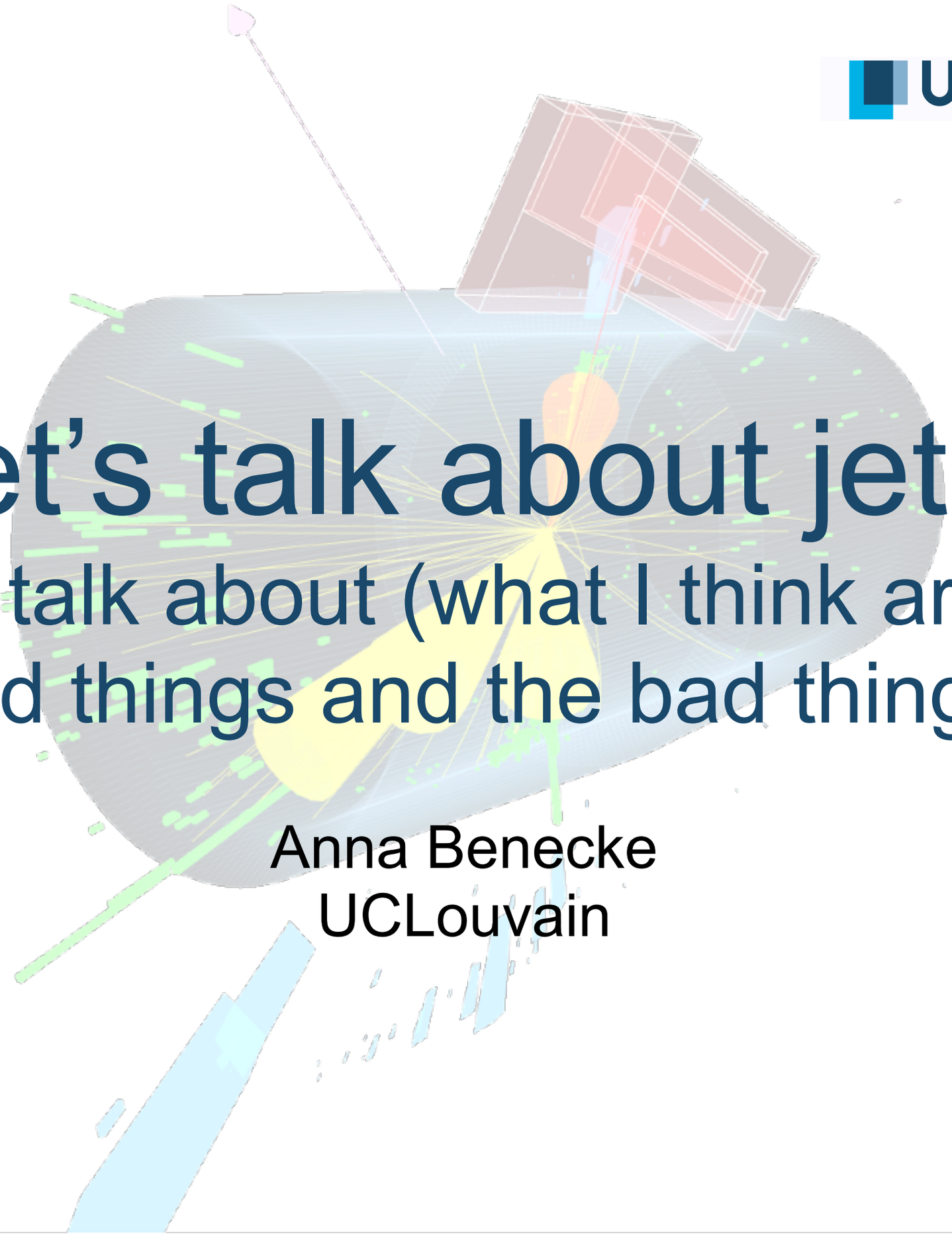


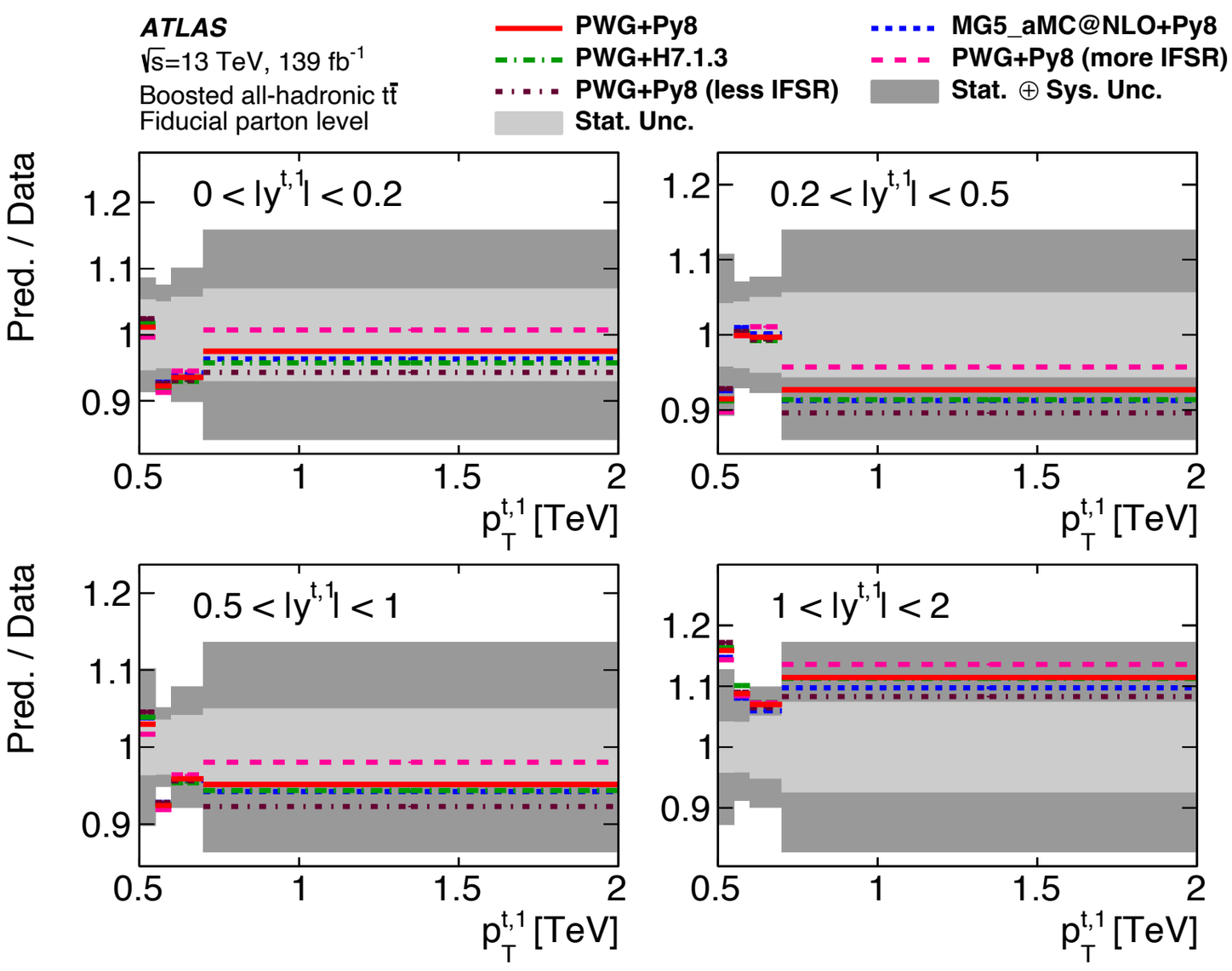
Let’s talk about jets!

- Let’s talk about (what I think are) the good things and the bad things -

Anna Benecke
UCLouvain

Precision measurements with jet substructure

arxiv:2205.02817



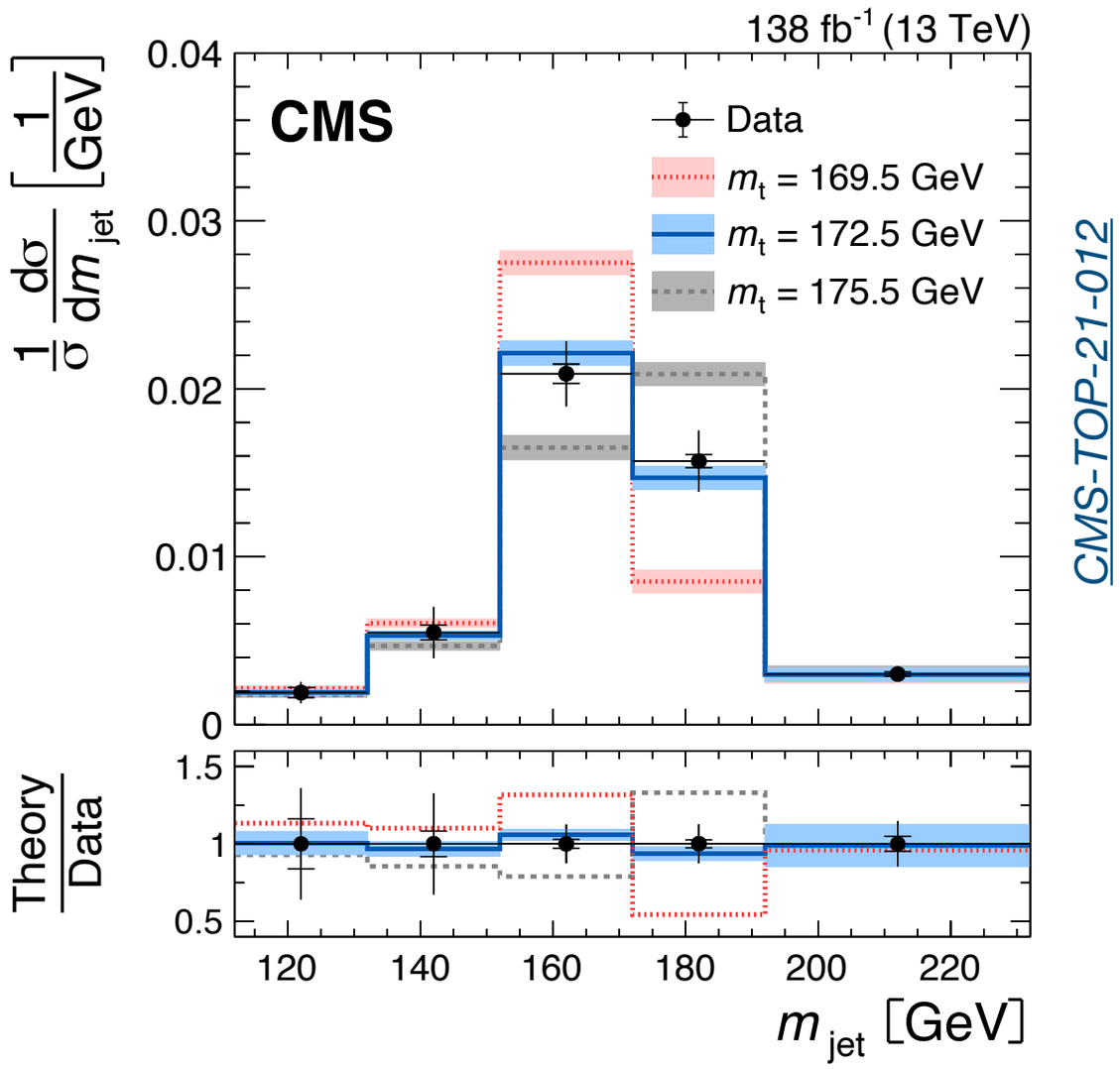
Differential $t\bar{t}$ cross-section measurements using boosted top quarks in the all-hadronic final state with 139 fb^{-1} of ATLAS data

- In the ATLAS TDR 15 top quarks play an important role → a lot of them to study
- "largest sample of tt events consists of six-jet events from the fully hadronic decay mode"
- Reduces combinatorics significantly if large-R jets are considered
- By now precision measurements of boosted top quarks

Let's find out about the agreement in the second leading jet and how good we can constrain EFT parameters with this

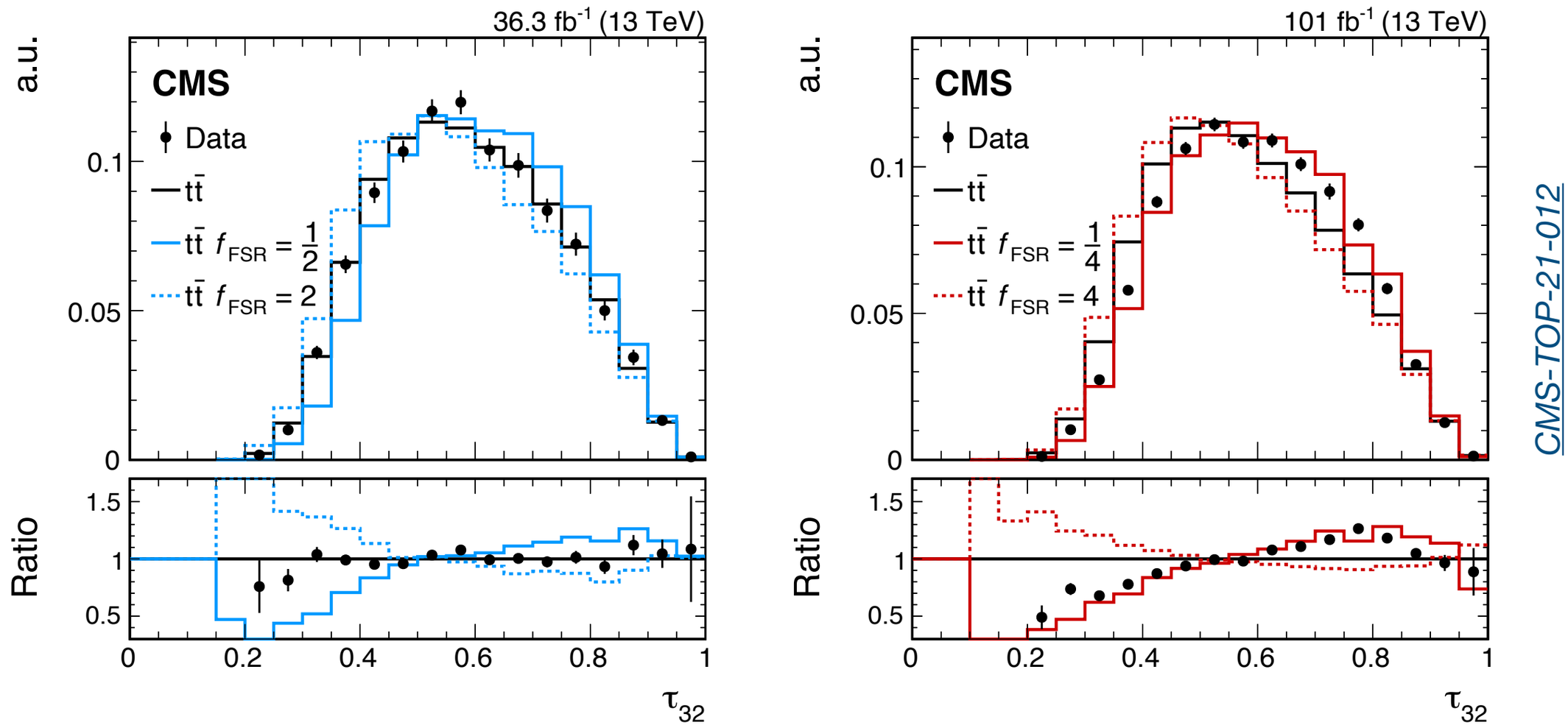
talk by Adam

Top quark mass measurement with large-R jets



- Measured the top quark mass to 173.06 ± 0.84 GeV → compatible with other measurements (l+jets & all-hadronic resolved)
- Reduced systematic uncertainty by
  1. dedicated calibration of the jet mass scale using the W as constrain
  2. study of the effects of final state radiation inside large-radius jets

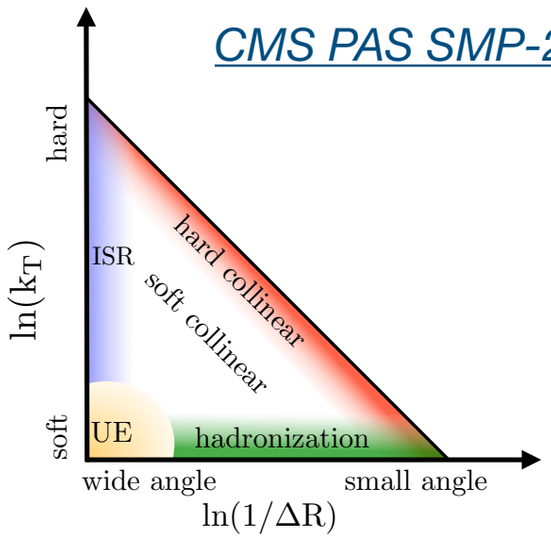
Improving MC = improving substructure modeling?

