Recent measurements of exclusive processes in ultra-peripheral collisions

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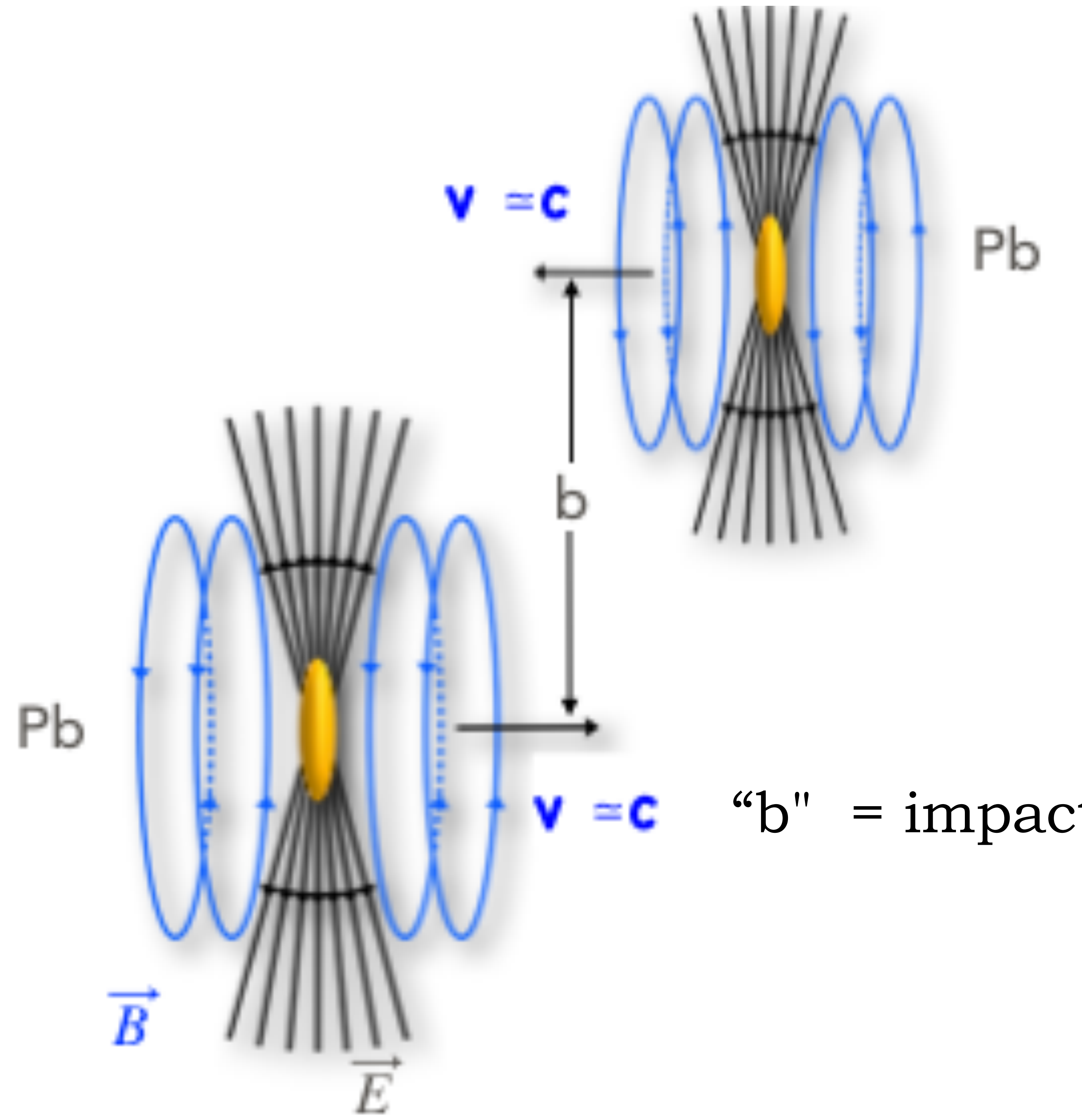
Outline

- ☑ Introduction to photon-induced processes
- ☑ Part I : Results from $\gamma\gamma$ interactions
- ☑ PartII : Results from photonuclear interactions
- ☑ Summary and outlook

Relativistic heavy-ion collisions: Electromagnetic field emitter

LHC or RHIC: acts as source of photon collider

Relativistic heavy-ions are strong EM field emitters



"b" = impact parameter

Equivalent Photon Approximation (EPA) : EM fields can be treated in terms of photon quanta or flux

Electromagnetic fields

In heavy-ion collisions (HICs) :

$|E| \sim 5\times10^{16} - 10^{18}$ V/cm

$|B| \sim 10^{14} - 10^{16}$ T

V. Skokov et al, *Int.J.Mod.Phys.A* 24 (2009) 5925-5932

Magnetic field in other systems

Pulsar ~ 10^{11} T

Earth ~ 10^{-5} T

Strongest EM fields created in the Laboratory

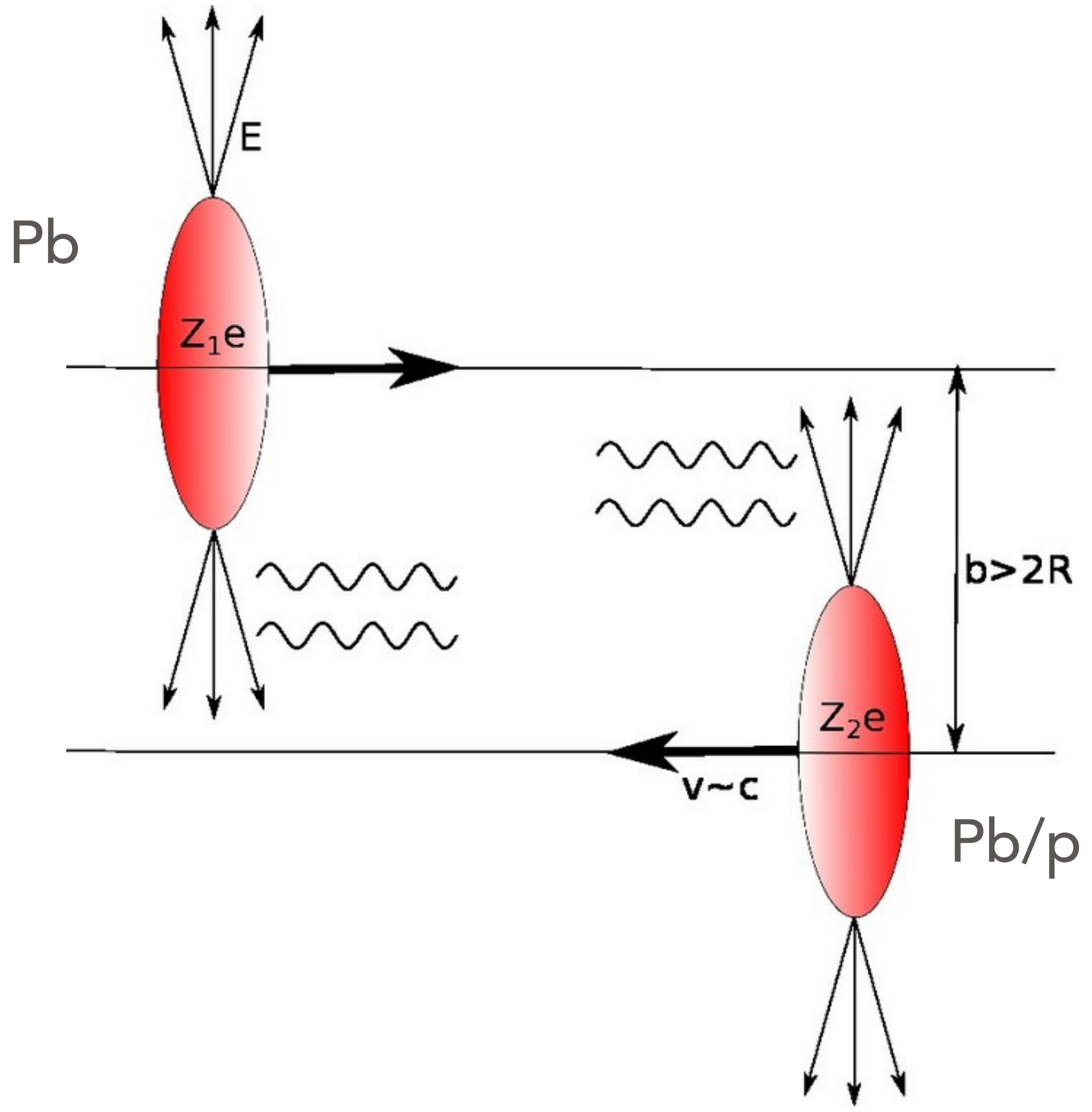
QM@2023, Peter Steinberg

maximum energy $E_{\gamma,max} \sim \gamma(\hbar c/R)$	80 GeV in Pb+Pb@LHC 3 GeV in Au+Au@RHIC
typical p_T (& virtuality) $p_{Tmax} \sim \hbar c/R$	O(30) MeV @ RHIC & LHC

Photon-induced processes in UltraPeripheral collisions

UltraPeripheral Collisions (UPCs) : $b > R_1 + R_2$

Types of interactions



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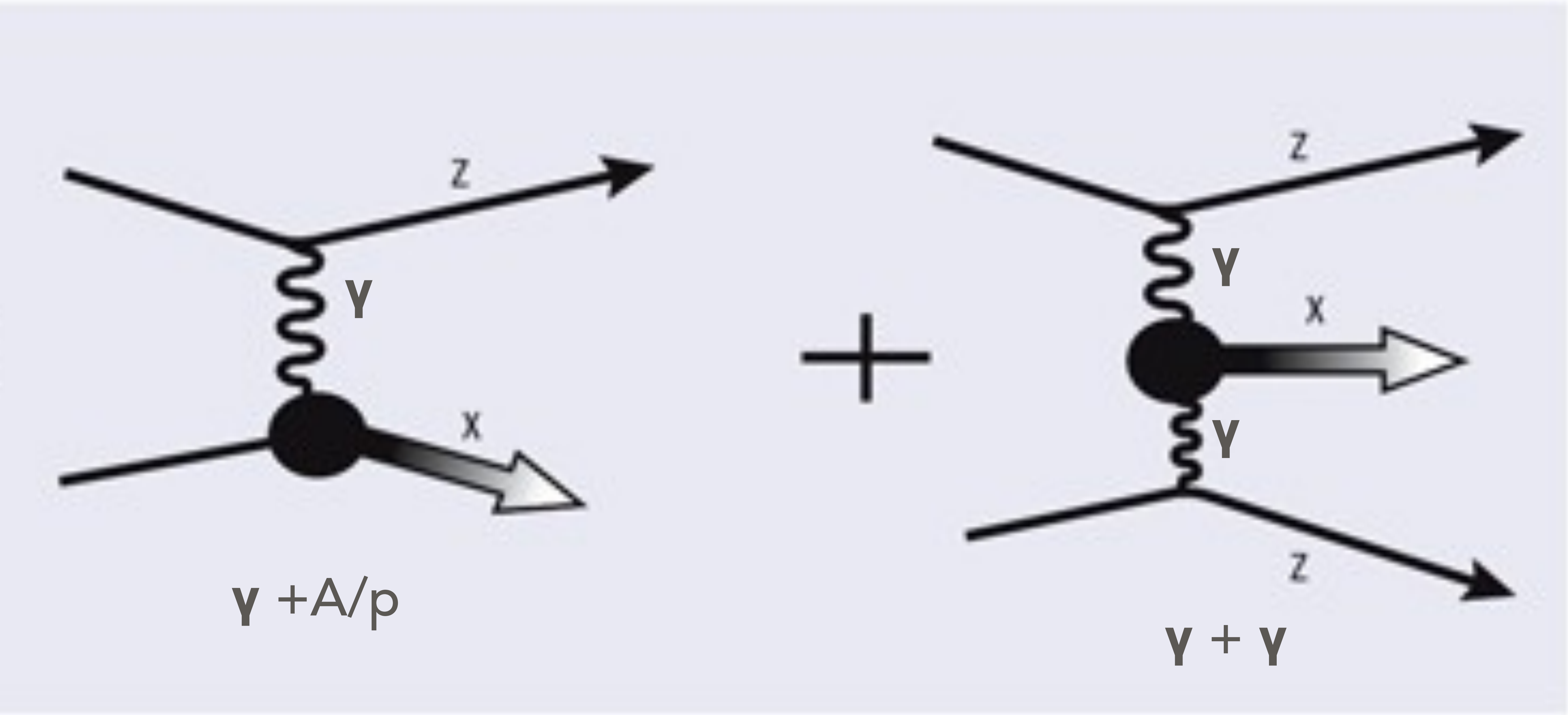

Electromagnetic interactions are dominant, QED processes play crucial role

Flux of photons on other nucleus ~ Z^2 (nuclei >> proton)

Flux of photons on photons ~ Z^4

Measurements available: Exclusive $\gamma\gamma$ processes in UPCs

UPC 2023 : /indico.cern.ch/event/1263865/

Dileptons	$\gamma\gamma\rightarrow ee$	JHEP 06 (2023) 182
	$\gamma\gamma\rightarrow\mu\mu$	Phys. Rev. C 104 (2021) 024906
	$\gamma\gamma\rightarrow\tau\tau$	Phys. Rev. Lett. 131 (2023) 151802
Exotica	$\gamma\gamma\rightarrow\gamma\gamma$	Nature Physics 13 (2017) 852 Phys. Rev. Lett. 123 (2019) 052001
	$\gamma\gamma\rightarrow$ALP	JHEP 03 (2021) 243

G. Breit and J. A. Wheeler, "Collision of two light quanta," *Phys. Rev.* **46** (1934) 1087.
JADE Collaboration, W. Bartel *et al.*, "Lepton pair production in double tagged two photon interactions," *Z. Phys. C* **30** (1986) 545.
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CERES/NA45 Collaboration, R. Bauer *et al.*, "Measurement of electromagnetically produced e^+e^- pairs in distant S-Pt collisions," *Phys. Lett. B* **332** (1994) 471.
STAR Collaboration, J. Adams *et al.*, "Production of e^+e^- pairs accompanied by nuclear dissociation in ultra-peripheral heavy ion collision," *Phys. Rev. C* **70** (2004) 031902, arXiv:nucl-ex/0404012.
STAR Collaboration, J. Adam *et al.*, "Measurement of e^+e^- momentum and angular distributions from linearly polarized photon collisions," *Phys. Rev. Lett.* **127** (2021) 052302, arXiv:1910.12400 [nucl-ex].
PHENIX Collaboration, S. Afanasiev *et al.*, "Photoproduction of J/ψ and of high mass e^+e^- in ultra-peripheral Au+Au collisions at $\sqrt{s}$ = 200 GeV," *Phys. Lett. B* **679** (2009) 321, arXiv:0903.2041 [nucl-ex].

ALICE Collaboration, E. Abbas *et al.*, "Charmonium and e^+e^- pair photoproduction at mid-rapidity in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV," *Eur. Phys. J. C* **73** (2013) 2617, arXiv:1305.1467 [nucl-ex].
CMS Collaboration, S. Chatrchyan *et al.*, "Search for exclusive or semi-exclusive photon pair production and observation of exclusive and semi-exclusive electron pair production in pp collisions at $\sqrt{s}$ = 7 TeV," *JHEP* **11** (2012) 080, arXiv:1209.1666 [hep-ex].
CMS Collaboration, A. M. Sirunyan *et al.*, "Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV," *Phys. Lett. B* **797** (2019) 134826, arXiv:1810.04602 [hep-ex].
CMS Collaboration, A. Hayrapetyan *et al.*, "Measurements of the light-by-light scattering and the Breit–Wheeler processes, and searches for axion-like particles in ultraperipheral PbPb collisions at 5.02 TeV." CMS-PAS-HIN-21-015, 2024.

Model

STARlight : S.R.Klein, et.al., Comput.Phys.Commun.212(2017) 258

SuperChic : Lucian Harland-Lang, Eur. Phys. J. C 80, 925 (2020)

gamma-UPC : Hua-Sheng Shao et al., JHEP 09 (2022) 248

NLO correction calculations for dimuon and ditaun-pairs: Hua-Sheng Shao et al., arXiv:2407.13610

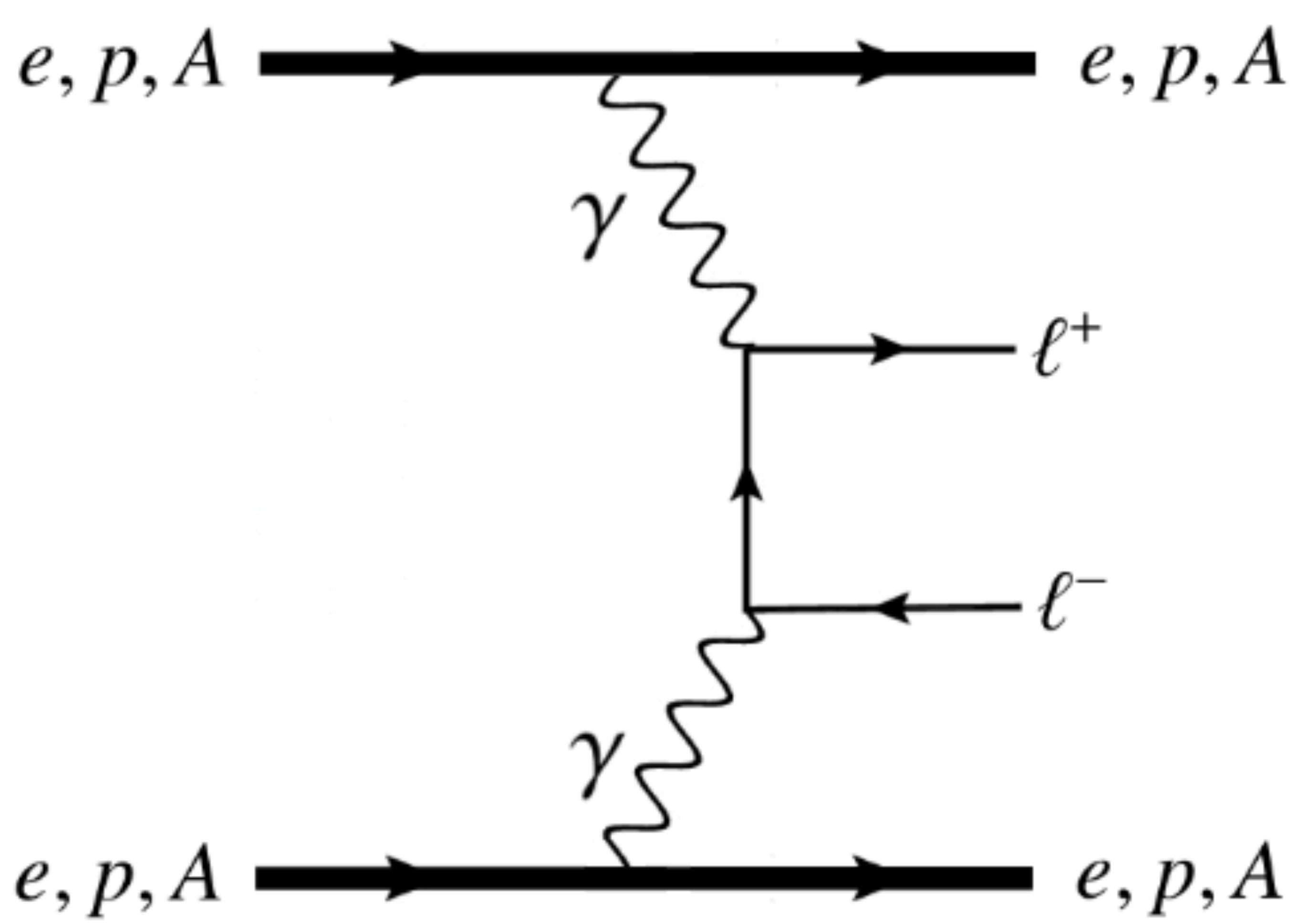
Study of Higgs boson production and its $b\bar{b}$ decay in γ–γ processes in proton-nucleus collisions at the LHC

David d'Enterria and Jean-Philippe Lansberg
Phys. Rev. D **81**, 014004 – Published 7 January 2010

*In this talk, results will be discussed based on personal choice

Exclusive $\gamma\gamma$ processes in UPCs

Lepton pair production

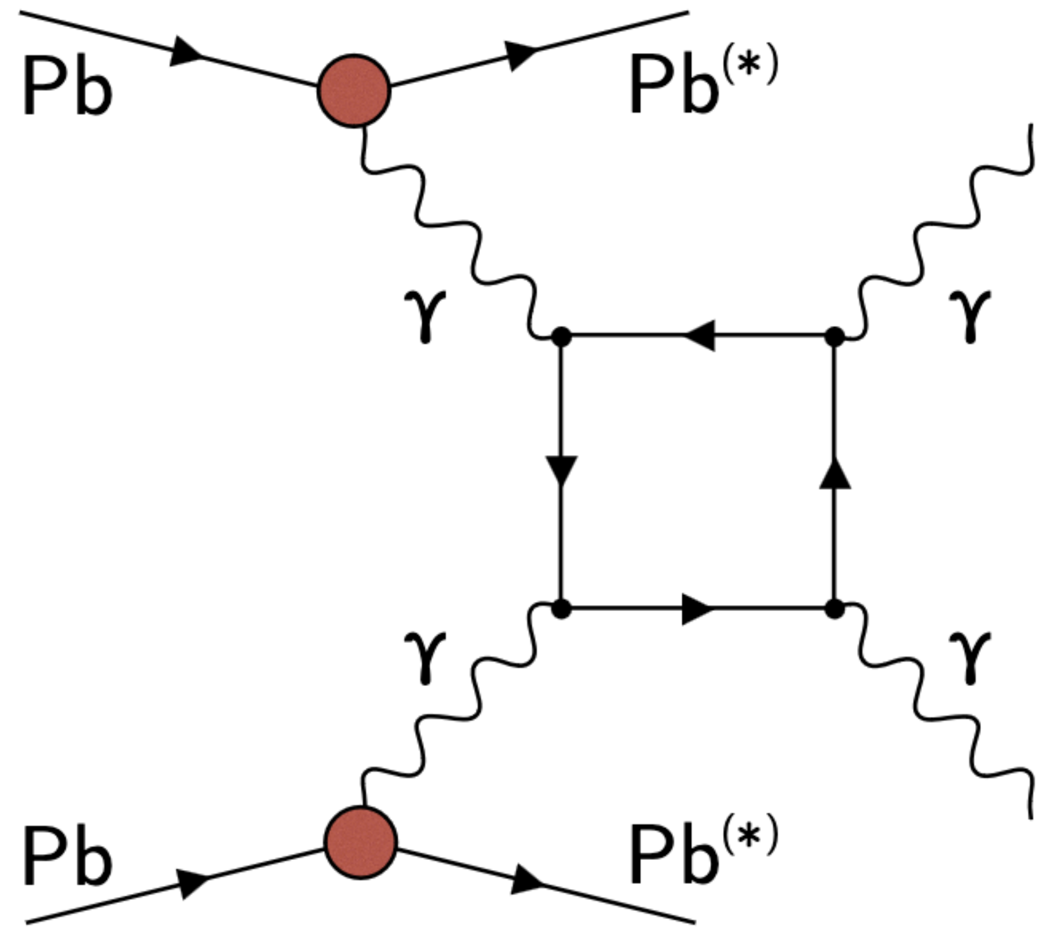


Breit-Wheeler processes and higher muon and tau-lepton pairs production

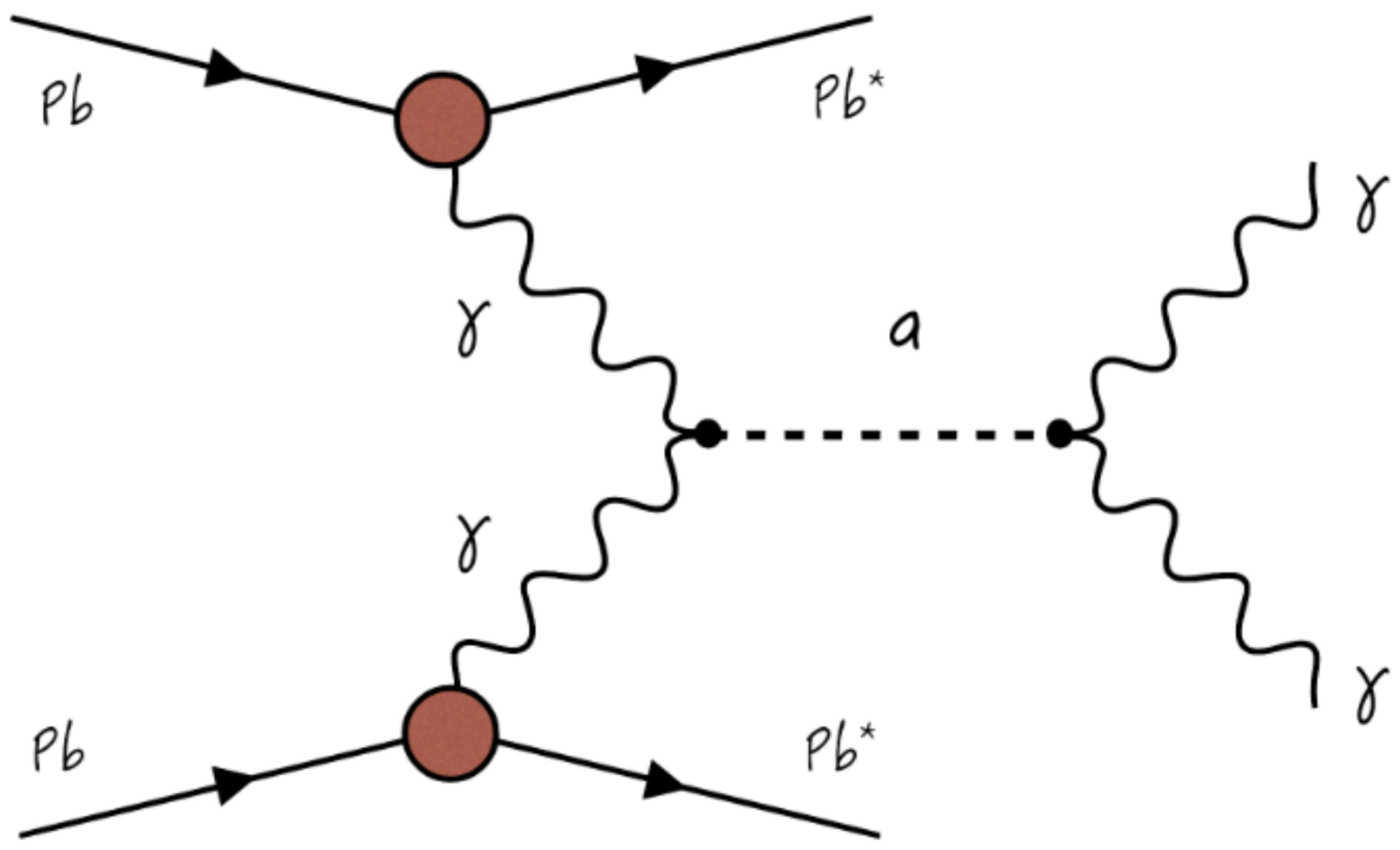
G. Breit, Phys. Rev. 46 (1934) 1087

Photon pair productions

S. Knapen et al., Phys. Rev. Lett. 118, 171801



Light by Light scattering via box diagram



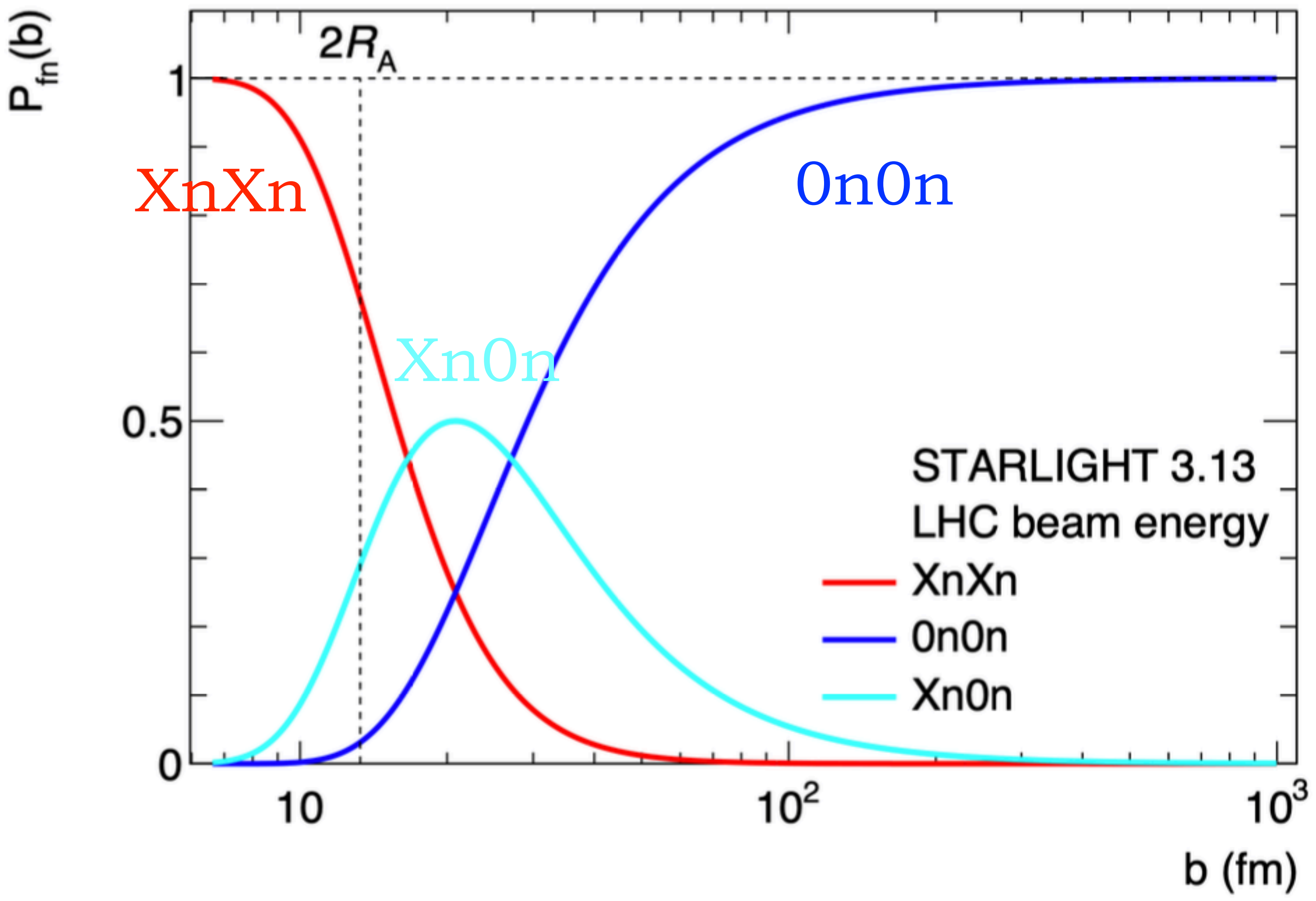
Light by Light: new physics or BSM
i.e., Axion like particle (ALPs)

