Forward physics and UPC in ALICE

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NO^2 Seminar

Kraków
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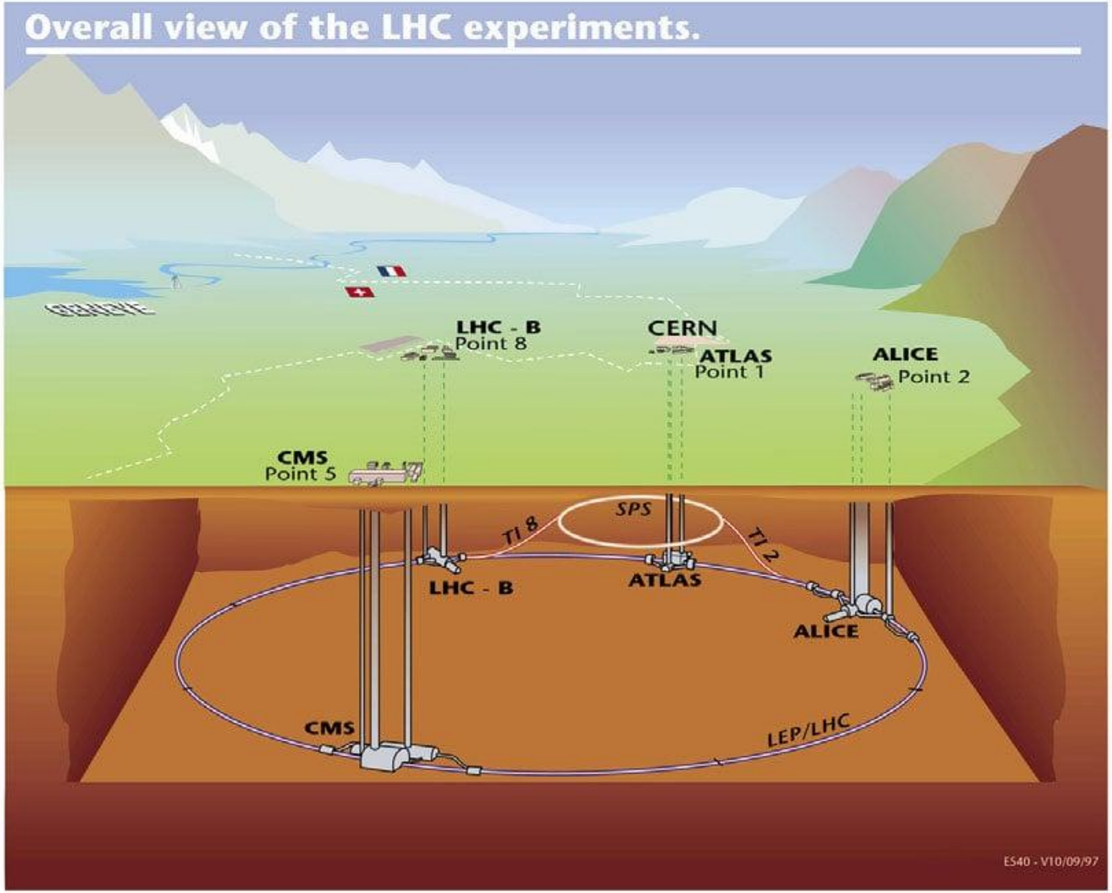
Outline

- LHC
- Experimental apparatus in Run 2 and Run 3
- Ultra-peripheral collisions
- Motivation
- Measurements
  - Electromagnetic dissociation in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
  - J/ψ photoproduction in UPC of Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
  - $\mu^+\mu^-$, J/ψ and ψ(2S) photoproduction in UPC of Pb-Pb at $\sqrt{s_{NN}}$ = 5.36 TeV
  - Inclusive measurements in UPC of Pb-Pb at $\sqrt{s_{NN}}$ = 5.36 TeV
- ALICE Krakow group
- Perspectives
- Bonus
- Summary

LHC

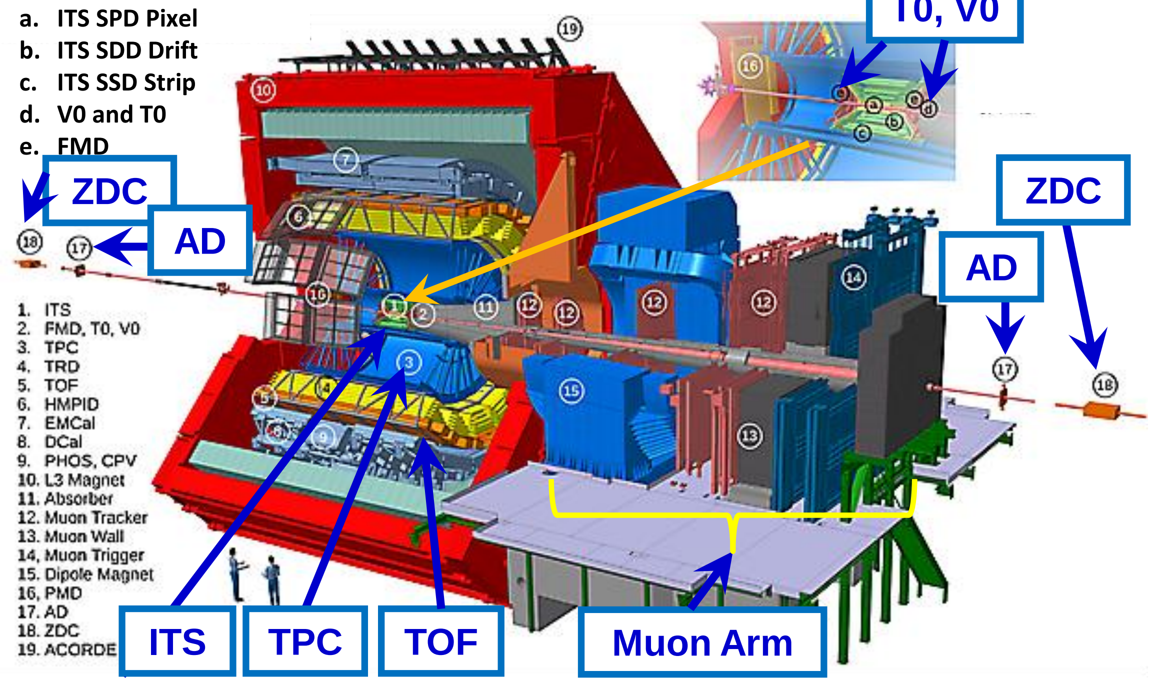


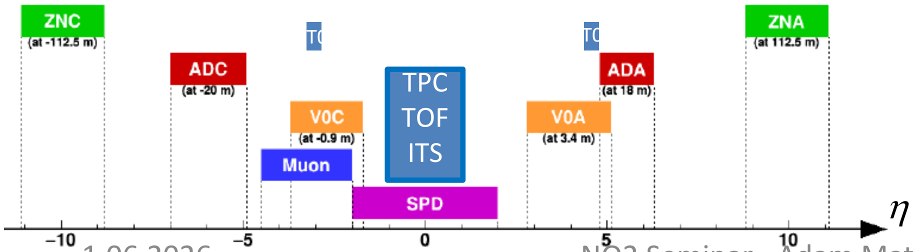
Period	Years
Run 1	2010 – 2013
Run 2	2015 – 2018
Run 3	2022 – 2026

System	Period	$\sqrt{s_{NN}}$, (TeV)
pp	Run 1	0.9, 2.36, 7, 8
	Run 2	13
	Run 3	13.6
Pb-Pb	Run 1	2.76
	Run 2	5.02
	Run 3	5.36
p-Pb	Run 1	5.02
	Run 2	8.16
Xe-Xe	Run 2	5.44
OO	Run 3	5.36
pO	Run 3	9.62
Ne-Ne	Run 3	5.36

ALICE detector in Run 2

ALICE: *JINST* **3** S08002 (2008);
Int. J. Mod. Phys. A29 (2014) 1430044



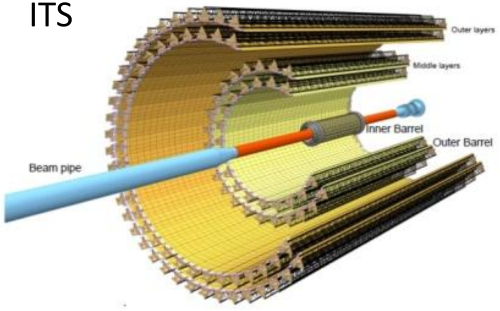


- **Central Barrel tracking ($e^{\pm}$, $\mu^{\pm}$, $h^{\pm}$)**
  - $|\eta| < 0.9$, $0 < \varphi < 2\pi$
  - ITS - silicon detector
  - TPC - gas drift detector
  - TOF - resistive plate chambers
- **PID:**
  - TPC
  - TOF
- **Forward tracking ($\mu^{\pm}$)**
  - $-4 < \eta < -2.5$
  - Absorber (11)
  - Muon tracker (12)
  - Muon trigger (14)
  - Dipole magnet (15)
- **Diffractive detectors**
  - T0 - scintillator counter
  - V0 - scintillator counter
  - AD - scintillator counter
  - ZDC - sampling calorimeter
- **Vertex**
  - ITS

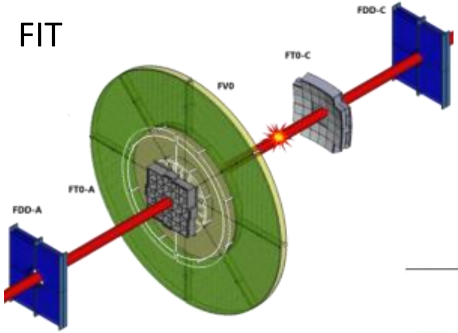
ALICE detector in Run 3

ALICE upgrade:
JINST 19 P05062 (2024)

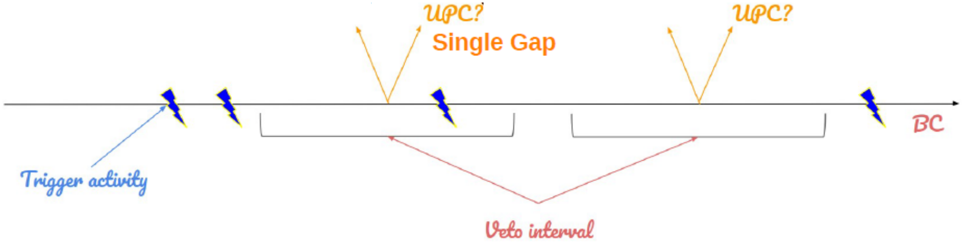
ITS



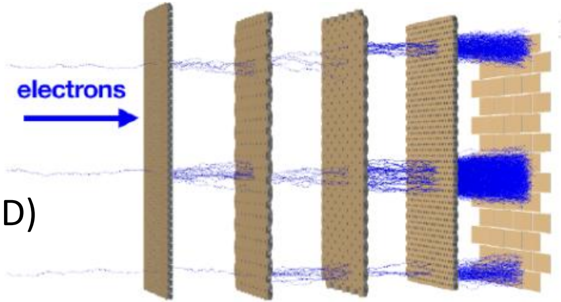
FIT

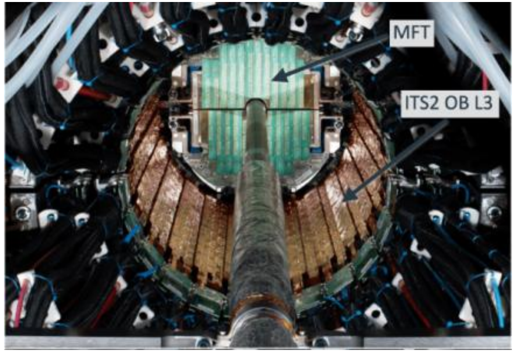


- Major **upgrade** during LS2
  - **I**nner **T**racking **S**ystem – full pixel layers
  - **T**ime **P**rojection **C**hamber – GEM readout
  - New **M**uon **F**orward **T**racker
  - New **F**ast **I**nteraction **T**rigger (FV0 + FT0 + FDD)
  - New Event Processing Nodes Farm
  - Upgraded readout for most of detectors
  - ⇒ **streaming readout** at high rate
- **Pb-Pb data** taking at 50 kHz
  - **All data stored** on tape
- pp data taking at 500 – 1000 kHz
  - Software based trigger

