Overview of ALICE results on ultra-peripheral collisions

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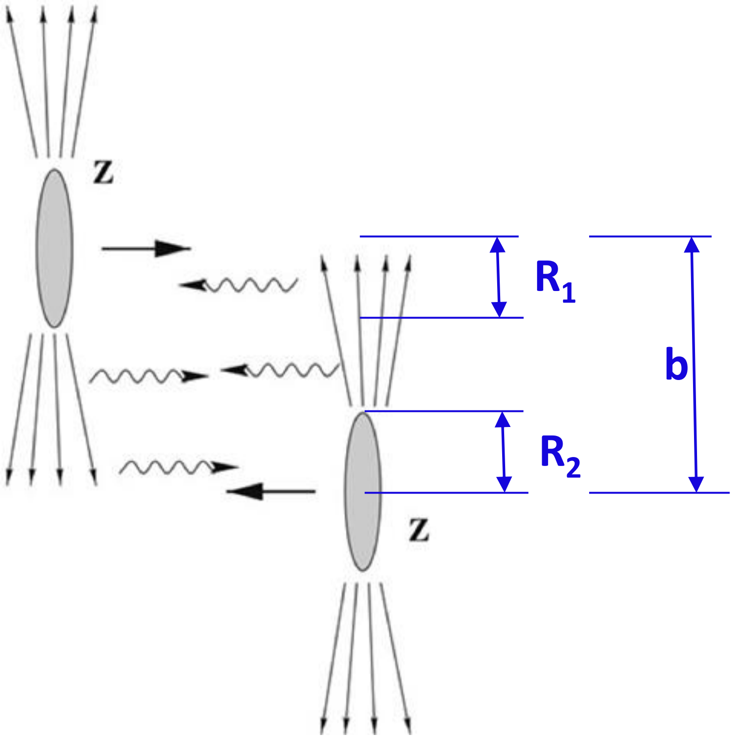
on behalf of ALICE collaboration

XXIV International Baldin Seminar on High Energy Physics Problems
”Relativistic Nuclear Physics and Quantum Chromodynamics”
20 September 2018

LHC as a $\gamma\gamma$, γp and γPb collider



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

$\rightarrow$ hadronic interactions strongly suppressed

High photon flux

$\rightarrow$ well described in Weizsäcker-Williams approximation (quasi-real photons)

$\rightarrow$ flux proportional to Z^2

$\rightarrow$ high cross section for γ-induced reactions

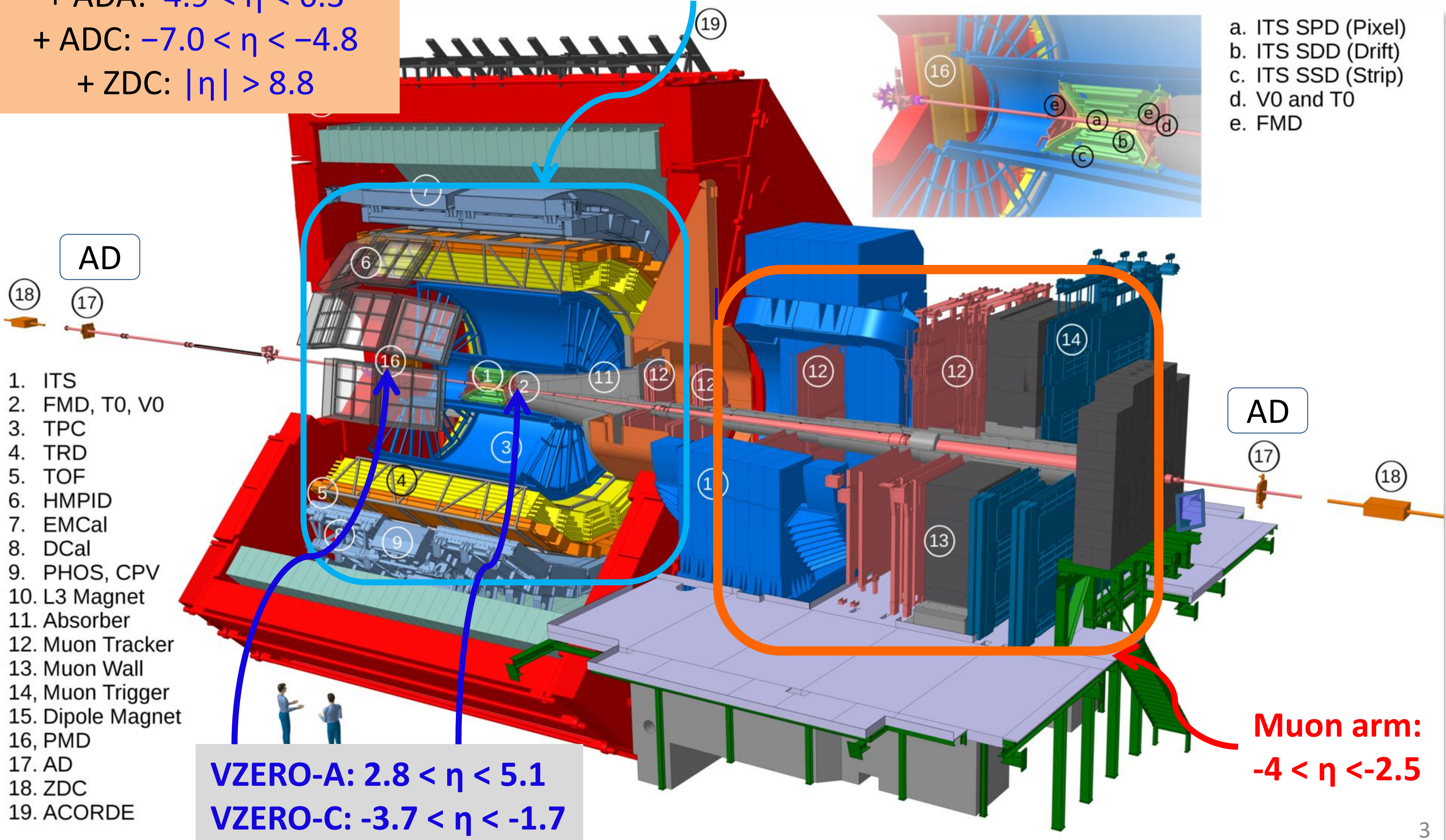
Pb-Pb UPC at LHC can be used to study γ- γ, γ-p, γ-Pb interactions at higher center-of-mass energies than ever before

Recent reviews on UPC physics:
A.J. Baltz et al, Phys. Rept. 458 (2008) 1
J.G. Contreras, J.D. Tapia Takaki. Int.J.Mod.Phys. A30 (2015) 1542012

Looking for two tracks in an otherwise empty detector…

Continuous coverage:
-3.7 < η < 5.1
+ ADA: 4.9 < η < 6.3
+ ADC: −7.0 < η < −4.8
+ ZDC: |η| > 8.8

Central barrel: |η|< 0.9
Inner SPD layer: |η|< 2.0

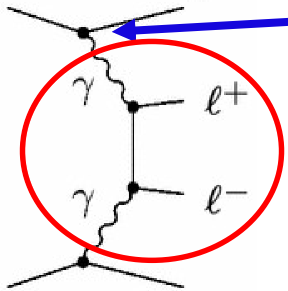


Muon arm:
-4 < η <-2.5

VZERO-A: 2.8 < η < 5.1
VZERO-C: -3.7 < η < -1.7

$\gamma\gamma \rightarrow$ dileptons
in ultraperipheral Pb-Pb collisions

$\gamma\gamma \rightarrow$ dileptons in Pb-Pb

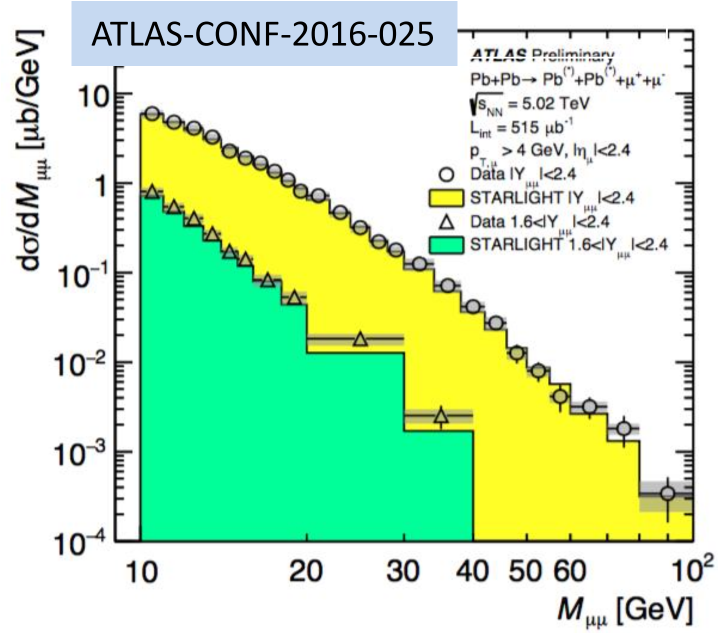


Photon flux proportional to Z^2

Leading order QED

Good agreement between LHC data and LO QED predictions

ATLAS-CONF-2016-025



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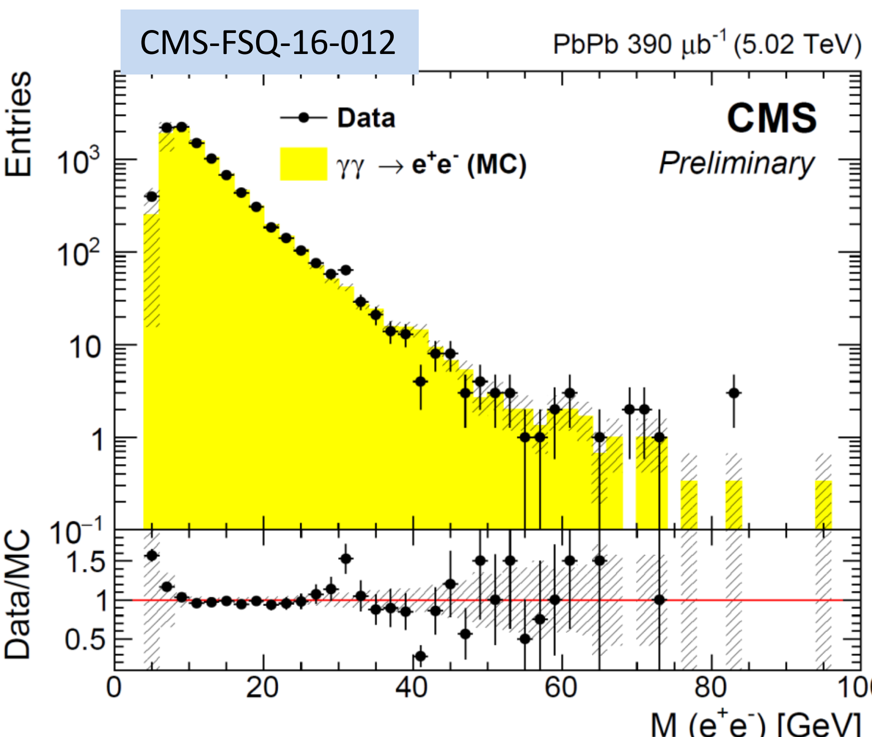
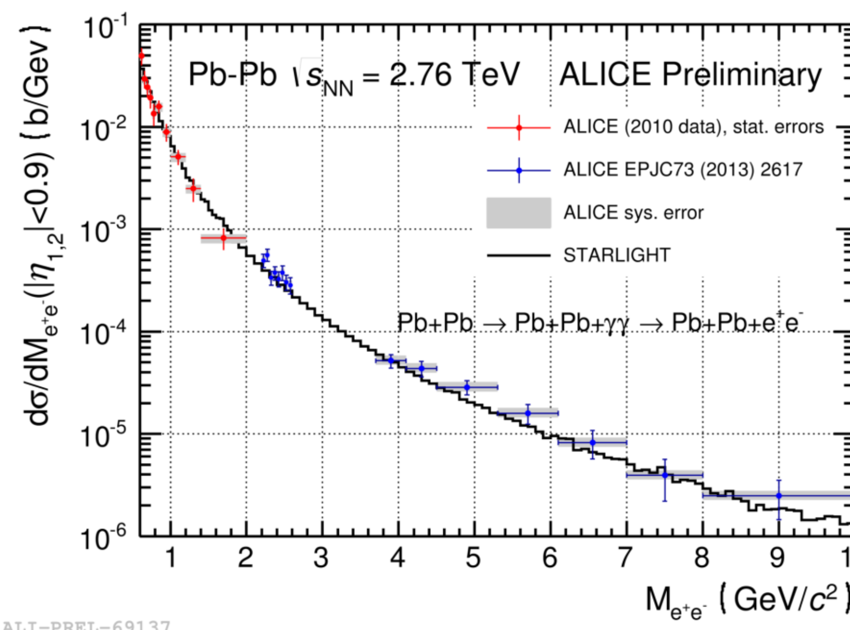


