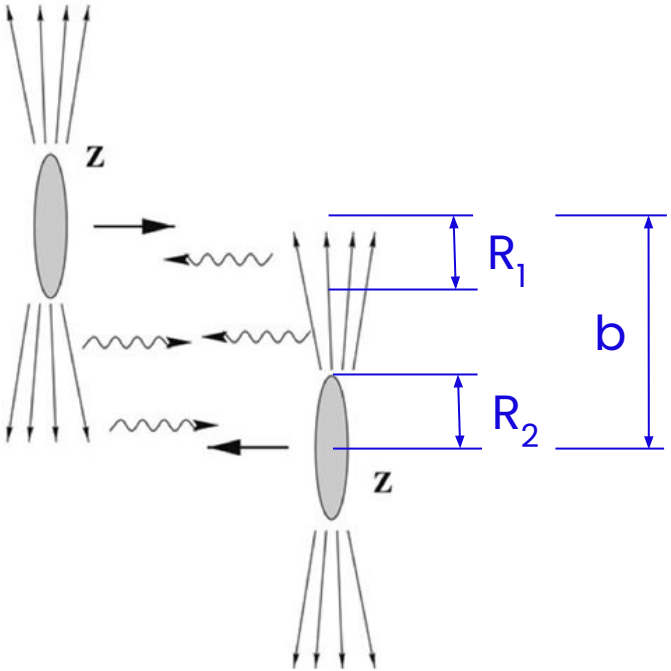
Quarkonia photoproduction and dilepton production in UPCs with ALICE

Nazar Burmasov on behalf of the ALICE Collaboration

ICHEP 2024

July 18, 2024, Prague, Czech Republic

LHC as hadron and photon collider



Ultraperipheral collisions (UPC): $b > R_1+R_2$

➔ Hadronic interactions strongly suppressed

Electromagnetic fields:

➔ Treated as quasi-real photon fluxes

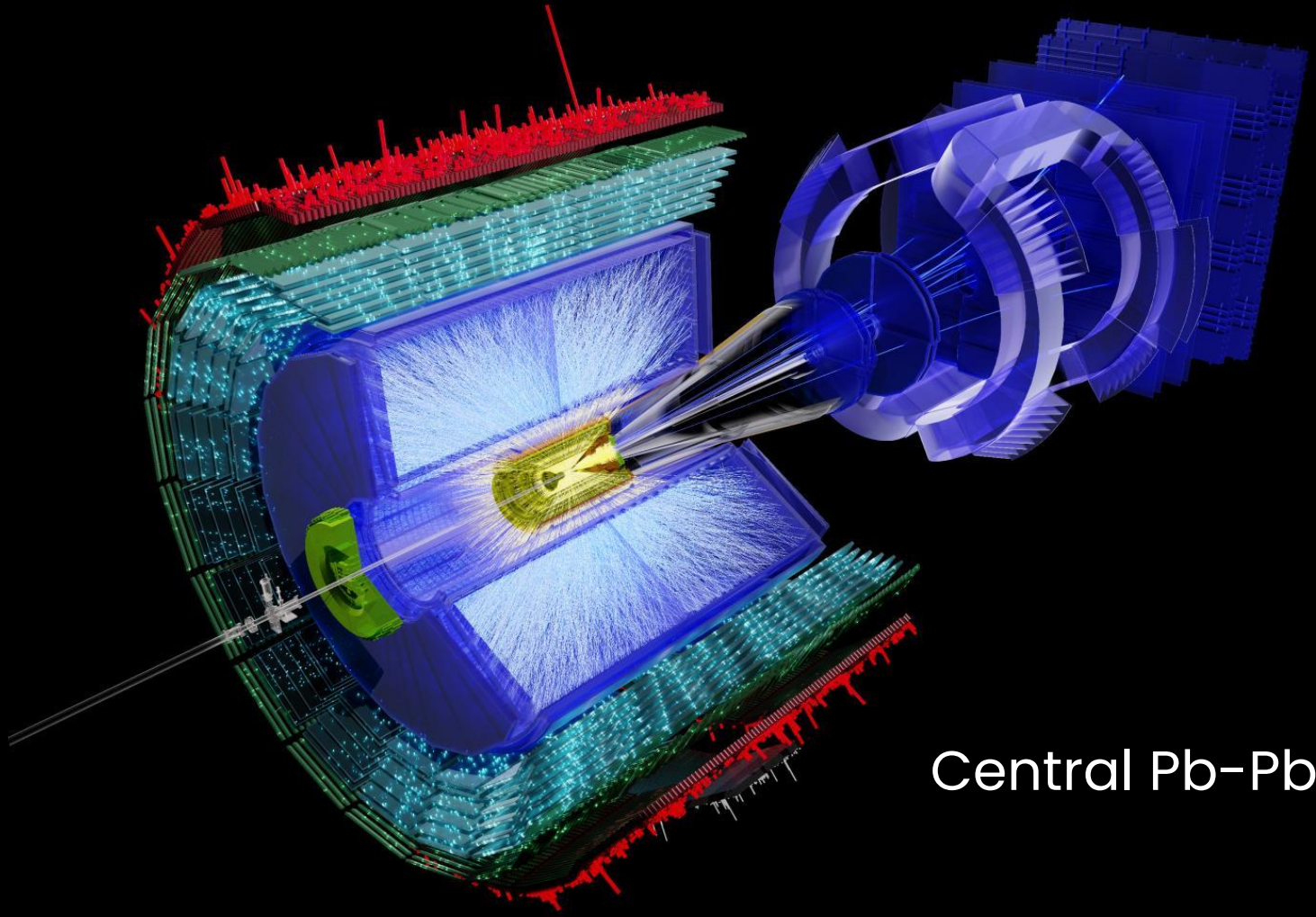
➔ Small virtuality $Q < 1/R \sim 30$ MeV

➔ Proportional to Z^2

UPC physics reviews:

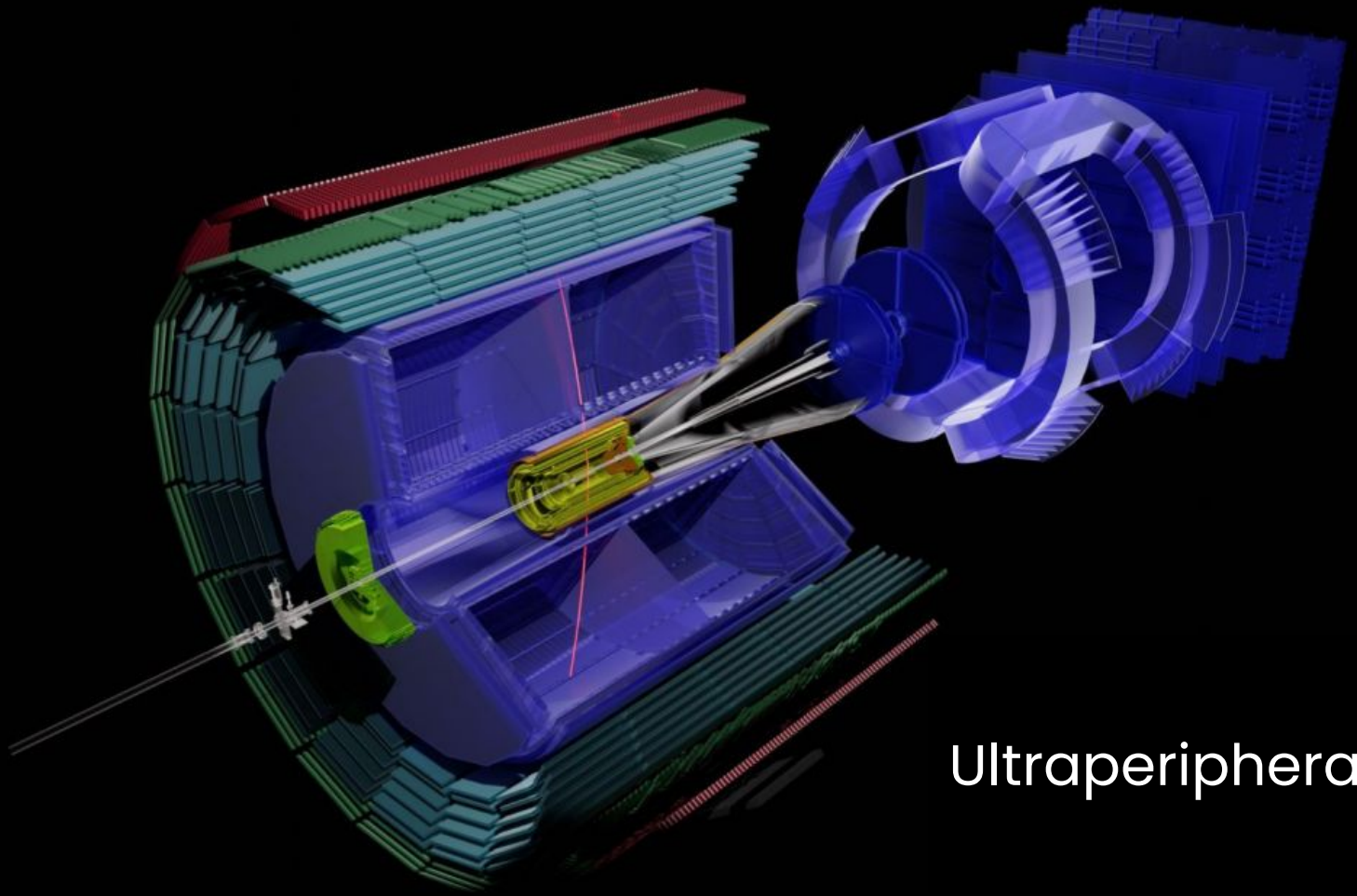
- A.J. Baltz et al., Phys. Rept. 458 (2008) 1-171
- J.G. Contreras, J.D. Tapia Takaki, IJMP A30 (2015) 1542012
- S. Klein and P. Steinberg, Ann. Rev. Nuclear Part. Sci. 70 (2020) 323

