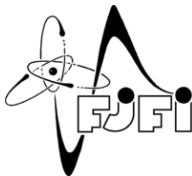


# ALICE results on ultraperipheral Pb+Pb and p+Pb collisions



Jaroslav Adam

On behalf of the ALICE Collaboration

Faculty of Nuclear Sciences and Physical Engineering  
Czech Technical University in Prague

May 2013



Workshop on proton-nucleus collisions at the LHC, Trento, Italy

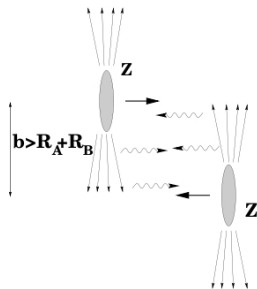
# High energy photonuclear reactions

## Physics measurements

- Parton distribution at low Bjorken- $x$
- Photonuclear cross section  $\sigma_X^\gamma(k)$  of vector meson production depends on gluon distribution

## Ultra-peripheral collision (UPC)

- Experimental opportunity to create high energy photonuclear reaction
- Impact parameter  $b$  larger than sum of nuclear radii
- Hadronic interactions suppressed, but strong electromagnetic field
- Field consists of virtual photon flux,  $dN/dk$
- Photoproduction cross section  
$$\sigma_X = \int dk (dN/dk) \sigma_X^\gamma(k)$$



## Collision systems

- Pb+Pb:  $\gamma$ Pb reactions, source and target nuclei
- p+Pb:  $\gamma$ p reactions, Pb most likely the photon source

# Photoproduction processes

## $\gamma$ Pb reactions

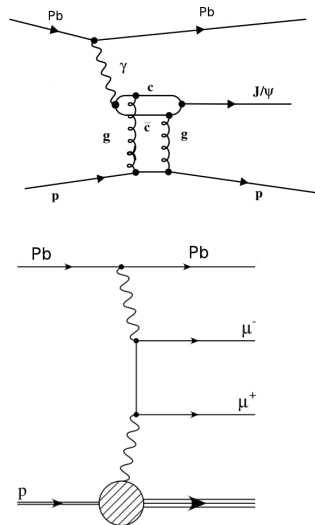
- Coherent vector meson production
  - ▶ Photon couples coherently to almost all nucleons
  - ▶  $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$  MeV/c
  - ▶ No neutron emission in  $\sim 80\%$  cases
- Incoherent vector meson production
  - ▶ Photon couples to a single nucleon
  - ▶  $\langle p_T \rangle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

## $\gamma p$ reactions

- Elastic photoproduction
  - ▶ Proton does not break
- Dissociative photoproduction
  - ▶ Excited proton after photoproduction reaction

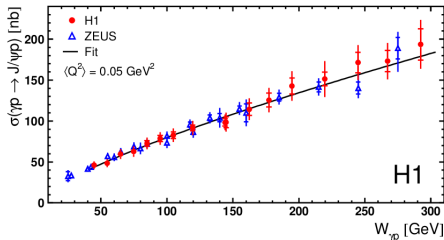
## Lepton pair production (Pb + Pb or p + Pb)

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



# $J/\psi$ photoproduction in $\gamma p$

$$\frac{d\sigma_{\gamma p \rightarrow p J/\psi}}{dt} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48 \alpha_{em}} \frac{\alpha_S^2(\bar{Q}^2)}{\bar{Q}^8} [xg_N(x, \bar{Q}^2)]^2 \exp[B_{J/\psi}(s)t]$$



H1: A. Aktas et al. Eur.Phys. J.C46:585-603,2006

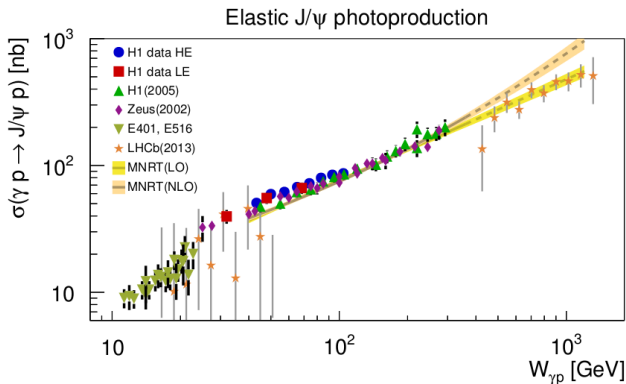
## Physics motivation

- $\gamma p \rightarrow J/\psi$ 
  - ▶ Perturbative QCD
  - ▶ Gluon saturation
- $\gamma Pb \rightarrow J/\psi$ 
  - ▶ Nuclear gluon shadowing

