ALICE Results on Ultra-Peripheral Production

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Plan of Talk

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

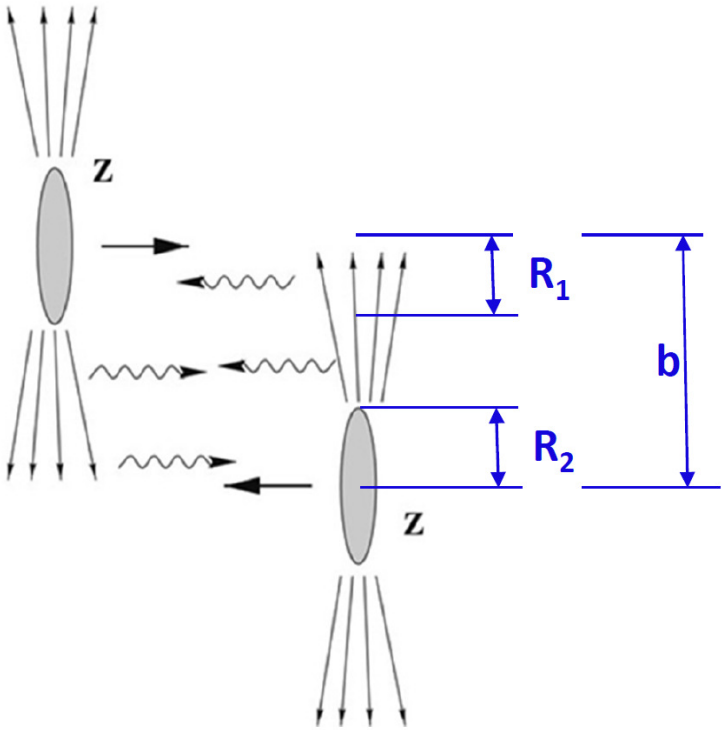
Introduction

ALICE

- **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 vector meson production in Pb-Pb collisions, in particular the ρ, J/ψ and ψ'.
  - The ALICE programme has other facets: we also have results in p-Pb (not discussed this time), and intend to extend our range to include (e.g.) ϕ in run 2

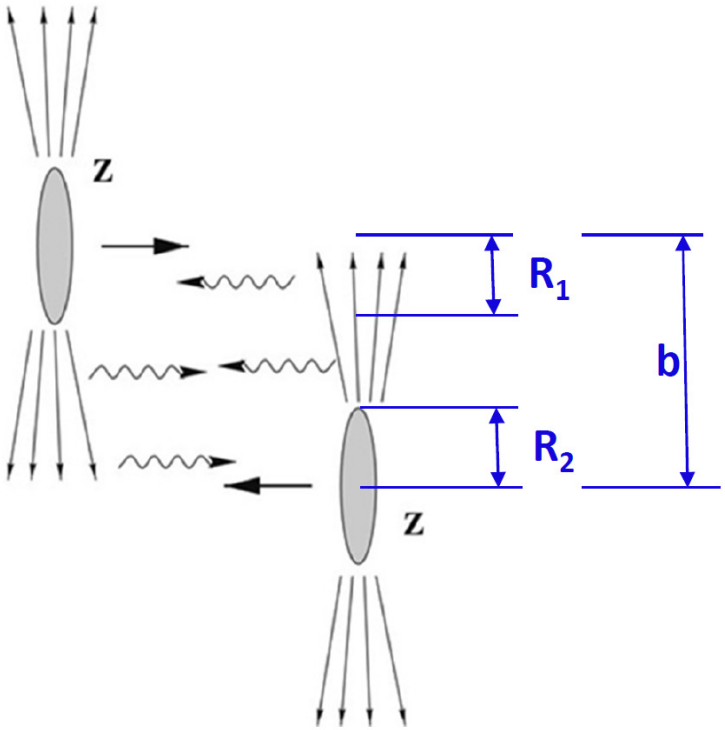
ULTRA-PERIPHERAL INTERACTIONS

γPb at the LHC



- When $b > (R_1 + R_2)$, hadronic interactions are very much suppressed, and photon processes become important.
- Photon flux $\propto Z^2$ $Q^2 = (\hbar c / R)^2$
- Photons are quasi-real; virtuality limited by size of nuclei.
  - γ from Pb → $Q^2 \sim (35\ \text{MeV})^2$
- Photon energy determined by boost of emitting particle.
  - γ from Pb: $E_\gamma^{\max} \approx 40\ \text{GeV}$

γPb at the LHC



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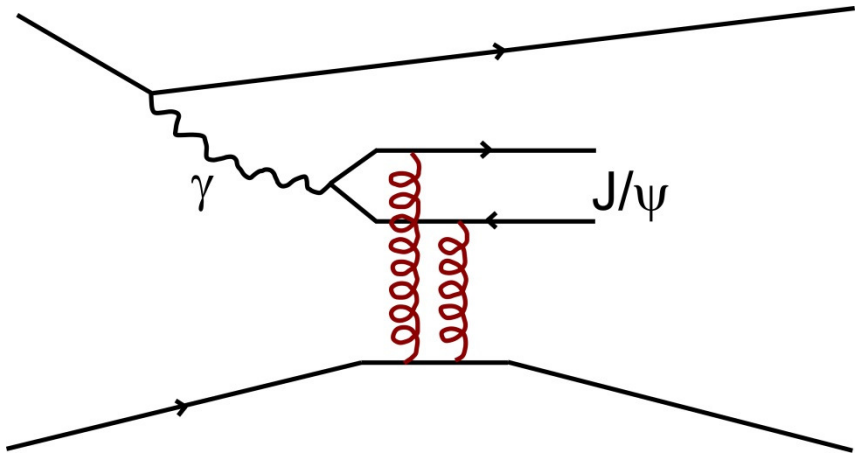
- Photons are quasi-real; virtuality limited by size of nuclei.
  - γ from Pb → $Q^2 \sim (35\ \text{MeV})^2$
- Photon energy determined by boost of emitting particle.
  - γ from Pb: $E_\gamma^{\max} \approx 75\ \text{GeV}$

RUN 2

J/ψ photoproduction

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



- 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.

J/ψ photoproduction

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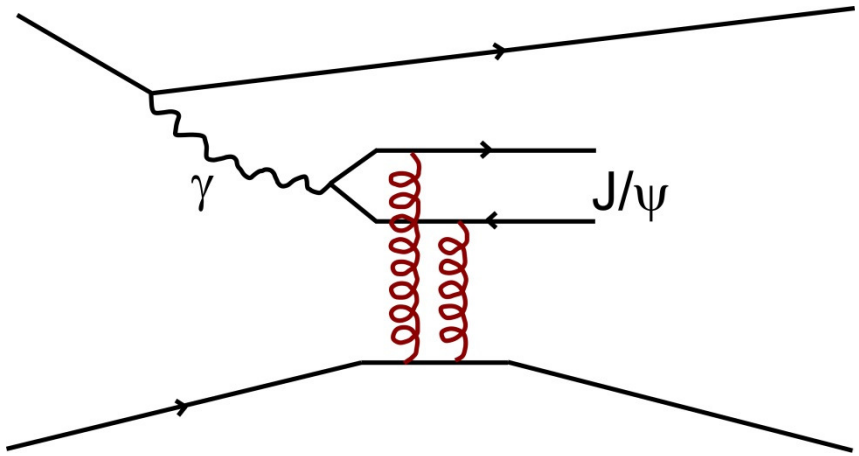

