



06-13.07.2022

J/ψ photoproduction and the production of dileptons via photon-photon interactions in hadronic Pb—Pb collisions measured with ALICE

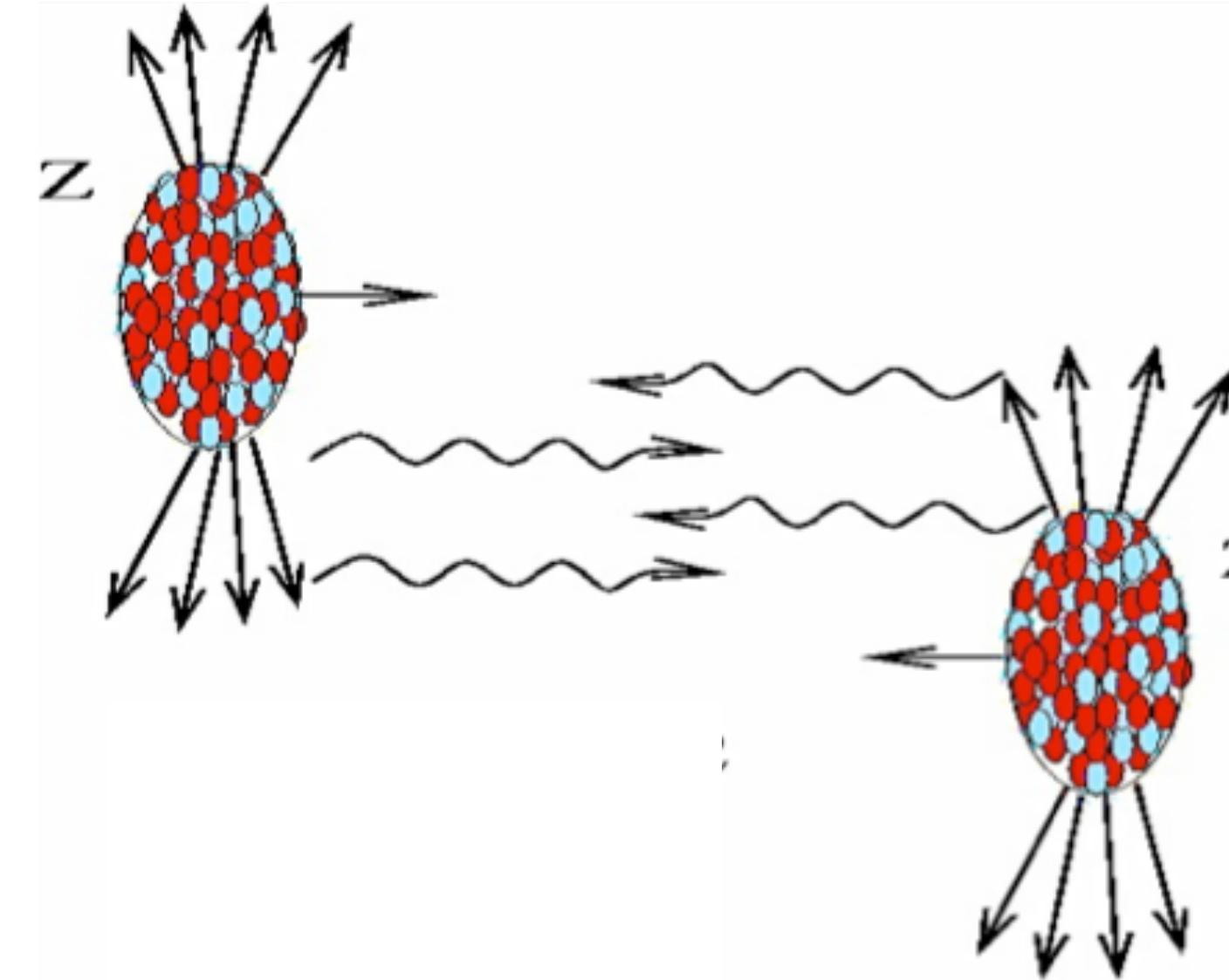
Raphaelle Bailhache on behalf of the ALICE Collaboration



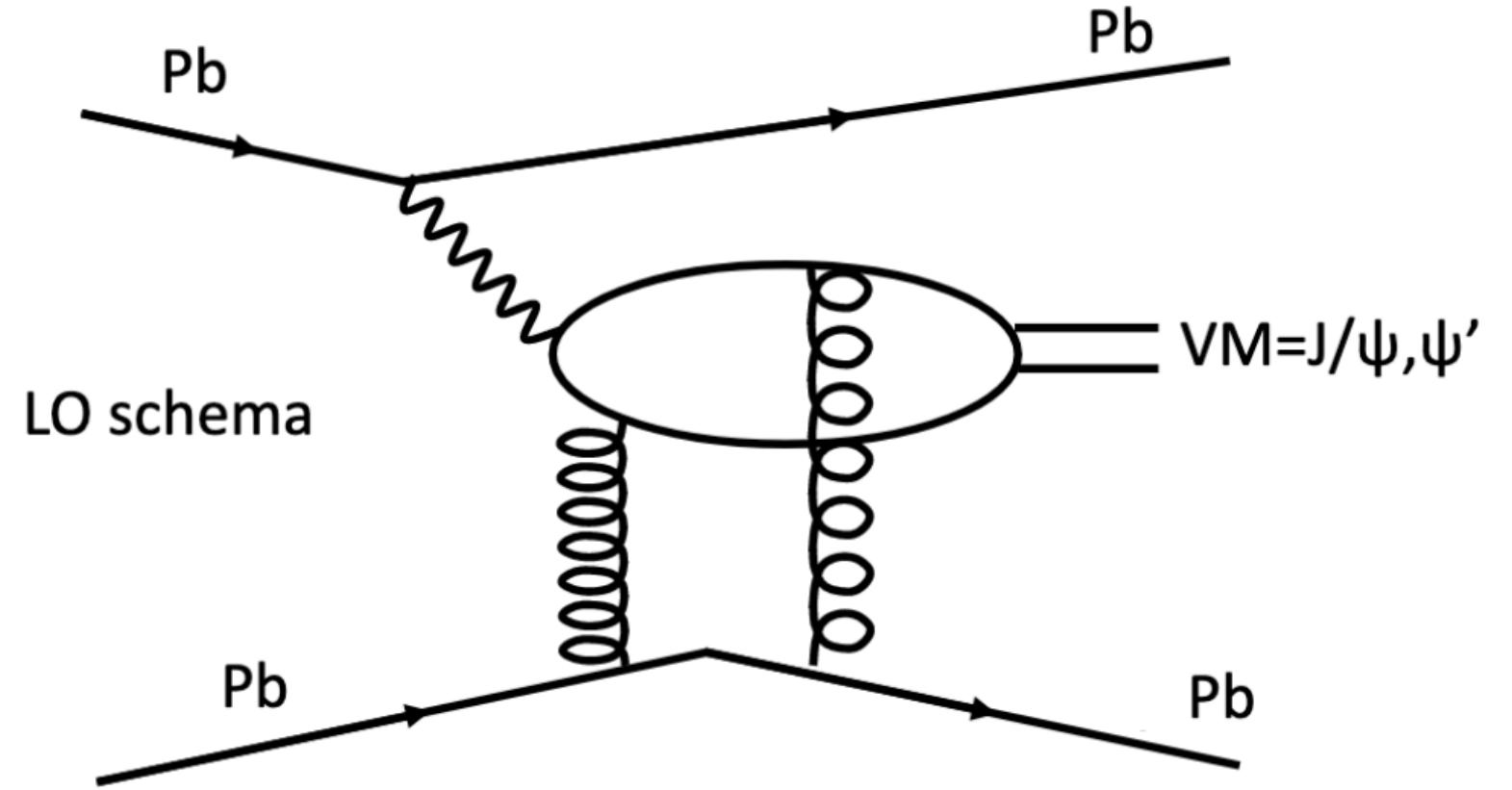
ALICE

Raphaelle Bailhache

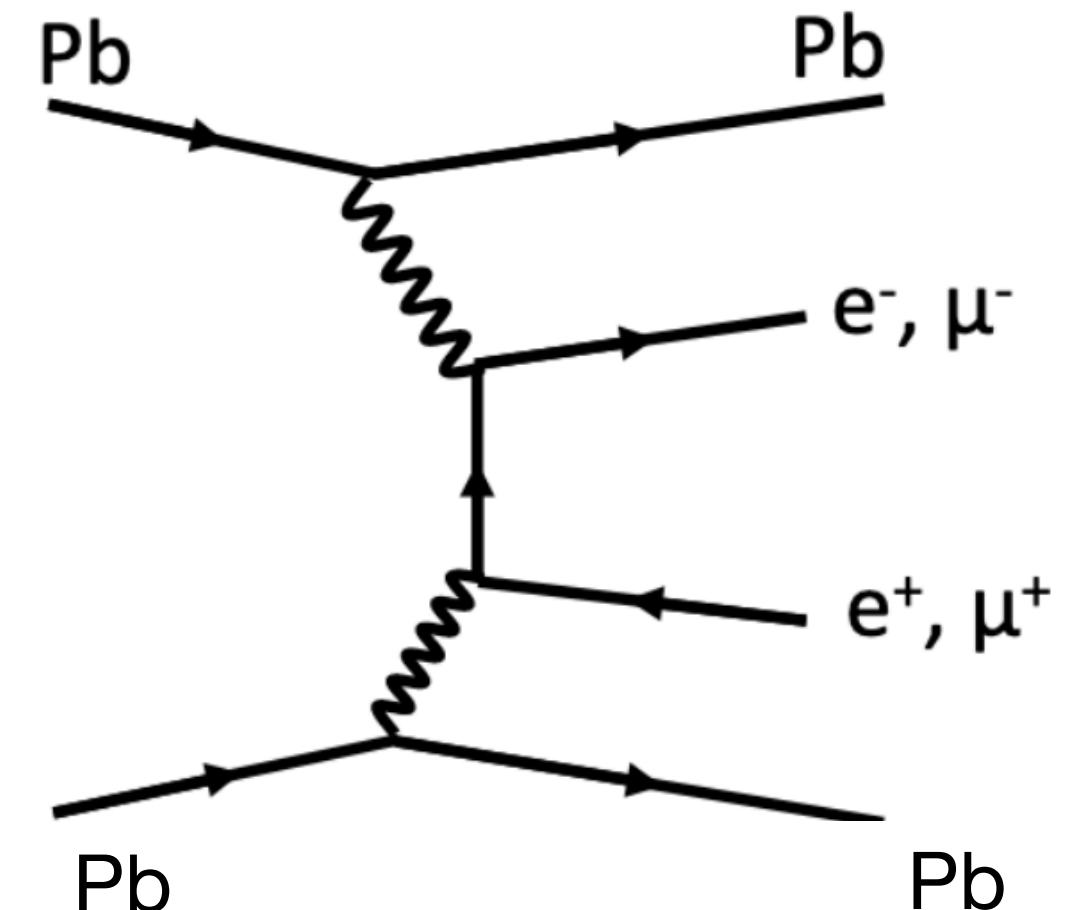
Photon induced processes in heavy-ion collisions



Production of vector mesons

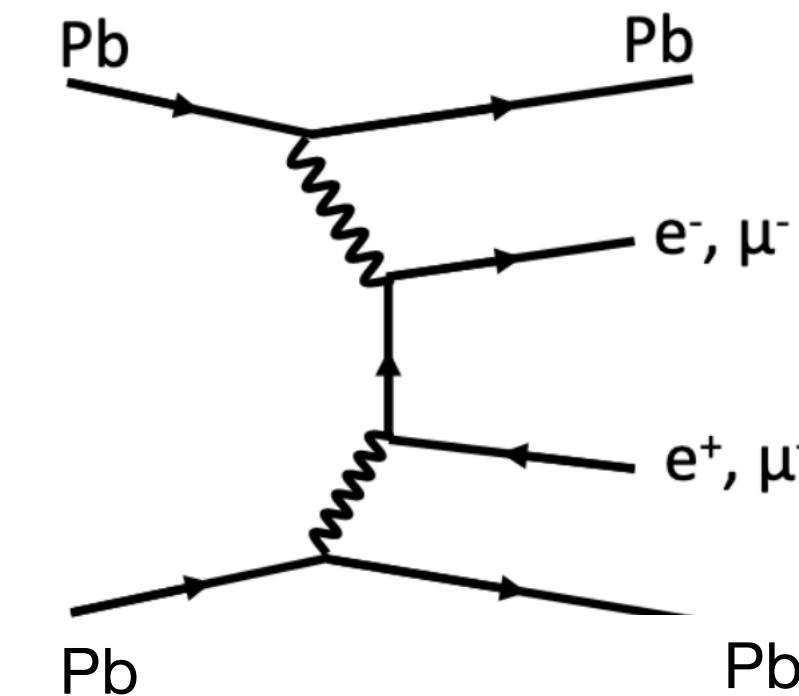


Dilepton production



- **Strong electromagnetic (EM) fields** produced by Lorentz-contracted nuclei
→ **quasi-real photon flux** with coherent strengths (rates) $\propto Z^2$
- Photon-induced reactions **well studied in ultraperipheral collisions (UPC)**:
 - **Production of vector mesons** → Access to gluon distributions in nucleus
 - **Dilepton production via $\gamma\gamma$ interactions** → test QED, map EM field

