Coherent J/ψ photo-production in peripheral and ultra-peripheral Pb-Pb collisions with ALICE

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ALICE

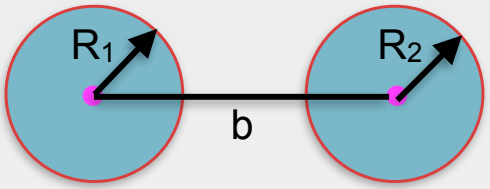
UNIVERSITY OF BERGEN

Overview

- Introduction
- The ALICE detector
- J/ψ photo-production in ultra-peripheral Pb-Pb collisions
- Low-p_T J/ψ yields in peripheral Pb-Pb collisions

Introduction

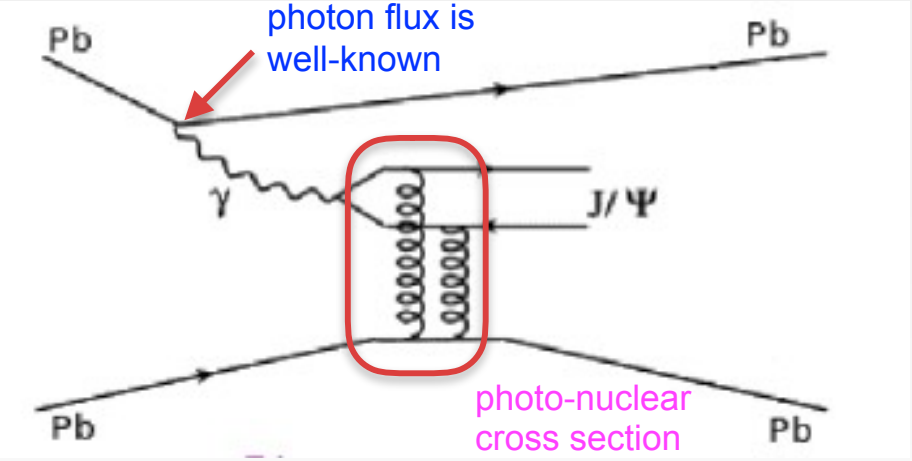
- Ultra-peripheral collisions (UPC):



impact parameter $b > R_1 + R_2$ (sum of nuclear radii)

- hadronic interactions are strongly suppressed
- electromagnetic interactions are dominant

- ➤ The electromagnetic field of Pb nuclei can be interpreted as a beam of quasi-real photons.
- ➤ Number of photons $\propto Z^2$
- ➤ Very clean experimental signature
  - vector mesons with low p_T
  - large rapidity gaps



Cross section for J/ψ photo-production

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y} = k_1 \times \frac{\mathrm{d}n}{\mathrm{d}k_1} \times \sigma_{\gamma+\mathrm{A}_2\to \mathrm{J}/\psi+\mathrm{A}_2} + k_2 \times \frac{\mathrm{d}n}{\mathrm{d}k_2} \times \sigma_{\gamma+\mathrm{A}_1\to \mathrm{J}/\psi+\mathrm{A}_1}$$

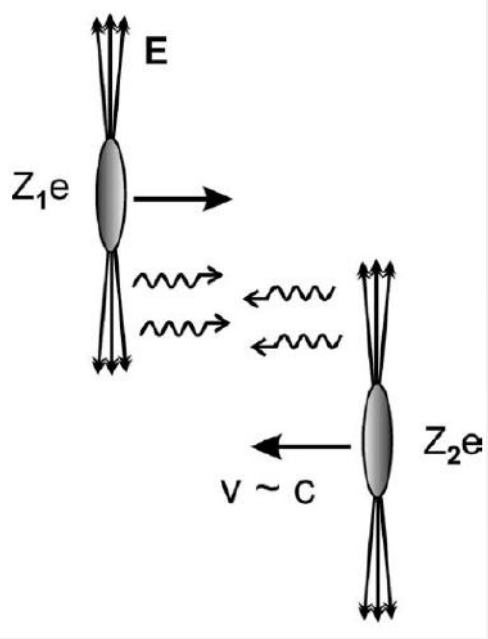
- blue: photon flux
- magenta: photo-nuclear cross section
  - sensitive to nuclear gluon distribution function

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

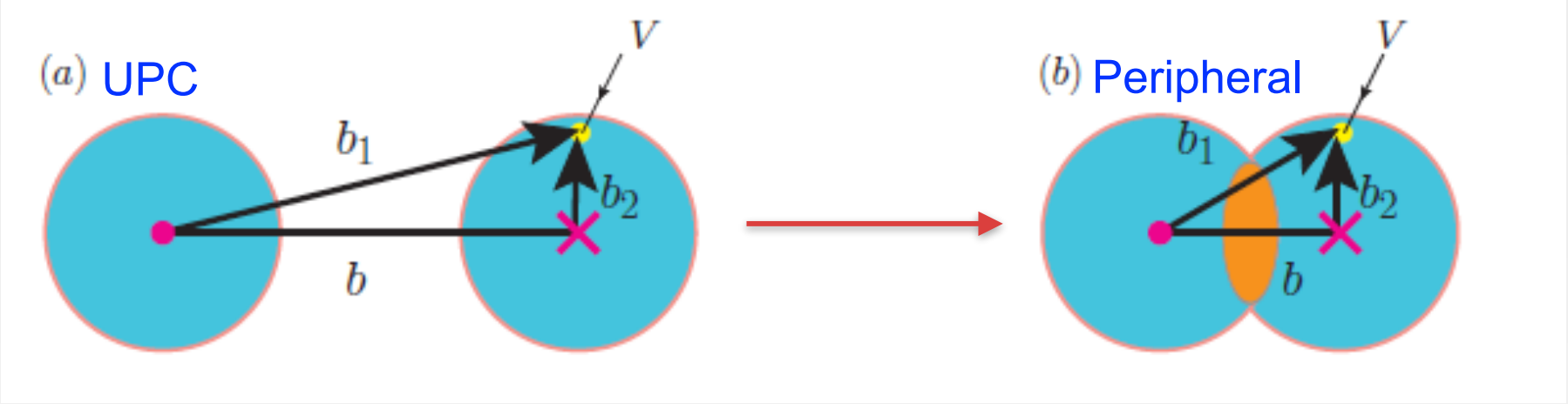
Ryskin 1993

J/ψ photo-production

- Coherent photo-production
  - Photon couples coherently to all the nucleons.
  - J/ψ $\langle p_T \rangle \approx 60$ MeV/c.
  - Target nucleus does not break up.
- Incoherent photo-production
  - Photon couples to part of the nucleus.
  - J/ψ $\langle p_T \rangle \approx 500$ MeV/c.
  - Target nucleus breaks up.



Peripheral collisions



- impact parameter $b < R_1 + R_2$
- electromagnetic interactions still occur
- hadronic interactions in overlap region
- "absorption" effect expected in overlap region
  - effective photon flux
  - effective photo-nuclear cross section
  - azimuthal anisotropy of the produced vector mesons? (v1, v2) → appendix (slide 22)

PRC 97 044910 (W.Zha et al.)

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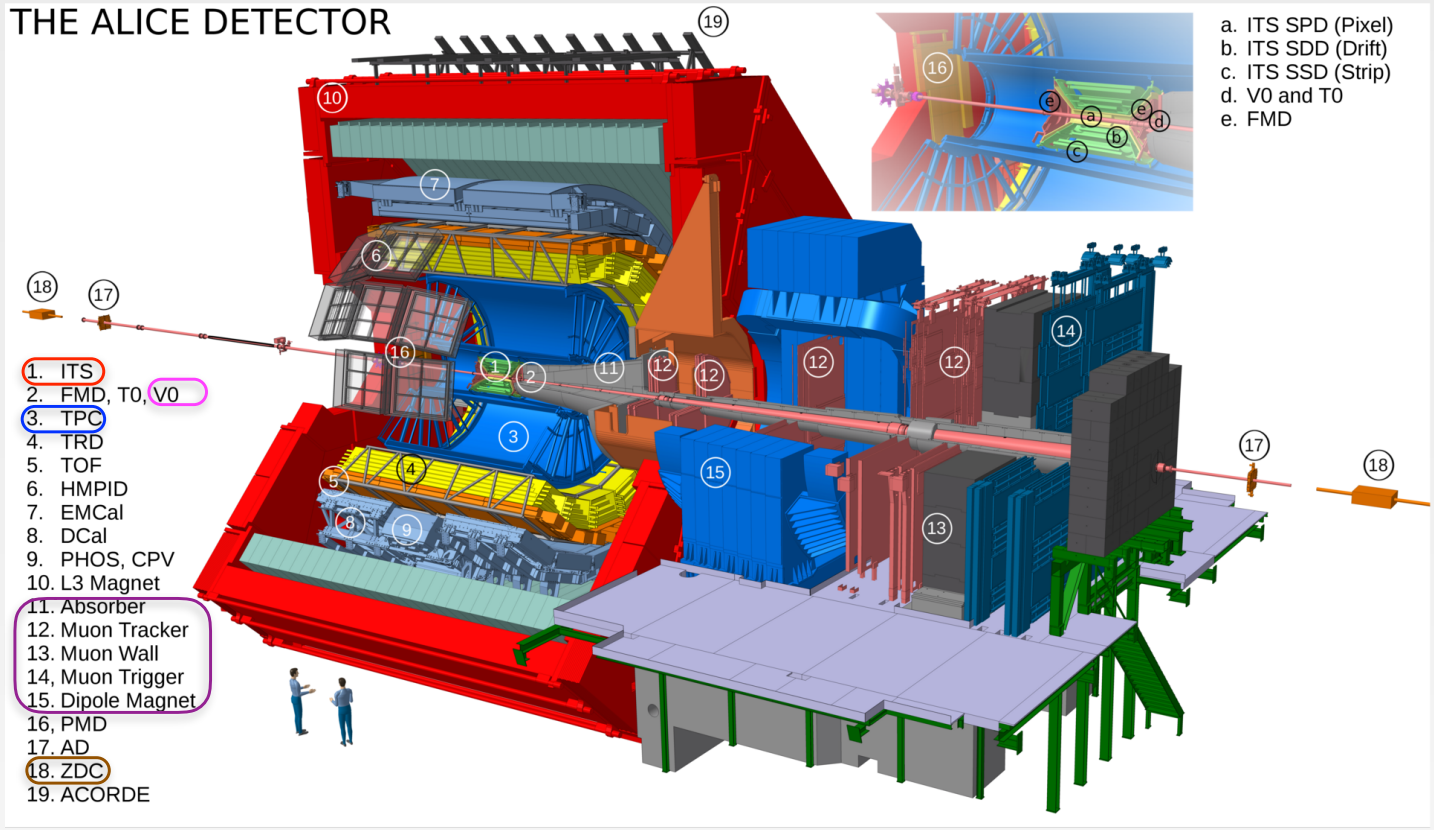
ALICE detector LHC Run-2