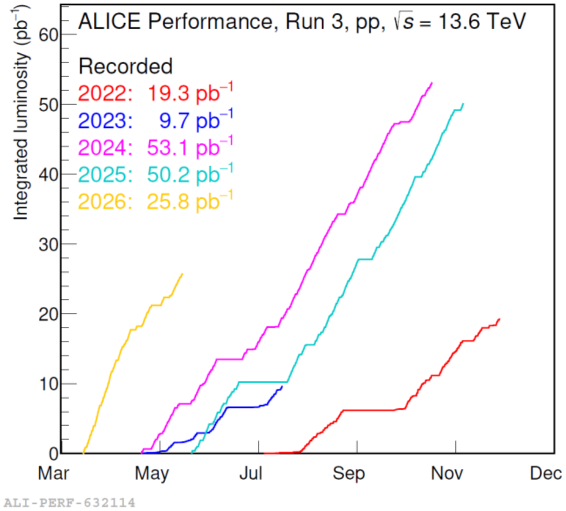


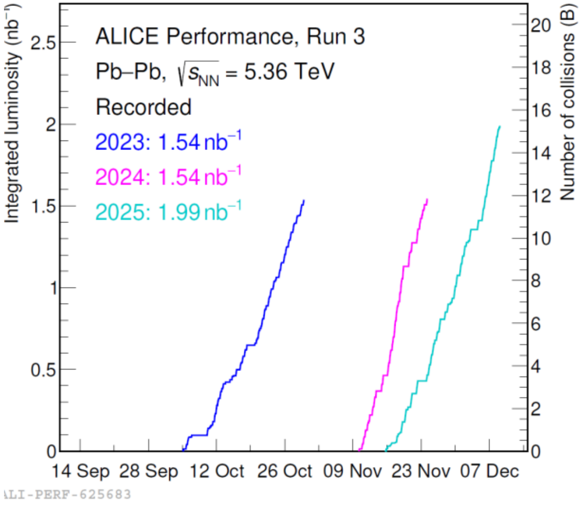
TPC

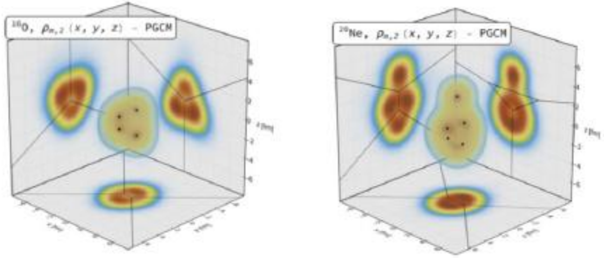




Datasets collected

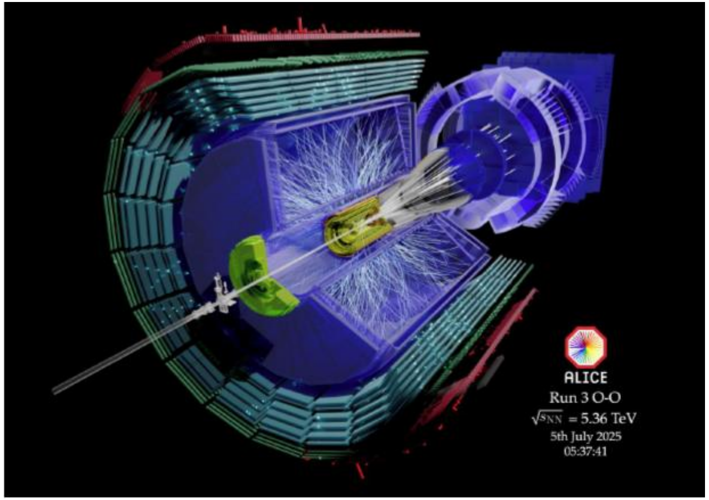




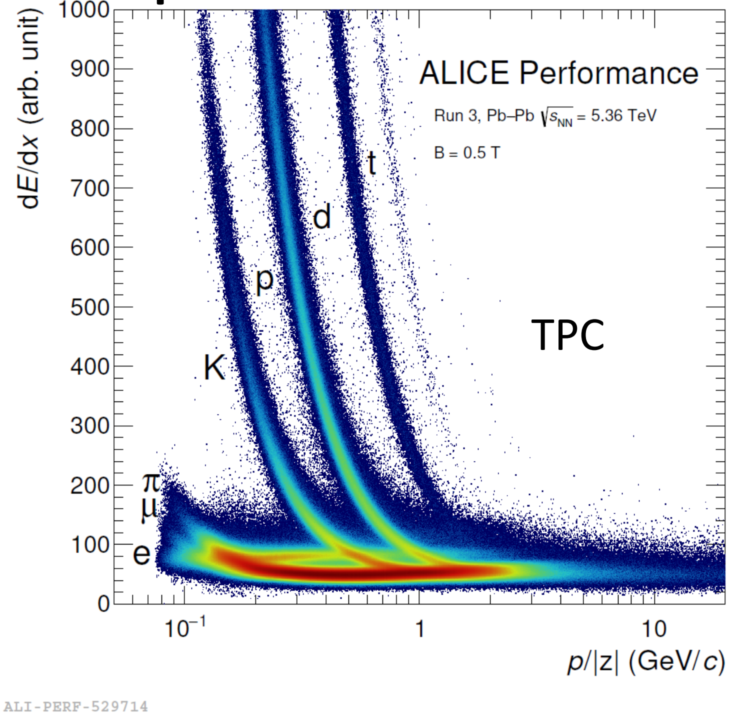


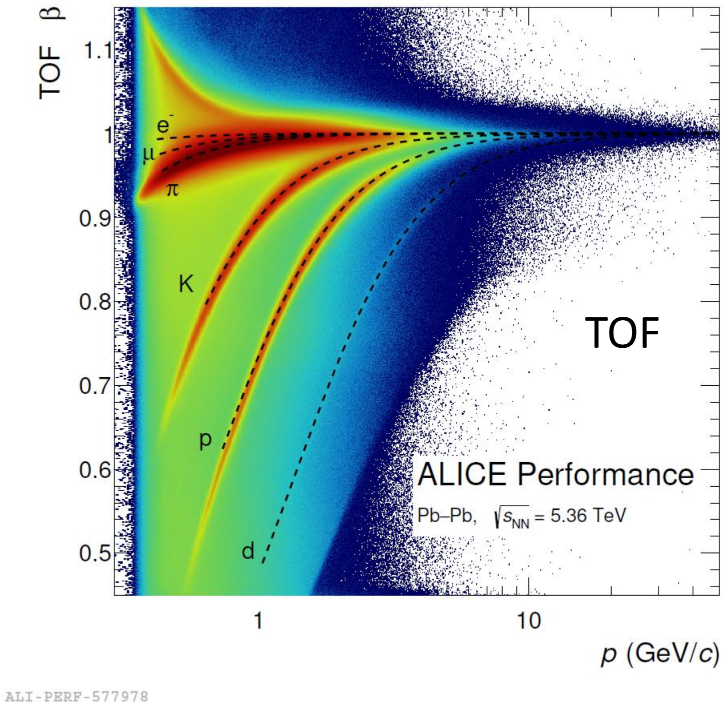
Collected statistics:

- pp: ~158 pb^{-1}
- Pb-Pb: ~5 nb^{-1} + ongoing data taking
- pO: 7.24 nb^{-1} (1-2 July 2025)
- OO: 5.01 nb^{-1} (4-5 July 2025)
- Ne-Ne: 0.84 nb^{-1} (8 July 2025)



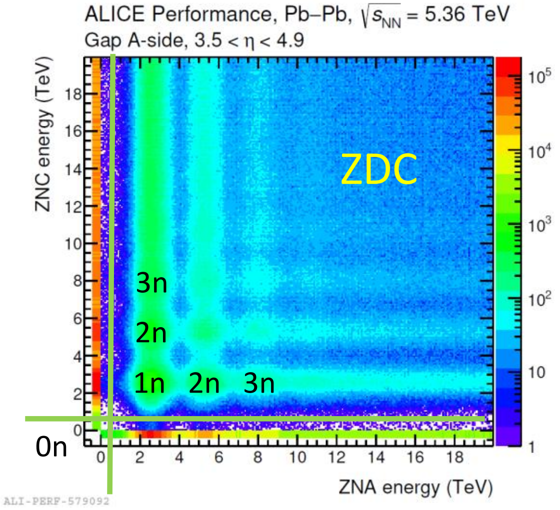
ALICE performance in Run 3

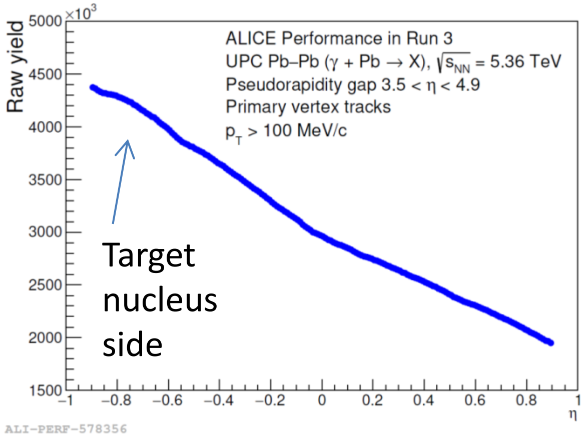


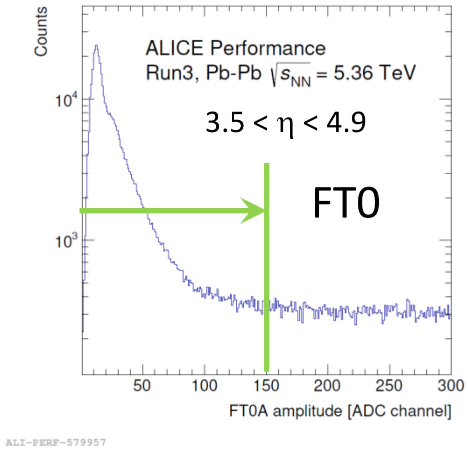


- Excellent tracking capabilities
- Information in TPC and TOF in complementary particles momenta
- Down to p = 100 MeV/c
- Various particle species from electrons to tritium

ALICE performance in Run 3





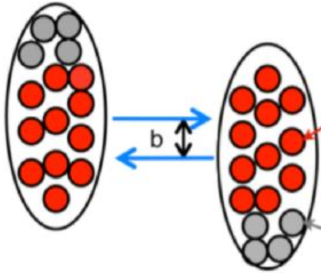


- Clear separation between neutron classes in ZDC:
  - 0n0n, Xn0n, 0nXn, XnXn
- Asymmetric rapidity distribution due to gap requirement on one side

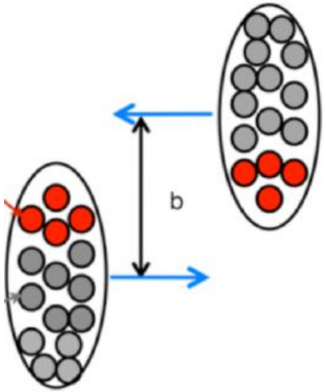
  → better detector and continuous readout
- FT0 threshold tuned to 1 or 2 $e^{\pm}$ production

From central to ultra-peripheral collisions

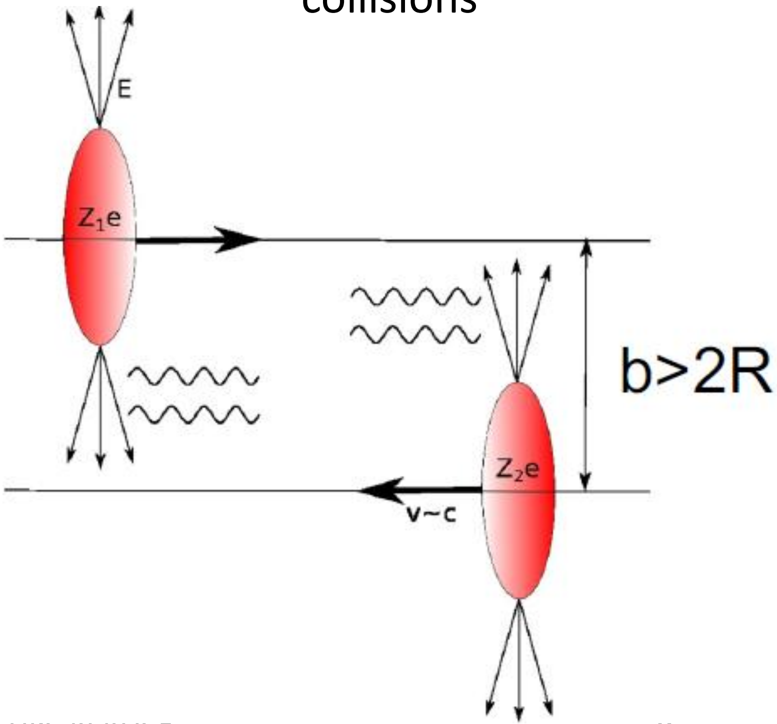
Central collisions



Peripheral collisions

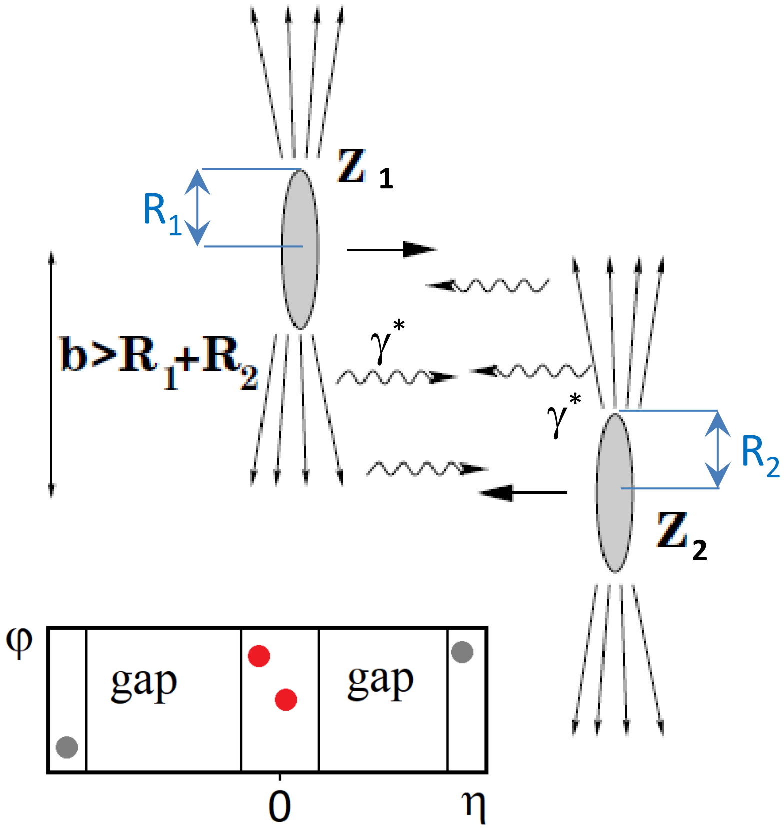


Ultra-peripheral collisions



Ultra-peripheral collisions (UPCs)