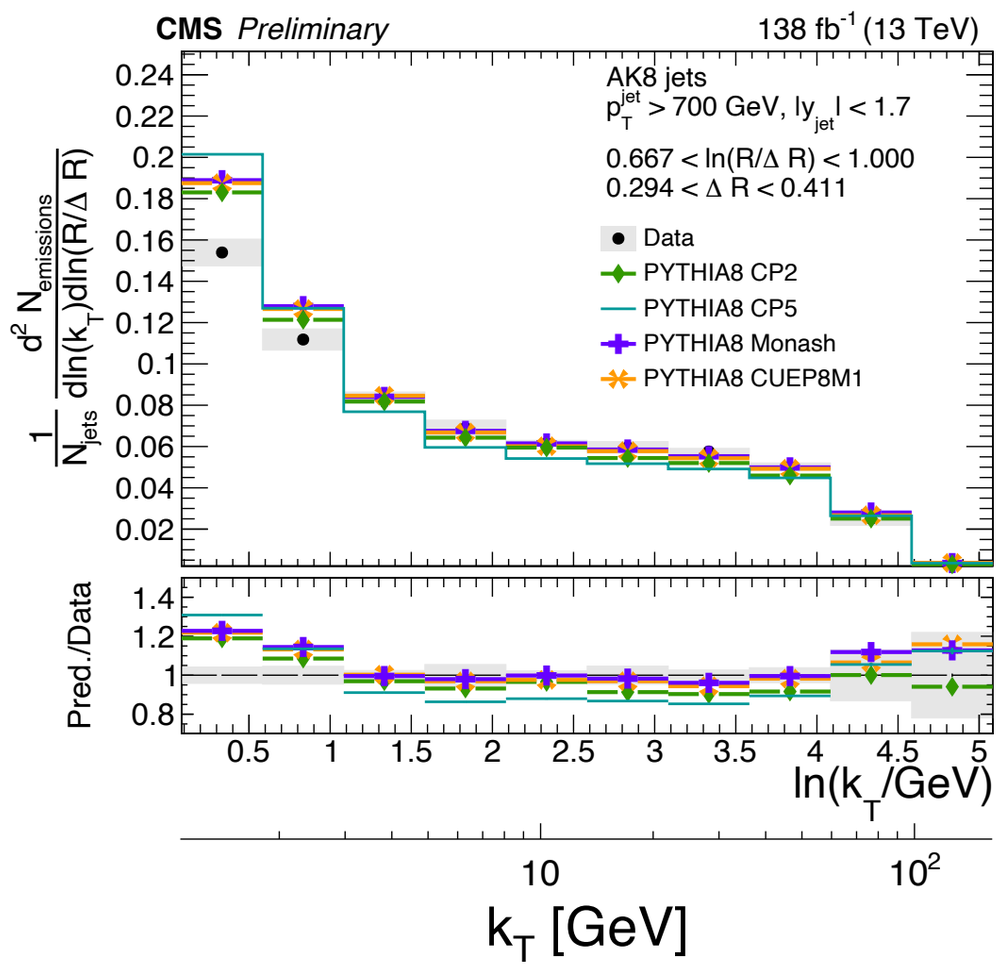


CMS-TOP-21-012

- CMS changed their PYTHIA tune from 2016 (CUETP8M1) to 2017 (CP5) which showed improvement in several phase spaces (CMS-GEN-17-001)
- Major change in $\alpha_s^{\mathrm{FSR}}(m_Z^2)$ from 0.1365 to 0.118
- Variables like N-subjettiness very sensitive to these changes

Jet substructure measurements



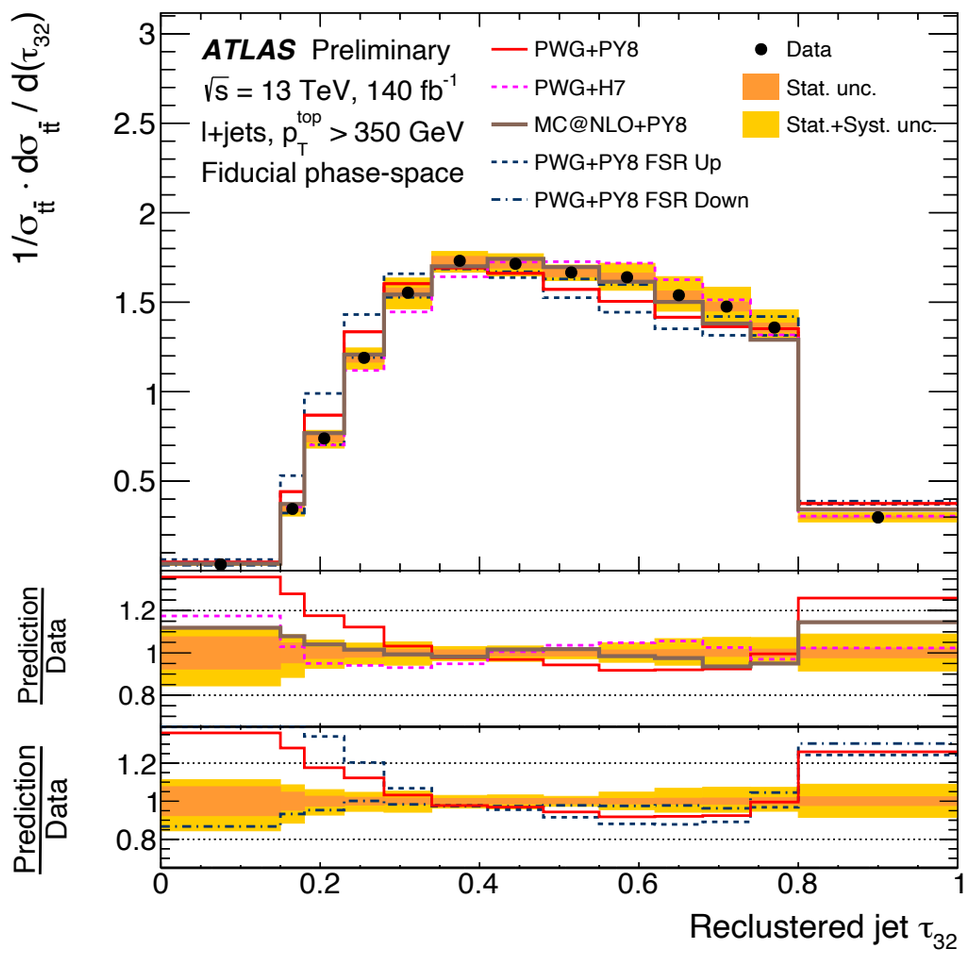


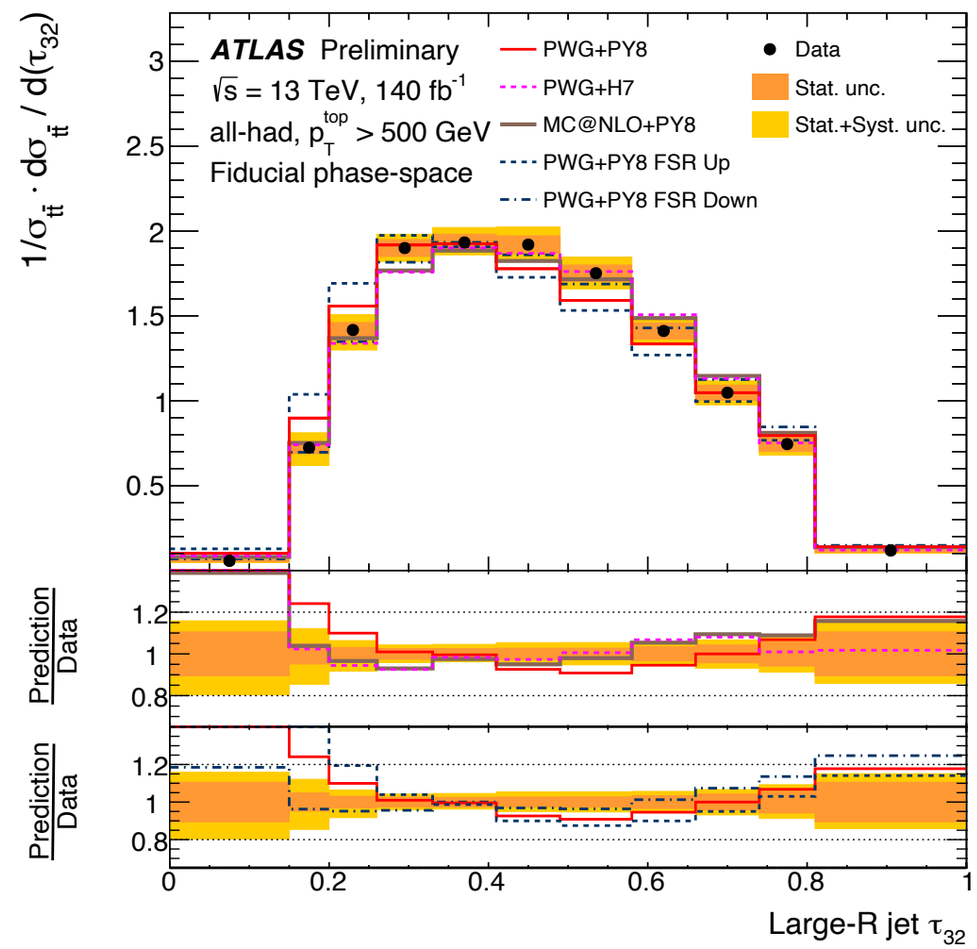
- Similar behaviour of the FSR seen in recent Lund Jet Plane (LJP) measurement
- LJP = a representation of the phase space of emissions inside jets
- For the first time done for large-R jets with charged particles only
- can be used as an input to improve event generators and parton showers

Let's find out about the agreement in other areas of the Lund Jet Plane

talk by Cristian

Jet substructure measurements





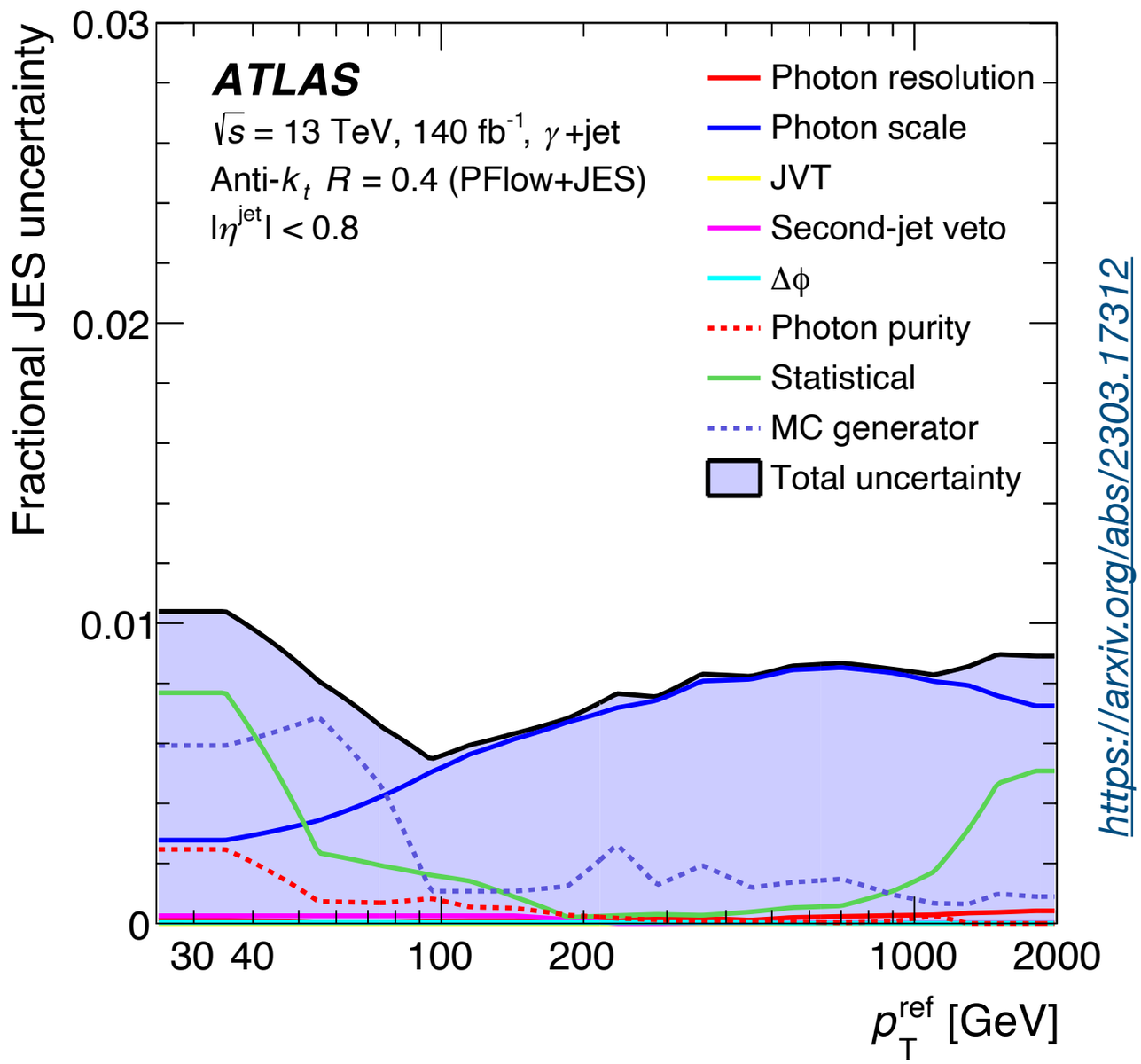
ATLAS-CONF-2023-027

- Combination of lepton+jets and all-hadronic final states → enable measurements of the substructure of with average $p_T > 500$ GeV
- Variable defined using charged particles only
- A lot of different substructure variables measured

Let's see more substructure variables in the

talk by Adam

Jet calibration



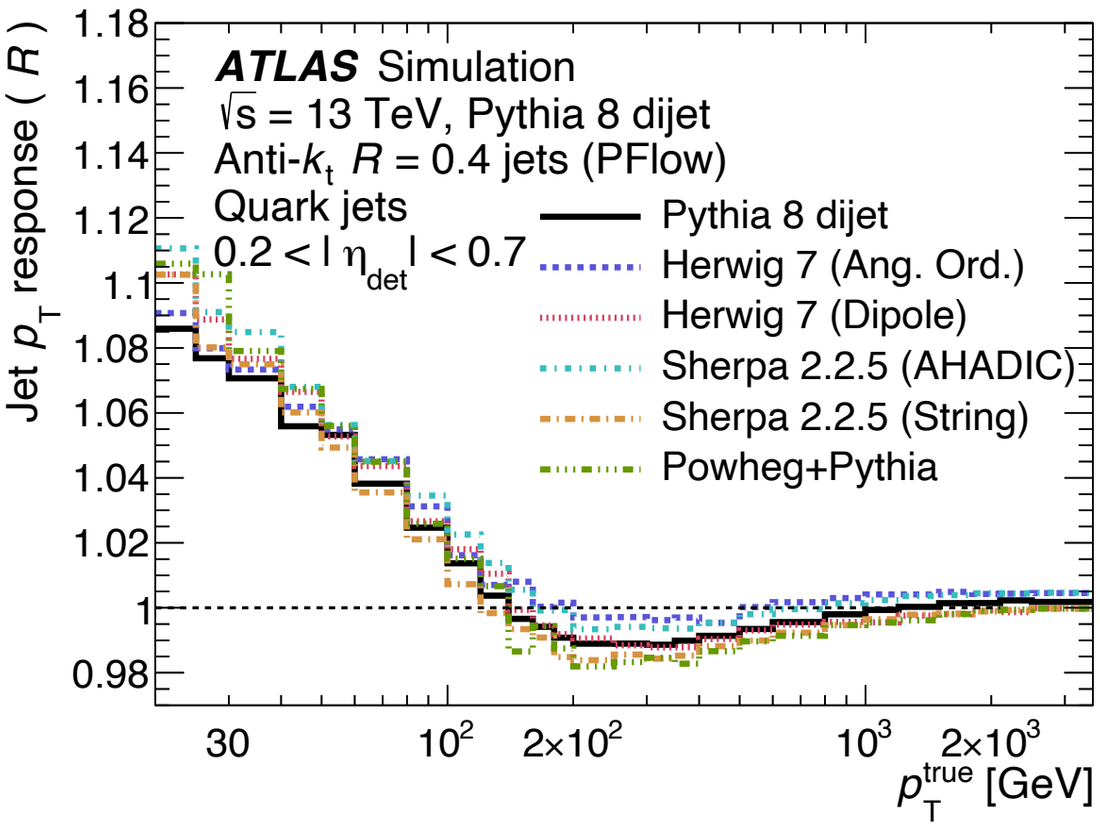
https://arxiv.org/abs/2303.17312

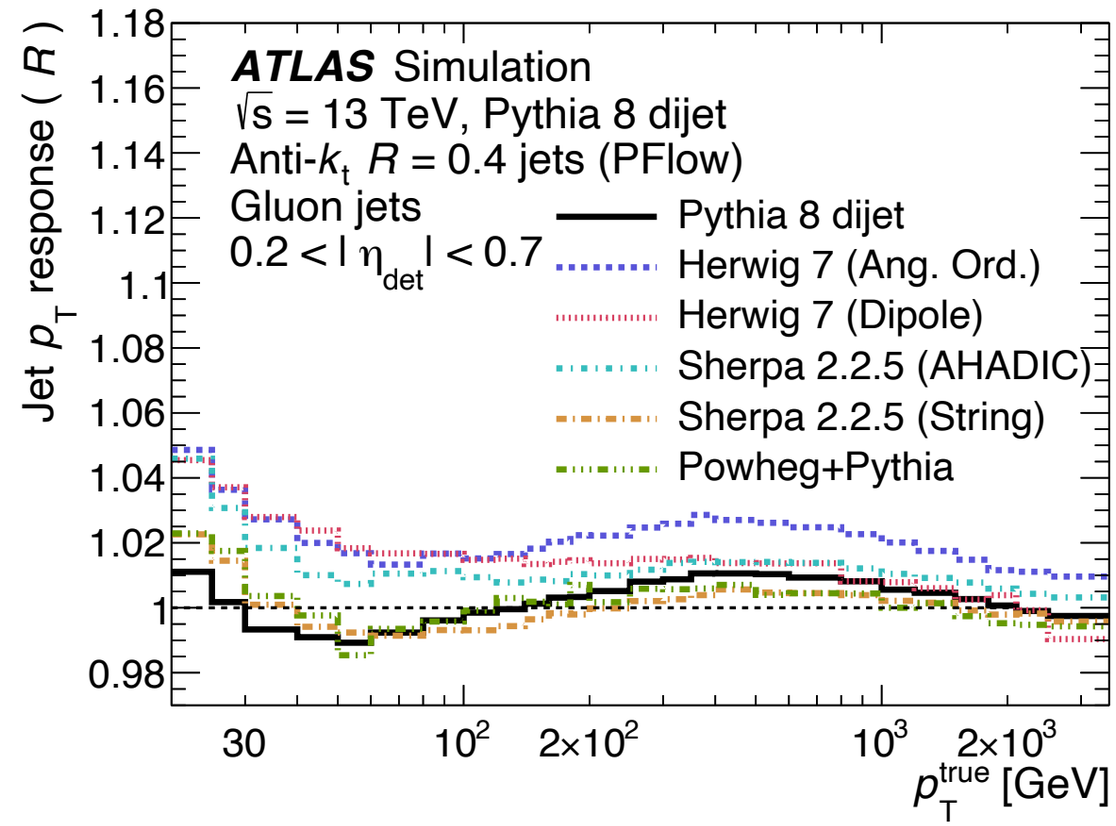
- The calibration of jets depends on the simulation
- One leading uncertainty at low p_T comes from the MC generators
- At high p_T it is the photon scale → we need a good understanding of the detector as well

