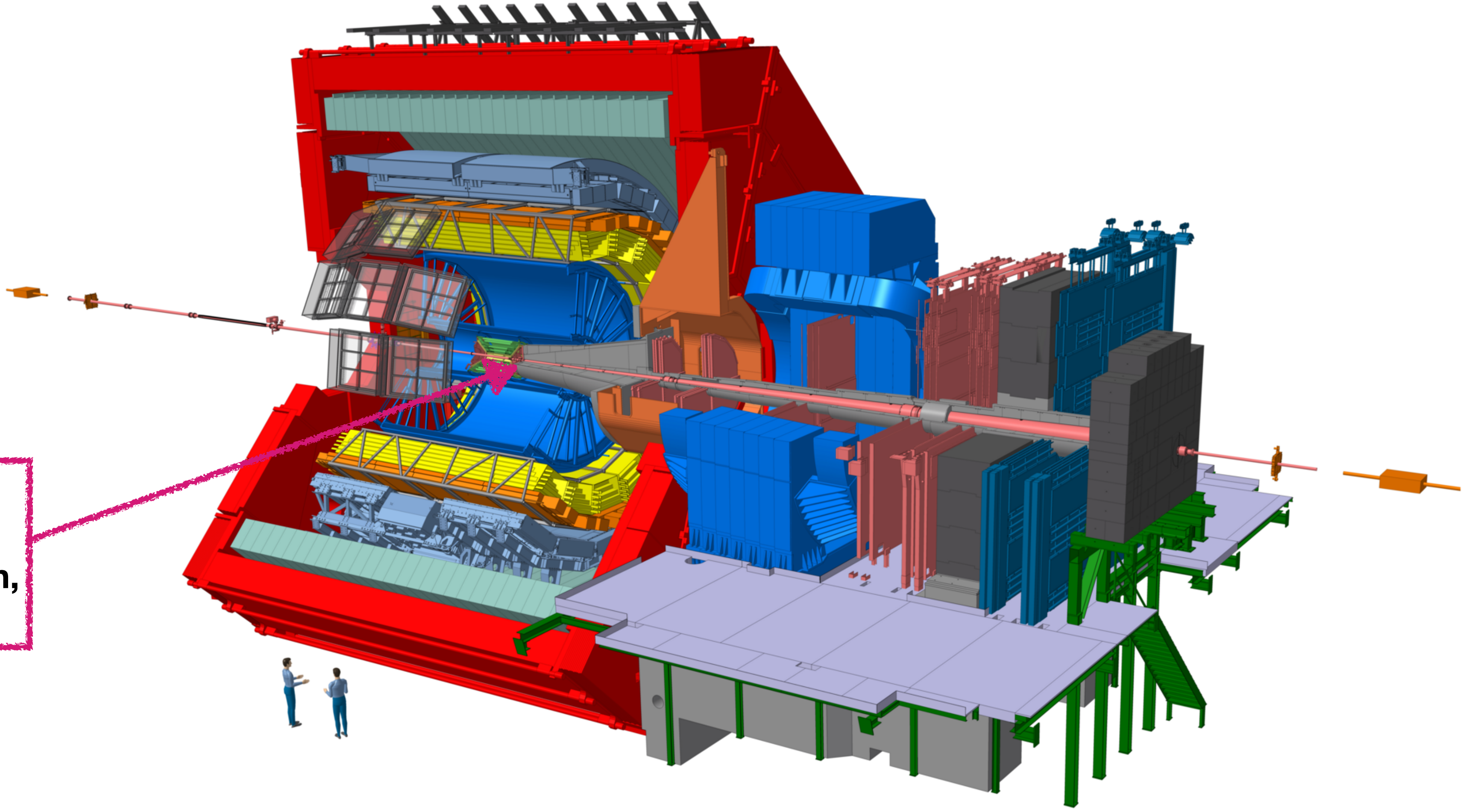


- Vector meson photoproduction
 - Probe gluon distribution in different Bjorken- x regions in nuclei ($10^{-5} < x < 10^{-2}$ at LHC energies)
 - Test the coherence while nucleus breaking during hadronic collision
- Dilepton photoproduction
 - Map EM fields generated by highly Lorentz-contracted nuclei
- Possible QGP medium effects

ALICE detector in Run 2

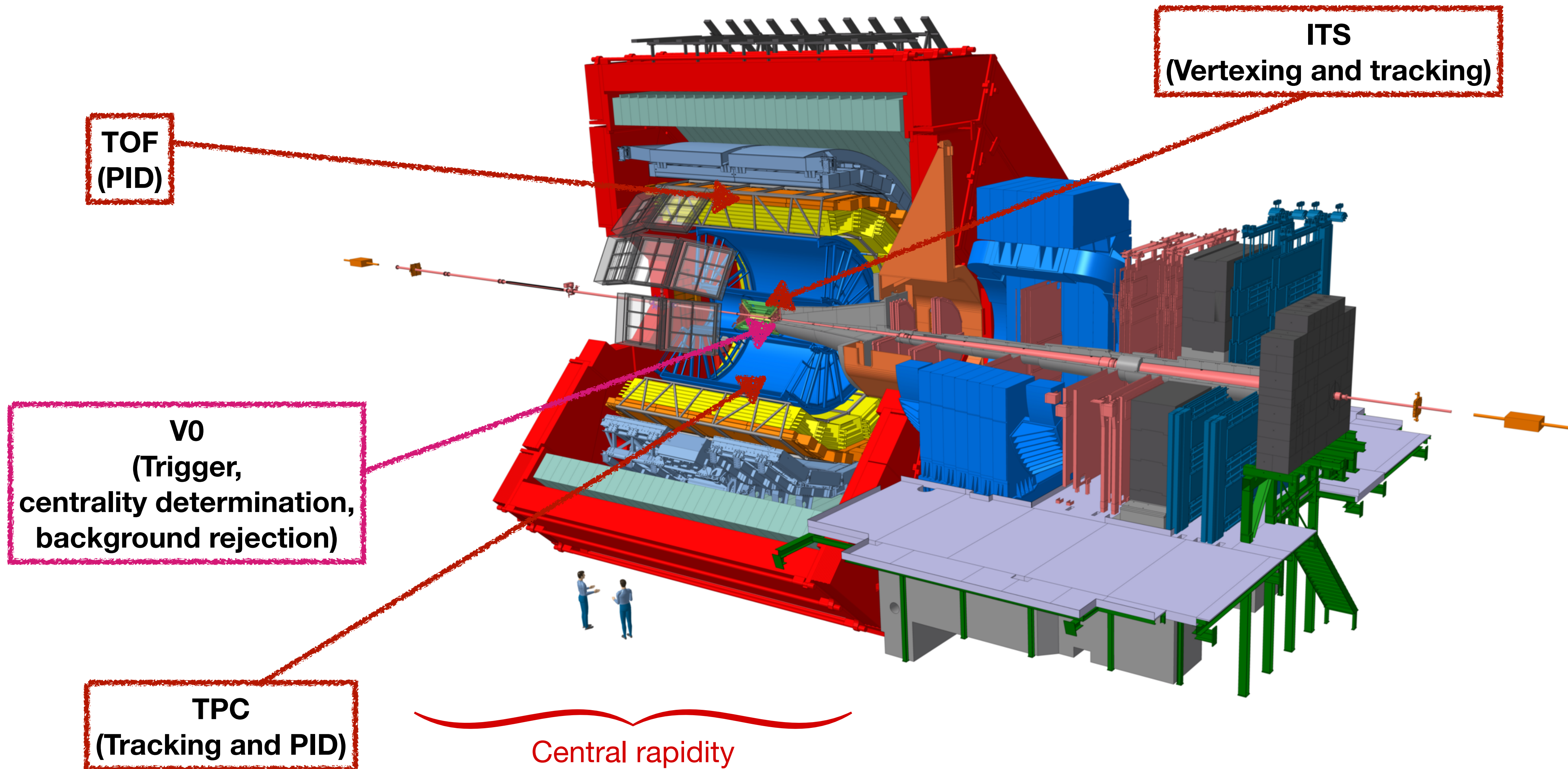


ALICE detector in Run 2



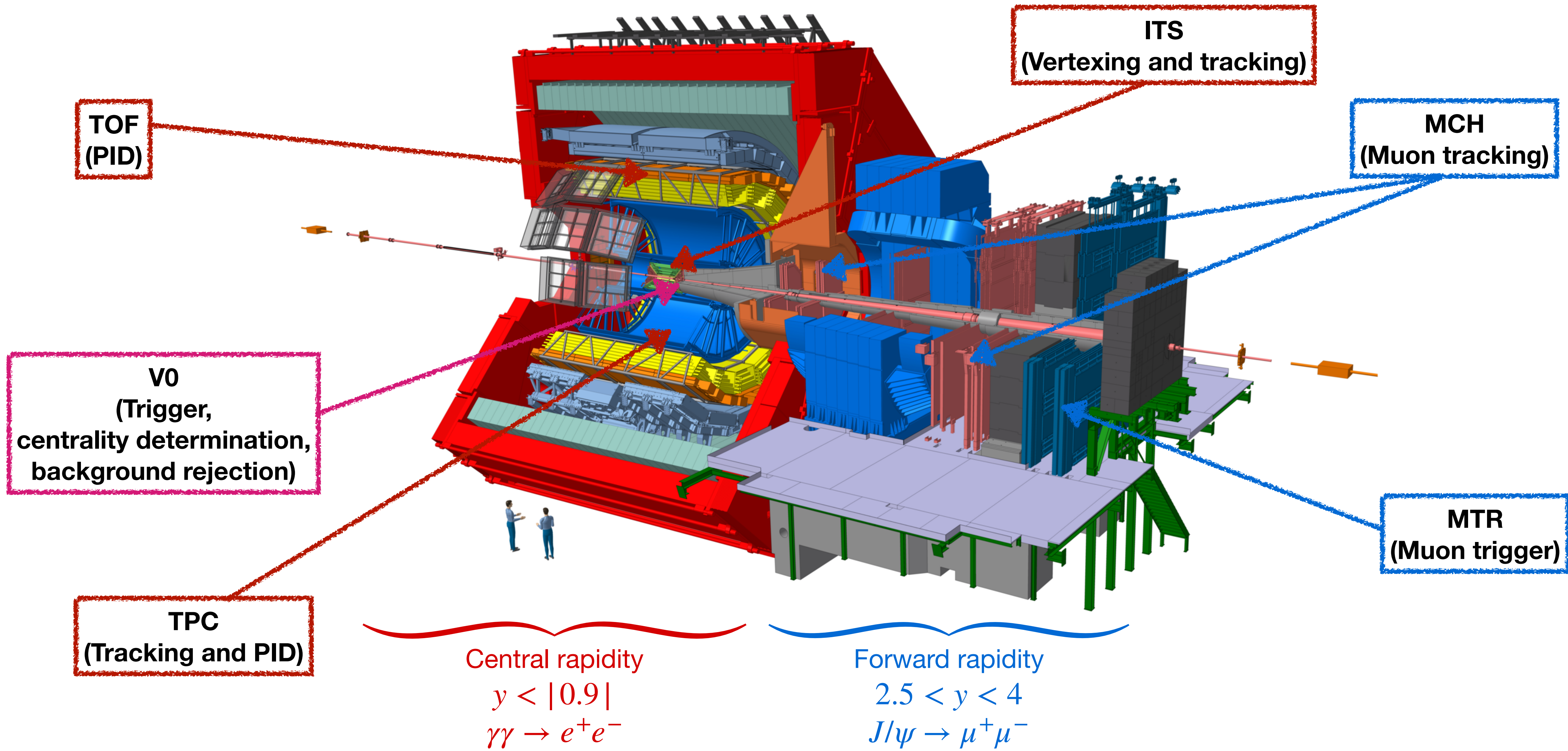
V0
(Trigger,
centrality determination,
background rejection)

ALICE detector in Run 2



Central rapidity
 $y < |0.9|$
 $\gamma\gamma \rightarrow e^+e^-$

ALICE detector in Run 2

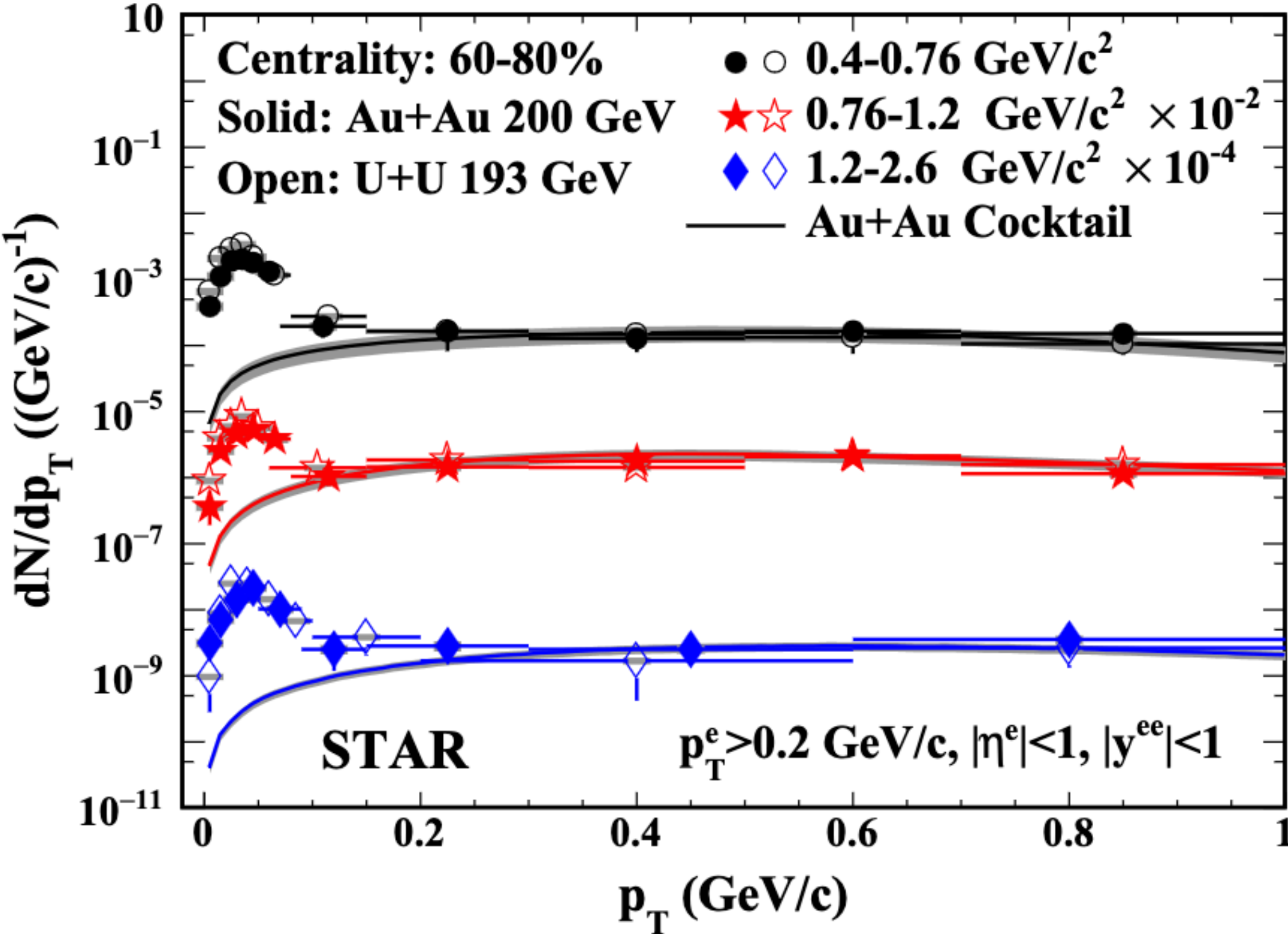


Dielectron photoproduction in events with nuclear overlap

Dielectron in Pb–Pb collisions with nuclear overlap



Measured in STAR and ATLAS (*PRL 121, 212301 (2018)*)



