J/Ψ photoproduction and the production of dileptons via photon–photon interactions in hadronic Pb–Pb collisions measured with ALICE

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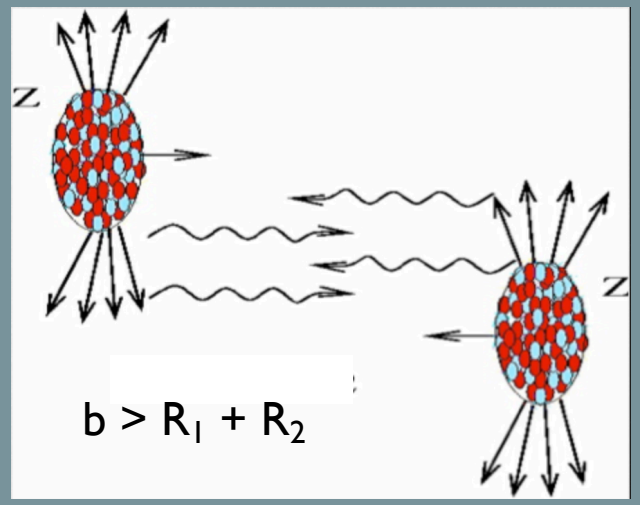
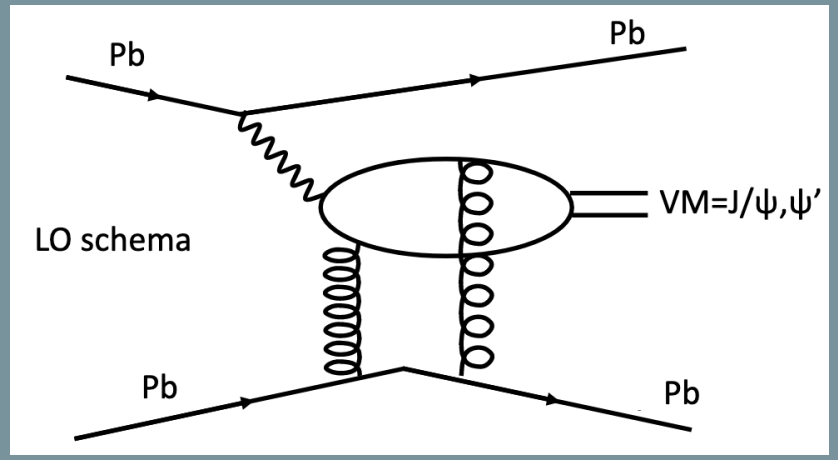
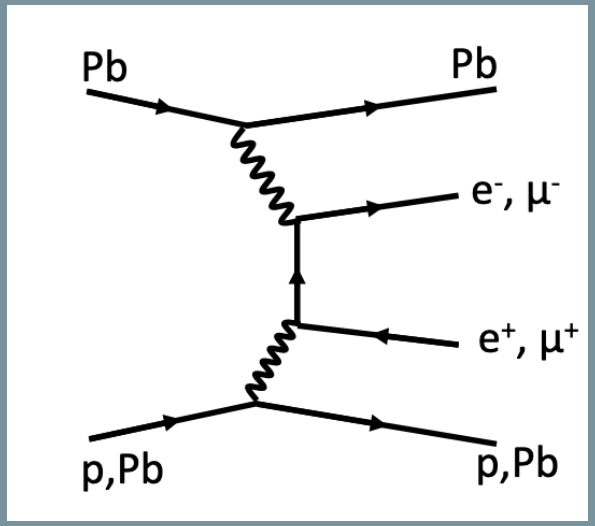
SQM2022, 13-17th June 2022, Busan, Republic of Korea (hybrid)

Photon induced processes in ultraperipheral heavy-ion collisions





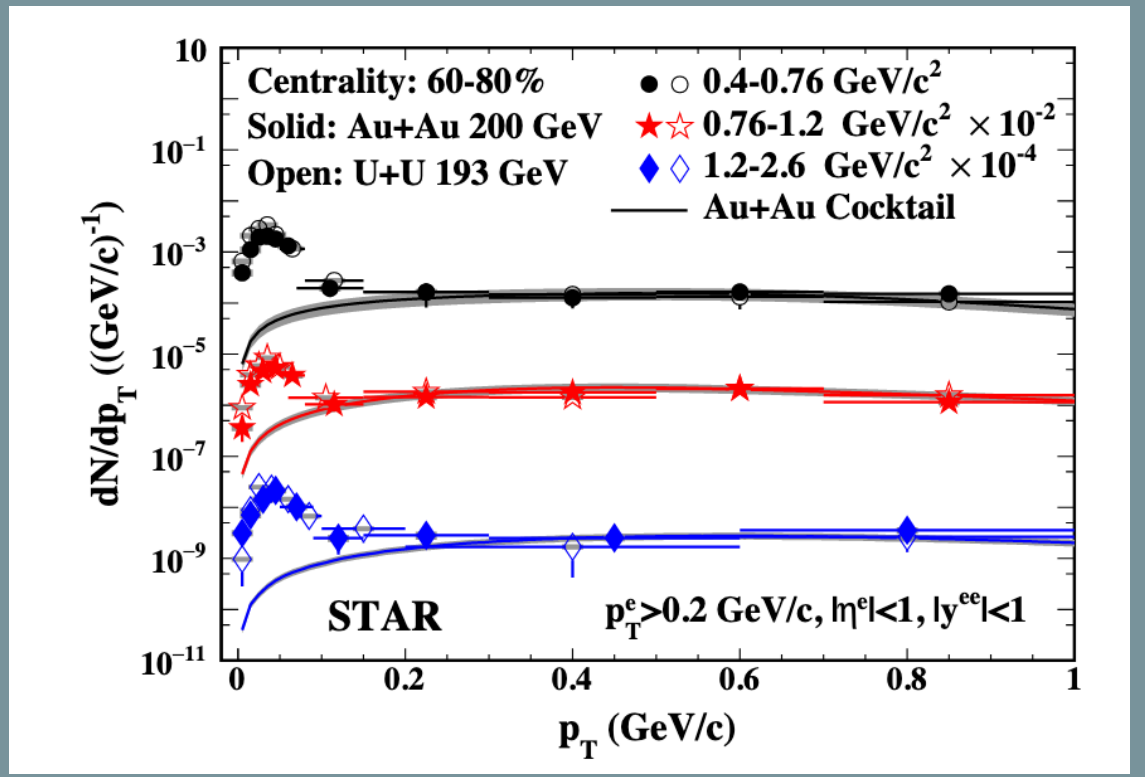


- The EM field of ultrarelativistic moving Pb nuclei described as beam of quasi-real photons
- Photon induced reactions well studied in ultraperipheral collisions UPC ($b > R_1 + R_2$)
  - Access to gluon distributions in nuclei at low Bjorken-x ($10^{-5} < x < 10^{-2}$) with Vector Meson (VM) photoproduction
  - Test QED and map the EM field produced in heavy-ion collisions (HIC) with dilepton production via $\gamma\gamma$ interactions
- Clean experimental signature in UPC : hadronic interaction suppressed, low-p_T production for VM and l^+l^- pair
  - Photoproduction of VM can be either coherent or incoherent