Let's find out more about the new jet calibration techniques for Run3

talk by Margherita

Jet calibration





https://arxiv.org/abs/2303.17312

- Jet response of quark and gluon jets very different especially at low p_T
- Gluon response depends a lot on the MC generator / tune used
- LEP data tunes like Sherpa ahadic++ help to tune the charged hadron content

Let's find out more about the new jet calibration techniques for Run3

talk by Margherita

Jet mass and energy scale

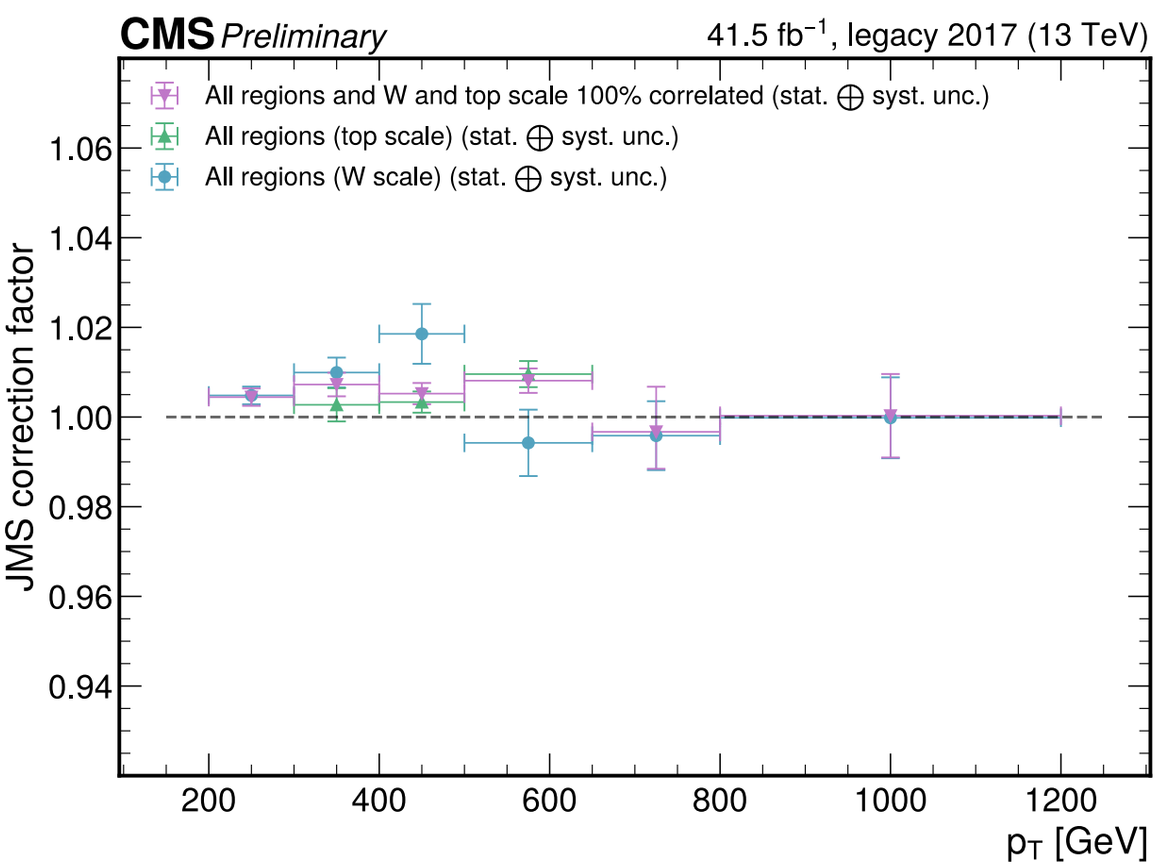
Future Directions (?)

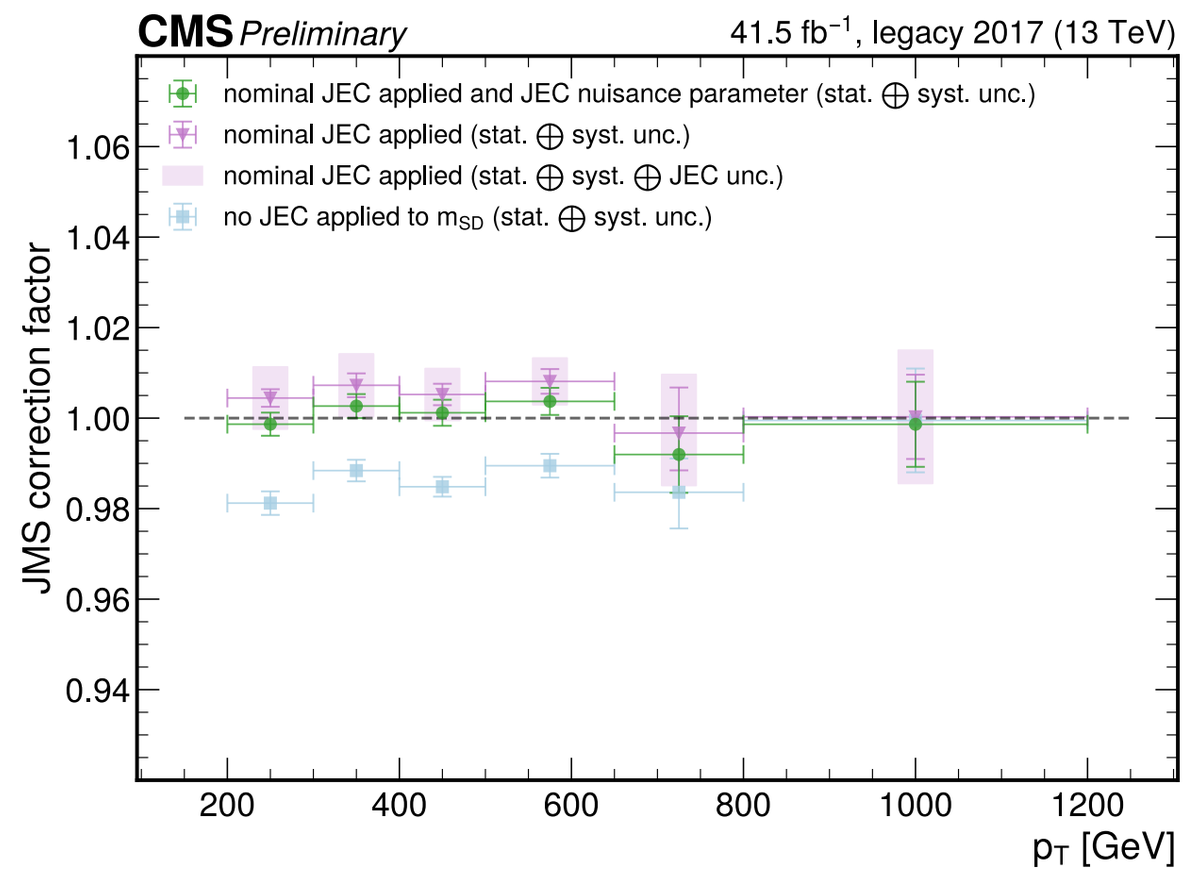
Boost 2018 - Advances in jet substructure for tagging by Roman

- **Combine advantages of PF and TCC in ATLAS**
  - Single, optimal reconstruction of final state for all use cases
- **CMS PF developed with low PU in mind**
  - Fantastic performance, even at Run 2
  - Developments needed for HL-LHC
    - Upgraded detectors with longitudinal segmentation, higher granularity, extended η coverage…
    - Improvements can help already now
- **More consistent treatment of JES, JER, JMS and JMR**
  - Simultaneous determination
  - Factorized approach has advantages, but can introduce double-counting of uncertainties, unknown correlations

Jet mass and energy scale

CMS DP-2023/044

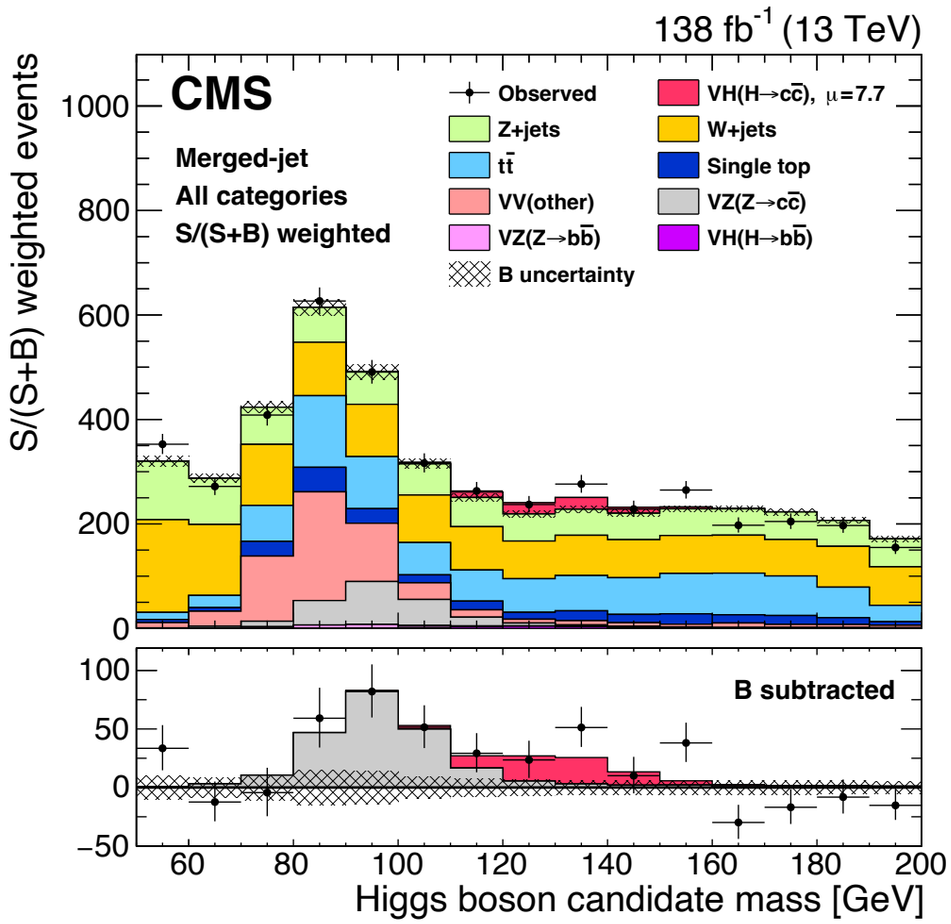


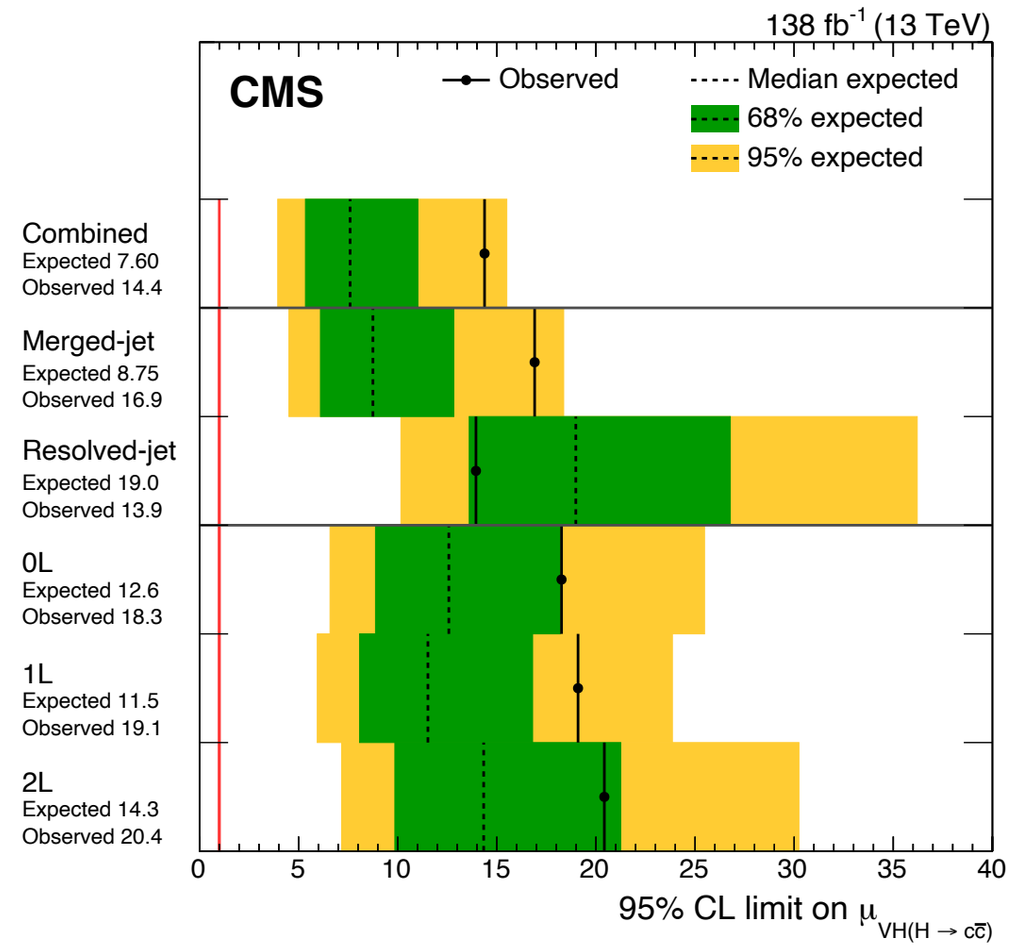


- Calibration of the jet mass scale in two independent samples
- Correlation between jet energy and mass scale
- Good agreement of jet mass scale also between the samples
- Next step: particle dependent energy scale correlation

Doing the impossible?

CMS-HIG-21-008





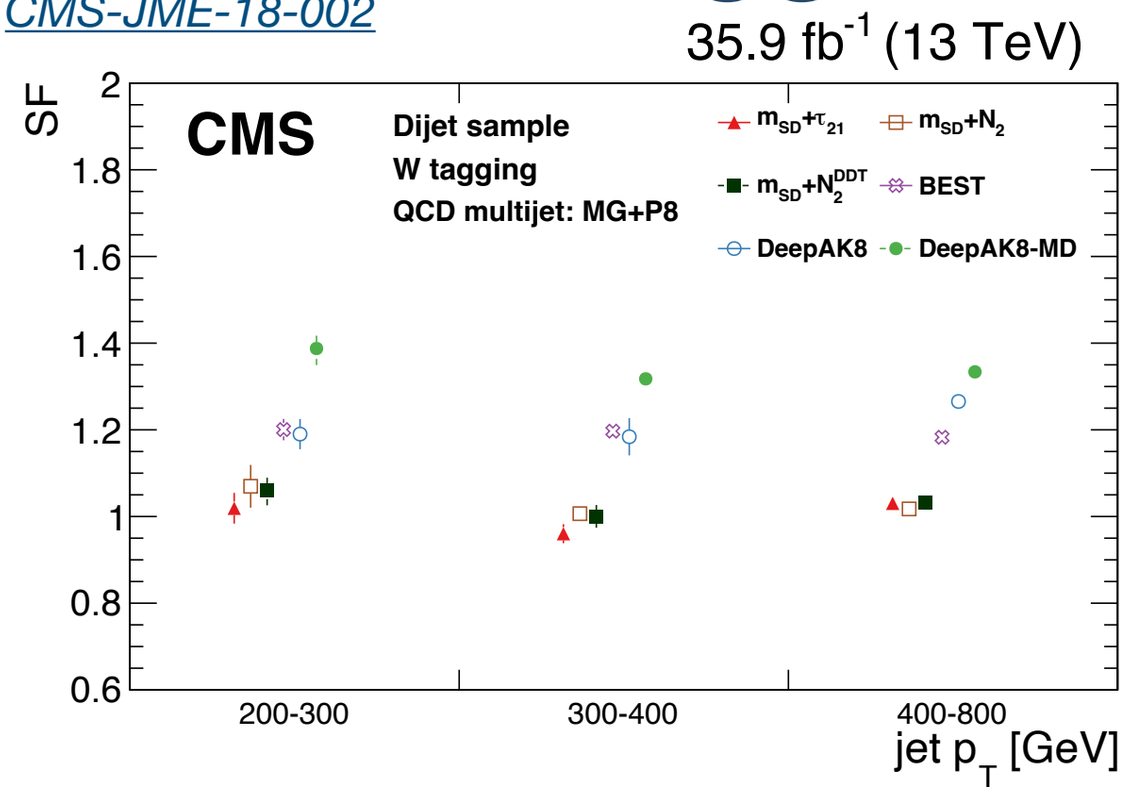
- CMS TDR (2006): “The [Higgs] decay modes into cc [..] pairs [..] do not play a relevant role at the LHC.”