Dilepton production via $\gamma\gamma$ interaction

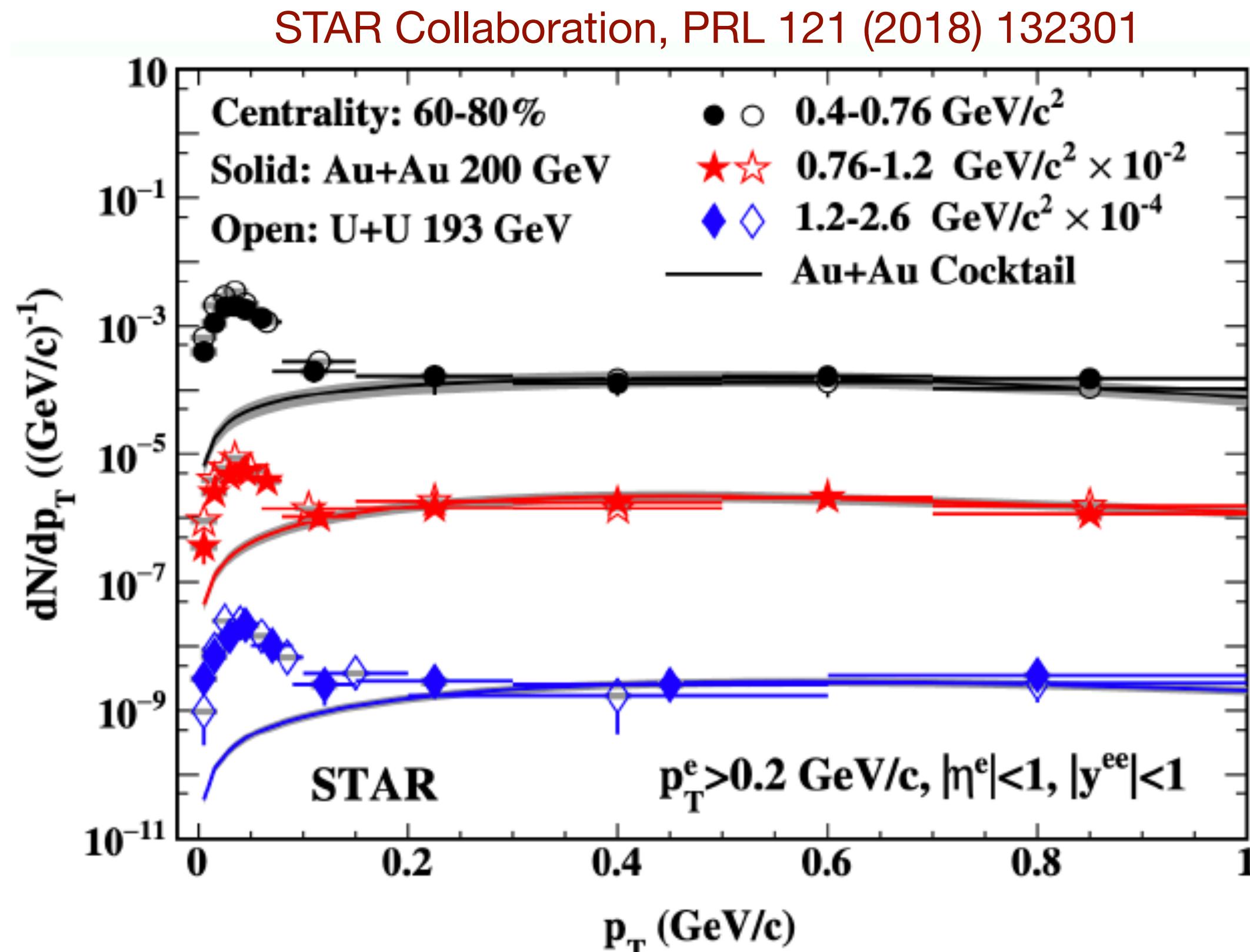


Very low p_T dileptons

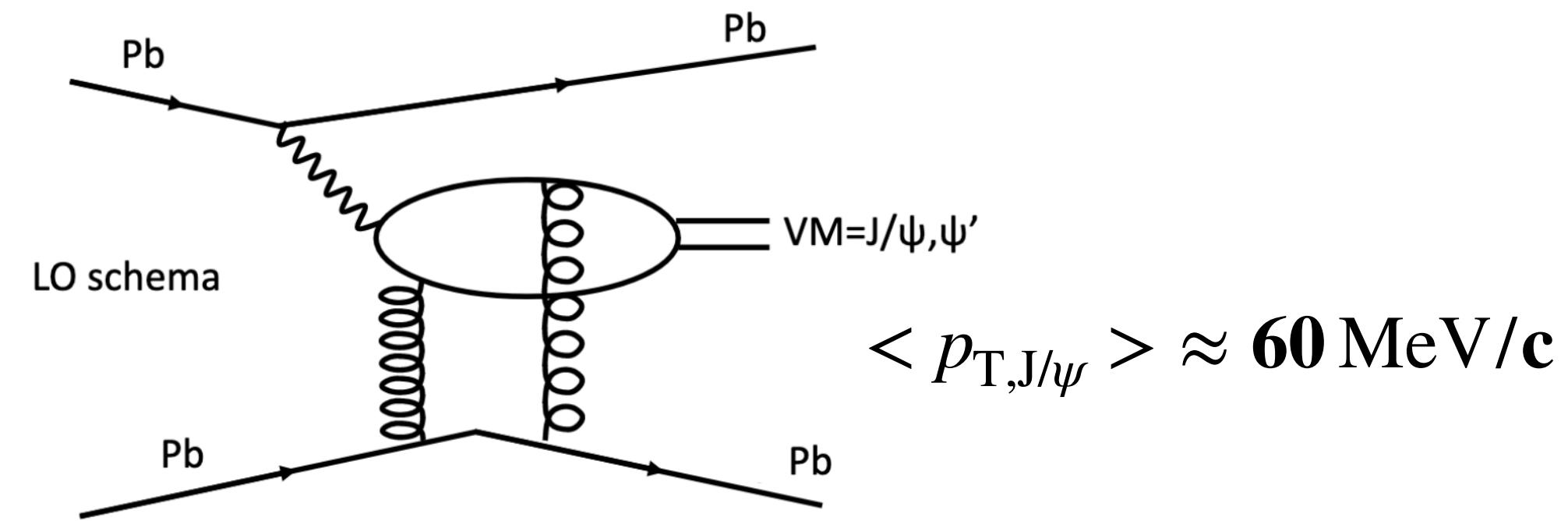
- Measured in heavy-ion collisions with nuclear overlap:
 - RHIC: STAR in peripheral collisions ($0.4 < m_{e^+e^-} < 2.6 \text{ GeV}/c^2$)
 - LHC: ATLAS towards central Pb–Pb collisions ($4 < m_{\mu^+\mu^-} < 45 \text{ GeV}/c^2$)
(PRL 121 (2018) 212301)
- Broadening of pair p_T & acoplanarity ($\alpha = 1 - \frac{|\Delta\varphi|}{\pi}$) increasing in central collisions
- Data reproduced by models including impact parameter dependence of photon transverse momentum without need of hot-medium effects



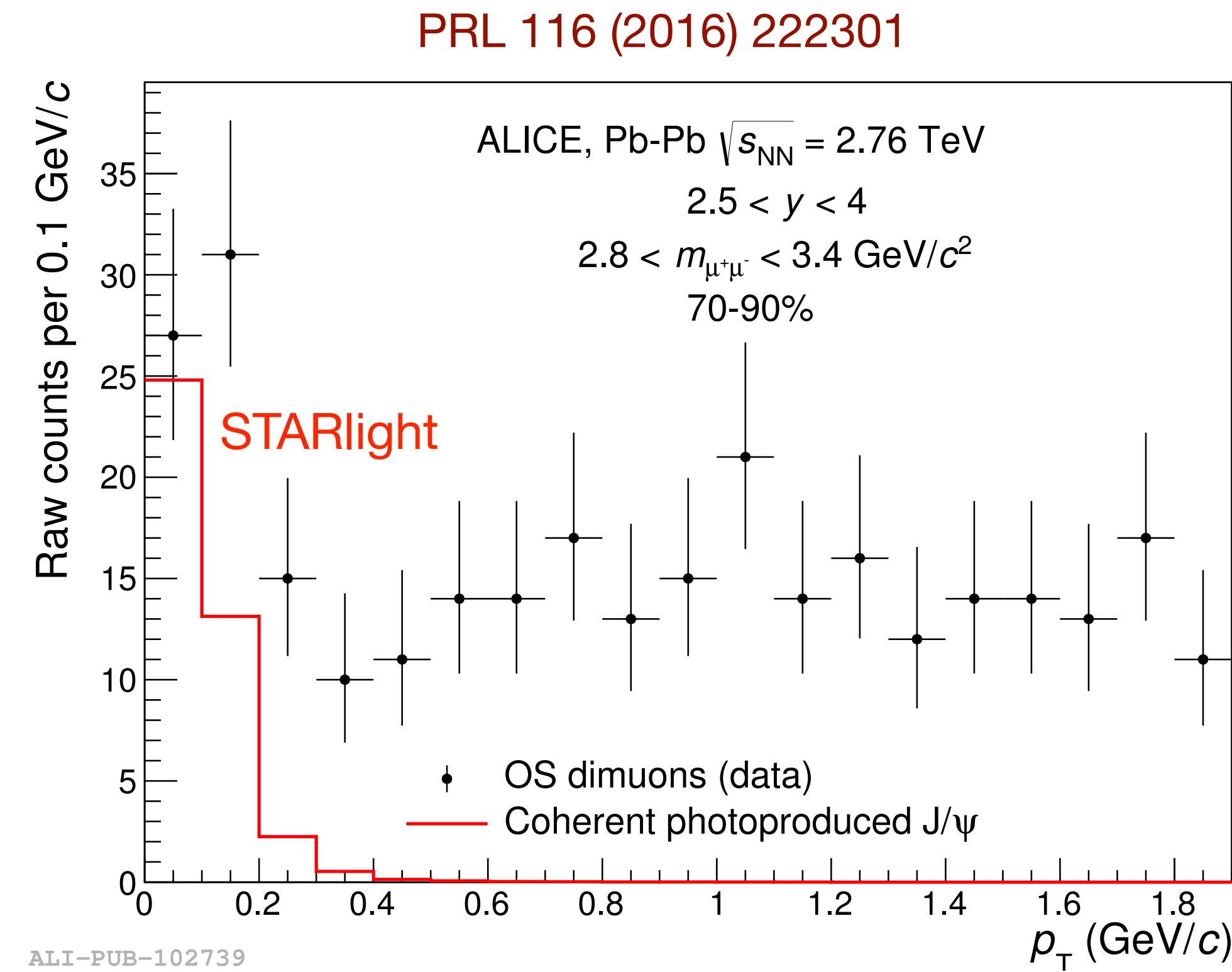
First measurement of very low- p_T e^+e^- for $0.4 < m_{e^+e^-} < 2.7 \text{ GeV}/c^2$
at the LHC in hadronic Pb–Pb collisions



Coherent J/ψ photoproduction



- **Measured in hadronic collisions with nuclear overlap:**
 - By **ALICE** in peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76 \text{ TeV}$
 - By **STAR** in U–U and Au–Au collisions at RHIC (PRL 123 (2019) 132302)
 - By **LHCb** in peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$
(PRC 105 (2022) 3, L032201)
- **Theoretical challenges:** Survival of coherence condition for a broken nucleus, time-ordering of interactions, QGP effects on J/ψ



First p_T -differential measurement at midrapidity in peripheral Pb–Pb collisions
Measurement towards central Pb–Pb collisions at forward rapidity

