Discoveries in Ultra-Peripheral Collisions:

past, present, future

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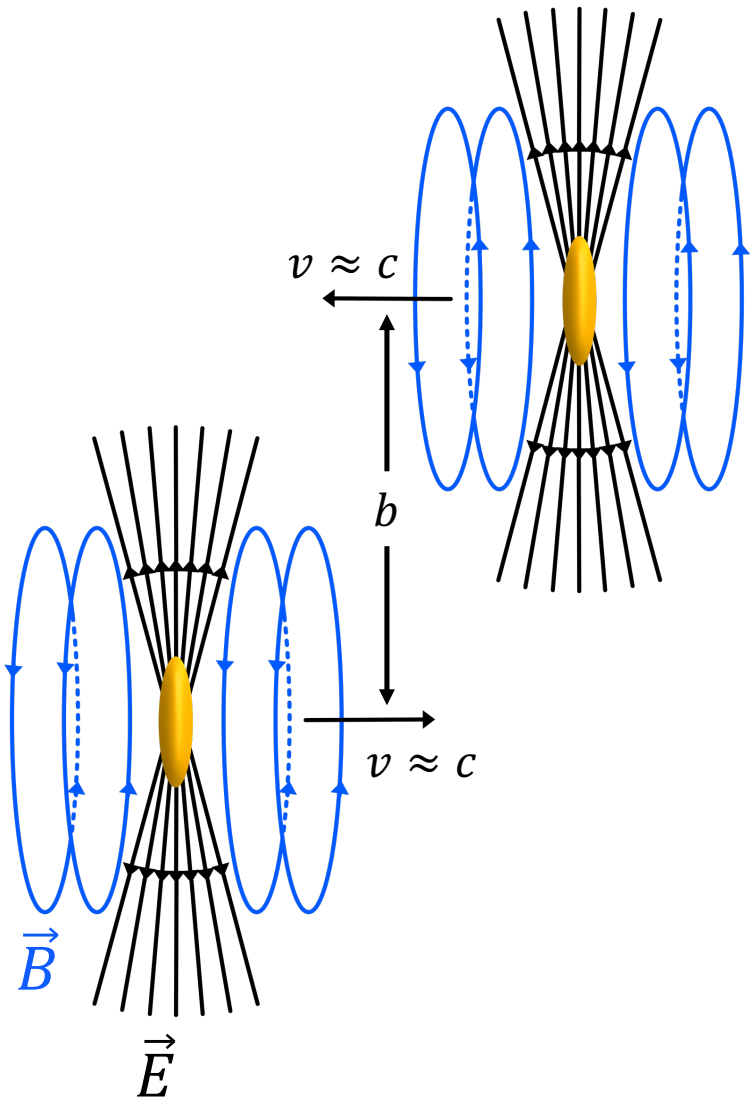
Quark Matter 2023

Houston, Texas, USA

U.S. Department of Energy

Office of Science

UPCs : The Strongest Electromagnetic Fields



- In heavy-ion collisions:

$$E_{max} = \frac{Ze\gamma}{b^2} \approx 5\times10^{16} - 10^{18}\ \text{V/cm}$$

$$B_{max} \sim 10^{14} - 10^{16}\ \text{T}$$

  - Strongest EM fields in the **Universe**
  - But very short lifetime – not constant

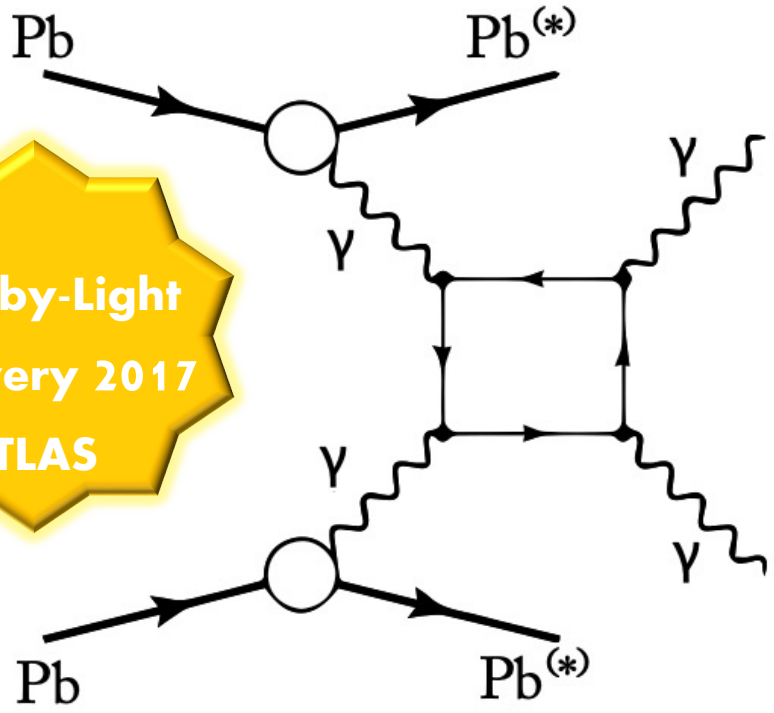
Must be treated in terms of photon quanta

$$E_{\gamma,\max} \approx \gamma\hbar c/R$$

80 GeV @ LHC
3 GeV @ RHIC

Types of Processes in UPCs

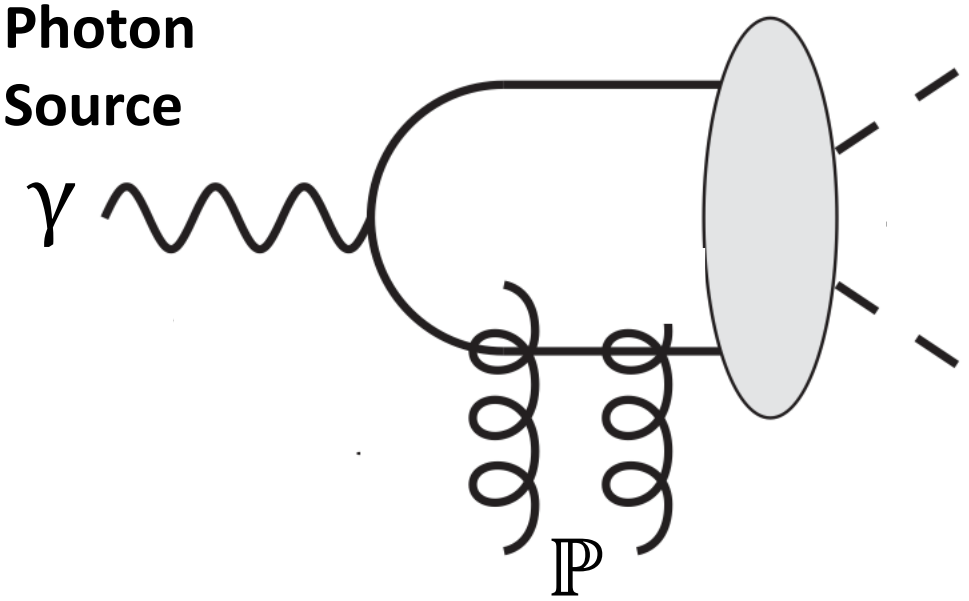
Photon + photon



Light-by-Light Discovery 2017 ATLAS

1. Explore non-linear QED
2. Discoveries -> now tools
3. Test for Physics Beyond Standard Model
4. …

Photon + target

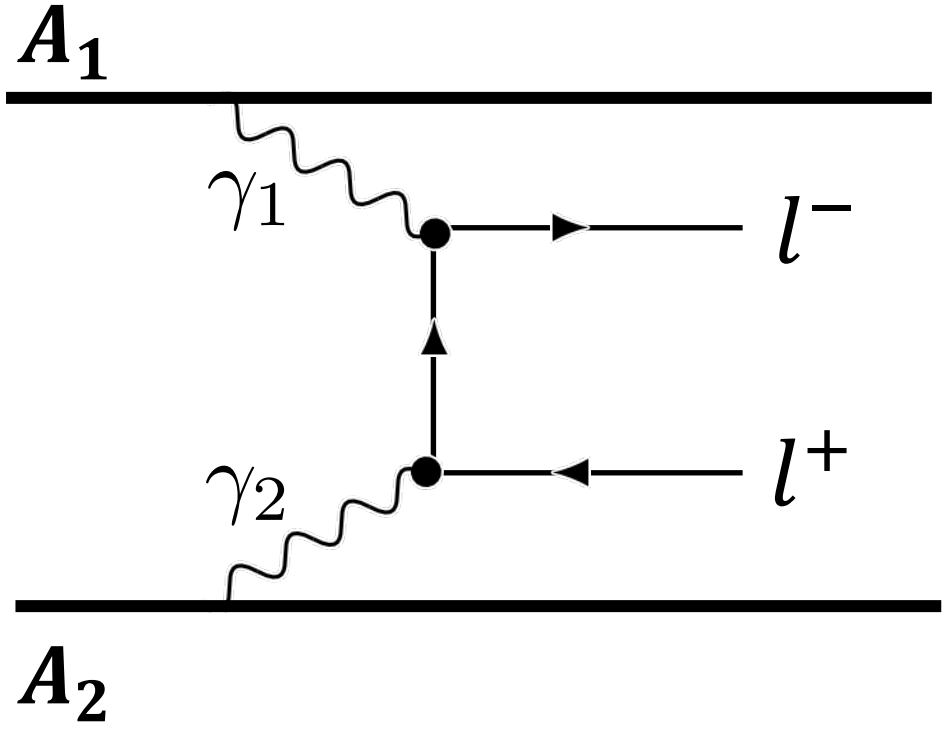


Gluons from nucleus (target)

1. ‘Image’ nuclear gluon distributions
2. Test gluon saturation predictions
3. Investigate sub-nucleonic fluctuations
4. …

Types of Processes in UPCs

Photon + photon



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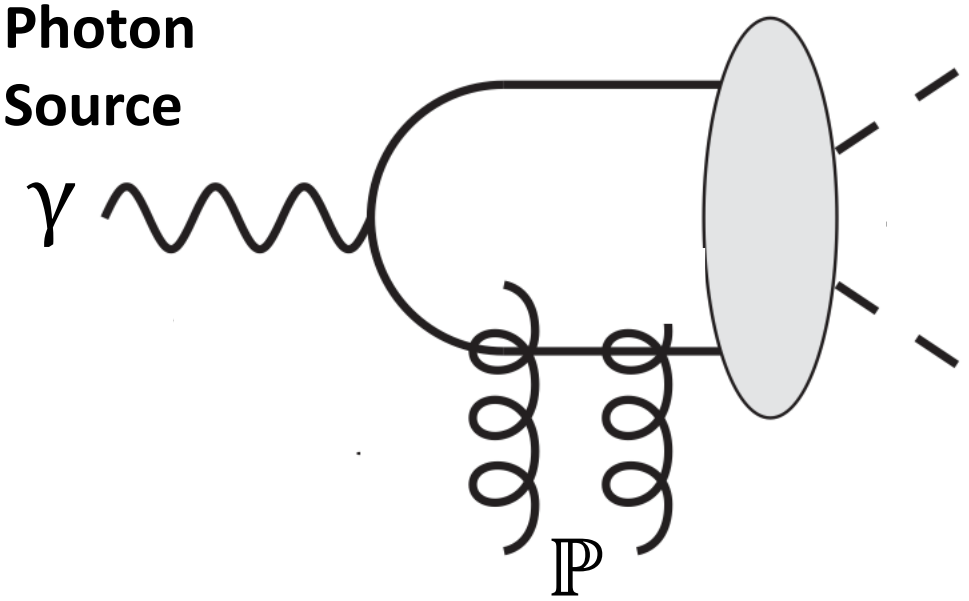

Gluons from nucleus (target)

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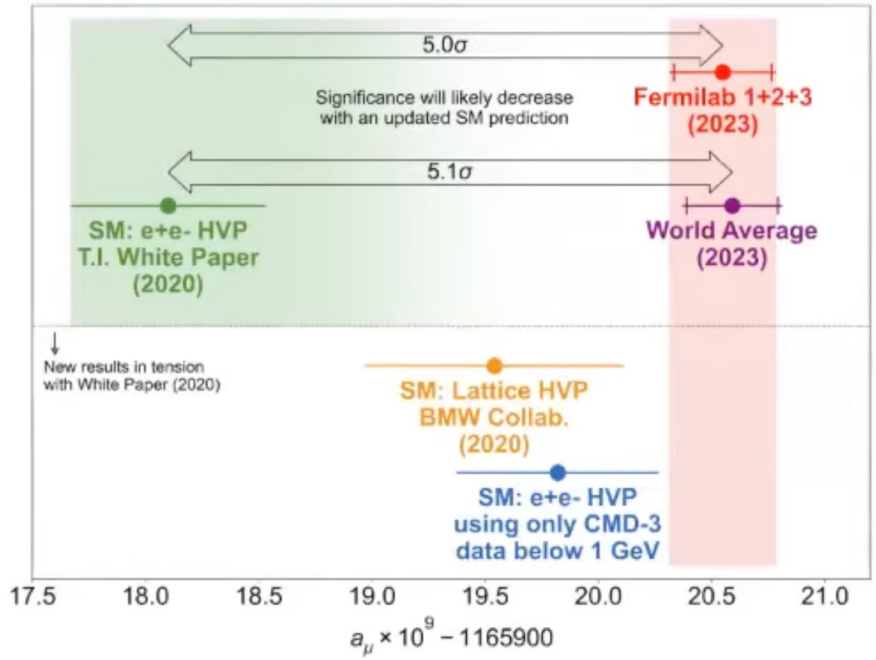
$\gamma\gamma \to \tau^+\tau^-$ Process

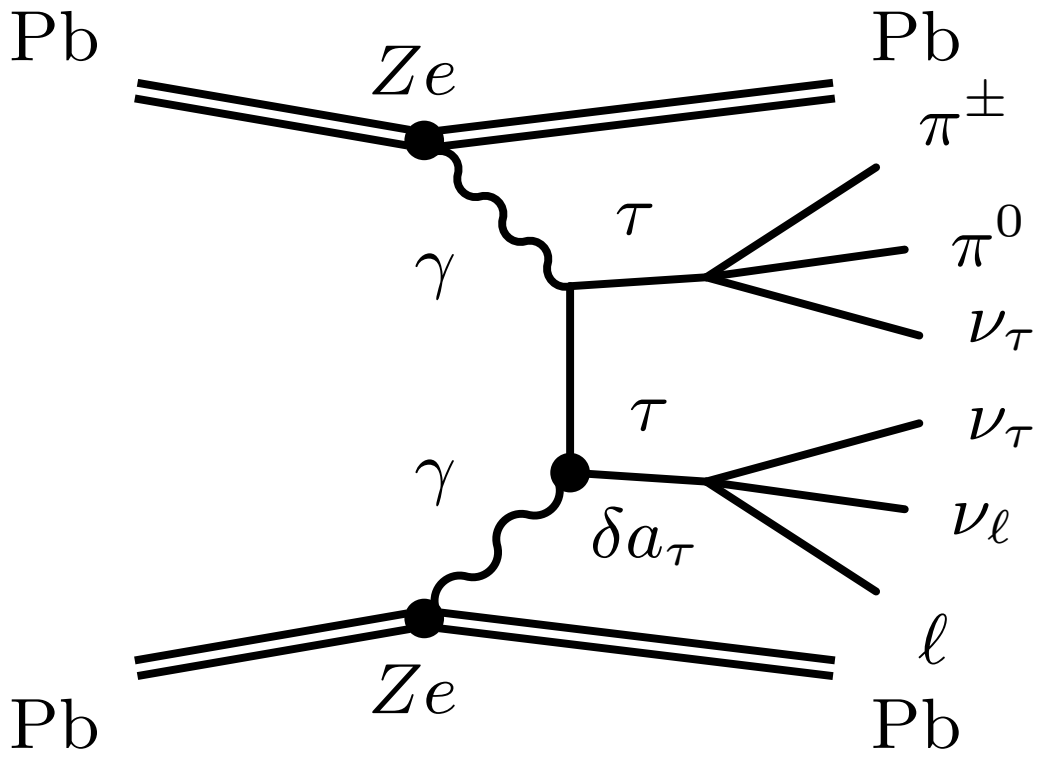
- Sensitivity to the tau anomalous magnetic moment!
- BSM sensitivity $\delta\alpha_l \propto m_l^2 \sim 280$x more sensitive than μ

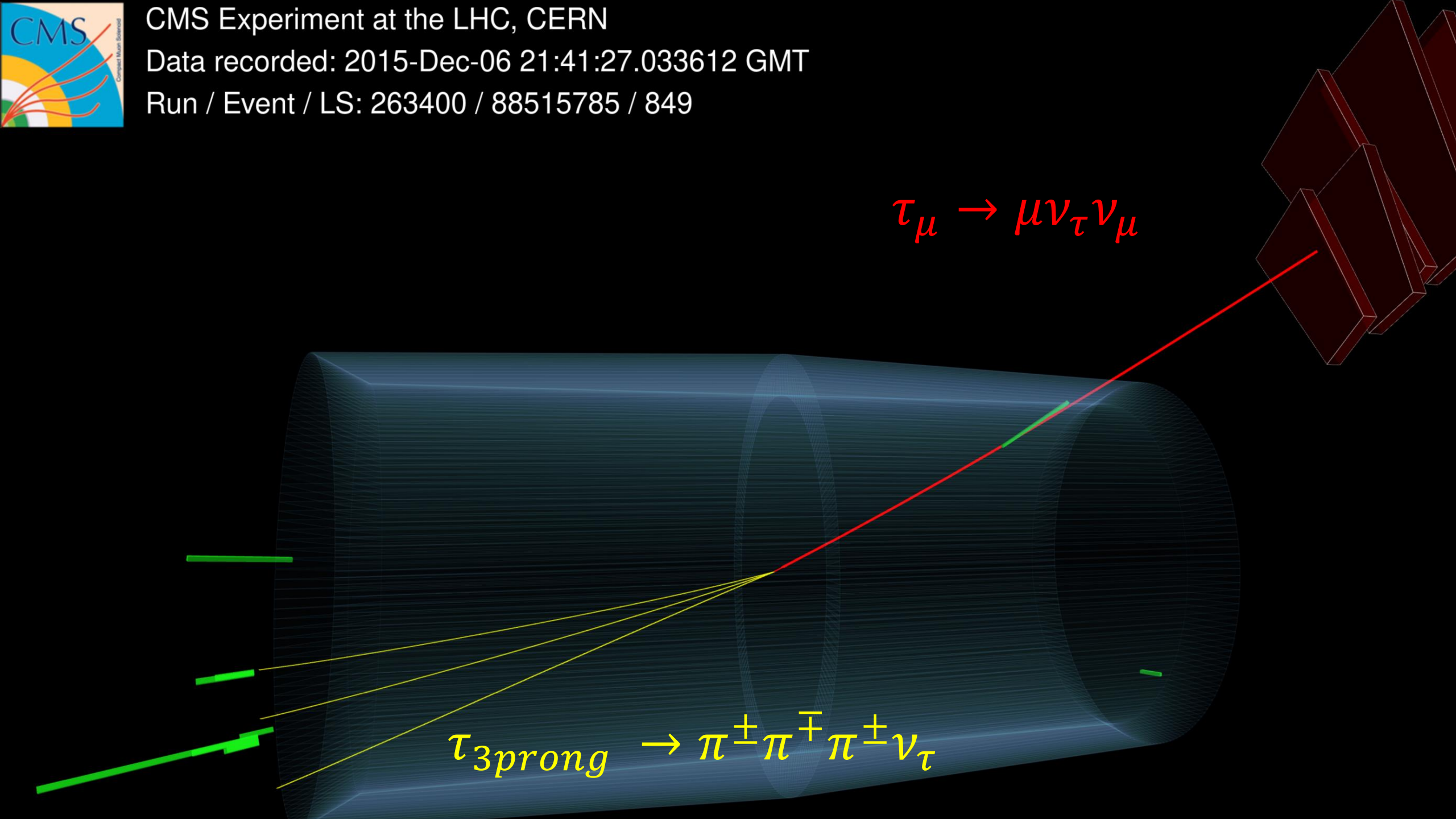
$$a_\tau = \frac{g_\tau - 2}{2}$$

Three channels available: eμ, μ+track, μ+3 tracks
Use $\gamma\gamma \to \mu^+\mu^-$ to help reduce systematic uncertainty from photon flux



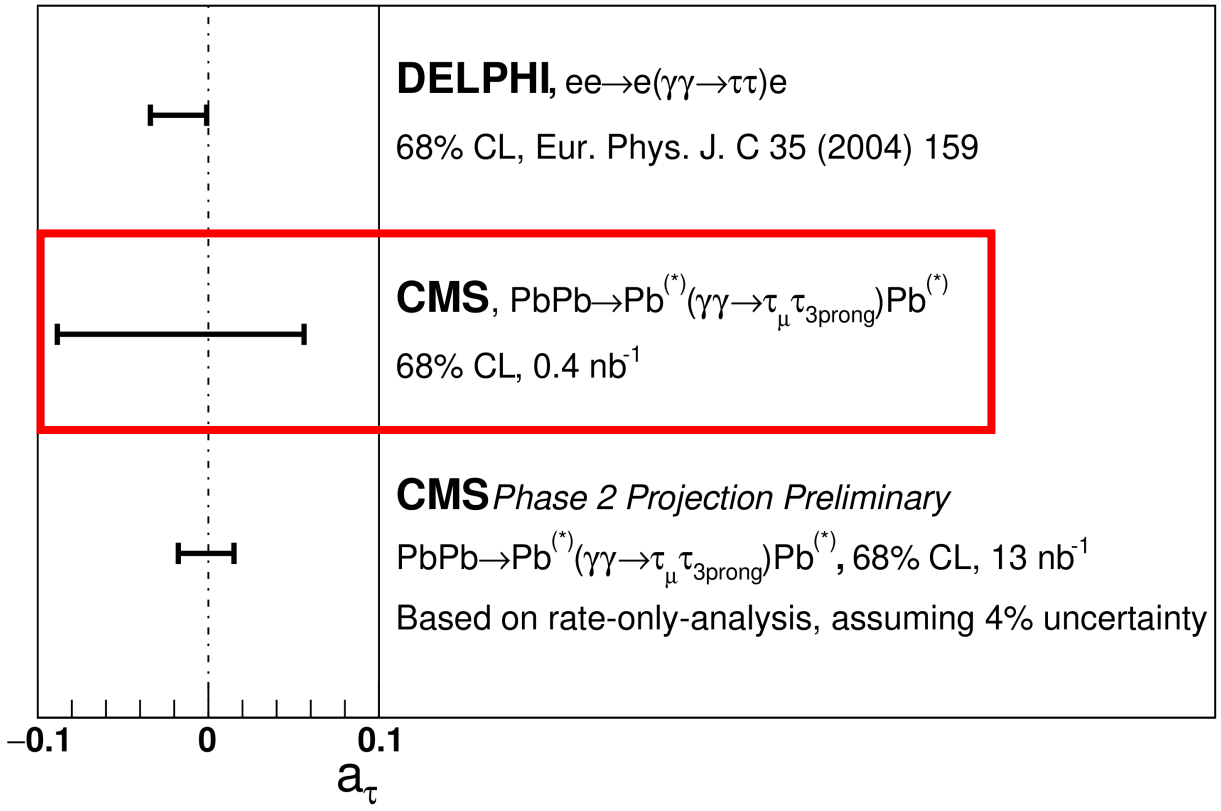
[(Muon g–2 Collaboration) arXiv:2308.06230]




CMS Experiment at the LHC, CERN
Data recorded: 2015-Dec-06 21:41:27.033612 GMT
Run / Event / LS: 263400 / 88515785 / 849
$\tau_\mu \rightarrow \mu\nu_\tau\nu_\mu$
$\tau_{3prong} \rightarrow \pi^{\pm}\pi^{\mp}\pi^{\pm}\nu_\tau$

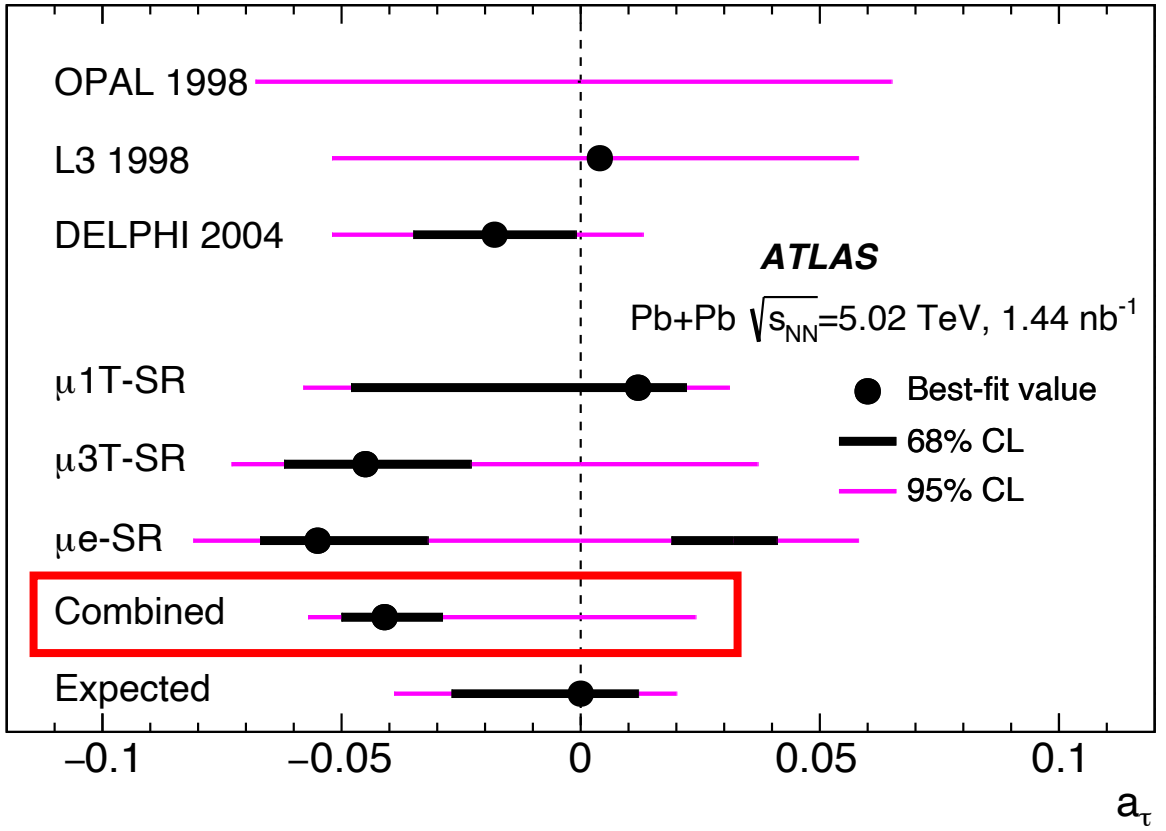
Anomalous Magnetic Moment of tau

Matthew Nickel (CMS)



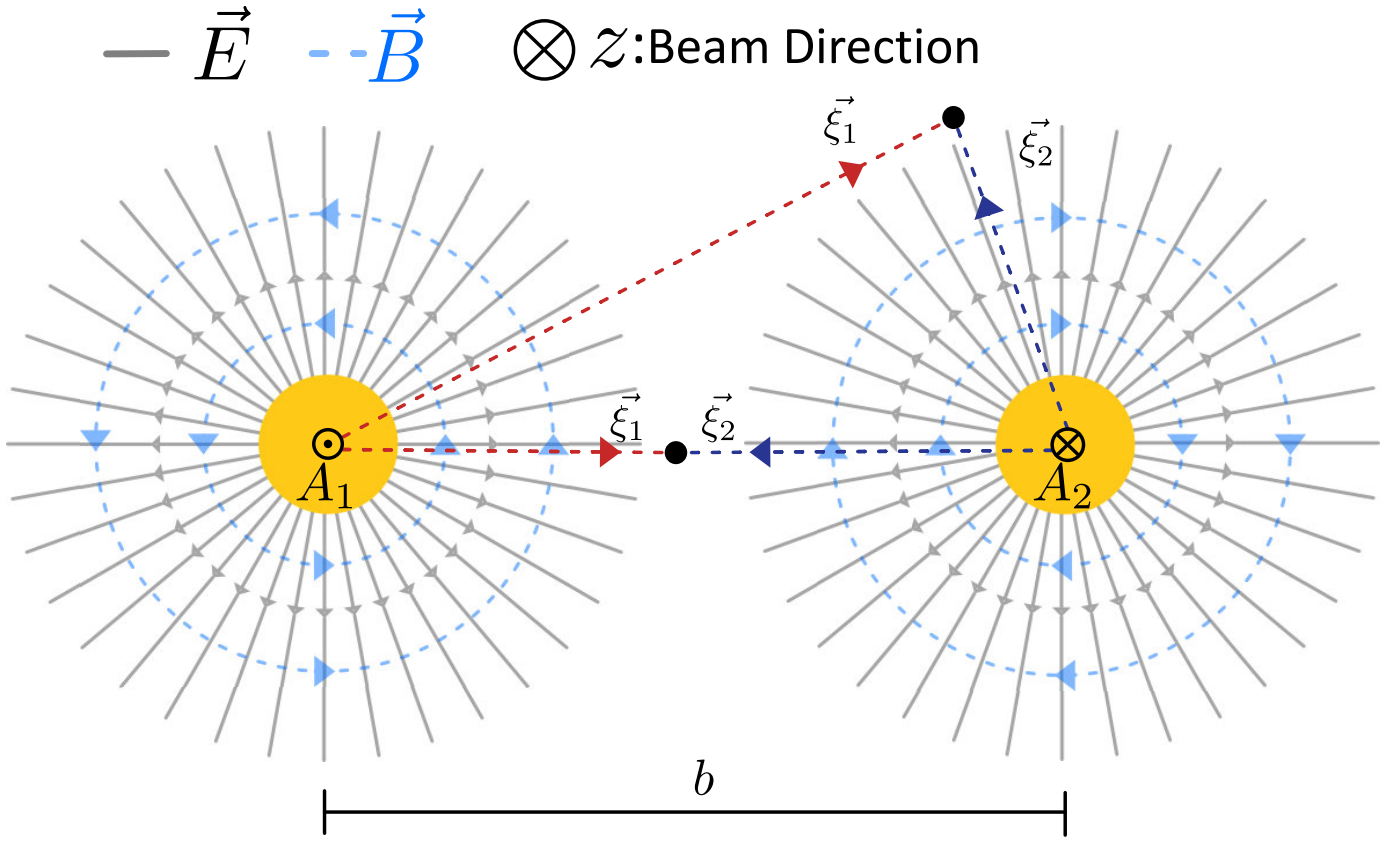
arXiv:2206.05192
Accepted to PRL as Editor's suggestion

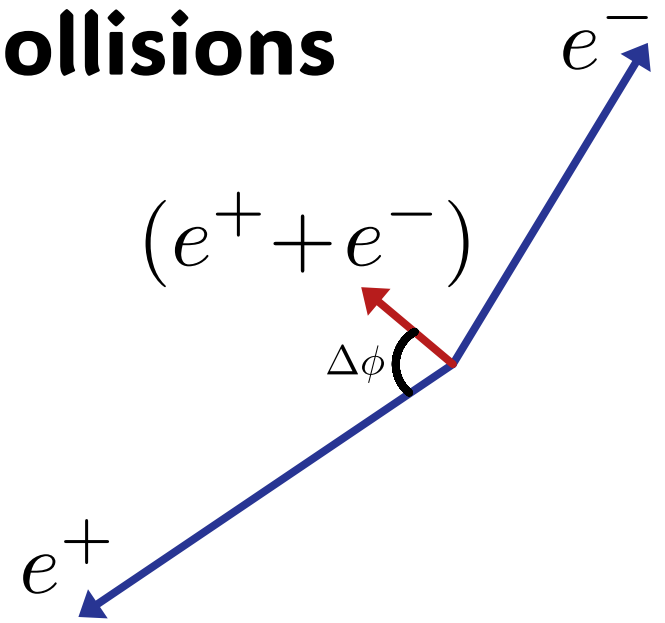
Peter Steinberg (ATLAS)



arXiv:2204.13478 acc. by PRL

Photon *Polarization* In Ultra-Peripheral Collisions





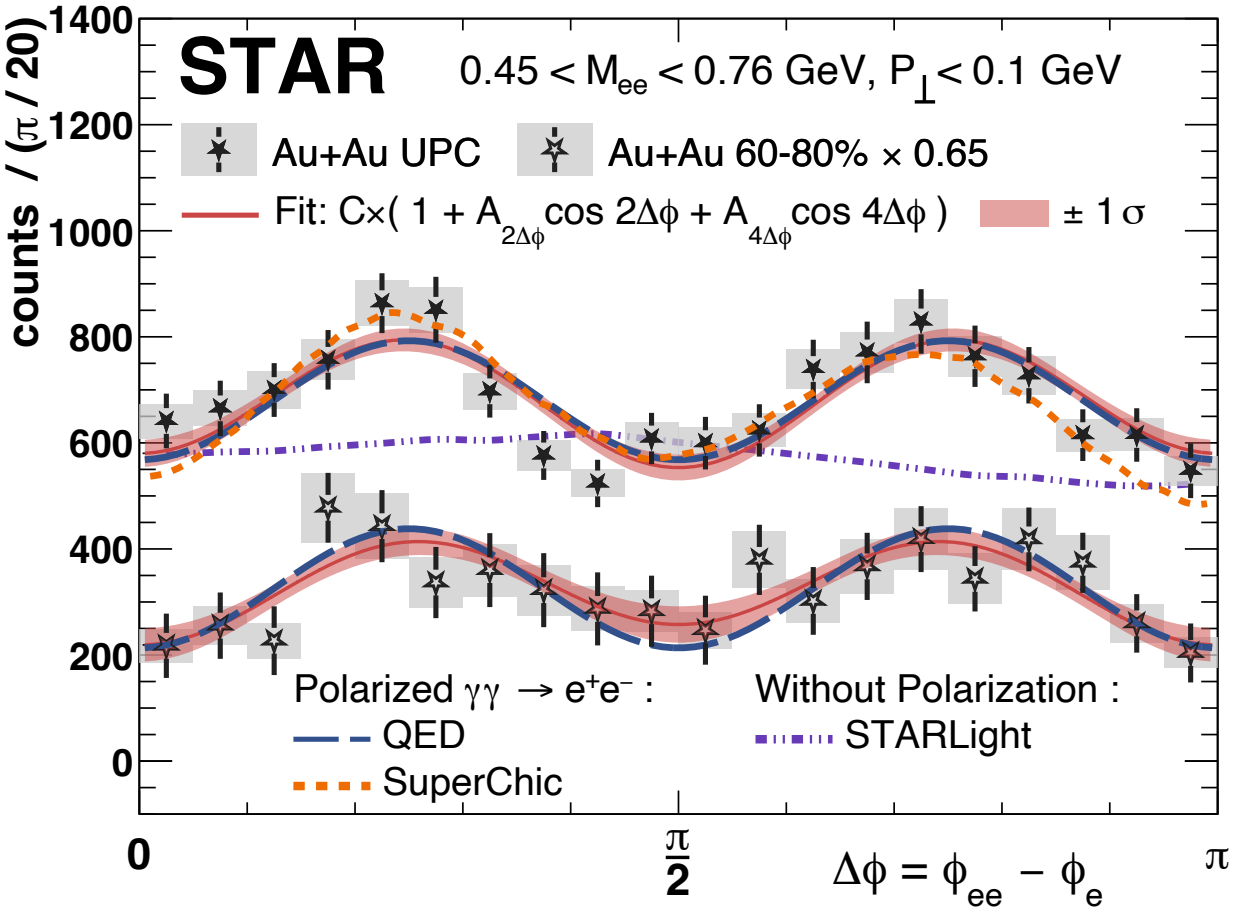
- Polarization vector ξ: aligned radially with the "emitting" source
- Intrinsic photon spin converted into **orbital angular momentum**
- Observable as anisotropy in $e^{\pm}$ momentum

For decades it was believed the polarization info was lost due to random event-by-event orientation!