a is the new pseudoscalar, often referred to as an axion-like particle

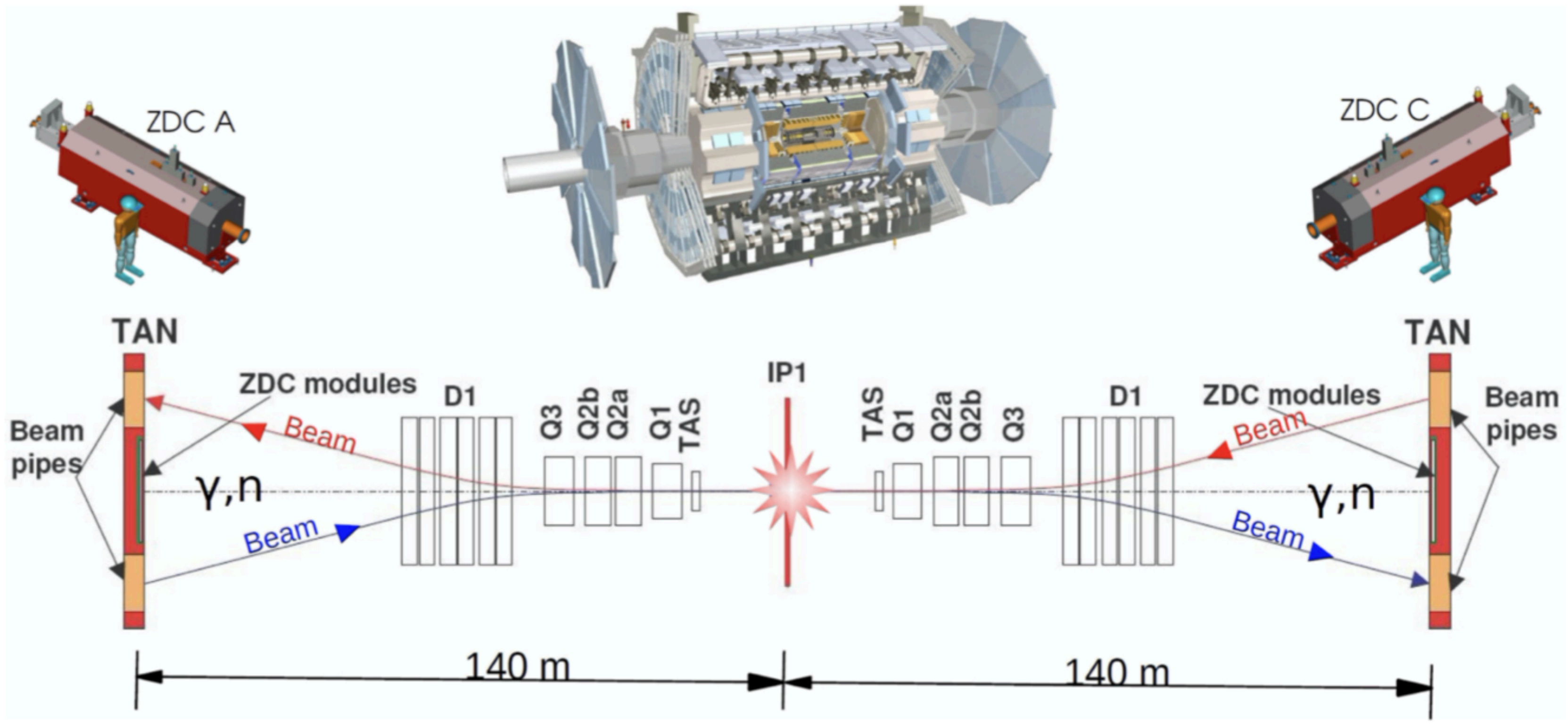
Excellent probe for QED & new physics search (BSM)

Differentiate difference processes: Zero Degree Calorimeters (ZDC)

Each category probes different impact parameters (b)



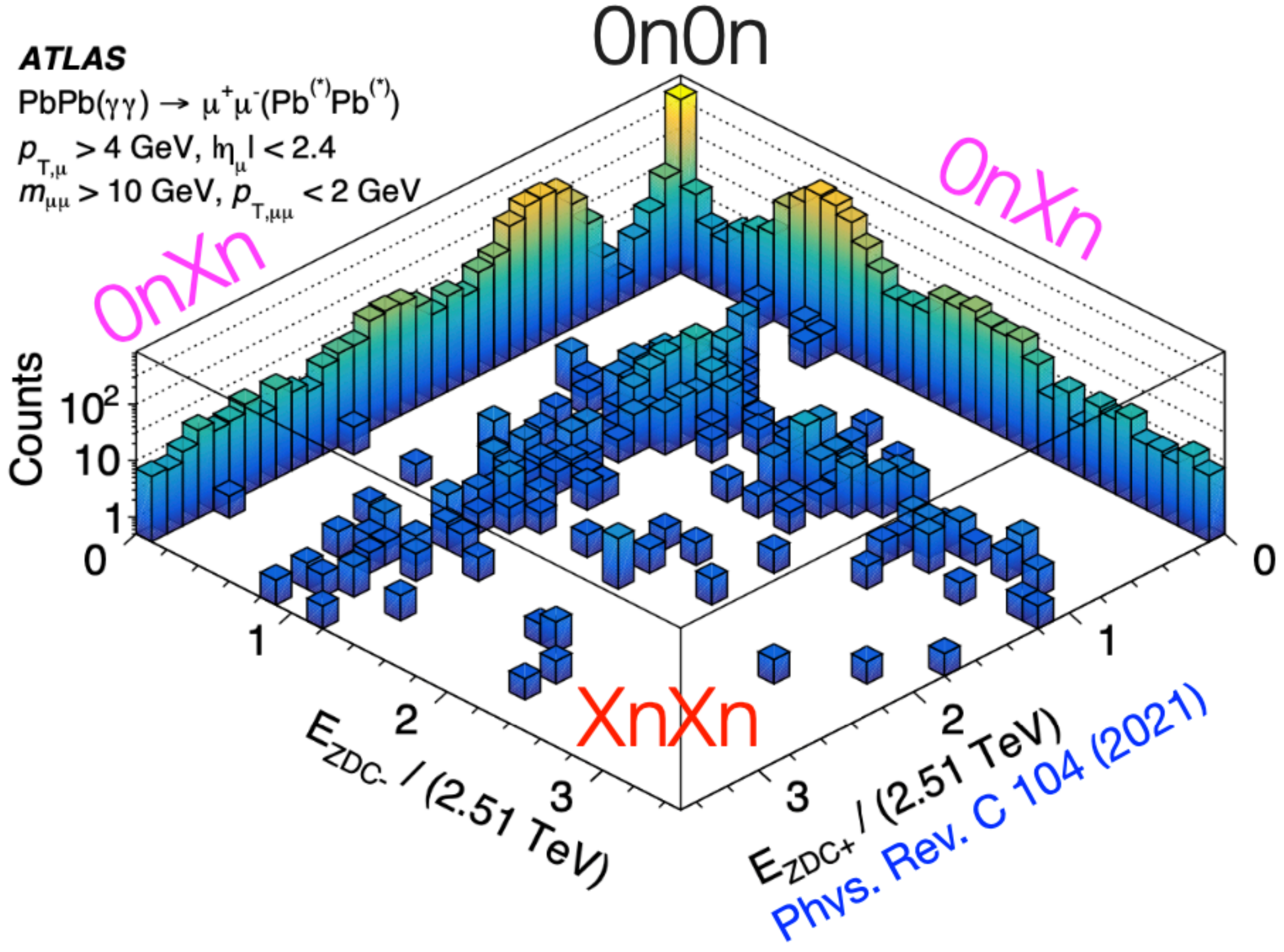
Ann.Rev.Nucl.Part.Sci. 70 (2020) 323-354



- ZDC are 140 m away from the IP (|η|> 8.3)

Detect neutral particles: e.g. neutrons, photons

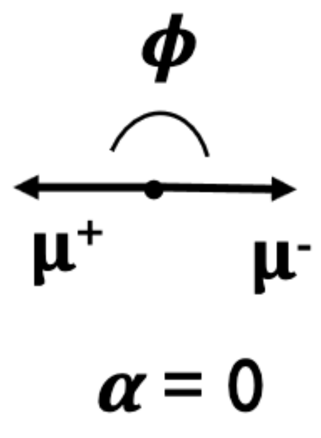
Events are categorised into: 0n0n/0nXn/XnXn



- ❑ Separate UPCs from inelastic Pb—Pb collisions
- ❑ Exclusive $\gamma\gamma$ processes: mostly 0n0n
- ❑ Photonuclear processes: typically 0nXn

Acoplanarity in $\gamma\gamma \to ll$ with differnent nuclear break up

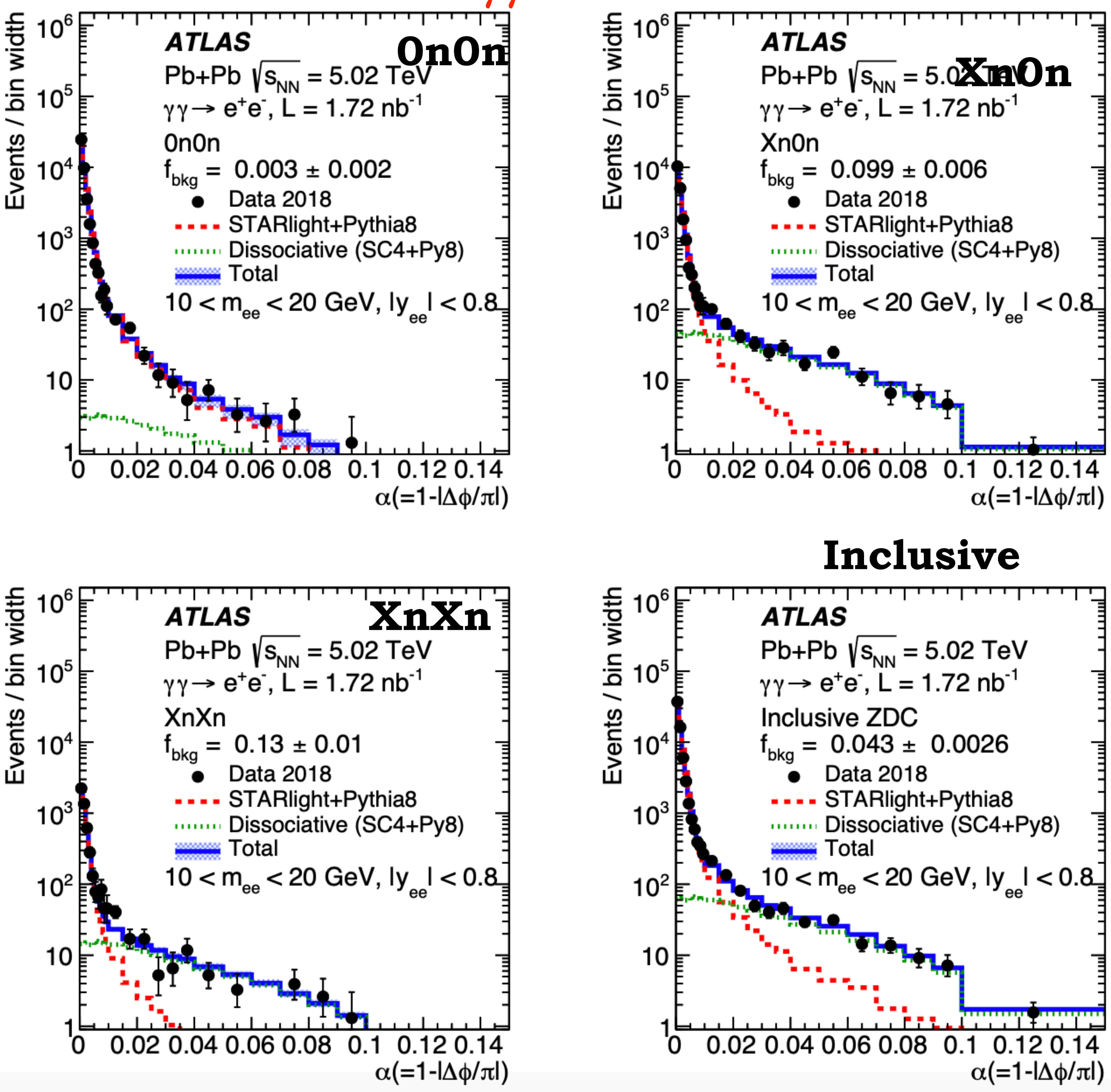
- Acoplanarity is a key tool for distinguishing these processes: $\alpha = 1 - |\Delta\varphi|/\pi$



- Clear differences between samples selected with ZDC topologies:
- 0n0n: excellent agreement with STARlight+Pythia8
- 0nXn and XnXn clear contributions from dissociative processes (modelled with SuperChic)

p_{Te} > 2.5 GeV/c, $|\eta_e|$ < 2.47, m_{ee} > 5 GeV/c², p_{Tee} < 2 GeV/c

$\gamma\gamma \to e^+e^-$



STAR: $\gamma\gamma \to e^+e^-$, Phys. Rev. C 70, 031902(R) (2004) ,

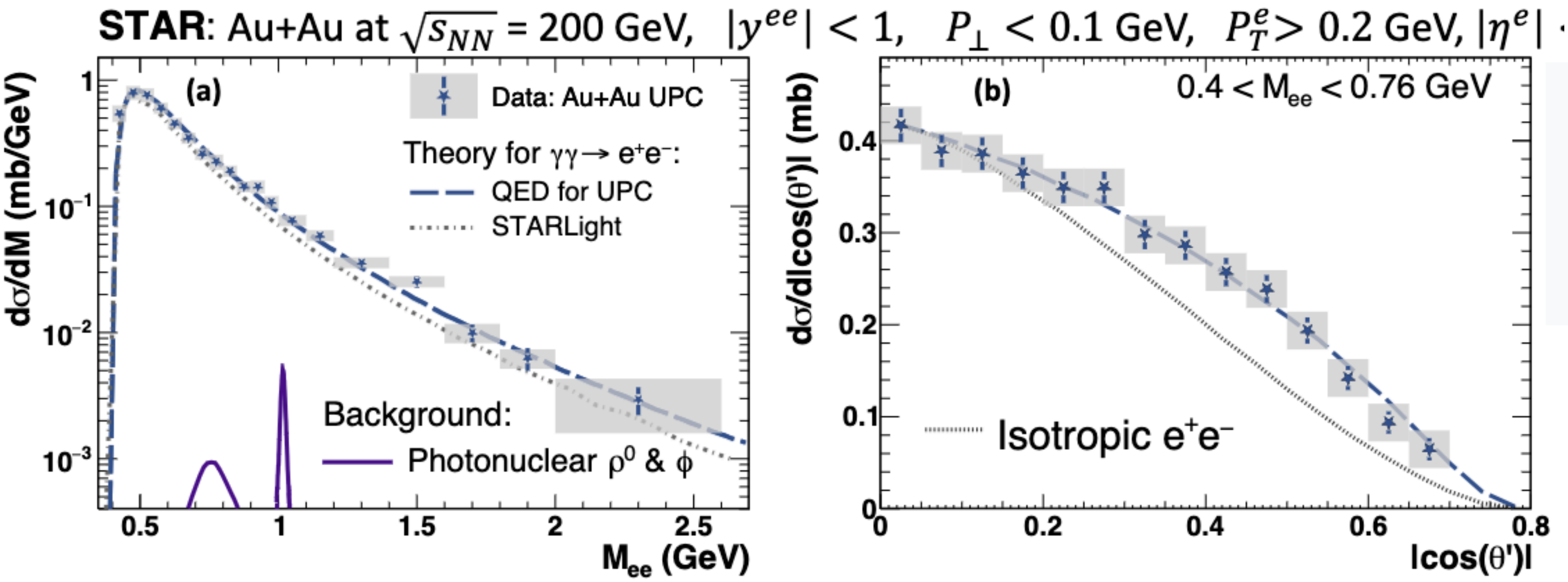
ATLAS: $\gamma\gamma \to \mu^+\mu^-$, Phys. Rev. C 104, 024906 (2021), $\gamma\gamma \to e^+e^-$, JHEP 06 (2023) 182

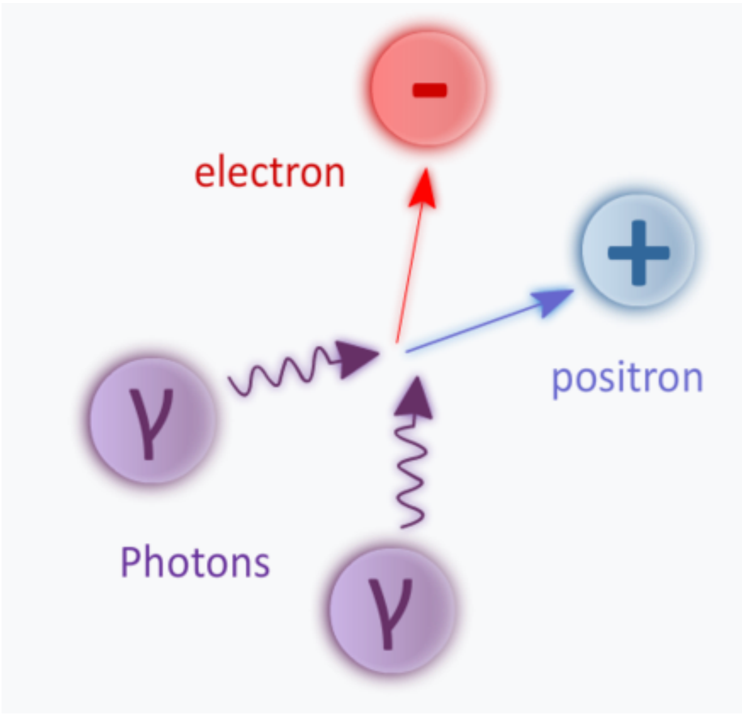
CMS: $\gamma\gamma \to \mu^+\mu^-$, JHEP 01 (2012) 052,

STARlight: S.R.Klein, et.al., Comput.Phys.Commun.212(2017) 258

SuoperChic:Lucian Harland-Lang, Eur. Phys. J. C 80, 925 (2020)

Observation Of Breit-wheeler processes: $\gamma\gamma \to e^+e^-$





Measure θ', the angle between the e+ and beam axis in pair rest frame

- Pure QED 2 → 2 scattering : $d\sigma/dM \propto E^{-4} \approx M^{-4}$
- No vector meson contribution

STARLight: S.R. Klein, et.al. *Comput.Phys.Commun.* 212(2017) 258

QED: W.Zha et al., , Phys. Lett. B 800 (2020) 135089

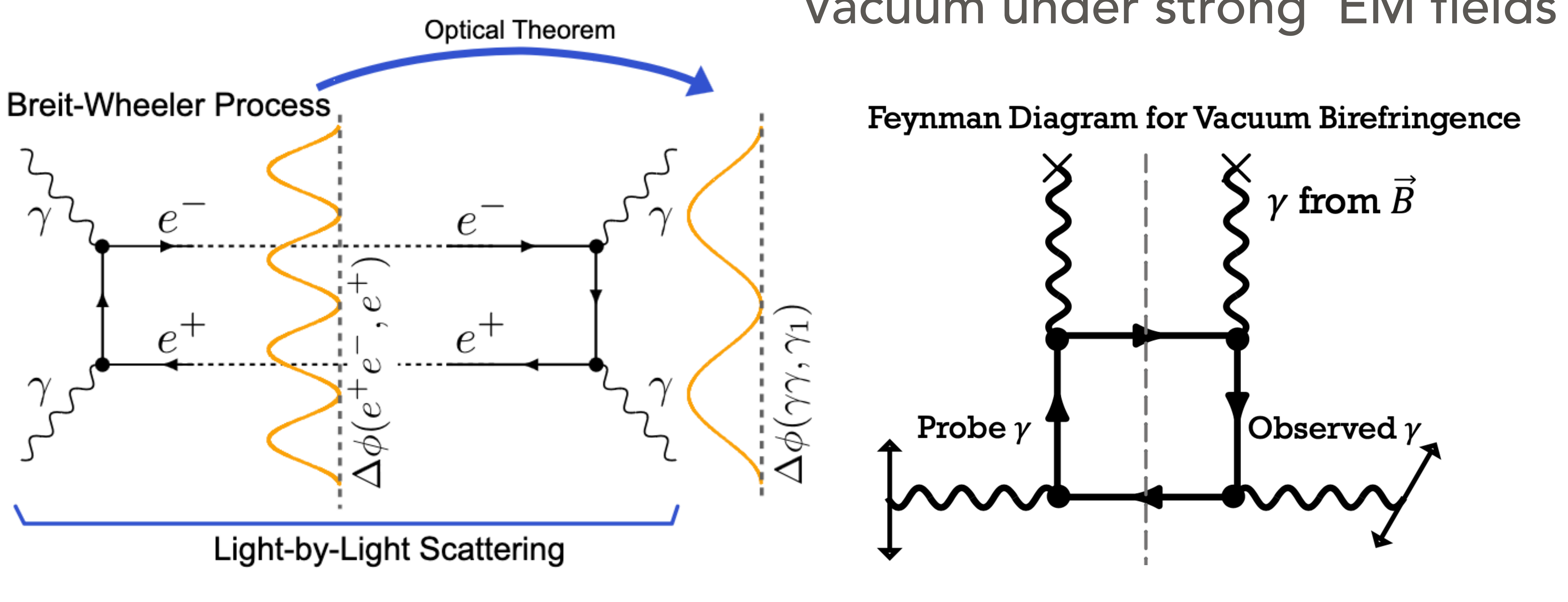
Measurement of total cross section agrees with theory calculations

Observation OF Breit-wheeler processes: γγ -> e+e-

Birefringence of the QED vacuum

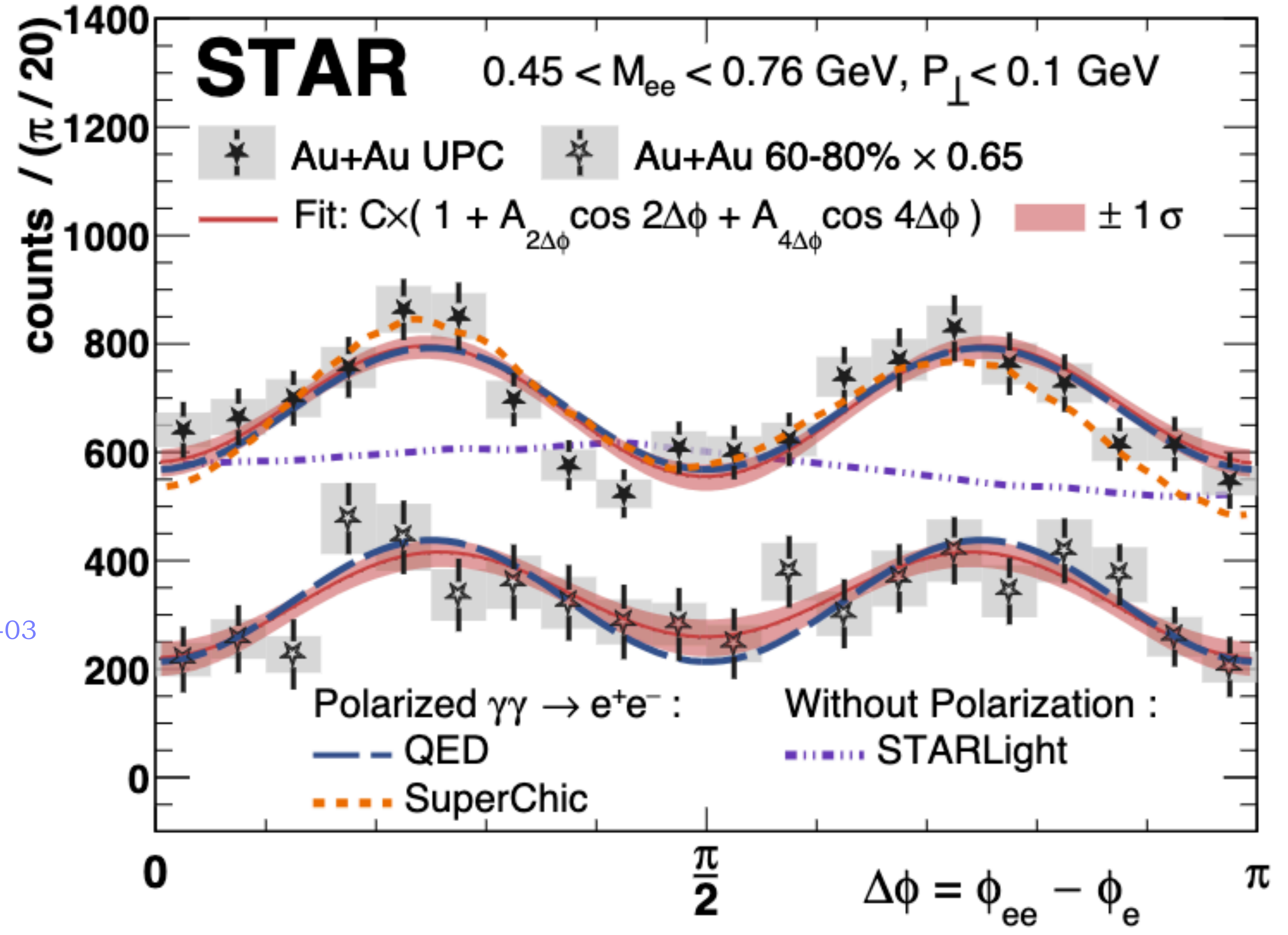
R. P. Mignani, *et al.*, *Mon. Not. Roy. Astron. Soc.* 465 (2017), 492

Vacuum under strong EM fields



S. Bragin, et. al., *Phys. Rev. Lett.* 119 (2017), 250403

STAR Collaboration, Phys. Rev. Lett. 127 (2021) 052302



- Intrinsic photon spin converted into orbital angular momentum -> anisotropy in e+- momentum
- Results are consistent with QED or SuperChic with linear photon polarized
- Similar observation also seen for muon-pairs

