U.S. DEPARTMENT OF ENERGY

Office of Science

Recent results and prospects of UPC and diffraction physics at ALICE

Daniel Tapia Takaki

798. WE-Heraeus-seminar

Bad Honnef, October 25, 2023

KU THE UNIVERSITY OF KANSAS

ALICE publications using Run 2 data

- Coherent J/ψ photoproduction at forward rapidity in ultra-peripheral Pb–Pb collisions at √s = 5.02 TeV
  Phys. Lett. B798 (2019) 134926
- Coherent photoproduction of ρ0 vector mesons in ultra-peripheral Pb–Pb collisions at √s = 5.02 TeV
  JHEP 06 (2020) 035
- Coherent J/ψ and ψ′ photoproduction at midrapidity in ultra-peripheral Pb-Pb collisions at √s = 5.02 TeV
  Eur. Phys. J. C 81 (2021) 712
- First measurement of coherent ρ0 vector mesons in ultra-peripheral Xe–Xe collisions at √s = 5.44 TeV
  Phys. Lett B 820 (2021) 136481
- First measurement of the |t| dependence of coherent J/ψ photonuclear production
  PLB 817 (2021) 136280
- Neutron emission in ultraperipheral Pb–Pb collisions at √s = 5.02 TeV
  Phys. Rev. C 107 (2023) 6, 064902 -- published on June 5

ALICE UPC analyses recently submitted for publication

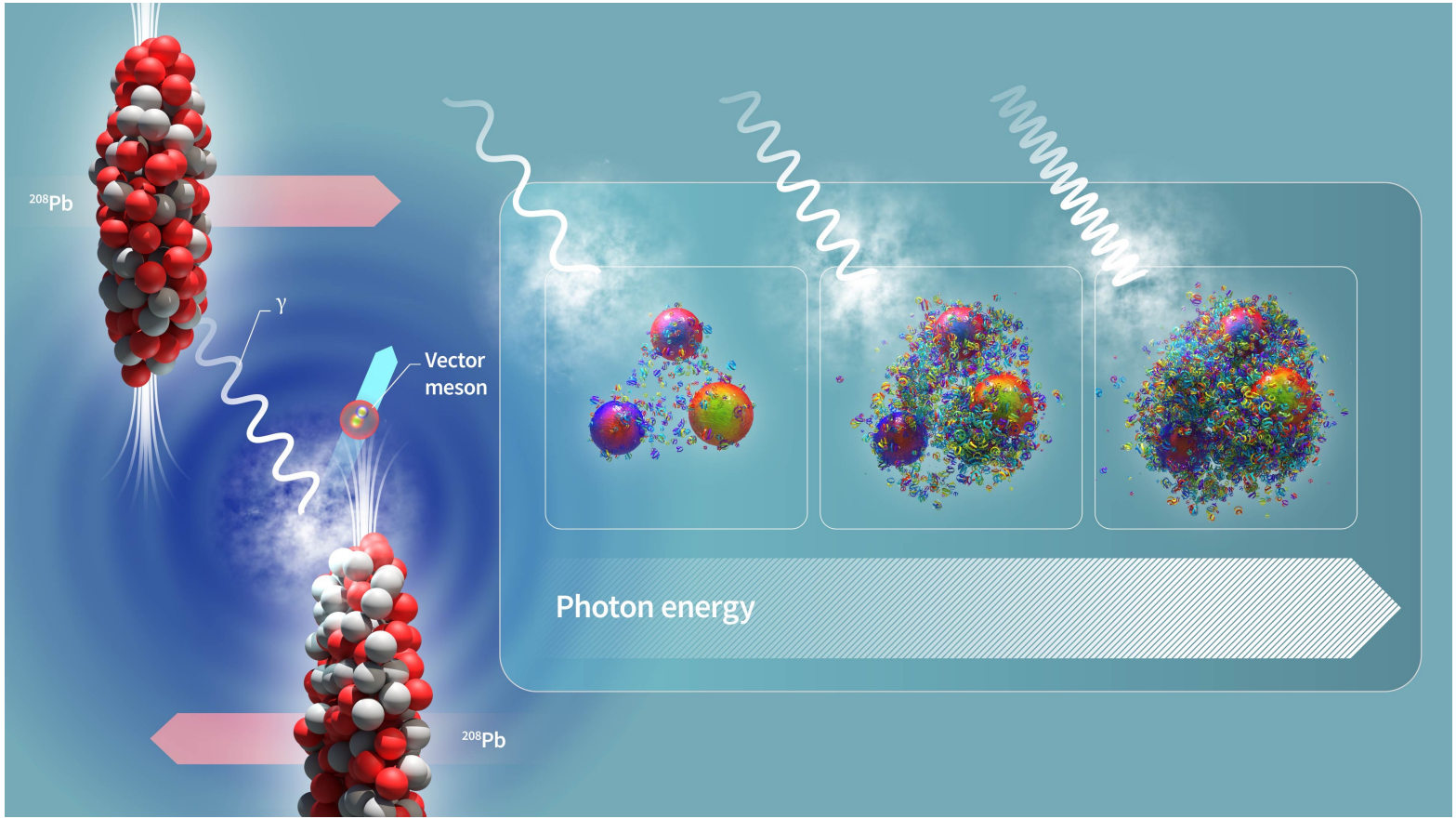
- **Energy dependence of coherent photonuclear production of J/ψ mesons in ultra-peripheral Pb-Pb collisions at 5.02 TeV**
  https://arxiv.org/abs/2305.19060
  https://doi.org/10.1007/JHEP10(2023)119
  Published by JHEP, October 20

- **Exclusive and dissociative J/ψ photoproduction, and exclusive dimuon production, in p−Pb collisions at 8.16 TeV**
  https://arxiv.org/abs/2304.12403
  Accepted for publication by PRD

- **First measurement of the |t|-dependence of incoherent J/ψ photonuclear production**
  https://arxiv.org/abs/2305.06169
  Submitted to PRL

- **First polarisation measurement of coherently photoproduced J/ψ in ultra-peripheral Pb−Pb collisions at 5.02 TeV**
  https://arxiv.org/abs/2304.10928
  Submitted to PLB

Ultra peripheral collisions (UPC)



RHIC and LHC as Photon Colliders

- **Ultra Peripheral Collisions (UPC)** can explore a wide range of energies using almost real photons

  $k = \gamma M_V \exp(\pm,y)$
  Up to several TeV in γp
  Up to ~ 700 GeV/nucleon in γA
  Up to ~ 150 GeV in $\gamma\gamma$ using UPC PbPb,
  ~ 4 TeV in in $\gamma\gamma$ using UPC pp

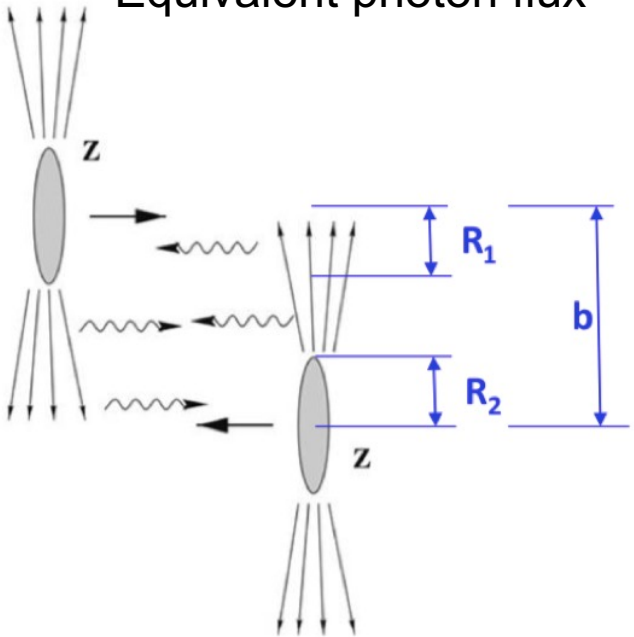
- UPCs at the LHC probe the hadronic structure over a broad and unique Bjoren *x* region, yet the precision not compatible to DIS machines like the EIC

  $x = M_V/\gamma m_p \exp(\pm,y)$

See talk by V. Guzey and O. Villalbos Baillie

Interactions mediated by the EM interactions

Equivalent photon flux



Gluon saturation

At high energies, or for heavy nuclei at lower energies, gluon saturation is predicted

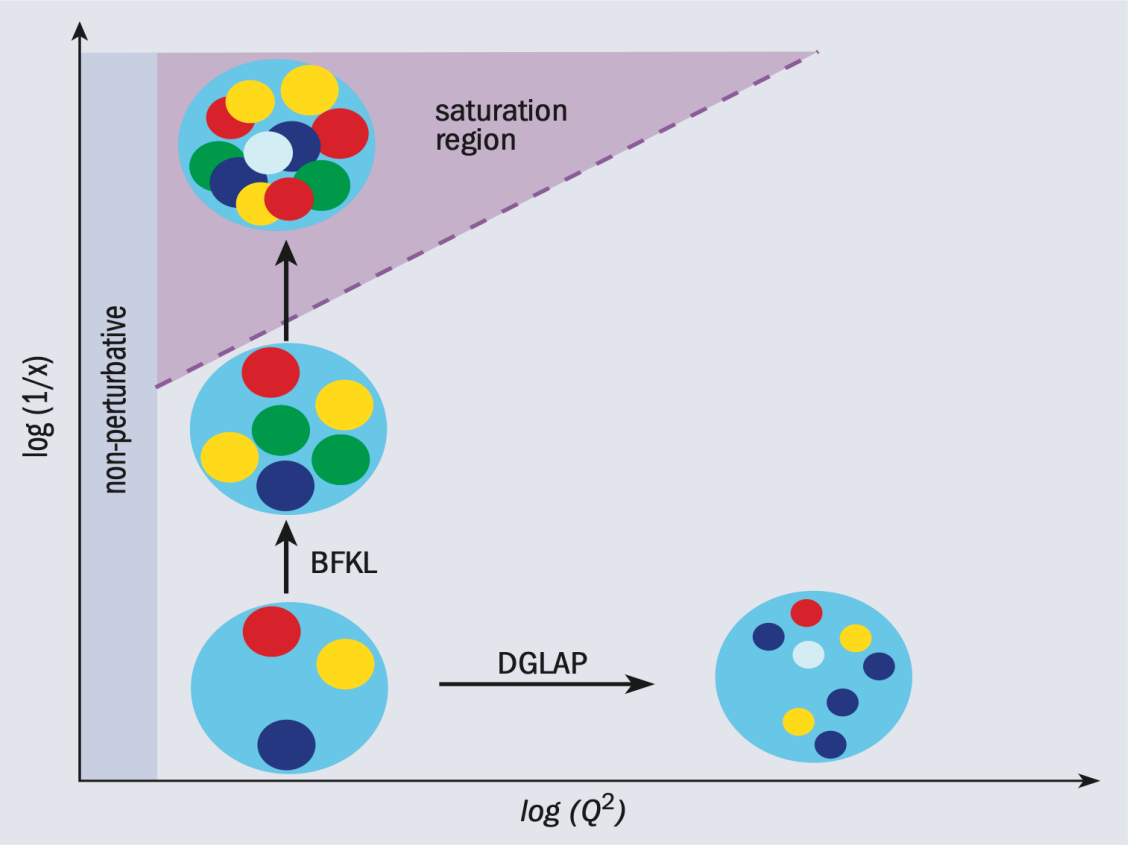
gluon emission

gluon recombination

Dynamical equilibrium of gluon saturation state reached

- Non-linear QCD evolution equations introduced, but how is gluon saturation triggered?
- Can we determine experimentally the saturation scale (Q_S)?
- Is there a state of matter formed by gluon saturated matter with universal properties?

