Vector meson photo-production in ultra-peripheral p-Pb and Pb-Pb collisions at the LHC with ALICE

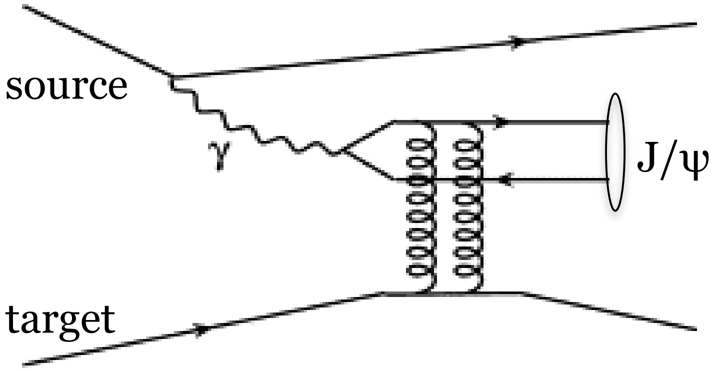
Michal Broz

Czech Technical University in Prague

On behalf of the ALICE Collaboration

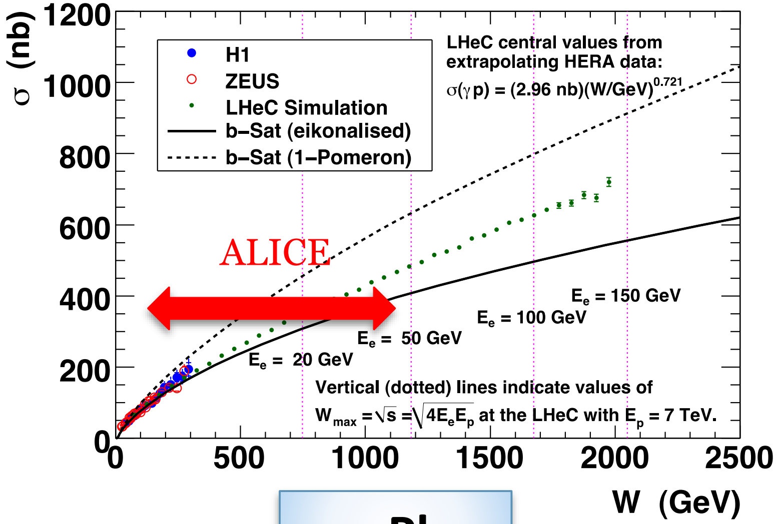
Ultra-peripheral collisions

- Ultra-peripheral collision = Impact parameter larger than sum of nuclear radii
- The EM field of protons and ions can be viewed as a beam of quasi real photons (intensity ≈ Z^2)
- 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
- ALICE is using LHC as a photon-hadron collider!
- Charmonium photo-production permits us to study perturbatively non linear effects at low x in the gluon distribution of the target (key words: shadowing, saturation)



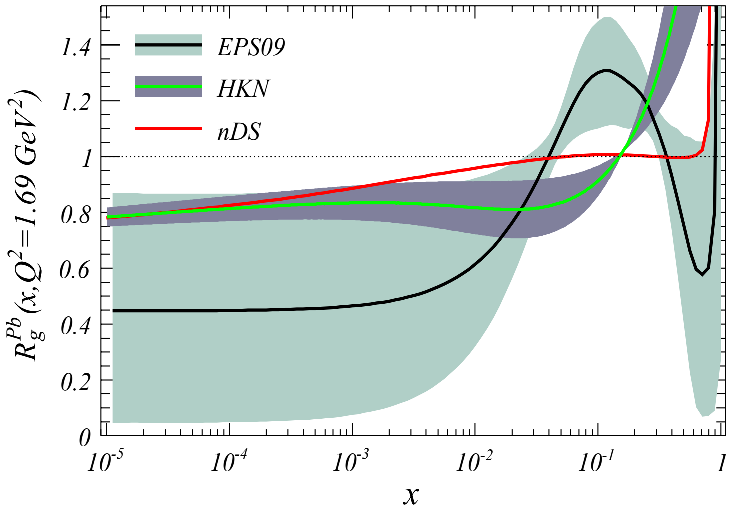
γp

LHeC Study group, ArXiv: 1211.4831



γ-Pb

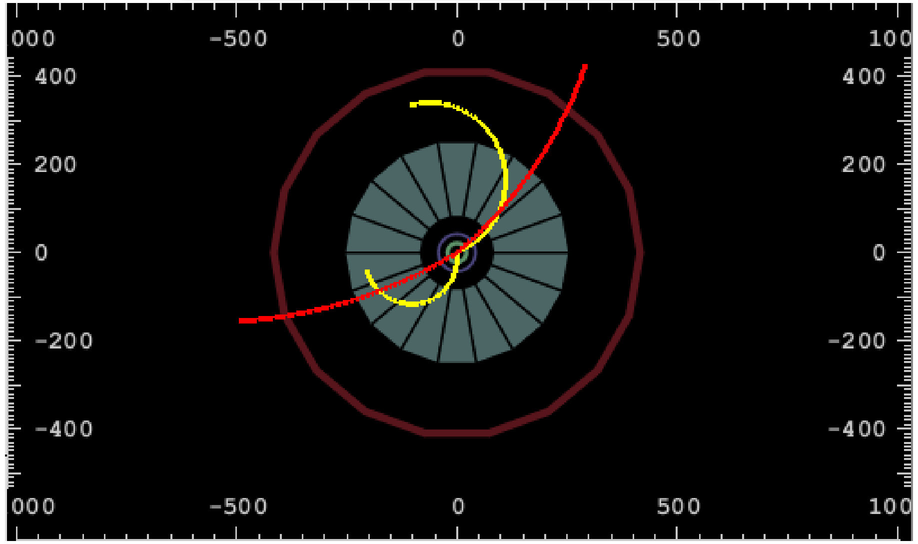
C. A. Salgado *et al* 2012 *J. Phys. G: Nucl. Part. Phys.* 39 015010



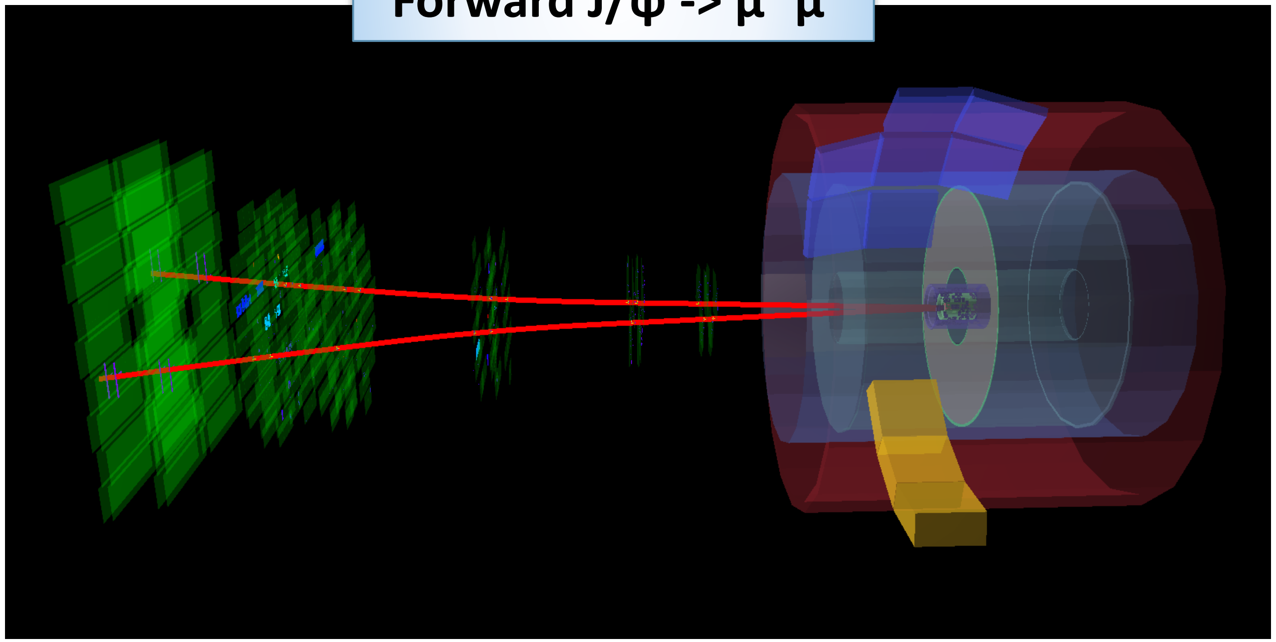
Ultra-peripheral collisions

- Very clean signature - two or four tracks in an otherwise empty detector
- Decay channels:
  - $\rho^0 \to \pi^+ \pi^-$
  - $J/\psi \to l^+ l^-$
  - $\psi(2S) \to l^+ l^-$
  - $\psi(2S) \to J/\psi\, \pi^+ \pi^-$

