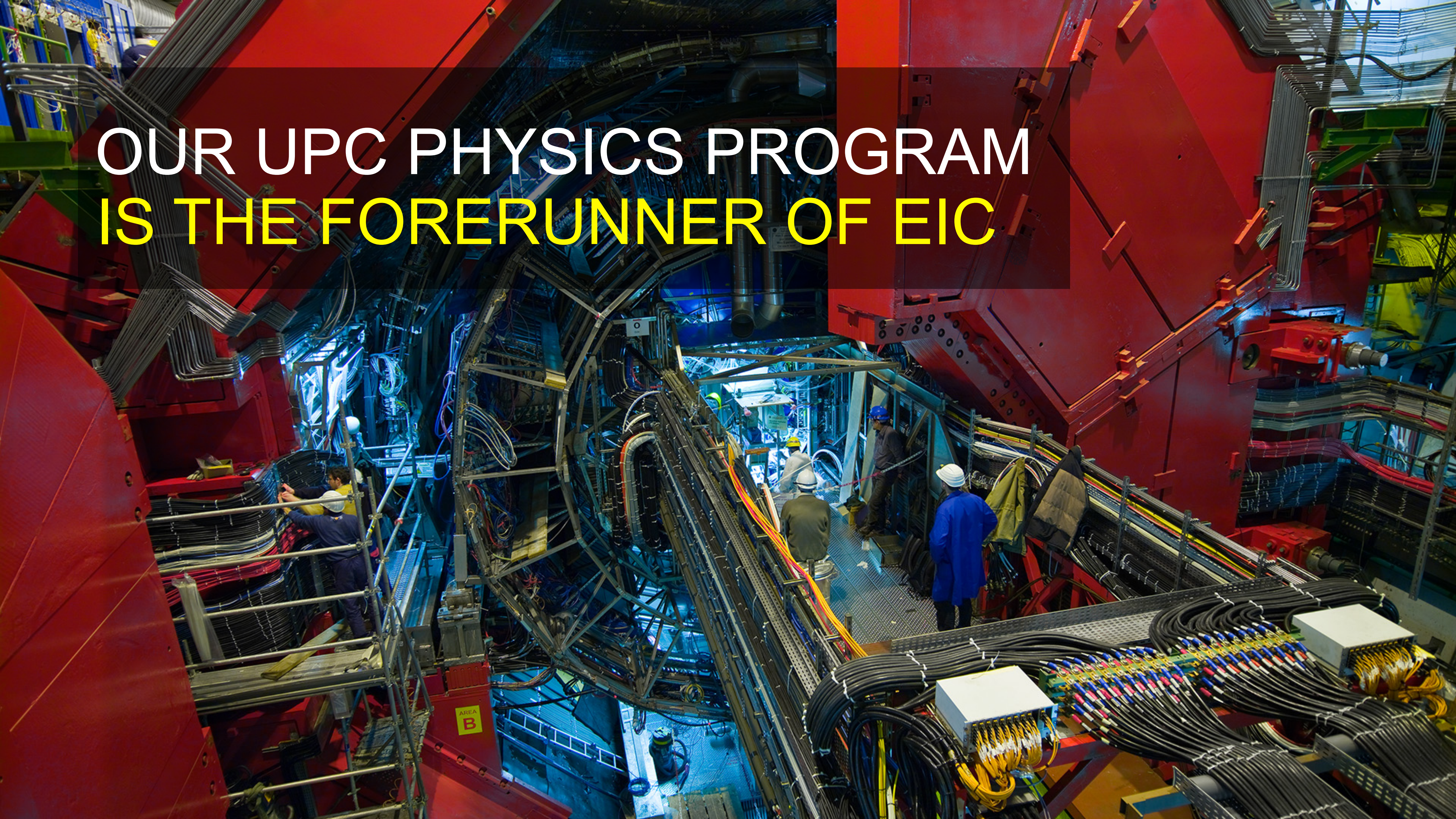
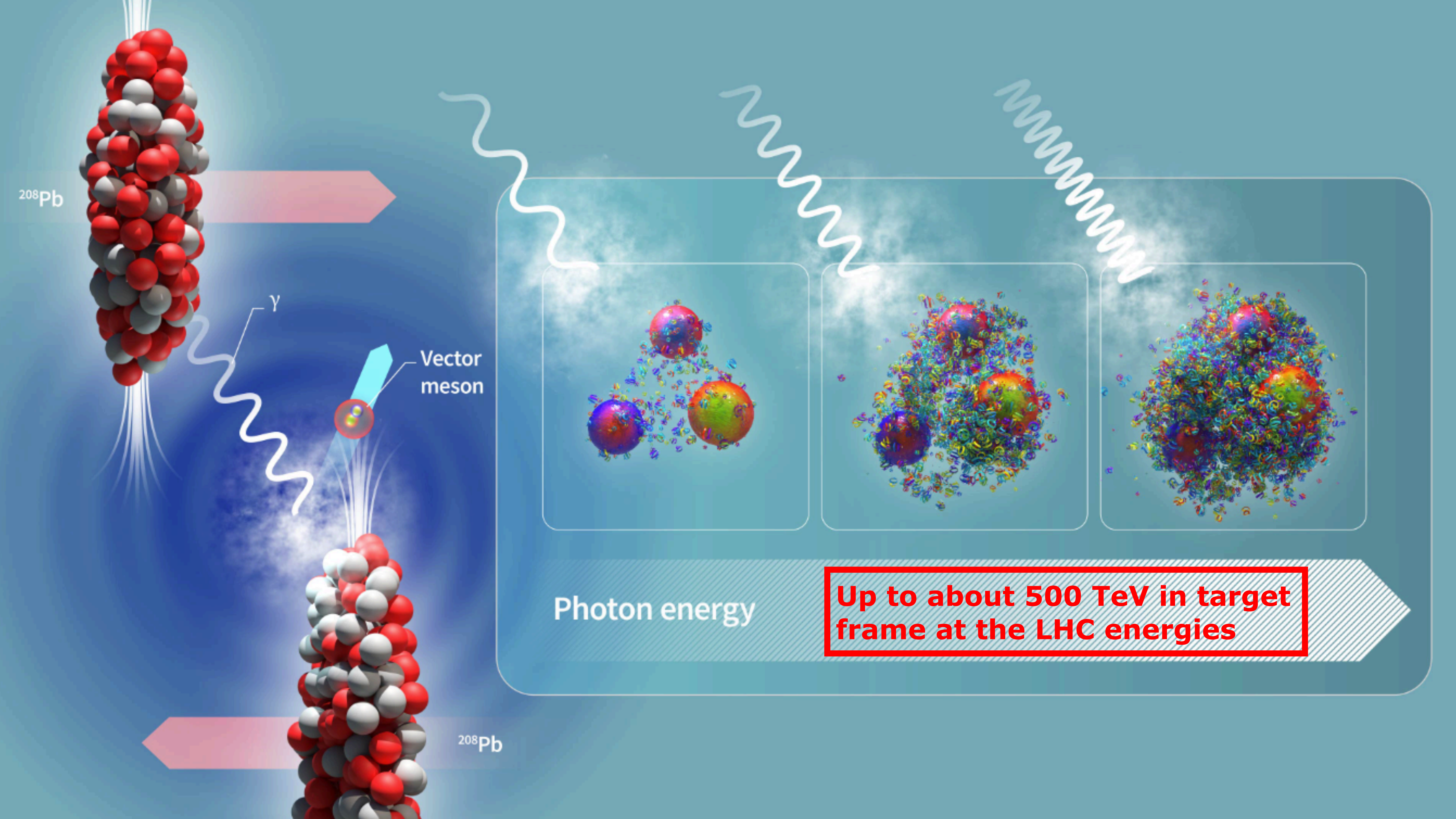
Overview of latest ALICE UPC and photonuclear results

Simone Ragoni,
on behalf of the ALICE collaboration
Creighton University, USA

U.S. DEPARTMENT OF ENERGY | Office of Science

OUR UPC PHYSICS PROGRAM
IS THE FORERUNNER OF EIC





^{208}Pb
γ
Vector meson
^{208}Pb
Photon energy
Up to about 500 TeV in target frame at the LHC energies

Outline

- Excited ρ^0 states
- Exclusive charged KK production
- Quasireal photons and experimentally available observables
- The future of UPC in ALICE

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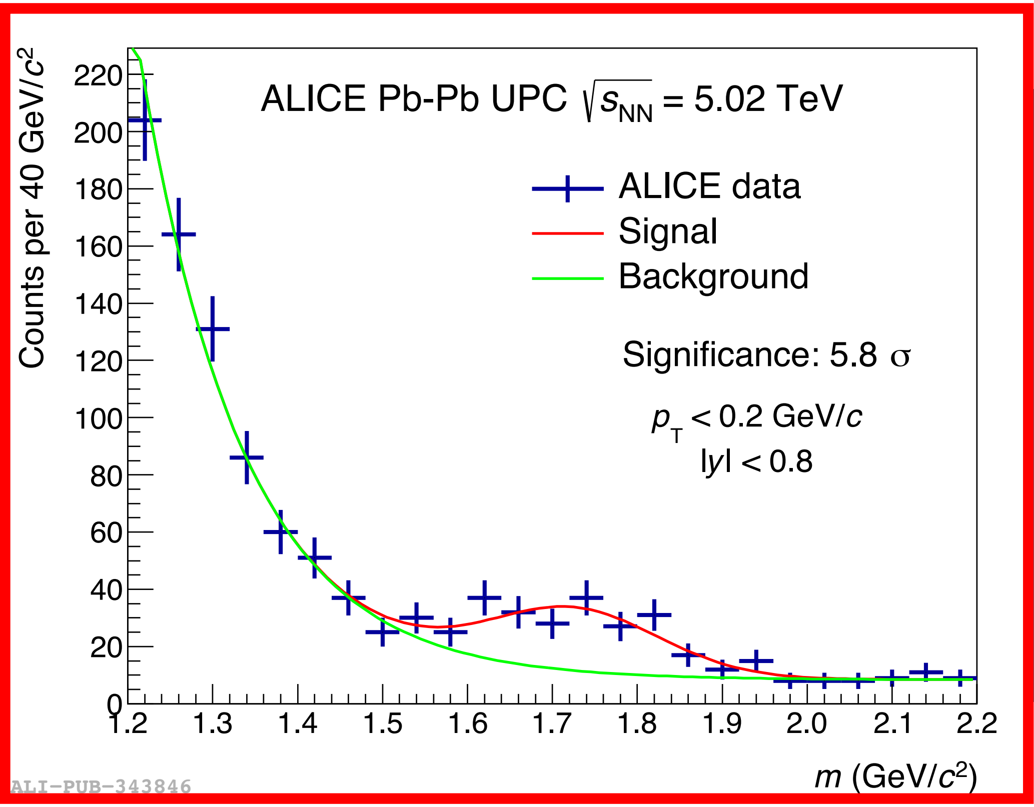
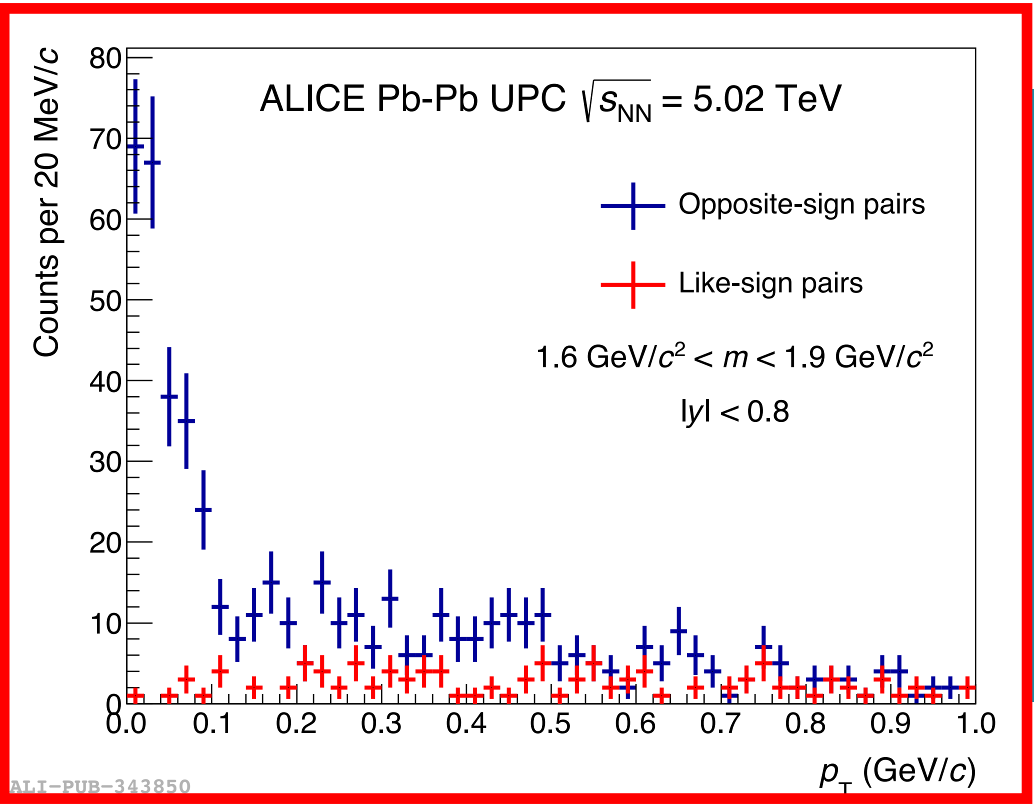
Photoproduction of excited ρ-meson states



