ATLAS
EXPERIMENT

BLOIS 2023

MEASUREMENTS OF JET PRODUCTION AND THE STRONG COUPLING CONSTANT AT ATLAS

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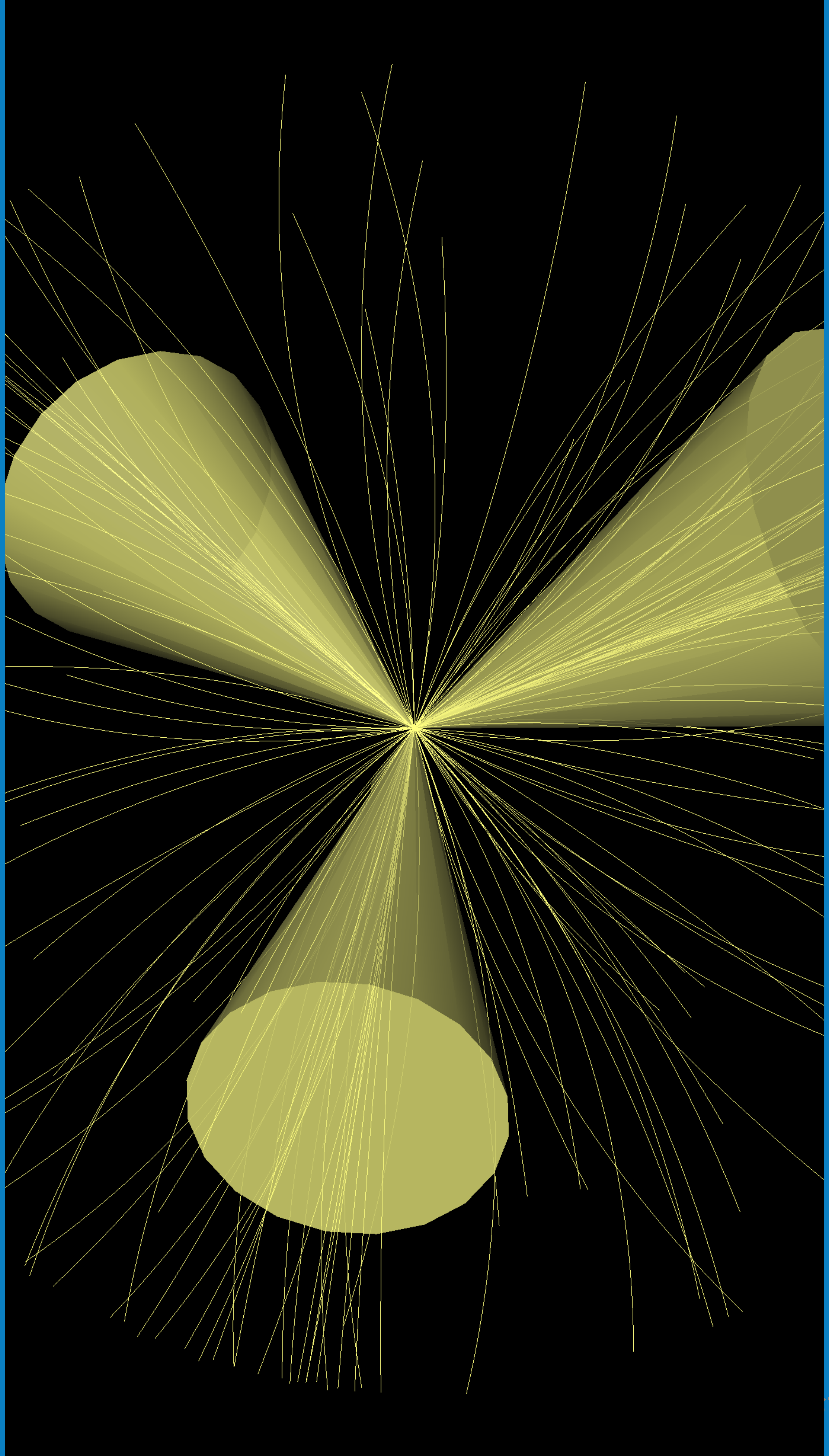

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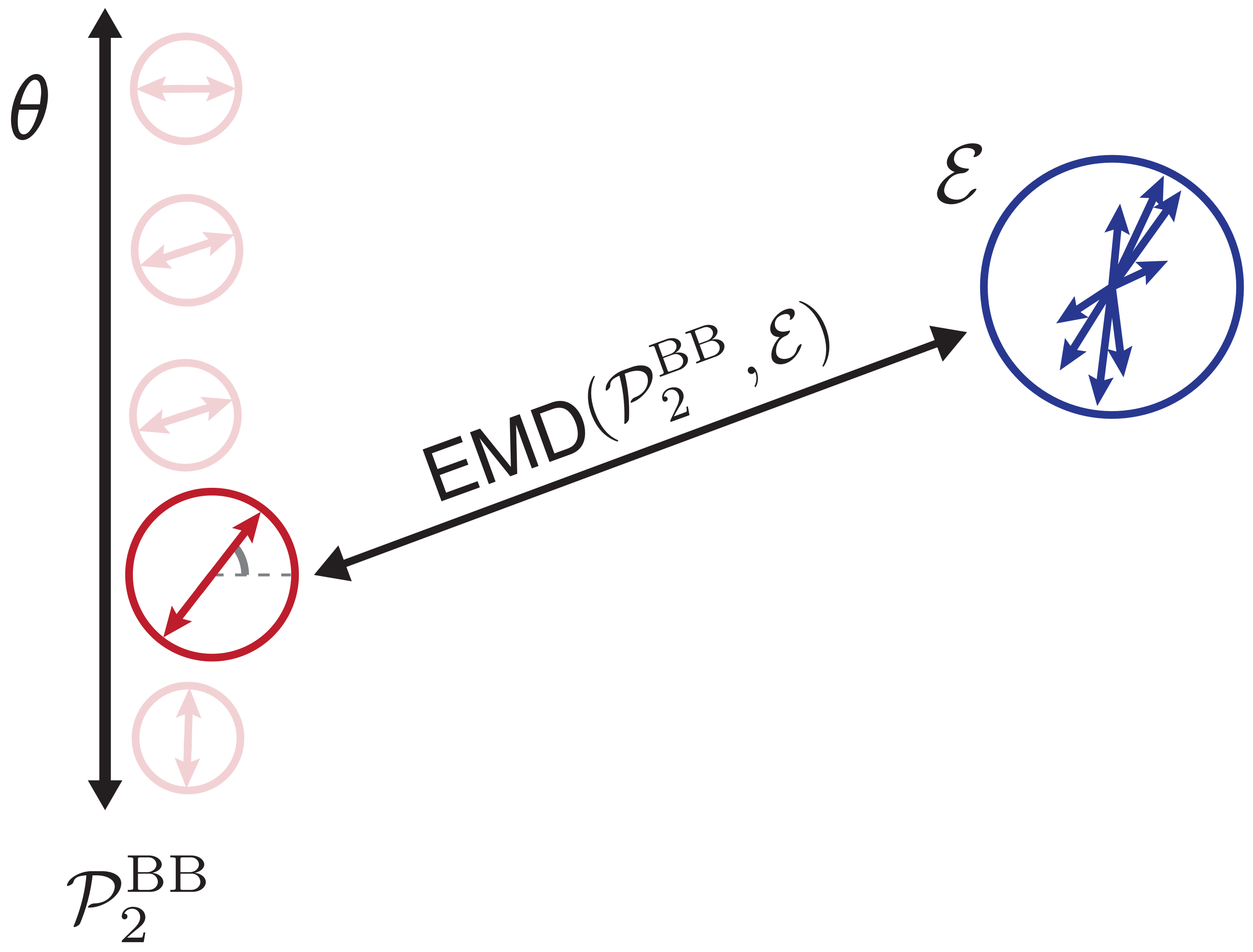
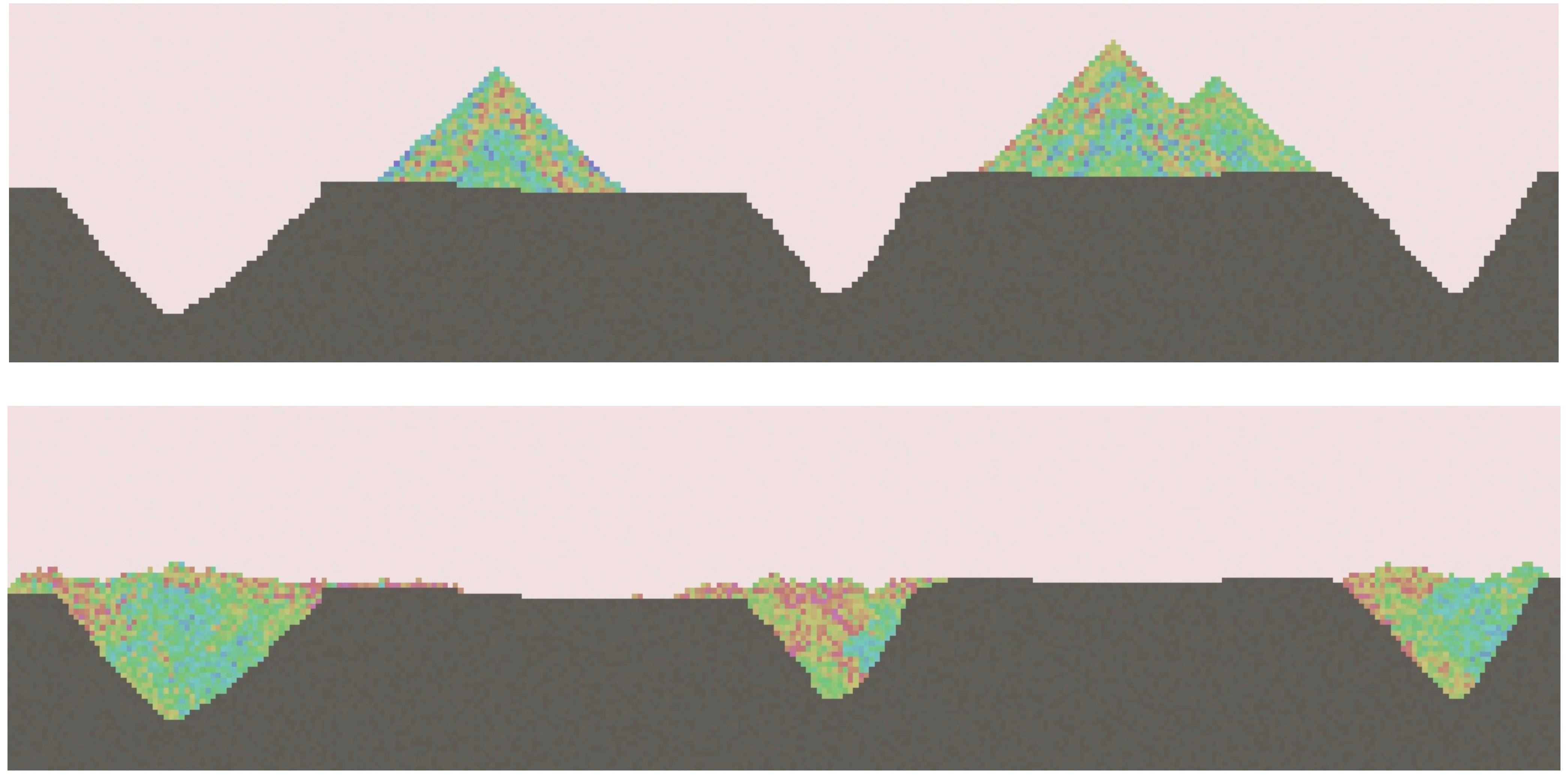
JET SHAPE AND ENERGY MOVERS DISTANCE



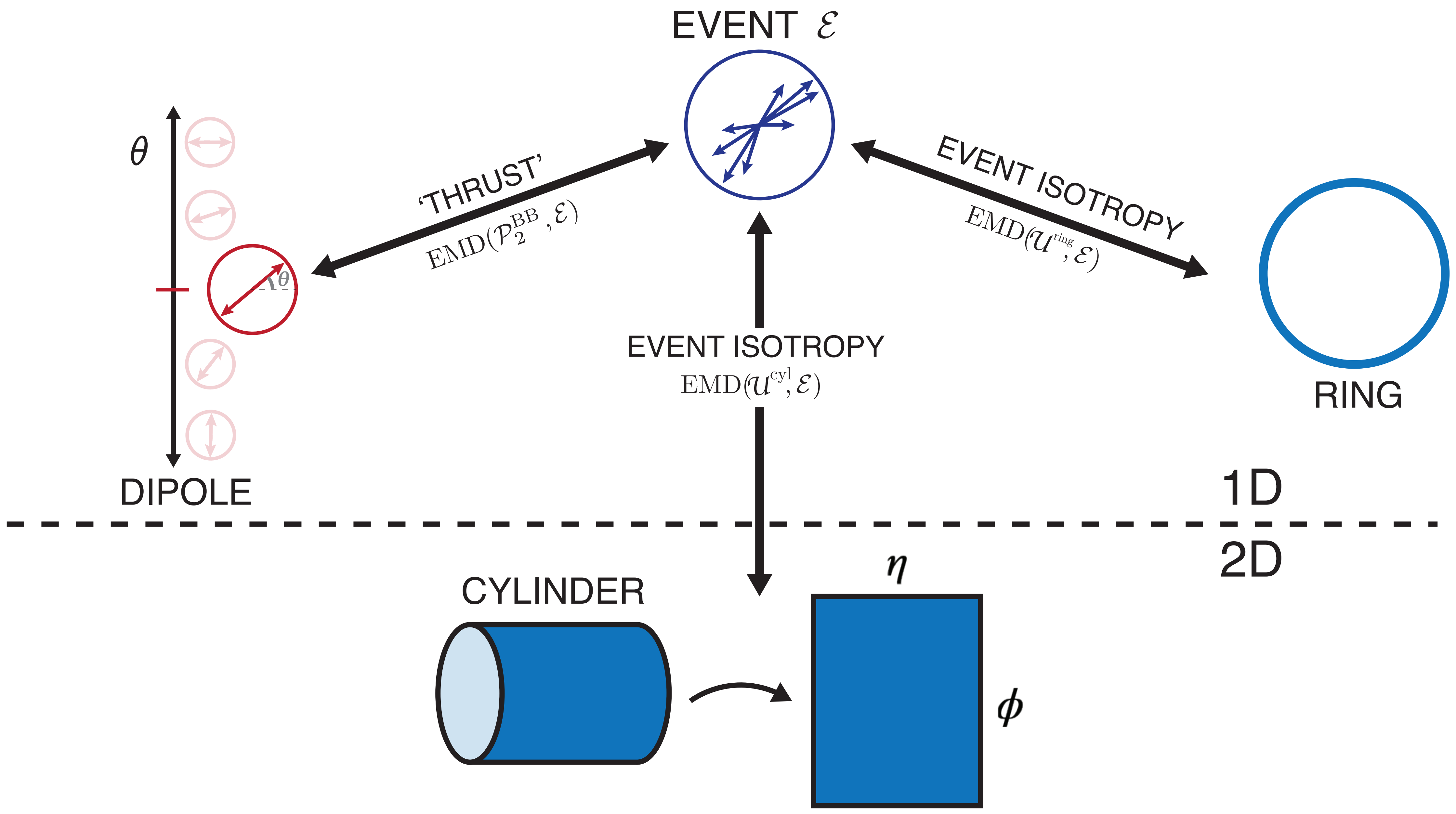
- You have to fill in holes with piles of sand - what is the least number of steps that you would need to take carrying a bucket of sand?
- This is a generic measure of the difference between two point collections.



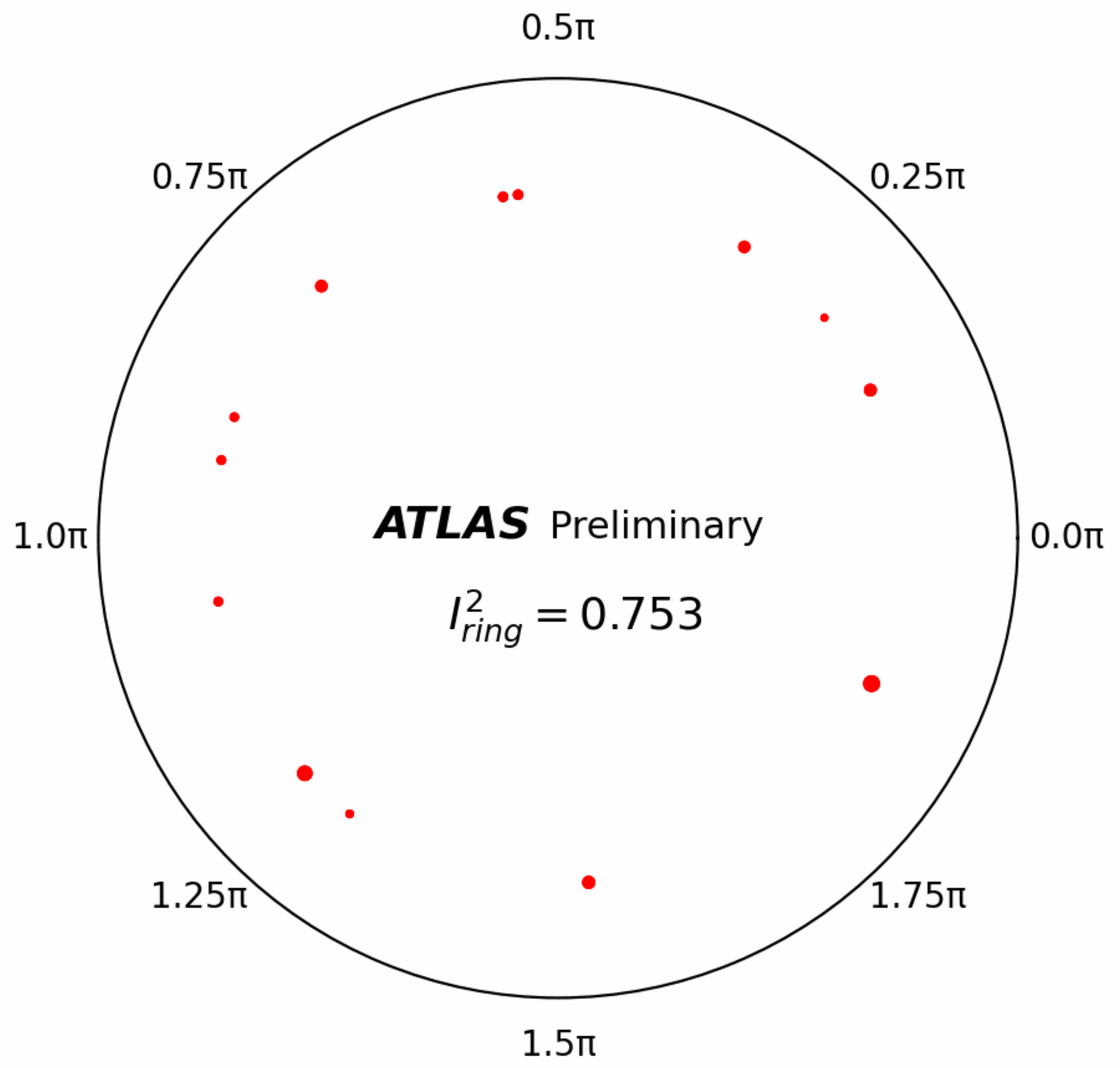
- Event/jet shape variables involving a minimisation can often be expressed in terms of EMD.
- For example; thrust, its specialisations and the Fox-Wolfram moments.
- This is convenient, as lots of libraries to solve EMD exist.

