Electroweak probes as tools for understanding initial state effects in heavy ions with CMS

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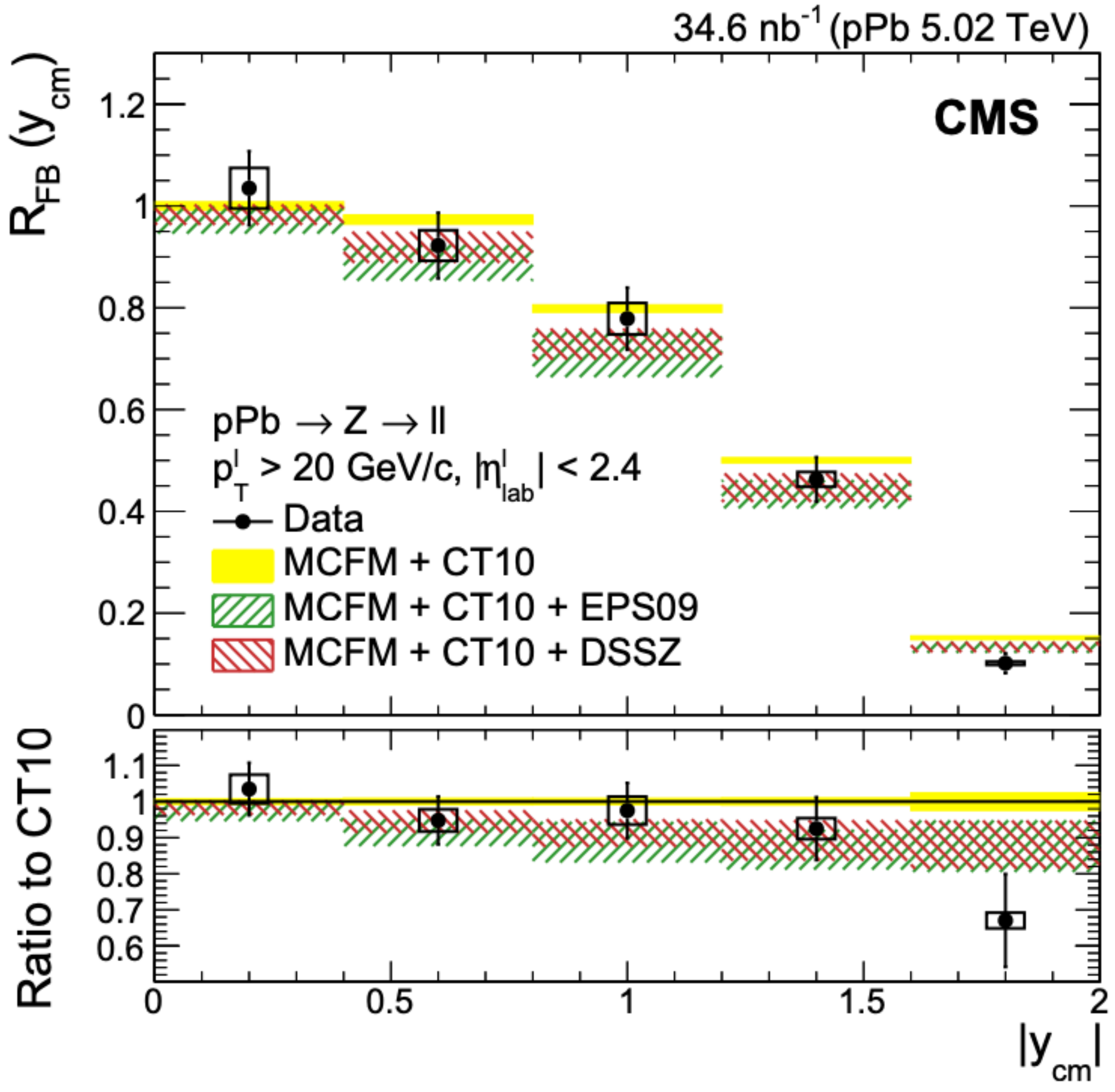
Drell-Yan in 8.16 TeV pPb
JHEP 05 (2021) 182

Z in 5 TeV PbPb
PRL 127, 102002 (2021)

Z/γ^* in Heavy Ions

- Z/γ^* lifetime is ~ the QGP formation time in HI collisions
  - Should not be modified by QGP - cleanly probe initial state
- Previous yield and v_2 measurements support this
  - Limited precision in peripheral events
- Sensitive to valence and sea quark distributions - tests nPDFs
  - pPb data used in nPDF fits currently limited to Z mass region

Phys.Lett.B 759 (2016) 36–57



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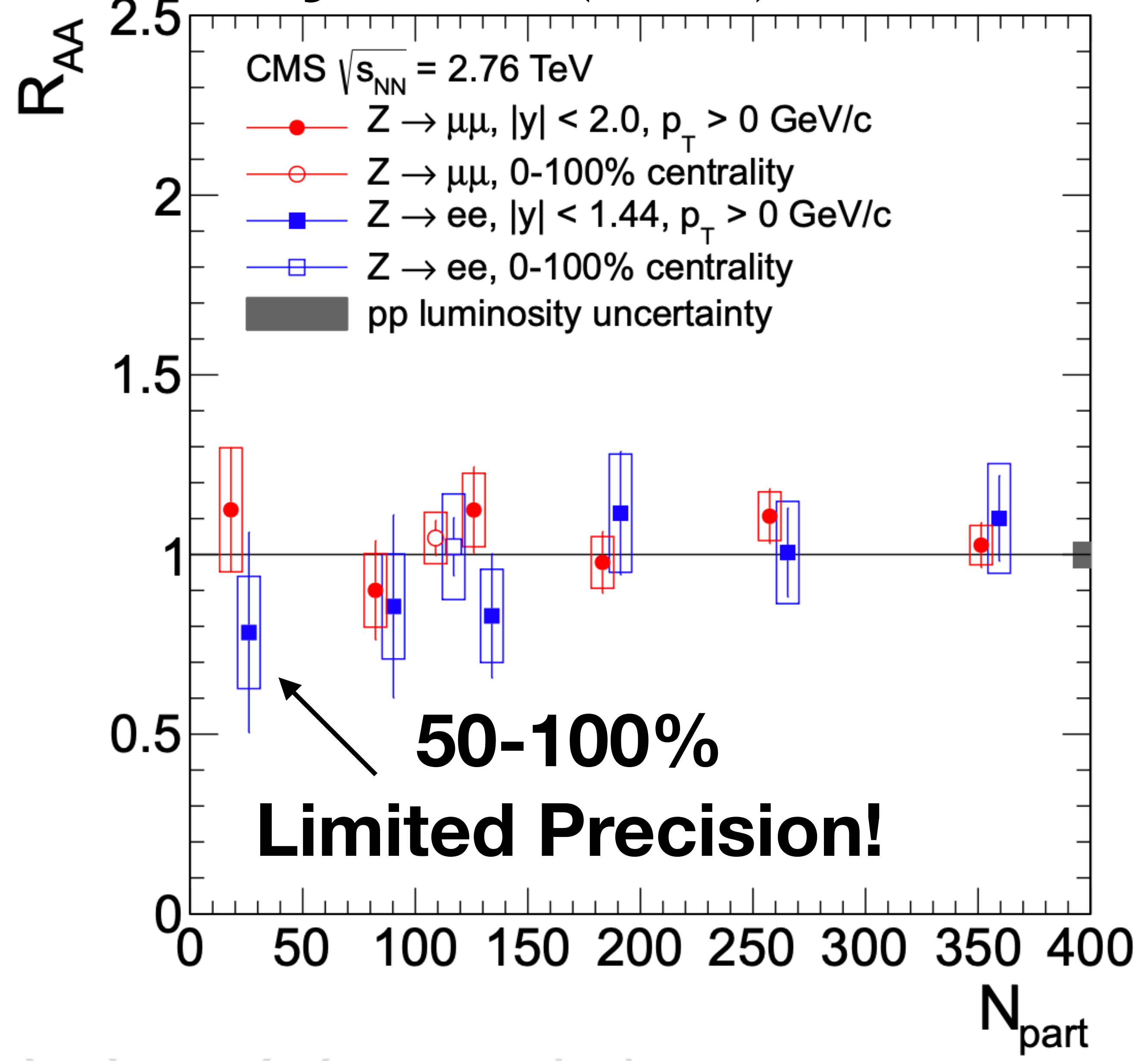
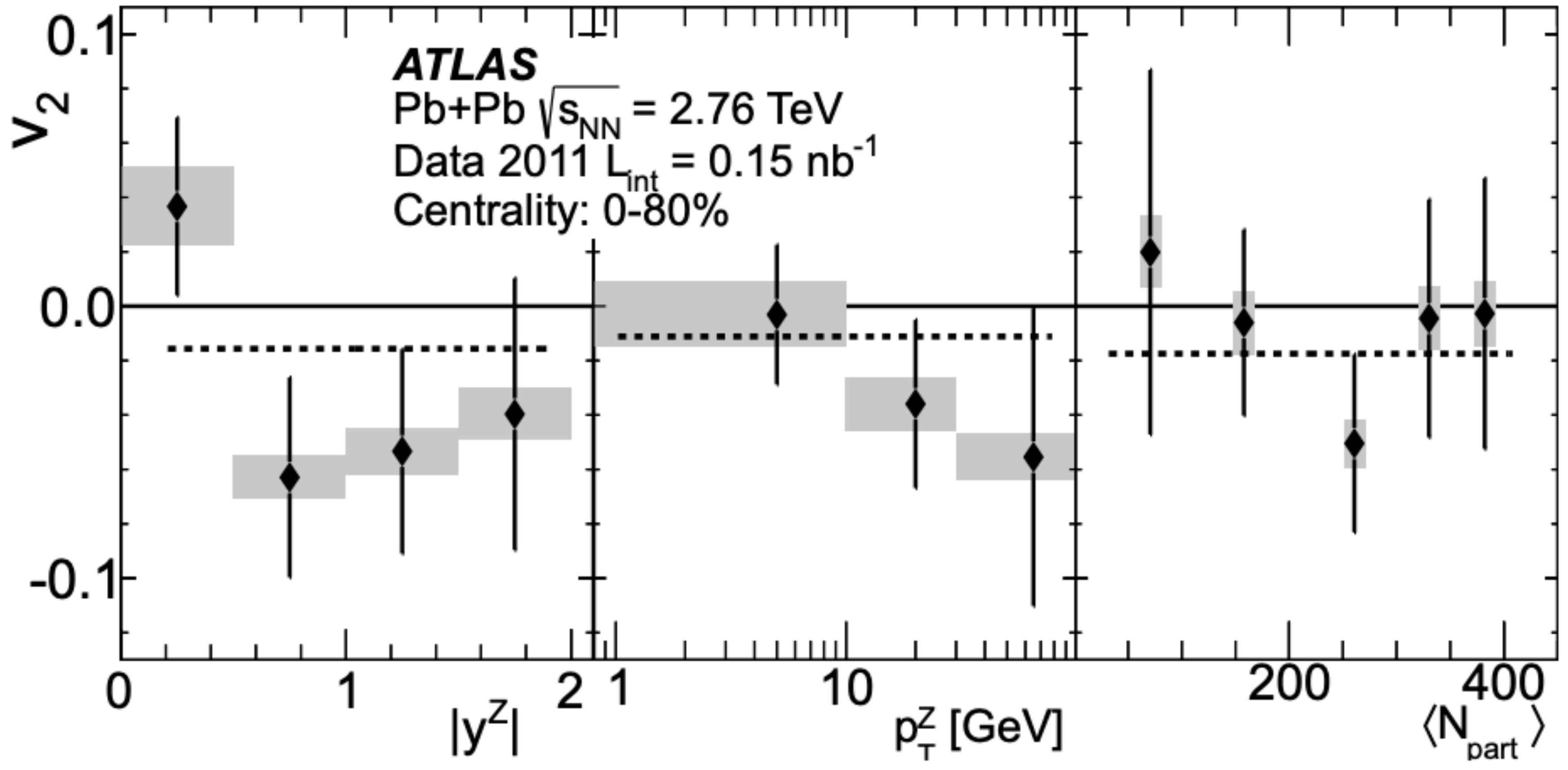
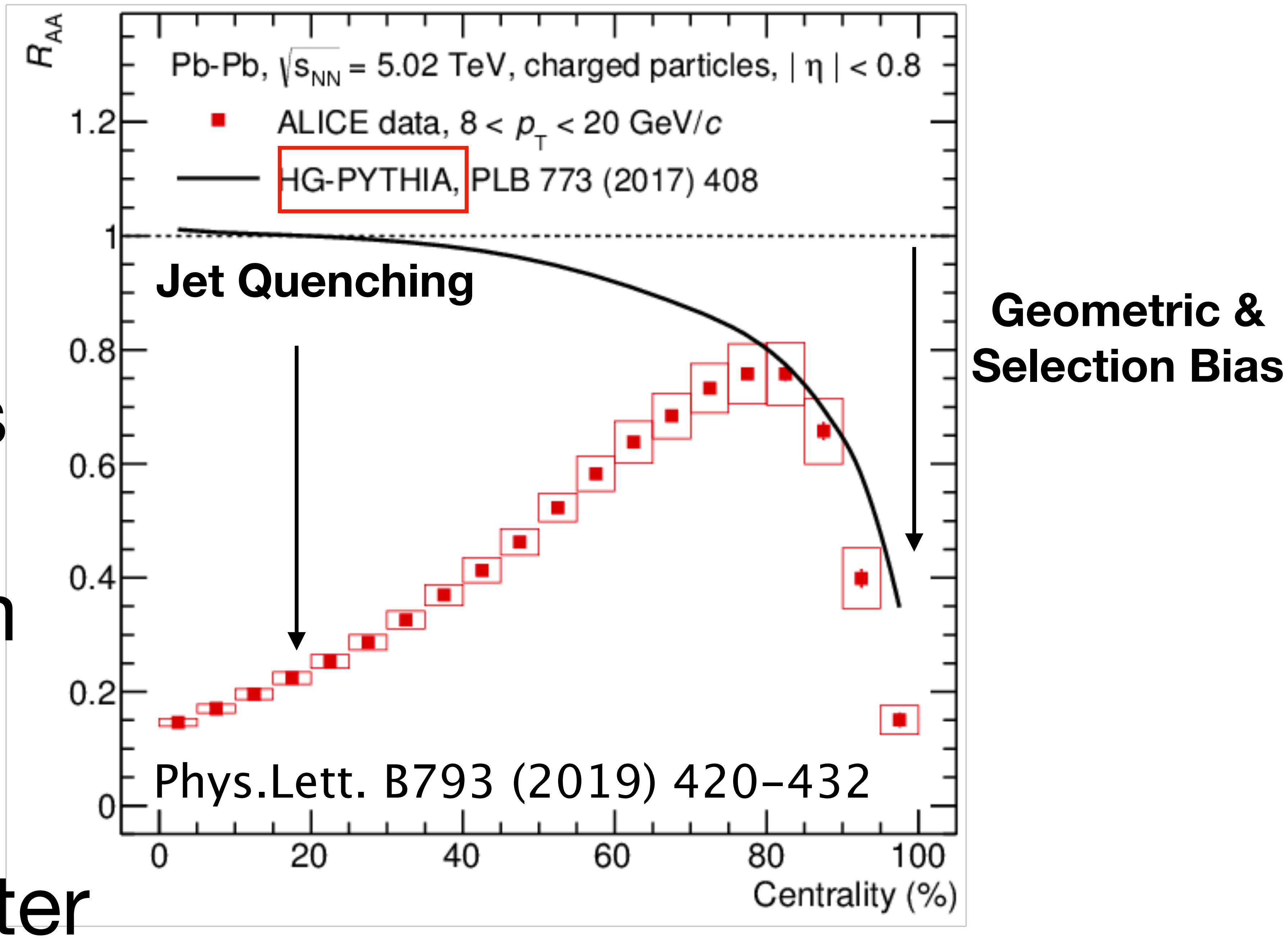


