Kinematic Analysis of Minimum Bias and Hard Probes jet streams at ATLAS-LHC

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With the guidance and support
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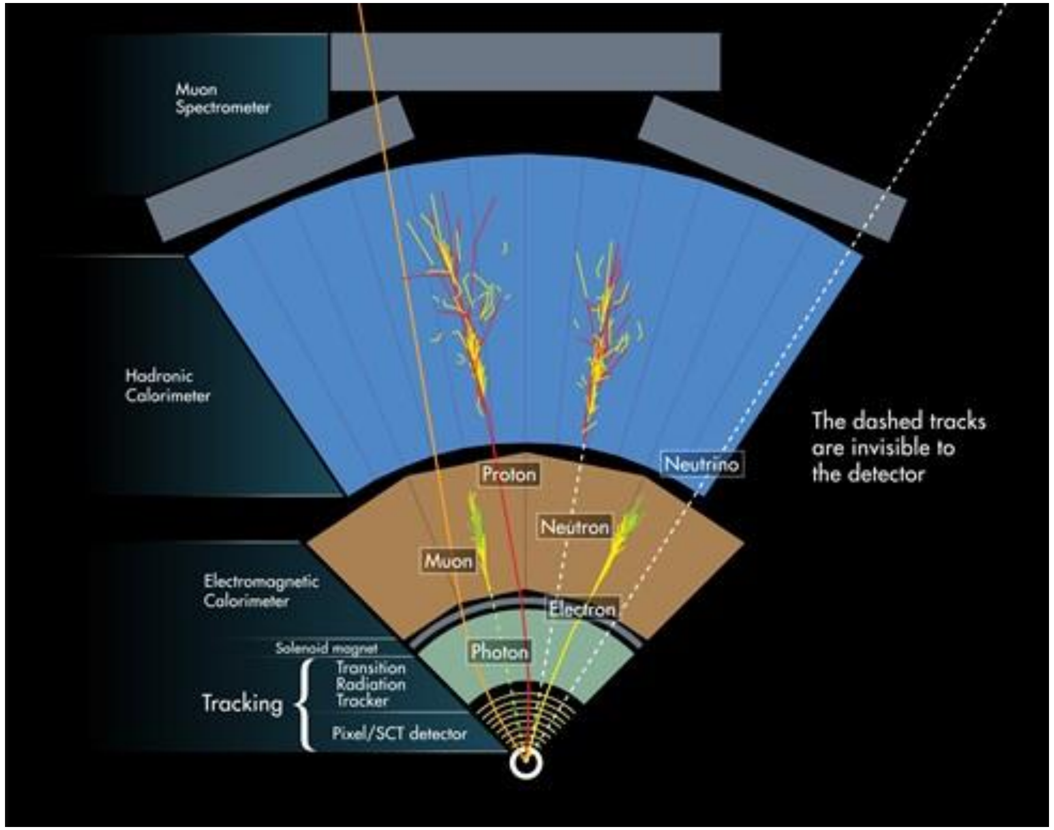
Introduction – ATLAS experiment

- ATLAS is a general-purpose experiment in the LHC, taking advantage of its wealth of sensors to accumulate large sets of data.

- The detector is used both for analysis of p-p and heavy nuclei collisions.

- The high energy of the collisions (when lead nuclei are used, this energy is 5.5 TeV per nucleon pair), requires the very sensitive set of various sensors present.



How ATLAS detects particles: diagram of particle paths in the detector

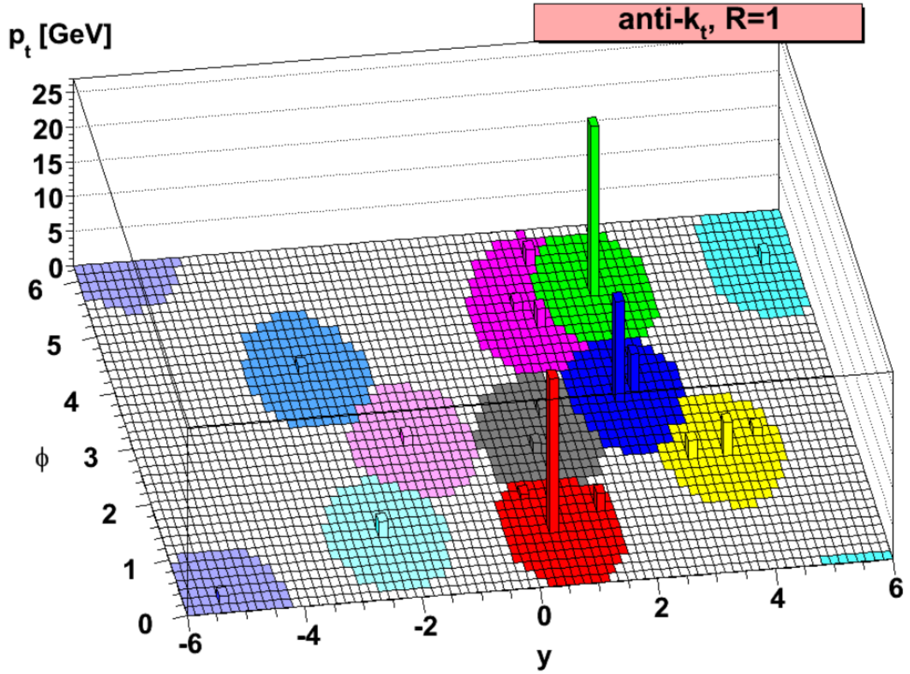
https://cds.cern.ch/record/1505342?ln=pt

