**Low x meeting**
**Kyoto**

# Recent results from ALICE on p-Pb and Pb-Pb UPC

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On behalf of the **ALICE** Collaboration

June 19, 2014

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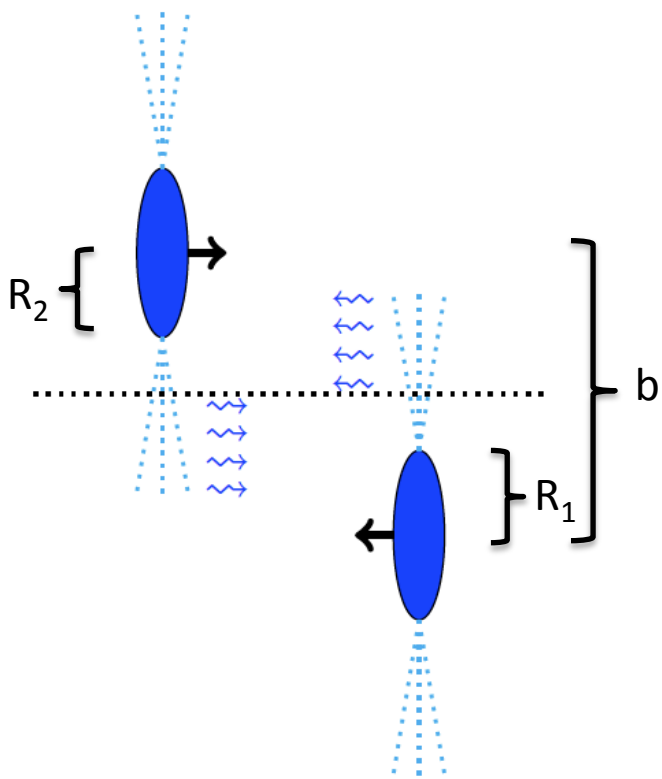
# What are ultra-peripheral collisions (UPC)?

# Ultra-peripheral collisions (UPC)




$R_1+R_2<b \rightarrow$ UPC

- ✓ The EM field of fast charged particles can be viewed as a beam of quasi real photons

  The virtuality of the emitted photons is restricted by the radius R of the source to be around $hc/(2\pi R)^2$,

  $\gamma$ from Pb: $Q^2 \approx (30\ \text{MeV})^2$

- ✓ For collisions at impact parameters (b) larger than the sum of the radii of the incoming particles, hadronic interactions are suppressed and EM interactions dominate

  Photoproduction processes can be cleanly studied in hadron colliders using

  Ultra-peripheral collisions (UPC),

# Ultra-peripheral collisions at the LHC

- ✓ The intensity of the photon beam is proportional to $Z^2$

  The photon flux from lead nuclei is very intense → large cross sections

- ✓ The maximum energy of the photons in the laboratory system is determined by the boost of the source.

  At the LHC during RUN1:

  $\gamma$ from p: $E^{\gamma}_{max} \approx 1200$ GeV

  $\gamma$ from Pb : $E^{\gamma}_{max} \approx 50$ GeV

**Using**

**pp, Pb-Pb and p-Pb**

**data at the LHC it is possible to study**

**$\gamma$-Pb, $\gamma$p and $\gamma\gamma$**

**processes in UPC at higher center of mass energies than ever before**

# UPC processes

- ✓ One possibility to select UPC is to study exclusive processes:
  1. Measure the complete exclusive final state
  2. Make sure there is nothing else in the detector

- ✓ ALICE has measured the following UPC processes with the lead nucleus as the photon source:
  1. Continuum di-lepton production in photon-photon interactions

     This is a standard QED process, but with a strong coupling: $\alpha Z \sim 0.6$
     Interest from theory to know the size of higher order contributions

  2. Diffractive photoproduction of vector mesons

     This QCD process allows us to study the energy evolution of the cross section at a fixed scale, given by the mass of the vector meson.
     The measurement of different vector mesons allows us to scan the scale dependence of this process.

# ALICE and UPC

# Data

- ✓ Pb-Pb at a center of mass energy of 2.76 TeV

  **2010** Luminosity for UPC: 0.2 $\mu b^{-1}$

  **2011** Luminosity for UPC ~23 $\mu b^{-1}$ (central) and 55 $\mu b^{-1}$ (forward)

- ✓ p-Pb at a center of mass energy of 5.02 TeV

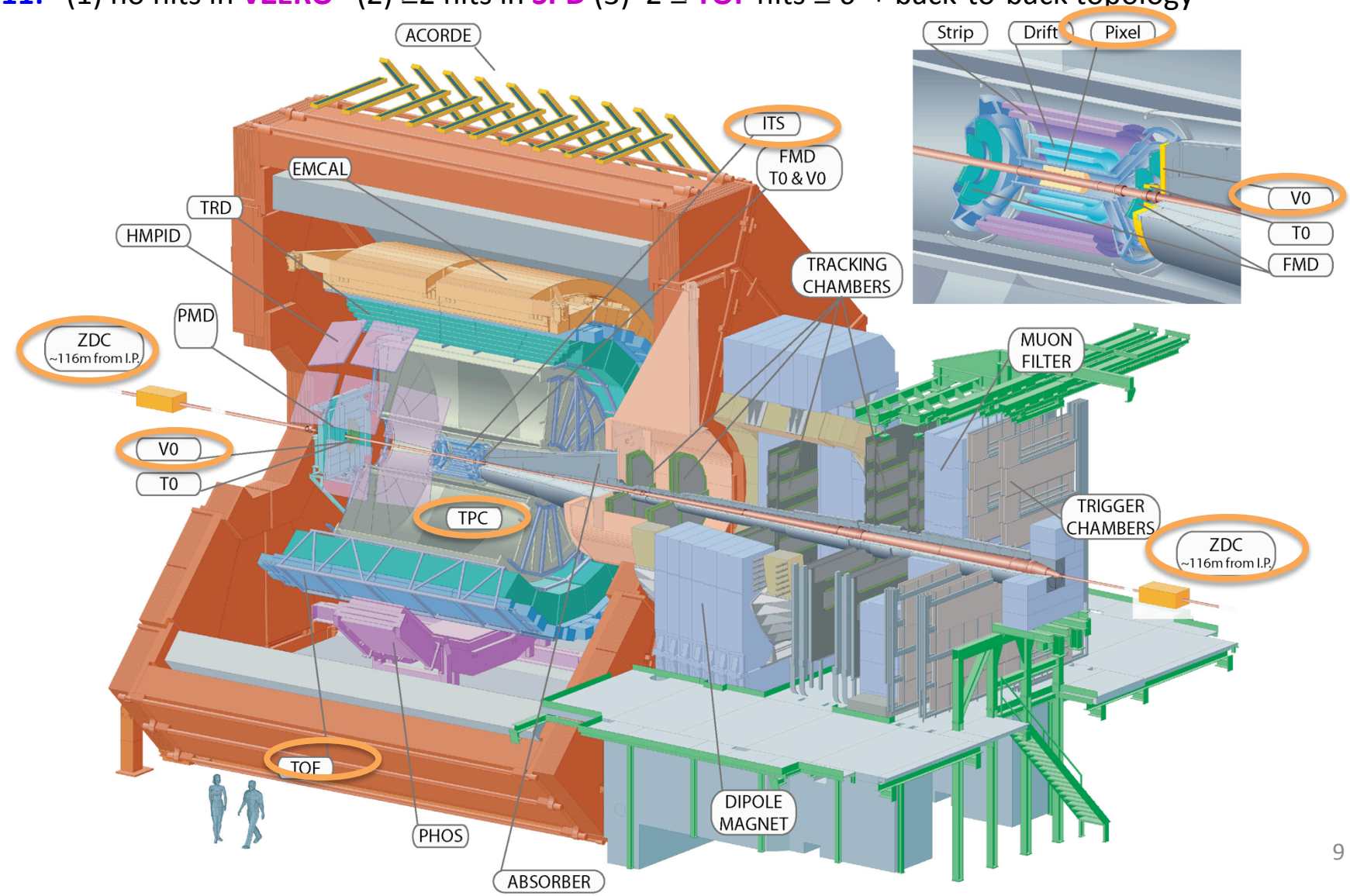
  **2013:** Luminosity for UPC: 3.9 $nb^{-1}$ (p-Pb) and 4.5 $nb^{-1}$ (Pb-p)