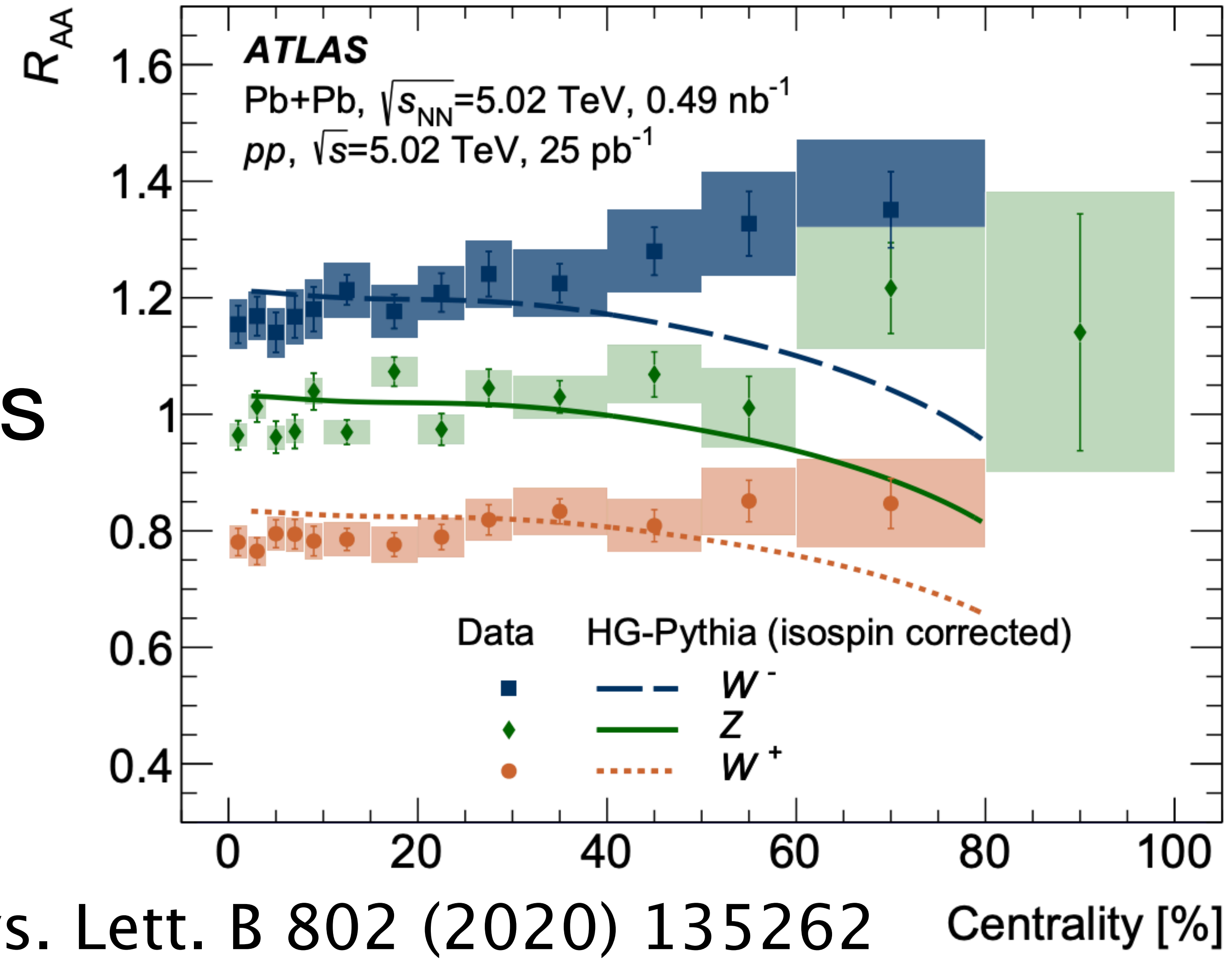
PRL 110, 022301 (2013)



Search for onset of jet quenching

- Studies of high p_T charged hadrons have indicated a suppression in peripheral events
  - Problem for jet quenching interpretation in peripheral events
- Recently HG-PYTHIA proposes a mechanism for non-medium suppression in charged hadrons
  - Geometric biases on initial nucleon-nucleon impact parameter
  - Centrality selection biases - hard/soft correlations
- ATLAS data seems to indicate opposite trend for Z, W bosons
  - Precise peripheral yield measurements needed





Phys. Lett. B 802 (2020) 135262

Testing nPDFs with Drell-Yan in 8.16 TeV pPb

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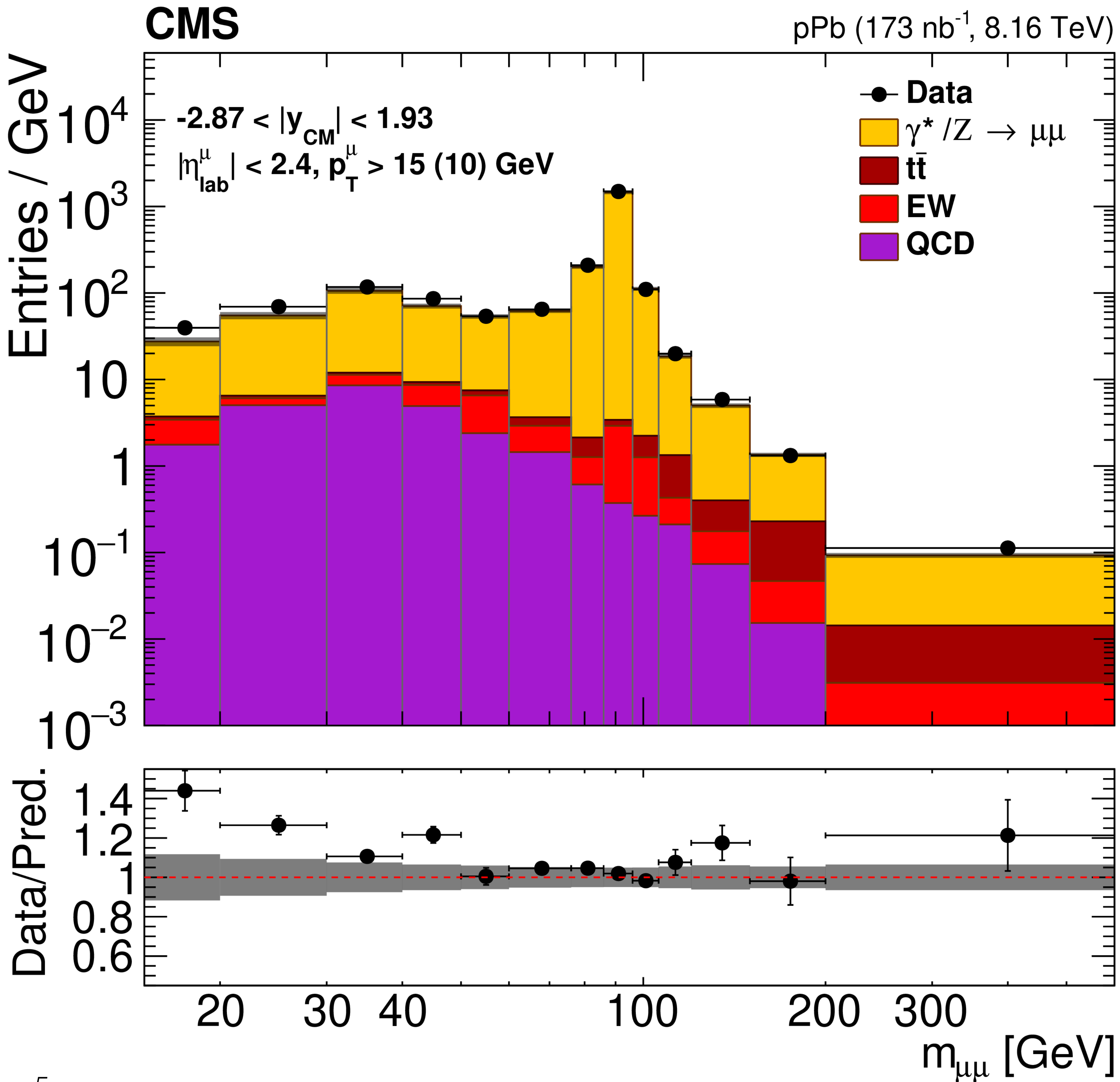
Dimuon Mass Distribution

- 2016 8.16 TeV pPb (173 nb^{-1})
- $Z/\gamma^* \rightarrow \mu^+\mu^-$ Channel
- $10 < m_{\mu\mu} < 600\ GeV$
  - Able to probe to lower x region!
- $t\bar{t}$, Electroweak, QCD backgrounds subtracted
- Large signal/background ratio
- Data overshoots Powheg at low $m_{\mu\mu}$



