ALICE Results on Ultra-Peripheral Production

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Plan of Talk

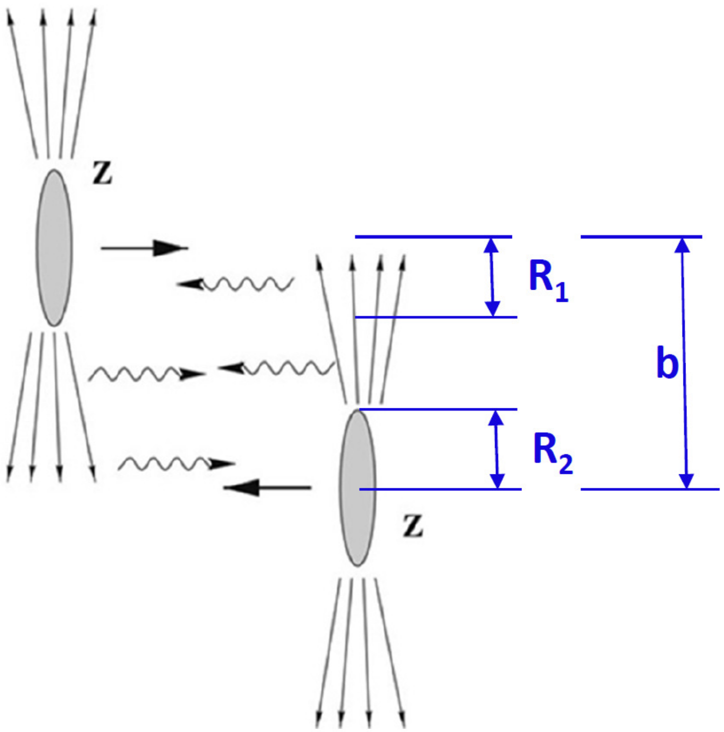
- Introduction
- Ultra-Peripheral Collisions
  - Pb-Pb Results
  - p-Pb Results
- Forthcoming studies
- Summary

Introduction

- **Ultra-Peripheral Production**
  - Interactions between beam projectiles (Pb-Pb, p-Pb, even pp) for large impact parameter ($b > (R_1 + R_2)$)
  - Basic mechanism is *photon-gluon interactions*, allowing access to gluon distribution functions. Vector meson production is of particular interest, as the photon in the parton level process couples to vector mesons.
  - This talk will focus on J/ψ production, both in Pb-Pb and in pPb collisions.
  - The ALICE program has other facets: forward look to new results "coming soon" which extend the current studies.

ULTRA-PERIPHERAL INTERACTIONS

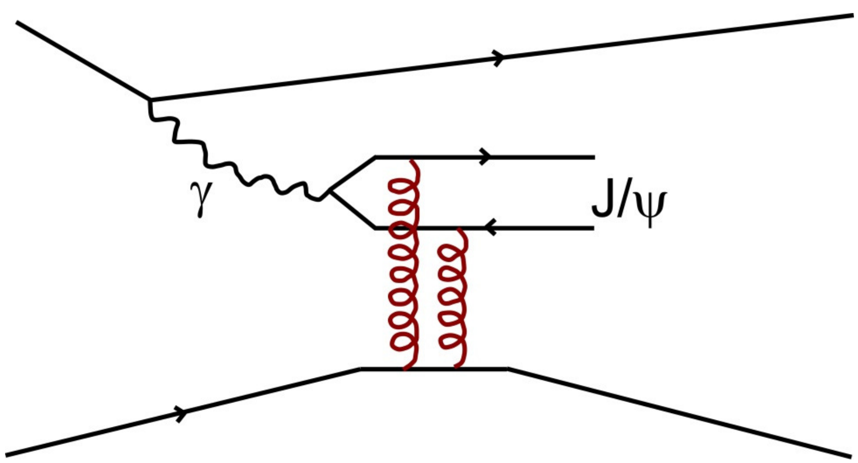
γp and γPb at the LHC



- When $b > (R_1 + R_2)$, hadronic interactions are very much suppressed, and photon processes become important.
- Photon flux $\propto Z^2$
- Photons are quasi-real; virtuality limited by size of nuclei. $Q^2 = (\hbar c / R)^2$
  - γ from p → $Q^2 \sim (250\ \text{MeV})^2$
  - γ from Pb → $Q^2 \sim (35\ \text{MeV})^2$
- Photon energy determined by boost of emitting particle.
  - γ from p (4 TeV): $E_\gamma^{\max} \approx 1200\ \text{GeV}$
  - γ from Pb: $E_\gamma^{\max} \approx 50\ \text{GeV}$

J/ψ photoproduction

$$\frac{d\sigma_{\gamma^* \mathrm{p/Pb}}(t=0)}{dt} = \frac{16\Gamma_{ee}\pi^3}{3\alpha_{\mathrm{em}} M_{J/\psi}^5}\left\{\alpha_s\left(Q^2\right) G_{\mathrm{p/Pb}}\left(x, Q^2\right)\right\}^2$$



- J/ψ photoproduction cross-section is proportional to square of gluon structure function (at LO)
- J/ψ sets a hard scale $Q^2 \sim \frac{M_{J/\psi}^2}{4} \sim 2.5\ \mathrm{GeV}^2$.
- At LHC energies, $x_{\mathrm{Bj}} \sim 10^{-2}$-$10^{-5}$ is accessible.
- J/ψ photoproduction in Pb-Pb UPC gives information on gluon shadowing in nuclei at low x.

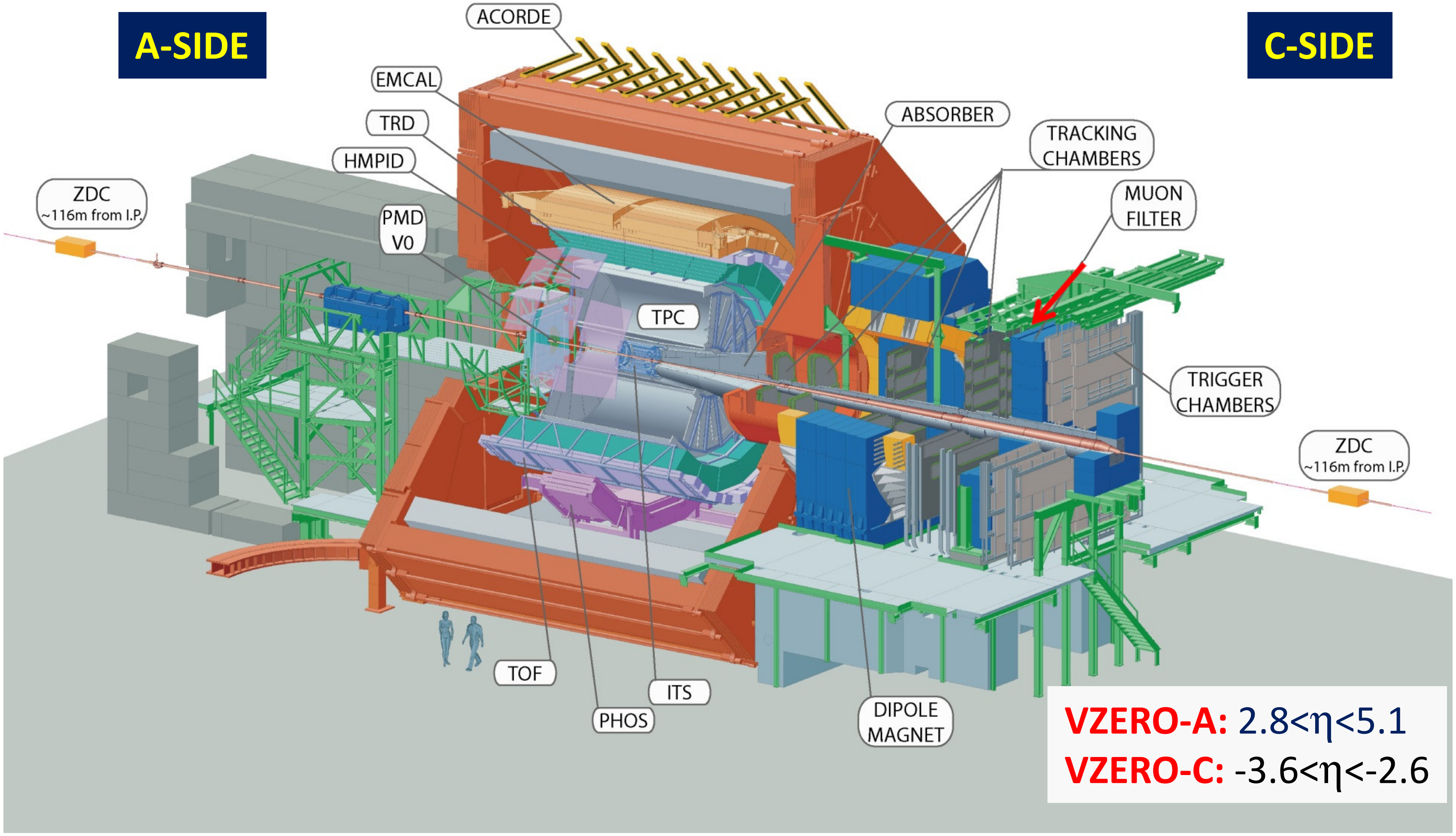
$$R_g^A(x, Q^2) = \frac{G_A(x, Q^2)}{G_p\left(x, Q^2\right)}$$

J/ψ Photoproduction

- In principle, there is an ambiguity in the energy $W_{\gamma p/Pb}$ of the measurement, according to whether the photon is emitted from one projectile or the other.
  - For a J/ψ produced with rapidity y, the two solutions are of the form
    $$x = \left(M_{J/\psi} / \sqrt{s_{NN}}\right)\exp(\pm y)$$
- Two solutions coincide for $y=0$, but forward rapidity and identical beams an *ansatz* is needed to weight the two solutions.
- In p-Pb (Pb-p) the ambiguity is essentially lifted, as the photon is preferentially emitted from the Pb nucleus (~95% STARLIGHT estimate).