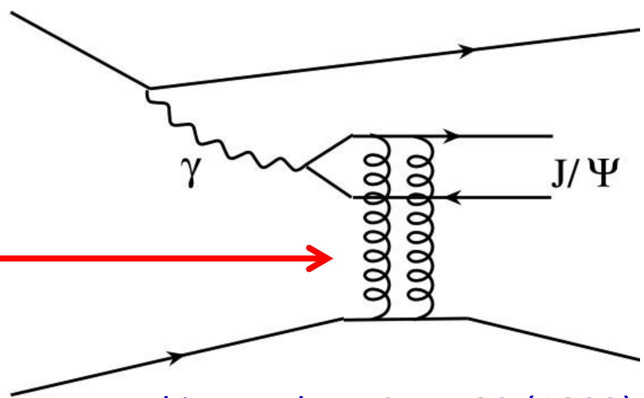


J/ψ photoproduction in ultraperipheral p-Pb collisions

J/ψ photoproduction in p-Pb

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

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



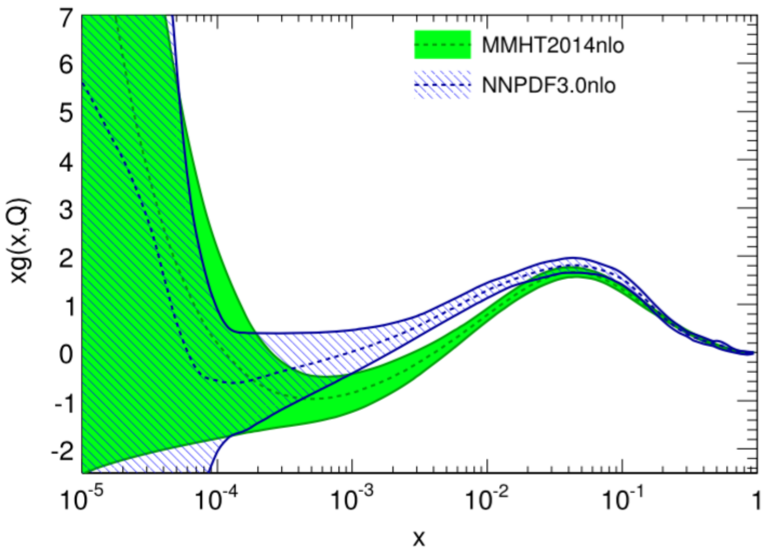
Ryskin: Z. Phys. C 57, 89 (1993)

- J/ψ mass serves as a hard scale:

$$Q^2 \sim \frac{M^2_{J/\psi}}{4} \sim 2.5\ \mathrm{GeV}^2$$

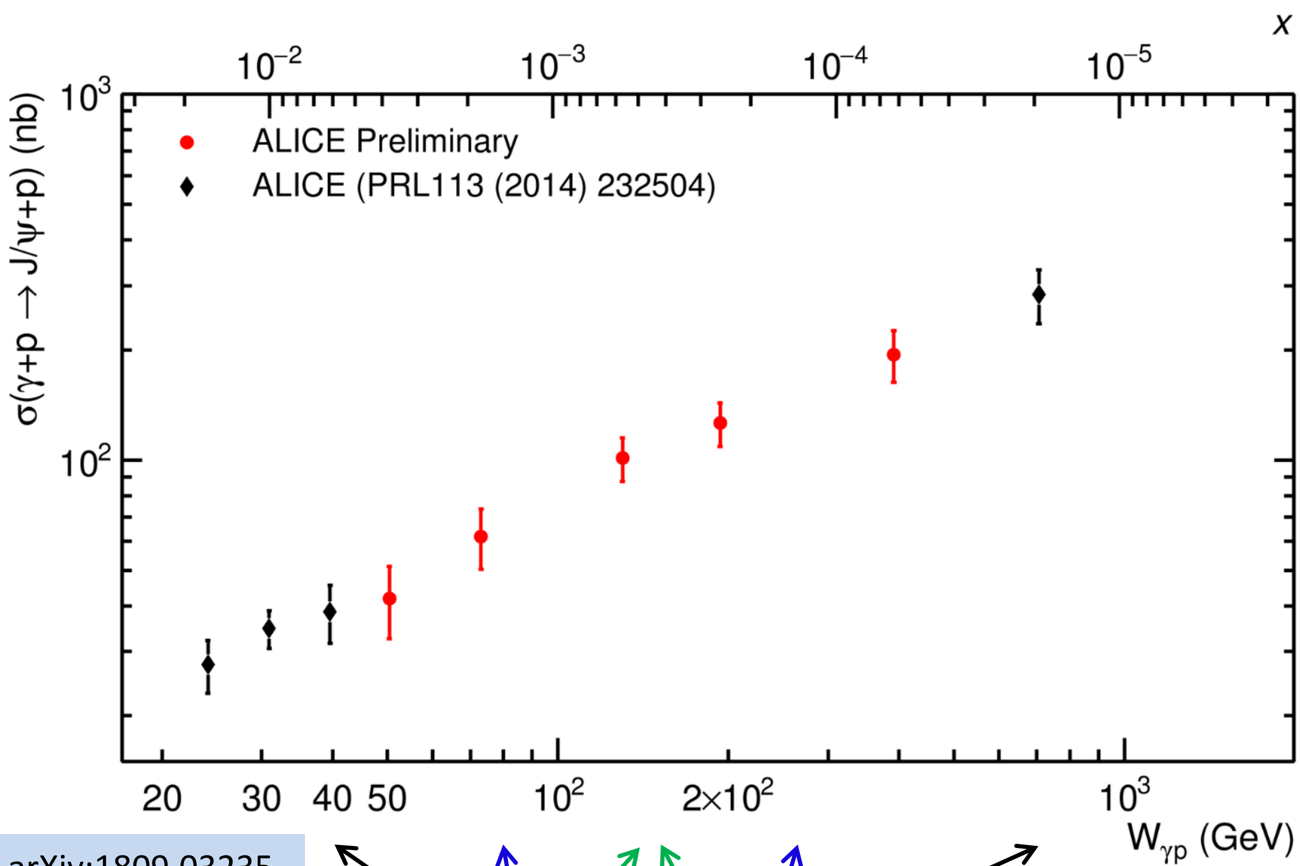
- Bjorken x ~ $10^{-2} - 10^{-5}$ accessible at LHC:

$$x = \frac{M^2_{J/\psi}}{W^2_{\gamma p}} = \frac{M_{J/\psi}}{2E_p}\exp(\pm y)$$



Vector meson photoproduction in UPC allows one to probe poorly known **gluon distributions at low *x*** and search for **saturation effects**

Exclusive J/ψ in p-Pb UPC

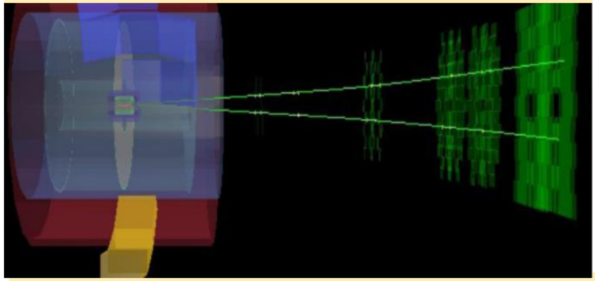


arXiv:1809.03235

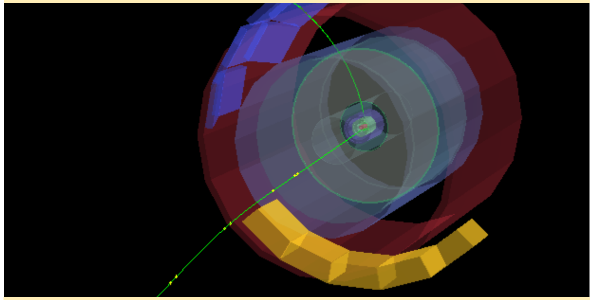
p-Pb

Pb-p

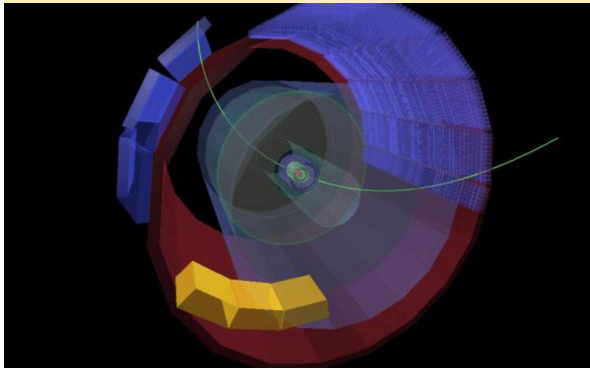
both muons in the muon arm



one muon in the muon arm, the other in the barrel



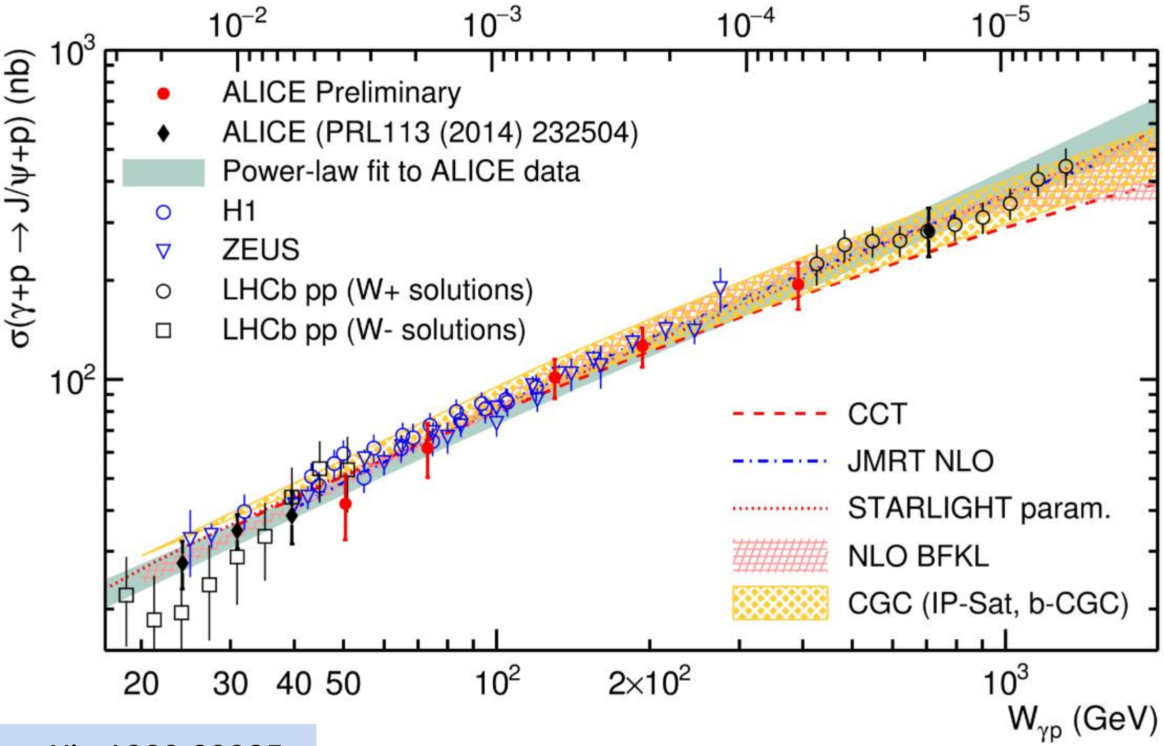
both leptons in the barrel



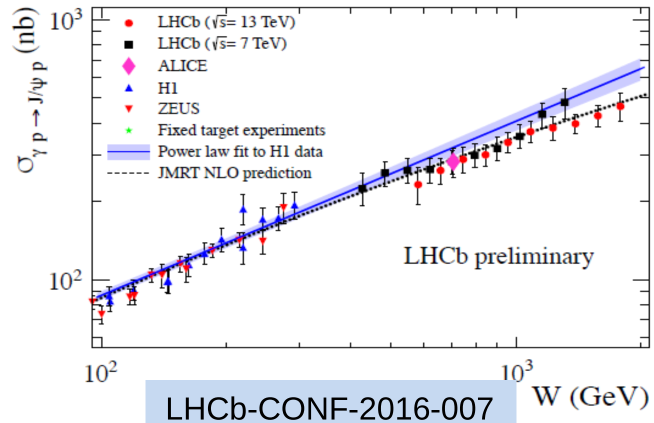
Wide energy range in ALICE extends HERA coverage:

- 2 beam configurations (p-Pb and Pb-p)
- 3 options to measure dilepton J/ψ decays

J/ψ photoproduction off a proton



arXiv:1809.03235



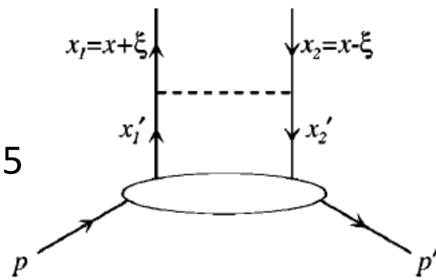
LHCb-CONF-2016-007

- Energy dependence described with a power law fit with an exponent 0.70 ± 0.05
- Nice agreement between HERA, LHCb and ALICE
- No clear signs of saturation

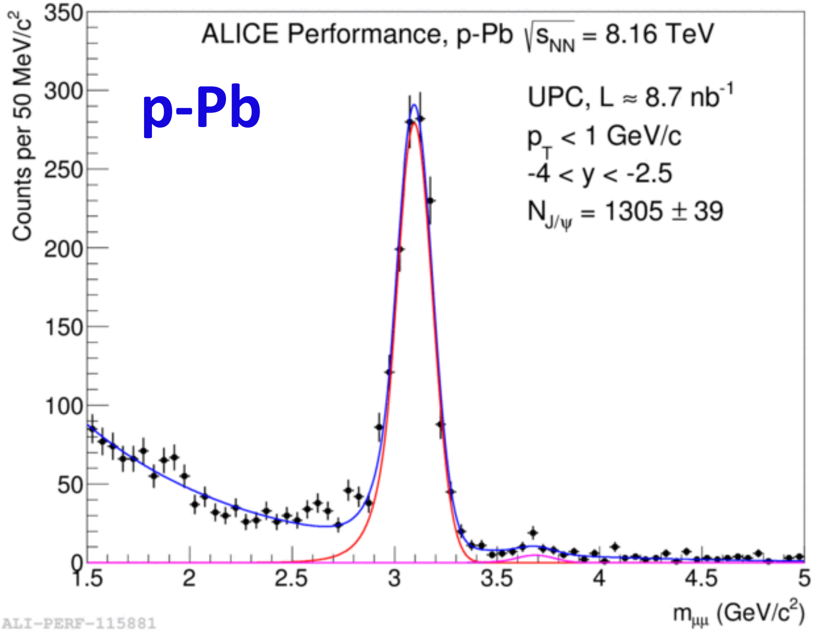
Can we use this data to constrain gluon PDFs?

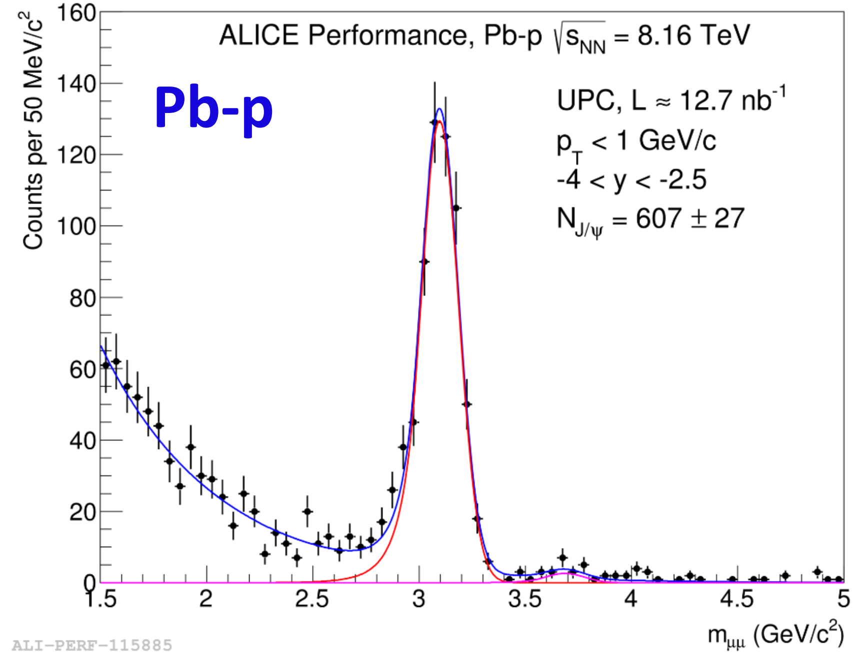
Caveats:

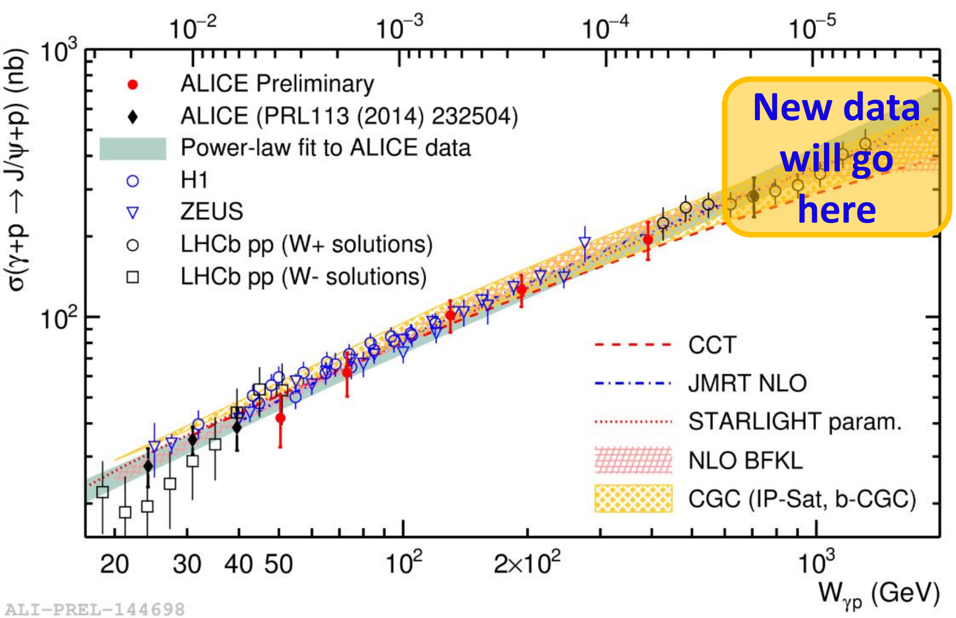
- J/ψ photoproduction probes generalized gluon distributions (two gluons have different x values):
  - Connected with collinear PDFs via Shuvaev transform: PRD 60 (1999) 014015
- Scale uncertainty ($\mu^2 \sim 2.4$-$3\ \mathrm{GeV}^2$ is a reasonable choice)
- Large NLO contributions



p-Pb @ 8.16 TeV







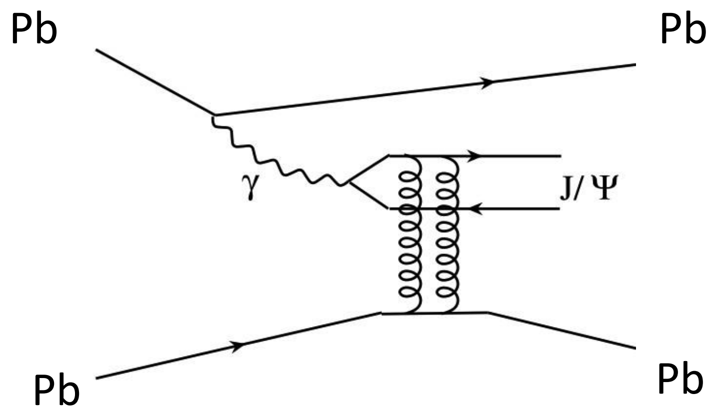
- x10 more stat at high $W_{\gamma p}$ ~ 0.7-1.4 TeV
- new AD detector in run 2 covering very forward rapidities up to η~6
- Aim to study exclusive and proton-dissociative cross section behaviour at high $W_{\gamma p}$

Charmonium photoproduction in ultraperipheral Pb-Pb collisions

J/ψ photoproduction on a Pb target

Coherent J/ψ photoproduction cross section is proportional to the **square of the gluon density in Pb target**

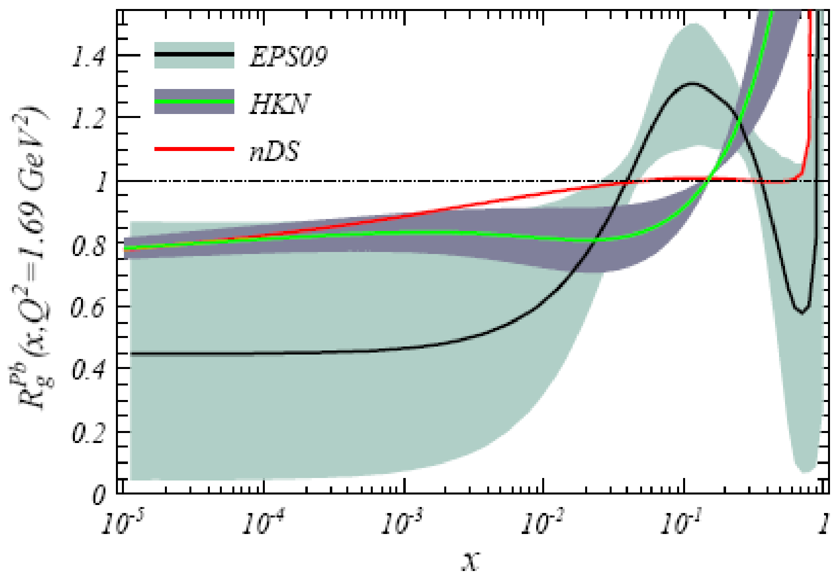
$$\left.\frac{d\sigma_{\gamma A\to J/\psi A}}{dt}\right|_{t=0} = \frac{M^3_{J/\psi}\Gamma_{ee}\pi^3\alpha_s^2(Q^2)}{48\alpha_{\rm em}Q^8}\left[xg_A(x,Q^2)\right]^2$$