Related ICHEP talk: Roman Lavicka, J/ψ production and polarization in photon-induced reactions in Pb-Pb collisions with ALICE



ALICE
Run 3 Pb-Pb
$\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV

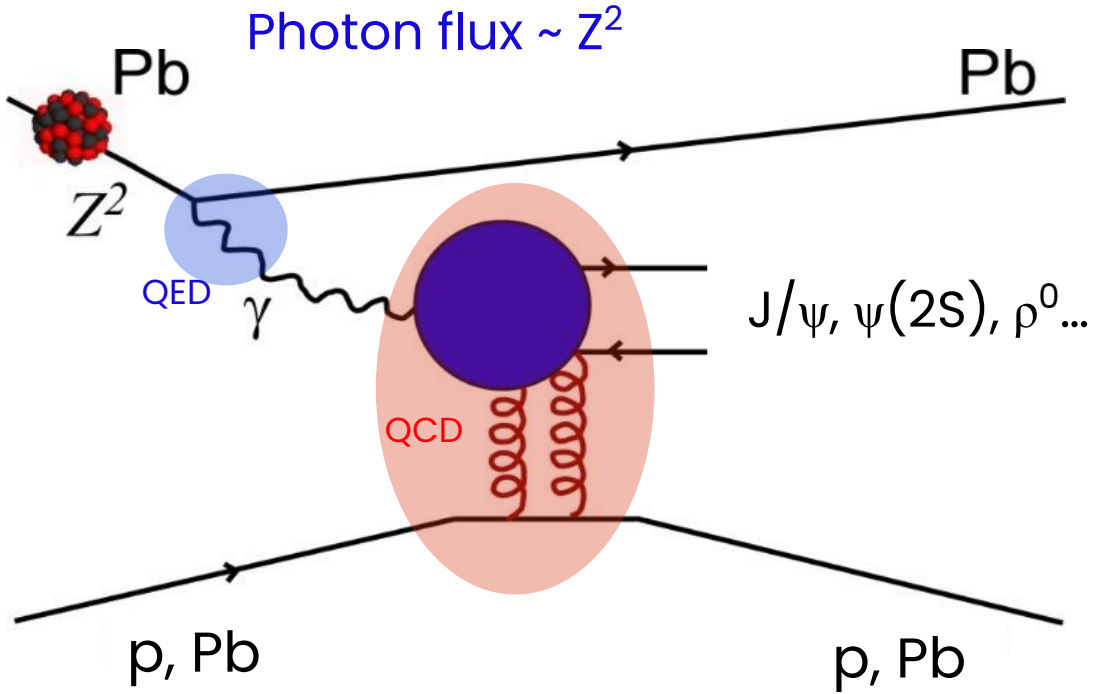
Central Pb-Pb collision



ALICE
Run 3 Pb-Pb
$\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV

Ultraperipheral collision

Vector meson photoproduction

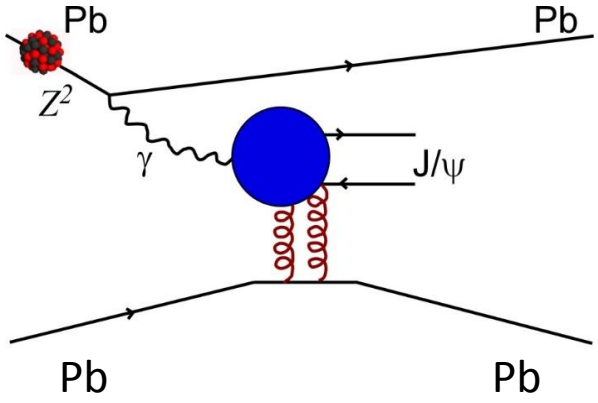


$$\frac{\mathrm{d}\sigma_{\mathrm{PbPb}}(y)}{\mathrm{d}y} = n_\gamma(y)\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y)\sigma_{\gamma\mathrm{Pb}}(-y)$$

Factorize UPC cross section:

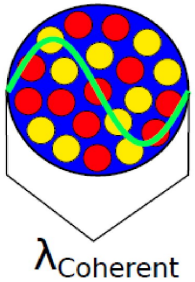
- QED: flux of quasi-real photons
- QCD: photonuclear cross section $\sigma_{\gamma Pb}$

Coherent and incoherent photoproduction

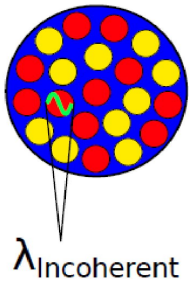


LO : Ryskin, Z.Phys.C 57 (1993), 89-92
NLO: K. Eskola et al., PRC 106 (2022), 035202

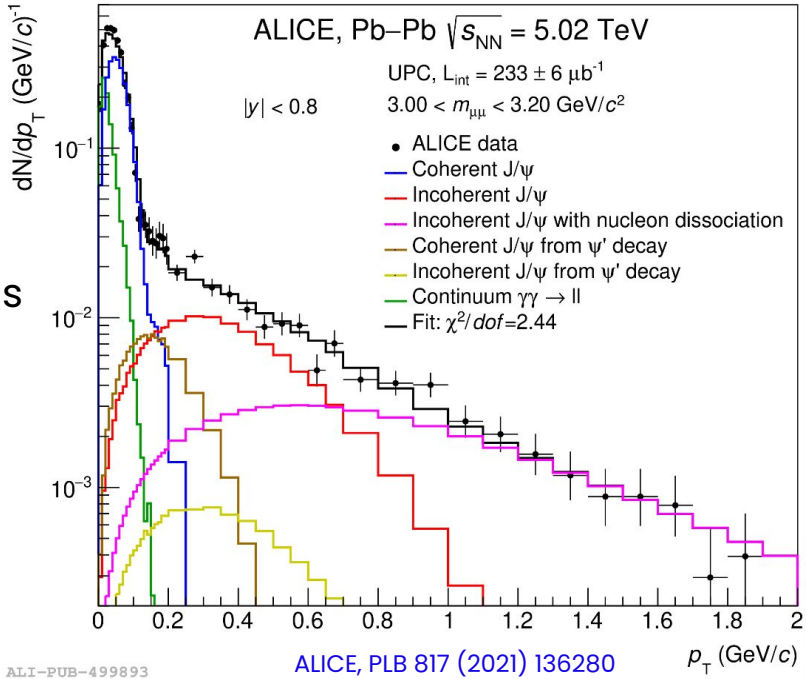
$$\left.\frac{d\sigma_{\gamma A\to J/\psi A}}{dt}\right|_{t=0} = \frac{M_{J/\psi}^3\Gamma_{ee}\pi^3\alpha_s^2(Q^2)}{48\alpha_{\rm em}Q^8}\left[xg_A(x,Q^2)\right]^2$$



