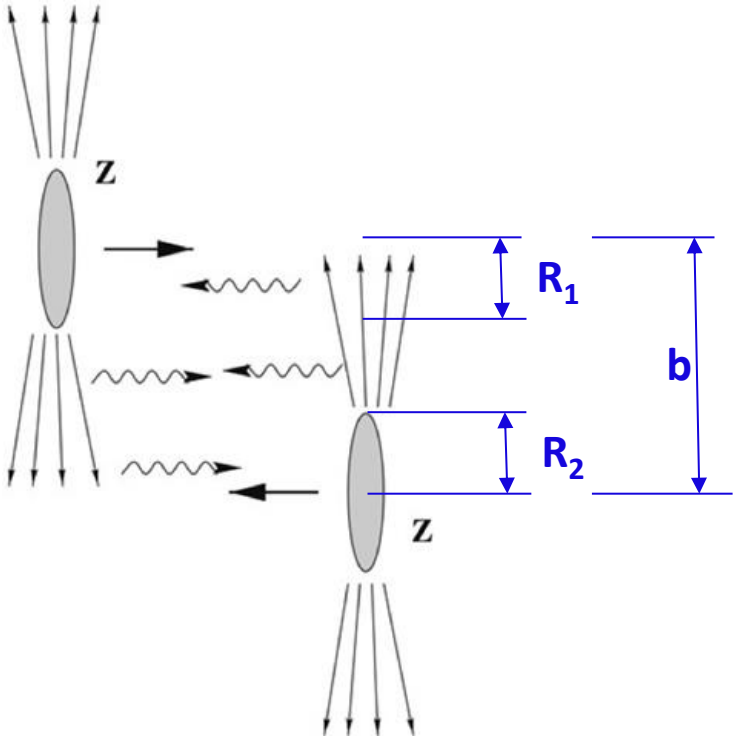
Overview of ALICE results on ultra-peripheral collisions

Evgeny Kryshen
for the ALICE collaboration

XXXVII International Workshop on High Energy Physics
“Diffraction of hadrons: Experiment, Theory, Phenomenology”
Protvino, 23 July 2025

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

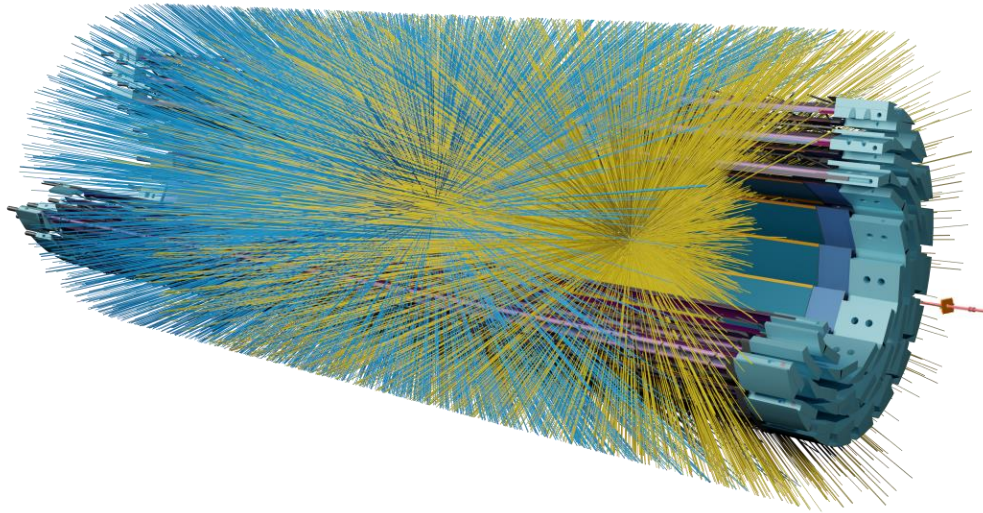
→ high cross section for γ-induced reactions

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

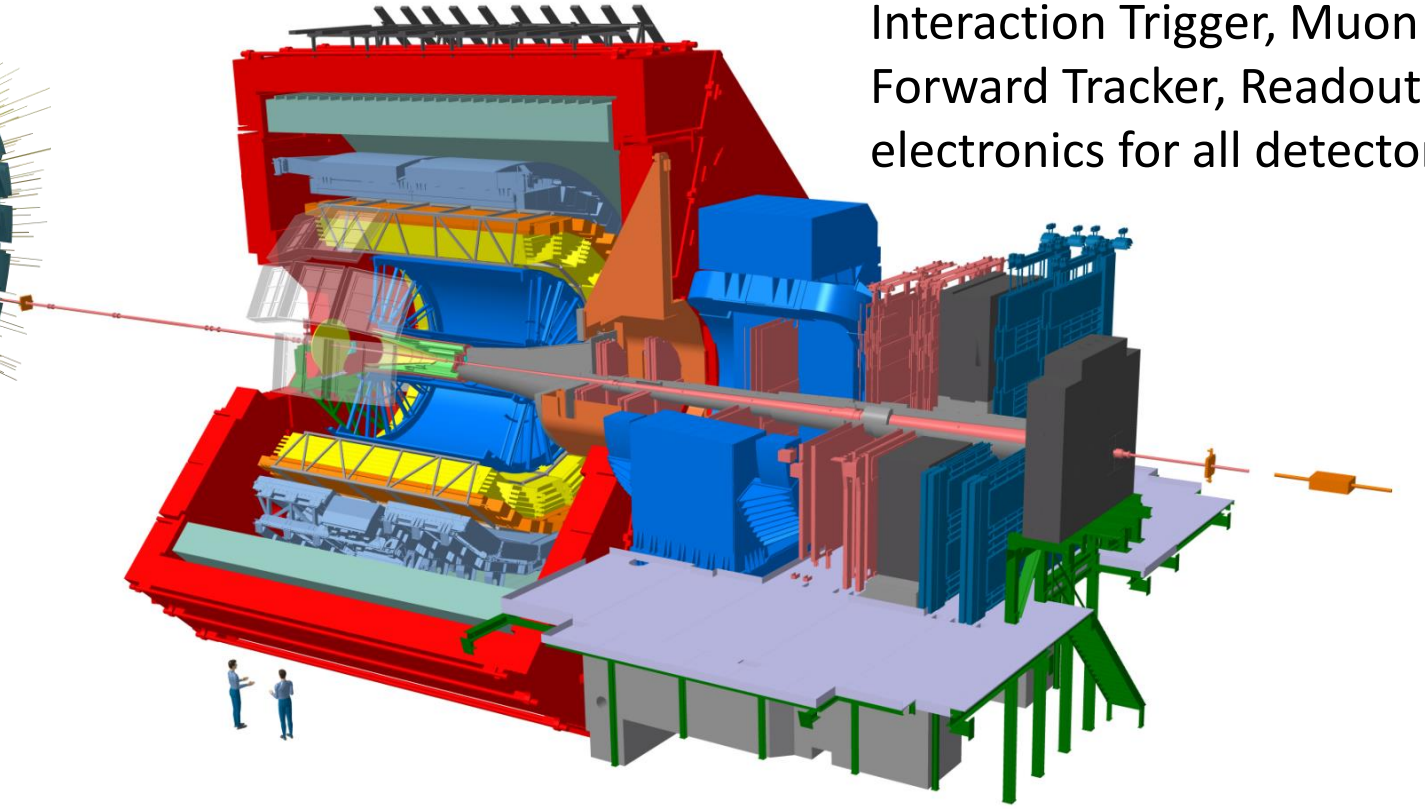
Recent reviews on UPC physics:
A.J. Baltz et al, Phys. Rept. 458 (2008) 1
J.G. Contreras, J.D. Tapia Takaki. Int.J.Mod.Phys. A30 (2015) 1542012
S.Klein and P. Steinberg, Ann. Rev. Nuclear Part. Sci. 70 (2020) 323

ALICE in Run 3

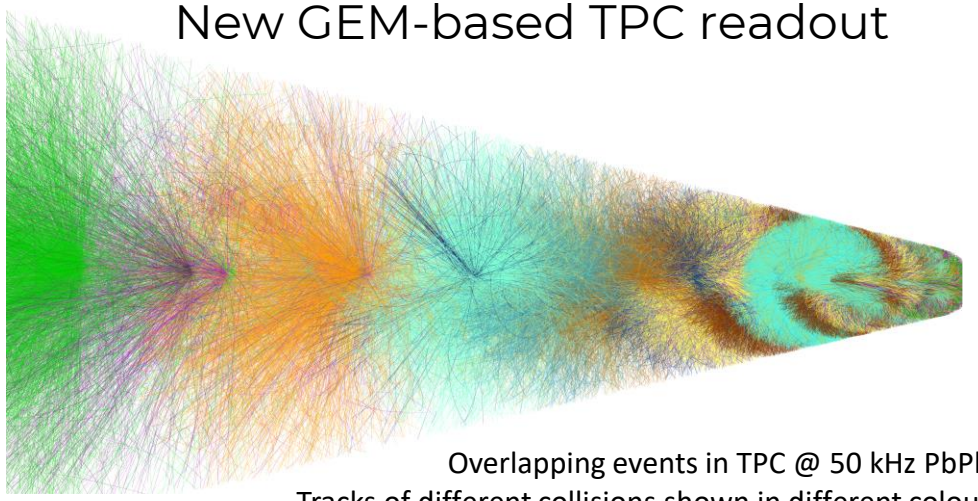
All-pixel Inner Tracking System



Massive upgrade: ITS, TPC, Fast Interaction Trigger, Muon Forward Tracker, Readout electronics for all detectors…

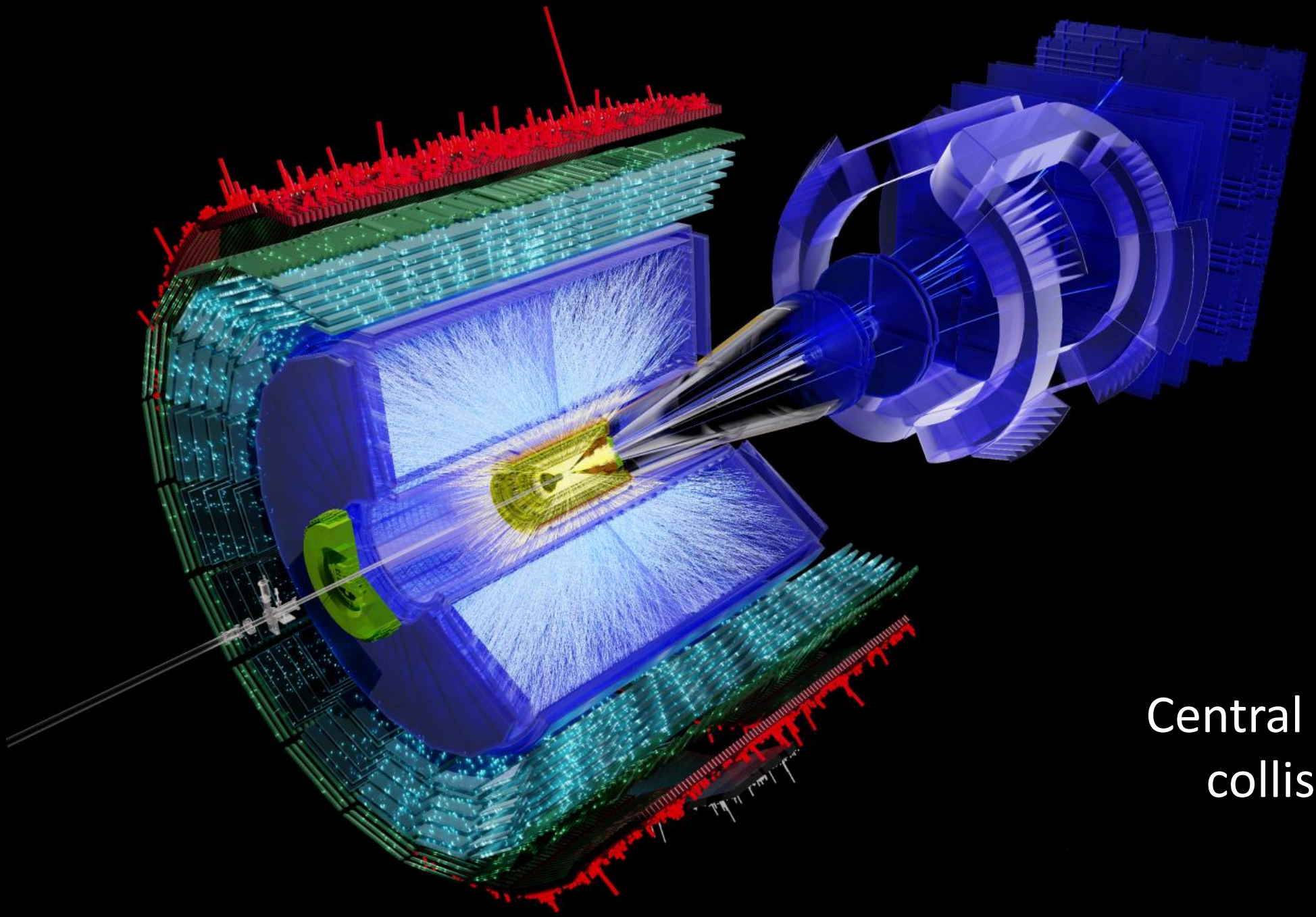


New GEM-based TPC readout

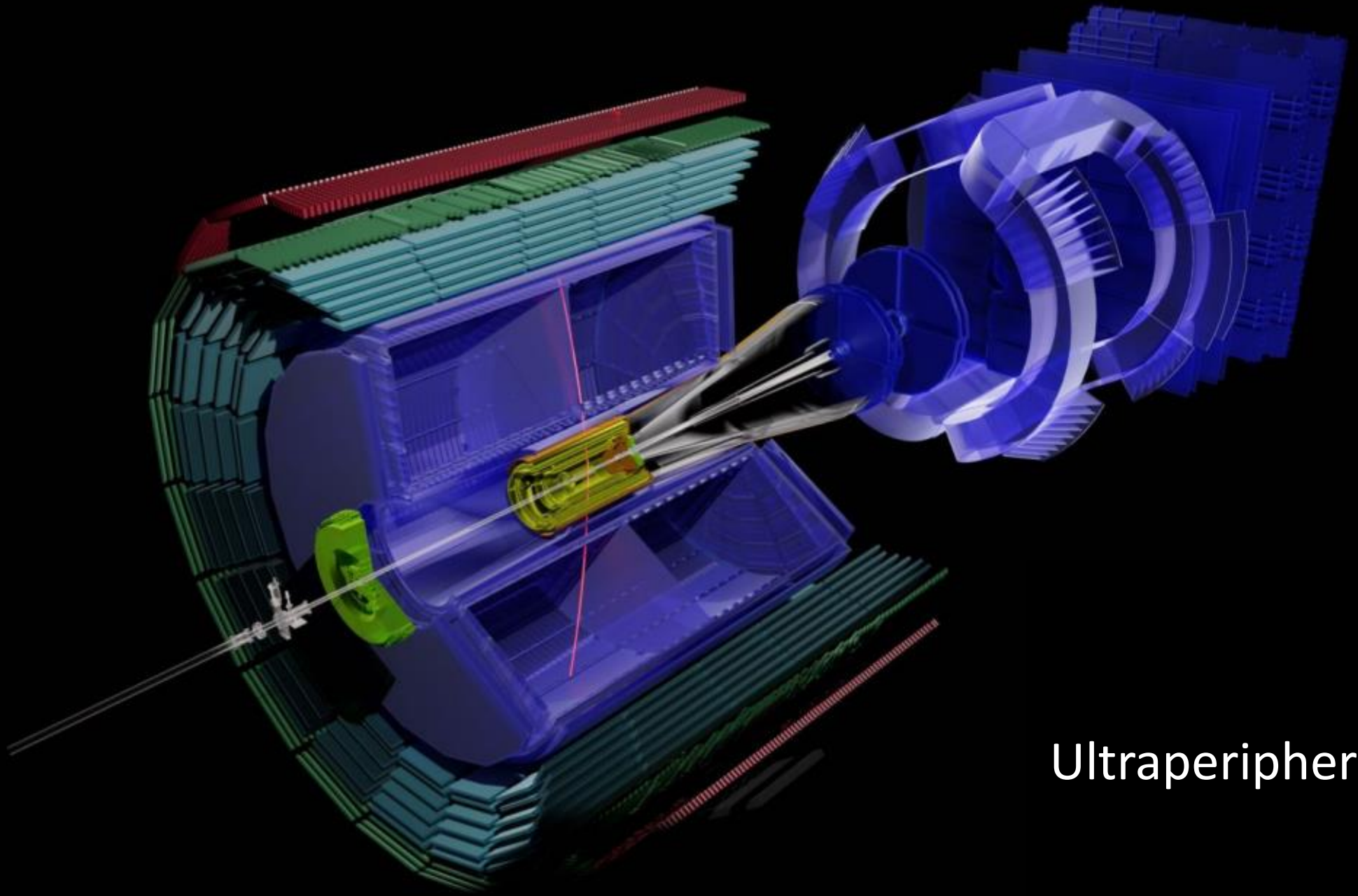


Overlapping events in TPC @ 50 kHz PbPb
Tracks of different collisions shown in different colour