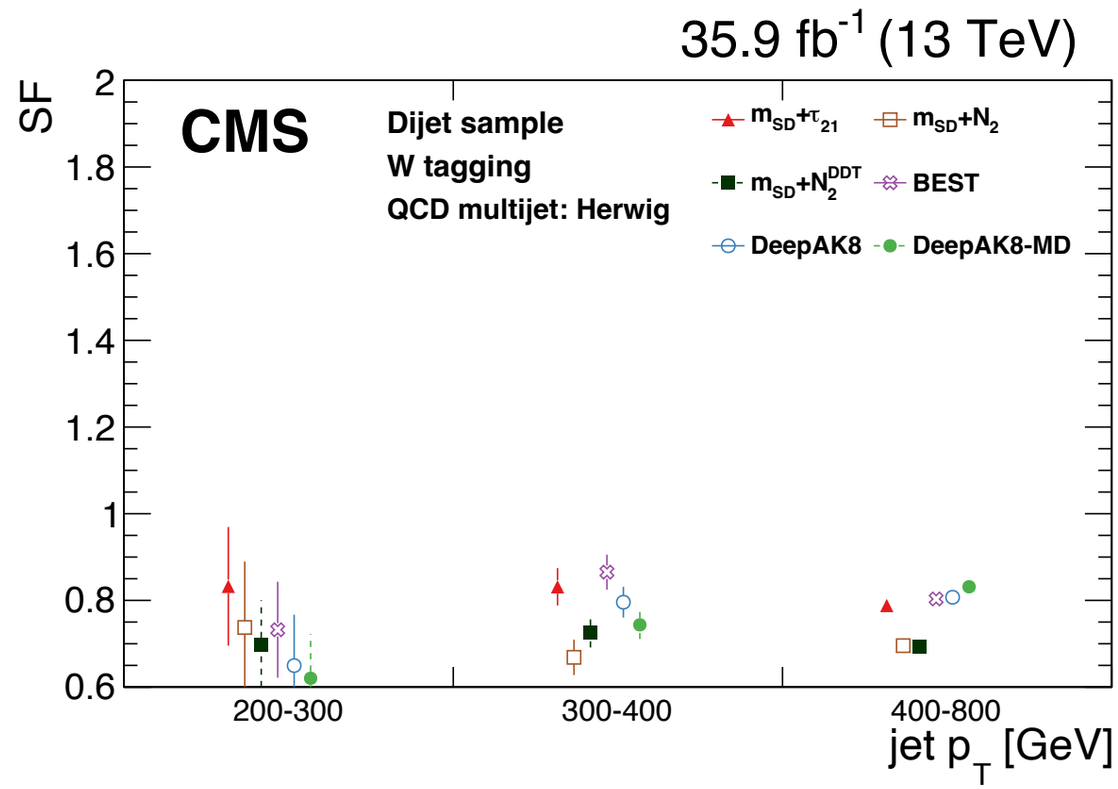
[as pointed out by Clemens last year]

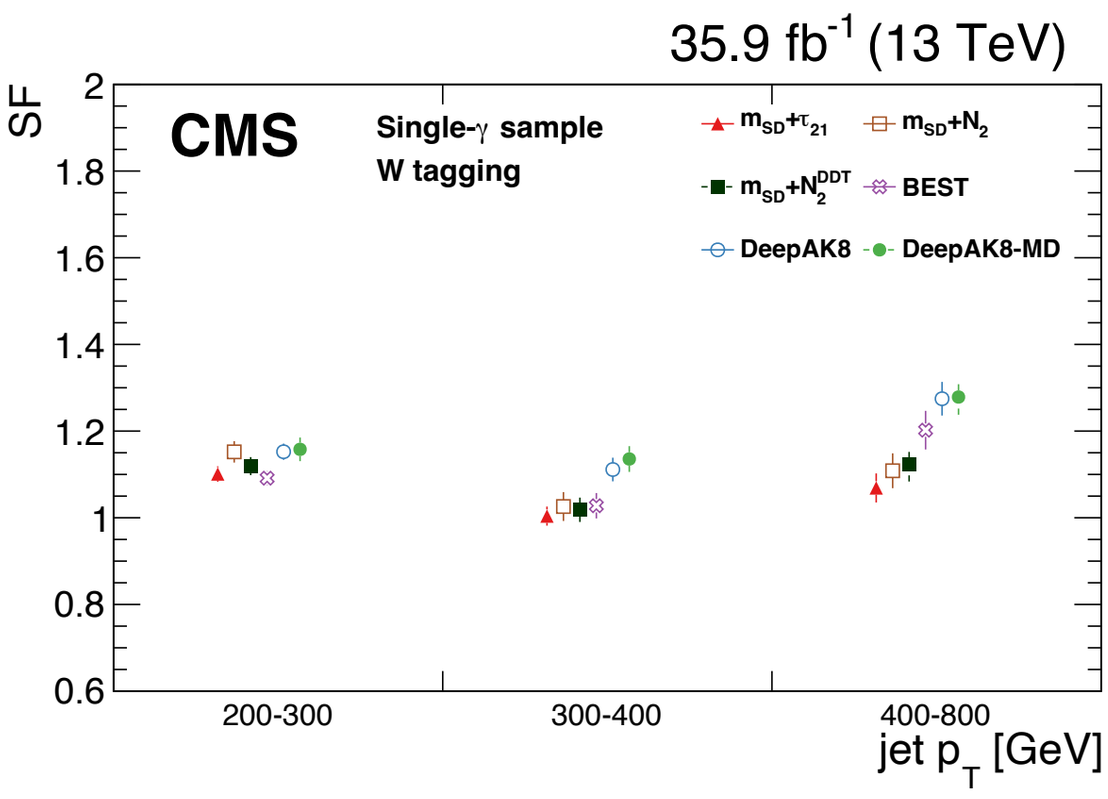
- The BOOST community made it possible :)

ML tagger & MC mismodeling

CMS-JME-18-002

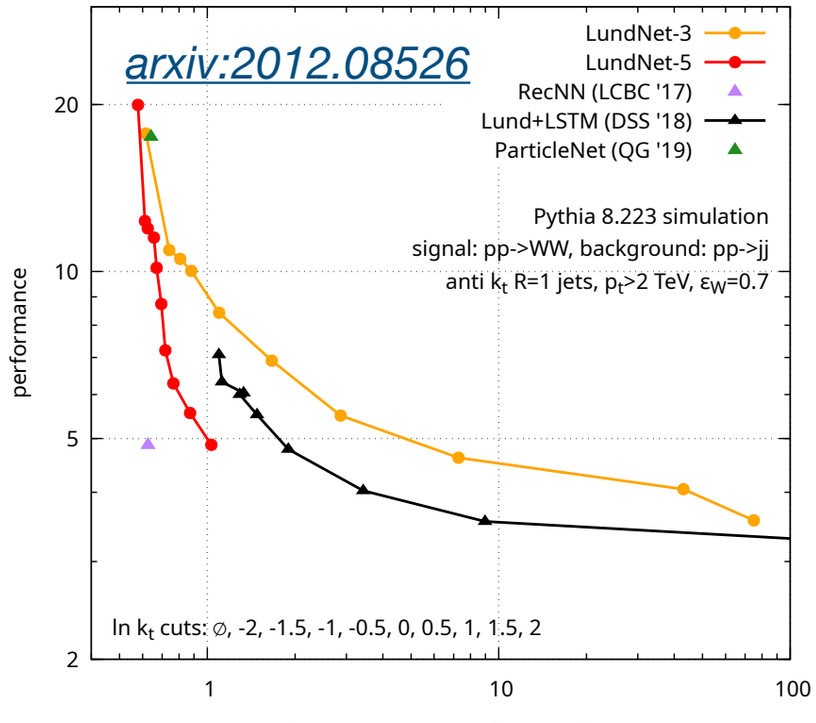






- ML taggers are all around us → Improve sensitivity
- But strongly depend on MC (at the moment)
- Huge disagreement between data and MC when increasing complexity
- Different mismodeling rate in different samples

Lund Jet Plane tagger

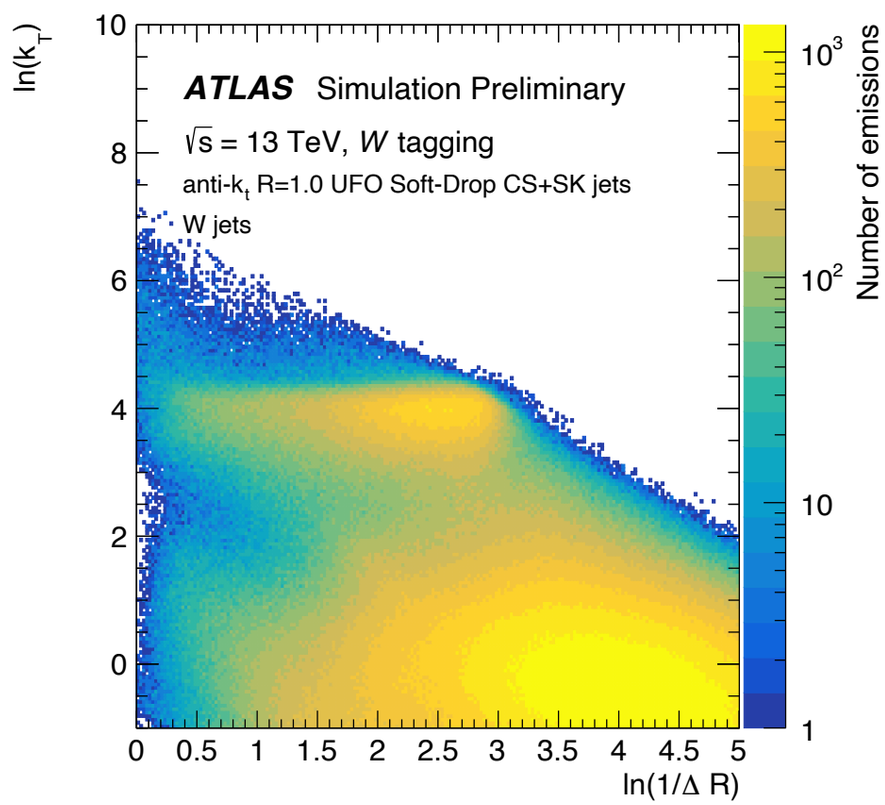


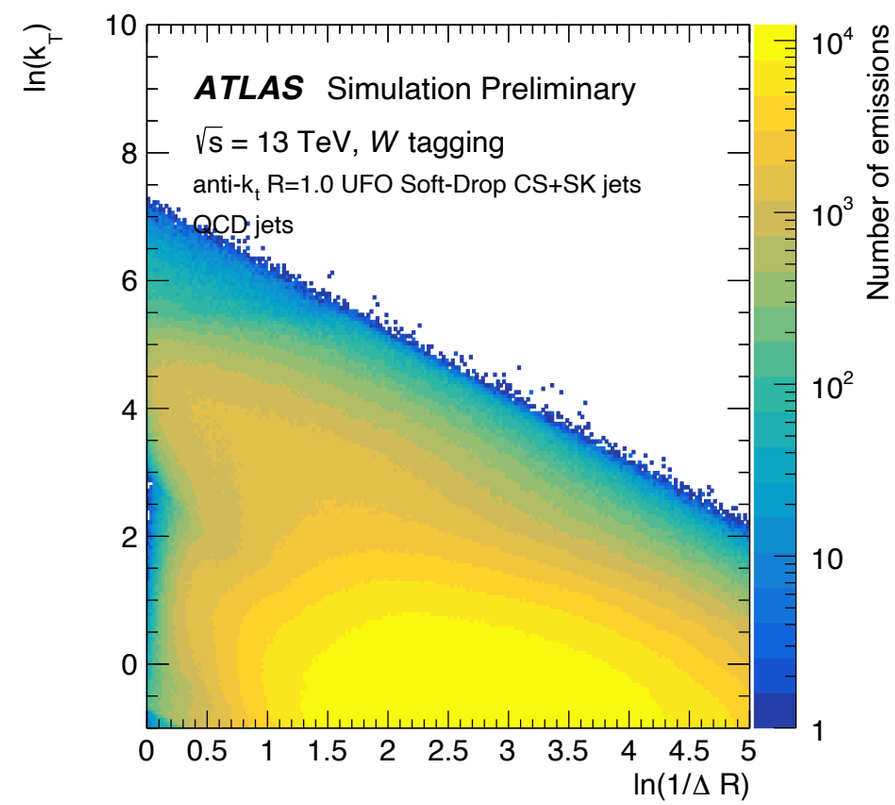
- Tagger based on the Lund Jet Plane can be very resilient
- Tested by ATLAS for W tagging
- Also studied the performance with different MC generators

