Ultra-peripheral collision measurements from ALICE

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ALICE Collaboration

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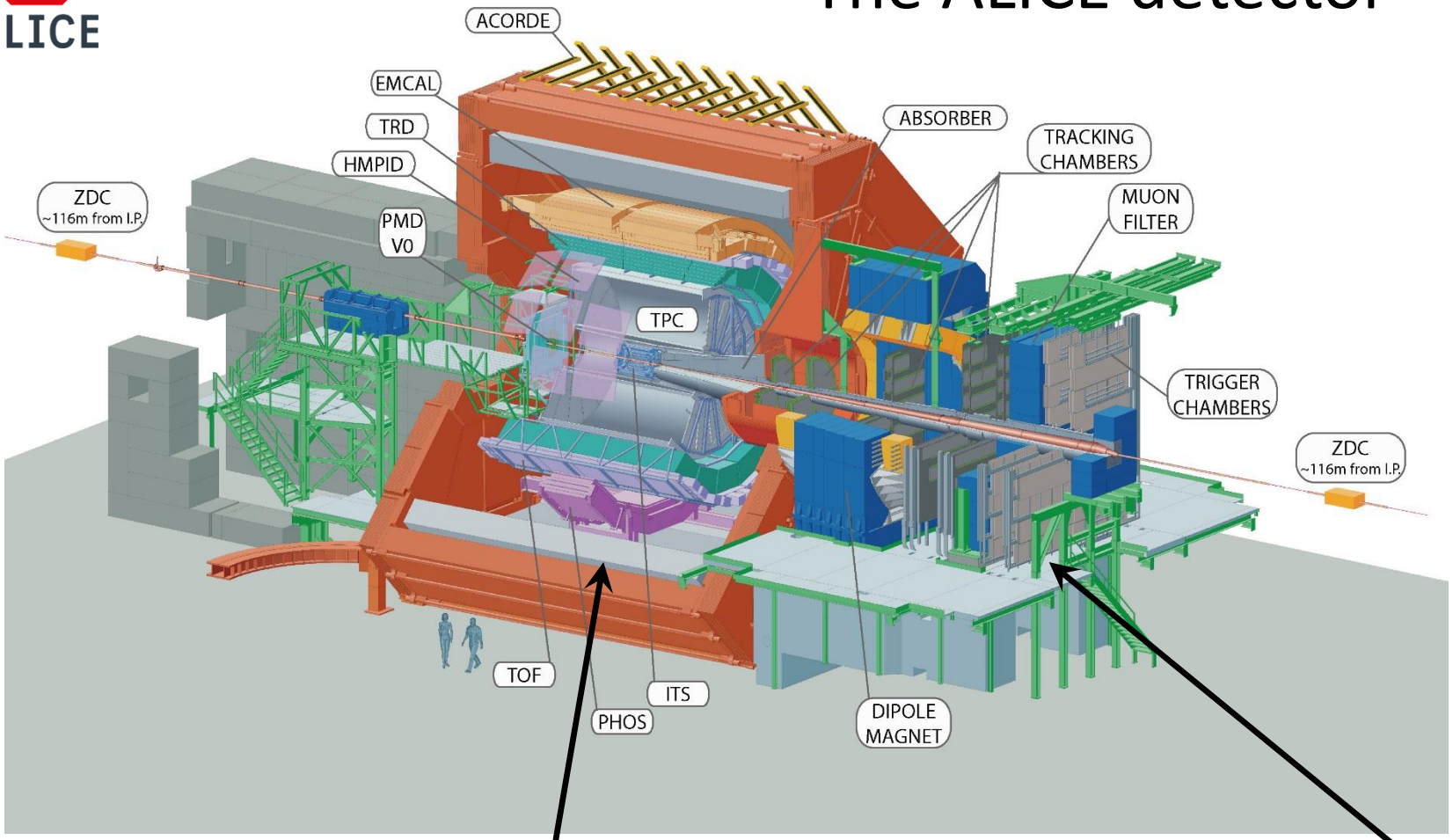
Outline

- ALICE detector
- Run 1 triggers
- UPC background material
- Results from Run 1 analyses
- Trigger changes for Run 2
- Ongoing and planned analyses for Run 2

The ALICE detector



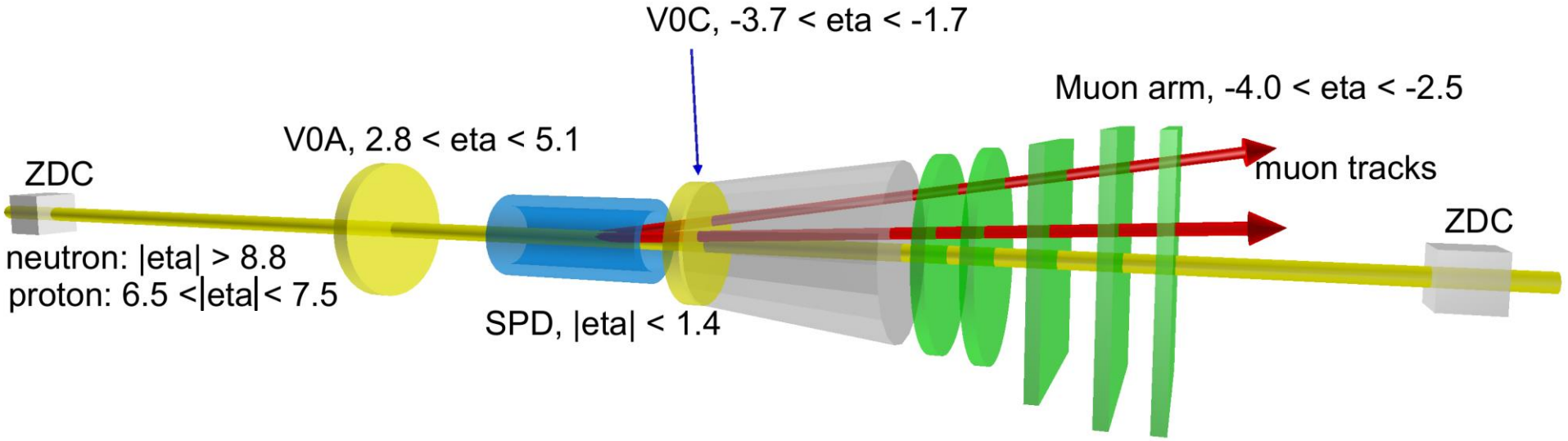
Central detectors:

- TPC for tracking and particle identification ($|\eta|<0.9$)
- TOF and SPD for triggering

Central detectors

Muon Arm

Muon Arm and forward detectors



Muon Arm and trigger detectors

- ❑Triggering, tracking and muon identification
- ❑V0 counters provide veto to exclude events with hadronic interactions
- ❑ZDC can measure n & p from photo-dissociation
- ❑AD (not shown) since Run 2 for improved veto: $(-6.9 < \eta < -4.9)$ and $(4.9 < \eta < 6.3)$

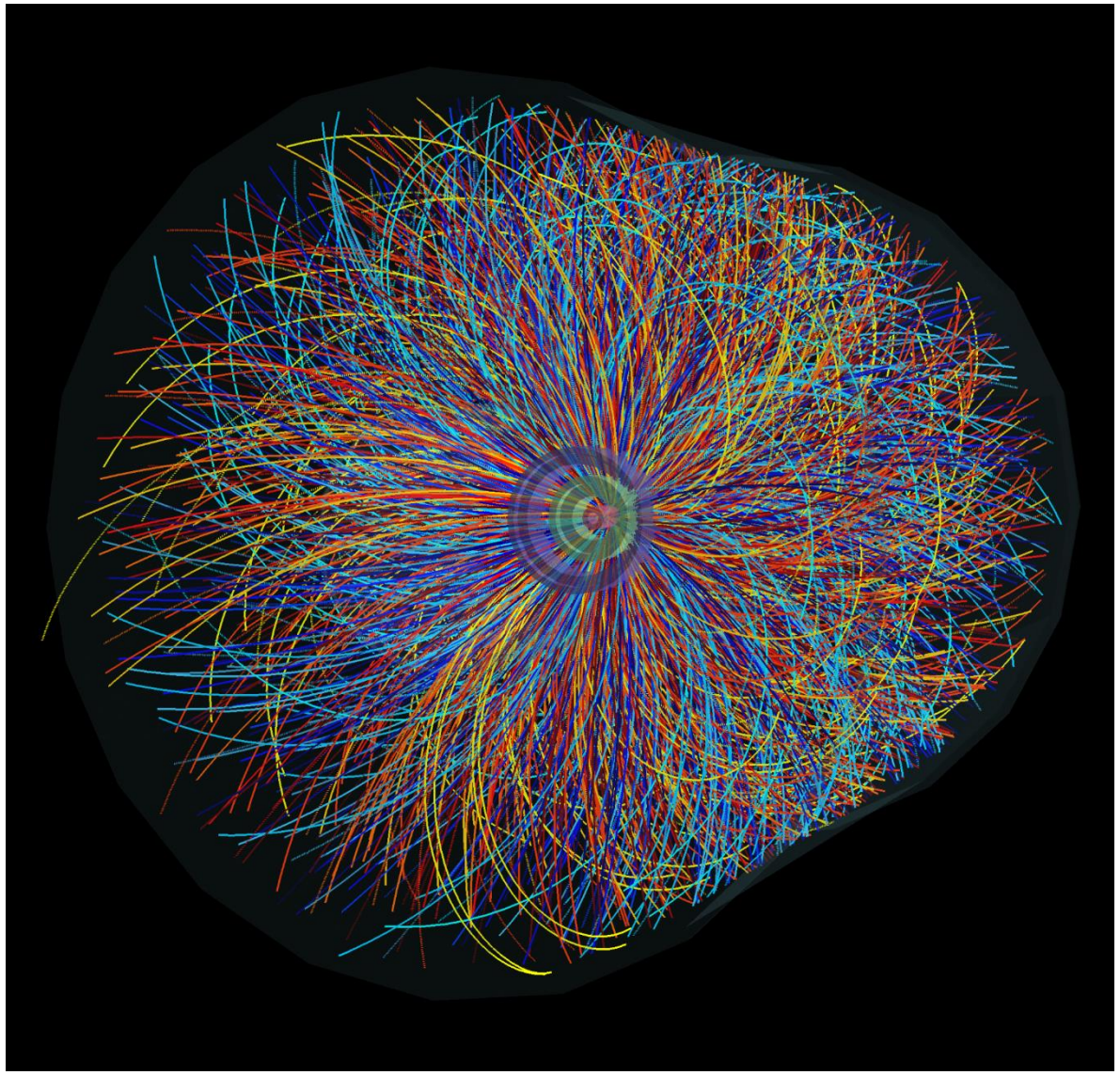
Run 1 UPC triggers

	Mid-rapidity triggers			Muon arm triggers				
	≥2 TOF hits	≥2 SPD hits	V0 veto	1 muon	Di-muon	Muon pt	V0C signal	V0A veto
Pb-Pb 2010		✓*						
		✓	✓	✓				
Pb-Pb 2011		✓ **BtoB†**	✓	✓	✓		**> 1 GeV/c**	✓	✓
p-Pb 2013		✓ **BtoB†**	✓ **BtoB†**	✓	✓	✓	**> 0.5 GeV/c**		✓