Dilepton production via $\gamma\gamma$ interaction in HIC with nuclear overlap

- Very low-p_T dielectron excess observed by STAR, at mid y for $0.4 < m_{e^+e^-} < 2.6$ GeV/c^2 in peripheral Au–Au and U–U collisions
  - Excess compatible with expectations from $\gamma\gamma$ interaction processes, but p_T^2 distribution not reproduced
- Observation by ATLAS of centrality-dependent acoplanarity for muon pairs produced via $\gamma\gamma$ scattering in hadronic Pb–Pb collisions (PRL 121, 212301 (2018)), for $4 < m_{\mu^+\mu^-} < 45$ GeV/c^2
  - Interpreted as a sign of electromagnetic scattering of the muons with a hot and dense medium
  - Inclusion of a b-dependence in QED calculations permits now to reproduce the data !! Phys. Rev. D 101 (2020), 034015

STAR Collaboration, PRL 121, 132301 (2018)



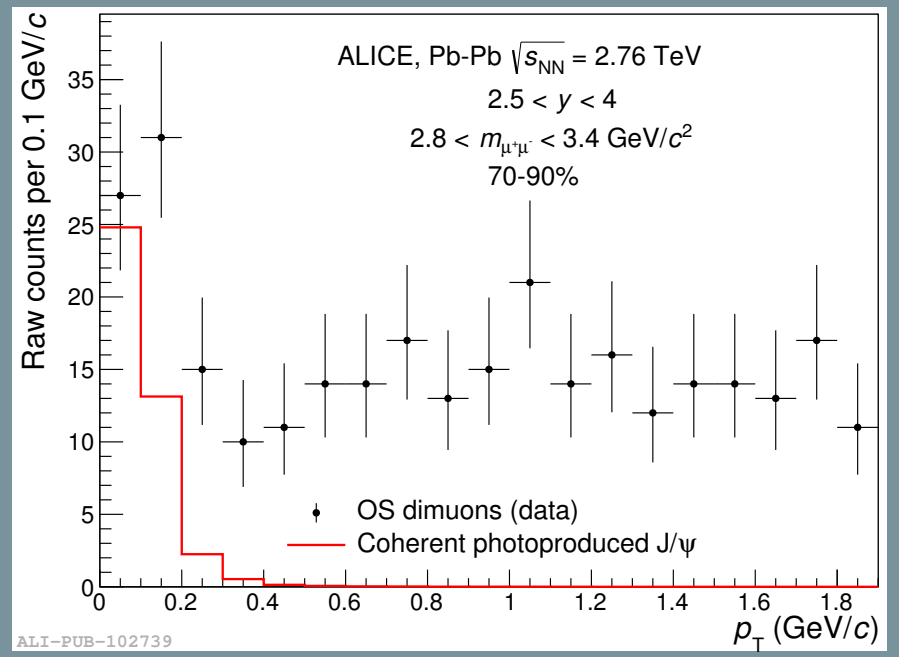
new

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

VM photoproduction in HIC with nuclear overlap

- Very low-p_T J/ψ excess in peripheral Pb–Pb collisions first measured in ALICE at forward y and $\sqrt{s_{NN}}$ = 2.76 TeV
  - Interpreted as coherent photoproduction
- Similar observation by STAR Collaboration at lower energy in U–U and Au–Au collisions (PRL 123, 132302 (2019))
  - First measurement of the t-dependence of the J/ψ excess
- Observation confirmed at $\sqrt{s_{NN}}$ = 5.02 TeV by LHCb (PRC 105 (2022) 3, L032201)
  - p_T and y-differential J/ψ excess yield measurement

PRL 116, 222301 (2016)

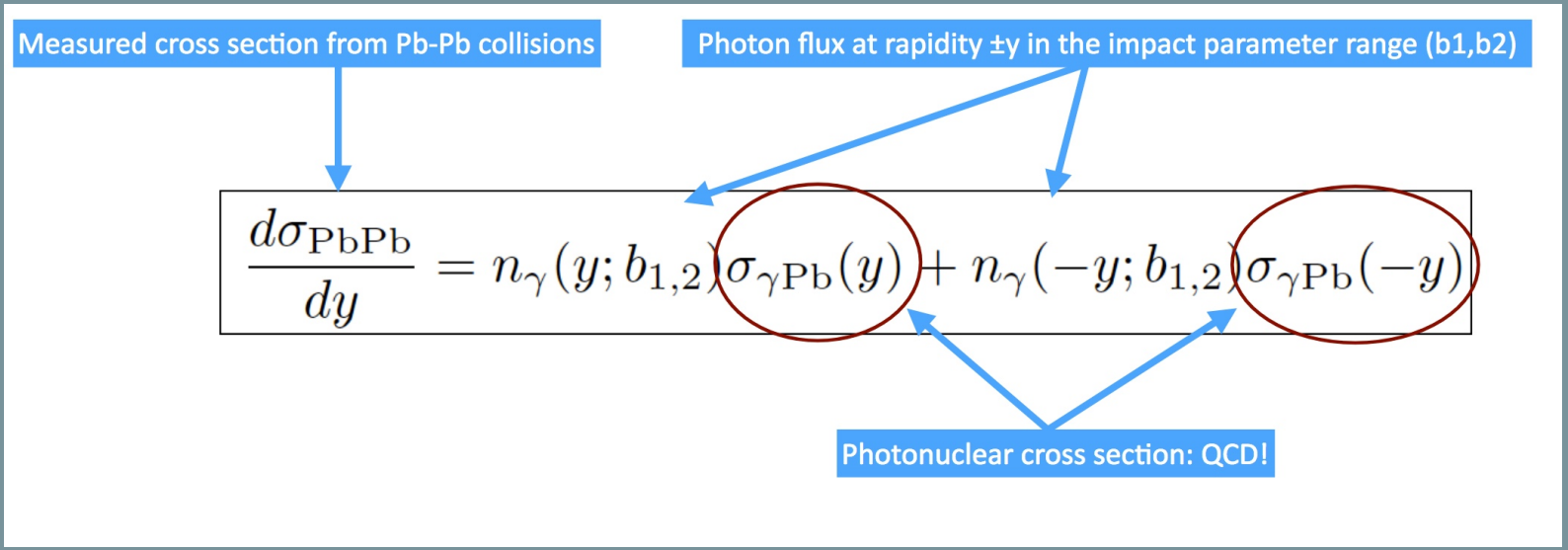


new First p_T -differential measurement of the J/ψ excess at mid y in peripheral Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE

new Coherent J/ψ photoproduction cross section measured towards most central Pb–Pb collisions ($\sqrt{s_{NN}}$ = 5.02 TeV) at forward y with ALICE (5σ significance in 30-50%)