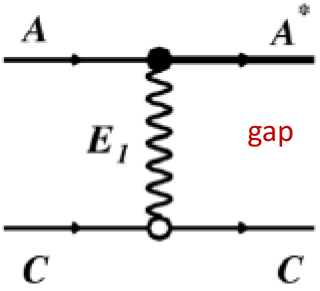
- Impact parameter $b > R_1 + R_2$
  - Hadronic interactions suppressed
- Photon induced reactions:
  - Well described in Weizsäcker-Williams approximation
  - Photon flux ~ Z^2 (Z_{Pb} = 82)
  - Large γ-induced interaction cross section
- Clear signature:
  - Low detector activity
  - Rapidity gap(s)



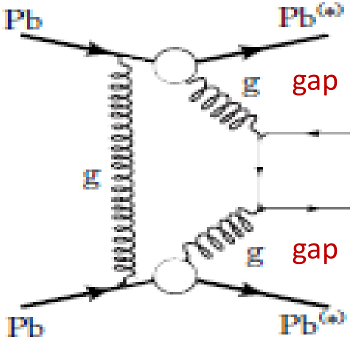
- **Maximum photon energy** at Run 3:
  – $E_\gamma^{max} \approx \gamma\hbar c/R \approx$ **80 GeV**
- **Small photon virtuality** at LHC
  – $Q^2 \approx (\hbar c/R_{nucleus})^2 \approx$ **(30 MeV)^2**
- Linearly polarised photons
- $W_{\gamma N}{}^2 = 2E_N M_{VM} e^{\mp y}$
  – **$40 \lesssim W_{\gamma N} \lesssim 900$ GeV**

Classes of processes

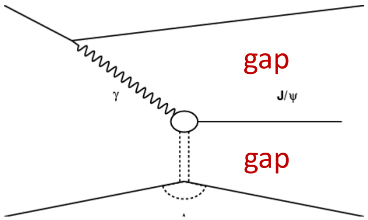
- Exclusive processes (no colour exchange)



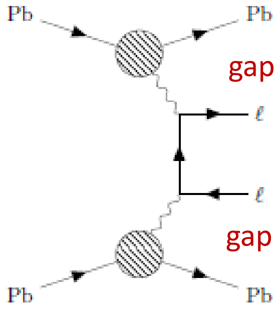
Electromagnetic dissociation (EMD) single or mutual

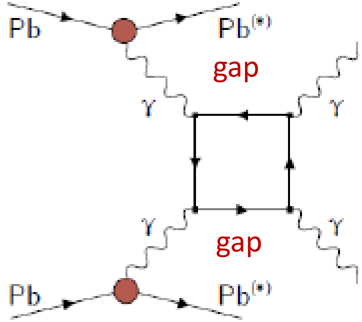


Pomeron – Pomeron CEP



Photoproduction
Coherent or Incoherent



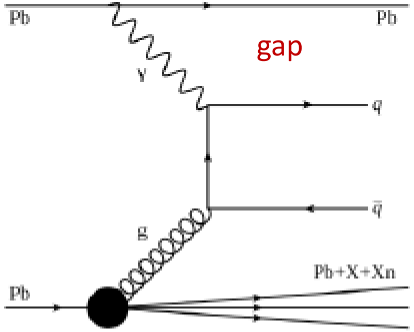


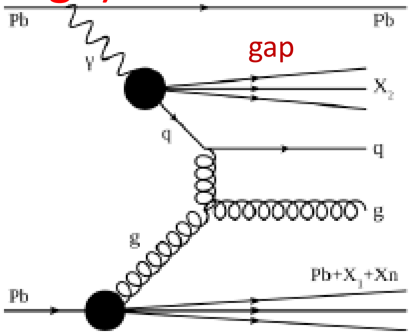
Double photon exchange

- Inclusive processes (with colour exchange)

Direct production

- Photon itself takes part in the hard scattering

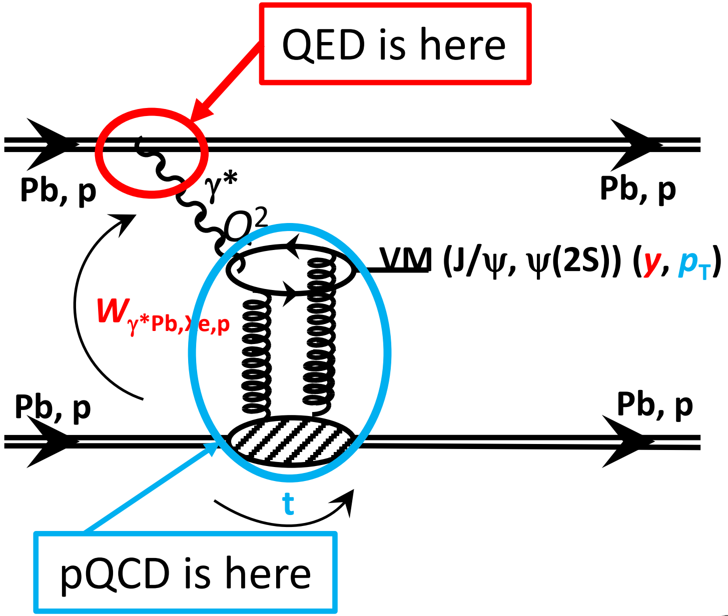




Resolved production

- Virtual excitation of the photon
- Participants of the hard scattering:
  - qq-bar pair
  - multiple gluons

Photoproduction and main variables



- Momentum scale $Q^2 \sim M_{VM}^2 / 4$
  - Hard scale assured by high mass of J/ψ, ψ', Υ(nS) meson
  - Semi-hard scale for ρ^0 meson
- Vector Meson (VM) quantum numbers:
  - $J^{PC} = 1^{--}$
- Bjorken-*x:* fraction of longitudinal momentum of proton

$$x_B = \frac{M_{VM}}{\sqrt{s_{NN}}} e^{\pm y}$$

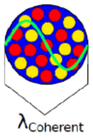
  - Photoproduction is sensitive to gluon density evolution at low x_B
  - There are new NLO calculations
- Photon-target centre-of-mass energy

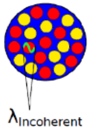
$$W^2_{\gamma^* N} = 2E_N M_{VM} e^{\mp y}$$

- 4-momentum transfer t
  - Gluon distribution in the transverse plane $|t| \sim p_T^2$

Photoproduction types

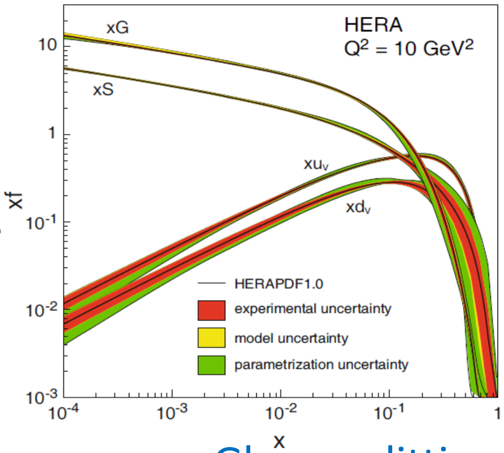
- **Coherent** photoproduction
  - Photon couples to whole nucleus
  - $\langle p_T^{VM} \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
- **Incoherent** photoproduction
  - Photon couples to single nucleon
  - $\langle p_T^{VM} \rangle \sim 1/R_p \sim 450$ MeV/c



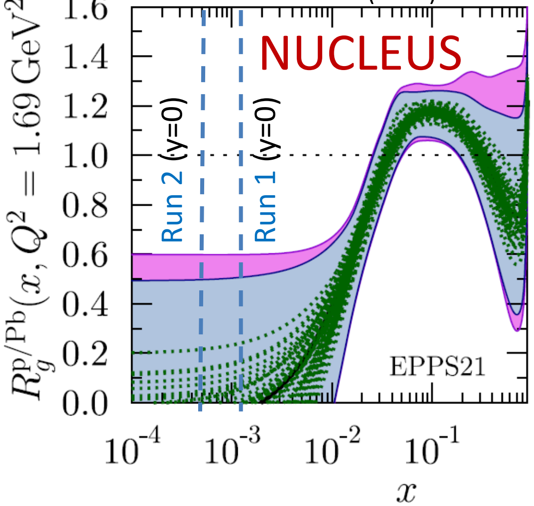


Motivation

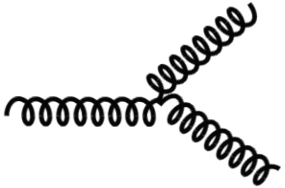
- Studies of **gluon PDFs**
- Different **proton ↔ nuclear PDF**
  - Gluon **shadowing** (destructive interference at low x_B caused by coherent multiple scattering)
  - Gluon **saturation** (equilibrium between gluon splitting and recombination)
    - Saturation scale enhanced for nuclei by factor $A^{1/3}$: $(Q_s^A)^2 \approx cQ_0^2\ [A/x]^{1/3}$
- **Heavy flavour** → probe **nuclear PDF** in large phase space down to $x_B \sim 10^{-4}$
- Search for **QGP signatures** in small systems like γ+Pb collisions
  - Radial, elliptic, triangular flow
  - Baryon to meson ratio (K^0/Λ)
  - D^0 production
- Lepton pairs → test of **QED**, **photon fluxes** and **BSM**



Eskola et al.: EPJ C 82 (2022) 413



Gluon splitting



Recombination

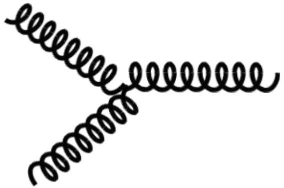
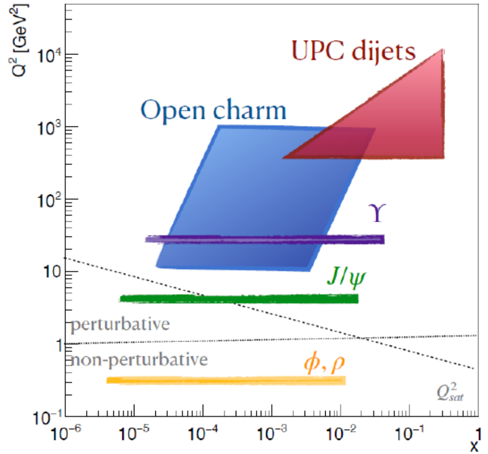
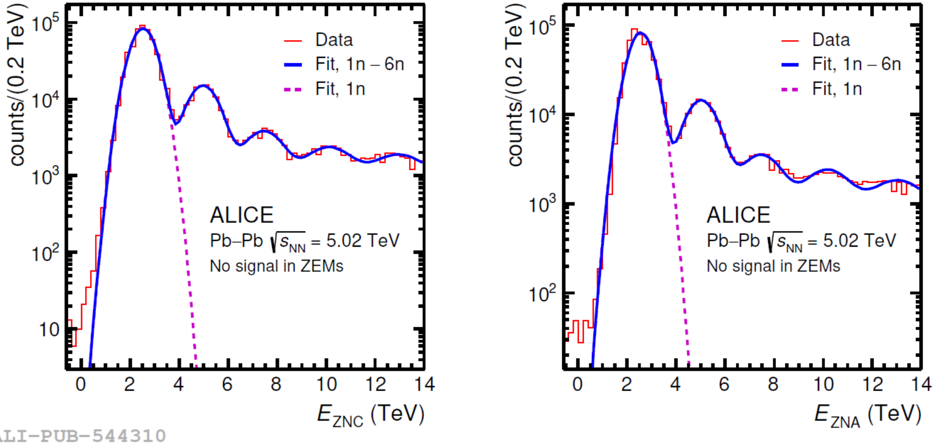


Fig. from A. Ogrodnik



Neutron emission in UPC

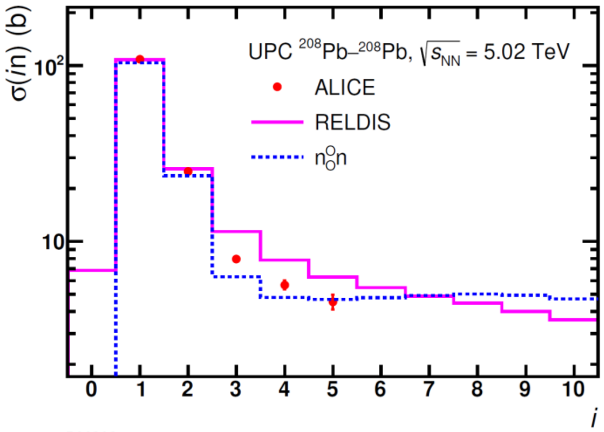
PRC 107 (2023) 064902



ALI-PUB-544310

ZN	$\sigma(in)$ (b)	$\sigma^{RELDIS}(in)$ (b)	$\sigma^{n_O^On}(in)$ (b)
1n	$108.4 \pm 0.1 \pm 3.7$	108.0 ± 5.4	103.7 ± 2.1
2n	$25.0 \pm 0.1 \pm 1.3$	25.9 ± 1.3	23.6 ± 0.5
3n	$7.95 \pm 0.04 \pm 0.23$	11.4 ± 0.6	6.3 ± 0.1
4n	$5.65 \pm 0.03 \pm 0.33$	7.8 ± 0.4	4.8 ± 0.1
5n	$4.54 \pm 0.03 \pm 0.44$	6.3 ± 0.3	4.7 ± 0.1
1n–5n	$151.5 \pm 0.2 \pm 4.6$	159.8 ± 5.6	143.1 ± 2.2