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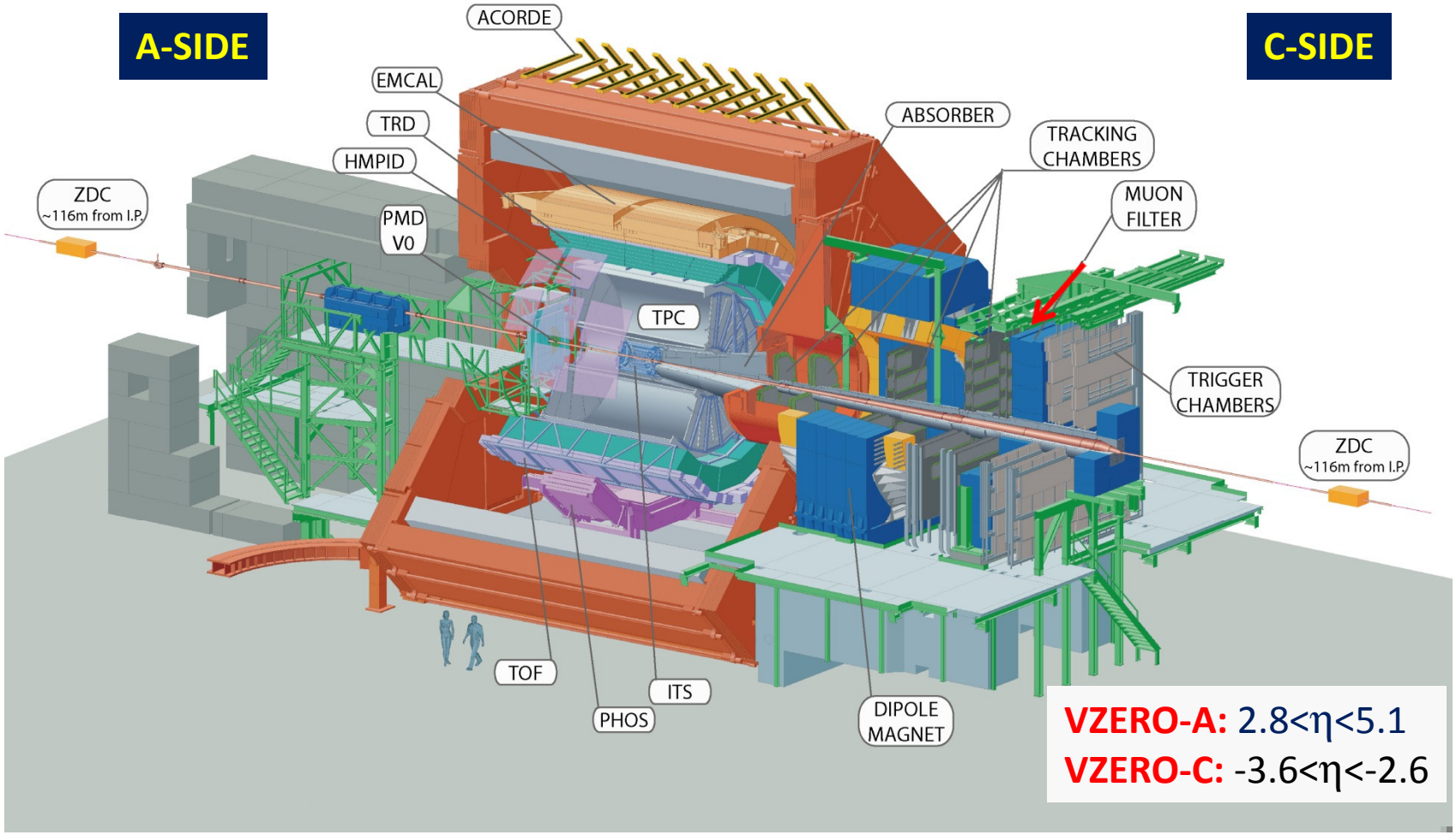
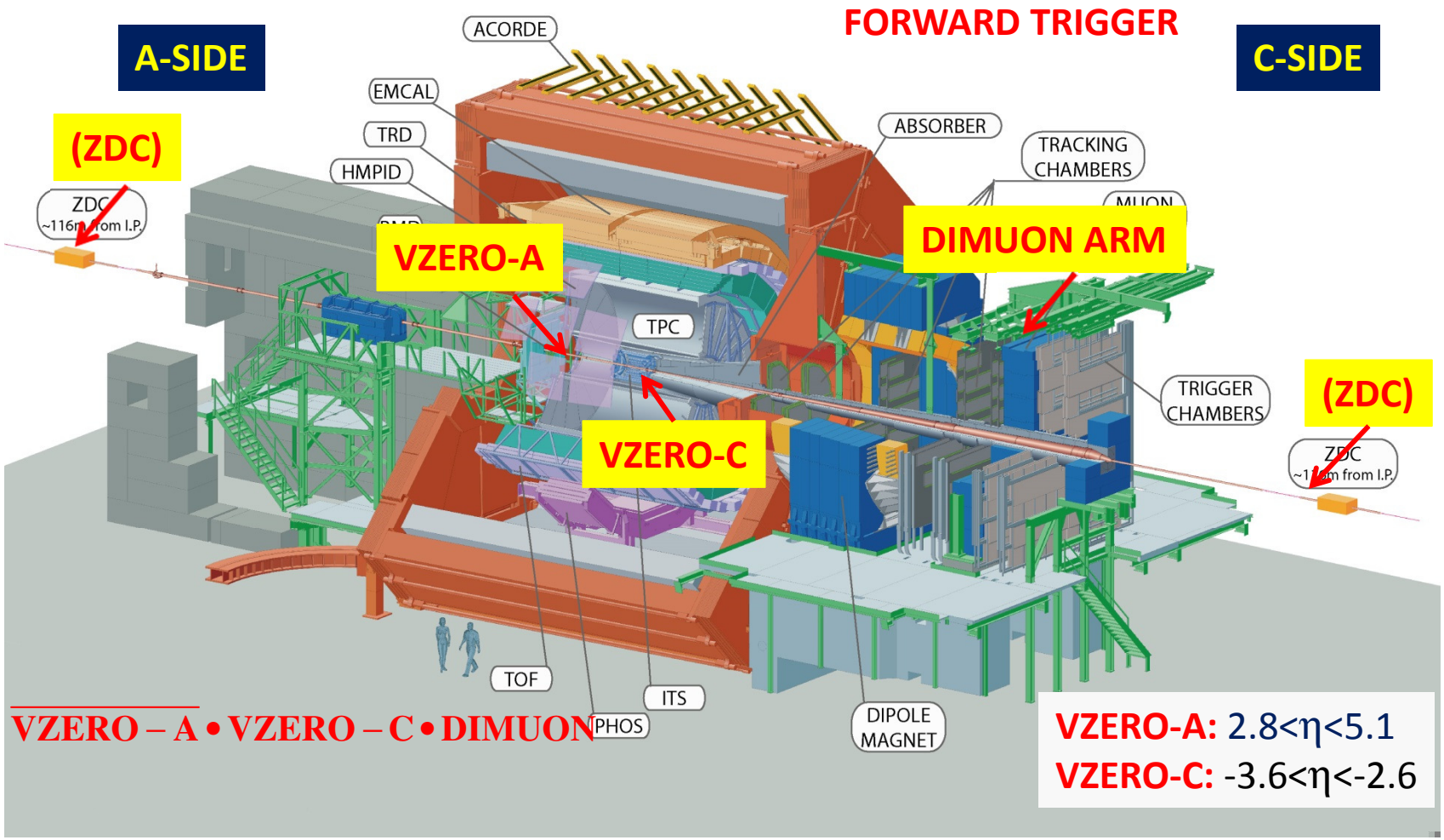
Factor ~2 lower in run 2