C. Li, J. Zhou, Y. Zhou, Phys. Lett. B 795, 576 (2019)
C. Li, J. Zhou & Y. Zhou Phys. Rev. D 101, 034015 (2020).

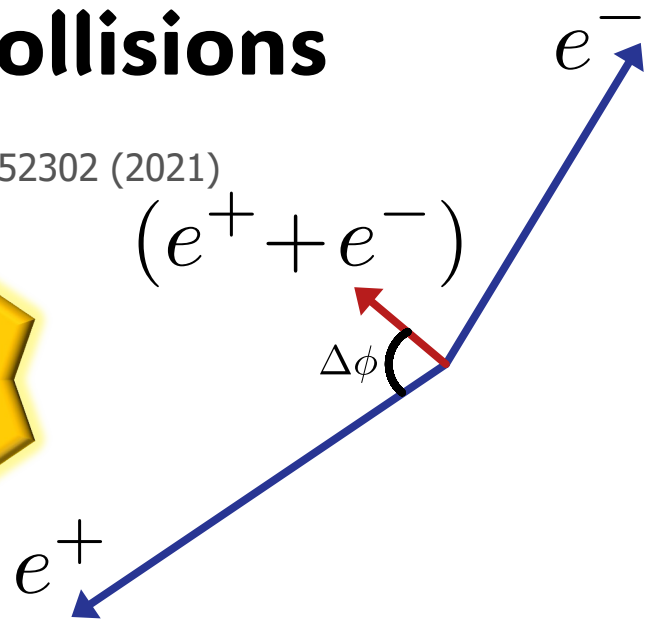
S. Bragin, et. al., *Phys. Rev. Lett.* 119 (2017), 250403
R. P. Mignani, *et al.*, *Mon. Not. Roy. Astron. Soc.* 465 (2017), 492

Photon *Polarization* In Ultra-Peripheral Collisions



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

Breit-Wheeler Discovery 2021 STAR



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Experimental access to photon polarization demonstrated

C. Li, J. Zhou, Y. Zhou, Phys. Lett. B 795, 576 (2019)
C. Li, J. Zhou & Y. Zhou Phys. Rev. D 101, 034015 (2020).

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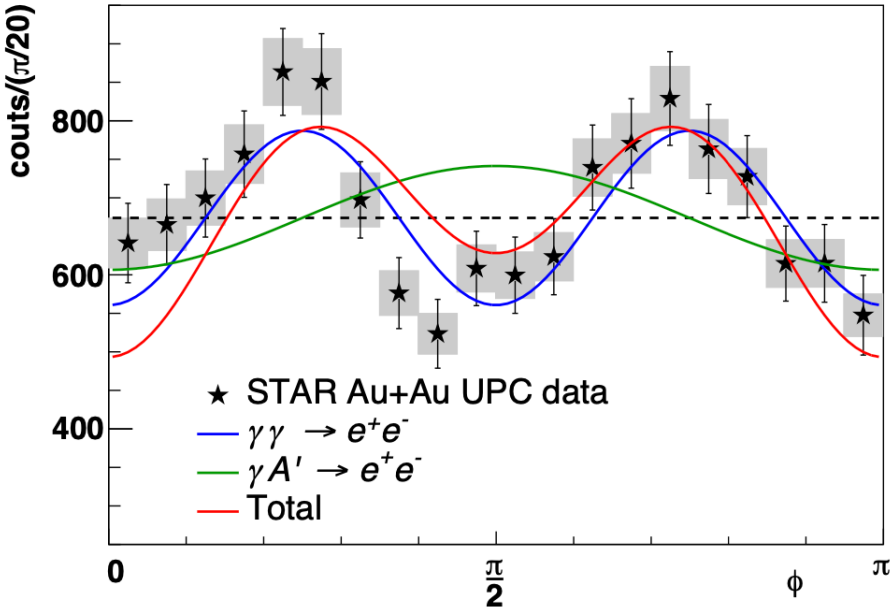
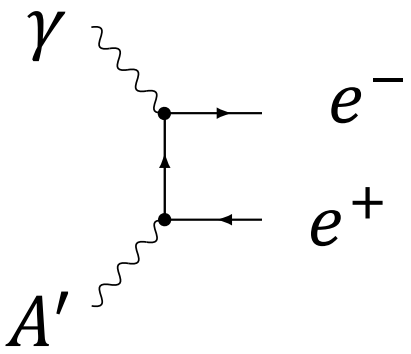
Applications of $\gamma\gamma \rightarrow l^+l^-$

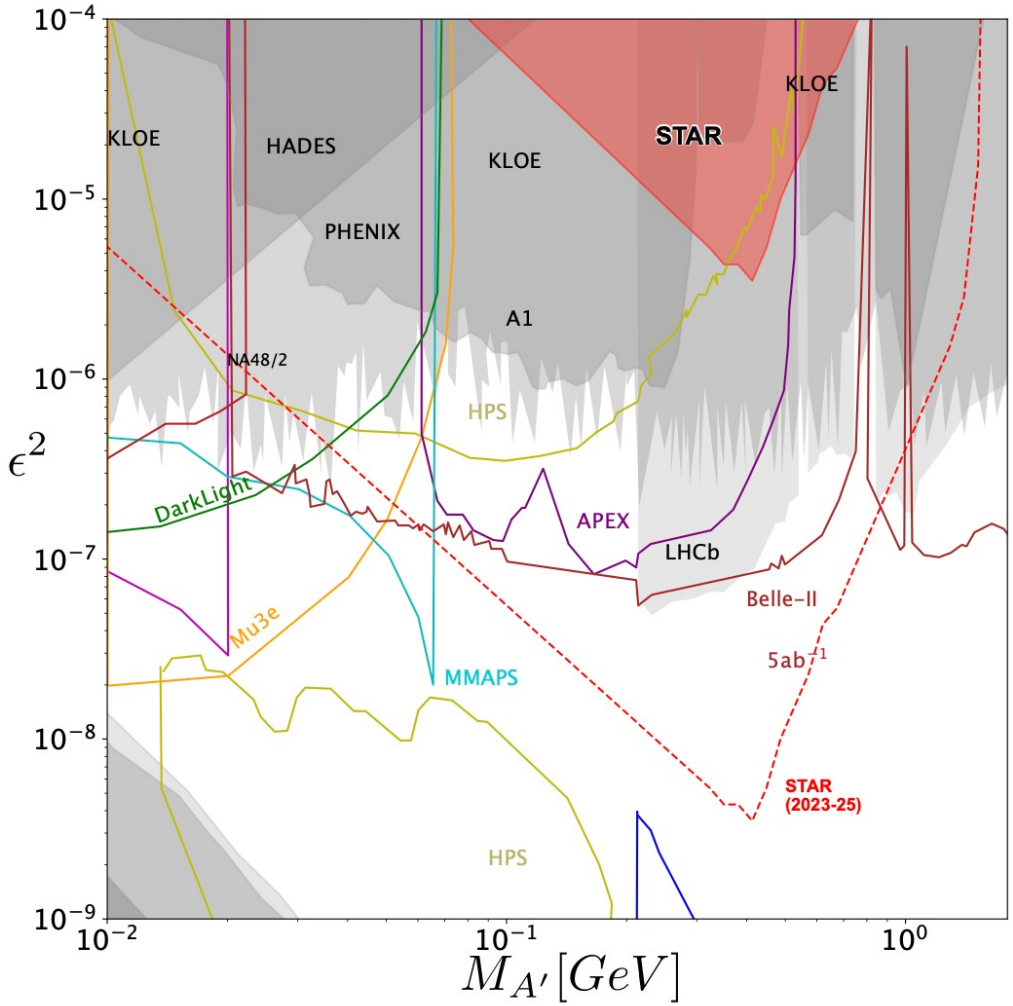
Xiaofeng Wang (STAR)

Sensitivity to spin states → novel approach for constraining massive dark photons



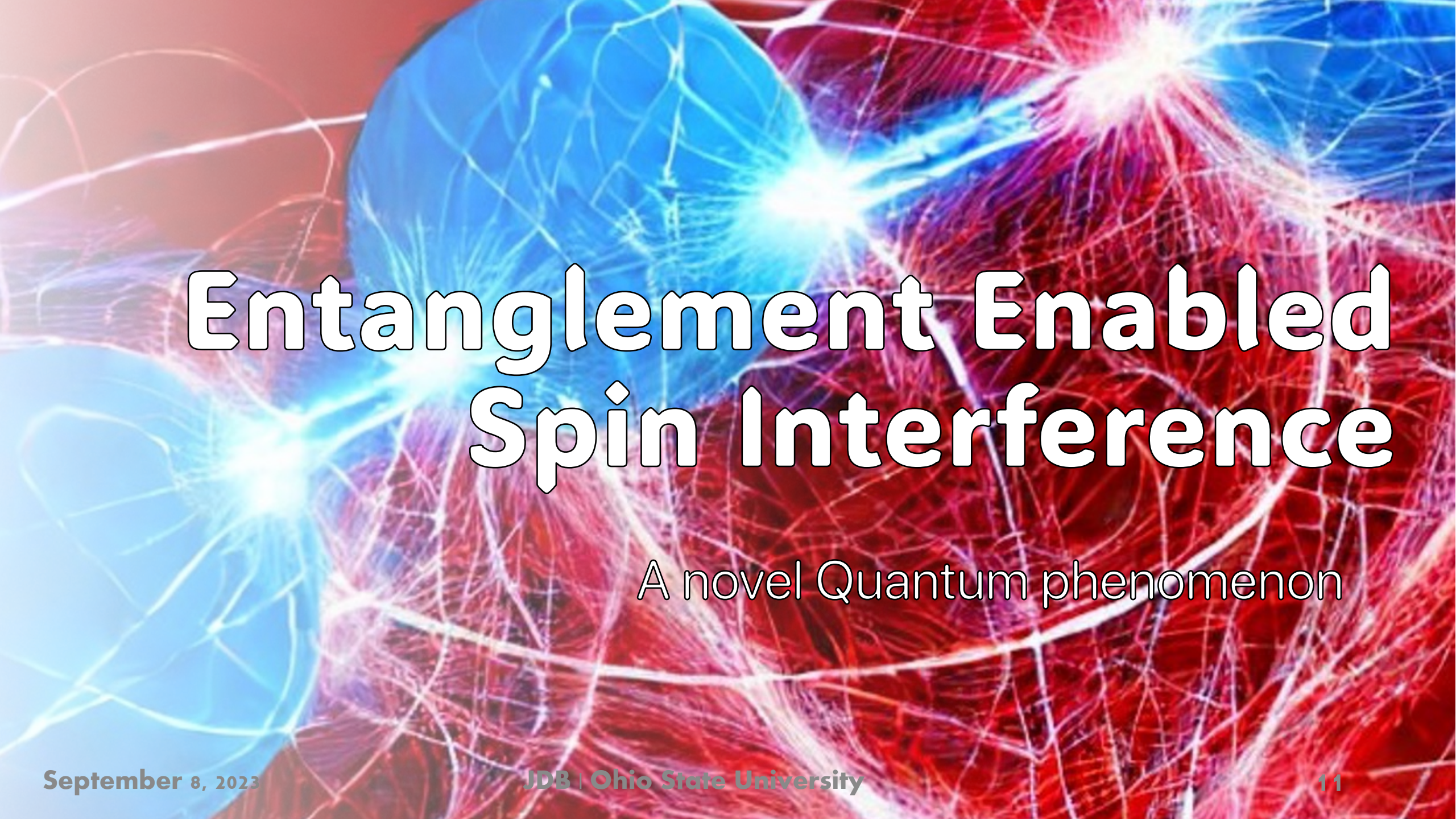


Dark photon



Isabel Xu, Nicole Lewis, Xiaofeng Wang, James Daniel Brandenburg, Lijuan Ruan
arxiv:2211.02132

Relevant for LHC Axion search in Light-by-Light scattering
JDB, W. Zha, and Z. Xu, Eur. Phys. J. A 57, 299 (2021)

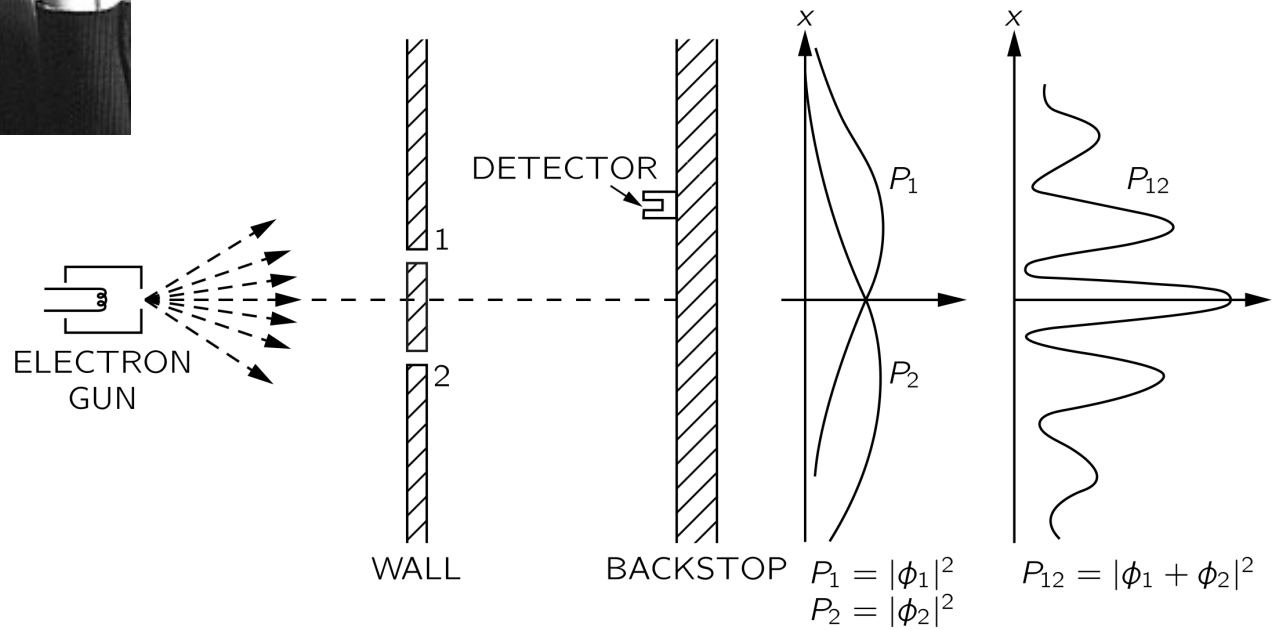


Entanglement Enabled Spin Interference

A novel Quantum phenomenon

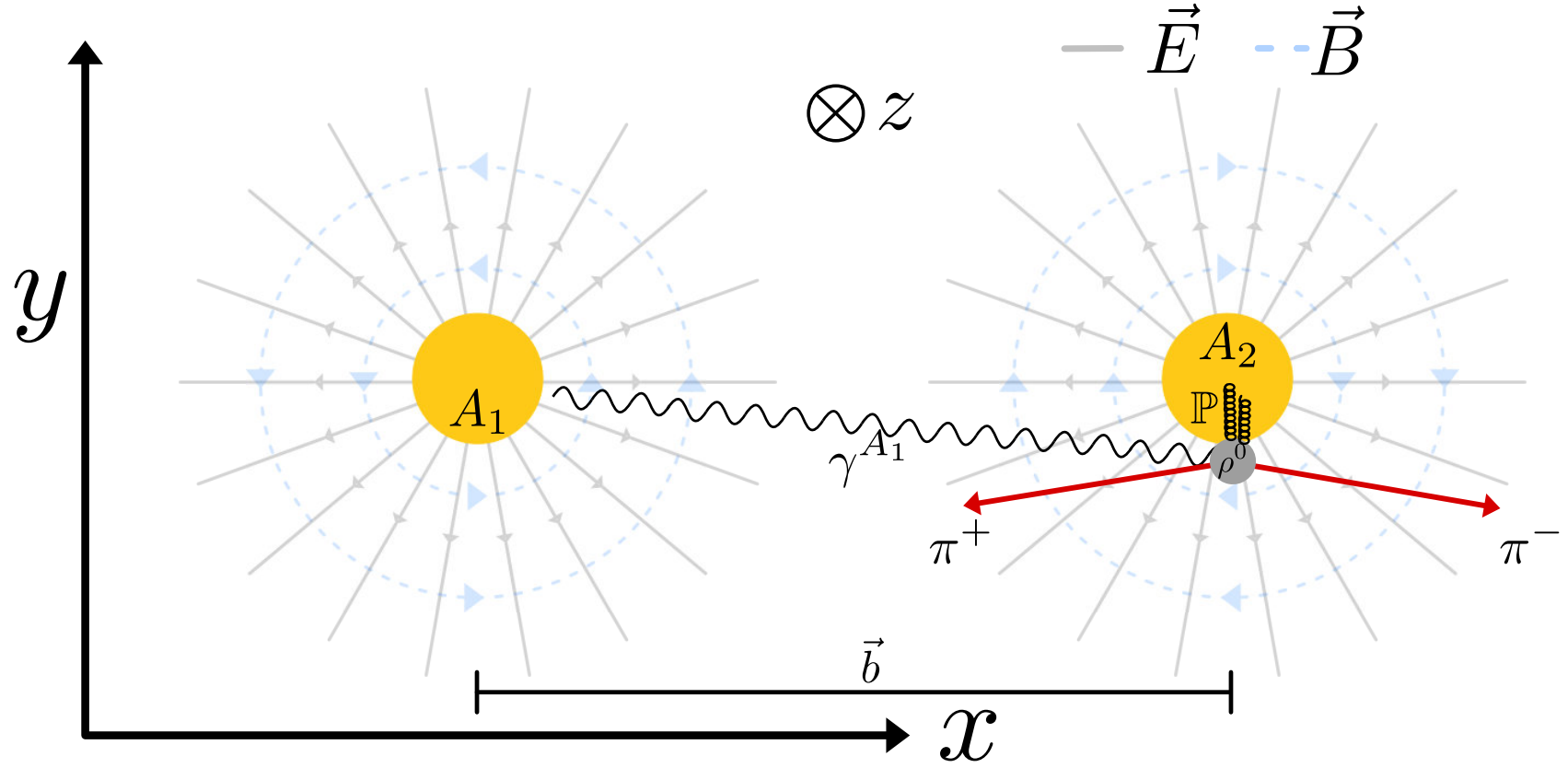
I will take just this one experiment, which has been designed to contain all of the *mystery* of quantum mechanics, to put you up against the *paradoxes* and *mysteries* and *peculiarities* of nature one hundred per cent. Any other situation in quantum mechanics, it turns out, can always be explained by saying, *'You remember the case of the experiment with the two holes? It's the same thing*'.

-Richard Feynman



Imaging the Nucleus with Polarized Photons

What is NEW with transversely polarized photons?



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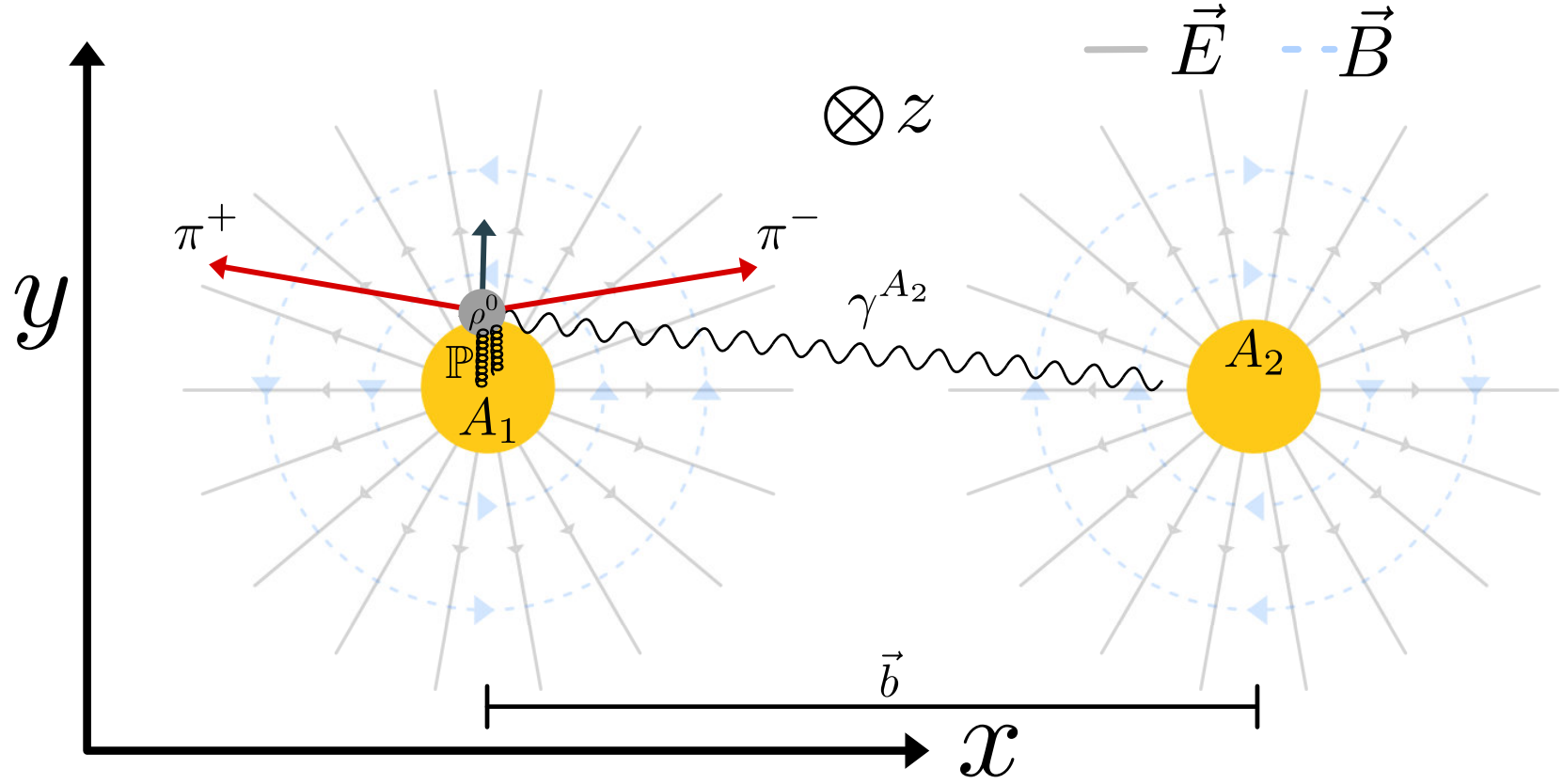

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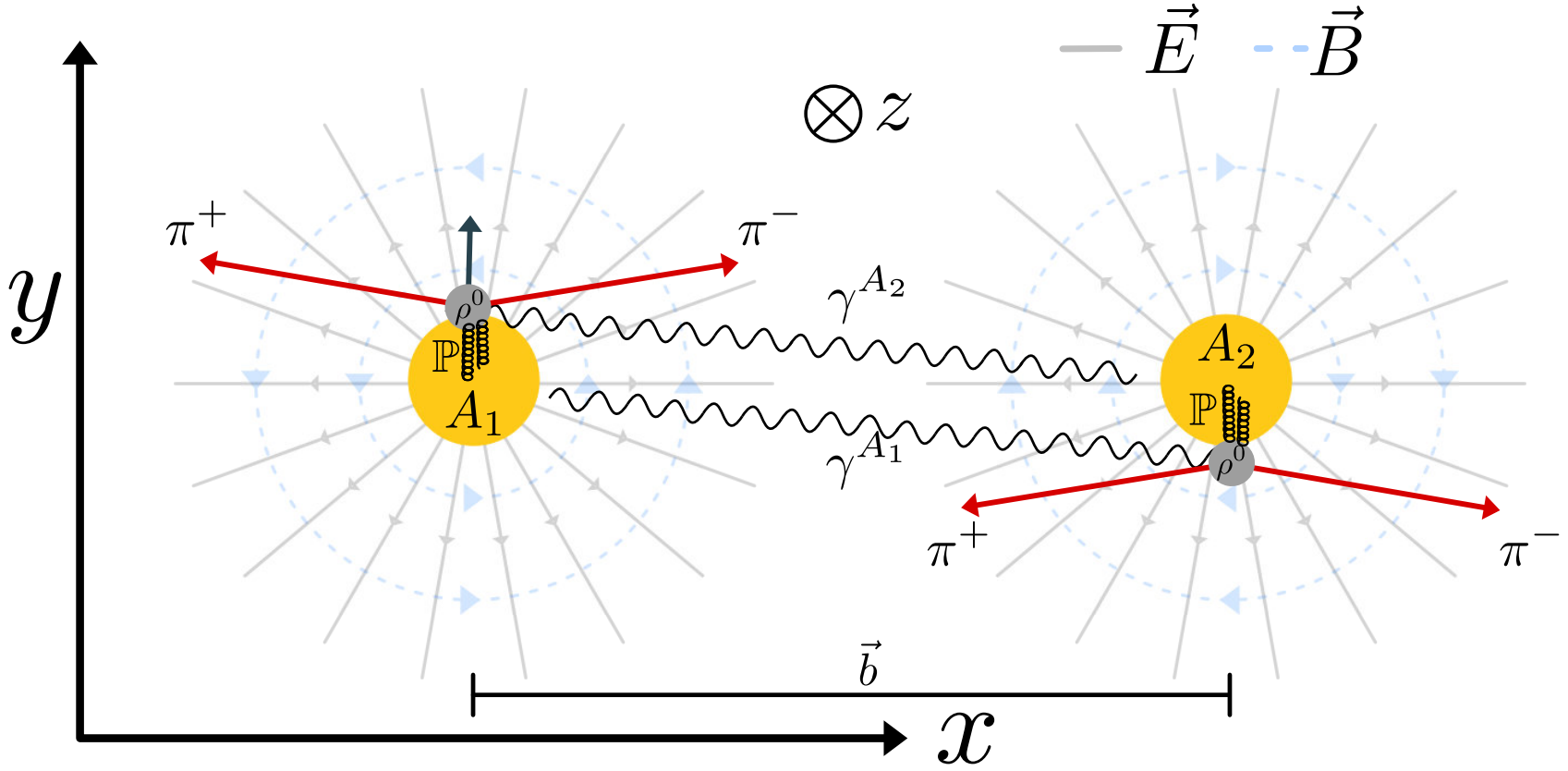
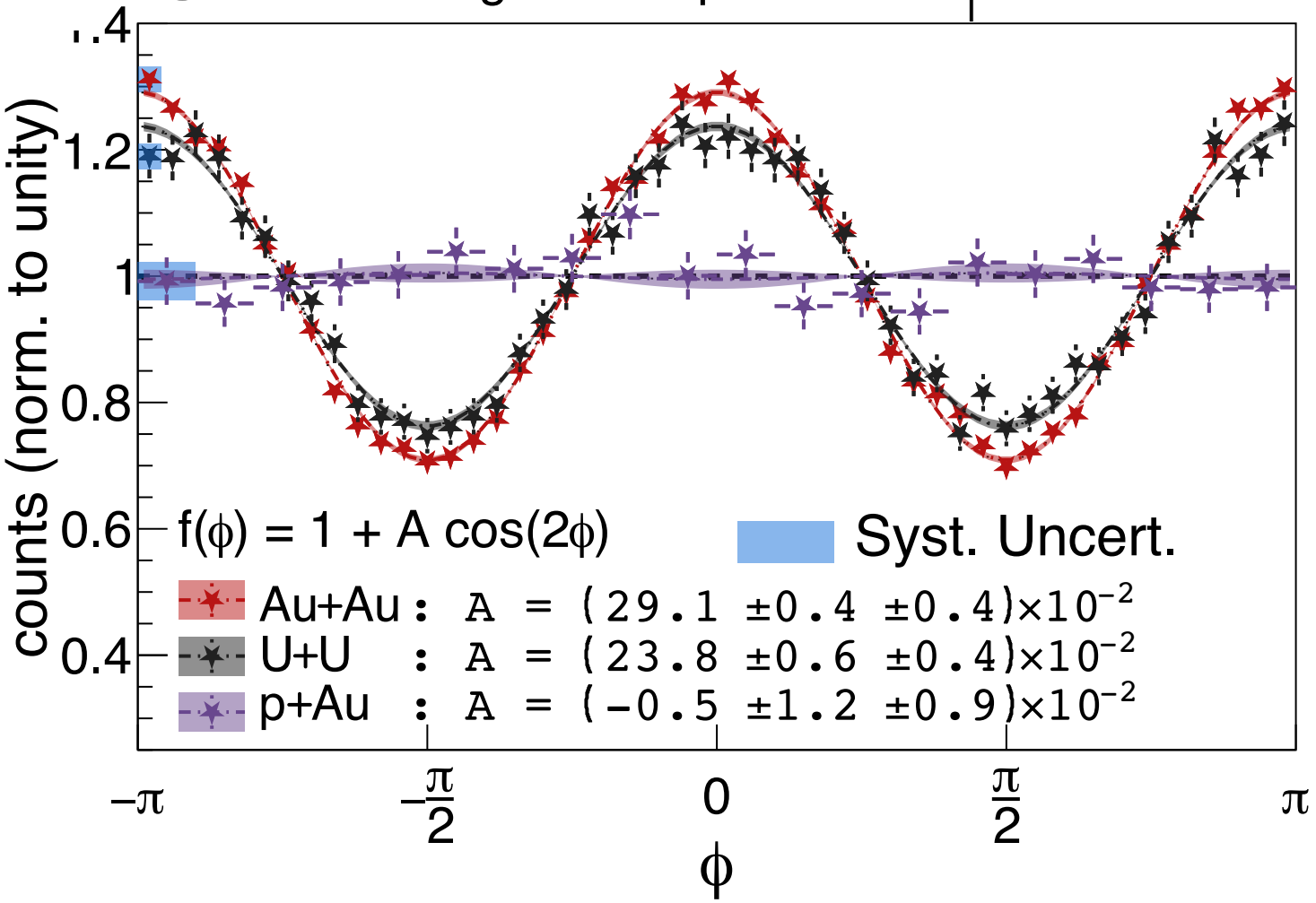
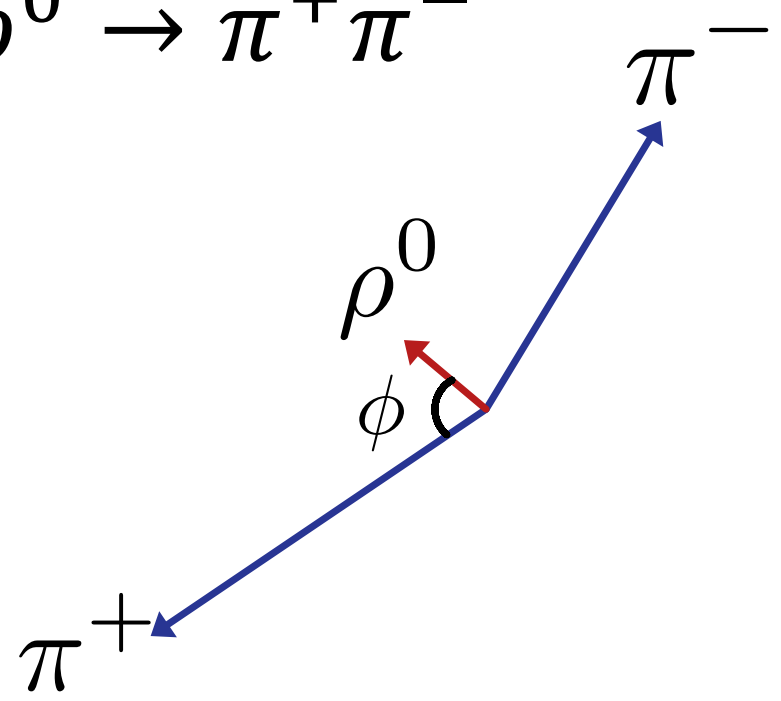


Both possibilities occur simultaneously

Observation of Interference in $\rho^0 \to \pi^+\pi^-$

STAR: Signal $\pi^+\pi^-$ pairs with $P_T < 60$ MeV





- Intrinsic photon spin transferred to ρ^0
- ρ^0 spin converted into **orbital angular momentum** between pions
- Observable as anisotropy in $\pi^\pm$ momentum

STAR Collaboration, Sci. Adv. **9**, eabq3903 (2023).