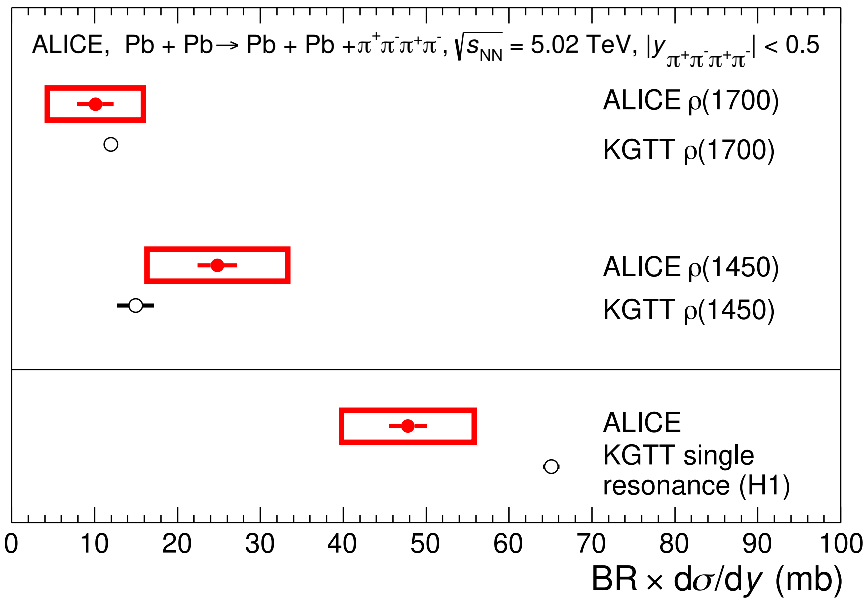


ALICE, JHEP 06 (2020) 035

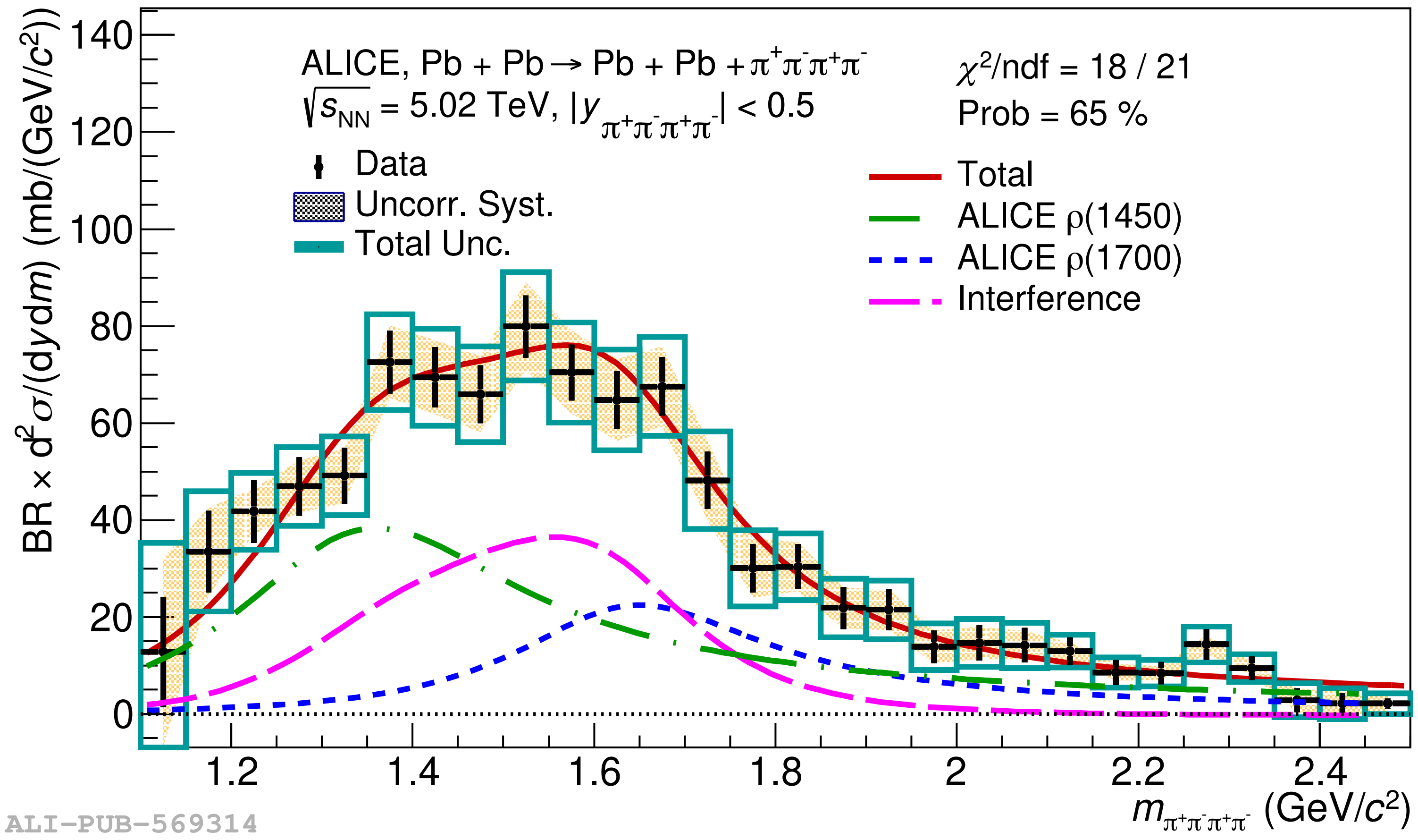
- Resonance-like structure observed in $\pi^+\pi^-$ invariant mass distribution
- Observed by STAR too

Exclusive 4π photoproduction

- Also tested with single Breit-Wigner but bad fit quality
- Two interfering BW: $\rho(1450)$ and $\rho(1700)$
  - Cross sections in better agreement with KGTT calculations



ALICE, arXiv:2404.07542



KGTT: M. Klusek-Gawenda, D. Tapia Takaki, Acta Rhys. Polon- B 51 (2020) 1393

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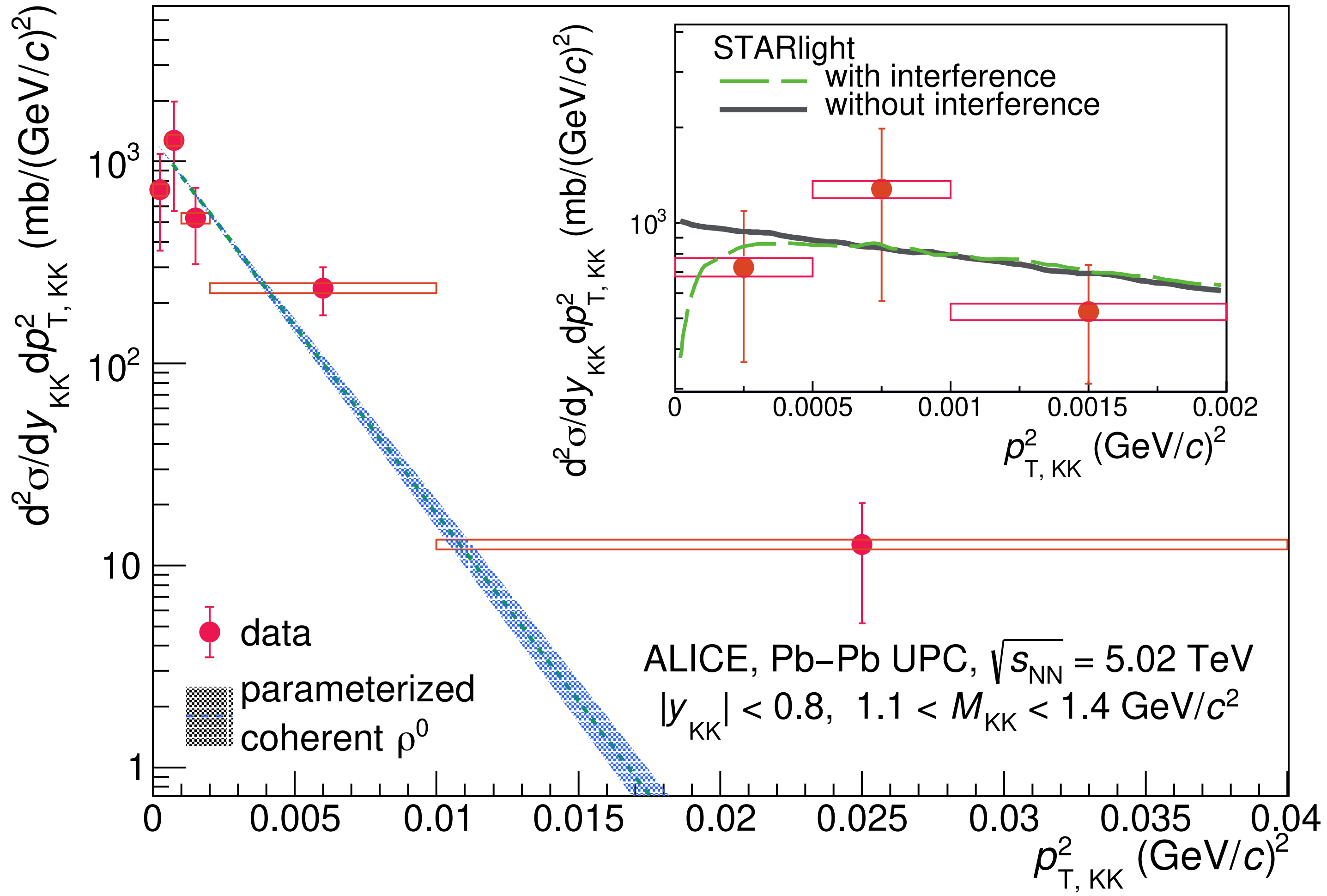
p_T^2 distribution of K^+K^- photoproduction…

- Exclusive K^+K^- photoproduction as a function of $p_T^2 \sim |t|$
- Simple exponential function from parametrised coherent ρ^0 describes the data fairly well
- Cross section at low values of p_T^2 agree with photoproduction with destructive interference
  - Both nuclei can be photon source or targets

ALICE, *Phys.Rev.Lett.* 132 (2024) 22, 222303

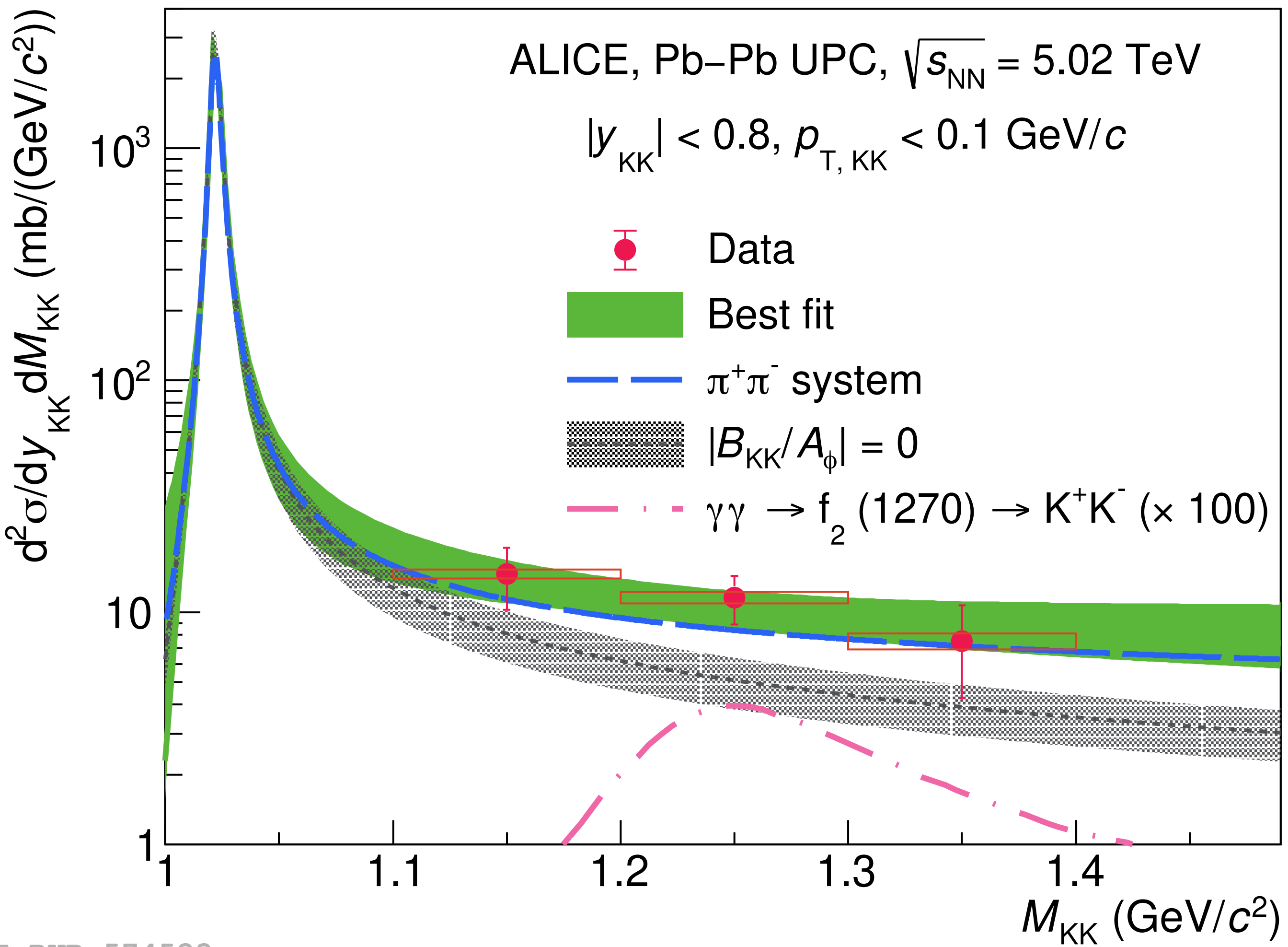


ALI−PUB−574529

…and its invariant mass distribution

- Possible background from $\gamma\gamma \to f_2 \to KK$ small
  - Signal composition of $\phi \to KK$ and non-resonant KK

