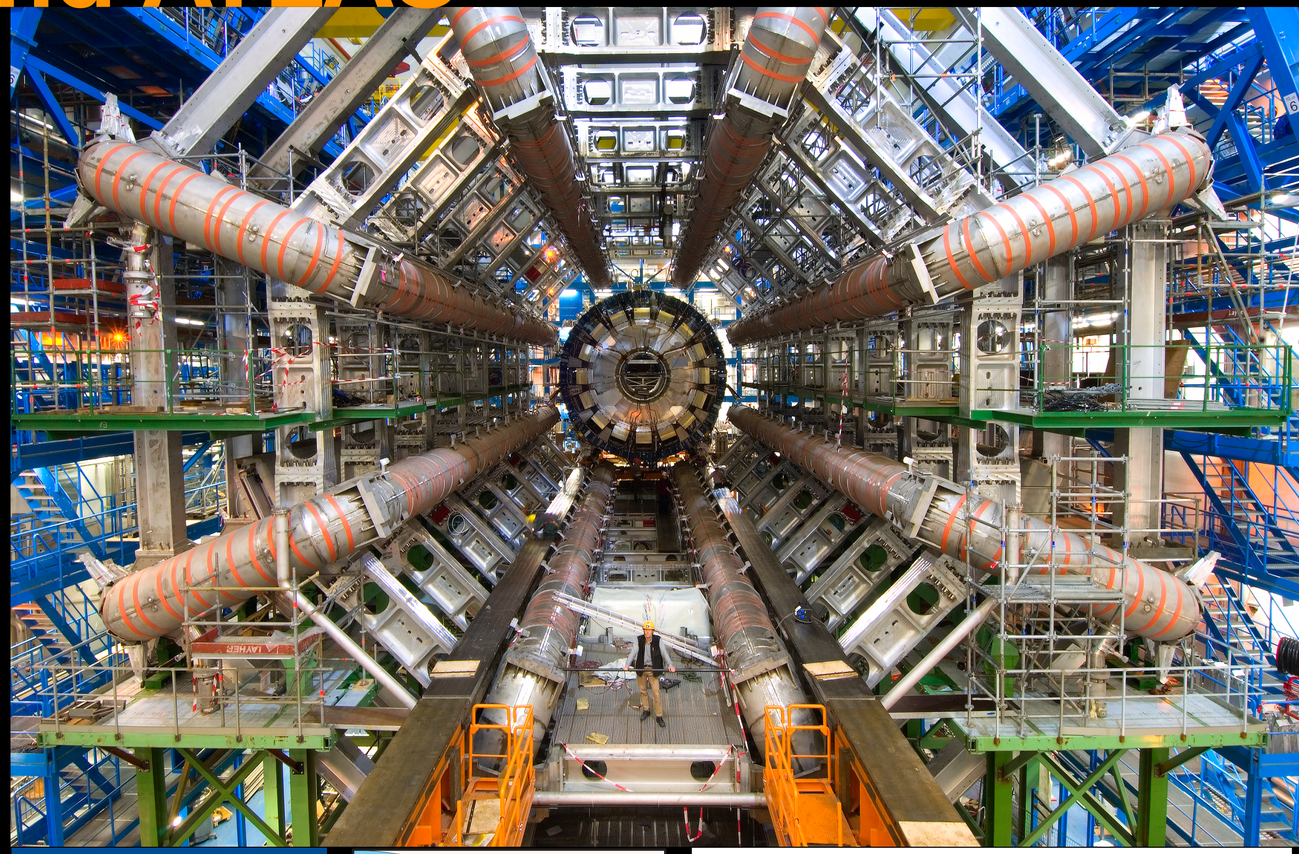
Exploring jets: substructure and flavour tagging in CMS and ATLAS



Andrea Malara

Université Libre de Bruxelles

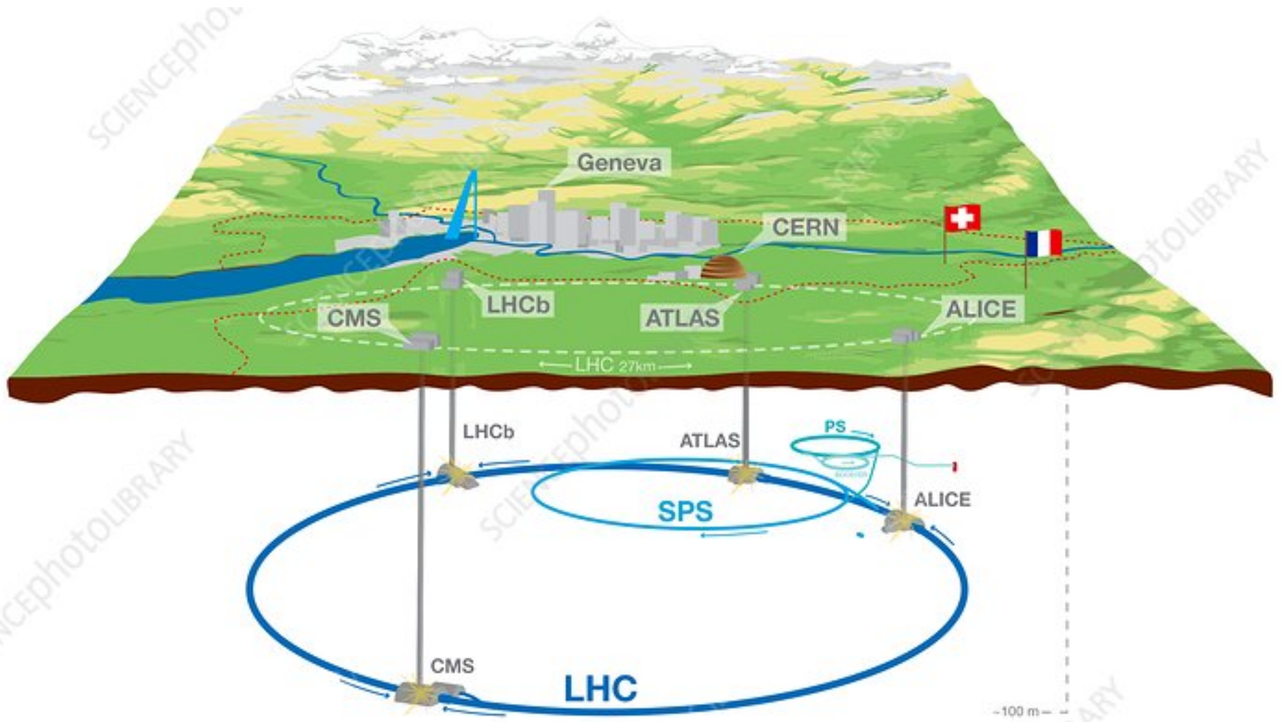
On behalf of the

ATLAS and CMS collaborations

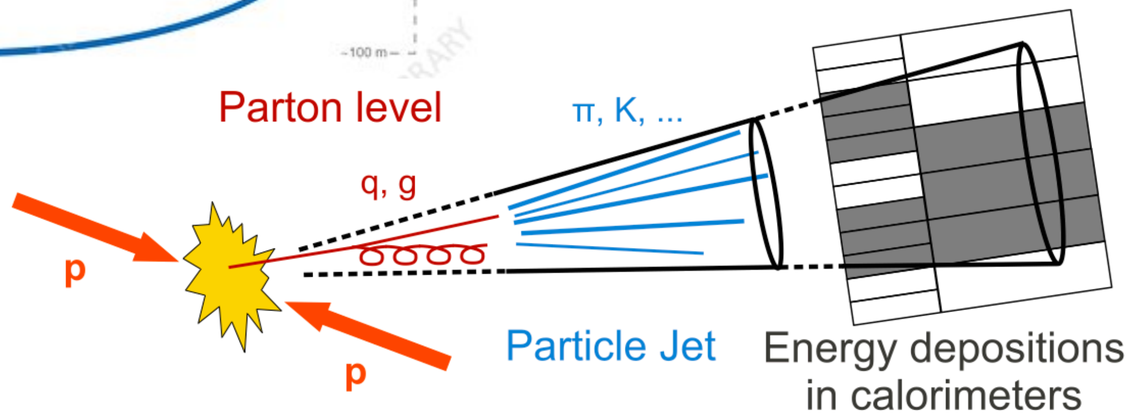
07 June 2024

Hadronic environment @ LHC

- Proton-proton collider
  - 27 km circumference
  - Up to $\sqrt{s}$ = 14 TeV
- Host of 4 large experiments (+ several others)
  - ATLAS
  - CMS
  - LHCb
  - ALICE
- Abundance of quarks and gluons in pp collisions



Click me



- As a consequence of the hadronisation of quarks and gluons produced in pp collisions, a collimated shower of hadrons (jet) is produced.

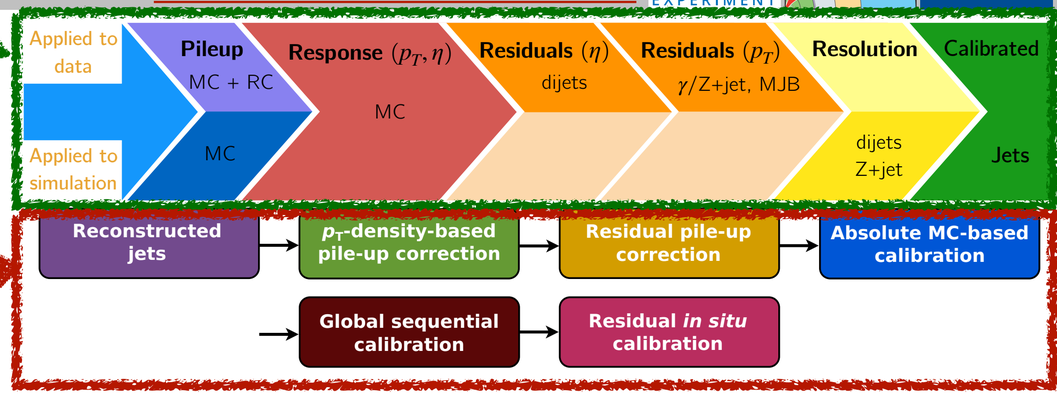
Jet calibration

CMS-DP-2021-033

ATLAS: arXiv:2303.17312

Energy

- Traditional calibration in Run2 both in CMS and ATLAS
  - Factorised approach: pileup→simulation→residuals



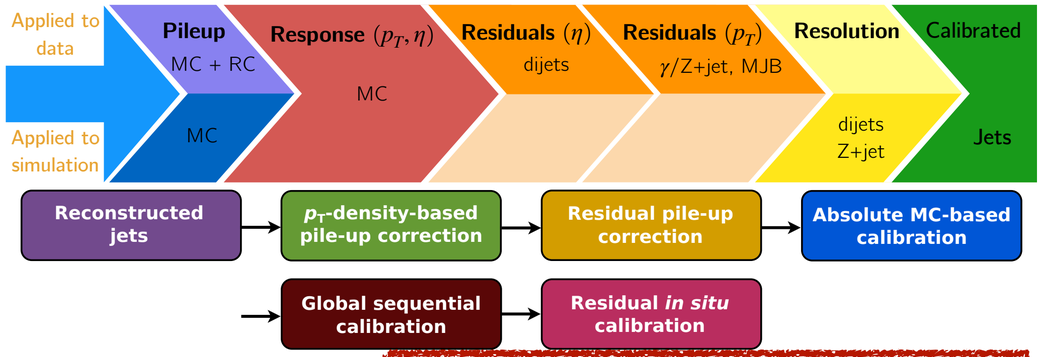
Jet calibration

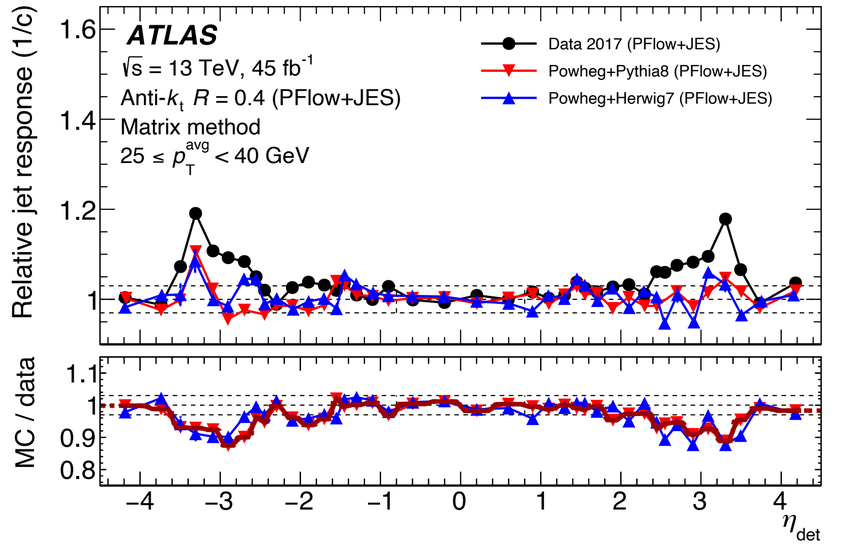
CMS-DP-2021-033

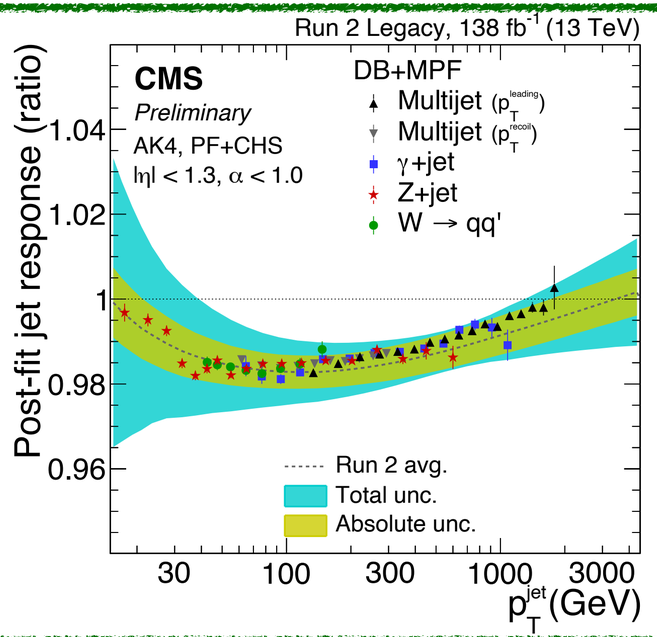
ATLAS: arXiv:2303.17312

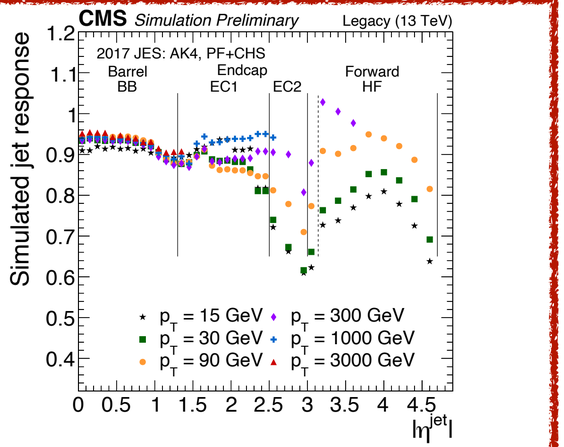
Energy

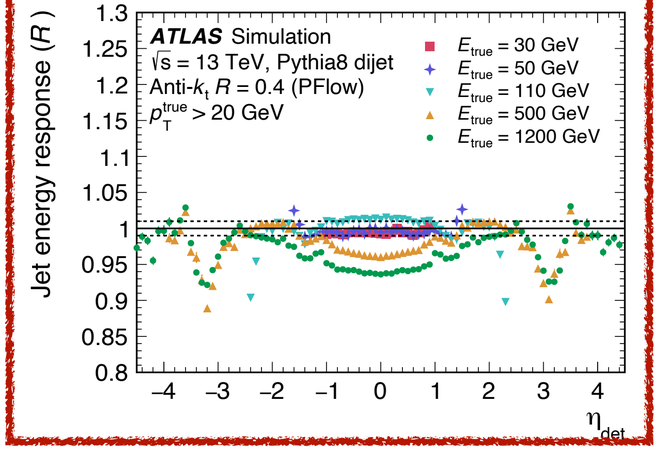
- Traditional calibration in Run2 both in CMS and ATLAS
  - Factorised approach: pileup→simulation→residuals
- Simulation-based corrections
- In-situ calibration of data
  - Eta-intercalibration
- Combination of Z+jet, γ+jet, multijet