H. Xing, C. Zhang, J. Zhou and Y. J. Zhou, JHEP 10(2020), 064.

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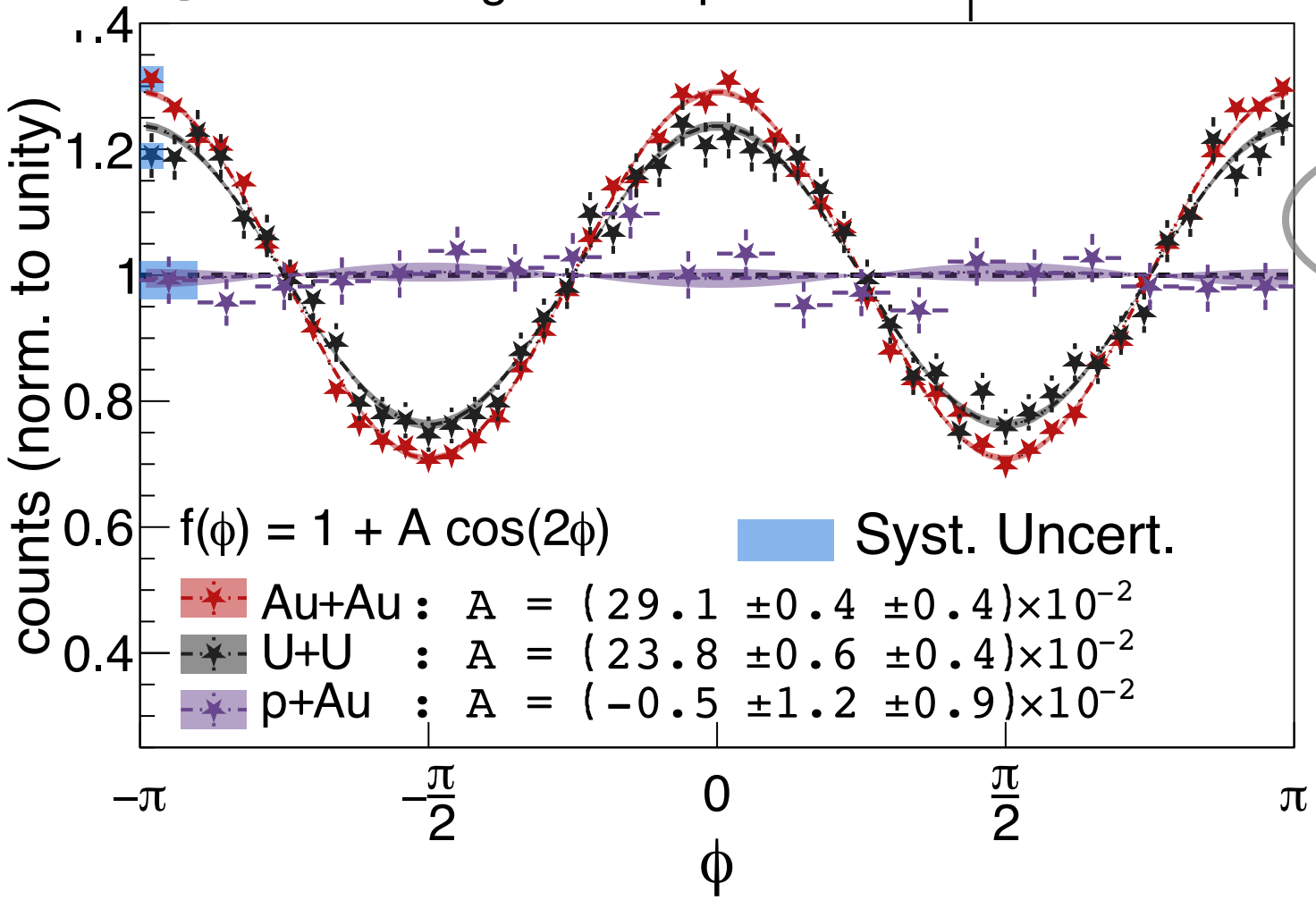

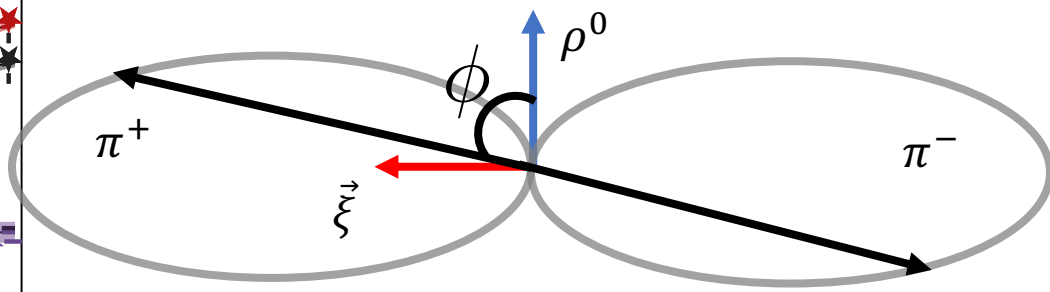

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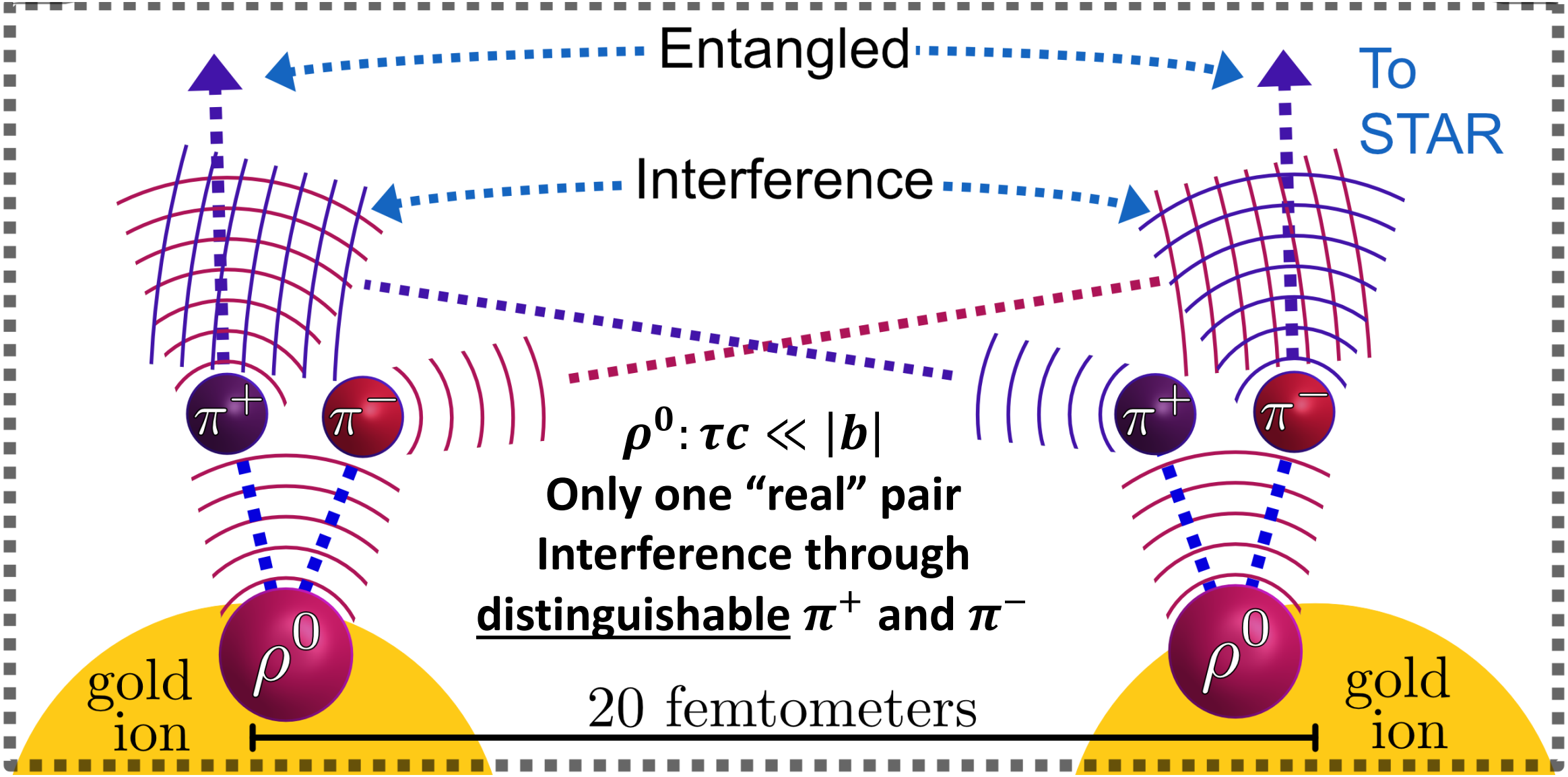
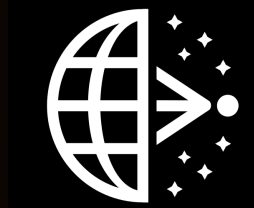
Interference of Amplitudes, so what!?



Analogy to Interferometry in Astro-Physics

Quantum Interference provides sub-diffraction limited imaging

M87 Supermassive Black hole



Event Horizon Telescope

Analogy to Interferometry in Astro-Physics

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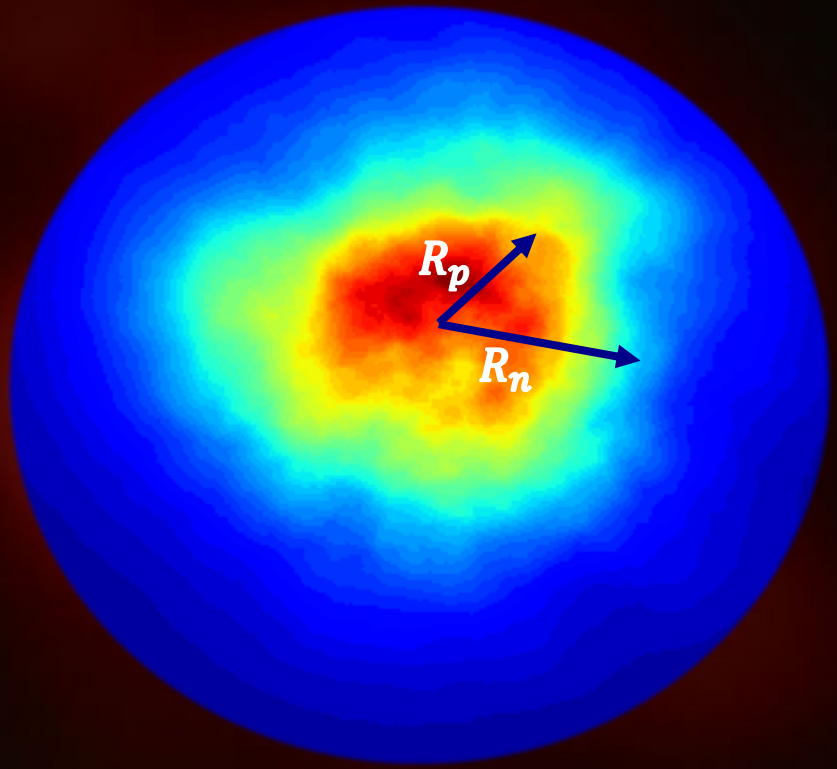
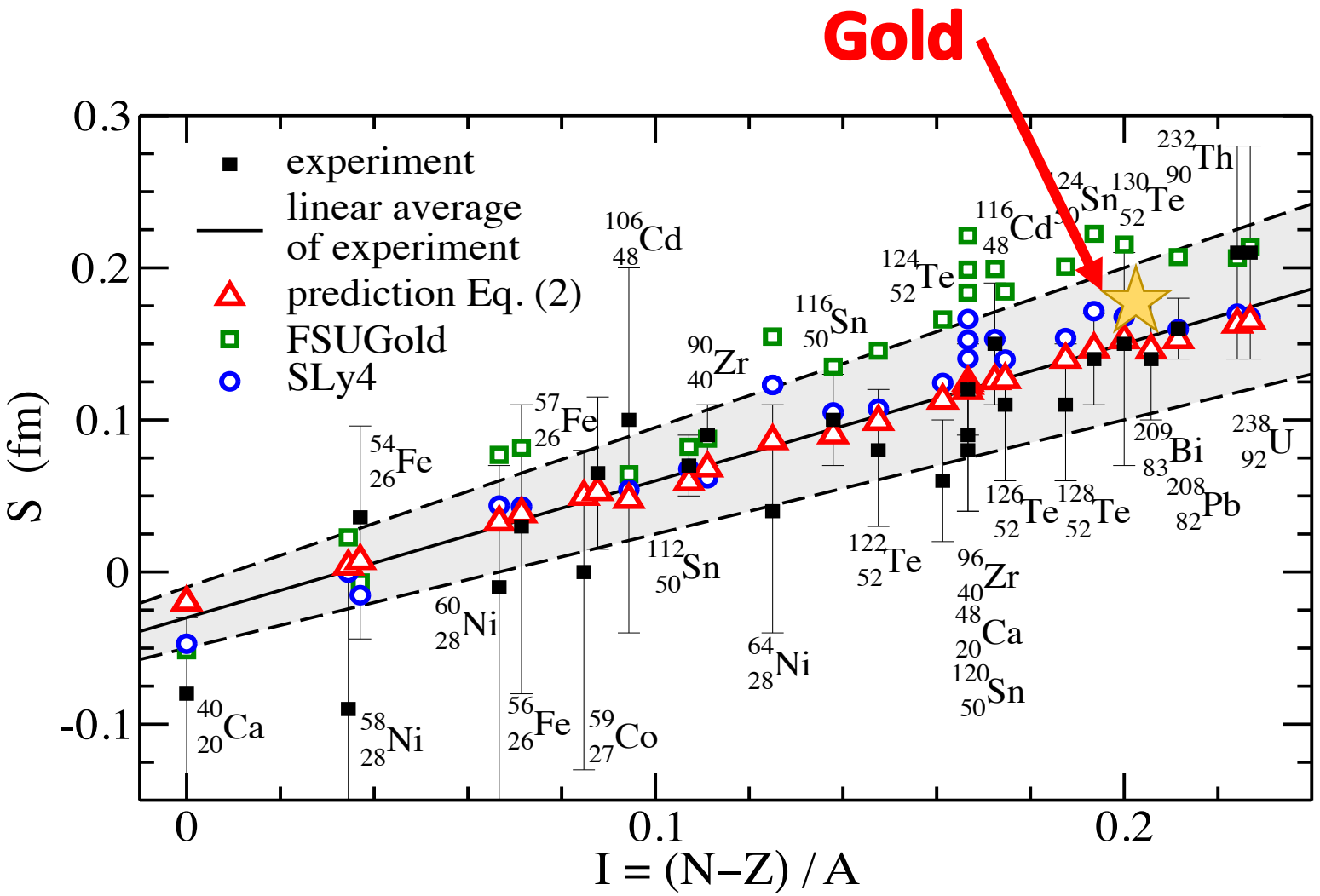


Nuclear Gluon distribution

Access to details of gluon distribution and neutron skin at high energy

Neutron Skins at High-Energy



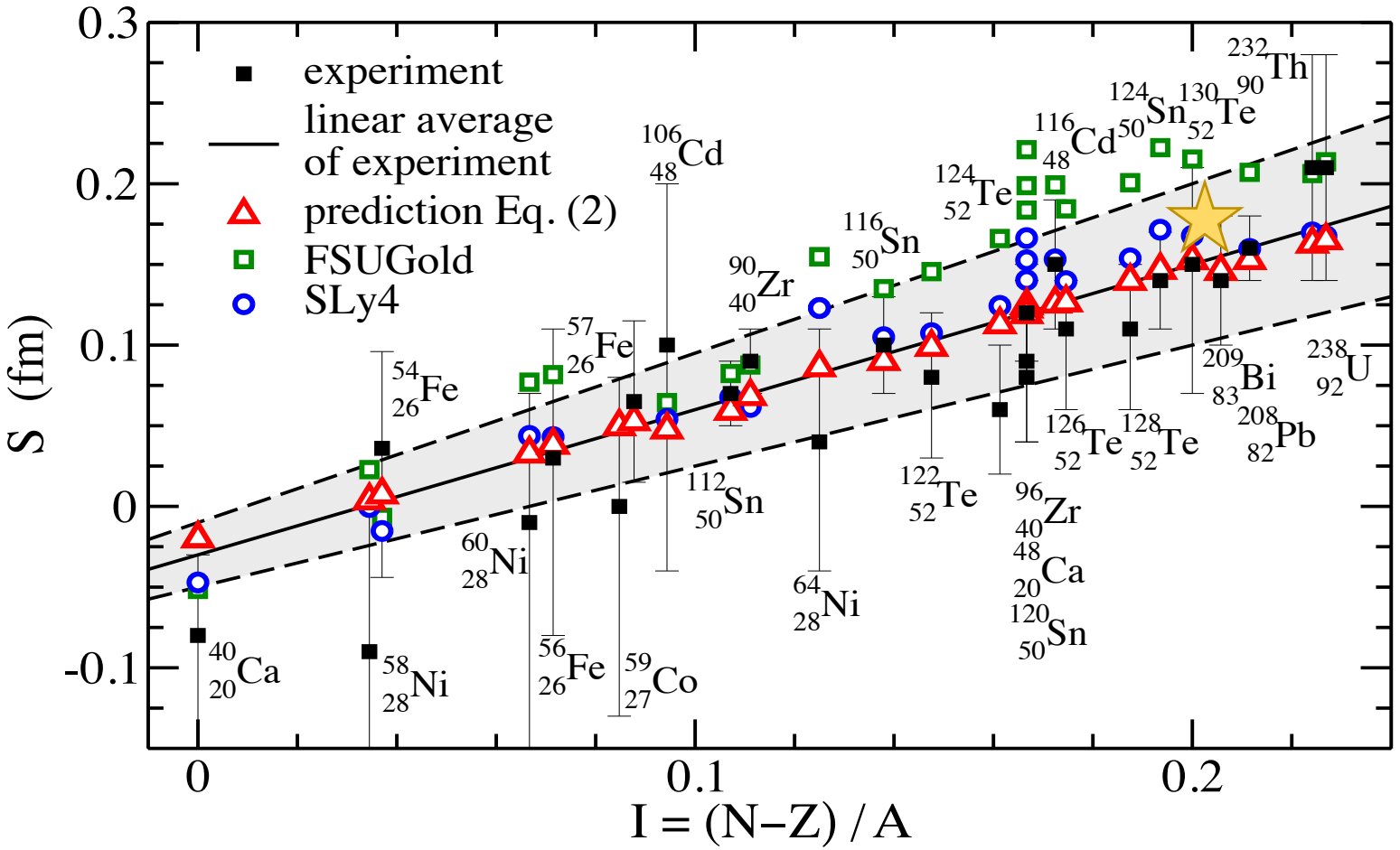
$$S_{Au} = 0.17 \pm 0.03(\text{stat.}) \pm 0.08(\text{syst.})\ \text{fm}$$

$$S_{Au}^{MR-EDF} = 0.17\ \text{fm}$$

Bally, B., Giacalone, G. & Bender, M. *Eur. Phys. J. A* **59**, 58 (2023).

- Gold agrees well with state-of-the-art energy density functional calculations
- Consistent with trend from low energy measurements

Neutron Skins at High-Energy



Uranium

$S_U = 0.44 \pm 0.05$ (stat.) ± 0.08 (syst.) fm

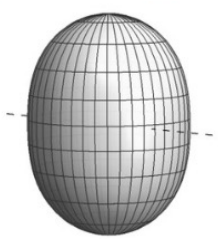
- Uranium neutron skin appears surprisingly large?
- Above trend and low-energy measurements?

Robust Theoretical Description

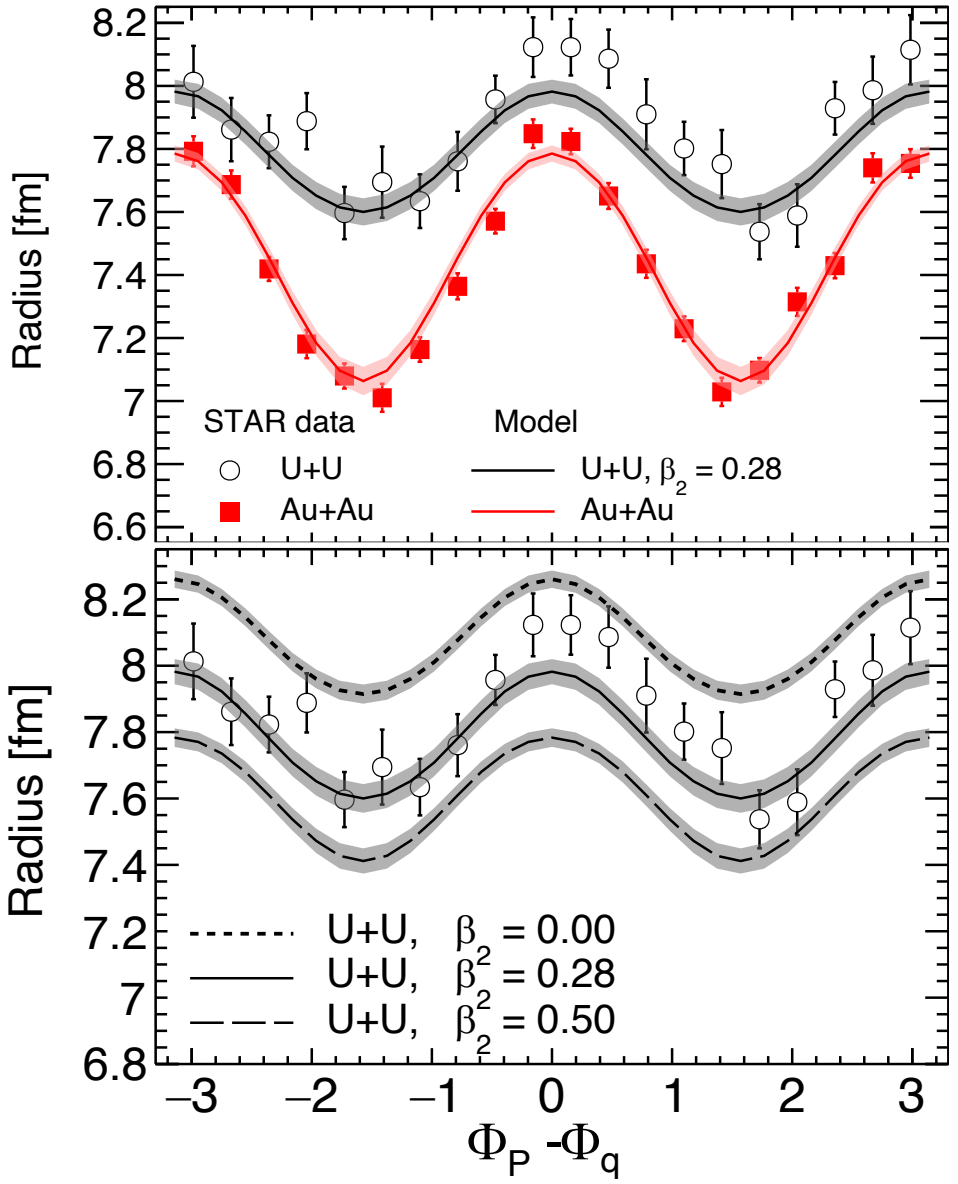
Wenbin Zhao

- First theoretical prediction for deformed Uranium
- Sensitivity to nuclear geometry!

β_2



- 2D Tomography possible through Interference effect
- Also require very large U radius
- Assumes amplitude interference for coherent process



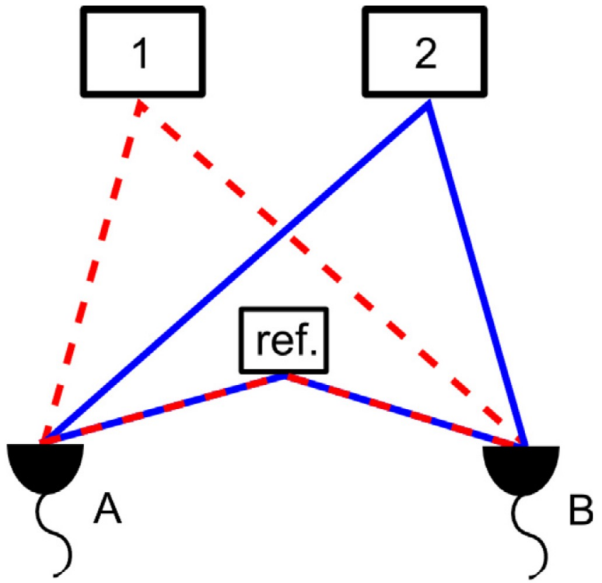
H.Mantysaari, F. Salazar, B.Schenke, C. Shen and W. Zhao, in preparation.

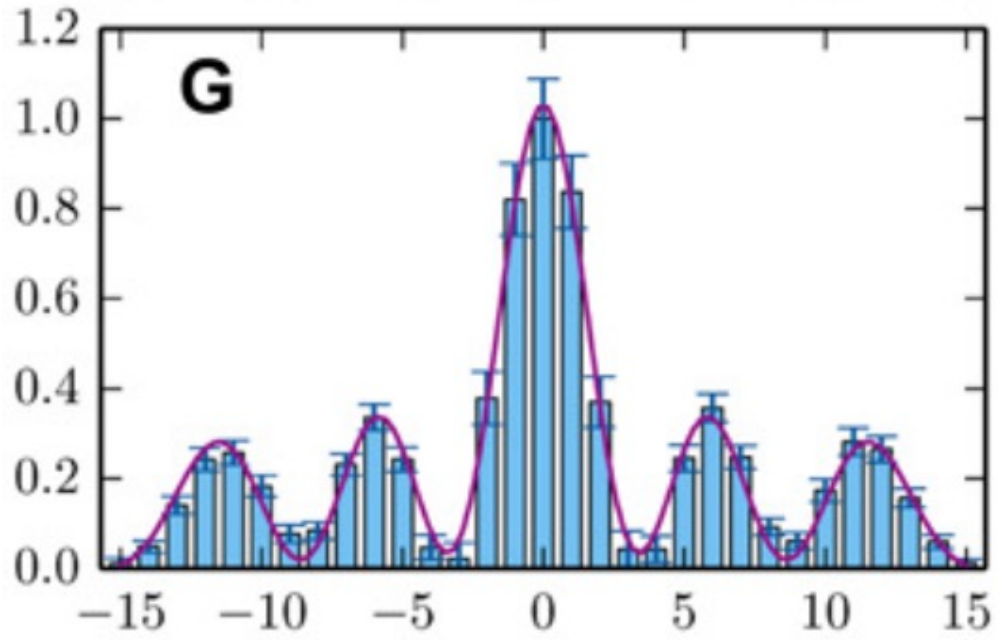
Entanglement enabled Intensity Interferometry from exclusive $\pi^+\pi^-$ measurements in UPC's as an inverse Cotler-Wilczek process

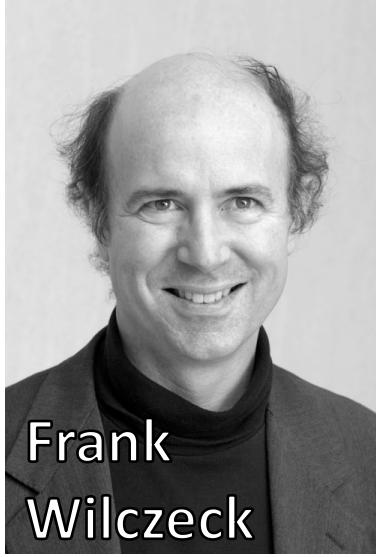
Haowu Duan, Raju Venugopalan, Zhoudunming Tu, Zhangbu Xu, James Daniel Brandenburg, In preparation

Cotler-Wilczek Process: use entanglement 'filter' to convert **different wavelengths** of light to a common state→ interference

Annals of Physics Volume 424, 168346 (2021)







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Haowu Duan, Raju Venugopalan, Zhoudunming Tu, Zhangbu Xu, James Daniel Brandenburg, In preparation

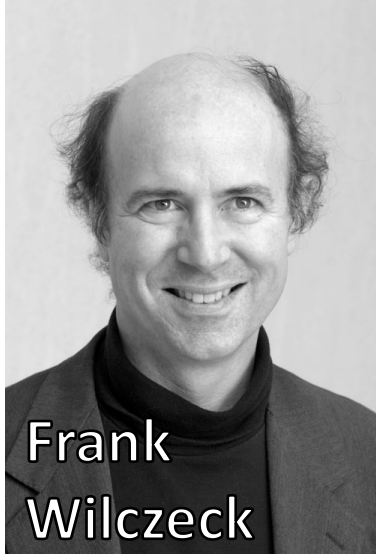
Inverse Cotler-Wilczek Process: 'Filter' ρ^0 state comes first.

