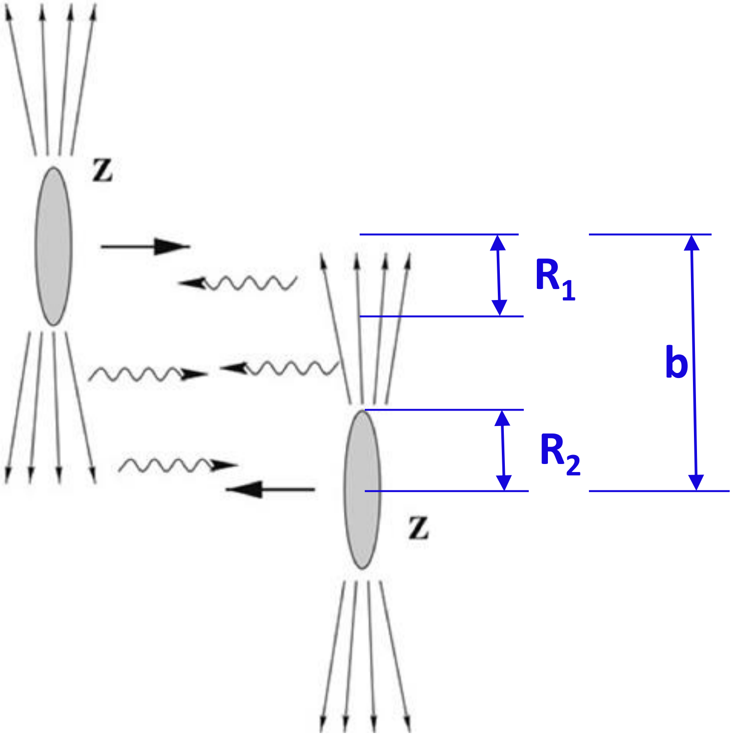
Shedding light on hadron structure with ultra-peripheral collisions in ALICE

New results on J/ψ photoproduction and projections for Run3-4

Evgeny Kryshen
(NRC KI, Petersburg Nuclear Physics Institute, Russia)
for the ALICE collaboration

CERN LHC Seminar
18 June 2019

LHC as a γp and γPb 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

Recent reviews on UPC physics:
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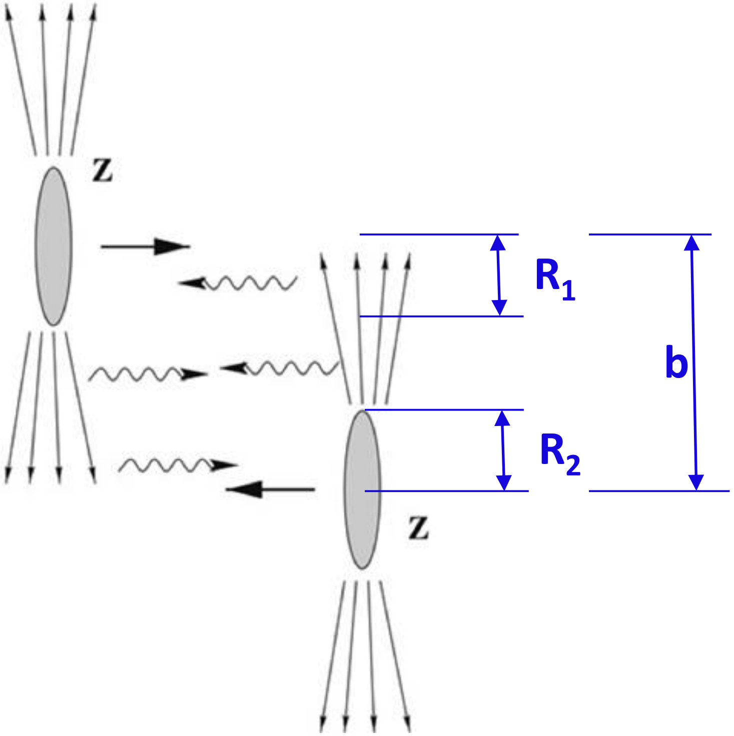

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Pb-Pb UPC at LHC can be used to study $\gamma\gamma$, γ-p and γ-Pb interactions at higher center-of-mass energies than ever before

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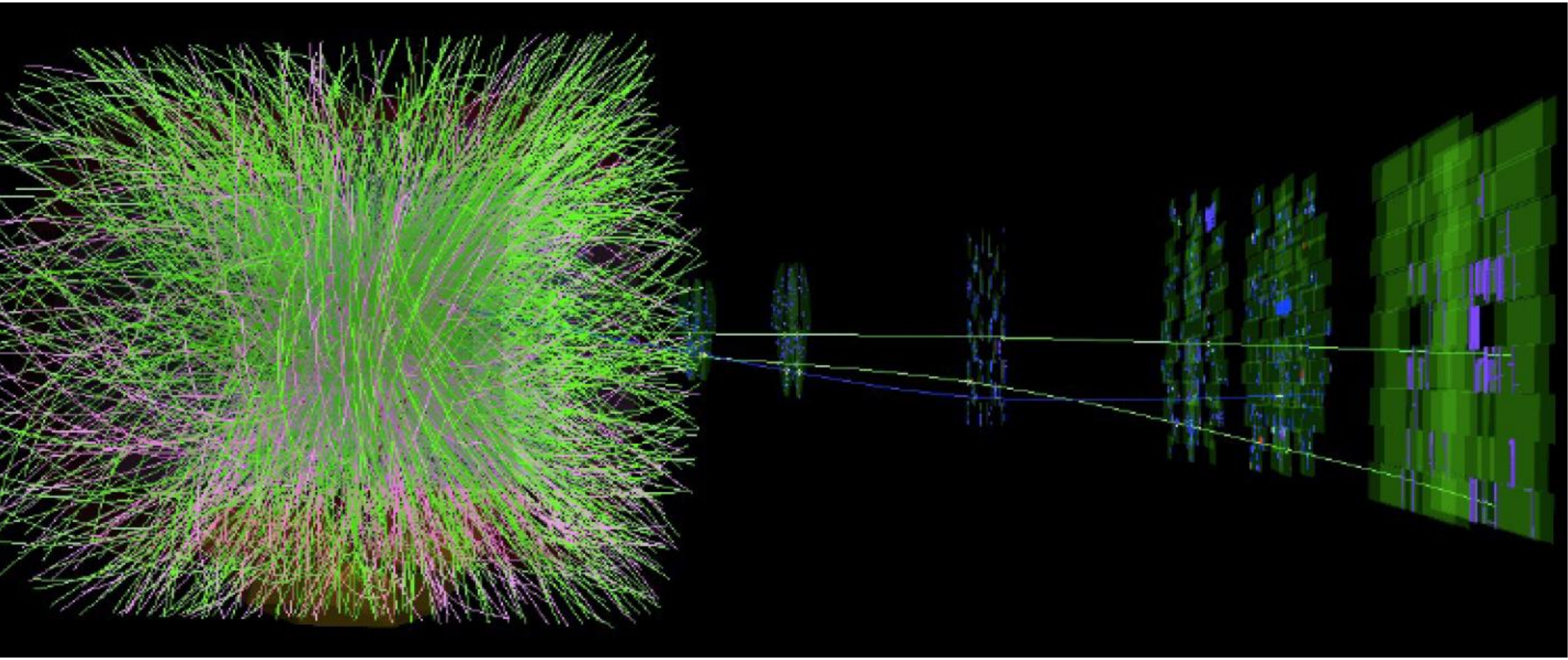
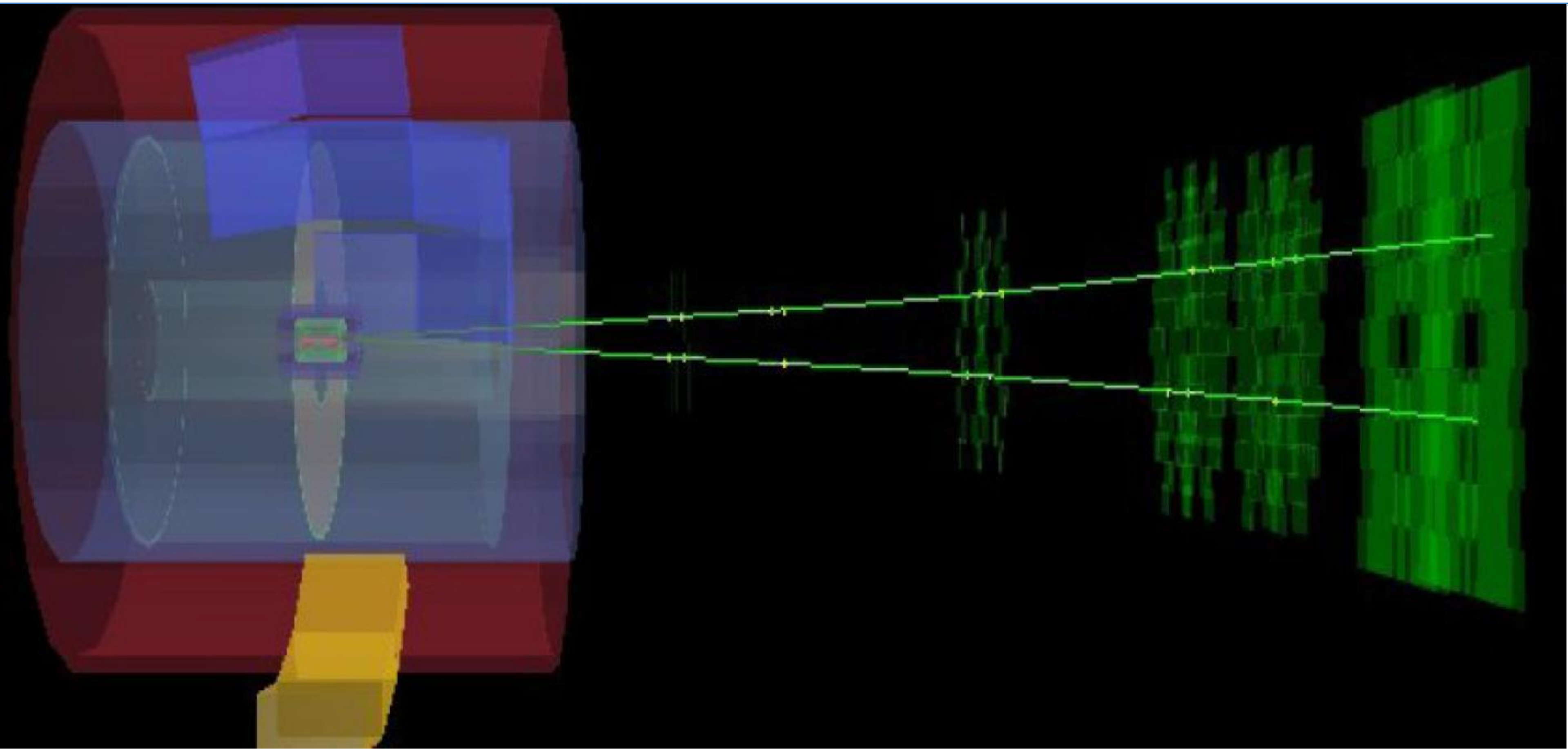
From typical hadronic interaction…

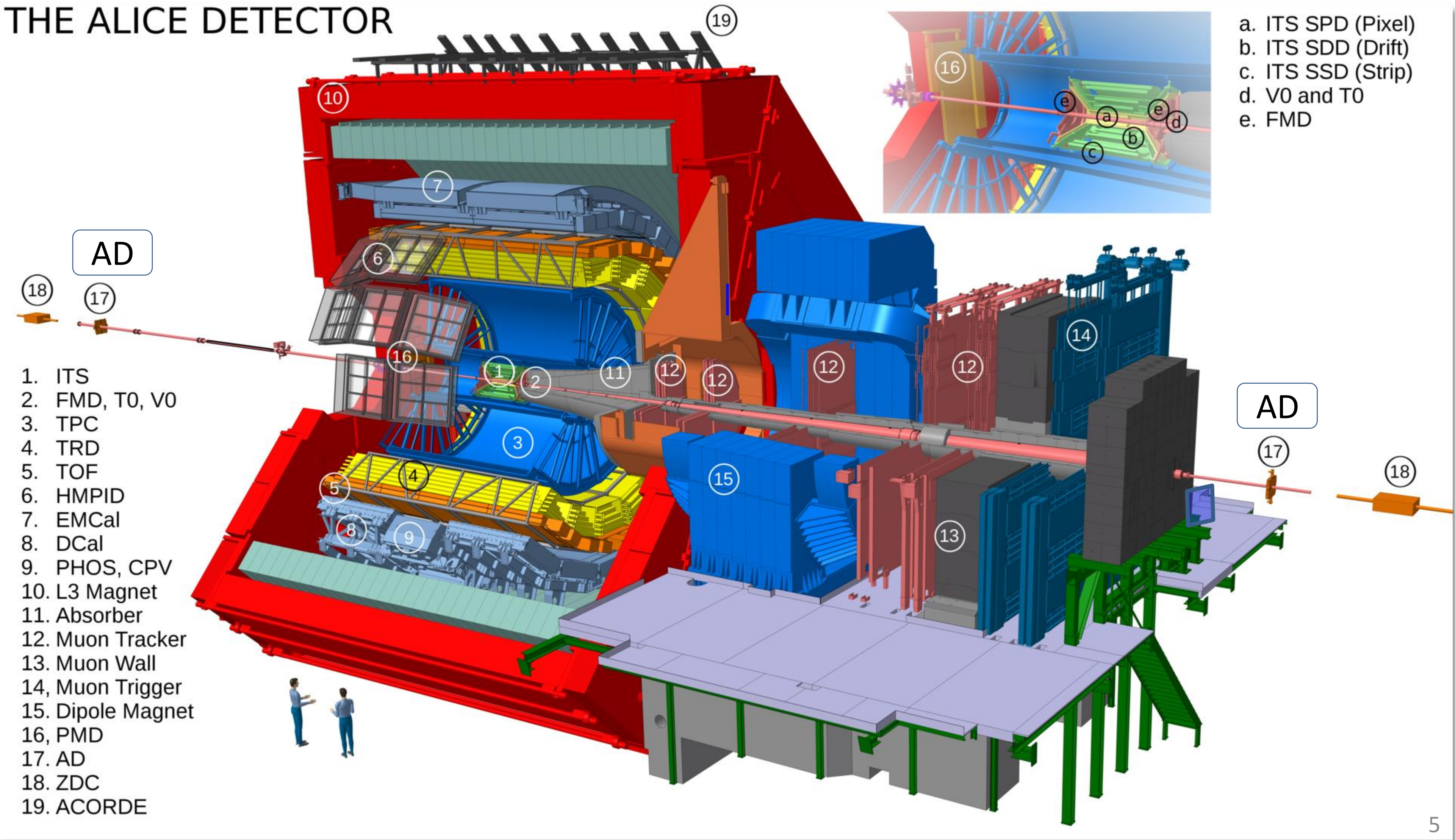


to ultra-peripheral collisions



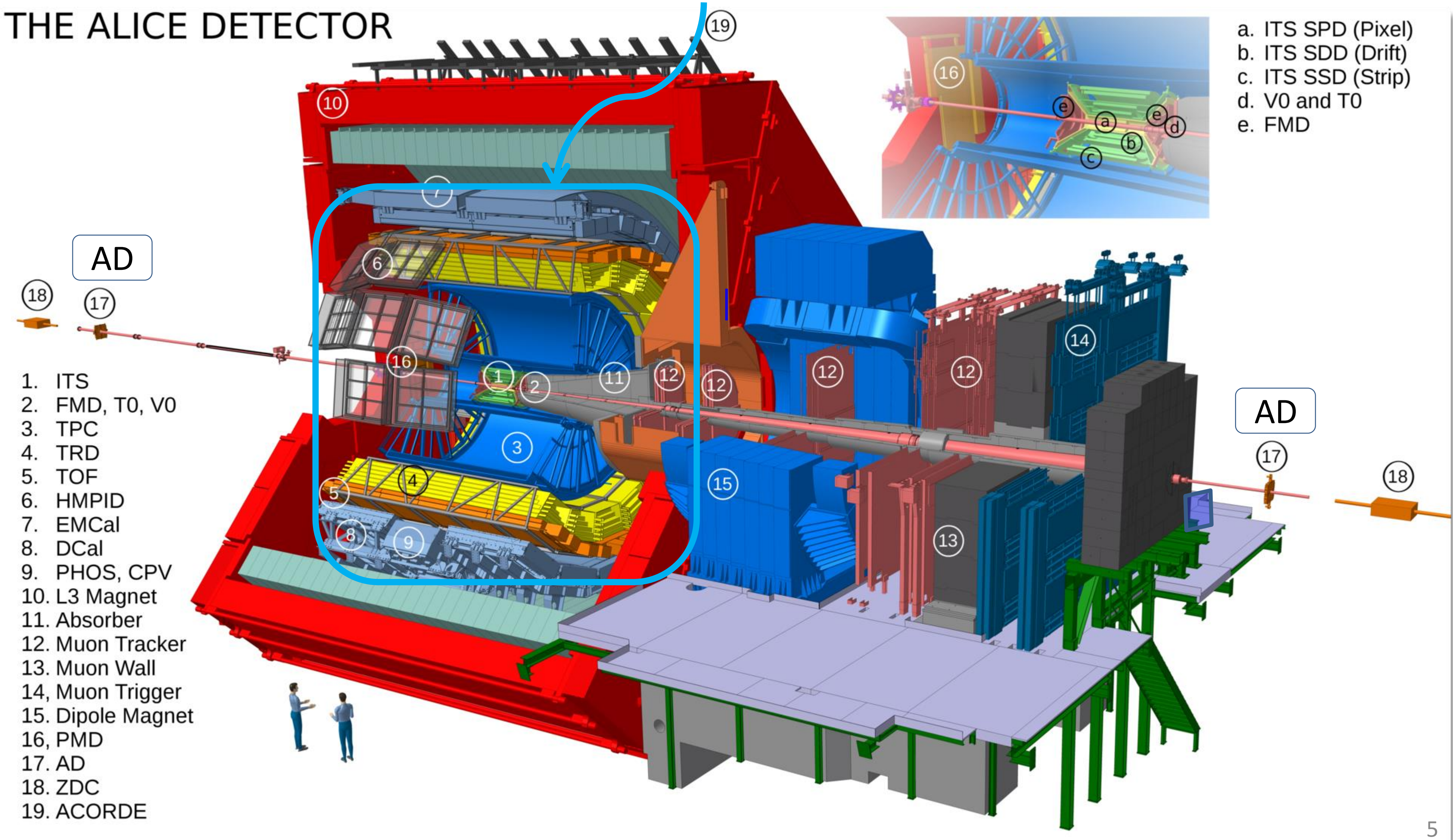
- Experimental signature: few signal tracks in an otherwise empty detector
- Wide acceptance coverage is important to ensure event emptiness
- Trigger challenge

Looking for two tracks in an otherwise empty detector…



Looking for two tracks in an otherwise empty detector…

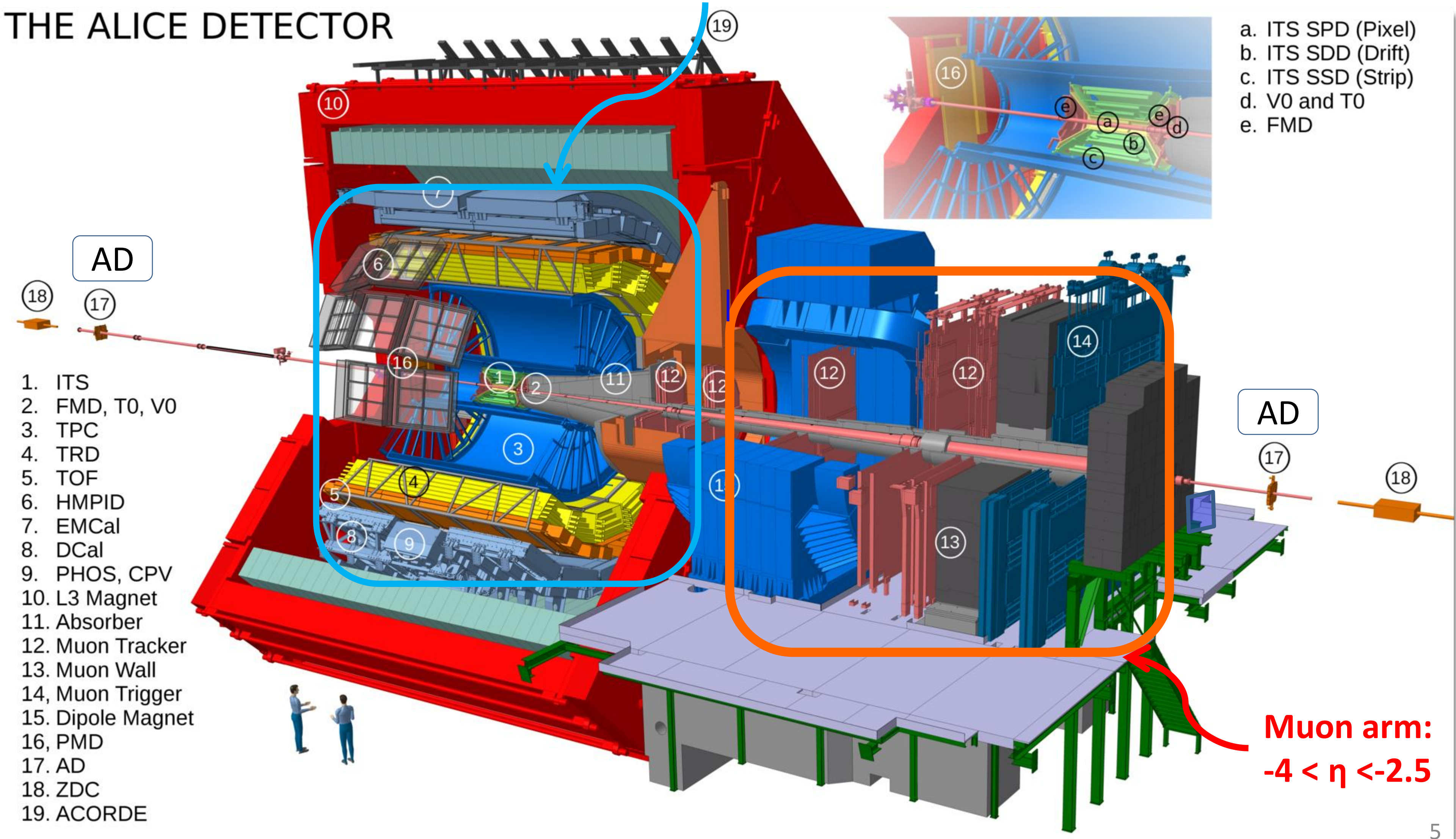
Central barrel: $|\eta| < 0.9$
Inner SPD layer: $|\eta| < 2.0$



THE ALICE DETECTOR

Looking for two tracks in an otherwise empty detector…

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



Muon arm:
-4 < η <-2.5

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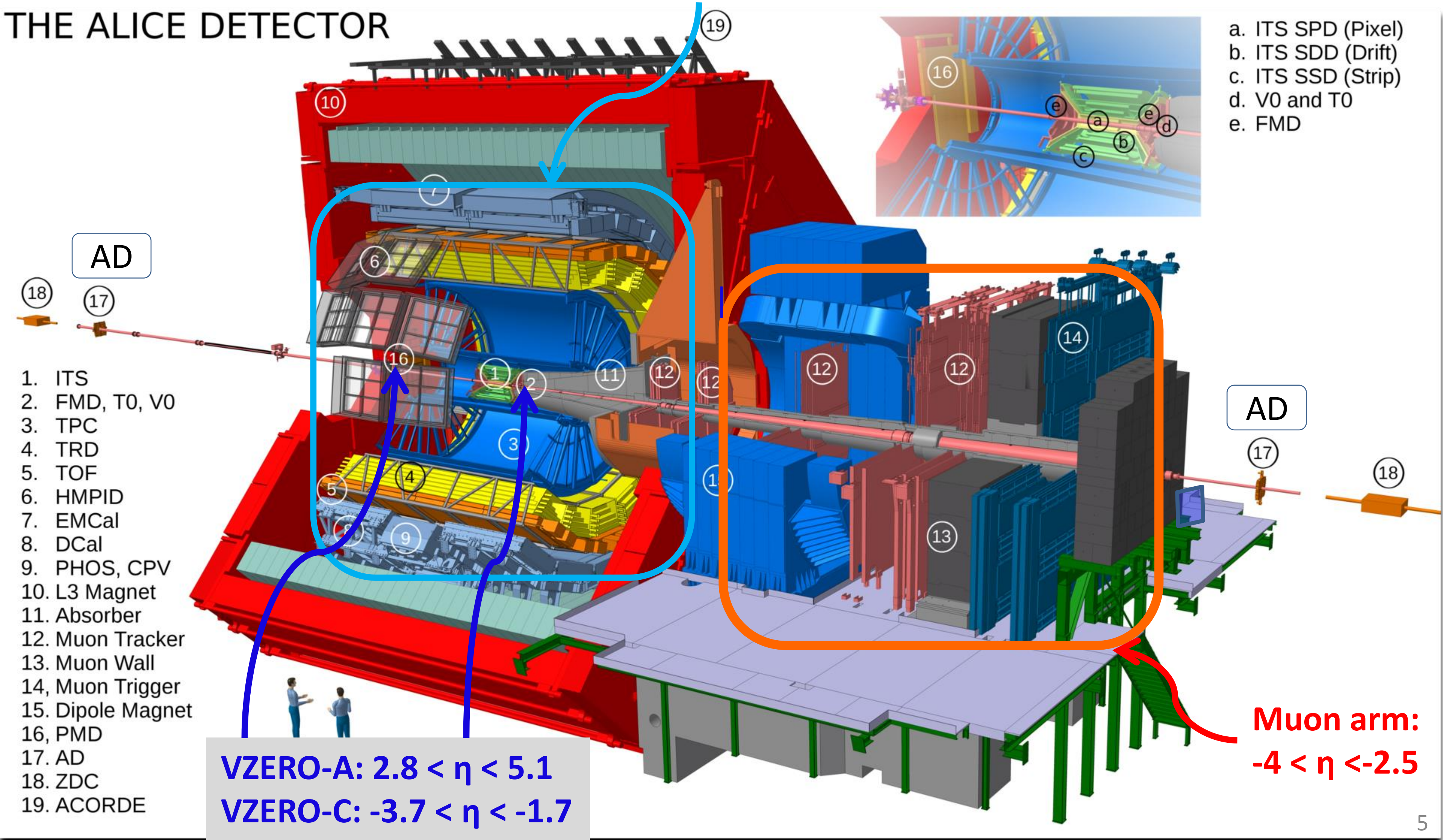


VZERO-A: $2.8 < \eta < 5.1$

VZERO-C: $-3.7 < \eta < -1.7$

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

Looking for two tracks in an otherwise empty detector…

Continuous coverage:

$-3.7 < \eta < 5.1$

New in Run2

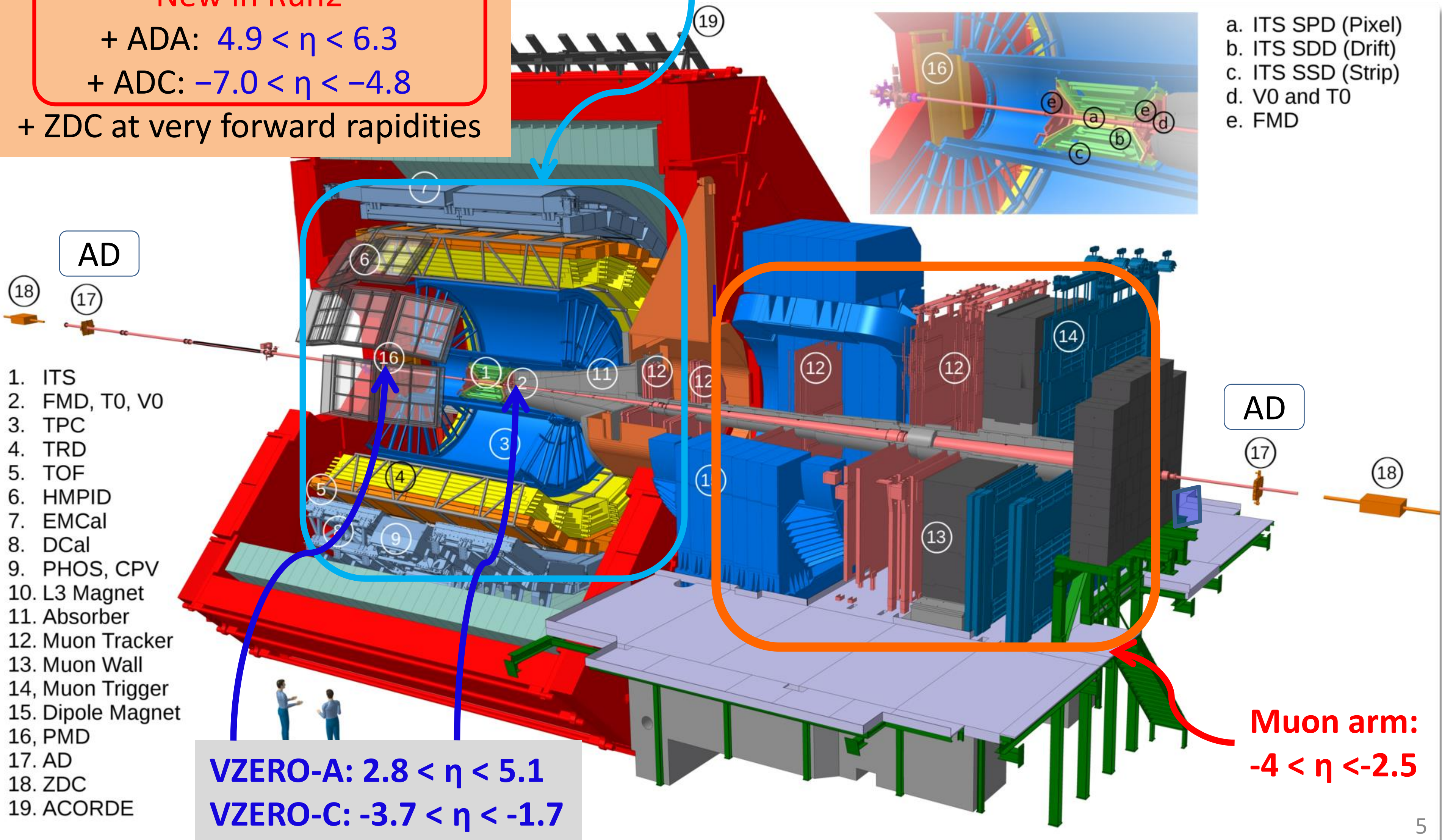
+ ADA: $4.9 < \eta < 6.3$

+ ADC: $-7.0 < \eta < -4.8$

+ ZDC at very forward rapidities

Central barrel: $|\eta| < 0.9$

Inner SPD layer: $|\eta| < 2.0$



a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14, Muon Trigger
15. Dipole Magnet
16, PMD
17. AD
18. ZDC
19. ACORDE

