J/ψ photoproduction in ultra-peripheral Pb-Pb and p-Pb collisions with the ALICE detector

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High energy photonuclear reactions

Physics measurements

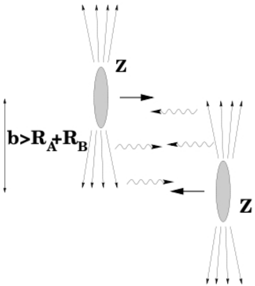
- Parton distribution at low Bjorken-x
- Photonuclear cross section $\sigma_X^{\gamma}(k)$ of vector meson X production depends on the square of the gluon distribution (PDF) in the target
- At the LHC is possible to have photonuclear reactions at higher energies than ever before

Ultra-peripheral collision (UPC)

- Impact parameter b larger than sum of nuclear radii
- Hadronic interactions suppressed, but strong electromagnetic field
- Field consists of virtual photon flux, $\mathrm{d}N/\mathrm{d}k$
- Photoproduction cross section $\sigma_X = \int \mathrm{d}k(\mathrm{d}N/\mathrm{d}k)\sigma_X^{\gamma}(k)$

ALICE UPC results

- Pb-Pb: ALICE Collaboration, Phys. Lett. B 718 (2013) 1273 (forward rapidities), arxiv:1305.1467 (central rapidities)
- p-Pb: new preliminary results presented here



Collision systems

- Pb-Pb: γ-Pb reactions, both nuclei are source of virtual photons
- p-Pb: γp reactions, Pb most likely the photon source

Photoproduction processes

γ-Pb reactions

- Coherent vector meson production
  - Photon couples coherently to the nucleus
  - $< p_T > \sim 1/R_{Pb} \sim$ 60 MeV/c
  - No neutron emission in $\sim$80% cases
- Incoherent vector meson production
  - Photon couples to a single nucleon
  - $< p_T > \sim 1/R_p \sim$ 500 MeV/c
  - Target nucleus normally breaks up

γp reactions

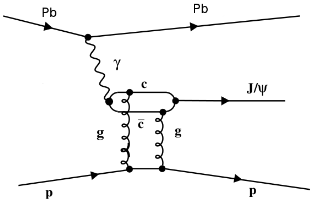
- Quasi-elastic photoproduction
  - Proton does not break
- Dissociative photoproduction
  - Excited proton after photoproduction reaction

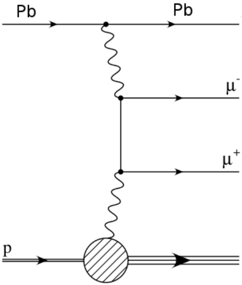
Lepton pair production (Pb-Pb or p-Pb)

- $\gamma\gamma \to \mu^+\mu^-$ or e^+e^-
- In case of γp, proton may dissociate

Physics motivation

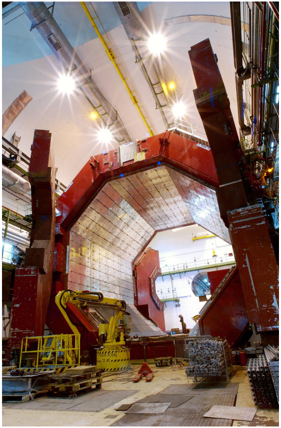
- γp $\to J/\psi$: perturbative QCD, gluon saturation
- γ-Pb $\to J/\psi$: nuclear gluon shadowing



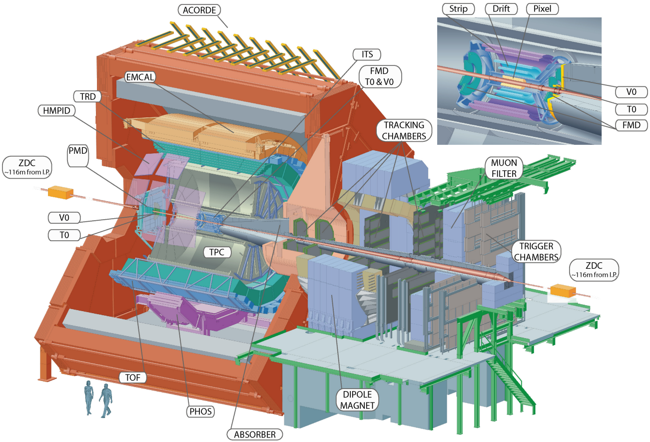


The ALICE experiment (A Large Ion Collider Experiment)

- Central barrel detectors, $|\eta| < 0.9$
- Muon spectrometer $-4.0 < \eta < -2.5$
- Forward triggering detectors, V0-VZERO, ZDC