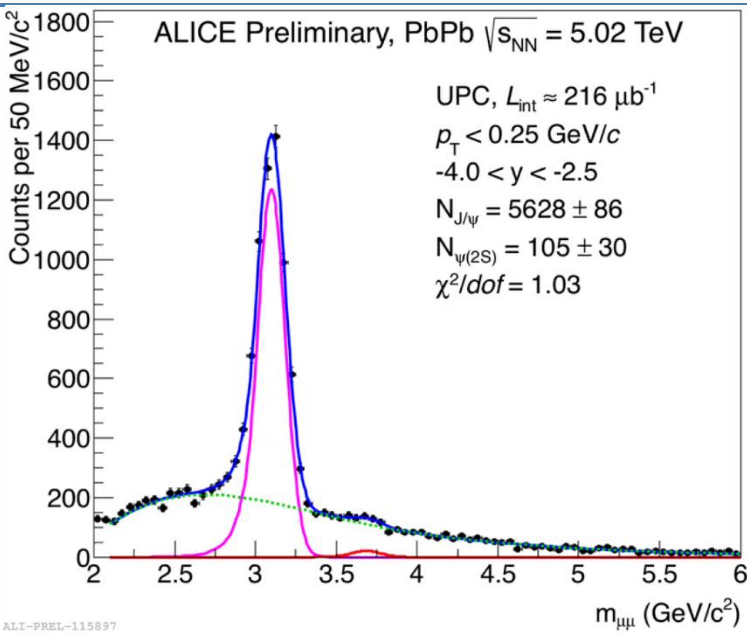
J/ψ photoproduction in Pb-Pb UPC (lead target) provides information on **gluon shadowing in nuclei at low x**

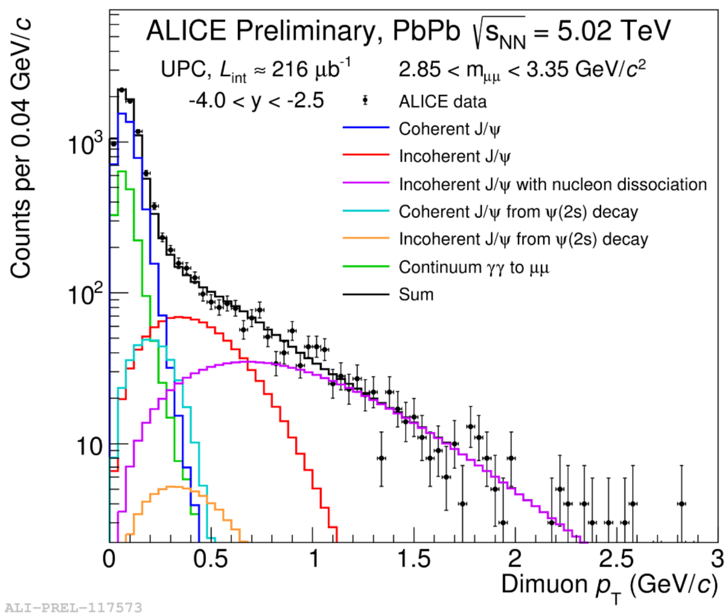
$$R_g^A(x,Q^2) = \frac{g_A(x,Q^2)}{Ag_p(x,Q^2)}$$

– gluon shadowing factor



Coherent and incoherent photoproduction



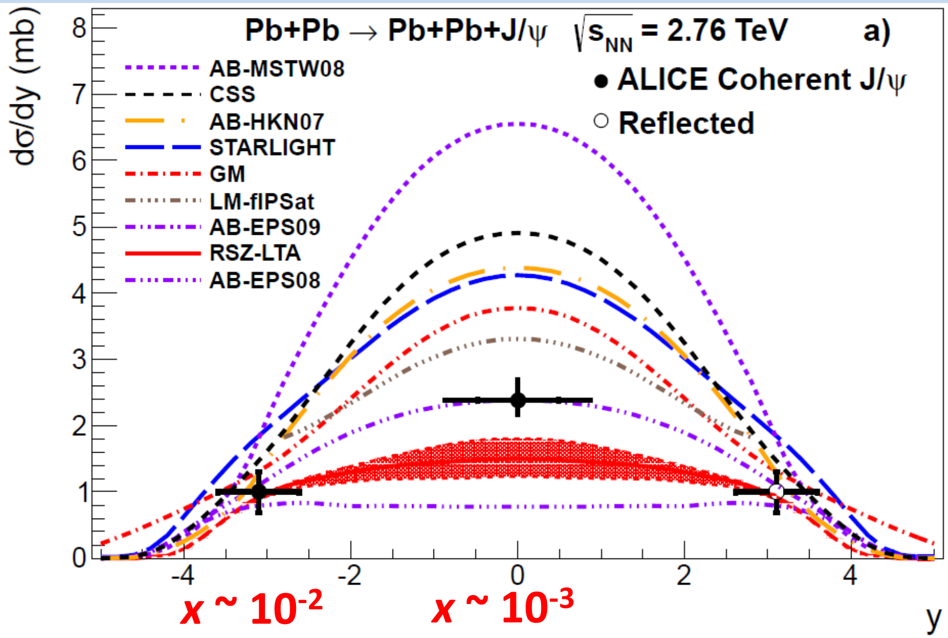


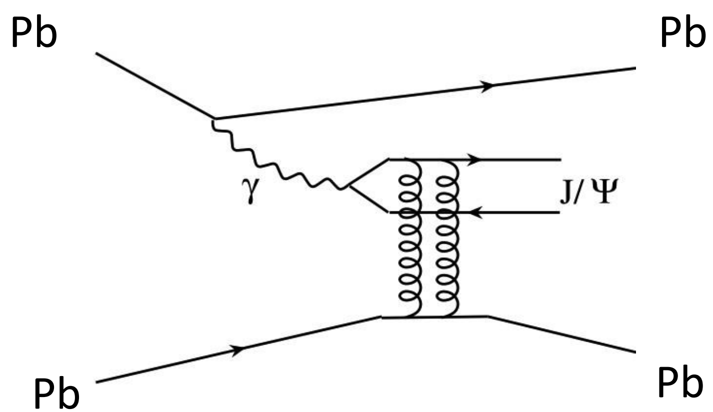
Contributions (templates from MC):

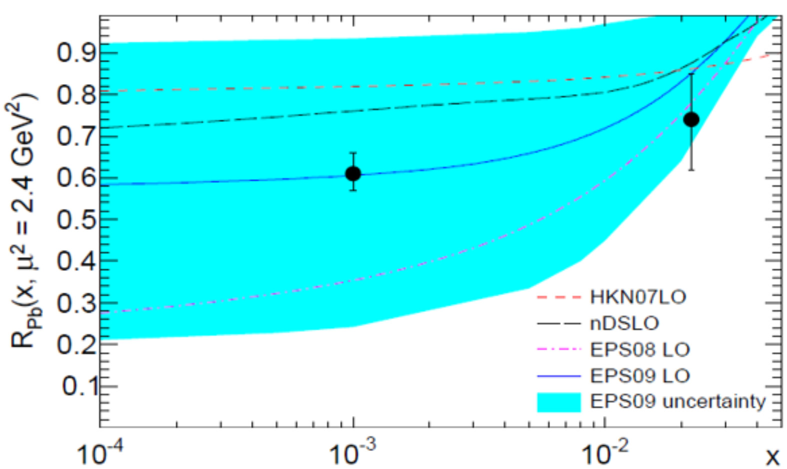
- **Coherent J/ψ:**
  - photon couples coherently to all nucleons
  - $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
- **Incoherent J/ψ:**
  - photon couples to a single nucleon
  - $\langle p_T \rangle \sim 1/R_p \sim 450$ MeV/c
- **Incoherent J/ψ with nucleon dissociation:**
  - shape parameters from HERA
- **J/ψ from coherent and incoherent ψ' decays:** fixed wrt primary J/ψ (~5-6%)
- **γγ →μμ:** fixed integral wrt J/ψ peak (~5%)

Results from Run 1

ALICE: Phys. Lett. B718 (2013) 1273, Eur. Phys. J. C73 (2013) 2617







Guzey, EK et al. PLB726 (2013) 290

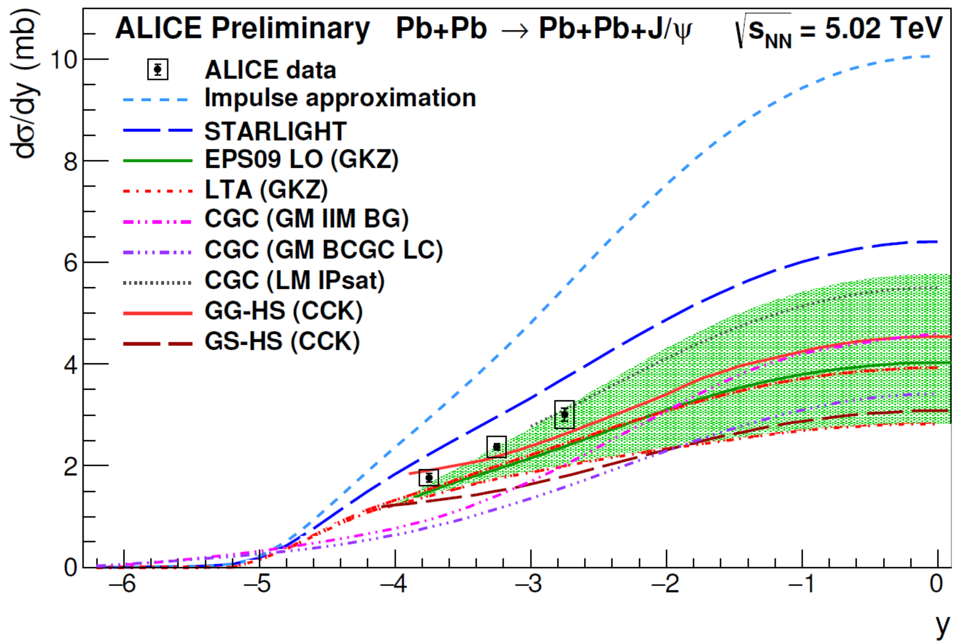
Experimental cross section in Pb-Pb UPC divided by the photon flux

$$S(W_{\gamma p}) \equiv \left[\frac{\sigma^{\rm exp}_{\gamma {\rm Pb}\to J/\psi {\rm Pb}}(W_{\gamma p})}{\sigma^{\rm IA}_{\gamma {\rm Pb}\to J/\psi {\rm Pb}}(W_{\gamma p})}\right]^{1/2}$$

Impulse approximation (derived from forward photoproduction cross section on proton)

Good agreement with EPS09 and LTA shadowing

Coherent J/ψ cross section in Run2



$$\frac{d\sigma_{UPC}}{dy} = n(\omega_1)\sigma_{\gamma T}(\omega_1) + n(\omega_2)\sigma_{\gamma T}(\omega_2)$$

Low energy (high-x) High energy (low-x)

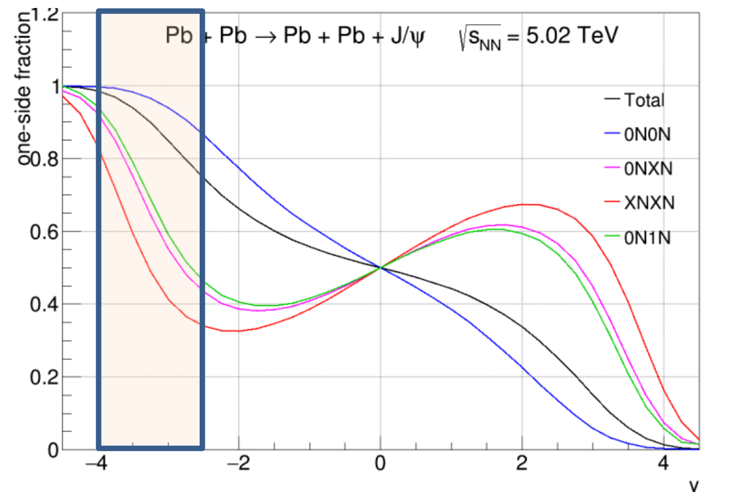
- 90-95% contribution of high-x: 0.7-3 x 10^{-2}
- Back-of-the-envelope calculation (neglect low-x): ALICE/Impulse approximation ~ 0.6 => shadowing factor $\sim \sqrt{0.6} \sim 0.8$ (see Phys. Lett. B726 (2013) 290 for details)