## ALICE capability

- $E_{max}(\gamma) \approx 940 \text{ GeV}$  ( $p$ )
- $E_{max}(\gamma) \approx 47 \text{ GeV}$  ( $Pb$ )
- $\gamma p$  CM energy  $W_{\gamma p, max} \approx 1 \text{ TeV}$

# Current results on elastic $J/\psi$ production cross section measurements\*



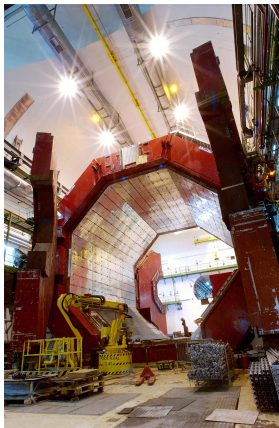
HERA\*  $ep$ , LHCb\*\*  $pp$  and fixed target experiments results on  $\gamma p \rightarrow J/\psi$  production cross section

\* <http://arxiv.org/abs/1304.5162>

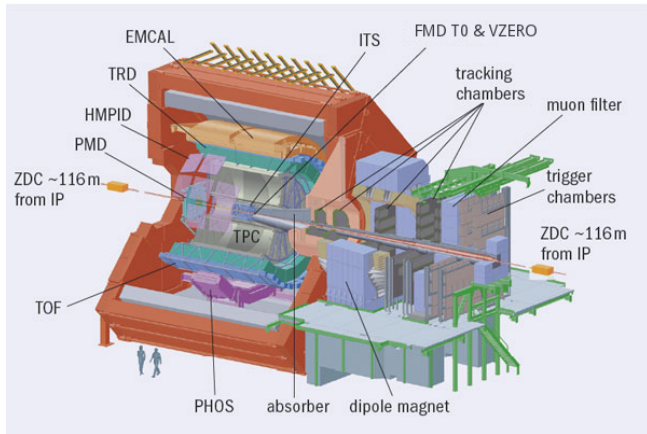
\*\* J. Phys. G 40 (2013) 045001

# The ALICE experiment (A Large Ion Collider Experiment)

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



Solenoid magnet, 30000 A, 0.5 T



See backup for detailed description

# Exclusive dileptons trigger strategy

## Forward rapidity

- Both tracks in muon arm
- Dimuon unlike-sign,  $p_T > 0.5 \text{ GeV}/c$
- 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
- $2 \leq \text{TOF hits} \leq 6$   
+ back-to-back topology
- $\geq 2$  hits in SPD
- Empty VZERO (both sides)

# Exclusive dileptons offline event selection

## Exclusivity selection

- UPC trigger
- VZERO fired cells - energy deposition in muon arm side, opposite side empty
- Low signal in ZDC to reduce contribution from hadronic interactions
- Central barrel activity checked according the presence of SPD tracklets
- Just two tracks in an otherwise empty detector

## Tracks quality requirements

- Radial position at the end of absorber and  $p_T$  dependent DCA cut for muon tracks
- ITS hits, TPC clusters and TOF information for central tracks
- Pseudorapidity inside the nominal acceptance

## Dimuon selection

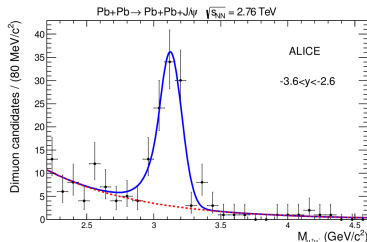
- $p_T$  limits: separation of the coherent and incoherent samples
- Rapidity interval according acceptance of the detectors



# Pb+Pb analysis

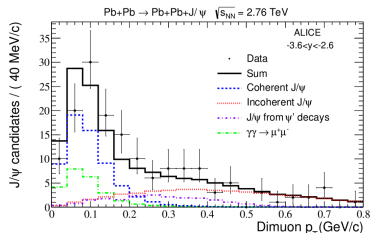
# Coherent $J/\psi$ photoproduction in Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV in forward rapidity\*