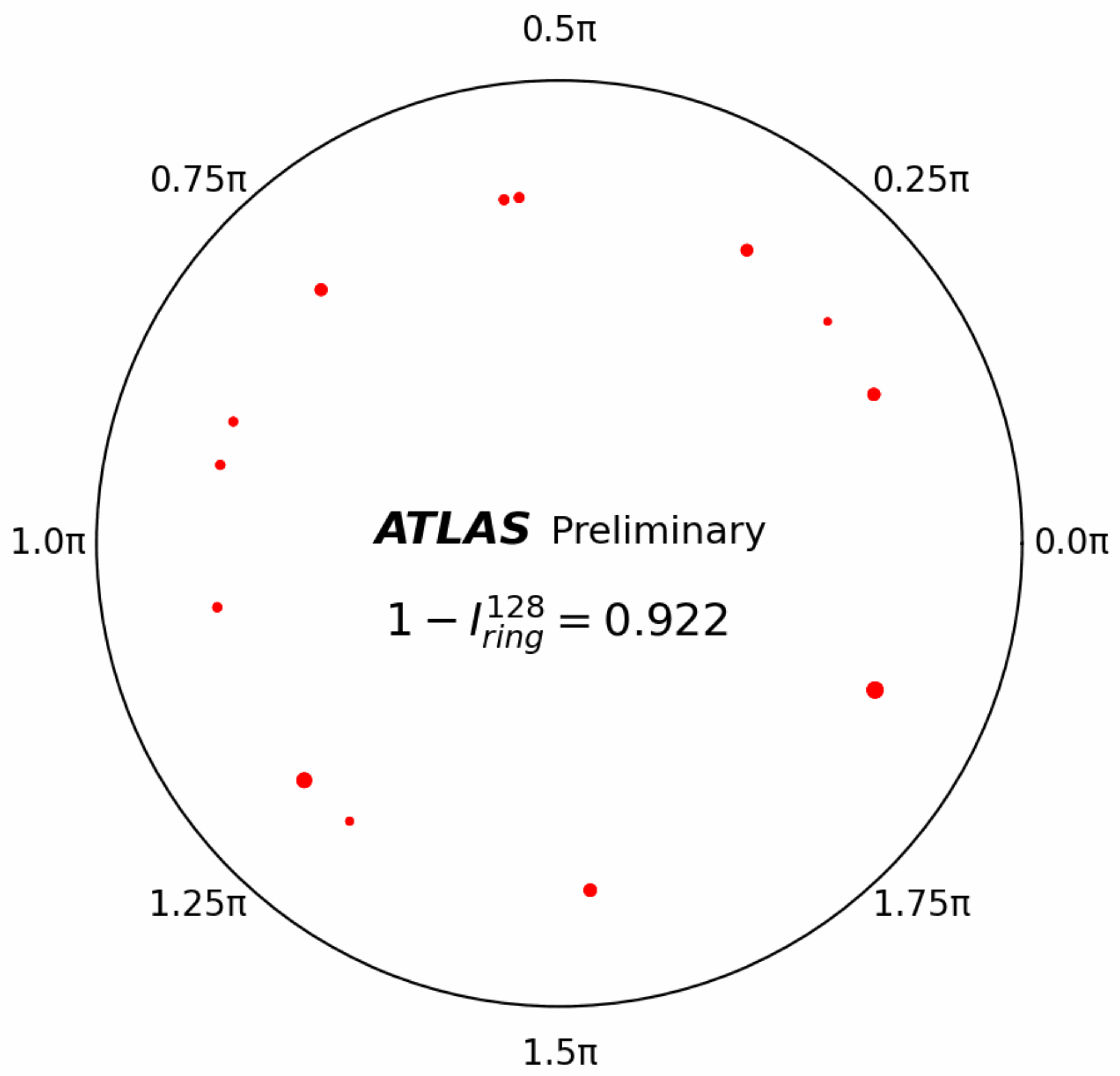
THRUST AND ISOTROPY

- atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2022-056/
- This study considers 3 event shapes;
  - ➡ Thrust, defined as usual. This can be seen as the EMD to a dipole configuration.
  - ➡ 2D event isotropy. This is the EMD to a ring of 128 points.
  - ➡ 3D event isotropy. This is the EMD to a cylinder of 16 by 22 points.
- They are applied to multi jet ($N_{jets} > 2$) events with $H_{T2} > 400$GeV where H_{T2} is the scalar sum of the two largest jet $|p_T|$.



THRUST AND 2D ISOTROPY





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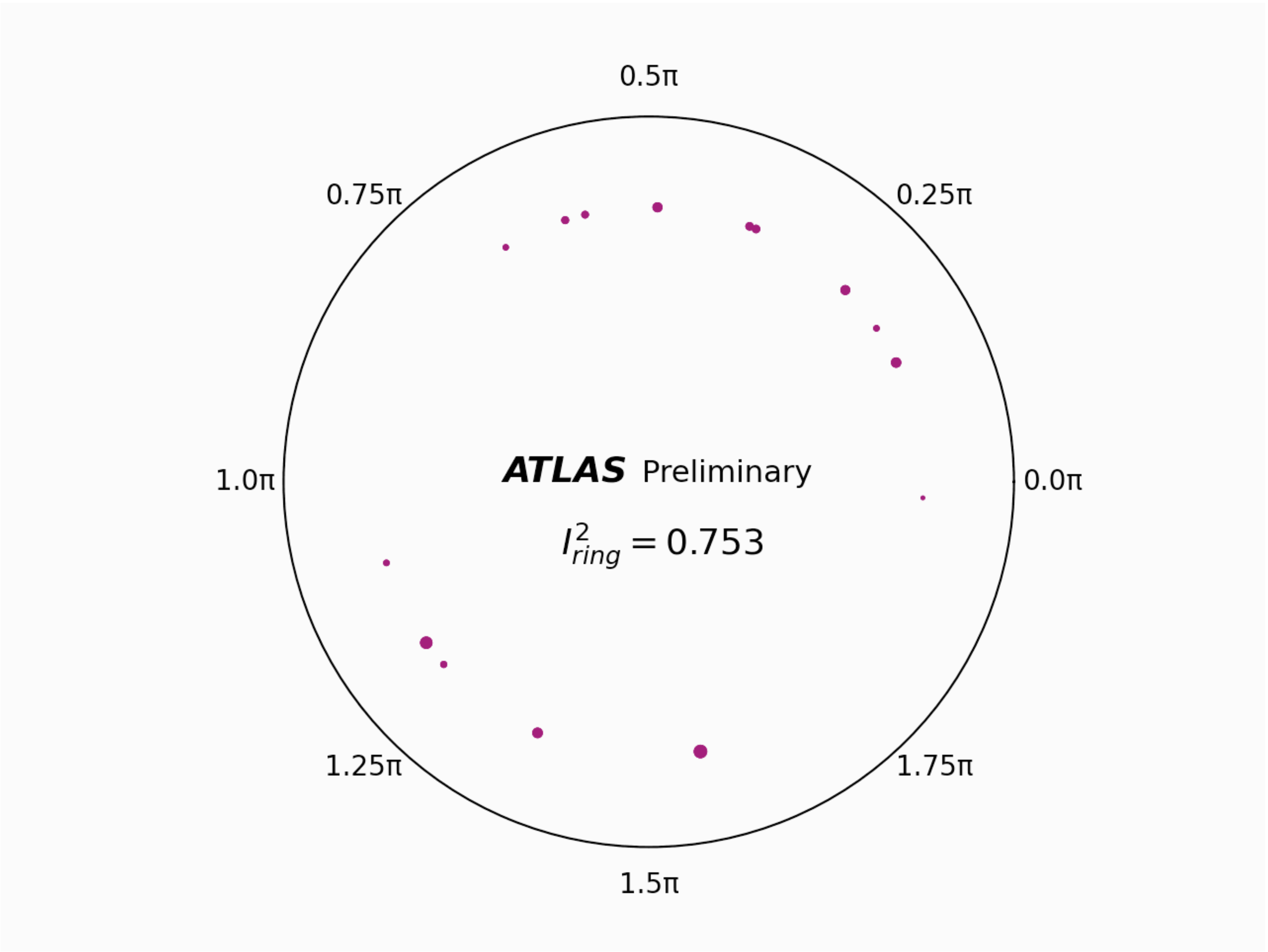

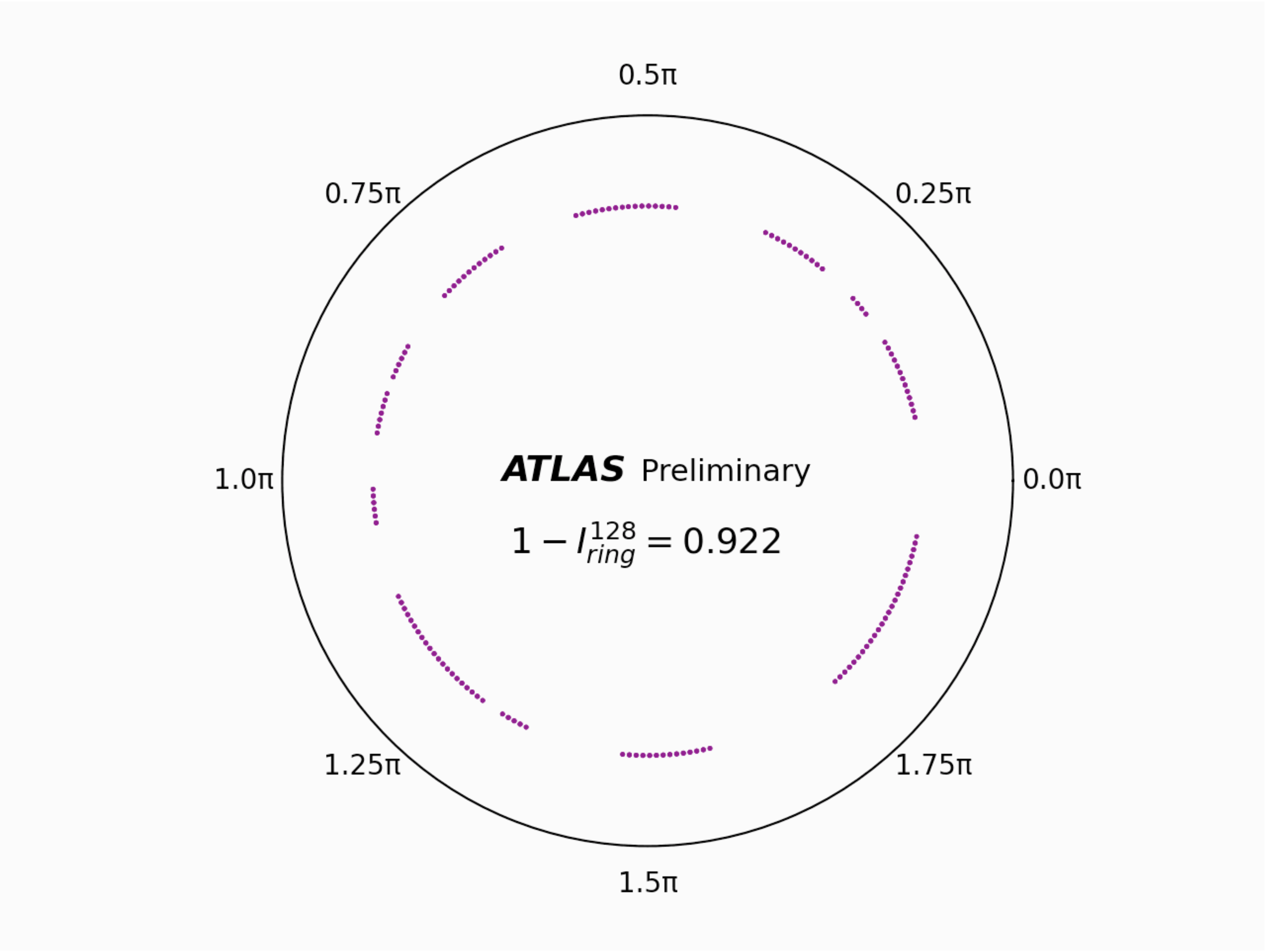

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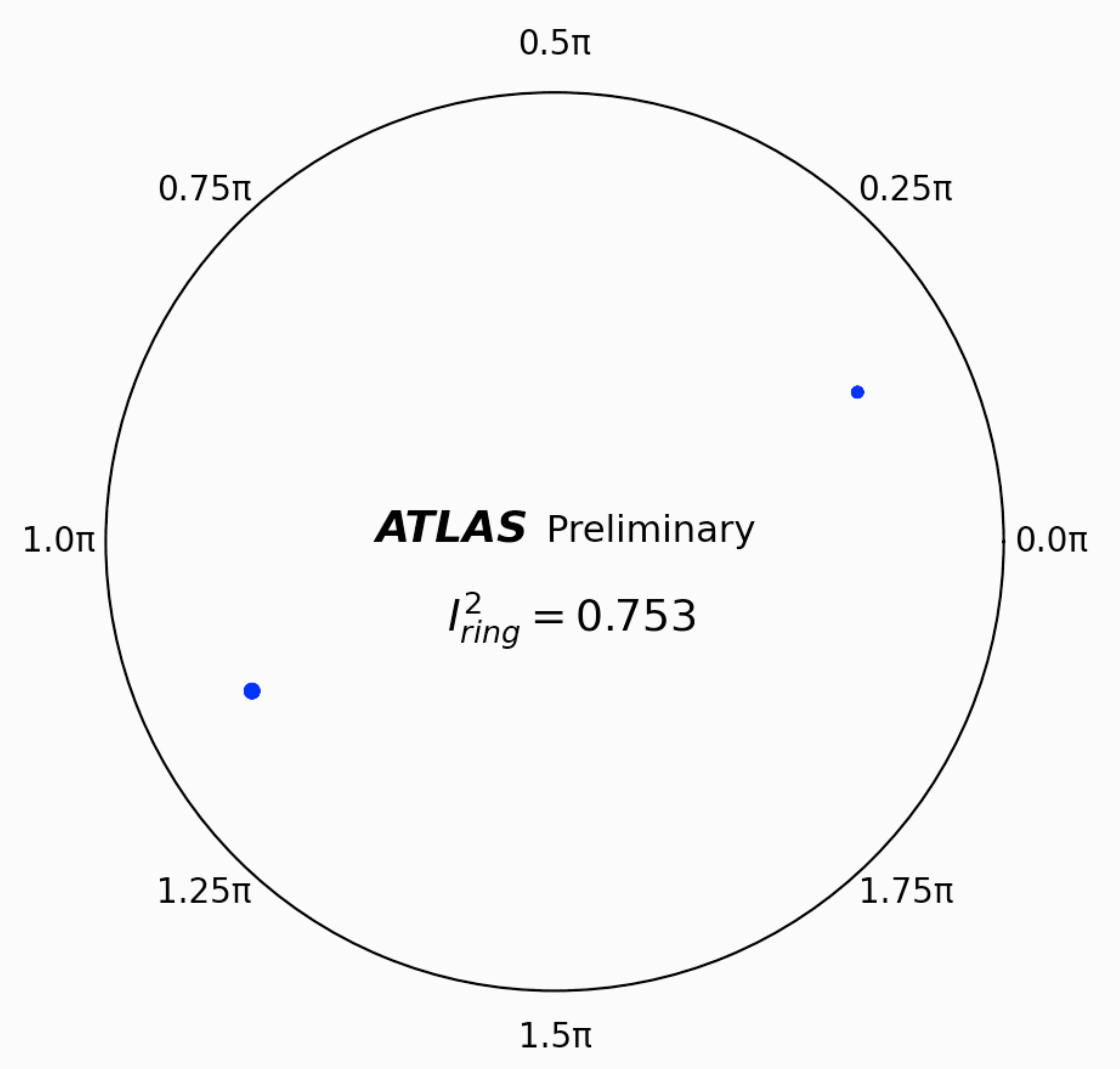

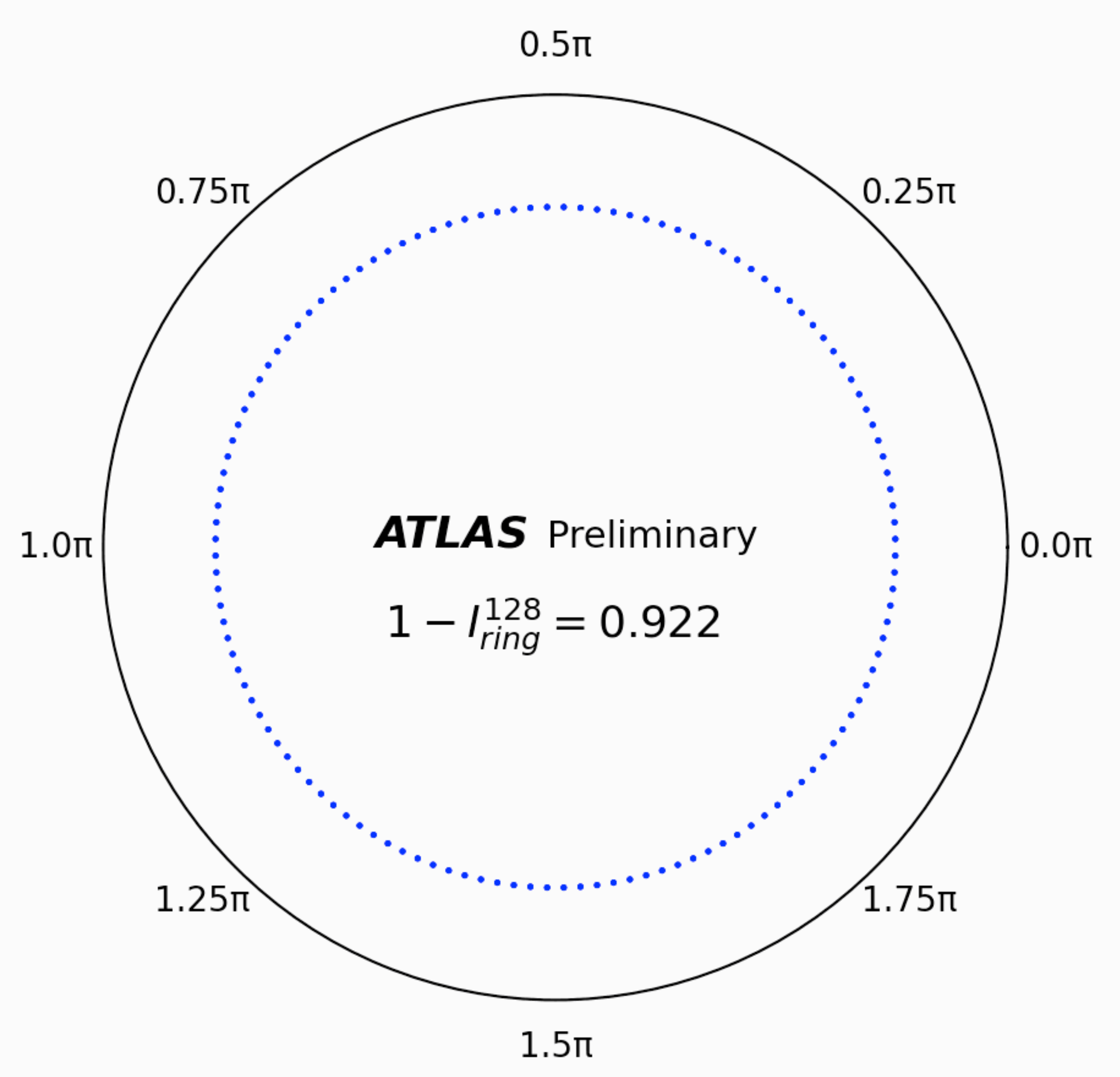

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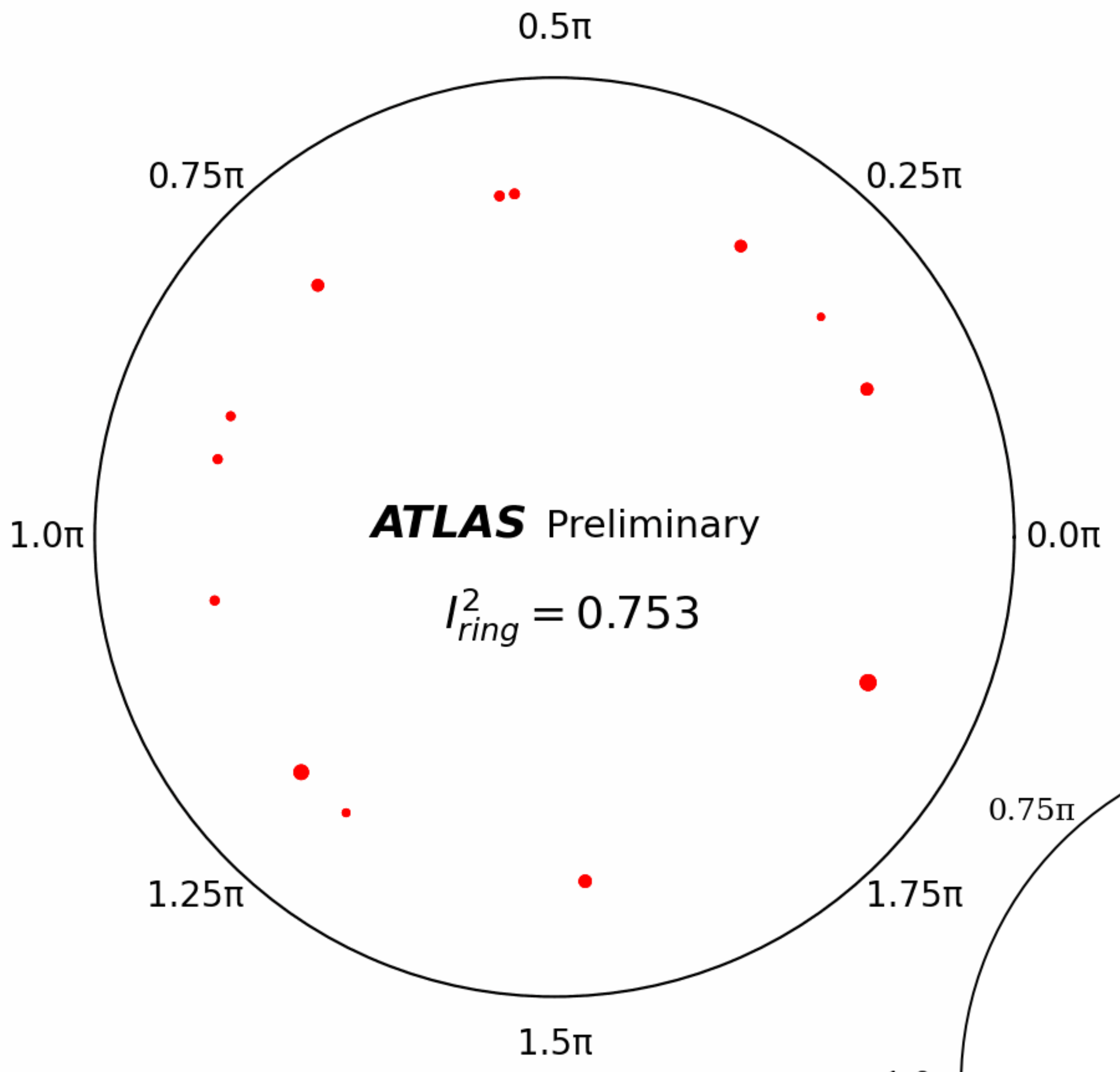