# UPC at mid rapidity with ALICE

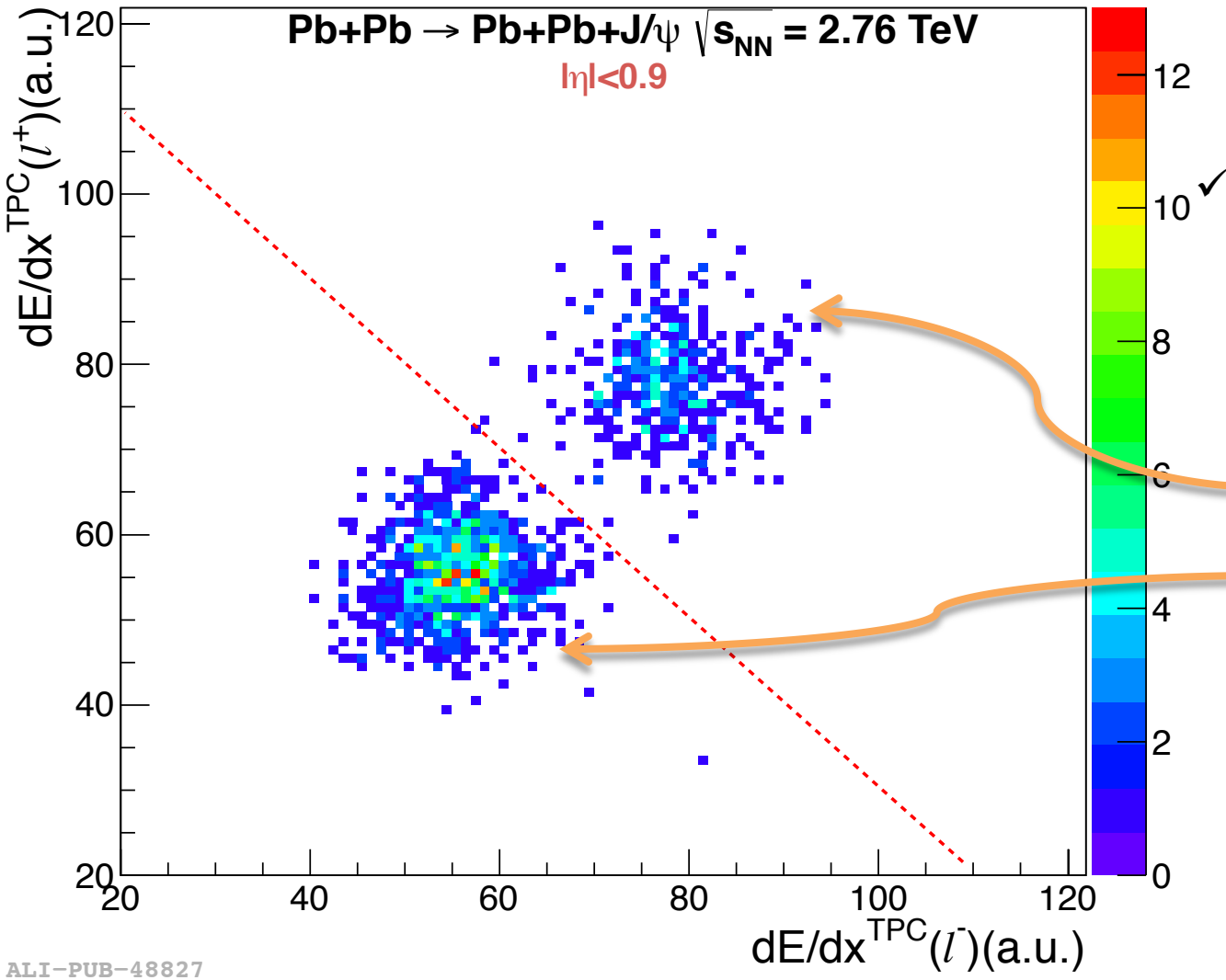
**UPC central barrel trigger:**

**2010**: (1) no hits in **VZERO** (2) ≥2 hits in **SPD** (3) 2 ≤ **TOF** hits

**2011:** (1) no hits in **VZERO** (2) ≥2 hits in **SPD** (3) 2 ≤ **TOF** hits ≤ 6 + back-to-back topology



# Particle identification using dE/dx




✓ The measurement of dE/dx performed by the TPC allows a clear separation of

electrons

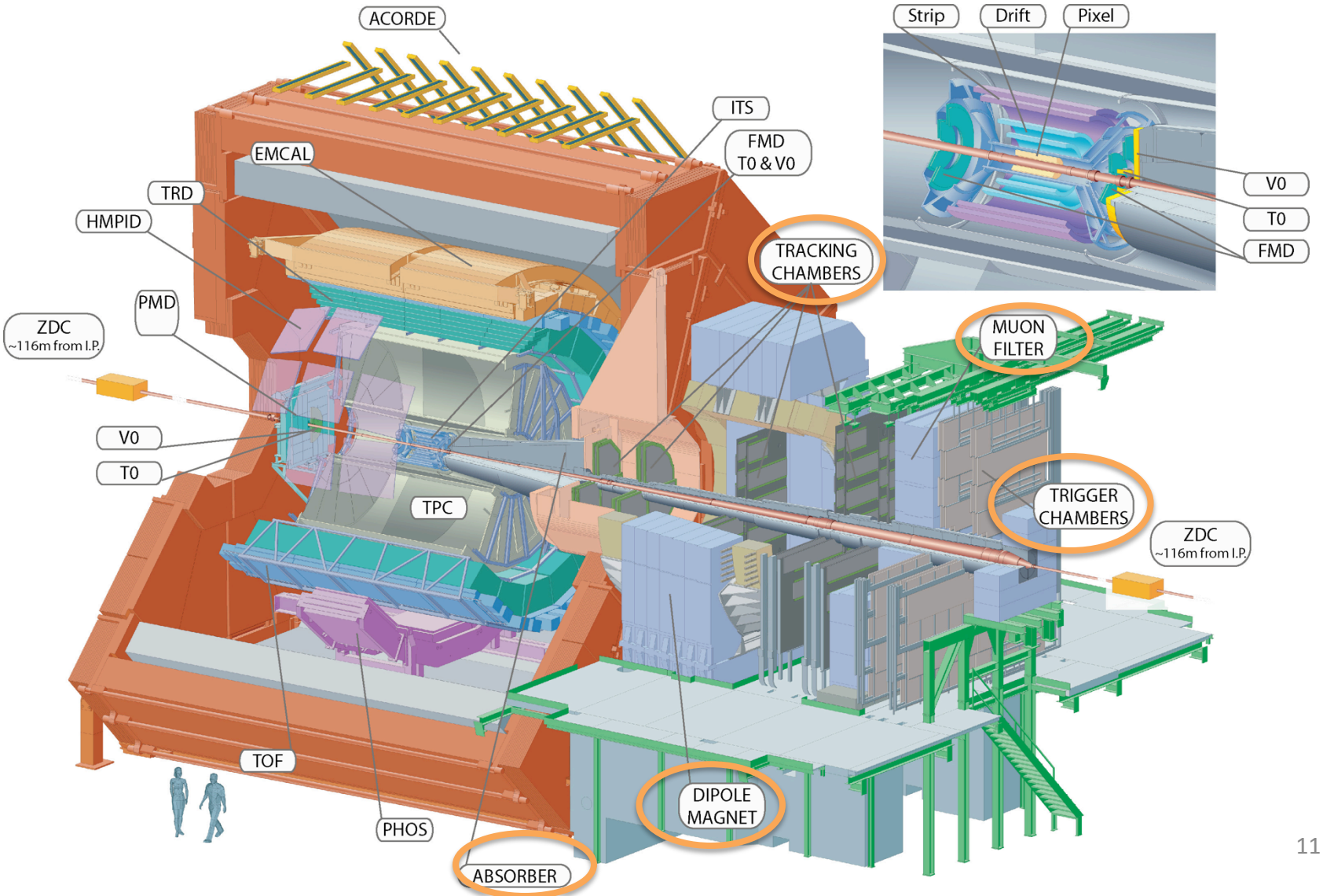
muons/pions

# UPC at forward rapidity with ALICE

**UPC central barrel trigger:**

**2011**: (1) no hits in **VZERO-A** (2) hits in **VZERO-C** (3) single **muon** with $p_T$>1 GeV/c

**2013:** (1) no hits in **VZERO-A** (2) hits in **VZERO-C** (3) di-**muon** each with $p_T$>0.5 GeV/c



# UPC measurements in Pb-Pb

2.1 Continuum $\gamma\gamma \rightarrow e^+e^-$ production

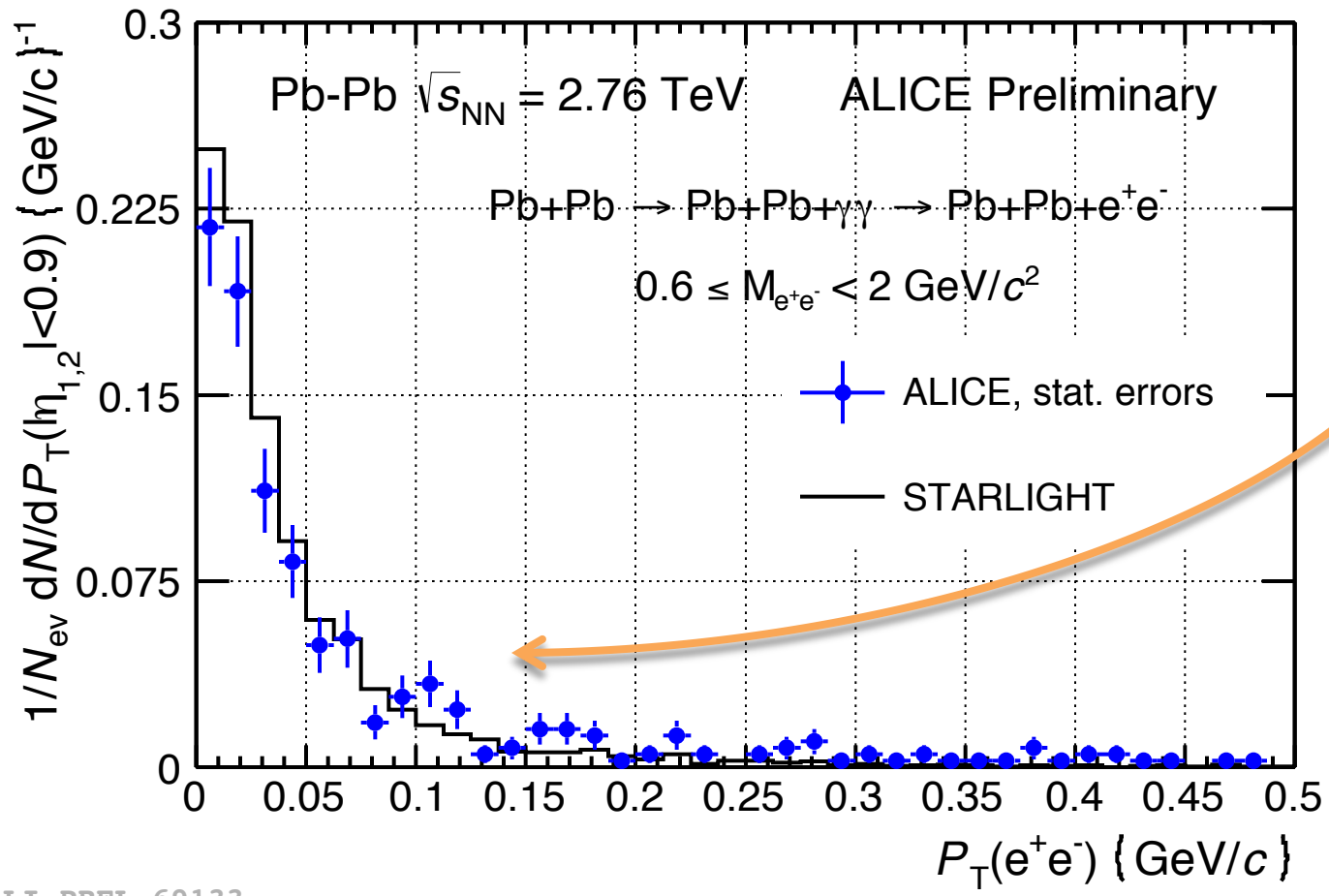
2.2 Coherent $\rho$ production

2.3 Coherent and incoherent $J/\psi$ production

2.4 Coherent $\psi(2s)$ production

# Continuum $\gamma\gamma \rightarrow e^+e^-$ production

- ✓ Two well measured tracks oppositely charged identified as electrons
- ✓ Rapidity of pair $|y|<0.5$ Small transverse momentum of pair (coherent emission of both photons)

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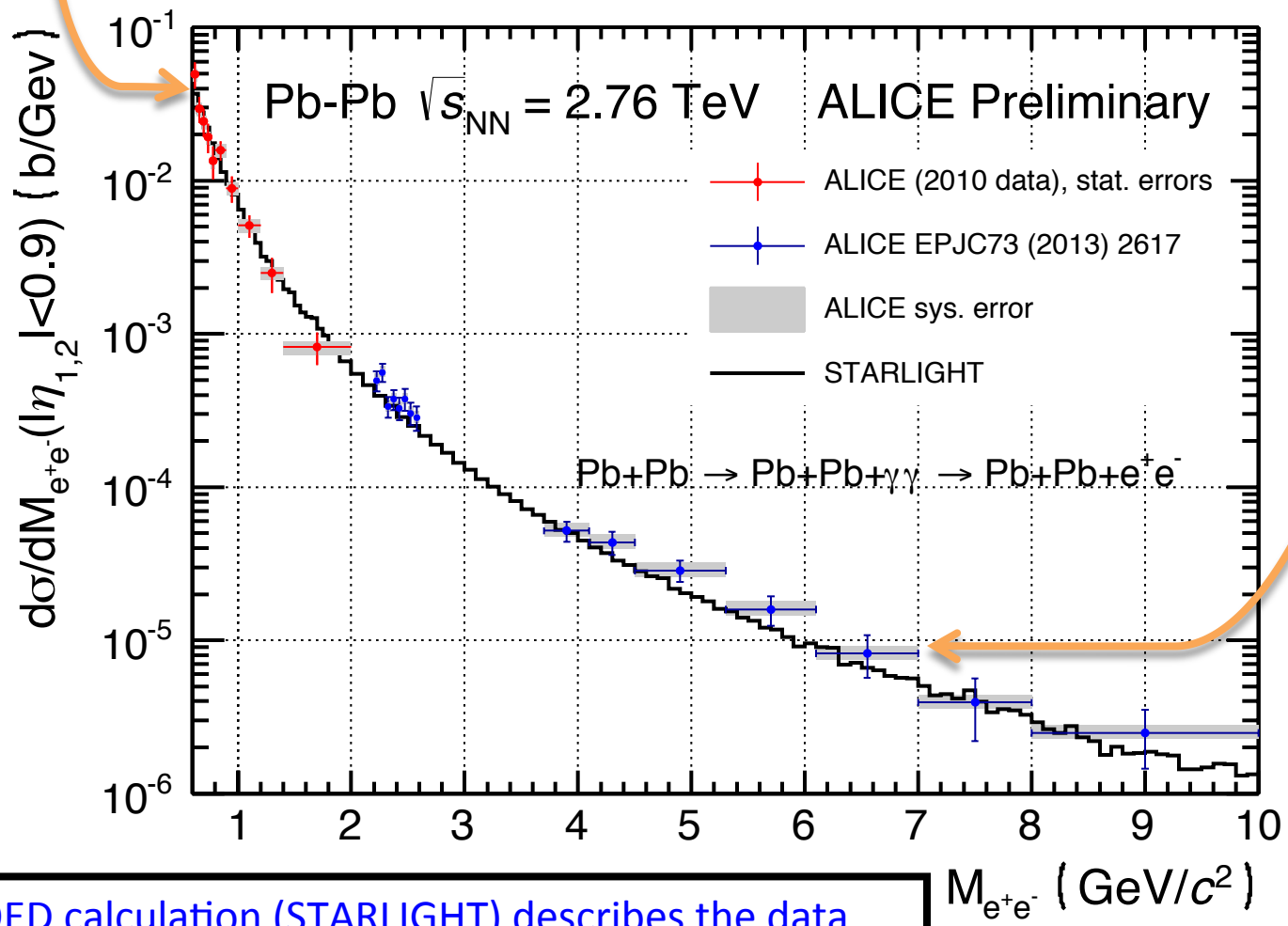
# Continuum $\gamma\gamma \rightarrow e^+e^-$ production: cross section