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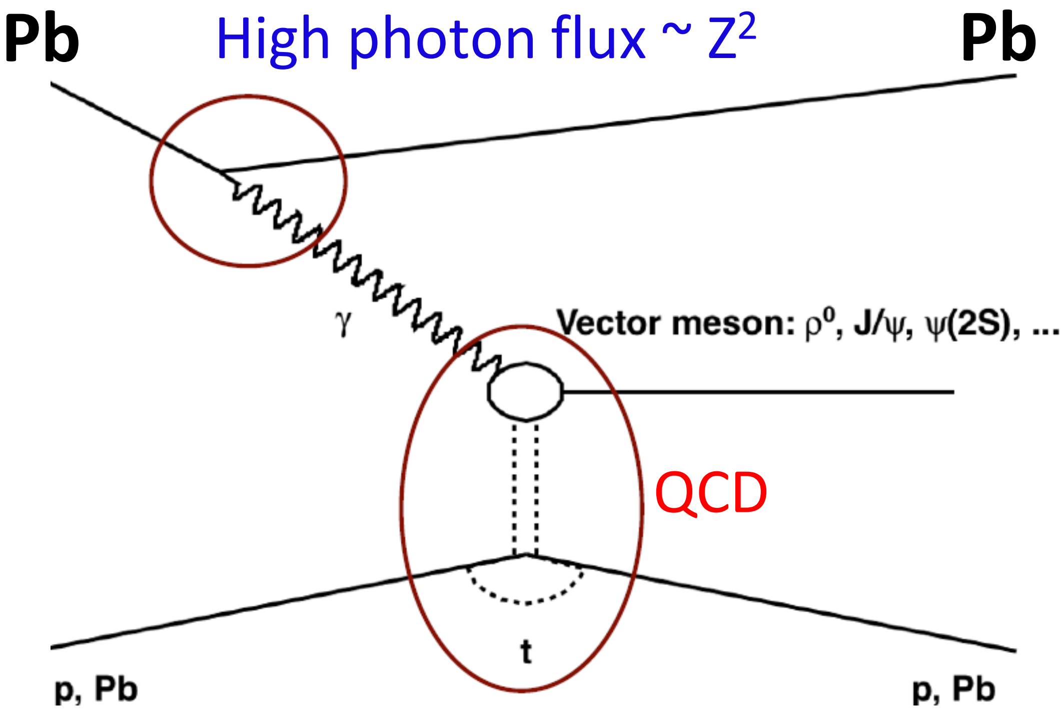
Vector meson photoproduction in UPC



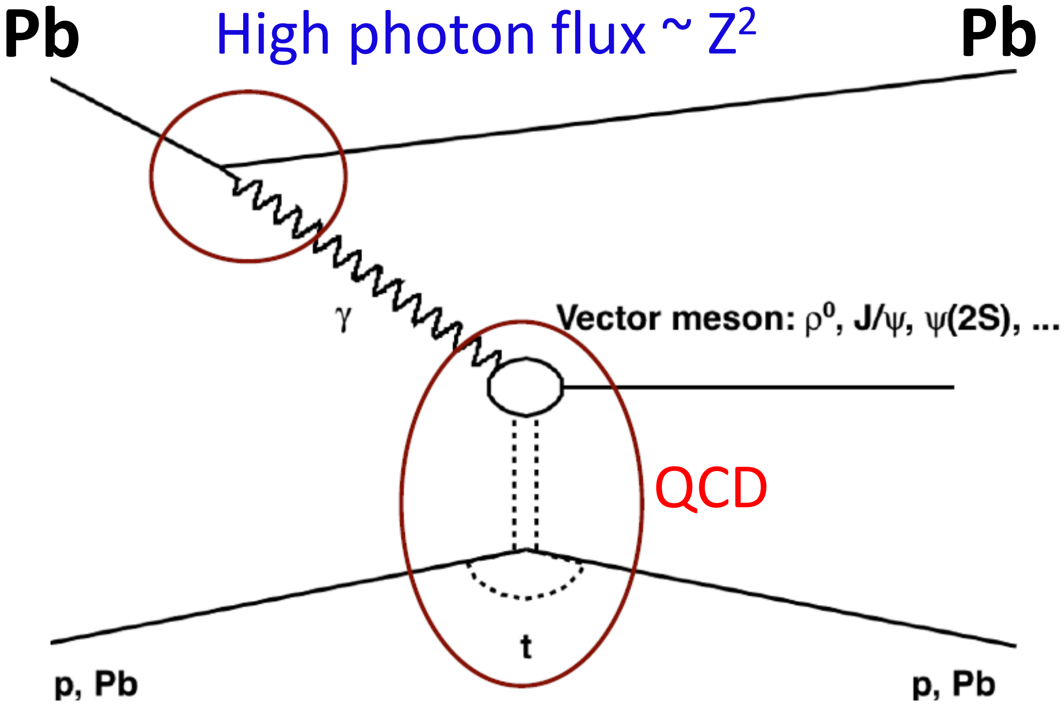
Exclusive vector meson production cross section in UPC can be factorized in two parts:

- QED: photon flux
- QCD: vector meson photoproduction: $\sigma(W_{\gamma p})$

Vector meson photoproduction in UPC

$$N_{\gamma/Z}(k) = \frac{2Z^2\alpha_{\mathrm{em}}}{\pi}[\zeta K_0(\zeta)K_1(\zeta) - \frac{\zeta^2}{2}(K_1^2(\zeta) - K_0^2(\zeta))]$$

$$\zeta = k(2R_A/\gamma_L)$$



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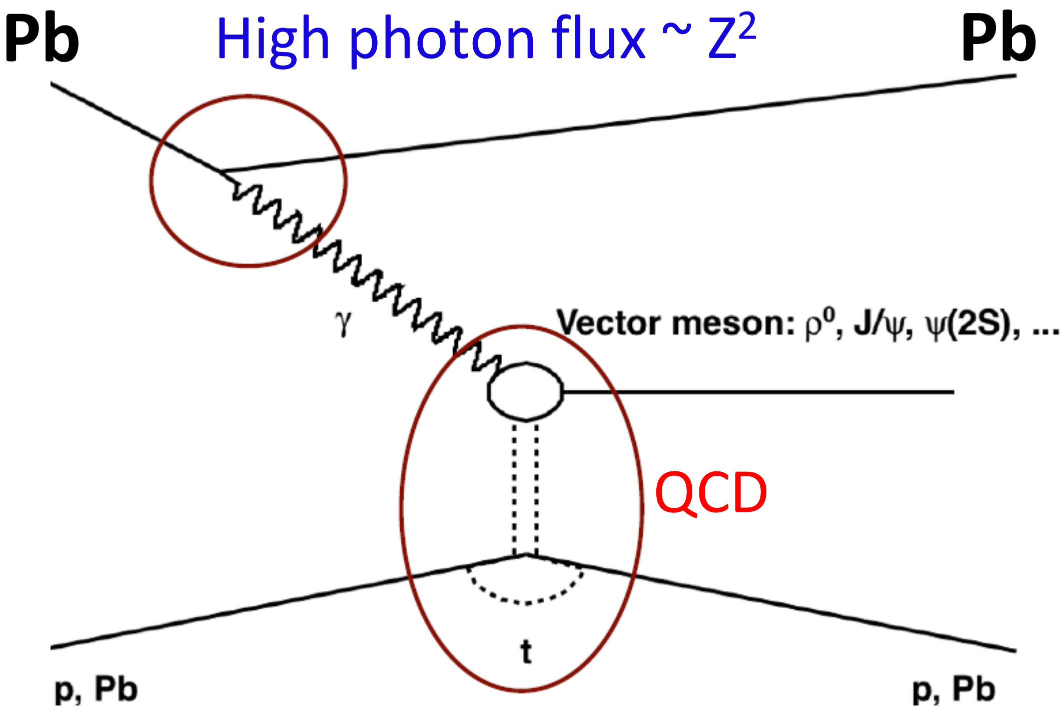
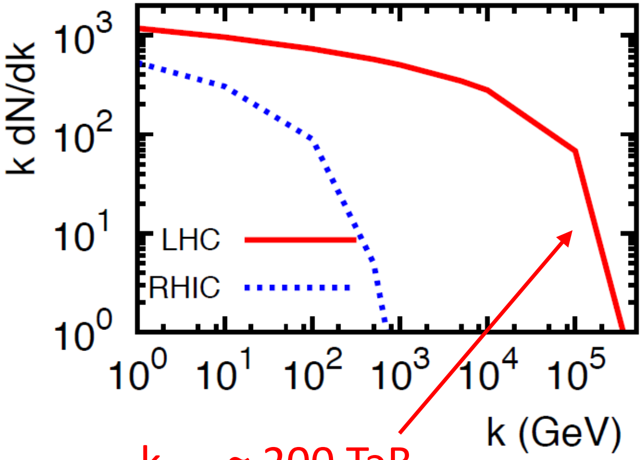
High photon flux ~ Z^2



Equivalent photon spectra in the target rest frame



k_{max} ≈ 200 ТэВ

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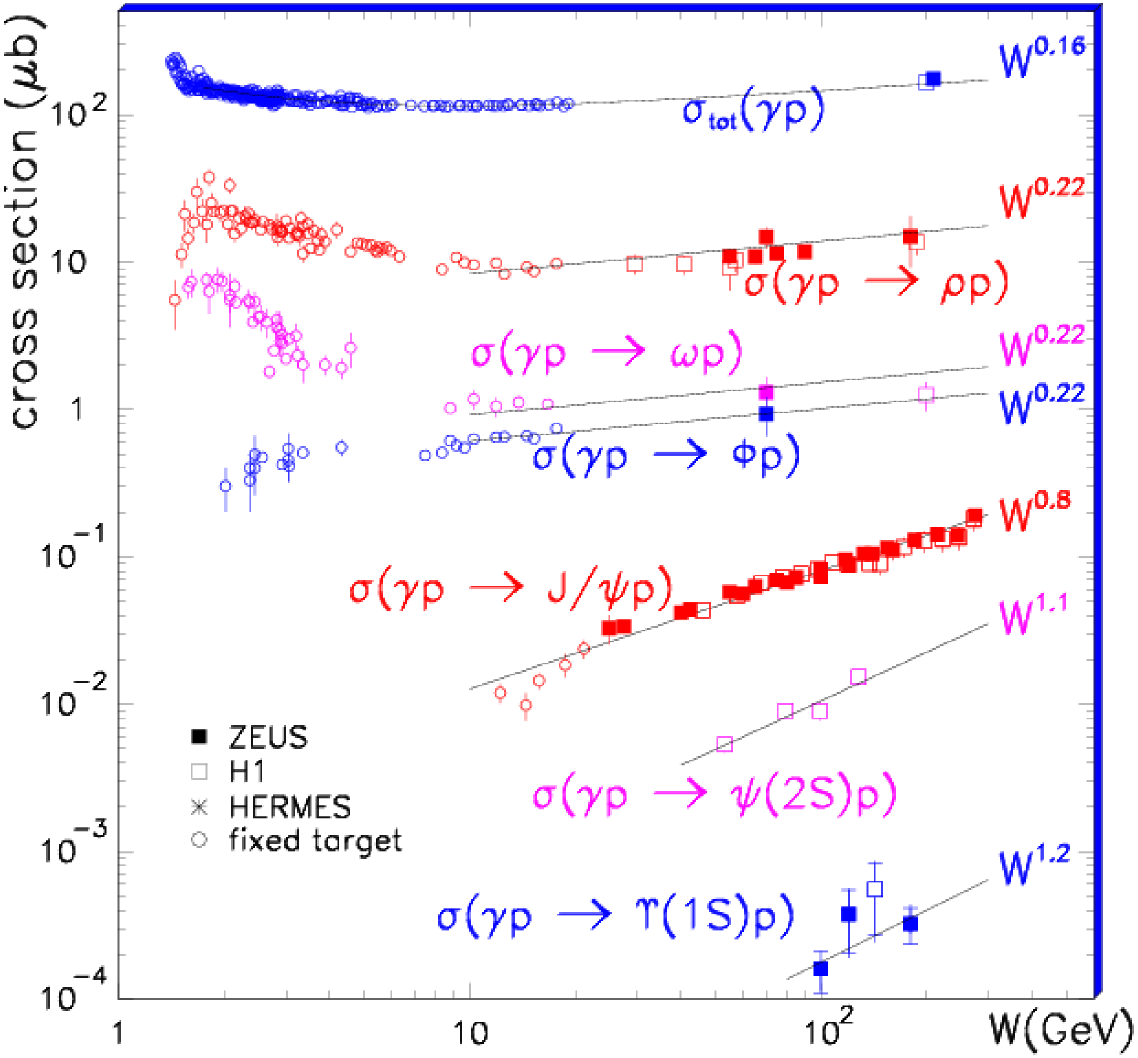
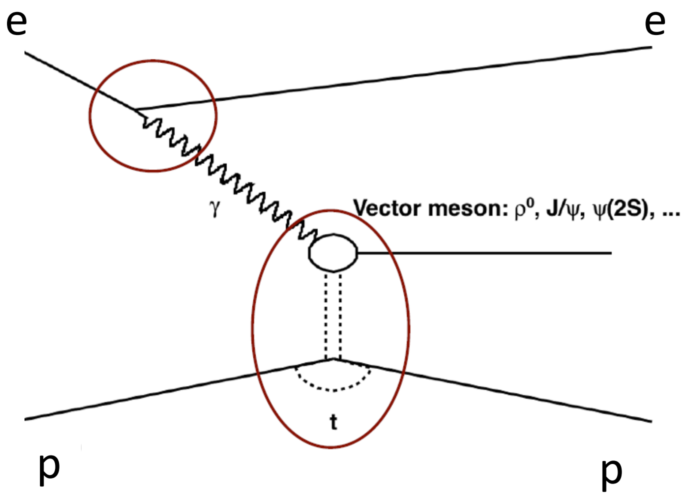
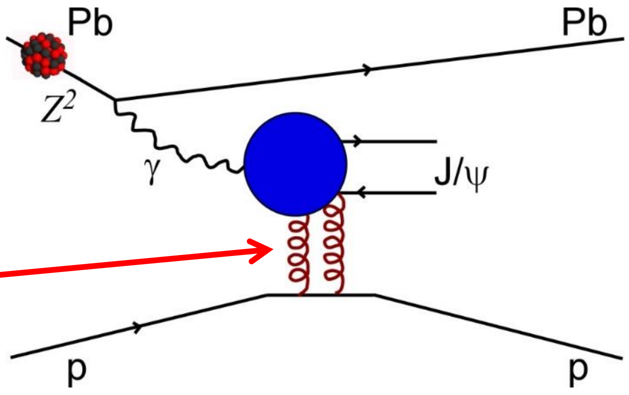
Vector meson photoproduction at HERA





- Studied with quasi-real photons emitted by electrons
- H1 and ZEUS measured various vector meson photoproduction cross sections covering six orders of magnitude
- $W_{\gamma p}$ up to ~ 300 GeV

Heavy vector meson photoproduction



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

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

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

- 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:

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

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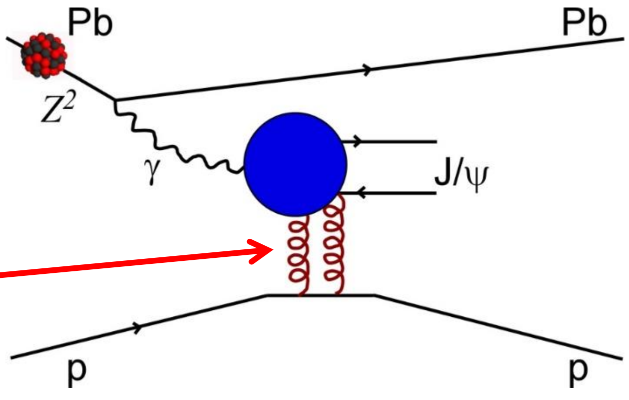

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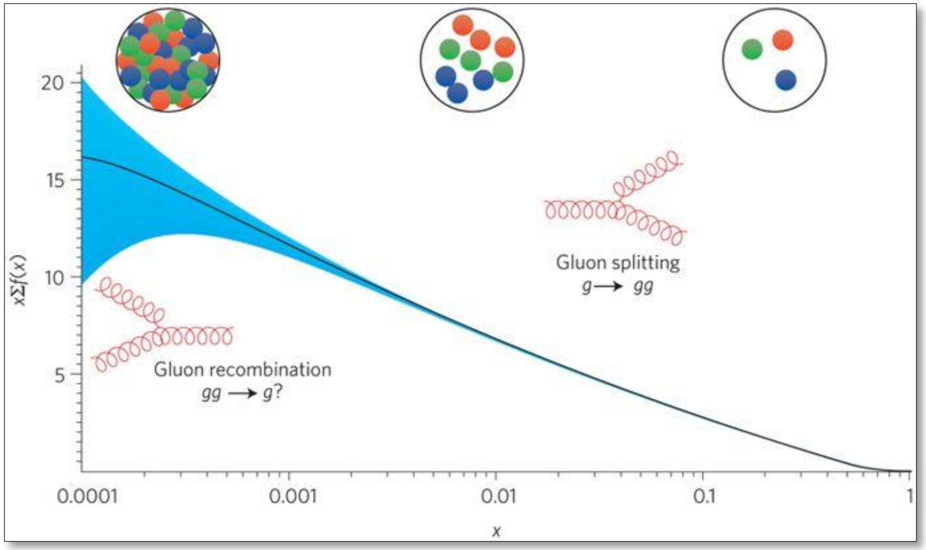

Figure courtesy of Voica Radescu, DESY

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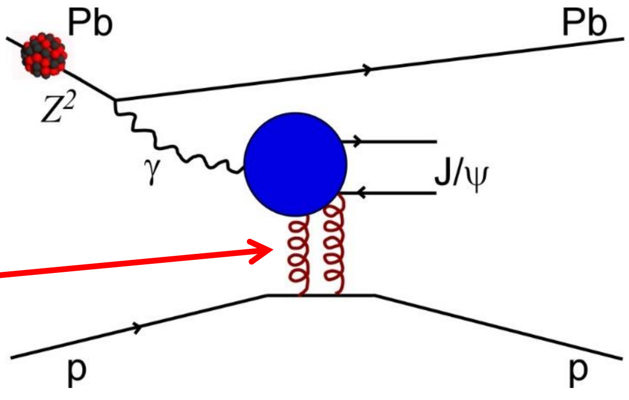

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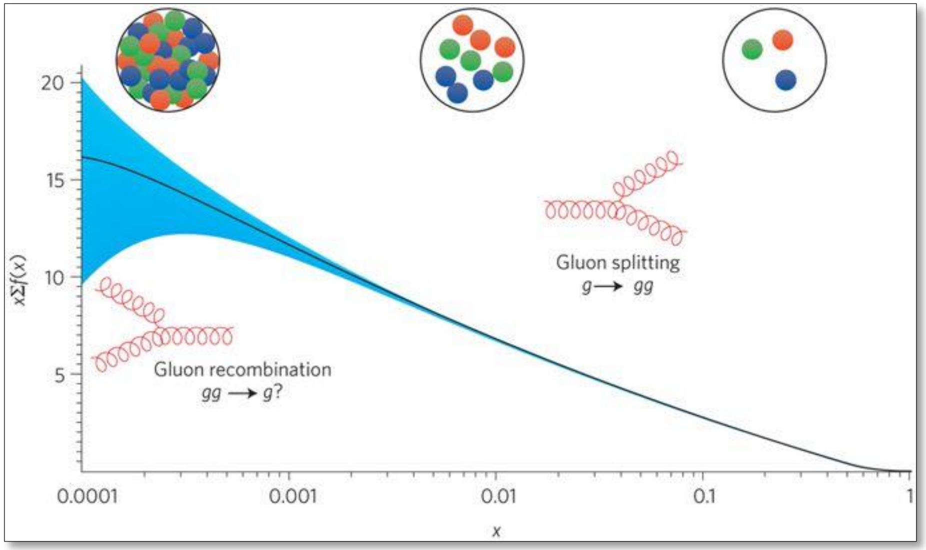
Vector meson photoproduction in UPC allows one to probe poorly known **gluon distributions at low *x*** and search for **saturation effects**



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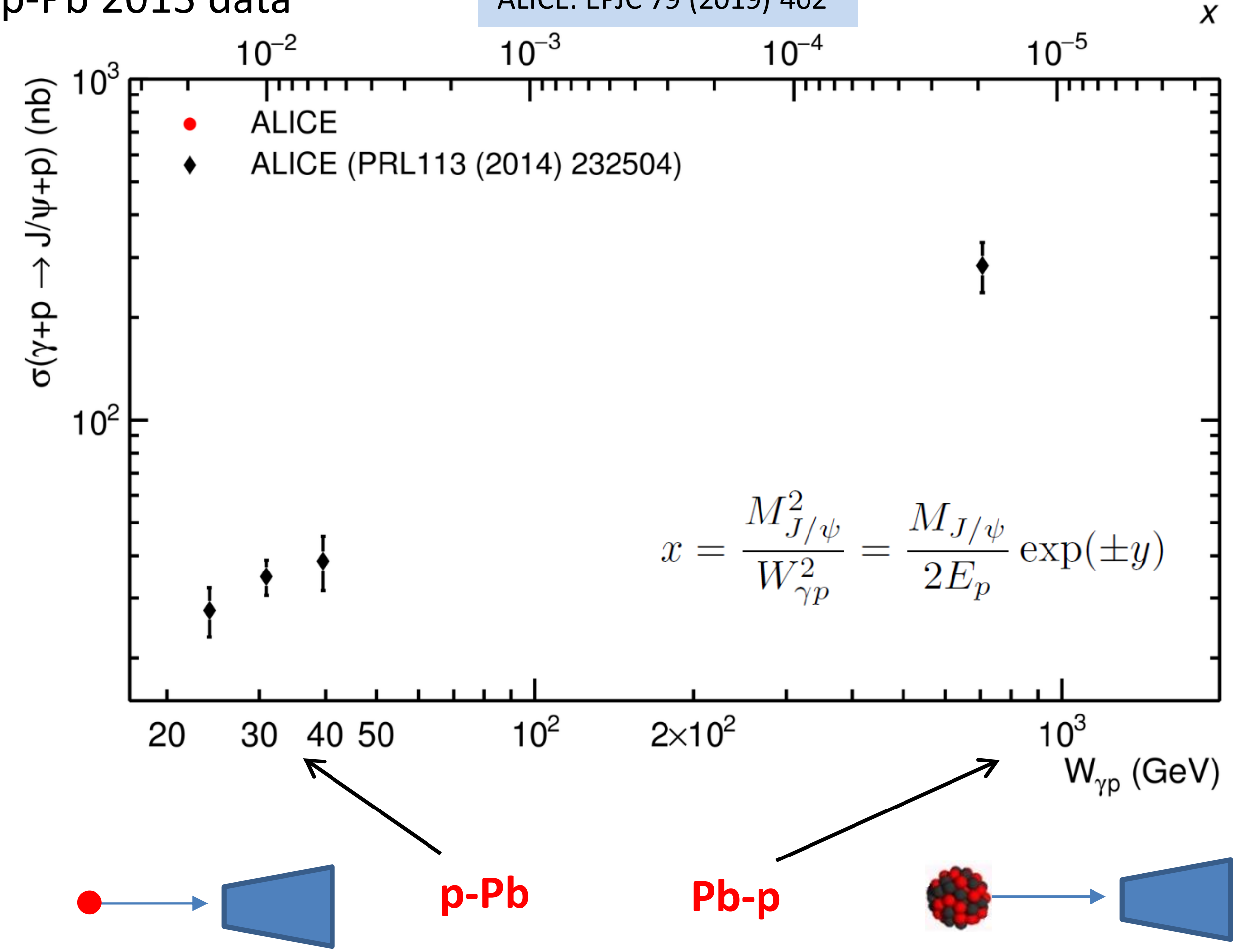
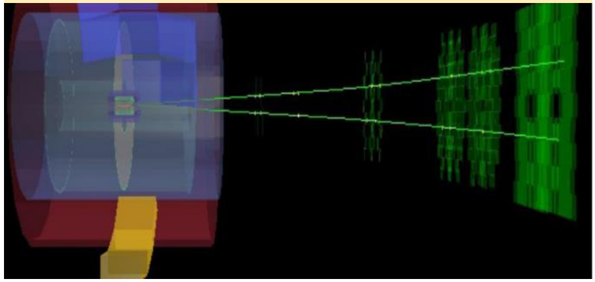
Exclusive J/ψ in p-Pb UPC

p-Pb 2013 data

ALICE: EPJC 79 (2019) 402



both muons in the muon arm



Wide energy range in ALICE extends HERA coverage:

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

Exclusive J/ψ in p-Pb UPC

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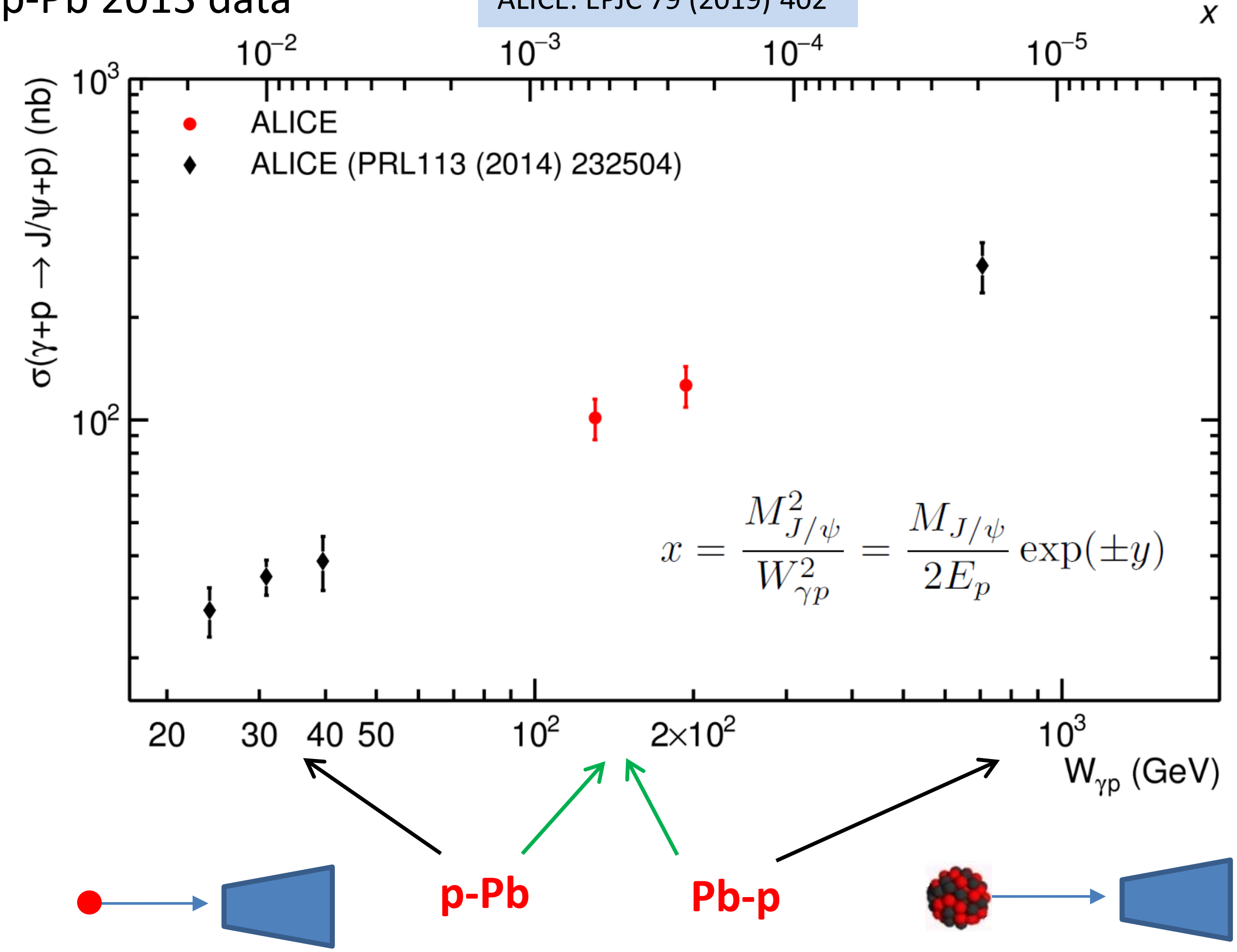

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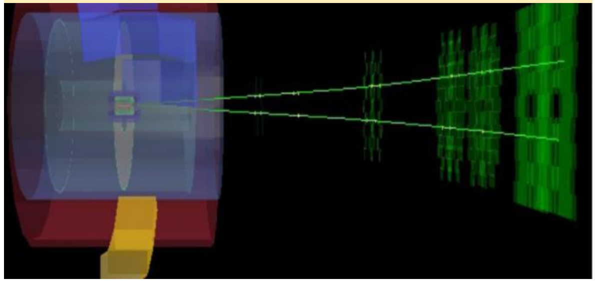
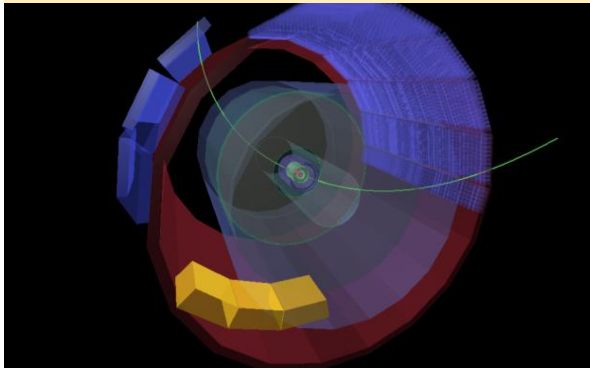


both leptons in the barrel



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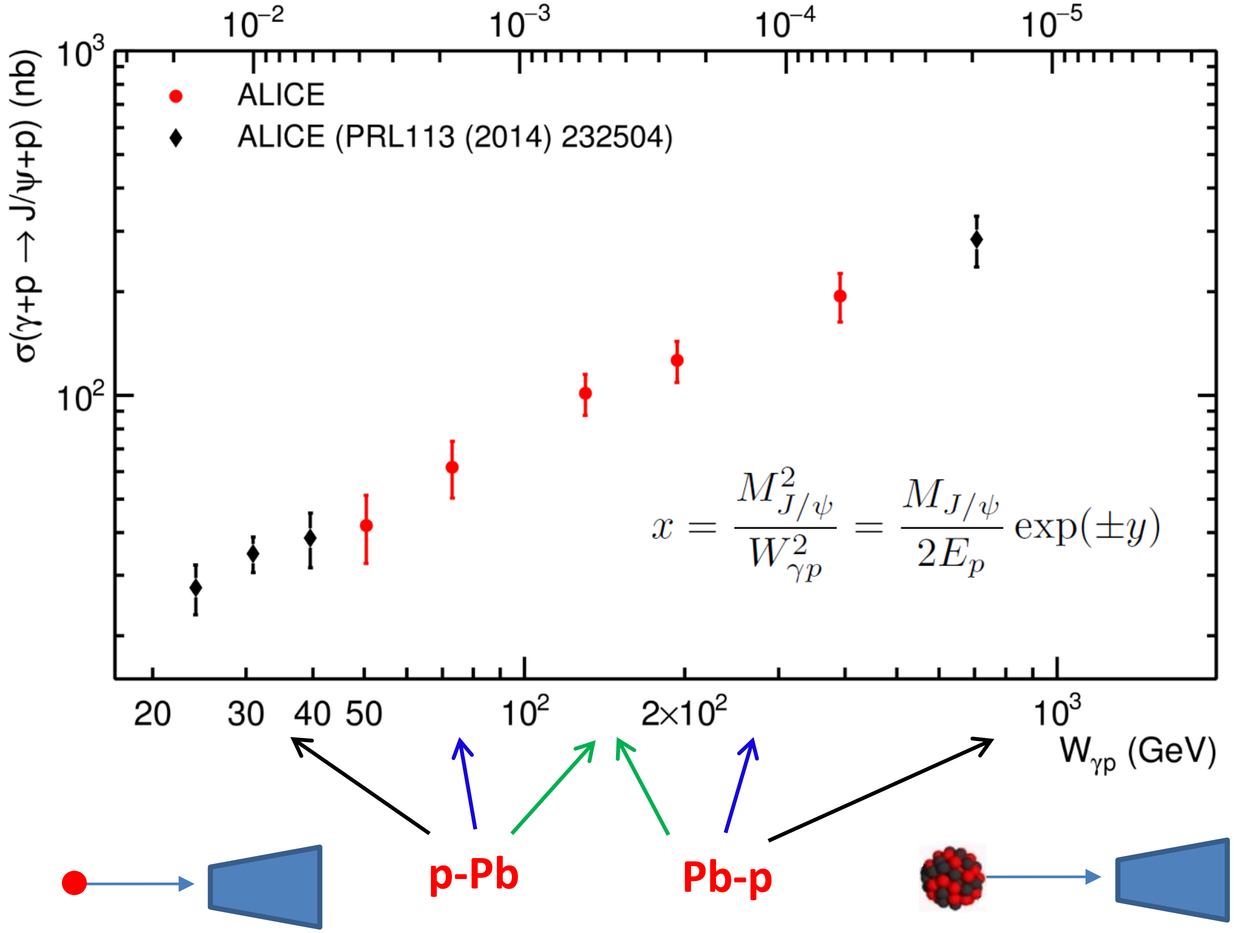

