Workshop on Forward Physics and QCD at the LHC, the future Electron Ion Collider and Cosmic Ray Physics

18th - 21st November 2019

Guanajuato

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

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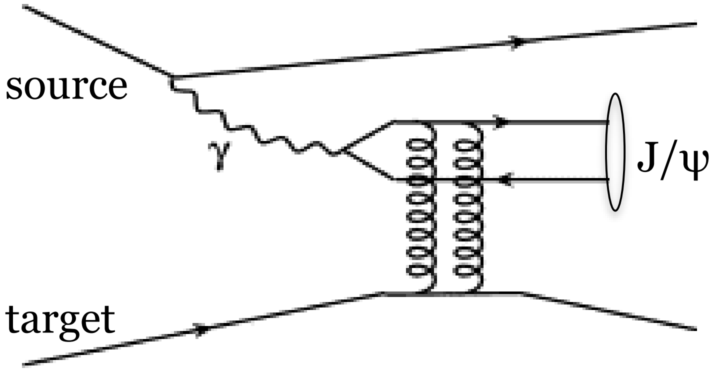
On behalf of the ALICE Collaboration

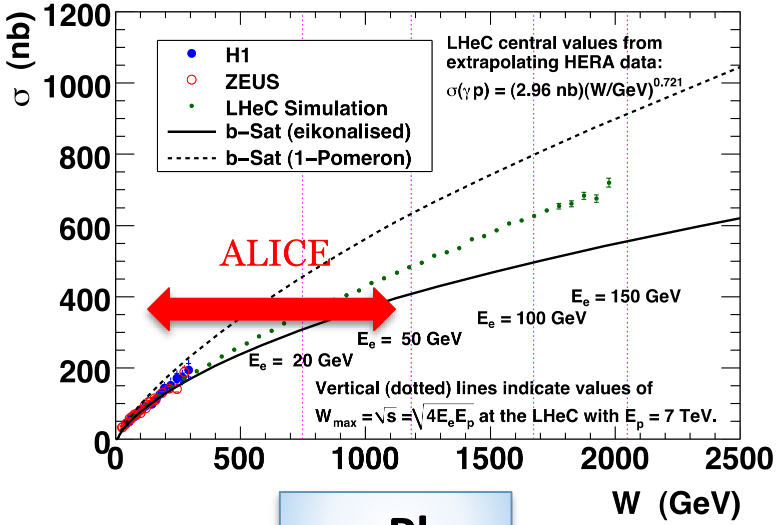
Ultra-peripheral collisions

- 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 also using the LHC as a photon-hadron collider!
- Charmonium photoproduction permits us to search for and study non linear effects at low x in the gluon distribution of the target (keywords: shadowing, saturation)



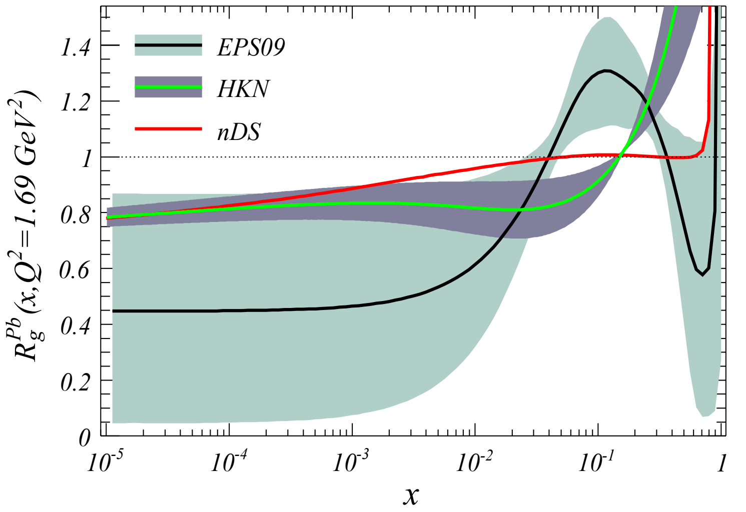
γp

LHeC Study group, ArXiv: 1211.4831



γ-Pb

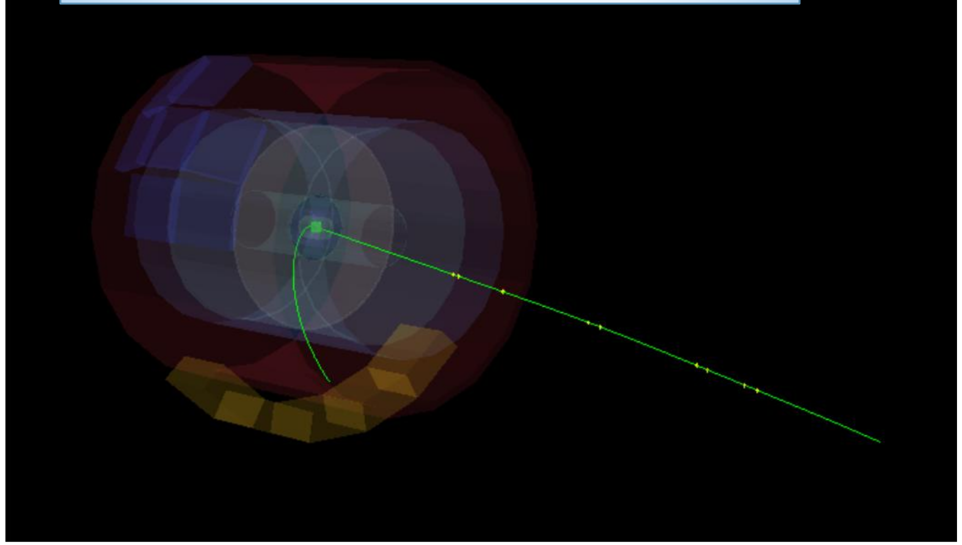
C. A. Salgado *et al* 2012 *J. Phys. G: Nucl. Part. Phys.* 39 015010