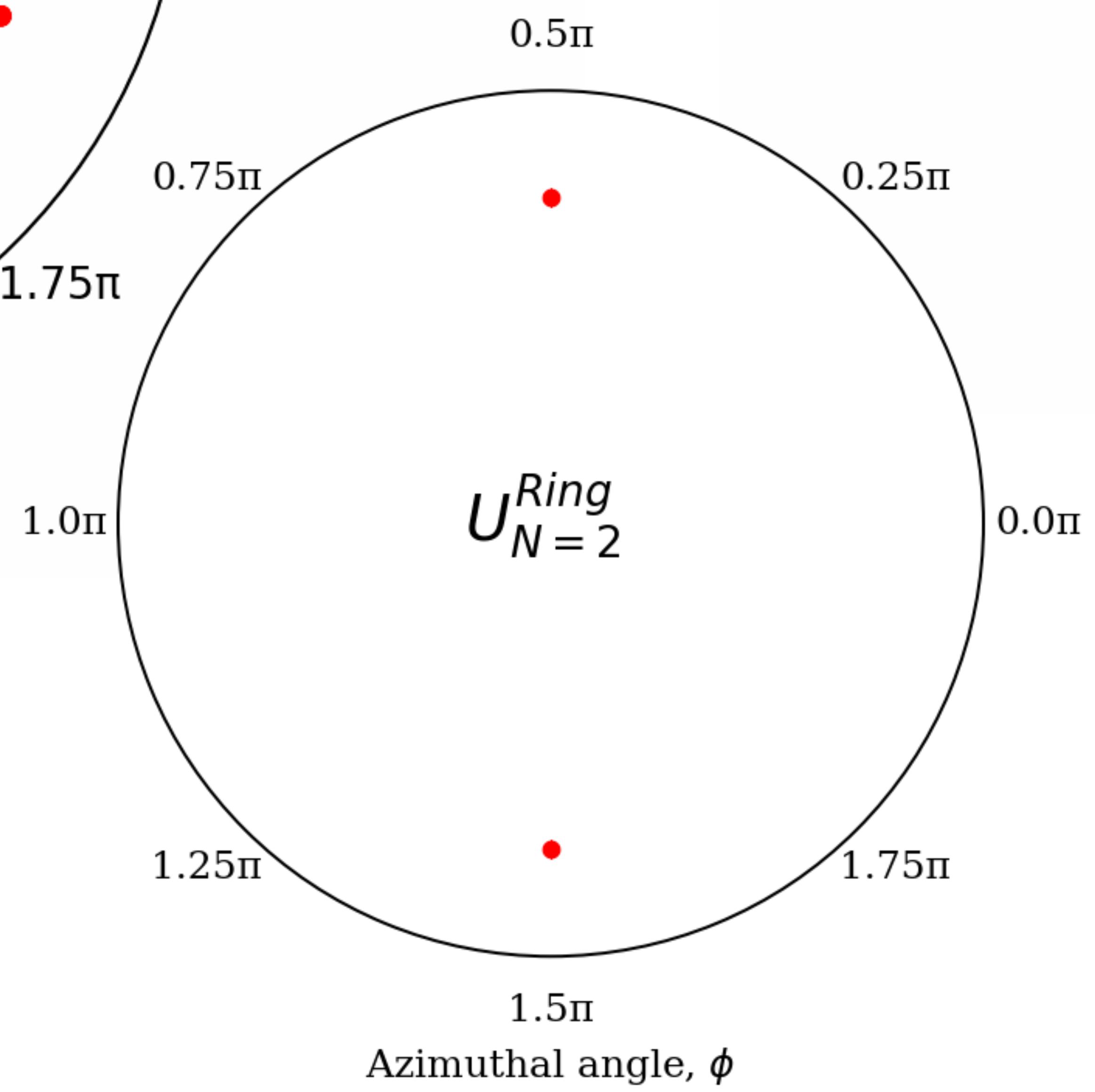

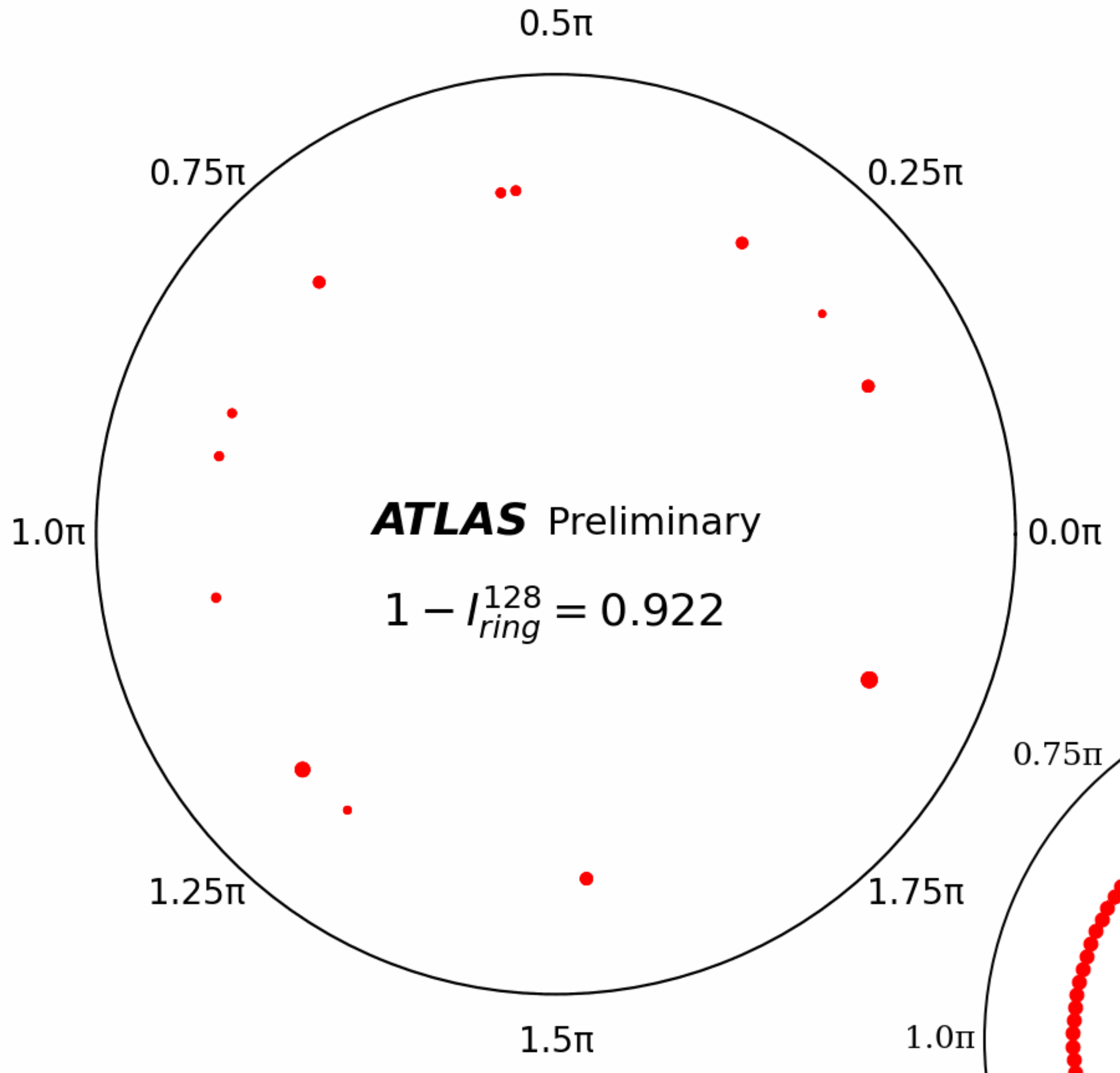

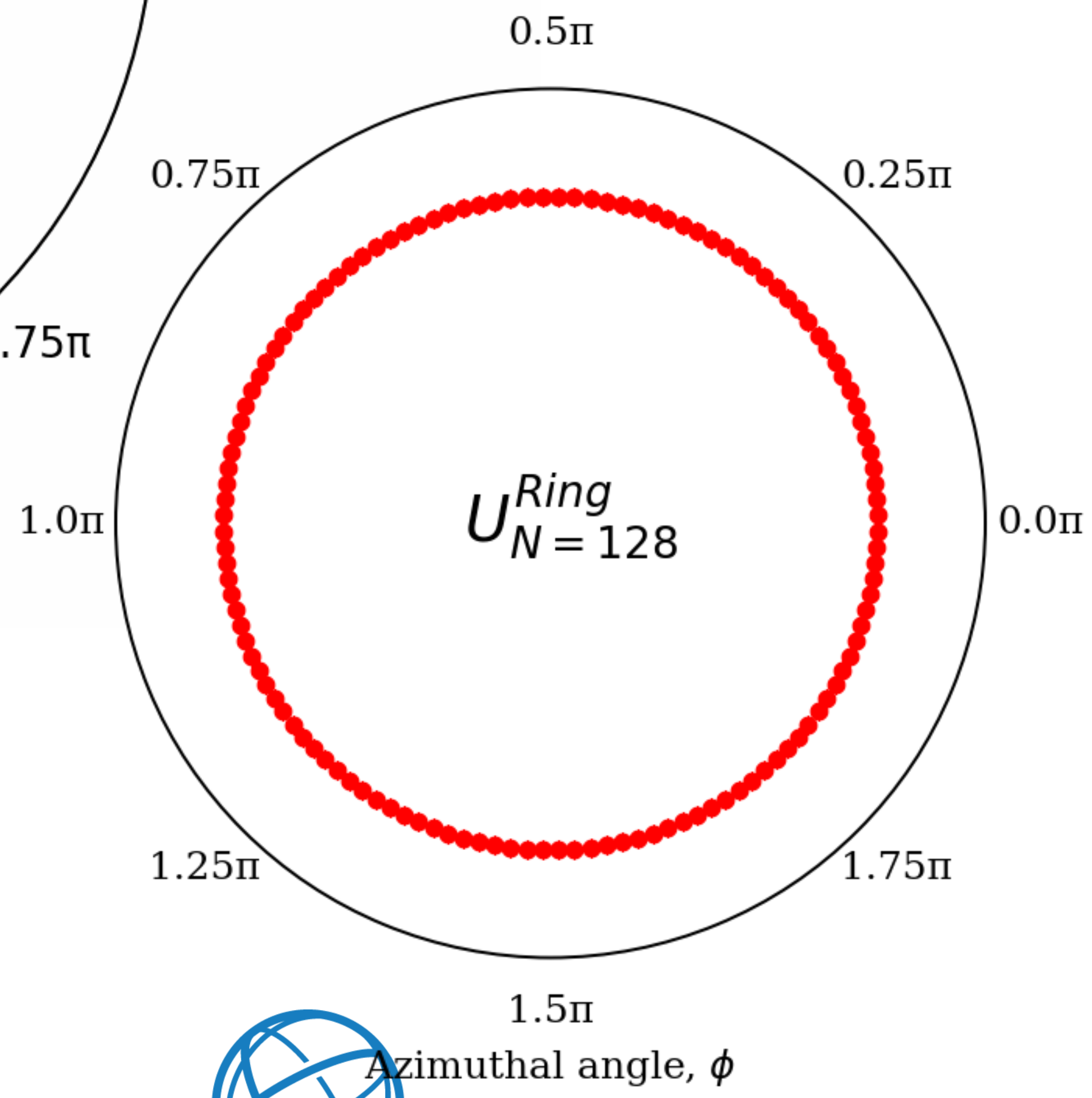

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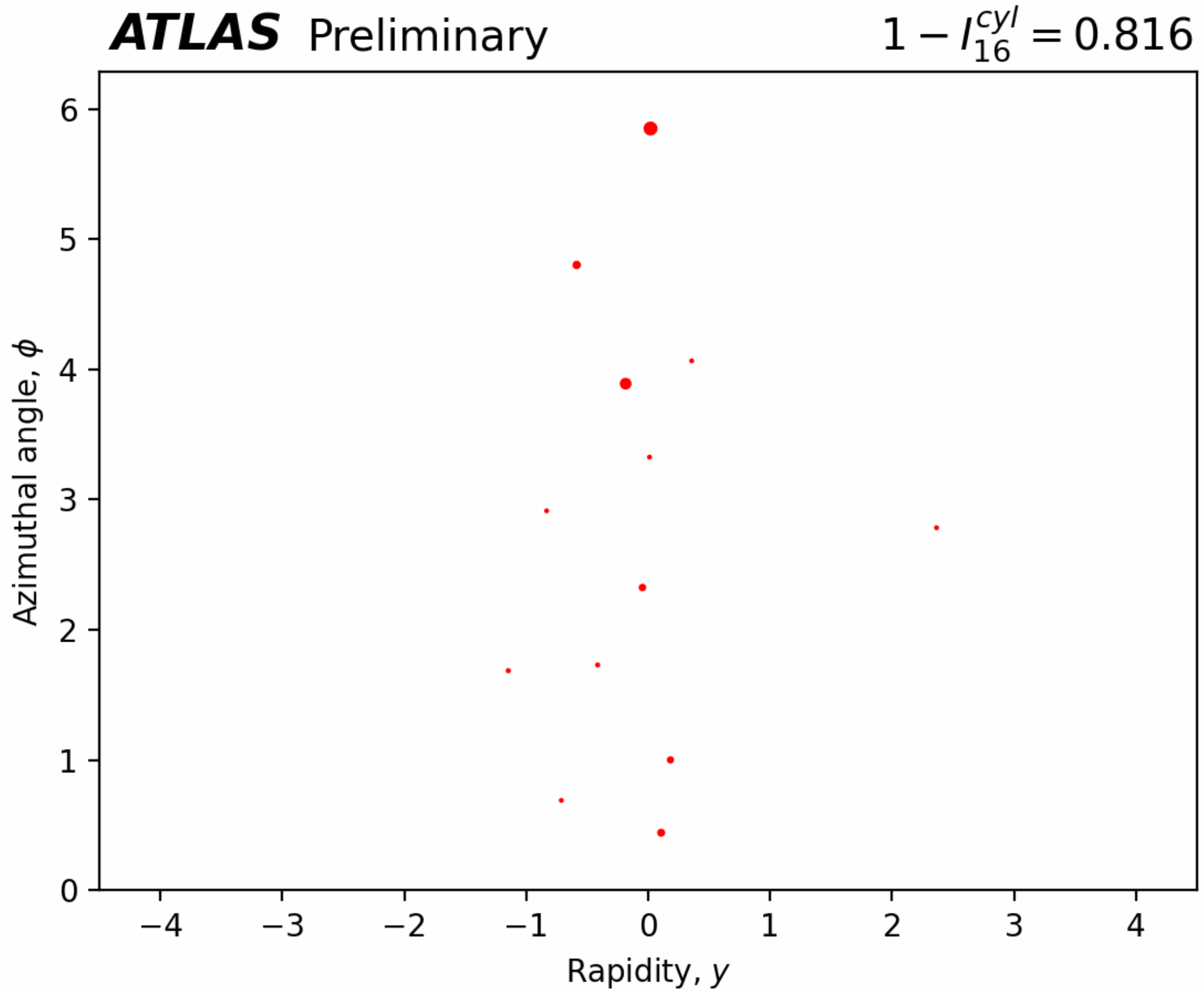
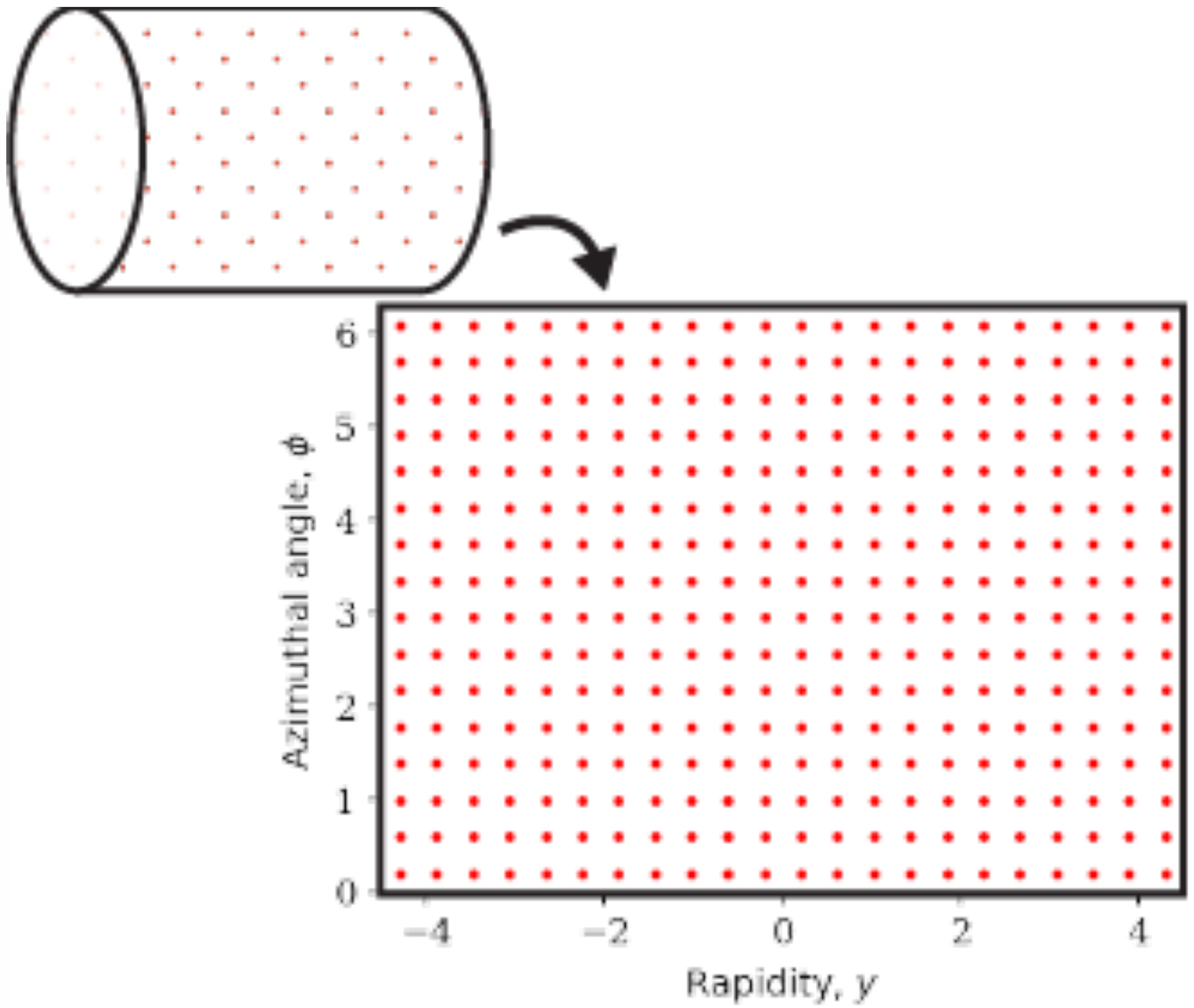
CYLINDRICAL ISOTROPY





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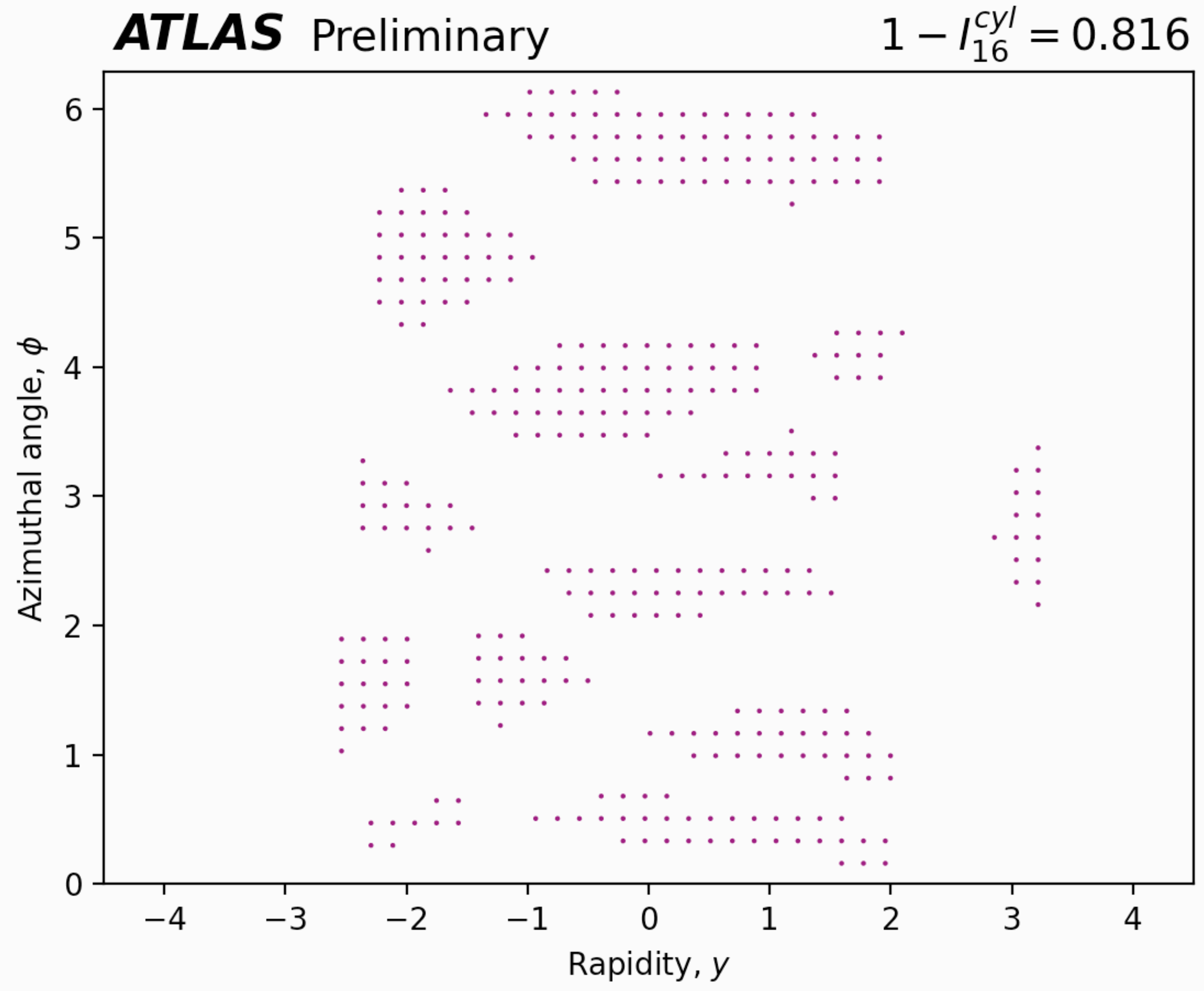