rapidity ranges covered for:

- the central barrel
  $-0.9 < y < 0.9$
- the muon spectrometer
  $2.5 < y < 4.0$

- Inner Tracking System (ITS) — vertex reconstruction, tracking.
- Time Projection Chamber (TPC) — tracking, particle identification.
- V0 scintillators (V0) — triggering, centrality.
- Zero Degree Calorimeters (ZDC) — background rejection, event selection.
- muon spectrometer — measurement of muons at forward rapidity.

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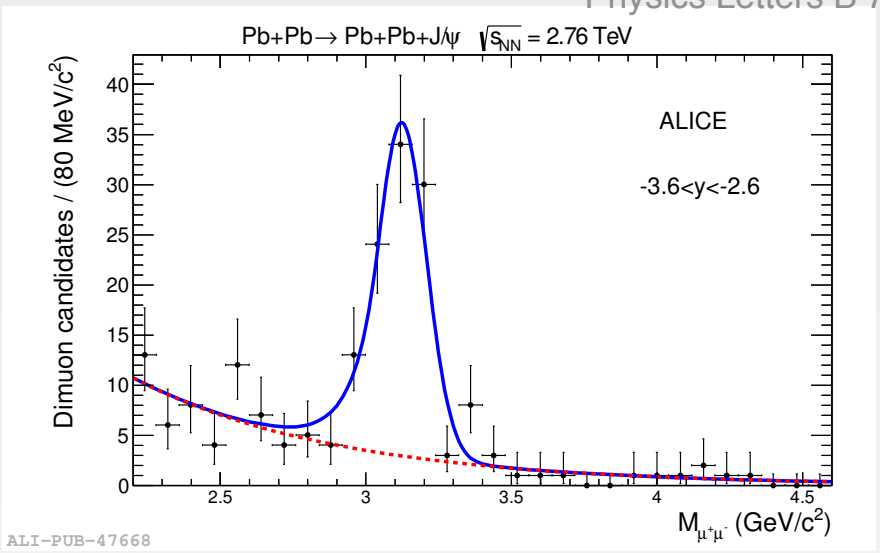
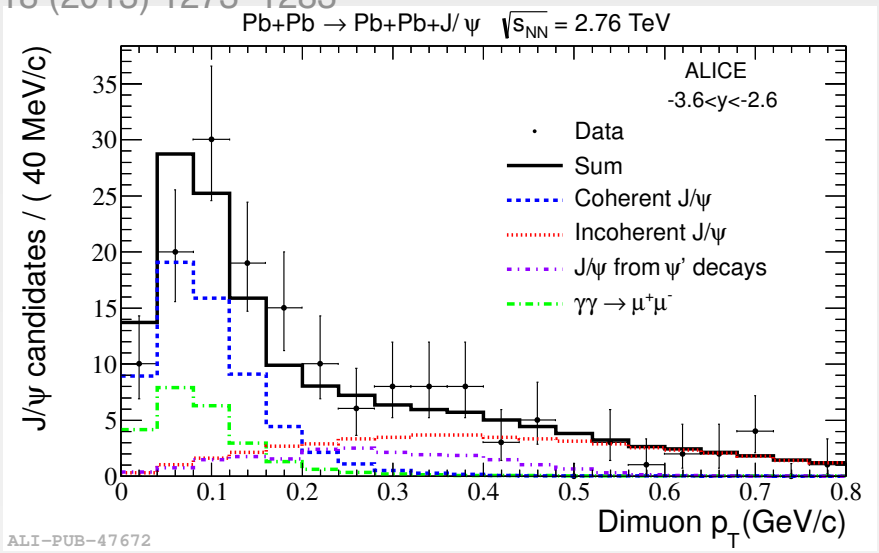
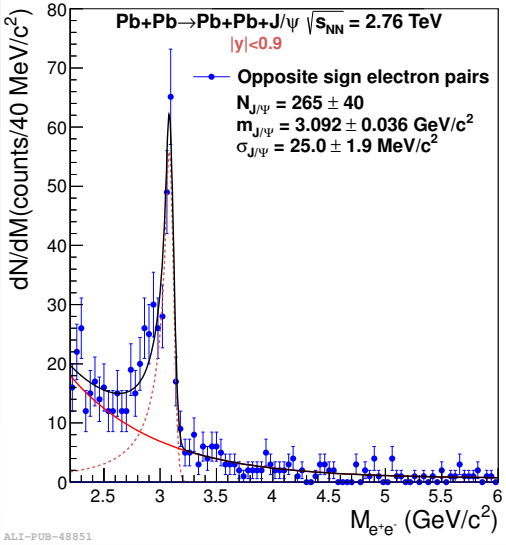
J/ψ production in UPC in Pb-Pb @ 2.76 GeV