Entanglement of daughter pions enables interference

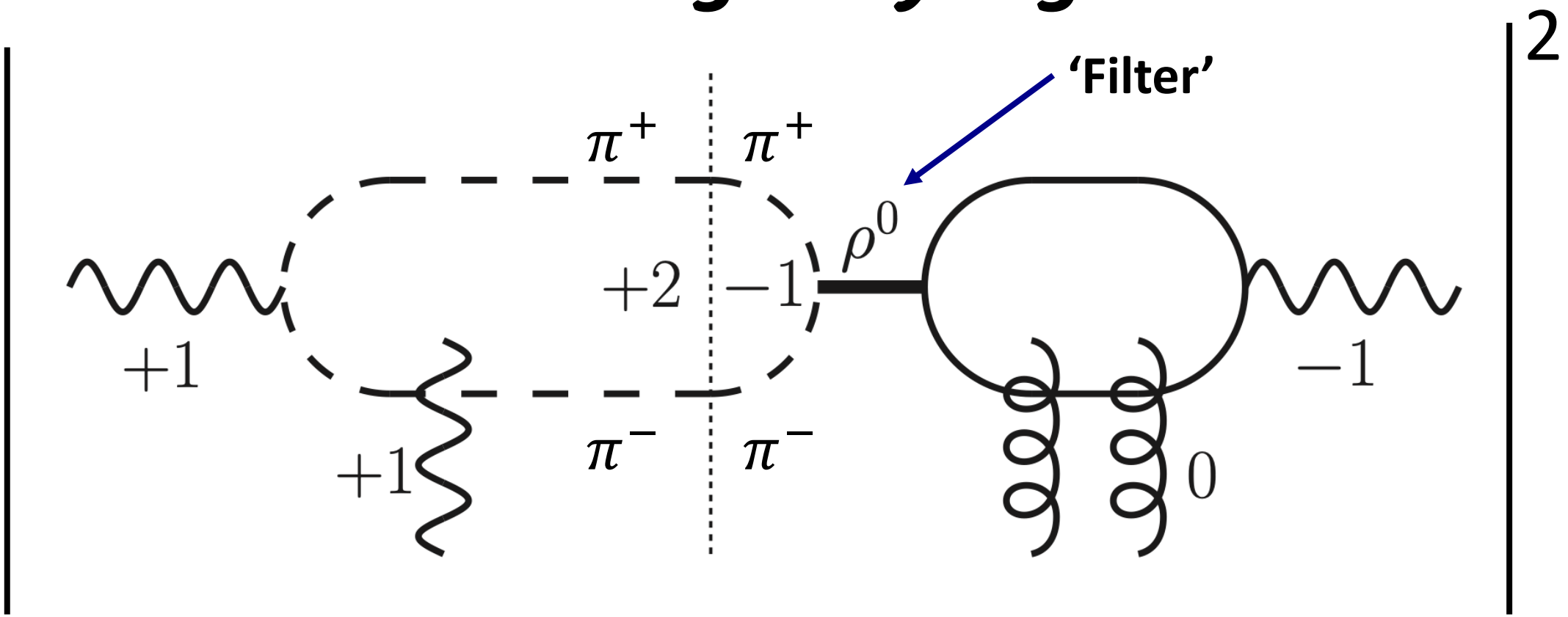
$$
\begin{aligned}
< N_A N_B|\pi^+\pi^- > &= < N_A N_B|\rho_A >< \rho_A|\pi^+\pi^-, A > \\
&\times < \pi^+\pi^-, A|\Big(|\pi^+, 1 > |\pi^-, 2 > + |\pi^+, 2 > |\pi^-, 1 > \Big) \\
&+ < N_A N_B|\rho_B >< \rho_B|\pi^+\pi^-, B > \\
&\times < \pi^+\pi^-, B|\Big(|\pi^+, 1 > |\pi^-, 2 > + |\pi^+, 2 > |\pi^-, 1 > \Big) .
\end{aligned}
\tag{16}
$$

Interference only occurs if final state particles are <u>entangled!</u>


Jordan Cotler


Frank Wilczeck

Access to Hadronic Light-by-Light

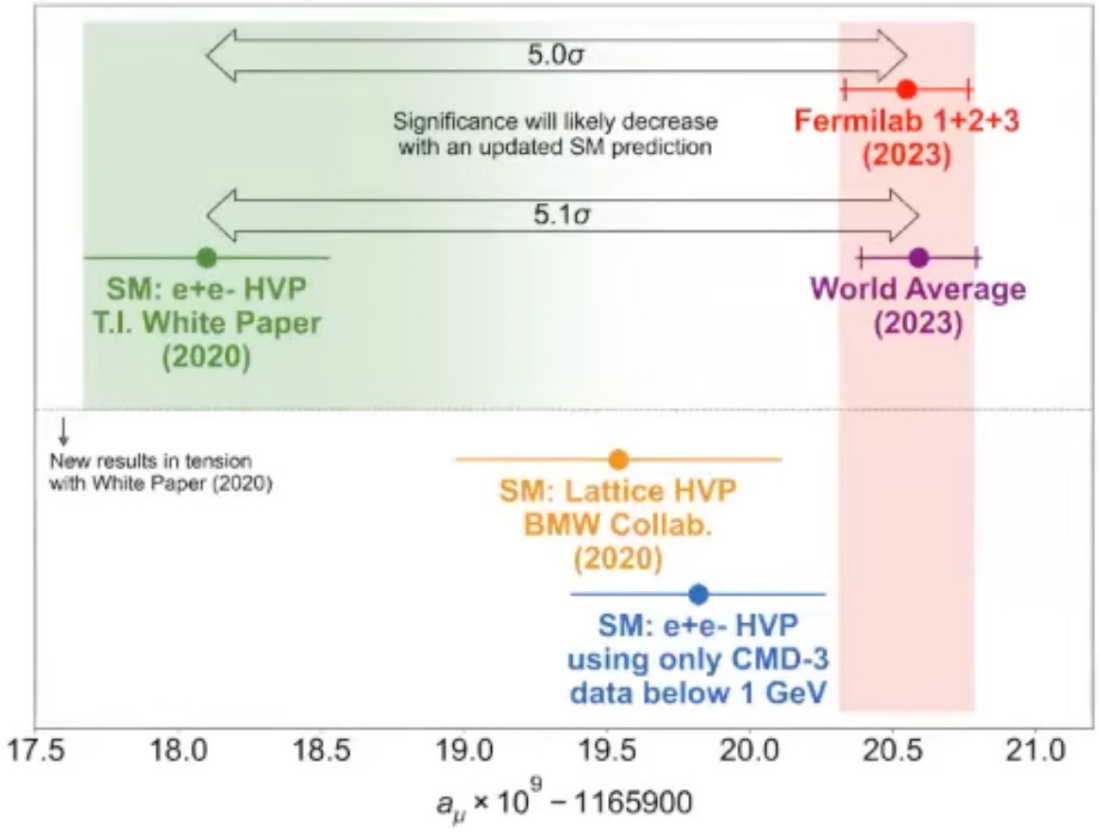


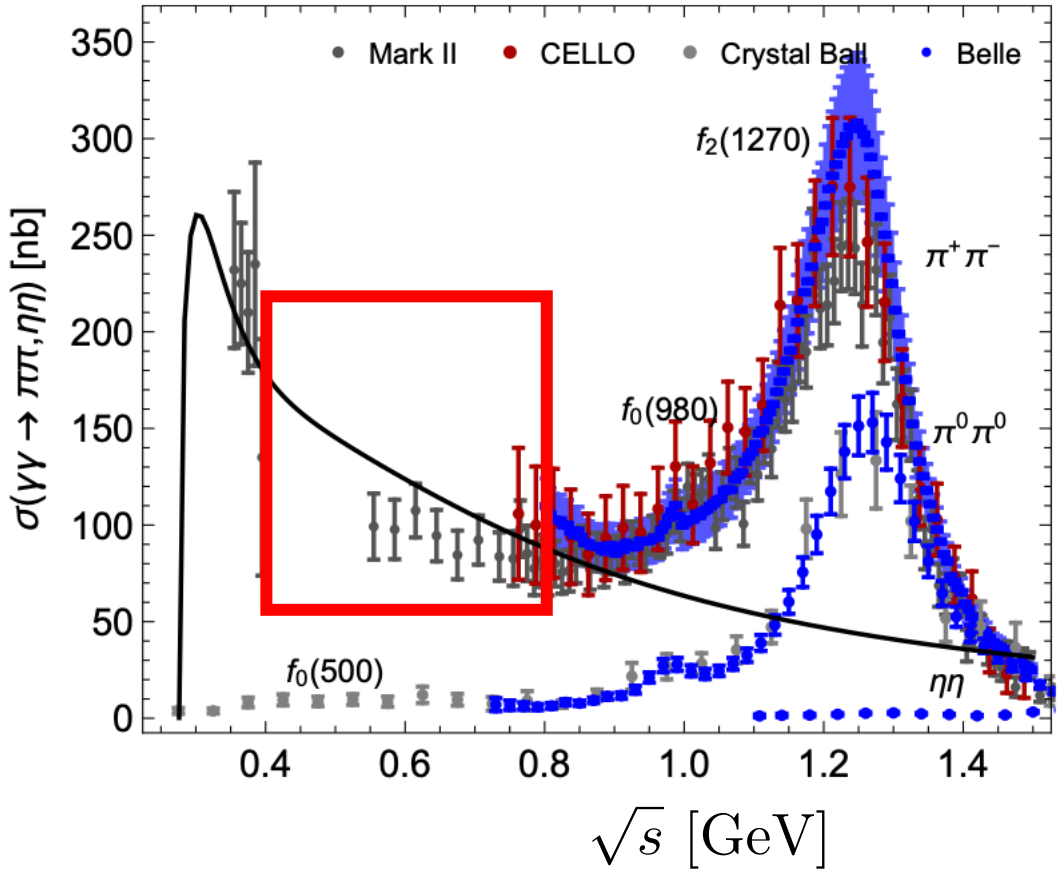
Interference with the hadronic light-by-light diagram

Leads to a unique signature -> odd spin configurations

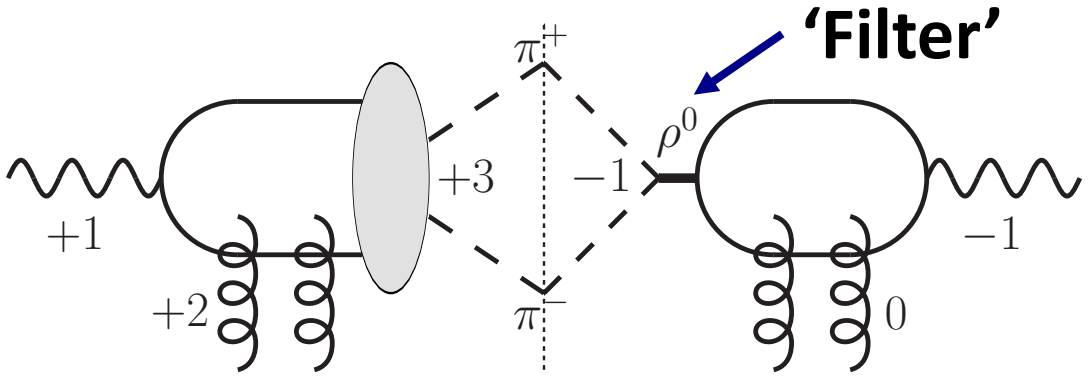
Novel Experimental input for muon g-2

Contribution from Hadronic Vacuum Polarization and Hadronic Light-by-Light are **the largest theoretical uncertainties** for Standard Model muon g-2





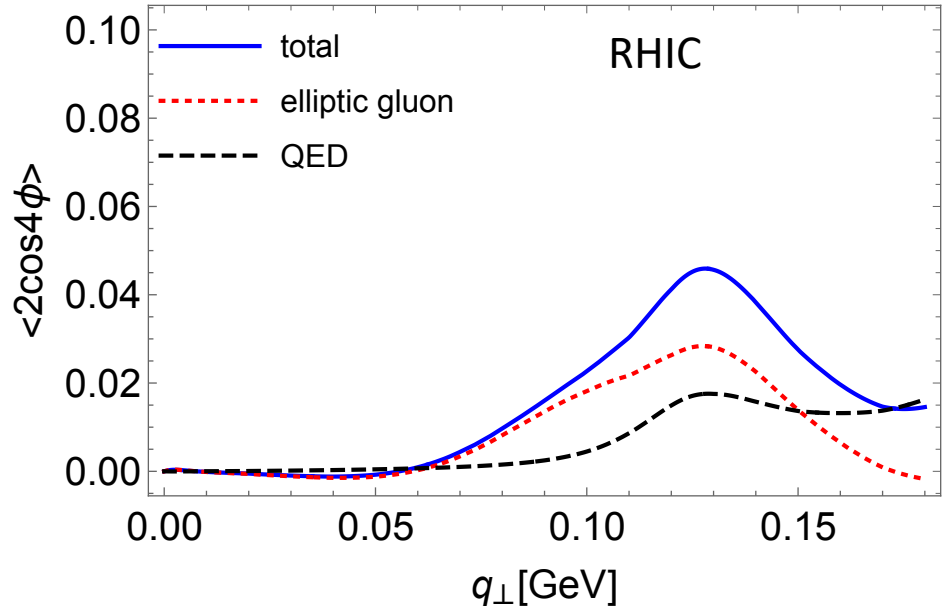
Elliptic Gluon Tomography (Tensor Pomeron)

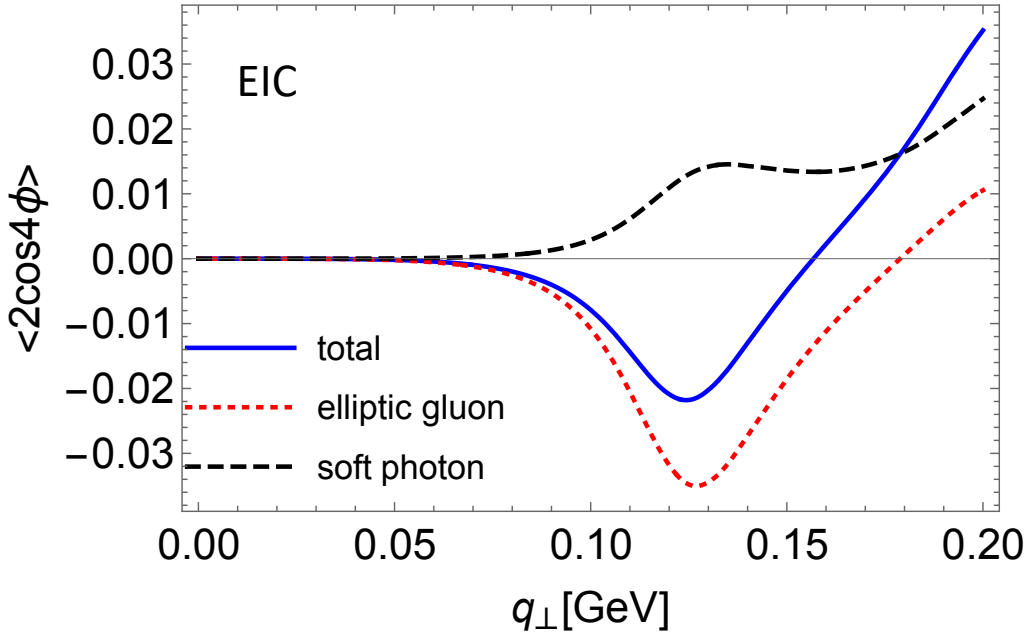


Phys. Rev. D **104**, 094021 (2021)

Elliptic gluon distribution: correlation between impact parameter and momentum

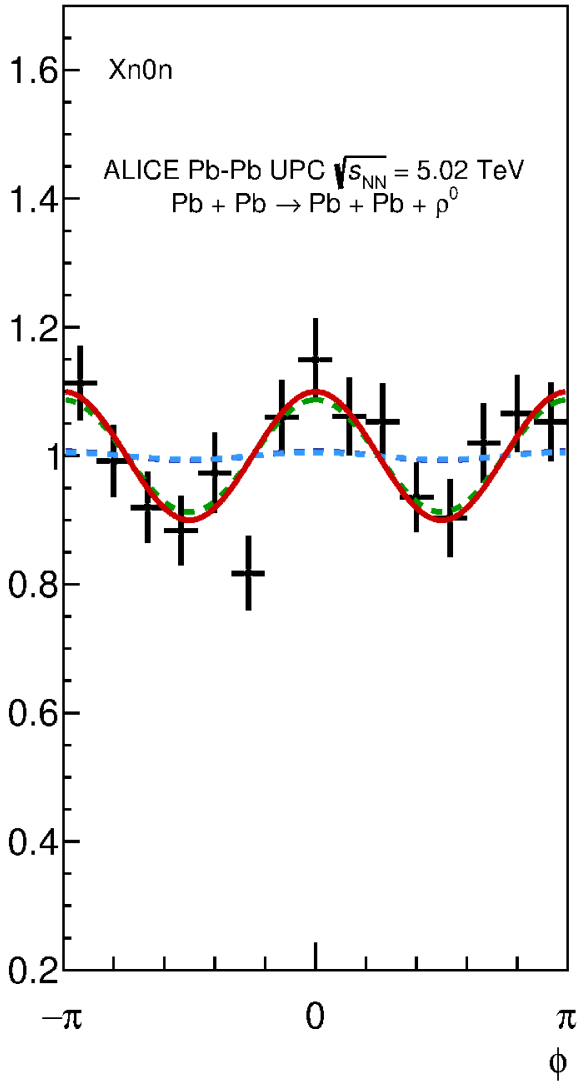
- Clear signature of elliptic gluon distribution within nuclei.
- Complimentary measurements at RHIC and EIC



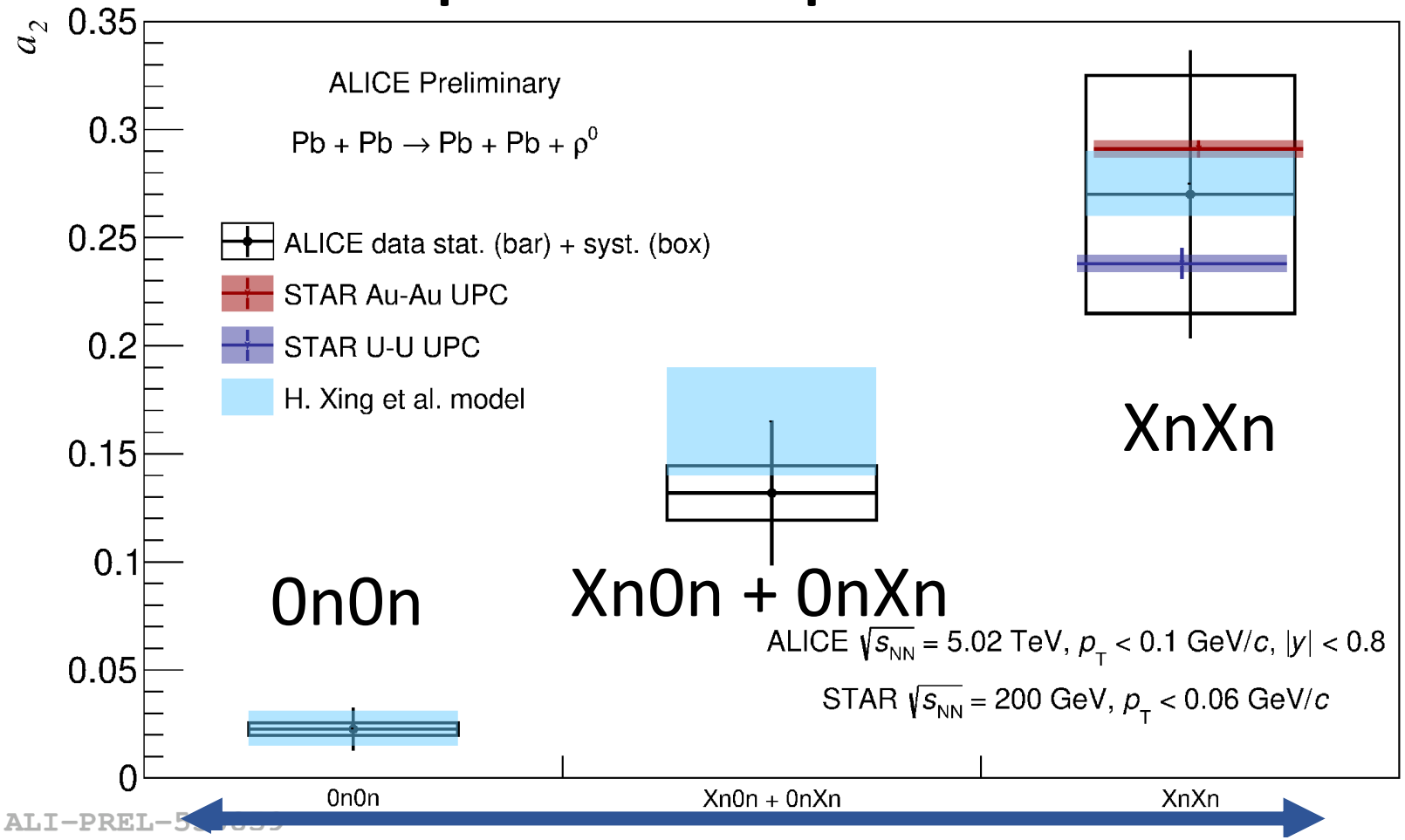


Confirmation from ALICE

Andrea Riffero (ALICE)



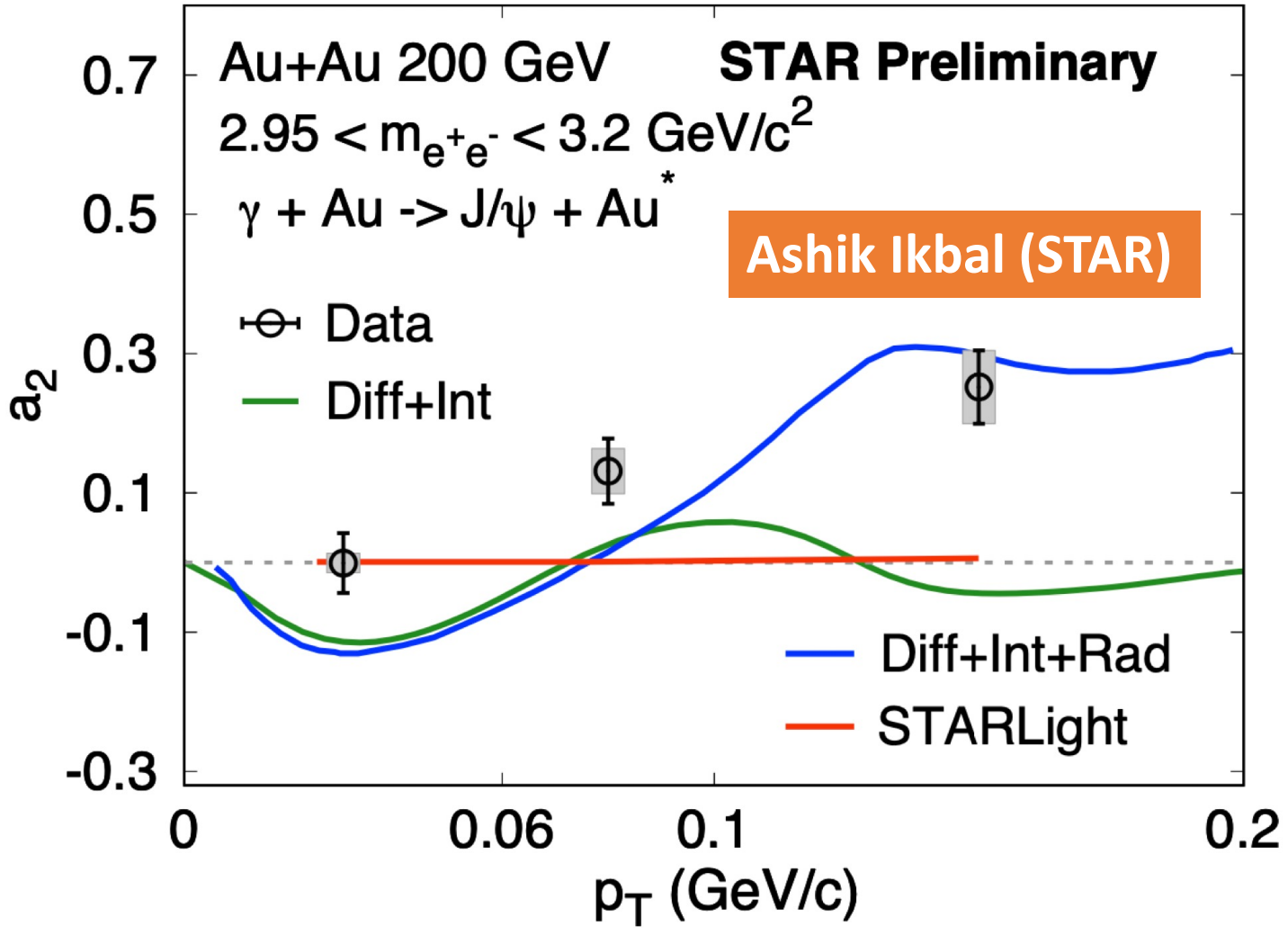
Neutron emission categories test the impact parameter dependence



Polarization effects: coherent diffractive J/ψ

- New STAR measurement of J/ψ
- Consistent within error with Diffraction + Interference (Diff+Int) effect at low p_T
- Effect of Soft Photon radiation (Rad) visible at higher p_T

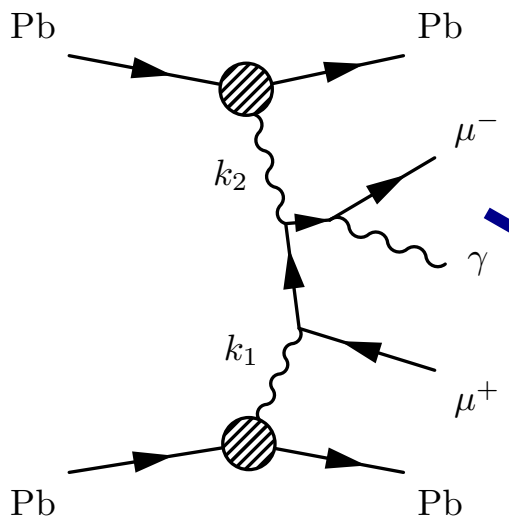
- New results on soft photon radiation (Sudakov effect) from ATLAS (See Peter Steinberg's talk)

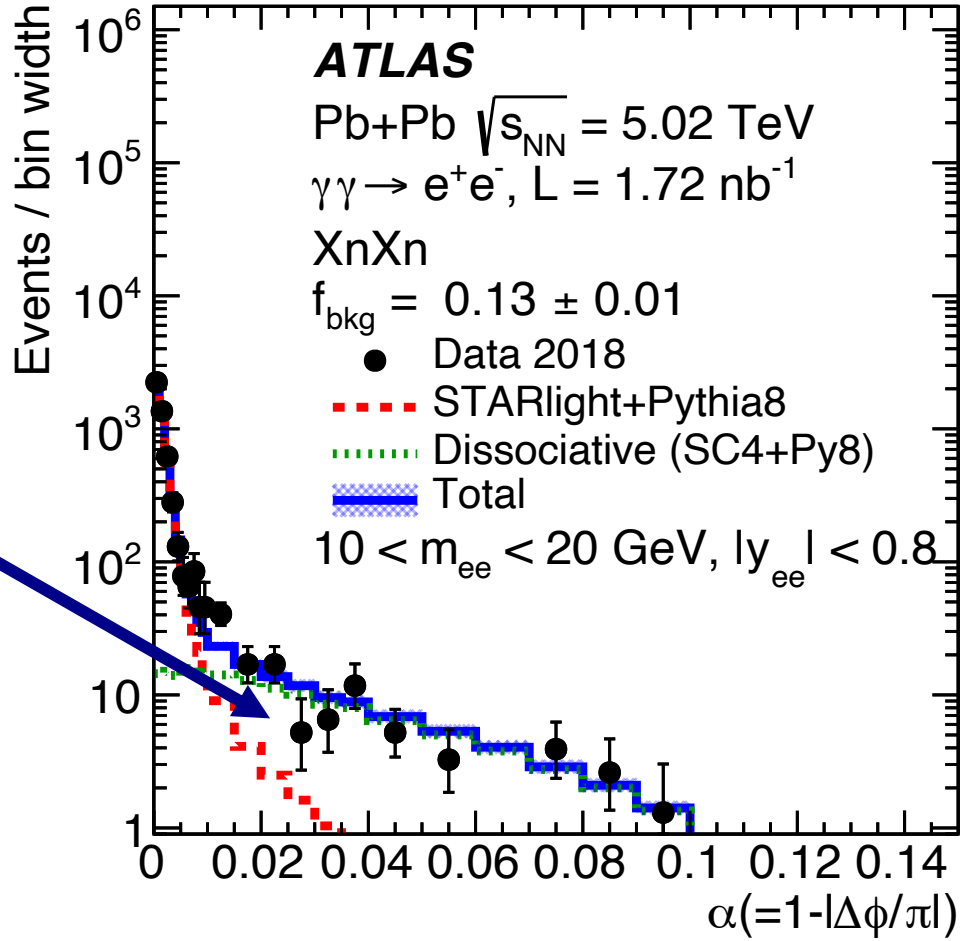


Constraints on Soft Photon Radiation

- New STAR measurement of J/ψ
- Consistent within error with Diffraction + Interference (Diff+Int) effect at low p_T
- Effect of Soft Photon radiation (Rad) visible at higher p_T
- New results on soft photon radiation (Sudakov effect) from ATLAS (See Peter Steinberg's talk)

Peter Steinberg (ATLAS)