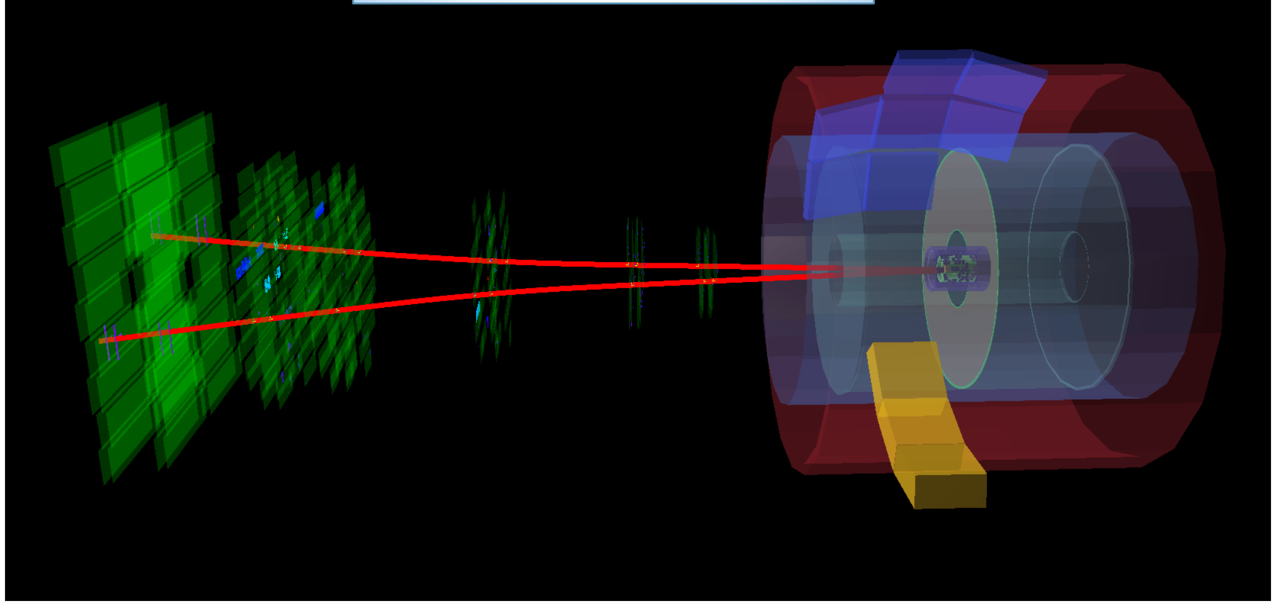
Vector meson production in UPC

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

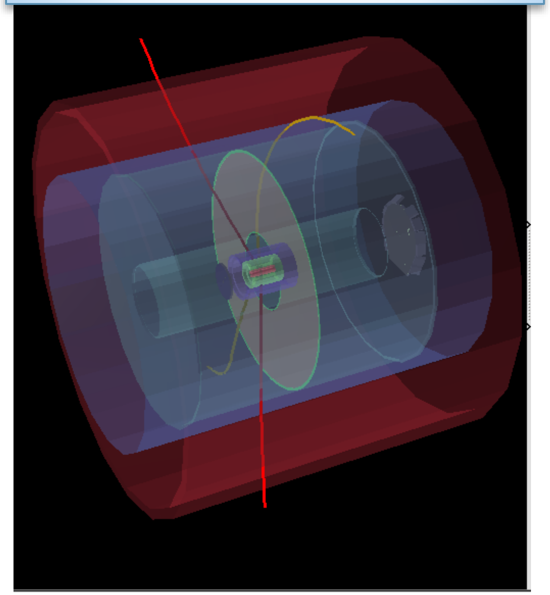
Semi-Forward $J/\psi \to \mu^+ \mu^-$



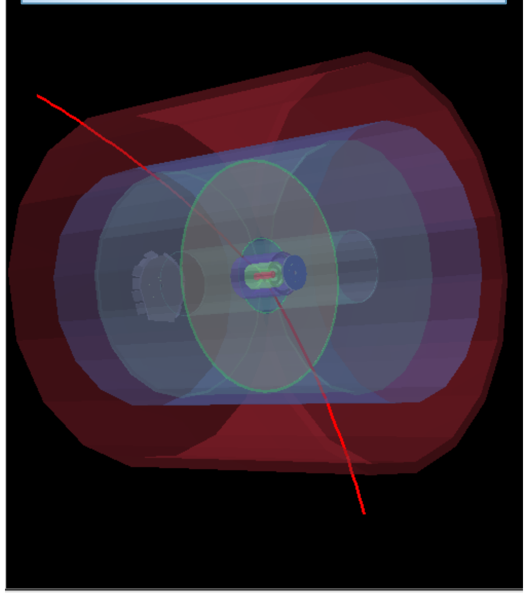
Forward $J/\psi \to \mu^+ \mu^-$



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

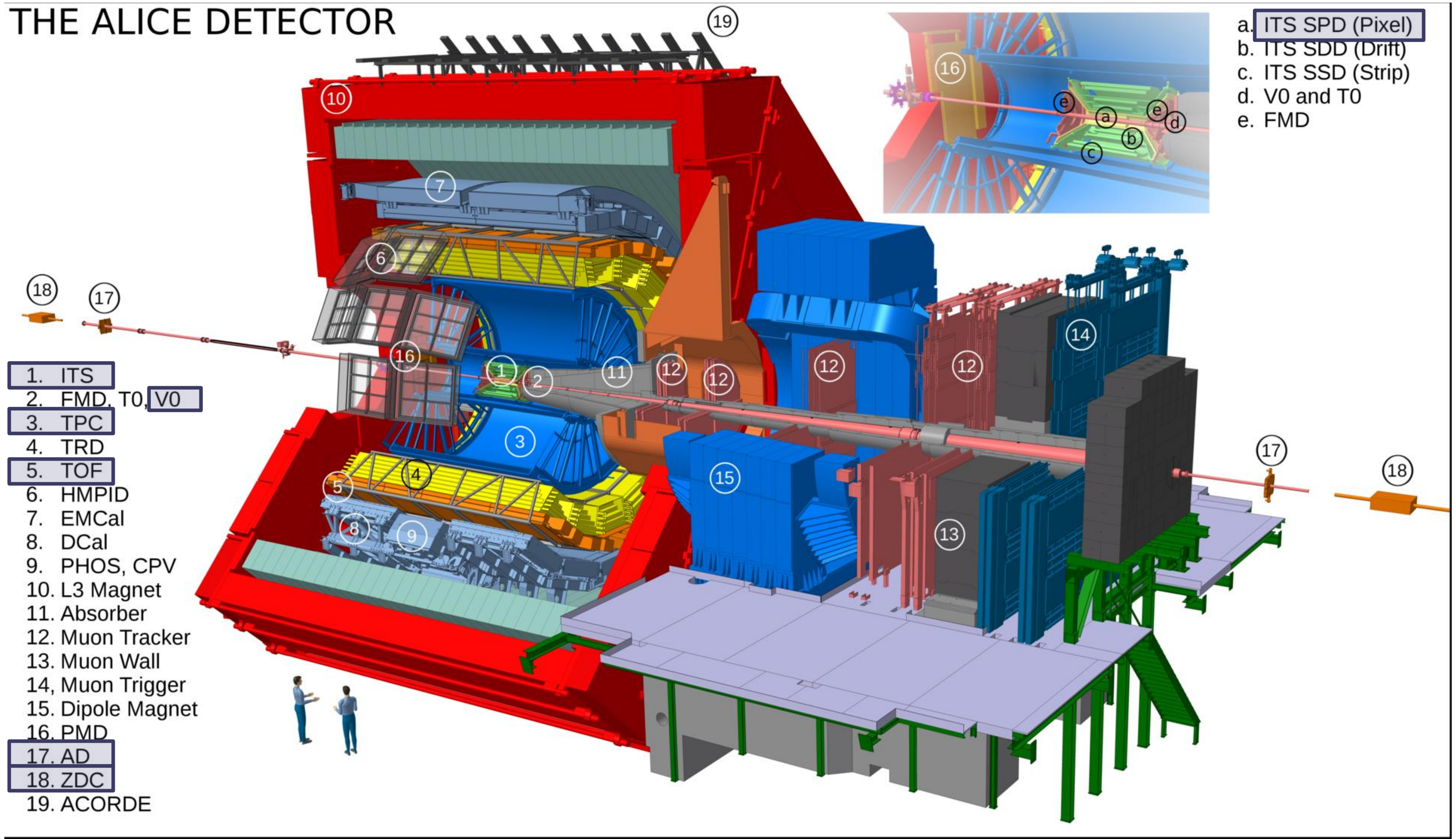


Central $J/\psi \to \mu^+ \mu^-$



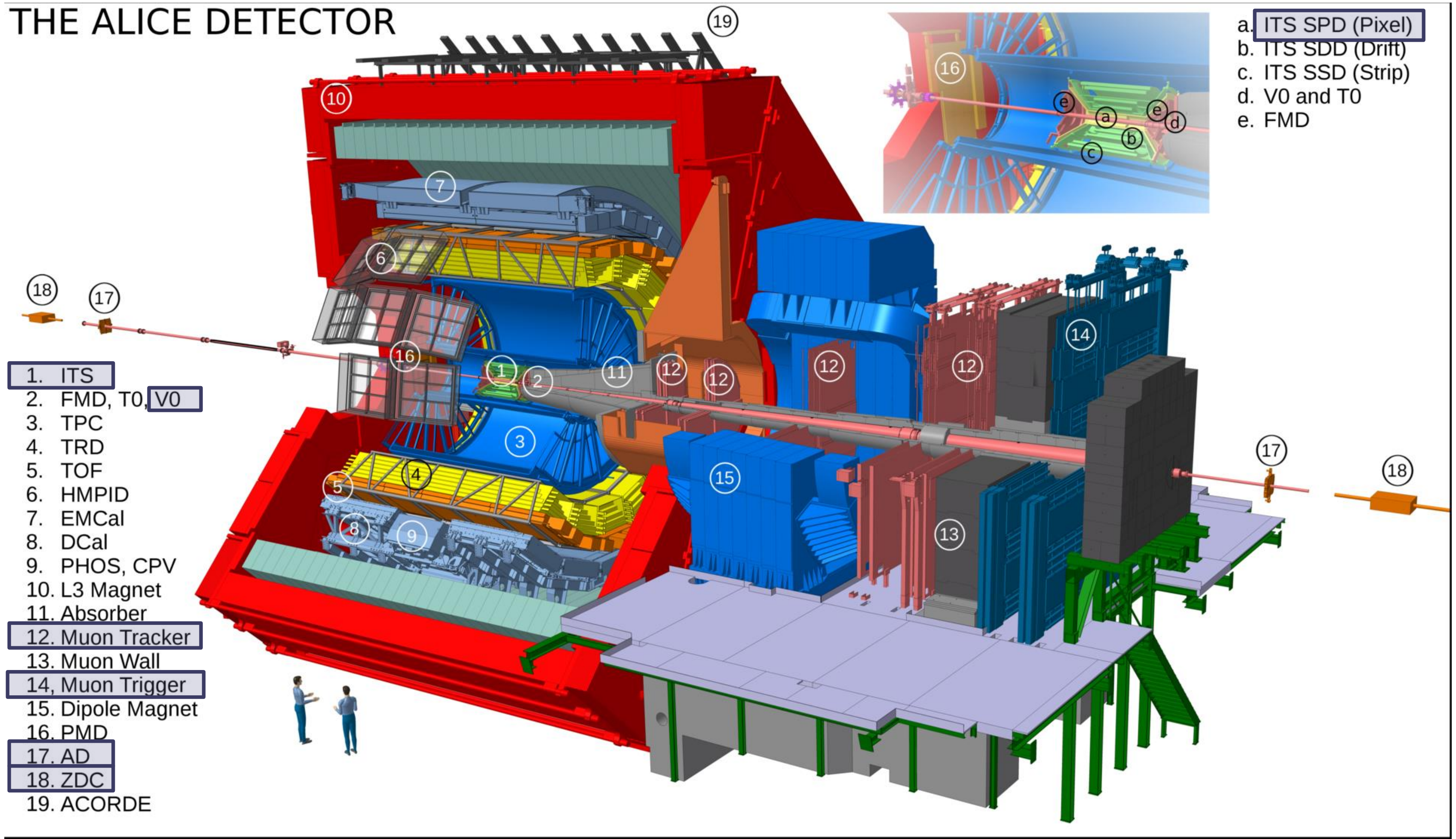
ALICE and UPC trigger for Pb-Pb and pPb

- 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
  - 2013/2015/2018: veto on V0, (veto on AD – Run2), hits in SPD ≥ 4 with back-to-back topology / 2 ≤ TOF hits ≤ 6 with back-to-back topology