- Coherent:
  - Coherent interaction with all nucleons
  - $\langle p_T \rangle \sim 1/R_{\rm Pb} \sim 60$ MeV/c
  - Exclusive process



- Incoherent:
  - Interaction with single nucleon
  - $\langle p_T \rangle \sim 1/R_{\rm p} \sim 450$ MeV/c
  - Can cause nuclear breakup



ALICE, PLB 817 (2021) 136280

Rapidity dependent cross section measurements

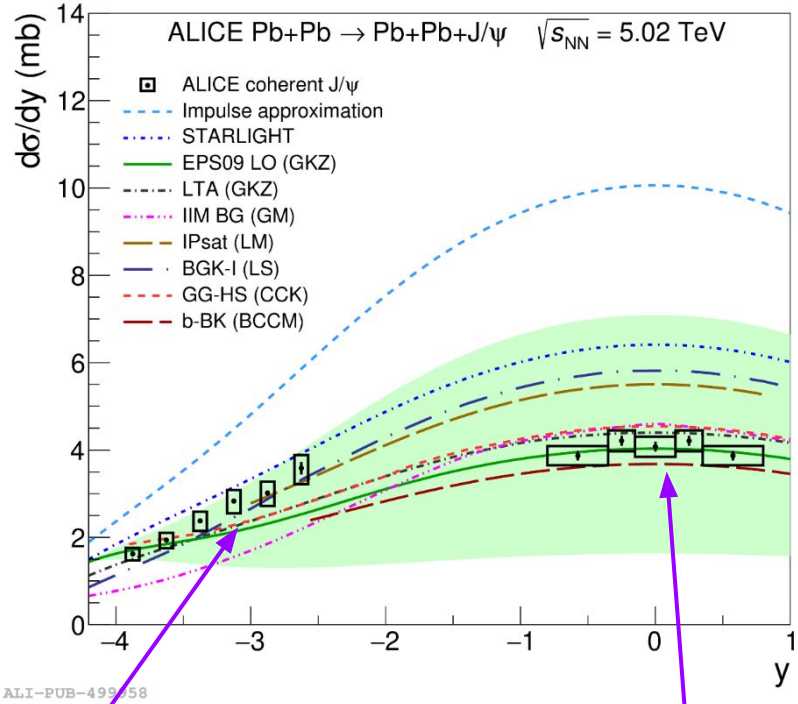
$$S_{\mathrm{Pb}} = \sqrt{\frac{\sigma_{\gamma\mathrm{Pb}}}{\sigma^{\mathrm{IA}}_{\gamma\mathrm{Pb}}}}$$ ~ 0.65 at y ~ 0 (x ~ 10^{-3})

Direct evidence for strong nuclear shadowing!

$$\frac{\mathrm{d}\sigma_{\mathrm{PbPb}}(y)}{\mathrm{d}y} = n_\gamma(y)\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y)\sigma_{\gamma\mathrm{Pb}}(-y)$$

low-energy photons — high-x gluons — high-energy photons — low-x gluons

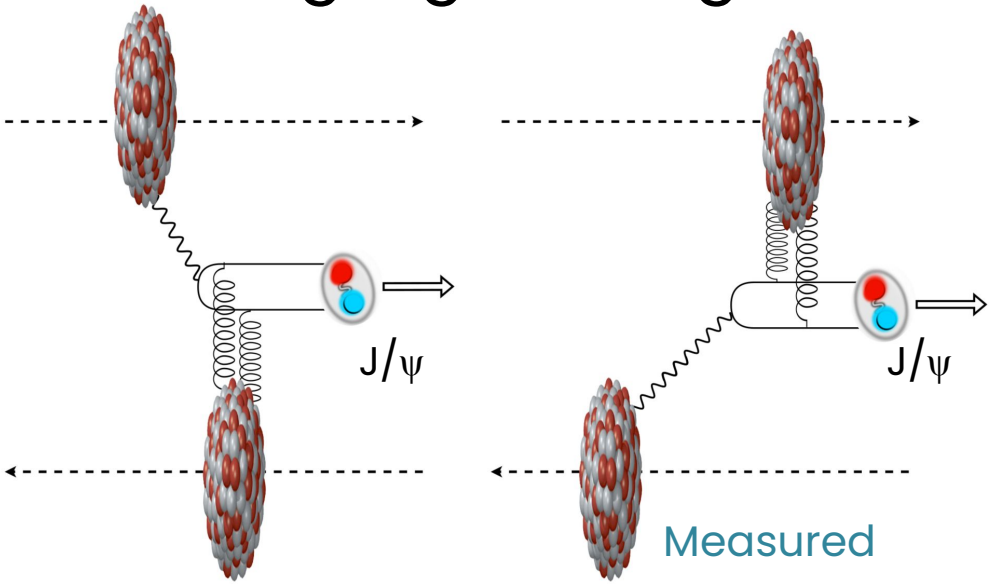
ALICE, PLB 798 (2019) 134926, PLB 817 (2021) 136280

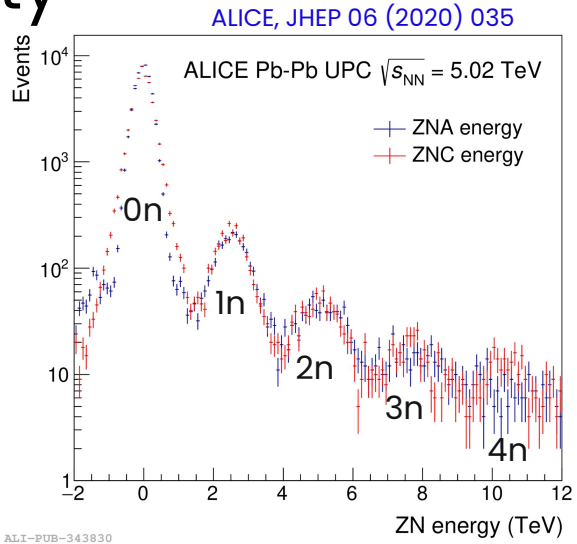


x ~ 10^{-2} (~95%)
x ~ 10^{-5} (~5%)

x ~ 10^{-3}

Disentangling low-high x ambiguity





Measured

Calculated photon fluxes

0n0n: no neutrons

$$\frac{\mathrm{d}\sigma^{\mathrm{0n0n}}_{\mathrm{PbPb}}(y)}{\mathrm{d}y} = n_{\gamma}^{\mathrm{0n0n}}(y)\sigma_{\gamma\mathrm{Pb}}(y) + n_{\gamma}^{\mathrm{0n0n}}(-y)\sigma_{\gamma\mathrm{Pb}}(-y)$$

