III Workshop on QCD and Diffraction at the LHC
joint with LHC Forward Physics and Diffraction WG
Kraków

Photoproduction of J/ψ in Pb-Pb and p-Pb collisions at the LHC with the ALICE detector

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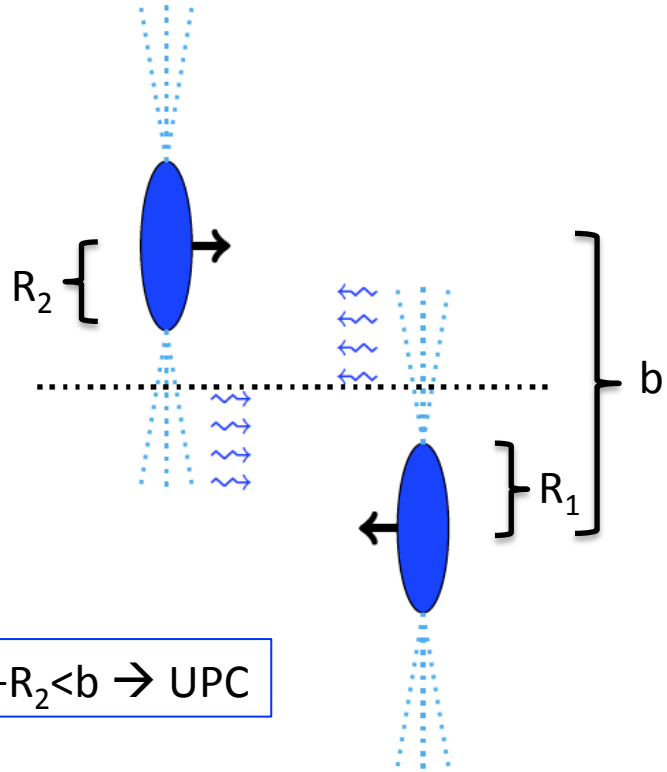
On behalf of the **ALICE** Collaboration

November 18, 2013

Brief remainder

Ultra peripheral Collisions at the LHC

- ✓ The EM field of protons and ions at the LHC can be viewed as a beam of quasi real photons



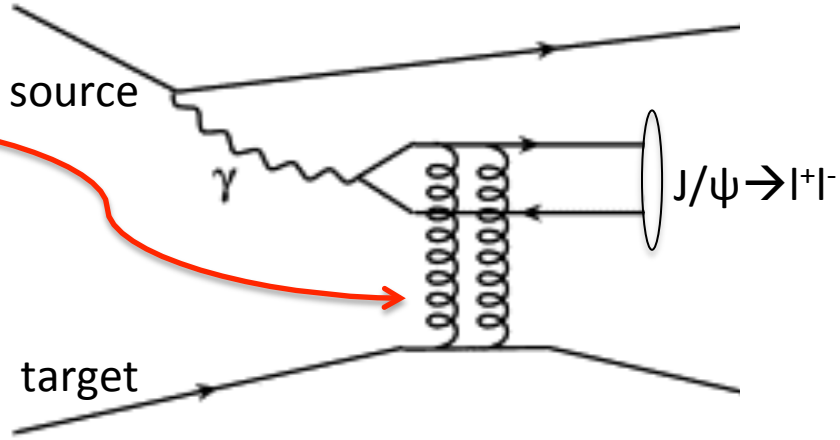
$R_1+R_2<b \rightarrow$ UPC

- ✓ The intensity of the photon beam is proportional to Z^2
- ✓ The virtuality of the photons is restricted by the radius of the emitting particle: $Q^2 \approx hc/(2\pi R)^2$
  - ➢ γ from p: $Q^2 \approx (250\ MeV)^2$
  - ➢ γ from Pb: $Q^2 \approx (30\ MeV)^2$
- ✓ The max energy of the photons in the lab system is determined by the boost of the emitting particle
  - ➢ γ from p (4TeV): $E^{\gamma}_{max} \approx 1200$ GeV
  - ➢ γ from Pb : $E^{\gamma}_{max} \approx 50$ GeV

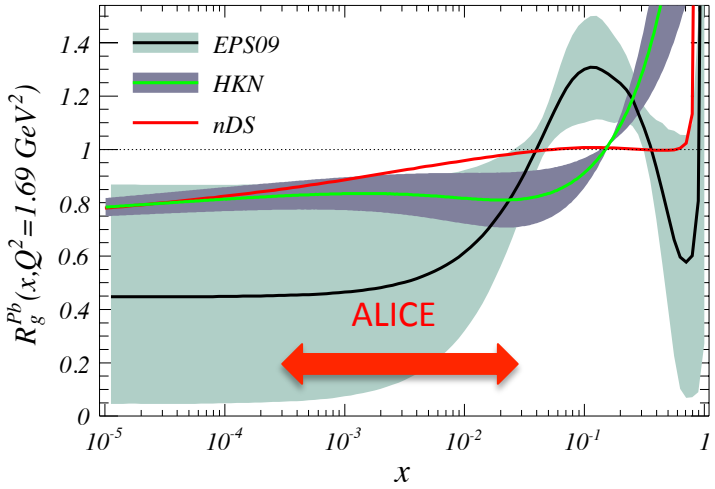
Using Pb-Pb and p-Pb data at the LHC it is possible to study γ-Pb, γp and γγ collisions at higher center of mass energies than ever before

Photoproduction of J/ψ

- Mass of J/ψ serves as a hard scale for pQCD calculations, which samples the square of the gluon distribution of the target (proton, Pb)
- J/ψ rapidity maps the photon-target center of mass energy
- Has a very clean signature in the leptonic decay channel: two low pt leptons in an otherwise empty detector

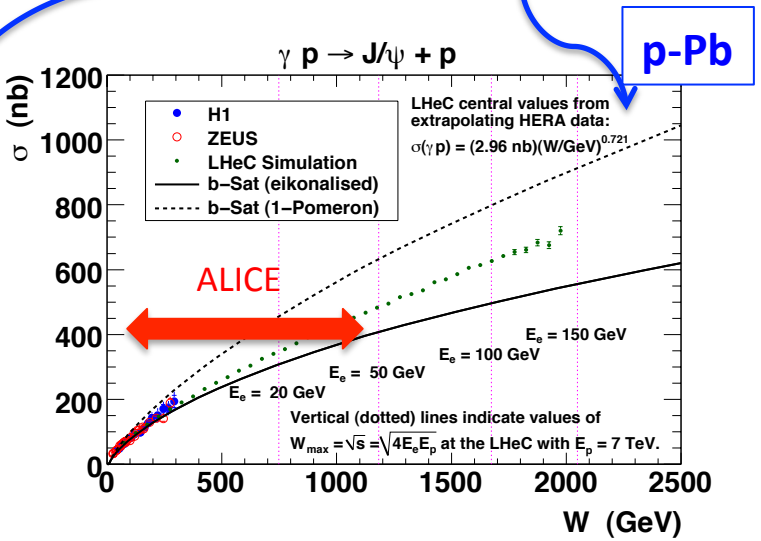


J/ψ photoproduction permits us to study perturbatively non linear effects at low x in the gluon distribution of the target (key words: shadowing, saturation)



Pb-Pb

p-Pb



C A Salgado *et al* 2012 *J. Phys. G: Nucl. Part. Phys.* **39** 015010

LHeC Study group ArXiv: 1211.4831

Photoproduction of J/ψ in Pb-Pb collisions

Results for the Pb-Pb system

Two ALICE publications:

Phys.Lett. B718 (2013) 1273-1283
(Forward sample)

Eur. Phys. J. C (2013) 73:2617
(Central Barrel sample)

- 2011 Pb-Pb data
- Central barrel and forward samples
- In γ-Pb collisions:
  - Coherent production
    Coupling to the whole nucleus
    $\langle p_T(J/\psi) \rangle \approx 60$ MeV
  - Incoherent production
    Coupling to a nucleon
    $\langle p_T(J/\psi) \rangle \approx 500$ MeV
- In γγ collisions:
  - Electron—positron production
    QED process with large coupling

