

Ultra-peripheral collisions: recent experimental progress

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12th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

(Hard Probes 2024)

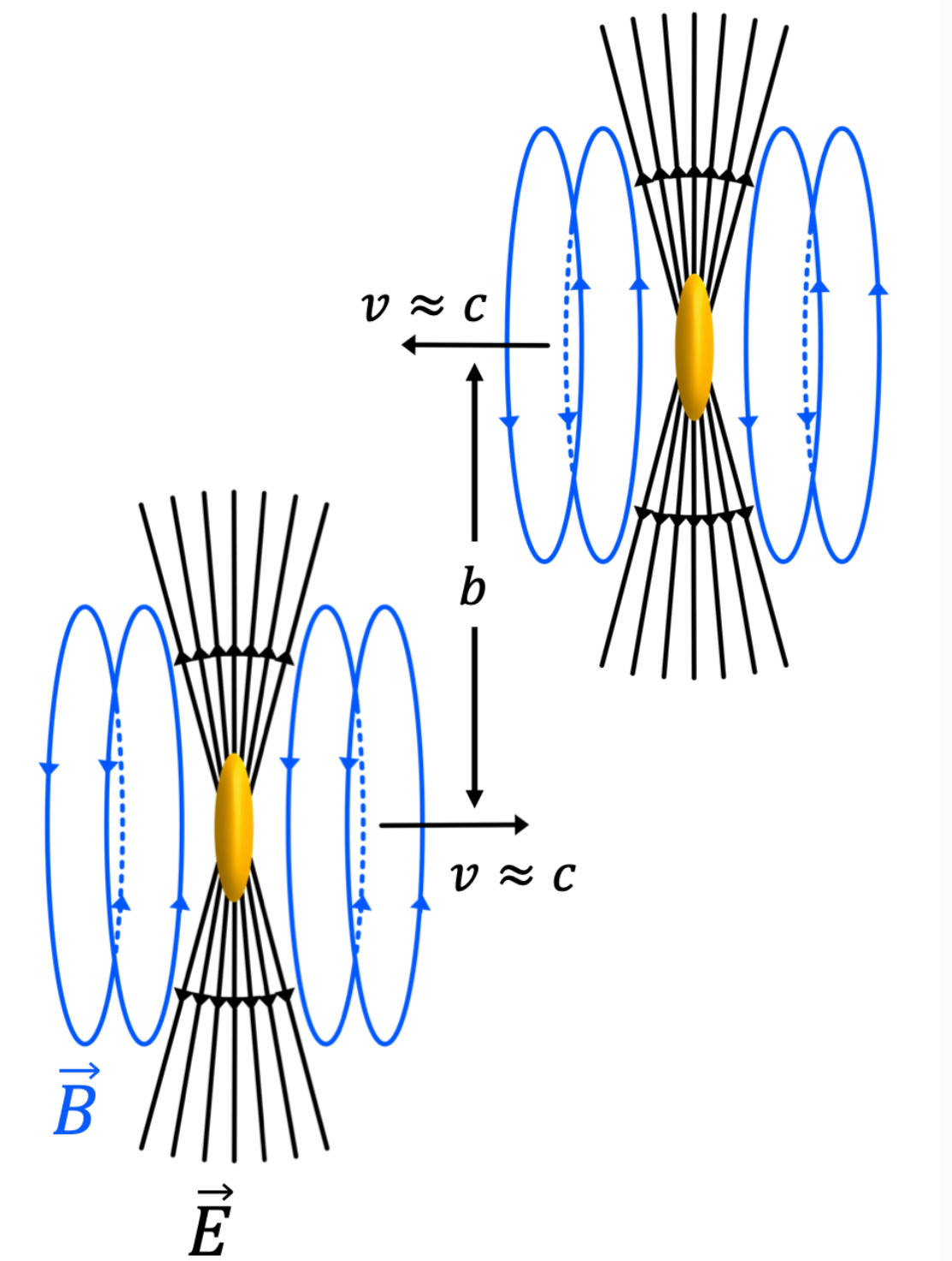
22. Sep. 2024 - 27. Sep. 2024

Nagasaki, Japan



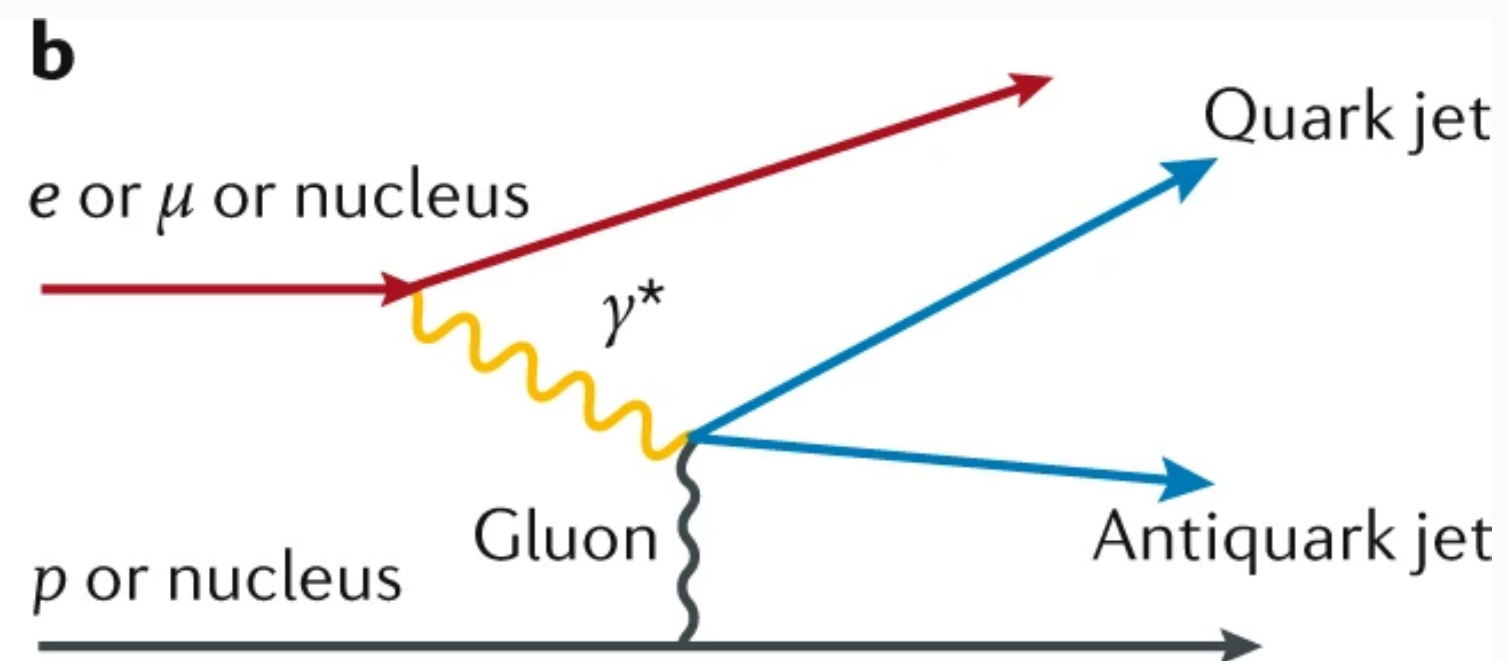
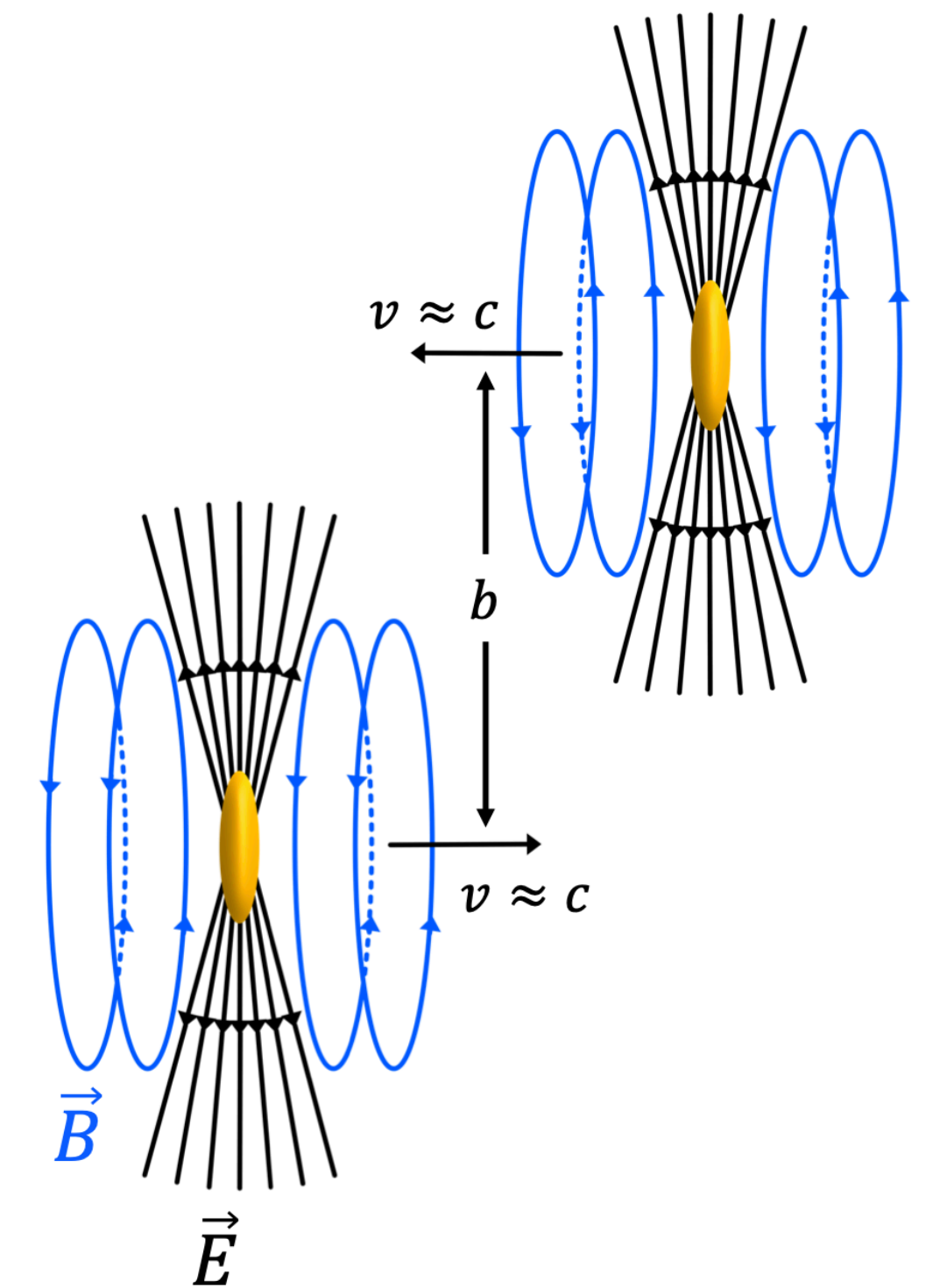
Ultra-peripheral heavy-ion collisions

- EM field from ultra-relativistic ions: a beam of quasi real photons (intensity $\approx Z^2$)
- ➔ Photon energy frontier: up to ~ 500 TeV in target frame at the LHC energies



Ultra-peripheral heavy-ion collisions

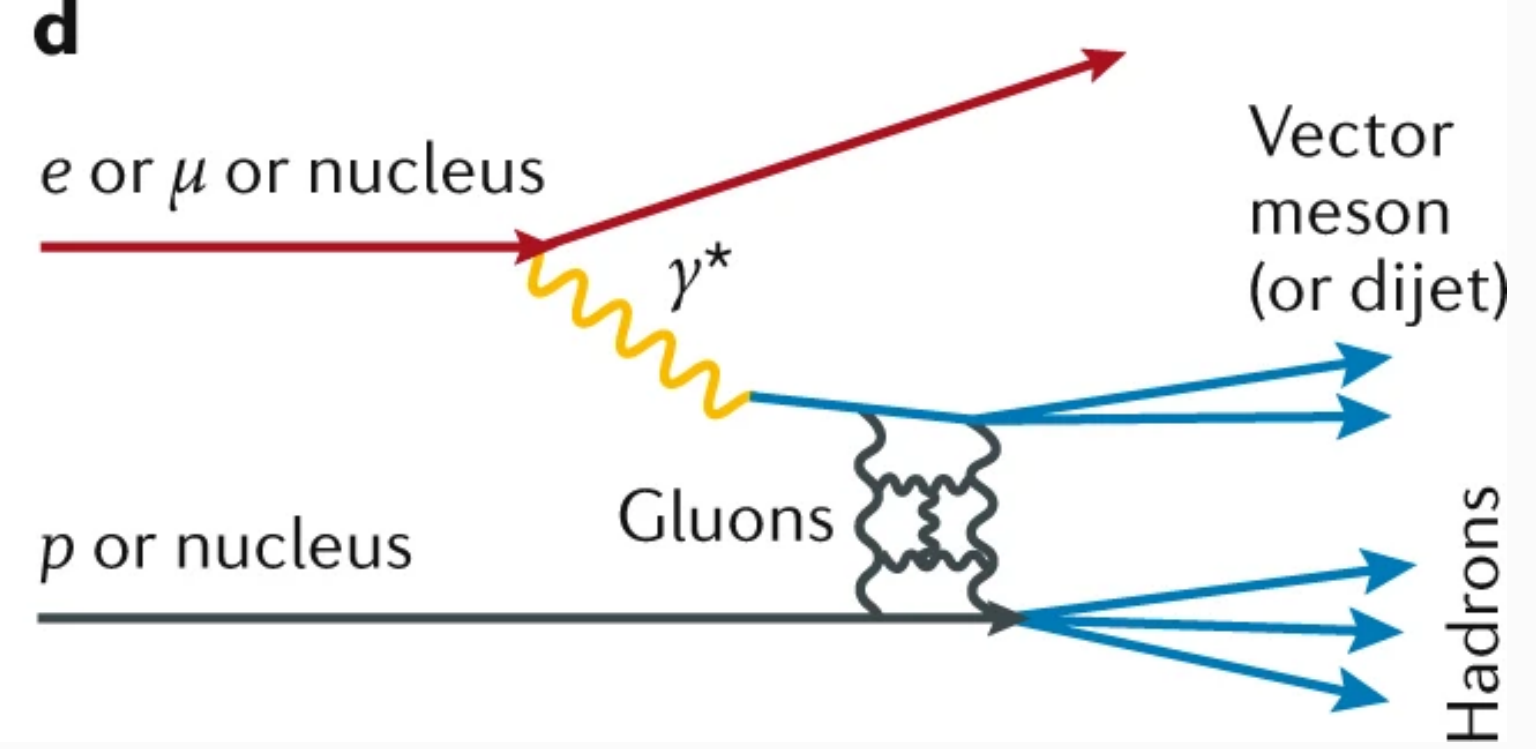
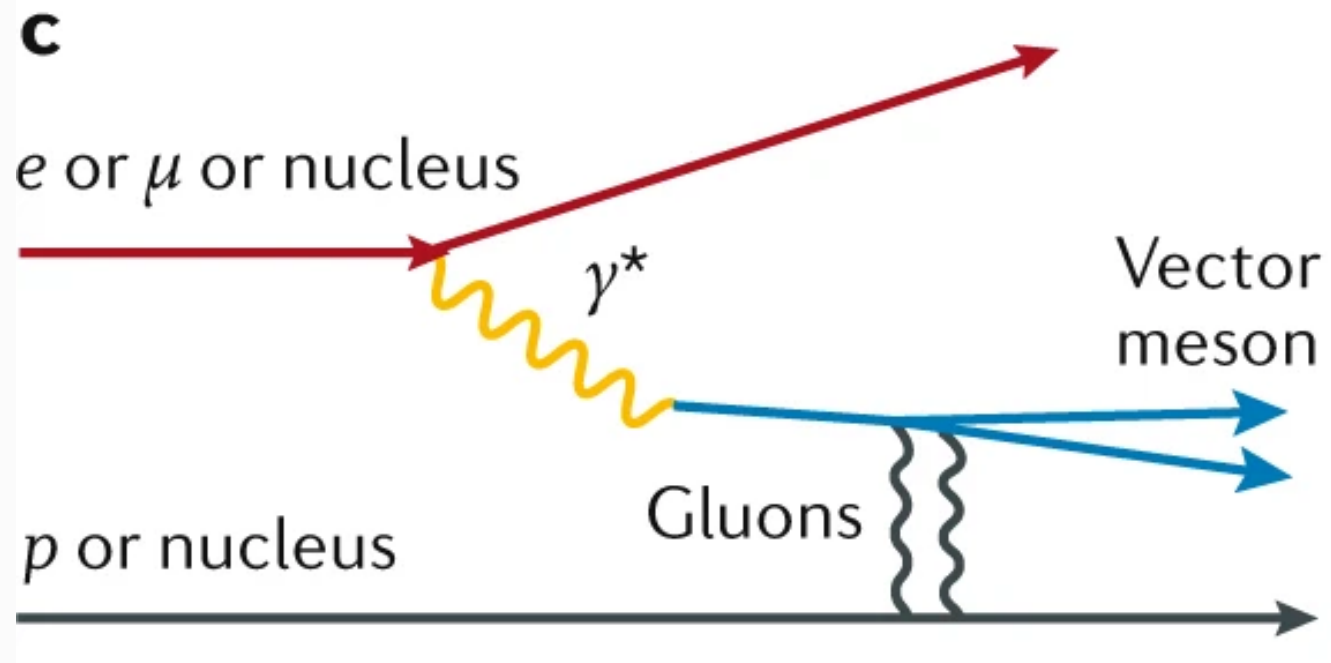
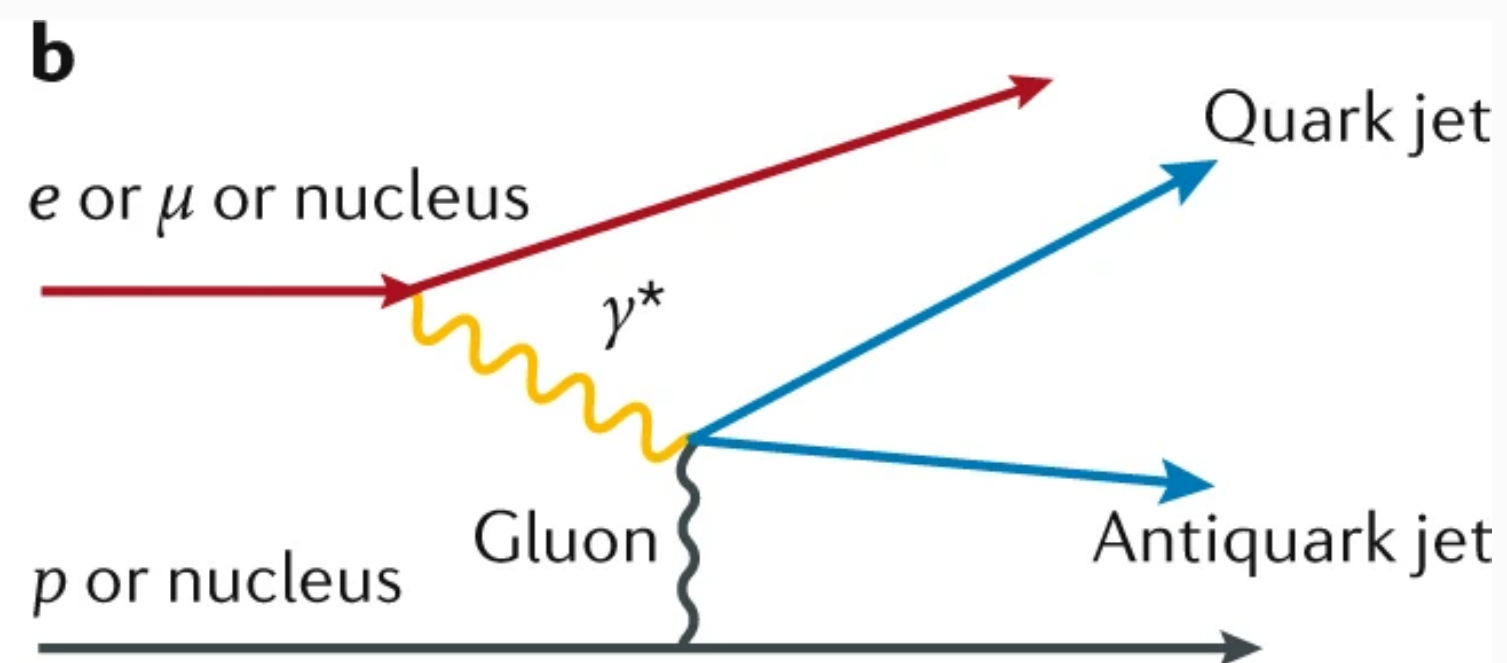
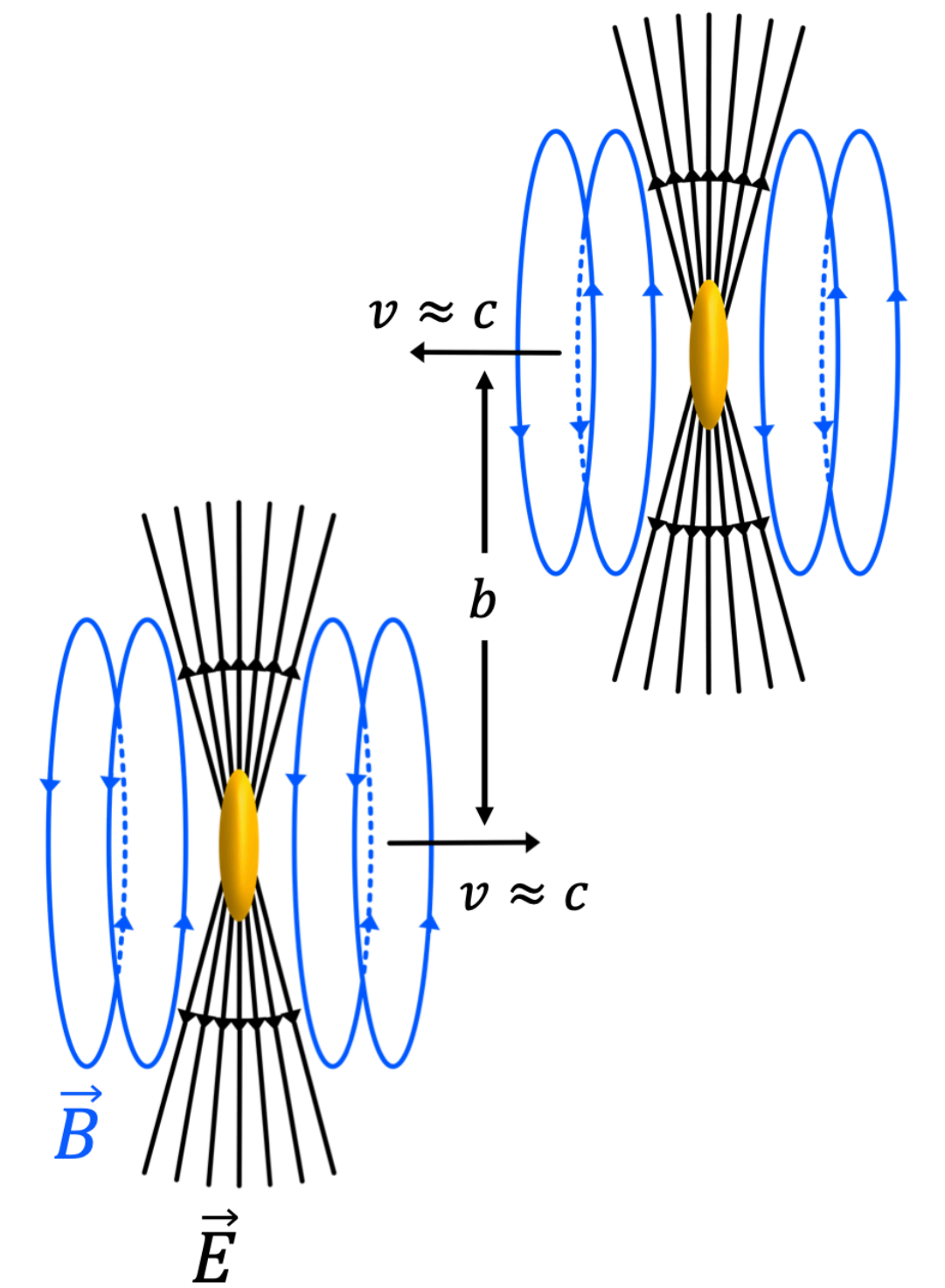
- EM field from ultra-relativistic ions: a beam of quasi real photons (intensity $\approx Z^2$)
- ➔ Photon energy frontier: up to ~ 500 TeV in target frame at the LHC energies
- Single gluon exchange:
 - Lowest-order cross section is directly proportional to the gluon distribution
 - Final state particles must be color-neutral: additional gluonic string forms between the target and final state leading to complex final state system



