Overview of Recent Experimental Electroweak Probes Results

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Hard Probes 2023
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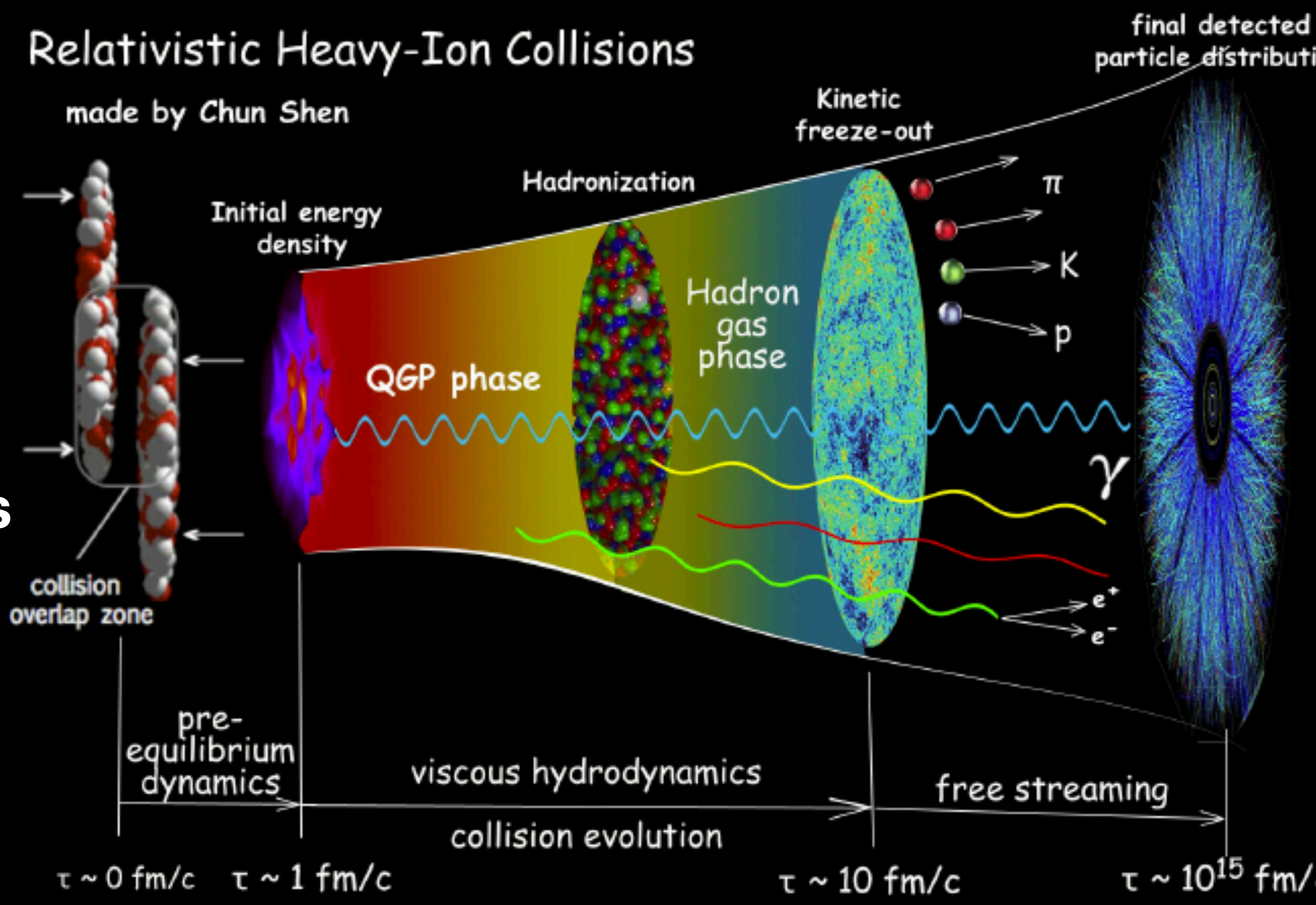
Electroweak probes

- Prompt bosons access initial state
  - nPDFs, Glauber model

- $\gamma\gamma \rightarrow l^+l^-$ in hadronic collisions
  - QED Process
  - UPCs as reference for QGP studies

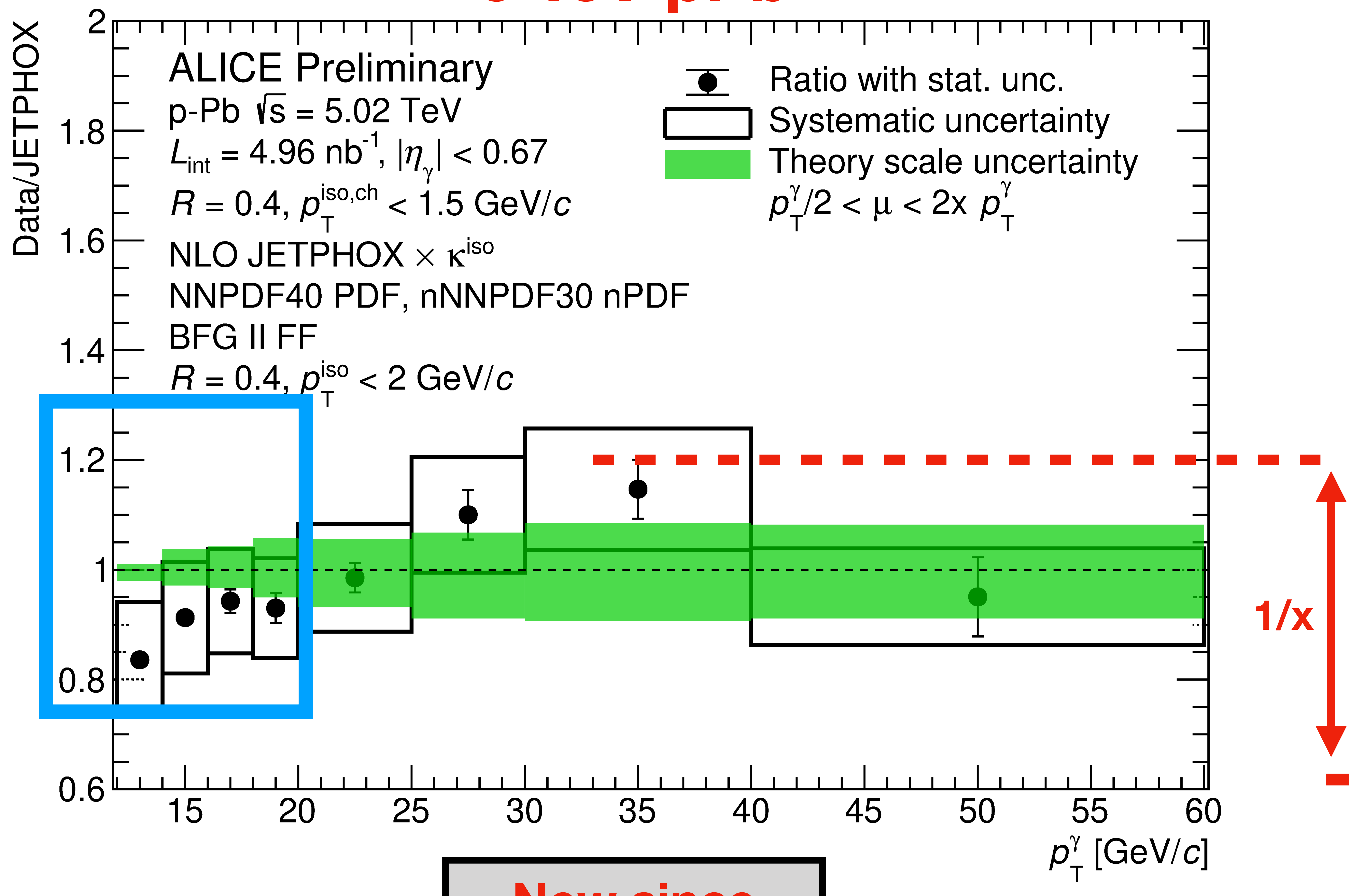
- Direct γ, dileptons
  - thermal properties of the medium



Prompt photon R_{pPb}

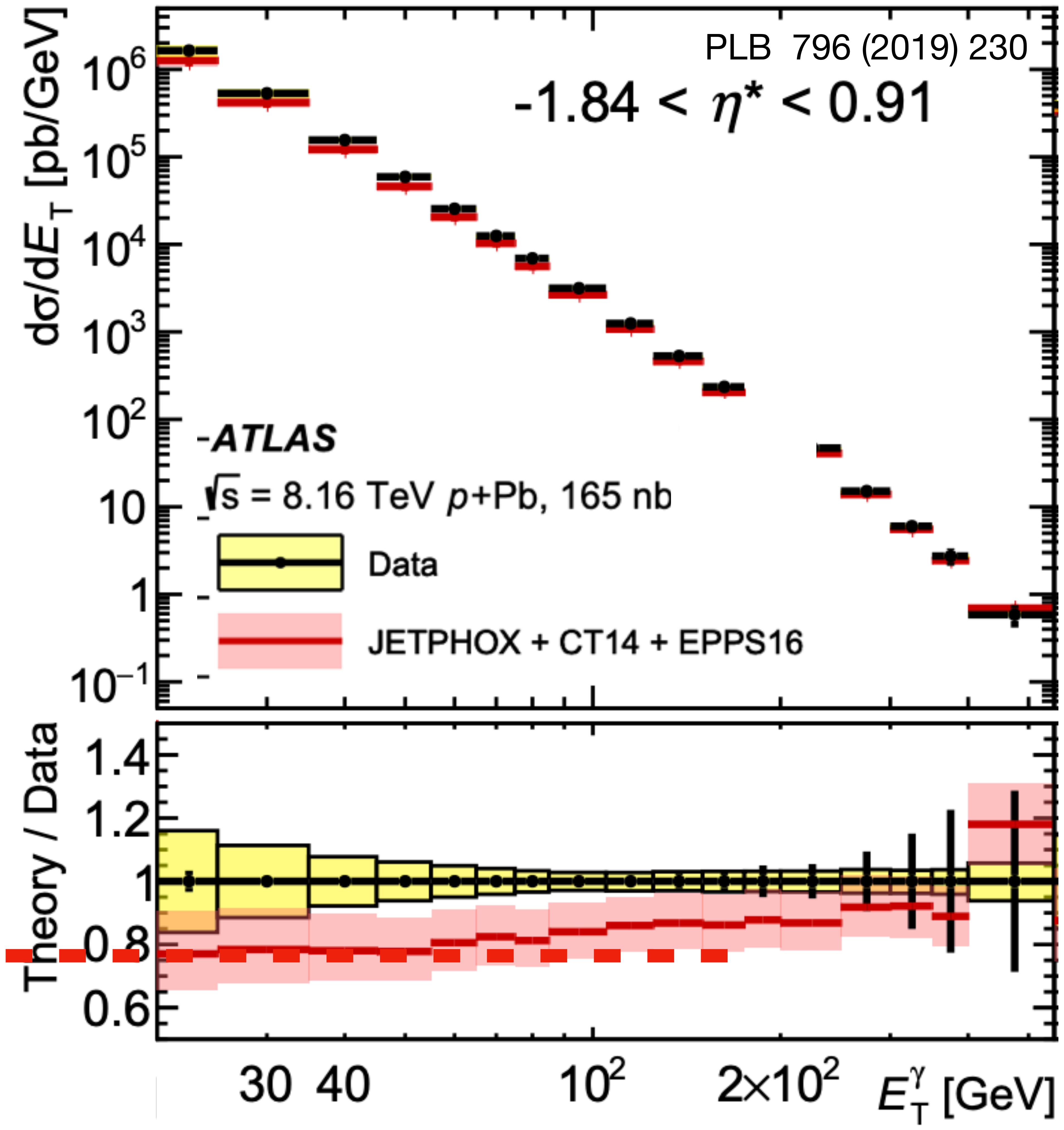
- **Measurements appear consistent at higher p_T**
- **Hint of JETPHOX+nNNPDF3.0 missing low-p_T trend?**

5 TeV pPb



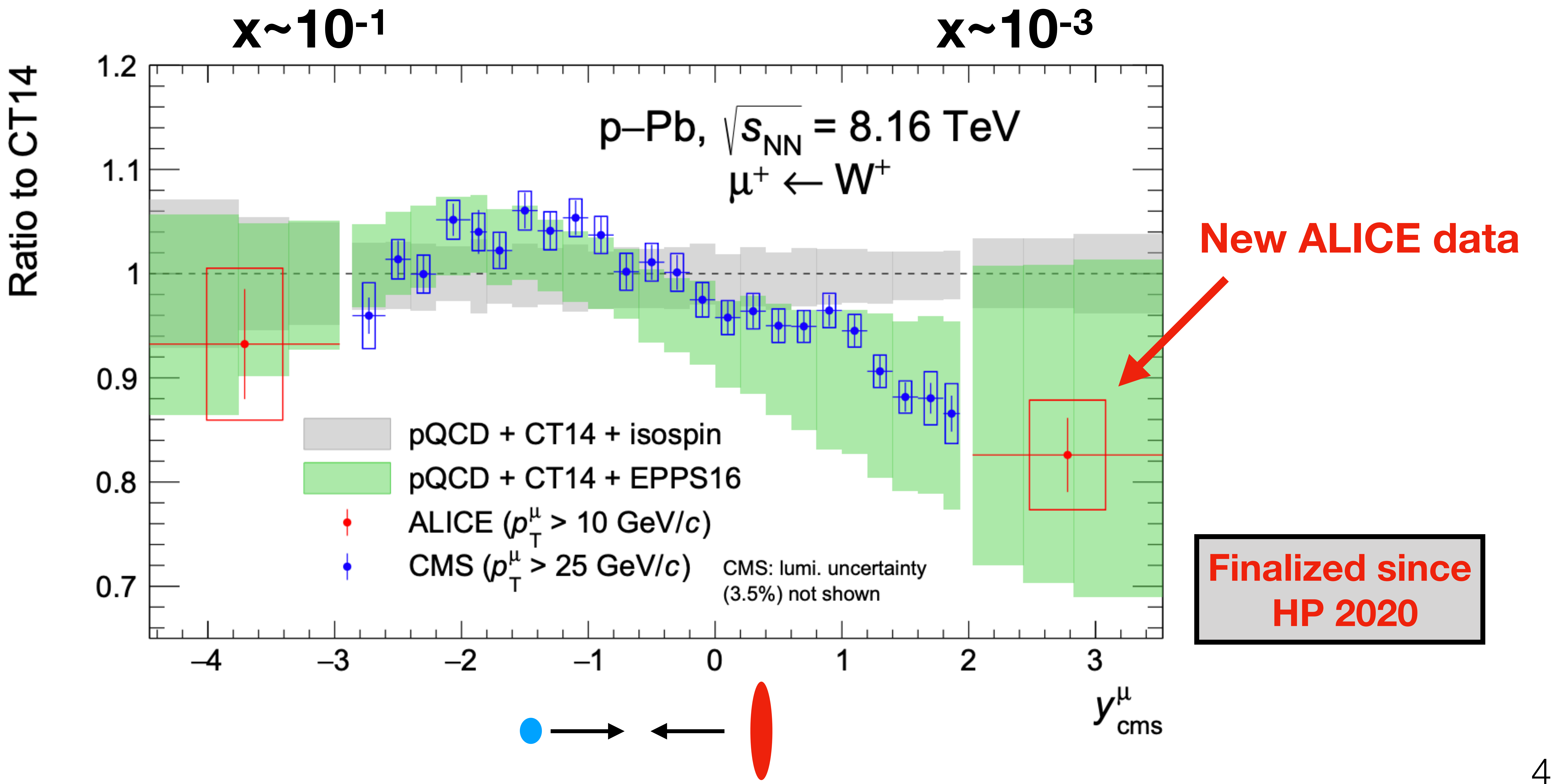
New since HP 2020

8.16 TeV pPb



ALICE W bosons in pPb

- **Starting to extend into EMC region**
- **Strong support for nPDF shadowing**

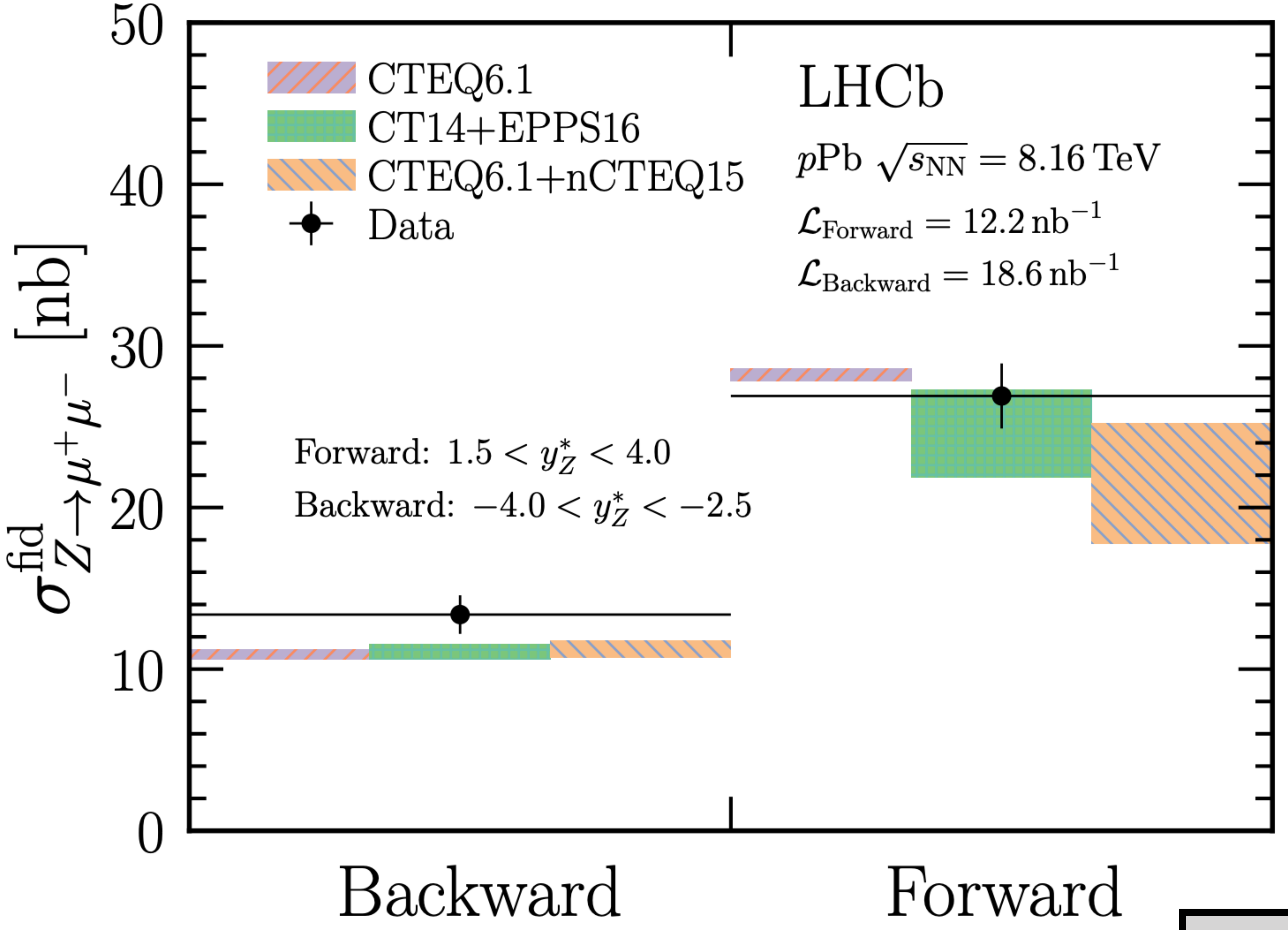


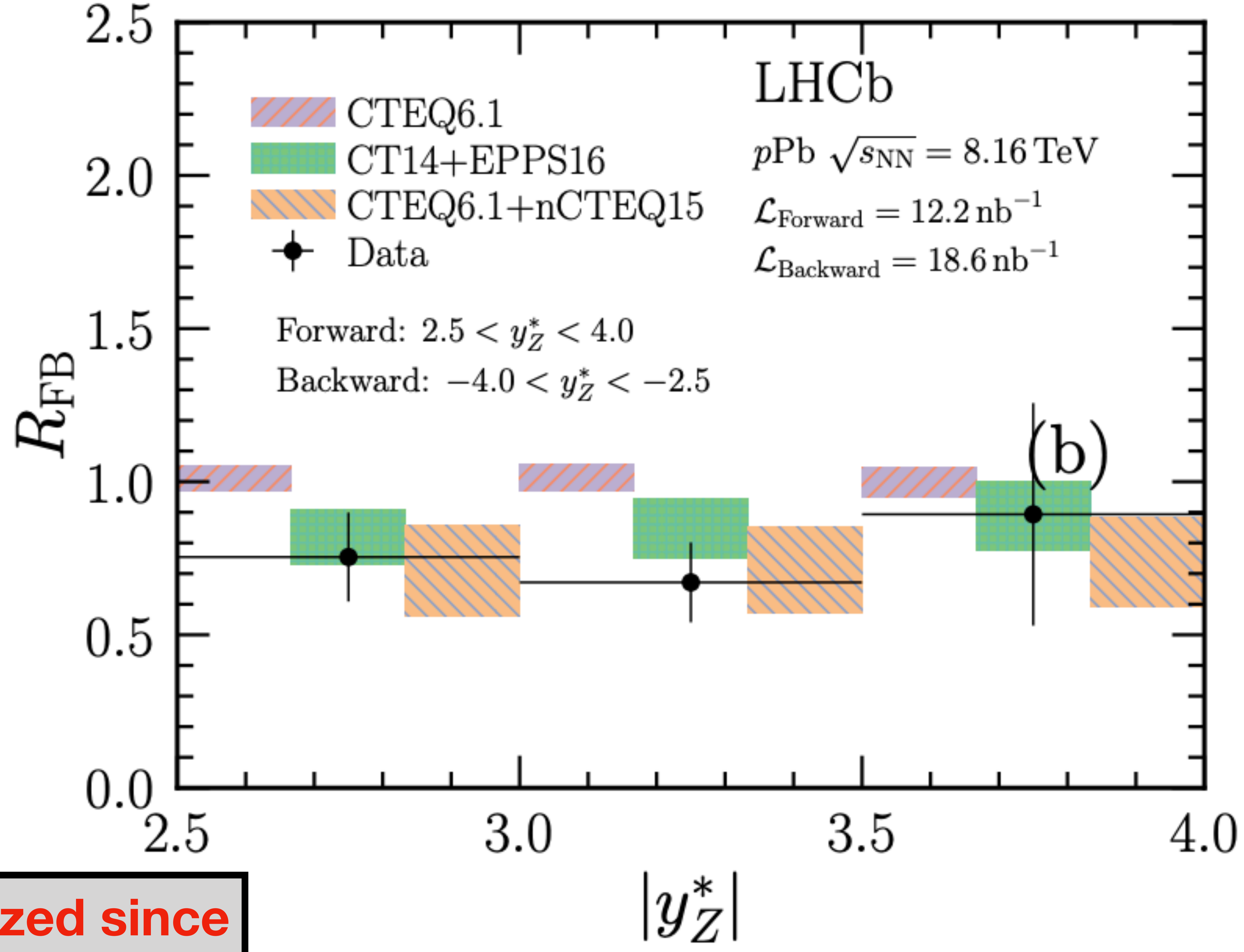
Finalized since HP 2020

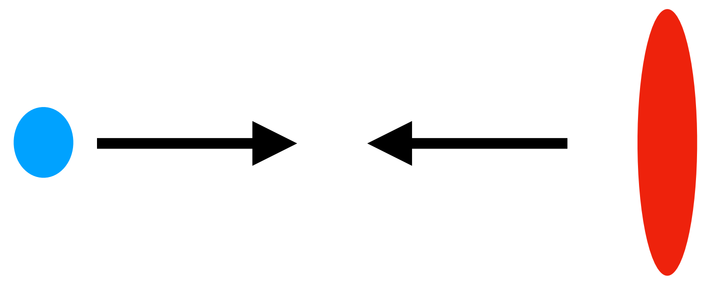
arXiv:2204.10640

LHCb Z bosons in pPb

- **Cross section favors more anti-shadowing and minor shadowing**
- **Ratio favors nPDF models**







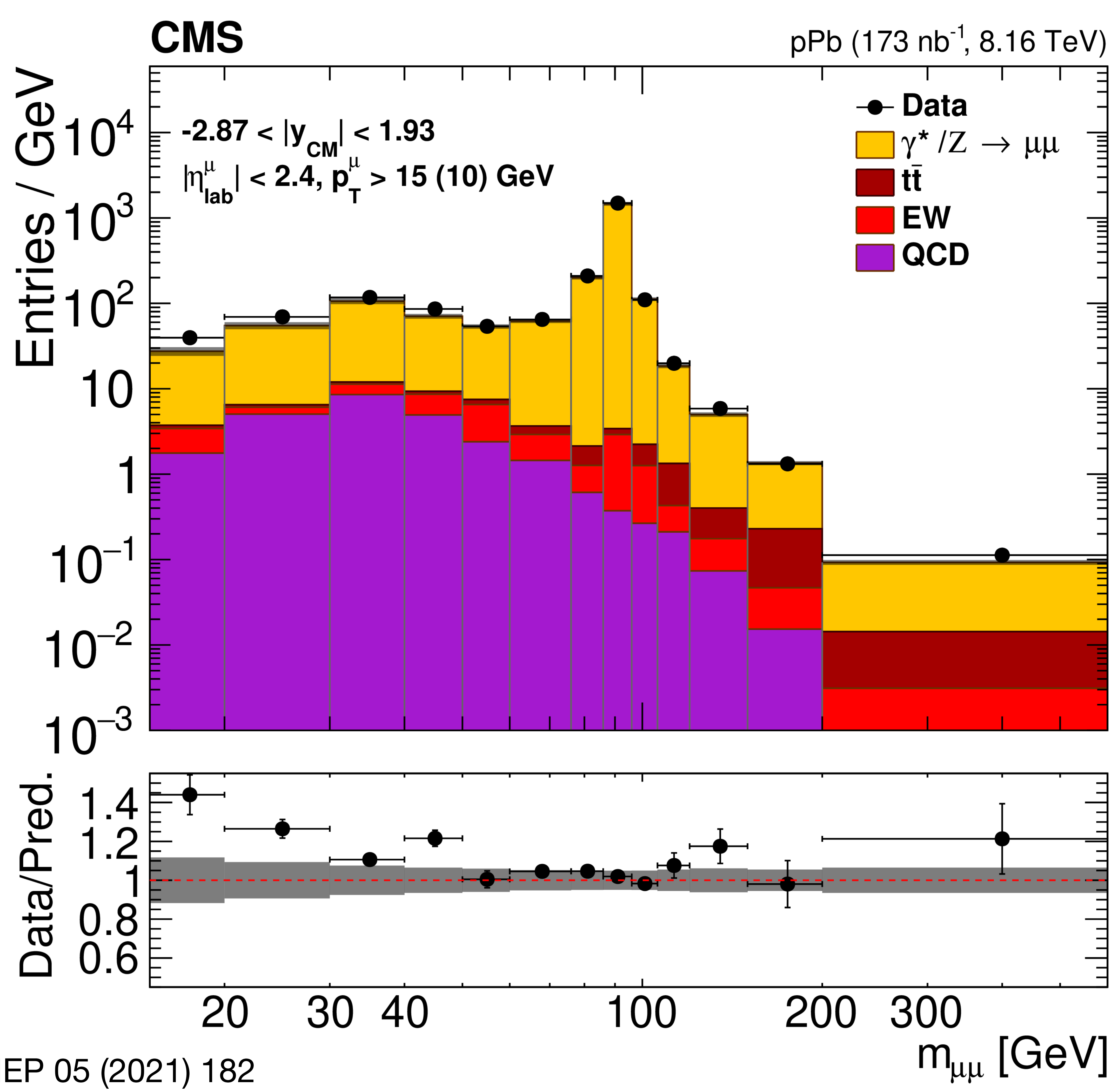
Finalized since HP 2020

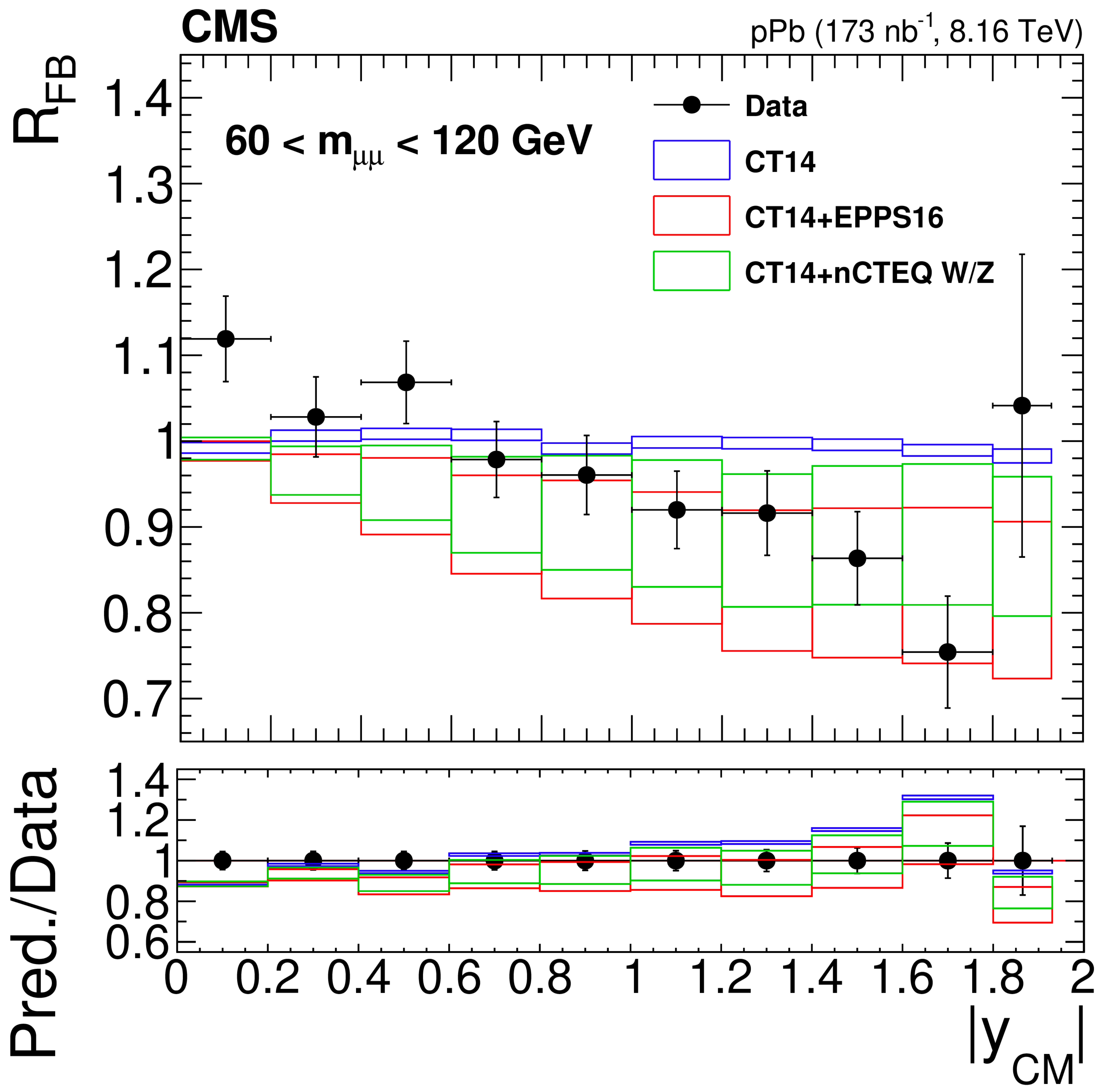
arXiv:2205.10213

CMS Drell-Yan in pPb

- **Wide dimuon mass range - larger range of x, Q^2**
- **R_{FB} for Z mass window more precise than nPDF models**