- Running in continuous readout mode:
  up to 50 kHz in Pb–Pb and 500-1000 kHz in pp
- Data harvest in Run 3:
  - Pb–Pb: ~3 nb^{-1} (24B collisions) all data is kept!
  - pp: ~82 pb^{-1} using software-based selection

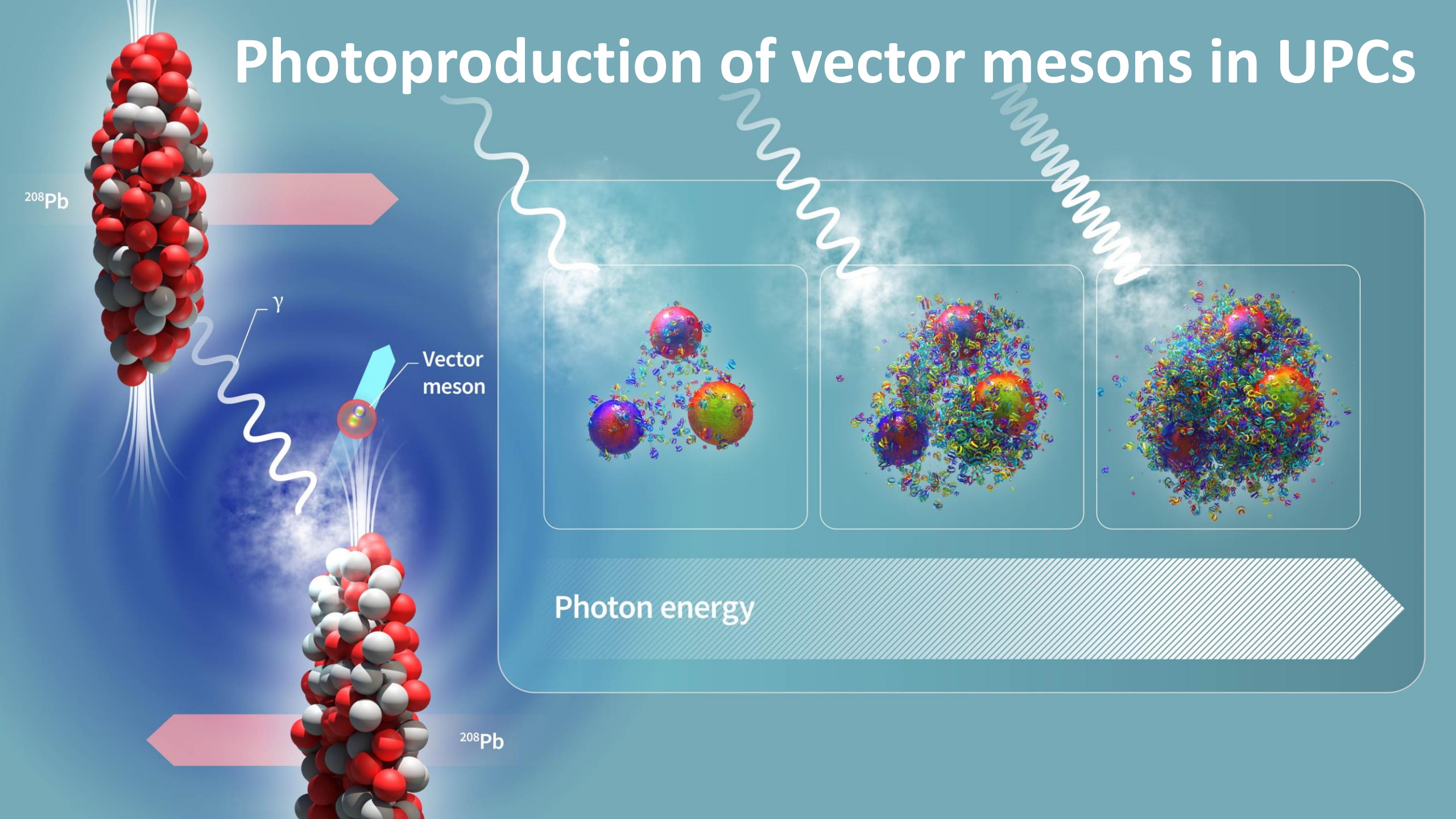


Central Pb-Pb collision



Ultraperipheral collision

Photoproduction of vector mesons in UPCs



Photoproduction of heavy vector mesons in UPCs

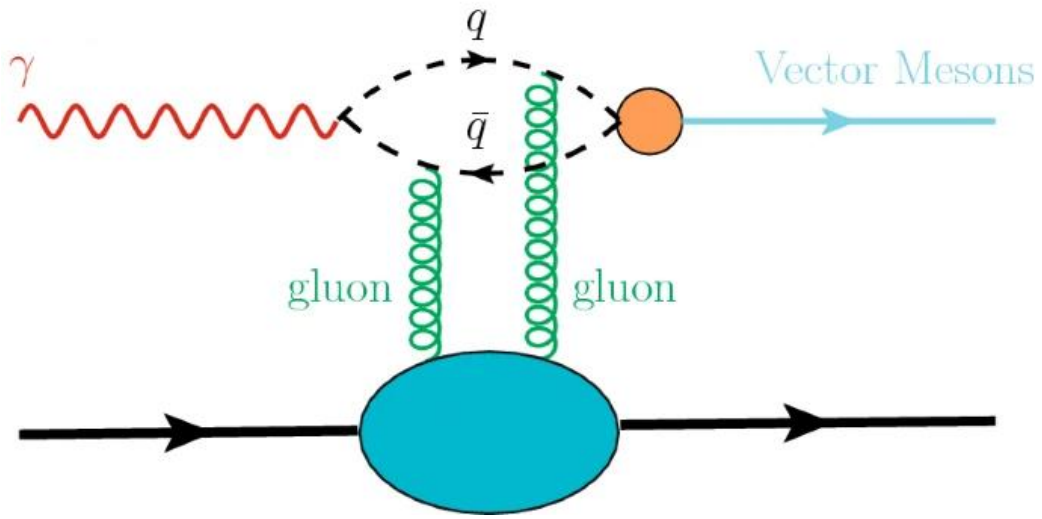
Exclusive heavy vector meson photoproduction is proportional to squared gluon density in the LO:

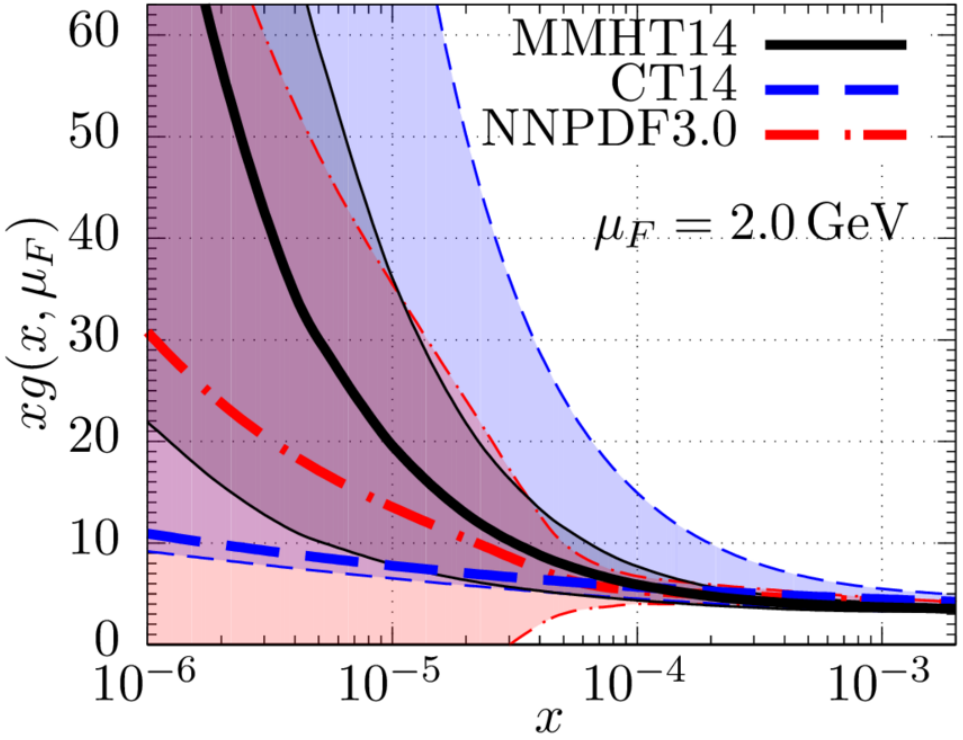
Ryskin: Z. Phys. C 57 (1993) 89

$$\left.\frac{\mathrm{d}\sigma_{\gamma p\to Vp}(W_{\gamma\mathrm{p}})}{\mathrm{d}t}\right|_{t=0} = \frac{\pi^3\Gamma_{ee}m_V^3}{48\alpha\mu^8}\alpha_s^2(\mu^2)[xg_p(x,\mu^2)]^2$$

For J/ψ:

$$\mu^2 = \tfrac{1}{4}m_{\mathrm{J}/\psi}^2 \sim 2.5\,\mathrm{GeV}^2 \qquad x = \frac{M_{J/\psi}^2}{W_{\gamma p}^2}$$ ~ 10^{-2} – 10^{-5} at LHC

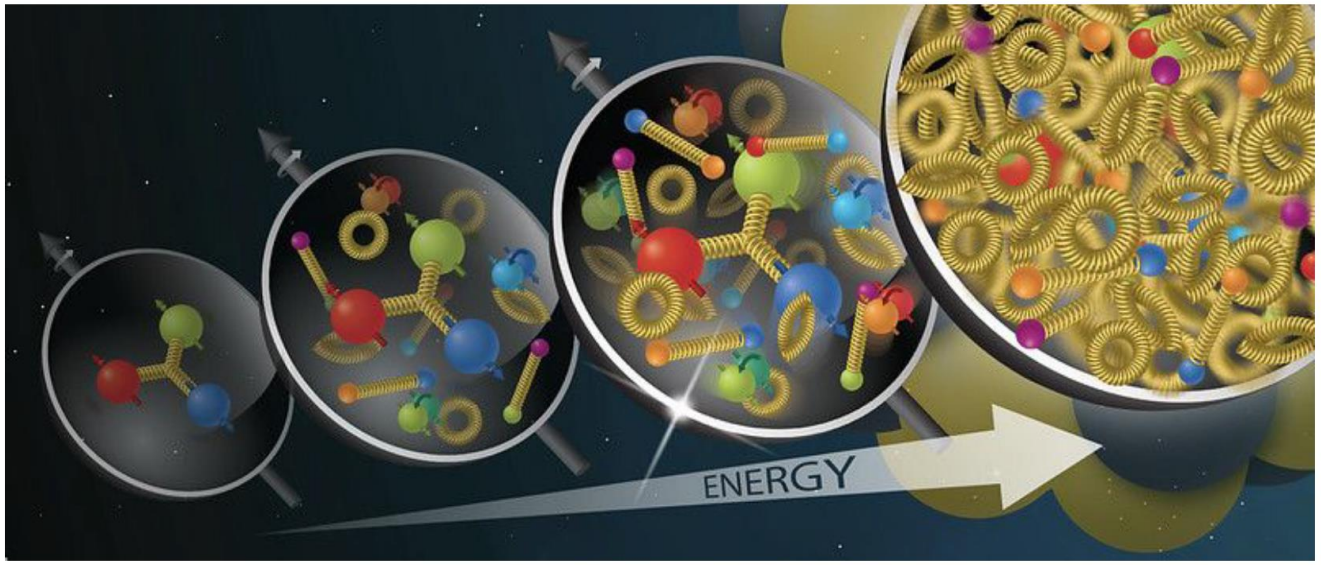




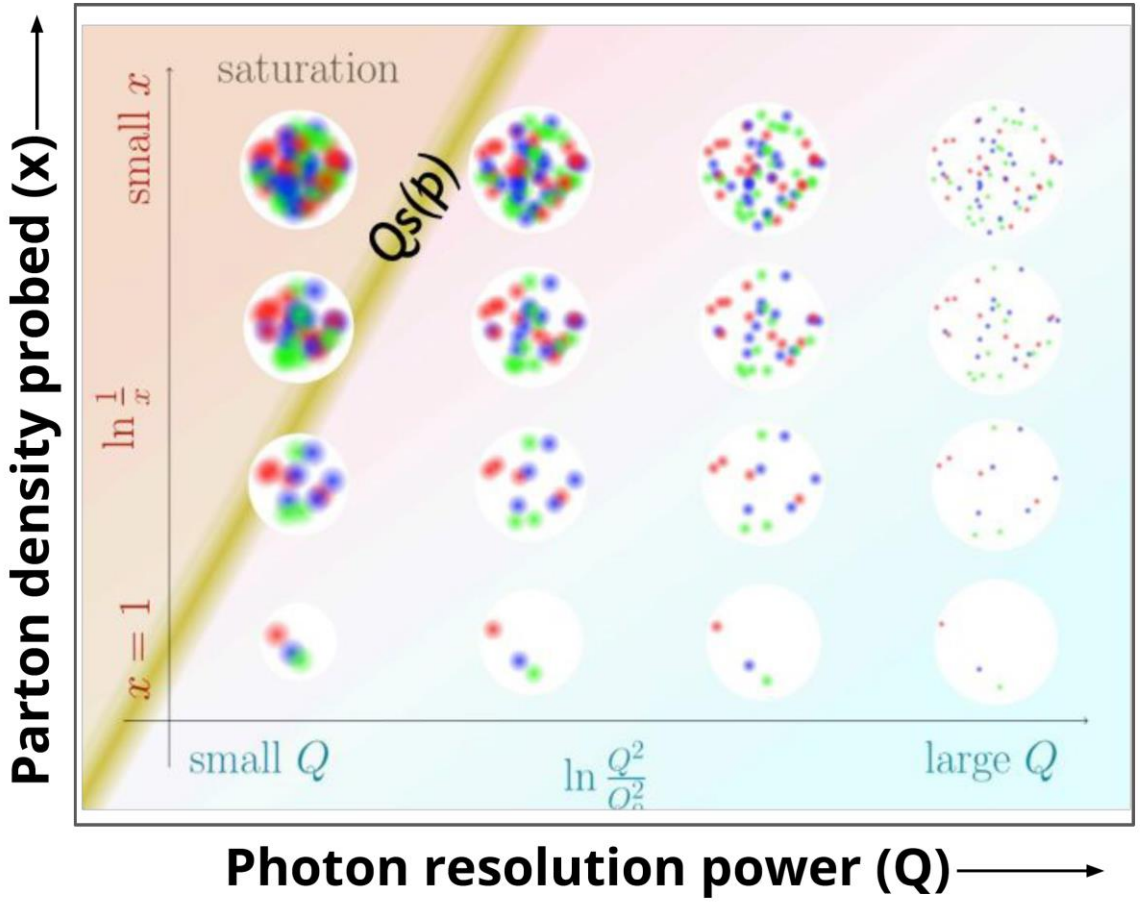
Oliveira, Martin, Ryskin, PRD 97(2018) 074021

Photoproduction of vector mesons can be used to probe gluon PDFs at low Bjorken-*x*

Saturation of gluon density



Smaller x



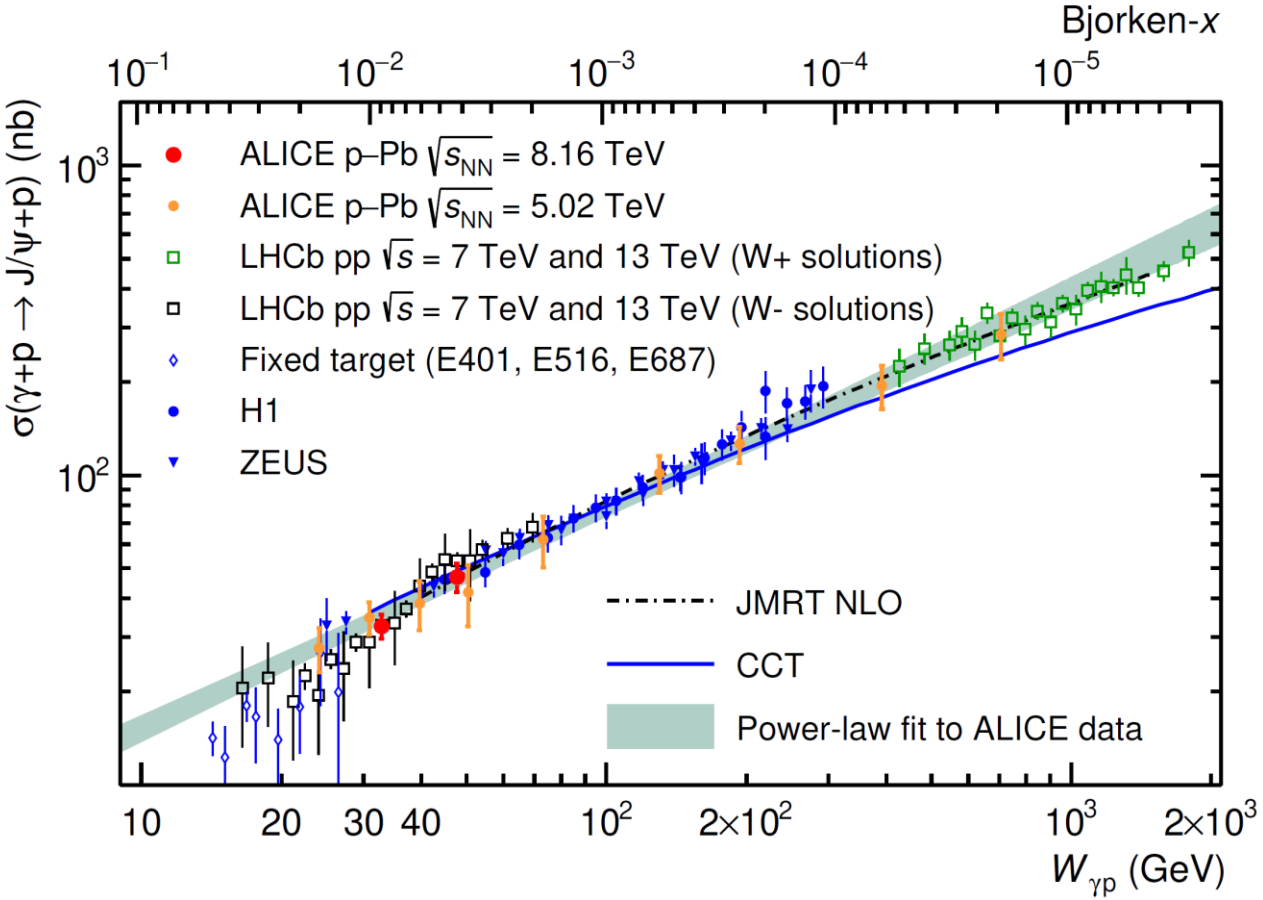
Power-law growth of gluon density is expected to saturate at low Bjorken-*x*

→Slow-down of vector meson cross section growth at high energy?