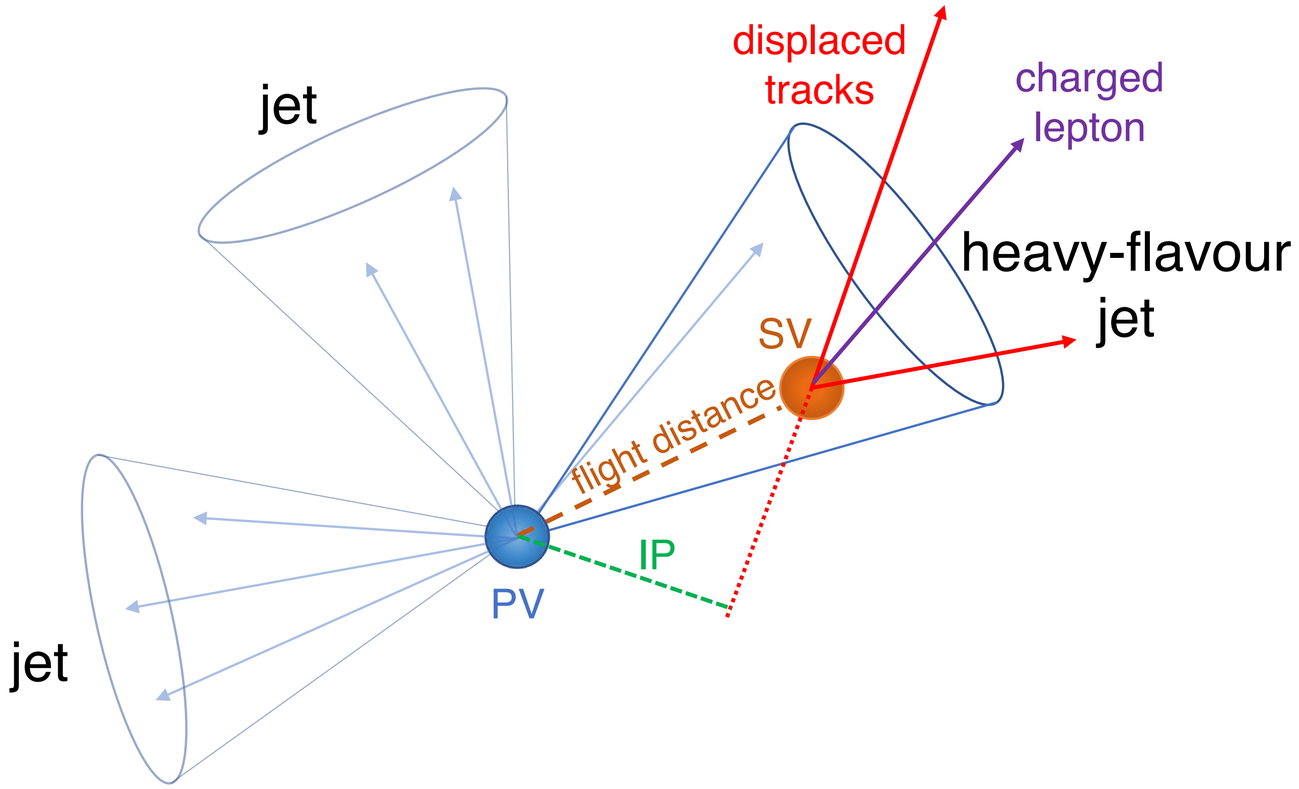




Jet identification (“tagging”)

Tagging

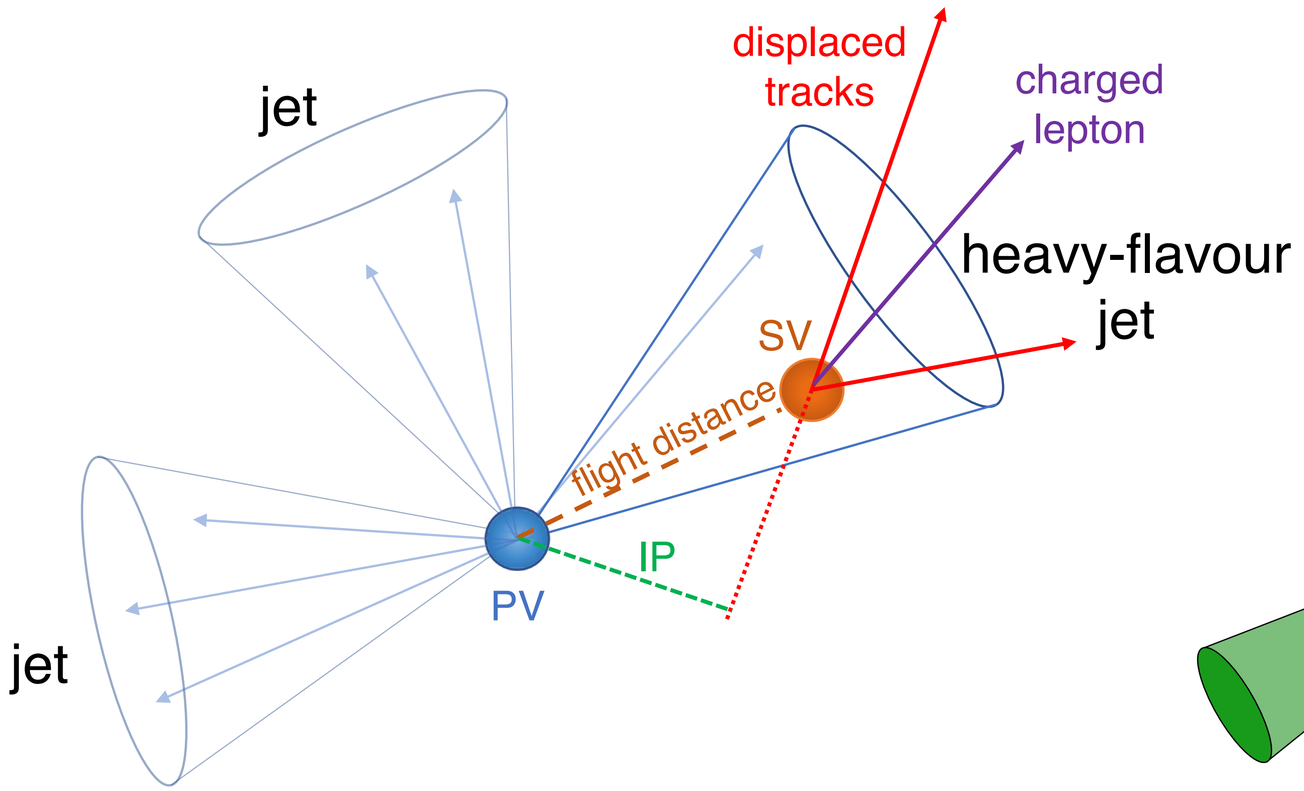
- Type of elementary particle that initiated the jet

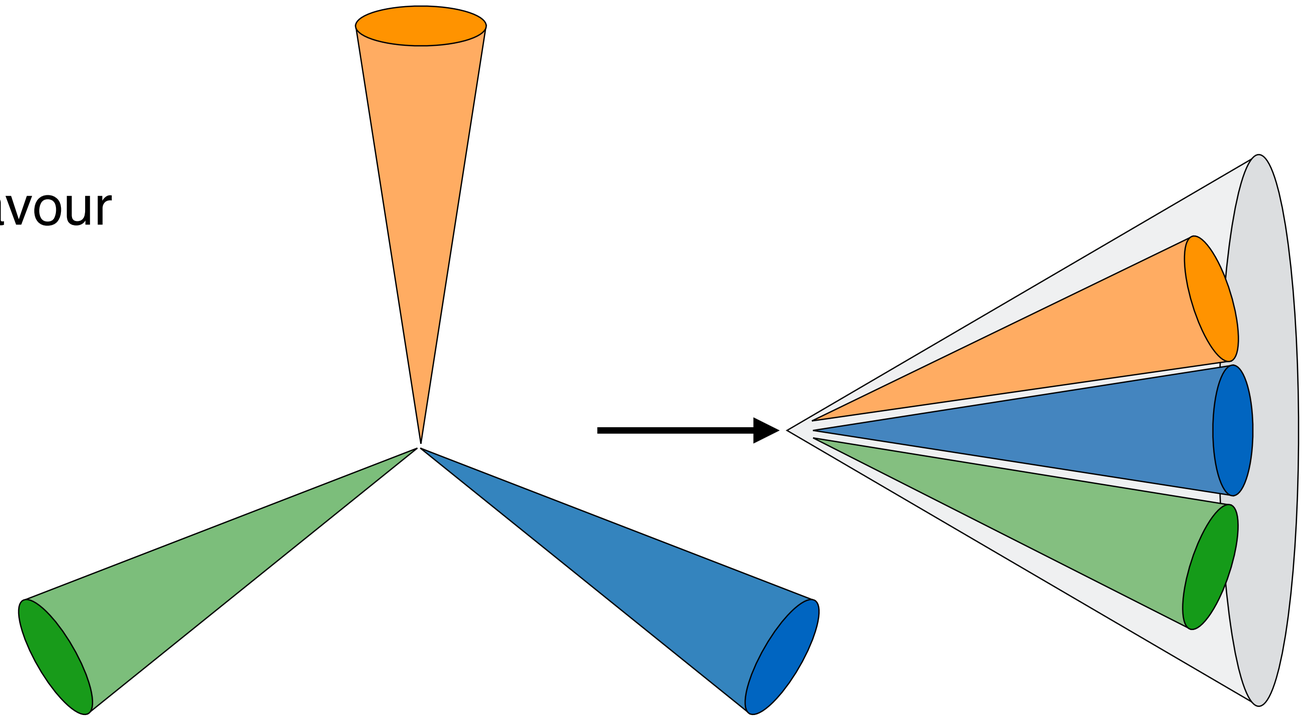


Jet identification (“tagging”)

Tagging

- Type of elementary particle that initiated the jet
  - Boosted topology -> Collimated decay products reconstructed as multi-prong objects

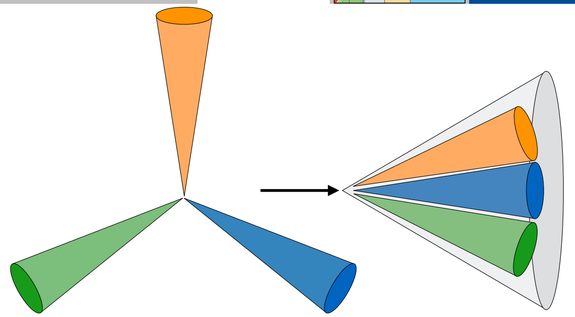


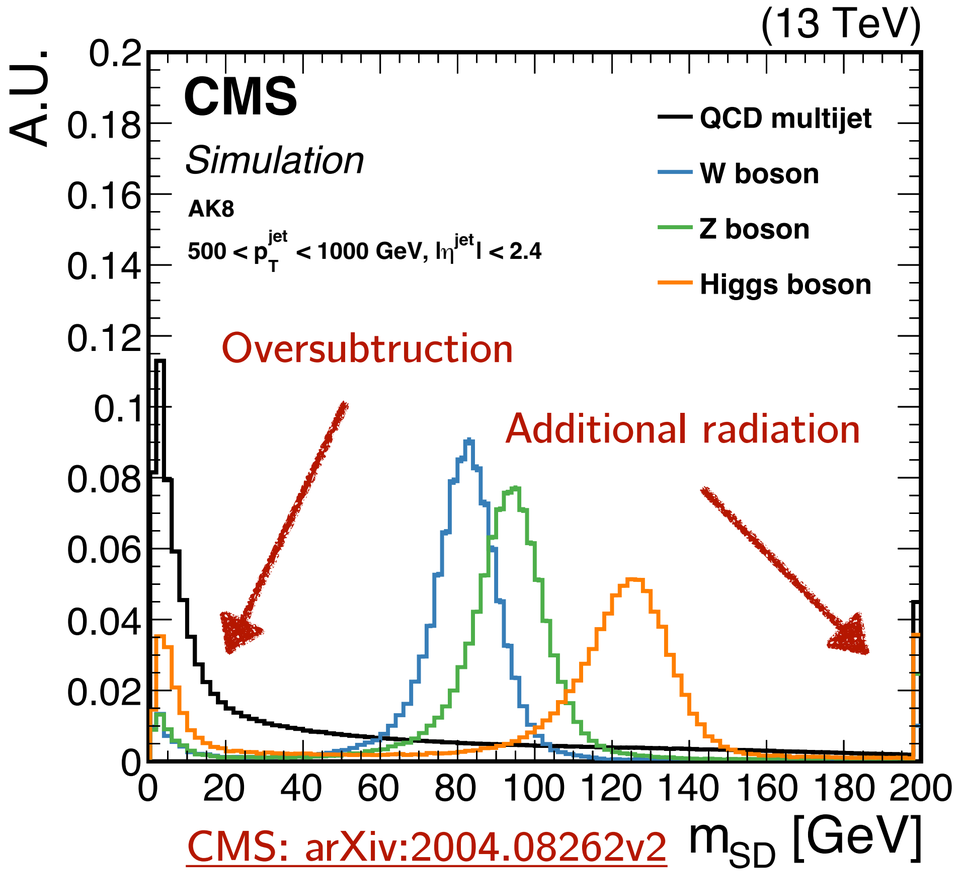


Jet identification (“tagging”)