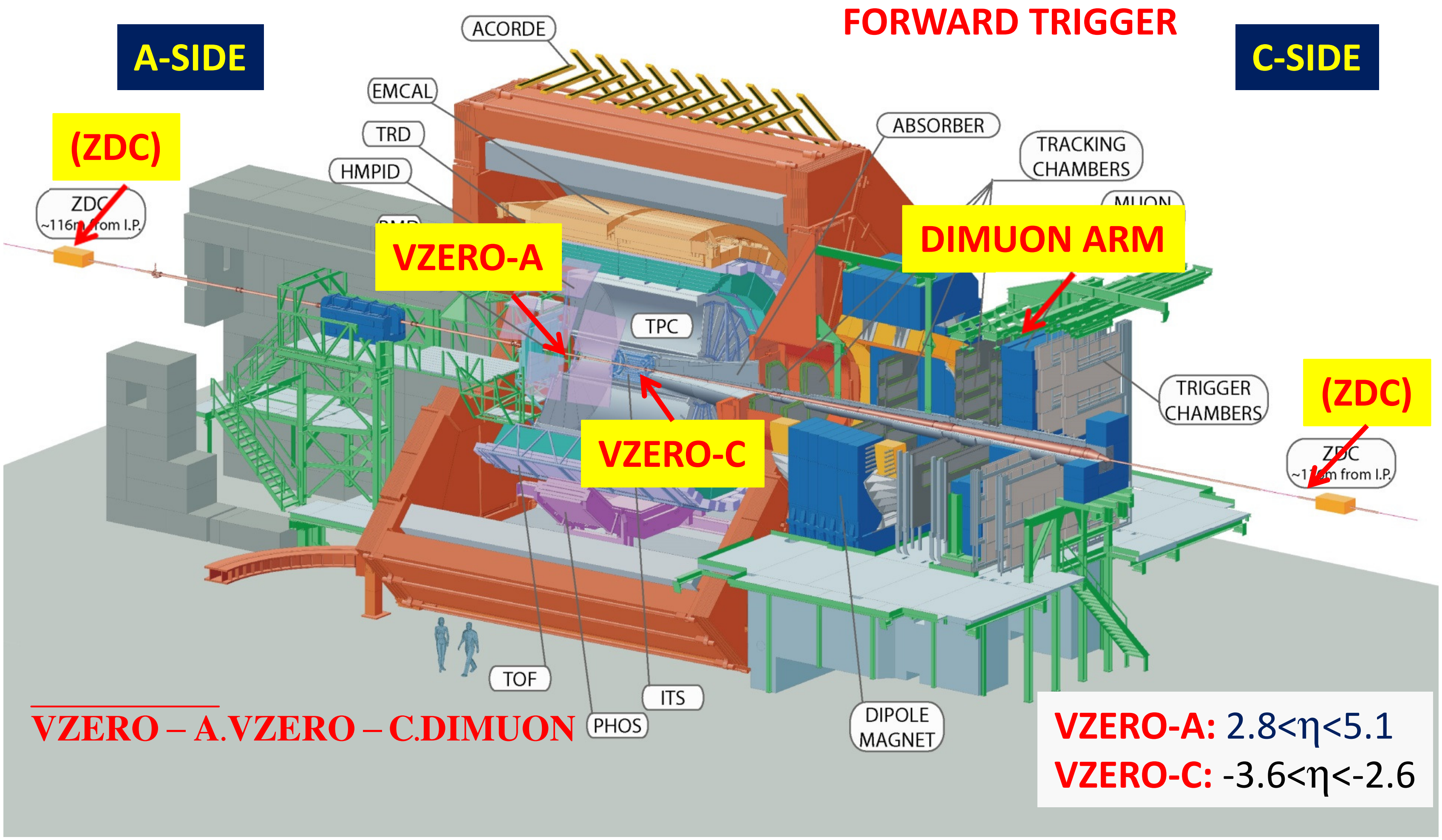
ALICE Detector

ALICE Apparatus

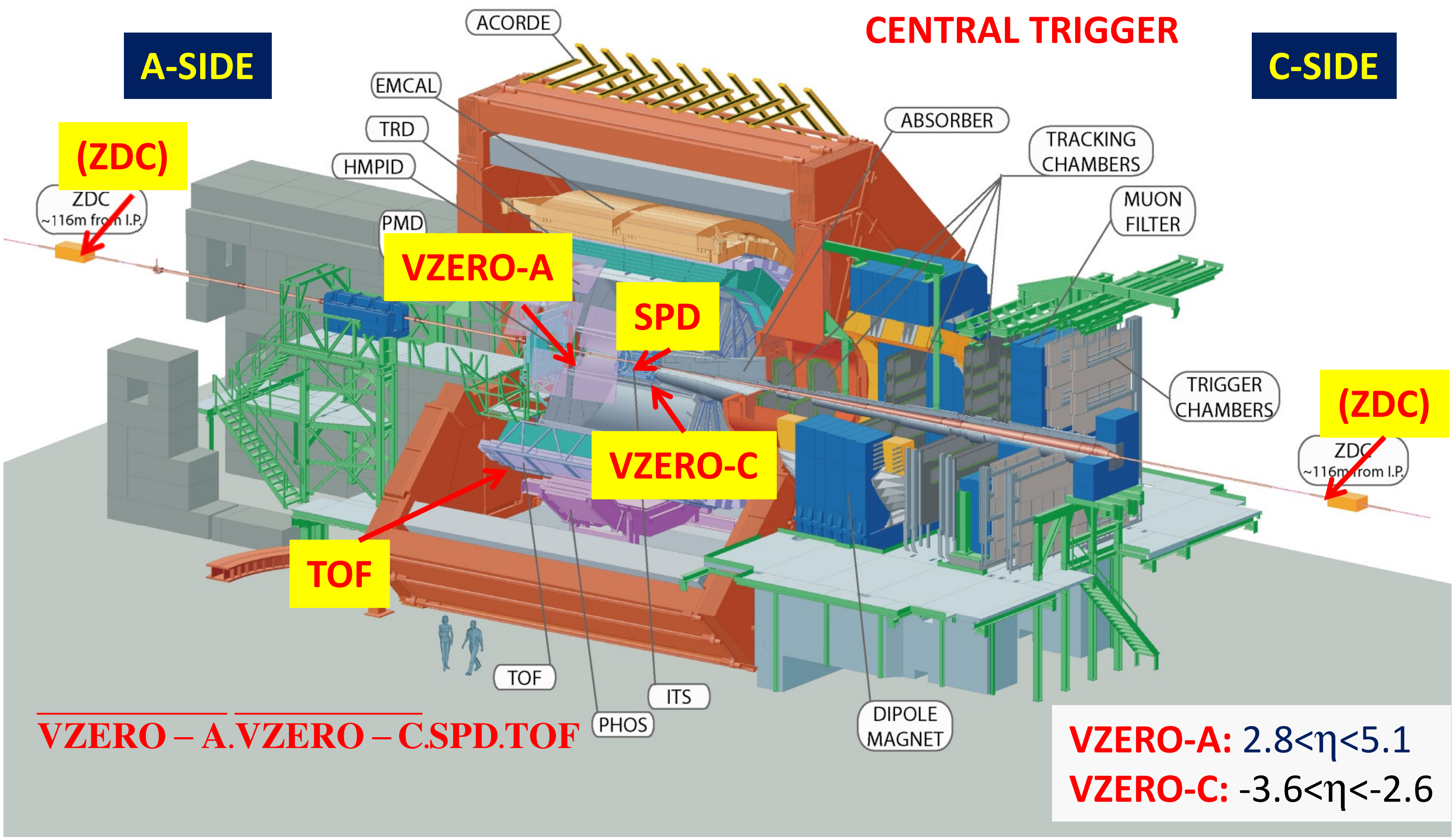


VZERO-A: $2.8<\eta<5.1$
VZERO-C: $-3.6<\eta<-2.6$

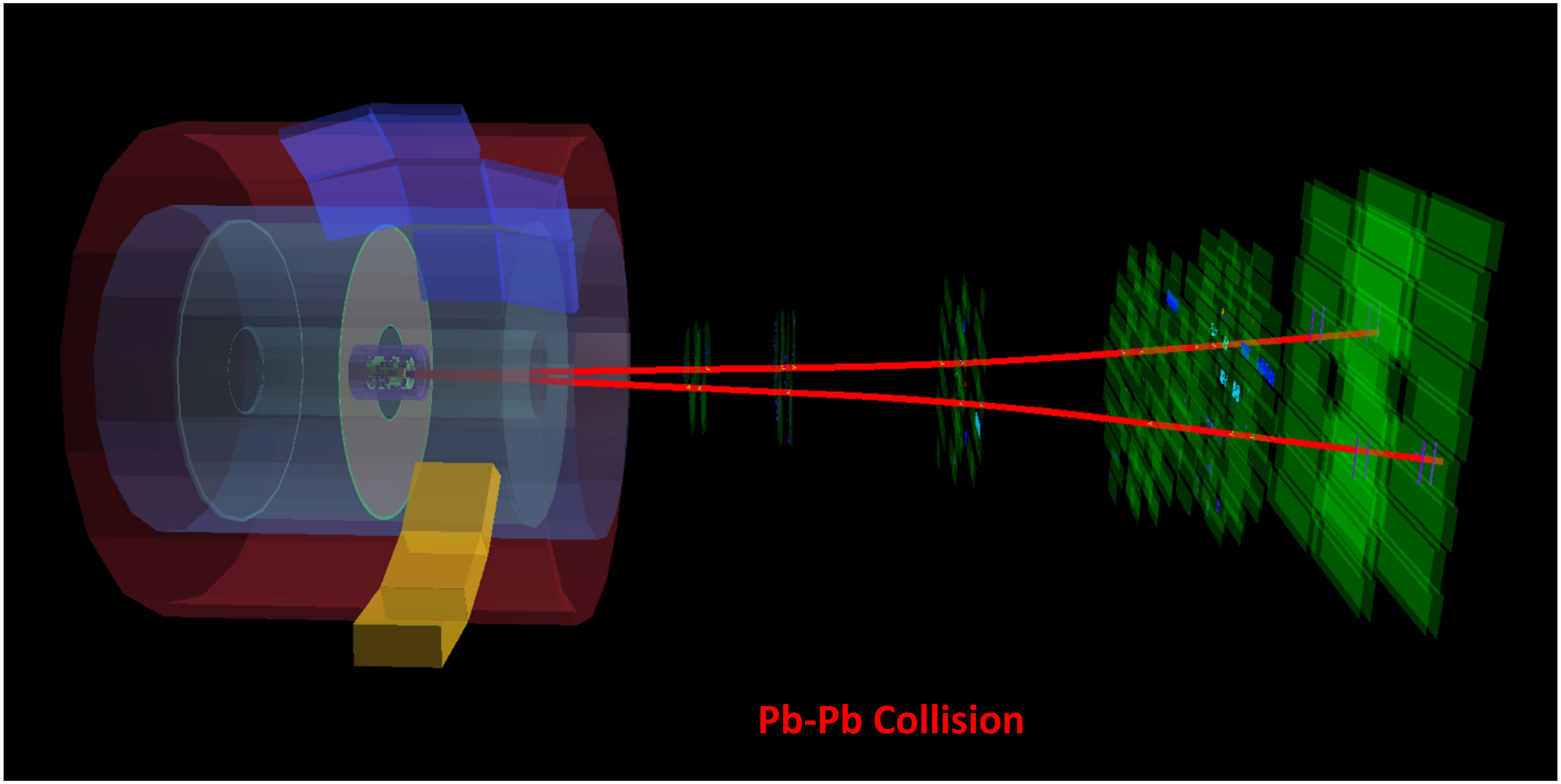
ALICE Apparatus



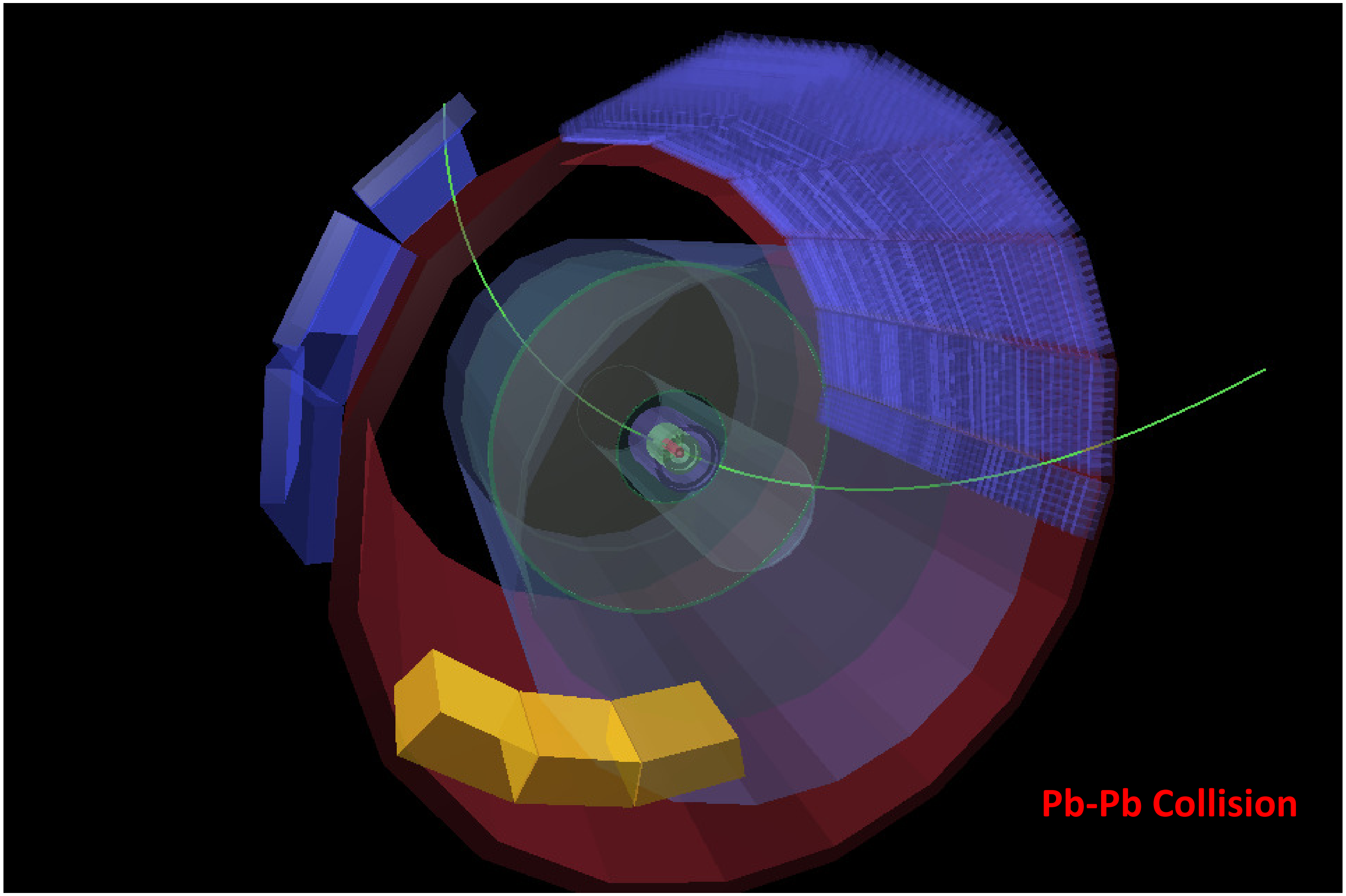
ALICE Apparatus



Forward J/ψ



Central J/ψ



Pb-Pb Measurements

B. Abelev et al., Phys. Lett. B718 (2013) 1273
E. Abbas et al., Eur. Phys Journal C73 (2013) 2617

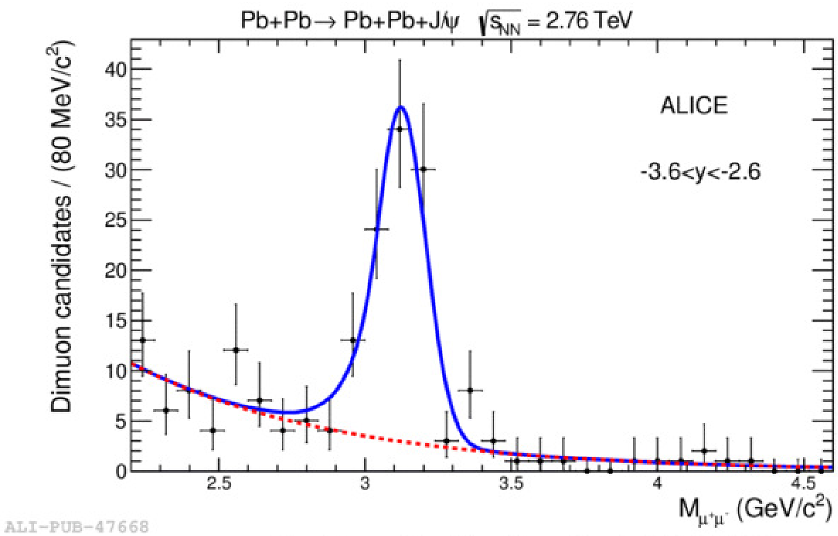
Analysis Strategy

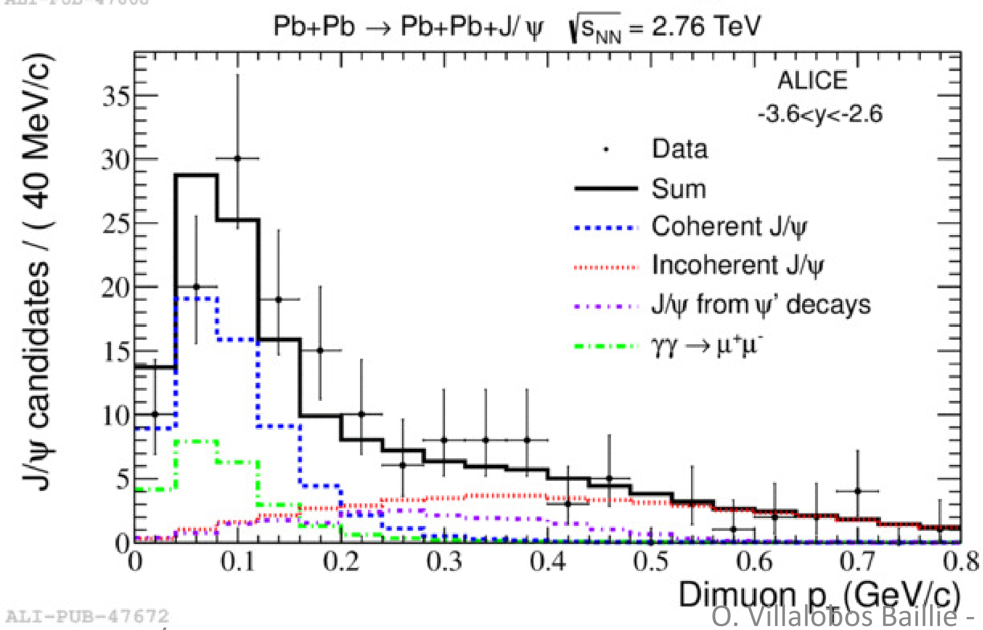
- Select a mass region around J/ψ
  - $2.2 < M_{ee} < 3.2$ GeV *electrons*