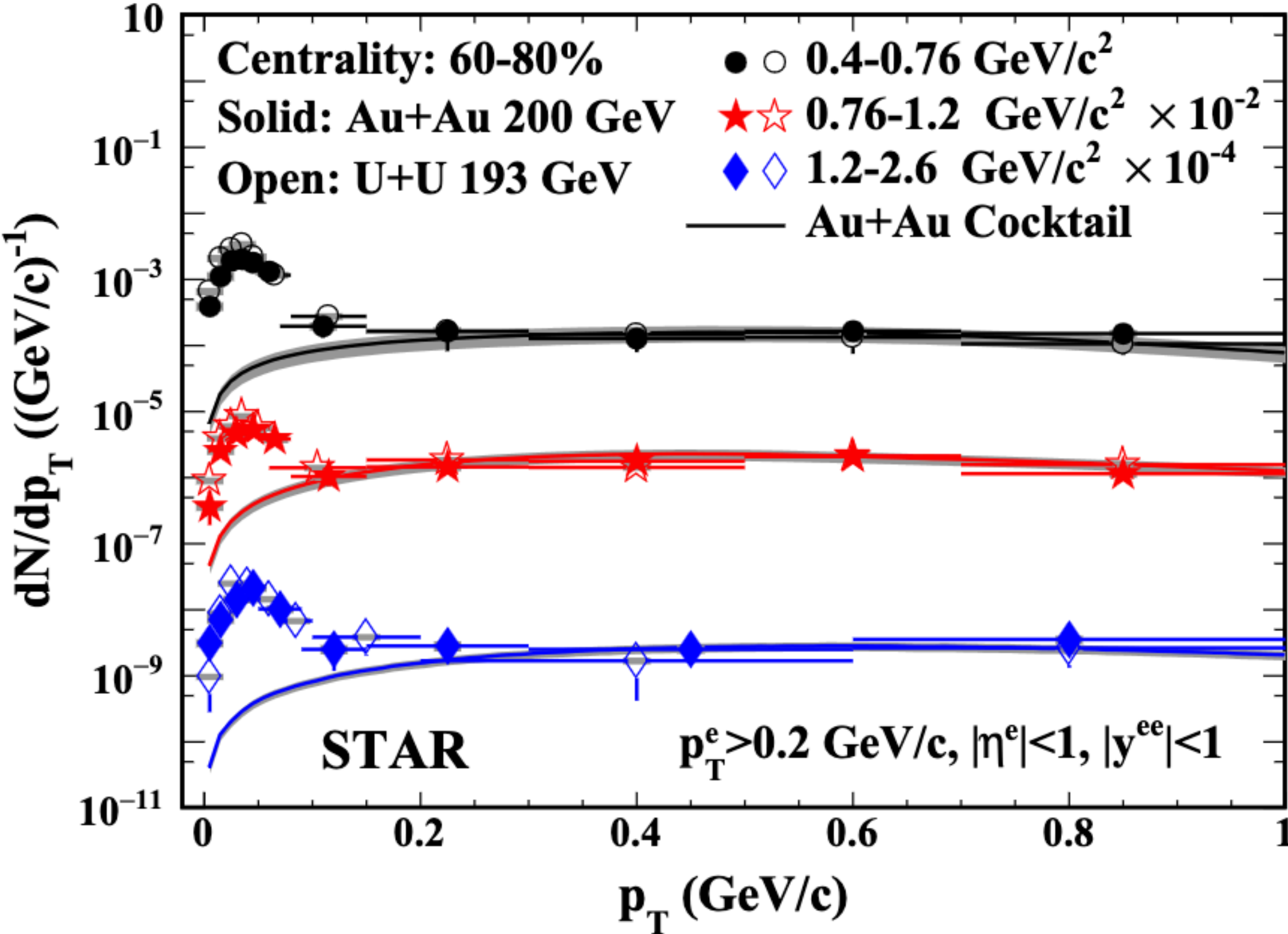
PRL 121, 132301 (2018)

Dielectron in Pb–Pb collisions with nuclear overlap



Measured in STAR and ATLAS (*PRL 121, 212301 (2018)*)

Dielectron excess w.r.t. hadronic cocktail

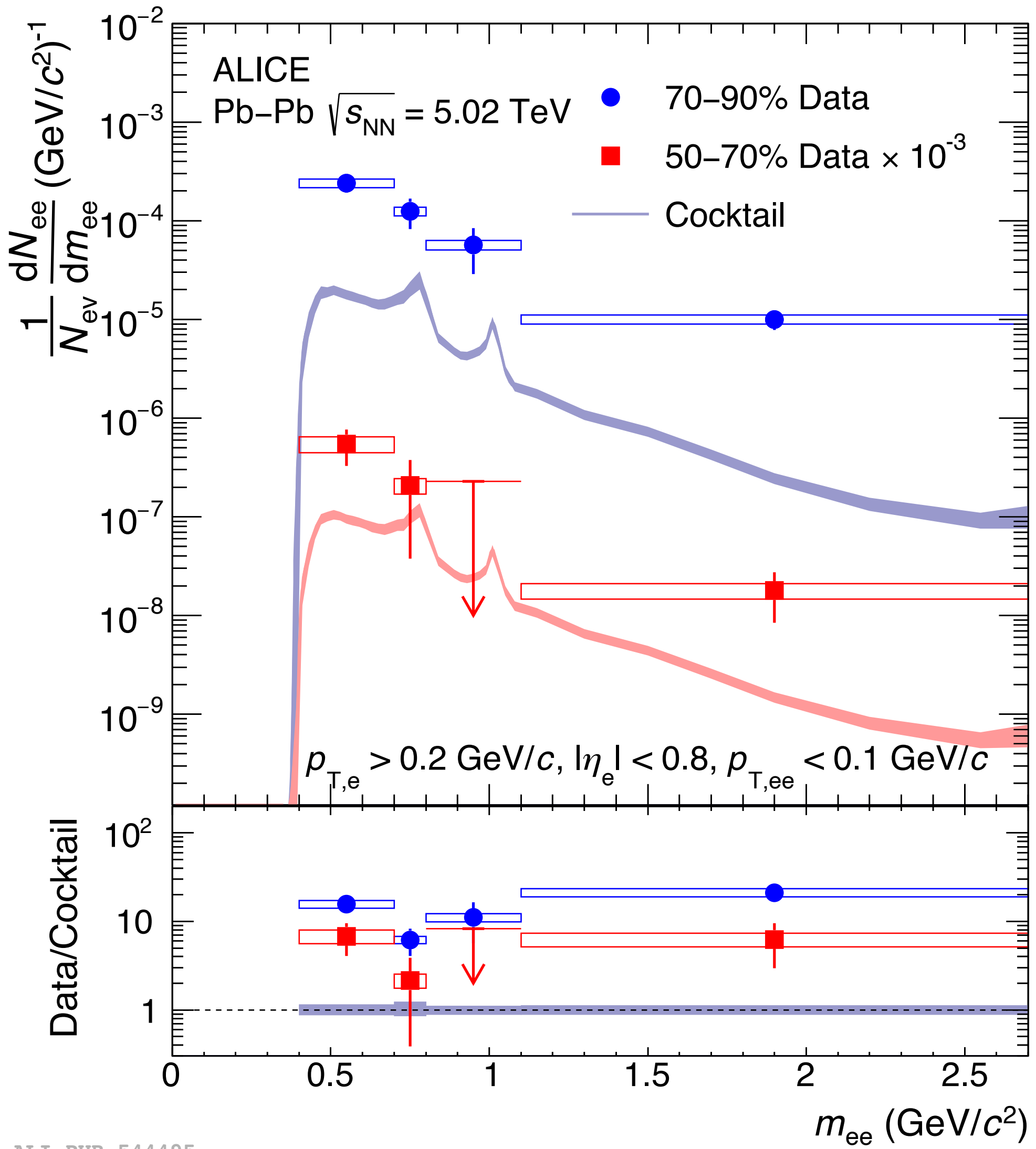


PRL 121, 132301 (2018)

Dielectron excess in Pb–Pb collisions with nuclear overlap



- Measurement of a low mass dielectron excess at very low p_T and **midrapidity** in peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV at LHC
- Efficiency-corrected dielectron invariant mass spectra in centrality 50-70 % and 70-90 %
 - Excess compared to hadronic expectation in both centrality classes, with larger significance in peripheral Pb–Pb collisions

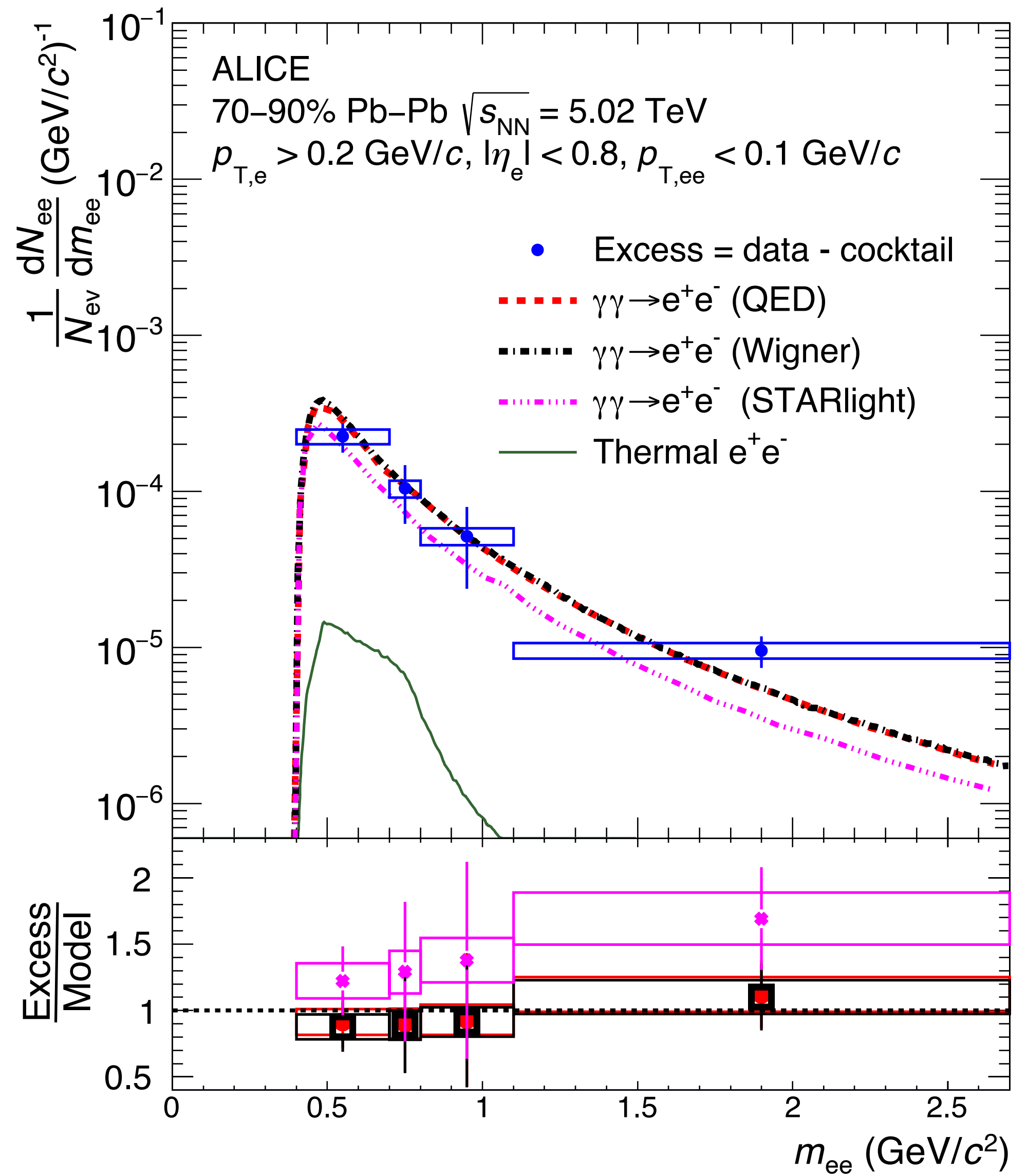


ALI-PUB-544495

JHEP 06 (2023) 024

Dielectron excess in Pb–Pb collisions with nuclear overlap

- Measurement of a low mass dielectron excess at very low p_T and **midrapidity** in peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV at LHC
- Thermal radiation from medium is expected to be at least one order of magnitude smaller than the measured excess