Find out more about the performance in different MC generators

Talk by Jad

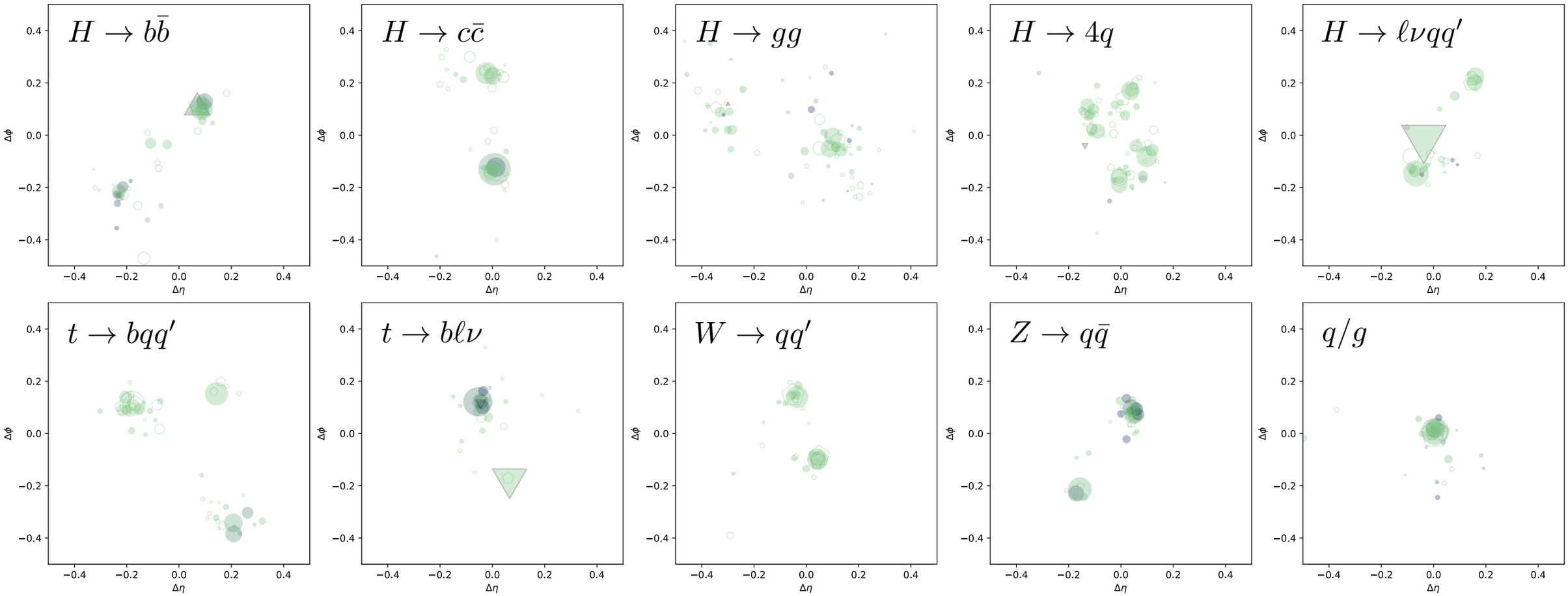
ATL-PHYS-PUB-2023-017





Exotic signatures

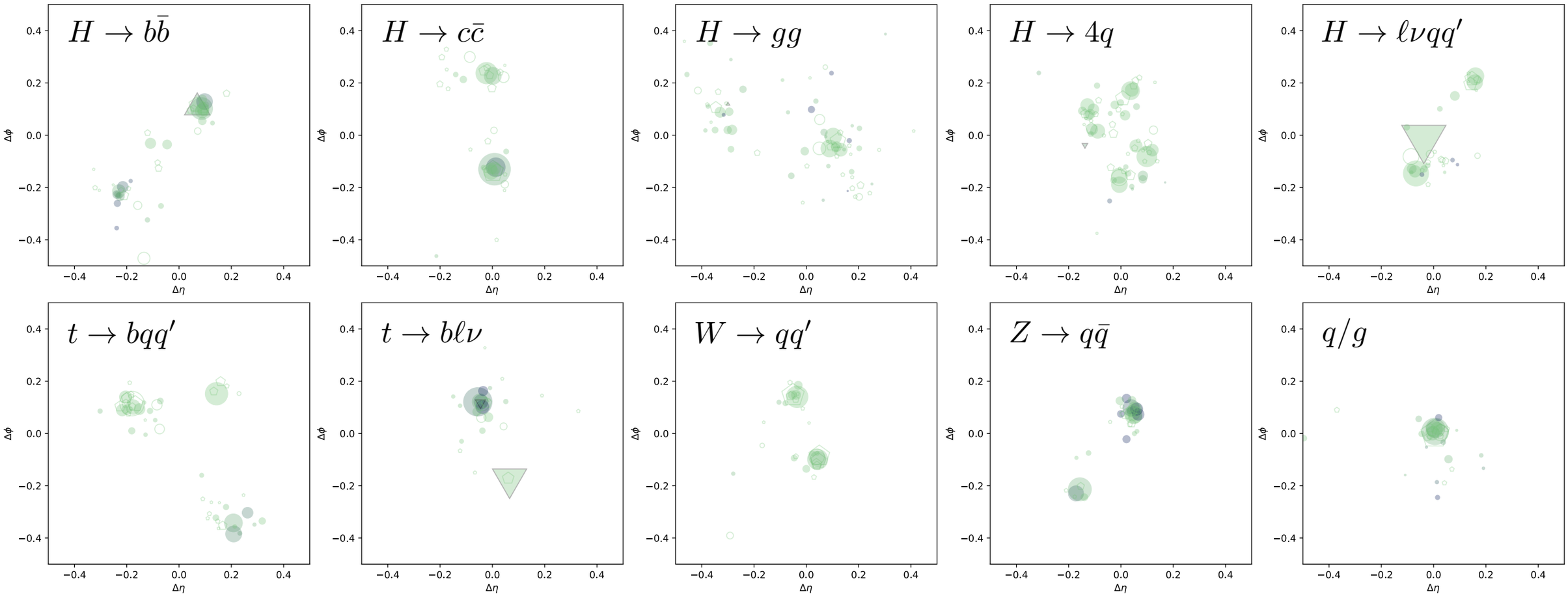
arxiv:2202.03772



- ML enables us to look into more exotic boosted signatures
- Like H → 4q

Exotic signatures

https://arxiv.org/abs/2202.03772

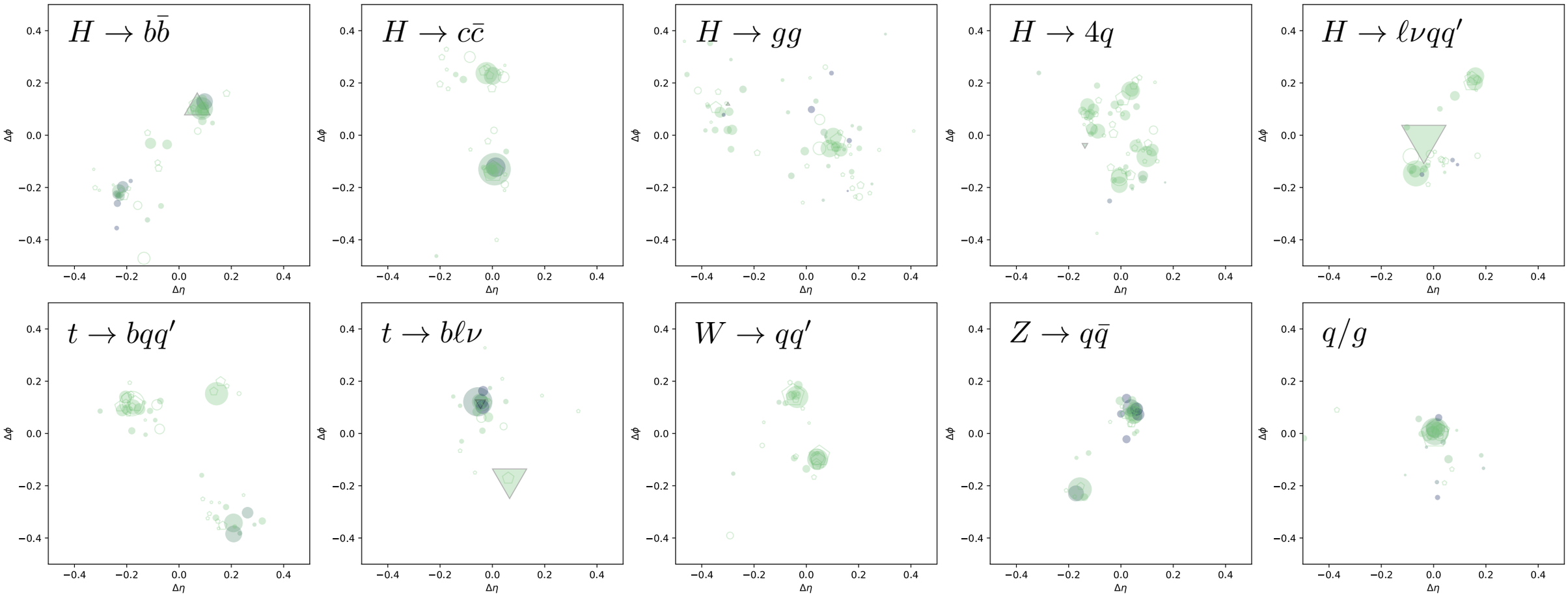


- ML enables use to look into more exotic boosted signatures
- Like ~~H~~ → 4q

  Anything

Exotic signatures

https://arxiv.org/abs/2202.03772



- ML enables use to look into more exotic boosted signatures
- Like ~~H~~ → 4~~q~~ Specify which quark combination

  Anything

Is it always useful to go as fine-grained as possible?

Calibrating high-prong jets

What we need to search for BSM

8

- Data ✓
- Tools (taggers, new variables) to suppress background and isolate the signal ✓
  - Most ML taggers still trained on MC...
- Background estimate (minimize uncertainty)
  - If dominated by ttbar, W+jets – get away with MC… ✓
  - QCD: tricky and messy (after lots of work… ✓)
- Signal efficiency (minimize uncertainty)
  - For top, W/Z, Higgs tagging – use standard candles ✓
  - For exotic signatures – ??? ✗

Petar Maksimovic, Johns Hopkins Experimental Intro

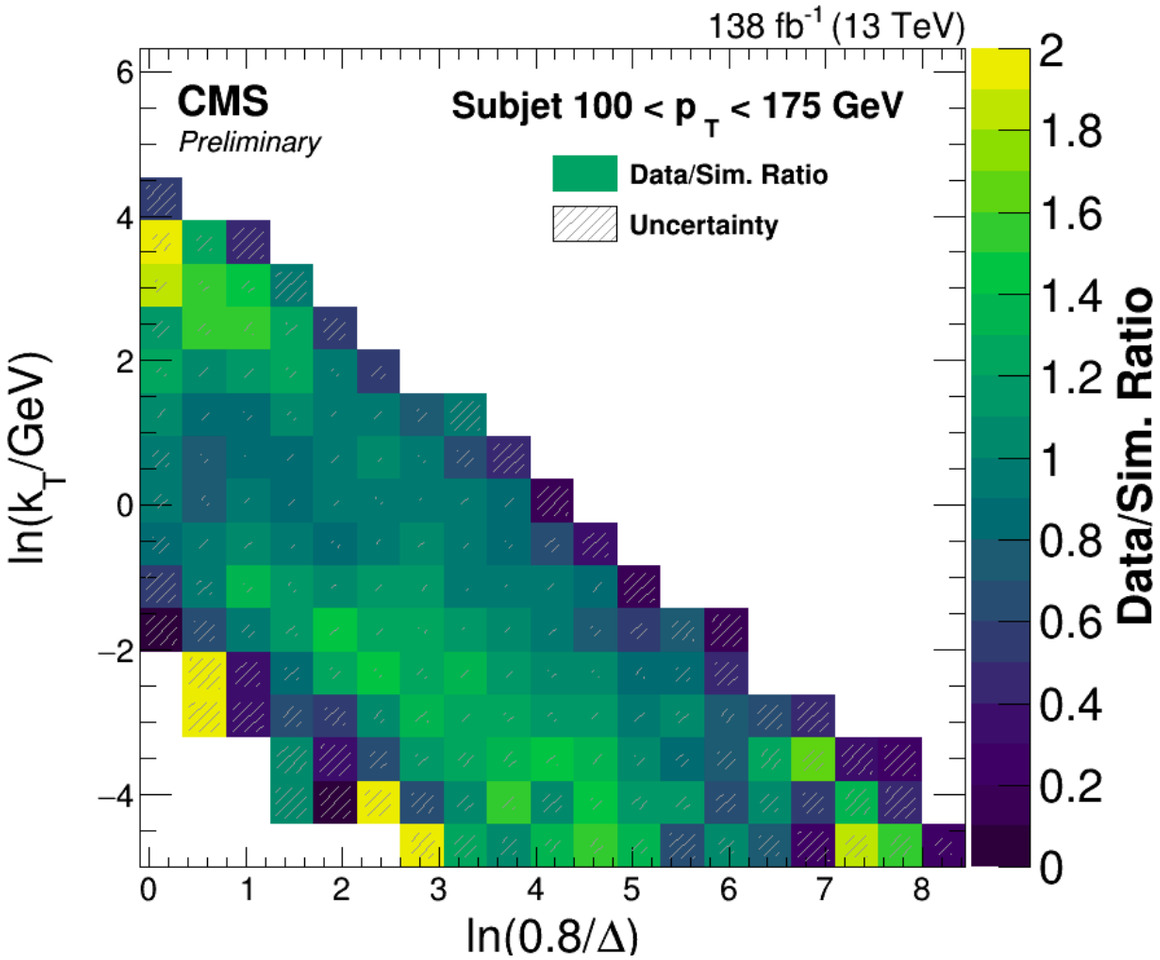
Boost 2019 - Intro-Talk by Petar

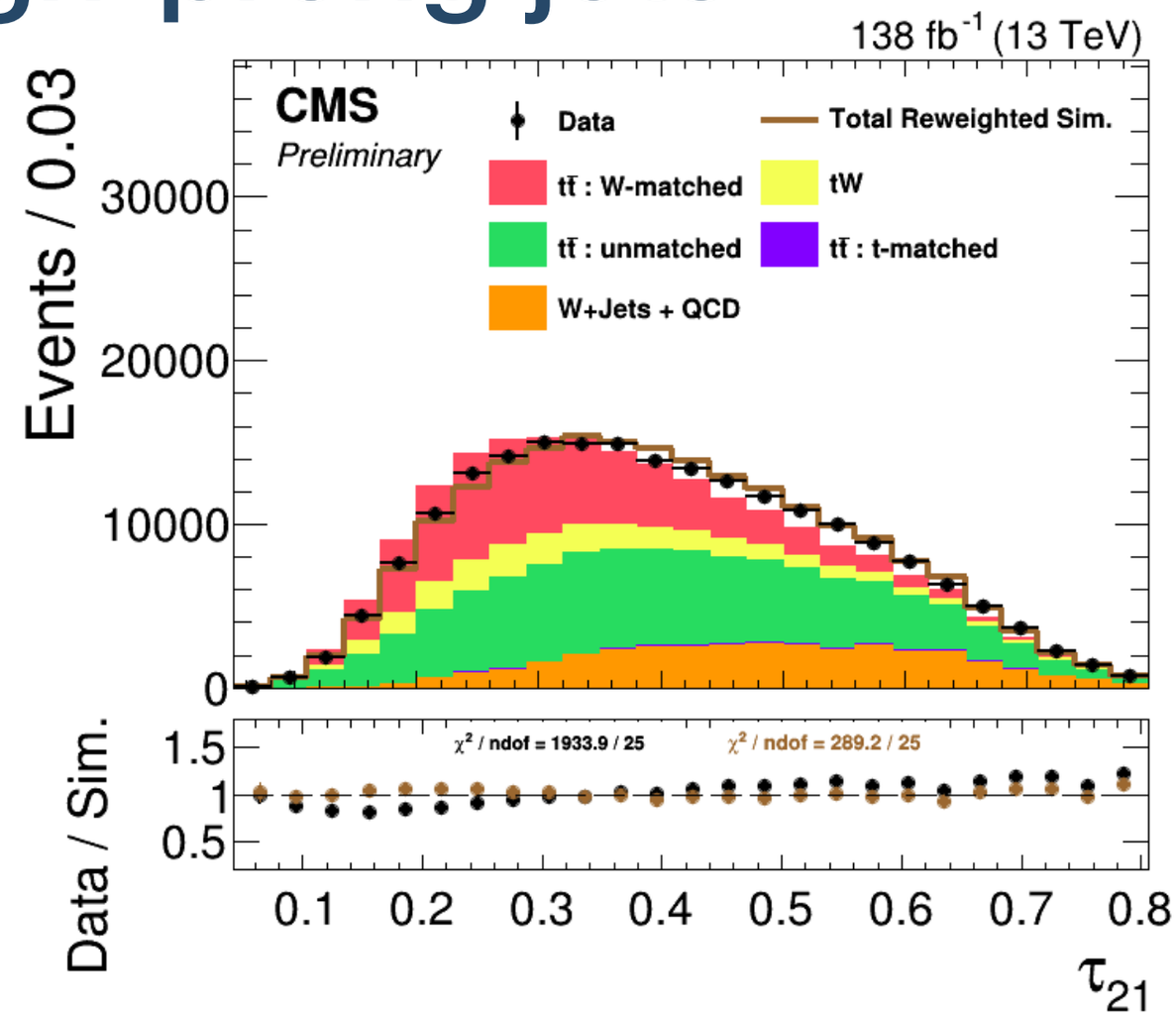
2022 Beyond the ROC: the mass decorrelation
the model independence
the IRC safety
the p_T stability
the stability with resonance masses
the data/MC (dis-)agreement
the lack of a real proxy in data
the uncertainty on your not-so-real proxy

Boost 2022 - Summary-Talk by Cristina

ALL OF THESE THINGS REALLY MATTER FOR A SEARCH

Calibrating high-prong jets



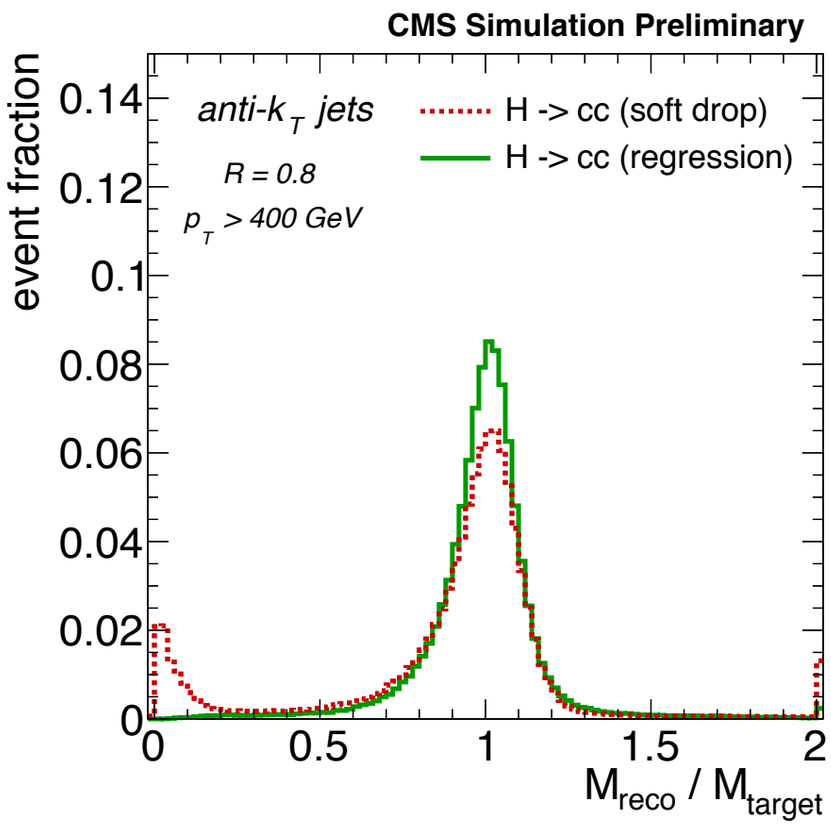


- Construct Lund Jet Plane for subjets of W candidates in data and simulation
- Derive the ratio to construct correction factors for splittings
- Reweight the simulation independent of the tagger/signature targeted
- Still some systematic sources to be studied, but very helpful for exotic signatures!