VM photoproduction in HIC with nuclear overlap

- Theoretical challenges:
  - Survival of coherence condition for a broken nuclei? Only spectator nucleons participating to coherence?
  - Current theoretical approches: UPC-like models with modified γ flux and/or modified $\sigma_{\gamma Pb}$ to account for overlap



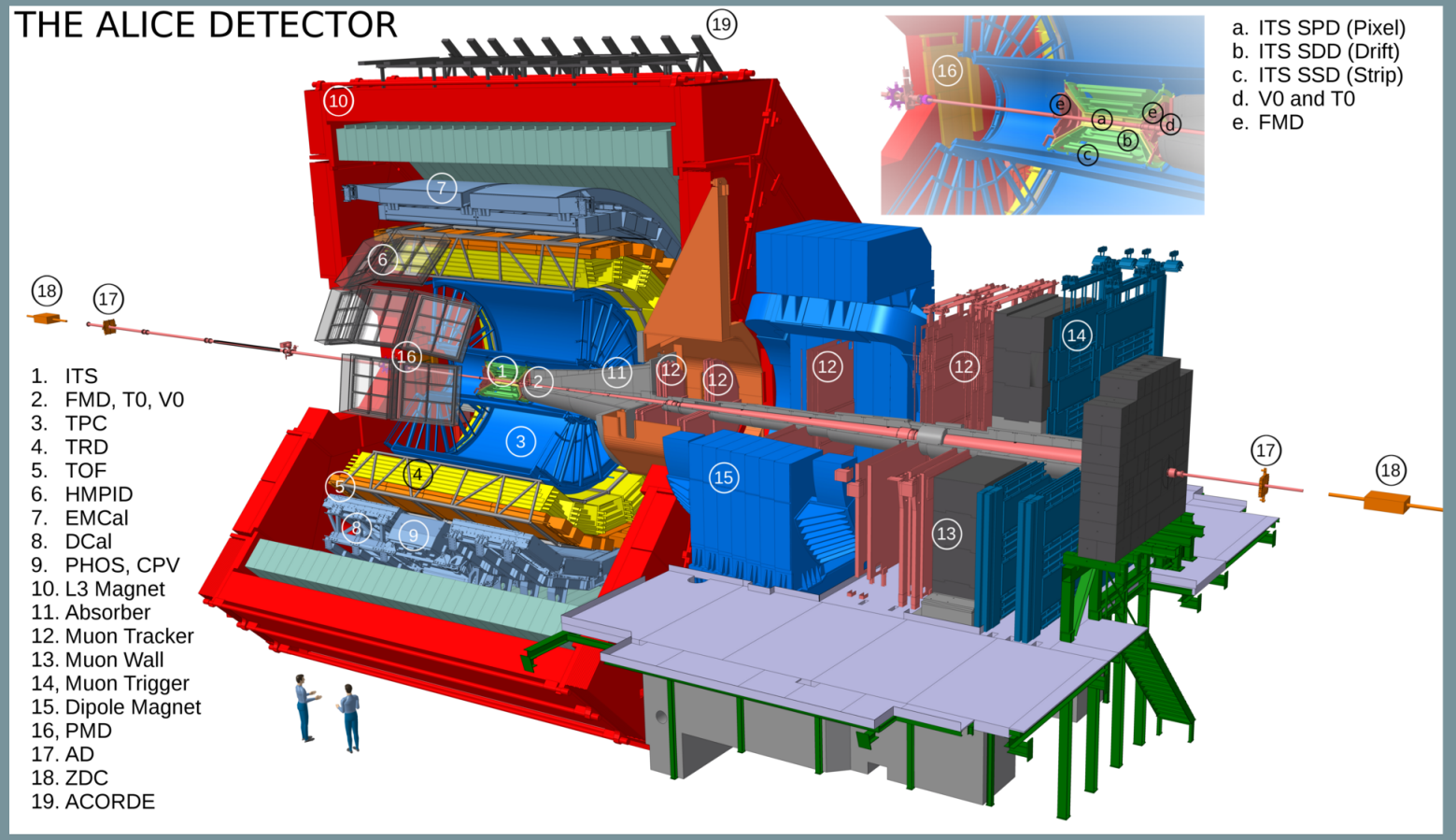
- A potential new probe of charmonium color screening in the QGP?
- A novel way to access $\sigma_{\gamma Pb}$ when combined to UPC measurement? (see J.G. Contreras, Phys. Rev. C 96, 015203 (2017), Zha et al., Phys. Rev. C97 (2018) 4, 044910) → Caveat: need to understand time ordering of the interaction and theoretical open questions related to the treatment of the nuclear overlap

The ALICE apparatus

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

Central barrel :
$|y| < 0.9$
low mass dielectrons
$J/\Psi \rightarrow e^+e^-$

ITS : tracking, vertex reconstruction
TPC : tracking, PID
TOF : PID



Muon spectrometer :
$2.5 < y < 4$
$J/\Psi \rightarrow \mu^+\mu^-$

Muon tracker : tracking
Muon trigger : triggering

For ALICE quarkonium results in Pb–Pb, see talks from X. Bai, Tues. 14th June, 9 am and H. Hushnud, Tues. 14th June, 10 am

ZDC : background rejection
V0 : triggering, centrality determination, background rejection