ALICE apparatus

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

Central barrel:

$$|\eta| < 0.9$$

Low mass dielectrons

$$J/\psi \rightarrow e^+e^-$$

Inner Tracking System:

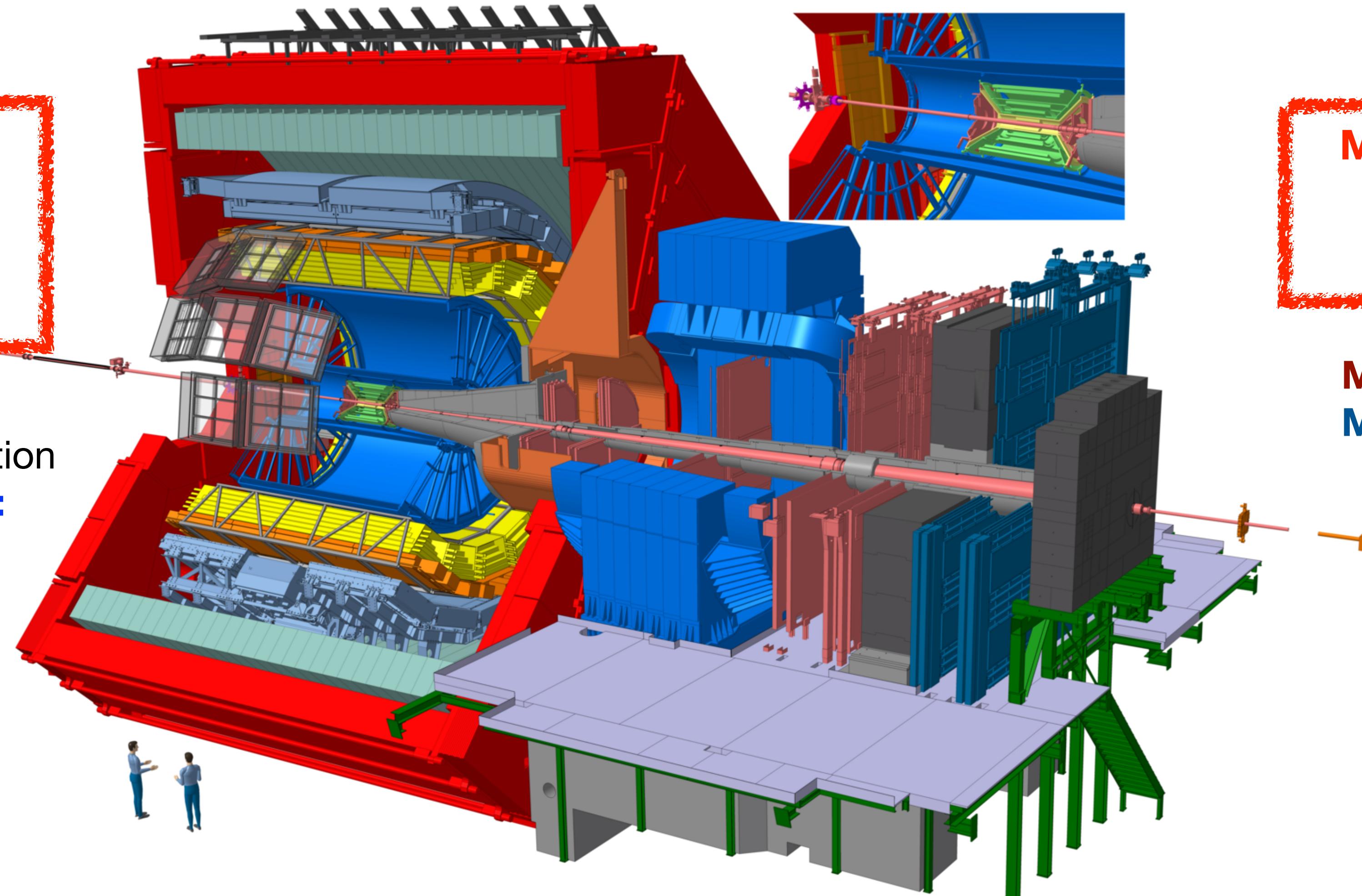
Tracking, vertex reconstruction

Time Projection Chamber:

Tracking, e^\pm identification

Time-Of-Flight detector:

e^\pm identification



Zero Degree Calorimeter: background rejection

V0: triggering, centrality determination, background rejection

Muon spectrometer:

$$2.5 < y < 4$$

$$J/\psi \rightarrow \mu^+\mu^-$$

Muon tracker: Tracking

Muon trigger: Triggering

ALICE apparatus

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

Central barrel:

$$|\eta| < 0.9$$

Low mass dielectrons

$$J/\psi \rightarrow e^+e^-$$

Inner Tracking System:

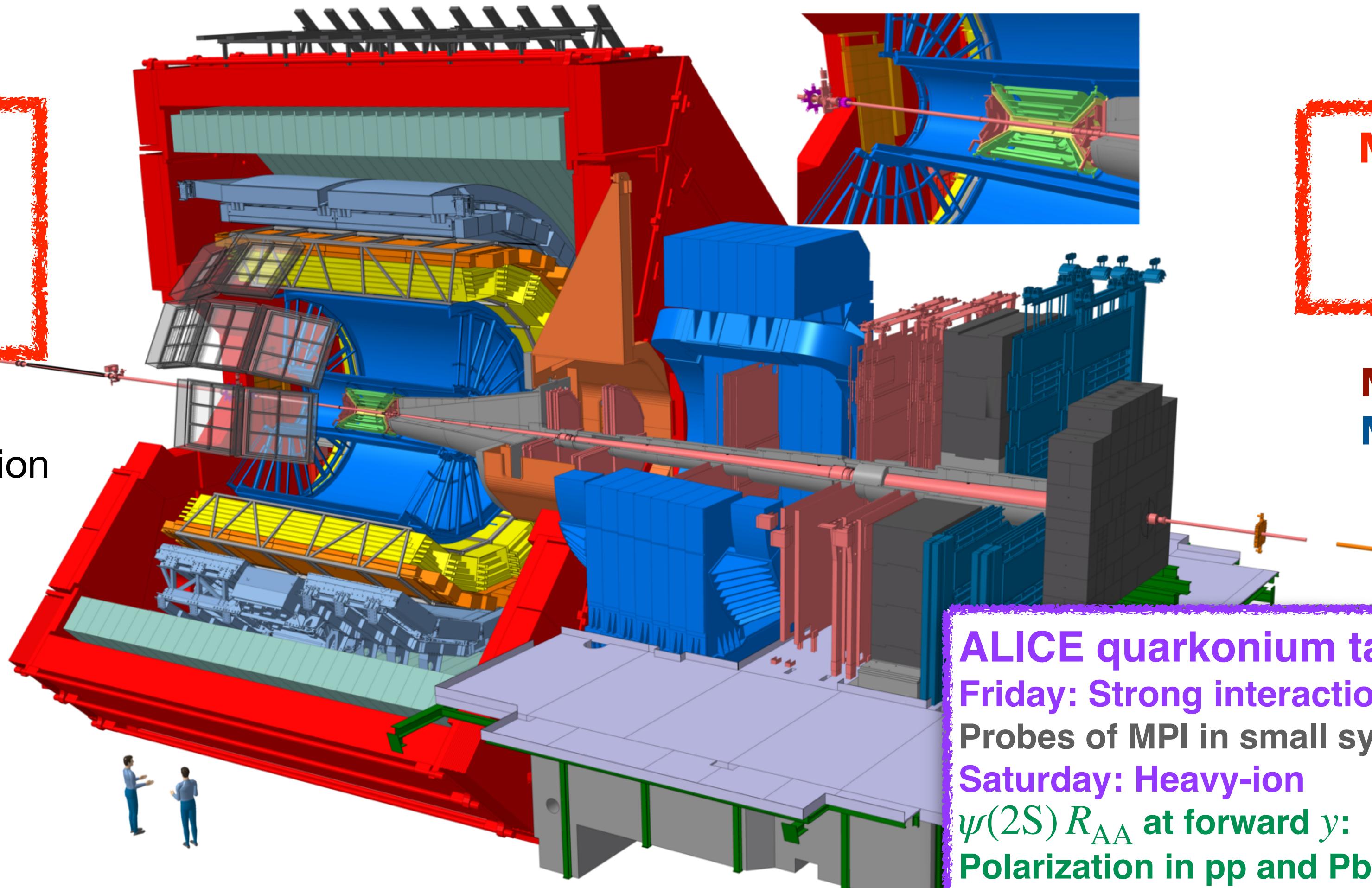
Tracking, vertex reconstruction

Time Projection Chamber:

Tracking, e^\pm identification

Time-Of-Flight detector:

e^\pm identification



Zero Degree Calorimeter: background rejection
V0: triggering, centrality determination, background rejection

ALICE quarkonium talks

Friday: Strong interactions & Hadron Physics

Probes of MPI in small systems: Theraa Tork 18:35

Saturday: Heavy-ion

$\psi(2S) R_{AA}$ at forward y : Biswarup Paul 09:35

Polarization in pp and Pb—Pb: Yanchun Ding 10:10

(non-)Prompt J/ψ at mid y : Himanshu Sharma 12:05

Yield and v_2 in small systems: Maurice Coquet 11:15

$\gamma\gamma \rightarrow e^+e^-$ production in peripheral Pb—Pb collisions

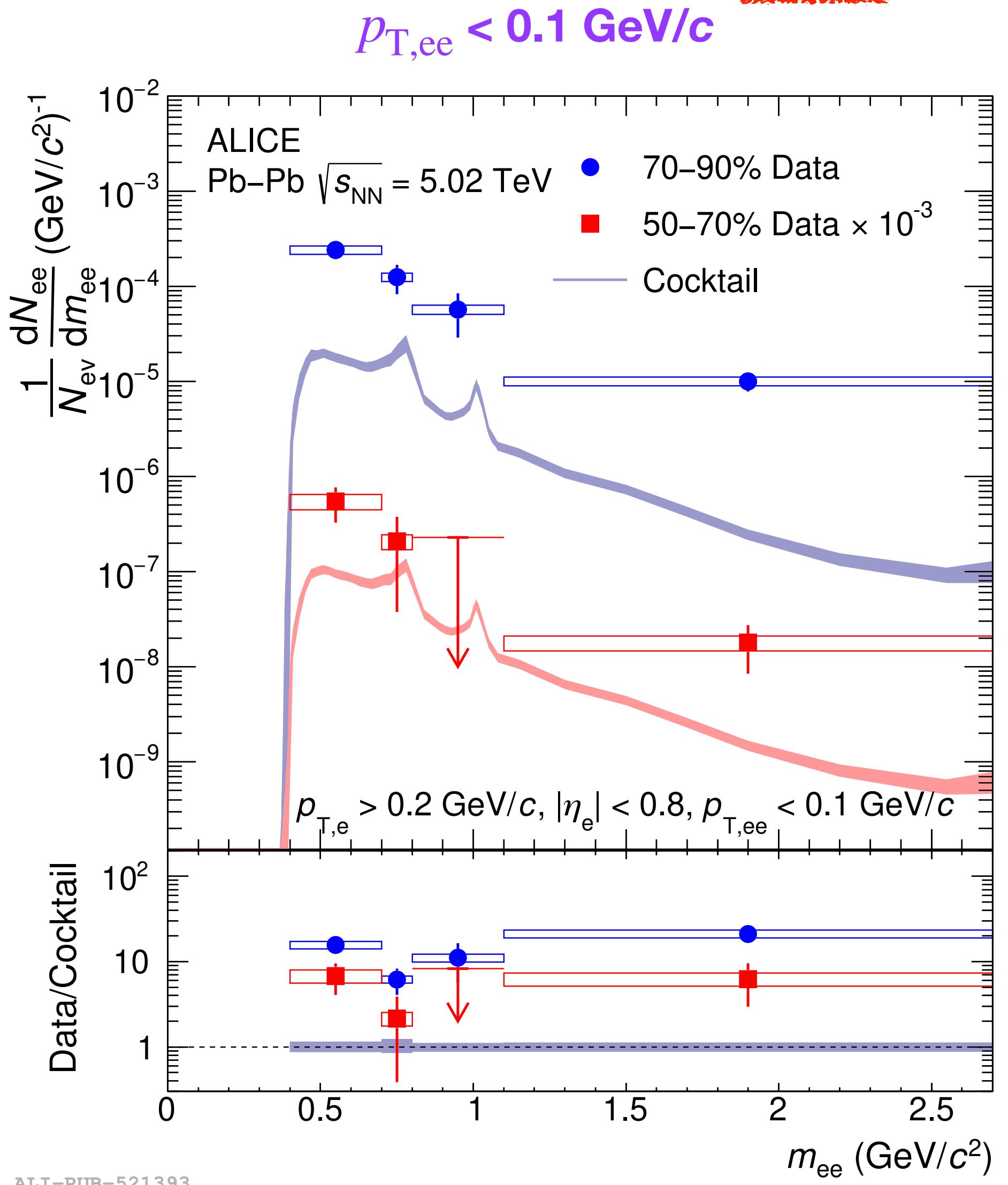


New

arXiv:2204.11732

- First measurement of an e^+e^- excess at very low- $p_{T,ee}$ ($< 0.1 \text{ GeV}/c$) and low m_{ee} ($< 2.7 \text{ GeV}/c^2$) at the LHC
- Data in 50-70% and 70-90% Pb—Pb collisions not described by cocktail of e^+e^- expected from hadronic sources
- Significance of the excess larger in most peripheral events
- Not explained by thermal radiation from the medium (expected one order of magnitude smaller)