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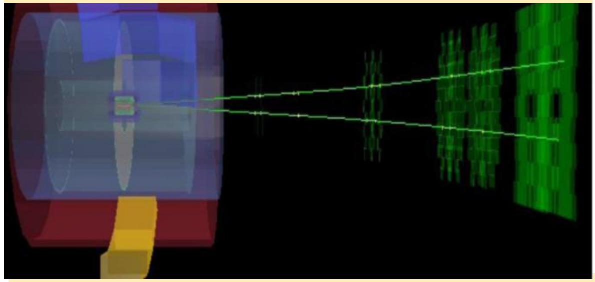
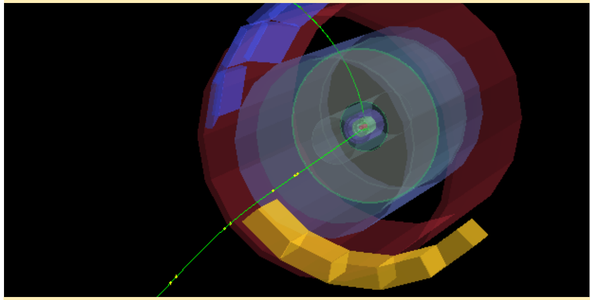
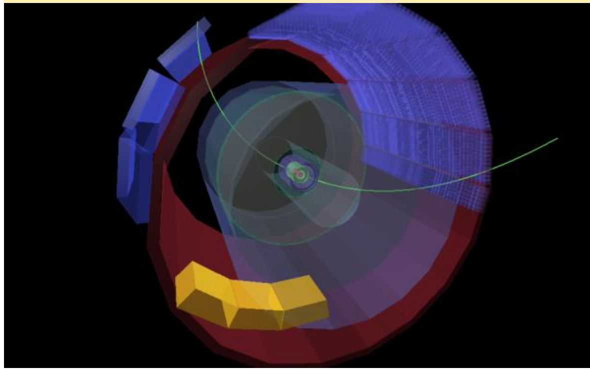


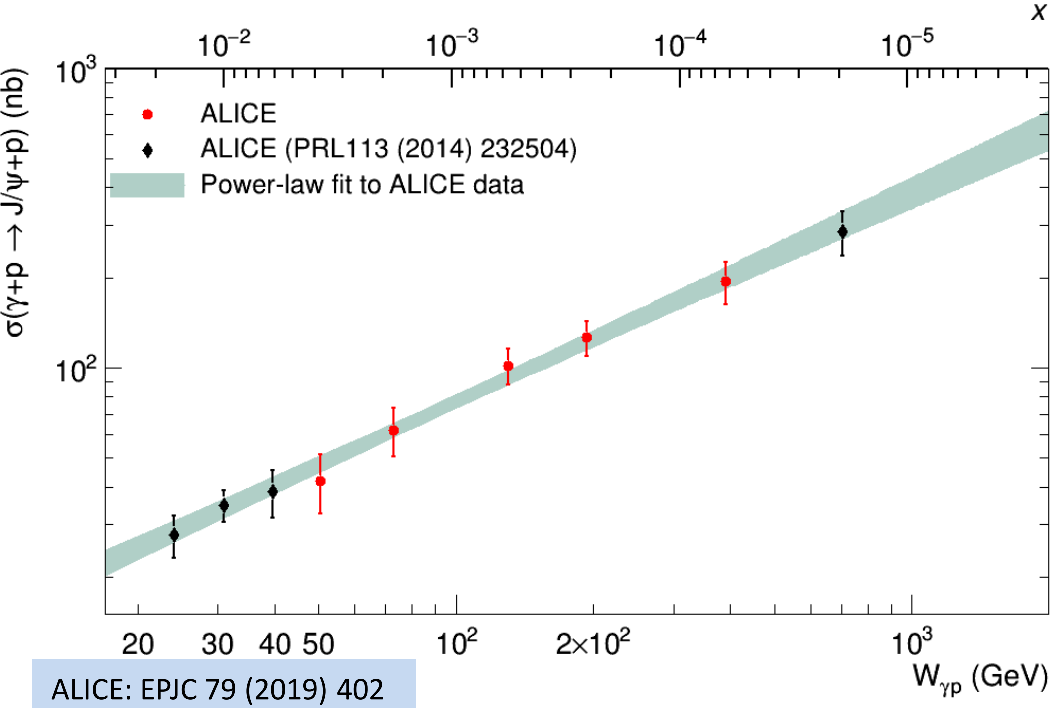
one muon in the muon arm,
the other in the barrel



both leptons in the barrel

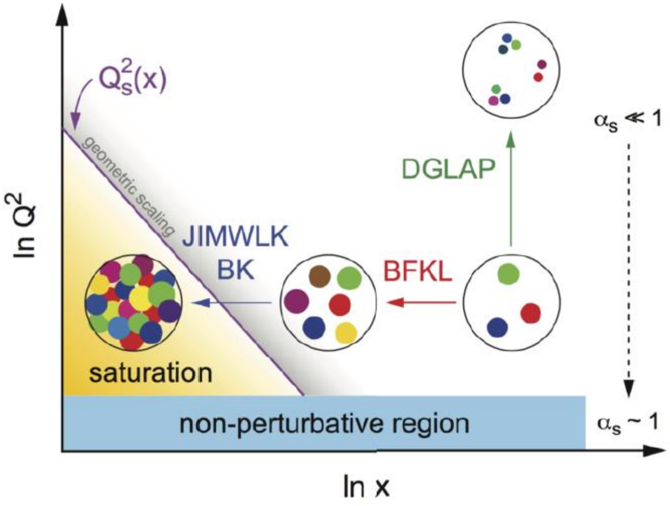


No clear signs of saturation yet



ALICE: EPJC 79 (2019) 402

- Energy dependence well described with a power law fit → no clear signs of saturation



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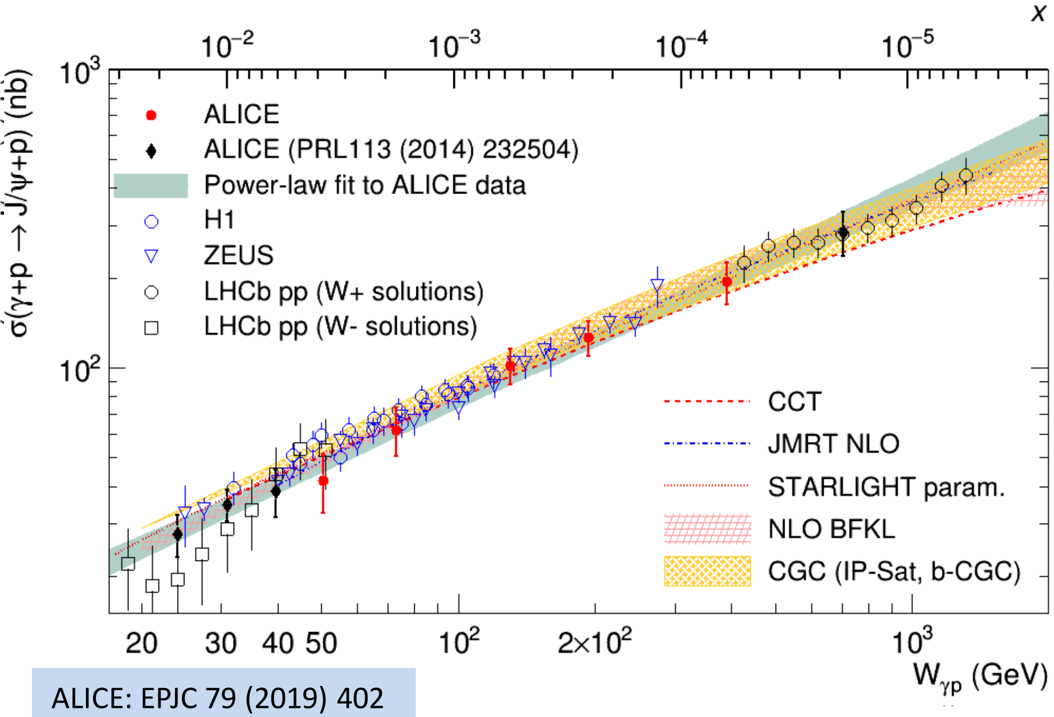

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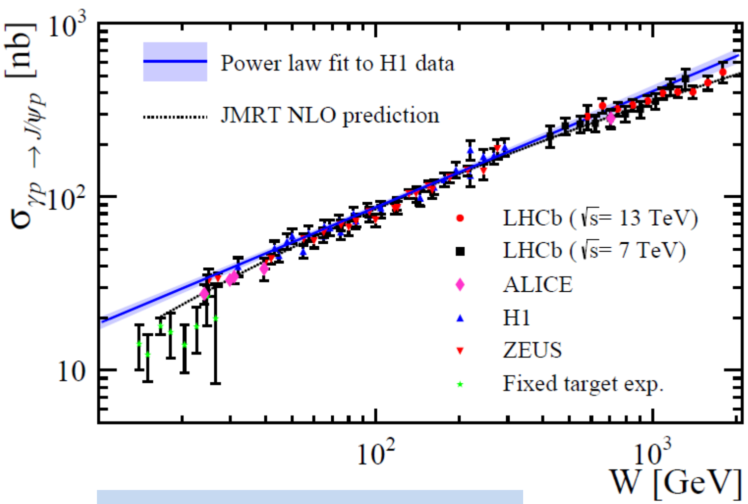

LHCb JHEP 10 (2018) 167

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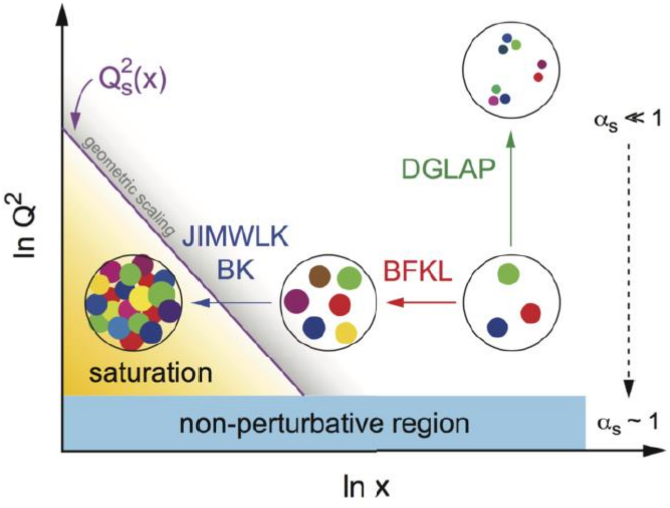
- Nice agreement between HERA in ep, LHCb in pp and ALICE in p-Pb



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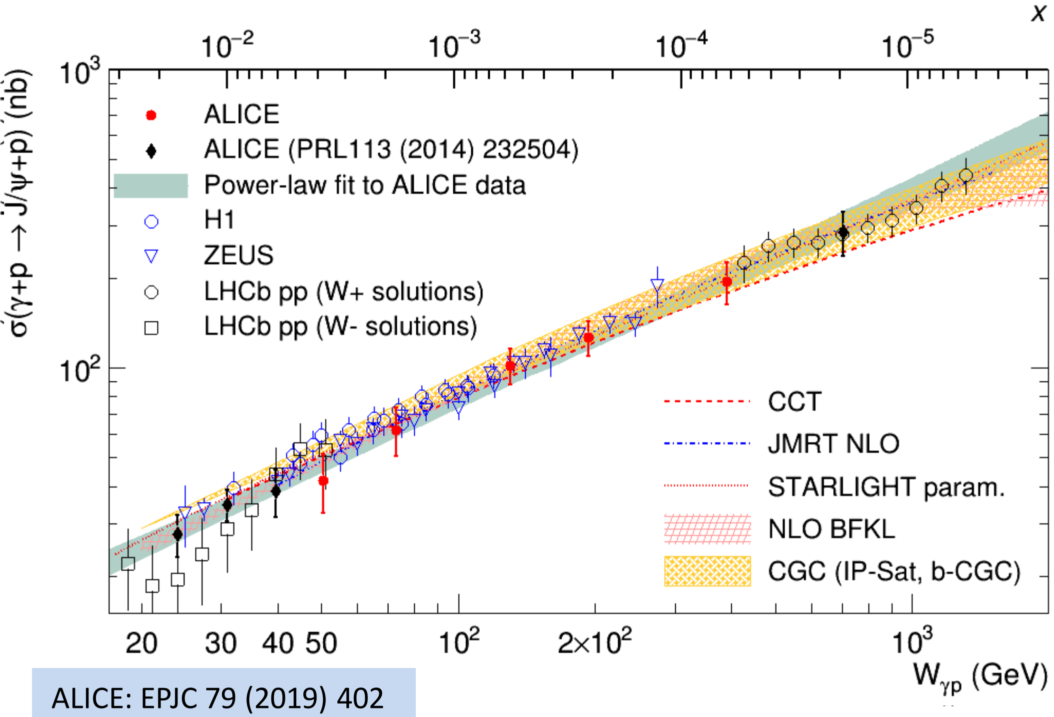

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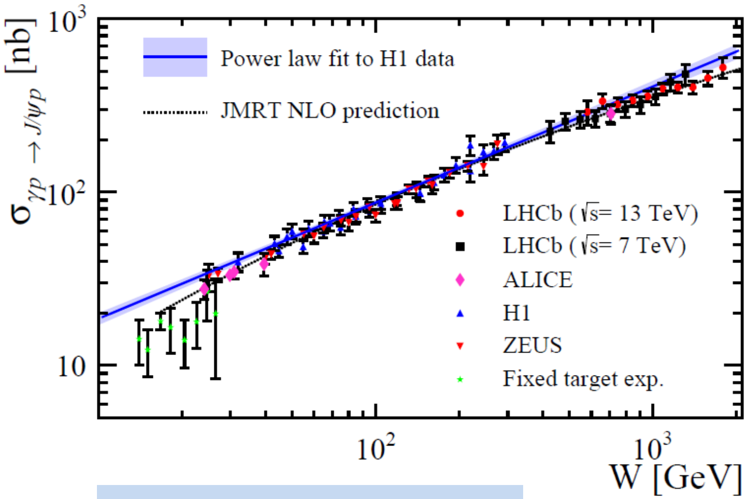

LHCb JHEP 10 (2018) 167

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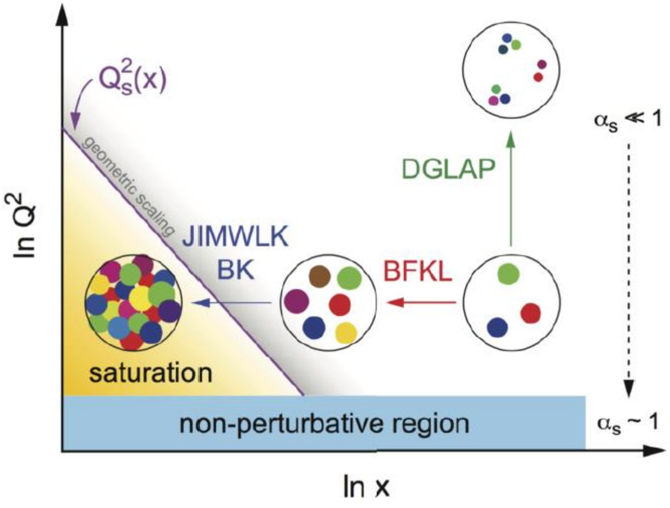
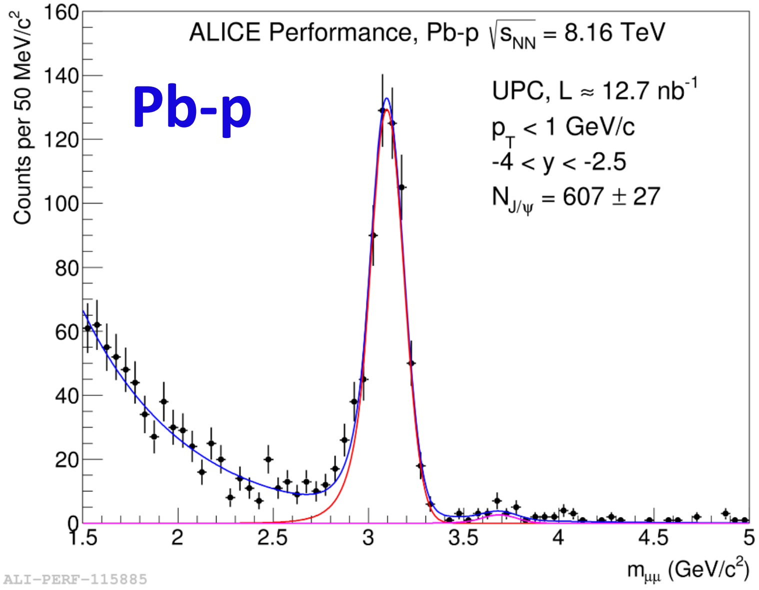
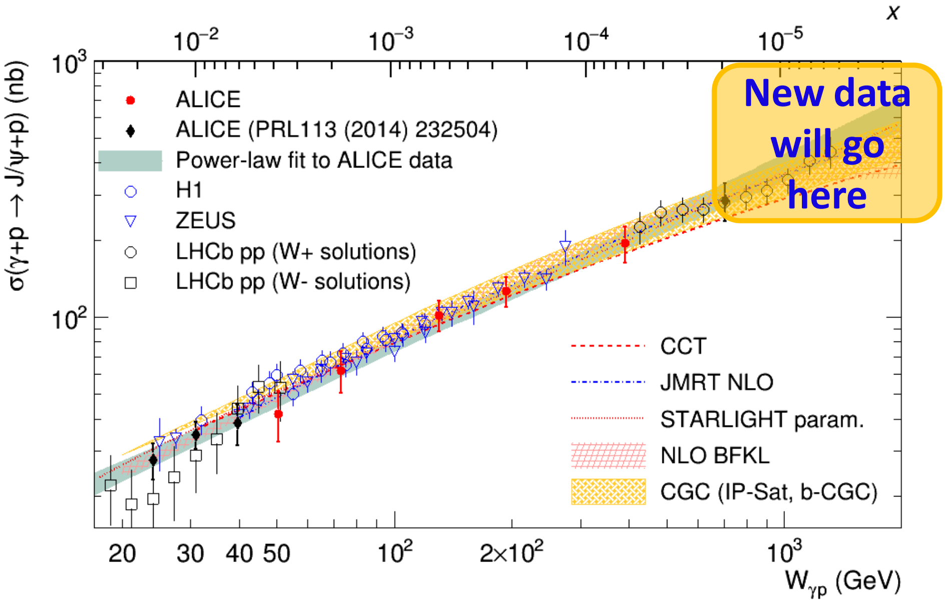
- Caveat: saturation models (CGC) are also consistent with data at these energies



p-Pb @ 8.16 TeV





New data will go here

- x10 more stat at high $W_{\gamma p}$ ~ 0.7-1.4 TeV

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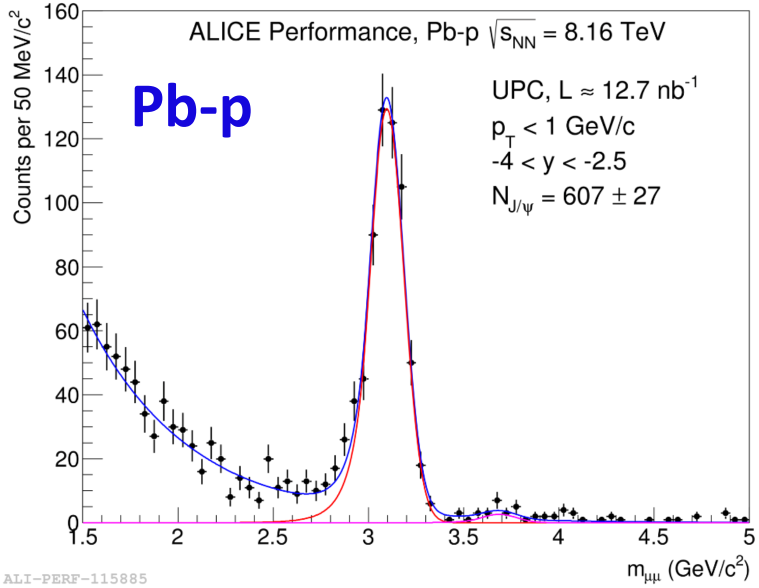

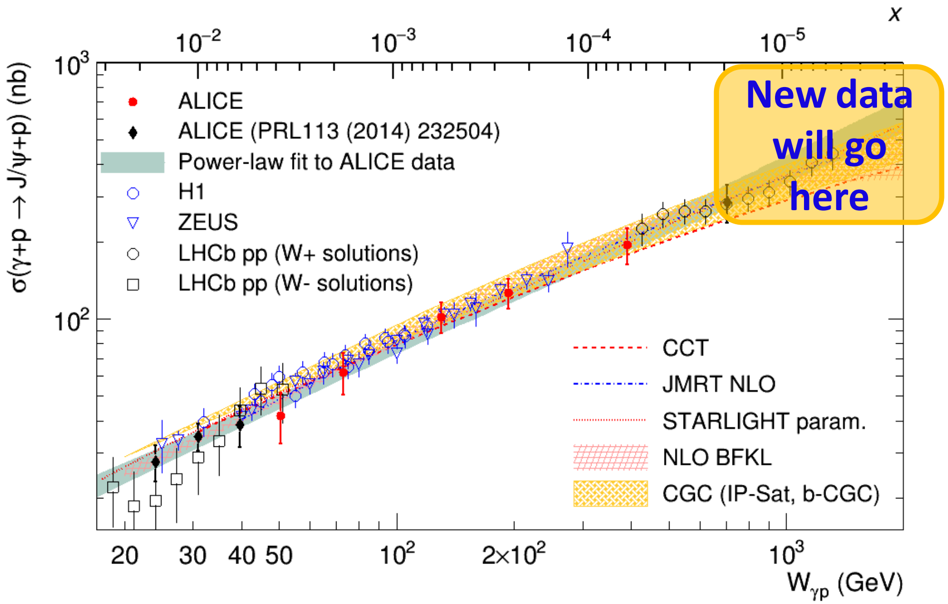

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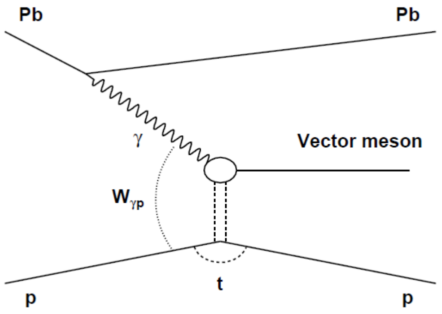
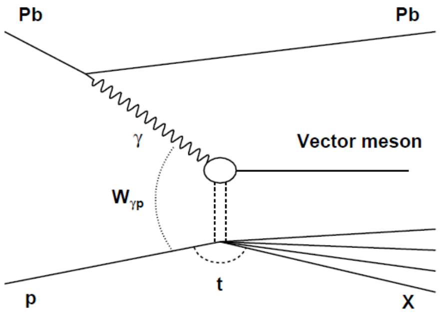
- new AD detector in run 2 covering very forward rapidities up to η~6
- aim to study exclusive and proton-dissociative cross section behaviour at high $W_{\gamma p}$



exclusive



proton-dissociative

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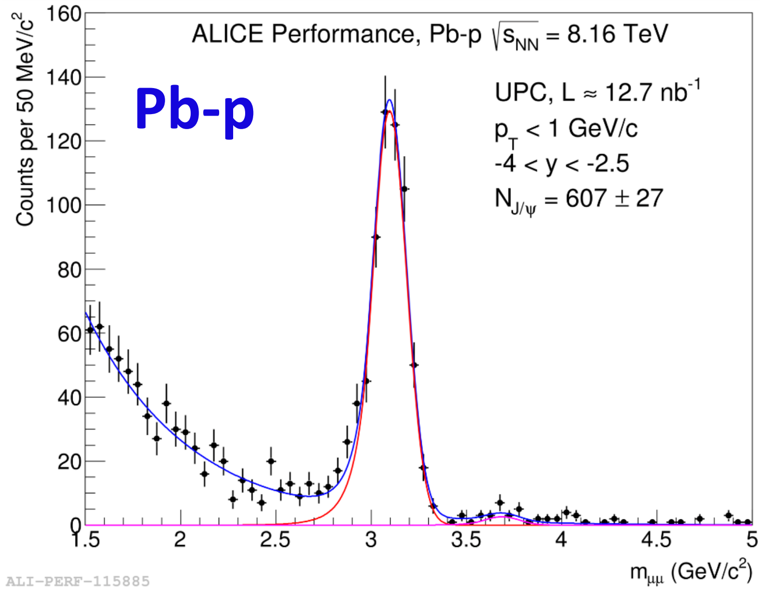

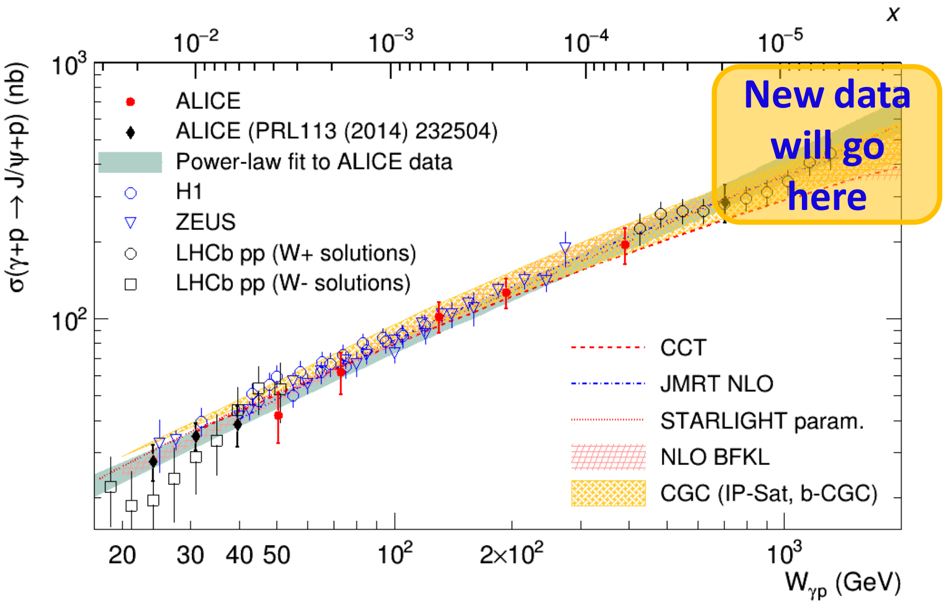

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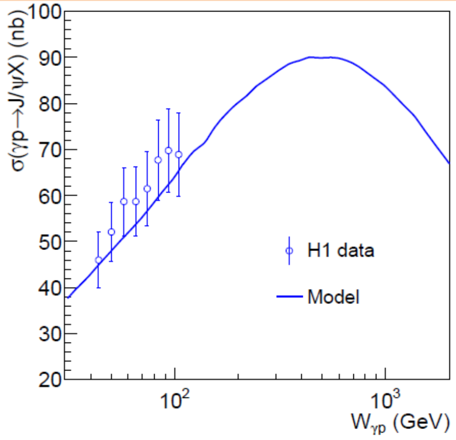
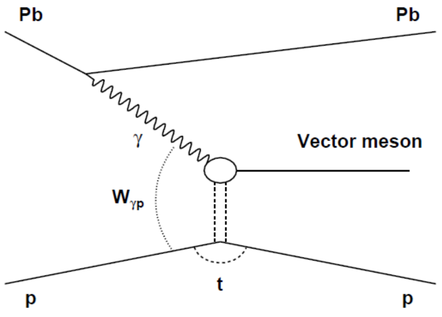
Predictions for proton-dissociative cross section





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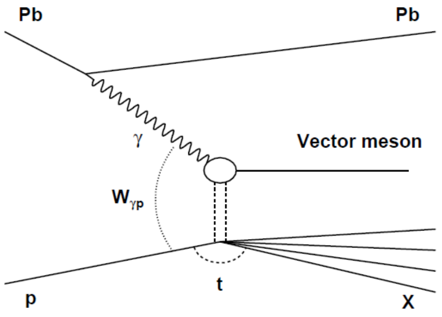
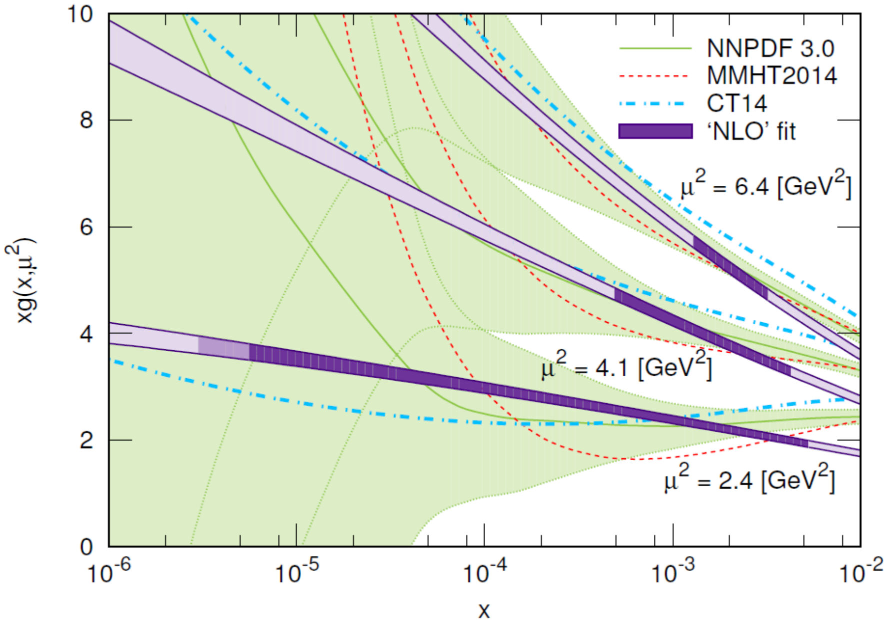


proton-dissociative

Cepila, Contreras, Takaki: PLB766 (2017) 186

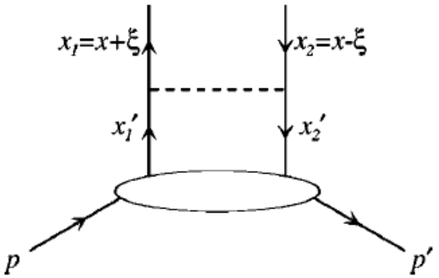
Can we use photoproduction data to constrain gluon PDFs?