ALICE and UPC trigger for Pb-Pb and pPb

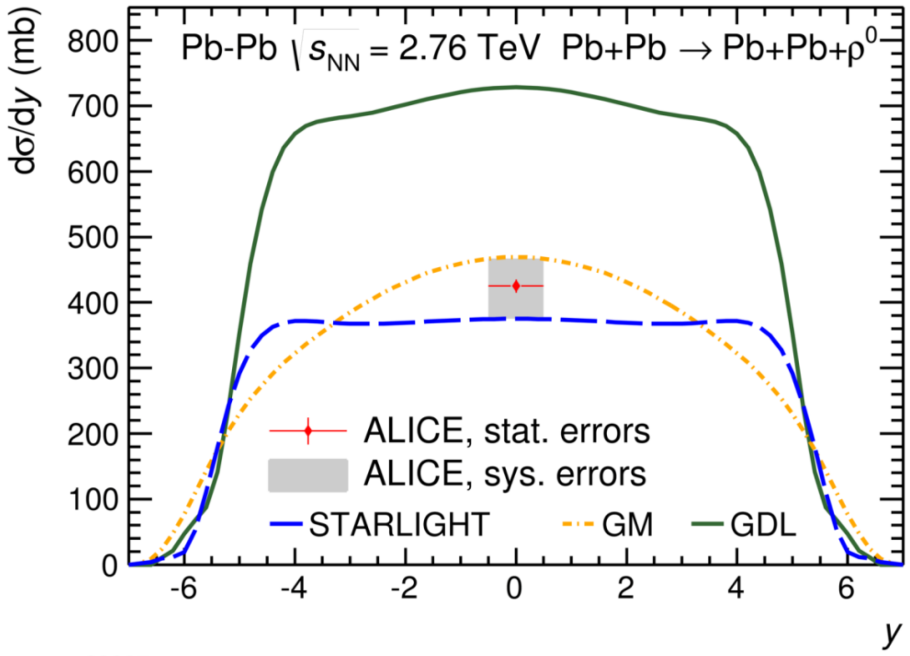
- Forward rapidity trigger on UPC
  - 2011/2016: veto on V0-A , hits in V0-C , single muon with $p_T > 1$ GeV/c
  - 2013/2016: veto on V0-A , hits in V0-C , di-muon, each with $p_T > 0.5$ GeV/c
  - 2015/2018: veto on V0-A, veto on AD, di-muon, each with $p_T > 1$ GeV/c
- Semi-forward rapidity trigger on UPC
  - 2013/2016: veto on V0-A , hits in V0-C , hits in SPD ≥ 2, single muon with $p_T > 0.5$ GeV/c



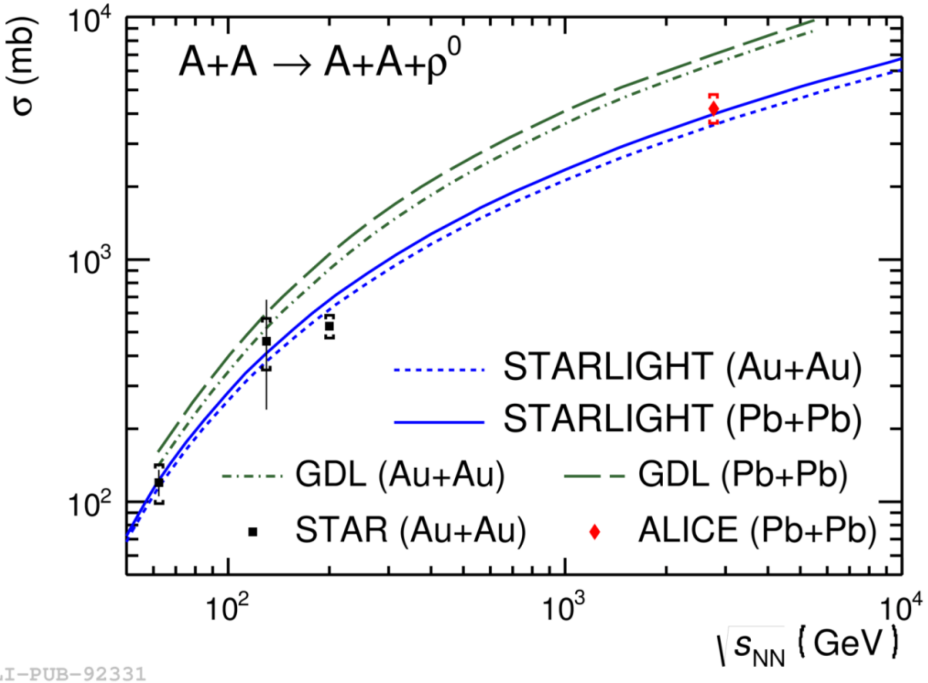
ρ^0 in Pb-Pb central rapidity

- **2011 Pb-Pb data**
- Cross section obtained by integrating the resonance contribution over $[2m_\pi, M_\rho + 5\Gamma]$
- GDL: 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)



ALI-PUB-92327



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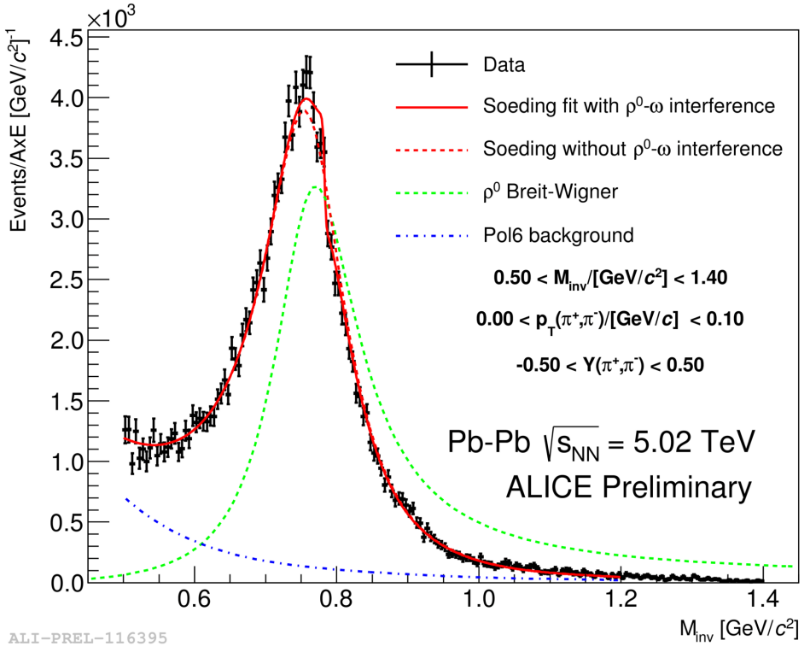
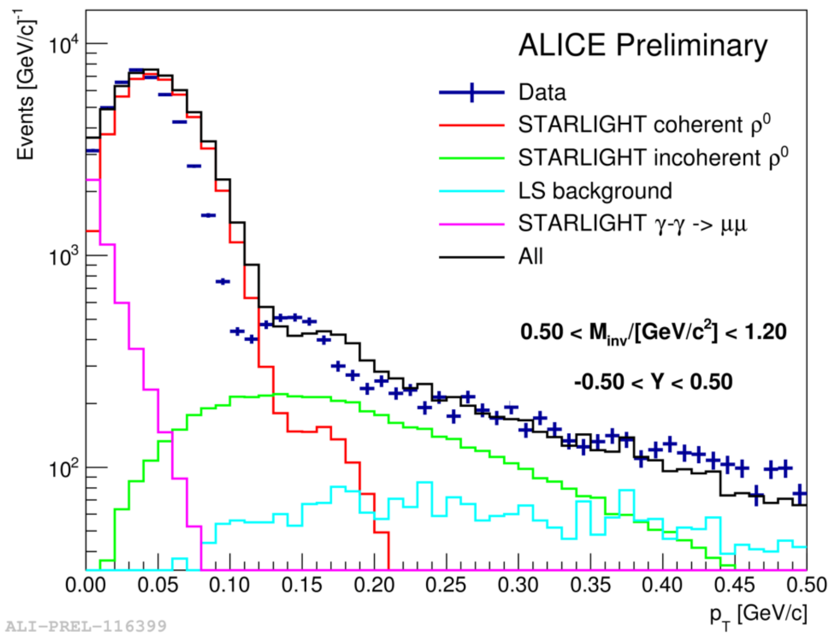
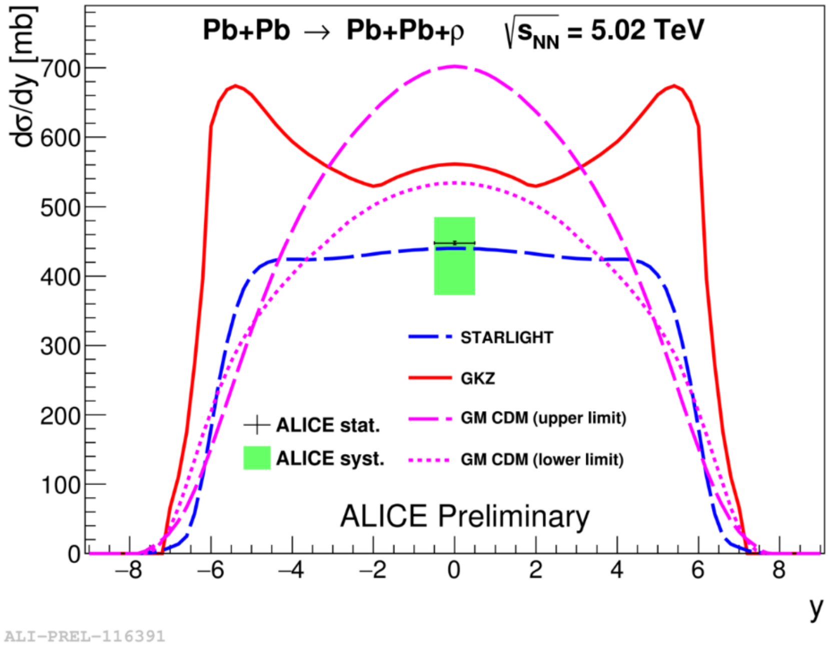
ρ^0 in Pb-Pb central rapidity