PRC 107 (2023) 064902



ALI-PUB-544313

- Up to 5 neutrons
- Hadronic cross section $\sigma_{had} = 7.67 \pm 0.24$ b
- Good description of 1n and 2n emission , but other classes are not so well described

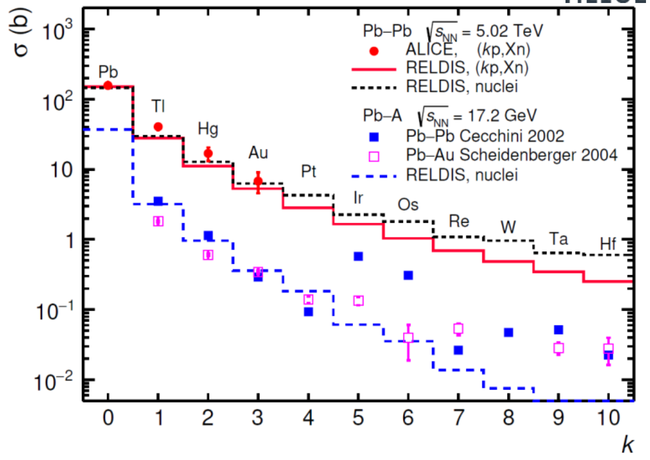
RELDIS: Phys. Part. Nucl. 42 (2011) 215.
N00N: Comput. Phys. Commun. 253 (2020) 107181.

Proton emission in EMD of ^{208}Pb

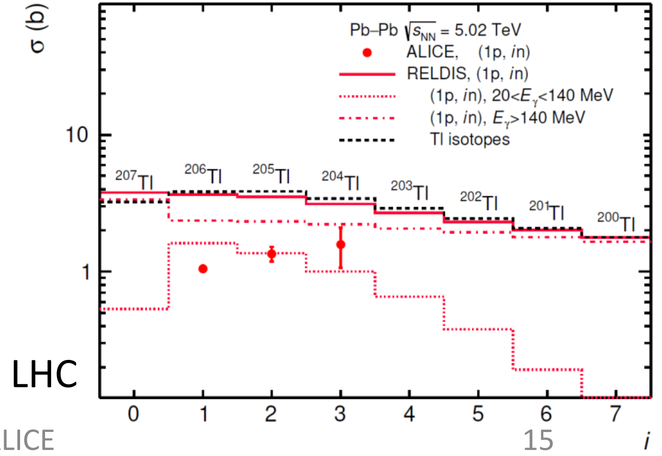
- Absorption of photons (E_γ > 140 MeV)
  - → emission of several neutrons and protons
- Proton emission accompanied by at least 1 neutron emission
  - → Large production cross section of Thallium, Mercure, GOLD
  - → 0p and 3p agree with RELDIS predictions, but 1p and 2p underestimated by 17-25%
- Single proton emission accompanied by 1, 2, 3 neutrons
  - → production of the isotopes ^{206,205,204}Tl
  - → RELDIS overestimates the data 2-3x
  - → Better description for E_γ > 20 MeV, but opposite trend
- Confirms very good ZDC performance
- Possibility to measure 1n or 2n classes:
  - → access to different impact parameters
- Relevant constraints on models for Tl

Media release: ALICE detects the transformation of lead into gold at the LHC

PRC 111 (2025) 054906



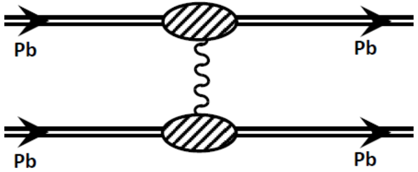
ALI-PUB-606626



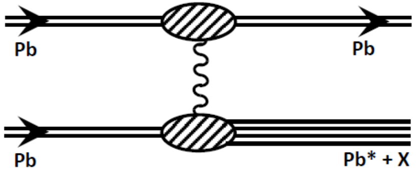
ALI-PUB-606630

Impact parameter dependence and 2-fold ambiguity

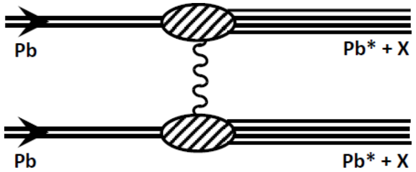
No breakup (0n0n)

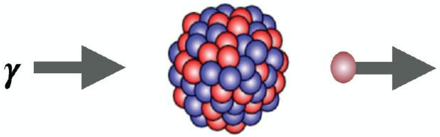


Single breakup (Xn0n + 0nXn)



Double breakup (XnXn)





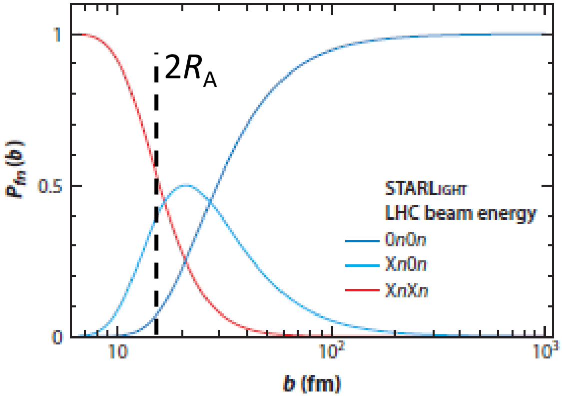
- Excitation of the nuclei possible through the secondary photon exchange

$\Rightarrow$ Giant dipole resonance

All protons vibrating against all neutrons
$\rightarrow$ knocks out neutrons

- UPC event clasifier: 0n0n, 0nXn, XnXn

$\rightarrow$ via electromagnetic dissociation (EMD)



S. Klein, P. Steinberg, Annu. Rev. Nucl. Part. Sci. 70(1), 323 (2020)

- Single measurement cannot distinguish emmiter vs. target

$$\frac{d\sigma_{AA\to AA'J/\psi}}{dy} = N(\omega_{\gamma 1})\sigma_{\gamma A}(\omega_{\gamma 1}) + N(\omega_{\gamma 2})\sigma_{\gamma A}(\omega_{\gamma 2})$$

Peripheral:
Contreras, PRC 96, 015203 (2017).
EMD:
Guzey at al., EPJC 74 (2014) 7, 2942.

To disentangle both photon contributions we need to measure the same proces in peripheral collisions or with EMD!

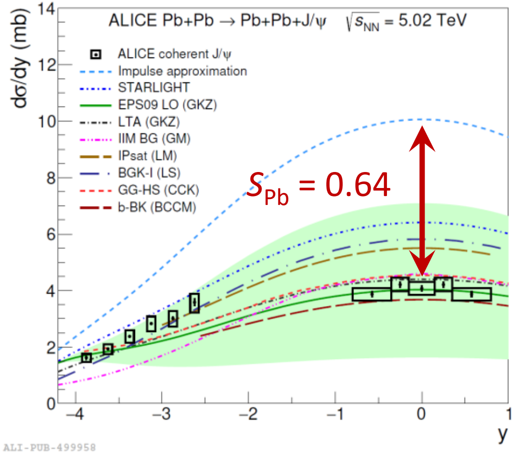
$$\boxed{\frac{d\sigma_{PbPb}{}^{0N0N}}{dy}} = \boxed{N^{0N0N}(\omega_{\gamma 1},+y)}\sigma_{\gamma Pb}(\omega_{\gamma 1},+y) + \boxed{N^{0N0N}(\omega_{\gamma 2},-y)}\sigma_{\gamma Pb}(\omega_{\gamma 2},-y)$$

$$\boxed{\frac{d\sigma_{PbPb}{}^{0NXN}}{dy}} = \boxed{N^{0NXN}(\omega_{\gamma 1},+y)}\sigma_{\gamma Pb}(\omega_{\gamma 1},+y) + \boxed{N^{0NXN}(\omega_{\gamma 2},-y)}\sigma_{\gamma Pb}(\omega_{\gamma 2},-y)$$

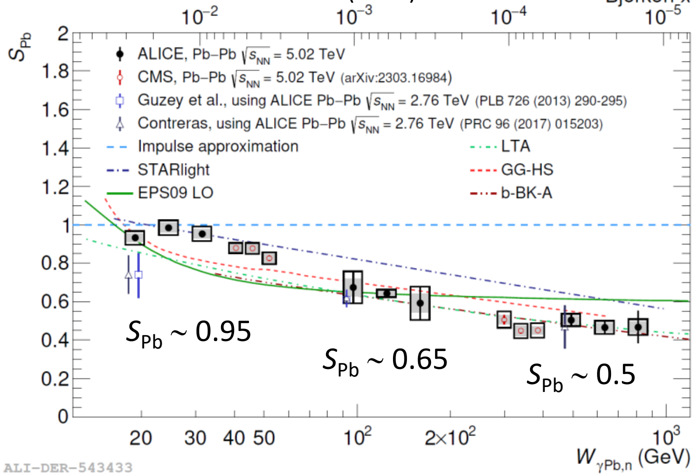
measured theory extracted

J/ψ photoproduction

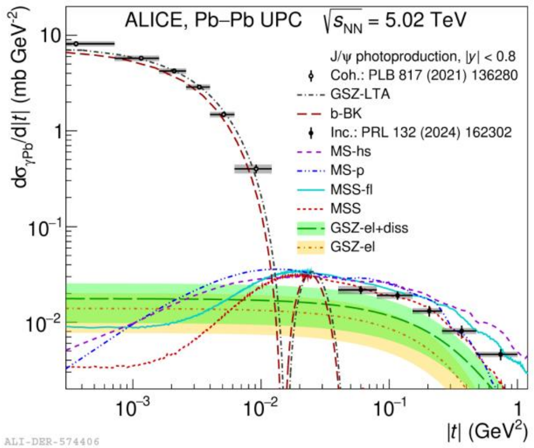
EPJ C 81 (2021) 712



JHEP 10 (2023) 119



PLB 817 (2021) 136280, PRL 132 (2024) 162302

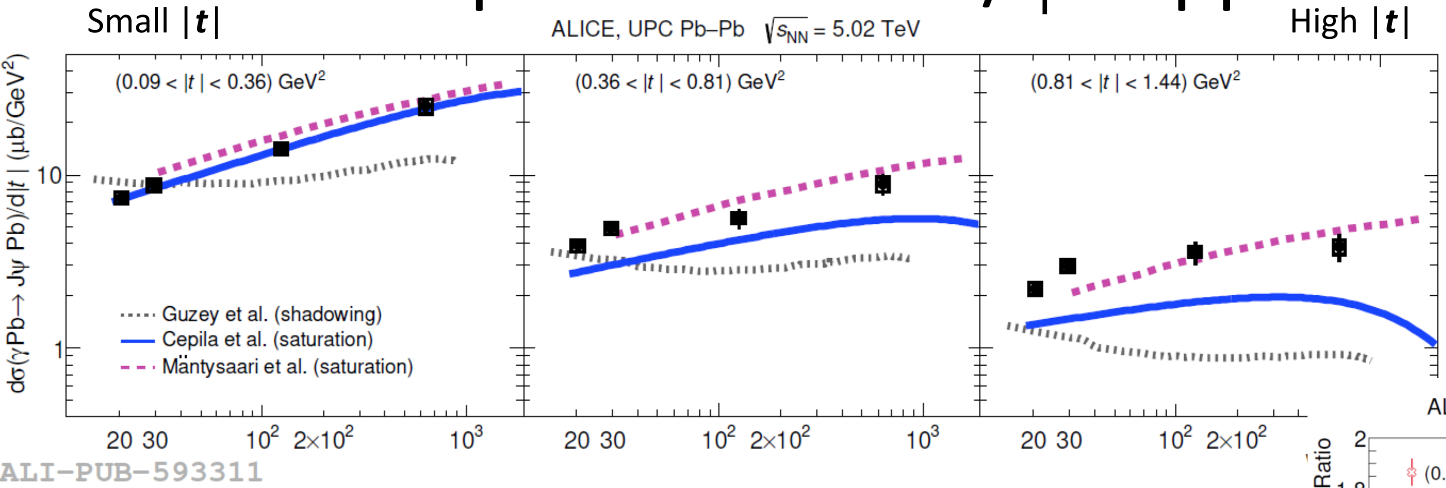


- Coherent J/ψ shows moderate nuclear suppression in a wide **rapidity** range
  - **Nuclear gluon shadowing factor** for $0.3 \times 10^{-3} < x_B < 1.4 \times 10^{-3}$ is $S_{Pb} = 0.64 \pm 0.04$
  - No model describes the full rapidity dependence
- Energy dependence of the photonuclear cross section down to $x_B \sim 10^{-5}$
  - High energy (low x_B) data favours both saturation (b-BK-A, GG-HS) and shadowing (LTA) models
- (Slope of) data of incoherent $|t|$ dependent J/ψ photoproduction cross section favour models with subnucleon fluctuations

$$S_{Pb} = \sqrt{\frac{\sigma_{\gamma Pb}}{\sigma^{IA}{}_{\gamma Pb}}}$$

STARlight: CPC, 212 (2017) 258-268.
GG-HS (saturation): PRC 97 (2) (2018) 024901.
EPS09 LO (shadowing): JHEP 04 (2009) 065.
LTA (shadowing): PRC 95 (2) (2017) 025204.
b-BK (saturation): arXiv:2006.12980 [hep-ph].
MS (saturation): PLB 772 (2017) 832.
GSZ (shadowing): PRC 99 (2019) 015201.
MSS (saturation): PRD 106, 7 (2022) 074019.