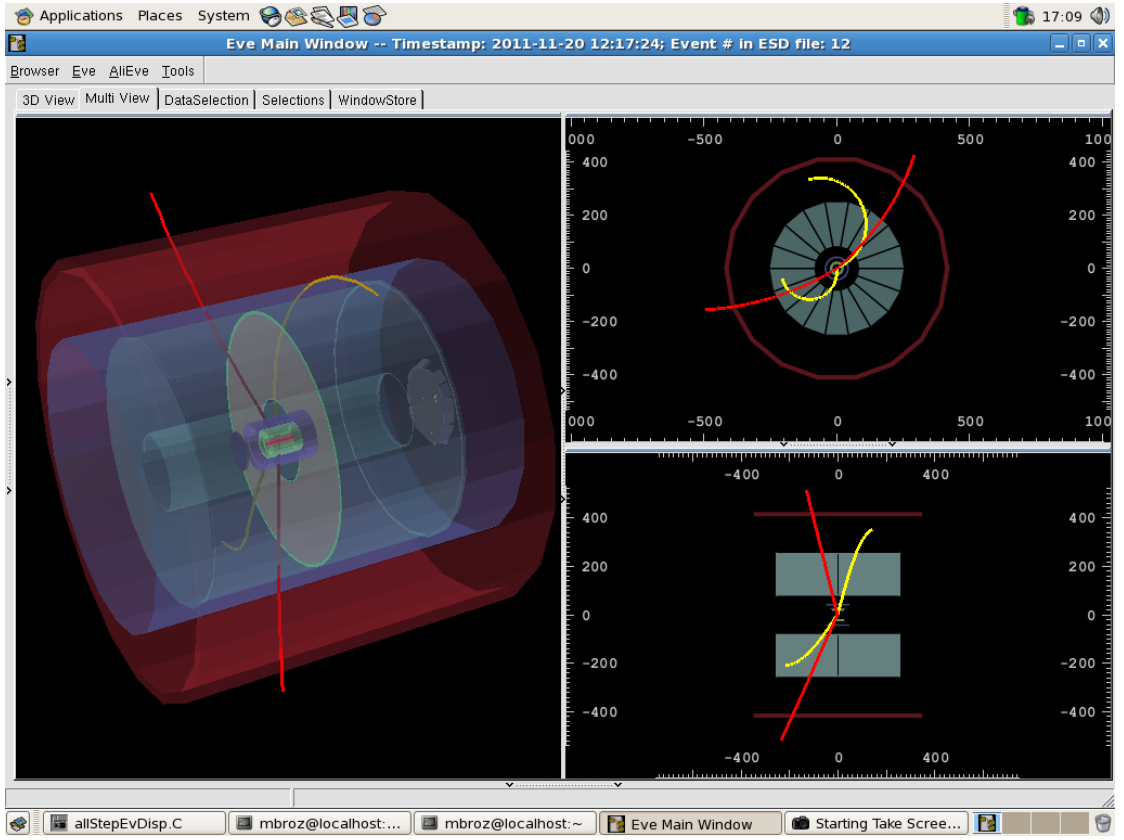
*early, low luminosity runs

† BtoB = back-to-back topology requirement

ALICE events



- ALICE has excellent PID capabilities regardless of event multiplicity

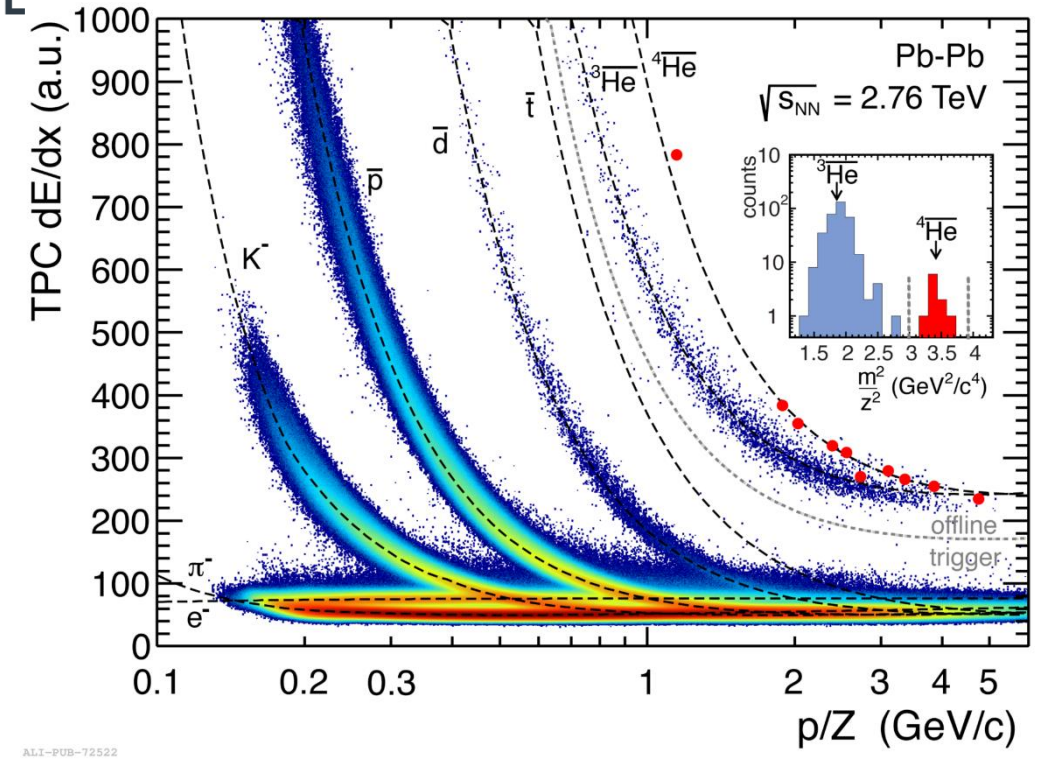


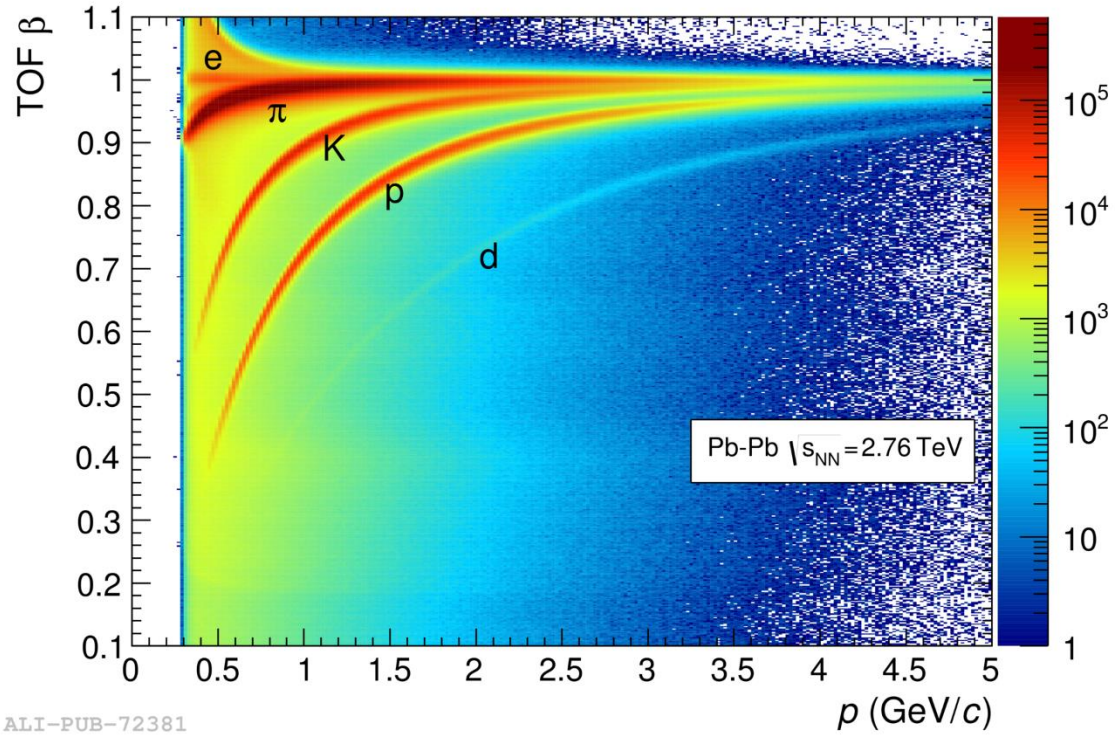
$\psi(2s) \rightarrow \mu^+ \mu^- \pi^+ \pi^-$

Red tracks: μ^+, μ^- Yellow tracks: π^+, π^-

ALICE Collaboration, Phys. Lett. B 752 (2016) 267 (TPC), Int. J. Mod. Phys. A 29 (2014) 1430044 (TOF)