S. Klein, H. Mäntysaari, [Nature Reviews Physics](#) 1, 662–674 (2019)

Ultra-peripheral heavy-ion collisions

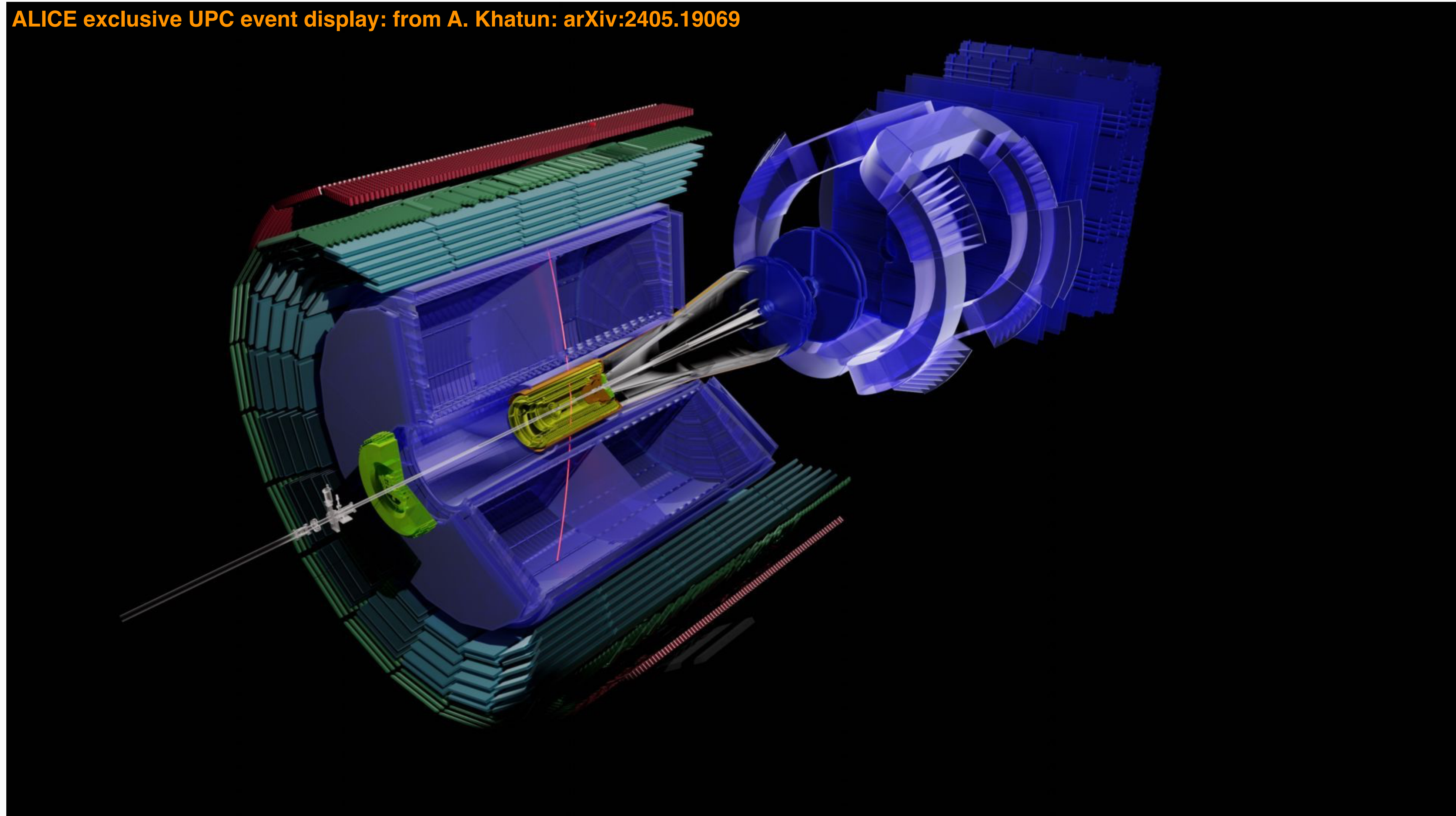
- EM field from ultra-relativistic ions: a beam of quasi real photons (intensity $\approx Z^2$)
- ➔ Photon energy frontier: up to ~ 500 TeV in target frame at the LHC energies
- Exclusive vector meson photoproduction:
 - No net color charge transfer: at least two gluon exchange
 - Rapidity gap around the produced particle
 - Some caveats in connection with PDF (gluon distribution)



S. Klein, H. Mäntysaari, *Nature Reviews Physics* 1, 662–674 (2019)

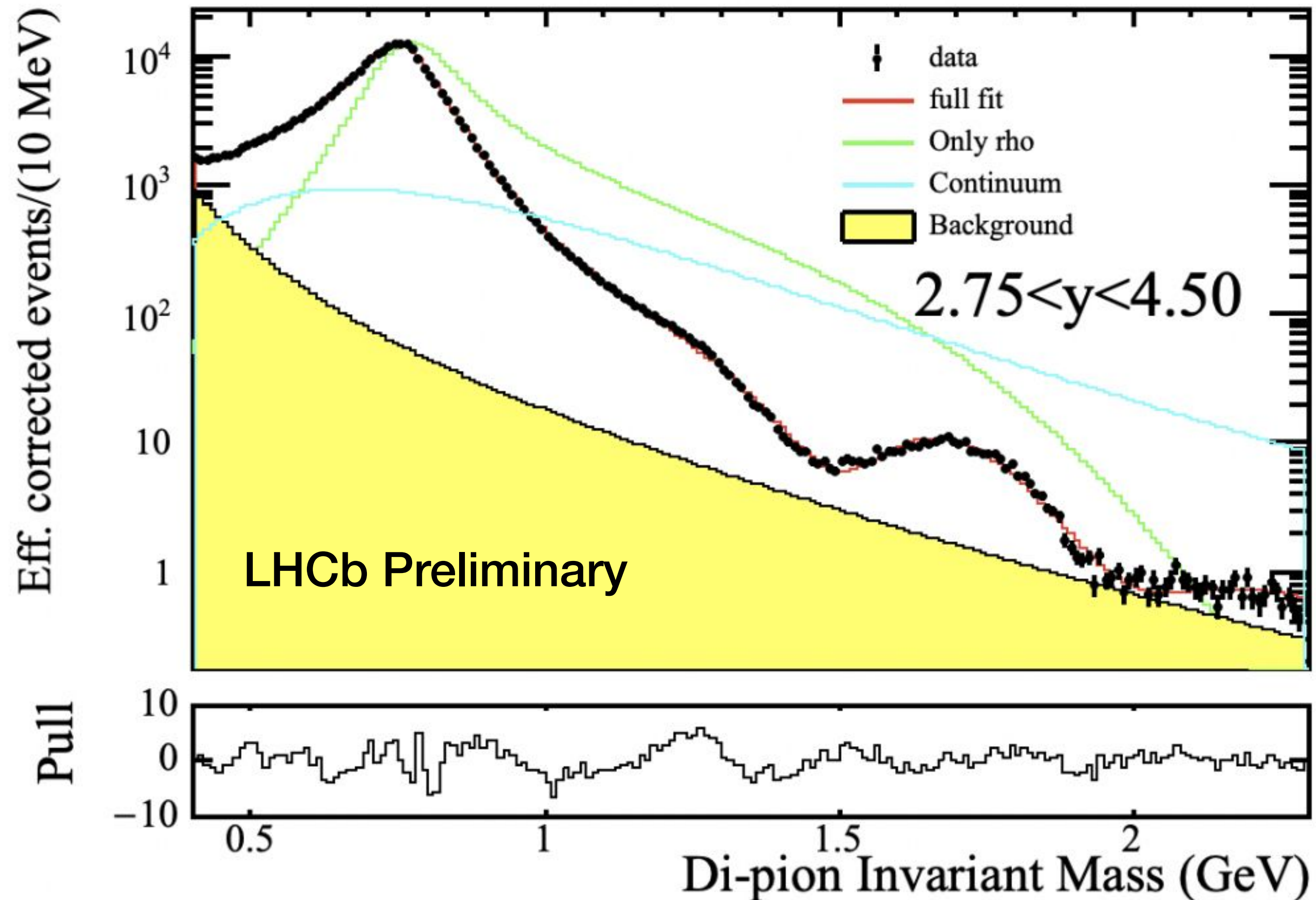
Exclusive photoproduction (mainly vector meson but more!)

ALICE exclusive UPC event display: from A. Khatun: arXiv:2405.19069



Exclusive $\pi^+\pi^-$ photoproduction

LHCb-PAPER-2024-042

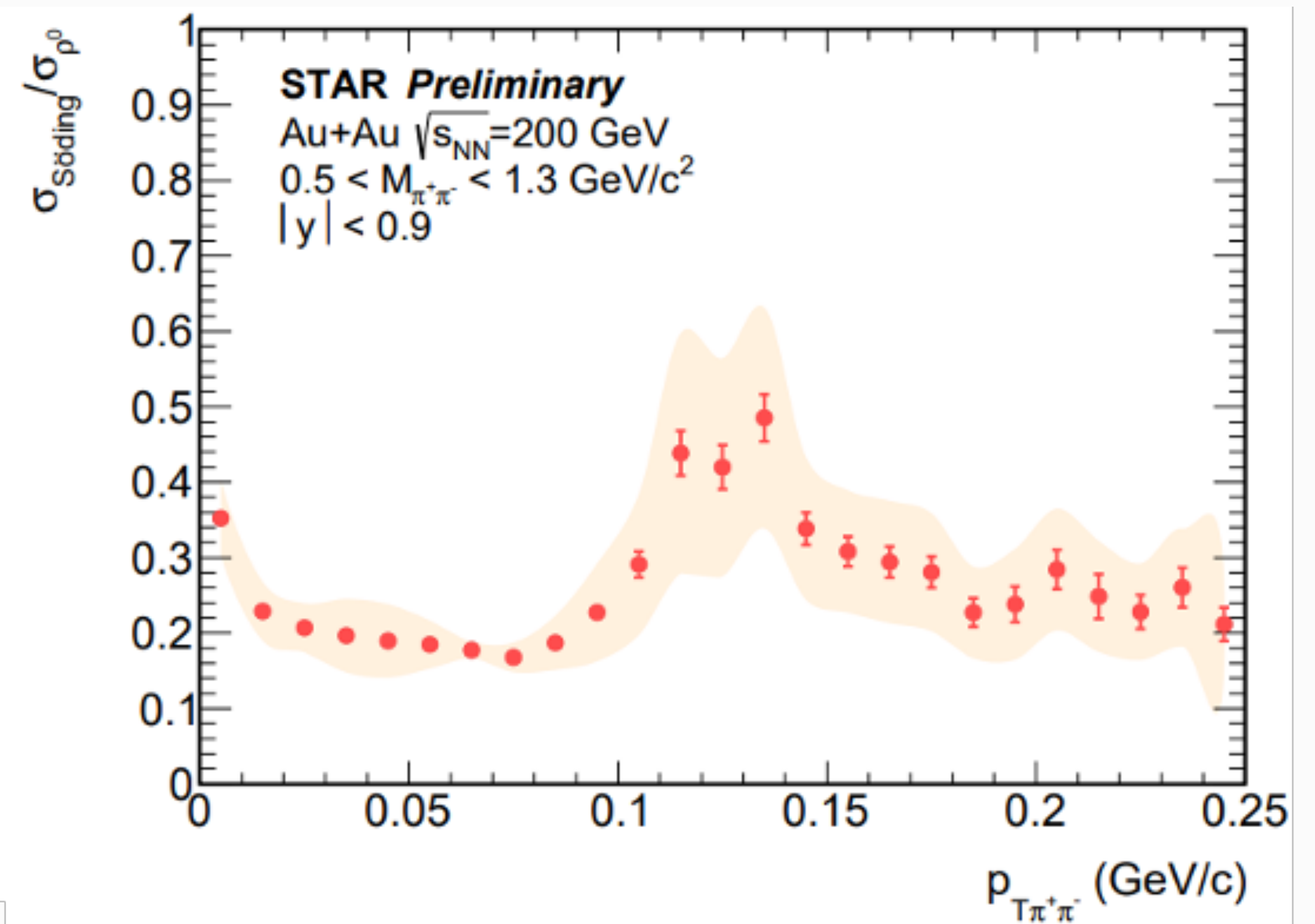
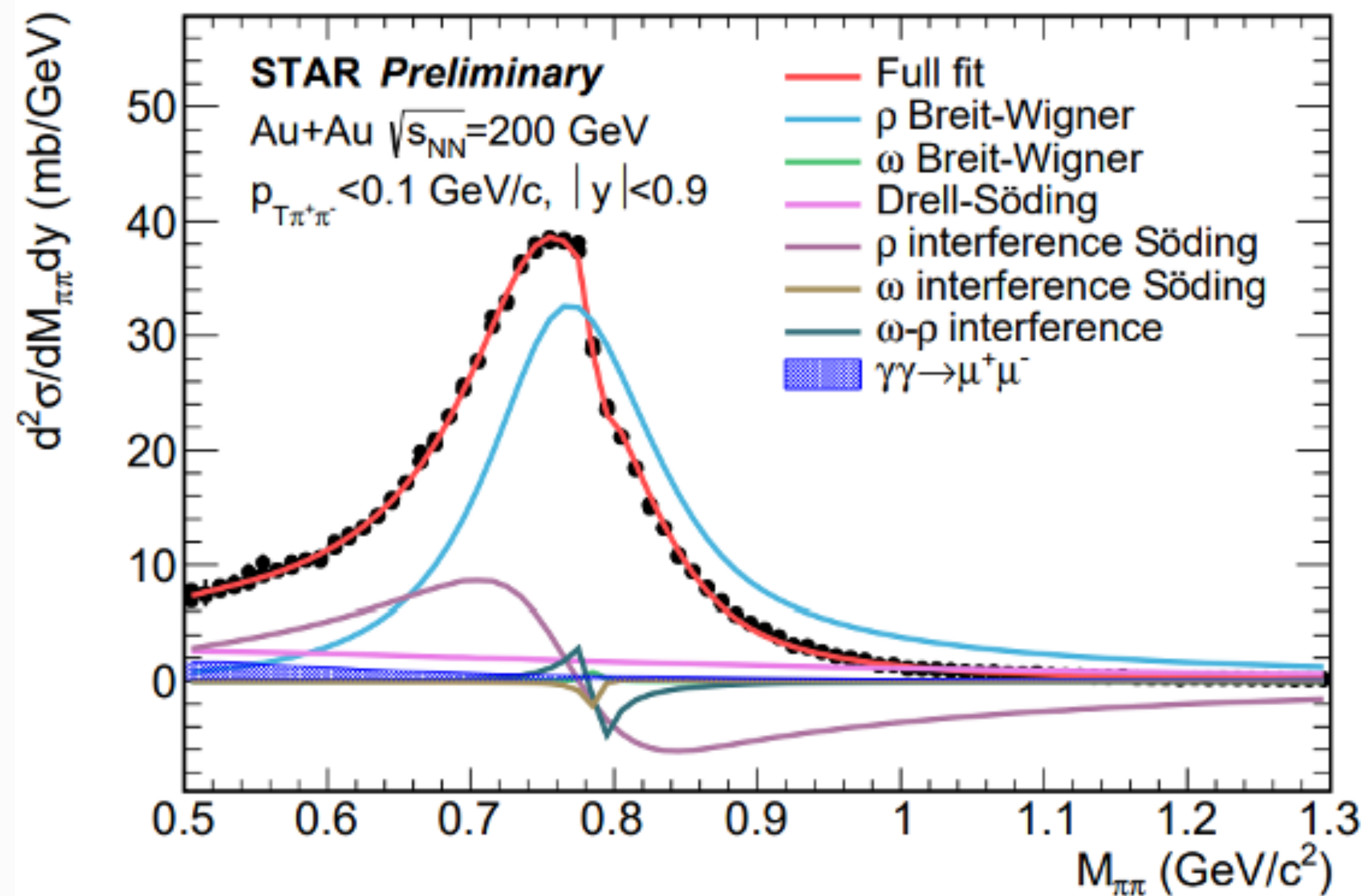


A. Donohoe Wed. 9:00

- Composed with vector meson decay products, continuum production and their interference
- First access of $\pi^+\pi^-$ photoproduction in forward rapidity in UPCs with wide invariant mass range
- Distinct and well-resolved resonance observed ~ 1.7 GeV; matches with STAR and ALICE

Exclusive $\pi^+\pi^-$ photoproduction

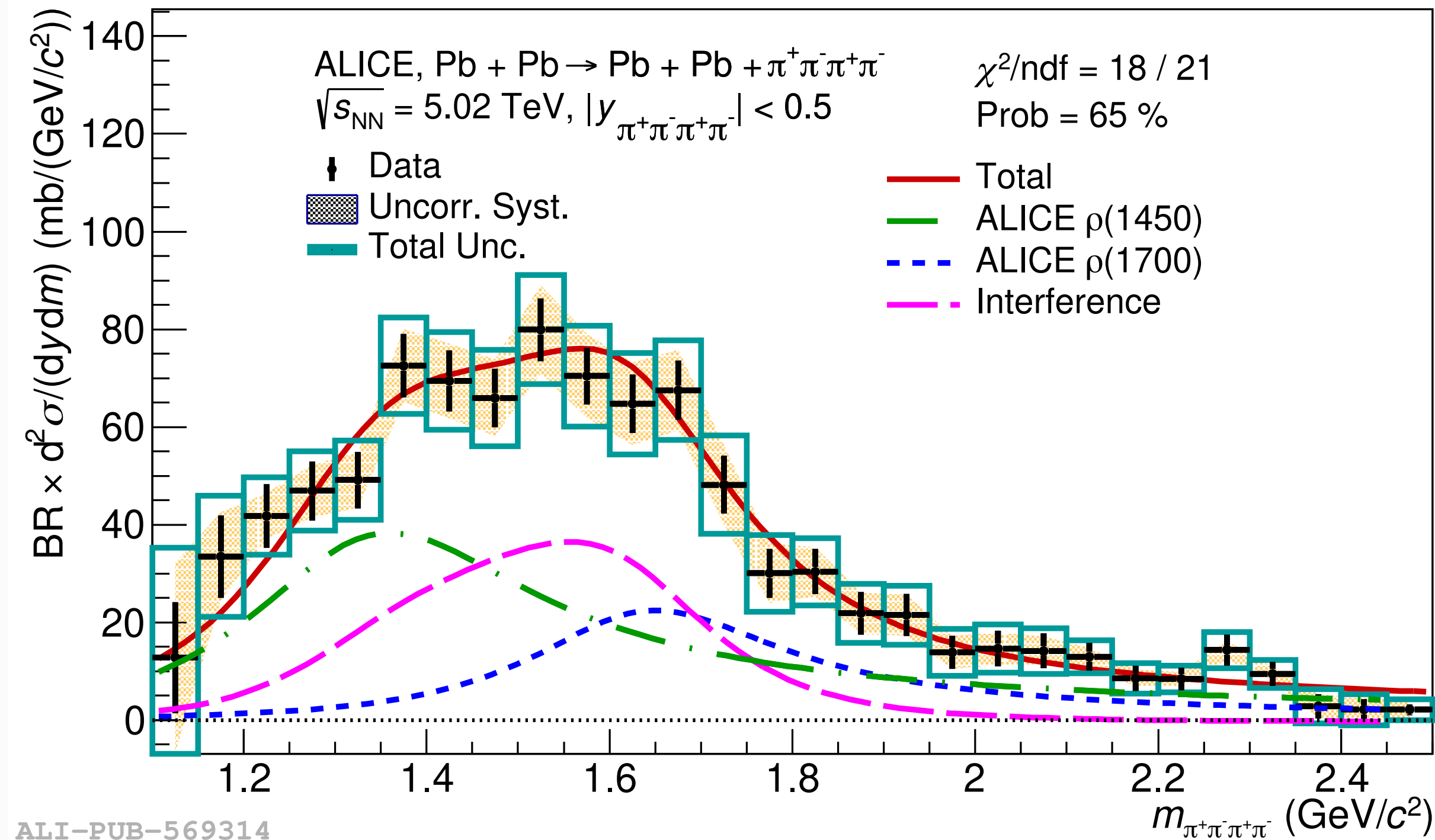
X. Li, Poster #129



- Composed with vector meson decay products, continuum production and their interference
- First access of transverse momentum dependent Drell-Soding (continuum) cross section (and angular modulation)
- Measure the different scattering behaviors and deeper understanding on interference