- **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 preliminary cross section is compatible with STARLIGHT predictions within 1 σ
- Models based on Color Dipole Model (CDM) and a GKZ calculations based on Gribov-Glauber shadowing approach overestimate the data



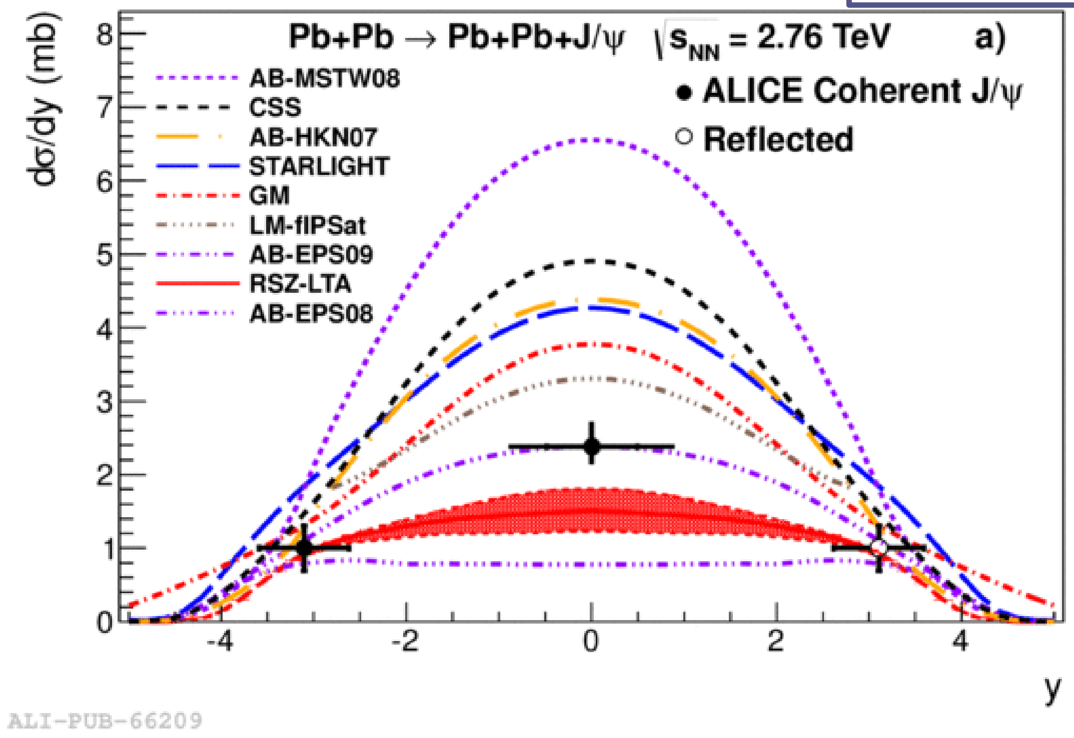


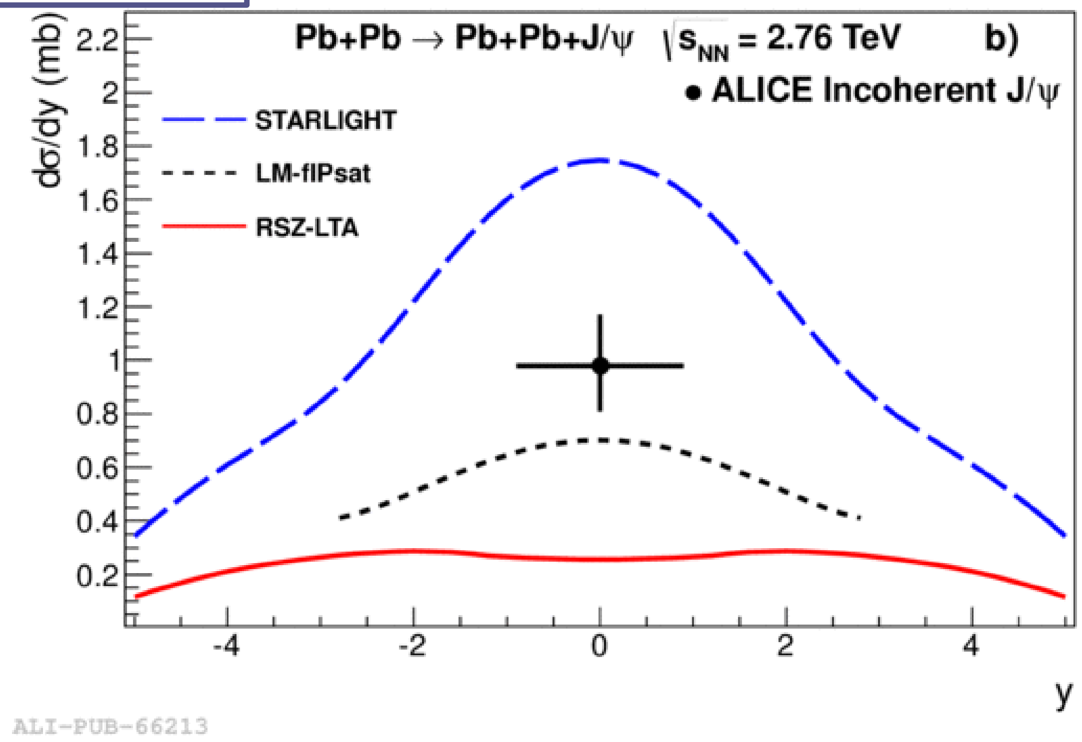


Mid-rapidity J/ψ in 2011 data

- ALICE results are able to distinguish between the different models
- No nuclear effects: AB-MSTW08
- Glauber-like approach: STARLIGHT
- Dipole model approach: 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)

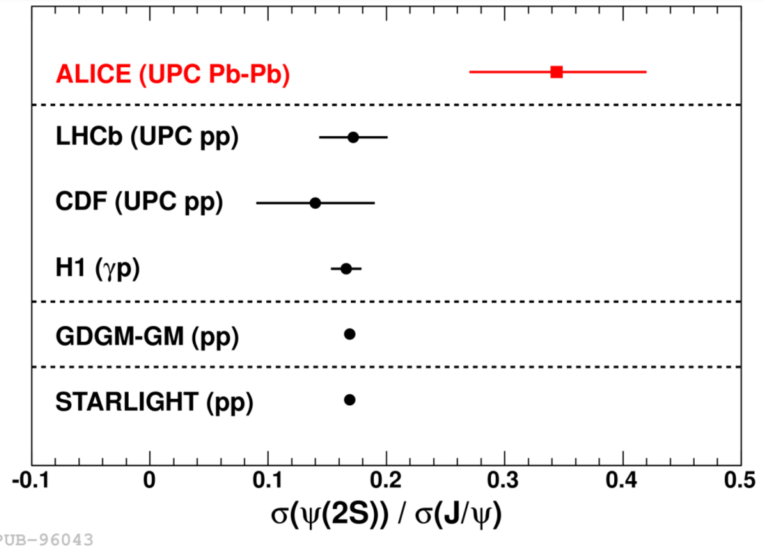




Coherent ψ(2s) cross section

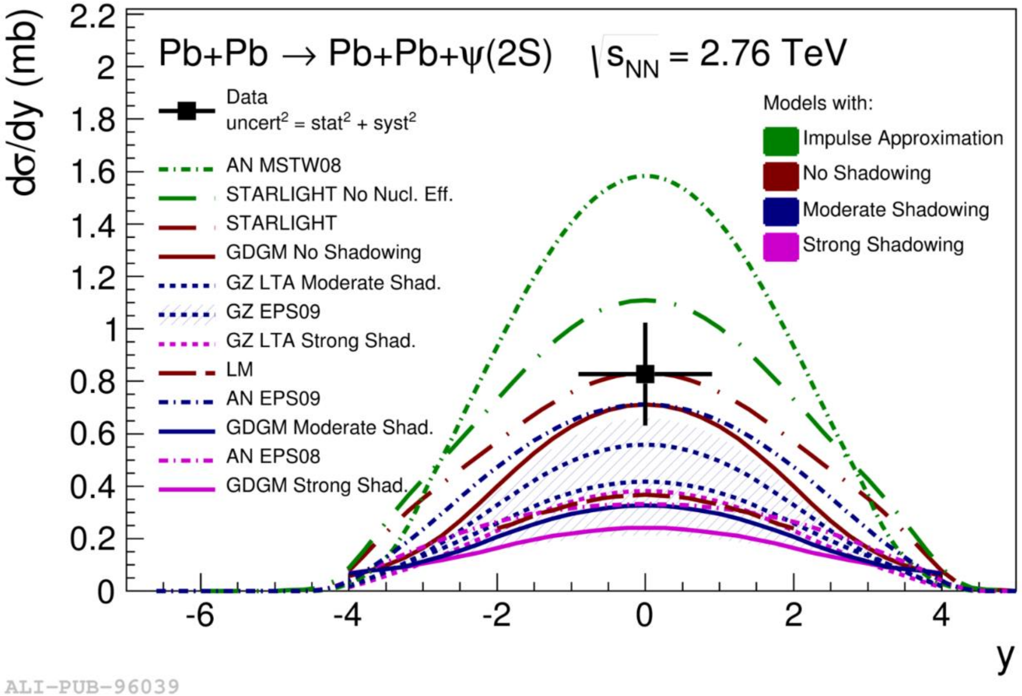
- Data disfavor models using impulse approximation and strong nuclear shadowing
- Difficult to give a preference between models with mild shadowing (EPS09) or Glauber nuclear treatment (STARLIGHT, GDGM, LM)
- $R\ [\sigma(\psi(2S))/\sigma(J/\psi)] = 0.34\ ^{+0.08}_{-0.07}$ (stat+syst)
- Measured ratio 2 sigma away from expectations