Finalized since HP 2020



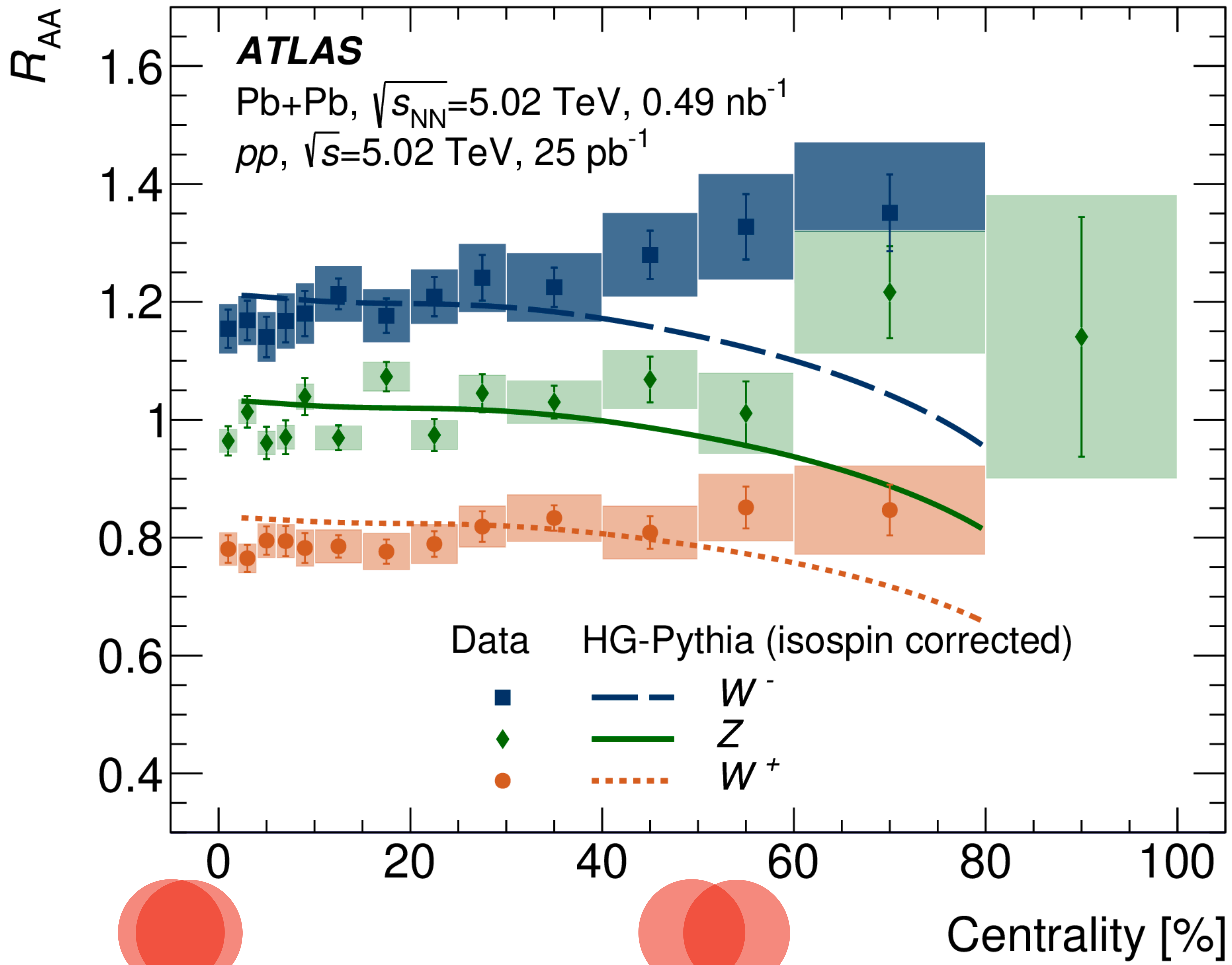


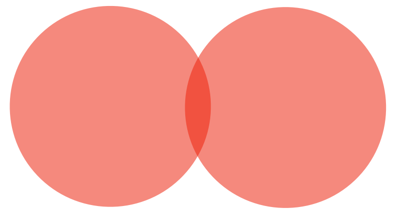
JHEP 05 (2021) 182

ATLAS Midrapidity Z/W in PbPb

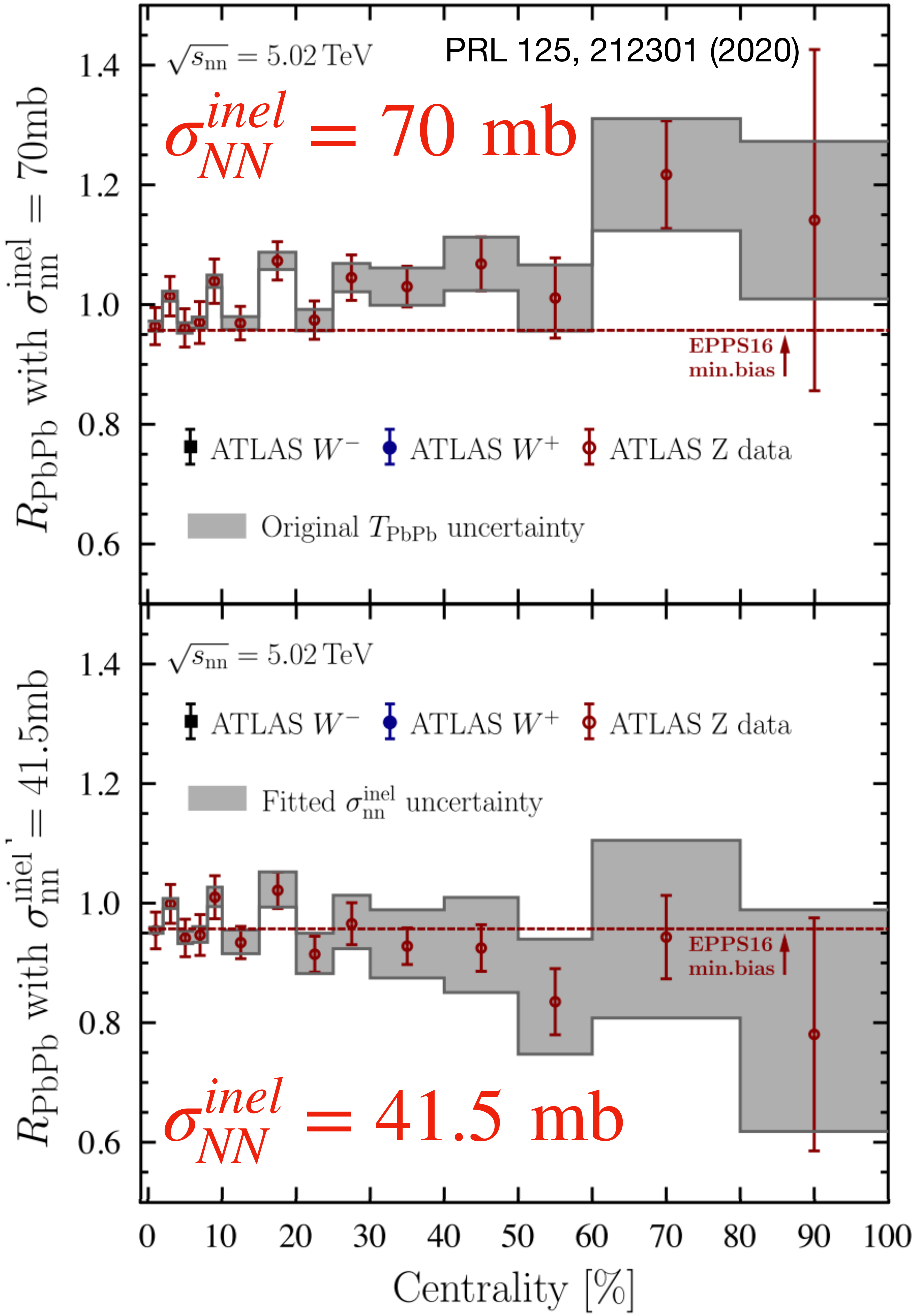
- **Measure Z/W to test Glauber scaling**
- **Rising trend in ATLAS data**
  - **Shadowing of total NN cross section?**

PLB 802 (2020) 135626



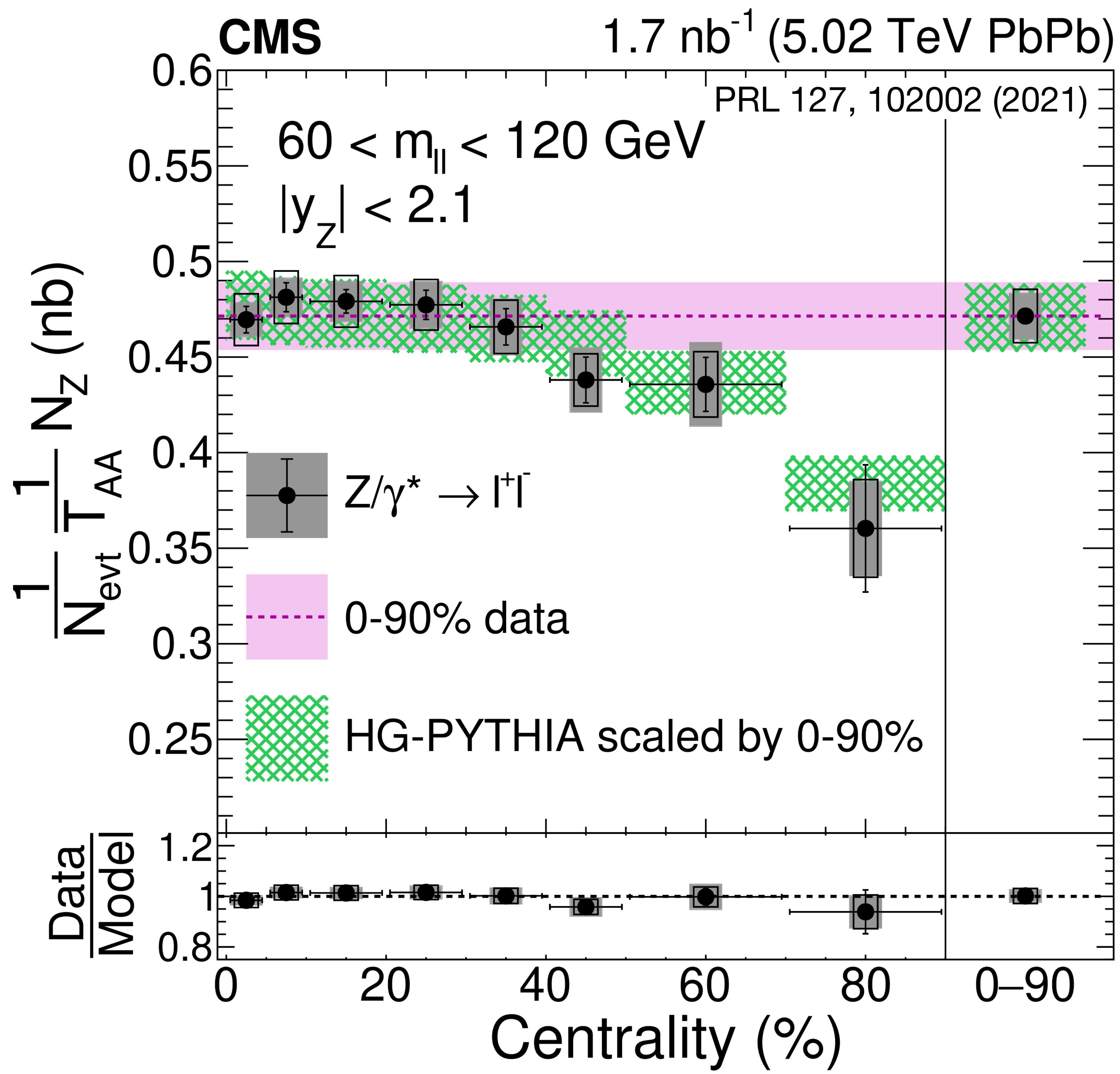


PRL 125, 212301 (2020)

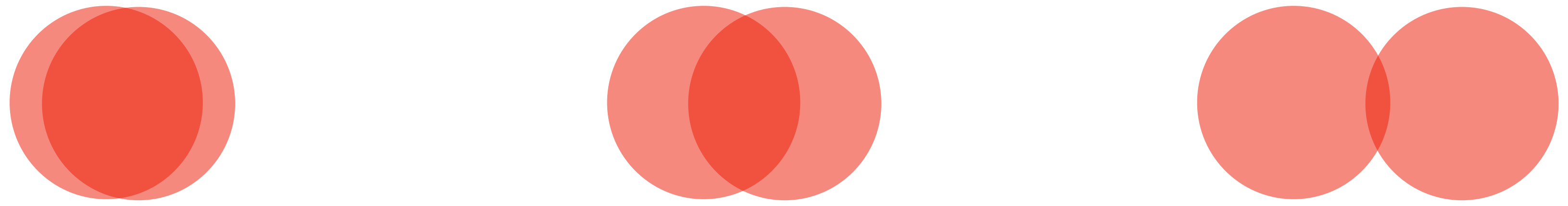


CMS Midrapidity Z in PbPb

- **CMS data supports downward trend & HG-PYTHIA model**
- **NN impact parameter + centrality selection effects?**

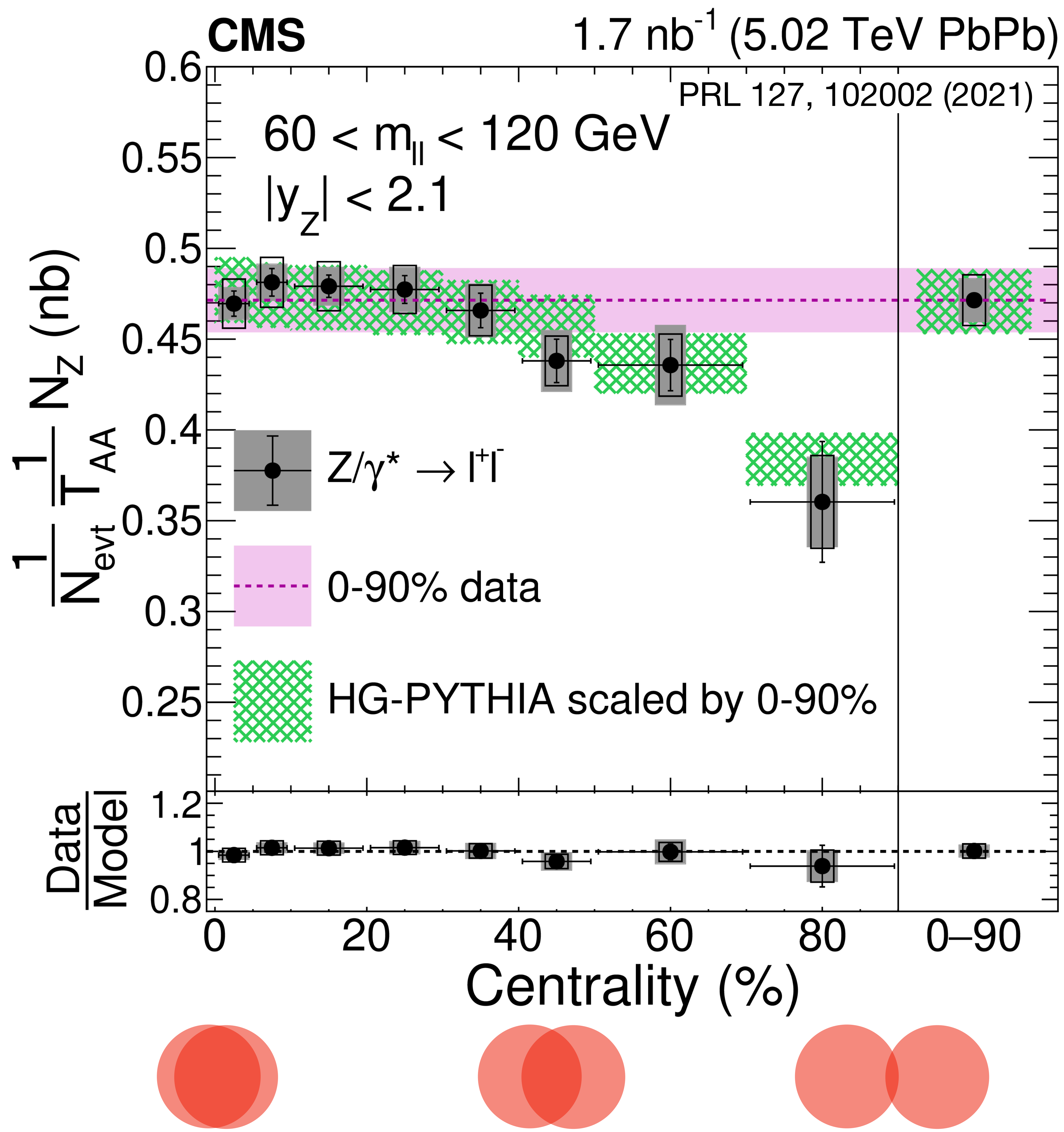


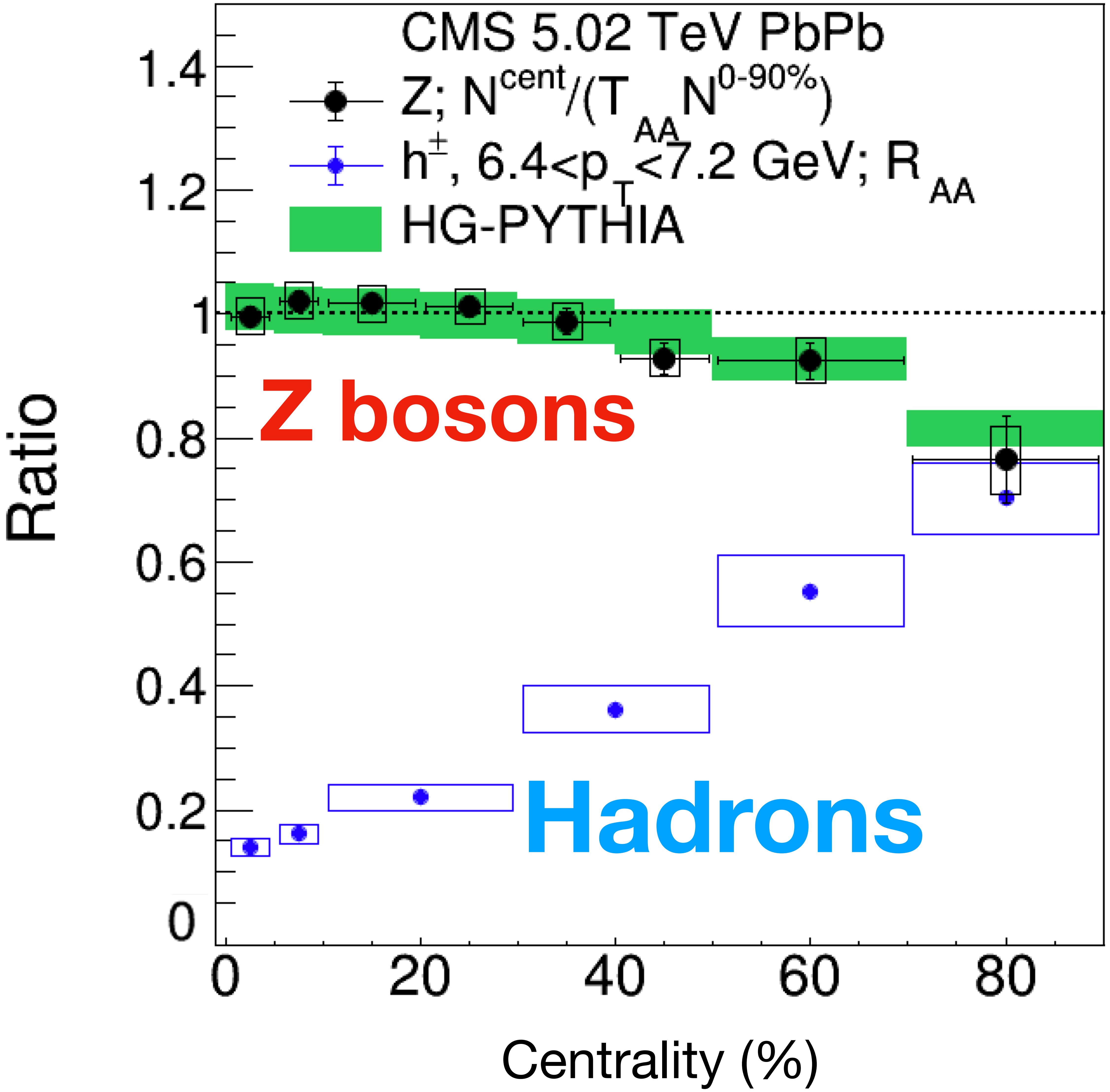
Finalized since HP 2020



CMS Midrapidity Z in PbPb

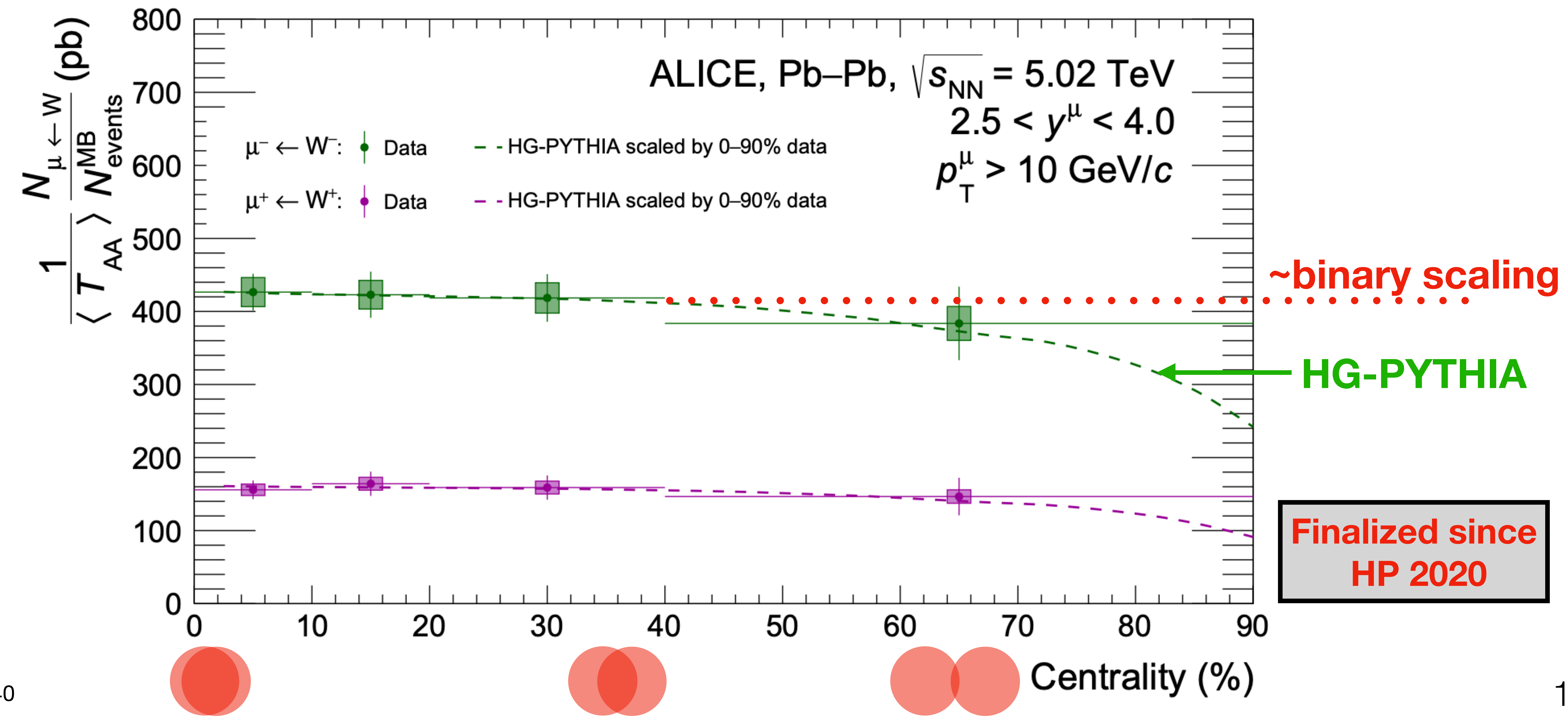
- **Could also affect interpretation of peripheral suppression of other probes**