2010: Low luminosity, but trigger allows to cover the low mass region

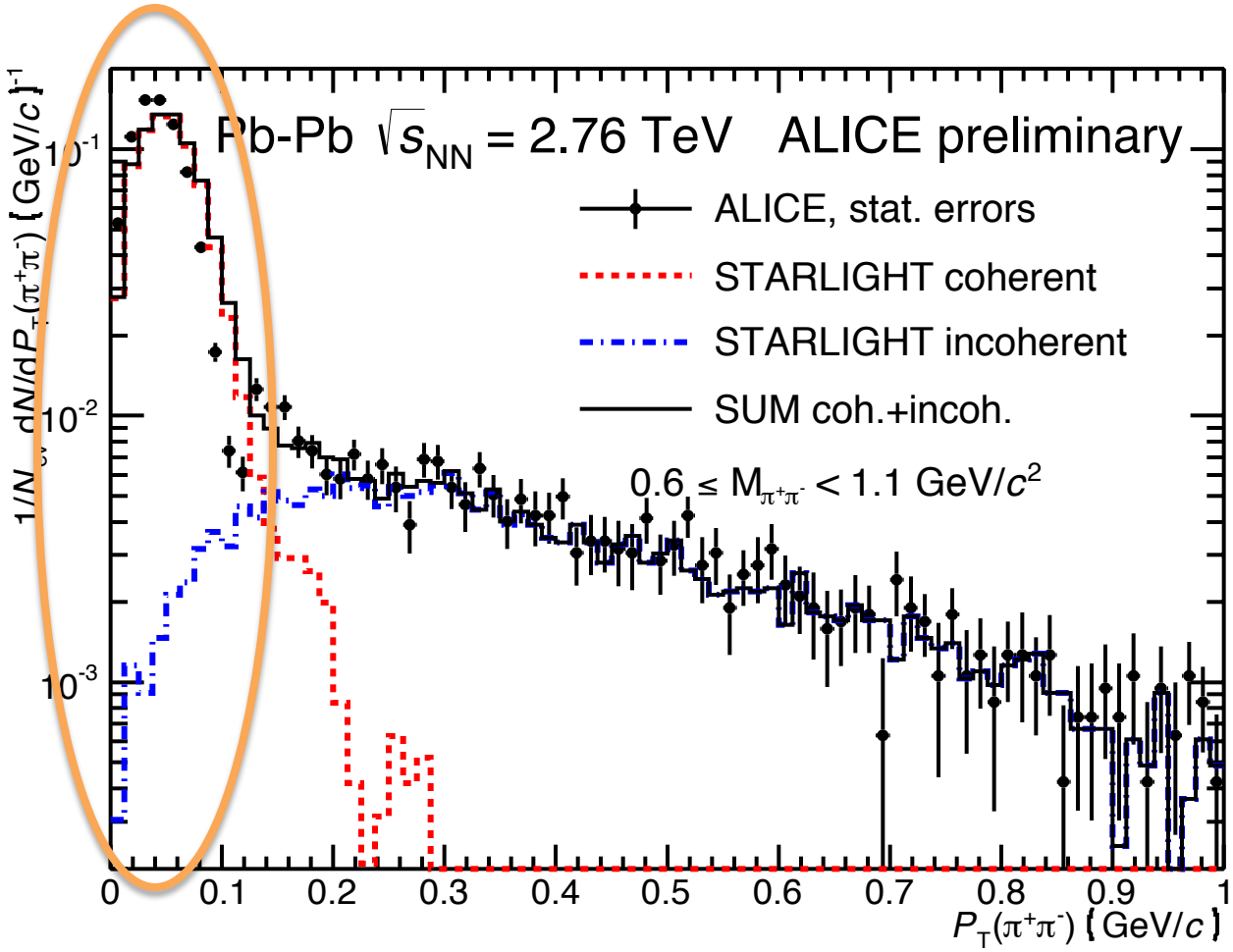
2011: High luminosity, measurement to higher masses possible




A LO QED calculation (STARLIGHT) describes the data
Strong constraint on NLO contributions

# Coherent ρ production

- ✓ 2010 data
- ✓ Decay into $\pi^+\pi^-$
- ✓ Transverse momentum less than 150 MeV/c to reject incoherent (photon couples to a nucleon) contribution

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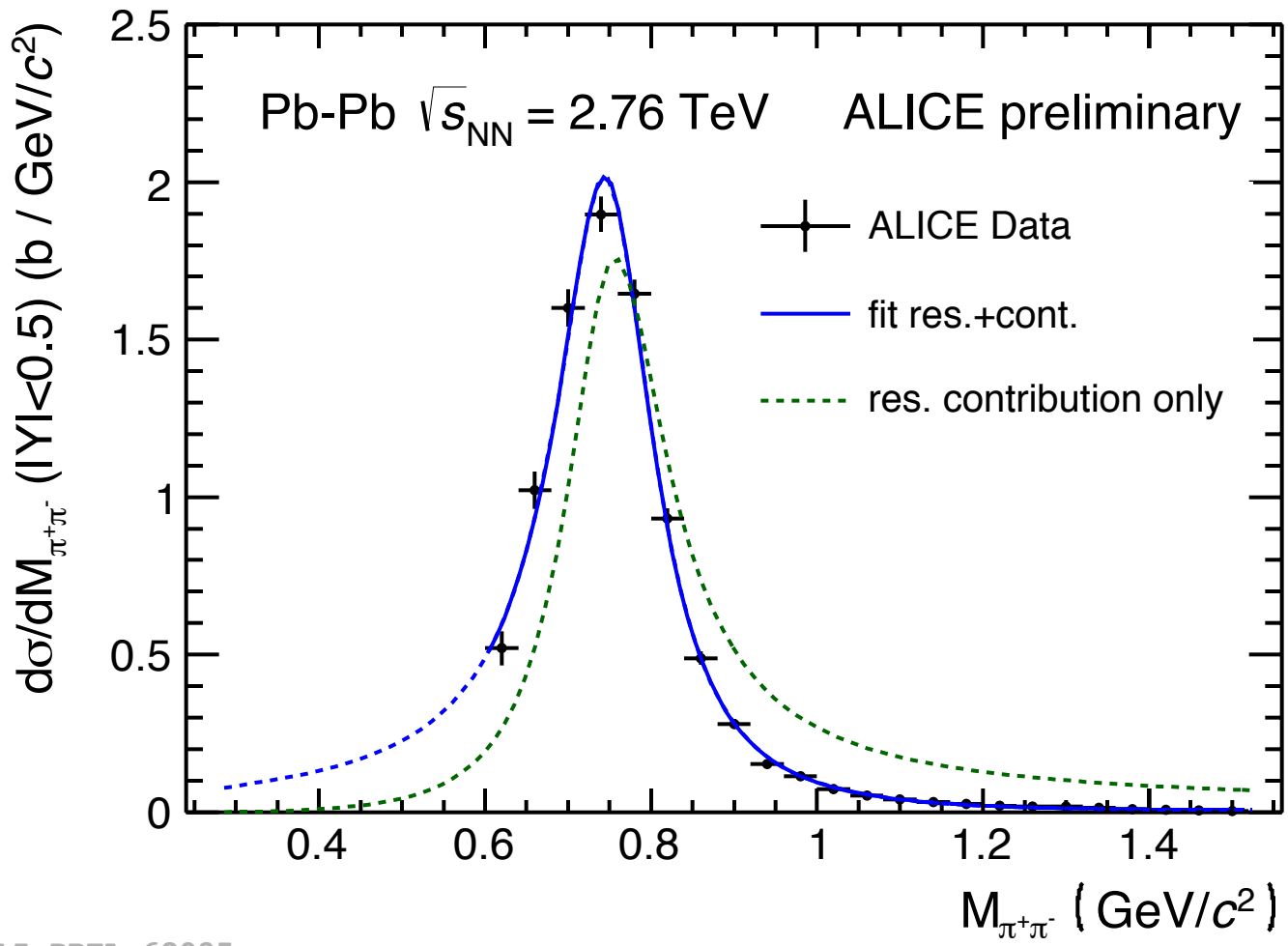
# Coherent ρ production: mass distribution

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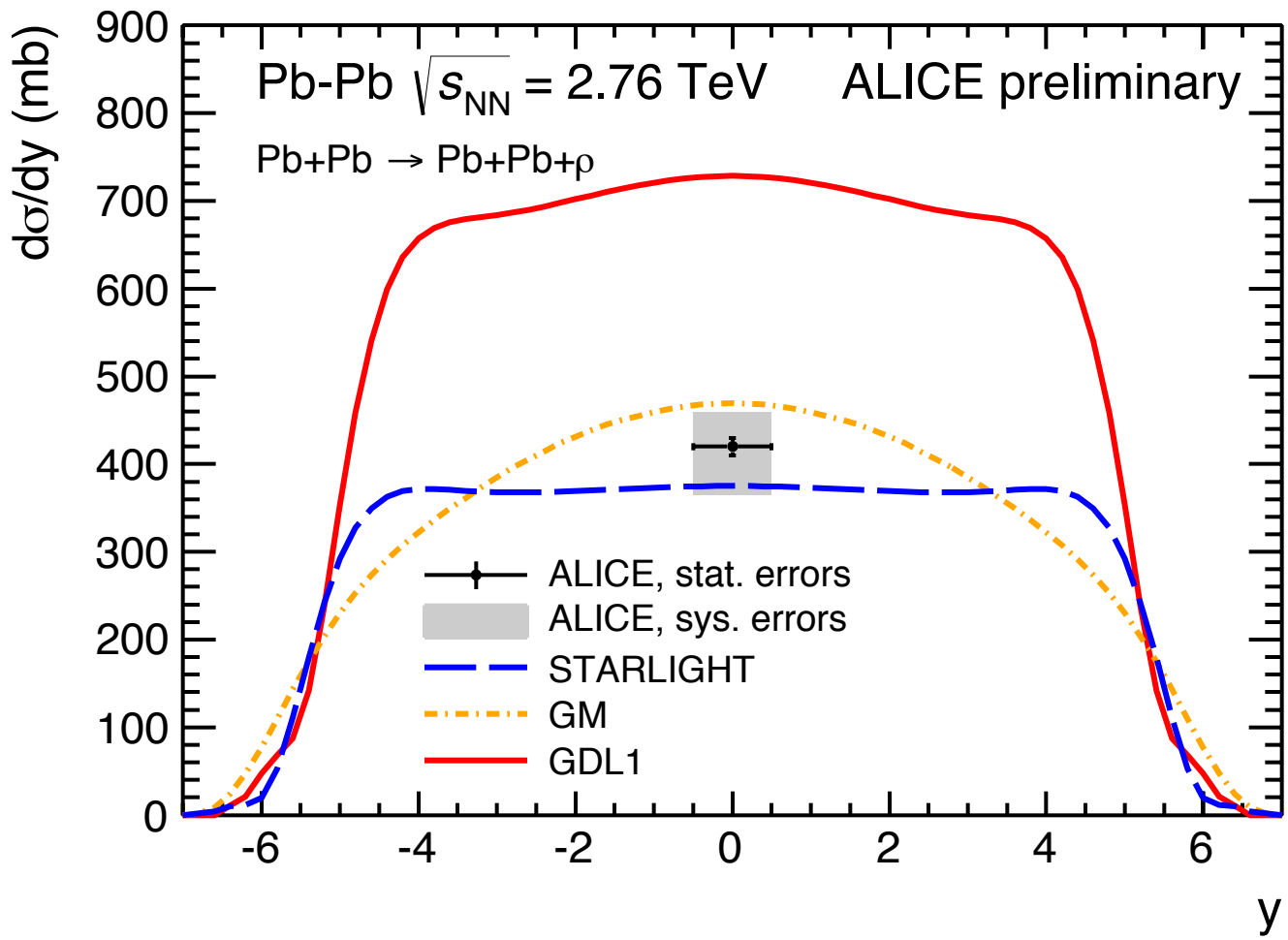
# Coherent ρ production: cross section