ALICE PID



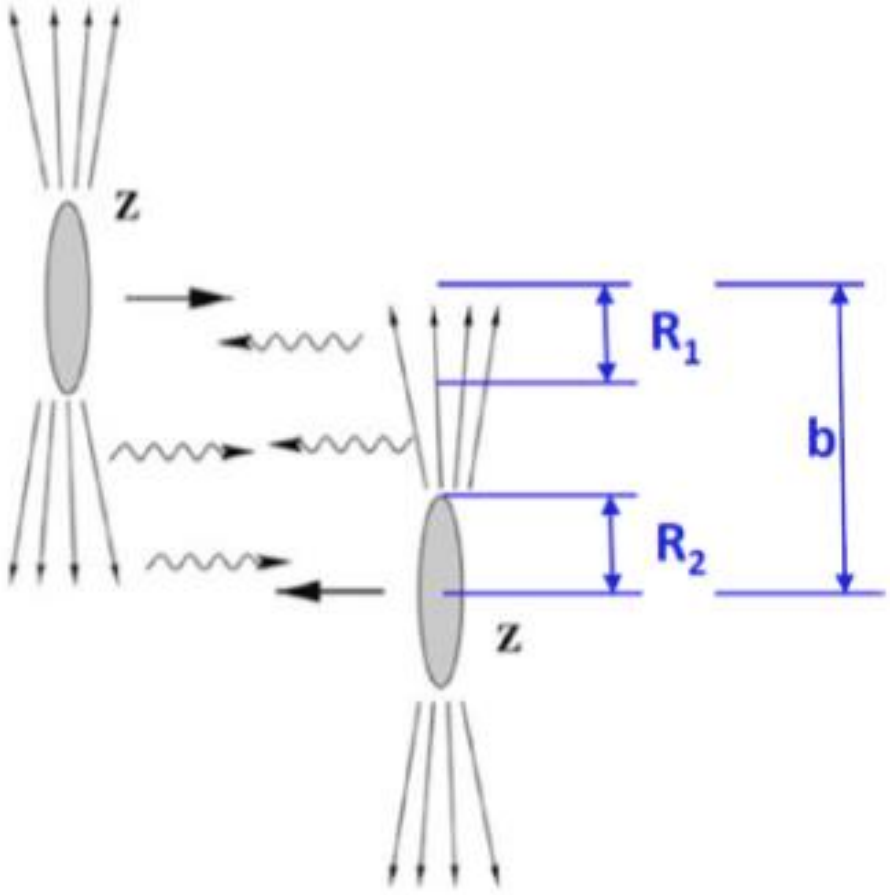


- TPC identifies particles effectively at lower p. In UPC, p_T<0.4 GeV/c for $\pi^{\pm}$.
- $\pi^+\pi^-$ and remaining e^+e^- and $\mu^+\mu^-$ distinguishable using TPC dE/dx.

- TOF identifies particles more effectively at higher p than TPC.

The combined response from different detectors may be used in particle identification.

Photoproduction in ultra-peripheral collisions



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- Ultra-peripheral collisions have impact parameter $>R_1+R_2$.
- EM field of relativistic heavy ion/proton equivalent to photon flux.
- Photon flux $\propto Z^2$ (=6724 for Pb) so heavy ions are an excellent photon source.
- Photo-nuclear, photon-nucleon and γγ interactions can occur in ultra-peripheral collisions.
- Photon energy spectrum extends to $\gamma\hbar c/R$
  - γ = Lorentz factor
  - R≈7 fm for heavy ions

Nuclear gluon distribution and dσ/dy

- The cross section dσ/dy for the interaction A+A->A+A+V is given by

$$\frac{d\sigma}{dy} = \omega_1 \frac{dn_\gamma}{d\omega_1} \sigma_{\gamma A \rightarrow VA}(\omega_1) + \omega_2 \frac{dn_\gamma}{d\omega_2} \sigma_{\gamma A \rightarrow VA}(\omega_2)$$

  where 1, 2 label which colliding particle emitted the photon.

- Ryskin[†] (1993) relates dσ/dt and the gluon distribution g(x,Q^2):

$$\left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{\alpha_s{}^2 \Gamma_{ee}}{3\alpha M V^5} 16\pi 3 \left[x g\left(x, \frac{M^2}{4}\right)\right]^2$$

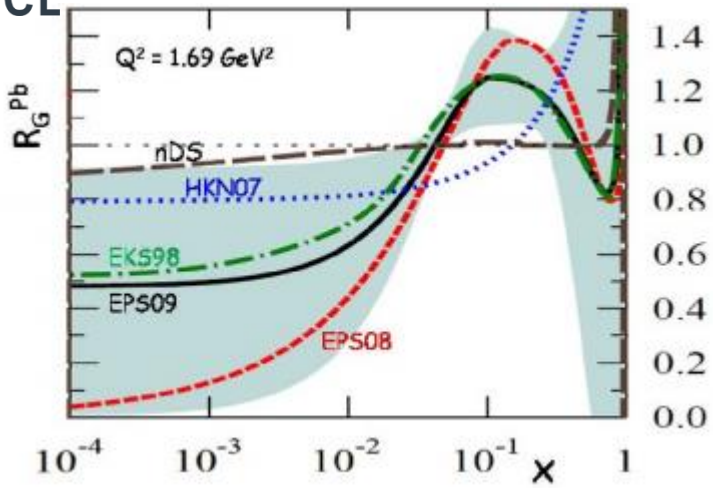
  for the interaction γ + A → V + A.

- During the calculation of dσ/dy from dσ/dt the proportionality dσ/dt $\propto$ [g(x,Q^2)]^2 factorizes leading to

$$\frac{d\sigma}{dy} \propto [g(x,Q^2)]^2$$

[†] Z. Phys. C 57 (1993) 89-92

JHEP 0904 (2009) 065
& arXiv:1106.5682



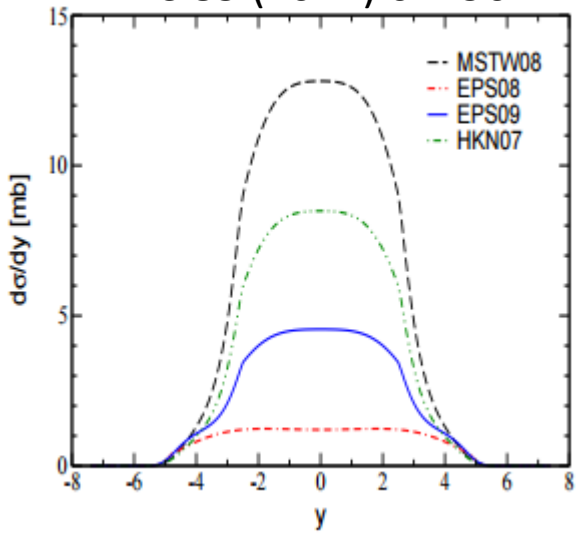
Exclusive J/ψ production

- Uncertainty in the nuclear gluon distribution,

$$R_G = \frac{g_A(x,Q^2)}{A \cdot g_p(x,Q^2)}$$

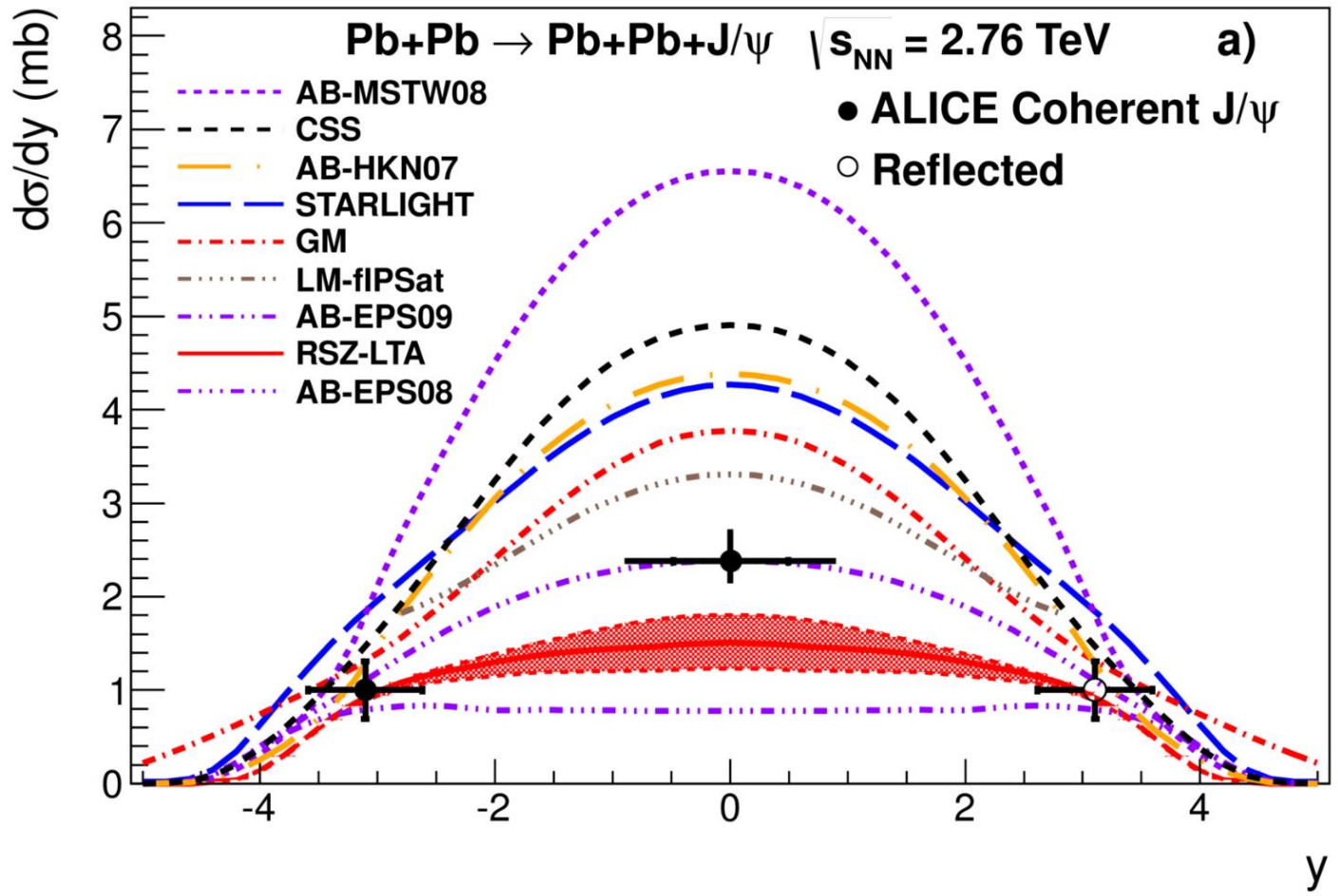
leads to uncertainty in the cross section $d\sigma/dy$.