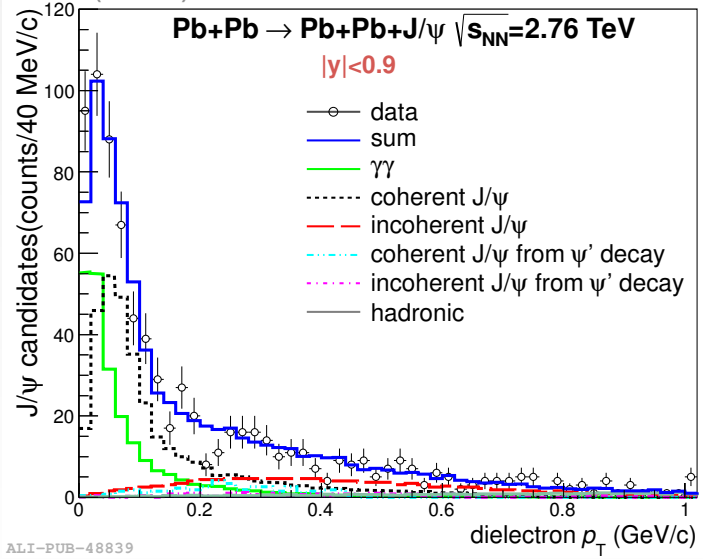
Physics Letters B 718 (2013) 1273–1283





Eur. Phys. J. C (2013) 73:2617





top: J/ψ → u^+u^-

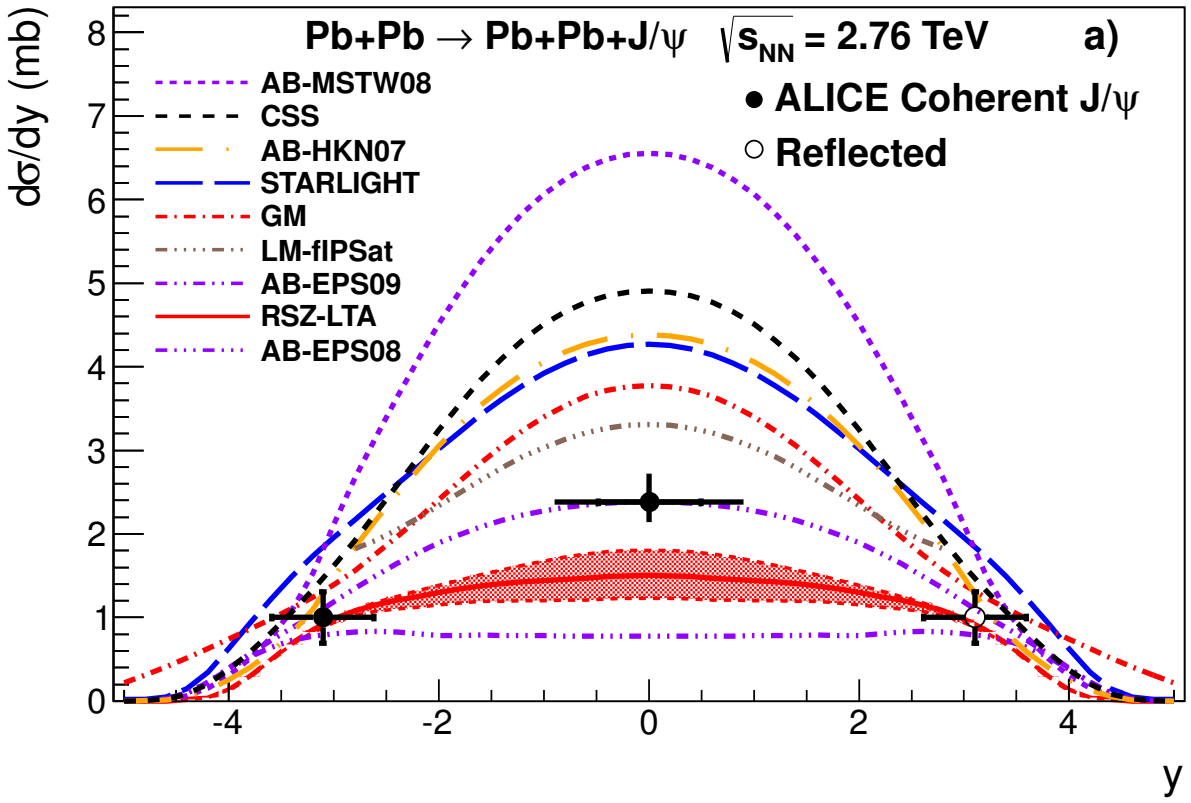
bottom: J/ψ → e^+e^-

- clear J/ψ signal in invariant mass distributions (left)
- Starlight calculations in good agreement with data (right)
- coherent J/ψ extracted by template fit with Starlight calculations

▶ Clear J/ψ signal has been found in both channels.

Coherent J/ψ in Pb-Pb in UPC @ 2.76 GeV

Phys.Lee. B 718 (2013) 1273-1283 and Eur. Phys. J. C (2013) 73:2617

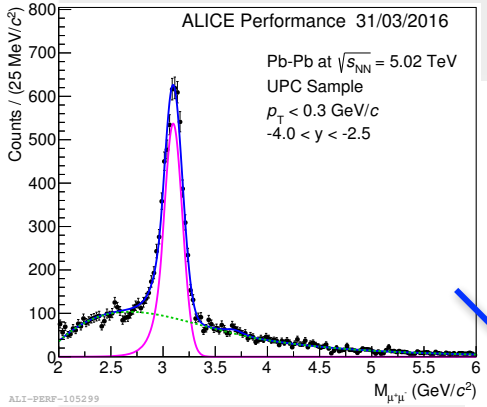


- **AB:** collinear approach with different amount of shadowing
- **Starlight:** fit to HERA data
- **CSS:** kt-factorisation
- **GM, LM:** color dipole model with saturation
- **RSZ:** leading twist approximation

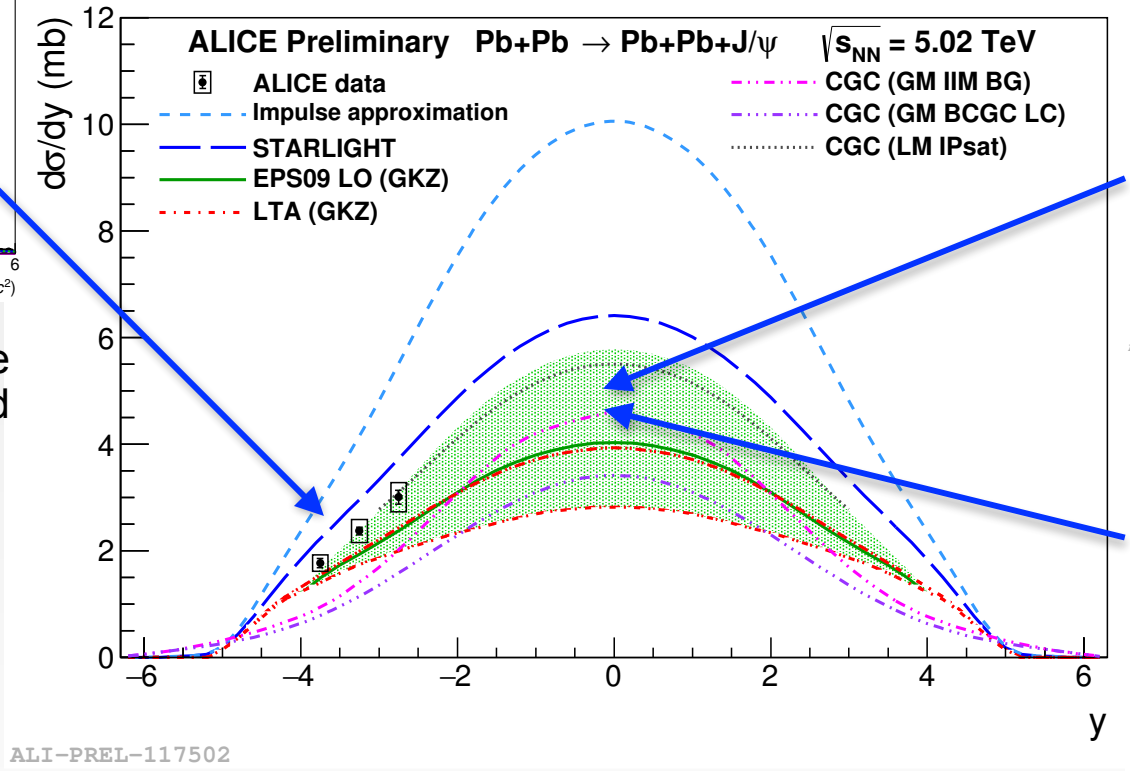
The model with moderate amount of shadowing (AB-EPS09) describes data best

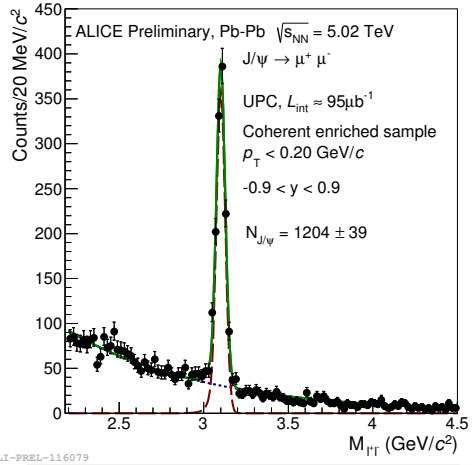
⇒ Direct evidence of moderate nuclear shadowing!

Coherent J/ψ in Pb-Pb in UPC @ 5.02 TeV

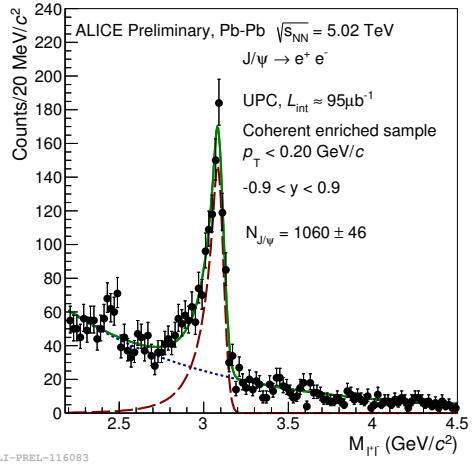


At forward rapidity, the analysis confirms and improves Run-1 results.





At mid-rapidity, work in progress.



- EPS09 LO: leading-order EPS09.
- LTA: Leading Twist Approximation.
- CGC: Color Glass Condensate.