Jets

- From the energy distribution detected in the sensors of the detector (around the colliding beams), jets (bunches of collimated particles) can be defined, pointing to the existence of point-like streams of particles as a consequence of the collisions.

- These jets are separated and delimited with the aid of algorithms, and the chosen one for this data set was an anti-k algorithm, constructing somewhat circular jets, mostly around hard scattering events.

- Various snapshots of a collision are taken, these being called events, and in each of these the jets are constructed from the energy deposits.



Jet construction with anti-k algorithm

Cacciari, Matteo, Gavin P. Salam, and Gregory Soyez. "The anti-kt jet clustering algorithm." Journal of High Energy Physics 2008.04 (2008): 063.

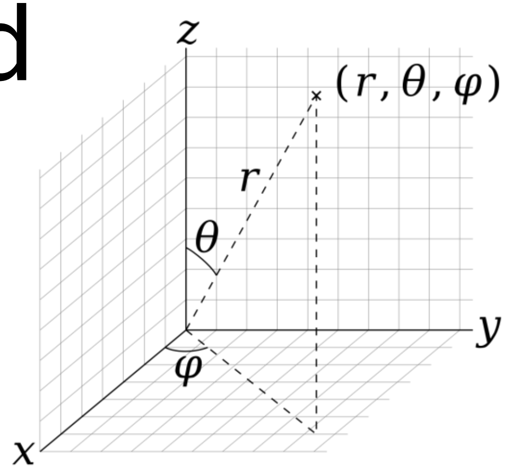
Jets - continuation

- In heavy nuclei collisions, in the short period after the beams' impact, a Quark-Gluon Plasma (QGP) is formed, where scattered partons linger in a dense and hot environment.

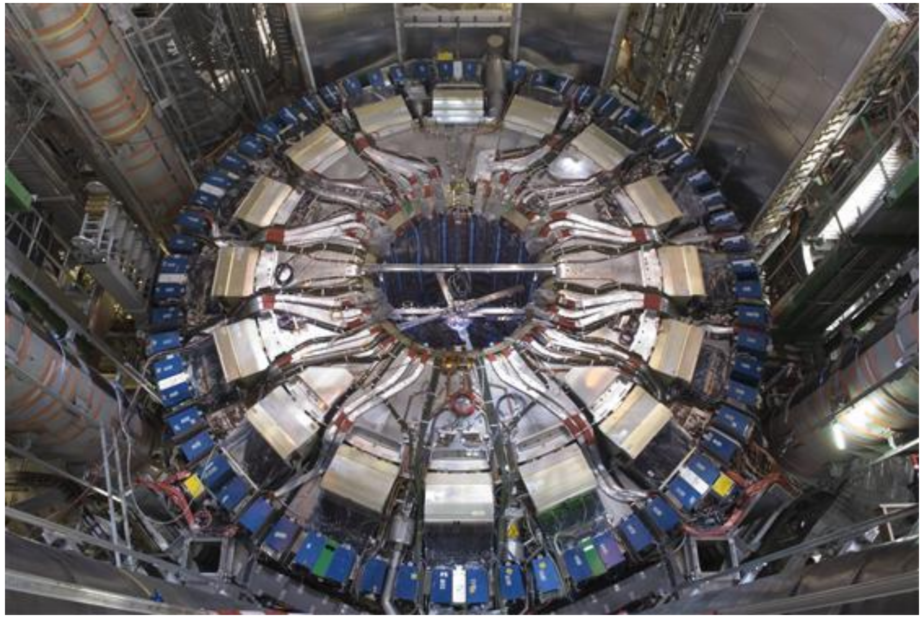
- The jets observed are affected by this medium, one such interaction/consequence being the reduction of the number of detected jets at a given transverse momentum, due to parton energy loss. The discrepancy between predicted and observed allows insight into the QGP.

- While it is expected that only hard scattering is responsible for jet production, soft scattering may induce the algorithmic construction of false jets, which, when analyzed, would reveal the presence of inexistent particles, so filtering is required.

ATLAS experiment – Coordinates used



- The z axis is defined as the direction of the beams at the detector
- Φ is the azimuthal angle of the particles detected around the cylindrical collider.
- θ is the polar angle of the ejected particles, being null when these are aligned with the positive direction of the beam axis
- η is called pseudo-rapidity, defined as $\frac{1}{2}\ln\frac{E+p_z}{E-p_z}$, p_z being the momentum of particles projected on the beam axis. In the case of high-energy particles, this can be approximated as -ln[tan(θ/2)].