ALICE Forward Ws in PbPb

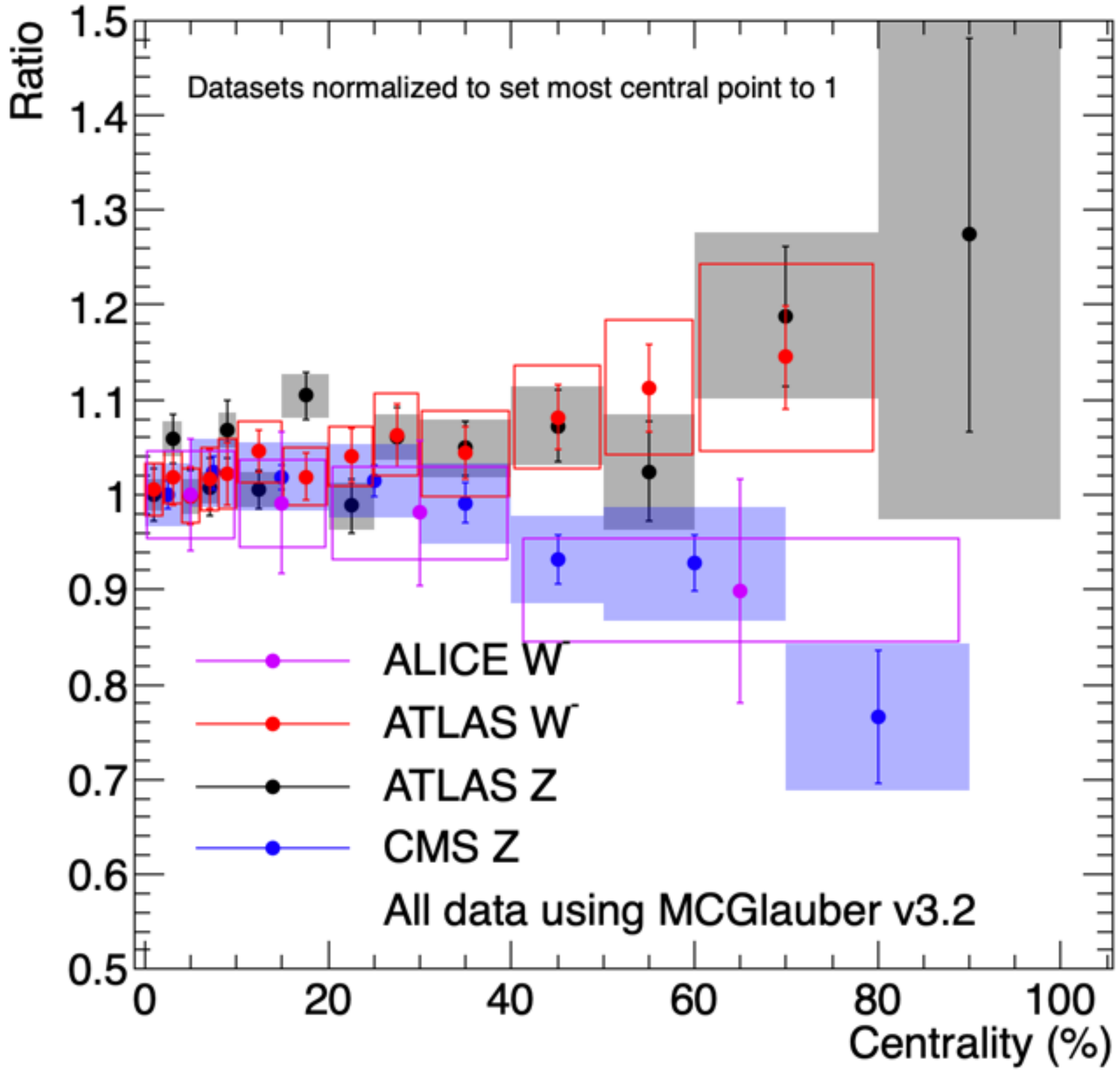
- **Consistent with both HG-PYTHIA and binary scaling assumptions**
- $\sigma_{NN}^{inel} = 41.5\ \mathrm{mb}$ **does *not* improve agreement w/ pQCD calculations**



arXiv:2204.10640

Summary of W/Z in PbPb

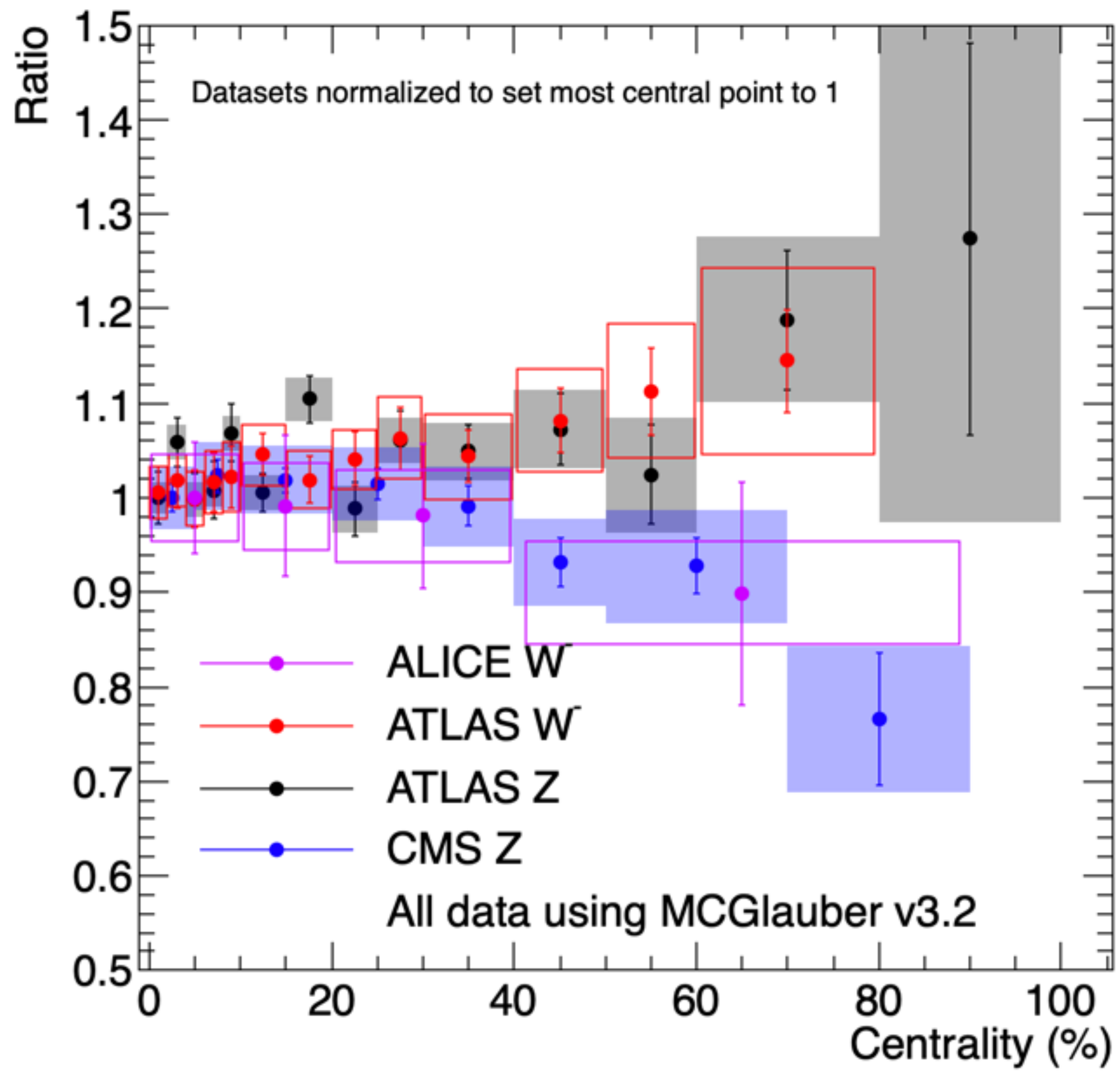
- **Results have correlated T_{AA} uncertainties - still some tension**
- **Should clarify b/c differing interpretations (small σ_{inel}^{NN} vs peripheral suppression)**



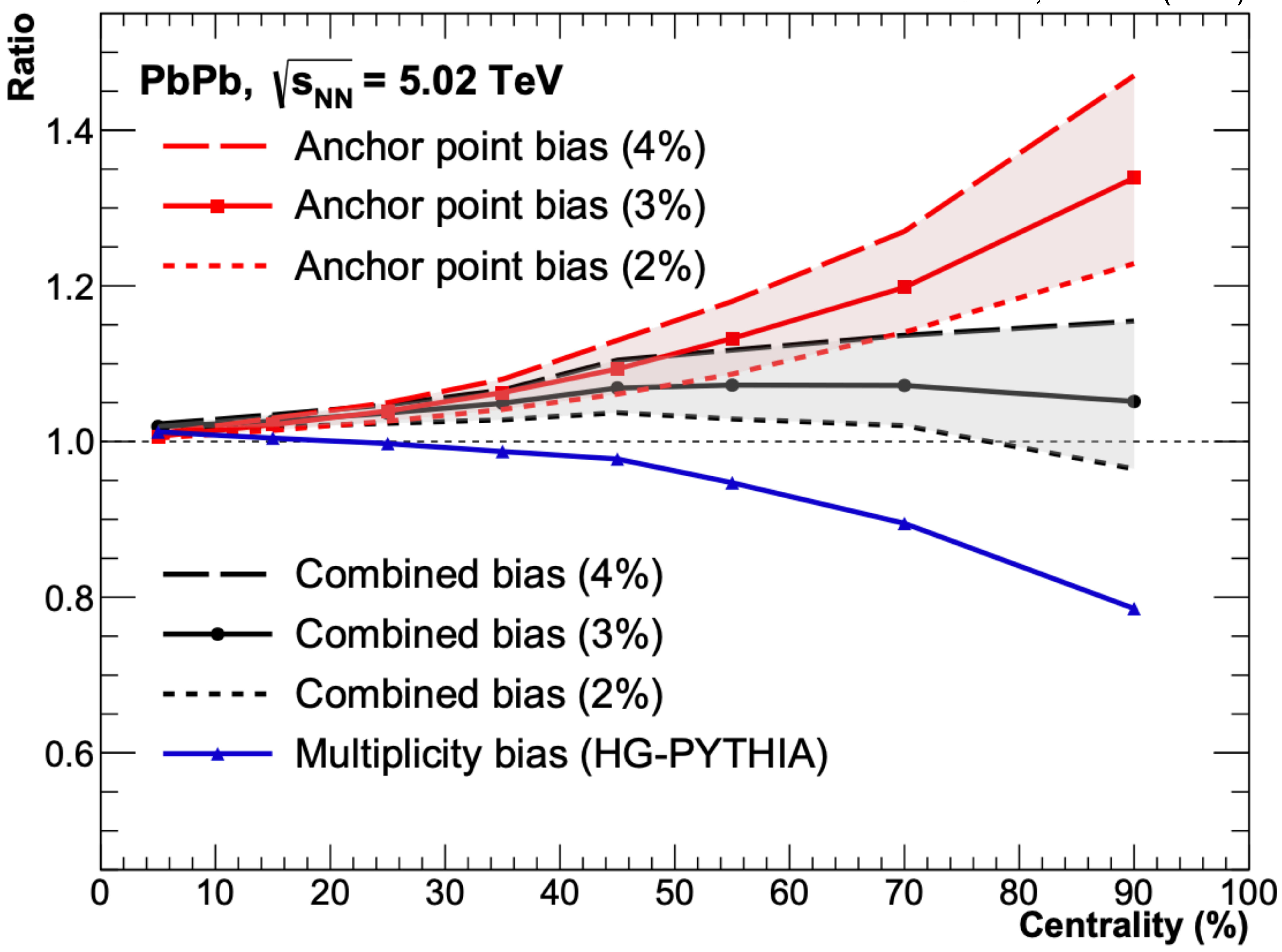
Only W- shown for clarity.
See backup for W+.

Looking forward

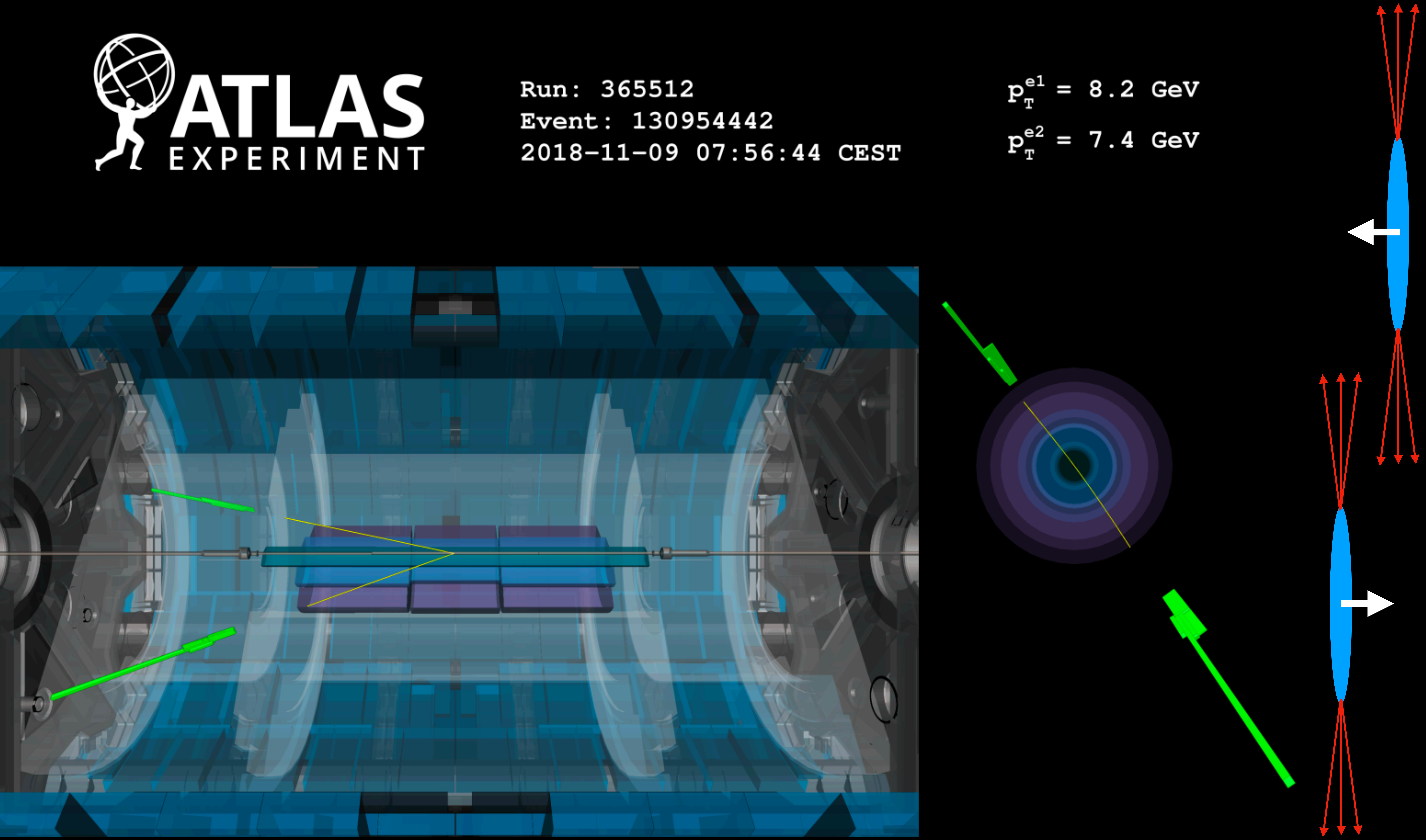
- **Run 3 will lower stat. and syst. uncertainties**
  - **Crucial to pay special attention to centrality 'anchor point'**

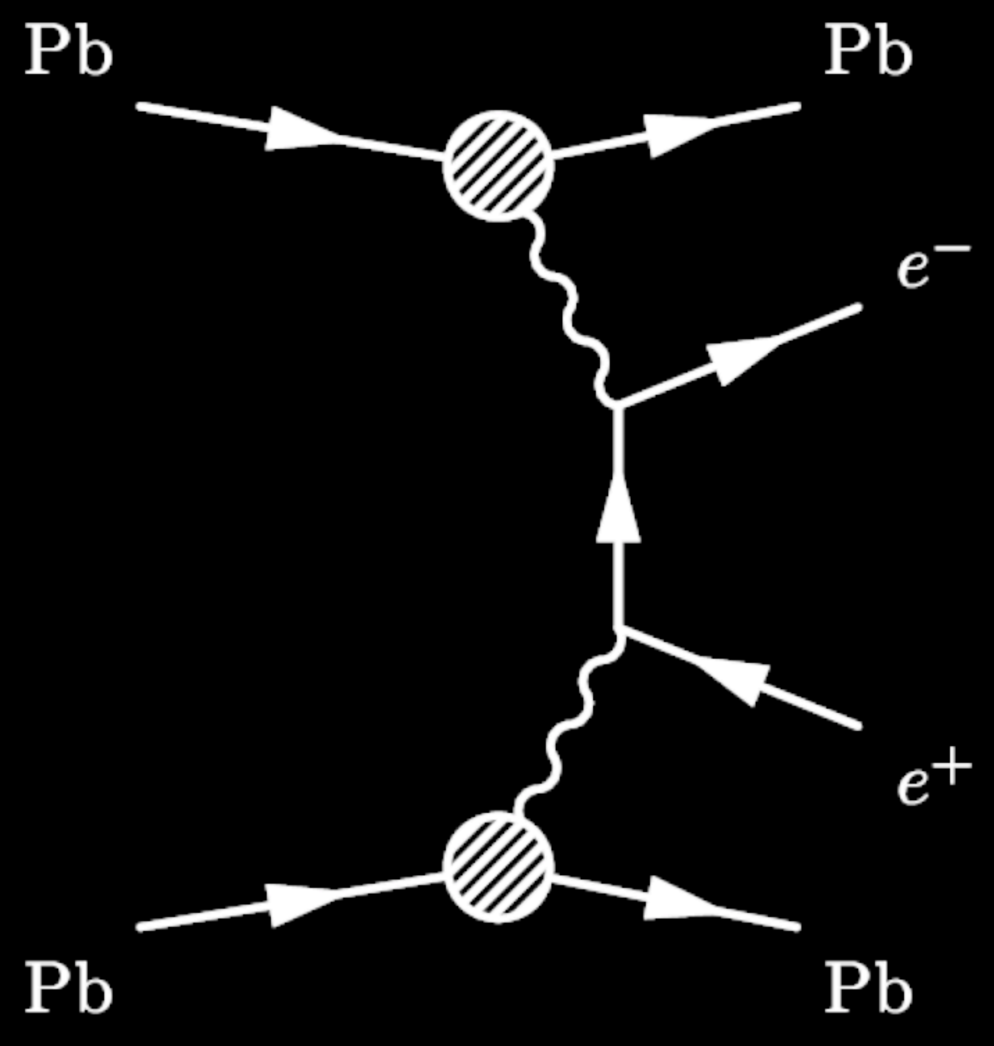


PRC 104, 044905 (2021)



UPC Dileptons

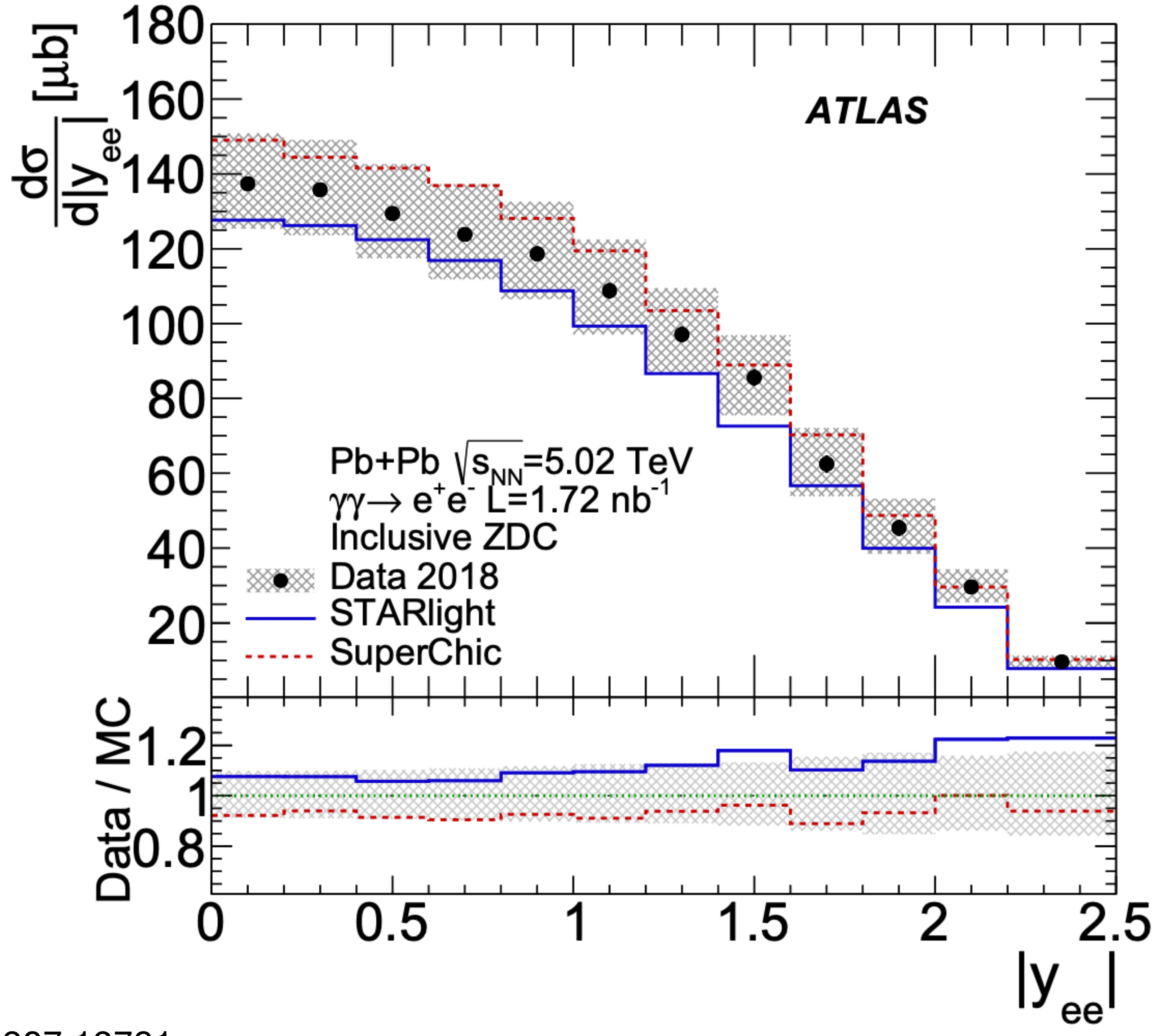


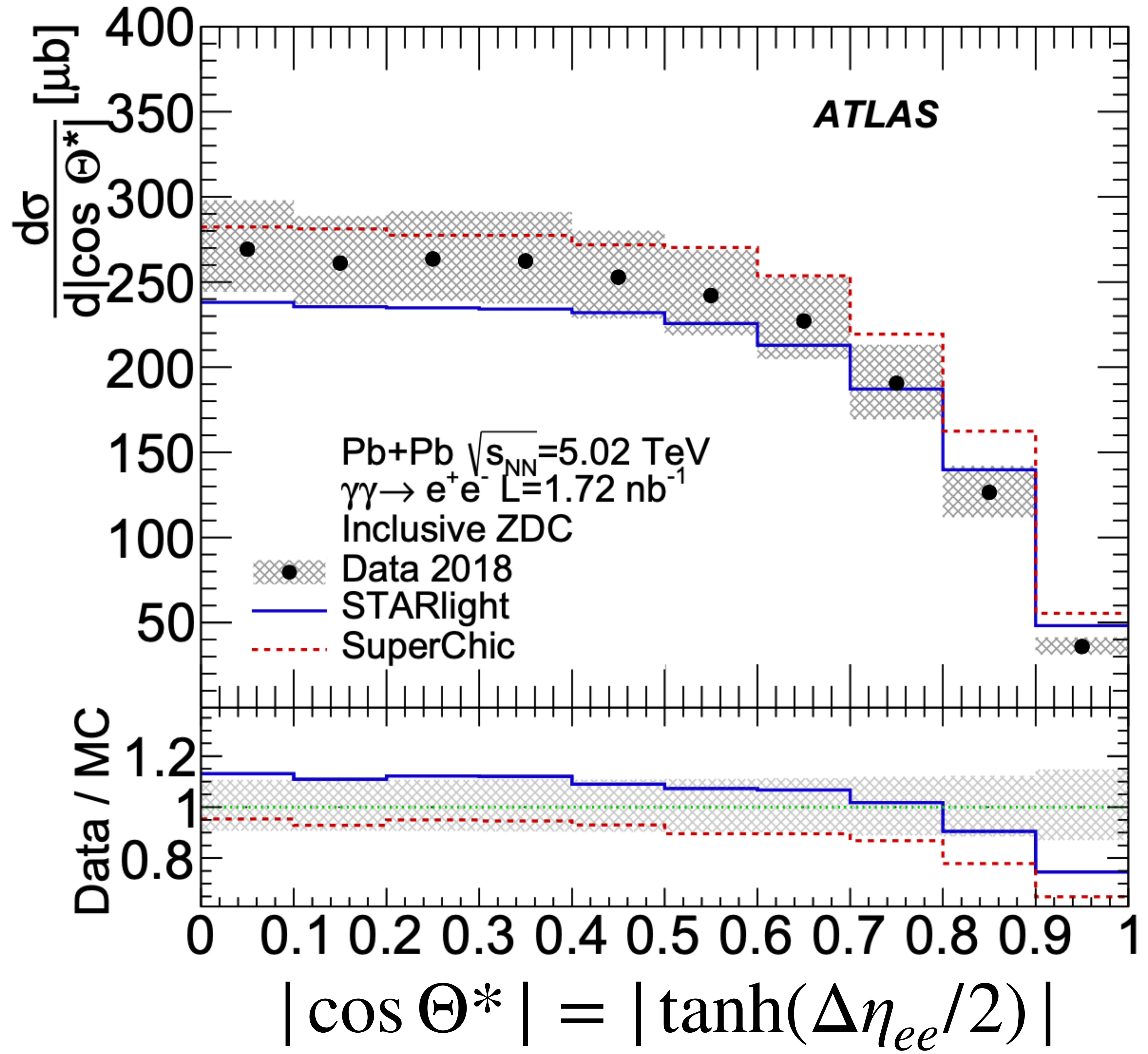


UPC $\gamma\gamma \to e^+e^-$

- **STARlight & SuperChic can predict total cross section**

Finalized since HP 2020





arXiv:2207.12781

UPC $\gamma\gamma \rightarrow e^+e^-$

- **STARlight & SuperChic can predict total cross section**
- **Models seem to do worse for higher-energy initial photons**