  - $3.0 < M_{\mu\mu} < 3.2$ GeV *muons*

Electrons have big radiative tail

- Use p_T range to separate coherent from incoherent
  - coherent dominates at low p_T
    - <300 MeV/c for electrons
    - <200 MeV/c for muons
  - correct for portion of spectrum (coherent/incoherent) missed by this procedure (template from STARLIGHT)

Pb-Pb Measurements

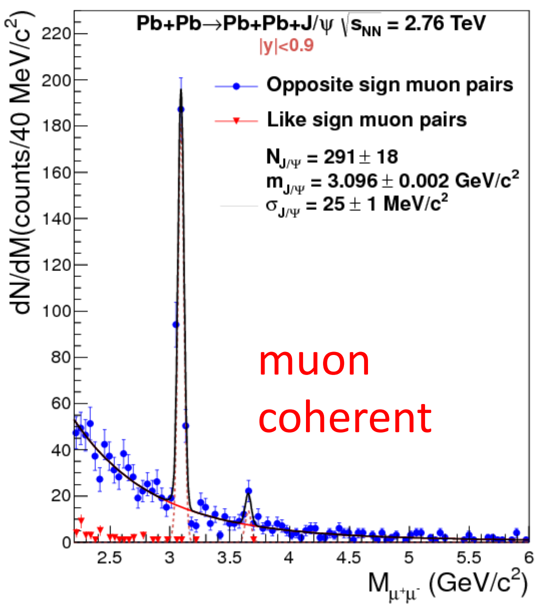


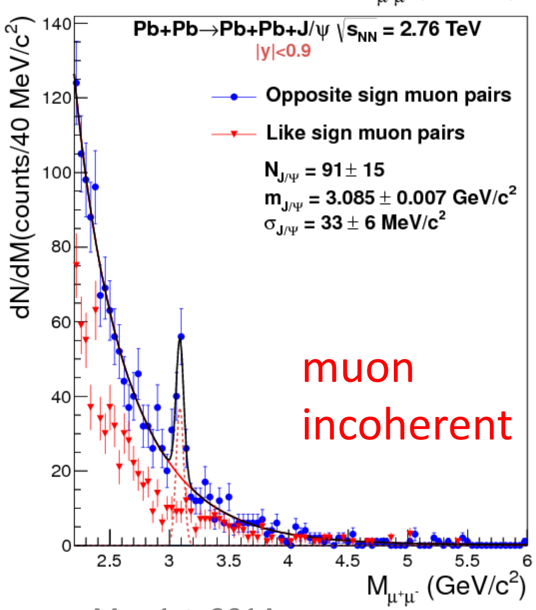


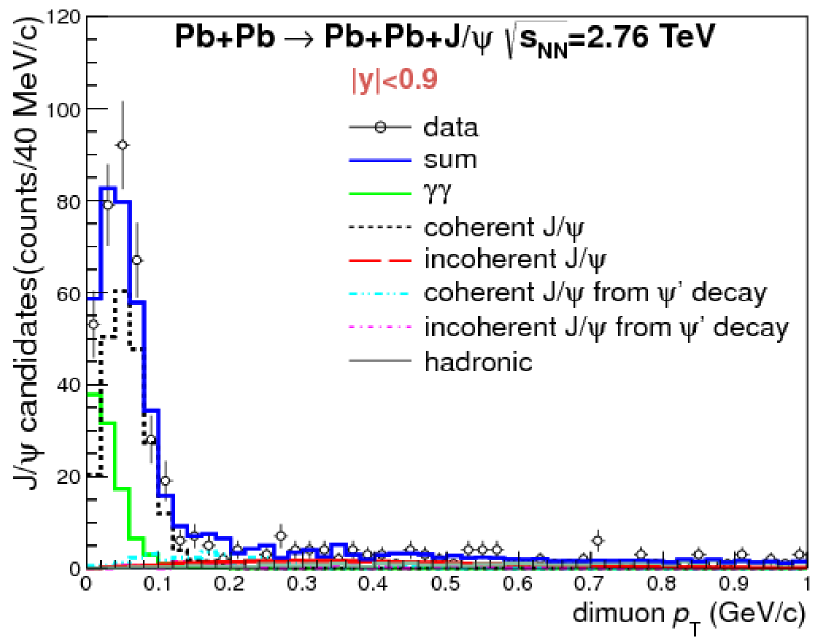
- **Forward** (2.6<y<3.6)
- Clear mass peak on exponentially dropping background
- p_T spectrum for J/ψ candidates shows peak at low p_T corresponding to coherent interactions