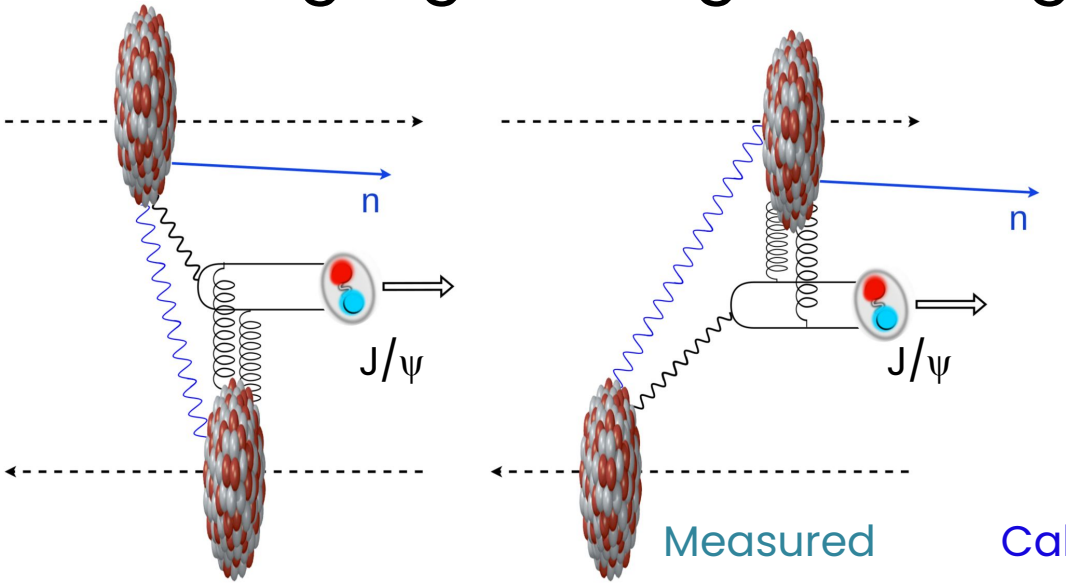
0nXn: neutrons on one side

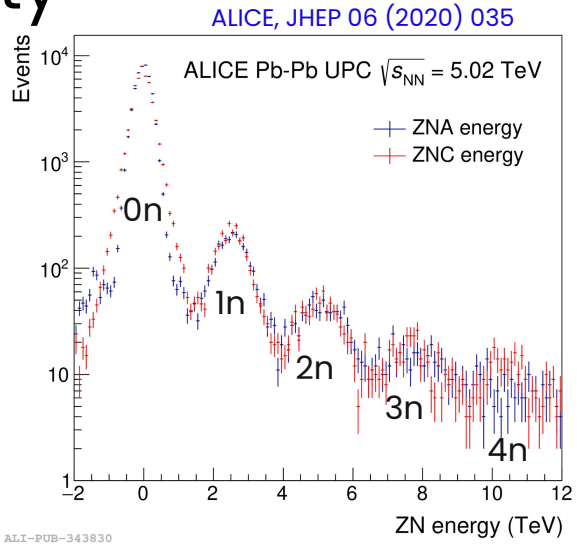
$$\frac{\mathrm{d}\sigma^{\mathrm{0nXn}}_{\mathrm{PbPb}}(y)}{\mathrm{d}y} = n_{\gamma}^{\mathrm{0nXn}}(y)\sigma_{\gamma\mathrm{Pb}}(y) + n_{\gamma}^{\mathrm{0nXn}}(-y)\sigma_{\gamma\mathrm{Pb}}(-y)$$

Unknown photonuclear cross sections

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

Disentangling low-high x ambiguity





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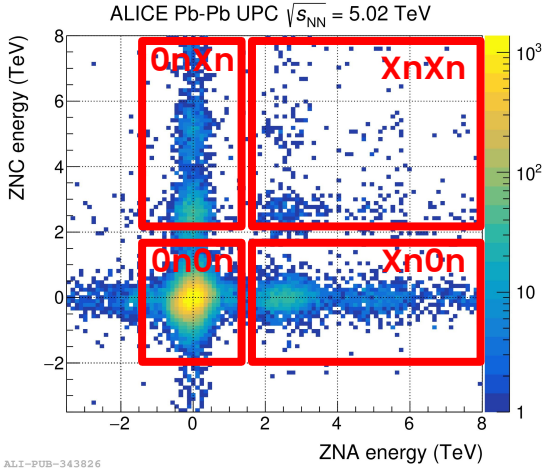
Unknown photonuclear cross sections

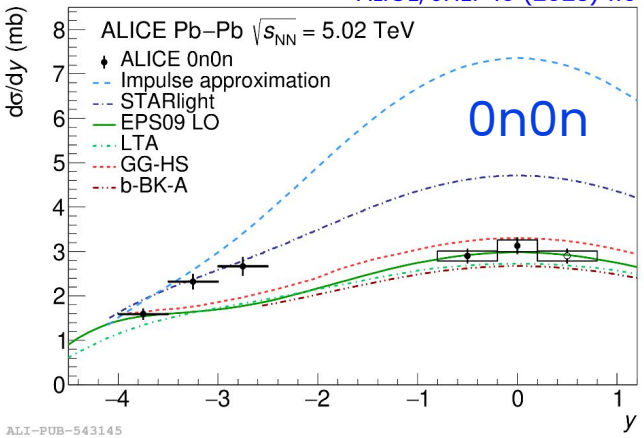
Guzey, Strikman, Zhalov, EPJC 74 (2014) 7, 2942

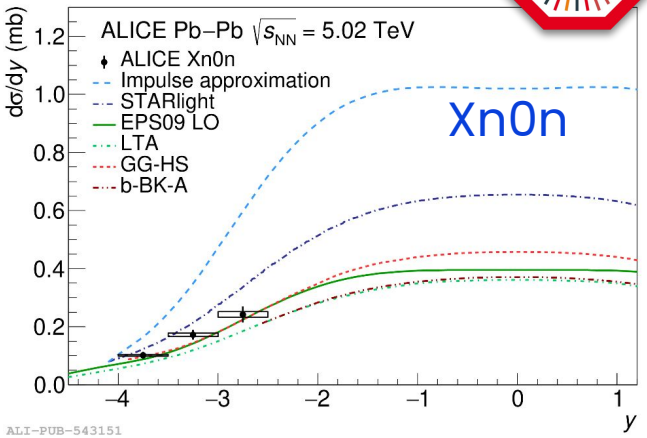
Coherent J/ψ photoproduction + neutron emission

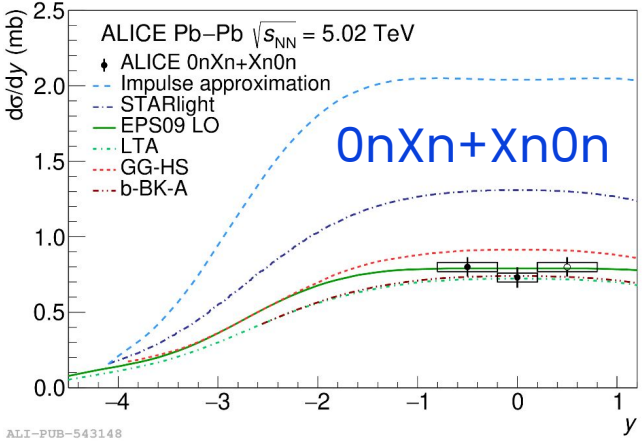
ALICE, JHEP 06 (2020) 035

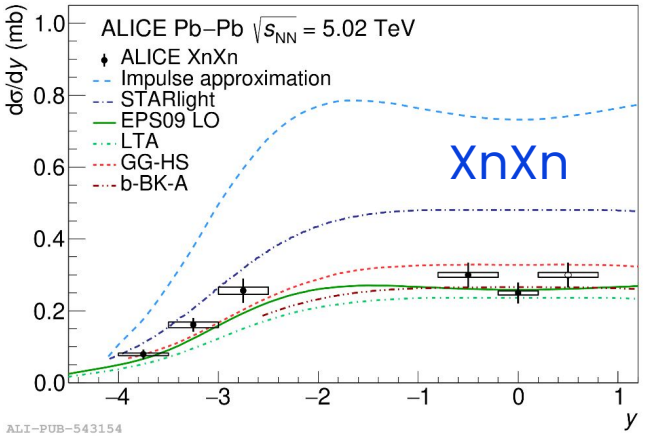


ALICE, JHEP 10 (2023) 119



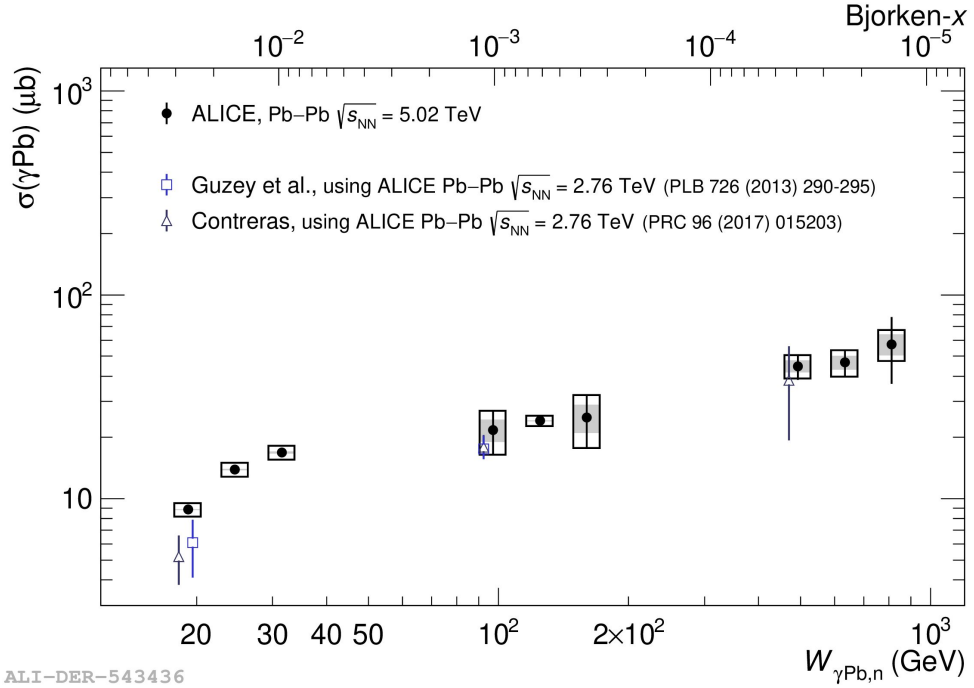






Photonuclear cross section as function of energy

- ALICE: photonuclear cross section was measured at energies ~ 813 GeV, for the first time!