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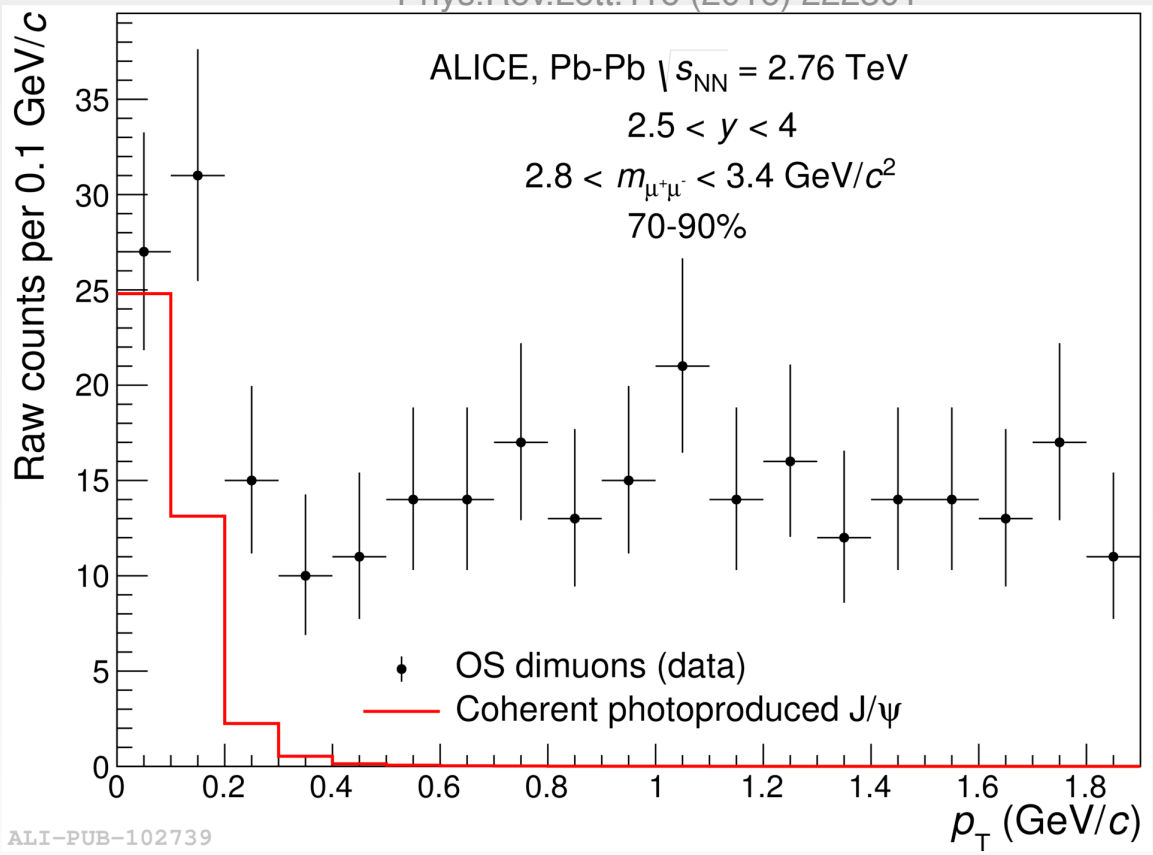
Low-p_T J/ψ yield excess in Pb-Pb @ 2.76 TeV

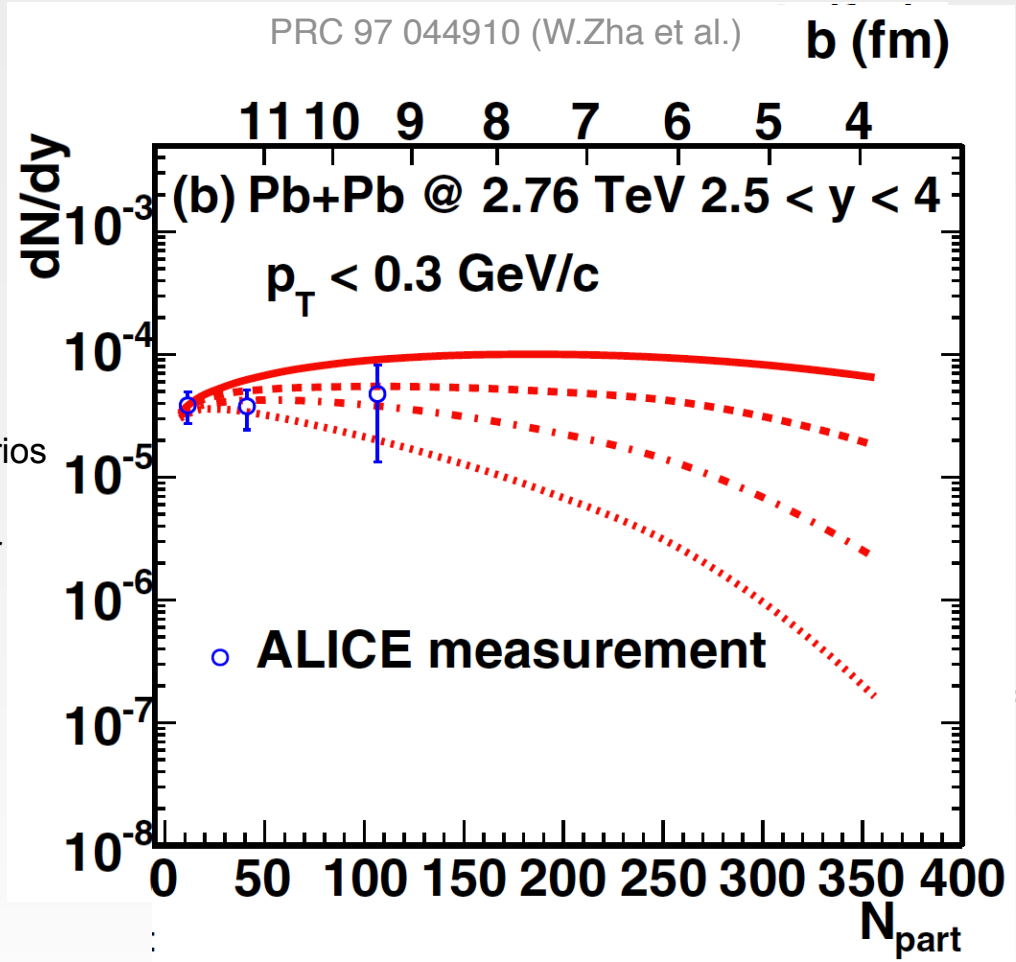
In LHC Run-1, ALICE measured for the first time an excess of J/ψ at very low p_T in peripheral Pb-Pb collisions at forward rapidity.

Phys.Rev.Lett.116 (2016) 222301



- Opposite sign di-muon pairs in the muon spectrometer with invariant mass around the J/ψ mass (black)
- STARLIGHT calculations (red), scaled to match the integral of the excess yield of data

Comparison with model calculations



coupling scenarios
N: nucleus
S: spectator

N + N
N + S
S + N
S + S

coupling scenarios

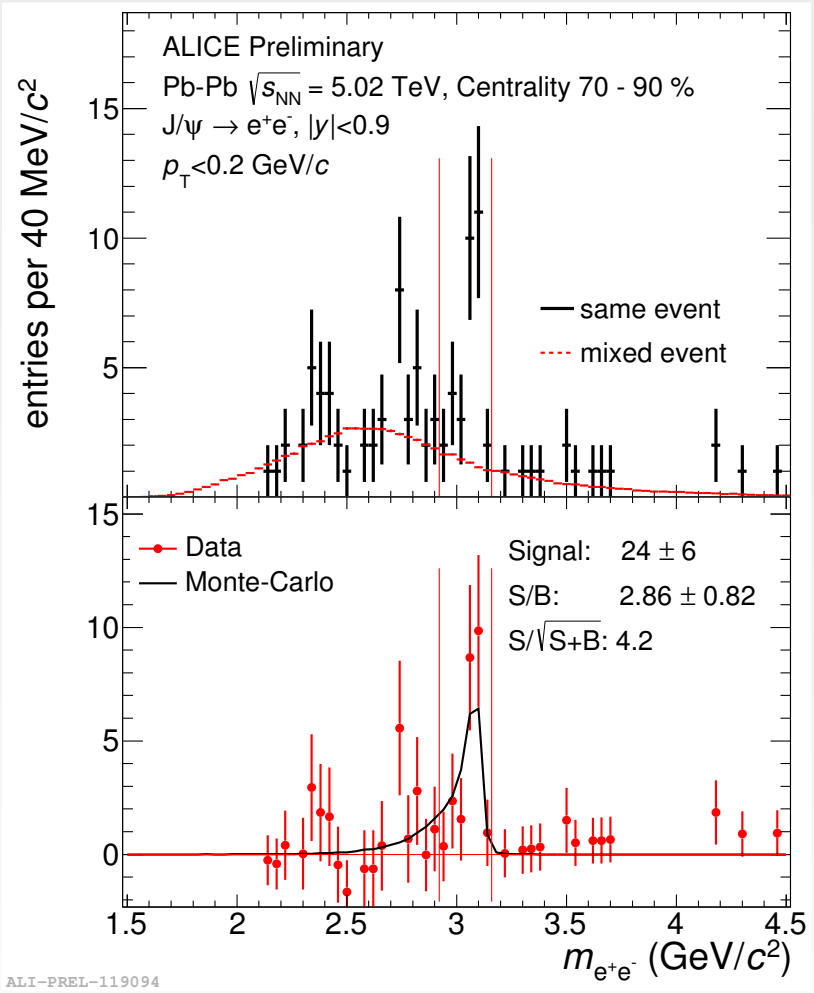
- Spectator nucleons:
  Free of hadronic interactions, can still act coherently
- Participating nucleons:
  Violent hadronic interactions and losses of longitudinal momenta leading to the destruction of coherent action. Full solution not available.