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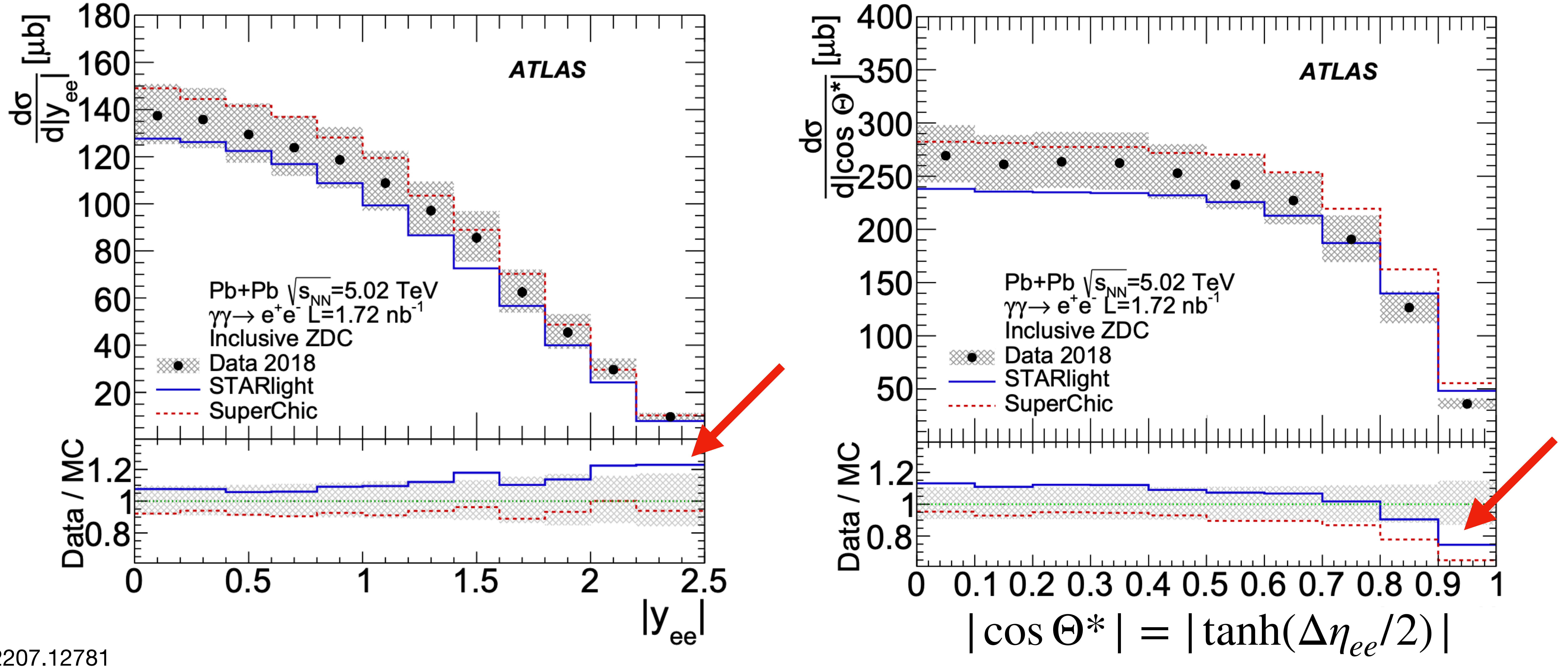
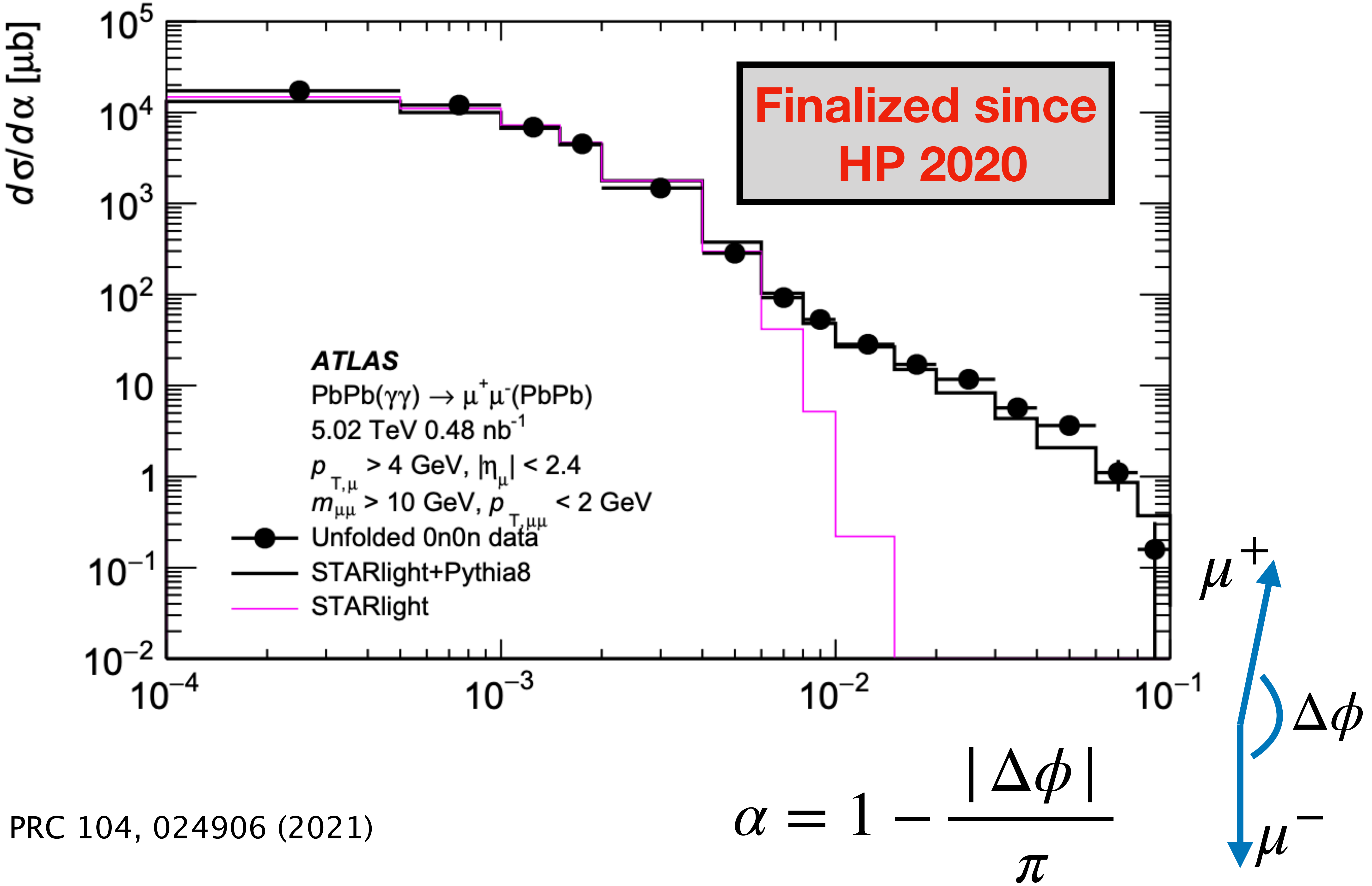


arXiv:2207.12781

UPC $\gamma\gamma \rightarrow \mu^+\mu^-$

- **'Core' of α distribution dominated by LO contributions - not perfectly modeled**

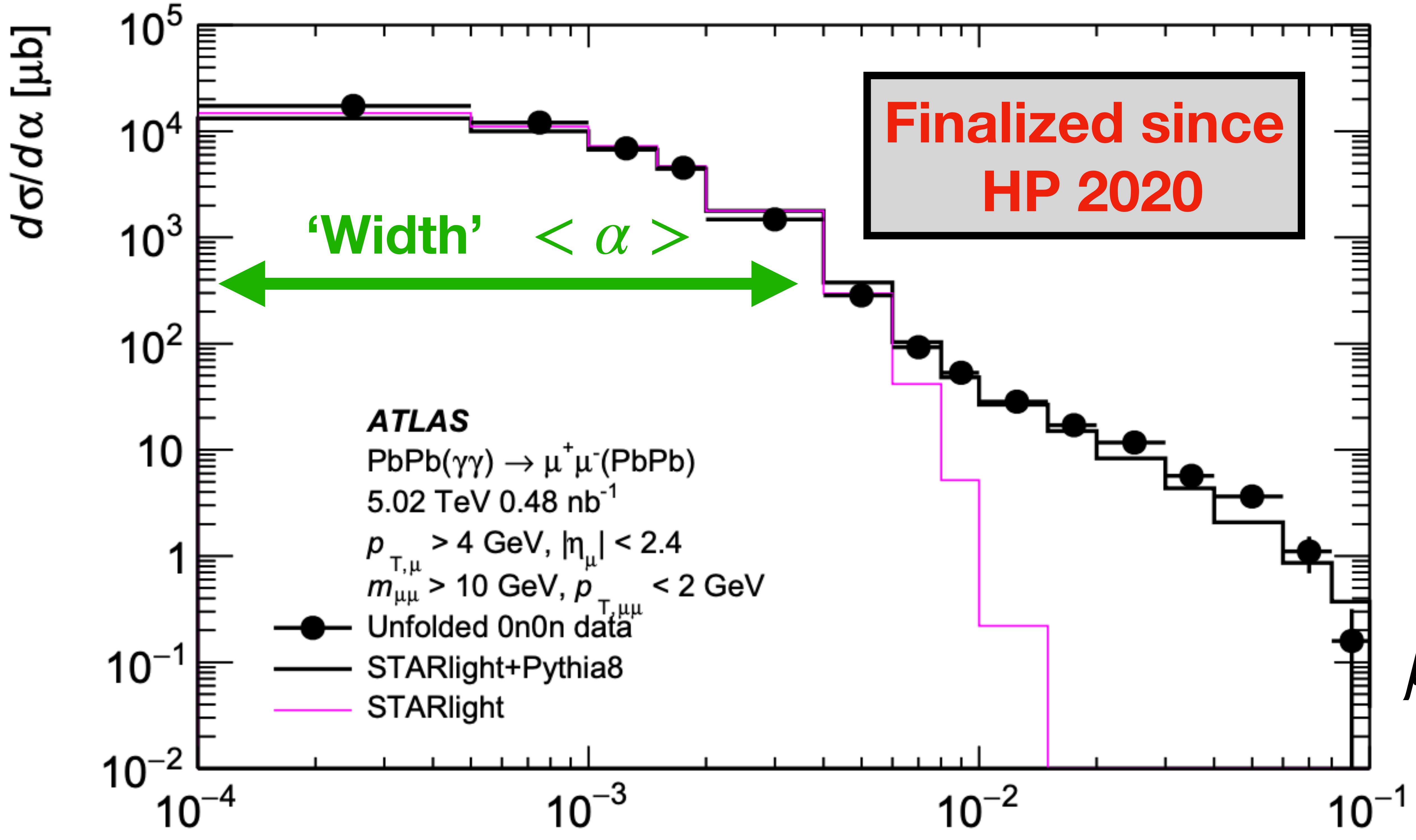


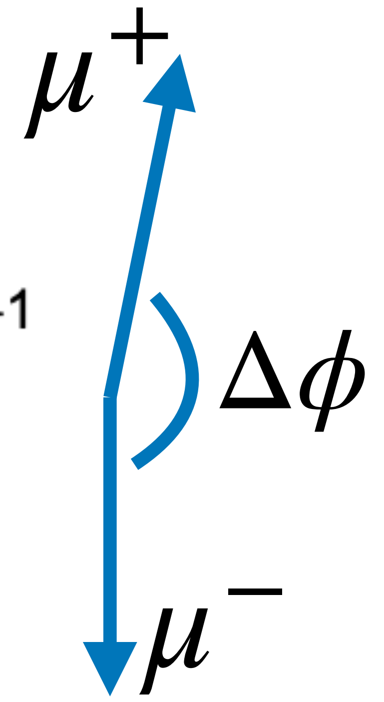
$$\alpha = 1 - \frac{|\Delta\phi|}{\pi}$$

PRC 104, 024906 (2021)

UPC $\gamma\gamma \rightarrow \mu^+\mu^-$

- **'Core' of α distribution dominated by LO contributions - not perfectly modeled**





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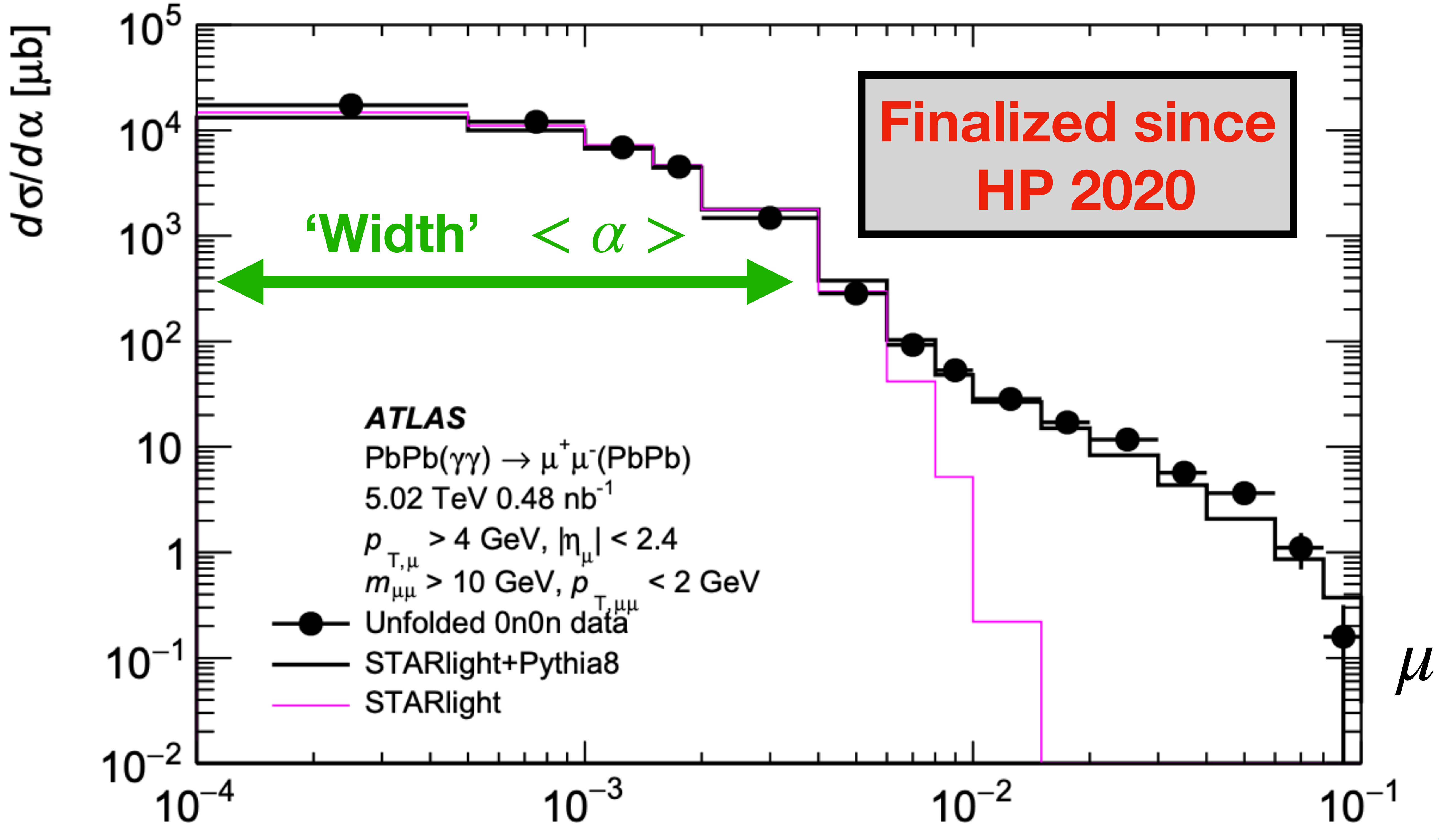
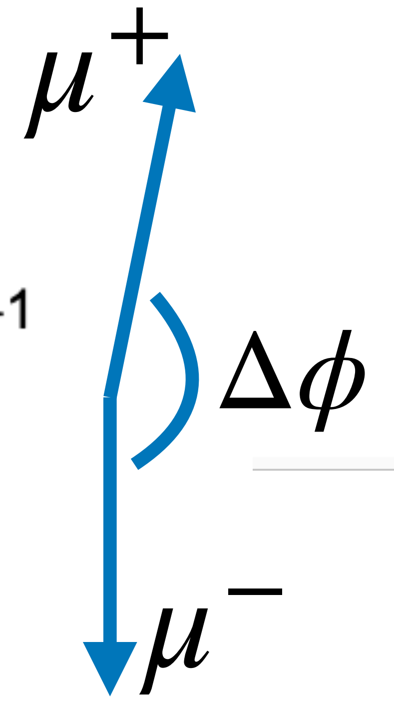
PRC 104, 024906 (2021)

UPC $\gamma\gamma \rightarrow \mu^+\mu^-$

- **'Core' of α distribution dominated by LO contributions - not perfectly modeled**
- **Full QED needed to capture b-dependence of photon p_T**

Finalized since HP 2020





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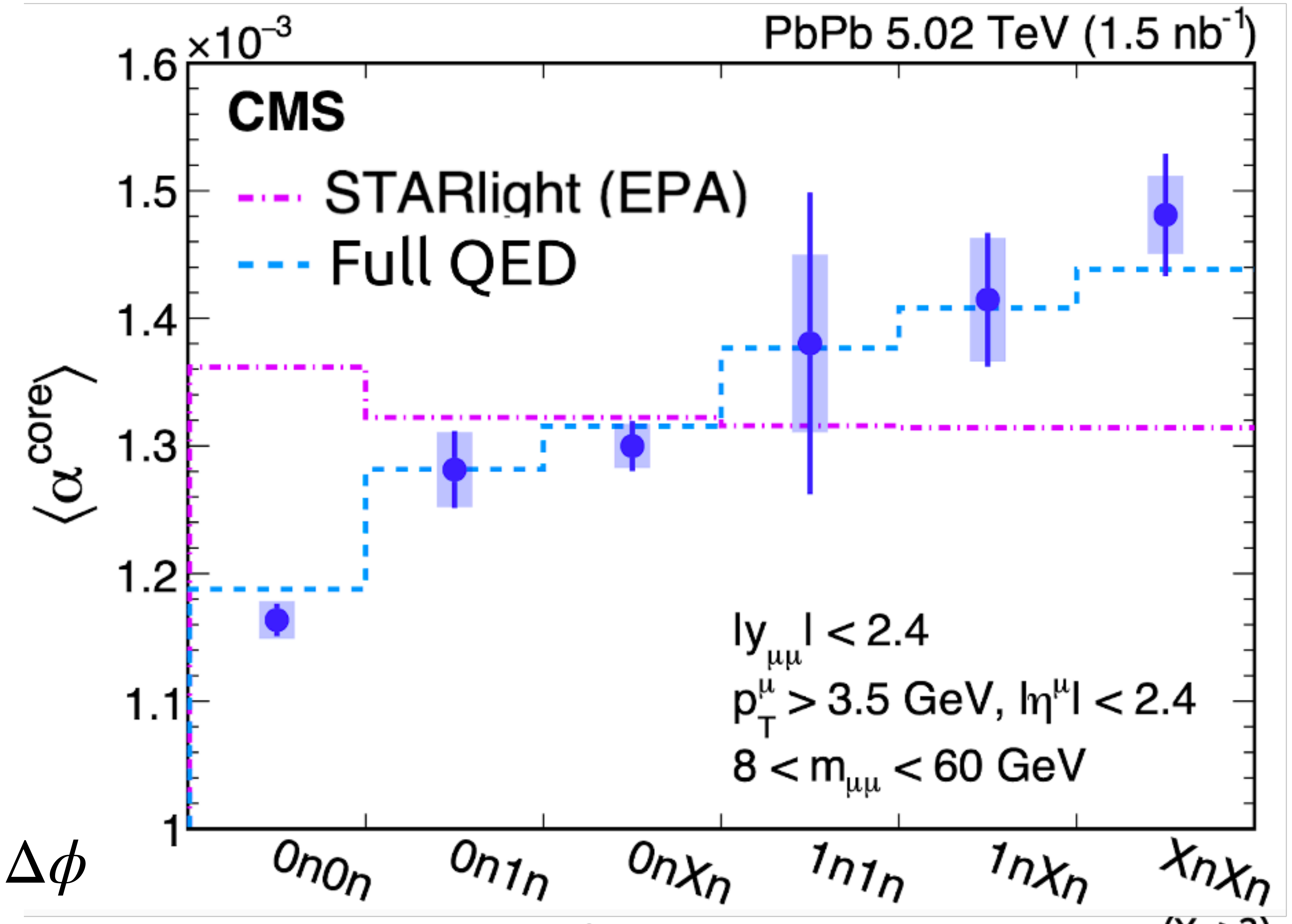
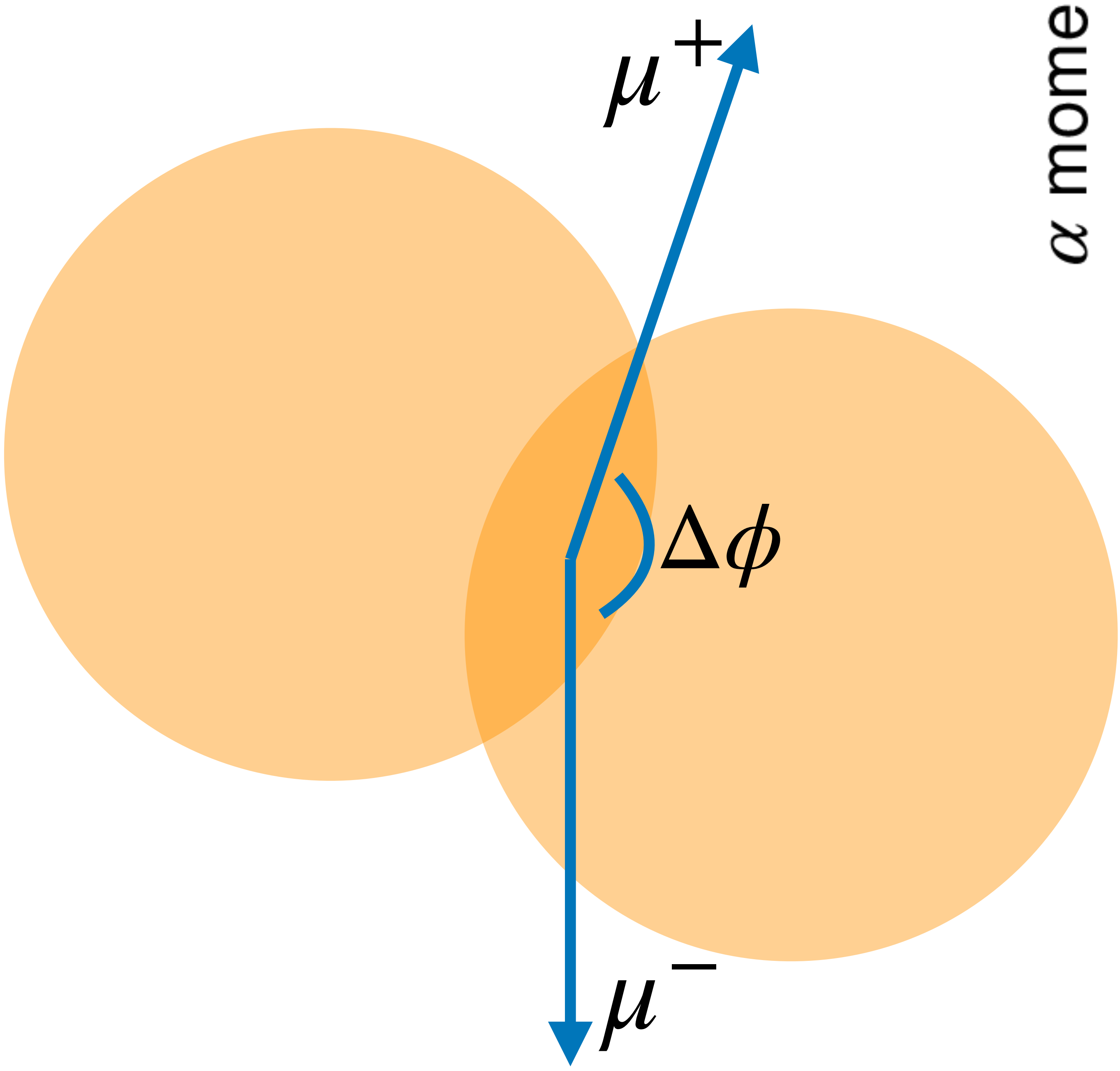


Higher b, lower p_T^γ ⟷ Lower b, higher p_T^γ

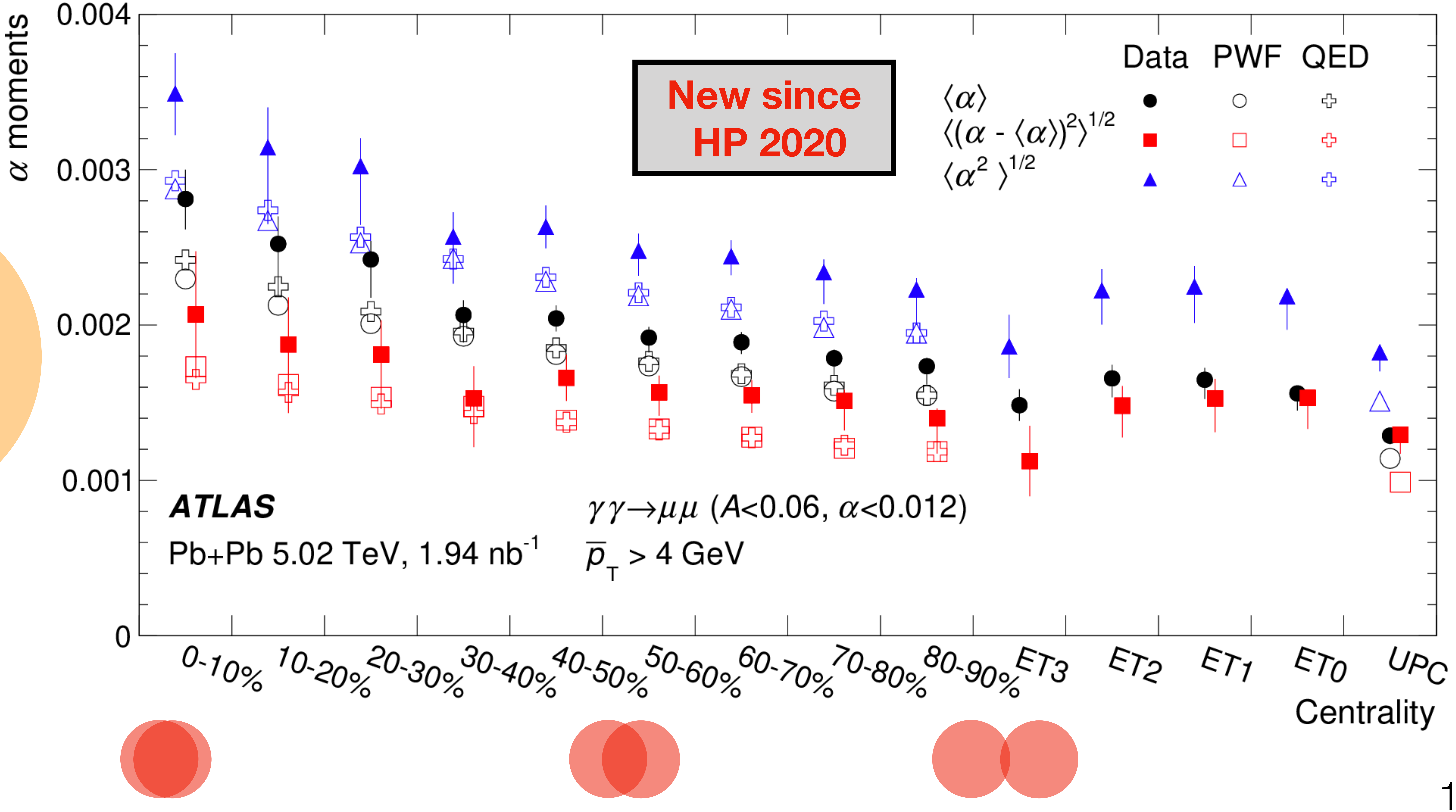
PRC 104, 024906 (2021)
PRL 127 (2021) 122001