ALICE Detector

ALICE Apparatus



ALICE Apparatus



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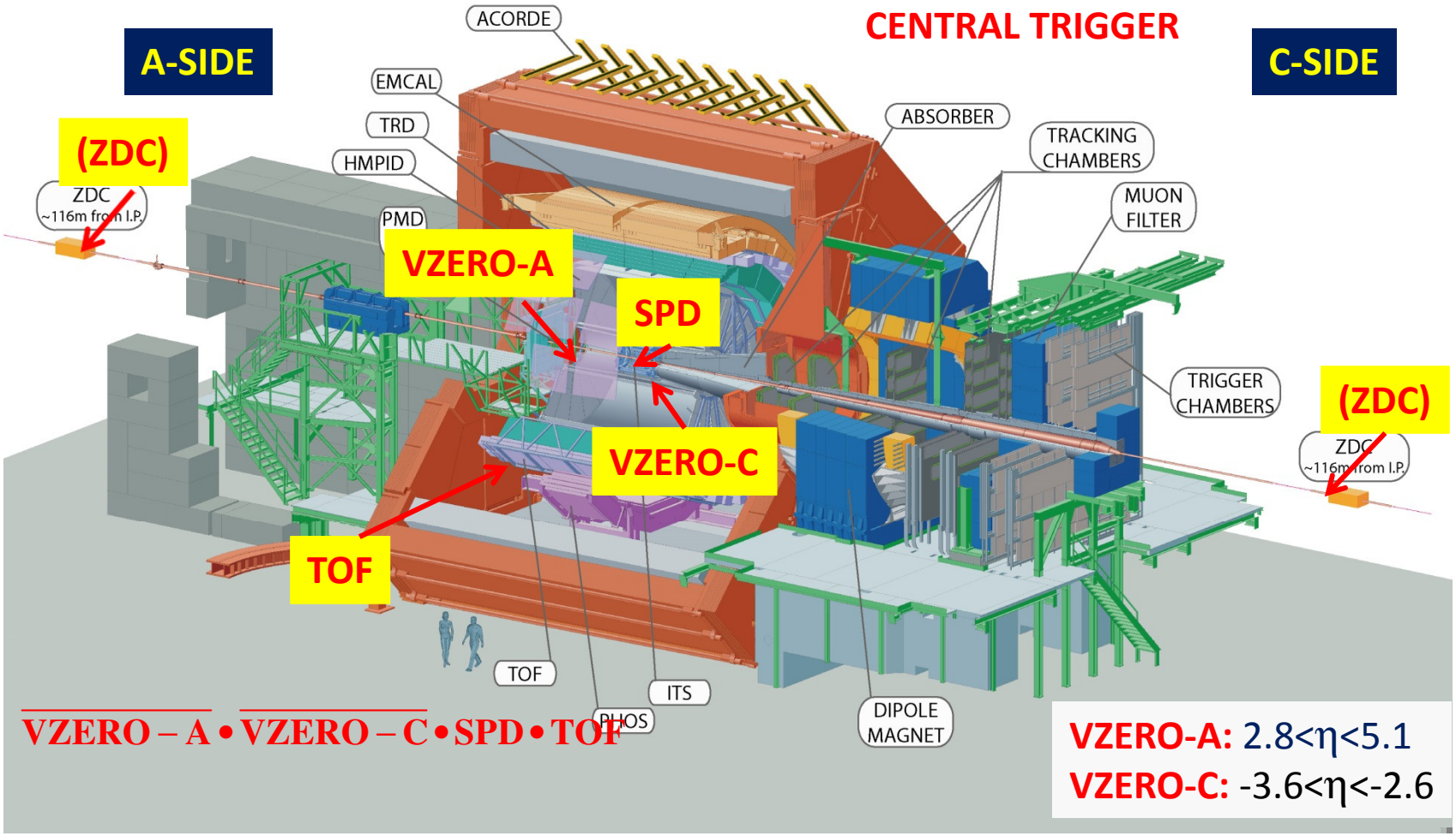
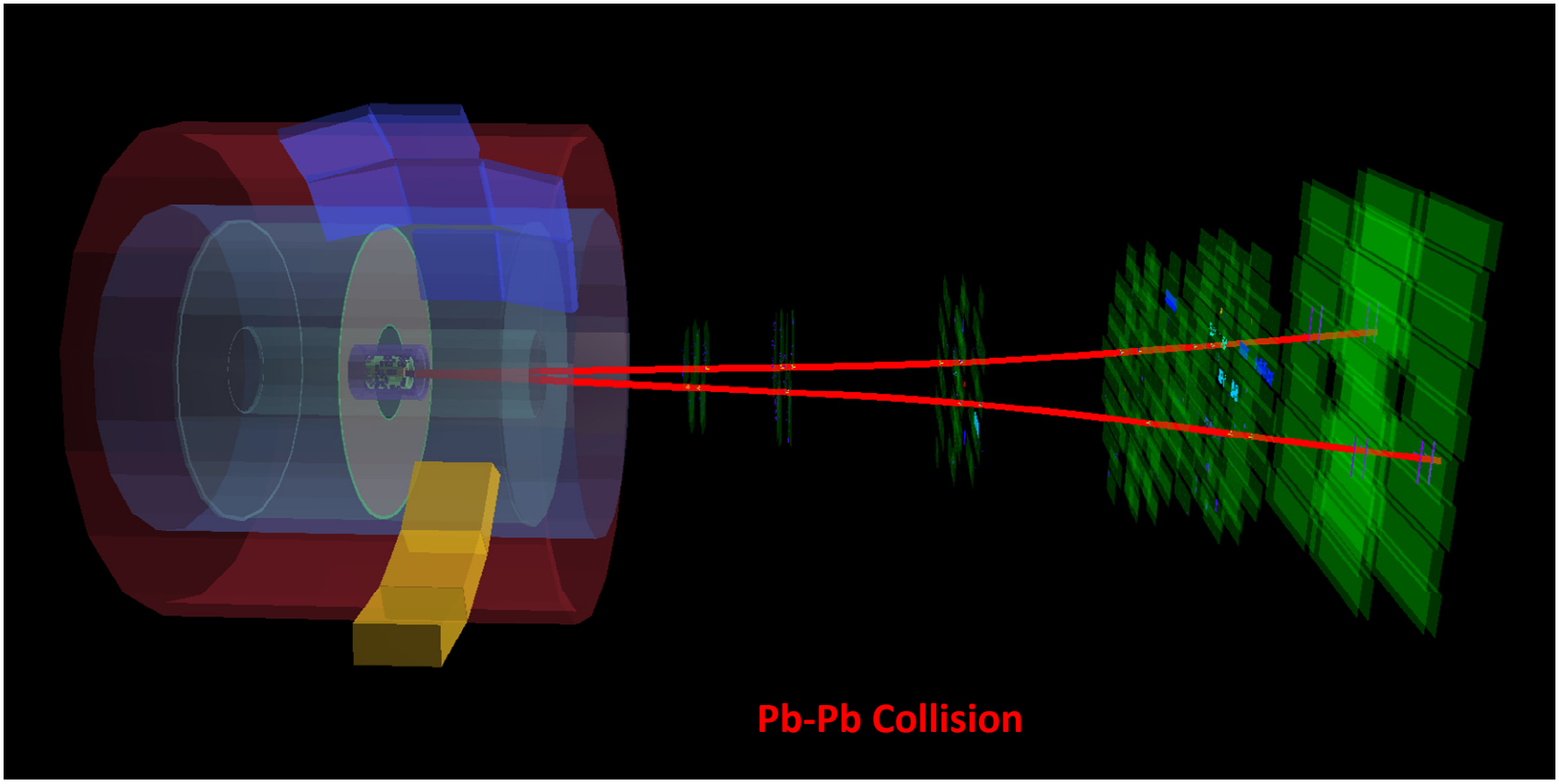
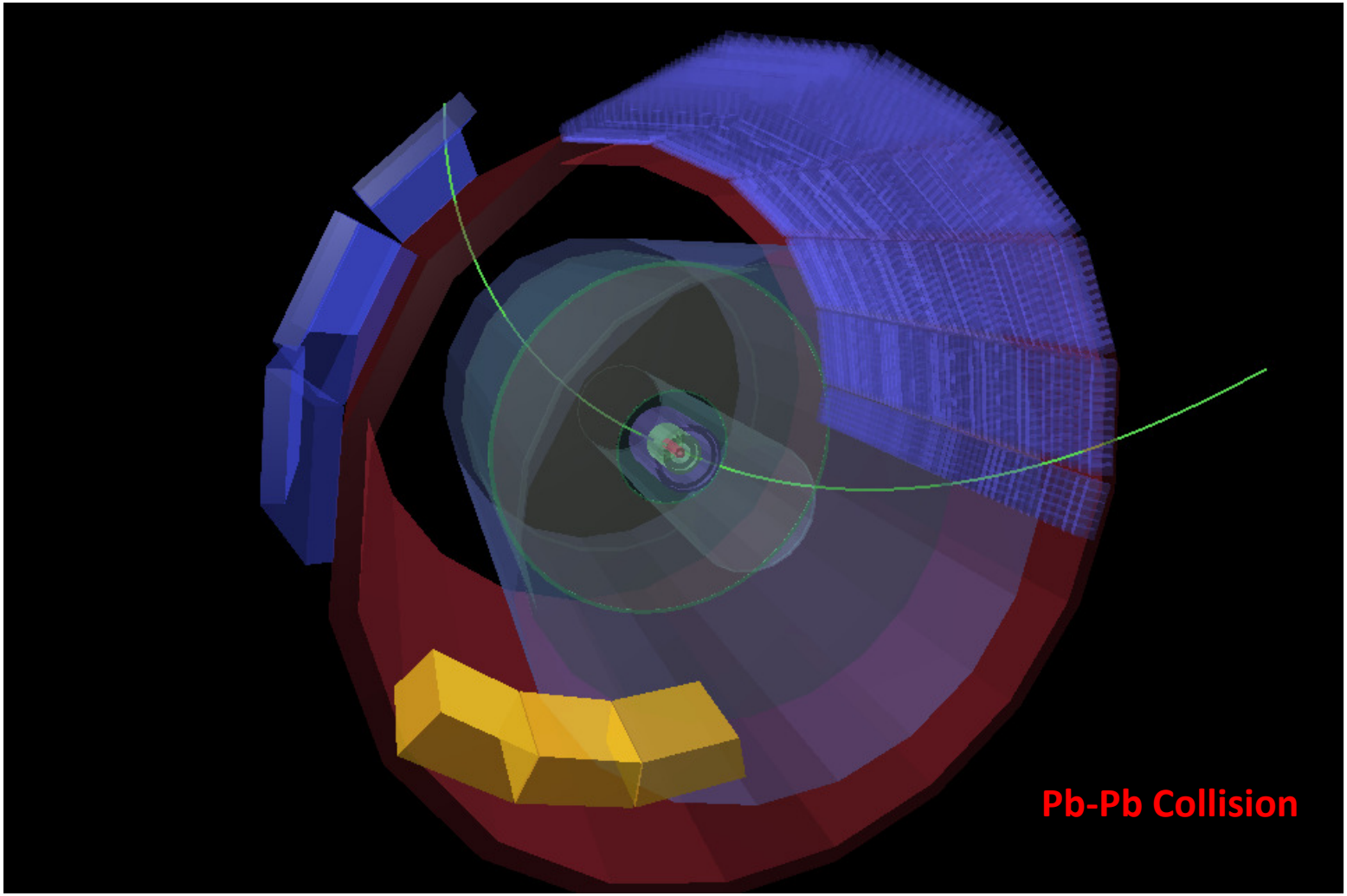


Forward J/ψ



Central J/ψ



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*)

* **STARLIGHT website** http://starlight.hepfog.org/

Analysis Strategy

- Select a m
  - 2.2 < M
  - 3.0 < M

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  incoherent
  - coherent dominates at low p_T
    - <300 MeV/c for electrons
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  - correct for portion of spectrum (coherent/incoherent) missed by this procedure (template from STARLIGHT*)

Coherent: nucleus reacts *as a whole*. Typically no forward fragments.

Incoherent: interaction with a nucleus *constituent*, giving rise to a few forward fragments.

* **STARLIGHT website** http://starlight.hepfog.org/

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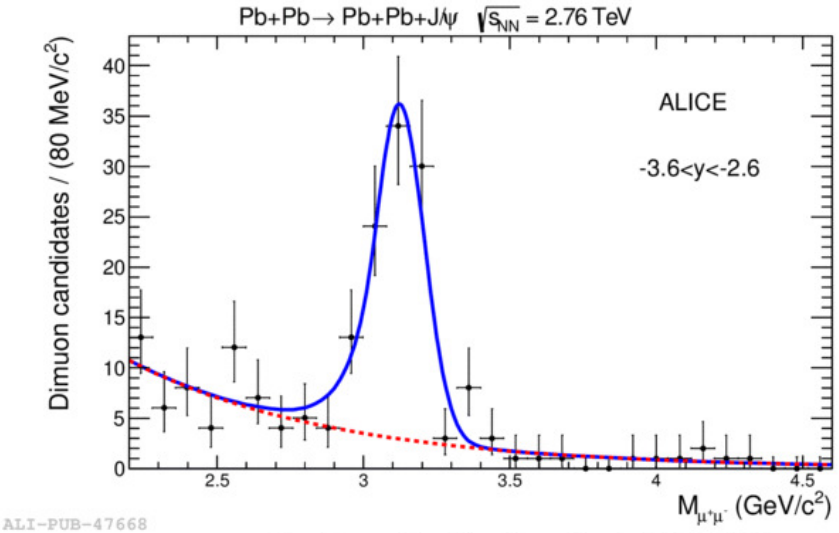
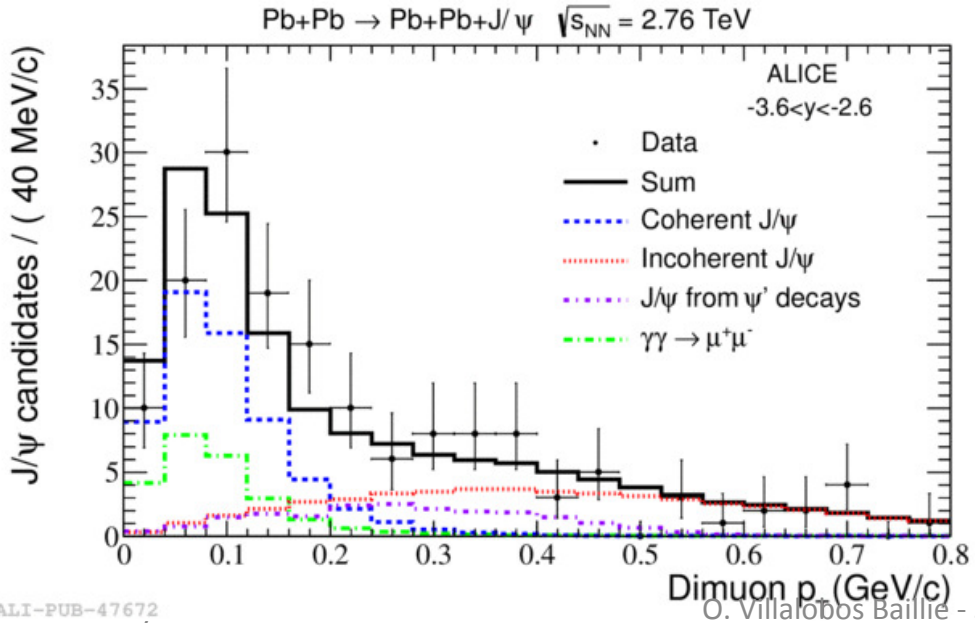
Pb-Pb Measurements

