ALICE results on vector meson photoproduction in ultraperipheral p-Pb and Pb-Pb collisions

Evgeny Kryshen (CERN)
on behalf of the ALICE collaboration

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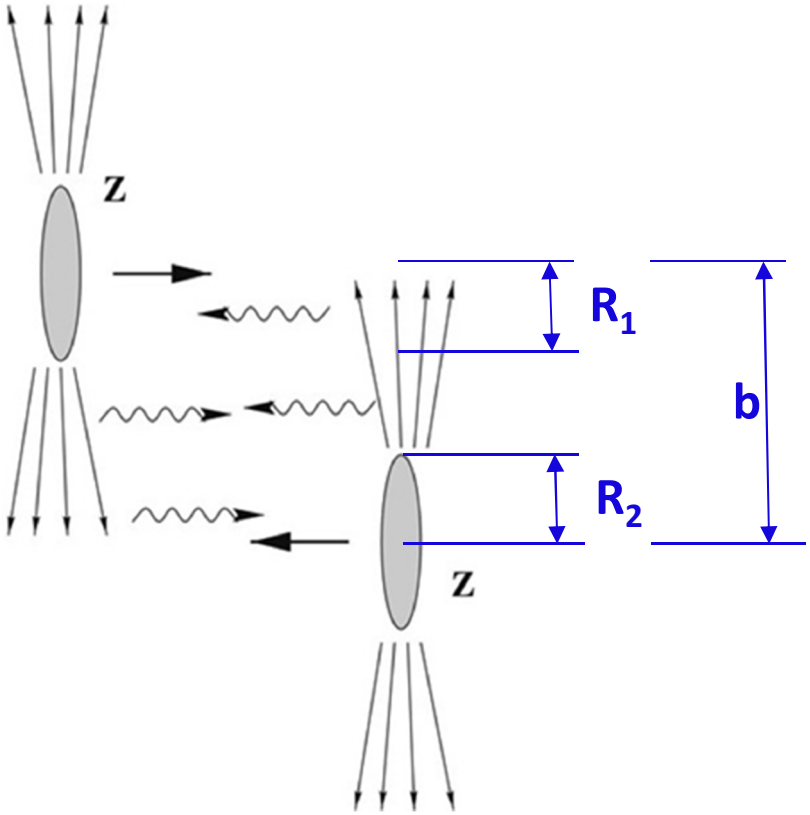
August 28, 2014

LHC as a γPb and γp collider



Ultra-peripheral (UPC) collisions: $b > R_1+R_2$

→ hadronic interactions strongly suppressed

High photon flux

→ well described in Weizsäcker-Williams approximation (quasi-real photons)

→ flux proportional to Z^2

→ high cross section for γ-induced reactions

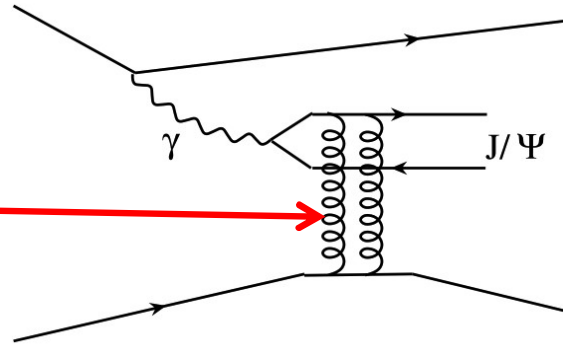
Pb-Pb and p-Pb UPC at LHC can be used to study γ-Pb, γp and γγ interactions at higher center-of-mass energies than ever before

Recent review on UPC physics: Phys. Rept. 458 (2008) 1-171

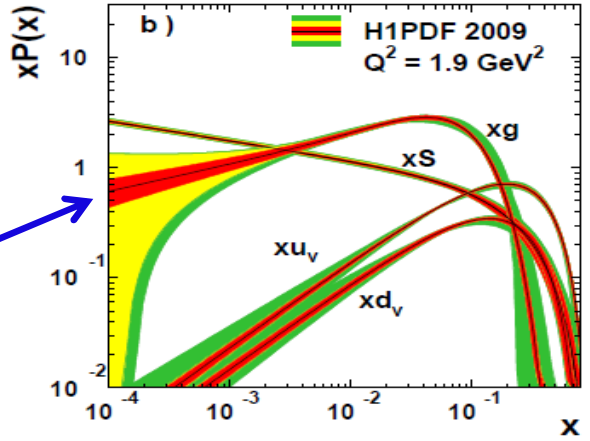
J/ψ photoproduction in UPC

- LO pQCD: coherent J/ψ photoproduction cross section is proportional to the **square of the gluon density in the target**:

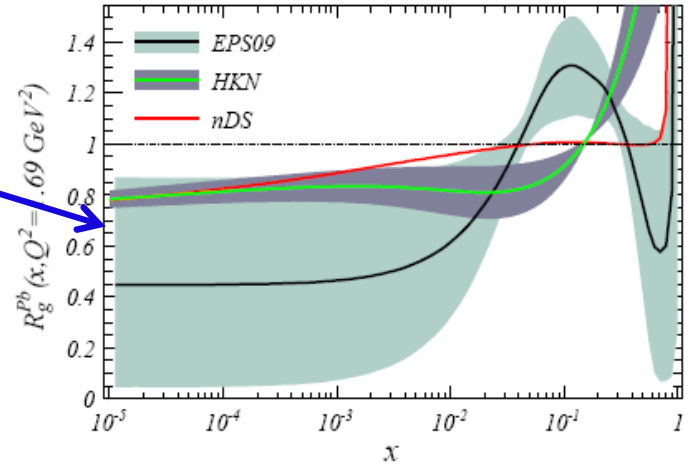
$$\left.\frac{d\sigma_{\gamma A\to J/\psi A}}{dt}\right|_{t=0} = \frac{M_{J/\psi}^3 \Gamma_{ee} \pi^3 \alpha_s^2(Q^2)}{48\alpha_{\rm em} Q^8}\left[x g_A(x,Q^2)\right]^2$$



- Mass of J/ψ serves as a hard scale: $Q^2 \sim \frac{M_{J/\psi}^2}{4} \sim 2.5\ \mathrm{GeV}^2$
- Bjorken x ~ 10^{-2} – 10^{-5} accessible at LHC: $x = \frac{M_{J/\psi}^2}{W_{\gamma p}^2}$
- J/ψ photoproduction in p-Pb UPC (proton target) allows one to probe poorly known **gluon distribution in the proton at low x** and search for **saturation effects**



- J/ψ photoproduction in Pb-Pb UPC (lead target) provides information on **gluon shadowing in nuclei at low x** which is essentially unconstrained by existing data



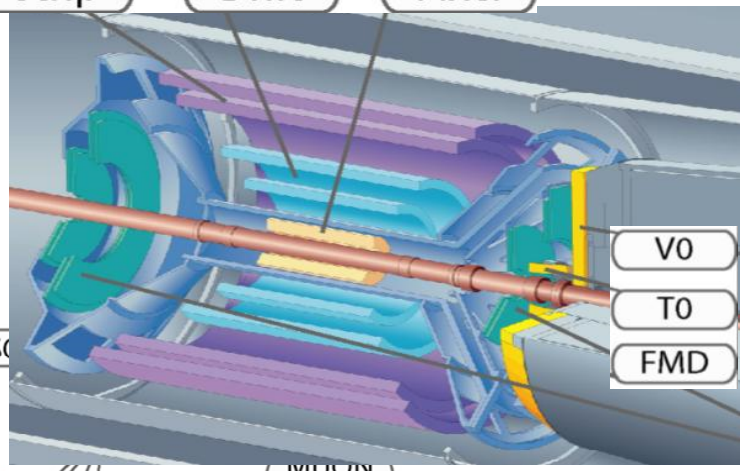
$$R_g^A(x,Q^2) = \frac{g_A(x,Q^2)}{A g_p(x,Q^2)}$$ – gluon shadowing factor