Comparison to pp data and models



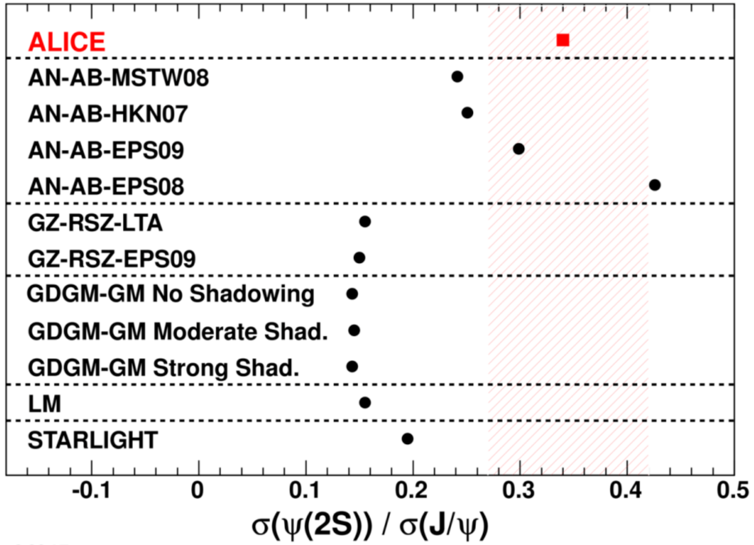
ALI-PUB-96043

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



ALI-PUB-96039

Comparison to Pb-Pb models

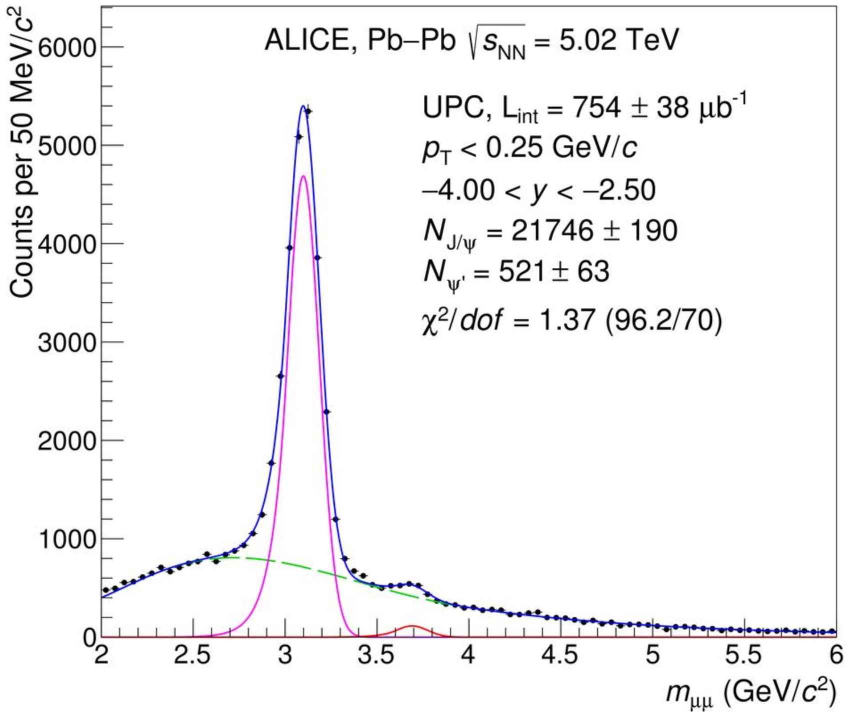


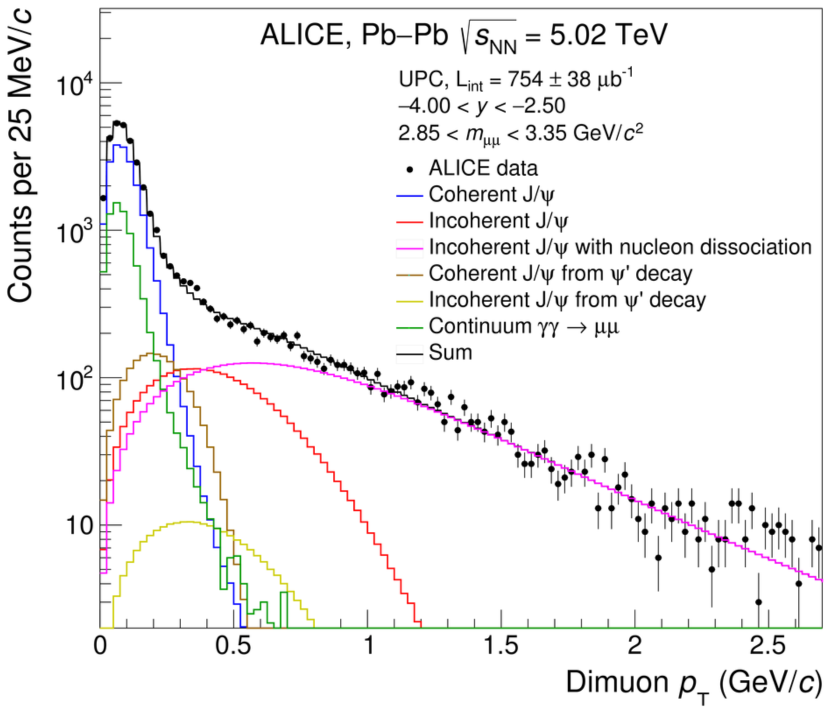
ALI-PUB-96047

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 function
- 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
- Various p_T templates by STARLIGHT
- High-pt tail (J/ψ with nucleon dissociation) fitted with H1 parameterization