Searching for resonance and exotic hadrons

ALICE Collaboration, arXiv:2404.07542

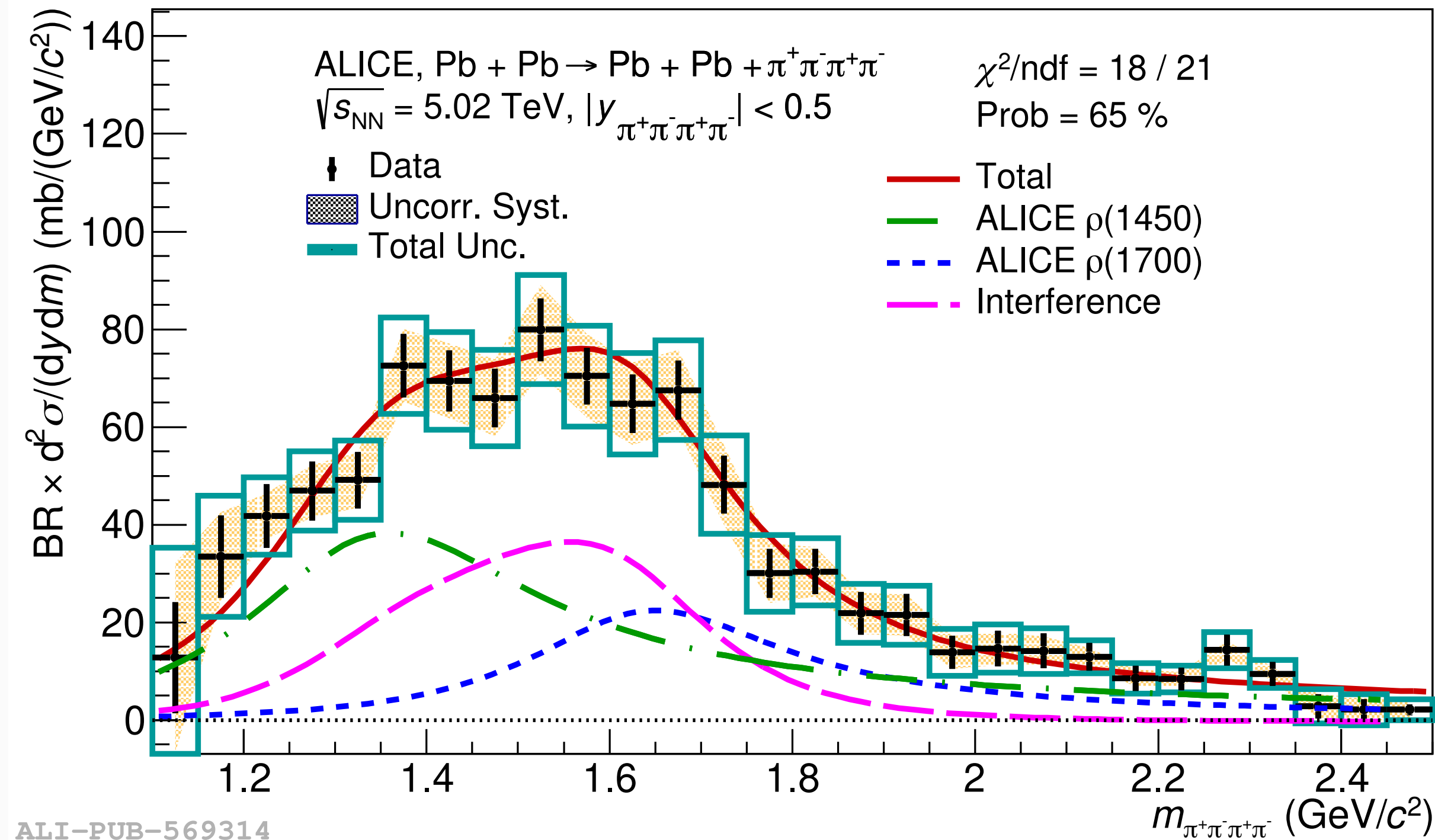


M.Kim Wed. 9:40

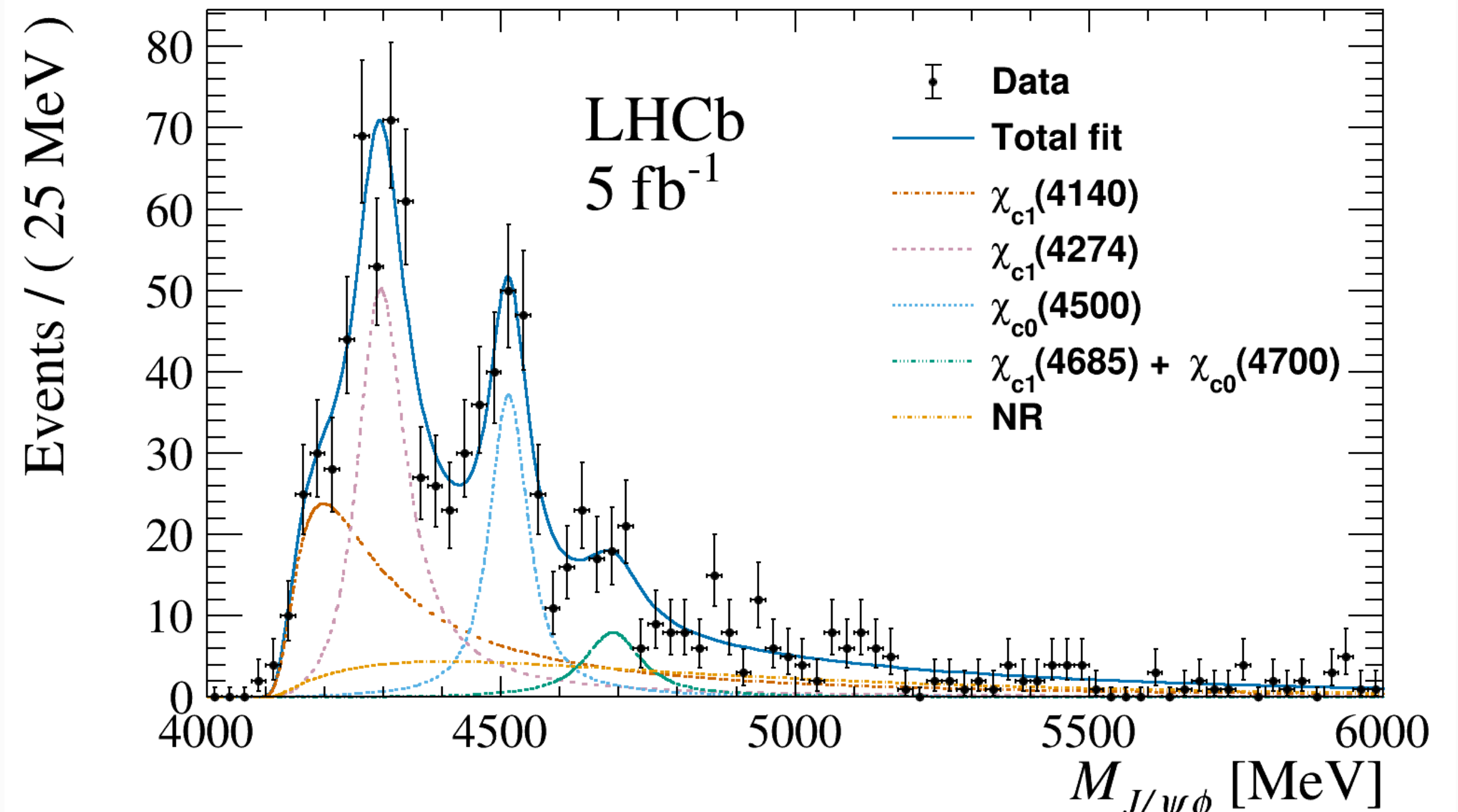
- Exclusive production of multiple tracks in final states \rightarrow resonance structure in invariant mass distribution
- $\pi^+\pi^-\pi^+\pi^-$ state favors two interfering resonances with a mixing angle

Searching for resonance and exotic hadrons

ALICE Collaboration, arXiv:2404.07542



LHCb Collaboration, arXiv:2407.14301



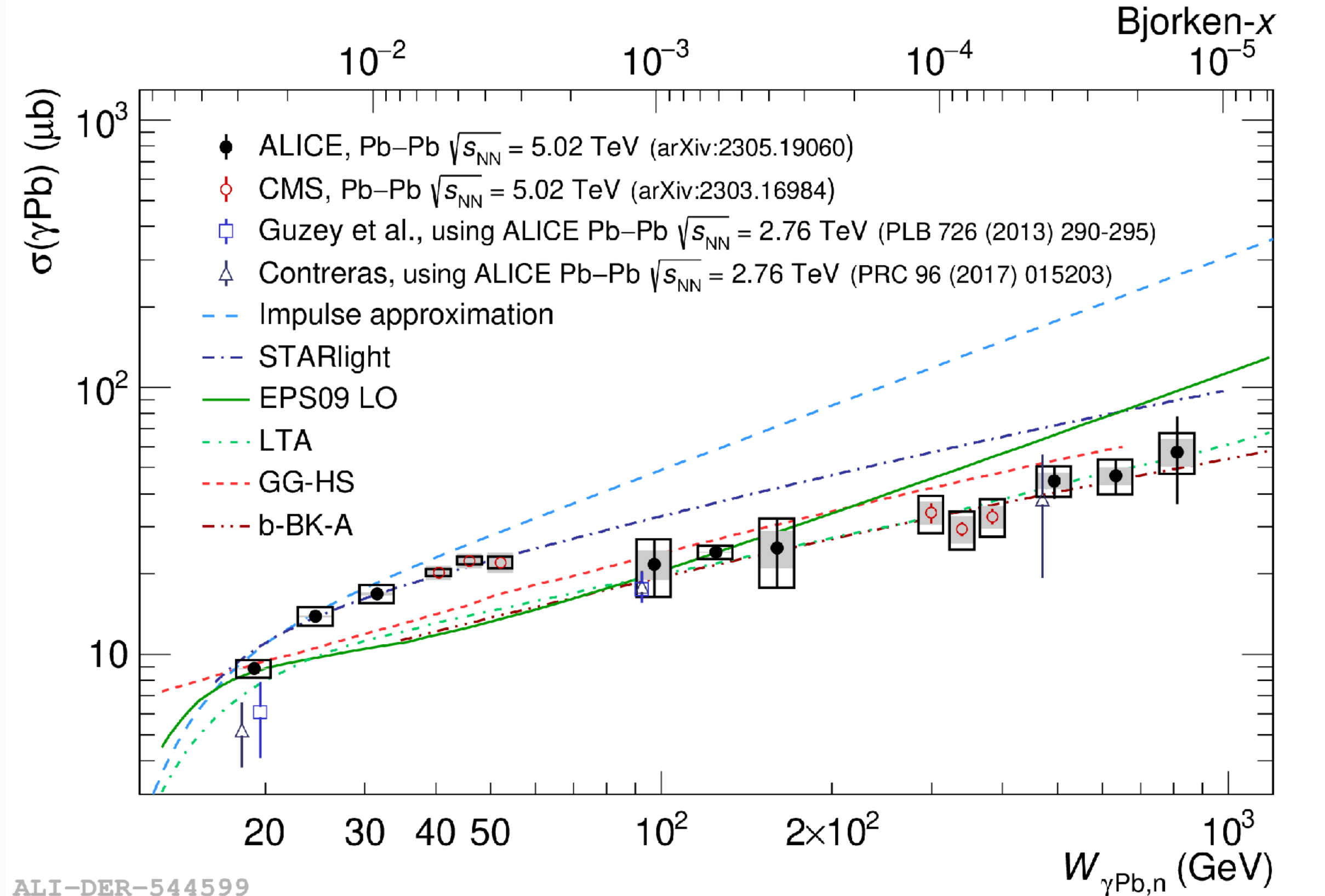
M.Kim Wed. 9:40

M. Durham Tue. 15:00

- Exclusive production of multiple tracks in final states \rightarrow resonance structure in invariant mass distribution
- $J/\psi(\rightarrow \mu^+\mu^-)\phi(\rightarrow K^+K^-)$ shows tetraquark candidates previously observed in $B^\pm \rightarrow J/\psi\phi K^\pm$ decays
- Caveat: production mechanism? i.e. double pomeron exchange

J/ψ photoproduction: region of moderate shadowing

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

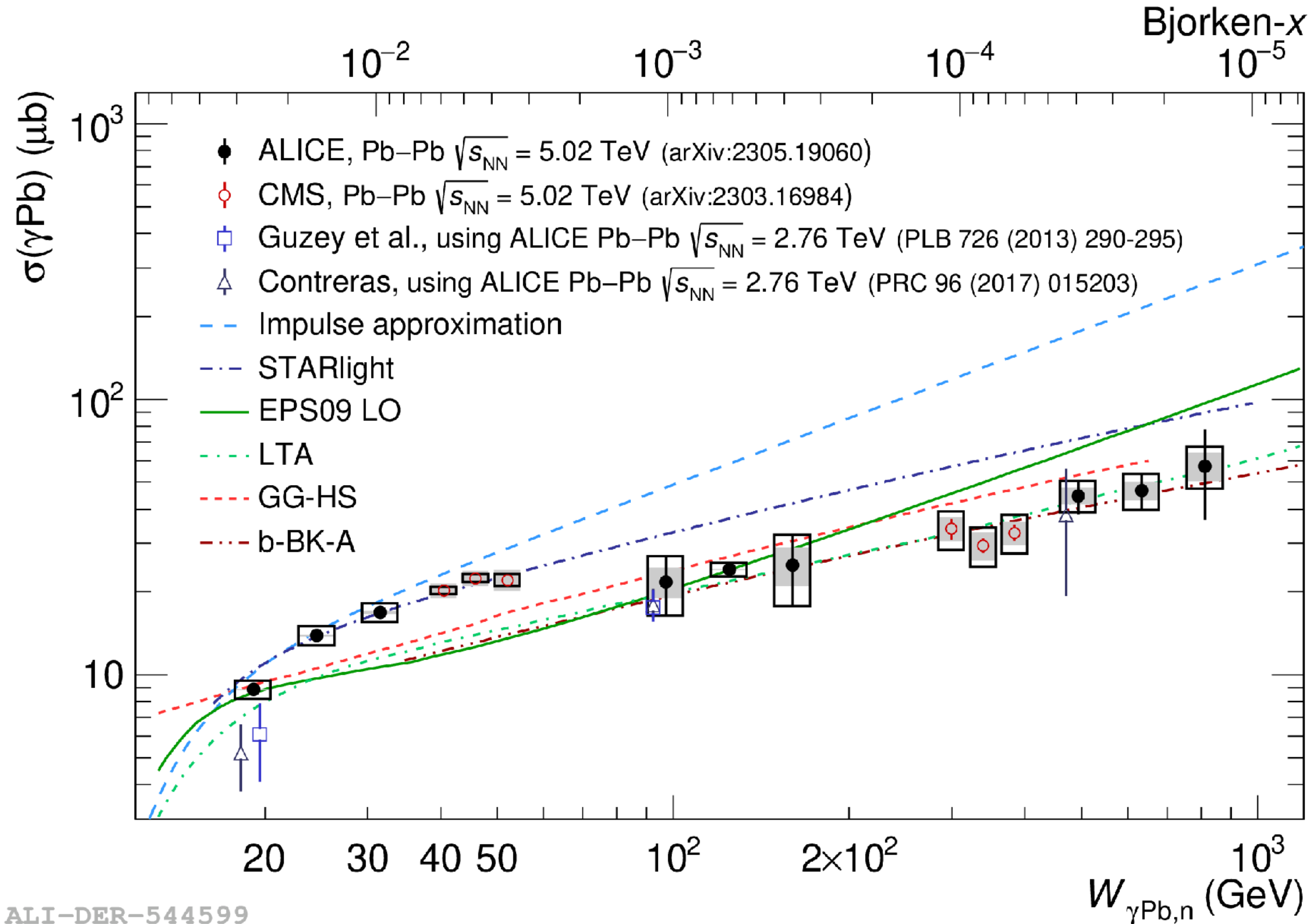


ALI-DER-544599

- **Coherent production: photon interacts with the whole nucleus**
- **No single model describes measured cross section in full range of center of mass energy (Bjorken x)**
- ➡ **Lower- x better described with models including shadowing/saturation while Glauber calculation works better in higher- x**

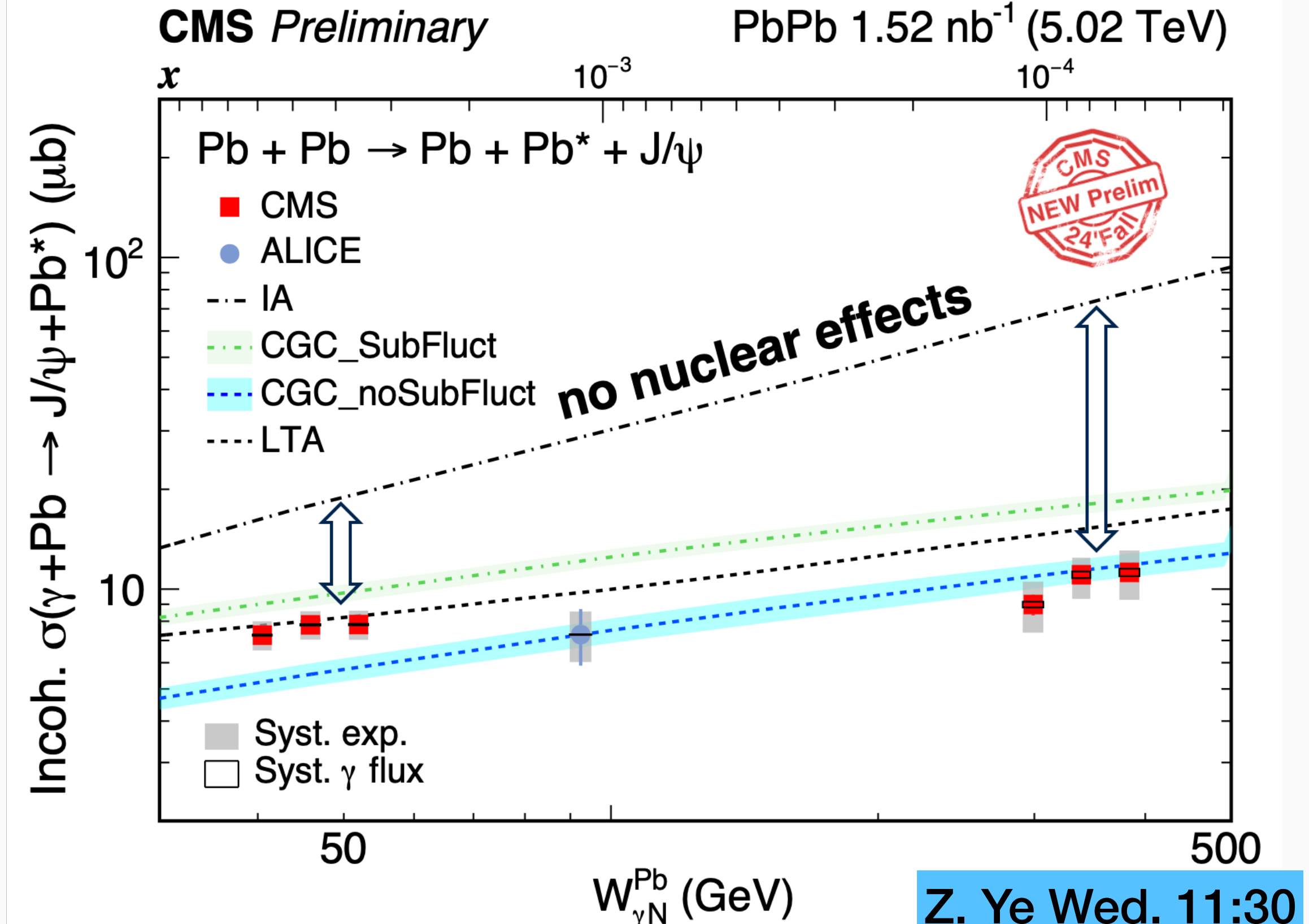
J/ψ photoproduction: region of moderate shadowing