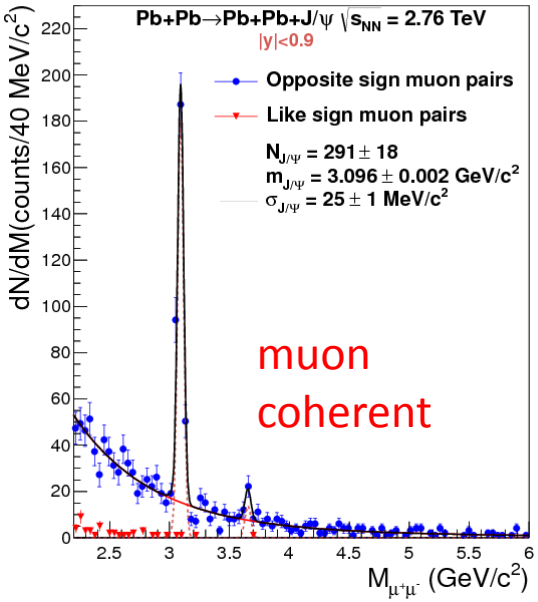


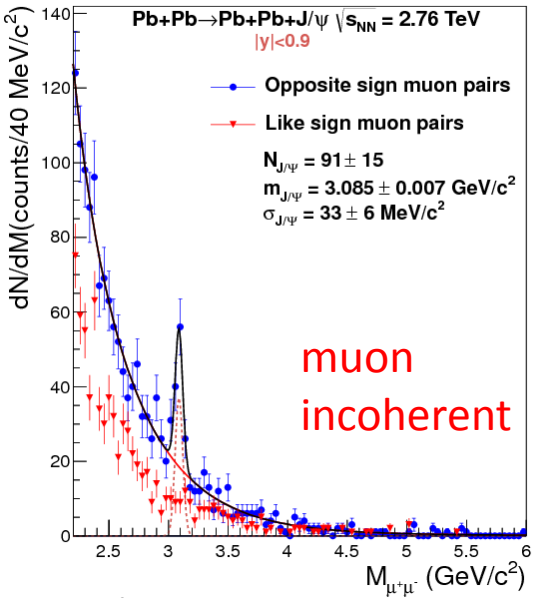


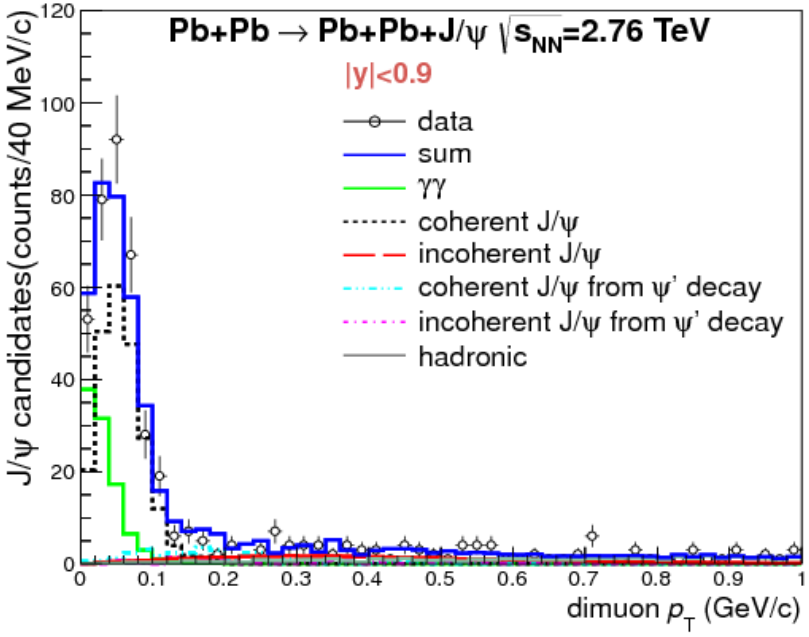
- **Forward** (2.6<y<3.6)
- Clear mass peak on exponentially dropping background
- p_T spectrum for J/ψ candidates shows peak at low p_T corresponding to coherent interactions
  - (Scatter off the whole nucleus.)

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

Pb-Pb Measurements





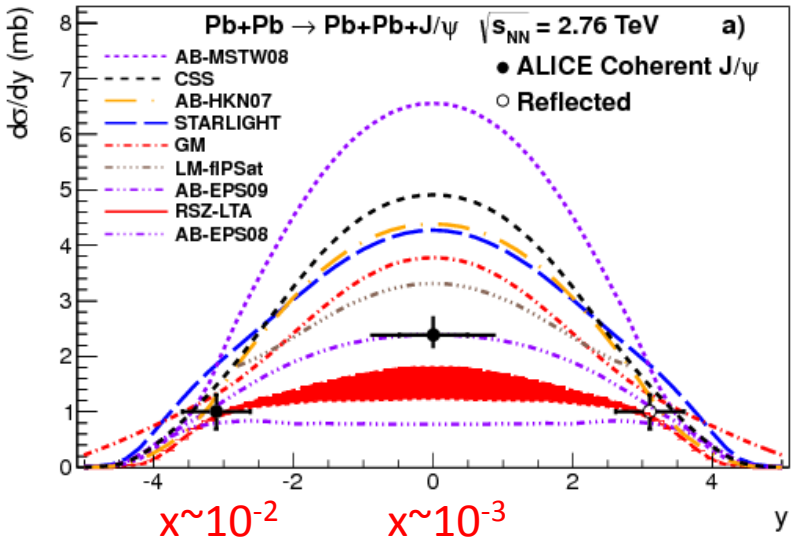


mid-rapidity
(|y|<0.9)

- 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



COHERENT

Agreement is best for models incorporating moderate nuclear gluon shadowing.

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

- **STARLIGHT: Klein, Nystrand, PRC60 (1999) 014903**
- VDM + Glauber approach where J/ψ+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

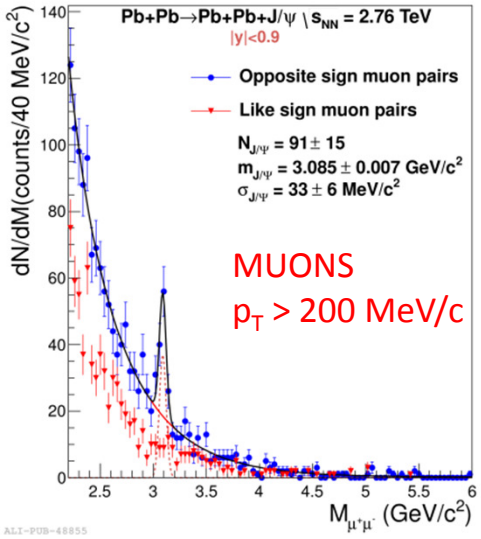
- **AB: Adeluyi and Bertulani, PRC85 (2012) 044904**
- LO pQCD calculations: AB-MSTW08 assumes no
- nuclear effects for the gluon distribution, other AB
- models incorporate gluon shadowing effects according
- to the EPS08, EPS09 or HKN07 parameterizations

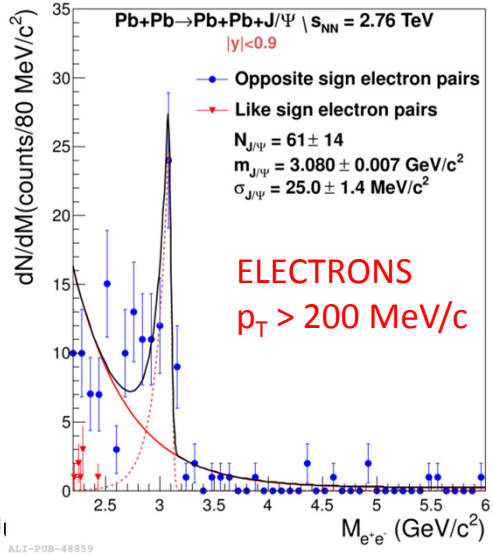
- **CSS: Cisek, Szczurek, Schäfer, PRC86 (2012) 014905**
- Glauber approach accounting $c\bar{c}g$ intermediate states

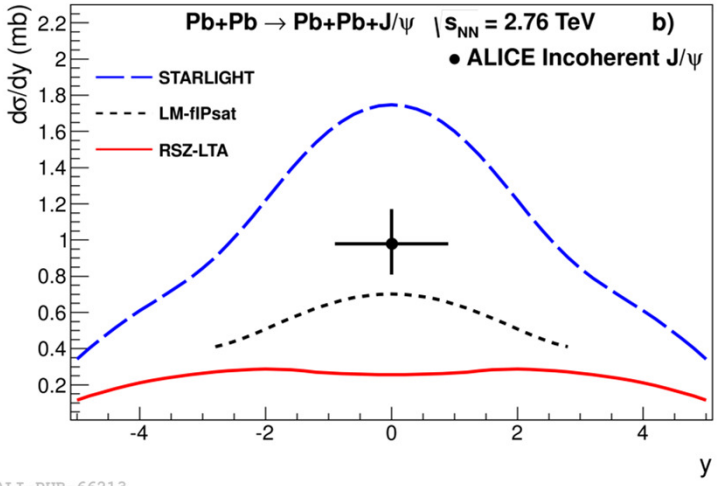
- **RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252**
- LO pQCD calculations with nuclear gluon shadowing
- computed in the leading twist approximation

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

Pb-Pb Measurements







INCOHERENT

- First measurement in Pb-Pb. 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.