- 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  $J/\psi$
- $J/\psi$  from  $\psi'$  decays
- $\gamma\gamma \rightarrow \mu^+\mu^-$

## Number of candidates

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

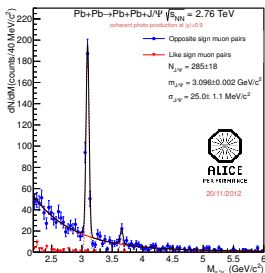
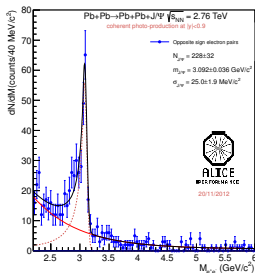
( $f_I$  and  $f_D$ : incoherent and feed-down fractions)

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

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

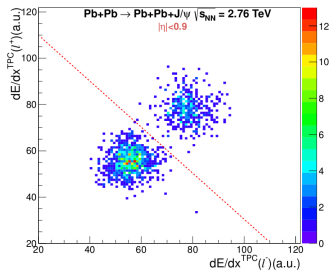
# $J/\psi$ photoproduction in Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV in central rapidity

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



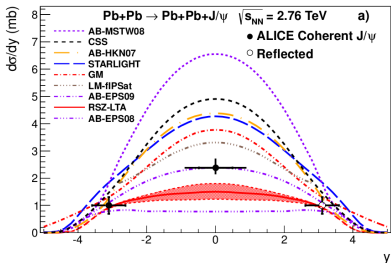
Coherent  $e^+e^-$  (left) and  $\mu^+\mu^-$  (right) invariant mass

## $dE/dx$ selection in TPC



- $dE/dx$  compatible with  $e/\mu$  energy loss
- But no distinction between  $\mu$  and  $\pi$

# Coherent $J/\psi$ results in Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV\*



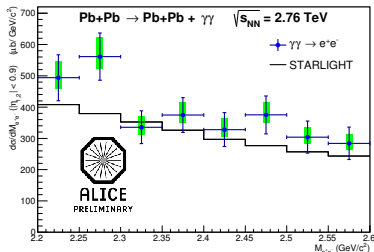
Forward and central cross section

- Large nuclear suppression in Pb at small  $x$
- Best agreement with nuclear gluon shadowing predicted by AB-EP09

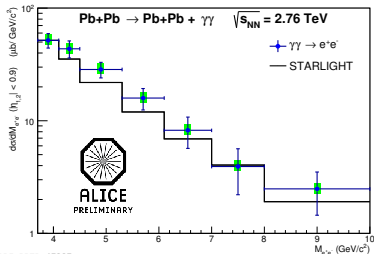
- **AB:** Adelyi, Bertulani, PRC85 (2012) 044904  
LO pQCD scaled by an effective constant to correct for missing contributions. MSTW assumes no nuclear effects, the other incorporate nuclear effects according different effects
- **CSS:** Cisek, Szczurek, Schäfer, PRC86 (2012) 014905  
Color dipole model 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  $\gamma p$  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

\* arXiv:1305.1467 [nucl-ex]

# $\gamma\gamma \rightarrow e^+e^-$ in Pb+Pb



ALI-PREL-47283



ALI-PREL-47287

## Alice measurement

- $|\eta| < 0.9$
- Measurement precision improved

### Inv. mass interval $2.2 < M_{inv} < 2.6 \text{ GeV}/c^2$

- ALICE preliminary  
 $\sigma_{\gamma\gamma} = 154 \pm 11(\text{stat})^{+16.6}_{-10.8}(\text{sys}) \mu\text{b}$
- STARLIGHT prediction  $\sigma_{\gamma\gamma} = 128 \mu\text{b}$

