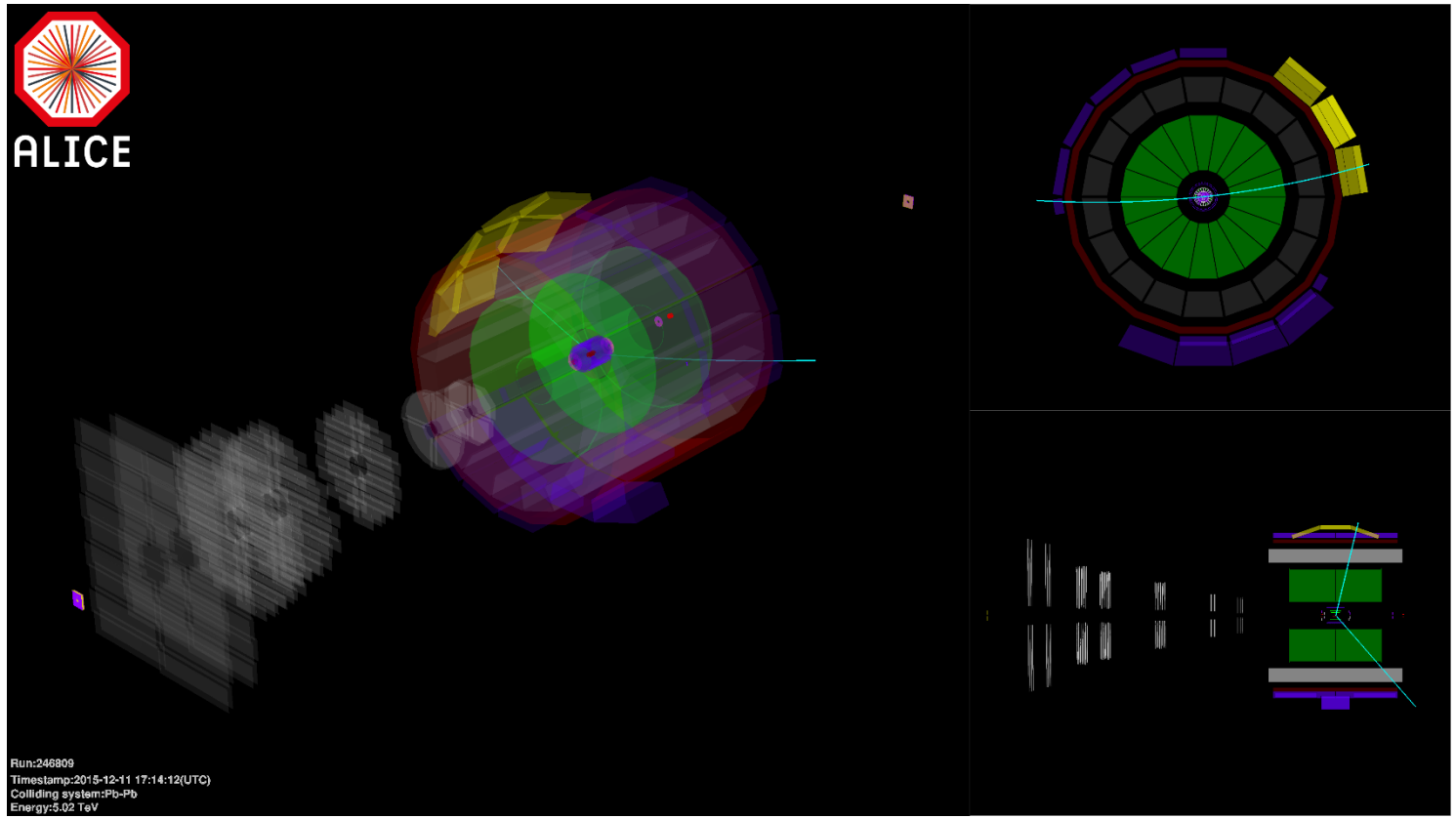
Photoproduction of vector mesons in ultra-peripheral Pb-Pb interactions with ALICE



Christopher Anson

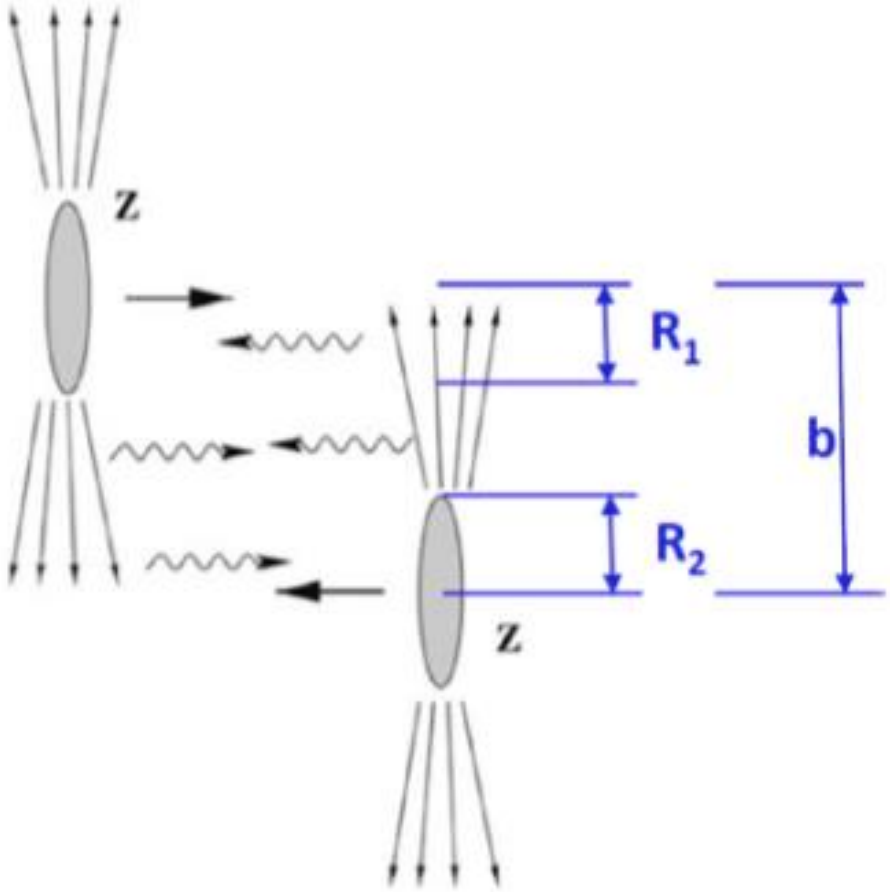
ALICE Collaboration

Creighton University

Outline

- Ultra-peripheral collisions (UPCs)
- Run 1 results
- Run 2 ALICE detector and triggers
- Run 2 results for ρ^0, J/ψ and ψ(2S) in Pb-Pb
- Next steps for Run 2 UPC measurements

Photoproduction in ultra-peripheral collisions



PoS (DIS2016) 191

- Ultra-peripheral collisions have impact parameter $>R_1+R_2$.
- EM field of relativistic heavy ion equivalent to photon flux.
- Photon flux $\propto Z^2$ (=6724 for Pb-Pb) so heavy ions are an excellent photon source.
- Photon energy spectrum extends to $\gamma\hbar c/R$. With $R_{Pb}\approx 7$ fm
  - Run 1: $E_{max} \approx 83$ GeV (489 TeV in target rest frame)
  - Run 2: $E_{max} \approx 151$ GeV (1615 TeV in target rest frame)
- Photo-nuclear, photon-nucleon and $\gamma\gamma$ interactions can occur in ultra-peripheral collisions.