J/ψ and ψ(2S) in ultraperipheral Pb-Pb collisions

Looking for two tracks in an otherwise empty detector…

Continuous coverage:
$-3.7 < \eta < 5.1$
+ ZDC at very forward rapidities

Central barrel: $|\eta| < 0.9$
Inner SPD layer: $|\eta| < 2.0$



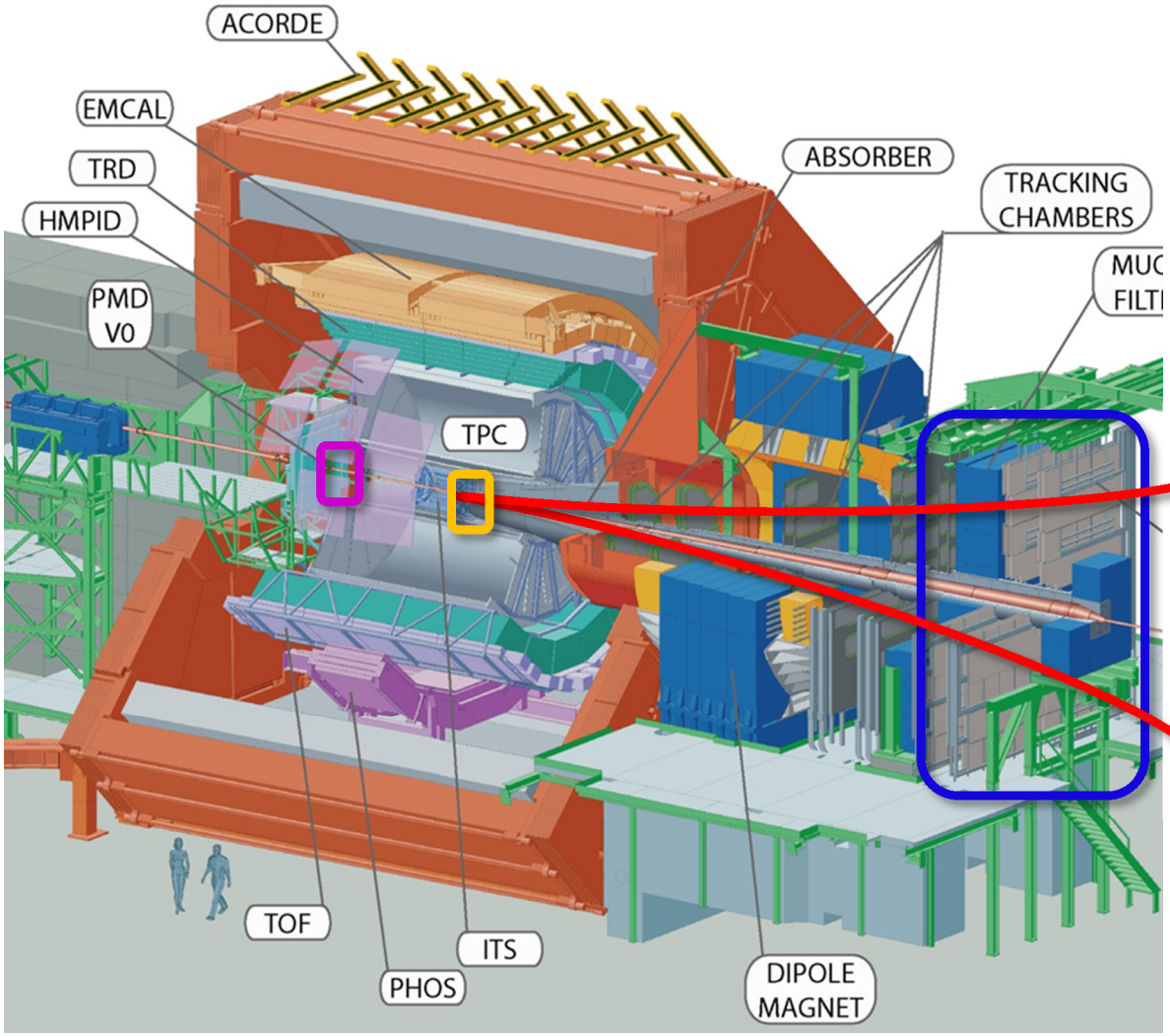
VZERO: $2.8 < \eta < 5.1$; $-3.7 < \eta < -1.7$
FMD: $1.7 < \eta < 5.0$; $-3.4 < \eta < -1.7$

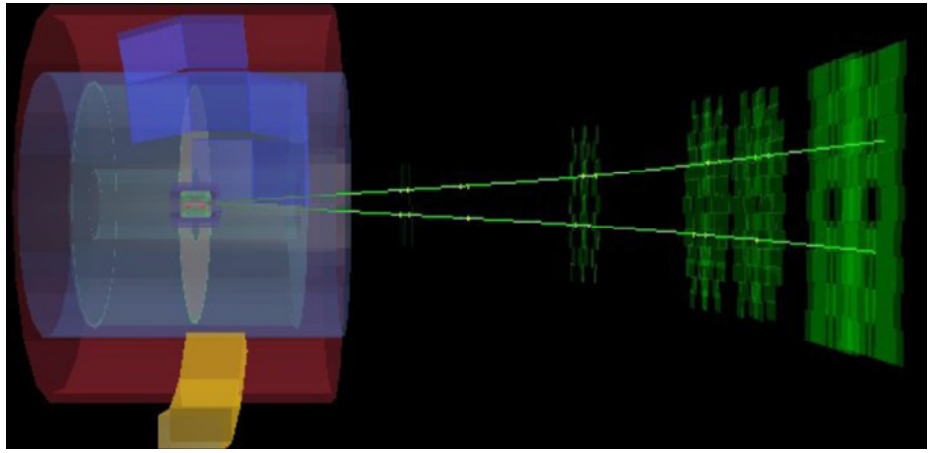
Muon arm: $-4 < \eta < -2.5$

J/ψ at forward rapidity

UPC forward trigger:

- single **muon trigger** with $p_T > 1$ GeV/c ($-4 < \eta < -2.5$)
- hit in **VZERO-C** ($-3.7 < \eta < -1.7$)
- no hits in **VZERO-A** ($2.8 < \eta < 5.1$)





Pb-Pb integrated luminosity ~ 55 μb^{-1}

Offline event selection:

- Beam gas rejection with VZERO
- Hadronic rejection with ZDC and SPD

Track selection:

- muon tracks: $-3.7 < \eta < -2.5$
- matching with the trigger
- radial position for muons at the end of absorber: $17.5 < R_{abs} < 89.5$ cm
- p_T dependent DCA cut
- opposite sign dimuon: $-3.6 < y < -2.6$

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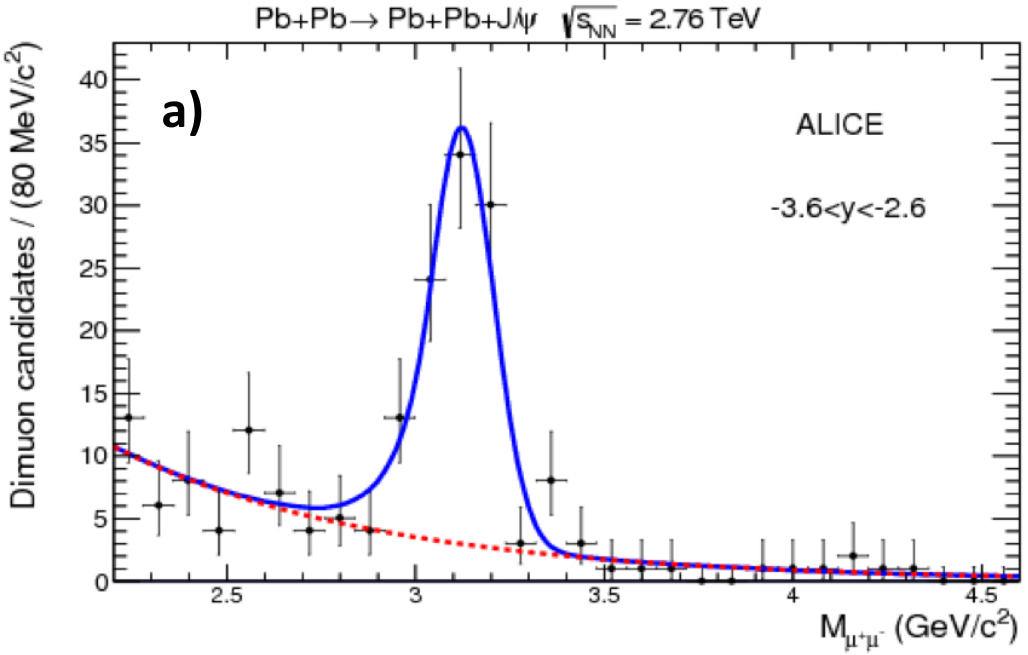
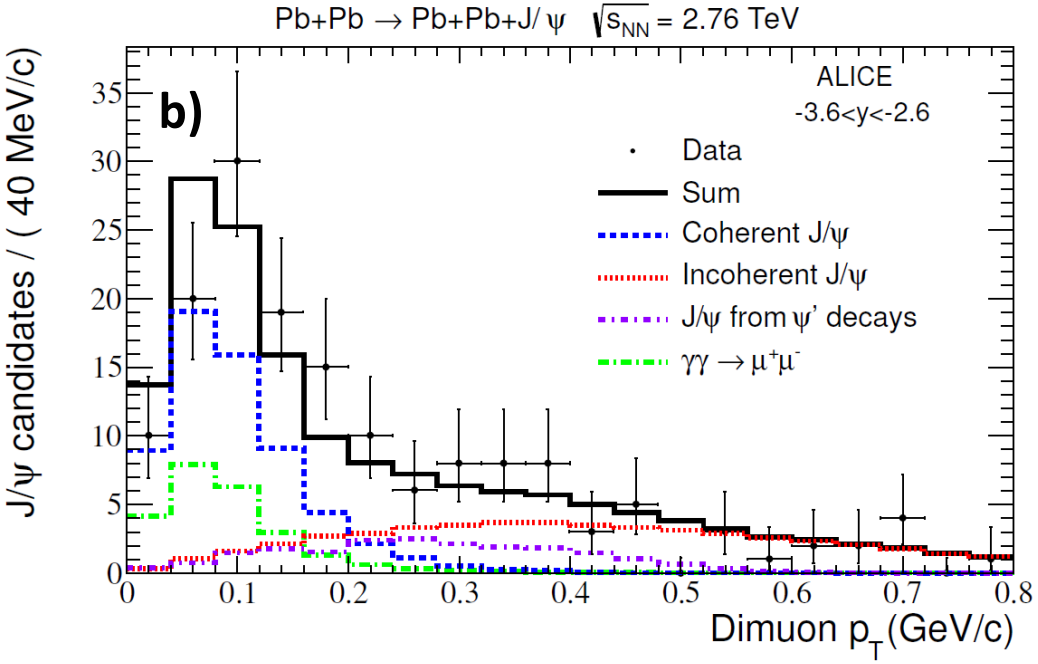
J/ψ at forward rapidity





Invariant mass distribution:

- Dimuon p_T< 0.3 GeV/c
- Signal fitted to a Crystal Ball shape
- Background well described by exponential shape compatible with expectations from γγ →μμ process

Four contributions in the p_T spectrum:

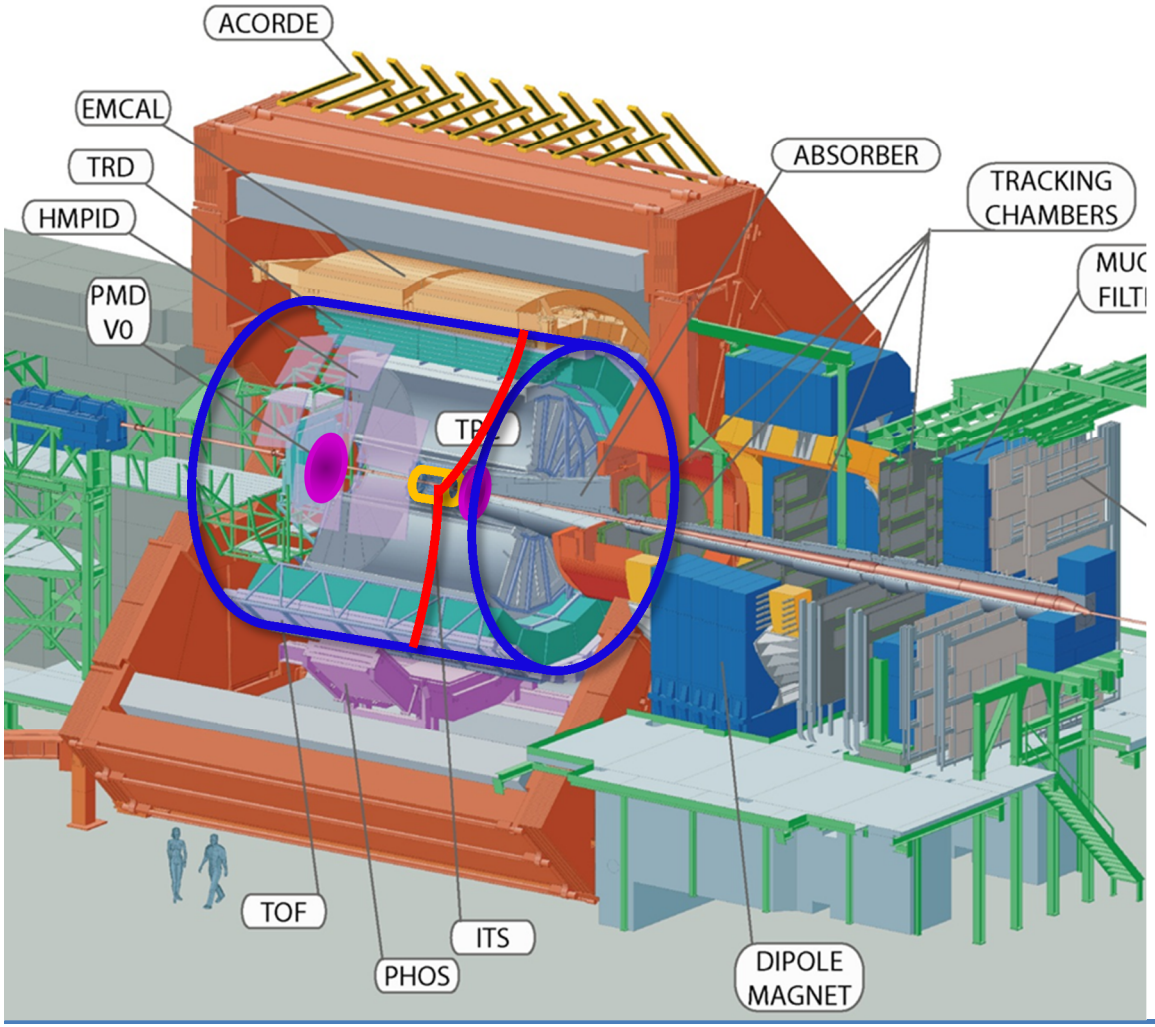
- **Coherent J/ψ:**
  - photon couples coherently to all nucleons
  - $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
  - no neutron emission in ~80% of cases
- **Incoherent J/ψ:**
  - photon couples to a single nucleon
  - $\langle p_T \rangle \sim 1/R_p \sim 450$ MeV/c
  - target nucleus normally breaks up
- **J/ψ from ψ' decays**
- **γγ →μμ**

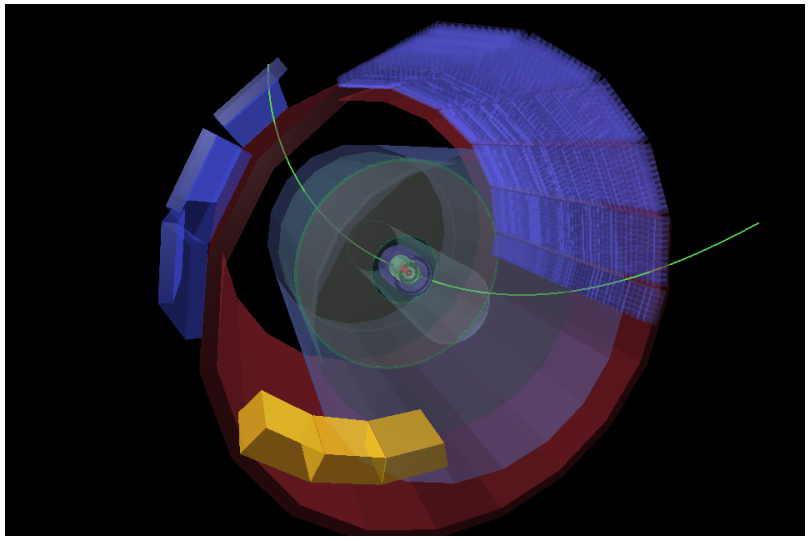
ALICE: Phys. Lett. B718 (2013) 1273

J/ψ at central rapidity

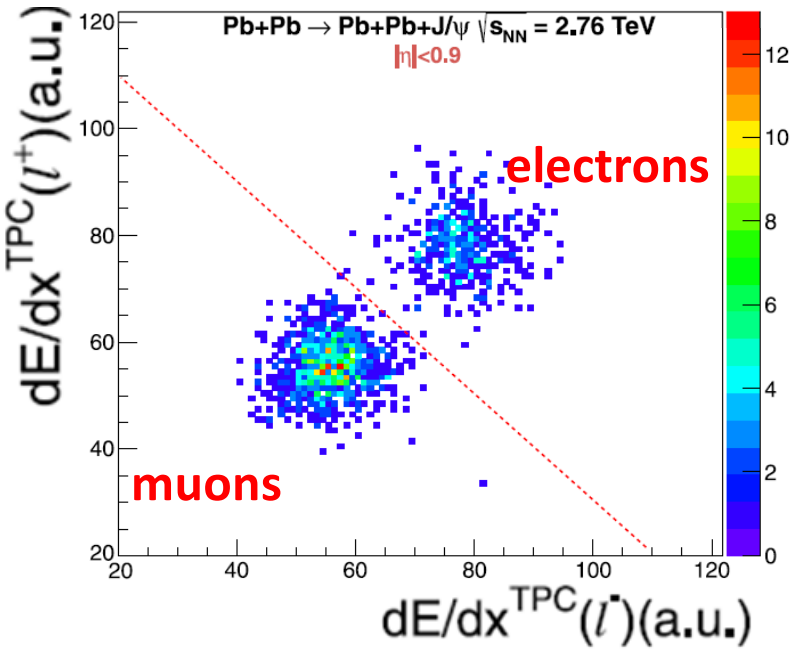
UPC central barrel trigger:

- $2 \leq$ **TOF** hits ≤ 6 ($|\eta| < 0.9$)
  + back-to-back topology ($150^\circ \leq \varphi_{TOF} \leq 180^\circ$)
- ≥ 2 hits in **SPD** ($|\eta| < 1.5$)
- no hits in **VZERO** (C: $-3.7 < \eta < -1.7$, A: $2.8 < \eta < 5.1$)





Pb-Pb integrated luminosity ~ 23 μb^{-1}



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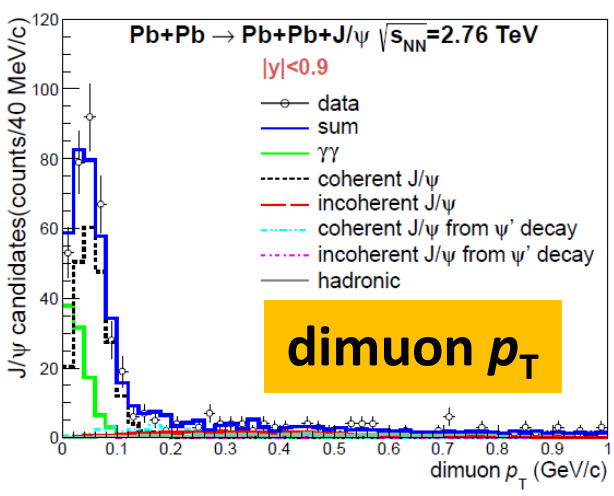
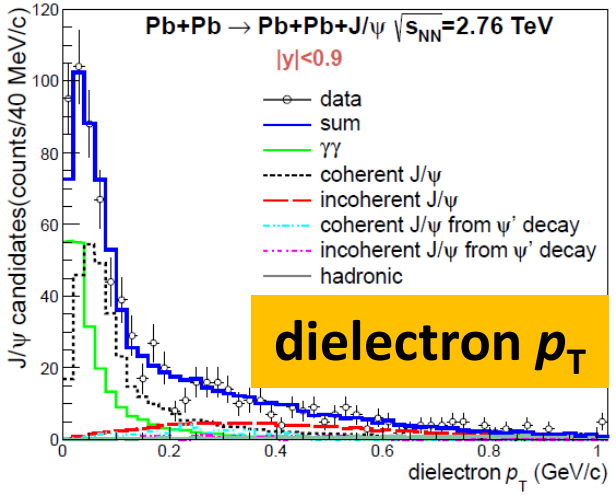
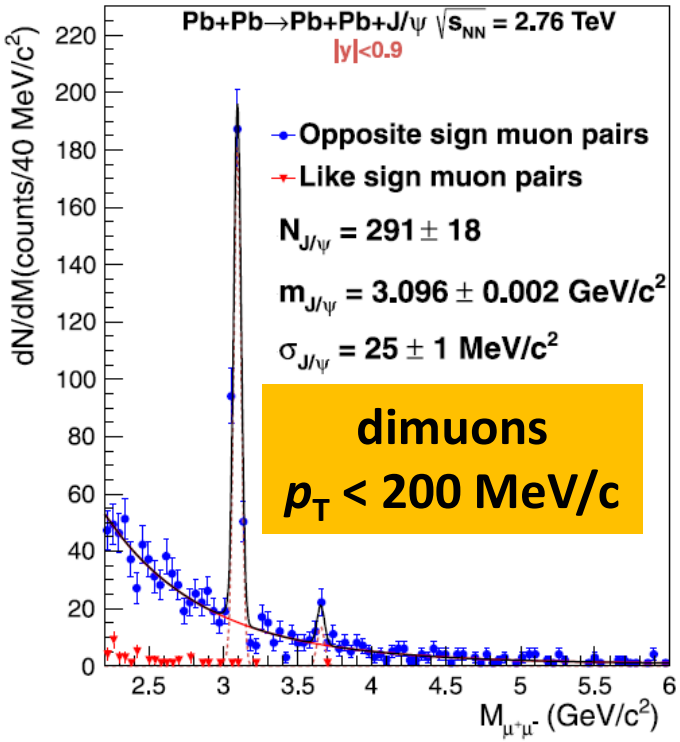
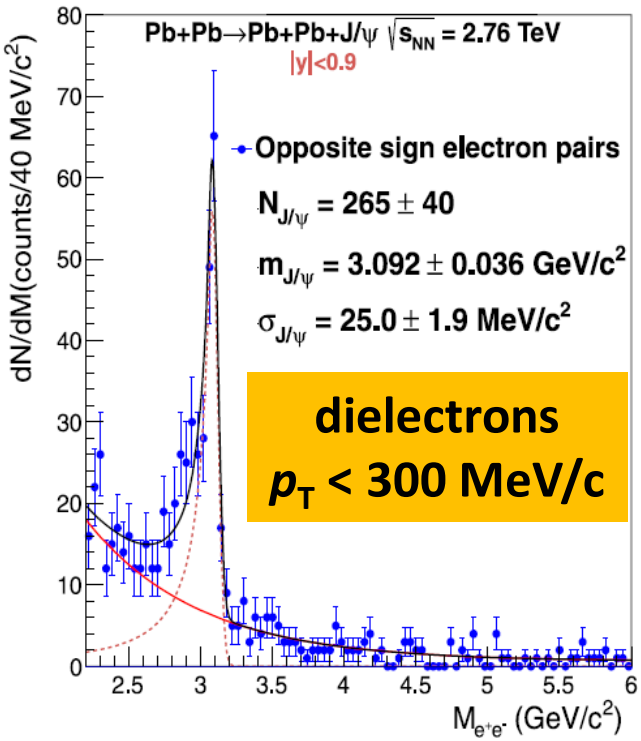
J/ψ at central rapidity