Calorimeter insertion between toroids in the ATLAS experiment detector - https://cds.cern.ch/images/CERN-EX-0607014-02

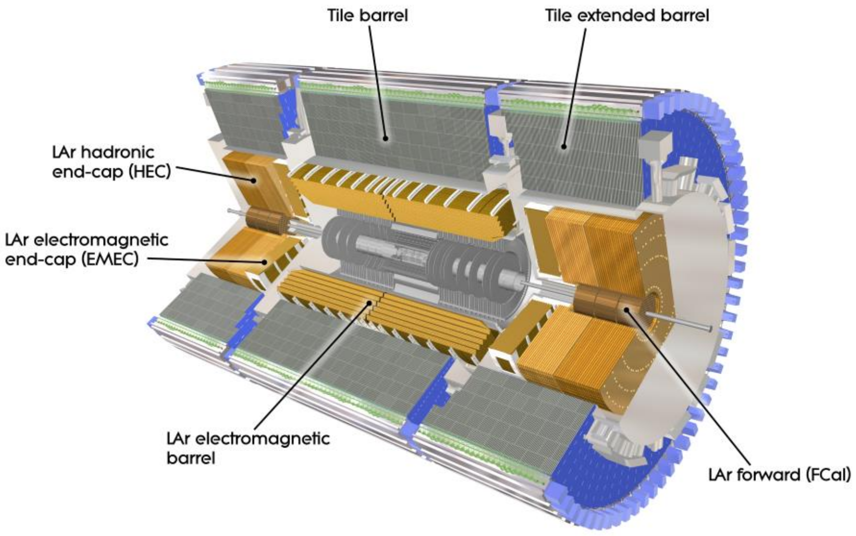
ATLAS experiment – Kinematic variables

- The Liquid Argon Forward Calorimeter (FCal) is integrated in the end-caps of the detector, and registers FCal_Et – Transverse Energy per event (a snapshot of the collision);

- pT – Transverse Momentum is the jet variable measuring t magnitude of momentum projected on the x-y plane;

- NPV – Number of Primary Vertices (a primary vertex represents an initial collision point);

- μ – Number of visible p-p interactions per bunch crossing;



Computer Generated image of the ATLAS calorimeter

https://cds.cern.ch/images/CERN-GE-0803015-01

Analysis methodology

- The data analyzed was from one run (the 2022 Pb+Pb pilot run), using Minimum Bias Triggers (MB) and Hard Probes Triggers (HP) – the latter was analyzed with 3 different software releases.

- Histograms of jet variables pT, Φ and η were produced, using the ROOT package and LIP Pauli machines – dividing the jets in 3 groups: inclusive, leading and sub-leading (according to their pT).

- Cuts were applied to the jets according to selection criteria regarding FCal_Et, NPV and μ (Event variables), as well as the jets' pT (this one only visible in Φ and η graphs), to filter out false jets from noise or soft scattering energy deposits.

Variable Cuts

- FCal_Et > 0.1 GeV to remove events with negative or null Transverse energy, and therefore not physical;

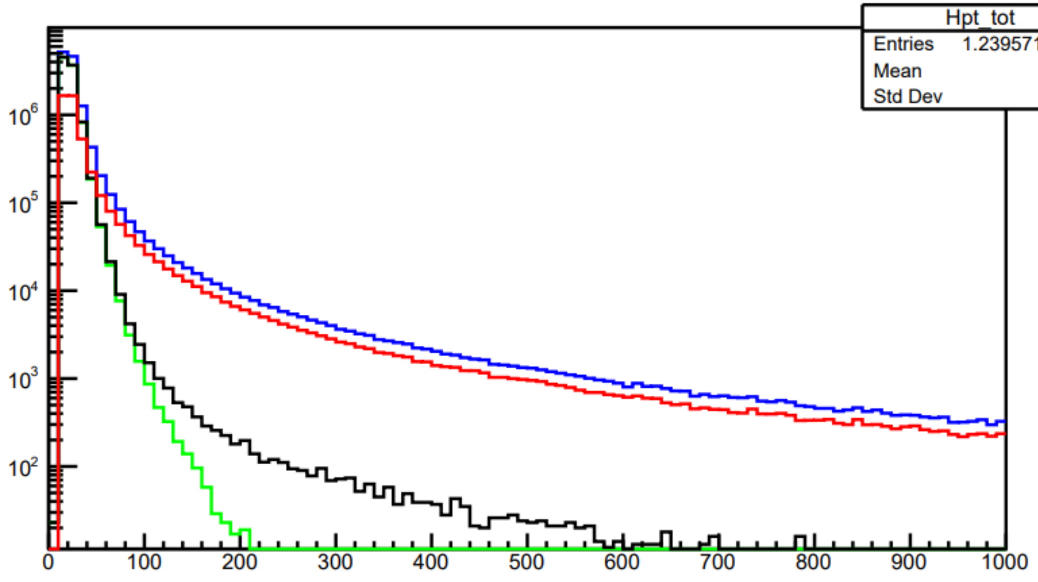
- NPV = 1 to select events characterized with a single collision vertex and prioritize hard scattering;

