

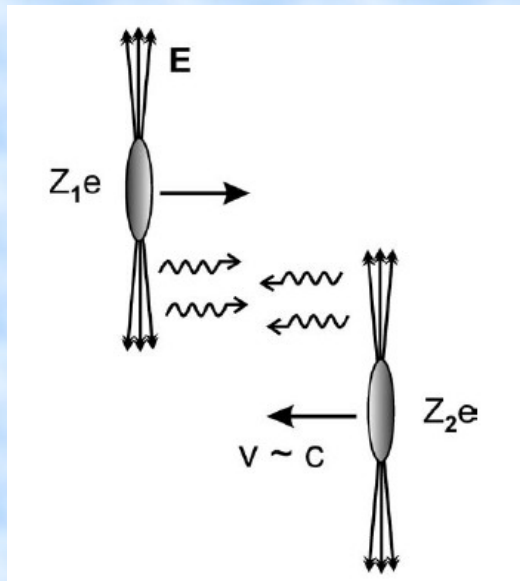
# Vector meson photoproduction at the LHC studied by the ALICE experiment

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# Photoproduction in ultra-peripheral collisions



The EM fields correspond to an equivalent flux of photons.

These can lead to two-photon or photonuclear interactions in collisions where no hadronic interactions occur ( $b > 2R$ ).

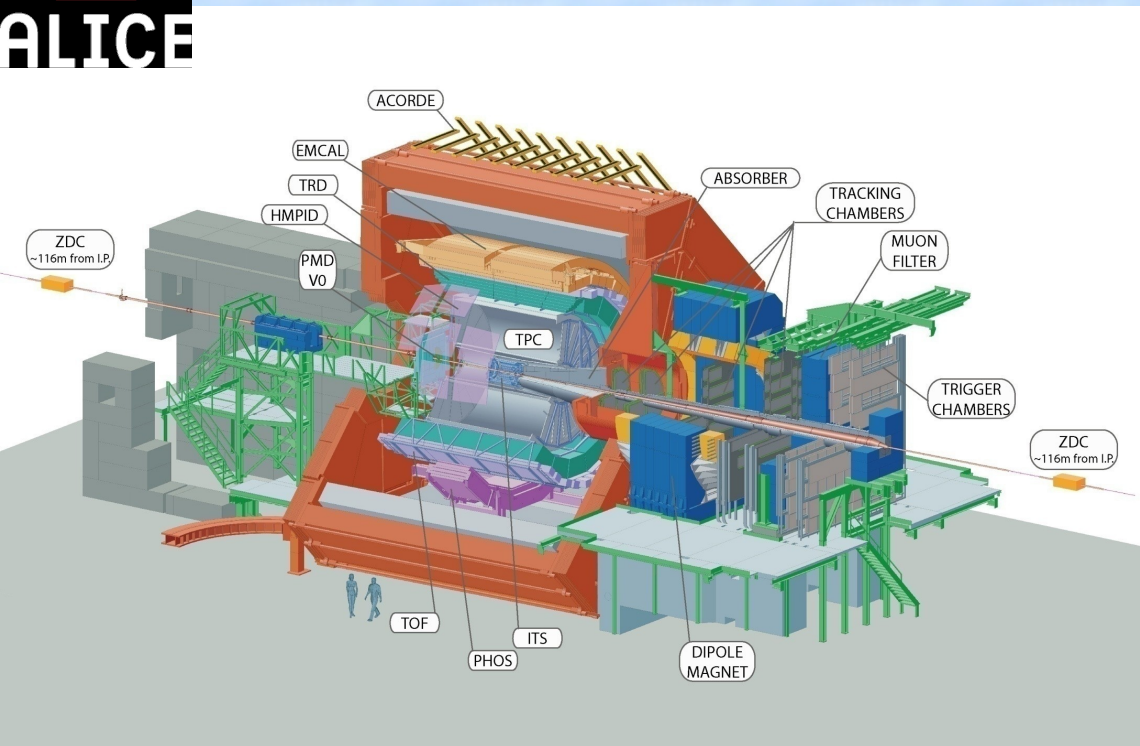
Exclusive vector meson production ( $\gamma + A \rightarrow V + A$ ) of particular interest as a probe of gluon distribution.

Also possible to study  $\gamma + p \rightarrow V + p$  in p-Pb collisions at the LHC. The Pb-nucleus acts as photon emitter (enhanced flux by factor  $Z^2 \approx 7000$  compared to the photon flux from the proton).

Pb-Pb: ALICE Collaboration, Phys. Lett. B 718 (2013) 1273 (Muon arm), arxiv:1305.1467 (Central Barrel).

p-Pb: new preliminary results presented here.