⇒ N+N (entire nucleus) and S+S (only spectator) coupling scenarios should bracket the actual case

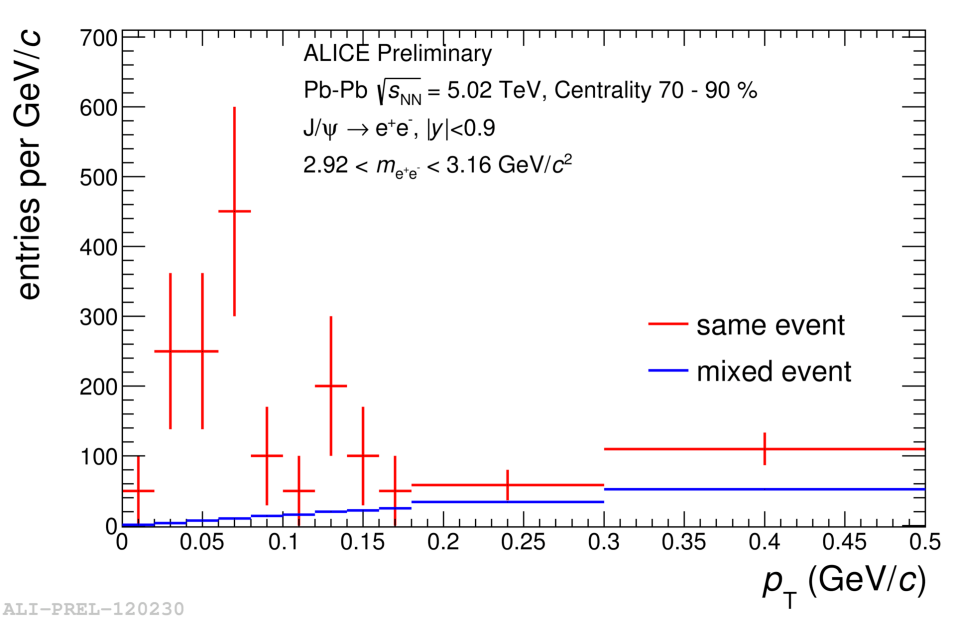
- ALICE Run-1 data (blue) are consistent with all four scenarios within the uncertainties.
- ALICE Run-2 data will provide better statistical precision and coverage to more central events to constrain the models.

Low-p_T J/ψ yield excess in Pb-Pb @ 5.02 TeV

The low p_T J/ψ excess was also observed at mid-rapidity



significance of ~ 4, but very good S/B ratio

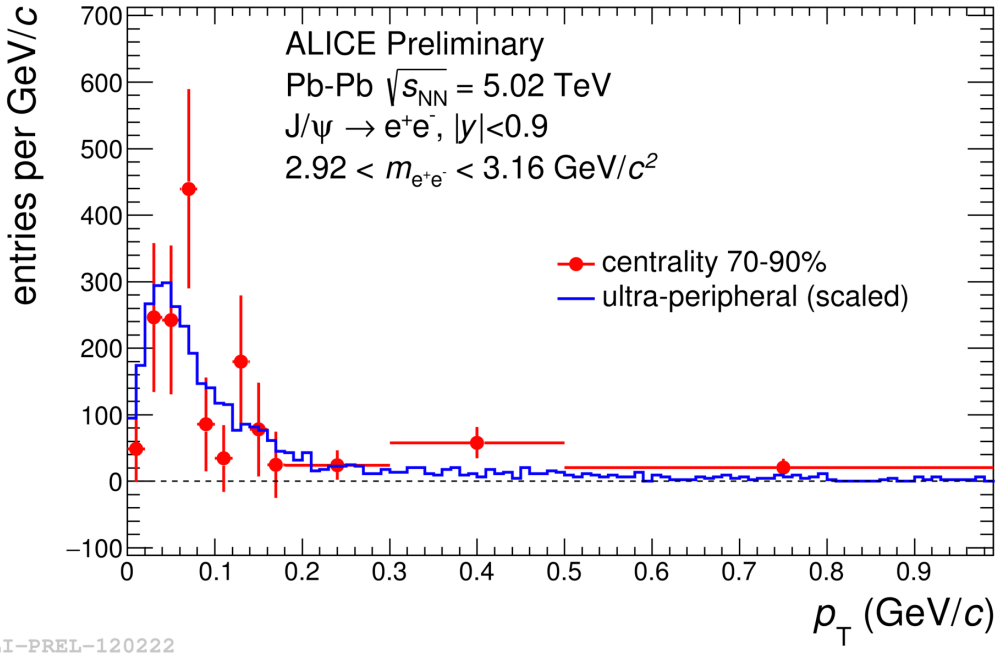


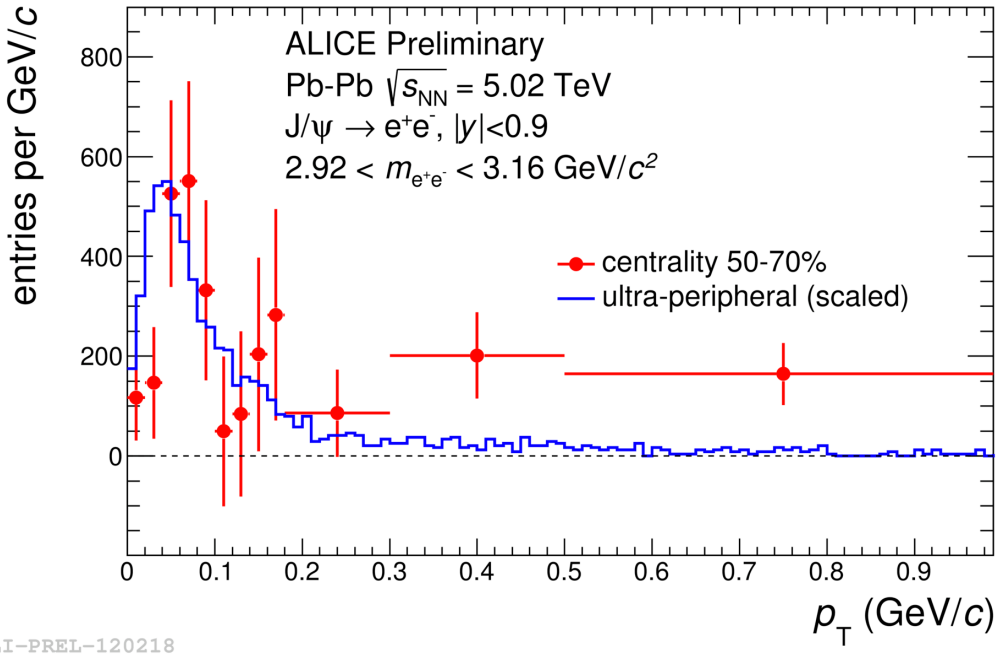
raw counts of e^+e^- pairs in J/ψ mass region (red)
low combinatorial background (blue)

- The higher resolution at mid-rapidity allows the measurement of p_T spectrum (an important signature for coherent J/ψ photo-production).

Comparison between peripheral and UPC measurements

- peripheral measurements (red) after subtraction of combinatorial background
- UPC measurements (blue) are scaled to match the integral of peripheral measurements



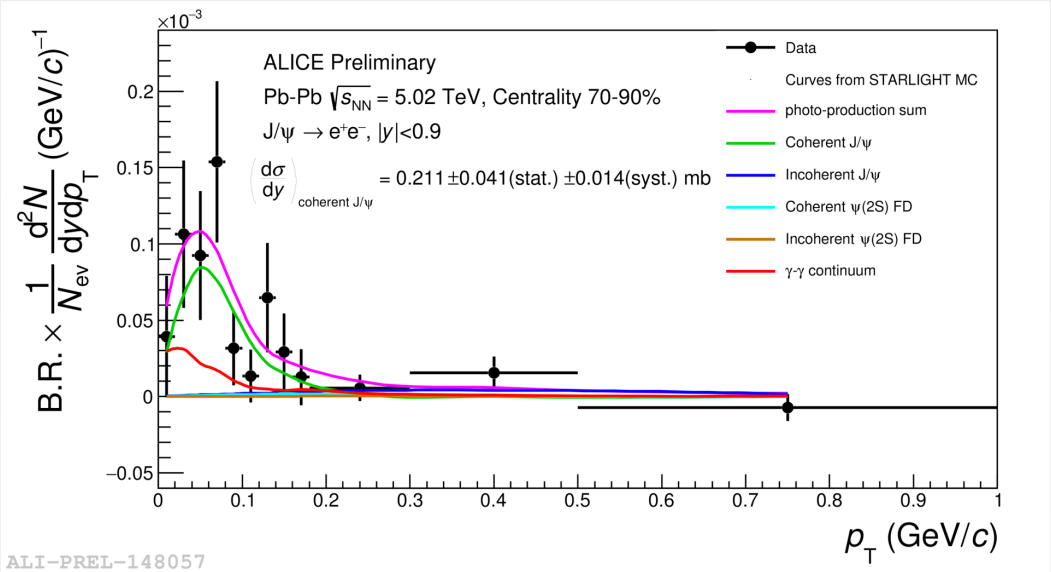


- ▲ good agreement with the UPC measurements in the region p_T < 300 MeV/c
- ▲ difference observed in the region p_T > 300 MeV/c
  - ➤ due to contribution from hadronically produced J/ψ