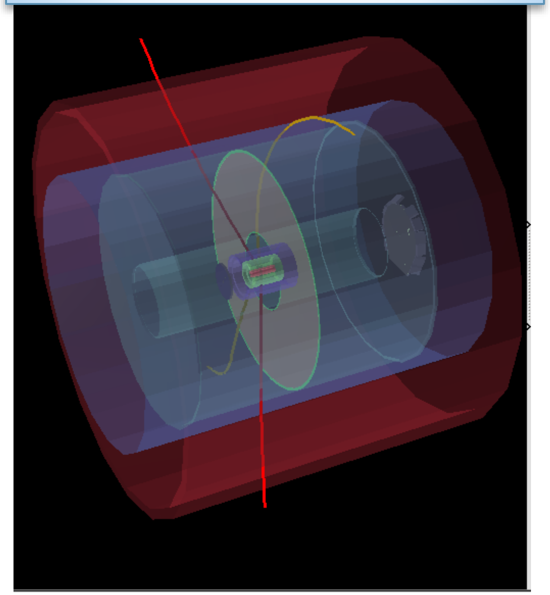
$\psi(2s) \to e^+ e^- + \pi^+ \pi^-$



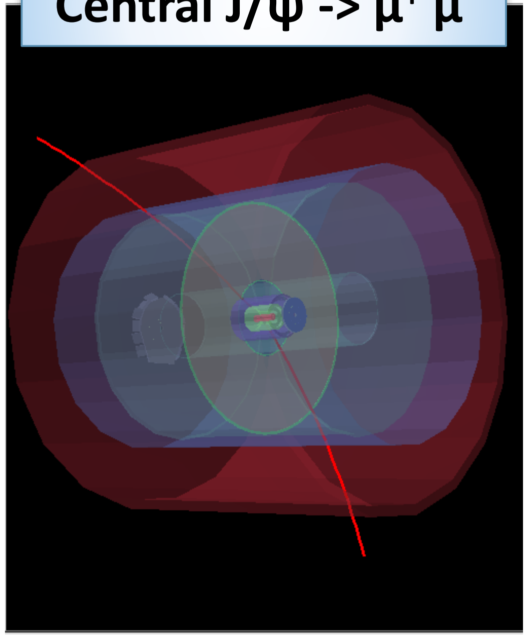
Forward $J/\psi \to \mu^+ \mu^-$



$\psi(2s) \to e^+ e^- + \pi^+ \pi^-$

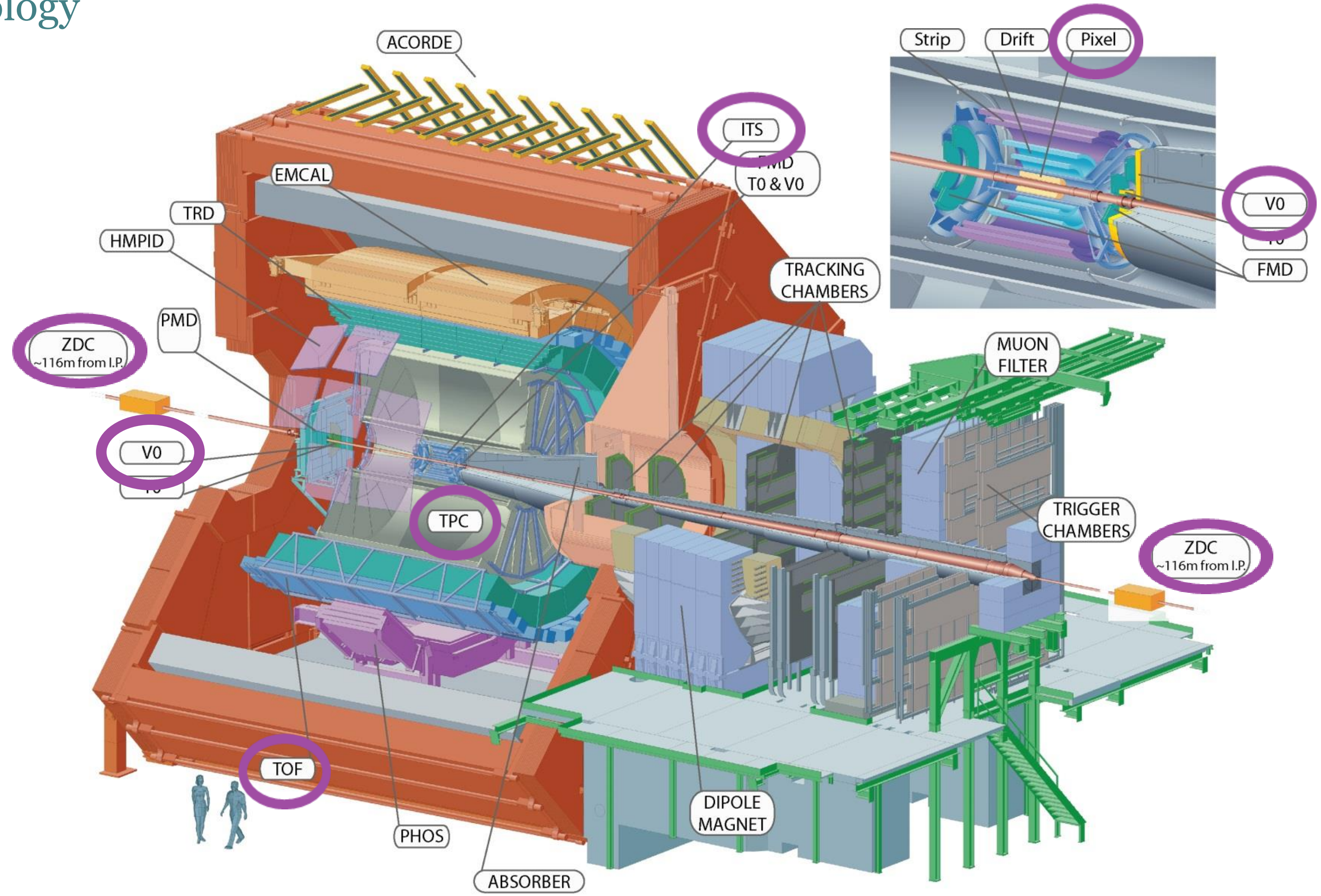


Central $J/\psi \to \mu^+ \mu^-$



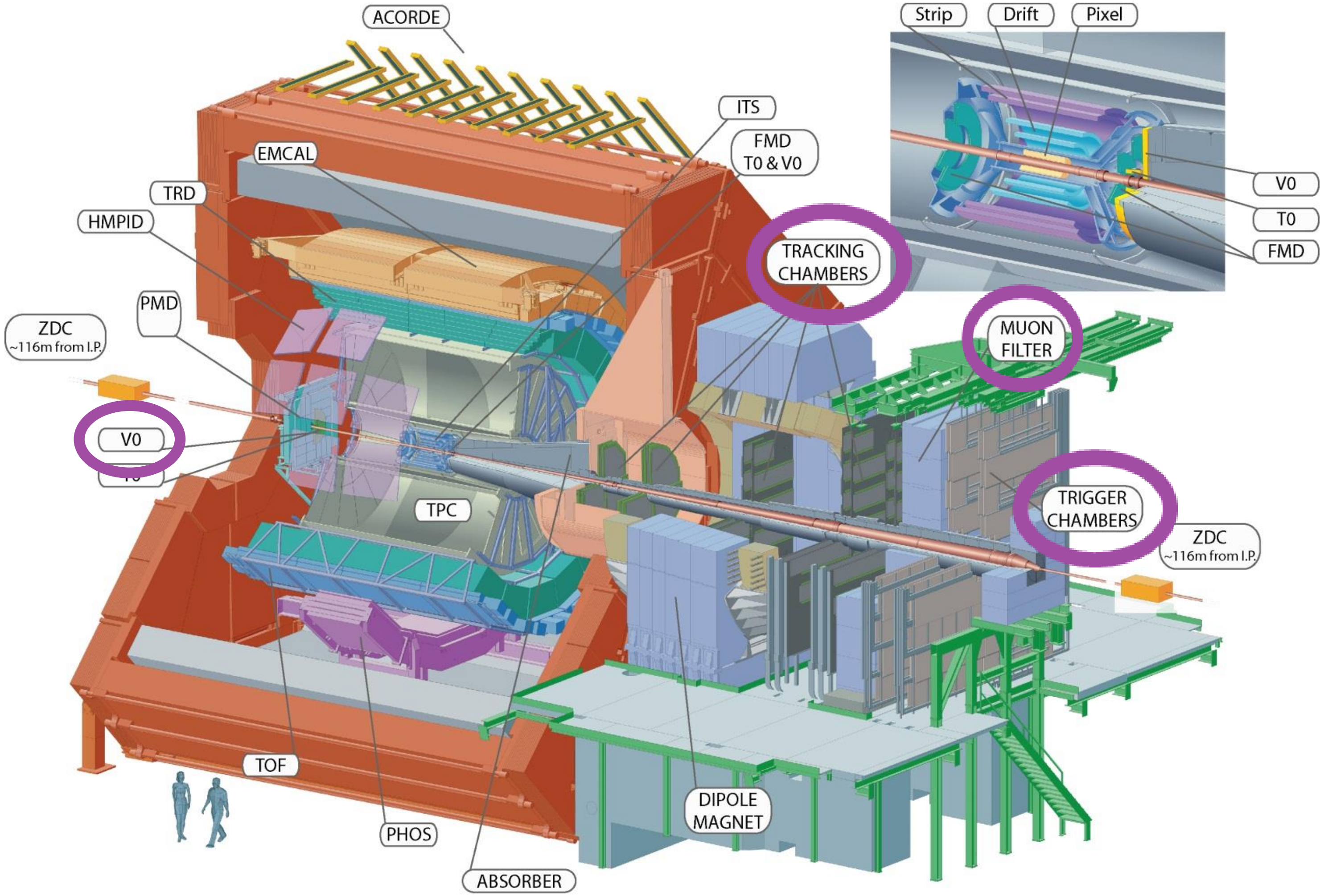
ALICE and UPC trigger

- Central barrel trigger on UPC
  - 2010: veto on V0, hits in SPD ≥ 2 , TOF hits ≥ 2
  - 2011: veto on V0, hits in SPD ≥ 2 , 2 ≤ TOF hits ≤ 6 with back-to-back topology
  - 2015: veto on V0, veto on AD, hits in SPD ≥ 4 with back-to-back topology / TOF hits ≤ 6 with back-to-back topology