ATLAS $\gamma\gamma \rightarrow \mu^+\mu^-$ in peripheral AA

- **Confirm broadening of α as a function of centrality - k_T kicks to muons?**
- **Not consistent with B-field induced broadening**



$$\alpha = 1 - \frac{|\Delta\phi|}{\pi}$$

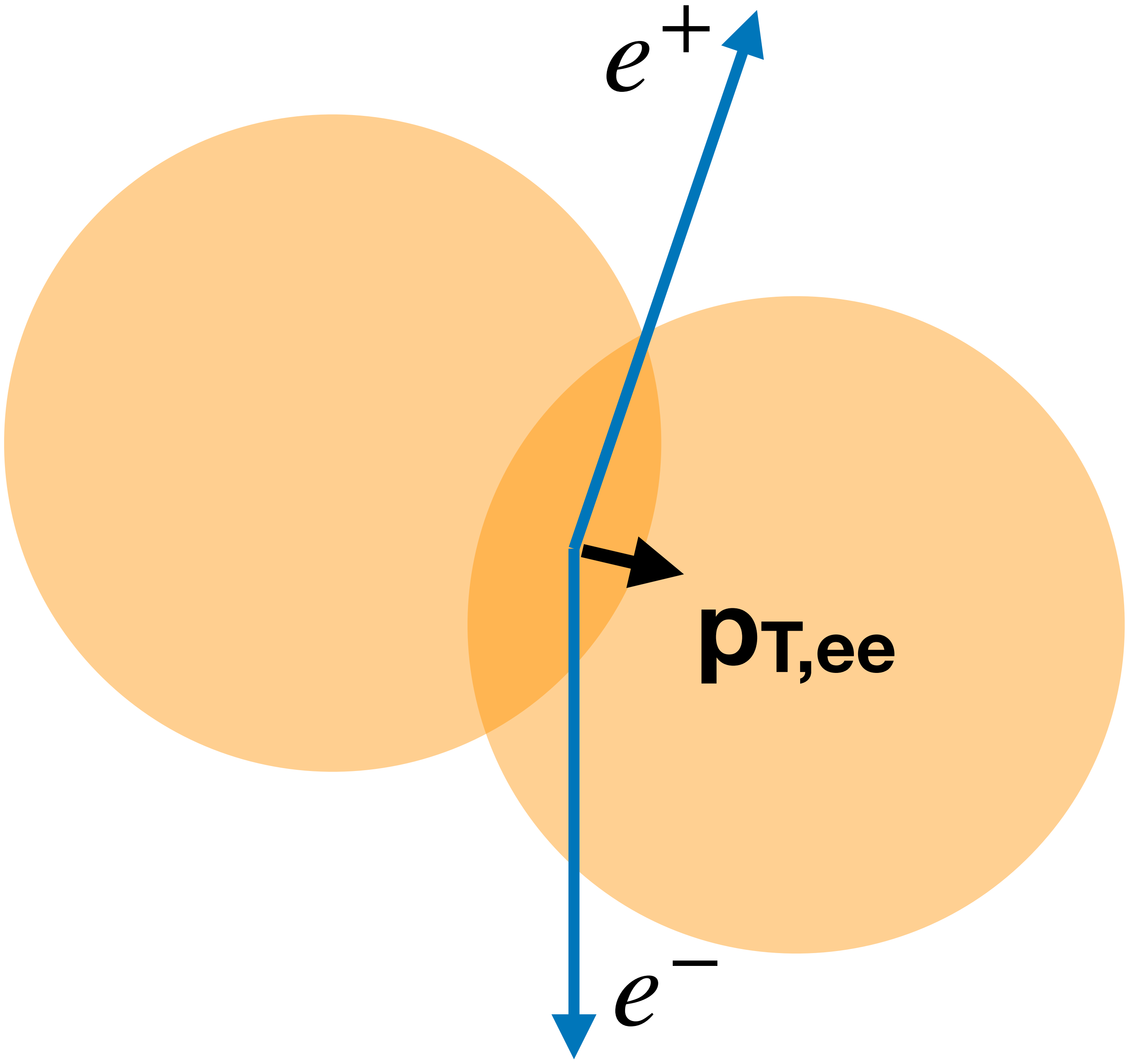


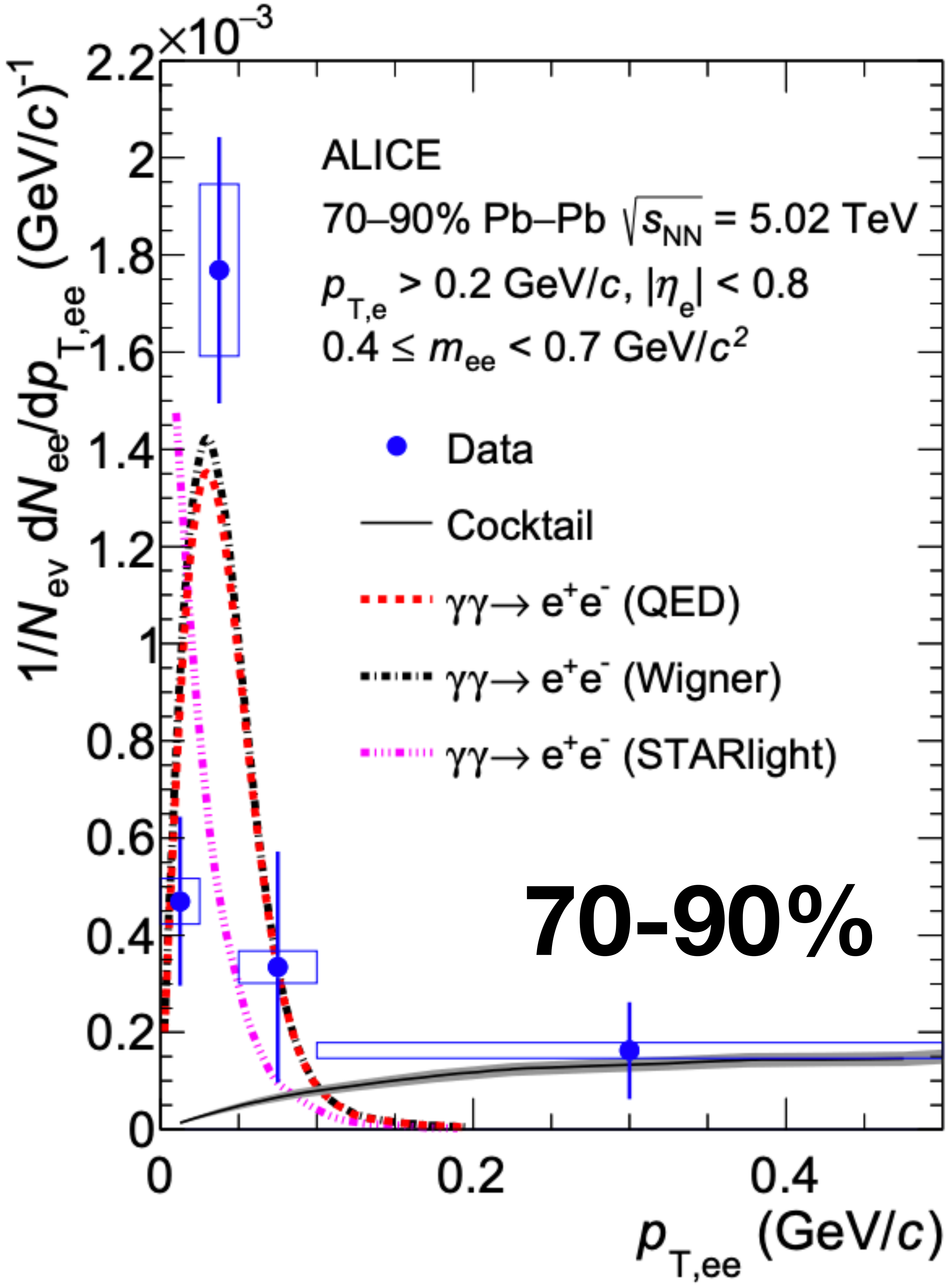
arXiv:2206.12594

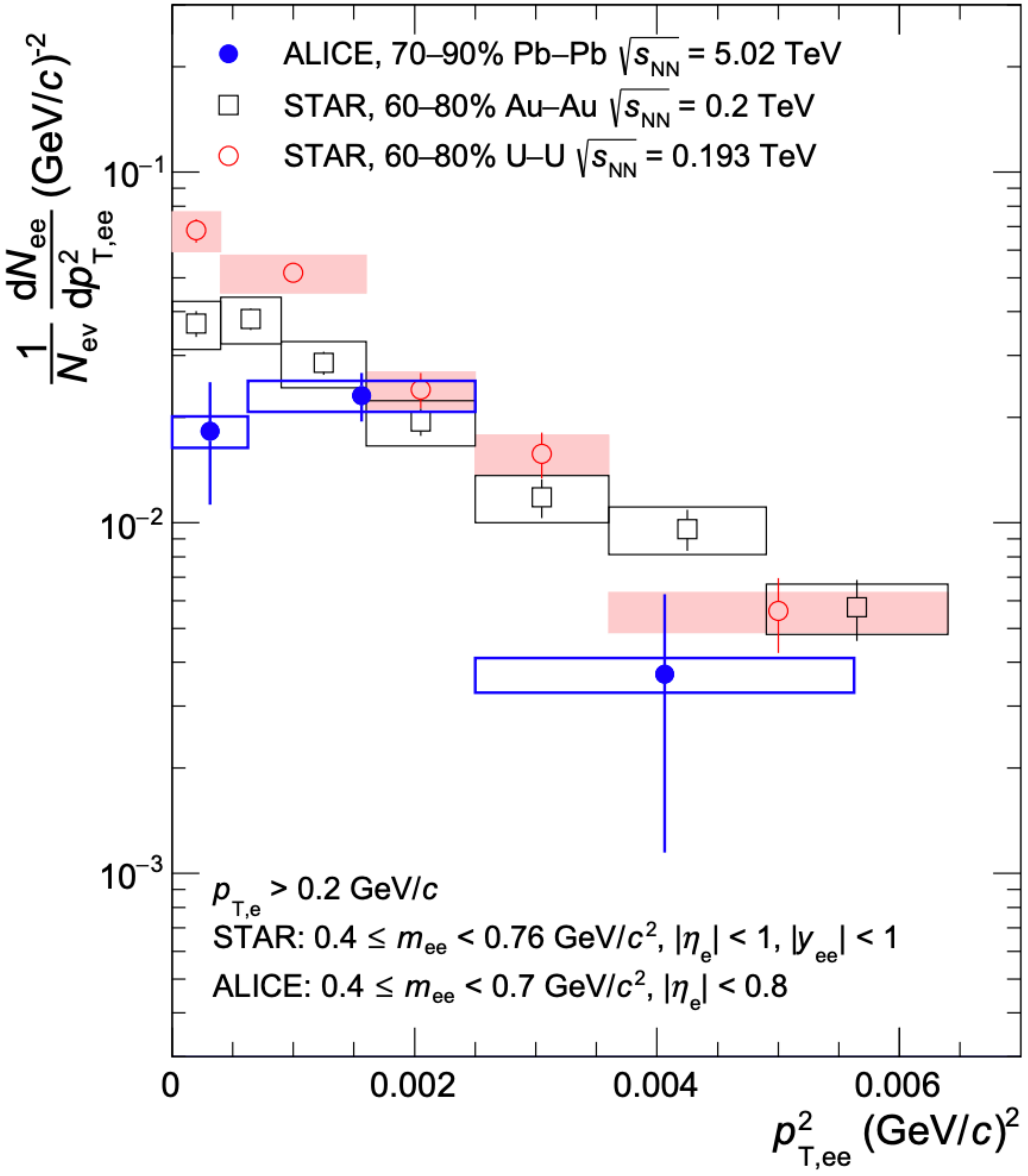
ALICE $\gamma\gamma \rightarrow e^+e^-$ in peripheral AA

- **Excess at low $p_{T,ee}$ clearly favors models w/ b-dependent photon p_T**
- **Similar to STAR results**

New since HP 2020



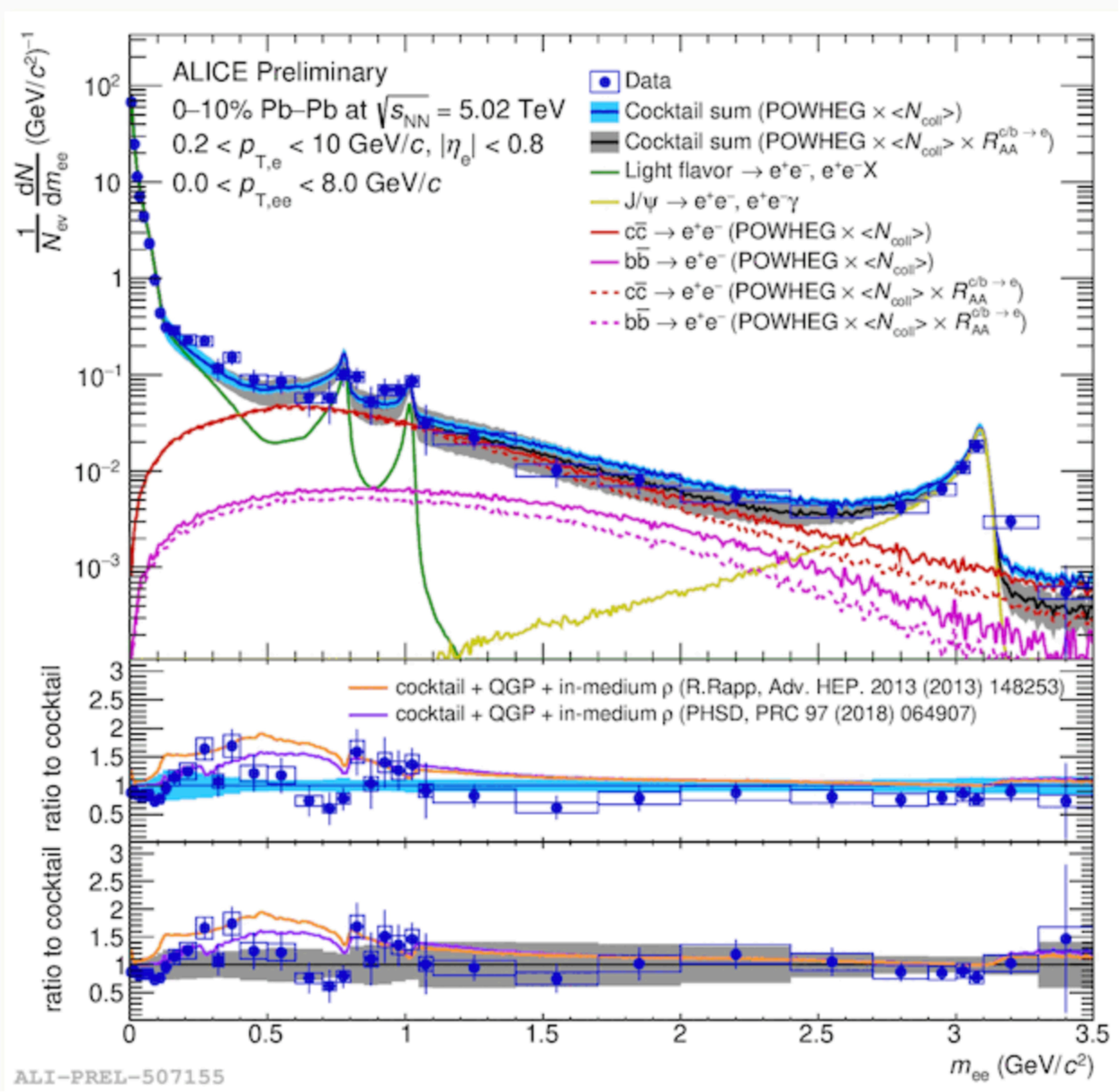


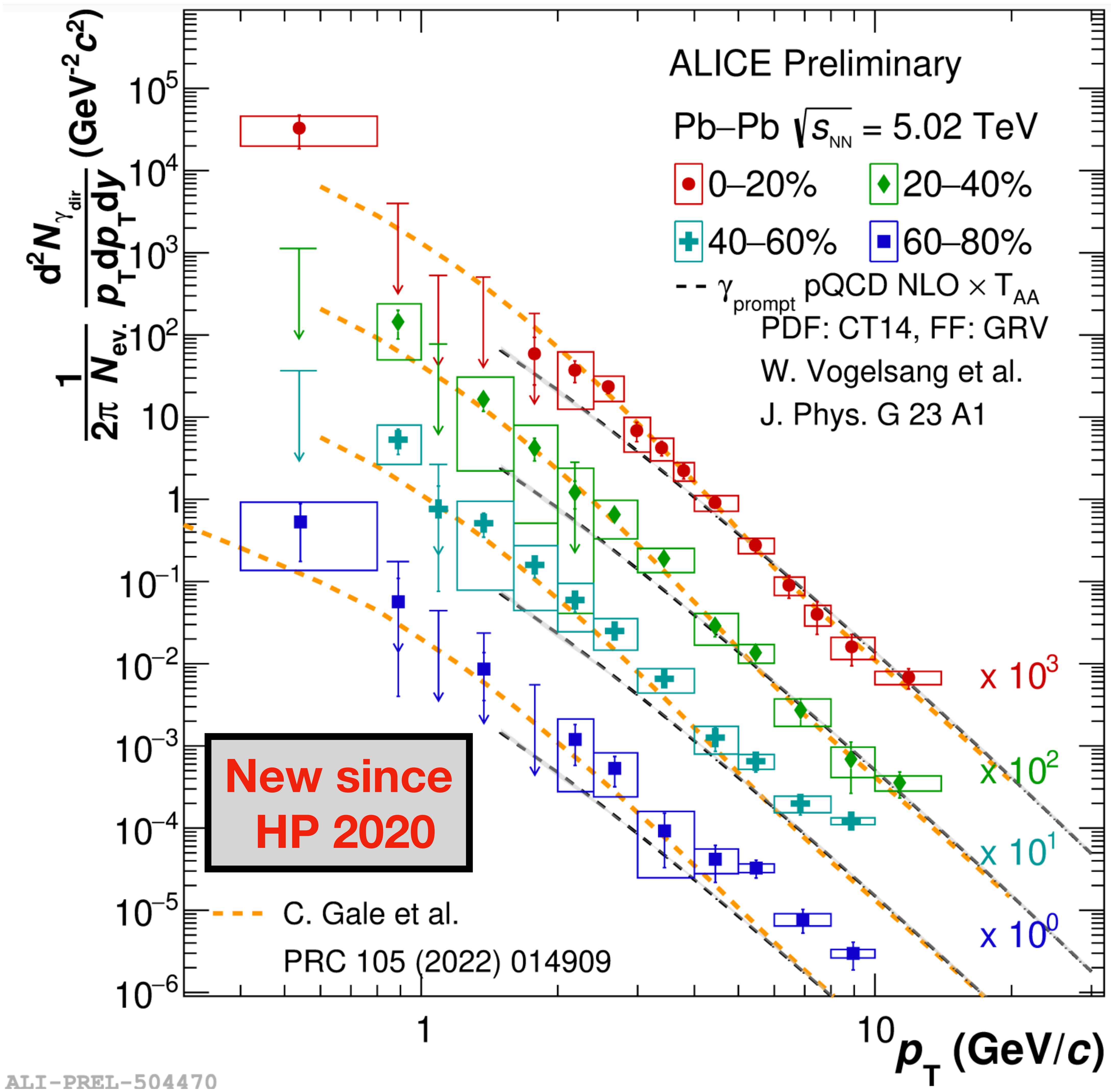


arXiv:2204.11732

Dielectrons, Direct γ in PbPb

- **dielectron data captures trends of cocktail+QGP+ρ model (except at 0.7 GeV?)**
- **Full treatment of collision evolution improves agreement w/ direct photons**

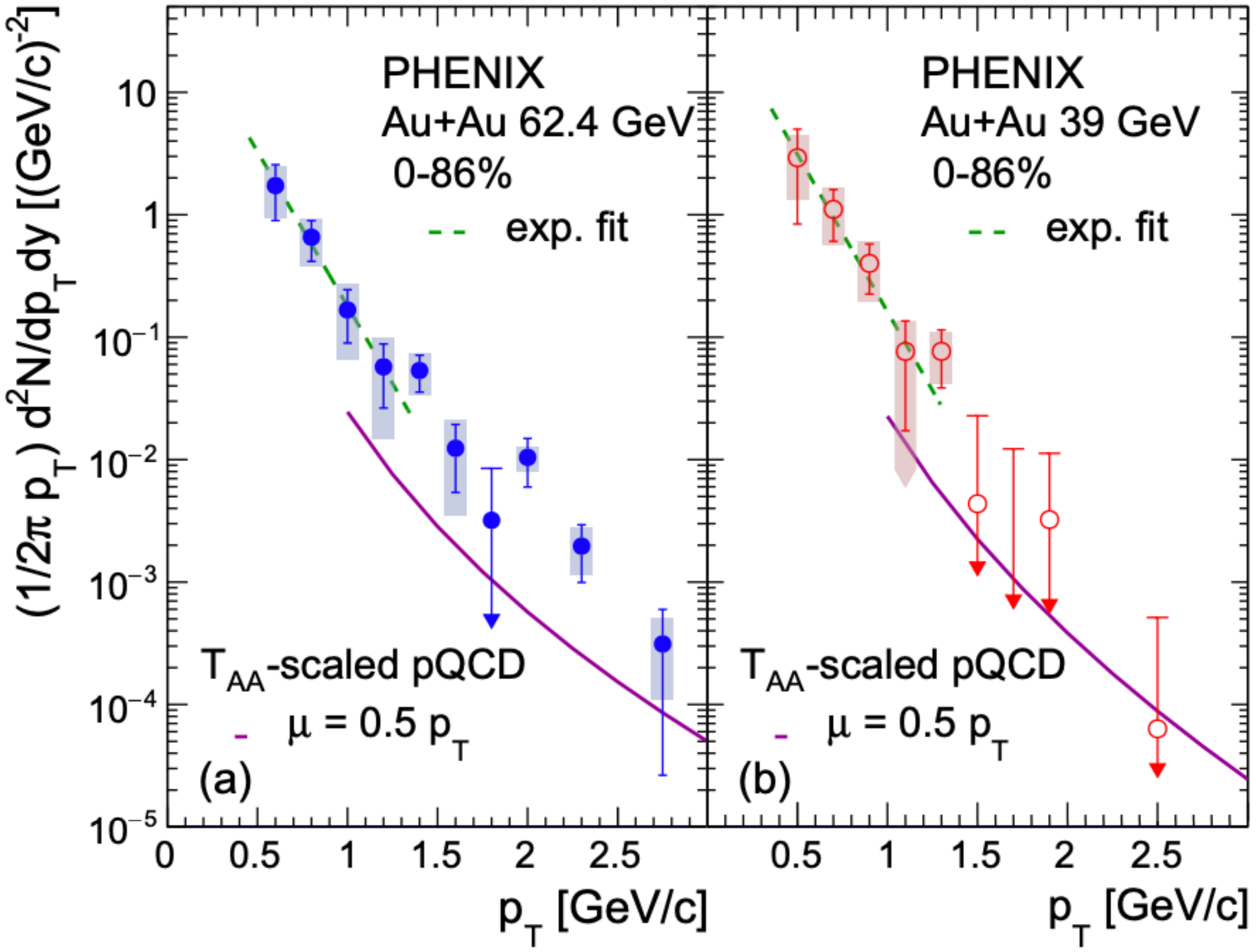




Direct photons with PHENIX

- **Shape of low-p_T direct photons analyzed at lower beam energies**

PRC 107, 024914 (2023)



Finalized since HP 2020

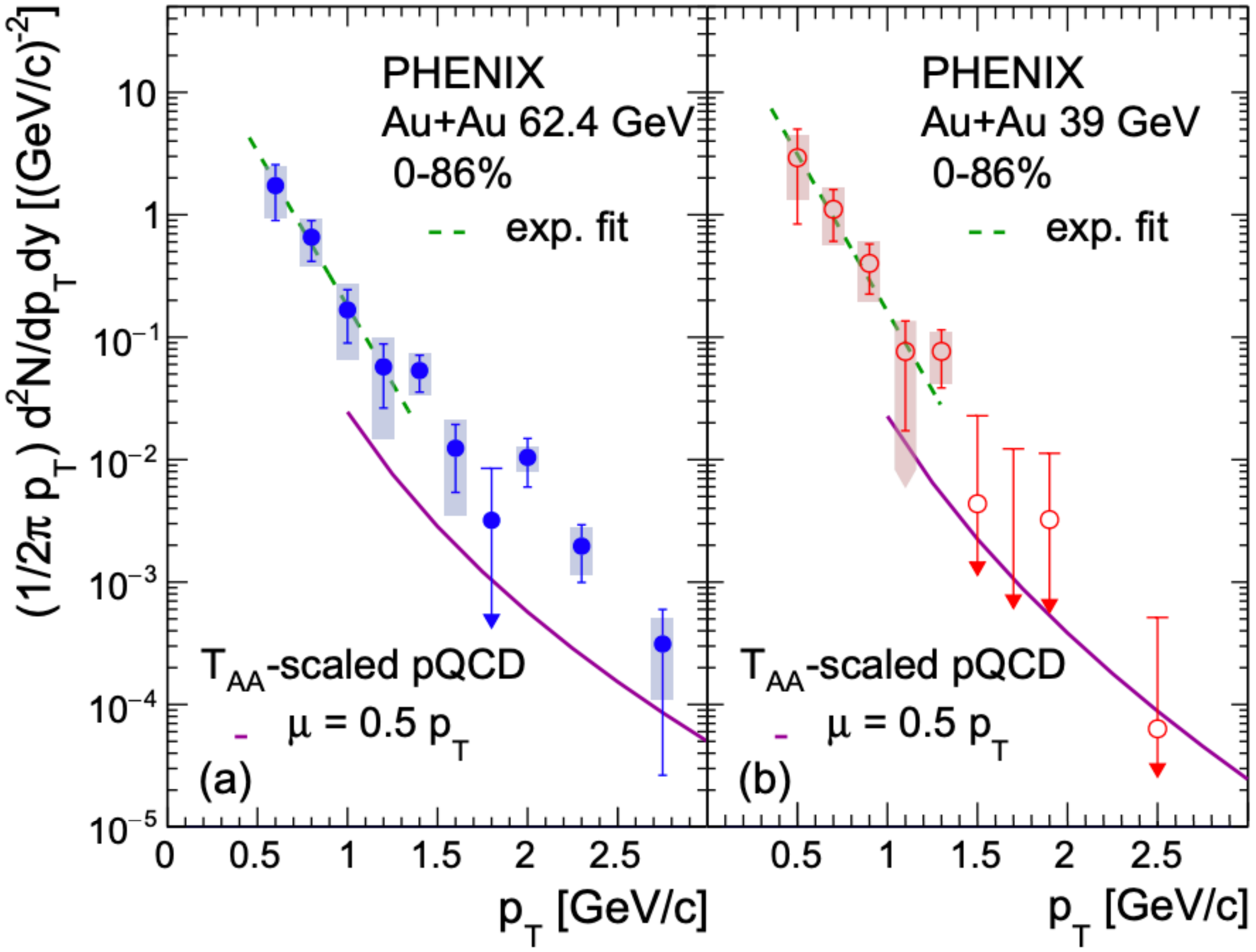
Direct photons with PHENIX

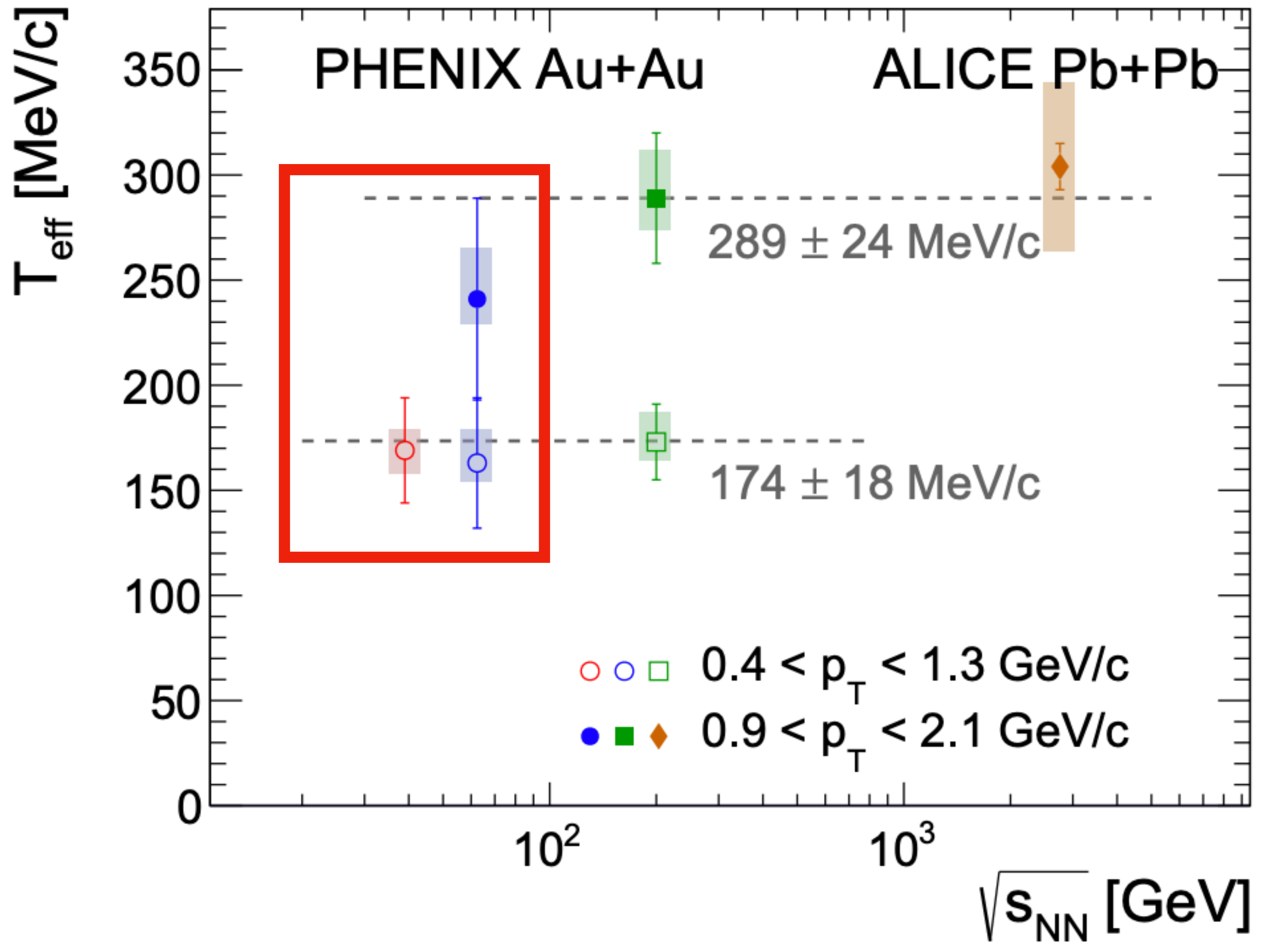
- **Shape of low-p_T direct photons analyzed at lower beam energies**

PRC 107, 024914 (2023)

- **Relatively small $\sqrt{s_{NN}}$ dependence of T_{eff}**
  - **Common source from fireball evolving through phase transition?**