  - (Scatter off the whole nucleus.)

B. Abelev et al., Phys. Lett. B718 (2013) 1273

Pb-Pb Measurements





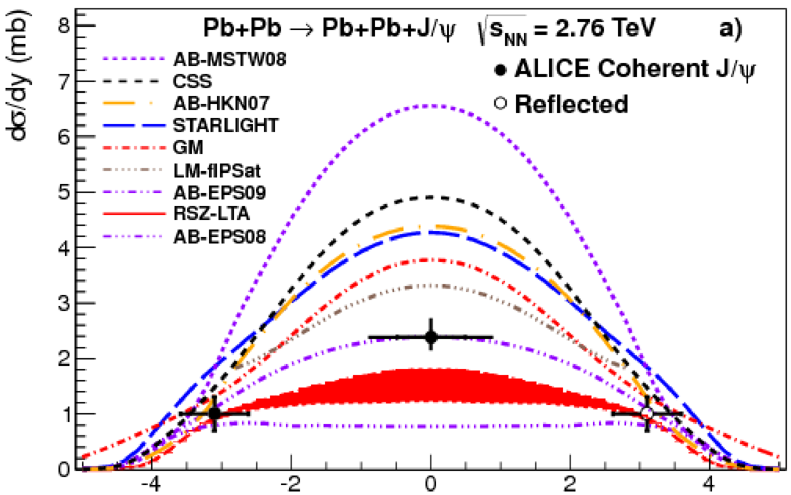


mid-rapidity
(|y|<0.9)

- Much more comprehensive measurements at central rapidities.
- Both dimuon and dielectron channels have been studied.
- Analysis has been carried out both for coherent and incoherent J/ψ production.

E. Abbas et al., Eur. Phys Journal C73 (2013) 2617

Pb-Pb Measurements



$x \sim 10^{-2}$ $x \sim 10^{-3}$

COHERENT

Agreement is best for models incorporating nuclear gluon shadowing.