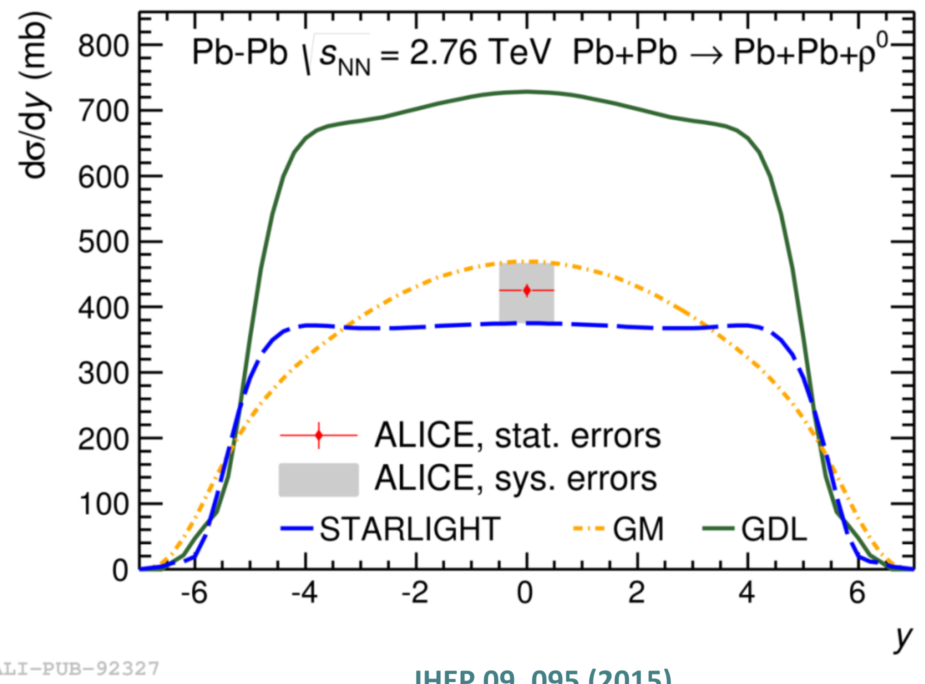
ALICE and UPC trigger

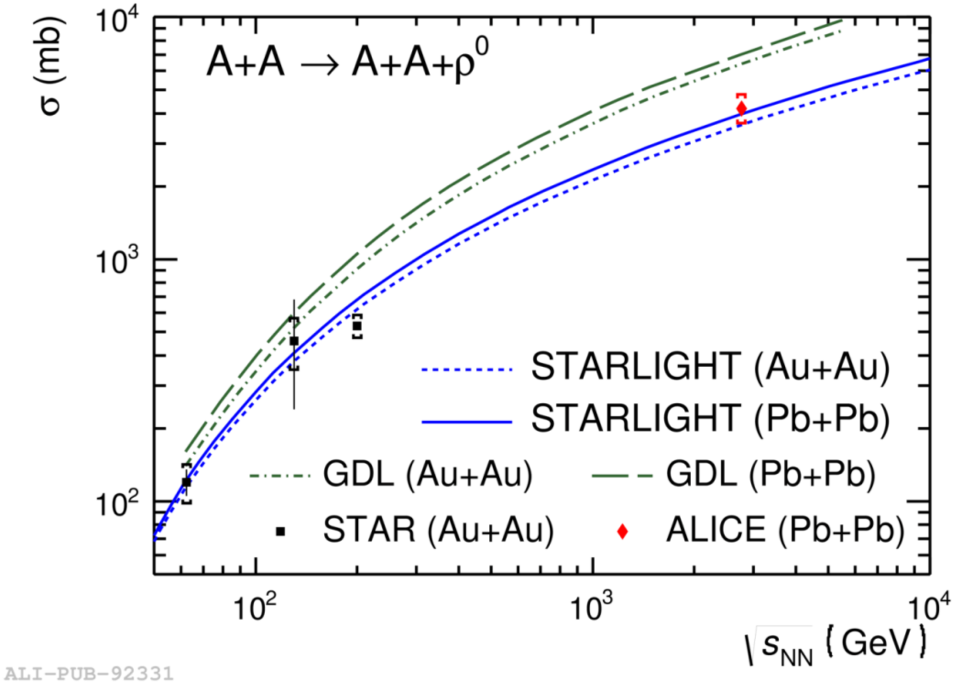
- Forward rapidity trigger on UPC
  - 2011: veto on V0-A , hits in V0-C , single muon with $p_T > 1$ GeV/c
  - 2013: veto on V0-A , hits in V0-C , di-muon, each with $p_T > 0.5$ GeV/c
  - 2015: veto on V0-A, veto on AD, di-muon, each with $p_T > 1$ GeV/c



ρ^0 in Pb-Pb central rapidity

- **2011 Pb-Pb data**
- Cross section obtained by integrating the resonance contribution over $[2m_\pi, M_\rho + 5\Gamma]$
- GDL: Proper QM Glauber calculation for scaling $\sigma(\gamma p) \Rightarrow \sigma(\gamma A)$
- GM: Based on the color dipole model with saturation implemented by the Color Glass Condensate formalism
- STARLIGHT: Scales the experimentally measured γp cross section using a Glauber model, neglecting the elastic nuclear cross section

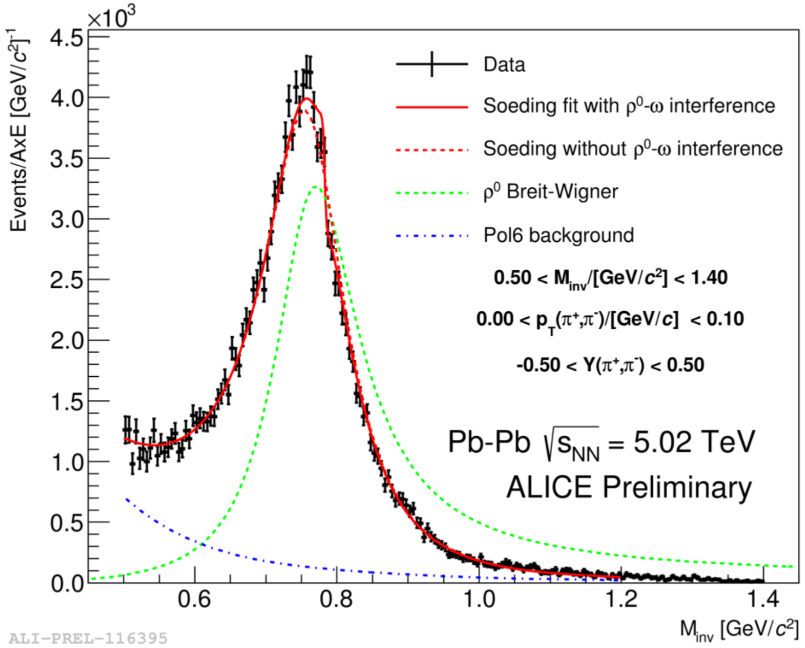


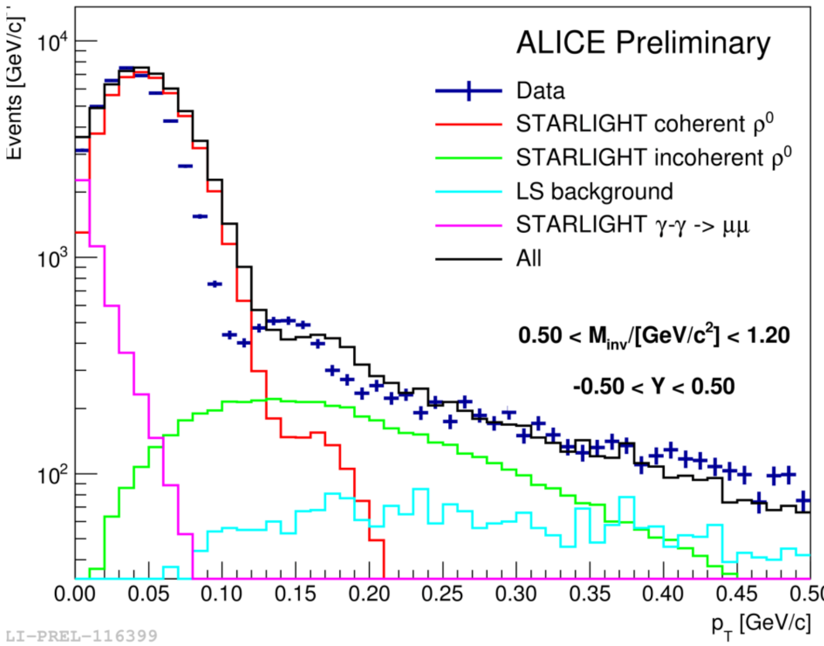


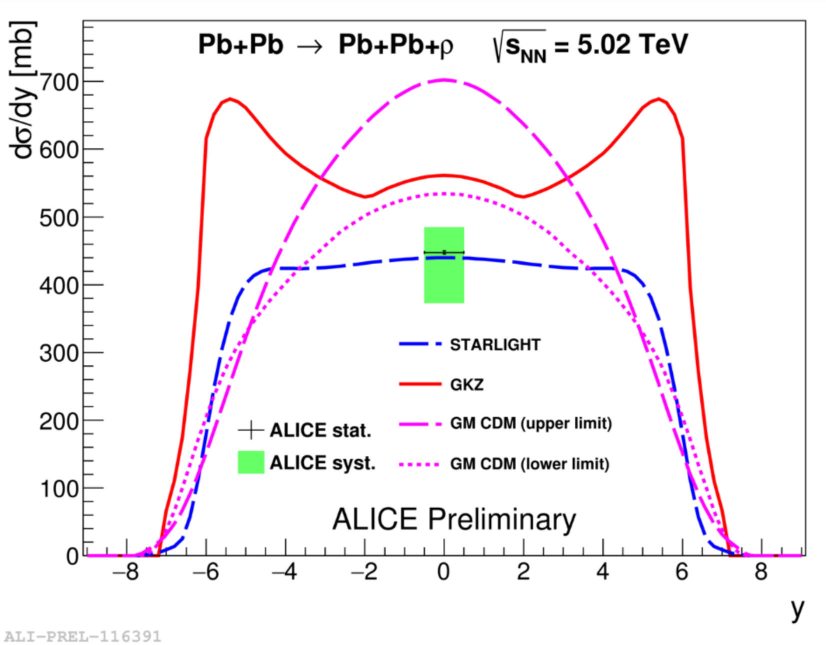
JHEP 09, 095 (2015)