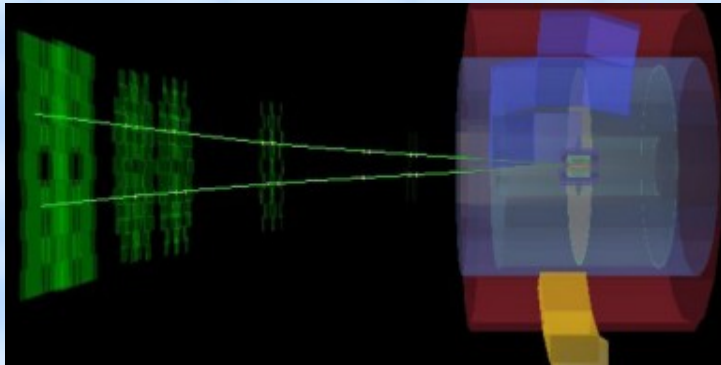
# The ALICE Experiment at the LHC



- A central tracking system (ITS + TPC) with particle identification.
- Acceptance  $|\eta| \leq 0.9$ ,  $p_T > 100 \text{ MeV}/c$
- Trigger from SPD and TOF

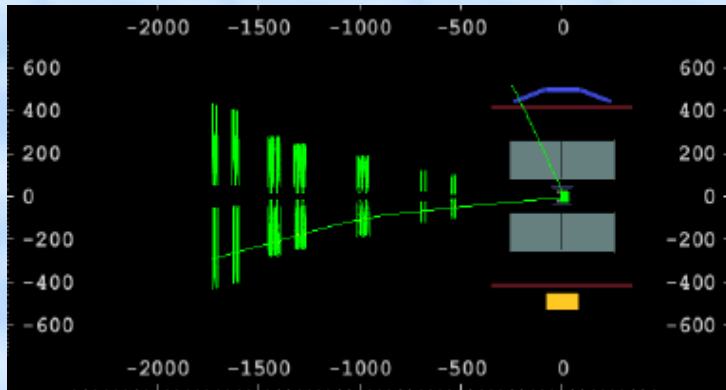
- A muon arm at forward rapidities  $-4.0 < \eta < -2.5$ .
- Triggering, tracking and identification of muons.
- VZERO counters for triggering and vertex determination; used here as veto detectors to define rapidity gaps ( $-3.7 < \eta < -1.7$ ) and ( $2.8 < \eta < 5.1$ ).
- Zero-Degree Calorimeters (ZDC) – 116 m from interaction point.

# Possible Configurations for $J/\psi$ in UPC in ALICE



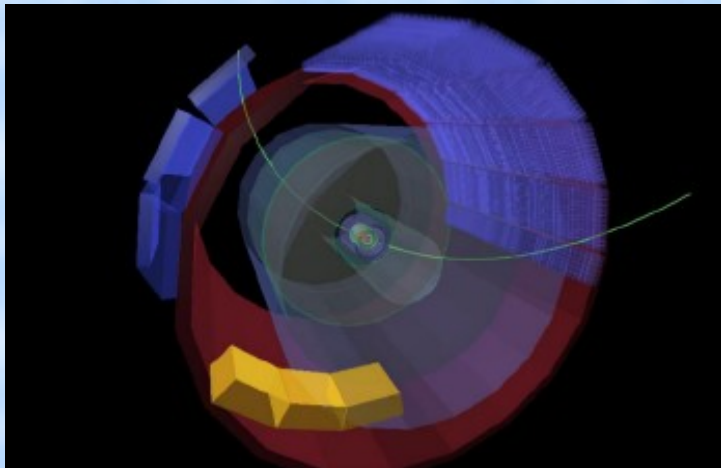
Both muons in muon arm  
 $J/\psi$  rapidity:  $4.0 < y < 2.5$

Pb-Pb and p-Pb



One muon in muon arm, one in central barrel  
 $J/\psi$  rapidity:  $2.5 < y < 1.3$

p-Pb



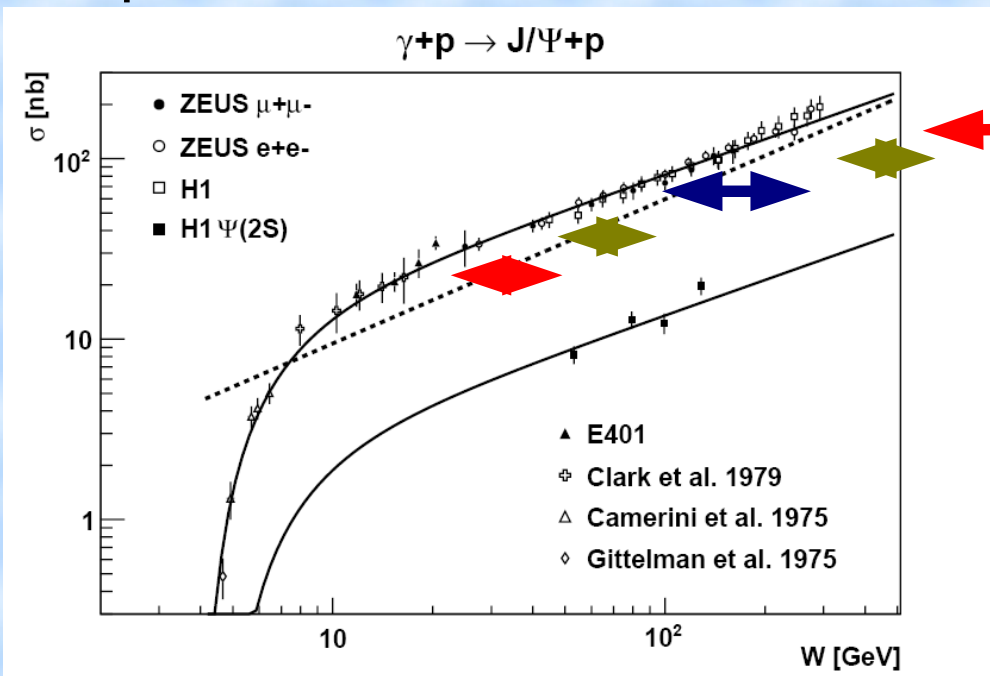
Both muons/electrons in central barrel  
 $J/\psi$  rapidity:  $-0.9 < y < 0.9$