- $\mu < 1.0$ to remove events where a high number of interactions causes a high accumulation of energy deposits and greatly hinders the segmentation of the results into the underlying processes (this cut only affects the MB data, as HP data was always beneath this threshold);

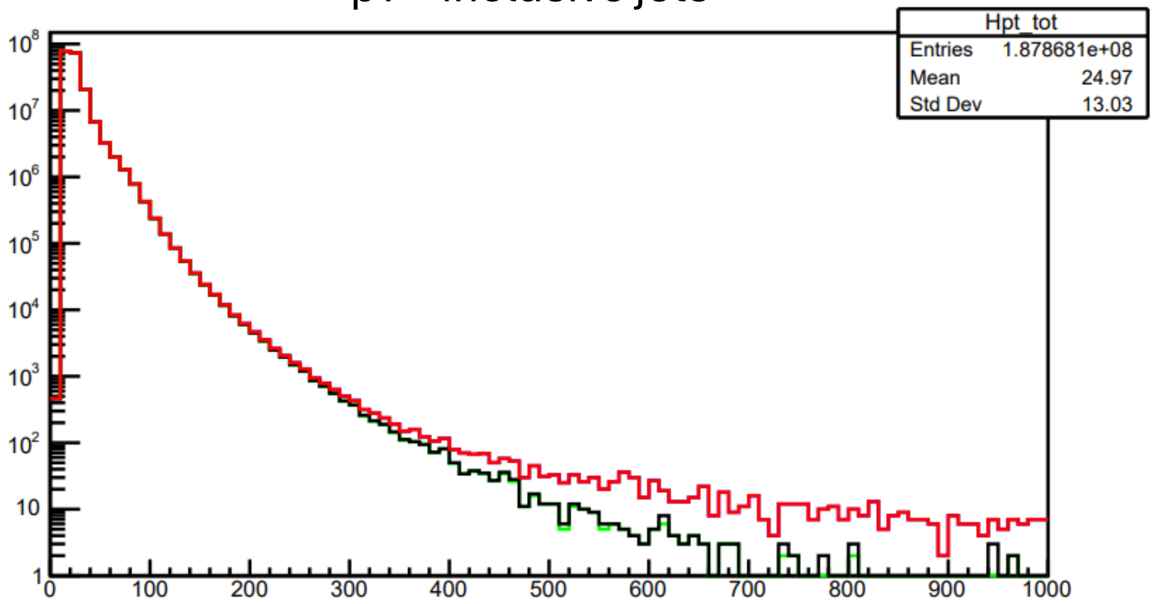
- pT > 10 GeV to avoid registering detector electronic noise;
- pT > 30 GeV to partially avoid including the Underlying Event, comprised of soft scattering.

Event Variable Cuts – MB & HP Comparison (pT)

MB pT – inclusive jets



HP - r22 pT – inclusive jets



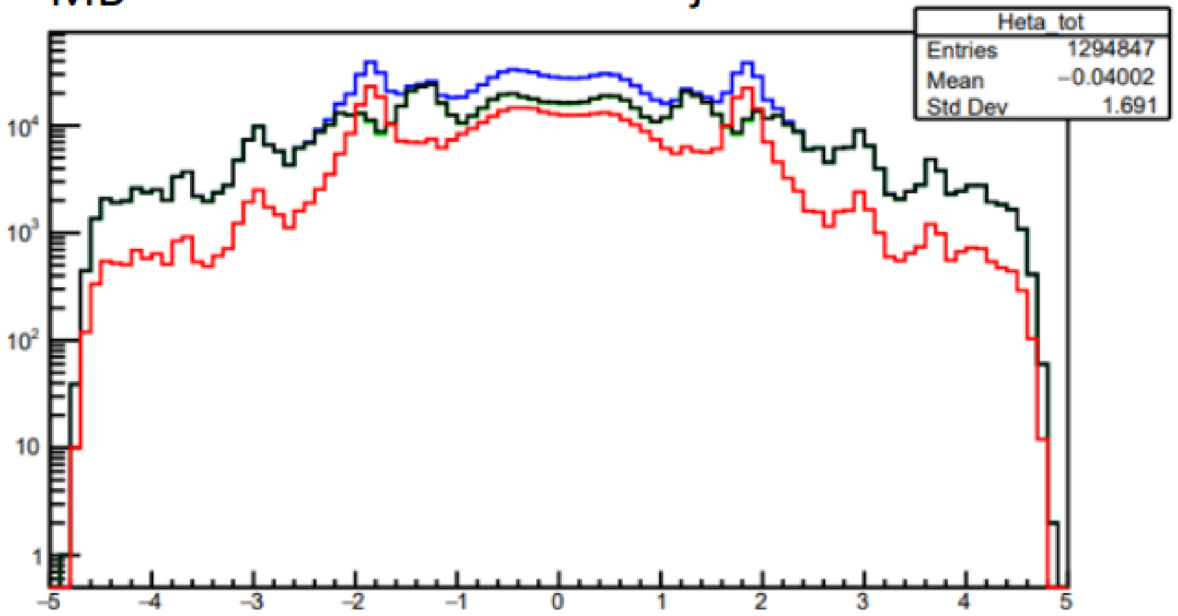
- All jets (No Cuts)
- FCal_Et > 0.1 TeV
- NPV = 1
- μ <= 1