- **STARLIGHT: Klein, Nystrand, PRC60 (1999) 014903**
- VDM + Glauber approach where $J/\psi+p$ cross section is
- obtained from a parameterization of HERA data

- • **GM: Gonçalves, Machado, PRC84 (2011) 011902**
- color dipole model, dipole nucleon cross section taken
- from the IIM saturation model

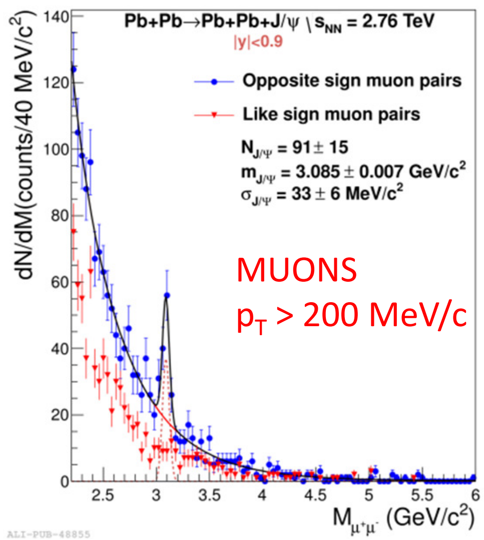
- • **AB: Adeluyi and Bertulani, PRC85 (2012) 044904**
- LO pQCD calculations: AB-MSTW08 assumes no
- nuclear effects for the gluon distribution, other AB
- models incorporate gluon shadowing effects according
- to the EPS08, EPS09 or HKN07 parameterizations

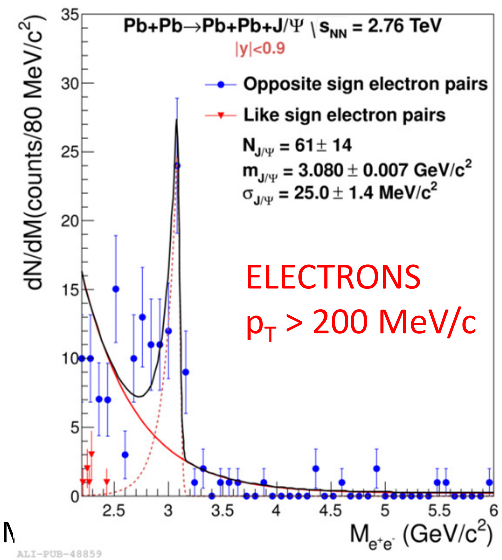
- • **CSS: Cisek, Szczurek, Schäfer, PRC86 (2012) 014905**
- Glauber approach accounting $c\bar{c}g$ intermediate states

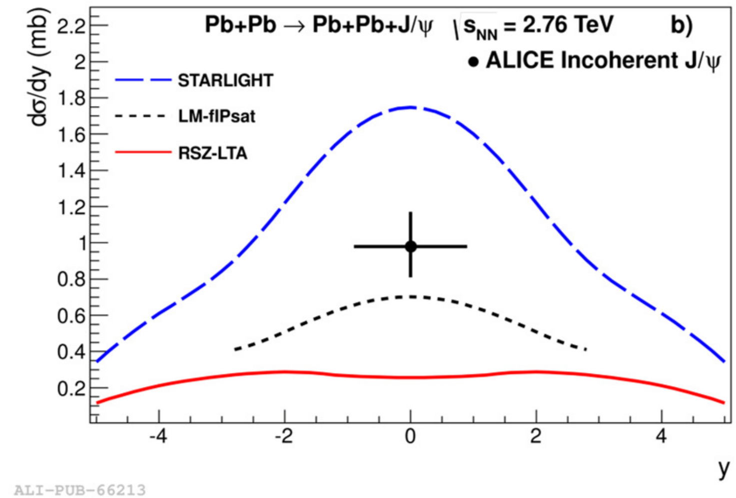
- • **RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252**
- LO pQCD calculations with nuclear gluon shadowing
- computed in the leading twist approximation

- • Lappi, Mäntysaari, PRC87 (2013) 032201: color dipole
- model + saturation

Pb Pb Measurements





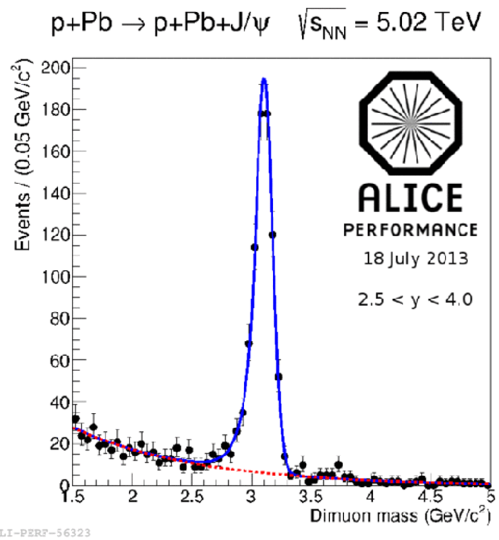


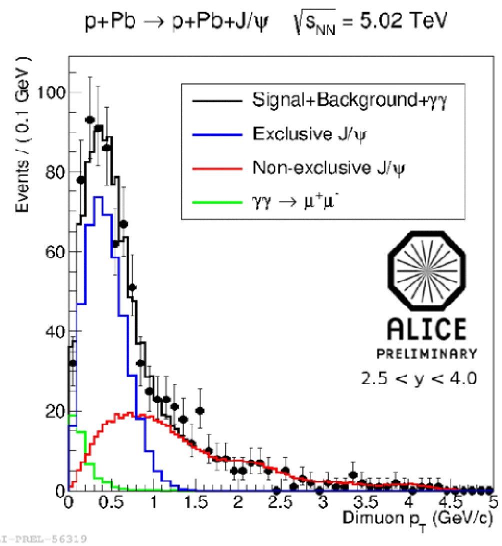
INCOHERENT

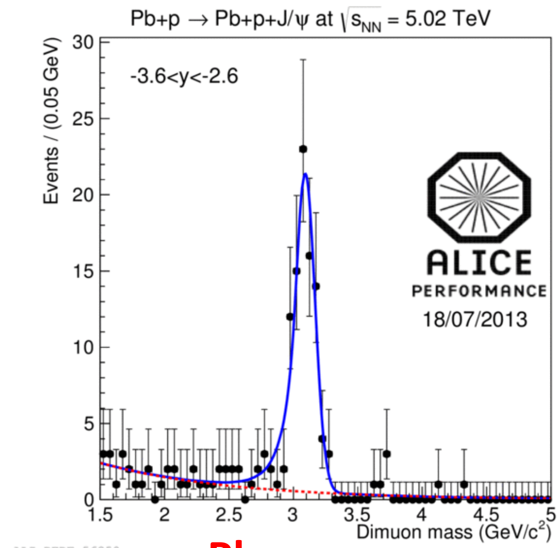
- First measurement in PbPb. Helps to constrain models
- Note photon flux cancels between coherent and incoherent measurements, so *ratio* coherent/incoherent is also a useful parameter.
- STARLIGHT overshoots both but gets ratio right.

p-Pb Measurements

p-Pb Measurements





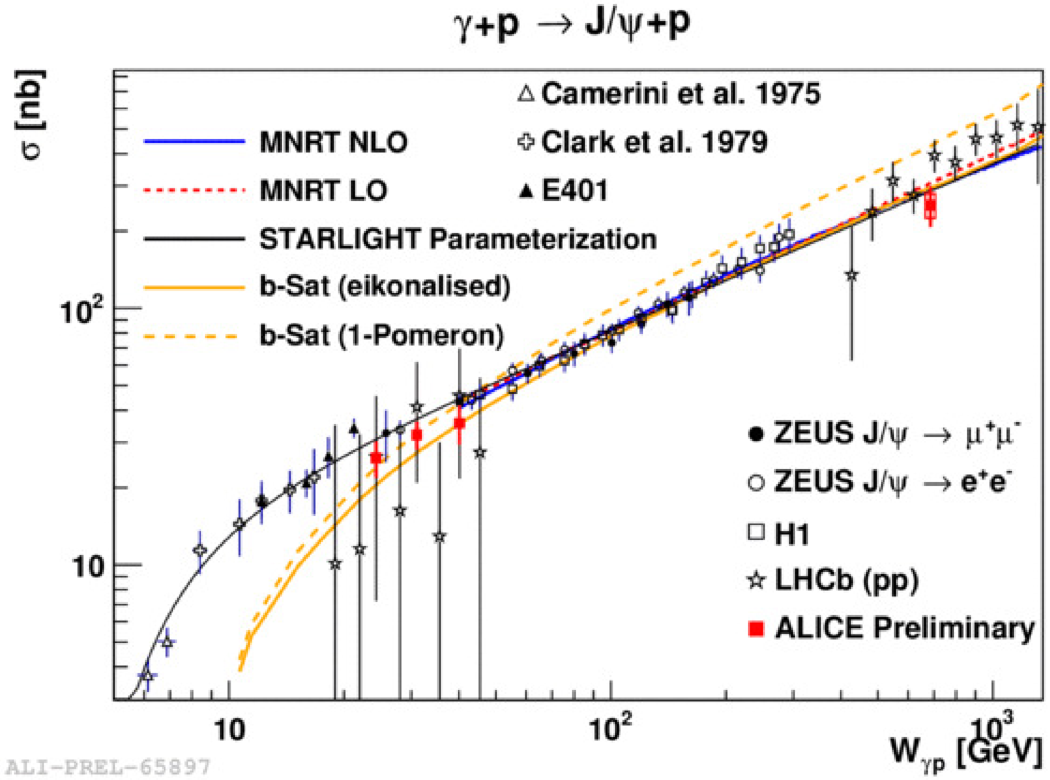


p-Pb **Pb-p**

- The fact that the Pb nucleus is the dominant photon emitter allows us to separate the two $W_{\gamma p}$ regimes unambiguously.
  - “p-Pb” (*) corresponds to the *lower* energy range
  - “Pb-p” corresponds to the *higher* energy range.