- **Impulse approximation: no nuclear effects**
- **STARLIGHT: VDM + Glauber,** Klein, Nystrand et al: Comput. Phys. Commun. 212 (2017) 258
- **EPS09 L0 (GKZ): EPS09 shadowing** Guzey, Kryshen, Zhalov, PRC93 (2016) 055206
- **LTA (GKZ): Leading Twist Approximation** Guzey, Kryshen, Zhalov, PRC93 (2016) 055206
- **GM: Color dipole model + IIM/BCGC CGC** Goncalves, Machado et al.: PRC 90 (2014) 015203, JPG 42 (2015) 105001
- **LM IPSat: Color dipole model + IPSat CGC** T. Lappi, H. Mäntysaari, PRC 83 (2011) 065202; 87 (2013) 032201
- **GG-HS, GS-HS (CCK):** Hot spot model, Cepila, Contreras et al. PRC97 (2018) 024901

Coherent J/ψ cross section in agreement with moderate nuclear gluon shadowing

Next…

- Study J/ψ photoproduction accompanied by neutron emission (measured with Zero Degree Calorimeters) => access x~10^{-5}
- J/ψ polarization
- Incoherent cross-section

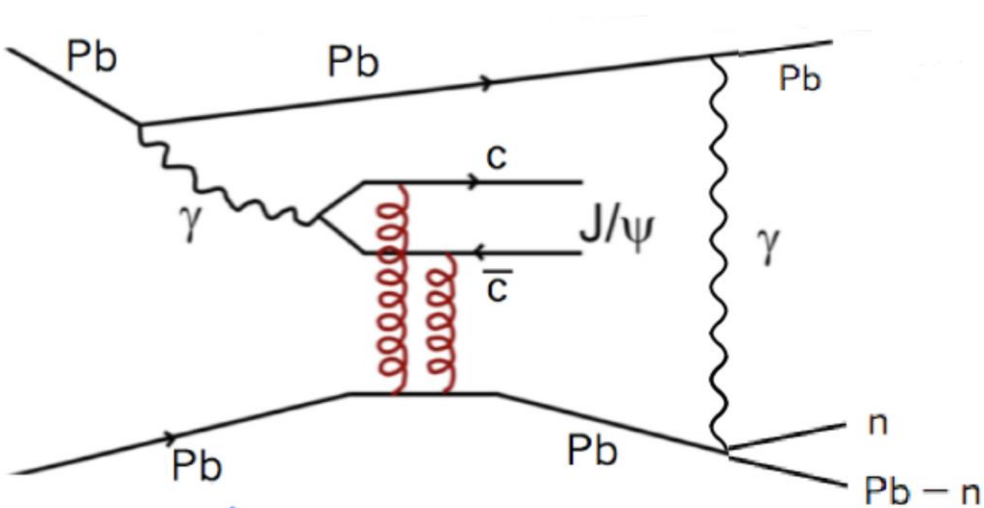


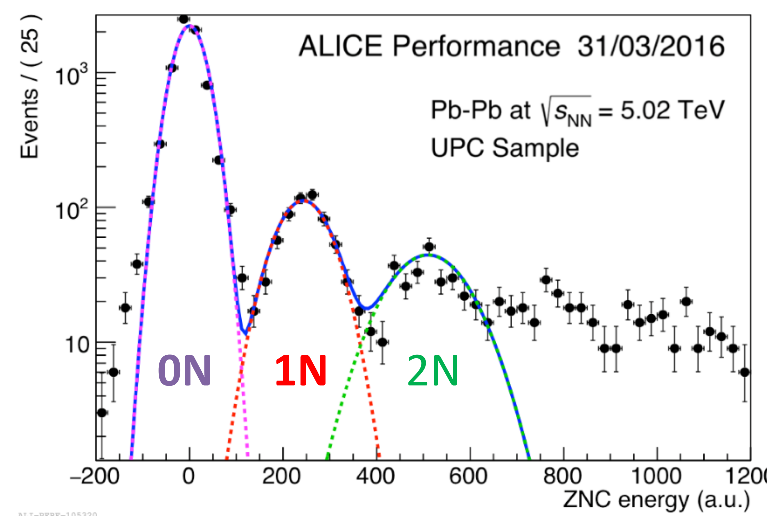
Derived from V. Guzey, EK, M. Zhalov, **PRC93 (2016), 055206**

$$\frac{d\sigma_{UPC}}{dy} = n(\omega_1)\sigma_{\gamma T}(\omega_1) + n(\omega_2)\sigma_{\gamma T}(\omega_2)$$

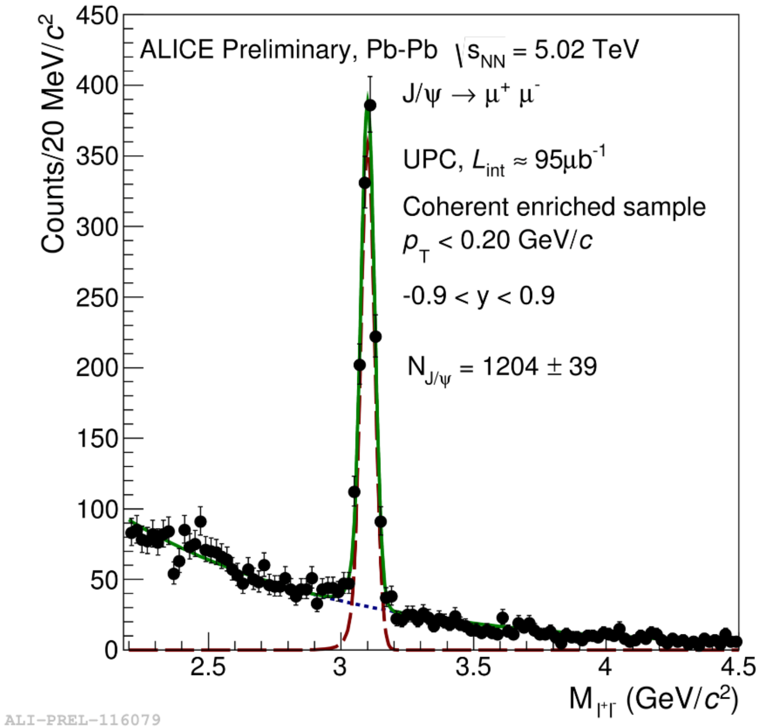
Low energy (high-x)

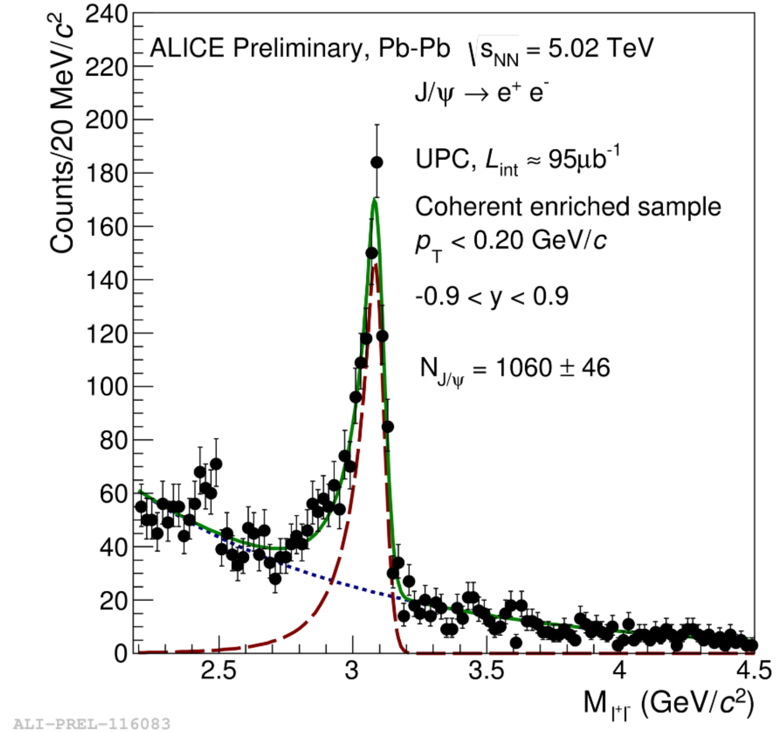
High energy (low-x)