L. Frankfurt, M. Strikman, M. Zhalov (GDL1): QM Glauber + DL fit to HERA data

V.P. Gonçalves, M.V.T. Machado (GM): Color dipole model with CGC-like saturation

S.R. Klein, J. Nystrand (STARLIGHT): Classical Glauber model + fit to HERA data

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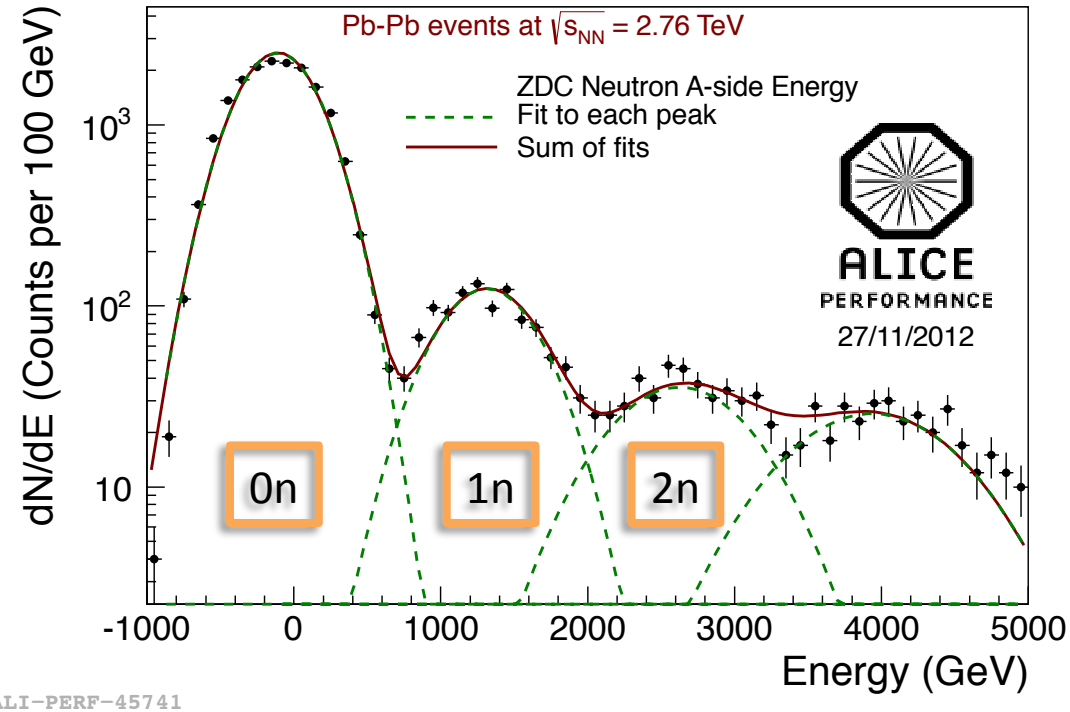
# Coherent ρ production: nuclear break-up

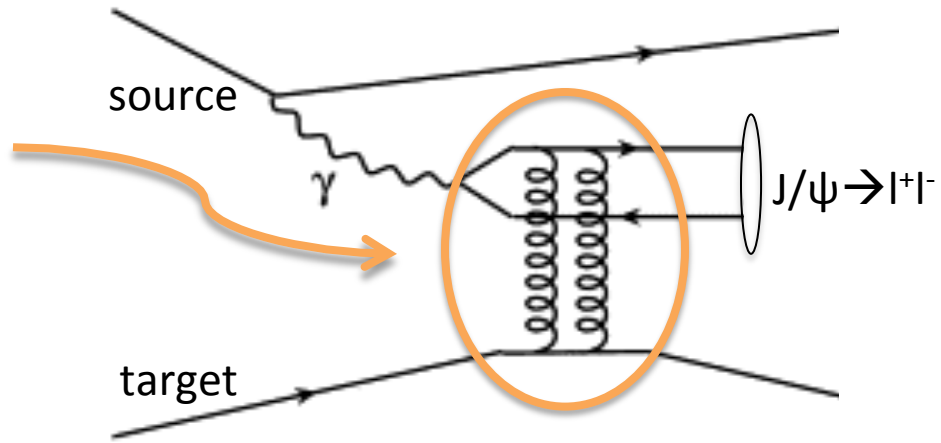
- ✓ Independent photon interactions break up the nuclei
- ✓ Forward neutrons emitted and measured by the ZDC
- ✓ Cases:
  none of the nuclei breaks up (0N0N)
  at least one nucleus breaks up (XN)



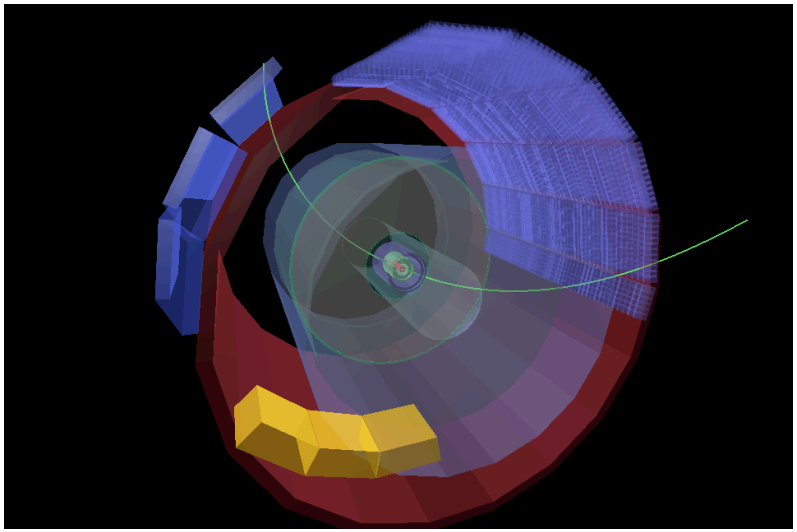

| Case | ALICE (%) | STARLIGHT | GDL1 |
|---|---|---|---|
| 0N0N | **84.7±0.4(stat)+0.4/-1.9 (sys)** | 79% | 84% |
| XN | **16.1+0.4(stat)+2.2/-0.5(sys)** | 21% | 16% |

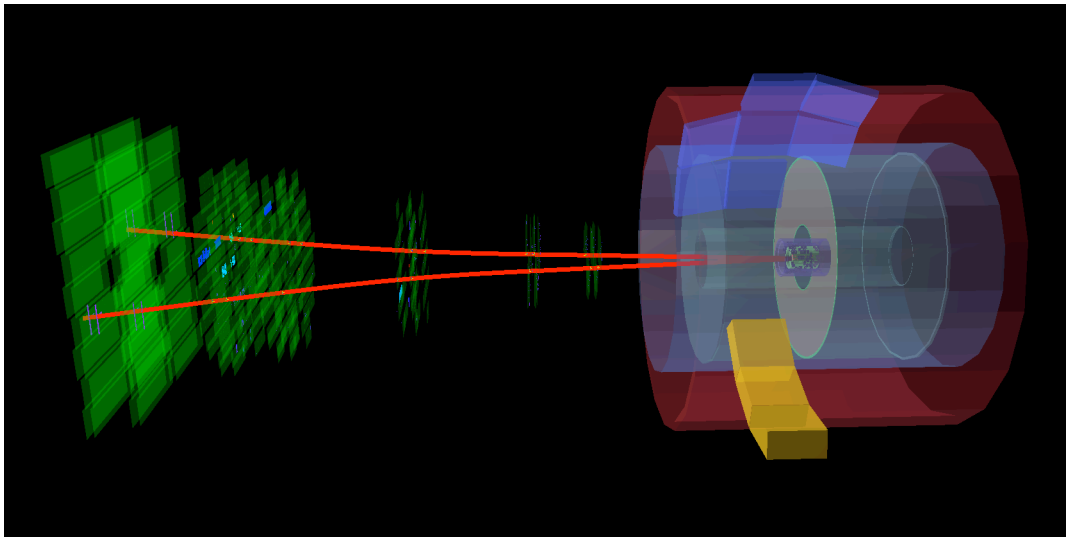
# Coherent and incoherent J/ψ production

- ✓ Mass of J/ψ serves as a hard scale for pQCD calculations, which at LO sample the **square** of the gluon distribution of the target
- ✓ J/ψ rapidity maps the photon-target center of mass energy and hence x-Bjorken



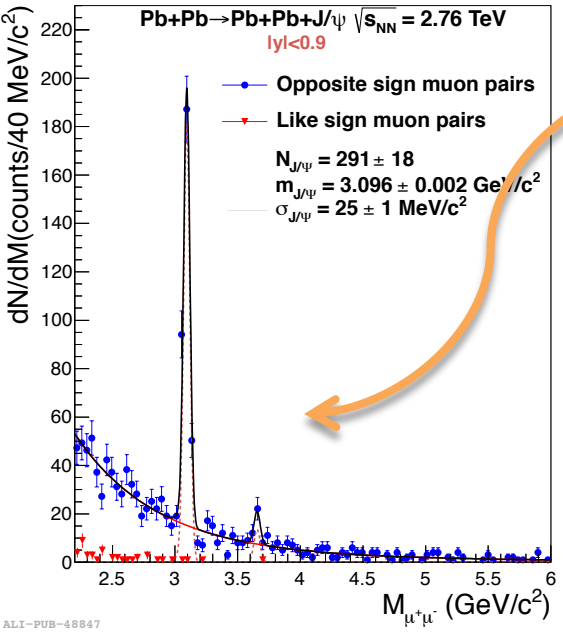

- ✓ J/ψ identified in the leptonic decay channel: $\mu^+\mu^-$ (forward and central) $e^+e^-$ (central)