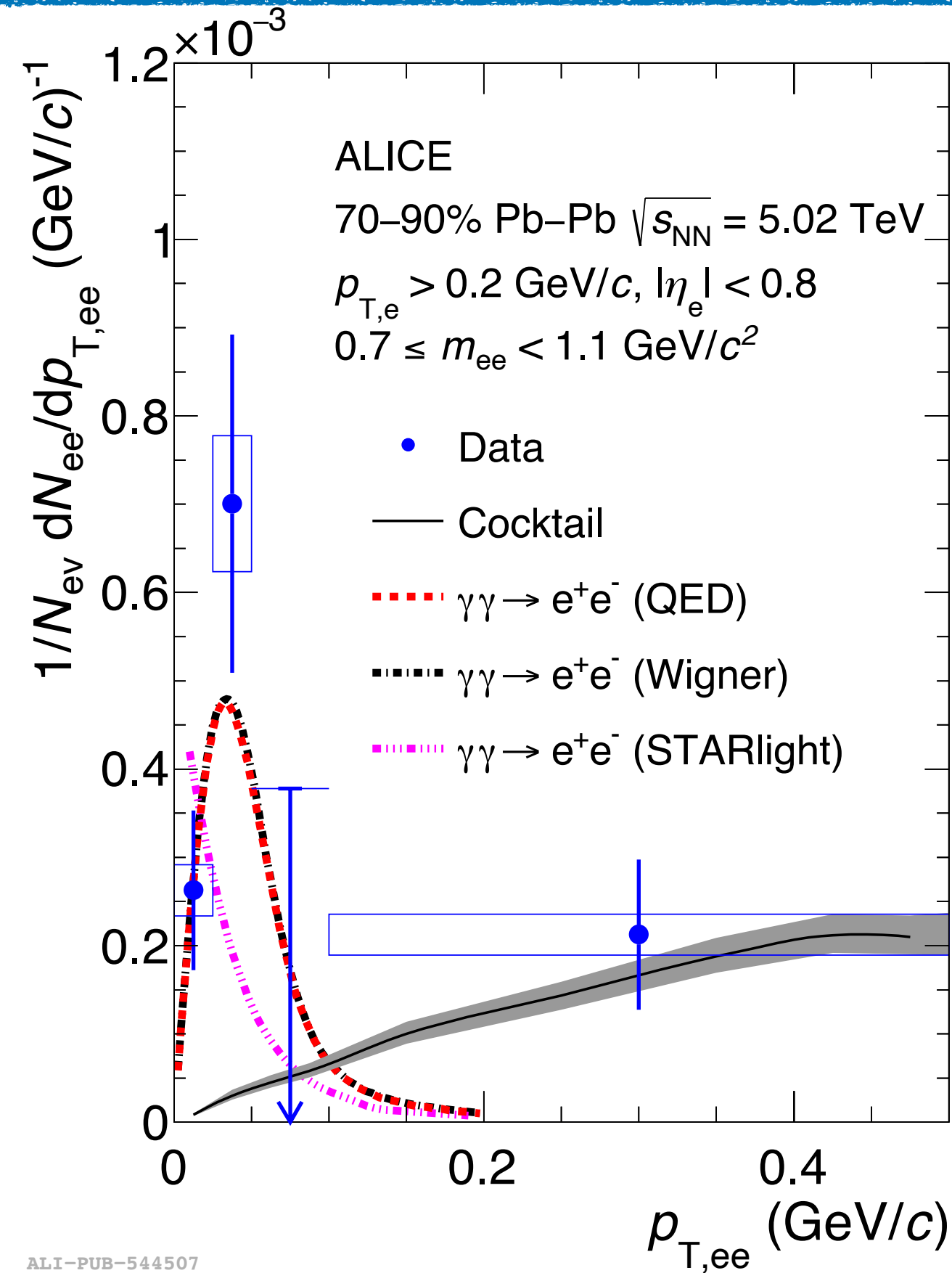
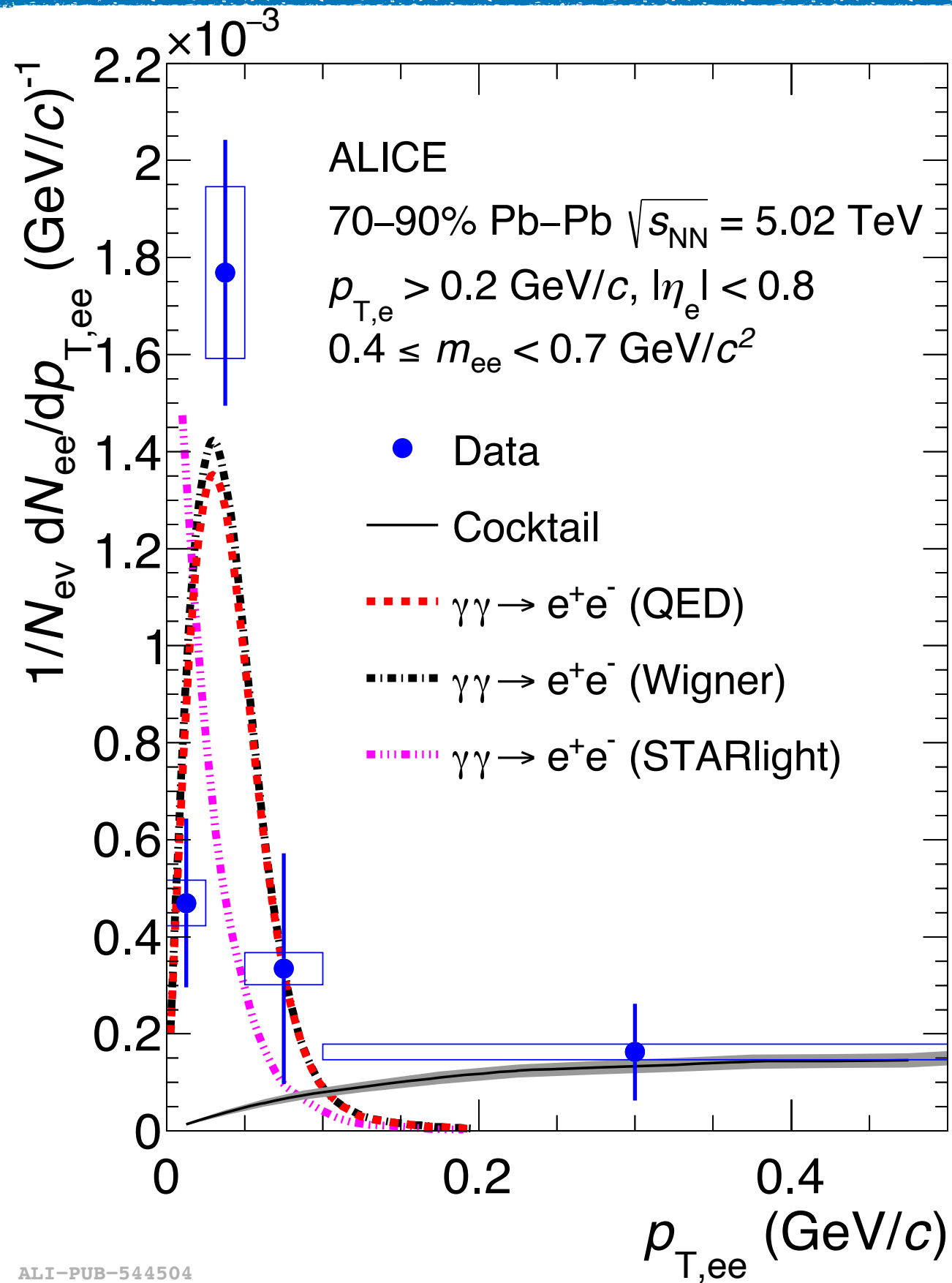
QED:
 W. Zha et al., *Phys. Lett. B* 800 (2020) 135089
 J. D. Brandenburg et al., *Eur. Phys. J. A* 57 (2021) 299

Wigner:
 M. Klusek-Gawenda et al., *Phys. Lett. B.* 814 (2021) 136114

STARlight:
 S.R. Klein et al., *Comput. Phys. Commun.* 212 (2017) 258
 S.R. Klein, *Phys. Rev. C.* 97 (2018) 054903

JHEP 06 (2023) 024

ALI-PUB-544501



- Clear peak observed for $p_{T,ee} < 0.1$ GeV/c in all m_{ee} intervals in centrality range 70-90 %
- Data described by $\gamma\gamma$ models including impact parameter dependence of photon k_T distribution
- STARlight model does not reproduce excess at very low $p_{T,ee}$

JHEP 06 (2023) 024

QED:

W. Zha et al., *Phys. Lett. B* 800 (2020) 135089
J. D. Brandenburg et al., *Eur. Phys. J. A* 57 (2021) 299

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S.R. Klein, *Phys. Rev. C.* 97 (2018) 054903

Coherent photoproduced J/ψ y – differential cross section at forward rapidity

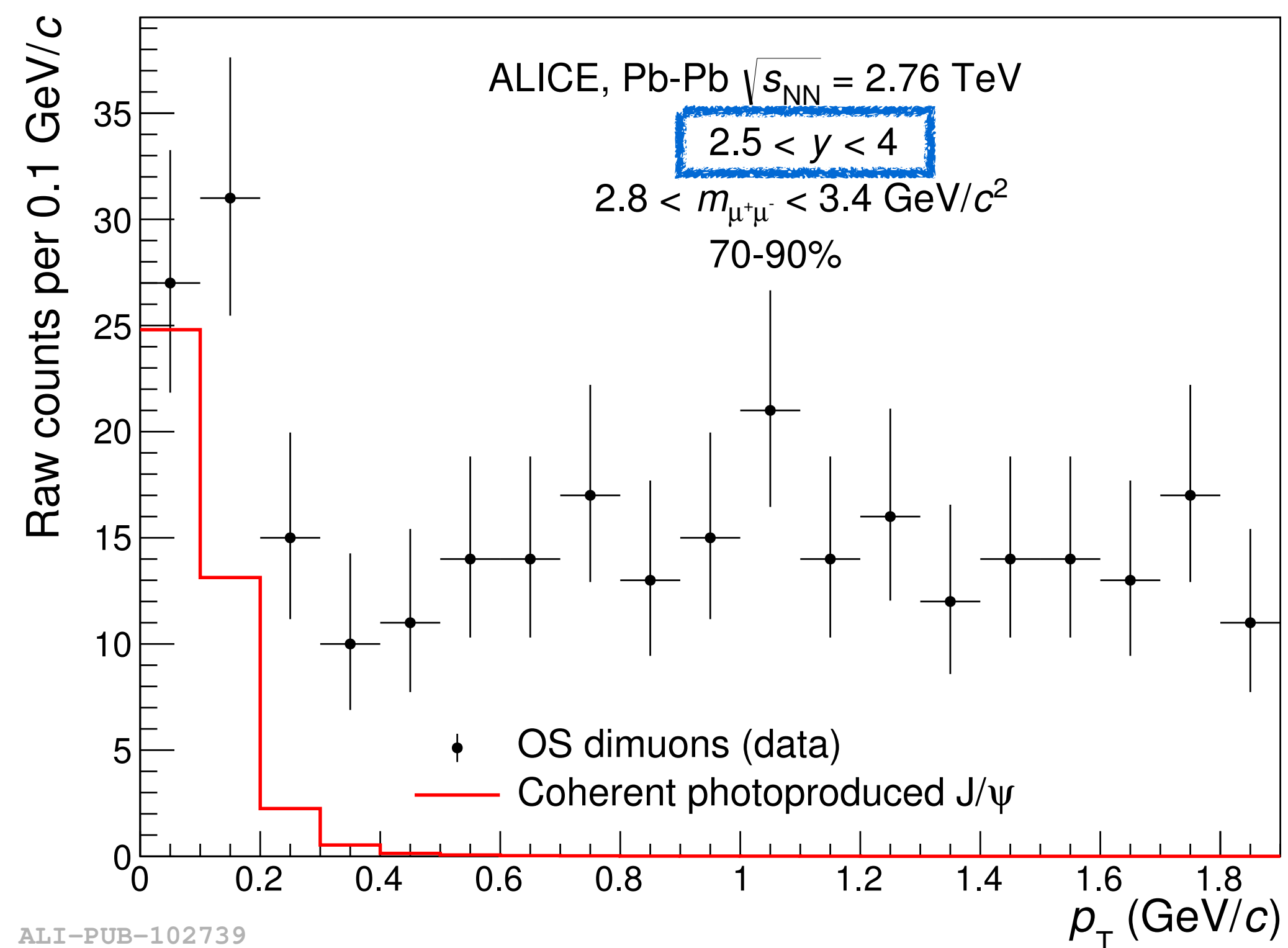
Vector meson photoproduction in events with nuclear overlap

J/ψ yield excess in Pb–Pb with nuclear overlap

J/ψ excess observed at very low $p_T < 0.3$ GeV/c and **forward rapidity** in peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and 5.02 TeV

PRL 116, 222301(2016)

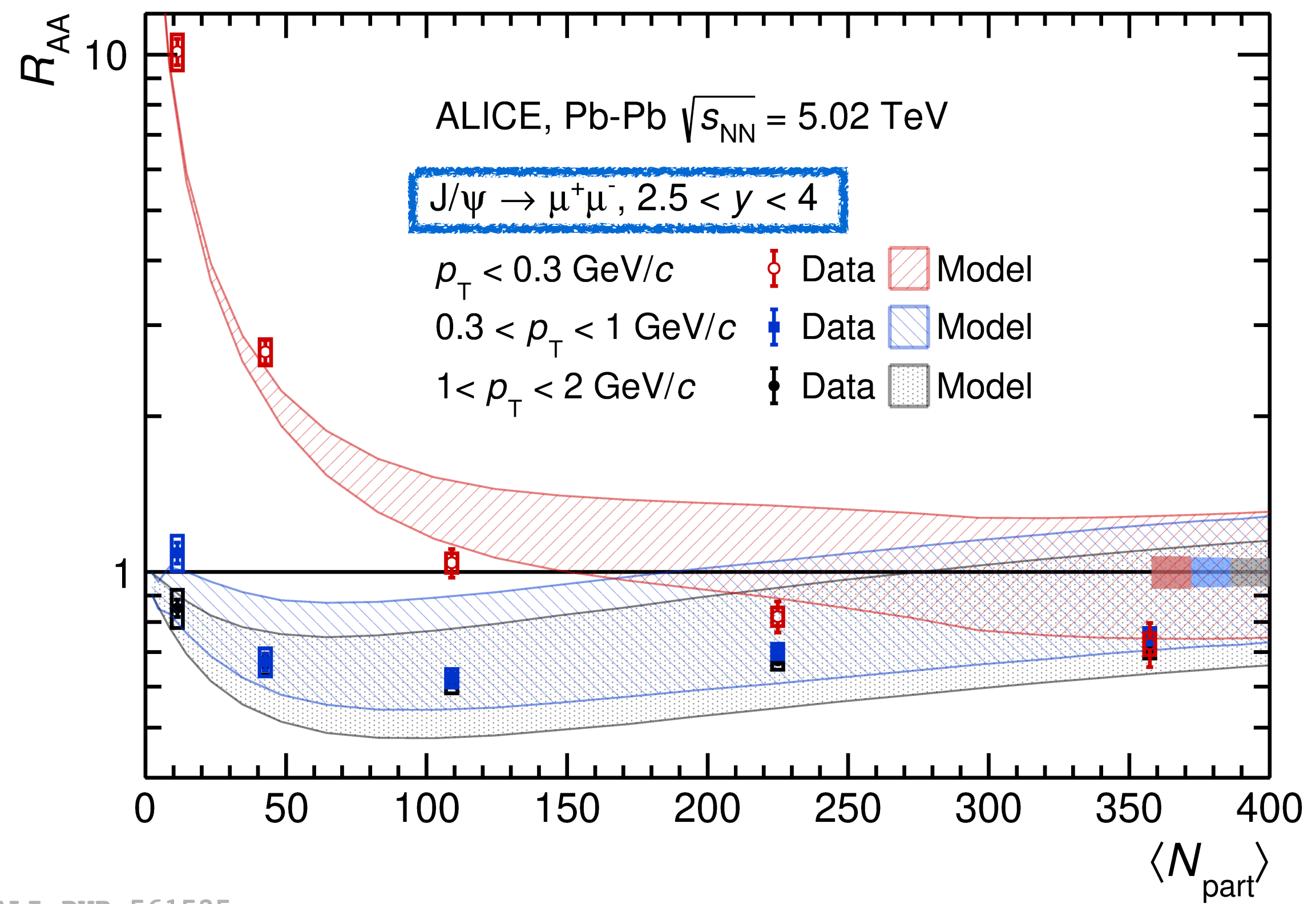
STARlight: S.R. Klein et al., Comput. Phys. Commun. 212 (2017) 258



ALI-PUB-102739

Phys. Lett. B 846 (2023) 137467

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



ALI-PUB-561525

Increase of J/ψ R_{AA} in agreement with model including a dominant photoproduction mechanism at low p_T in most peripheral collisions

How to obtain the coherent photoproduced J/ψ contribution ?

Coherently photoproduced J/ψ yield :

$$Y_{J/\psi}^{\text{coherent}} = \frac{Y_{J/\psi}^{\text{excess}}}{1 + f_I + f_D}$$

f_I : fraction of incoherently photoproduced J/ψ
 f_D : fraction of J/ψ feed down from coherently photoproduced $\psi(2S)$

Fractions taken from UPC measurements

How do we extract the J/ψ yield excess?

J/ψ yield excess in Pb–Pb with nuclear overlap

The J/ψ yield excess can be expressed as :

$$Y_{J/\psi}^{\text{excess}} = Y_{J/\psi}^{\text{raw}} - Y_{J/\psi}^{\text{hadronic}}$$

Hadroproduced J/ψ yield is estimated with :

$$Y_{J/\psi}^{\text{hadronic}} \equiv \int_0^{0.3} \frac{dN_{AA}^h}{dp_T} (p_T) dp_T = \mathcal{N} \int_0^{0.3} \frac{d\sigma_{pp}^h}{dp_T} (p_T) \times R_{AA}^h (p_T) \times A\varepsilon_{AA}^h (p_T) dp_T$$