Tagging

- Type of elementary particle that initiated the jet
- Jet mass



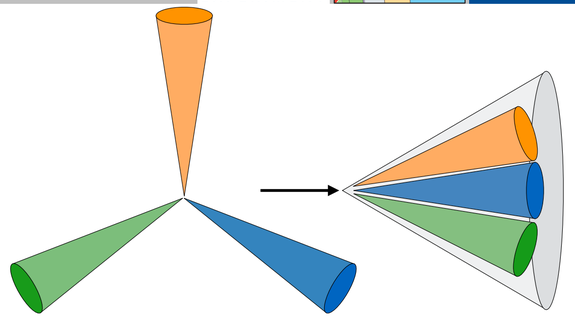


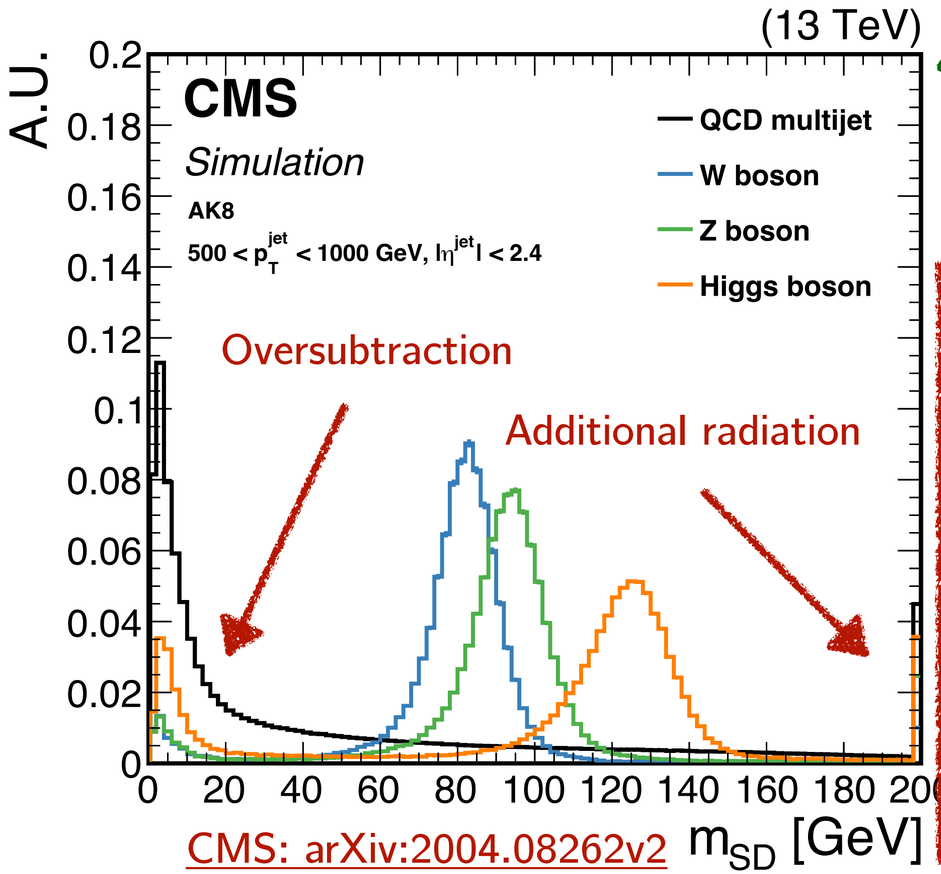
CMS: arXiv:2004.08262v2

Jet identification (“tagging”)

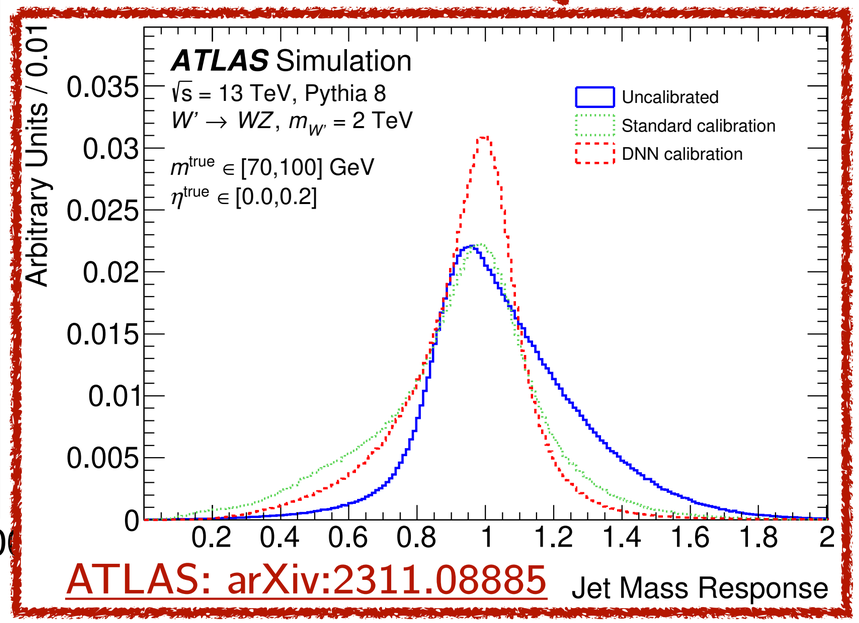
Tagging

- Type of elementary particle that initiated the jet
- Jet mass → ML with regression

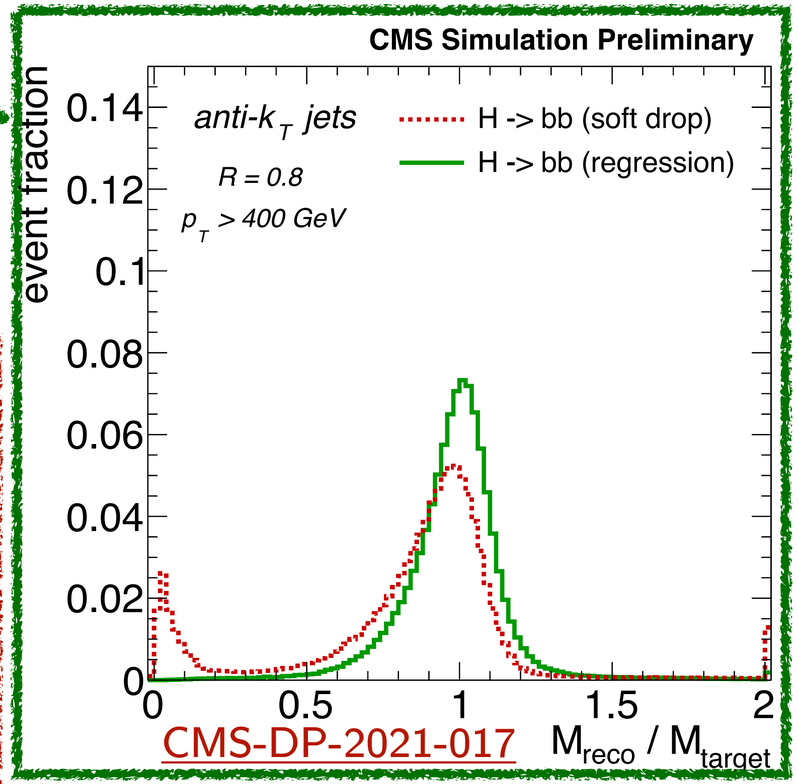




CMS: arXiv:2004.08262v2



ATLAS: arXiv:2311.08885

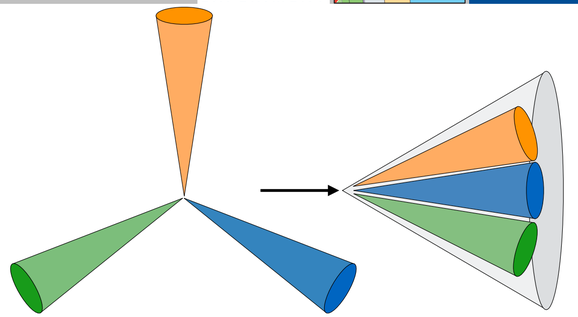


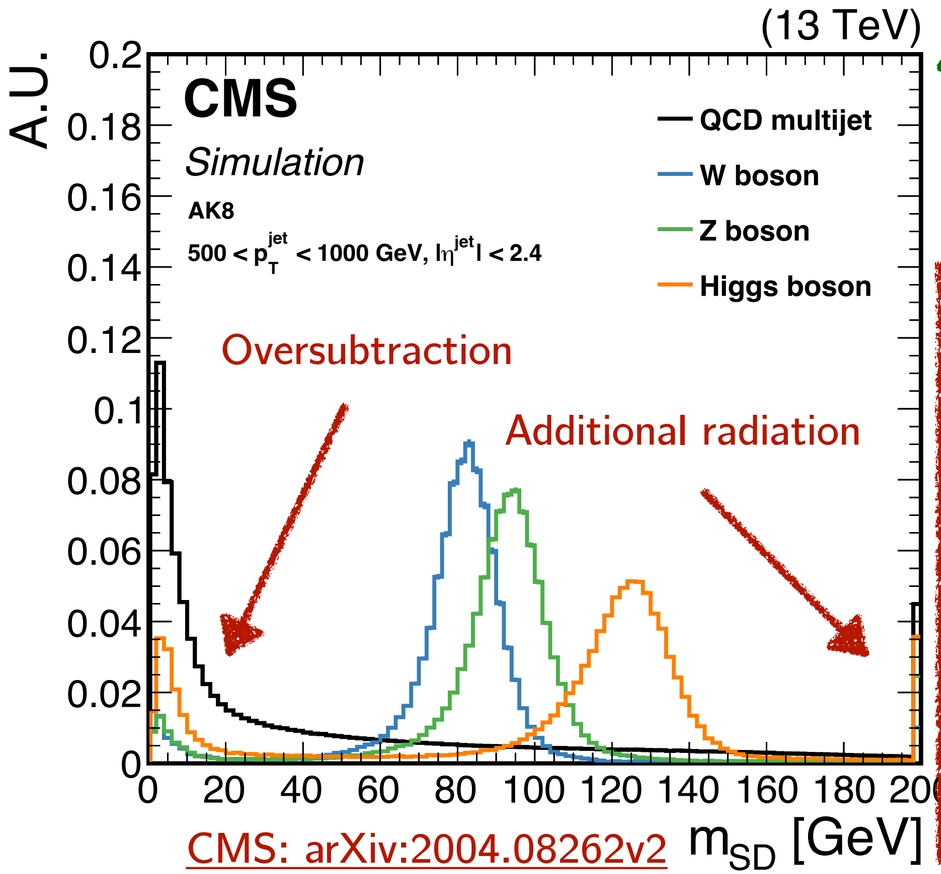
CMS-DP-2021-017

Jet identification (“tagging”)

Tagging

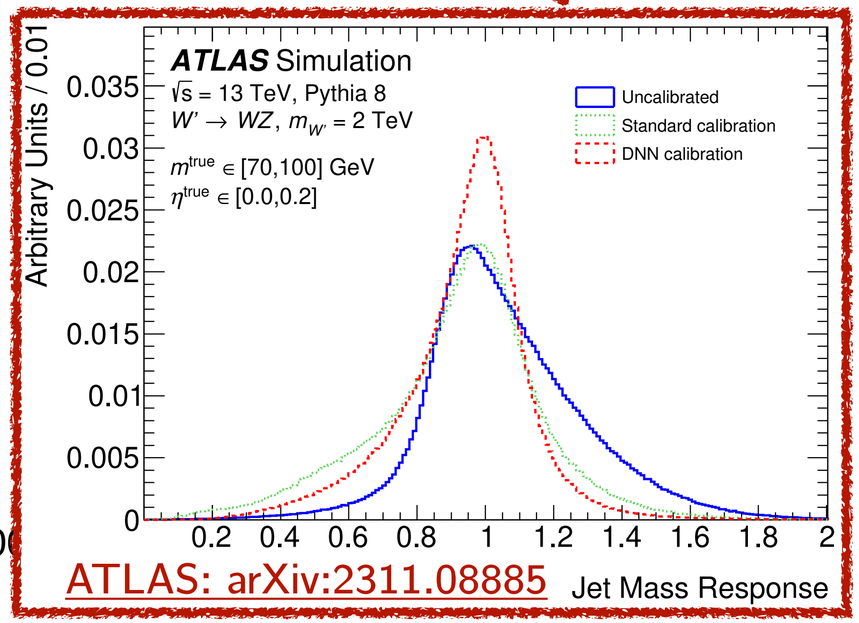
- Type of elementary particle that initiated the jet
- Jet mass → ML with regression



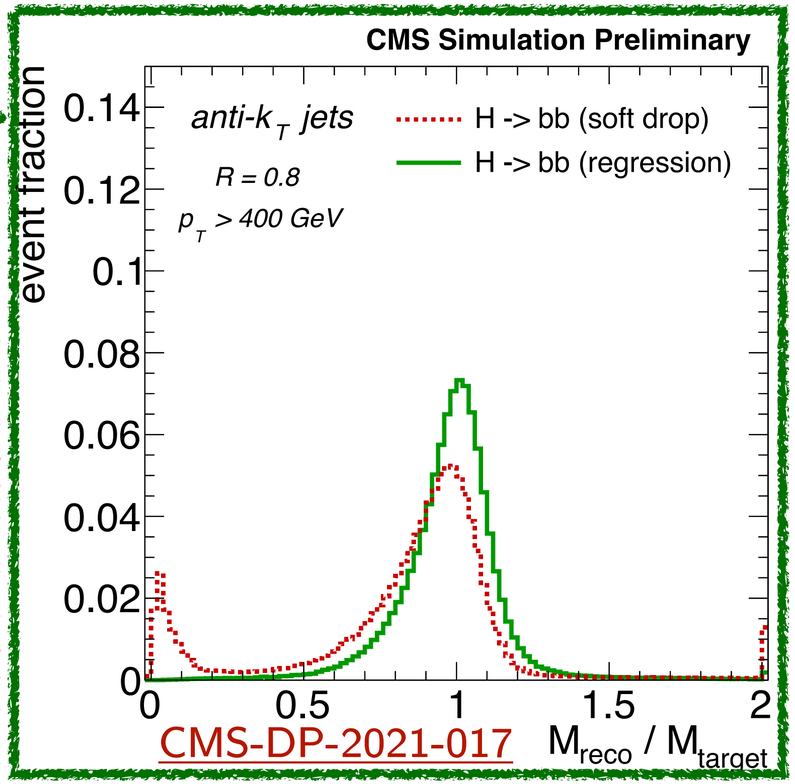


CMS: arXiv:2004.08262v2

ATLAS: Simultaneous mass and energy regression for large radius jets



ATLAS: arXiv:2311.08885



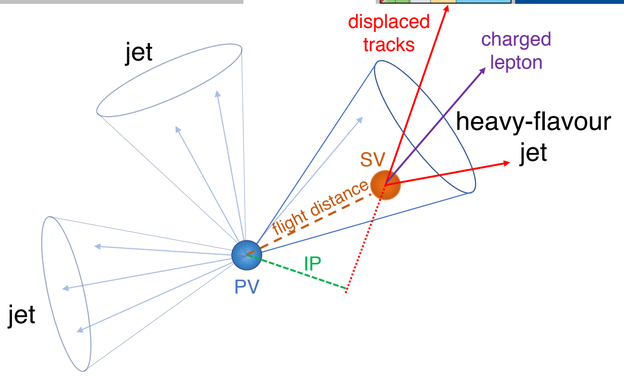
CMS-DP-2021-017

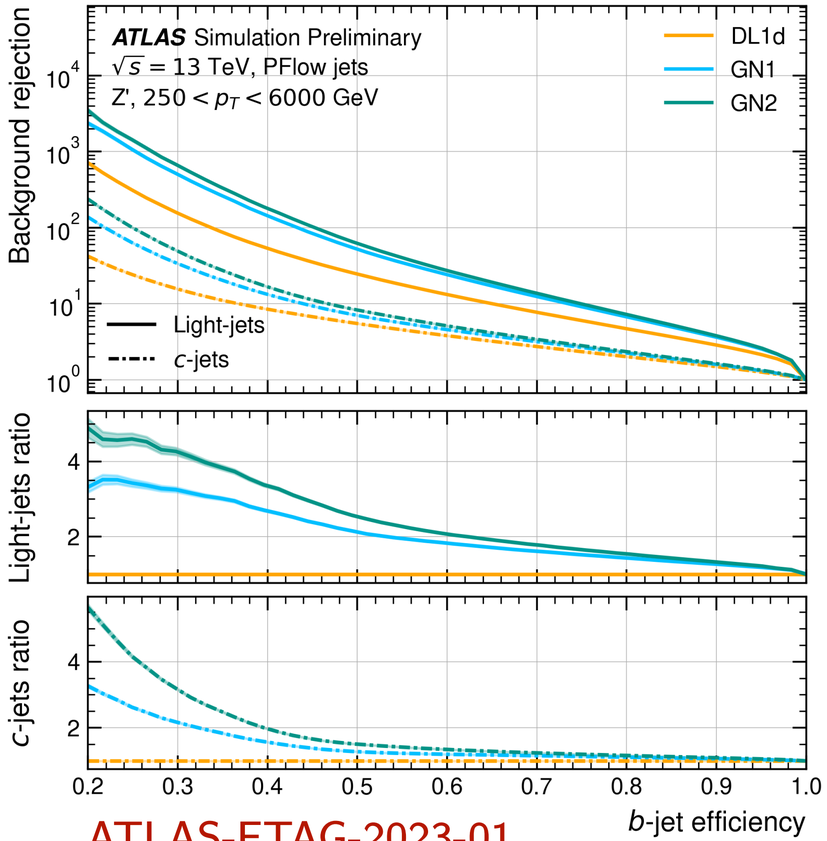
Jet identification (“tagging”)