- On the MB data it is observed a great discrepancy between the 'No Cuts' line and the NPV and FCal_Et cuts, indicating the usefulness of this filters to eliminate high pT false jets.

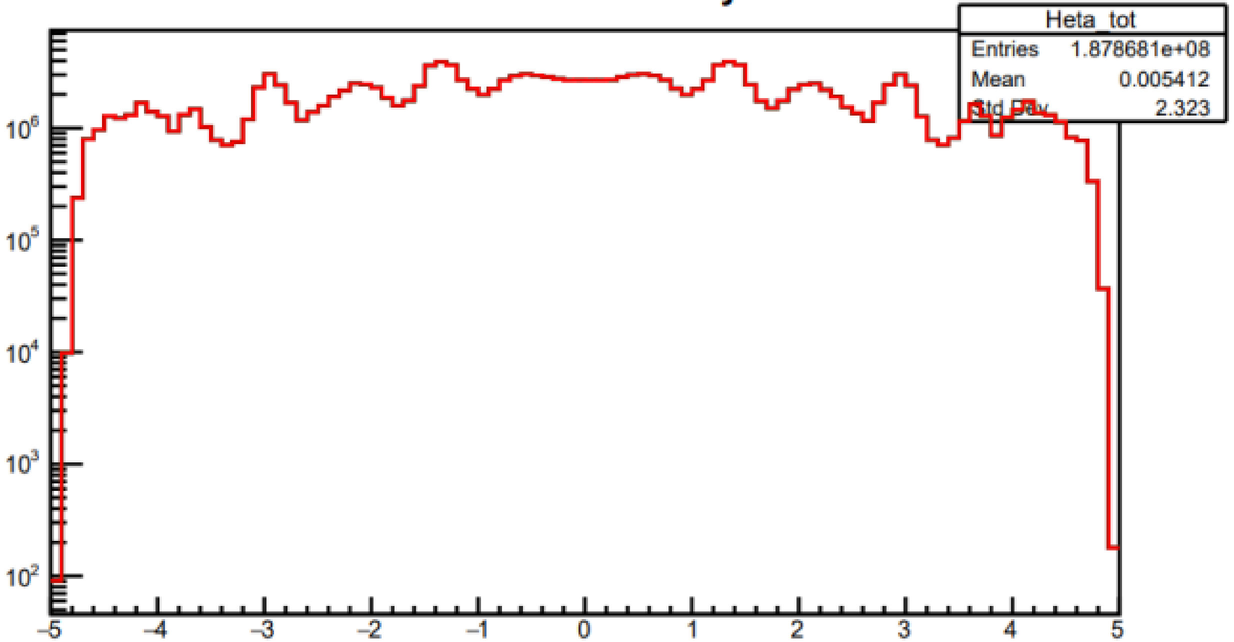
- On the HP-r22 data a smaller difference is observed, but here the NPV and FCal_Et cuts overlap.

Event Variable Cuts – MB & HP Comparison (η)