ALICE, *Phys.Rev.Lett.* 132 (2024) 22, 222303



ALI−PUB−574533

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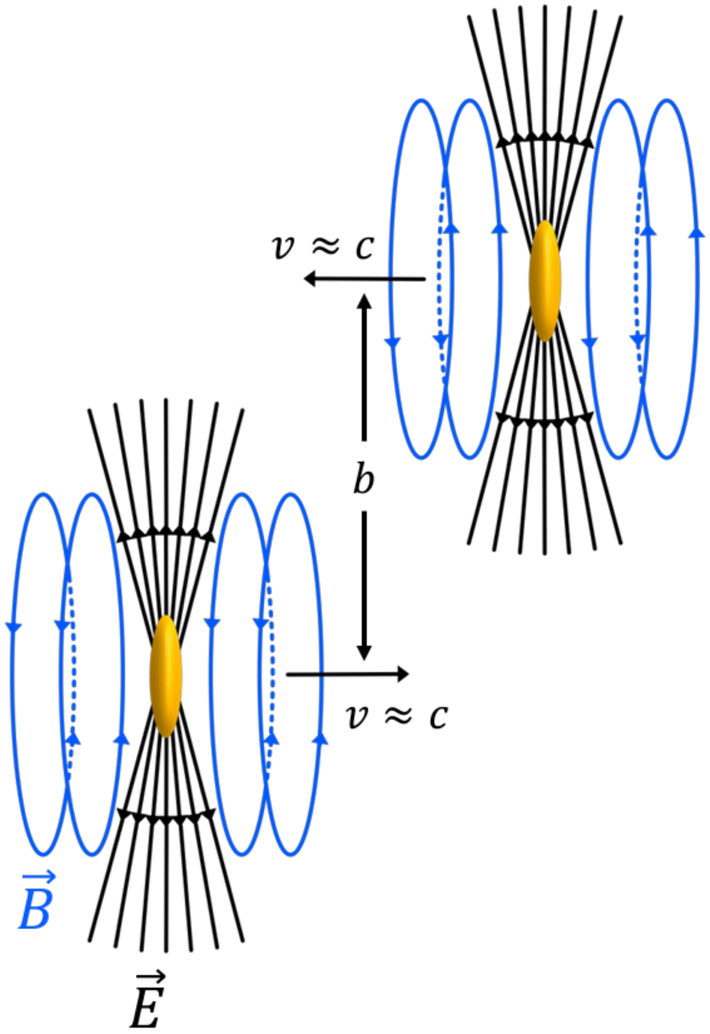
Photons in UPC are linearly polarised

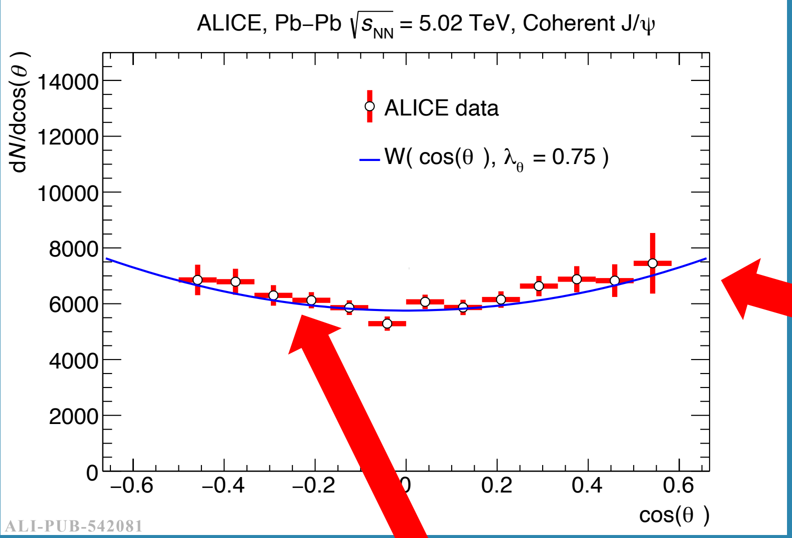
- Ultra-relativistic charged nuclei produce highly Lorentz contracted electromagnetic fields
- Quasireal photons should be linearly polarised in the transverse plane
- Different tools to appreciate it:
  - Birefringence of the QED vacuum
  - Polarisation of photoproduced vector mesons
  - Anisotropy in ρ^0 photoproduction

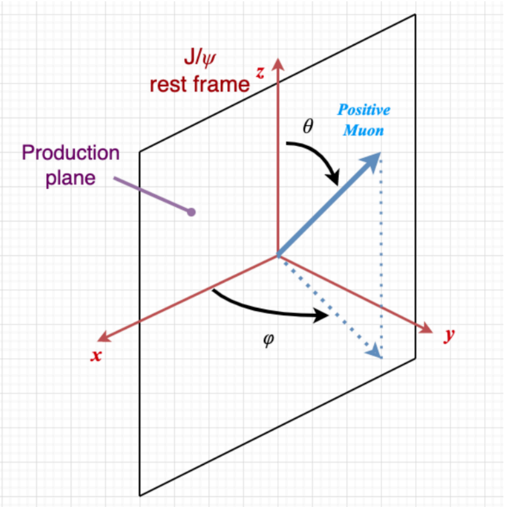
Fig. from D. Brandenburg

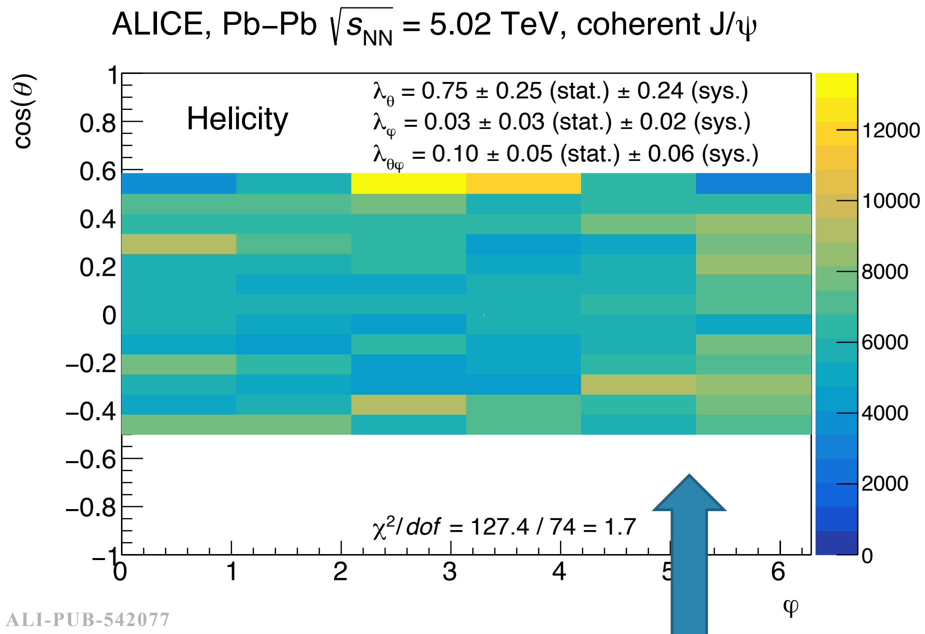


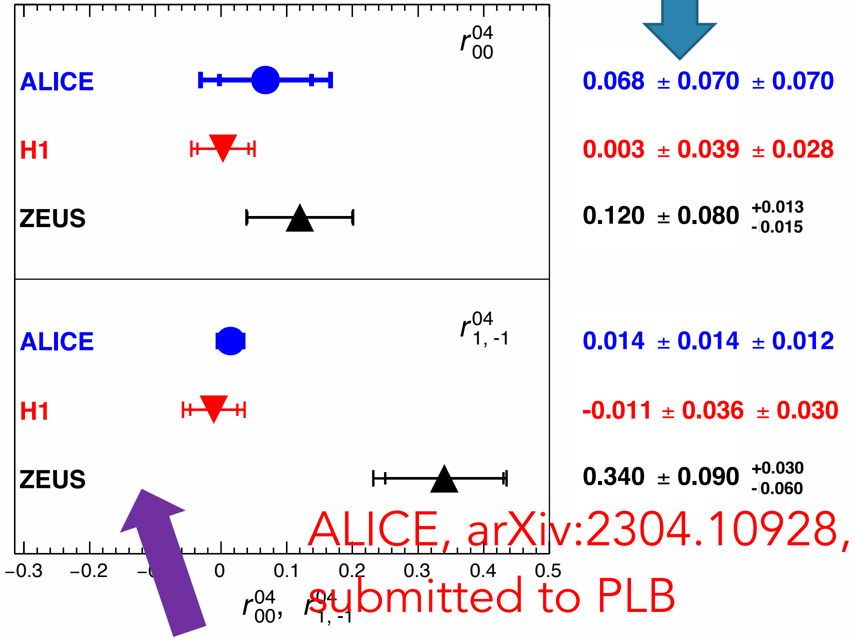
Coherent J/ψ polarisation

- Quasireal photons ($Q^2 \sim 0$): s-channel helicity conservation suggests transverse polarisation for the vector meson
- Agreement with H1 (photoprod.)
- ZEUS measures electroprod.









$$r^{04}_{00} = \frac{1-\lambda_\theta}{3+\lambda_\theta}$$

$$r^{04}_{1,-1} = \frac{\lambda_\varphi}{2} \cdot (1 + r^{04}_{00})$$

Upward parabolic shape in $\cos(\theta)$ typical of transverse polarisation

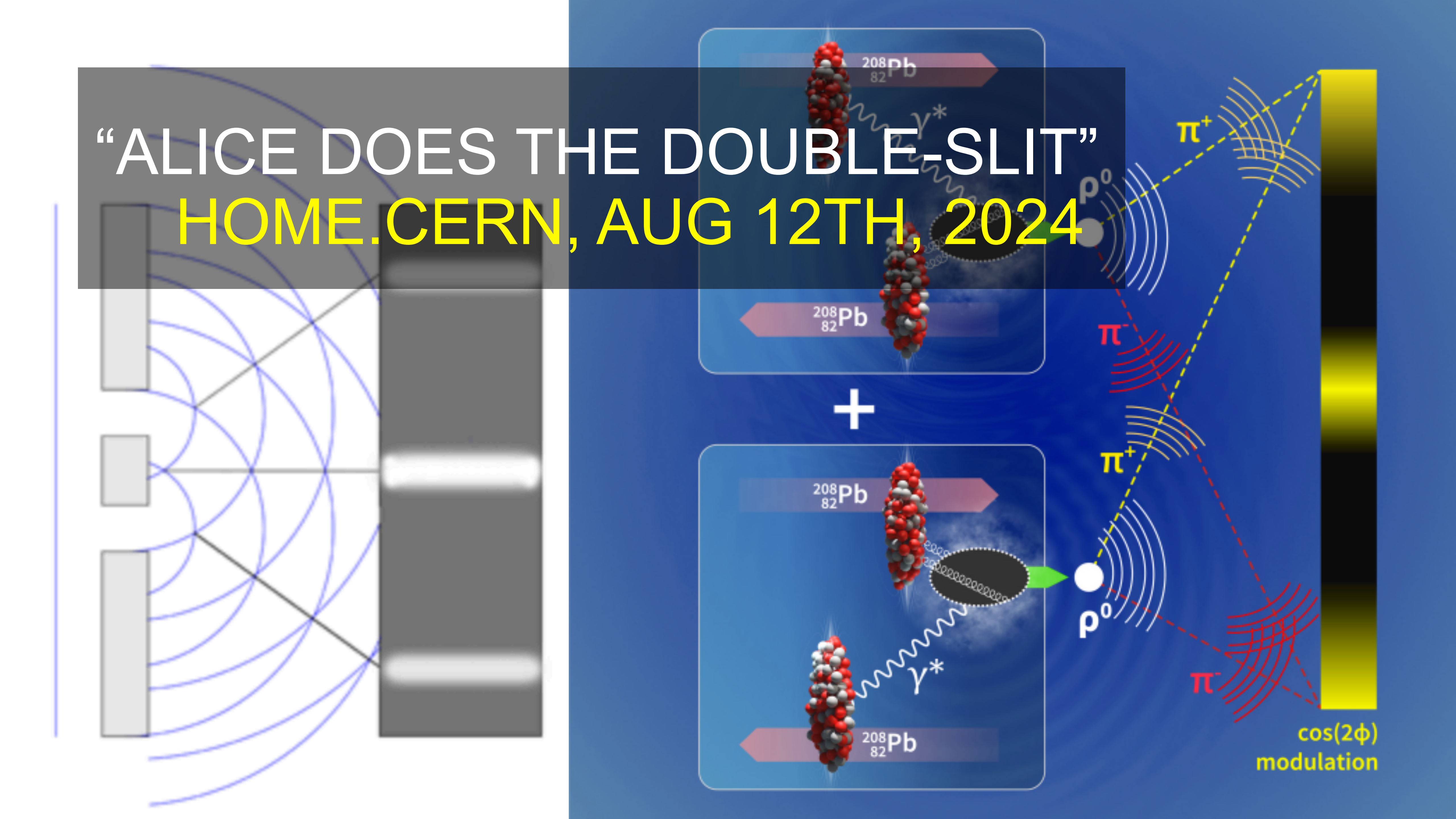
ALICE, arXiv:2304.10928, submitted to PLB

Results with the spin-density matrix elements

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

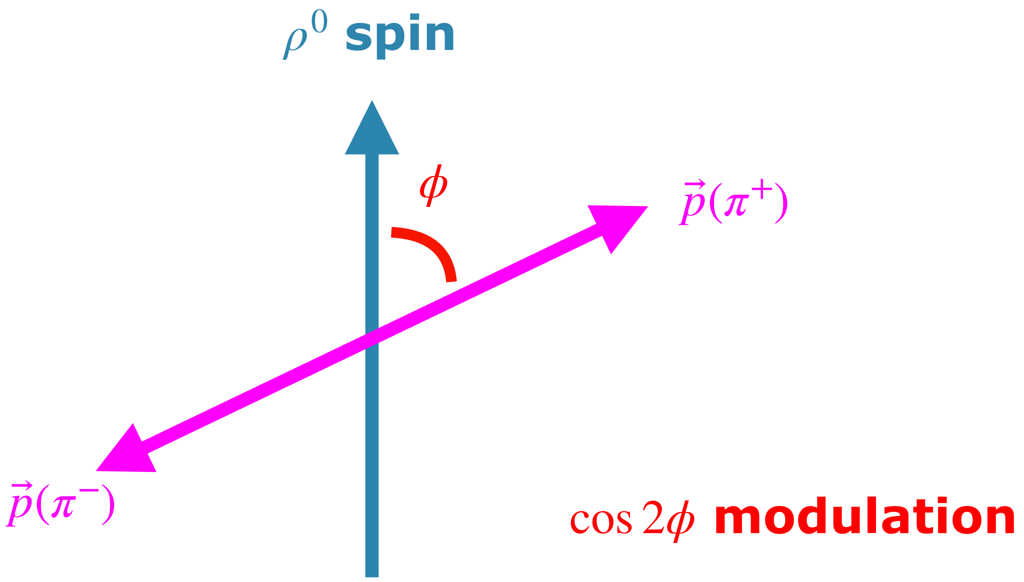
“ALICE DOES THE DOUBLE-SLIT”

HOME.CERN, AUG 12TH, 2024



Where does the interference comes from?