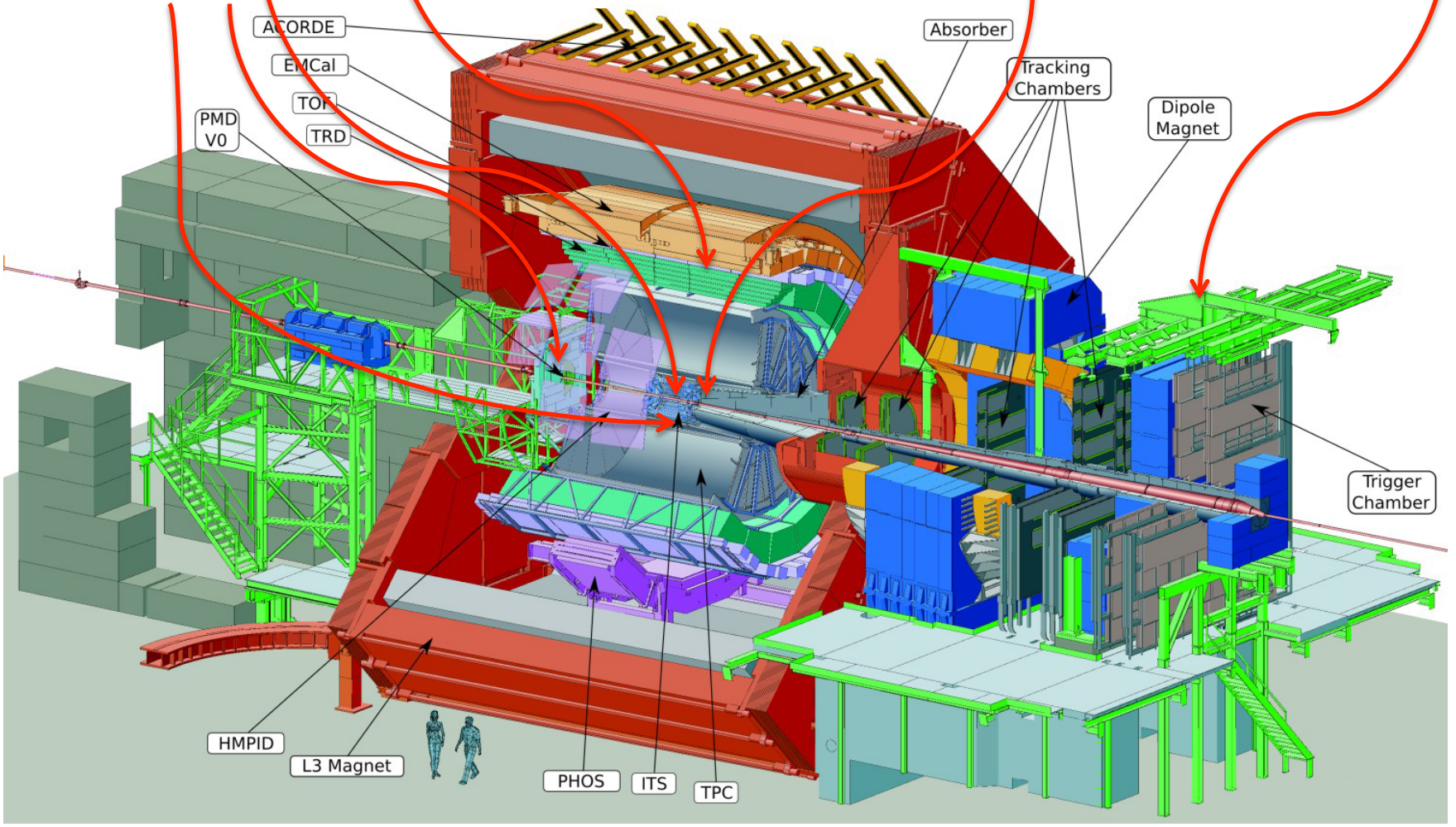
Triggering photoproduction of J/ψ →l^+l^- in 2011 Pb-Pb

UPC central barrel trigger:

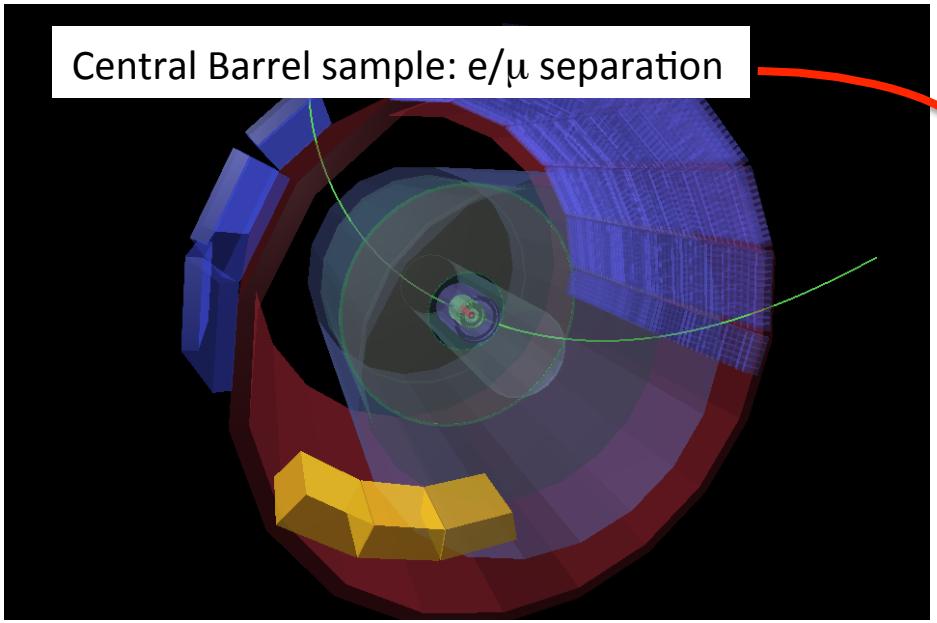
- 2 ≤ **TOF** hits ≤ 6 + back-to-back topology
- ≥2 hits in **SPD**
- no hits in **VZERO**

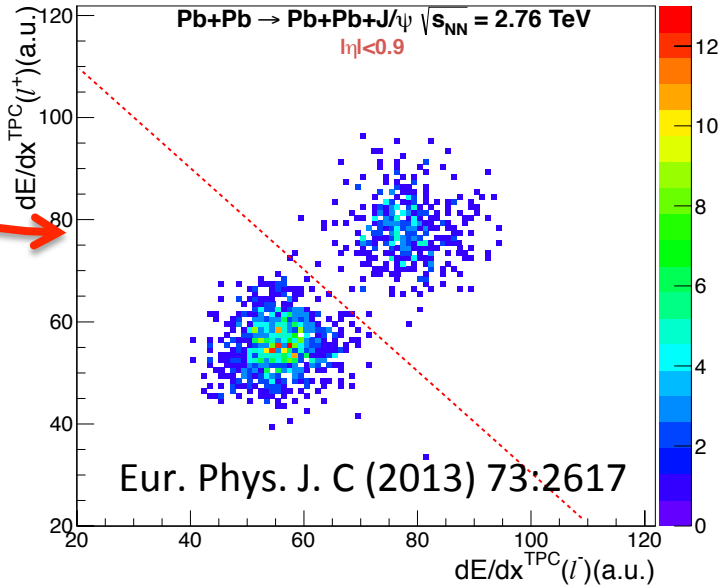
UPC forward trigger:

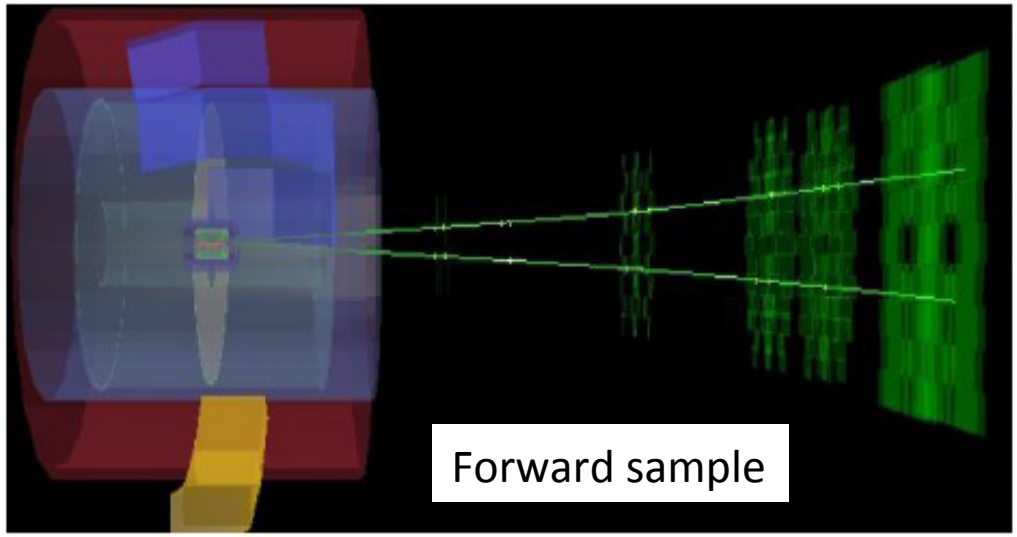
- single **muon trigger** with $p_T > 1$ GeV/c
- hit in **VZERO-C** no hits in **VZERO-A**



J/ψ →l^+l^- samples in ALICE







Coherent J/ψ production in Pb-Pb collisions (Forward)

From the 2011 Pb-Pb run: Phys.Lett. B718 (2013) 1273-1283

Physics Letters B 718 (2013) 1273–1283

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Coherent J/ψ photoproduction in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV ☆