ALICE, JHEP 10 (2023) 119

Photonuclear cross section as function of energy

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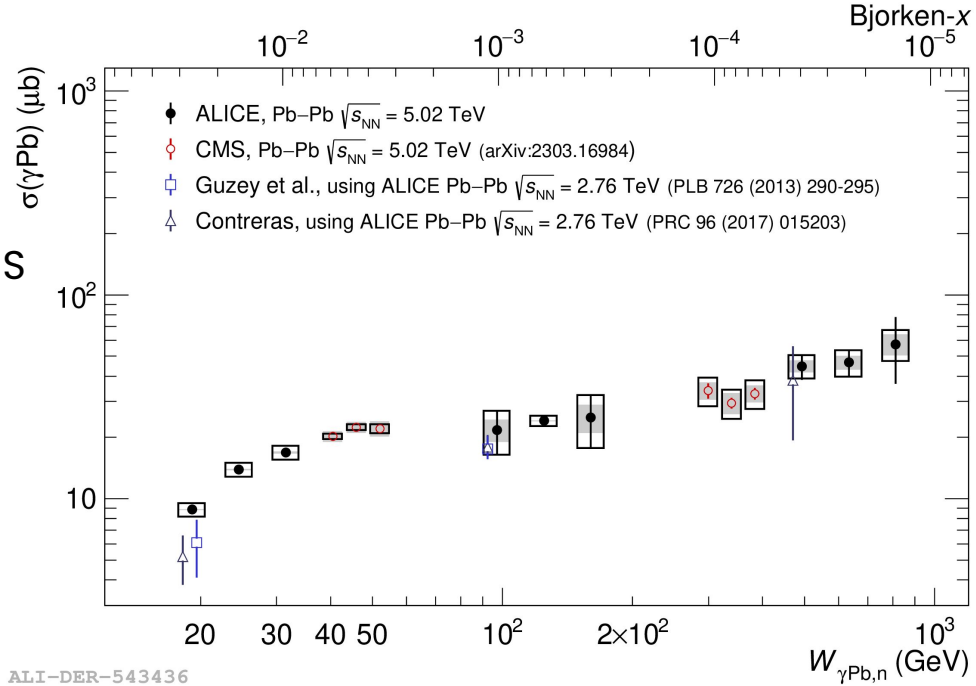
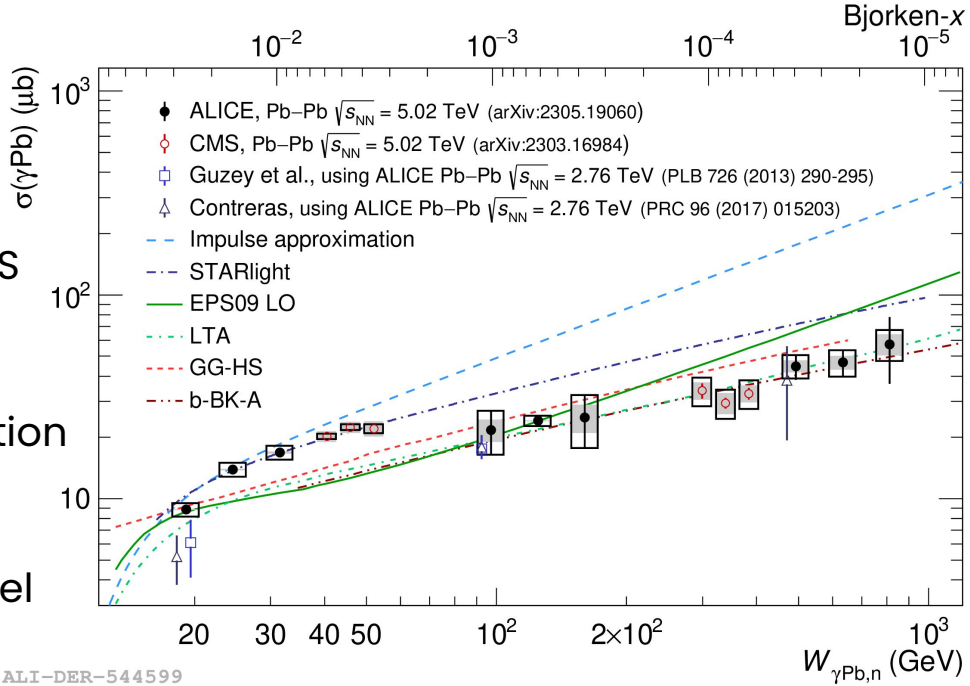
- Good agreement between ALICE and CMS



ALICE, JHEP 10 (2023) 119
CMS, PRL 131 (2023) 262301

Photonuclear cross section as function of energy

- ALICE: photonuclear cross section was measured at energies ~ 813 GeV, for the first time!
- Good agreement between ALICE and CMS
- Experiment vs Theory:
  - At low energies: compatible with Impulse Approximation and hadronic models
  - At large energies: compatible with LTA and dipole model (b-BK-A, GG-HS)



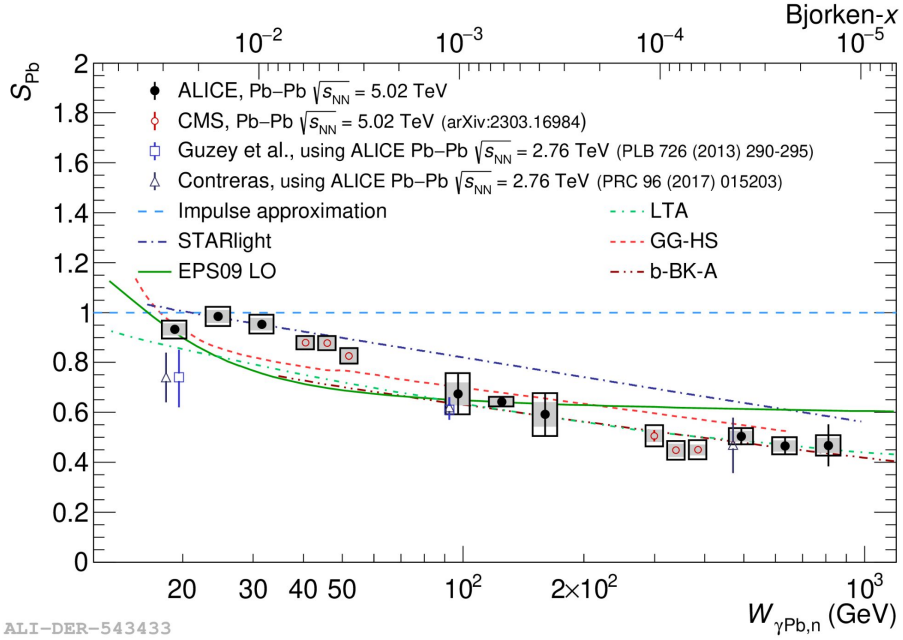
ALICE, JHEP 10 (2023) 119
CMS, PRL 131 (2023) 262301

Nuclear suppression factor

- For the first time, nuclear suppression factor is measured down to x ~ 10^{-5}!