Particle Transformer

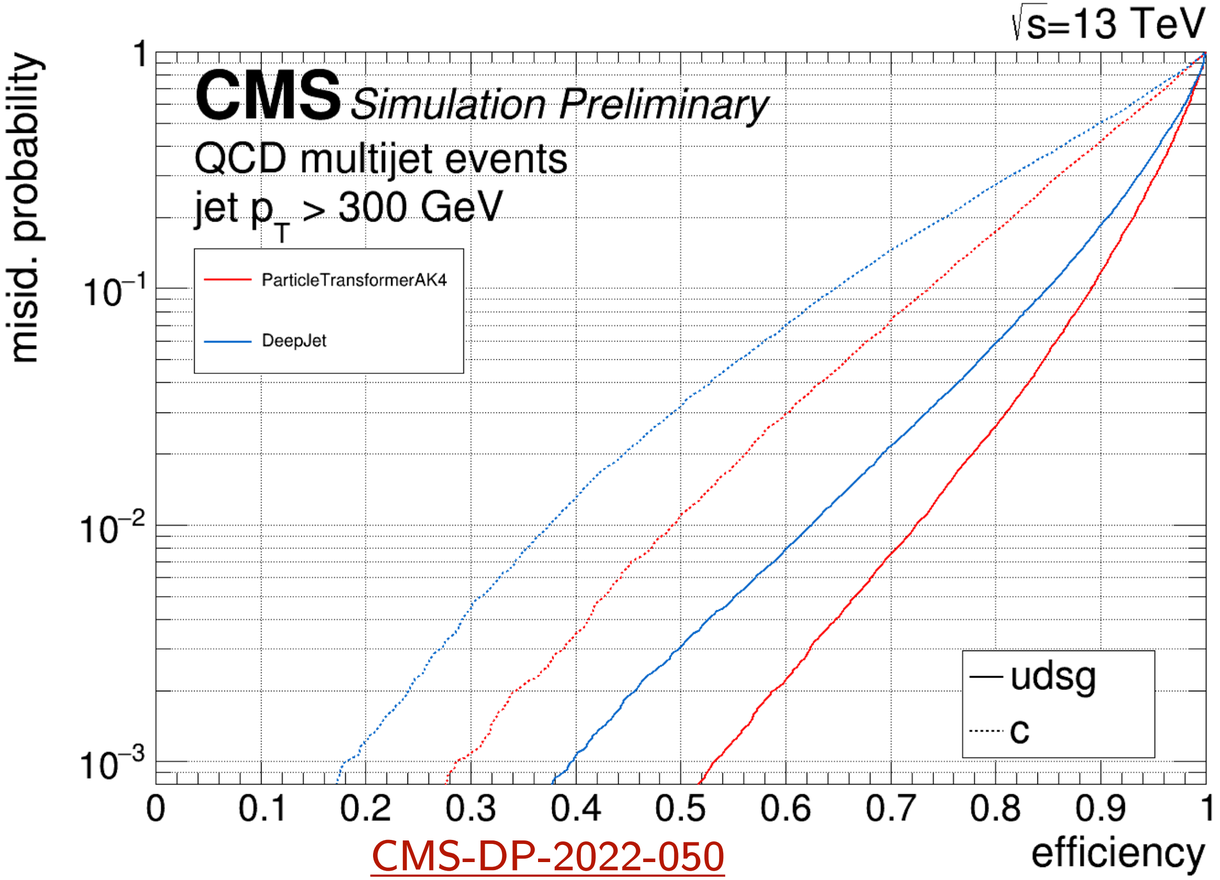
Tagging

- Type of elementary particle that initiated the jet
- Jet mass → ML with regression
- Jet flavour (b vs light, b vs c, g vs light) → $R = 0.4$





ATLAS-FTAG-2023-01



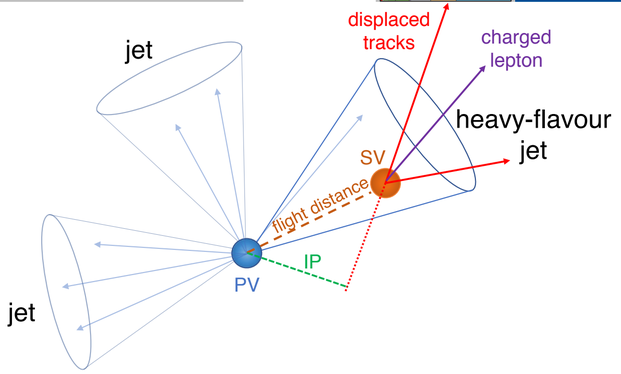
CMS-DP-2022-050

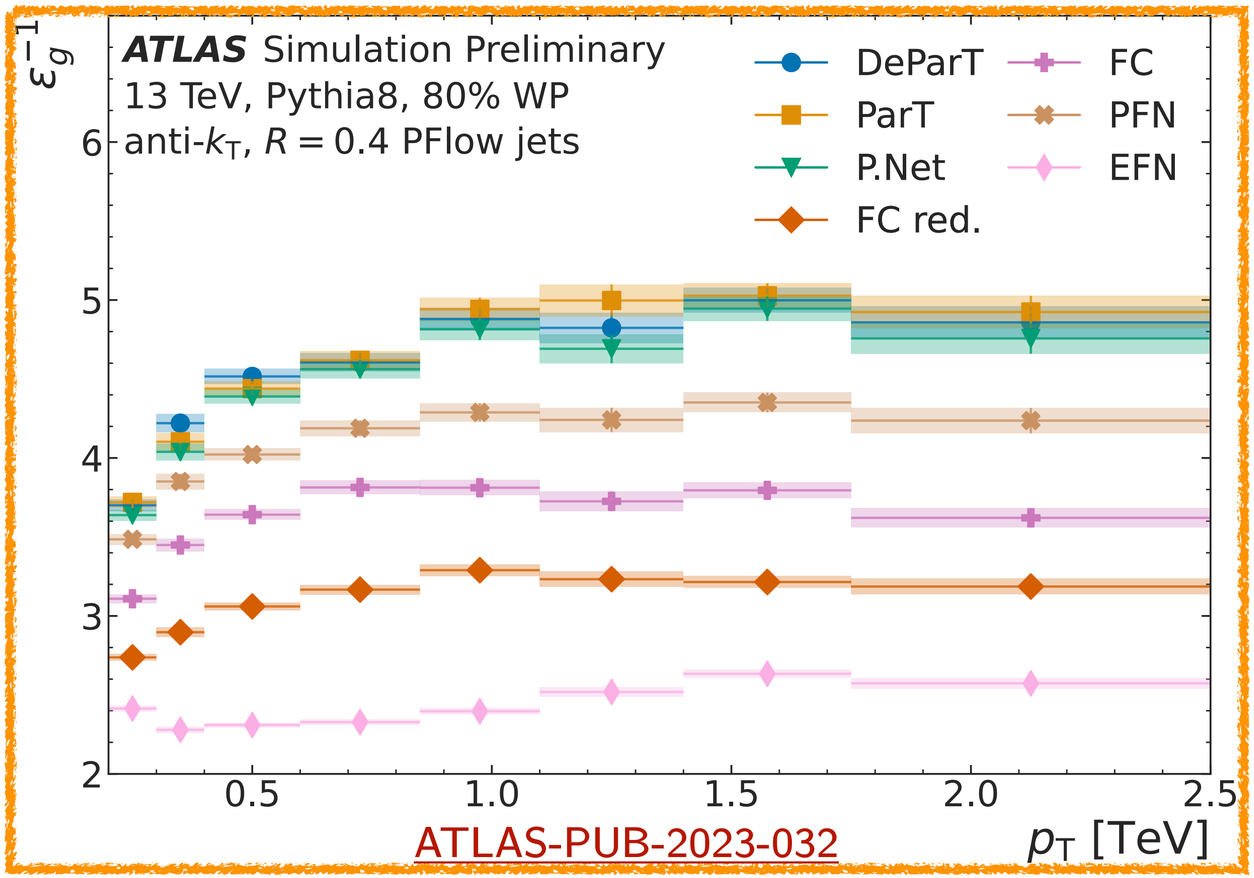
Jet identification (“tagging”)

Particle Transformer

Tagging

- Type of elementary particle that initiated the jet
- Jet mass → ML with regression
- Jet flavour (b vs light, b vs c, g vs light) → $R = 0.4$

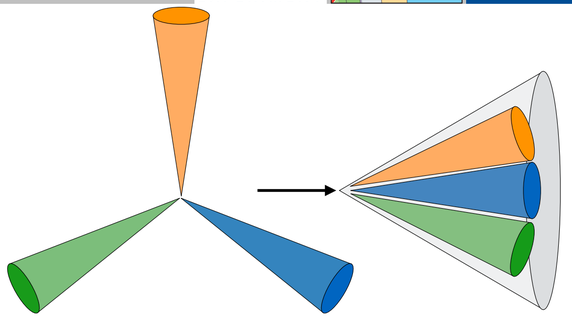


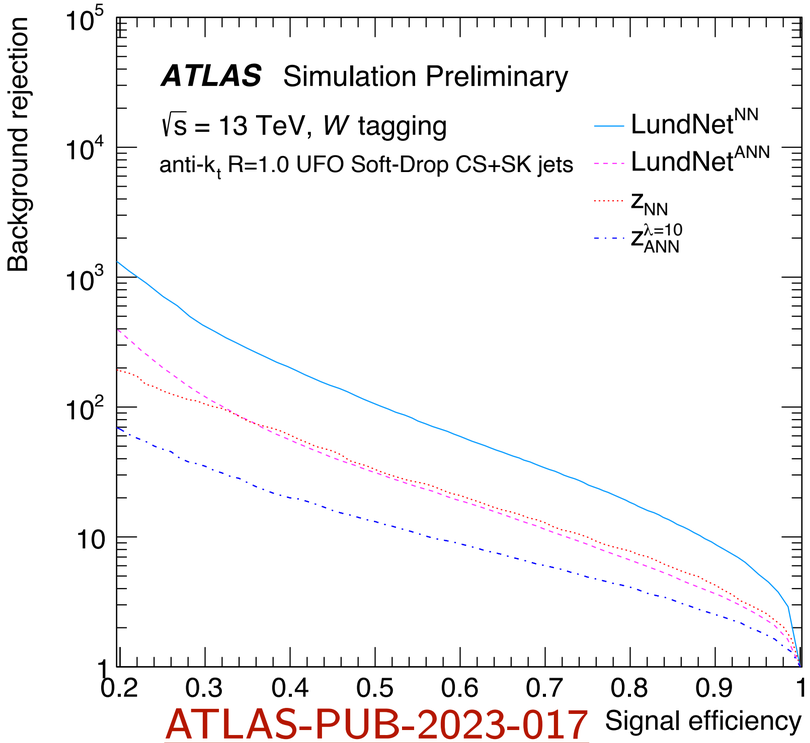


Jet identification (“tagging”)

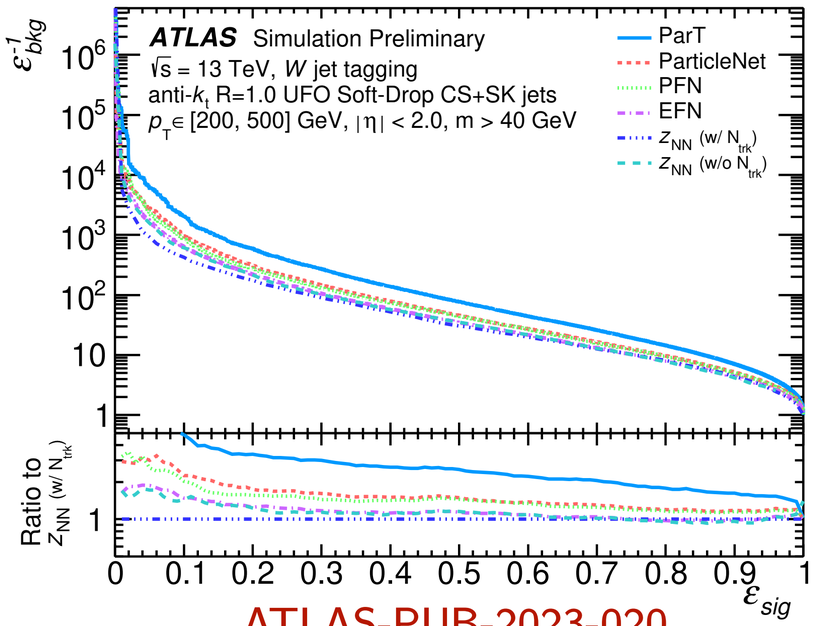
Tagging

- Type of elementary particle that initiated the jet
- Jet mass → ML with regression
- Jet flavour (b vs light, b vs c, g vs light) → $R = 0.4$
- Jet substructure (top, W/Z, H) → $R = 0.8$ or 1.0