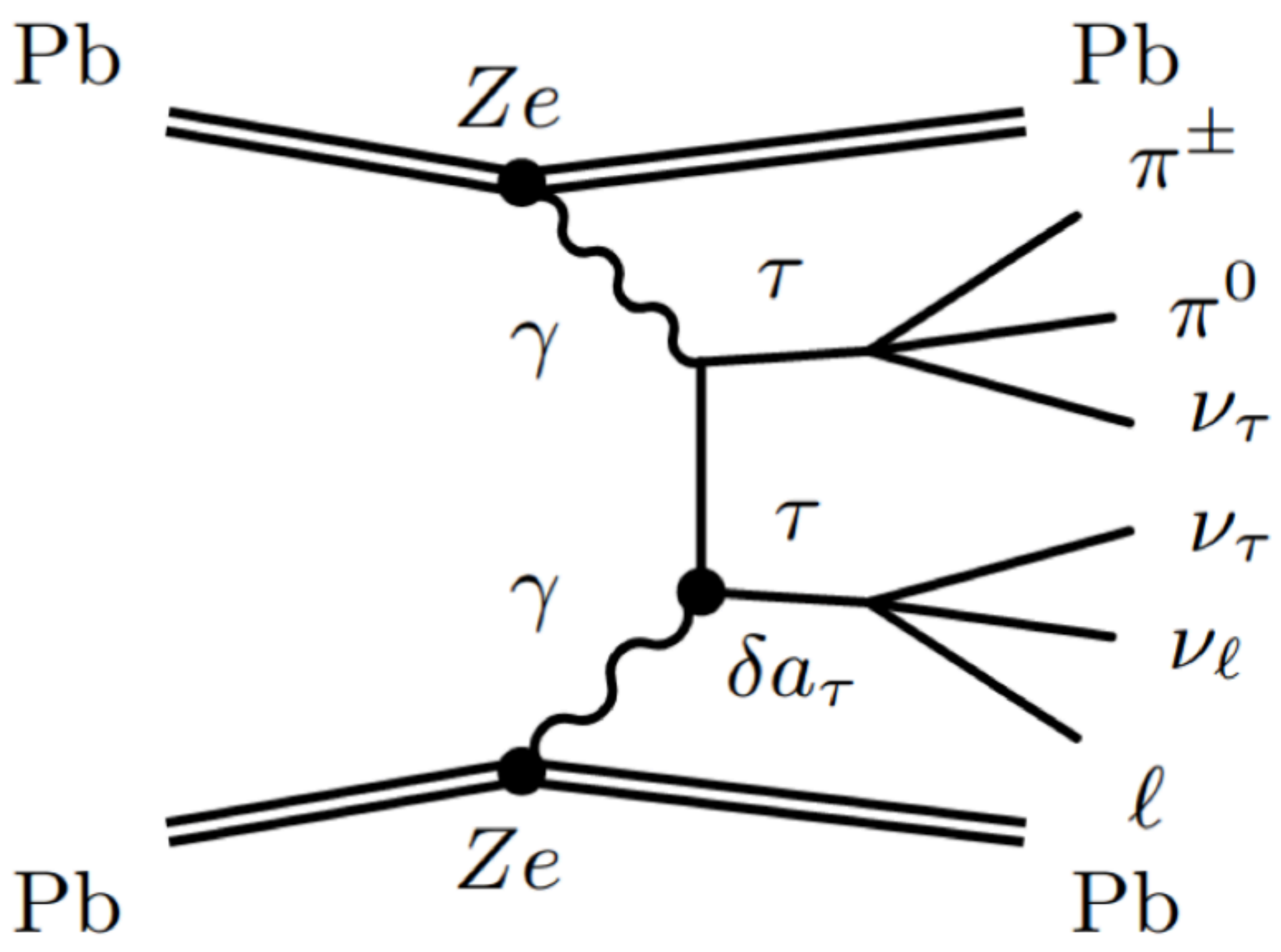
$$\Delta\phi = \Delta\phi[(e^+ + e^-), (e^+ - e^-)] \approx \Delta\phi[(e^+ + e^-), e^+]$$

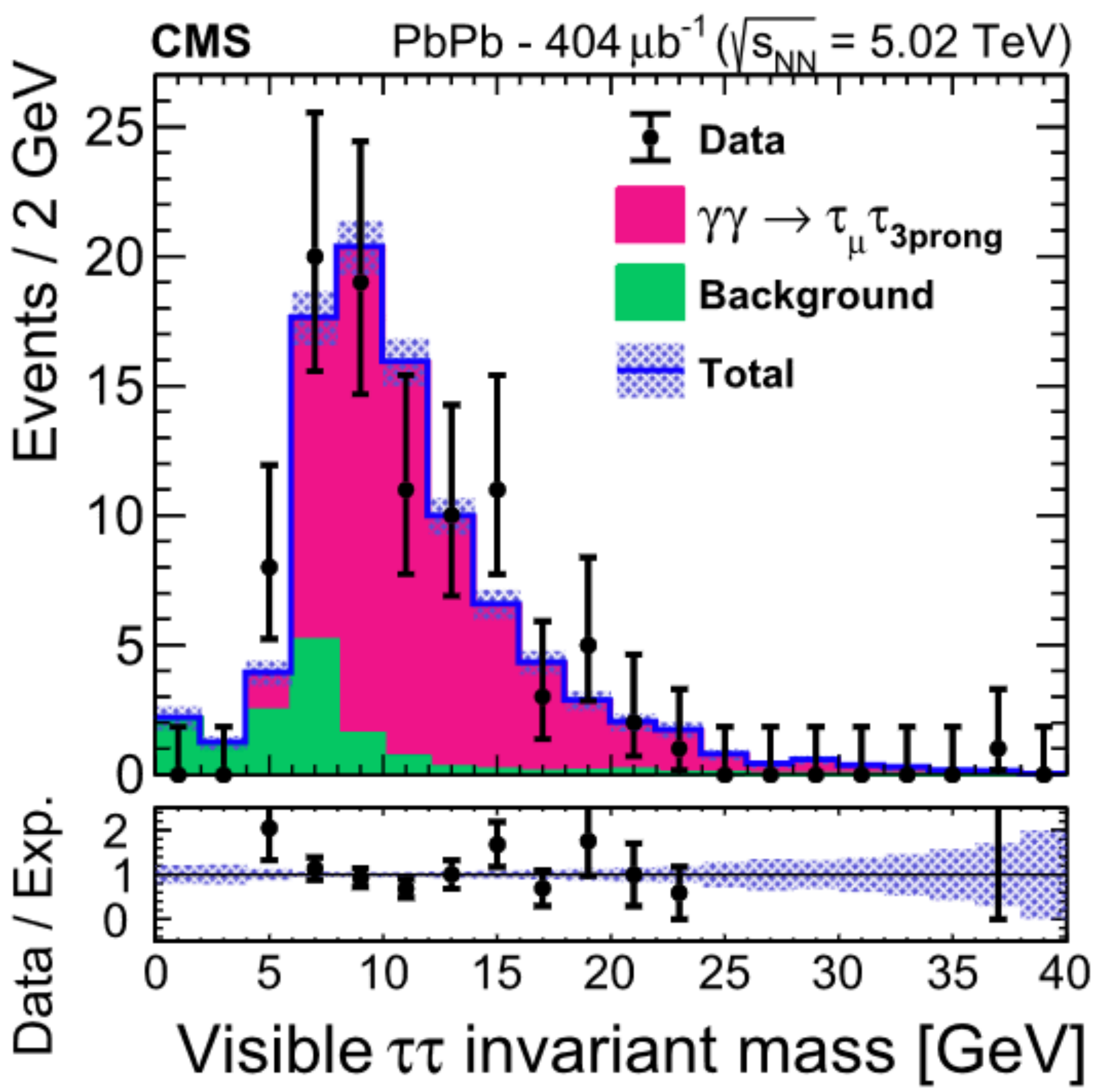
Observed cos(**Δ**φ) modulation for produced e+e-

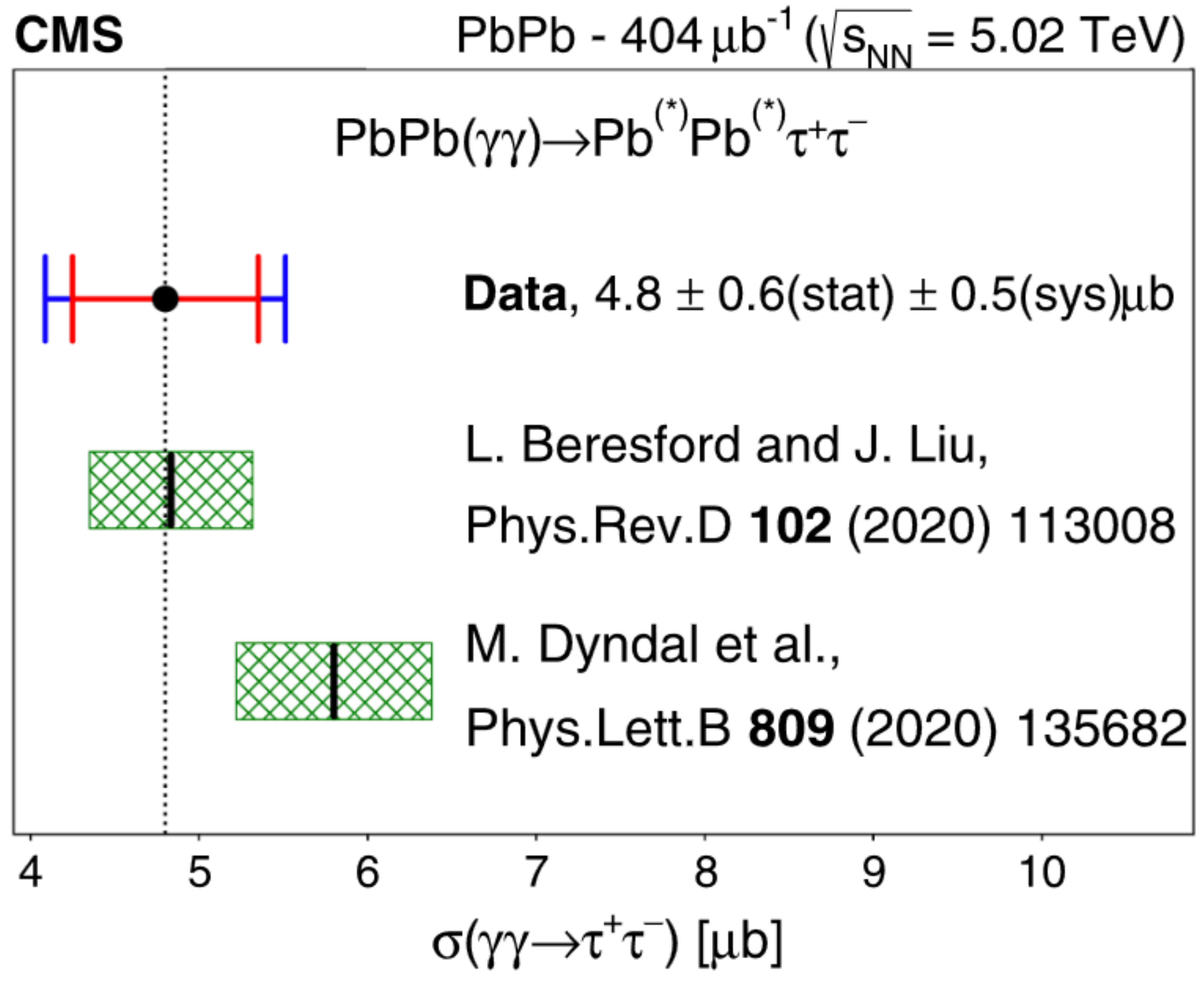
Experimental demonstration to access transverse linearly polarized of photon and QED vacuum Birefriengence

Dilepton pair production in higher order decay channel: $\gamma\gamma \to \tau^+\tau^-$

CMS, Phys. Rev. Lett 131, 151803 (2023)



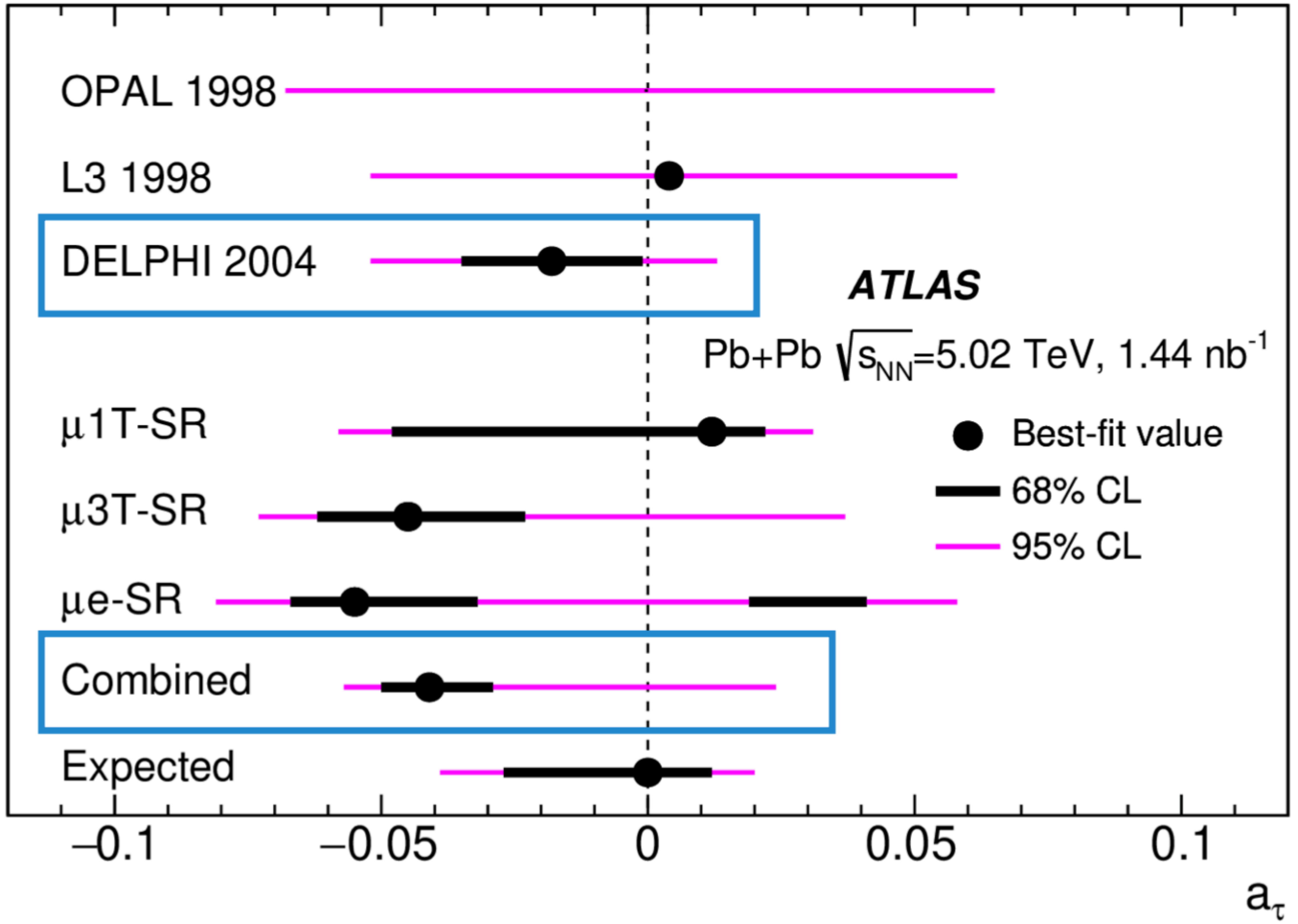




- τ-leptons pair production observed at LHC energies
- Constraints on τ-lepton anomalous magnetic moment, a_τ, $a_\tau = (g_\tau - 2)/2$
- Its value is sensitive to new physics search, such as many BSM models
- Dirac equation (classical assumption) : no internal structure, spin =1/2, g = 2, any deviation from g-2 is considered as anomalous magnetic moment

Tau-lepton anamolos magnetic moment : $\gamma\gamma \to \tau^+\tau^-$

ATLAS, Phys. Rev. Lett. 131, 151802



- Dirac equation (classical assumption) : no internal structure, spin =1/2, g = 2, any deviation from g-2 is considered as anomalous magnetic moment

$$a_\tau = (g_\tau - 2)/2$$

Three signal regions defined:

μ1T-SR: muon + 1 track (e/μ/hadron)

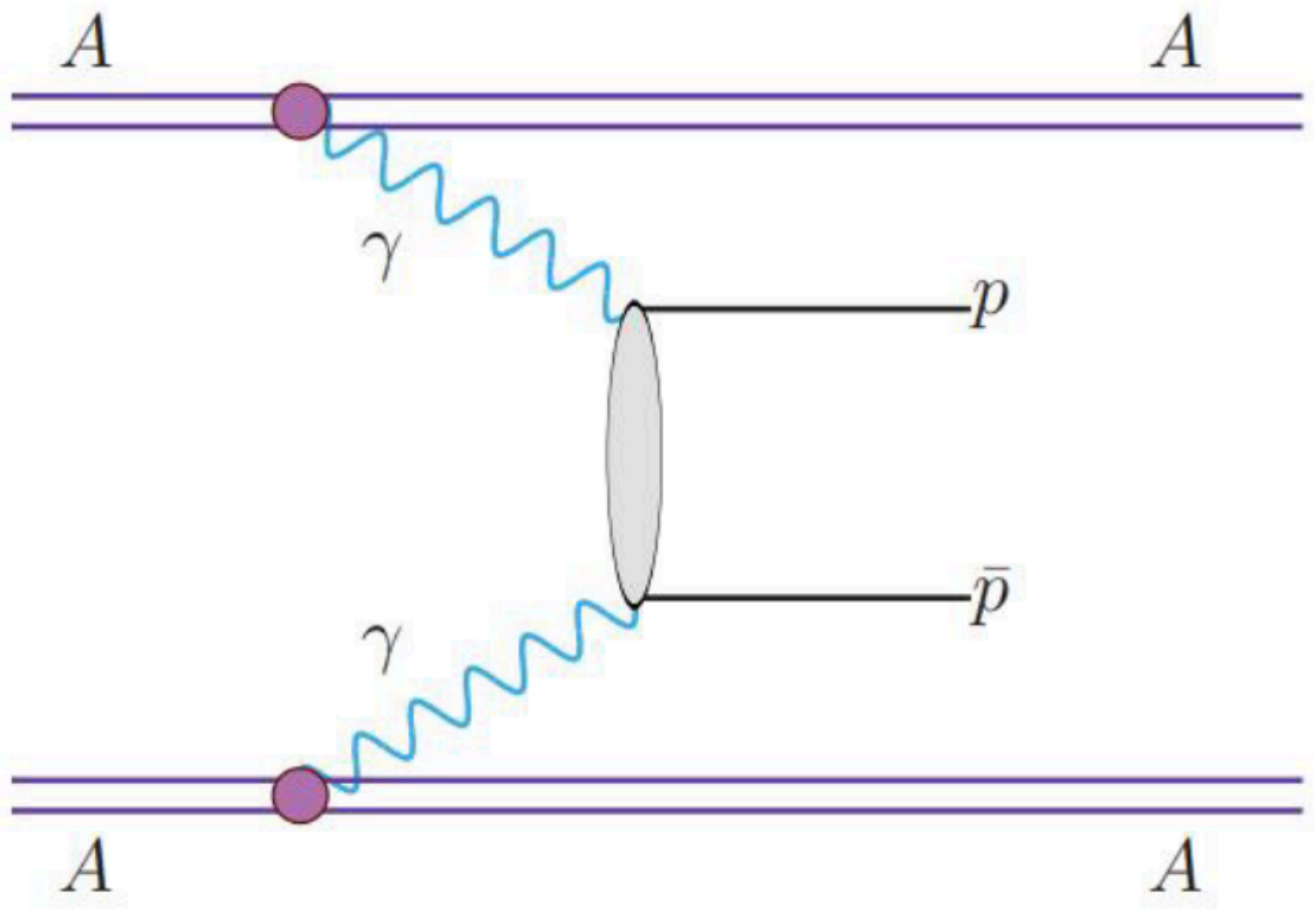
μ3T-SR: muon + 3 tracks (3 hadrons)

μe-SR: muon + electron,

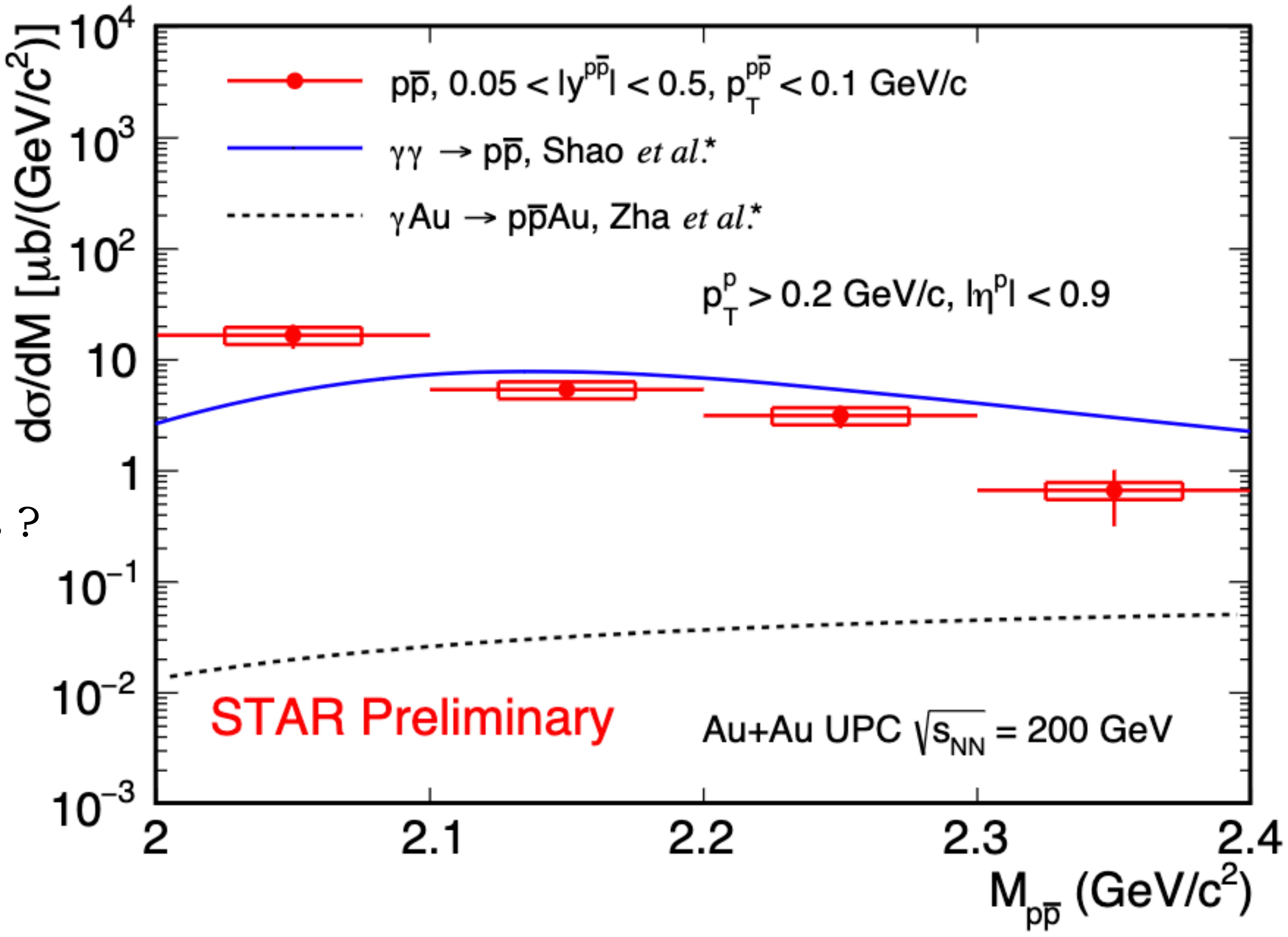
SR = signal regions

- Observed 95% CL limits: $a_\tau \in (-0.057, 0.024)$
- First time put limits using LHC energies since LEP era, $a_\tau \in (-0.052, 0.013)$, EPJC 35 (2004) 159
- Statistical uncertainties dominant → expected to improve with Run-3 data

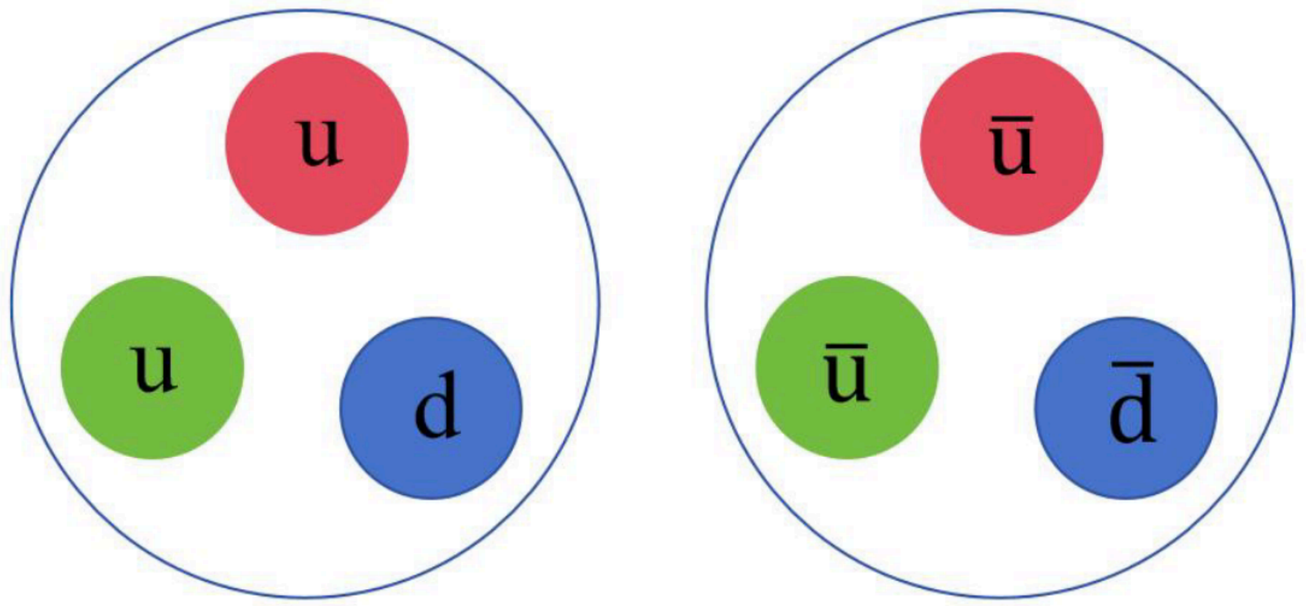
Baryon-antibaryon Production in Au—Au UPC at RHIC



[Xin Wu, SQM 2024]



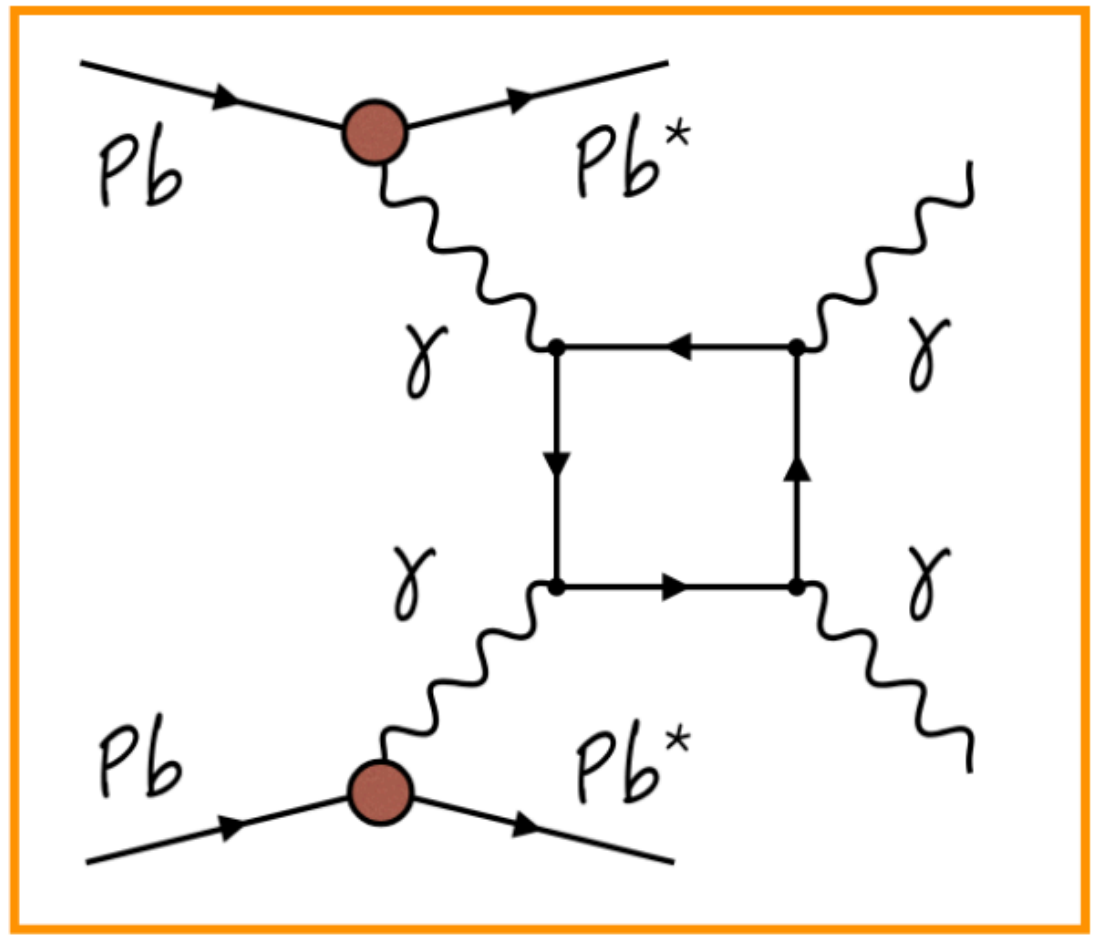
Can $\gamma\gamma$ produces more complex baryon anti baryon pairs ?