MB Eta – inclusive jets



HP – r22 Eta – inclusive jets

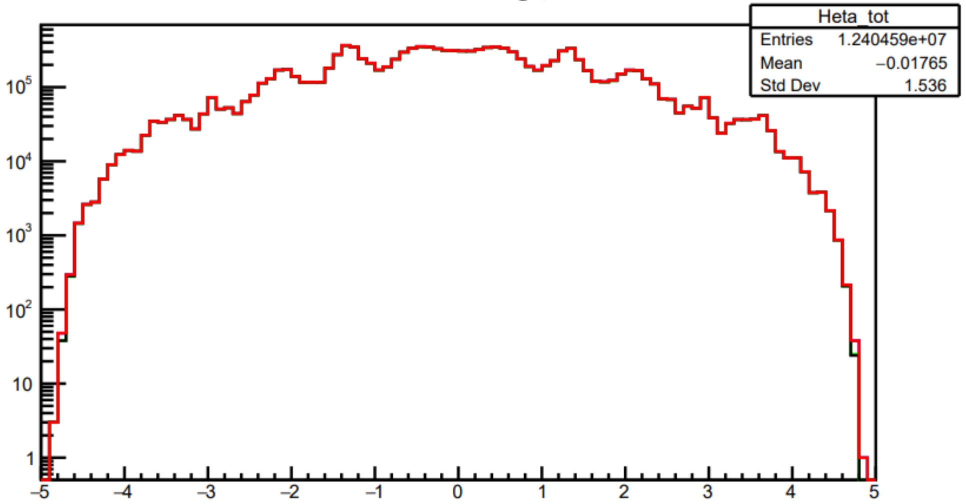


- All jets (No Cuts)
- FCal_Et > 0.1 TeV
- NPV = 1
- μ <= 1

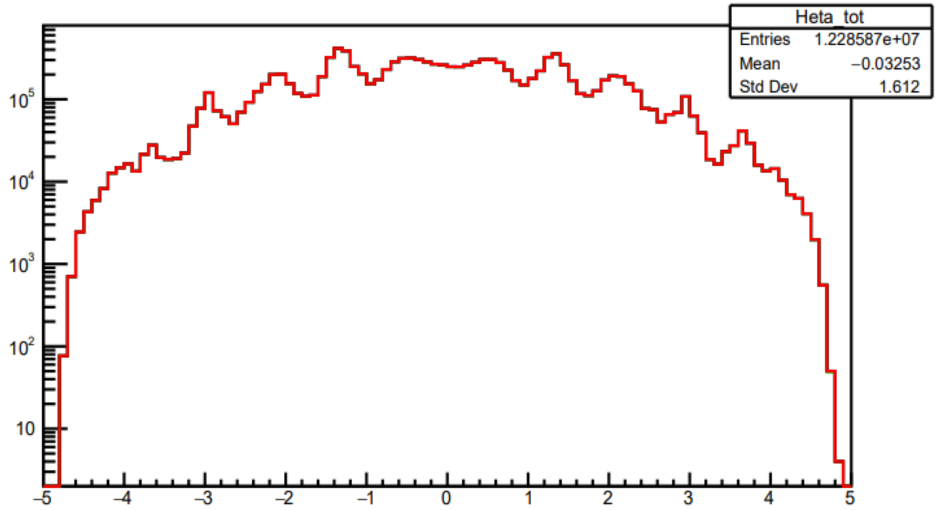
- On the MB data, the 'μ <= 1' cut has removed significant jets from the higher η magnitude region, and in the central region the spikes are a sum of the spikes from the 'μ <= 1' cut, and the 'FCal_Et > 0.1 TeV' and 'NPV = 1' cuts.
- On the HP-r22, the η distribution is unaffected by the cuts, and it is much more homogeneous than in MB

Jet data sets – HP r22 Comparison (η)