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



ALI-DER-544599

CMS-PAS-HIN-23-009

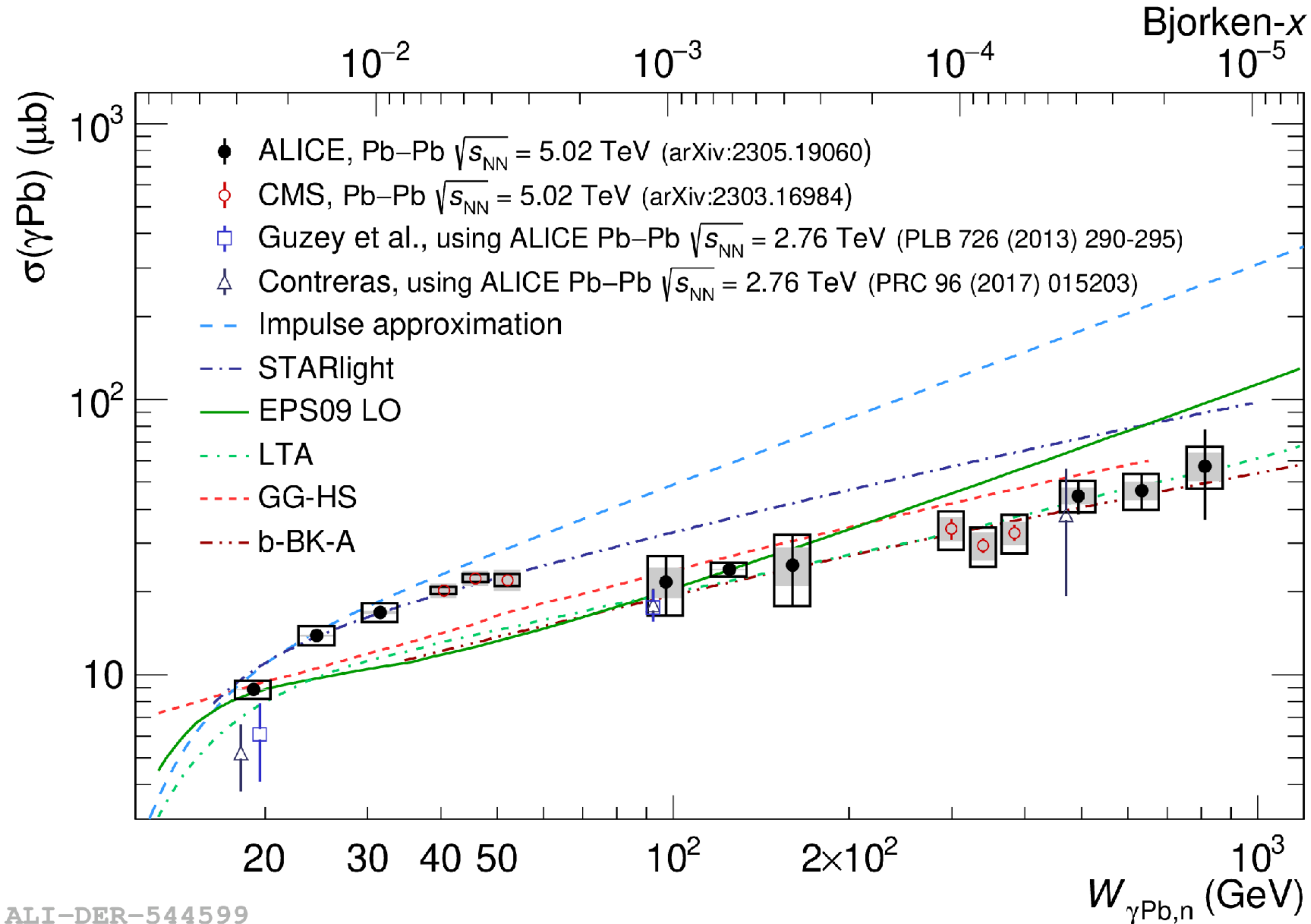


Z. Ye Wed. 11:30

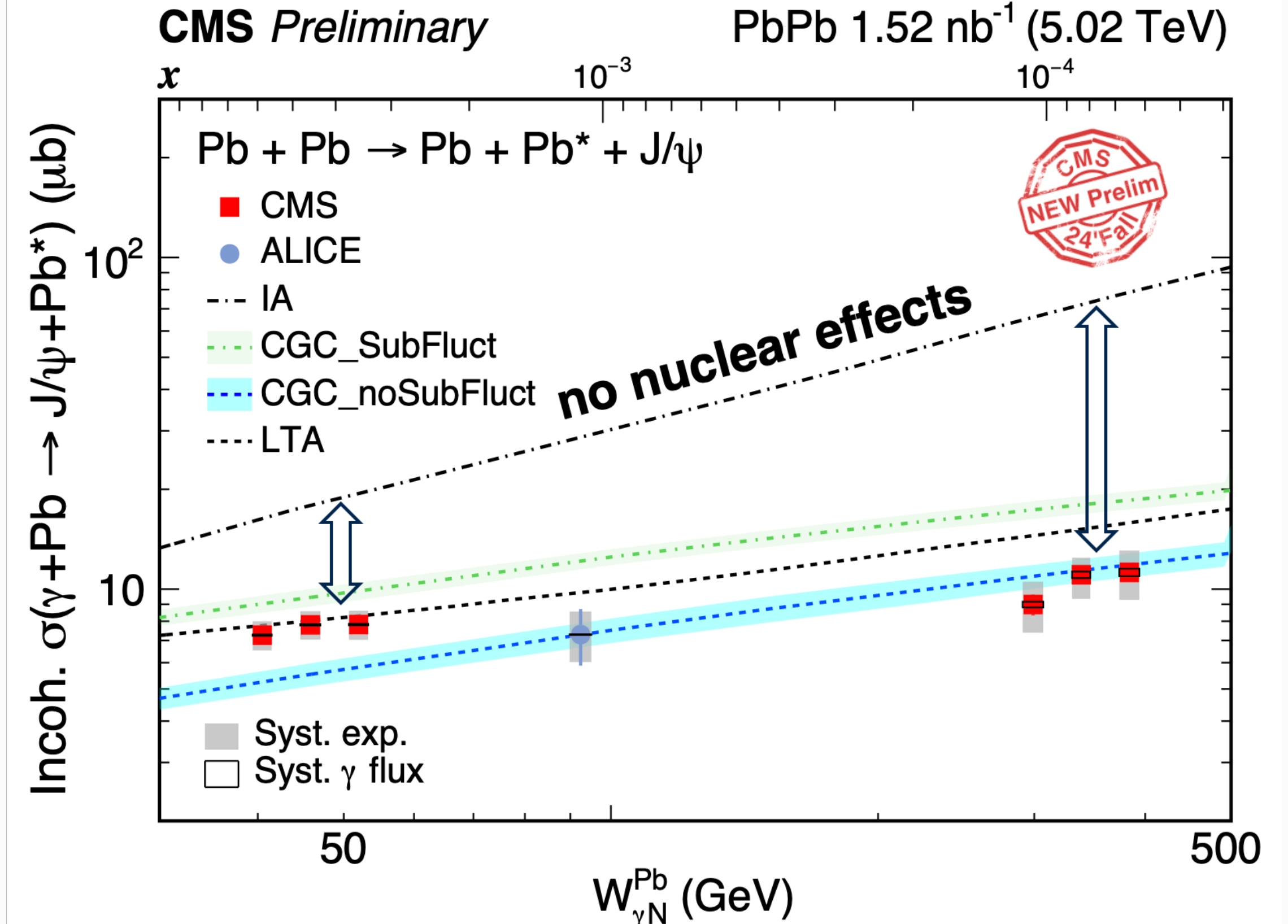
- Incoherent production: photon interacts with single nucleon/subnucleonic structure
- LTA and CGC describes general trend of measured cross section, yet no single model describes measured cross section in full range
- ➔ Open questions: role of sub-nucleonic fluctuations, onset of saturation,....?

J/ψ photoproduction: region of moderate shadowing

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



CMS-PAS-HIN-23-009

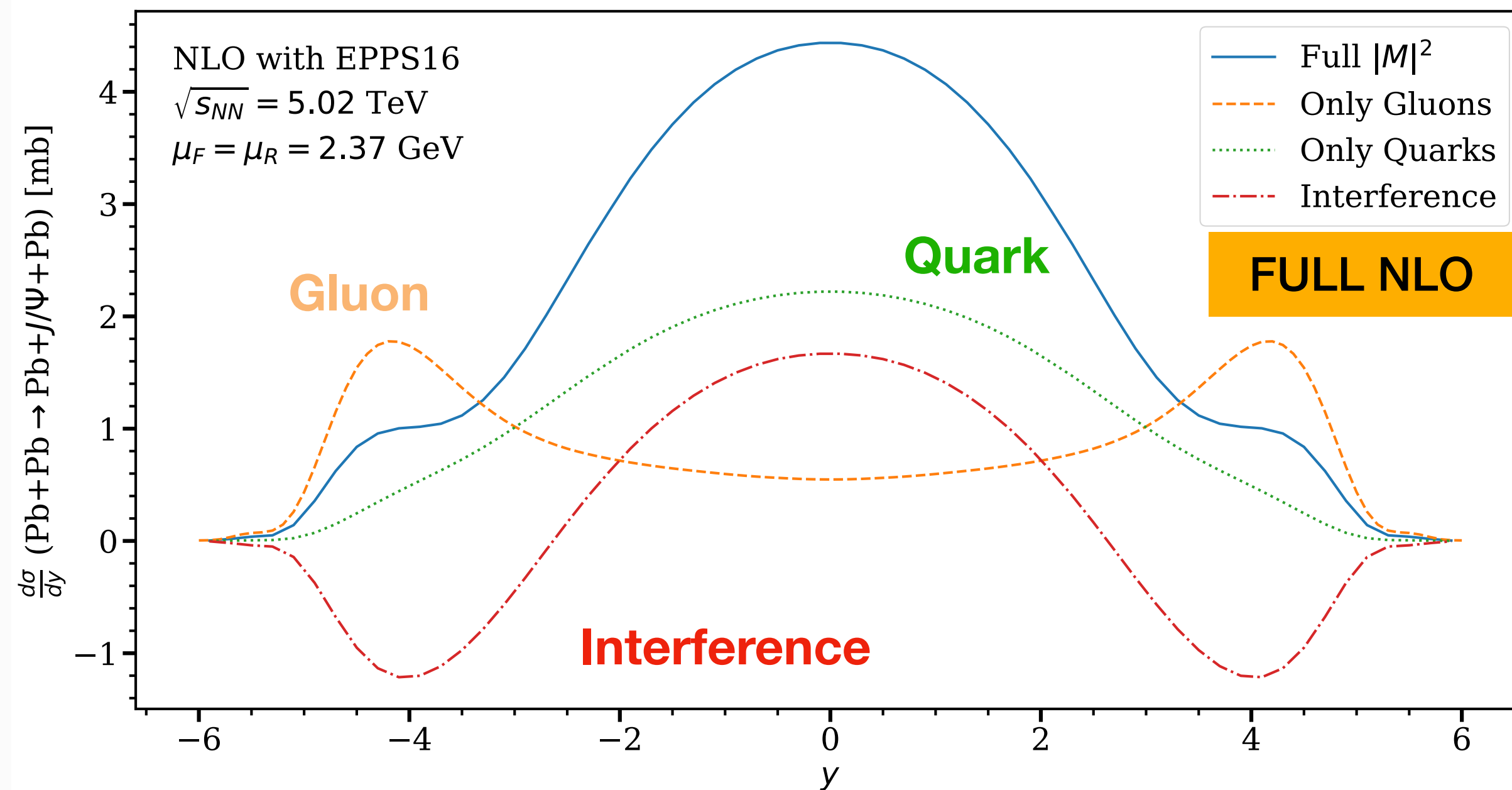


- Incoherent production: photon interacts with single nucleon/subnucleonic structure
- LTA and CGC describes general trend of measured cross section, yet no single model describes measured cross section in full range

New theoretical developments + more differential measurements (i.e. $|t|$) with better granularity measurements required!

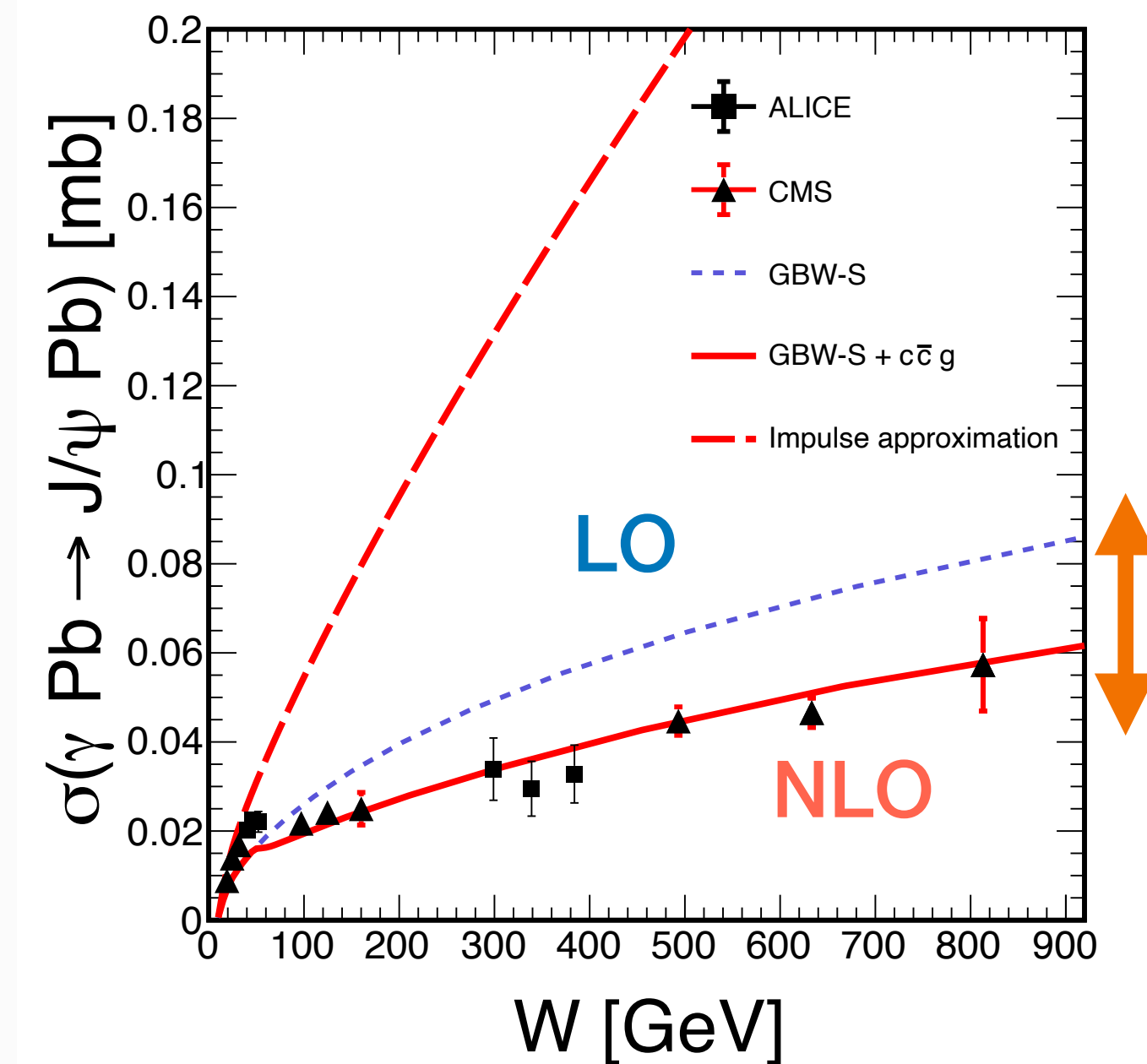
Caveat: Sizable impact of NLO on J/ψ photoproduction

K. J. Eskola et. al., PRC 106 (2022) 035202



H. Mäntysaari, J. Penttala, PLB 823 (2021) 136723

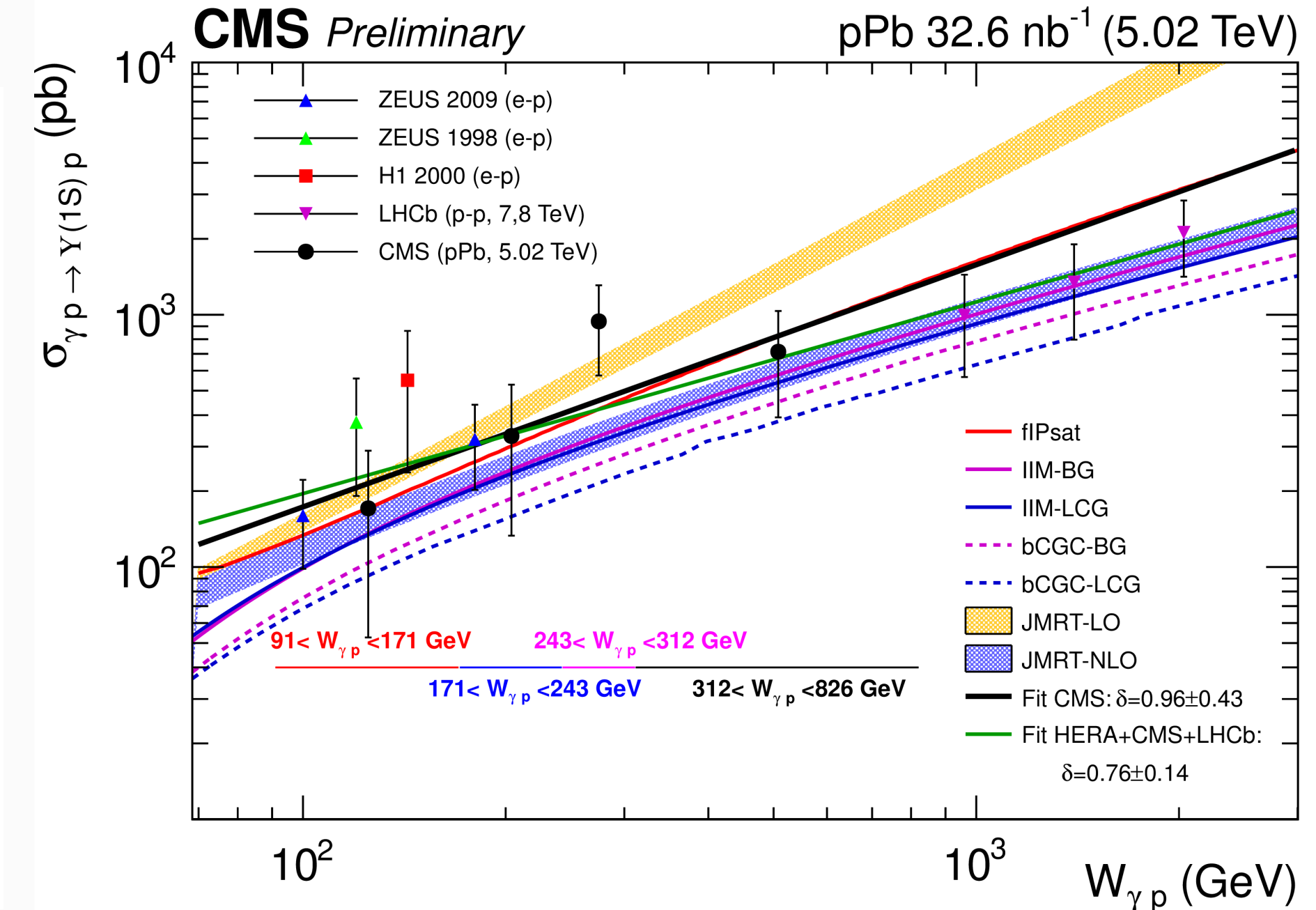
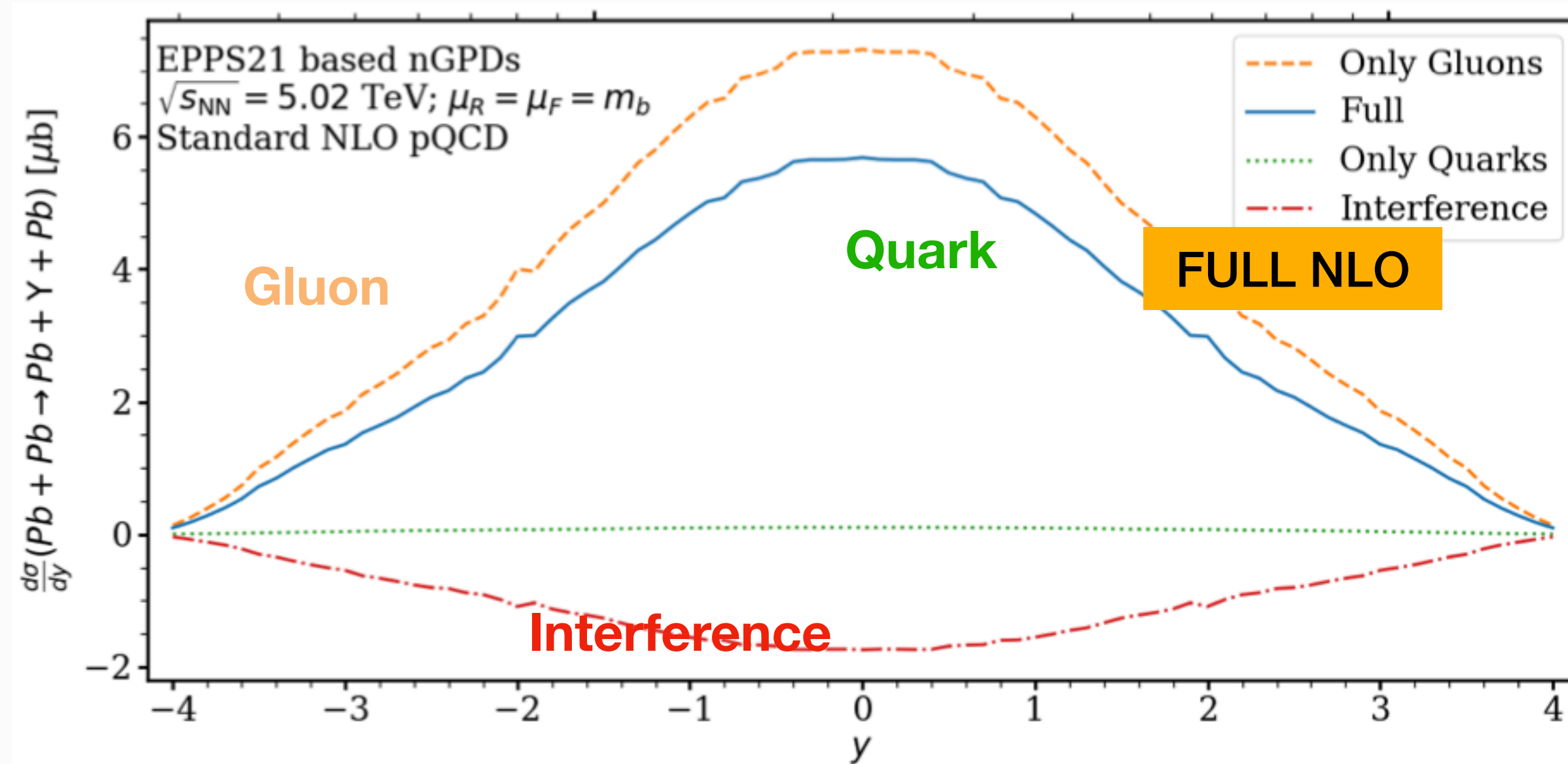
A. Łuszczak, W. Schäfer, PLB 856 (2024) 138917



- pQCD NLO: LO and NLO gluon amplitudes cancel to a large degree; different quark/gluon density sensitivity than LO
- Sizable impact of NLO contribution in dipole picture, better describes the measurements
- Can we (experimentalists) do better in terms of studying low-x gluon?