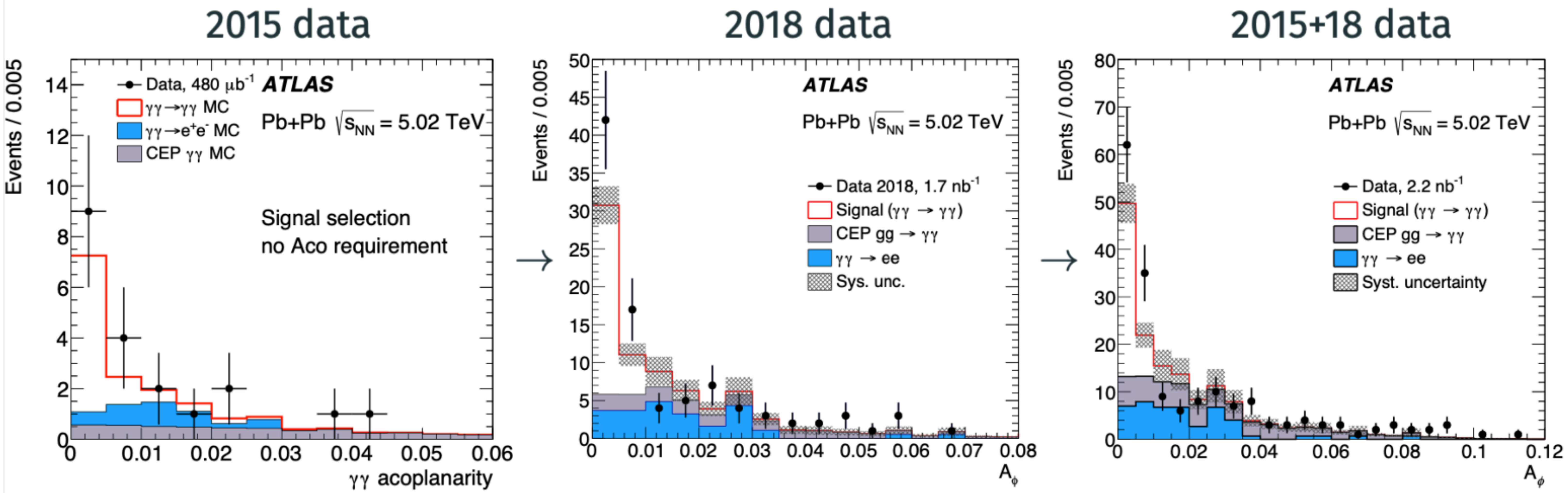
- Observed process $\gamma\gamma$ —> $p\bar{p}$ in UPCs

Measurement of light-by-light scattering (LbL) $\gamma\gamma \to \gamma\gamma$

Light-by-light (LbyL) scattering: key example of rare SM process probed in UPC



$$A_{\phi}^{\gamma\gamma} = |1 - \frac{\Delta\phi^{\gamma\gamma}}{\pi}|$$



ATLAS, Nature Phys. 13 (2017) 852 — Phys. Rev. Lett. 123, 052001 (2019) — JHEP 03 (2021) 243

- Fiducial cross-section: 120 ± 17(stat.) ± 13(syst.) ± 4 (lumi) nb

Compare to theoretical predictions: 80 ± 8 nb, M. Kłusek-Gawenda et al, Phys. Rev. C 93, 044907

78 ± 8 nb (SuperChic 3, Lucian Harland-Lang, Eur. Phys. J. C 80, 925 (2020)

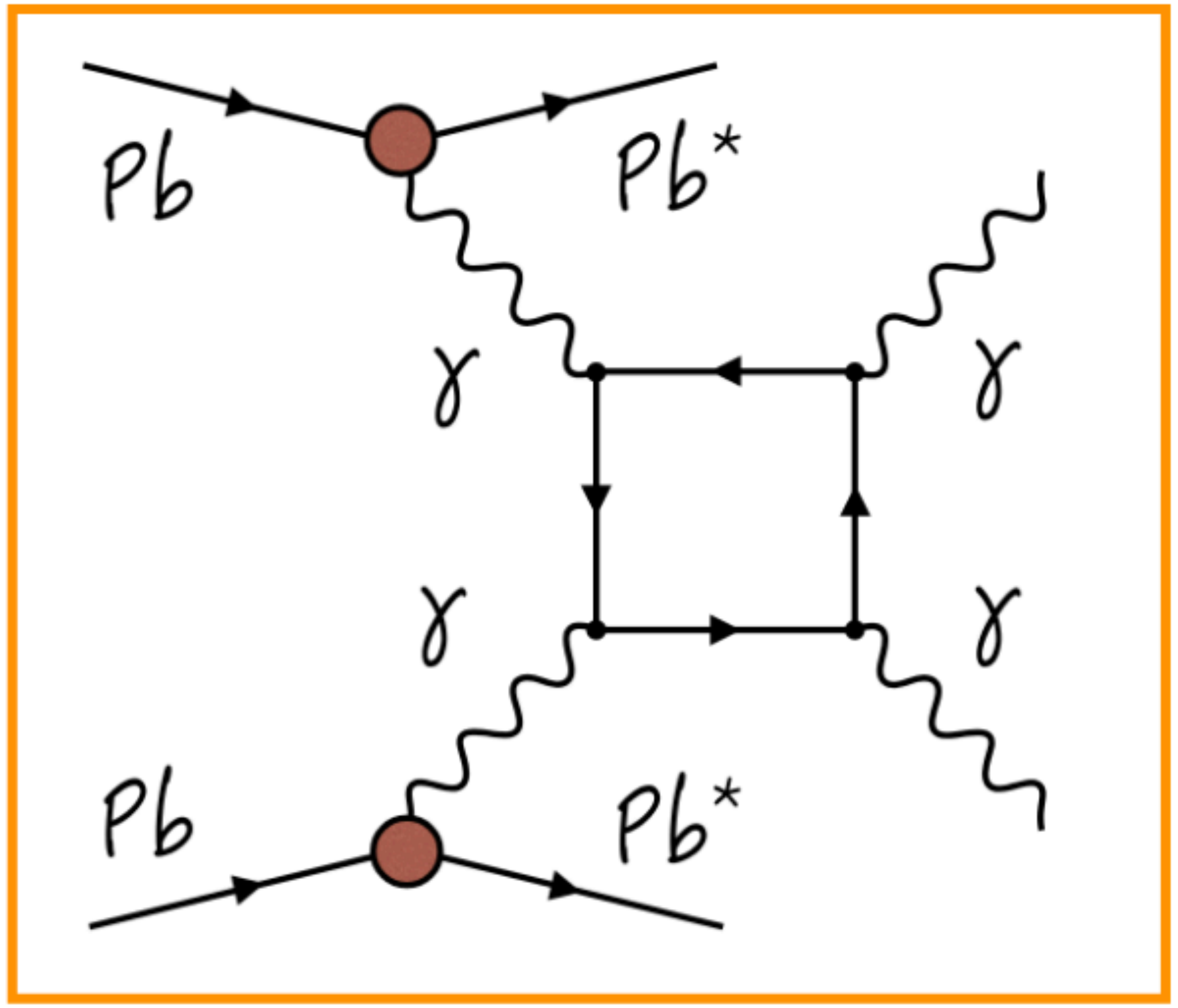
- Not allowed classically, but possible in QED at $O(\alpha^4)$
  — 2015 data -> evidence at 4.4 σ
  — 2018 data -> evidence at 8.2 σ
  — 2015 + 2018 data -> differential cross section

Differential measurements ($m_{\gamma\gamma}$, $|y_{\gamma\gamma}|$, $p_{T\gamma}$, $|\cos\theta^*|$) are reasonably good agreement of distribution shapes with SuperChic3 predictions

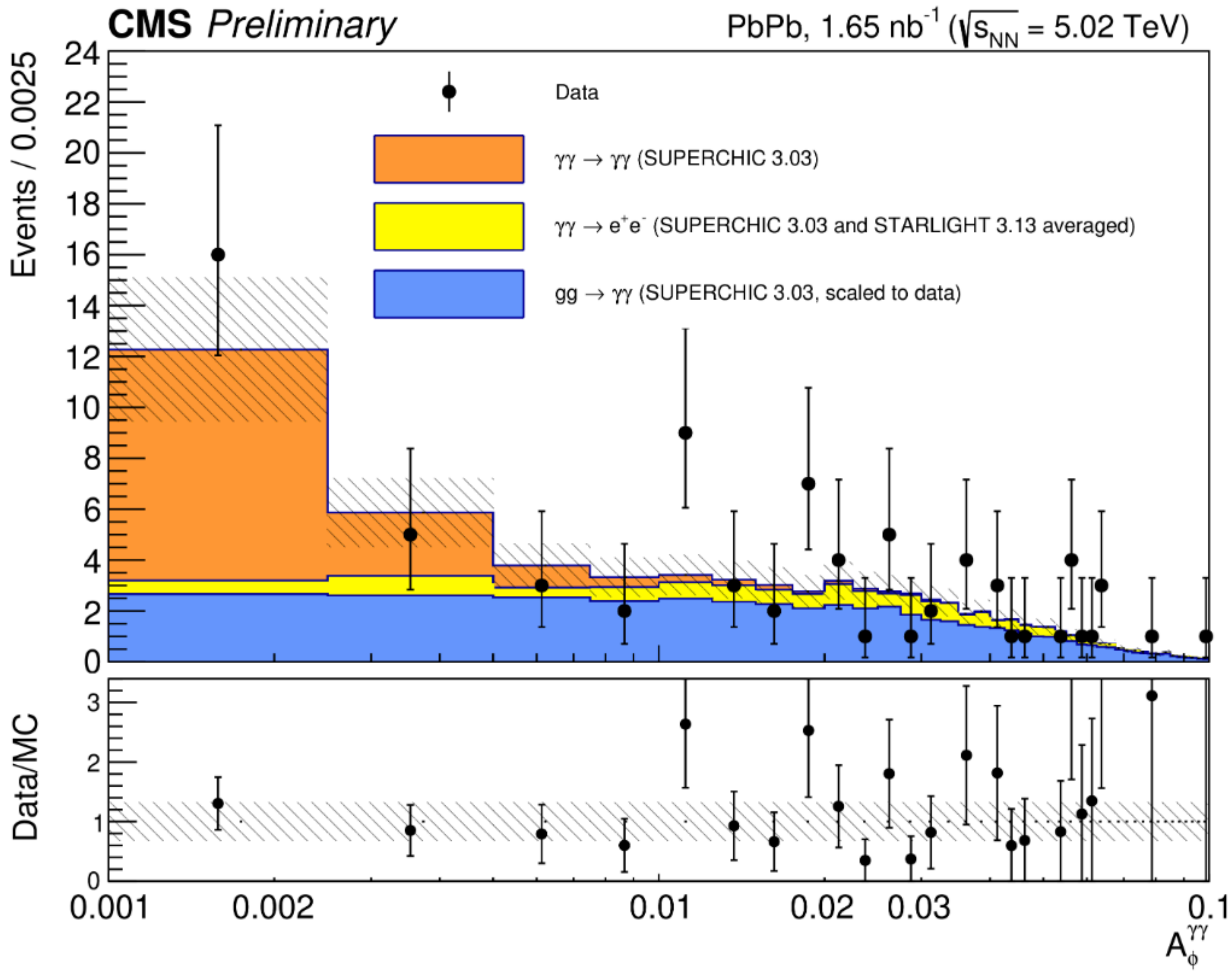
Measurement of light-by-light scattering (LbL): $\gamma\gamma \rightarrow \gamma\gamma$

Light-by-light (LbyL) scattering: key example of rare SM process probed in UPC

CMS-PAS-HIN-21-015



$$A_{\phi}^{\gamma\gamma} = |1 - \frac{\Delta\phi^{\gamma\gamma}}{\pi}|$$



26 exclusive diphoton candidates observed for 12.8 ±3.1 signal events expected

—> significance of the LbL signal = 5.2 standard deviations

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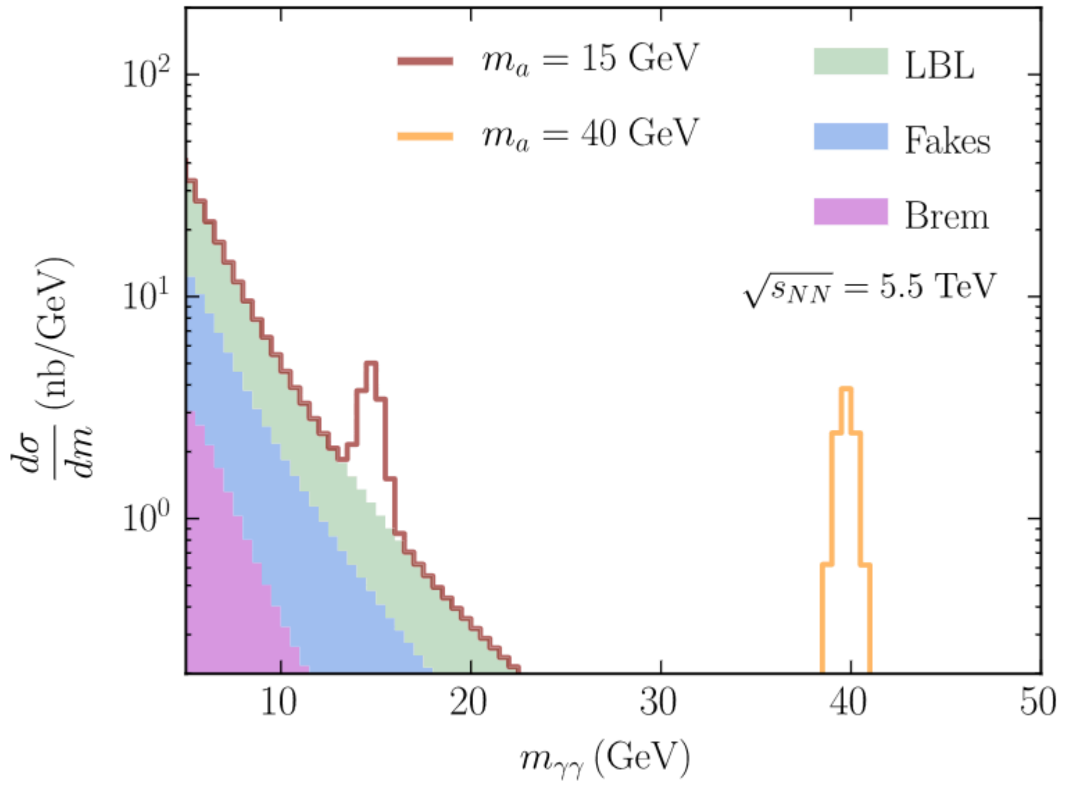
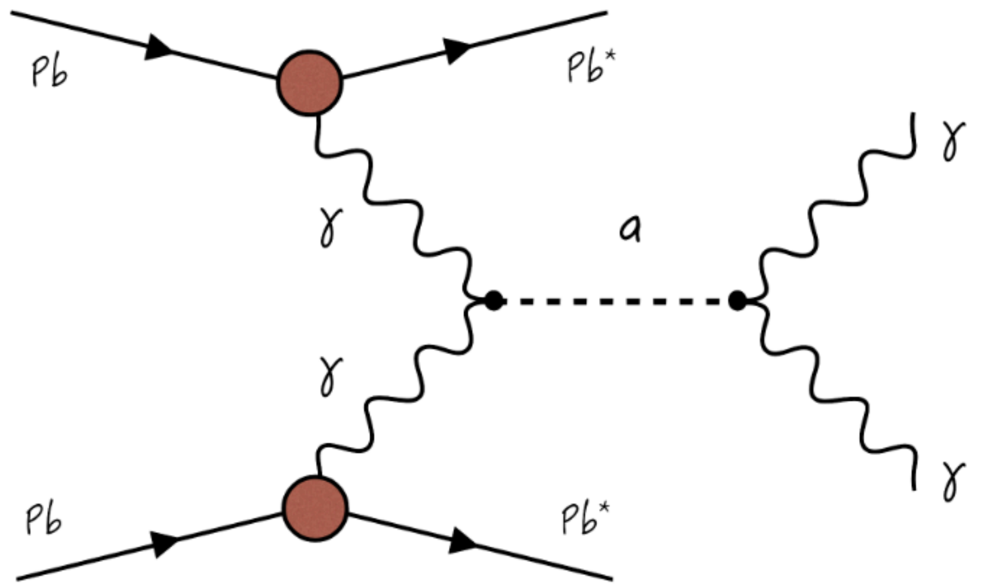
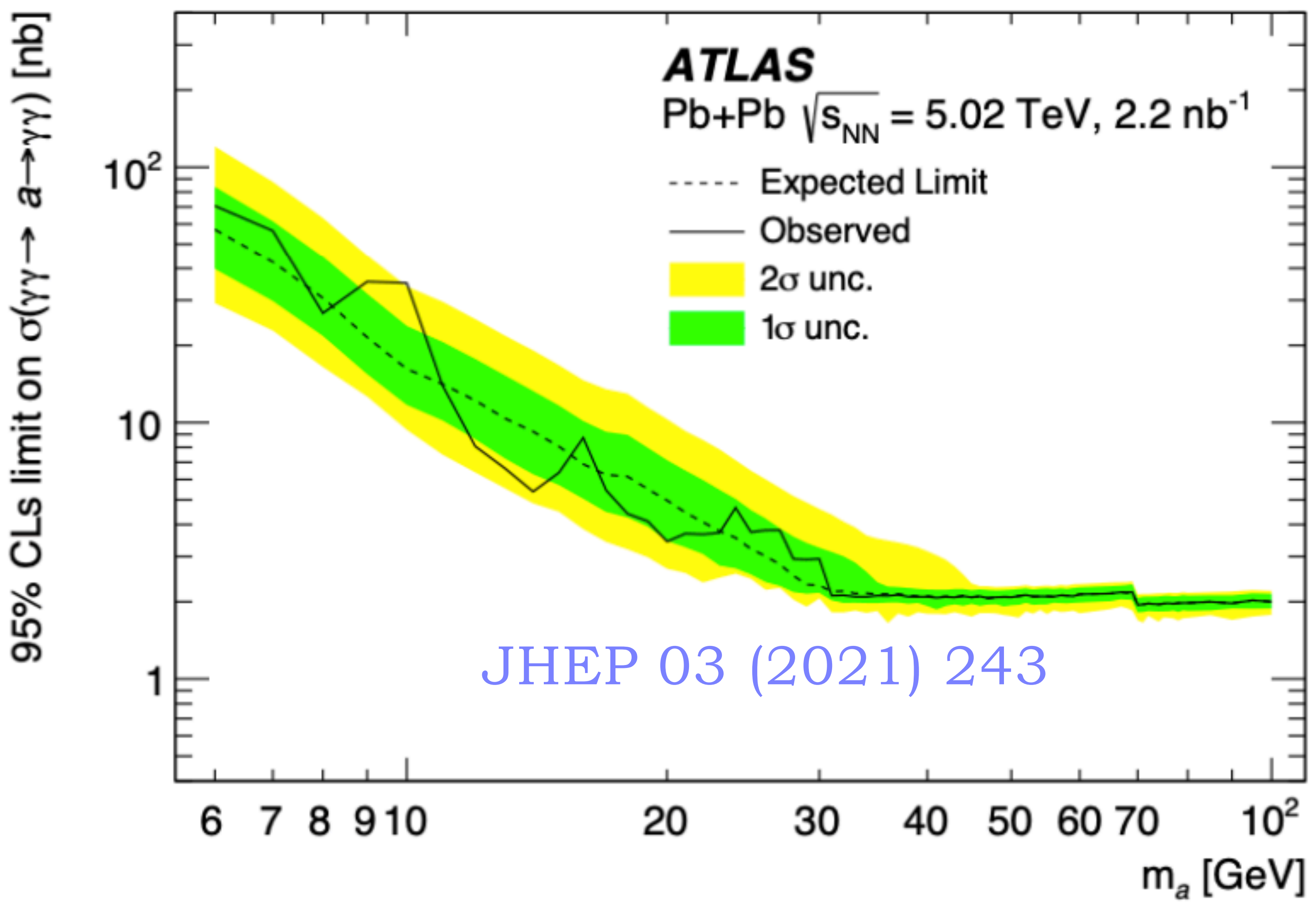
Limits on search for axion-like particles

Axion-like particles can couple to photons in initial- and final-state of $\gamma\gamma \rightarrow \gamma\gamma$

S. Knapen et al., Phys. Rev. Lett. 118, 171801







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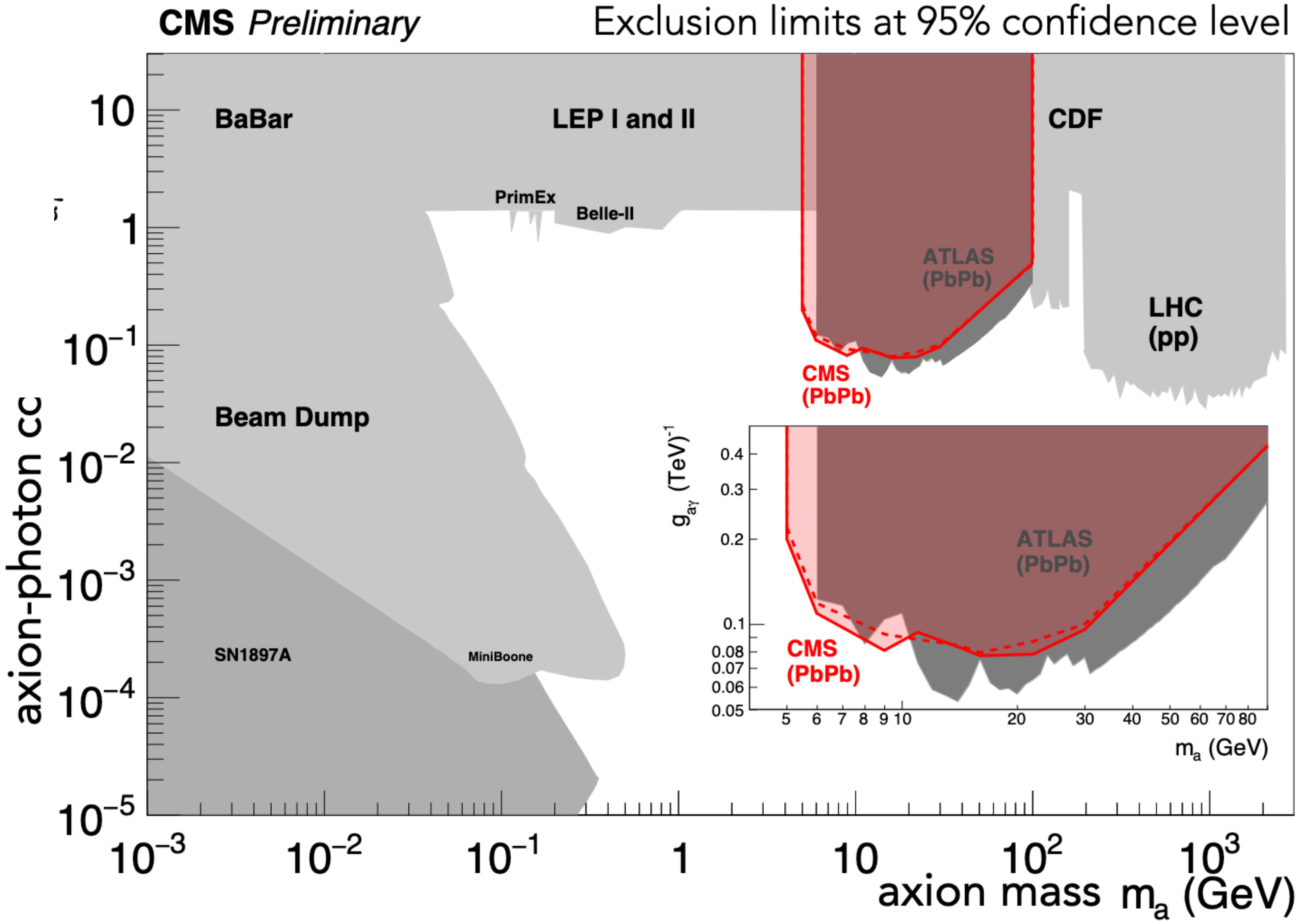
- No significant deviation from SM

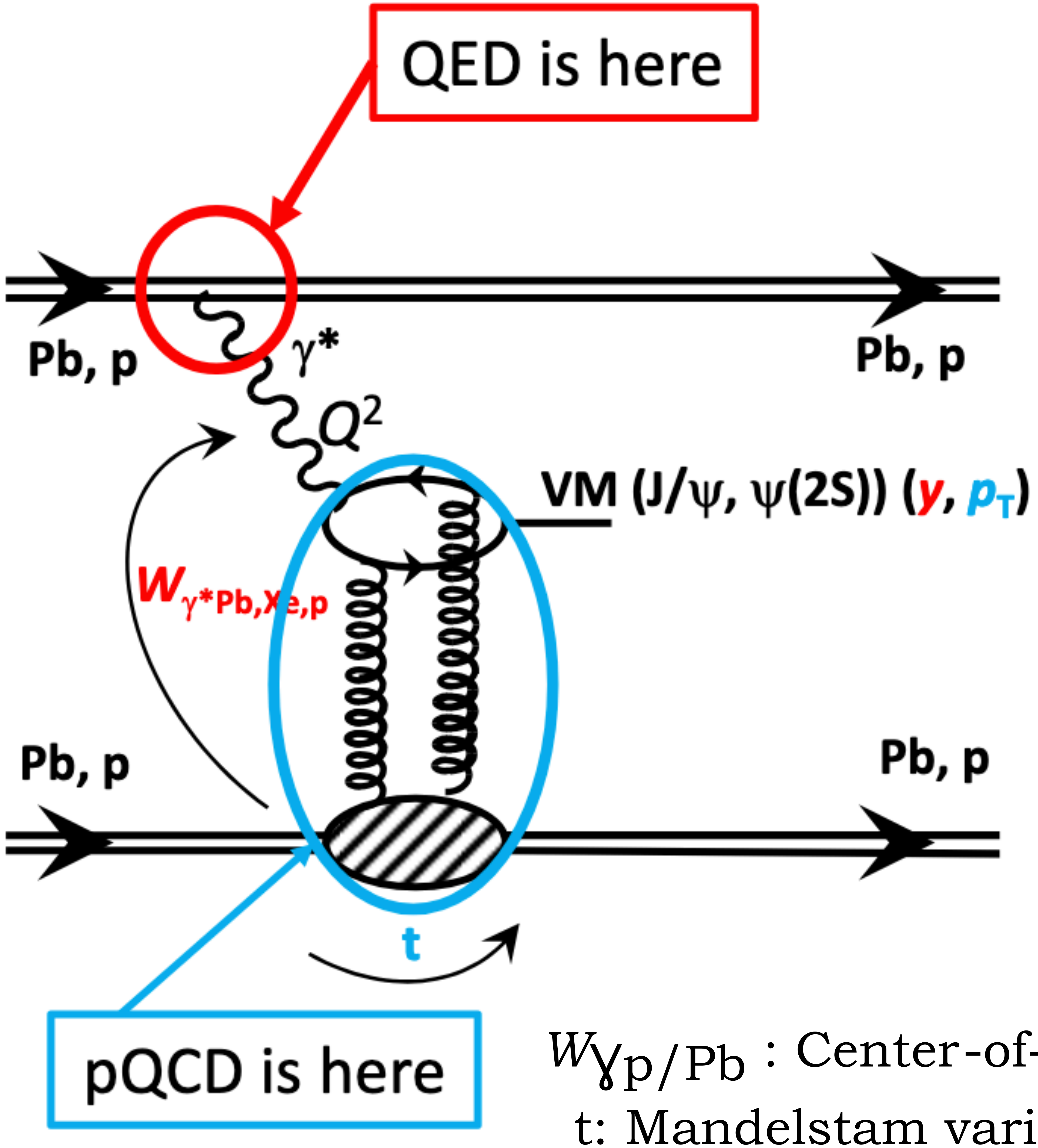
CMS-PAS-HIN-21-015



- Most stringent constraints in the mass range
  CMS : 5–100 GeV
  ATLAS : 6-100 GeV

photoproduction of vector mesons

Photonuclear interactions:



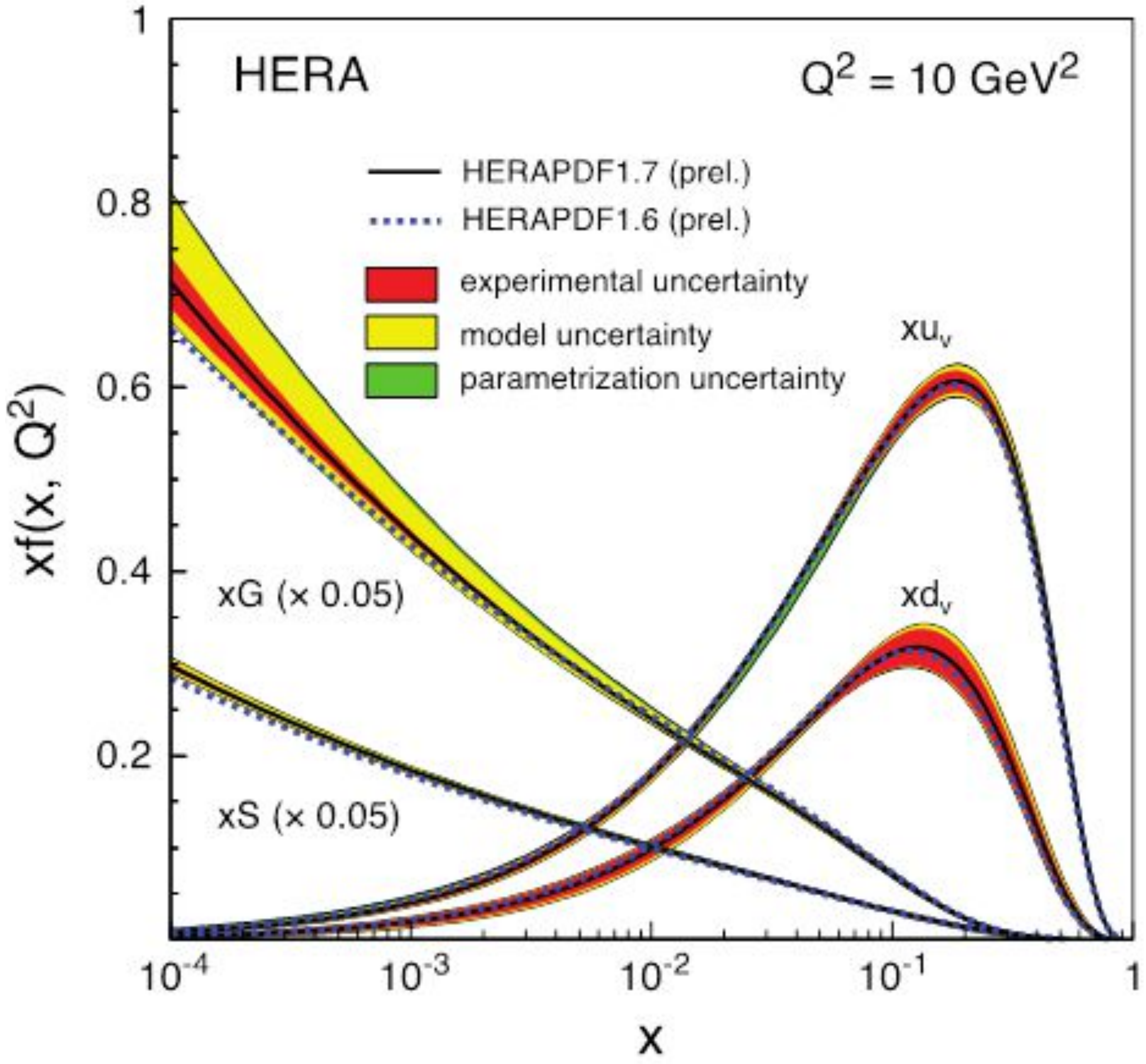
- ❑ Clean experimental signature
- ❑ VM photoproduction :
  - -> Probing density distributions inside nucleon/nucleus at low Bjorken-x

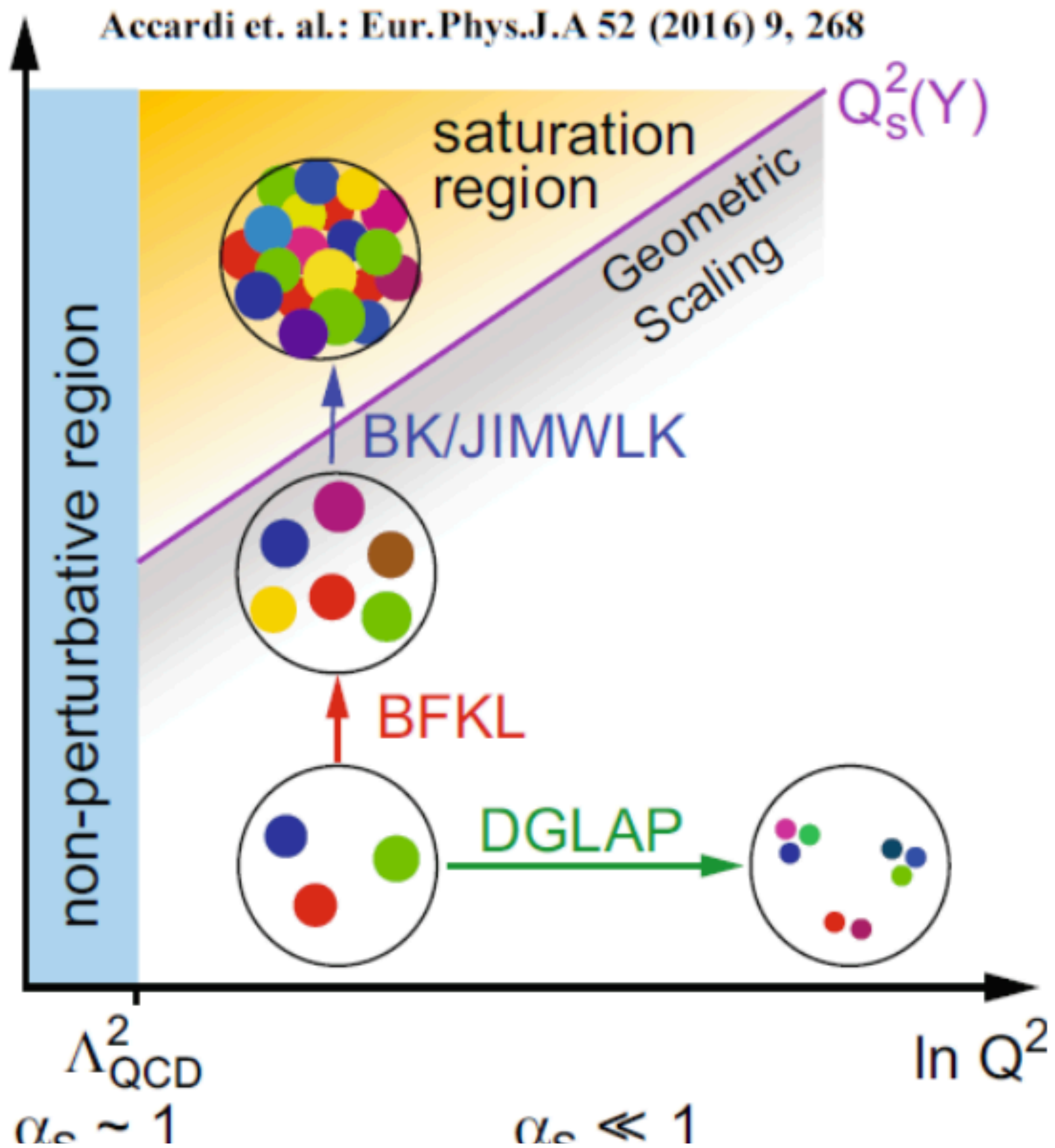
$$x = \frac{m_{J/\psi}}{\sqrt{s_{\rm NN}}} \times \exp(\pm y)$$

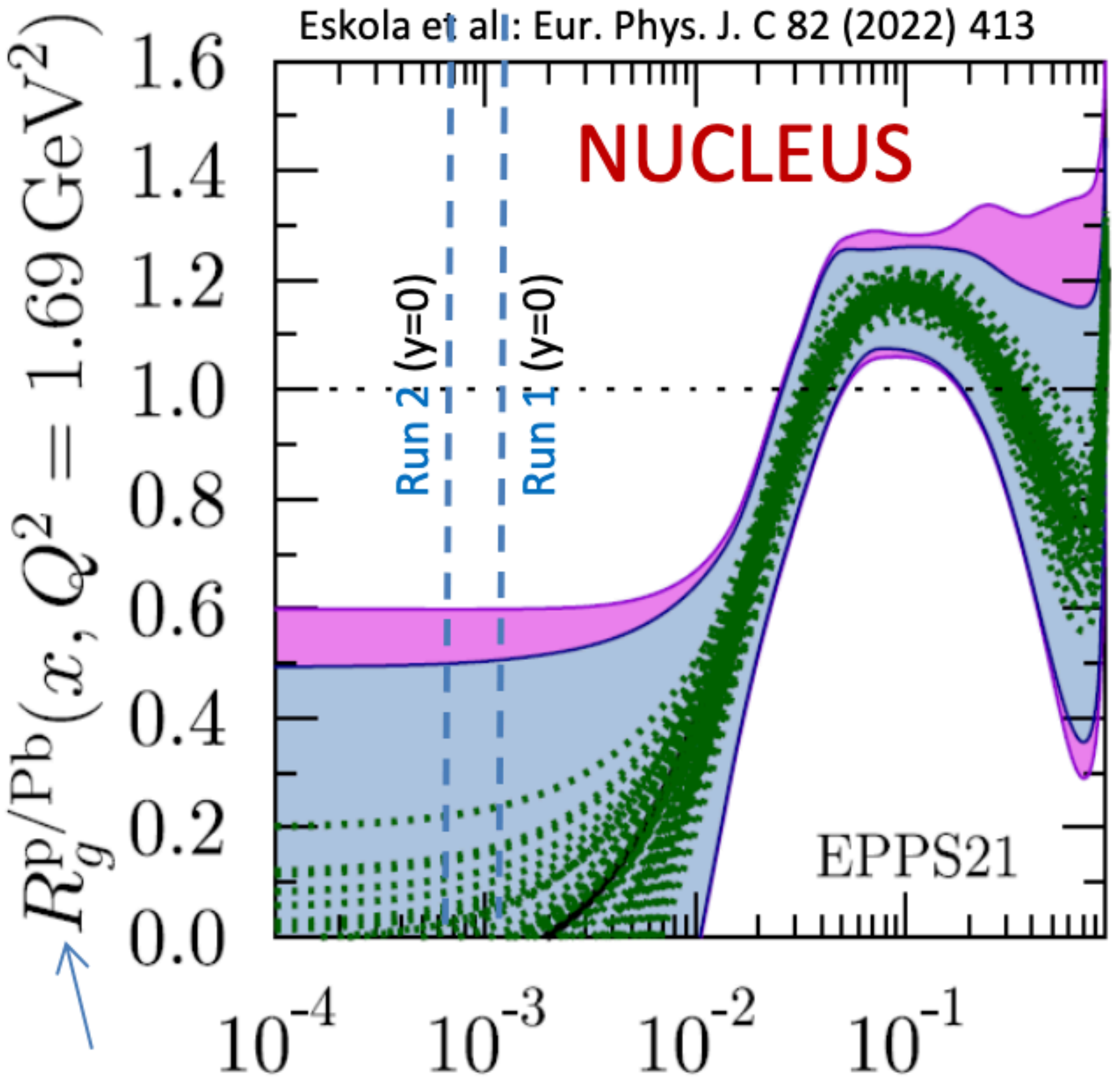
$W_{\gamma p/Pb}$: Center-of-mass energy of photon-lead system

t: Mandelstam variable = - p_T^2

Motivation: Photoproduction of vector mesons







- How to probe gluon saturation?

— To probe gluon saturation effects inside nucleon or nucleus at low Bjorken-x

- How well do we model photon flux ?
- Constrain parameters of models and test pQCD

Ideal probe: photoproduction of coherent vector mesons (ρ, J/Ψ, Ψ2S),Υ(nS))

Different photon-induced processes

Coherent photo production

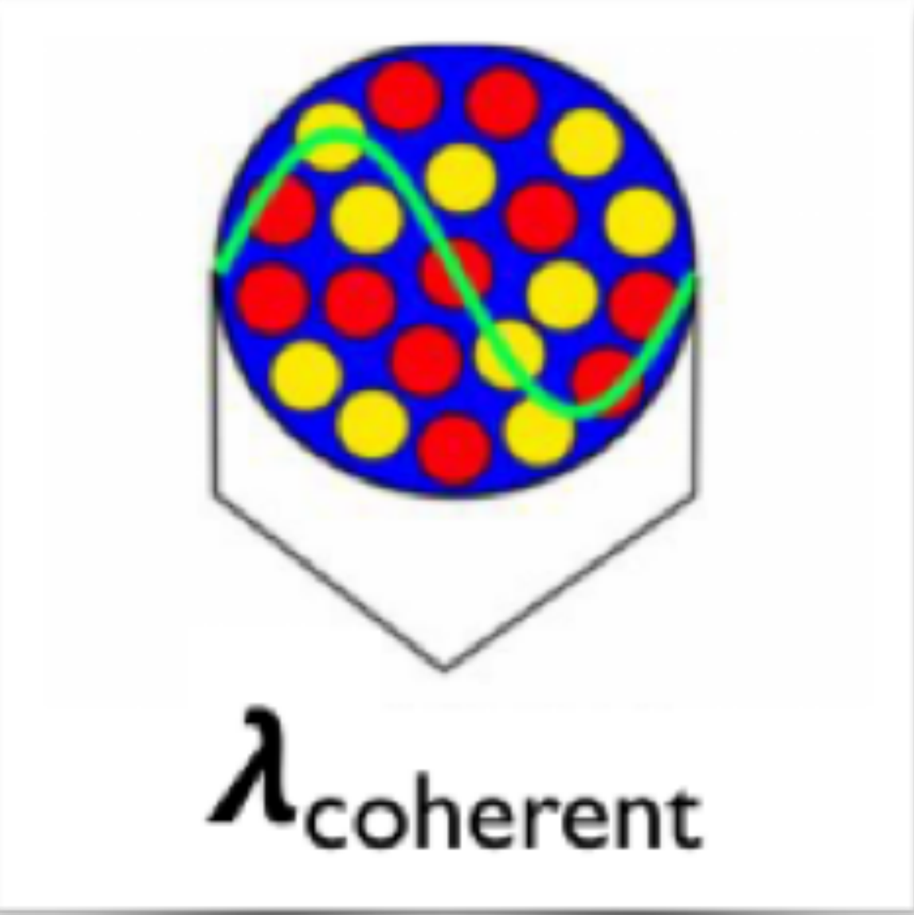
Photon (γ) couples coherently to all nucleons

$<p_T>_{J/\Psi} \sim 1/R \sim 60$ MeV/c

Usually no breaking of target

– Does this include nuclear excitation ?

– Does this include coherent breakup



Incoherent photo production

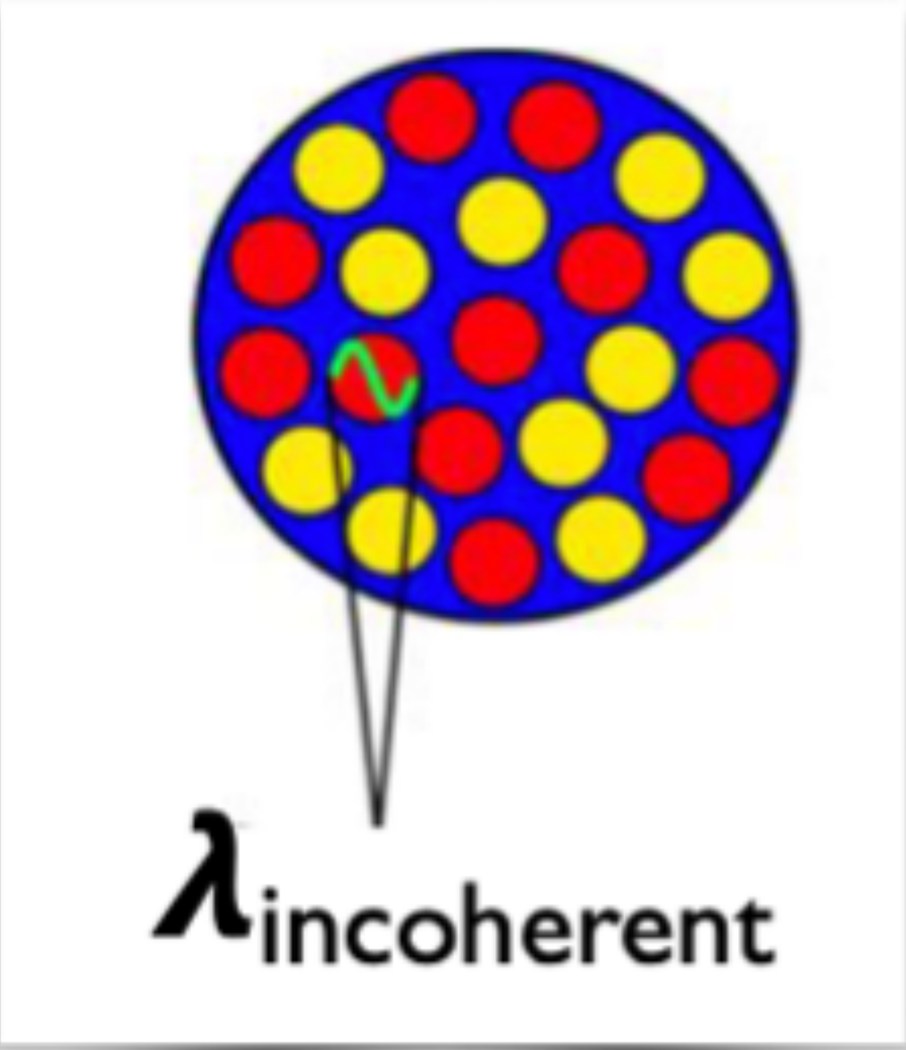
Photon (γ) couples to single nucleon

$<p_T>_{J/\Psi} \sim 500$ MeV/c

Usually target nucleus breaks

— neutrons are observed

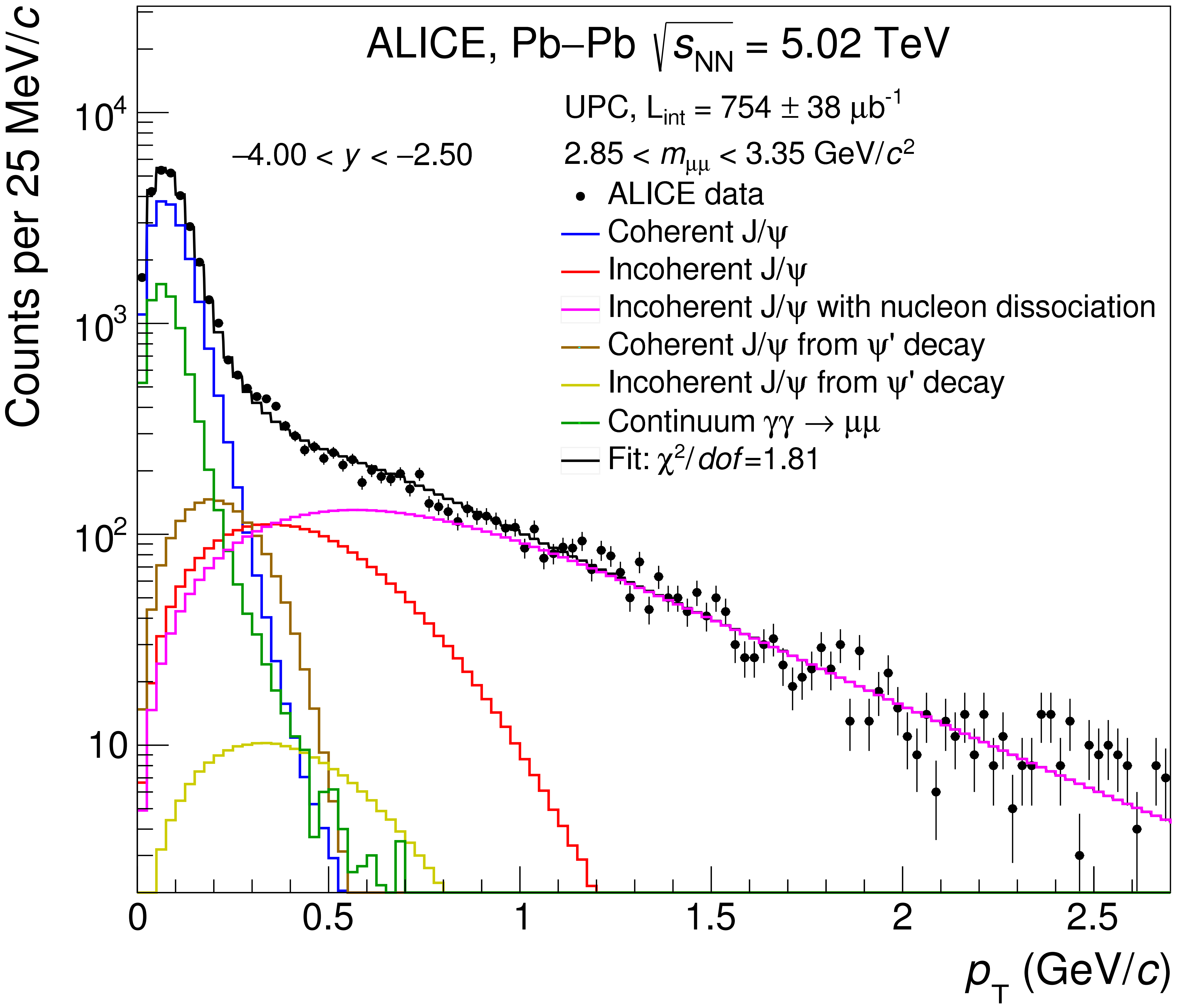
— p_T distribution follows exp(bt), b small



Clear definition require between the theory and (variable) experimental

Photoproduction of VM in UPCs

p_T distributions for different processes Phys. Lett. B798 (2019) 134926



t: Mandelstam variable = - p_T^2, helps to constrain transverse gluonic structure at low Bjorken-x, Mantysaari, Schenke, PLB 772 (2017) 832

- Coherent photoproduction tells about transverse dependence of the gluon shadowing

STARlight: Comp. Phys. Comm. 212 (2017) 258.

Coherent photoproduction of VMs are dominant at low transverse momentum (p_T) region

VM photo production cross section vs. y at LHC experiments

Forward region (ALICE, CMS, LHCb):

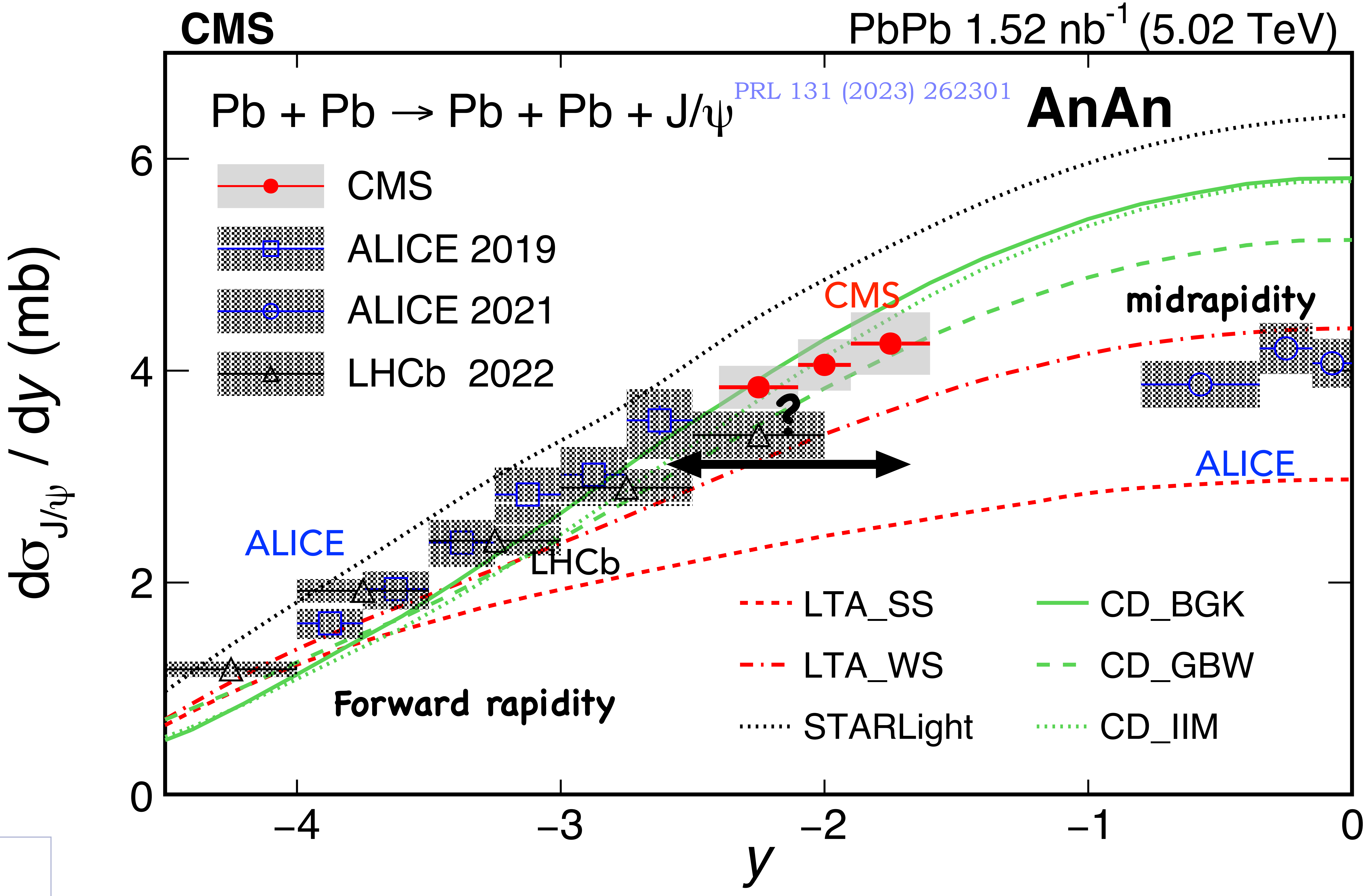
$J/\Psi \longrightarrow \mu^+\mu^-$

Midrapidity region (ALICE) :

$J/\Psi \longrightarrow \mu^+\mu^-$, e^+e^-, $p\bar{p}$

Compatibility between ALICE and LHCb at forward rapidity but values are found different among experiments in the rapidity,