ALICE Collaboration

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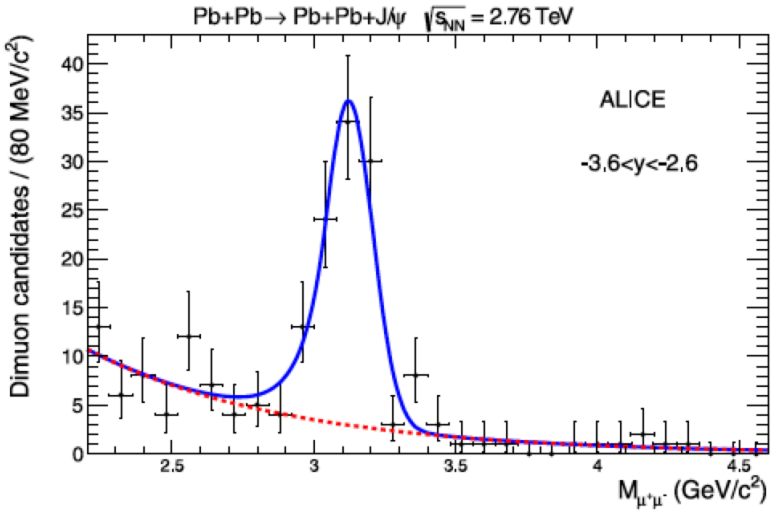
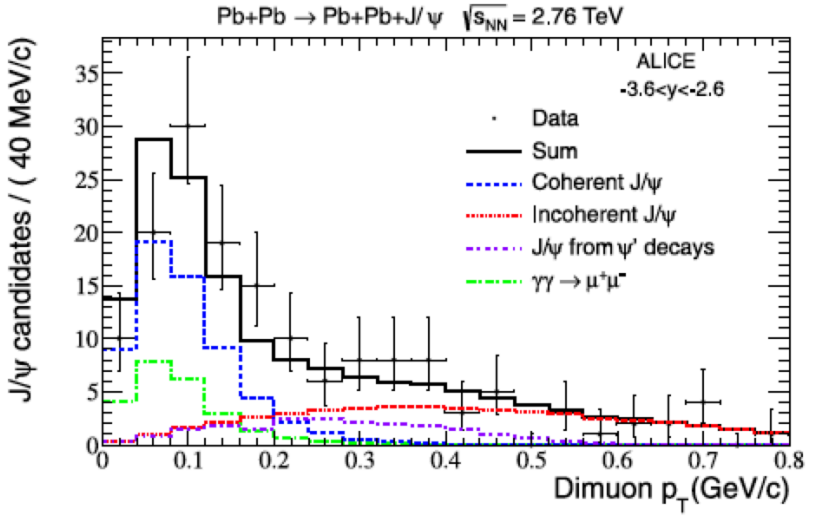
ABSTRACT

The ALICE Collaboration has made the first measurement at the LHC of J/ψ photoproduction in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The J/ψ is identified via its dimuon decay in the forward rapidity region with the muon spectrometer for events where the hadronic activity is required to be minimal. The analysis is based on an event sample corresponding to an integrated luminosity of about 55 μb^{-1}. The cross section for coherent J/ψ production in the rapidity interval $-3.6 < y < -2.6$ is measured to be $d\sigma^{coh}_{J/\psi}/dy = 1.00 \pm 0.18(stat)^{+0.24}_{-0.26}(syst)$ mb. The result is compared to theoretical models for coherent J/ψ production and found to be in good agreement with those models which include nuclear gluon shadowing.

ALICE Collaboration / Physics Letters B 718 (2013) 1273–1283



ALICE Collaboration / Physics Letters B 718 (2013) 1273–1283

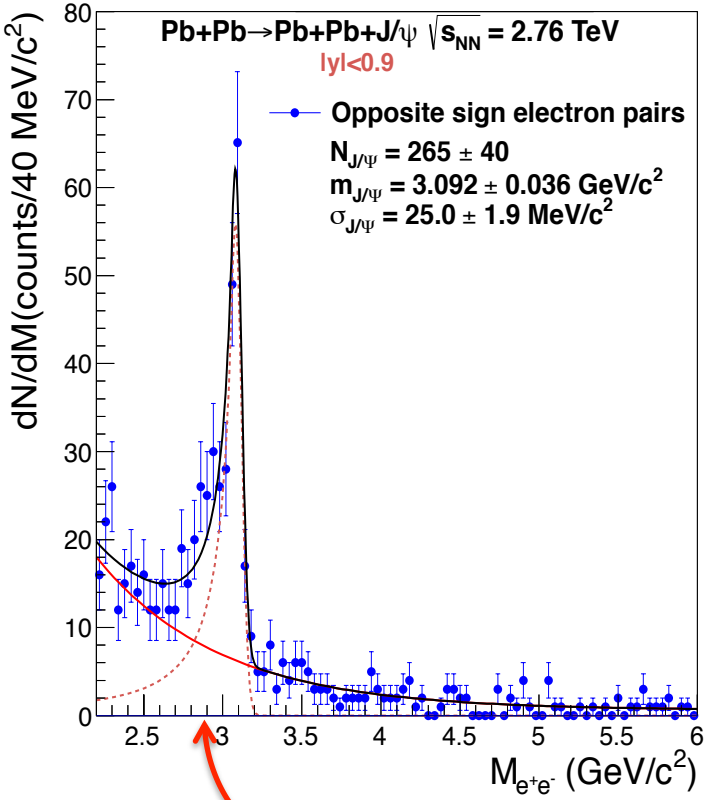


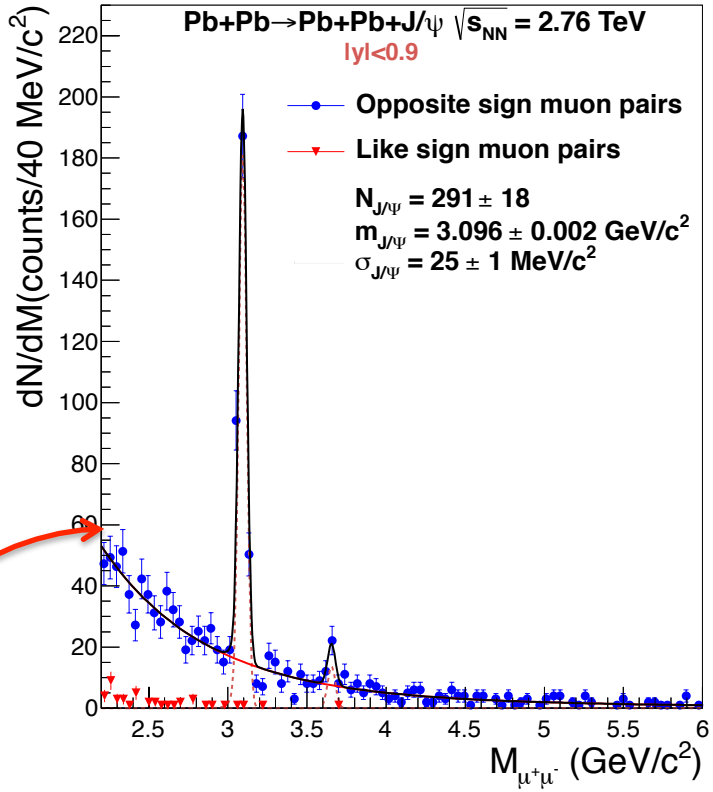
J/ψ with low transverse momentum as expected from coherent production

Forward J/ψ coherent photo-production samples the gluon distribution of Pb nuclei at x≈10^{-2}

Coherent J/ψ production in Pb-Pb collisions (Central Barrel)

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



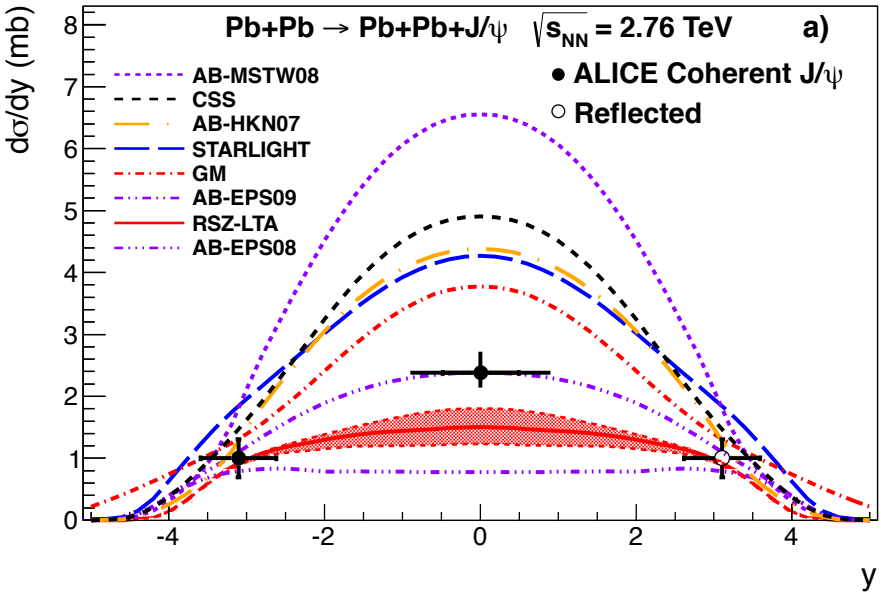


Electron and muon channels are both accessible when using the central barrel detectors