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

More Pb-Pb Measurements

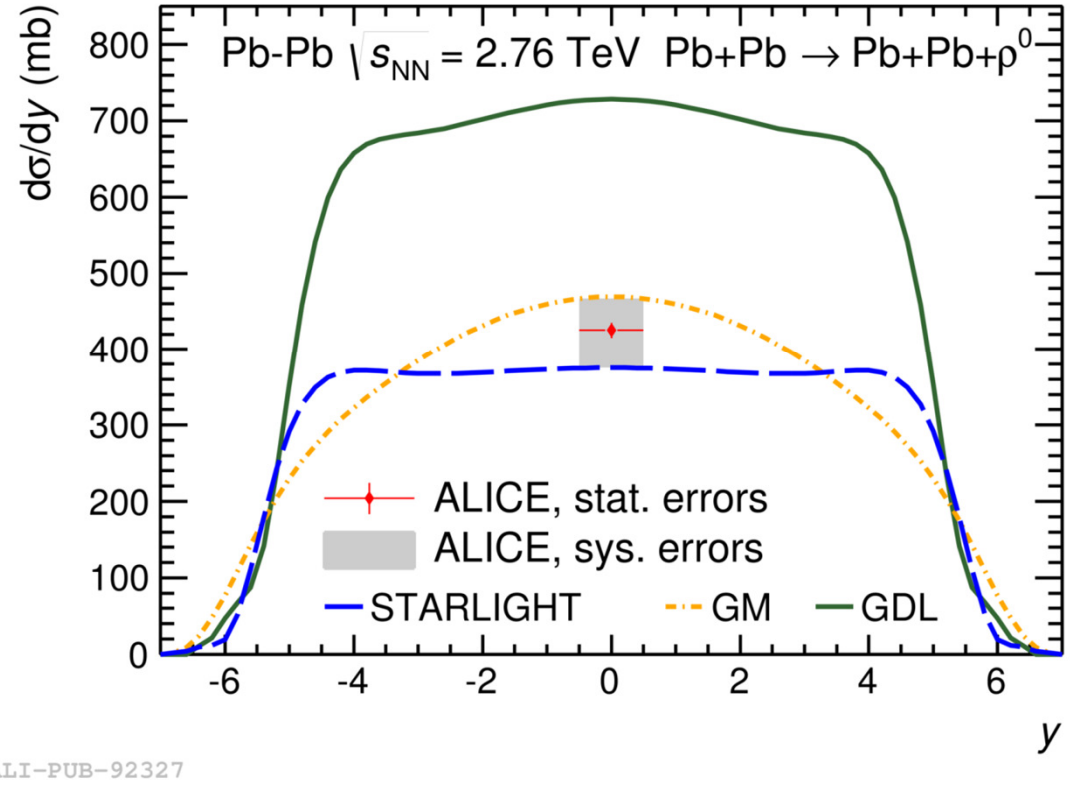
- Two other particles have been studied, both at central rapidity (i.e. using particles measured in the barrel:
  - $\psi(2S)$. Similar to J/ψ but with a slightly heavier mass, a more complicated wavefunction and a larger radius.
  - ρ^0. Much lighter mass, (so not describable with pQCD) but accessible through *vector dominance* model, where ρ is most copiously produced particle. Also measured in heavy ion collisions at RHIC.

More Pb-Pb Measurements

$\rho^0 \rightarrow \pi^+\pi^-$

- Use d*E*/d*x* consistency on both tracks to separate pion pairs from electron pairs.
  - (Ensure no other hits in SPD or in VZERO)
- Use STARLIGHT templates to separate coherent and incoherent contributions to p_T spectrum
- Use appropriate line-form (Söding or Ross/Stodolsky) to represent ρ peak.

More Pb-Pb Measurements

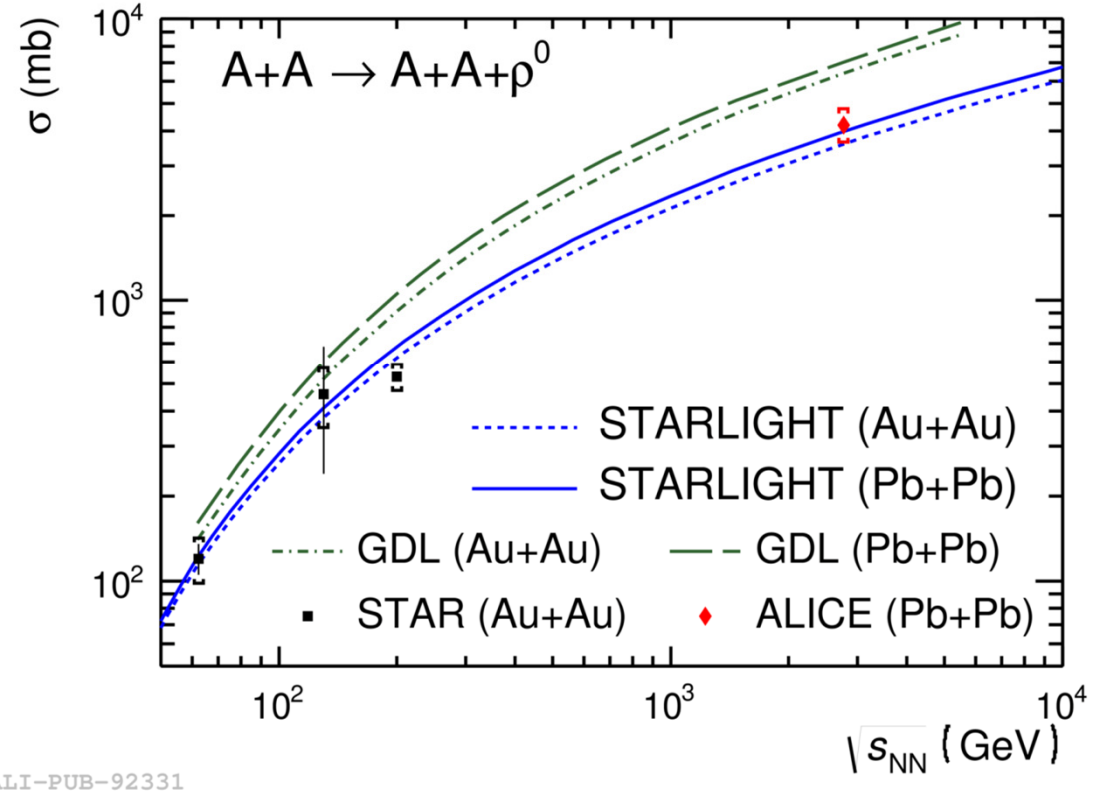


ρ^0

ArXiv:1503.09177

- First measurement constrains models
- STARLIGHT and GM (Gonçalves-Machado) OK, GDL (Glauber-Donnachie-Landshoff) is off

More Pb-Pb Measurements



ρ^0

ArXiv:1503.09177

- STARLIGHT correctly describes energy dependence from RHIC to LHC.
- $\sigma_{\rho(UPC)}/\sigma_{INEL}$ increases from ~0.1 at RHIC to ~0.5 at LHC

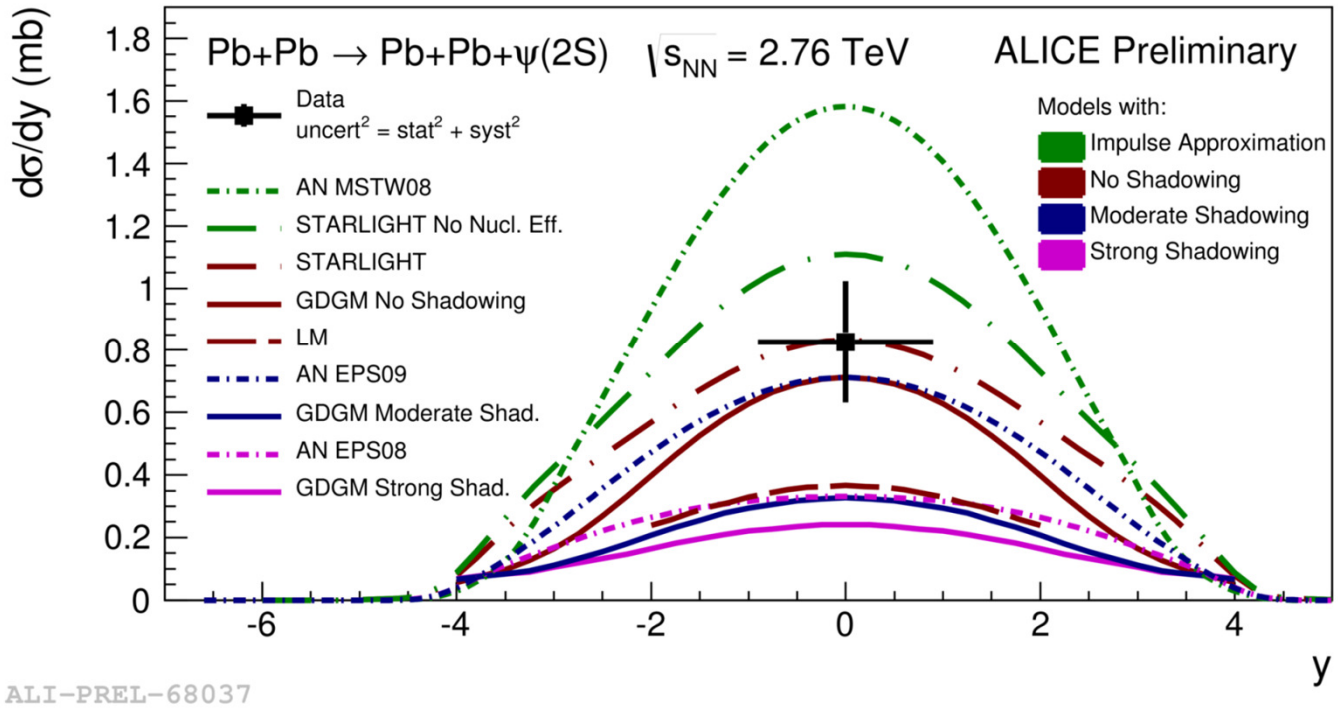
More Pb-Pb Measurements

- $\psi(2S)$ studied in four final states
  - $\psi(2S) \rightarrow e^+e^-$
  - $\psi(2S) \rightarrow \mu^+\mu^-$
  - $\psi(2S) \rightarrow J/\psi\ \pi^+\pi^-;\ J/\psi \rightarrow e^+e^-$
  - $\psi(2S) \rightarrow J/\psi\ \pi^+\pi^-;\ J/\psi \rightarrow \mu^+\mu^-$

ALL AT MID-RAPIDITY

- Taking into account branching ratios, acceptances, reconstruction efficiencies, etc., all the channels give roughly equal data sample size.