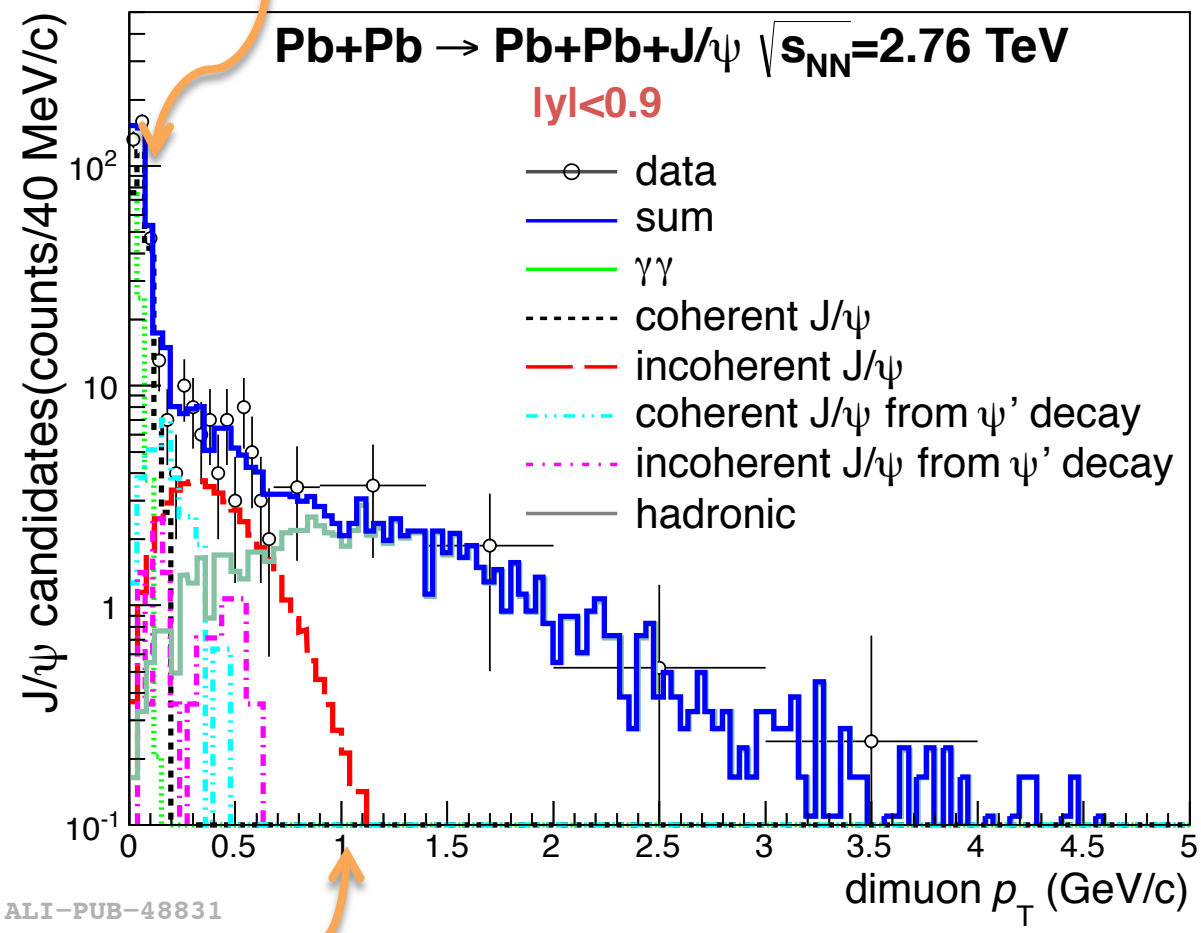


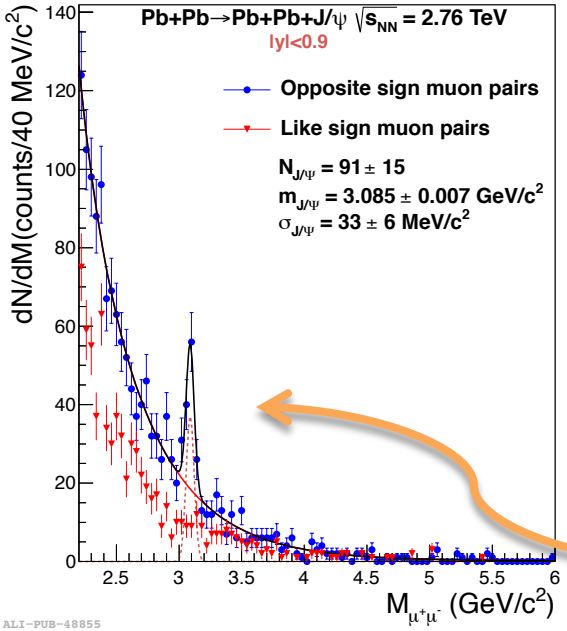
# Coherent and incoherent J/ψ production: mass and pt

Muon channel central barrel




Coherent ($p_T$<0.2GeV)




Incoherent ($p_T$>0.2GeV)

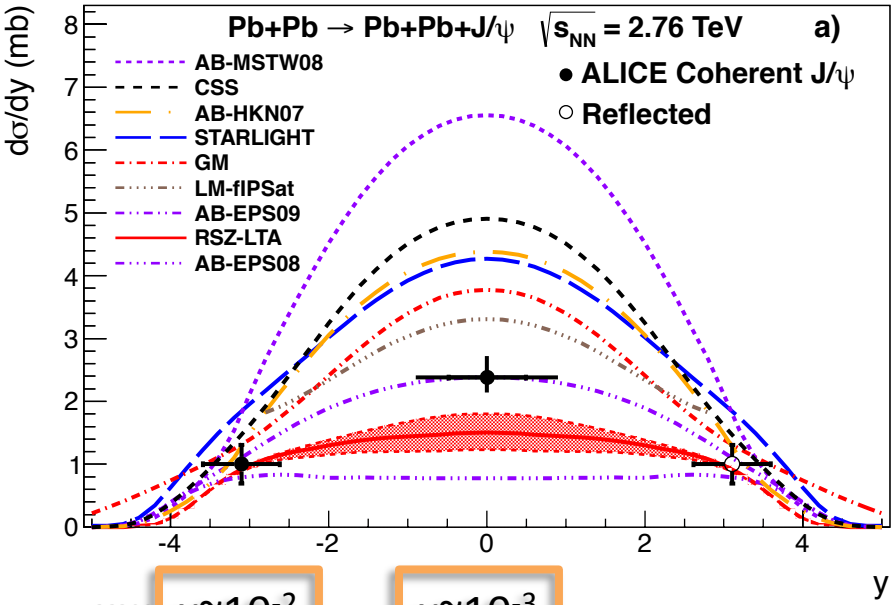
# Coherent and incoherent J/ψ production: cross sections

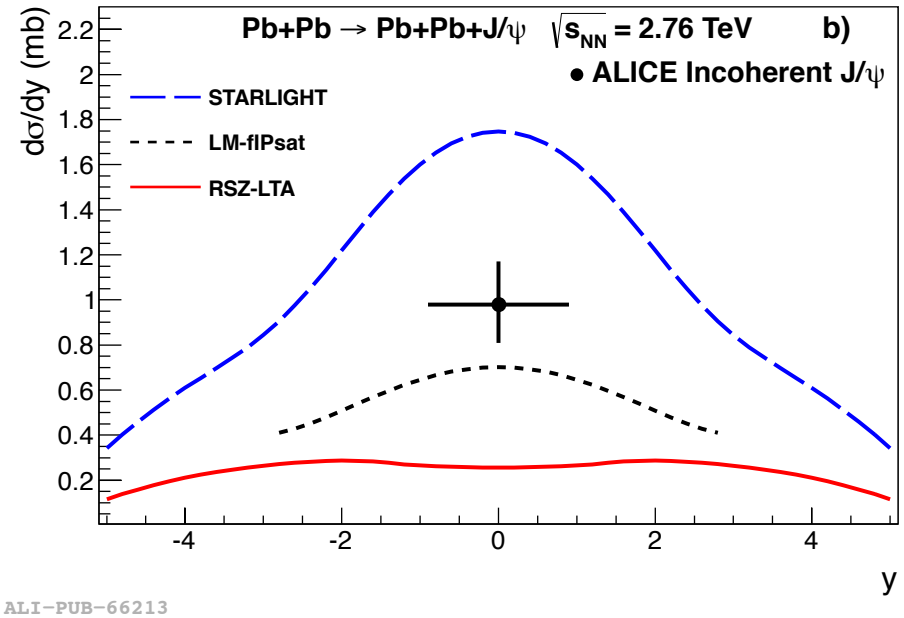
ALICE: Phys.Lett. B718 (2013) 1273-1283 and Eur. Phys. J. C (2013) 73:2617

L. Frankfurt, M. Strikman, M. Zhalov (GDL1): QM Glauber + DL fit to HERA data

T. Lappi, H. Mäntysaari : color dipole model with saturation + Glauber

S.R. Klein, J. Nystrand (STARLIGHT): Classical Glauber model + fit to HERA data




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

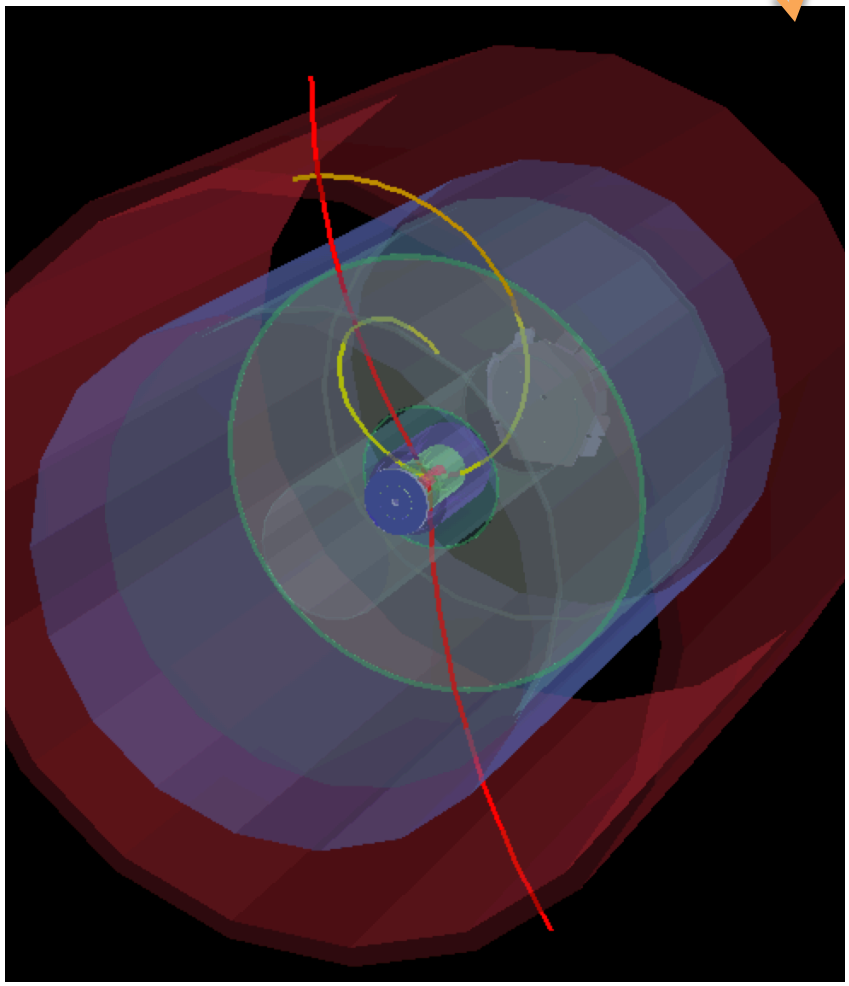
Cisek, Szczurek, Schäfer (CSS): Color dipole model with unintegrated gluon distribution

V.P. Gonçalves, M.V.T. Machado (GM): Color dipole model with CGC-like saturation

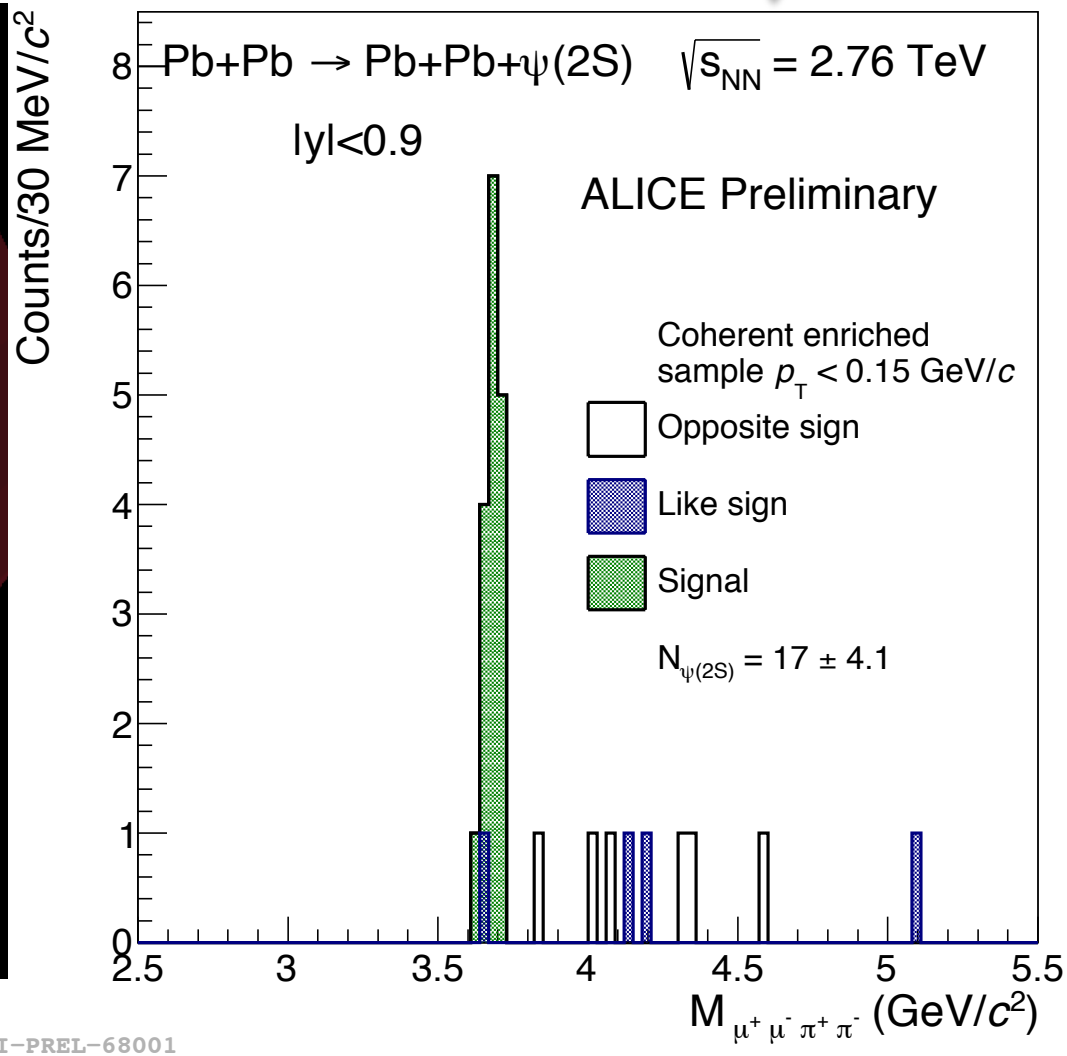
Adeluyi and Bertulani, (AB): LO pQCD + K-factor + nuclear PDFs