Evolution of the hadronic structure with Bjorken-x and Q^2

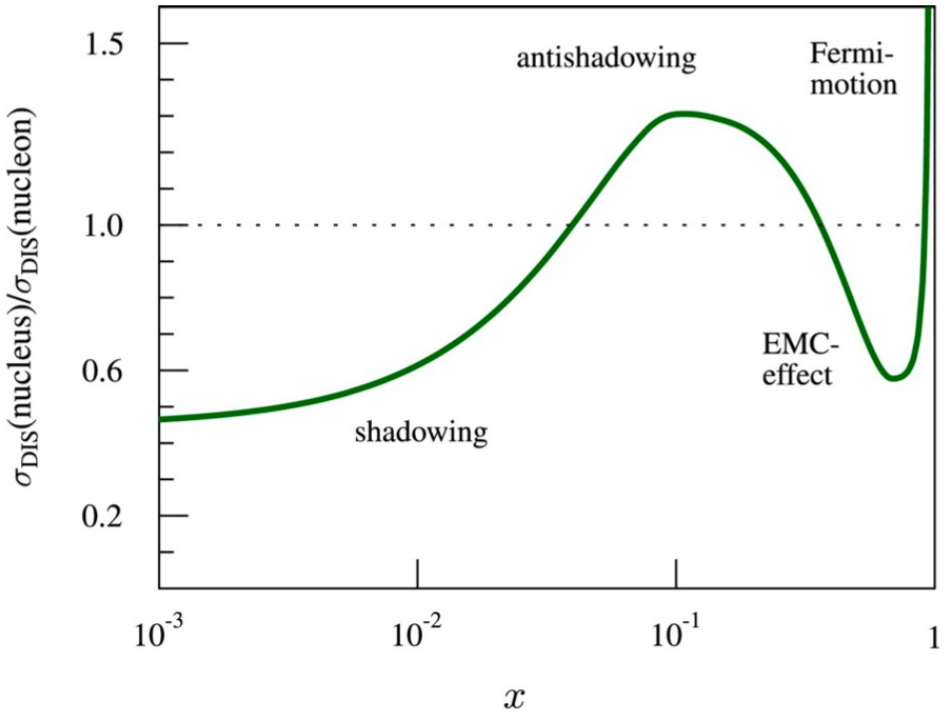


- Experimental observables needed to map out the transition between the dilute and saturation regimes
- For nuclei, the saturation scale is enhanced by a $A^{1/3}$ factor

$$(Q_s^A)^2 \approx cQ_0^2 \left[\frac{A}{x}\right]^{1/3}$$

Nuclear shadowing experimentally confirmed, but not fully understood

$$R = \frac{f_{i/A}}{A f_{i/p}} \approx \frac{\text{measured}}{\text{expected if no nuclear effects}}$$



- Experimental observation that parton distributions are different for protons and nuclei
- What's the mechanism responsible for shadowing? How is gluon saturation related?
- The knowledge of the initial state of nuclei also needed for understanding the QGP evolution

Coherent J/ψ in UPC Pb-Pb

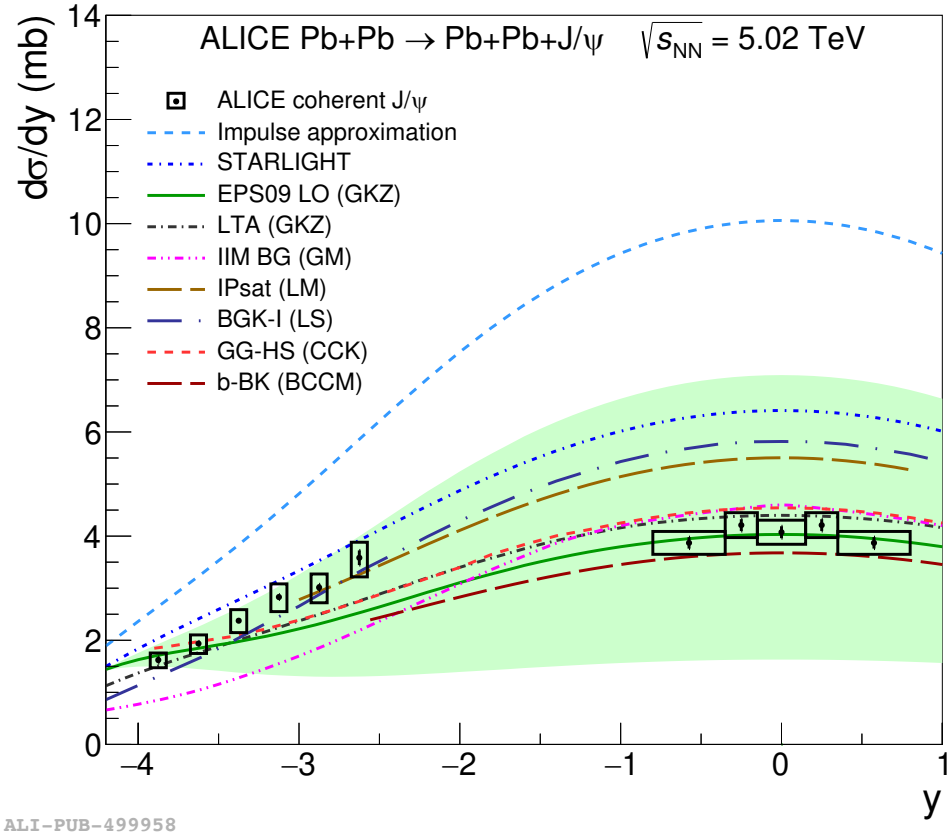
Eur. Phys. J. C 81 (2021) 712

- Confirmation of nuclear shadowing with Run 2 data
- No model can describe the rapidity dependence

$$W^2_{\gamma p} = 2E_p M_{J/\psi} e^{\pm y}$$

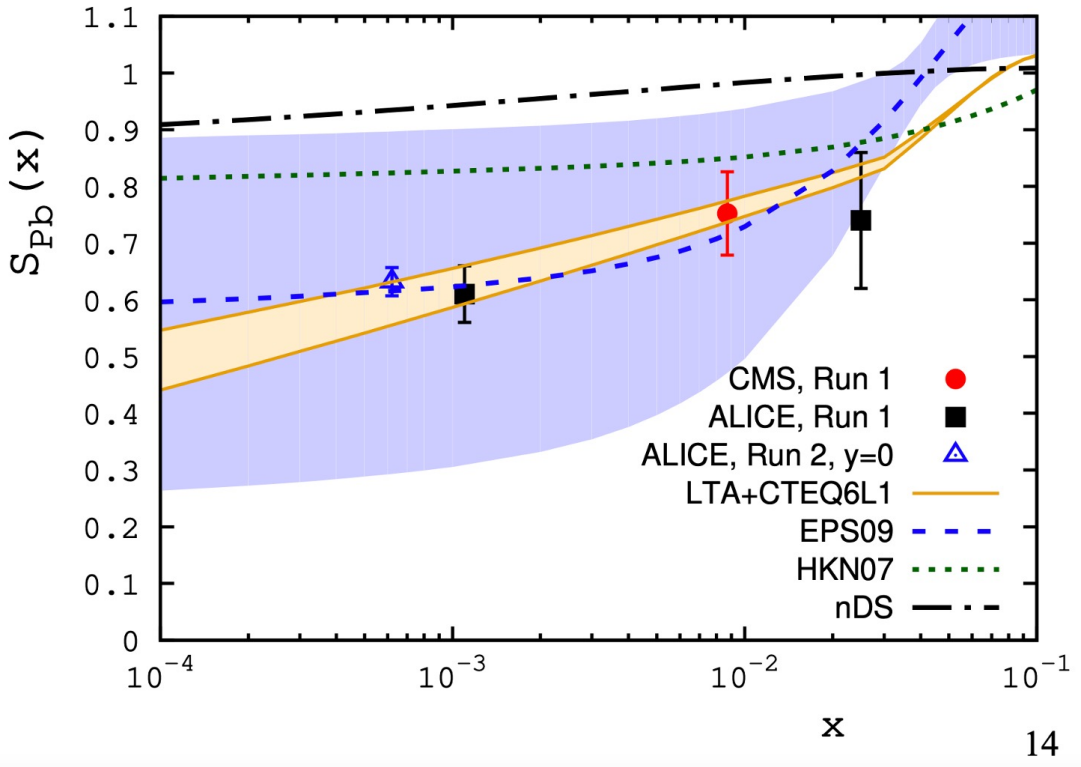
Mid-rapidity x ~10^{-3}

Forward rapidity 95% at x ~ 10^{-2}
5% at x ~ 10^{-5}



Nuclear suppression factor for UPC J/ψ: Comparing γPb to γp

V. Guzey et al. PLB 726 (2013)



An experimental definition, which can be linked to PDFs at LO

$$S_{Pb}(x) = \sqrt{\frac{\sigma_{\gamma A \to J/\psi A}(W_{\gamma p})}{\sigma^{\mathrm{IA}}_{\gamma A \to J/\psi A}(W_{\gamma p})}} = \kappa_{A/N} \frac{x g_A(x,\mu^2)}{A x g_N(x,\mu^2)}$$

Run 1 data from ALICE was the first at indicating nuclear gluon shadowing at x ~ 10^{-3}

Large scale NLO uncertainties should cancel in the $S_{Pb}(x)$ ratio

ALICE results at y=0 have no ambiguity on the photon energy

Two-fold ambiguity on the photon direction in symmetric systems

$$W^2_{\gamma p} = 2E_p M_{J/\psi} e^{\pm y}$$

Symmetric systems (pp, A-A) suffer from the two-fold ambiguity on the photon direction

Positive rapidity Negative rapidity

$$\frac{d\sigma}{dy} = n(+y)\sigma(\gamma p, +y) + n(-y)\sigma(\gamma p, -y)$$

Analyses of UPC asymmetric systems (p-Pb) provide a model independent way to study the energy dependence of $\sigma(\gamma p)$

Neutron-dependence of coherent J/ψ in UPC Pb-Pb

The photon flux (n) depends on the impact parameter

Decomposed in terms of neutron configurations emitted in the forward region

$$\frac{d\sigma}{dy} = \frac{d\sigma(\mathrm{0n0n})}{dy} + 2\frac{d\sigma(\mathrm{0nXn})}{dy} + \frac{d\sigma(\mathrm{XnXn})}{dy}$$

Solving the linear equations resolves the two-fold ambiguity for VMs at y ≠ 0

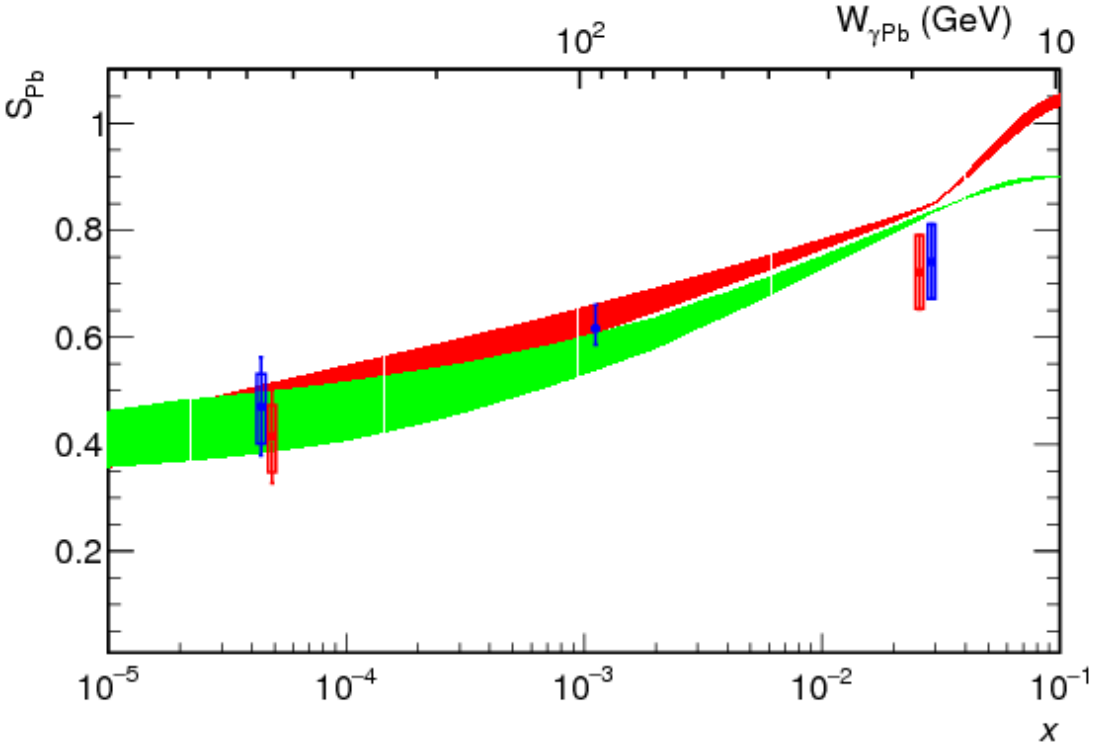
Positive rapidity Negative rapidity

$$\frac{d\sigma}{dy} = n(+y)\sigma(\gamma\mathrm{p}, +\mathrm{y}) + \mathrm{n}(-\mathrm{y})\sigma(\gamma\mathrm{p}, -\mathrm{y})$$

Guzey, Strikman, Zhalov, EPJC 74 (2014) 7, 2942

Nuclear suppression factor for peripheral (not UPC) J/ψ

J.G. Contreras, *Phys. Rev .C* 96 (2017) 1, 015203



Run 1 data from ALICE observed Coherent-like J/ψ from peripheral hadronic PbPb events. Process later confirmed by STAR

The photon flux depends on the impact parameter, these peripheral J/ψ explore γP energies beyond coherent J/ψ at the same y interval at the same cms energy