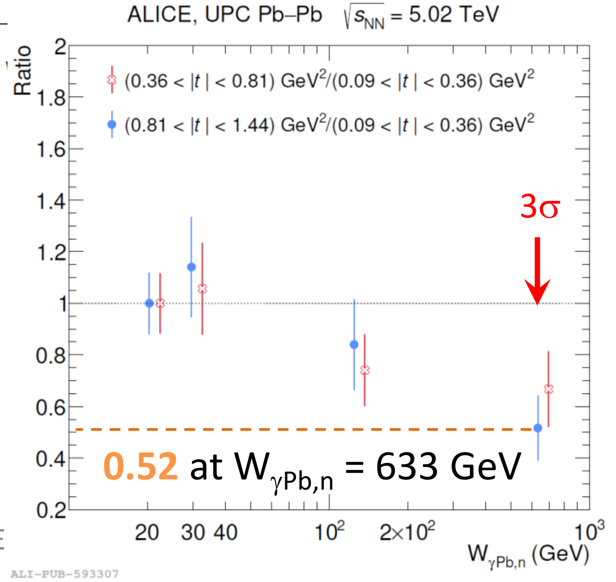
Incoherent photonuclear J/ψ suppression



arXiv:2503.18708
Accepted by **PRL**

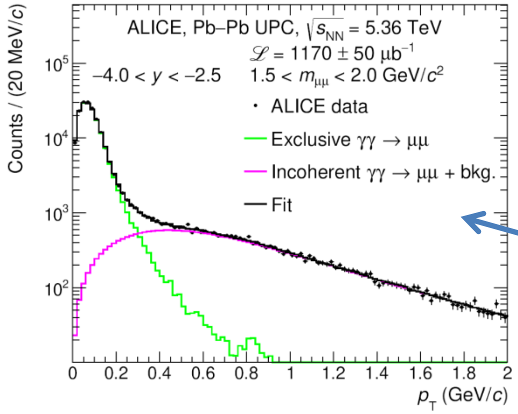
Guzey - PRC 99, 015201 (2019)
Cepila - PLB 852, 138613 (2024)
Mantysaari - PRD 106, 074019 (2022), arXiv:2312.04194 (2024)

- Double differential $W_{\gamma Pb,n}$ and $|t|$ measurement of the incoherent J/ψ photonuclear cross section
- The measurement extends from $W_{\gamma Pb,n}$ = 20 GeV to $W_{\gamma Pb,n}$ = 633 GeV
- R = 0.52 ± 0.13 (> 3 σ effect!) between data points
- Another hint in the search for gluon saturation at smaller spatial scales
  - $|t|$ = 0.1 GeV² corresponds to scale ~ 0.6 fm in size
  - $|t|$ = 1 GeV² ↔ ~ 0.2 fm
- LTA weak shadowing model is disfavoured

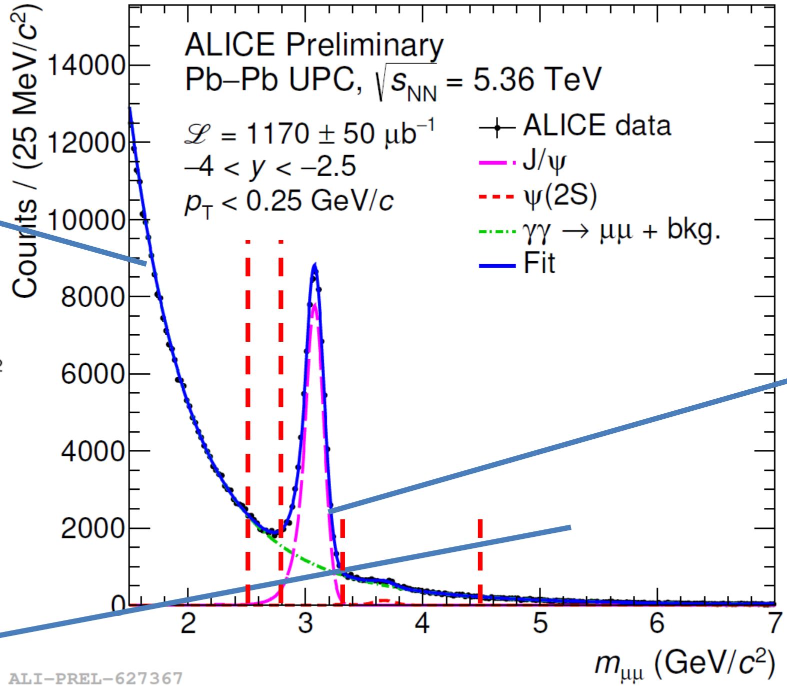


$\mu^+\mu^-$, coherent J/ψ and ψ(2S) production

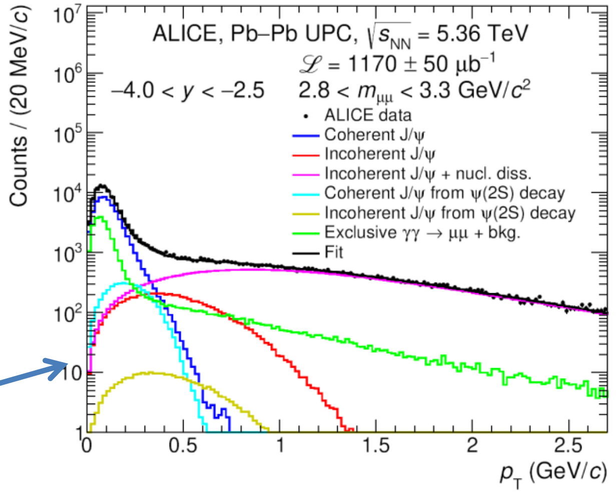
arXiv:2605.13569



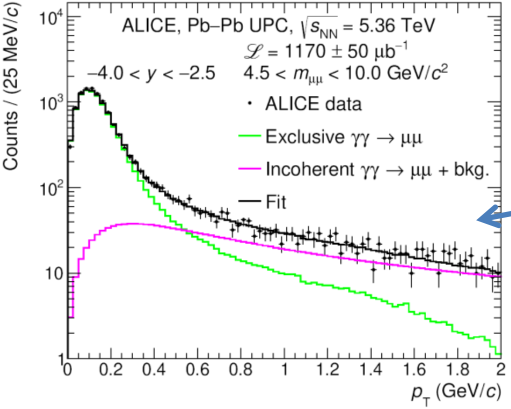
ALI-PUB-630266



ALI-PREL-627367



ALI-PUB-630261



ALI-PUB-630271

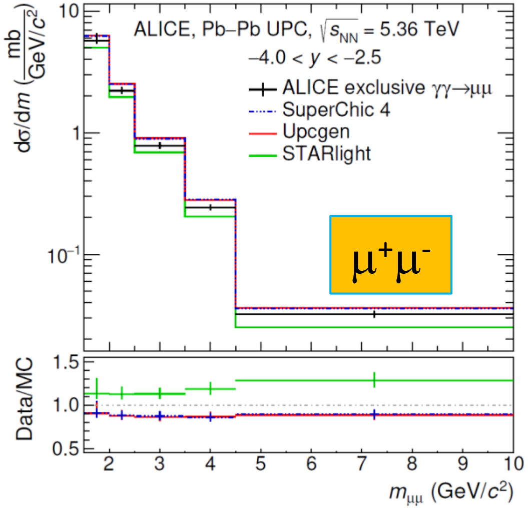
- No hardware trigger on single-muon p_T → increased statistics at lower invariant masses
- Streaming readout mode → 3x more statistics of J/ψ

- MC-based template for Coherent, Incoherent, feed-down J/ψ from coherent ψ(2S) and incoherent ψ(2S) decays
- H1 parametrization for incoherent J/ψ with nucleon dissociation:
- Data-driven template for γγ→μμ
- Fraction of incoherent J/ψ:
  - 3.7–5.9% for p_T < 0.25 GeV/c

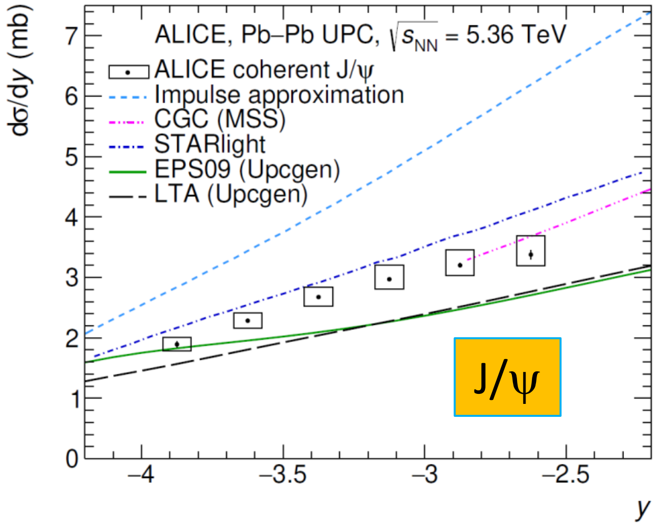
$\mu^+\mu^-$, coherent J/ψ and ψ(2S) production

STARlight: CPC, 212 (2017) 258-268
Upcgen: CPC, 277 (2022) 108388
SuperChic: EPJC, 80 (2020) 925
CGC: PRD 109 (2024) L071504

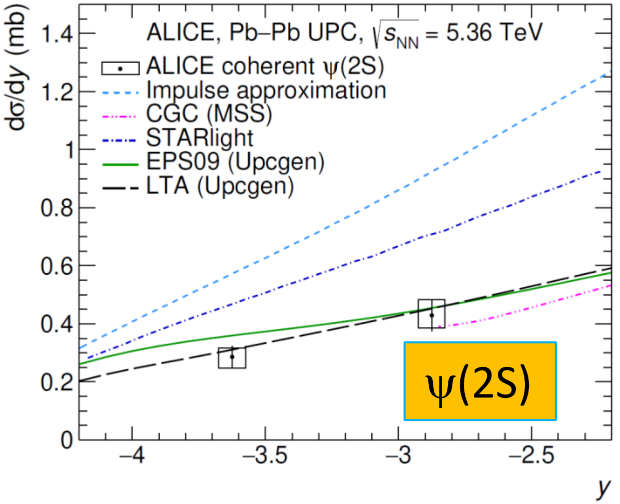
ALICE



ALI-PUB-630291



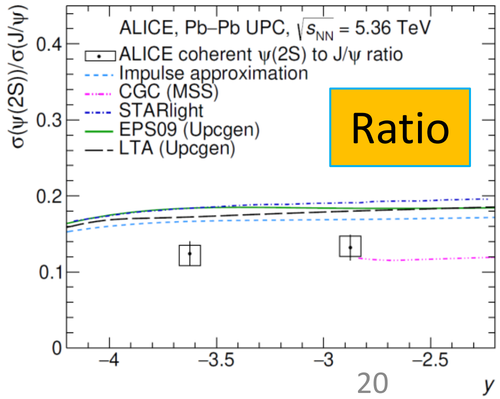
ALI-PUB-630276



ALI-PUB-630281

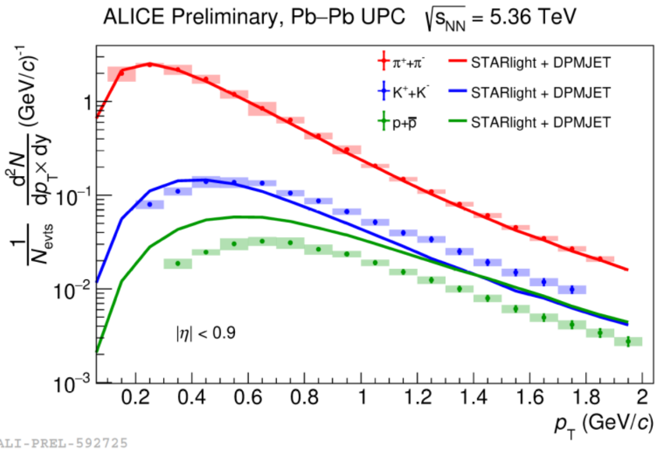
- Test of photon flux with μ pairs
  - STARlight describes data at -3<y<-2.5 but underpredicts by 40% in other regions
  - Upcgen and SuperChic4 overpredict data by 10-20%
- Measured J/ψ and ψ(2S) cross section
  - Suppression wrt. IA ($S_{Pb}^{J/\psi} \sim 0.76$, $S_{Pb}^{\psi(2S)} \sim 0.71$)
  - STARlight overpredicts data — Glauber-like rescattering is not enough
  - EPS09 (central set) and LTA (weak shadowing) **underestimate** measured **J/ψ** cross section but **consistent** with **ψ(2S)** data
  - **Good agreement of CGC** model with shape fluctuations
- Ratio$|_{-4<y<-2.5}$ = 0.131 ± 0.012 (stat.) ± 0.013 (syst.) → **1.4-1.9σ** below all models, except **CGC**