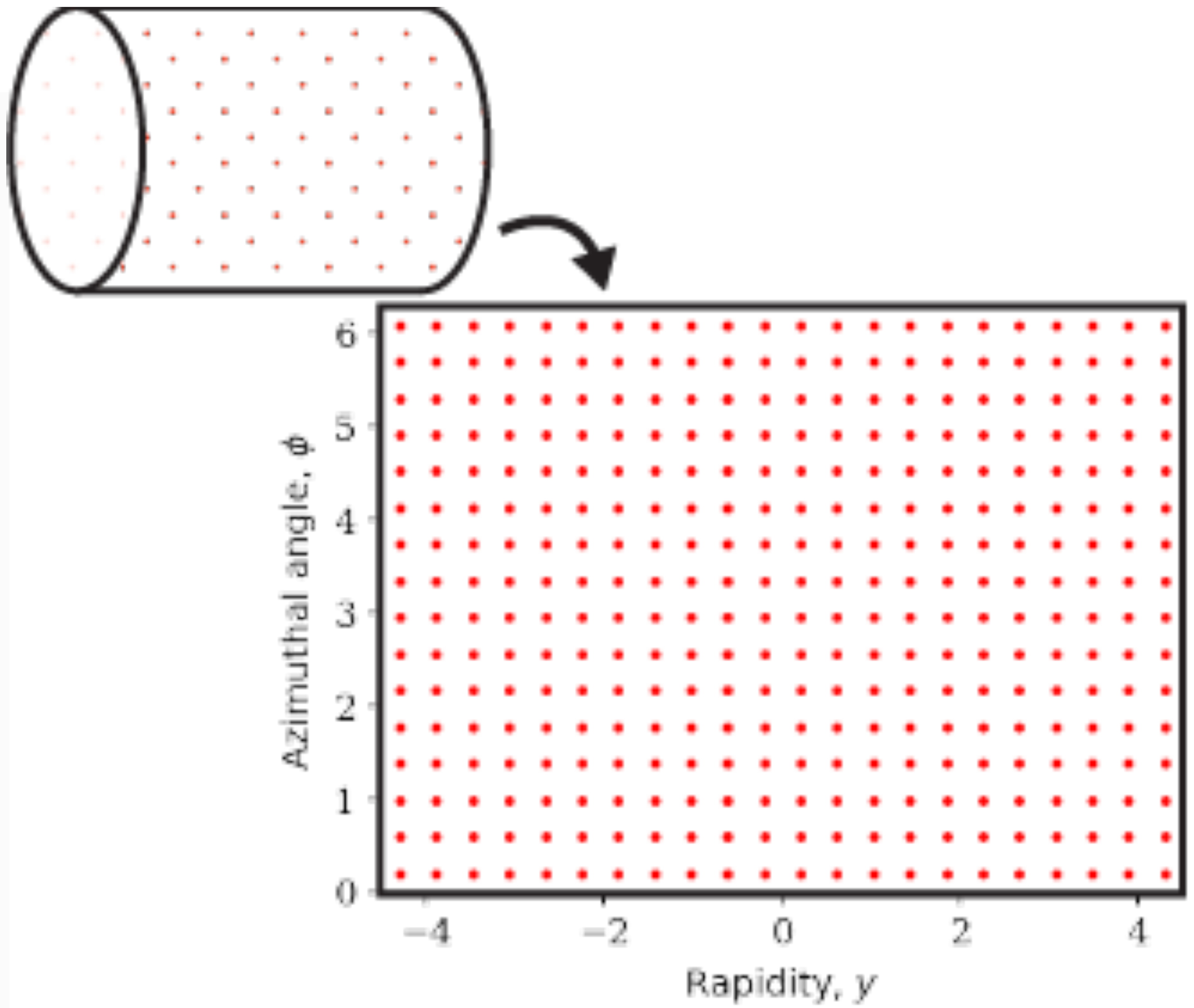

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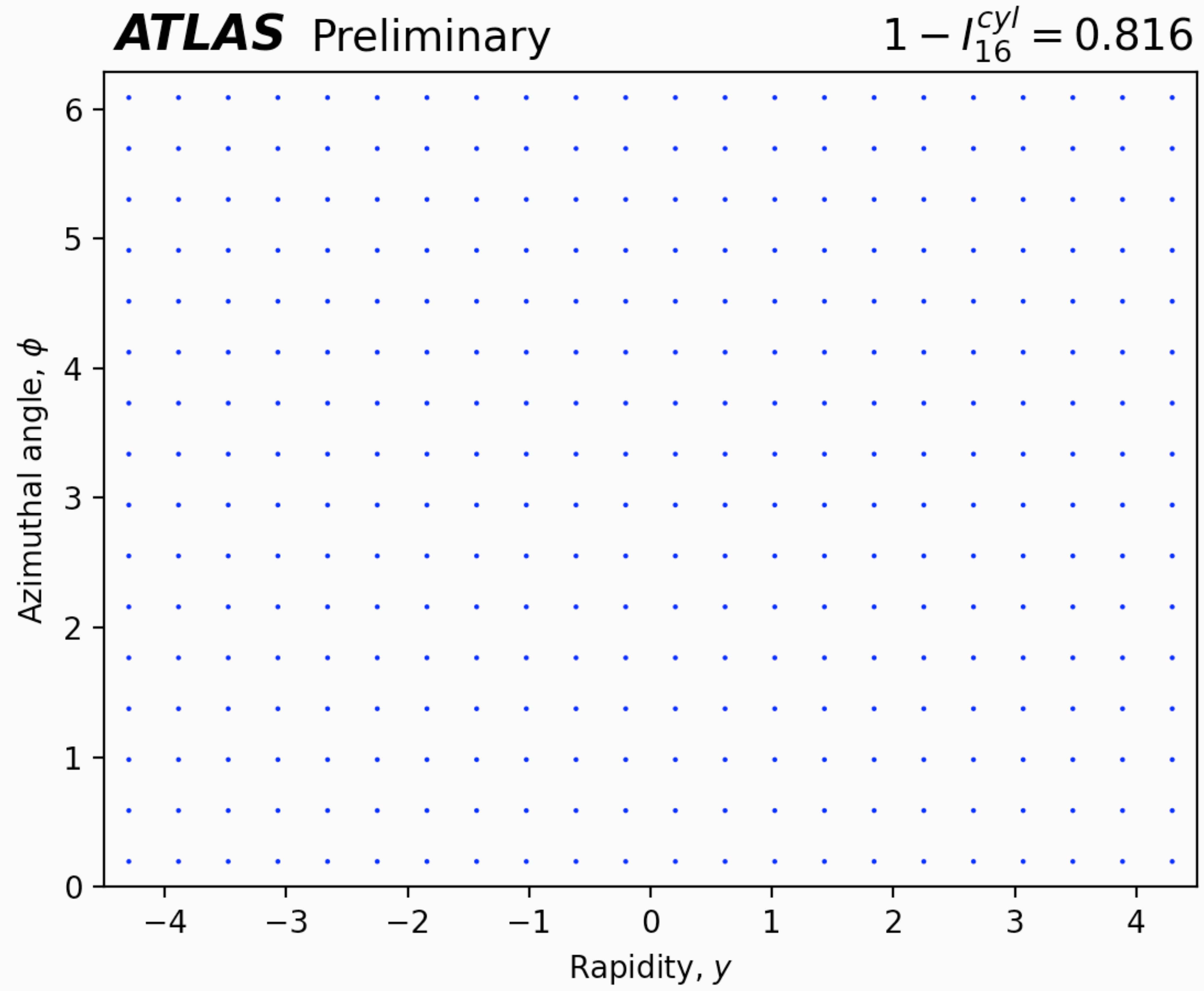
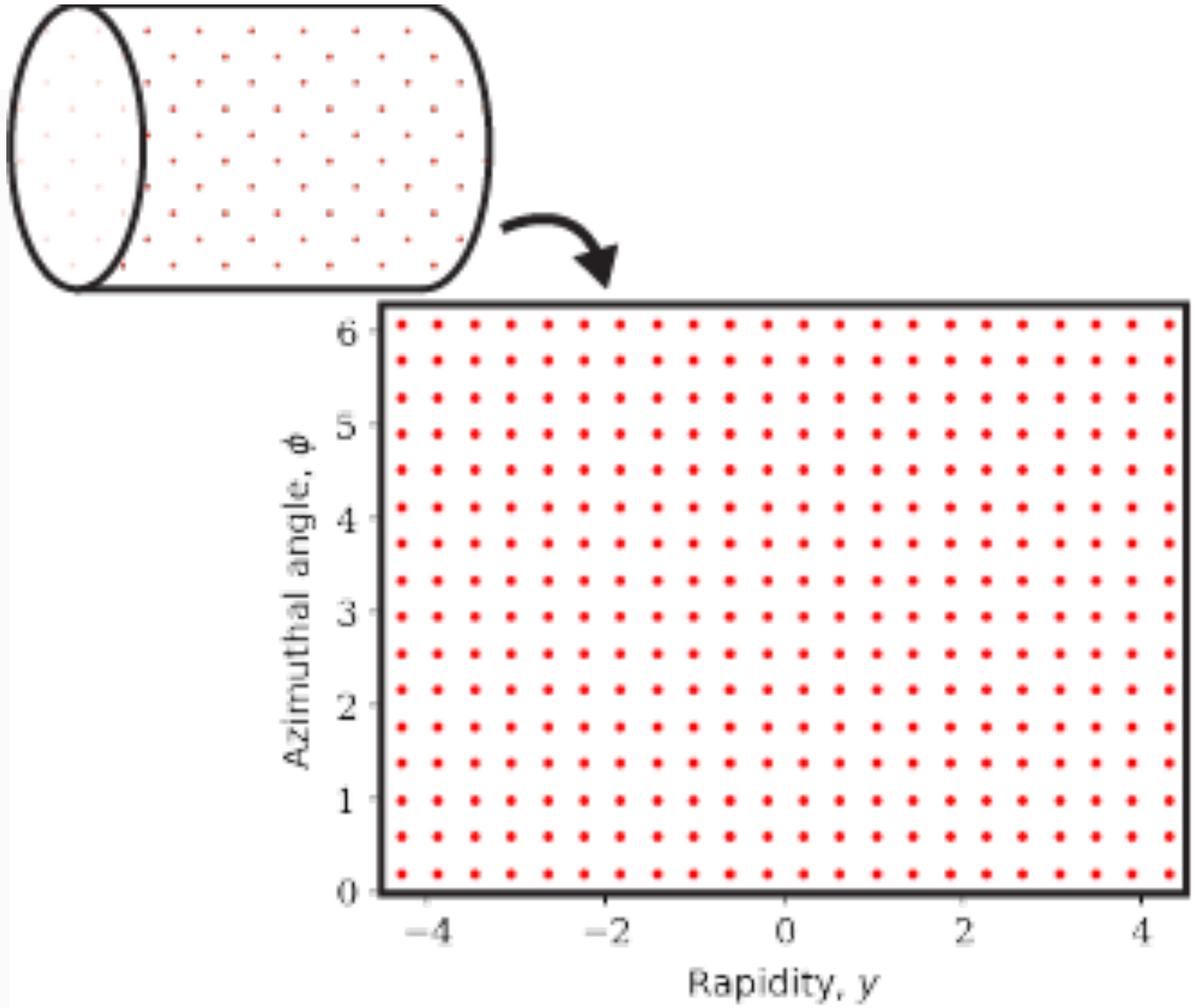
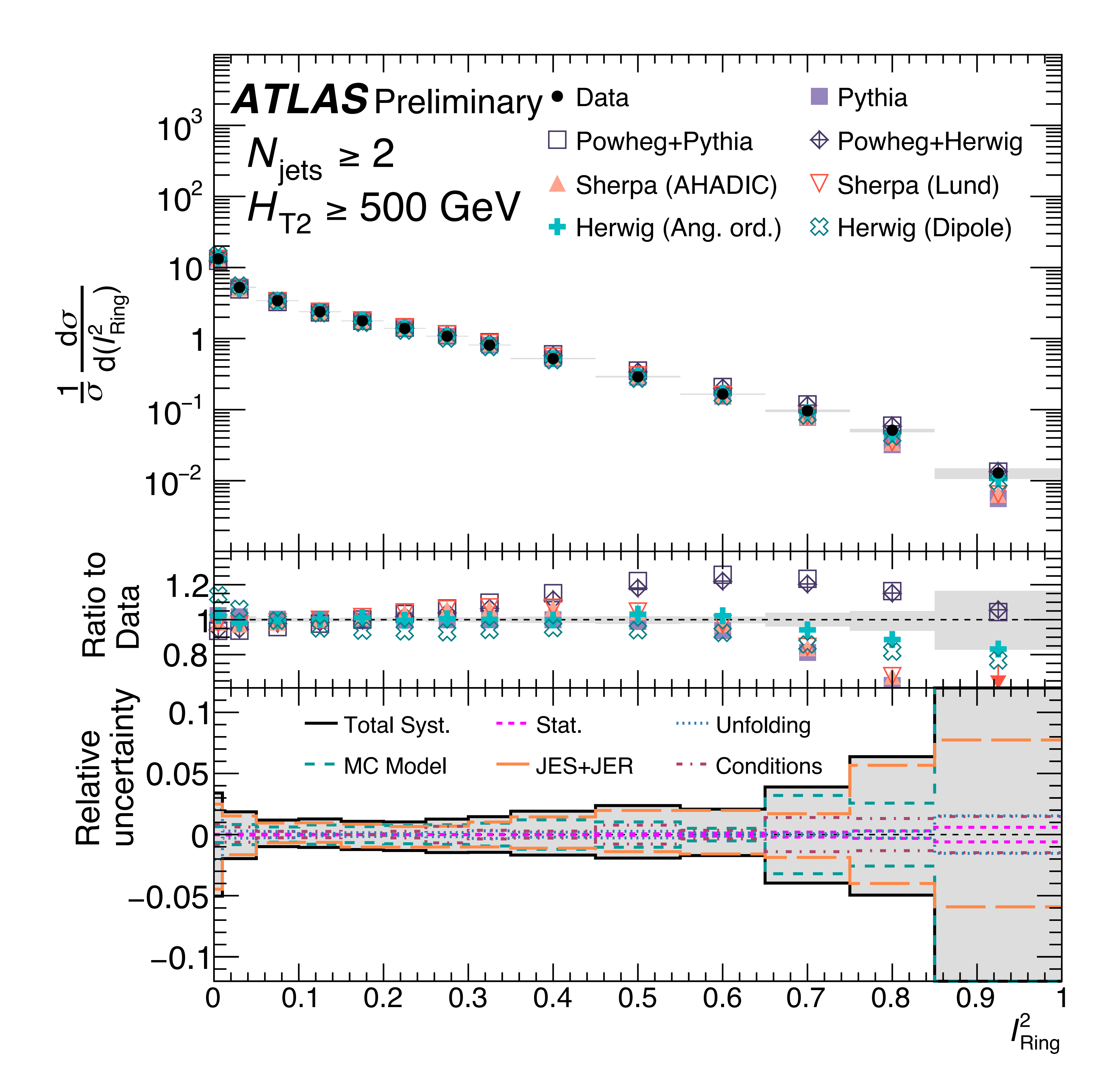
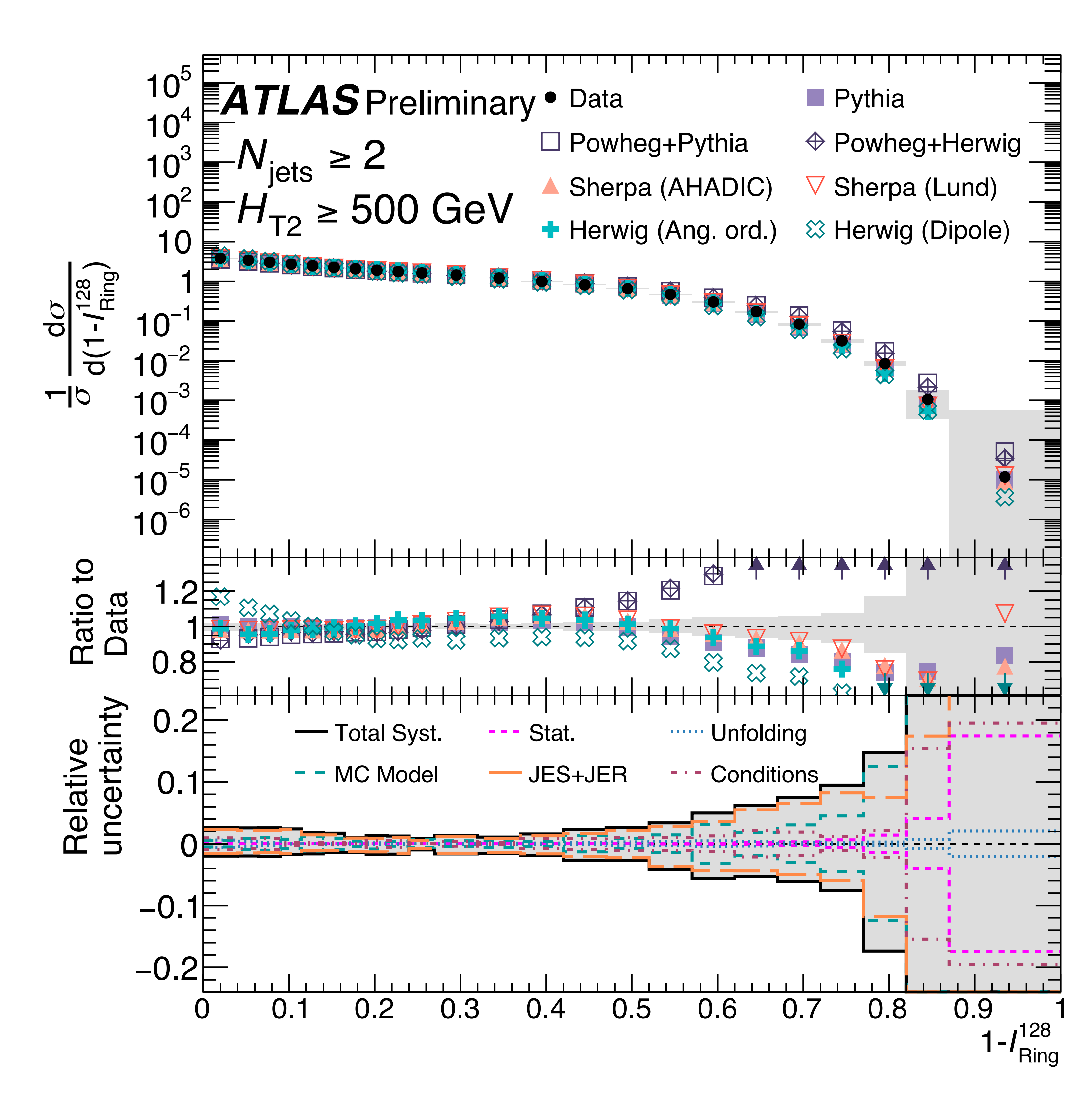




INFLUENCE OF SHOWER MODEL ON JET SHAPE - RINGS



- For the dipole, minimal values are 2 back to back jets. Maximal values are balanced tri-jets.
- MC uncertainty rises as the event becomes more isotropic.
- For the ring, the value used is 1 - EMD, and there is a greater dynamic range.
- Different showering algorithms give strongly diverging predictions.
- Statistical uncertainties become large at high isotropies.