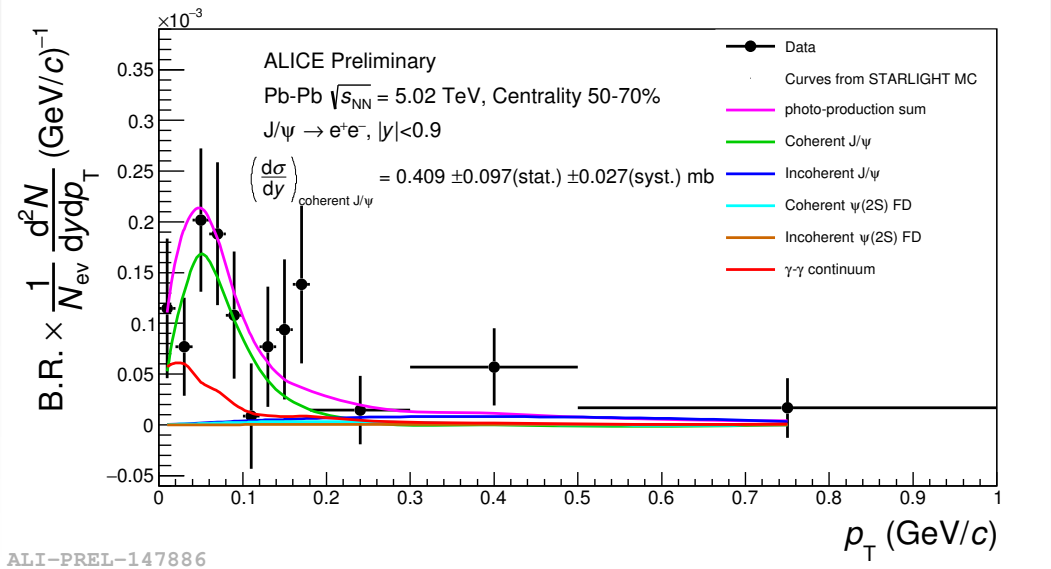
★ Comparison with UPC measurements strengthens the hypothesis that the origin of low-p_T J/ψ yield excess is from photo-production.

★ The upcoming Pb-Pb data will allow the observations of modifications of the p_T spectrum and its centrality dependent.

Coherent J/ψ yield excess with template fit



The corrected coherent J/ψ yields vs. p_T for 70-90% (top) and 50-70%(bottom) with template fits

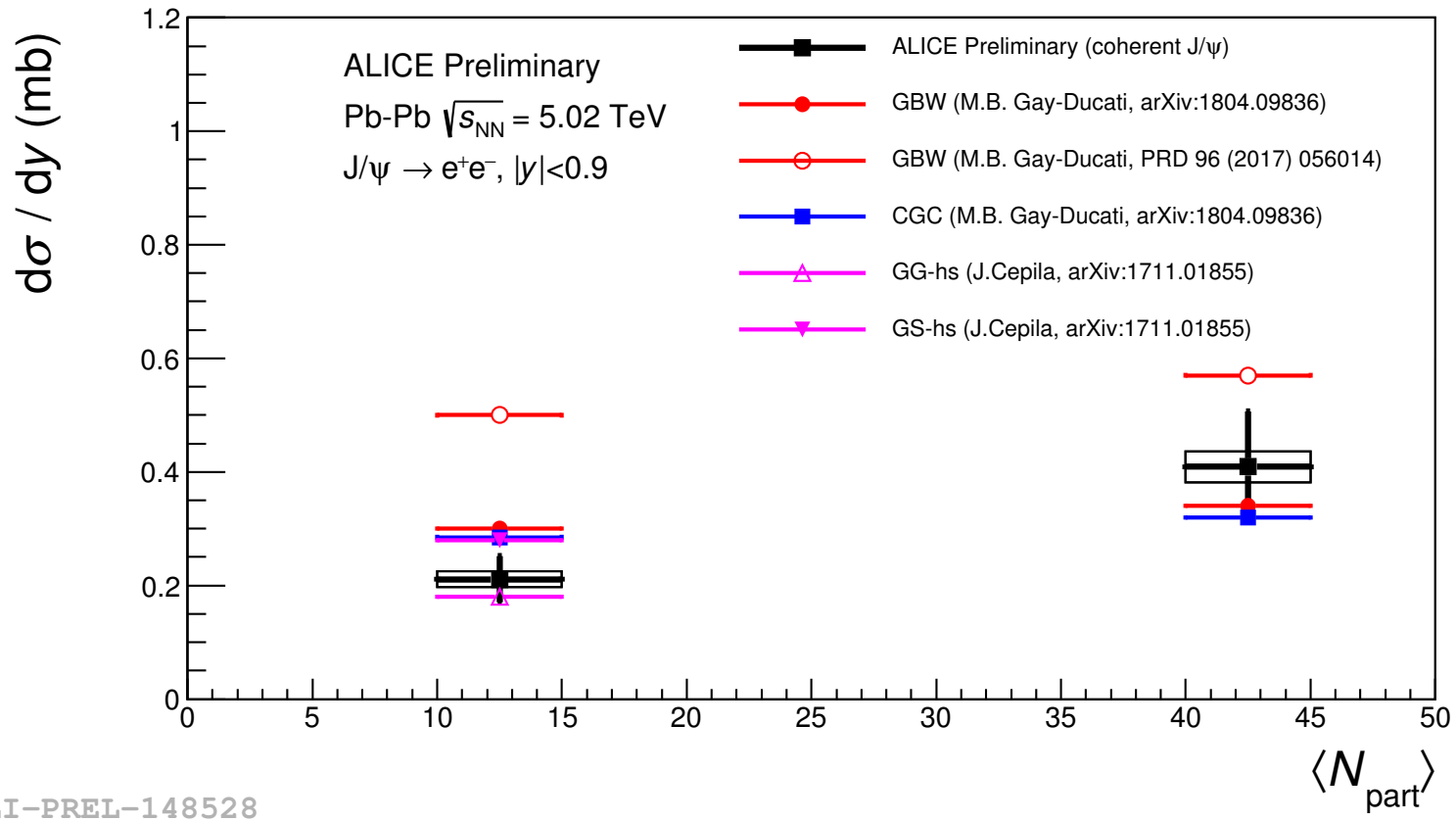


Signal extraction using template fit

- coherent J/ψ
- incoherent J/ψ
- coherent ψ(2S) feed-down
- incoherent ψ(2S) feed-down
- $\gamma\gamma$ continuum → e^+e^-

- The relative weights between the different components are kept fixed from the UPC measurement.
- The overall scale was fitted to data.

Cross section comparison with model calculations



ALI-PREL-148528

GBW 2017:
γ flux with nuclear overlap

GBW 2018:
γ flux modified

CGC:
color-glass condensate

GG-hs, GS-hs:
energy-dependent hot spot models

Agreement with all model calculations except GBW 2017

→ GBW 2017 neglects the nuclear overlap region, in GBW 2018, “absorption” effects has been taken into account by modification to photon flux.