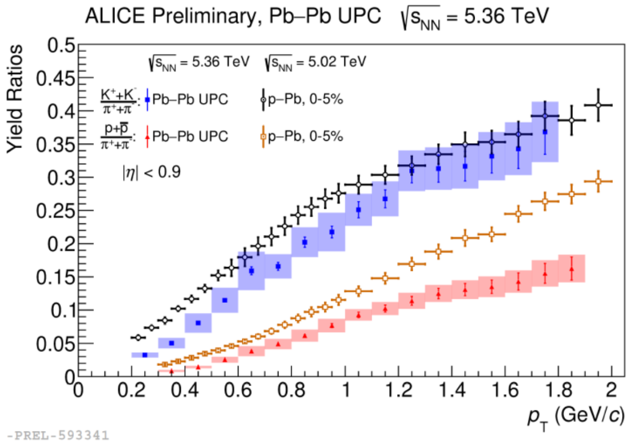
arXiv:2605.13569

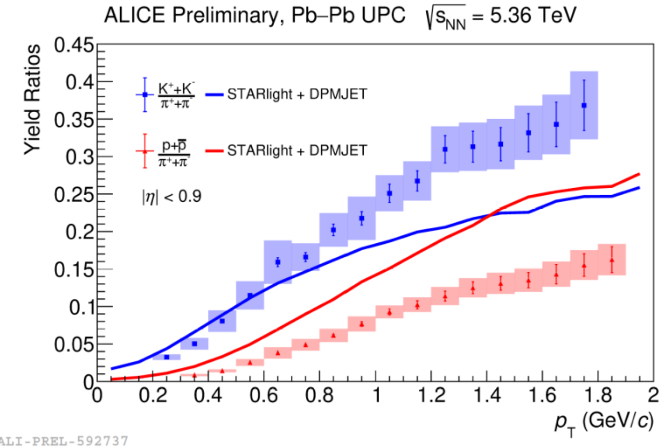


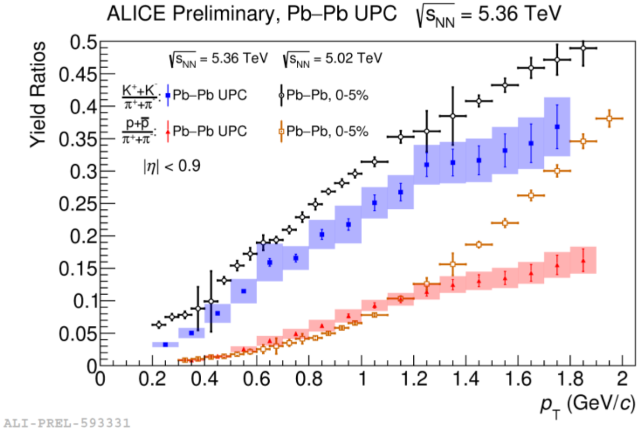
ALI-PUB-630286

p_{T} spectra for identified hadrons in inclusive UPC





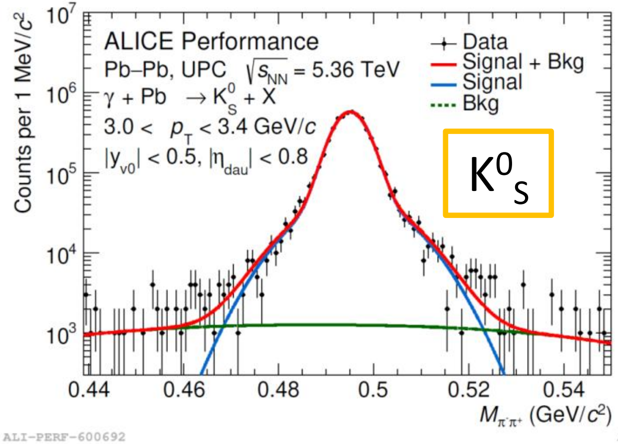


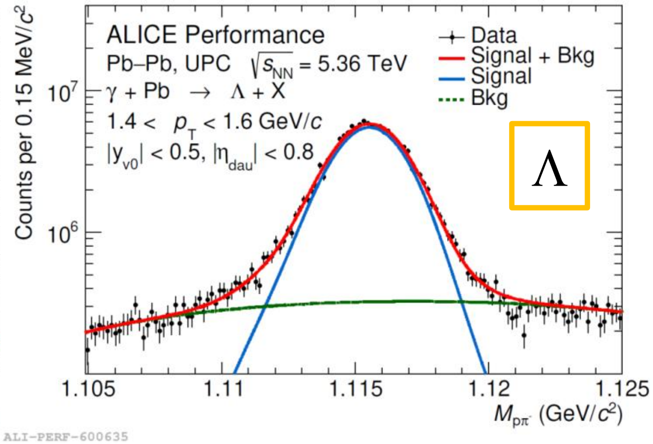


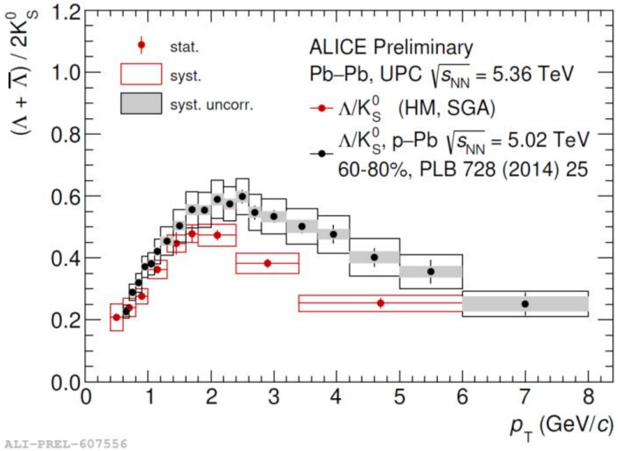
- Corrected yields of π, K, p
- Spectra compared to STARLight (photon flux) + DPMJET (nuclear breakup)
- MC failed to describe ratios
  - Similar behaviour to pp collisions
- Comparison to other systems
  - K/π: γ-Pb shape similar to p-Pb and Pb-Pb
  - p/π: γ-Pb shape similar to smaller systems (p-Pb or pp)

STARlight: CPC, 212 (2017) 258-268
DPMJET: Phys. Rev. C 83 (2011) 041901

Strangeness in single gap UPC events







- K^0_S mesons and Λ baryons spectra measured in inclusive photonuclear reactions
- Baryon/meson enhancement at the intermediate p_T
- Similar (and better) shape to ratios in low multiplicity p-Pb collisions ($8 < N_{ch} < 41$) than in MB p-Pb collisions ($0 < N_{ch} < 41$)
- Studies of collective expansion in UPC
  - Vector Meson Dominance model → effectively hadron-Pb collisions

ALICE Kraków group

- Prof. dr hab. Marek Kowalski
  - Team Leader (up to 31.05.2026)
  - Collaboration Board Member

- Prof. dr hab. Jacek Otwinowski
  - **FIT Project Leader**
  - Management Board Member
  - FoCal Institutional Board Member
  - Collaboration Board Member
  - Team Leader (since 1.06.2026)

IFJ Seminar 21.05.2026
NO2 Seminar 29.06.2026

- Prof. dr hab. Andrzej Rybicki

- Dr hab. Adam Matyja
  - Physics Working Group - Ultra-peripheral Collisions and Diffraction (**PWG-UD**) **convener**
  - Physics Board Member
  - **Run Manager** (4x)

From Robert Munzer at ALICE Week 14.07.2025

- Dr inż. Iwona Sputowska
  - Physics Analysis Group (**PAG**): Event-by-Event / Fluctuations **coordinator**
  - Conference Committee (**CC**) Member

IFJ Seminar 04.12.2025

- Dr Sahil Upadhyaya
  - **FIT System Run Coordinator**
  - **Run Manager**

- Dr Sandor Lokos
  - **FIT System Run Coordinator**

Białasówka 13.03.2026

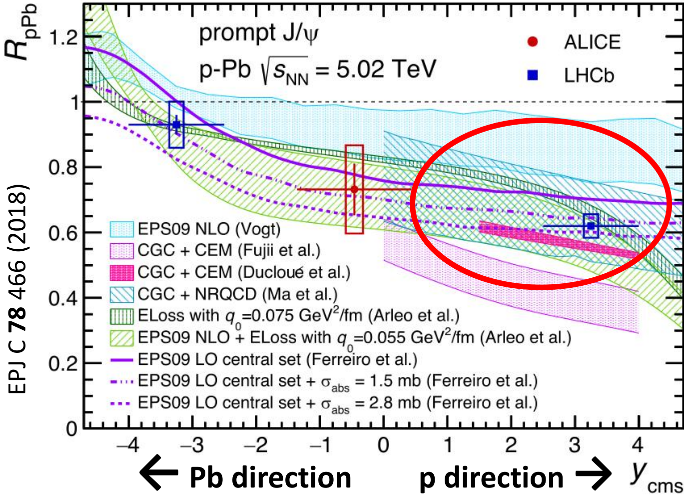
Studies of Drell-Yan process

Sahil Upadhyaya

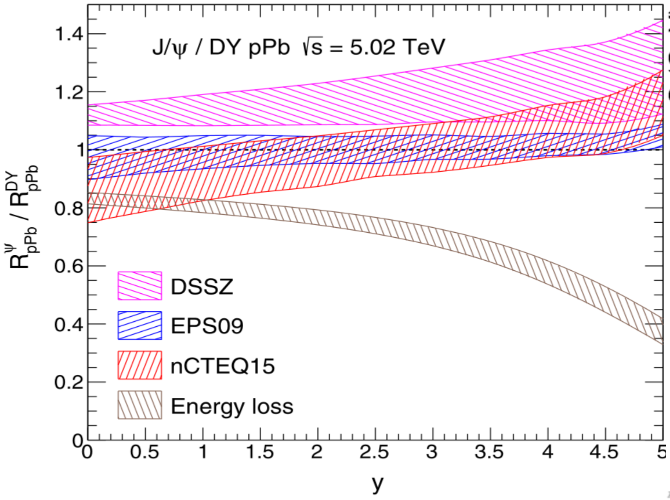
- Leading-order process → clean probe for parton distribution functions (PDFs)
- Nuclear PDFs (nPDFs) can be studied using the **nuclear modification factor** (R_{pA})
  - Larger suppression at forward rapidity in p-going direction for prompt J/ψ
- **Double ratio**: Cancellation of nPDF effects and sensitivity to coherent energy loss
  - → study Charmonia production at LHC energies
  - More sensitive for low invariant mass region (< 20 GeV/c²)
- Access to **low Bjorken-*x*** ~ 10^{-5} with MFT

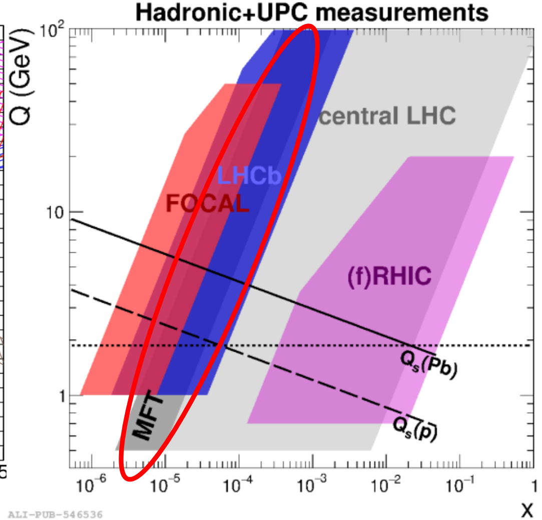
$$R_{\mathrm{pA}}(y,\, p_{\mathrm{T}}) = \frac{1}{\mathrm{A}} \frac{\mathrm{d}^2\sigma_{\mathrm{pA}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}^2\sigma_{\mathrm{pp}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}$$

$$\mathcal{R}^{\psi/\mathrm{DY}}_{p\mathrm{A}}(y) \equiv R^{\psi}_{p\mathrm{A}}(y)/R^{\mathrm{DY}}_{p\mathrm{A}}(y)$$