PRC 85 (2012) 044904



ALICE Collaboration, Phys. Lett. B 718 (2013) 1273 (Muon arm), EPJC 73 (2013) 2617 (Central Barrel)

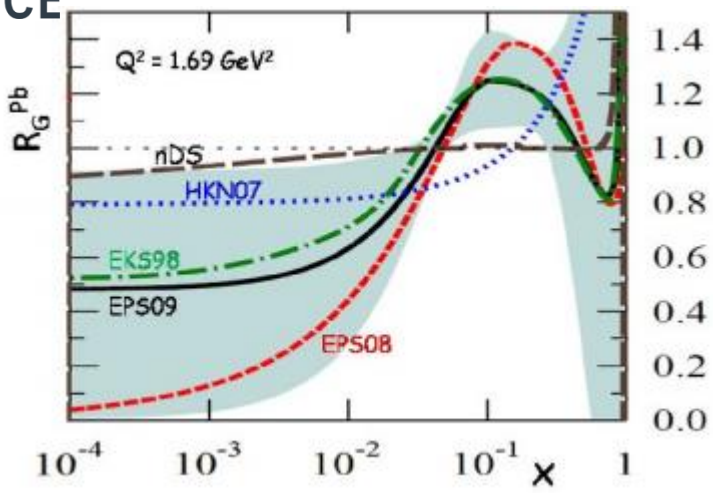
Exclusive J/ψ production



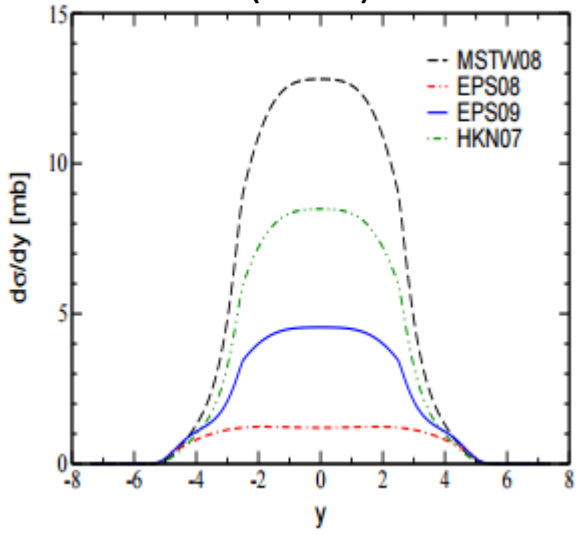
- Cross section much smaller than impulse approximation and STARLIGHT
- Consistent with models with moderate gluon shadowing (AB-EPS09 parameterization)

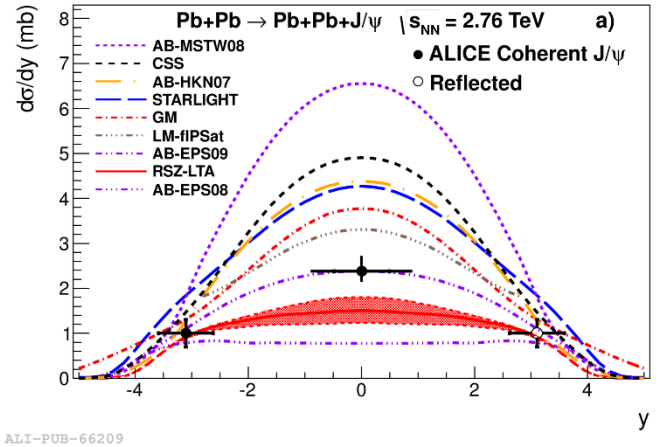
Exclusive J/ψ production

JHEP 0904 (2009) 065
& arXiv:1106.5682



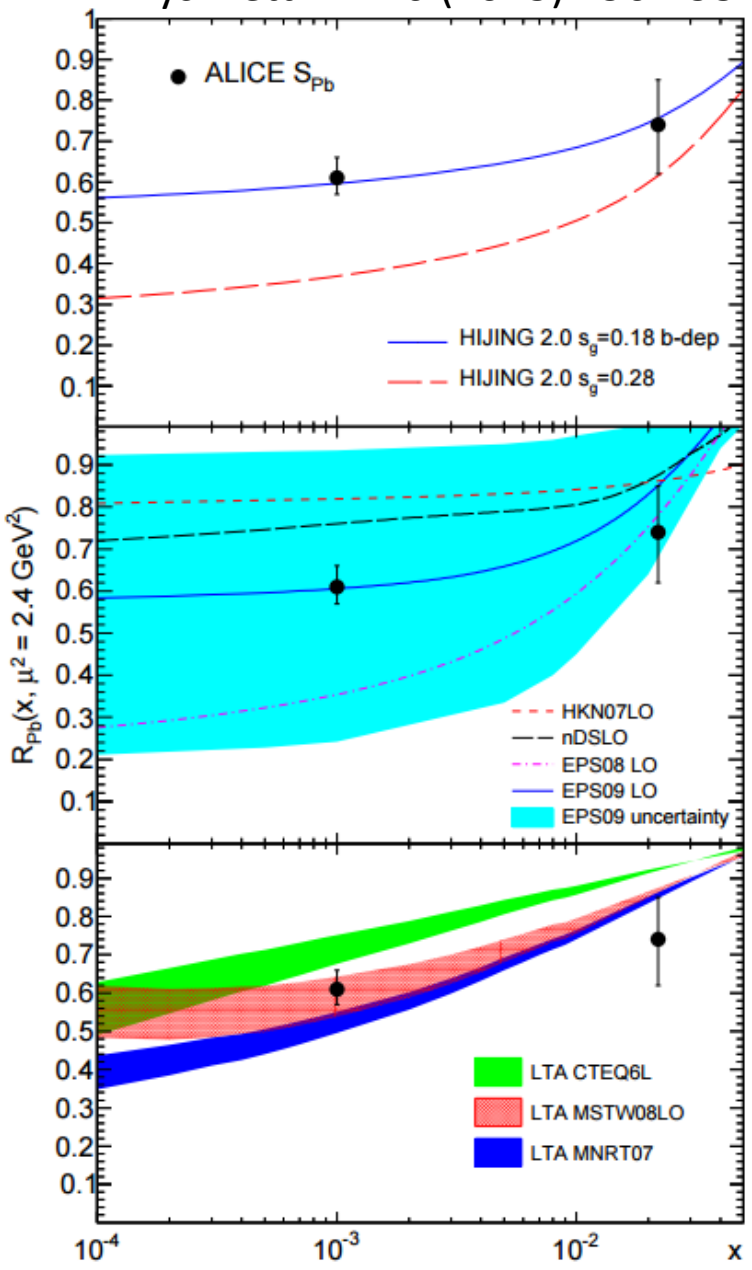
PRC 85 (2012) 044904





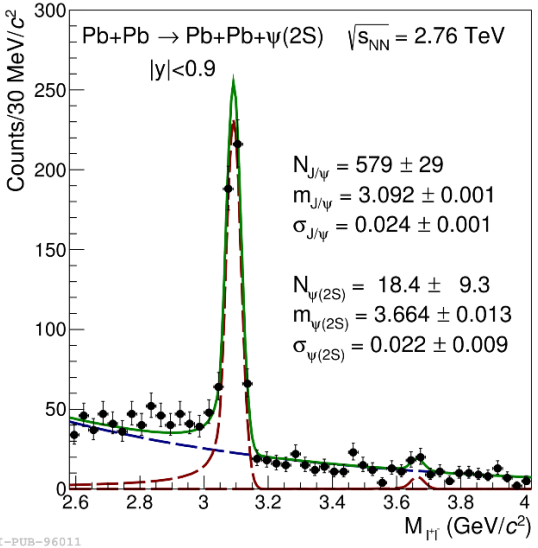
- Guzey, Kryshen, Strikman and Zhalov (2013) converted ALICE dσ/dy values back to R_G^{Pb} values.
- The dσ/dy measurements provide significant constraints on the models.

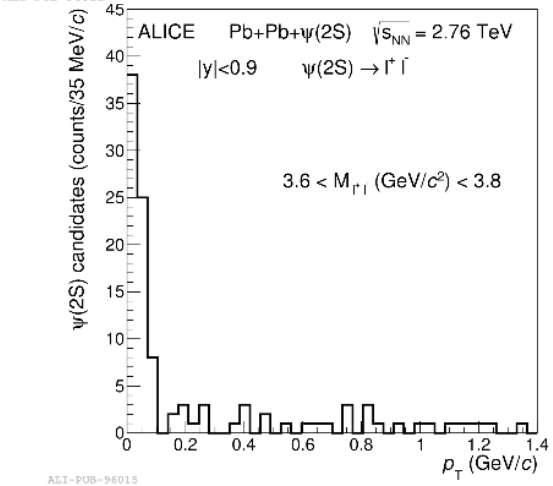
Phys. Lett. B 726 (2013) 290-295



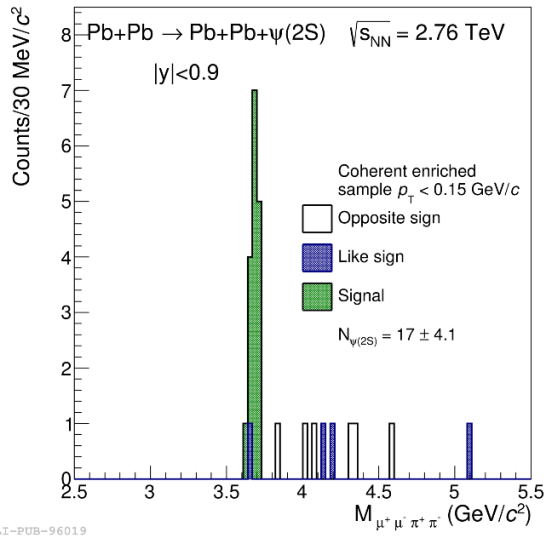
ALICE Collaboration Phys. Lett. B 751 (2015) 358