Nuclear gluon distribution and dσ/dy

- The cross section dσ/dy for the interaction A+A→A+A+V is given by

$$\frac{d\sigma}{dy} = \omega_1 \frac{dn_\gamma}{d\omega_1} \sigma_{\gamma A \to VA}(\omega_1) + \omega_2 \frac{dn_\gamma}{d\omega_2} \sigma_{\gamma A \to VA}(\omega_2)$$

  where 1, 2 label which colliding particle emitted the photon.

- Ryskin[†] (1993) relates dσ/dt and the gluon distribution g(x,Q^2):

$$\left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{\alpha_s{}^2 \Gamma_{ee}}{3\alpha M V^5} 16\pi^3 \left[x g\left(x, \frac{M^2}{4}\right)\right]^2$$

  for the interaction γ + A → V + A.

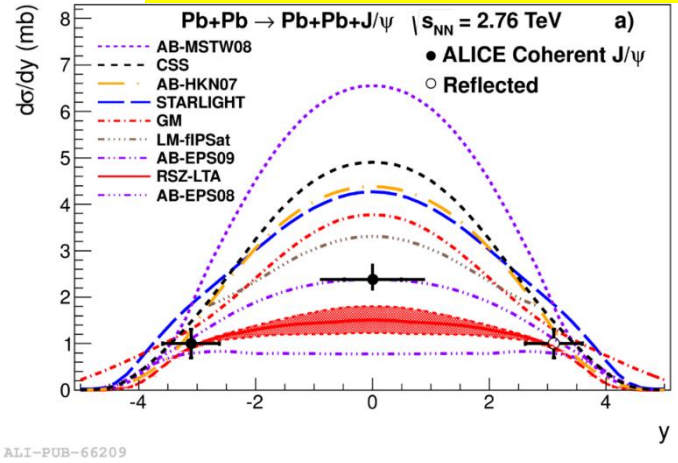
- During the calculation of dσ/dy from dσ/dt the proportionality dσ/dt $\propto$ [g(x,Q^2)]^2 factorizes, leading to

$$\frac{d\sigma}{dy} \propto [g(x,Q^2)]^2$$

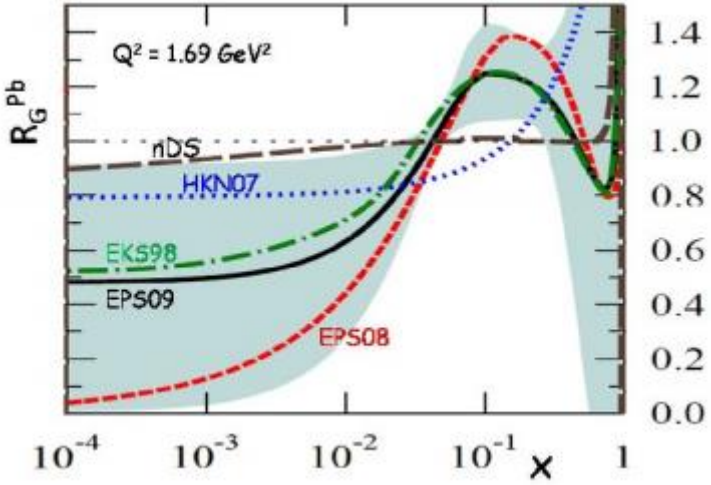
[†] Z. Phys. C 57 (1993) 89-92

Phys. Lett. B 718 (2013) 1273 (Muon arm), EPJC 73 (2013) 2617 (Central Barrel)

Exclusive J/ψ production (Run1)



JHEP 0904 (2009) 065 & arXiv:1106.5682

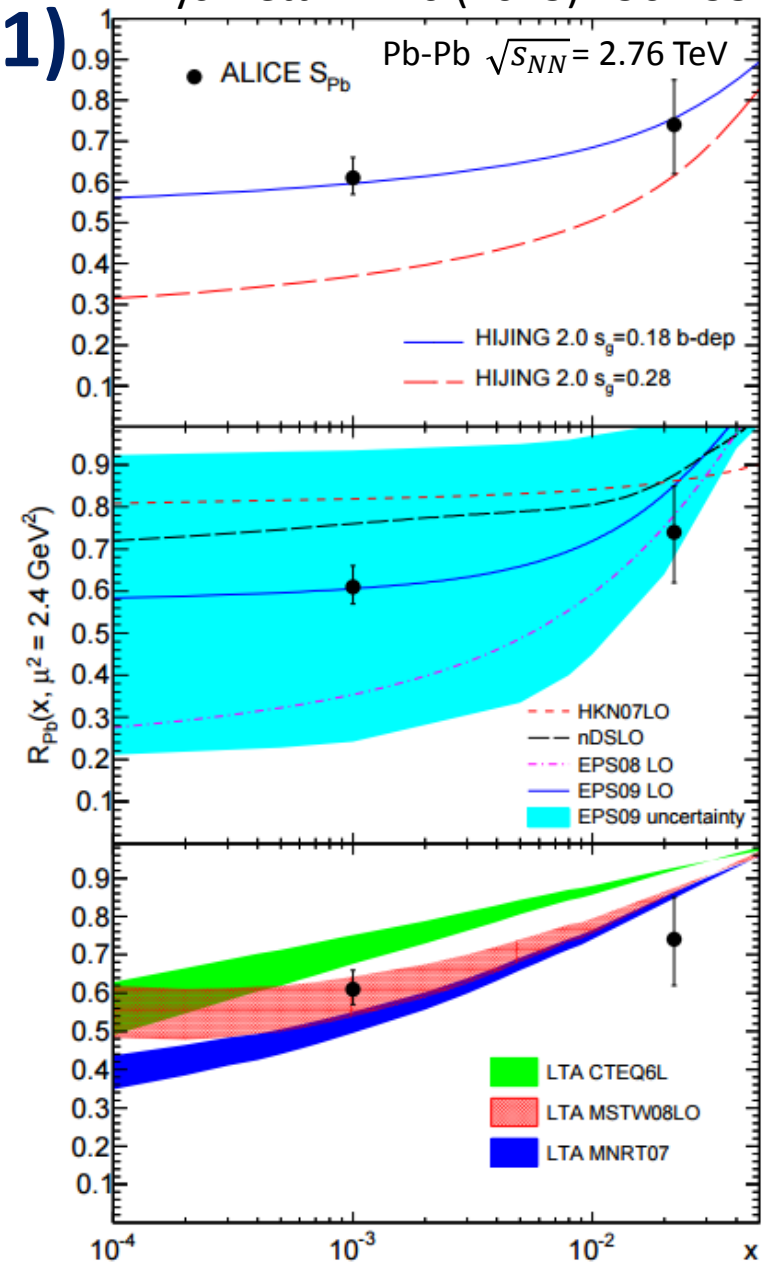


- Correspondence between uncertainty in nuclear gluon distributions and cross-sections.
- Modification as a function of *x* due to nucleus:

$$R_G^A = \frac{g_A(x,Q^2)}{A \cdot g_p(x,Q^2)}$$

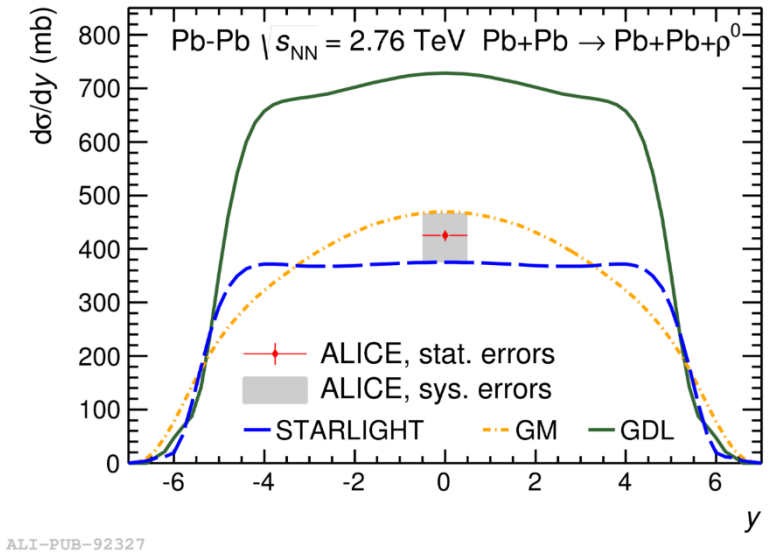
- Guzey, Kryshen, Strikman and Zhalov (2013) converted ALICE $d\sigma/dy$ values back to R_G^{Pb} values.
- The $d\sigma/dy$ measurements provide significant constraints on the models.