More Pb-Pb Measurements

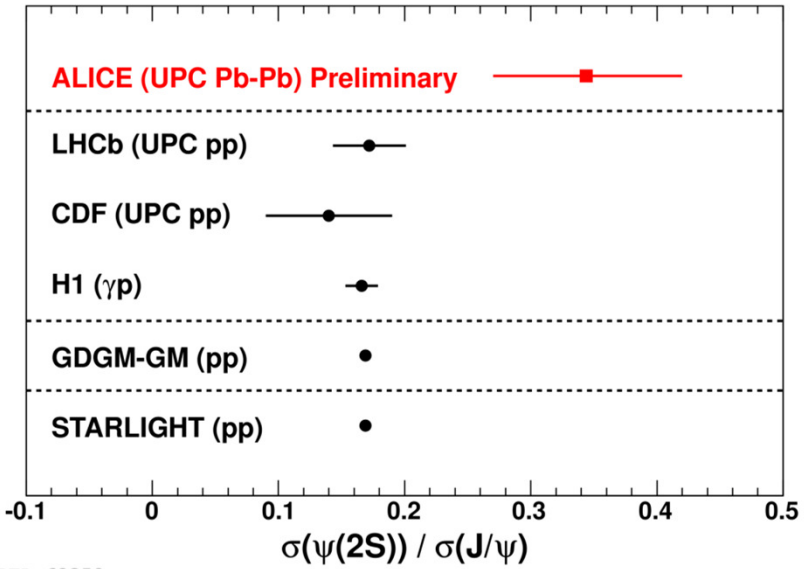


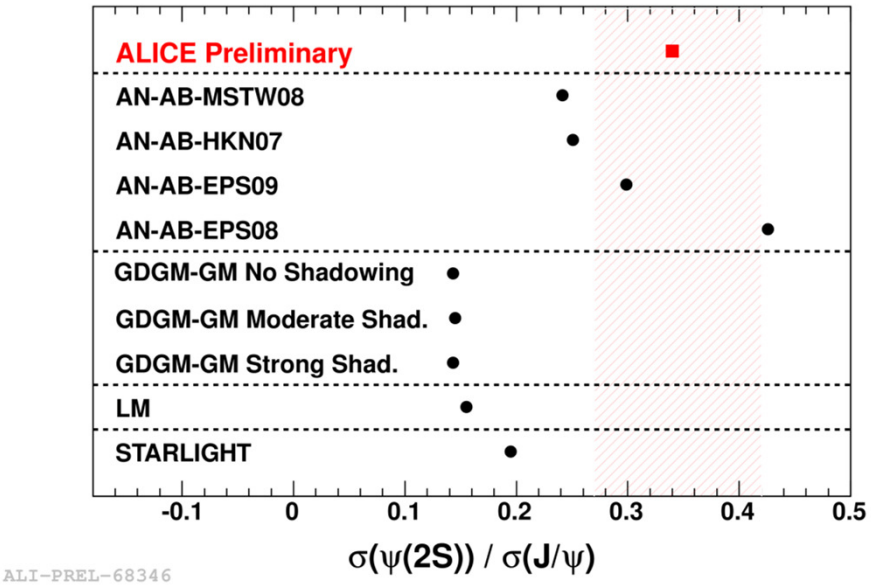
ψ(2S)

- Measurement consistent with moderate or no shadowing, not conclusive on mechanism

More Pb-Pb Measurements

ψ(2S)





- Ratio of ψ(2S)/J/ψ is different in Pb-Pb from pp, and is hard to reproduce in models. In the AN (Adeluyi and Nguyen) models, which are in general closest, ψ(2S) production is proportional to gluon distribution squared.

Run 2

- J/ψ. We aim to collect ~20K events, allowing a much more detailed study of mechanism.
  - d*N*/d*y*
  - d*N*/d*t*
- ψ(2S). We aim to collect ~500 events, allowing ψ(2S) studies at about the same level of detail as J/ψ in Run 1.
- Hope to see ϒ(1S, 2S, 3S) if sufficient statistics.
- Try to separate γγ from γ-Pomeron by selecting resonance with quantum numbers not accessible for γ-Pomeron (e.g. η_C)
- New detector (AD) extends pseudorapidity coverage to η~7, leading to a more effective veto on additional tracks and a cleaner trigger.

Summary

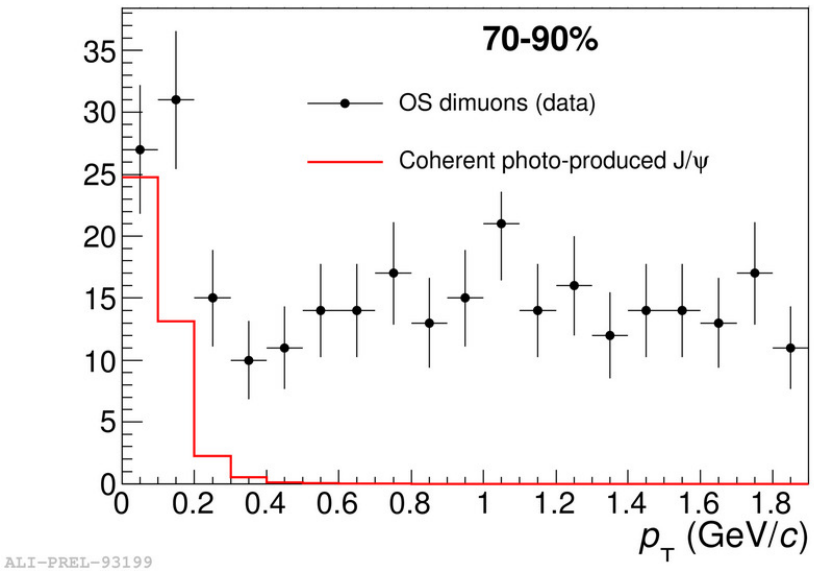
- Ultra-Peripheral collisions (UPC) provide a powerful tool for studying gluon distributions, both in nuclei and protons.
- ALICE UPC results in J/ψ in Pb-Pb (Run 1) are constraining models on nuclear gluon shadowing in the region $x \sim 10^{-3}$. A gluon shadowing component appears to be needed
  - B. Abelev et al., Phys. Lett. **B718** (2013) 1273
  - E. Abbas et al., Eur. Phys Journal **C73** (2013) 2617
- New results for ρ^0 and ψ(2S) production give new insights both into the nature of the nucleus (possible shadowing effects) but also into the nature of the probe. ArXiv:1503.09177
- More work still needed in this new and emerging field.
- RUN 2. Expect over an order of magnitude increase in statistics, and access to lower *x*-values.