Jones, Martin, Ryskin, Teubner, J.Phys. G44 (2017) 03LT01

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: μ^2 ~ 2.4 GeV^2 is a reasonable choice:
  - JMRT, J. Phys. G 43 (2016) 035002
  - Guzey, Zhalov: JHEP 1310 (2013) 207
- Large NLO contributions

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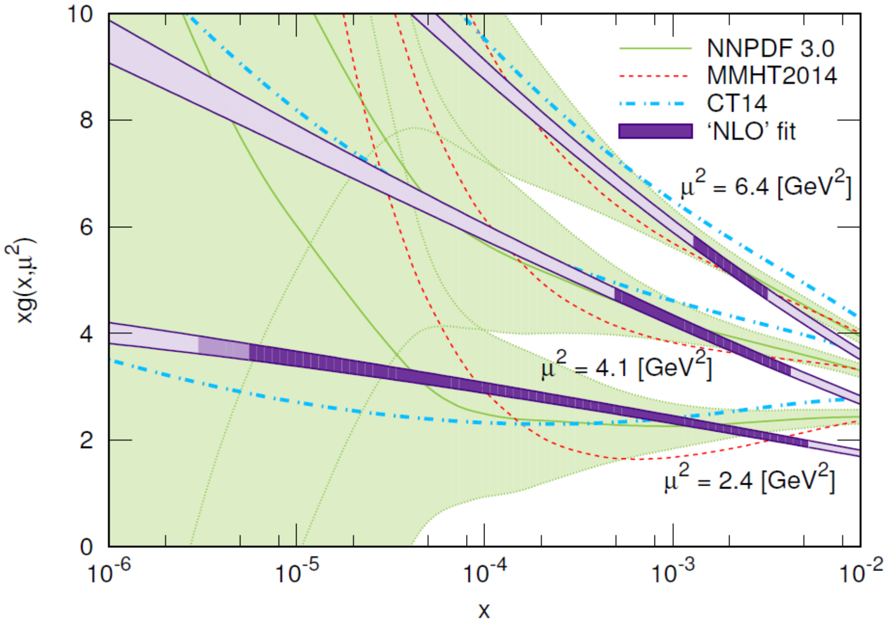
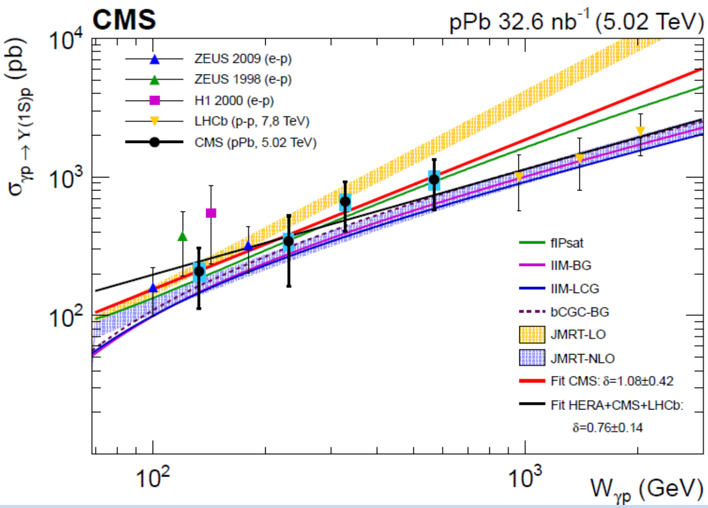


Jones, Martin, Ryskin, Teubner, J.Phys. G44 (2017) 03LT01



CMS: EPJC 79 (2019) 277, LHCb: JHEP 09 (2015) 084

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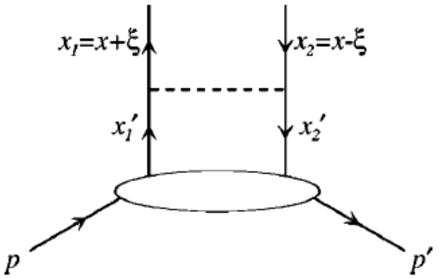

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  - Guzey, Zhalov: JHEP 1310 (2013) 207
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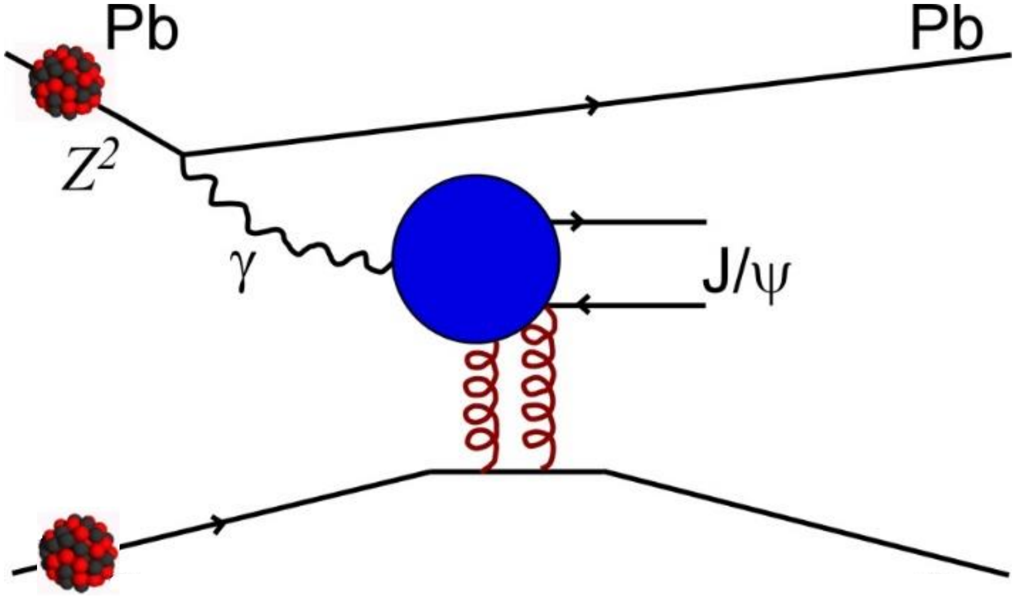
  - Υ measurements reveal importance of NLO effects

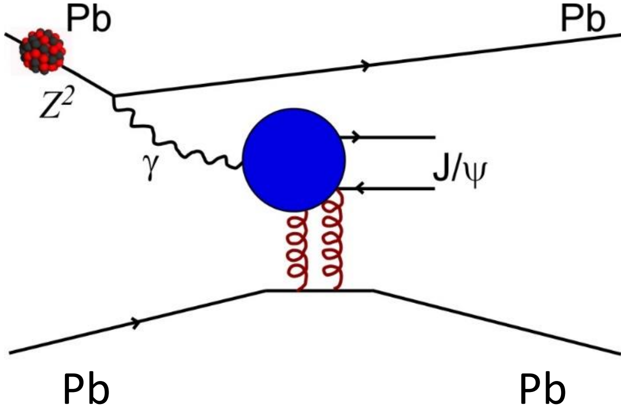
J/ψ photoproduction on Pb target



Pb Pb

J/ψ photoproduction on Pb target

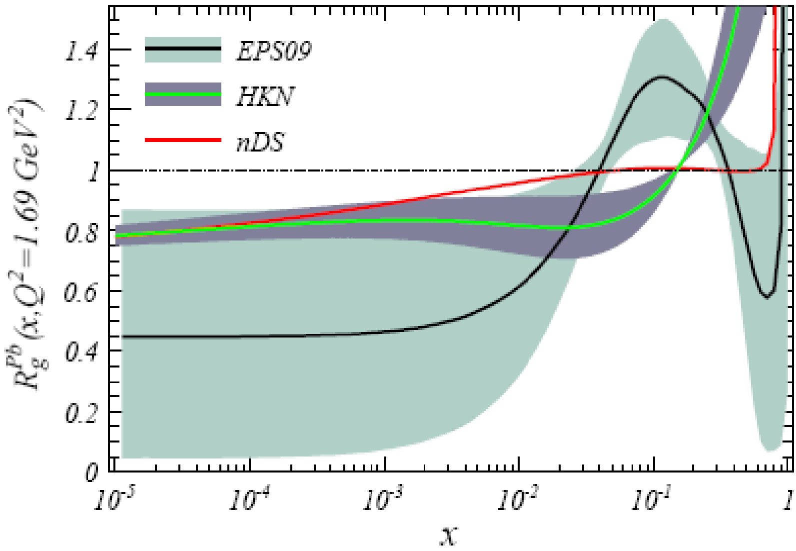
Coherent J/ψ photoproduction cross section is proportional to the **square of the gluon density in nuclei**



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

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

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

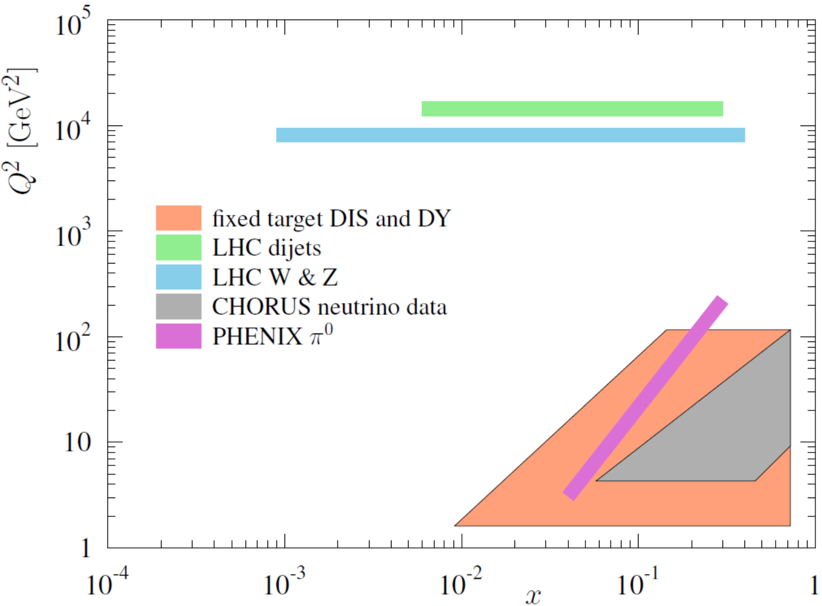


Parton distributions in nuclei (nPDFs)

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

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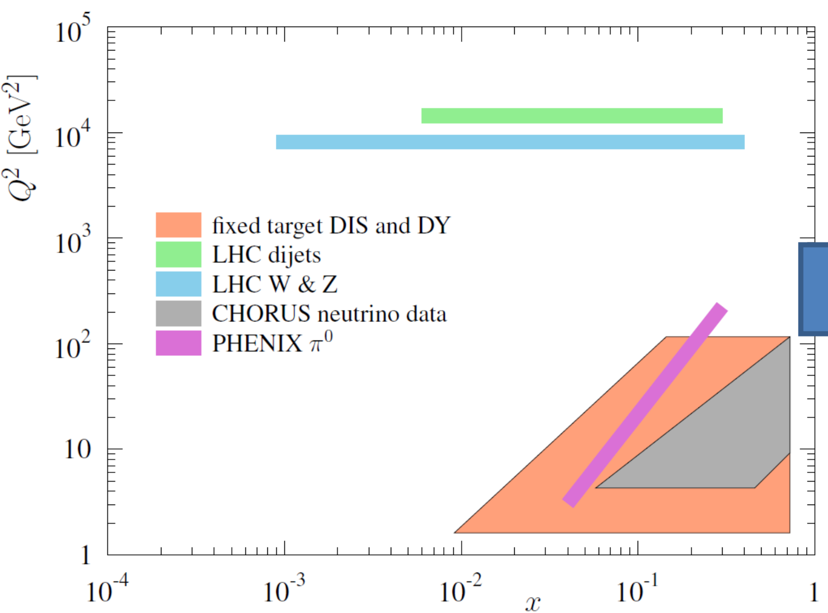
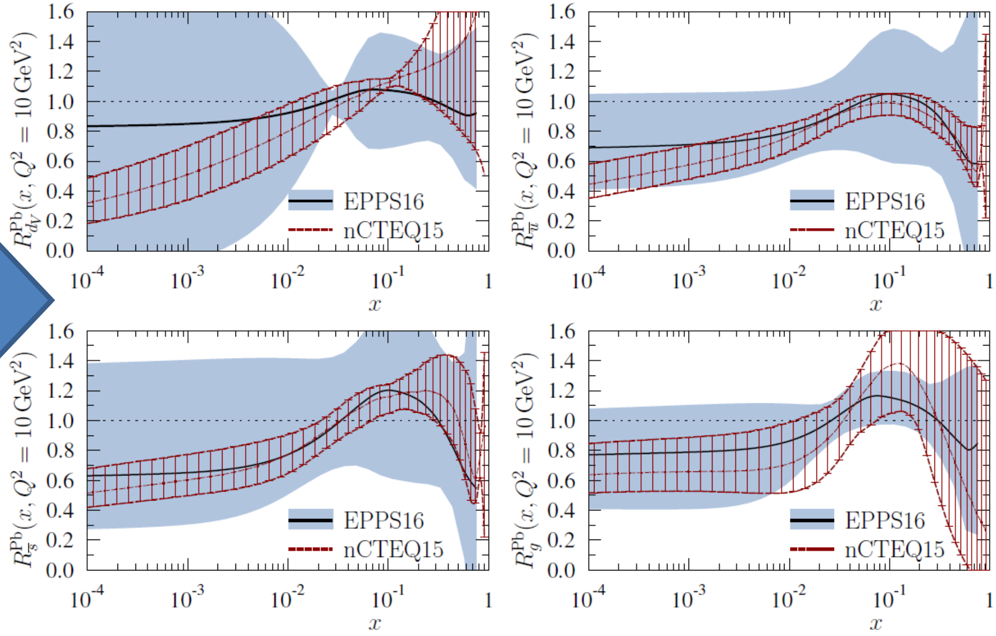


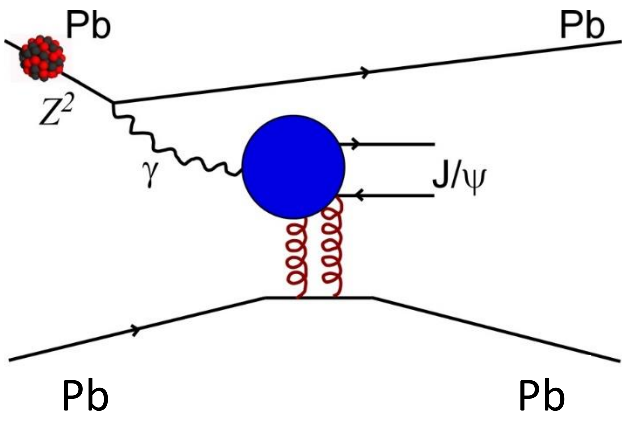
EPPS16 : EPJ C (2017) 77

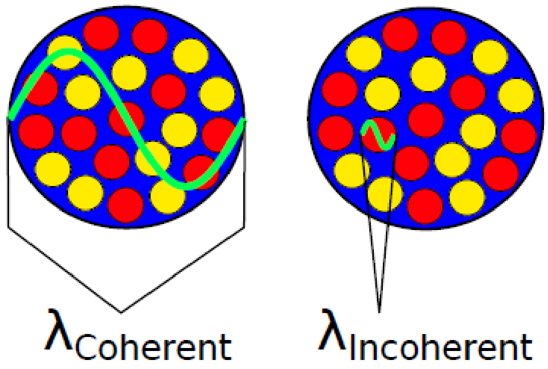


Resulting nPDFs have rather **large uncertainties, especially for small-x gluons** due to:

- Limited kinematics ($x>10^{-2}$ at low Q^2)
- Indirect extraction of gluons via Q^2 evolution

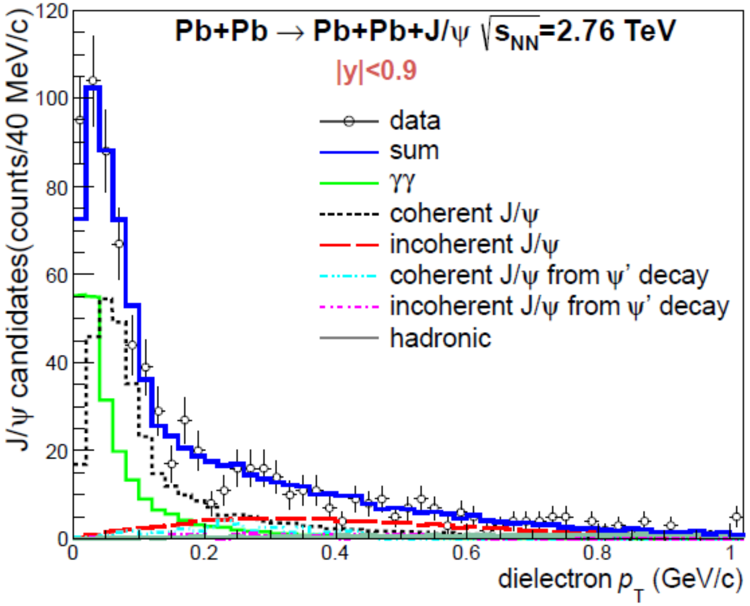
Coherent and incoherent photoproduction





Two types of photoproduction processes:

- **Coherent:**
  - photon couples coherently to all nucleons
  - $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
- **Incoherent:**
  - photon couples to a single nucleon
  - $\langle p_T \rangle \sim 1/R_p \sim 450$ MeV/c
  - usually accompanied by neutron emission

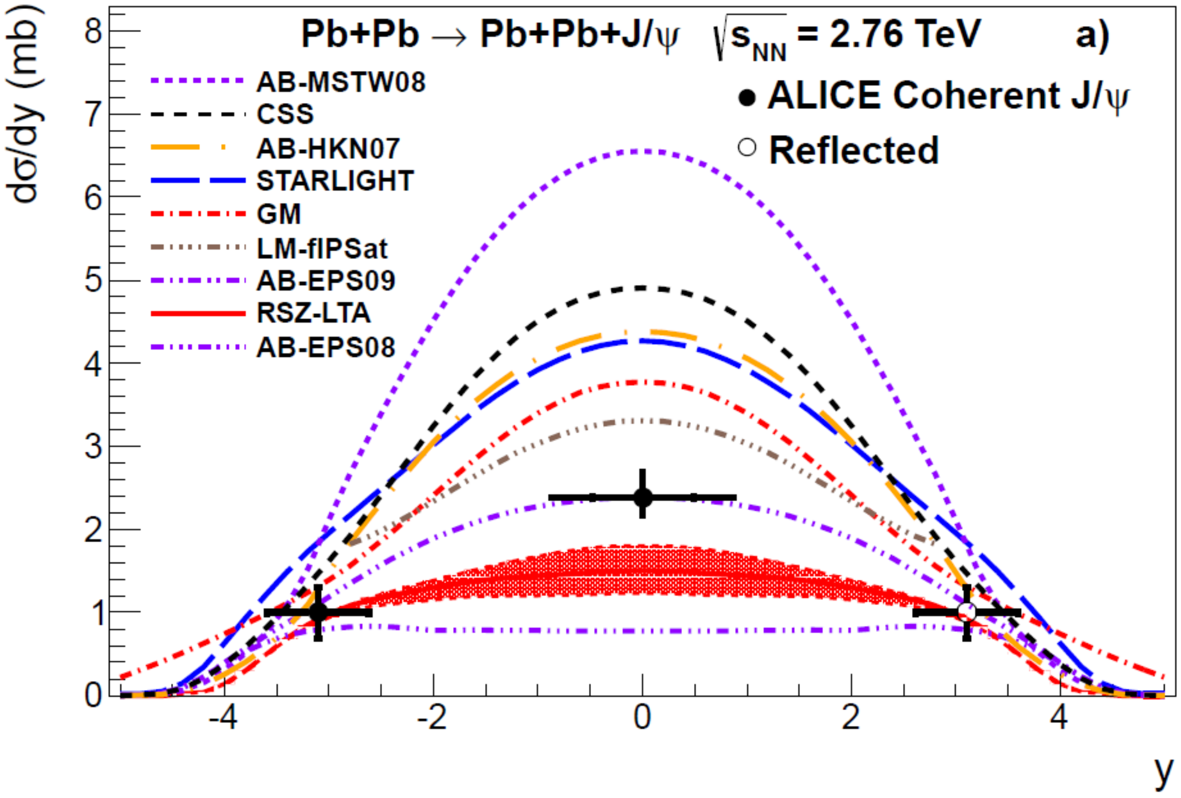


ALICE. Eur. Phys. J. C73 (2013) 2617

Other contributions: J/ψ from coherent and incoherent ψ' decays and $\gamma\gamma \rightarrow ll$

Reminder: Coherent J/ψ results from Run 1

ALICE: PLB718 (2013) 1273, EPJC73 (2013) 2617



- Measured both at forward and central rapidity
- best agreement with models based on EPS09 shadowing

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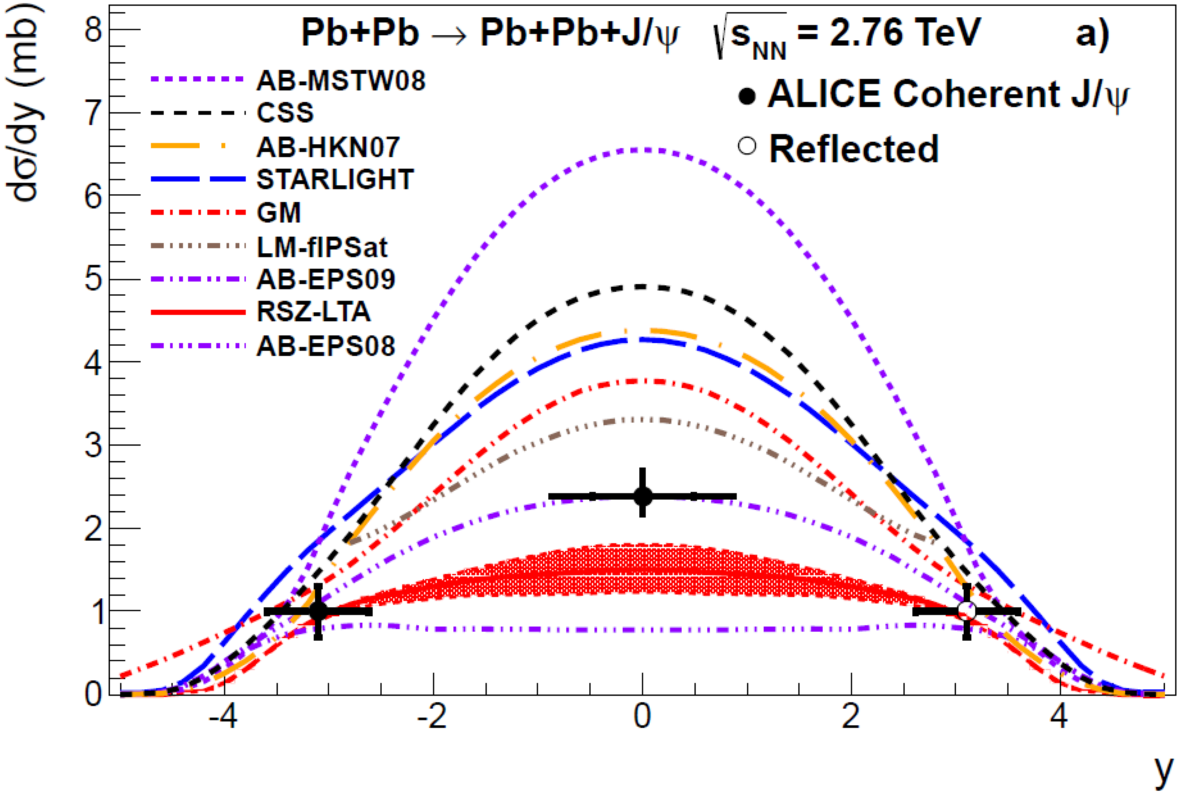
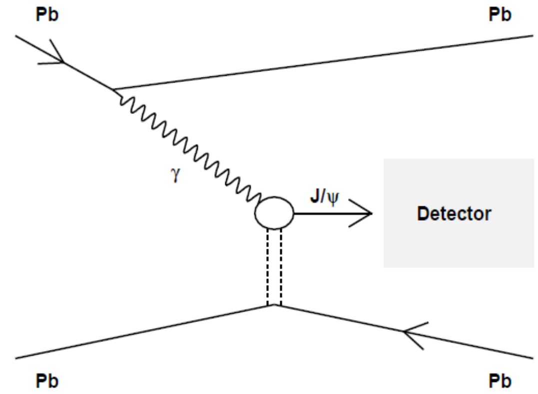
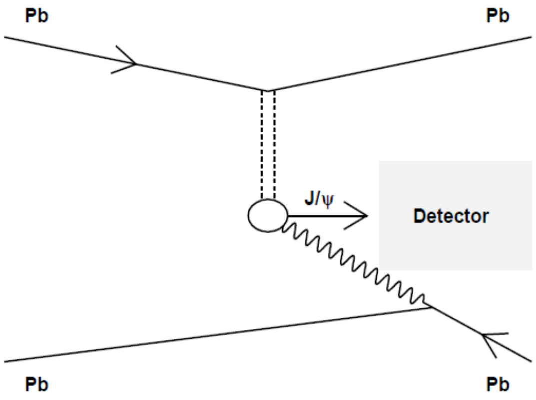
ALICE: PLB718 (2013) 1273, EPJC73 (2013) 2617



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





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$$\sigma(y) = n(+y)\sigma_{\gamma\mathrm{Pb}}(+y) + n(-y)\sigma_{\gamma\mathrm{Pb}}(-y)$$

high-energy photons

low-x gluons

low energy photons

high-x gluons

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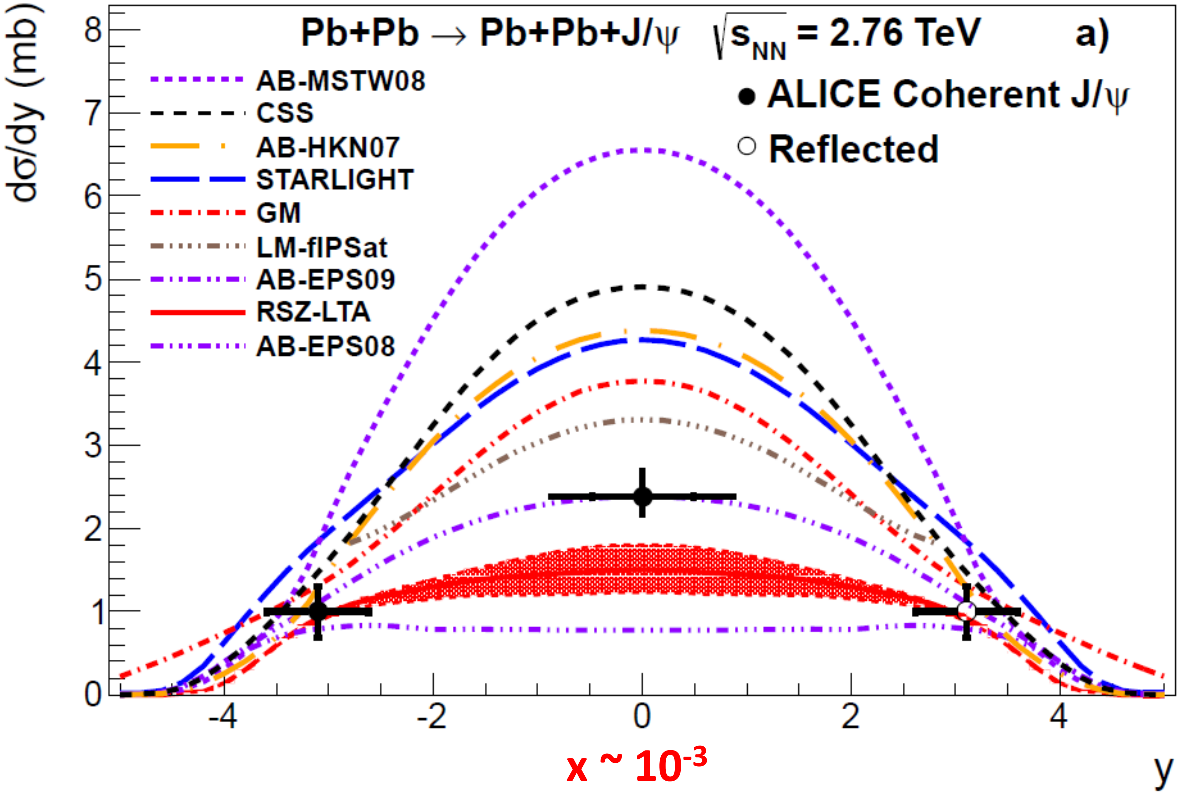
ALICE: PLB718 (2013) 1273, EPJC73 (2013) 2617



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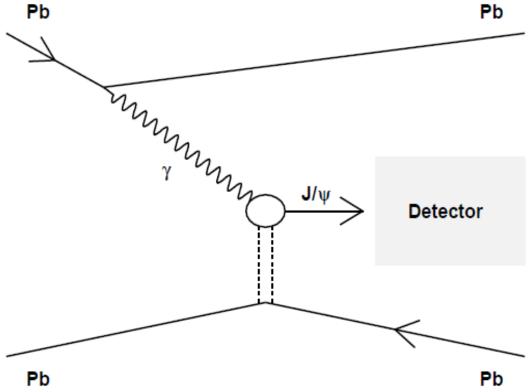