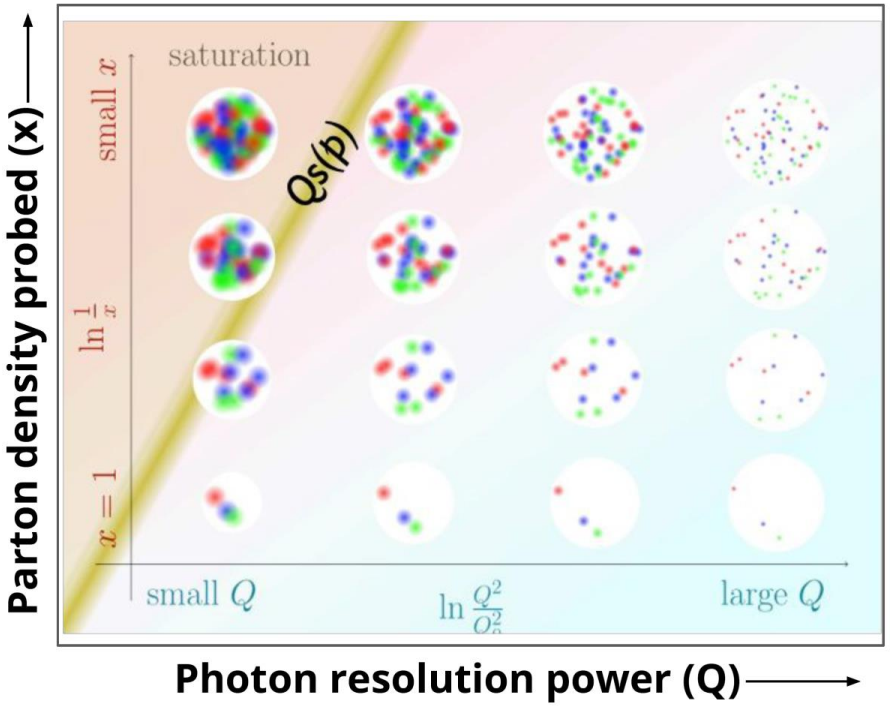
Exclusive J/ψ photoproduction of proton (p-Pb UPCs)

ALICE: PRL 113 (2014) 232504
ALICE: EPJC 79 (2019) 402
ALICE: PRD 108 (2023) 112004

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



$$\sigma_{\gamma p \to J/\psi p}(W_{\gamma p}) = \frac{1}{n_\gamma(y)}\frac{\mathrm{d}\sigma_{\mathrm{pPb}\to\mathrm{pPb}J\psi}(y)}{\mathrm{d}y}$$

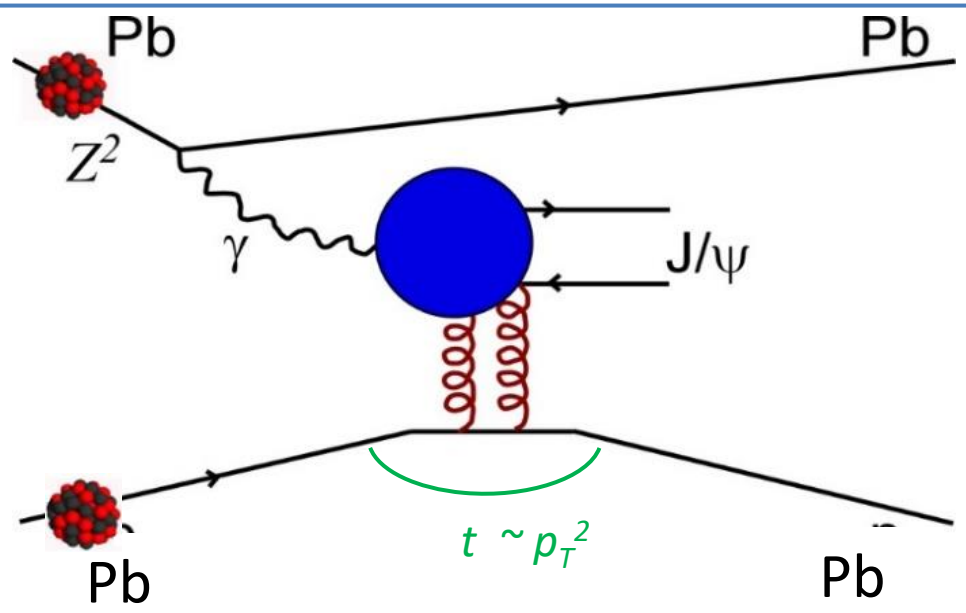


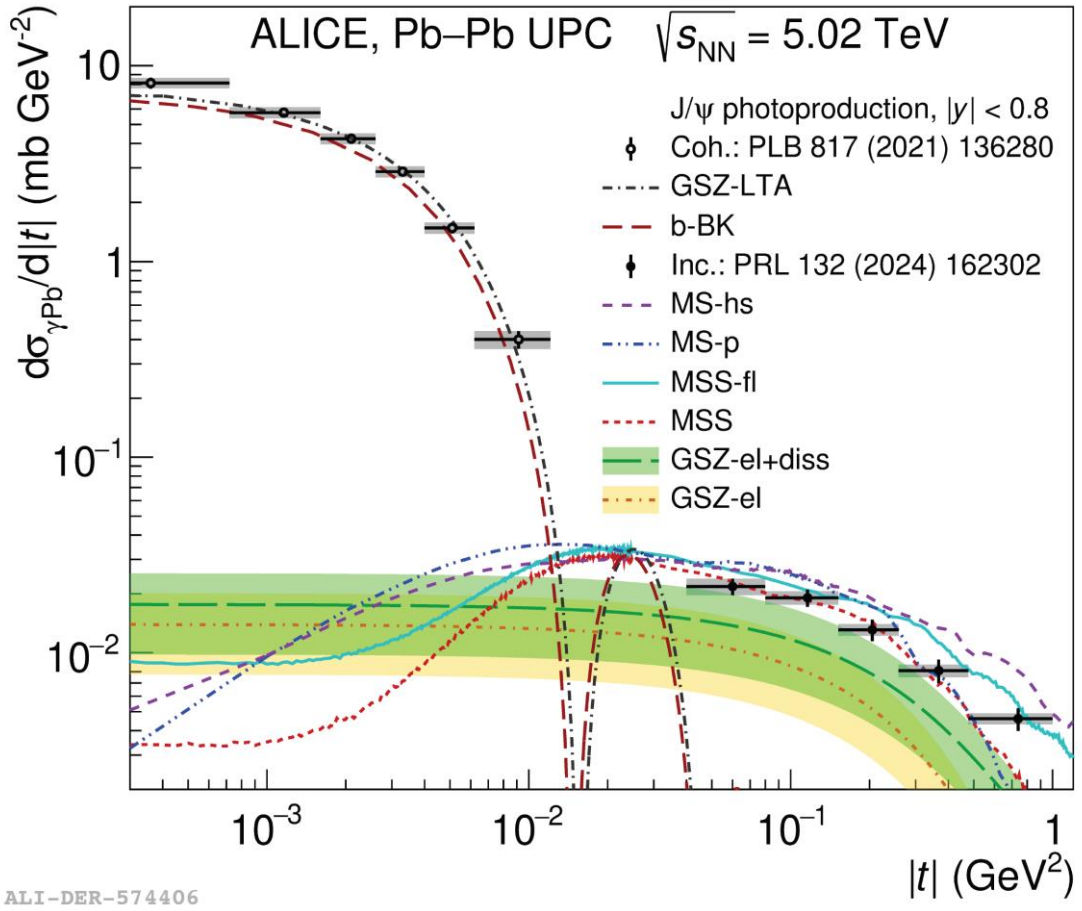
- Agreement with H1 and ZEUS at moderate energies
- Agreement with LHCb (pp collisions)
- Measurements well described by power-law:

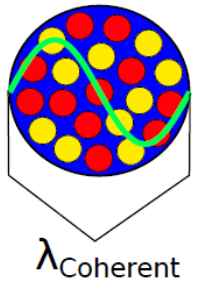
$$\sigma_{\gamma p \to J/\psi p} \sim W_{\gamma p}^{\delta} \qquad \delta = 0.70 \pm 0.04$$

- No clear signs of saturation

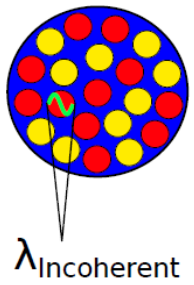
Coherent and incoherent photoproduction in Pb-Pb







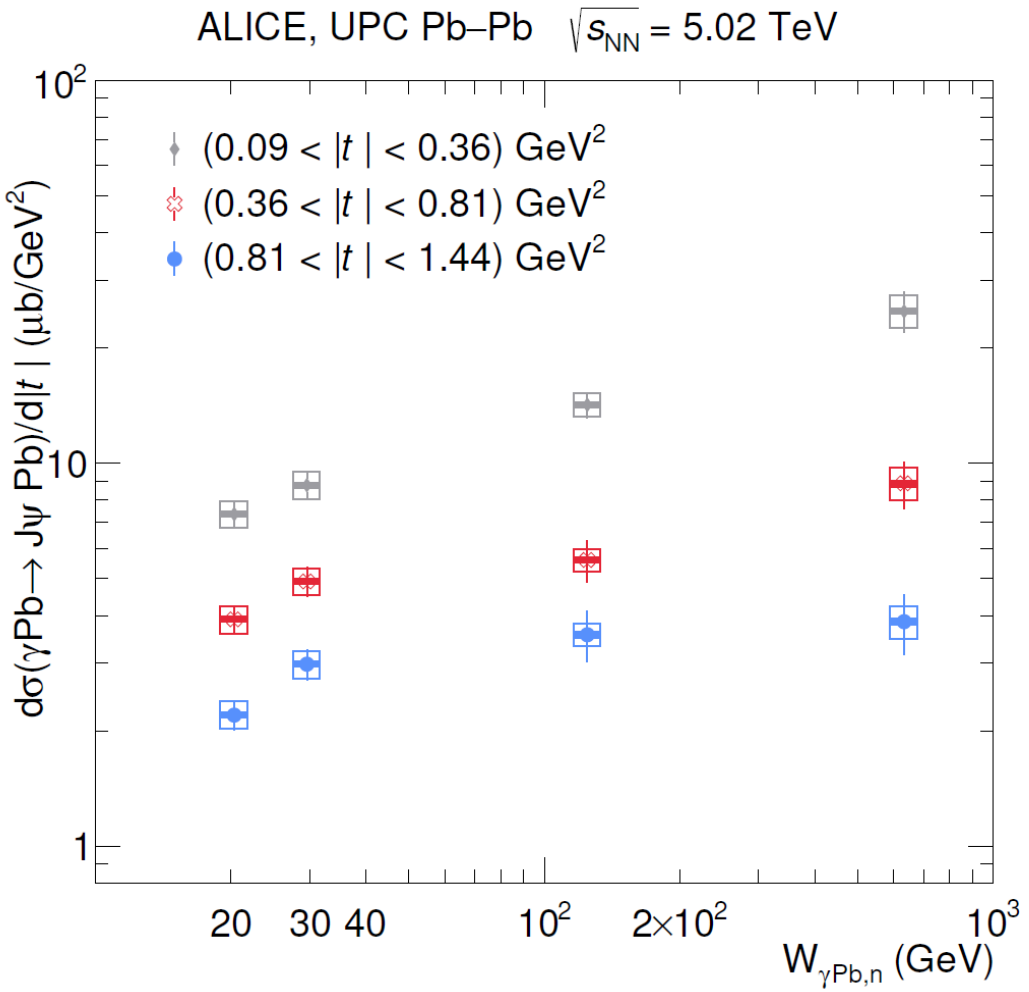
- **Coherent:**
  - Coherent interaction with the whole nucleus
  - $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
  - exclusive process

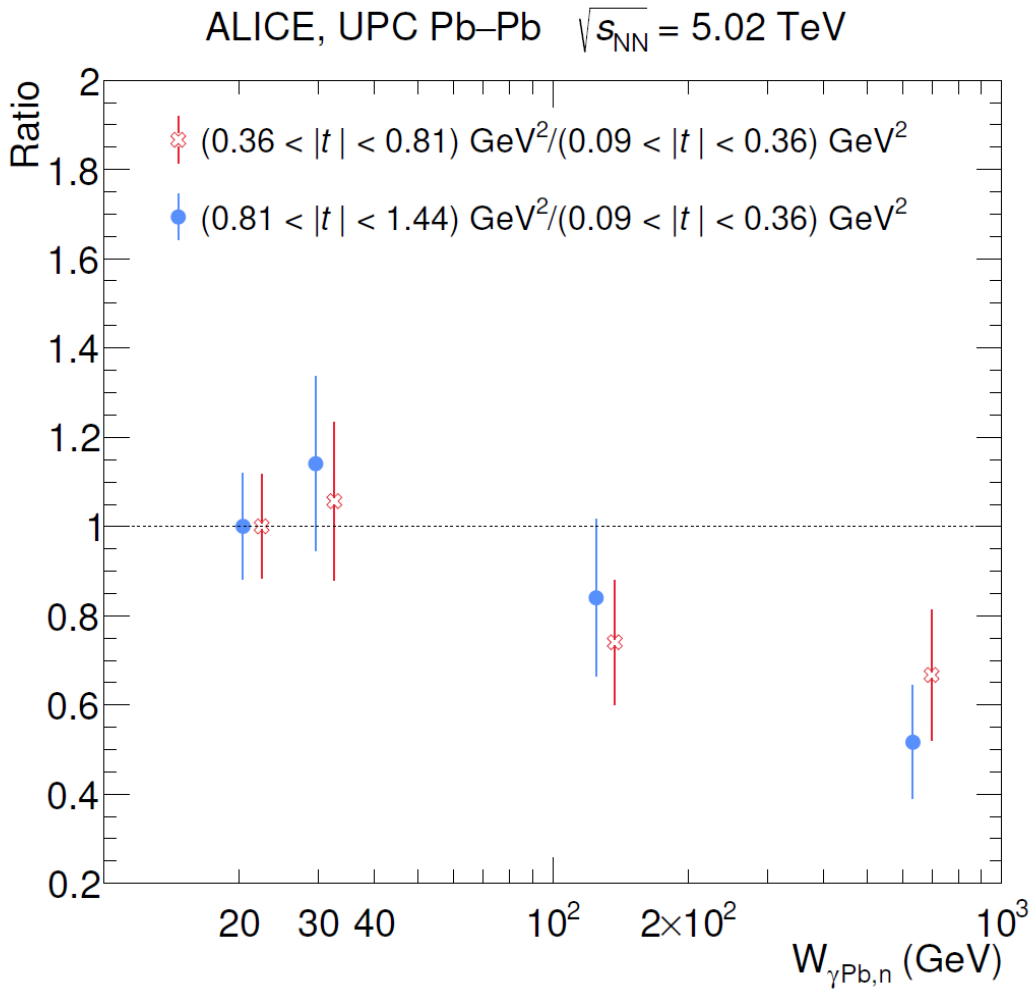


- **Incoherent:**
  - Interaction with single nucleons or subnucleon structures
  - $\langle p_T \rangle \sim 1/R_p \sim 450$ MeV/c
  - Breakup of the target nucleus