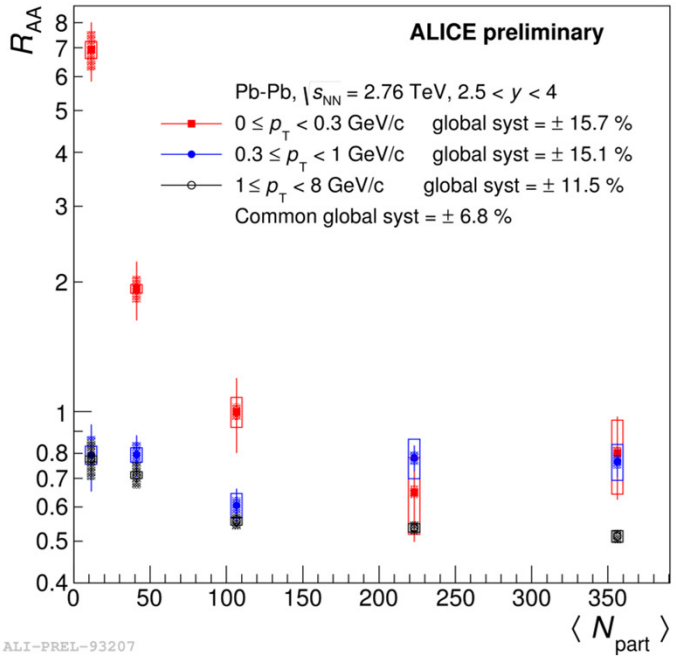
Back-Up


PER
ARDUA
AD
ALTA


ALICE

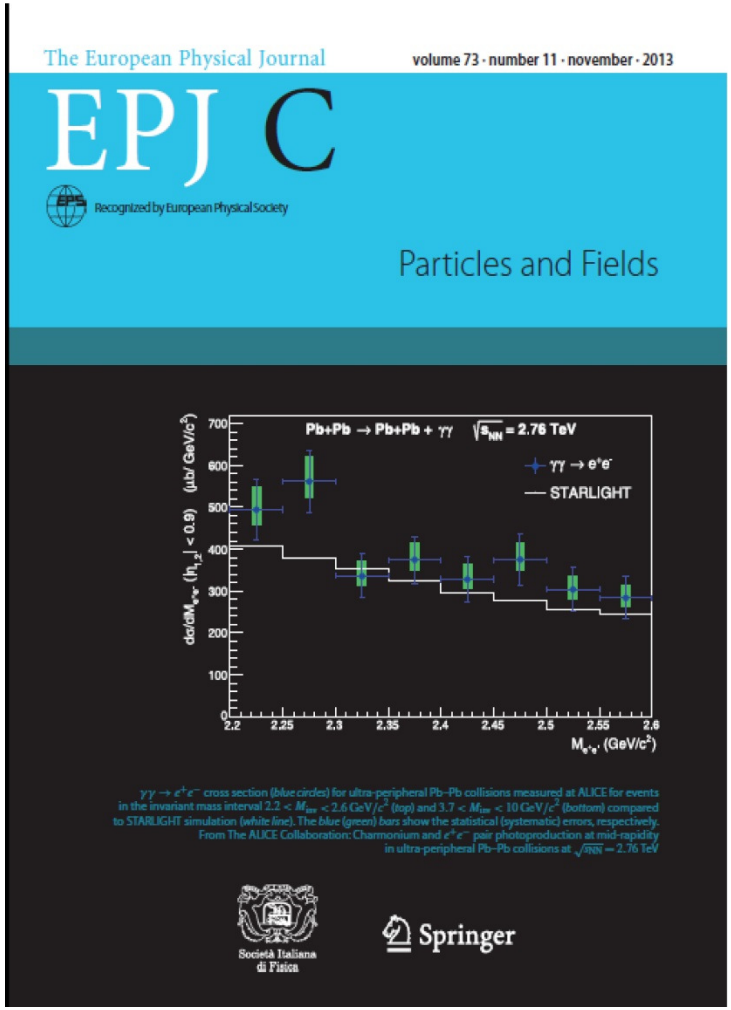
J/ψ in *Peripheral* Pb-Pb





- There is a very narrow peak in the p_T spectrum, similar to that from coherent *UPC* collisions.
- Coherent J/ψ production via the photon-gluon mechanism is *expected*, essentially from the spectators, along with peripheral (strong) interactions.
- Cross-sections approximately match, showing observed peak is consistent with this hypothesis.

Recent Issue EPJC



$\gamma\gamma \to e^+e^-$ cross section (*blue circles*) for ultra-peripheral Pb–Pb collisions measured at ALICE for events in the invariant mass interval $2.2 < M_{ee} < 2.6$ GeV/c^2 (top) and $3.7 < M_{ee} < 10$ GeV/c^2 (bottom) compared to STARLIGHT simulation (*white line*). The *blue* (green) *bars* show the statistical (systematic) errors, respectively. From The ALICE Collaboration: Charmonium and e^+e^- pair photoproduction at mid-rapidity in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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

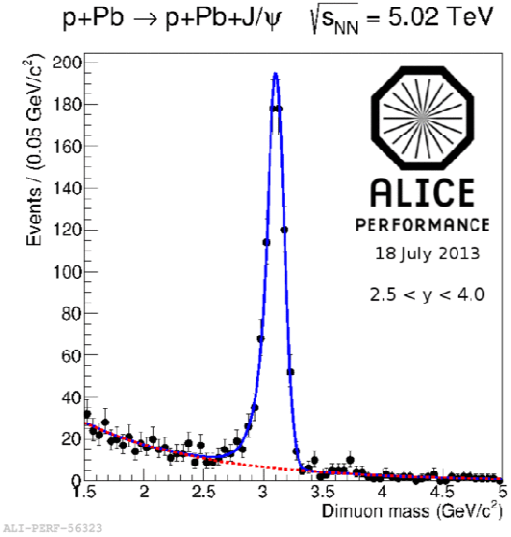
$$x = \left(M_{J/\psi} / \sqrt{s_{NN}}\right) \exp(\pm y)$$

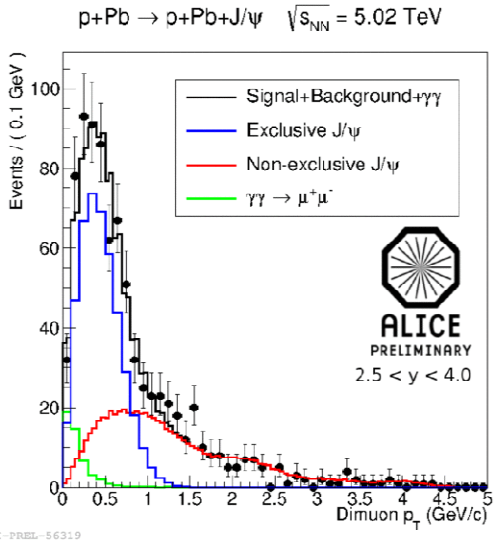
- Two solutions coincide for $y=0$, but forward rapidity and identical beams an *ansatz* is needed to weight the two solutions.

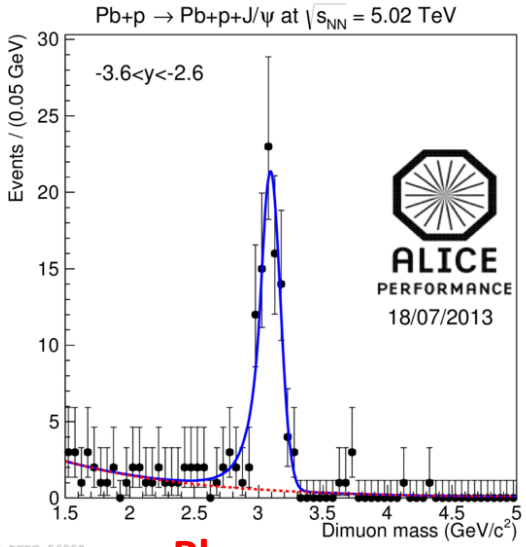
p-Pb Measurements

B. Abelev et al., Phys. Rev. Lett. **113** (2014) 232504

p-Pb Measurements





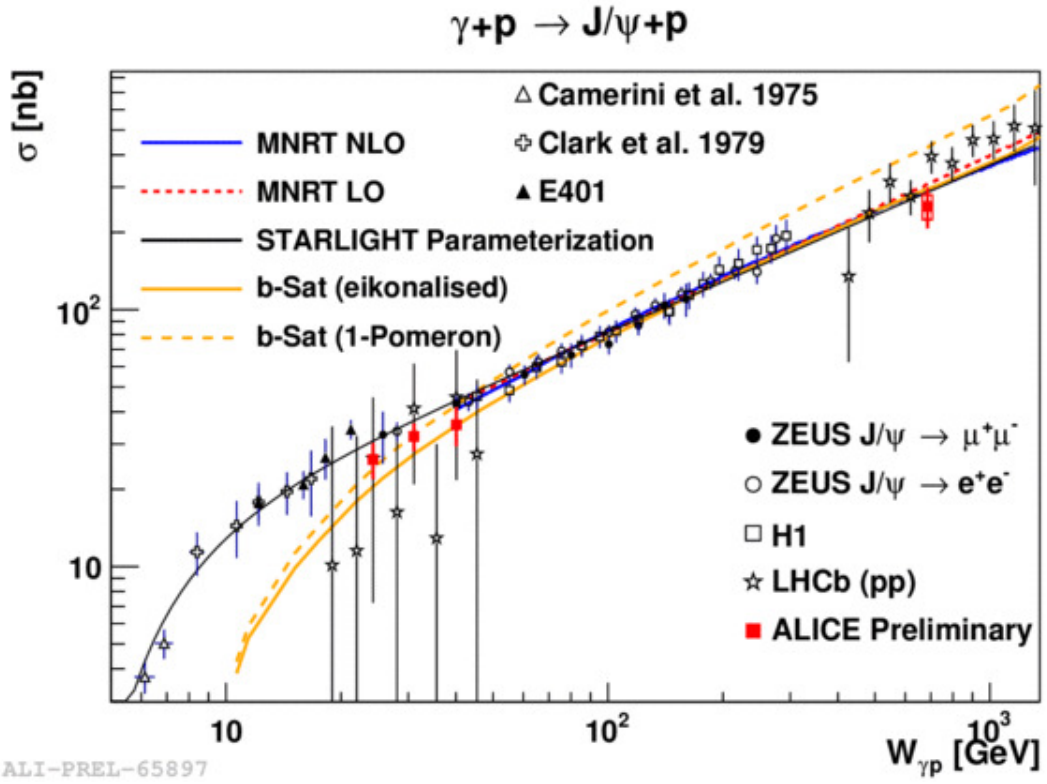


p-Pb **Pb-p**

- 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

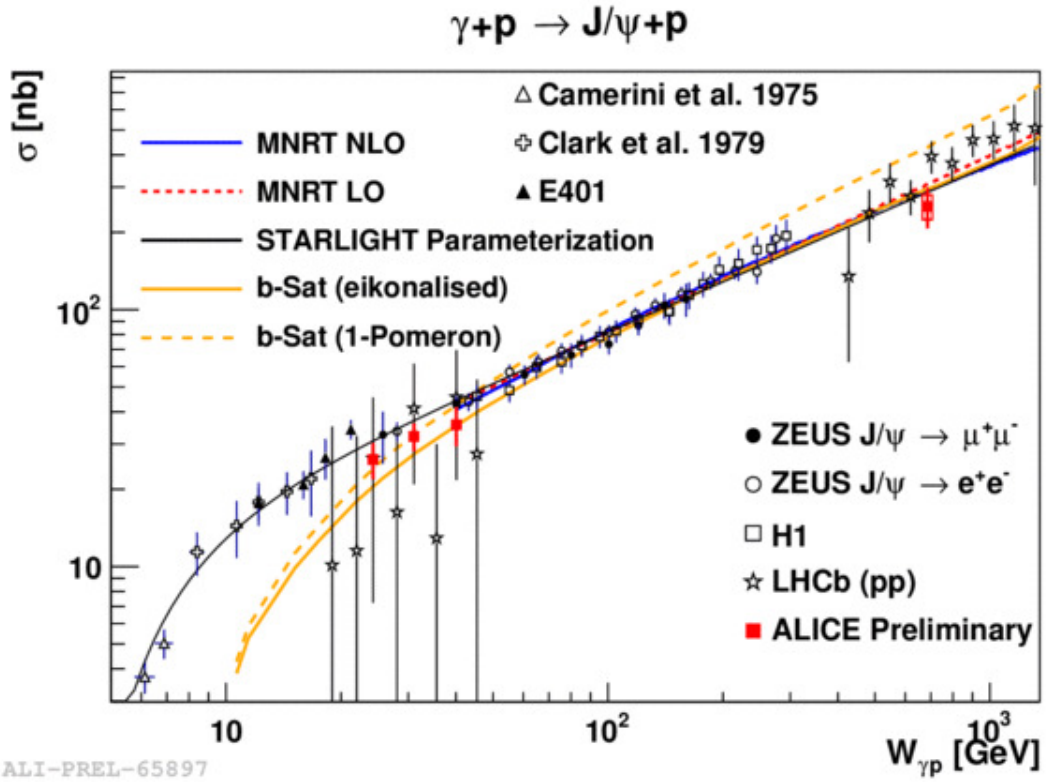


$$\frac{\mathrm{d}\sigma}{\mathrm{d}y}\left(\mathrm{p}+\mathrm{Pb}\rightarrow\mathrm{p}+\mathrm{Pb}+J/\psi\right)=k\frac{\mathrm{d}n}{\mathrm{d}k}\sigma\left(W_{\gamma\mathrm{p}}\right)$$