### Inv. mass interval $3.7 < M_{inv} < 10.0 \text{ GeV}/c^2$

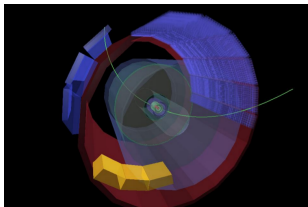
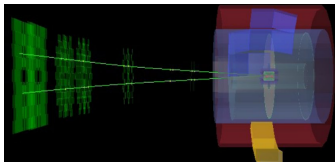
- ALICE preliminary  
 $\sigma_{\gamma\gamma} = 91 \pm 10(\text{stat})^{+10.9}_{-8.0}(\text{sys}) \mu\text{b}$
- STARLIGHT prediction  $\sigma_{\gamma\gamma} = 77 \mu\text{b}$

# $p+Pb$ result and outlook

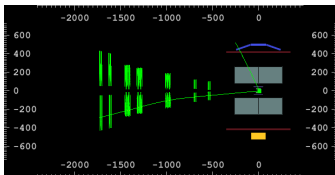
# Exclusive dilepton with ALICE in p+Pb

Basic experimental signature: two tracks in an otherwise empty detector

**Forward rapidity**  $-4.0 < y < -2.5$ ,  $\mu^+\mu^-$       **Mid-rapidity**  $|\eta| < 0.9$ ,  $\mu^+\mu^-$ ,  $e^+e^-$



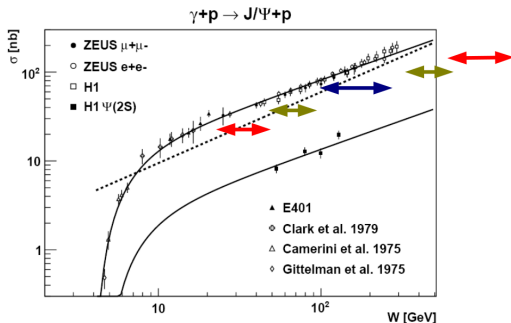
**Semi-forward**  $-2.5 < y < -1.3$ ,  $\mu^+\mu^-$



## Accessible kinematics regions in p+Pb

- 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

# Accessible kinematics regions in p+Pb

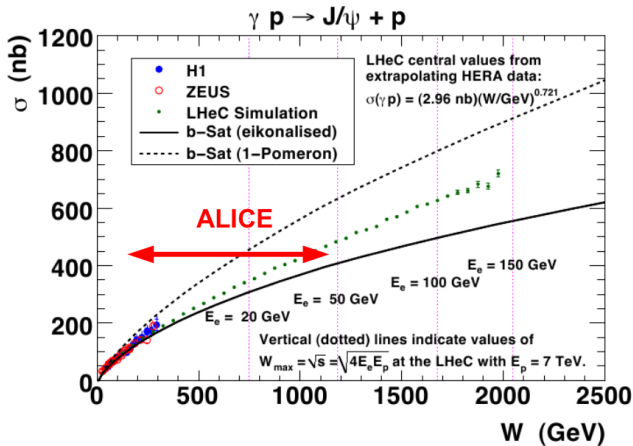


## $\gamma p$ CM energies

- 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



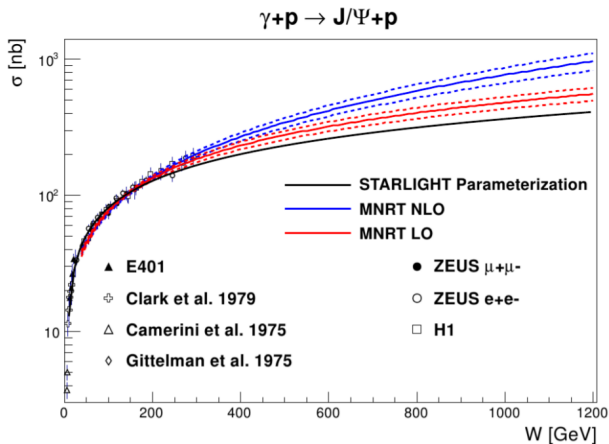
# LHeC prediction for elastic $J/\psi$ photoproduction\*



\* arxiv:1211.4831

# pQCD model for elastic $J/\psi$ photoproduction prediction\*

- Martin, Nockles, Ryskin, Teubner (MNRT)\*
- pQCD, Ryskin Formula (LO), NLO contributions