* Proton travels in the same direction as the J/ψ.

p-Pb Measurements

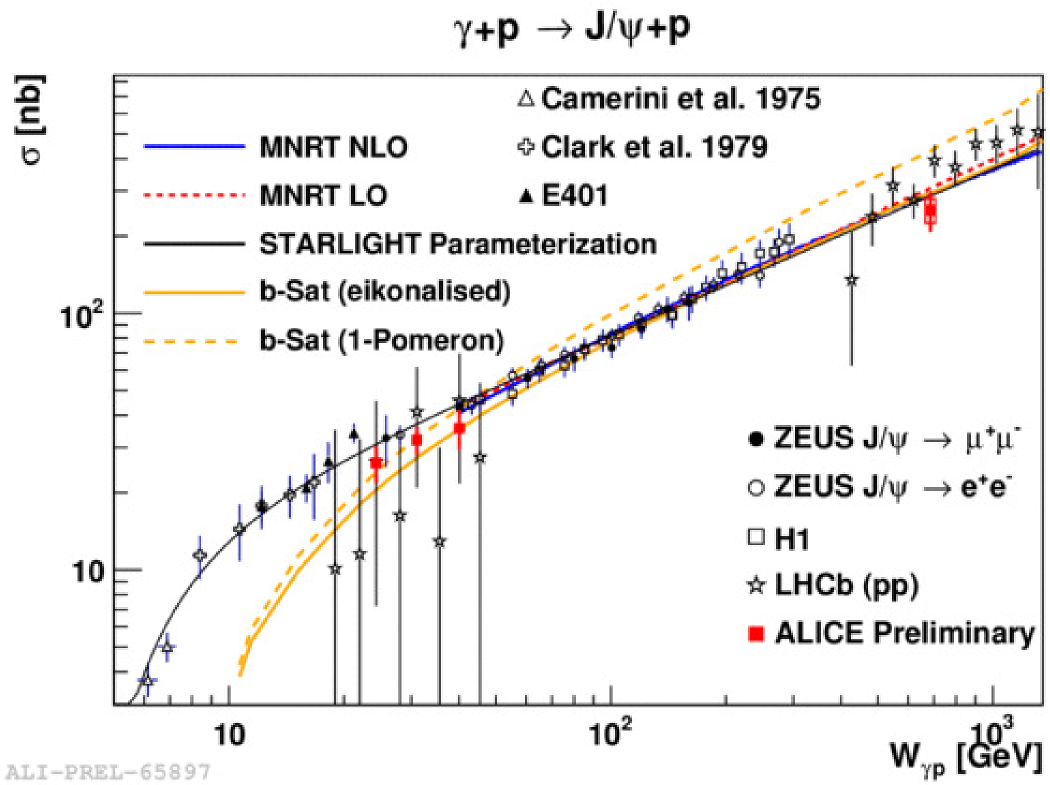


$$\frac{d\sigma}{dy}\left(p+Pb\rightarrow p+Pb+J/\psi\right)=k\frac{dn}{dk}\sigma\left(W_{\gamma p}\right)$$

Our knowledge of the photon emitter allows us to solve for $\sigma(W_{\gamma p})$ using the measured $d\sigma/dy$

A power law fit ($\sigma(W)\sim W^{\delta}$) to ALICE data points gives $\delta=0.67\pm0.06$.

p-Pb Measurements



$$\frac{d\sigma}{dy}(p+Pb \to p+Pb+J/\psi) =$$

HERA Measurements

H1	δ=0.67±0.03
ZEUS	δ=0.69±0.02

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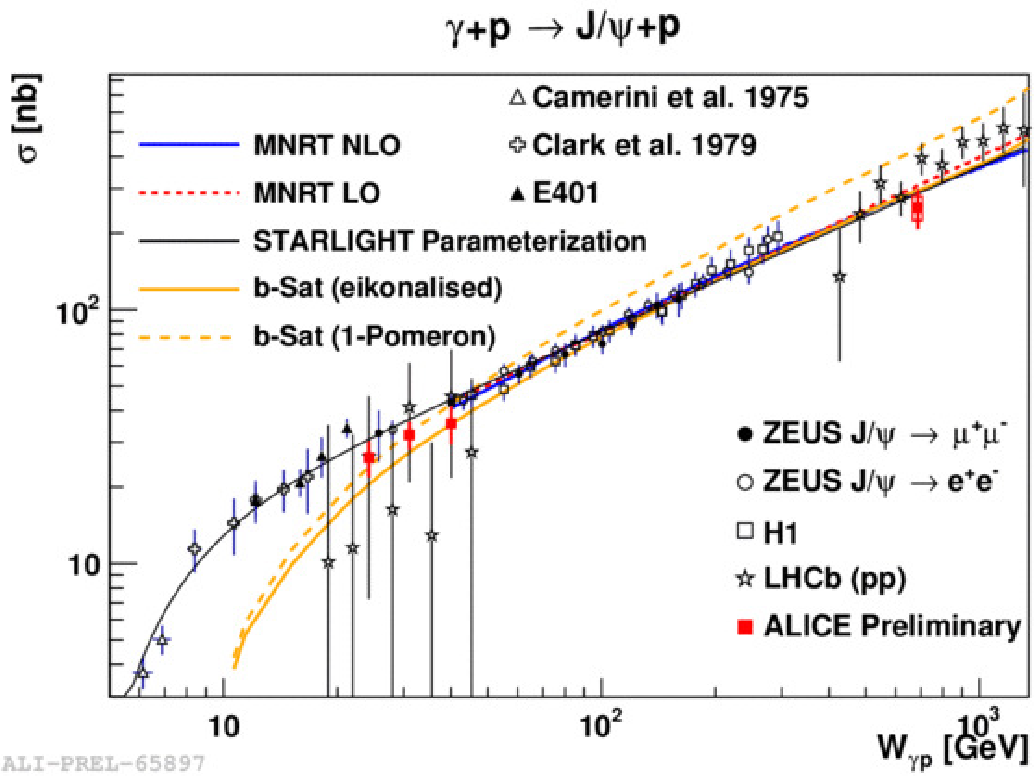


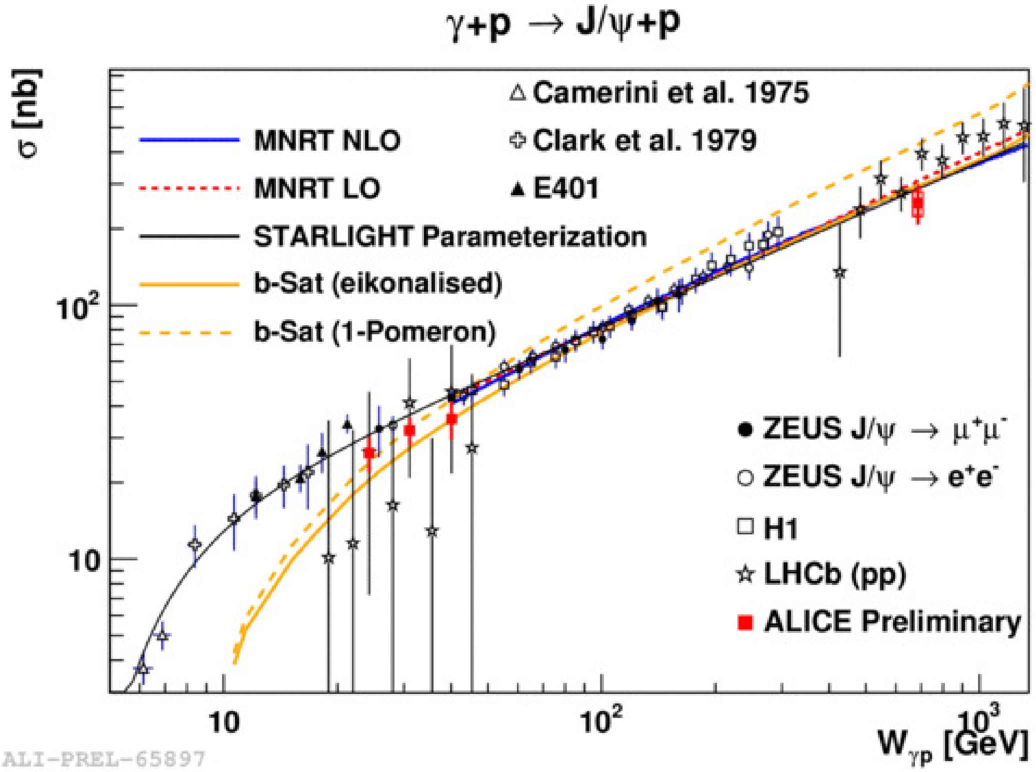
- MNRT give two models, one LO and one with additional NLO terms. ALICE data lie about 1 sigma below curve.