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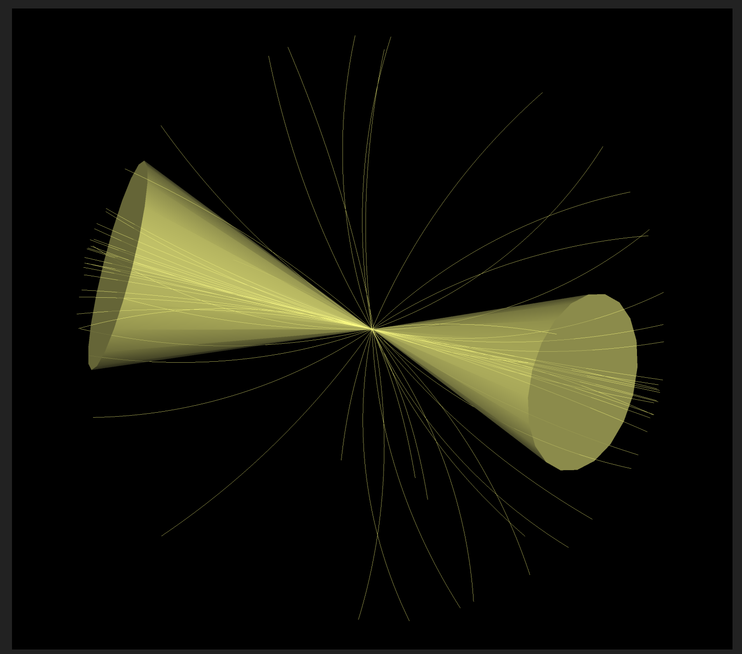

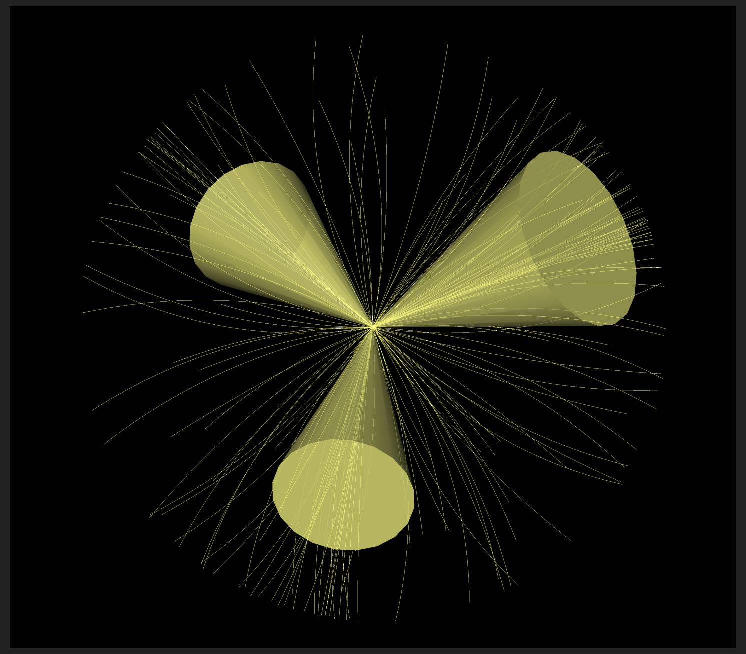

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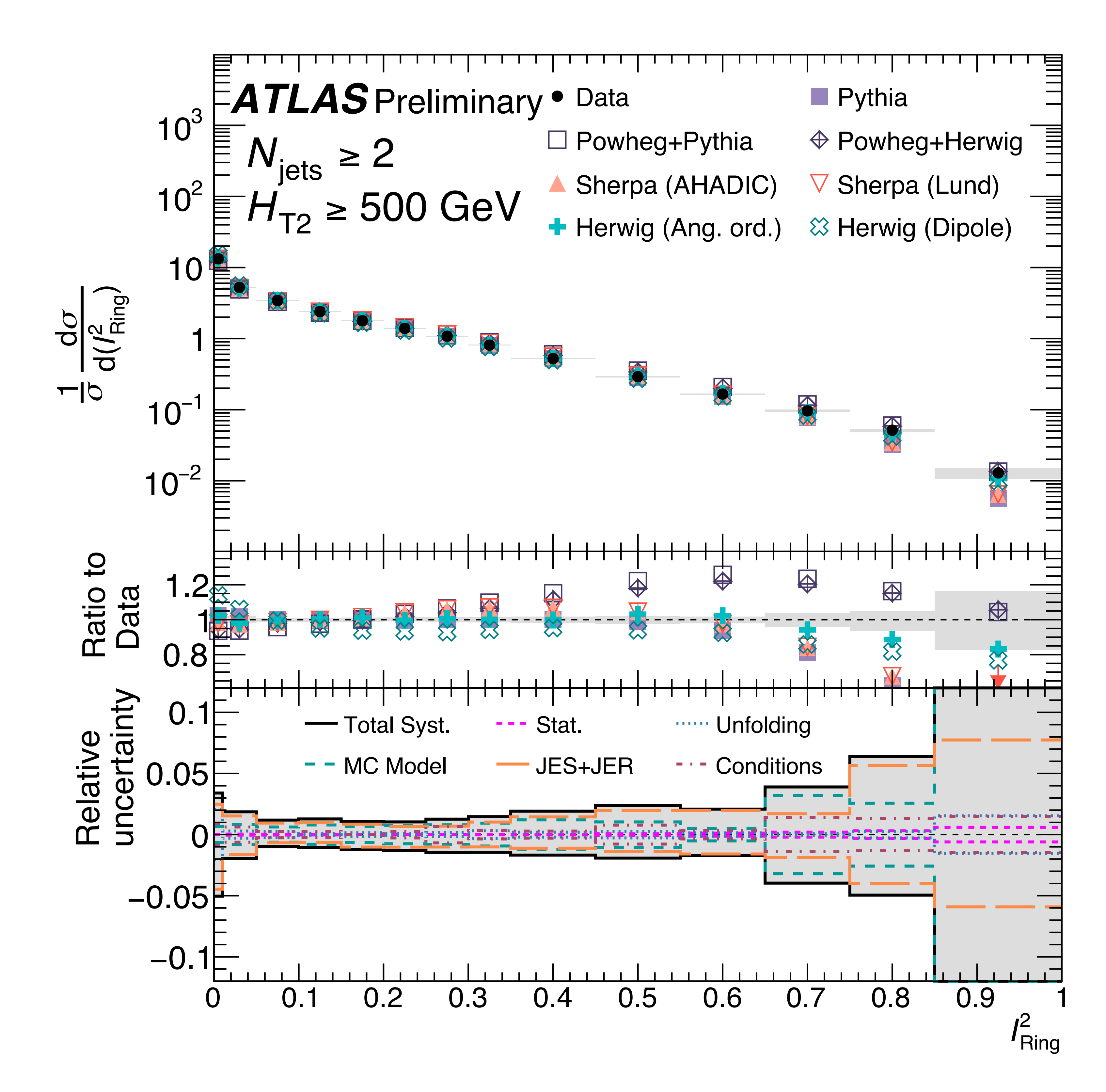

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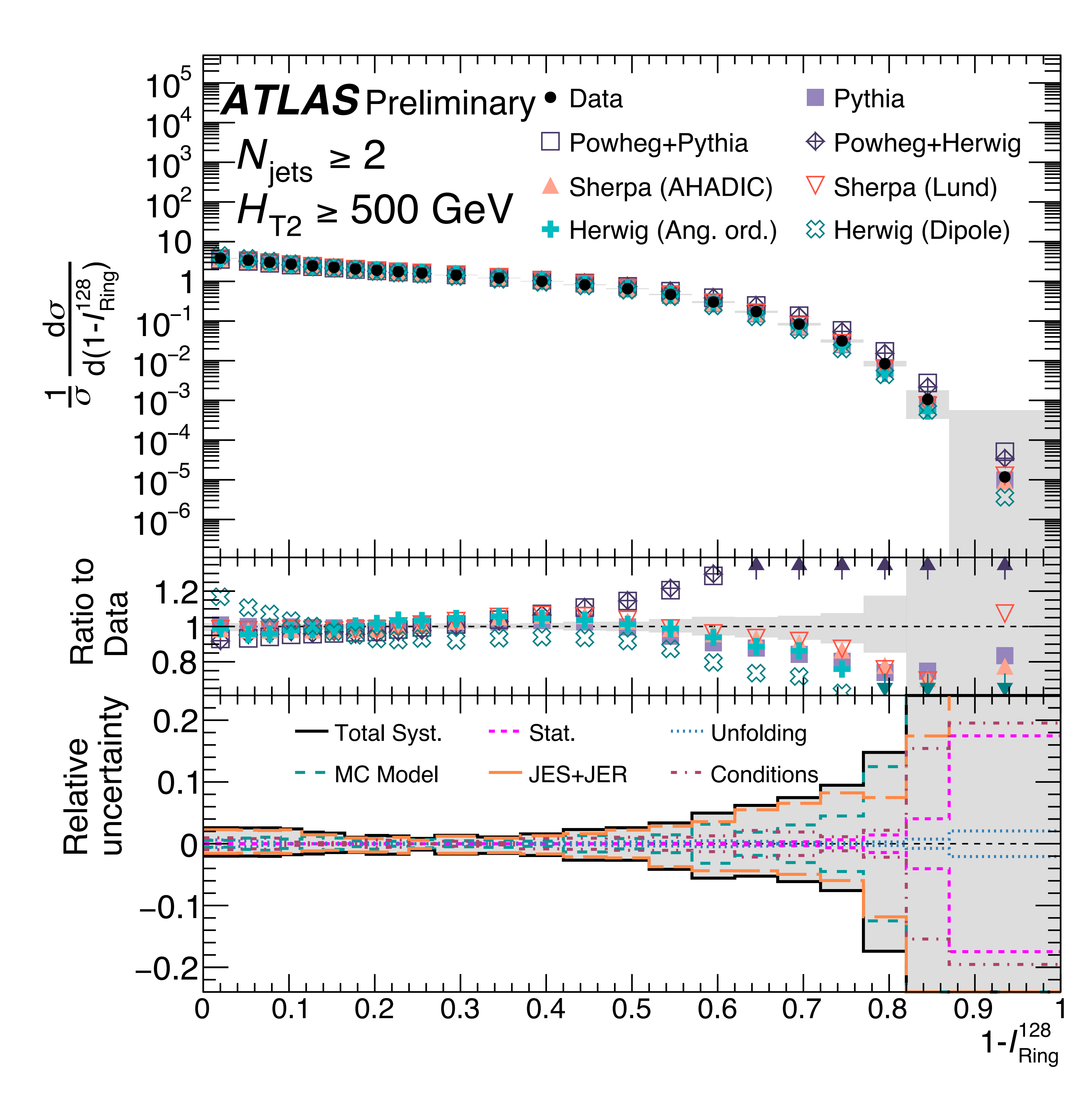

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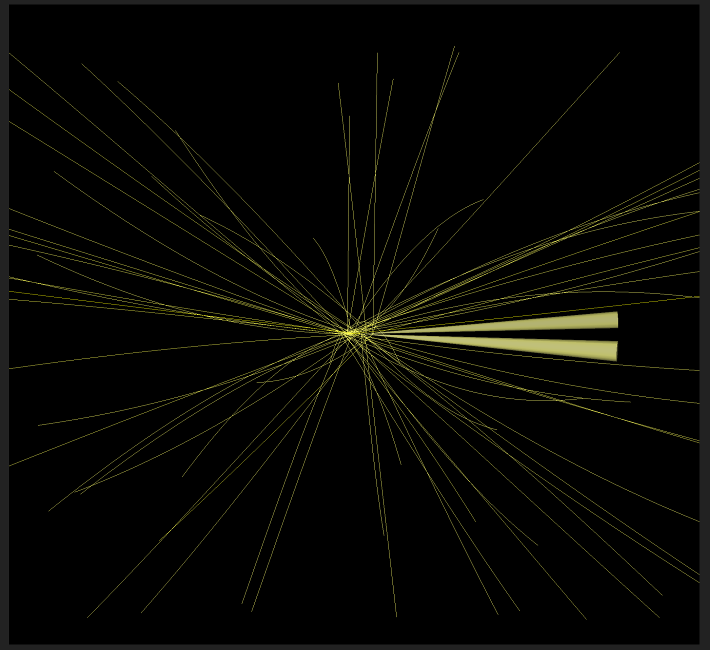
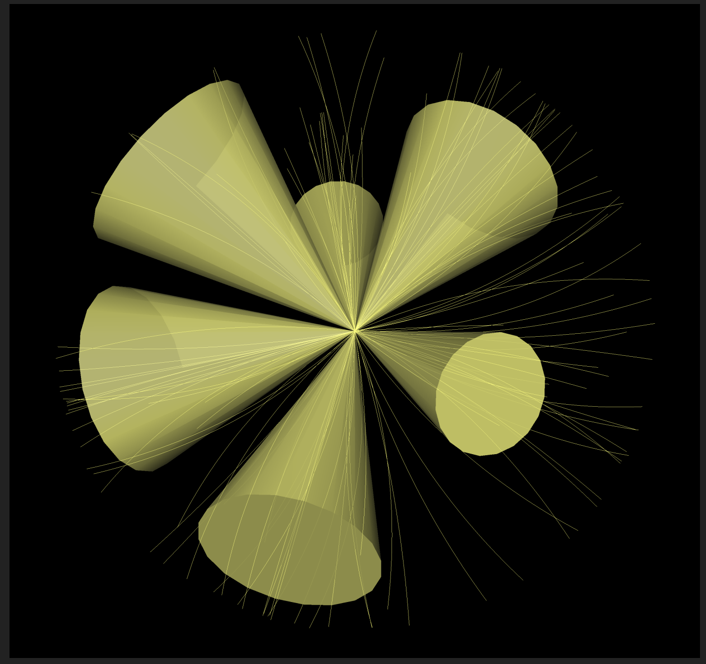
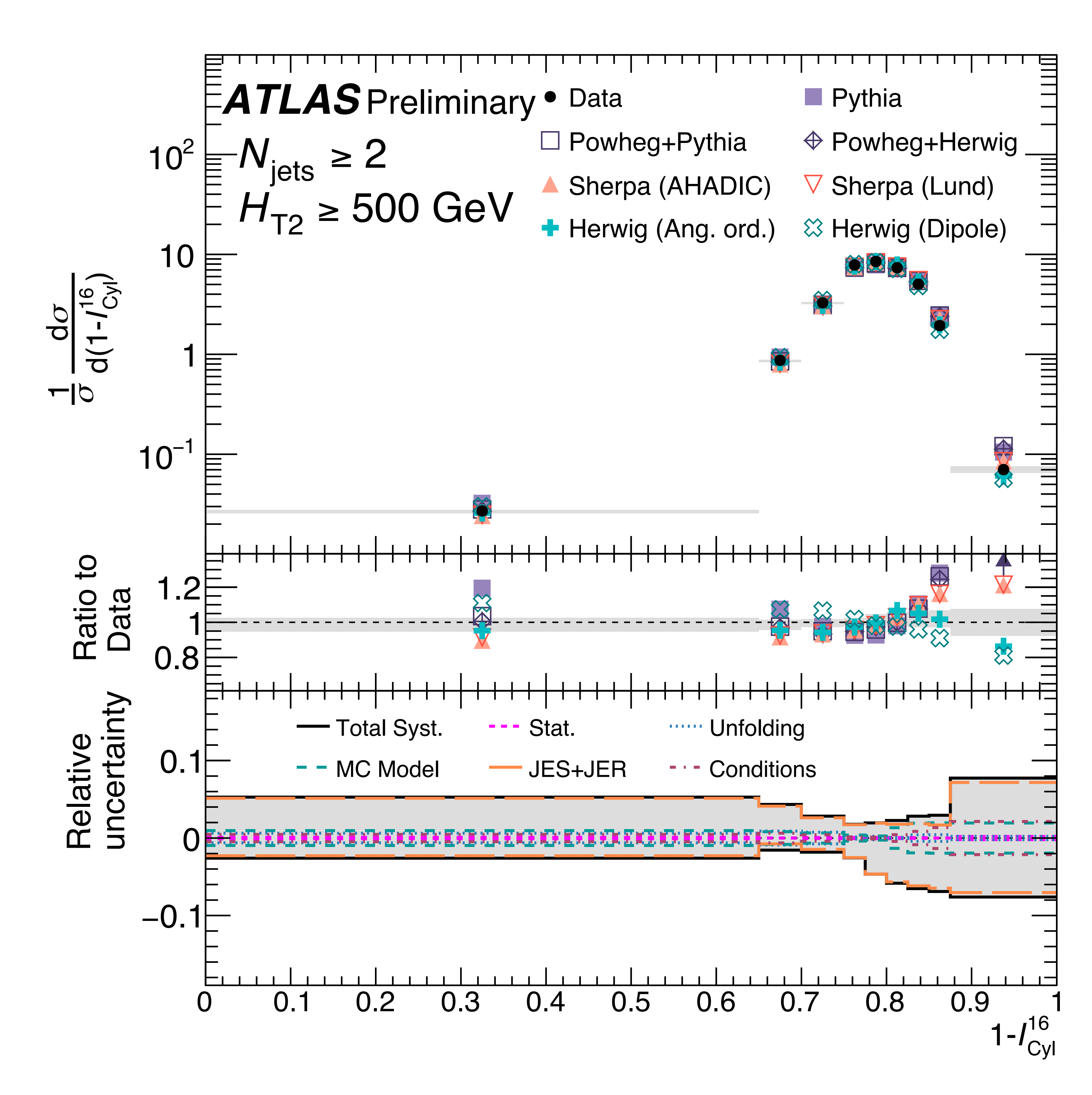




INFLUENCE OF SHOWER MODEL ON JET SHAPE - ISOTROPY

- For the cylinder 3D isotropy, the value measured is 1-EMD.
- The smaller values correspond to highly collimated uneven events, while larger values are those that distribute energy evenly in the barrel.
- A unique shape; the location of the peak is correlated with the average number of jets.
- All the MC generators struggle to match the peak shape.



For this new set of event shapes, no event generator accurately recreates all distributions.

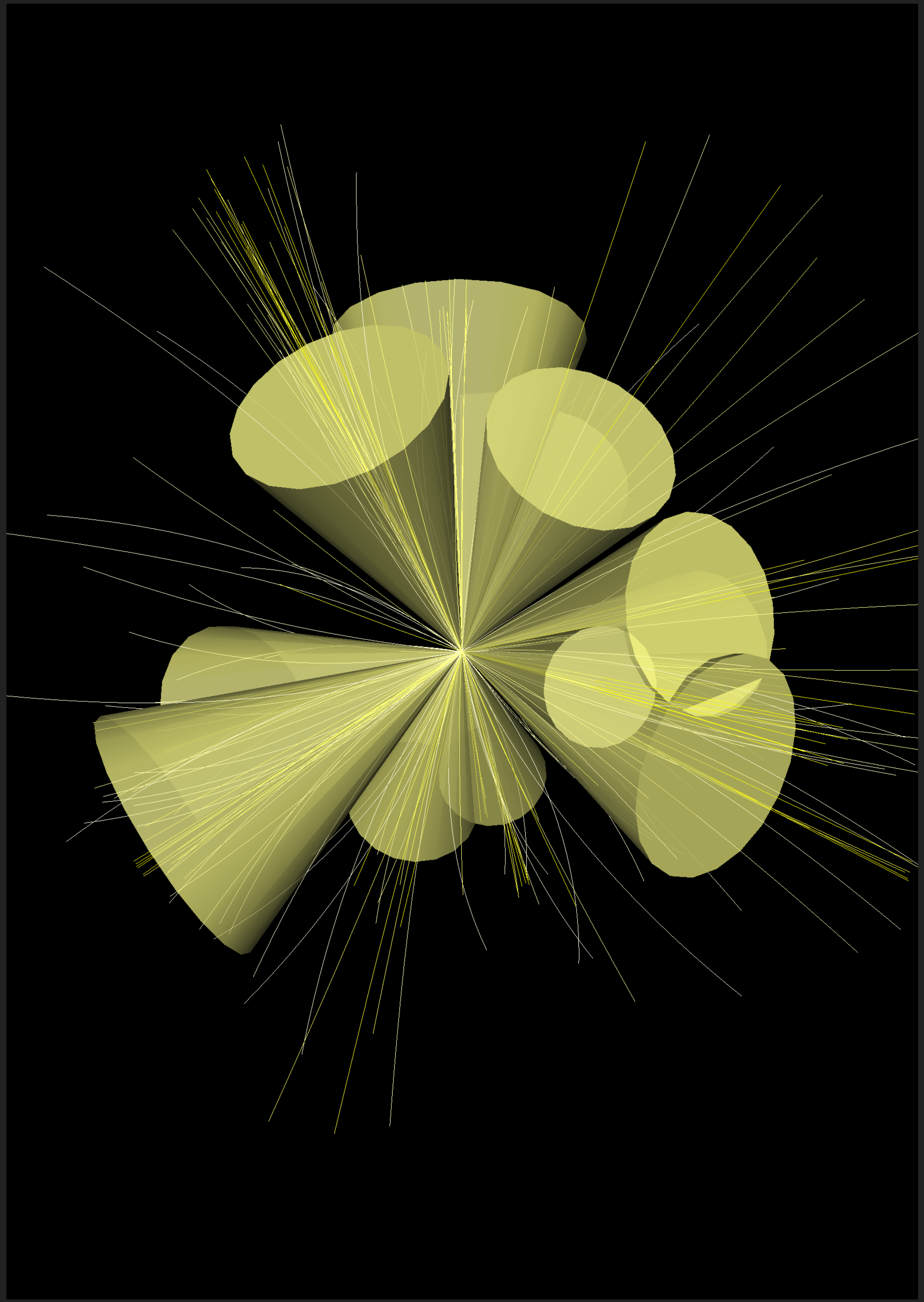
JET SHAPES TEEC AND ATEEC

- cds.cern.ch/record/2846586
- EEC = Energy-Energy Correlation. Product of jet energies, as a function of the opening angle between each pair of objects.

$$\frac{d\Sigma}{d\cos\phi} = \sum_{i,j} \int \frac{E_i E_j}{s^2} \delta(\cos\phi_{i,j} - \cos\phi)$$

- TEEC = Transverse Energy-Energy Correlation. Same as EEC, but only in the transverse plane.
- ATEEC = Asymmetry of Transverse Energy-Energy Correlation. Compares the forward (or acute angle) and backward (or obtuse angle) correlations.

$$\frac{d\Sigma'}{d\cos\phi} = \frac{d\Sigma}{d\cos\phi} - \frac{d\Sigma}{d\cos(\pi-\phi)}$$