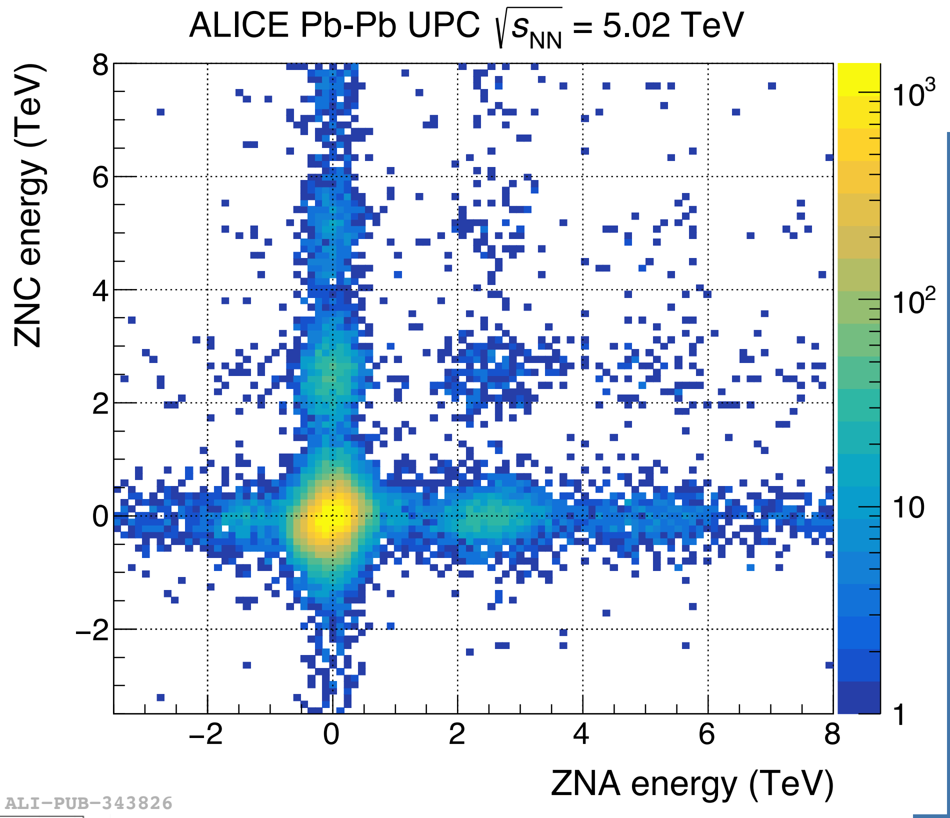
- Linearly polarised photons
- Polarisation transferred to ρ^0
- Azimuthal $\cos 2\phi$ modulation of decay products in momentum with respect to the spin direction
  - Spinless pions → polarisation transferred to orbital angular momentum
- Photon emission ambiguity (which nucleus was the photon emitter and the target) causes interference
  - Anisotropy preserved by a term $\exp(i\vec{p} \cdot \vec{b})$ in the cross section



Preparing a femtometre scale double-slit

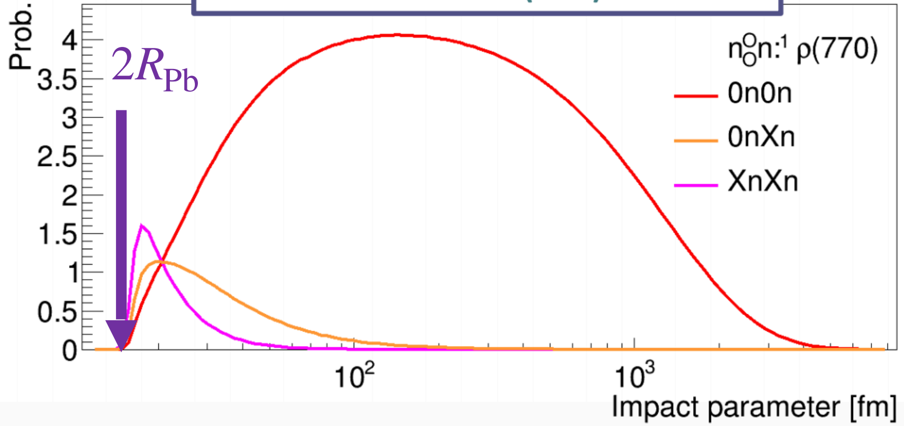
Neutron emission:

- Additional photon exchanges may lead to neutron emission



- Using the neutron ZDCs on the A and C side to detect the neutrons!
- E.g. 0N0N: no neutrons on either ZDCs
- E.g. 0NXN: neutrons only on one side

Broz et. al.: CPC 253 (2020) 107181



- Effectively leveraging on the impact parameter

Preparing a femtometre scale double-slit

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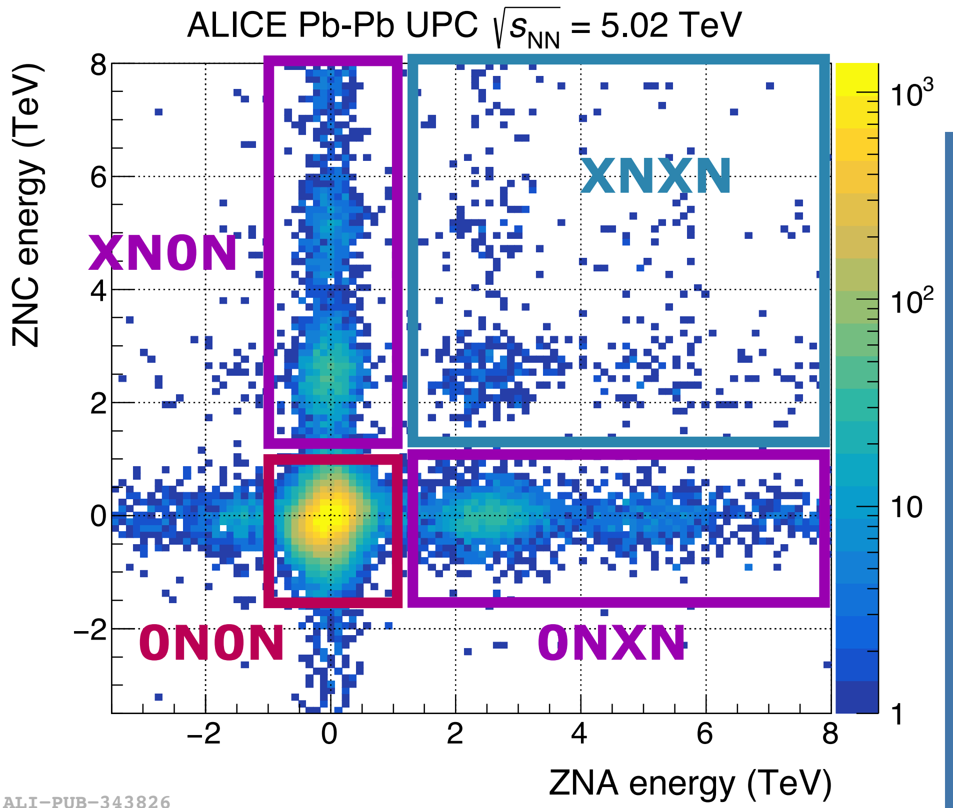

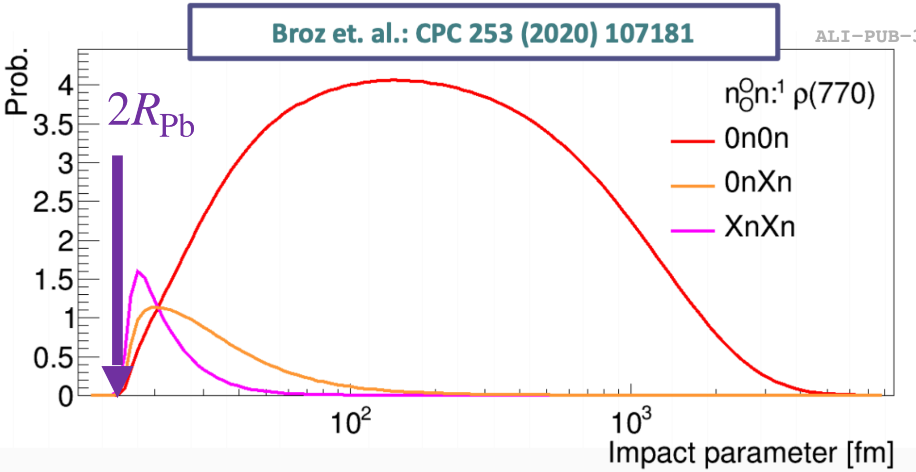

- Using the neutron ZDCs on the A and C side to detect the neutrons!
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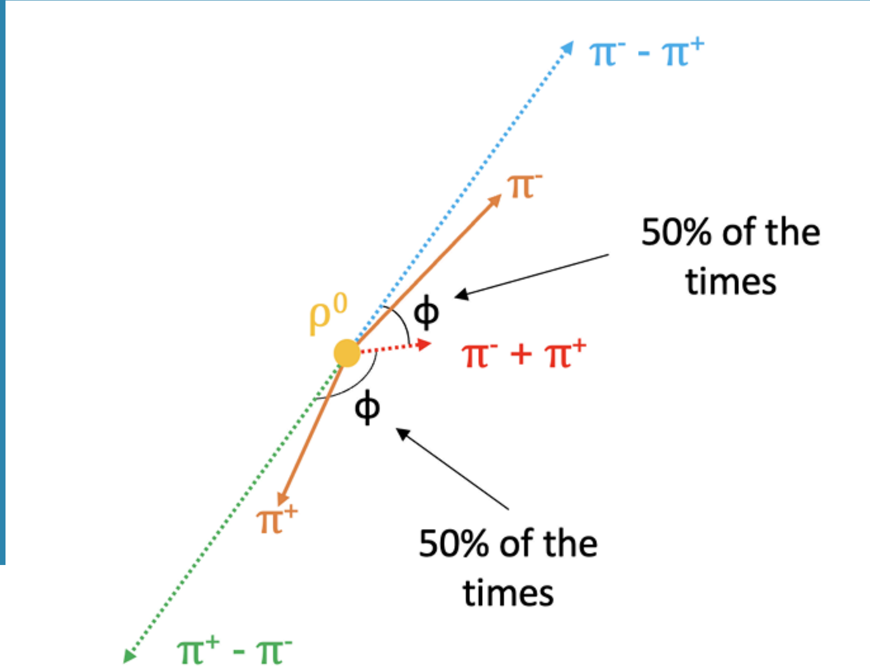
- Effectively leveraging on the impact parameter

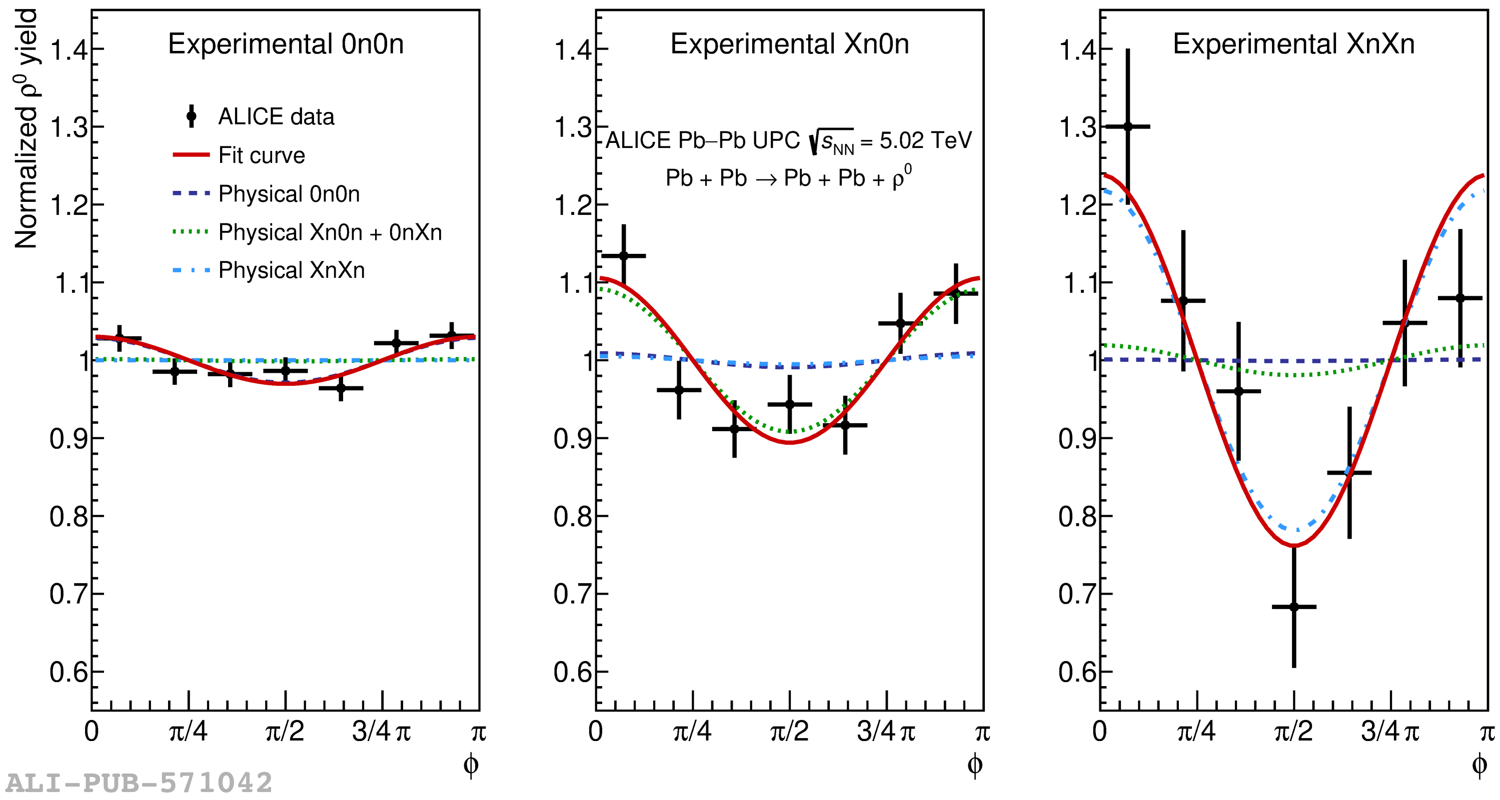
See talk by A. Khatun for more details of the neutron emission technique: https://indico.cern.ch/event/1354173/contributions/6078671/