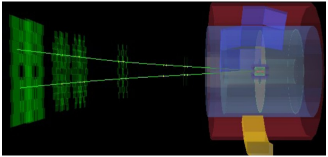


Solenoid magnet, 30000 A, 0.5 T



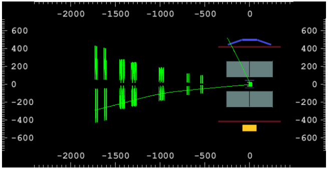
See backup for detailed description

Possible ALICE configurations for J/ψ in UPC



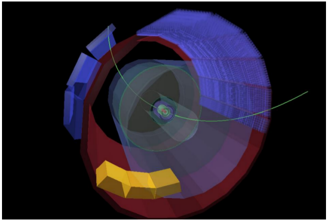
Forward

- Both tracks in muon arm
- J/ψ rapidity $-4.0 < y < -2.5$
- Pb-Pb and p-Pb



Semi-forward

- One muon in muon arm, one in central barrel
- J/ψ rapidity $-2.5 < y < -1.3$
- p-Pb



Mid-rapidity

- Both muons or electrons in central barrel
- J/ψ rapidity $-0.9 < y < 0.9$
- Pb-Pb and p-Pb

This talk describes forward and mid-rapidity analyses

Exclusive dileptons trigger strategy (UPC trigger)

Forward rapidity

- Both tracks in muon arm
- Dimuon unlike-sign, $p_T > 0.5$ GeV/c
- At least one cell fired in VZERO on muon arm side ($-3.7 < \eta < -1.7$)
- Empty VZERO on the opposite side ($2.8 < \eta < 5.1$)

Central rapidity

- Both tracks in central detectors
- $2 \leq$ TOF hits ≤ 6
  + back-to-back topology
- ≥ 2 hits in SPD
- Empty VZERO (both sides)

Exclusive dileptons offline event selection

Exclusivity selection

- UPC trigger
- Low signal in ZDC to reduce contribution from hadronic interactions
- Just two tracks in an otherwise empty detector

Muon arm

- VZERO fired cells - energy deposition in muon arm side ($-3.7 < \eta < -1.7$), opposite side empty ($2.8 < \eta < 5.1$)
- Tracks radial position at the end of absorber and p_T dependent DCA cut

Central barrel

- VZERO empty on both sides
- TPC dE/dx consistent with e or μ

Dimuon selection

- p_T limits: separation of the coherent and incoherent samples
- Rapidity interval according acceptance of the detectors

Pb-Pb analysis

Physics motivation for Pb-Pb

- When exclusive J/ψ is produced in forward rapidity $-3.6 < y < -2.6$, Bjorken-x at LHC energies takes values $10^{-2} \approx x \approx 10^{-5}$
- General cross section formula for J/ψ production in Pb-Pb collisions, $\sigma_{J/\psi}$ is $\gamma Pb \rightarrow J/\psi Pb$ cross section

$$\frac{\mathrm{d}\sigma(PbPb \rightarrow J/\psi PbPb)}{\mathrm{d}y} = N_\gamma(y)\sigma_{J/\psi}(y) + N_\gamma(-y)\sigma_{J/\psi}(-y)$$

(where N_γ is photon flux and y is J/ψ CM rapidity)

- Gluon distribution dependence

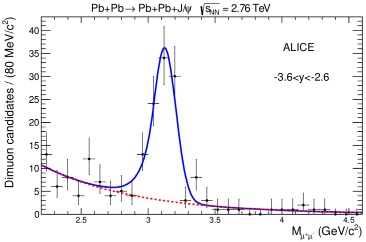
$$\sigma_{\gamma Pb \rightarrow J/\psi Pb}(s) = \frac{\mathrm{d}\sigma_{\gamma N \rightarrow J/\psi N}(s, t_{min})}{\mathrm{d}t} \cdot \left[\frac{G_A(M_{J/\psi}/s, Q^2_{eff})}{AG_N(M_{J/\psi}/s, Q^2_{eff})}\right]^2 \cdot F_A^2$$

(where s is γ-N scattering invariant energy, $t_{min} = -x^2 m_N^2$ and F_A is nuclear form factor)

- Photoproduction cross section in Pb-Pb related to the square of the gluon distribution