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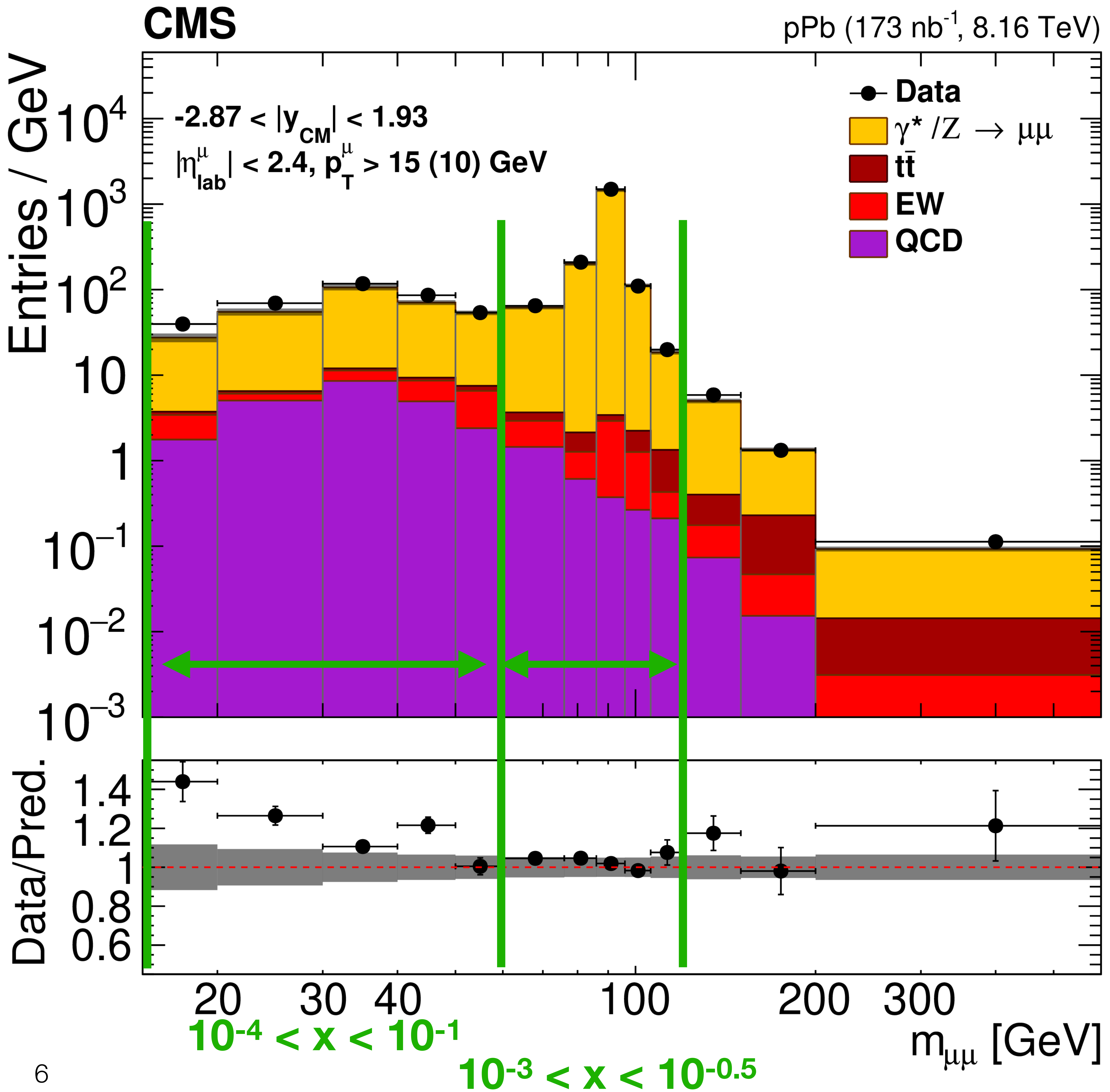
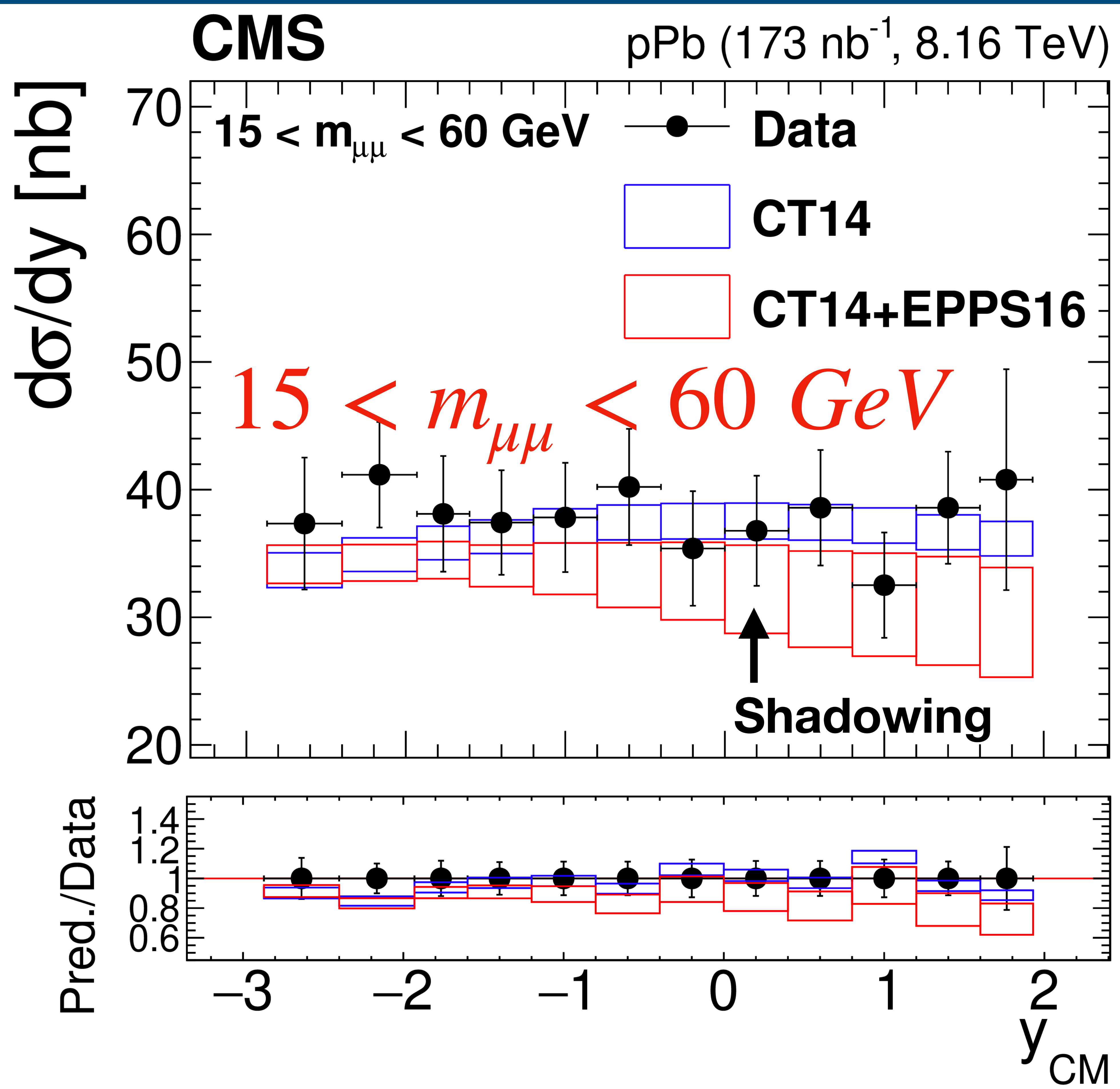
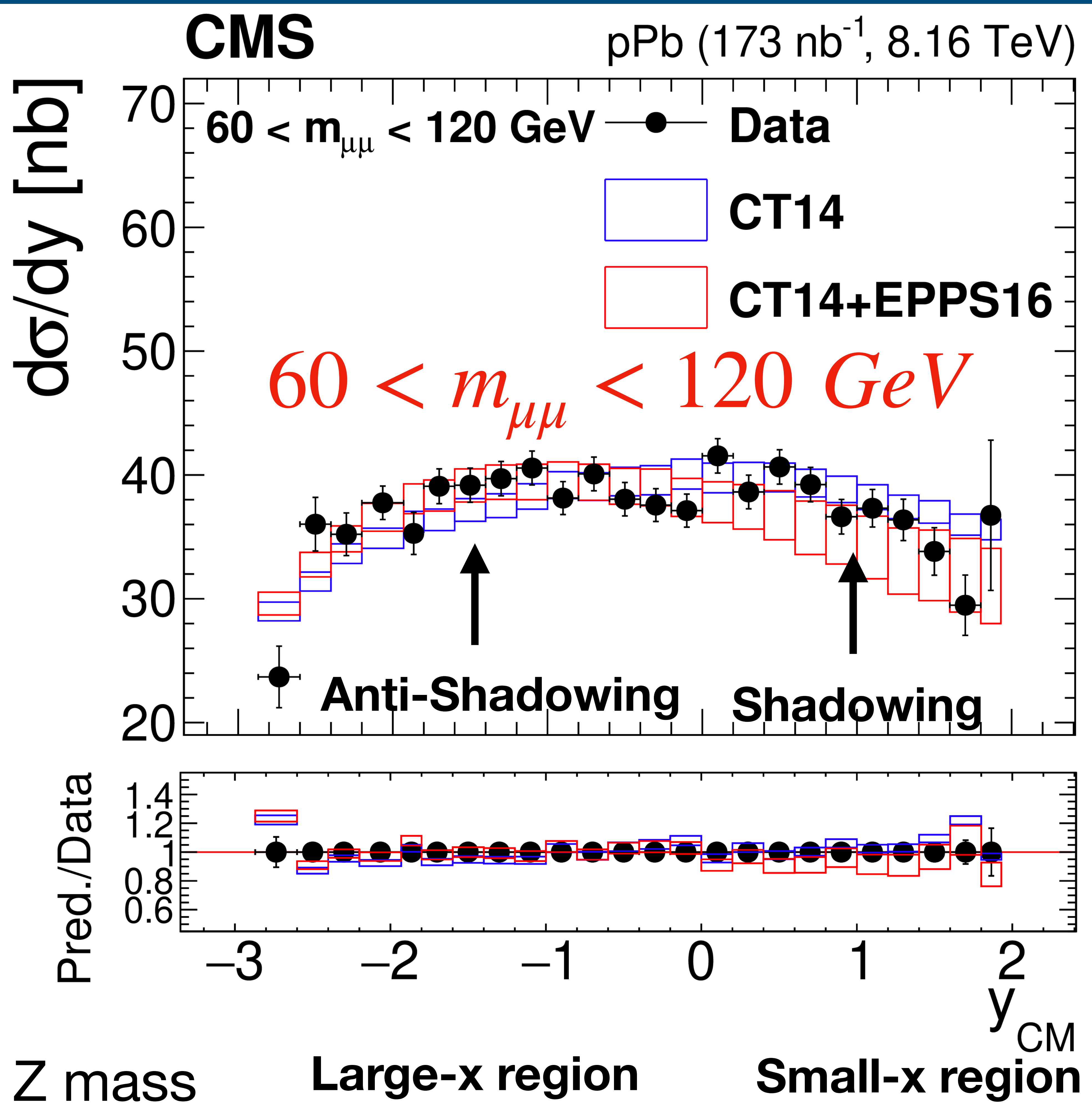
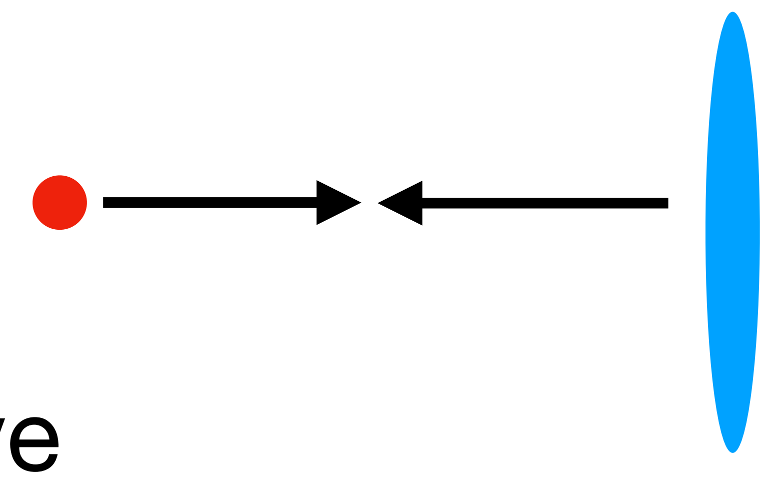


Rapidity Distributions





- Rapidity differential cross section measured for low and Z mass
  - Fiducial cross sections available (smaller experimental uncertainties)
- Compared to POWHEG with CT14 pdf and CT14+EPPS16 nPDF
- Favors nPDF around Z mass (χ^2/ndof = 1.46 vs 2.08); low mass inconclusive



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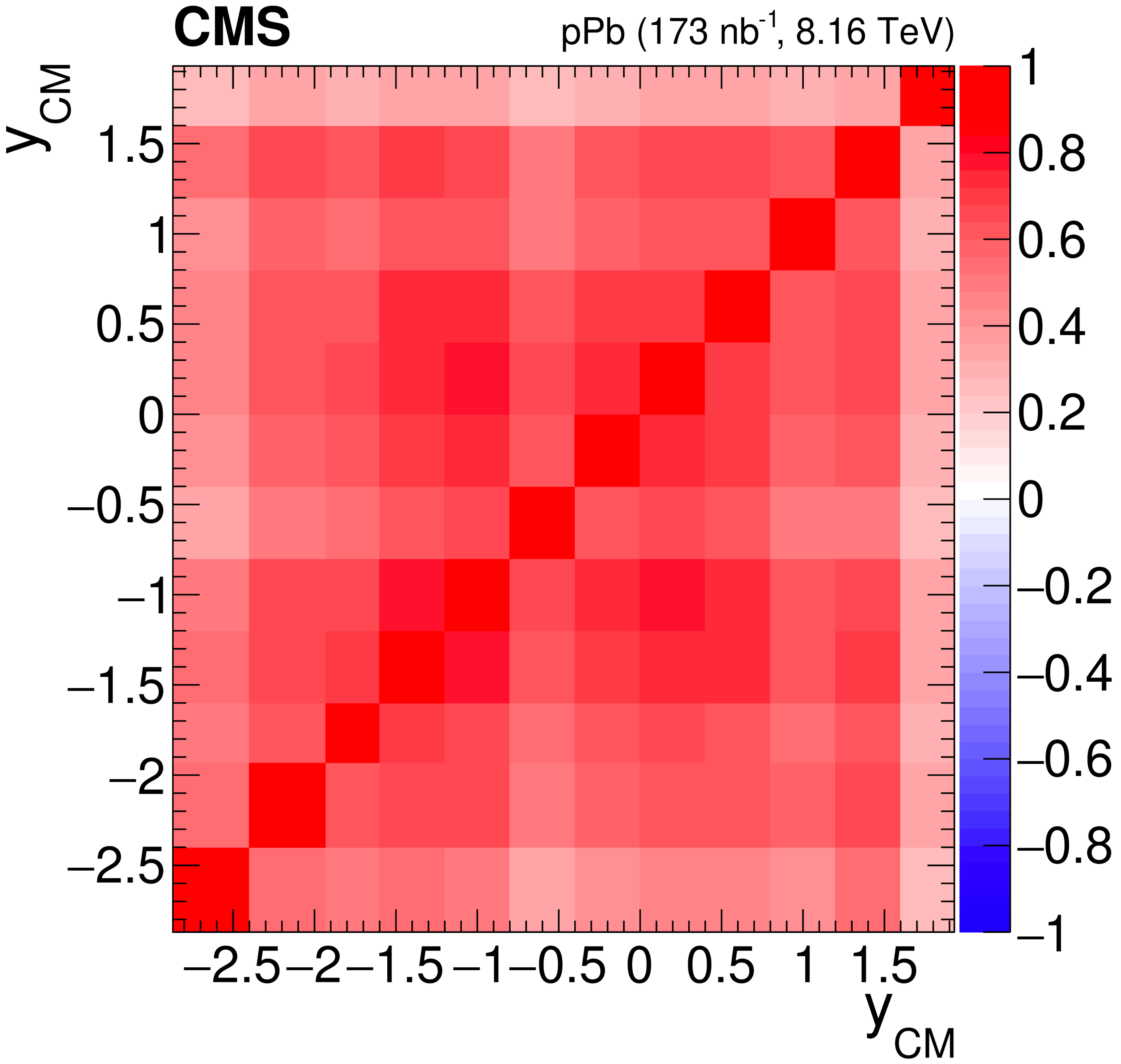
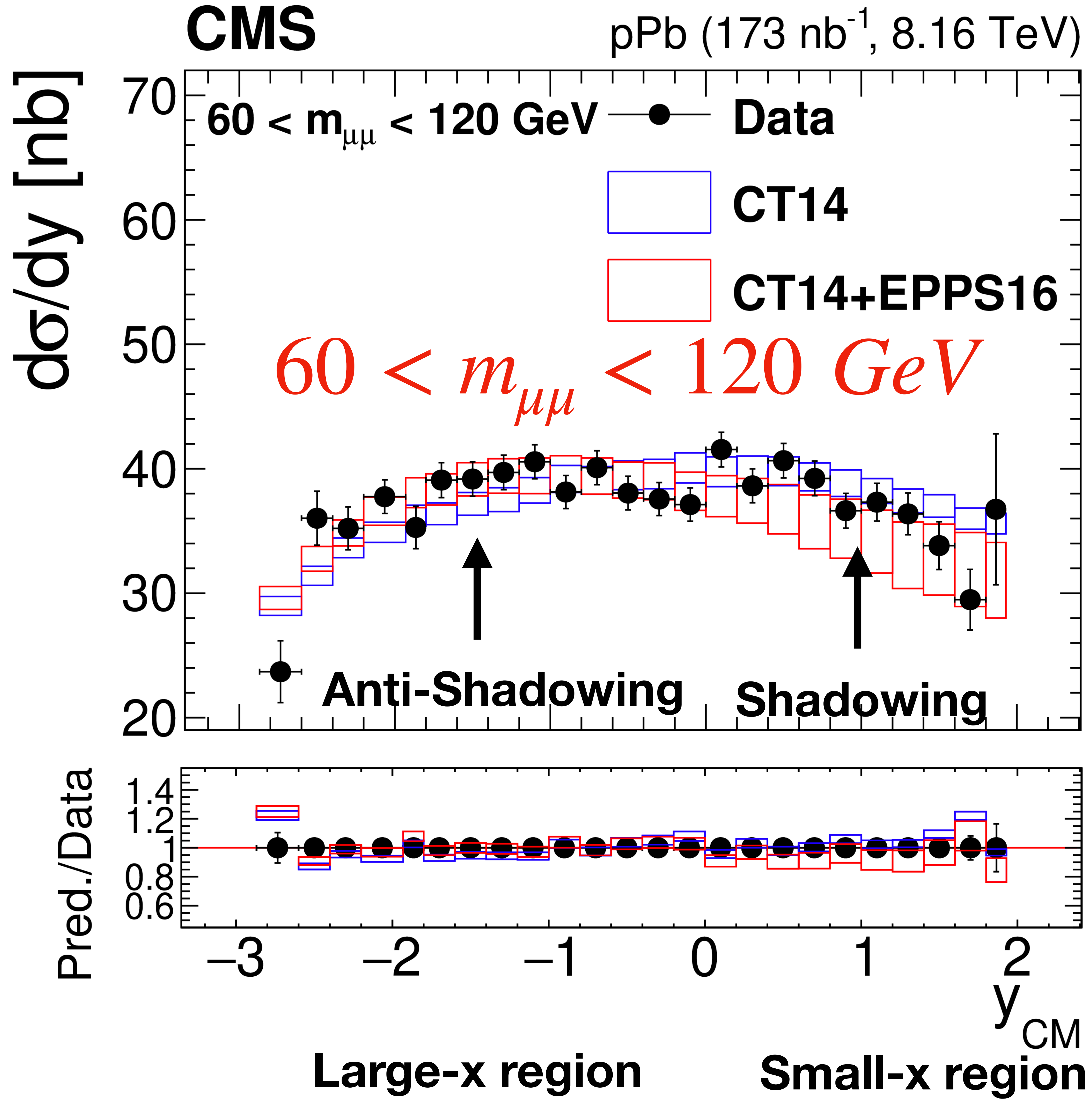
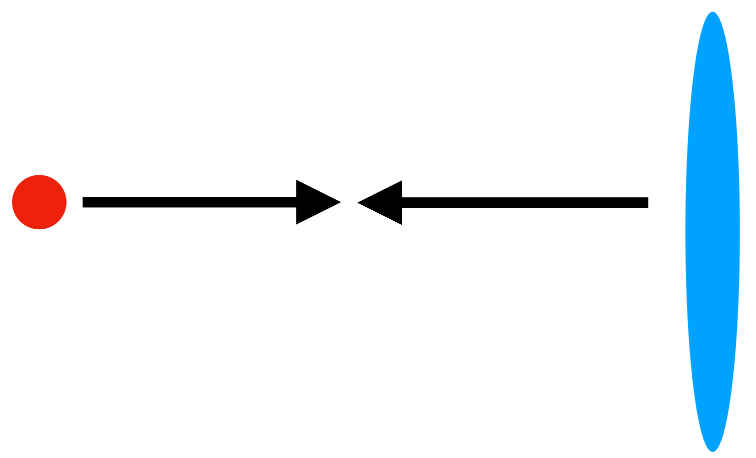
Rapidity Distributions