ρ^0 in Pb-Pb central rapidity

- **2015 Pb-Pb data**
- Pions are identified by TPC dE/dx
- Invariant mass fitted by Breit-Wigner resonance + continuum term (Söding)
- Second diffractive peak clearly visible
- Coherent p_T distribution from STARLIGHT significantly wider than data
- The measured cross section is compatible with STARLIGHT predictions within 1 σ Models based on Color Dipole Model (CDM) and a VMD calculations overestimate the data

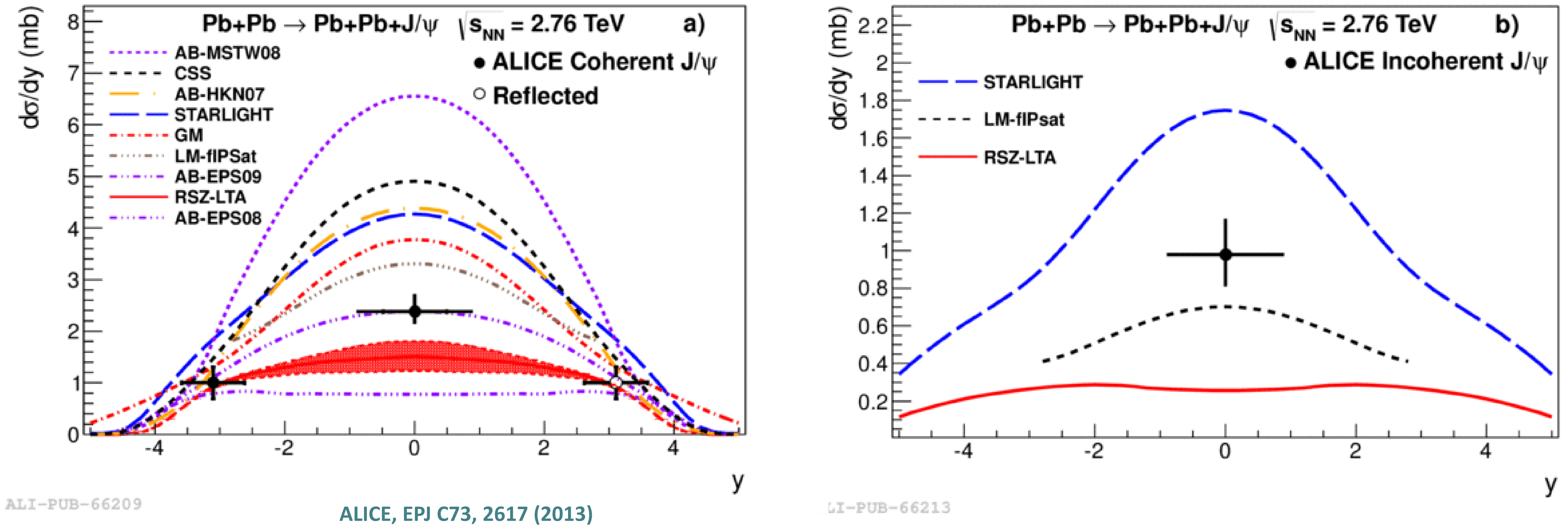






Cross section from 2011 data

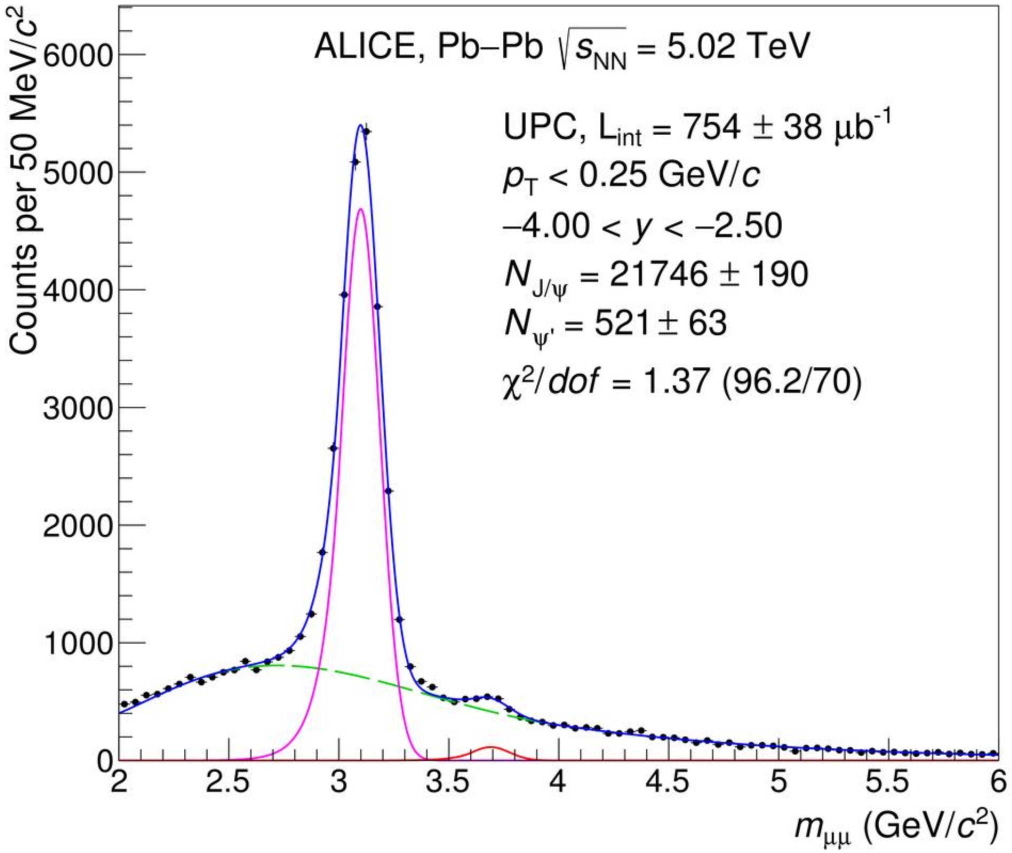
- ALICE results are able to distinguish between the different models
- No nuclear effects: AB-MSTW08
- Glauber approach: STARLIGHT, GM, CSS, LM
- Partonic models: RSZ-LTA, AB-EPS08,09, AB-HKN07
- Models with moderate nuclear gluon shadowing (EPS09) are favored
- STARLIGHT overestimated both cross sections, but got the ratio incoherent/coherent right (≈0.41)

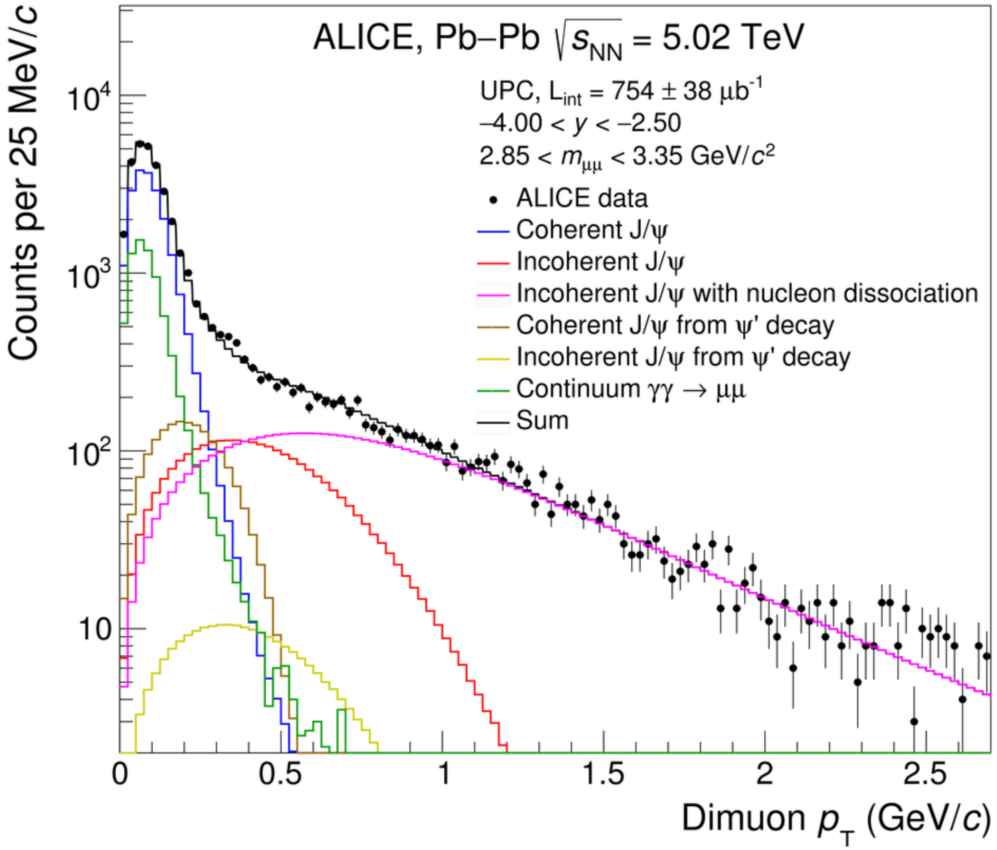


ALICE, EPJ C73, 2617 (2013)