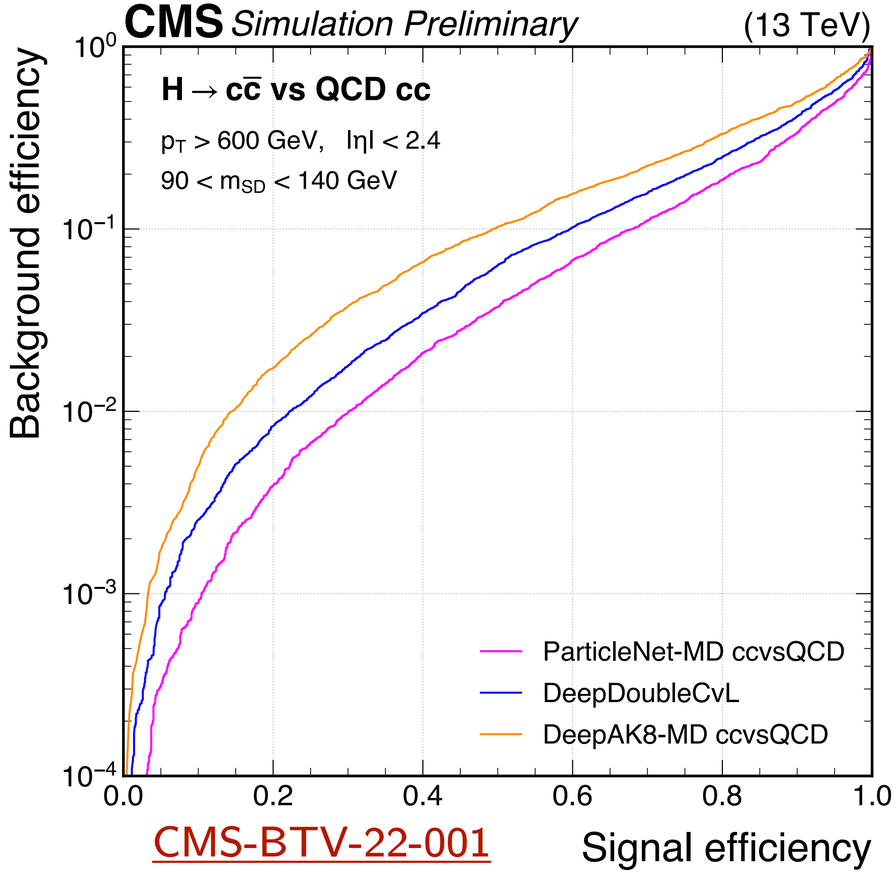




ATLAS-PUB-2023-017



ATLAS-PUB-2023-020

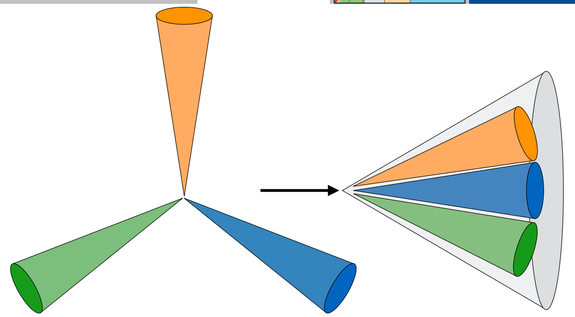


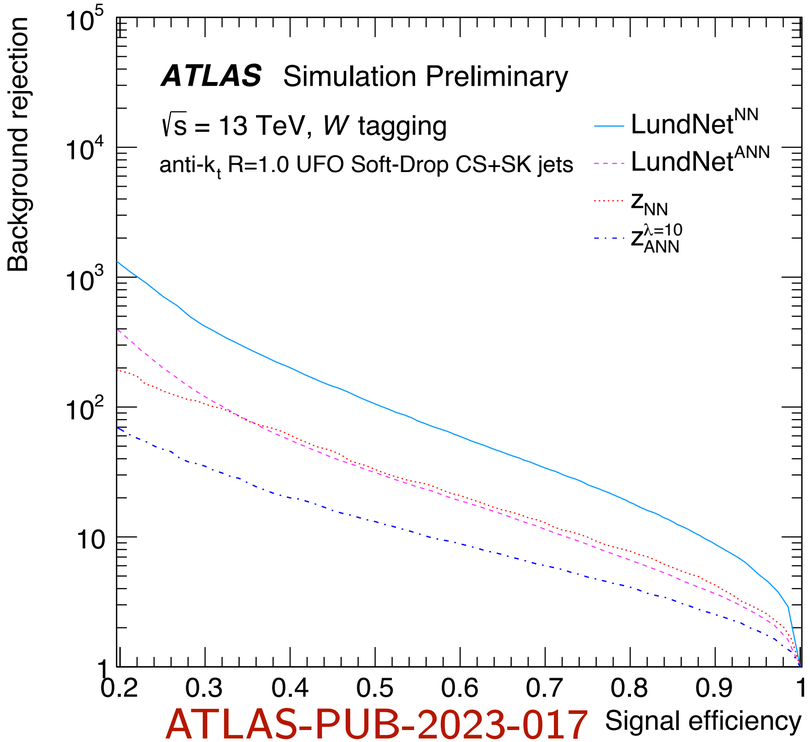
CMS-BTV-22-001

Jet identification (“tagging”)

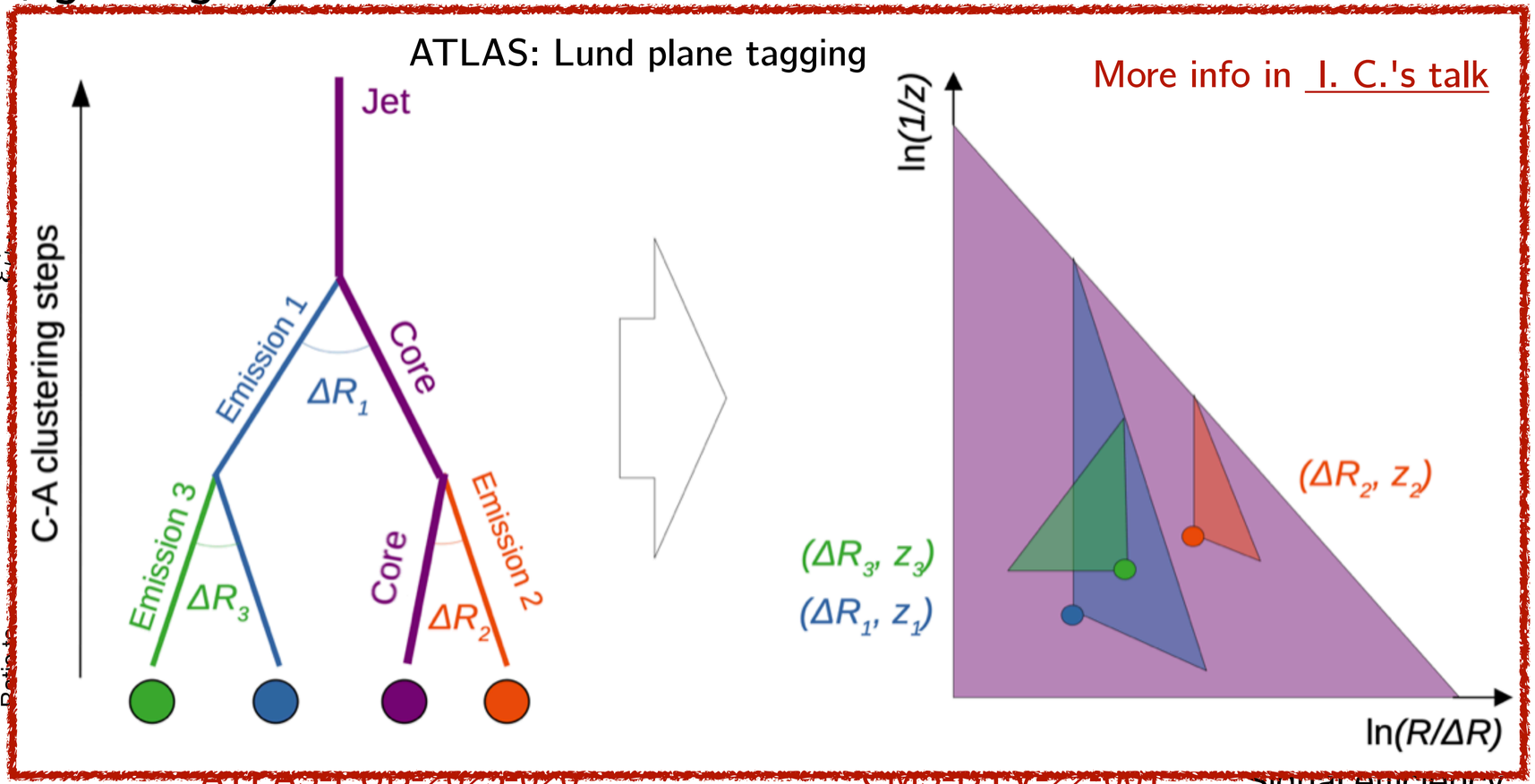
Tagging

- Type of elementary particle that initiated the jet
- Jet mass → ML with regression
- Jet flavour (b vs light, b vs c, g vs light) → $R = 0.4$
- Jet substructure (top, W/Z,





ATLAS-PUB-2023-017

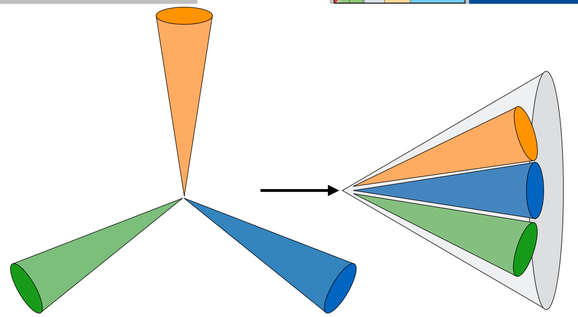


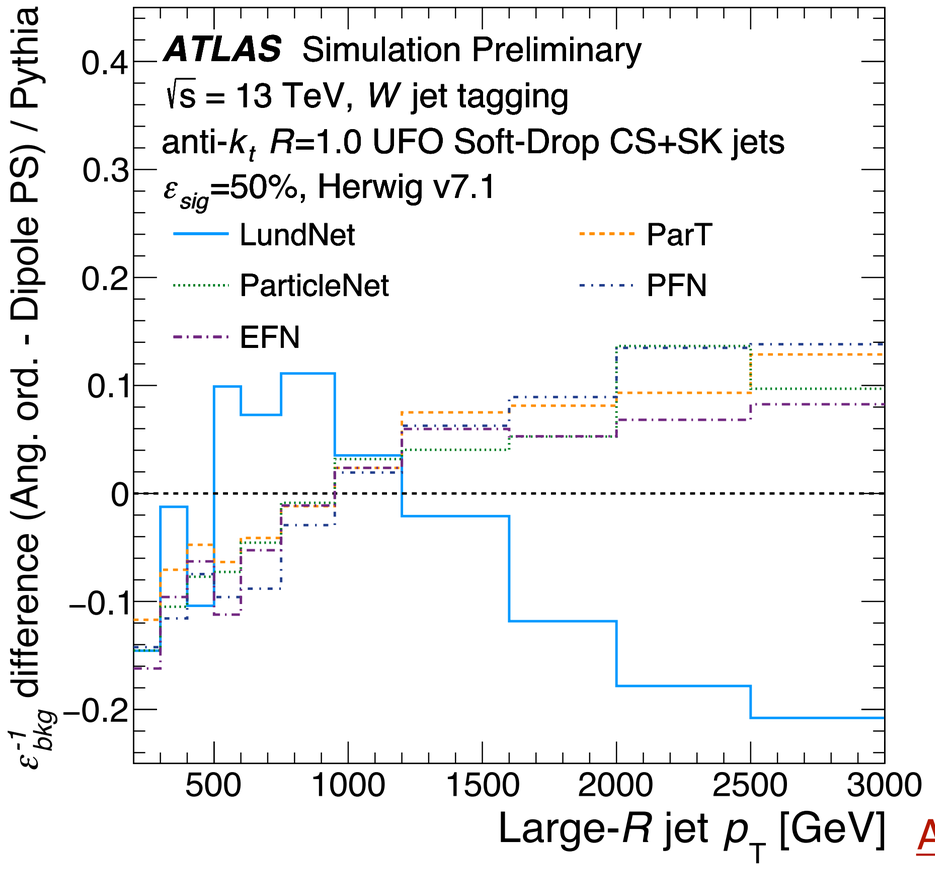
ATLAS-PUB-2023-020 CMS-BTV-22-001

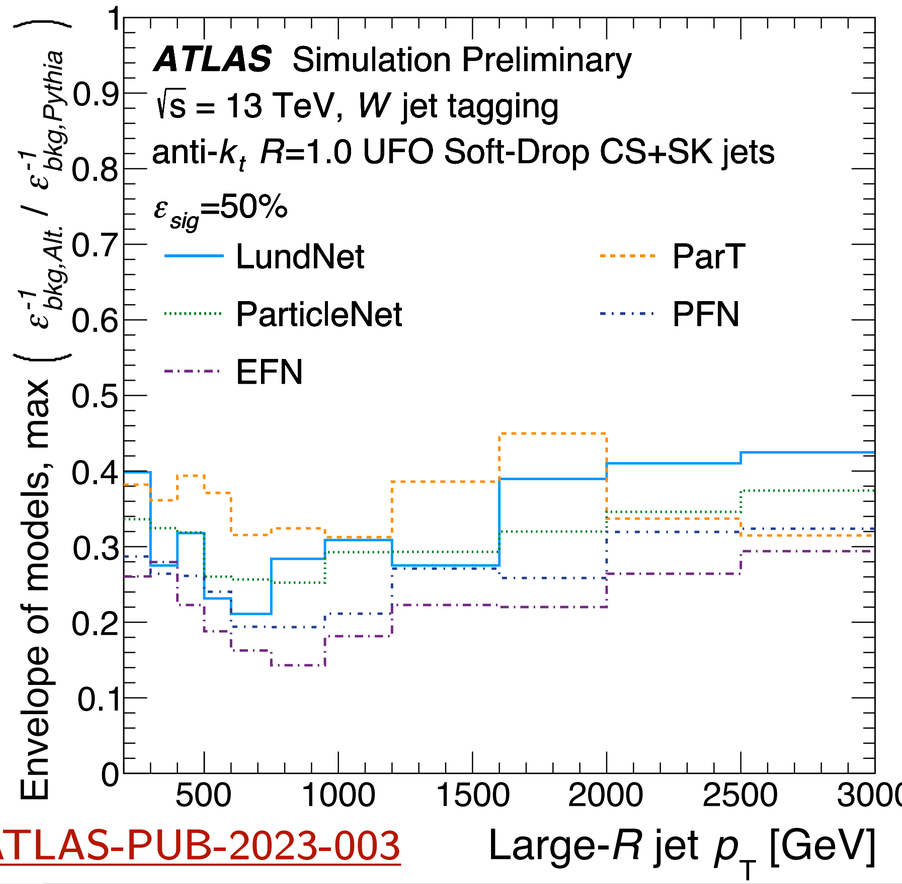
Jet identification (“tagging”) - modelling

Tagging -> modelling

- The more and more complex models/networks are being used
  - ... magnifying glass into substructure
  - ... need to understand in detail modelling uncertainty







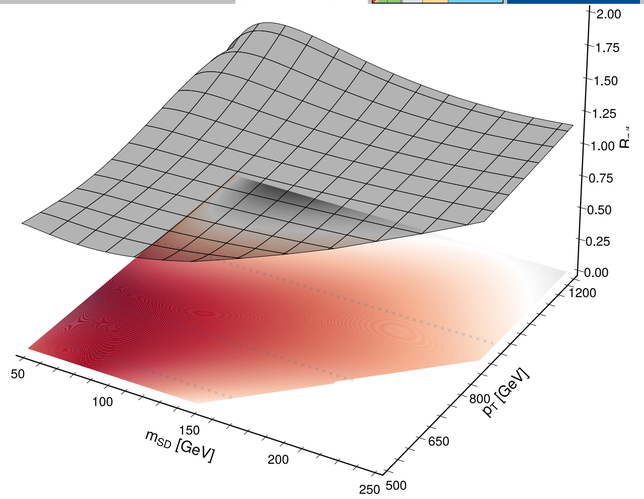
ATLAS-PUB-2023-003

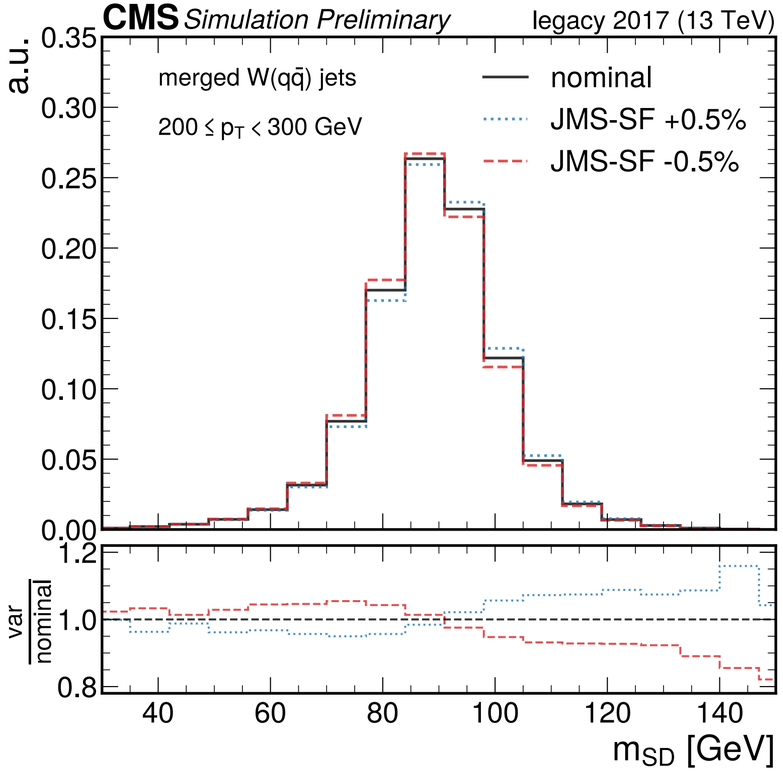
Jet mass and substructure -- Calibration