1. b-Sat (eikonalized) model gives a very similar prediction

- 2013 LHCb measurements in pp collisions give $\delta=0.92\pm0.15$. LHCb data are about one sigma below ours (low energy) or one sigma above (high energy).

$$\frac{d\sigma}{dy}(p+Pb \rightarrow p+Pb+J/\psi) = k\frac{dn}{dk}\sigma(W_{\gamma p})$$

p-Pb Measurements



MNRT	Phys. Lett. B662 (2008) 252
b-Sat	H. Kowalski, L. Motyka and G. Watt. PRD 74 074016
LHCb	A. Aaij et al. J. Phys. G 40 045001

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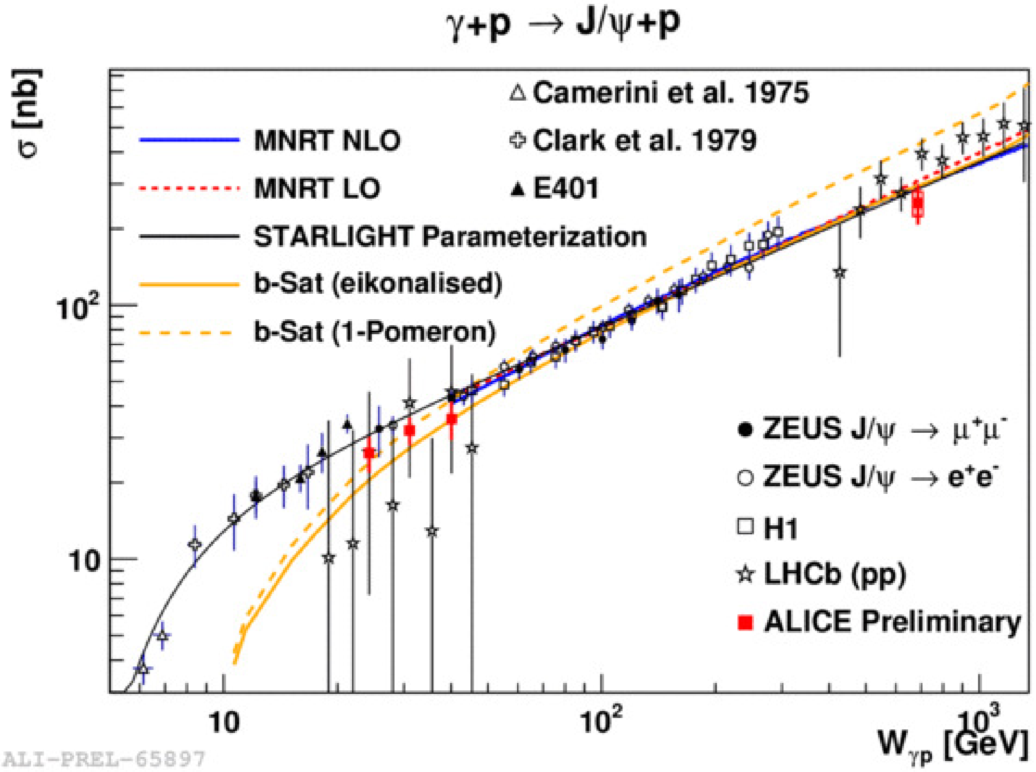

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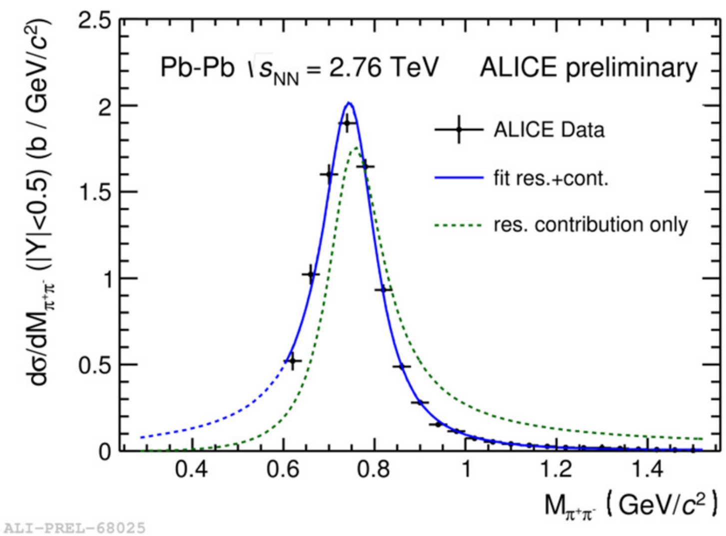
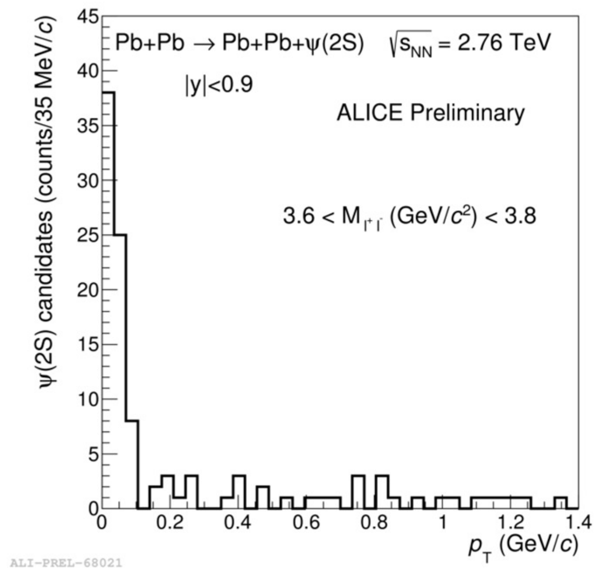
New (2014) LHCb points agree better with HERA and ALICE data. Figure to be updated.

Coming Soon

Pb Pb: ρ and ψ(2S) Measurements





- Important extensions to existing (J/ψ) measurements
- Allow (ρ) comparison with lower energies, (both) new tests for models.

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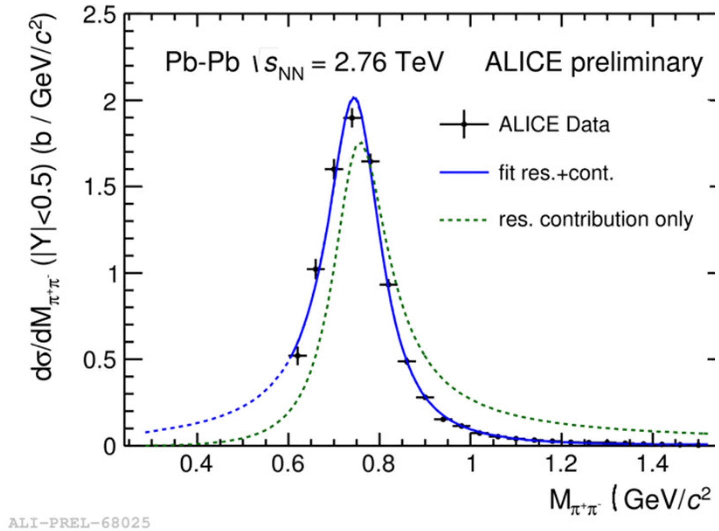