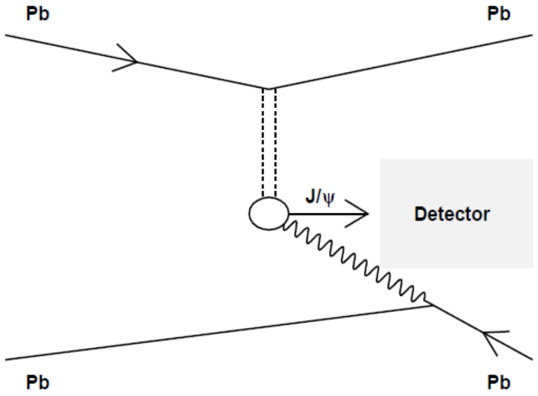

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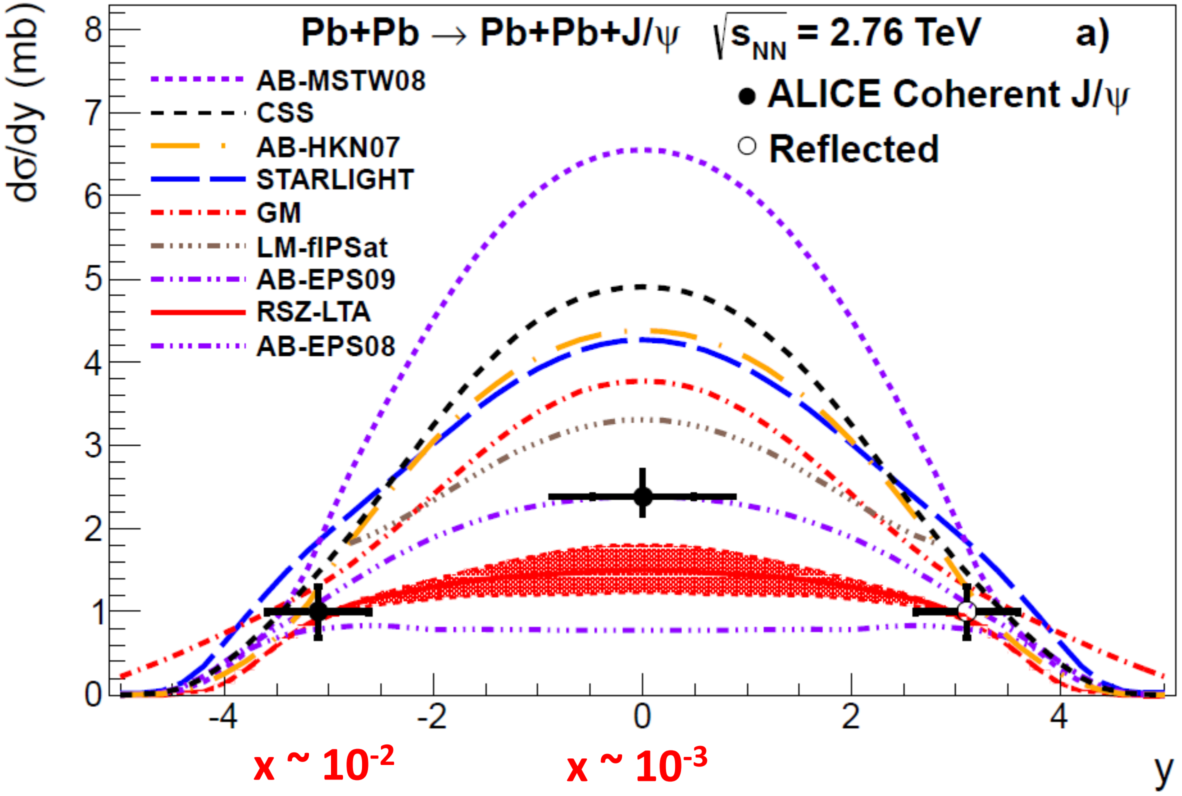
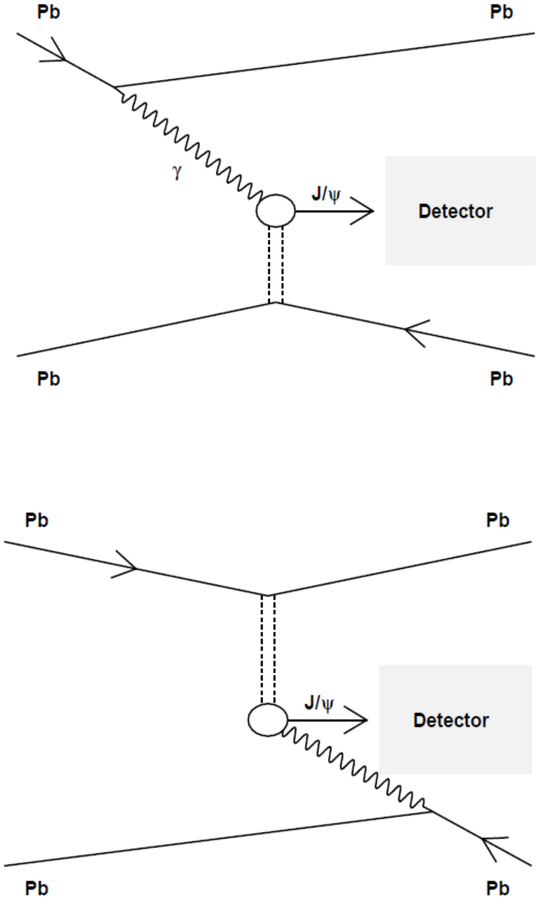


$x \sim 10^{-2}$ $x \sim 10^{-3}$

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



- Measured both at forward and central rapidity
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$$\sigma(y) = \underset{\substack{\uparrow\\\text{high-energy photons}}}{n(+y)}\underset{\substack{\nwarrow\\\text{low-x gluons}}}{\sigma_{\gamma\text{Pb}}(+y)} + \underset{\substack{\uparrow\\\text{low energy photons}}}{n(-y)}\underset{\substack{\uparrow\\\text{high-x gluons}}}{\sigma_{\gamma\text{Pb}}(-y)}$$

Gluon shadowing from photoproduction data

Nuclear suppression factor:

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

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

Impulse approximation:

forward photoproduction cross section off proton (HERA) times integral over squared Pb form-factor

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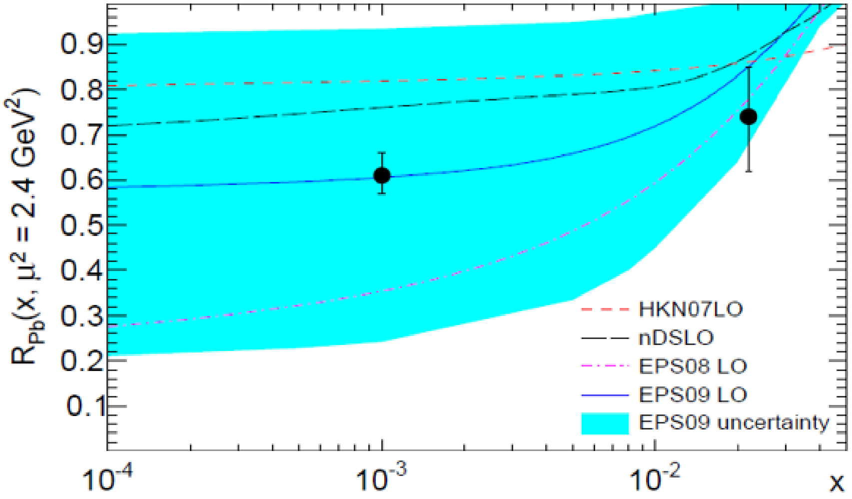


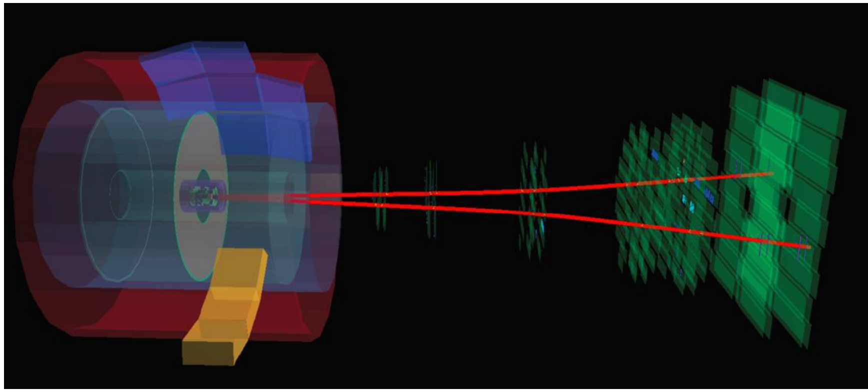
Guzey, EK et al. Phys. Lett. B726 (2013) 290
Guzey, Zhalov JHEP 1310 (2013) 207

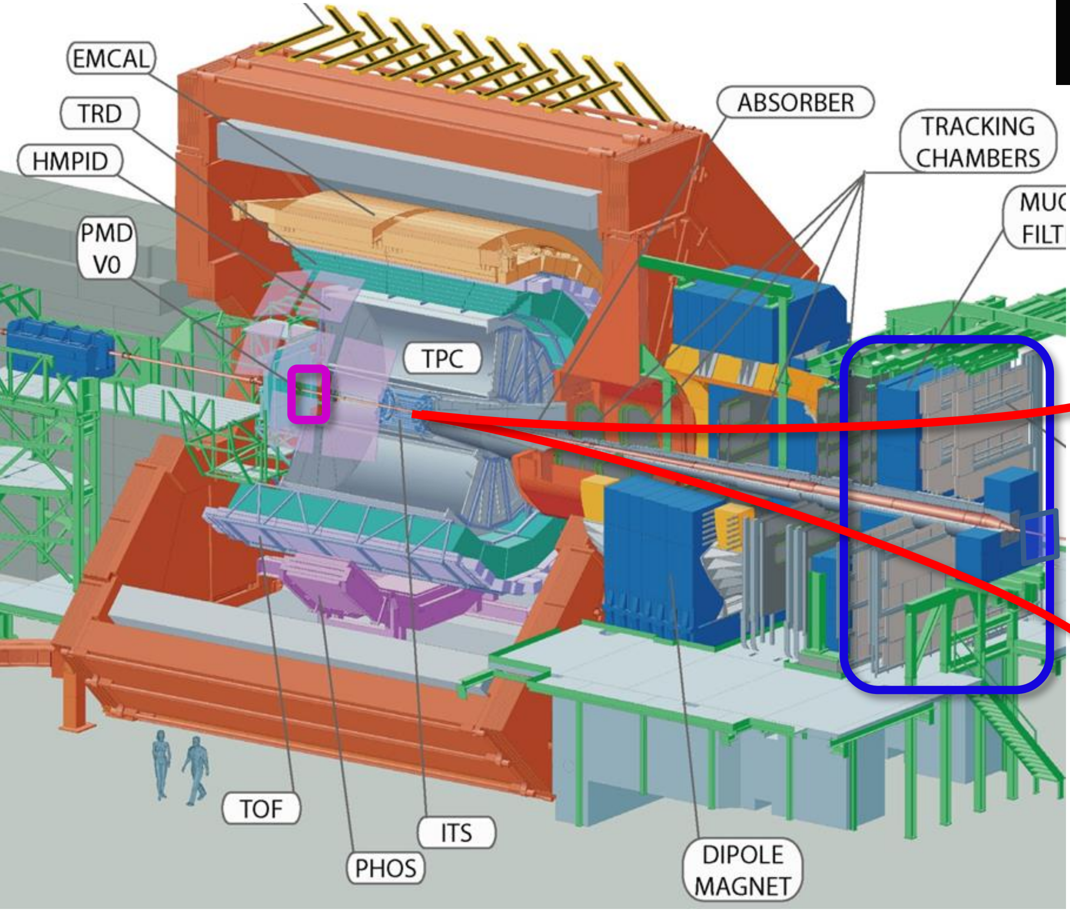
- Nuclear suppression factor S gives direct access to $R_g(x, \mu \sim 2.4\ \mathrm{GeV})$
- First direct evidence of large gluon nuclear shadowing: $R_g(x, \mu \sim 2.4\ \mathrm{GeV}) \sim 0.6$
- Many complications (skewness, NLO, scale uncertainty and higher-twist corrections) are likely minimized

J/ψ at forward rapidity: 2015+2018 data

UPC forward trigger:

- 2 unlike-sign tracks with p_T>1 GeV/c ($-4 < \eta < -2.5$)
- no hits in **AD-A** ($4.9 < \eta < 6.3$)
- no hits in **AD-C** ($-7.0 < \eta < -4.8$)
- no hits in **VZERO-A** ($2.8 < \eta < 5.1$)





- Pb Pb @ 5.02 TeV
- Integrated luminosity ~ 750 μb^{-1} (216 μb^{-1} in 2015 + 535 μb^{-1} in 2018)
- muon tracks: $-4 < \eta < -2.5$

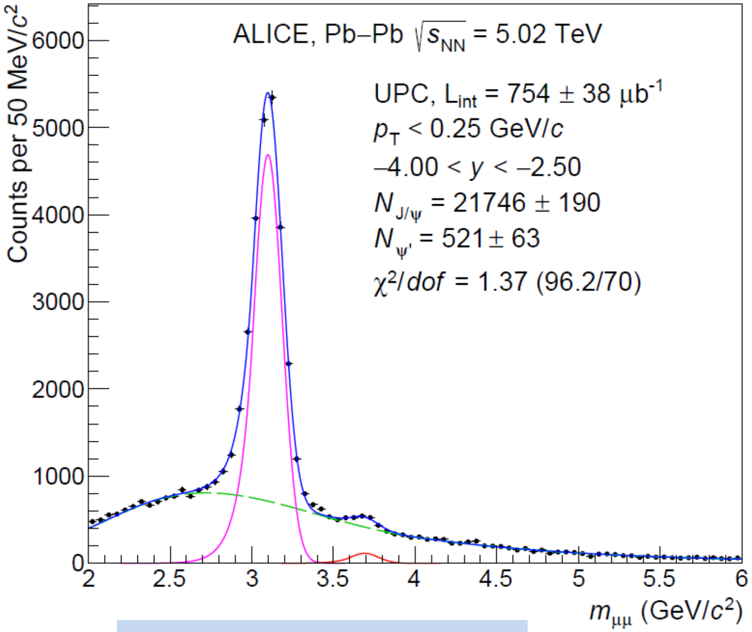
Invariant mass distribution

- x200 increase in statistics wrt Run 1
- Coherent-enriched sample: dimuon $p_T < 0.25$ GeV/c
- J/ψ and ψ’ fitted to a Crystal Ball function
- background (exponent × turn-on polynomial) perfectly described by γγ →μμ shape from Starlight MC
- ψ’-to-J/ψ yield ratio:

$$R_N = \frac{N(\psi')}{N(J/\psi)} = 0.0250 \pm 0.0030(\text{stat.}) \pm 0.0035(\text{syst.}),$$

- Primary coherent ψ’-to-J/ψ cross section ratio:

$$R = \frac{\sigma(\psi')}{\sigma(J/\psi)} = 0.150 \pm 0.018(\text{stat.}) \pm 0.021(\text{syst.}) \pm 0.007(\text{BR})$$



ALICE, arXiv:1903.06272

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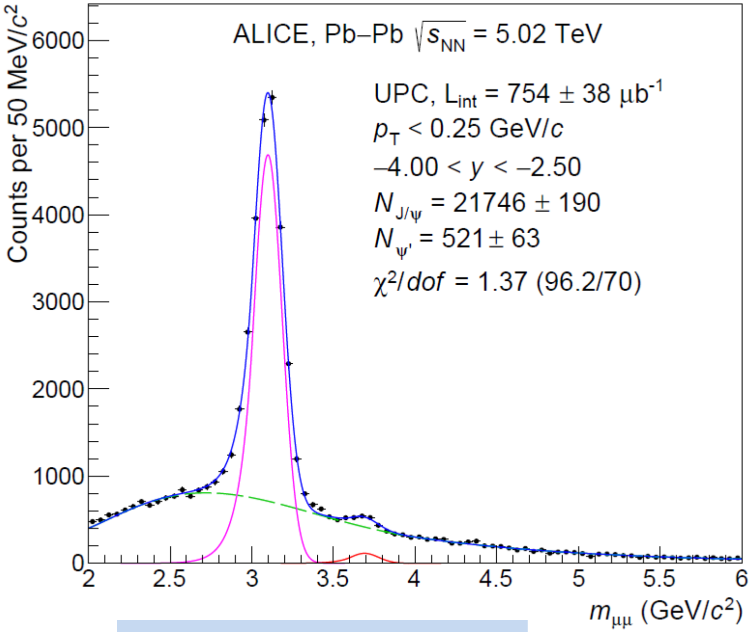
  - H1 in ep: $R = 0.166 \pm 0.007(\mathrm{stat.}) \pm 0.008(\mathrm{syst.}) \pm 0.007(\mathrm{BR})$
  - LHCb in pp double gap: $R \approx 0.19$



ALICE, arXiv:1903.06272

Coherent ψ′-to- J/ψ cross section ratio consistent with the ratio measured in photoproduction off protons

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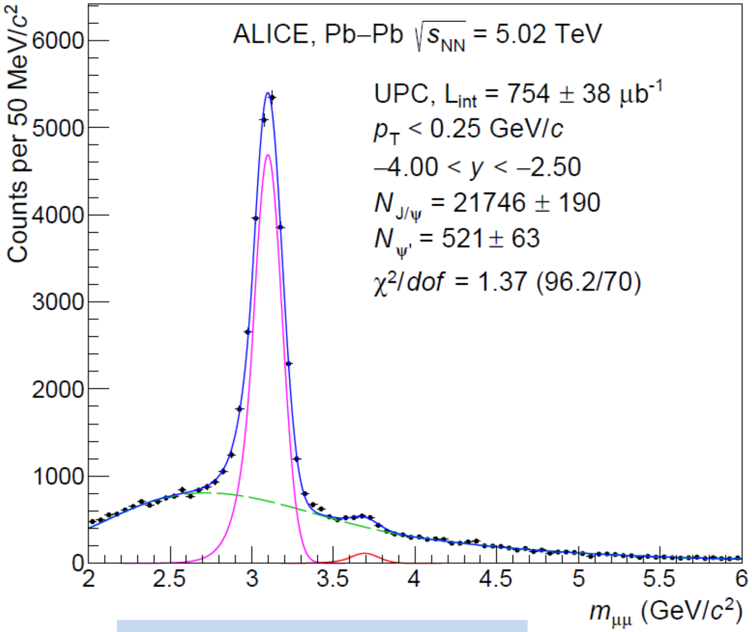
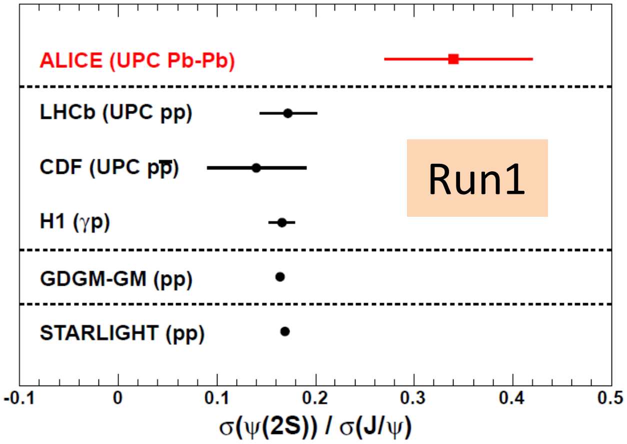
  - LHCb in pp double gap: $R \approx 0.19$
  - ALICE central barrel in Pb-Pb UPC from Run1: $R = 0.34^{+0.08}_{-0.07}$ ~2.5σ difference – need more precise measurement at central rapidity



ALICE, arXiv:1903.06272

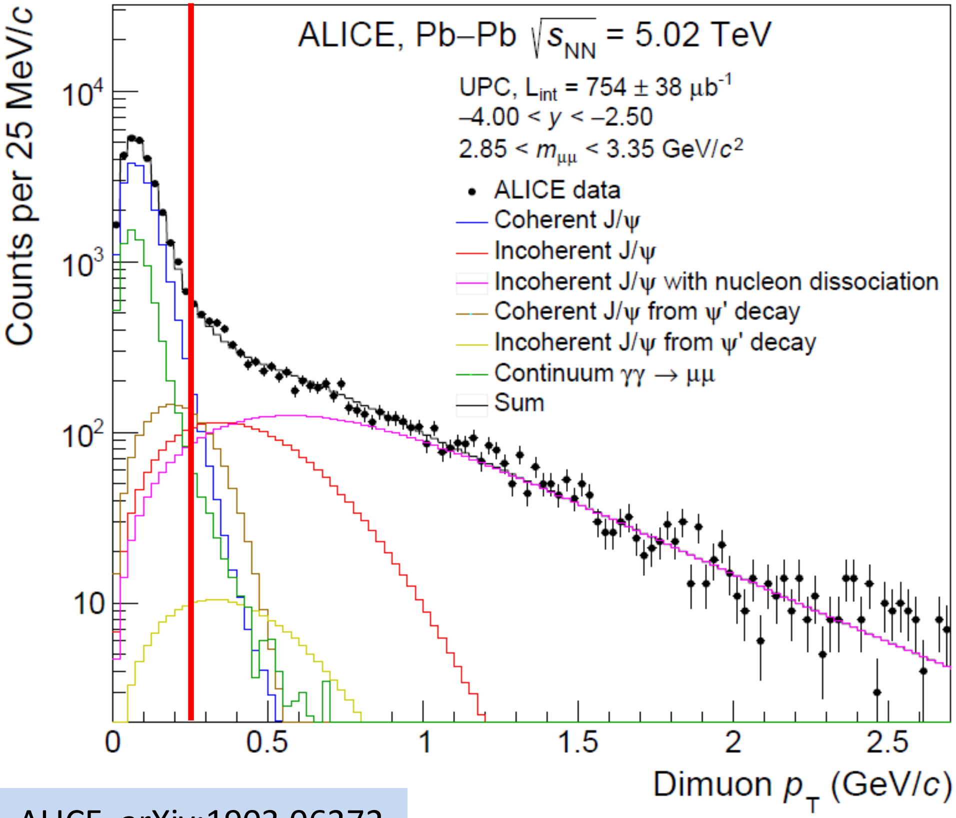


ALICE: PLB751 (2015) 358

Coherent ψ’-to- J/ψ cross section ratio consistent with the ratio measured in photoproduction off protons

p_T distributions

Main goal: determine the remaining contribution of incoherent J/ψ at low p_T (< 0.25 GeV/c)



ALICE, arXiv:1903.06272

Contributions (templates from MC):

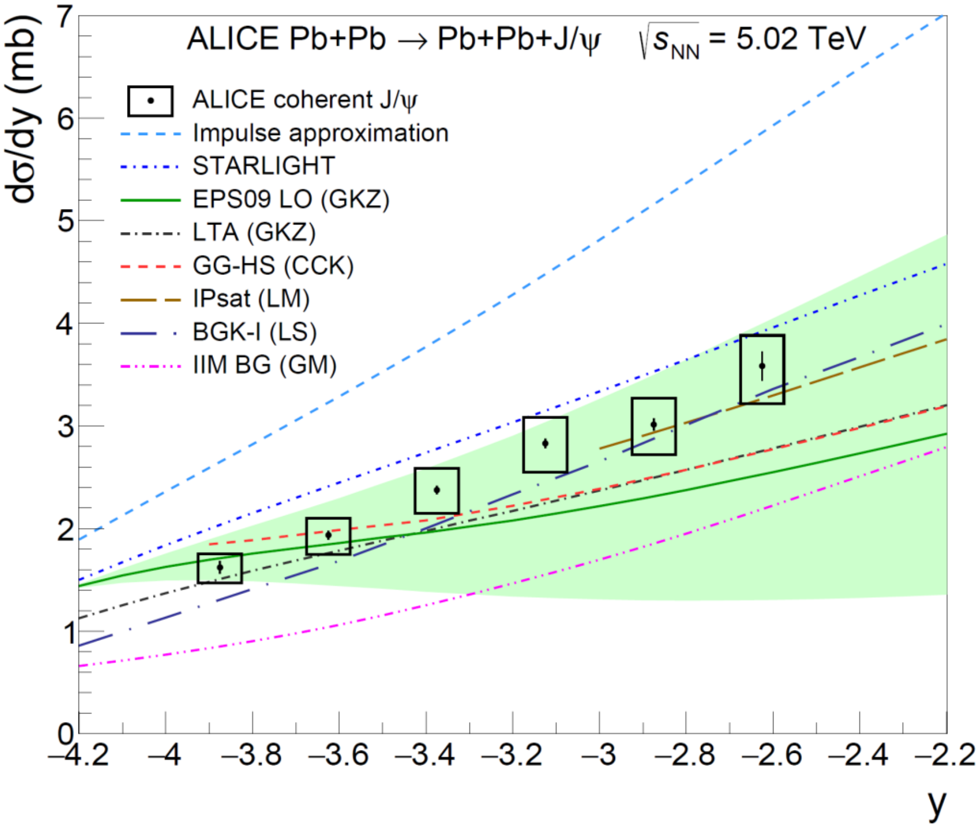
- **Coherent J/ψ:**
  - photon couples coherently to all nucleons
  - $\langle p_T \rangle \sim 1/R_{Pb} \sim$ 60 MeV/c
- **Incoherent J/ψ:**
  - photon couples to a single nucleon
  - $\langle p_T \rangle \sim 1/R_p \sim$ 500 MeV/c
- **Incoherent J/ψ with nucleon dissociation:** shape from HERA

$$\frac{dN}{dp_T} \sim p_T \left(1 + \frac{b_{pd}}{n_{pd}} p_T^2\right)^{-n_{pd}}$$

- **γγ →μμ:** fixed integral wrt J/ψ peak (~5%)
- **J/ψ from coherent and incoherent ψ' decays:** fixed wrt primary J/ψ (~5%)

Fraction of incoherent J/ψ at low p_T (< 0.25 GeV/c) is ~5%

Coherent J/ψ cross section

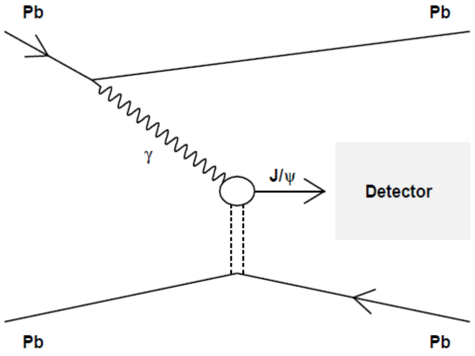


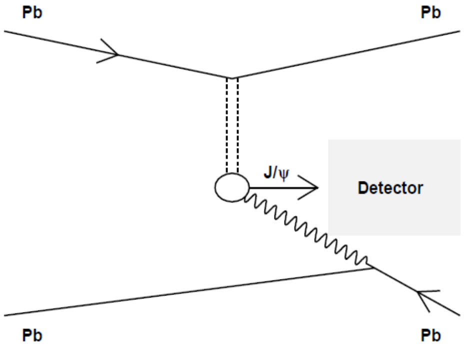
Coherent J/ψ cross section in agreement with moderate nuclear gluon shadowing

- **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 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
- **CCK: hot-spot model + Glauber-Gribov:**
  Cepila, Contreras, Krelina, PRC97 (2018) 024901
- **LS: Color dipole model + BGK-I CGC:**
  Luszczak, Schafer: arXiv:1901.07989

ALICE, arXiv:1903.06272

Low-x vs high-x ambiguity



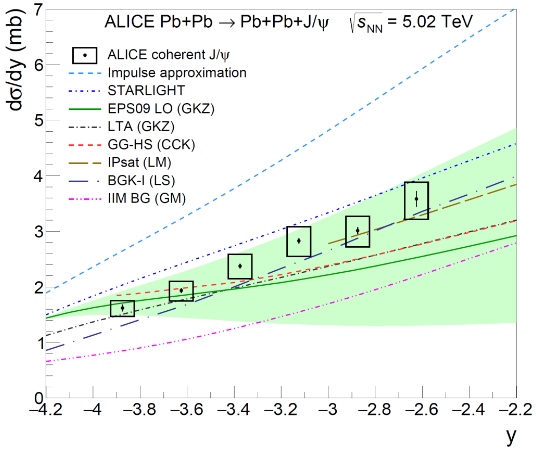


- Two terms in vector meson photoproduction cross section in UPC:

$$\sigma(y) = n(+y)\sigma_{\gamma\mathrm{Pb}}(+y) + n(-y)\sigma_{\gamma\mathrm{Pb}}(-y)$$

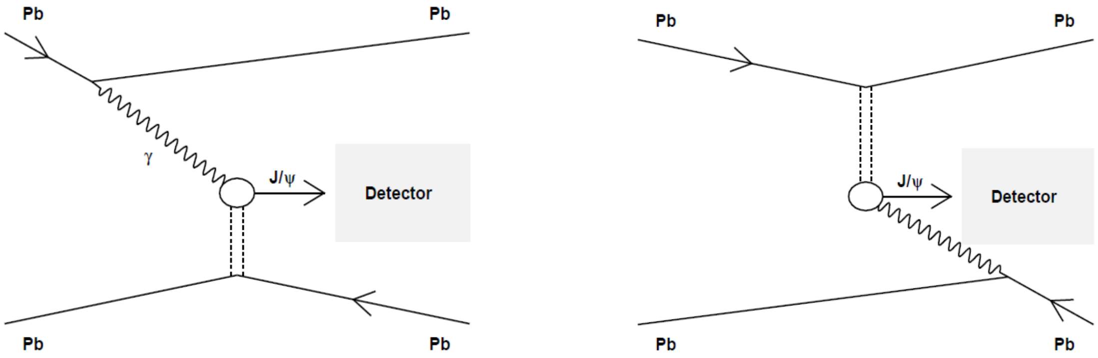
high-energy photons **low-x gluons (x ~ 10^{-5})** **low energy photons** **high-x gluons (x ~ 10^{-2})**

5-40% 60-95%



Dominant (60-95%) contribution of high-x gluons

Low-x vs high-x ambiguity



- Two terms in vector meson photoproduction cross section in UPC:

$$\sigma(y) = n(+y)\sigma_{\gamma\mathrm{Pb}}(+y) + n(-y)\sigma_{\gamma\mathrm{Pb}}(-y)$$

high-energy photons — $n(+y)$

low-x gluons ($x \sim 10^{-5}$) — $\sigma_{\gamma\mathrm{Pb}}(+y)$

low energy photons — $n(-y)$

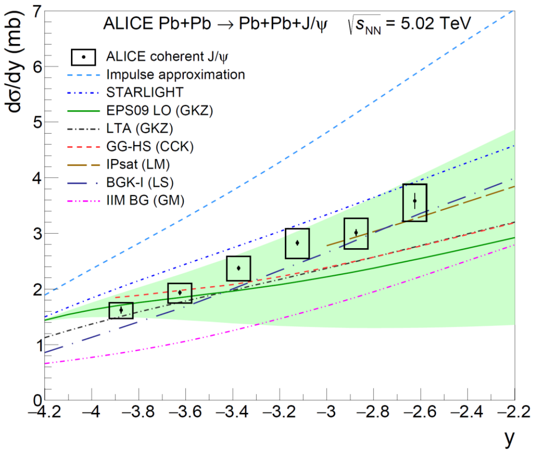
high-x gluons ($x \sim 10^{-2}$) — $\sigma_{\gamma\mathrm{Pb}}(-y)$