Prospect of Υ photoproduction measurement

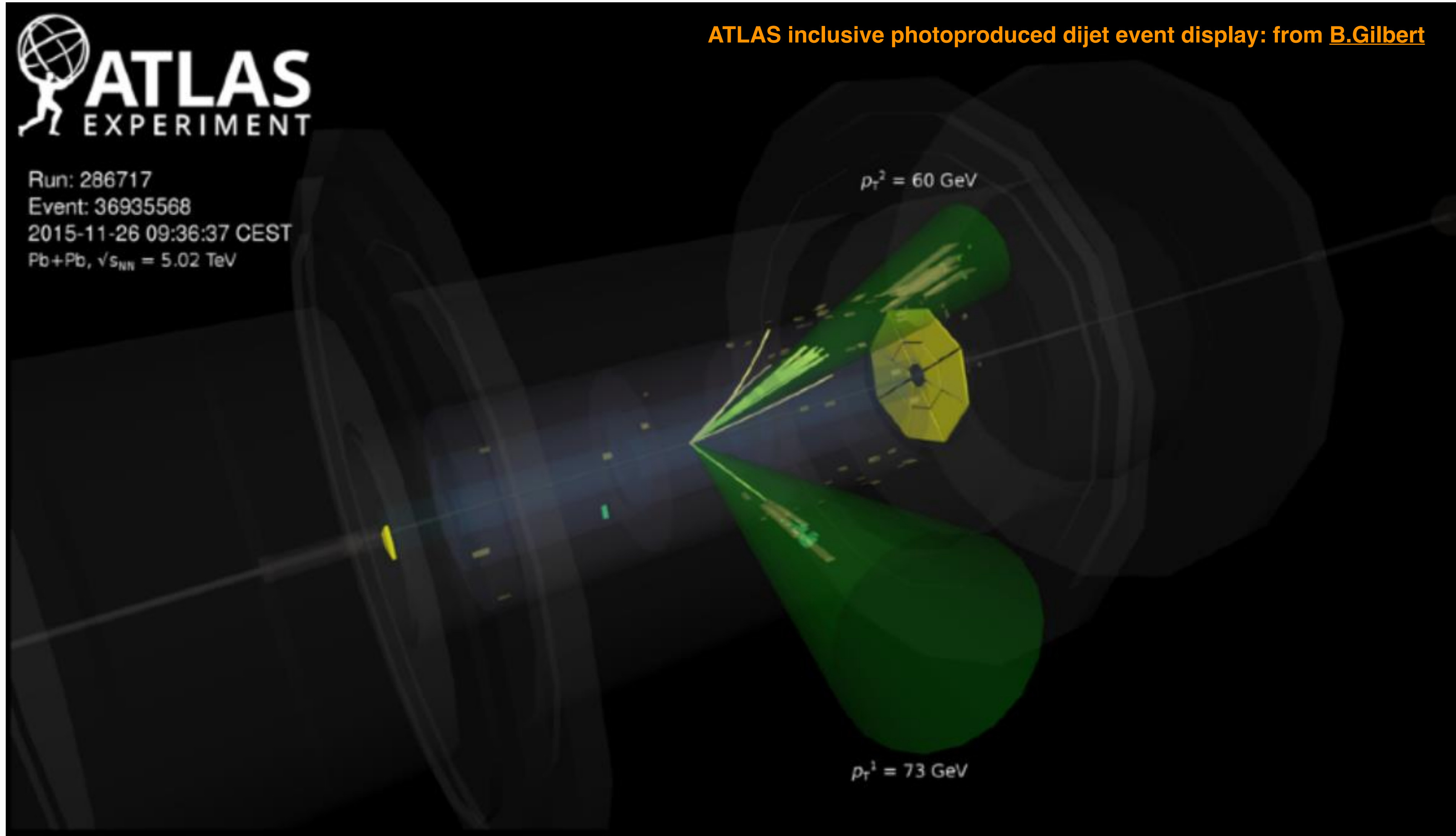
K. J. Eskola et. al., 2303.03007



P. Pujahari Wed. 11:50

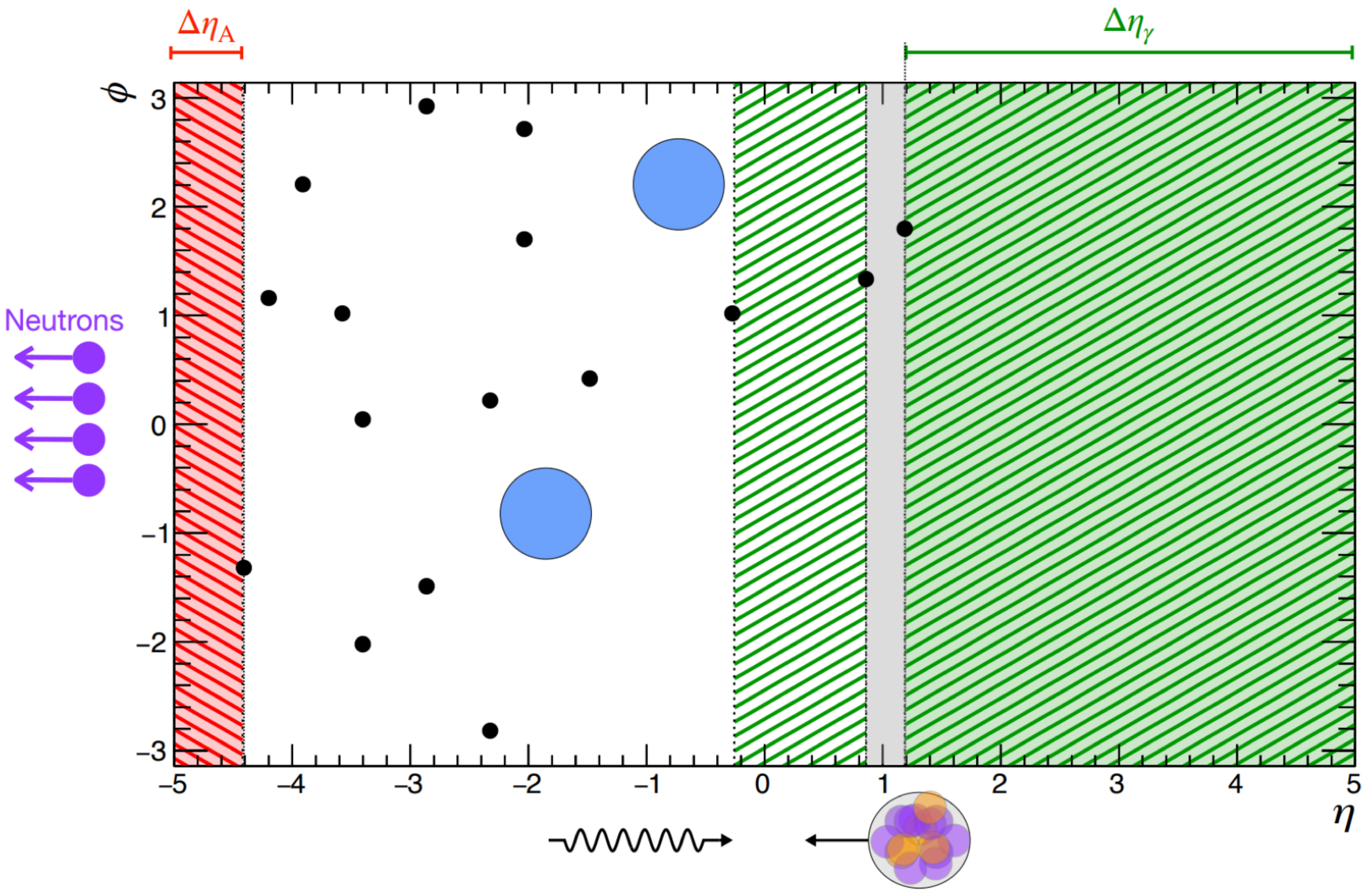
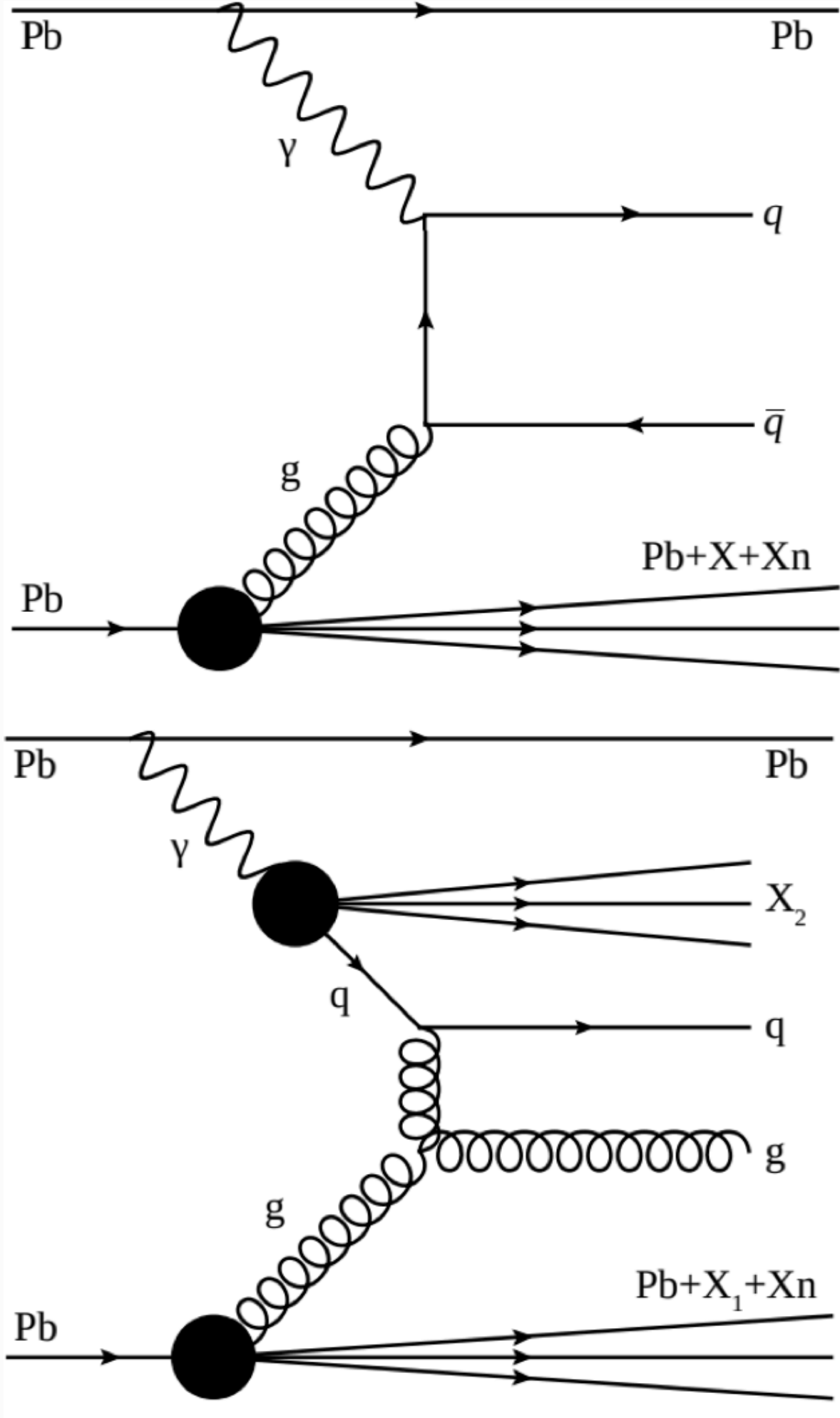
- ➔ Υ photoproduction: gluon dominated in NLO (at least) + weaker scale dependence
- ➔ Work in progress in p-Pb and Pb-Pb UPCs!

Inclusive photoproduction: new phase of UPC physics



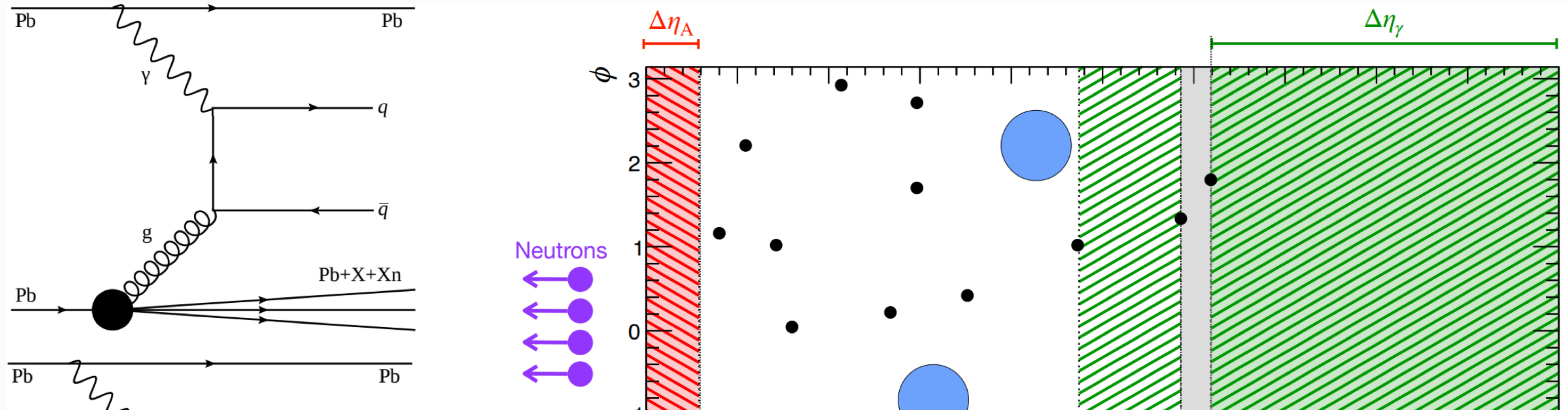
Inclusive photoproduction (mainly single gluon exchange)

Cartoons from B.Gilbert



Inclusive photoproduction (mainly single gluon exchange)

Cartoons from B.Gilbert

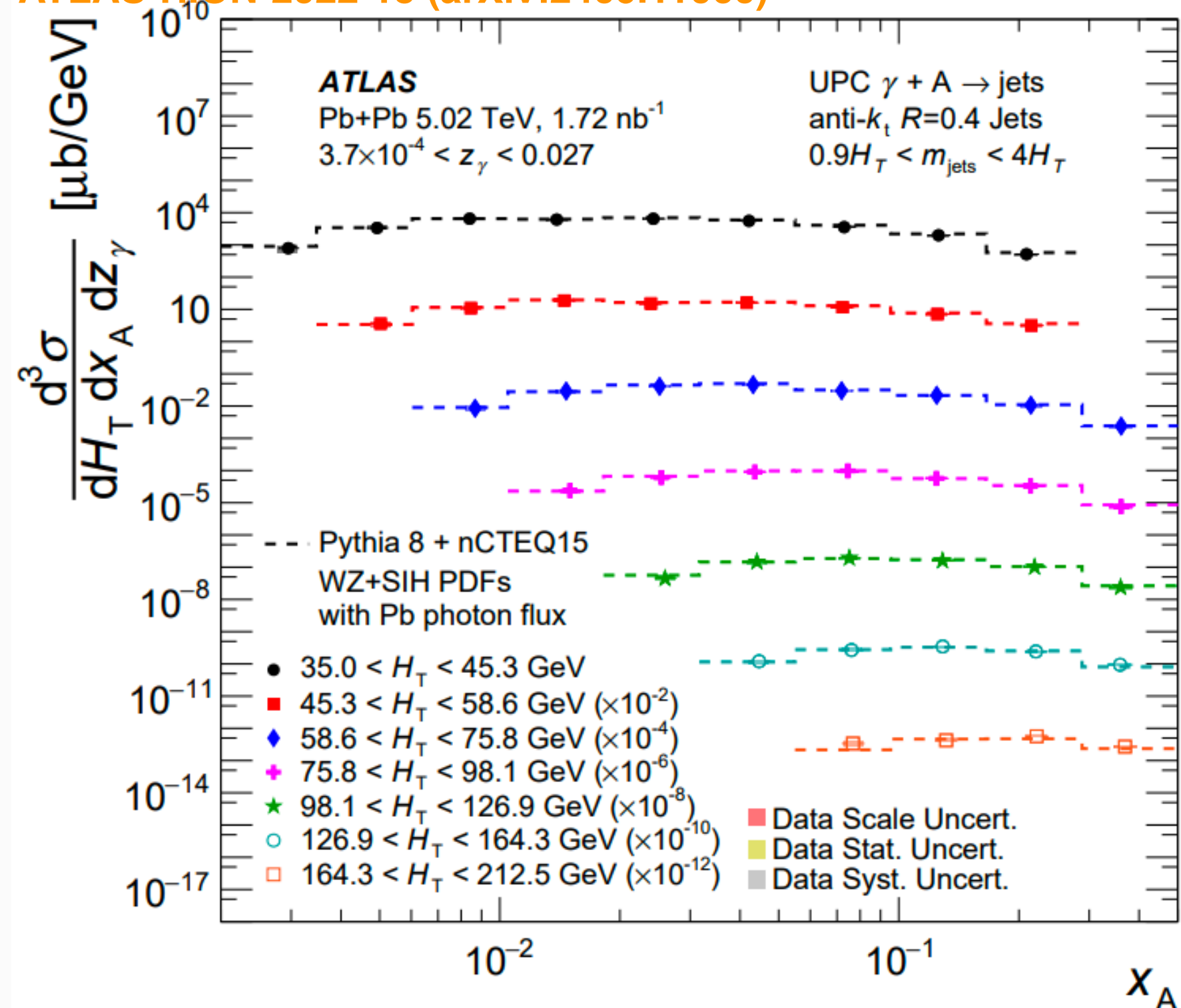


Innovative Measurements in UPCs: Technically challenging measurements

1. Parton fragmentation and hadronization
 2. Additional event-by-event fluctuation from resolved process
 3. Background from hadronic interactions of Pb-Pb on top of usual electromagnetic dissociation and two gamma process
- ✓ Extremely good control on event topology required to enable theoretical interpretation!