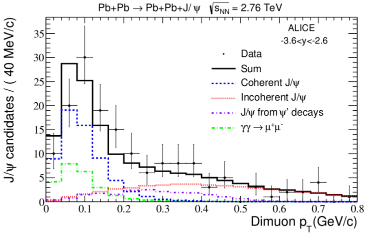
Coherent J/ψ photoproduction in Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV in forward rapidity*

- Both tracks in muon spectrometer
- Only $\mu^+\mu^-$



Invariant mass distribution

- Dimuons with $p_T < 0.3$ GeV/c
- Exponential function and Crystal Ball fit
- Exponential slope parameter compatible with MC expectation for $\gamma\gamma \rightarrow \mu^+\mu^-$



Contributions to p_T spectrum

- Coherent and incoherent J/ψ
- J/ψ from ψ' decays
- $\gamma\gamma \rightarrow \mu^+\mu^-$

Number of candidates

$$N^{coh}_{J/\psi} = \frac{N_{yield}}{1+f_I+f_D}$$

(f_I and f_D: incoherent and feed-down fractions)

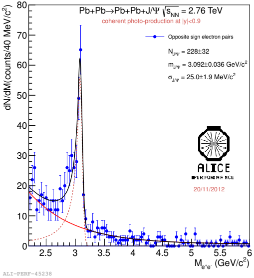
$$N^{coh}_{J/\psi} = 78 \pm 10(\text{stat})^{+7}_{-11}(\text{syst})$$

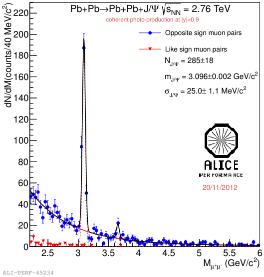
* Phys. Lett. B 718 (2013) 1273 - 1283

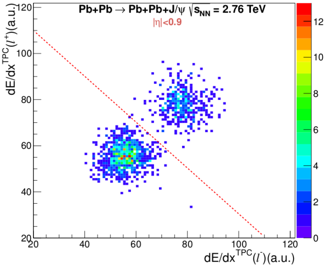
J/ψ photoproduction in Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV in central rapidity*

- Both tracks in central detectors
- Allows for $\mu^+\mu^-$ and e^+e^-

$\mathrm{d}E/\mathrm{d}x$ selection in TPC





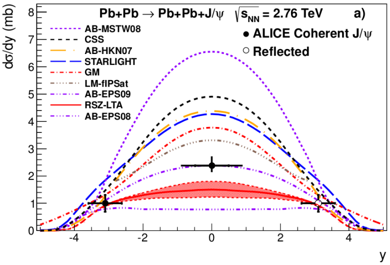


- $\mathrm{d}E/\mathrm{d}x$ compatible with e/μ energy loss
- But no distinction between μ and π

Coherent e^+e^- (left) and $\mu^+\mu^-$ (right) invariant mass

* arXiv:1305.1467 [nucl-ex]

Coherent J/ψ results in Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV*



Forward and central cross section

- Large nuclear suppression in Pb at small *x*
- Best agreement with the model which incorporates the nuclear gluon shadowing according to the EPS09 parameterization (AB-EPS09)

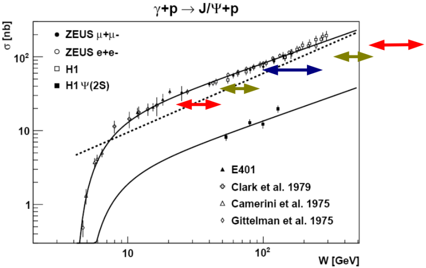
- **AB:** Adeluyi, Bertulani, PRC85 (2012) 044904
  LO pQCD scaled by an effective constant to correct for missing contributions. MSTW assumes no nuclear effects, the other incorporate nuclear effects according different nuclear PDFs
- **CSS:** Cisek, Szczurek, Schäfer, PRC86 (2012) 014905
  Color dipole model based on unintegrated gluon distribution of the proton
- **STARLIGHT:** Klein, Nystrand, PRC60 (1999) 01493
  GVDM coupled to a Glauber approach and using Hera data to fix the γp cross section
- **GM:** Goncalves, Machado, PRC84 (2011) 011902
  Color dipole model, where the dipole nucleon cross section is from the IIM saturation model
- **RSZ:** Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252
  Based on LO pQCD amplitude for two gluon exchange where the gluon density incorporates shadowing computed in leading twist approximation

* Phys. Lett. B 718 (2013) 1273 - 1283, arXiv:1305.1467 [nucl-ex]

p-Pb result and outlook

Accessible kinematics regions in p-Pb and Pb-p interactions

p-Pb: proton moves towards the muon arm
Pb-p: Pb-nucleus moves towards the muon arm



H1: A. Aktas et al. Eur.Phys. J.C46:585-603,2006
ZEUS: S. Chekanov et al., Nucl. Phys. B695 (2004) 3.