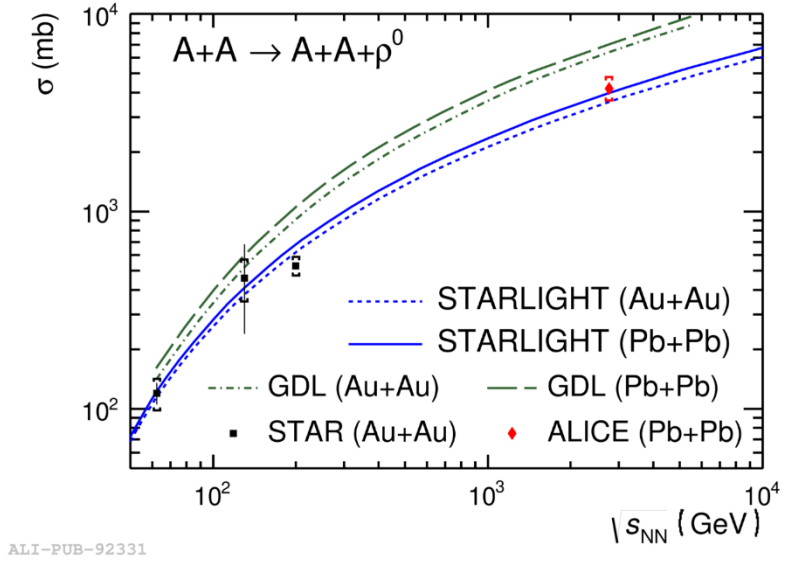
Phys. Lett. B 726 (2013) 290-295



ALICE Collaboration, JHEP 09 (2015) 095

Run 1 measurements

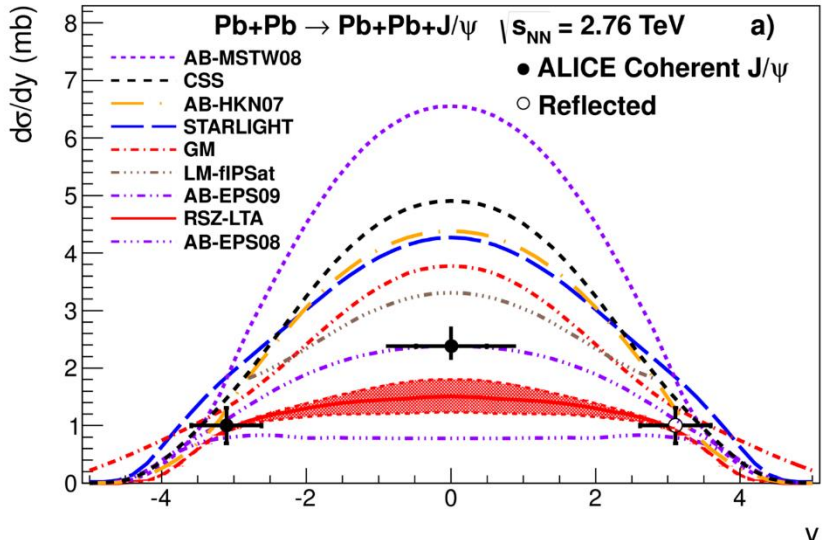


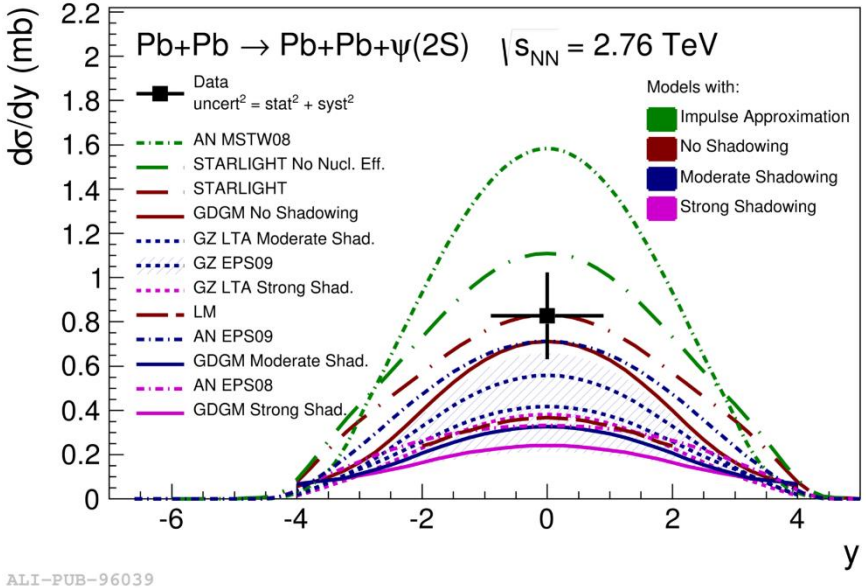


- Cross section for ρ^0 similar to STARLIGHT and GM models.
- Consistent with energy dependence found by STAR.
- Consistent with STARLIGHT.

ALICE Collaboration: Phys. Lett. B 718 (2013) 1273 (Muon arm), EPJC 73 (2013) 2617 (Central Barrel), Phys. Lett. B 751 (2015) 358 (*ψ(2S)*)