Similar observations by STAR at RHIC energies
(PRL 121 (2018) 132301)



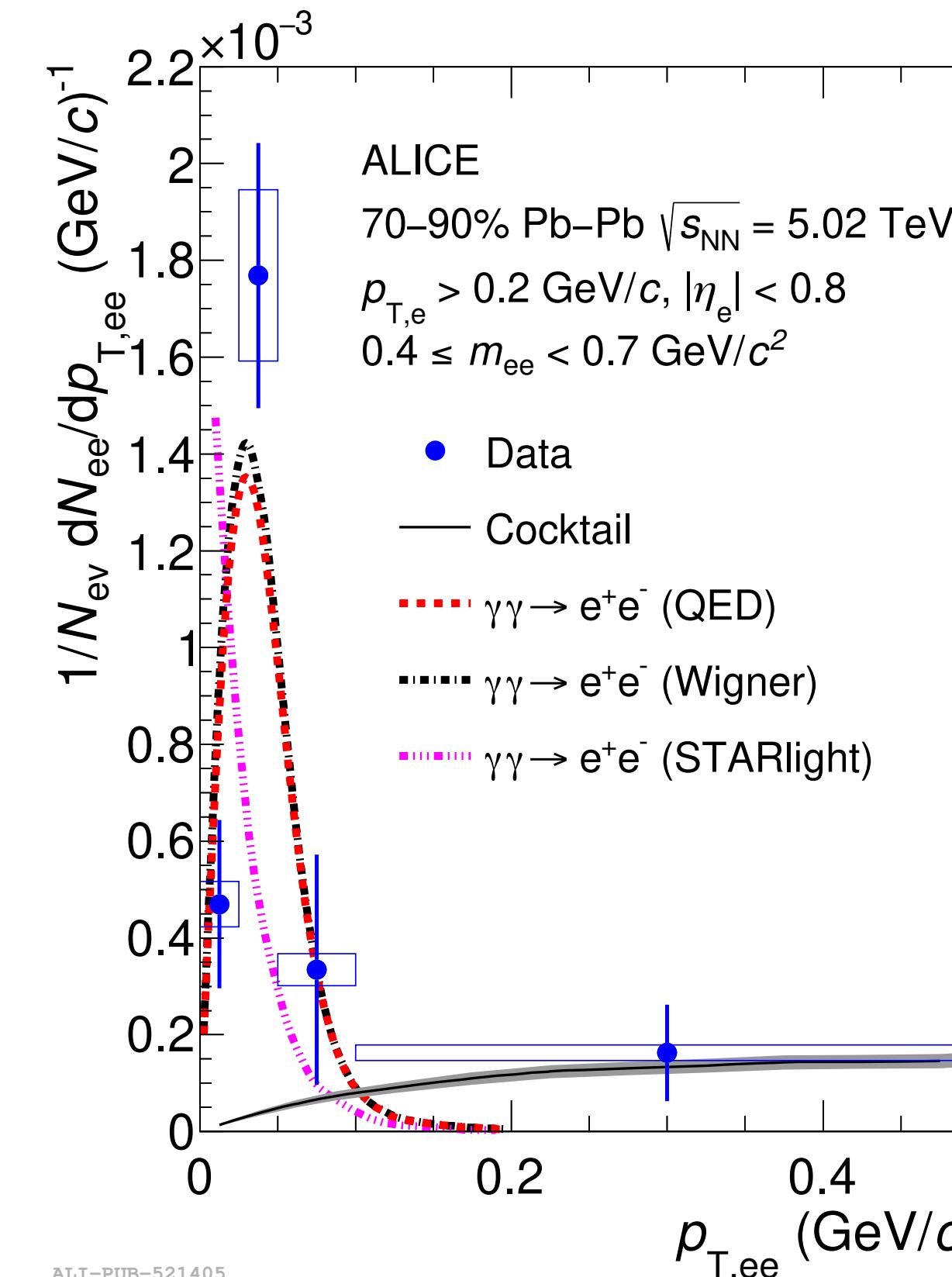
$\gamma\gamma \rightarrow e^+e^-$ production in peripheral Pb—Pb collisions



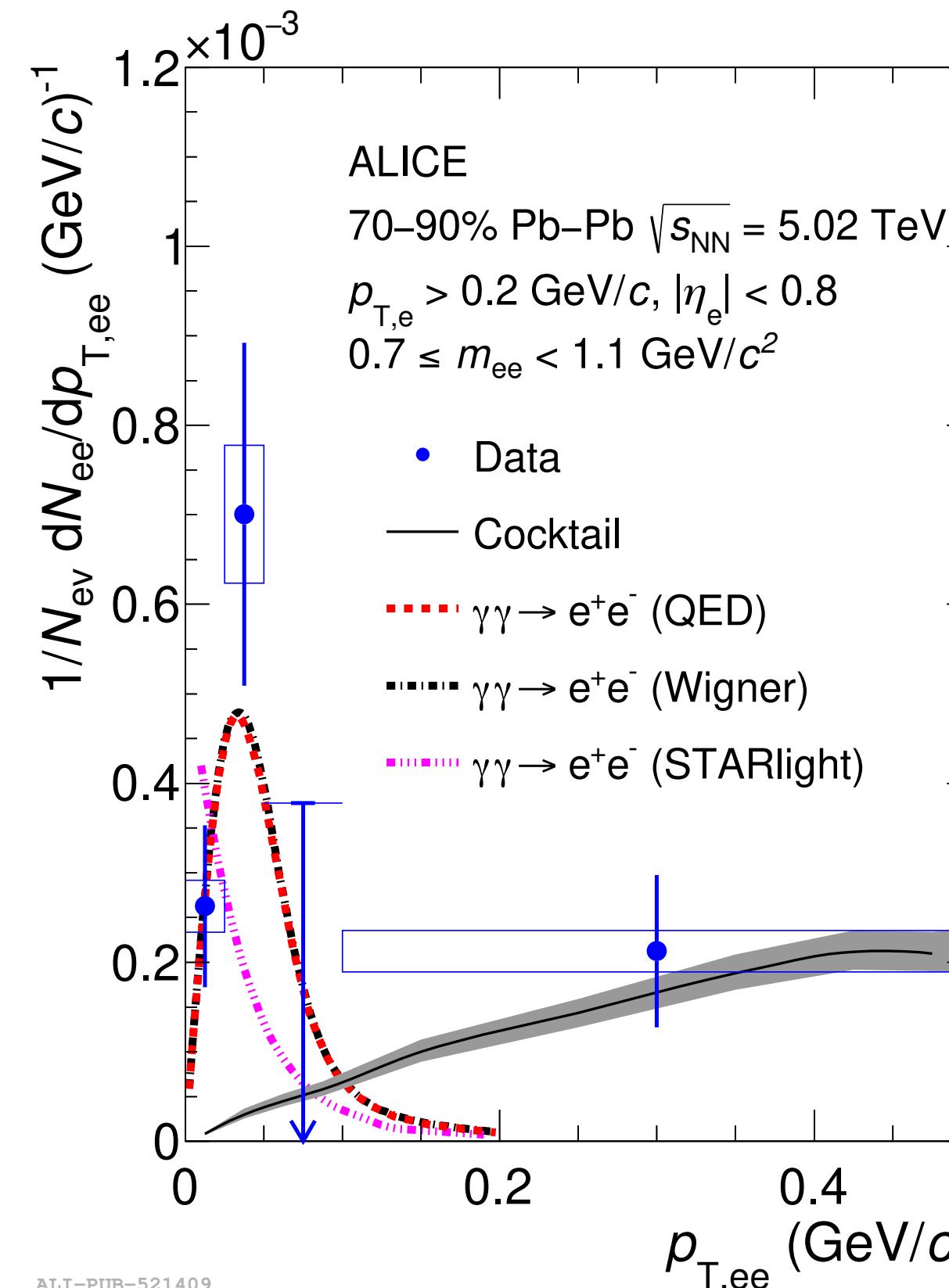
New

arXiv:2204.11732

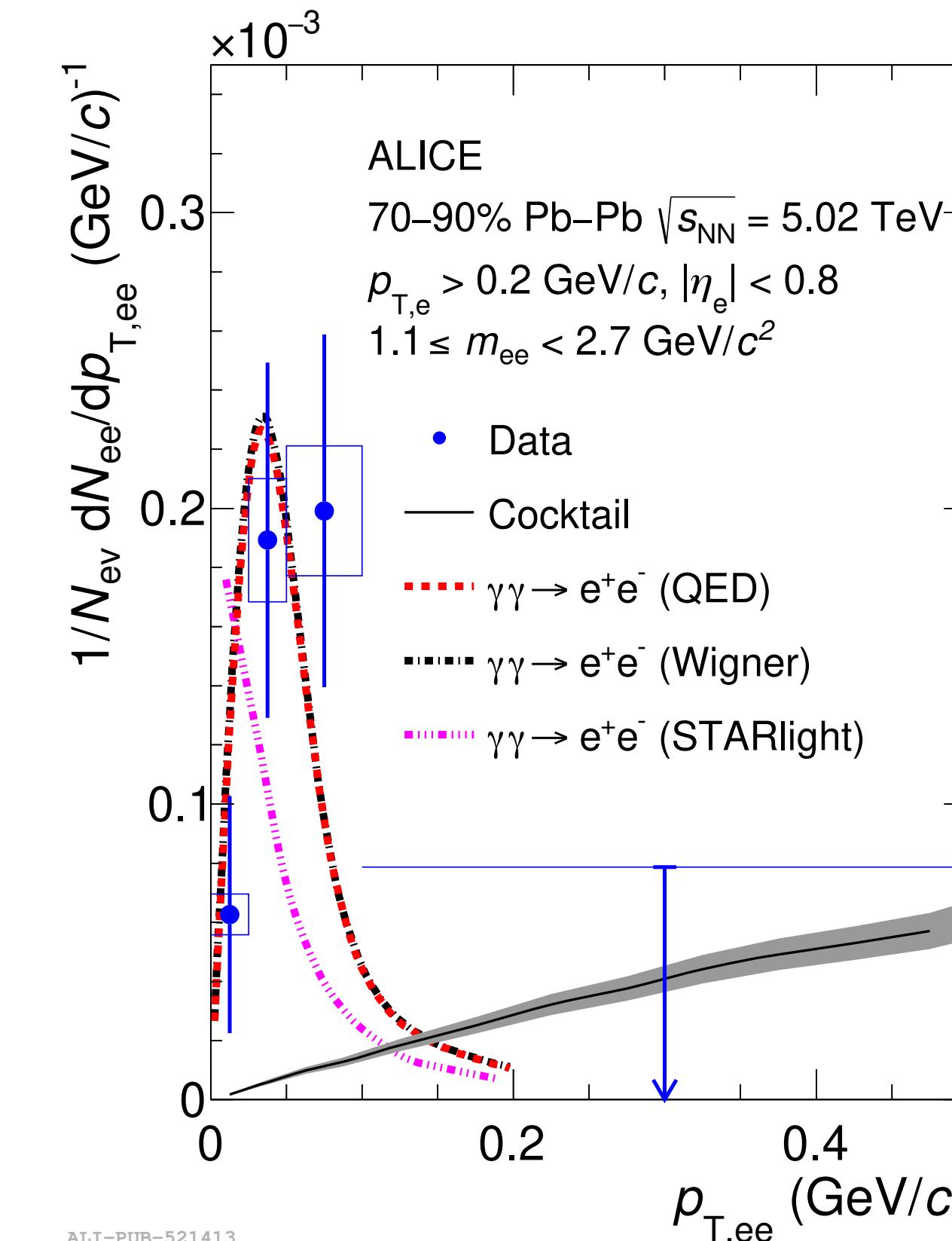
$$0.4 < m_{ee} < 0.7 \text{ GeV}/c^2$$



$$0.7 < m_{ee} < 1.1 \text{ GeV}/c^2$$



$$1.1 < m_{ee} < 2.7 \text{ GeV}/c^2$$



$\gamma\gamma \rightarrow e^+e^-$ predictions:

QED:

W. Zha *et al.*,
PLB 800 (2020) 135089
J. D. Brandenburg *et al.*,
EPJ A 57 (2021) 299

Wigner:

M. Klusek-Gawenda *et al.*,
PLB 814 (2021) 136114

STARlight:

S.R. Klein *et al.*,
CPC 212 (2017) 258
S.R. Klein,
PRC 97 (2018) 054903

- Peak observed at low $p_{T,ee}$ in 70–90% peripheral Pb—Pb collisions
- Data described by **QED & Wigner predictions with impact parameter (b) dependence of γ transverse momentum**
- **STARLIGHT** ($p_{T,ee}$ shape independent of b) disfavoured by the data

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

Midrapidity

New

- p_T -differential cross section

- Current theoretical approach of the models:

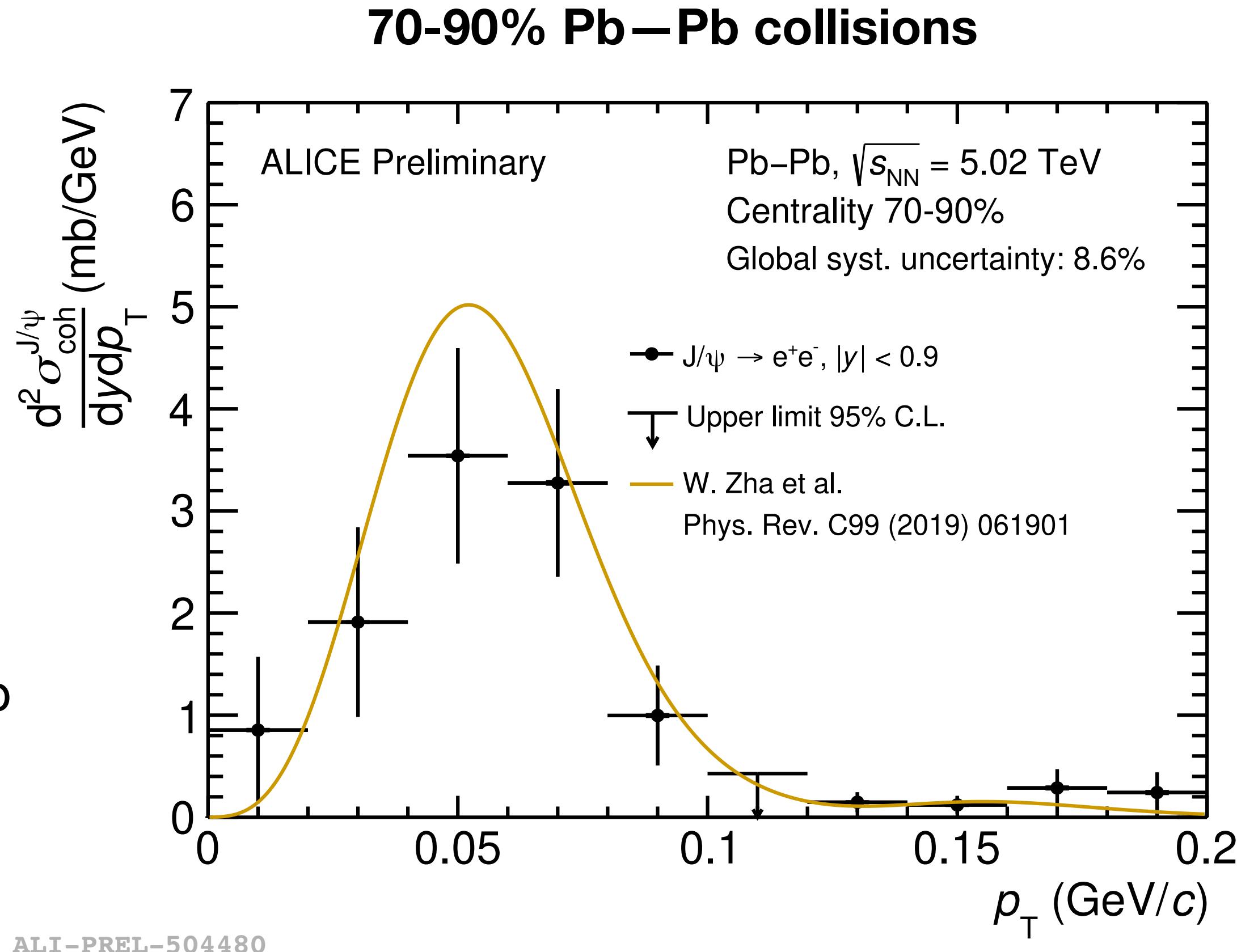
$$\frac{d\sigma_{\text{coherent } J/\psi}}{dy} = n_{\gamma,1} \times \sigma_{\gamma_1 + \text{Pb}_2 \rightarrow J/\psi + \text{Pb}_2} + n_{\gamma,2} \times \sigma_{\gamma_2 + \text{Pb}_1 \rightarrow J/\psi + \text{Pb}_1}$$

Photon flux Photonuclear cross section (QCD!)

With respect to UPC calculations:

Modified γ flux and/or modified $\sigma_{\gamma + \text{Pb} \rightarrow J/\psi + \text{Pb}}$ to account for overlap

- Data reproduced by a model with modified γ flux and $\sigma_{\gamma + \text{Pb} \rightarrow J/\psi + \text{Pb}}$
(Impact of overlap however limited in peripheral collisions)



W. Zha et al., PRC 99 (2019) 061901

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

Midrapidity

New

- p_T -differential cross section

- Current theoretical approach of the models:

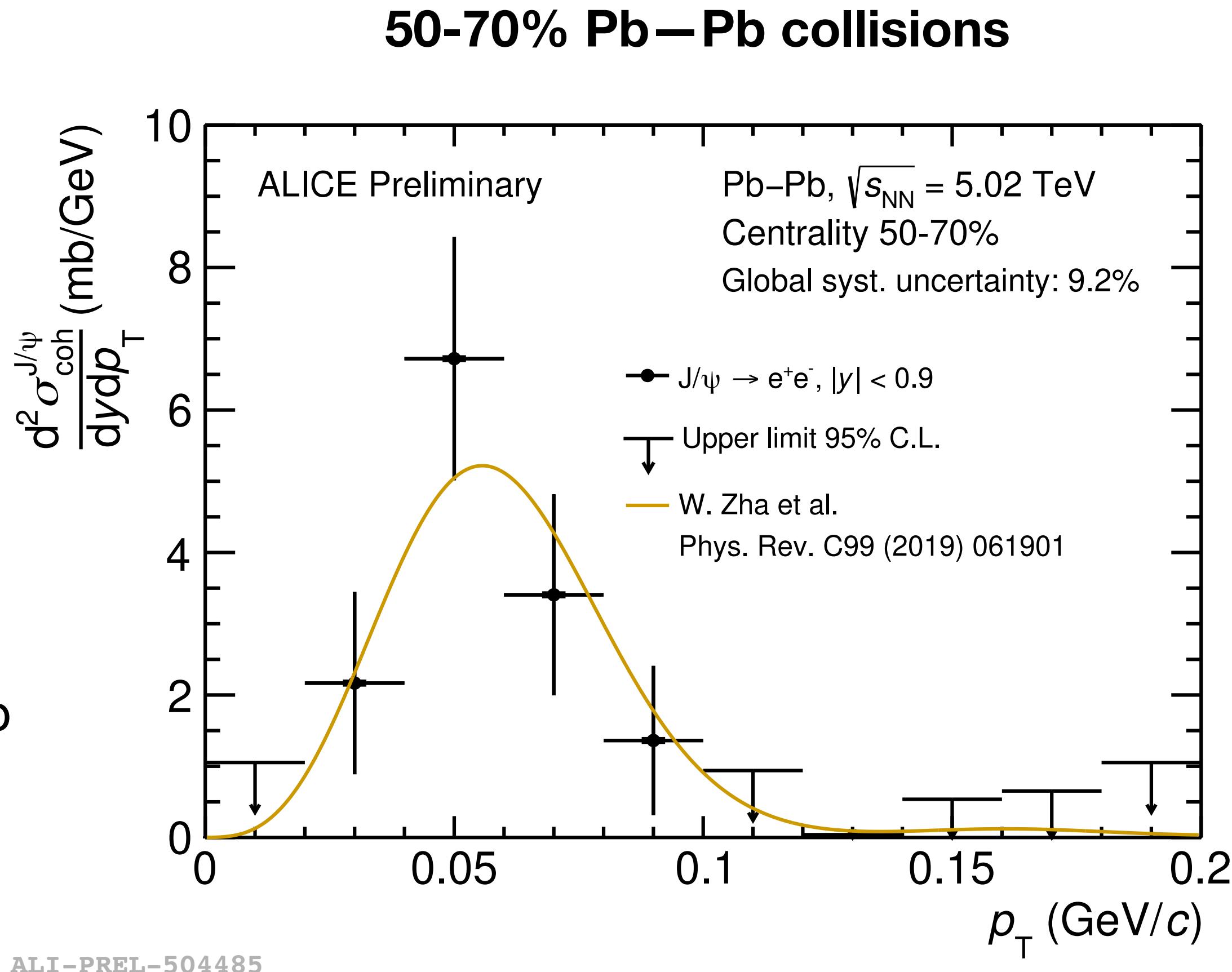
$$\frac{d\sigma_{\text{coherent } J/\psi}}{dy} = n_{\gamma,1} \times \sigma_{\gamma_1 + \text{Pb}_2 \rightarrow J/\psi + \text{Pb}_2} + n_{\gamma,2} \times \sigma_{\gamma_2 + \text{Pb}_1 \rightarrow J/\psi + \text{Pb}_1}$$

Photon flux Photonuclear cross section (QCD!)

With respect to UPC calculations:

Modified γ flux and/or modified $\sigma_{\gamma + \text{Pb} \rightarrow J/\psi + \text{Pb}}$ to account for overlap

- Data reproduced by a model with modified γ flux and $\sigma_{\gamma + \text{Pb} \rightarrow J/\psi + \text{Pb}}$
(Impact of overlap however limited in peripheral collisions)



W. Zha et al., PRC 99 (2019) 061901

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

Forward rapidity

arXiv:2204.10684

$2.5 < y < 4$

New

- **Centrality dependence**
- Significance of the measurement $> 5 \sigma$ in 30-50%
- Semi-central data **described by models with**
 - Either a **modified γ flux (VDM)**
 - Or a **modified γ flux + $\sigma_{\gamma+\text{Pb} \rightarrow J/\psi+\text{Pb}}$ (IIM/GBW S3)**