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

- At small x: results compatible both with LTA (based on gluon shadowing) and models based on gluon saturation



ALICE, JHEP 10 (2023) 119
CMS, PRL 131 (2023) 262301

Opportunities in Run 3 and 4

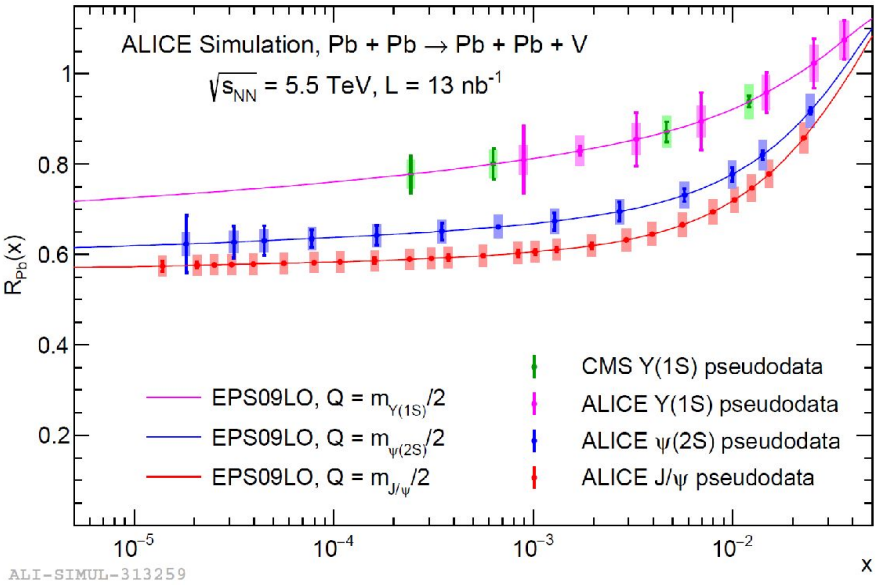
Expected vector meson statistics in Run 3-4 at 13 nb^{-1}

PbPb						
Meson	σ	All Total	$\|\eta\| < 0.9$	$\|\eta\| < 2.4$	$2.5 < \eta < 4$	$2 < \eta < 5$
$\rho \to \pi^+\pi^-$	5.2b	68 B	5.5 B	21B	4.9 B	13 B
$\rho' \to \pi^+\pi^-\pi^+\pi^-$	730 mb	9.5 B	210 M	2.5 B	190 M	1.2 B
$\phi \to K^+K^-$	0.22b	2.9 B	82 M	490 M	15 M	330 M
$J/\psi \to \mu^+\mu^-$	1.0 mb	14 M	1.1 M	5.7 M	600 K	1.6 M
$\psi(2S) \to \mu^+\mu^-$	30μb	400 K	35 K	180 K	19 K	47 K
$\Upsilon(1S) \to \mu^+\mu^-$	2.0 μb	26 K	2.8 K	14 K	880	2.0 K

Run 3-4 goals:

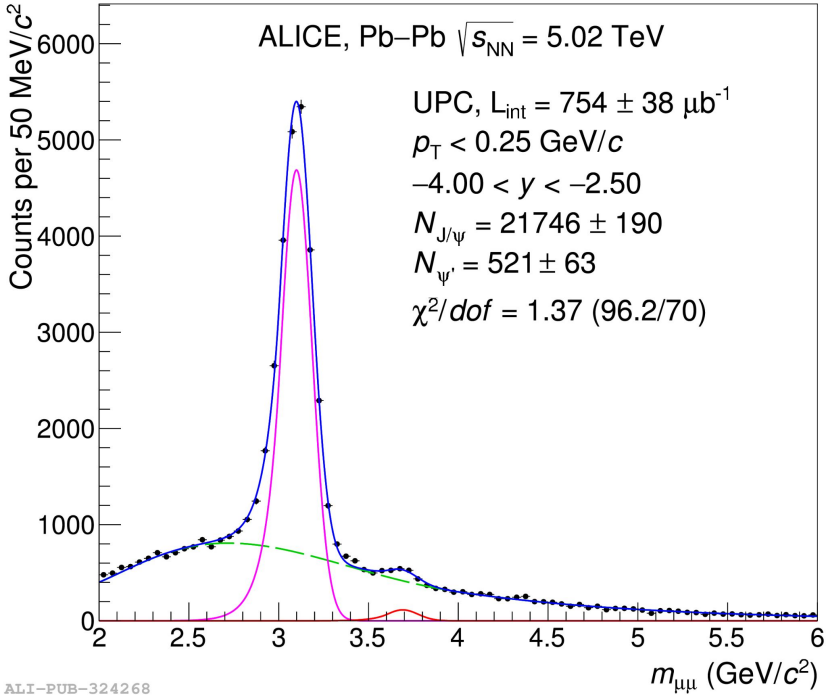
- Precise measurements of nuclear shadowing at small x
- Detailed study of nuclear shadowing as function of Q^2

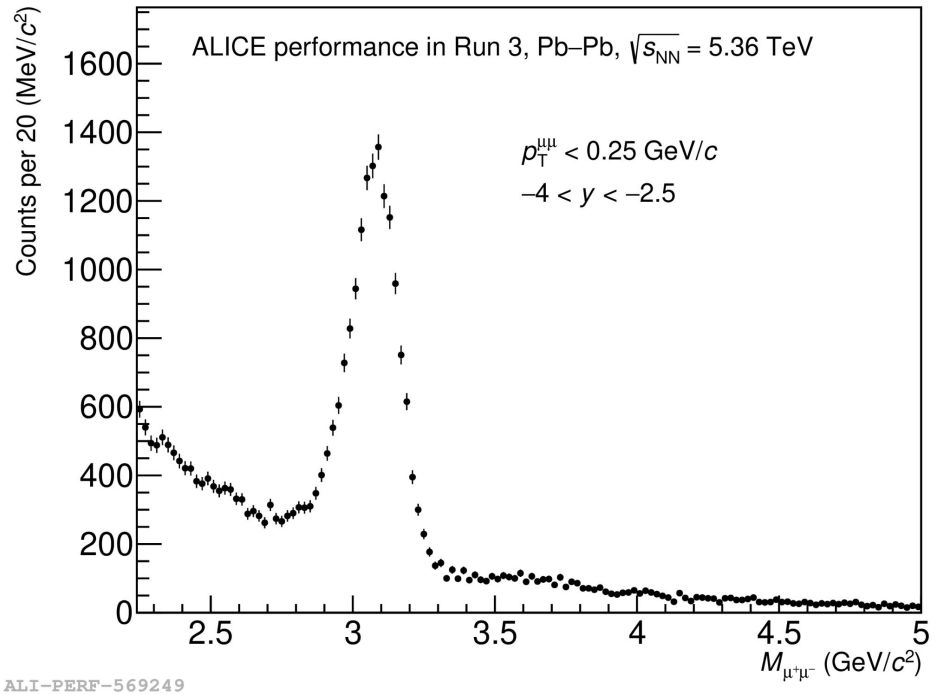
Z. Citron et al., CERN Yellow Rep. Monogr. 7 (2019) 1159



Opportunities in Run 3 and 4

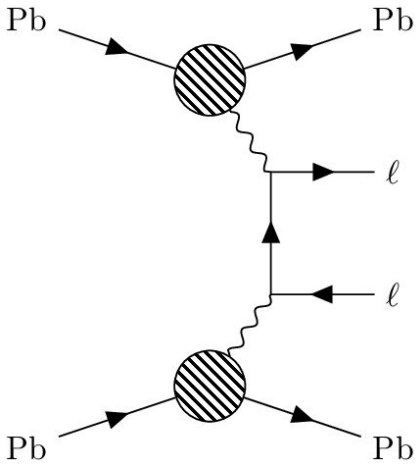
ALICE, PLB 798 (2019) 134926

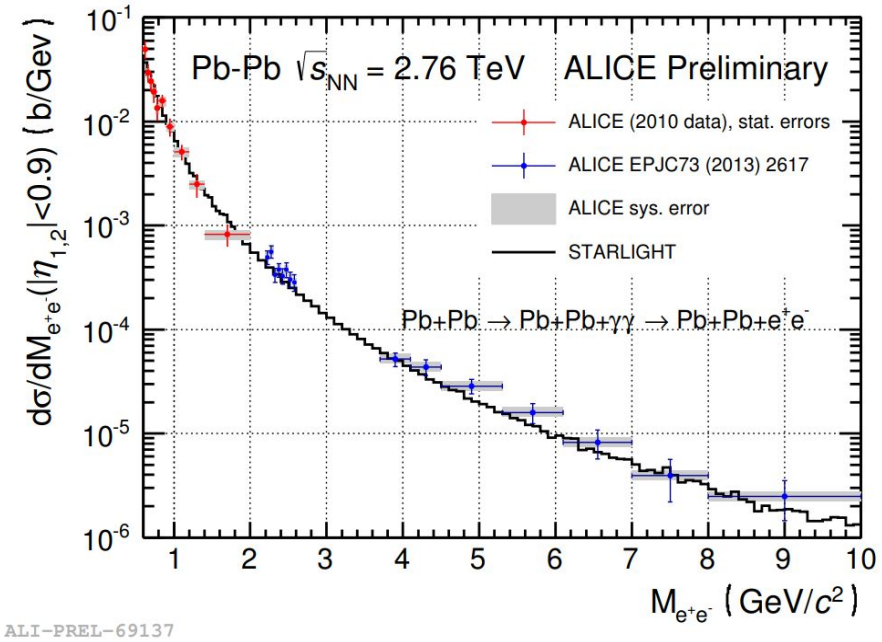




- Run 3 and trigger-less readout give an opportunity to go down to small invariant masses!