Finalized since HP 2020

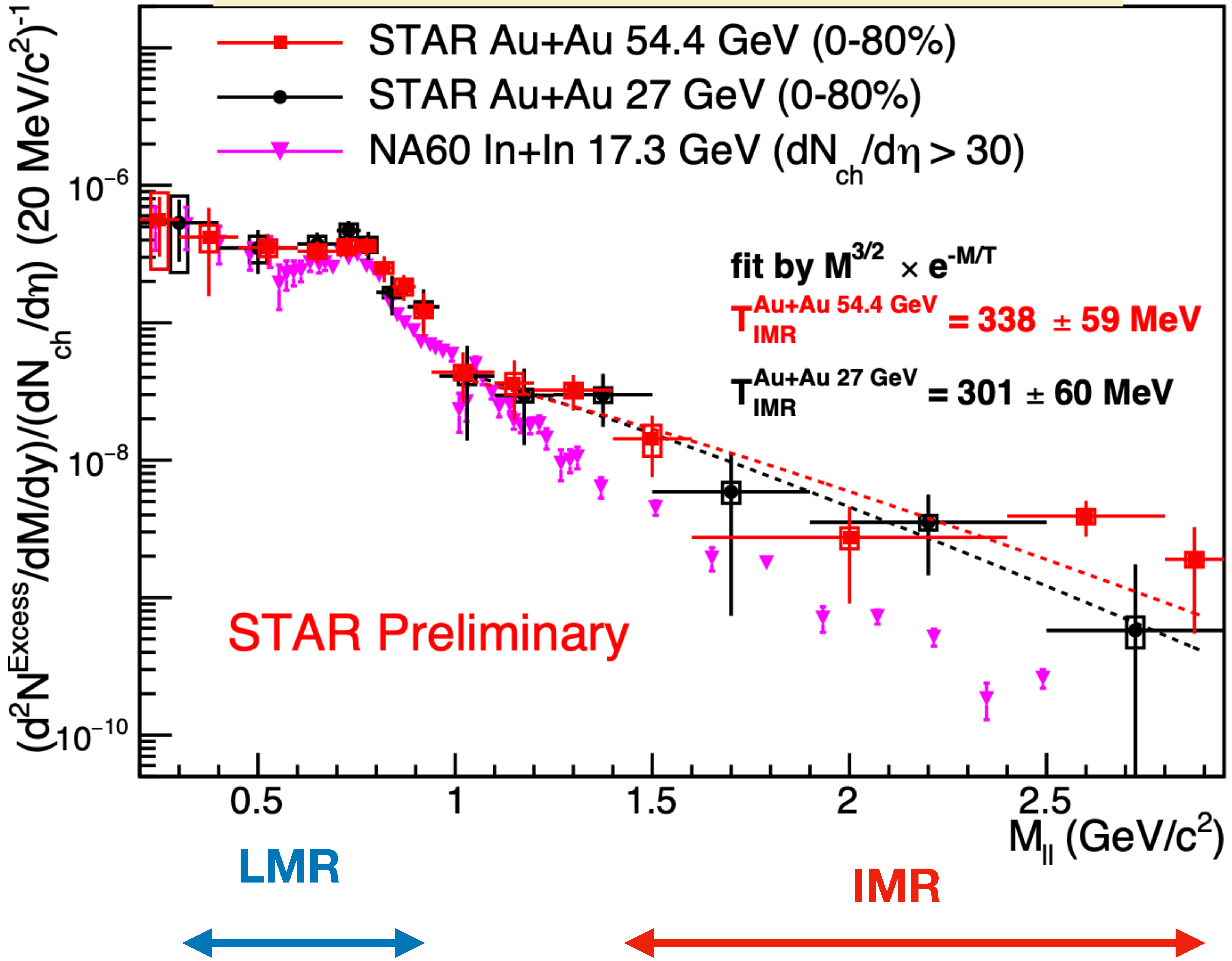


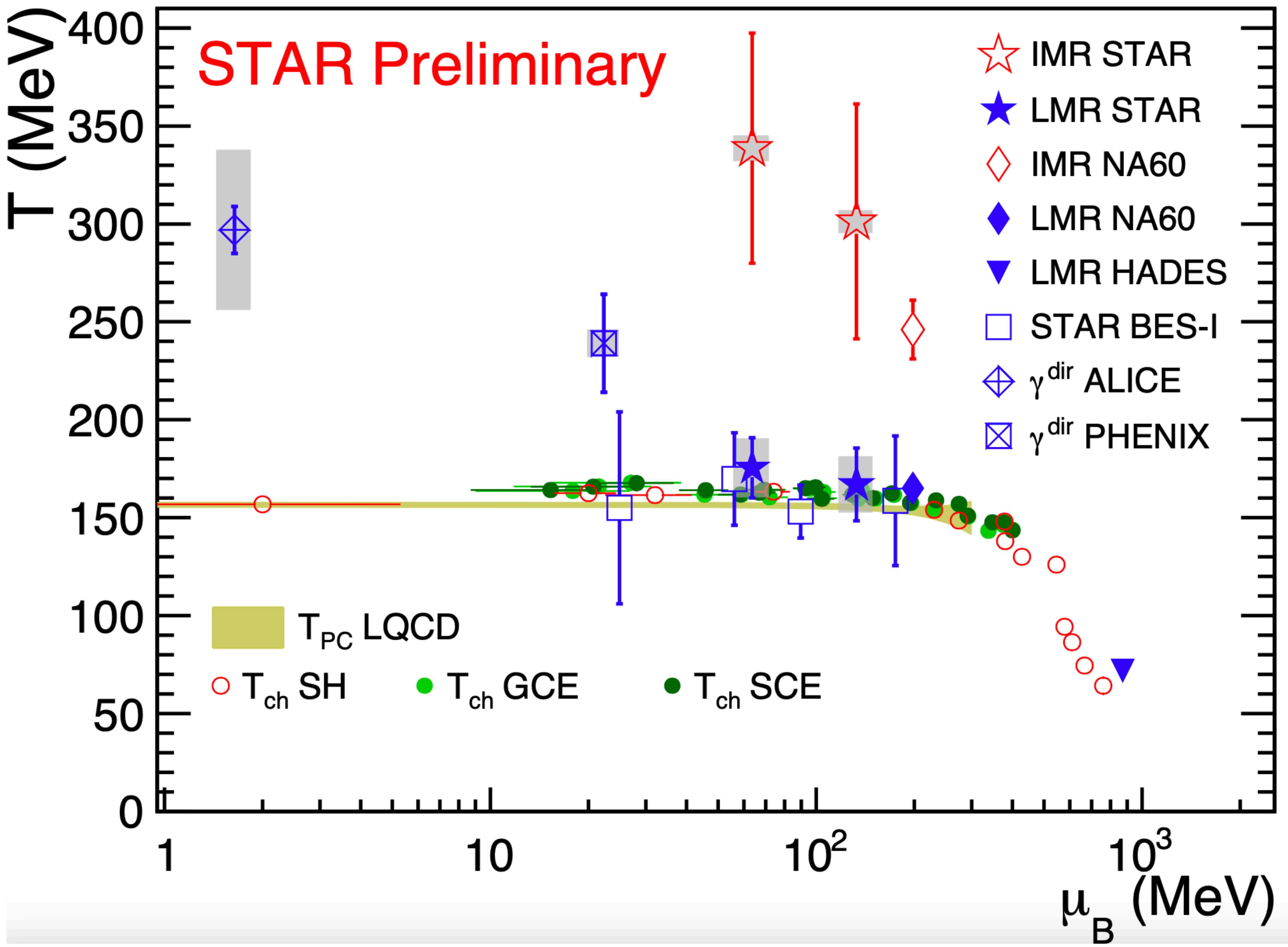


Dielectrons with STAR

- **Different trends of T vs μ_B for low-mass and intermediate-mass regions**
- **Different contributions from in-medium ρ vs QGP**
  - **Probe different stages of temperature evolution**

New since HP 2020





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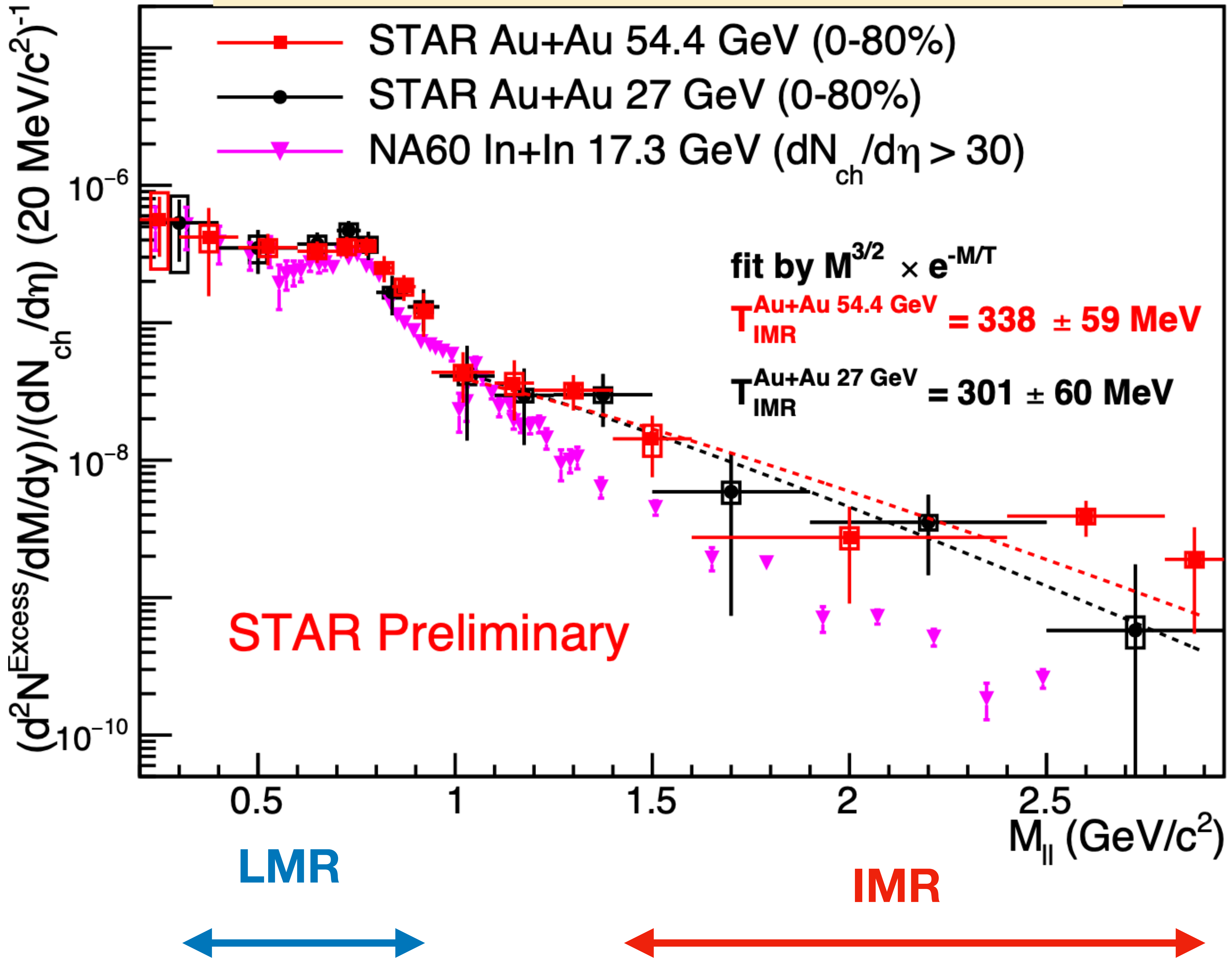
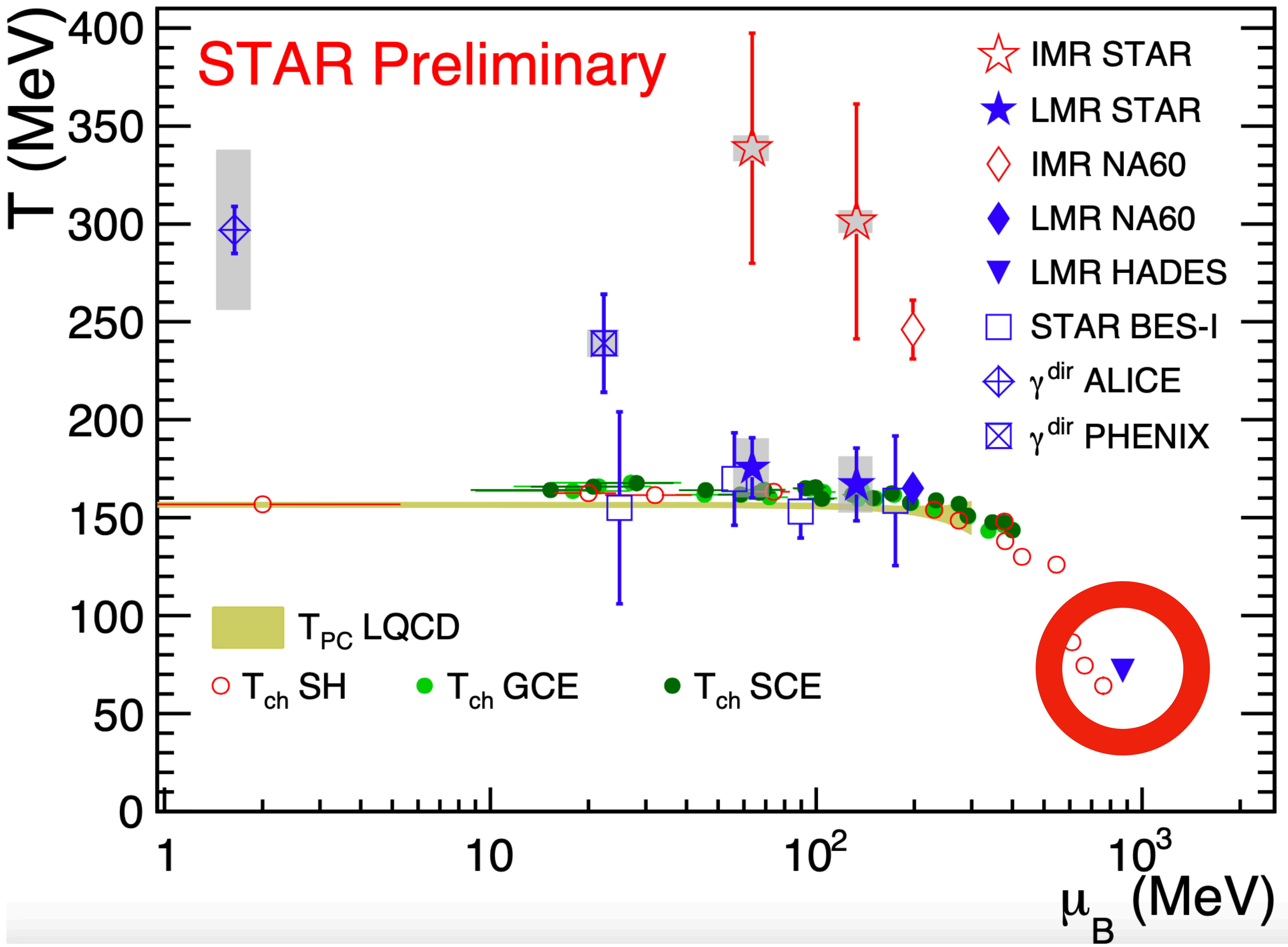
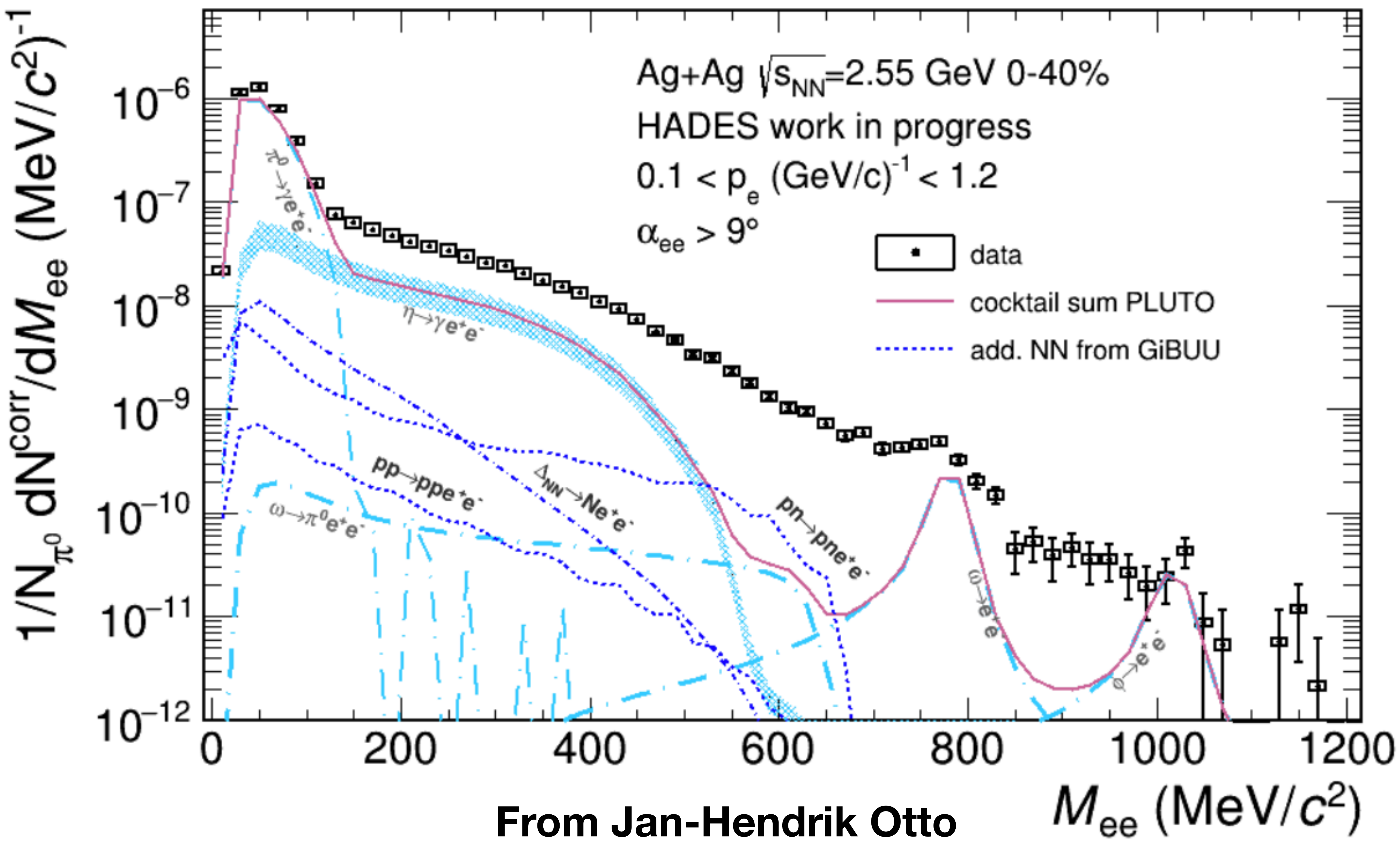




Dielectrons with HADES

- **Extremely detailed scan of low mass region at high μ_B**
  - **2.55 GeV AgAg collisions**
- **Looking forward to further updates!**



From Jan-Hendrik Otto
Quark Matter 2022 slides

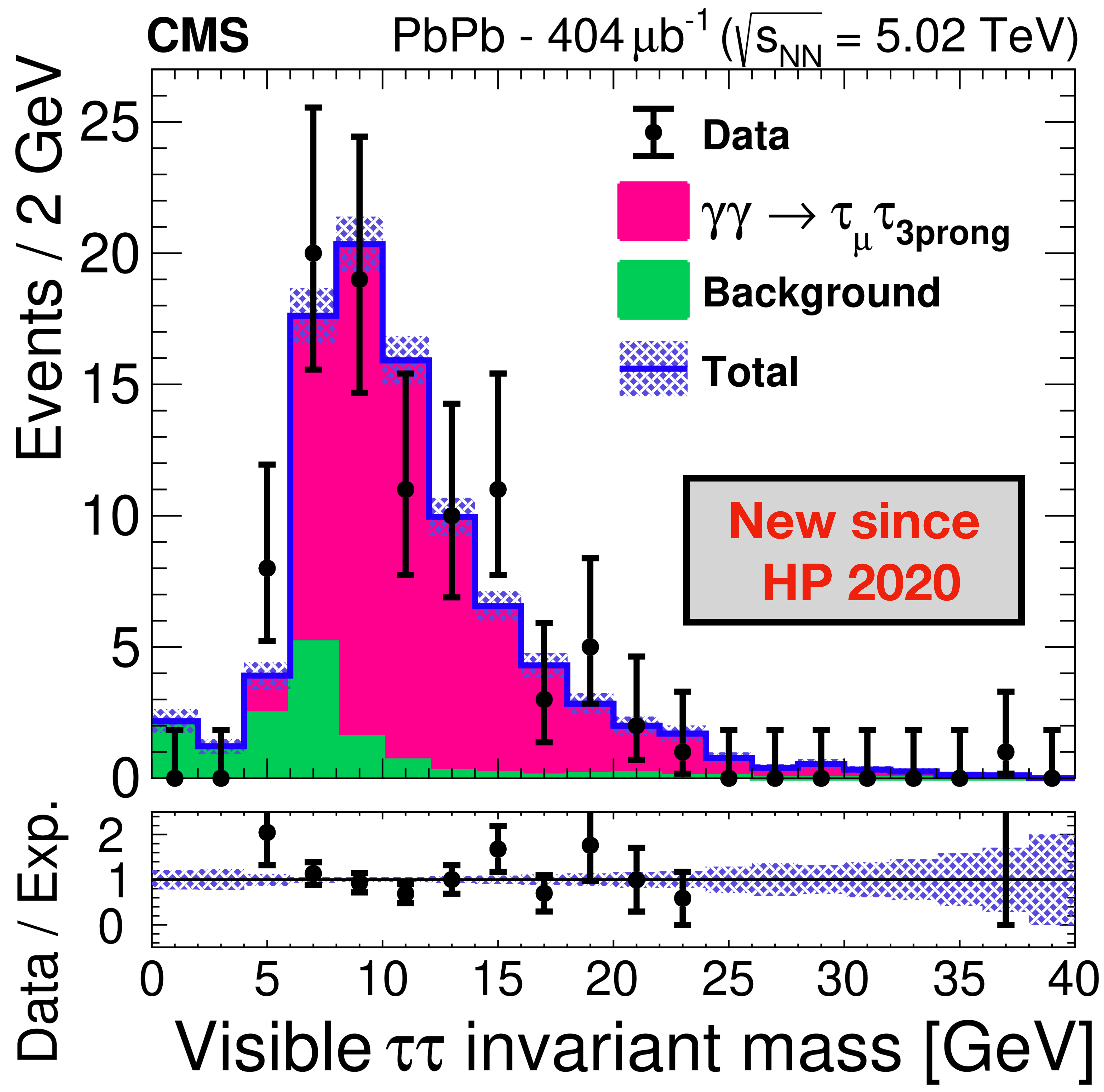
UPC $\gamma\gamma \to \tau\tau$

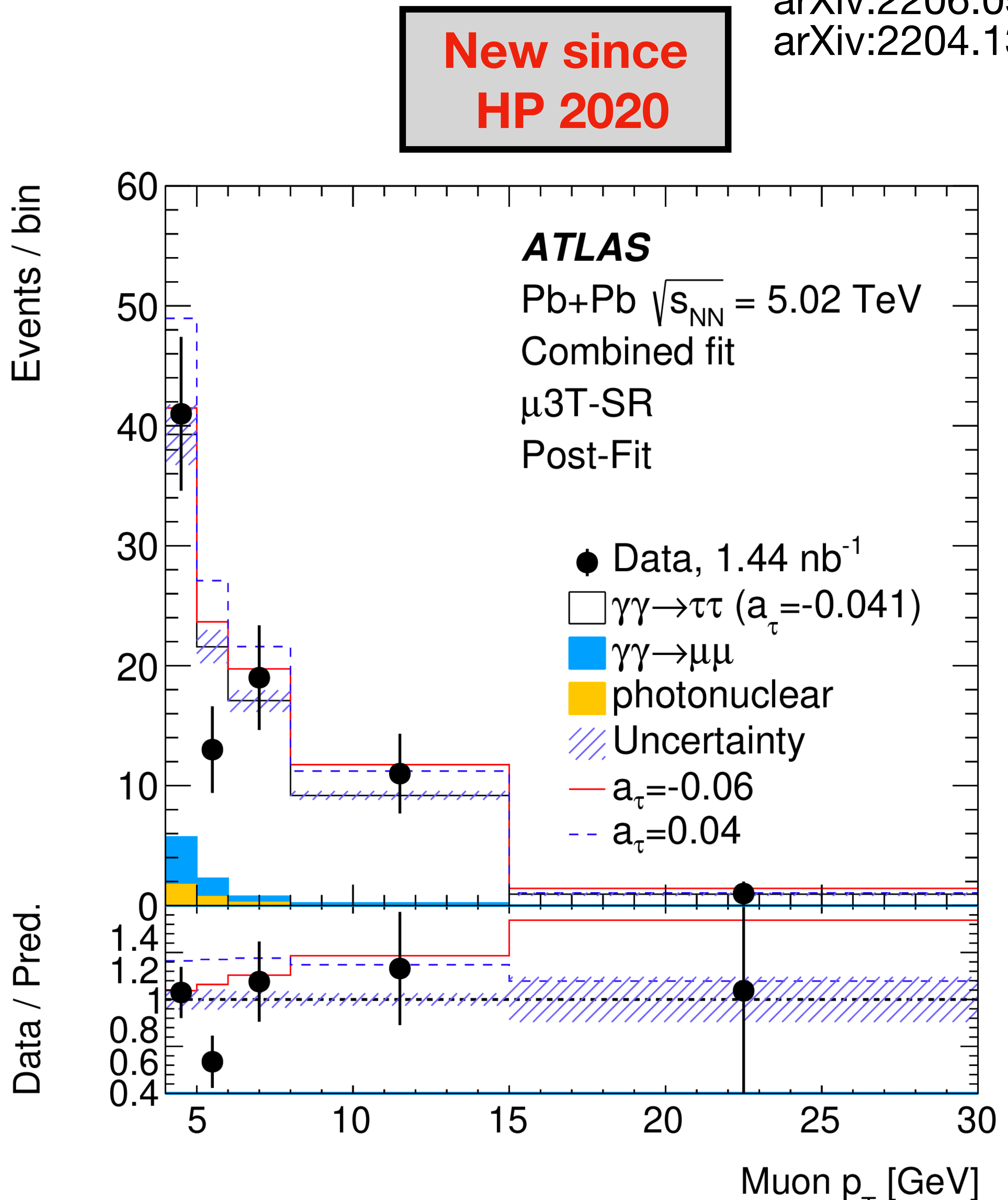
CMS Experiment at the LHC, CERN
Data recorded: 2015-Dec-06 21:41:27.033612 GMT
Run / Event / LS: 263400 / 88515785 / 849