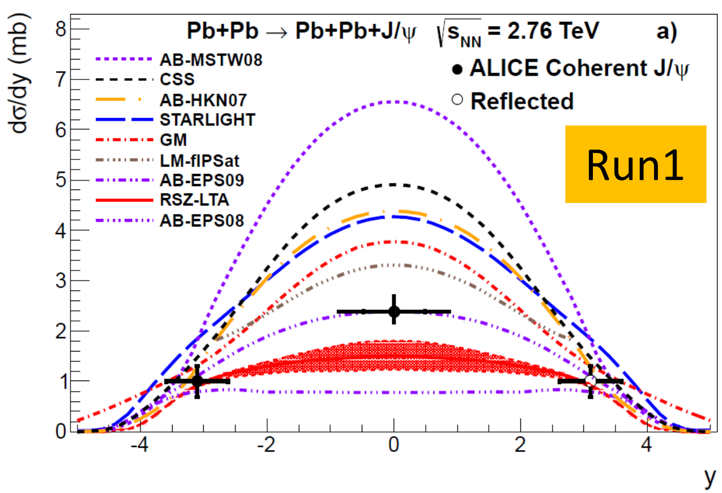


+ J/ψ in central barrel

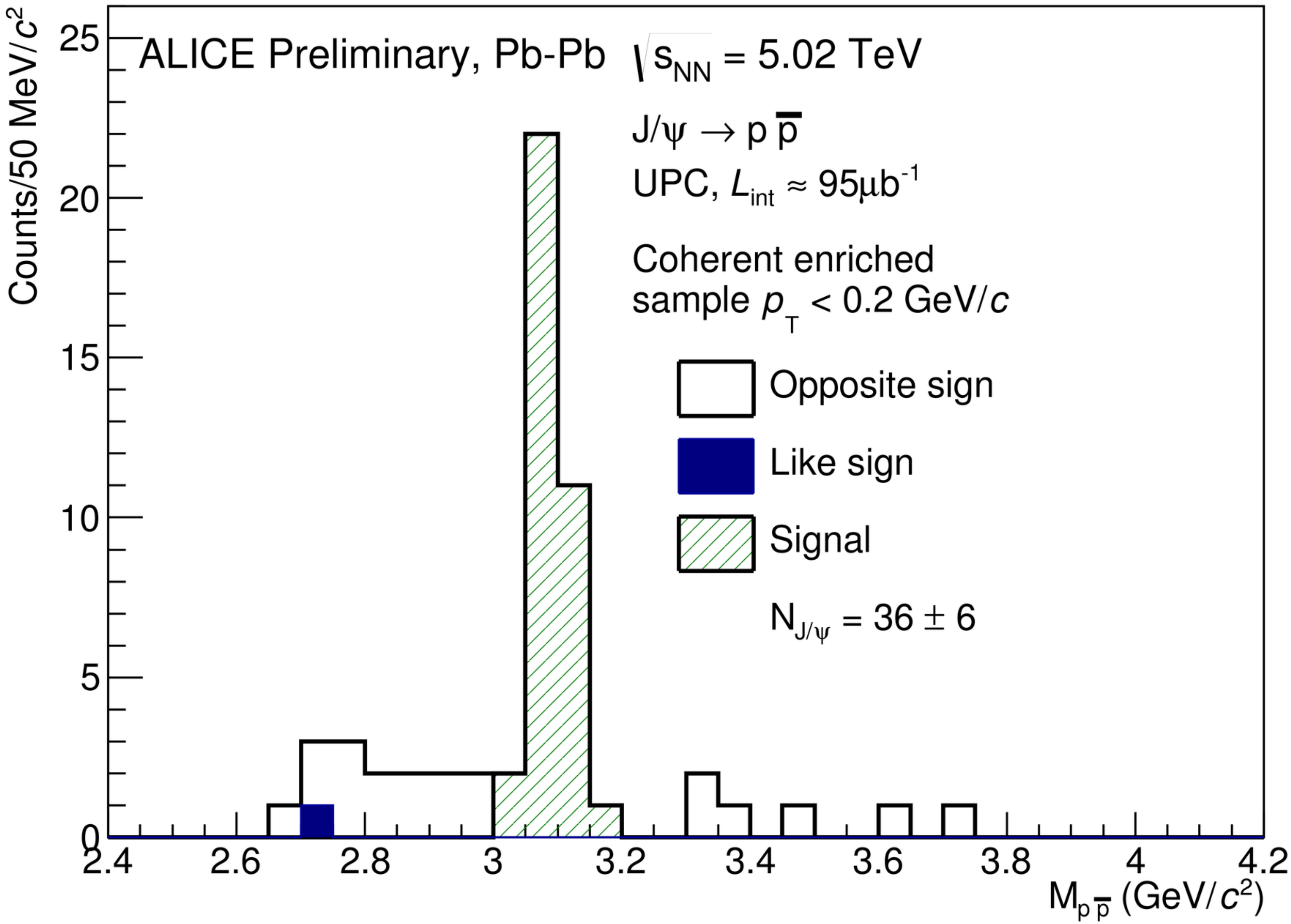




- x4 more statistics wrt Run1
- access to x ~ 0.5 x 10^{-3}

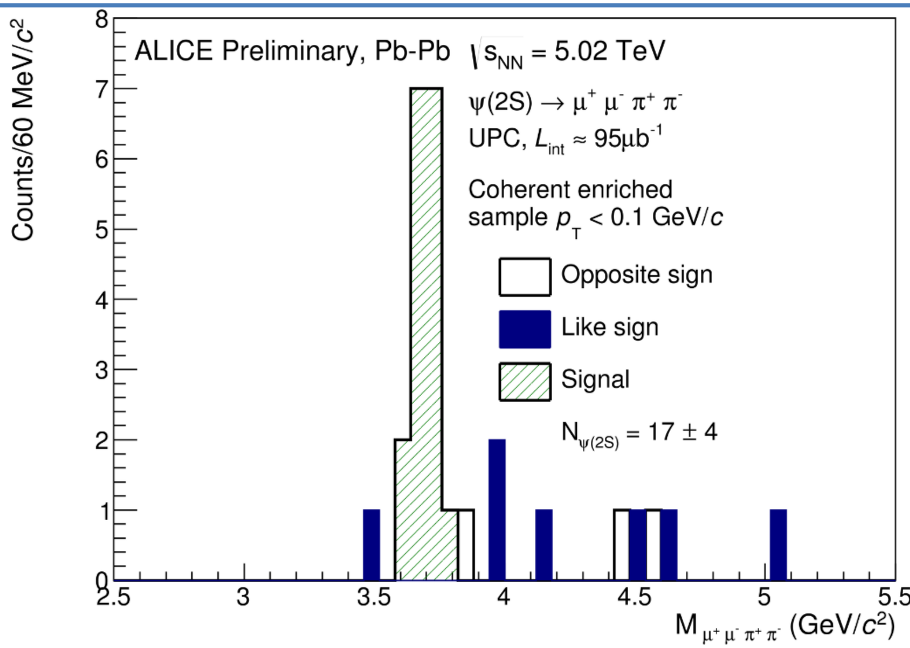


First observation in UPC: J/ψ→ $p\bar{p}$

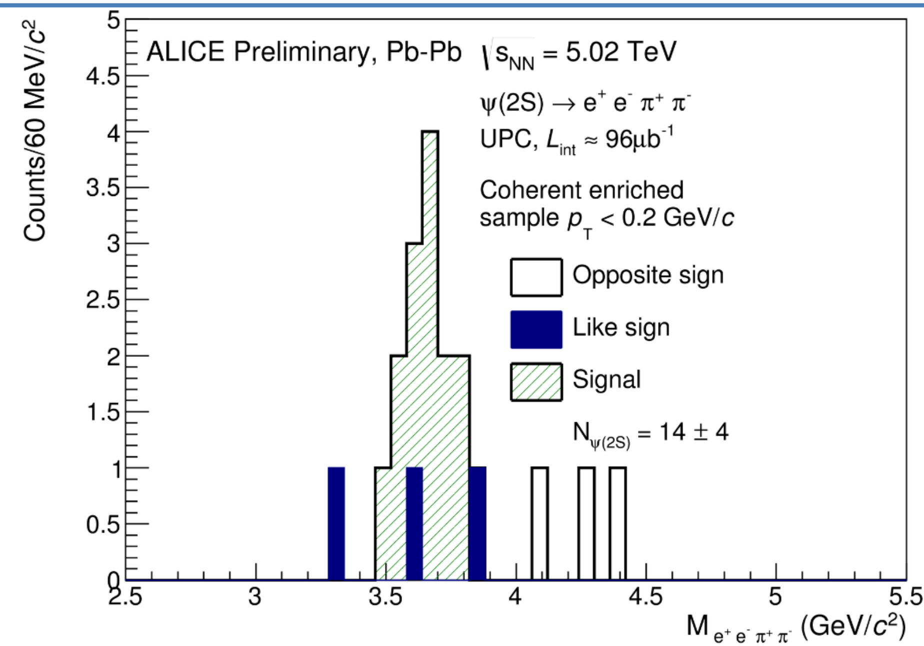


ALI-PREL-117138

+ ψ(2S) → J/ψππ

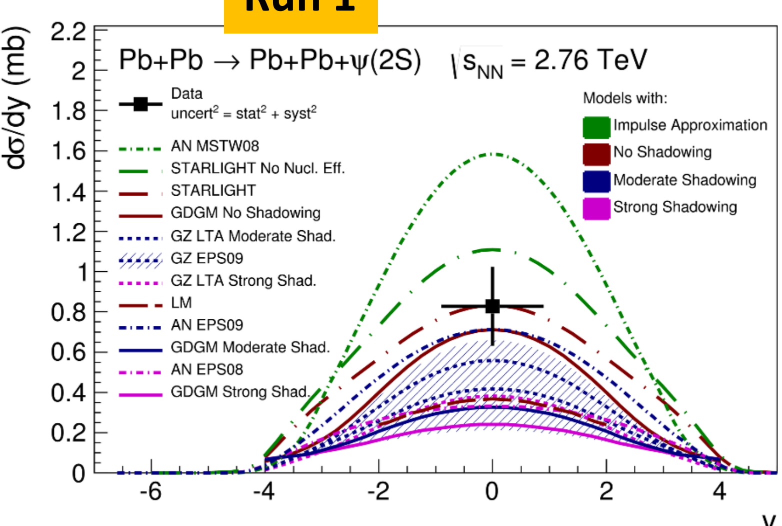


ALI-PREL-116095



ALI-PREL-116091

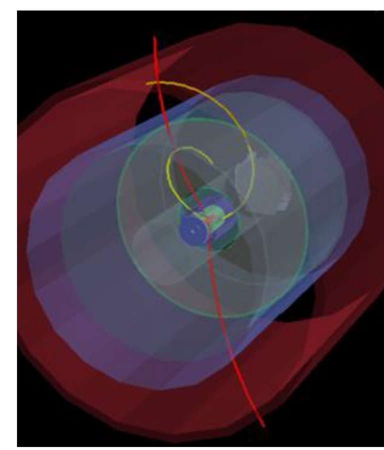
Run 1



ALI-PUB-96039

Hope to resolve puzzling result from Run 1:

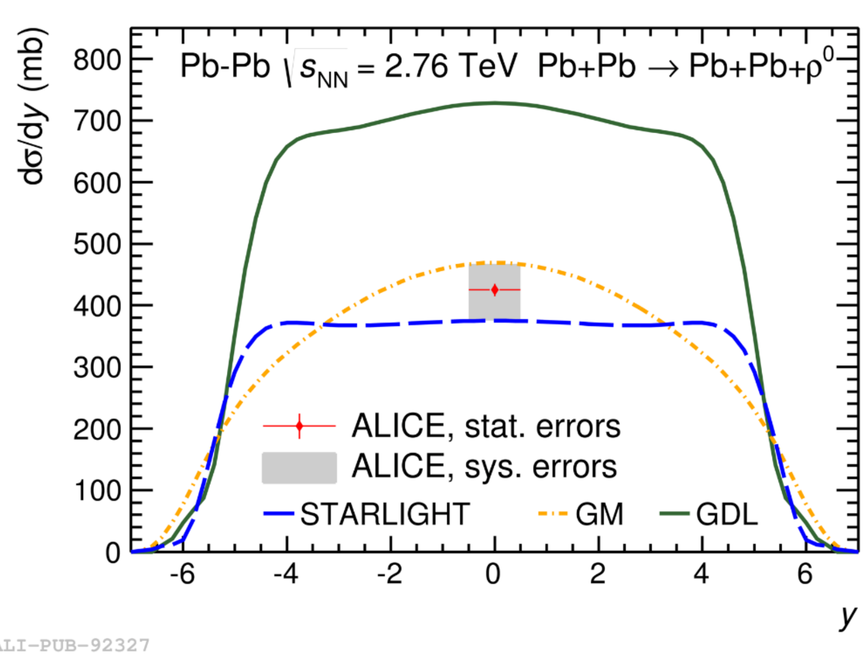
σ(ψ')/σ(J/ψ) ~ 0.34 ± 0.08 (stat+syst)
expected < 0.20