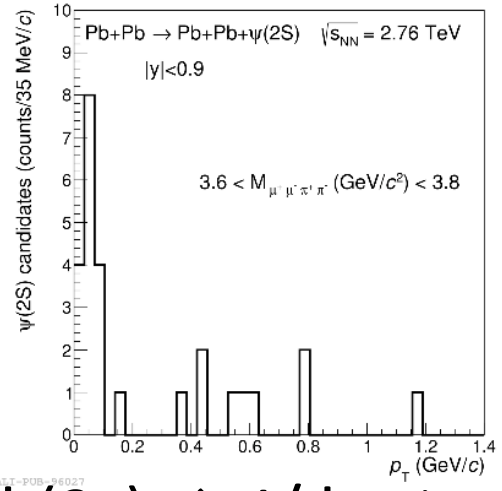
Exclusive ψ(2s) production



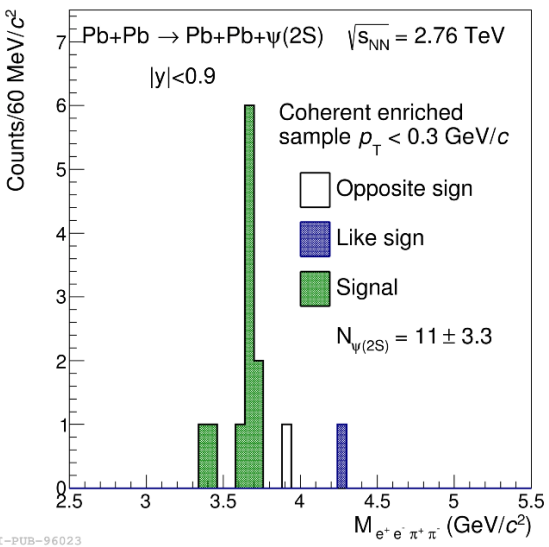


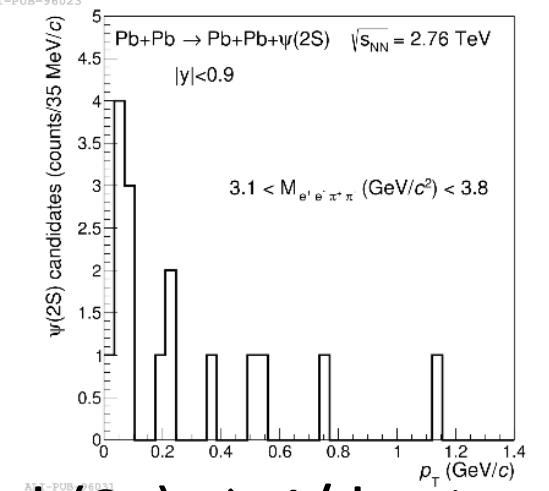
ψ(2s) → $l^+ l^-$





ψ(2s) → J/ψ $\pi^+ \pi^-$
→$\mu^+ \mu^- \pi^+ \pi^-$





ψ(2s) → J/ψ $\pi^+ \pi^-$
→$e^+ e^- \pi^+ \pi^-$

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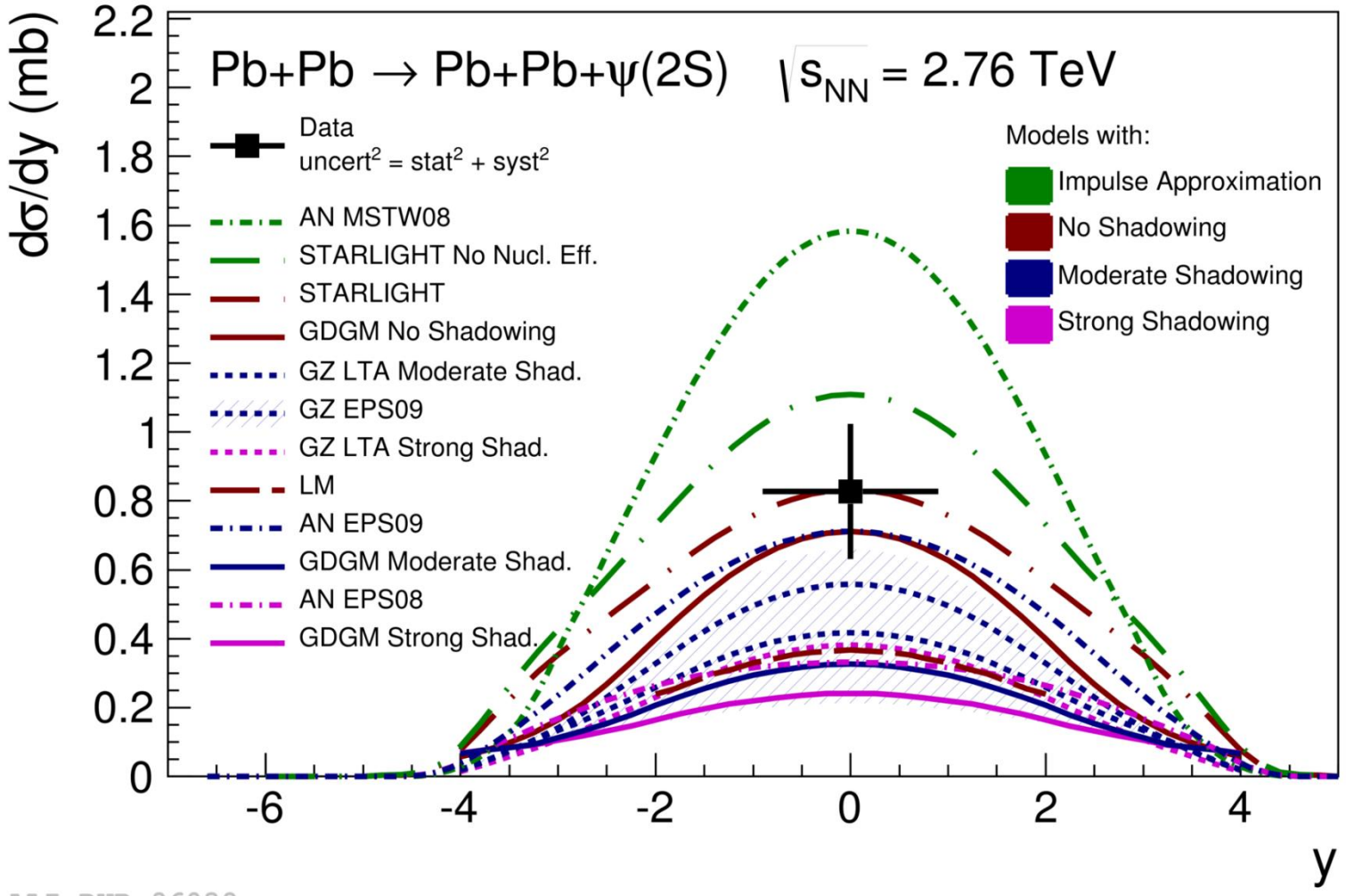
Exclusive ψ(2s) production



- Cross section smaller than impulse approximation
- Cross section larger than cases with strong shadowing
- Consistent with models with no shadowing or moderate shadowing (AN EPS09)
- Large (23%) uncertainties

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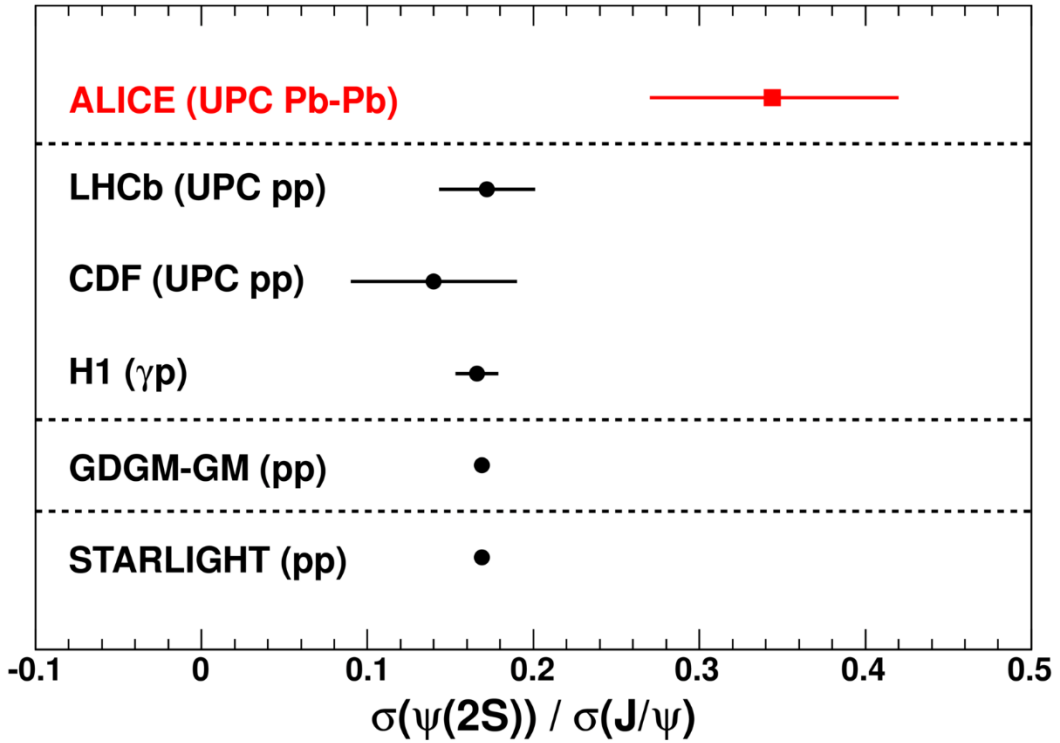
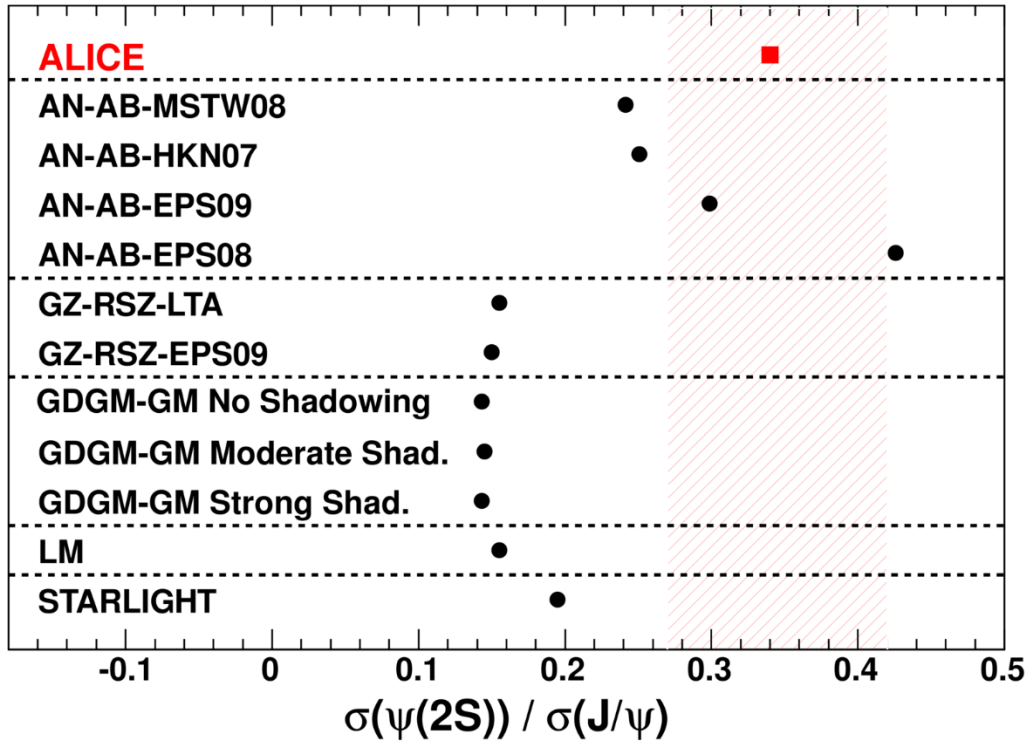
Exclusive ψ(2s) production