# Coherent ψ(2s) production

- ✓ Measured decay channels:
  $\psi(2s) \rightarrow l^+l^-$ and $\psi(2s) \rightarrow J/\psi\pi^+\pi^-$



- ✓ Few signal events
  Almost no background

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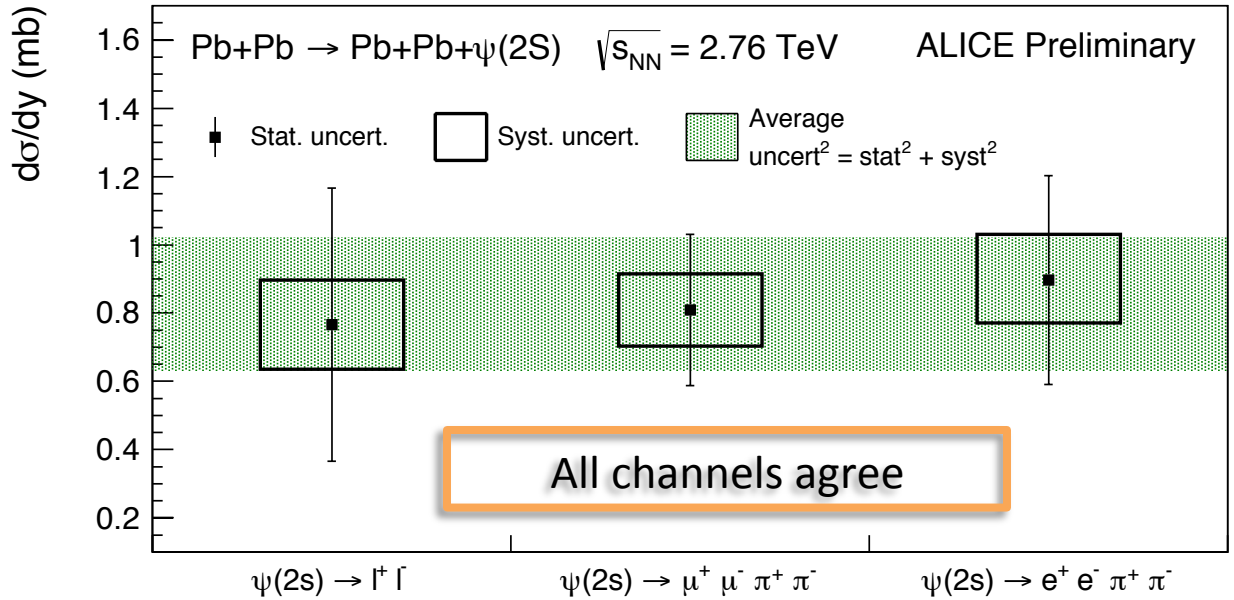
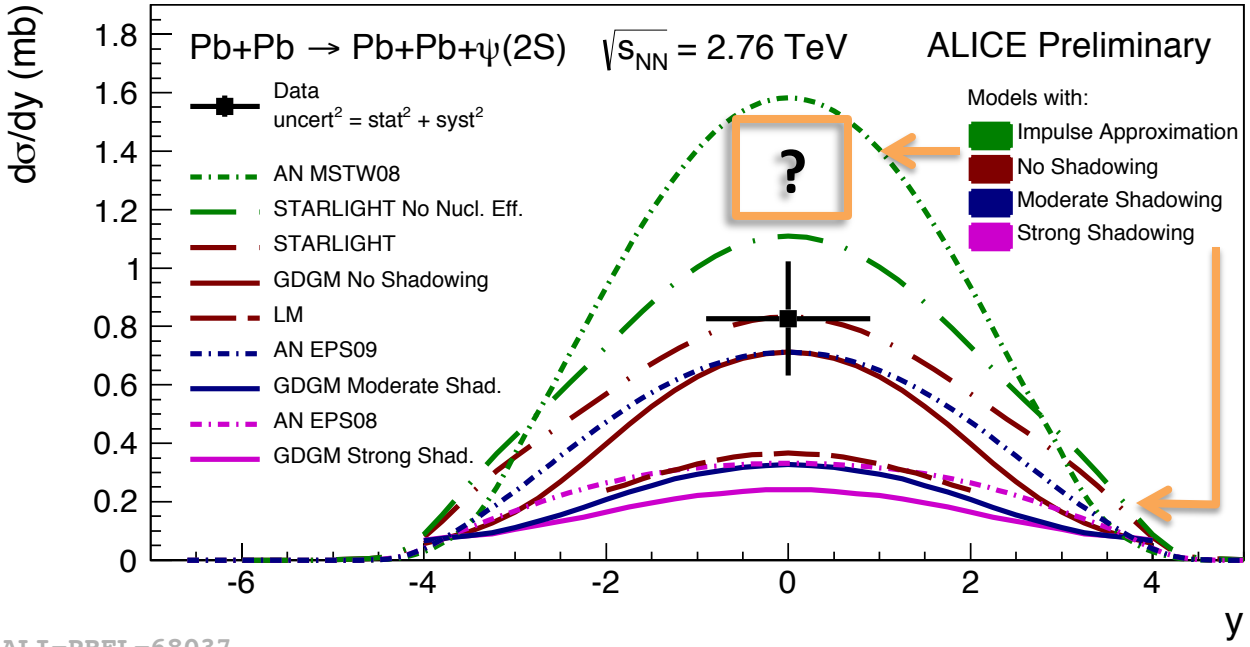
# Coherent ψ(2s) production: cross section

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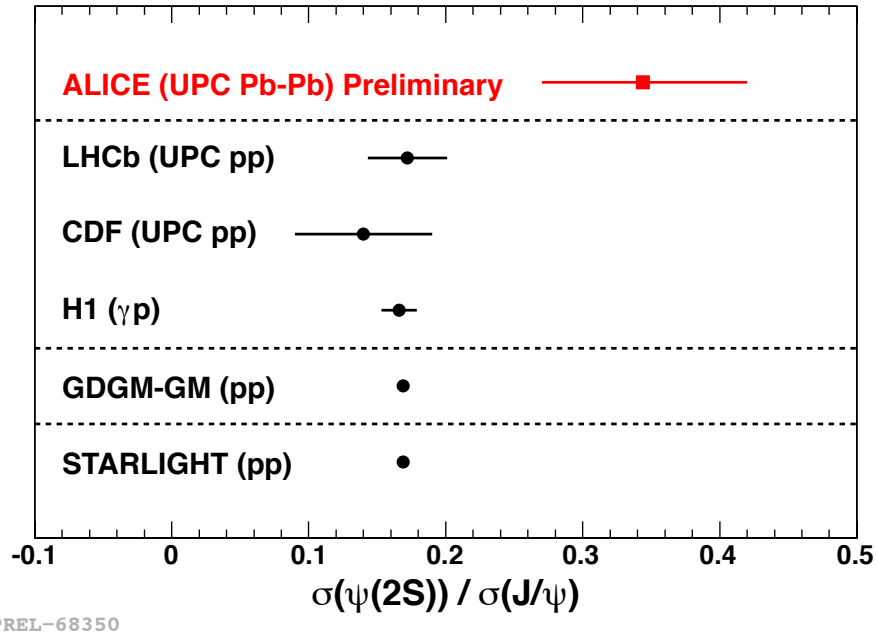
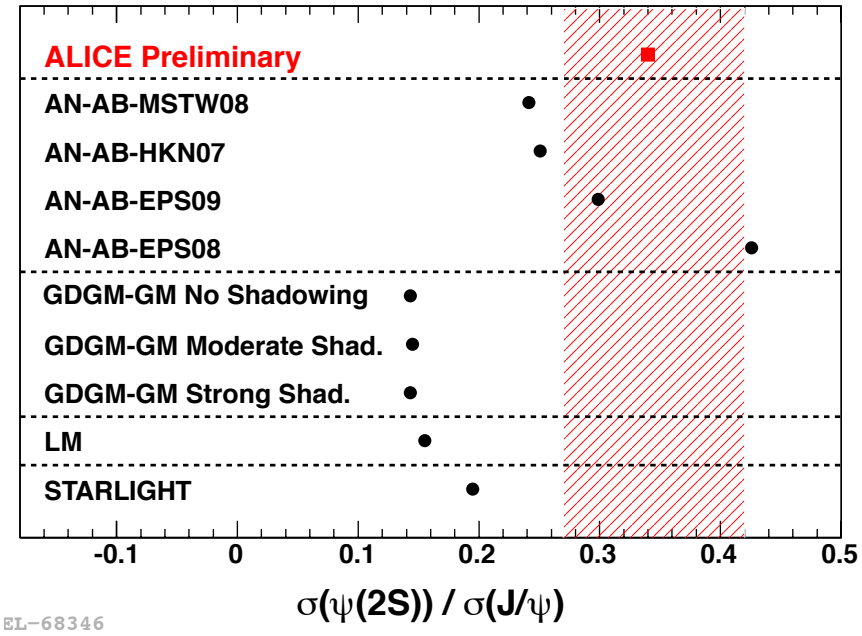
# Coherent ψ(2s) production: ratio to J/ψ

- ✓ The slight difference in photon fluxes and energy scales for the two states largely cancel in the ratio
- ✓ Ratio in nuclei seems to be larger than in proton … but experimental uncertainties are still large …
- ✓ AB shows a large dependence in the nuclear structure function. Other models agree among themselves but predict a smaller ratio
- ✓ The normalization to photo production off protons seems to be different in AB than in STARLIGHT




Do nuclear effects affect differently 1S and 2S states?

# UPC measurements in p-Pb

# Exclusive J/ψ production in p-Pb

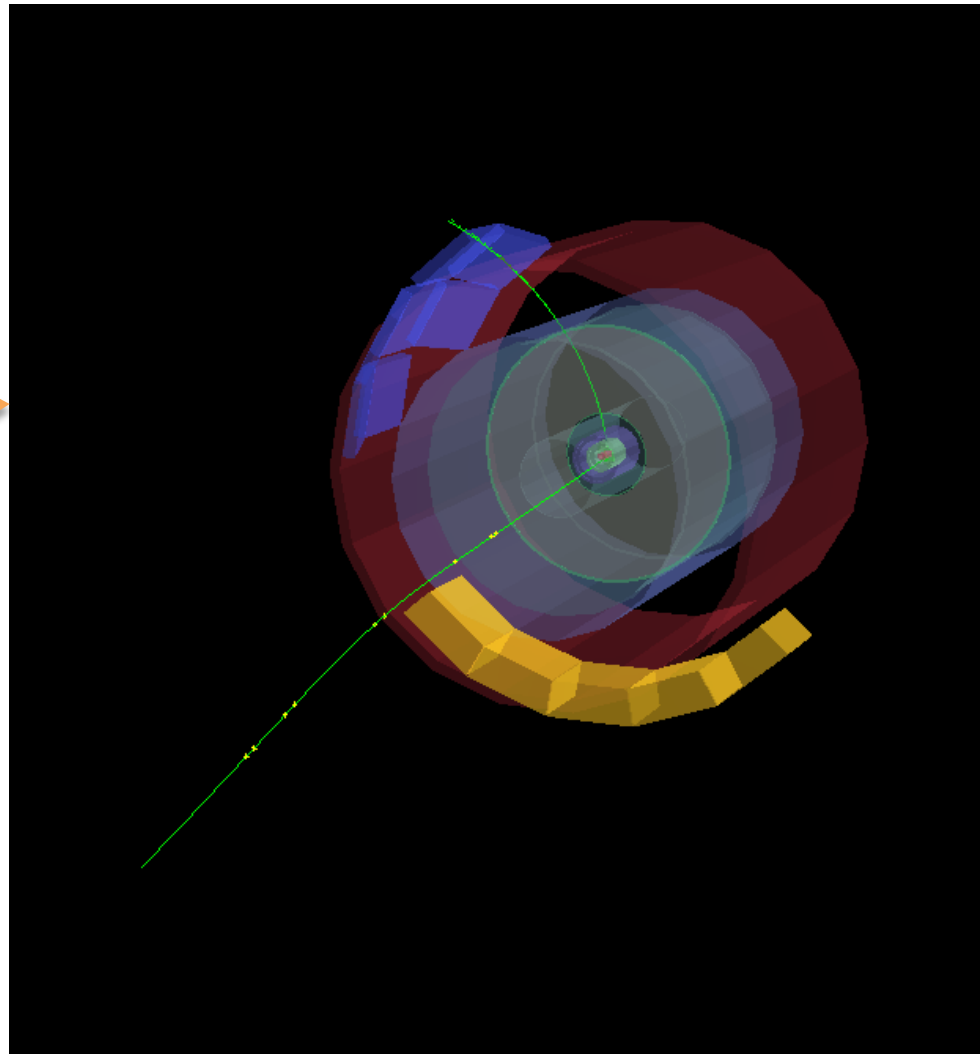
- ✓ In p-Pb the photon source is known: it is the lead ion in > 95% of the cases
  → rapidity of the J/ψ measures $W_{\gamma p}$
  ($W_{\gamma p}$ = center of mass energy of γp)