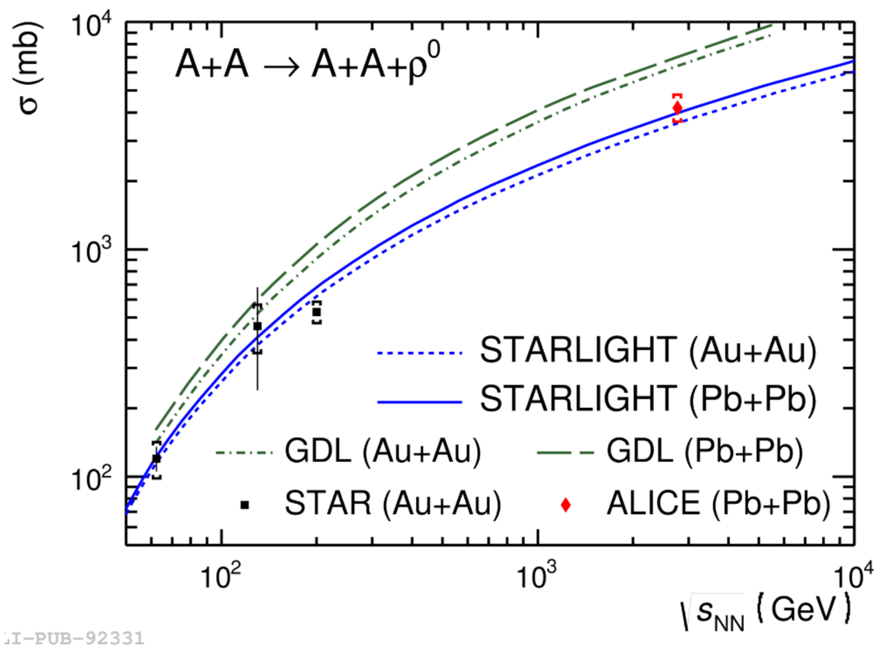


ρ^0 photoproduction in ultraperipheral Pb-Pb collisions

ρ^0 photoproduction in Pb-Pb @ 2.76 TeV

JHEP 1509 (2015) 095





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

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

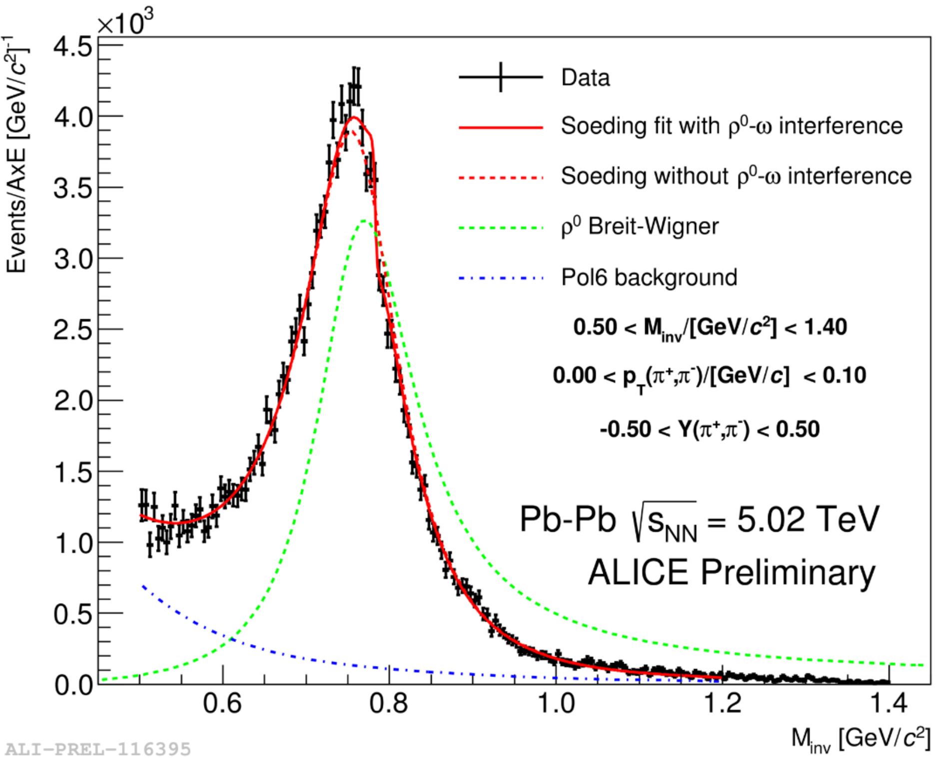
GM: Gonçalves, Machado [Phys. Rev. C 84 (2011) 011902]

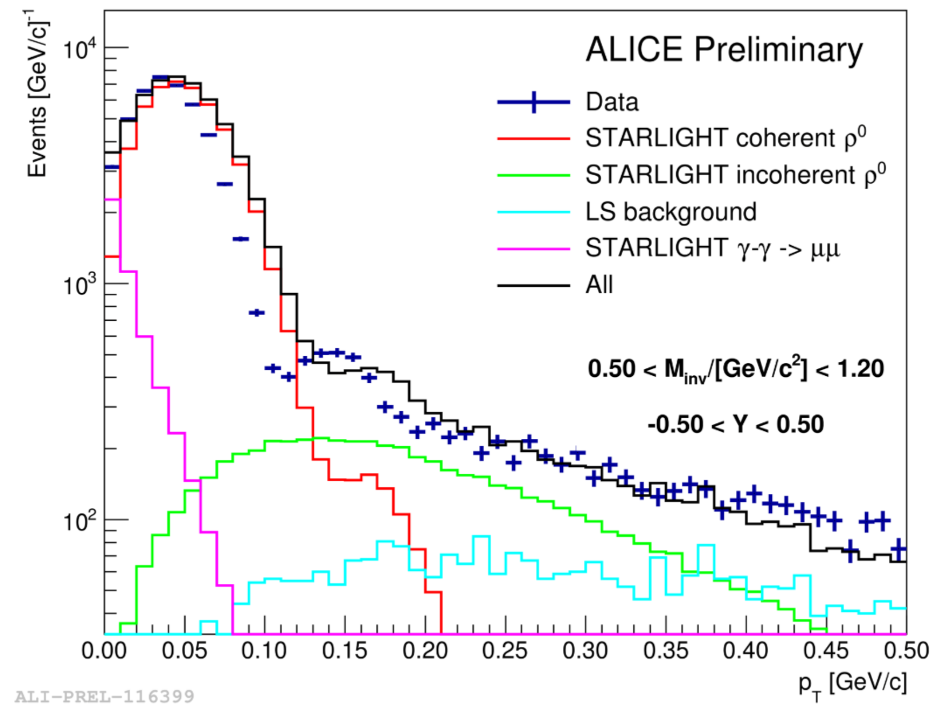
- Based on the color dipole model in combination with saturation from a CGC-IIM model.

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.

ρ^0 photoproduction in Pb-Pb @ 5 TeV

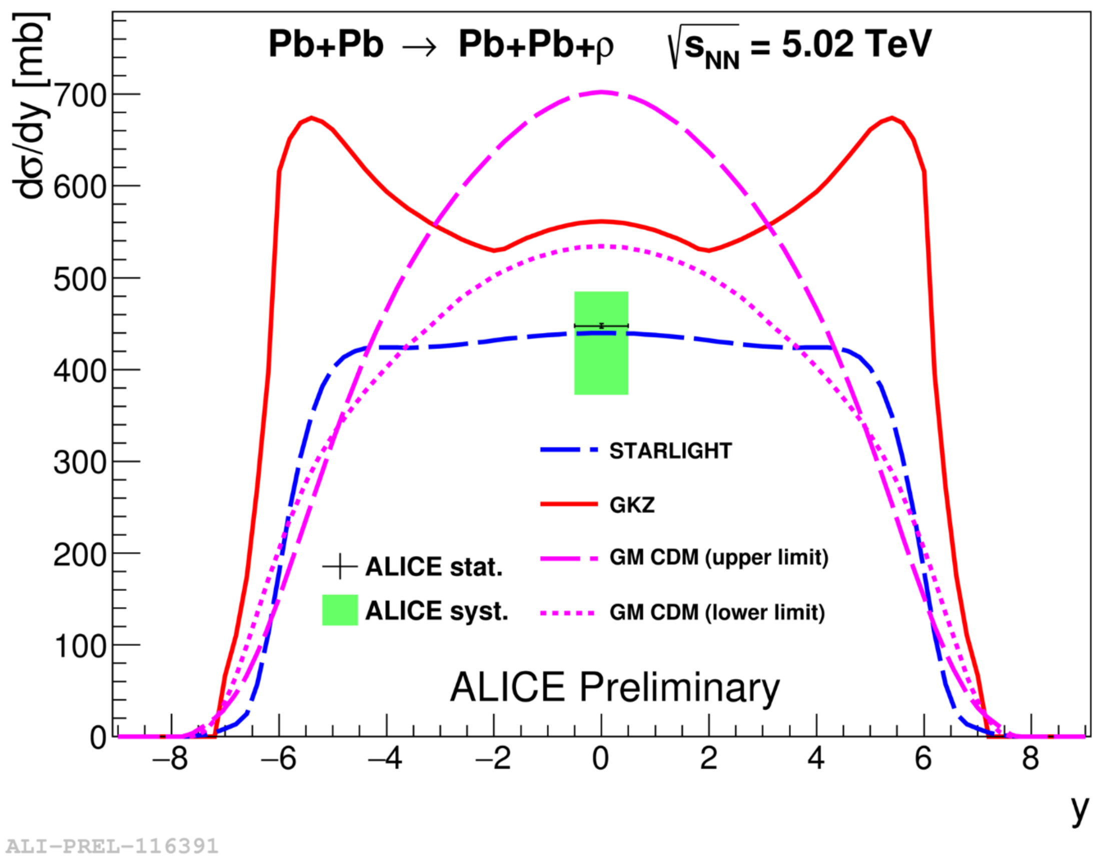




$$\frac{d\sigma}{dm_{\pi\pi}} = |A \cdot BW + B + C \cdot e^{i\phi} \cdot BW|^2 + N \cdot \mathrm{pol6}$$

- Second diffractive peak clearly visible
- Coherent p_T distribution from STARLIGHT significantly wider than data
  => access impact-parameter dependent shadowing effects (e.g. Guzey, Strikman, Zhalov: PRC 95, 025204 (2017))

Coherent ρ^0 cross section at 5 TeV



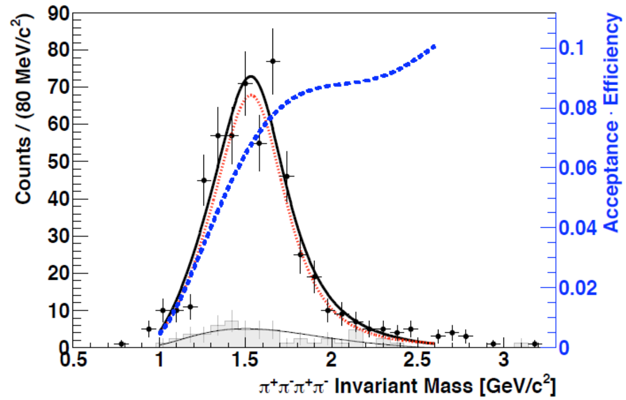
- **STARLIGHT: VDM + Glauber.** Klein, Nystrand et al: Comput. Phys. Commun. 212 (2017) 258
- **GKZ: Gribov-Glauber shadowing.** Guzey et al, PLB752 (2016) 51**,** PRC93 (2016) 055206
- **GM CDM**. Gonçalves, Machado et al, PRC80 (2009), 054901, PRC91 (2015) 025203

ρ photoproduction cross section compatible with STARLIGHT
but Gribov-Glauber shadowing predictions are still above data