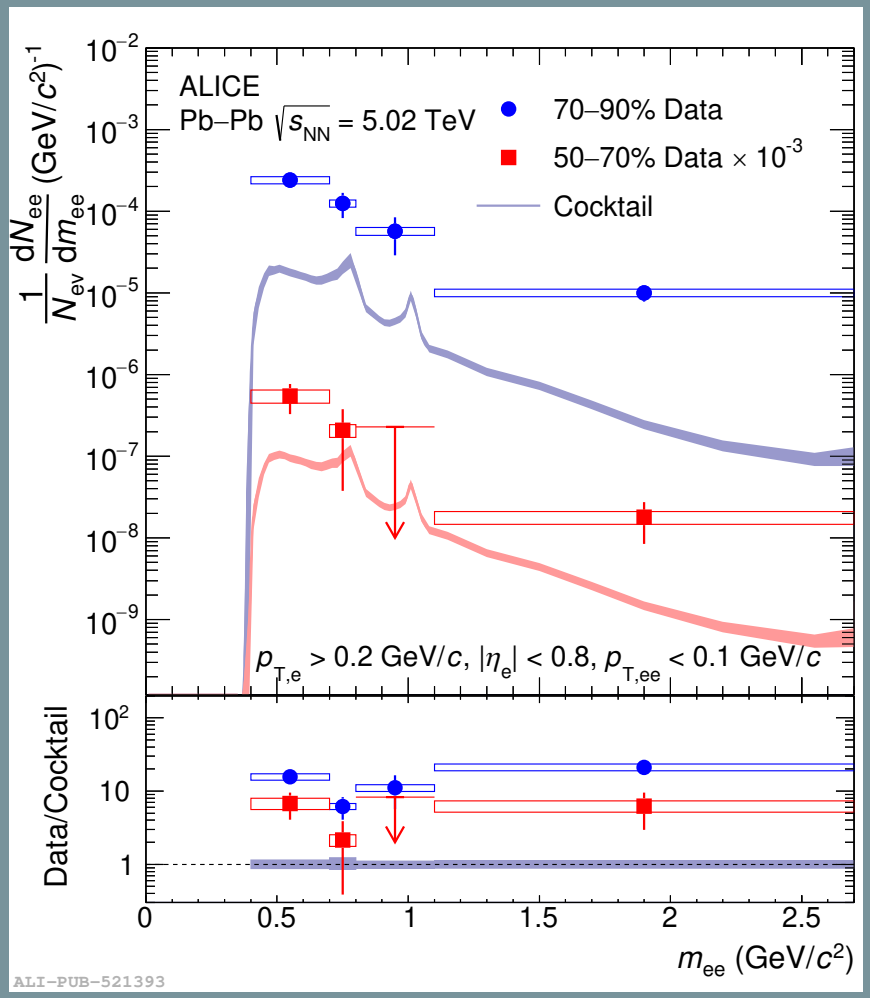
$\gamma\gamma \rightarrow e^+e^-$ production in Pb–Pb collisions with nuclear overlap

new

ALICE

arXiv:2204.11732

$p_{T,ee} < 0.1$ GeV/c

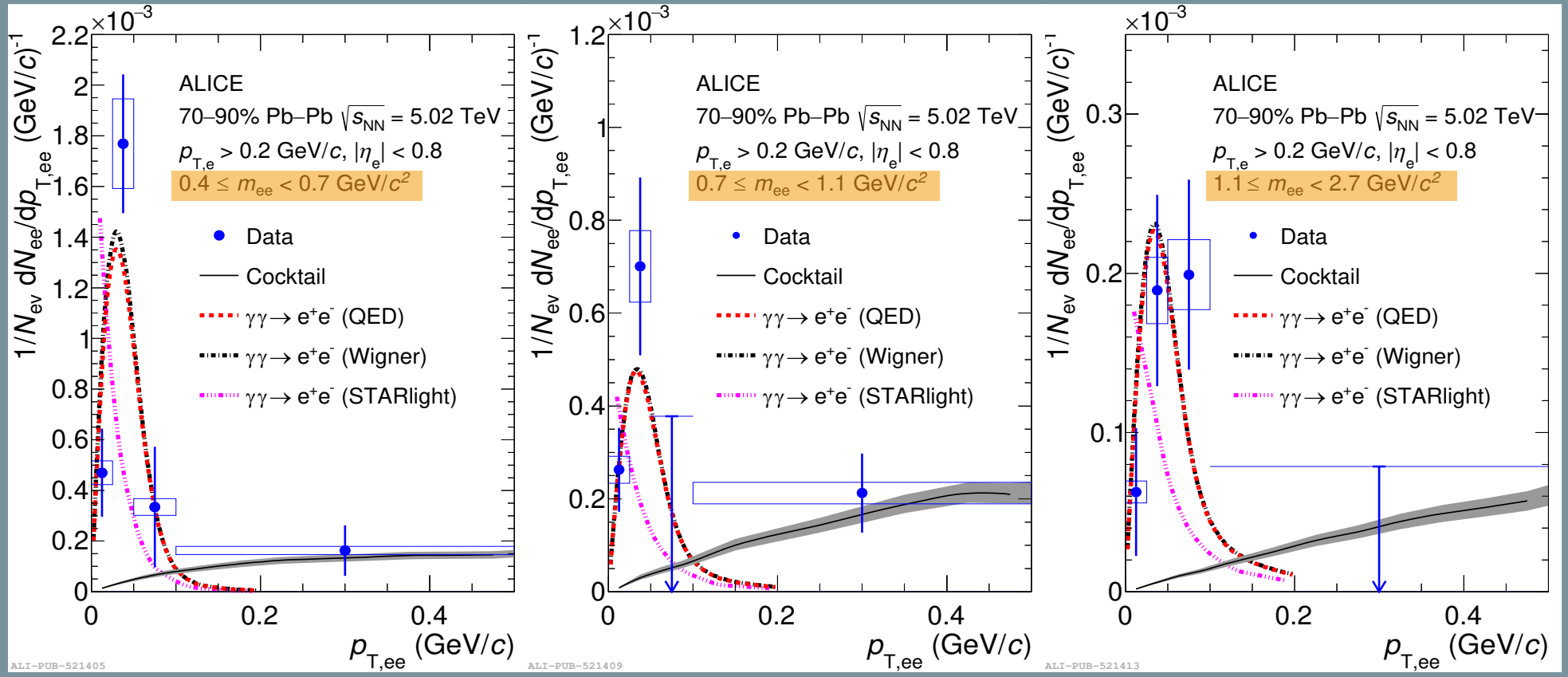


- First measurement at LHC of a dilepton excess at very low-p_T (< 0.1 GeV/c) for 0.4 < m_{e+e-} < 2.6 GeV/c^2 in peripheral Pb–Pb
- Corrected dielectron invariant mass distribution in centrality 50-70% and 70-90%, for $|\eta_e| < 0.8$ and $p_{T,ee} < 0.1$ GeV/c
  - Data cannot be described by cocktail of e^+e^- expected from hadronic sources
  - Significance of the excess larger in most peripheral events
  - At $p_{T,ee} < 0.1$ GeV/c, thermal radiation from medium are expected to be one order of magnitude smaller than the observed excess