This process samples the gluon distribution of lead nuclei at x≈10^{-3}

Cross section for coherent J/ψ photoproduction in Pb-Pb collisions

Phys.Lett. B718 (2013) 1273-1283
Eur. Phys. J. C (2013) 73:2617



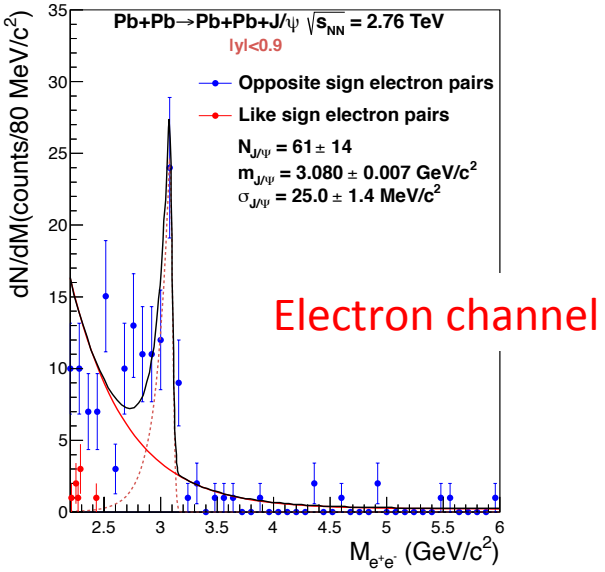
ALICE results are able to distinguish between the different models

LO pQCD models including nuclear gluon shadowing seem to be favored

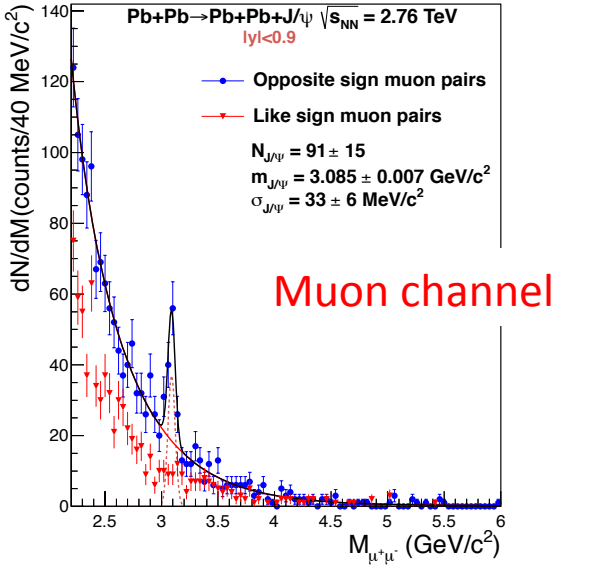
- ✓ **AB: Adeluyi and Bertulani, PRC85 (2012) 044904**
  These models use LO pQCD scaled by an effective constant to correct for missing contributions. MSTW08 assumes no nuclear effects, the other three incorporate nuclear effects according to different PDFs
- ✓ **CSS: Cisek, Szczurek, Schäfer PRC86 (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

Incoherent J/ψ production in Pb-Pb collisions (Central Barrel)

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

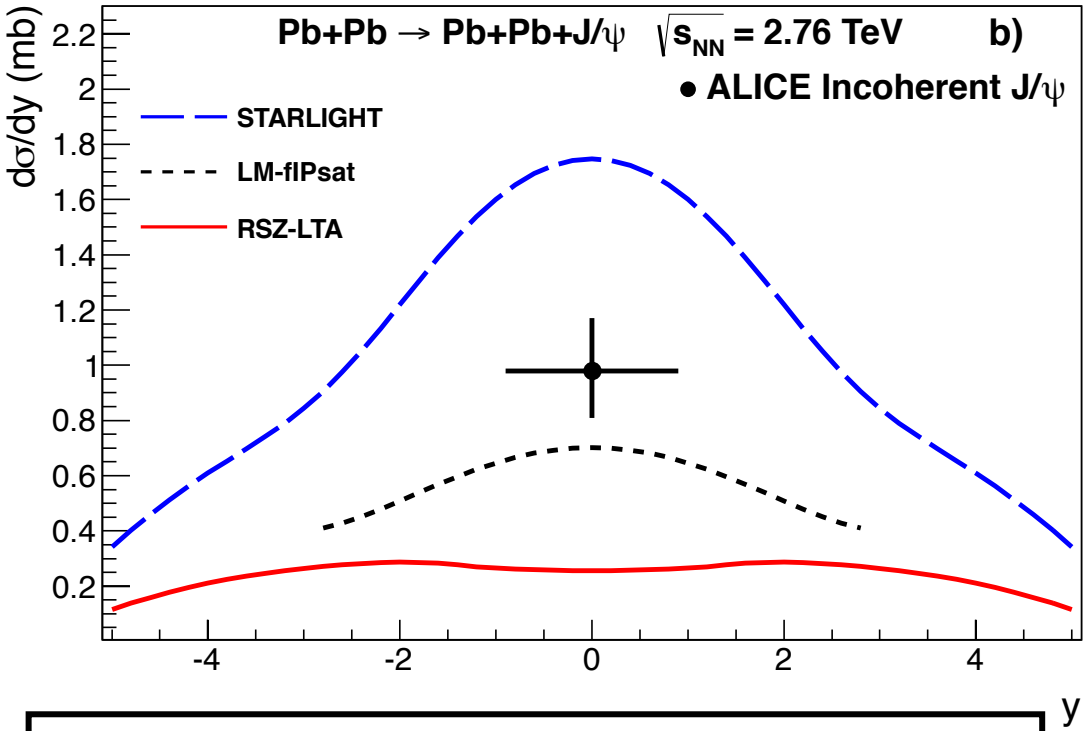


Electron channel



Muon channel

✓ **LM: Lappi, Mantysaari, PRC87 (2013) 032201**
Color dipole model based with Glauber approach and a saturation prescription

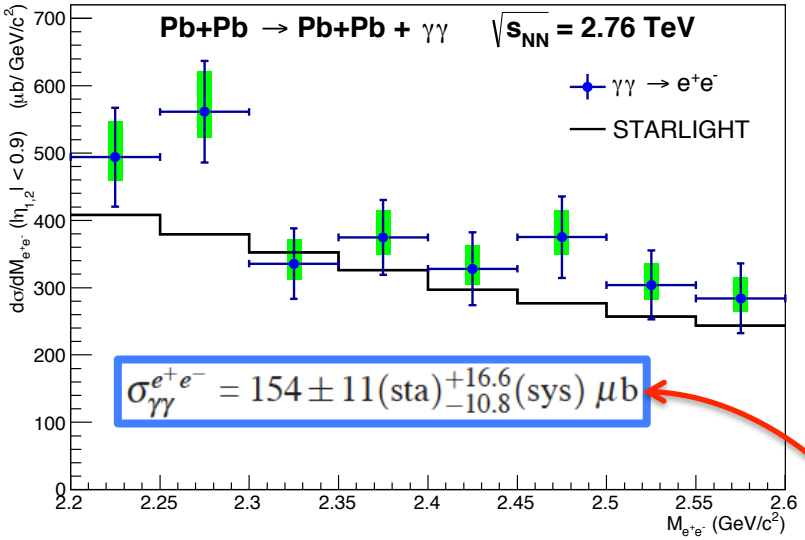


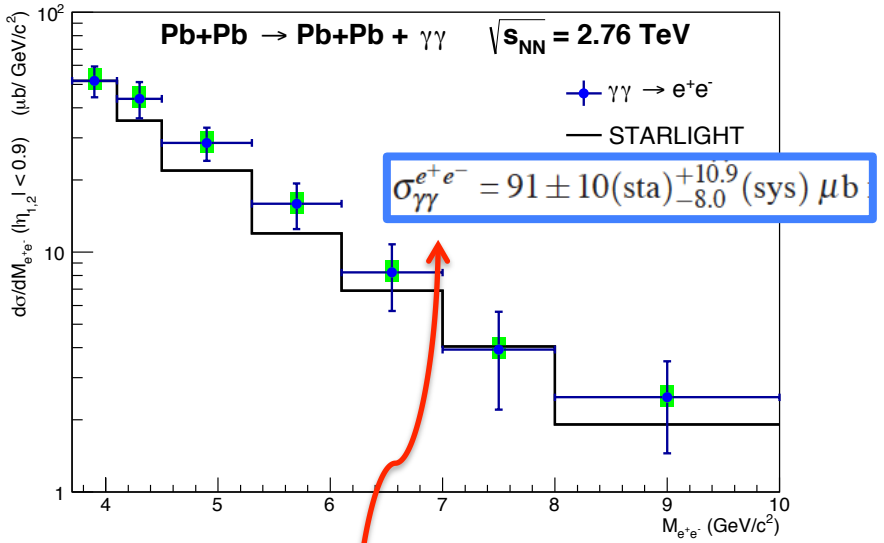
Three predictions for incoherent J/ψ photoproduction in Pb-Pb collisions, but differing almost by an order of magnitude