Incoherent photoproduction vs energy and |t|

ALICE, arXiv: 2503.18708

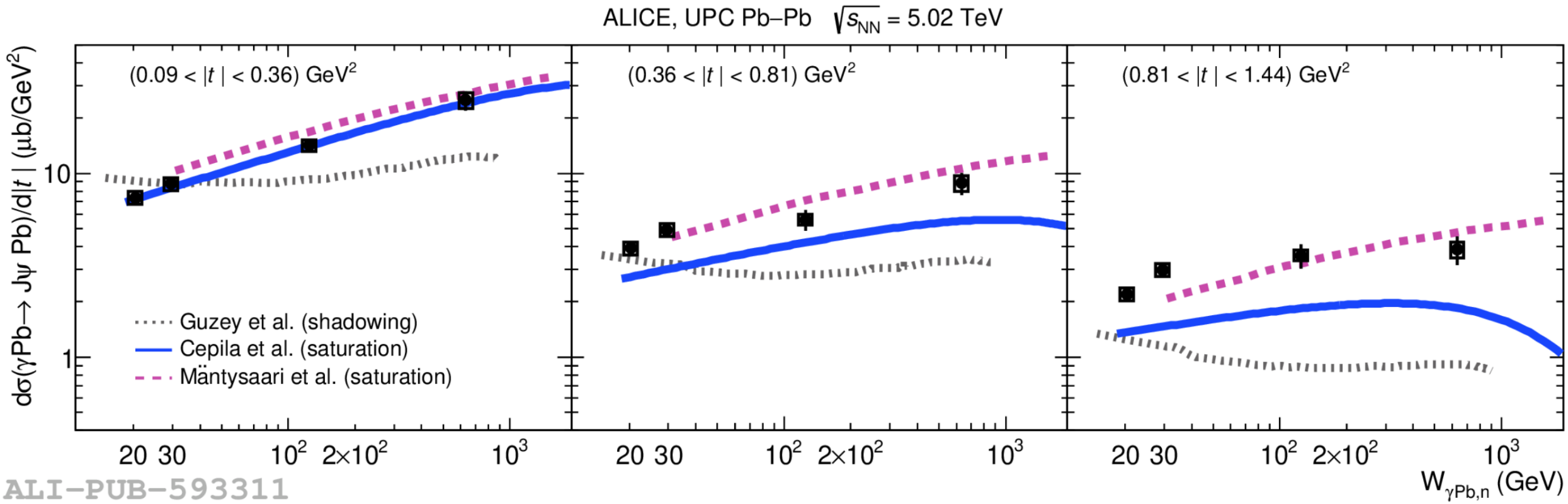




- Incoherent photoproduction measured as a function of energy and |t|
- Significant suppression at high energy and large |t| values

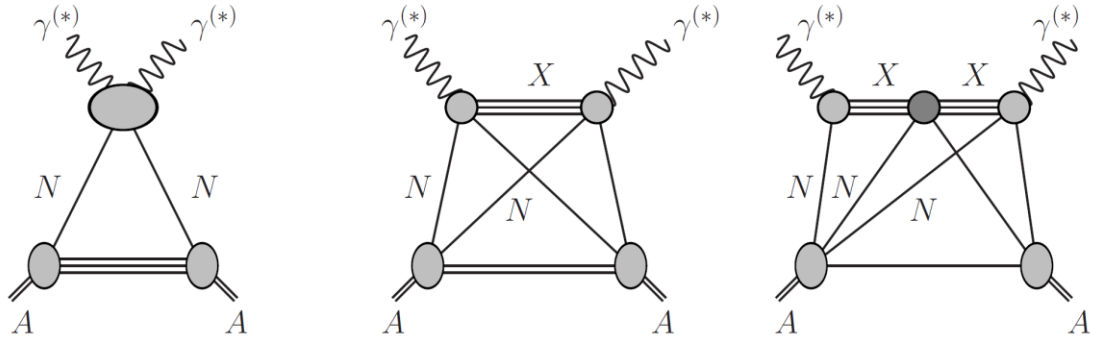
Incoherent photoproduction: signs of saturation?

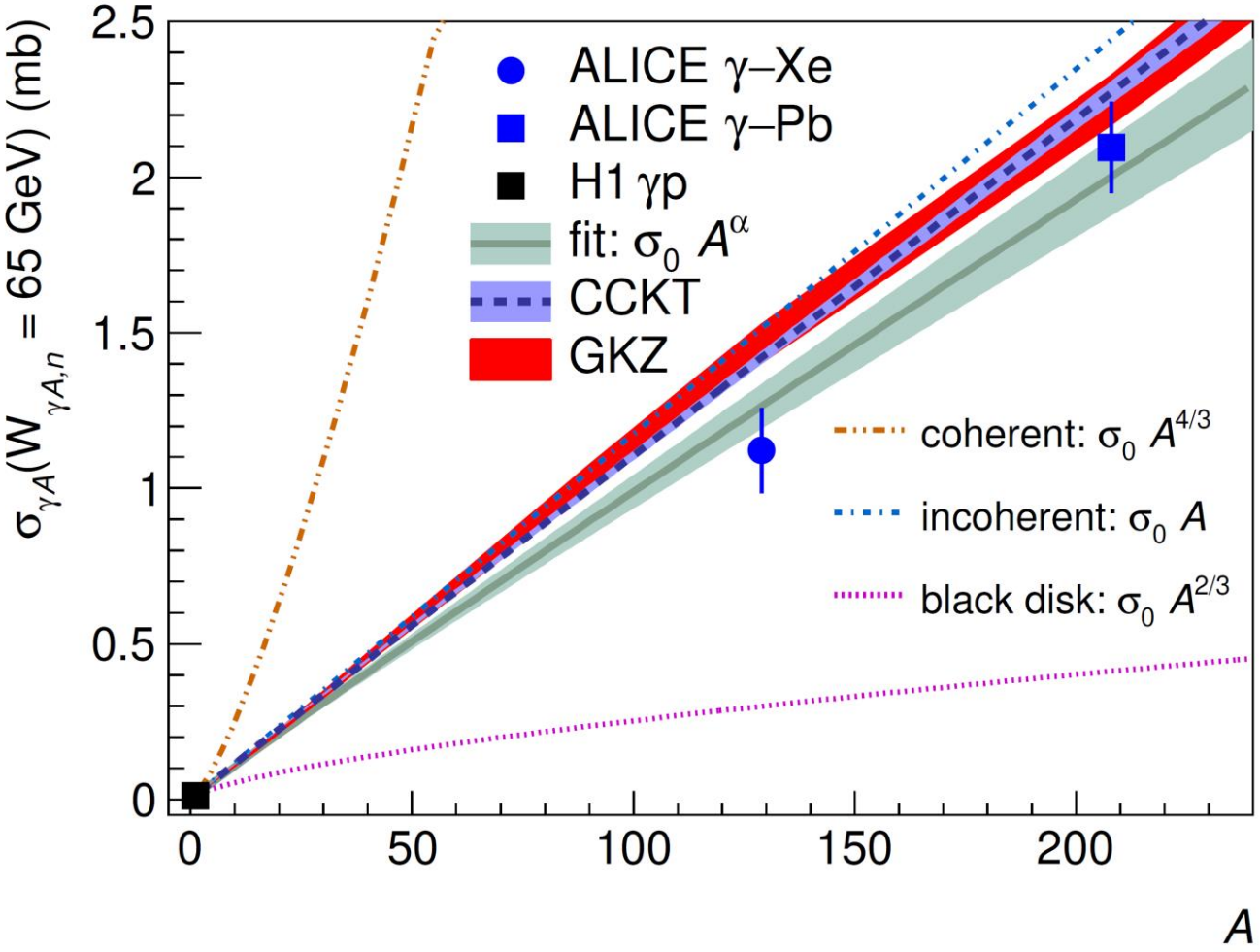
ALICE, arXiv: 2503.18708



- Saturation models tend to catch the observed trend

Coherent ρ^0 photoproduction

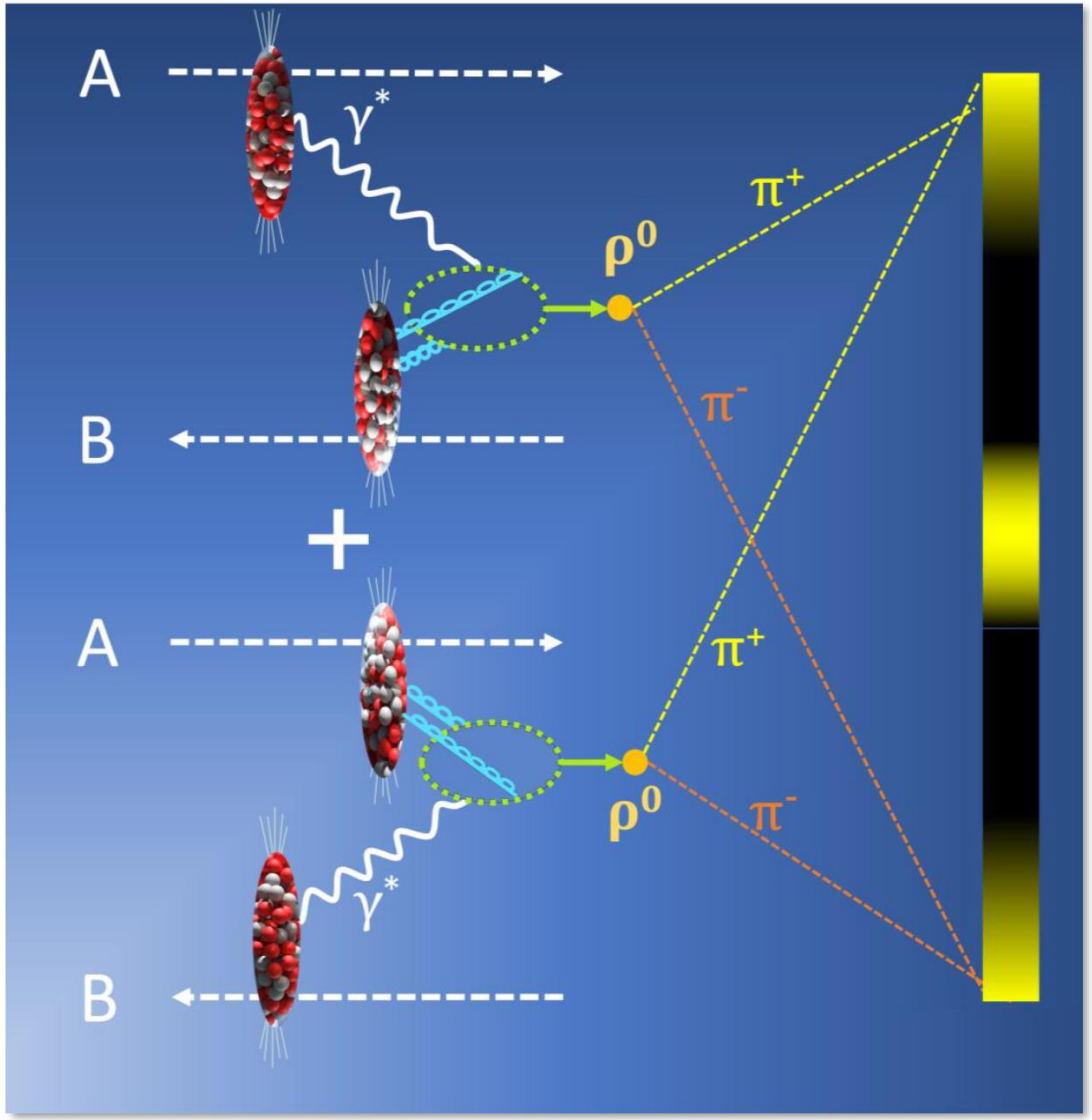




- Probing nuclear shadowing / saturation at semi-hard scales
- Strong suppression measured both in Xe-Xe and Pb-Pb collisions
- A-dependence $\sigma \sim A^{\alpha}$:
  - $\alpha = 4/3$ in case of no nuclear effects
  - $\alpha = 0.96 \pm 0.02$ – measured
- Just collected O-O and Ne-Ne data → new measurements expected soon

ALICE, PLB 820 (2021) 136481

Interference effects in ρ^0 photoproduction



- In UPCs, each nucleus can act as the source of the photon or as the target in the interaction

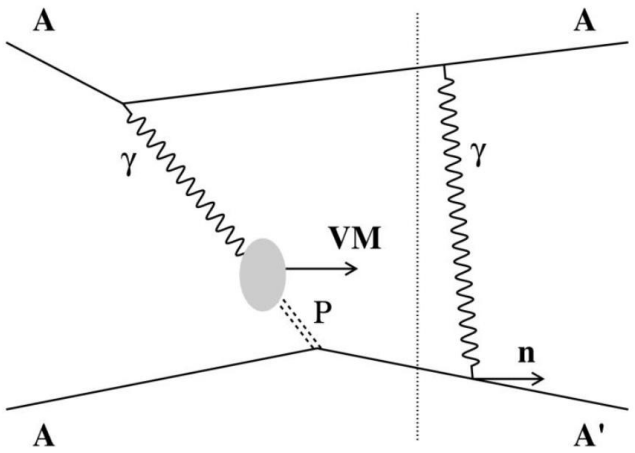
  → two indistinguishable amplitudes contribute to the cross section

- At midrapidity the coherent ρ photoproduction cross section reads:

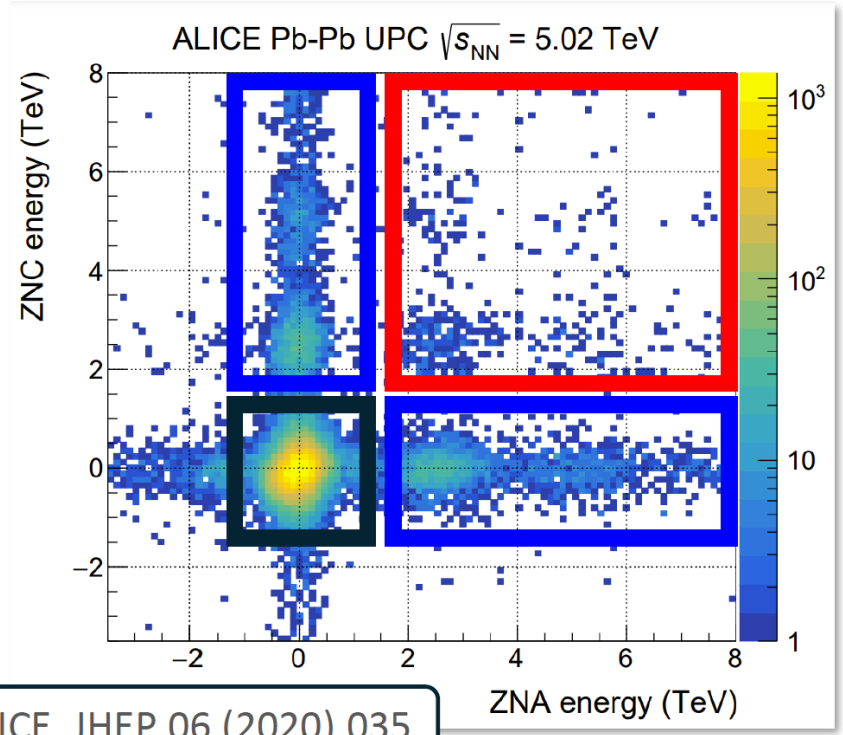
$$\sigma(p_T, b, y = 0) = \left| A(p_T, b) - A(p_T, b)\, e^{i\vec{p}\cdot\vec{b}} \right|^2$$

ALICE, PLB 858 (2024) 139017

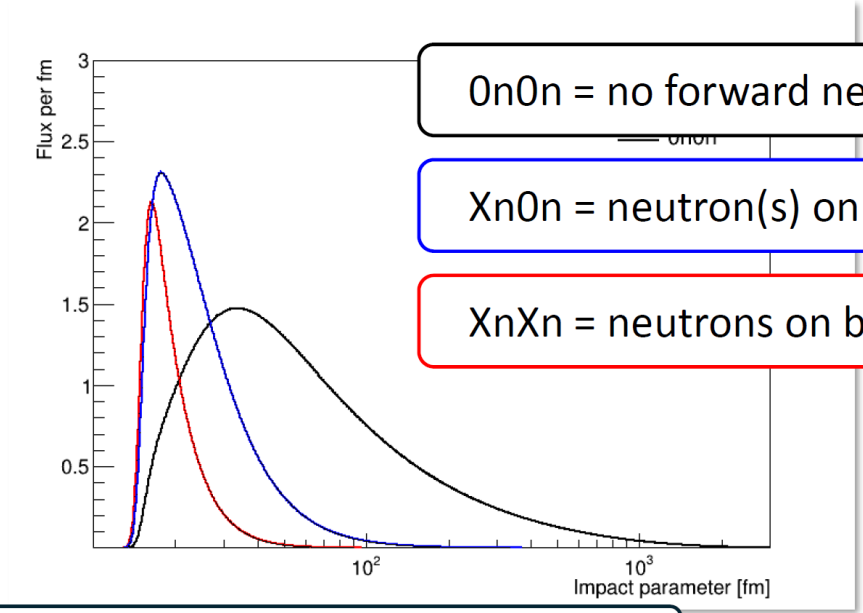
How to select impact parameter ranges?