Run 1 measurements





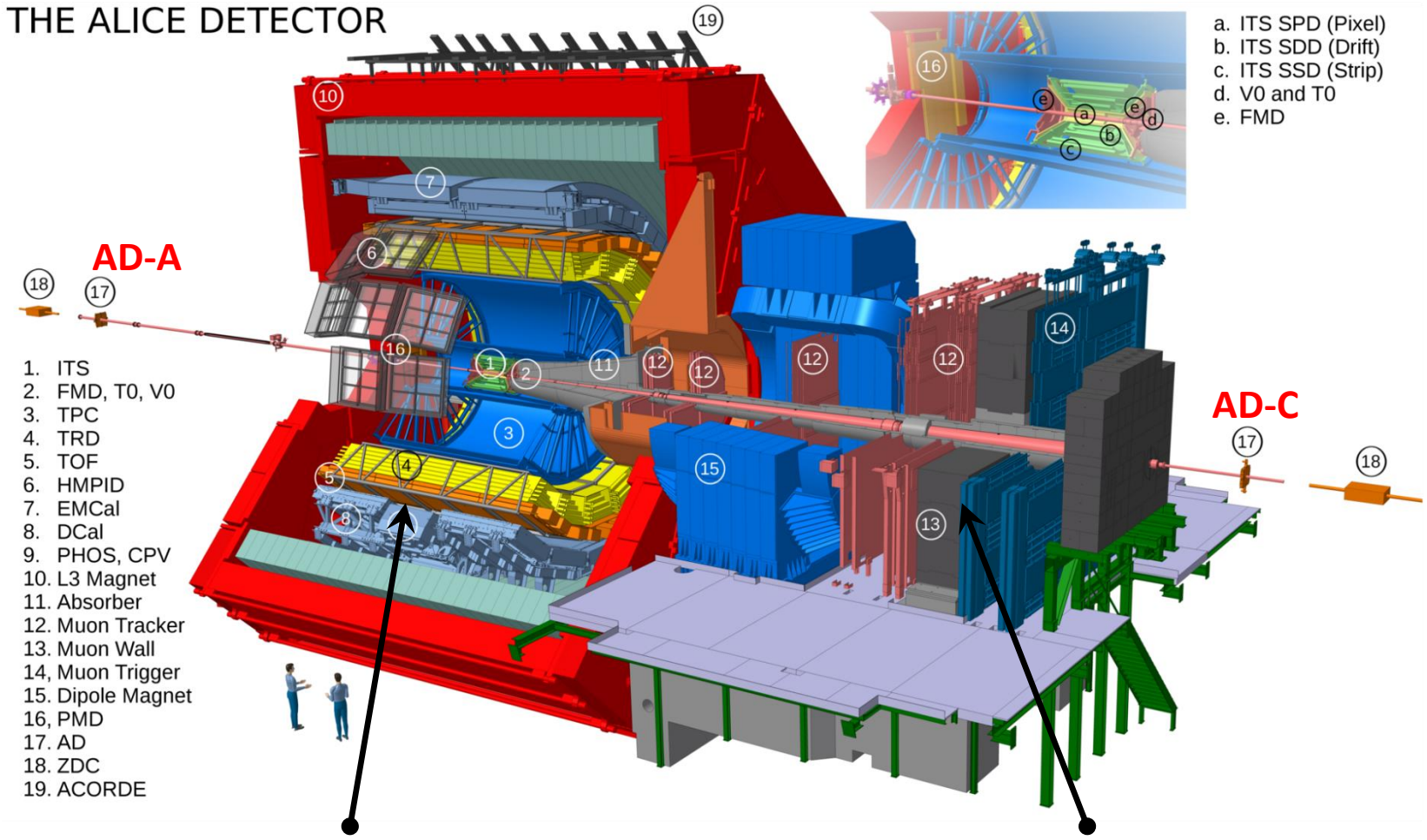
ALI-PUB-96039

- Cross sections for J/ψ.
- Consistent with models with moderate gluon shadowing (AB-EPS09 parameterization).

- Cross section for ψ(2S).
- Favors models with moderate gluon shadowing (AB-EPS09 parameterization) or no shadowing.

- $\sigma[\psi(2S)]/\sigma[J/\psi] = 0.34 \pm 0.08$ (sys+stat)
  - Expected < 0.2.
  - Run 2 result, in forward direction, will be shown later.

The ALICE detector



Central detectors

Muon Arm

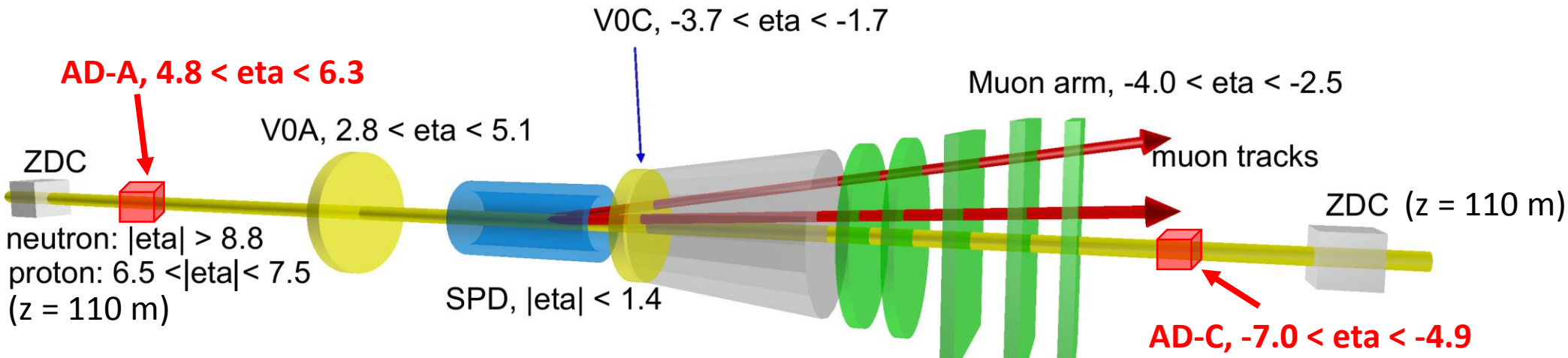
Central detectors:

- ❑ TPC for tracking and particle identification ($|\eta|<0.9$)
- ❑ TOF and SPD for triggering

Central UPC trigger:

- ≥ 2 back-to-back TOF hits
- ≥ 2 back-to-back SPD hits
- No hits in AD-A or AD-C
- No hits in V0-A or V0-C

Muon Arm and forward detectors



Distances are not to scale.

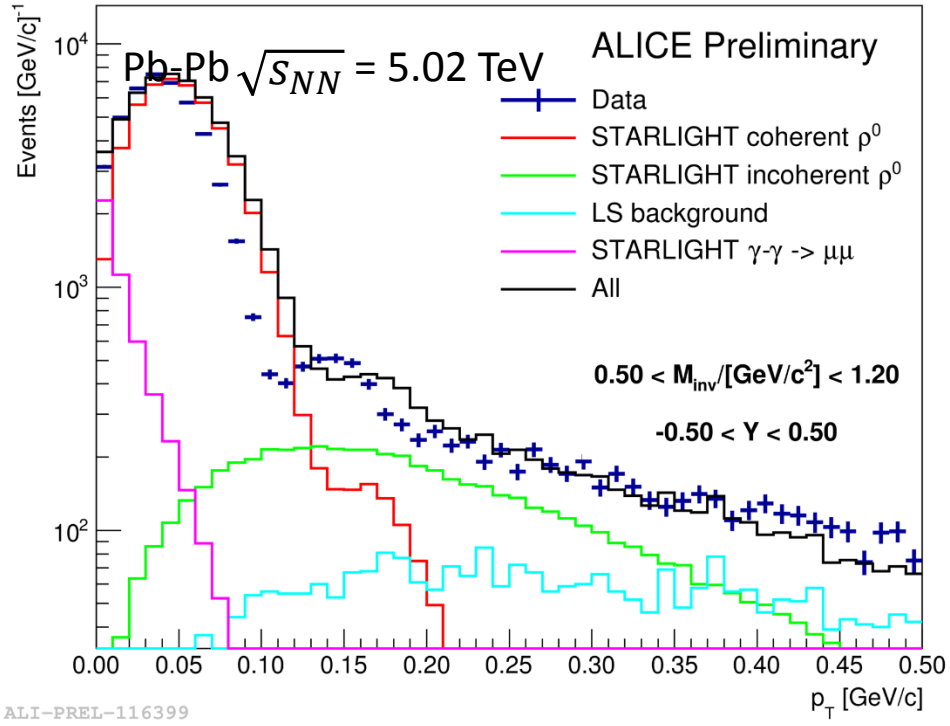
Forward UPC trigger:

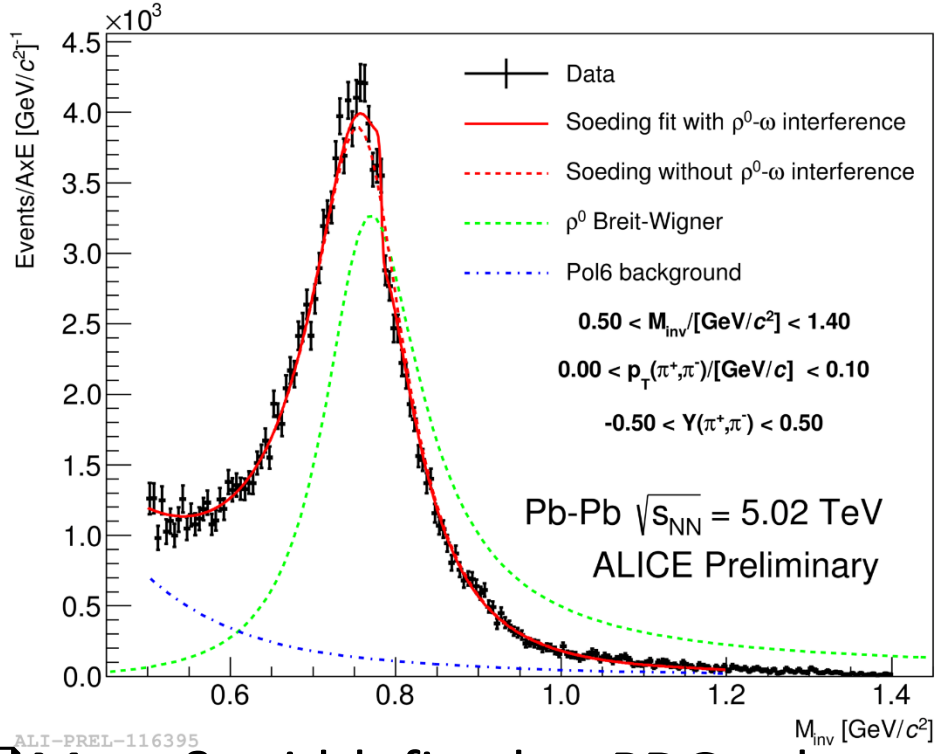
- 2 unlike-sign tracks, p_T>1 GeV/c
- No hits in AD-A or AD-C
- No hits in V0-A

Muon Arm and trigger detectors:

- ❑ Triggering, tracking and muon identification
- ❑ V0 counters provide veto to exclude events with hadronic interactions
- ❑ AD added for Run 2 for improved veto: (-7.0 < η < -4.9) and (4.8 < η < 6.3)
- ❑ ZDC can measure n & p from photo-dissociation

ρ^0 in Run 2





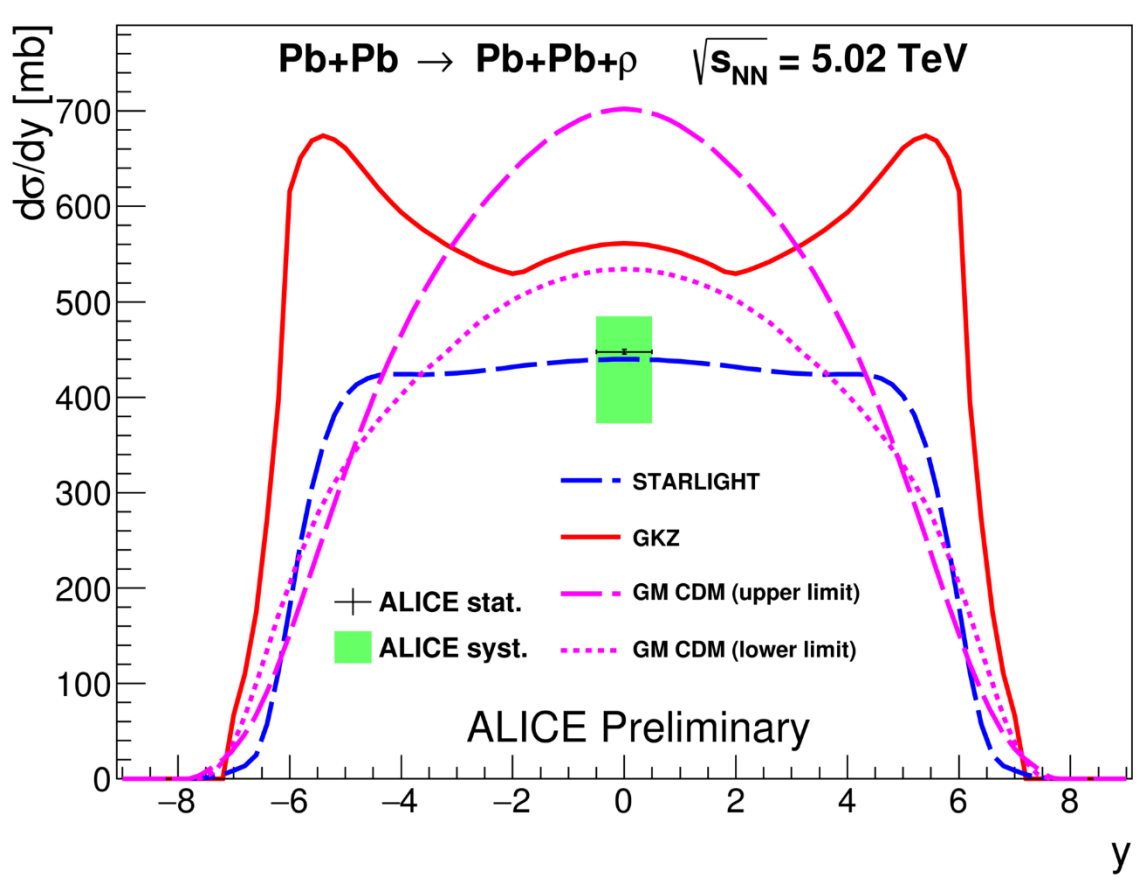
- First two diffractive peaks observed.
- STARLIGHT model exhibits some deviations.

- Mass & width fixed to PDG values.
- Fit with and without ω component.

$$\frac{d\sigma}{dm_{\pi\pi}} = \left|A \cdot BW + B + C \cdot e^{i\varphi} \cdot BW\right|^2 + N \cdot \text{pol6}$$

- Yield extraction of ρ^0 by integrating Breit-Wigner contribution from $2m_\pi$ to $M_\rho + 5\Gamma_\rho$.

ρ^0 in Run 2



ALI-PREL-116391

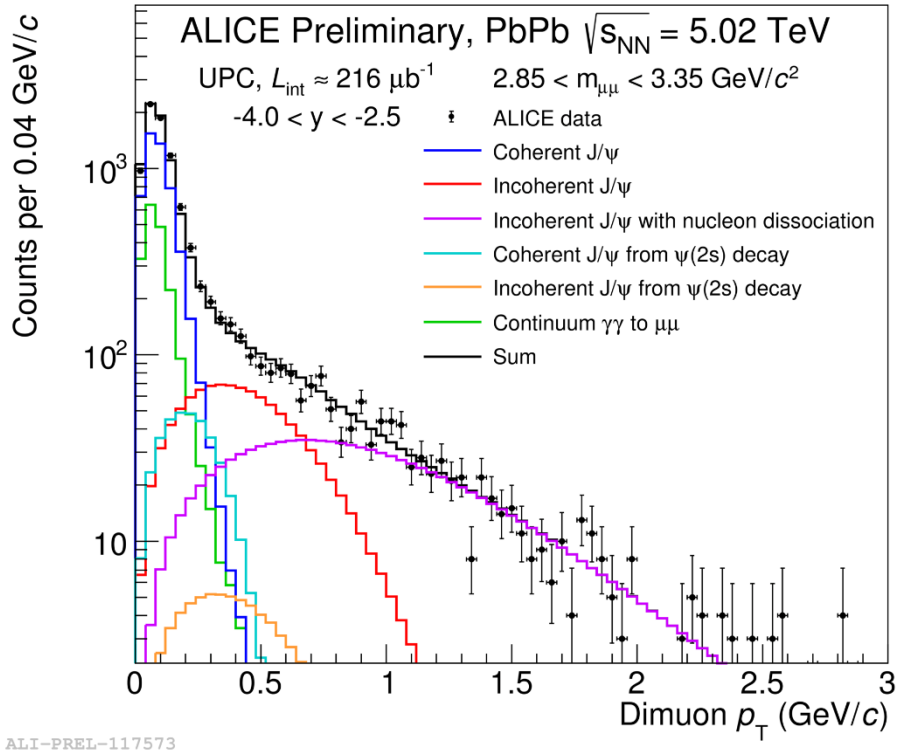
- Measured cross section:

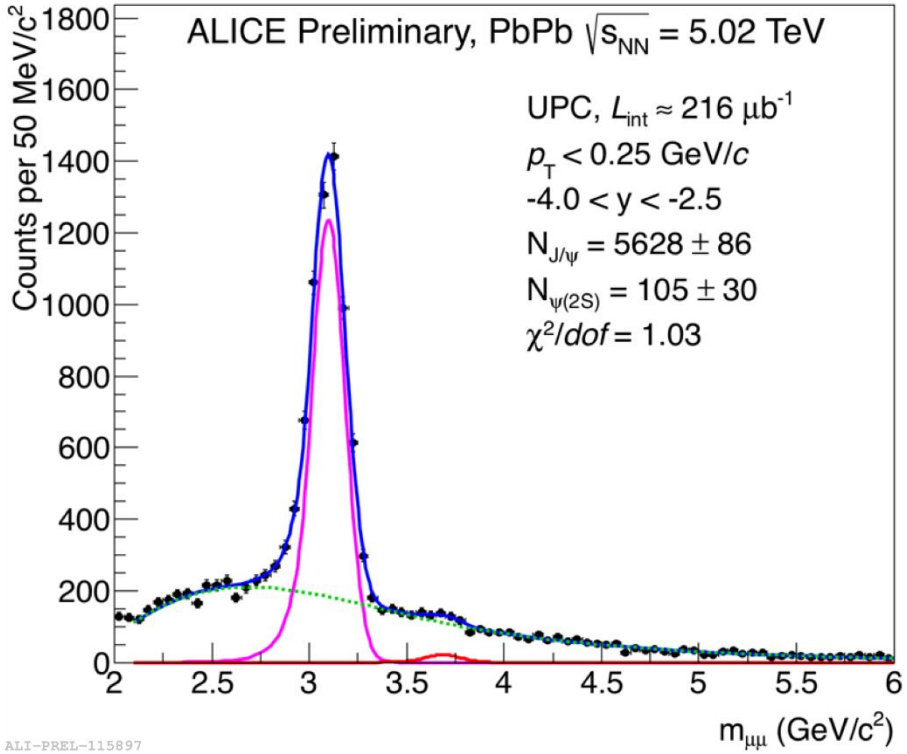
$$\frac{d\sigma}{dy} = 448 \pm 2(stat)\,^{+38}_{-75}(sys)\ \text{[mb]}$$

- Consistent with STARLIGHT.

- GM and GKZ over-predict ρ^0 cross section at mid-rapidity.

Coherent J/ψ at forward rapidity in Run 2



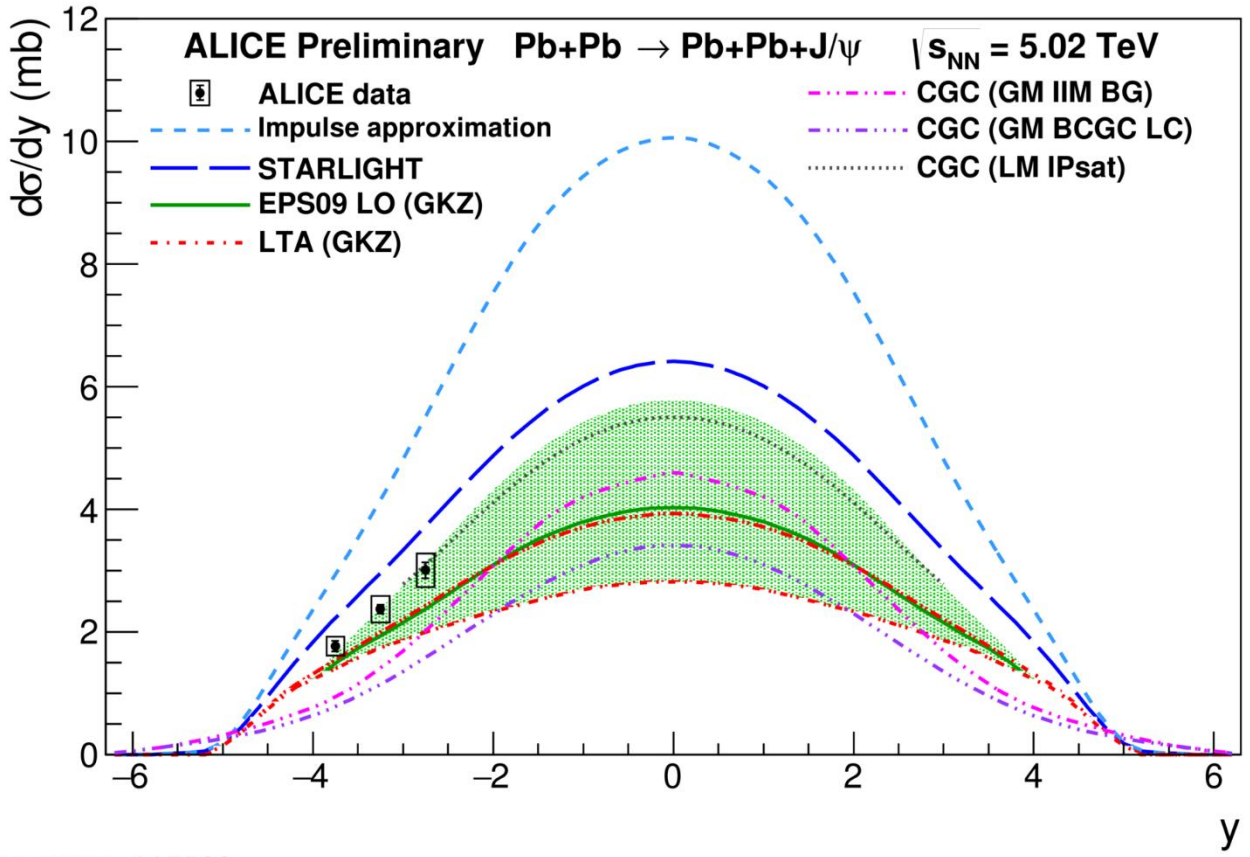


- Good match between data and templates from MC.

- J/ψ & ψ(2S) peaks fitted to Crystal Ball.