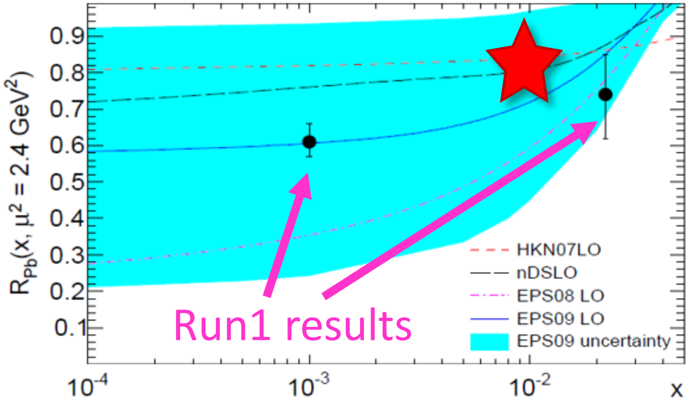
5-40%

60-95%

Dominant (60-95%) contribution of high-x gluons

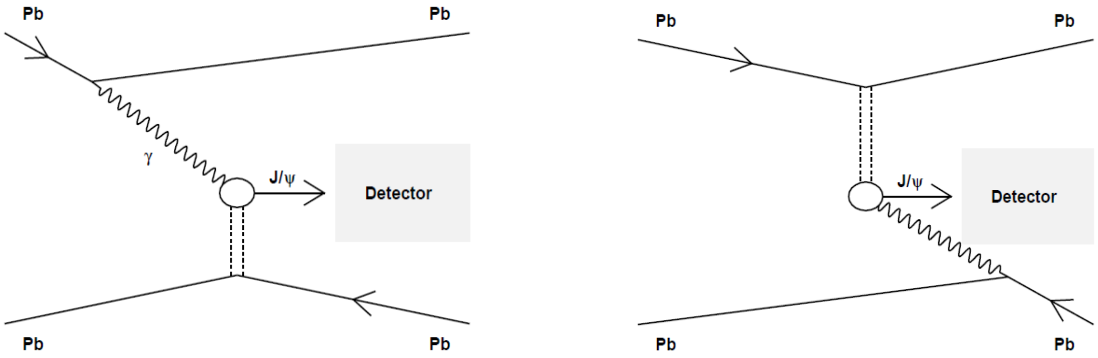
- Back-of-the-envelope calculation (neglect low-*x*): ALICE/Impulse approximation ~ 0.6
  => gluon shadowing factor $\sim \sqrt{0.6} \sim 0.8$





Run1 results

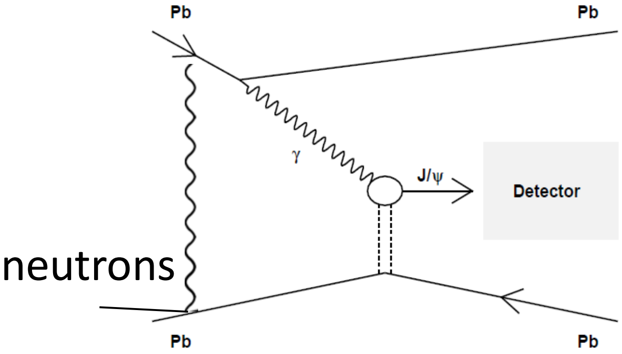
Ultimate goal: access gluon shadowing at $x \sim 10^{-5}$

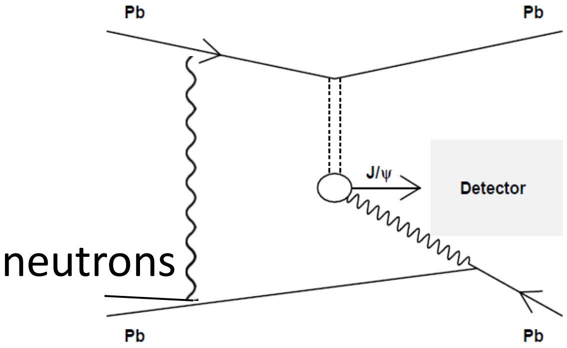


- Two terms in vector meson photoproduction cross section in UPC:

$$\sigma(y) = \underset{\substack{\uparrow\\ \text{high-energy}\\ \text{photons}}}{n(+y)}\sigma_{\gamma\mathrm{Pb}}\underset{\substack{\nwarrow\\ \text{low-x}\\ \text{gluons}}}{(+y)} + \underset{\substack{\uparrow\\ \text{low energy}\\ \text{photons}}}{n(-y)}\sigma_{\gamma\mathrm{Pb}}\underset{\substack{\uparrow\\ \text{high-x}\\ \text{gluons}}}{(-y)}$$

Ultimate goal: access gluon shadowing at x~10^{-5}





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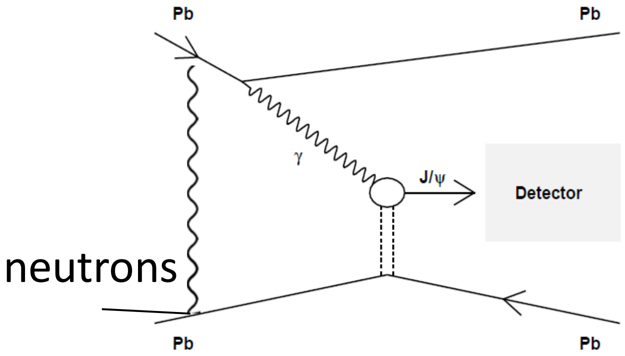
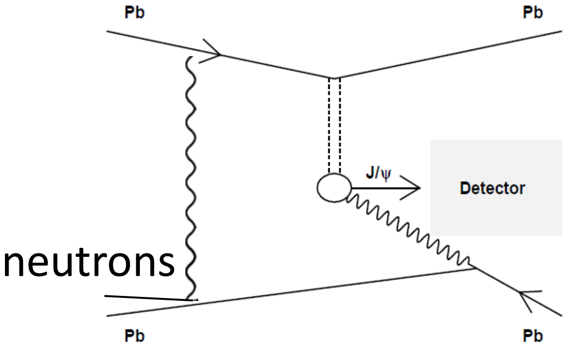
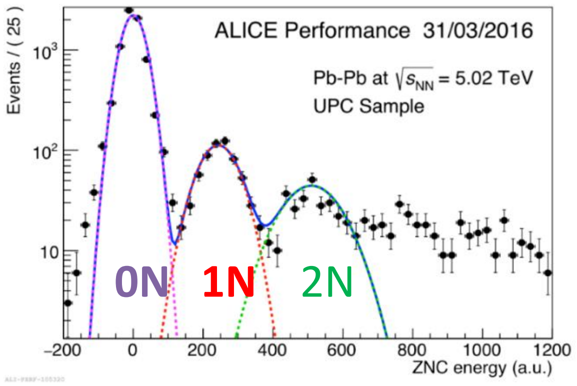
Ultimate goal: access gluon shadowing at x~10^{-5}







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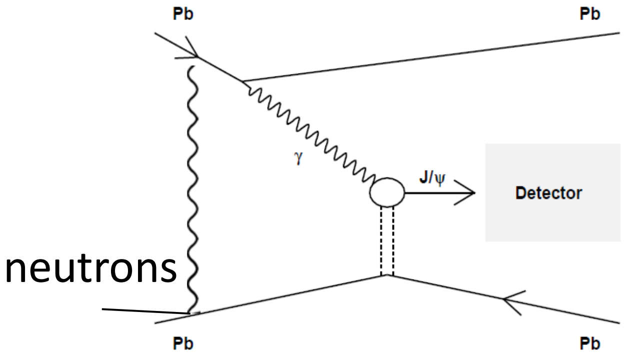

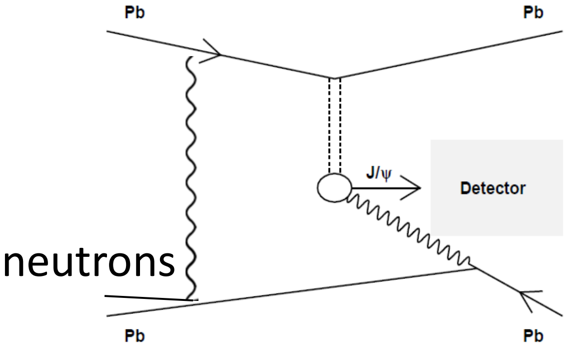

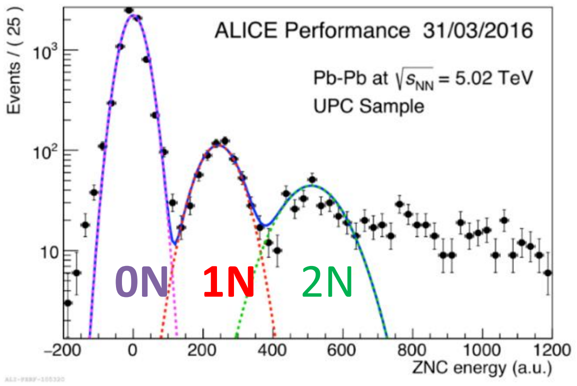

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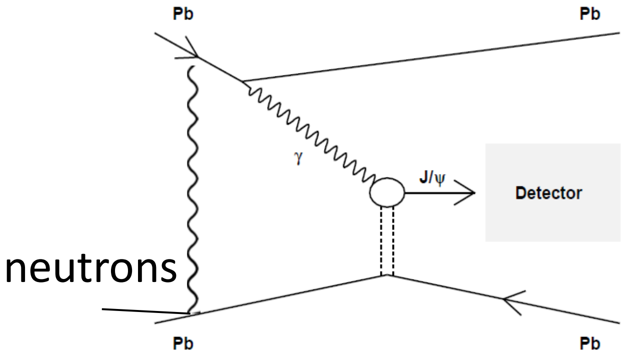
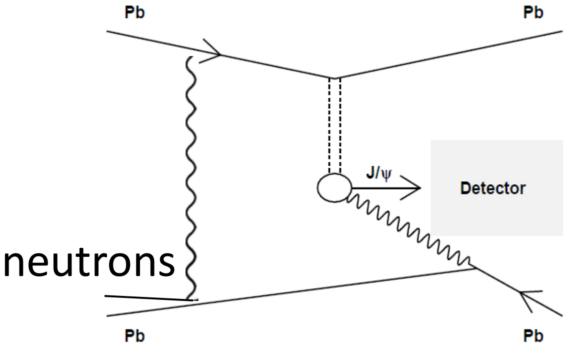
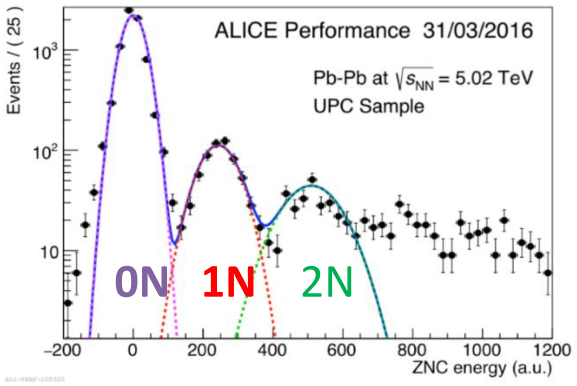
- Effective flux is modified in presence of additional photon exchange

Ultimate goal: access gluon shadowing at x~10^{-5}







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high-energy photons

low-x gluons

low energy photons

high-x gluons

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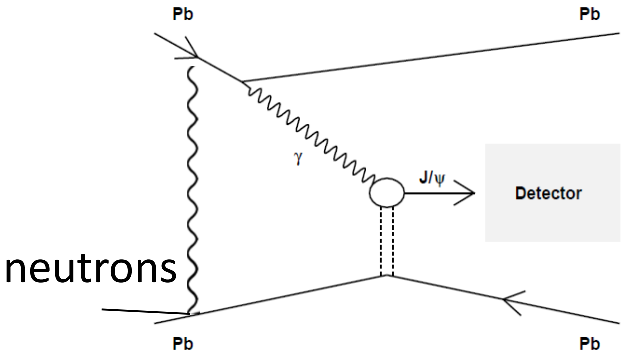
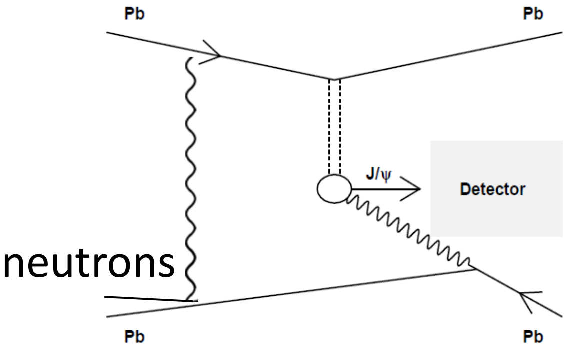
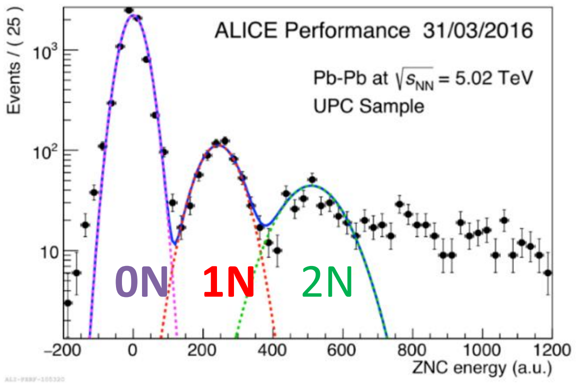
no neutrons: $\sigma_{0\mathrm{N}0\mathrm{N}}(y) = n_{0\mathrm{N}0\mathrm{N}}(+y)\sigma_{\gamma \mathrm{Pb}}(+y) + n_{0\mathrm{N}0\mathrm{N}}(-y)\sigma_{\gamma \mathrm{Pb}}(-y),$

neutrons on one side: $\sigma_{0\mathrm{N}X\mathrm{N}}(y) = n_{0\mathrm{N}X\mathrm{N}}(+y)\sigma_{\gamma \mathrm{Pb}}(+y) + n_{0\mathrm{N}X\mathrm{N}}(-y)\sigma_{\gamma \mathrm{Pb}}(-y)$

Ultimate goal: access gluon shadowing at x~10^{-5}







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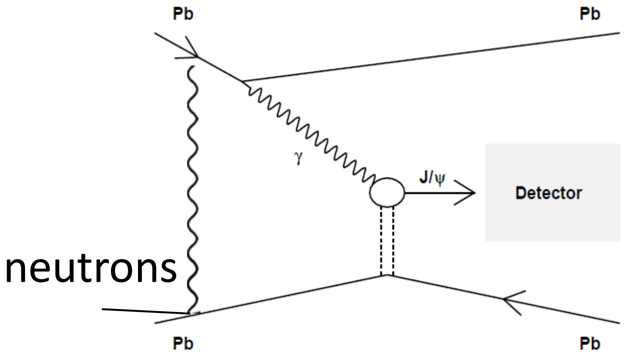
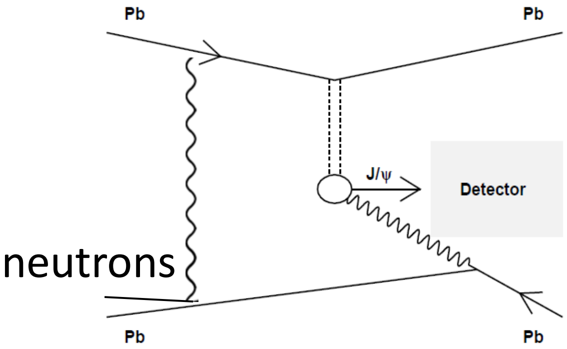
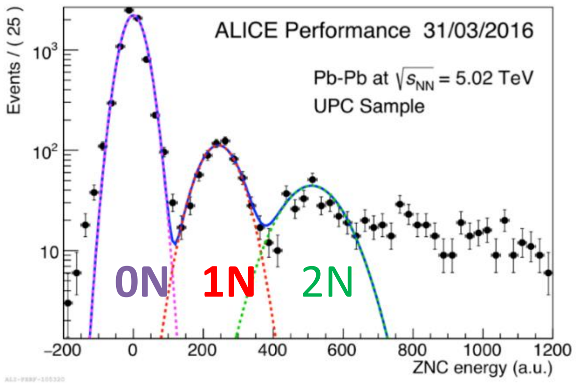
$$\begin{array}{lrcl} & \text{measured} & & \\ \text{no neutrons:} & \boxed{\sigma_{\rm 0N0N}(y)} & = & n_{\rm 0N0N}(+y)\sigma_{\gamma\rm Pb}(+y) + n_{\rm 0N0N}(-y)\sigma_{\gamma\rm Pb}(-y), \\ \text{neutrons on one side:} & \boxed{\sigma_{\rm 0NXN}(y)} & = & n_{\rm 0NXN}(+y)\sigma_{\gamma\rm Pb}(+y) + n_{\rm 0NXN}(-y)\sigma_{\gamma\rm Pb}(-y) \end{array}$$

Ultimate goal: access gluon shadowing at x~10^{-5}







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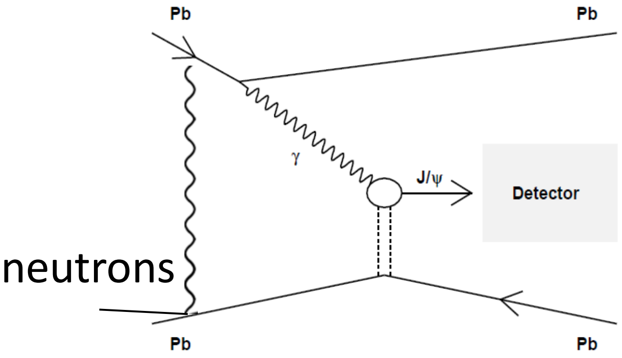
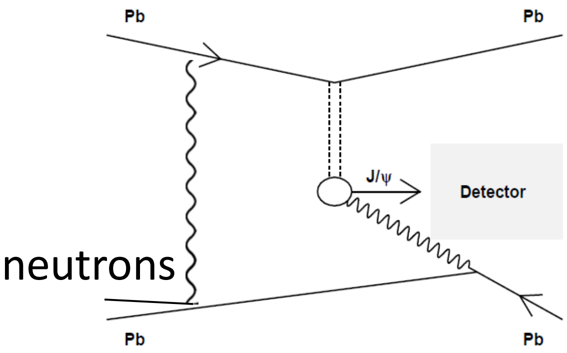
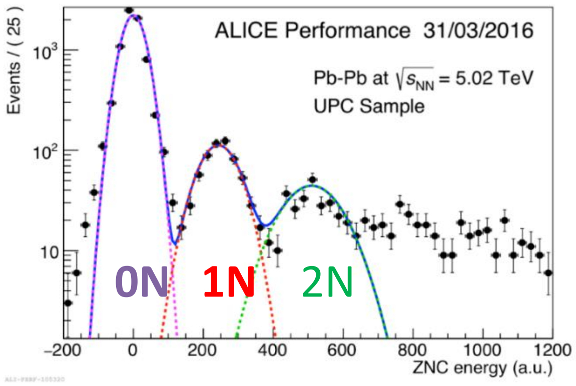
Ultimate goal: access gluon shadowing at x~10^{-5}







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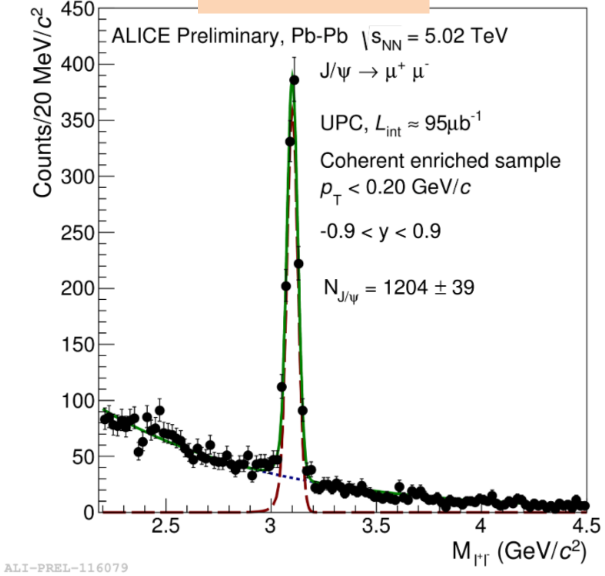
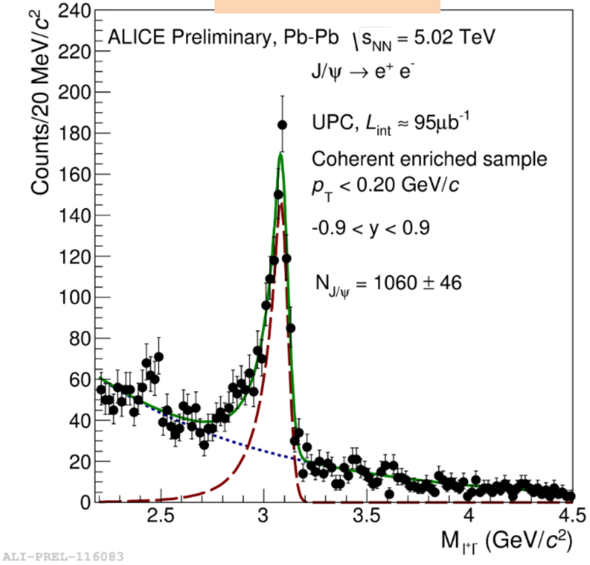
unknown photoproduction cross sections

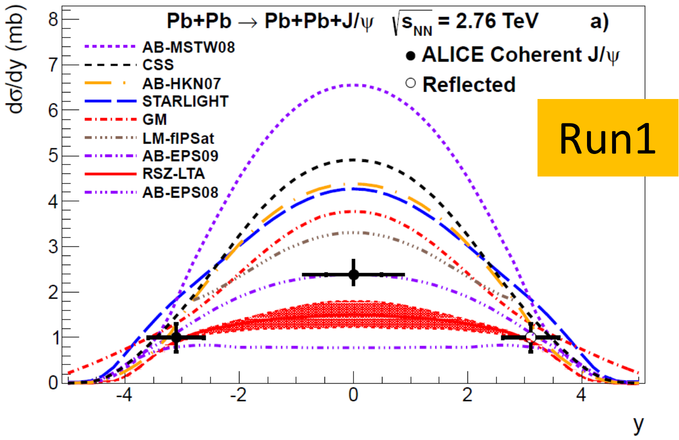
Central barrel J/ψ in Pb-Pb 2015

$J/\psi \rightarrow \mu\mu$



$J/\psi \rightarrow ee$



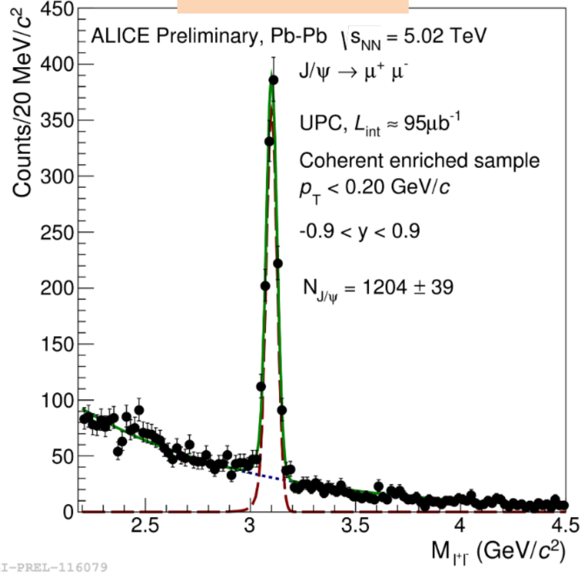


Run1

- access to $x \sim 0.5 \times 10^{-3}$ without low-x/high-x ambiguity – can test neutron emission models
- + factor 2 higher statistics in PbPb2018

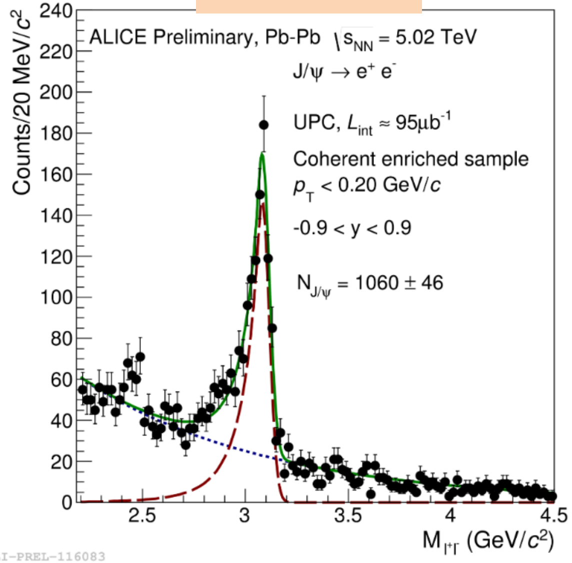
Central barrel J/ψ in Pb-Pb 2015

J/ψ → μμ

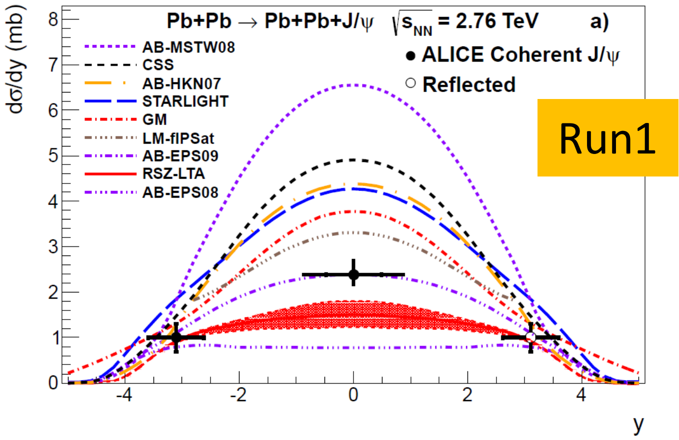


ALI-PREL-116079

J/ψ → ee

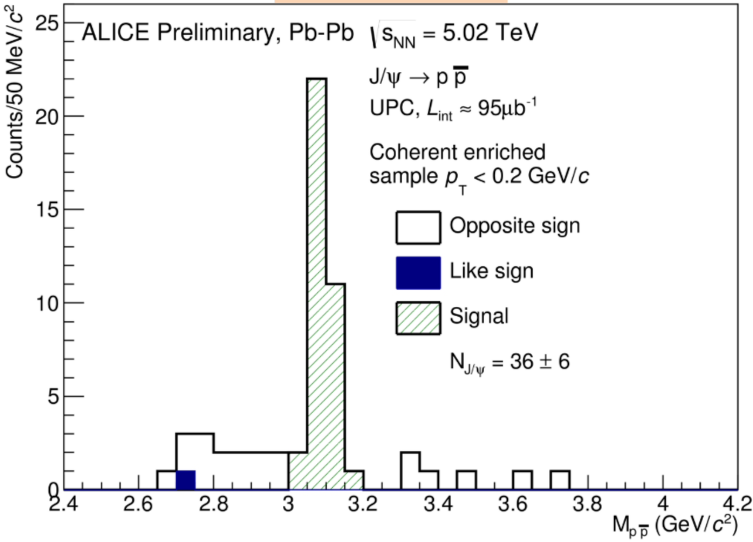


ALI-PREL-116083



- access to x ~ 0.5 x 10^{-3} without low-x/high-x ambiguity – can test neutron emission models
- + factor 2 higher statistics in PbPb2018

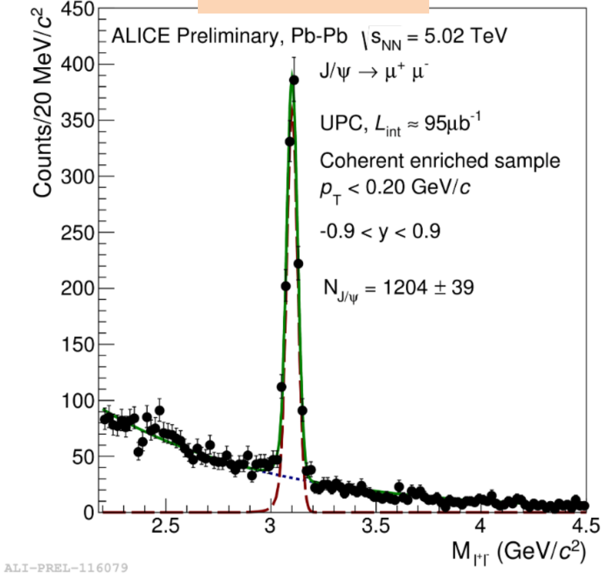
J/ψ → $p\bar{p}$



ALI-PREL-117138

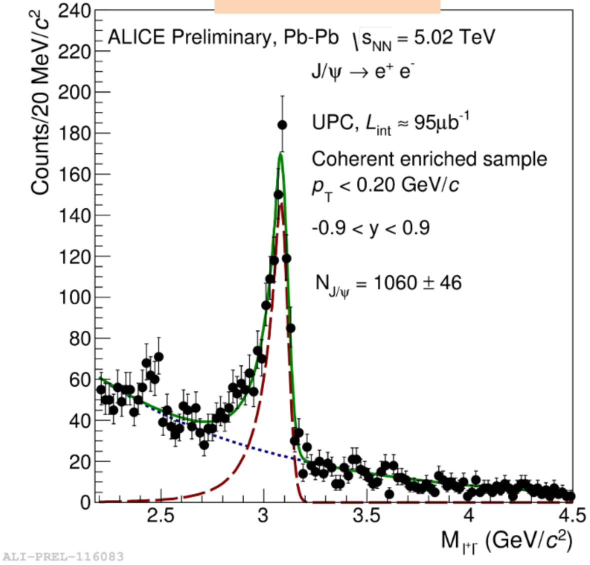
Central barrel J/ψ in Pb-Pb 2015

$J/\psi \to \mu\mu$



ALI-PREL-116079

$J/\psi \to ee$



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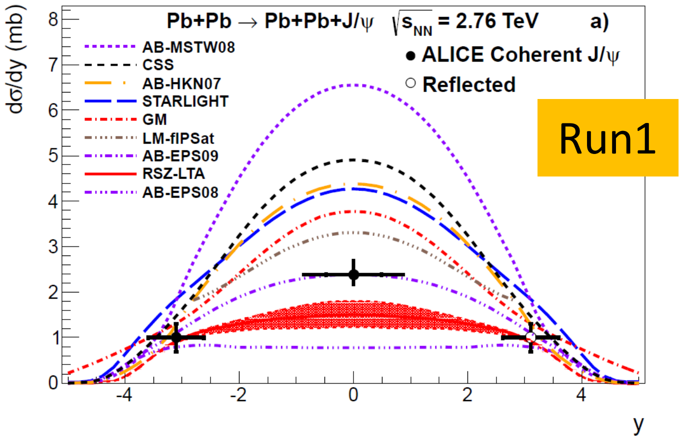
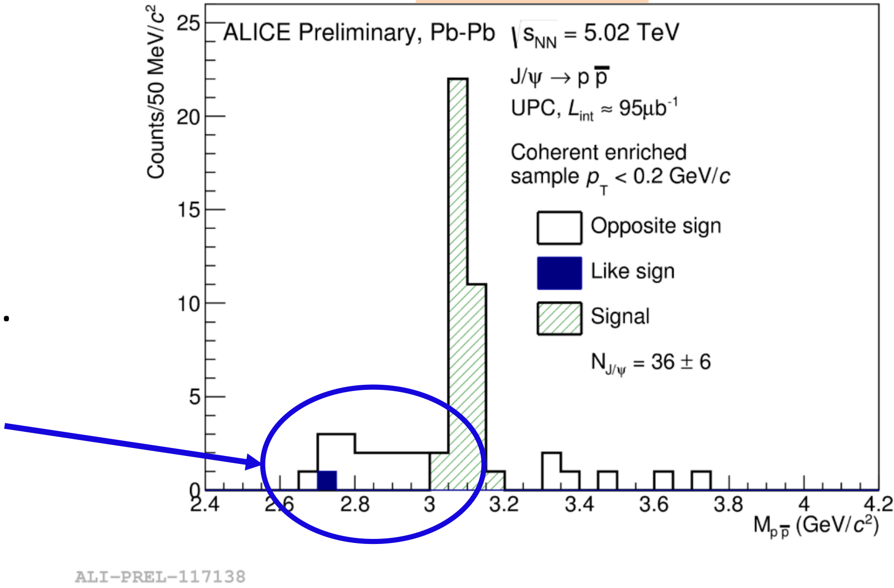