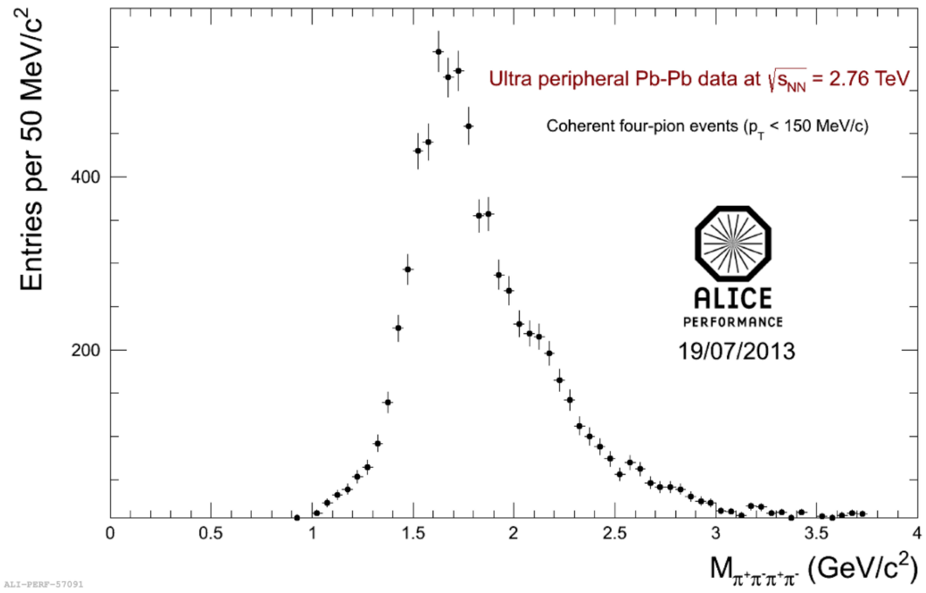
Four-pion final state

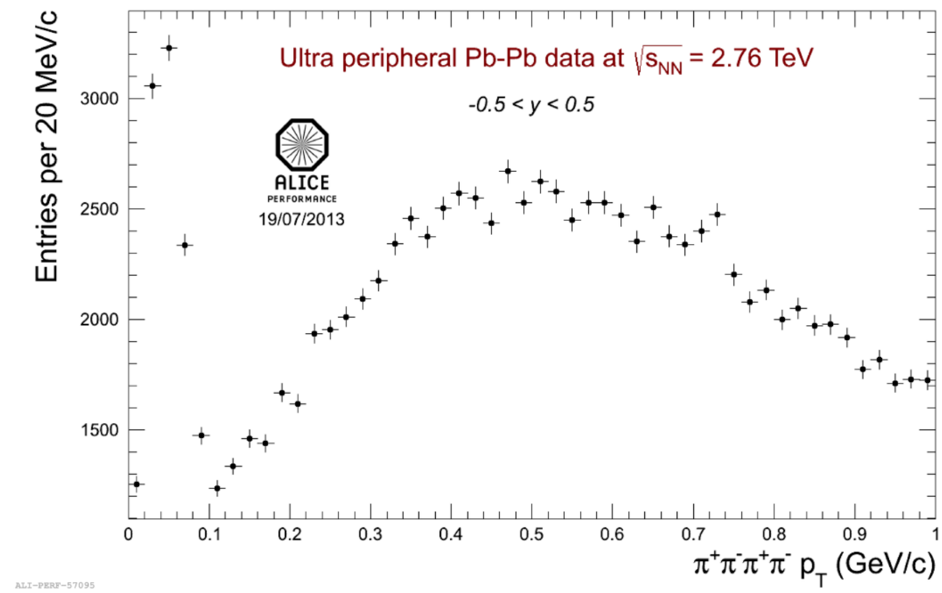
ρ‘ via double-ρ production

STAR Phys. Rev. C81 (2010) 044901



x10 more statistics than STAR



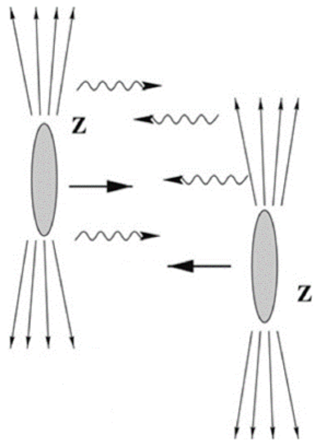


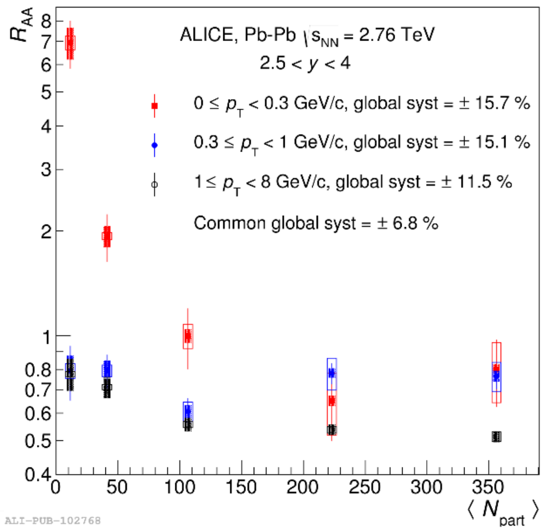
4-pion invariant mass for p_T (4π) < 0.15 GeV/c

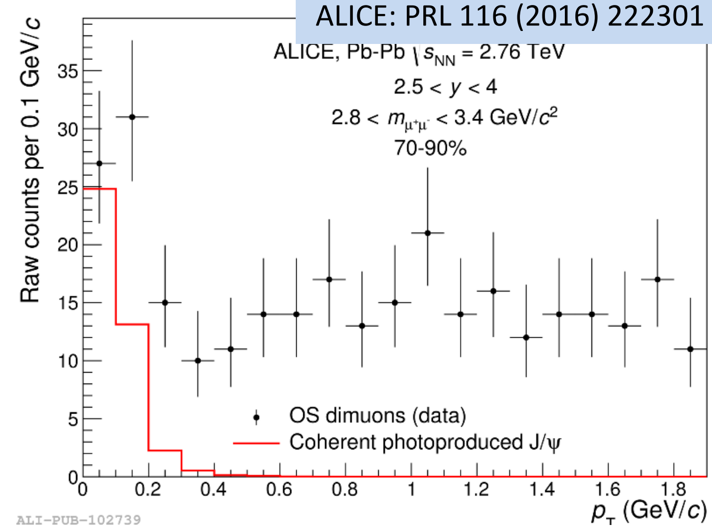
Coherent peak at low p_T (4π) on top of background

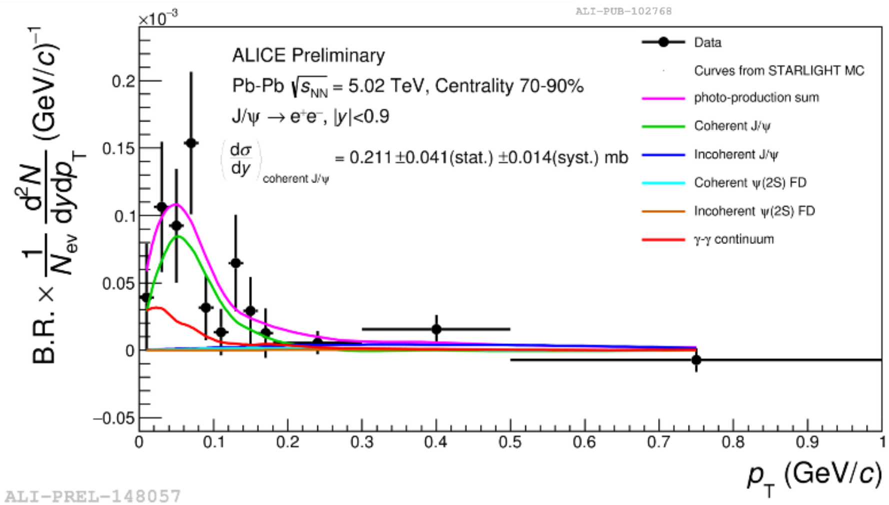
Photon-induced processes at b<2R

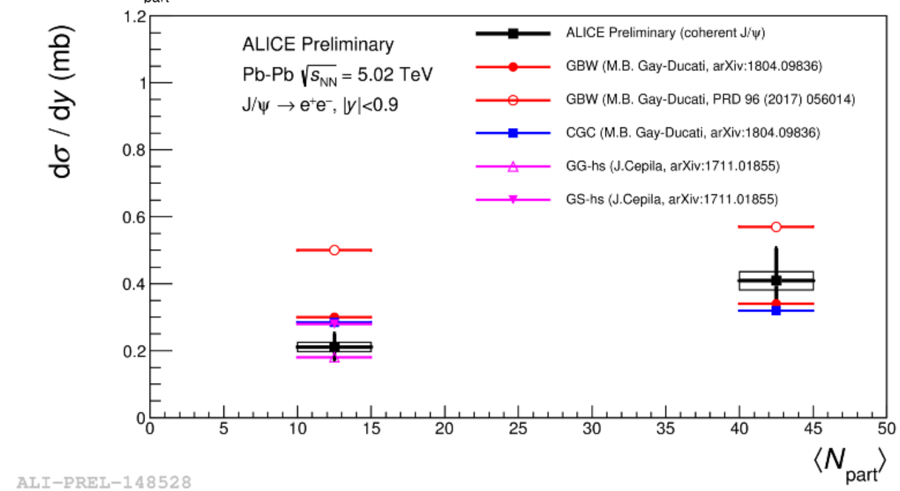
ALICE: PRL 116 (2016) 222301











See also: Zha, Klein, PRC97 (2018) 044910

- Data shows an excess of J/ψ at low p_T < 100 MeV/c (R_{AA} ~ 7)
- Possible interpretation: coherent photoproduction on nuclear fragments

Summary and outlook

- No signs of saturation in J/ψ photoproduction off a proton
- Coherent J/ψ photoproduction cross section in Pb-Pb UPC is in agreement with moderate nuclear gluon shadowing
- ρ photoproduction cross section compatible with STARLIGHT but Gribov-Glauber shadowing predictions are still above data
- More results from Run2 expected:
  - Incoherent J/ψ, ZDC-differential studies
  - J/ψ and ψ(2S) photoproduction in Pb-Pb at central rapidity
  - J/ψ photoproduction in p-Pb
- Looking forward to Run3+4 data: expect up to 12 nb^{-1} with upgraded detectors (continuous readout, new ITS etc)

BACKUP

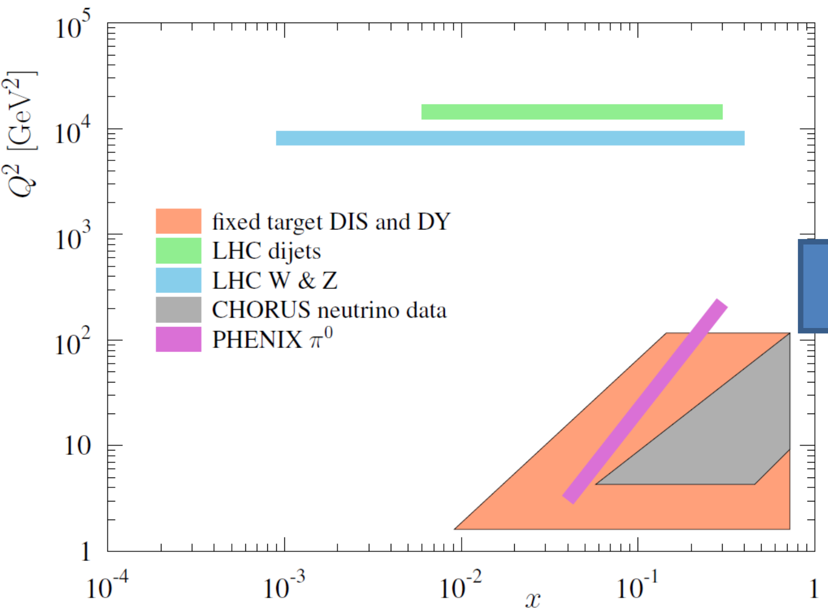
Parton distributions in nuclei (nPDFs)

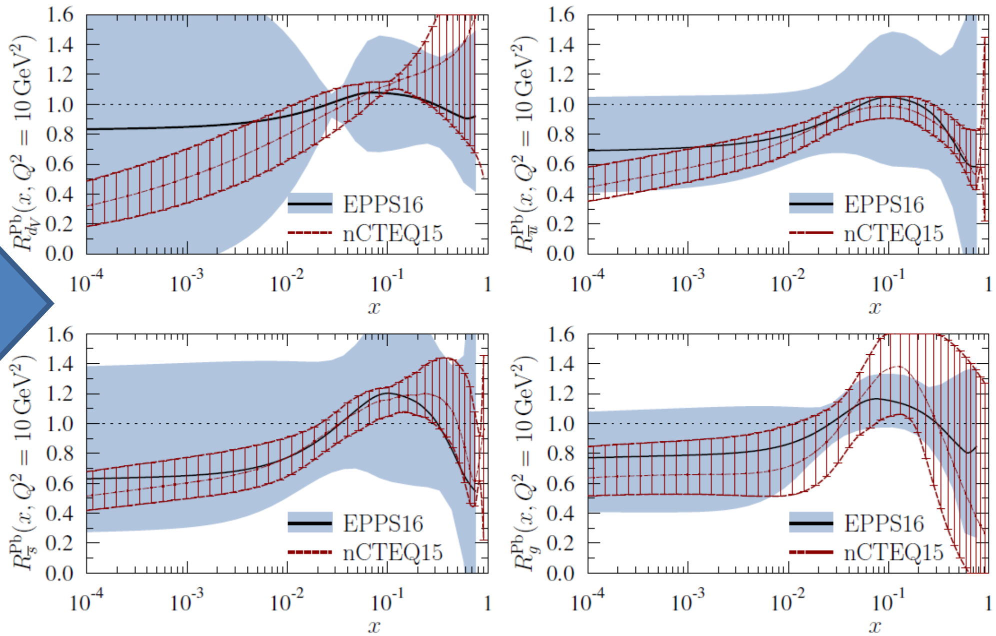
nPDFs are fundamental QCD quantities for the description of DIS, pA, AA collisions

- determine initial state in heavy ion collisions
- required for quantitative estimates for the onset of saturation

Determination of nPDFs:

EPPS16 : EPJ C (2017) 77





Resulting nPDFs have rather **large uncertainties, especially for small-x gluons** due to:

- Limited kinematics
- Indirect extraction of gluons via Q^2 evolution