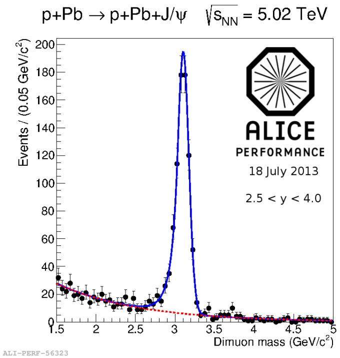
gamma-proton CM energies

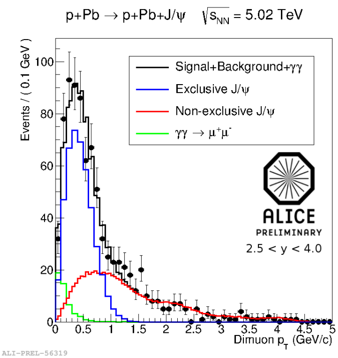
- Mid-rapidity: $100 < W_{\gamma p} < 250$ GeV
- p-Pb forward: $21 < W_{\gamma p} < 45$ GeV
- p-Pb semi-forward: $45 < W_{\gamma p} < 82$ GeV
- Pb-p forward: $550 < W_{\gamma p} < 1160$ GeV
- Pb-p semi-forward: $300 < W_{\gamma p} < 550$ GeV

- HERA energy range extended by factor of ~ 3
- Lower energy of the HERA experiments covered
- Energy range of exclusive J/ψ production

Signal extraction for forward J/ψ in p-Pb

- Forward rapidity p-Pb (p $\rightarrow$ muon arm side)
- Gamma-proton CM energy $21 < W_{\gamma p} < 45$ GeV, $< W >$ = 29.8 GeV
- Non-exclusive J/ψ contribution estimated from data, events with more than 2 hits in VZERO-C at muon arm side



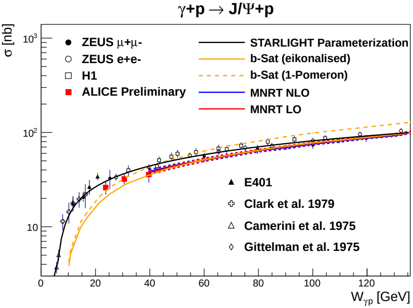


Invariant mass and p_T distribution for exclusive J/ψ candidates

Exclusive J/ψ cross section in p-Pb (ALICE preliminary)

Table: Forward cross section

rapidity	$d\sigma(\mathrm{p-Pb} \to \mathrm{p-Pb} + J/\psi)/dy(\mu\mathrm{b})$
-4.0 < y < -2.5	6.18 $\pm$ 0.42 (stat) $\pm$ 0.56 (sys)
-4.0 < y < -3.5	5.50 $\pm$ 0.72 (stat) $\pm$ 0.52 (sys)
-3.5 < y < -3.0	6.26 $\pm$ 0.55 (stat) $\pm$ 0.57 (sys)
-3.0 < y < -2.5	6.39 $\pm$ 0.94 (stat) $\pm$ 0.59 (sys)

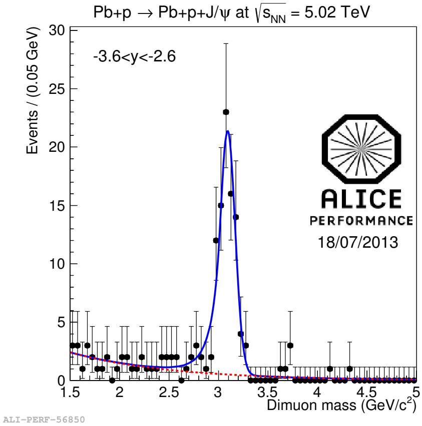


- ALICE cross section as a function of rapidity in the lab frame, comparison with fixed-target experiments and model calculations
- First step: consistency between ALICE and HERA exclusive cross section (overlap in measured values)
- Correction for feed down from ψ'
- From measured σ(p-Pb) to $\sigma(\gamma$+p): photon spectrum $n_\gamma(y)$
  $d\sigma(\mathrm{p-Pb} \to \mathrm{p-Pb} + J/\psi)/dy =$
  $n_\gamma(y)\sigma(\gamma+\mathrm{p} \to J/\psi+\mathrm{p})$

b-Sat: arxiv:1206.2913, 1211.4831
MNRT: PLB 662 (2008) 252

Exclusive J/ψ production in Pb-p collisions

- Pb-p: Pb $\rightarrow$ muon arm side
- Gamma-proton CM energy $578 < W_{\gamma p} < 972$ GeV, $< W >$ = 686 GeV
- Work in progress to measure cross section in this energy range