- Measured both in dielectron and dimuon channels
- Clear coherent peak from J/ψ and continuum $\gamma\gamma \rightarrow l^+l^-$
- Also contributions from:
  - incoherent J/ψ
  - J/ψ from ψ' feed down
  - hadronic contribution at high p_T









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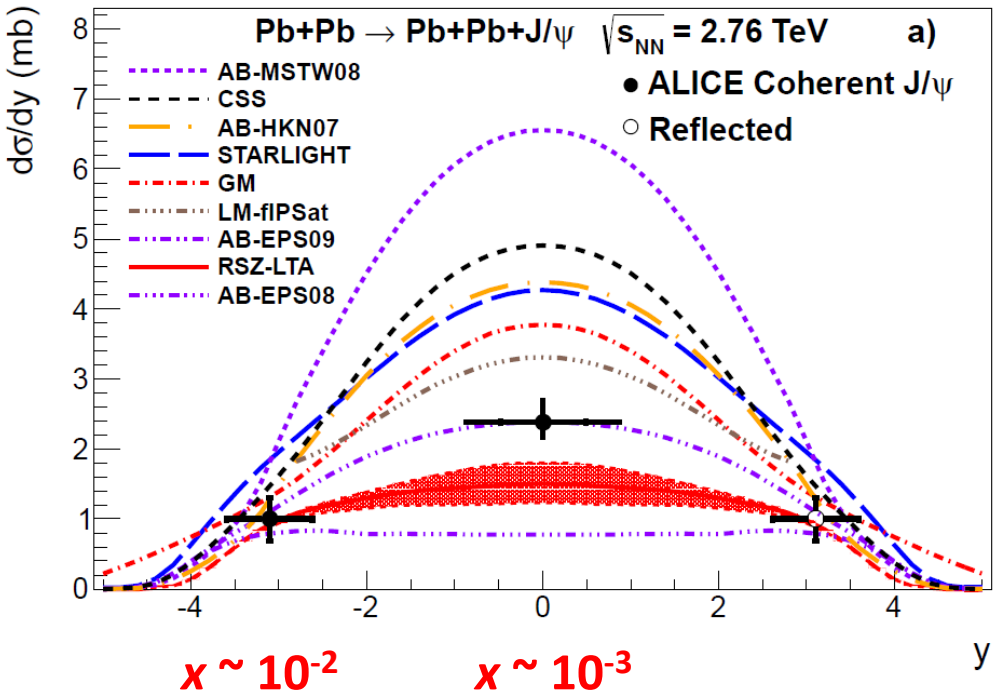
Coherent J/ψ: comparison to models



Good agreement with models which include nuclear gluon shadowing.
Best agreement with EPS09 shadowing
(shadowing factor ~0.6 at $x \sim 10^{-3}$, $Q^2 = 2.4$ GeV^2)

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- **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

Nuclear gluon shadowing from ALICE data

V. Guzei, E. Kryshen, M. Strikman, M. Zhalov. Phys. Lett. B726 (2013) 290

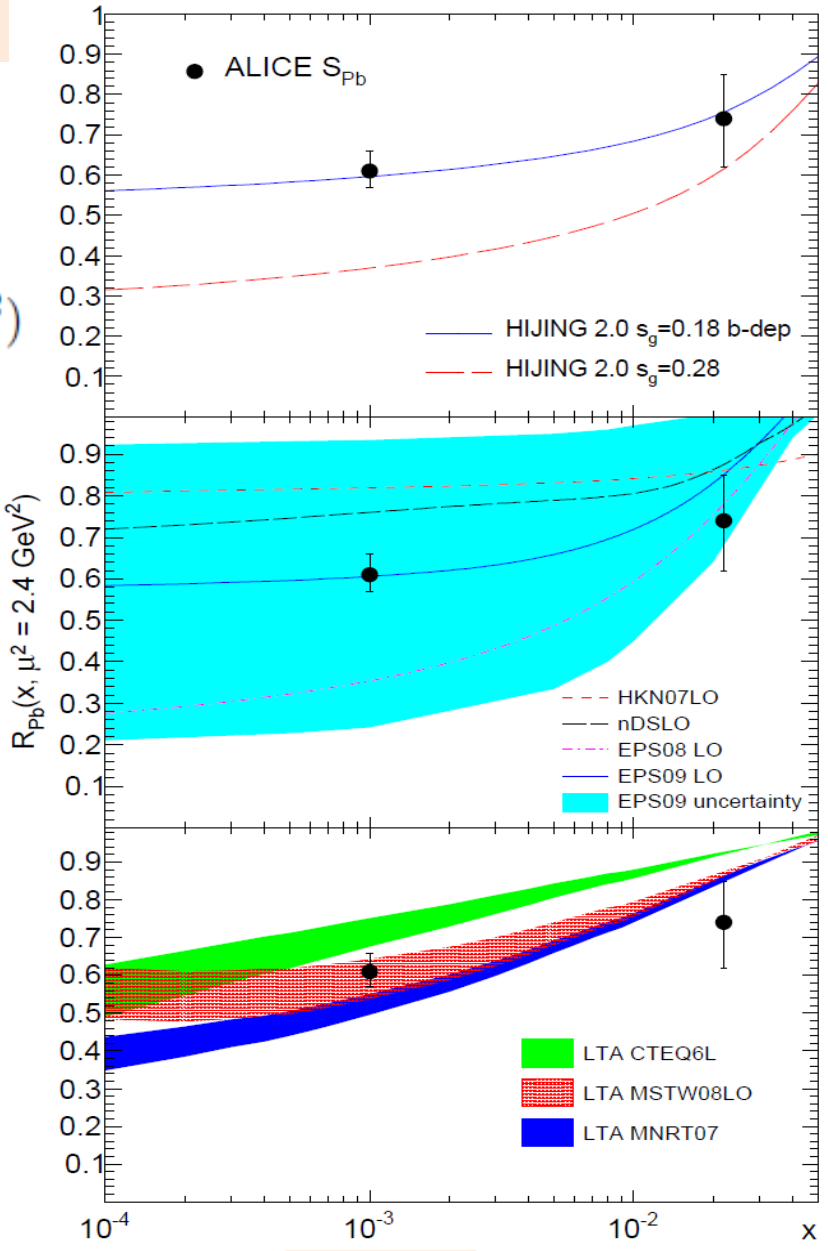
Nuclear suppression factor in J/ψ photoproduction:

ALICE data corrected for photon flux

$$S(W_{\gamma p}) \equiv \left[\frac{\sigma^{\mathrm{exp}}_{\gamma \mathrm{Pb}\to J/\psi \mathrm{Pb}}(W_{\gamma p})}{\sigma^{\mathrm{IA}}_{\gamma \mathrm{Pb}\to J/\psi \mathrm{Pb}}(W_{\gamma p})}\right]^{1/2} \Rightarrow R(x, \mu^2 = 2.4\ \mathrm{GeV}^2)$$

Impulse Approximation: J/ψ photoproduction cross section from HERA corrected for the integral over squared Pb form-factor