$\gamma\gamma \rightarrow e^+e^-$ production in Pb–Pb collisions with nuclear overlap

new

arXiv:2204.11732



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

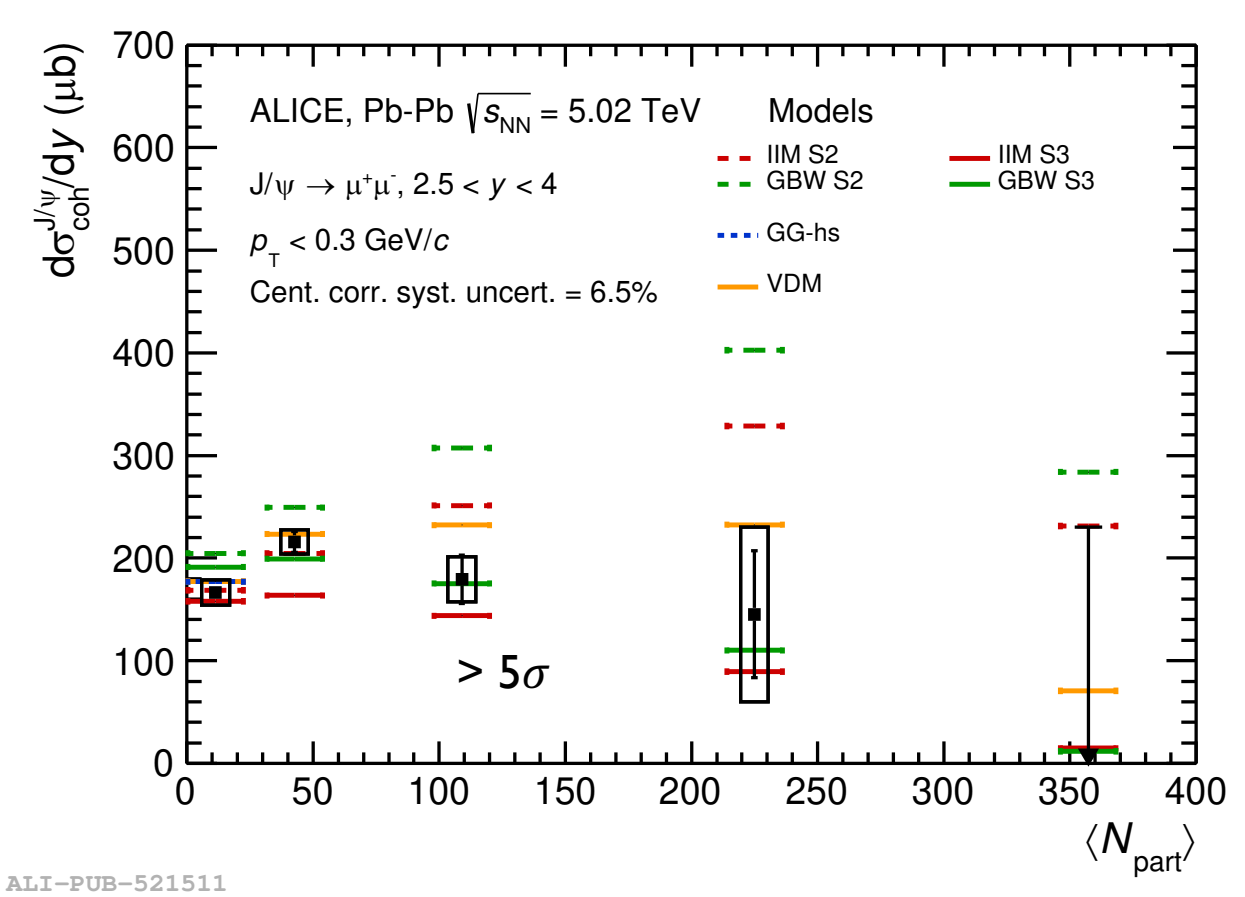
STARlight:
S.R. Klein *et al.*, Comput. Phys. Commun. 212 (2017) 258
S.R. Klein, Phys. Rev. C. 97 (2018) 054903

- Clear peak observed at low p_T, ee in 70-90%, for three invariant mass ranges
- Data described by $\gamma\gamma$ interaction models including the *b*-dependence of the photon-k_T distribution (QED, Wigner)
- STARLIGHT ($p_{T,ee}$ shape independent of b) disfavored by data

J/ψ photoproduction in Pb–Pb collisions with nuclear overlap (forward y)

new

arXiv:2204.10684



Centrality (70-90%) (50-70%) (30-50%) (10-30%) (0-10%)

Caveat : No normalization to the centrality interval width!

- No centrality dependence of the coherent J/ψ photoproduction cross section within uncertainties
- Models with either a modification of the γ flux (VDM) or a modification of the γ flux + photonuclear cross section (IIM/GBW S3) describe semicentral data

GG-hs: J. Cepila et al., Phys. Rev. C. 97 (2018) 024901
- γ flux with constraints on impact parameter range

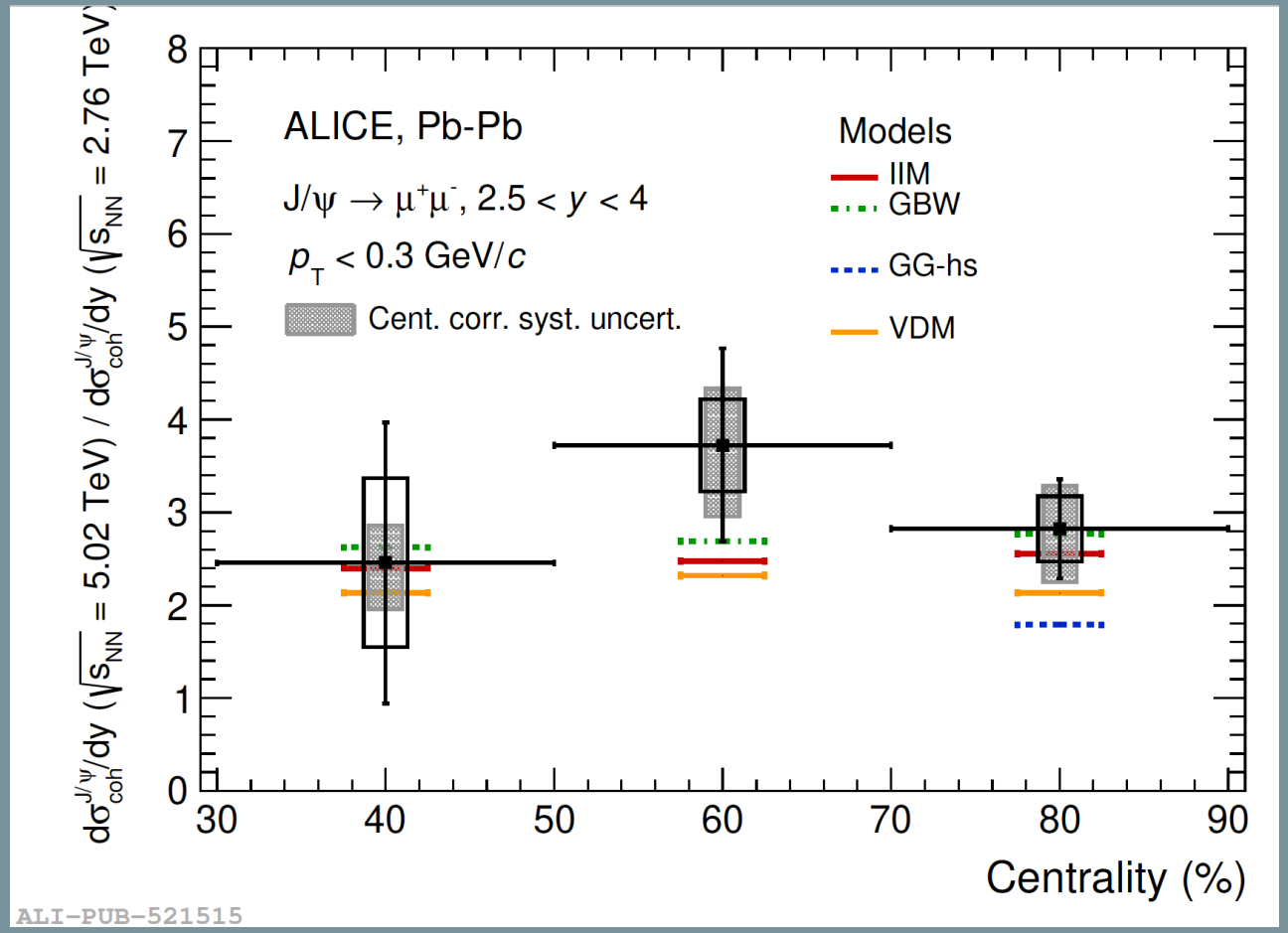
VDM : M. Klusek-Gawenda et al., Phys. Lett. B. 790 (2019) 339
- γ flux : γ reaching the overlap region not considered [fixed area], no modification of $\sigma_{\gamma Pb}$