Angular anisotropy ρ^0 with neutron emission

ALICE, arXiv:2405.14525 [nucl-ex], submitted to PLB

- ϕ: angle between the transverse components of $\vec{p}_+$ and $\vec{p}_-$ with $\vec{p}_\pm = \vec{\pi}_1 \pm \vec{\pi}_2$ with random assignment of the pion tracks (no charge)
- Simultaneous fit to all classes to account for class migrations





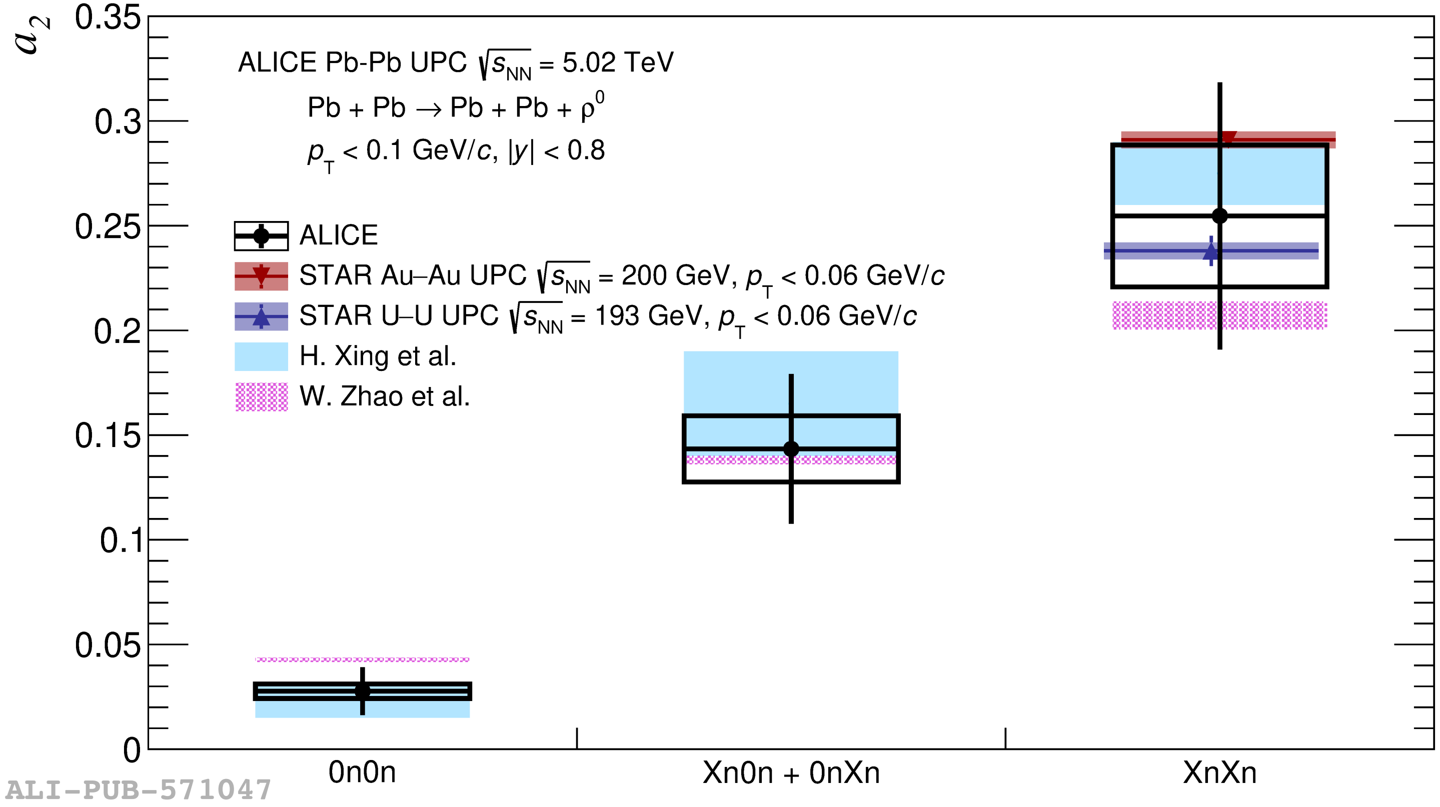
https://home.cern/news/news/physics/alice-does-double-slit

Same technique: neutron emission classes → impact parameter range

Angular anisotropy ρ^0 with neutron emission

- Modulation increases as the impact parameter lowers
- ALICE results compatible with both theory and STAR results
- Modulation: linearly polarised photons + quantum interference at the fermi scale

ALICE, arXiv:2405.14525 [nucl-ex], submitted to PLB



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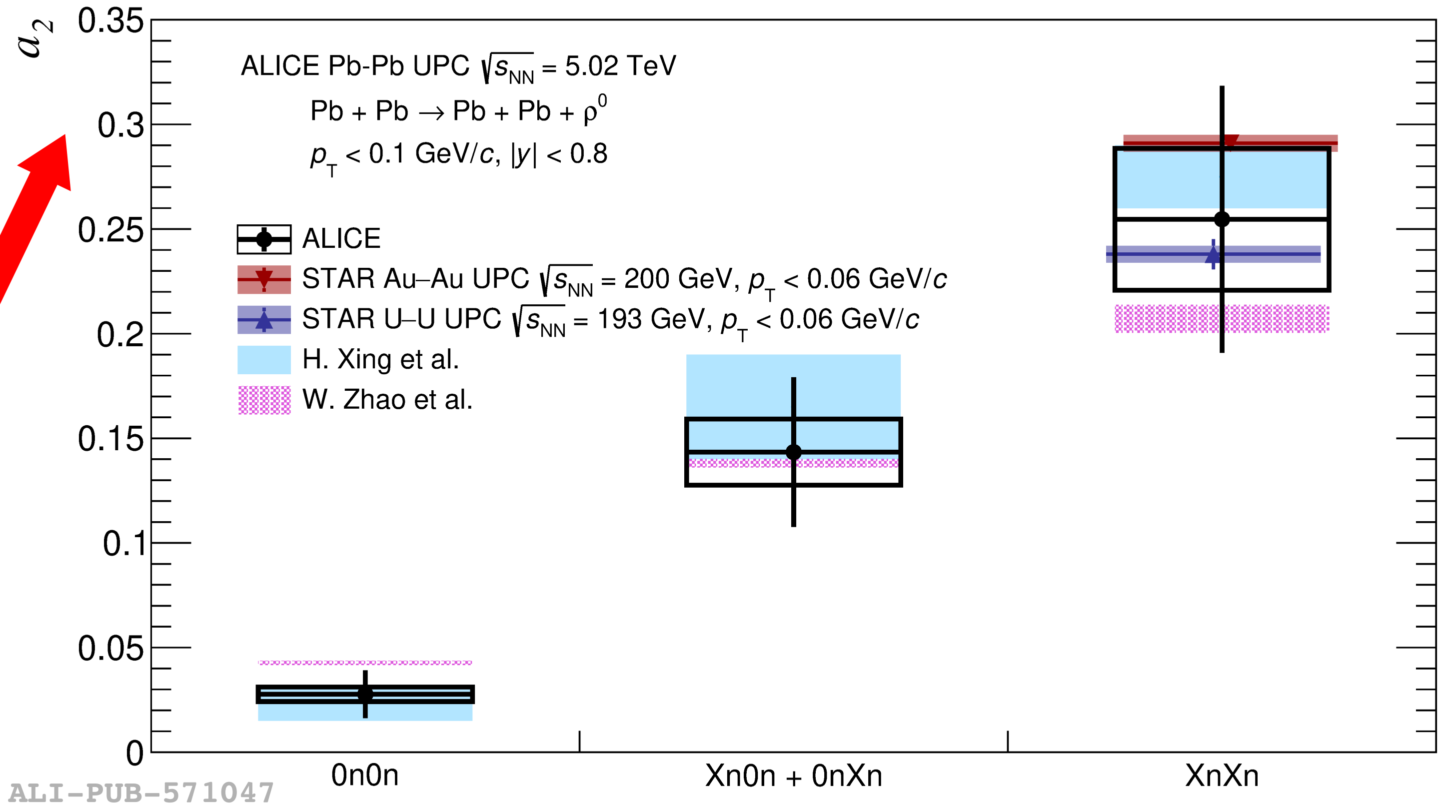
Amplitudes of the $\cos 2\phi$ modulation



https://home.cern/news/news/physics/alice-does-double-slit

Same technique: neutron emission classes → impact parameter range

ALICE IN THE FUTURE

UPGRADES IN RUN 3 AND 4

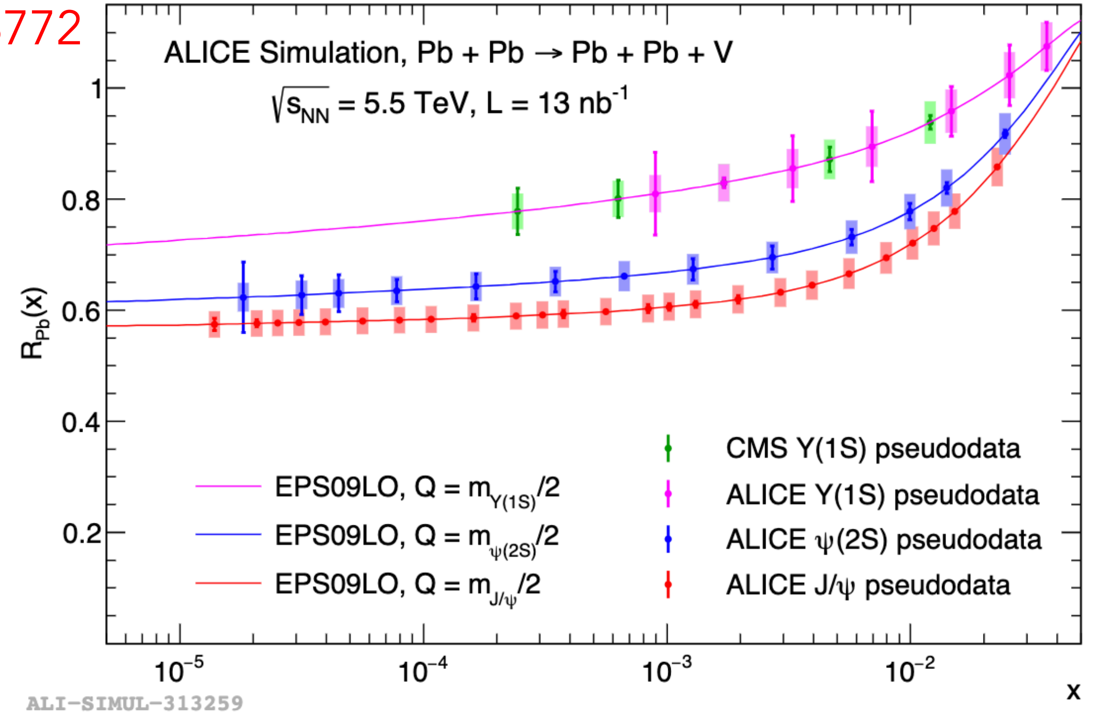
ALICE in Run 3 and 4

- Significant increase in integrated lumi from about 0.8 nb^{-1} for Run 2 to 13 nb^{-1} for Run 3 and Run 4 together
- Great increase in statistics with continuous readout
- Uncertainties for nuclear suppression factor expected to be at the level of 4%
  - Nuclear shadowing studied as a function of x and Q^2
- New measurements e.g. bottomonium states
- MFT in Run 3, FoCal in Run 4!

	PbPb		
Meson	σ	Central 1 Total	Forward 1 Total 1
$\rho \to \pi^+\pi^-$	5.2b	5.5 B	4.9 B
$\rho' \to \pi^+\pi^-\pi^+\pi^-$	730 mb	210 M	190 M
$\phi \to K^+K^-$	0.22b	82 M	15 M
$J/\psi \to \mu^+\mu^-$	1.0 mb	1.1 M	600 K
$\psi(2S) \to \mu^+\mu^-$	30μb	35 K	19 K
$\Upsilon(1S) \to \mu^+\mu^-$	2.0 μb	2.8 K	880