ALICE sets strong constraints on models

$\gamma+\gamma \rightarrow e^+ + e^-$ production in Pb-Pb (Central Barrel)

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





- ✓ QED process … but uncertainties due to
  - ➢ Higher order corrections because the coupling is enhanced by a factor of Z
  - ➢ Nuclear form factor and the minimum momentum transfer in the interaction

→ Different models predict a reduction of the LO cross section up to 30%

→ (see for example: A. J. Baltz, Phys. Rev. C 80 (2009) 034901; Phys. Rev. Lett. 100 (2008) 062302)

- ✓ Measurement in two different mass ranges: [2.2,2.6] and [3.7,10] GeV/c^2
- ✓ Precision of 12% and 16% respectively
- ✓ Data slightly above STARLIGHT, a LO prediction

ALICE data sets stringent limits on the contribution from high order terms

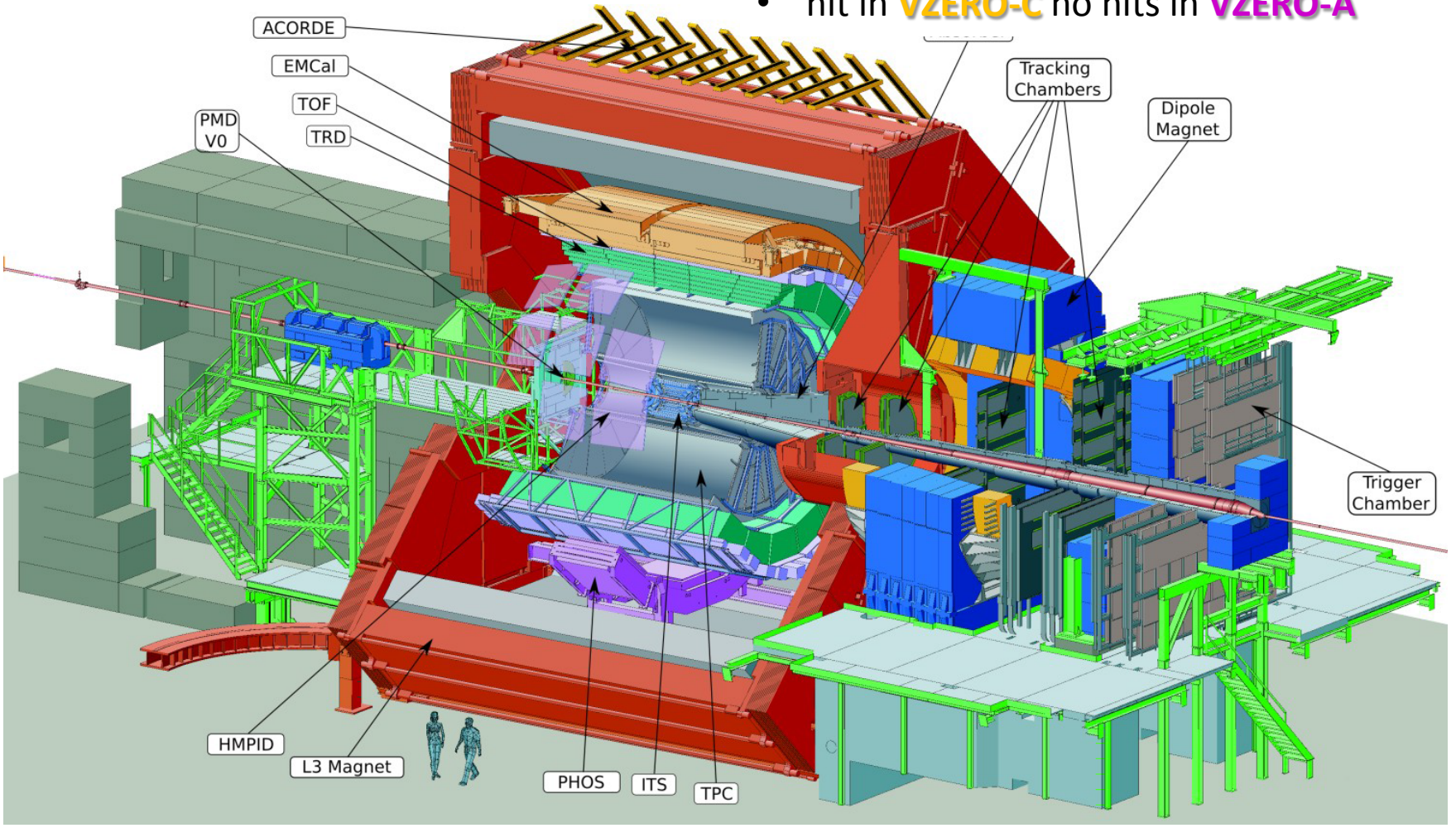
J/ψ in p-Pb and Pb-p collisions

Triggering photoproduction of J/ψ →l^+l^- in 2013 p-Pb

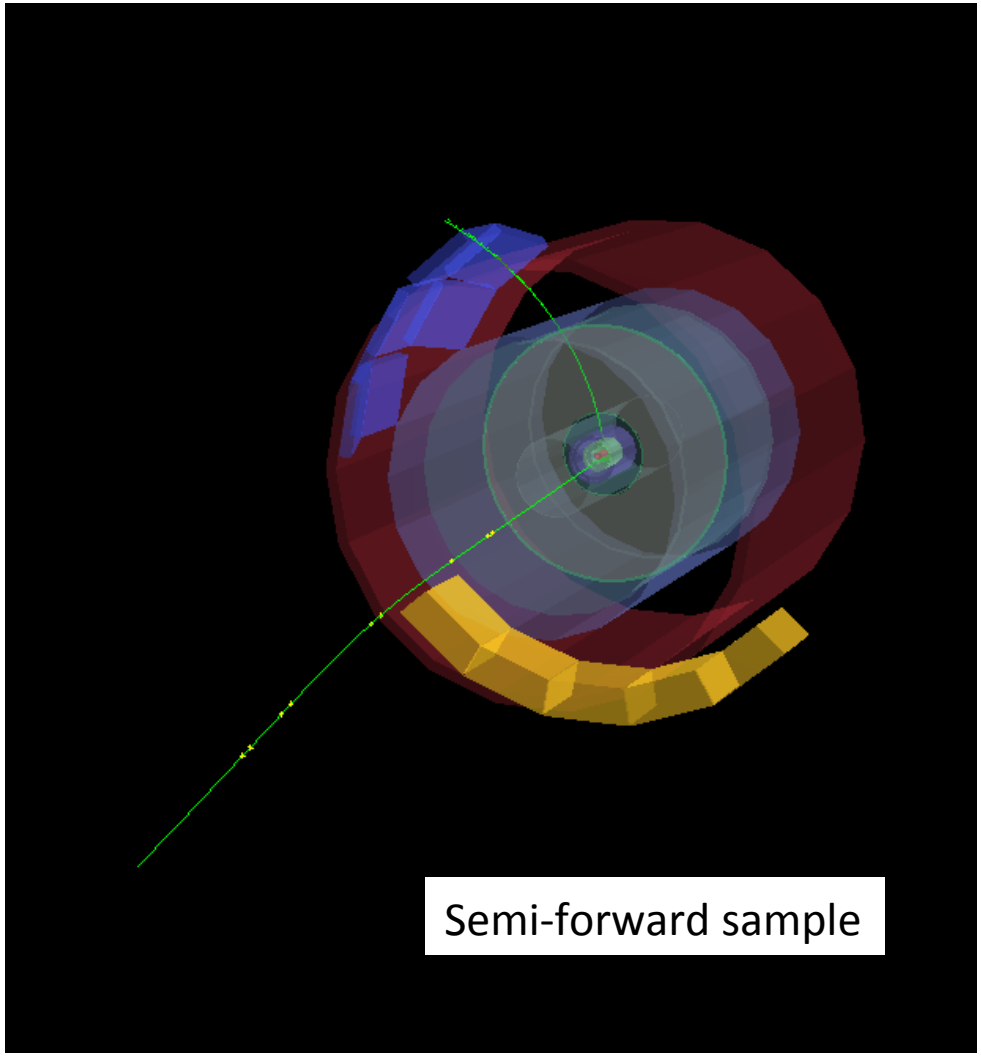
UPC central barrel trigger and UPC forward trigger
Similar triggers as in Pb-Pb 2011

UPC semi-forward trigger:

- single **muon trigger** with $p_T > 0.5$ GeV/c
- Little central activity
- hit in **VZERO-C** no hits in **VZERO-A**