Photonuclear dijet production

ATLAS-HION-2022-15 (arXiv:2409.11060)

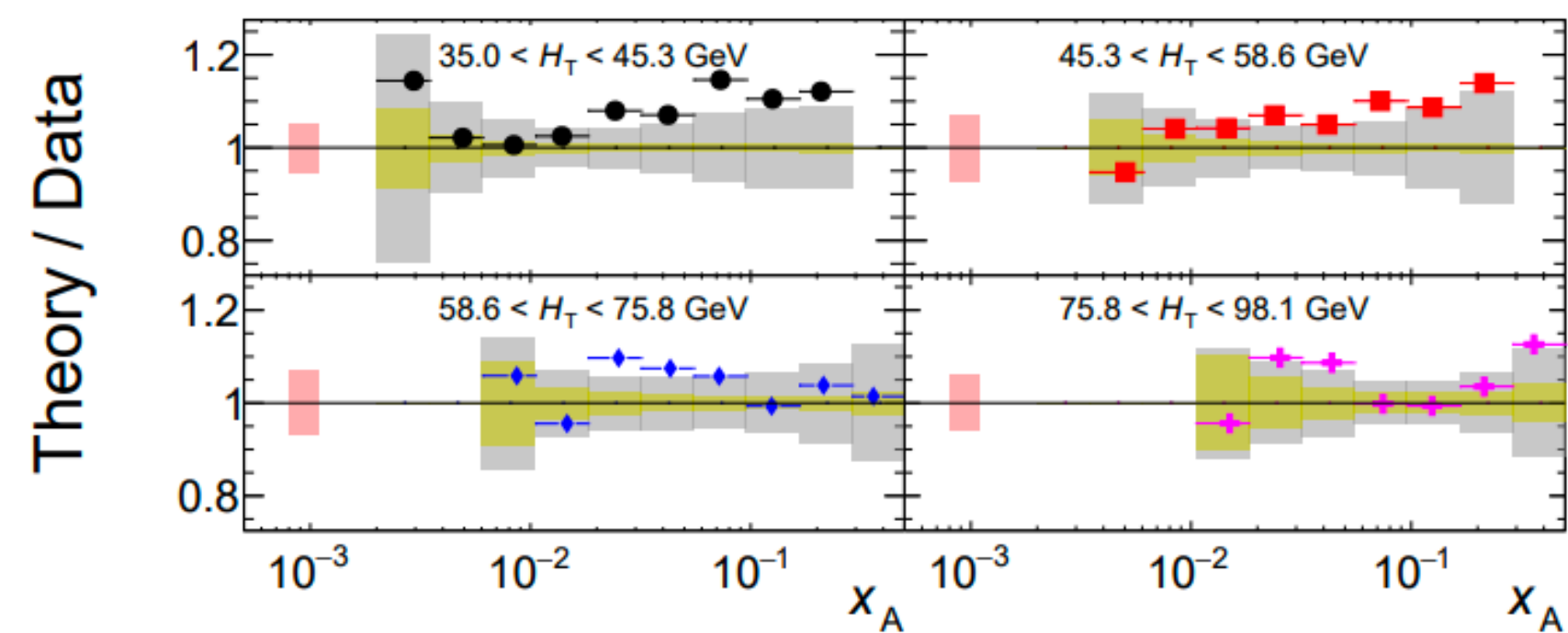


- Triple differential cross section of dijet

$$H_T = \sum_i p_T^i \quad x_A = \frac{M_{jets} e^{-y_{jets}}}{\sqrt{s_{NN}}} \quad z_\gamma = \frac{M_{jets} e^{+y_{jets}}}{\sqrt{s_{NN}}}$$

- First measurement of inclusive dijet photoproduction in UPCs

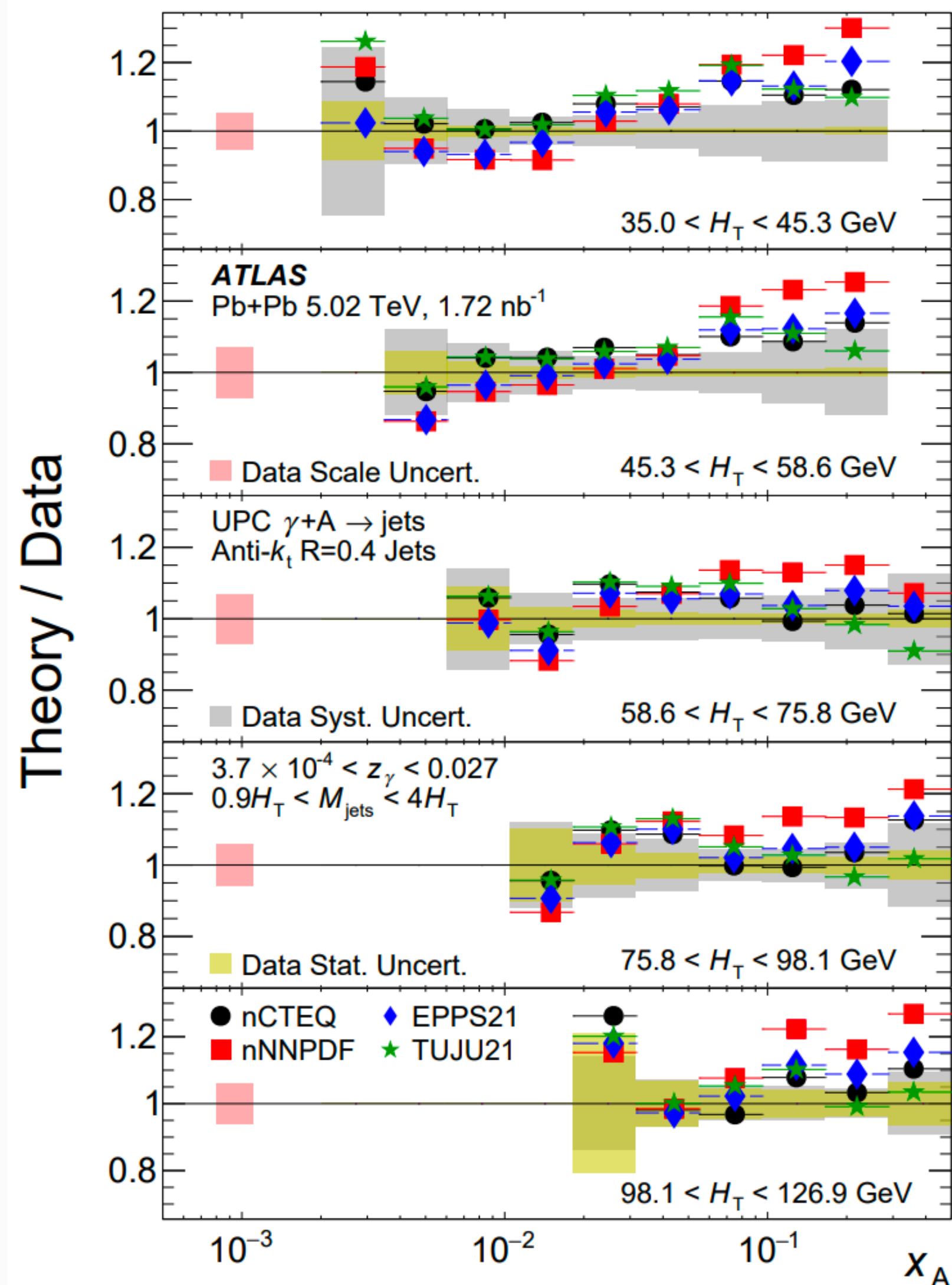
All nPDF models have excess anti-shadowing
 Unique kinematic coverage w.r.t. existing (as well as upcoming EIC) nPDF constraints



B. Gilbert Wed. 12:10

Photonuclear dijet production

ATLAS-HION-2022-15 (arXiv:2409.11060)



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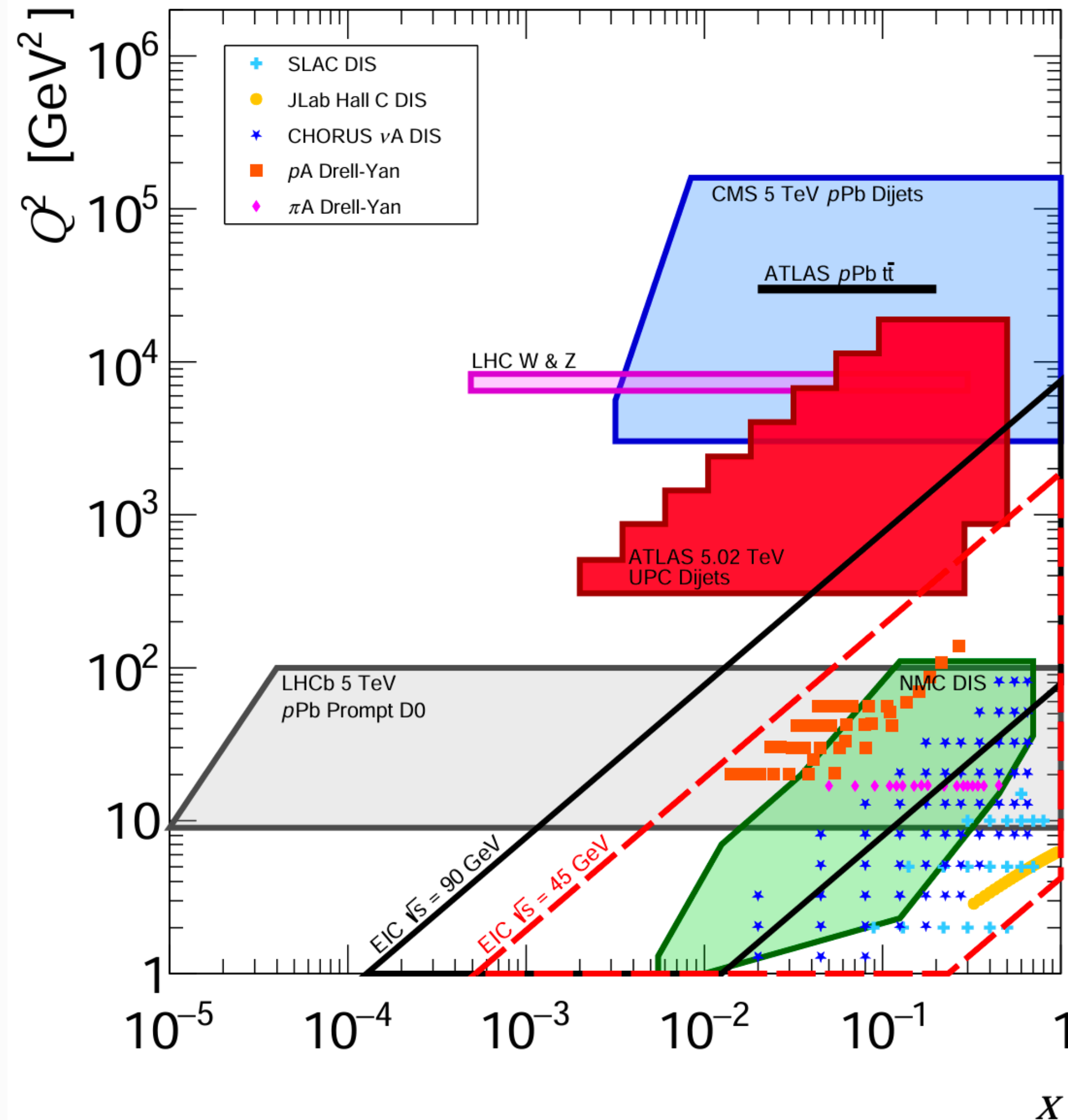
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B. Gilbert Wed. 12:10

Photonuclear dijet production

ATLAS-HION-2022-15 (arXiv:2409.11060)



- Triple differential cross section of dijet

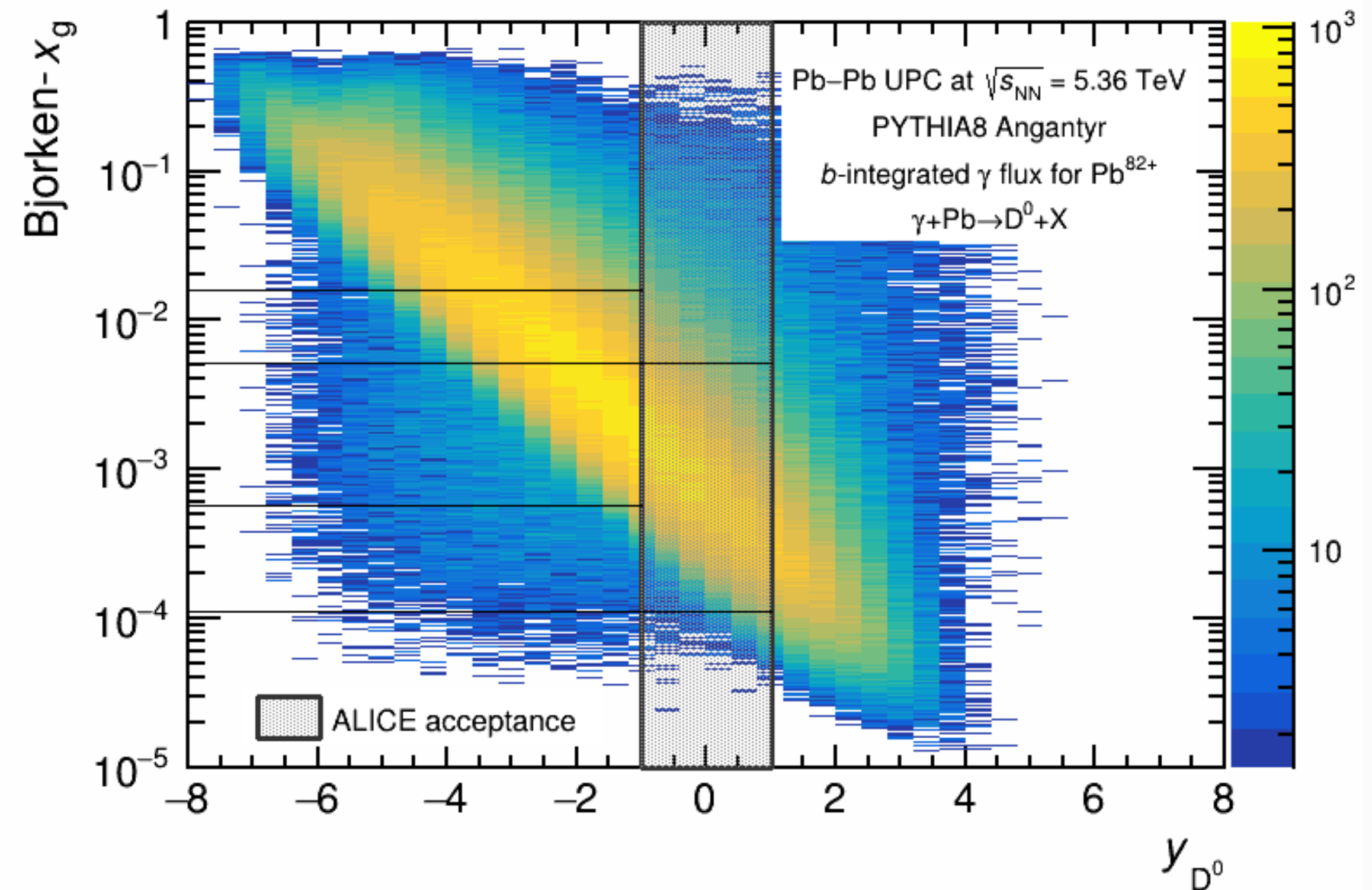
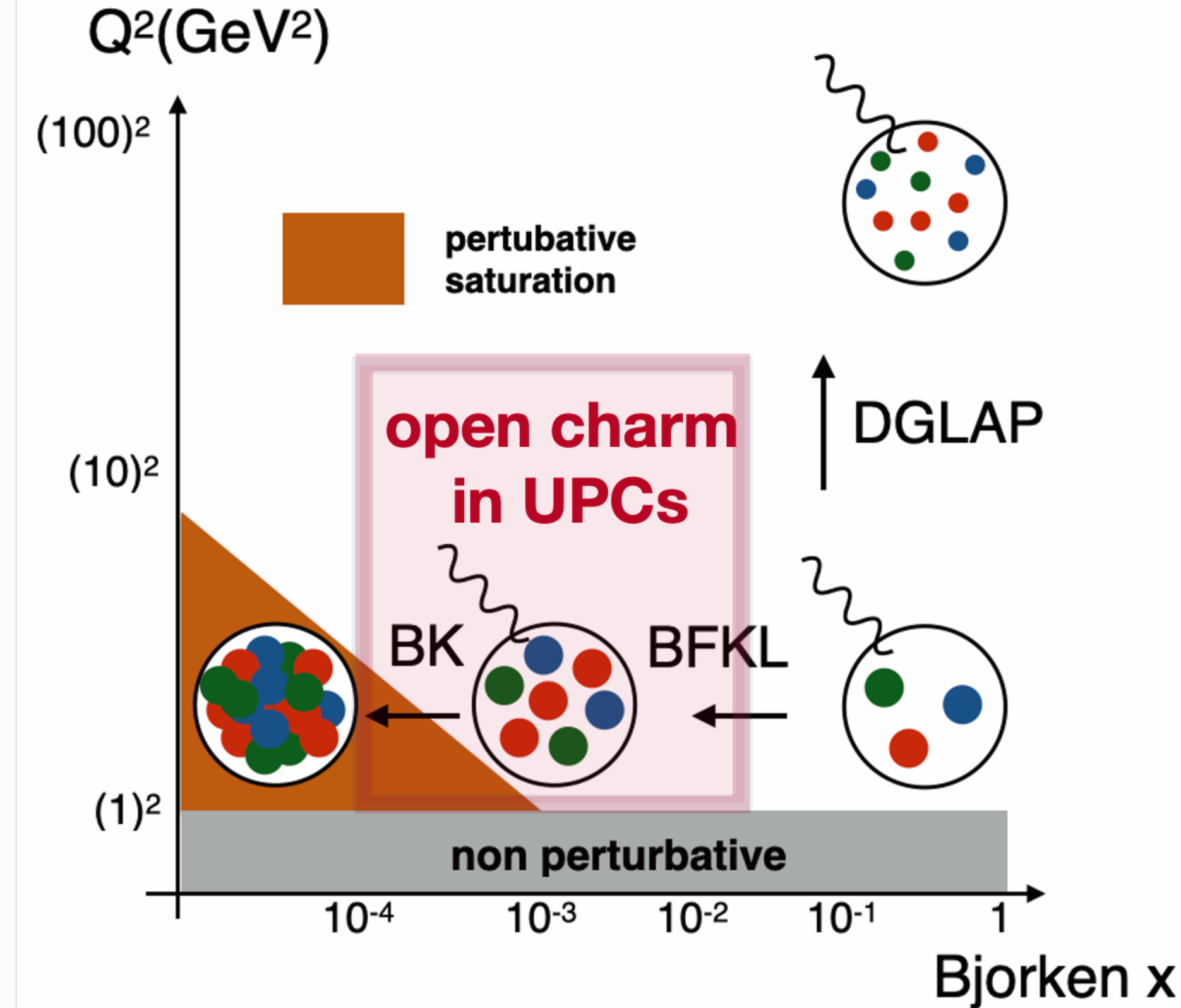
$$H_T = \sum_i p_T^i \quad x_A = \frac{M_{jets} e^{-y_{jets}}}{\sqrt{s_{NN}}} \quad z_Y = \frac{M_{jets} e^{+y_{jets}}}{\sqrt{s_{NN}}}$$

- First measurement of inclusive dijet photoproduction in UPCs
- All nPDF models have excess anti-shadowing
- Unique kinematic coverage w.r.t. existing (as well as upcoming EIC) nPDF constraints