\* Phys. Lett. B 662 (2008) 252

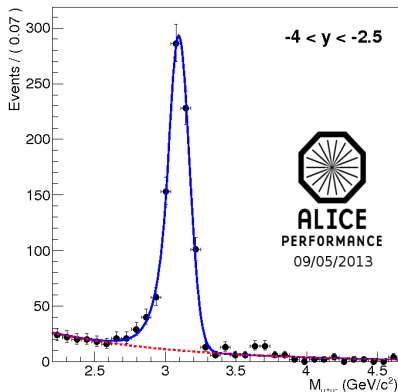
## Collected data sample in p+Pb

- LHC 2013 p+Pb run in January and February
- $\sqrt{s} = 5.02$  TeV
- Special trigger classes for forward, semi-forward and central UPC events
- Beam directions: p+Pb: p  $\rightarrow$  muon arm side, Pb+p: Pb  $\rightarrow$  muon arm side
- $J/\psi$  detection efficiency similar to Pb+Pb

# Signal extraction for forward $J/\psi$ in p+Pb

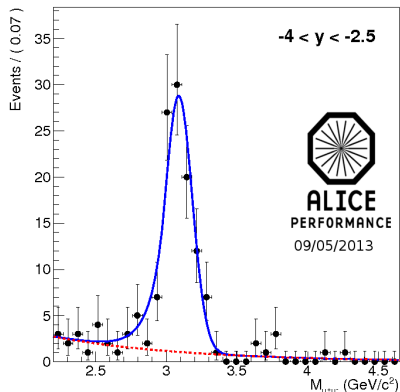
## p+Pb system

p+Pb  $\rightarrow$  p+Pb+ $J/\Psi$   $\sqrt{s_{NN}} = 5.02$  TeV



## Pb+p system

Pb+p  $\rightarrow$  Pb+p+ $J/\Psi$   $\sqrt{s_{NN}} = 5.02$  TeV



Similar signals also in semi-forward and central rapidity

## Pb+Pb photoproduction results

- First LHC measurement on exclusive  $J/\psi$  photoproduction in Pb+Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV by ALICE experiment\*
- Preliminary results on mid-rapidity  $J/\psi$  photoproduction and  $\gamma\gamma \rightarrow e^+e^-$  measurement
- Models including nuclear gluon shadowing consistent with the EPS09 parametrisation are favoured

## p+Pb photoproduction analysis

- Analyses ongoing - stay tuned

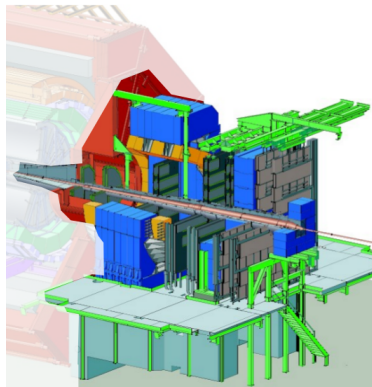
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\* Phys. Lett. B 718 (2013) 1273 - 1283

# Backup

# 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  $100\mu\text{m}$



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

## Inner Tracking System (ITS)

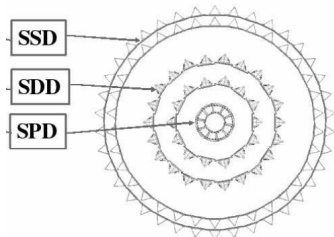
- 6 layers of silicon pixel, drift and strip detectors
- Inner pixel  $|\eta| < 1.5$

## Time Projection Chamber (TPC)

- Gaseous tracking detector

## Time of Flight (TOF)

- MRPC strips, surrounds the TPC



$R_{out} = 43.6 \text{ cm}$  ALICE ITS

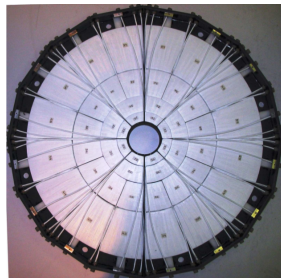


ALICE TPC

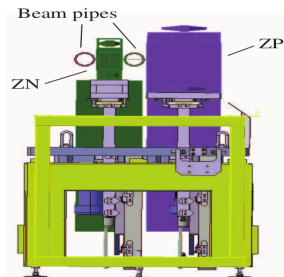


## Alice forward detectors

- 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