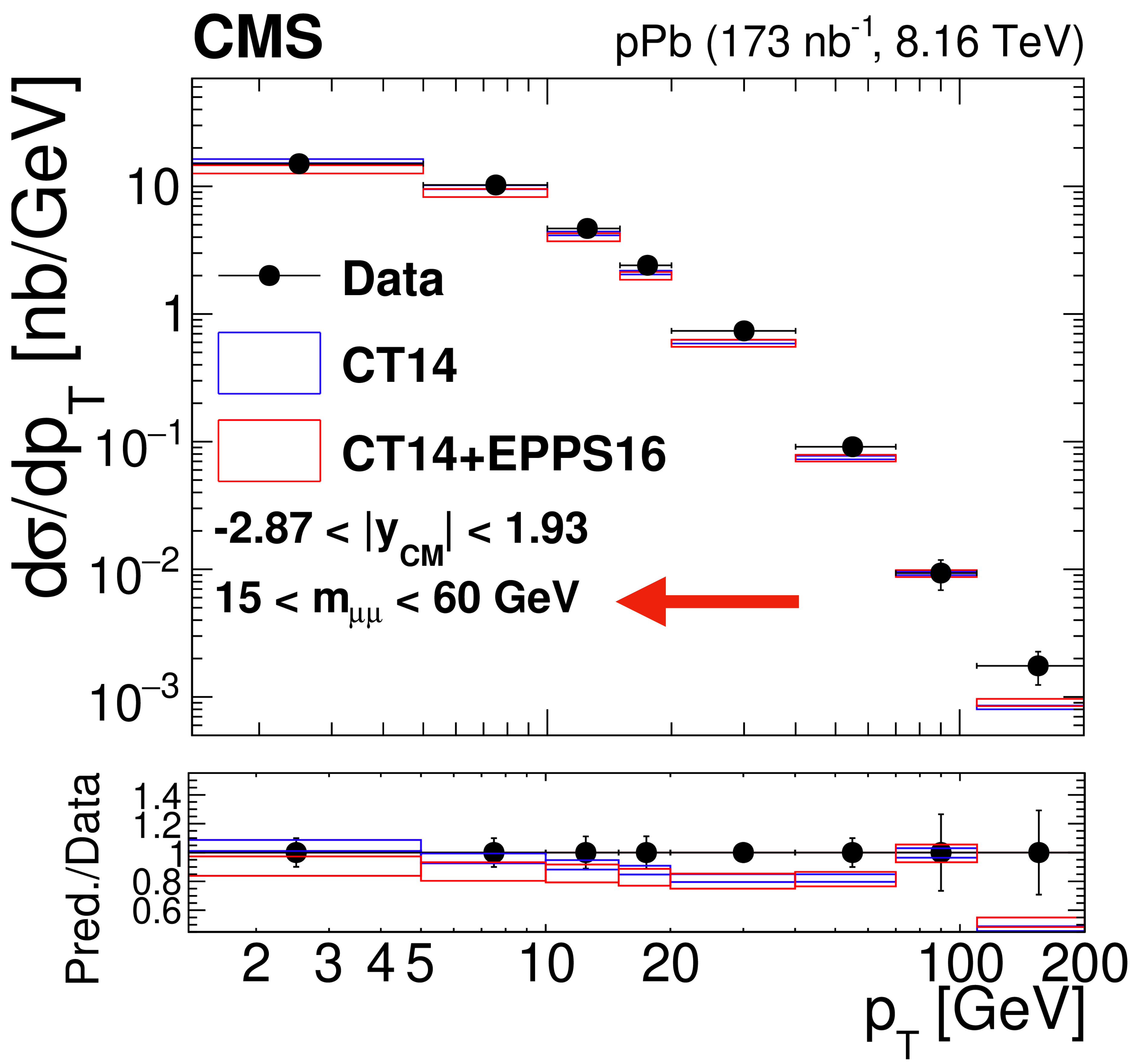


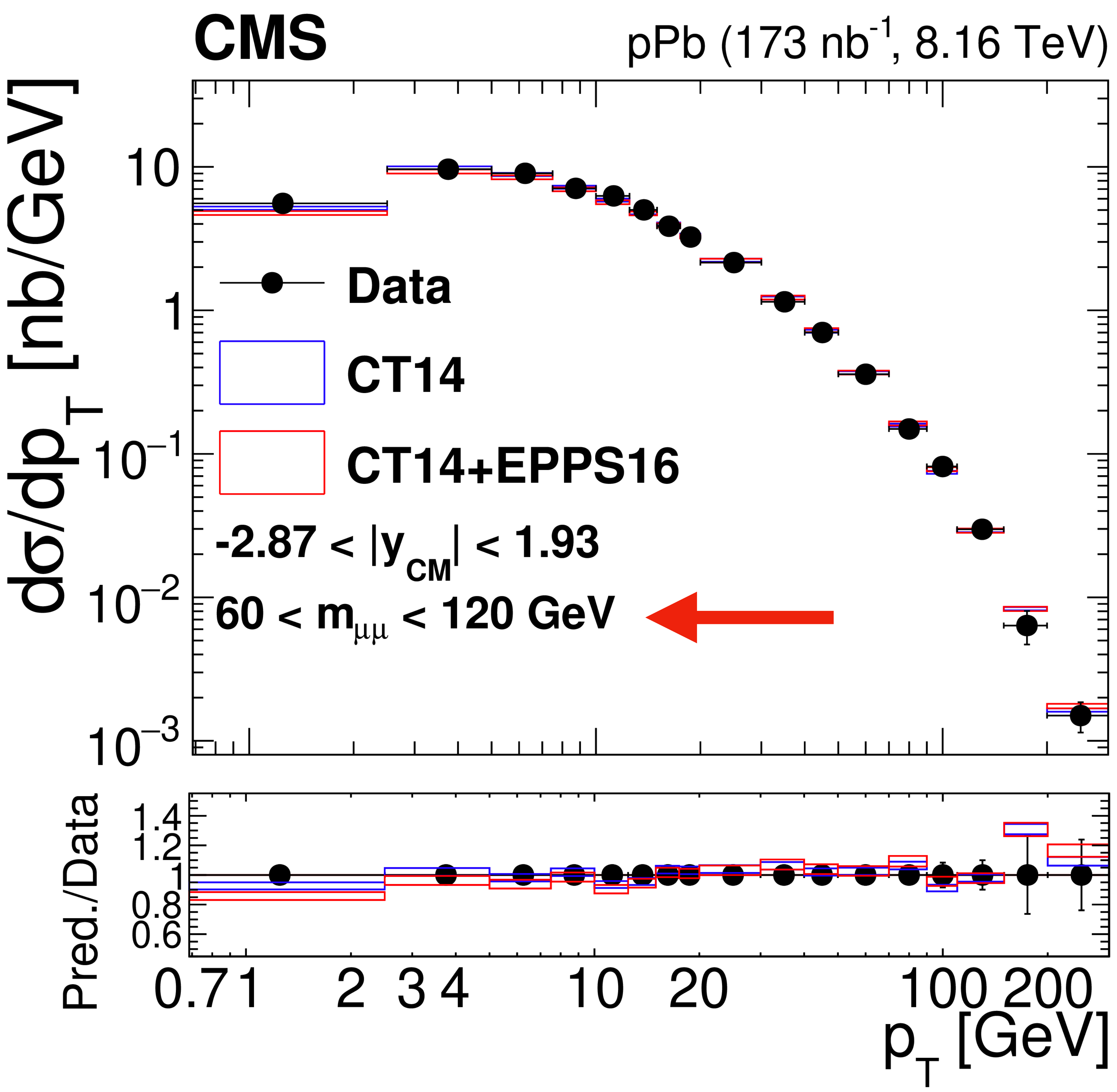


- Uncertainties are comparable to nPDF uncertainties
- Full correlation matrix available
  - Allows correct treatment of correlated uncertainties in global fits
- Included in nNNPDF3.0!



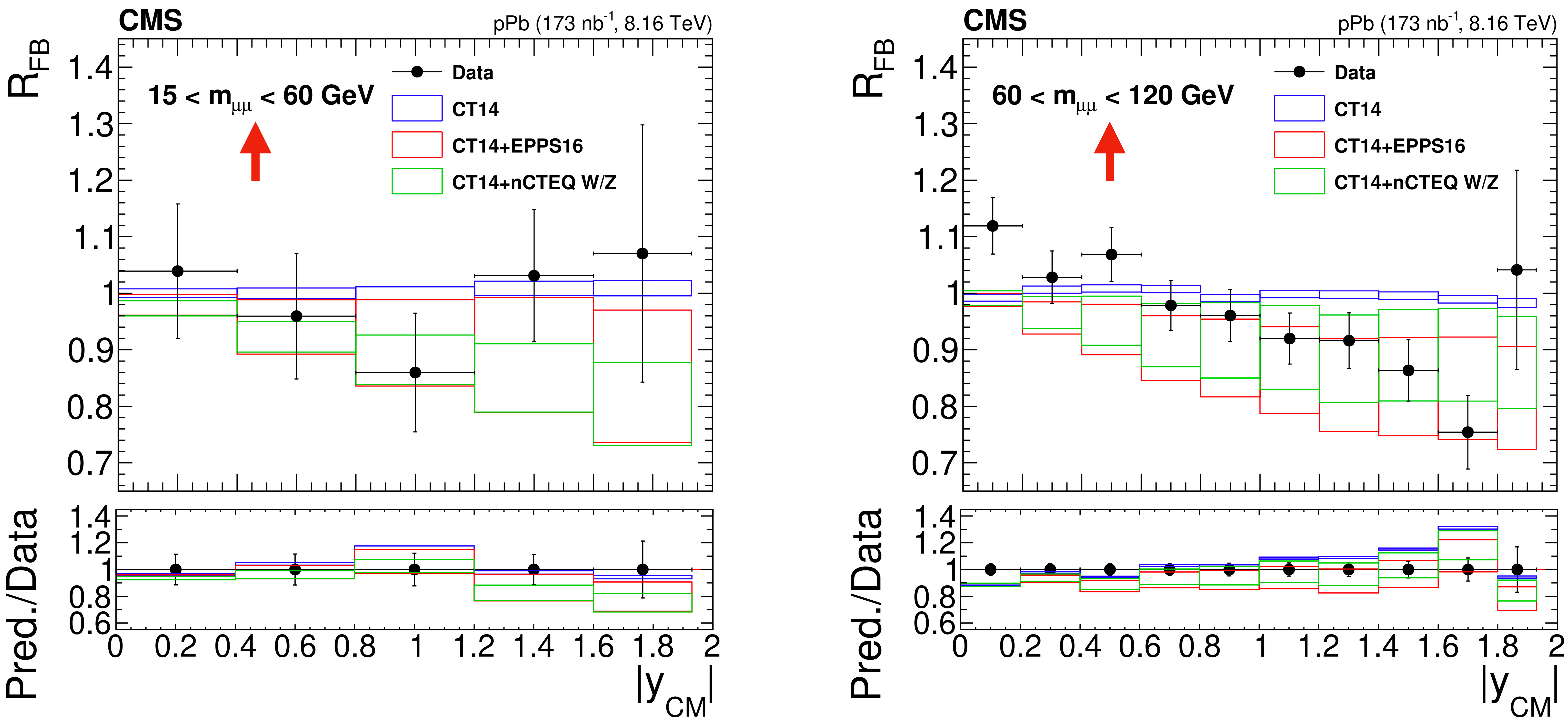
p_T Distributions



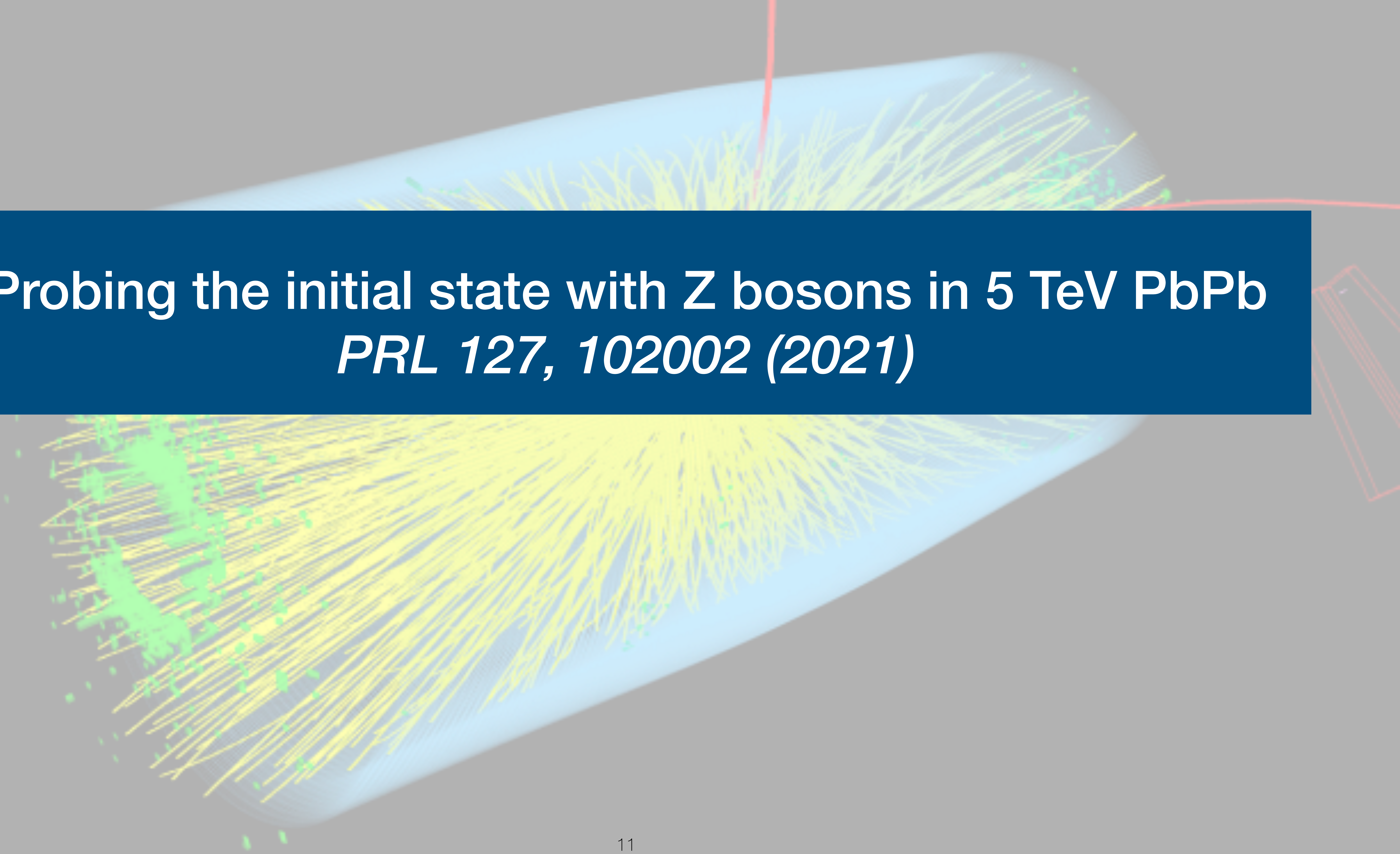


- Differential cross sections
- Difficult to distinguish between different (n)PDFs
- Powheg undershoots data at low p_T, $m_{\mu\mu}$ - better modeling needed in this region