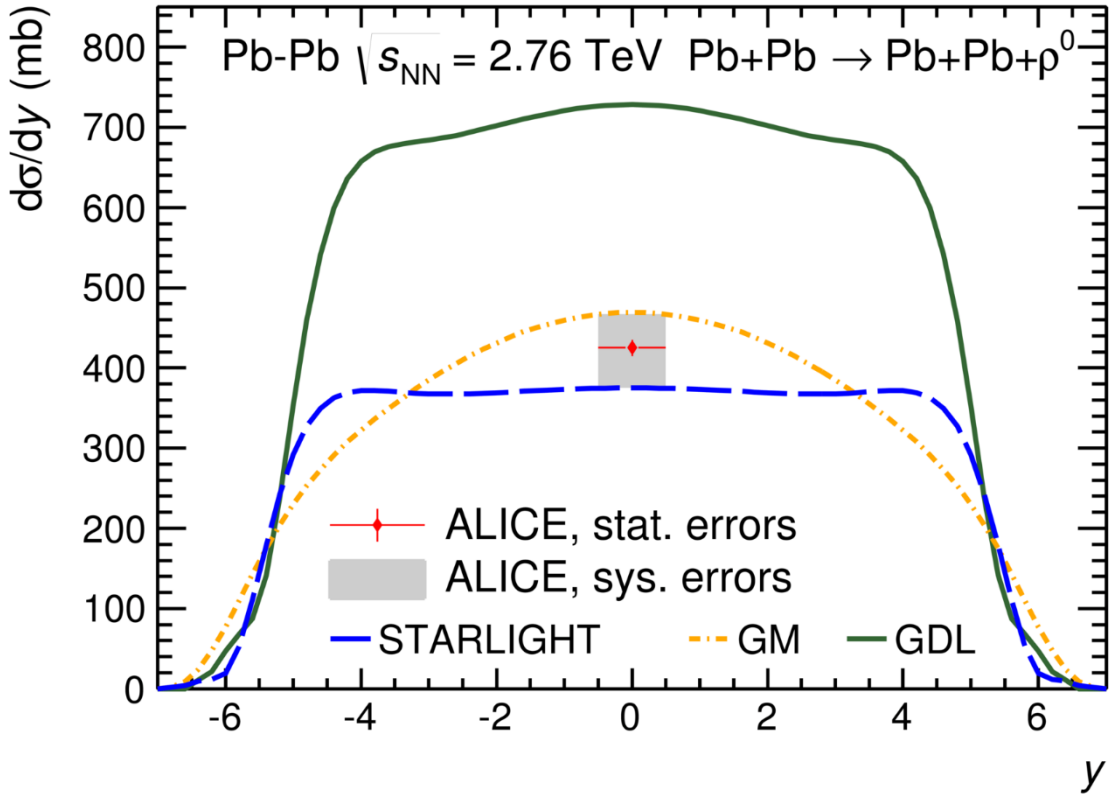


- Enhancement of ψ(2s) cross section relative to J/ψ in Pb-Pb compared to p-p
- Large error, so needs confirmation

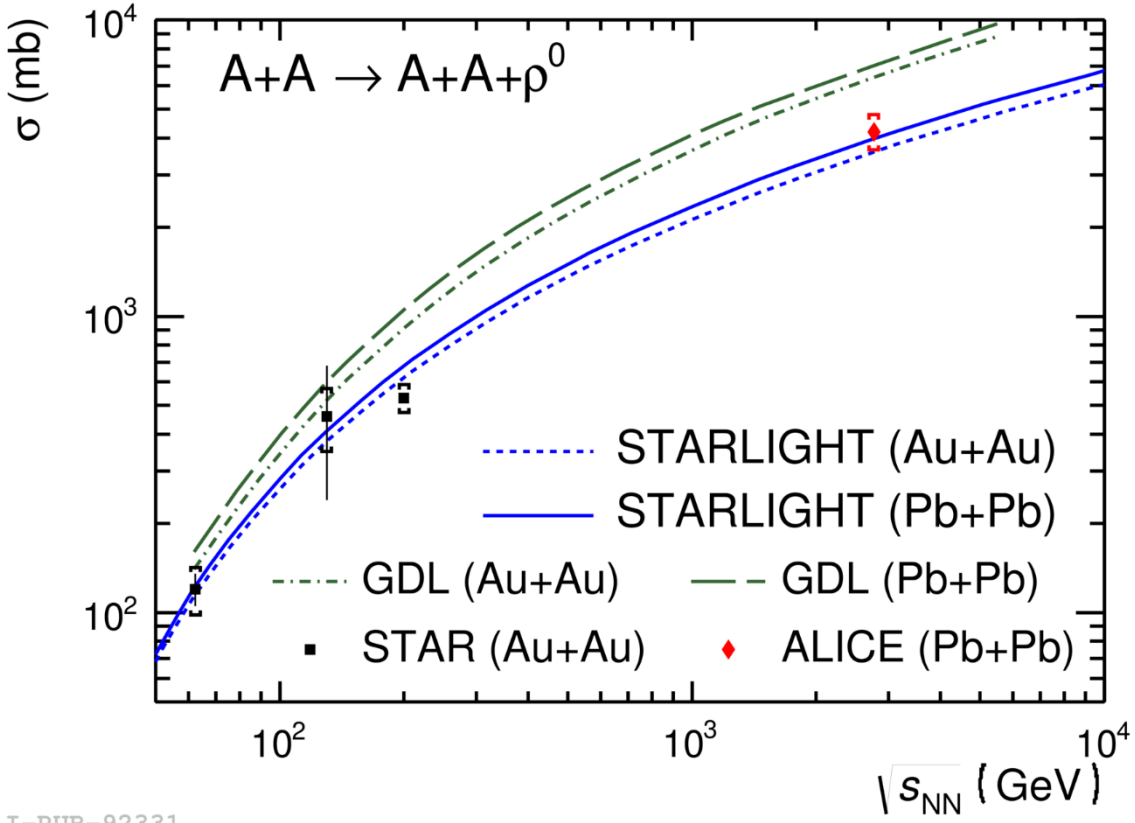
- Measurement consistent with moderate gluon shadowing (AN-AB-EPS09)

ALICE Collaboration, JHEP 09 (2015) 095

Exclusive ρ^0 production



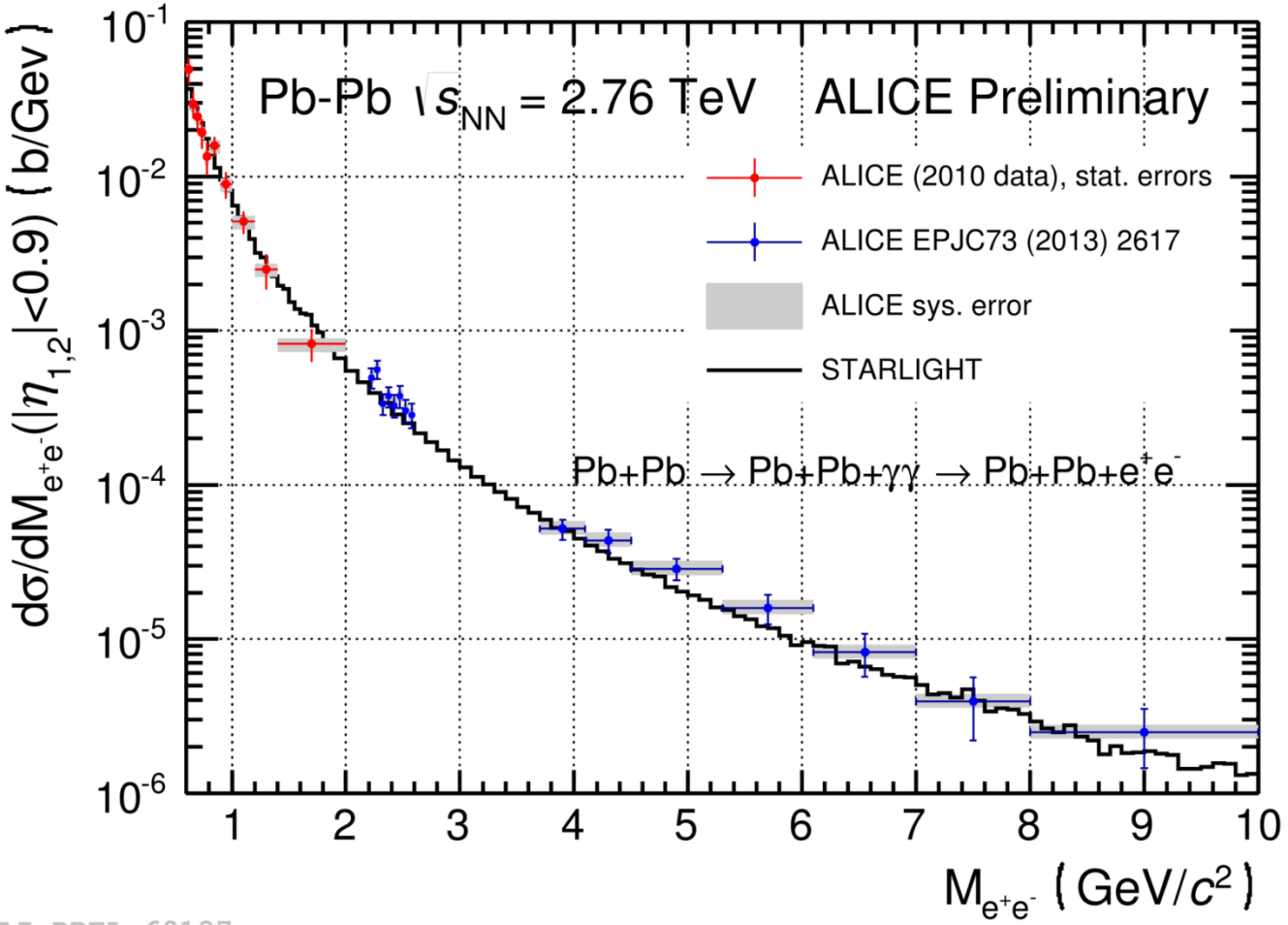
- GDL 2X larger than STARLIGHT
- ρ^0 measurement consistent with STARLIGHT and GM