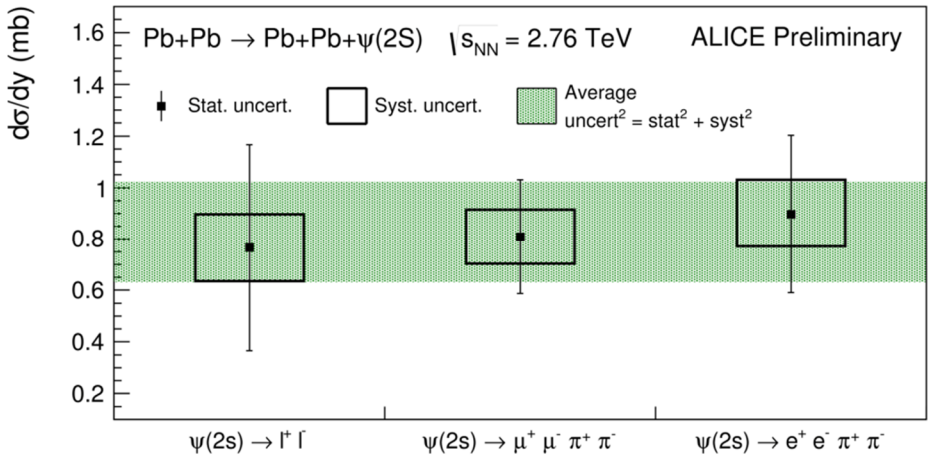
- **Hijing:** scale-independent gluon shadowing, characterized by parameter s_g
- **Shadowing parametrizations (EPS,nDS,HKN07)** use DIS and Drell-Yan data + π^0 data from RHIC (EPS) – gluon shadowing essentially unconstrained at low x
- **Leading twist approximation:** propagation of color dipoles in nuclei via intermediate diffractive states (Gribov-Glauber shadowing theory). Incorporates diffractive parton distributions in proton (from HERA)



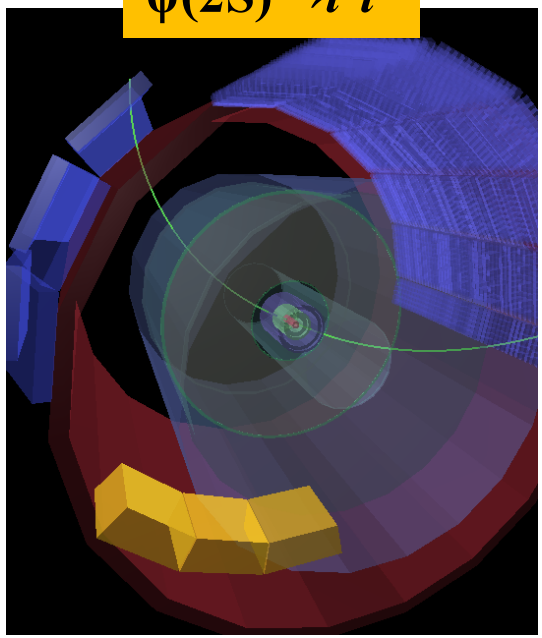
ranges of x probed by ALICE

Coherent ψ(2S) in Pb-Pb

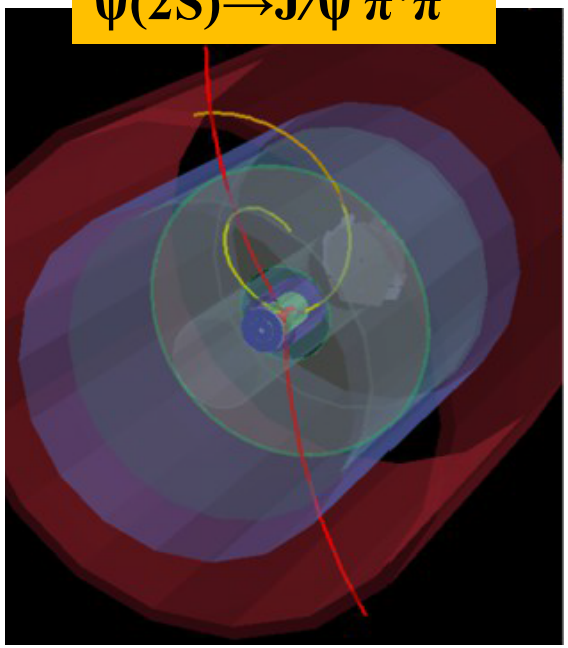
- Measured decay channels:
  - $\psi(2S) \rightarrow l^+l^-$
  - $\psi(2S) \rightarrow J/\psi\ \pi^+\pi^-$
- Moderate number of candidates, but very clean signal