Pb-Pb and p-Pb

# Kinematic ranges for p+Pb and Pb+p interactions

p+Pb: proton moves towards the muon arm.

Pb+p: Pb-nucleus moves towards the muon arm.



- Extends the energy range reached at HERA by about a factor of 3.
- Also covers the lower energy range of the HERA experiments.
- A unique possibility to study the energy dependence of exclusive J/psi production.

Ranges in gamma+proton CM energies:

**Muon arm p+Pb:**  $21 \leq W_{\gamma p} \leq 45 \text{ GeV}$

**Muon+Barrel p+Pb:**  $45 \leq W_{\gamma p} \leq 82 \text{ GeV}$

**Central barrel:**  $100 \leq W_{\gamma p} \leq 250 \text{ GeV}$

**Muon+Barrel Pb+p:**  $300 \leq W_{\gamma p} \leq 550 \text{ GeV}$

**Muon arm Pb+p:**  $550 \leq W_{\gamma p} \leq 1160 \text{ GeV}$



# ALICE triggers for UPC

2010 Pb-Pb at  $\sqrt{s_{NN}} = 2.76$  TeV: Central barrel trigger based on TOF, SPD, VZERO. Sensitive to exclusive  $\rho^0$  production. Not discussed here.

2011 Pb-Pb at  $\sqrt{s_{NN}} = 2.76$  TeV:

Central barrel trigger based on TOF, SPD, VZERO.

Muon arm trigger with  $p_T > 1$  GeV/c.

2013 p-Pb at  $\sqrt{s_{NN}} = 5.02$  TeV:

Central barrel trigger based on TOF, SPD, VZERO.

Muon arm trigger with  $p_T > 0.5$  GeV/c; allows for cases with one muon in the muon arm and the other in the central barrel.

# Exclusive $J/\psi$ production in Pb-Pb collisions

# Exclusive $J/\psi$ production in Pb-Pb collisions

Integrated luminosities:  $\approx 55 \mu\text{b}^{-1}$  (Muon arm) and  $\approx 23 \mu\text{b}^{-1}$  (Central barrel).

Event selection (summary):

==> Based on “two tracks in an otherwise empty detector”.

Muon arm:

- coherent production,  $p_T < 0.3 \text{ GeV}/c$
- Rapidity gap defined by VZERO-A ( $2.8 < \eta < 5.1$ )
- Low signal in ZDC

Central barrel:

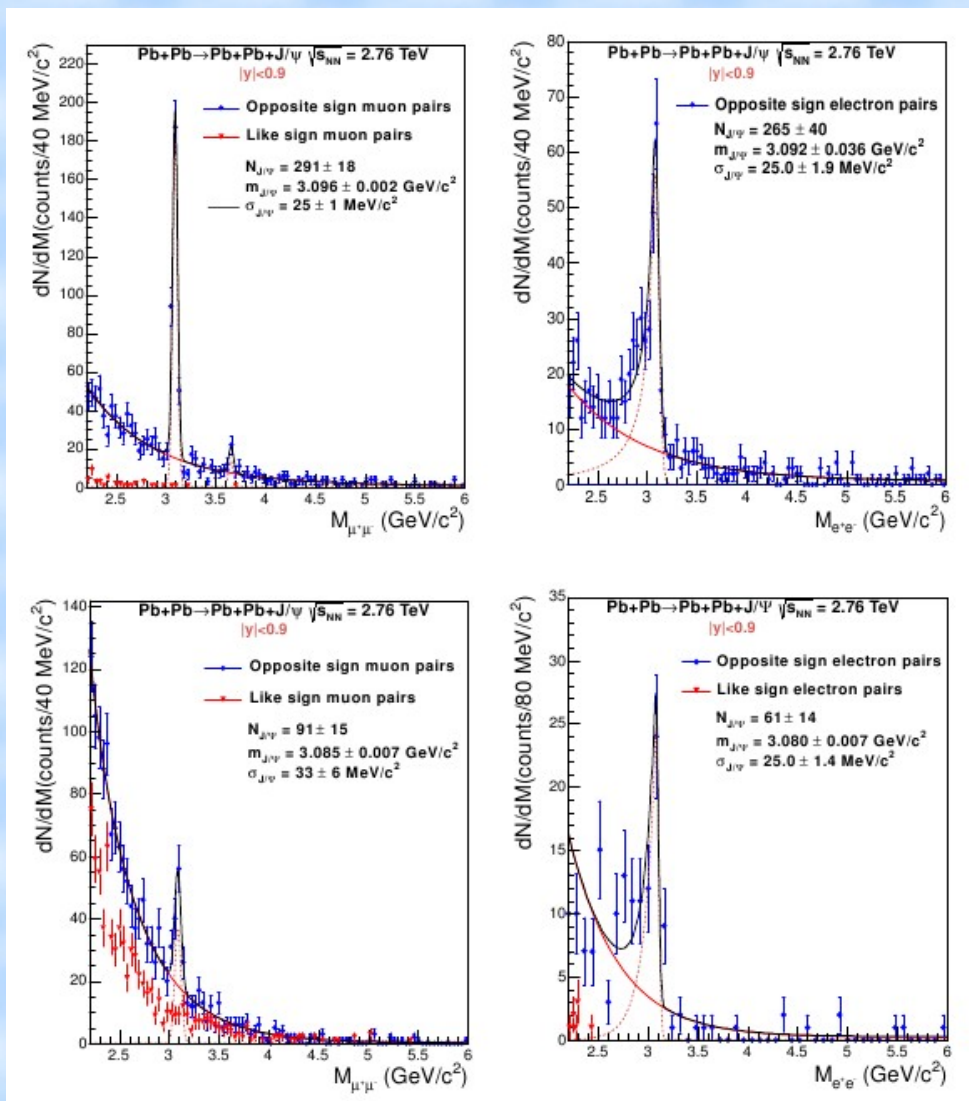
- coherent and incoherent production, separated by cut on  $p_T$ .
- VZERO-A/C veto ( $-3.7 < \eta < -1.7$ ,  $2.8 < \eta < 5.1$ )
- Low ZDC signal for coherent events
- TPC  $dE/dx$  consistent with e or  $\mu$ .