- ρ^0 cross section follows trend at STAR
- STARLIGHT matches ρ^0 measurements
- Difference in models due to inelastic nuclear shadowing.

Joakim Nystrand (ALICE), arXiv:1408.0811

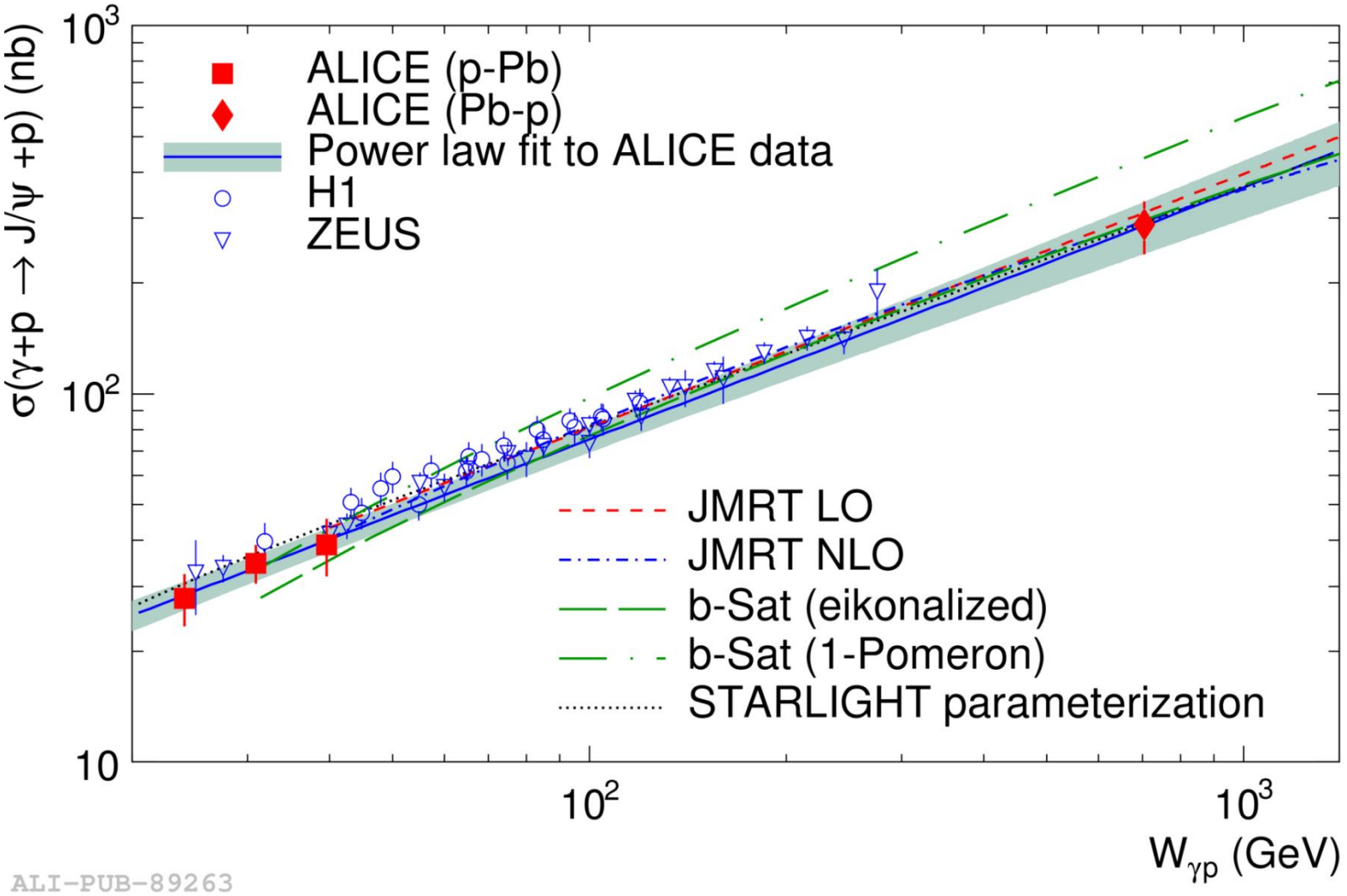
γγ→e⁺e⁻ measurement



- Good agreement between measured γγ→e⁺e⁻ cross sections and STARLIGHT for $0.6 < M_{ee} < 10$ GeV/c^2.
- ATLAS finds similar agreement with STARLIGHT for γγ→ μ⁺μ⁻ from $10 < M_{ee} < 100$ GeV/c^2.
- Is there room for "strong field effects" not included in STARLIGHT?

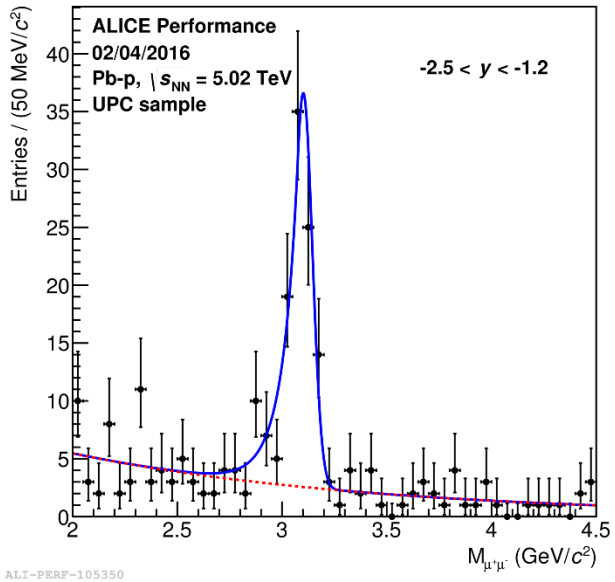
ALICE Collaboration, PRL 113 (2014) 232504

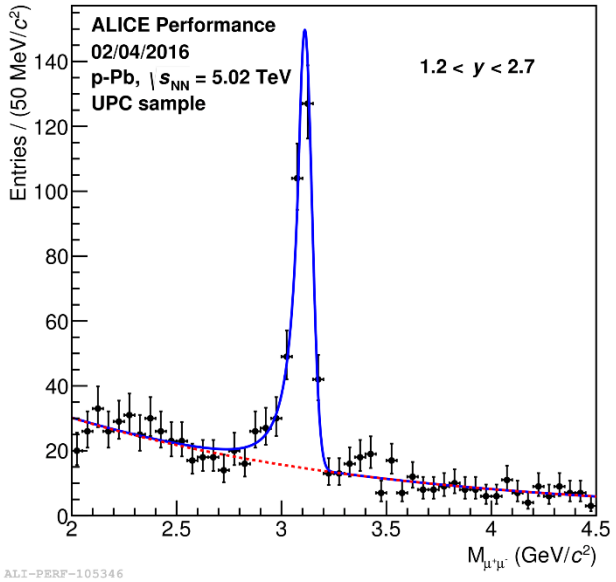
Exclusive J/ψ production in p-Pb

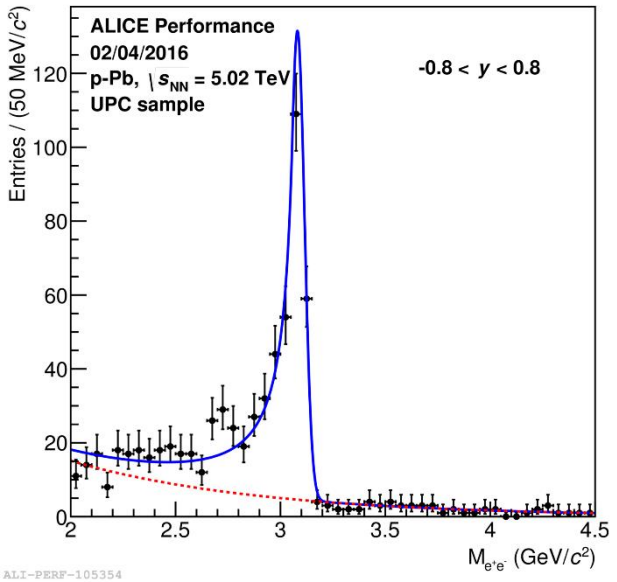


- Good agreement with previous measurments for $21 < W_{\gamma p} < 45$ GeV (p-Pb)
- Measurement for $580 < W_{\gamma p} < 950$ GeV (p-Pb) consistent with power law: $\sigma \propto W_{\gamma p}^{\delta}$
  - ALICE: $\delta = 0.68 \pm 0.06$
  - ZEUS: $\delta = 0.69 \pm 0.04$
  - H1: $\delta = 0.67 \pm 0.03$
- Suggests no change in gluon PDF for proton from HERA to LHC energies - PRL 113 (2014) 232504