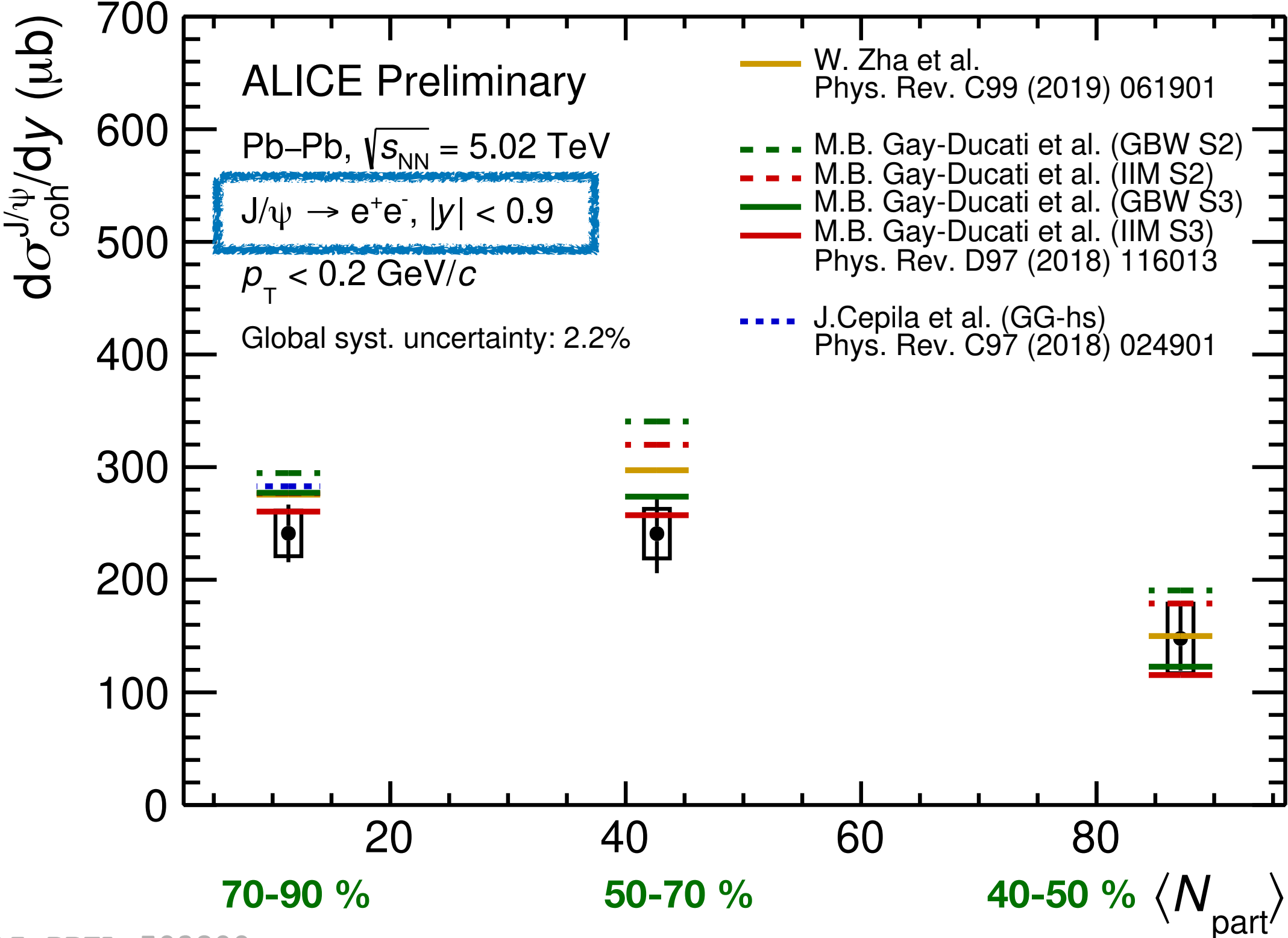
Normalization factor

Hadronic J/ψ cross section in pp collisions

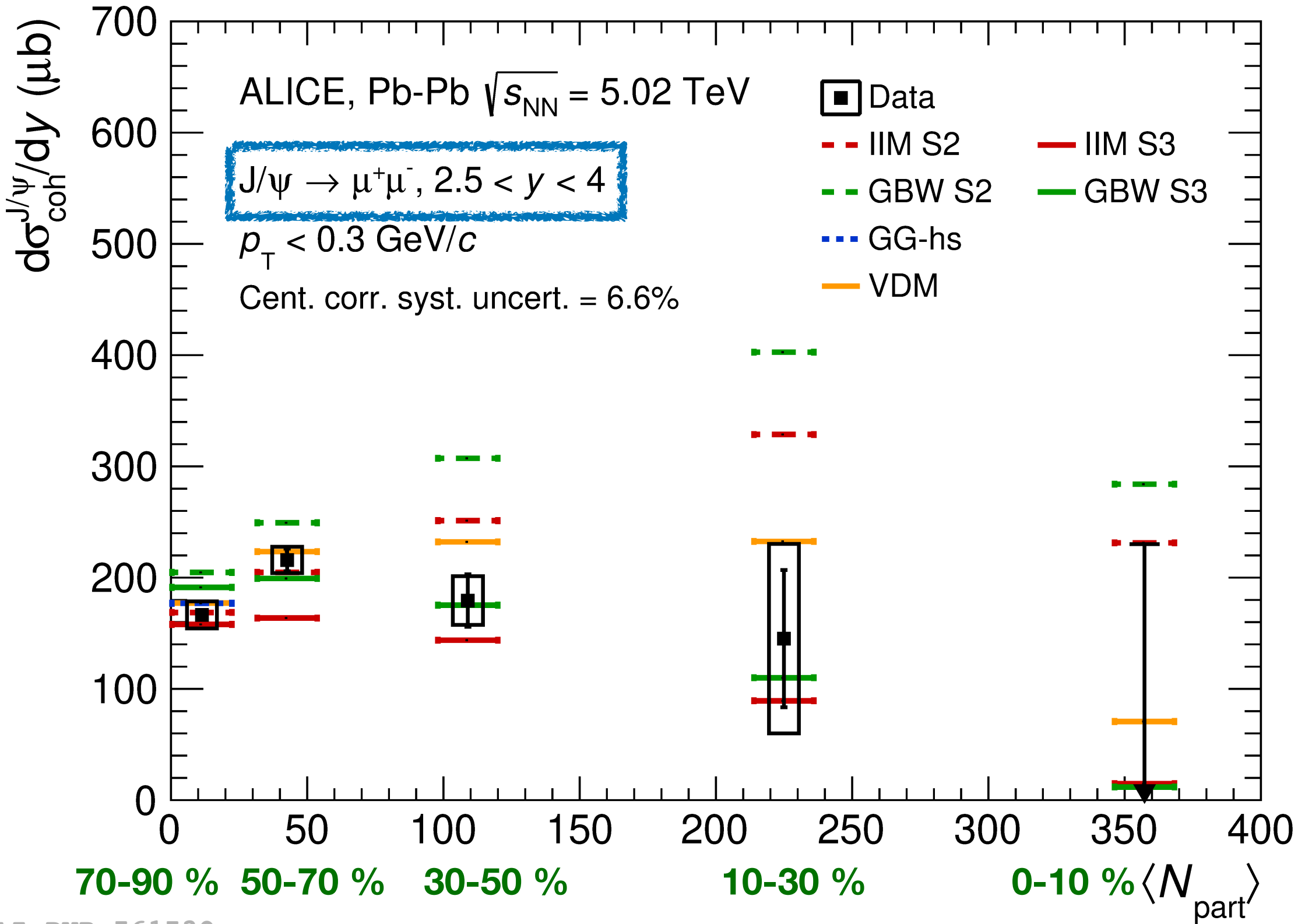
Hadronic J/ψ nuclear modification factor

Acceptance efficiency in Pb–Pb

Centrality dependence



ALI-PREL-503800



ALI-PUB-561530

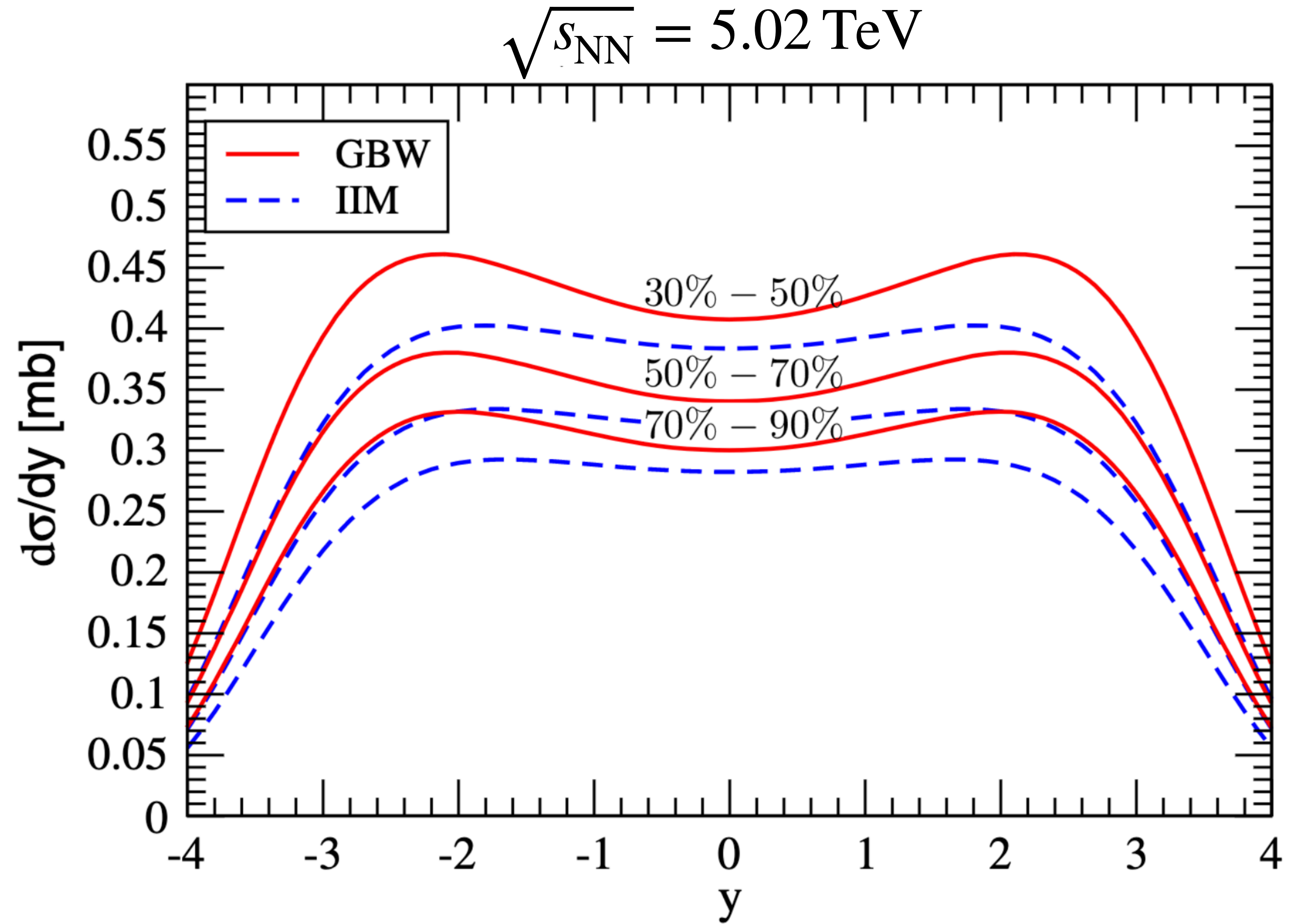
- Measurements of the coherent photoproduced J/ψ cross section at mid and forward rapidity show **no significant centrality dependence**
- Data qualitatively described by UPC models extended to describe events with nuclear overlap

Caveat : cross section not normalized to the centrality bin width

Coherent J/ψ photoproduction in Pb–Pb with nuclear overlap

Rapidity dependence

- Theoretical models predict a **strong rapidity dependence** for vector meson photoproduction cross section
- New y –**differential** measurement performed in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with nuclear overlap

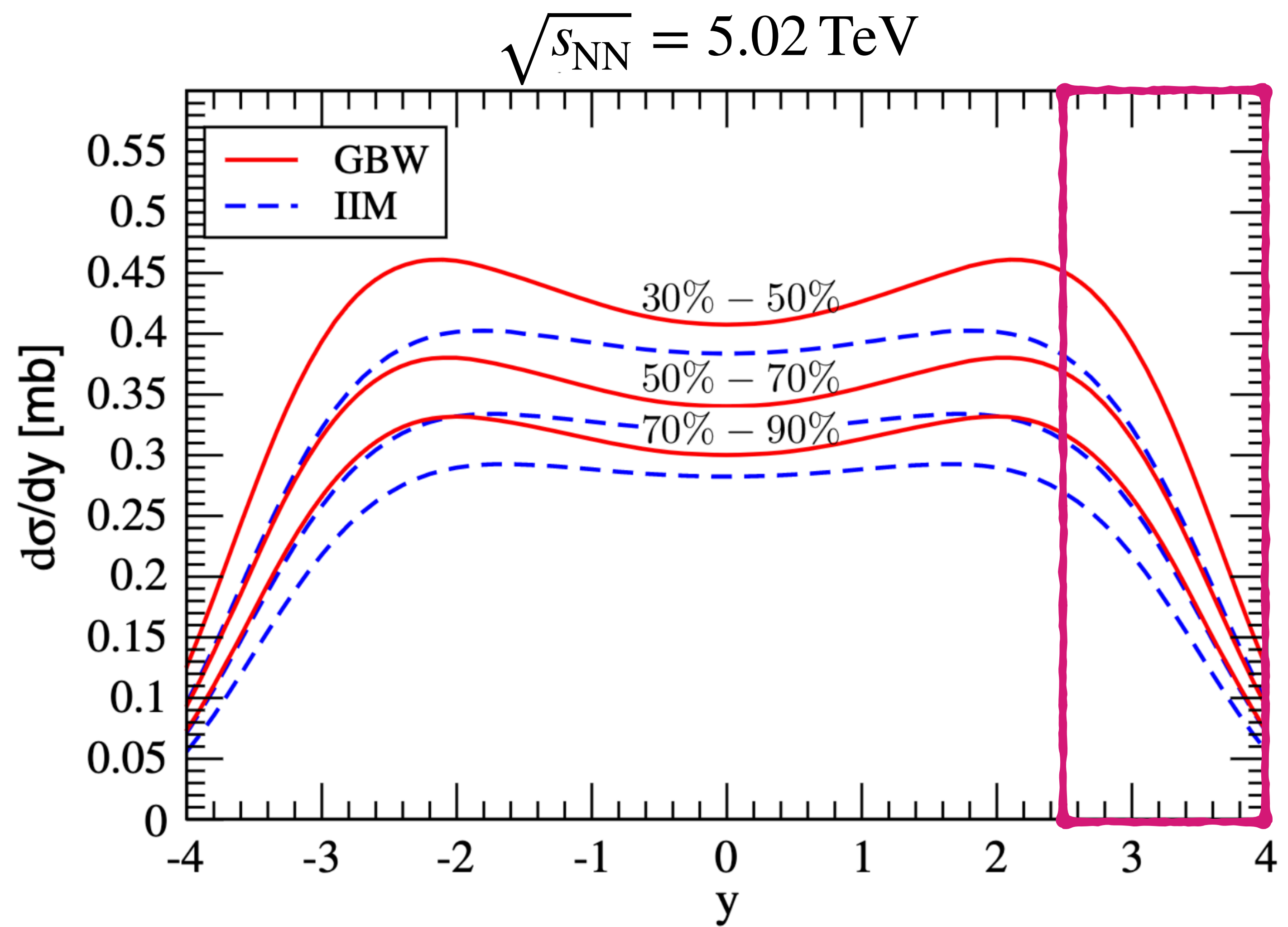


M. B. Gay Ducati et. al, PRD 97, 116013 (2018)

Coherent J/ψ photoproduction in Pb–Pb with nuclear overlap

Rapidity dependence

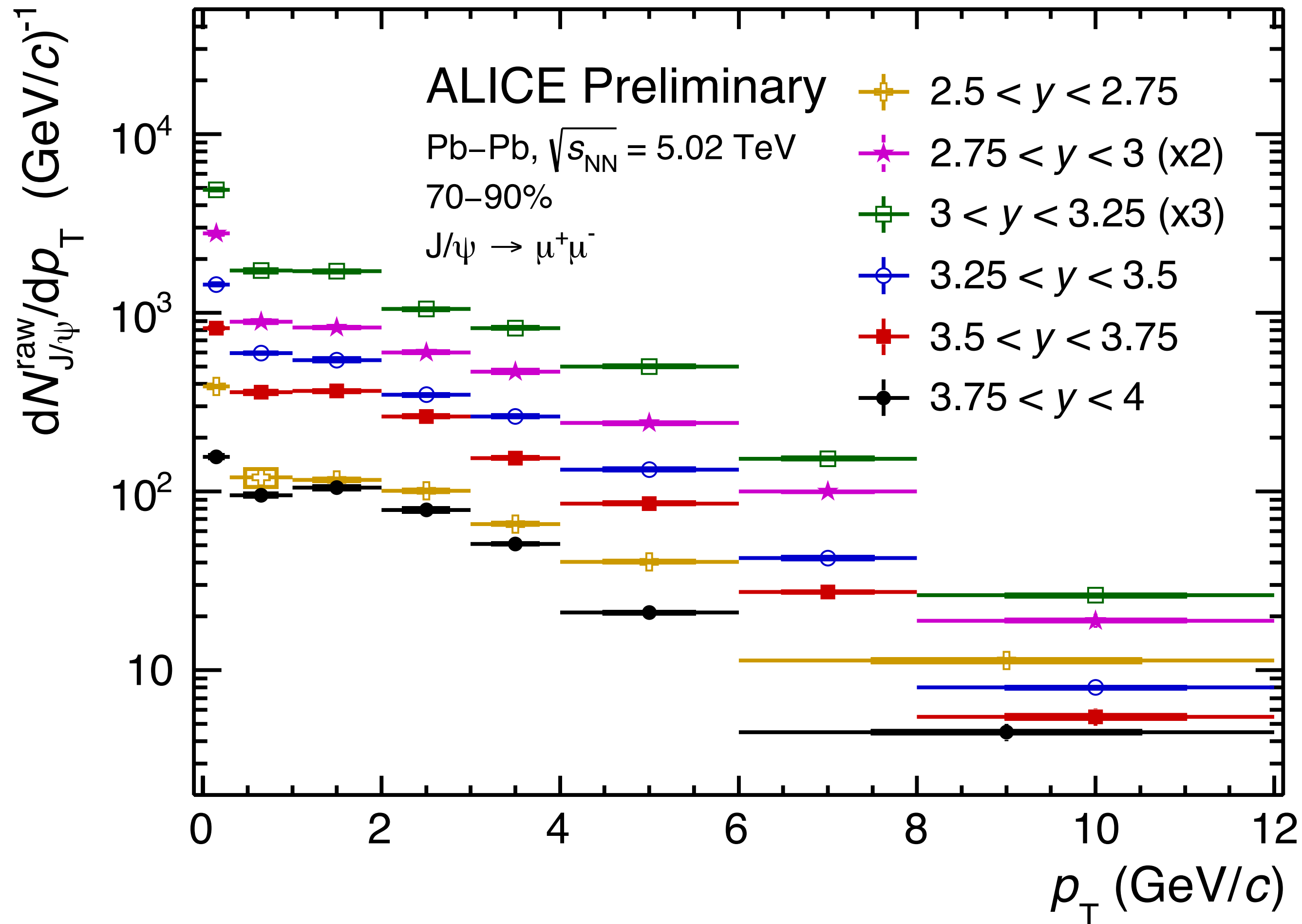
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M. B. Gay Ducati et. al, PRD 97, 116013 (2018)