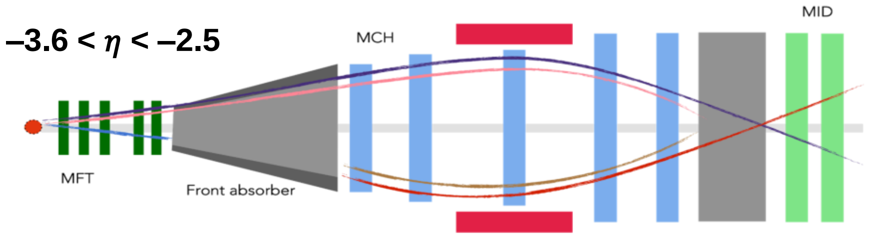


F. Arleo, S. Peigné, PRD **95** 011502(R) (2017)





First measurements of Drell-Yan process

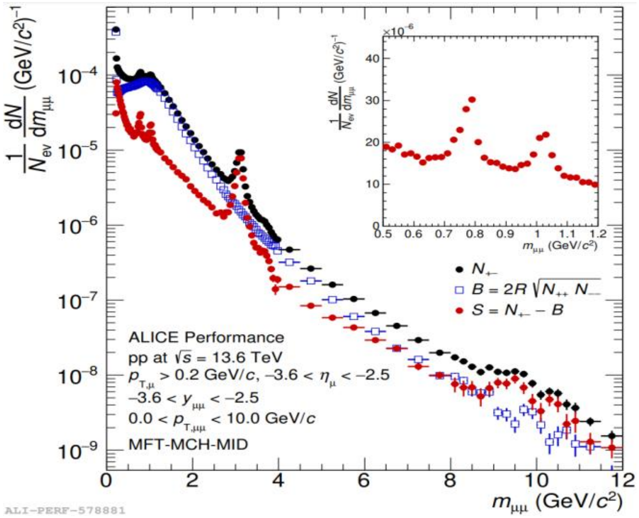


DY with muonic decay channel

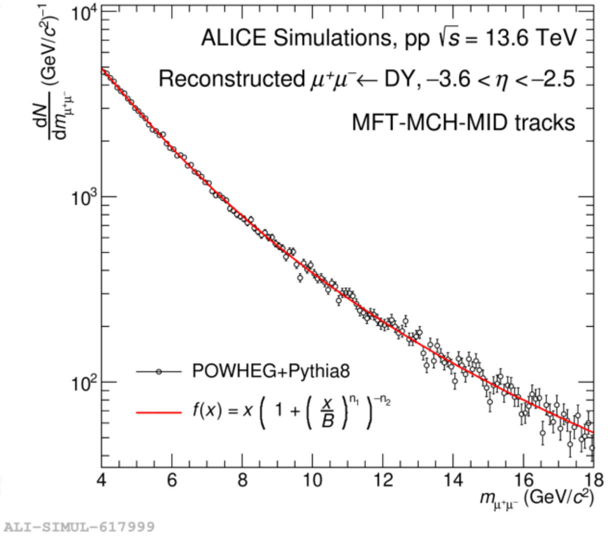
Sahil Upadhyaya

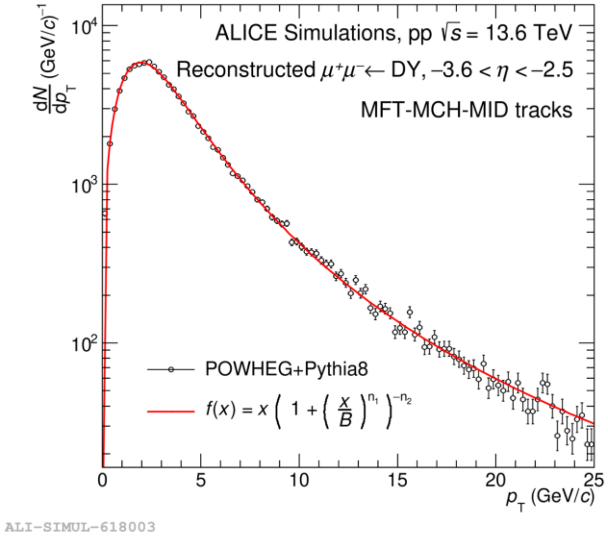
GOAL:

Measurement of low-mass DY lepton pairs ($m_{\mu^+\mu^-}^{DY}$ down to 4 GeV/c^2) in pp, pO, p-Pb collisions to constrain nPDFs at low-Q^2 and small-x (<10^{-4})



ALICE Run 3 muons data





POWHEG+Pythia8 Drell-Yan simulations for ALICE Run 3

Initial state entanglement $\leftrightarrow$ entropy

- Proton is entangled partonic system
- To observe it we use DIS or pp data
- Observable:
  - von Neumann entropy of IS
    $\rightarrow$ proxy: Shannon entropy of FS
  - final state distribution of charged particles

Sandor Lokos

$$S_{\text{parton}} \stackrel{?}{=} S_{\text{hadron}}$$

- pQCD calculations with maximal entropy agrees with DIS data

$\rightarrow$ More data in proton-proton!

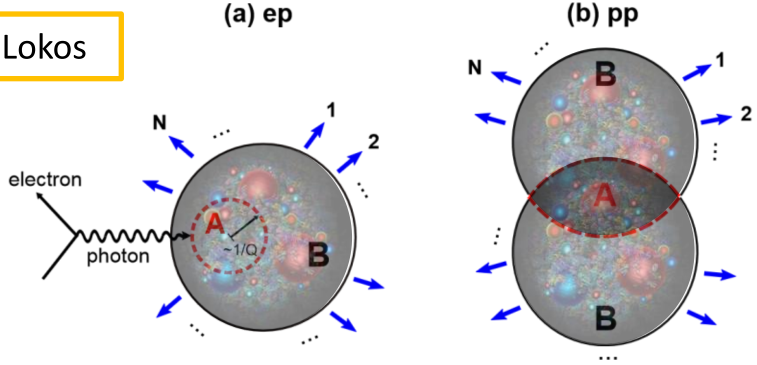
- Maximal entropy or Maximally entangled: partonic microstates have equal probability

$$P(N) \sim Uniform(N)$$

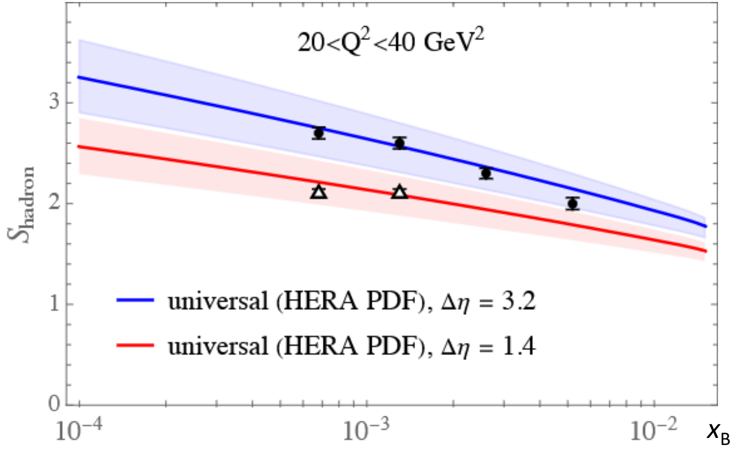
EPJ C82 (2022) 2, 111

$$S = \ln\left(N(x,Q^2)\right) = \ln\left(\frac{2}{3}\left(xq(x,Q^2) + xg(x,Q^2)\right)\right)$$

PRL 124 (2020) 6, 062001



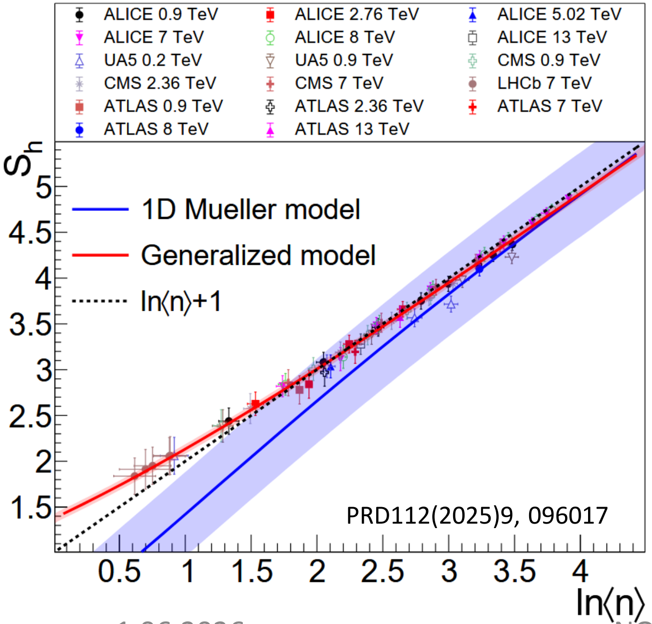
$$S_A = -tr[\hat{\rho}_A \ln \hat{\rho}_A] = S_B = -tr[\hat{\rho}_B \ln \hat{\rho}_B] \stackrel{?}{=} S_{\text{hadron}} = -\sum P(N) \ln P(N)$$

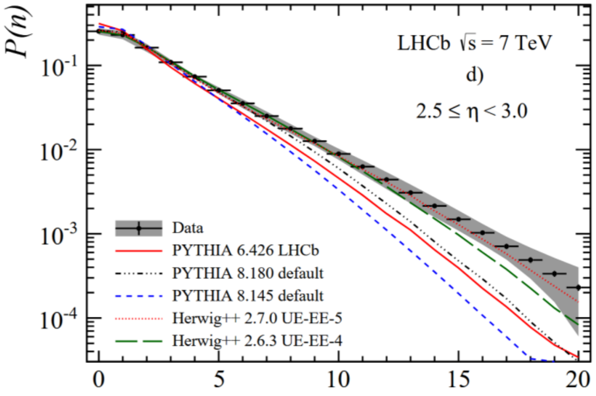


Rep. Prog. Phys. 87 120501

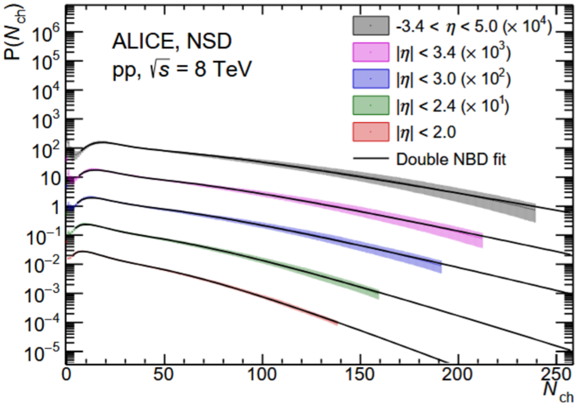
From final state distributions to Results

- $P(n)$ measured
  - moving rapidity window (LHCb, H1)
  - opening rapidity window (ALICE, CMS)
- Calculable directly from data
  - $\ln\langle n\rangle = \ln \sum_n nP(n)$
  - $S = -\sum_n P(n) \ln P(n)$





EPJC(2014)74:2888



EPJC(2017)77:852

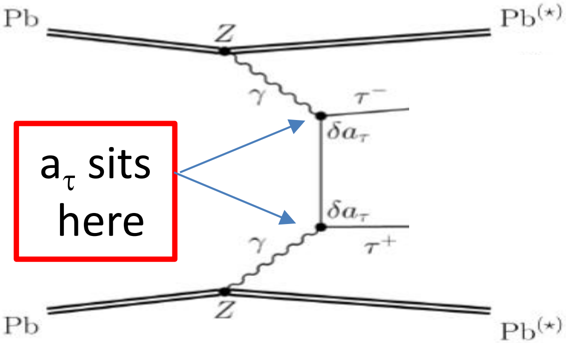
Sandor Lokos

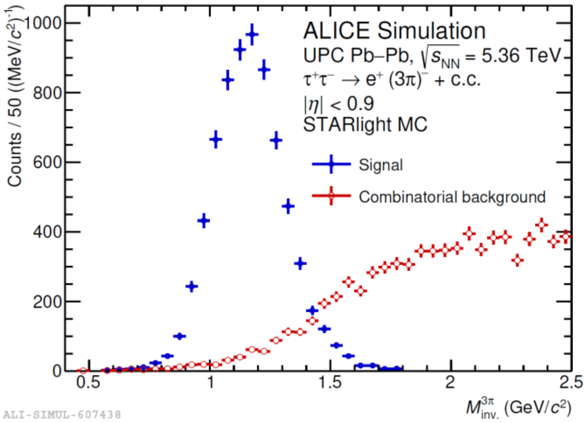
- Data from 200 GeV to 13 TeV
- Deviation from the Mueller model at low multiplicities (single fluctuating source)
- General model (Superposition of many fluctuating particle sources) describes the data (no recombination!)
- Both converge to the maximal entropy case
- What is the outcome of the lowest multiplicities? → UPC

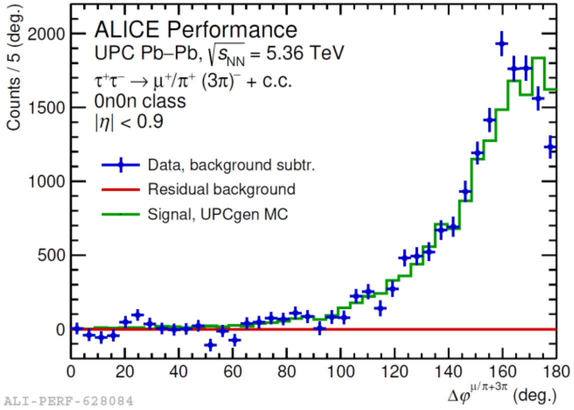
Exclusive τ pair production

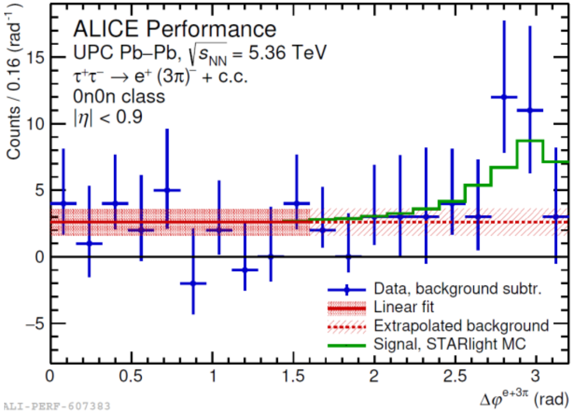
- τ pair photoproduction in Pb-Pb UPC → Cross section scales with Z^4
- τ leptons decays quickly and can not be observed directly
  - Difficult due to at least 1 ν in each τ decay
- τ pair photoproduction in Pb-Pb UPC channels
  - $\mu/\pi + 3\pi$
  - $e+3\pi$
- Sensitive to anomalous magnetic moment of τ lepton