Invariant mass for exclusive J/ψ in Pb-p

Conclusions

Pb-Pb photoproduction results

- First LHC measurement on exclusive J/ψ photoproduction in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV by ALICE experiment*
- Models including nuclear gluon shadowing consistent with the EPS09 parametrisation are favoured

p-Pb photoproduction analysis

- First measurement of exclusive J/ψ production in p-Pb LHC collisions by ALICE experiment
- Results in good agreement with data from lower energies ($21 < W_{\gamma p} < 45$ GeV)
- Work in progress for J/ψ cross section in $578 < W_{\gamma p} < 972$ GeV energy range

* Phys. Lett. B 718 (2013) 1273 - 1283 , arXiv:1305.1467 [nucl-ex]

Backup

J/ψ photoproduction cross section

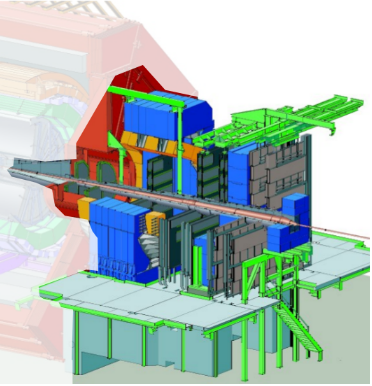
$$\frac{\mathrm{d}\sigma_{\gamma p \to pJ/\psi}}{\mathrm{d}t} = \frac{\Gamma_{ee} M^3_{J/\psi} \pi^3}{48\alpha_{em}} \frac{\alpha_S^2(\bar{Q}^2)}{\bar{Q}^8} [x g_N(x, \bar{Q}^2)]^2 \exp[B_{J/\psi}(s)t]$$

$$\sigma_{\gamma Pb \to J/\psi Pb}(s) = \frac{\mathrm{d}\sigma_{\gamma N \to J/\psi N}(s, t_{min})}{\mathrm{d}t} \cdot [\frac{G_A(M_{J/\psi}/s, Q^2_{eff})}{A G_N(M_{J/\psi}/s, Q^2_{eff})}]^2 \cdot F_A^2$$

(where s is γ-N scattering invariant energy, $t_{min} = -x^2 m_N^2$ and F_A is nuclear form factor)

Alice muon spectrometer

- Coverage $-4.0 < \eta < -2.5$
- Absorber for muon filtering, 10 interaction length thick
- Dipole magnet, integrated field 3 Tm
- 5 tracking stations, each composed of two multi-wire proportional chambers (MWPC)
- Trigger system
  - Four planes of resistive plate chambers (RPC)
  - Selection with $p_T >$ given programmable threshold
- Tracking resolution 100μm



Alice central barrel detectors, $|\eta| < 0.9$

Inner Tracking System (ITS)

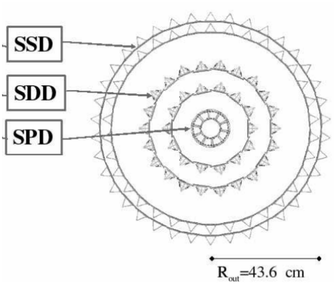
- 6 layers of silicon pixel, drift and strip detectors
- Inner pixel $|\eta| < 1.5$

Time Projection Chamber (TPC)

- Gaseous tracking detector

Time of Flight (TOF)

- MRPC strips, surrounds the TPC

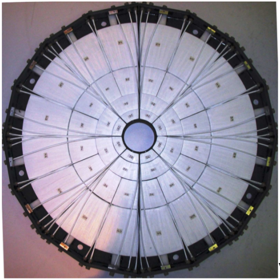


ALICE ITS

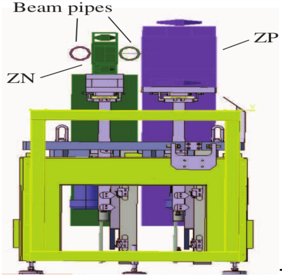
ALICE TPC

Alice forward detectors

- VZERO - scintillator detectors VZERO-A and VZERO-C at $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$, triggering and event selection
- Zero Degree Calorimeters (ZDC), 116 m on both sides of interaction point, very forward neutrons



VZERO



ZDC