Forward-Backward Ratios



- Ratio of forward-backward yields cancels systematic uncertainties
- Clear preference for CT14+EPPS16 and CT14+NCTEQWZ around Z mass
- Uncertainties significantly smaller than existing nPDF uncertainties

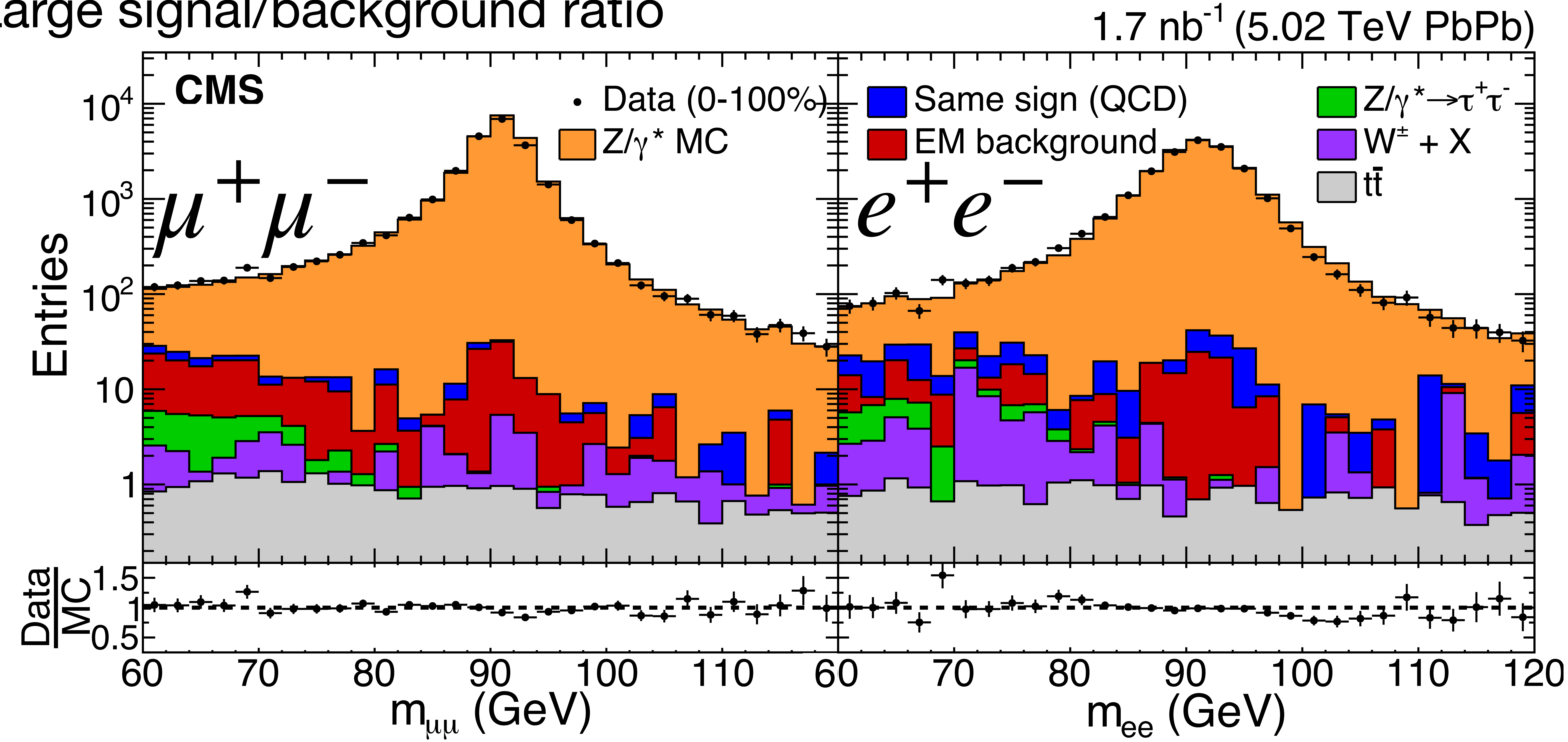


Probing the initial state with Z bosons in 5 TeV PbPb

PRL 127, 102002 (2021)

Mass Peaks

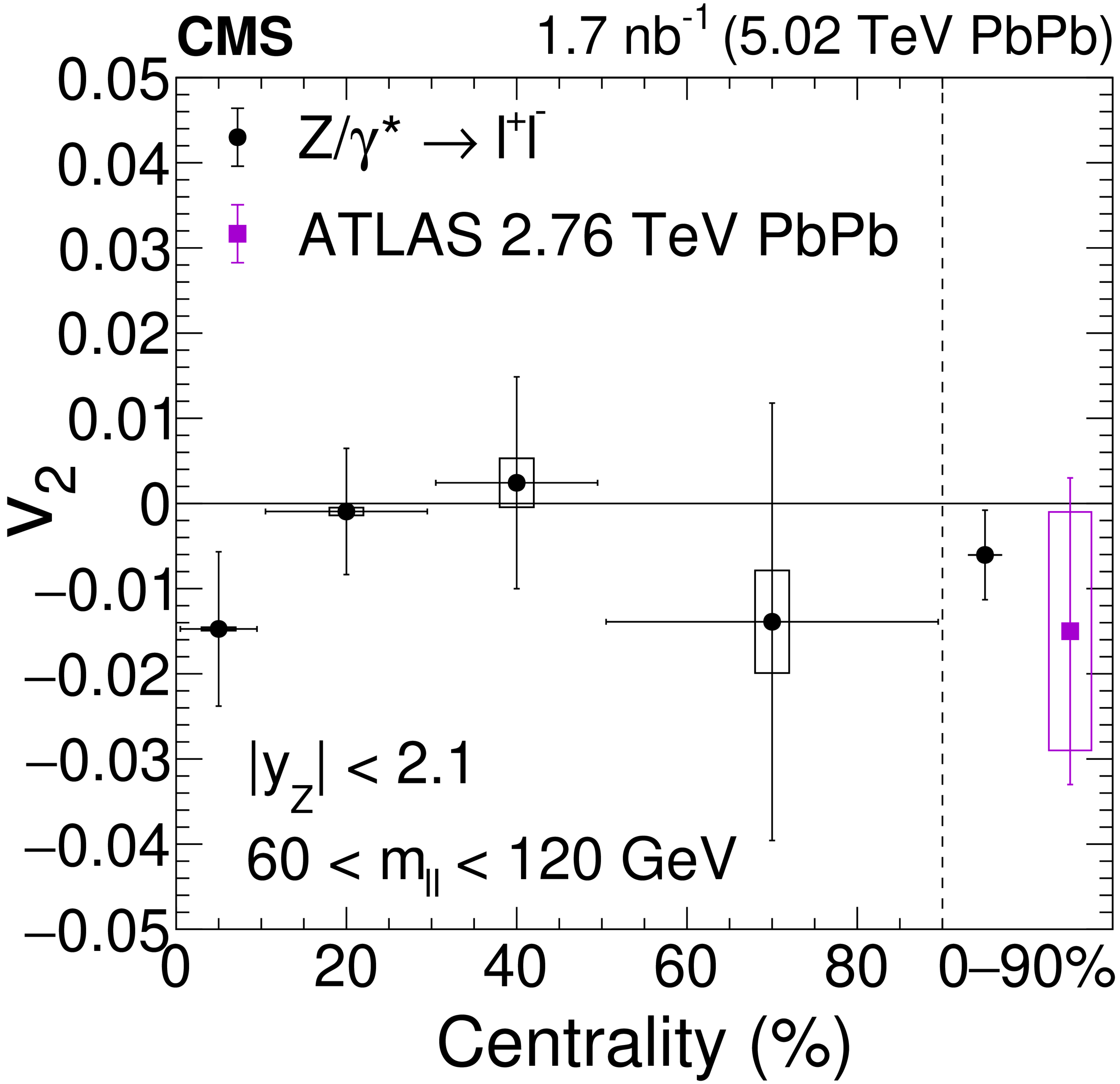
- 2018 5 TeV PbPb (1.7 nb^{-1})
- $|\eta_\mu| < 2.4,\ |\eta_e| < 2.1,\ p_T^l > 20\ GeV$
- Large signal/background ratio



v_2

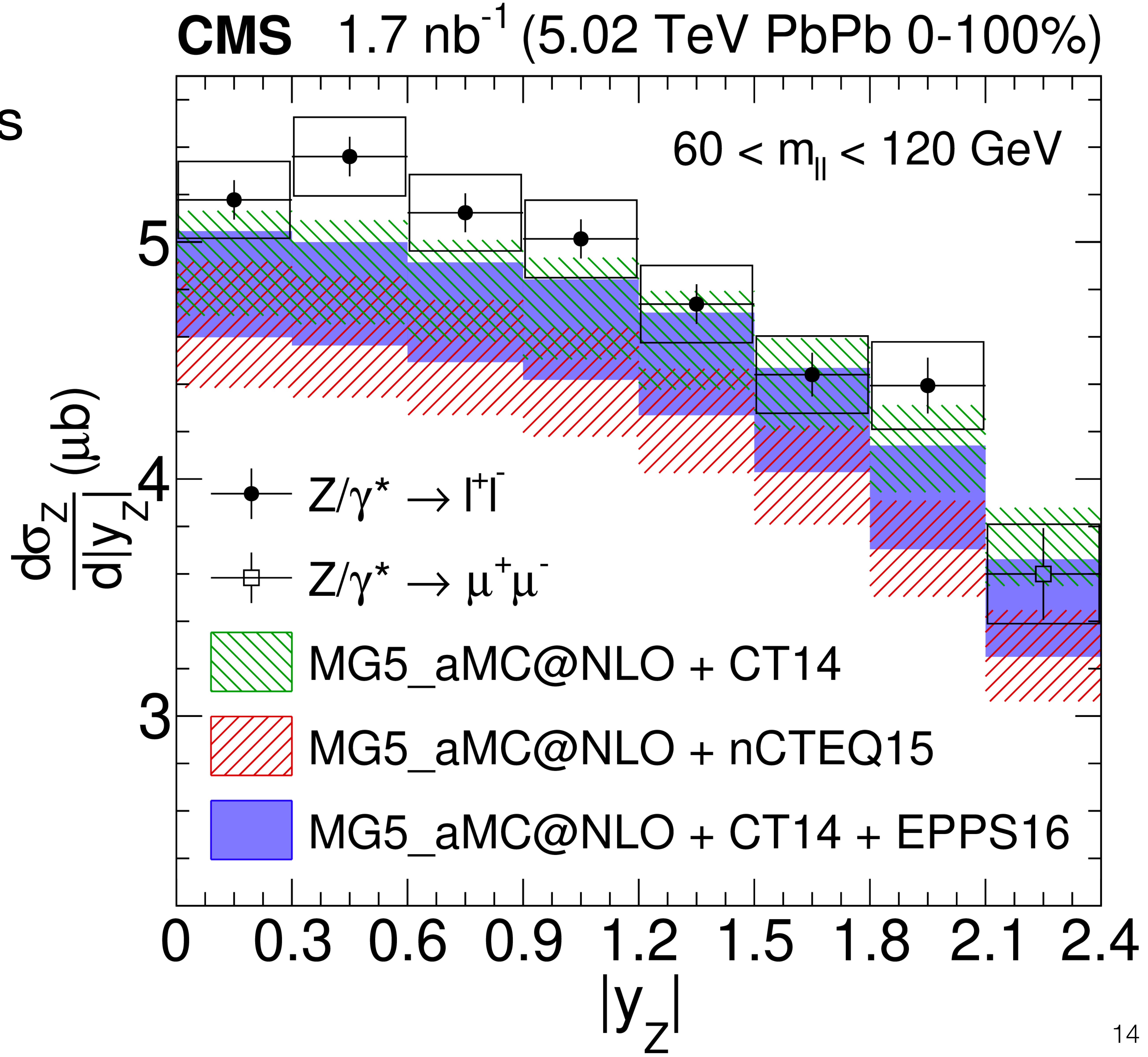
- v_2 measured with 3-subevent method (forward calorimeters and tracker)
- η-gap of >3 units (suppresses non-flow)
- Both channels combined
- Consistent with Z bosons being created early and not being modified by medium

$$v_2 = \frac{\langle Q_Z Q_A^* \rangle}{\sqrt{\frac{\langle Q_A Q_B^* \rangle \langle Q_A Q_C^* \rangle}{\langle Q_B Q_C^* \rangle}}}.$$



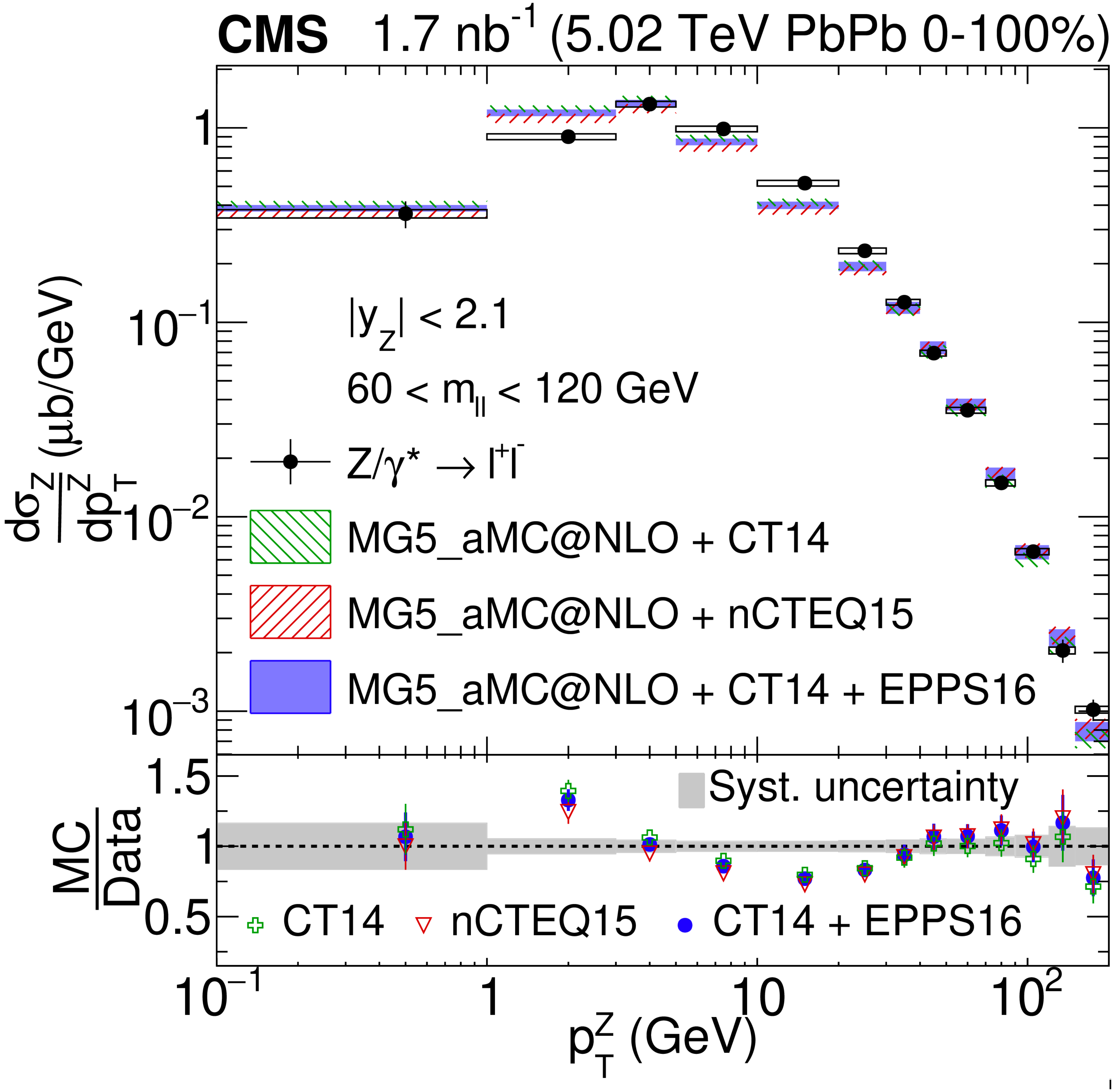
Rapidity compared to models

- Differential cross section compared to MadGraph5_aMC@NLO + 3 (n)PDF sets
- Models scaled by A^2 for normalization
- NNLO effects tend to push points higher compared to NLO
- Data slightly favors steeper decrease in forward region
- Can't conclusively distinguish between (n)PDF sets with current precision



p_T differential cross section

- Similar comparison made for p_T differential cross section
- p_T modeling of aMC@NLO is not perfect
  - No gluon resummation at low p_T
- Deviation between models observed at p_T>40 GeV
  - Potentially a useful probe of nPDFs at high-p_T in the future?