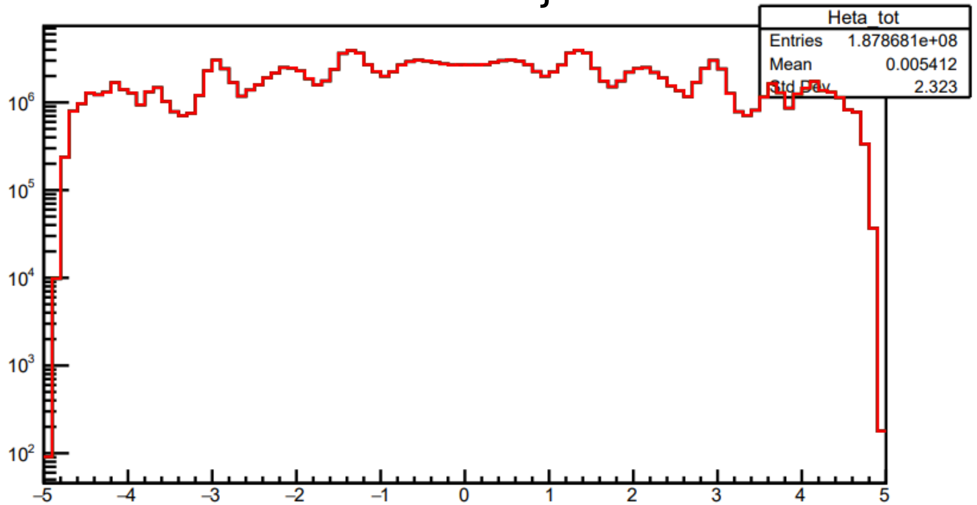
Eta – leading jets



Eta – sub-leading jets



Eta – inclusive jets

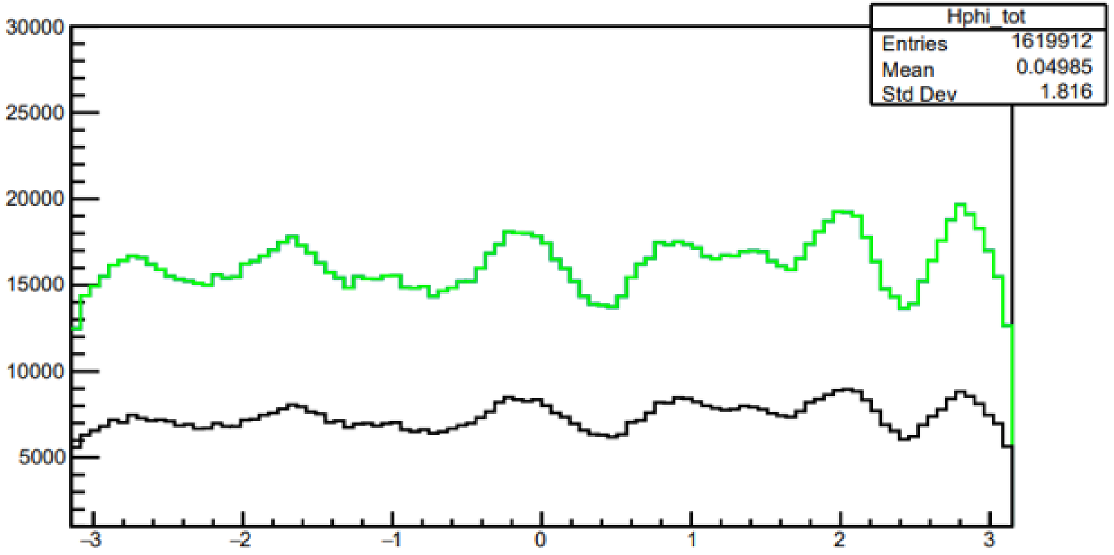


- Leading and sub-leading jets form a peak around η = 0, indicating that higher |η| jets have on average lower pT.

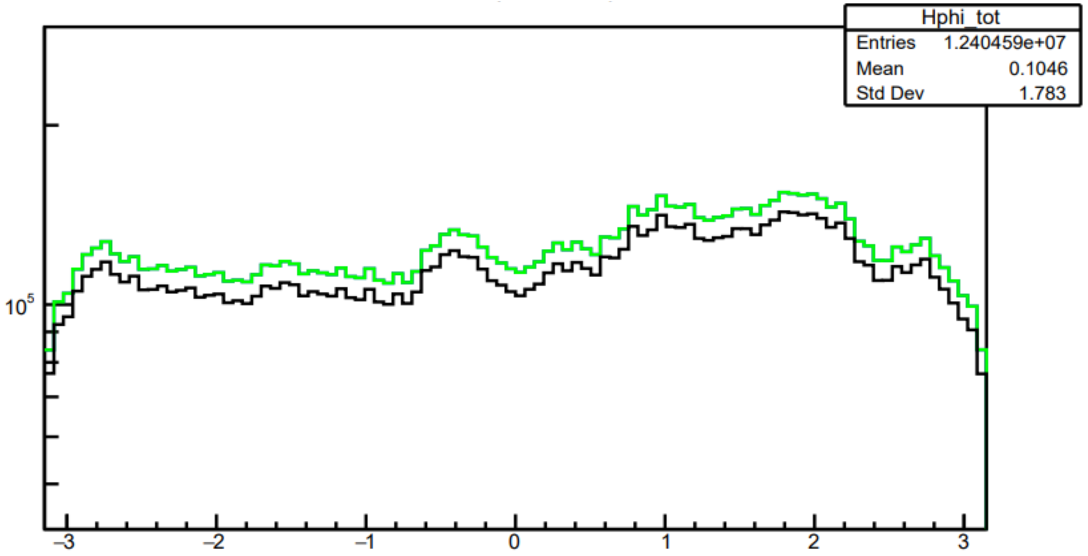
- The spikes registered in the inclusive data set are still present in the leading and sub-leading sets.

Jet pT cuts – MB & HP comparison (Φ leading)

MB Phi – leading jets (pT cut)



HP-r22 Phi – leading jets (pT cut)



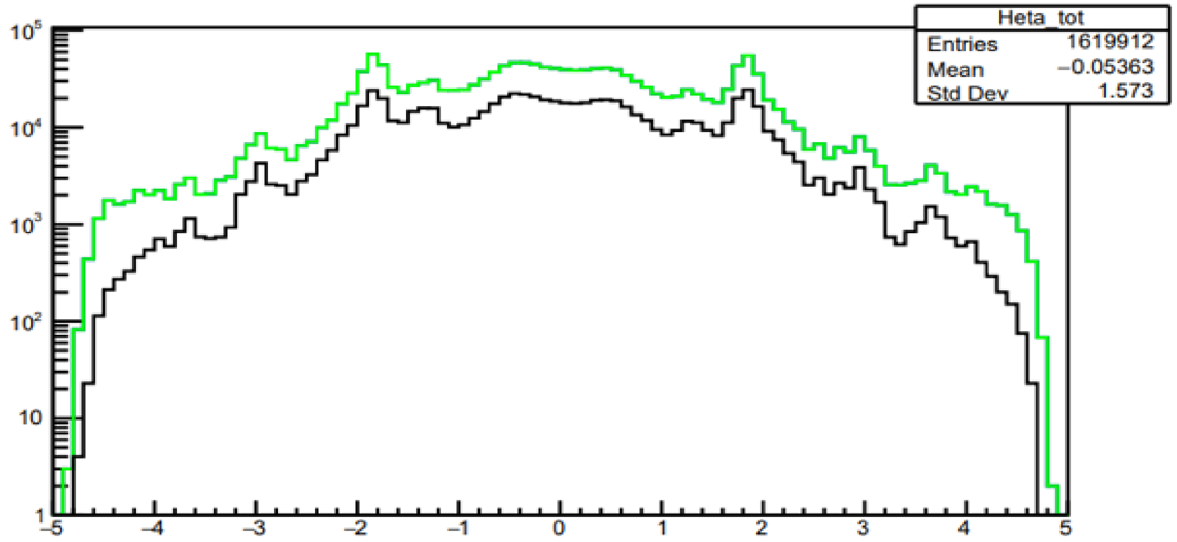
- All jets (No Cut)
- pT > 10 GeV
- pT > 30 GeV