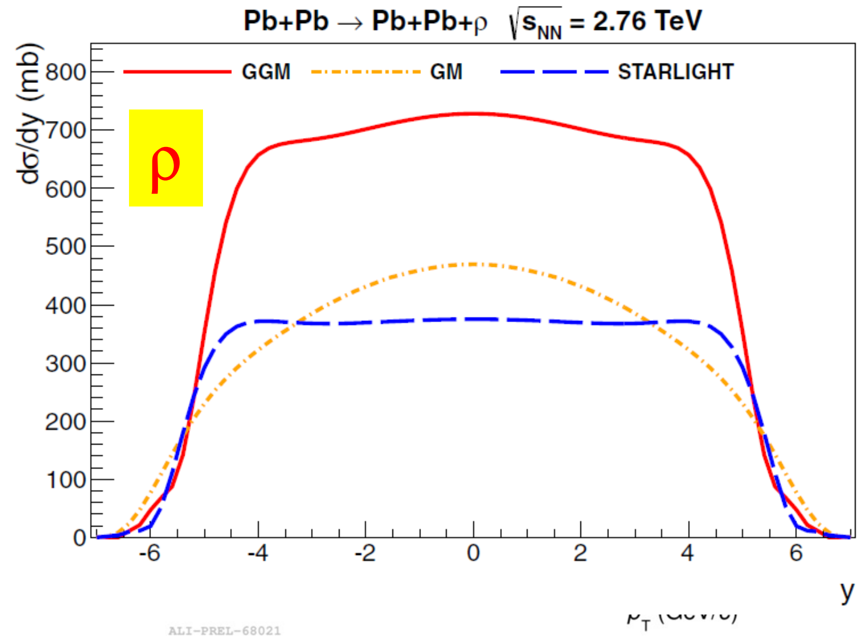

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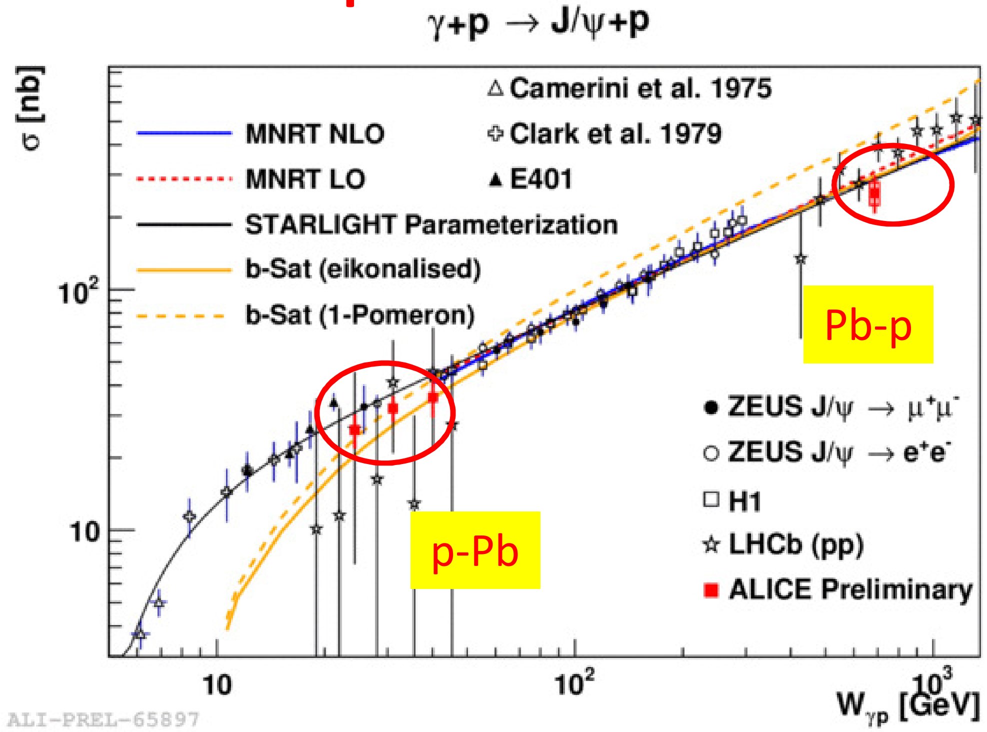
p-Pb – Data points at more rapidities



- Data shown so far use muon spectrometer (forward rapidity)
- Can also do two further ranges of rapidity, giving four extra points (p-Pb and Pb-p)
- Bridge energy range between existing low and high energy points.

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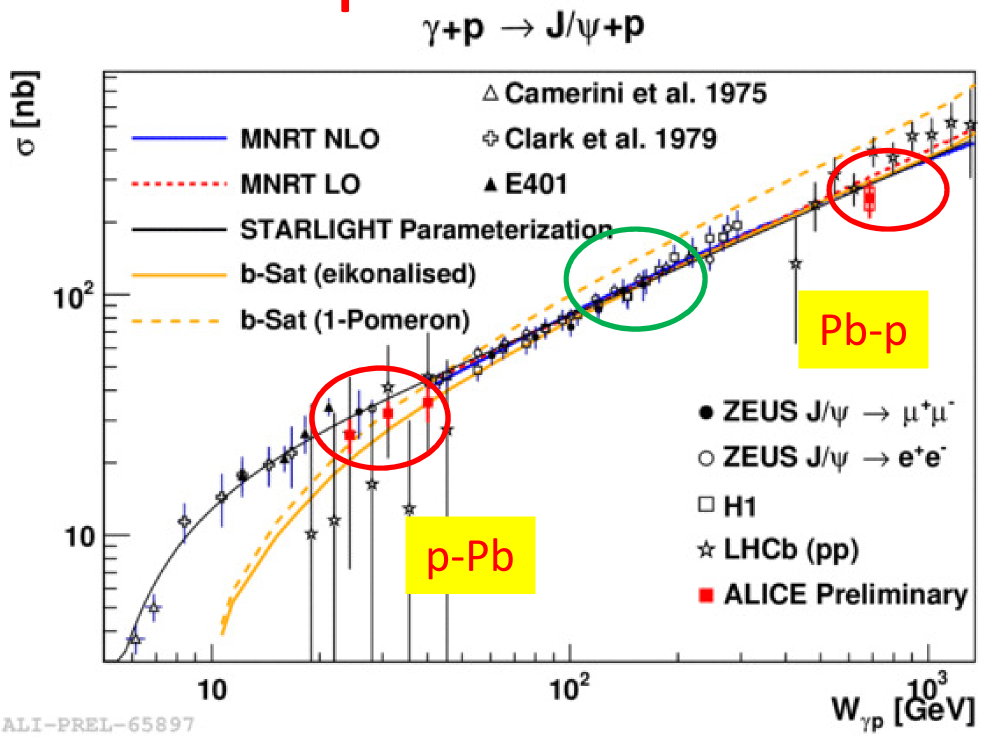

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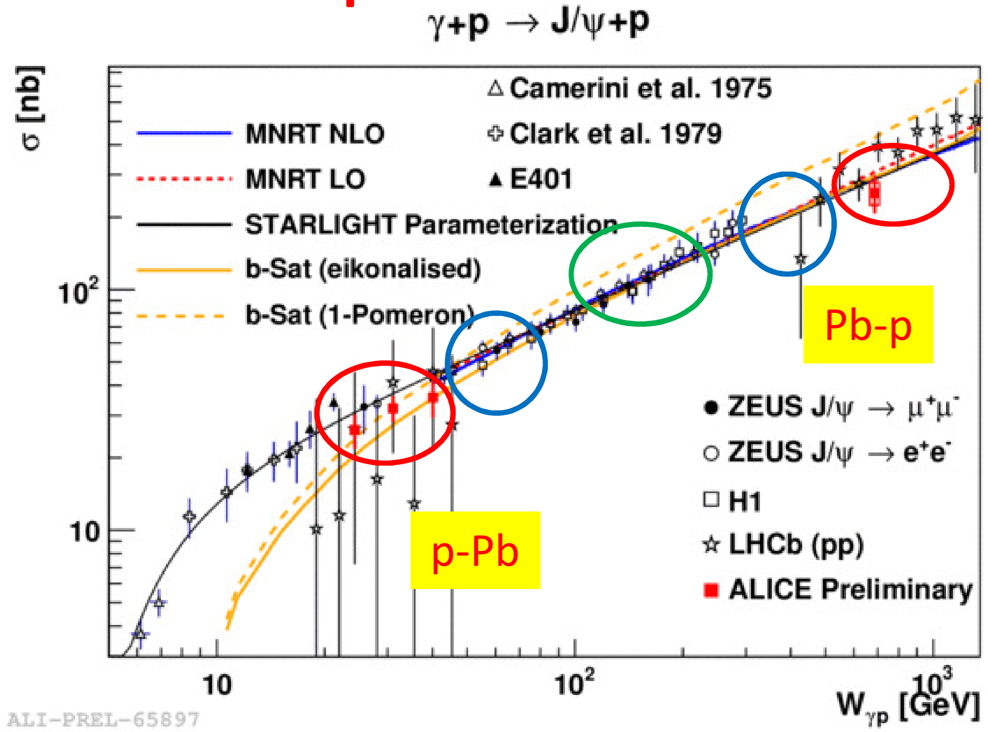

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Summary

- Ultra-Peripheral collisions (UPC) provide a powerful tool for studying gluon distributions, both in nuclei and protons.
- ALICE UPC results in Pb-Pb are constraining models on nuclear gluon shadowing in the region $x \sim 10^{-3}$. A gluon shadowing component appears to be needed
    - B. Abelev et al., Phys. Lett. **B718** (2013) 1273
    - E. Abbas et al., Eur. Phys Journal **C73** (2013) 2617
  - Results for two new particles (ρ and ψ(2S)) coming soon.
- Results from 2013 p-Pb run allow us to measure the proton photoproduction cross-section for J/ψ production to ~700 GeV.
    - In p-Pb/Pb-p the Pb nucleus tags the photon emitter
  - Results at *forward* rapidity now available (and will be published soon); results at two other pseudorapidity ranges (giving at least four additional points) will be available soon.

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