Raw J/ψ yield in rapidity intervals

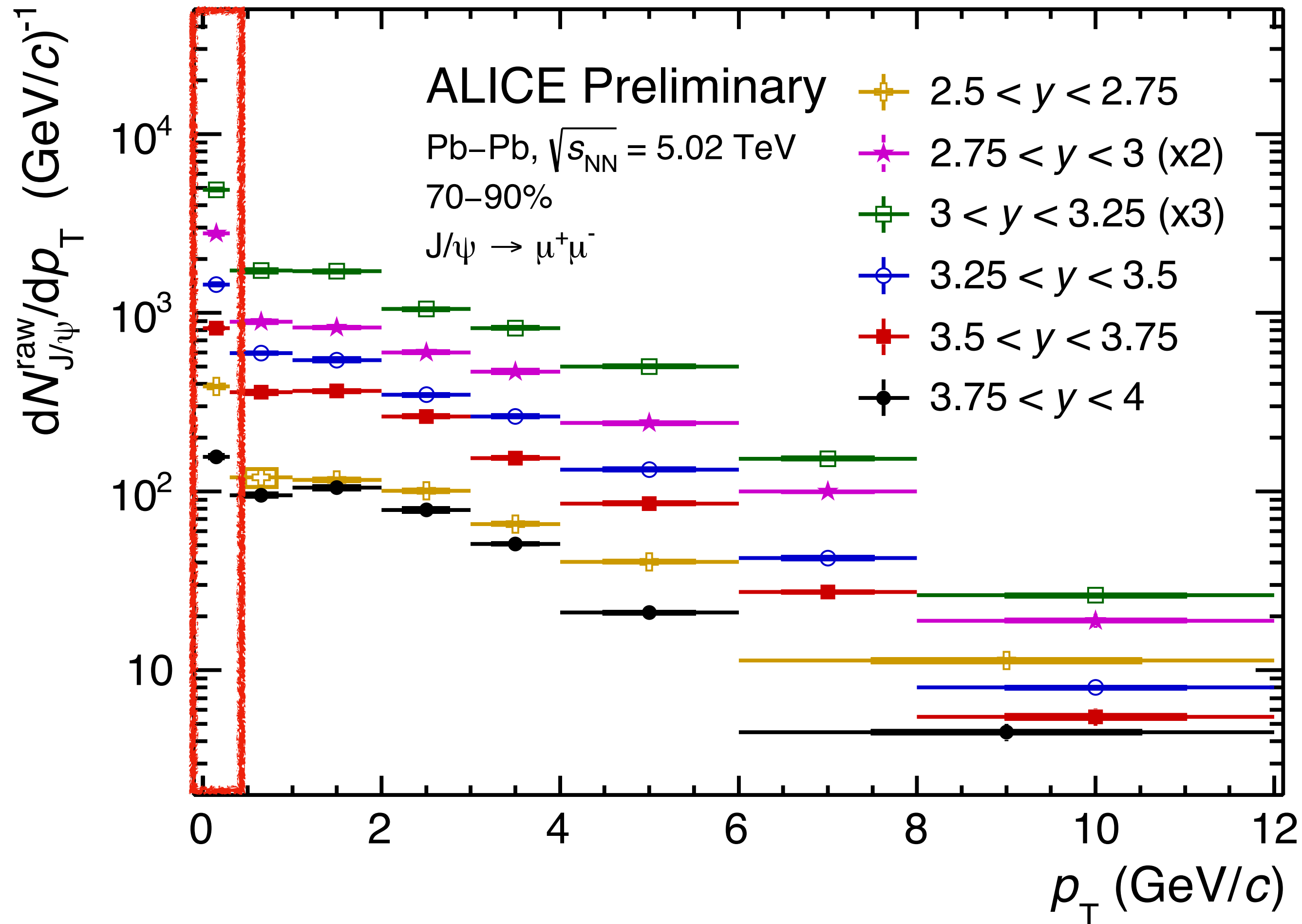
J/ψ signal extracted in **different rapidity intervals** from the dimuon invariant mass spectra



ALI-PREL-548019

Raw J/ψ yield in rapidity intervals

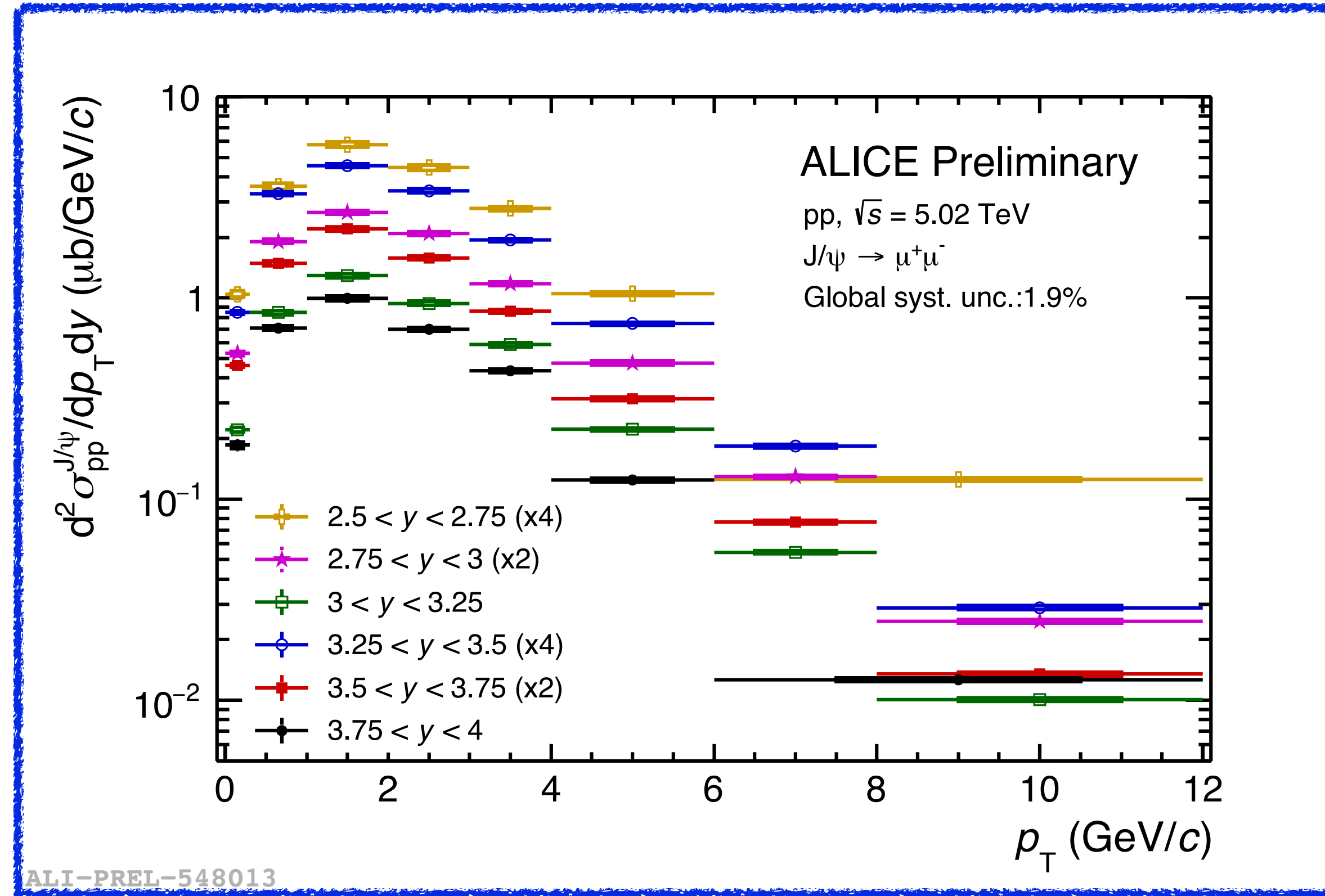
J/ψ signal extracted in **different rapidity intervals** from the dimuon invariant mass spectra



Excess observed for $p_T < 0.3$ GeV/c in all rapidity intervals

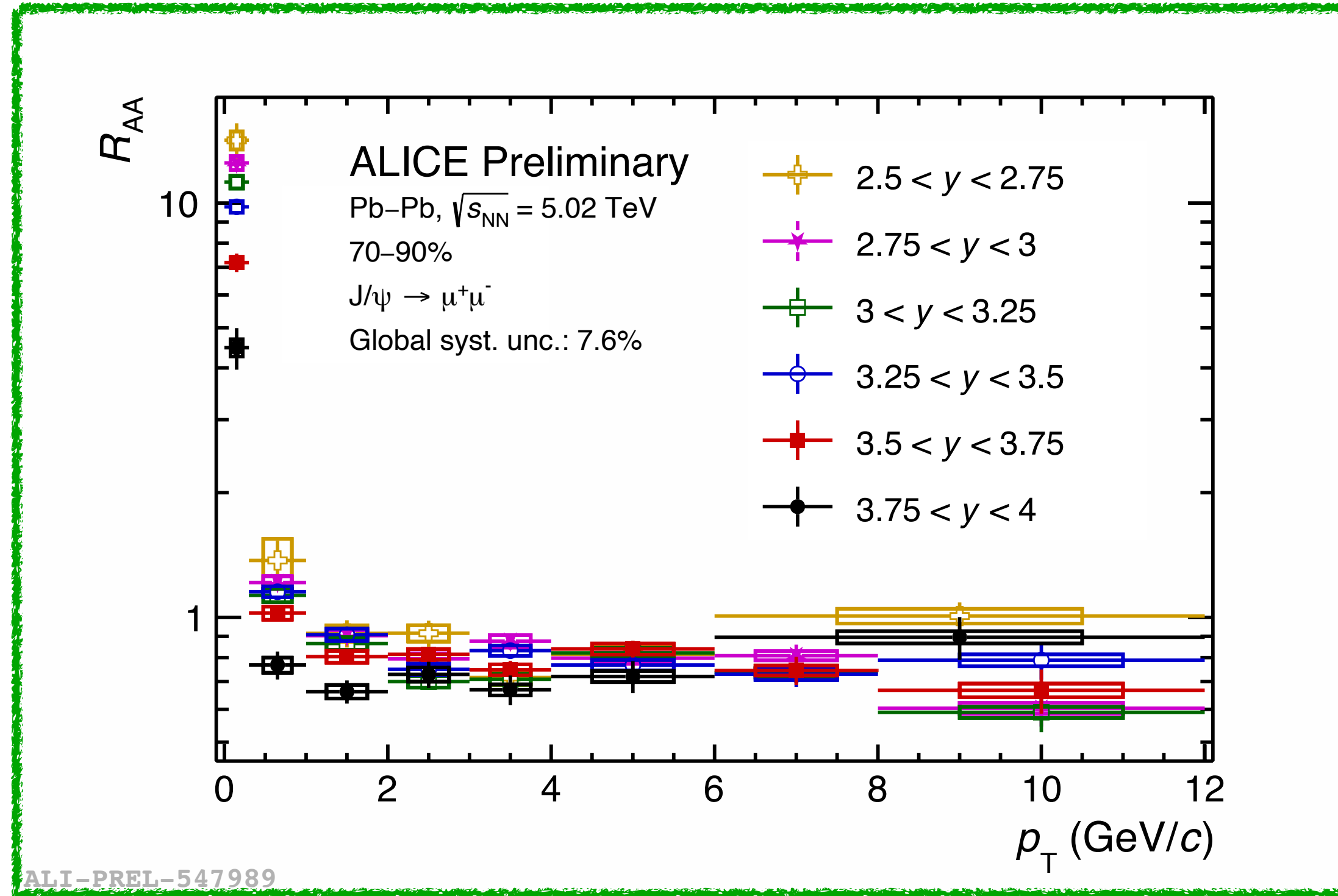
ALI-PREL-548019

Hadronic J/ψ yield modeling at very low p_T



$$Y_{J/\psi}^{\text{hadronic}} \equiv \int_0^{0.3} \frac{dN_{AA}^h}{dp_T}(p_T) dp_T = \mathcal{N} \int_0^{0.3} \frac{d\sigma_{pp}^h}{dp_T}(p_T) \times R_{AA}^h(p_T) \times A\varepsilon_{AA}^h(p_T) dp_T$$

Hadronic J/ψ yield modeling at very low p_T



- R_{AA} strongly increases at low $p_T < 0.3$ GeV/c for **all rapidity intervals**
- Using R_{AA} (excluding excess region and assuming instead smooth evolution of R_{AA} from high to low p_T), and J/ψ cross section in pp, the expected hadronic J/ψ yield is modeled as :