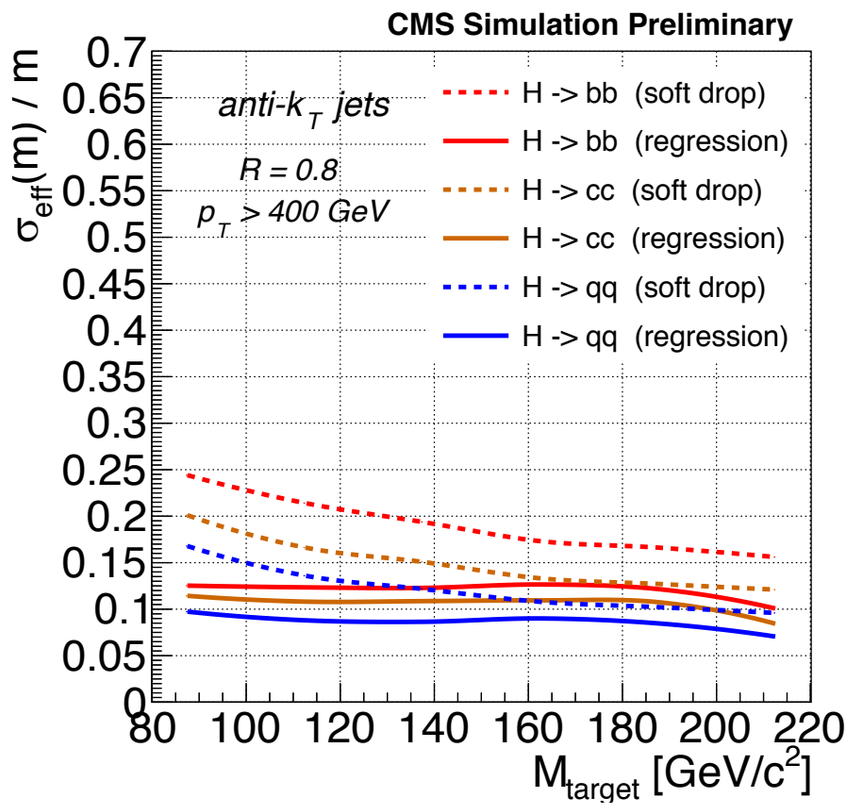
Find out if it also works for top quarks and higher prong jets

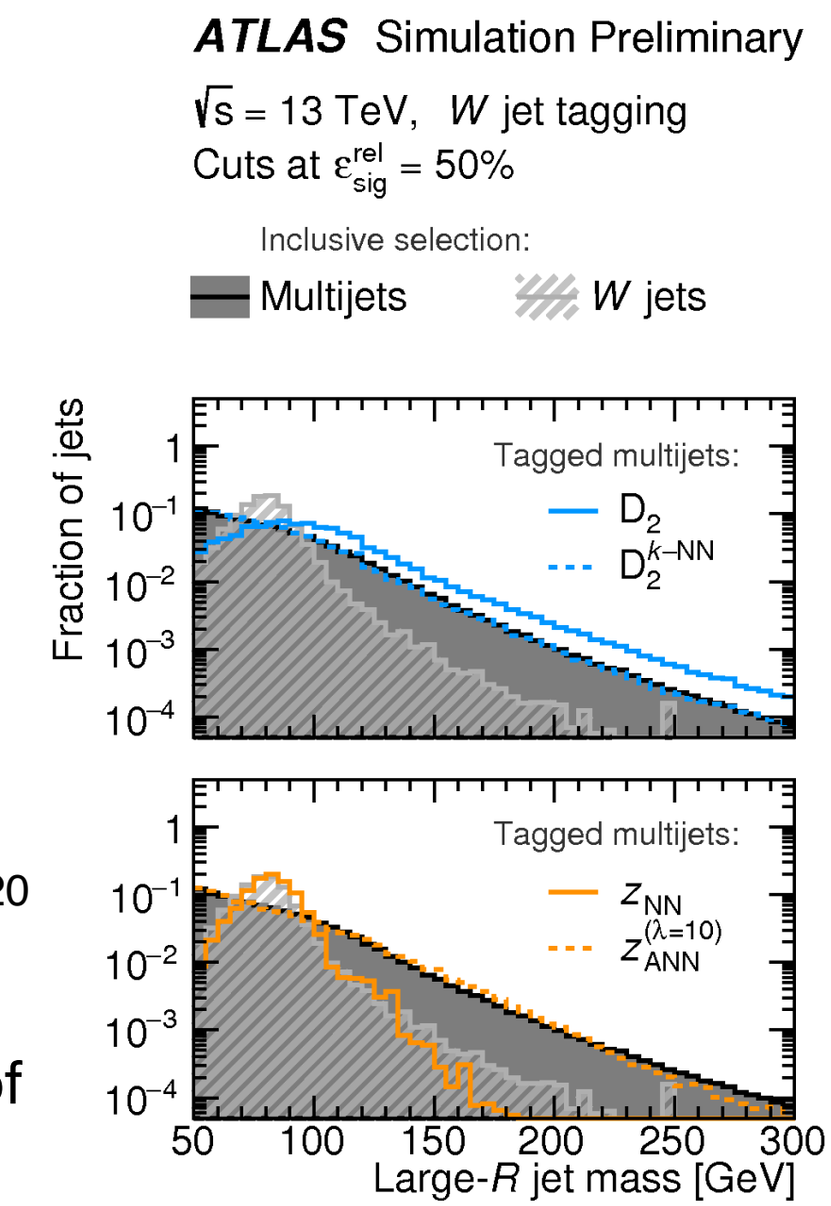
talk by Oz

Mass regression & decorrelation



CMS-DP-2021-017

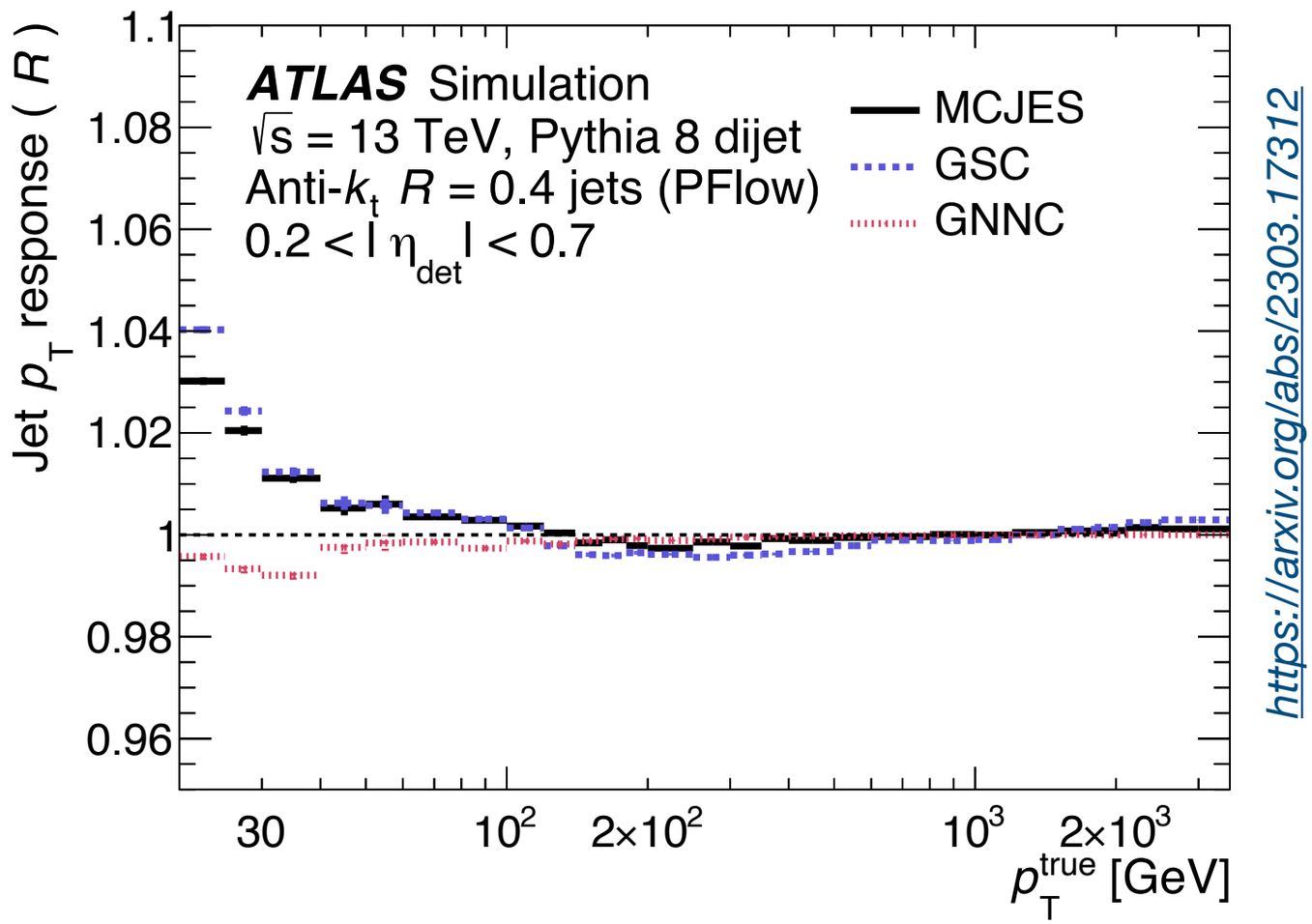




ATL-PHYS-PUB-2018-014

- ML does more than "just" tagging → reconstruction of specific quantities
- Better decorrelation of tagger output and mass
- Better mass resolution
- Next: p_T regression for AK4 jets!

Towards jet p_T regression



https://arxiv.org/abs/2303.17312

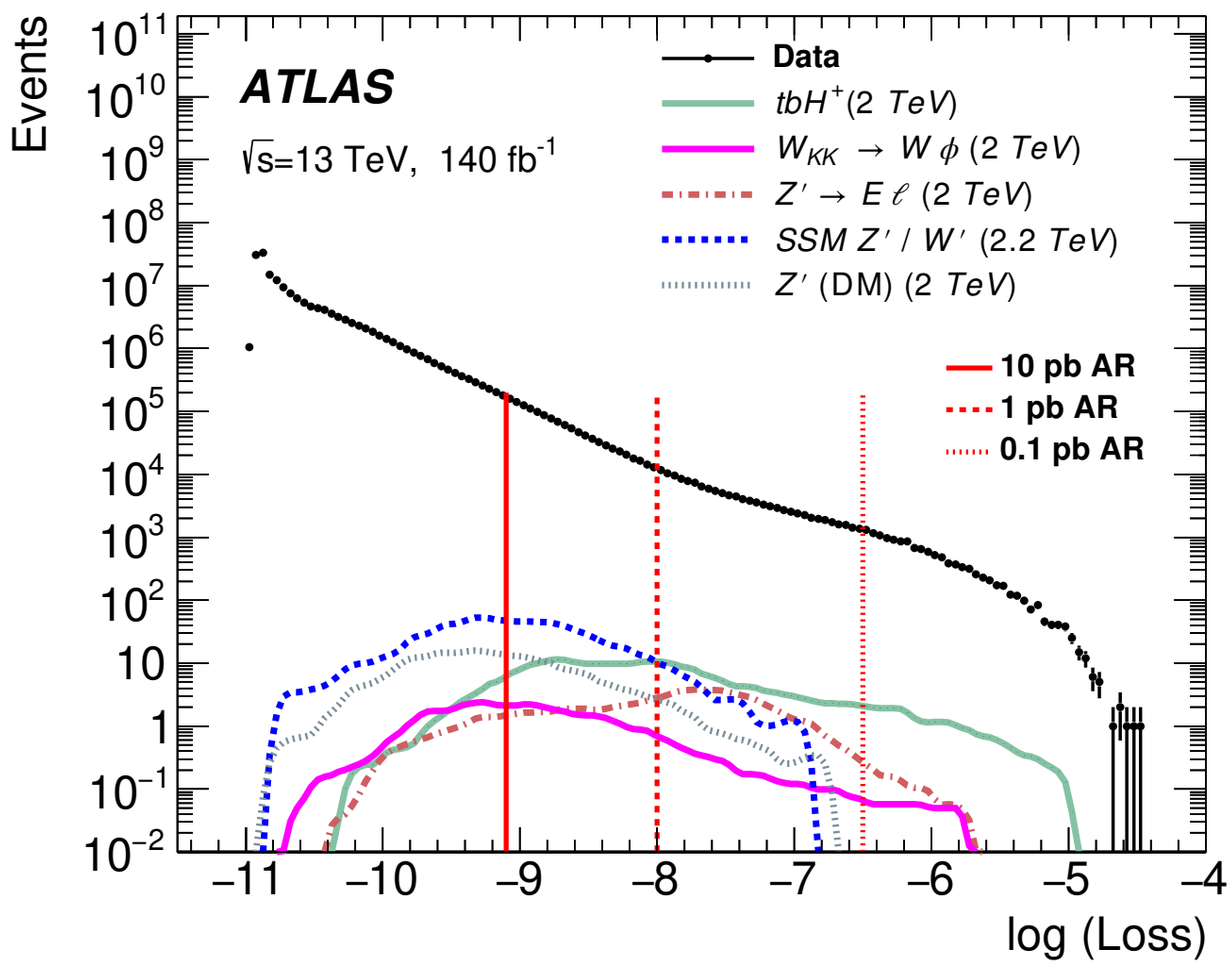
- Jet p_T response depends on the flavor and the MC generator used
- Additional correction step to improve the jet resolution by 6 different (mostly) uncorrelated variables
- With ML you can take correlated varaibles and improve the performance further!

Let's find out more about the advantages of ML in jet calibration

talk by Margherita

Model-independent searches with ML

arxiv:2307.01612

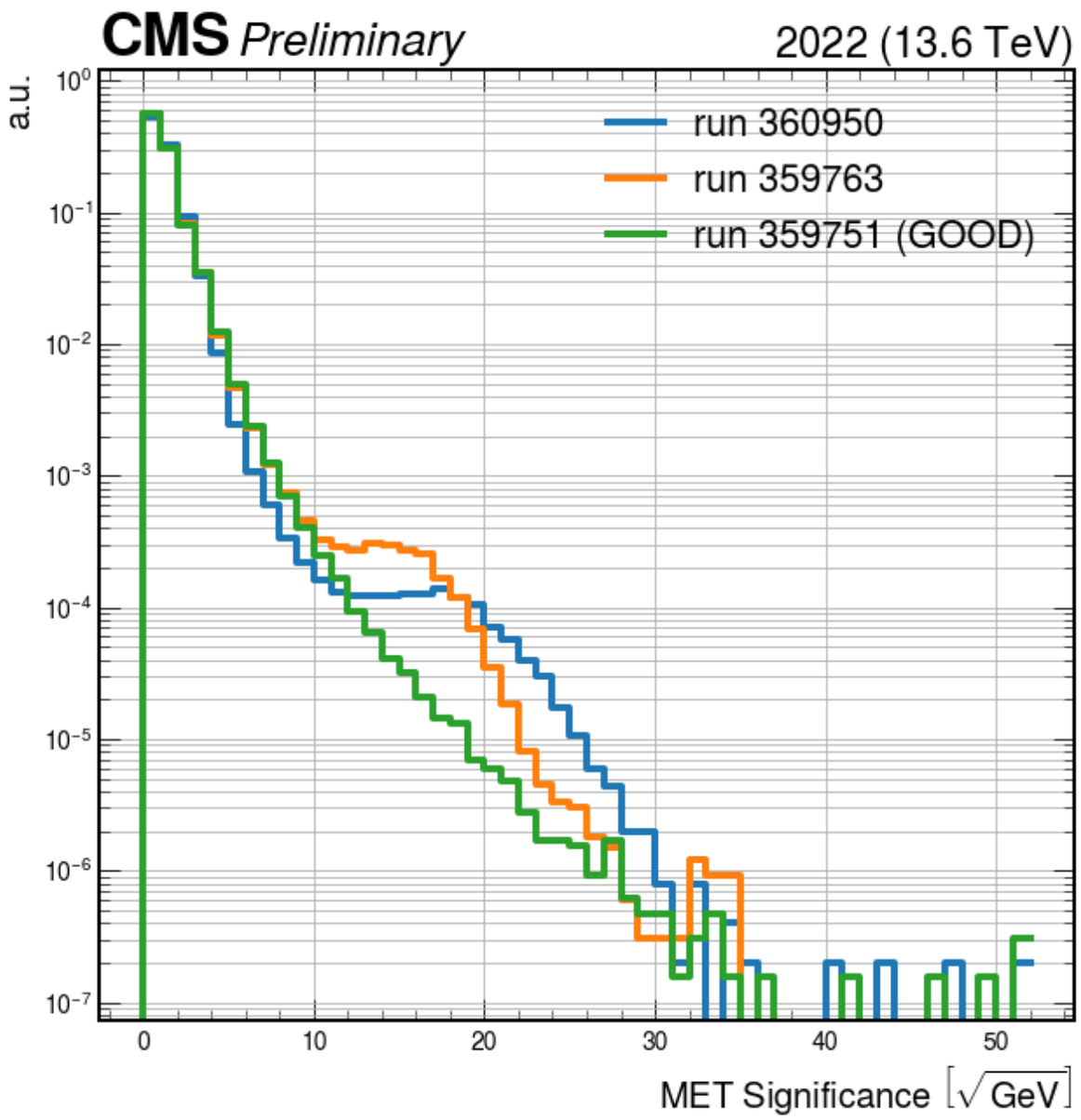


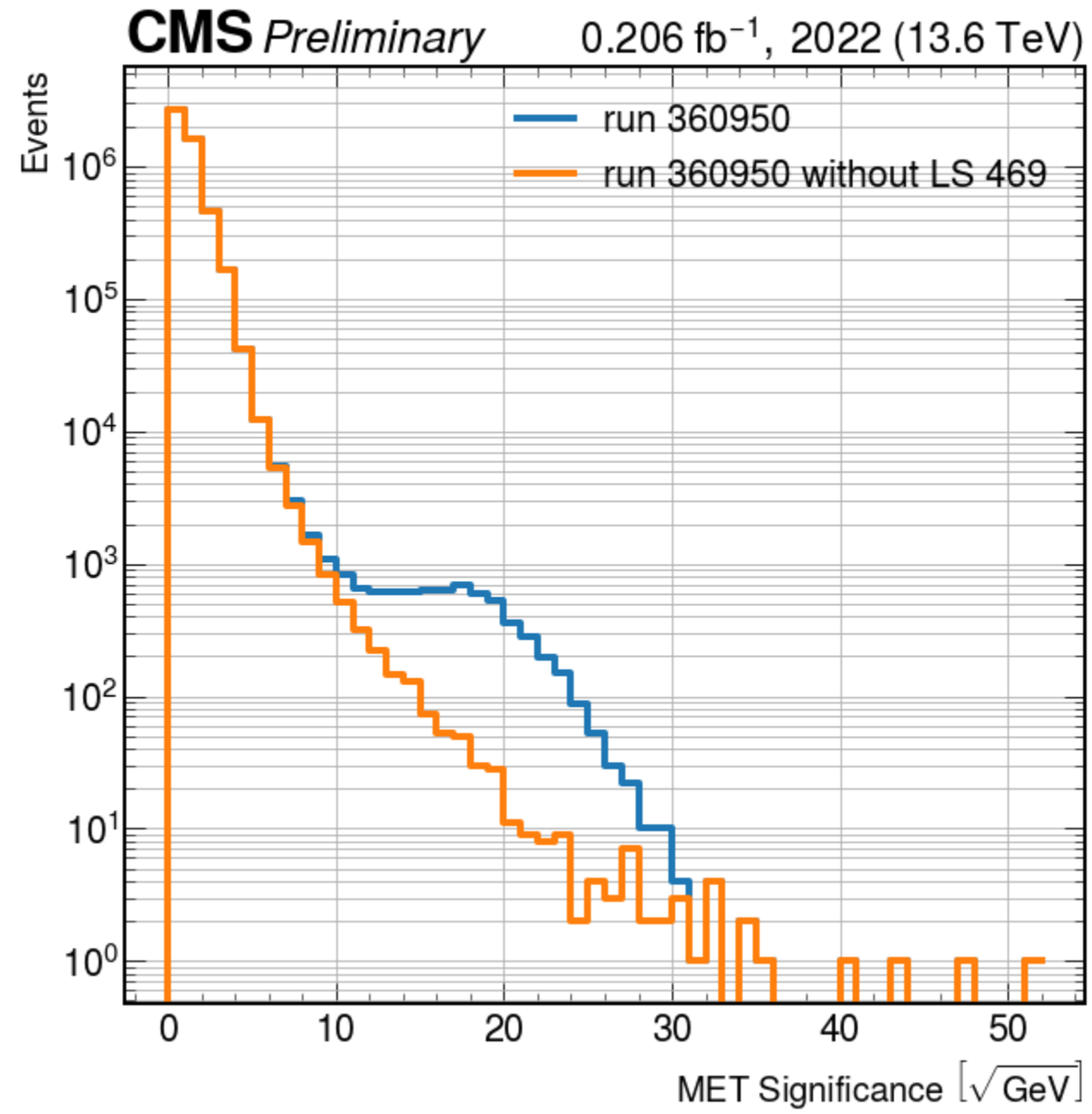
- So many different BSM models on the market
- Model-independent searches interesting approaches to “scan” bigger phase space
- AutoEncoders is a good way to detect anomalies
- 9 different invariant mass regions to detect new physics