- Events are classified in different EMD classes using neutron detection in ZDCs
- Different mean impact parameters in different classes



ALICE, JHEP 06 (2020) 035



0n0n = no forward neutron

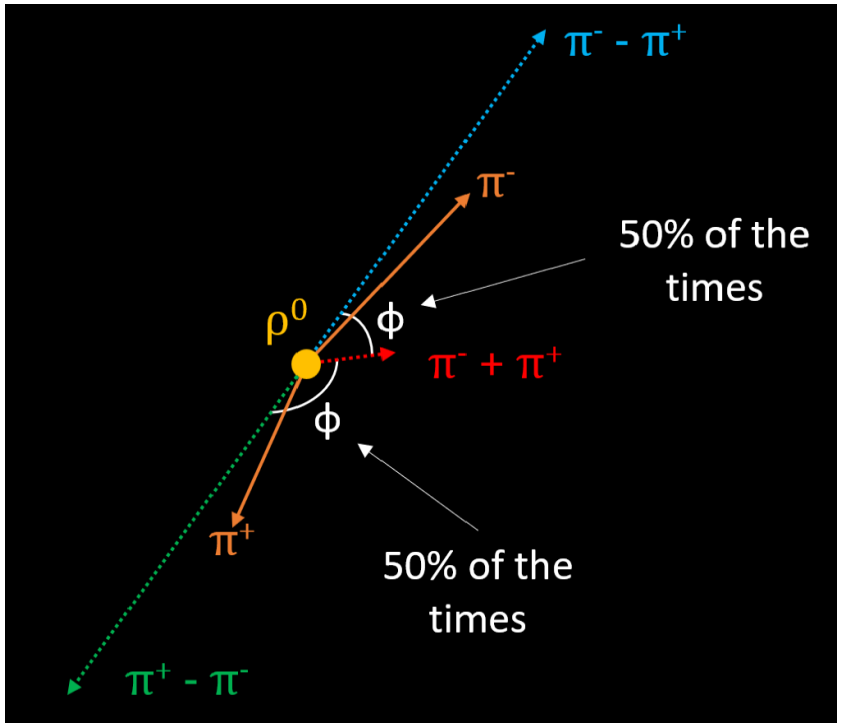
Xn0n = neutron(s) on one side of the IP

XnXn = neutrons on both sides of the IP

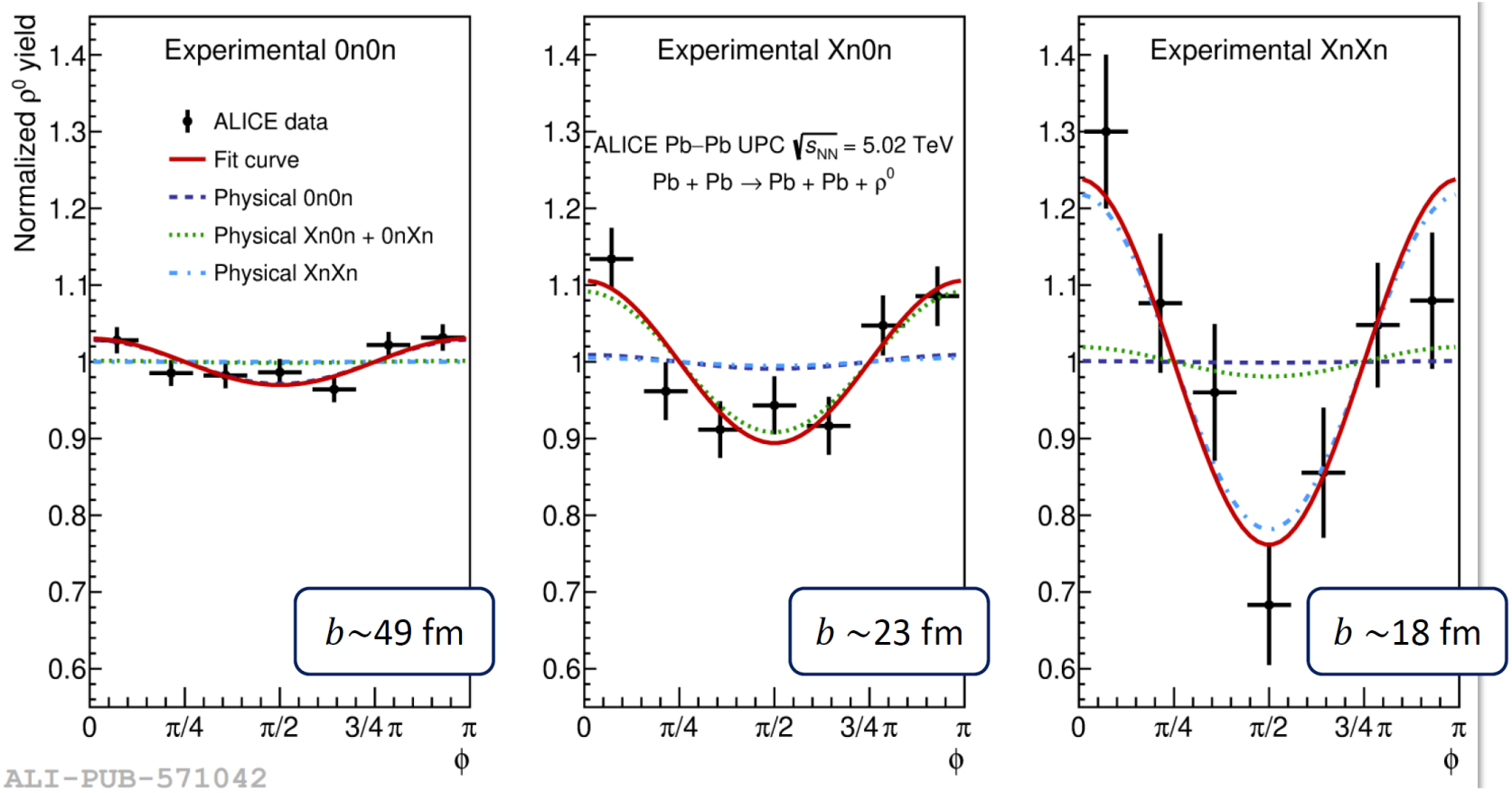
Broz et al., Comput. Phys. Comm. (2020) 107181

EMD class	Median b from $\mathrm{n}^{0}_{0}\mathrm{n}$
0n0n	49 fm
Xn0n	23 fm
XnXn	18 fm

Angular anisotropy in ρ^0 decays



$$\vec{p}_{\pm} = \vec{p}_{\mathrm{T},1} \pm \vec{p}_{\mathrm{T},2}$$

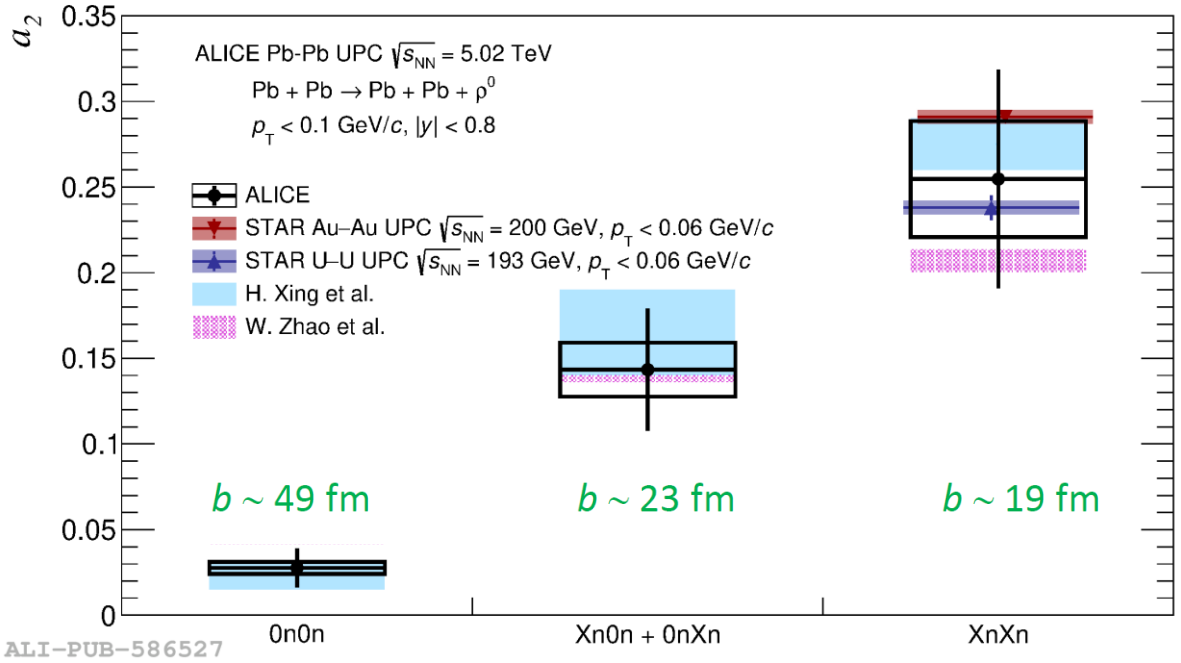


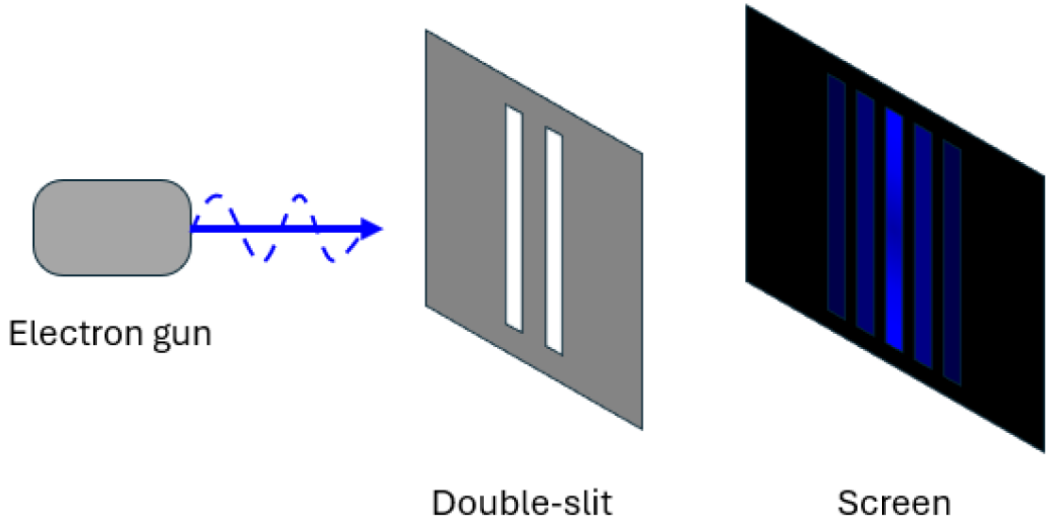
- First measurement of the impact-parameter dependent angular anisotropy in the decay of coherently photoproduced $\boldsymbol{\rho^0}$
- The amplitude (a_2) of the modulation increases by one order of magnitude as $\boldsymbol{b}$ decreases → compatible with expectations from interference

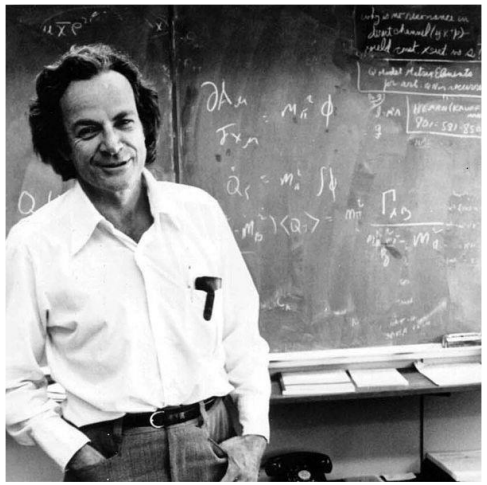
ALICE, PLB 858 (2024) 139017

A double-slit experiment at the femtometer scale

ALICE, PLB 858 (2024) 139017



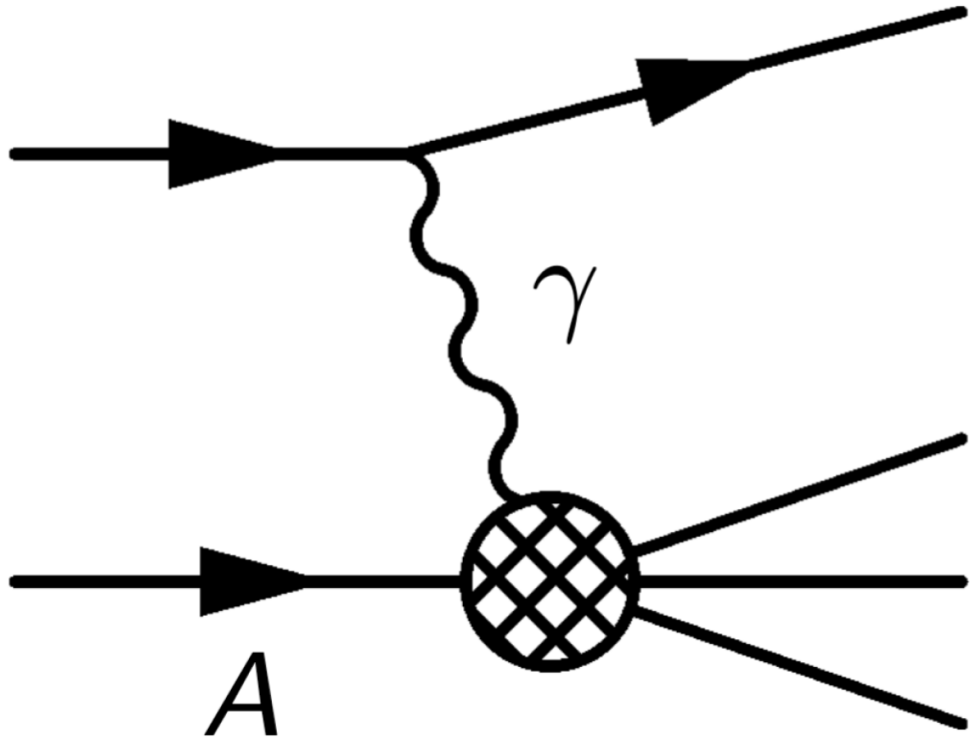




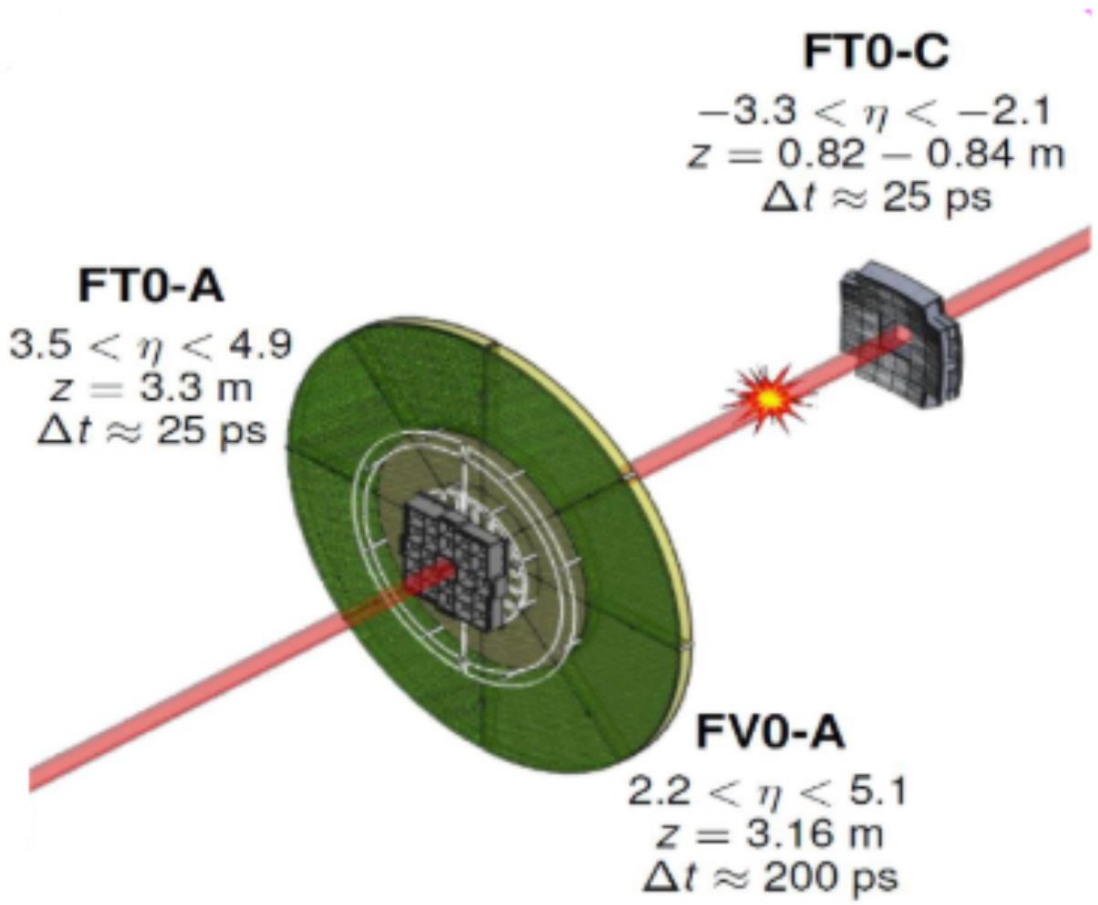
I will take just this one experiment, which has been designed to contain all of the mystery of quantum mechanics, to put you up against the paradoxes and mysteries and peculiarities of nature one hundred per cent. Any other situation in quantum mechanics, it turns out, can always be explained by saying, ***'You remember the case of the experiment with the two holes? It's the same thing'.***