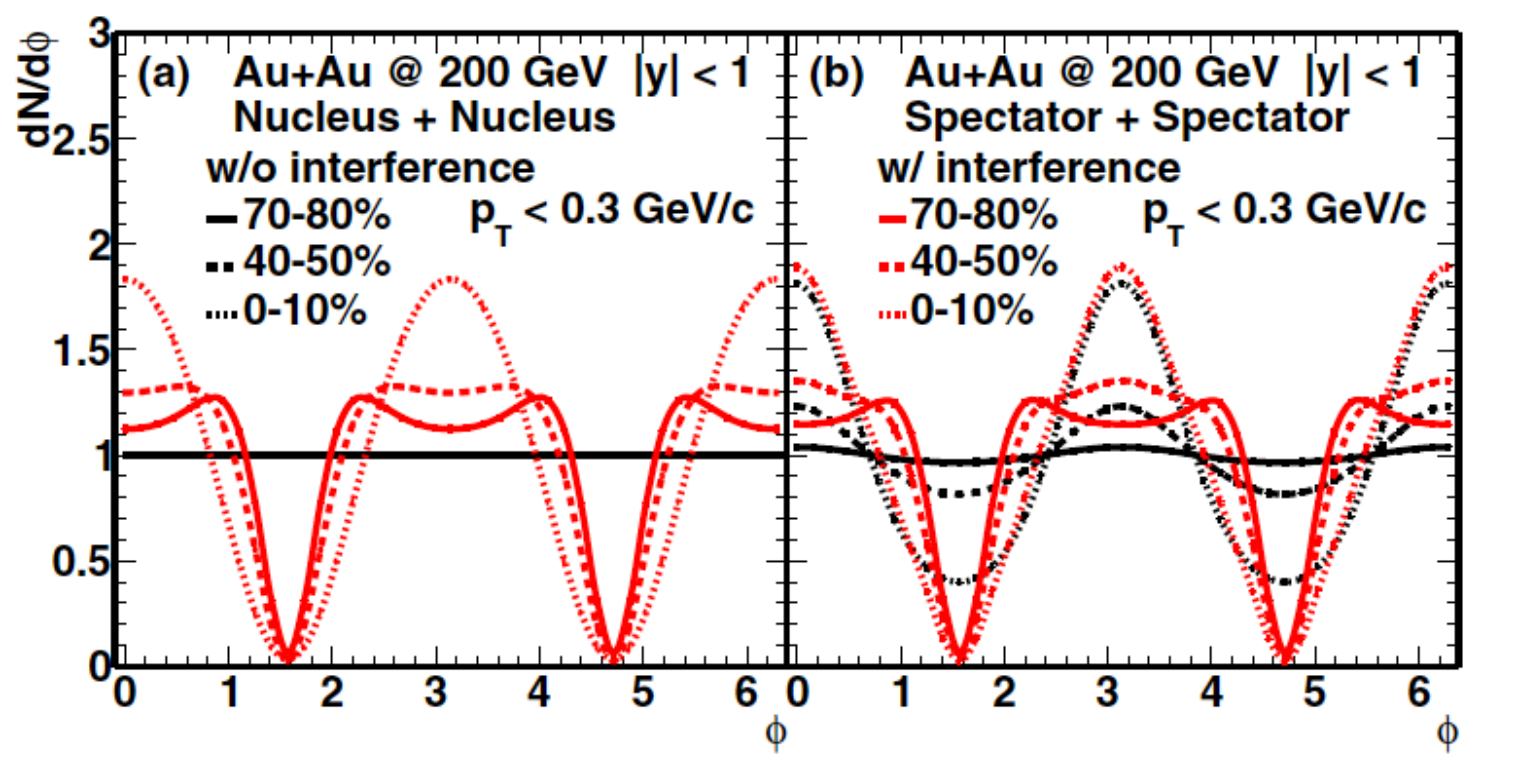
Summary

- Coherent J/ψ photo-production in UPC
  - The coherent J/ψ cross section strongly constrains models.
  - The results at 2.76 TeV favor a moderate amount of shadowing in the Bjorken-x range relevant for J/ψ production

- Coherent J/ψ photo-production in peripheral collisions
  - An excess of J/ψ compared to expectations from hadronic production was observed at both forward and mid-rapidity by ALICE.
  - It illustrates the origin of low-p_T J/ψ excess is from photo-production.
  - The cross section of coherent J/ψ photo-production agrees with various model calculations within the statistical precision.
  - Higher precision of the upcoming Pb-Pb data will allow to measure the excess in more central collisions and distinguish the various scenarios.

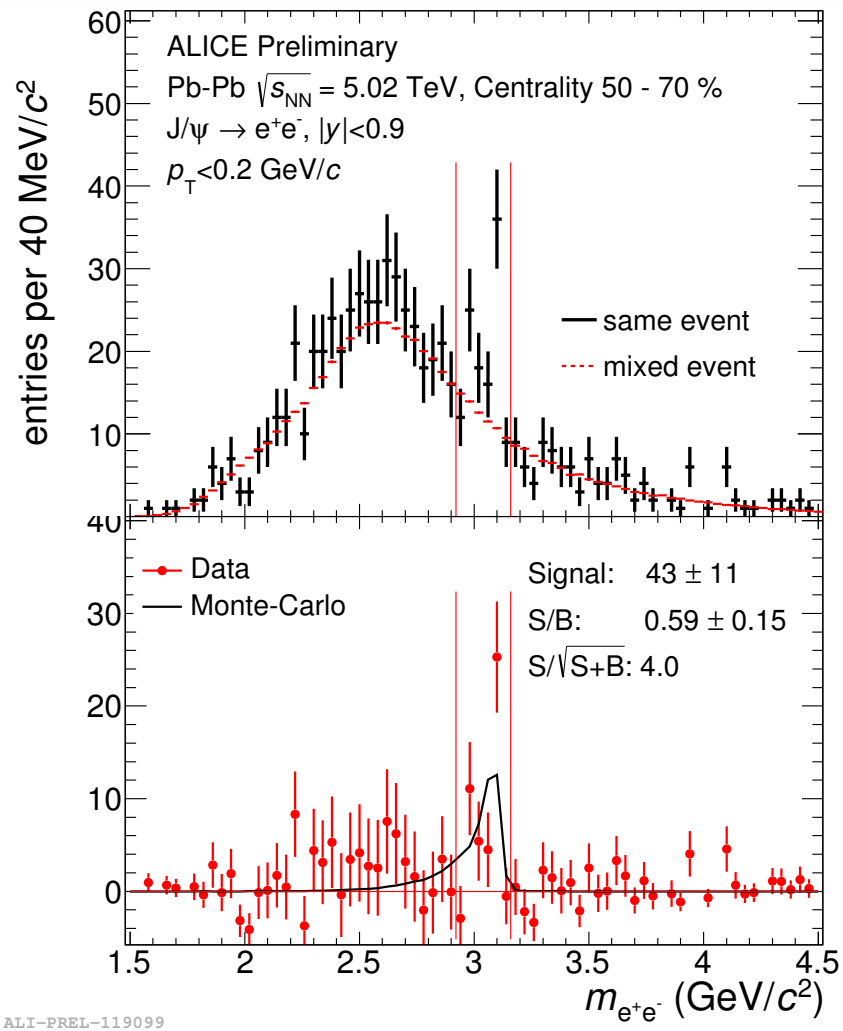
Appendix

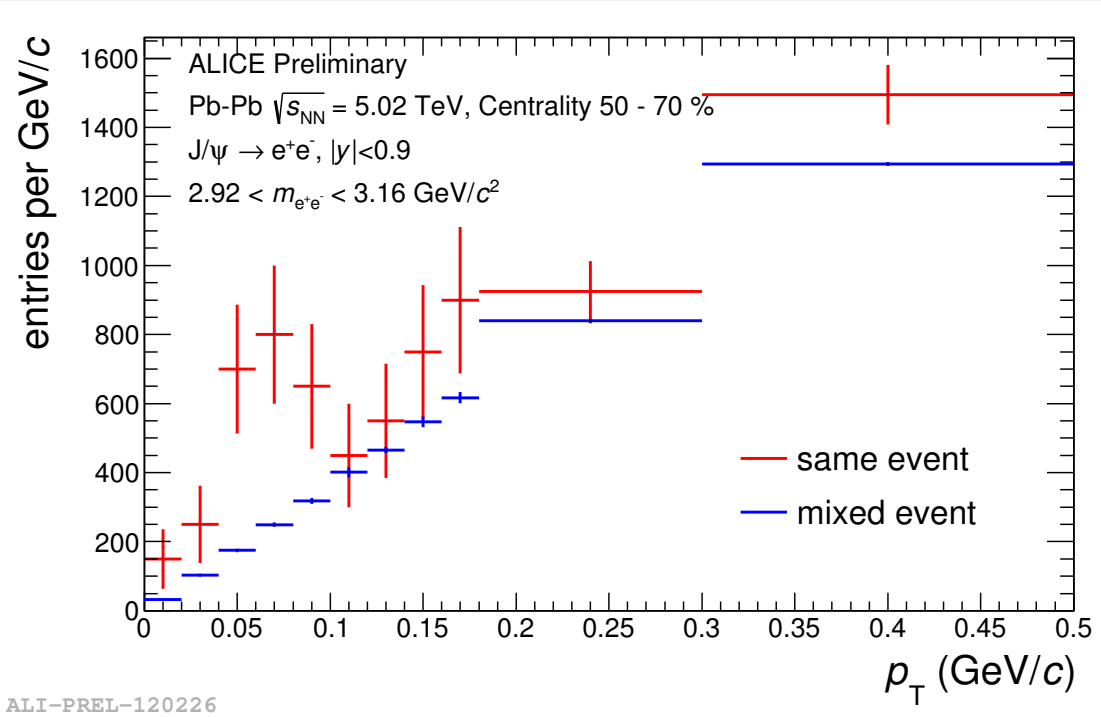
The angular distributions of coherent J/ψ with respect to the reaction plane



The reaction plane spanned by the impact parameter and the beam axis, can be determined from the azimuthal anisotropies of produced particles due to the asymmetric collision geometry.