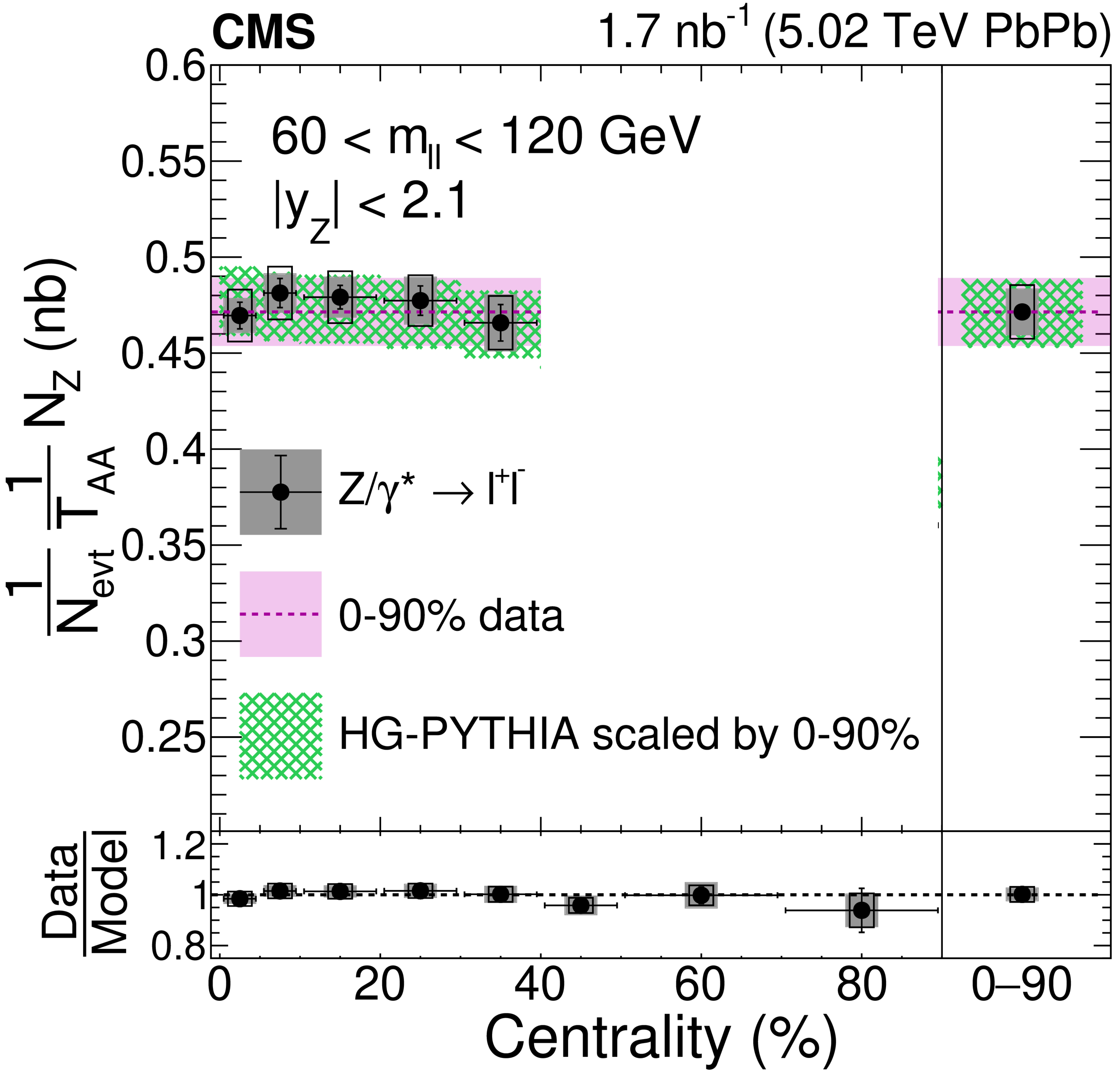


Centrality Dependence

- $\frac{N_Z}{N_{MB} T_{AA}}$ plotted versus centrality

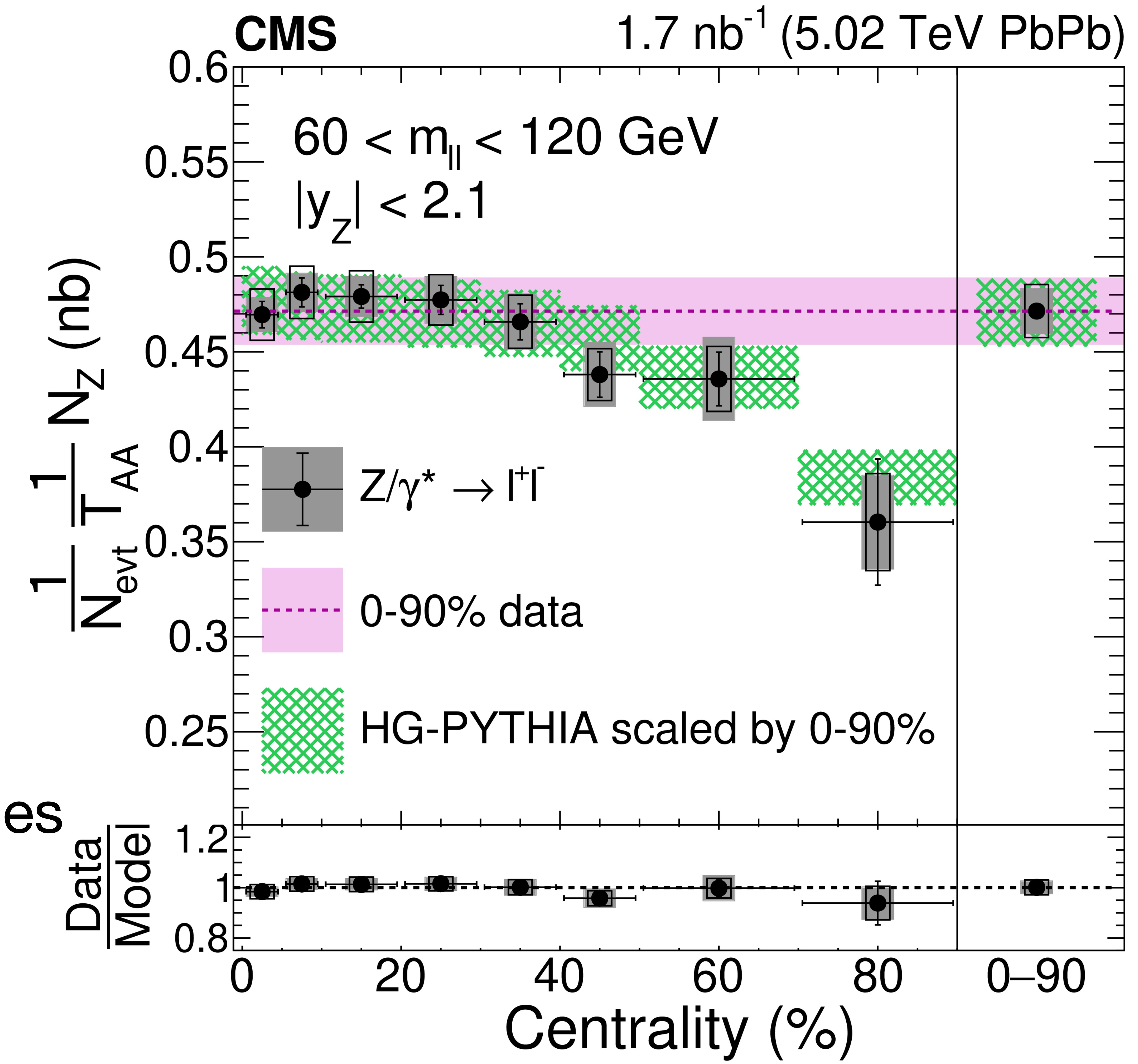
- Numerator of R_{AA}
  - Compare against Inclusive 0-90% data

- Data is flat in 0-40%
- Consistent with previous measurements



Peripheral events

- 40-90% deviates from flat scaling
- 2.2σ effect in 70-90%
- Effects considered in HG-PYTHIA
  - Initial geometry biases in NN impact parameter
  - Centrality selection biases
    - Hard process correlated with more soft production
- Uncertainties close to Glauber uncertainties
- Replace T_{AA} with $\frac{N_Z}{\sigma_Z^{NN} N_{MB}}$
  - Possible cancellation of biases



Conclusions

- Finalized pPb Drell-Yan measurement extended to lower mass region to offer new nPDF constraints
- Shadowing in EPPS16 and nCTEQWZ favored over free nucleon pdf
- Finalized PbPb Z boson v_2 consistent with zero and yields support N_{coll} scaling in central events
- Downward trend seen in peripheral Z boson yields - seems to be described by HG-PYTHIA
- Z provides data-driven method to study bias effects when searching for onset of jet quenching