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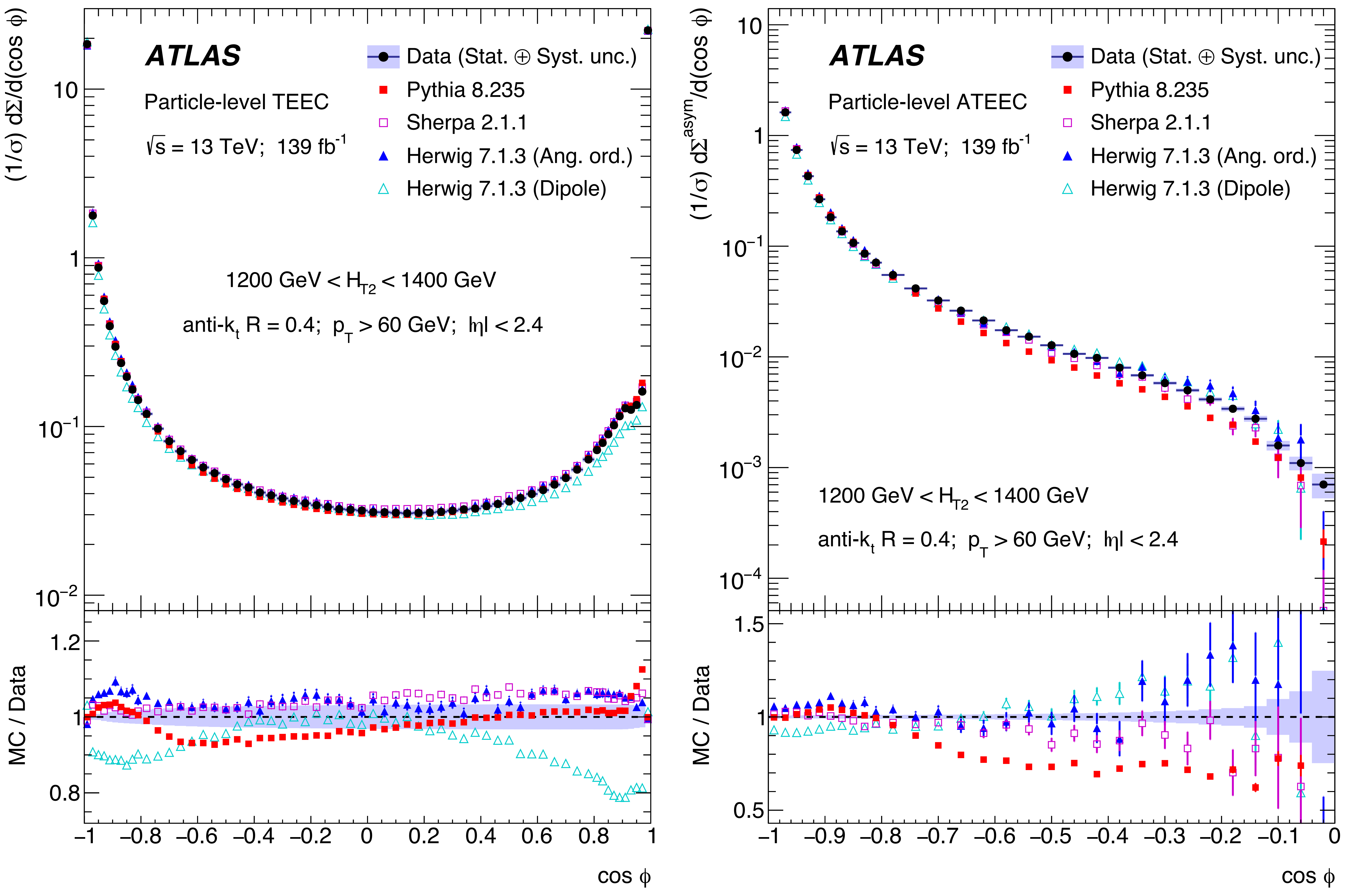
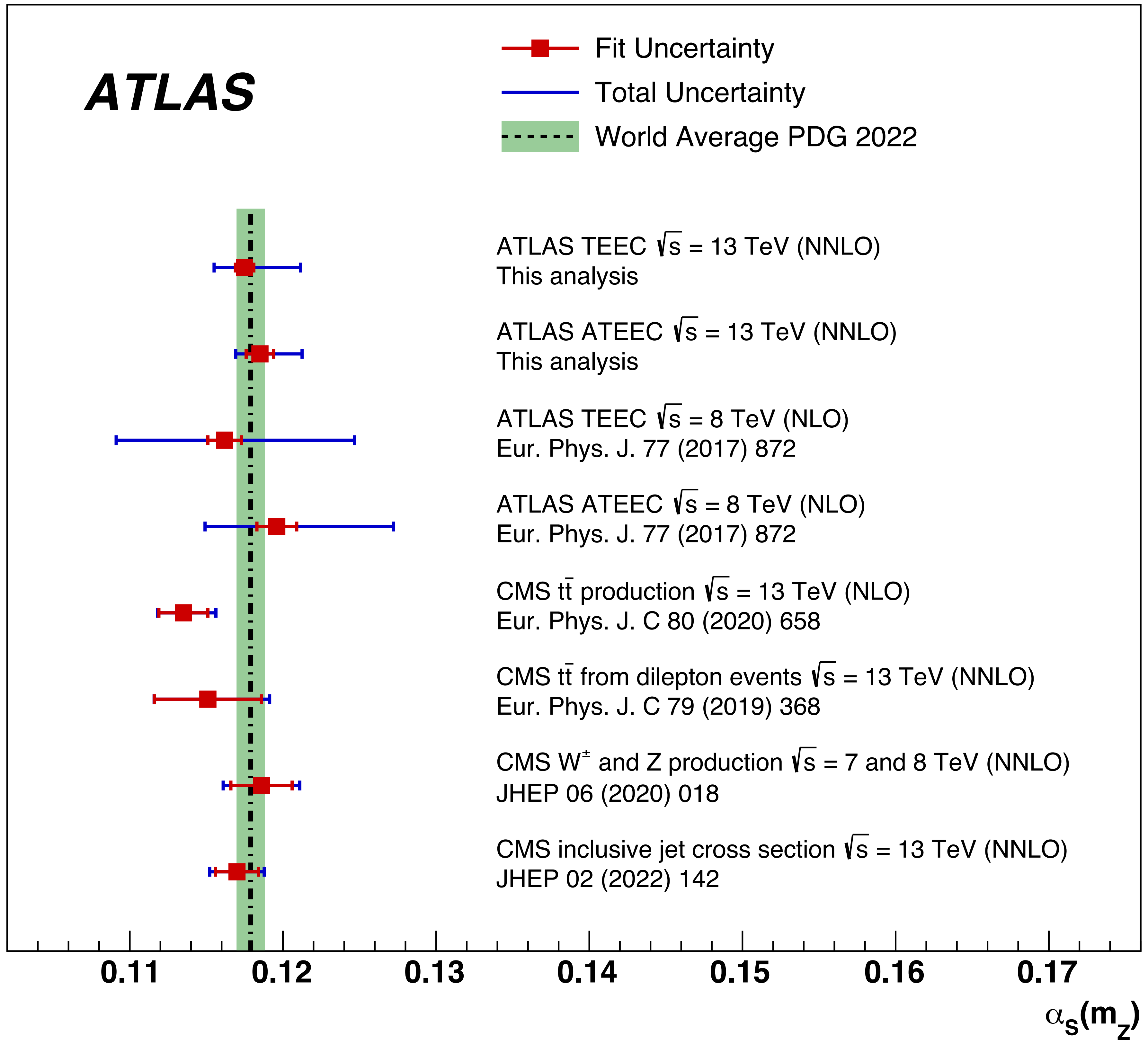
SHOWER MODEL FITS

- Jets are Anti-K_T 0.4
- 3 different MC generators;
  - ➡ Pythia 8; NNPDF 2.3 LO; pT ordered shower.
  - ➡ Sherpa; CT14NNLO; Catani Seymour Subtraction (CSS) shower.
  - ➡ Herwig 7; MMHT2014 NLO; angle ordered
  - ➡ Herwig 7; MMHT2014 NLO; CSS with dipole
- Plots shown are low H_{T2} region, all values of H_{T2} > 1000 GeV considered.
- No single MC method works at all values, but Sherpa and Herwig 7 (angle ordered) are preferred.



STRONG COUPLING CONSTANT

- Predictions for TEEC and ATEEC are fit to each bin of H_{T2} and cos(φ).
- First fit to use NNLO theory predictions for this measurement.
- Value of $\alpha_s(m_Z)$ from TEEC = 0.1175 ± 0.0006 (exp.)$^{+0.0034}_{-0.0017}$ (theo.)
- Value of $\alpha_s(m_Z)$ from ATEEC = 0.1185 ± 0.0009 (exp.)$^{+0.0025}_{-0.0012}$ (theo.)



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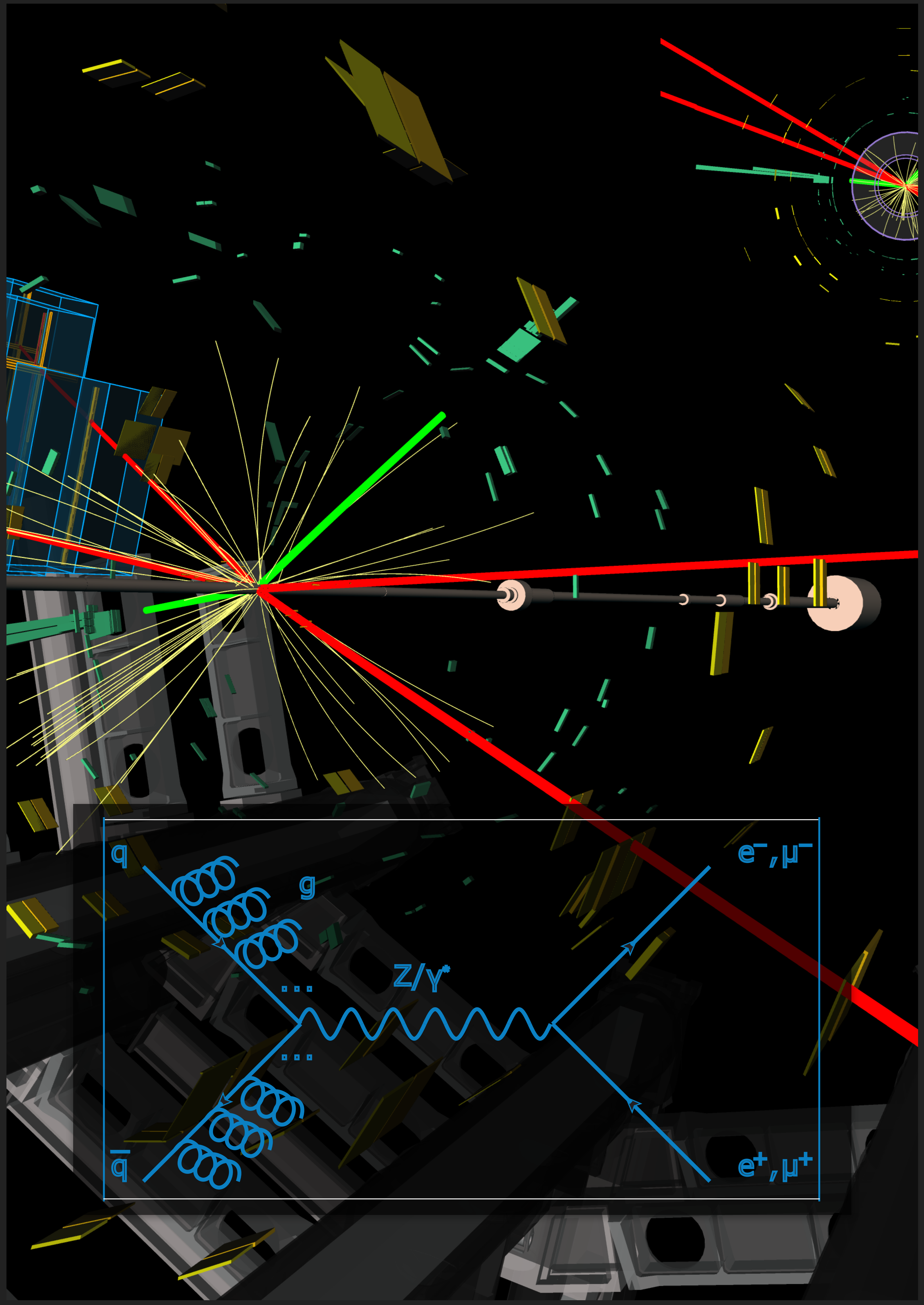
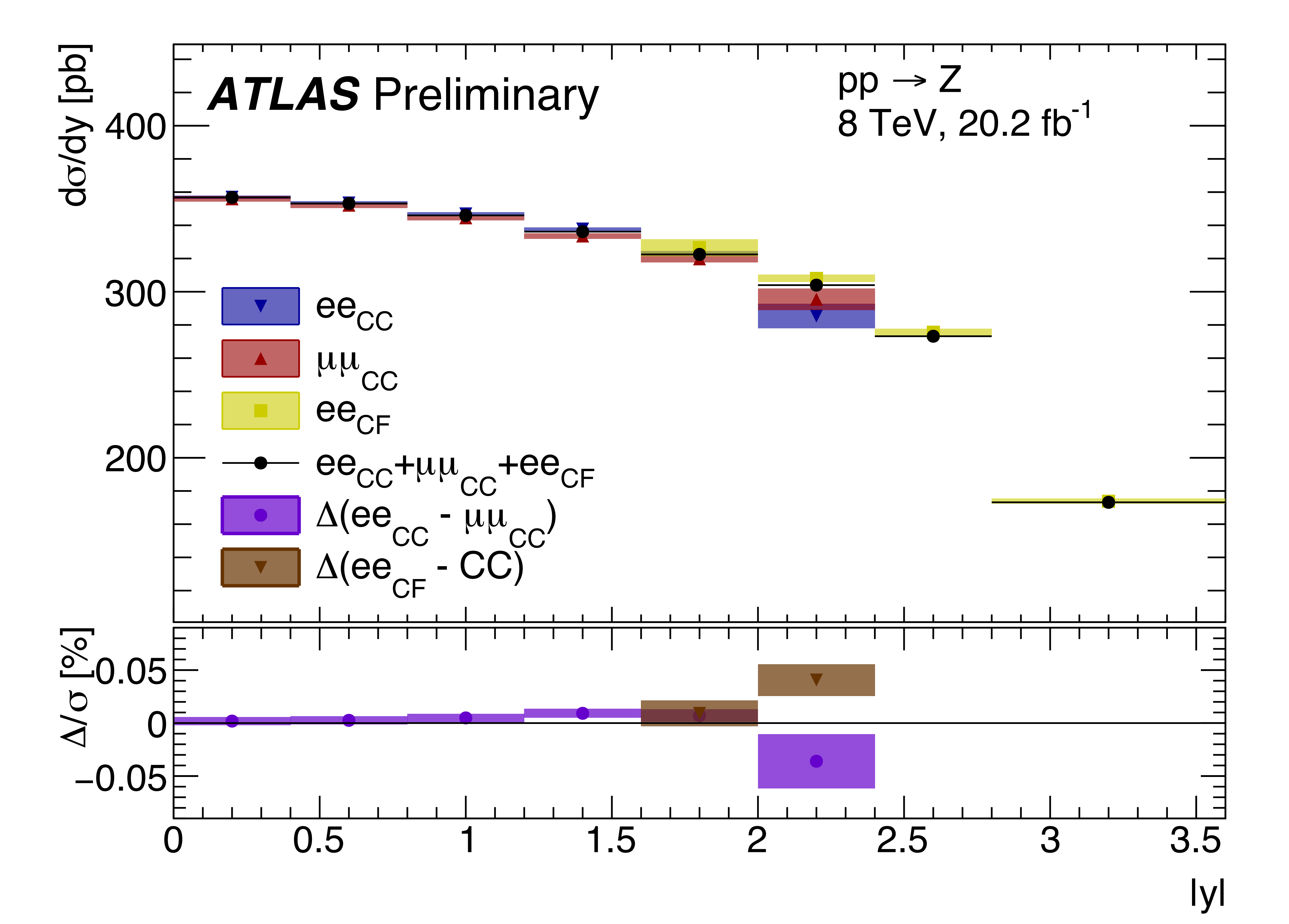
Z BOSON DRELL-YAN

- cds.cern.ch/record/2854867
- Measurement based on 15.3 mill decays $Z \rightarrow e^{-}e^{+}$ or $\mu^{-}\mu^{+}$
- Binned in p_T and rapidity (y).
- Collins-Soper frame is used to simplify the θ - φ dependancy.
- Polynomials with coefficients containing p_T and y dependance are used the create templates for unfolding.
- This fitting method allows use of predictions from the complete lepton phase space.
- Excellent sensitivity to the strong coupling constant.



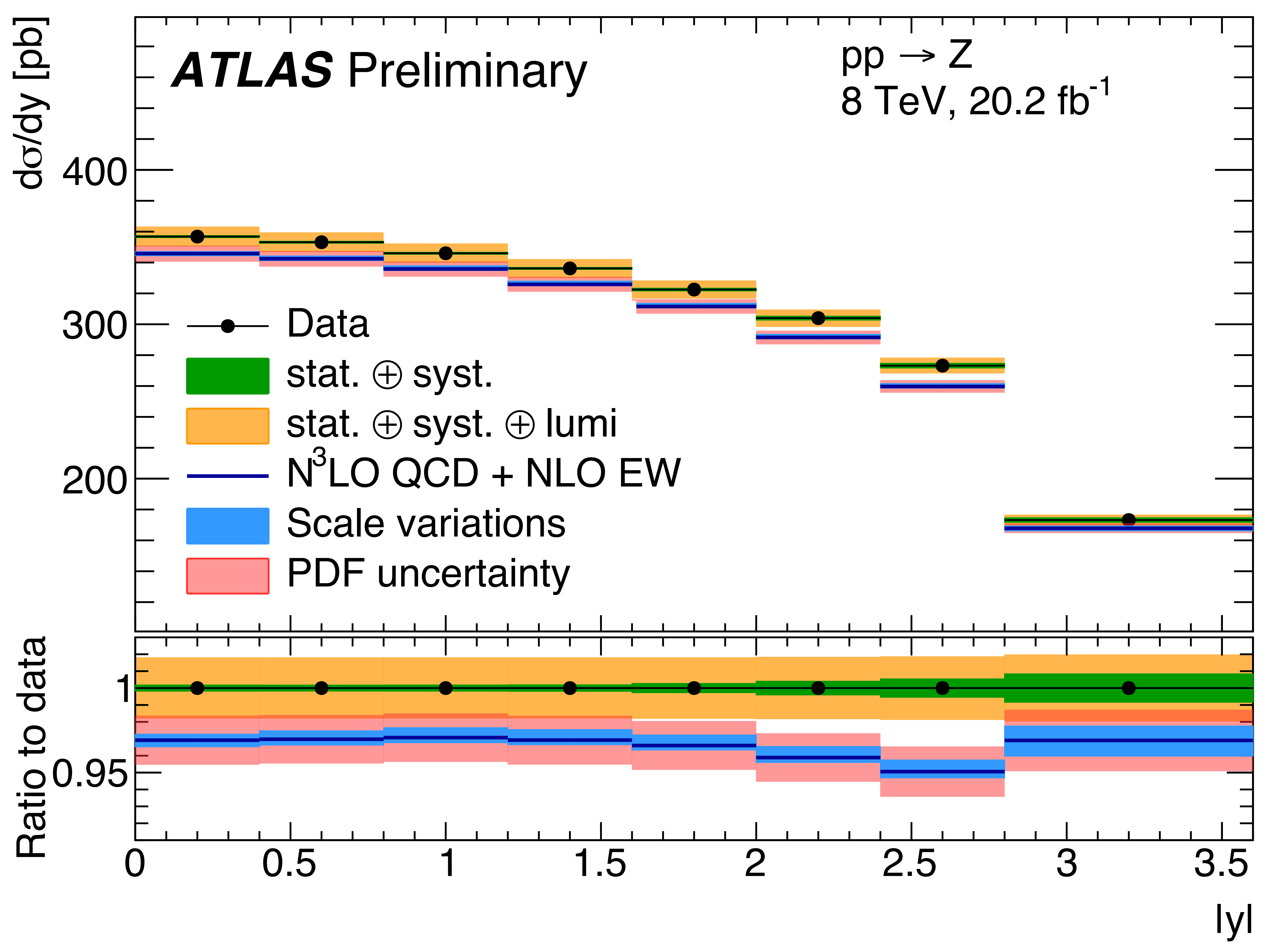
Z BOSON CHANNEL COMPARISON

- Three samples;
  1. Pair of central ($|\eta| < 2.4$) muons; $\mu\mu_{CC}$
  2. Pair of central electrons; ee_{CC}
  3. One central, one forward ($2.5 < |\eta| < 4.9$) electron pair; ee_{CF}
- Require mass near m_Z; $80 < m_{ll} < 100$GeV
- All channels are found to be compatible within uncertainties.