Partially done with Szymon Cisek
and Przemysław Blicharz



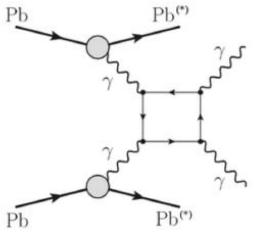


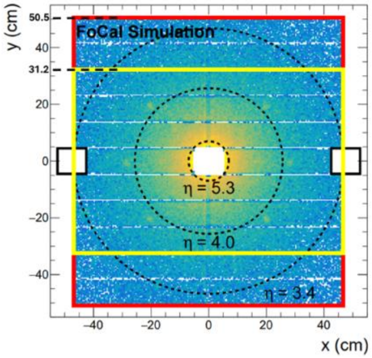


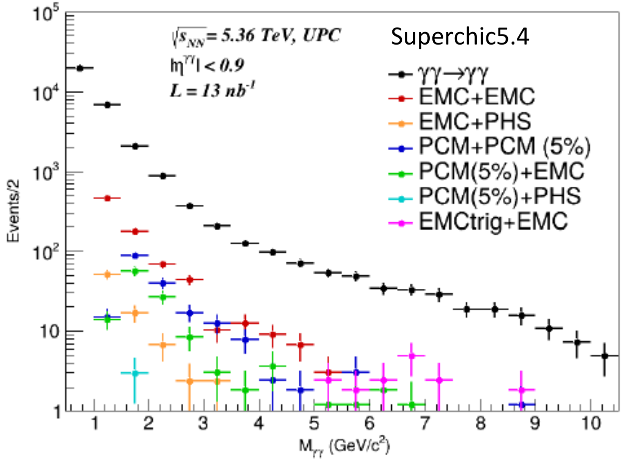


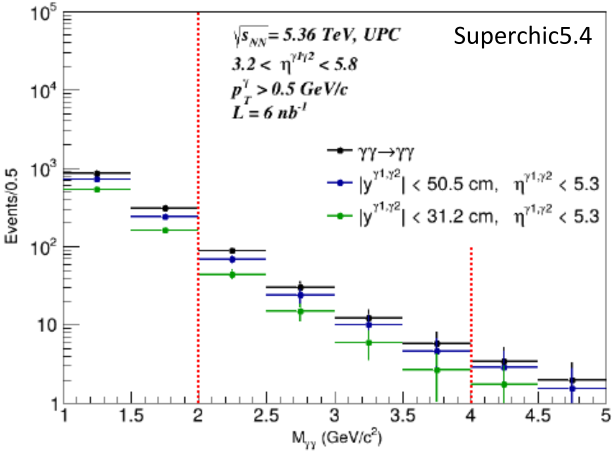
Light-by-light scattering feasibility studies

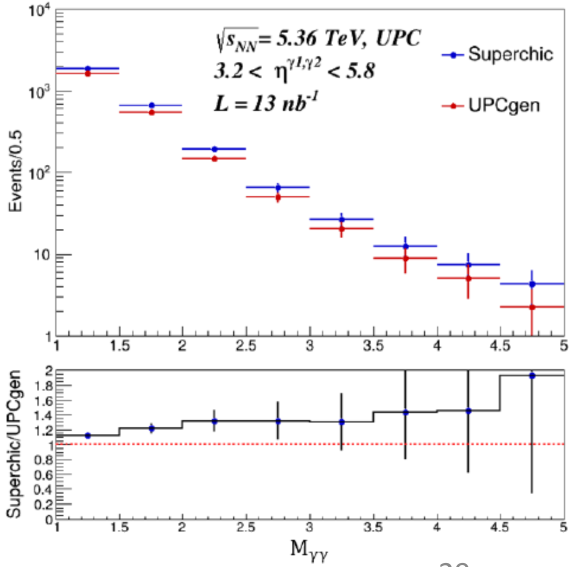
- Many topologies in Central Barrel and in FoCal
  - PCM, EMCal, PHOS, FoCal
- Comparison between Superchic and UPCgen
  - → different photon flux implementation most visible in a forward direction
- Sensitive to BSM physics









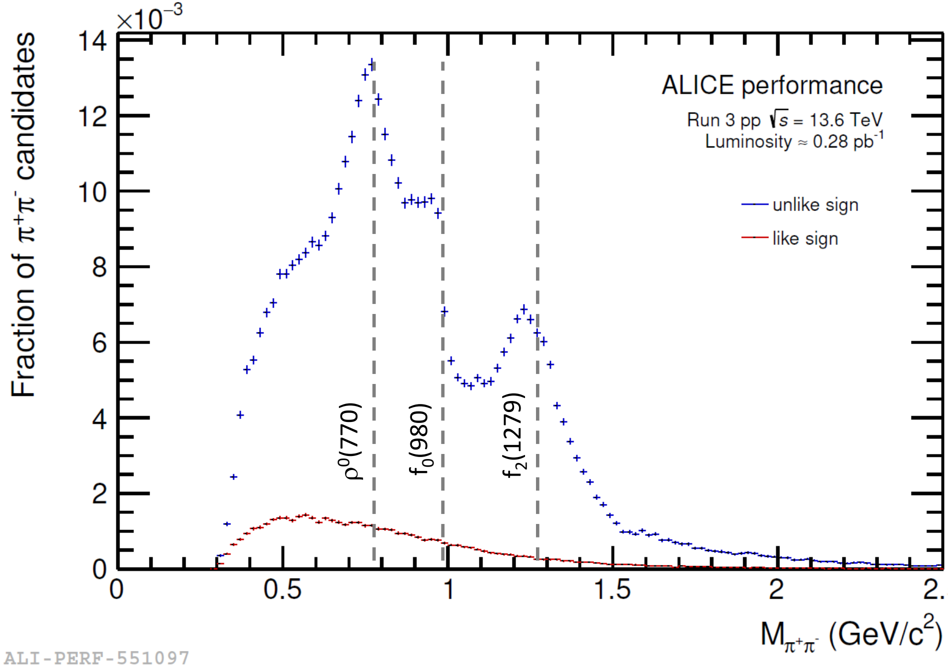


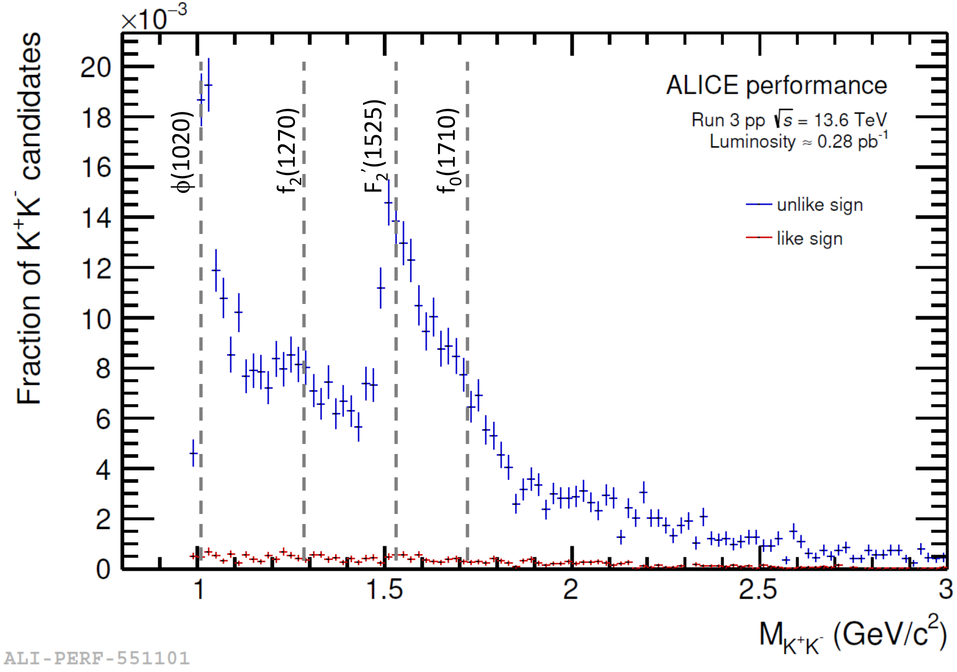
K.Zajac, A.M., Acta Phys. Pol. B Proc. Suppl. **18**, 5-A36 (2025)

Run 3 data analysis in pp: CEP

- Resonance structure visible in
  - $\pi\pi$ - $\rho^0(770)$, $f_0(980)$, $f_2(1279)$
  - KK - $\phi(1020)$, $f_2(1270)$, $f_2'(1525)$, $f_0(1710)$

500 x more data!

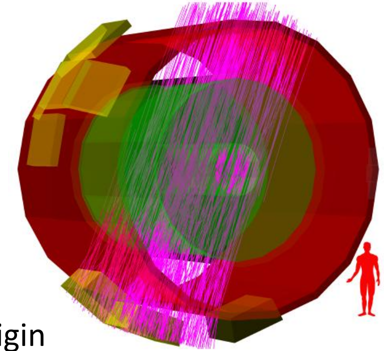


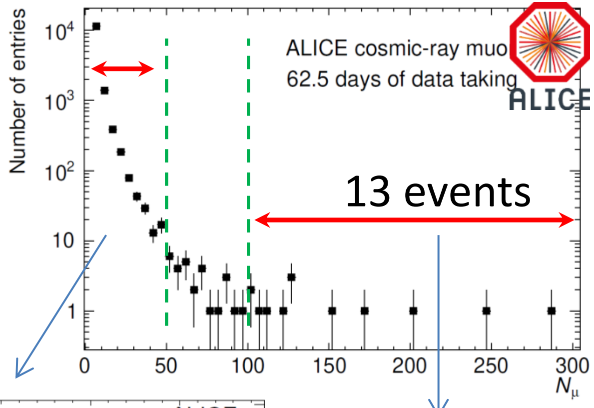


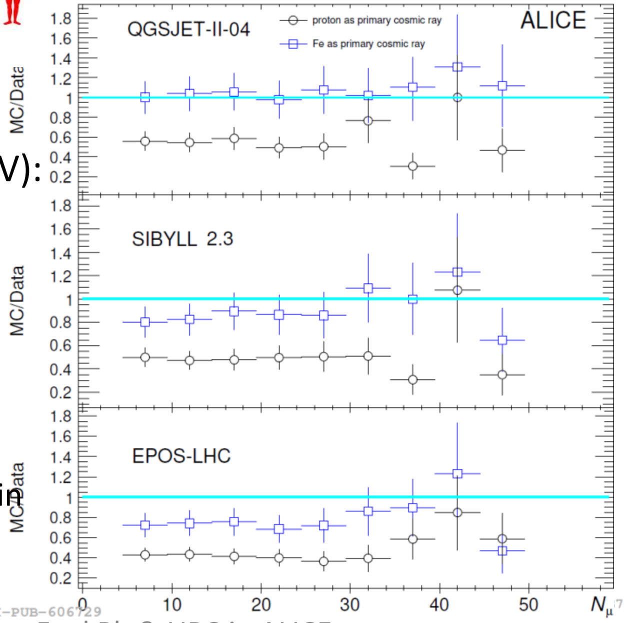
Multimuons in cosmic-ray events

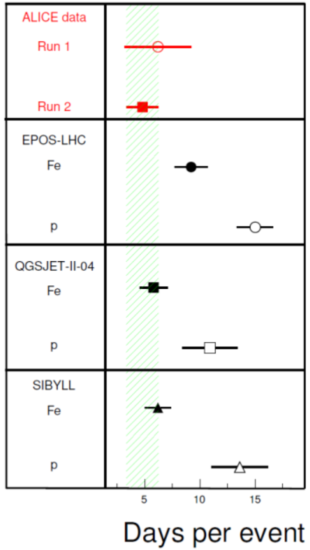
Bonus

- Run 2: 2x Run 1 live time
- Two ranges:
  - $4 < N_\mu < 50$ (spectra)
  - $N_\mu > 100$ (rate)
- Two extreme hypothesis:
  - Proton as primary cosmic ray origin
  - Fe as primary cosmic ray origin
- Comparison to three high energy hadronic interactions models + Corsika event generator (low energy <100 GeV):
  - Best description by heavy component with **QGSJET-II-04**
    - Mixed-ion composition not suported
    - Muon deficit in low multiplicity range
  - Muon deficit in **SIBYLL 2.3**
  - Muon deficit in **EPOS-LHC**
- HMM shows better description by QGSJET-II-04 and SIBYLL 2.3
  - Compatible with energy production in a range of a knee in the cosmic-ray
  - Constrain production mechanisms









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Summary

- Neutron and proton emission have been measured
  - Access to various impact parameter classes
- New constraints on the nuclear PDFs, inner structure, saturation or shadowing models, photoproduction mechanisms imposed with J/ψ and $\psi(2S)$ measurements
  - Onset of saturation with double differential measurement?
- New and first measurement in UPC Run 3 with J/ψ, $\psi(2S)$ and $\mu^+\mu^-$ pairs
- Studies of collectivity with inclusive measurements
- QED studies with lepton pair production
- Many ongoing analyses $\rightarrow$ stay tuned
- ALICE is truly multi-purpose experiment
  - Not only QCD (QGP) studies, but QED and astroparticle measurements