Semi-forward J/ψ →l^+l^- in 2013 p-Pb



J/ψ rapidity, $W_{\gamma p}$ and ALICE

- Measuring the rapidity of the VM w.r.t. the direction of the target the energy in the photon target system can be determined

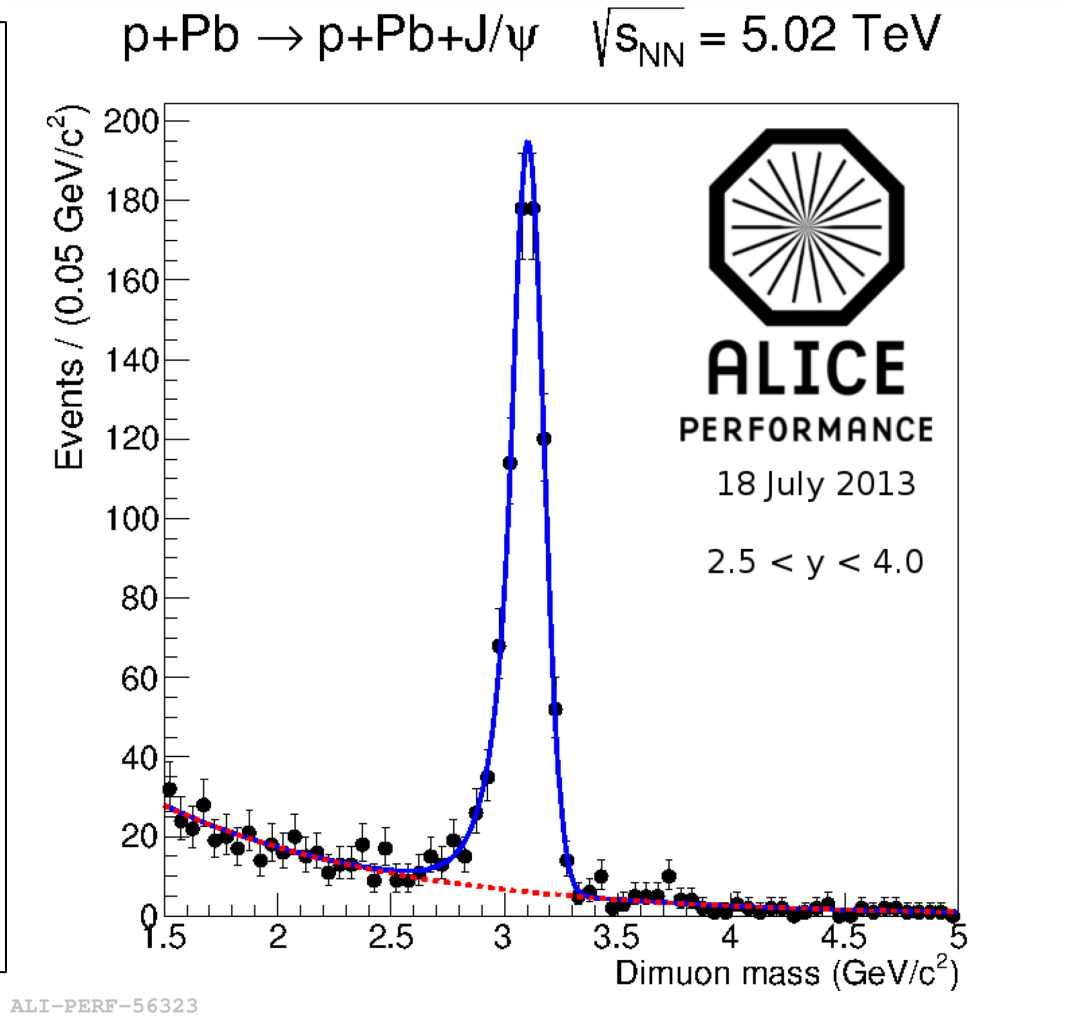
- Unique to p-Pb (Pb-p) is that the source of the photon is known (big adventage w.r.t. pp and Pb-Pb)

- ALICE can measure J/ψ→l^+ l^- with the following 'topologies'

  - Central:
    Both leptons in central barrel:
    Wγp = 100-250 GeV
  - Semi-forward:
    One muon in MUON, the other in central barrel
    Wγp = 45-80 GeV (p-Pb)
    Wγp = 300-550 GeV (Pb-p) → beyond the reach of HERA
  - Forward:
    Both muons in MUON
    Wγp = 20-45 GeV (p-Pb)
    Wγp = 550-1100 GeV (Pb-p) → beyond the reach of HERA

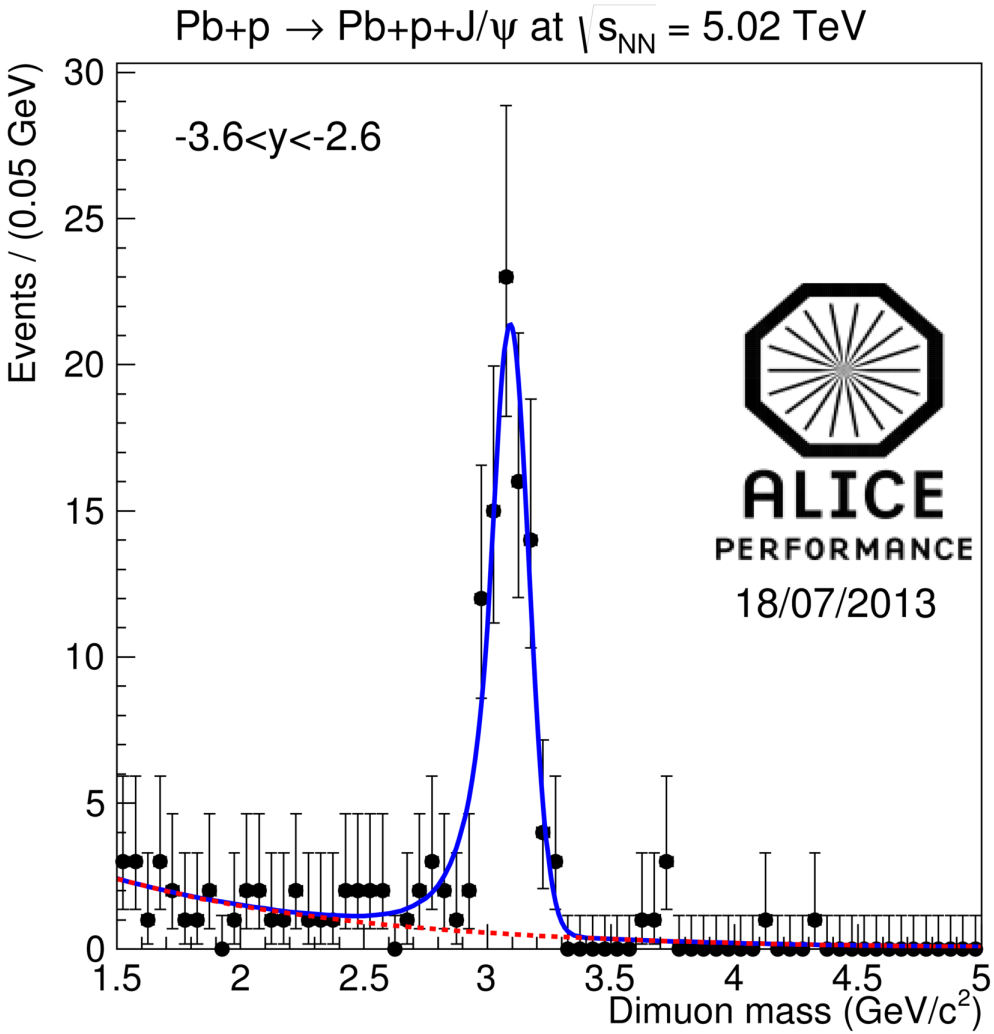
Forward sample in p-Pb: Preliminary results

- The cross section for p-Pb has been measured (preliminary result)
- Small background contribution estimated with data (templates in transverse momentum)
- Same method applied to obtain the $\sigma(\gamma\gamma \rightarrow \mu\mu)$ in 1.5<m<2.5 GeV giving $1.76 \pm 0.12\ (stat) \pm 0.16\ (sys)\ \mu b$ STARLIGHT prediction compatible within statistical error
- Flux from STARLIGHT used to extract the photoproduction cross section
- The cross section is measured in in three rapidity bins (three $W\gamma p$ energy ranges)