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Drell-Yan in pPb
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Z in PbPb
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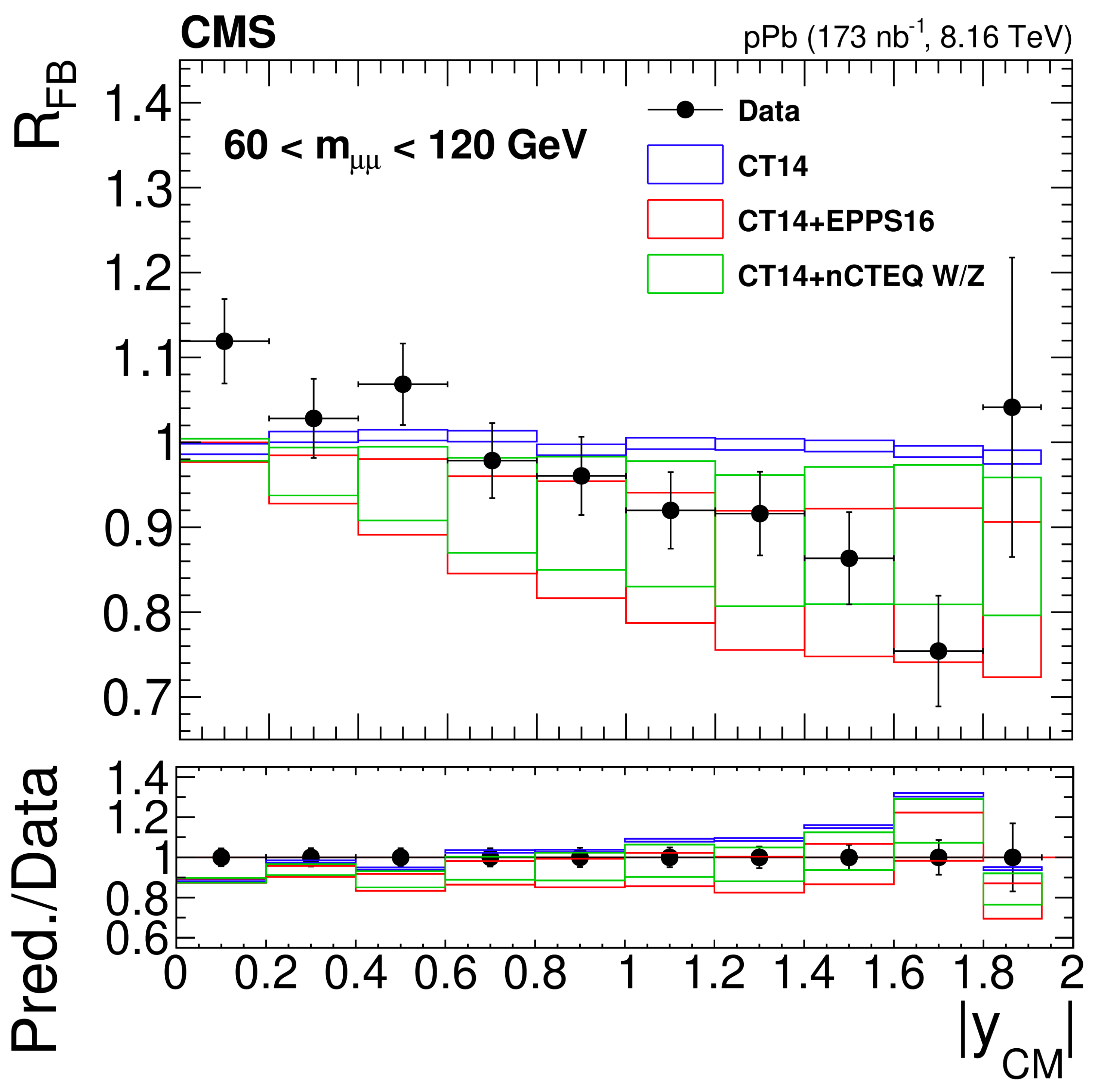
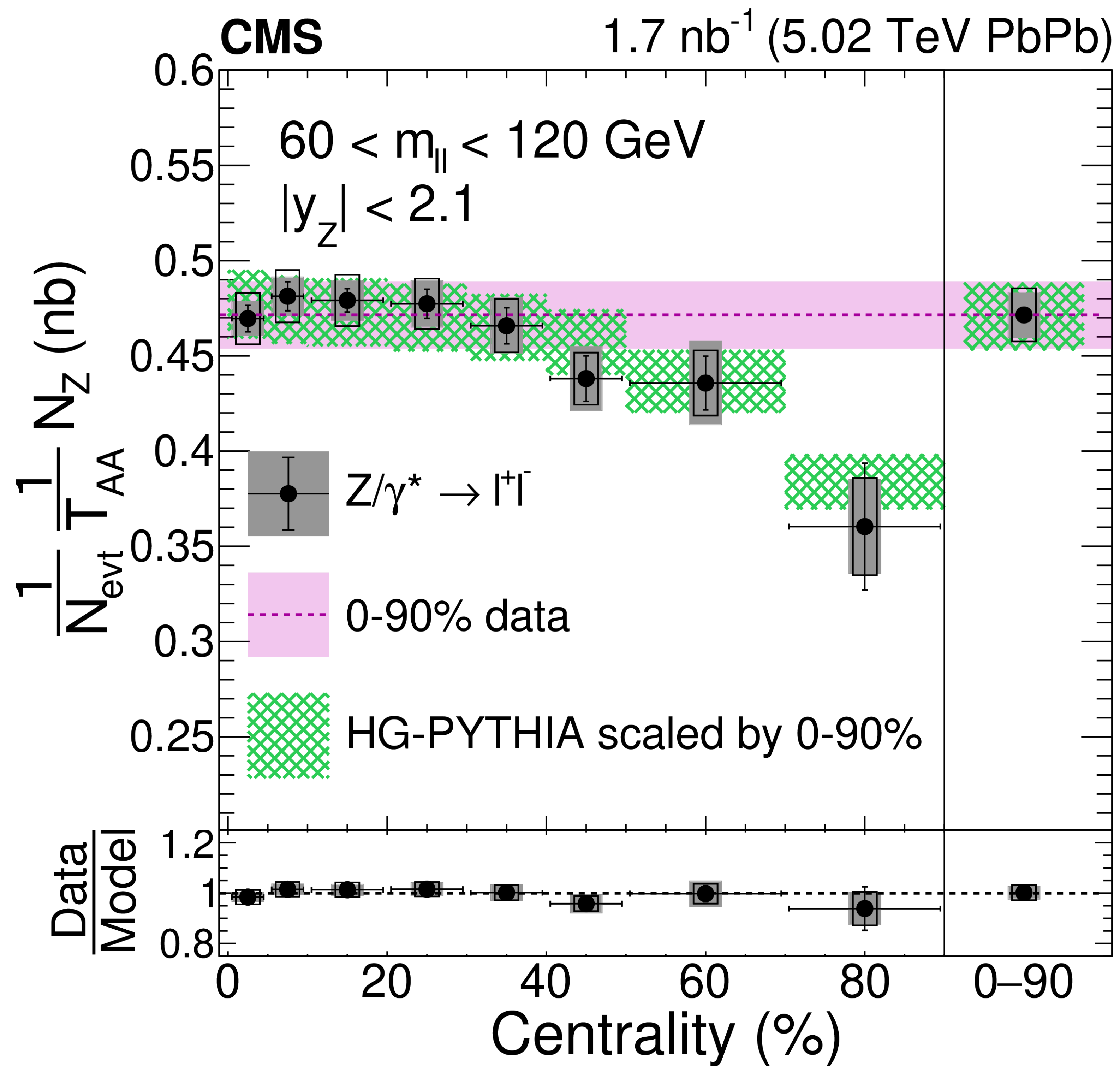
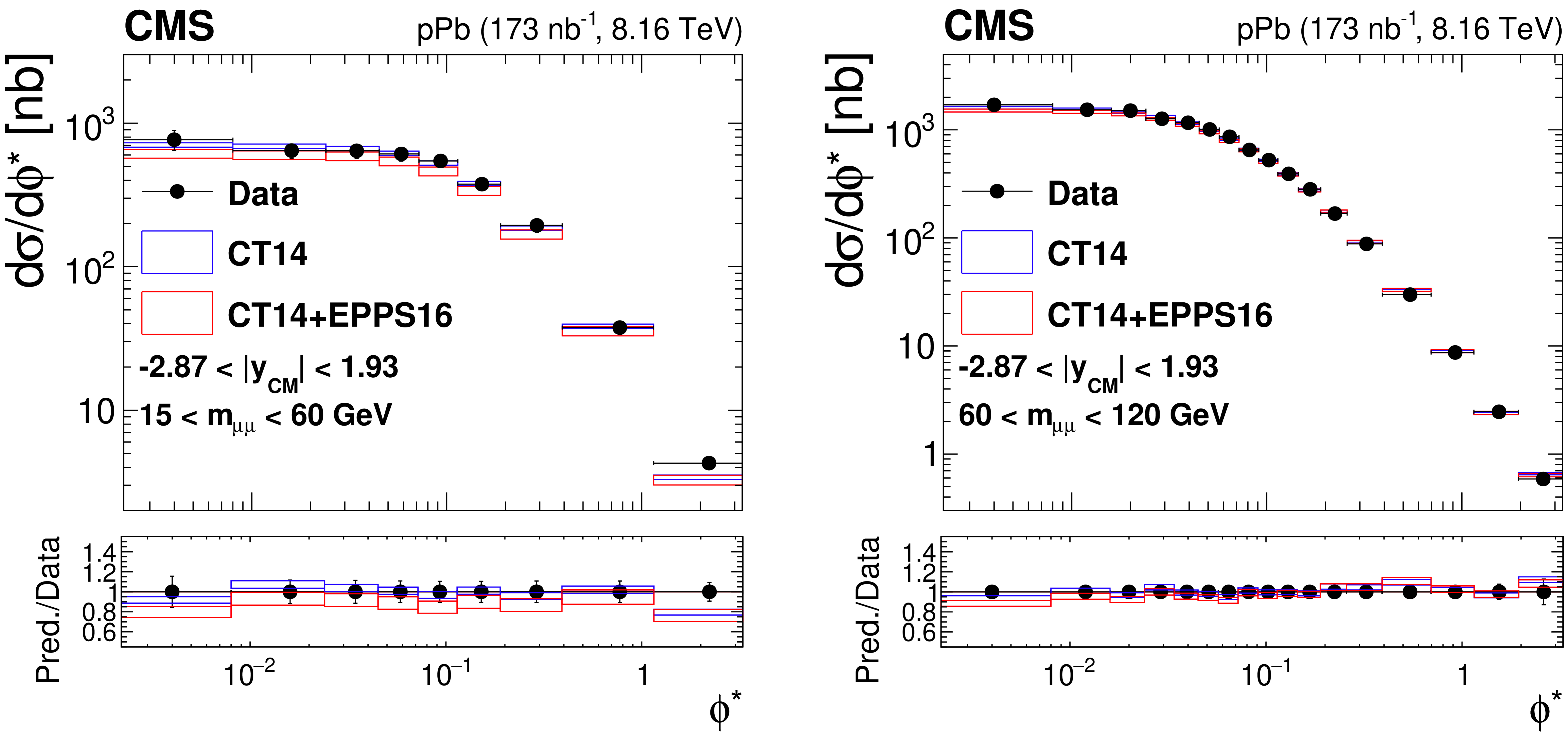




Backup

pPb ϕ^* Distributions



$$\phi^* \approx p_T/m_{\mu\mu} \qquad \phi^* \equiv \tan\left(\frac{\pi - \Delta\phi}{2}\right)\sin(\theta^*_\eta), \qquad \cos(\theta^*_\eta) = \tanh(\Delta\eta/2),$$

- Only depends on angular variables - better resolution than p_T measurement

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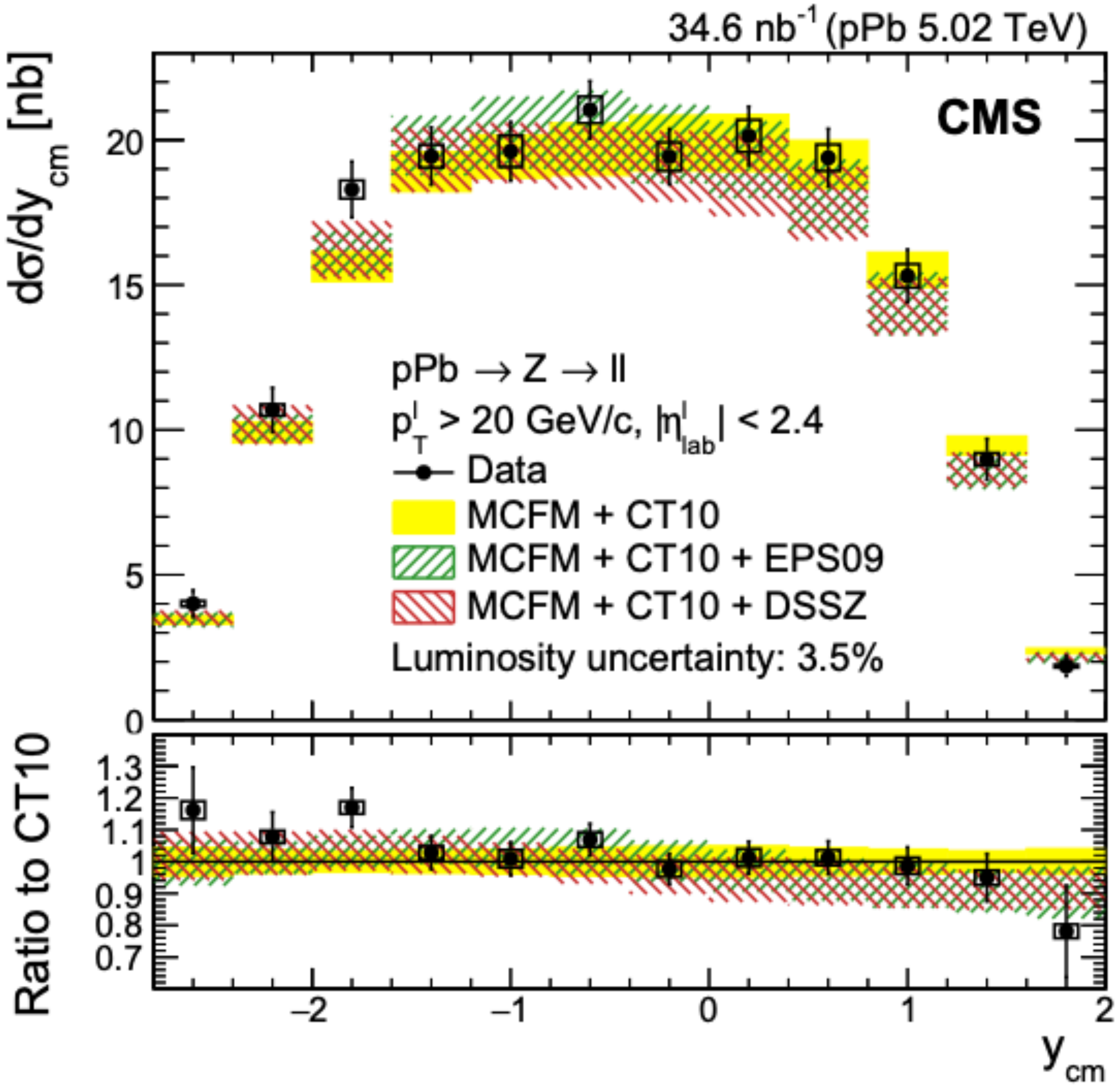
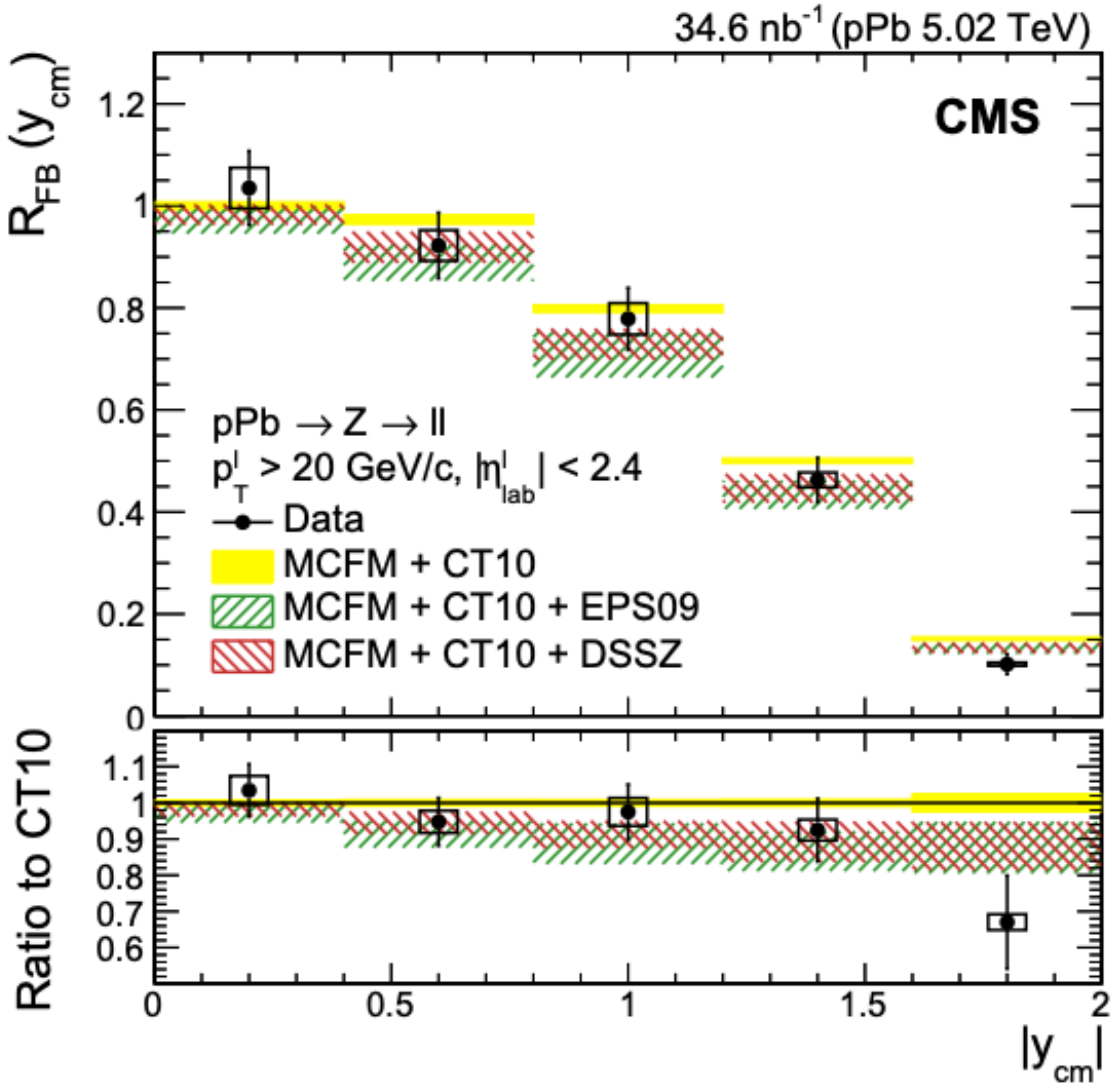
Previous pPb result