Sensitivity to x ~ 10^{-5}

Energy dependence of coherent J/ψ in γPb – ALICE Run 1 and Run 2 data

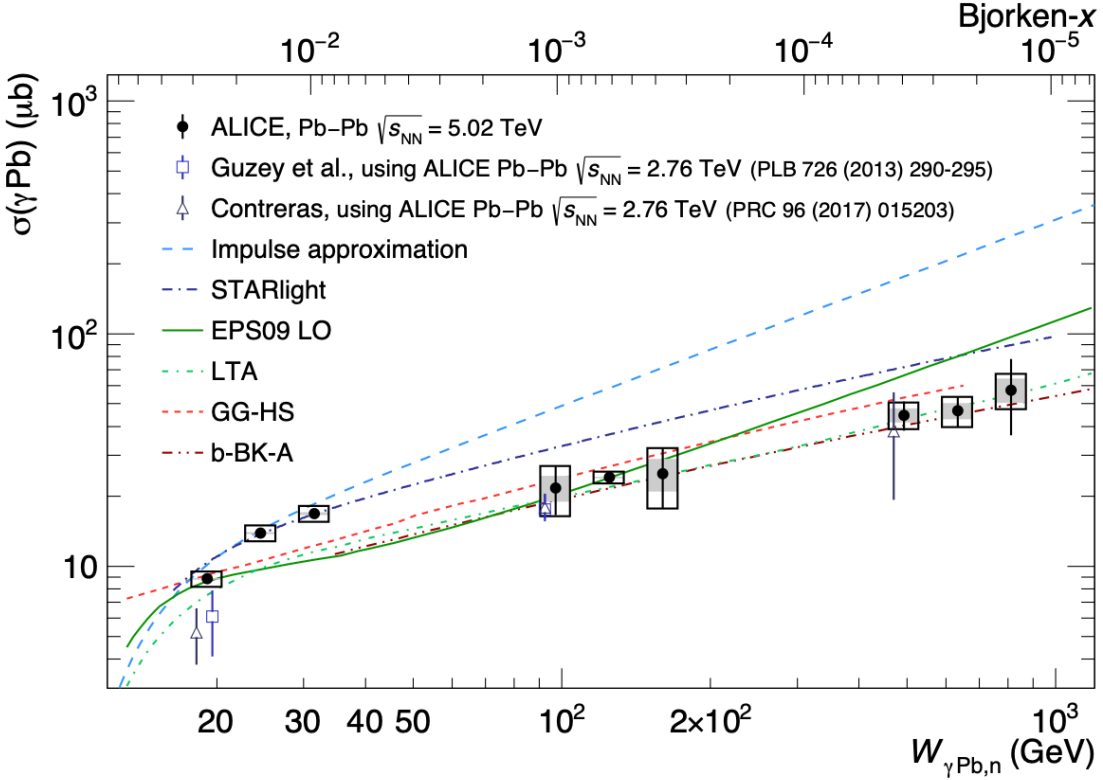
Confirmed Run 1 results. At low x, both shadowing and saturation models describe the data

Energy dependence across the whole range not described by models

In a single experiment exploring (20,800) GeV in $W_{\gamma Pb}$ and x from 10^{-2} to 10^{-5}

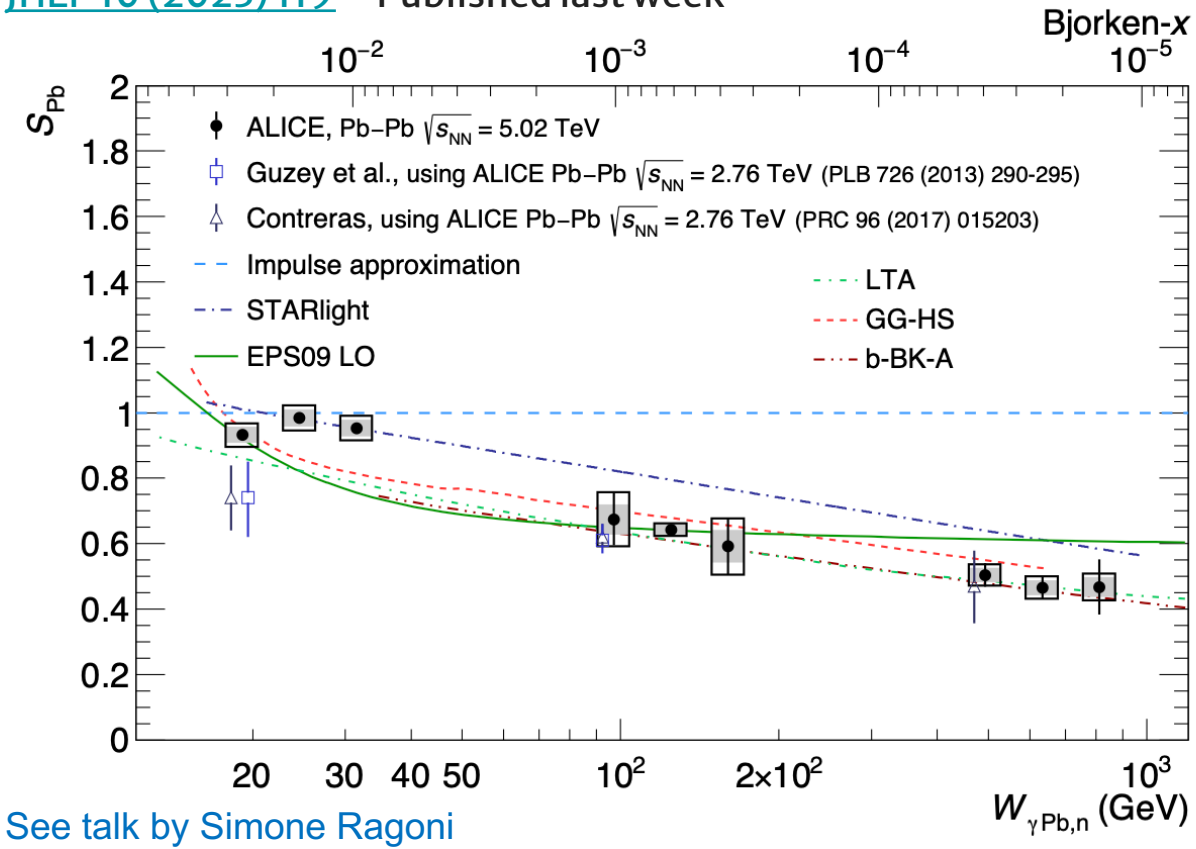
See talk by Simone Ragoni

JHEP 10 (2023) 119 – Published last week



Nuclear suppression factor – ALICE Run 1 and Run 2 data

JHEP 10 (2023) 119 – Published last week



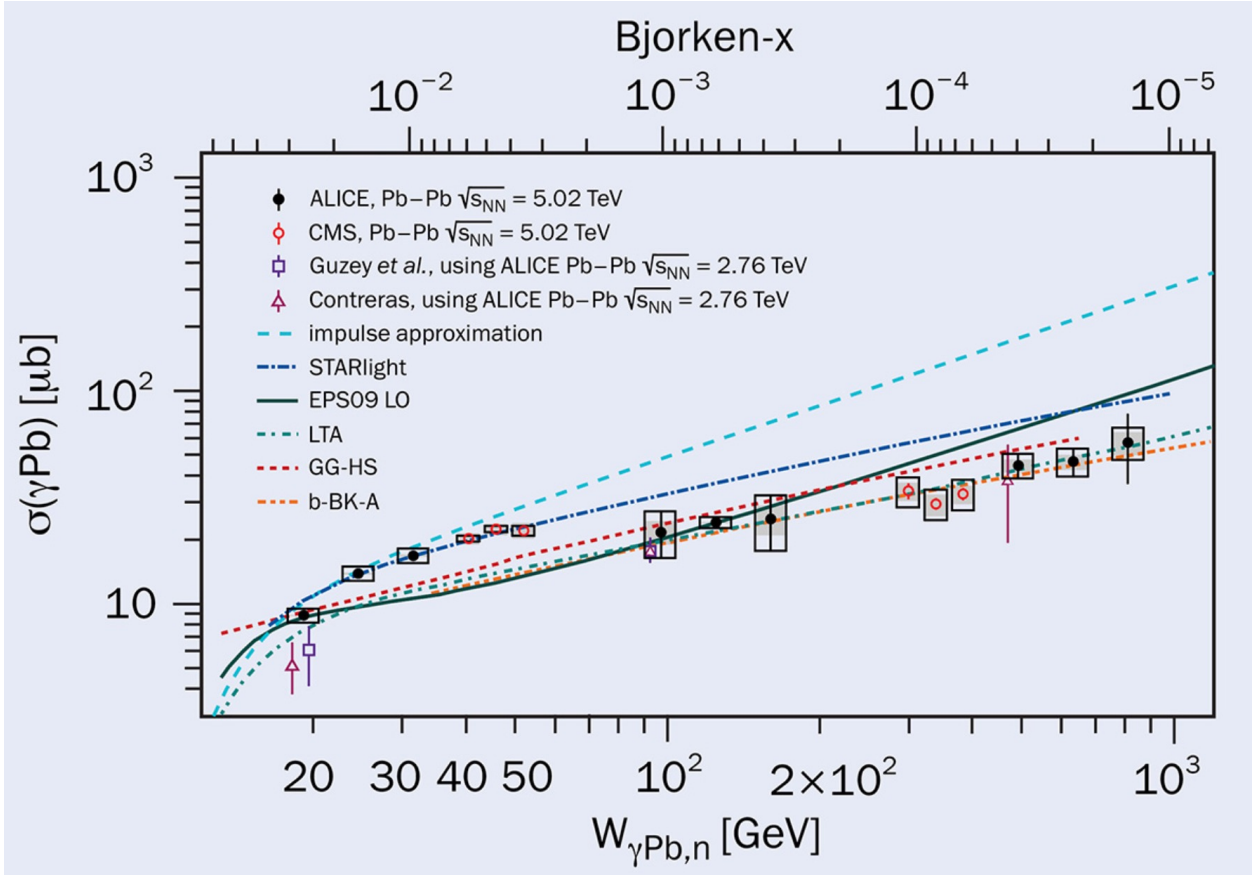
See talk by Simone Ragoni

At low x, both shadowing and saturation models describe the data

Confirmation that peripheral hadronic events can be used to extract the energy dependence. Already explored down to $x = 4.4 \times 10^{-5}$ using Run 1 data

With the neutron-dependent analysis using Run 2 data, down to $x = 1.1 \times 10^{-5}$, Run 2

Energy dependence of coherent J/ψ in γPb



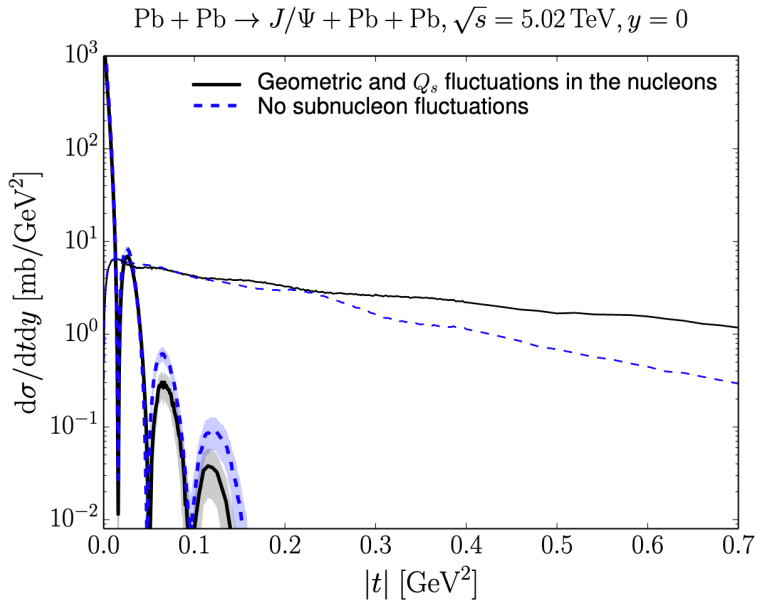
JHEP 10 (2023) 119
Published last week

Both gluon saturation and shadowing describe the data at high energies

At low energies the data cannot be described by these models

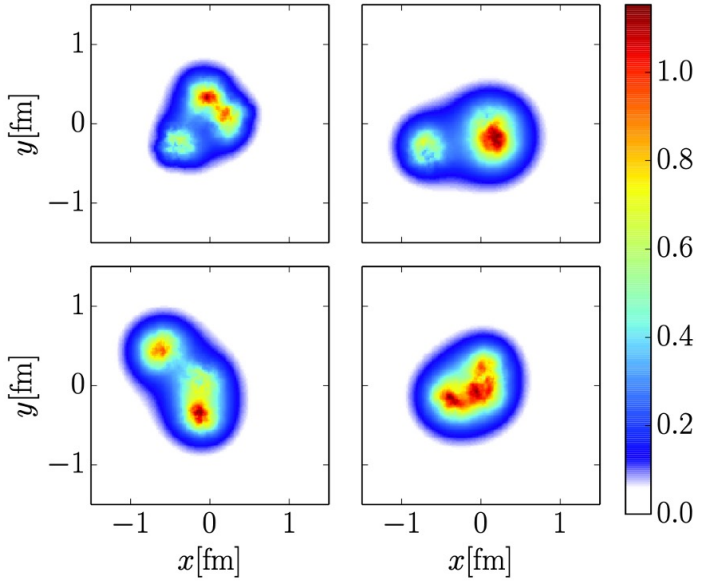
Dissociative/incoherent J/ψ in γp

H. Mantysaari and B. Schenke,
Phys. Lett. B772 (2017) 832



J. Cepilia, J.G. Contreras and DTT
Phys. Lett. B 766 (2017) 186-191

Event-by-event fluctuations



Mantysaari and Schenk, PRD 94, 034042 (2016)
S. Klein arXiv:2301.014018

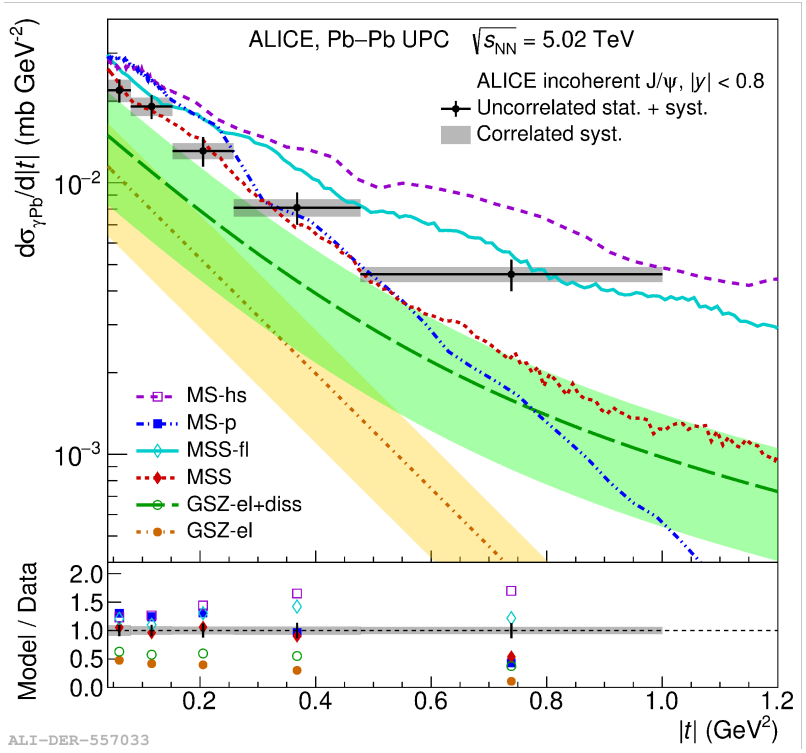
In the Good-Walker approach, sensitive to subnucleonic fluctuations of the gluon density