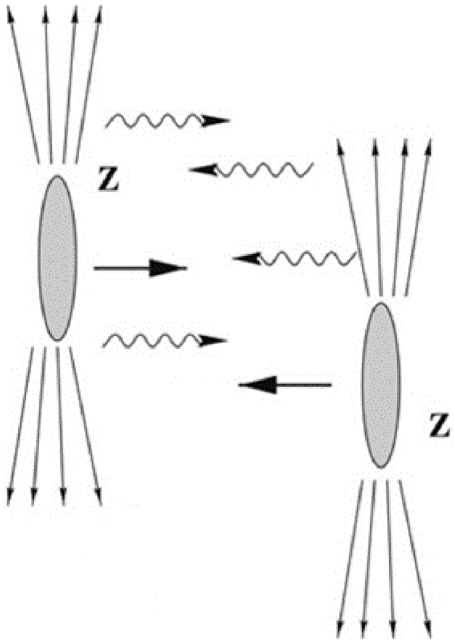
$J/\psi \to p\bar{p}$



ALI-PREL-117138

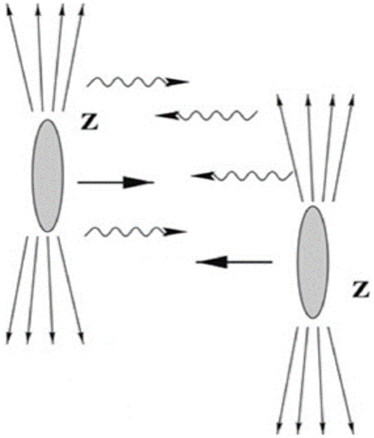
- access to x ~ 0.5 x 10^{-3} without low-x/high-x ambiguity – can test neutron emission models
- + factor 2 higher statistics in PbPb2018
- Continuum $\gamma\gamma \to p\bar{p}$ might be also interesting, e.g. Kłusek-Gawenda, Lebiedowicz, Nachtmann, Szczurek: PRD96 (2017) 094029

Photon-induced processes in peripheral events

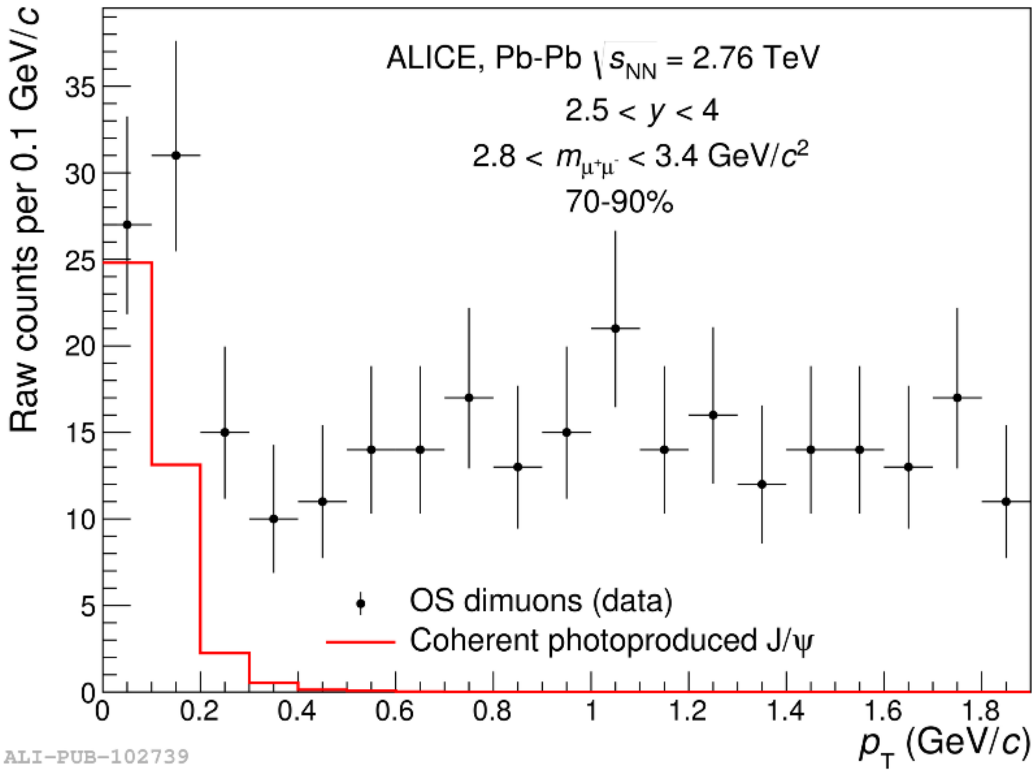


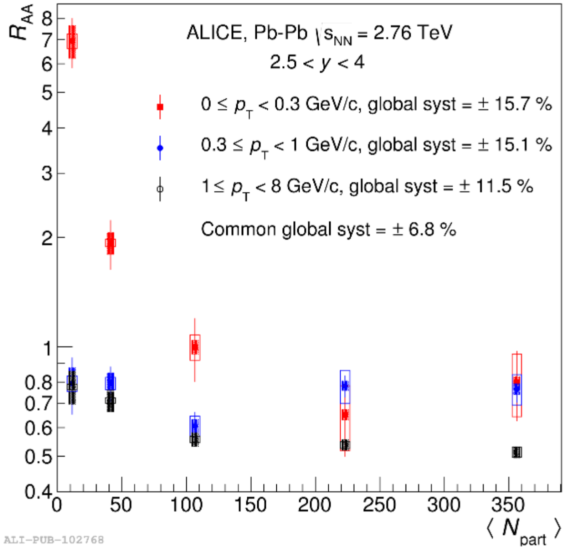
$b < 2R$

Coherent J/ψ in peripheral collisions?



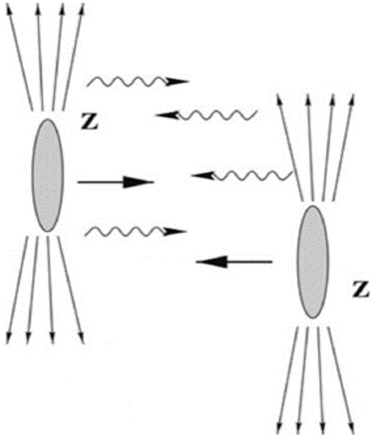
ALICE: PRL 116 (2016) 222301

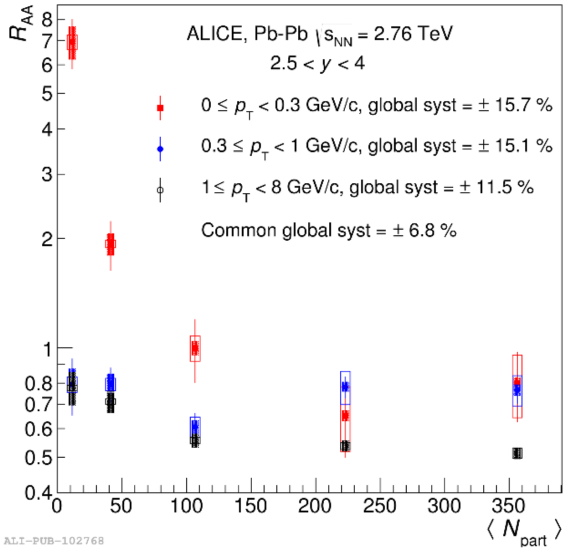




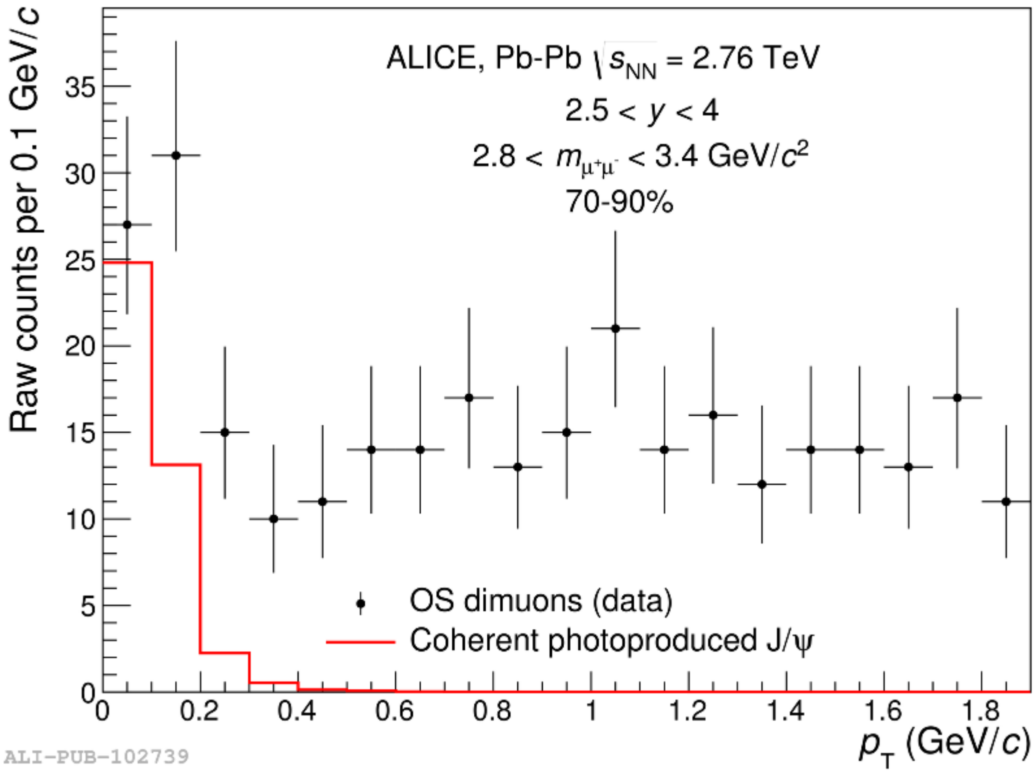
- Data shows an excess of J/ψ at low $p_T < 200$ MeV/c (R_{AA} ~ 7)

Coherent J/ψ in peripheral collisions?





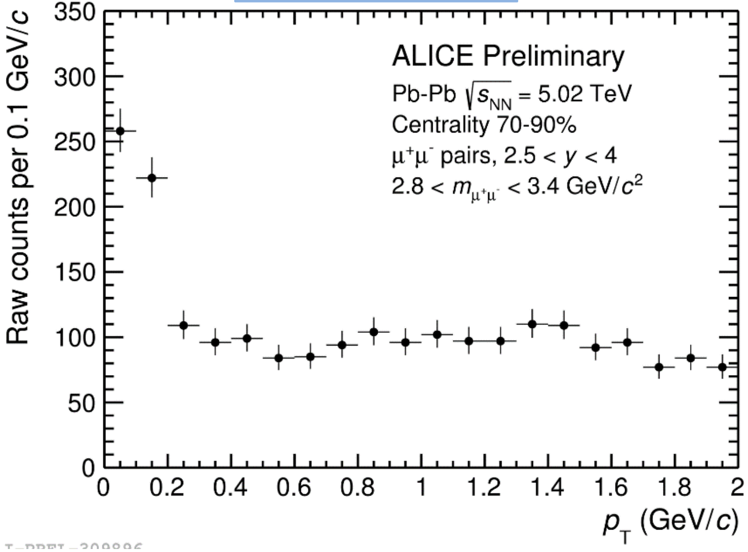
ALICE: PRL 116 (2016) 222301



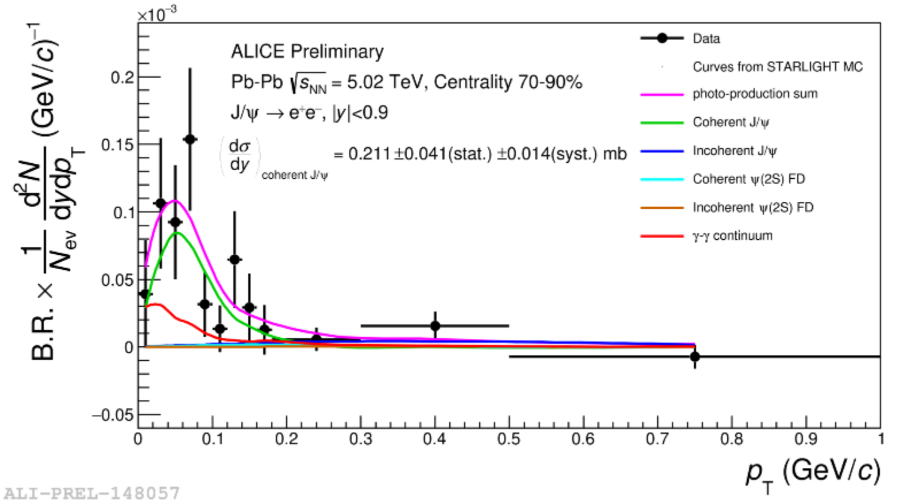
- Data shows an excess of J/ψ at low $p_T < 200$ MeV/c ($R_{AA} \sim 7$)
- Possible interpretation: coherent photoproduction on nuclear fragments

Coherent J/ψ in peripheral collisions: news from Run2

Forward J/ψ



Central barrel J/ψ



Coherent J/ψ in peripheral collisions: news from Run2

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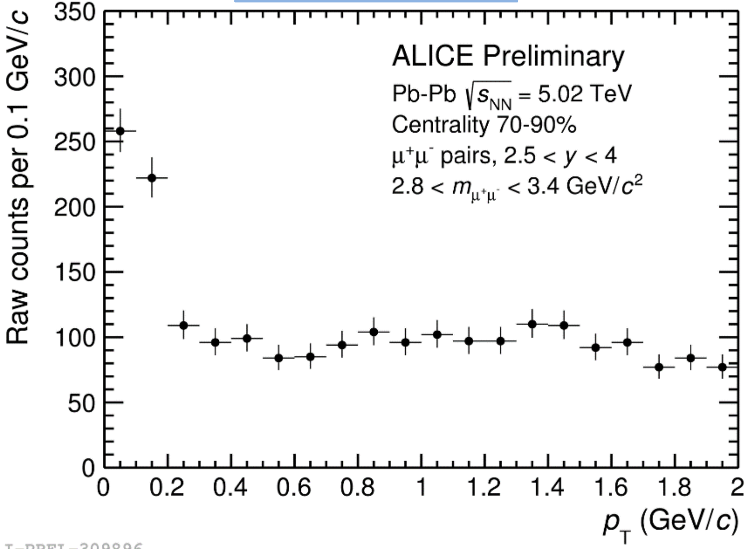
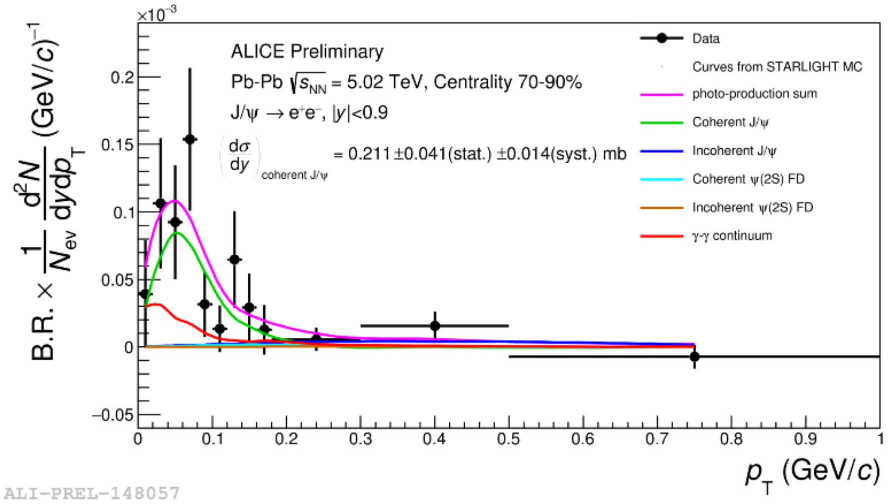
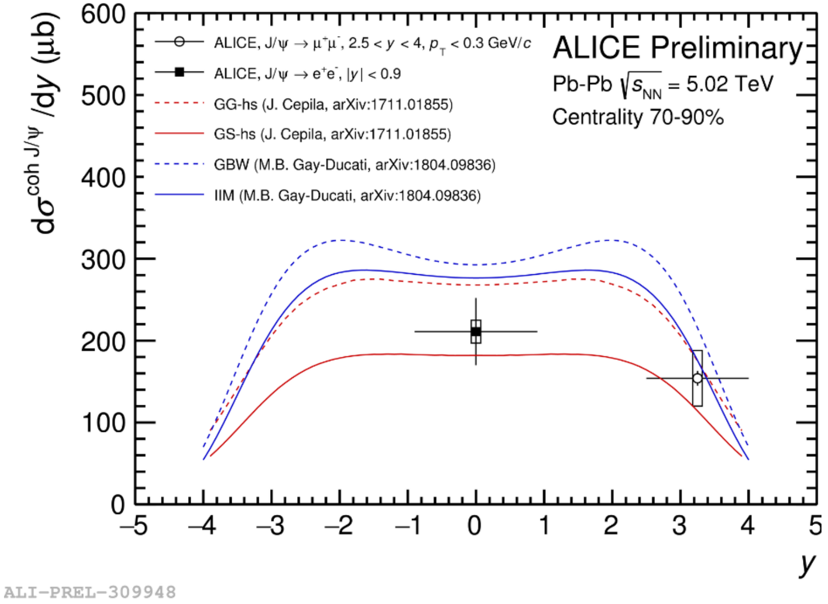


Central barrel J/ψ



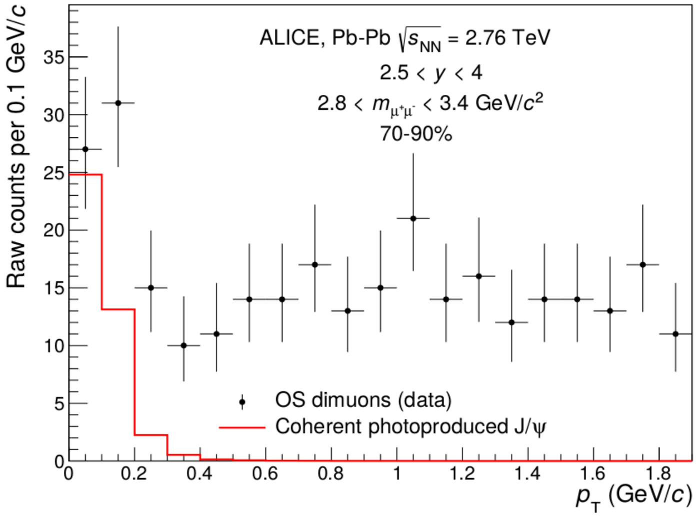


Theoretical challenge:

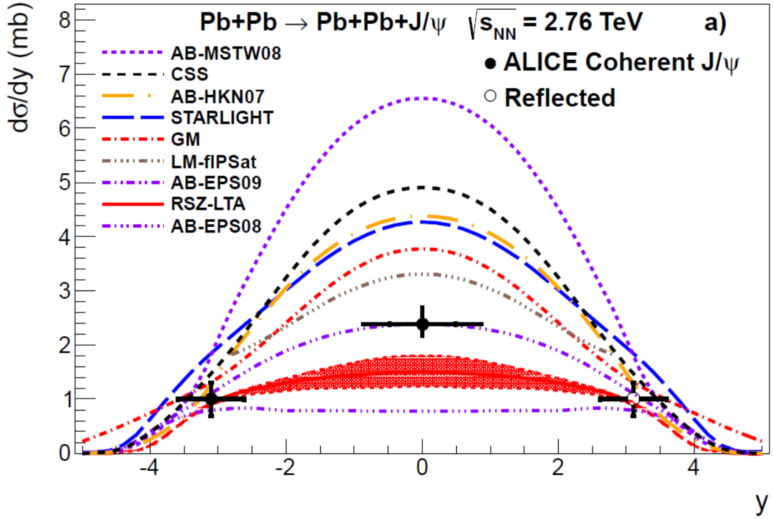
- How can the coherence condition survive when both nuclei are broken by hadronic interaction?
- Do only spectator nucleons participate in the coherence?

Low-x gluons with coherent J/ψ in hadronic collisions?

J/ψ in peripheral collisions (b<2R)

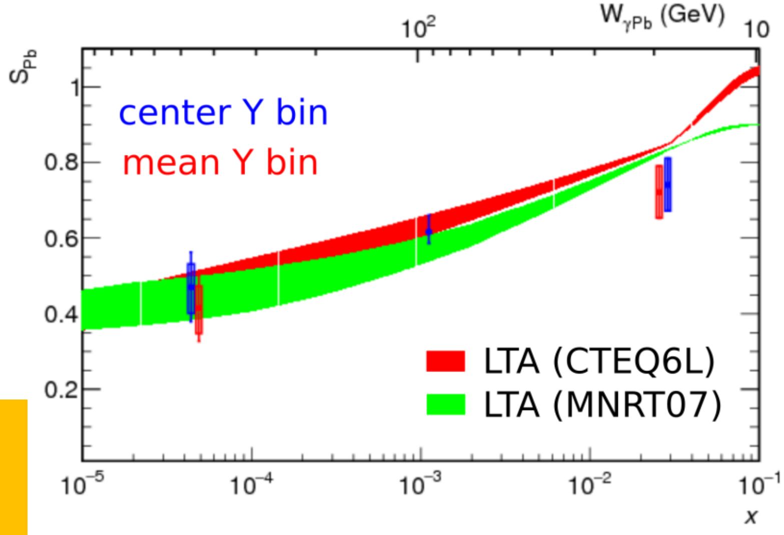


J/ψ in ultra-peripheral collisions (b>2R)



$$\sigma_{\gamma\mathrm{Pb}}(-y) = \left(n_\gamma^P(y)\frac{d\sigma^U_{\mathrm{PbPb}}}{dy} - n_\gamma^U(y)\frac{d\sigma^P_{\mathrm{PbPb}}}{dy}\right)/F(y)$$

$$\sigma_{\gamma\mathrm{Pb}}(y) = \left(n_\gamma^U(-y)\frac{d\sigma^P_{\mathrm{PbPb}}}{dy} - n_\gamma^P(-y)\frac{d\sigma^U_{\mathrm{PbPb}}}{dy}\right)/F(y)$$

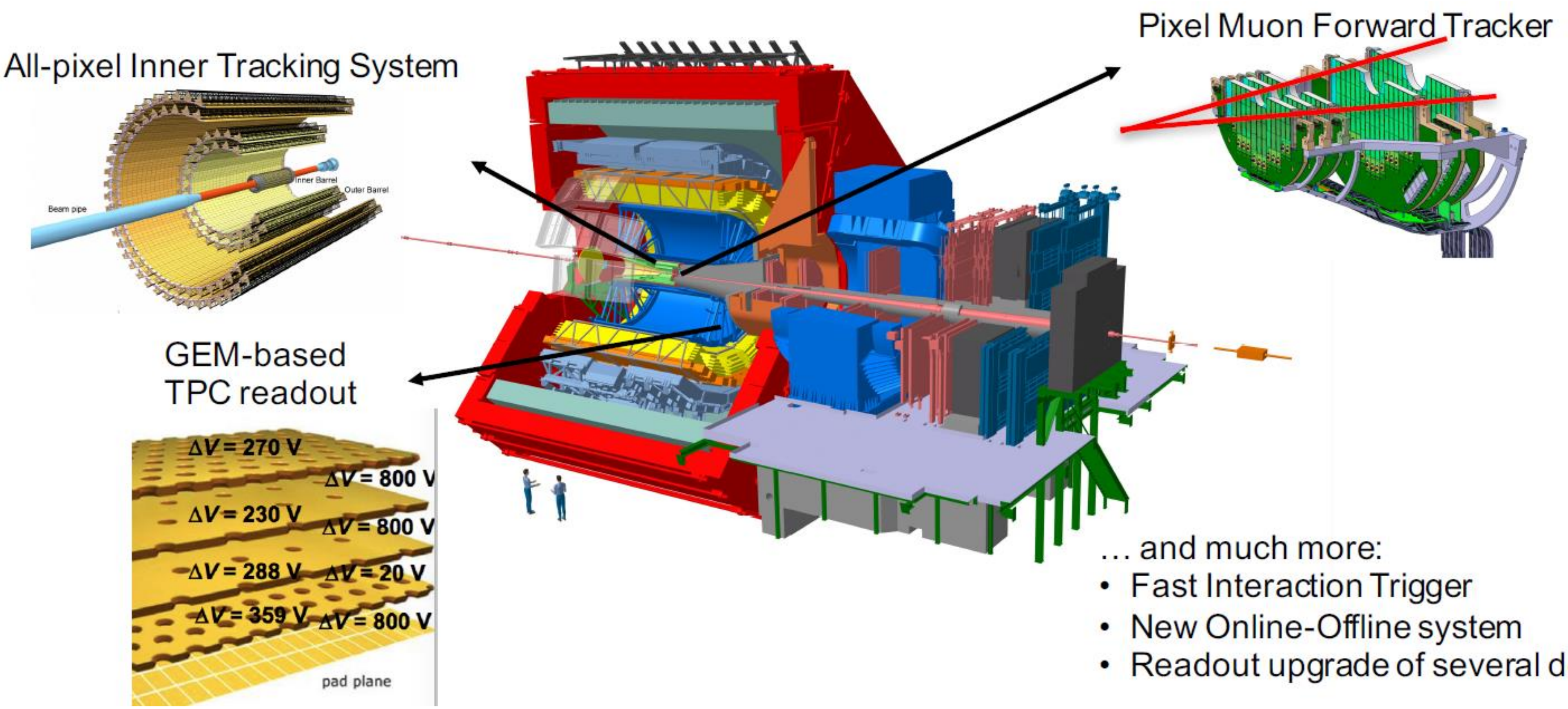


G. Contreras, PRC96 (2017) 015203

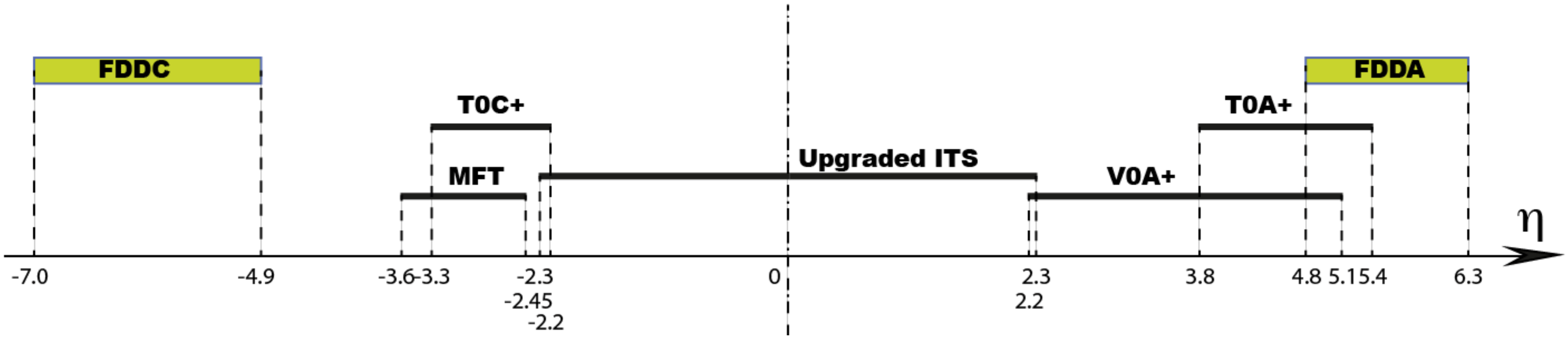
Coherent J/ψ in UPC+peripheral events - promising tool to extract low-x gluon shadowing

UPC in Run3 and 4

UPC perspectives in view of ALICE upgrade



… and much more:
- Fast Interaction Trigger
- New Online-Offline system
- Readout upgrade of several detectors

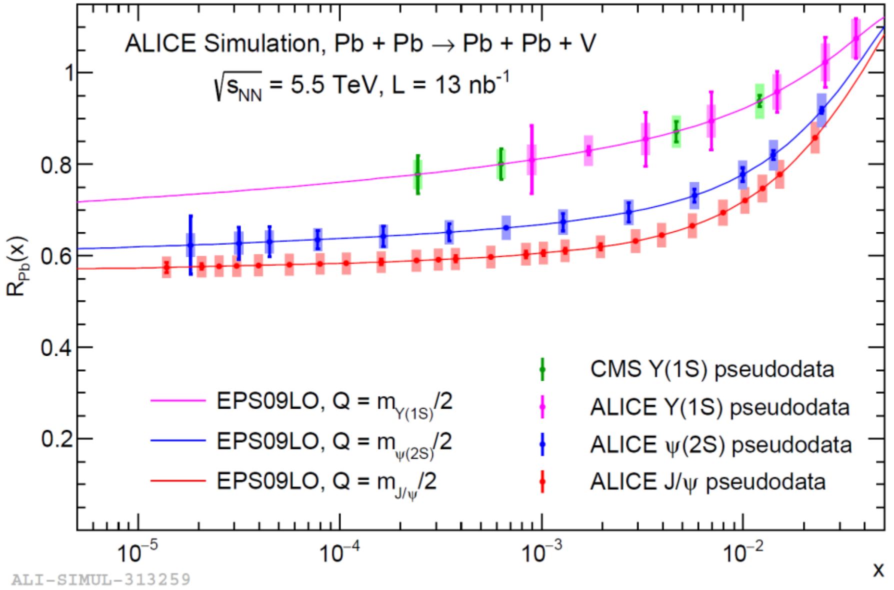


Run3-4 projections in Pb-Pb UPC

- Expected statistics in Run 3-4 (13 /nb):