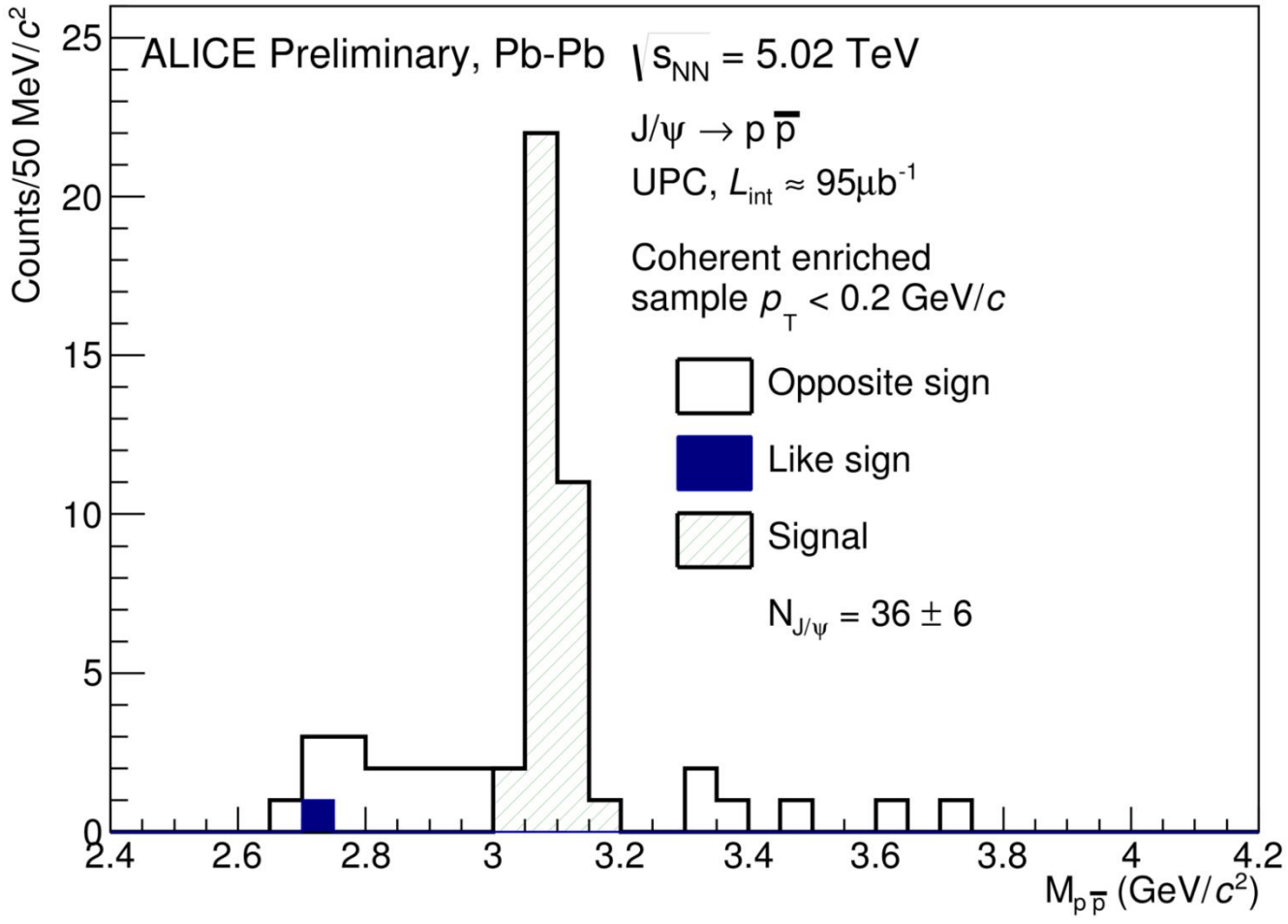
- ψ(2S) has 3σ significance.
- σ[ψ(2S)]/σ[J/ψ] ratio close to HERA γp results (0.166 ± 0.011).

Coherent J/ψ at forward rapidity in Run 2



- Higher statistics allow three points at forward rapidity.
- Consistent with moderate nuclear gluon shadowing.

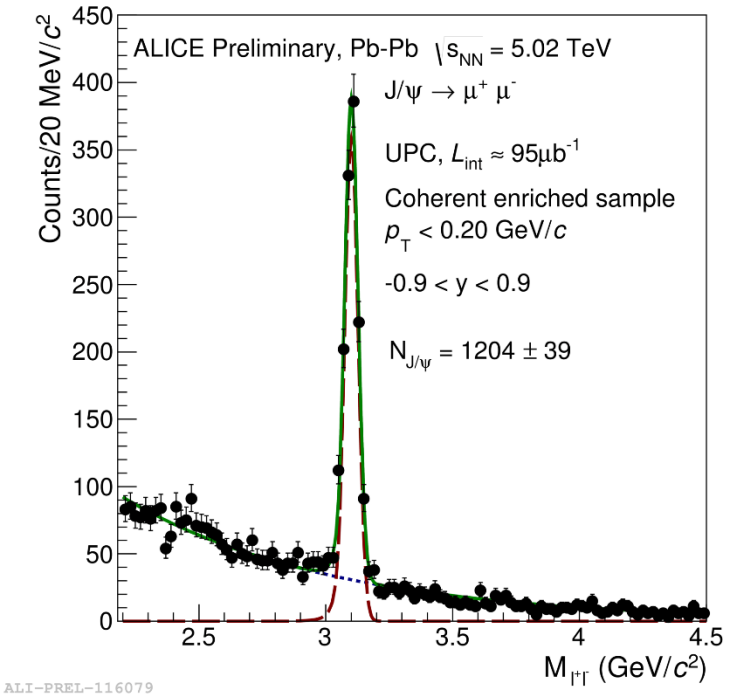
First measurement of J/$\psi \rightarrow p\bar{p}$ in UPC

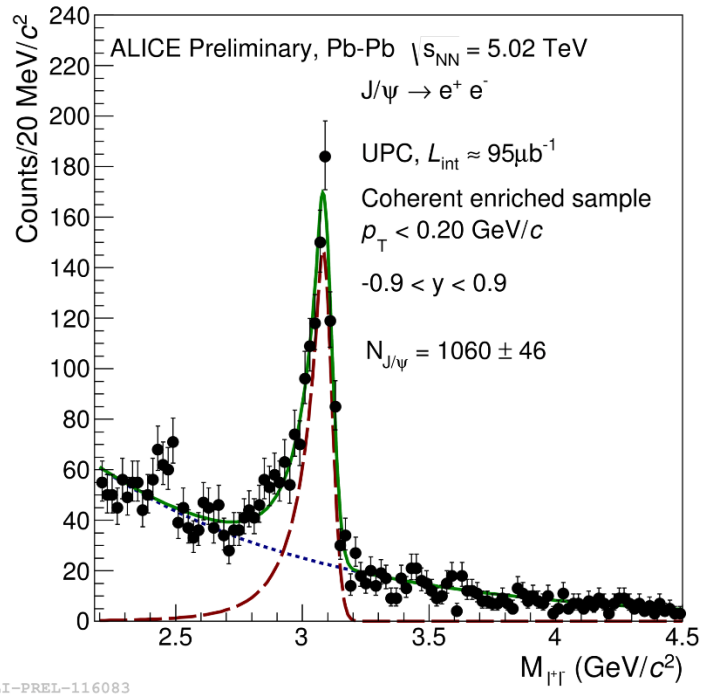


- J/$\psi \rightarrow p\bar{p}$ has very clean signal
- May also contain $\gamma\gamma \rightarrow p\bar{p}$