Let's find out more about the gain in sensitivity by AE in the

talk by Elham

ML for data certification





CMS DP -2023/010

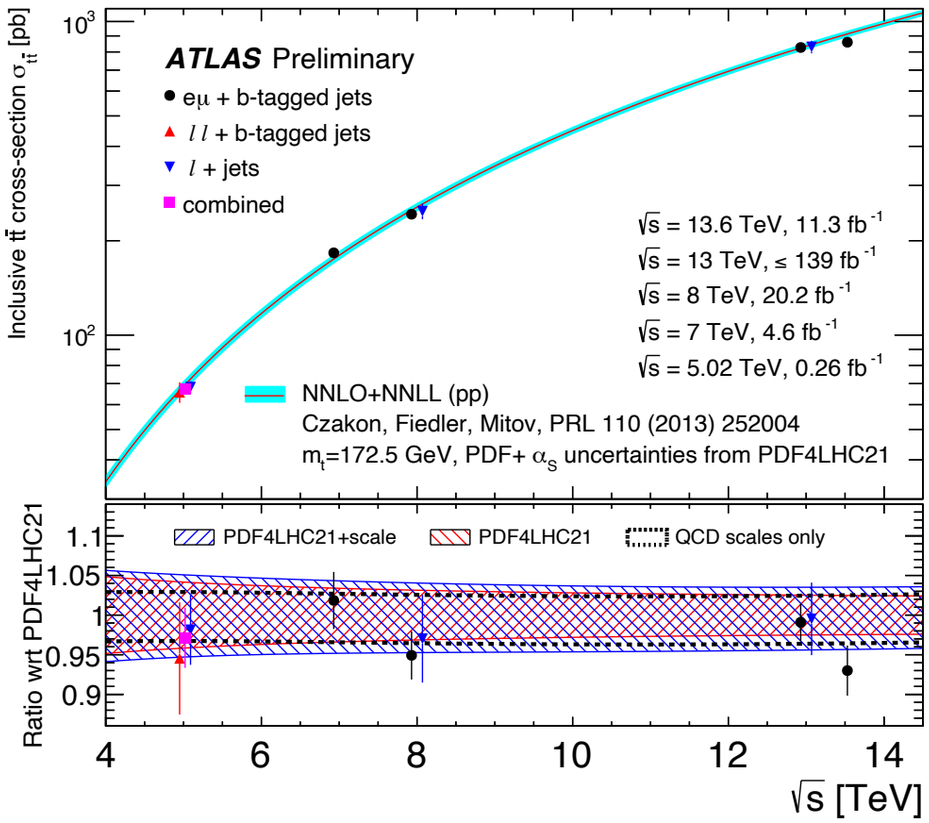
- Lumi sections are around 23 seconds of data taking → grouped to run [O(1000)LS] which is monitored
- Unsupervised ML based on AutoEncoder used

Let's find out more about the advantages of ML in data certification

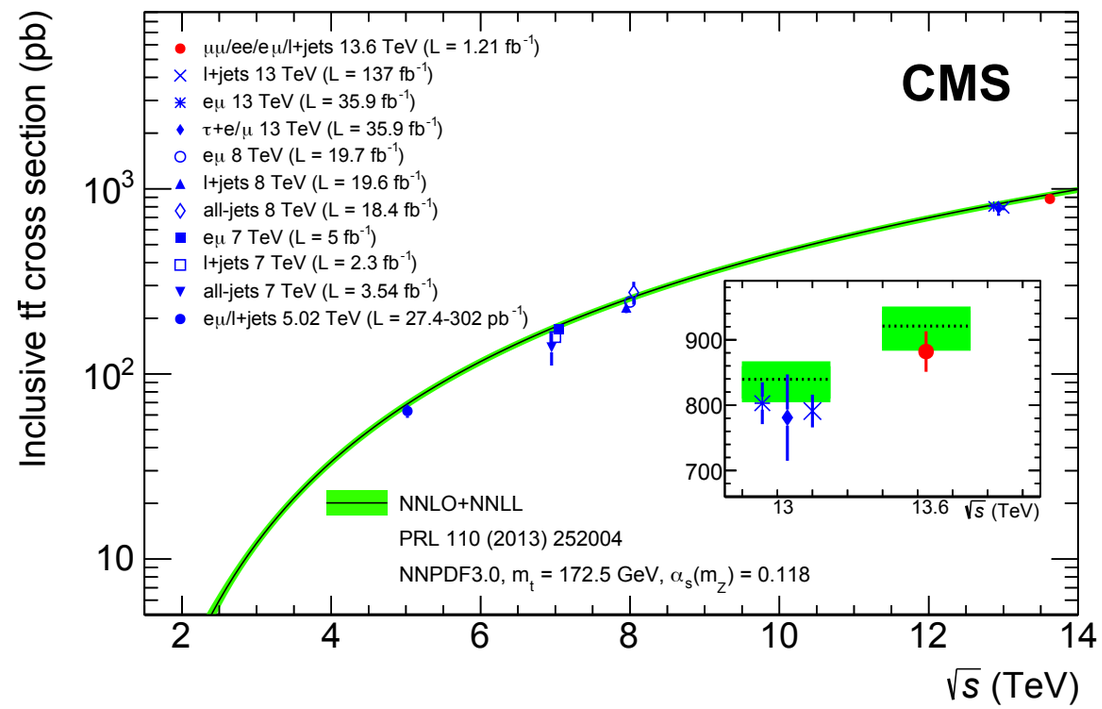
talk by Steffen

First Run3 cross section results

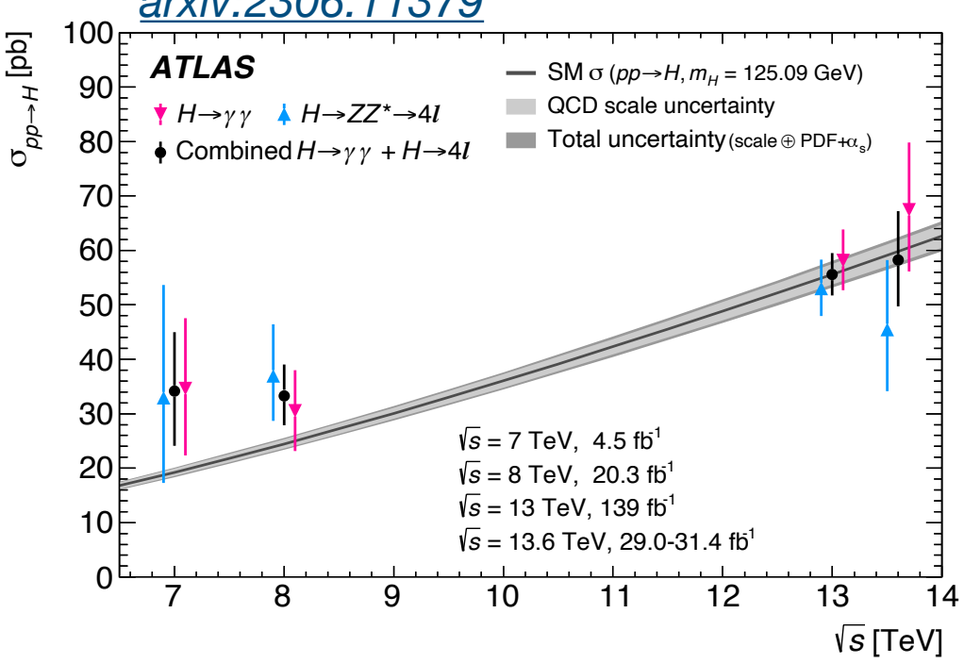
ATLAS-CONF-2023-006



CMS-TOP-22-012

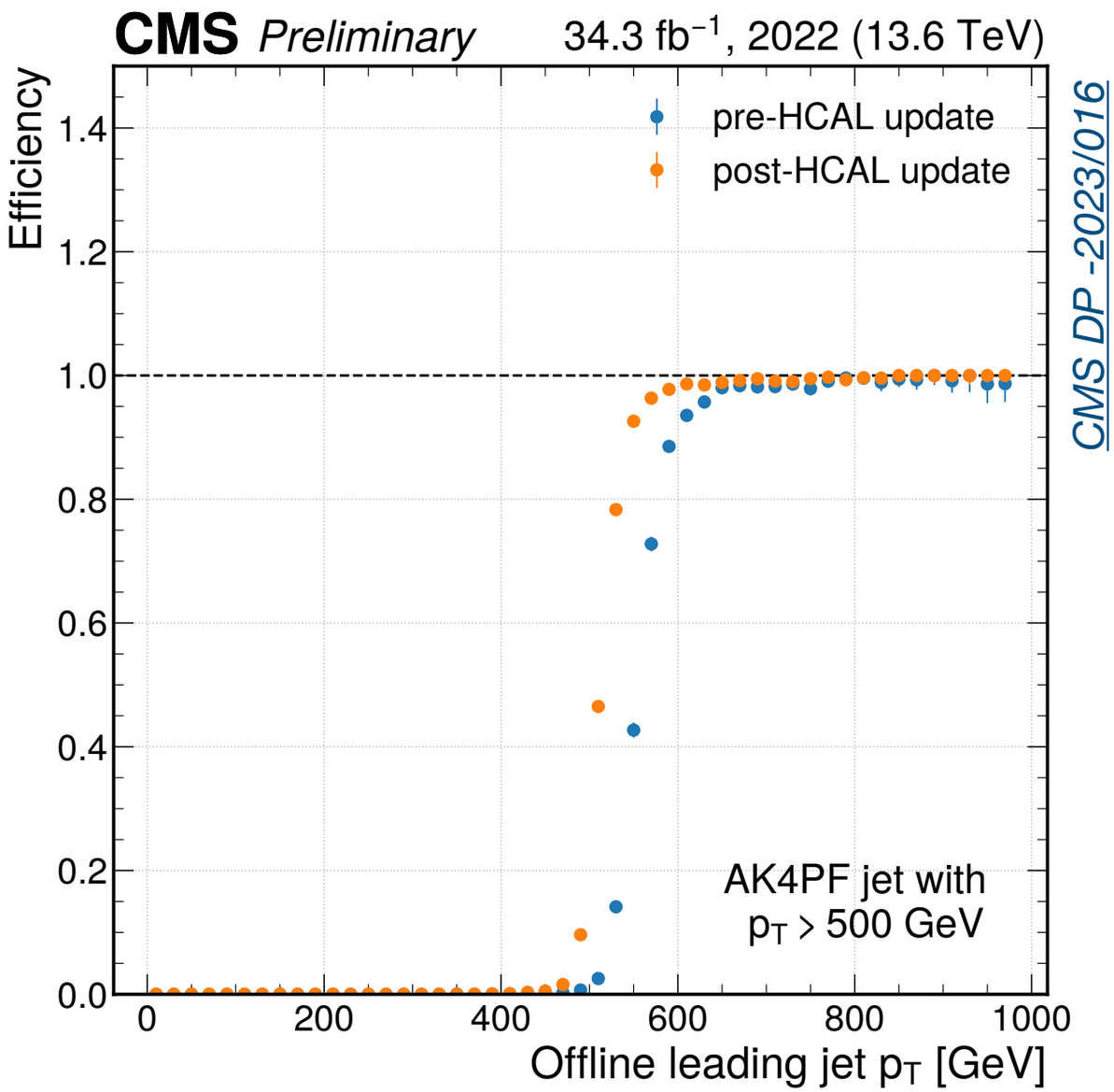


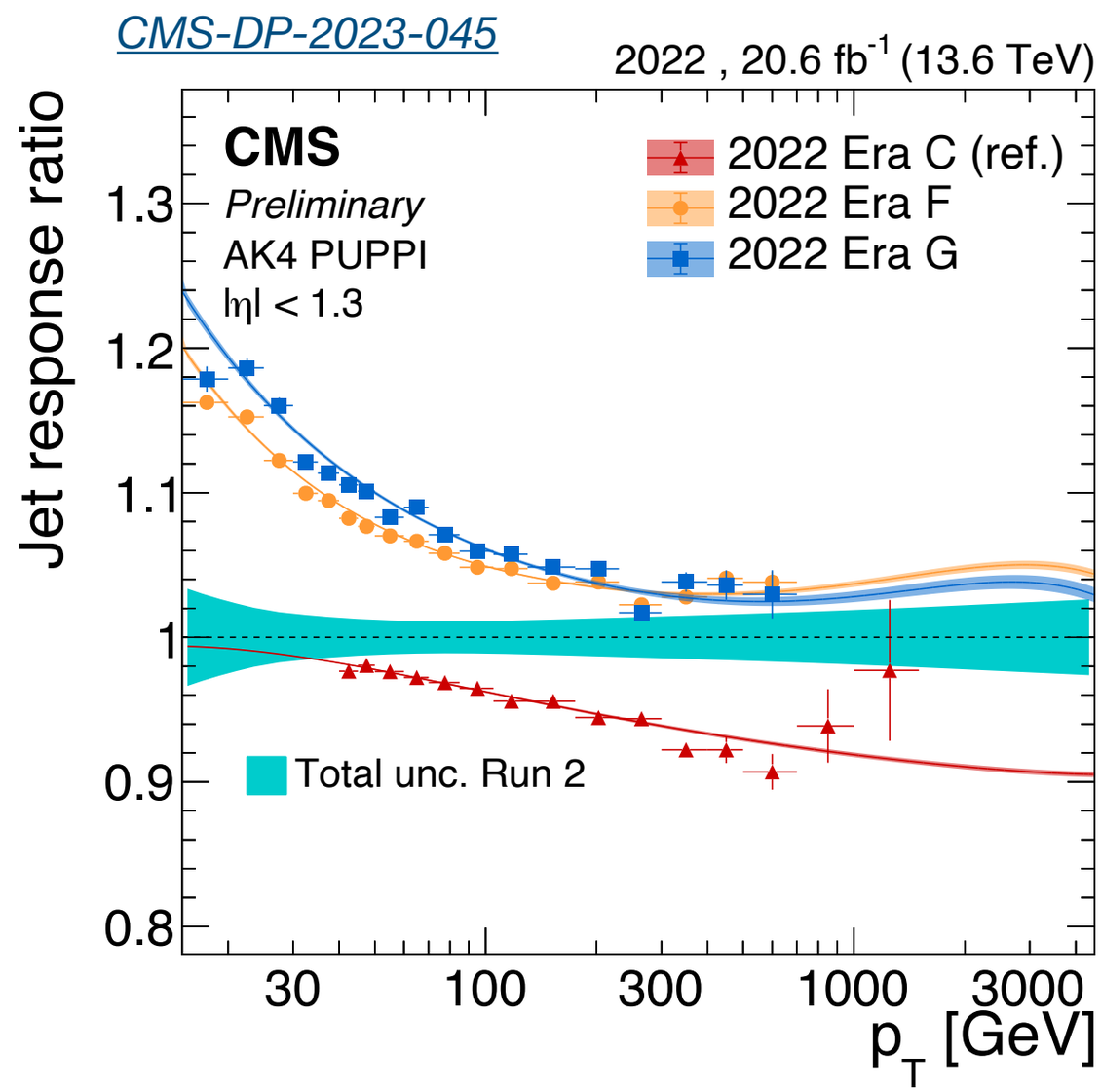
arxiv:2306.11379



- We have first Run3 results!
- In good agreement with the SM
- No substructure yet → too complicated?

New data - Calibration at the start of Run3





- We are collected new exciting data, however, not well calibrated nor understood YET
- Jets are complex objects involving a lot of detector subsystems
- First jet energy calibrations of Run3 are very sensitive to detector effects

Summary

An exiting week ahead with new results about

- Jet substructure measurements
- New jet calibration techniques
- New tagger ideas to improve data-to-simulation agreement
- New calibration techniques of the more fine-grained taggers
- ML application in various areas

First Run3 results available

- Calibration of the detector and objects ongoing
- Jet substructure affected by many detector subsystems

My wish: Let's boost together to calibrate Run3 data from the detector subsystems to jet substructure at least as good as in Run2! And get amazing results from combinations!