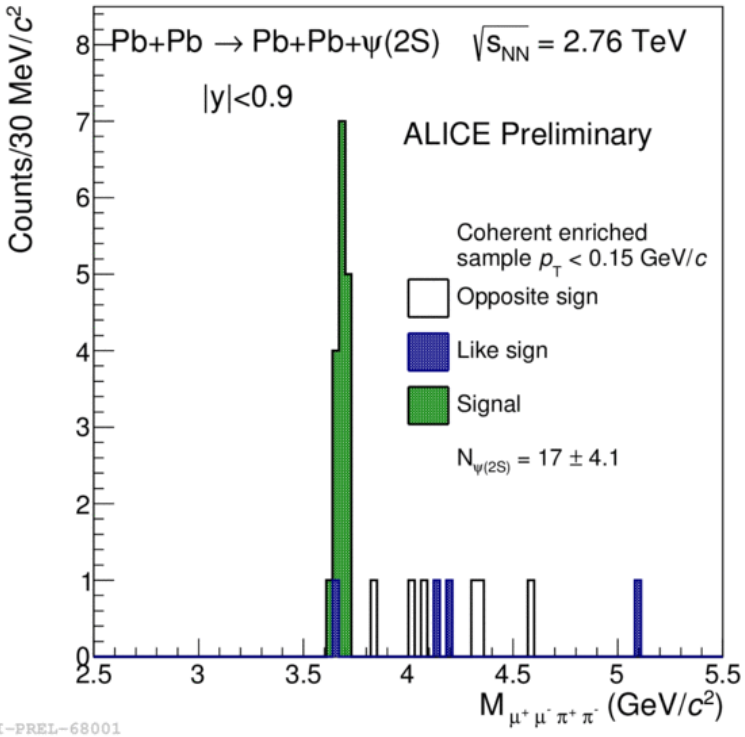


$\psi(2S) \rightarrow l^+l^-$

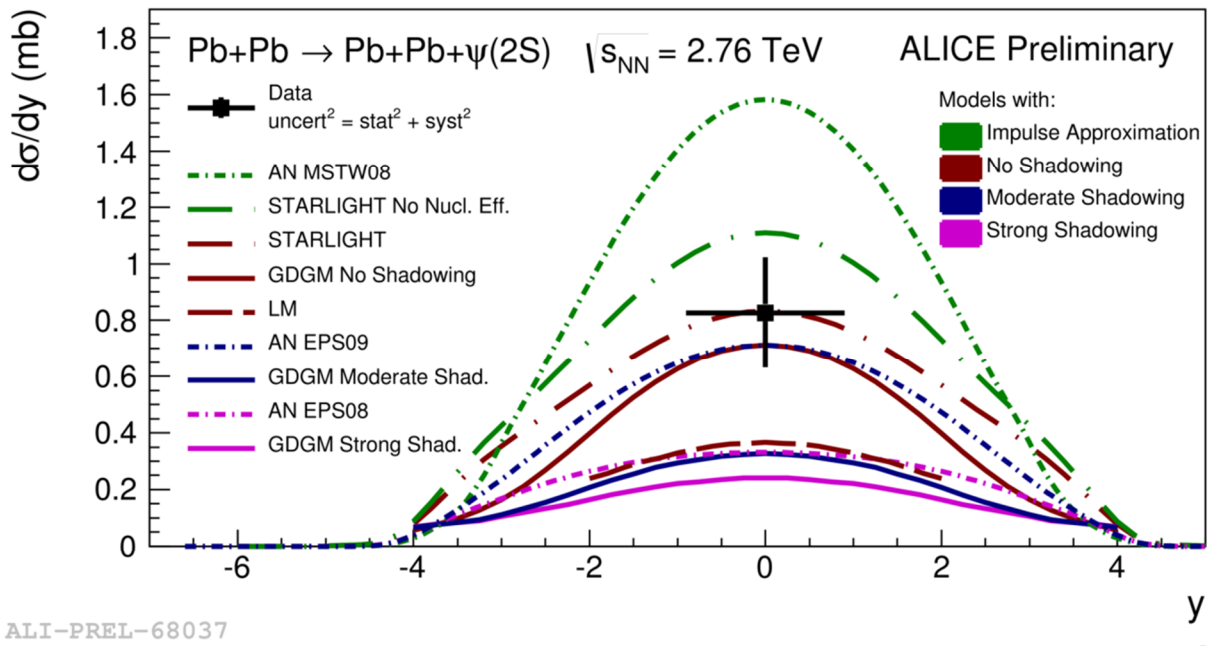


$\psi(2S) \rightarrow J/\psi\ \pi^+\pi^-$

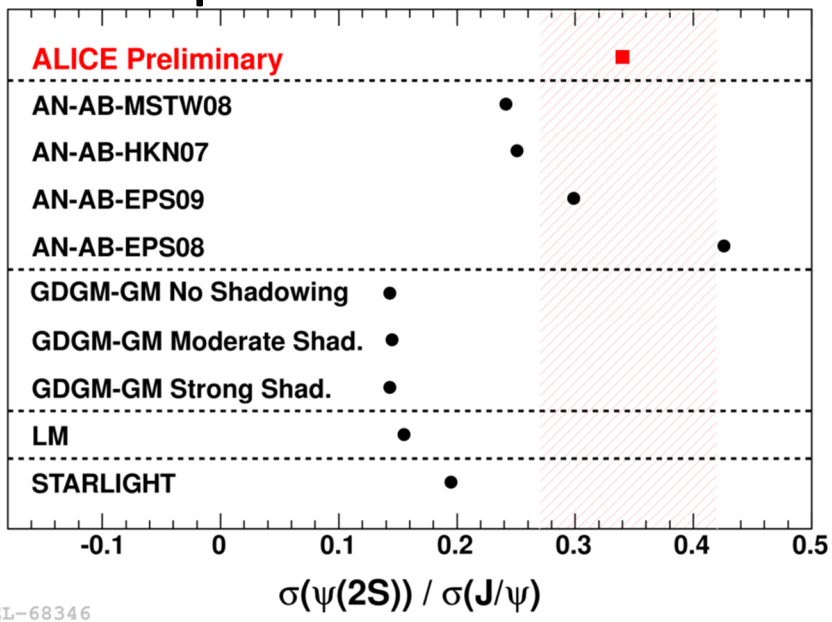




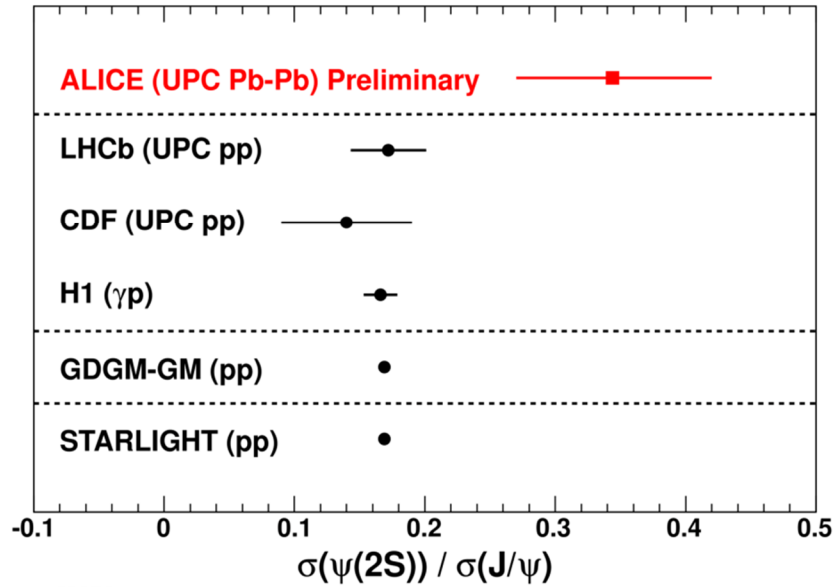
Coherent ψ(2S) in Pb-Pb: model comparison



Comparison to Pb-Pb models



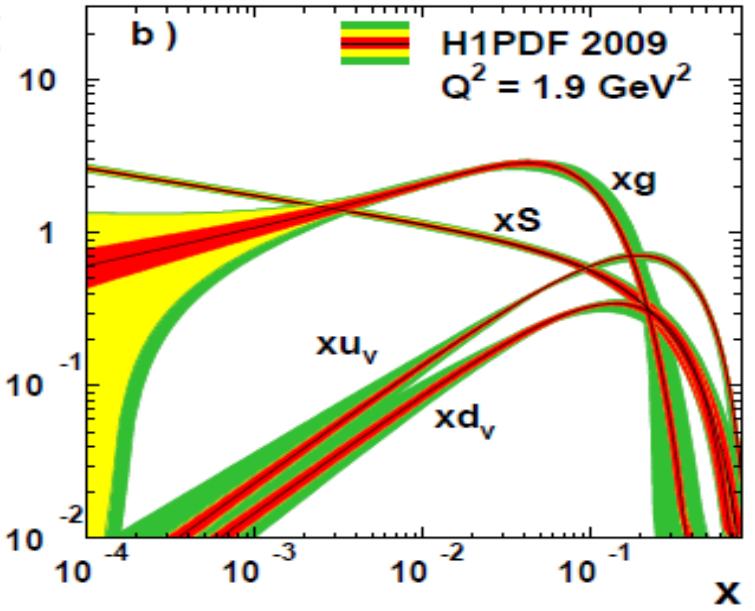
- Disfavour models with no nuclear effects and models with strong gluon shadowing
- Caveat: **large uncertainty on the γp reference** used for theory predictions
- Experimental systematic **uncertainties** (and theoretical uncertainties) largely **cancel in the σ(ψ(2S))/σ(J/ψ) ratio**
- Do nuclear effects affect differently the 1S and 2S states?



J/ψ in ultraperipheral p-Pb collisions

J/ψ photoproduction off proton

$$\left.\frac{d\sigma_{\gamma p\to pJ/\psi}}{dt}\right|_{t=0} = \frac{M_{J/\psi}^3\Gamma_{ee}\pi^3\alpha_s^2(Q^2)}{48\alpha_{\rm em}Q^8}\left[xg_p(x,Q^2)\right]^2$$

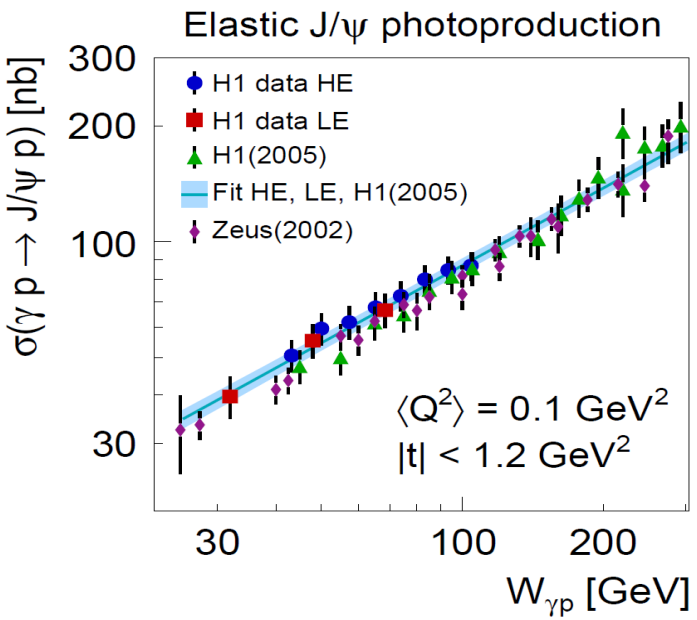


- J/ψ photoproduction off proton allows one to probe poorly known **gluon distribution in the proton at low x** and search for **saturation effects**

- HERA: J/ψ photoproduction in ep (x down to 10^{-4})
  - Consistent with power law (no hint for saturation)
  - Data was used to extract gluon PDFs (MNRT, JMRT)

- CDF: exclusive J/ψ in $p\bar{p}$ @ 2 TeV
  - compatible with HERA (W~100 GeV, x~10^{-3})

- LHCb: exclusive J/ψ in pp @ 7 TeV
  - forward rapidity (x~10^{-2} + x~10^{-5})
  - photon emitter unknown -assumed power law to separate low and high-energy contributions



p-Pb UPC with ALICE

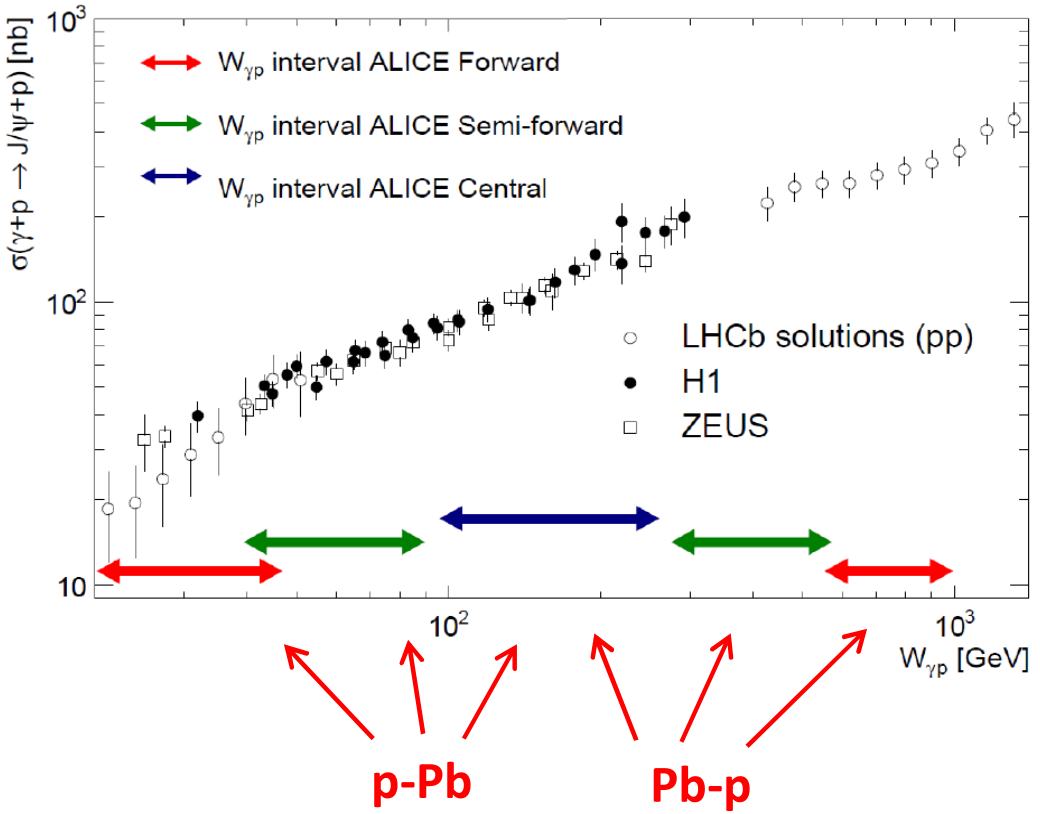
Data collected in 2013:

p-Pb: p towards muon spectrometer

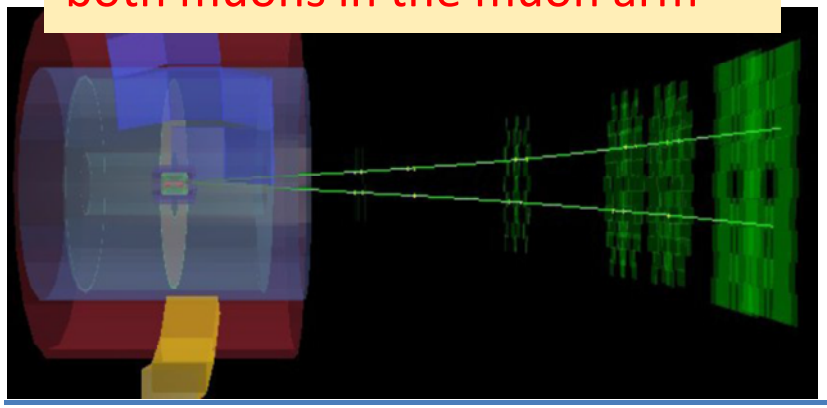
Pb-p: Pb towards muon spectrometer

Advantage of p-Pb collisions wrt pp:

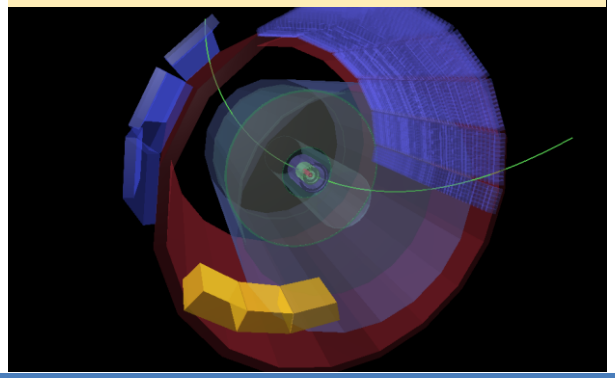
- Large photon flux from Pb
- Photon source is known
  → no assumption required to separate low and high energy contributions
- Hadronic contribution can be strongly suppressed by ensuring Pb nuclei are intact (no signal in ZDC)
- Contamination from central exclusive χ_c production negligible



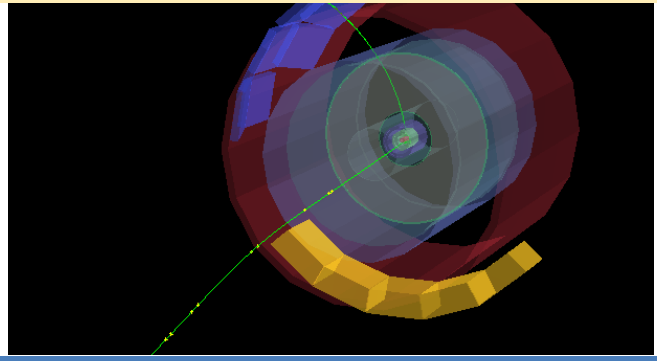
both muons in the muon arm



both leptons in the barrel



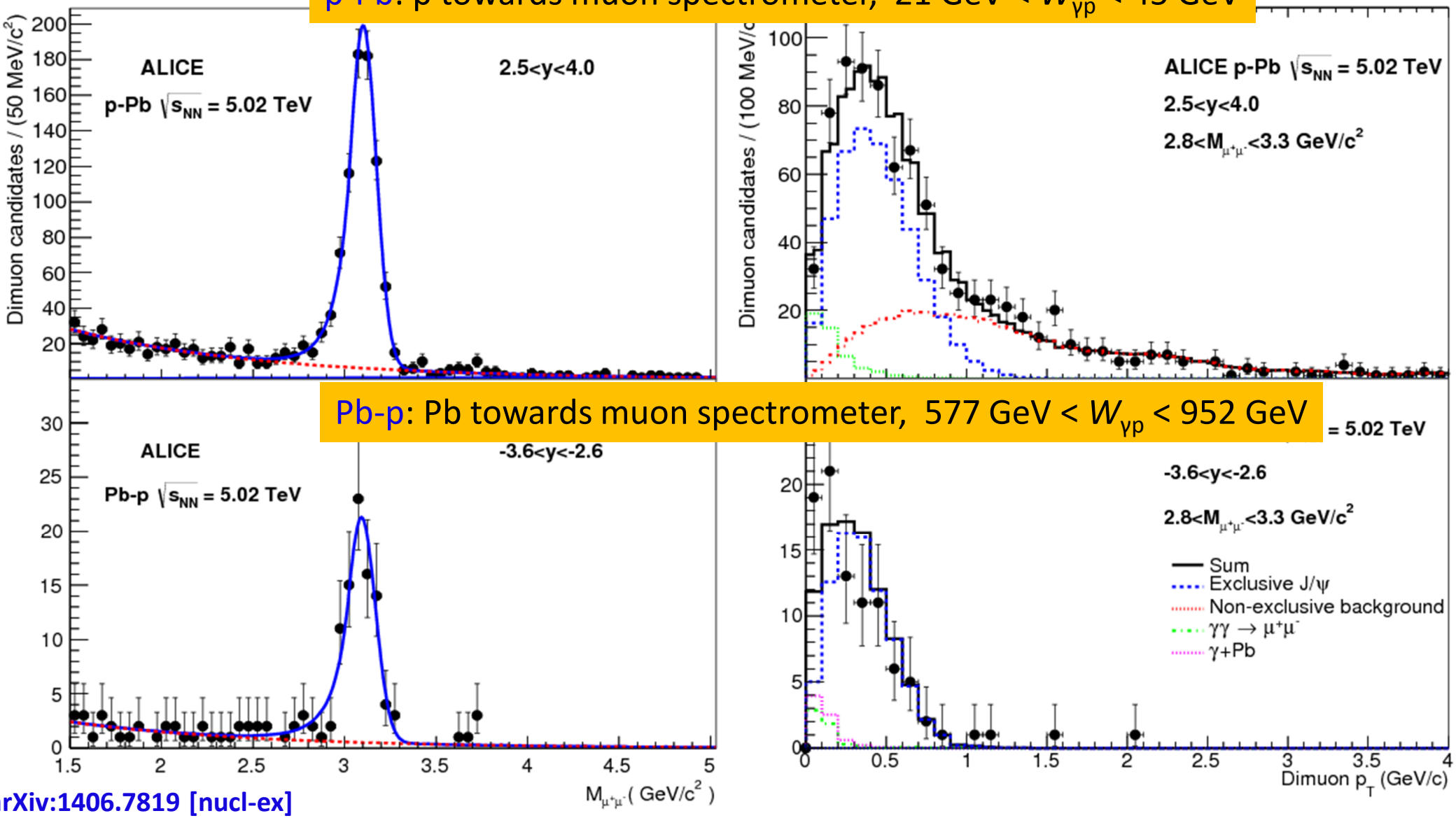
one muon in the muon arm, second in the barrel



Results in forward p-Pb and Pb-p collisions

- Using p_T-templates to extract contribution of exclusive J/ψ

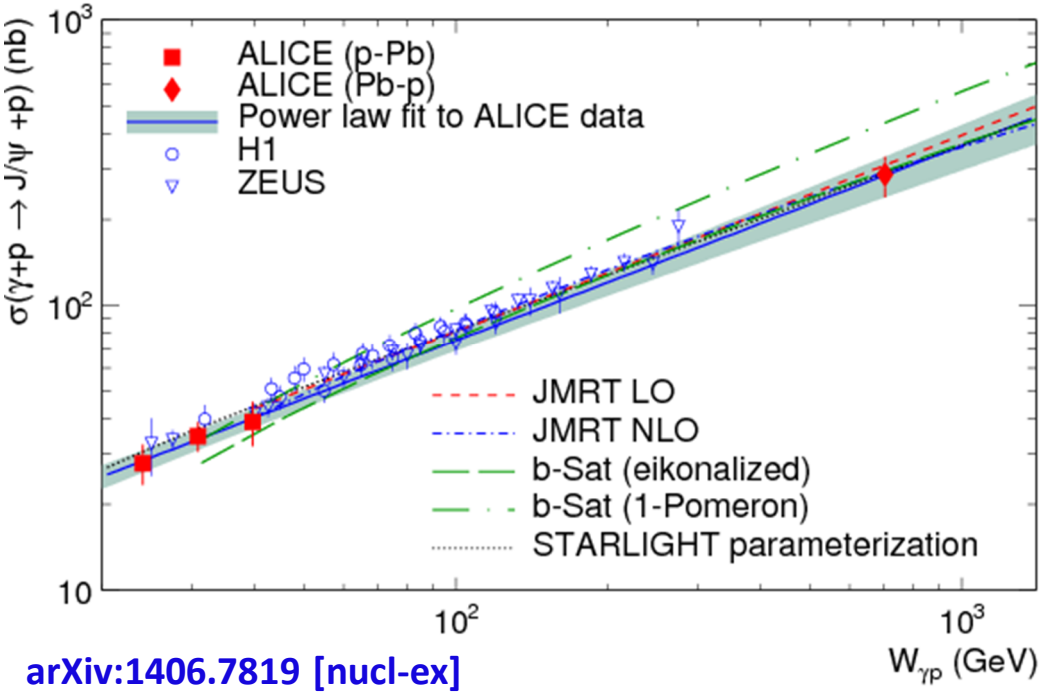
p-Pb: p towards muon spectrometer, 21 GeV < $W_{\gamma p}$ < 45 GeV

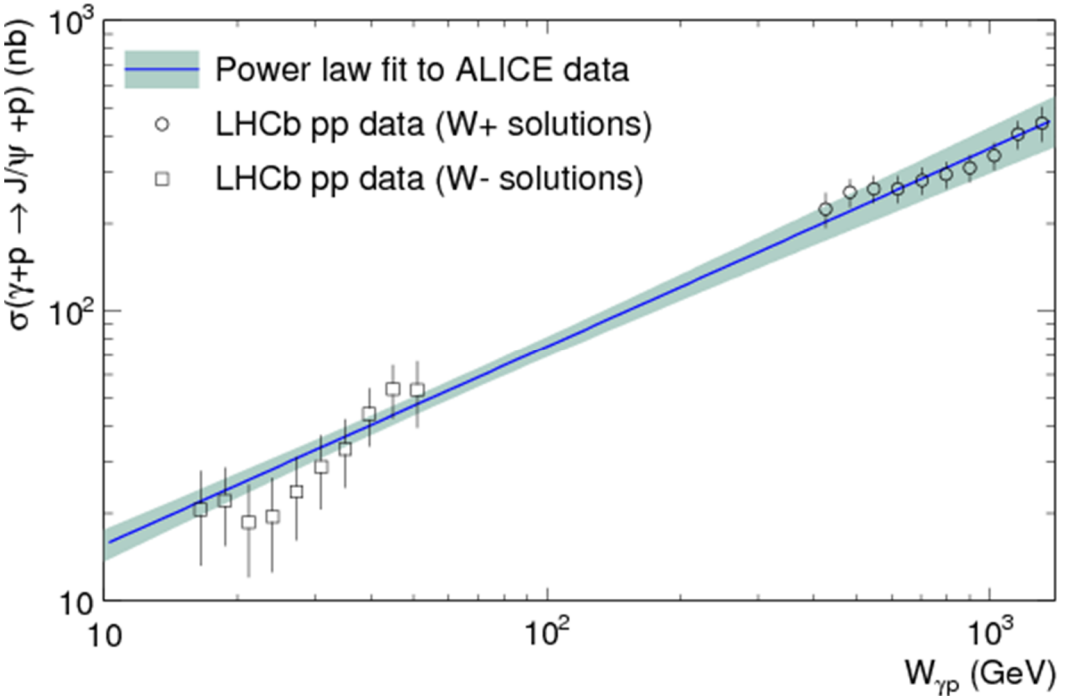


arXiv:1406.7819 [nucl-ex]