More details in ALICE Collaboration Phys. Lett. B 718 (2013) 1273 (Muon arm), arxiv:1305.1467 (Central Barrel).



# Exclusive $J/\psi$ production in Pb-Pb collisions

## Invariant mass distributions – Central barrel

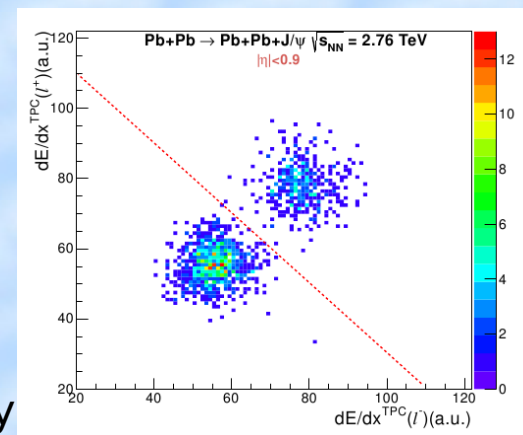


Coherent selection.  
 $p_T < 0.2(\mu) / 0.3 (e)$  GeV/c.

$J/\psi$  and continuum  $\gamma\gamma \rightarrow l^+l^-$  contribution.

Incoherent selection.  
 $p_T > 0.2 (\mu) / 0.3 (e)$  GeV/c.

$e/\mu$  separation  
 TPC dE/dx.



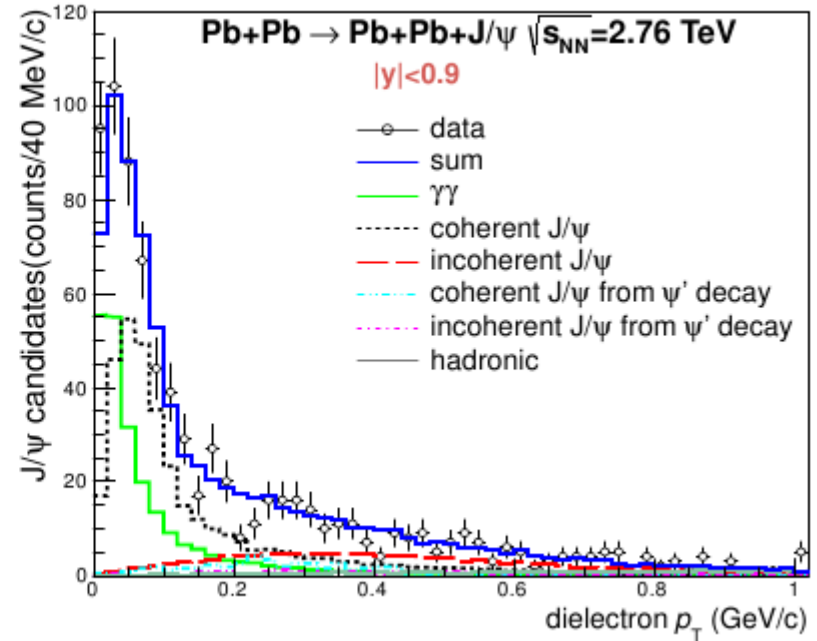
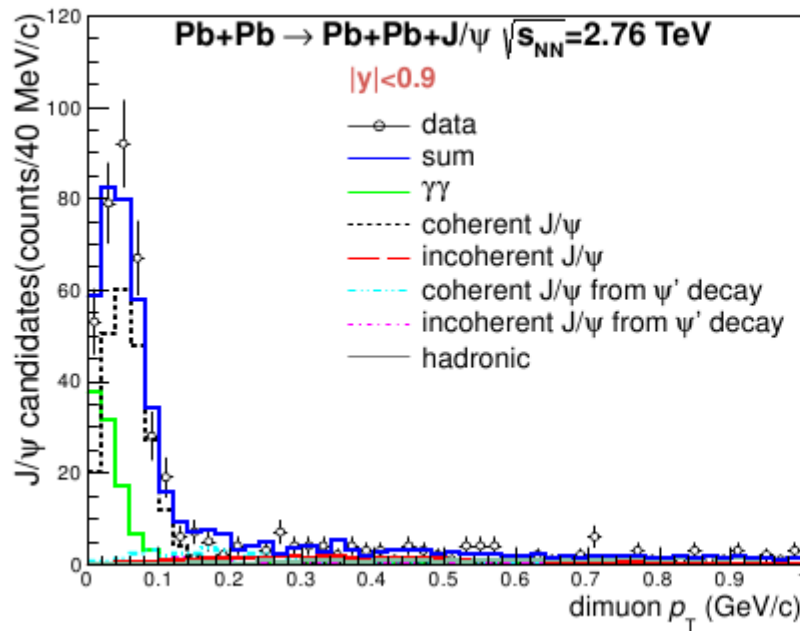
ALICE Collaboration, arxiv:1305.1467