Forward J/ψ in 2015+2018 data

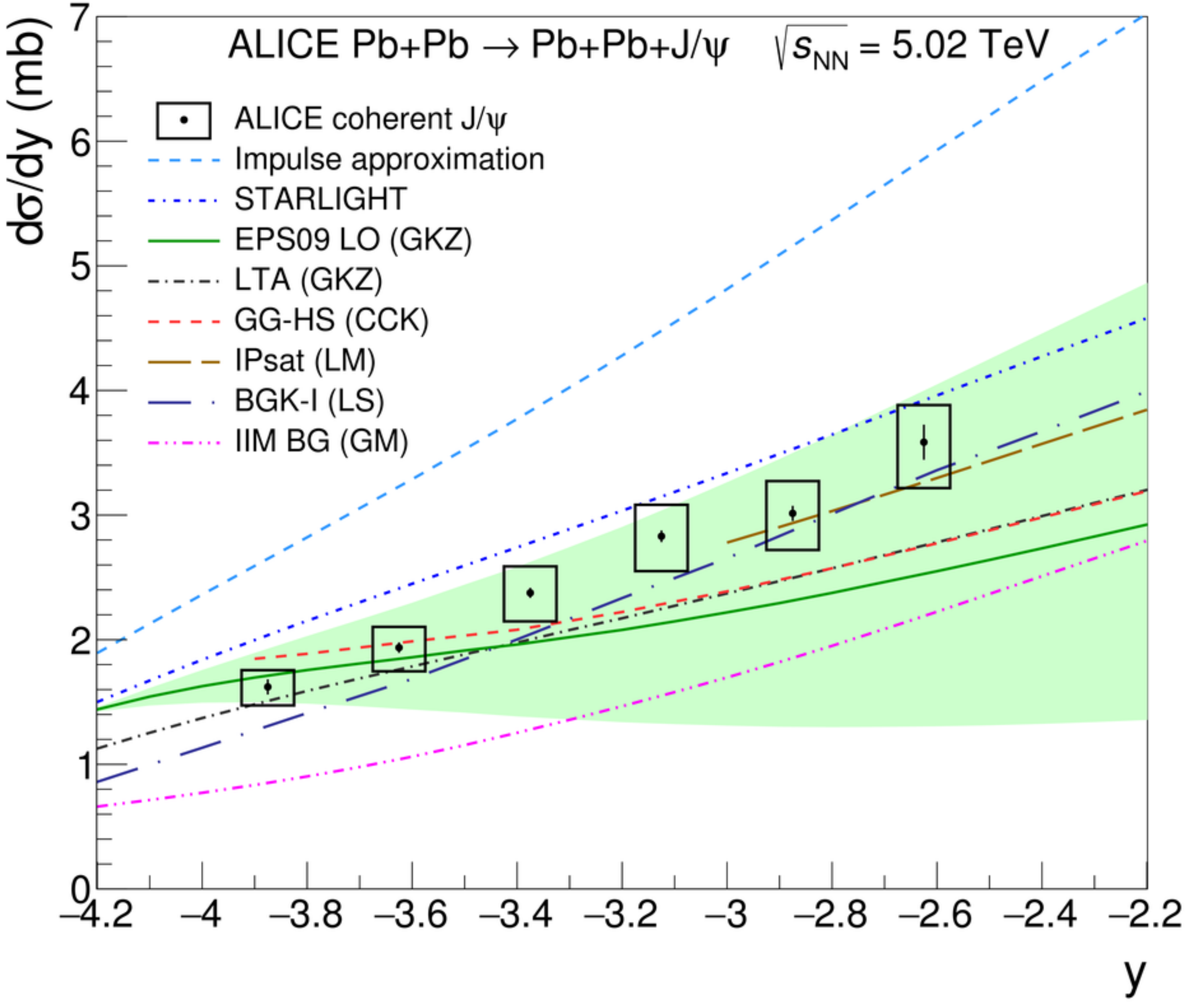
- J/ψ -> $\mu^+ \mu^-$ measured in the muon arm
- J/ψ and ψ(2S) fitted by crystal ball
- ψ(2S) at 3σ significance σ(ψ(2S))/σ(J/ψ) ratio close to HERA γp results
- Background, dominated by γγ->μμ process, is essentially exponential with low-mass decrease due to trigger condition which is fitted by fourth-order polynomial





Forward J/ψ in 2015+2018 data

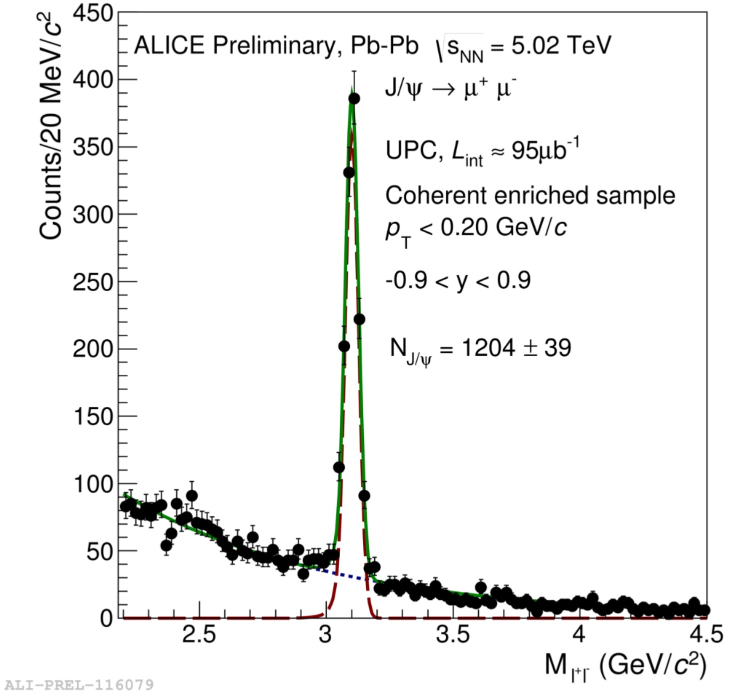
- No nuclear effects: Impulse approximation
- STARLIGHT: VDM + Glauber
- EPS09 LO: EPS09 shadowing
- LTA: Leading twist approximation
- GM, LM: Color dipole model
- Models with moderate nuclear gluon shadowing (EPS09) are favored

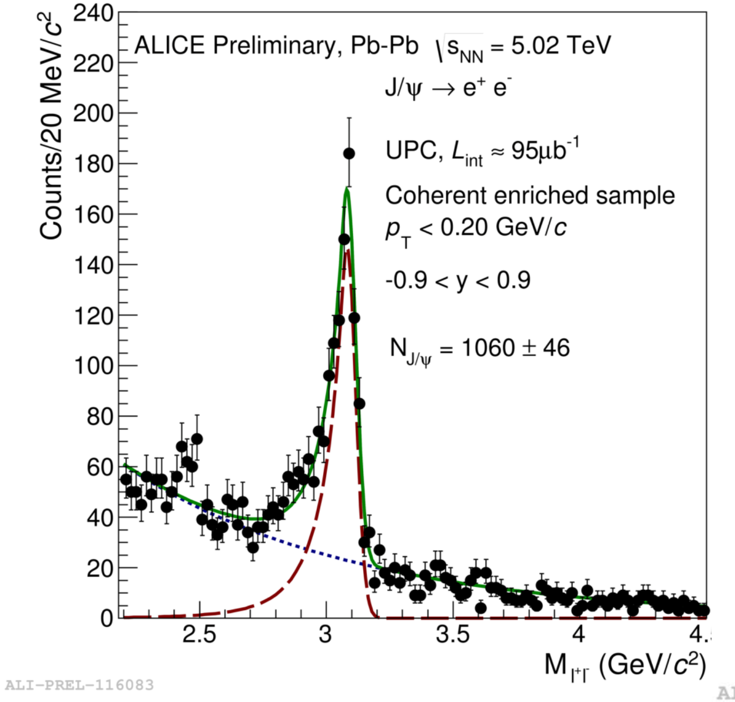


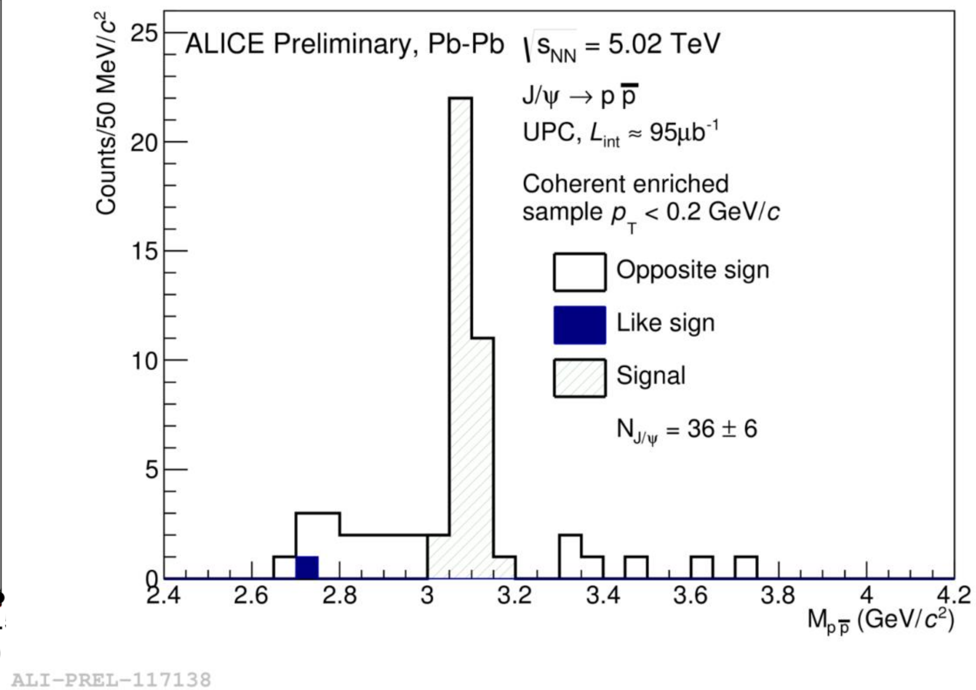
Mid-rapidity J/ψ in 2015 data

- New data with 4x more statistics
- J/ψ photoproduction accompanied by neutron emission (measured with Zero Degree Calorimeters)
- Incoherent cross section

- **First observation of J/ψ->pp in UPC**
- Protons identified by Time-Of-Flight
- Moderate number of candidates, but very clean signal