Observation of $\gamma\gamma \rightarrow \tau\tau$ in AA

- **Clean signals with little background**

arXiv:2206.05192
arXiv:2204.13478

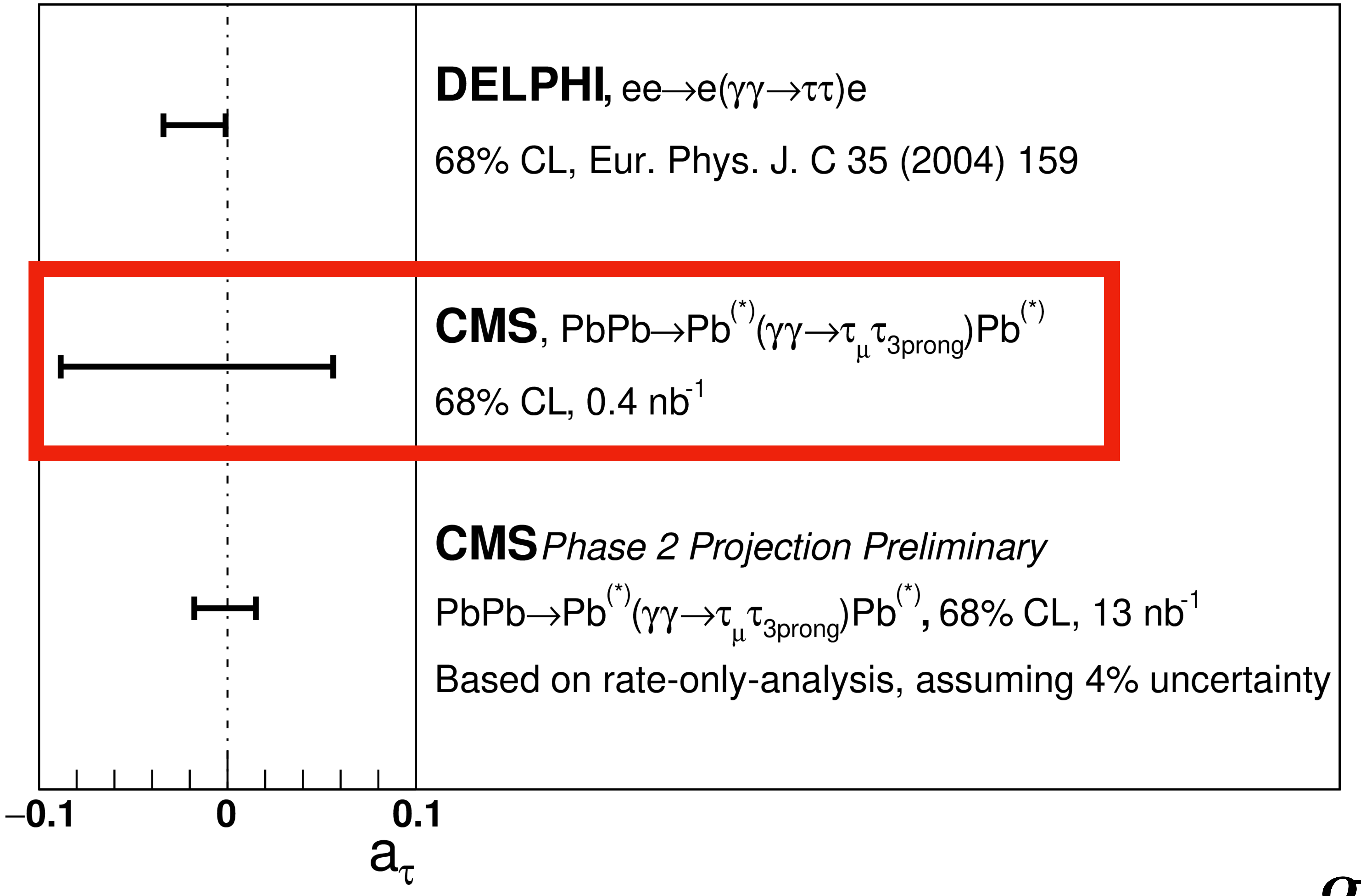


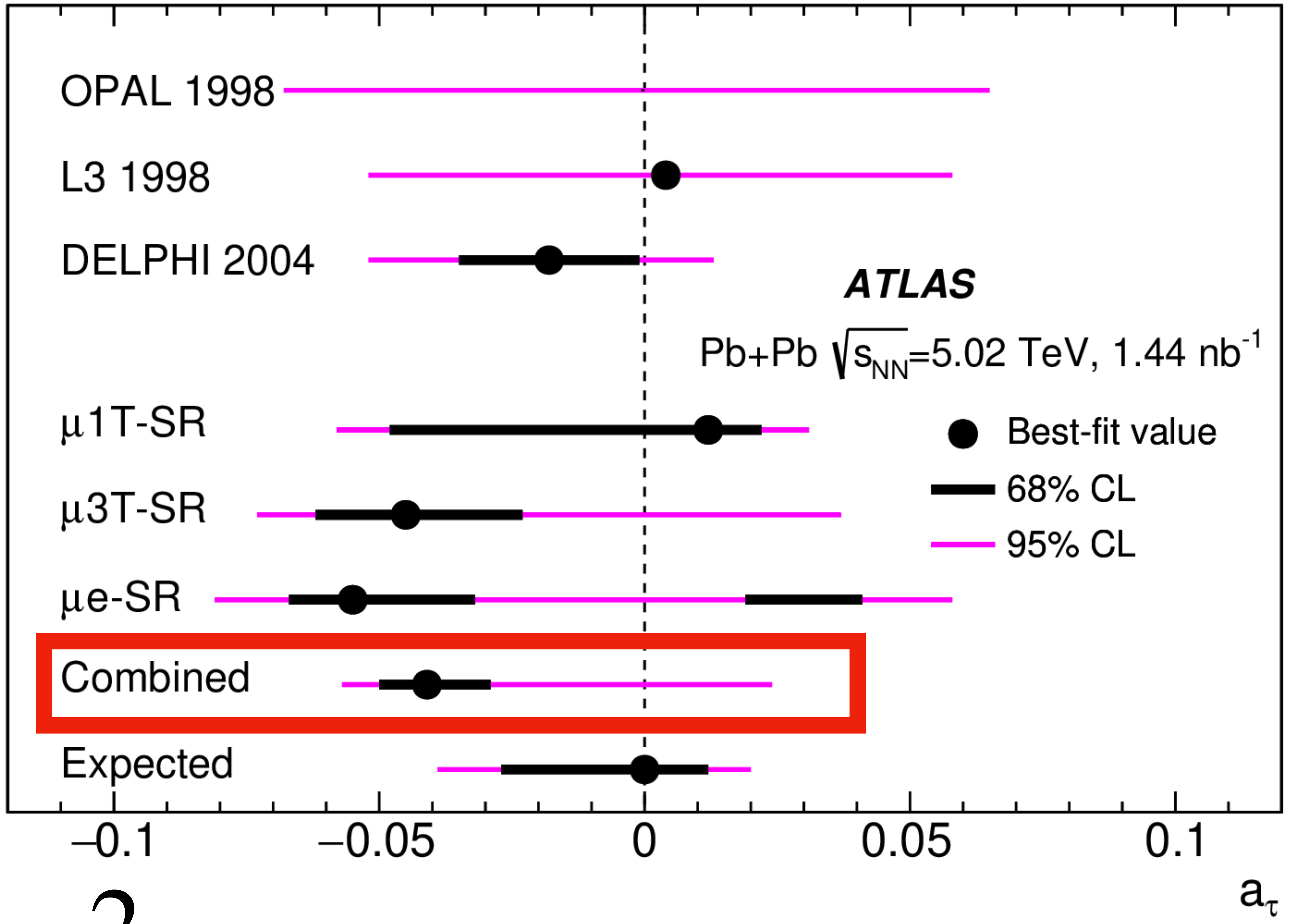


Observation of $\gamma\gamma \to \tau\tau$ in AA

arXiv:2206.05192
arXiv:2204.13478

- **Extract anomalous magnetic moment**
- **Sensitive to higher-order corrections from new particles - BSM test**

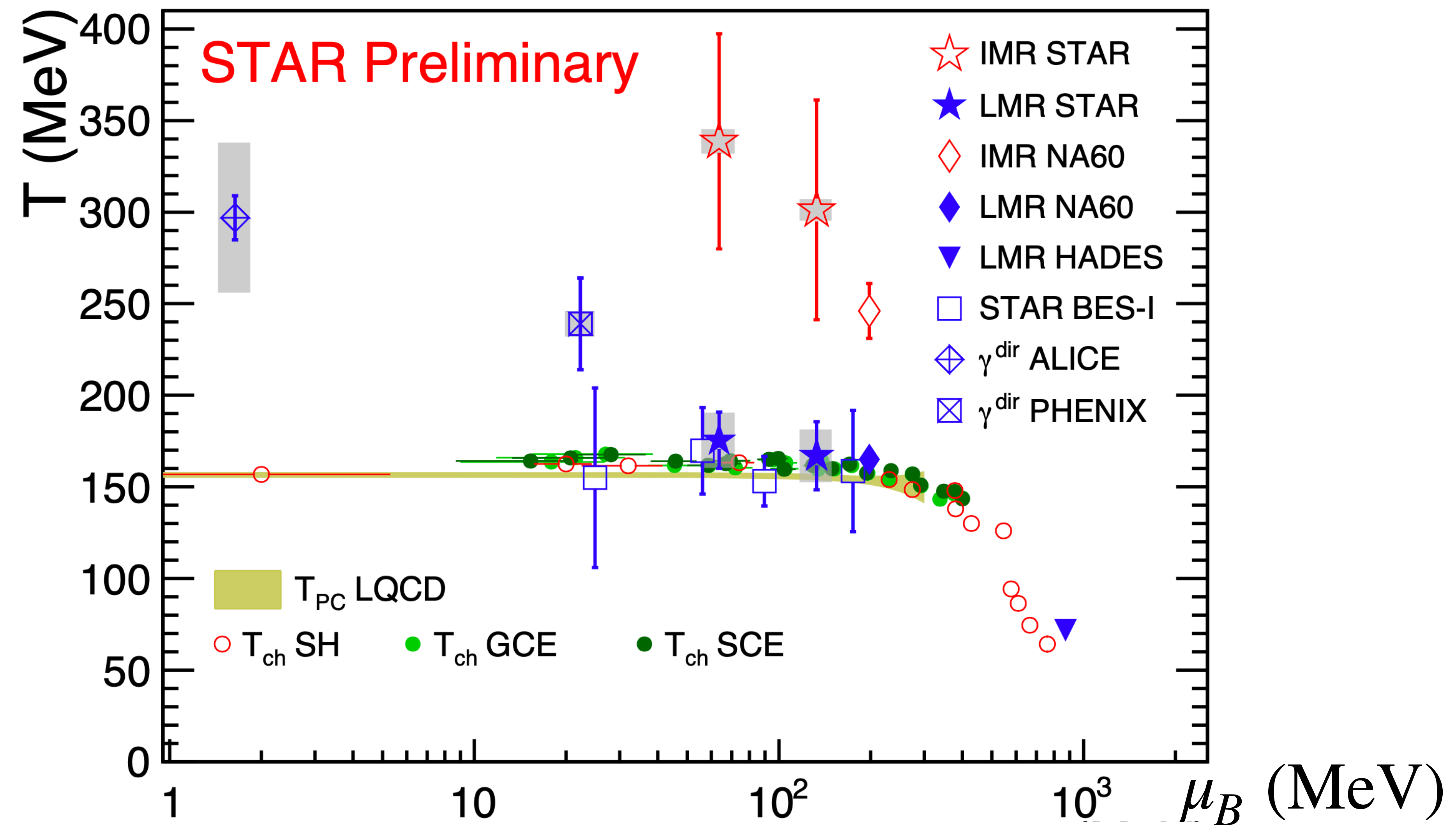


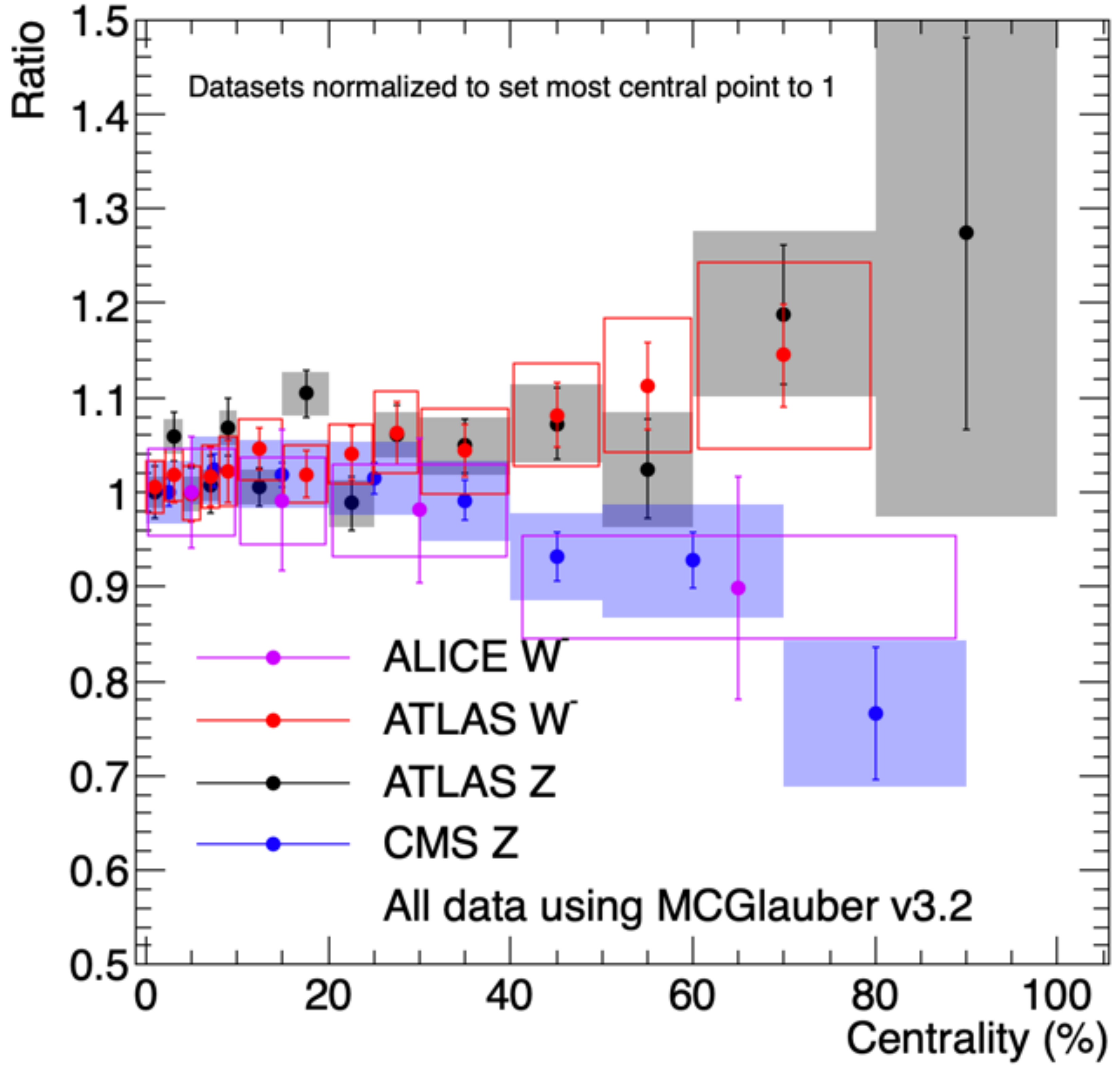


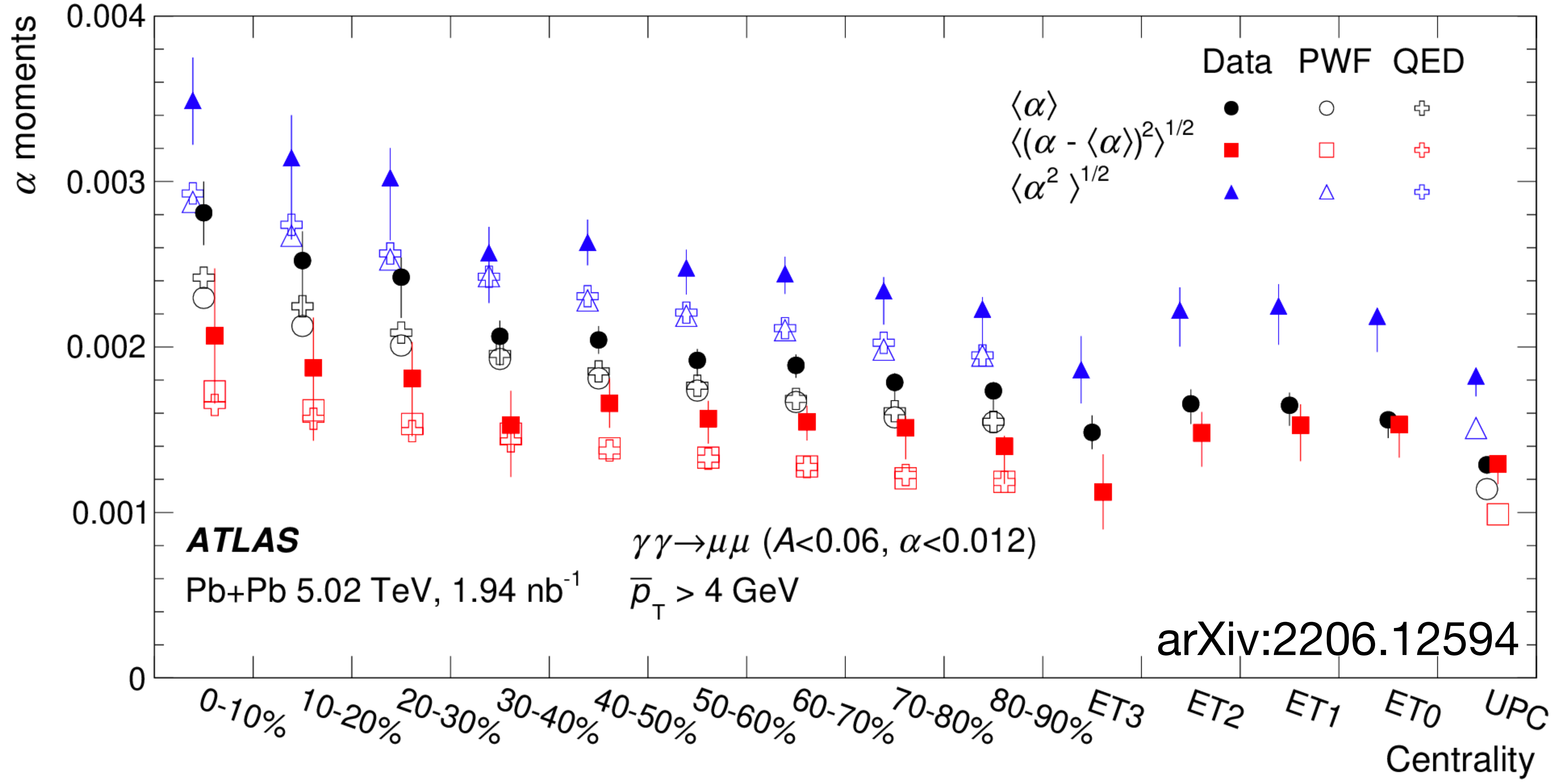
$$a_\tau = \frac{g-2}{2}$$

Conclusions

- **New data constraining nPDFs**
- **LHC Z/W data unclear in peripheral region**
  - **Run 3 will help clarify**
- $\gamma\gamma \rightarrow l^+l^-$ **can probe QGP!**
  - **b-dependence of photon p_T important**
- **New data to explore T_{eff} vs μ_B**



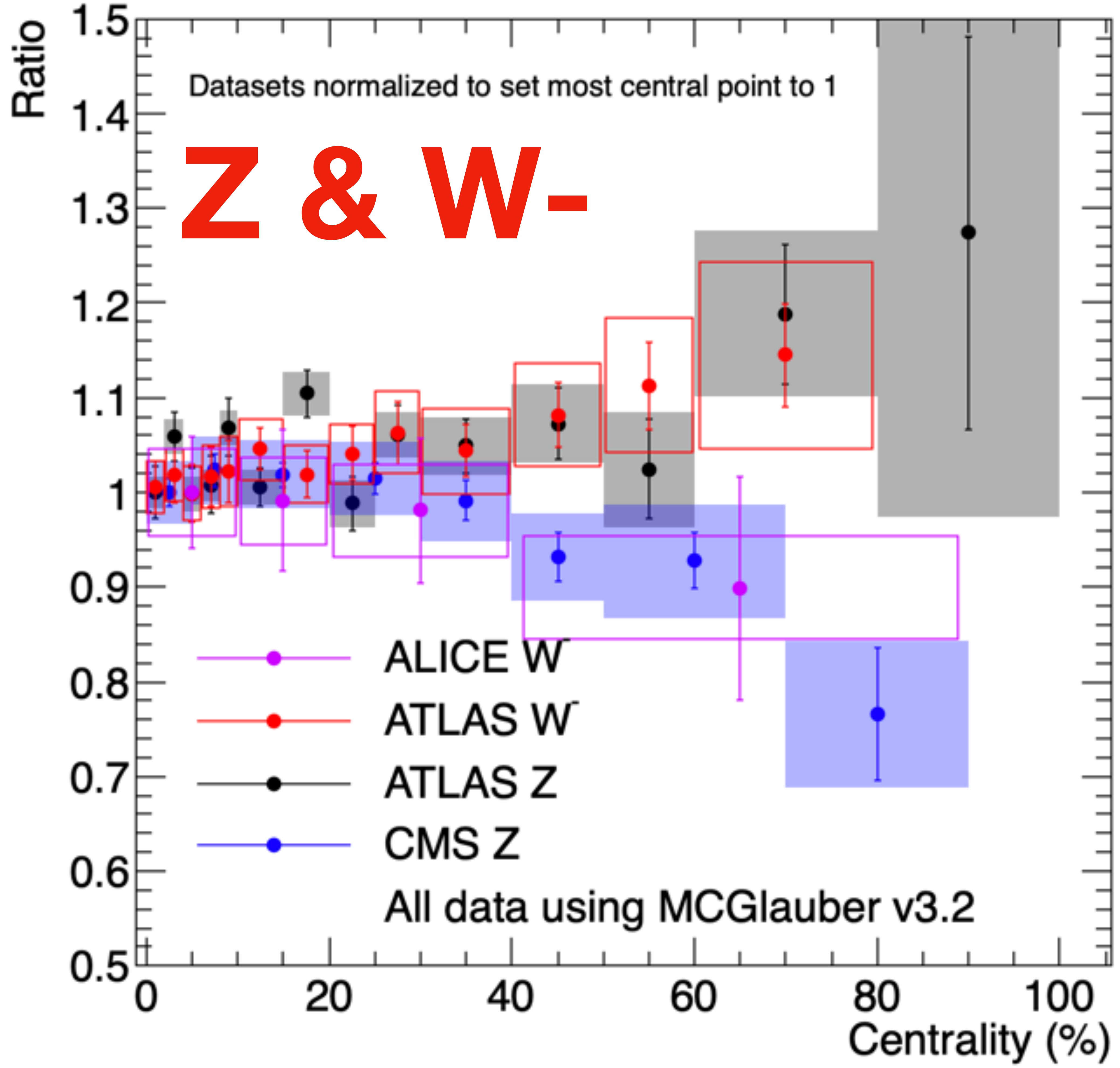


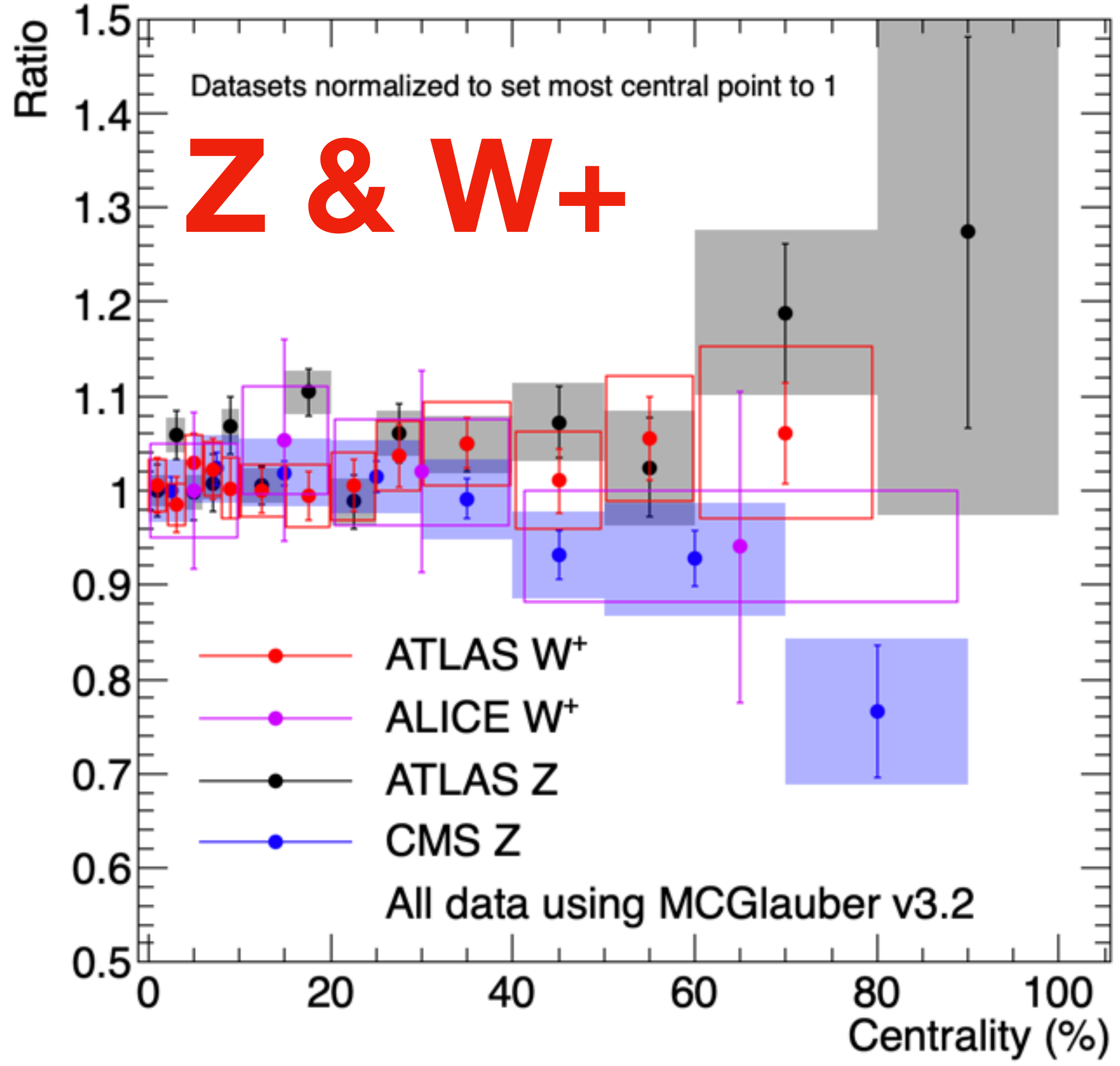


Backup

Z/W Summary Plot

- **Data have their normalization fixed so the most central point = 1**
- **Using ATLAS MCGlauber v3.2 data points instead of v2.4 improves agreement**

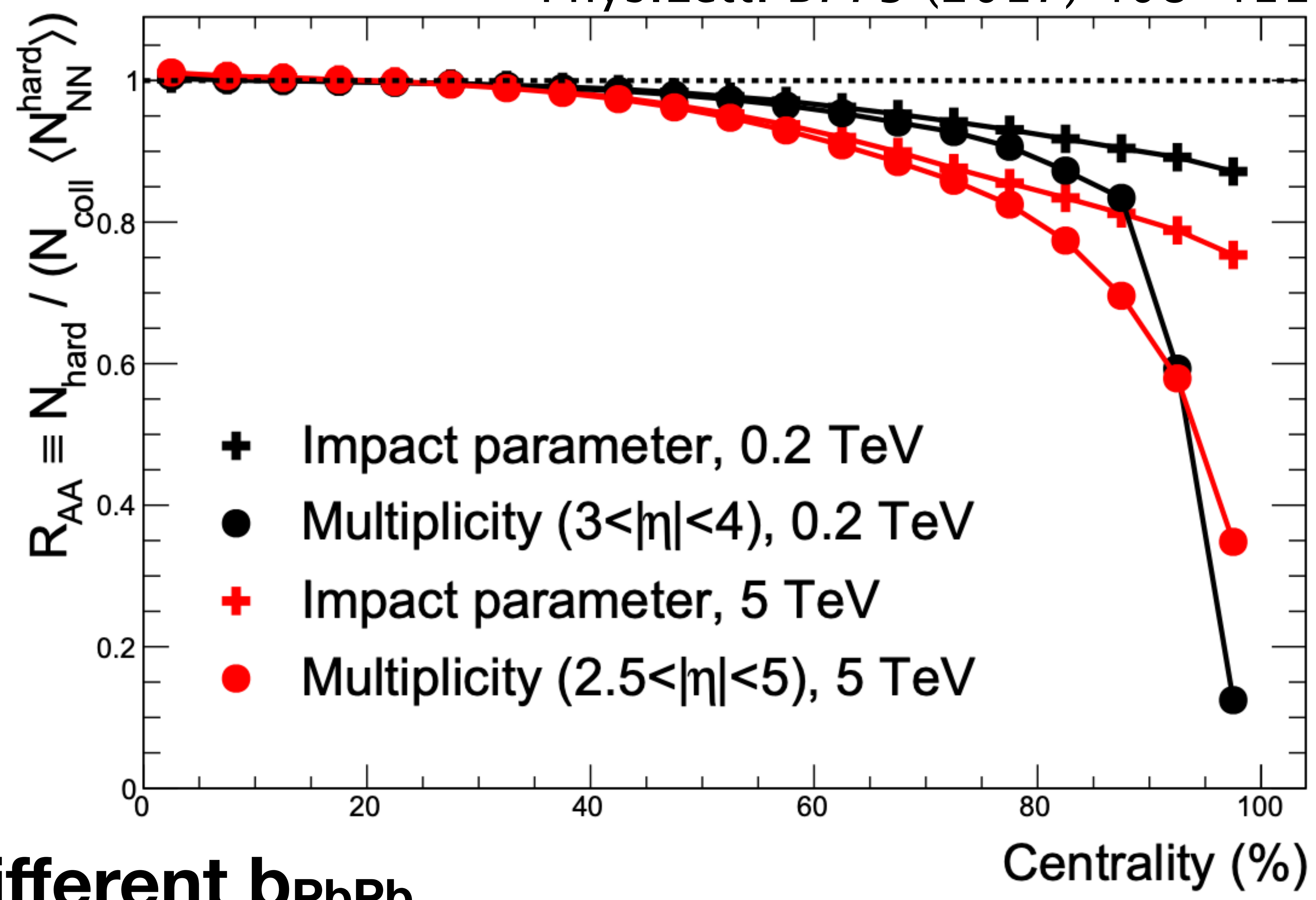




HG-PYTHIA

- Run HIJING to calculate N_{coll} and N_{MPI}
- Superimpose N_{coll} Pythia MB events that have the same number of MPIs
  - These events have no QGP physics
- Perform a centrality calibration
- Plot R_{AA} by comparing to cross section from pp collisions