Phys.Lett. B798 (2019) 134926

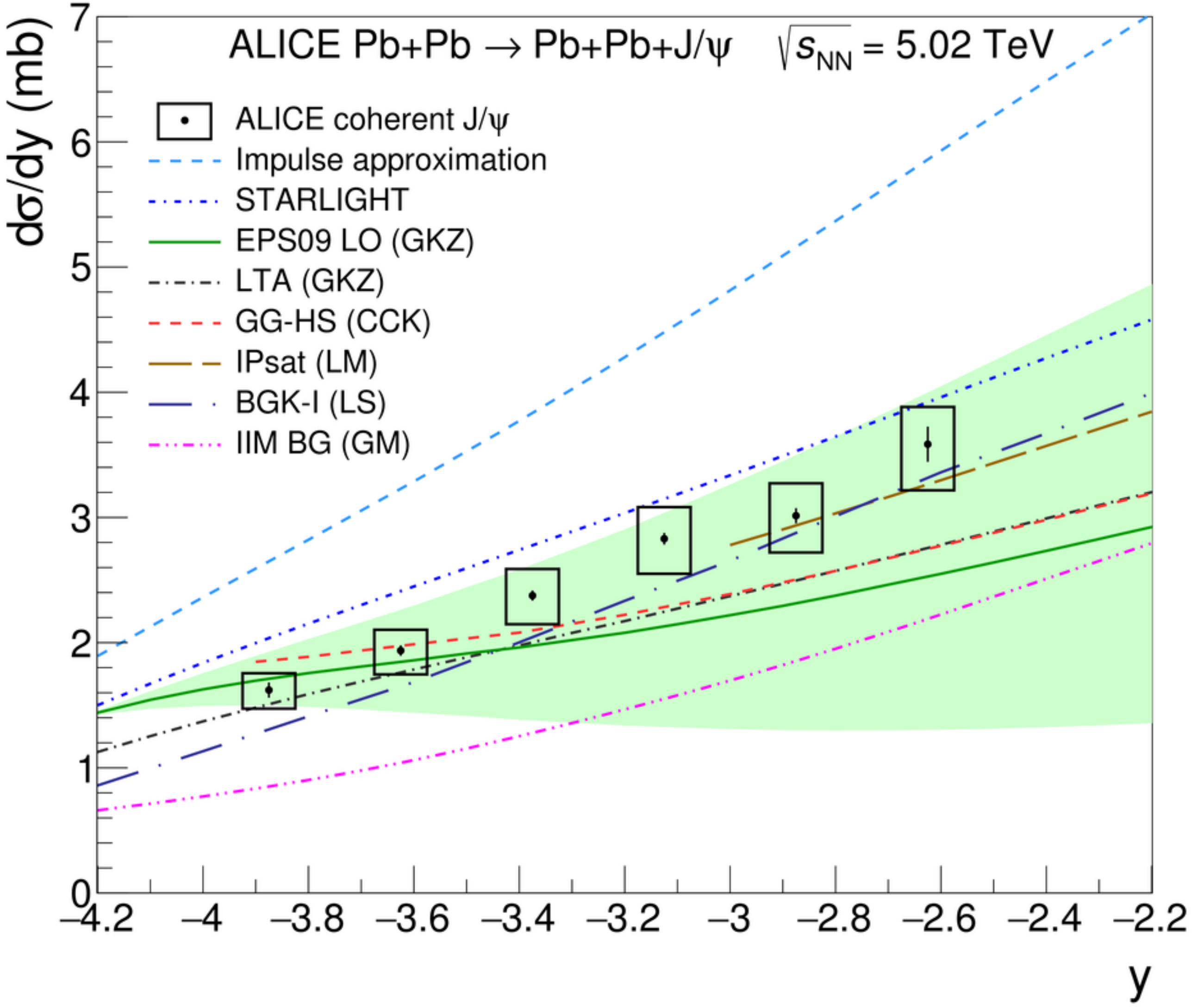




Forward J/ψ in 2015+2018 data

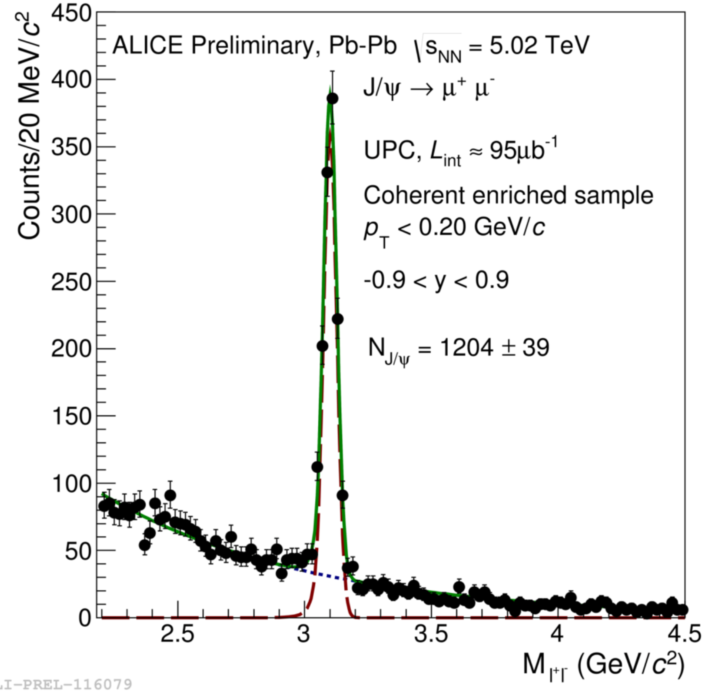
Phys.Lett. B798 (2019) 134926

- No nuclear effects: Impulse approximation
- STARLIGHT: VDM + Glauber
- EPS09 LO: EPS09 shadowing
- LTA: Leading twist approximation
- GM, LM, LS: Color dipole model
- CCK: energy-dependent hot-spot model
- Difference between data and impulse approximation is a direct measurement of moderate nuclear shadowing

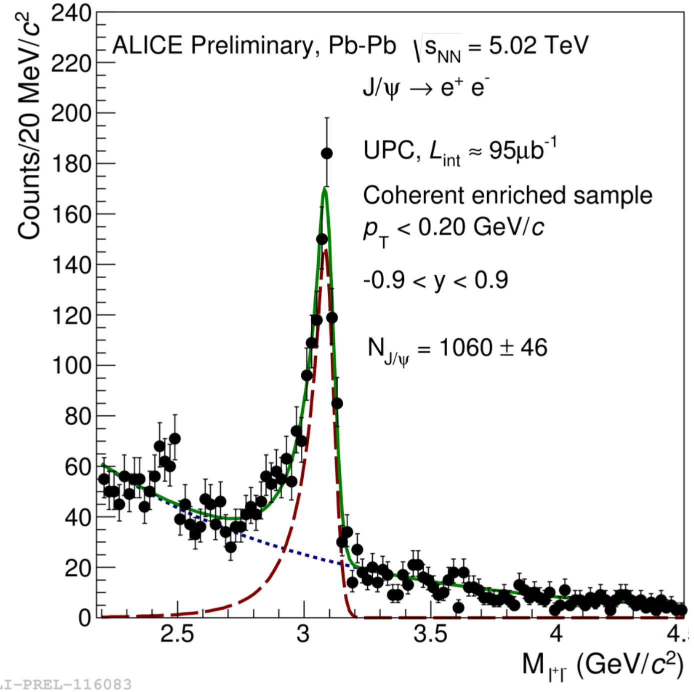


Mid-rapidity J/ψ in 2015 data

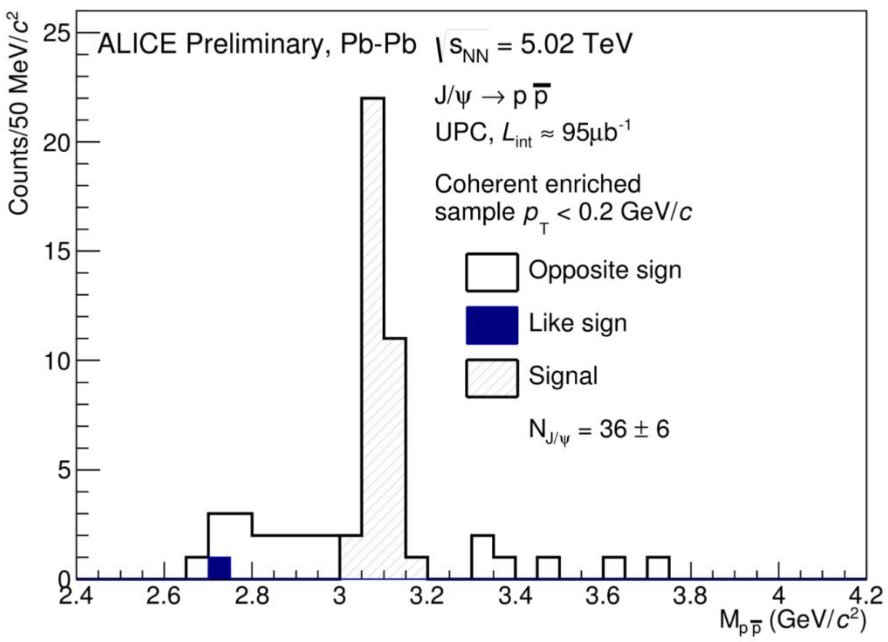
- 2015 data yielded a 4x larger sample than 2011, but we also have 2018 data
- First observation of J/ψ->pp in UPC
- Protons identified by Time-Of-Flight
- Moderate number of candidates, but very clean signal