- A complete overlap between the 'No Cut' and 'pt > 10 GeV' cut is observed, showing that only a very small amount of data was cut to remove Electronic Noise.

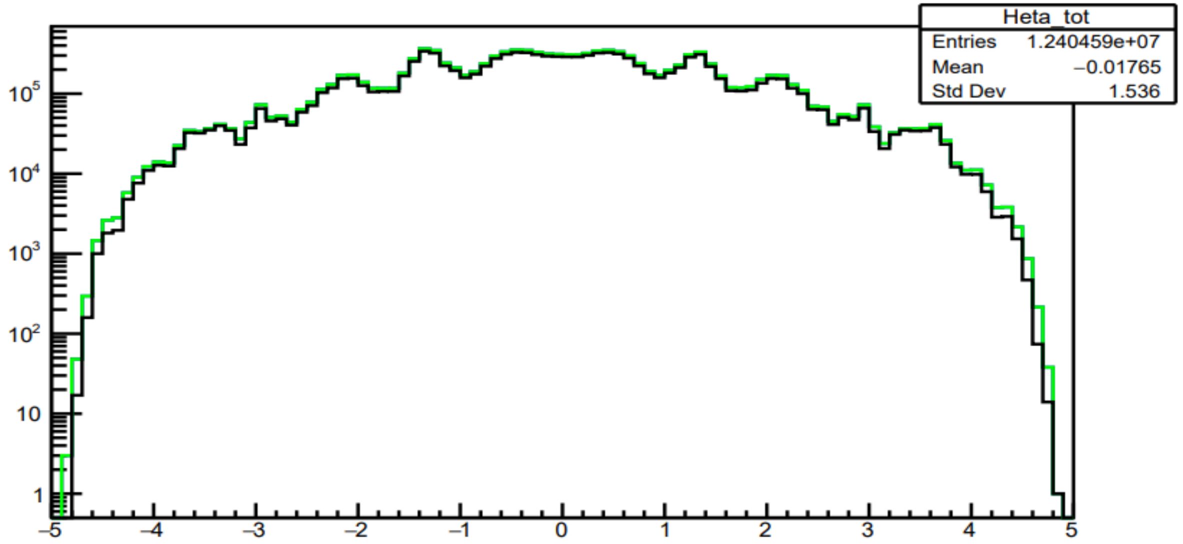
- Even though the 'pt > 30 GeV' cut removed a significant part of the data in the MB, in both of these it preserved all spikes, indicating no significant angular difference between both cuts.

Jet pT cuts – MB & HP comparison (η leading)

Eta - leading jets (pT cut)



Eta - leading jets (pT cut)



- All jets (No Cut)

- pT > 10 GeV

- pT > 30 GeV

- The 'pT > 30 GeV' cut is much more visible on the MB data-set.

Conclusions

- The ‘pT > 30 GeV’ cut is quite pertinent in conjunction with a Minimum Bias Trigger, removing little data in the Hard Probes trigger data-set.

- The ‘FCal_Et > 0.1 TeV’ and ‘NPV = 1’ cuts were useful both for the MB and HP data-sets, in eliminating high-pT jets that may be falsely constructed, being nevertheless more visible on the MB set.

- Leading and sub-leading data-sets showed a central ‘peak’ in η distributions, corroborating that higher η jets tend to have lower pT.

References

- https://atlas.cern/Discover/Detector
  Aad, Georges, et al. "The ATLAS experiment at the CERN large hadron collider." (2008). – used in slide 2

- Cunqueiro, Leticia, and Anne M. Sickles. "Studying the QGP with Jets at the LHC and RHIC." Progress in Particle and Nuclear Physics 124 (2022): 103940. – used in slide 3 and 4

- Efthymiopoulos, Ilias. "Overview of the ATLAS detector at LHC." *Acta Phys. Pol. B* 30.ATL-CONF-99-002 (1999): 2309-2329.

- The data in the analysis presented here was from the following files:

MB:

user.mrybar.5TeV_HI_2022_MinBias_PVReq_tight_r001.root

HP-r22:
user.mrybar.data18_hi.00367134.physics_HardProbes_r22.0.68_all_EXT0_HIJeTVal_r002_ANALYSIS.root