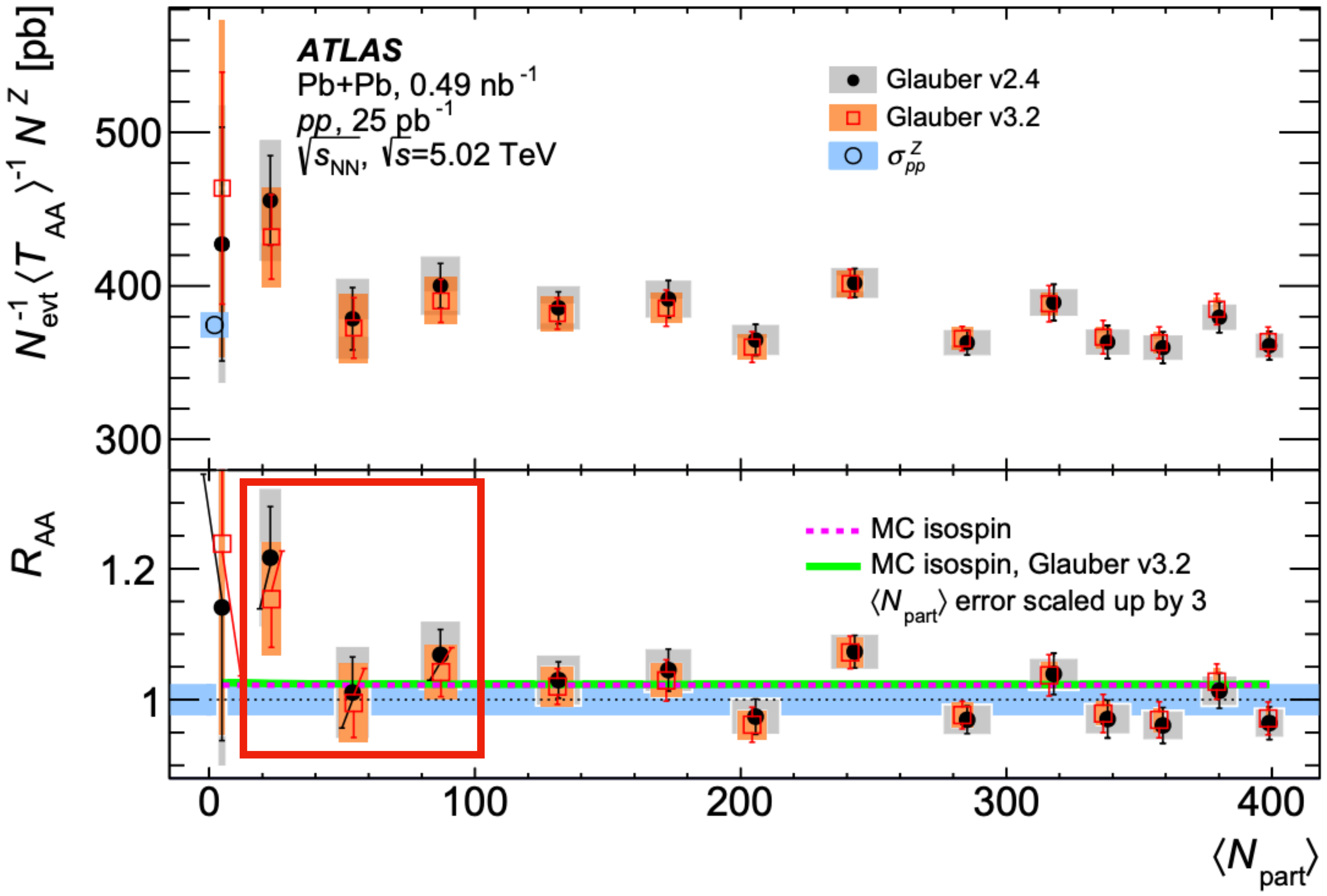
Phys.Lett. B773 (2017) 408-411



- Geometry biases - $\langle b_{NN} \rangle$ can be biased for different b_{PbPb}
- Centrality selection bias - correlations in hard/soft production can cause migration of event with hard processes to higher centrality
  - Leads to depletion in peripheral events

Comparison to ATLAS - Glauber versions

Phys. Lett. B 802 (2020) 135262



- **ATLAS RAA compilation plot uses v2.4 but they also provided v3.2**
- **CMS & ALICE use v3.2**
  - **Orange points should be used for a fair comparison**

SuperCHIC vs Starlight

- None of them simulates a FSR contribution
- In **STARlight formalism** photon spectrum is calculated in impact parameter space, Comput.Phys.Commun. 212 (2017) 258-268

$$d^2N/dk_1dk_2 = \int_{b_1>R_1} db_1 \int_{b_2>R_2} db_2\, n(k_1, b_1) n(k_2, b_2)\, P_{fn}(b)\, (1 - P_H(b))$$

dilepton pairs are not formed within either nucleus

Probability of forward neutron topology

beam projectiles do not interact hadronically (Glauber calculation)

- In **SuperChic formalism** different implementation of the non-hadronic overlap condition of the Pb ions, SciPost Phys. 11, 064 (2021)

$$\sigma_{N_1N_2\to N_1XN_2} = \int \mathrm{d}x_1 \mathrm{d}x_2\, n(x_1) n(x_2) \hat{\sigma}_{\gamma\gamma\to X}$$

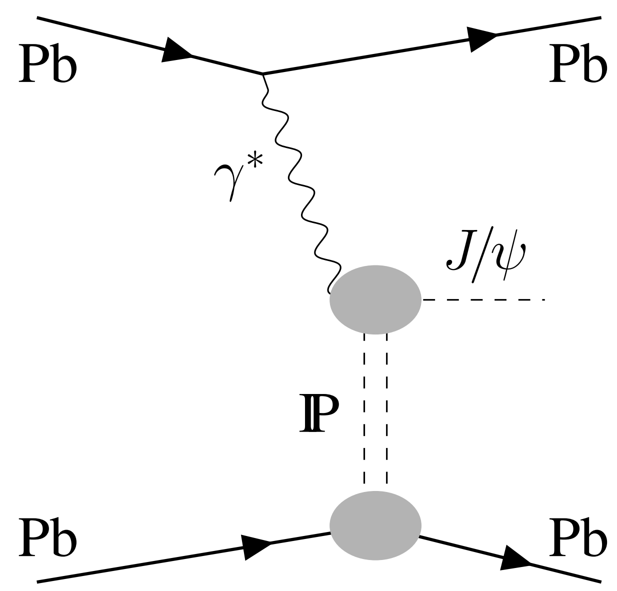
$$n(x_i) = \frac{\alpha}{\pi^2 x_i} \int \frac{\mathrm{d}^2 q_{i_\perp}}{q_{i_\perp}^2 + x_i^2 m_{N_i}^2} \left(\frac{q_{i_\perp}^2}{q_{i_\perp}^2 + x_i^2 m_{N_i}^2} (1 - x_i) F_E(Q_i^2) + \frac{x_i^2}{2} F_M(Q_i^2) \right)$$

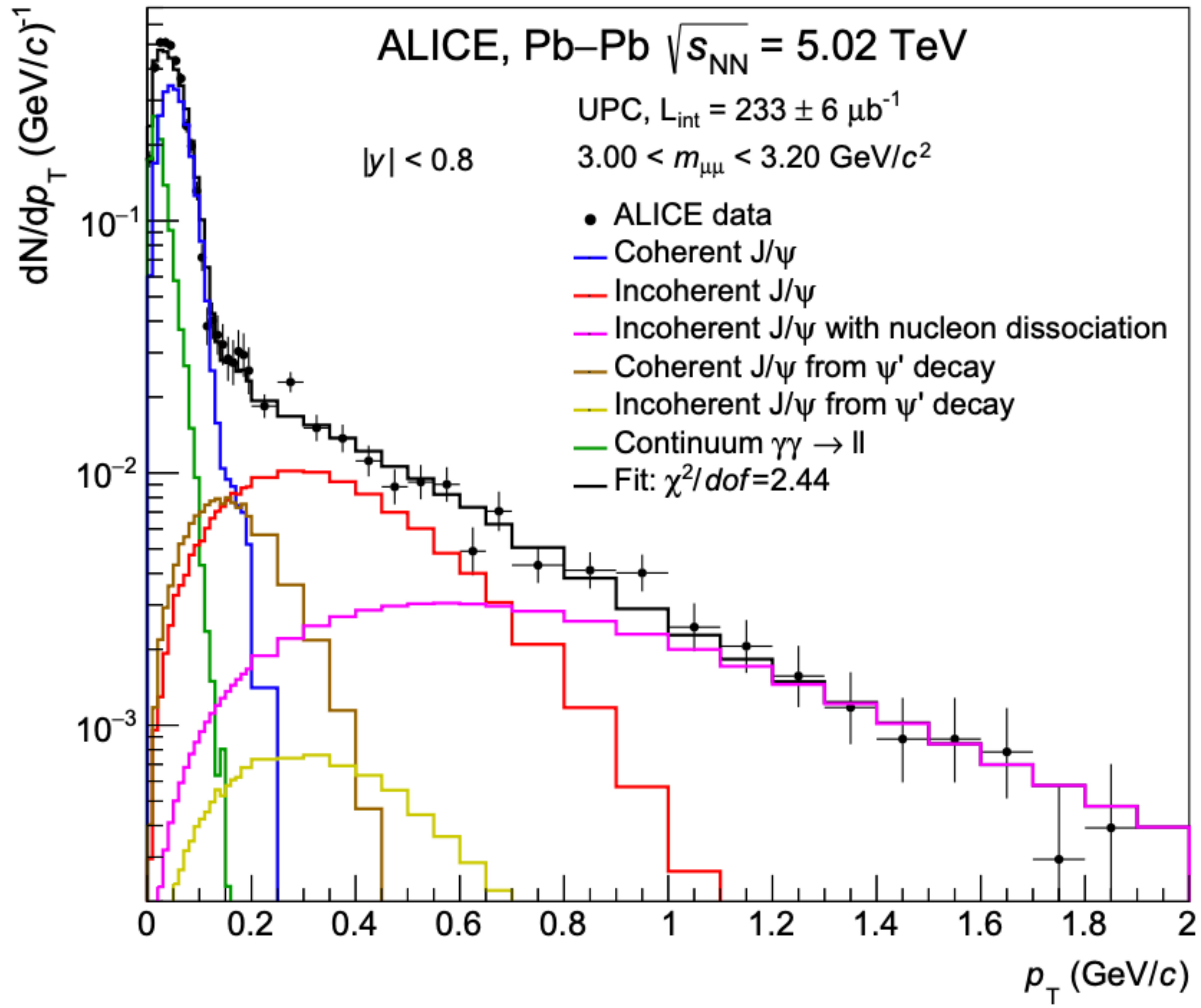
- SuperChic includes survival and polarization effects at amplitude level, but not forward neutrons

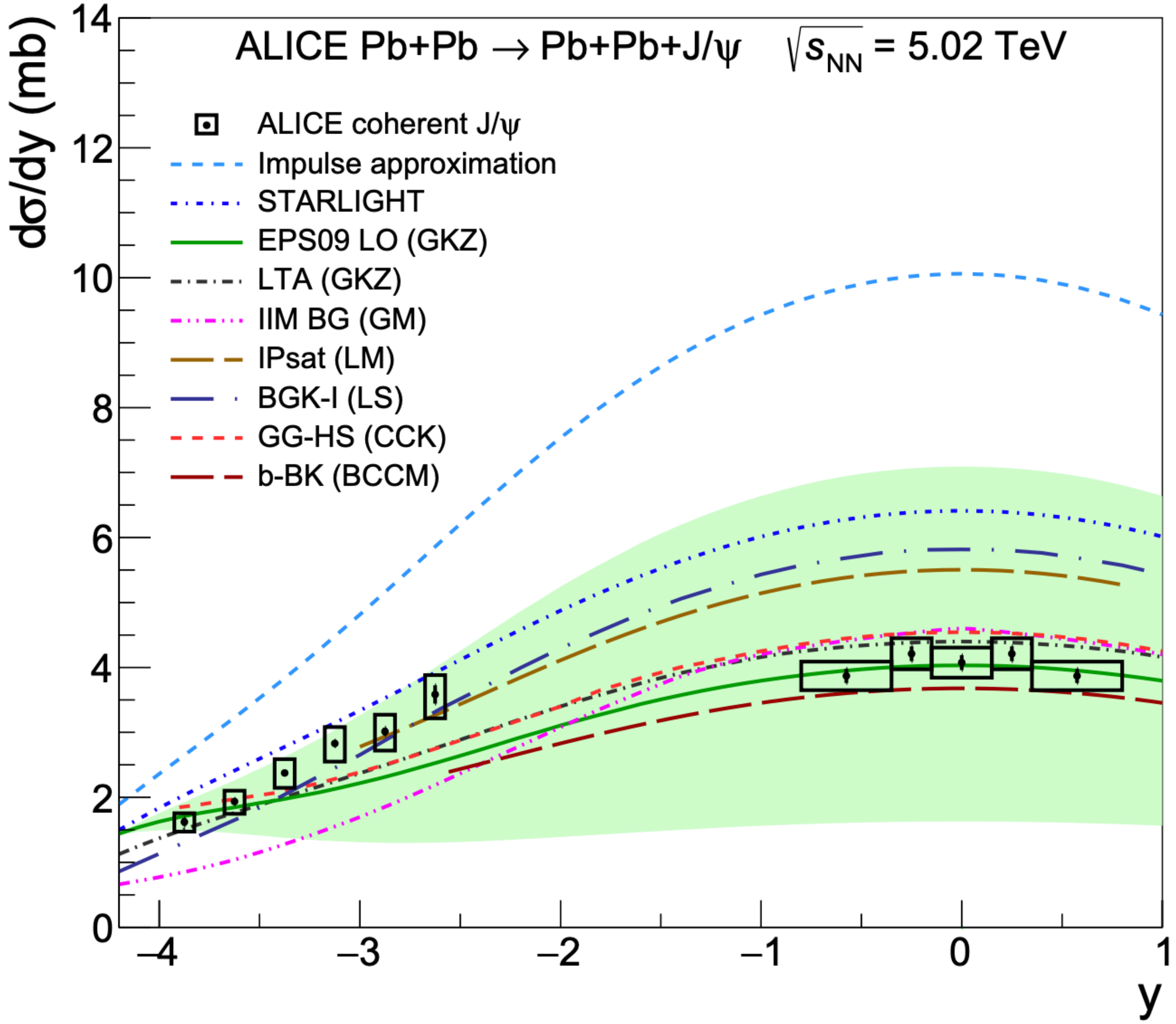
Taken from Agnieszka Ogrodnik's slides from ISMD 2022

ALICE Coherent J/Ψ in UPC

- **Coherent part interacts with whole nucleus**
- **Measured w/ low-pt contribution**
- **Sensitive to gluon distribution**

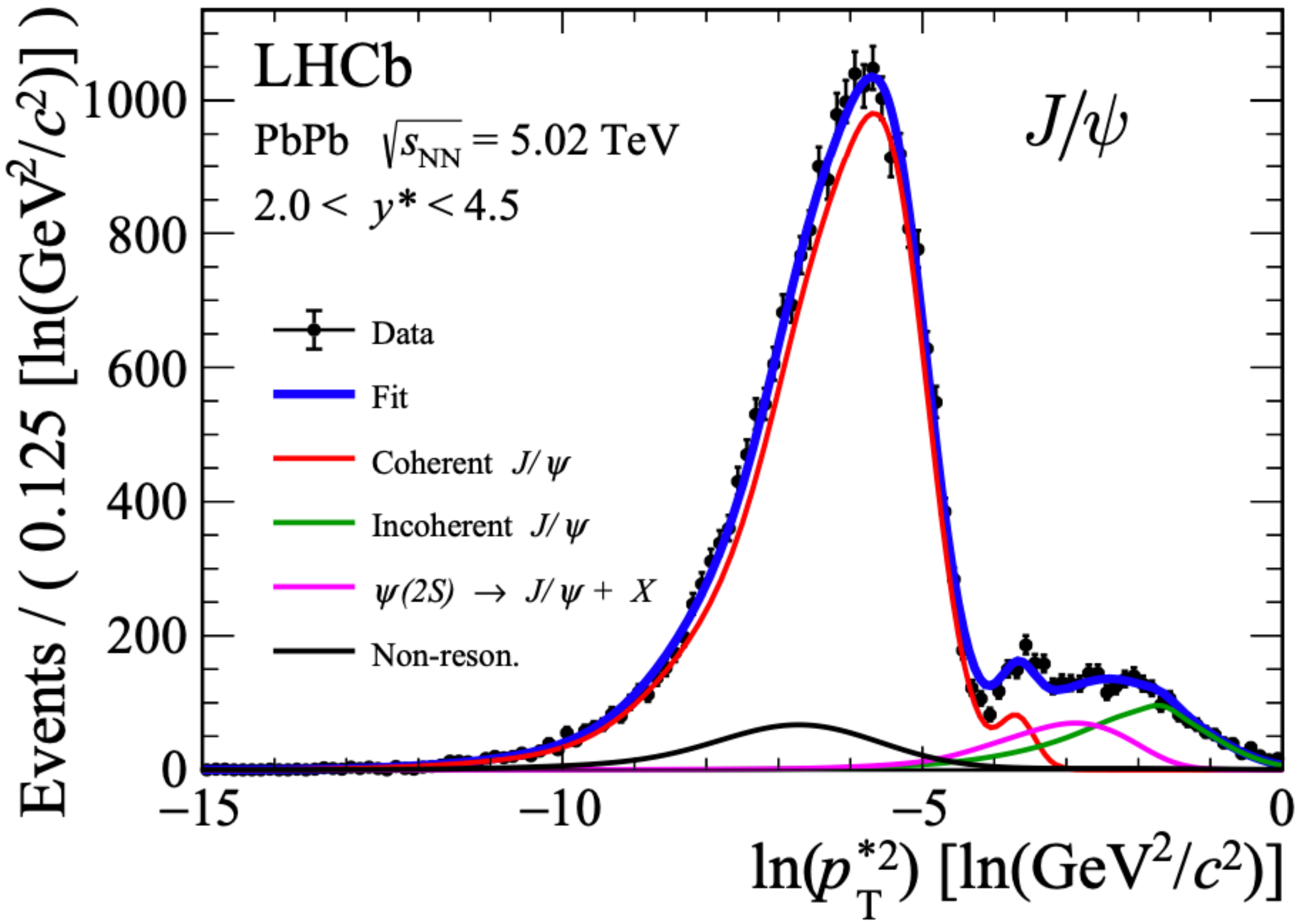


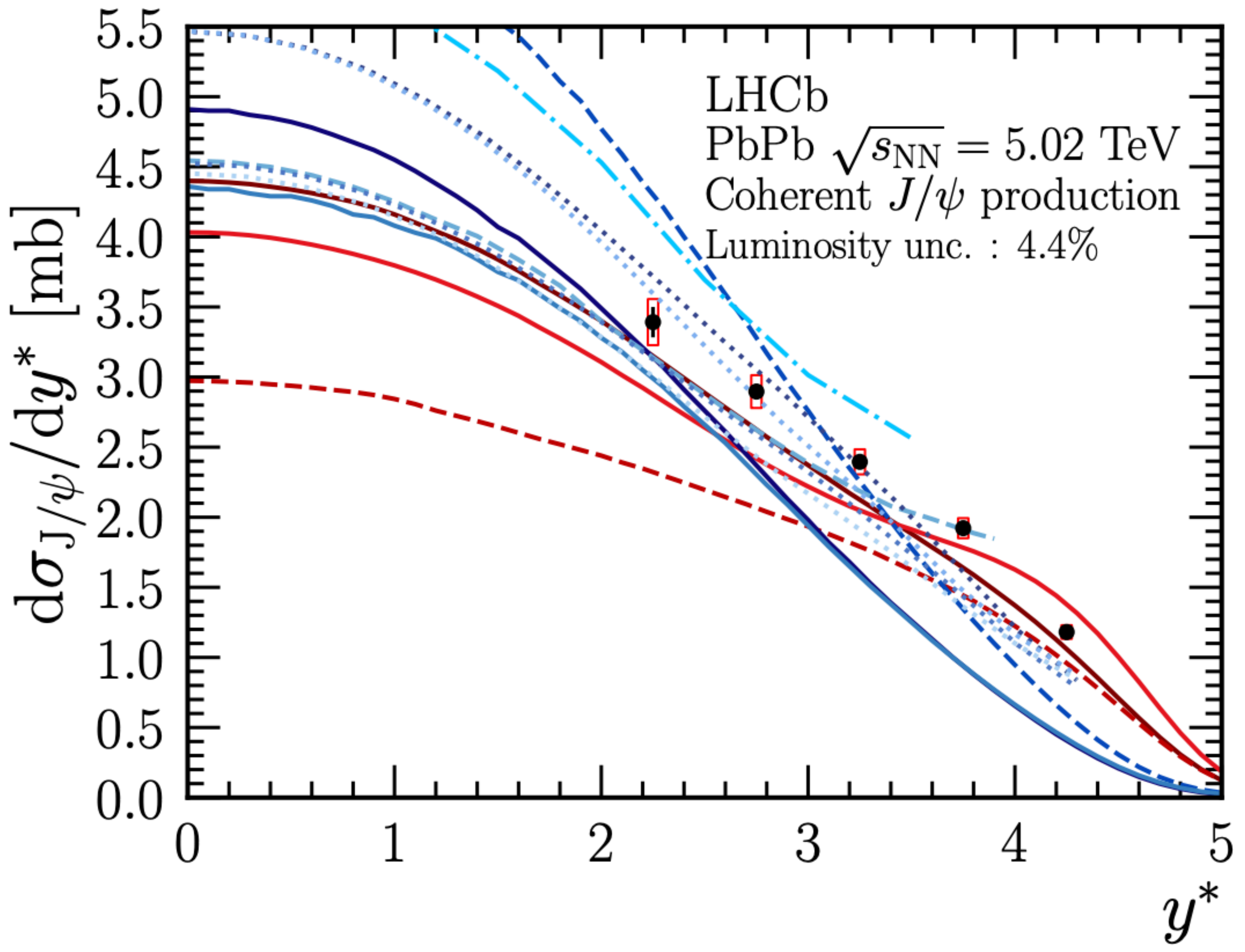




LHCb Coherent J/Ψ in UPC

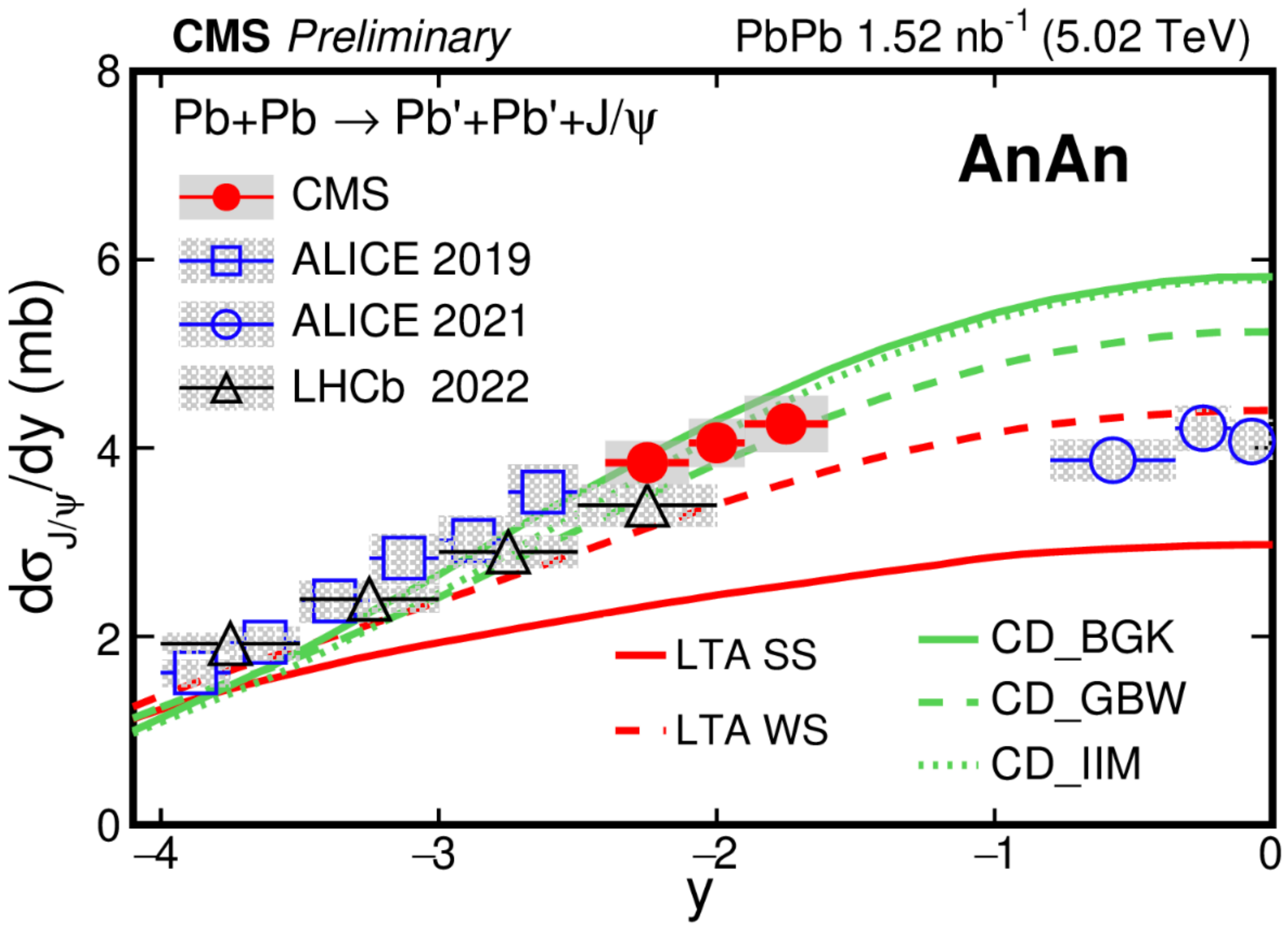
- **Probes similar region to ALICE forward data**

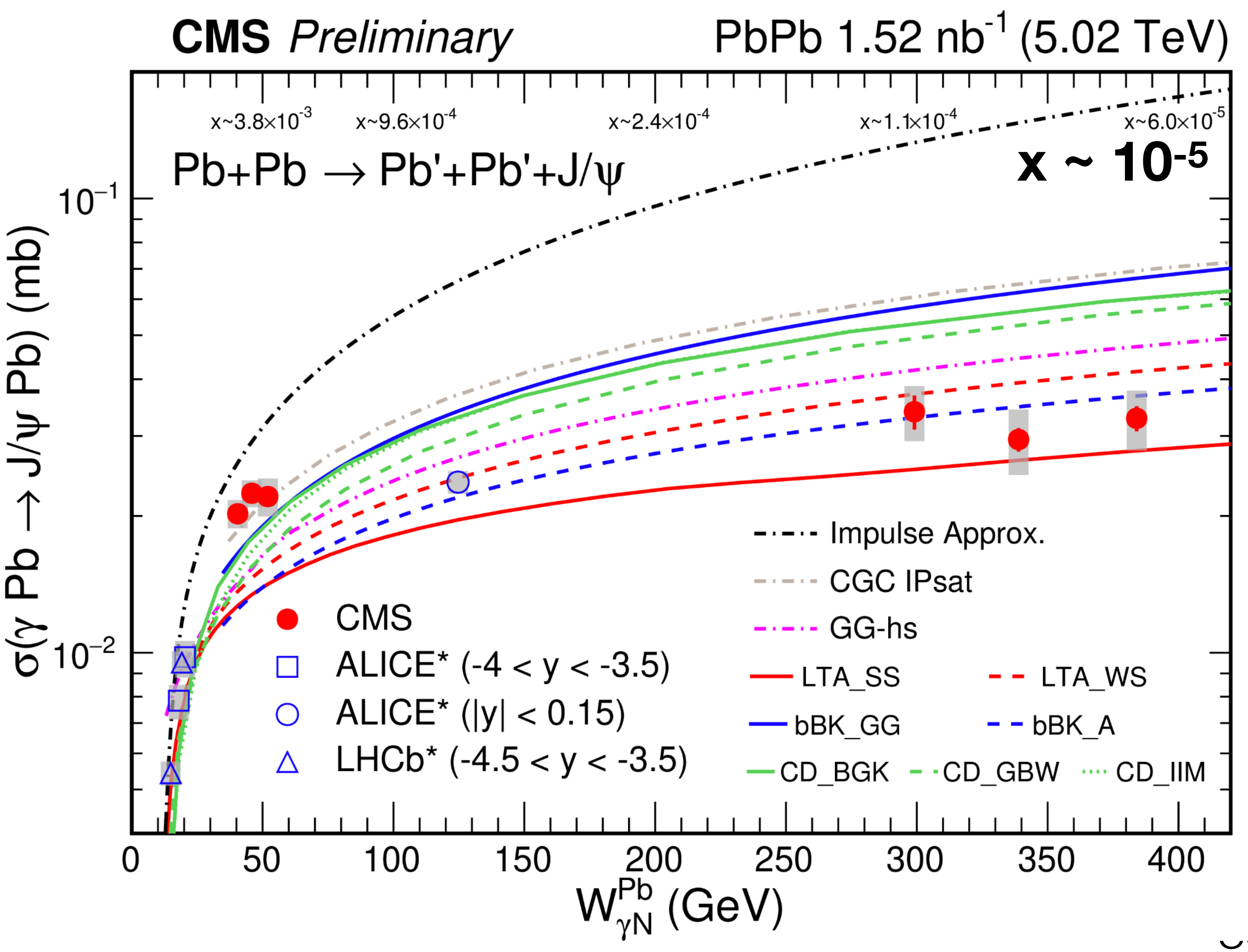




CMS Coherent J/Ψ in UPC

- **ZDC tagging technique to 'fill gap'**
- **Need photon flux to convert to W**
- **Global trend from data can not be predicted by models well**





v_2 in γp collisions

- **Photon emitted by Pb ion collides w/ proton**
  - **Bridging gap between HERA and LHC, pre-EIC**
- **First study of v_2 in γp collisions**
- **v_2 of products found to match MC simulation well**
  - **Suggests absence of collective effects at probed multiplicities**