IIM/GBW : M. Gay Ducati et al., Phys. Rev. D. 97 (2018) 116013
- γ flux : γ reaching the overlap region not considered [b-dependent area]
- S2: no modification of $\sigma_{\gamma Pb}$
- S3: overlap not considered in $\sigma_{\gamma Pb}$ computation

J/ψ photoproduction in Pb–Pb collisions with nuclear overlap (forward y)

new

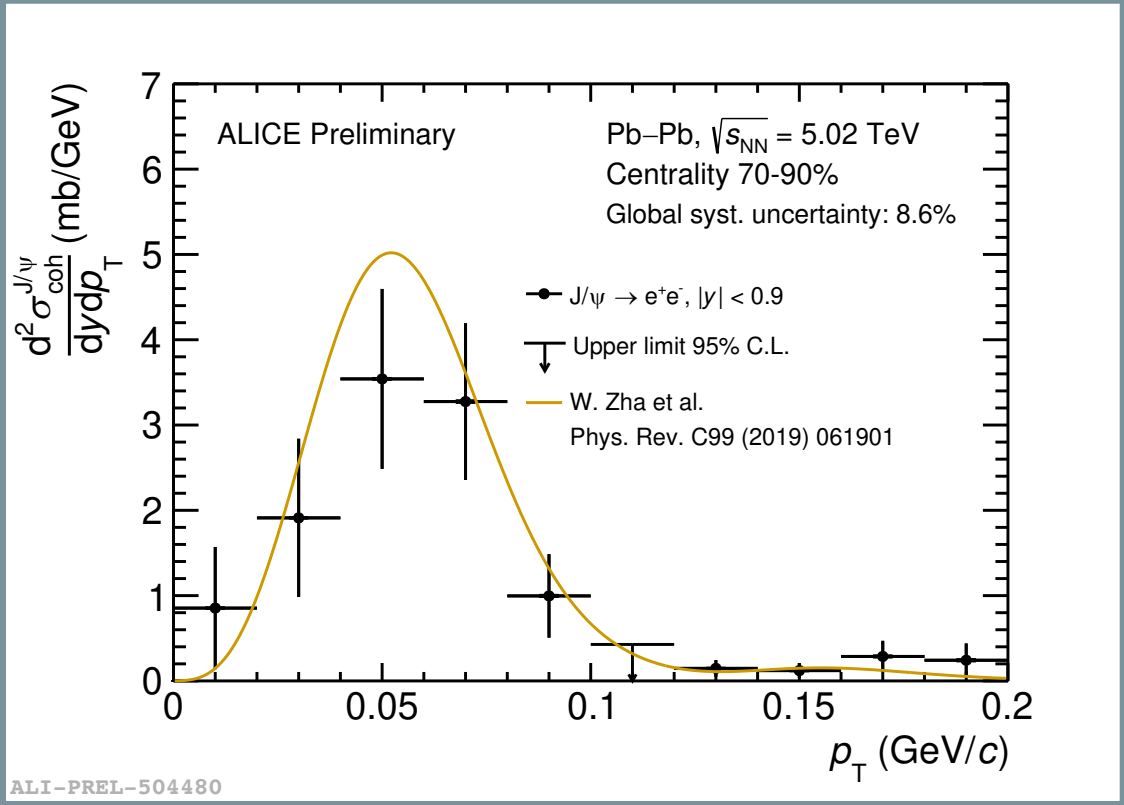
arXiv:2204.10684

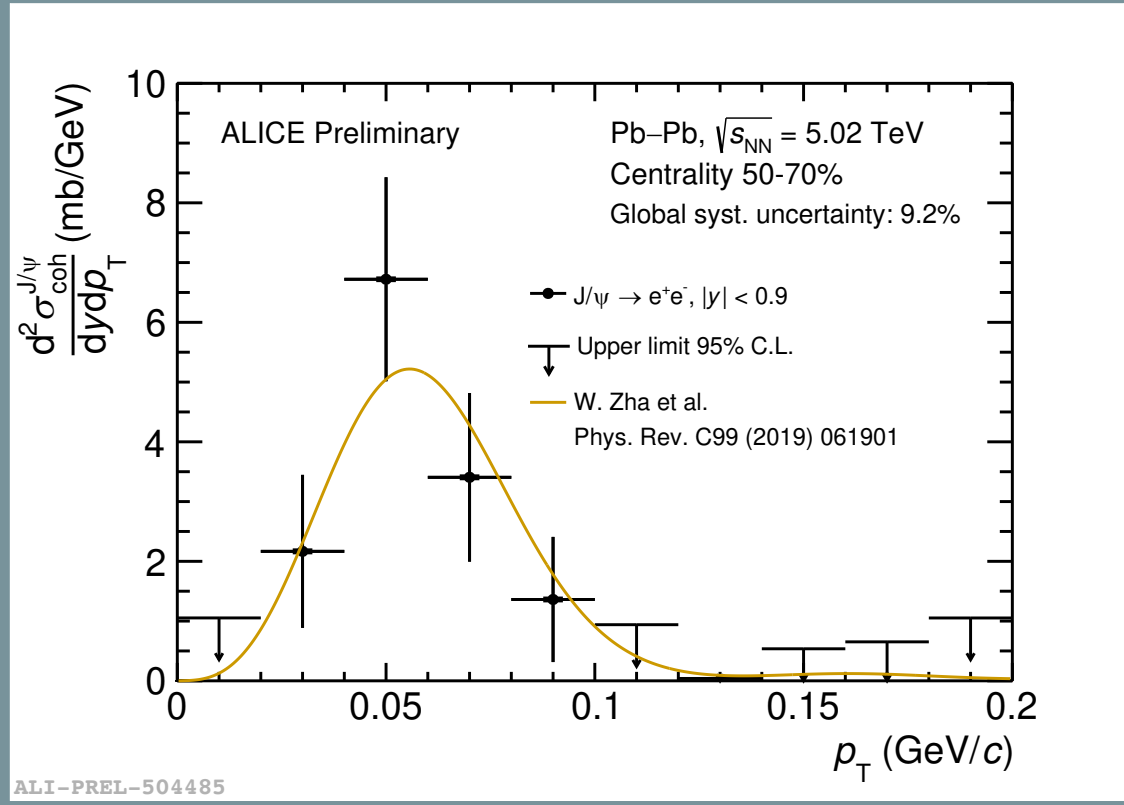


- J/ψ photoproduction cross section increase with the c.m.s energy doesn't depend on the centrality
- VDM and IIM/GBW models reproduce fairly the cross section ratio in the three centrality intervals

J/ψ photoproduction in Pb–Pb collisions with nuclear overlap (mid y)

new

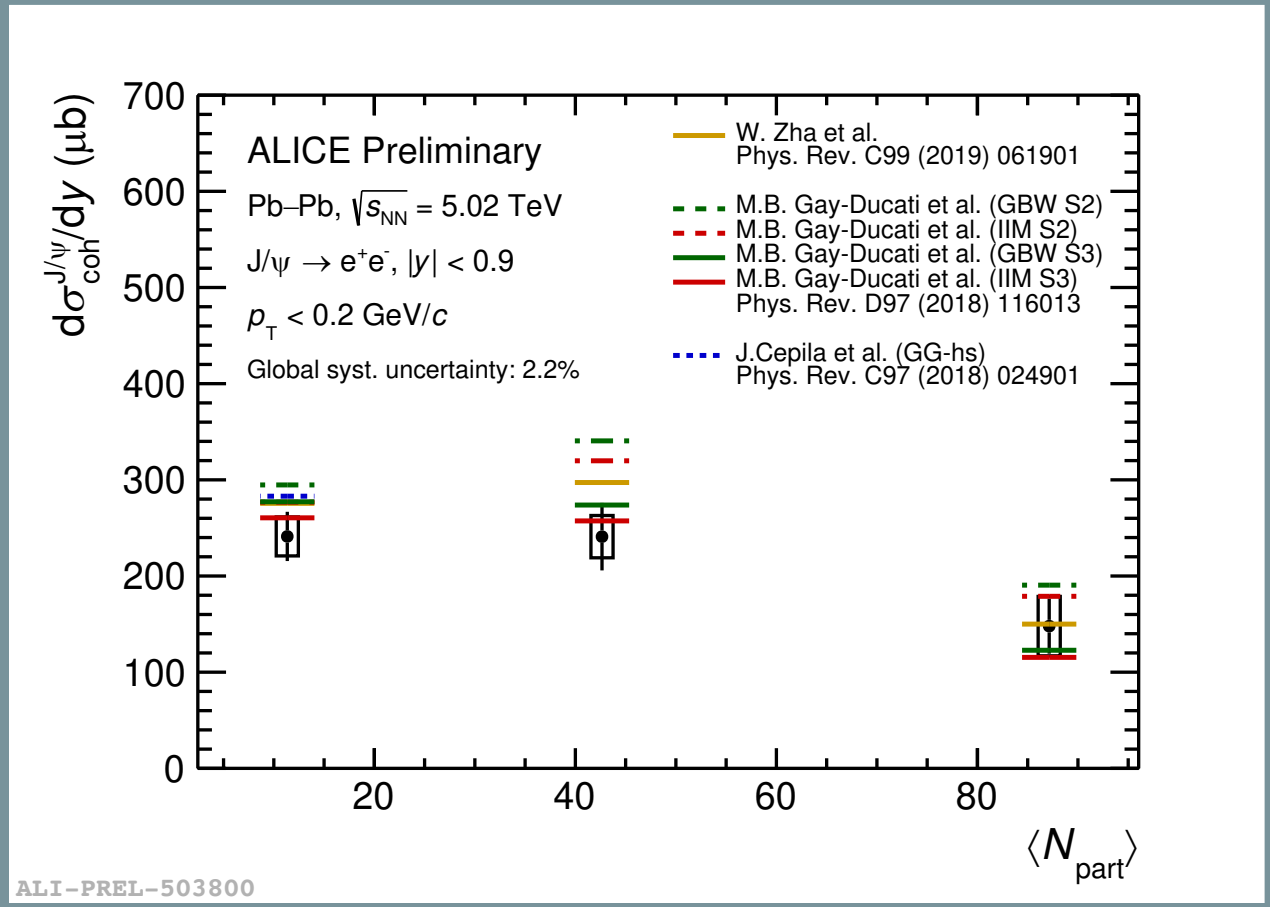




- p_T -differential J/ψ photoproduction cross section measured in 50-70% and 70-90% at mid y
- p_T shape reproduced by model (W. Zha et al., Phys. Rev. C99 (2019) 061901) including modified γ flux and $\sigma_{\gamma Pb}$ to account for the overlap (impact from overlap however limited in peripheral events)

J/ψ photoproduction in Pb–Pb collisions with nuclear overlap (mid *y*)

new



- No centrality dependence of the coherent J/ψ photoproduction cross section within uncertainties
- Same models (GG-hs, GBW/IIM) reproduce at the same time the order of magnitude of the cross section at mid and forward rapidity
- Current precision in semicentral collisions do not permit to distinguish between models with modifications of γ flux only, or models with modification of γ flux + $\sigma_{\gamma Pb}$

Centrality (70-90%) (50-70%) (40-50%)