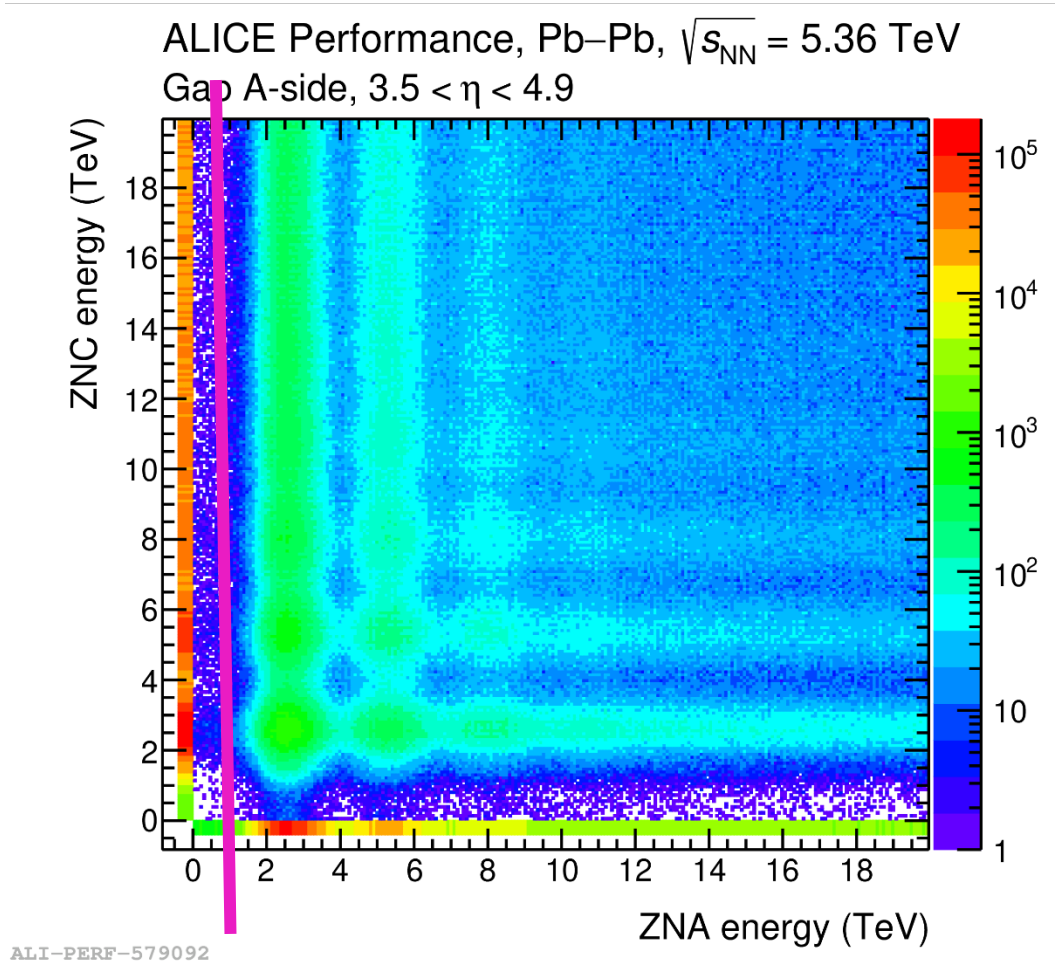
Richard Feynman *in "The Character of Physical Law, chapter 6"*

Inclusive photonuclear interactions with ALICE



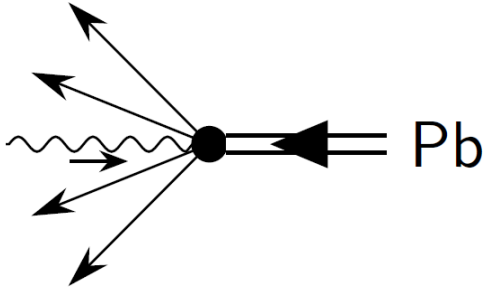
Selecting inclusive photonuclear events with ALICE

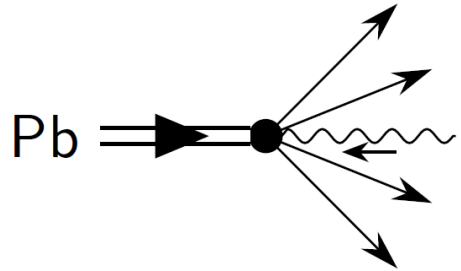


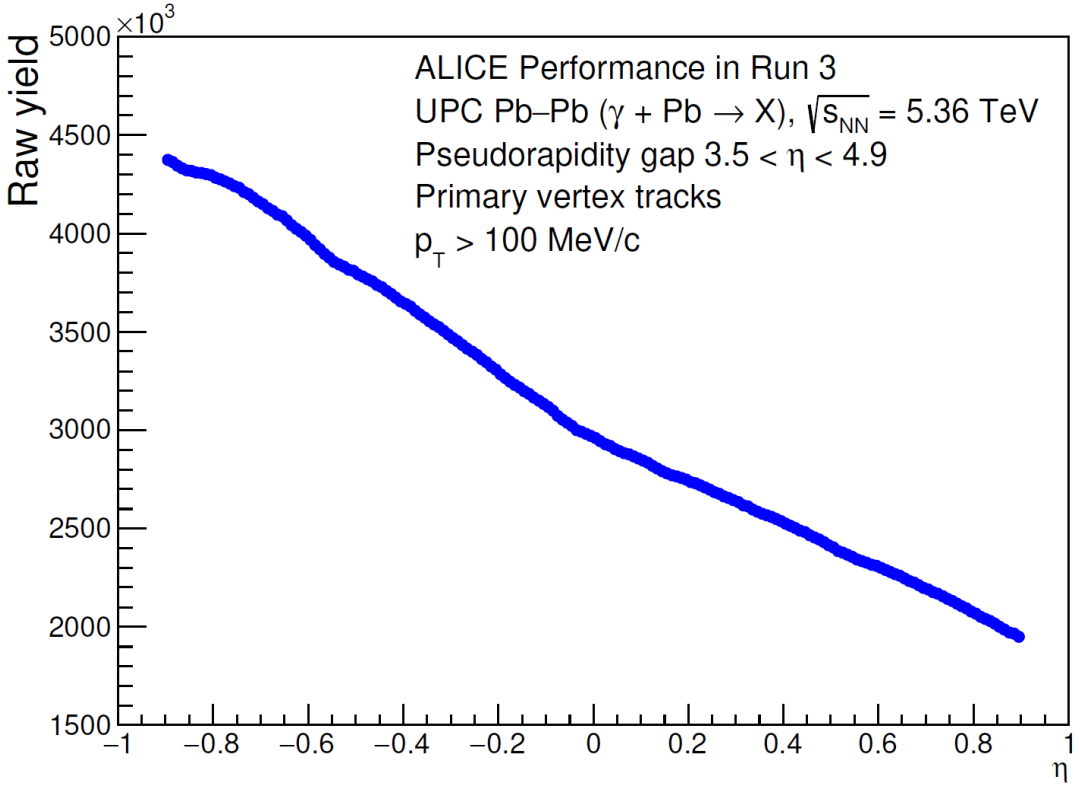


- No activity in FT0 above threshold on the photon-going side
- 0 neutrons in ZDC on the photon-going side