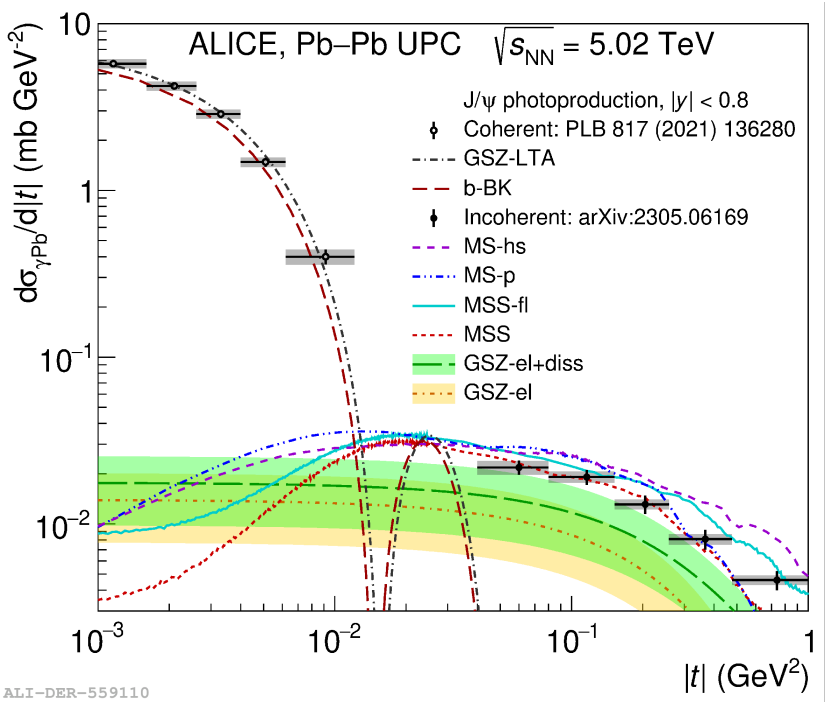
$$\frac{d\sigma(\gamma p\to \mathrm{J}/\psi Y)}{dt}=\frac{R_g^2}{16\pi}\left(\left\langle\left|A(x,Q^2,\vec{\Delta})\right|^2\right\rangle-\left|\left\langle A(x,Q^2,\vec{\Delta})\right\rangle\right|^2\right)$$

t-dependence of coherent and incoherent J/ψ in UPC PbPb

First measurement of the |t|-dependence of incoherent J/ψ photonuclear production
https://arxiv.org/abs/2305.06169

Probing for gluonic ”hot spots” in Pb using UPCs for the first time!



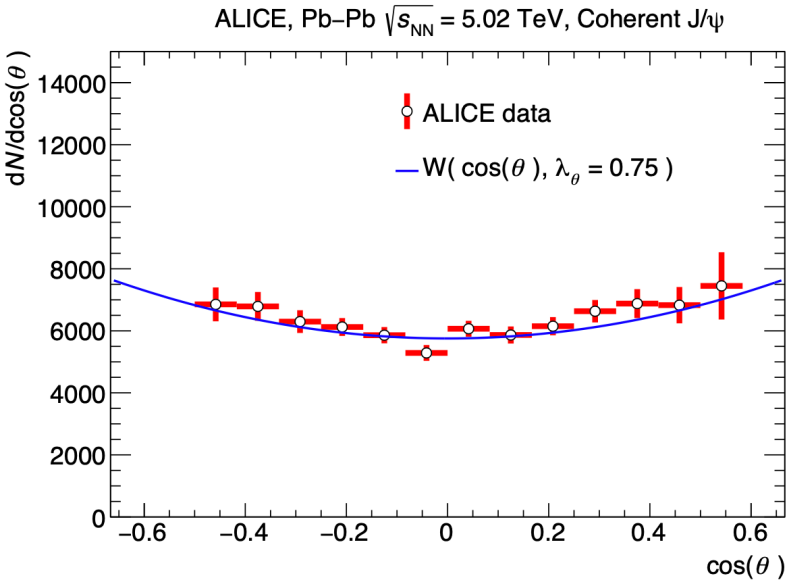


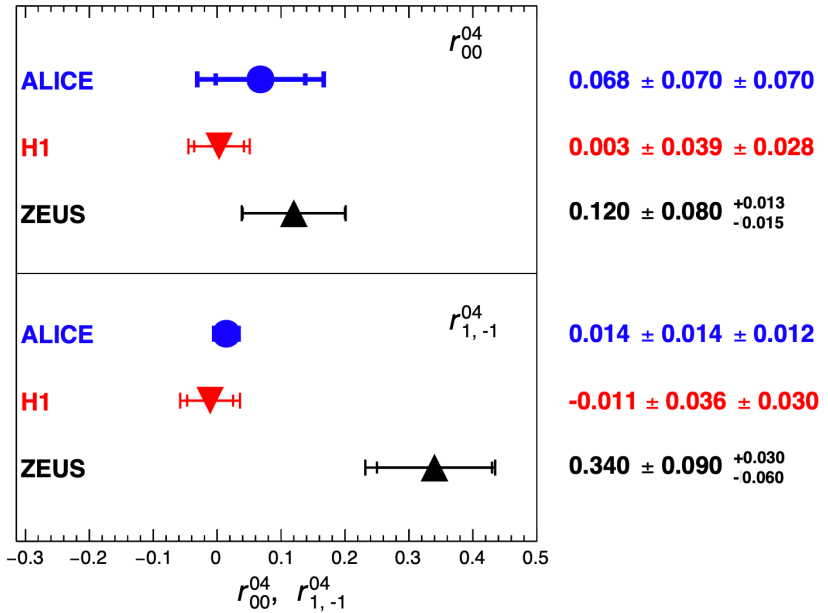
Polarization of coherent J/ψ in UPC Pb-Pb

First polarisation measurement of coherently photoproduced J/ψ in ultra-peripheral Pb−Pb collisions at 5.02 TeV

https://arxiv.org/abs/2304.10928

$$W(\cos\theta,\varphi) \propto \frac{1}{3+\lambda_\theta}\left[1+\lambda_\theta\cos^2\theta+\lambda_\varphi\sin^2\theta\cos 2\varphi+\lambda_{\theta\varphi}\sin 2\theta\cos\varphi\right].$$

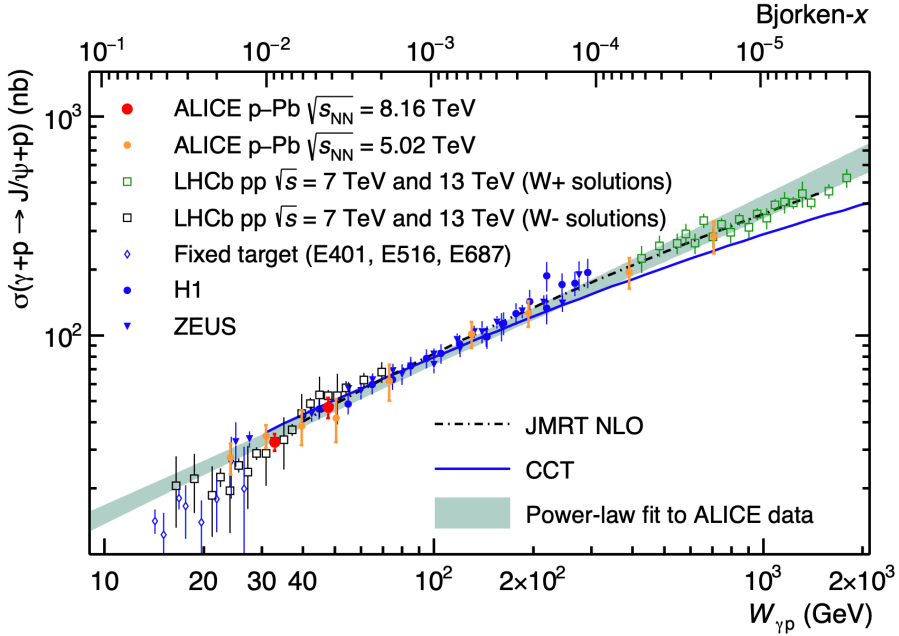


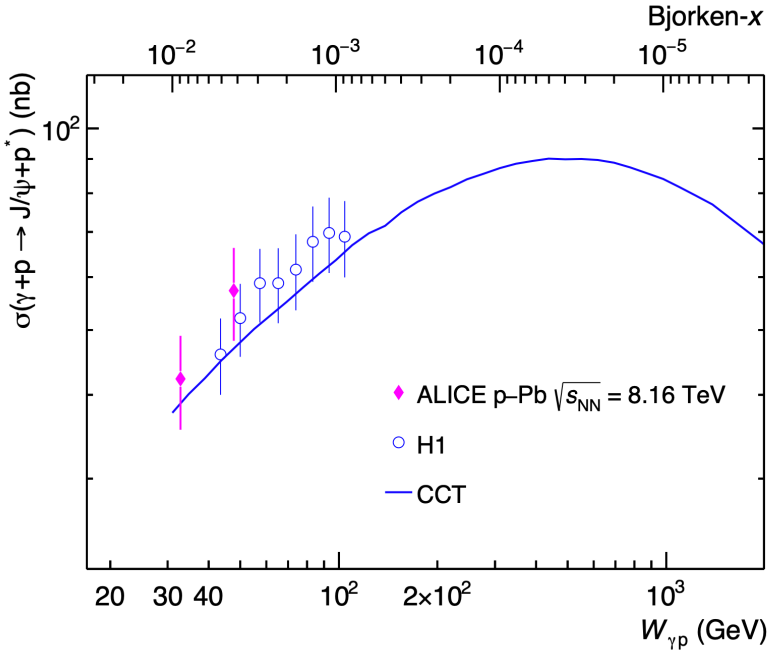


Exclusive and dissociative J/ψ in UPC pPb

Exclusive and dissociative J/ψ photoproduction, and exclusive dimuon production, in p−Pb collisions at 8.16 TeV