Joakim Nystrand, EPS HEP 2013, Stockholm, Sweden, 18-24 July

# Exclusive $J/\psi$ production in Pb-Pb collisions

Transverse momentum distributions – Central barrel

ALICE Collaboration, arxiv:1305.1467



Clear coherent peak from  $J/\psi$  and continuum  $\gamma\gamma \rightarrow l^+l^-$  observed at low  $p_T$ .

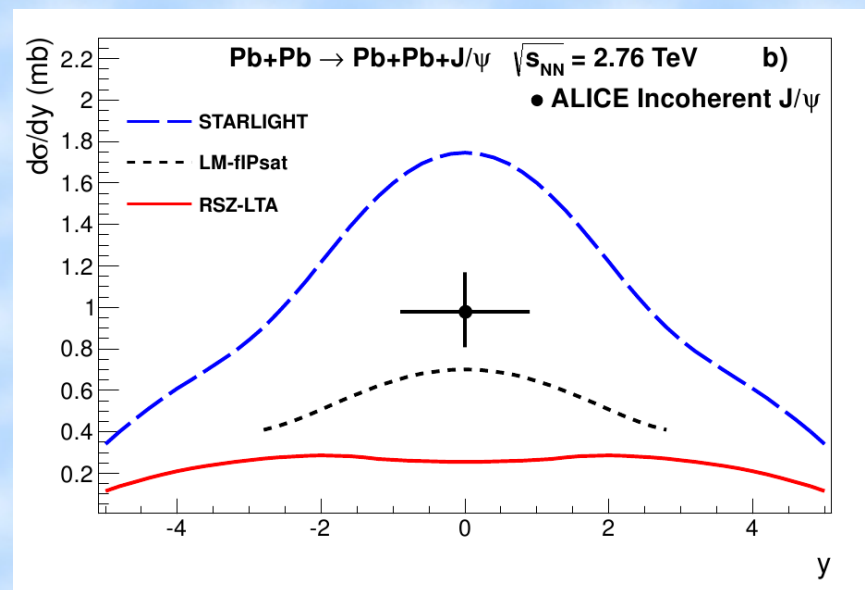
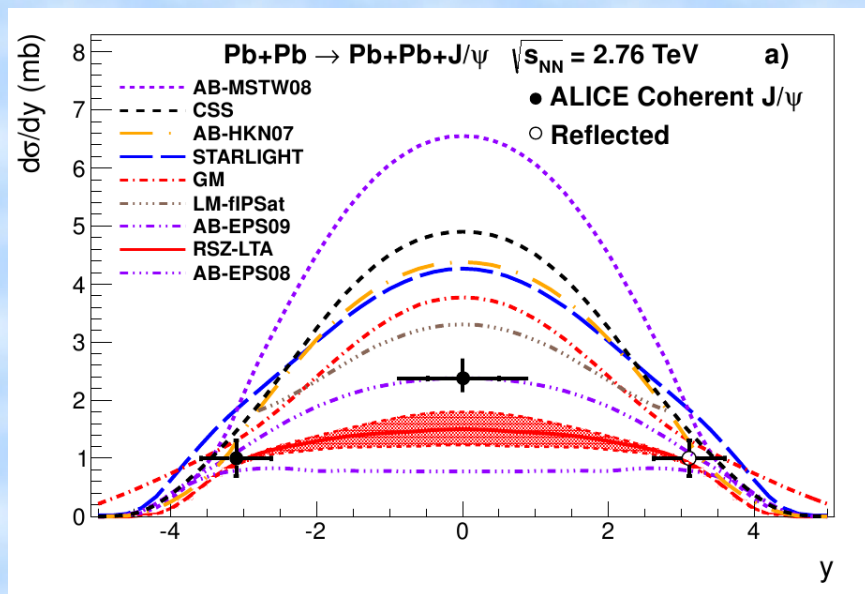
Full spectrum explained by, in addition, incoherent  $J/\psi$ ,  $J/\psi$  from feed down from  $\psi'$ , and some hadronic contribution at high  $p_T$ .