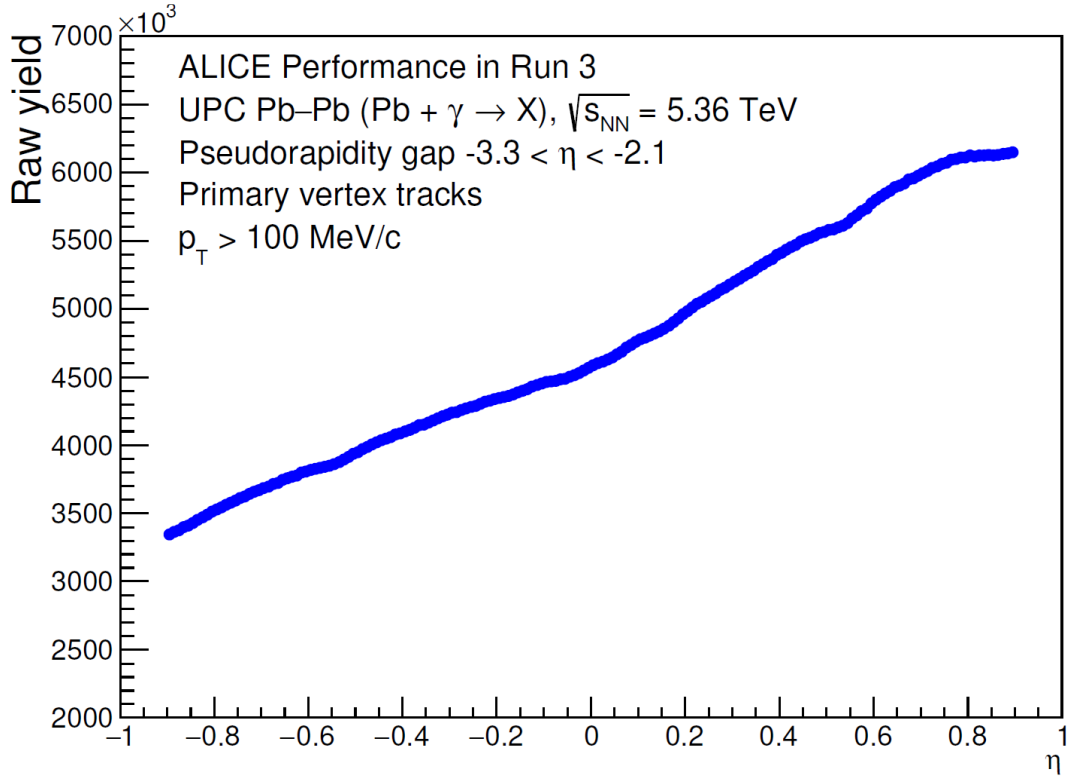
Asymmetric pseudorapidity distributions







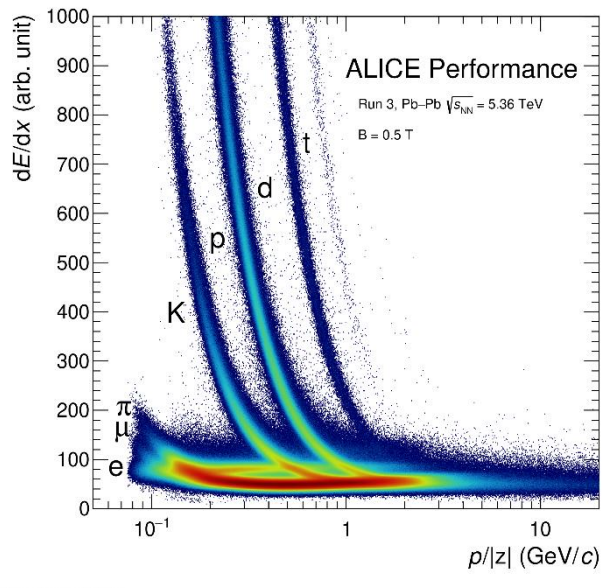
ALI-PERF-578356

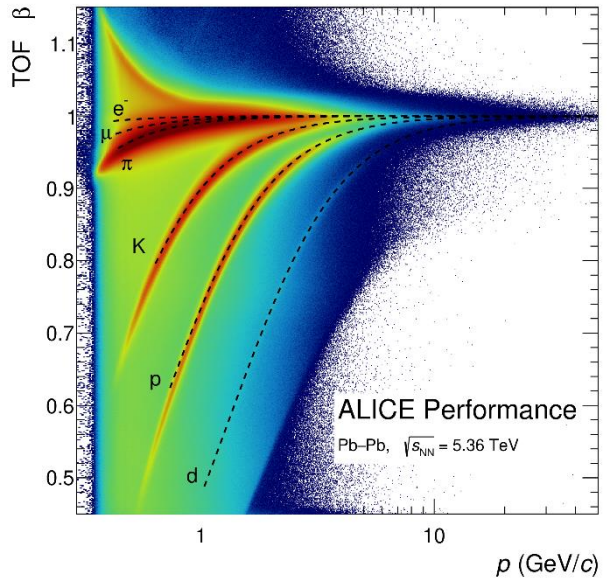


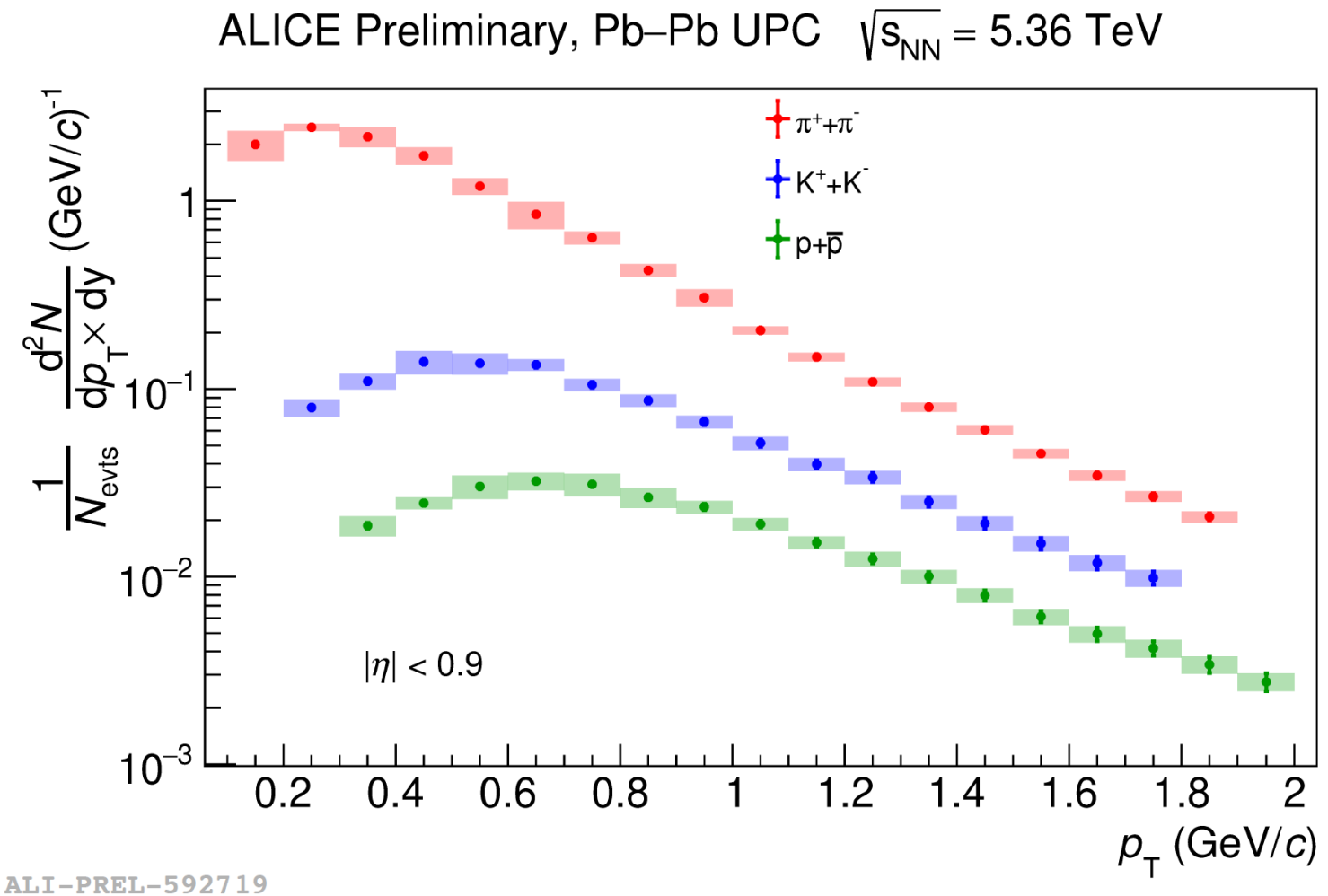
ALI-PERF-578360

Particle production mainly in the Pb-going direction

Identified particle spectra in UPCs



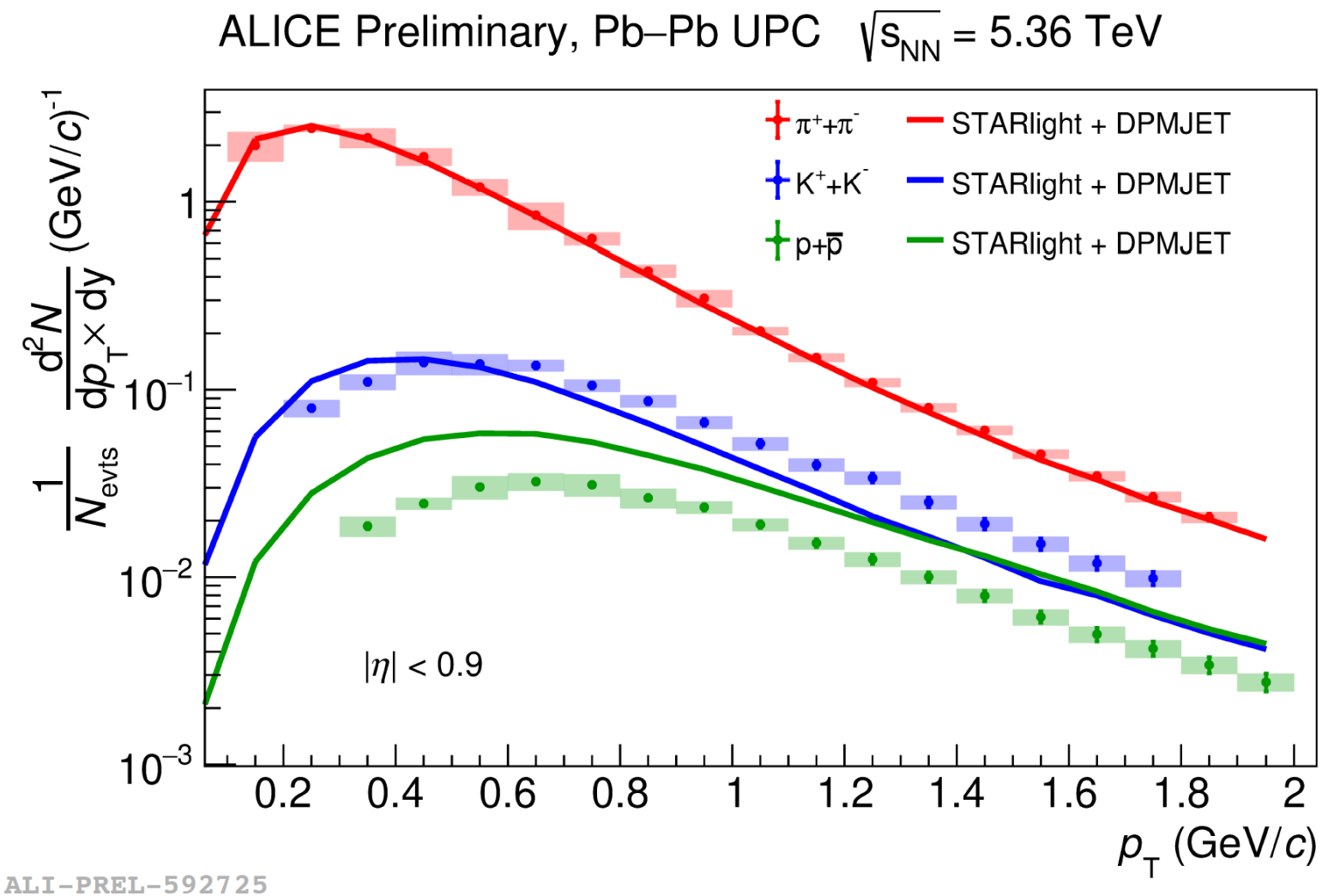




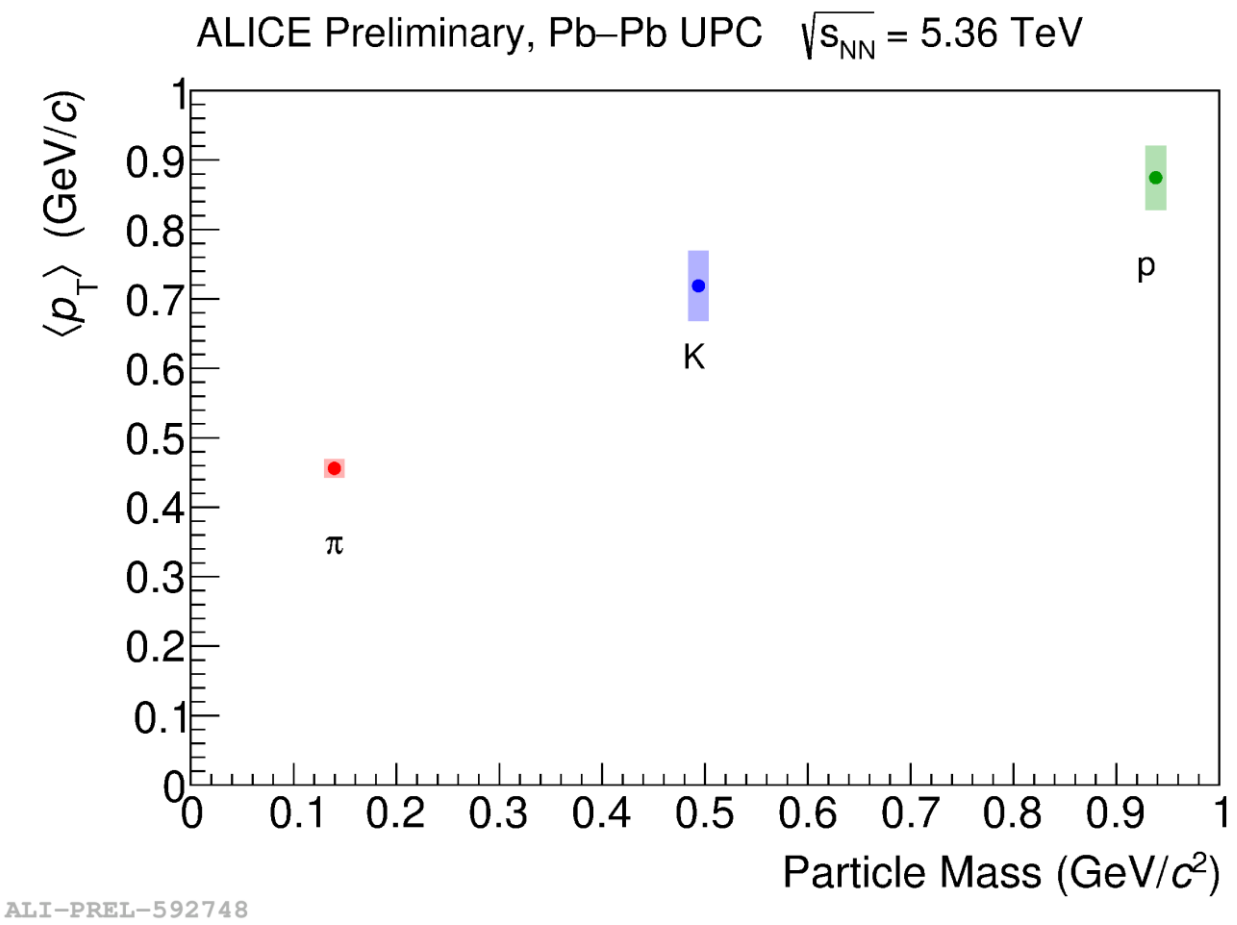
- Fully corrected spectra of pions, kaons and protons in UPCs measured using dE/dx and TOF infortmation

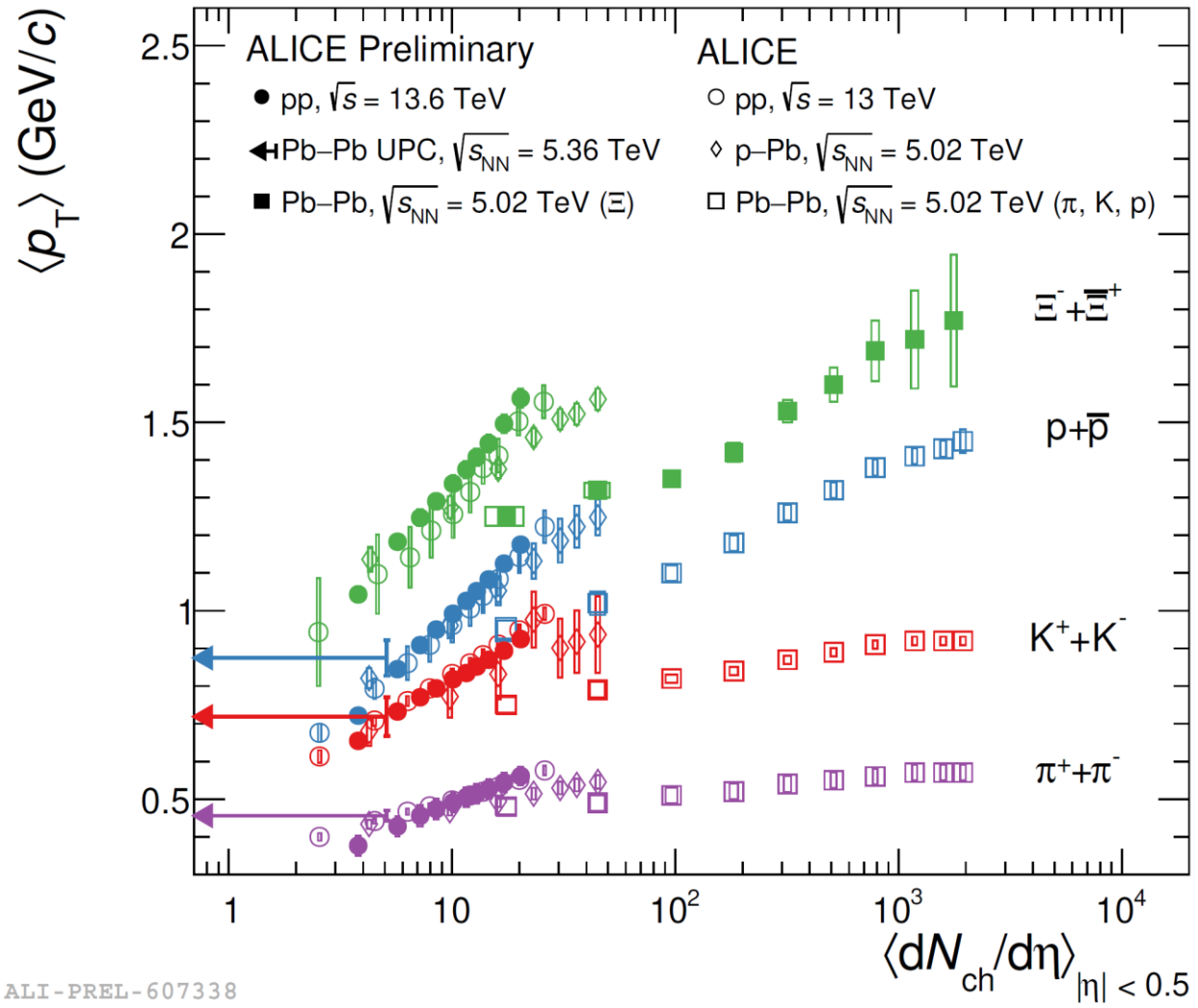
Identified particle spectra: model comparison

- STARlight+DPMJET
  - photon flux from STARlight
  - Photonuclear interaction with DPMJET
- Very good agreement in the pion sector
- Normalization and shape for kaons and protons is not described well