ALI-PREL-117138

Coherent J/ψ at mid-rapidity



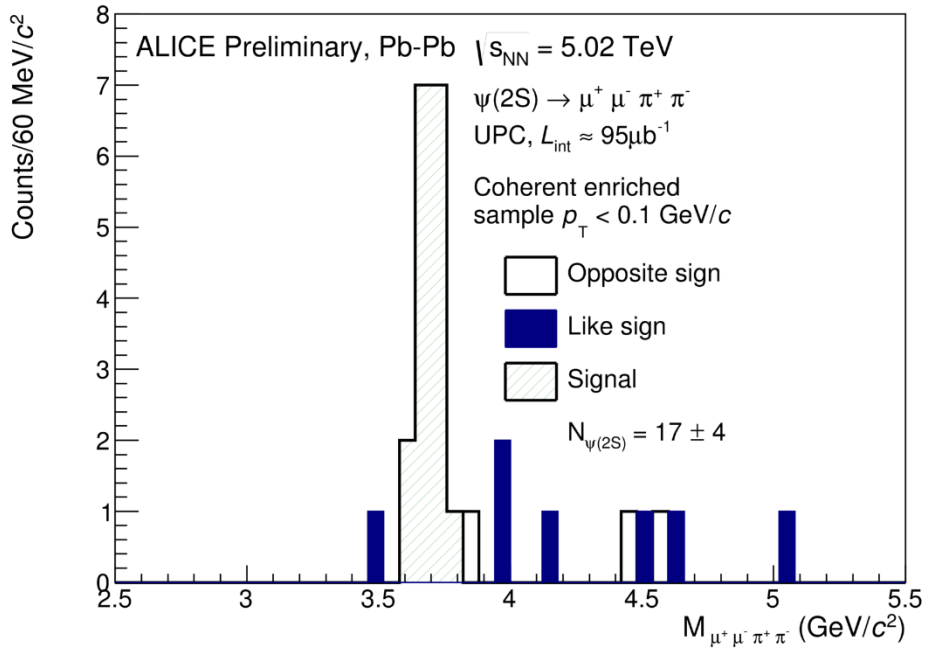


- $J/\psi \rightarrow \mu^+\mu^-$
- $N_{J/\psi}$ = 1204 ± 39

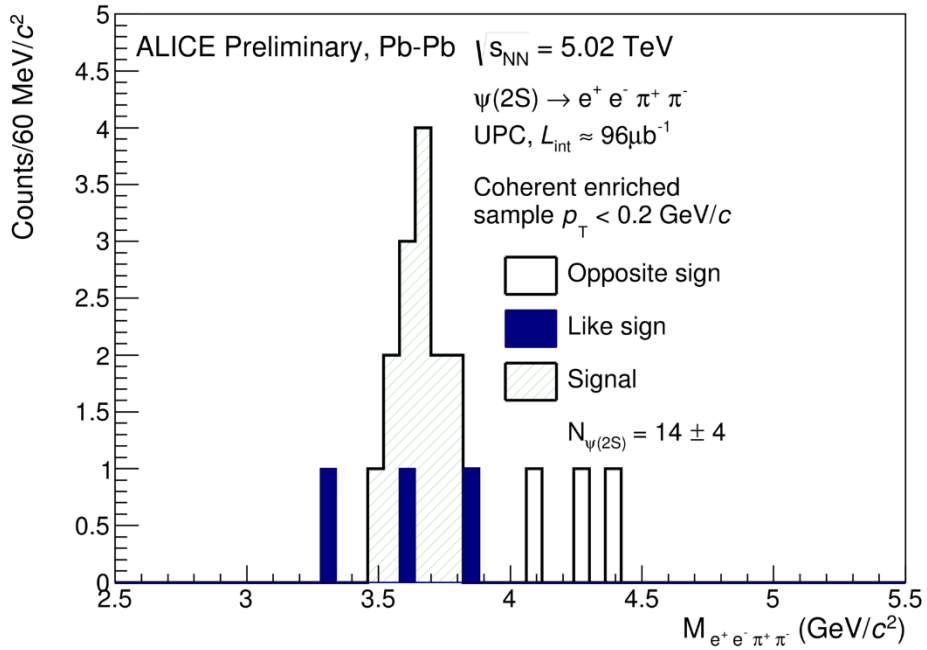
- $J/\psi \rightarrow e^+e^-$
- $N_{J/\psi}$ = 1060 ± 46

- 4 times more statistics than Run 1
- Access to $x \approx 5 \times 10^{-4}$

Coherent ψ(2S) at mid-rapidity



ALI-PREL-116095



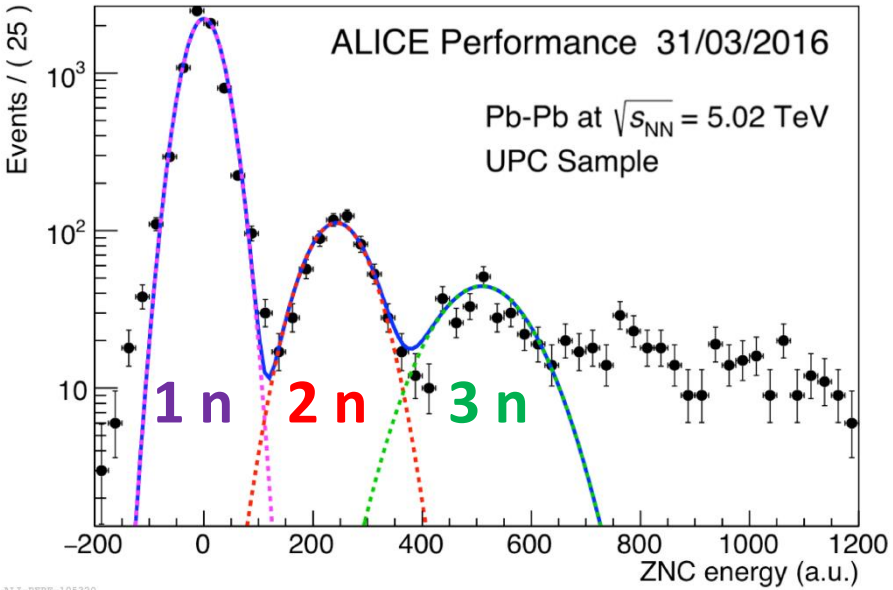
ALI-PREL-116091

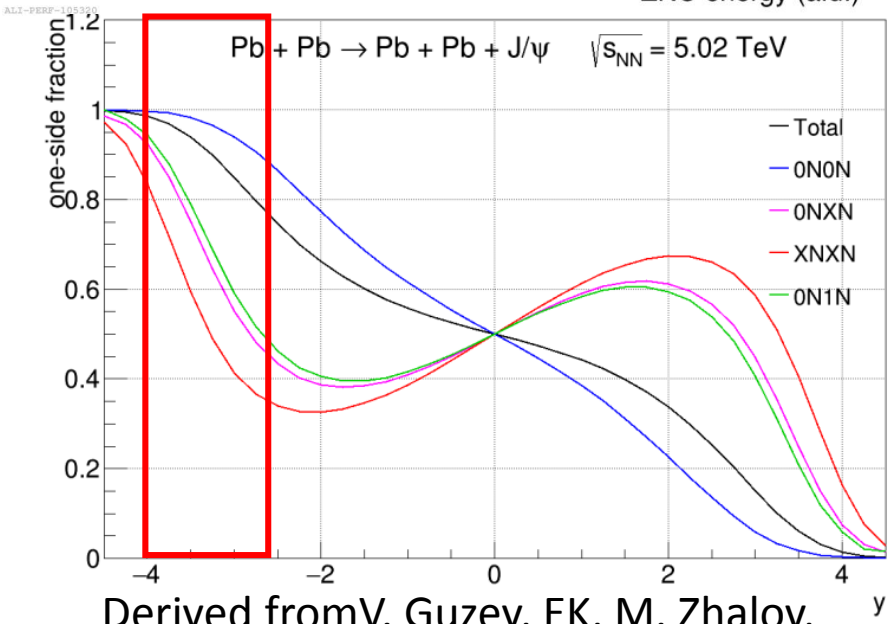
- Coherent ψ(2S) in muon channel $\psi(2S) \rightarrow \mu^+\mu^-\pi^+\pi^-$
- $N_{\psi(2S)} = 17 \pm 4$

- Coherent ψ(2S) in electron channel $\psi(2S) \rightarrow e^+e^-\pi^+\pi^-$
- $N_{\psi(2S)} = 14 \pm 4$

What's next?

- Study J/ψ with neutron dissociation (0n0n, 0nXn, 0n1n, XnXn)
  - Count neutrons with Zero Degree Calorimeters (ZDC).
  - Compare fractions to model predictions.
  - Access to x ≈ 10^{-5}.
- J/ψ polarization
- Incoherent cross sections
- Try measuring other particles in UPCs (η_c, Υ, ω, φ, etc.)





Derived fromV. Guzey, EK, M. Zhalov, **PRC93 (2016), 055206**

Summary

- Run 2 Pb-Pb measurements are providing results at higher energies, with higher statistics and with smaller statistical and systematic uncertainties.
- The higher statistics are allowing for more differential measurements (J/ψ at three forward rapidity or with/without neutron dissociation, for example).
- Results continue to favor models with moderate gluon shadowing.
- With higher statistics, the ratio $\sigma[\psi(2S)]/\sigma[J/\psi]$ at forward rapidity appears similar to HERA.
- The decay $J/\psi \rightarrow p\bar{p}$ has been observed for the first time in UPCs.
- Studies of ρ^0, J/ψ, ψ(2S) and other particles like η_C, Υ, ω, and φ are progressing.