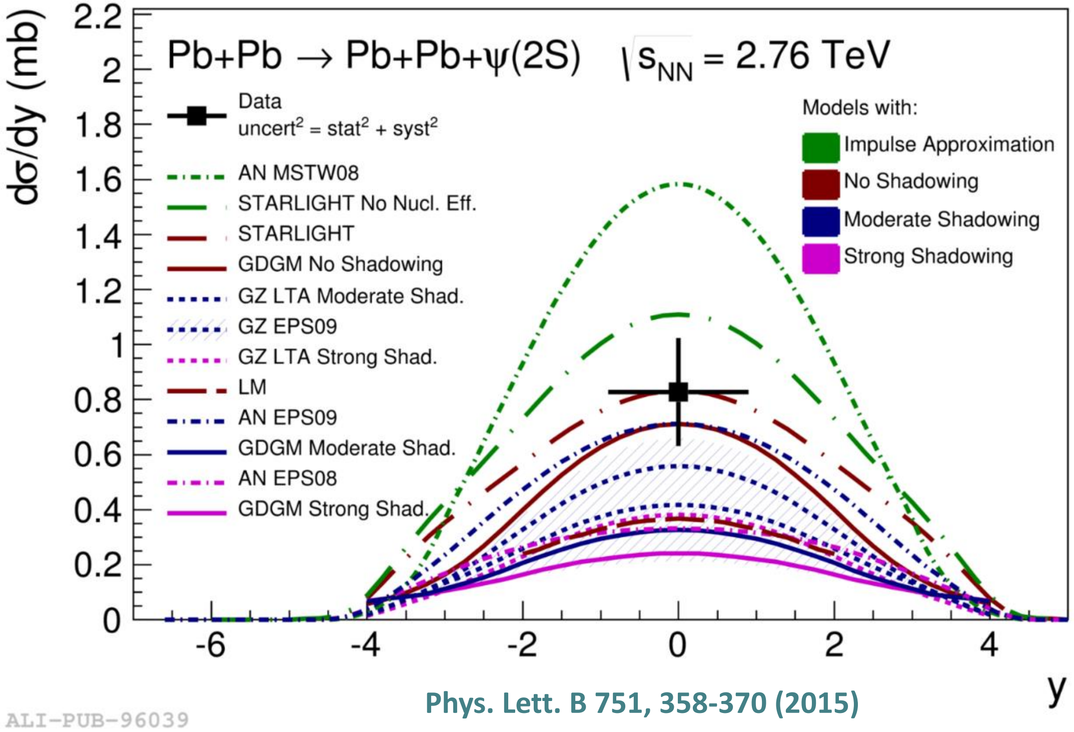






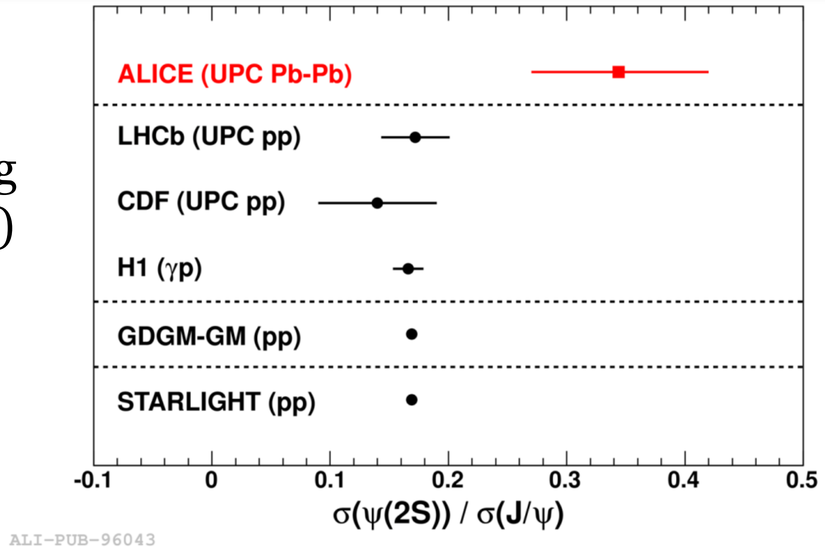
Coherent ψ(2s) cross section

- Data disfavor models using impulse approximation and strong nuclear shadowing
- Difficult to give a preference between models with mild shadowing (EPS09) or Glauber nuclear treatment (STARLIGHT, GDGM, LM)
- R [σ(ψ(2S))/σ(J/ψ)] = $0.34\,^{+0.08}_{-0.07}$ (stat+syst)
- Change of the ratio from pp to Pb-Pb may indicate that nuclear effects affect 1S and 2S states differently

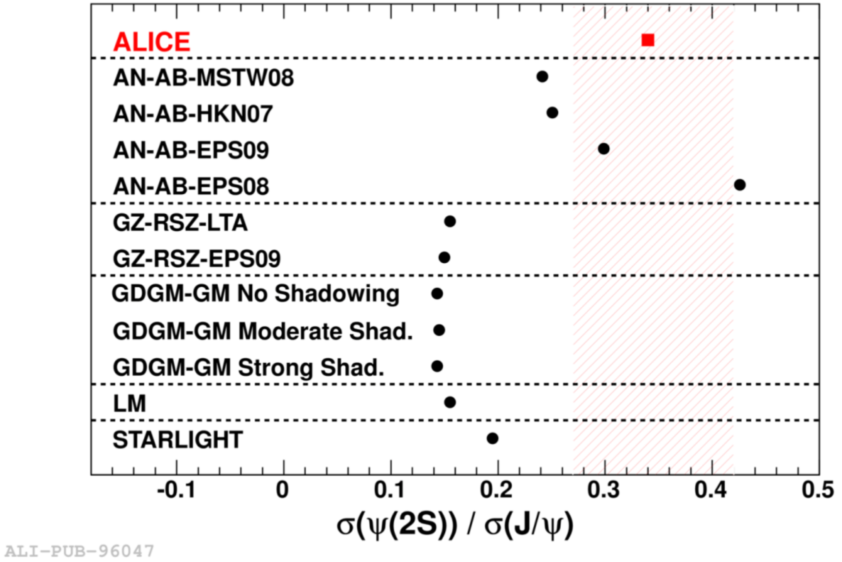


Phys. Lett. B 751, 358-370 (2015)

Comparison to pp data and models

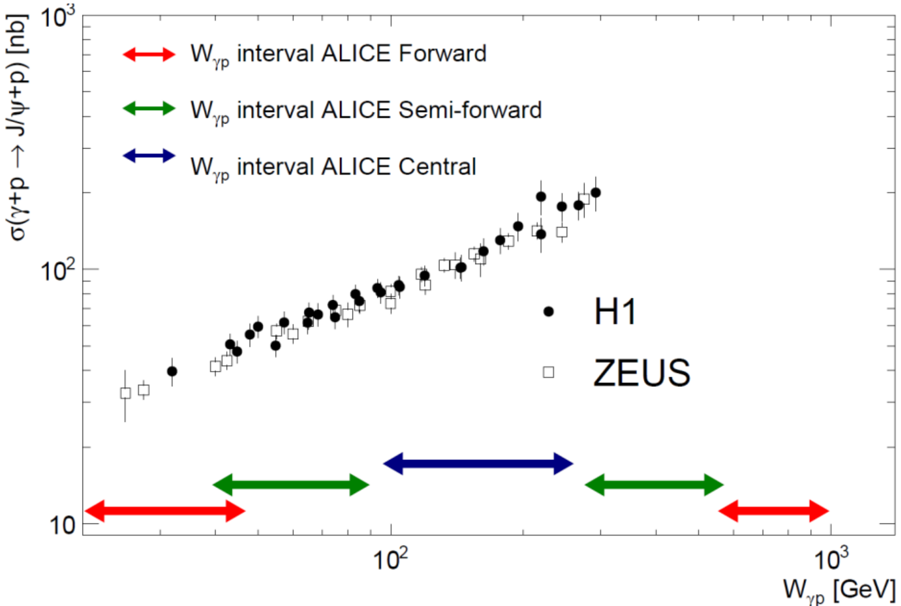


Comparison to Pb-Pb models



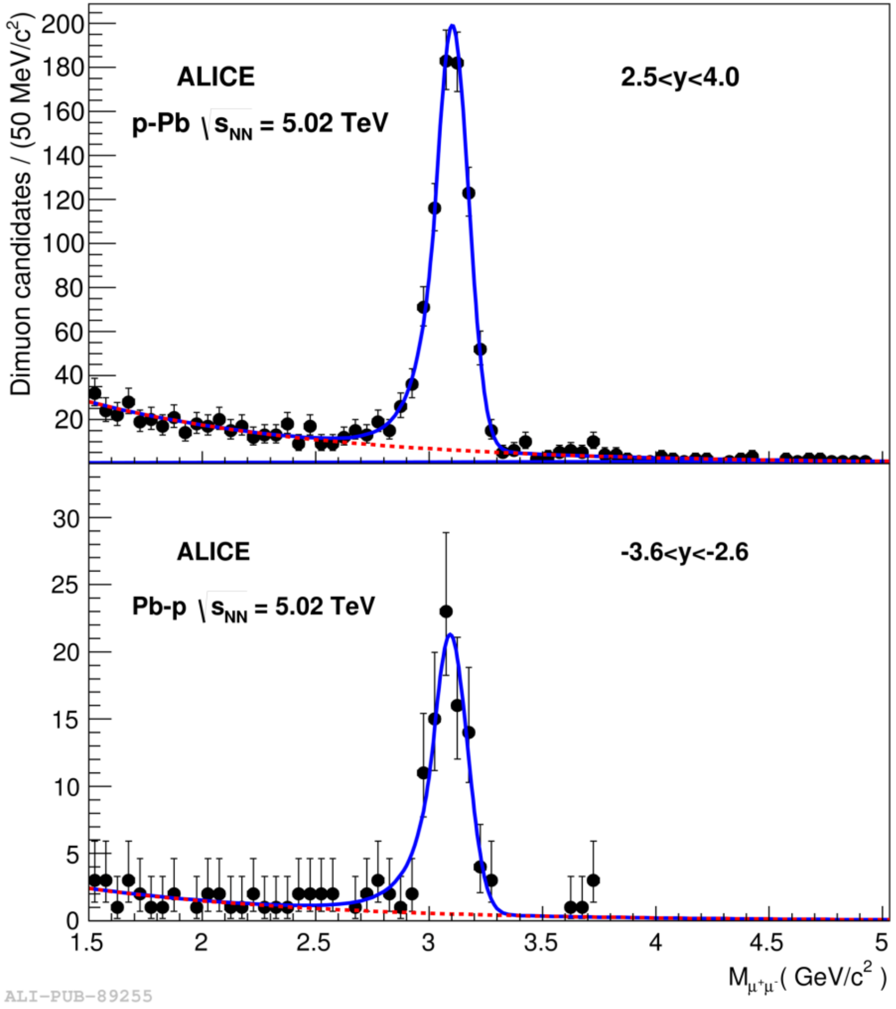
J/ψ in p-Pb and Pb-p

- 2013 p-Pb data
- Measuring the charmonium rapidity 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 advantage w.r.t. pp and Pb-Pb)
- **Central**: Both leptons in central barrel
- **Semi-forward**: One muon in MUON, the other in central barrel
- **Forward**: Both muons in MUON