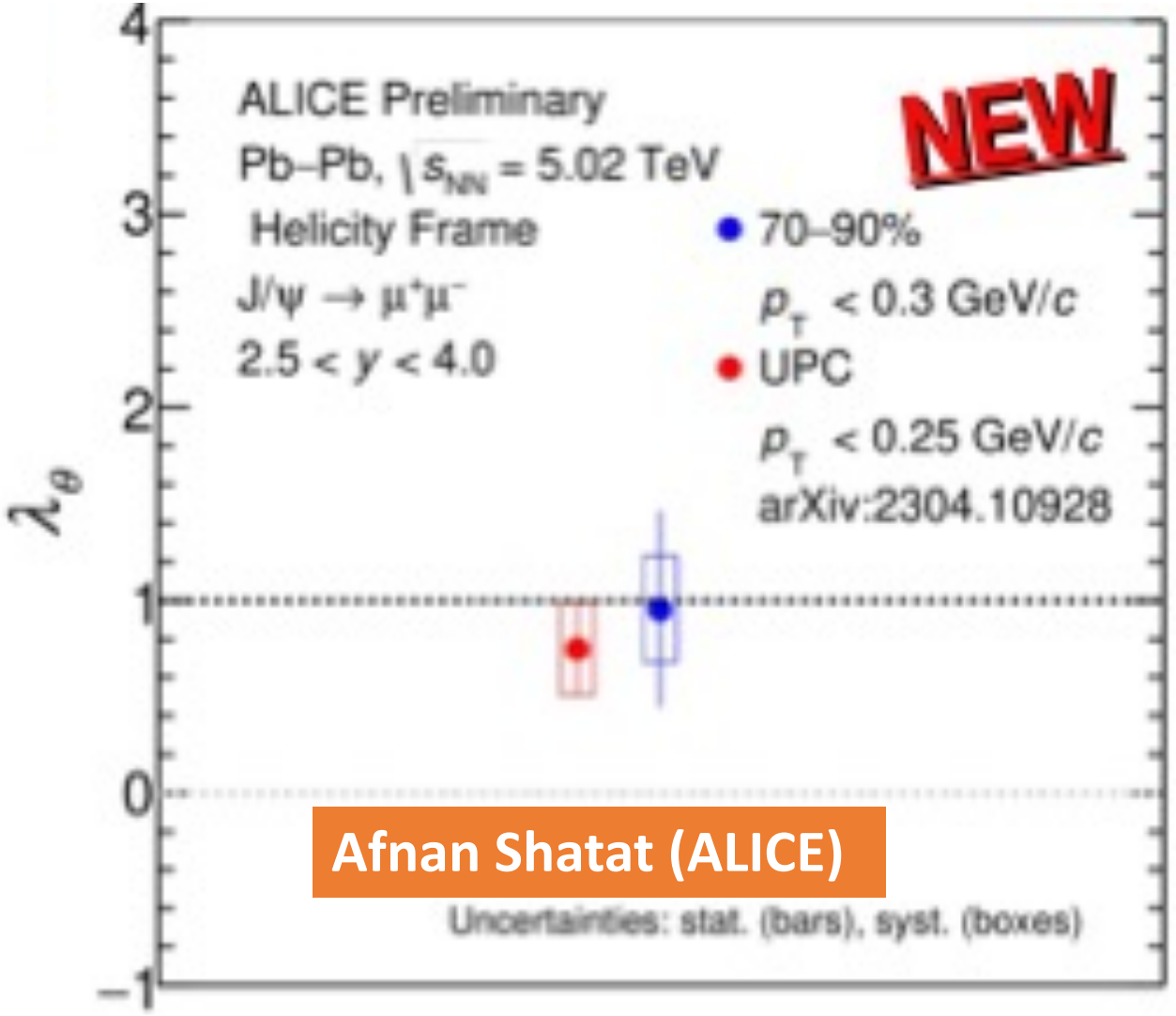




Polarization effects: coherent diffractive J/ψ

- ALICE measurement of spin density matrix elements of J/ψ
- 'Standard' spin alignment at forward rapidity
- Not related to interference effects

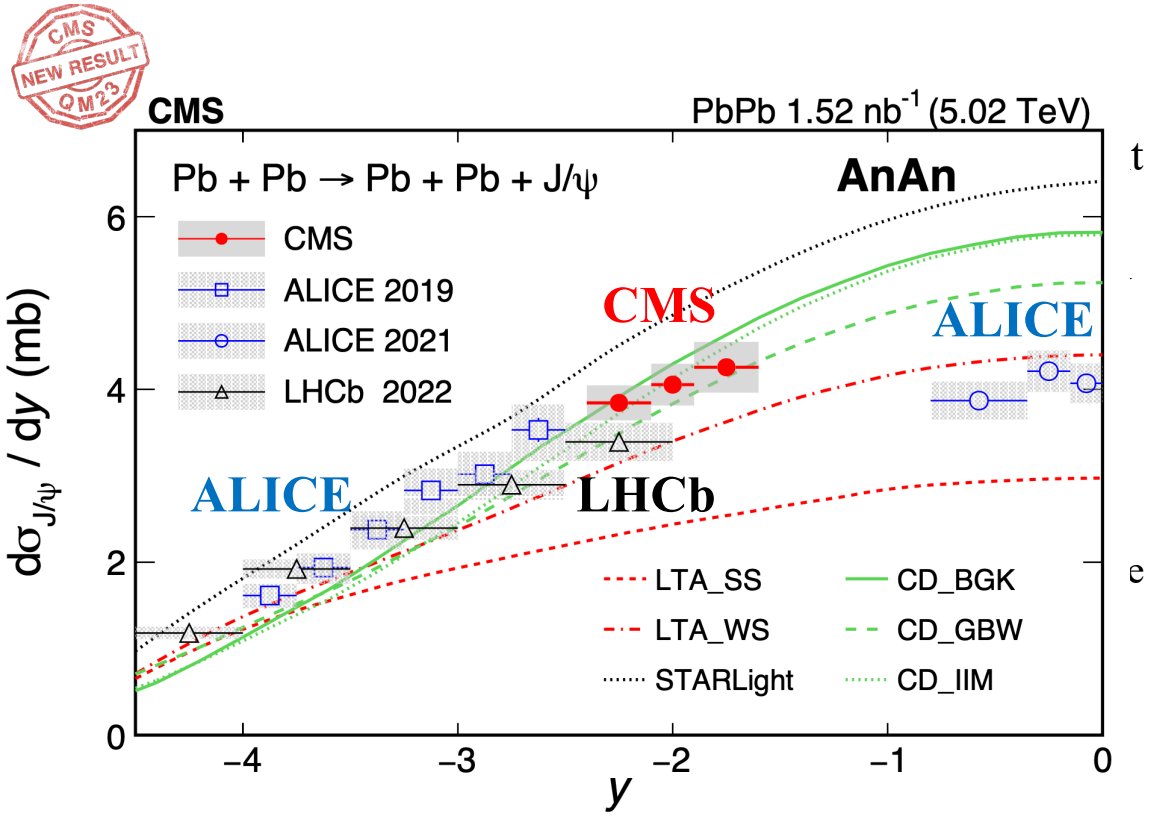
- Consistent with transverse polarized J/ψ

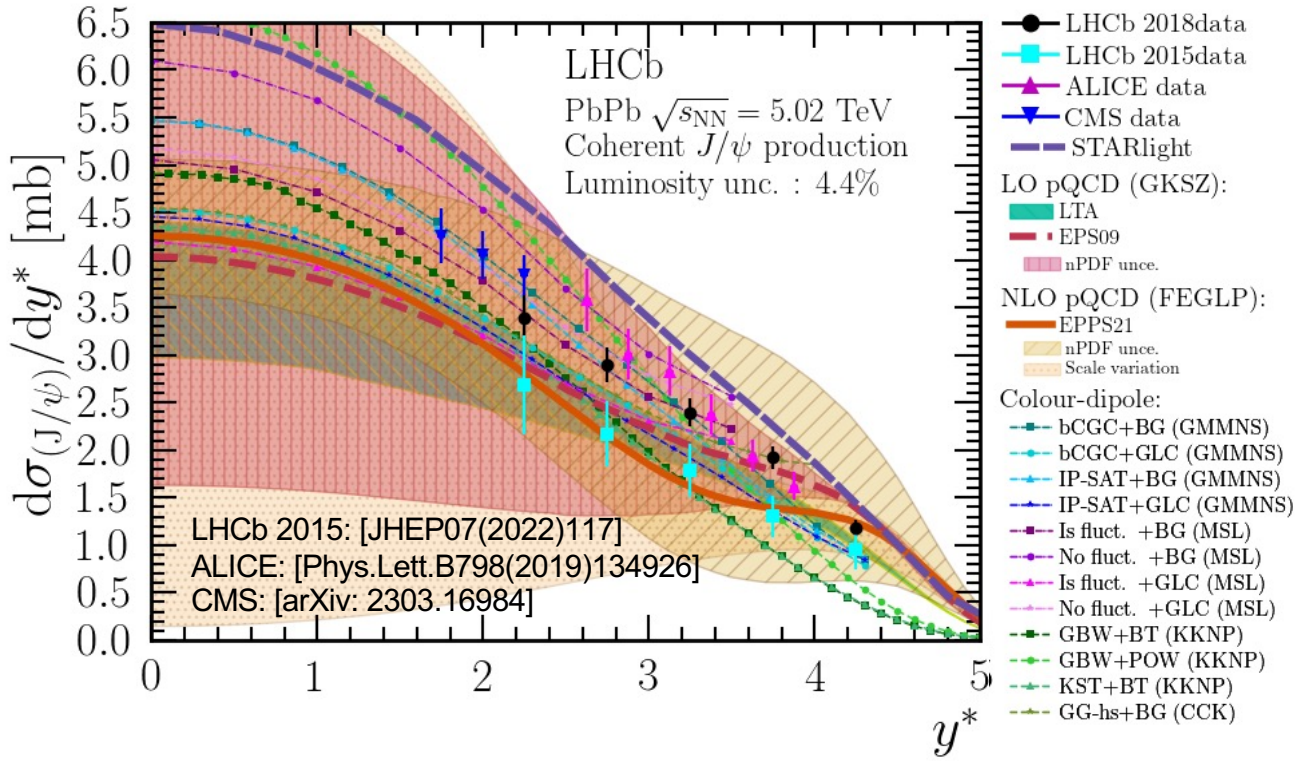


Coherent J/ψ Production away from Mid-Rapidity

- Rapidity dependence is key to distinguishing physics

JHEP 06 (2023) 146

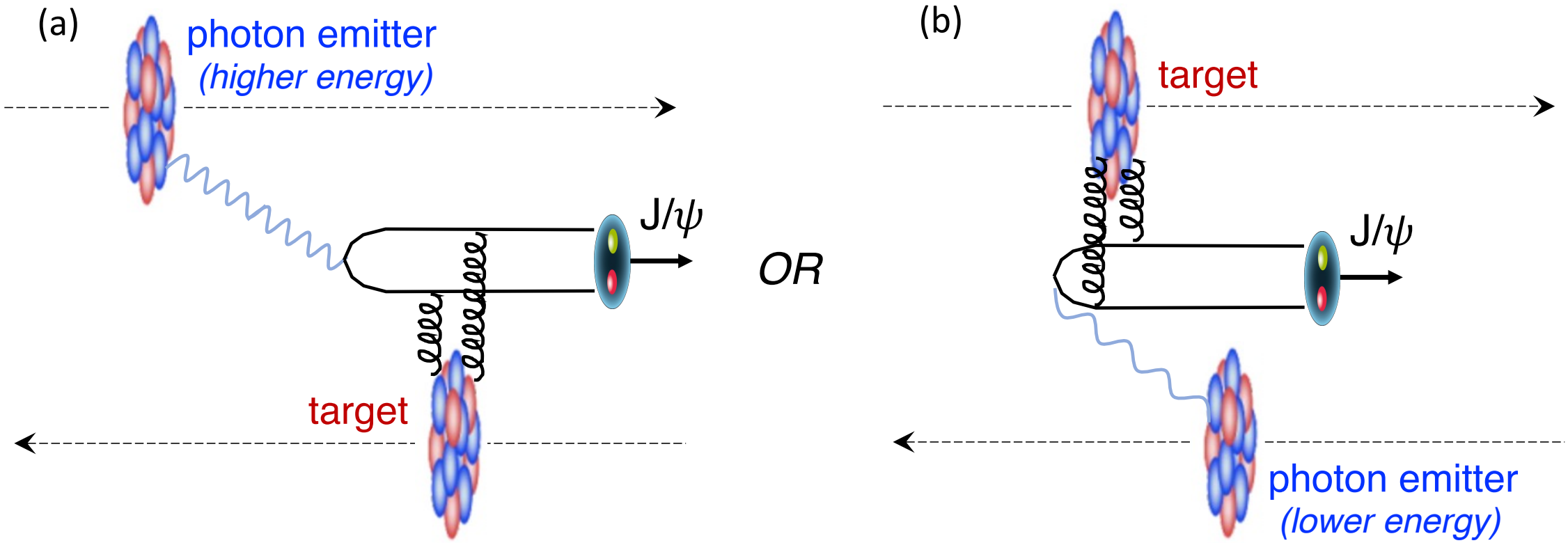




JiaZhao Lin (CMS)

Xiaolin Wang (LHCB)

Photon Energy Ambiguity



Utilize rapidity dependence & neutron emission to resolve ambiguity

Explore process in terms of $W_{\gamma n} \rightarrow x$-dependence

New insights into the gluon distribution and dynamics

Photon Energy Ambiguity

Dominant b ranges of different neutron classes:

- 0n0n: b > 40 fm
- 0nXn: b ~ 20 fm
- XnXn: b < 15 fm

What is measured | Photon flux from theory | What we want

$$\frac{d\sigma^{0n0n}_{AA\to AAJ/\psi}}{dy} = N^{0n0n}_{\gamma/A}(y)\cdot\sigma_{\gamma A\to J/\psi A'}(y) + N^{0n0n}_{\gamma/A}(-y)\cdot\sigma_{\gamma A\to J/\psi A'}(-y)$$

$$\frac{d\sigma^{0nXn}_{AA\to AA'J/\psi}}{dy} = N^{0nXn}_{\gamma/A}(y)\cdot\sigma_{\gamma A\to J/\psi A'}(y) + N^{0nXn}_{\gamma/A}(-y)\cdot\sigma_{\gamma A\to J/\psi A'}(-y)$$

$$\frac{d\sigma^{XnXn}_{AA\to A'A'J/\psi}}{dy} = N^{XnXn}_{\gamma/A}(y)\cdot\sigma_{\gamma A\to J/\psi A'}(y) + N^{XnXn}_{\gamma/A}(-y)\cdot\sigma_{\gamma A\to J/\psi A'}(-y)$$

Utilize rapidity dependence & neutron emission to resolve ambiguity

Explore process in terms of $W_{\gamma n}$

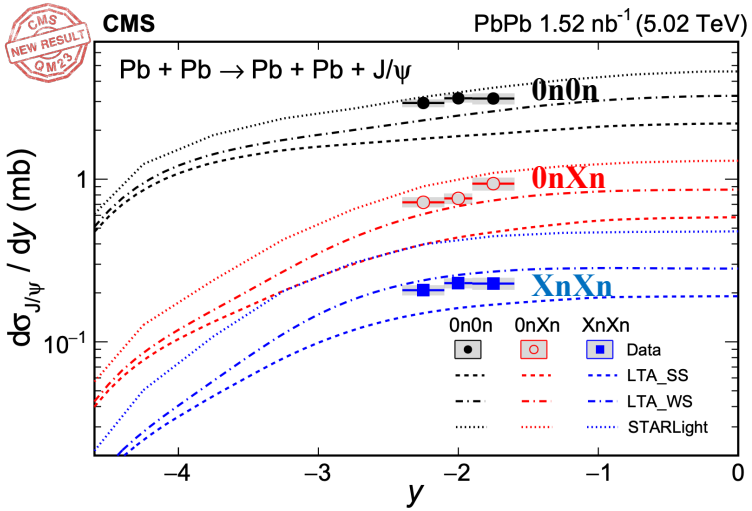
New insights into the gluon distribution and dynamics

Photon Energy Ambiguity

JiaZhao Lin (CMS)

What is measured | Photon flux from theory | What we want

arXiv:2303.16984



$$\frac{d\sigma^{0n0n}_{AA\to AAJ/\psi}}{dy} = N^{0n0n}_{\gamma/A}(y)\cdot\sigma_{\gamma A\to J/\psi A'}(y) + N^{0n0n}_{\gamma/A}(-y)\cdot\sigma_{\gamma A\to J/\psi A'}(-y)$$

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Utilize rapidity dependence & neutron emission to resolve ambiguity

Explore process in terms of $W_{\gamma n}$

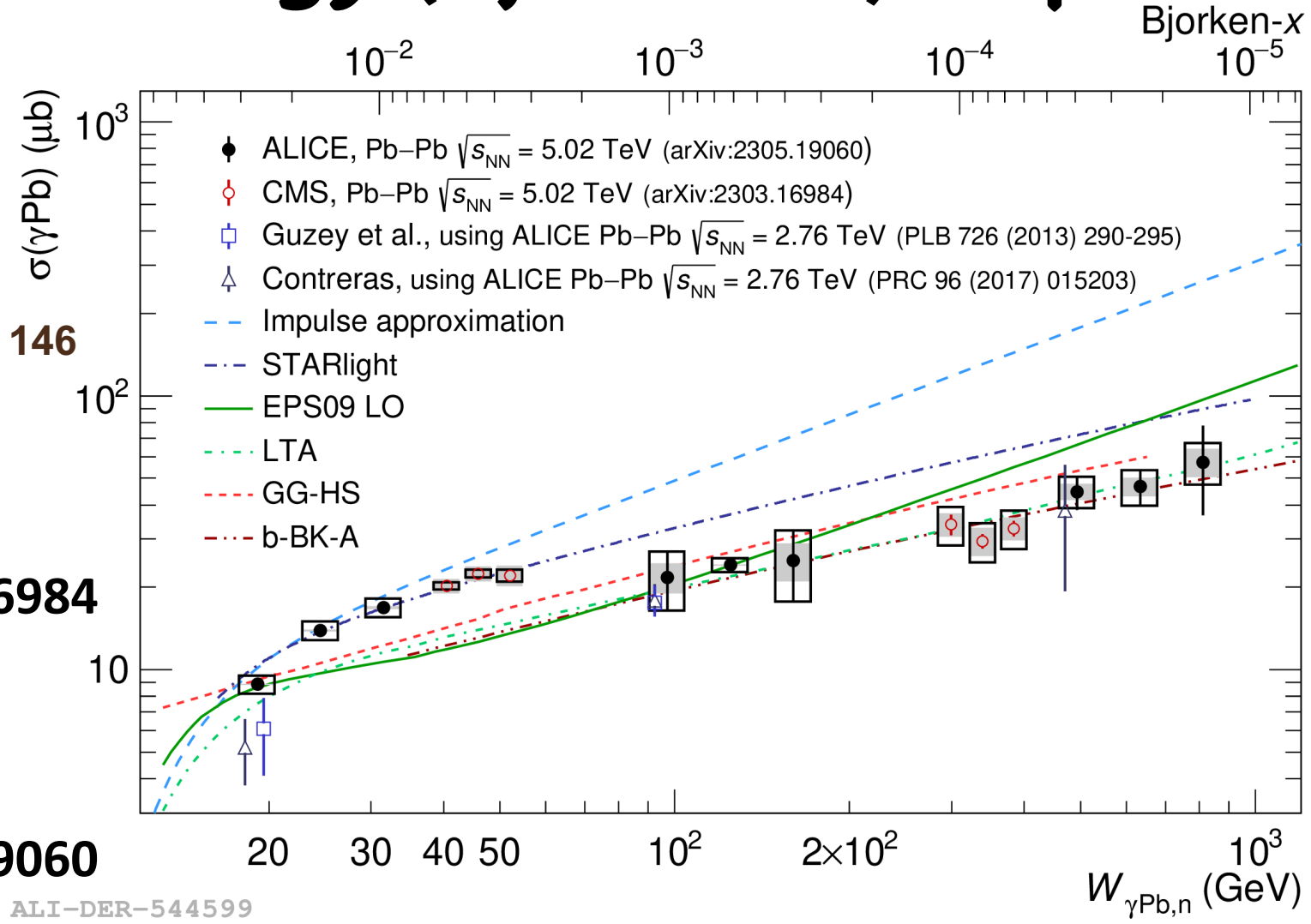
New insights into the gluon distribution and dynamics

Photon Energy (Bjorken-x) Dependence

LHCB
JHEP 06 (2023) 146

CMS
arXiv:2303.16984

ALICE
arXiv:2305.19060



ALI-DER-544599

JiaZhao Lin (CMS)

Simone Ragoni (ALICE)

Xiaolin Wang (LHCB)

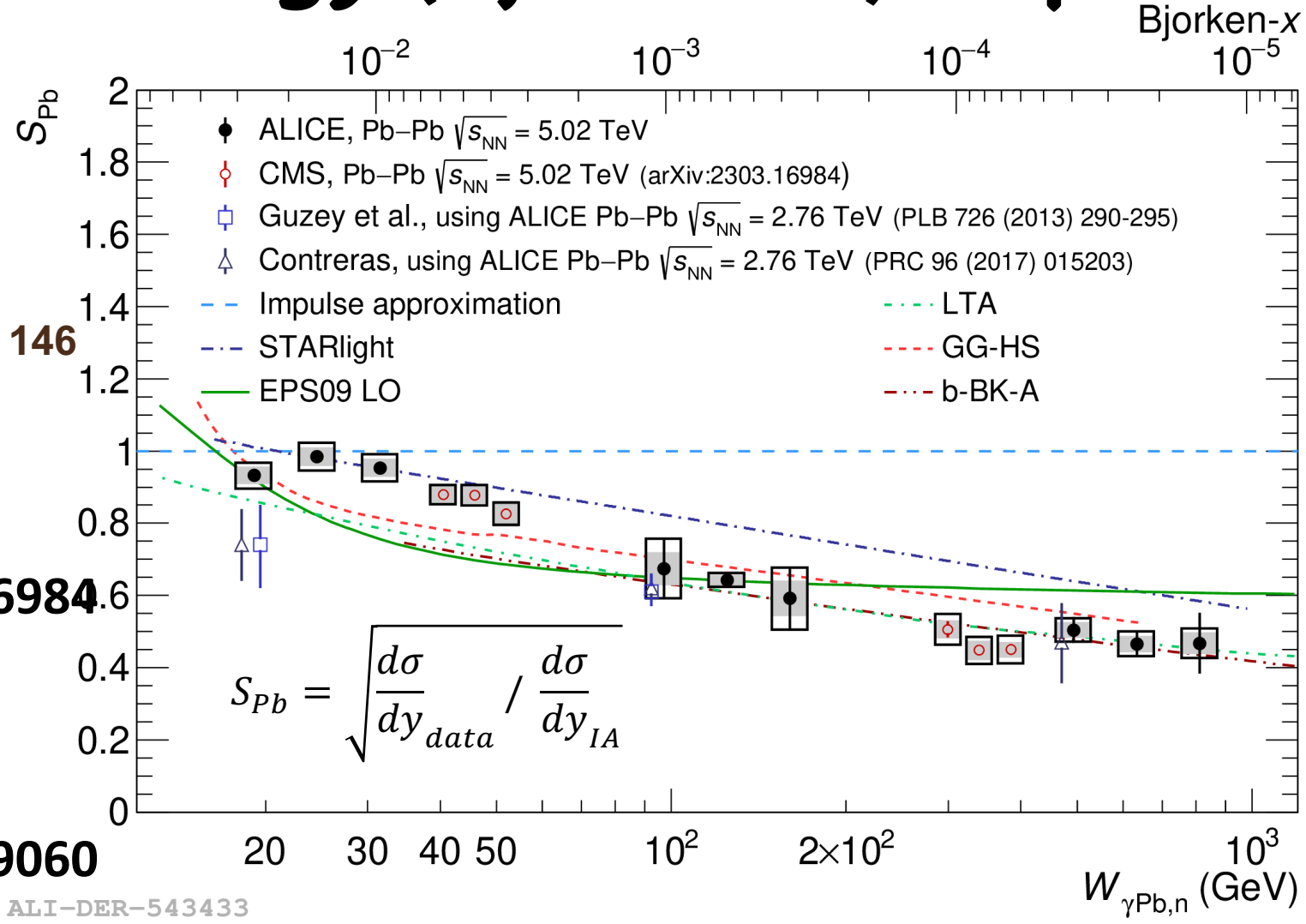
The impulse approximation assumes that the nuclear scattering is given by the superposition of the scattering on the individual nucleons

Photon Energy (Bjorken-x) Dependence

LHCB
JHEP 06 (2023) 146

CMS
arXiv:2303.16984

ALICE
arXiv:2305.19060



JiaZhao Lin (CMS)

Simone Ragoni (ALICE)

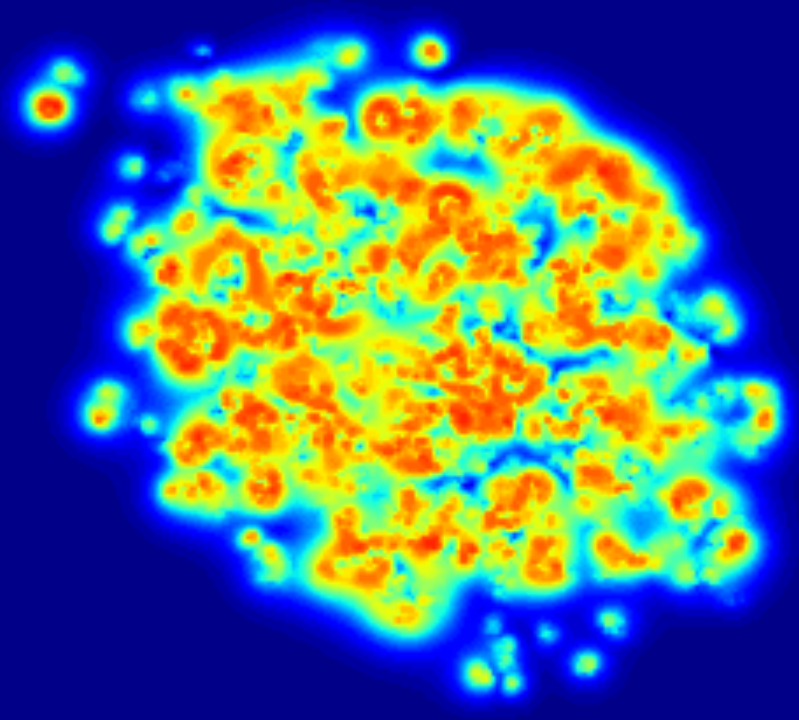
Xiaolin Wang (LHCB)

As much as 50% suppression at low-x

No single model describes data, more to learn!

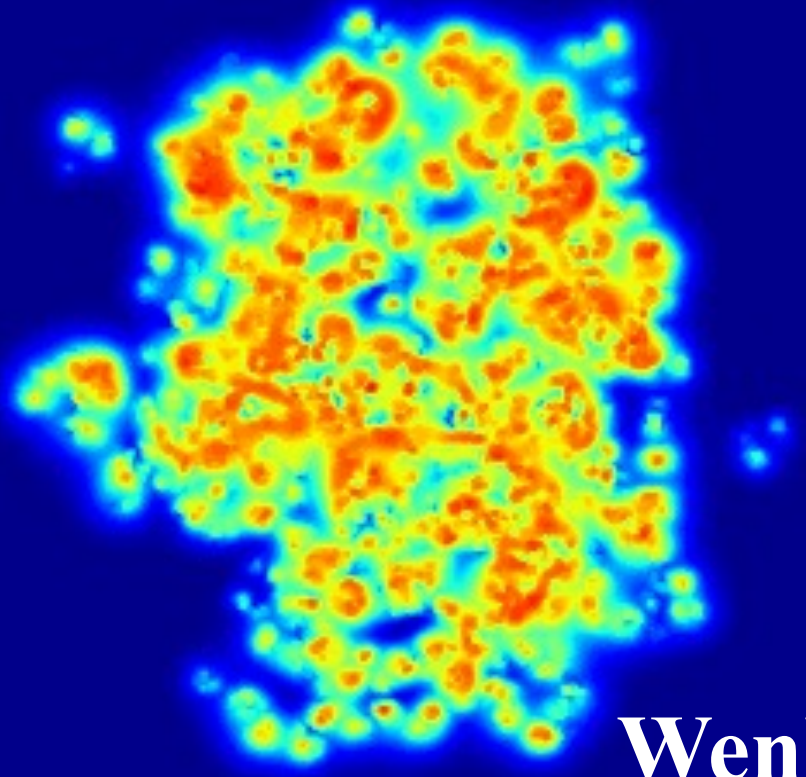
Sub-Nucleonic Imaging

$^{238}\mathrm{U}, \beta_2 = 0.5$



event-1

$^{238}\mathrm{U}, \beta_2 = 0.5$

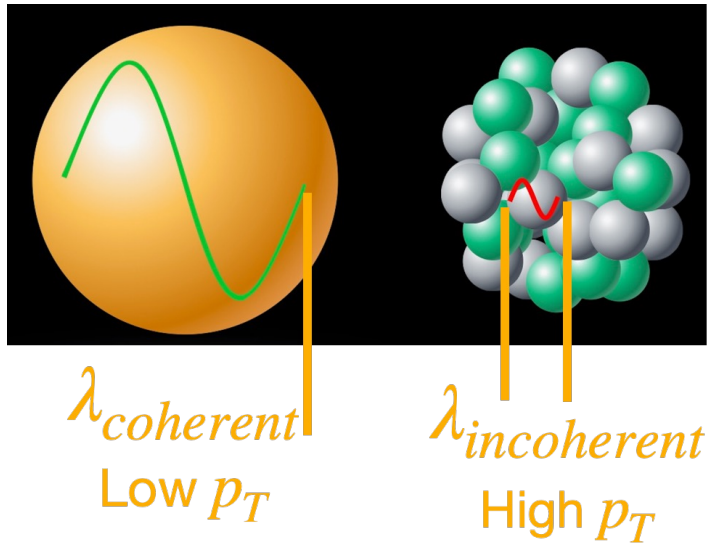


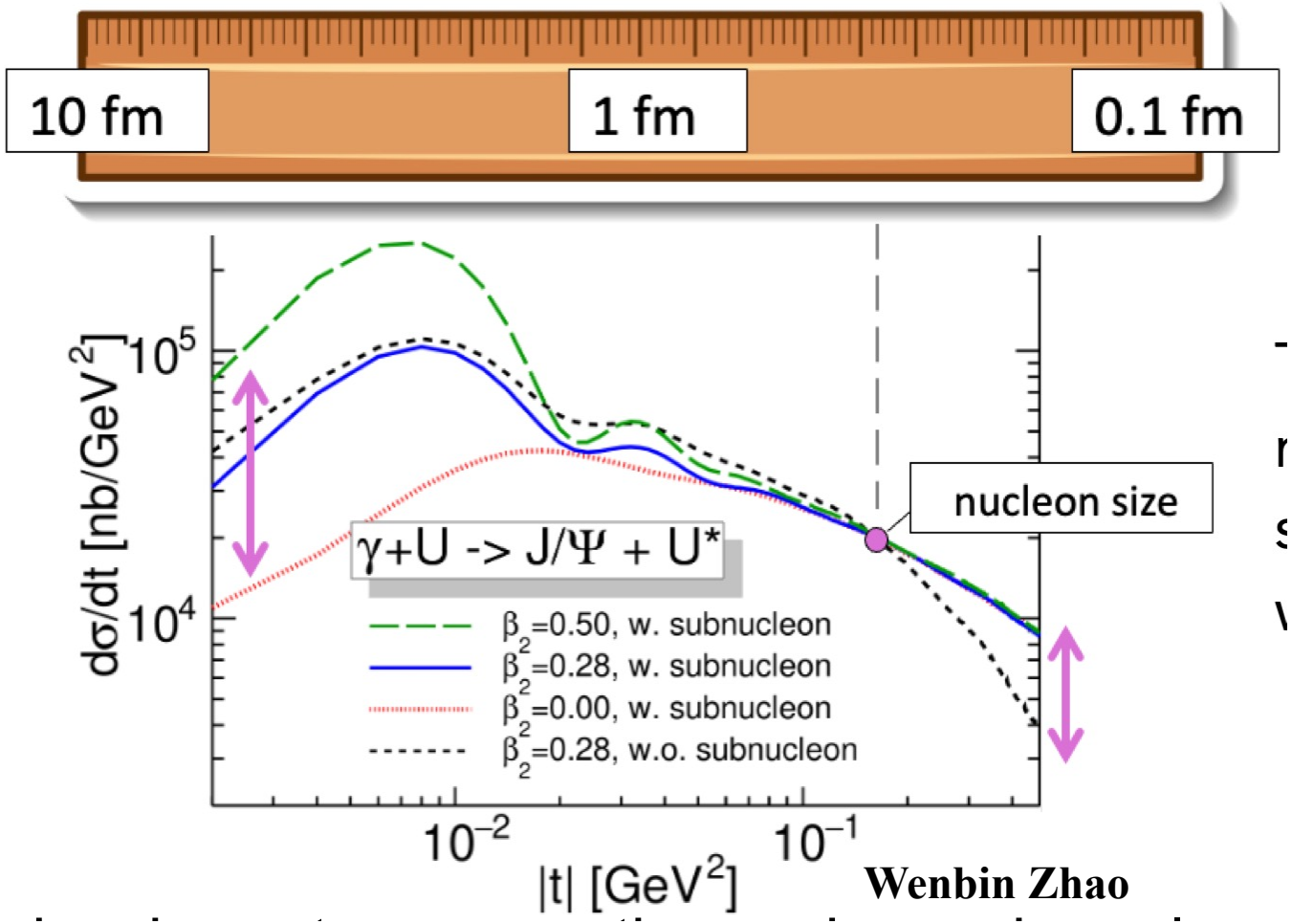
event-2

Wenbin Zhao

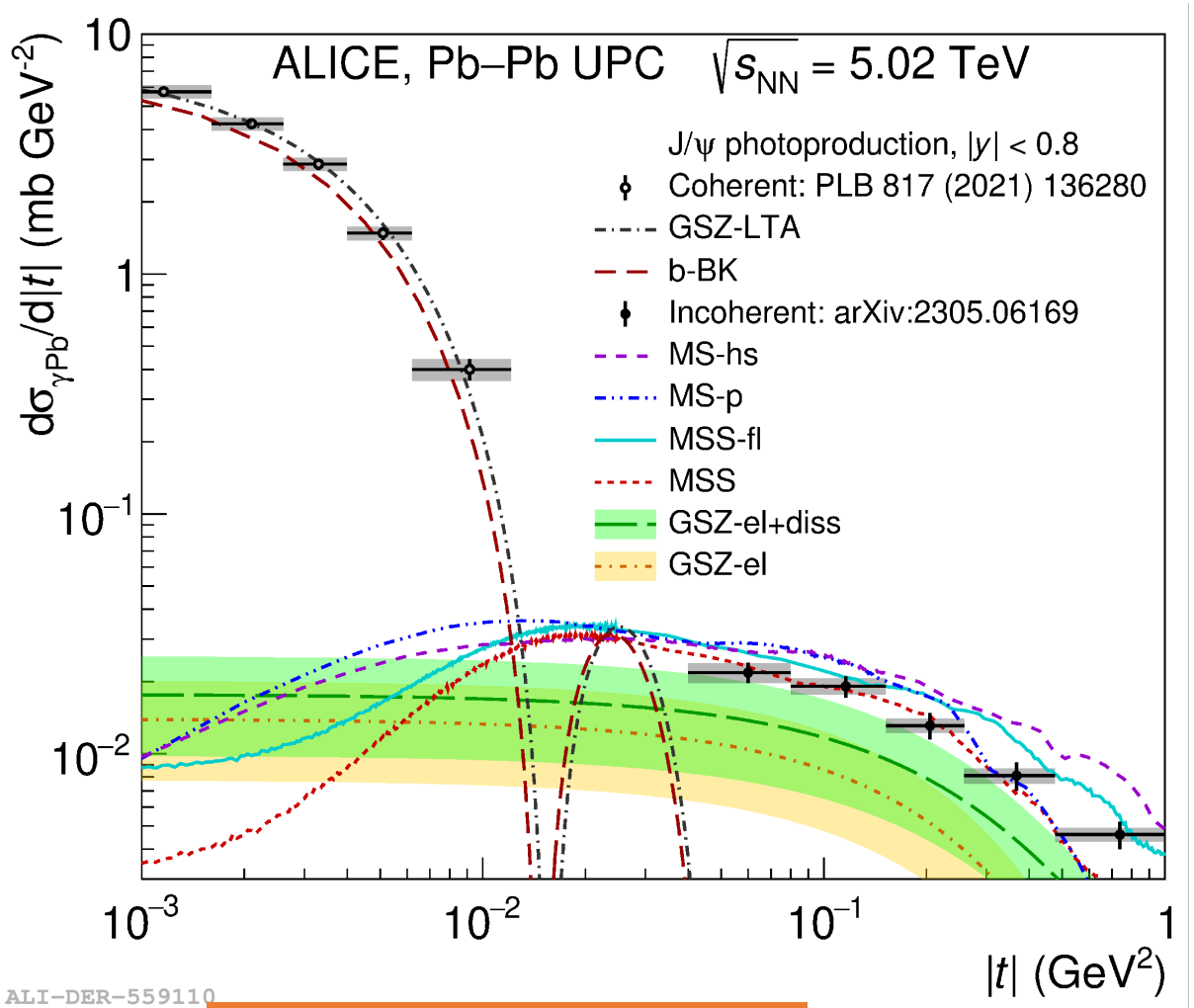
Incoherent Process, Not just a Background!