$-2.5 < y < -1.5$

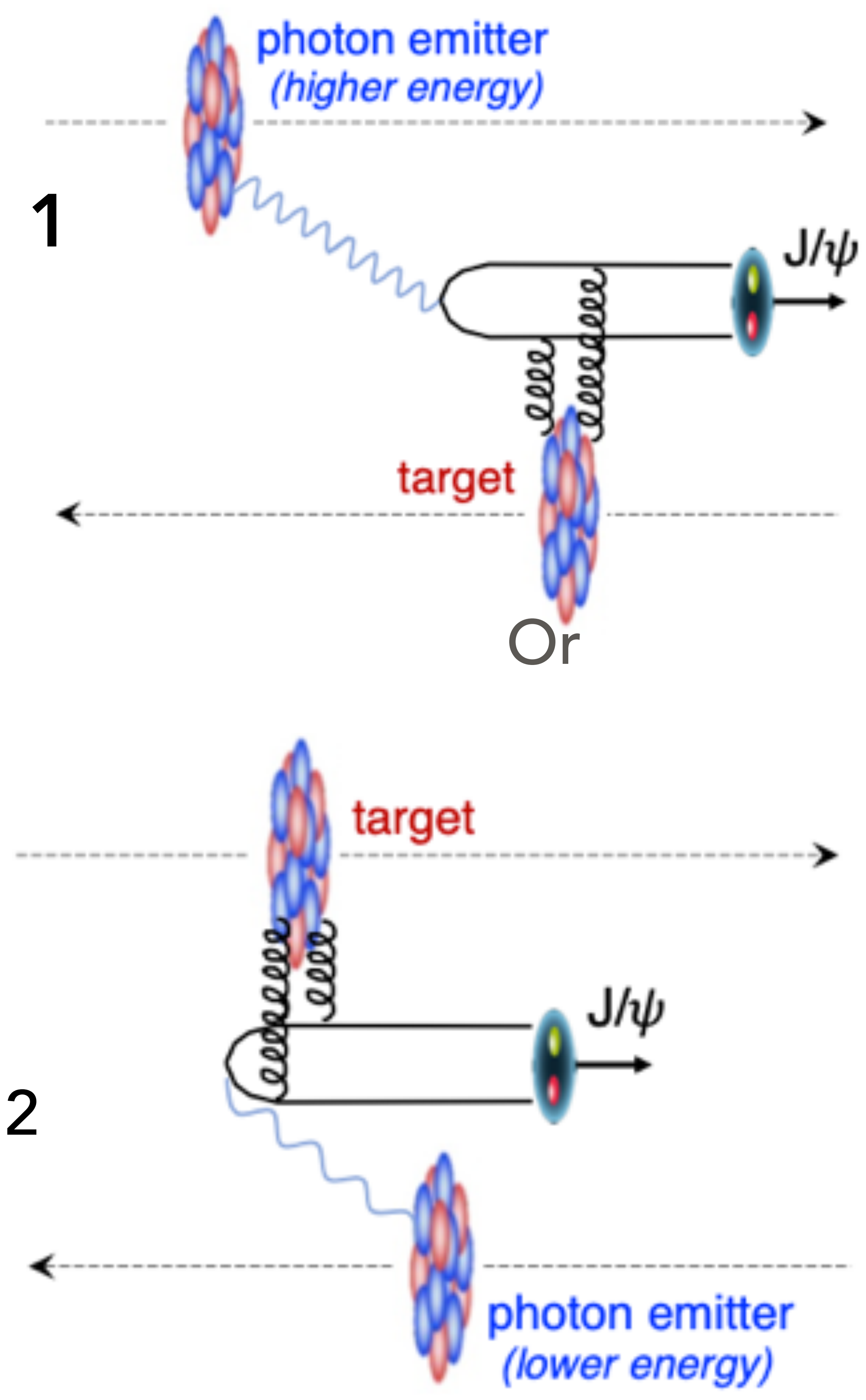


ALICE: EPJ C 81 (2021) 712
LHCb: JHEP 07 (2022) 117, JHEP 06 (2023) 146
CMS: PRL 131 (2023) 262301

Models cannot describes the full rapidity dependence

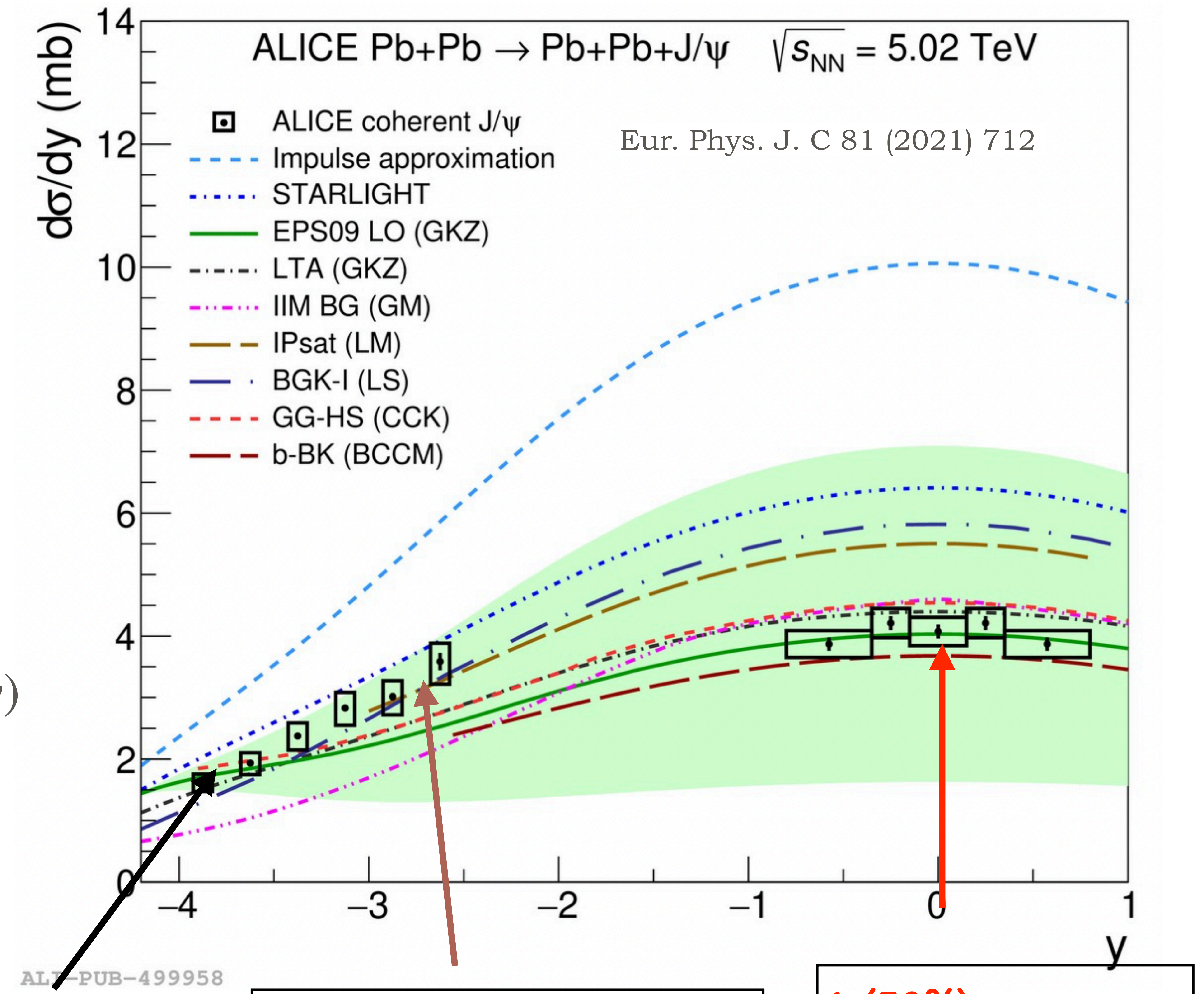
Rapidity dependence : Photon energy ambiguity

In symmetric collisions, depending on the photon emitter: two values of Bjorken-x probed



$$x = \frac{m^2_{J/\psi}}{W^2_{\gamma \mathrm{Pb}}}$$

$$x = \frac{m_{J/\psi}}{\sqrt{s_{\mathrm{NN}}}} \times \exp(\pm y)$$



1 (5%), x ~ 1.1 x 10^{-5}
2 (95 %), x ~3.3 x 10^{-2}

1 (40%), x ~ 5.1 x 10^{-4}
2 (60 %), x ~ 0.7 x 10^{-2}

1 (50%)
2 (50%)
at y=0, x ~ 10^{-3}

Solution to photon energy ambiguity

Measured cross section from Pb-Pb collisions

Photon flux at rapidity ±y in the impact parameter range (b1,b2)

$$\frac{d\sigma_{\mathrm{PbPb}}}{dy} = n_\gamma(y;b_{1,2})\sigma_{\gamma\mathrm{Pb}}(y) + n_\gamma(-y;b_{1,2})\sigma_{\gamma\mathrm{Pb}}(-y)$$

Photonuclear cross section: QCD!

At y=0,

$$\frac{d\sigma_{\mathrm{PbPb}}}{dy} = 2n_\gamma(y,\{b\})\sigma_{\gamma\mathrm{Pb}}(y)$$

Proposed solution by [V. Guzey et al., PLB 726 (2013), 290-295 and J. G. Contreras, PRC 96, 015203 (2017)]

Electromagnetic dissociation of nuclei (EMD): modeling of photon fluxes associated to neutron emission

1. ALICE Collaboration, JHEP 10 (2023) 119
2. CMS Collaboration, PRL 131 (2023) 262301
3. STAR Collaboration, arXiv:2311.13632 (submitted to PRC), arXiv:2311.13637 (submitted to PRL)

Simultaneously solving the cross section measurements from UPCs and PCs

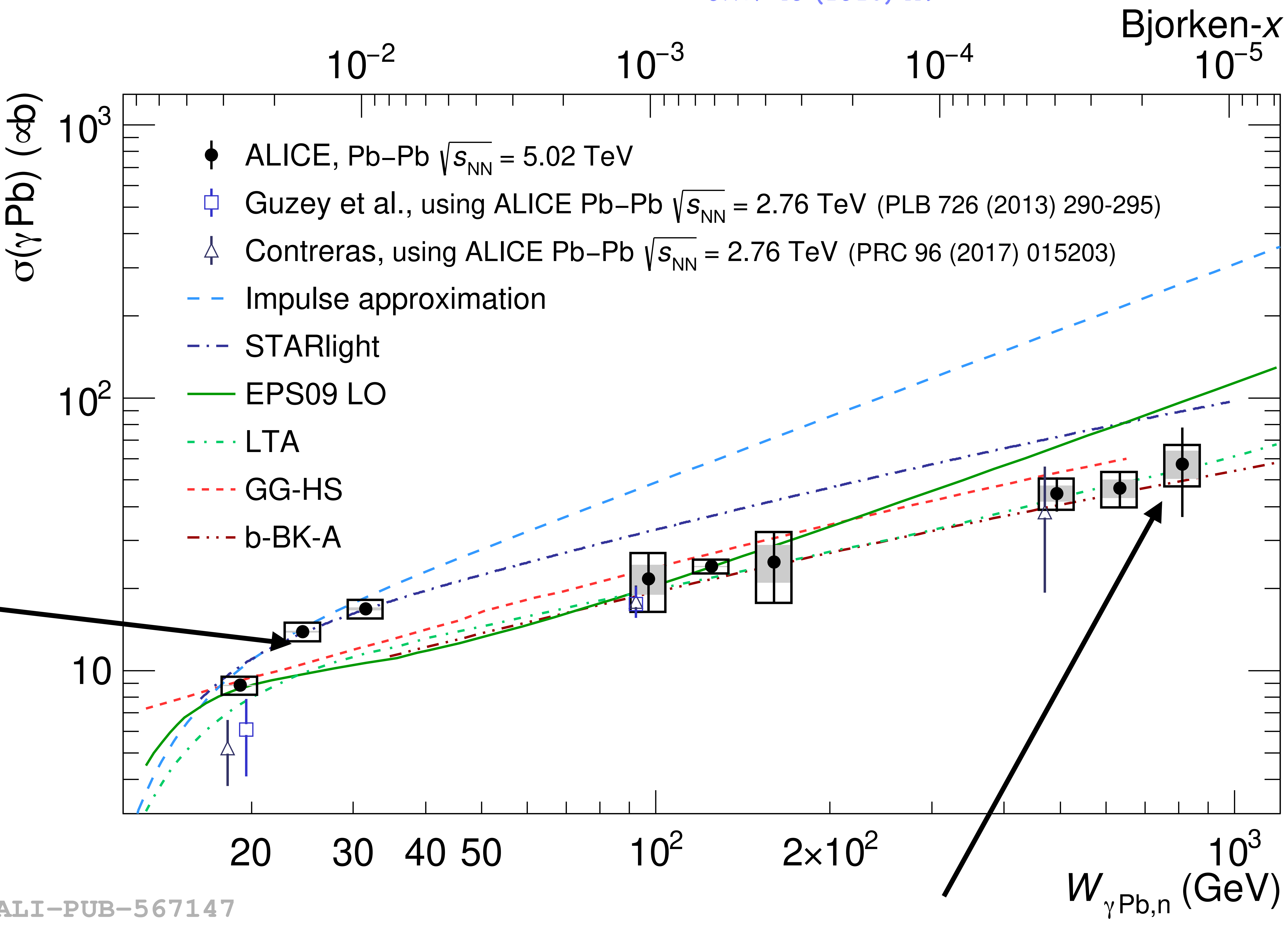
1. J. Contreras et al., PRC 96, 015203 (2017)

Photo production of VM: $\sigma_{\gamma Pb}$ vs. $W_{\gamma Pb}$ or x

Energy dependence of coherent J/Ψ production

JHEP 10 (2023) 119

First measurement of the energy dependence of the photonuclear cross section ($\sigma_{\gamma Pb}$) down to Bjorken-$x \sim 10^{-5}$



At low $W_{\gamma Pb}$: Impulse approximation (IA) and STARlight

Impulse approximation: [PRC88, 014910 (2013)]

STARLIGHT: [Comp. Phys. Comm. 212 (2017) 258]

EPS09 LO (GKZ): [PRC. 93(5), 055206 (2016)]

LTA (GKZ): [Phys. Rep.512, 255–393 (2012)]

GG-HS (CCK): [PRC. 97(2), 024901 (2018)], and [PLB 766, 186-191 (2017)]

b-BK (BCCM): [PLB 817, 136306 (2021)]

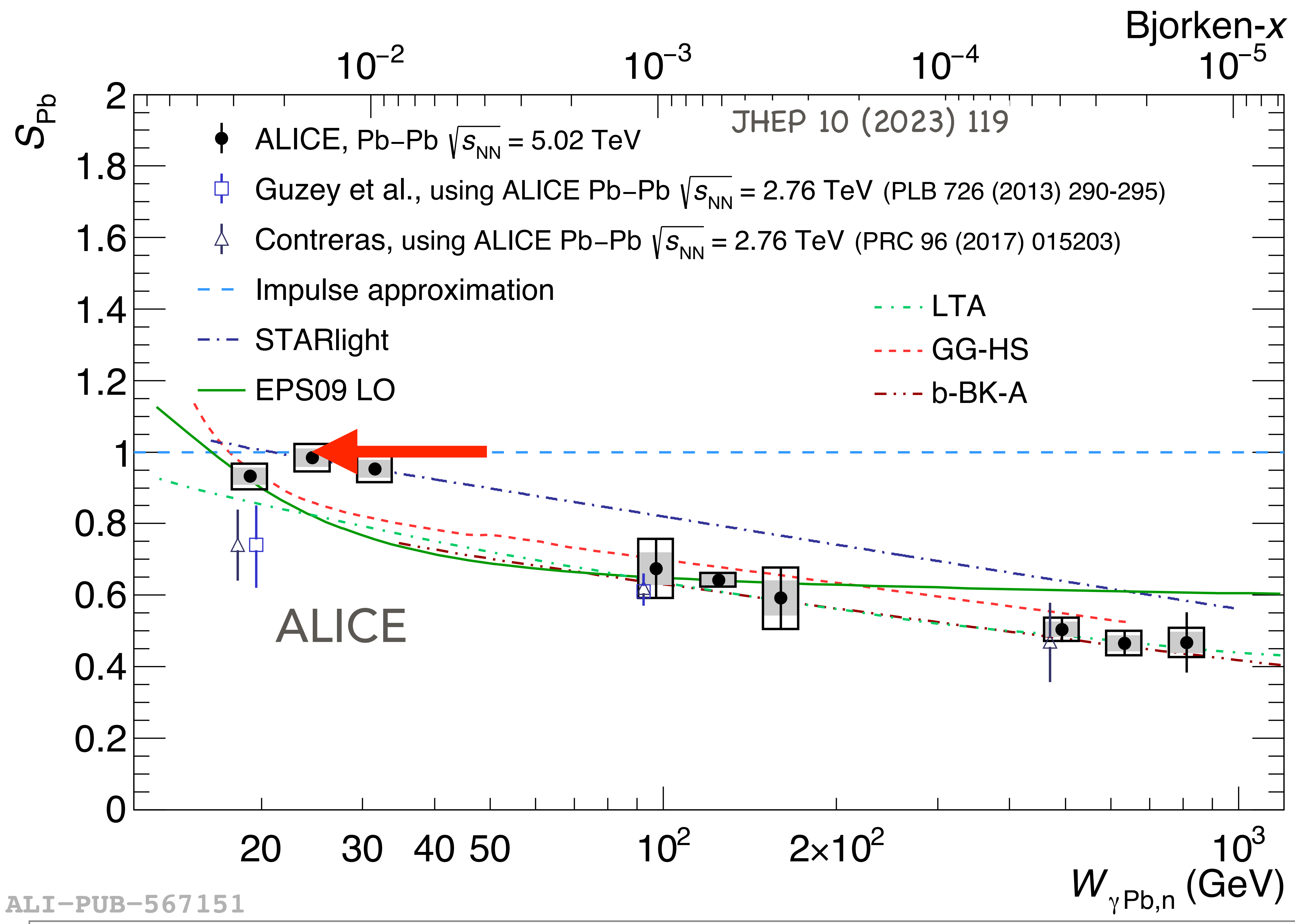
At high $W_{\gamma Pb}$: LTA and color dipole model (GG-HS, b-BK-A)

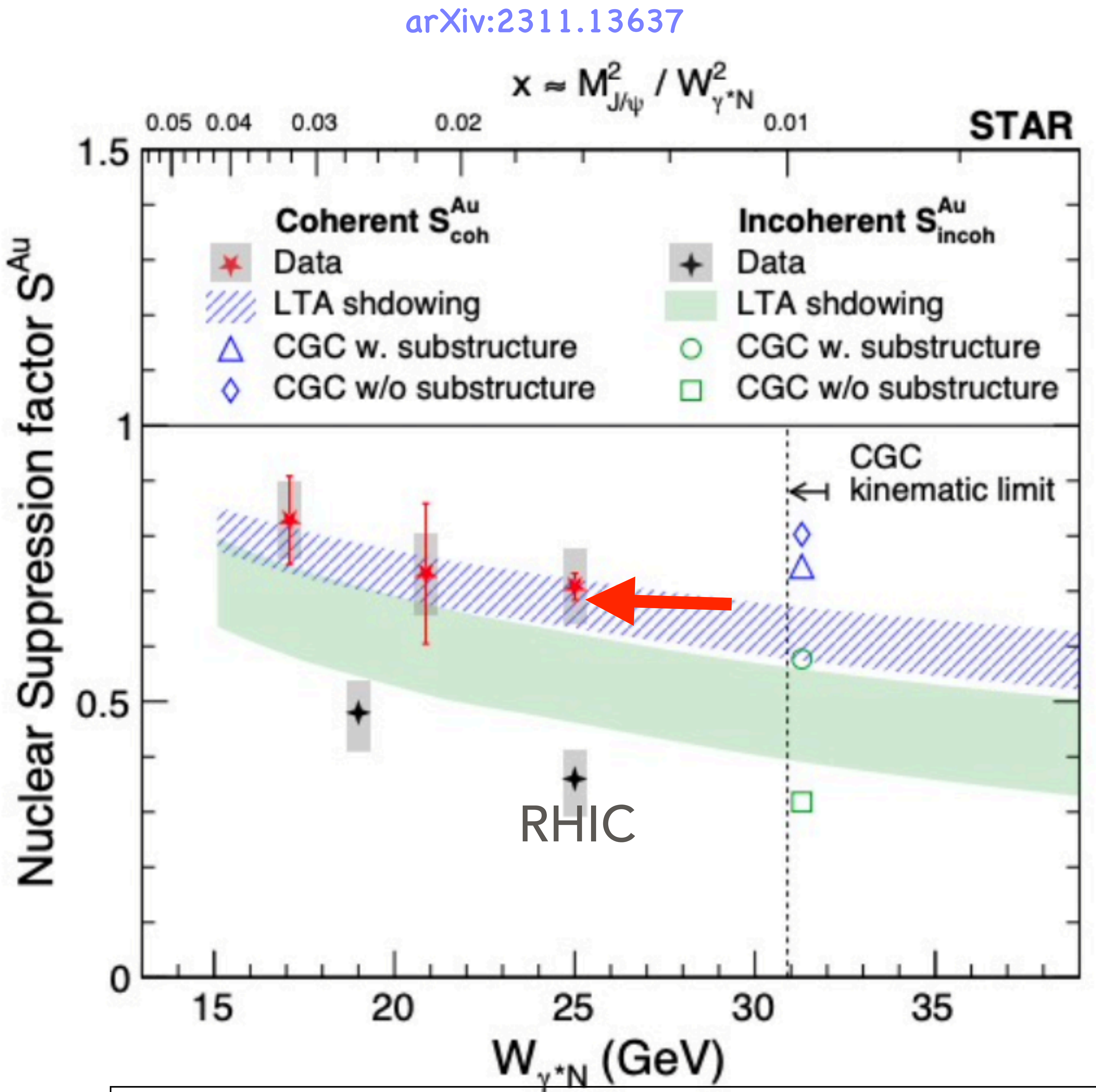
No model describes the whole energy/Bjorken-x range!

Nuclear suppression factor at LHC and RHIC energies

Nuclear suppression factor due to gluon shadowing

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





At LHC energies , $W_{\gamma Pb}$ = 813 GeV, S_{Pb} = 0.47 ± 0.05 ± 0.03

At RHIC energies, $W_{\gamma Au}$ = 25 GeV, S_{Au} = 0.71 ± 0.04 ± 0.07

CGC Model, H. Mäntysaari et al.,arXiv:2207.03712

LTA model, M.Strickman et al., arXiv:2303.12052

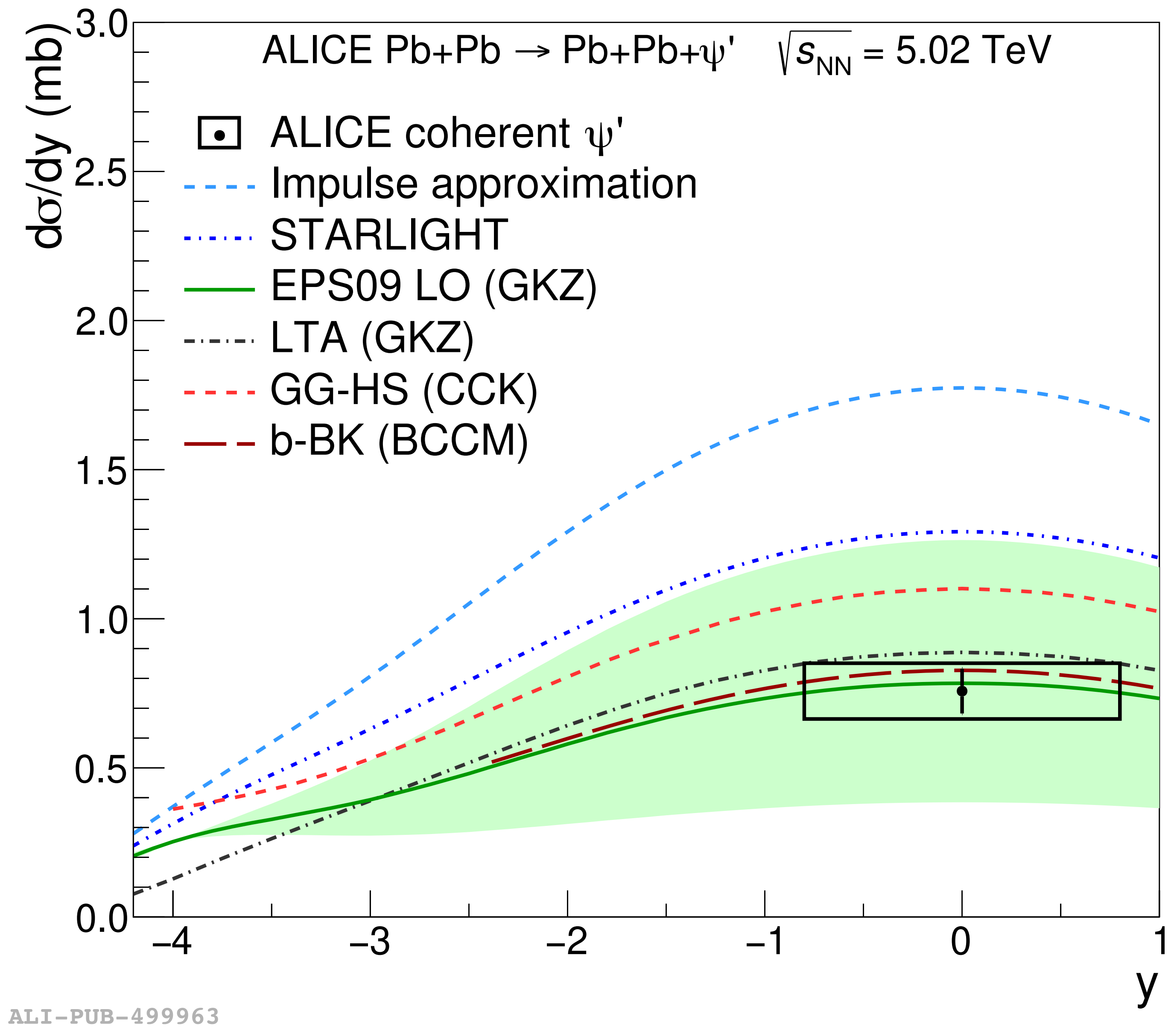
Strong suppression due to nuclear gluon shadowing is observed at both RHIC and LHC energies

At similar $W_{\gamma N}$ (~ 25 GeV), the suppression at ALICE is smaller than at RHIC