Tests of power law dependence

- Results compatible with predictions based on fits to HERA data
- Power law exponent from ALICE data alone: $\delta = 0.67 \pm 0.06$
- Exponent compatible with HERA:
  - H1: $\delta = 0.67 \pm 0.03$
  - ZEUS: $\delta = 0.69 \pm 0.02 \pm 0.03$
- LHCb solutions consistent with the power-law fit obtained from ALICE results





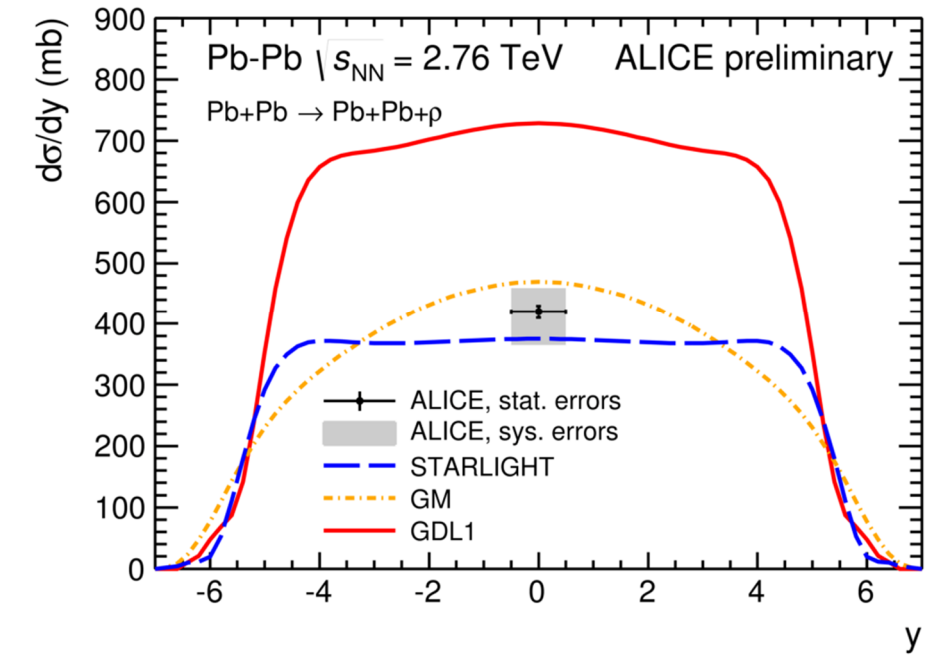
arXiv:1406.7819 [nucl-ex]

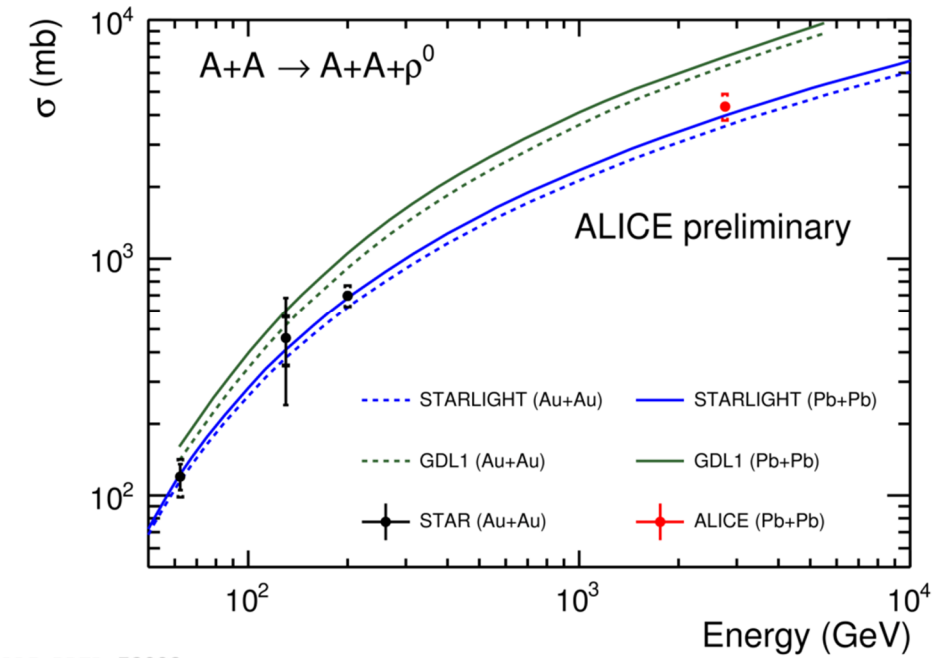
No significant change in the gluon density behaviour between HERA and LHC energies

$$\frac{d\sigma}{dy}_{pp\to pVp} = r(y)\left[k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to Vp}(W_+) + k_- \frac{dn}{dk_-}\sigma_{\gamma p\to Vp}(W_-)\right]$$

ρ^0 photoproduction in ultraperipheral Pb-Pb collisions

ρ^0 photoproduction in Pb-Pb





GDL: Frankfurt, Strikman, Zhalov [Phys. Lett. B 537 (2002) 51; Phys. Rev. C 67(2003) 034901]

- Vector Meson Dominance Model in the Gribov-Glauber approach.
- $\sigma_{\rho N}$ from Donnachie-Landshoff model.

GM: Gonçalves, Machado [Phys. Rev. C 84 (2011) 011902]

- Based on the color dipole model in combination with saturation from a CGC-IIM model.

STARLIGHT: Klein, Nystrand [Phys. Rev. C 60 (1999) 014903, http://starlight.hepforge.org/]

- Glauber model neglecting the elastic part of total cross section.
- Uses experimental data on $\sigma_{\rho N}$ cross section.

Prospects for Run2

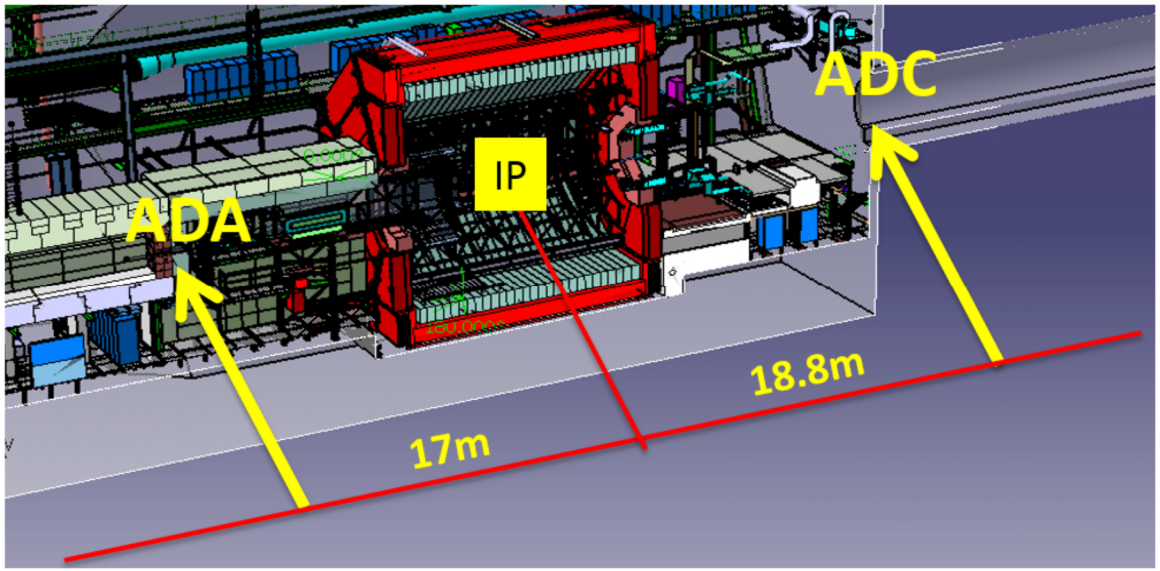
Harvest in Run1, Pb-Pb collisions @ 2.76 TeV:

Meson	Integrated lumi	Yield	Comment
ρ	0.26 ub^{-1}	~ 10^4	stat << syst
J/ψ central J/ψ forward	23 ub^{-1} 55 ub^{-1}	~500 ~100	stat < syst
Ψ(2S) central	23 ub^{-1}	~ 50	stat >> syst

Expected integrated luminosity in Run2: ~1 nb^{-1} Pb-Pb @ 5.1 TeV

New forward detector:

- Two scintillators (two layers each, in coincidence):
  - ADA: $5.5 < \eta < 7.5$
  - ADC: $-7.5 < \eta < -5.5$
- Can be used to make the veto to non UPC event stronger



Summary and outlook

- **Coherent J/ψ** photoproduction cross section in Pb-Pb in agreement with moderate nuclear gluon shadowing (EPS09, LTA)
- **Coherent ψ(2S)** cross section disfavours models with no nuclear effects and models with strong gluon shadowing. Looking forward to Run2: expected ψ(2S) statistics similar to J/ψ in Run1.
- **J/ψ photoproduction in p-Pb**: no significant change in the gluon density behaviour between HERA and LHC energies
- **ρ^0 photoproduction** consistent with STARLIGHT
- **Preparing for Run2 @ LHC**: increase in luminosity and center of mass energy of the photon-target system. Stay tuned!