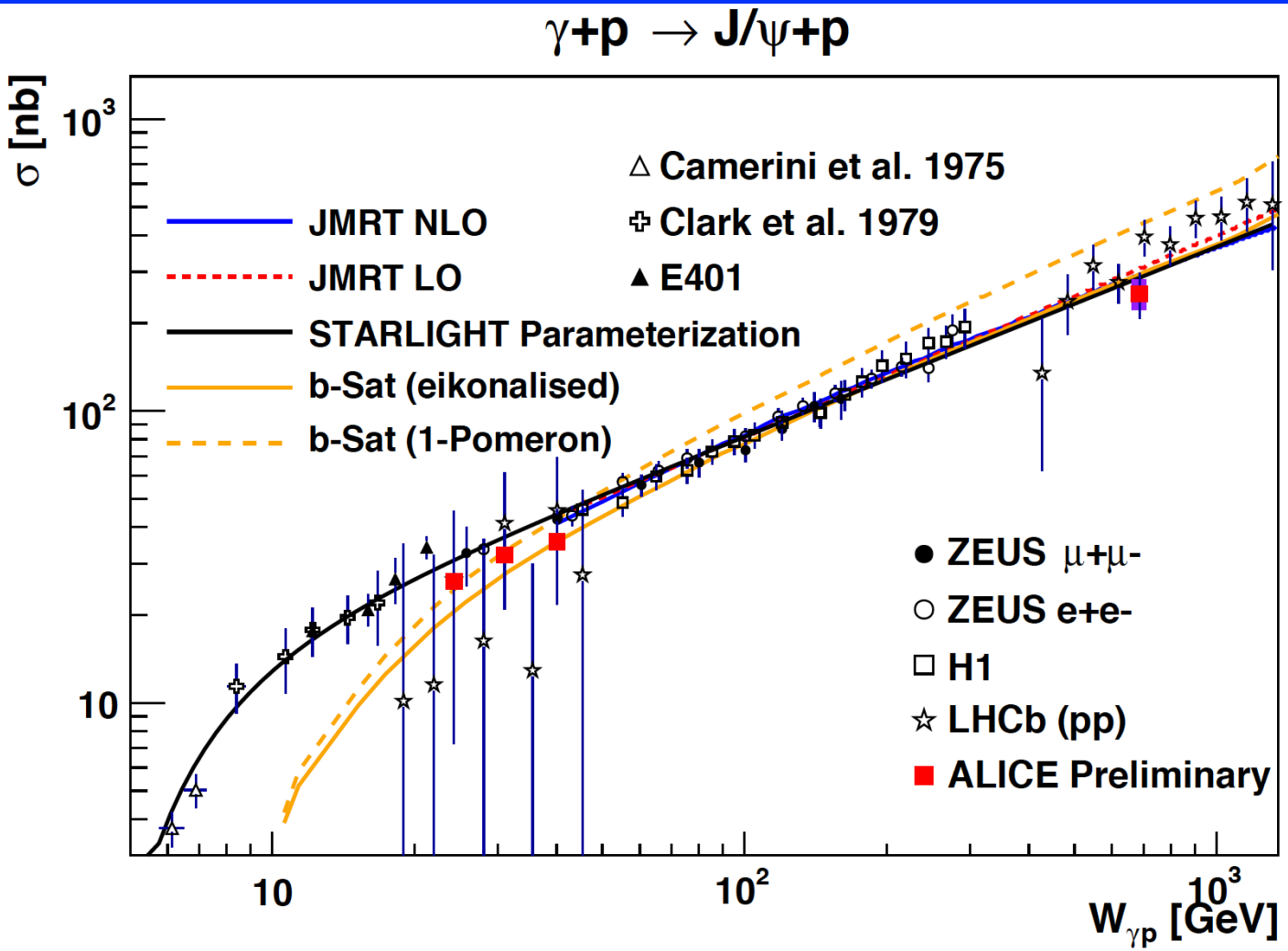


Forward sample in Pb-p: Preliminary results

- The cross section for Pb-p has been measured (preliminary result)
- Contribution from γPb obtained from our Pb-Pb measurement
- Flux from STARLIGHT used to extract the photoproduction cross section
  Flux at this energies has a 12% uncertainty
- The cross section is measured in one rapidity bin (one Wγp energy)