- ✓ LHC ran in p-Pb and Pb-p modes
  → large range of $W_{\gamma p}$ available in ALICE

Mid rapidity:
$W_{\gamma p}$ = 100-250 GeV
→ HERA range

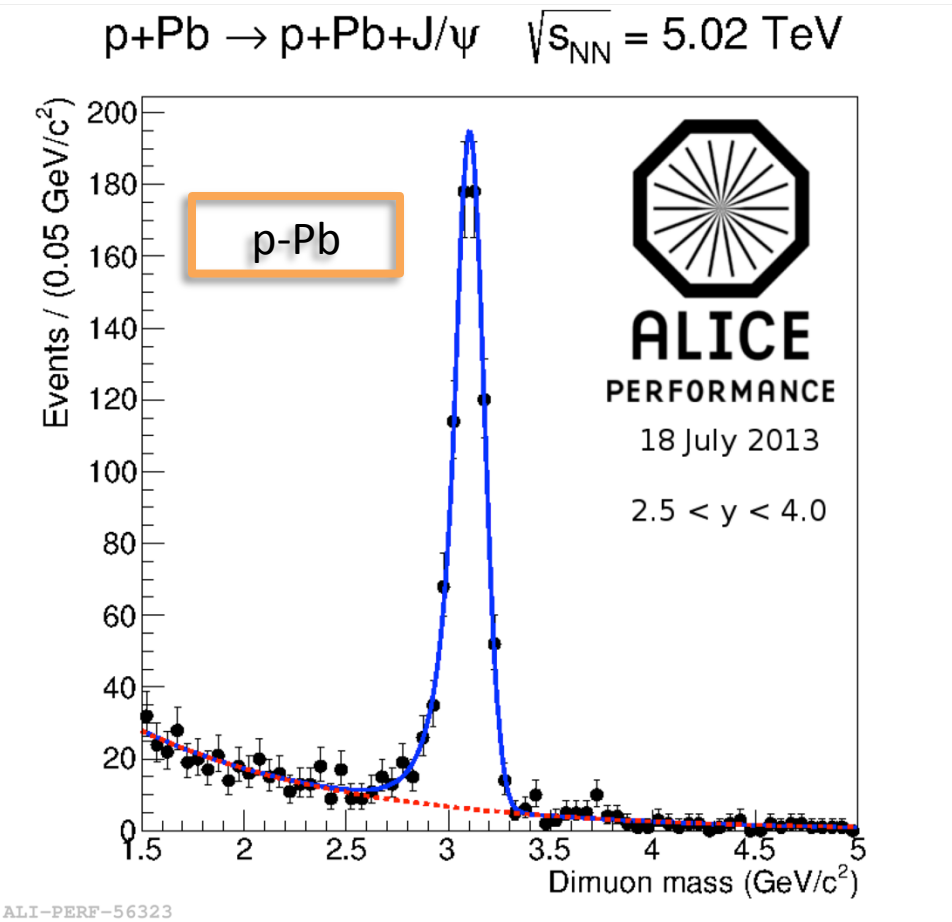
Semi-forward:
One trk fwd another central
$W_{\gamma p}$ = 45-80 GeV (p-Pb)
→ HERA range
$W_{\gamma p}$ = 300-550 GeV (Pb-p)
→ beyond the reach of HERA

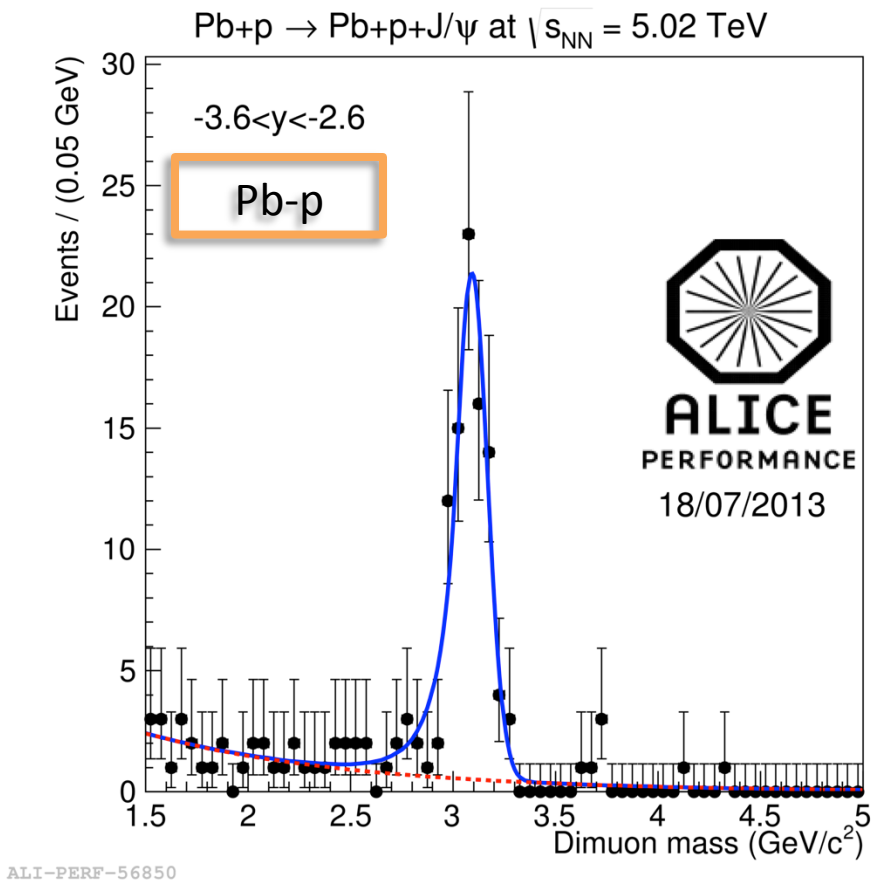
Forward:
$W_{\gamma p}$ = 20-45 GeV (p-Pb)
→ HERA range
$W_{\gamma p}$ = 550-1100 GeV (Pb-p)
→ beyond the reach of HERA



The following results are from the forward sample

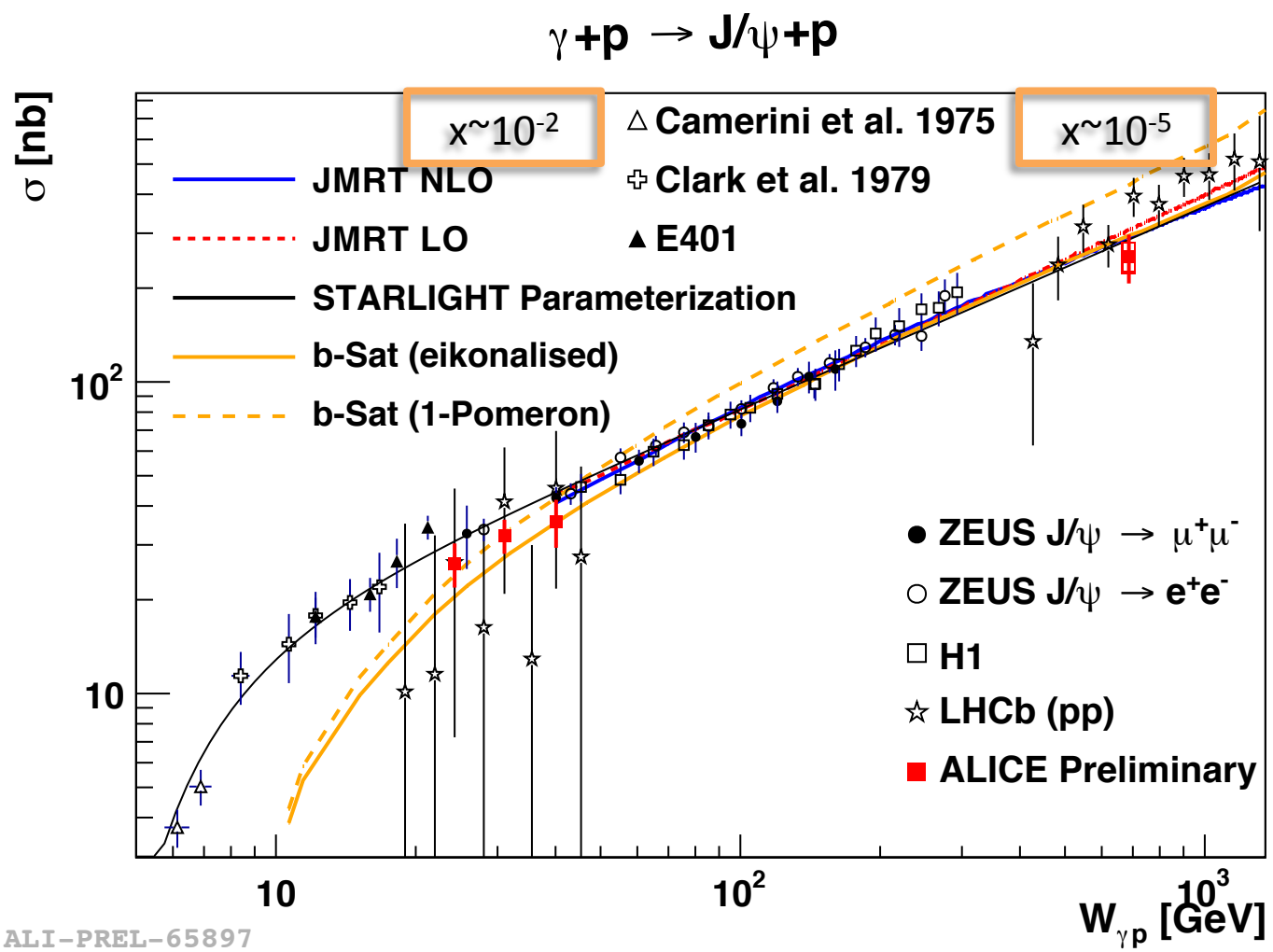
# Exclusive J/ψ production in p-Pb: mass