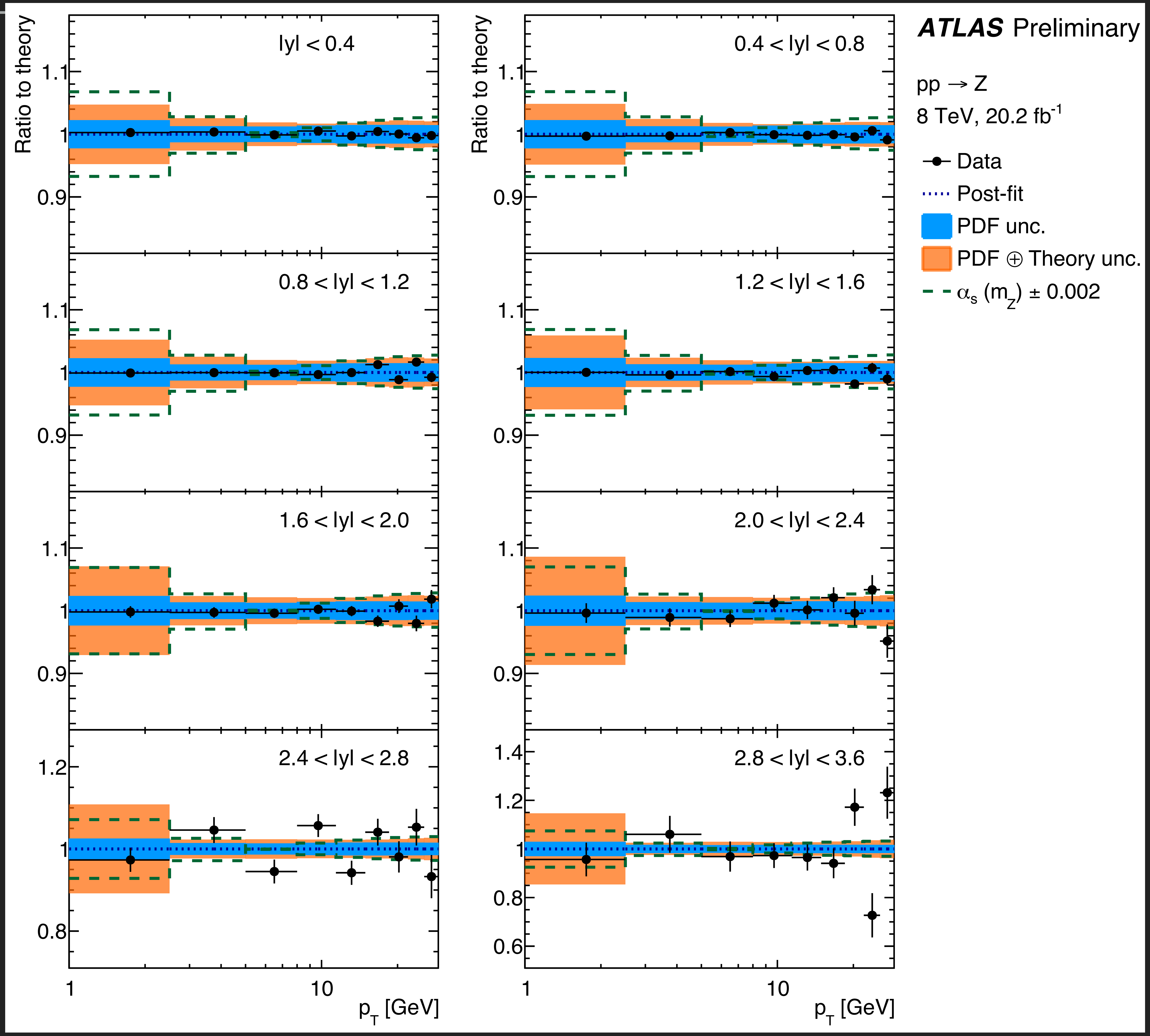
FIT IN RAPIDITY BINS

- Integrating over all p_T bins means that systematic uncertainties dominate.
- Data uncertainties from;
  - ➡ central electron systematics
  - ➡ muon systematics
  - ➡ forward electron systematics
  - ➡ + other smaller contributions
- Some theory uncertainties and some from PDF.
- Acceptable overall fit (p=11%)



FIT FOR STRONG COUPLING CONSTANT

- Fitted in 2D; p_T and rapidity bins.
- Used DYTurbo for theory predicitons.
- Interfaced DYTurbo to xFitter to get fits.
- Resulted in χ^2/dof = 82/72



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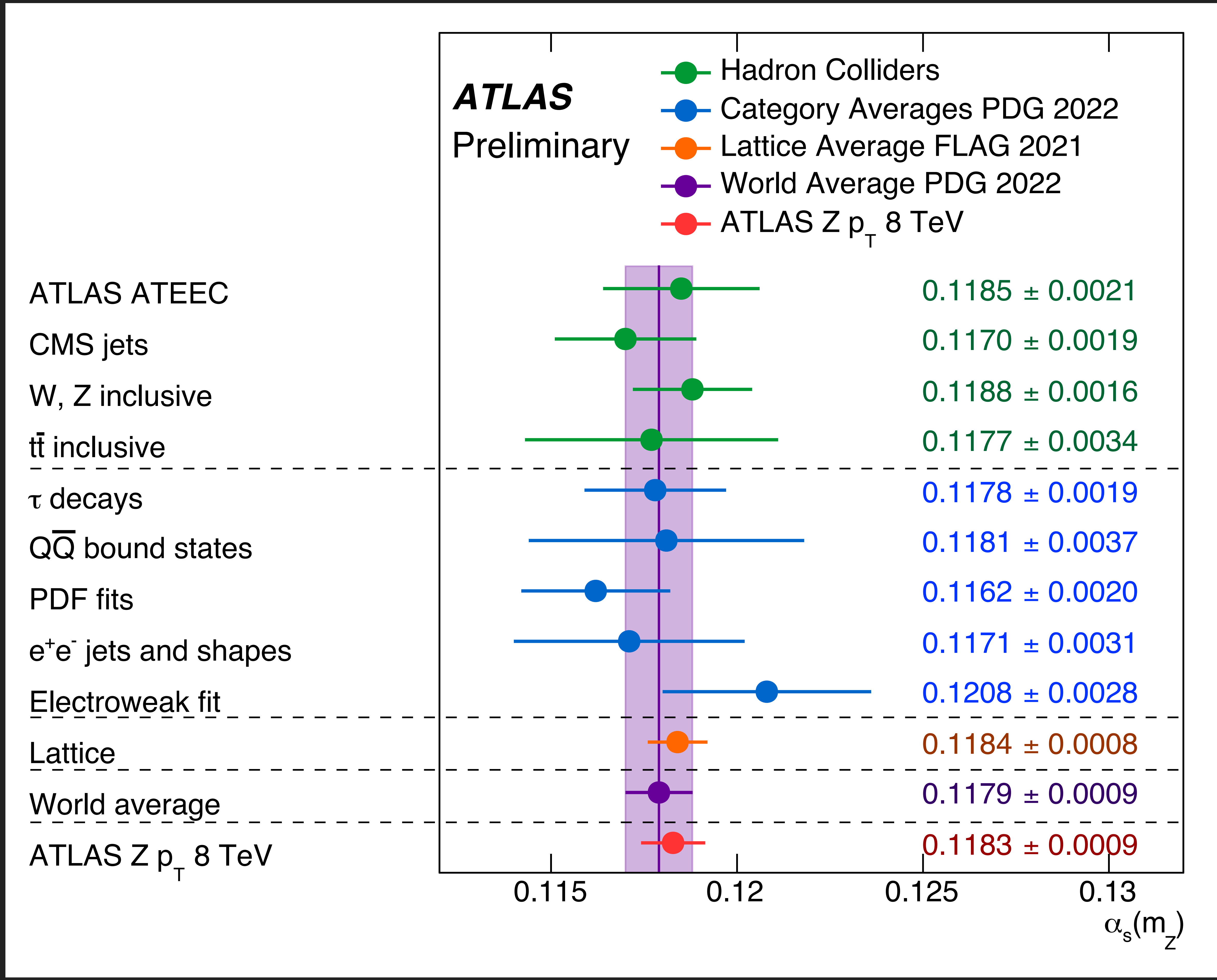
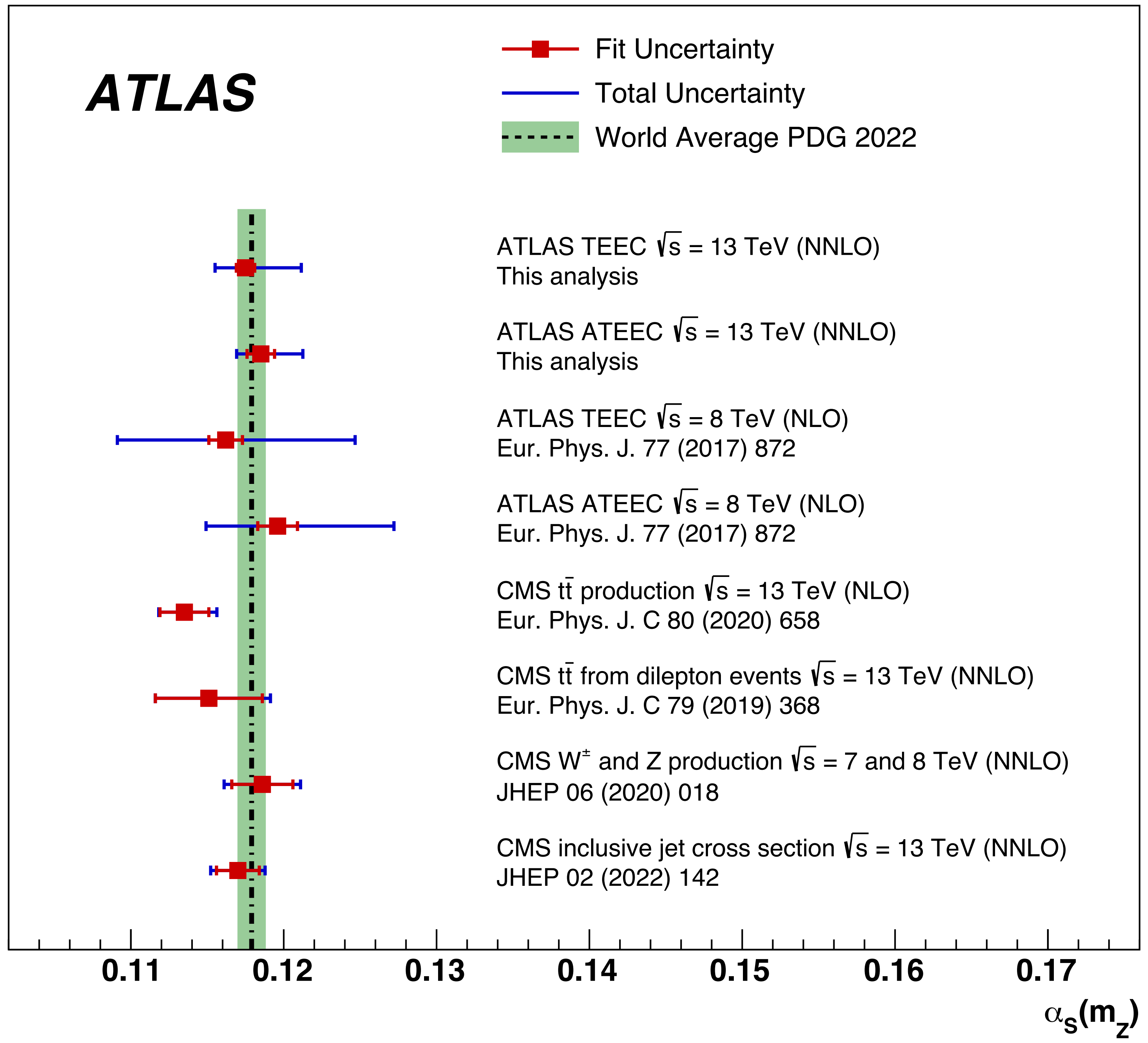
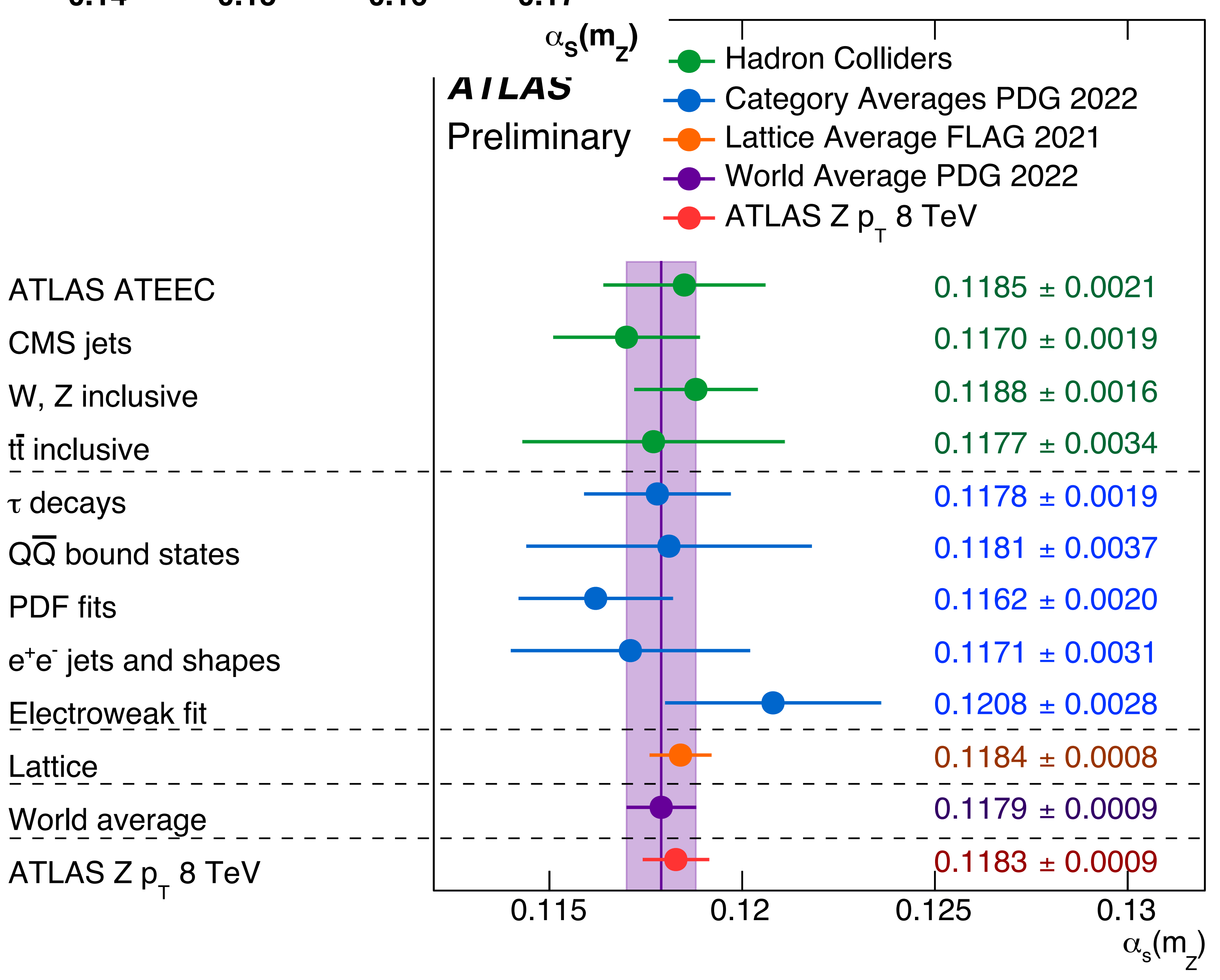
STRONG COUPLING CONSTANT

- Very precise determination of $\alpha_s(m_Z)$
- Avoided excessive theory uncertainties by using low-momentum Sudakov region. Not used in other studies.
- Ultimately dominated by PDF uncertainty.







CONCLUSION

- New event shapes may provide a handle to improve generators.
- The strong coupling constant has been derived from both multi-jet events and Z boson recoils.
- With judicious use of low transverse momentum phase space, The Z boson recoil has yielded the highest precision measurement of $\alpha_s(m_Z)$.

THANK YOU.

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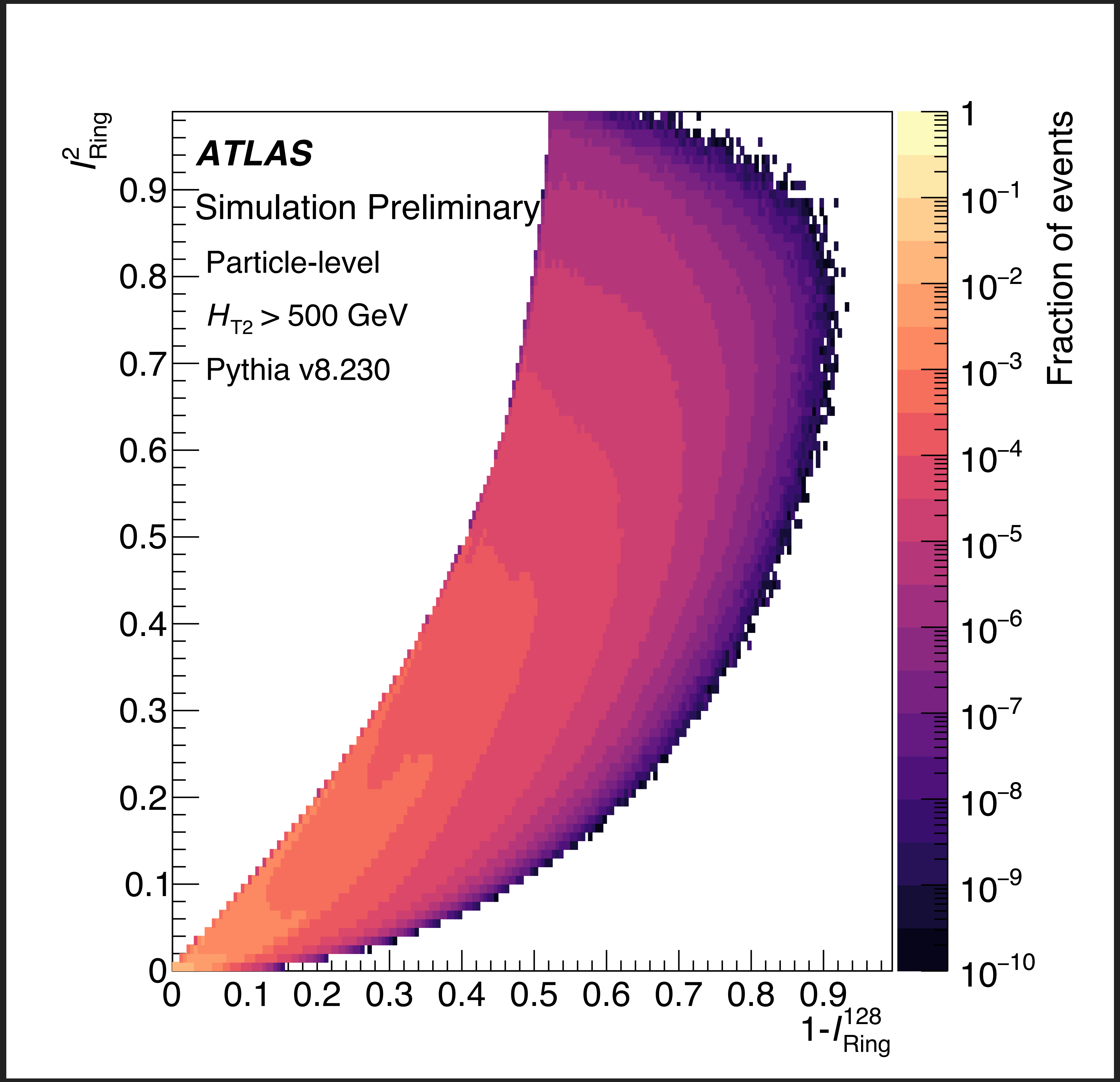
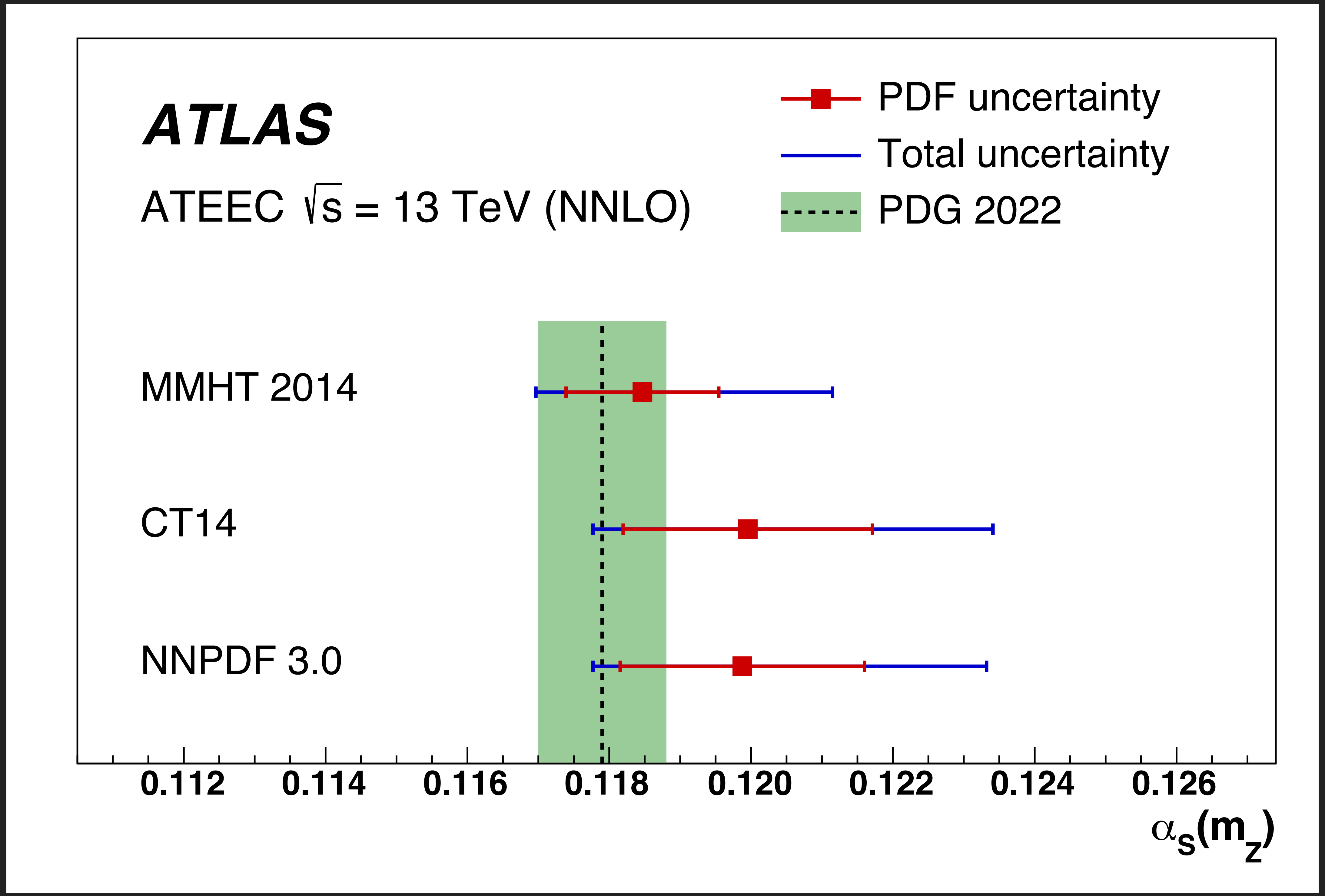
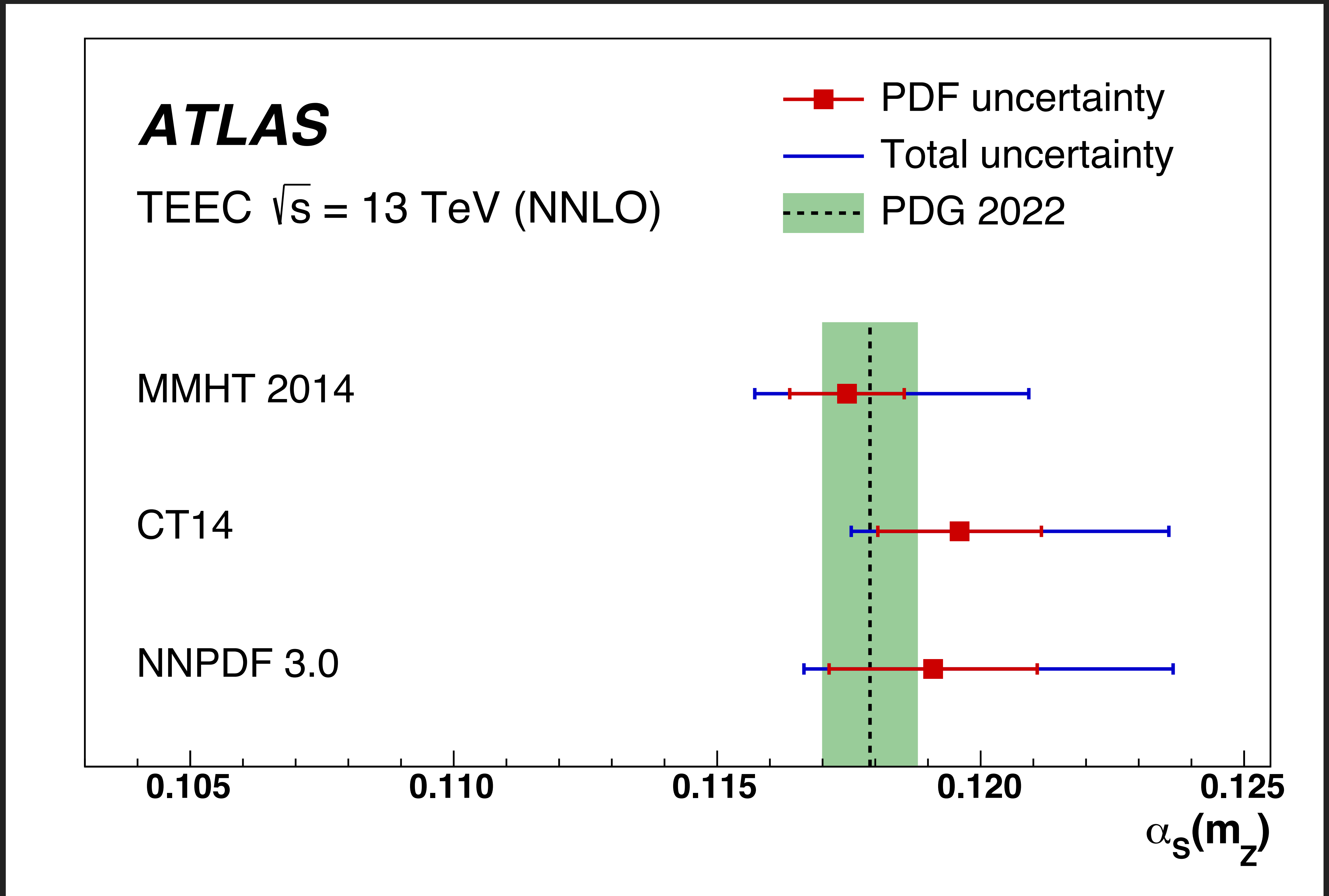
COMPARISON OF CYLINDER AND RING ISOTROPY