- Transverse momentum sets the length scale
- 'See' structures from whole nucleus, to nucleons, to quarks

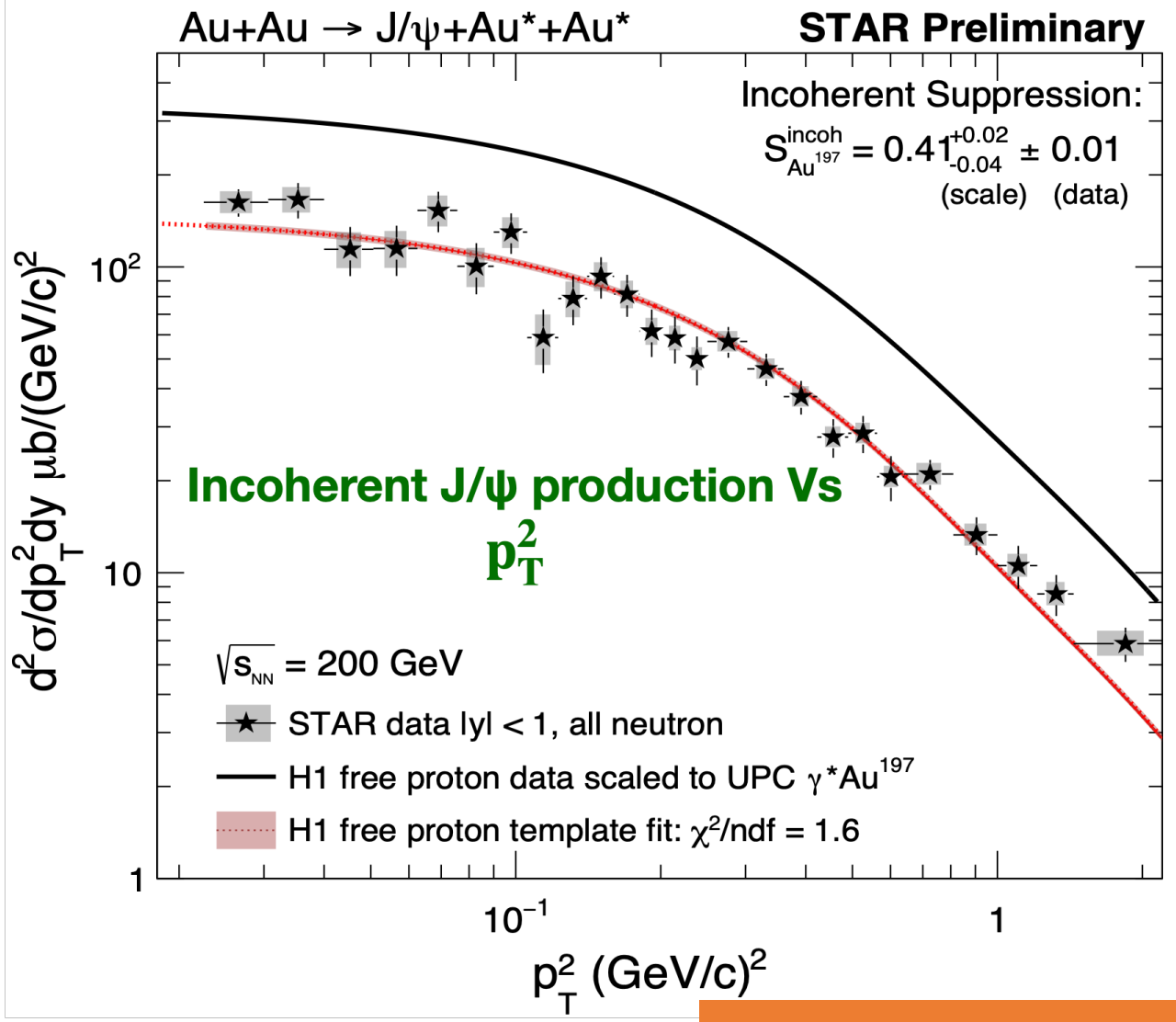




Incoherent J/ψ – Sub-Nucleonic Imaging

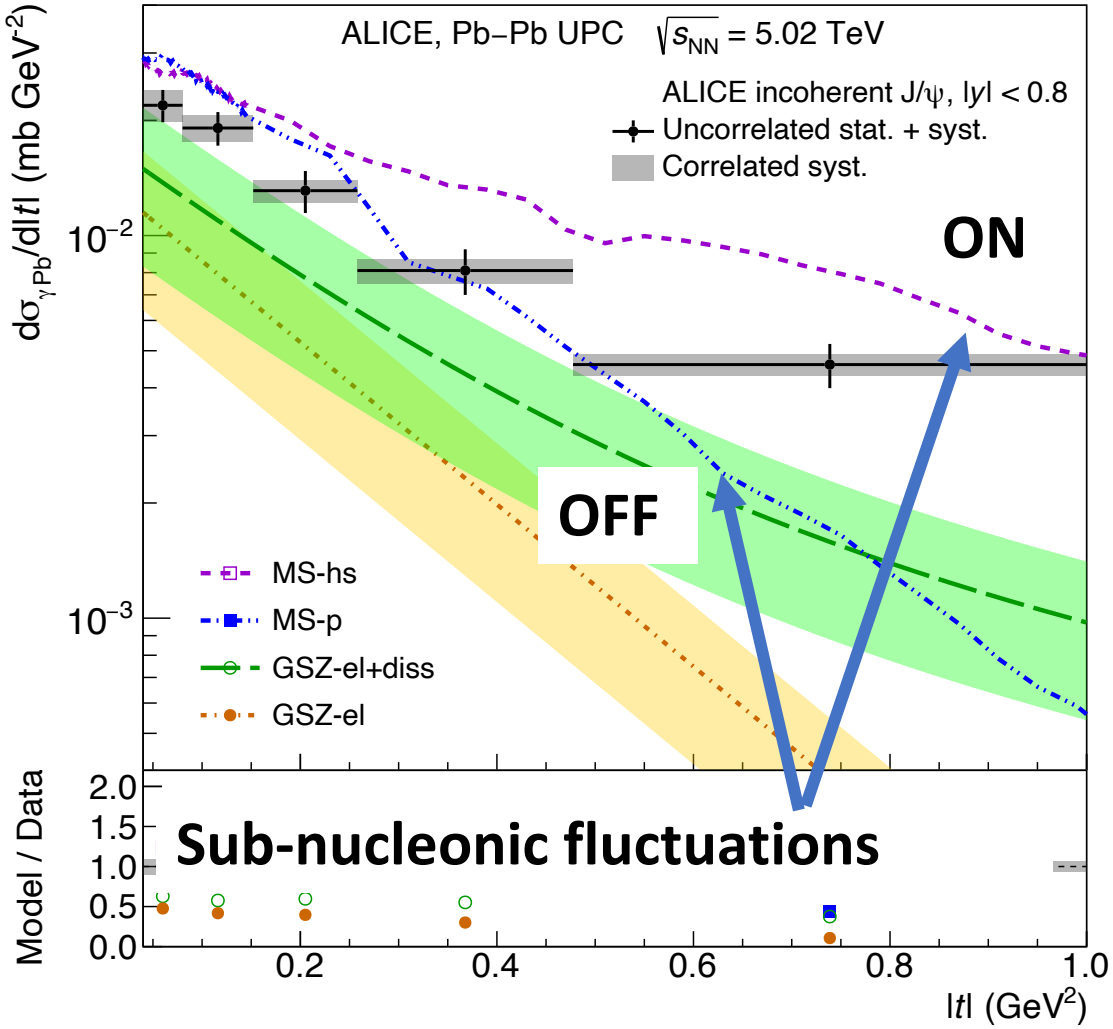


Adam Matvia (ALICE)

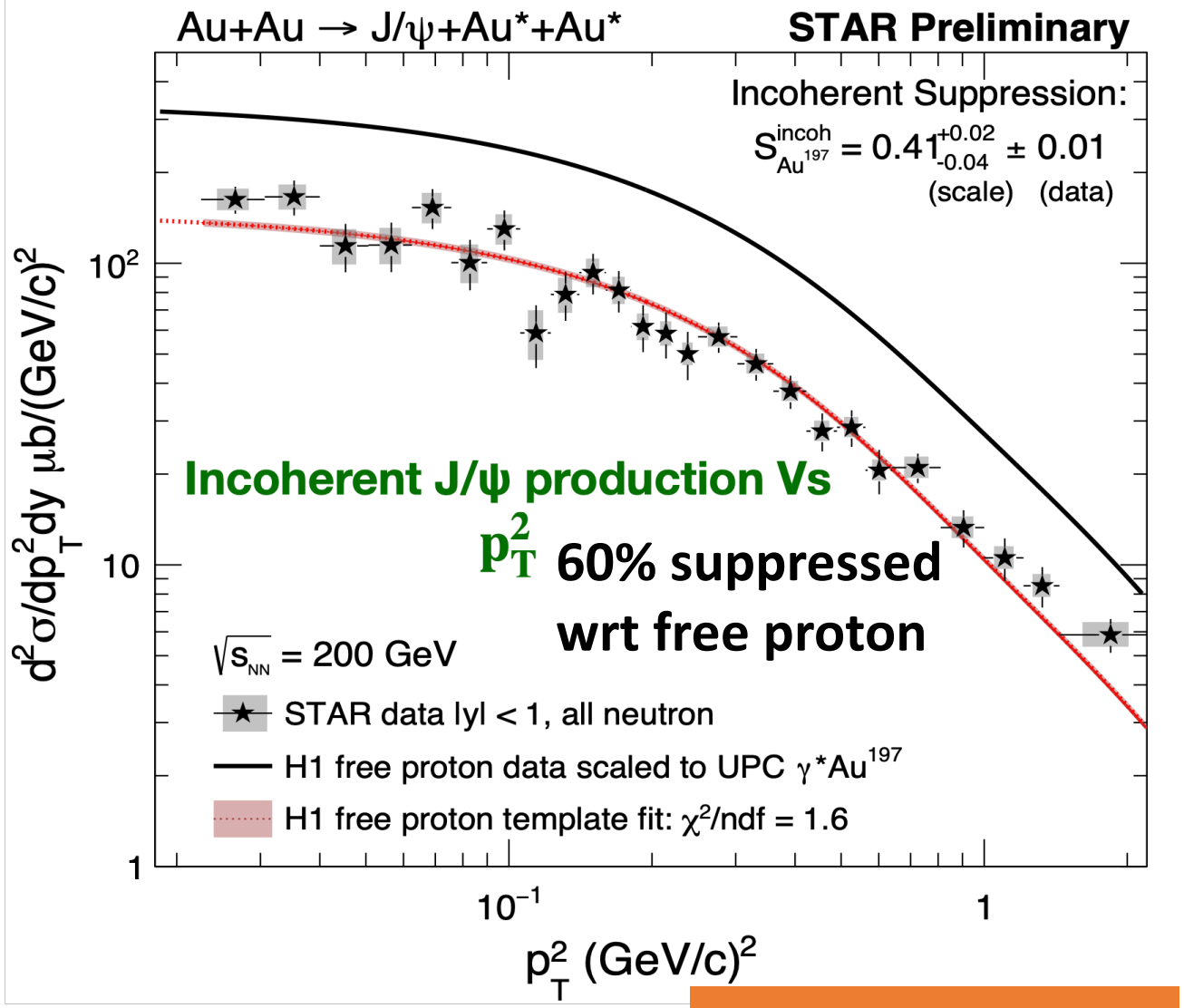


Ashik Ikbal (STAR)

Incoherent J/ψ – Sub-Nucleonic Imaging



Adam Matvia (ALICE)



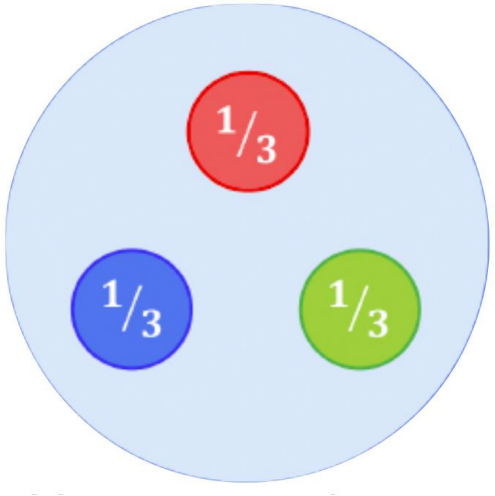
Ashik Ikbal (STAR)

Mäntysaari et. al, Phys. Rev. D **106** (2022) 7, 074019)

What carries the Baryon Number?

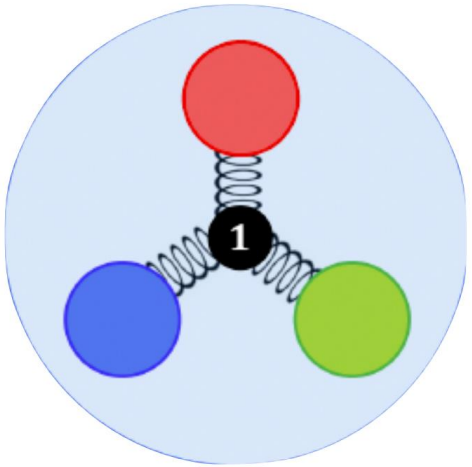
Chun Tsang (STAR)

Valence quark



Conventional picture

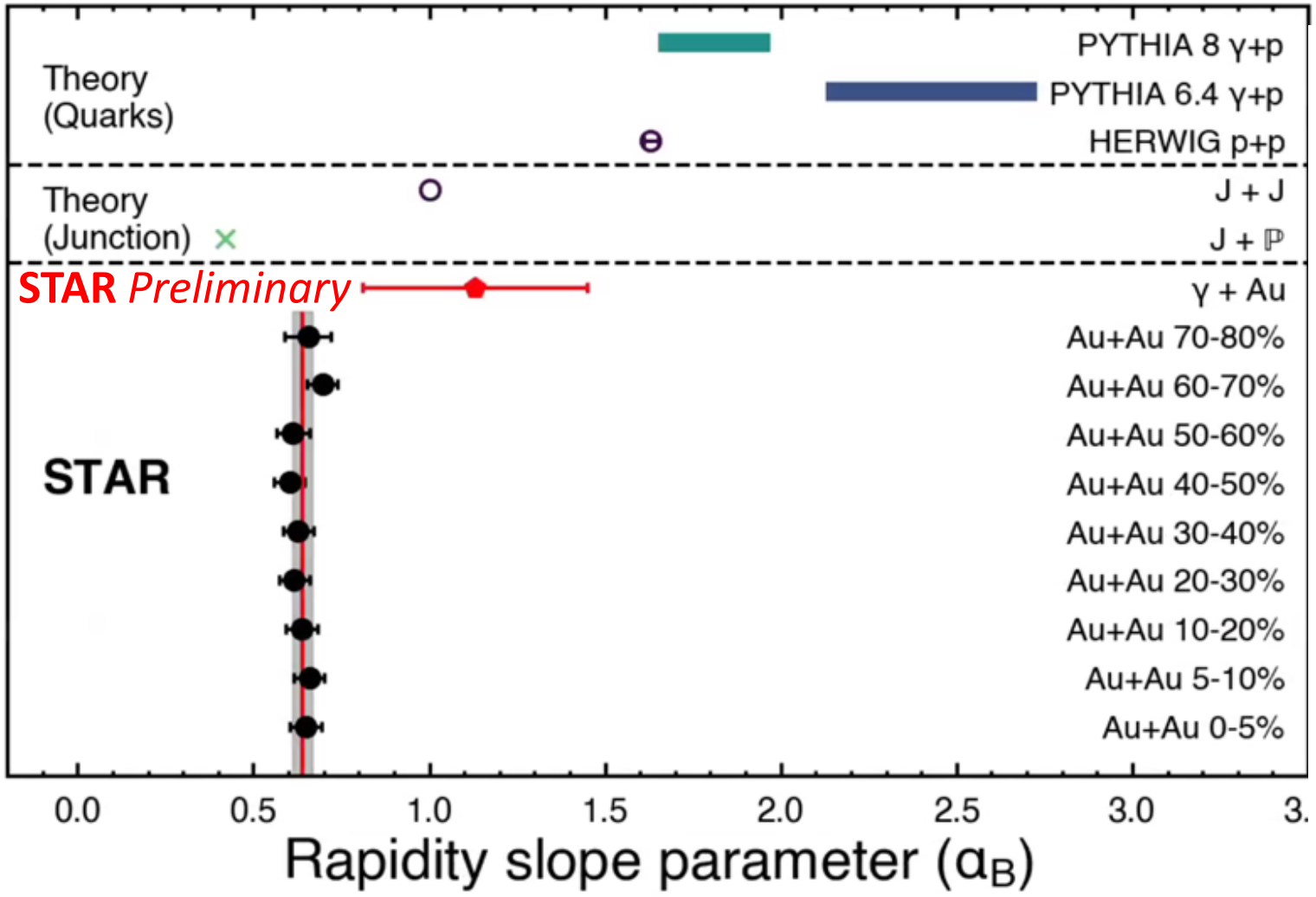
Baryon junction [1, 2]



[1]: Artru, X. String Model with Baryons: Topology, Classical Motion. Nucl. Phys. B 85, 442–460 (1975).
[2]: Rossi, G. C. & Veneziano, G. A Possible Description of Baryon Dynamics in Dual and Gauge Theories. Nucl. Phys. B 123, 507–545 (1977)

Net-Baryon in Photonuclear Collisions

Chun Tsang (STAR)



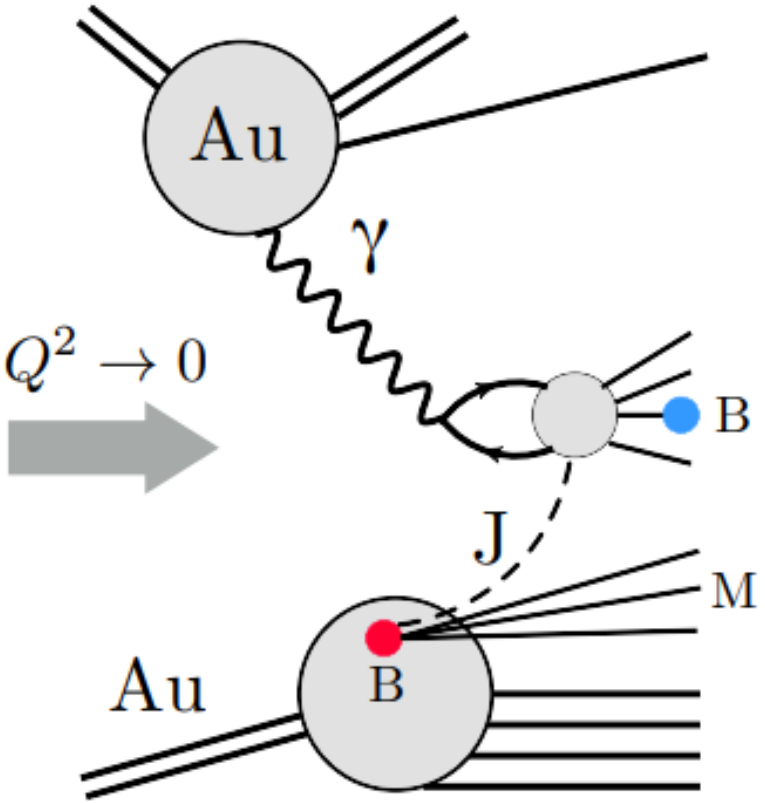
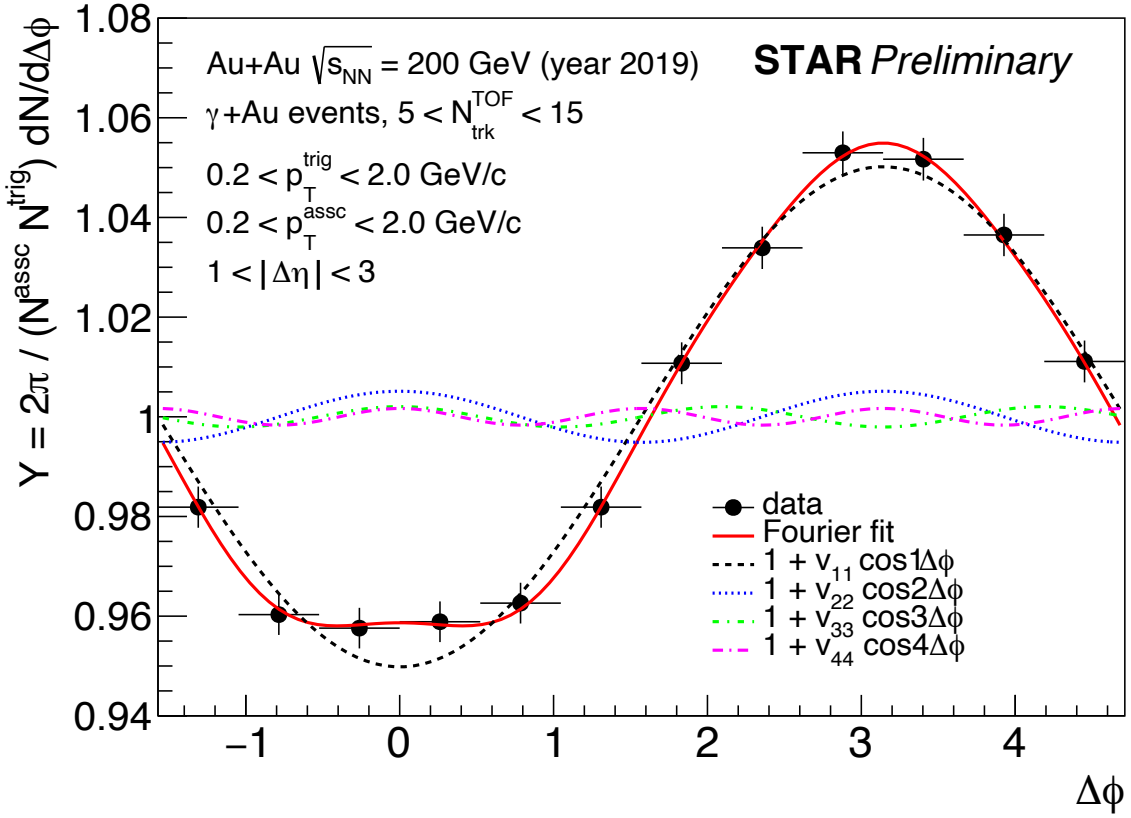


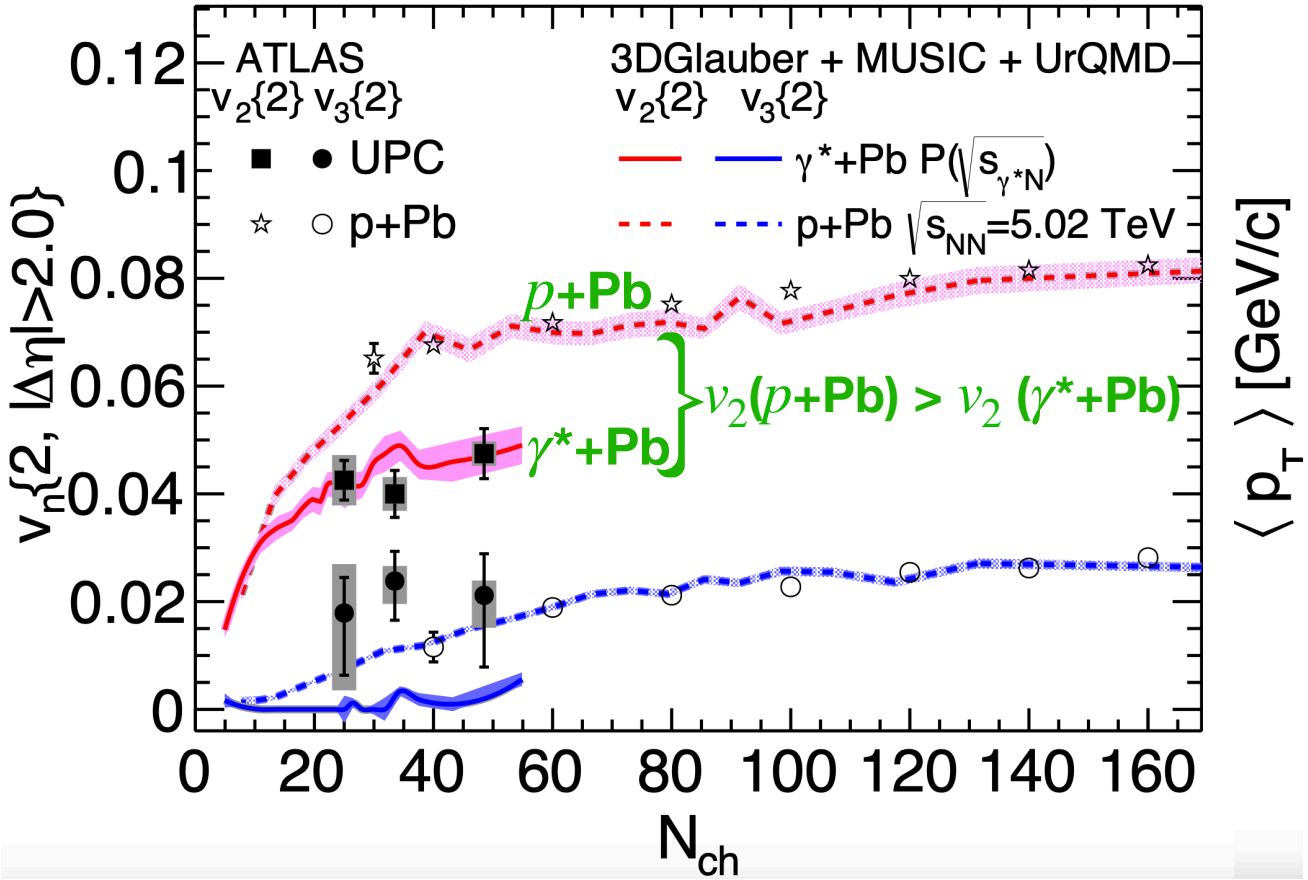
Figure from J. D. Brandenburg, N. Lewis, P. Tribedy, Z. Xu, arXiv:2205.05685 (2022)

QGP-like signatures in UPC?