Dilepton continuum



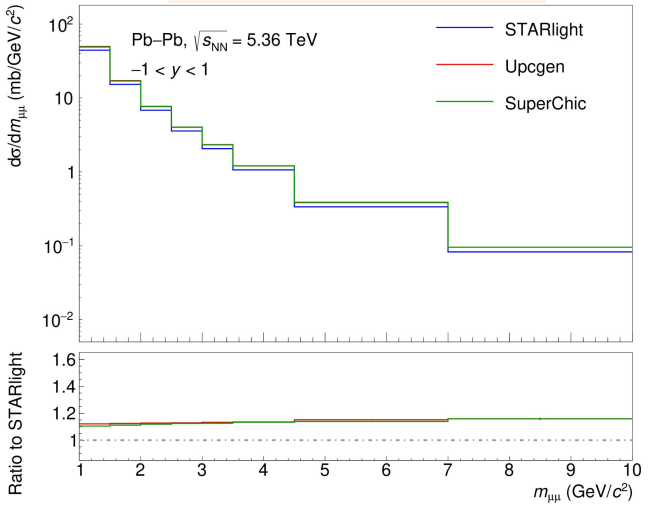


- ALICE: dielectron continuum at central rapidity in good agreement with LO QED

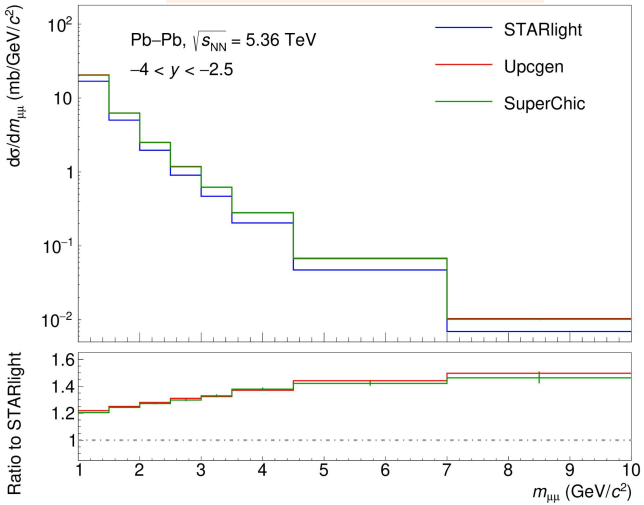
Dilepton continuum

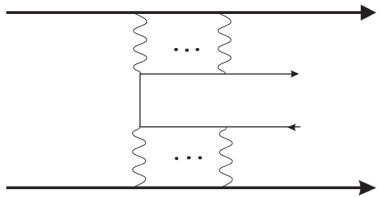
PRC, 75 (2007) 034903
JHEP, 08 (2021) 083

Mid-rapidity

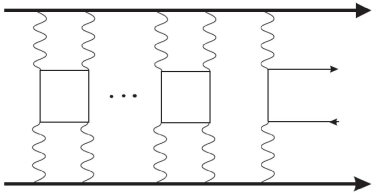


Forward rapidity





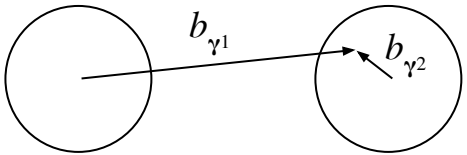
Unitarity?



Multiphoton interactions?

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

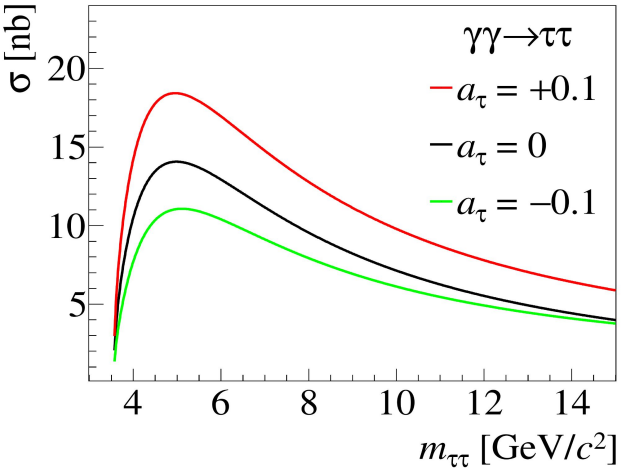
- STARlight: point-like flux, hard cut-off at $b_\gamma = R_A$
- SuperChic, Upcgen: realistic form-factor
- Visible differences at high rapidities

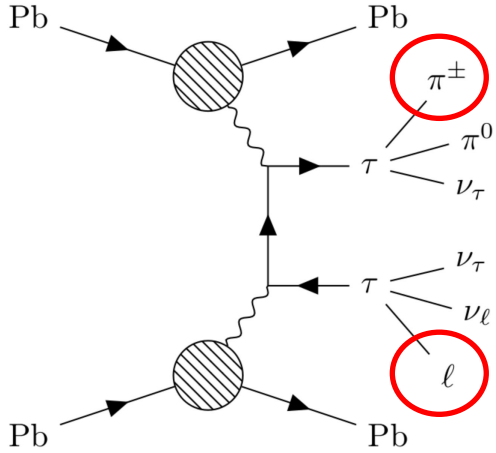


Photon flux treatment?