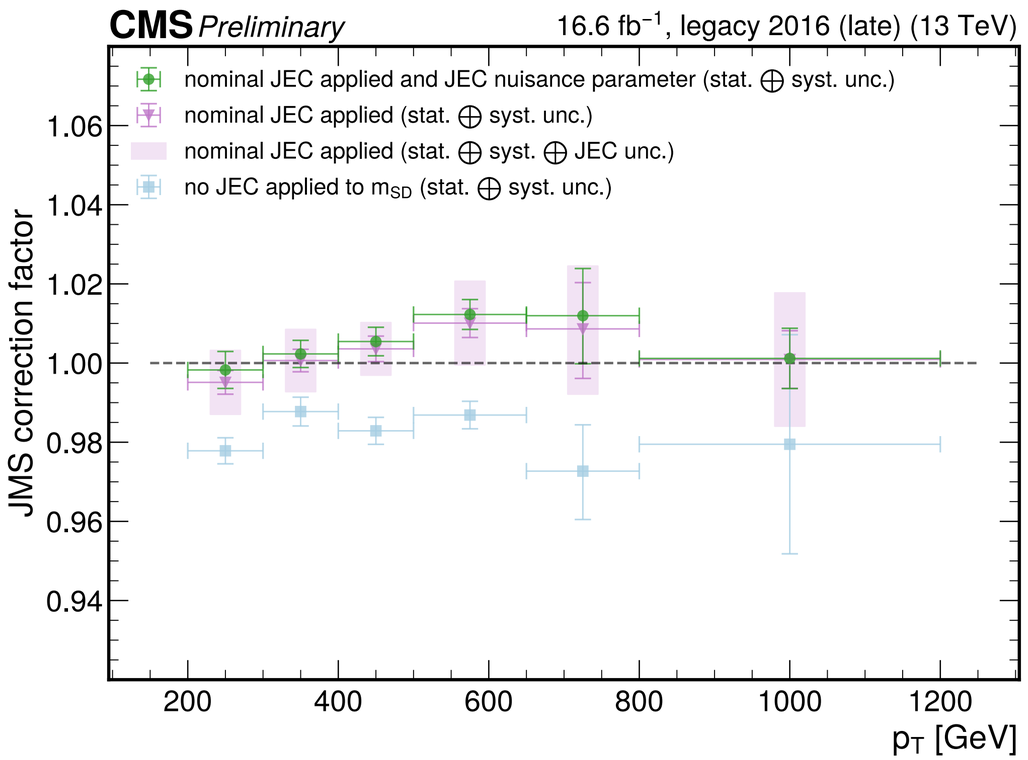
CMS-DP-2023-044

Jet substructure

- Correlation of mass and energy scale
  - Strong correlation observed ($\sim 80/90\,\%$) → Dedicated corrections
  - Corrections vary between $1-3\,\%$ depending on the correlation scheme





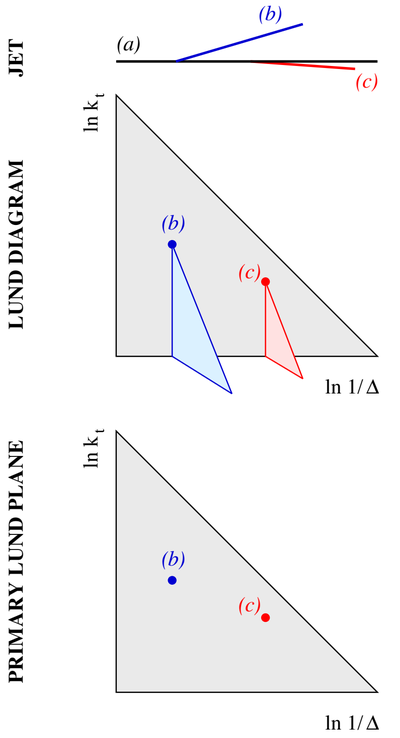


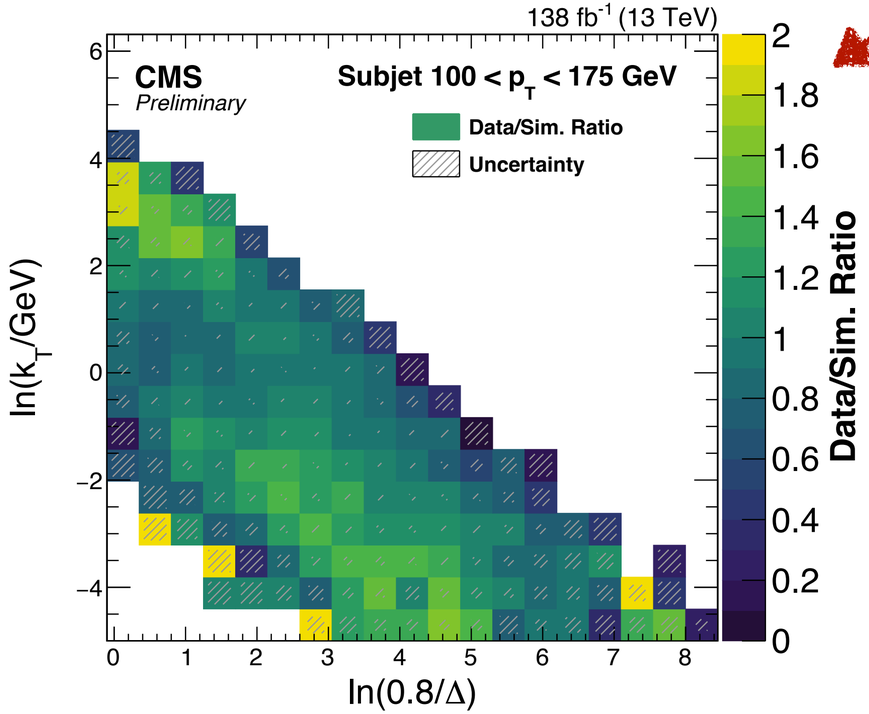
Jet mass and substructure -- Calibration

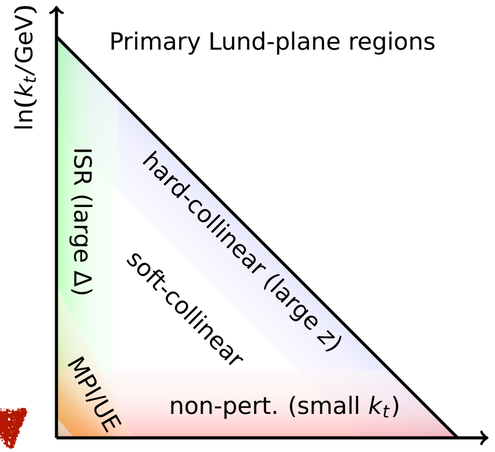
CMS-DP-2023-046

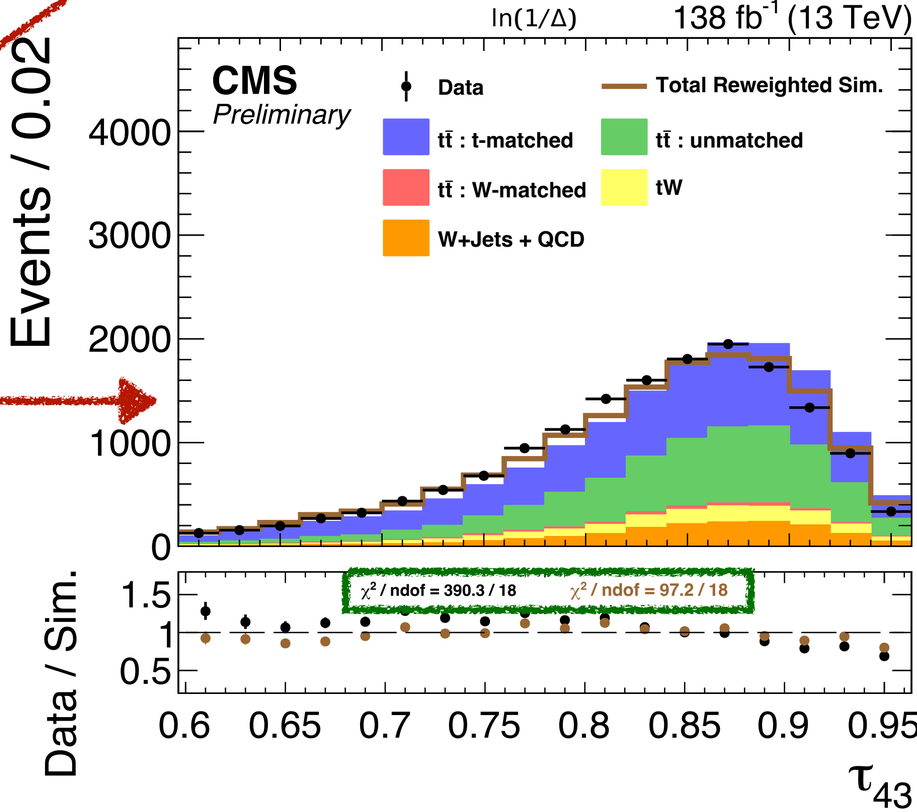
Jet substructure

- Correlation of mass and energy scale
- Lund plane reweighing technique
  - Novel approach to calibrate substructure jets with > 3 prongs
  - Allow calibration when no SM candle is present
  - Improve description of substructure variables





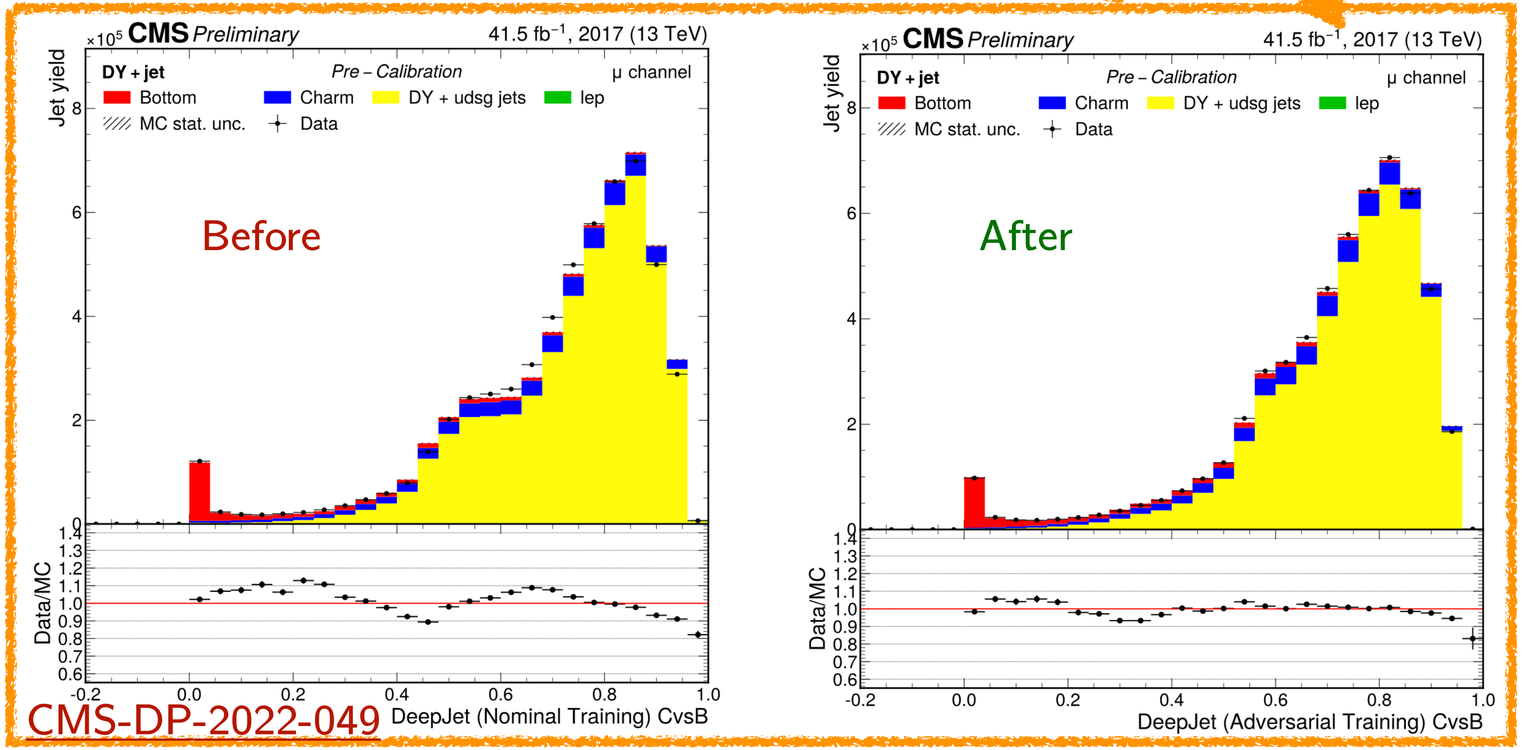


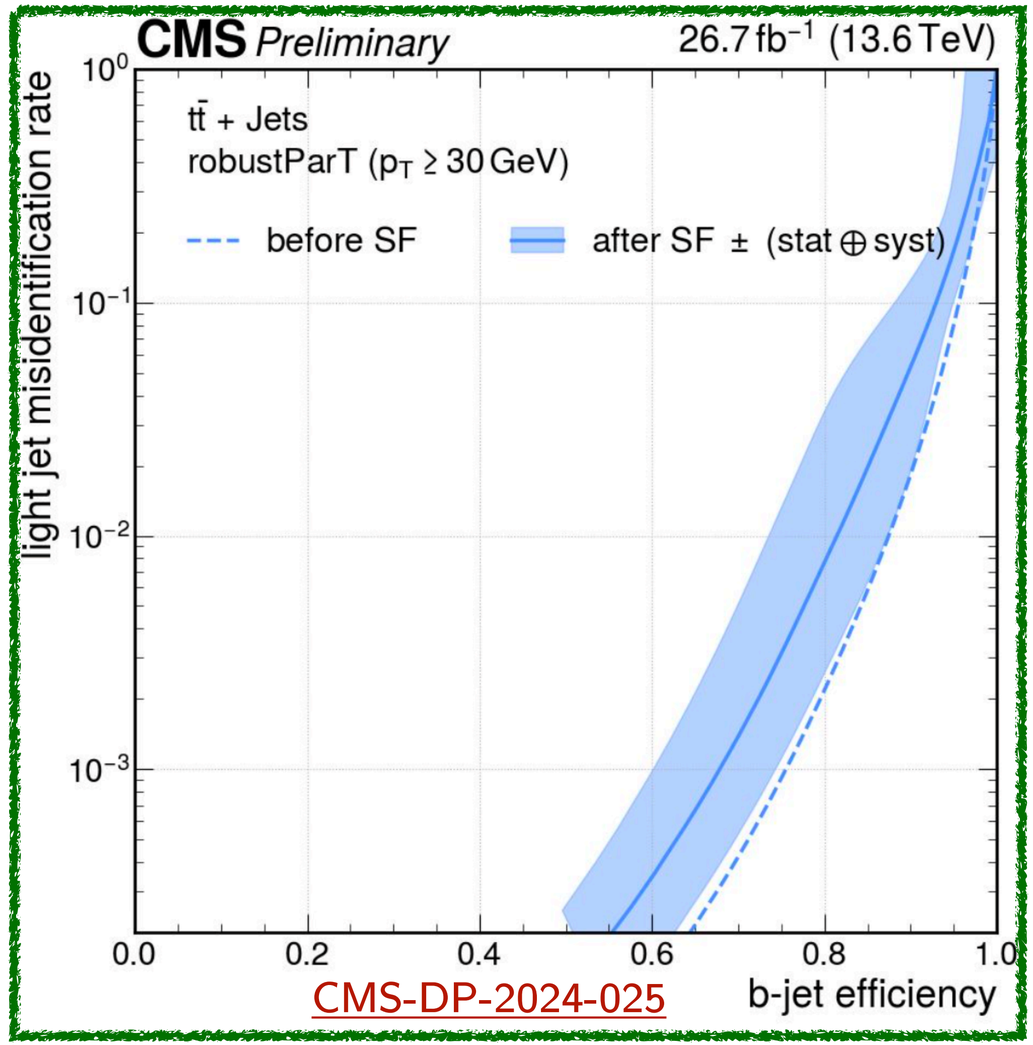


Jet mass and substructure -- Calibration

Jet substructure

- Correlation of mass and energy scale
- Lund plane reweighing technique
- Calibration of taggers
  - Important when comparing performance
  - Adversarial training to improve modelling