Yellow report on Run3-4: 1812.06772

PbPb, 13 nb^{-1}				
Meson	σ	Total	$\vert\eta\vert < 0.9$	$-4 < \eta < -2.5$
$\rho \to \pi^+\pi^-$	5.2b	68 B	5.5 B	4.9 B
$\rho' \to \pi^+\pi^-\pi^+\pi^-$	730 mb	9.5 B	210 M	190 M
$\phi \to \text{K}^+\text{K}^-$	0.22b	2.9 B	82 M	15 M
$\text{J}/\psi \to \mu^+\mu^-$	1.0 mb	14 M	1.1 M	600 K
$\psi(2\text{S}) \to \mu^+\mu^-$	30 μb	400 K	35 K	19 K
$\Upsilon(1\text{S}) \to \mu^+\mu^-$	2.0 μb	26 K	2.8 K	880



Main goals for Run3-4:

- access to gluon shadowing at **low x**
- study **scale dependence** of gluon shadowing with different meson species

$$x = \frac{m_V}{\sqrt{s_{NN}}} \exp(-y)$$

$$R_{\text{Pb}}(x) = \left(\frac{\sigma_{\gamma\text{Pb}}(x)}{\sigma_{\text{IA}}(x)}\right)^{1/2},$$

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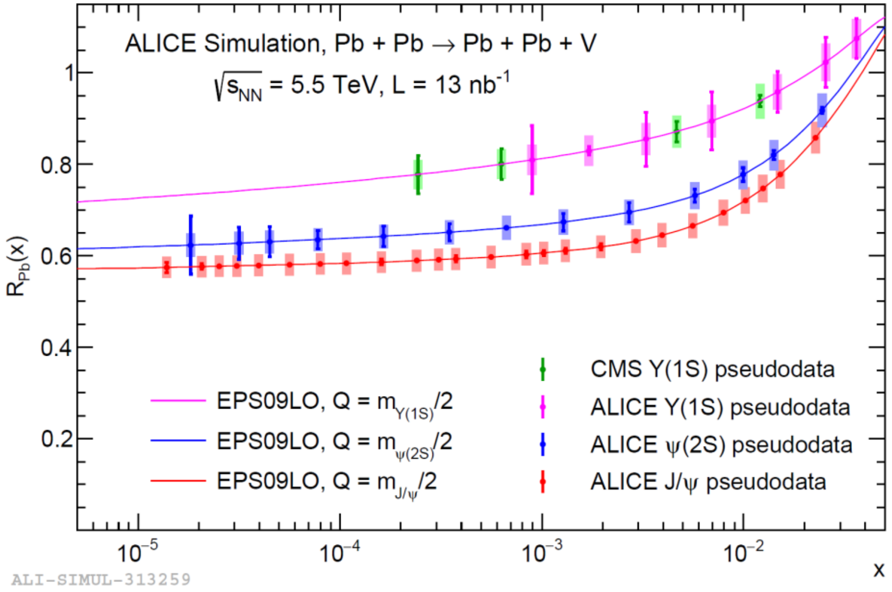
Main goals for Run3-4:

- access to gluon shadowing at **low x**
- study **scale dependence** of gluon shadowing with different meson species
- probe gluon distribution in **transverse plane**



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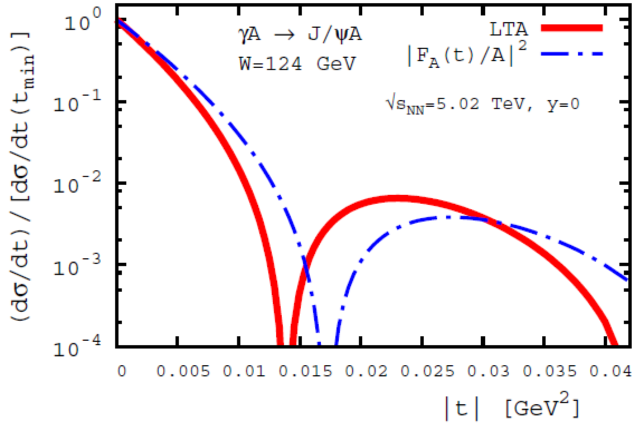


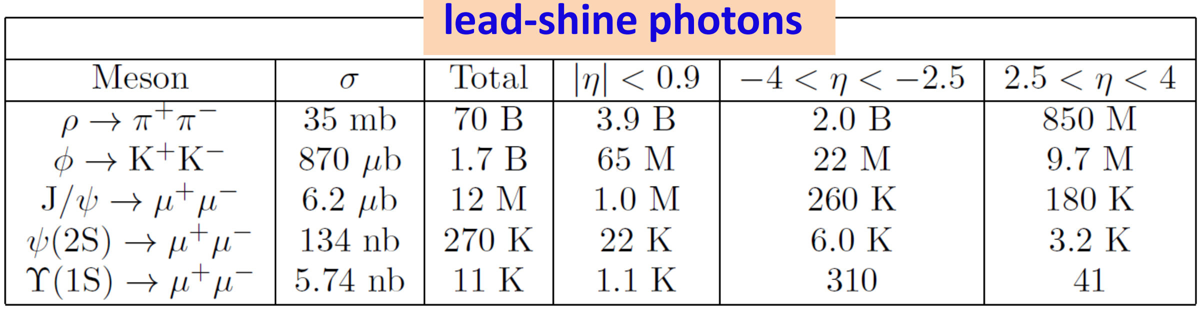
Guzey, Strikman, Zhalov PRC95 (2017) 025204

Run3-4 projections in p-Pb UPC

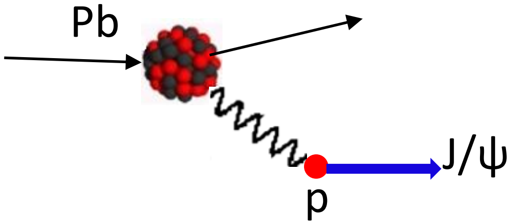
- Expected statistics in Run 3-4 (2/pb):

Yellow report on Run3-4: 1812.06772

lead-shine photons



Meson	σ	Total	$\|\eta\| < 0.9$	$-4 < \eta < -2.5$	$2.5 < \eta < 4$
$\rho \to \pi^+\pi^-$	35 mb	70 B	3.9 B	2.0 B	850 M
$\phi \to K^+K^-$	870 μb	1.7 B	65 M	22 M	9.7 M
$J/\psi \to \mu^+\mu^-$	6.2 μb	12 M	1.0 M	260 K	180 K
$\psi(2S) \to \mu^+\mu^-$	134 nb	270 K	22 K	6.0 K	3.2 K
$\Upsilon(1S) \to \mu^+\mu^-$	5.74 nb	11 K	1.1 K	310	41



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- Precision measurements on vector meson photoproduction off proton

Run3-4 projections in p-Pb UPC

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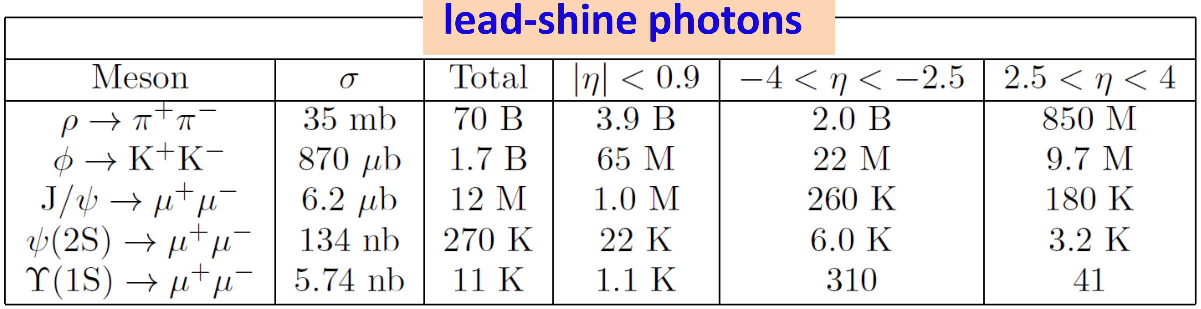

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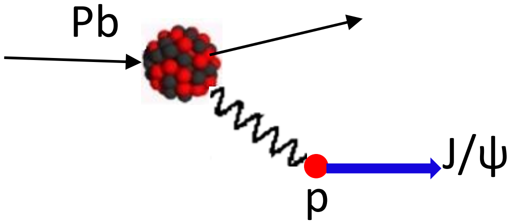
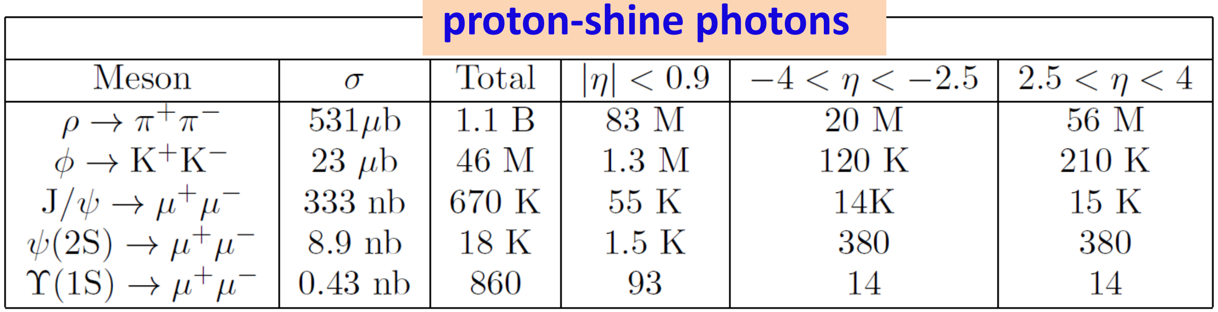


proton-shine photons



Meson	σ	Total	$\lvert\eta\rvert < 0.9$	$-4 < \eta < -2.5$	$2.5 < \eta < 4$
$\rho \to \pi^+\pi^-$	531μb	1.1 B	83 M	20 M	56 M
$\phi \to \mathrm{K}^+\mathrm{K}^-$	23 μb	46 M	1.3 M	120 K	210 K
$\mathrm{J}/\psi \to \mu^+\mu^-$	333 nb	670 K	55 K	14K	15 K
$\psi(2\mathrm{S}) \to \mu^+\mu^-$	8.9 nb	18 K	1.5 K	380	380
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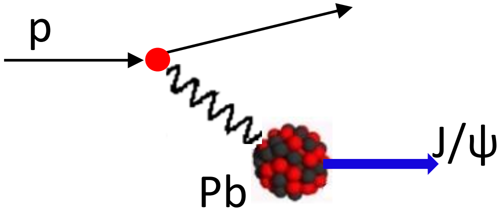

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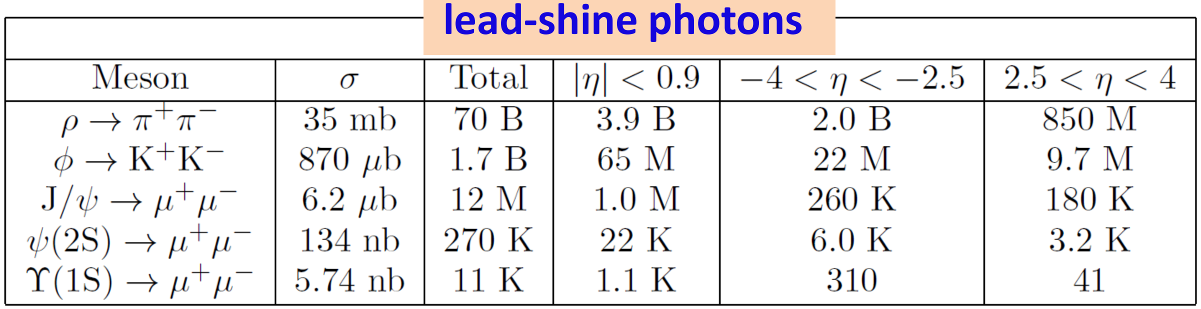
Yellow report on Run3-4: 1812.06772

lead-shine photons



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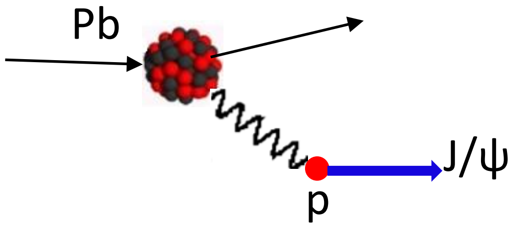

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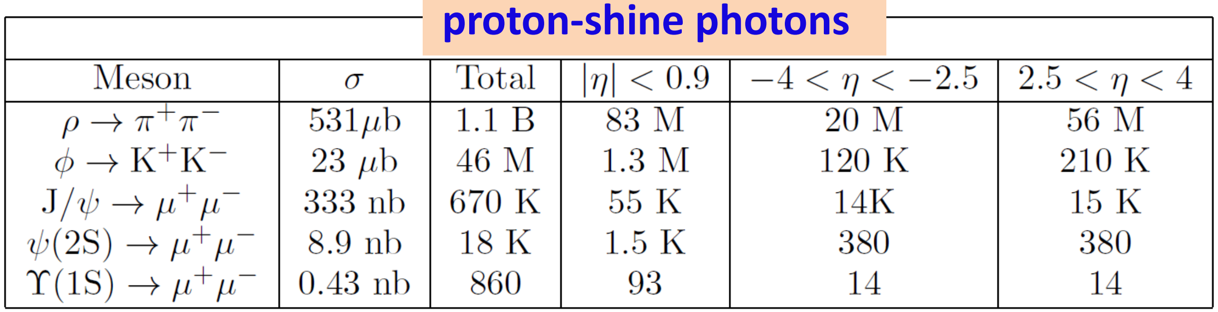

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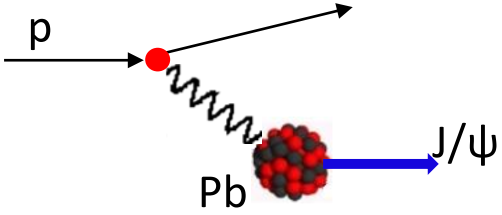
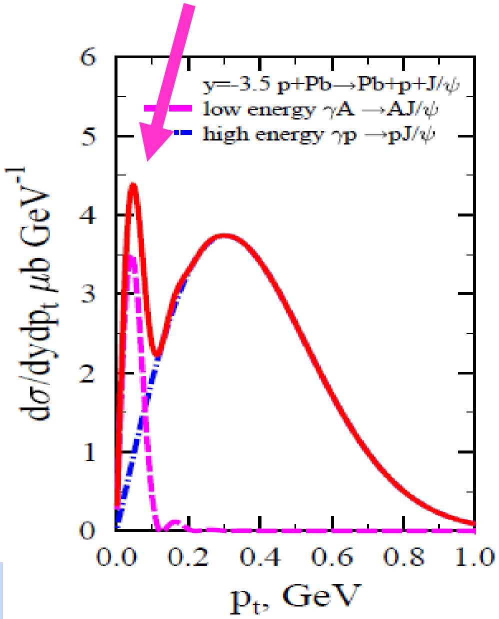




Main goals:

- Precision measurements on vector meson photoproduction off proton
- Access gluon shadowing at 10^{-5} with proton-shine gamma off lead

Guzey, Zhalov: JHEP 1402 (2014) 046

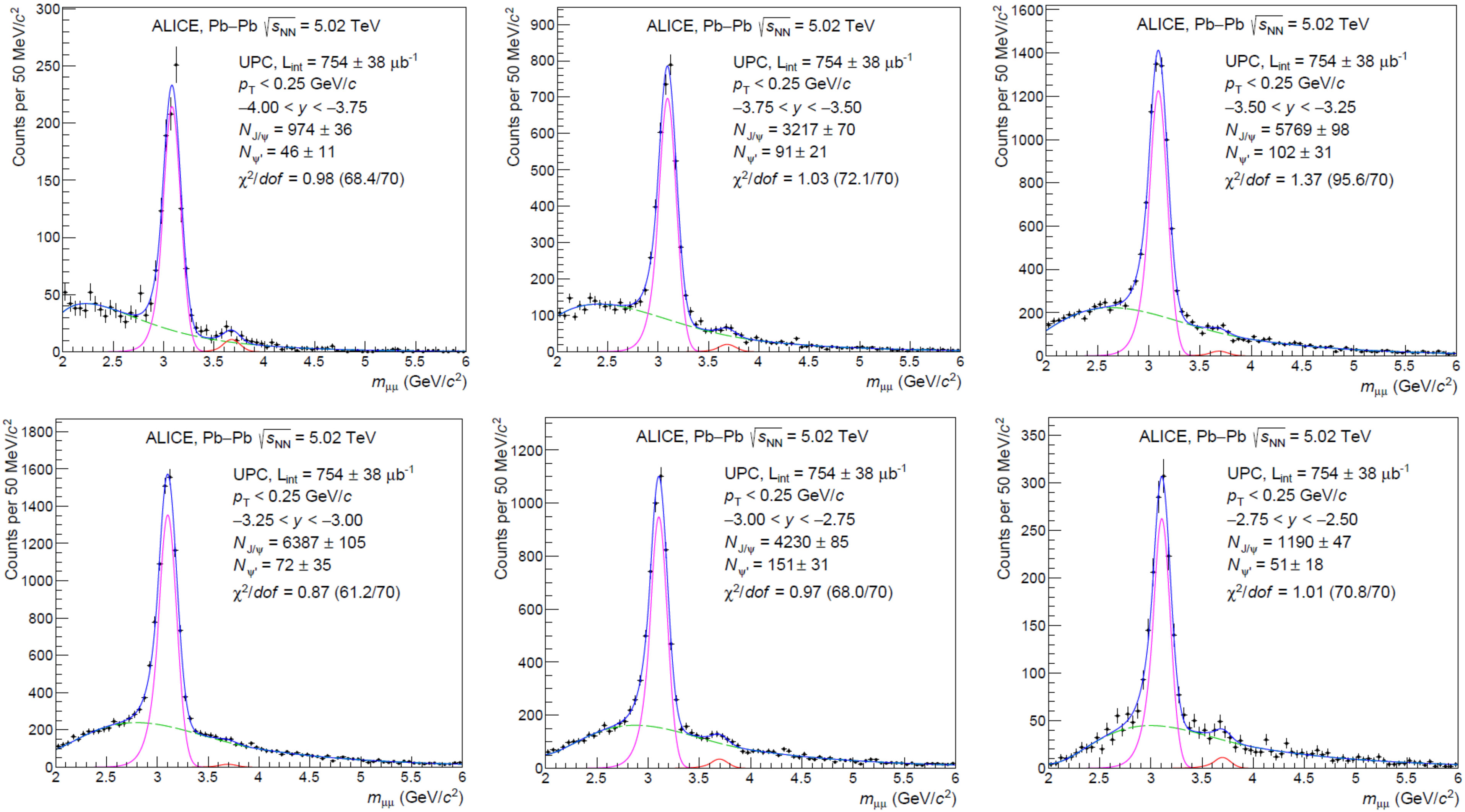
Summary and outlook

- **Shedding light on the partonic structure of protons and nuclei with UPCs:**
  - Exclusive J/ψ photoproduction shows no signs of gluon saturation well beyond HERA energies (down to x ~ 10^{-5})
  - New results on coherent J/ψ photoproduction cross section at forward rapidity in Pb-Pb at 5 TeV in agreement with moderate nuclear gluon shadowing scenario
  - Coherent ψ’-to-J/ψ cross section ratio consistent with the ratio measured in photoproduction off protons
- **Challenge: low-x vs high-x ambiguity and access to low-x gluon shadowing**
  - Vector meson photoproduction measurements accompanied by neutron emission
  - Coherent J/ψ in peripheral events – new tool to extract low-x gluon contributions?
  - Access gluon shadowing x~10^{-5} with proton-shine photons off lead in p-Pb collisions
- **Looking forward for high-precision measurements in Run3-4**

BACKUP

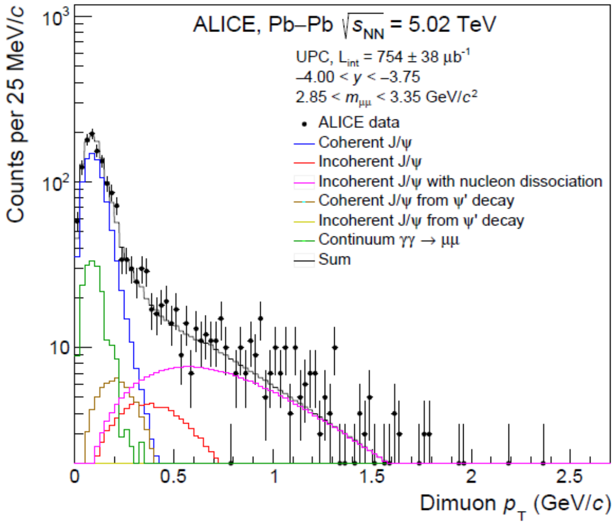
Invariant mass fits in rapidity bins

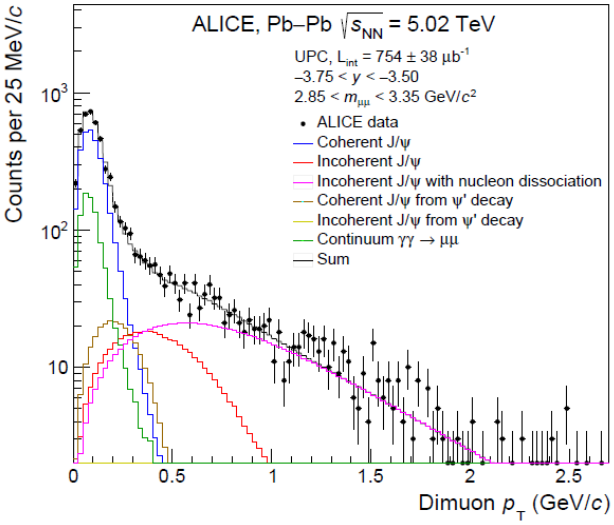
- Cross sections extracted in 6 rapidity bins

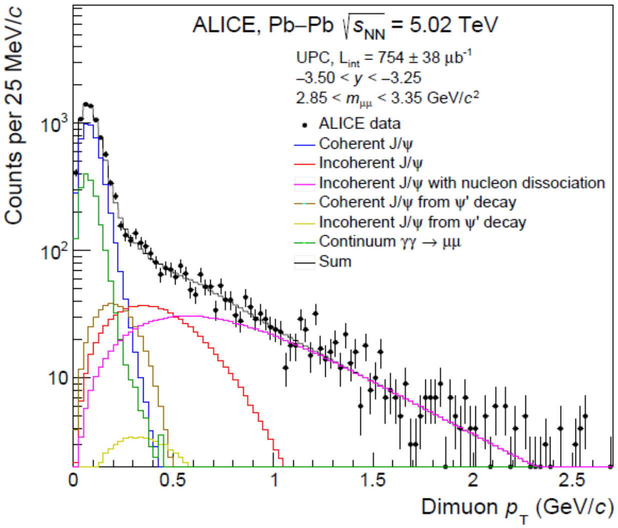


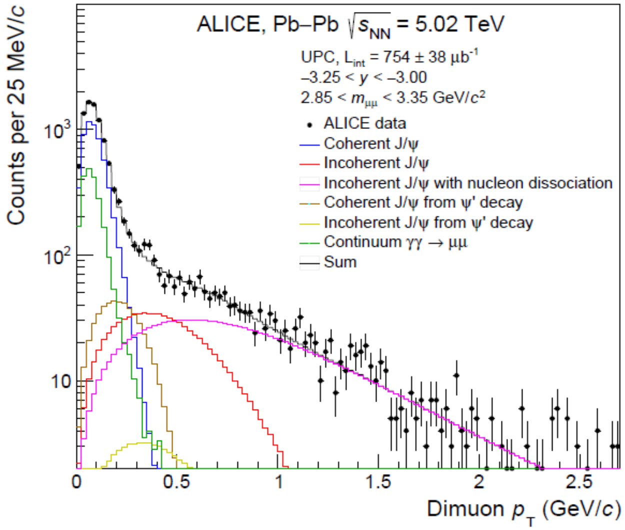
p_T fits in rapidity bins

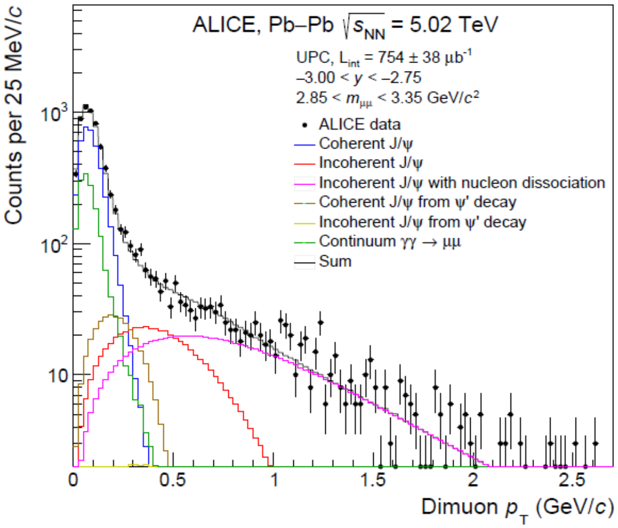
- Cross sections extracted in 6 rapidity bins

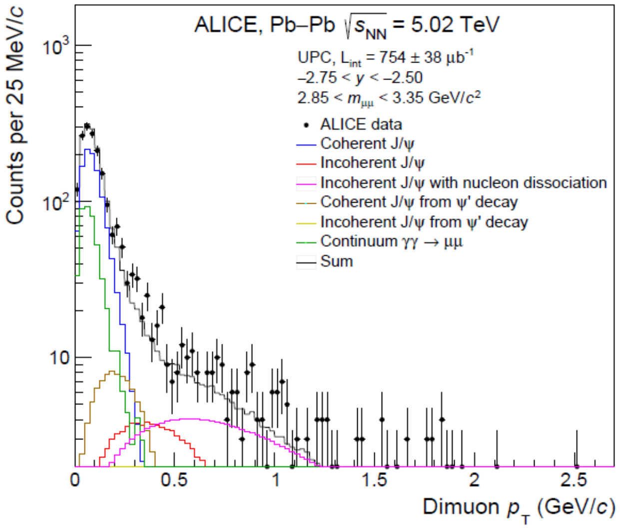




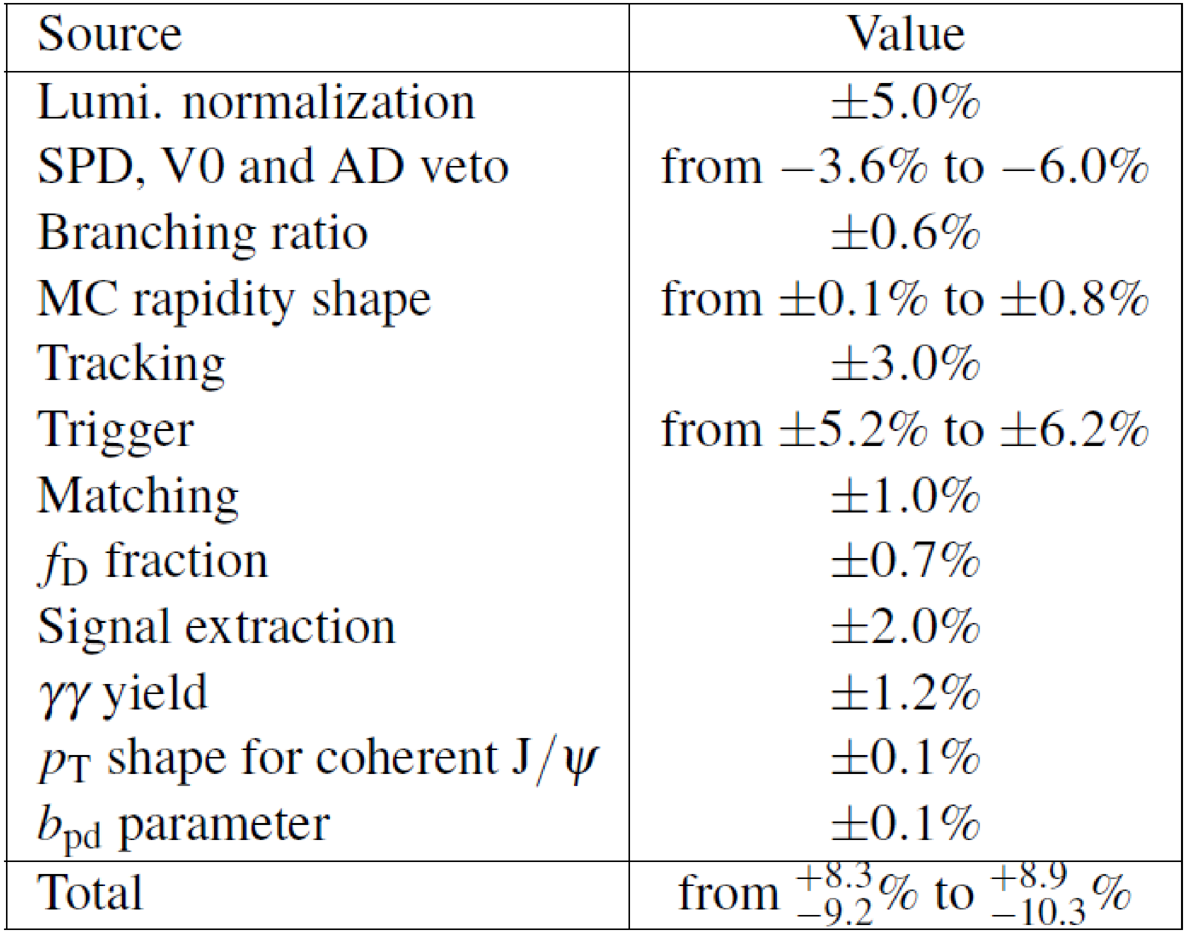








Systematic uncertainties



Source	Value
Lumi. normalization	±5.0%
SPD, V0 and AD veto	from −3.6% to −6.0%
Branching ratio	±0.6%
MC rapidity shape	from ±0.1% to ±0.8%
Tracking	±3.0%
Trigger	from ±5.2% to ±6.2%
Matching	±1.0%
f_D fraction	±0.7%
Signal extraction	±2.0%
$\gamma\gamma$ yield	±1.2%
p_T shape for coherent J/ψ	±0.1%
b_{pd} parameter	±0.1%
Total	from $^{+8.3}_{-9.2}$% to $^{+8.9}_{-10.3}$%

Using Glauber-based INEL cross section estimate

Due to analysis results with SPD tracklet veto

Due to MC-based vs data-driven technique to extract muon trigger turn-on

Variation of fD fraction within ψ’-to-J/ψ ratio uncertainty

ALICE, arXiv:1903.06272

EIC prospects