GG-hs: J. Cepila *et al.*, PRC 97 (2018) 024901

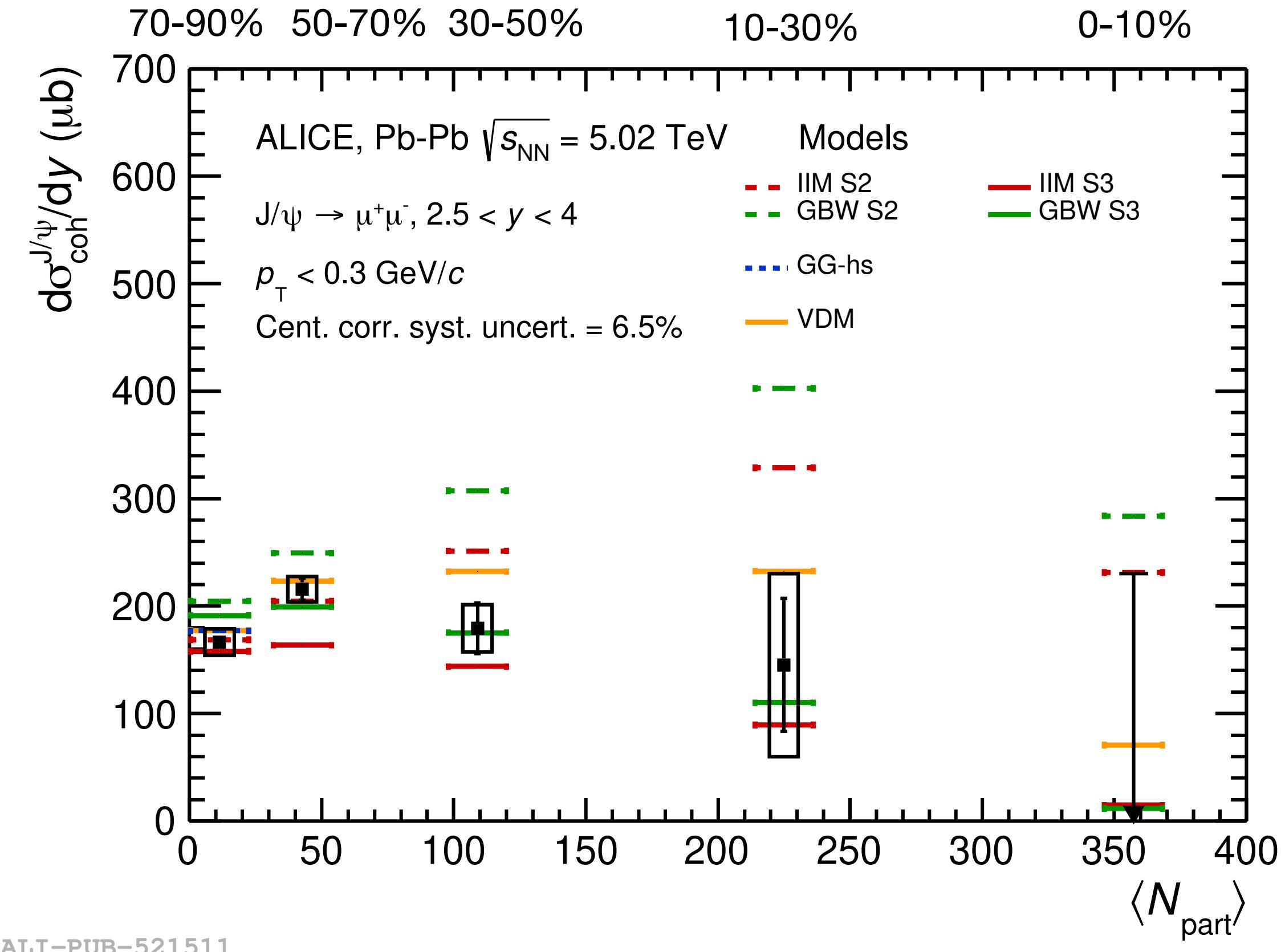
- γ flux with constraints on impact parameter range

VDM: M. Klusek-Gawenda *et al.*, PLB 790 (2019) 339

- γ reaching the overlap region not considered in γ flux [fixed area]

IIM/GBW: M. Gay Ducati *et al.*, PRD 97 (2018) 116013

- γ reaching the overlap region not considered in γ flux [b-dependent area]
 - S2: no modification of $\sigma_{\gamma+\text{Pb} \rightarrow J/\psi+\text{Pb}}$
 - S3: overlap not considered in $\sigma_{\gamma+\text{Pb} \rightarrow J/\psi+\text{Pb}}$ computation



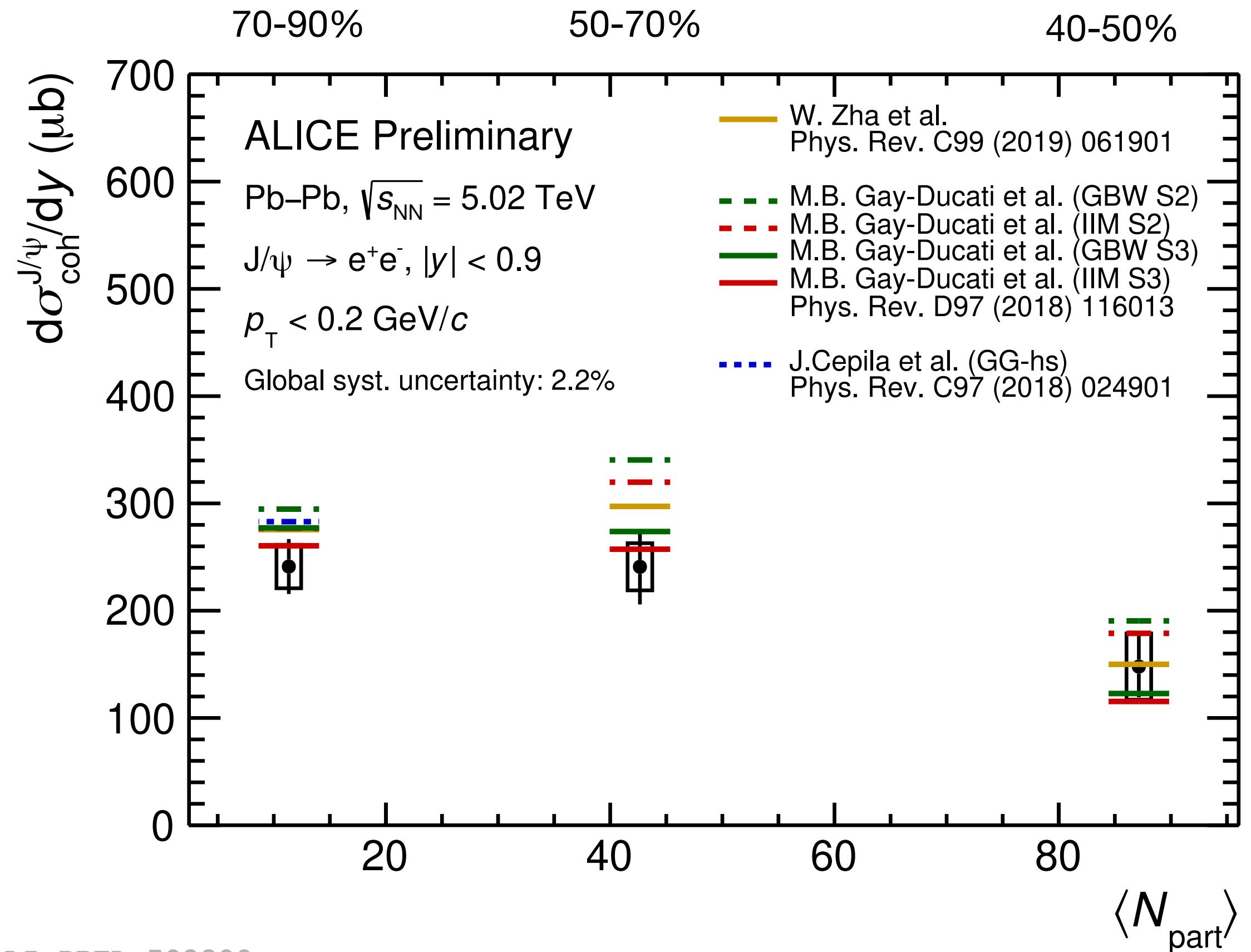
ALI-PUB-521511

Caveat: No normalisation to the centrality interval width !

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

Forward and mid y

$$|y| < 0.9$$

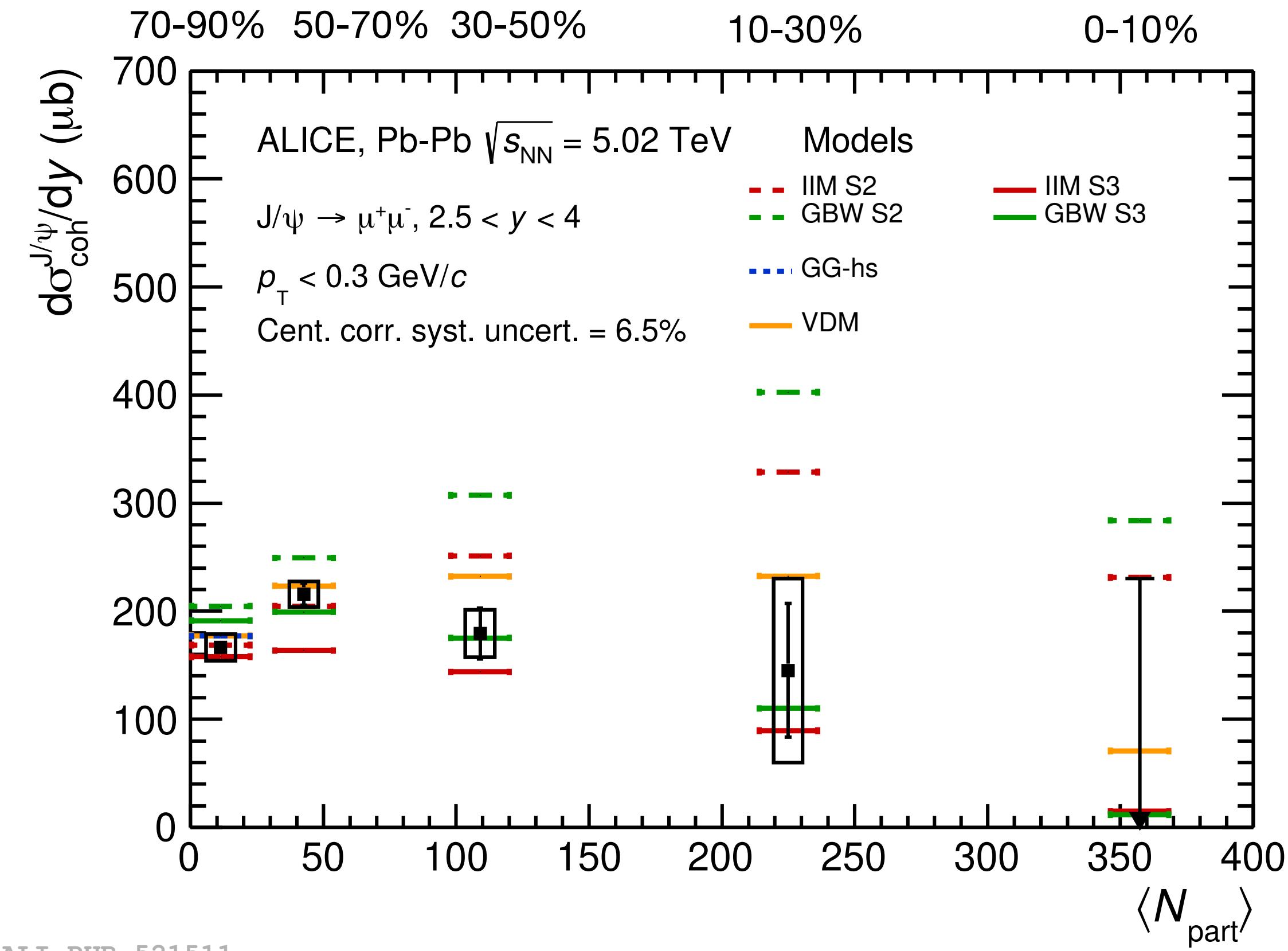


ALI-PREL-503800

arXiv:2204.10684

$$2.5 < y < 4$$

New



ALI-PUB-521511

- Same models (GG-hs, IIM/GBW S3) reproduce the order of magnitude of the cross section at mid and forward y
- Hint for larger J/ψ photoproduction cross section at midrapidity than at forward rapidity.