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



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

HERA Measurements	
H1	δ=0.67±0.03
ZEUS	δ=0.69±0.02

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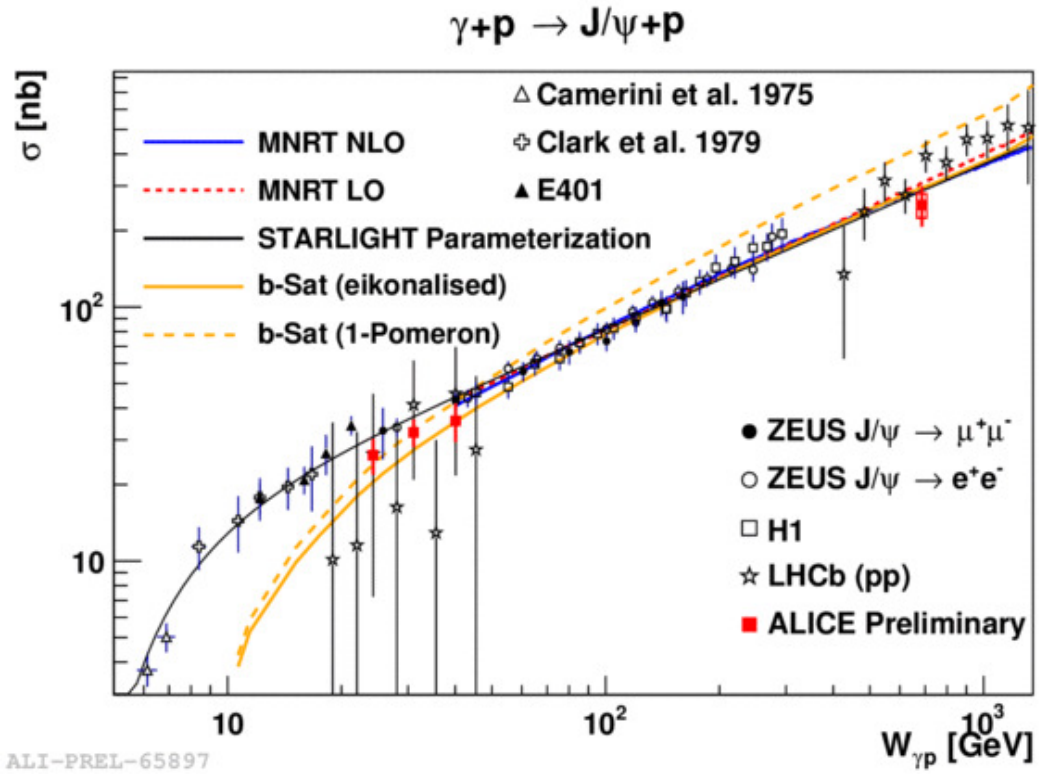
A power law fit ($\sigma(W) \sim W^{\delta}$) to ALICE data points gives $\delta = 0.67 \pm 0.06$.

p-Pb Measurements



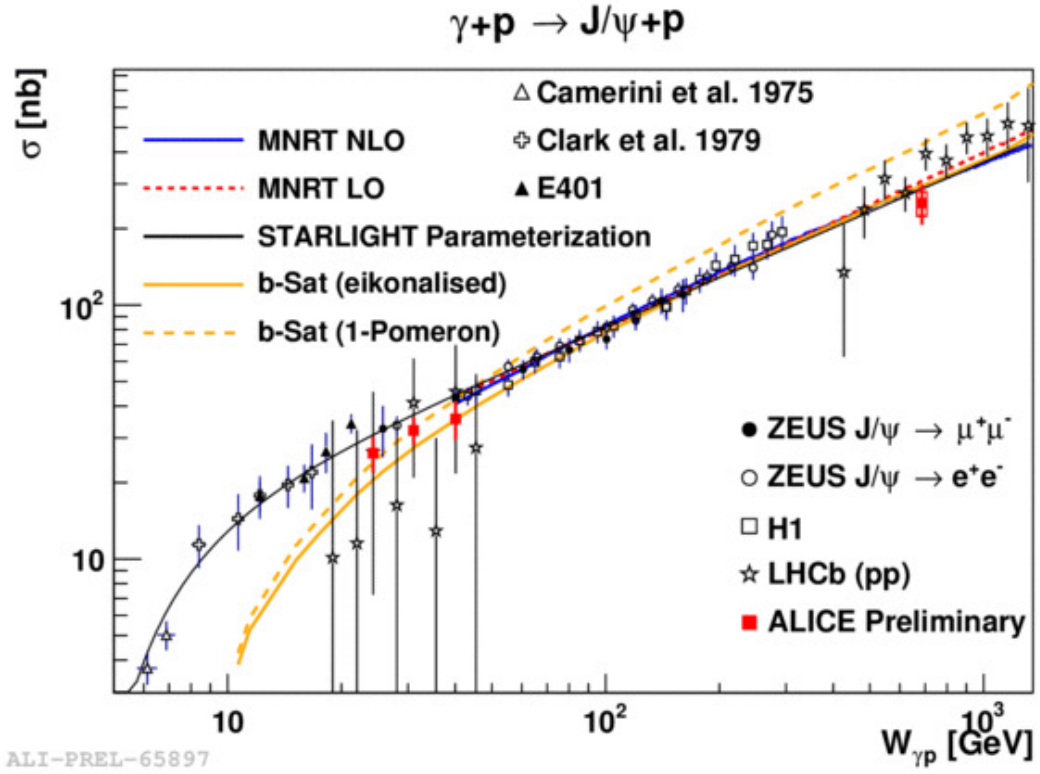
$$\frac{\mathrm{d}\sigma}{\mathrm{d}y}\left(\mathrm{p}+\mathrm{Pb}\rightarrow\mathrm{p}+\mathrm{Pb}+J/\psi\right)=k\frac{\mathrm{d}n}{\mathrm{d}k}\sigma\left(W_{\gamma\mathrm{p}}\right)$$

- 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).

p-Pb Measurements



$\frac{d\sigma}{dy}$

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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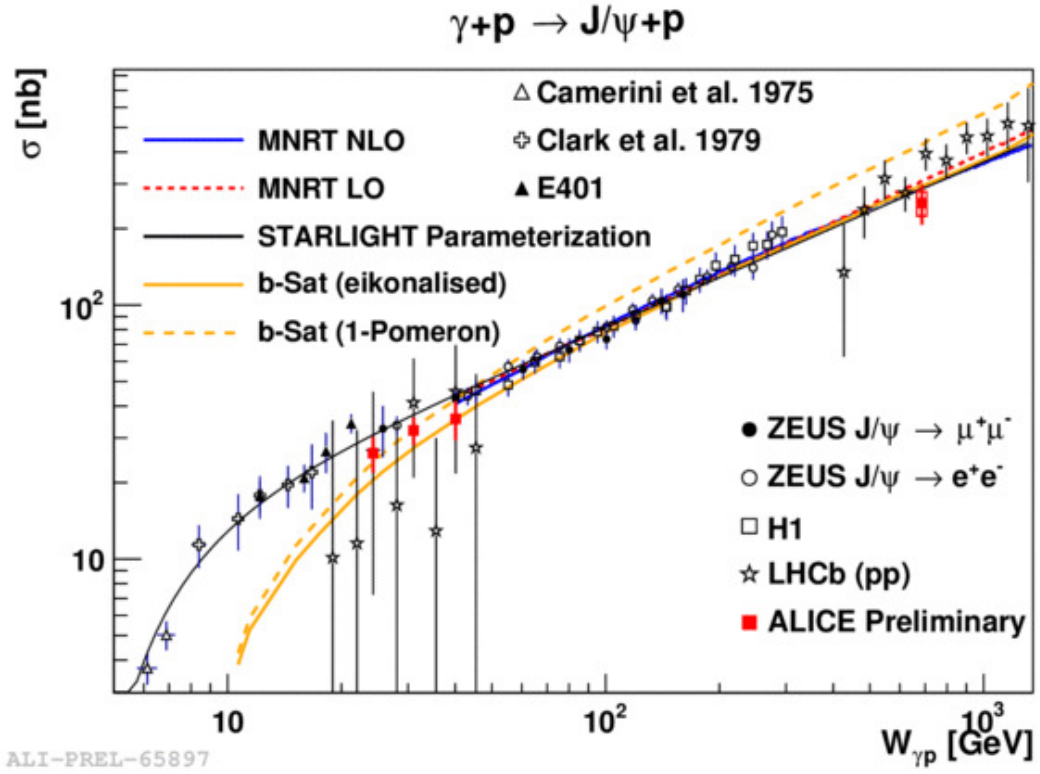

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New (2014) LHCb points agree better with HERA and ALICE data. Figure to be updated.