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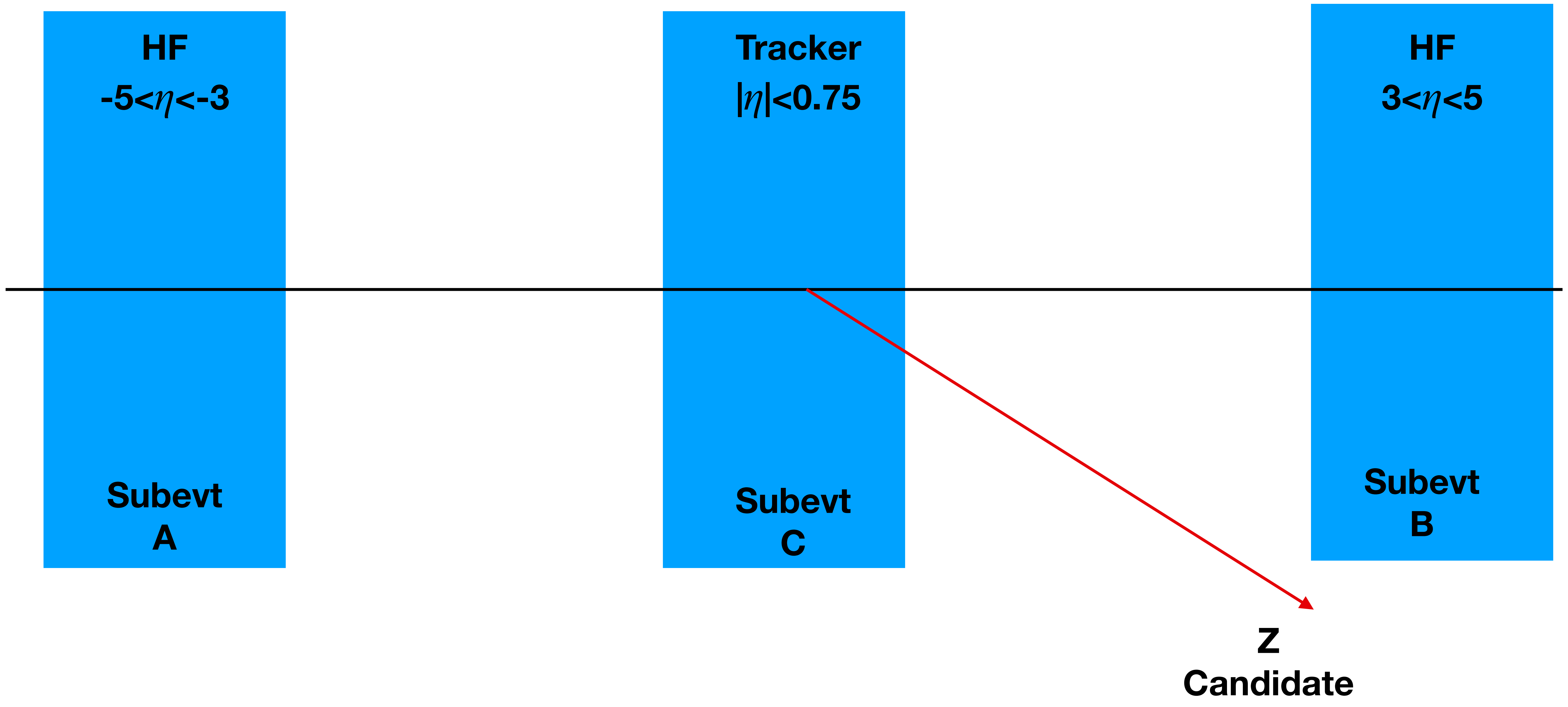
3-subevent v_2 method

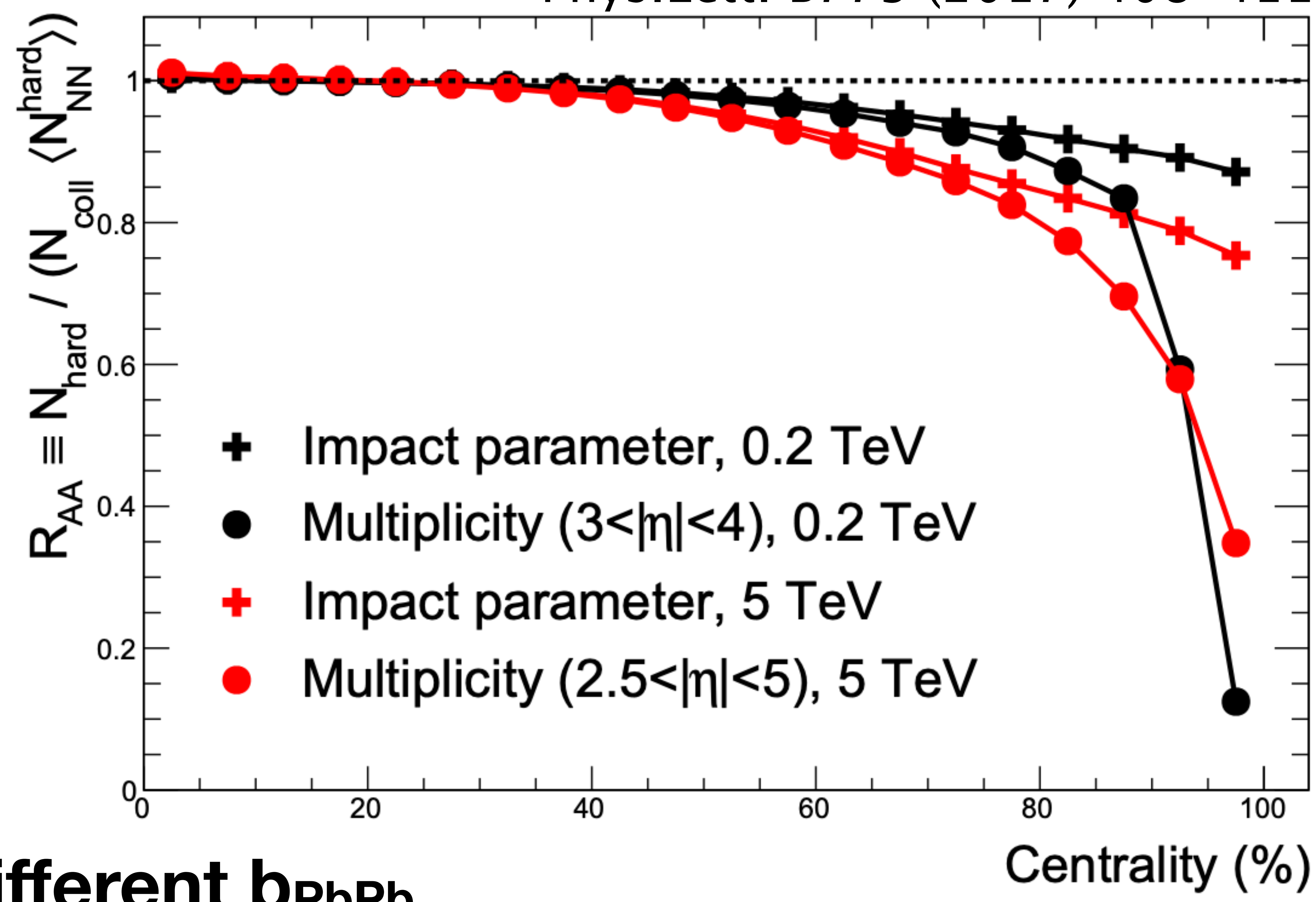
$$Q_n = \sum_{k=0}^{M} \omega_k e^{in\phi_k} \qquad v_2 = \frac{\langle Q_Z Q_A^* \rangle}{\sqrt{\frac{\langle Q_A Q_B^* \rangle \langle Q_A Q_C^* \rangle}{\langle Q_B Q_C^* \rangle}}}.$$



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

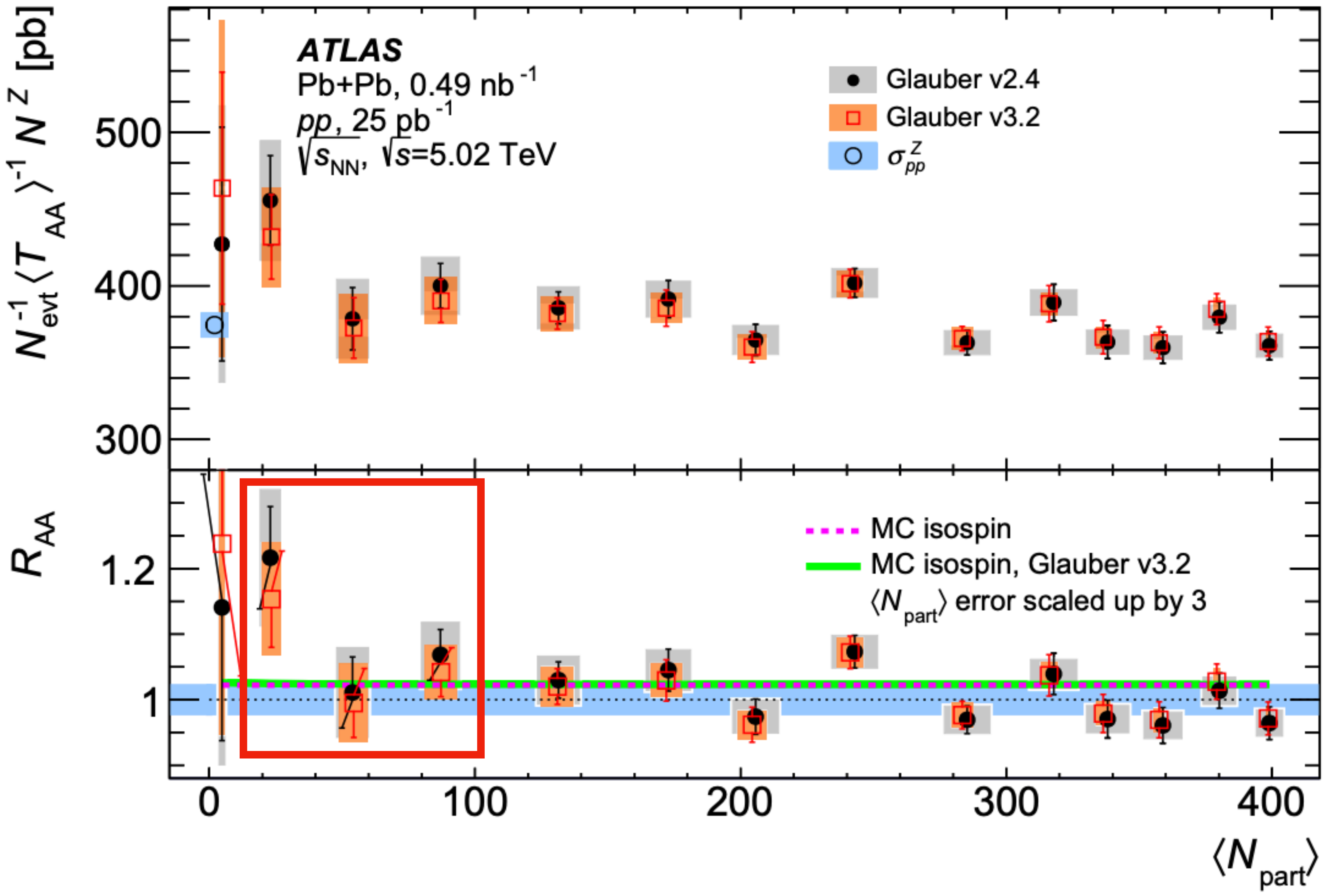
Phys.Lett. B773 (2017) 408–411



- 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



- **Choice of TGlauberMC version can affect peripheral results a bit**
- **CMS uses v3.2**
  - **Orange points should be used for a fair comparison with ATLAS**

Comparison to ATLAS

- **Scaled ATLAS RAA by CMS 0-90% to try to make a comparison**
  - **Note: could still be some difference in normalization**

- **Roughly estimated compatibility**
  - **CMS T_{AA} uncertainty ignored**

- **Central bins roughly consistent**

- **40-50% centrality: ~1.8σ deviation**

- **ATLAS 50-60% vs. CMS 50-70%: <1σ**

- **ATLAS 60-80% vs.**
  - **CMS 50-70%: ~2σ**
  - **CMS 70-90%: ~2.7σ**

ATLAS TGlauberMC v3.2 points
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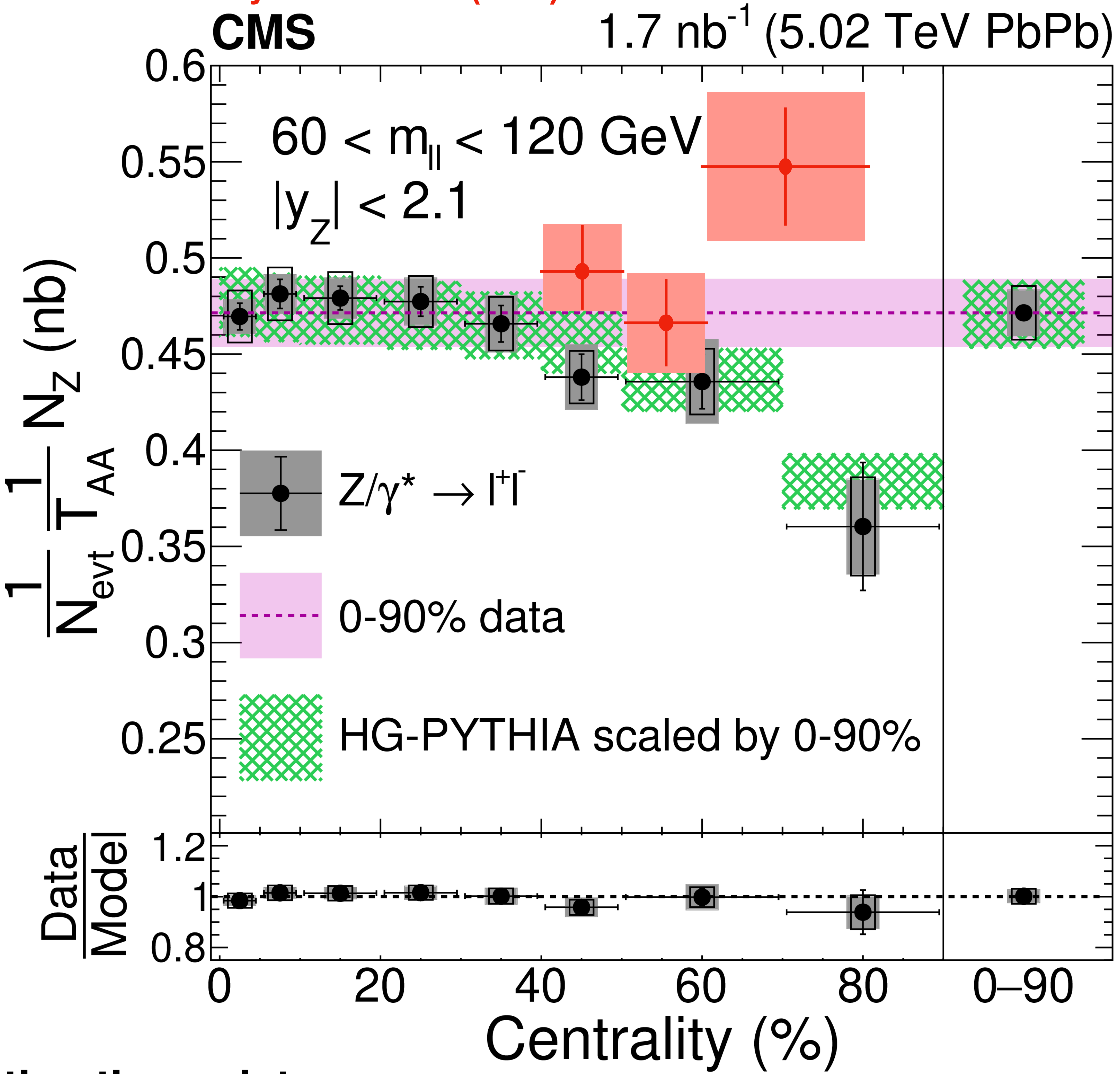

- **Correlations between centrality bins are important when interpreting these data**
  - **For example: the leading syst. uncertainty in the CMS 70-90% bin is quite correlated w/ 50-70%**