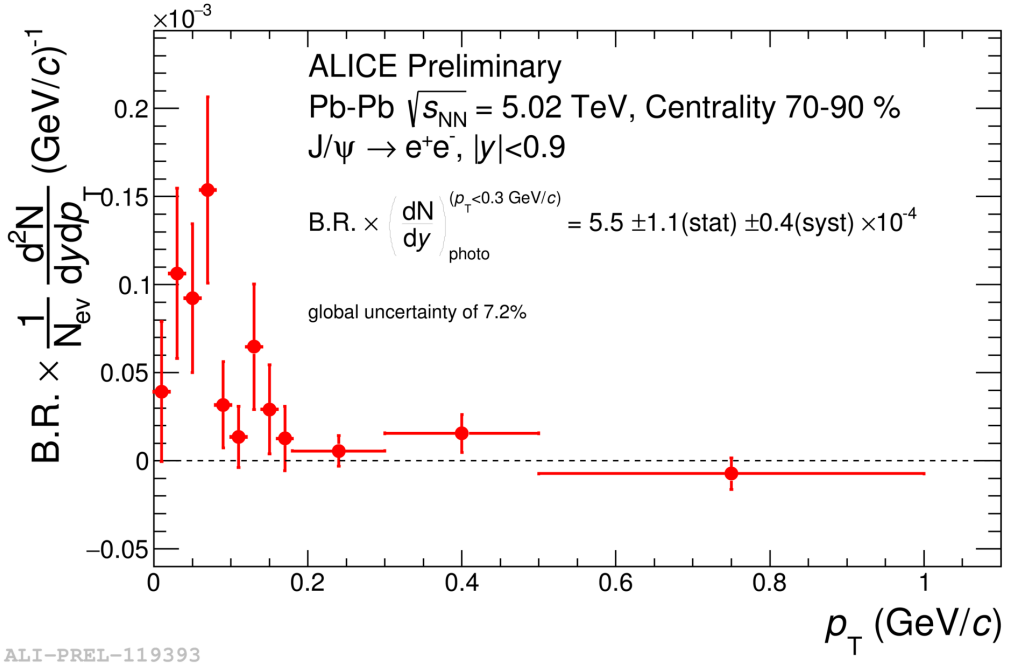
Low-p_T J/ψ yield excess in centrality 50-70%

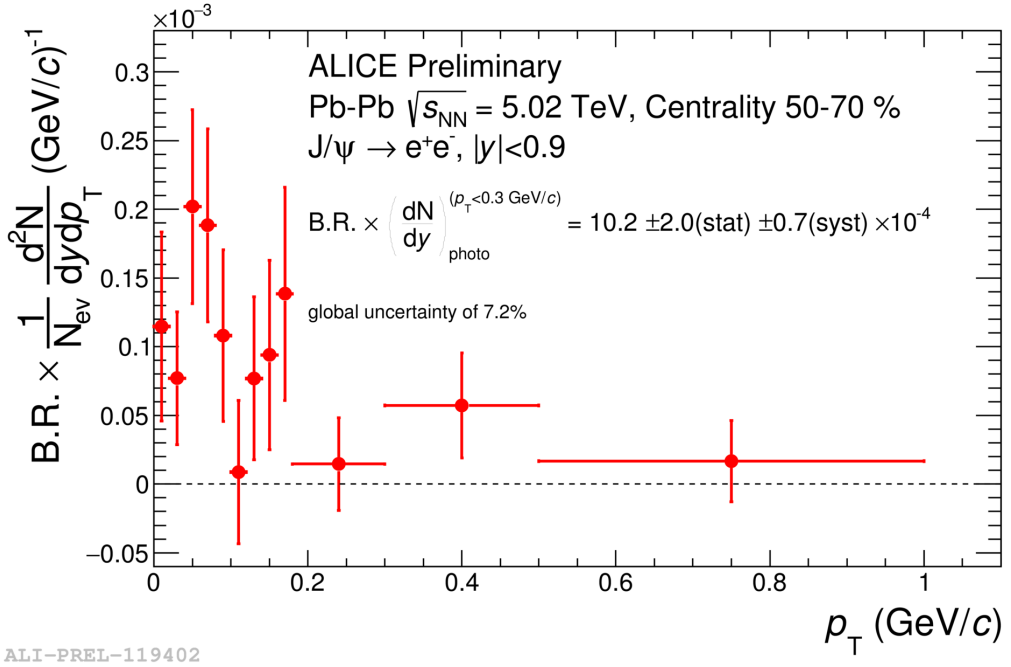




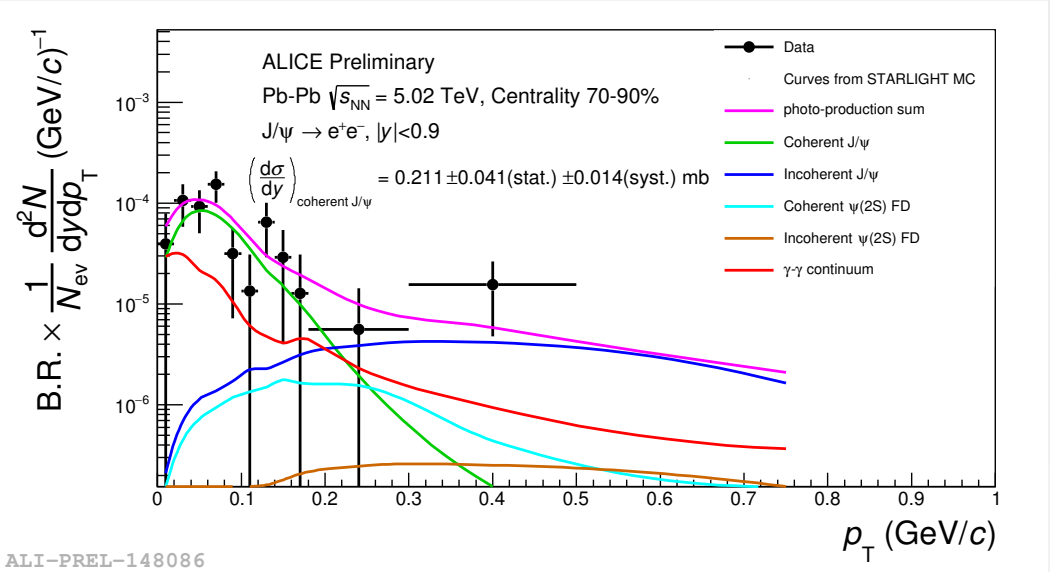
Corrected J/ψ yield excess in Pb-Pb @ 5.02 TeV

corrected J/ψ yield after subtraction of hadronic produced J/ψ (estimated)





Coherent J/ψ yield excess with log-Y axis



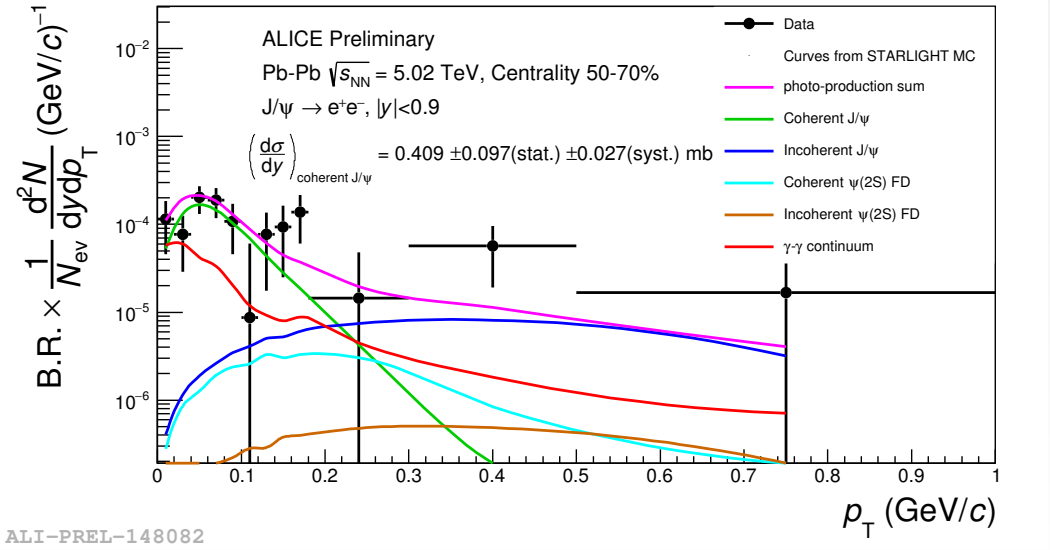
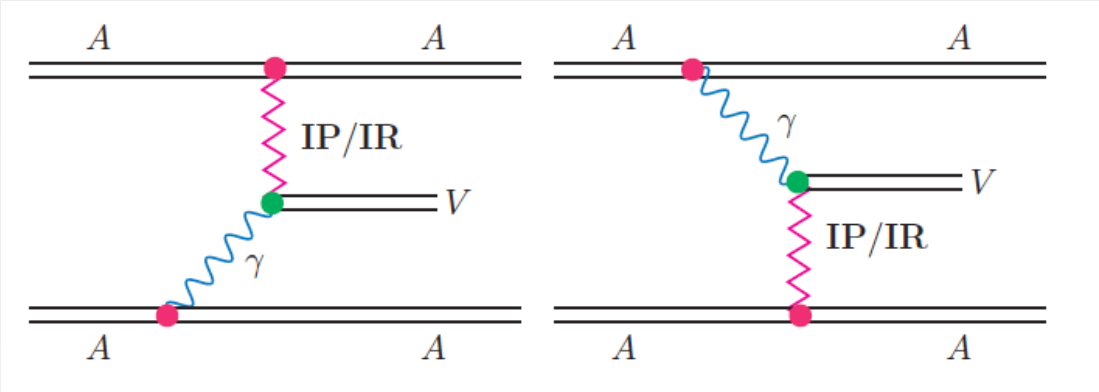


Photo-production mechanism



- Single vector meson production by photon-pomeron fusion

  - (i) the photon fluctuation into quark-antiquark pair (the dipole)

  - (ii) the dipole-target interaction

  - (iii) the recombination of the quark-antiquark into a vector meson.