B. Gilbert Wed. 12:10

Open charm production in UPCs: a new probe for small-x

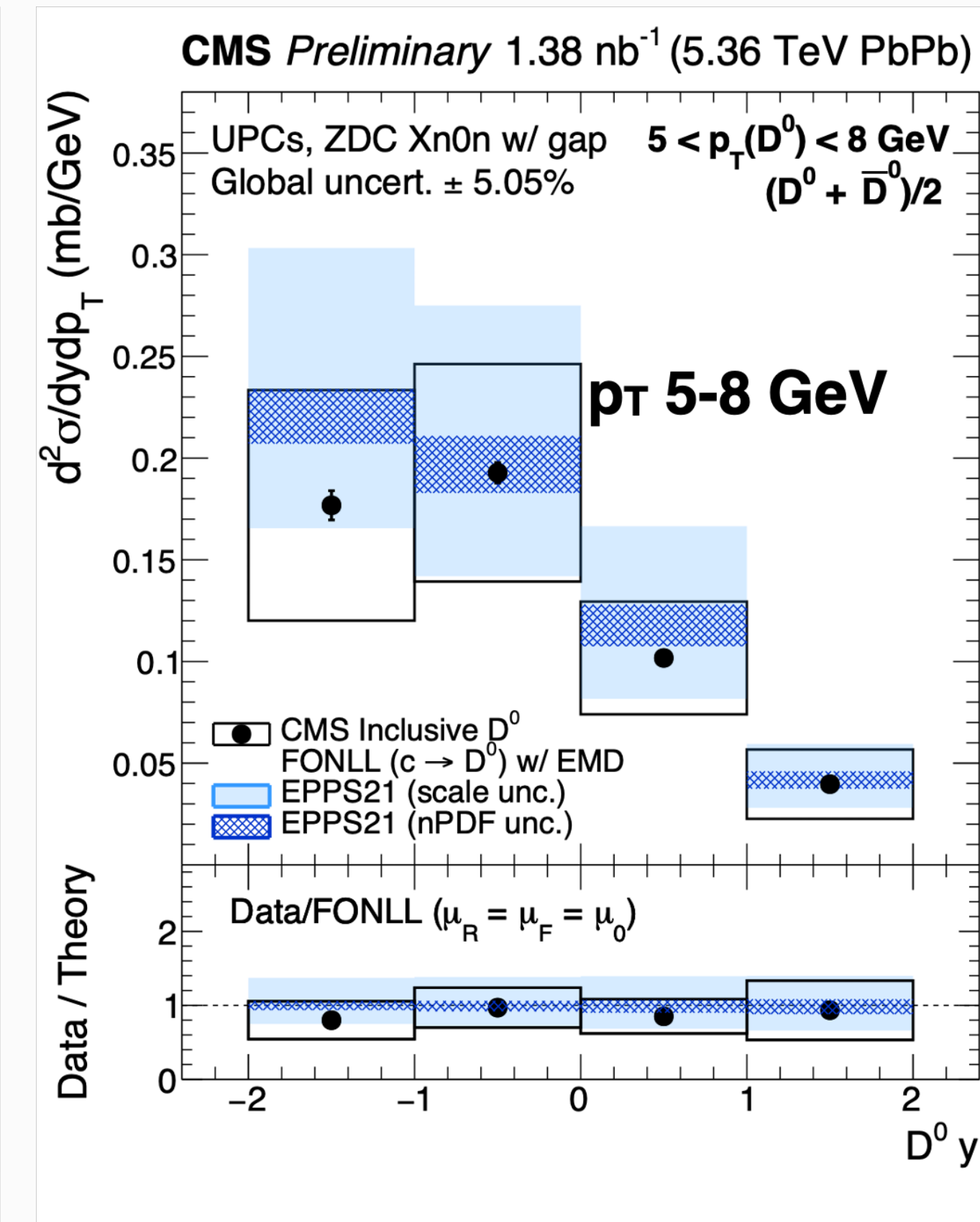
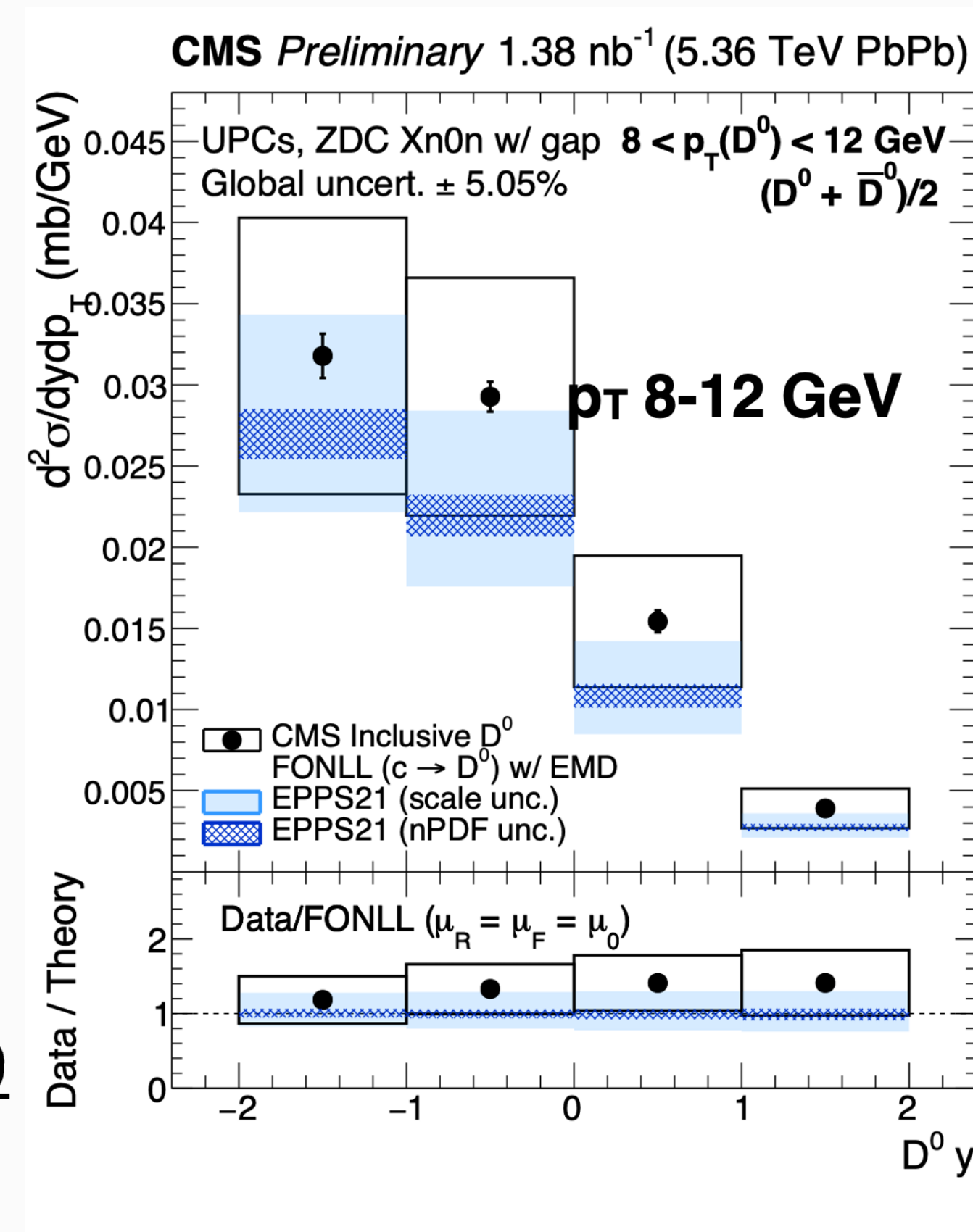
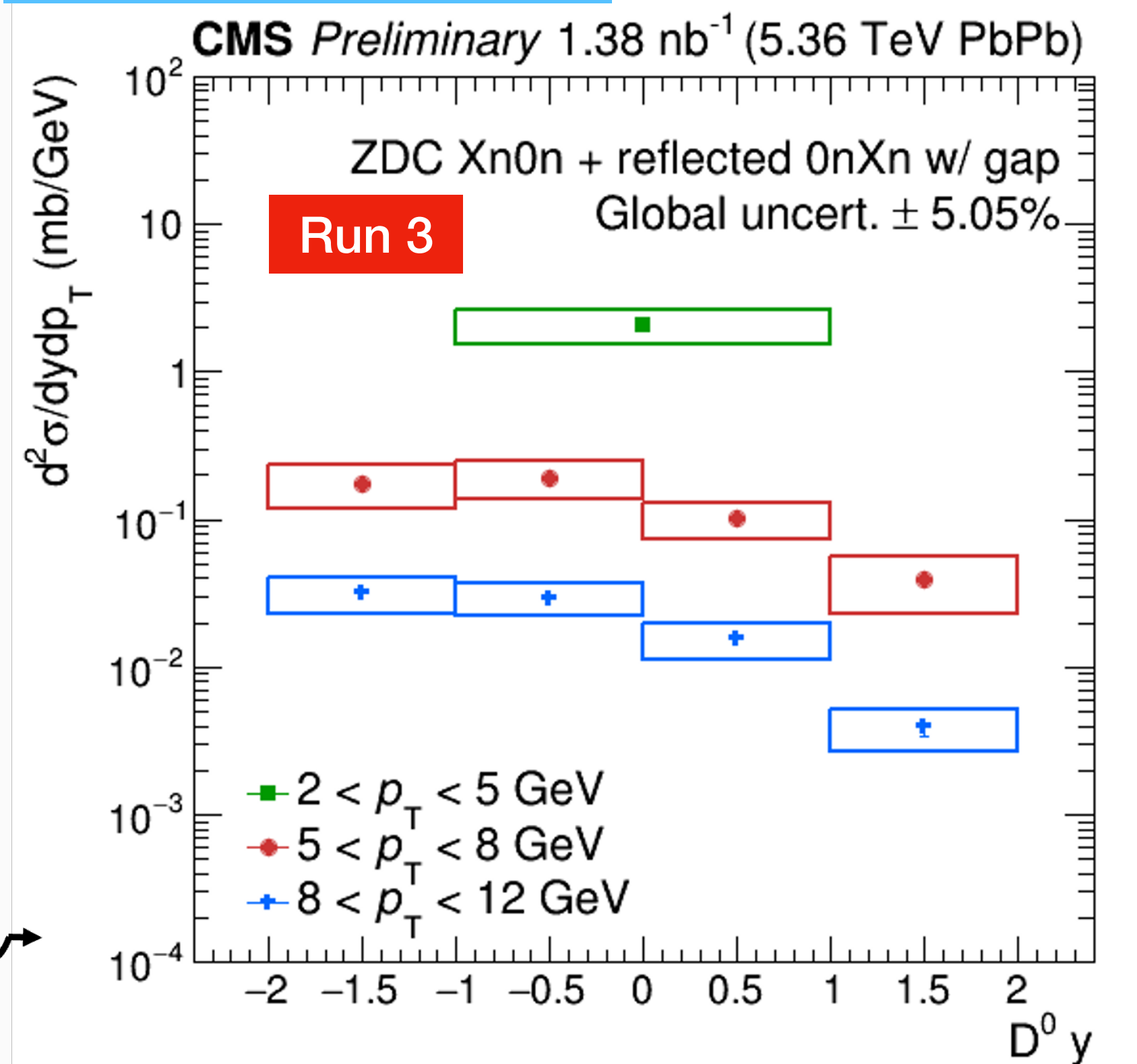
Cartoons from G.M. Innocenti



- First constraints on nuclear gluon PDFs over a wide region of Q^2 ($10 < Q^2 < \text{hundreds GeV}^2$) at low- x ($\sim 5 \cdot 10^{-4} < x < 10^{-2}$) in the absence of sizable final state effects
- Kinematic information of process accessible via differential measurement of final state open charm hadron

D⁰ photoproduction in UPCs

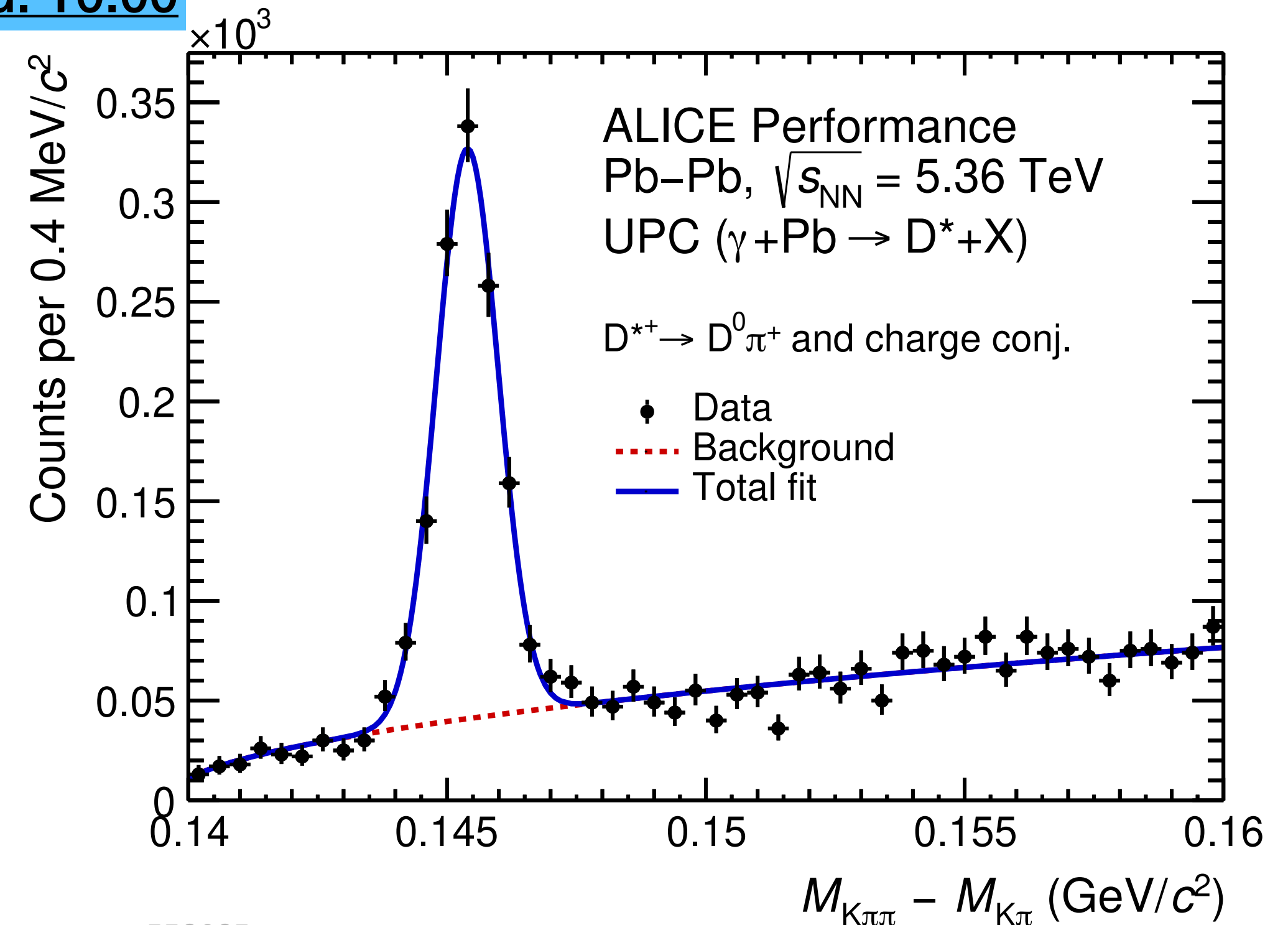
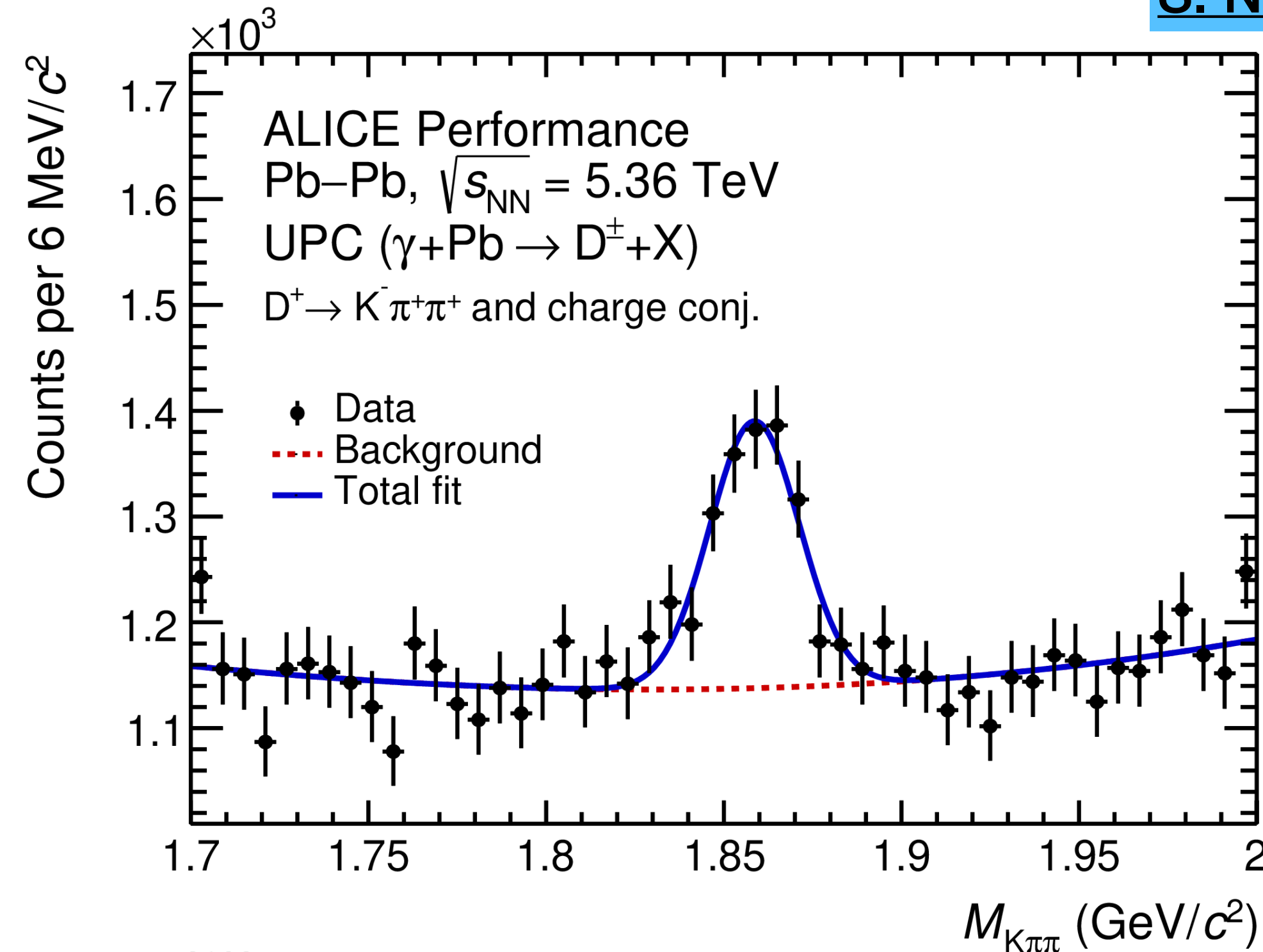
C. McGinn Wed. 10:50



- First measurement of D⁰ photoproduction in UPCs; good agreement with FONLL+nPDF
- Opens the way for a large program of open heavy-flavor hadrons, jets and correlations in UPCs collisions at the LHC

Open charm production in UPCs: more measurements are coming

S. Nese Wed. 10:00



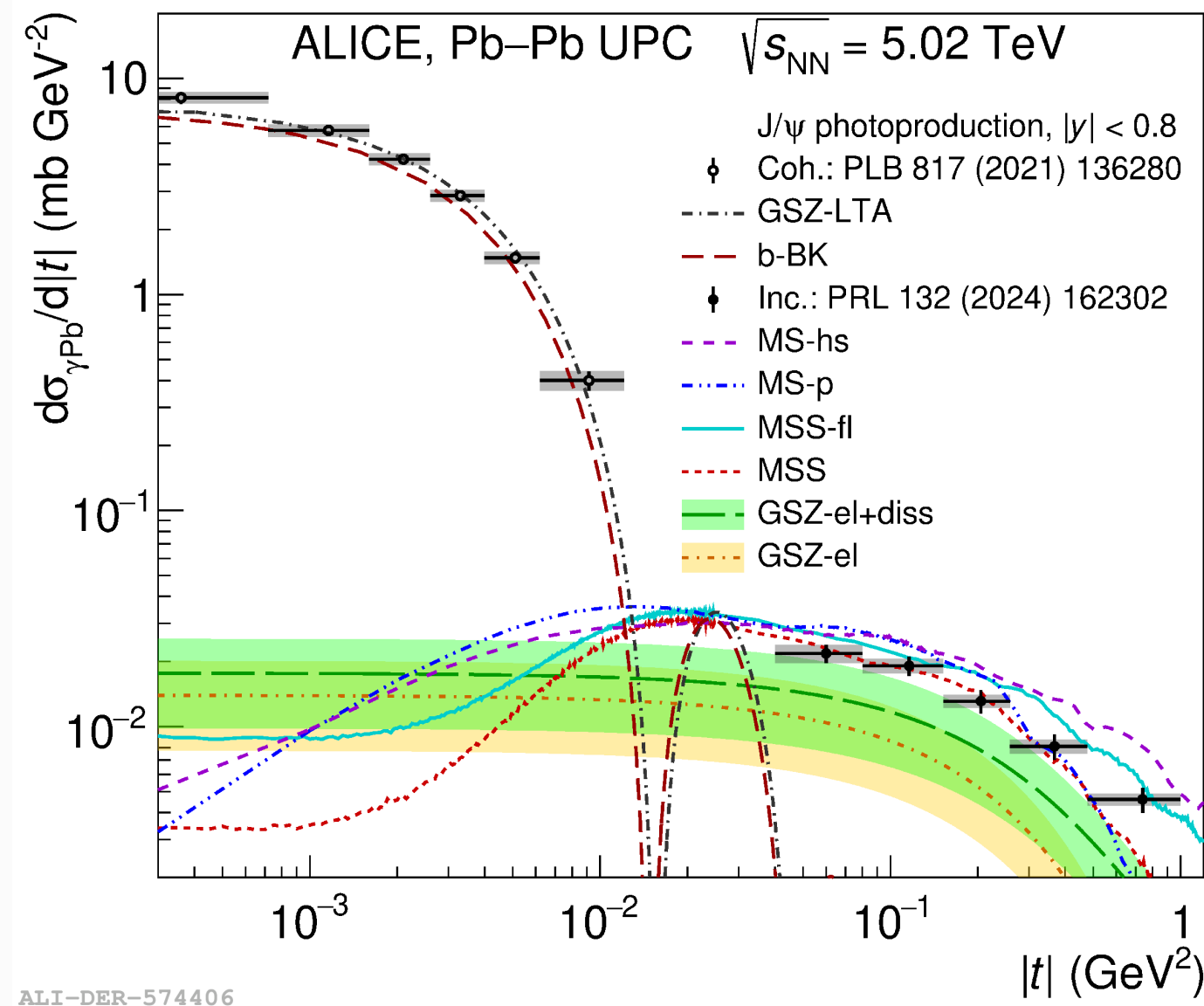
- First measurement of D0 photoproduction in UPCs; good agreement with FONLL+nPDF
- Opens the way for a large program of open heavy-flavor hadrons, jets and correlations in UPCs collisions at the LHC