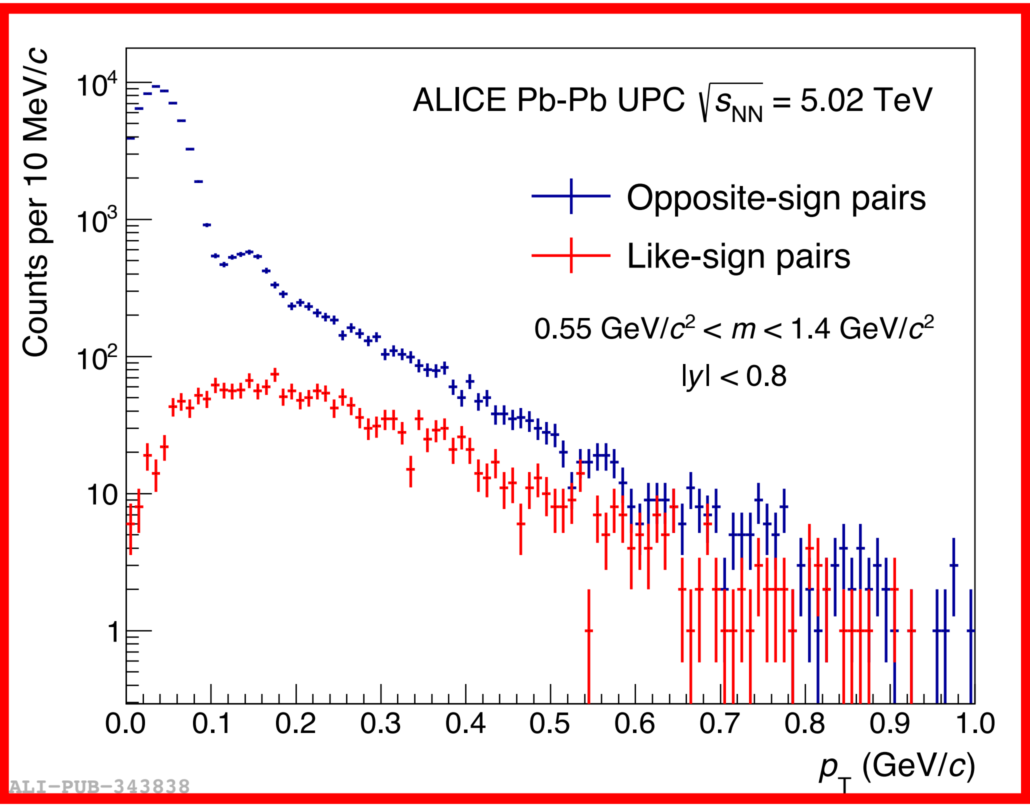
$|y| < 0.9$ $\quad 2.5 < |y| < 4$

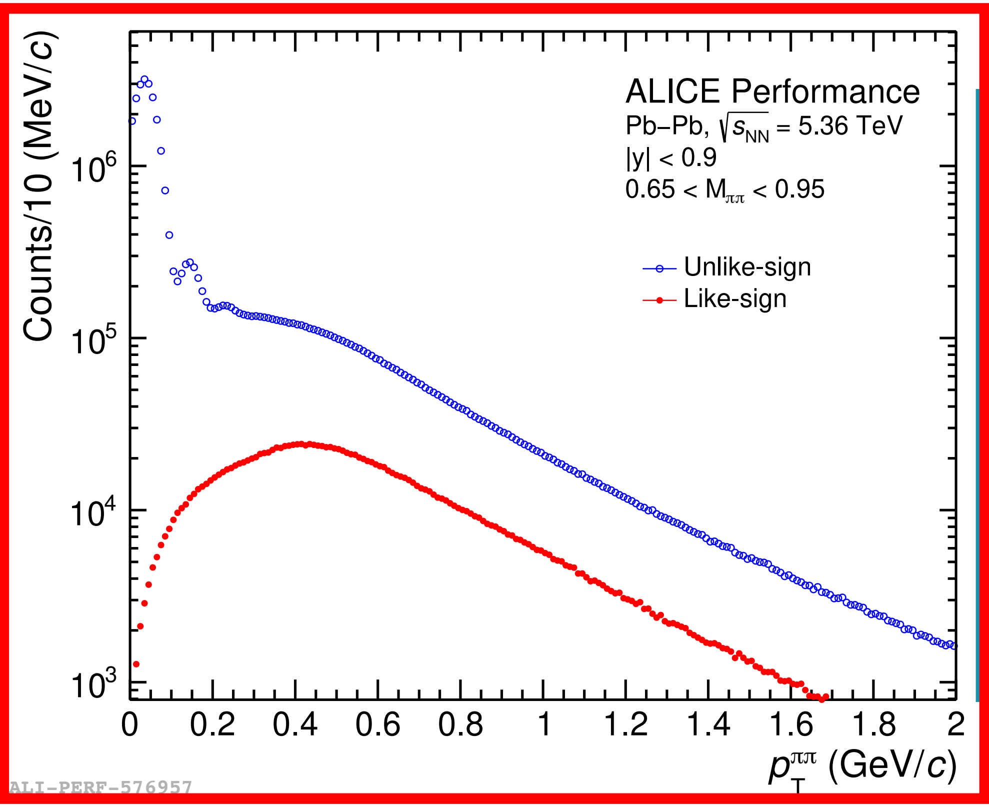
CERN Yellow Rep. Monogr. 7 (2019) 1159-1410, arXiv 1812.06772



Data then… …and now

ALICE, JHEP 06 (2020) 035



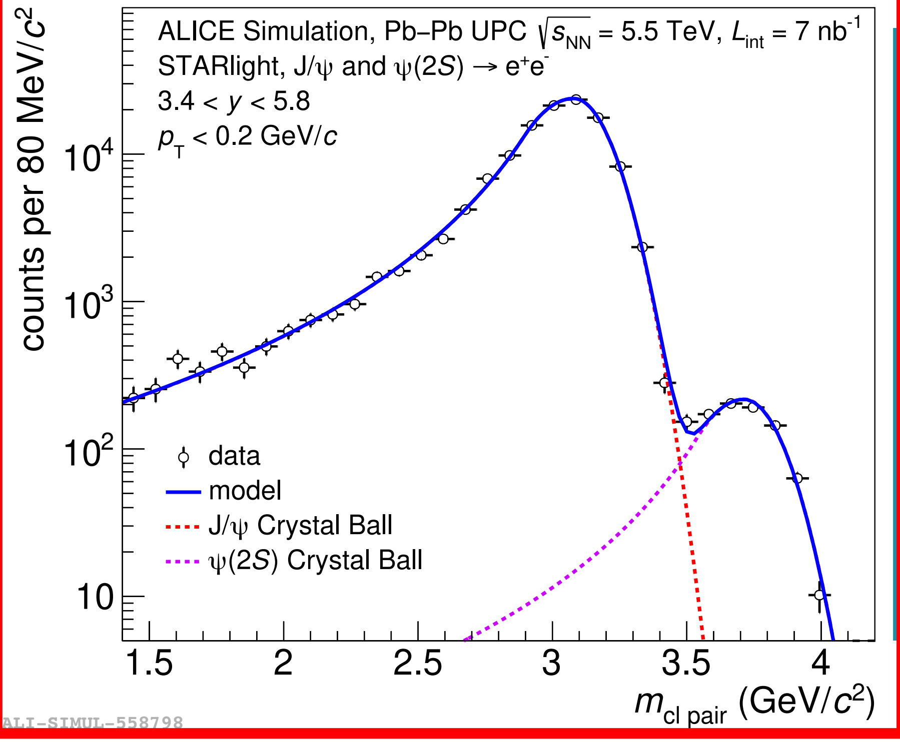


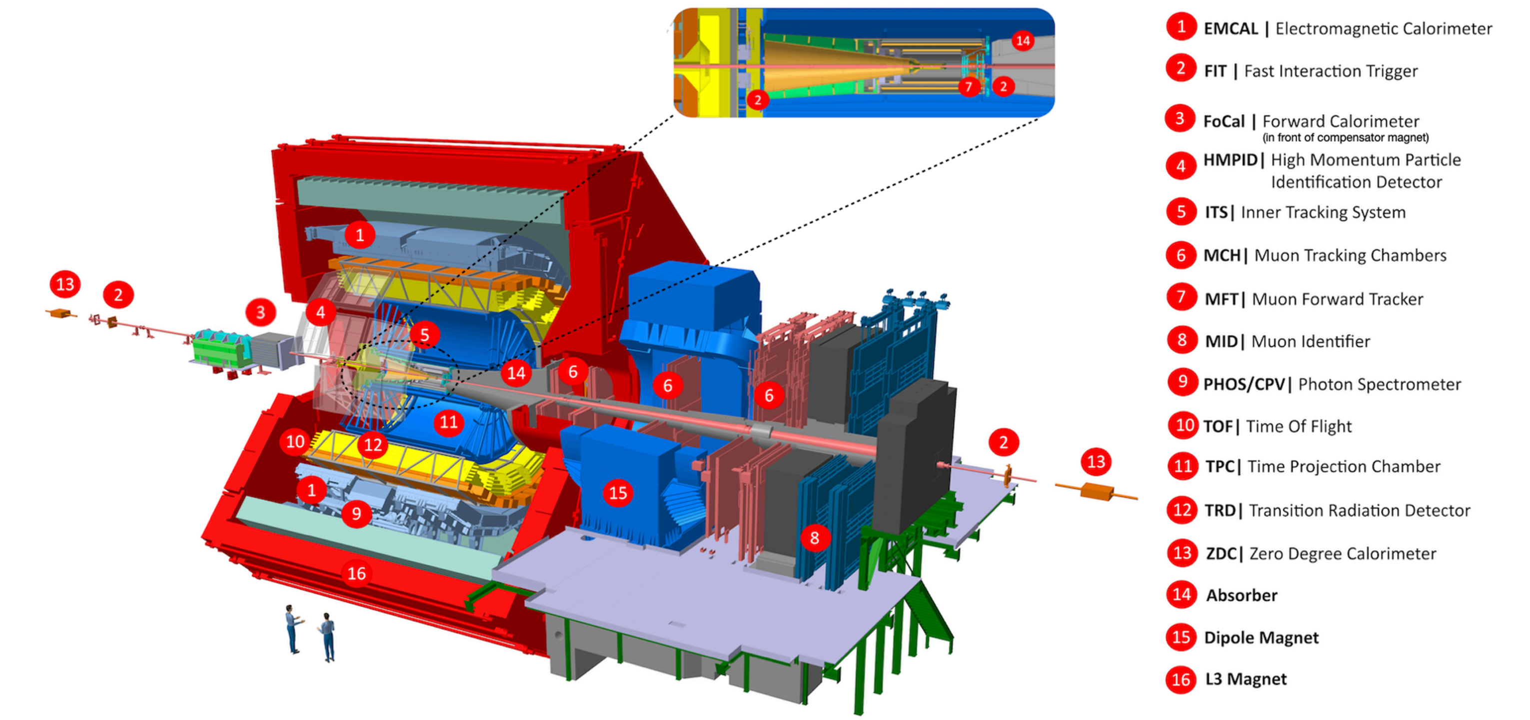
- About 50k raw ρ^0 in Run 2
- Even the anisotropy measurement was limited by statistics

- Millions of raw ρ^0 with only 2023 Pb-Pb data! More incoming

Charmonia photoproduction with FOCAL

$3.2 < \eta < 5.8$

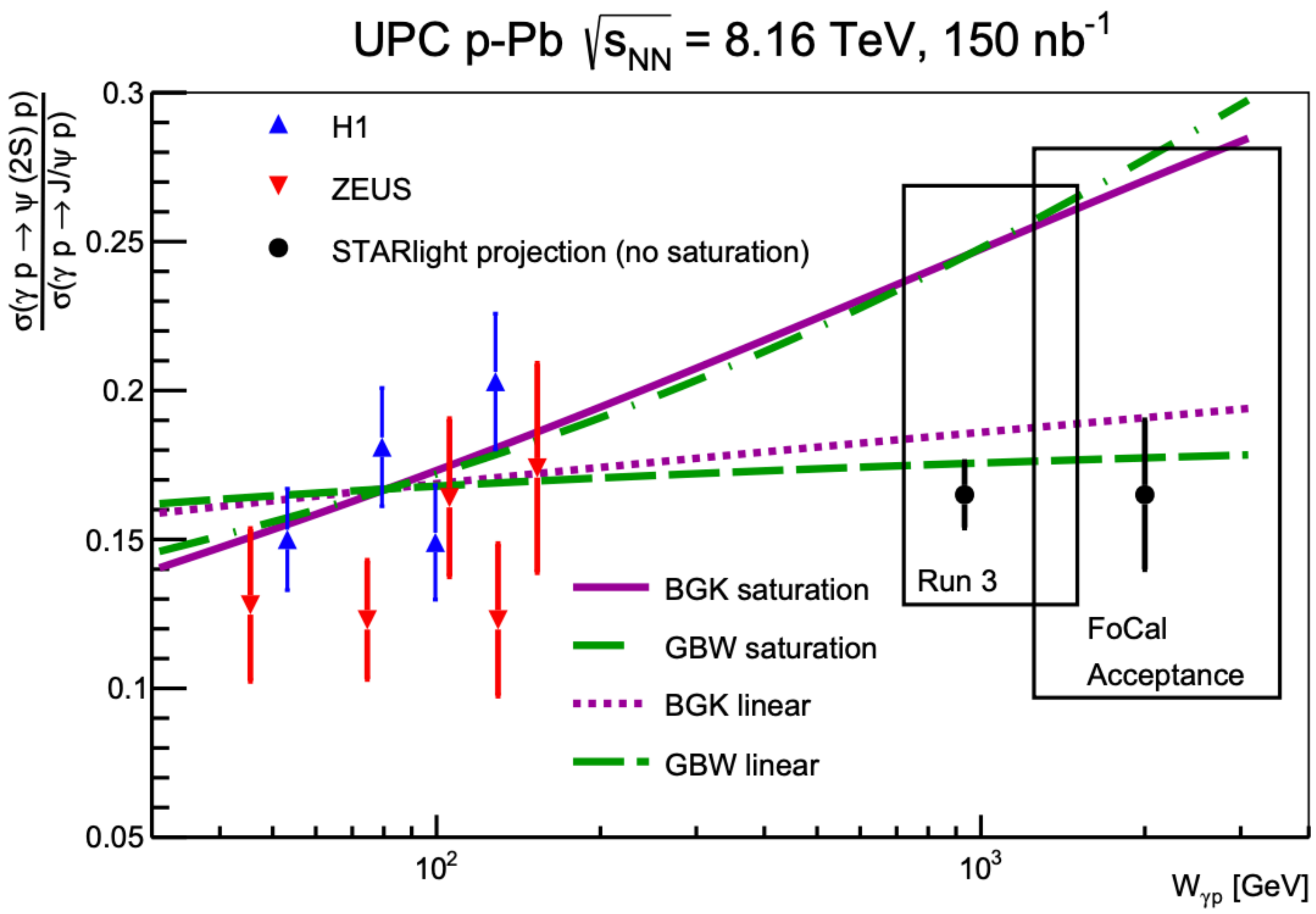




Technical Design Report of the ALICE Forward Calorimeter (FoCal), CERN-LHCC-2024-004

Charmonia photoproduction with FOCAL

- Measuring charmonia in FOCAL in the *ee* channel
- Reaching $W_{\gamma p} \sim 2$ TeV in pPb