Coherent Ψ(2S) photoproduction cross section

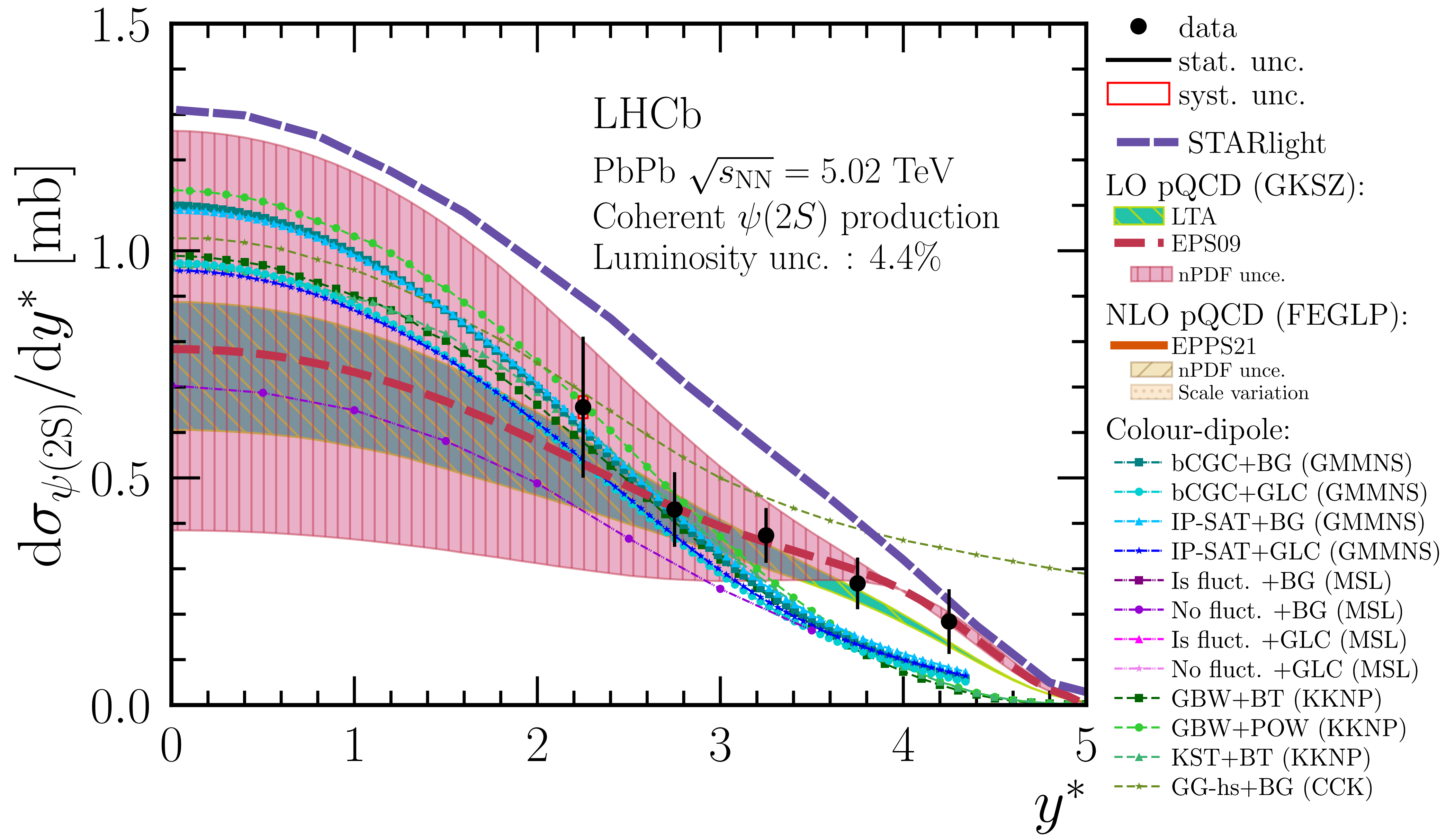
ALICE: Eur. Phys. J. C 81 (2021) 712

midrapidity



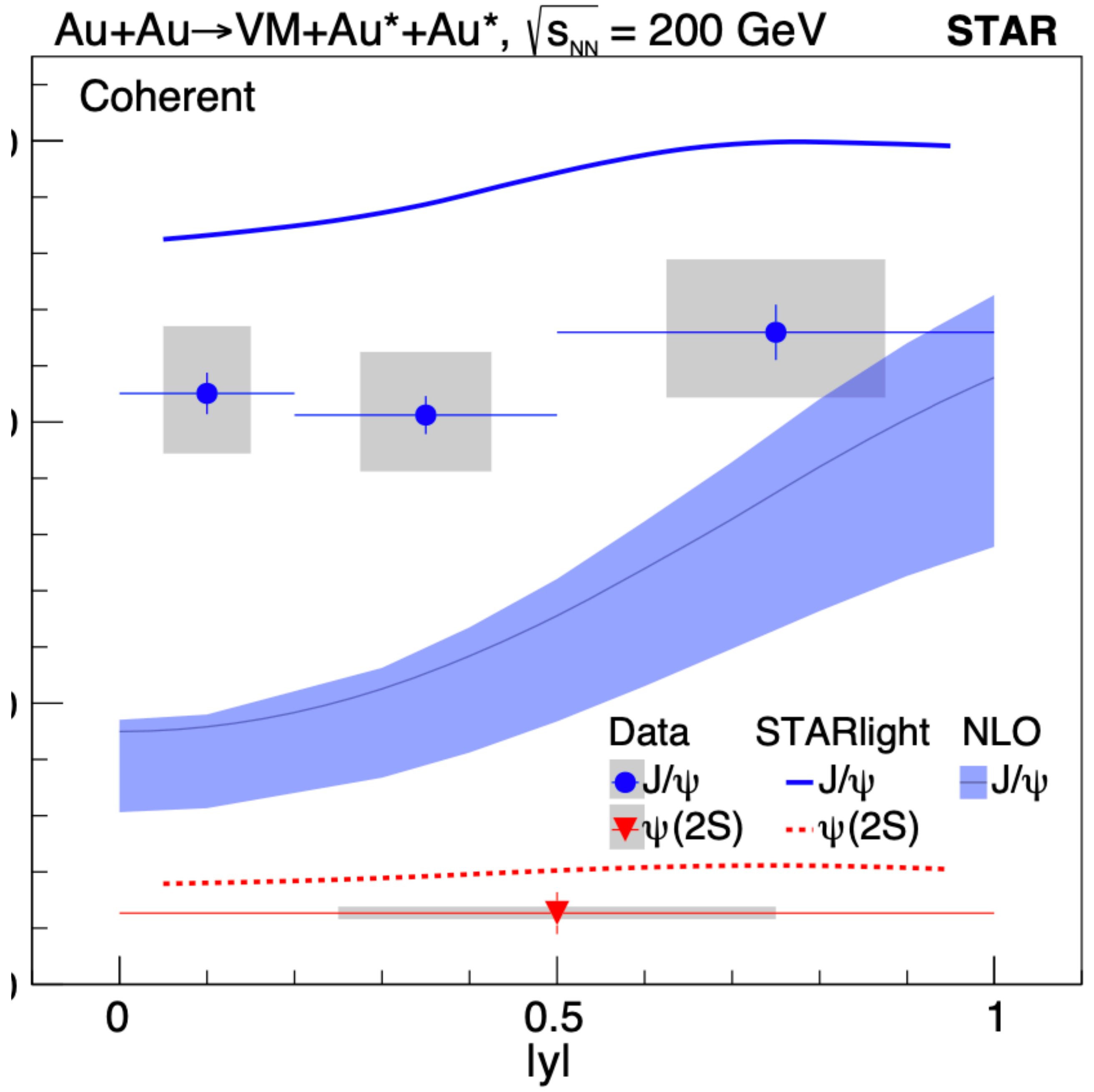
LHCb, JHEP 06 (2023) 146

forward rapidity



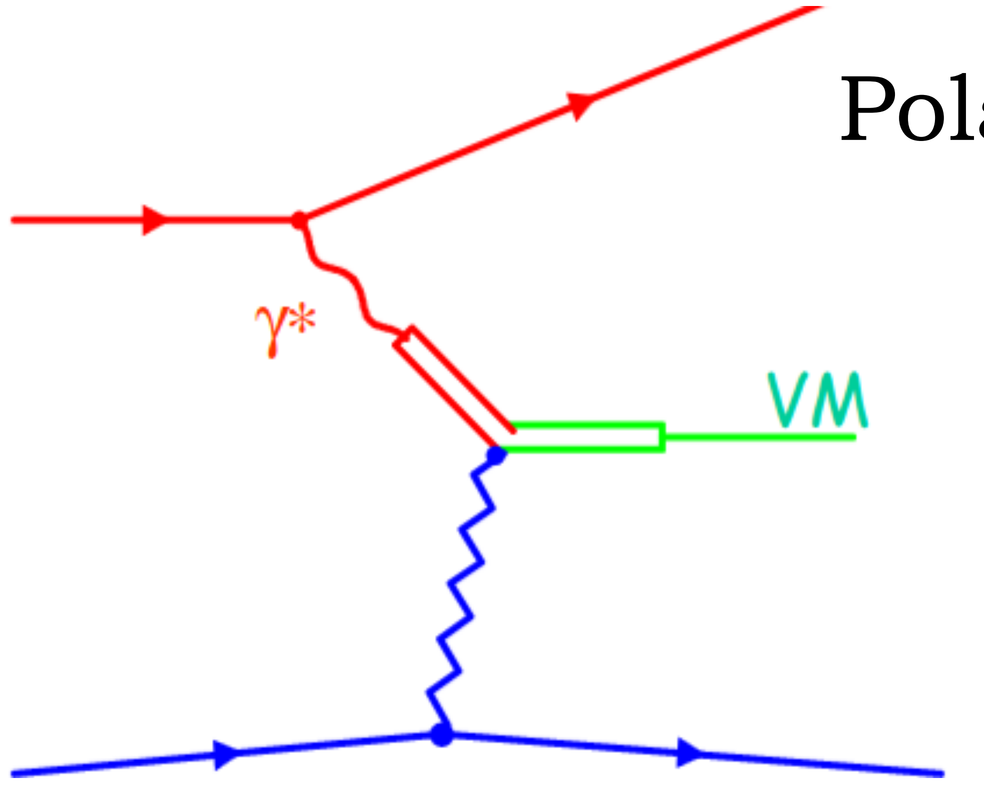
RHIC, arXiv:2311.13632

midrapidity



- Nuclear gluon shadowing factor, S_{Pb} = 0.66 ± 0.06, consistent with the value obtained from J/Ψ at midrapidty
- First y-differential Ψ(2S) photoproduction cross section by LHCb
- First midrapidity Ψ(2S) by STAR Collaboration

Polarization: Coherent vector meson photoproduction



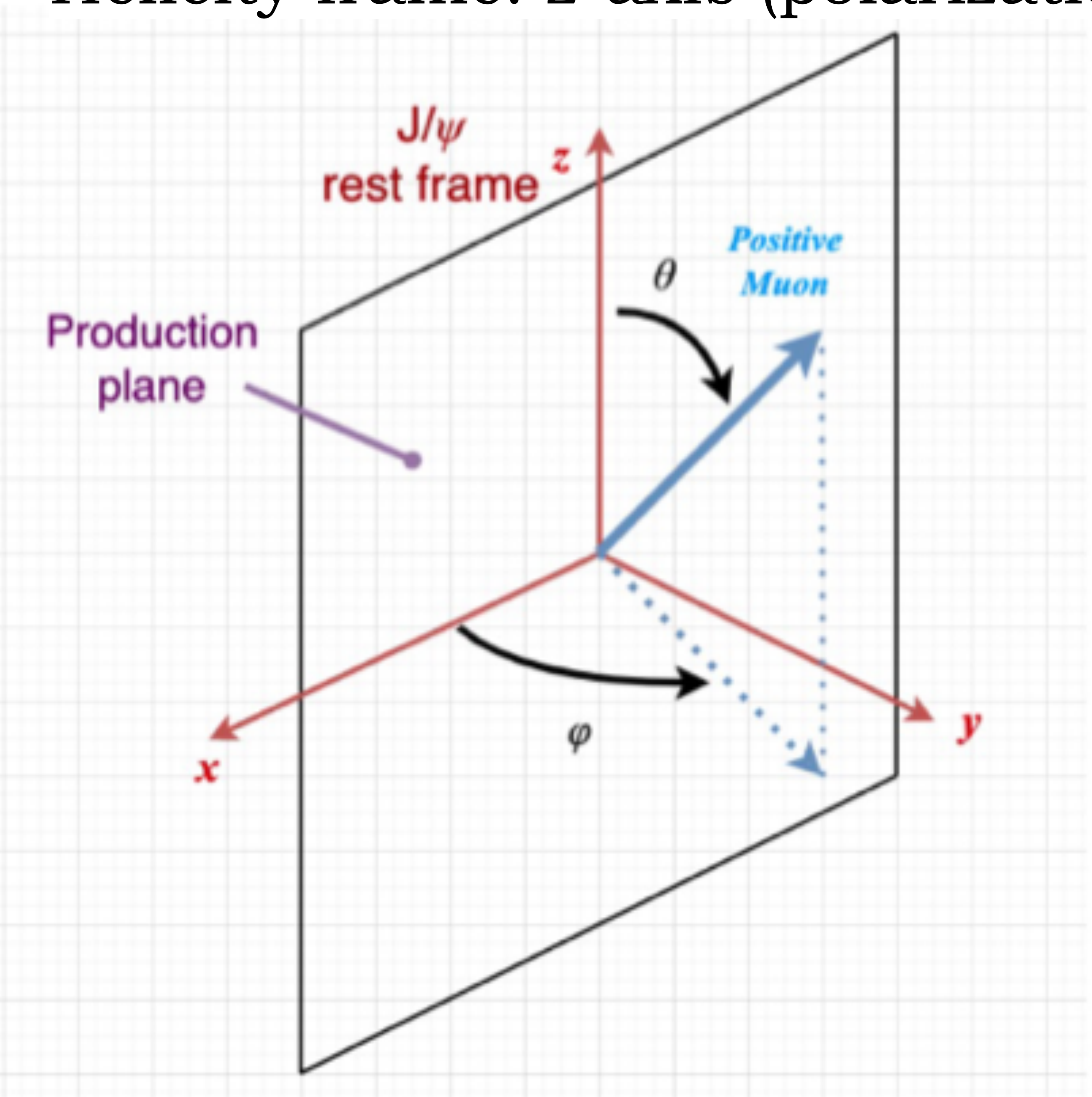
Polarization refers to the particle spin alignment with respect to a chosen direction

s-channel helicity conservation (SCHC): helicity or polarization of photon transferred to vector meson (J/ψ)

Vector meson (VM) has retained same helicity and polarization as that of the initial photon that interacted with the target

Phys. Lett. B 31 (1970) 387-390, JETP Lett. 68 (1998) 696-703

Helicity frame: z-axis (polarization axis): flight direction of the J/ψ in its rest frame



Dilepton decay angular distribution

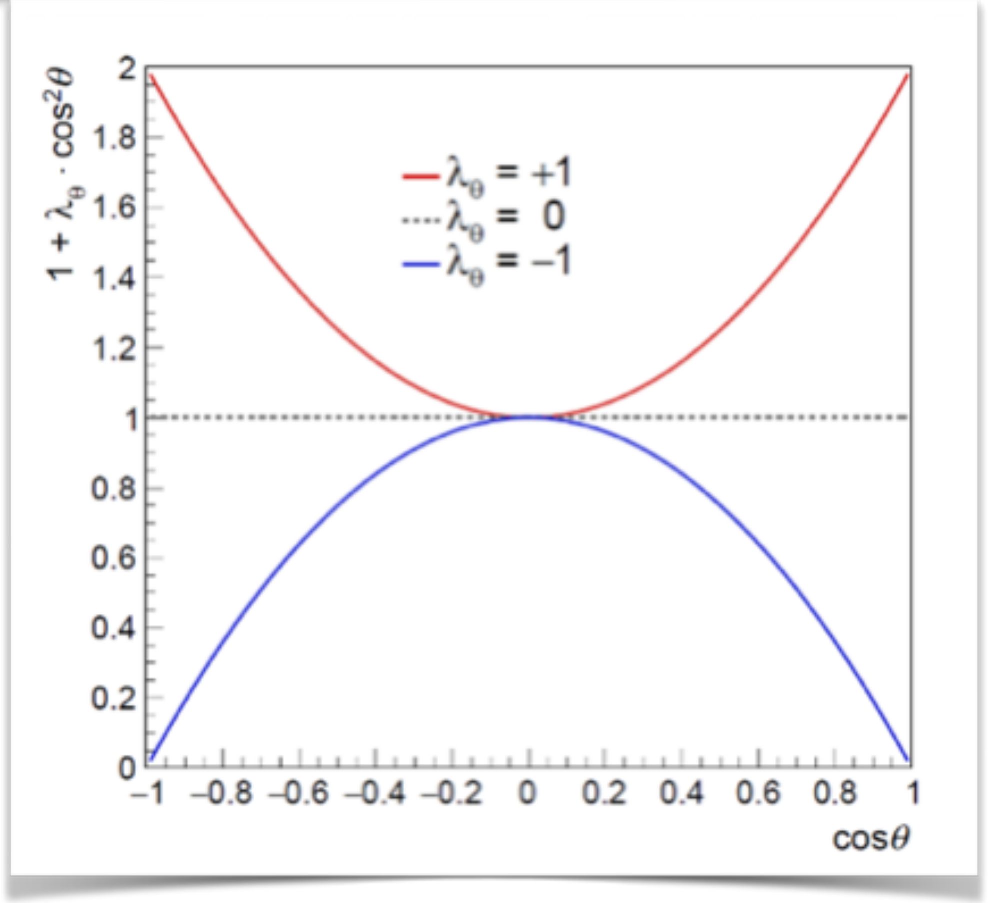
P. Faccioli et al., Eur.Phys.J.C69:657-673, 2010

$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_\theta}\cdot(1+\lambda_\theta\cos^2\theta+\lambda_\phi\sin^2\theta\cos2\phi+\lambda_{\theta\phi}\sin2\theta\cos\phi)$$

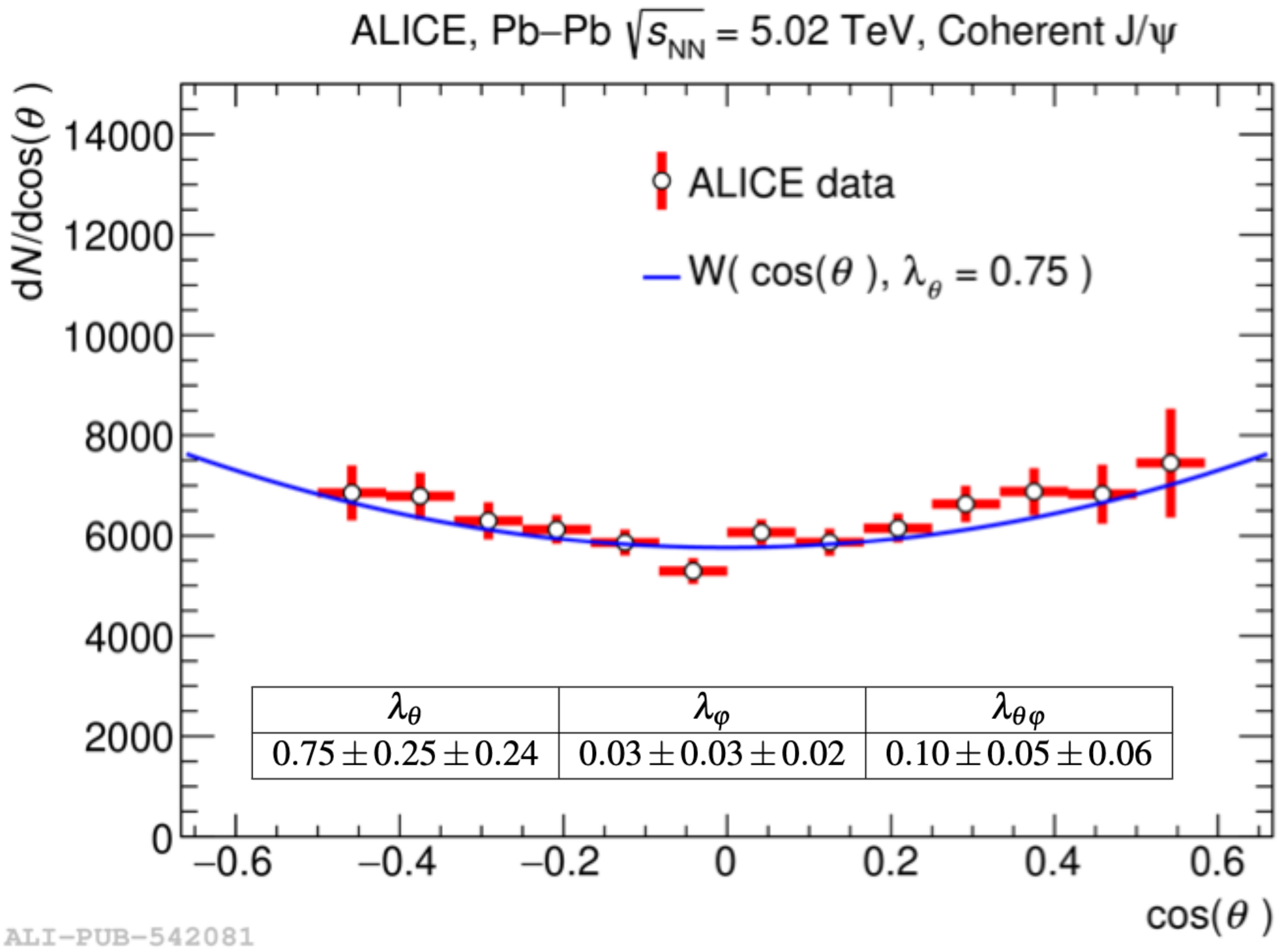
$(\lambda_\theta,\lambda_\phi,\lambda_{\theta\phi}) = (0,0,0) \Rightarrow$ No polarization

$(\lambda_\theta,\lambda_\phi,\lambda_{\theta\phi}) = (+1,0,0) \Rightarrow$ Transverse polarization

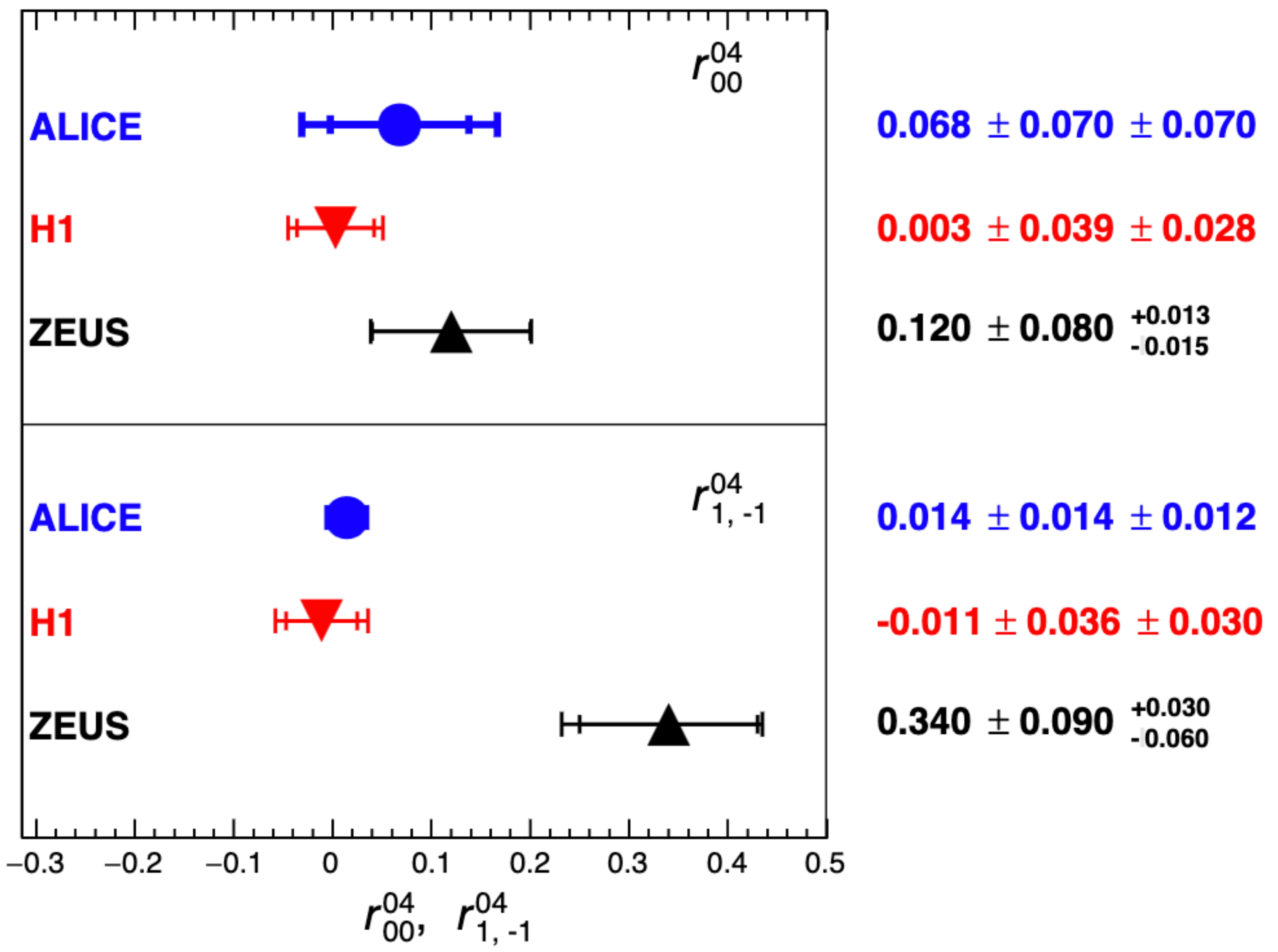
$(\lambda_\theta,\lambda_\phi,\lambda_{\theta\phi}) = (-1,0,0) \Rightarrow$ Longitudinal polarization



Polarization:Coherent vector meson photo production in UPC



ALICE : arXiv:2304.10928



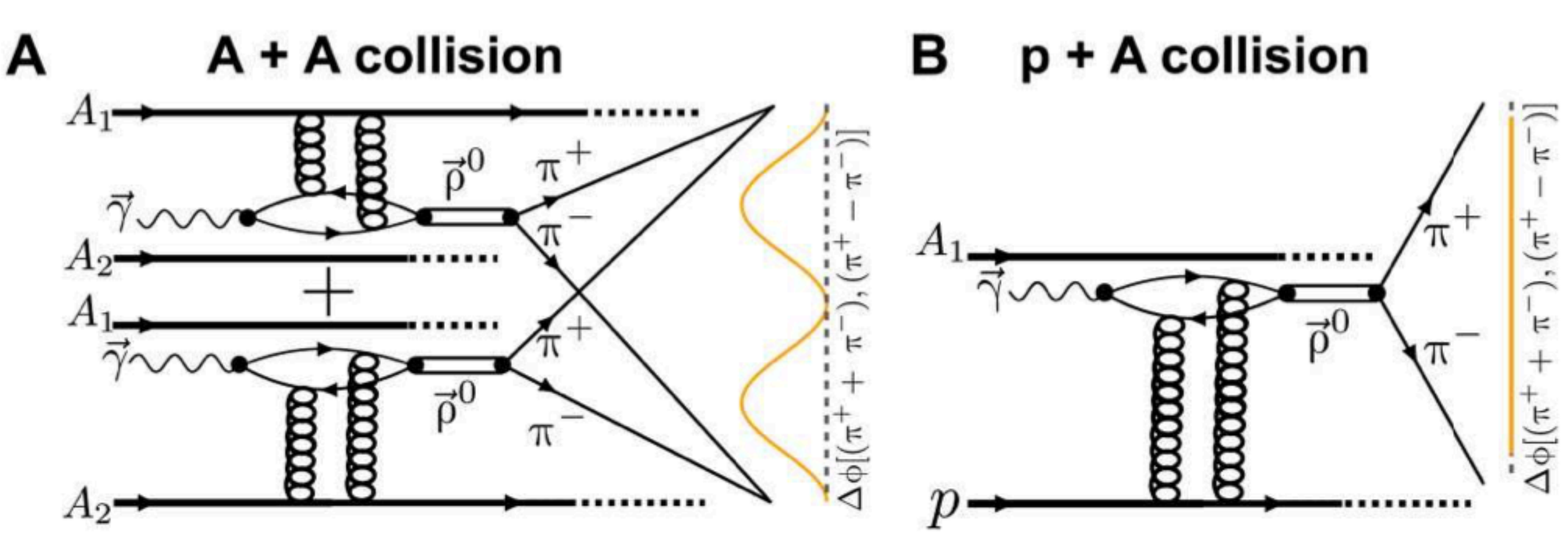
- Coherently photoproduced J/ψ in UPCs at LHC energies
  - ➡ Transversely polarized
  - ➡ Consistent with SCHC hypothesis

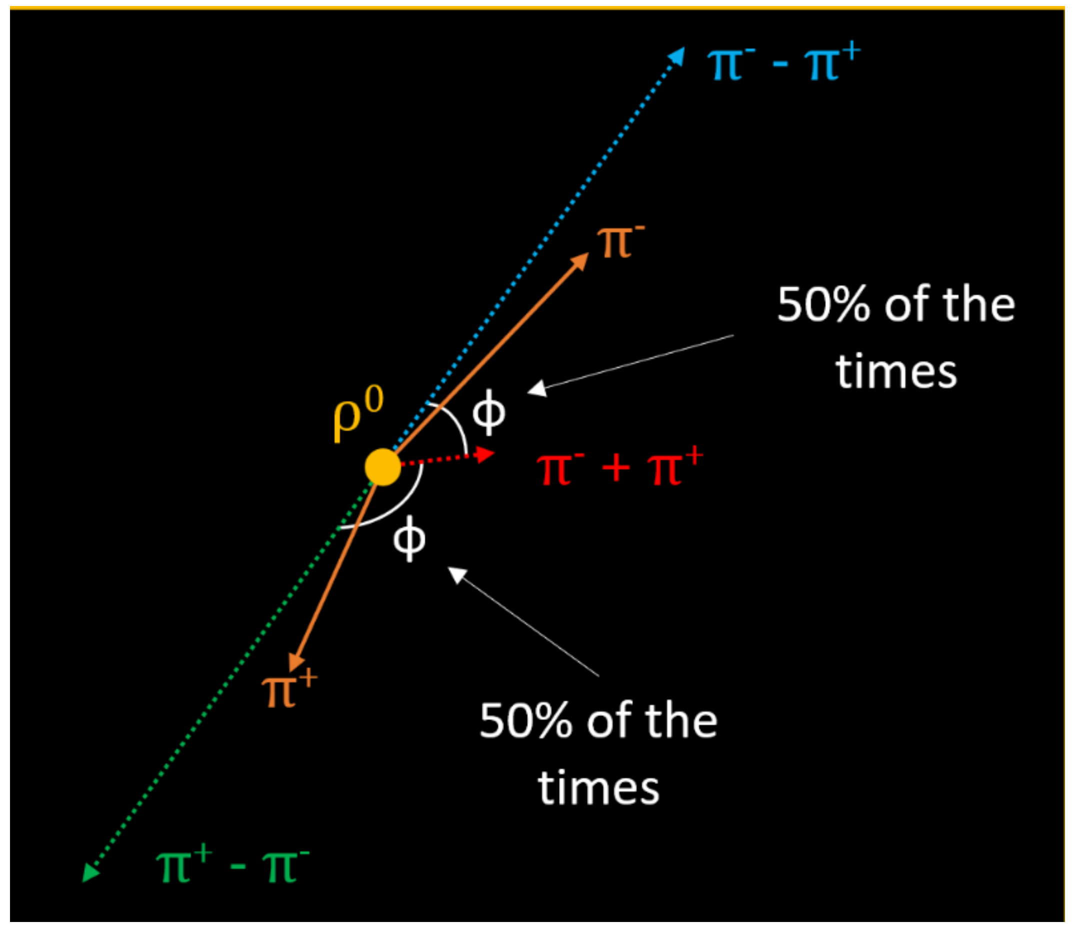
$$r^{04}_{00} = \frac{1-\lambda_\theta}{3+\lambda_\theta}$$

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

Entanglement-enabled spin interference in exclusive VM photoproduction

Tomography of ultrarelativistic nuclei with polarized photon-gluon collisions, Sci.Adv.g (2023) 1, abq3903