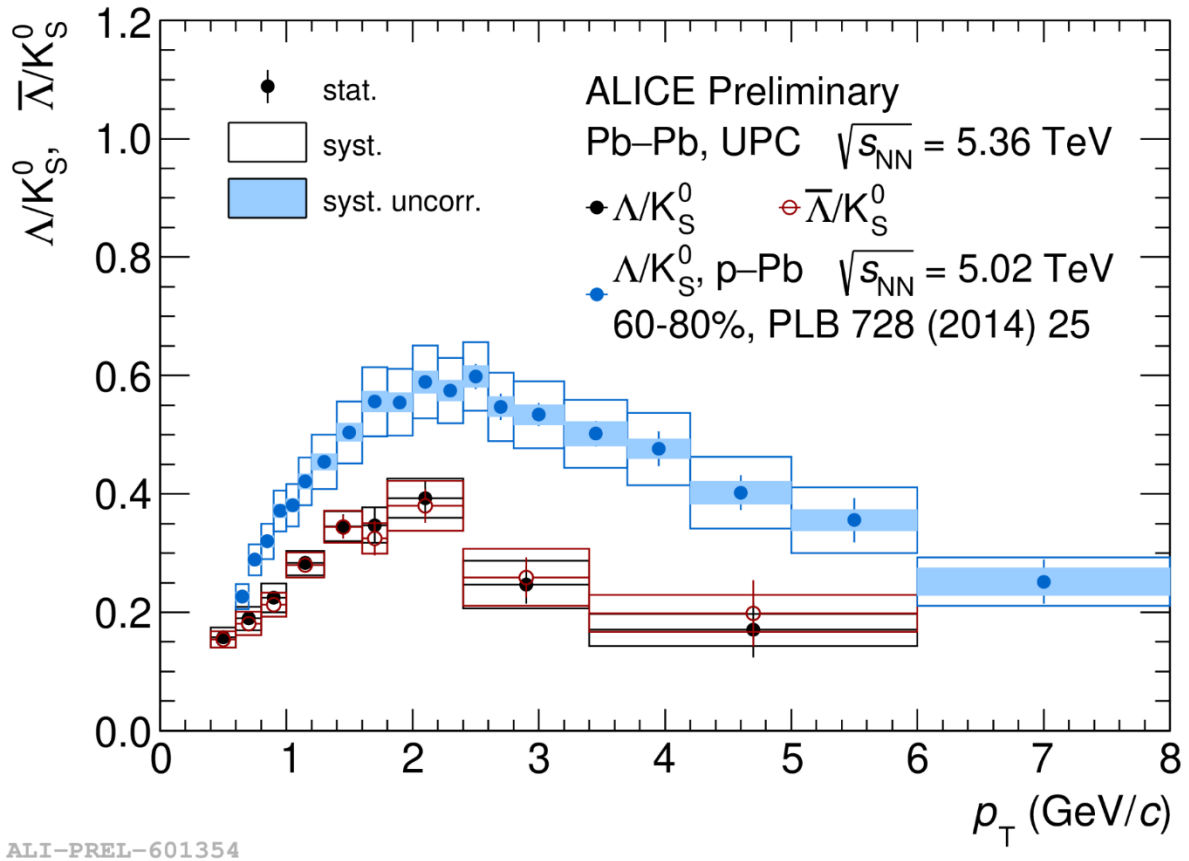
Mean p_T

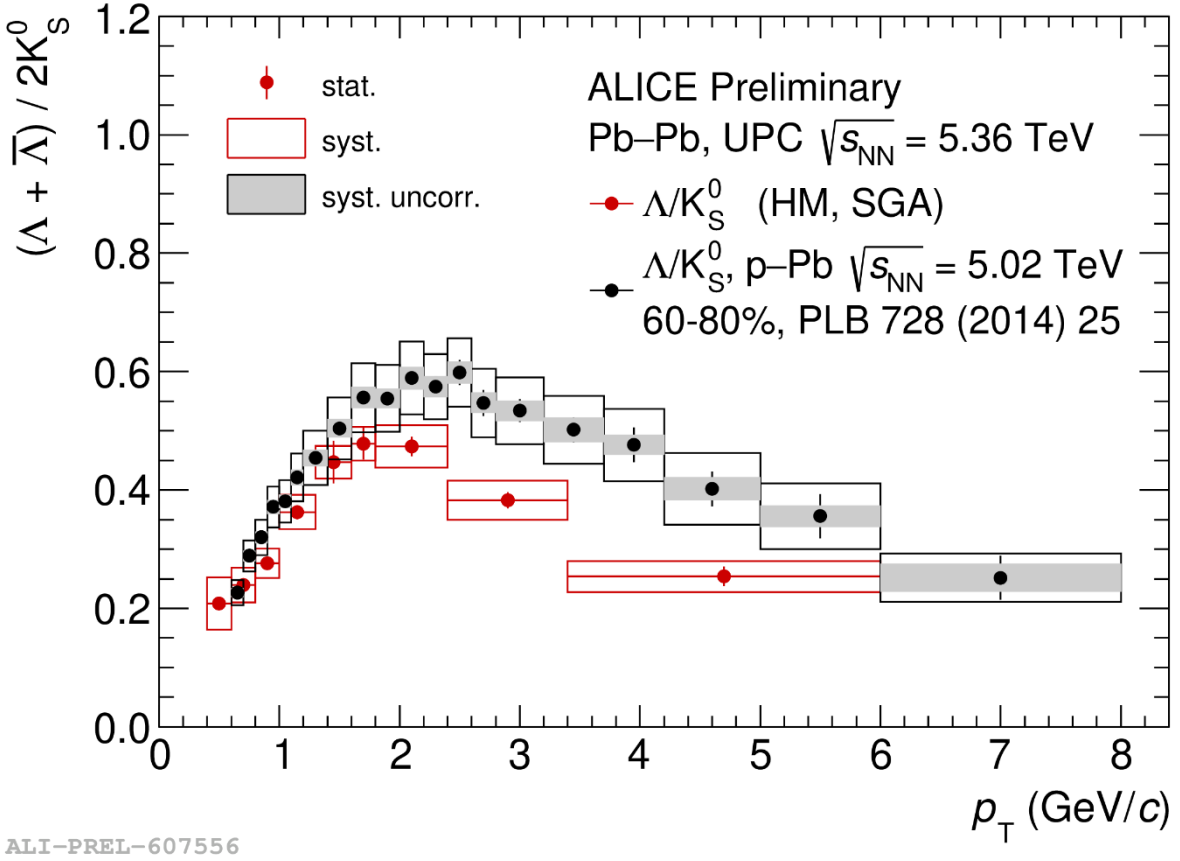


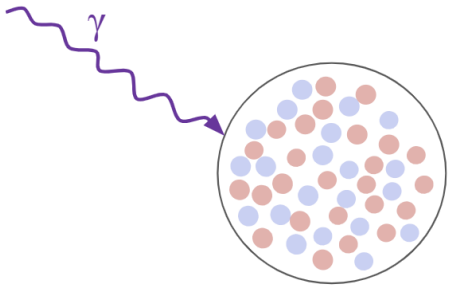


Mean p_T values agree well with low-multiplicity pp and Pb-Pb data

Emergence of QGP-like phenomena: strangeness sector







- Modification of Λ/K_s^0 ratio – one of the signatures of collective phenomena
- Λ/K_s^0 ratio in γ-Pb ~2x lower compared to p-Pb @ 60-80% centrality
- Observing modification of Λ/K_s^0 ratio in high-multiplicity photonuclear events

Open charm production in UPCs

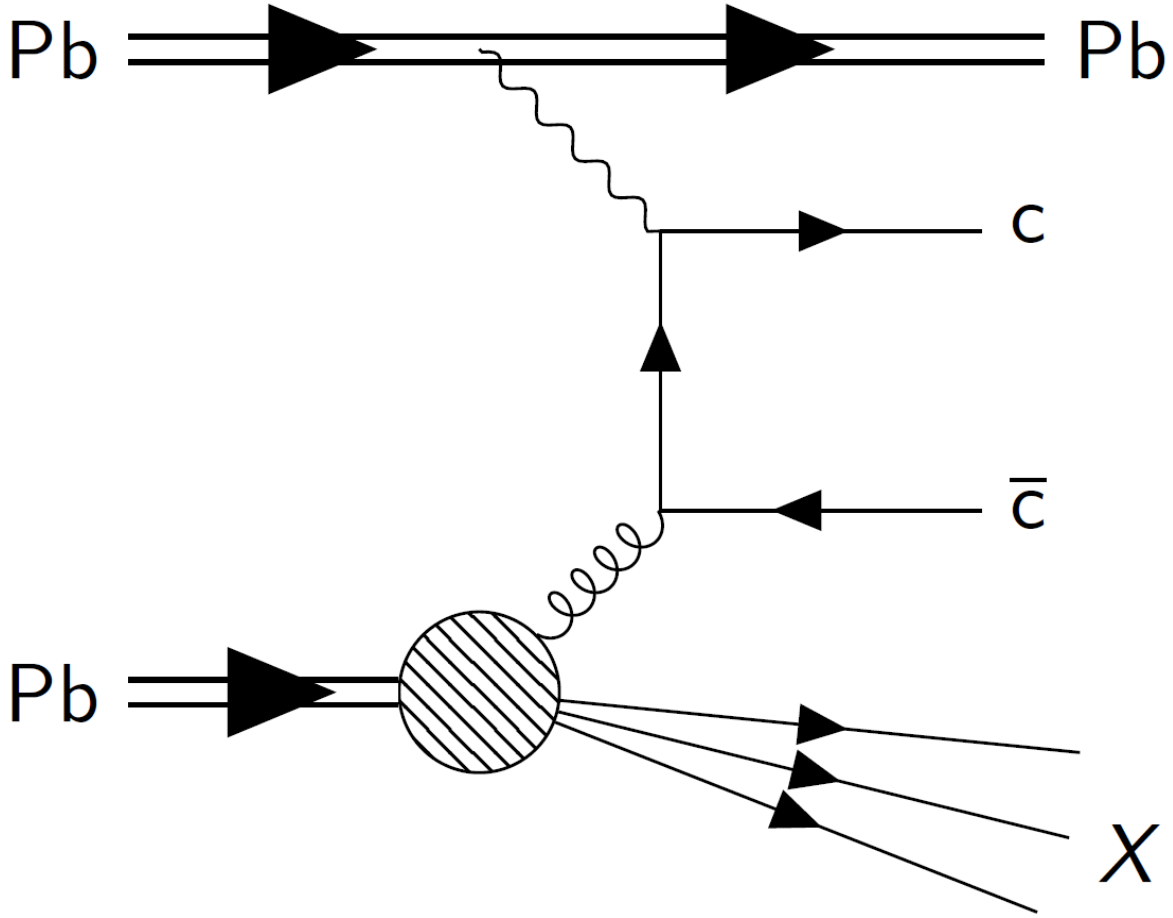
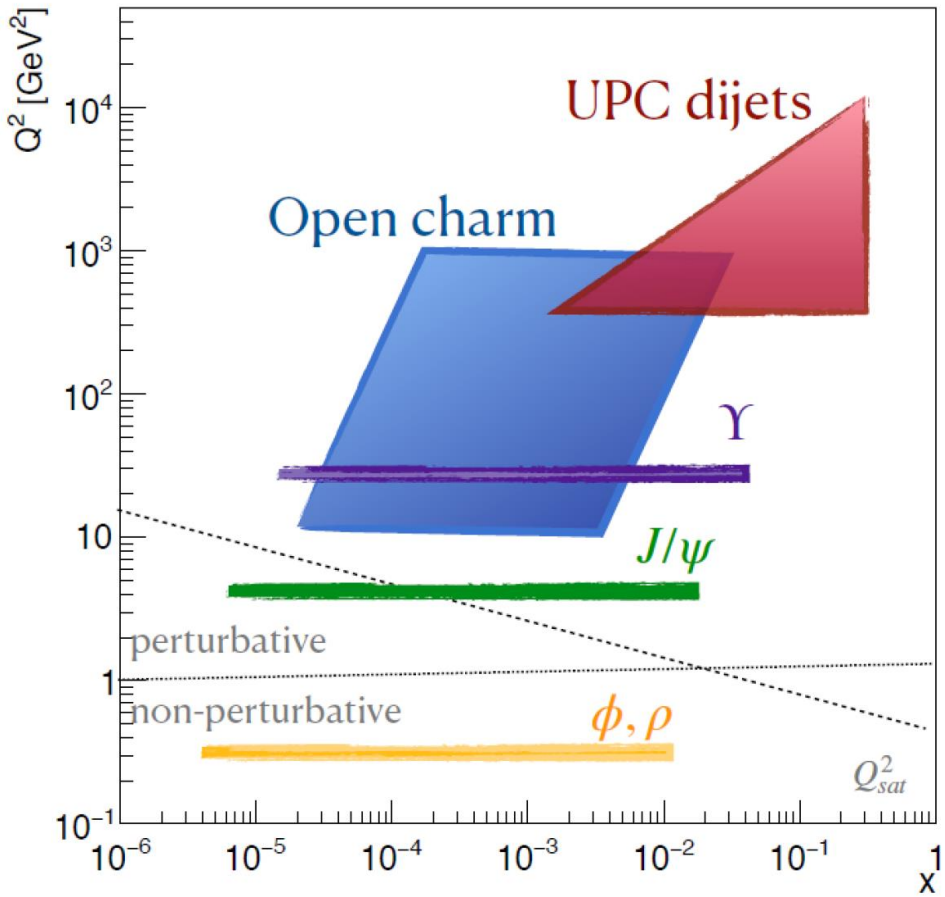
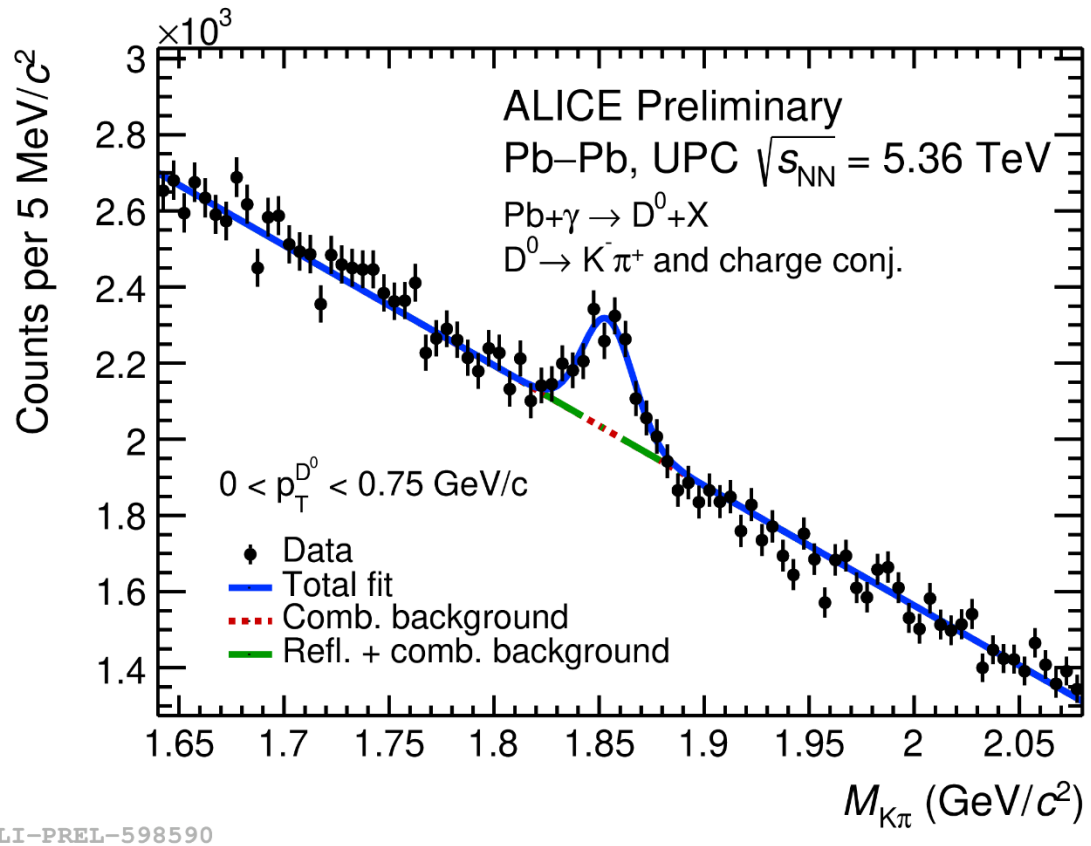


Fig. from A. Ogrodnik

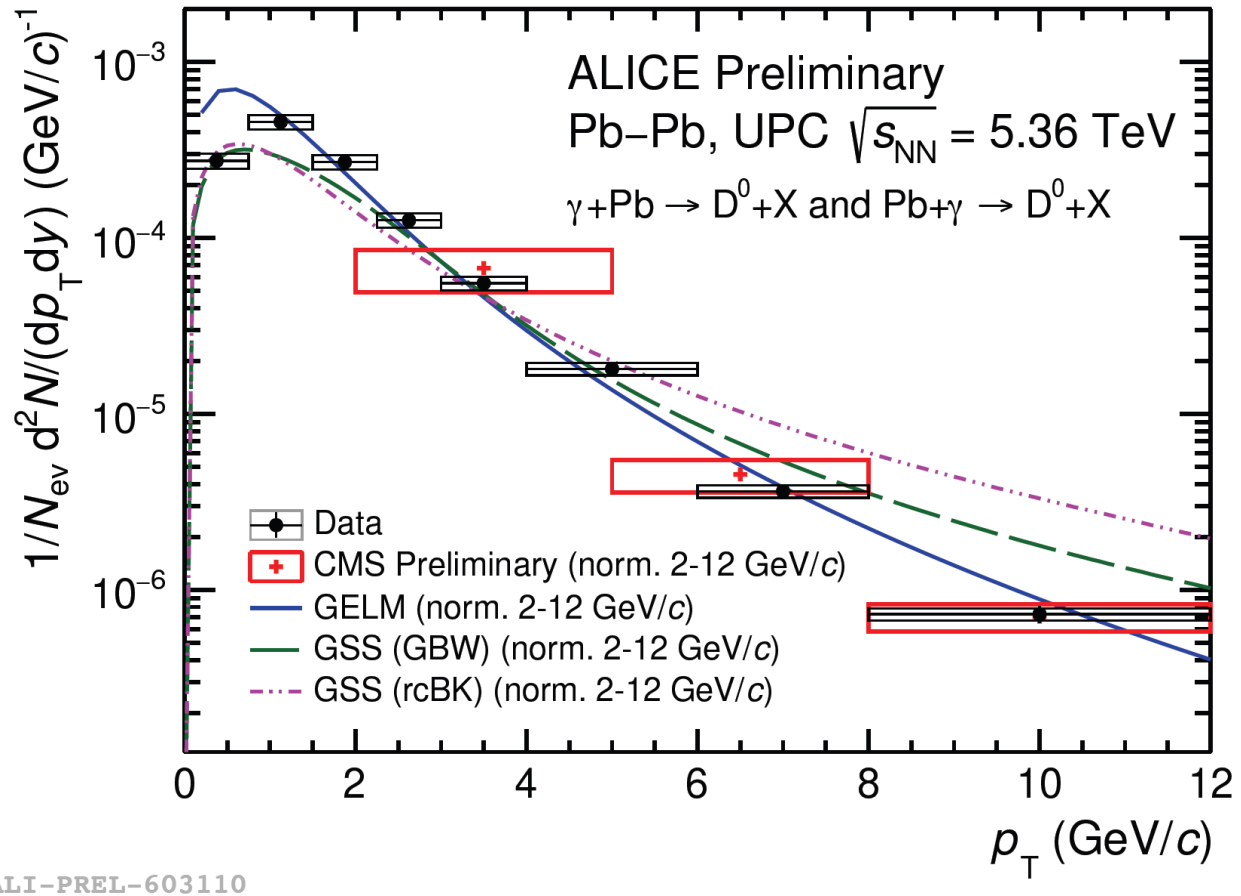


- Open charm production can be used to probe nuclear PDFs at intermediate scales

Open charm production in UPCs



ALI-PREL-598590



ALI-PREL-603110

- ALICE data normalized to the number of visible events
- Good agreement between ALICE and CMS
- Theory curves scaled for comparison
- GELM (CGC-based model) reproduces the shape for p_T > 1 GeV/c

Conclusions

- Upgraded ALICE detector – a powerful tool to study UPCs
- Vector meson photoproduction in UPCs sensitive to nuclear shadowing and saturation phenomena
- A wealth of data on inclusive photonuclear interactions in Run 3
  - particle production and collective behaviour in small systems
  - open charm in UPCs as a new probe for nuclear PDFs