Forward J/ψ -> $\mu^+ \mu^-$

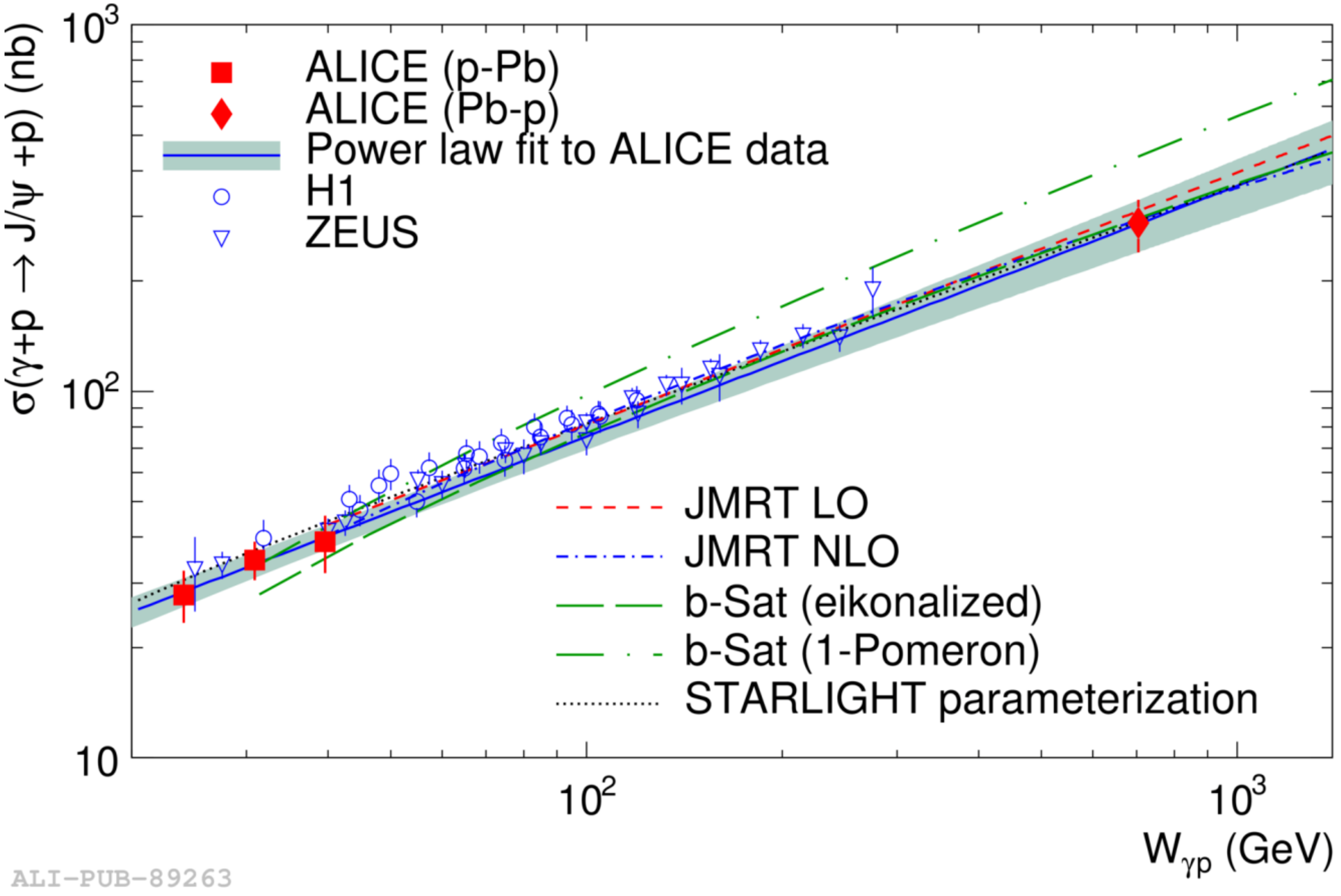
ALICE, Phys. Rev. Lett. 113, 232504 (2014)



Cross section for J/ψ in γp

- First direct γp measurement at the LHC
- ALICE data are 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)
- LHCb solutions consistent with the power-law fit obtained from ALICE results
- HERA and ALICE cross section points stay on the same power law
- The most straightforward interpretation is that no change in the behavior of the gluon PDF in the proton manifests itself between HERA and LHC

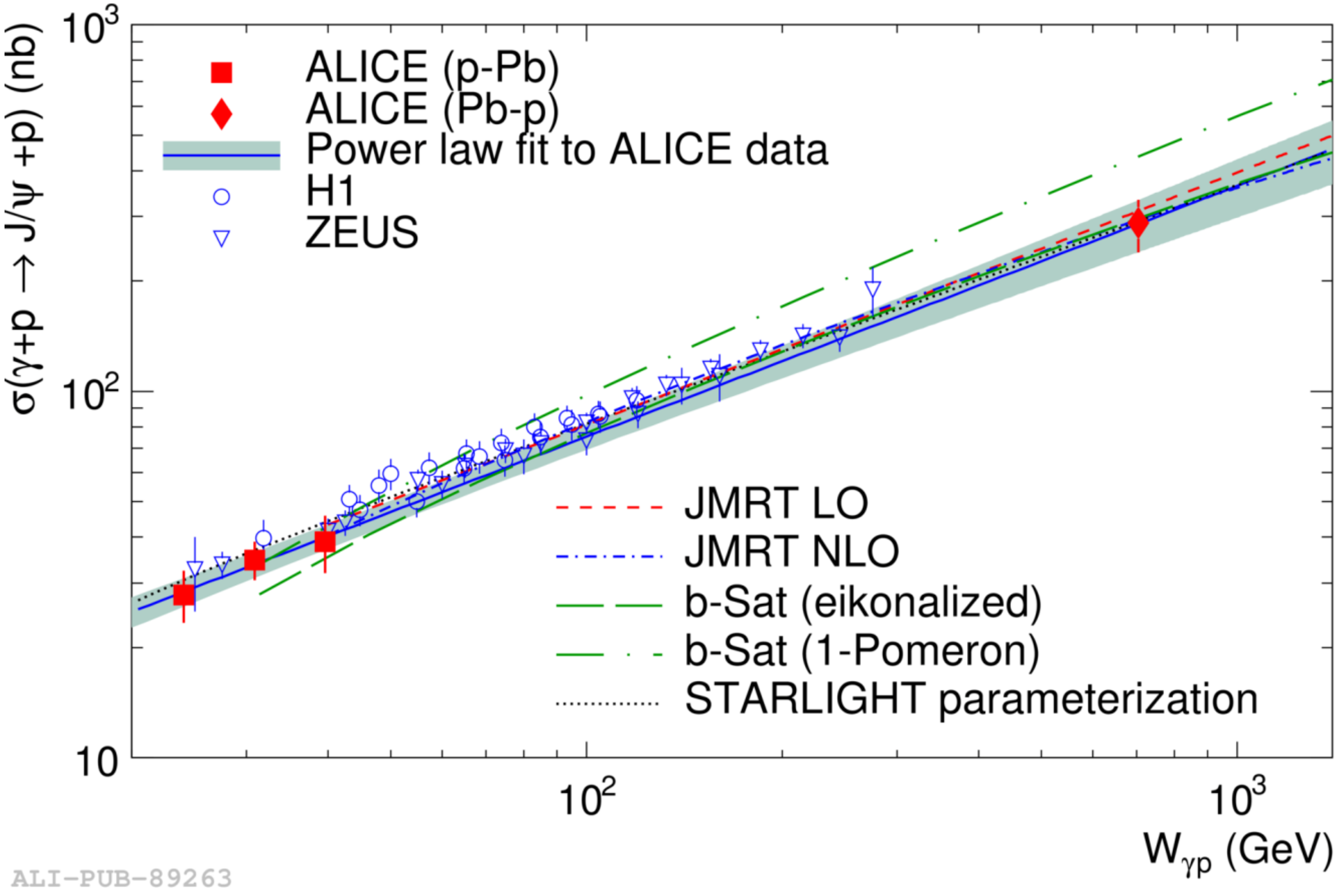
ALICE, Phys. Rev. Lett. 113, 232504 (2014)