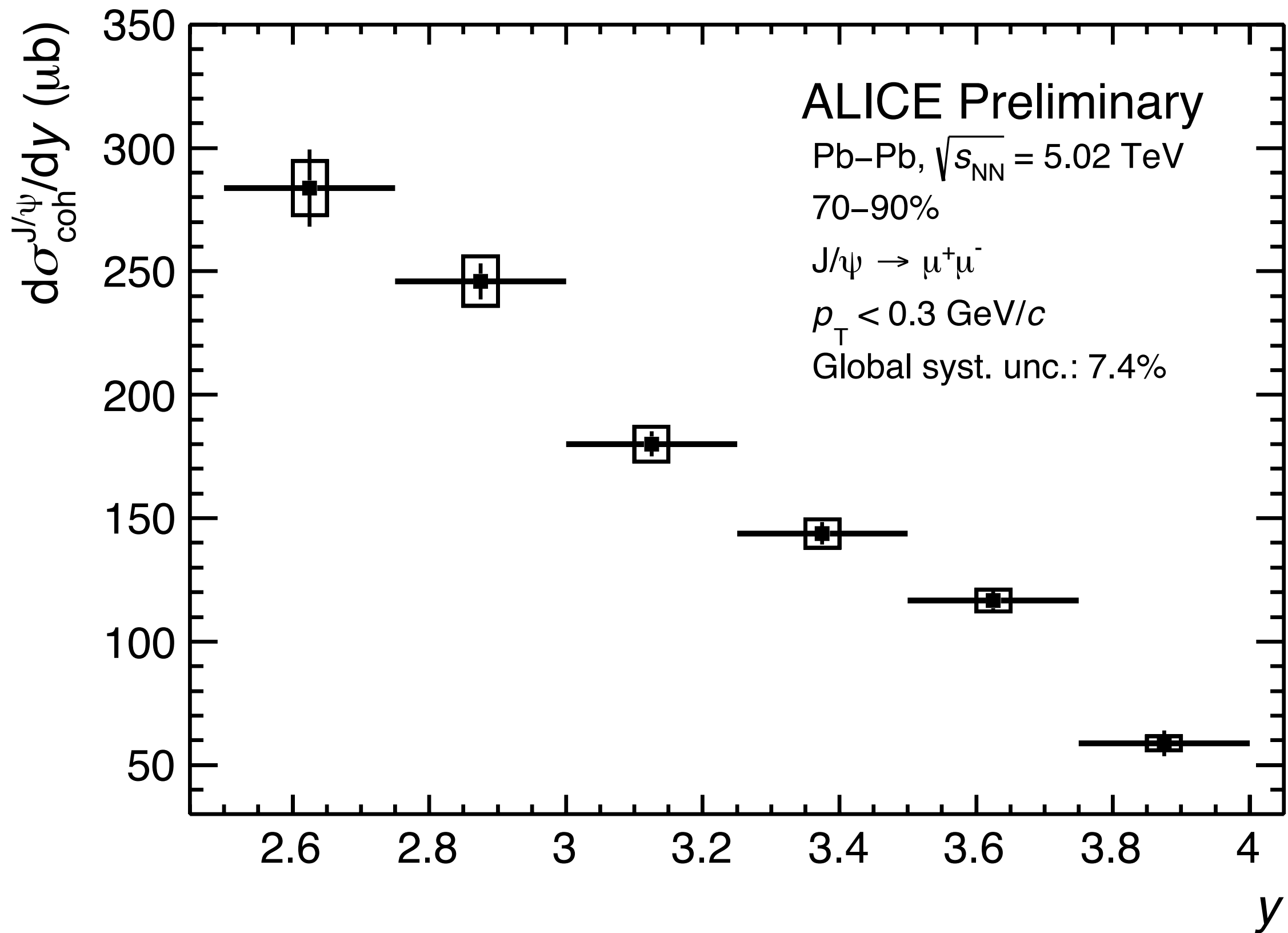
$$Y_{J/\psi}^{\text{excess}} = Y_{J/\psi}^{\text{raw}} - Y_{J/\psi}^{\text{hadronic}}$$

$$Y_{J/\psi}^{\text{hadronic}} \equiv \int_0^{0.3} \frac{dN_{AA}^h}{dp_T}(p_T) dp_T = \mathcal{N} \int_0^{0.3} \frac{d\sigma_{pp}^h}{dp_T}(p_T) \times R_{AA}^h(p_T) \times A\varepsilon_{AA}^h(p_T) dp_T$$

Coherently photoproduced J/ψ cross section



Rapidity dependence

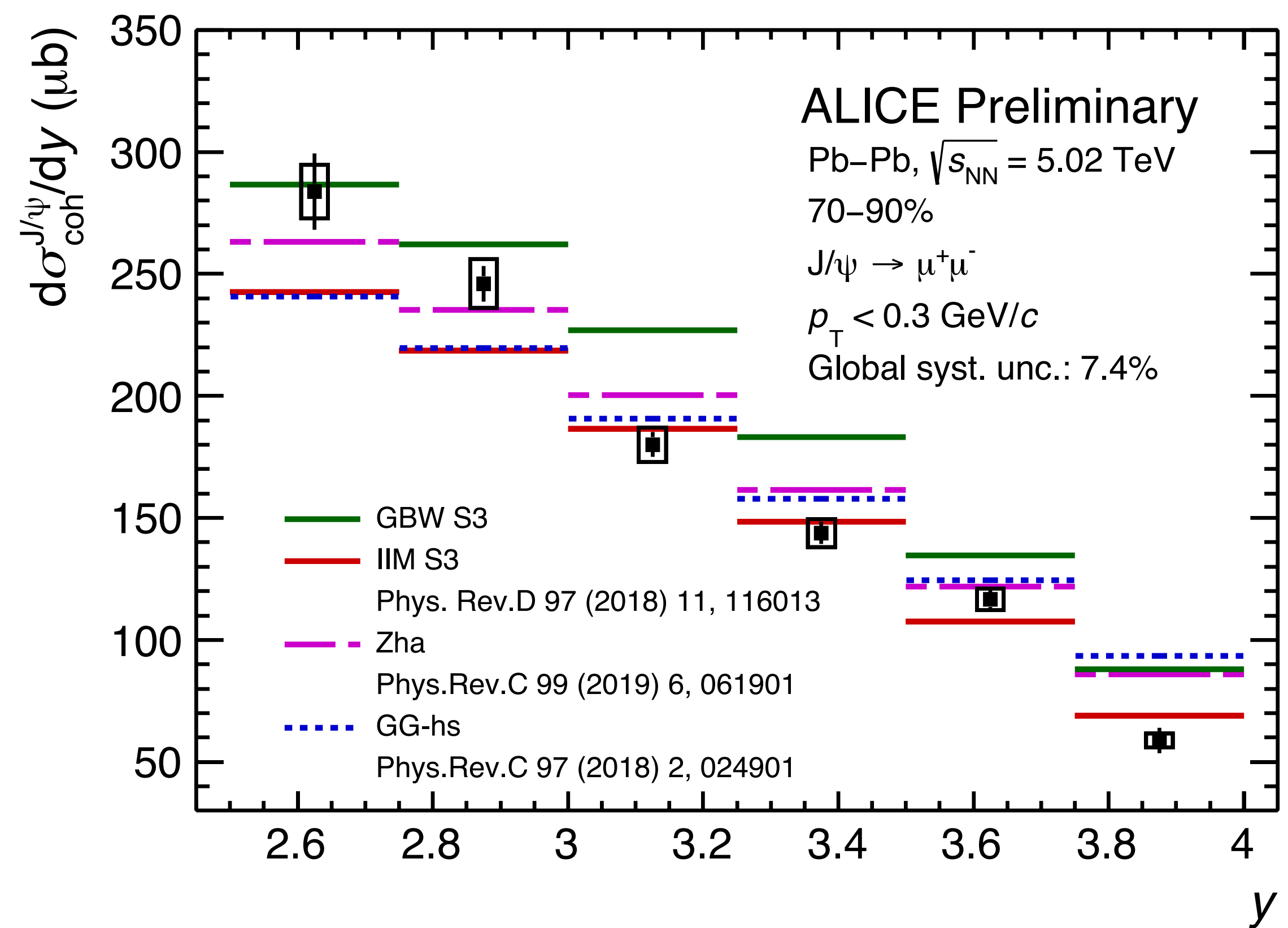


- Measurement shows a strong rapidity dependence in peripheral Pb–Pb collisions

ALI-PREL-548022

Coherently photoproduced J/ψ cross section

Rapidity dependence



ALI-PREL-547942

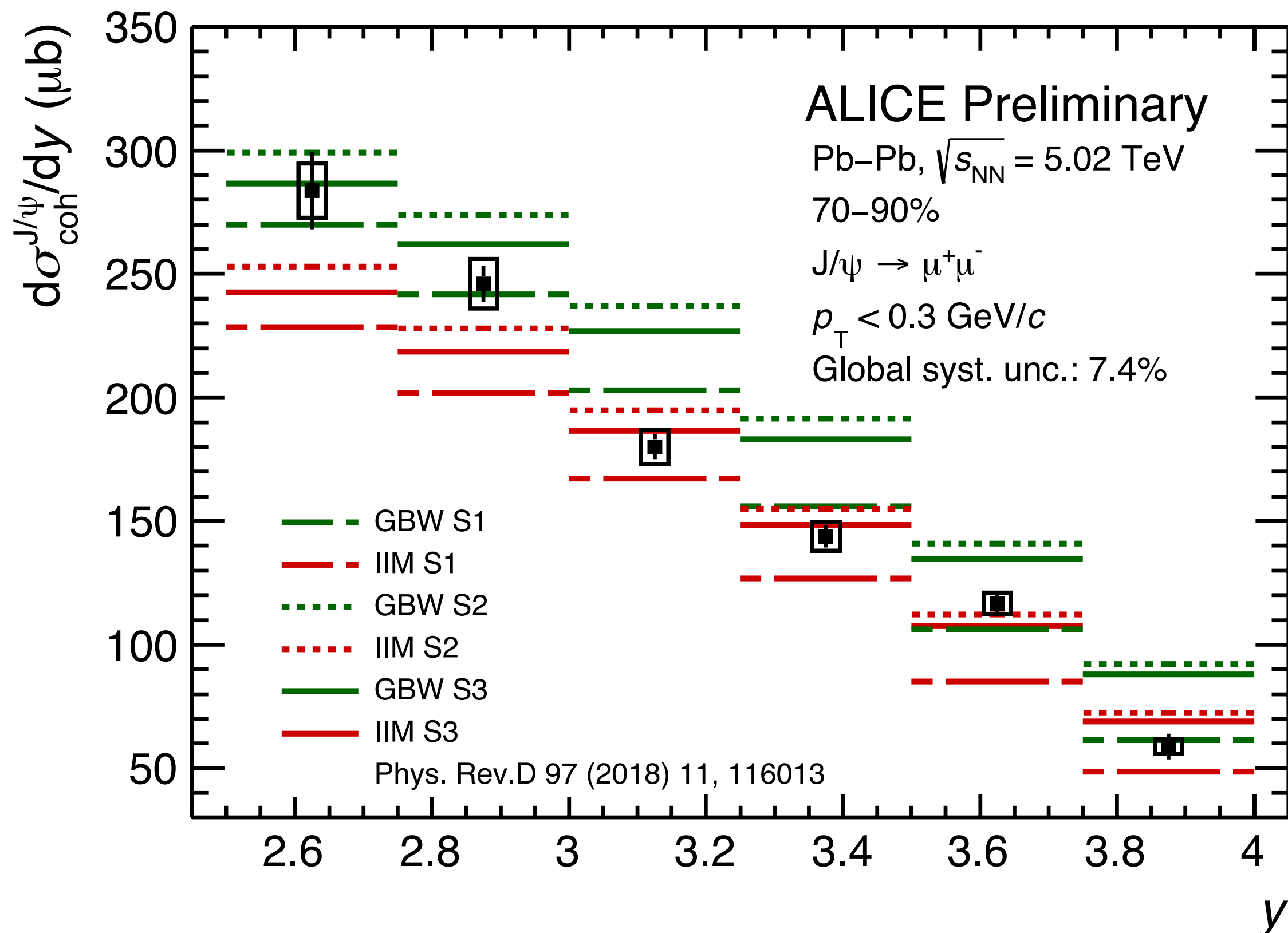
- Measurement shows a strong rapidity dependence
- Data **qualitatively** described by UPC models extended for collisions with nuclear overlap, but the **rapidity dependence is not reproduced**

Models :

- ▶ **GG-hs** : γ flux with constraints on impact parameter range
- ▶ **Zha** : assumptions on γ -pomeron coupling
- ▶ **GBW/IIM S3** : only γ reaching the spectator nucleon region considered + nuclear overlap is not considered in the calculation of $\sigma_{\gamma Pb}$

Coherently photoproduced J/ψ cross section

Rapidity dependence



- Focus on different scenarios for GBW/IIM models :

- GBW/IIM S1 : no relevant modifications w.r.t. UPC calculations
- ⋯ GBW/IIM S2 : only γ reaching spectator nucleon region considered + $\sigma_{\gamma Pb}$ unmodified
- GBW/IIM S3 : S2 + nuclear overlap not considered in $\sigma_{\gamma Pb}$ calculation

- All three scenarios are able to describe **qualitatively** the order of magnitude of the cross section

ALI-PREL-547985

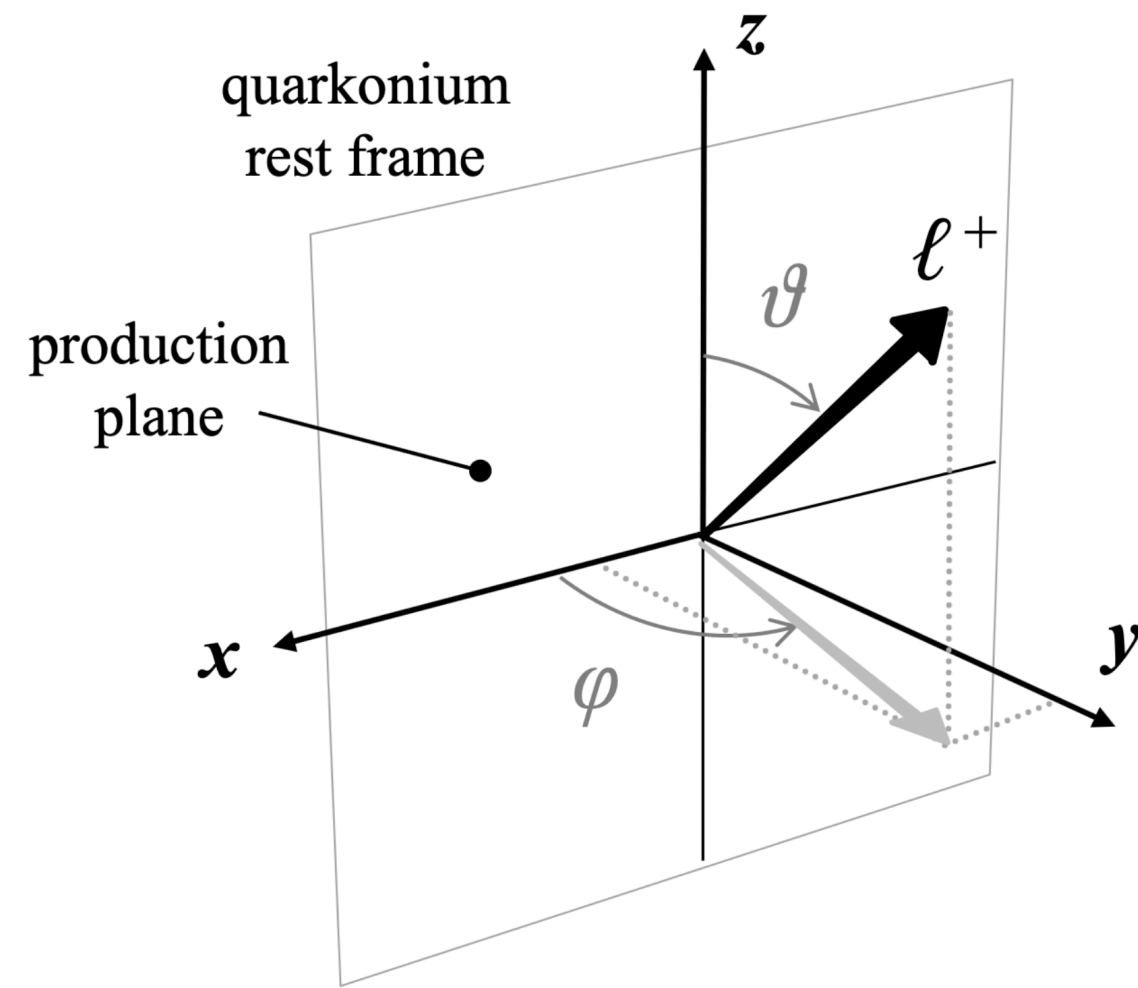
Inclusive J/ψ polarization

Vector meson photoproduction in events with nuclear overlap

Coherently photoproduced J/ψ polarization in Pb–Pb collisions

- Vector meson expected to keep the polarization of the incoming photon (s-channel helicity conservation)