https://arxiv.org/abs/2304.12403 - Accepted for publication by PRD

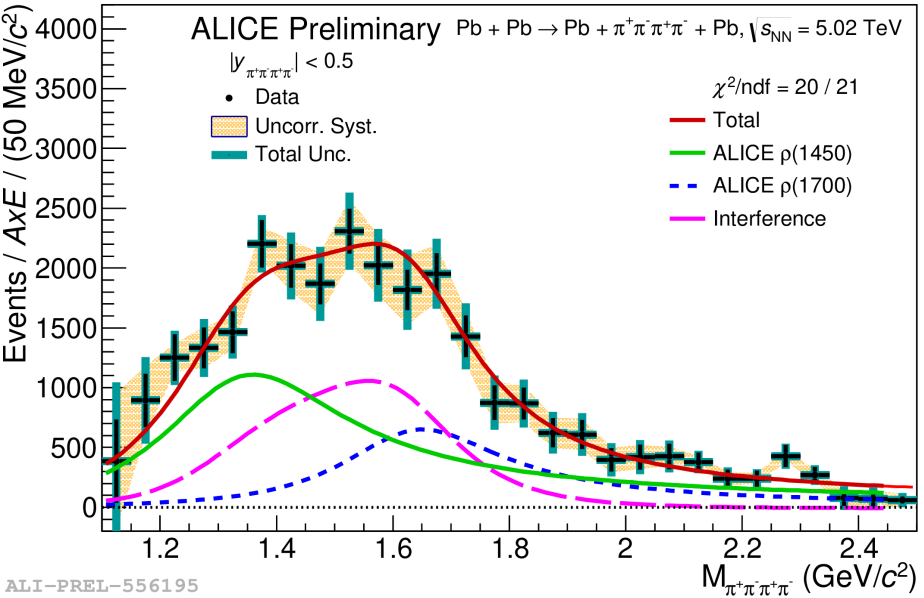


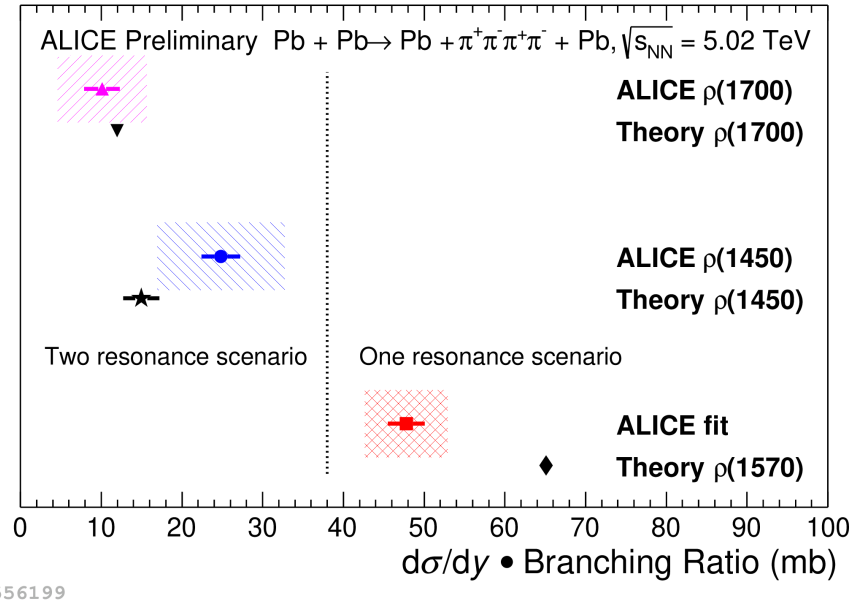


Exclusive four-pion in UPC PbPb – shown first QM 2023

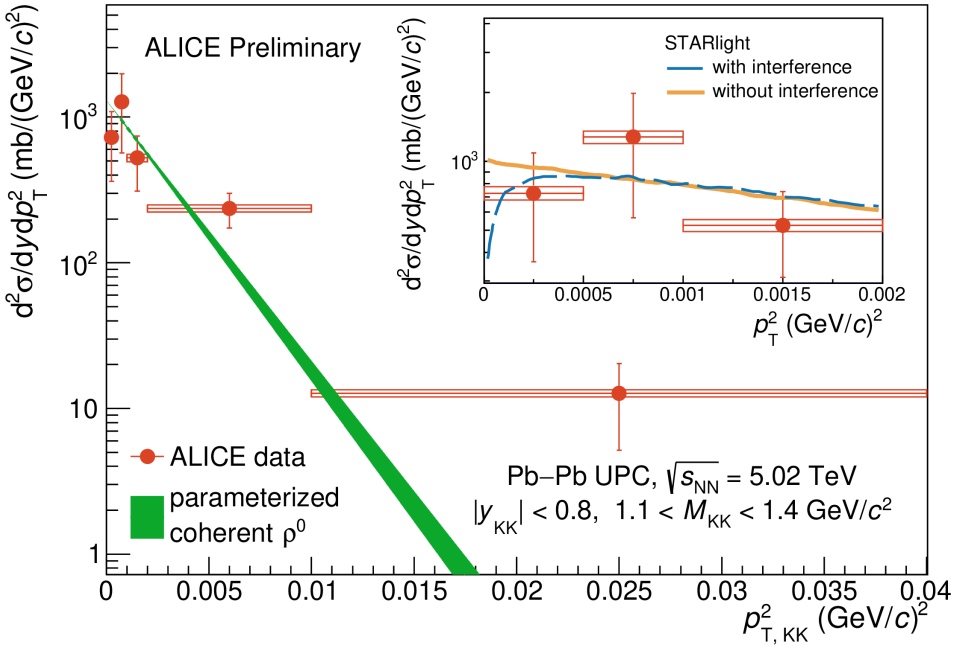
Excited ρ^0 states

M. Klusek-Gawenda and DTT
Acta Phys.Polon.B 51 (2020) 6, 1393-1404

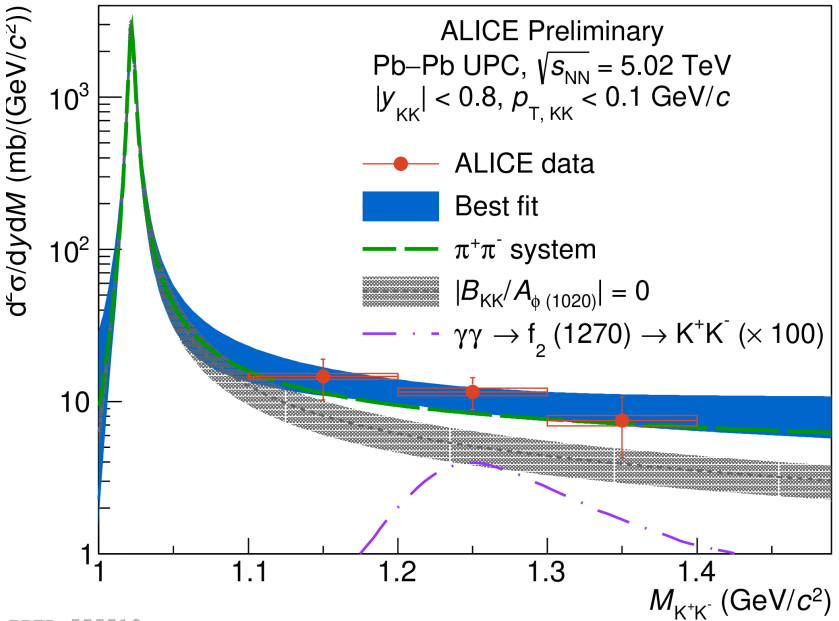




Exclusive K^+K^- in UPC PbPb - shown first QM 2023



ALI-PREL-551462

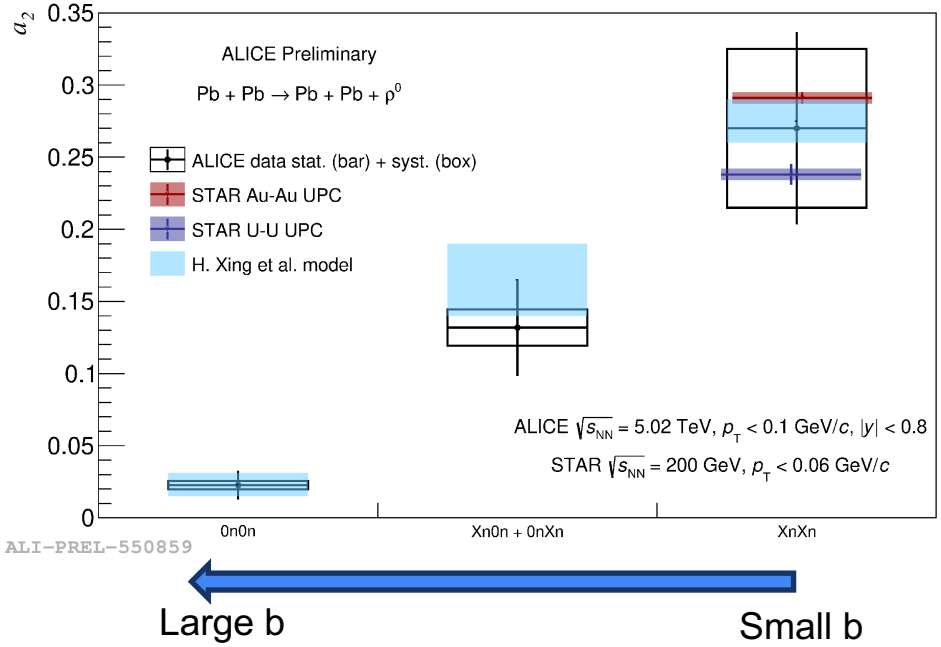


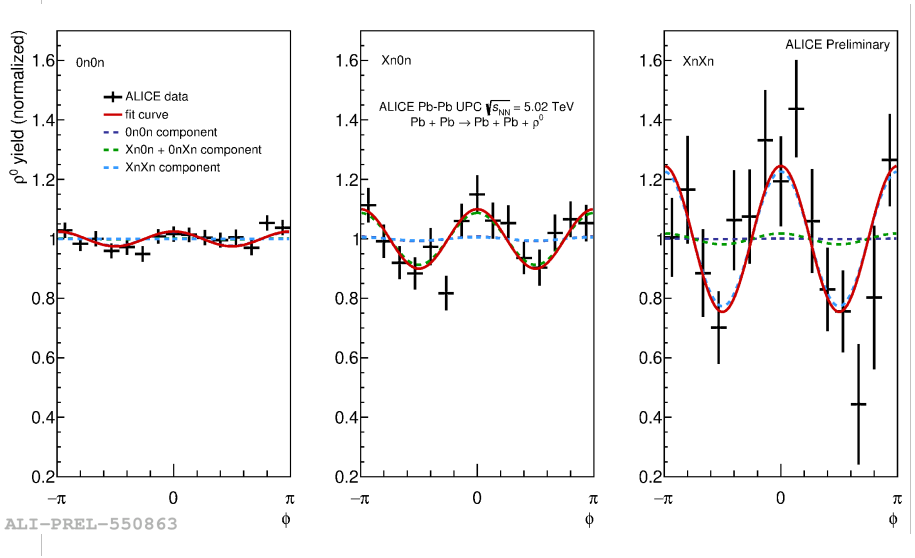
ALI-PREL-555519

Direct K^+K^- vs ϕ production

Azimuthal anisotropies of coherent ρ^0 - shown first QM 2023

First impact-parameter dependence

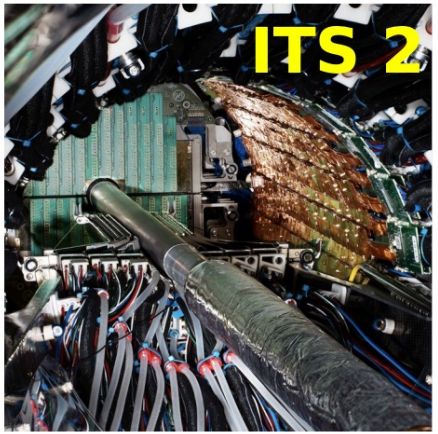


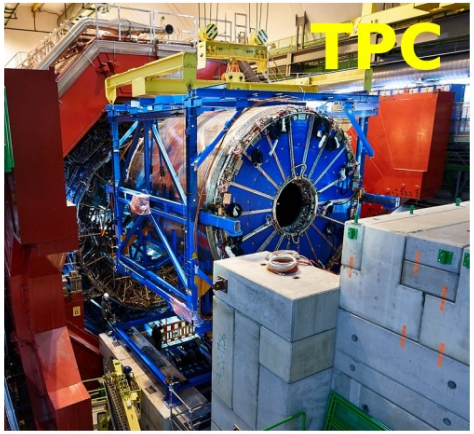


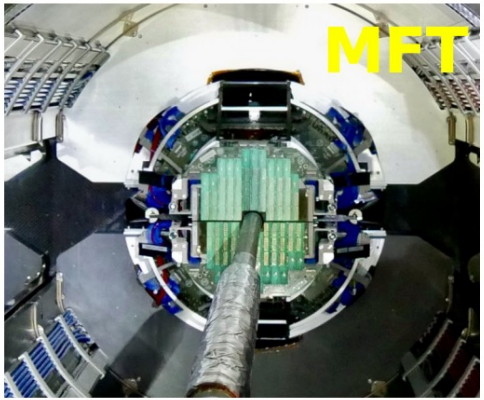
Large b

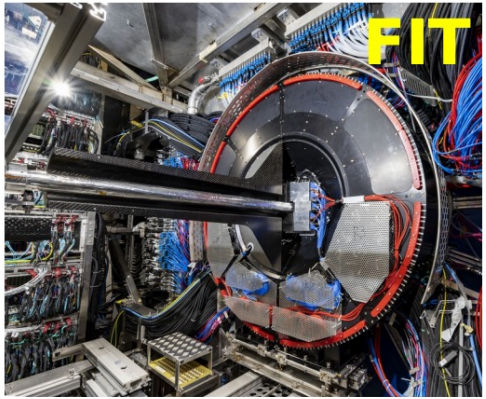
Small b

ALICE in Run 3: A major upgrade



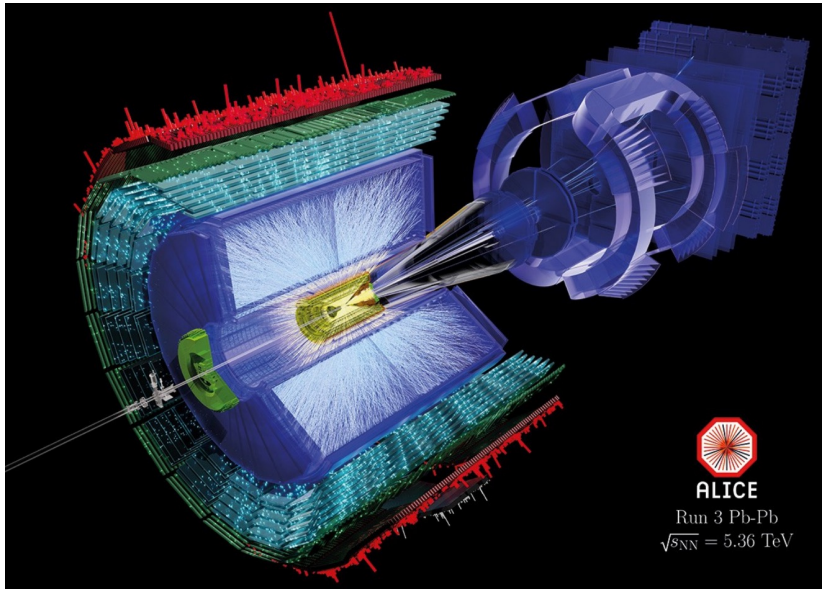


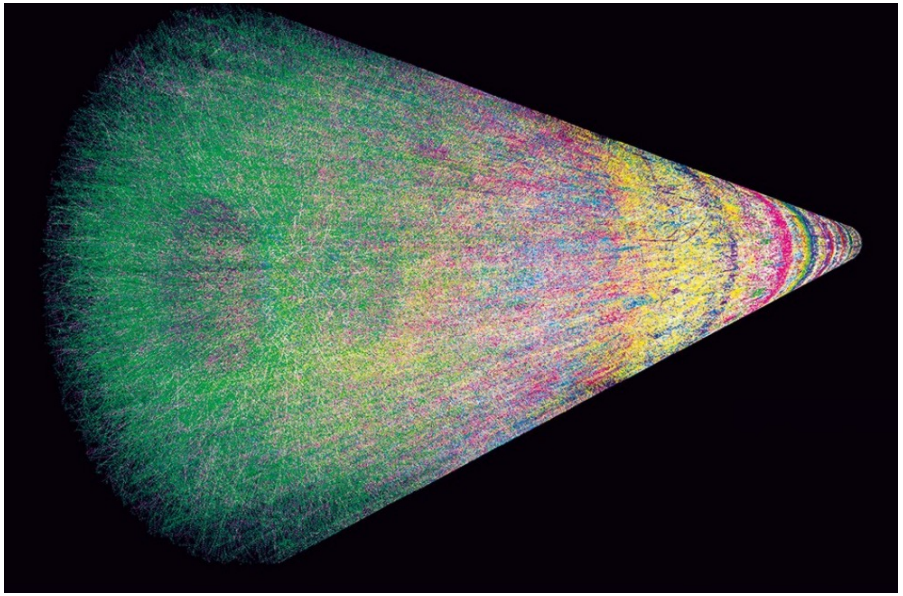




- 50 times increase in the readout rate
- 3 to 6x improvement in pointing resolution
- Secondary vertexing for forward muons