Cross section for J/ψ in γp

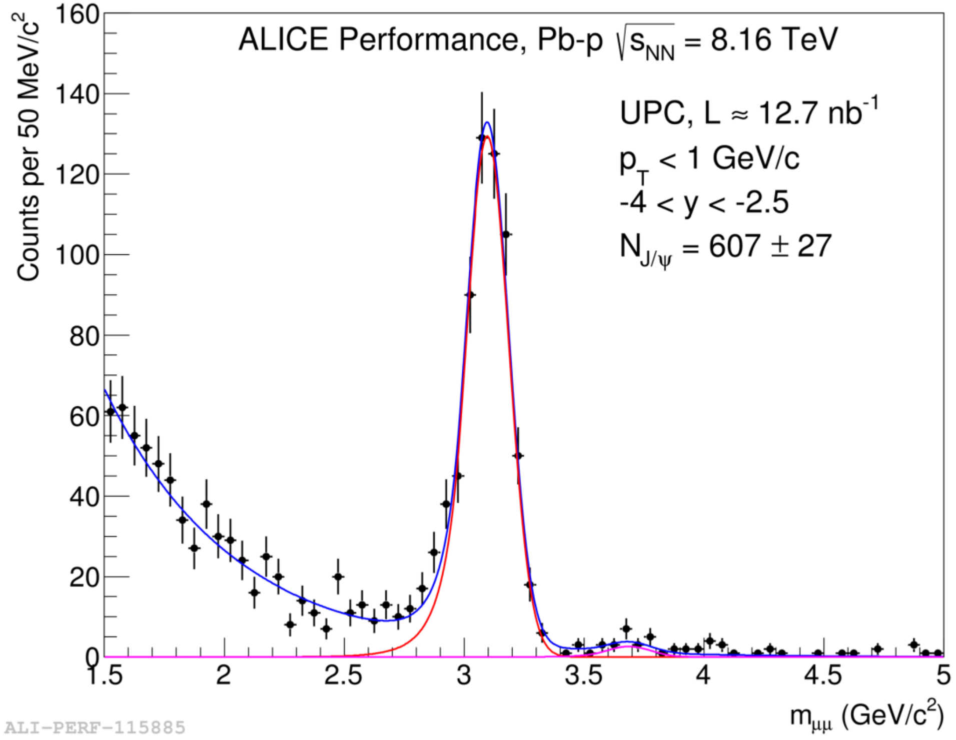
- First direct γp measurement at the LHC
- JMRT: LO model based on a power law. NLO model includes the expected main NLO contributions
- b-Sat (eikonalised) includes b-dependent saturation effects based on a CGC inspired model
- STARLIGHT parameterization is based on a power law fit using only fixed-target and HERA data
- HERA and ALICE cross section points stay on the same power law
- The most straightforward interpretation is that no change in the behavior of the gluon PDF in the proton manifests itself between HERA and LHC

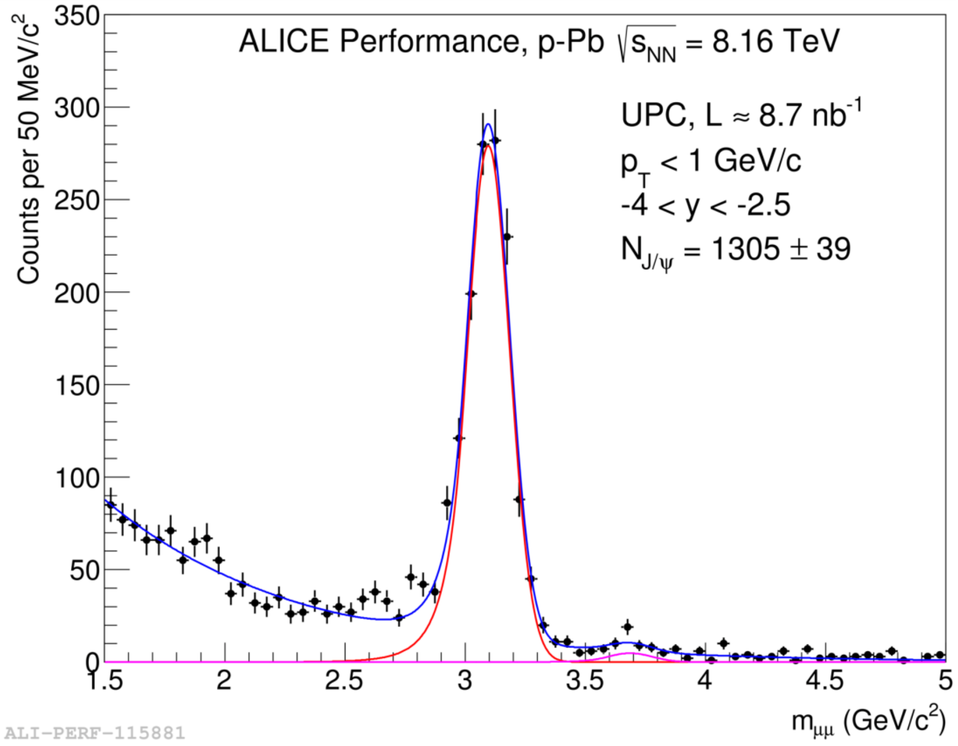
ALICE, Phys. Rev. Lett. 113, 232504 (2014)



p-Pb at 8 TeV

- Data at 5 Tev and 8 TeV p-Pb and Pb-p were recorded in 2016
- 10x more stats at high $W_{\gamma p}$ ~0.7 - 1.4 TeV
- Search for gluon saturation effects in p at low x
- Study proton-dissociative cross section at high $W_{\gamma p}$ using AD and ZDC





Summary and outlook

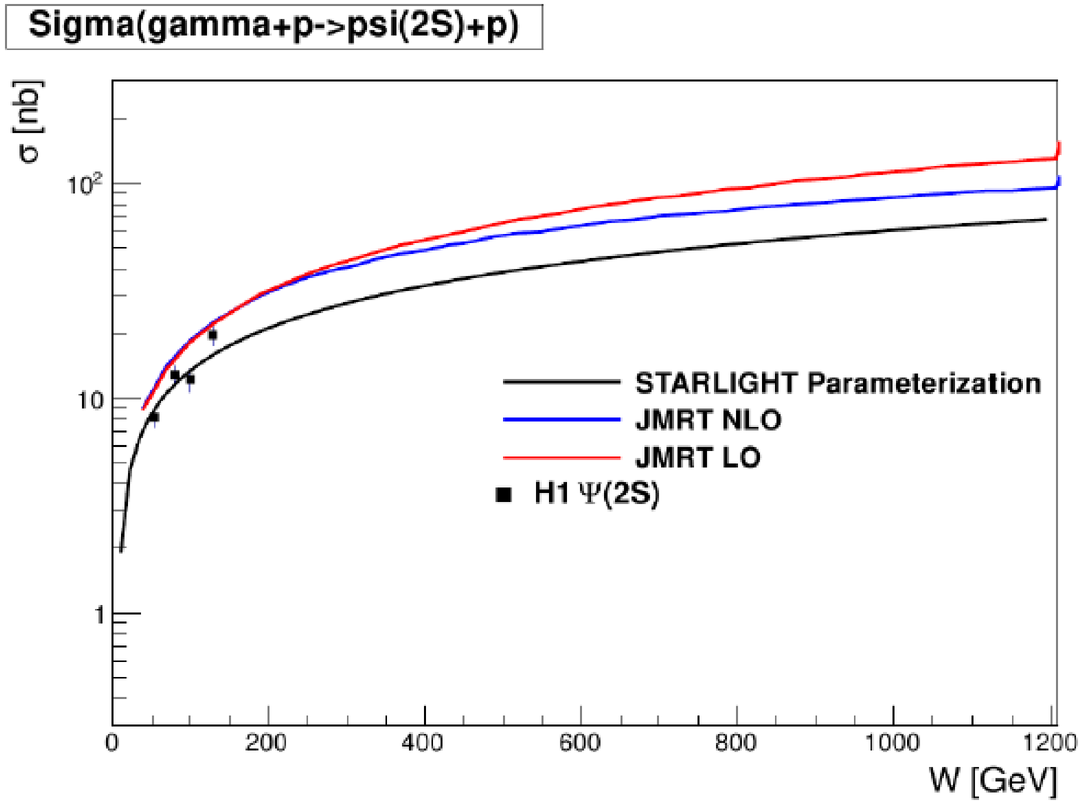
- ALICE has measured:
  - coherent and incoherent photo-production of J/ψ in Pb-Pb collisions
  - directly, exclusive J/ψ photo-production in γp collisions
  - the exclusive photo-nuclear production of ψ(2s)
- The cross section for the J/ψ found to be in agreement with models with moderate nuclear gluon shadowing (EPS09)
- The measured cross section for the ψ(2S) disfavors models with no nuclear effects and models with strong gluon shadowing.
- No change in the behavior of the gluon PDF in the proton between HERA and LHC
- ALICE is analyzing new data from Run2 of the LHC: increase in luminosity and center of mass energy of the photon-target system, new detectors for extended coverage in rapidity to veto non-exclusive reactions and to study dissociation – **Stay tuned!**

ALICE

Backup

γp cross section for ψ(2S)

- Photonuclear ψ(2S) production may probe nuclear gluon shadowing.
- However, to correctly interpret the nuclear effects, one has to understand the underlying γ+p -> ψ(2S)+p baseline.
- Here the uncertainties are much larger for ψ(2S) than for J/ ψ.



Cross section models in Pb-Pb

- **AB**: Adeluyi and Bertulani, PRC85 (2012) 044904 - 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 - LO pQCD amplitude for two gluon exchange where the gluon density incorporates shadowing computed in leading twist approximation
- **LM**: Lappi, Mantysaari, PRC87 (2013) 032201 - Color dipole model based with Glauber approach and a saturation prescription

J/ψ in Pb-Pb central rapidity

ALICE, EPJ C73, 2617 (2013)

- 2011 Pb-Pb data
- γPb interaction can be
  - Coherent – coupling to whole nucleus
    $\langle p_T \rangle \approx 60$ MeV/c
  - Incoherent – coupling to single nucleon
    $\langle p_T \rangle \approx 500$ MeV/c
- Measured at central rapidity
  - coherent ($p_T < 0.2$ GeV/c) incoherent ($p_T > 0.2$ GeV/c)
  - J/ψ -> $\mu^+ \mu^-$
  - J/ψ -> $e^+ e^-$
  - Leptons identified using d*E*/d*x* in TPC