Coherent J/ψ photoproduction in peripheral collisions and UPC

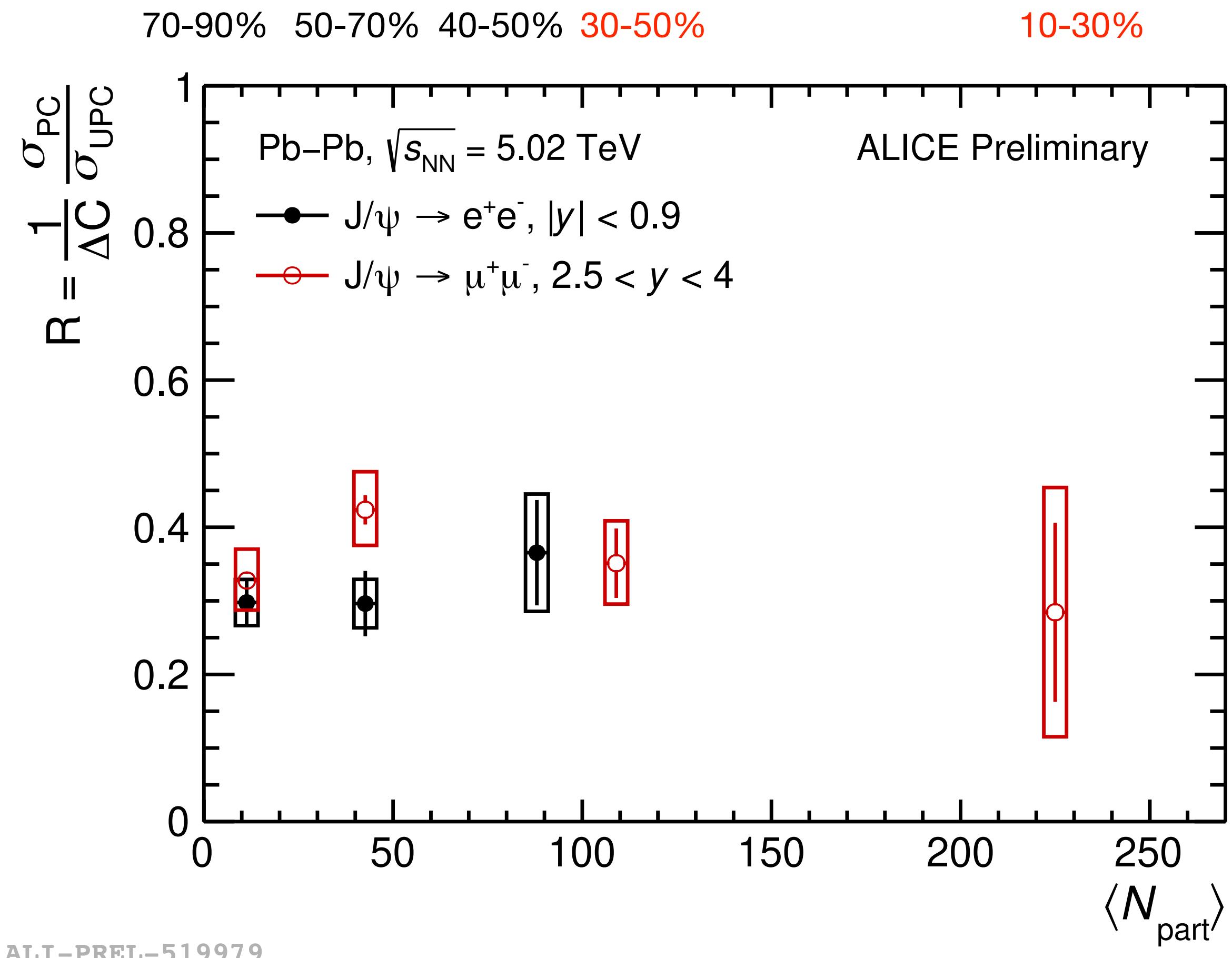
New

Forward and mid y

PC: arXiv:2204.10684

UPC: EPJC 81 (2021) 712, PLB 98 (2019) 134926

- Cross sections **in Pb–Pb collisions with nuclear overlap (σ_{PC}) and UPCs (σ_{UPC})**
- Similar ratios at **mid** and **forward** rapidity
- Ratio flat with centrality
 \rightarrow **No evidence for a decrease of σ_{PC} because of the overlap or medium effects**



ΔC : width of the centrality interval

Summary

- **First measurement of $\gamma\gamma \rightarrow e^+e^-$ production at the LHC for $0.4 < m_{ee} < 2.7 \text{ GeV}/c^2$ in Pb—Pb collisions**
 - Reproduced by models including impact parameter dependence of the photon transverse momentum
- **Coherently photoproduced J/ψ :**
 - Measured up to 10-30% central Pb—Pb collisions at forward y (upper limit for 0-10%)**
 - First p_T -differential measurement at mid y**
 - Data described by UPC-like models including modified γ flux and/or $\sigma_{\gamma+\text{Pb} \rightarrow J/\psi+\text{Pb}}$ accounting for nuclear overlap

Outlook

Target luminosity for Run 3 + 4 $L_{\text{int}} \approx 13 \text{ nb}^{-1}$

- **Dileptons from $\gamma\gamma$ interaction:**
 - High precision measurement of $p_{T,\text{ee}}$ & acoplanarity
 - Differential measurement as a function of event plane or rapidity gap between e^+ and e^-
- **Coherently photoproduced J/ψ :**
 - Significant signal at both mid and forward y in central events
 - Precise p_T -differential cross section at mid y
 - New observables: polarisation, flow, y -differential cross section, and other quarkonium states

Preparation of ALICE for LHC Run 3
Robert Munzer Jul 8, 2022, 9:00 AM

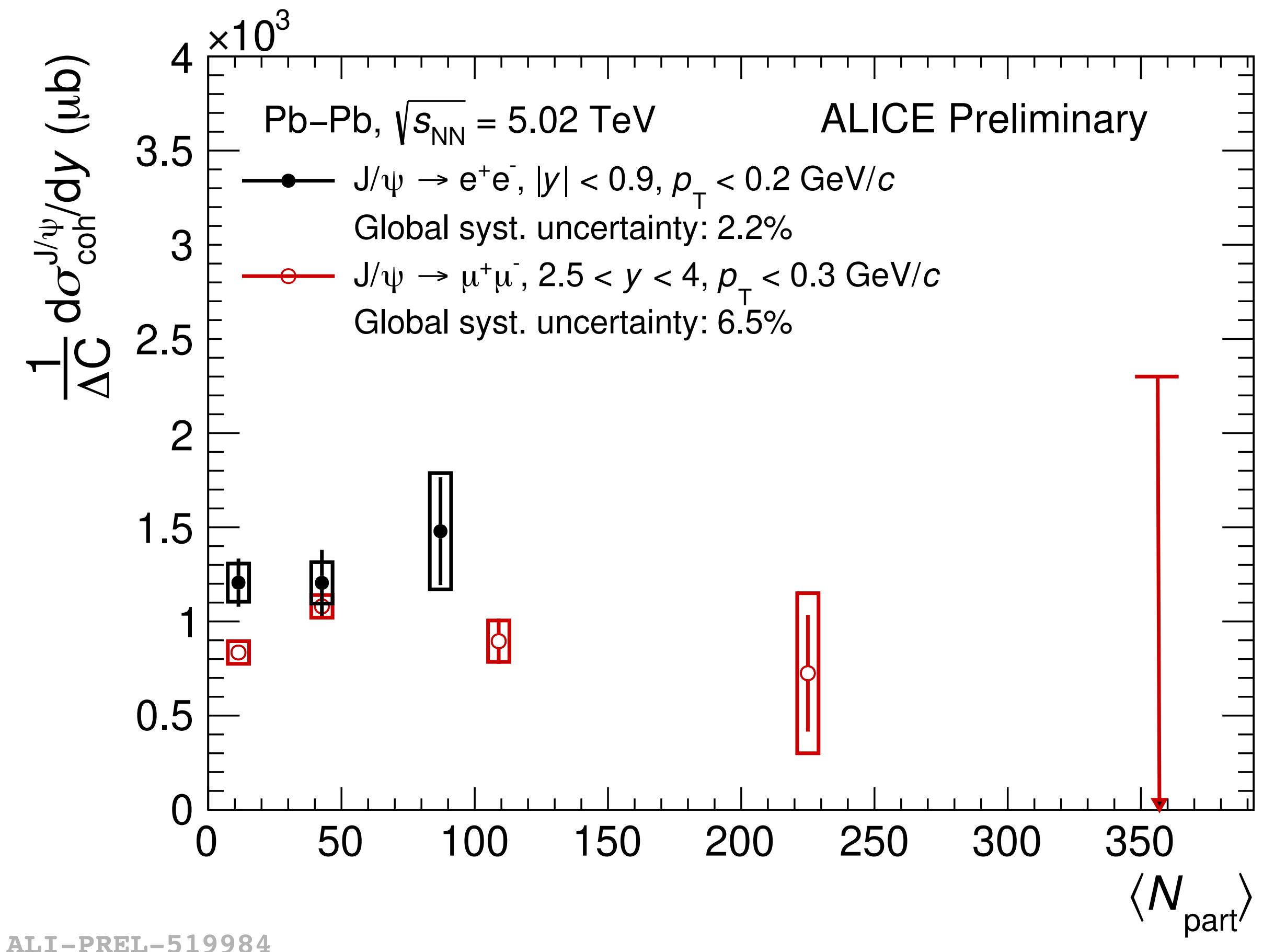
Physics performance of ALICE in LHC Run 3
Aimeric Landou Jul 8, 2022, 9:18 AM

Back-up

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

Forward and mid y

New



ΔC : width of the centrality interval

Photon flux

Photon flux modified considering only:

- **I:** γ s that reach the geometrical region of the target-nuclei
- **II:** γ s that reach the overlap region are not considered

$$N^{eff}(\omega, b) = \frac{1}{A_{eff}(b)} \int d^2 b_1 N(\omega, b_1) \theta(R_A - b_2) \theta(b_1 - R_A)$$

Difference between VDM and IIM/GBW is $A_{eff}(b)$:

- In **VDM** $A_{eff}(b)$ is replaced by πR_a^2
- In **IIM/GBW** $A_{eff}(b)$ corresponds to the grey area (after I and II)

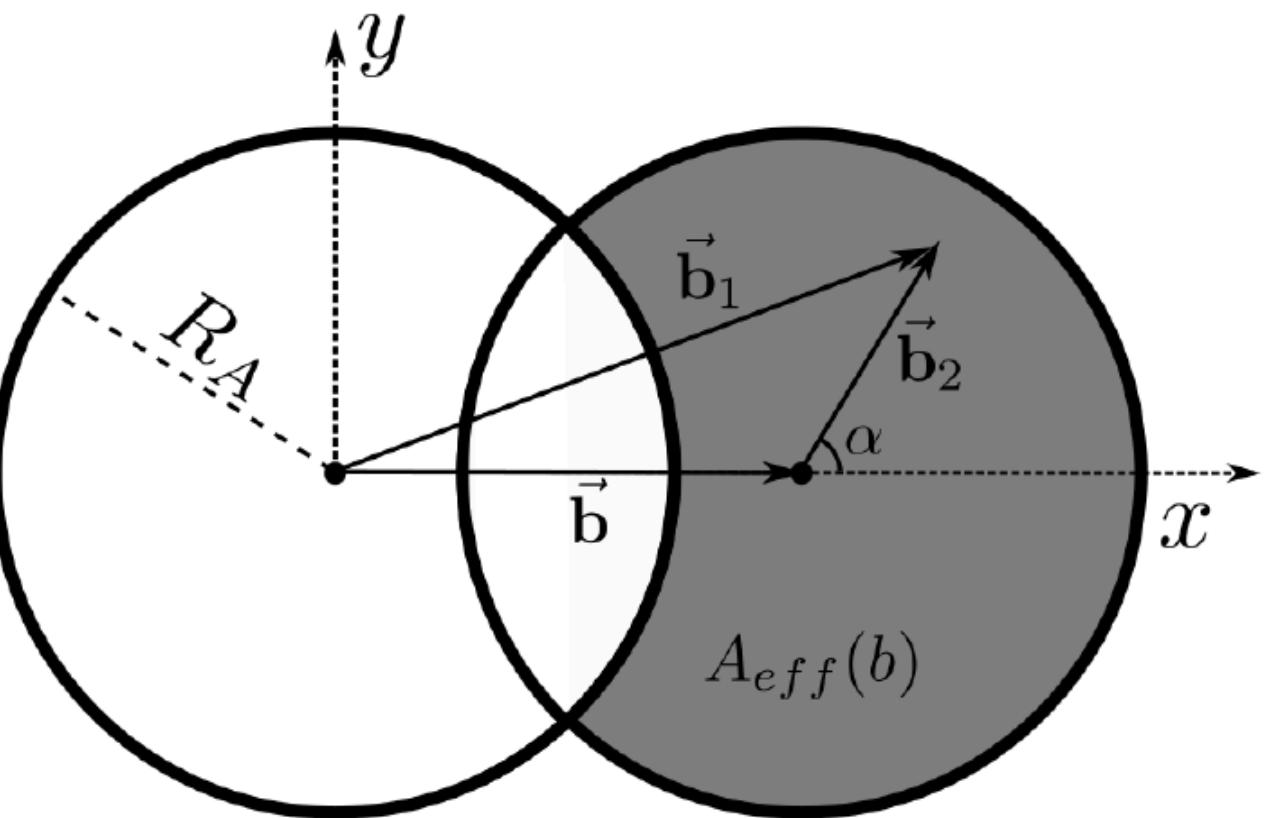


FIG. 2: Schematic drawing used in the construction of the effective photon flux.