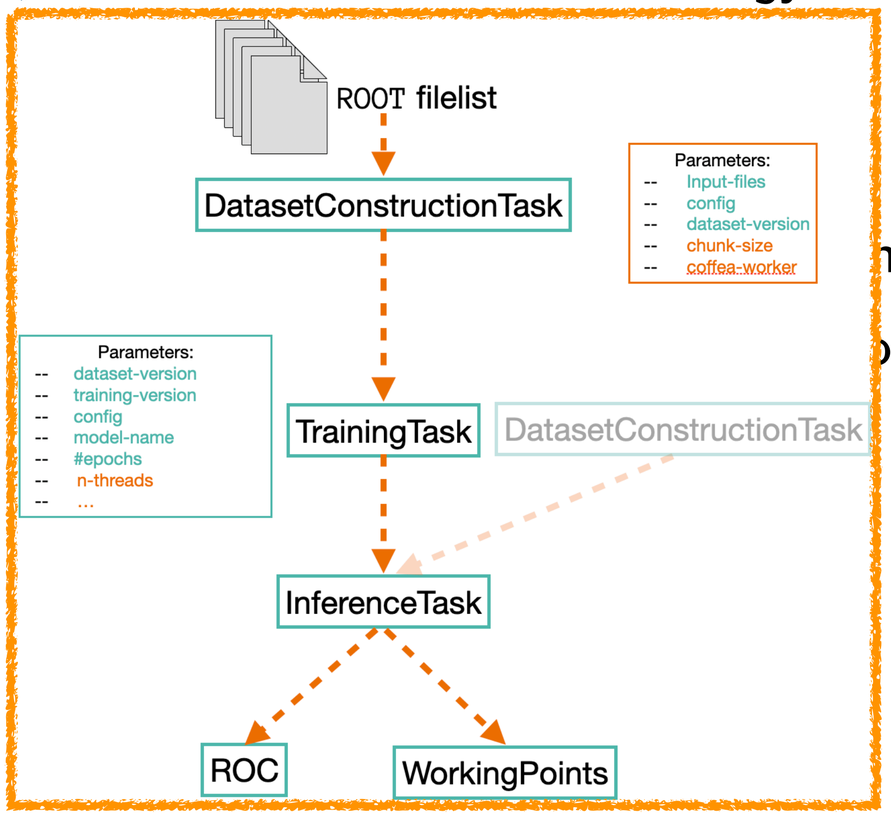




Jet mass and substructure -- Calibration

Jet substructure

- Correlation of mass and energy scale



mance

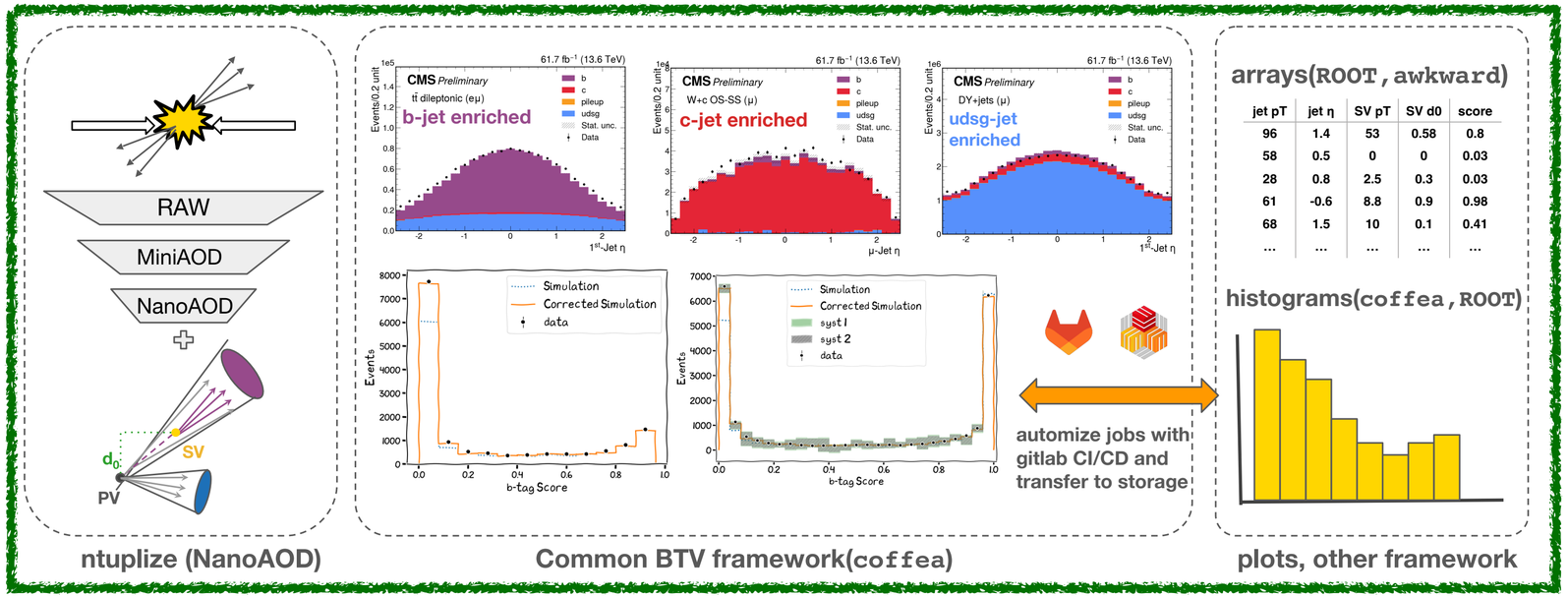
odelling

Find out more about new calibration methods and training frameworks in CMS!

CMS-DP-2024-020

CMS-DP-2024-024

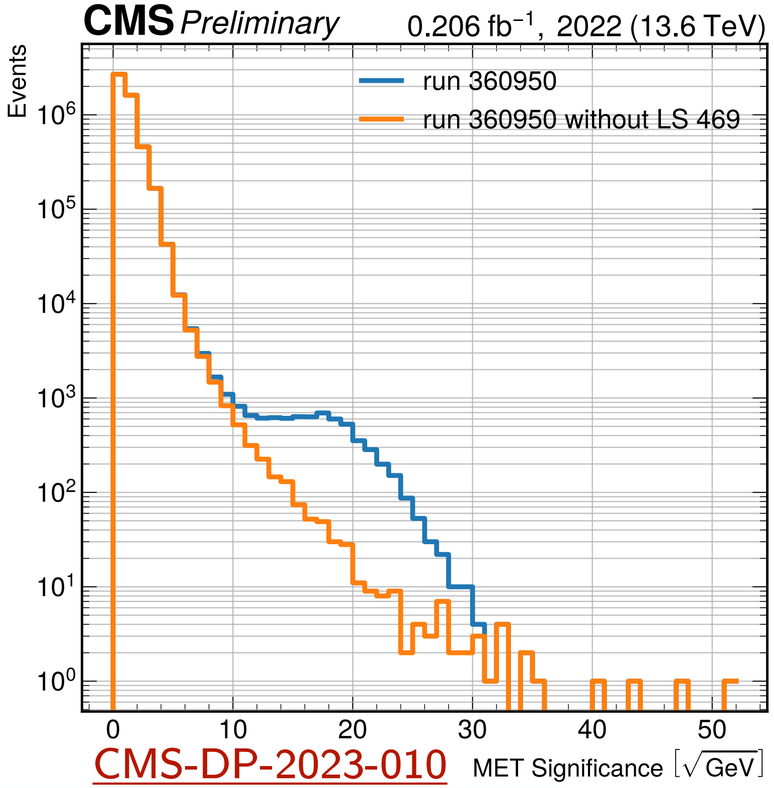
CMS-BTV-22-001



Run3 and beyond

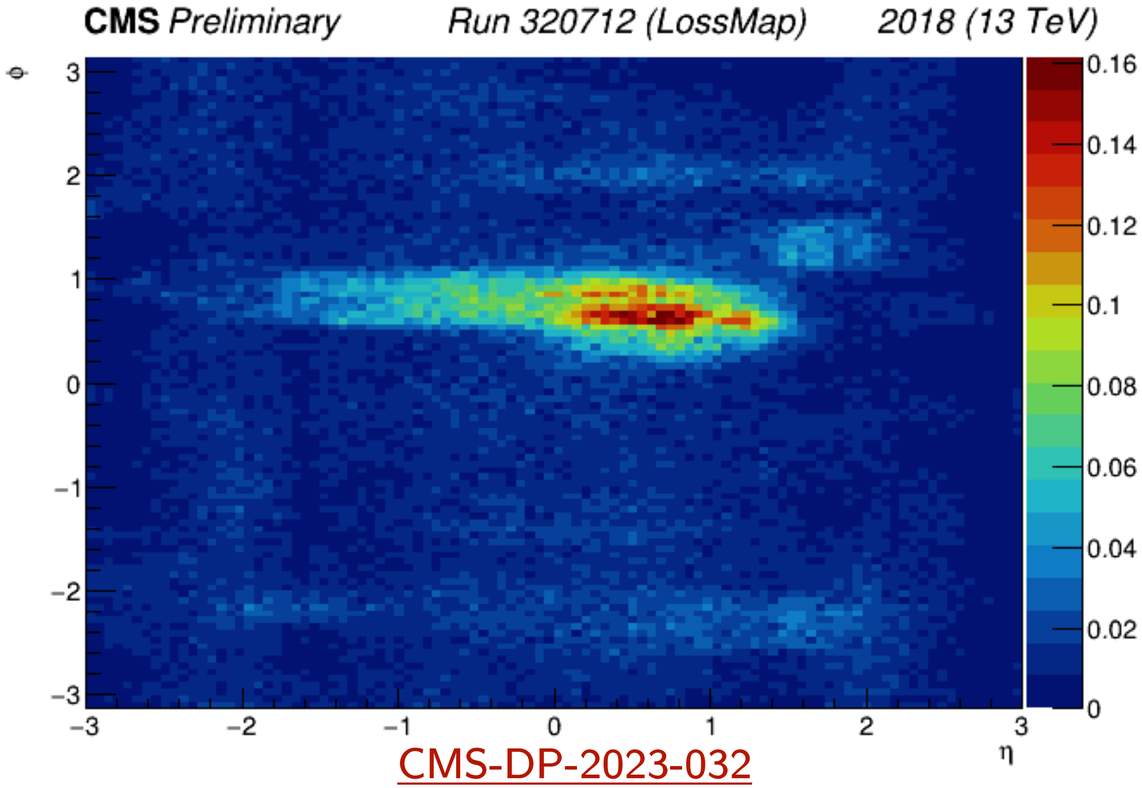
ML tools for data-certification

- Anomaly detection
  - Unsupervised training with AutoEncoder
  - detecting anomalies per lumi-section (LS)
  - Increase efficiency of collected data



CMS-DP-2023-010

- Anomalous detector regions:
  - Unsupervised training with AutoEncoder
  - 1D and 2D histograms to detect problematic phase-space
  - Reduce time spent and human error