Summary and outlook

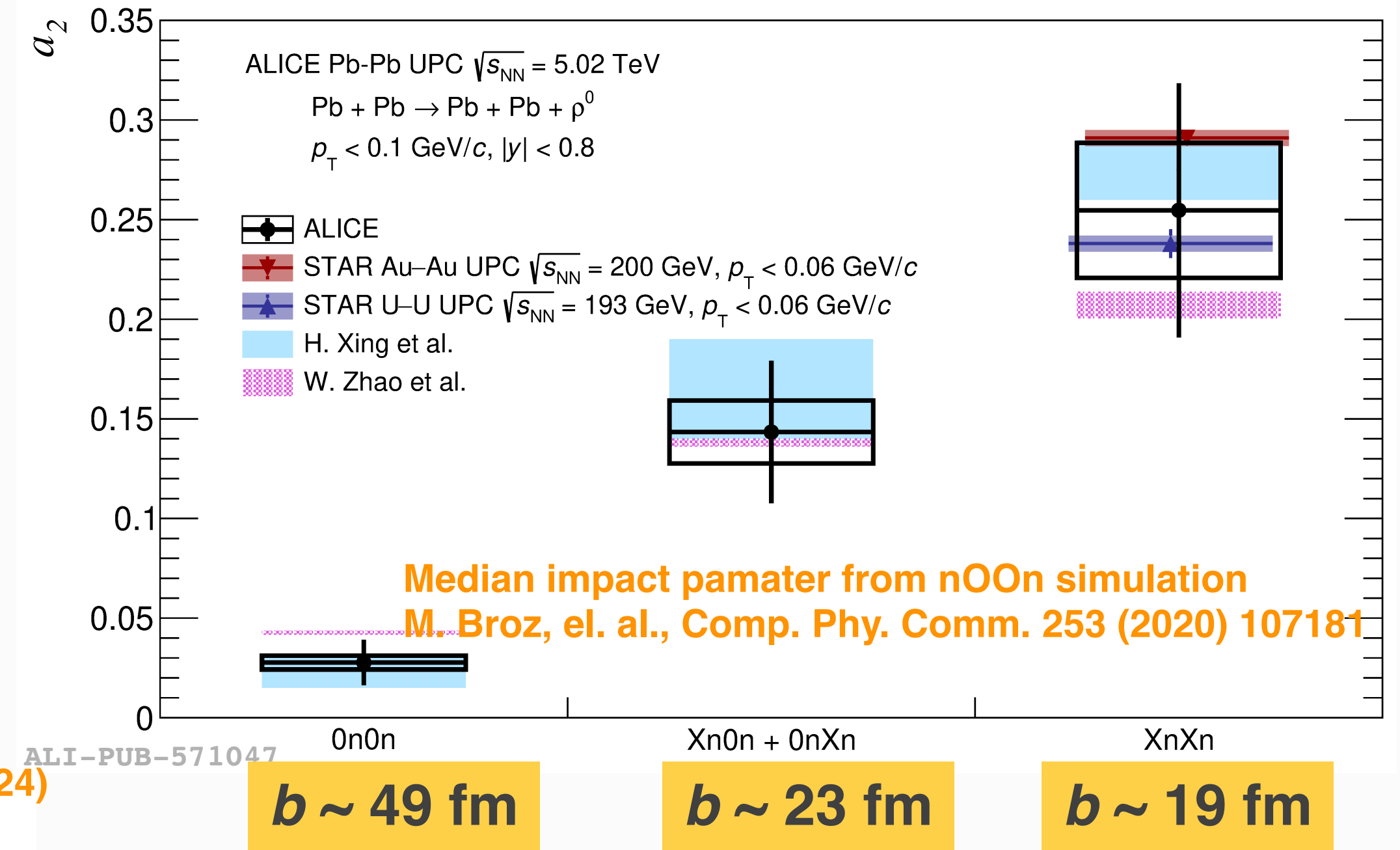
- Multiple probes of exclusive UPCs map the target (gluon) distribution in nuclei [M. Dyndal Wed. 11:10](#) [K. Wang Wed. 09:00](#)
 - Studying the nuclear structure at high energies (small Bjorken-x), dense gluon system towards extreme condition, i.e. black-disc limit approach of QCD, onset of saturation,..
 - Clean environment study offering insights into other (broader) areas of physics: various couplings between photon/hadron and mesons, discovery of new exotic hadrons, quantum interference effect and searching for new physics (BSM) and more....
 - More differential measurements with better granularity towards precision measurements together with new theoretical developments:
 - Capture the “dynamic” target (gluon) distribution of fluctuations
 - Better understanding photoproduction coming with QGP; impact parameter info. + new insight into QGP as well?
- New phase of UPC physics with measurements of inclusive production just started!
 - Lowest-order cross section is directly proportional to the gluon distribution
 - Strong constraint power on nPDF with wide kinematic ranges
 - Clean environment to study open questions arising from hadronic interaction: i.e. hadronization mechanism, parton shower,
- ◆ *Many thanks to all UPC speakers and poster presenters in HP2024, in particular, special thanks to Ionut Arsene, Zaochen Ye, G.M. Innocenti, Ben Gilbert, Amanda May Donohoe and Matt Durham*

Not covered in this talk: 1. more on vector mesons

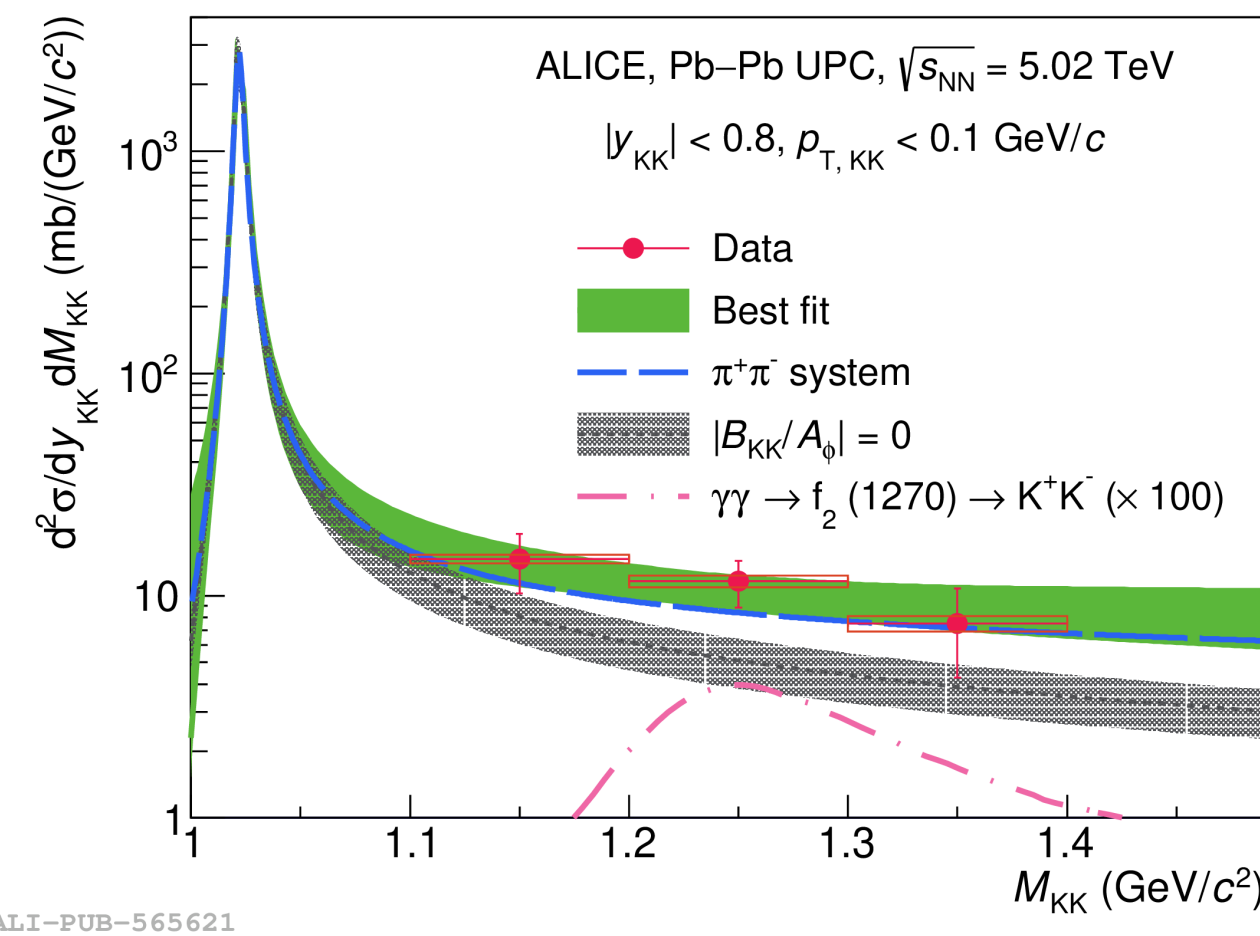
PLB 817 (2021) 136280 PRL 132 (2024) 162302



arXiv:2405.14525 (accepted by PLB)

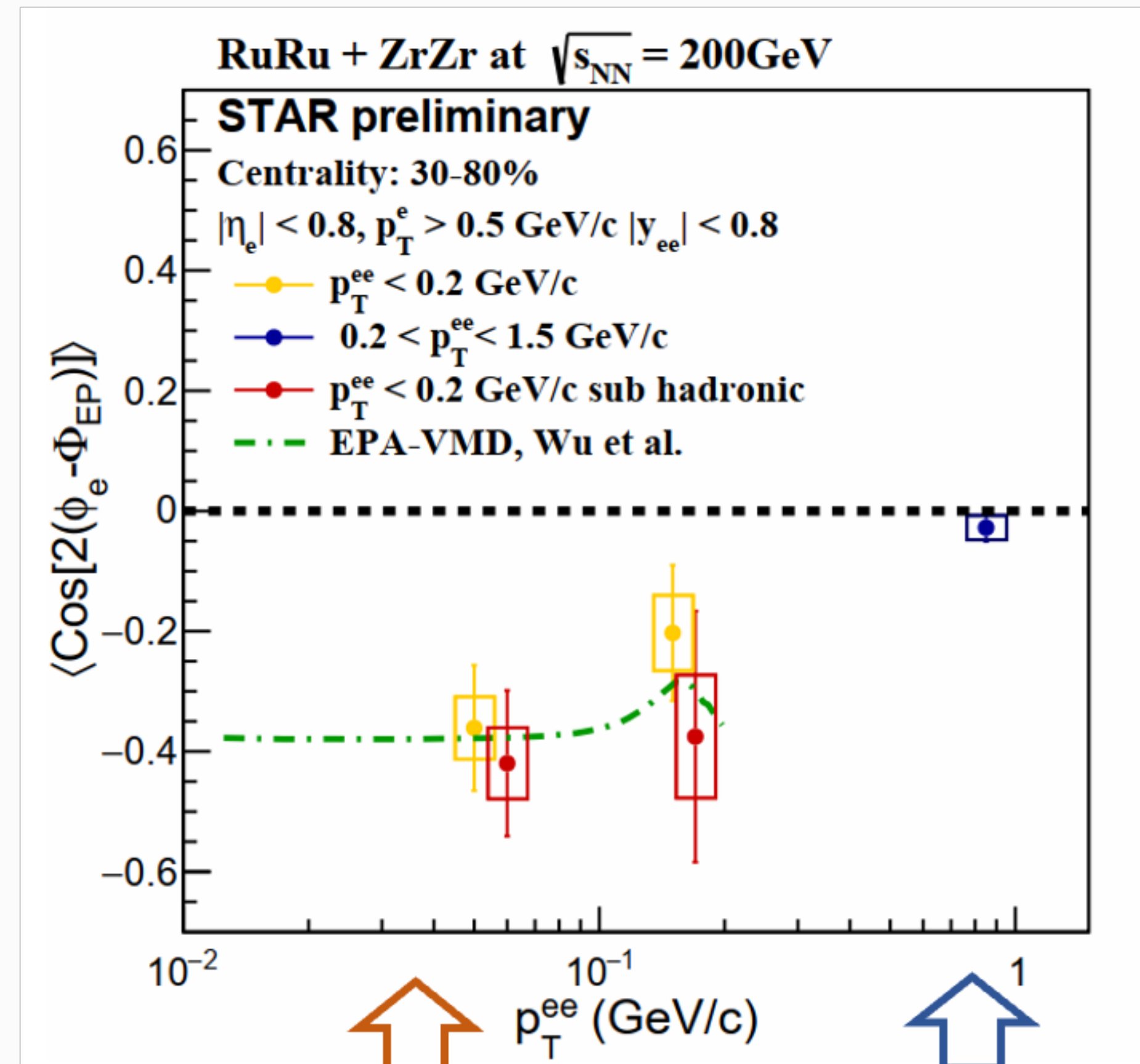
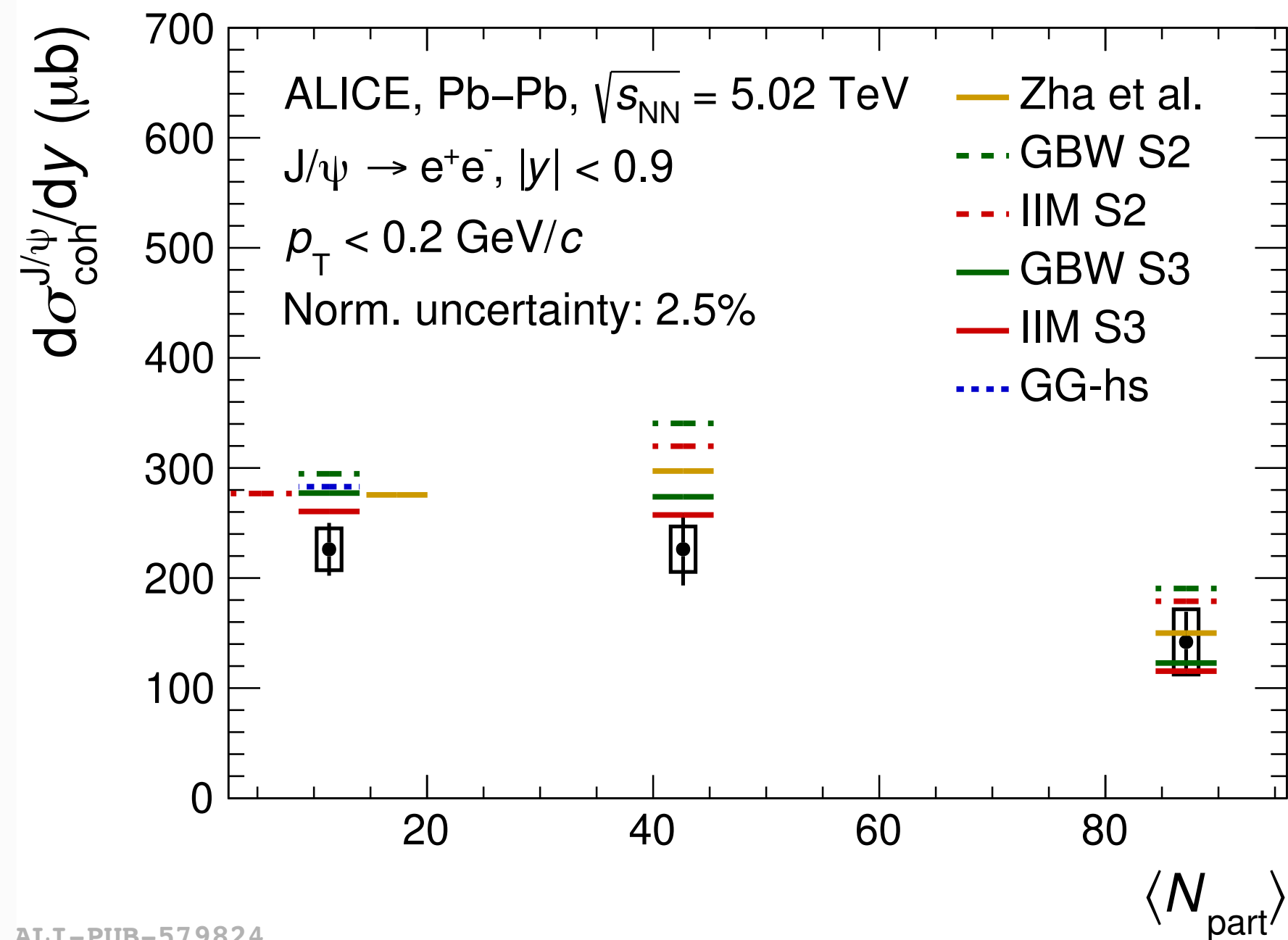


ALICE Collaboration, PRL 132, 222303 (2024)



Not covered in this talk: 2. in peripheral collisions

ALICE Collaboration: arXiv:2409.11940



Photon-induced dominant Hadronic processes dominant

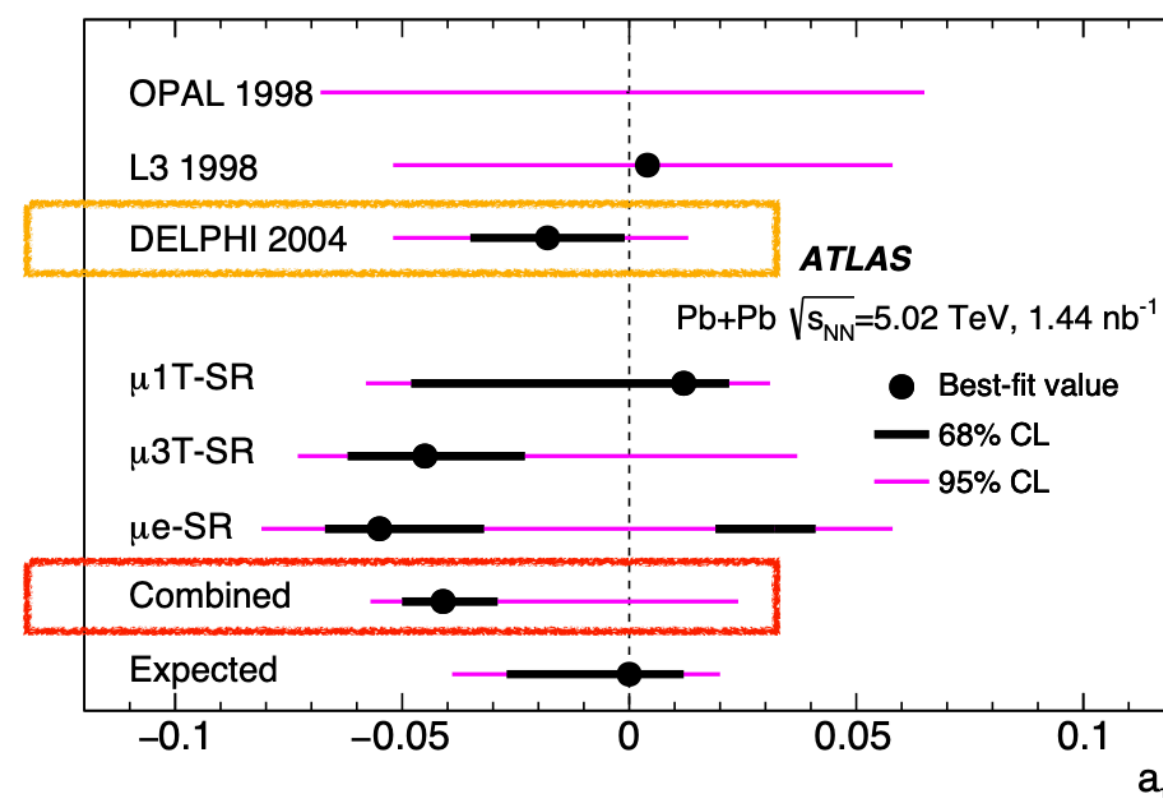
ALI-PUB-579824

Not covered in this talk: 3. connection to searching for new physics

Exclusive tau-pair production in Pb+Pb UPC

Phys. Rev. Lett. 131 (2023) 151802

- Measure $a_\tau = (g_\tau - 2)/2$ with template fit
 - Using muon pT distribution in the three SRs and 2μ-CR
- Constraints on a_τ similar to those observed at LEP



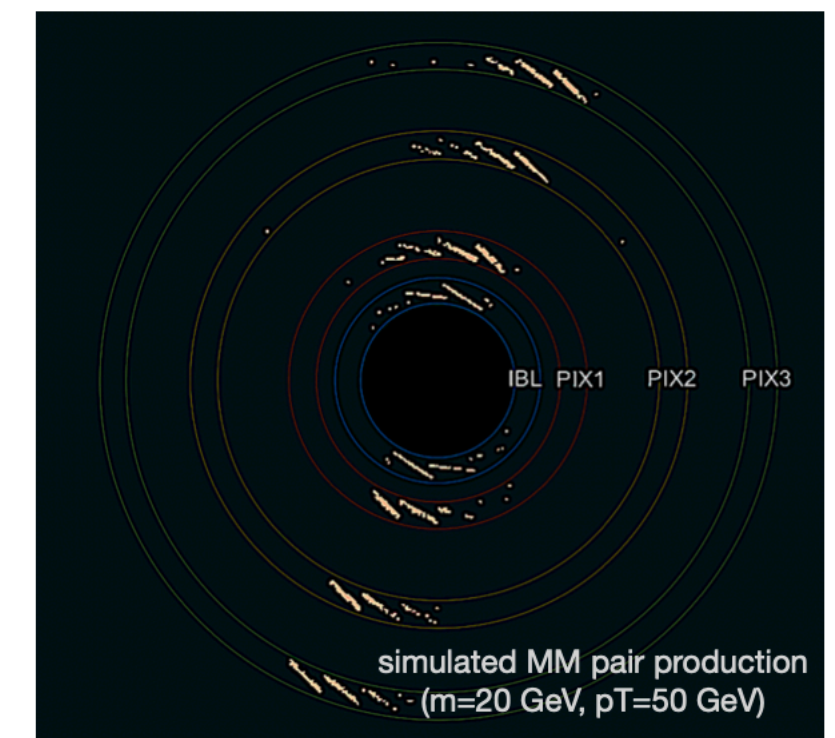
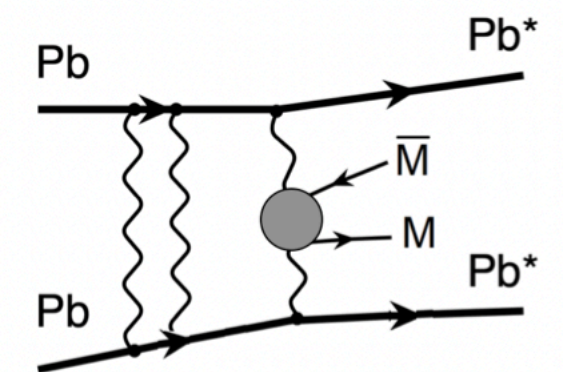
see also follow-up measurements from CMS (Mon session)

12

Magnetic monopole search in Pb+Pb UPC

arXiv:2408.11035

- Use 0.262/nb of 2023 Pb+Pb data at 5.36 TeV
- **Trigger strategy**
 - low-energy MM would loose energy primarily in the innermost Si layers
 - L1: coincidence of ZDC A+C signals + veto on total transverse energy in calo ($E_T < 10$ GeV)
 - HLT: > 100 Pixel clusters w/o any specific tracking selection
- **Event selection**
 - $N_{tracks} \leq 1, N_{topoclusters} \leq 1$ → removes collision background
 - $N_{PixelClusters} > 150$, including $N_{IBLclusters} > 50$ → suppress beam-induced background (BIB)
 - Fraction of Pixel clusters from a single module, $f_{leading-module} < 0.9$ → to suppress events from noisy modules



14

Not covered in this talk: 4. future perspectives