Taken from **IIM/GBW**:
M. Gay Ducati *et al.*, PRD 97 (2018) 116013

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

Forward rapidity

2.5 < y < 4

New

Predictions:

GG-hs: J. Cepila *et al.*, PRC 97 (2018) 024901

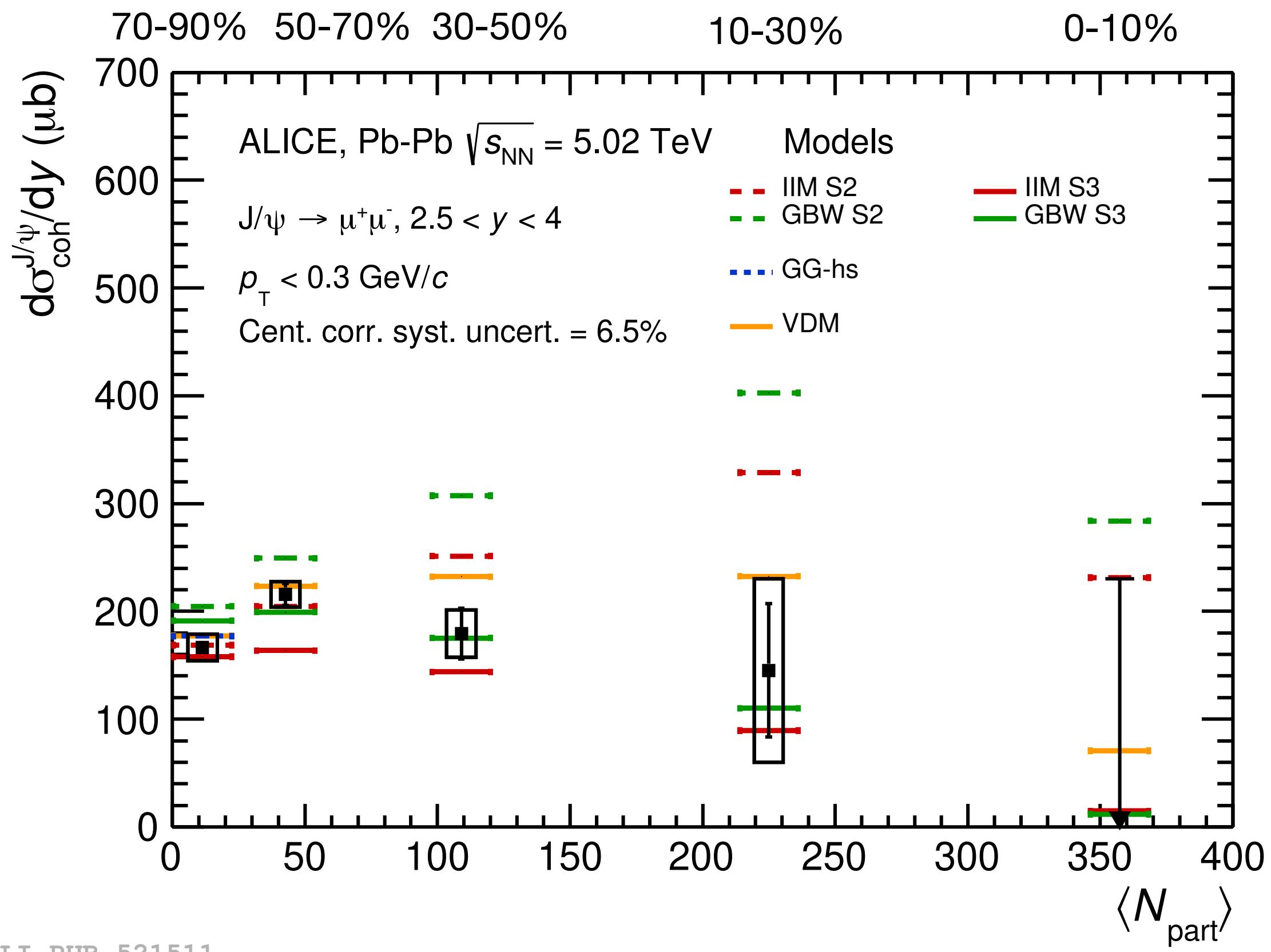
- γ flux with constraints on impact parameter range

VDM: M. Klusek-Gawenda *et al.*, PLB 790 (2019) 339

- γ reaching the overlap region not considered in γ flux [fixed area]
- No modification of $\sigma_{\gamma+\text{Pb} \rightarrow J/\psi+\text{Pb}}$

IIM/GBW: M. Gay Ducati *et al.*, PRD 97 (2018) 116013

- γ reaching the overlap region not considered in γ flux [b-dependent area]
- S2: no modification of $\sigma_{\gamma+\text{Pb} \rightarrow J/\psi+\text{Pb}}$
- S3: overlap not considered in $\sigma_{\gamma+\text{Pb} \rightarrow J/\psi+\text{Pb}}$ computation



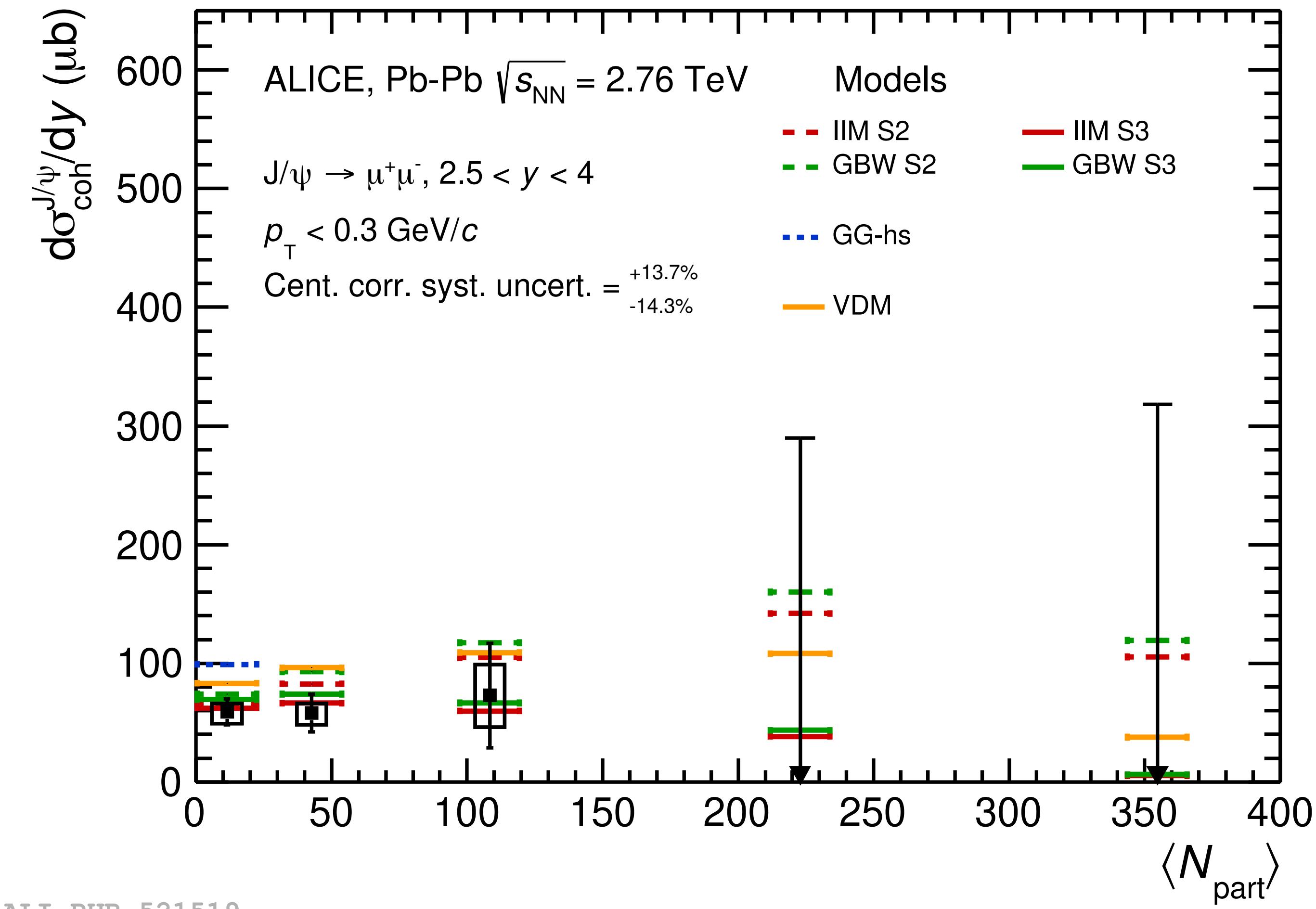
ALI-PUB-521511

Caveat: No normalisation to the centrality interval width !

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

Forward y

New

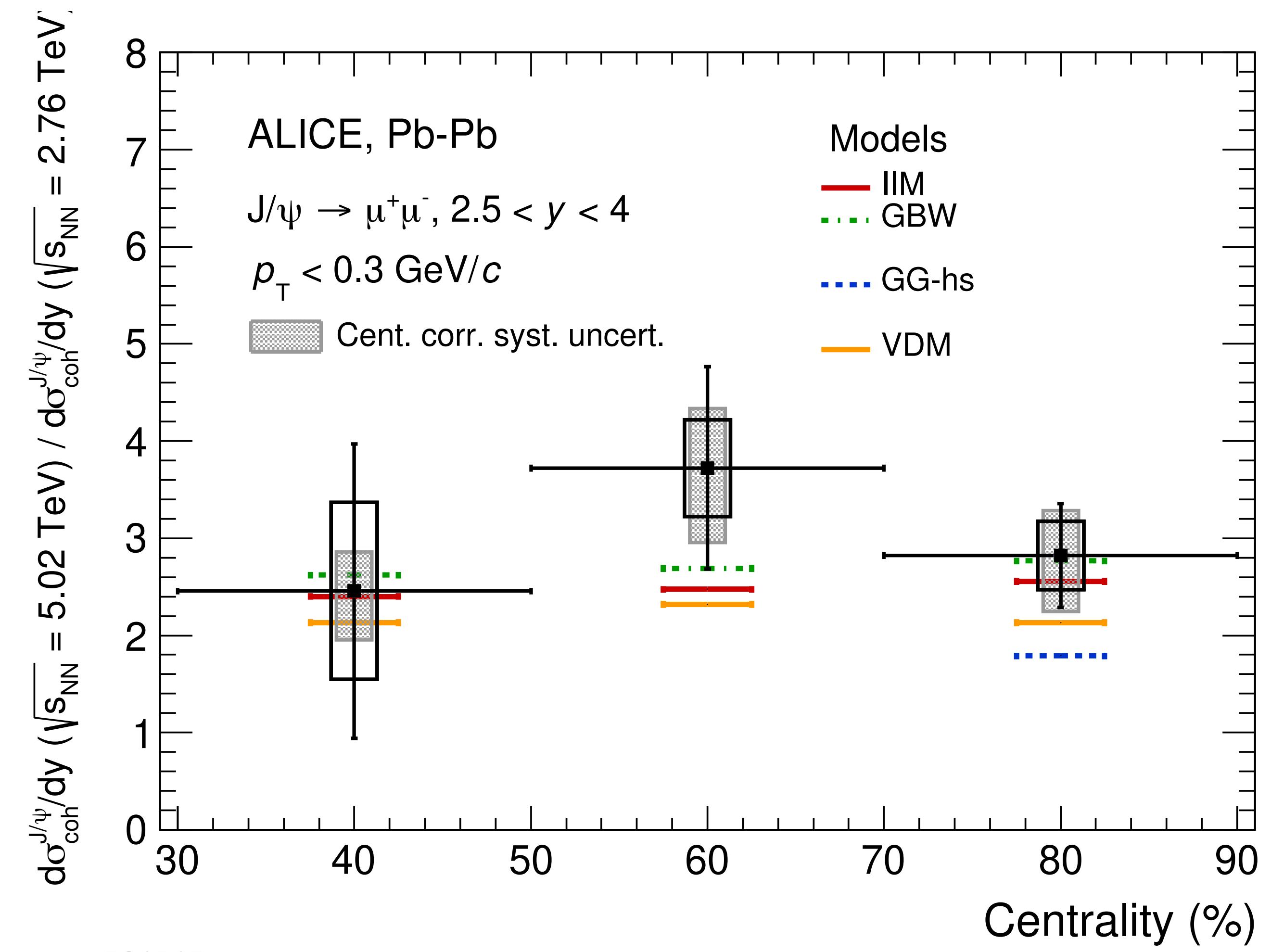


ALICE Collaboration, PRL 116 (2016) 222301

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

Forward y

New



ALI-PUB-521515

ALICE Collaboration, PRL 116 (2016) 222301 , arXiv:2204.10684