ALI-PREL-116079



ALI-PREL-116083



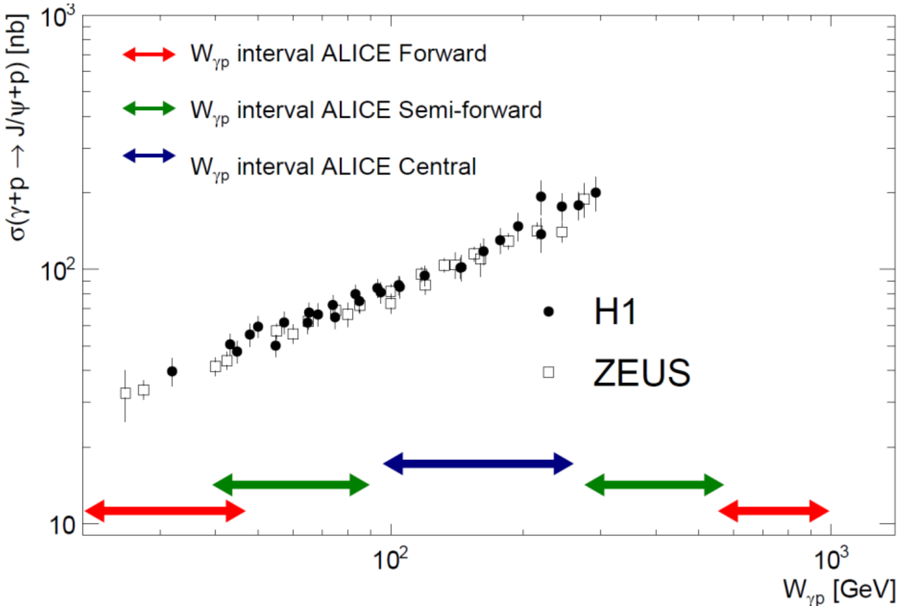
ALI-PREL-117138

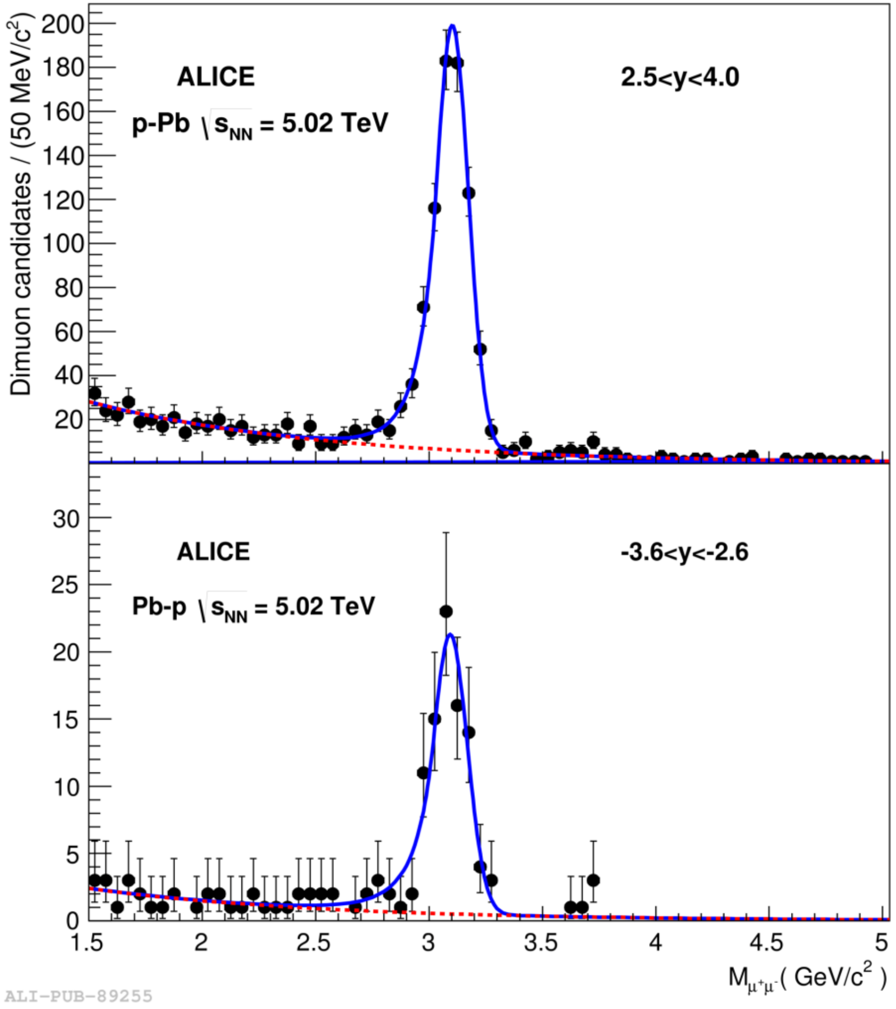
J/ψ in p-Pb and Pb-p

- 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)

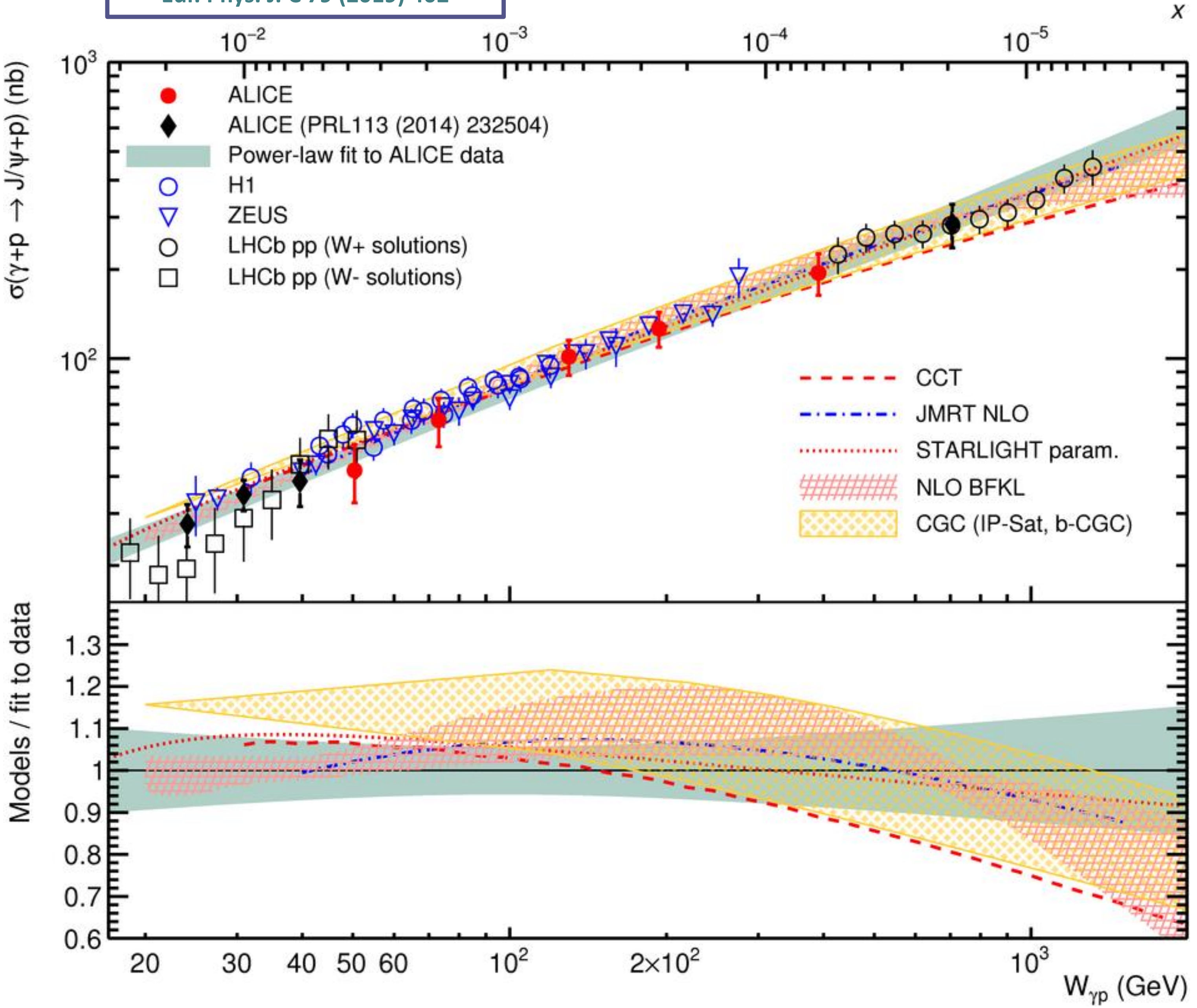




Cross section for J/ψ in γp

Eur. Phys. J. C 79 (2019) 402

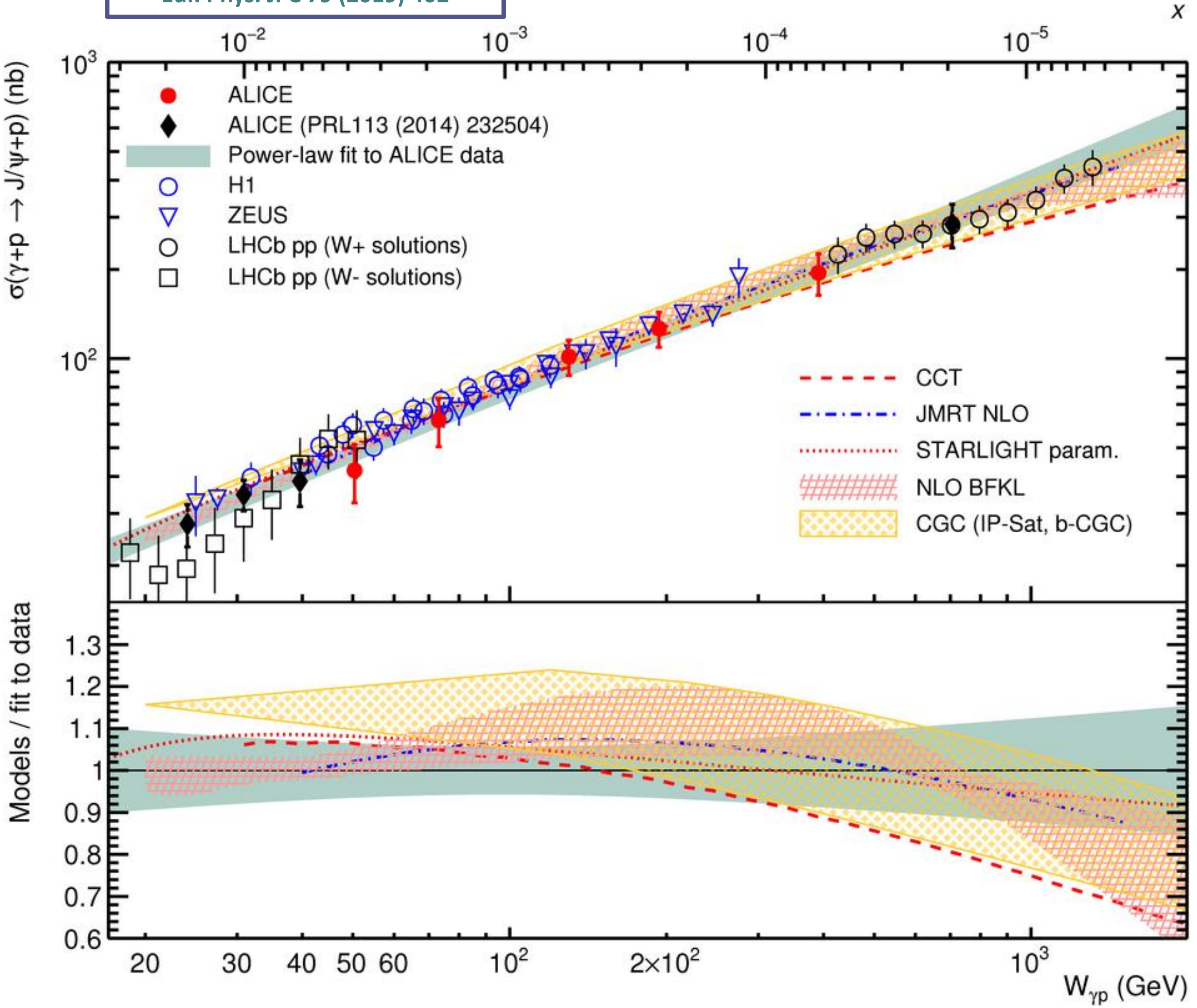
- ALICE data cover continuously from x=2. 10^{-2} to x= 2. 10^{-5}!
- ALICE data are compatible with a power law with exponent 0.70 ± 0.05
- Exponent is compatible with those from H1 (0.67±0.03) and ZEUS (0.69±0.02±0.03)
- LHCb solutions consistent with the power-law fit obtained from ALICE results
- 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