Templates from STARLIGHT Monte Carlo (photoproduction) and from data at higher centralities (hadronic).

# Exclusive $J/\psi$ production in Pb-Pb collisions

Measured coherent and incoherent  $d\sigma/dy$ .

Coherent cross section in best agreement with models which include moderate gluon shadowing consistent with the EPS09 parameterization (AB-EPS09, RSZ-LTA) in the  $x \approx 10^{-3}$  range.



ALICE Collaboration, arxiv:1305.1467

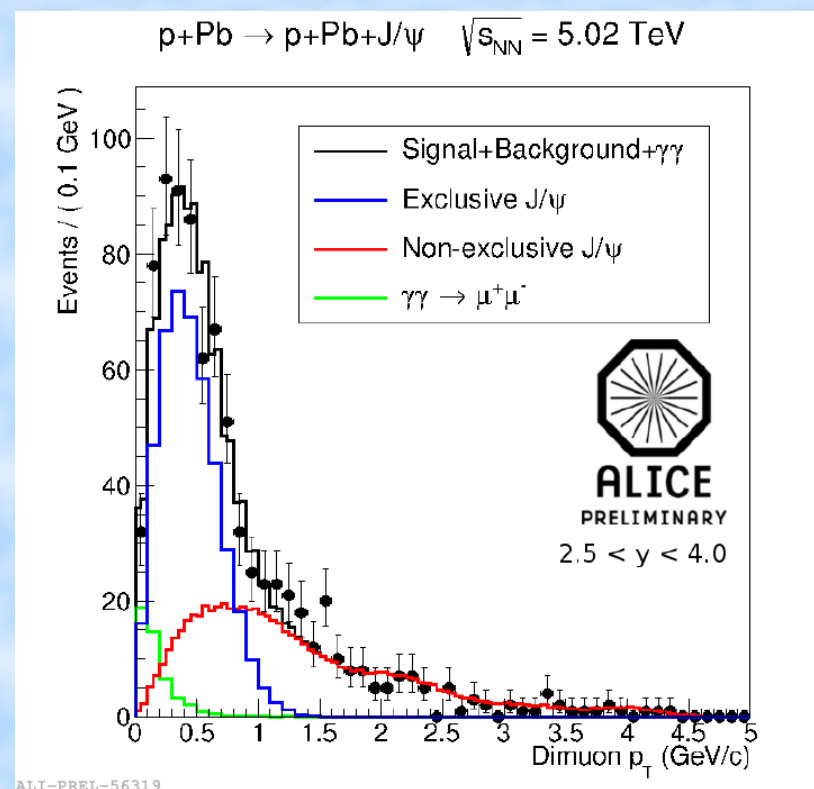
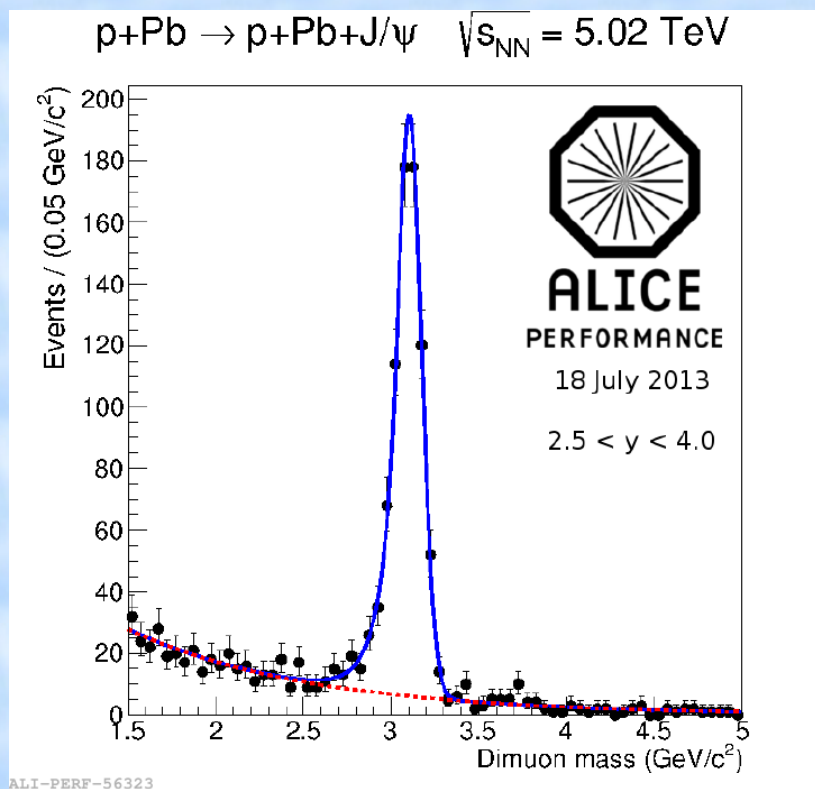
# Exclusive $J/\psi$ production in p-Pb collisions

# Exclusive $J/\psi$ production in p-Pb collisions

Invariant mass and transverse momentum distribution for exclusive  $J/\psi$  production in p+Pb collisions.