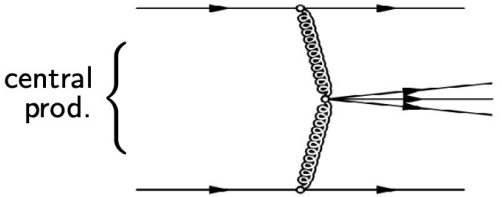
ALICE in Run 3: Trigger-less mode



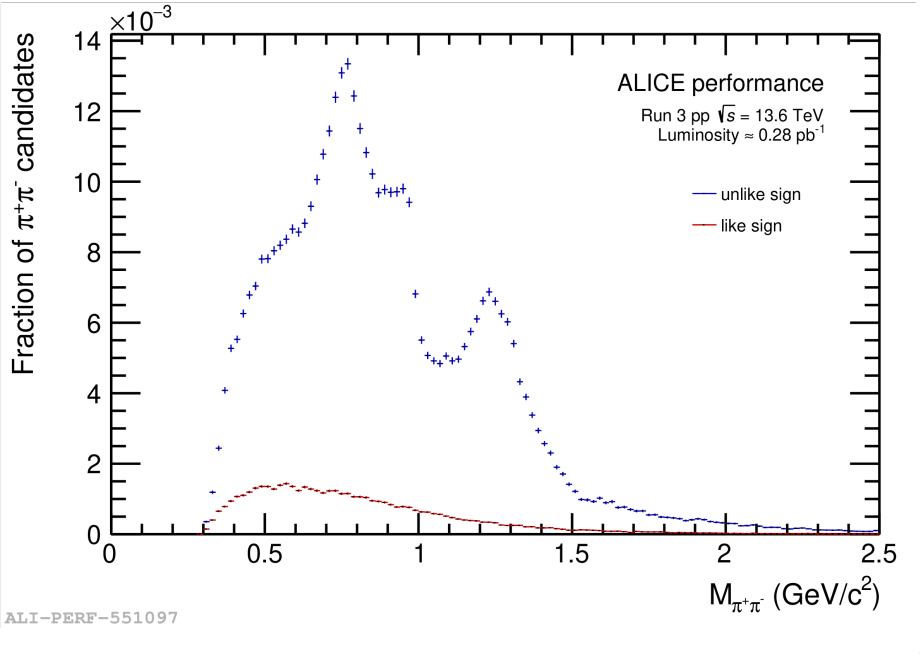


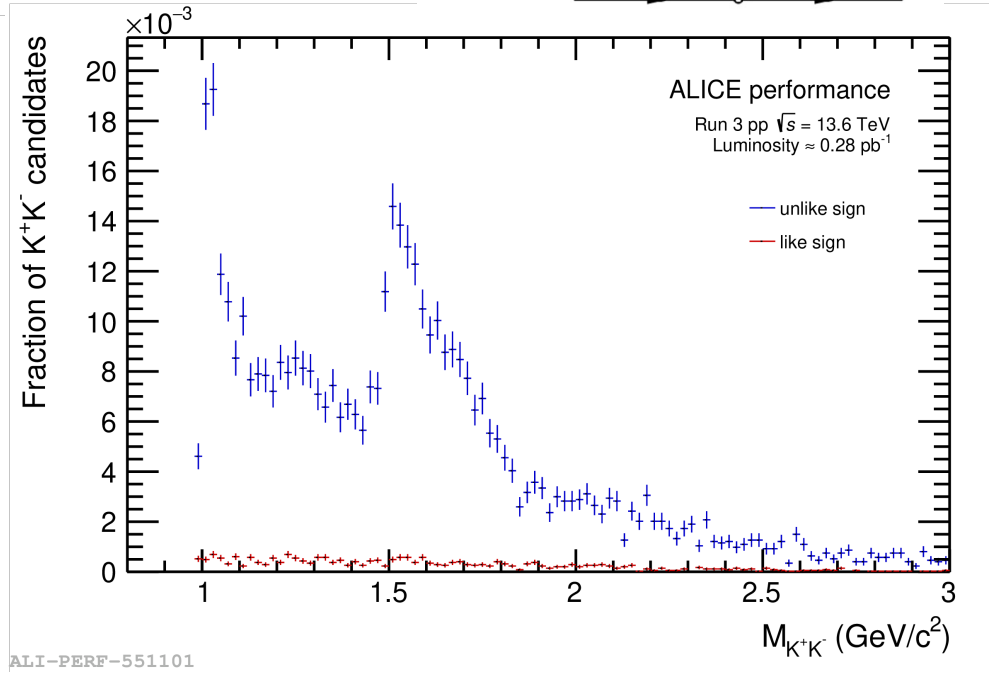
2 msec time frame of Pb-Pb collisions at a 50 kHz interaction rate in the TPC

CEP in 13.6 TeV pp – Run 3 data



Promising performance results

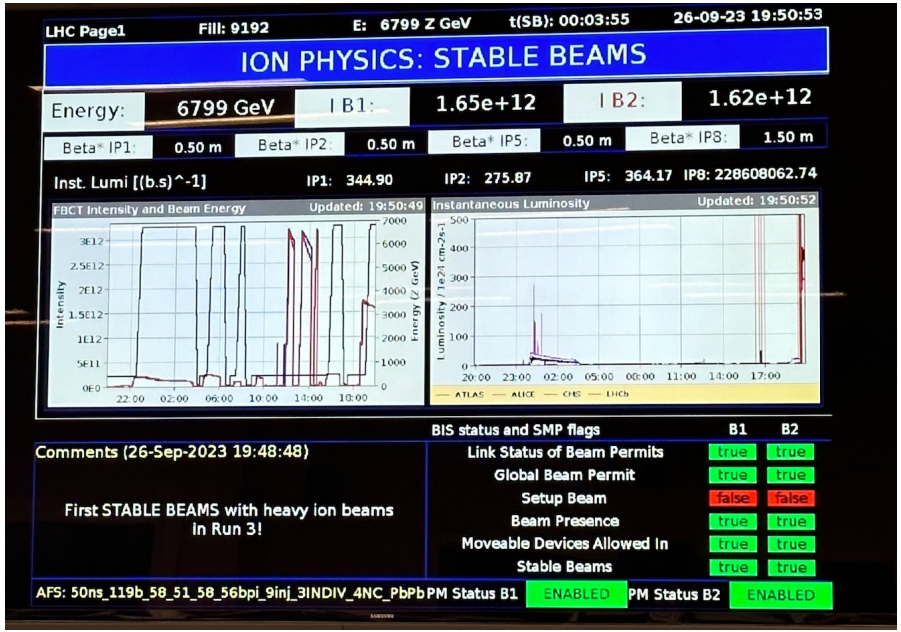


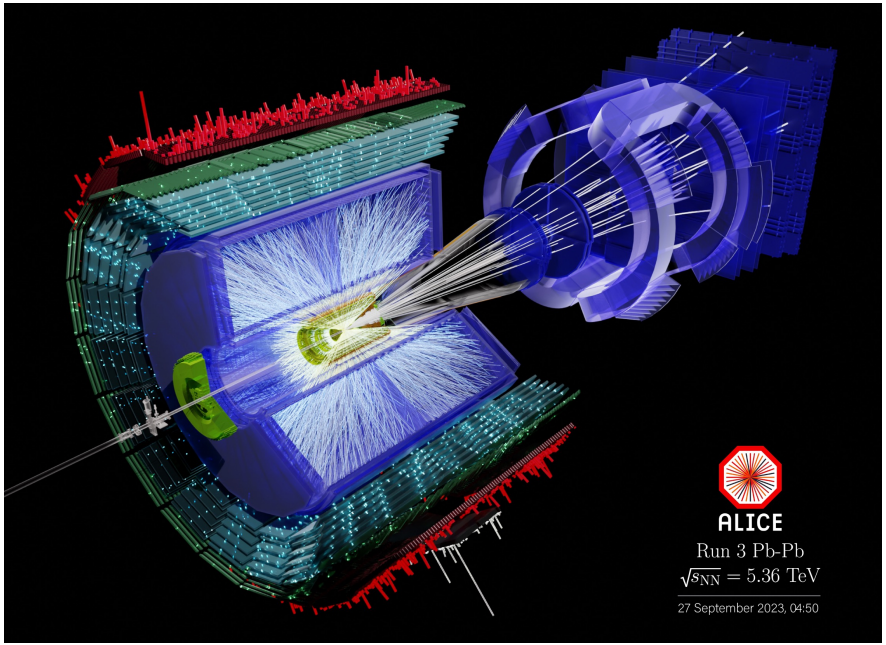


See talk by Rainer Schicker

EMMI workshop “Forward physics in ALICE 3”, October 2023

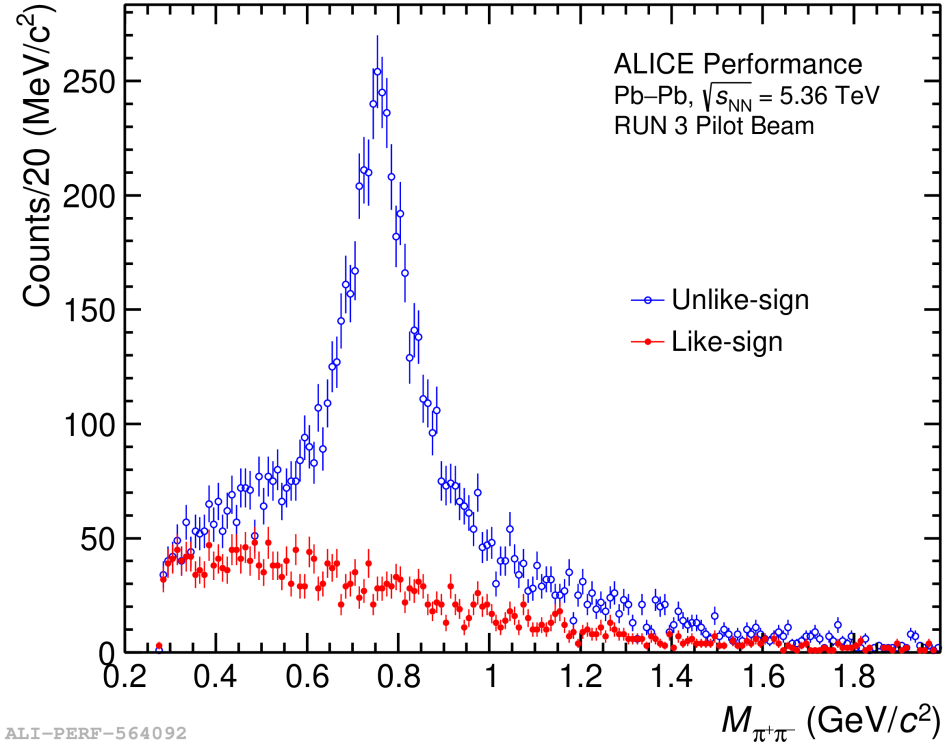
First stable Pb beams in Run 3: September 26, 2023