Cross section for J/ψ in γp

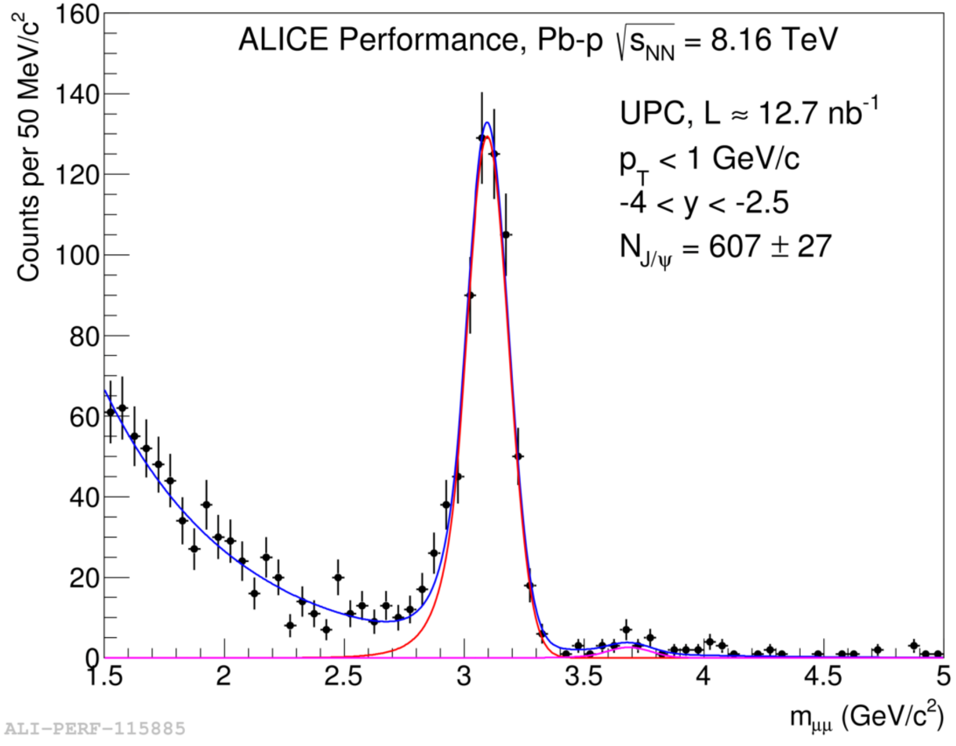
- JMRT: LO model based on a power law. NLO model includes the expected main NLO contributions
- CCT: energy-dependent hot-spot model
- CGC: Color dipole model
- NLO BFKL: BFKL evolution of HERA values
- STARLIGHT parameterization is based on a power law fit using only fixed-target and HERA data

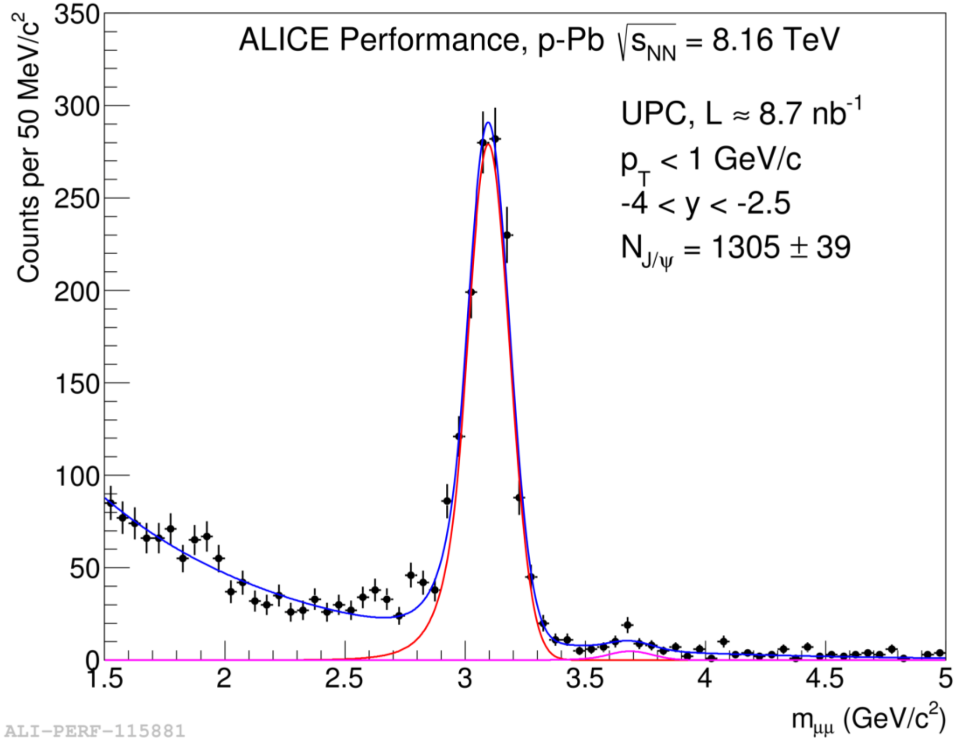
Eur. Phys. J. C 79 (2019) 402



p-Pb at 8 TeV

- Data at 5 TeV and 8 TeV p-Pb and Pb-p were recorded in 2016
- Allow us to extend the cover to the range from 700 GeV to 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





ALICE

Summary and outlook

- ALICE has measured:
  - coherent photoproduction of ρ^0 in Pb-Pb collisions
  - coherent and incoherent photoproduction of J/ψ in Pb-Pb collisions
  - directly, exclusive J/ψ photoproduction in γp collisions
  - the exclusive photo-nuclear production of ψ(2s)
  - coherent J/ψ production in peripheral Pb-Pb collisions (not shown)
- Difference between the J/ψ cross section data and impulse approximation is a direct measurement of moderate nuclear shadowing
- 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
- Bright prospects for Run 3 and Run 4: arXiv:1812.067 – **Stay tuned!**

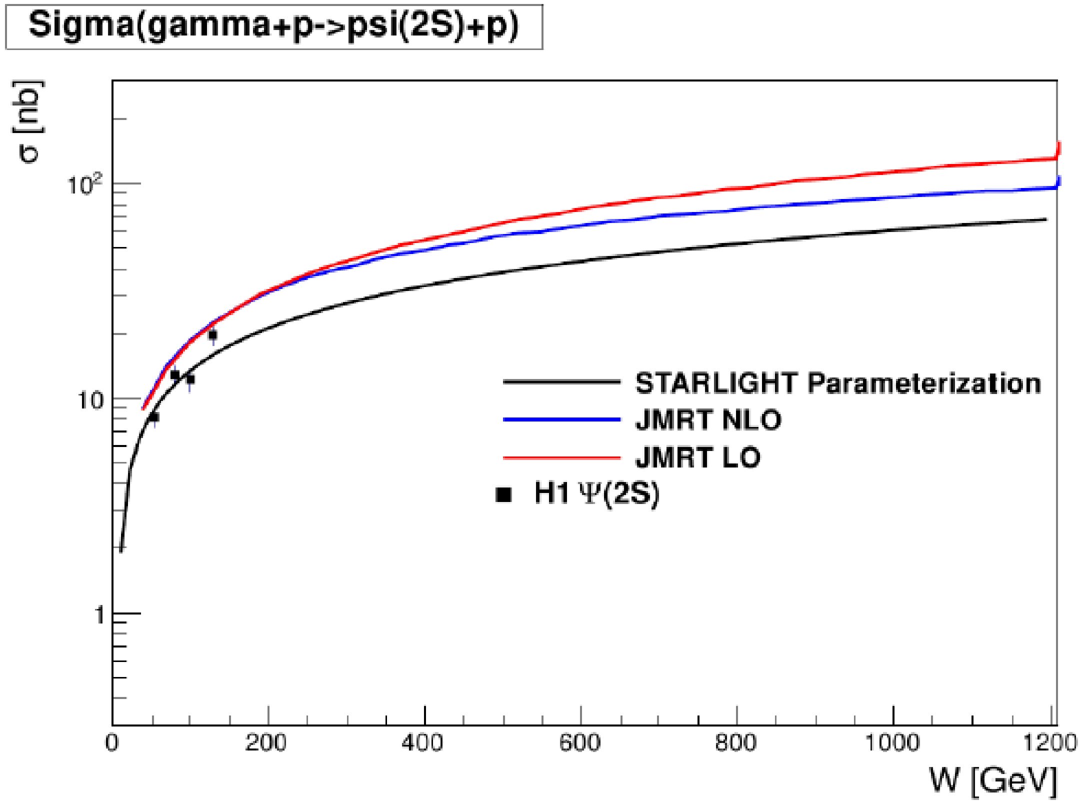
ALICE

Thank you

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
    $<p_T> \approx 60$ MeV/c
  - Incoherent – coupling to single nucleon
    $<p_T> \approx 500$ 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 dE/dx in TPC