$\gamma$ -proton CM energies:  $21 < W < 45$  GeV,  $\langle W \rangle = 29.8$  GeV.

Contribution from events where the proton breaks up (dissociation). Shape of non-exclusive  $J/\psi$   $p_T$  distribution estimated from data by considering events with more than 2 hits in VZERO-C.



# Exclusive $J/\psi$ production in p-Pb collisions

Measured cross sections (ALICE Preliminary):

$$d\sigma(p+Pb \rightarrow p+Pb+J/\psi)/dy \quad (-4.0 < y < -2.5) = 6.18 \pm 0.42 \text{ (stat.)} \pm 0.56 \text{ (sys)} \mu\text{b}$$

$$d\sigma(p+Pb \rightarrow p+Pb+J/\psi)/dy \quad (-4.0 < y < -3.5) = 5.50 \pm 0.72 \text{ (stat.)} \pm 0.52 \text{ (sys)} \mu\text{b}$$

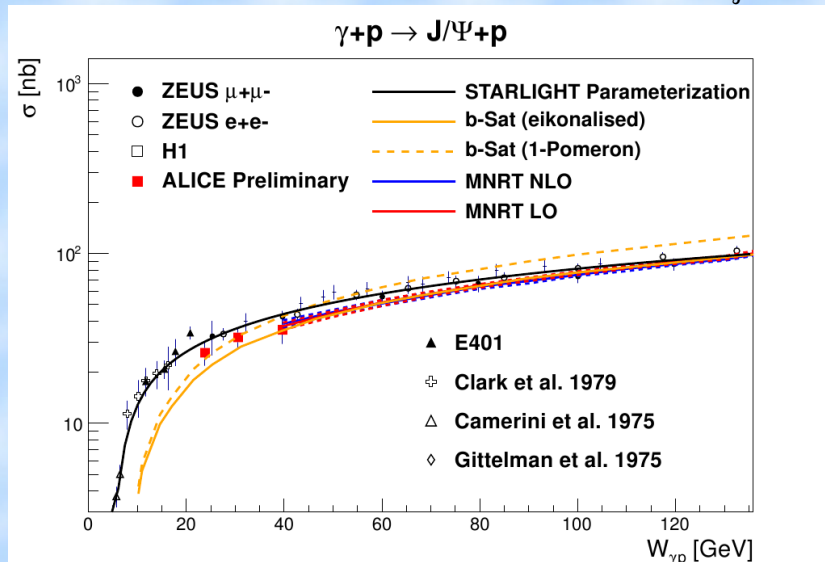
$$d\sigma(p+Pb \rightarrow p+Pb+J/\psi)/dy \quad (-3.5 < y < -3.0) = 6.26 \pm 0.55 \text{ (stat.)} \pm 0.57 \text{ (sys)} \mu\text{b}$$

$$d\sigma(p+Pb \rightarrow p+Pb+J/\psi)/dy \quad (-3.0 < y < -2.5) = 6.39 \pm 0.94 \text{ (stat.)} \pm 0.59 \text{ (sys)} \mu\text{b}$$

Corrected for feed down from  $\psi'$ . Note:  $y$  is the rapidity in the lab frame.

The measured  $d\sigma/dy$  related to  $\sigma(\gamma+p \rightarrow J/\psi+p)$  through the photon spectrum.

$$d\sigma(p+Pb \rightarrow p+Pb+J/\psi)/dy = n_\gamma(y) \sigma(\gamma+p \rightarrow J/\psi+p)$$



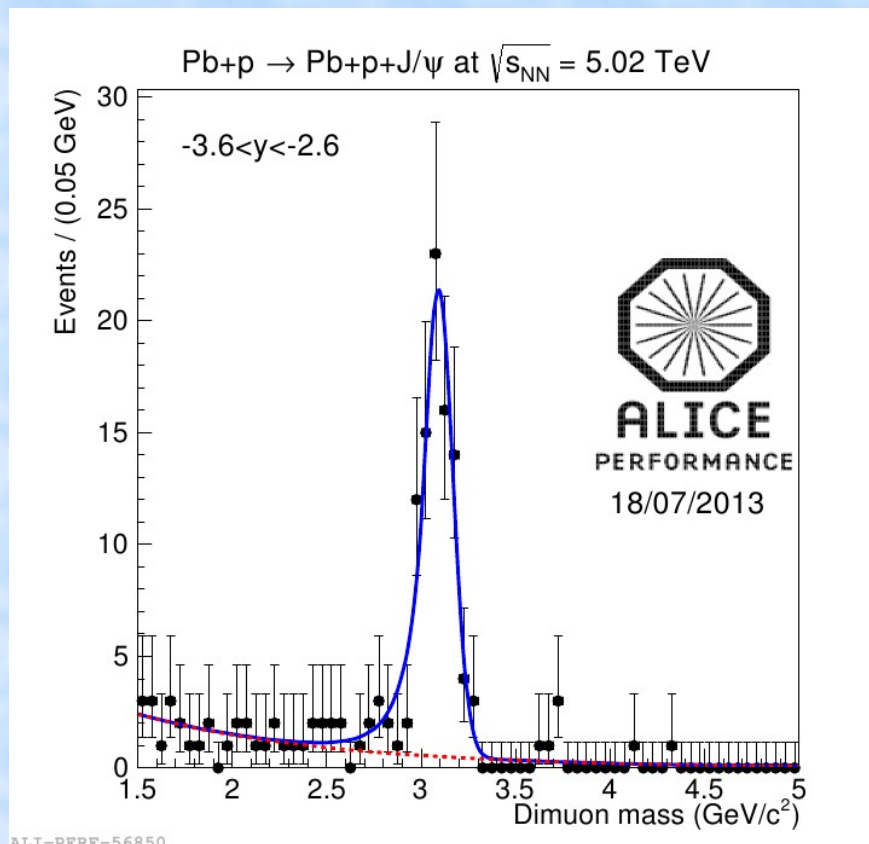
ALICE result compared with data from fixed target experiments and model calculations.