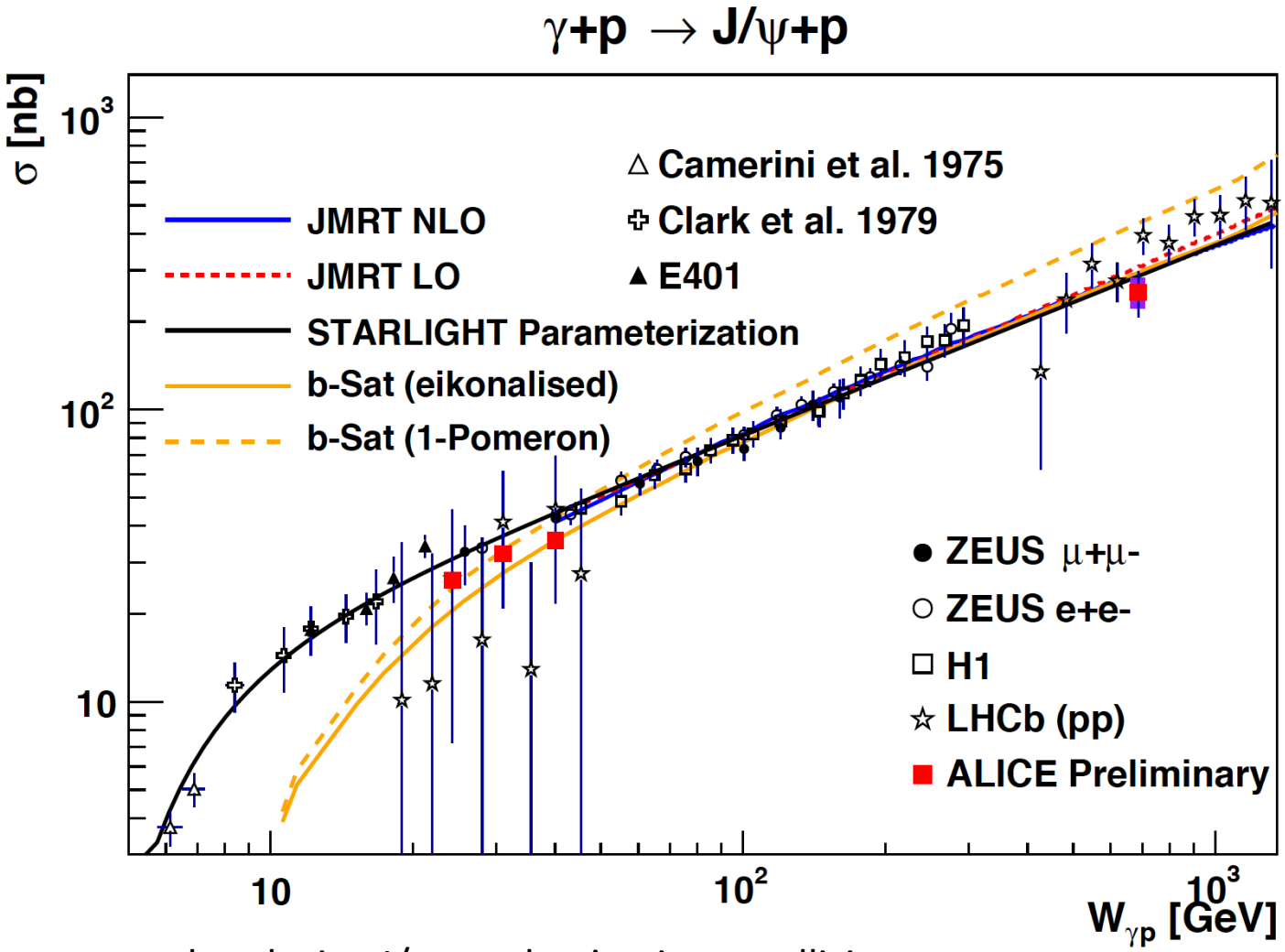


Comparing to HERA data



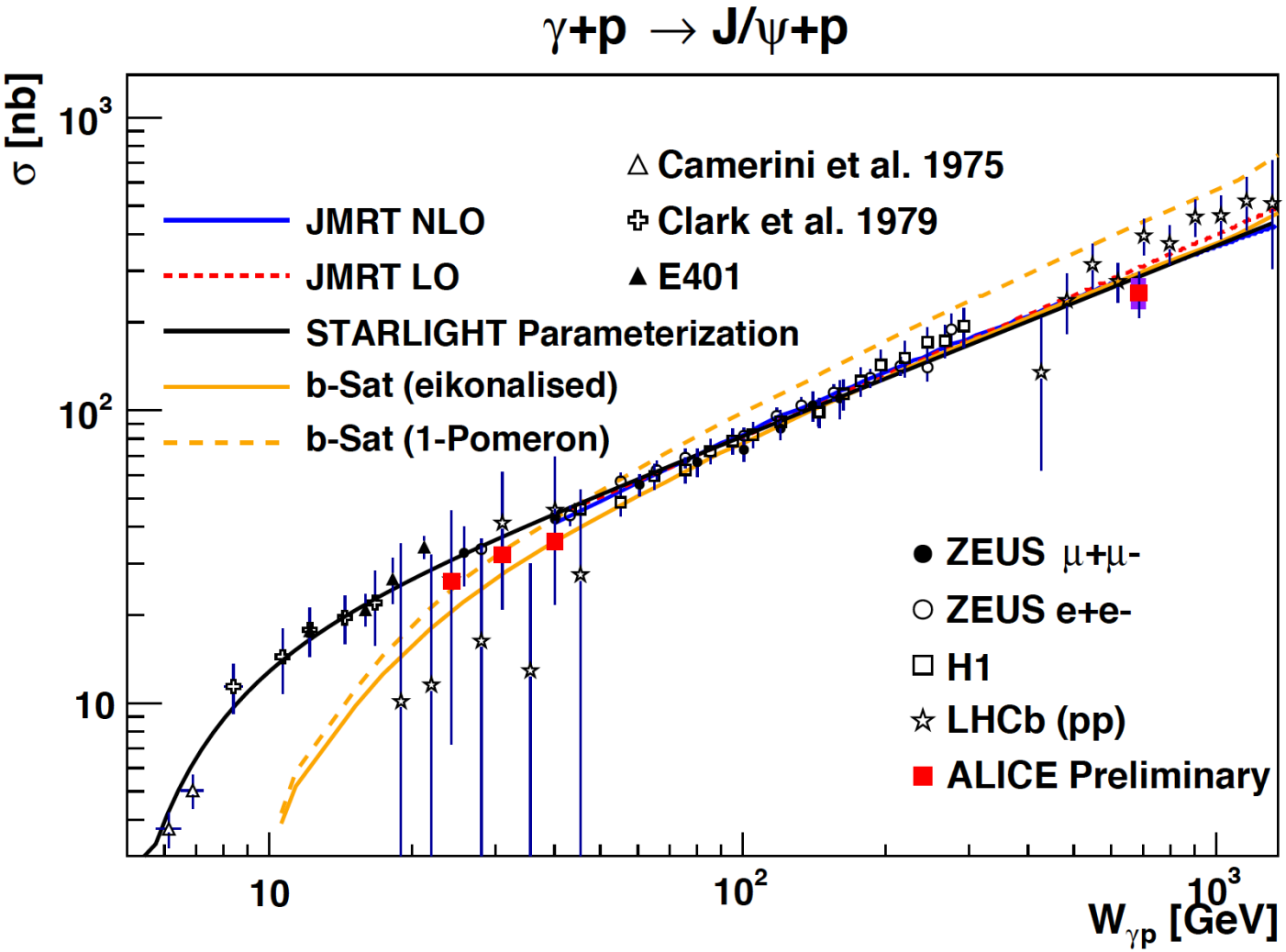
- ✓ ALICE data alone compatible with a power law with exponent ~0.67±0.06
- ✓ Exponent is compatible with those from H1 (0.67±0.03) and ZEUS (0.69±0.02±0.03)
- ✓ There is a relative normalization of about 1 sigma between different sets of HERA data. Similarly, ALICE data show a relative normalization of about 1 sigma wrt HERA data

Comparing to LHCb data



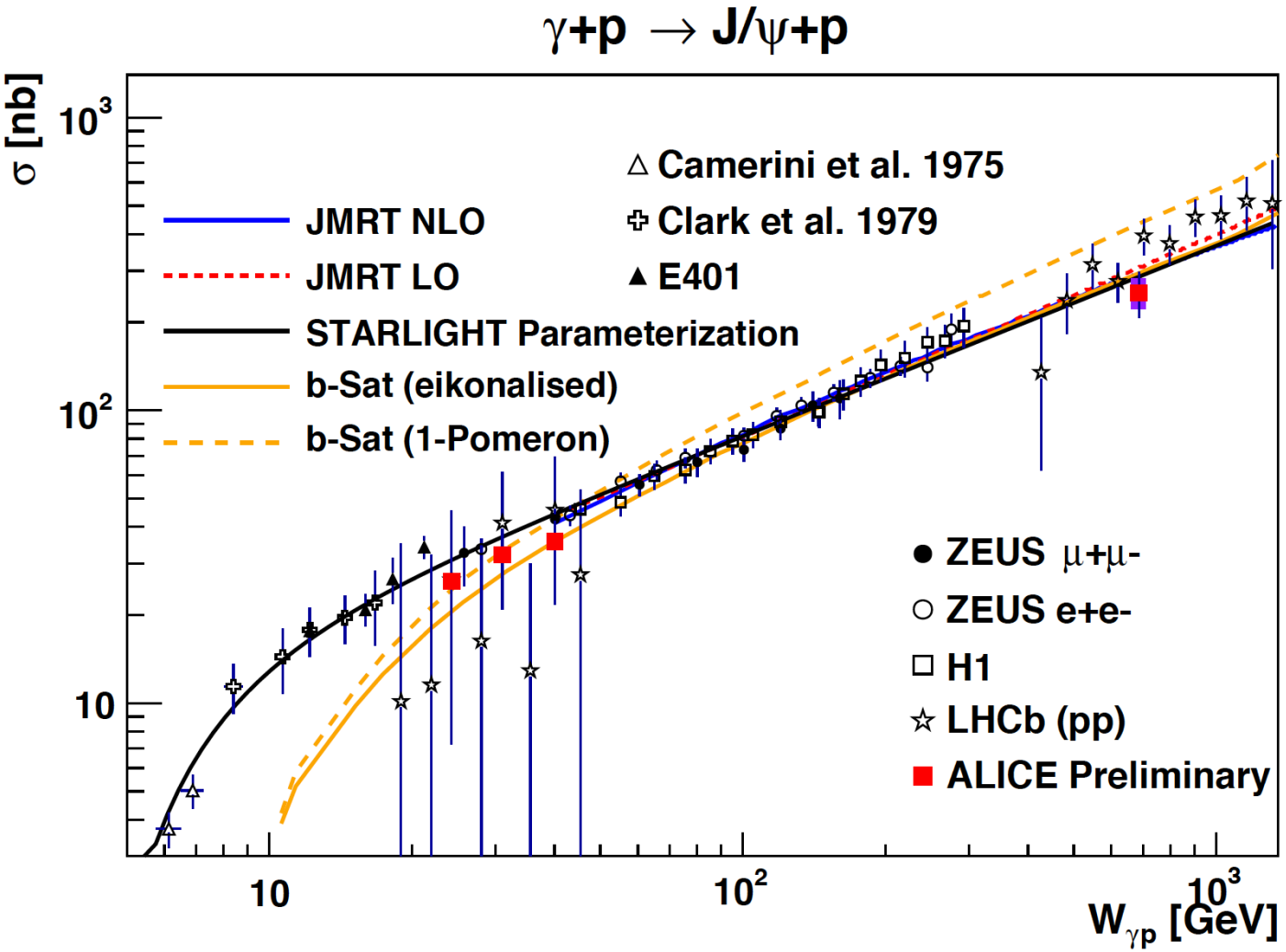
- ✓ LHCb measured exclusive J/ψ production in pp collisions.
  R. Aaij et al. (LHCb collaboration), J.Phys. G40, 045001(2013)
- ✓ Extraction of result in γp not trivial (see discussion in LHCb paper)
- ✓ Exponent from LHCb 0.92±0.15

Comparing to JMRT model



- ✓ LO model based on a power law. NLO model includes the expected main NLO contributions (S. Jones, A. Martin, M. Ryskin, and T. Teubner, (2013), arXiv1307.7099)
- ✓ Both models fitted independently to HERA data and to modified LHCb data
- ✓ Their predictions are about one sigma above our measurements

Comparing to b-Sat model



- ✓ b-Sat (eikonalised) includes b-dependent saturation effects based on a CGC inspired model
- ✓ Agrees with our measurements at low energies and with low energy HERA data
- ✓ It is slightly below HERA data around 200 GeV and slightly above ALICE high energy

Prospects

Propects for the photoproduction of VM in ALICE

- ✓ Very short term
  - ✓ Finish the analysis of the forward data

- ✓ Short term
  - ✓ Finish the analysis of the central and semi-forward data
  - ✓ Study the production of other vector meson both in p-Pb and Pb-Pb with existing data

- ✓ Medium term
  - ✓ Collect new data with a substantial increase in luminosity and increase in energy reach
  - ✓ Take advantage of new detectors to improve the exclusivity condition and the purity of the trigger
  - ✓ Explore new vector mesons and other processes

Summary and outlook

- ✓ ALICE has published the first results on coherent and incoherent photoproduction of J/ψ as well as continuum di-muon production in Pb-Pb collisions
- ✓ The first preliminary results for the exclusive photoproduction of J/ψ in p-Pb collisions are already available
- ✓ New results at energies beyond the reach of HERA will be available soon (semi-forward sample)
- ✓ The analyses of the photoproduction of other vector mesons is under way
- ✓ ALICE is also getting ready to collect new data in the Run2 of LHC which will provide a many fold increase in luminosity as well as increase the reach in the center of mass energy of the photon-target system
- ✓ The present data is very interesting and the future data promise to be even more so: STAY TUNED!