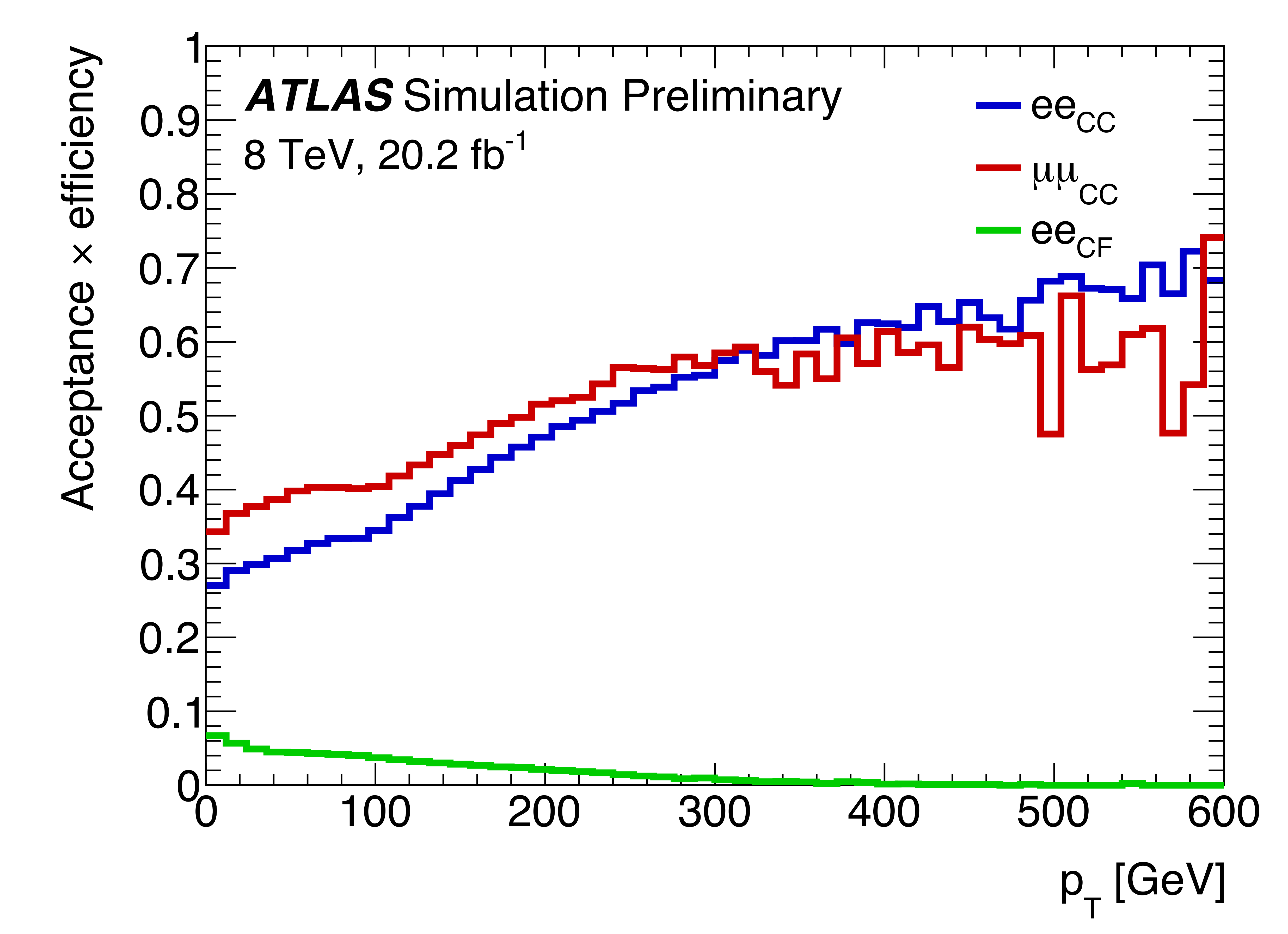


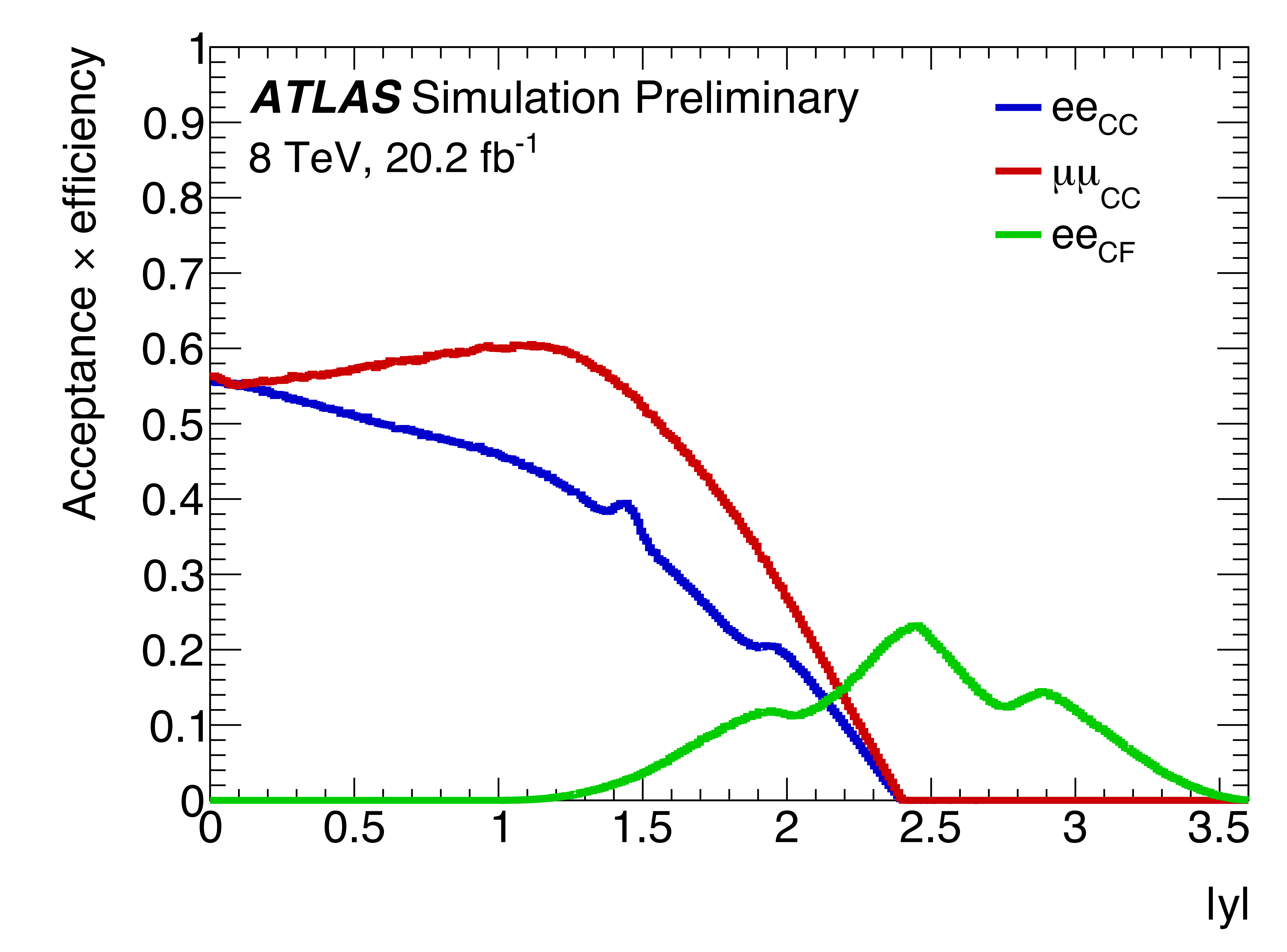
INFLUENCE OF PDF ON STRONG COUPLING





KINEMATICS OF THE Z BOSON CHANNELS





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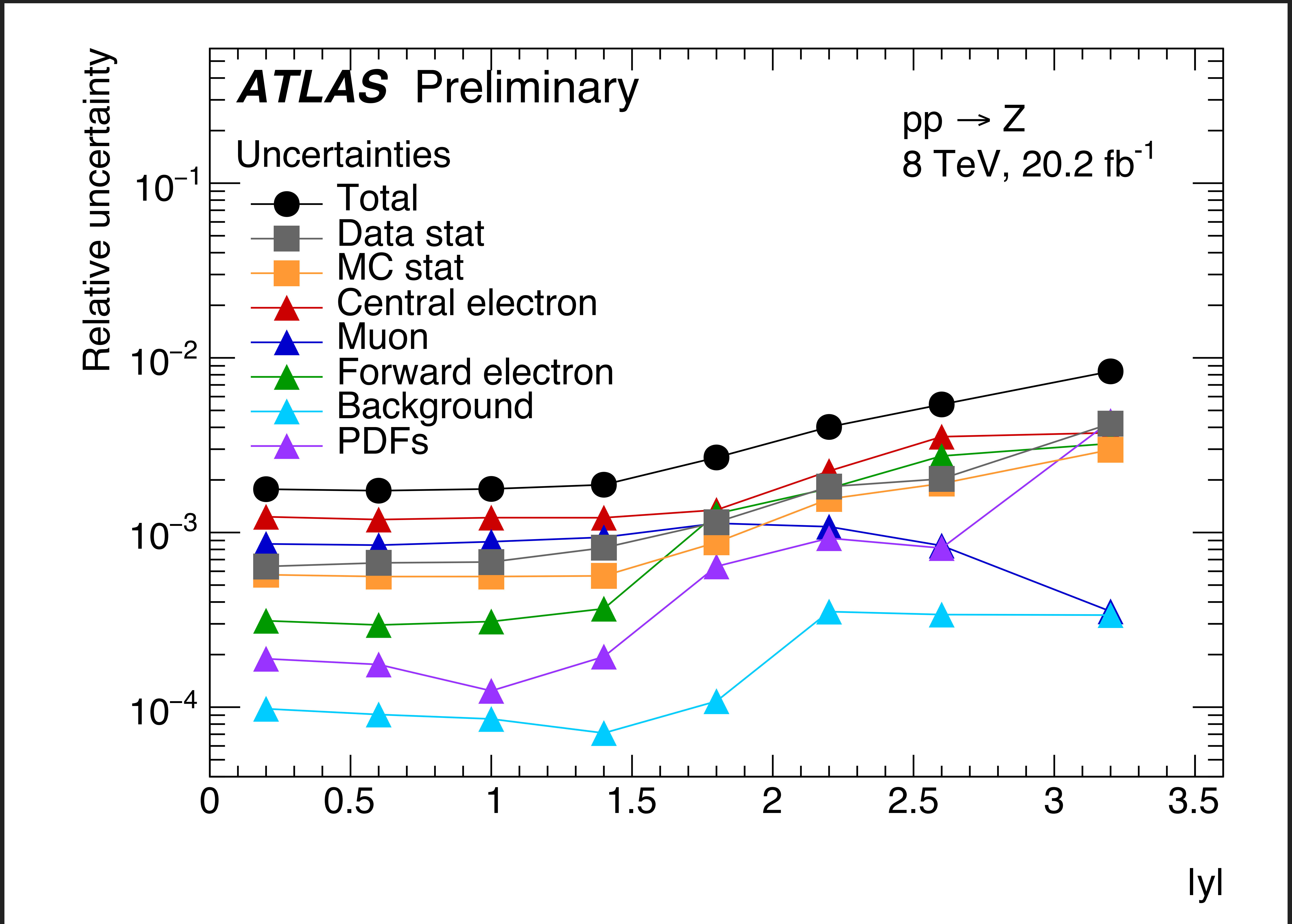
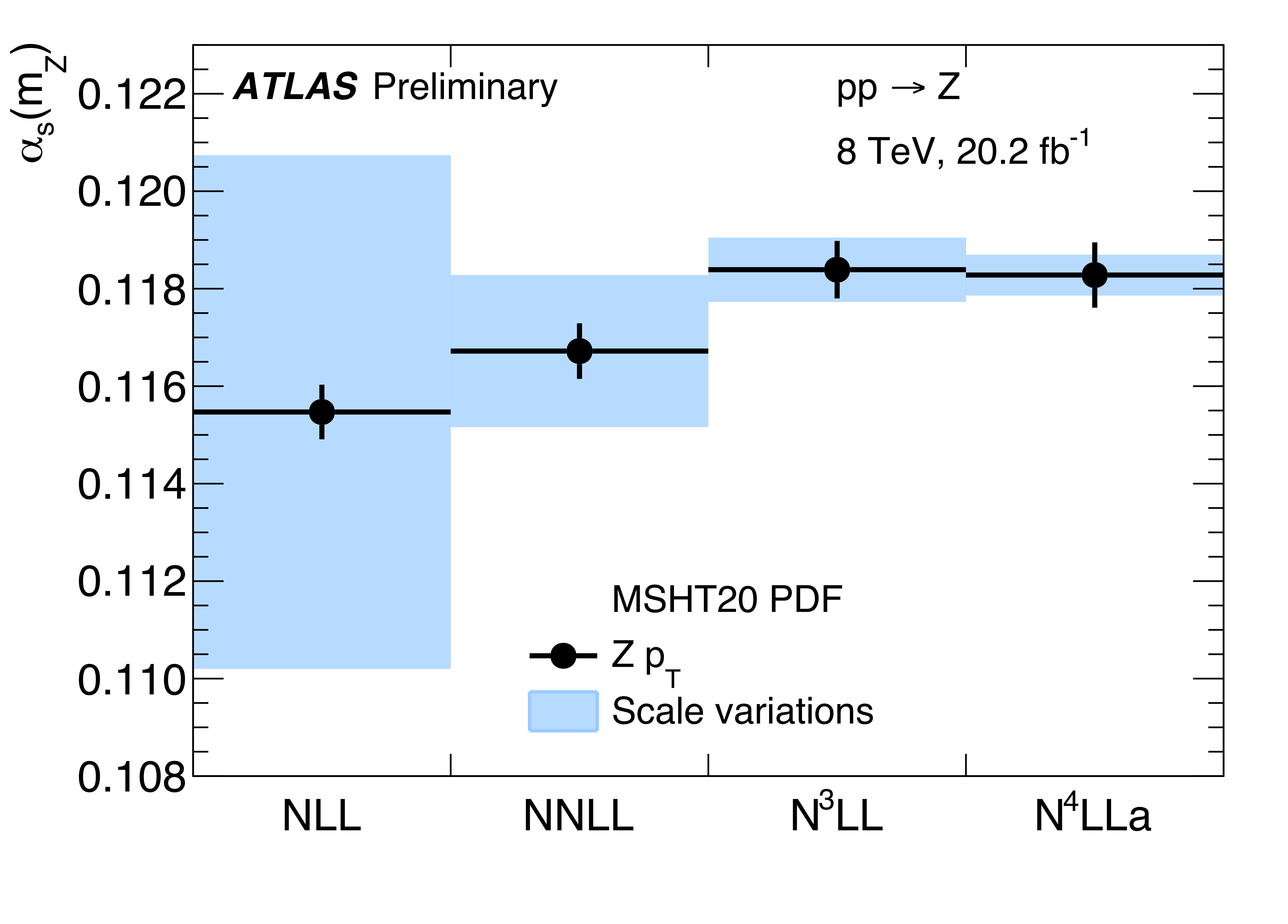
Z BOSON INTEGRATED UNCERTAINTIES.



Z BOSON PDF UNCERTAINTIES FROM SCALE VARIATION.



Z BOSON UNCERTAINTIES ON STRONG COUPLING.

Experimental uncertainty	+0.00044	-0.00044
PDF uncertainty	+0.00051	-0.00051
Scale variations uncertainties	+0.00042	-0.00042
Matching to fixed order	0	-0.00008
Non-perturbative model	+0.00012	-0.00020
Flavour model	+0.00021	-0.00029
QED ISR	+0.00014	-0.00014
N4LL approximation	+0.00004	-0.00004
Total	+0.00084	-0.00088

Strong coupling value = 0.1183

MSHT PDF UNCERTAINTIES

- New generation of PDFs, aN3LO.
- 'a' indicates additional uncertainty (as in the aNNLO PDFs from 2001)
- N3LO information available for DIS cross section computation.
- Worst of the uncertainties have minimal impact on this study.