P.Faccioli et al. Eur.Phys.J.C 69 (2010) 657-673



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

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

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

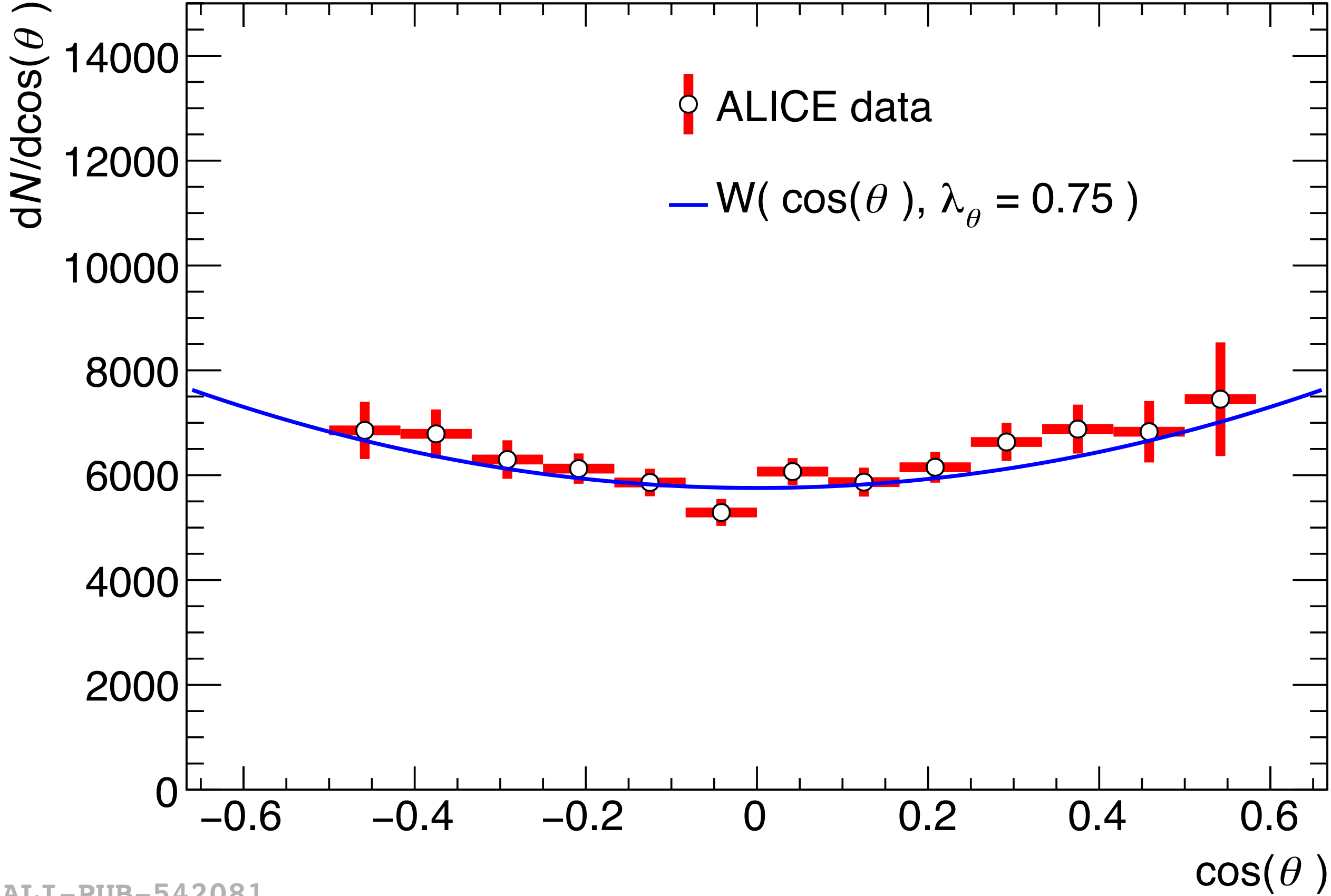
J/ψ polarization measured via dimuon decay channel where the dimuon angular distribution is :

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

Coherently photoproduced J/ψ polarization in Pb–Pb collisions



ALICE, Pb–Pb $\sqrt{s_{NN}} = 5.02$ TeV, Coherent J/ψ



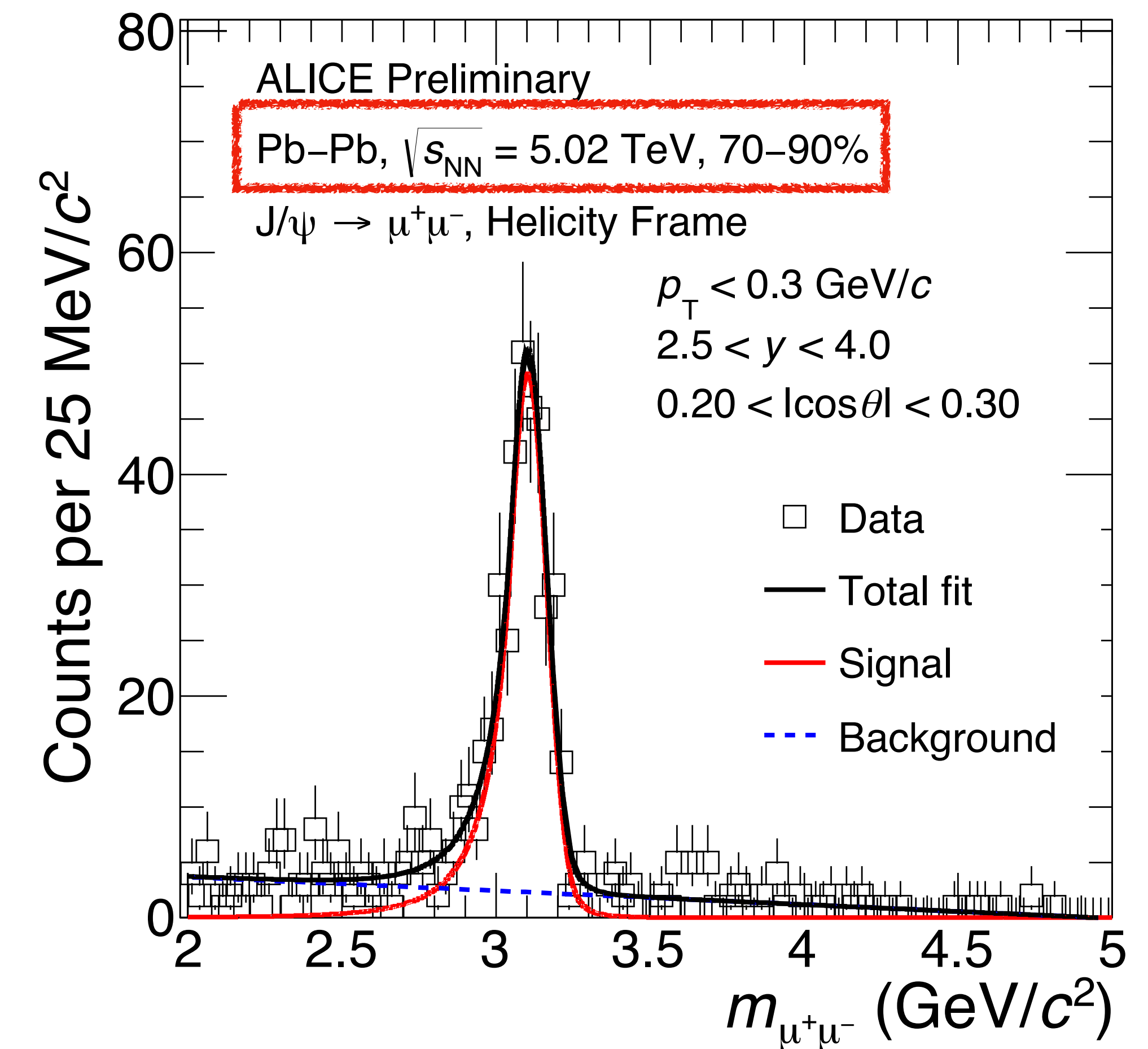
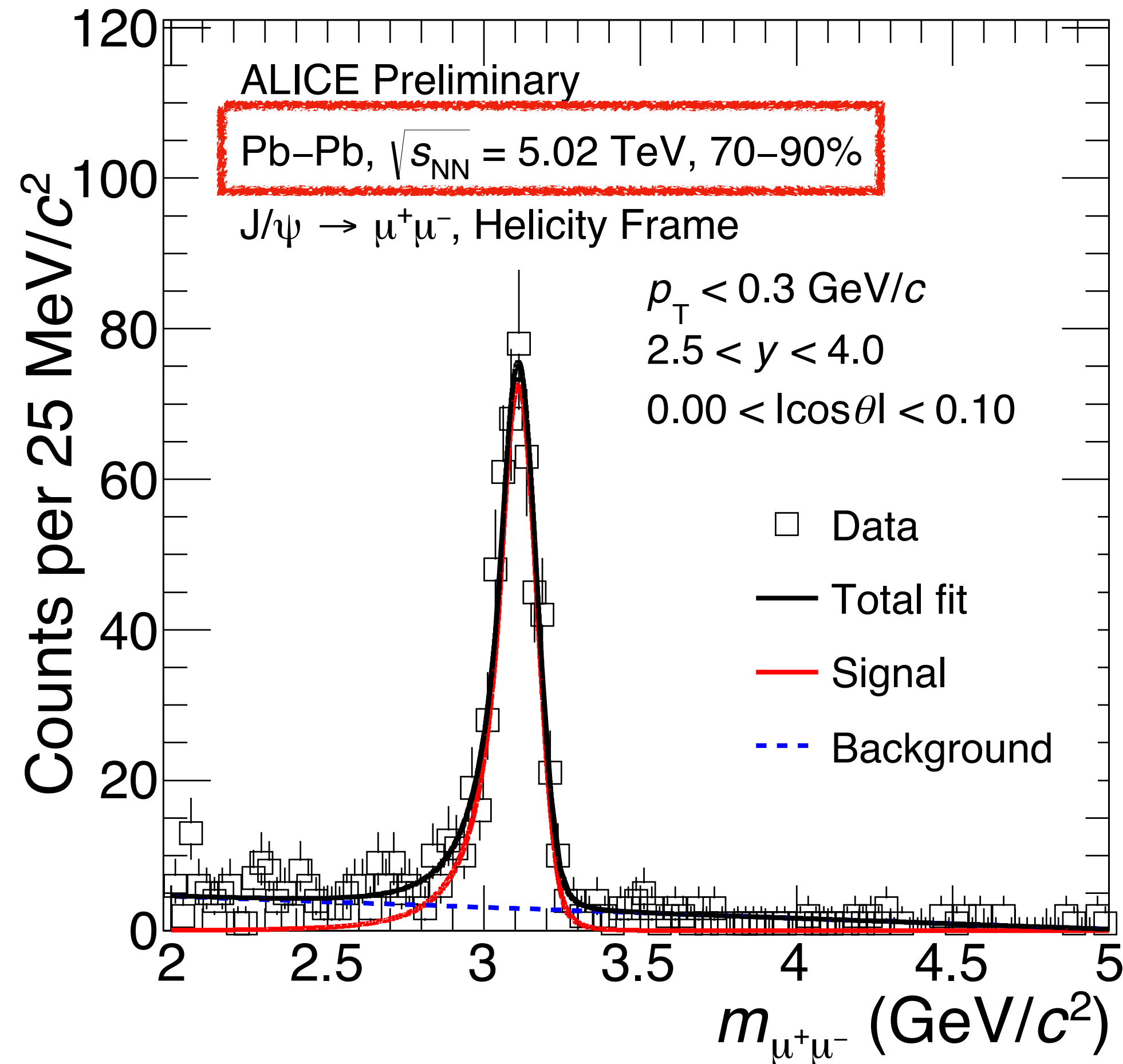
arXiv:2304.10928

ALI-PUB-542081

UPC results are found to be consistent with $\lambda_\theta = 1$, indicating a coherently photoproduced **J/ψ transverse polarization**

J/ψ signal extraction in angular intervals

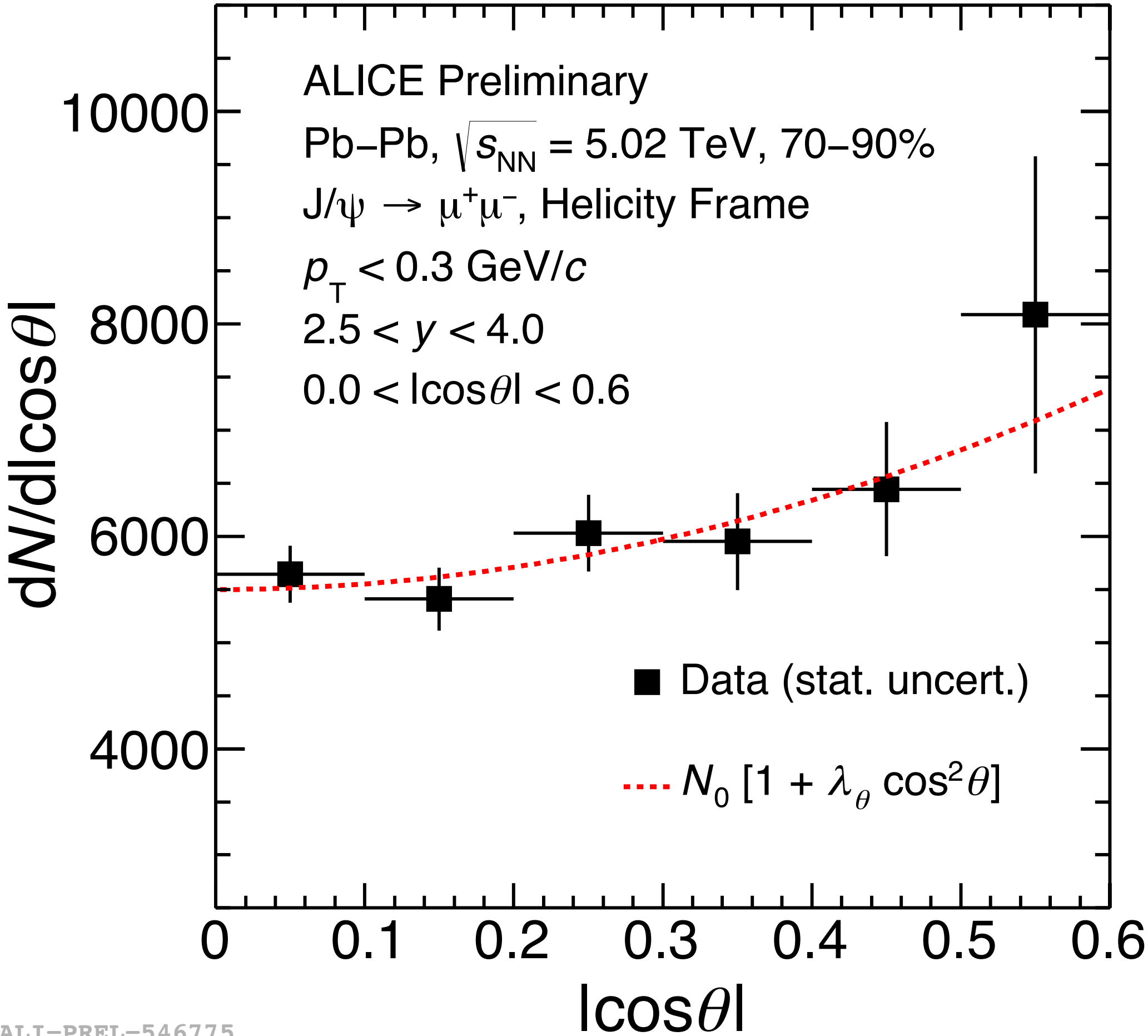
J/ψ signal is extracted for six different $\cos \theta$ intervals at low p_T ($p_T < 0.3 \text{ GeV}/c$) in **Pb–Pb peripheral collisions** from dimuon invariant mass spectra