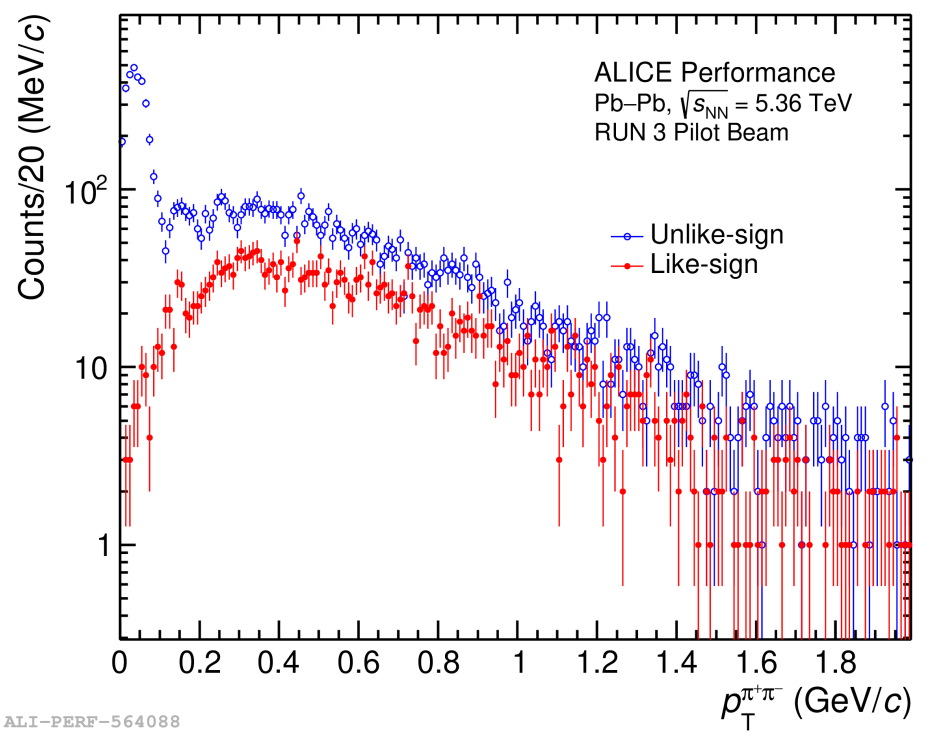




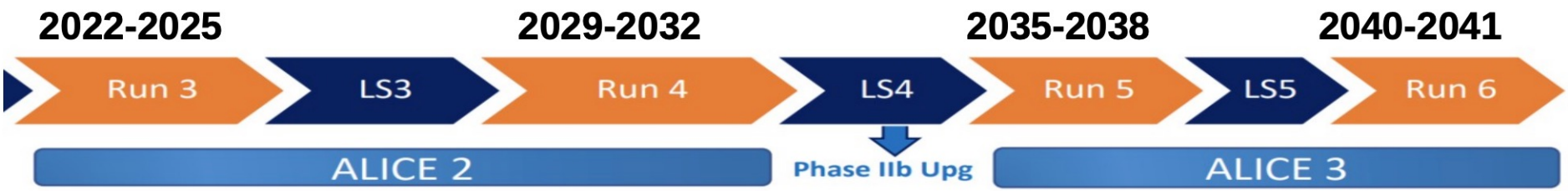
UPC results – Run 3 data from this month! - first shown here

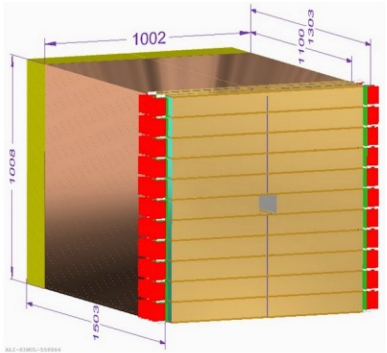
See talk by Anisa Khatun

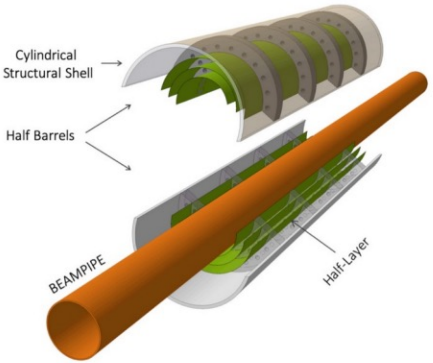


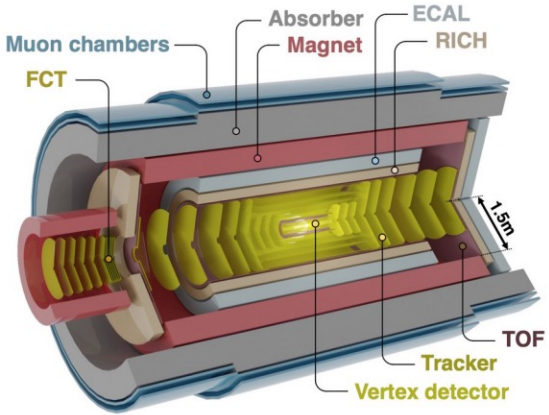


ALICE timeline





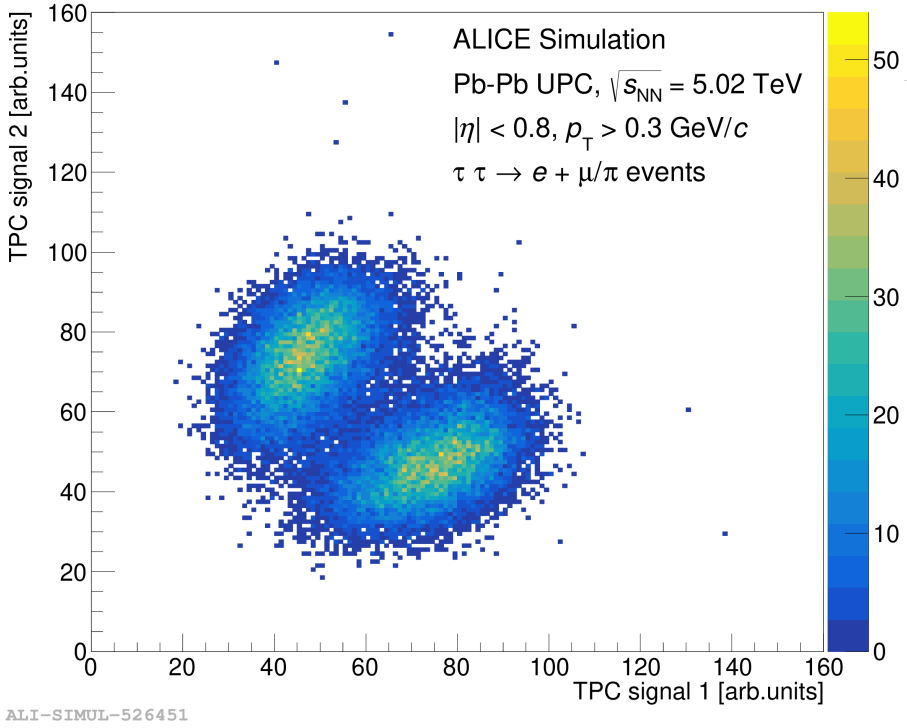




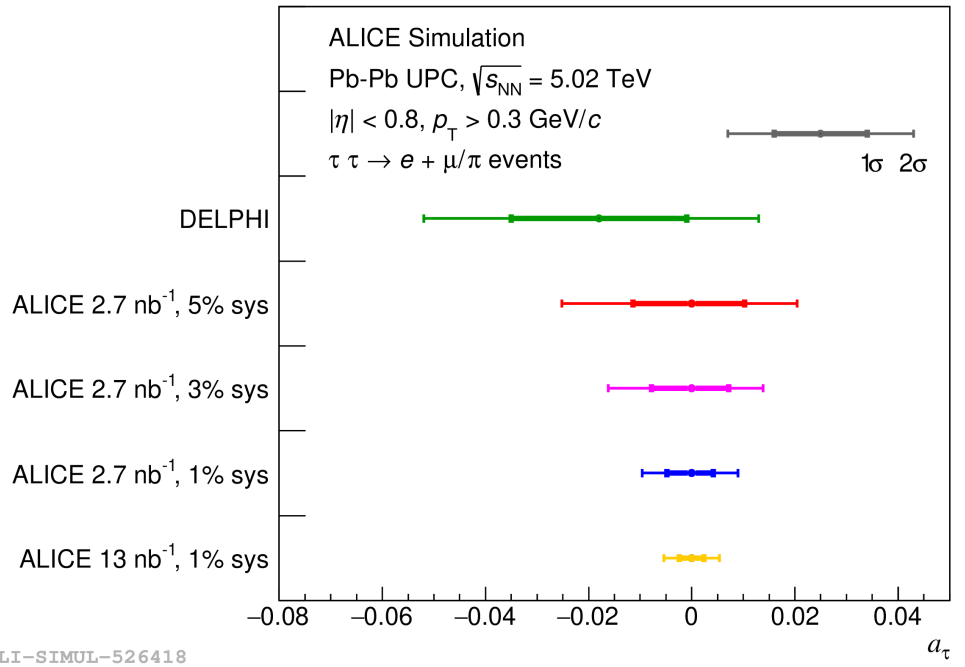
FoCal and ITS3

ALICE3

Prospects: tau analysis in UPCs with ALICE

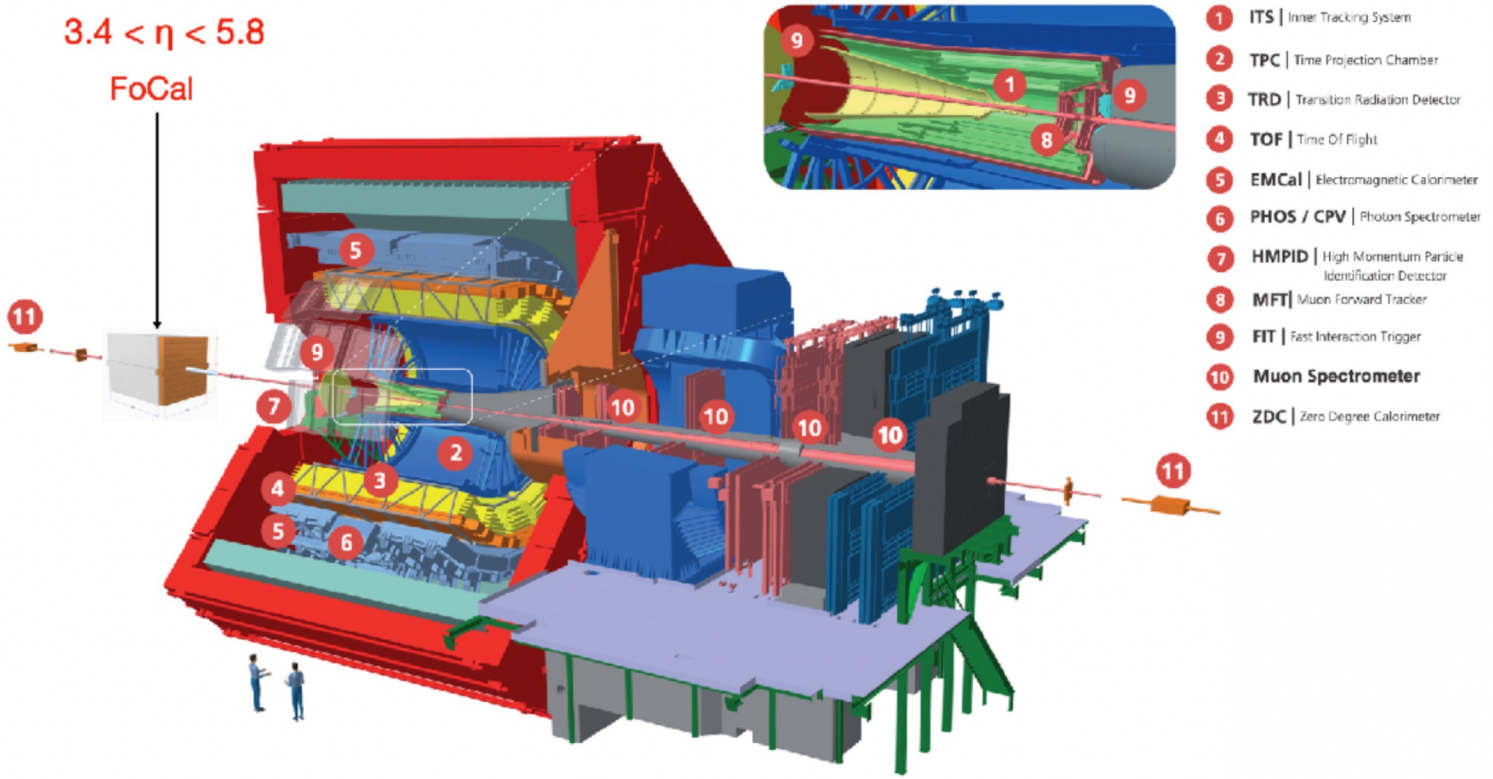


Tau anomalous magnetic moment



7600 events expected at 2.7 nb-1
36000 events expected at 13 nb-1→Run 3+4 statistics
Purity of the selection larger than 96%