Shengli Huang (STAR)

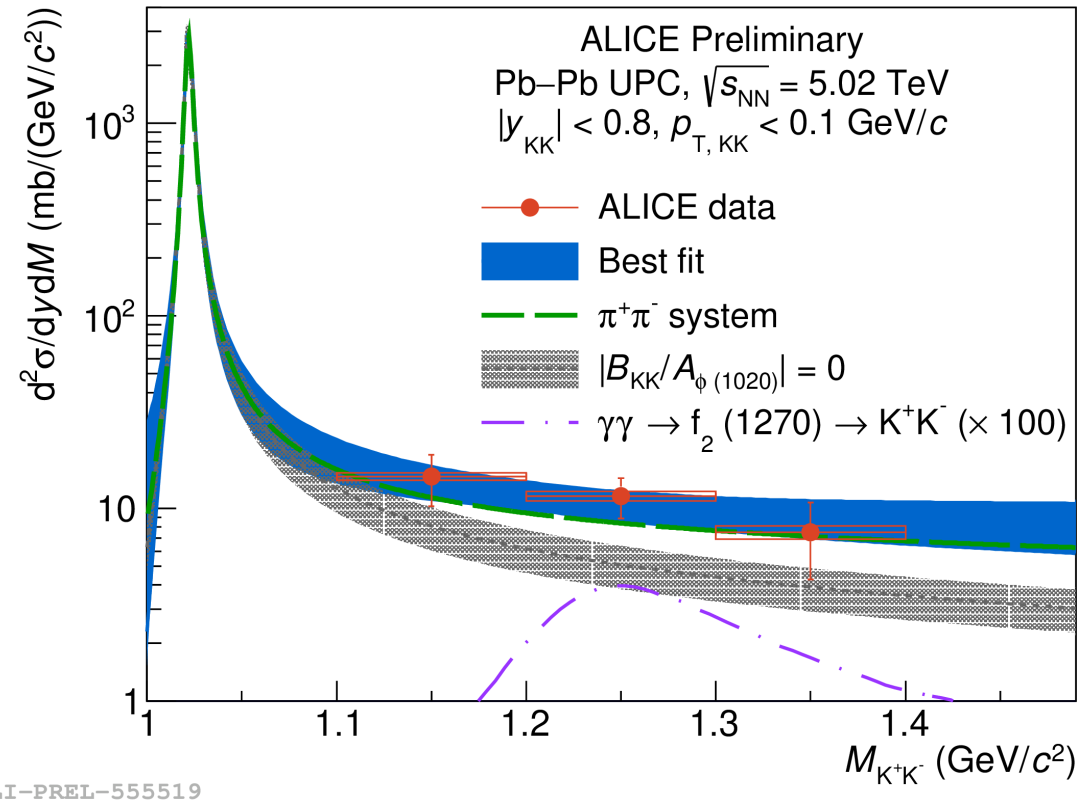


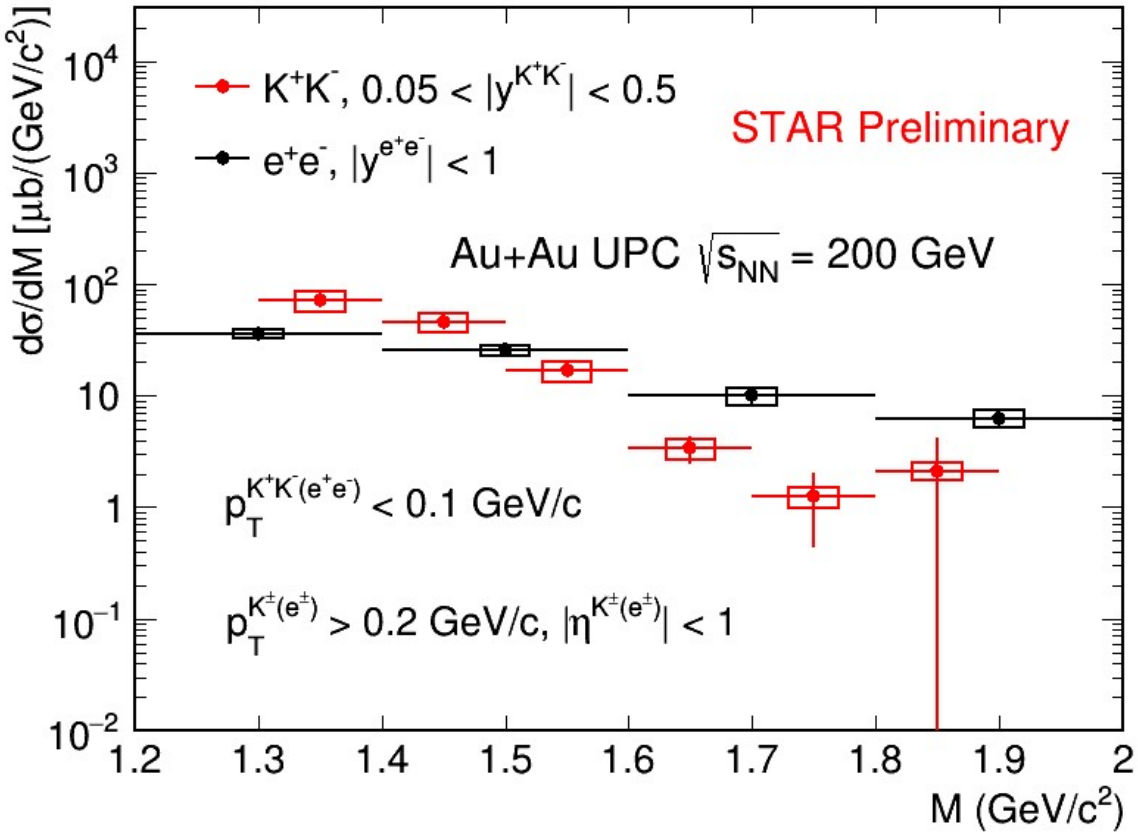
Sruthy Jyothi Das (ATLAS)



- First STAR study of flow in γA
- ATLAS: Flow even in UPCs -> hierarchy with pA

First measurement of Photonuclear K^+K^- production





Alexander Bylinkin (ALICE)

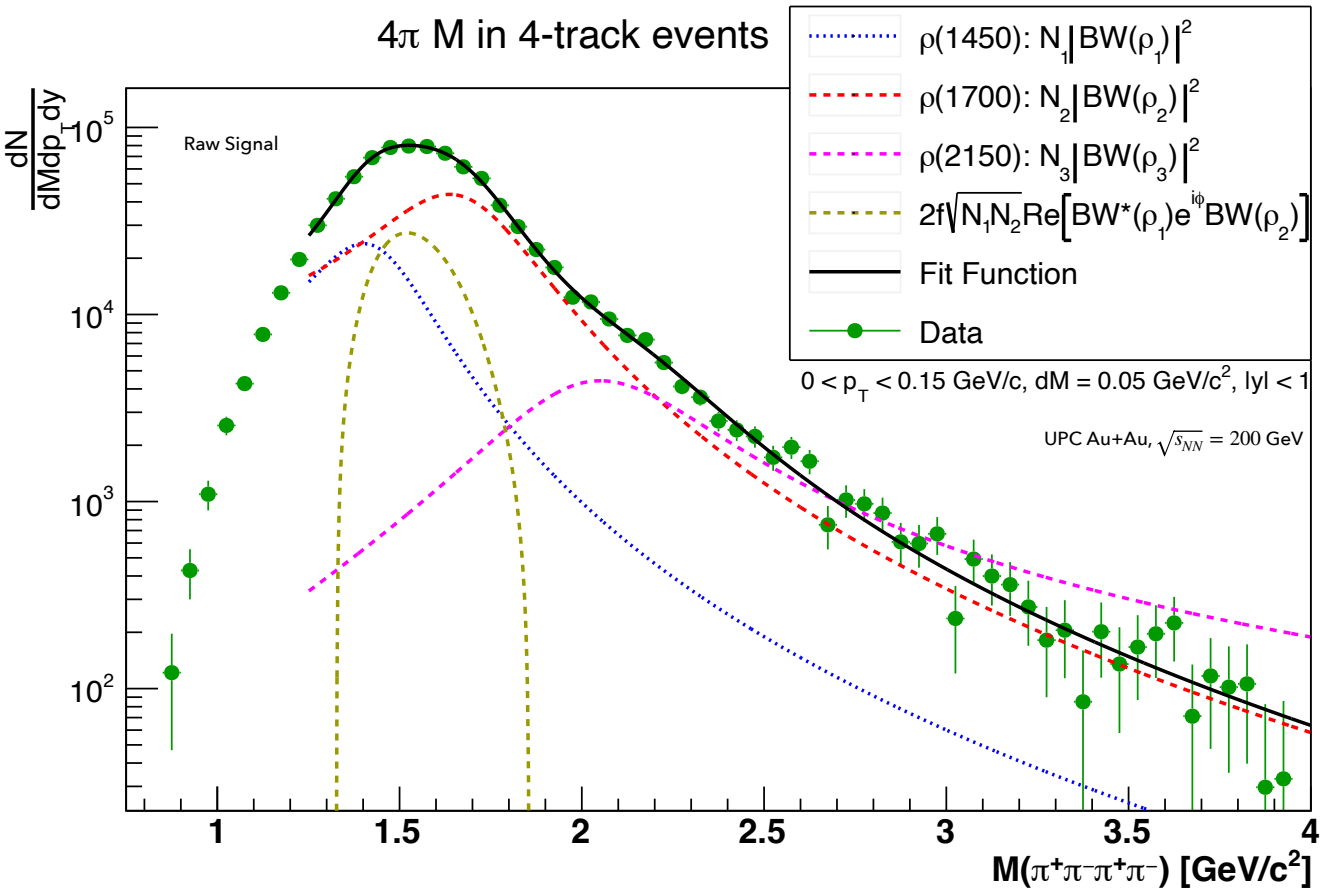
Xin Wu (STAR)

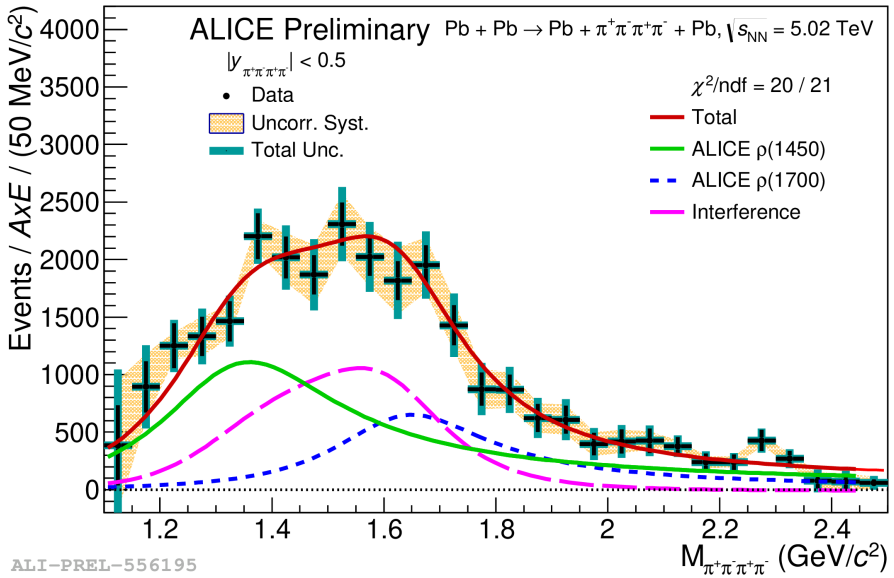
First measurements of Photonuclear $\pi^+\pi^-\pi^+\pi^-$ production

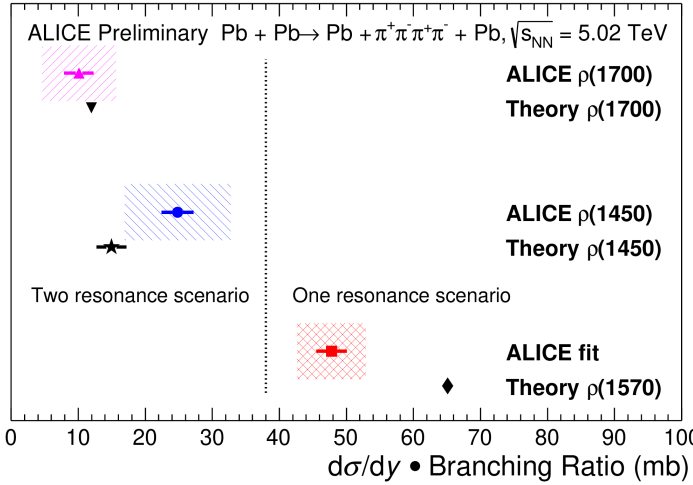
- STAR and ALICE: Data suggest multiple resonances

David Tlusty (STAR)

Alexander Bylinkin (ALICE)

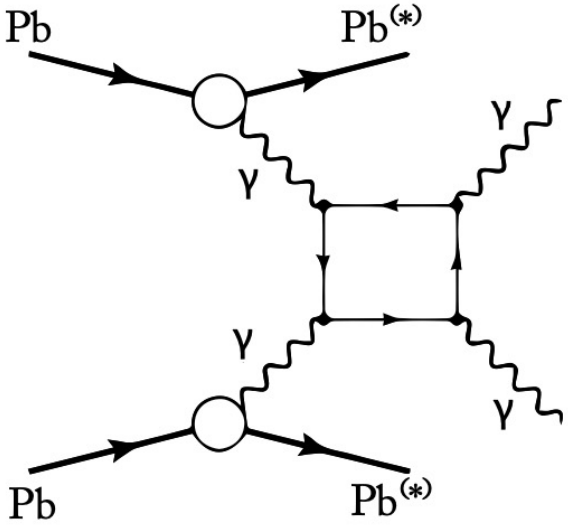






Recent Discoveries in Ultra-peripheral collisions:

2017: Light-by-Light



Open Access | Published: 14 August 2017

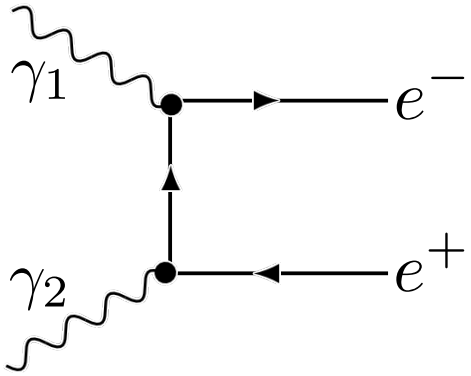
Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC

ATLAS Collaboration

Nature Physics **13**, 852–858 (2017) | Cite this article

41k Accesses | **185** Citations | **521** Altmetric | Metrics

2021: Breit-Wheeler



OUTPUTS FROM PHYSICAL REVIEW LETTERS

#42

of 37,322 outputs

2023: Entanglement Enabled Interference

Science Advances

AAAS

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Tomography of ultrarelativistic nuclei with polarized photon-gluon collisions

Overview of attention for article published in Science Advances, January 2023

Scientists See Quantum Interference between Different Kinds of Particles for First Time

A newly discovered interaction related to quantum entanglement between dissimilar particles opens a new window into the nuclei of atoms

UPC – Active and growing

What UPC Discovery is next!

> 8 Talks

Coherent J/ψ photoproduction and polarization in peripheral Pb-Pb collisions with ALICE — *Afnan Shatat*
Ballroom D, Hilton of the Americas 14:50 - 15:10

Probing small-x nuclear gluonic structure via coherent charmonium photoproduction in ultraperipheral PbPb collisio
Jiazhao Lin

Exclusive J/ψ Photoproduction and Entanglement-Enabled Spin Interference in Ultra-Peripheral Collisions at STAR
Ashik Ikbal Sheikh

First global study of super dense gluonic matter with UPCs by ALICE — *Simone Ragoni*
Ballroom A, Hilton of the Americas 09:10 - 09:30

Looking for QGP signatures in ultraperipheral PbPb collisions — *Sruthy Jyothi Das*
Ballroom A, Hilton of the Americas 09:30 - 09:50

Quarkonia production in ultra-peripheral PbPb collisions at LHCb — *Xiaolin Wang*
Ballroom A, Hilton of the Americas 09:50 - 10:10

Illuminating the impact-parameter dependence of UPC dijet photoproduction — *Petja Paakkinen*
Ballroom A, Hilton of the Americas 10:10 - 10:30

Measurement of dilepton and diphoton production from photon fusion processes in UPC in Pb+Pb collisions with the A
Peter Alan Steinberg

Measurements of azimuthal anisotropies in ^{16}O+^{16}O and γ+Au collisions from STAR
Shengli Huang

8 posters

169. Exploring light hadrons in UPCs with ALICE
Alexander Bylinkin (ITEP)
9/5/23, 5:30 PM
UPC Physics | Poster | Poster Session
The investigation of light hadrons in UPCs is of great interest for QCD studies. ALICE is a superb detector for studying these processes because of its excellent particle identification and tracking capabilities. The measured cross section of coherent ρ^0 mesons in photon-lead interactions has been found to be about 40% smaller than what is predicted by the

443. Measurements of baryon-antibaryon and meson-antimeson pairs from QED vacuum excitation in Au+Au ultra-peripheral collisions at $\sqrt{s_{NN}} = 200$ GeV from STAR
Xin Wu (University of Science...
9/5/23, 5:30 PM
UPC Physics | Poster | Poster Session
Relativistic heavy-ion collisions generate extremely strong electromagnetic fields, providing an ideal environment to study the electromagnetic excitation of the vacuum. Furthermore, the electromagnetic fields are sensitive to the charge distributions of the colliding nuclei which can be used to study the nuclear structure. The Breit-Wheeler process, the

695. Observation of $\mu^+\mu^-\mu^+\mu^-$ photoproduction in ultraperipheral heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV at the STAR detector
Dr David Tlusty (Creighton University)
9/5/23, 5:30 PM
UPC Physics | Poster | Poster Session
One of the most pressing questions in both hot and cold QCD communities is what the physics mechanism responsible for modified parton densities in heavy nuclei is. One promising channel to address this question is the photoproduction of vector mesons, which is considered a clean probe to the nuclear parton structures.

612. Observation of the $\gamma\gamma \to \tau^+\tau^-$ production in PbPb collisions with the CMS experiment
Matthew Nickel (The University of Ka...
9/5/23, 5:30 PM
UPC Physics | Poster | Poster Session
Ultraperipheral nucleus-nucleus collisions produce very large photon fluxes such that fundamental quantum-mechanical processes can be observed and studied in a novel way. In this presentation, an observation of the τ lepton photoproduction at LHC is reported, using ultraperipheral lead-lead collision data collected by CMS. This measurement

677. Photoproduction of e^+e^- in peripheral isobar collisions
Shuo Lin
9/5/23, 5:30 PM
UPC Physics | Poster | Poster Session
We investigate the photoproduction of di-electrons in peripheral collisions of $^{96}_{44}$Ru+$^{96}_{44}$Ru and $^{96}_{40}$Zr +$^{96}_{40}$Zr at 200 GeV. With the charge and mass density distributions given by the calculation of the density functional theory, we calculate the spectra of transverse momentum, invariant mass and azimuthal angle for di-electrons at 40-80% centrality. The ratios

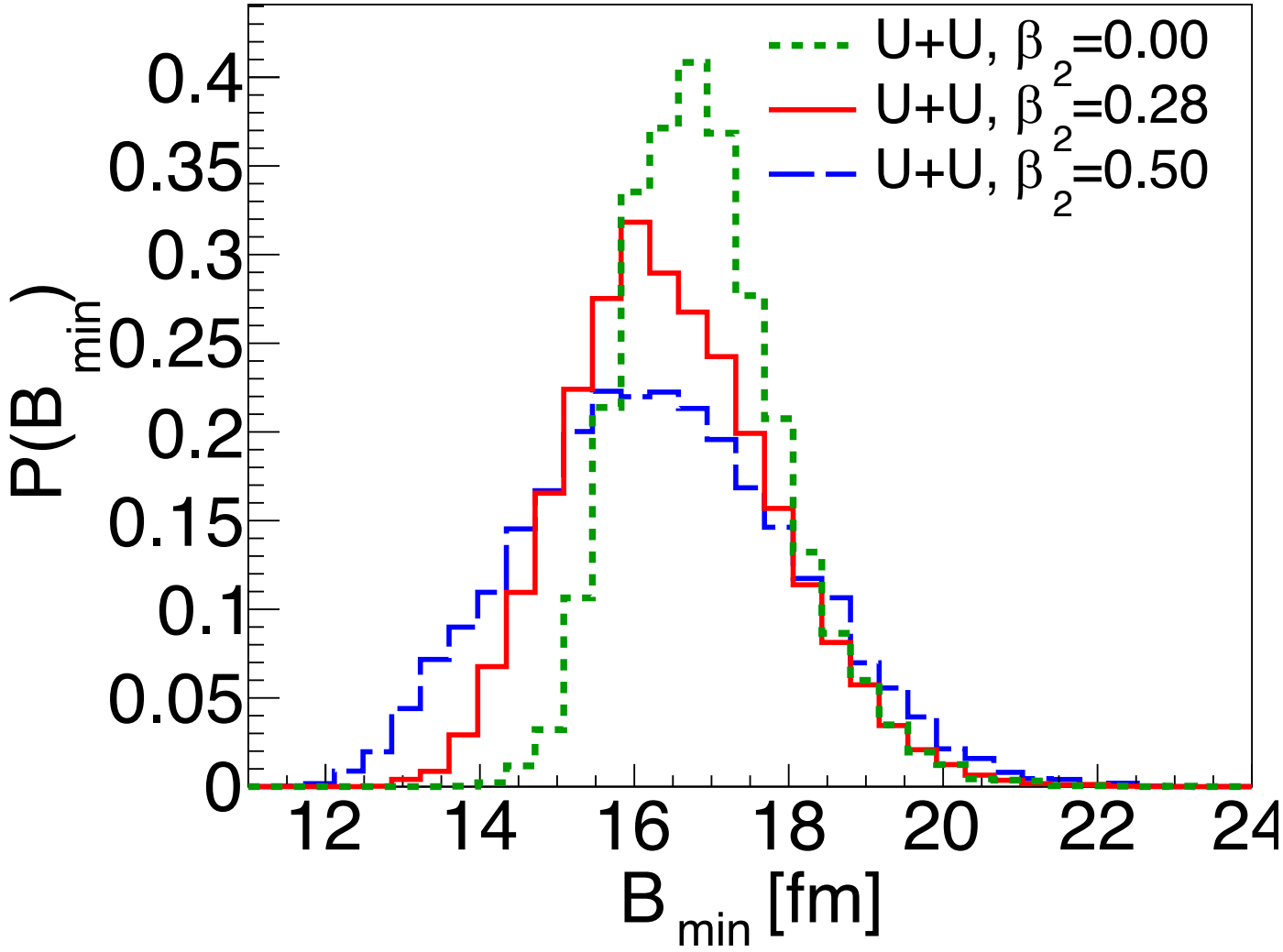
764. Physics prospects of central exclusive production in pp collisions with ALICE Run 3 data
Minjung Kim (University of Californ...
9/5/23, 5:30 PM
UPC Physics | Poster | Poster Session
Central exclusive production (CEP) is a diffractive process in which the colliding particles remain intact. Three different processes are involved: photon-photon exchange, photon-pomeron exchange and double-pomeron exchange. Each process produces distinguishable states with specific sets of quantum numbers, making CEP measurements a unique

469. Results on Breit-Wheeler Process in Heavy-Ion Collisions and its Application to Nuclear Charge Radius Measurements
Xiaofeng Wang (Shandong University)
9/5/23, 5:30 PM
UPC Physics | Poster | Poster Session
In ultra-relativistic heavy-ion collisions, strong electromagnetic fields arising from the Lorentz-contracted, highly charged nuclei can be approximated as a large flux of high-energy quasi-real photons that can interact via the Breit-Wheeler process to produce e^+e^- pairs. The collision energy dependence of the cross section and the transverse momentum

172. Studying the nucleus via angular correlations in UPCs with ALICE
Andrea Giovanni Riffero (University and INFN ...
9/5/23, 5:30 PM
UPC Physics | Poster | Poster Session
Angular correlations and polarization studies provide valuable insights into the vector meson production mechanism, including interference effects as well as information on the nuclear geometry of the target. In this talk, we present two new results: We will report the first measurement of the polarization of both coherent and incoherent J/ψ

Thank you!

Bmin distribution in UPCs



H.Mantysaari, B.Schenke, C. Shen and W. Zhao, Phys. Lett. B 833 (2022), 137348.

Net-Baryon in Photonuclear collisions

Chun Yuen Tsang (STAR)

If junction hypothesis is true:

- **Quasi-real $\gamma \rightarrow q\bar{q}$**
- **Interact with a junction in target Au nucleus**
- **Enhanced creation of mid-rapidity baryons**
  - Junction interaction time > quark interaction time
  - More baryons are stopped in junction picture
- **Regge theory: $dN/dy \propto e^{-\alpha_B \delta y}$, where**

  $\delta y = y_{beam} - y$ in the direction of the target
  - α_B is related to Regge intercept of junctions (J. D. Brandenburg, N. Lewis, P. Tribedy, Z. Xu, arXiv:2205.05685 (2022)).

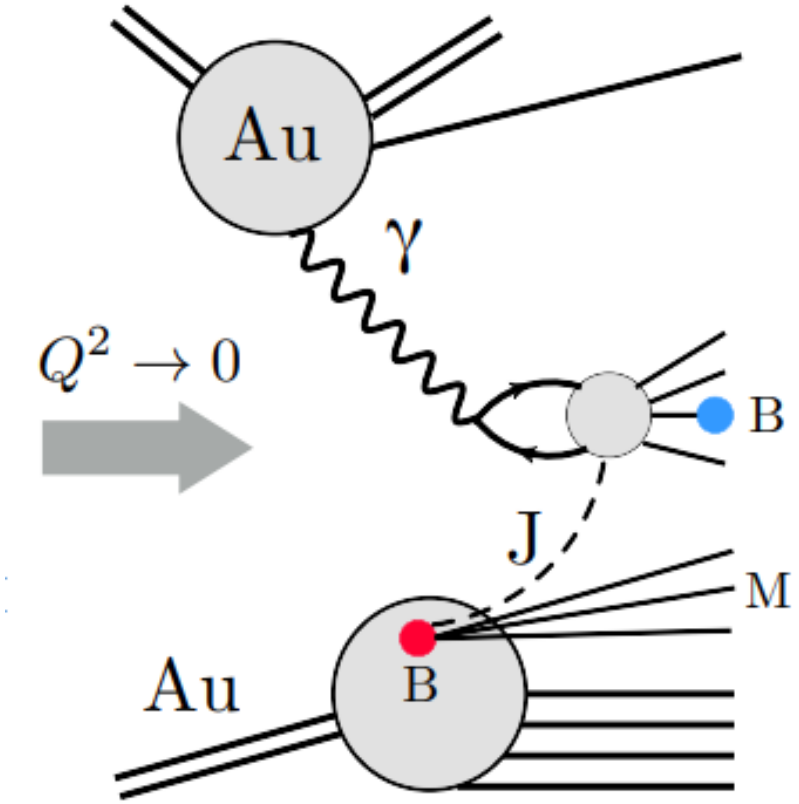


Figure from J. D. Brandenburg, N. Lewis, P. Tribedy, Z. Xu, arXiv:2205.05685 (2022)

Imaging the Nuclear Charge Distribution

$\gamma\gamma \rightarrow l^+l^-$ can be used to constrain nucleus charge distribution at RHIC energy

STAR data compared to EPA-QED

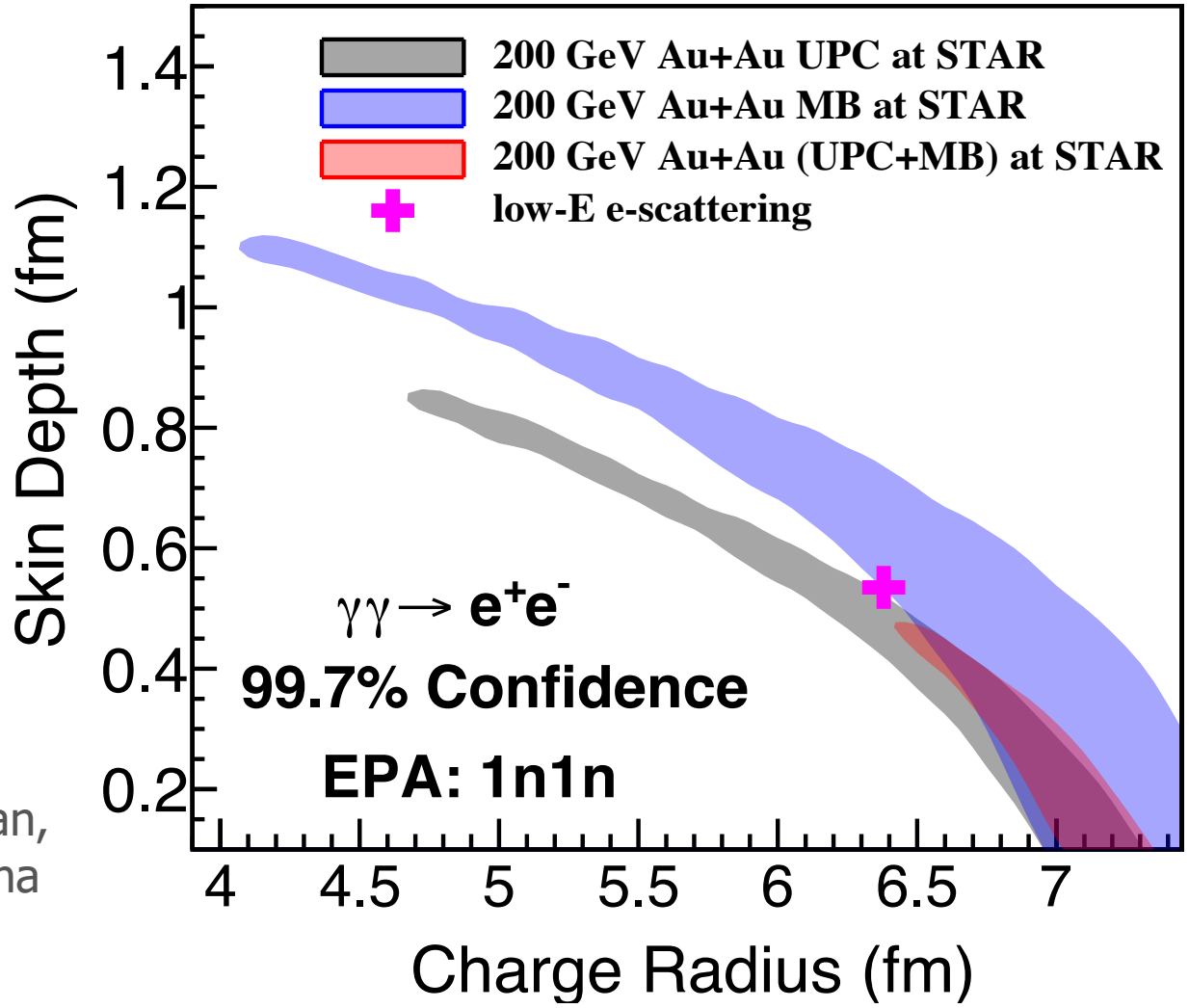
Low energy scattering: R=6.38 fm, d=0.535 fm

R. C. Barrett and D. F. Jackson, Nuclear Sizes and Structure (Oxford University Press, 1977)

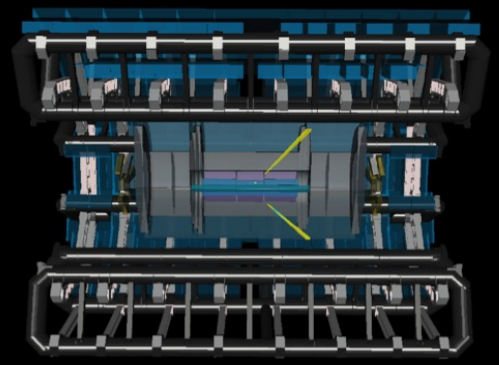
- Explore the effective charge distribution vs. energy and impact parameter

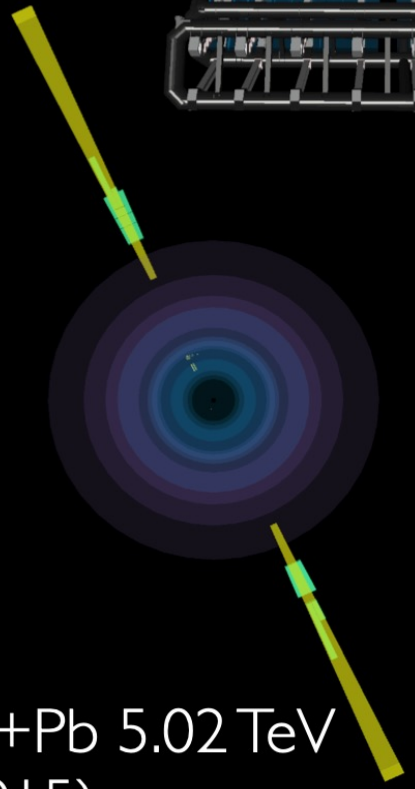
  Xiaofeng Wang, James Daniel Brandenburg, Lijuan Ruan, Fenglan Shao, Zhangbu Xu, Chi Yang, and Wangmei Zha