ALI-PREL-546762

ALI-PREL-546765

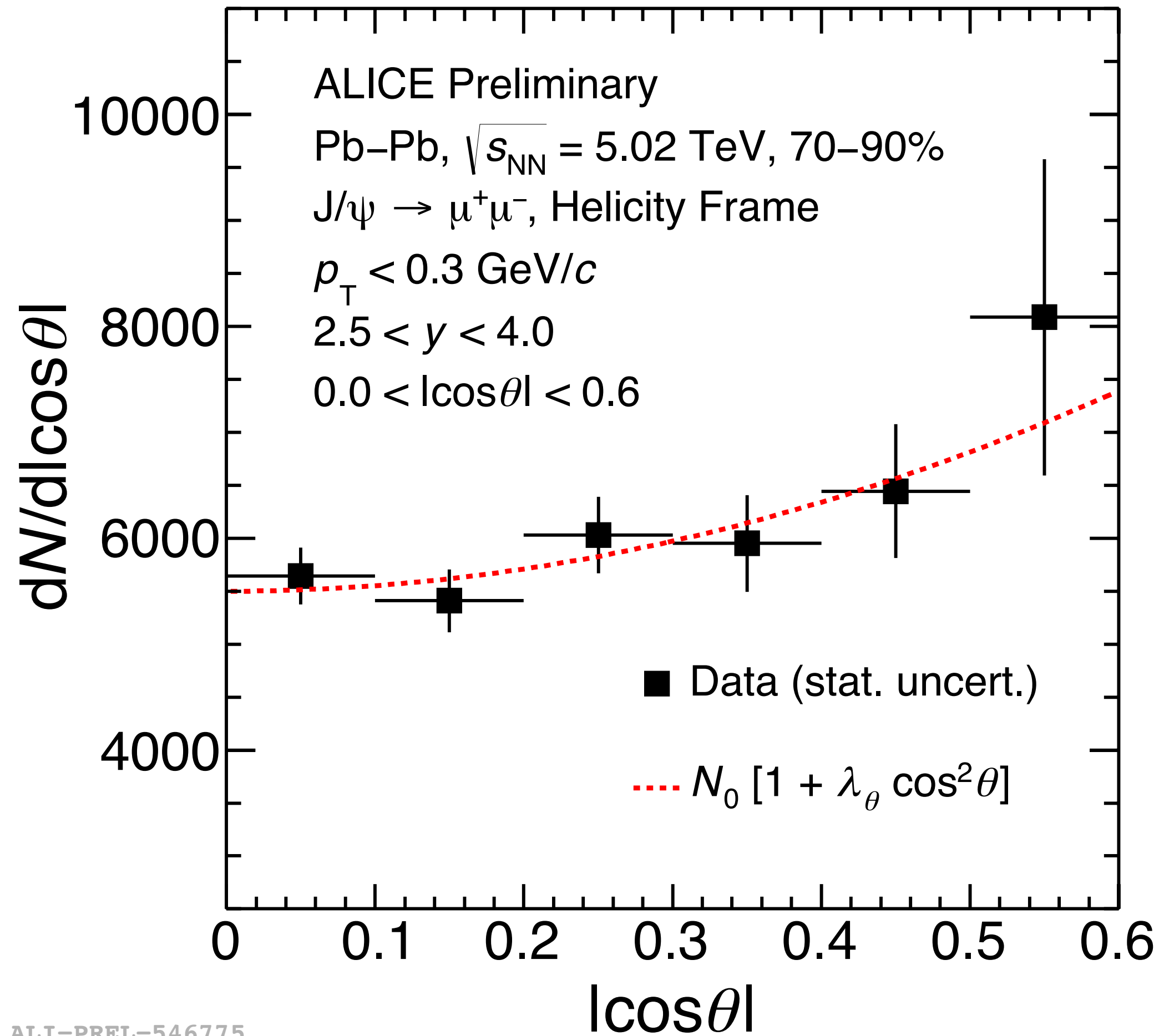
Inclusive J/ψ polarization in Pb–Pb collisions



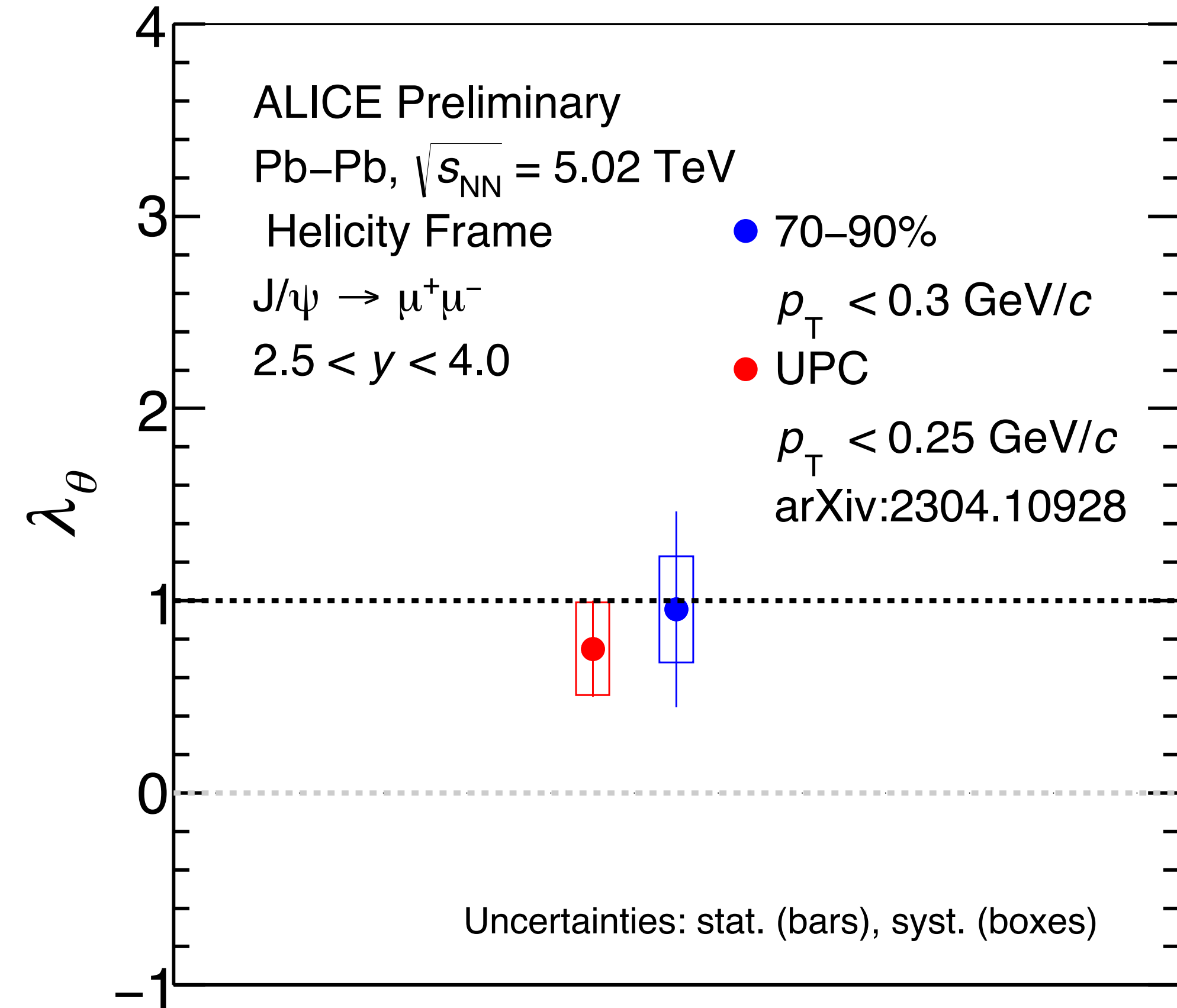
ALI-PREL-546775

Angular distribution suggests a **transverse polarization**

Inclusive J/ψ polarization in Pb–Pb collisions



ALI-PREL-546775



ALI-PREL-546778

Angular distribution suggests a **transverse polarization**

λ_θ value of inclusive J/ψ for $p_T < 0.3$ GeV/c consistent with UPC measurements

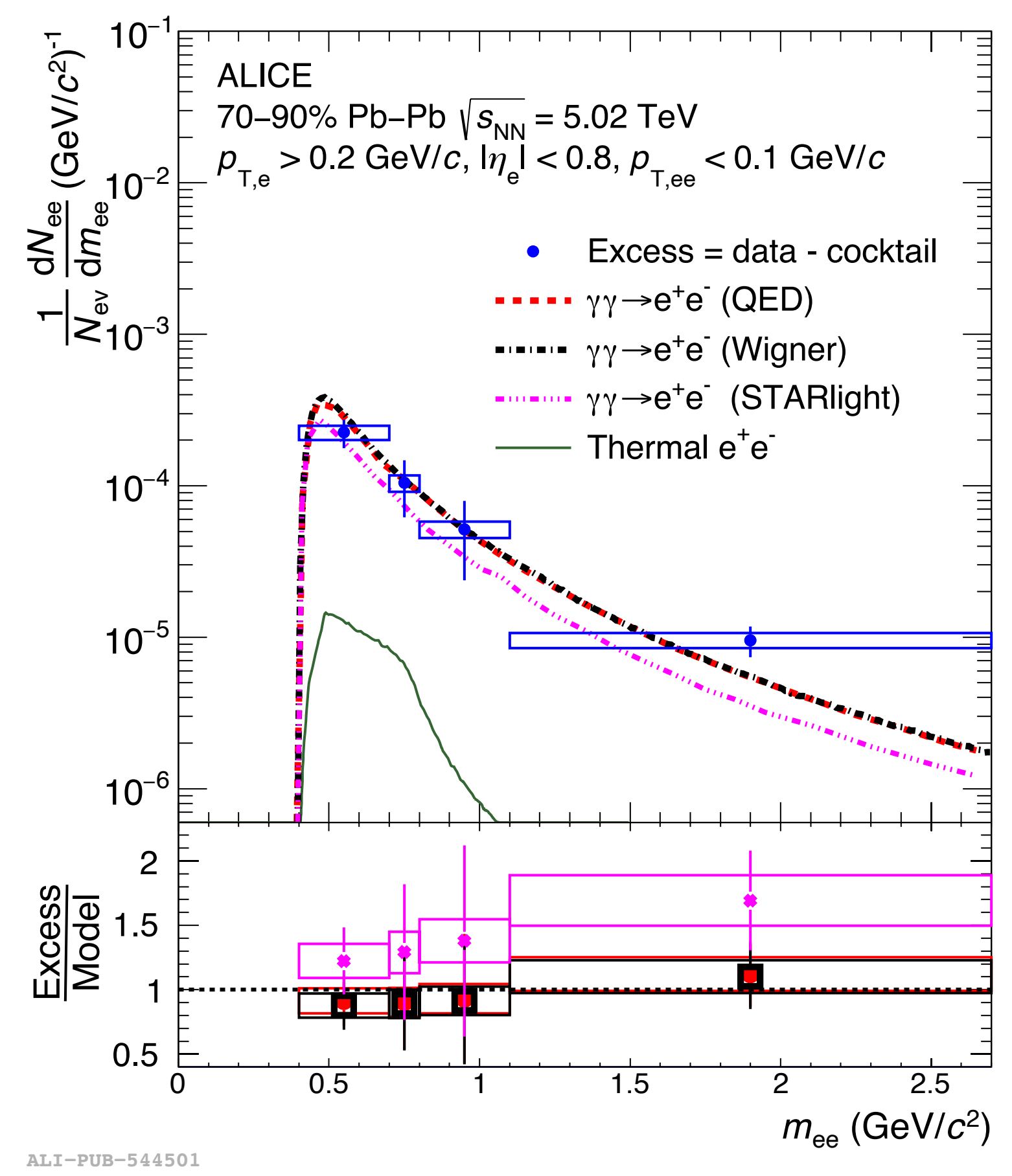
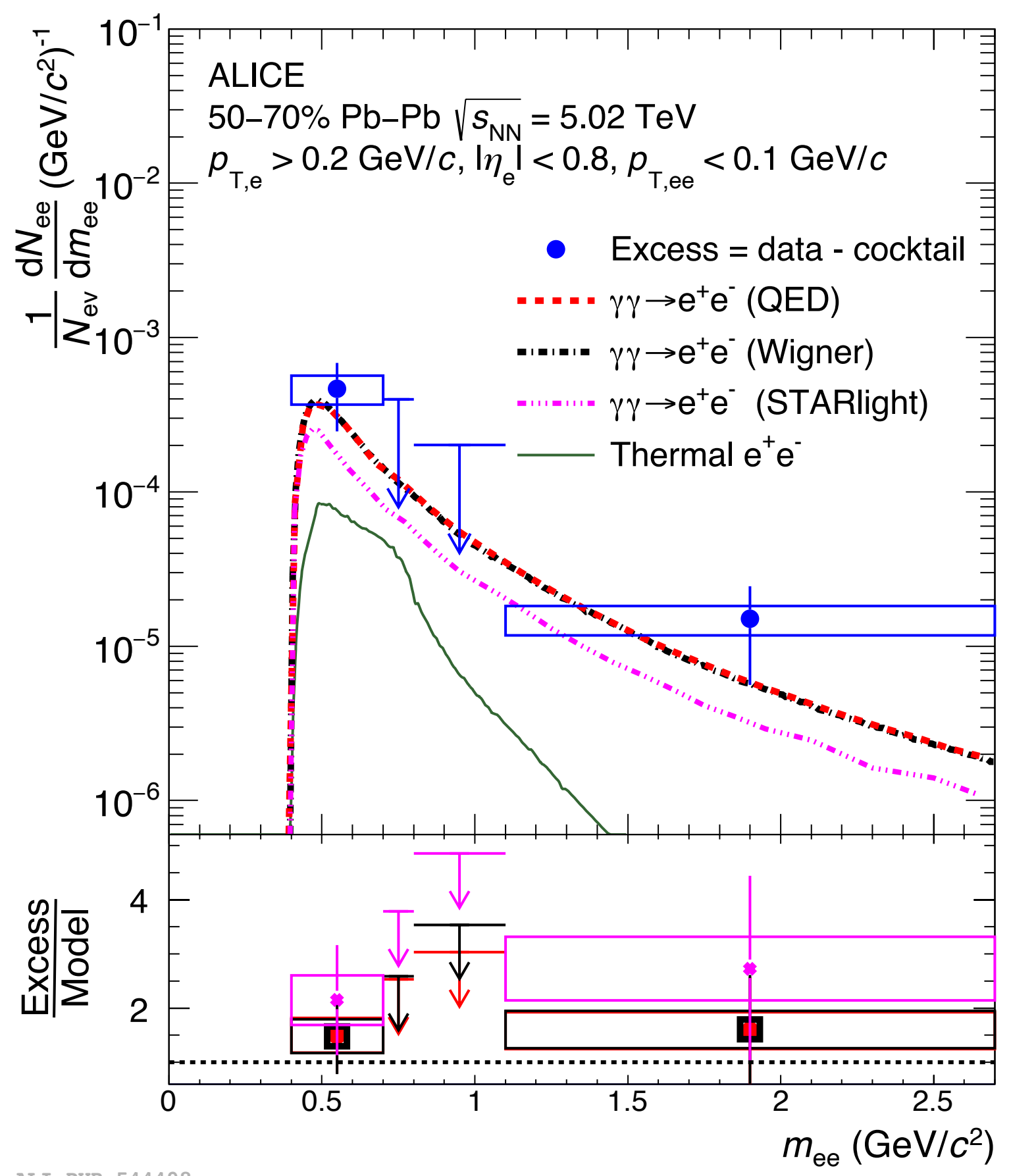
- **Dielectron excess measurement at midrapidity, low $p_{T,ee} < 0.2 \text{ GeV}/c$ and low dielectron invariant mass**
 - Agreement with $\gamma\gamma$ models including impact parameter dependence of the photon k_T distribution
- **y –differential coherently photoproduced J/ψ excess at forward rapidity and low $p_T < 0.3 \text{ GeV}/c$**
 - Comparison with UPC models extended to account for nuclear overlap offers qualitative data description. y –dependence of cross section not well reproduced
- **First J/ψ polarization measurement at forward rapidity**
 - Hint for transverse polarization of inclusive J/ψ for $p_T < 0.3 \text{ GeV}/c$
 - Agreement with expectations from s-channel helicity conservation and with UPC measurement

- **ALICE Run 3 and Run 4 will provide a larger Pb–Pb data sample :**
 - Study J/ψ photoproduction in more central events both at mid and forward rapidity
 - Better precision on cross section and polarization measurements to constrain the models
 - Access excited states like $\psi(2S)$, to look for possible QGP effects on the photoproduced vector meson

Thank you for your attention !

Back up

Dielectron excess in two centrality classes



$p_{T,ee}$ distributions in different invariant mass intervals