A. Bylinkin, J. Nystrand, D. Tapia Takaki, 2023 *J. Phys. G: Nucl. Part. Phys.* **50** 055105

Future opportunities

- ALPs
- τ anomalous magnetic moment
- Tetraquarks

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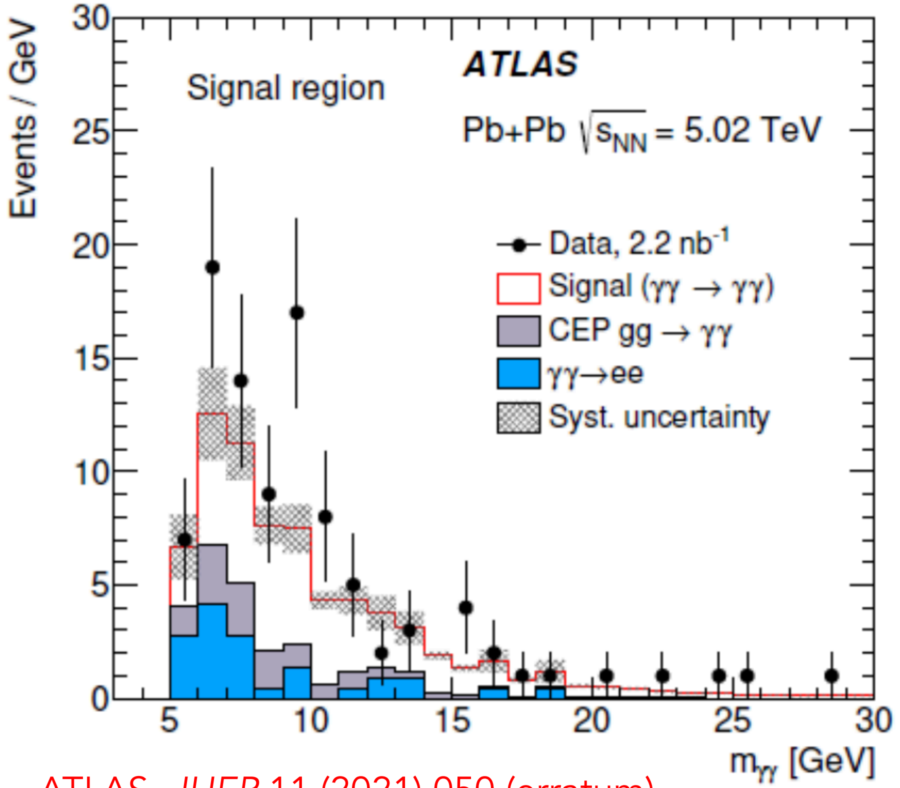
Mariola Kłusek-Gawenda et al., *Phys. Rev. D* 99 (2019) 9, 093013, e-Print: 1904.01243 [hep-ph]

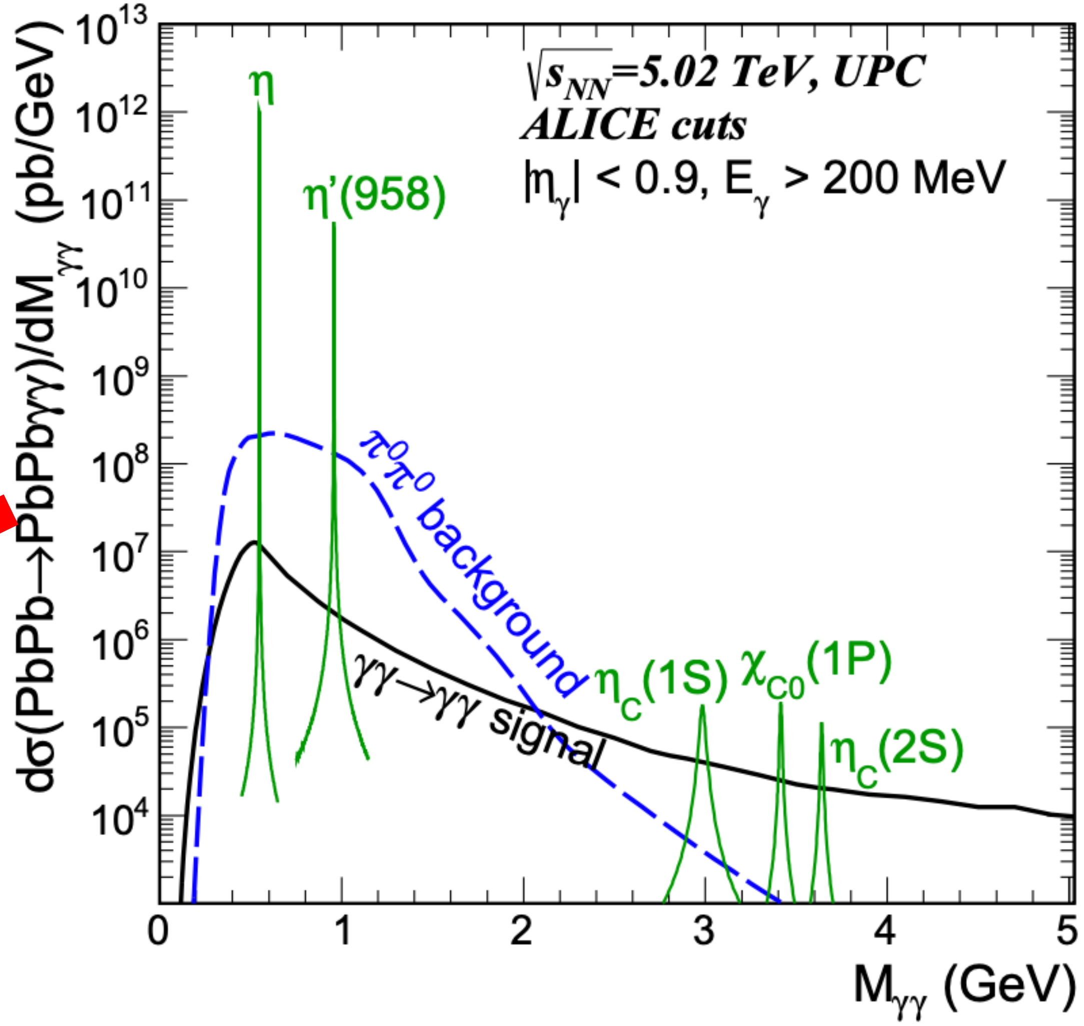
Axion-Like Particles (ALPs)

- ALICE focuses on the low invariant masses



ATLAS, *JHEP* 11 (2021) 050 (erratum), *JHEP* 03 (2021) 243 e-Print: 2008.05355 [hep-ex]

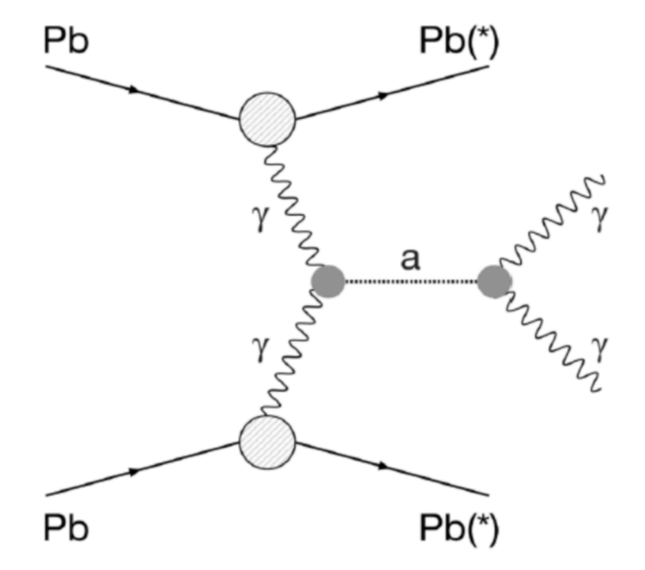
ALICE could push down to about 1 GeV in invariant mass the search for ALPs with EMCAL

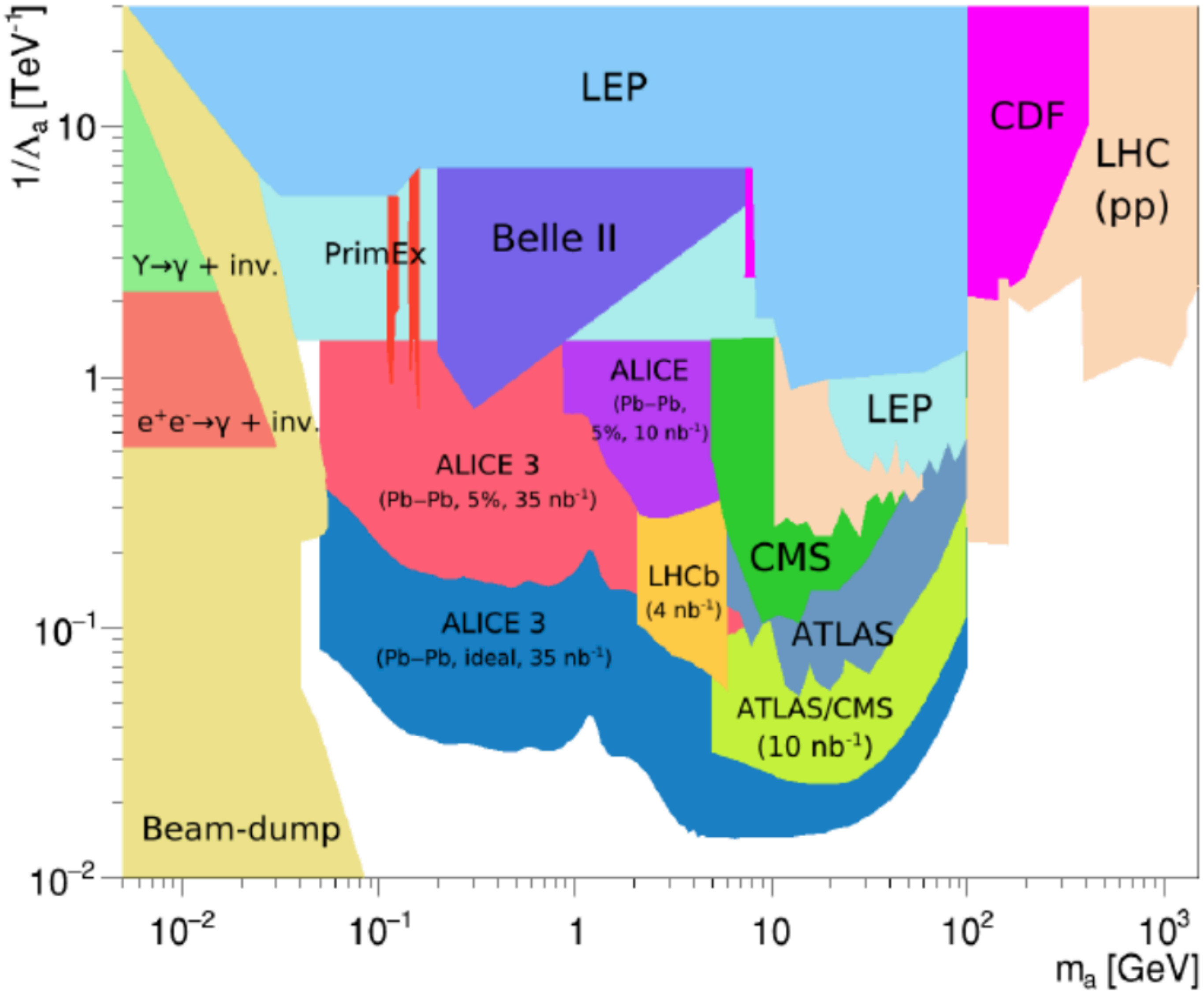


FOCAL is also an interesting opportunity for L-by-L scattering, see the poster at ICHEP 2024 by A. Szczurek and M. Klusek-Gawenda

Axion-Like Particles (ALPs)

- Measuring light-by-light scattering and looking for resonances in the invariant mass distribution





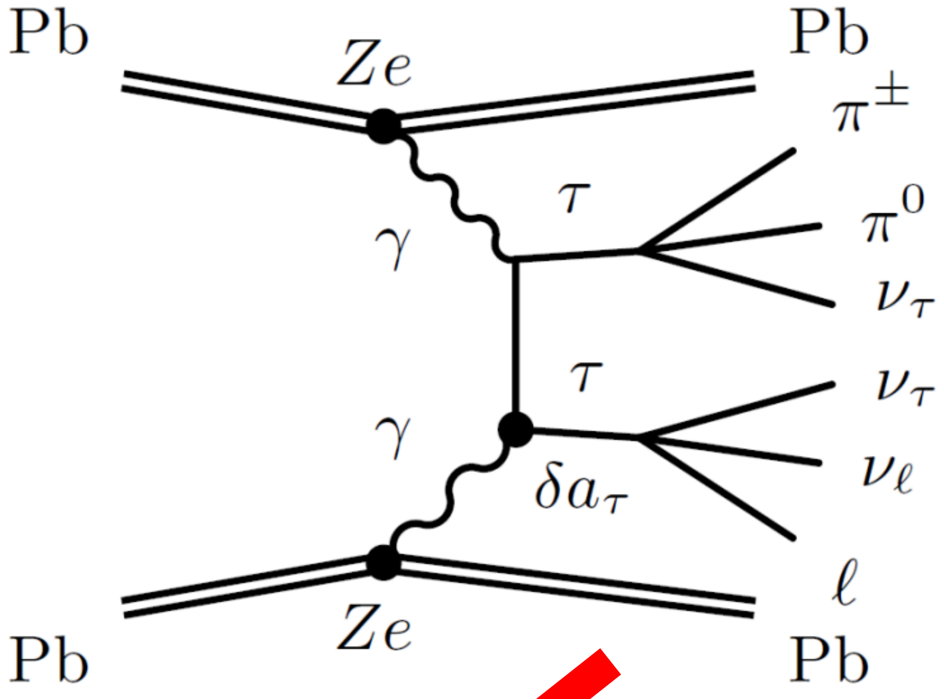
ALICE in Run 3+4+5 will cover a sizeable part of the unexplored phase space

Future opportunities

- ALPs
- τ anomalous magnetic moment
- Tetraquarks

τ anomalous magnetic moment

- $\vec{\mu}_s = g\dfrac{q}{2m}\vec{S}$
- Dirac magnetic moment: $g = 2$
- $a = \dfrac{g-2}{2}$
- Anomalous magnetic moment comes from corrections at higher order!
- Using UPC for the τ!