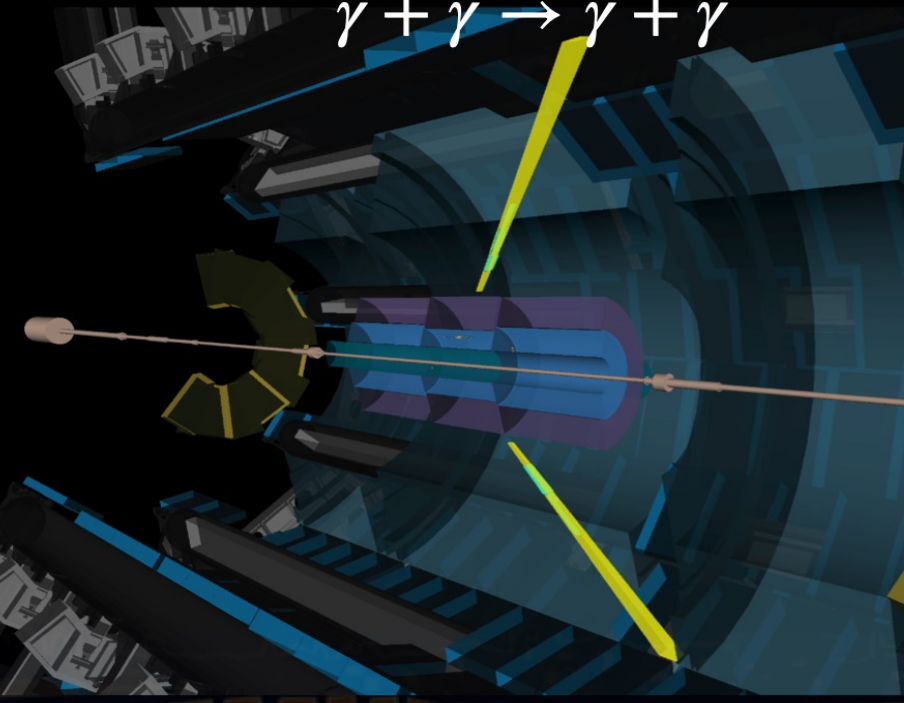
  Phys. Rev. C 107, 044906 (2023)



Light-by-Light Scattering







ATLAS EXPERIMENT

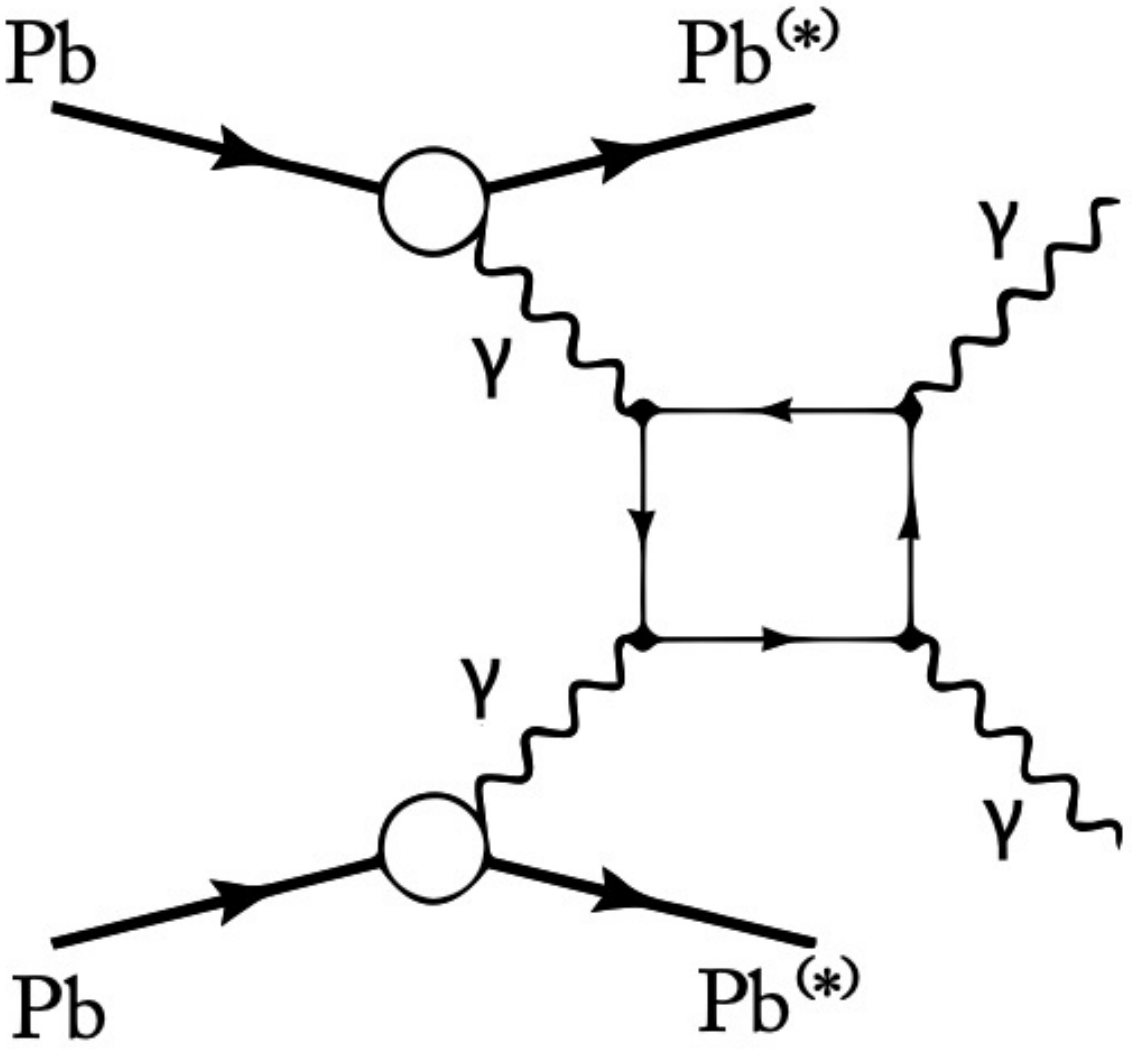
Run: 287931
Event: 461251458
2015-12-13 09:51:07 CEST

$\gamma + \gamma \rightarrow \gamma + \gamma$

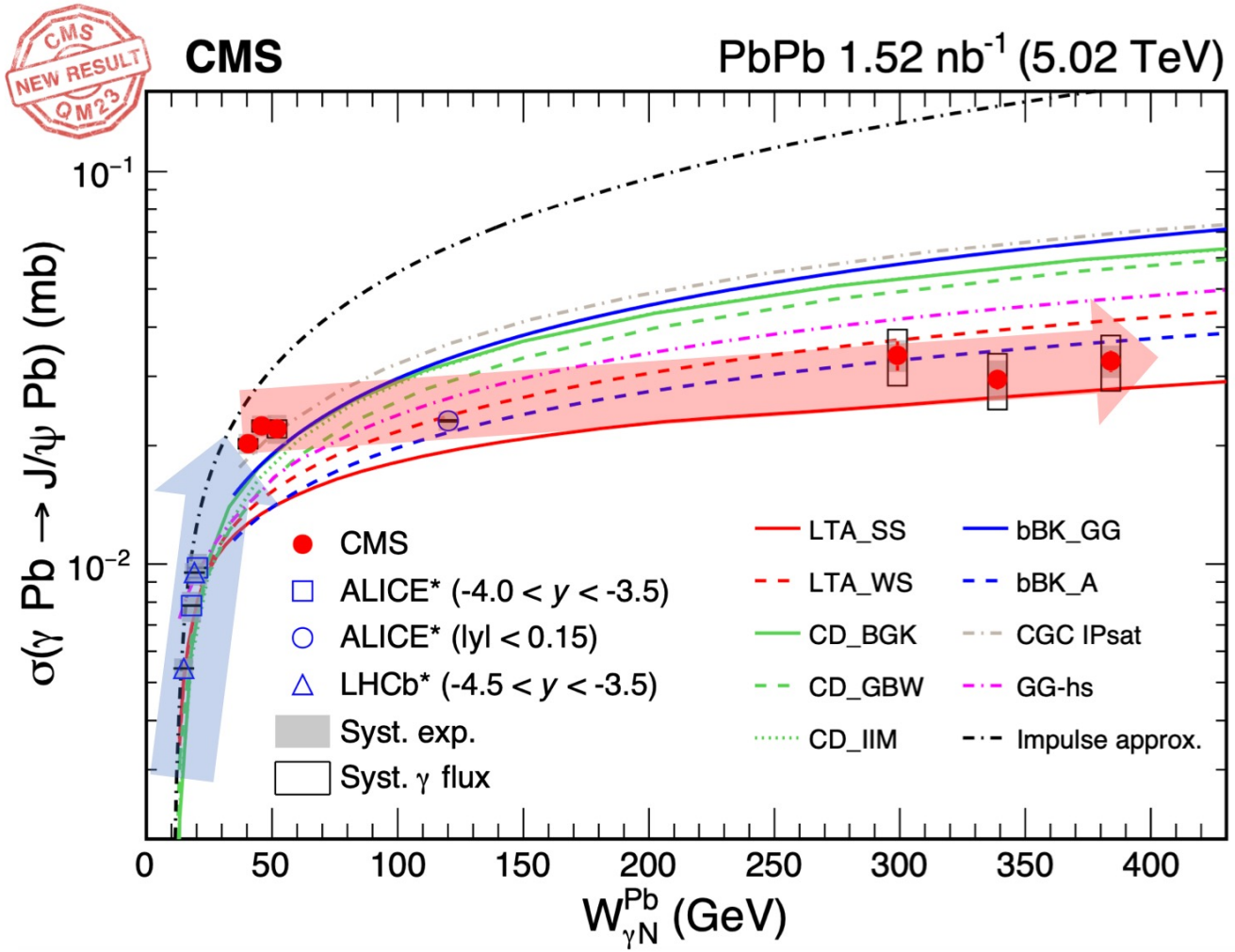
Pb+Pb 5.02 TeV
(2015)

Light-by-Light Scattering (LbyL)

- Maxwell's equations are manifestly linear -> Superposition principle
- LbyL is a purely quantum process
- $\sigma \sim \alpha_{em}^4$
- signals the transition into a non-linear regime of QED

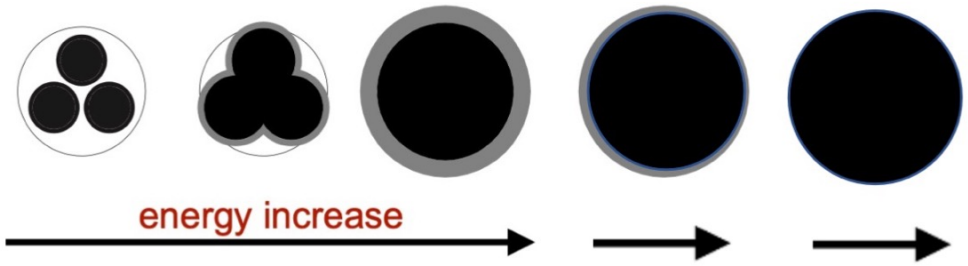


arXiv:2303.16984



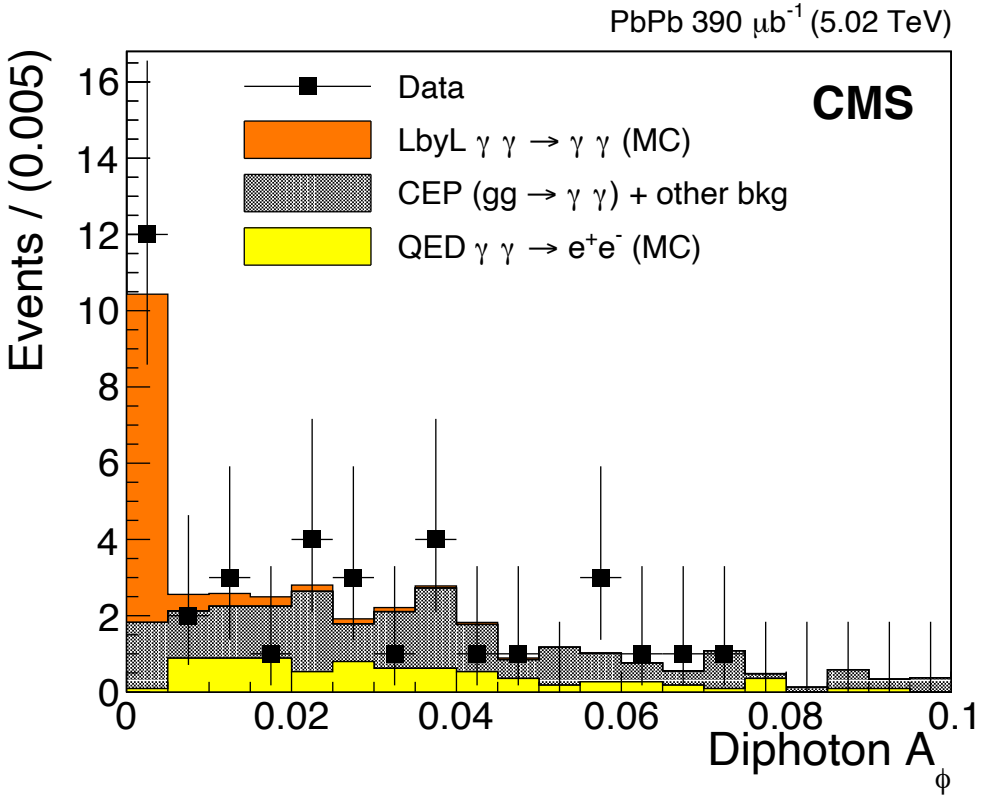
- Rapid grows reflect increased in gluon density
  - Amplitude of interaction is proportional to gluon density

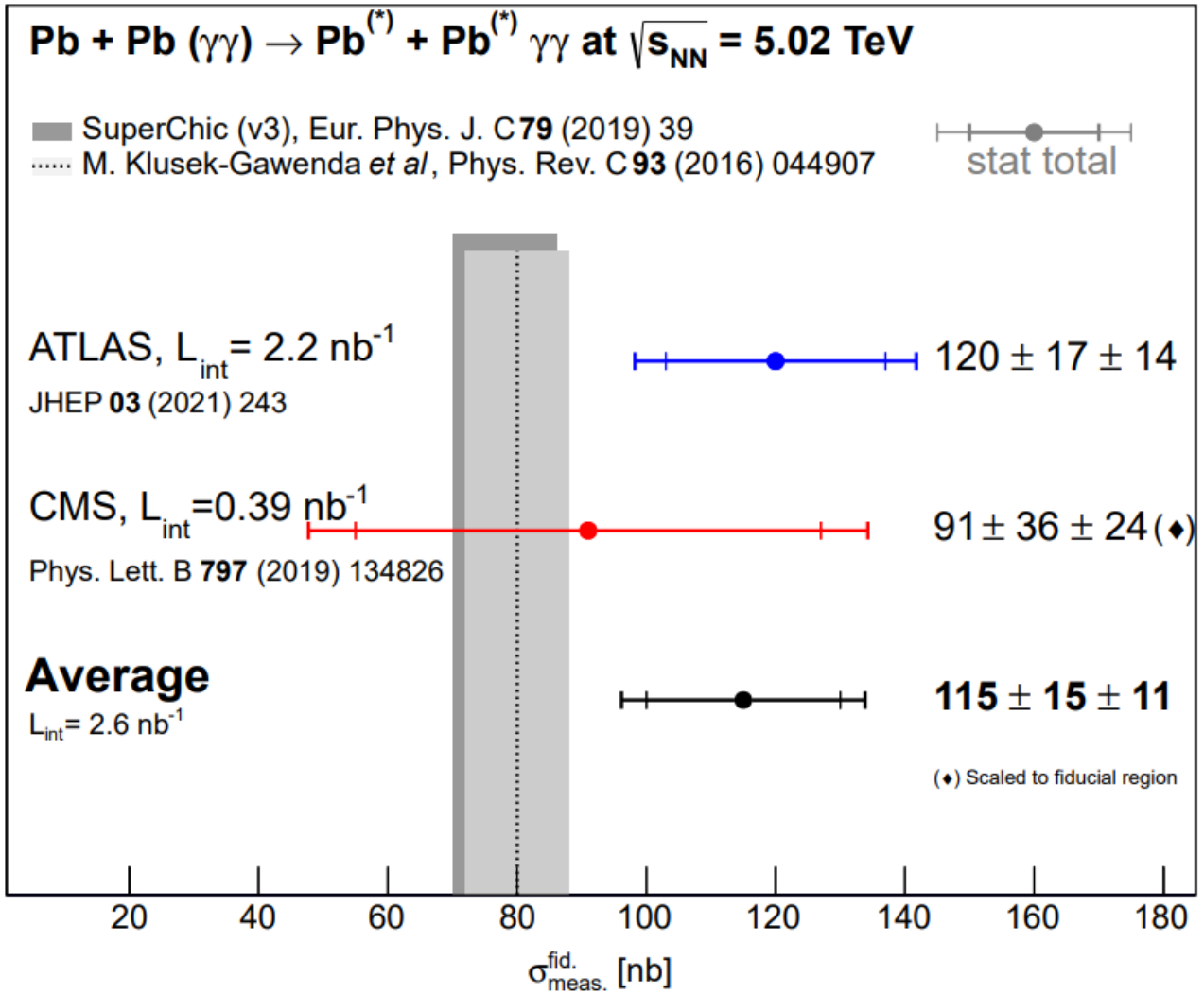
- Slow growth may suggest the periphery of the nucleus has not become fully "black"

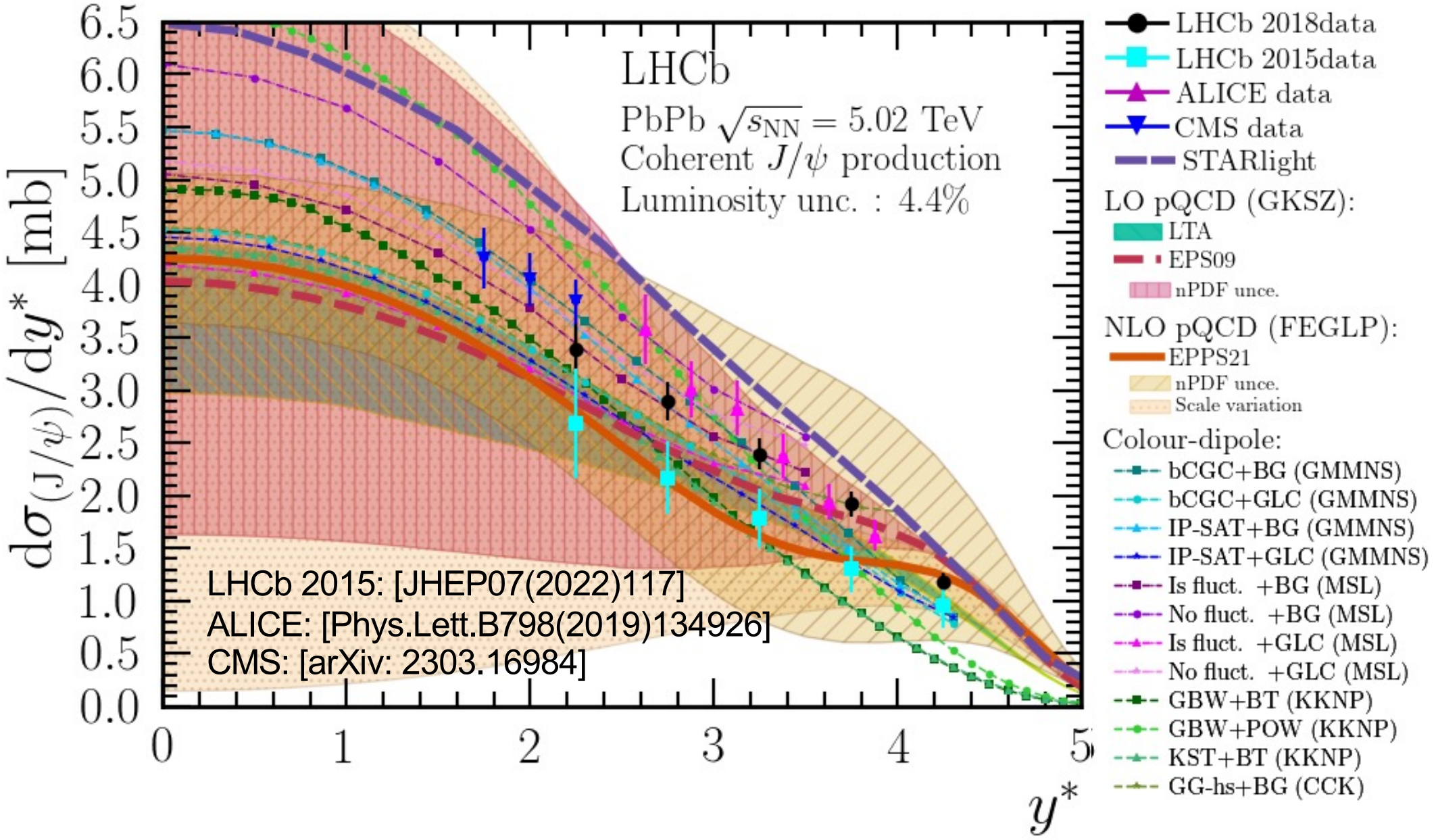


Light-by-Light scattering

- Observations by
  - ATLAS: JHEP 03 (2021) 243
  - CMS: Phys. Lett. B 797 (2019) 134826



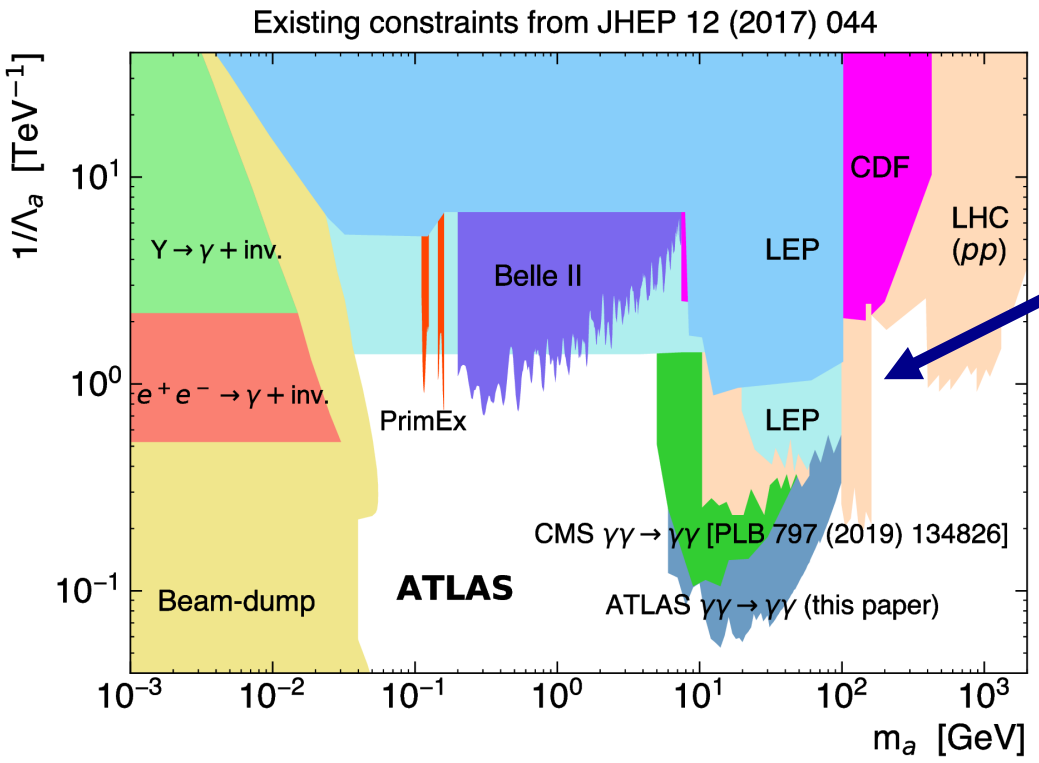


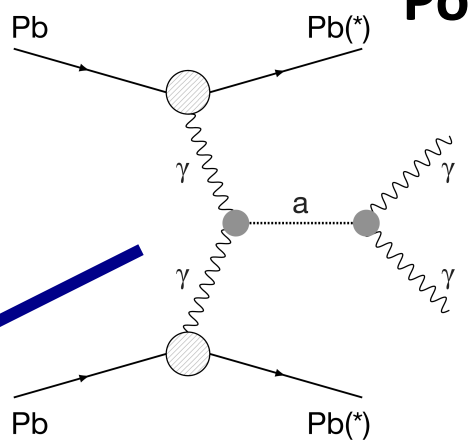

LHCb
PbPb $\sqrt{s_{NN}} = 5.02$ TeV
Coherent J/ψ production
Luminosity unc. : 4.4%
LHCb 2015: [JHEP07(2022)117]
ALICE: [Phys.Lett.B798(2019)134926]
CMS: [arXiv: 2303.16984]
$d\sigma_{(J/\psi)}/dy^*$ [mb]
y^*
LHCb 2018data
LHCb 2015data
ALICE data
CMS data
STARlight
LO pQCD (GKSZ):
LTA
EPS09
nPDF unce.
NLO pQCD (FEGLP):
EPPS21
nPDF unce.
Scale variation
Colour-dipole:
bCGC+BG (GMMNS)
bCGC+GLC (GMMNS)
IP-SAT+BG (GMMNS)
IP-SAT+GLC (GMMNS)
Is fluct. +BG (MSL)
No fluct. +BG (MSL)
Is fluct. +GLC (MSL)
No fluct. +GLC (MSL)
GBW+BT (KKNP)
GBW+POW (KKNP)
KST+BT (KKNP)
GG-hs+BG (CCK)

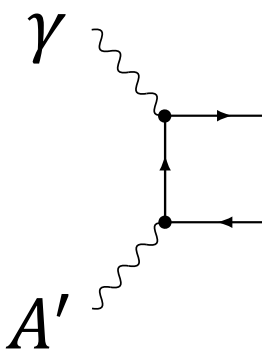
PAST Discoveries→Novel Tests of BSM Physics

▷Discoveries become tools to study new physics

Axion search in Light-by-Light Scattering

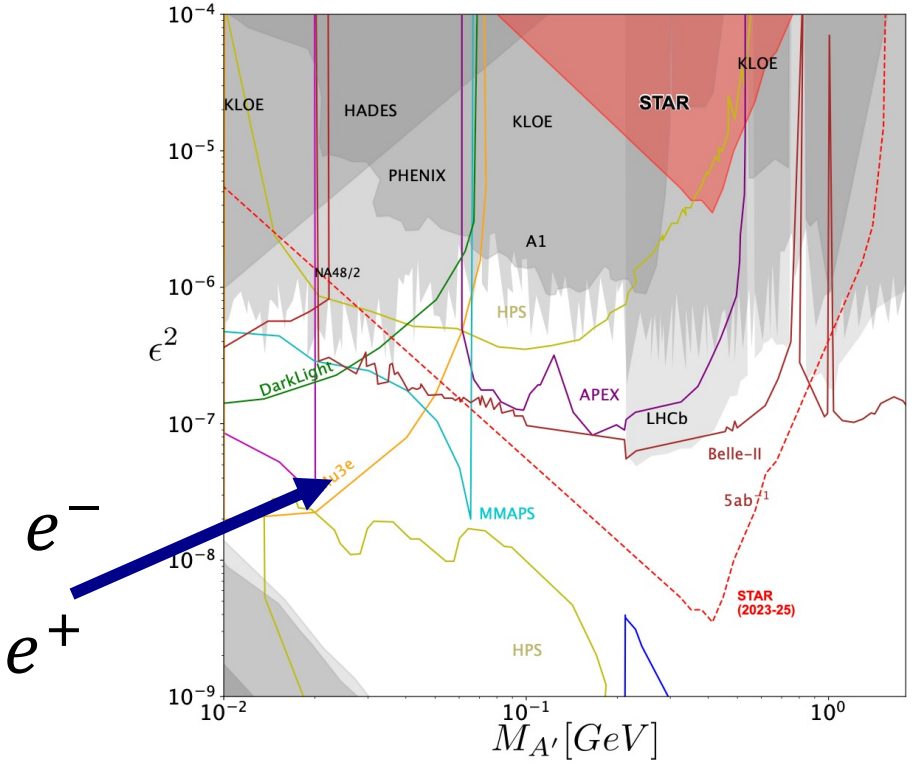






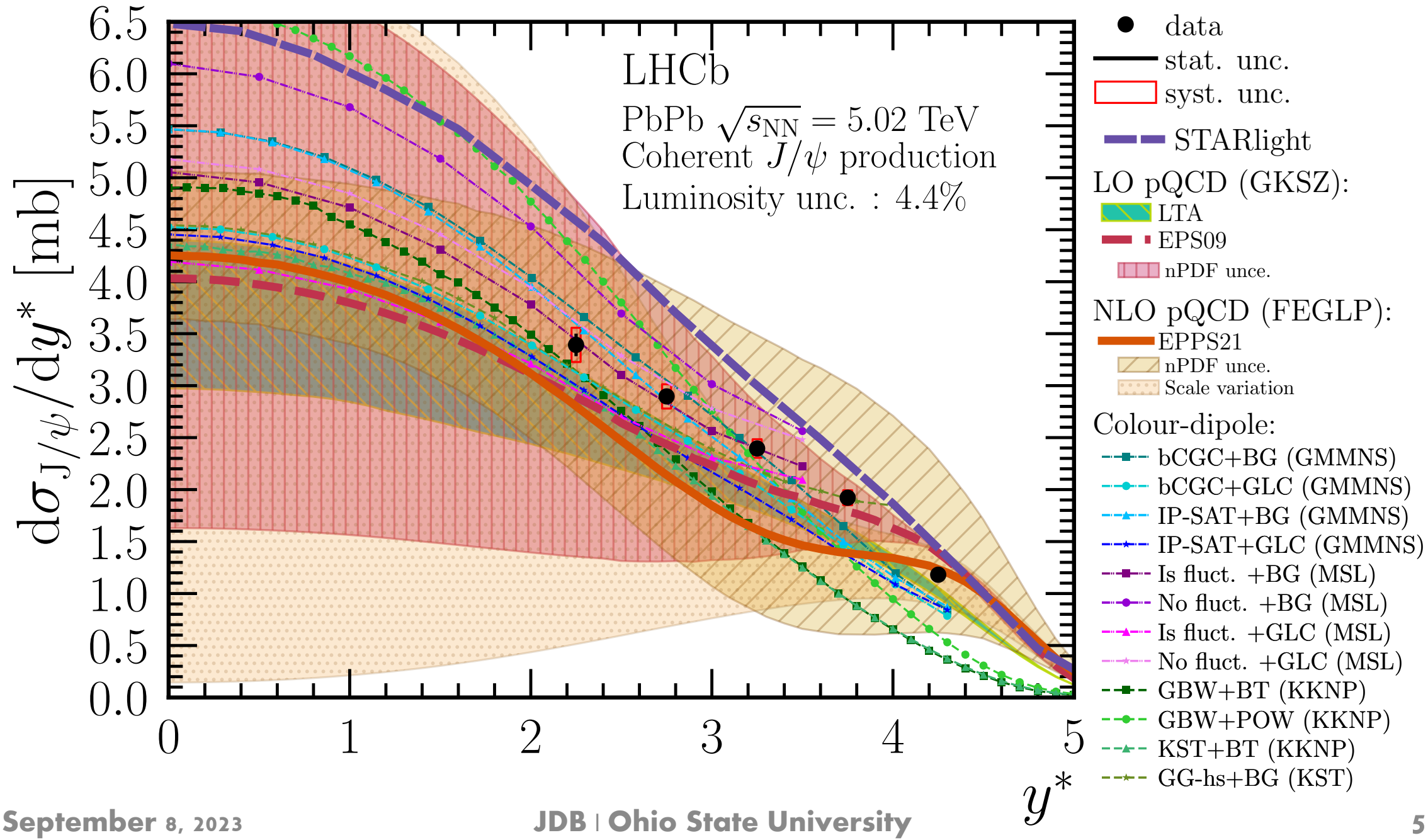
Dark photon

Dark Photon search with Polarized Breit-Wheeler Process



Isabel Xu, Nicole Lewis, Xiaofeng Wang, James Daniel Brandenburg, Lijuan Ruan

arxiv:2211.02132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