Exclusive J/ψ production in p-Pb







-2.5 < y < -1.2
41 < $W_{\gamma p}$ < 86 GeV

1.2 < y < 2.7
287 < $W_{\gamma p}$ < 549 GeV

-0.8 < y < 0.8
100 < $W_{\gamma p}$ < 246 GeV

- New measurements expected between current ones and in Run 2 at even larger $W_{\gamma p}$.
- ALICE will measure in range 21 < $W_{\gamma p}$ < 1160 GeV (x≈10^{-2} to 10^{-5})

Run 2 UPC triggers

	Mid-rapidity triggers				Muon arm triggers				
	≥2 TOF hits	≥2 SPD hits	AD veto	V0 veto	1 muon	Di-muon	Muon pt	V0C signal	V0A veto
Pb-Pb 2015		✓ **BtoB†**	✓ **BtoB†**	✓*	✓		✓	**> 1 GeV/c**	✓	✓
p-Pb 2016		✓ **BtoB†**	✓ **BtoB†**	✓*	✓	✓	✓	**> 0.5 GeV/c**		✓

* AD improves veto at forward rapidities: $(-6.9 < \eta < -4.9)$ and $(4.9 < \eta < 6.3)$

† BtoB = back-to-back topology requirement

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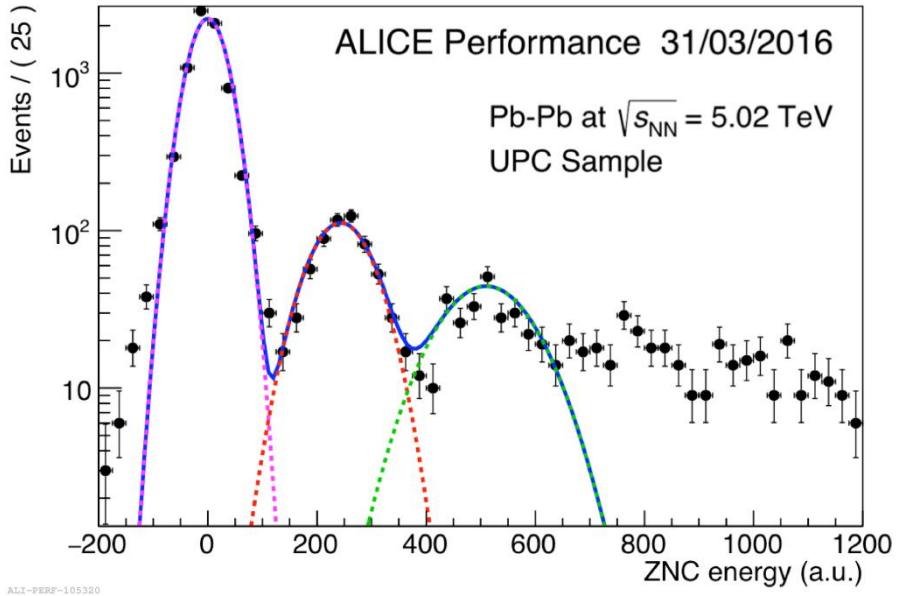
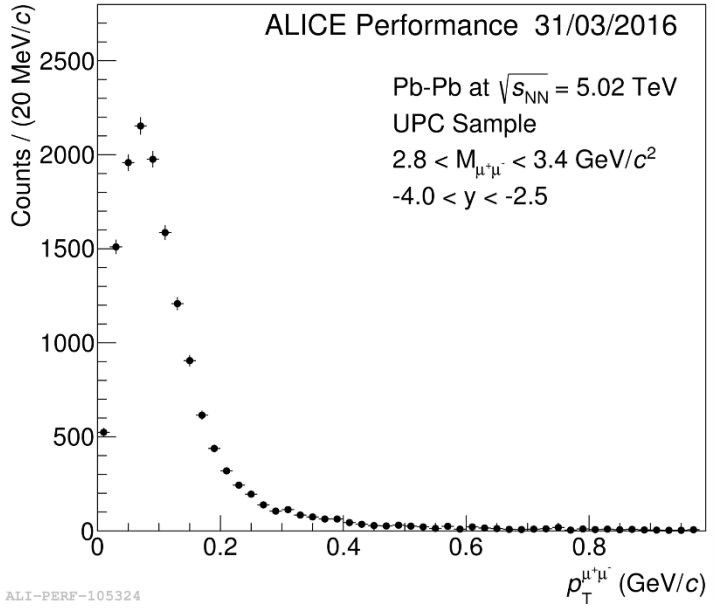
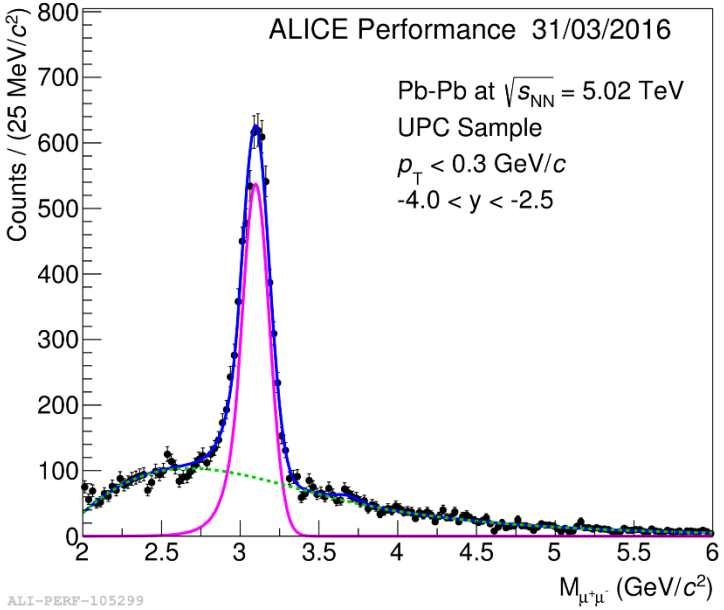
Run 2 Pb-Pb (Nov/Dec 2015)

- Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
  - Mid-rapidity: Integrated luminosity 6X larger than in Run 1
  - Muon arm: Integrated luminosity 50X larger than in Run 1
  - J/ψ cross section expected to increase by 50% (STARLIGHT)
  - ϒ cross section expected to increase by 300% (STARLIGHT)
  - Measure J/ψ at lower values of x using ZDCs to identify photodissociation events



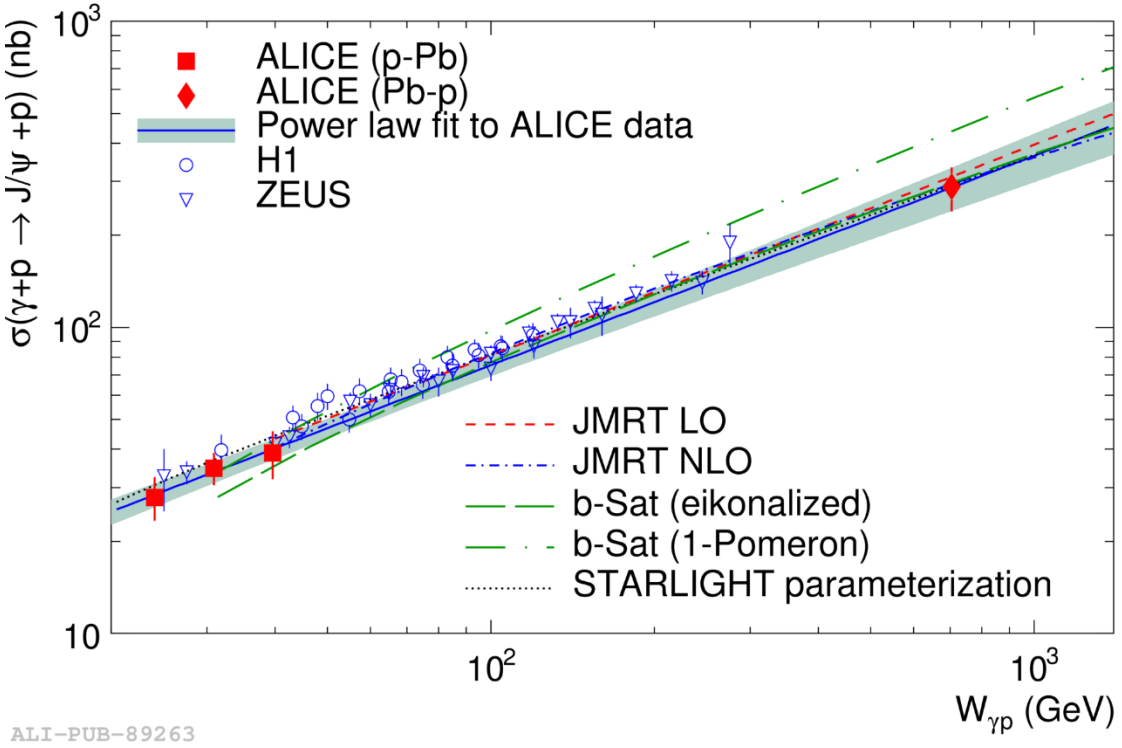




ALICE Collaboration, PRL 113 (2014) 232504

Run 2 p-Pb (Nov/Dec 2016)

- p-Pb at $\sqrt{s_{NN}}$ = 5 and 8 TeV
  - Pb-p at $\sqrt{s_{NN}}$= 8 TeV: can measure $W_{\gamma p}$ > 1 TeV.
  - Does gluon saturation occur?



?

- **Continued power law?**
- **Gluon saturation?**

Run 2 measurements

- Run 2 Pb-Pb and p-Pb data will allow for results at higher energies ($\sqrt{s_{NN}}$ and $W_{\gamma p}$) with higher statistics and smaller statistical and systematic uncertainties.
- Higher statistics will allow for more differential measurements in bins of y, p_T for example.
- At higher energies new particles may be measured such as η_C and Υ.
- Tighter constraints for models may be obtained.
- Some open questions may be investigated:
  - Does power law dependence of $\sigma_{\gamma p \to J/\psi p}$ continue for J/ψ?
  - Is the enhancement in ratio σ(ψ(2s))/σ(J/ψ) for Pb-Pb confirmed?

Summary

- A variety of Run 1 results from ALICE provide new constraints on models.
- The results tend to favor models with moderate gluon shadowing.
- Current results for J/ψ can't distinguish definitively whether saturation is occurring.
- Ongoing and planned analyses for Run 2 will provide more results at higher energies and with more statistics and smaller uncertainties.