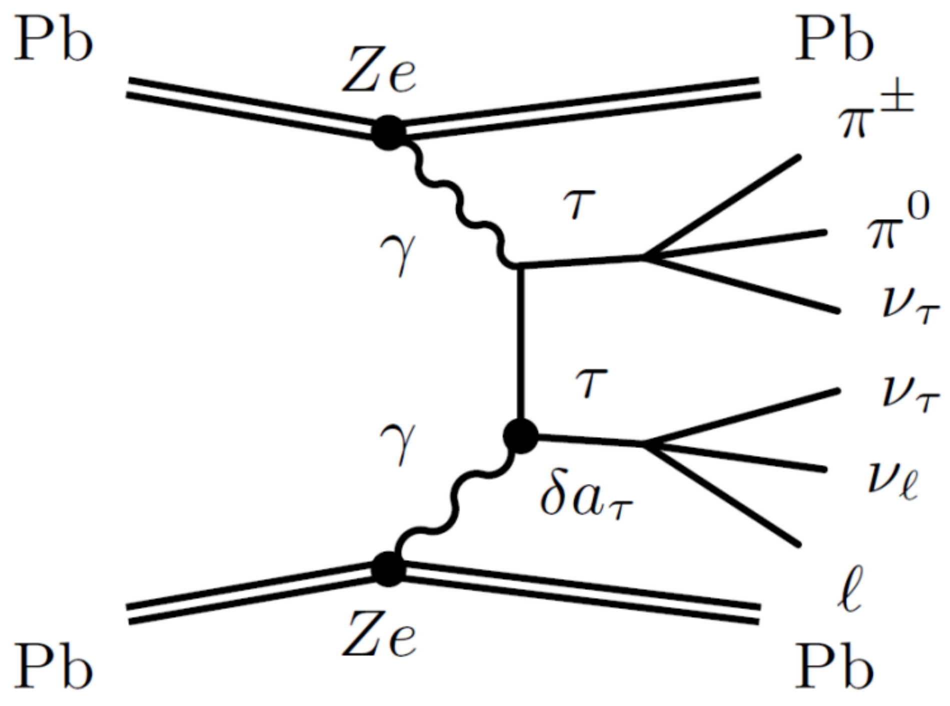


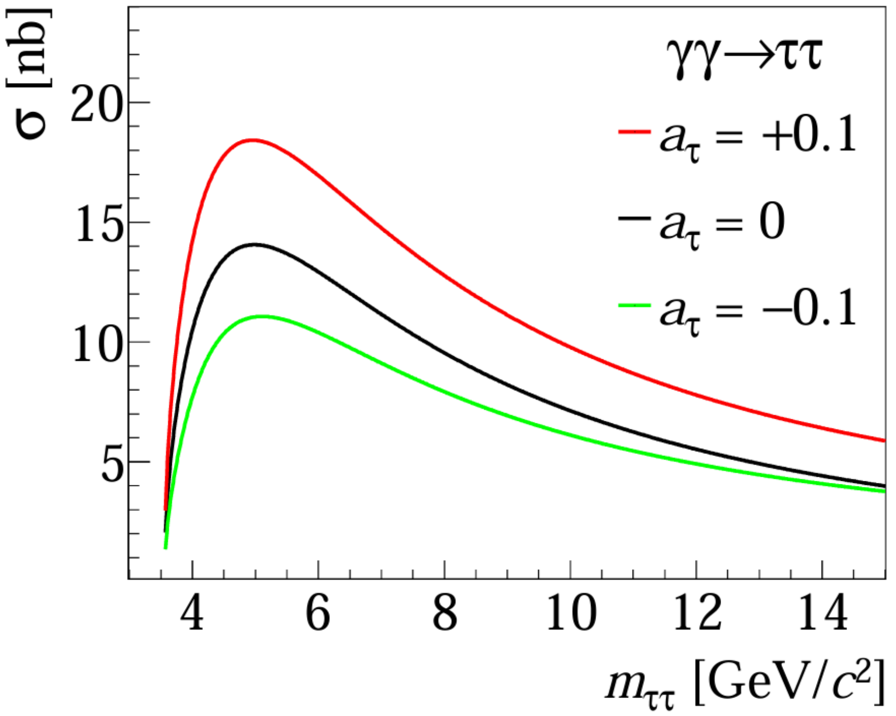
Possible SuSy as scale M_s leads to corrections $\delta a_l \sim (m_l/M_s)^2$

τ sector 280 times more sensitive to SuSy than the muon

- $BR(\tau \to e\nu_e\nu_\tau) = 17.8\,\%$
- $BR(\tau \to \mu\nu_\mu\nu_\tau) = 17.4\,\%$
- $BR(\tau \to \pi^\pm + n\pi^0 + \nu_\tau) = 45.6\,\%$

N. Burmasov et al., *Comput.Phys.Commun.* 277 (2022) 108388





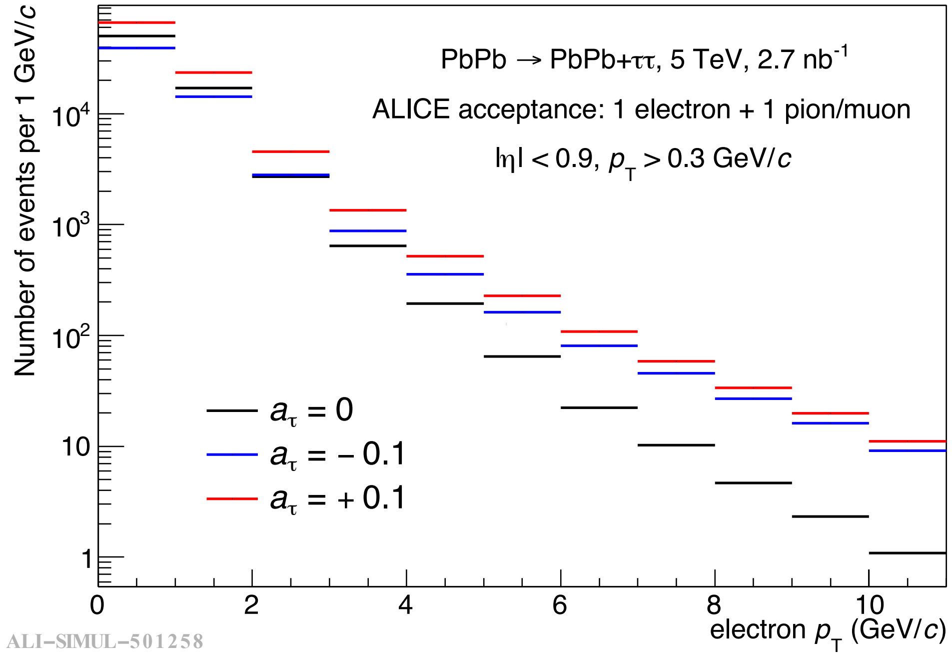
τ anomalous magnetic moment

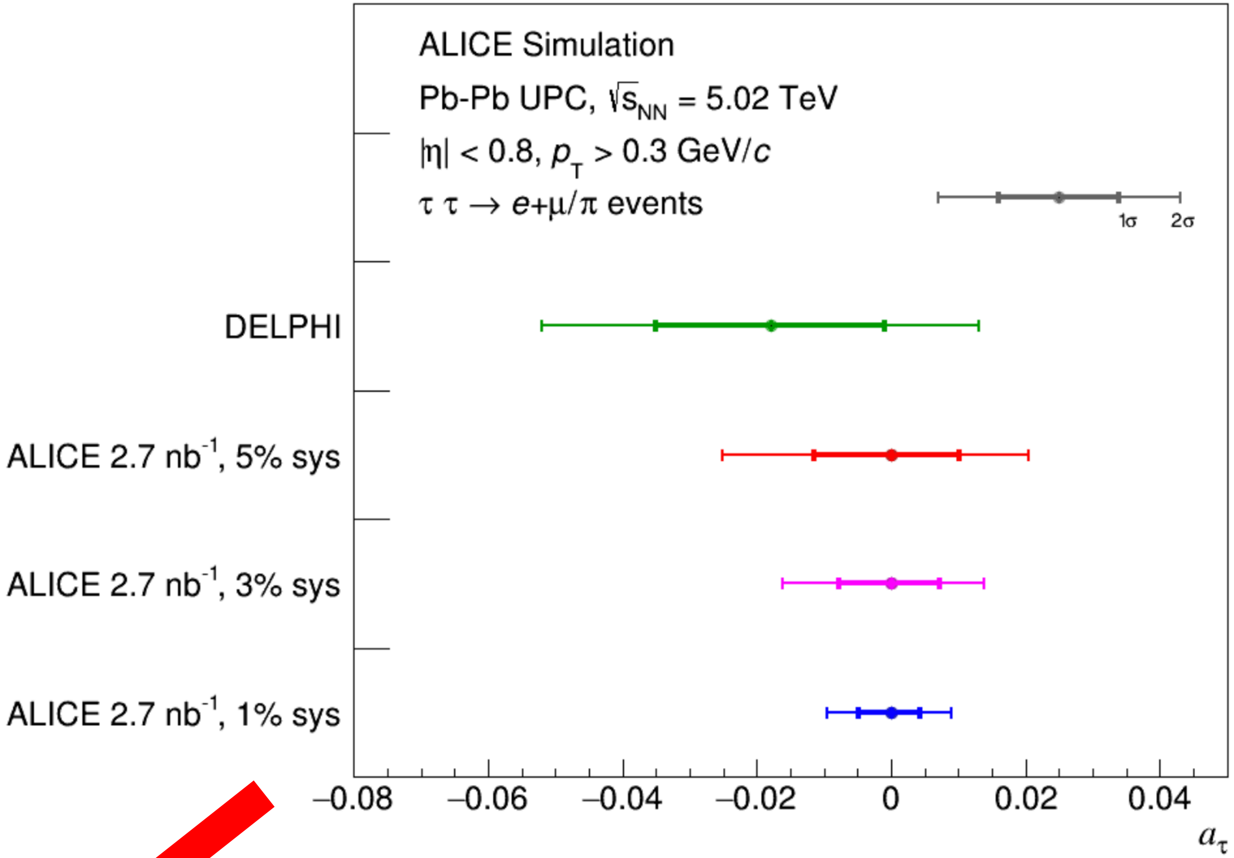
- Cross section of $\gamma\gamma \to \tau\tau$ sensitive to the anomalous magnetic moment

τ anomalous magnetic moment

ALICE can focus on low-p_T tracks where most of the statistics is focused

- Indirect measurement of the τ anomalous magnetic moment
- Run 3 will provide the most precise value in Pb-Pb





Possible to reduce the uncertainties by 2x in Run 3

Now also a new high precision measurement by CMS in pp

CMS-SMP-23-005

Future opportunities

- ALPs
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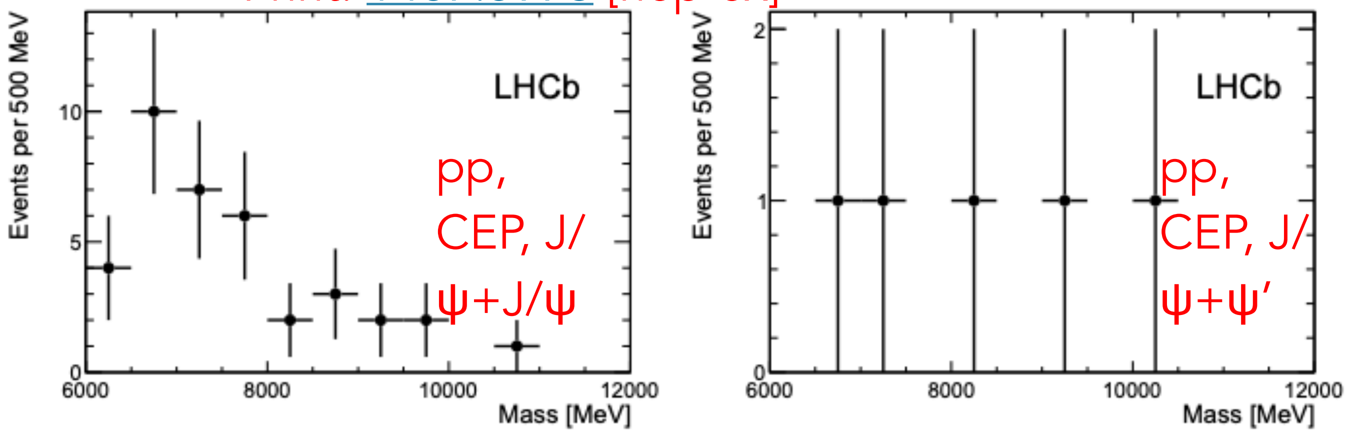
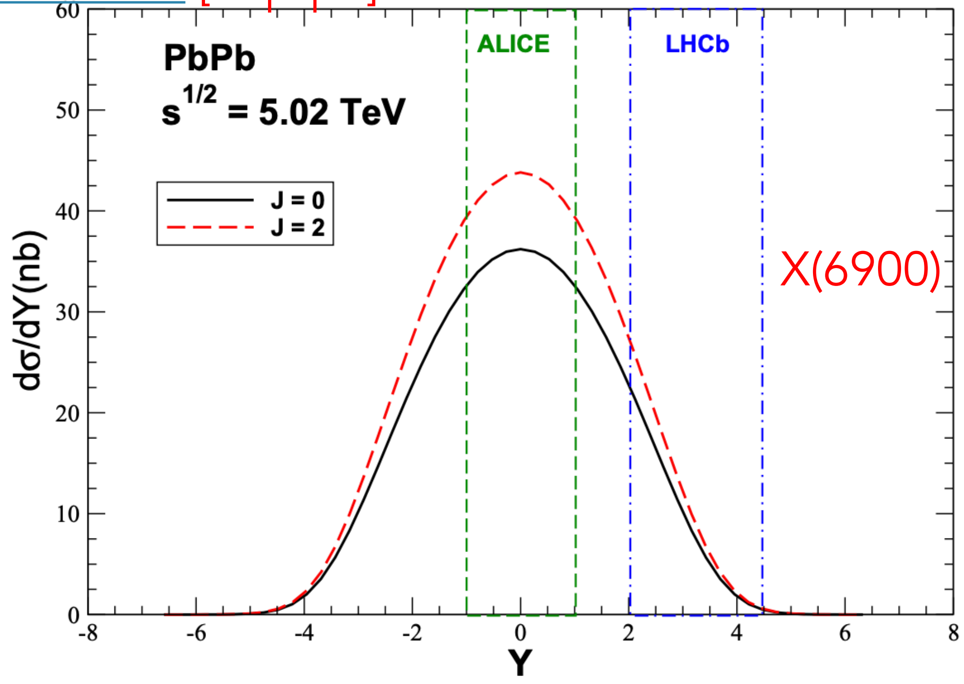
Tetraquarks

- Photon-induced reactions
- $\gamma\gamma \rightarrow T_{4c} \rightarrow 4l$
- Photon flux is well known: basically accessing the wave function of the tetraquark!
- If possible, important to test the production mechanism: true, molecular…?
- All the X(6900) family, X(3872), potentially more

LHCb, *J. Phys. G* 41 (2014) 11, 115002 e-Print: 1407.5973 [hep-ex]



V. Gonçalves, B. Moreira, *Phys. Lett. B* 816 (2021) 136249 e-Print: 2101.03798 [hep-ph]



Thank you!

Pb-Pb Run 2

$\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

- Linearly polarised UPC photons and related measurements
- New wealth of data from continuous readout and Run 3!
- Numerous exciting future opportunities leveraging on the very clean environment of UPCs!

Backup slides