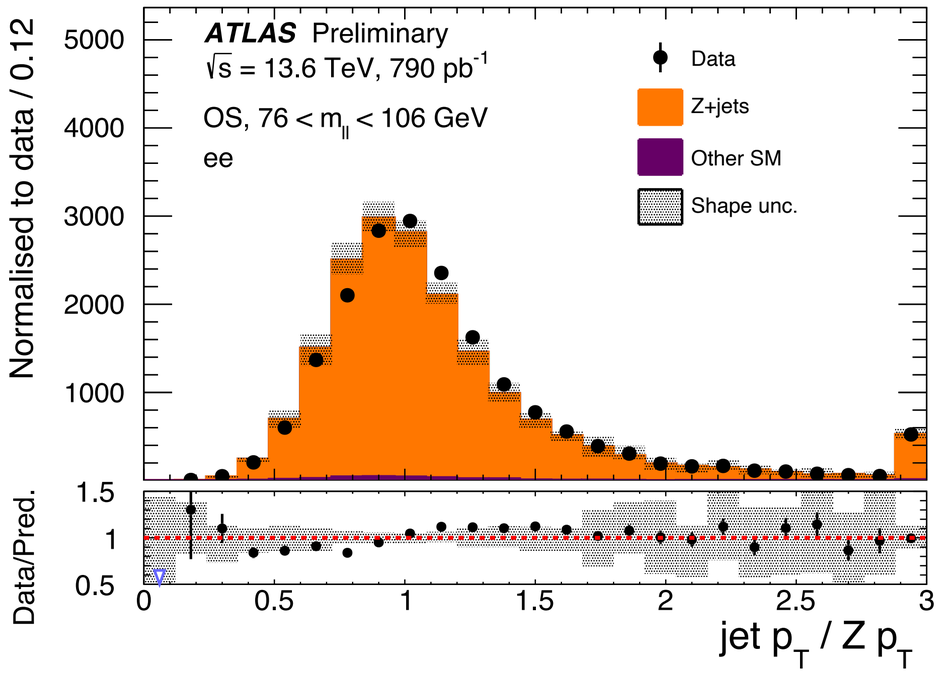


CMS-DP-2023-032

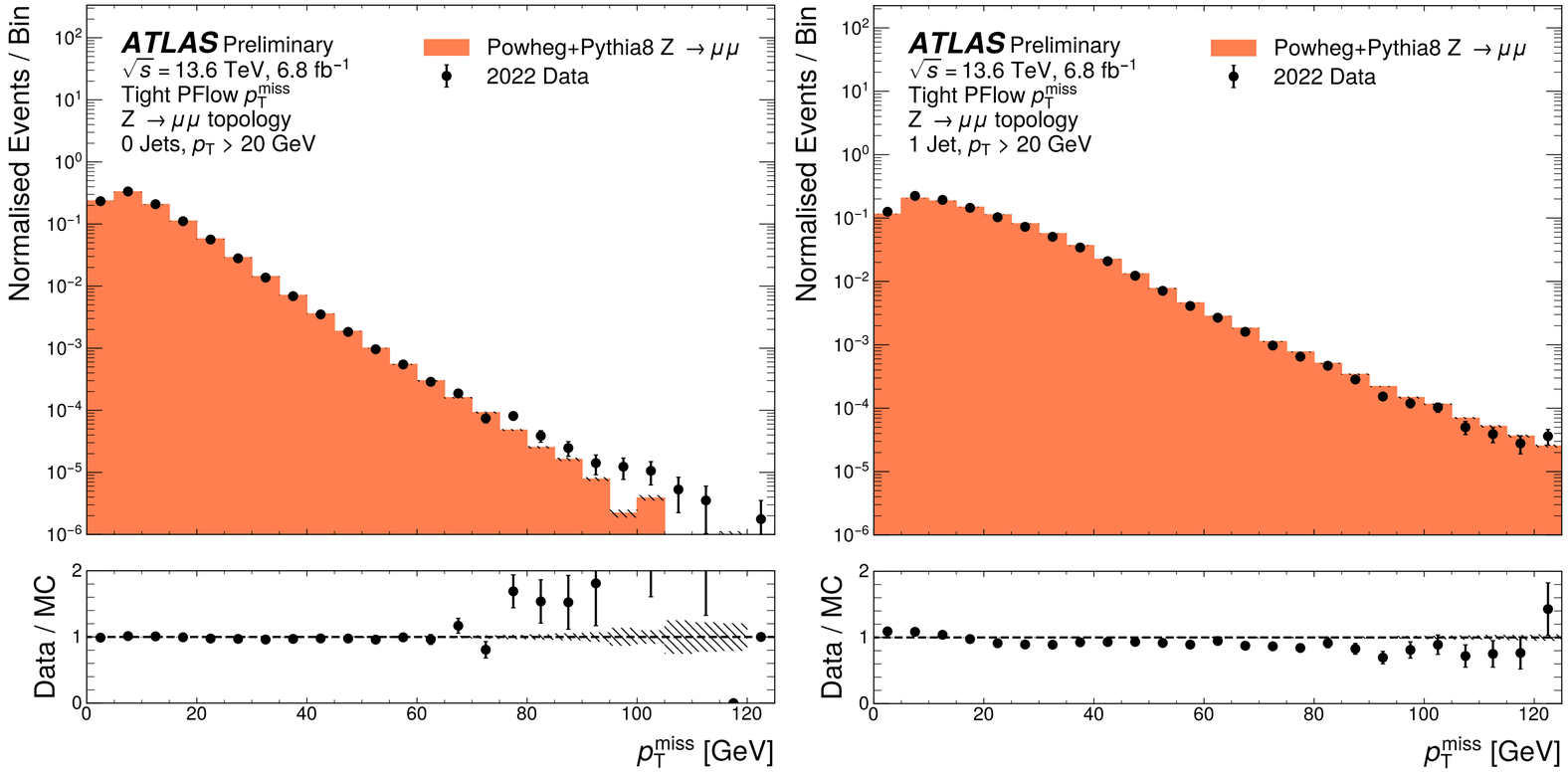
Run3 and beyond

Run 3 data: jet performance

- Successful data-taking in Run3 for CMS and ATLAS
  - Good overall object performance



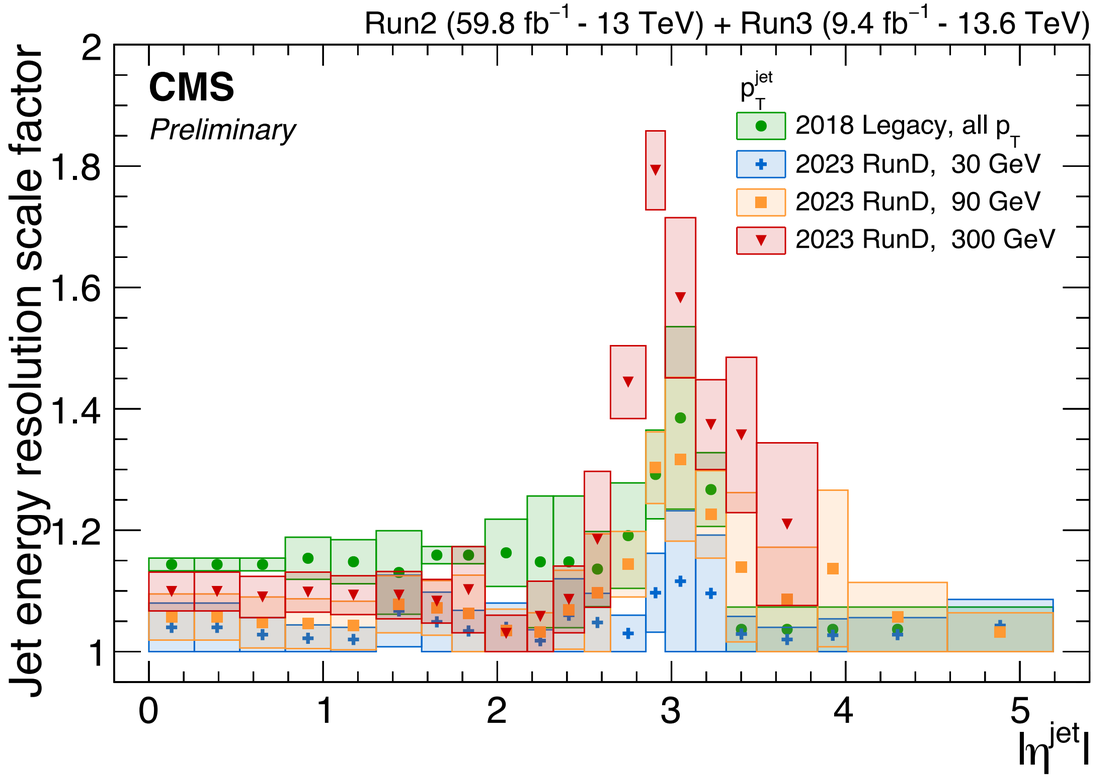
ATLAS: JETM-2022-007

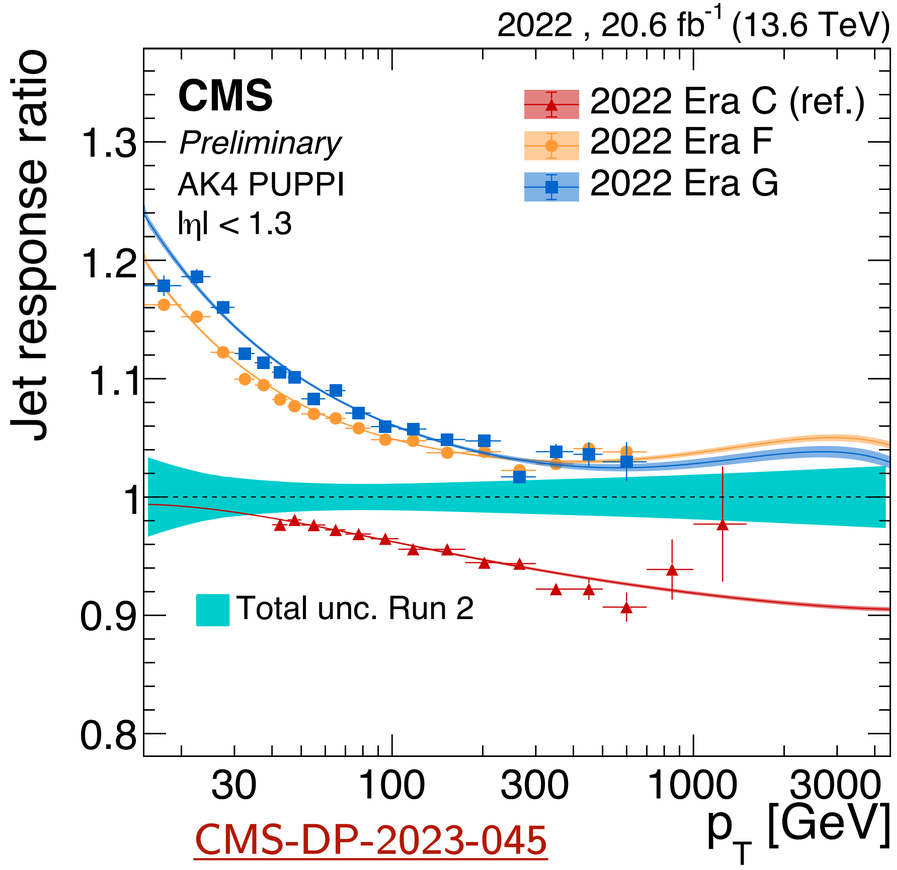


ATLAS: JETM-2022-009

Run 3 data: jet performance

- Successful data-taking in Run3 for CMS and ATLAS
  - Good overall object performance
  - CMS: Minor hiccup due to water leak in ECAL region, and several HCAL scale updates
  - CMS: improved resolution in central detector region

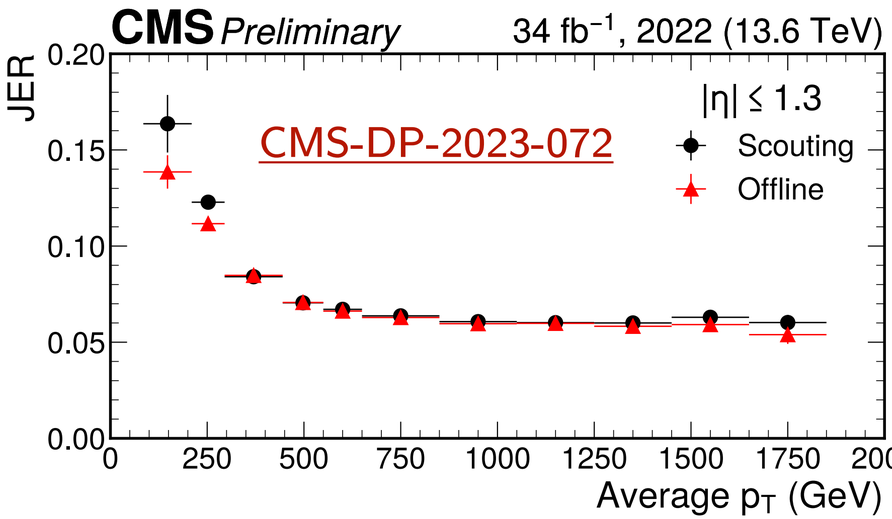


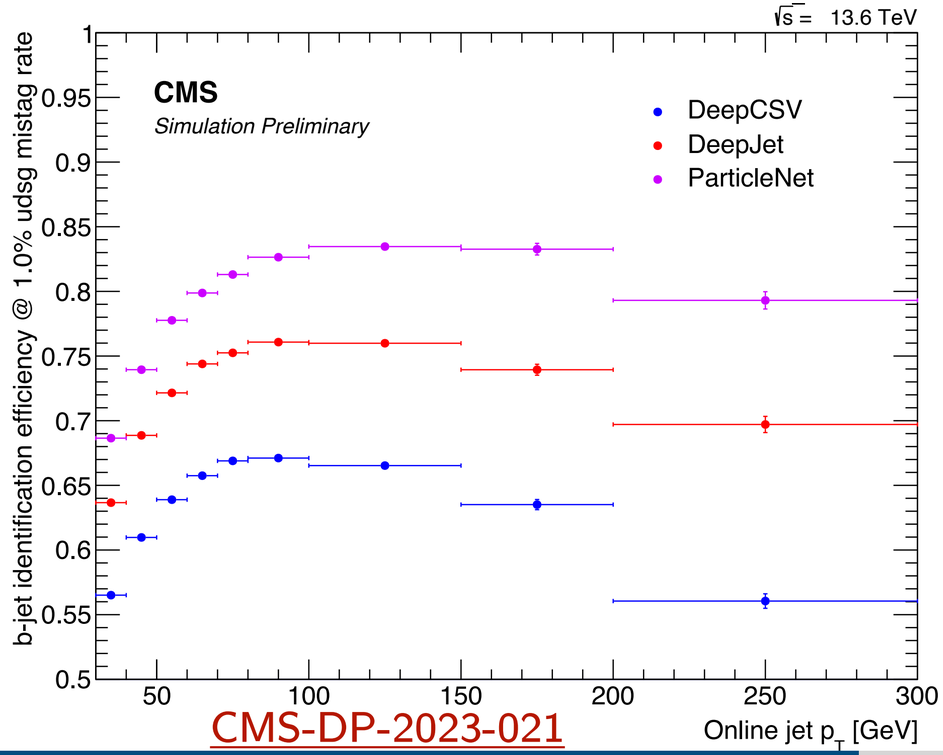


Run3 and beyond

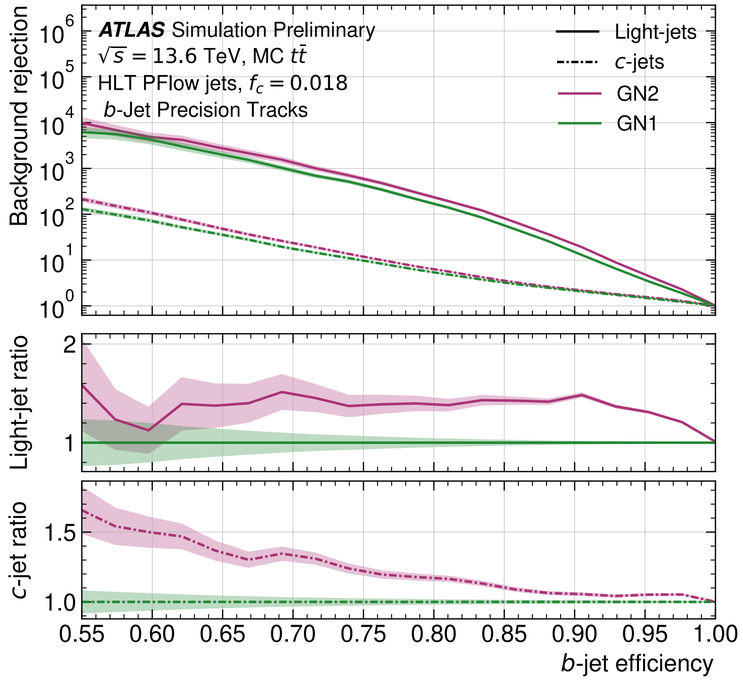
Run 3 data: jet performance

- Successful data-taking in Run3 for CMS and ATLAS
- Great performance of jets at trigger level
  - Scouting jets with similar JES/JER as offline jets
  - New flavour tagging at trigger level (HLT)

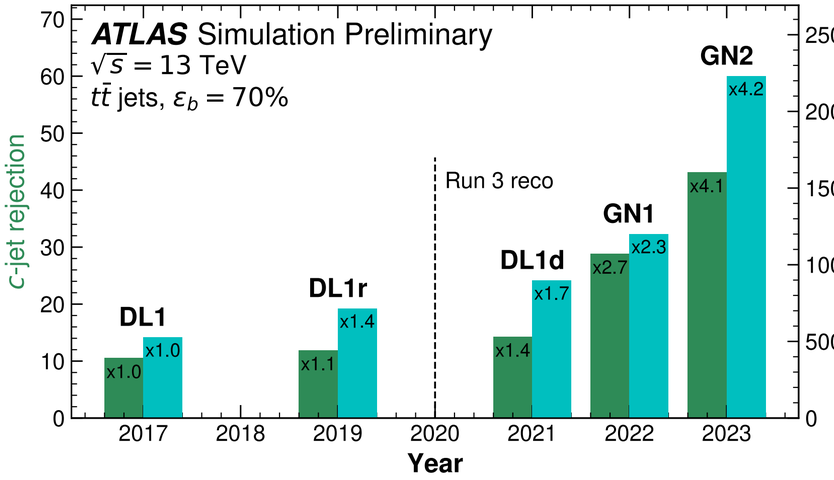




CMS-DP-2023-021



ATLAS: BJet Trigger ATLAS: btagging @HLT



ATLAS-FTAG-2023-01

Summary and Outlook

- Jets are the *"bread and butter"* that makes everything else possible

- Continuous evolution of techniques
  - State-of-the-art ML
  - New calibrations methods
  - Maximise the potential of ATLAS and CMS detectors to their fullest extent

- First Run3 results available
  - Calibration is still ongoing, but good overall performance
  - Large improvement is foreseen from the Run2 experience

Thank you for your attention!