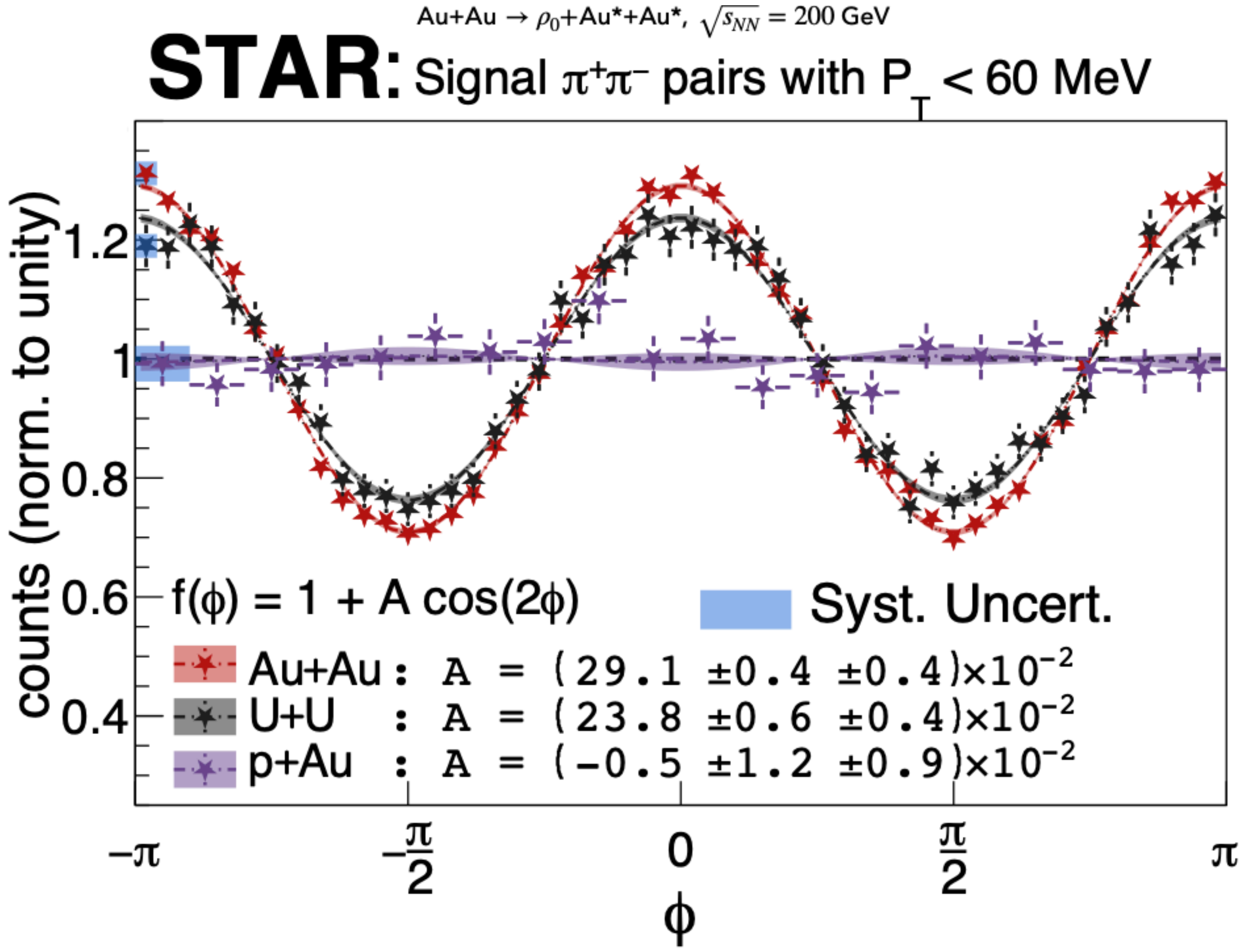


Observable :

ϕ = azimuth angle between p_+ and p_-

$p_{\pm} = \pi_1 \pm \pi_2$

π_1 (π_2) = 4-momentum of track 1(2), randomly assigned to the positive and negative tracks

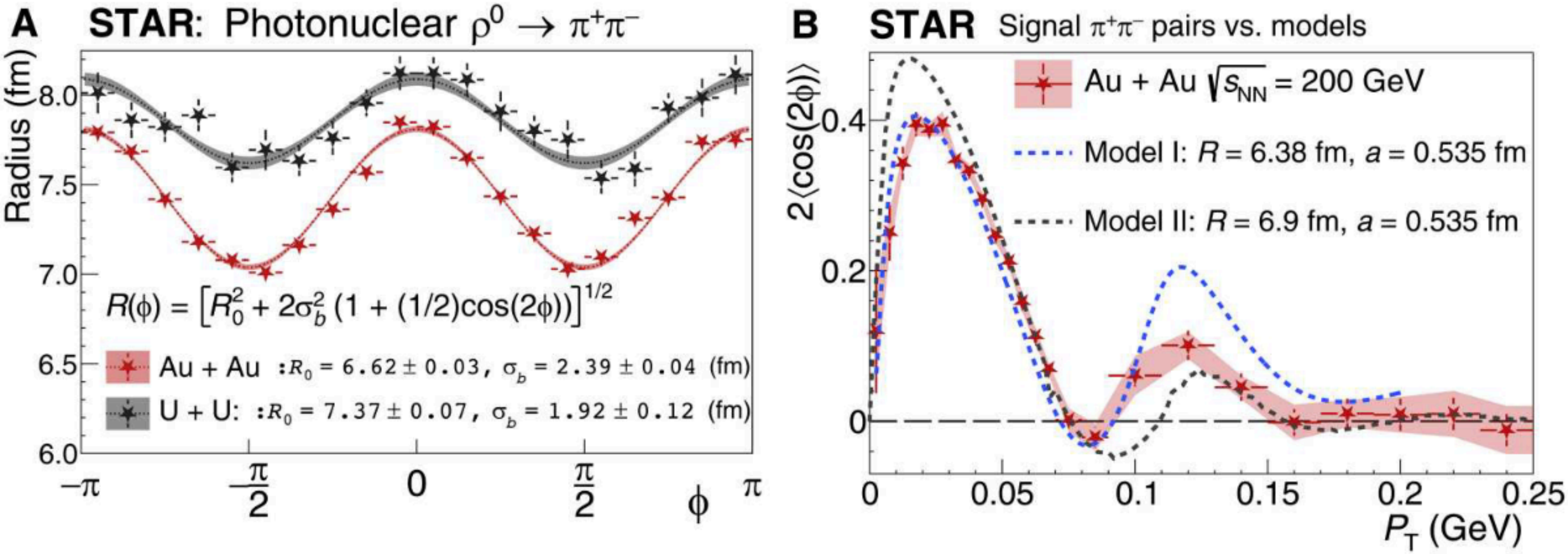


- Modulation is observed for ρ^0 in Au-Au, U-U collisions but not in p-Au collisions

- Demonstration of Einstein–Podolsky–Rosen (EPR) paradox (Linearly polarized photons + interference + entanglement effects)

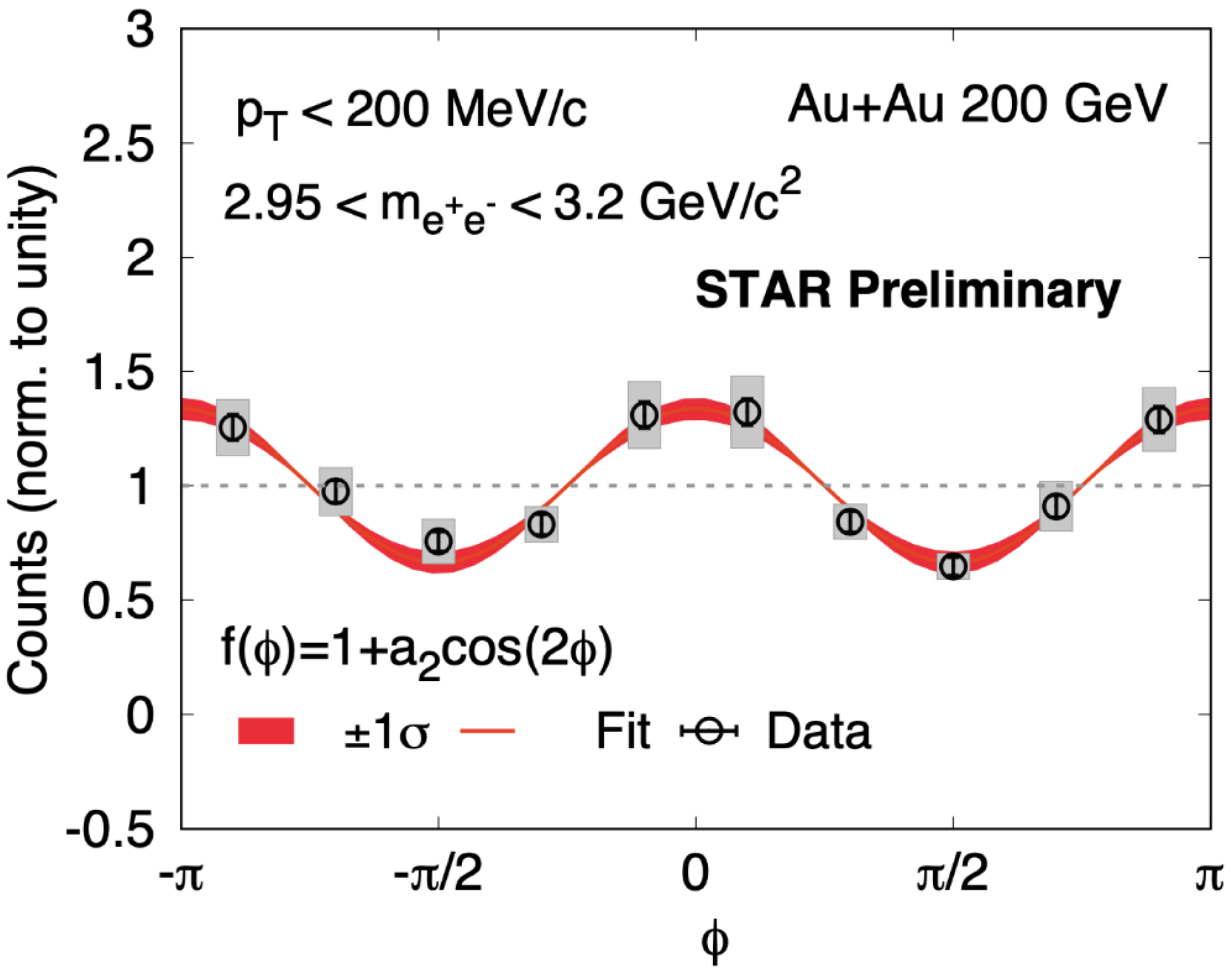
Extraction of nuclei Radii : Au and U nucleus

Tomography of ultrarelativistic nuclei with polarized photon-gluon collisions, Sci.Adv.g (2023) 1, abq3903



- Model I: implementing a photon and Pomeron interaction using a Woods-Saxon distribution, W. Zha, et al, Phys. Rev. D 103, 033007 (2021)
- Model II: implements a dipole and gluon interaction with the gluon distribution inside the nucleus given by a color glass condensate (CGC) model, H. Xing et al, J. High Energ. Phys. 2020, 064 (2020)

Entanglement-enabled spin interference in exclusive VM photoproduction



- ρ^0 : short lifetime (1 fm/c), localized wave function << b — interference occurs in the daughter pions (spin 0) level
- J/ψ has longer lifetime, extended wave function
- J/ψ decay daughters, electrons (spin 1/2) are fermions

- Measurements of the spin interference with J/ψ or higher VMs at LHC and EIC will provide more information

other highlights

Photoproduction of K^+K^- Pairs in Ultraperipheral Collisions

S. Acharya *et al.* (ALICE Collaboration)
Phys. Rev. Lett. **132**, 222303 – Published 31 May 2024

Measurement of the impact-parameter dependent azimuthal anisotropy in coherent ρ^0 photoproduction in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

ALICE Collaboration arXiv:2405.14525

Nuclear Experiment

[Submitted on 11 Apr 2024]

Exclusive four pion photoproduction in ultraperipheral Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

ALICE Collaboration arxiv:2404.07542

Exclusive J/ψ, $\psi(2s)$, and e^+e^- pair production in Au + Au ultraperipheral collisions at the BNL Relativistic Heavy Ion Collider

STAR Collaboration • M.I. Abdulhamid (American U., Cairo) et al. (Jul 31, 2024)

Published in: *Phys.Rev.C* 110 (2024) 1, 014911

Energy Dependence of Polarized $\gamma\gamma \rightarrow e^+e^-$ in Peripheral Au+Au Collisions at RHIC

STAR Collaboration (Jul 20, 2024)

e-Print: 2407.14821 [nucl-ex]

Search for magnetic monopole pair production in ultraperipheral Pb+Pb collisions at √sNN=5.36 TeV with the ATLAS detector at the LHC

ATLAS Collaboration (Jul 23, 2024)

Search for baryon junctions in photonuclear processes and isobar collisions at RHIC #2

Nicole Lewis (Brookhaven), Wendi Lv (Hefei, CUST), Mason Alexander Ross (East Carolina U.), Chun Yuen Tsang (Kent State U. and Hampton U.), James Daniel Brandenburg (Brookhaven) et al. (May 11, 2022)

Published in: *Eur.Phys.J.C* 84 (2024) 6, 590 • e-Print: 2205.05685 [hep-ph]

Summary

- ❑ Photon-photon and photonuclear reactions have been provided a reach set of physics opportunity in ultra peripheral collisions (UPCs)
- ❑ **Photon-photon interactions:**
  - ✓ Observed Breit-Wheeler processes, experimentally demonstrate mass -energy equivalence relation
  - ✓ Observed higher mass dilepton (muon, tau) pairs and search for new physics in tau-lepton pair production, along with precise measurement of tau-anomalous magnetic moment
  - ✓ Also seen light-by-light (LbL) scattering and possibility for search of ALPs particle
- ❑ **Photonuclear interactions:**
  - ✓ Coherent photoproduction cross section measurements provide constrain to model for modelling photon flux
  - ✓ Understanding photon-energy ambiguity in symmetric collisions
  - ✓ Polarization study test SHC hypothesis and transversely polarized nature of vector mesons
  - ✓ Spin-enabled interference effects: demonstration of EPR phenomena

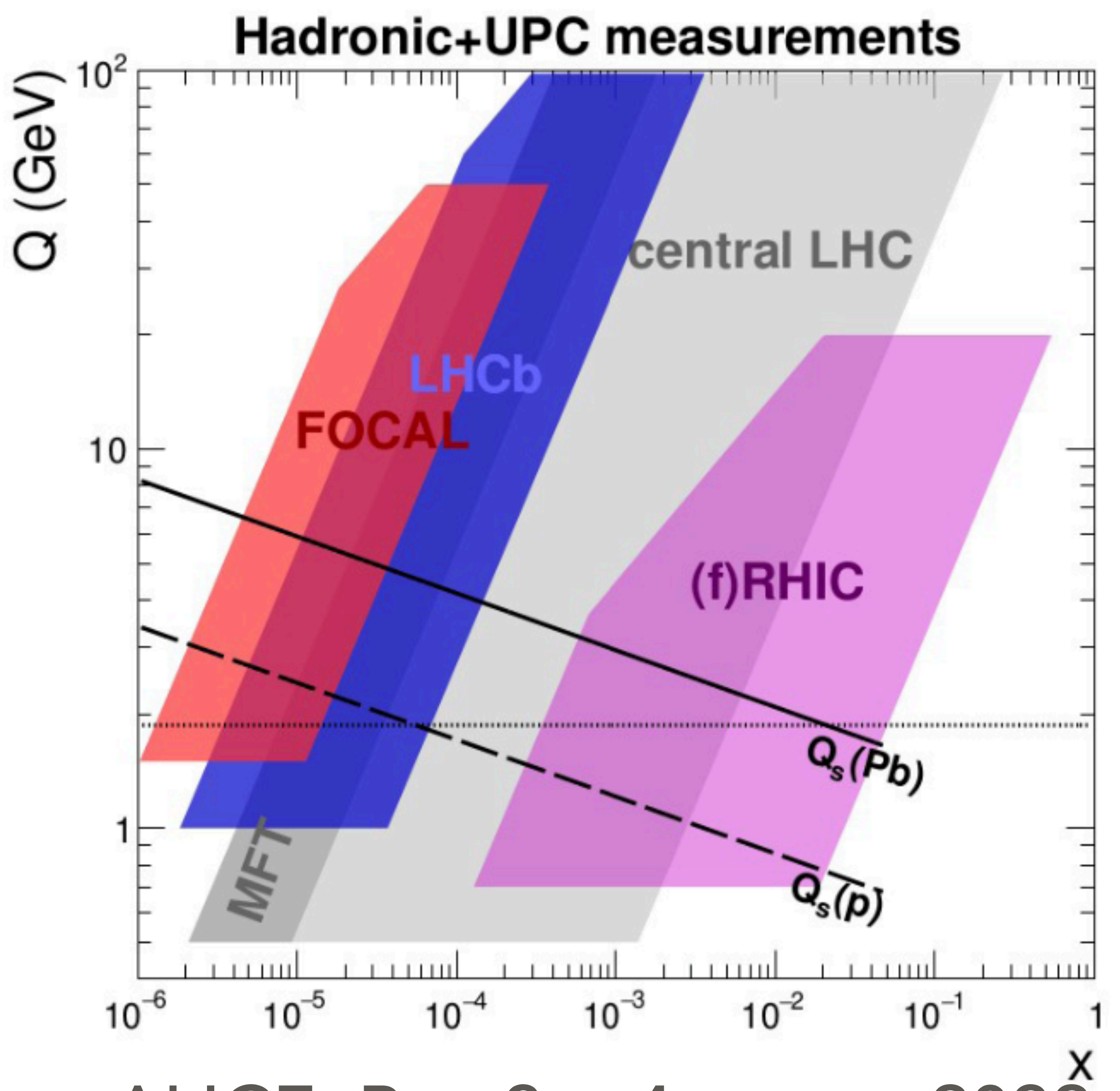
Outlook

Photon-photon interactions

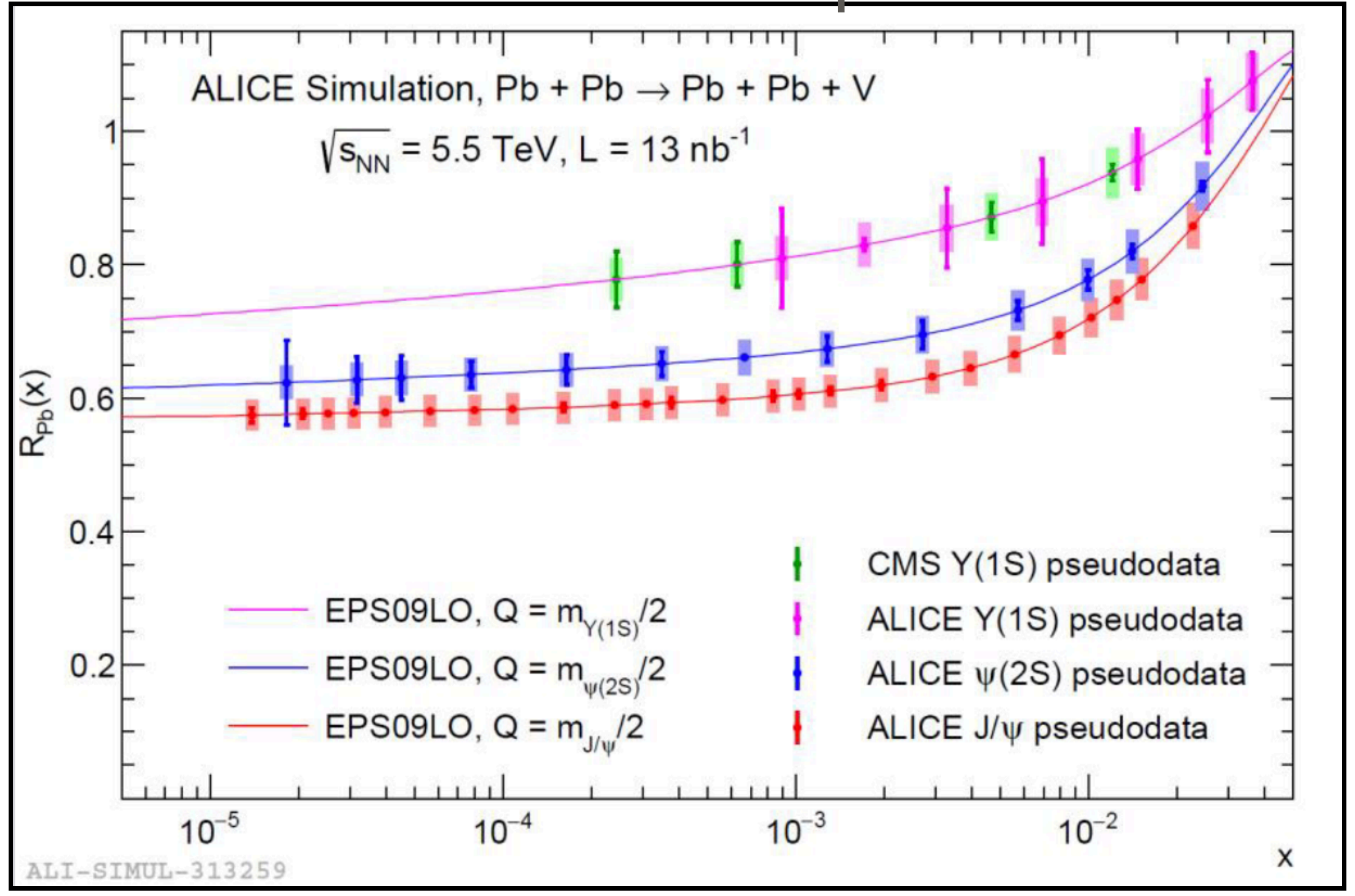
- Precise measurement on anomalous magnetic moment a_τ , LbyL at at low diphoton masses, $\pi^0\pi^0$ photoproduction
- Search for rare probe of SM and BSM physics (ALPs, etc)
- Higgs boson production in photon-photon collisions

Photonuclear interactions

- Precision and more differential studies (rapidity, polarization, azimuthal anisotropy, etc.)
- Bottomonia and open heavy-flavour (D-meson), strangeness
- Exclusive hadron pairs ($\pi\pi$,KK,pp etc.), phi-meson,double vector meson photoproduction
- Search of exotica (e.g. X(3872), 4ρ, or 6ρ etc.)
- Inclusive/semi inclusive UPCs e.g. inclusive J/ψ, jets in UPCs



ALICE: Run 3 + 4 : up to 2032



Back up

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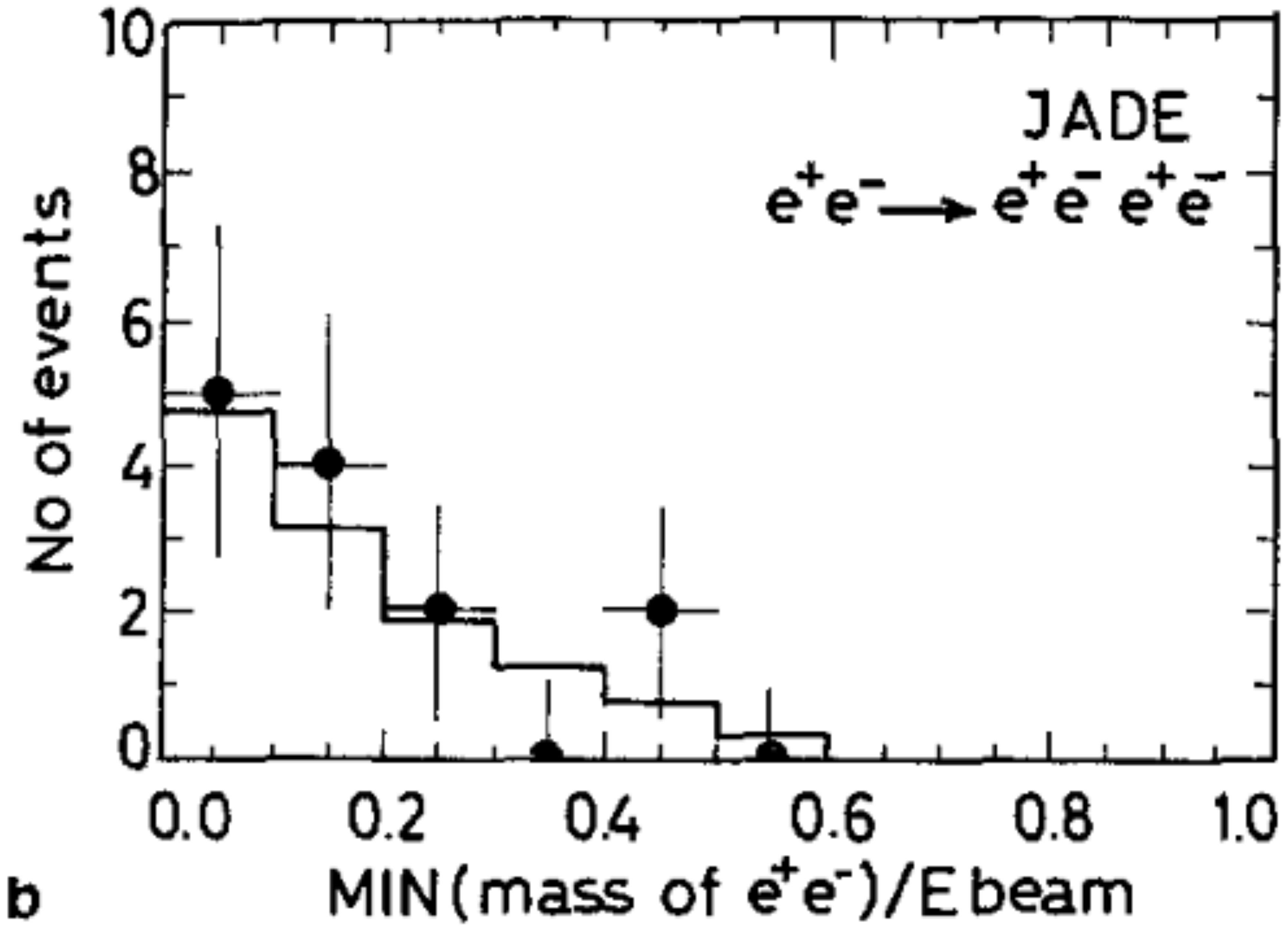
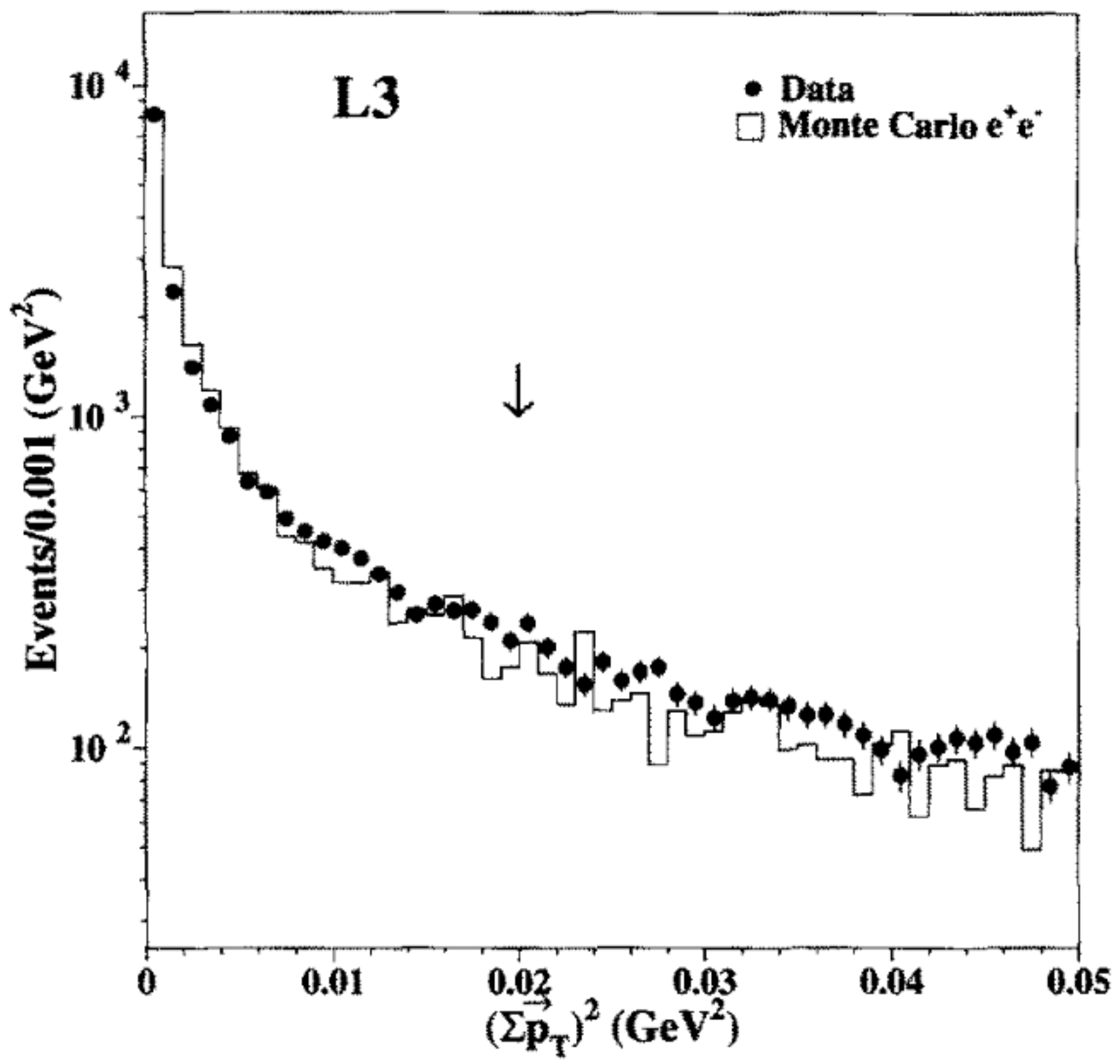
Results : $\gamma\gamma \rightarrow l^+l^-$

- JADE Collaboration, W. Bartel et al., "Lepton pair production in double tagged two photon interactions," Z. Phys. C 30 (1986) 545.
- L3 Collaboration, M. Acciarri et al., "Production of e, μ and τ pairs in untagged two photon collisions at LEP," Phys. Lett. B407 (1997) 341–350.
- C. R. Vane et al., "Electron positron pair production in Coulomb collisions of ultrarelativistic sulphur ions with fixed targets,"Phys. Rev. Lett. 69 (1992) 1911.

First experimental test of QED



Good agreement: measurements and QED expectation



Experimental verification:
Yield scale with Z^2