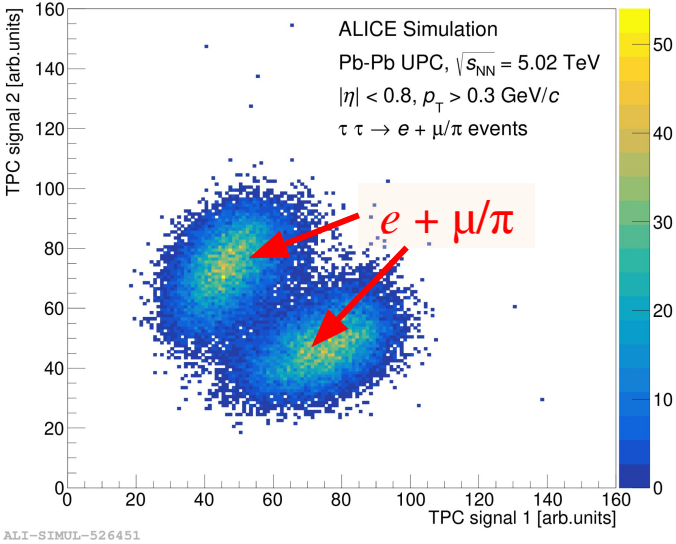
Tau anomalous magnetic moment

CPC, 277 (2022) 108388



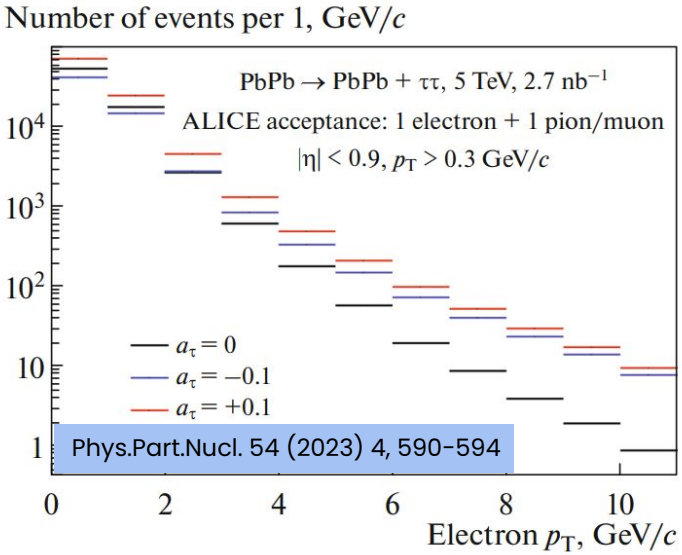


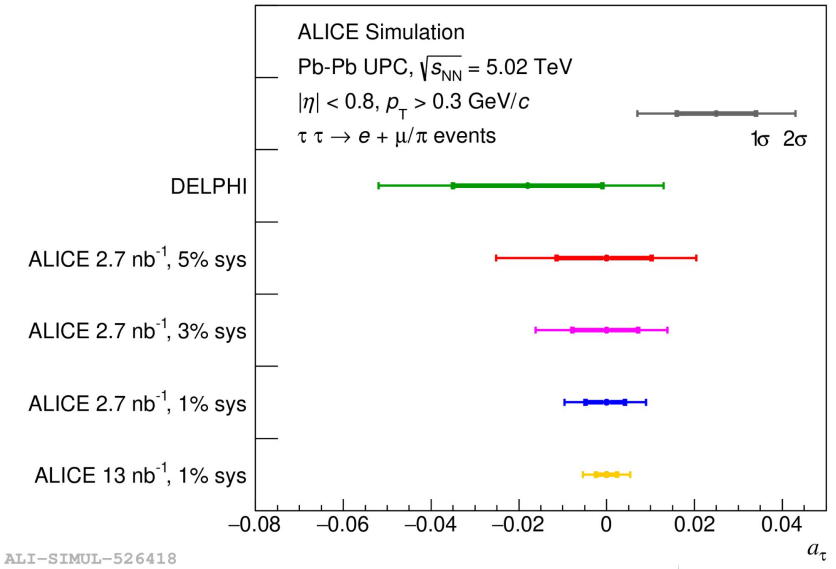
$$\mathrm{BR}(\tau^\pm \to \mathrm{e}^\pm + \nu_\mathrm{e} + \nu_\tau) = 17.8\%$$
$$\mathrm{BR}(\tau^\pm \to \mu^\pm + \nu_\mu + \nu_\tau) = 17.4\%$$
$$\mathrm{BR}(\tau^\pm \to \pi^\pm + \mathrm{n}\pi^0 + \nu_\tau) = 45.6\%$$
$$\mathrm{BR}(\tau^\pm \to \pi^\pm\pi^\mp\pi^\pm\nu_\tau + \text{neutral pions}) = 19.4\%$$



- Cross section of two-photon process $\gamma\gamma \to \tau\tau$ is sensitive to a_τ!
- DELPHI: $-0.052 < a_\tau < 0.013$ (95% CL) DELPHI, EPJC, 35 (2004) 159
- $a_\tau^{SM} = 0.00117721(5)$ Mod.Phys.Lett.A 22 (2007) 159-179

Tau anomalous magnetic moment





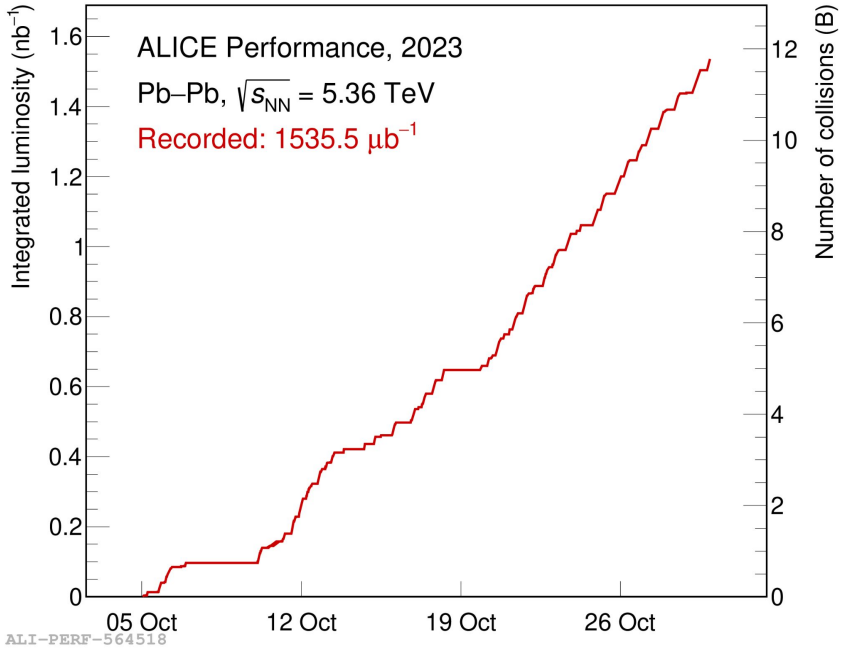
Deviation from SM

- Considering uncorrelated systematic uncertainties
- Precision limited by systematics

$$\chi^2 = \sum_{i=1}^{N_{\text{bins}}} \frac{[S_i(0) - S_i(a_\tau)]^2}{\sigma^2_{\text{stat}} + (\sigma^{\text{uncorr}}_{\text{syst}})^2}$$

Conclusions

- Unique opportunity for detailed studies of nuclear structure at small Bjorken-x
- Possibility to test QED in strong EM fields with ALICE continuous readout
- Prospects for searches of physics Beyond the Standard Model

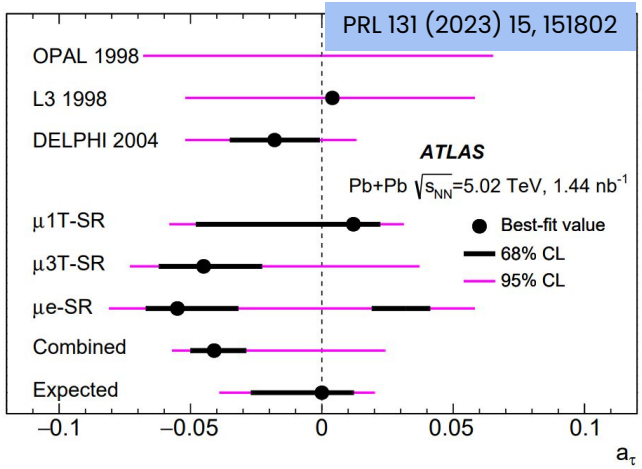



Thank you!

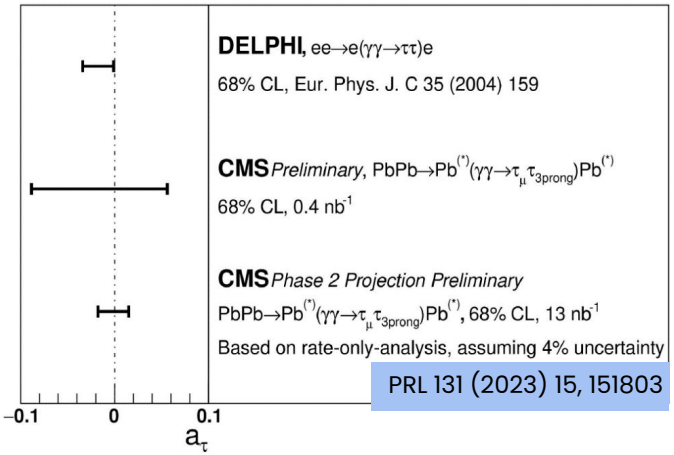
Backup

Tau anomalous magnetic moment

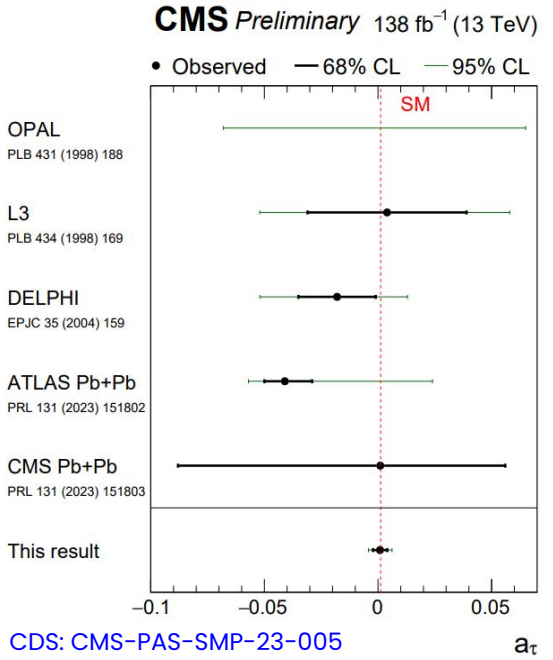
ATLAS Run 2 results



CMS Run 2 results



CMS Run 2 results (pp)



CDS: CMS-PAS-SMP-23-005

- Promising results from ATLAS and CMS