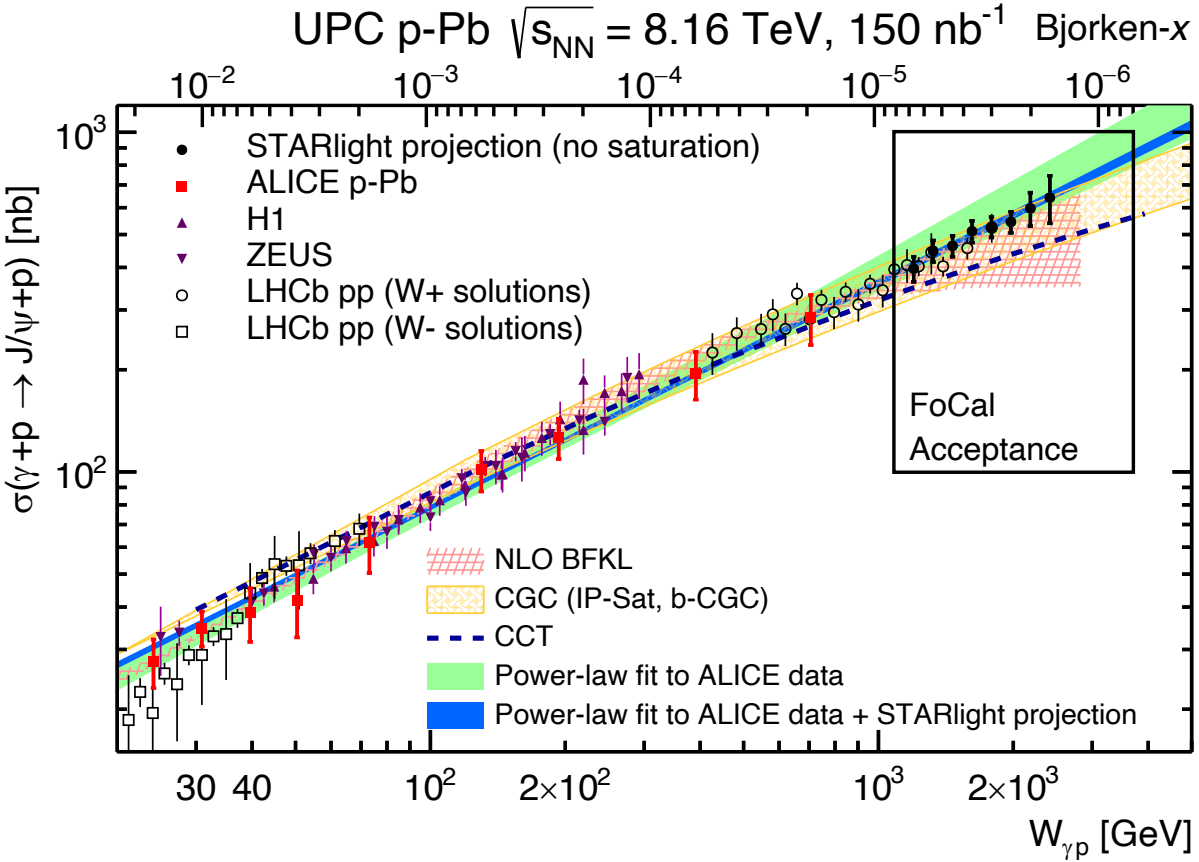
The ALICE FoCal project for Run 4



UPC VM projections for FoCal

VM	$\sigma(\mathrm{p}+\mathrm{Pb}\to\mathrm{p}+\mathrm{Pb}+\mathrm{VM})$	$\sigma(3.4\leq\eta_{1,2}\leq 5.8)$ p $\to$ FoCal	Yield p $\to$ FoCal
ρ^0	35 mb	140 nb	21,000
ϕ	1.7 mb	51 nb	7,700
J/ψ	98 μb	400 nb	60,000
$\psi(2S)$	16 μb	8.9 nb	1,300
$\Upsilon(1S)$	220 nb	0.38 nb	60
		Pb $\to$ FoCal	Pb $\to$ FoCal
ρ^0	35 mb	17 nb	2,600
ϕ	1.7 mb	5.3 nb	800
J/ψ	98 μb	36 nb	5,400
$\psi(2S)$	16 μb	0.53 nb	80
$\Upsilon(1S)$	220 nb	0.67 pb	~ 0

Projections for exclusive J/ψ off protons

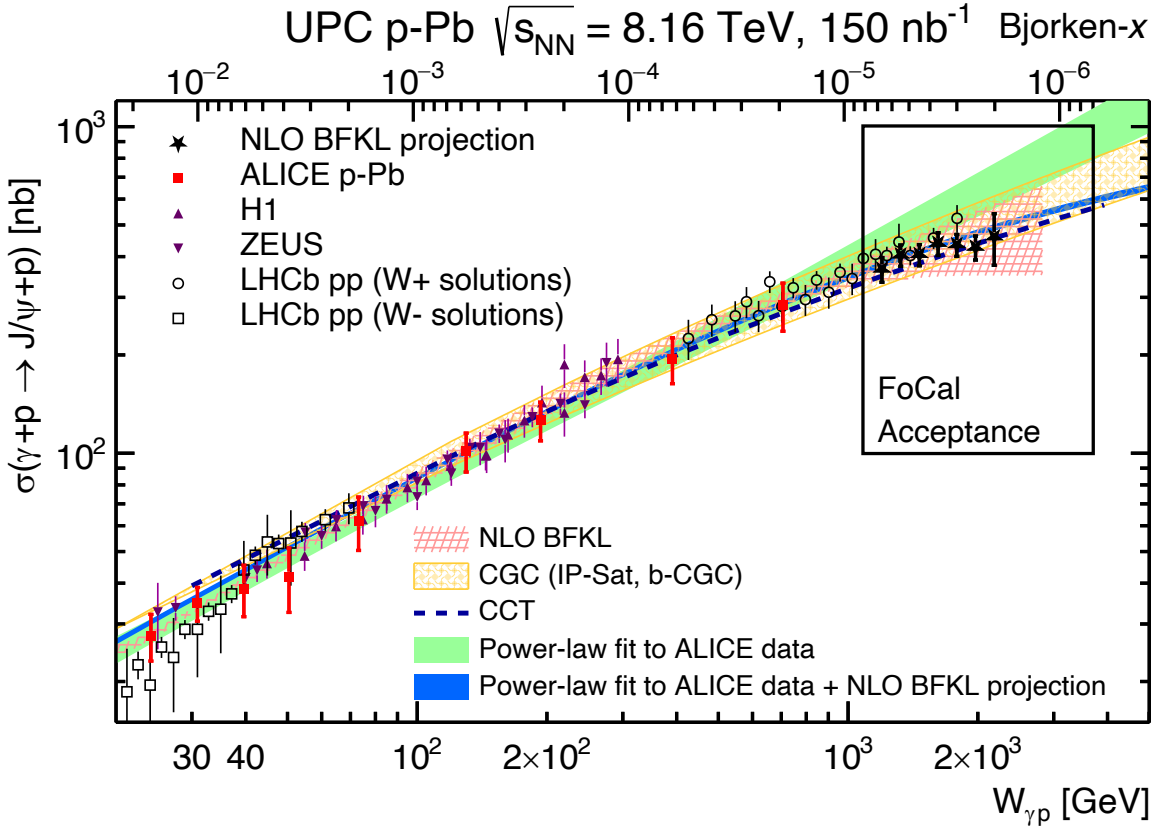


- Deviations from a power-law trend should signal non-linear QCD dynamics
- Here, projections based on STARlight which uses a parametrization based on HERA data

$$\sigma_0 \left(W_{\gamma p} / W_0 \right)^{\delta}$$

- For all figures, 60% efficiency. Conservative assumption after acceptance selection

Projections for exclusive J/ψ off protons

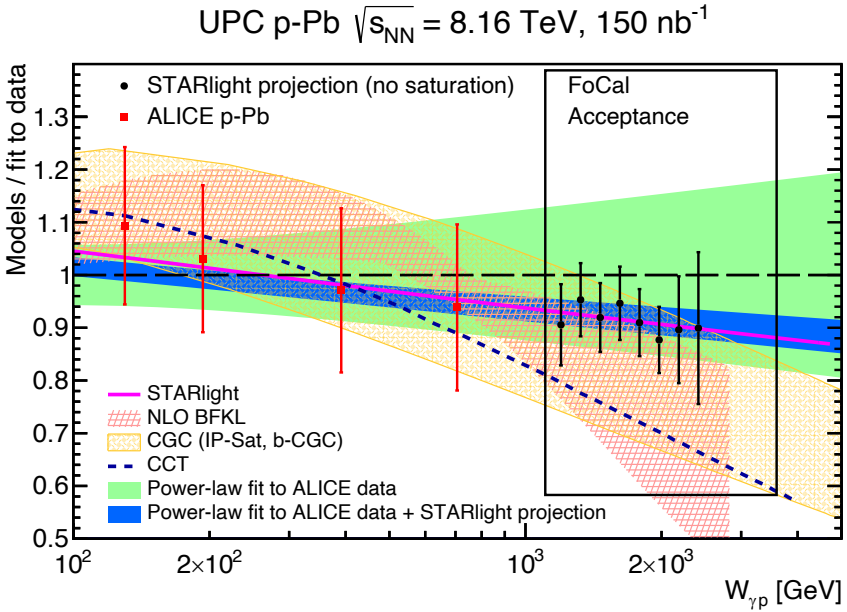


- Projections assuming a broken power-law
- Projected points based on NLO BFKL calculation

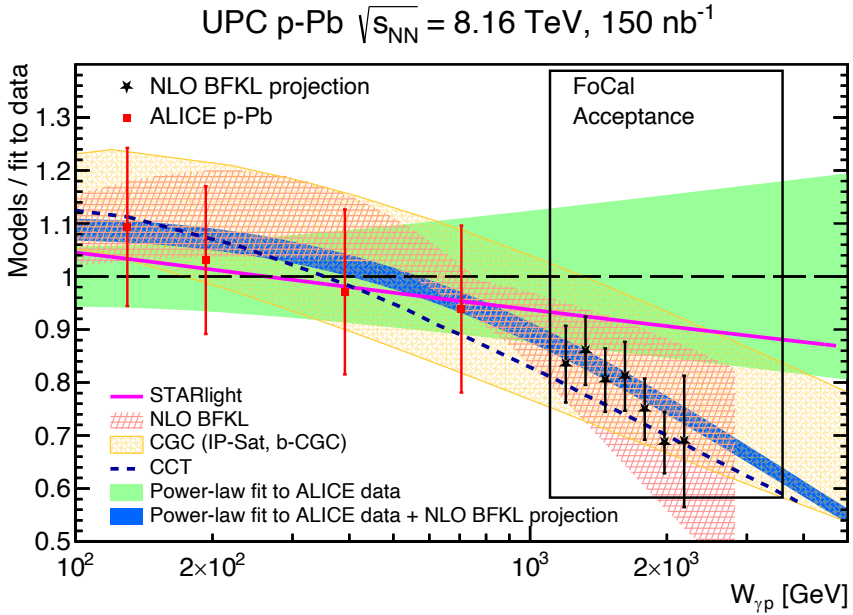
$$\sigma(\gamma p) \approx \frac{\sigma_0}{\frac{1}{W_{\gamma p}^{\delta}} + A}$$

Projections for exclusive J/ψ off protons

Power-law behavior (STARlight)

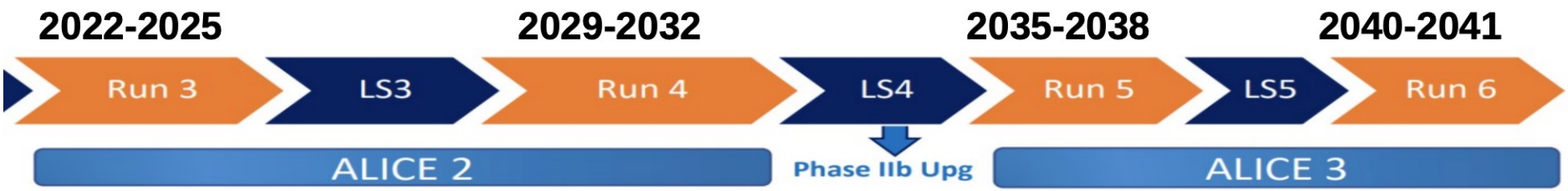


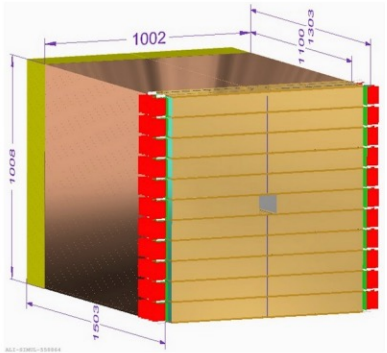
Broken power-law behavior (NLO BFKL)

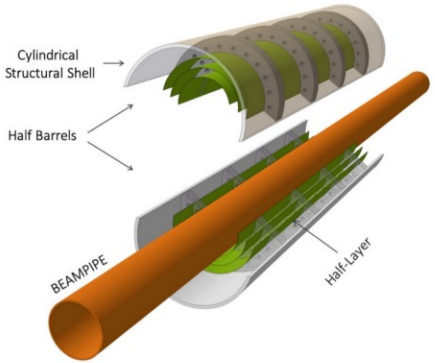


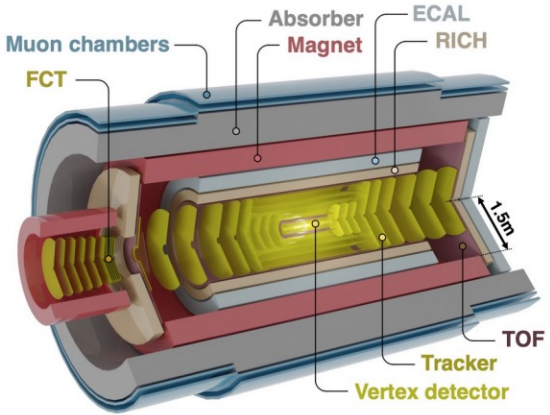
FoCal measurement would be sufficient to observe a deviation from a power law behavior, if exists

ALICE timeline









FoCal and ITS3

ALICE3

ALICE 3 prospects not discussed in this talk

https://indico.cern.ch/event/1263865

Registration and abstract deadline: September 15

Student day on December 10

Thanks!