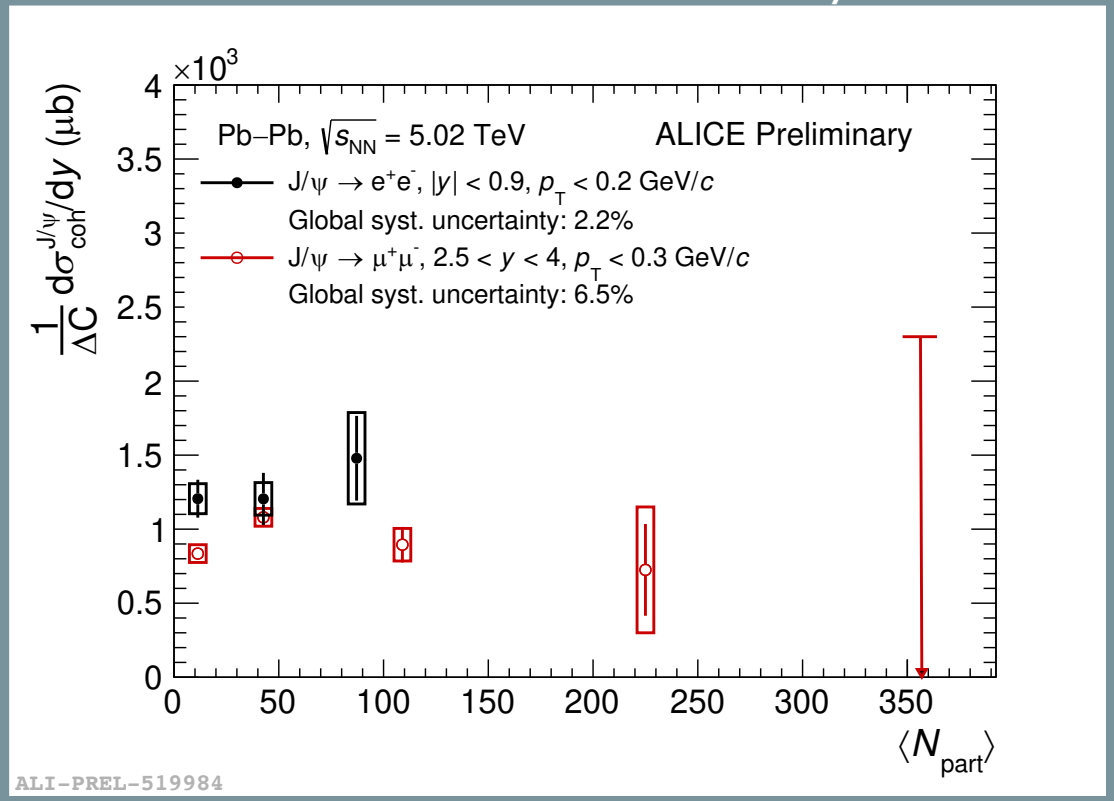
Caveat : No normalization to the centrality interval width!

J/ψ photoproduction in Pb–Pb collisions with nuclear overlap (mid *y* and forward *y* comparison + comparison to UPC)

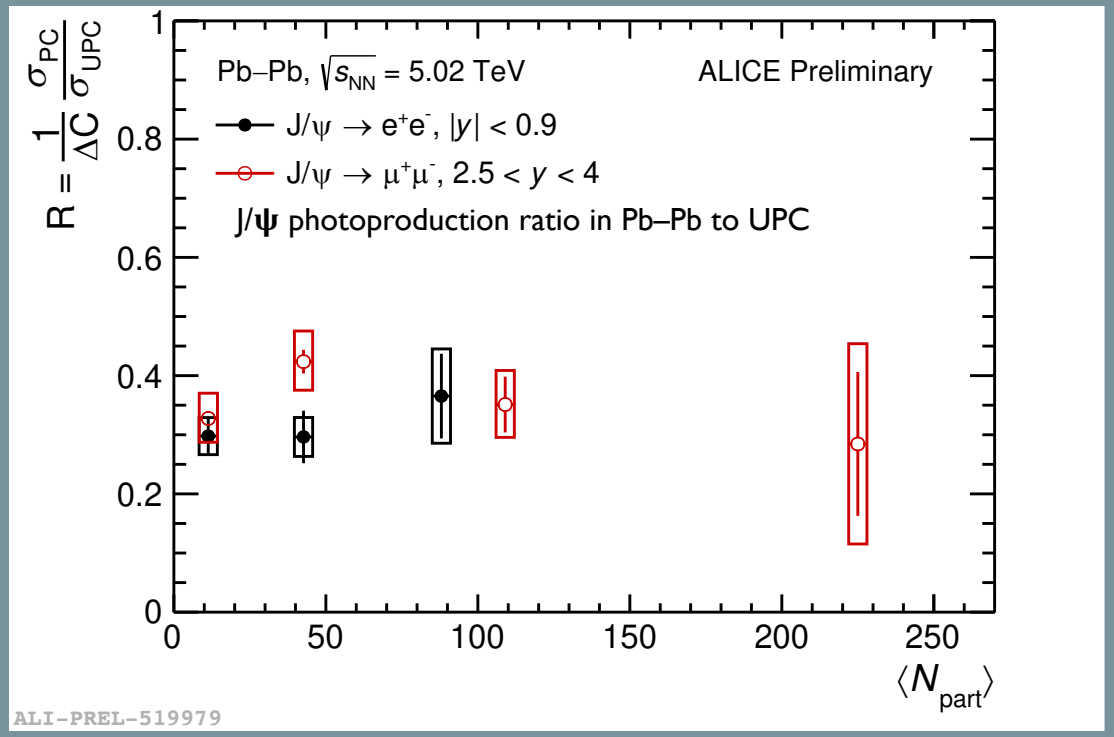
new

ALICE

ΔC : normalization to the size of centrality interval



PC: arXiv:2204.10684
UPC: EPJC 81 (2021) 712, PLB 98 (2019) 134926



- Hint for larger J/ψ photoproduction cross section at mid *y* than at forward *y* (as expected from models, see slide 9 and 12). No strong centrality dependence at both rapidities.
- J/ψ photoproduction ratio in Pb–Pb to UPC (in the same rapidity window) → similar ratio for mid *y* and forward *y*.
  - Ratio flat with centrality → no evidence for a decrease of σ_{PC} because of the overlap or medium effects

CONCLUSION AND OUTLOOK

- First measurement of photoproduced e^+e^- pair at the LHC for $0.4 < m_{e^+e^-} < 2.6$ GeV/c^2 in peripheral Pb–Pb
  - Reproduced by $\gamma\gamma$ interaction models including the b-dependence of the photon-k_T distribution

- Photoproduced J/ψ measured towards most central Pb–Pb collisions at forward y. First p_T -differential measurement at mid y
  - UPC-like models including modified γ flux and/or $\sigma_{\gamma Pb}$ accounting for nuclear overlap describe semicentral data

- Perspectives for Run 3 + 4 : target luminosity $L_{int} \sim 10$ nb^{-1}

  - Dileptons from $\gamma\gamma$ interaction:
    - High precision measurement of $p_{T,ee}$
    - Acoplanarity measurement, differential measurement as a function of event plane or rapidity gap between e^+ and e^-

  - 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 : polarization, flow, y-differential cross section, and other quarkonium states