Clean signals, small background

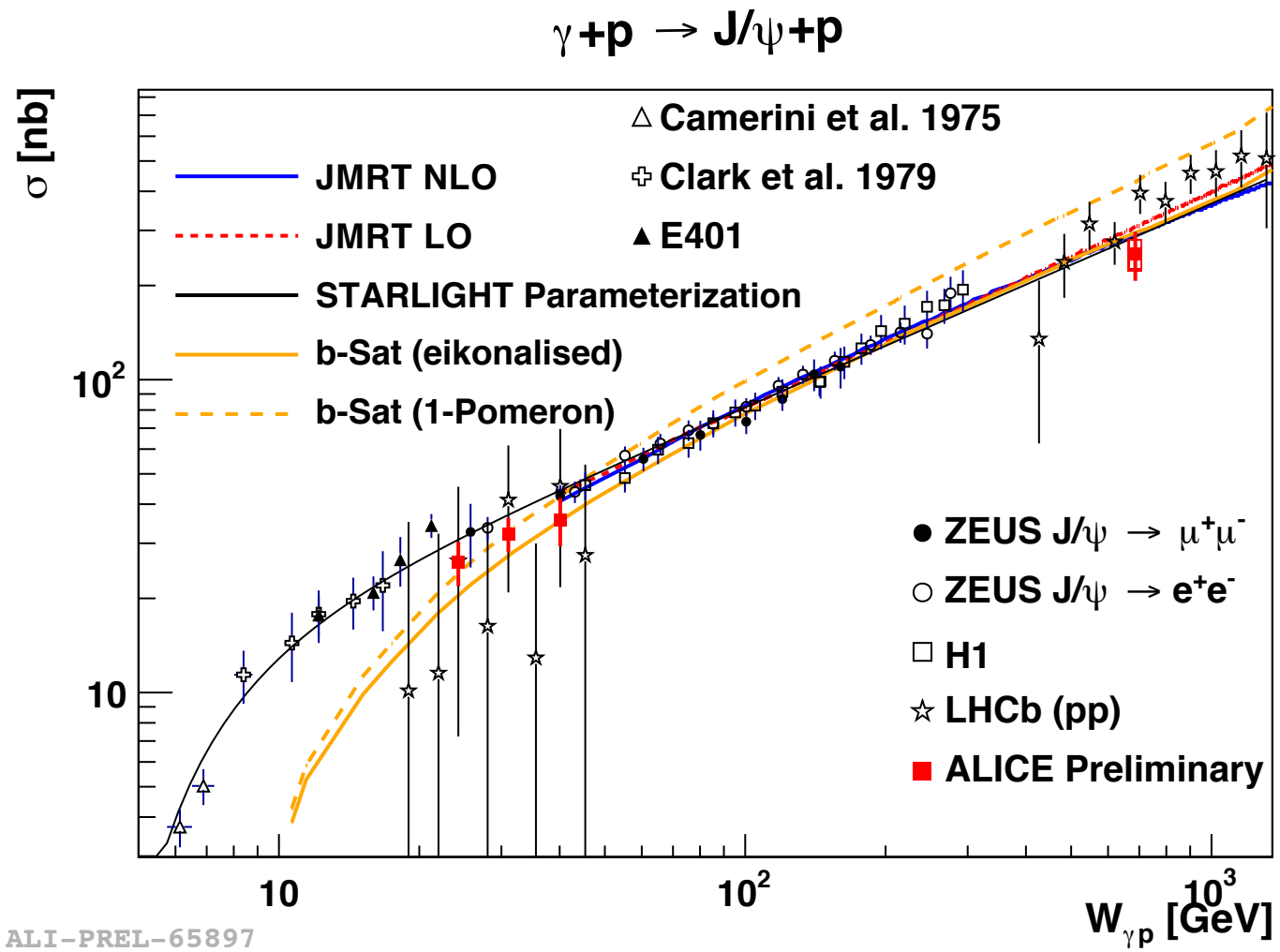
# Exclusive J/ψ production in p-Pb: cross sections




- ✓ 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)

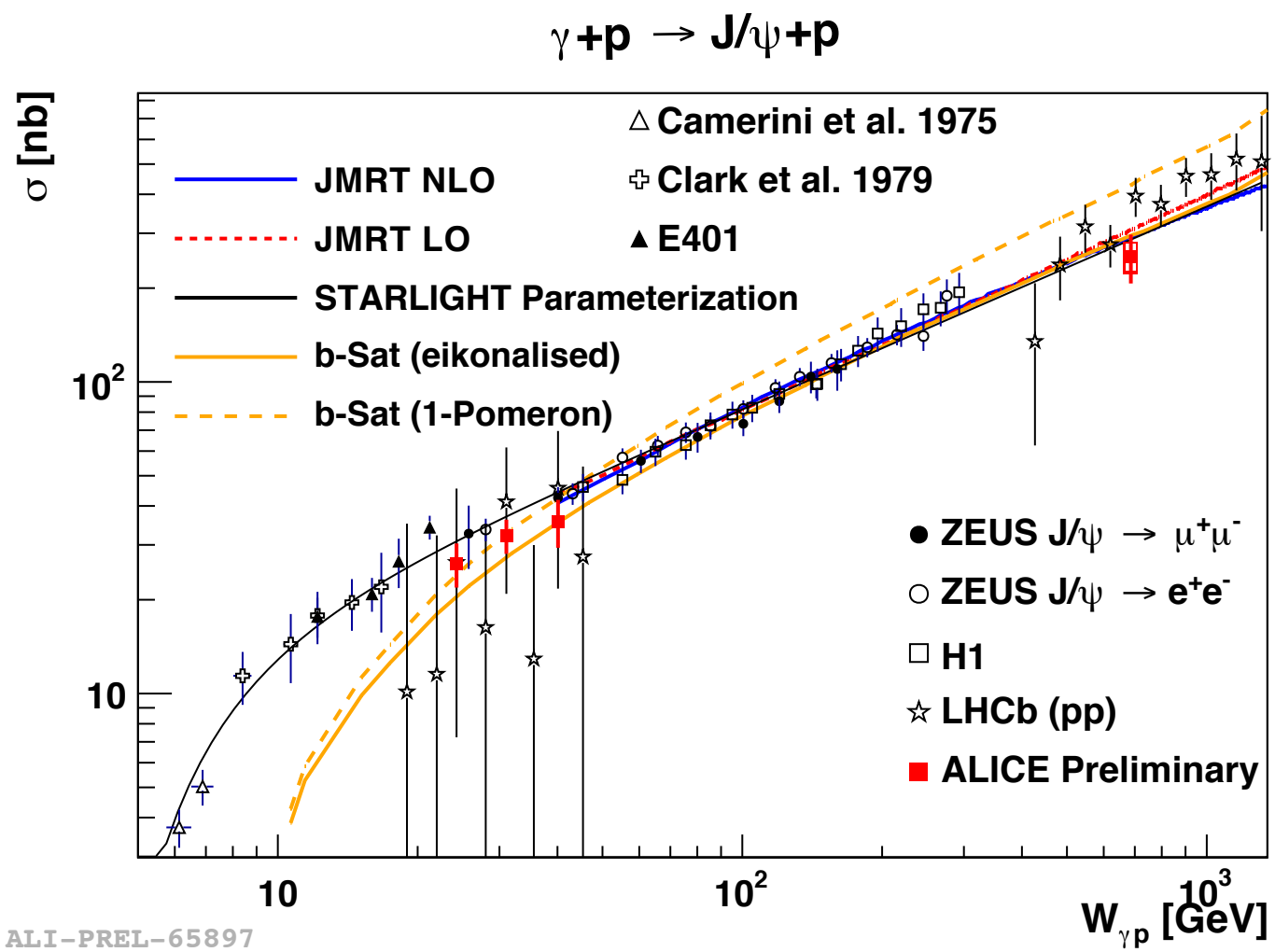
No change in the behavior of the gluon PDF observed from HERA to LHC

# Exclusive J/ψ production in p-Pb: JMRT models



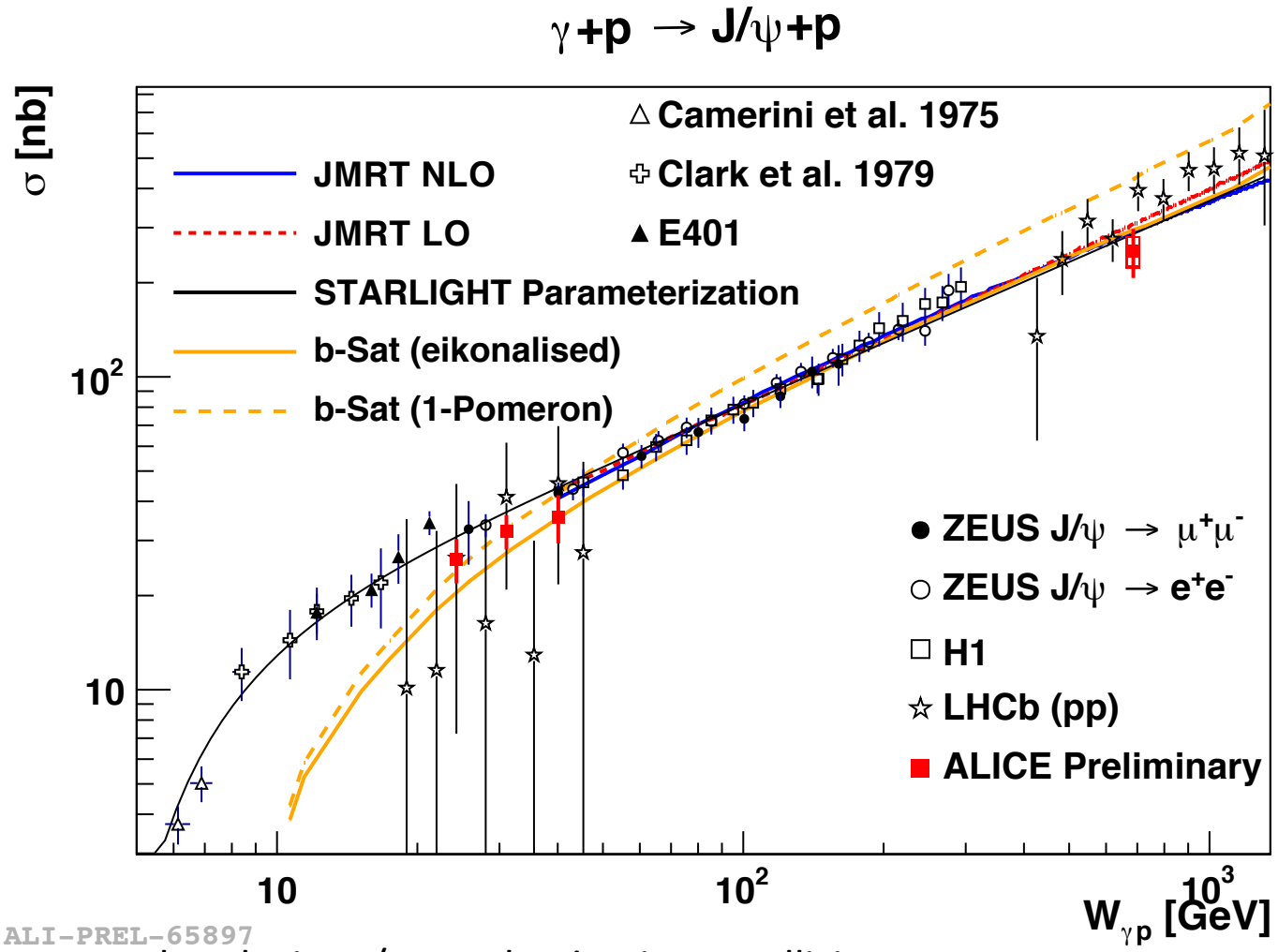

- ✓ LO model based on a power law. NLO model includes the expected main NLO contributions (S. Jones, A. Martin, M. Ryskin, and T. Teubner, (2013), arXiv1307.7099 )
- ✓ Both versions of the model fitted independently to the same set of data

# Exclusive J/ψ production in p-Pb: b-Sat models




- ✓ b-Sat (eikonalised) includes b-dependent saturation effects based on a CGC inspired model
- ✓ Quality of agreement to data similar to JMRT and STARLIGHT predictions

# Exclusive J/ψ production in p-Pb: LHCb solutions




✓ LHCb measured exclusive J/ψ production in pp collisions.
Extraction of result in γp not trivial and model dependent
See discussion in R. Aaij et al. (LHCb collaboration), J.Phys. G40, 045001(2013)
→ for each pp measurement, two γp solutions

# Outlook

# Prospects for studies of UPC in ALICE

- ✓ Very short term
  - ✓ Submit papers for the preliminary results presented here

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

- ✓ Medium term (LHC Run2)
  - ✓ 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

- ✓ ALICE has presented first results on di-lepton and vector meson production in UPC at the LHC using Pb-Pb and p-Pb interactions
- ✓ New results on J/ψ production 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!**