b-Sat: [arxiv:1206.2913](https://arxiv.org/abs/1206.2913); [1211.4831](https://arxiv.org/abs/1211.4831).  
MNRT: PLB 662 (2008) 252.

# Exclusive $J/\psi$ production in Pb-p collisions

Invariant mass distribution for exclusive  $J/\psi$  production in Pb-p collisions.

$\gamma$ -proton CM energies:  $578 < W < 972$  GeV,  $\langle W \rangle = 686$  GeV.



Work in progress to measure the cross section in this energy range!



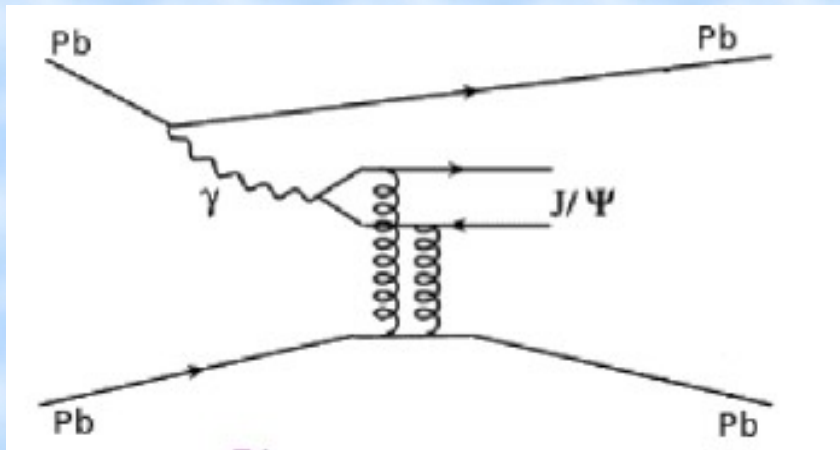
# Outlook and conclusions

- ALICE has made the first measurement of coherent and incoherent photoproduction of  $J/\Psi$  in Pb+Pb collisions at the LHC.
- The measured coherent cross section in agreement with models which include moderate nuclear gluon shadowing consistent with the EPS09 parameterization.
- ALICE has made the first measurement of exclusive  $J/\Psi$  production in p+Pb collisions at the LHC.
- The result is in good agreement with data from lower energies ( $21 < W < 45$  GeV). Work in progress to measure the  $J/\Psi$  cross section in the  $578 < W < 972$  GeV energy range.



# Backup

# Exclusive vector meson production



- Heavy vector mesons provide a hard scale.
- Exclusive production can be modelled through exchange of 2 gluons. (Ryskin 1993).

Several predictions for exclusive production  $Pb+Pb \rightarrow Pb+Pb+J/\Psi$  at the LHC:

- S.R. Klein, J. Nystrand Phys. Rev. C 60 (1999) 014903.
- V. Rebyakova, M. Strikman, M. Zhalov Phys. Lett. B 710 (2012) 647.
- A. Adeluyi, C.A. Bertulani Phys. Rev. C 85 (2012) 044904.
- V.P. Goncalves, M.V.T. Machado Phys. Rev. C 84 (2011) 011902.
- A. Cisek, W. Schäfer, A. Szczurek Phys. Rev. C 86 (2012) 014905.
- T. Lappi, H. Mäntysaari, Phys. Rev. C 87 (2013) 032201.

To be compared with data...

# Data on exclusive $J/\psi$ production in $\gamma$ -p collisions

E401: M. Binkley et al. Phys. Rev. Lett. 48 (1982) 73.

A.R. Clark et al.: Phys. Rev. Lett. 43 (1979) 187.

U. Camerini et al.: Phys. Rev. Lett. 35 (1975) 483.

B. Gittelman et al.: Phys. Rev. Lett. 35 (1975) 1616.

Zeus: Eur. Phys. J C24 (2002) 345.

H1: arxiv:1304.5162; Eur. Phys. J C46 (2006) 585.

## Transverse momentum distributions – Central barrel – log-scale