Backup

AutoEncoders

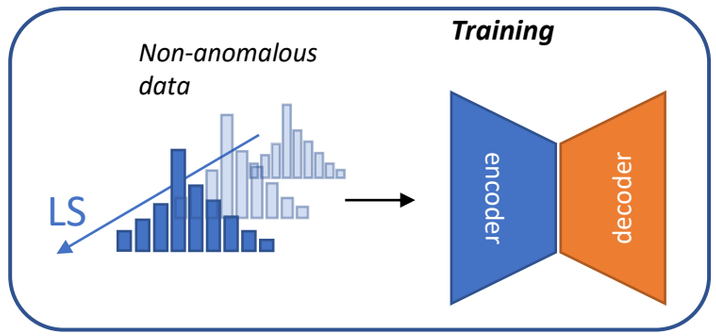
AutoEncoder-based Anomaly Detection Tool

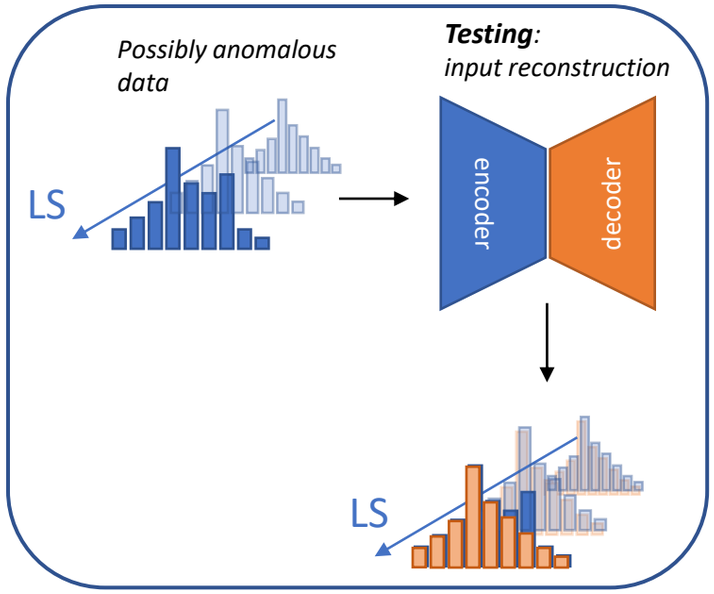
- The model is trained on non-anomalous data from *GOOD* runs: histograms of specific MEs are fed to the model with an LS granularity to allow the AE to learn a «normal» non-anomalous behavior of that specific ME. The training is performed via the minimization of the reconstruction loss, a measure of the distance between the input and output of the AE. In this case the reconstruction loss is the mean squared error:

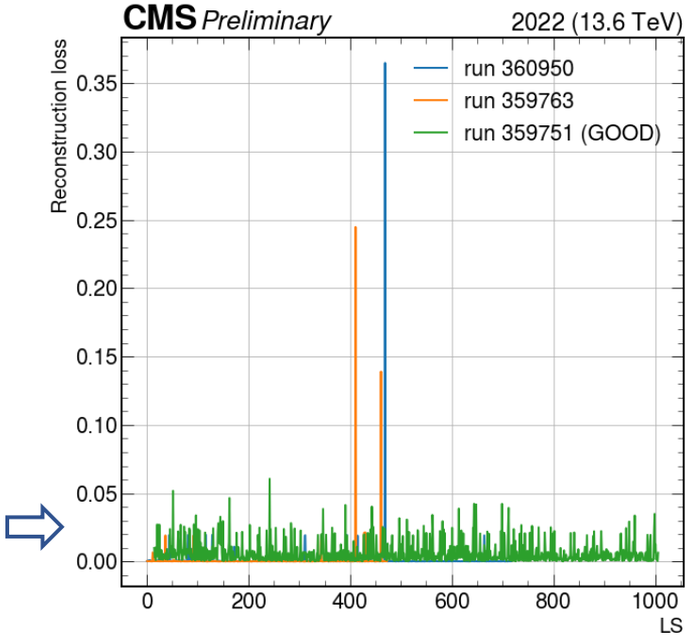
$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$$

  where y and $\hat{y}$ are respectively the input and the output of the AE and n is the bin number.

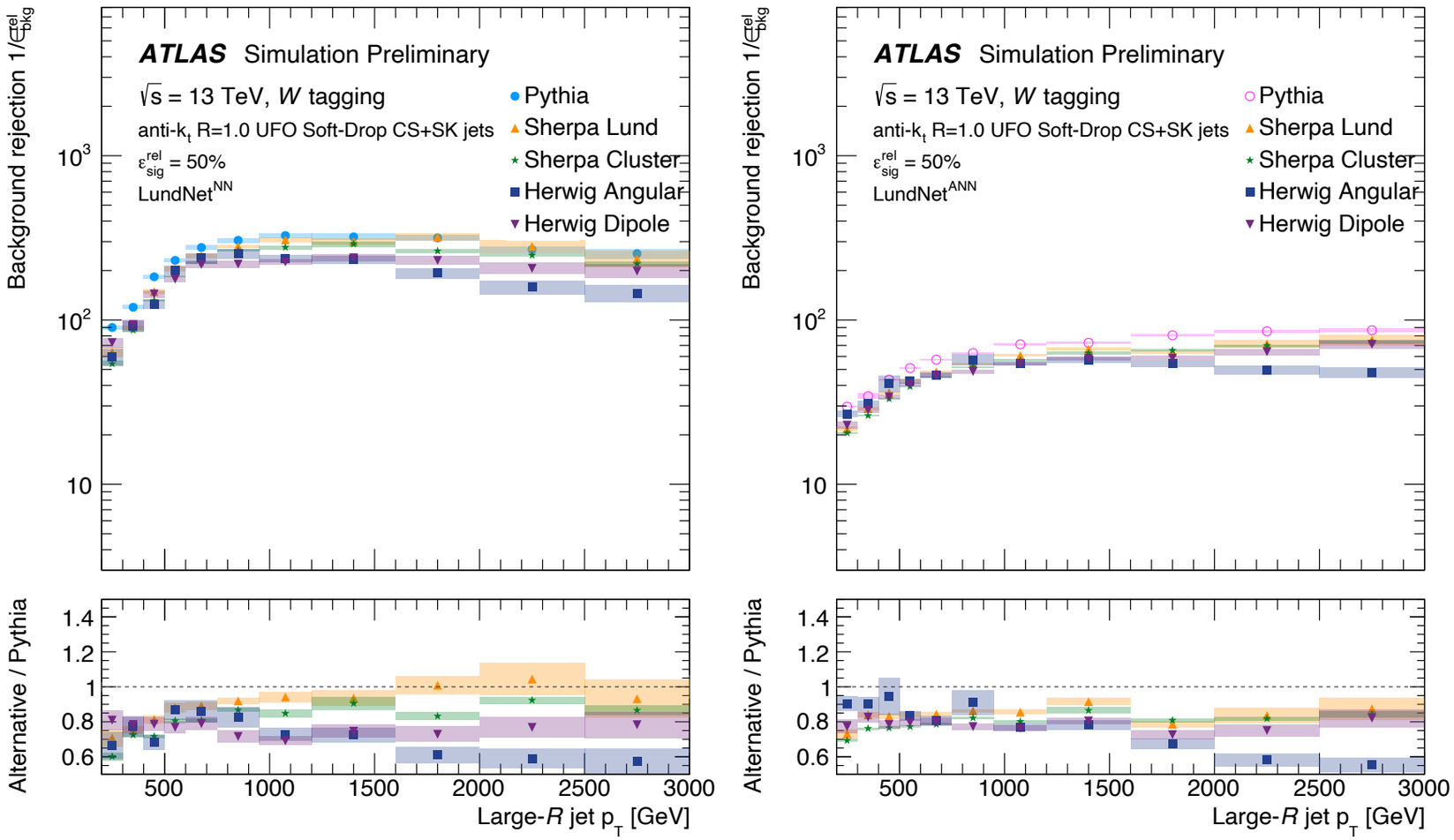
- Possibly anomalous runs under investigation are tested by looking again at the reconstruction loss: peaks in this function indicate LSs containing histograms that deviate from the learned behavior.
- The comparison between the reconstruction losses of the three runs under study is on the right.



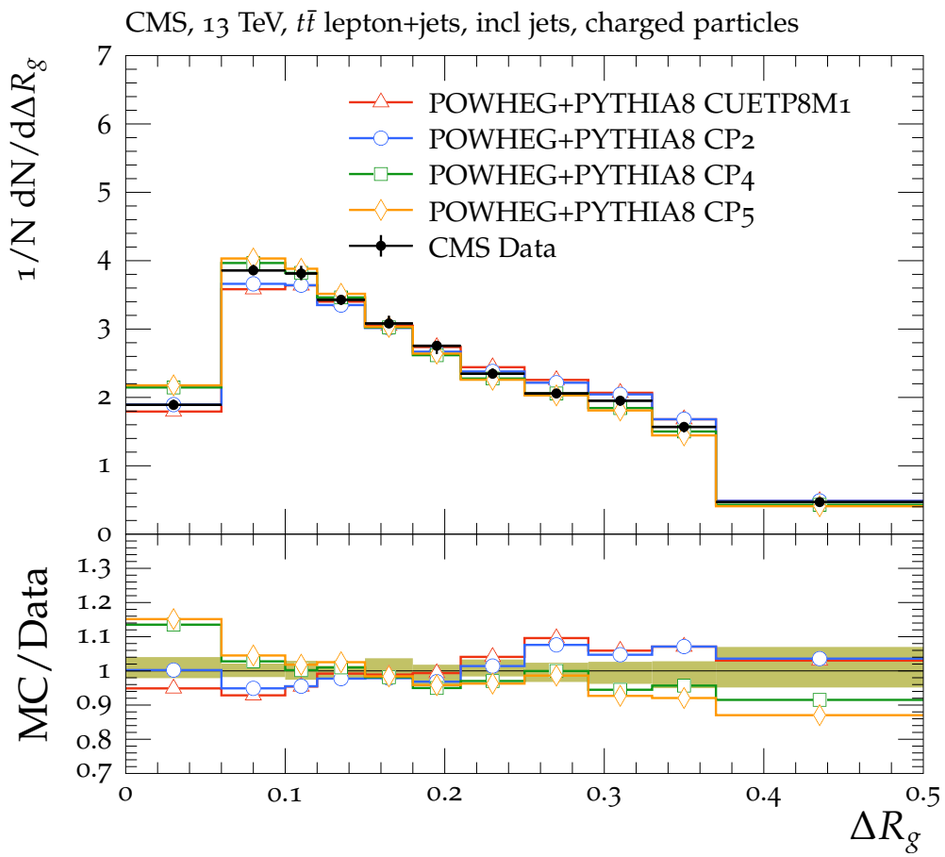


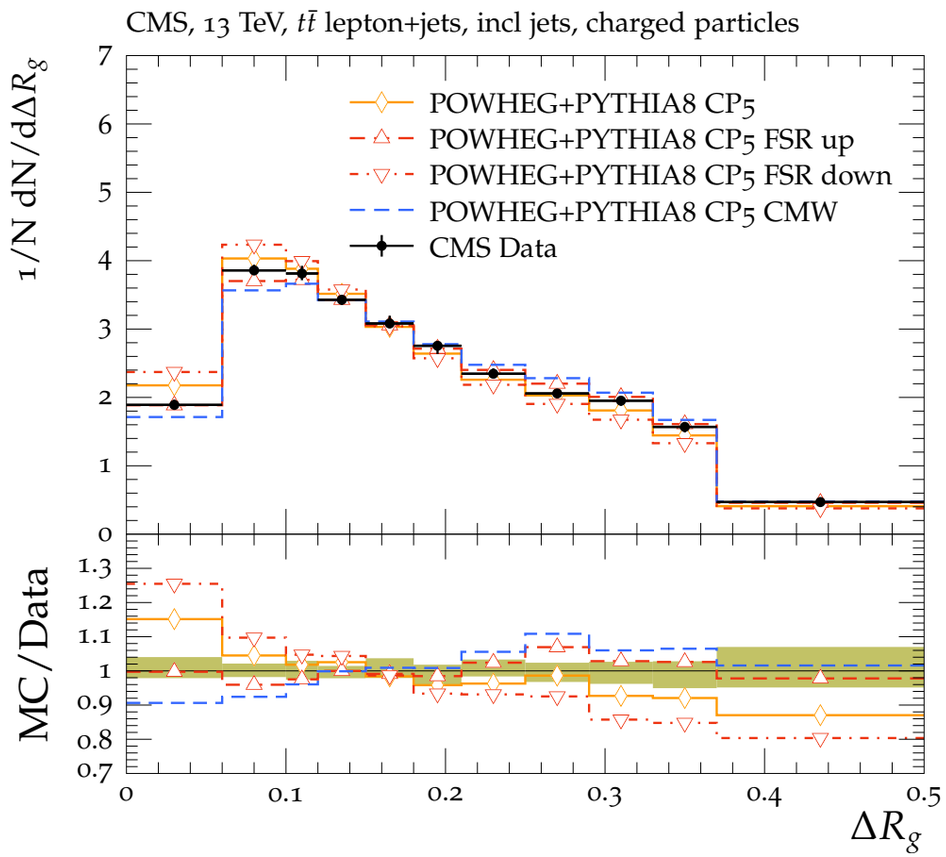


Lund Plane tagger



Data-to-simulation agreement

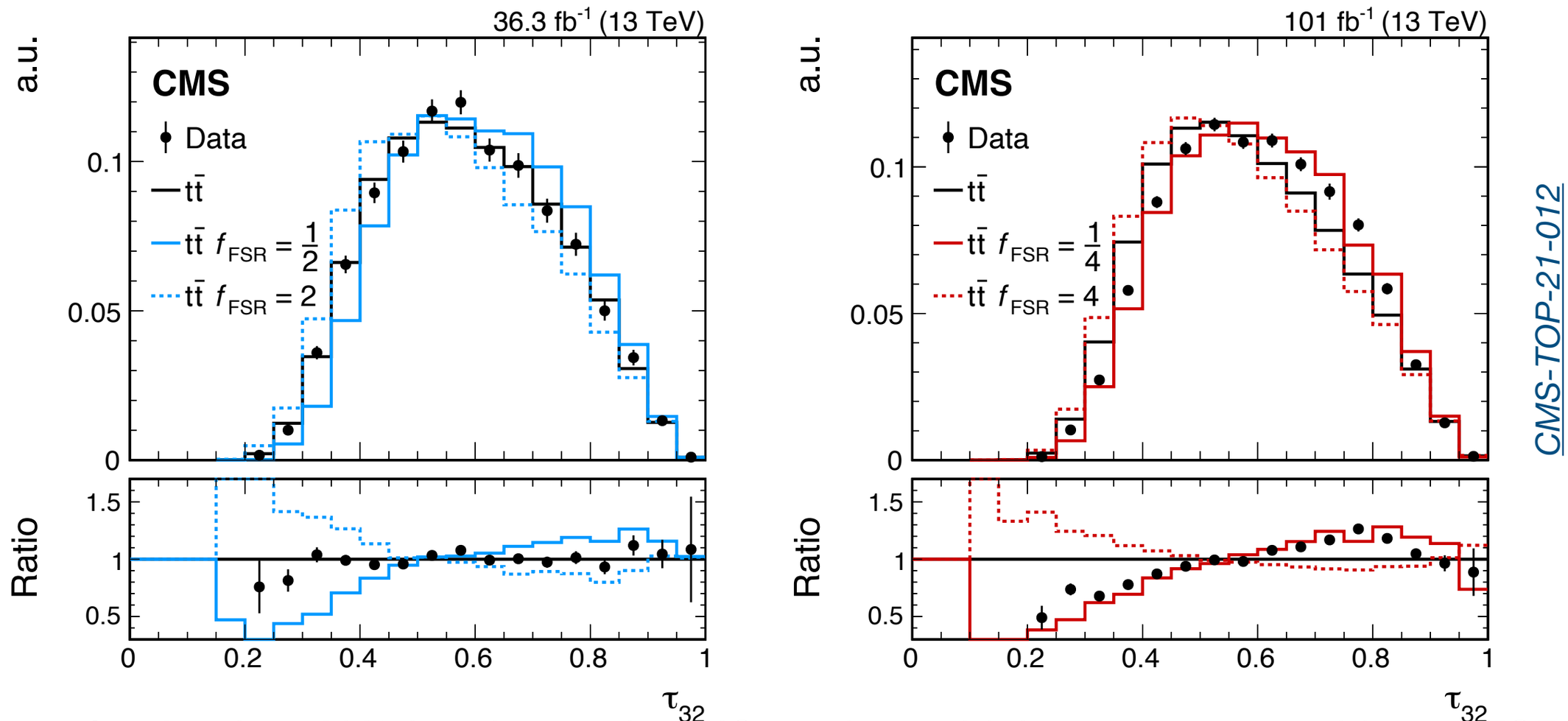




GEN-17-001

- We know that in general new simulation tunes improve the description of data
- However, sometimes worsening other phase spaces like jet substructure variables
- Also visible in the correction factors for W-tagging with τ_{21} CMS-DP-2020-025
  - CUETP8M1: 0.99 ± 0.11
  - CP5: 0.957 ± 0.074 (2017), 0.964 ± 0.032 (2018)

FSR study



CMS-TOP-21-012

- Same selection but AK8 jets instead of XCone jets which are more sensitive to FSR
- Matching between XCone and AK8 jets
- $\alpha_S^{\text{FSR}}(m_Z^2) = 0.1373^{+0.0017}_{-0.0018}$ for 2016
- $\alpha_S^{\text{FSR}}(m_Z^2) = 0.1416^{+0.0019}_{-0.0018}$ for 2016