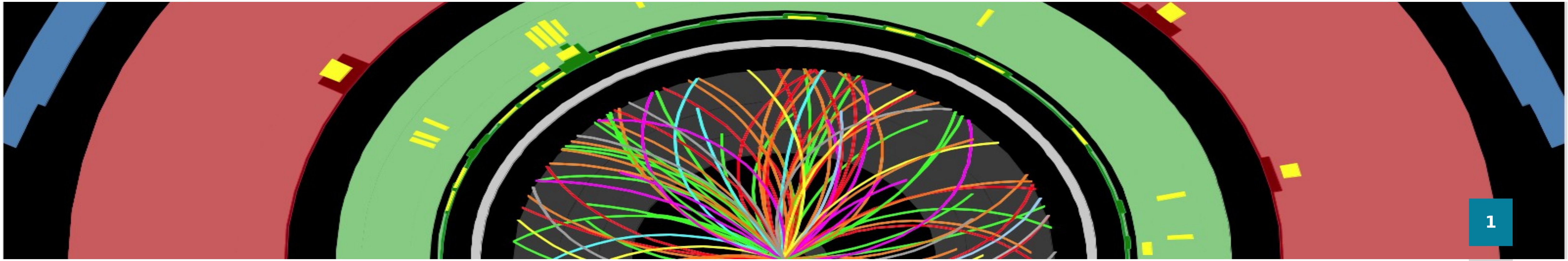
SPS Annual Meeting
12.9.2024

Extracting the jet energy resolution from pileup collisions

Antti Pirttikoski, Carlos Moreno Martinez, Mário Alves Cardoso, Steven Schramm, Vilius Čepaitis

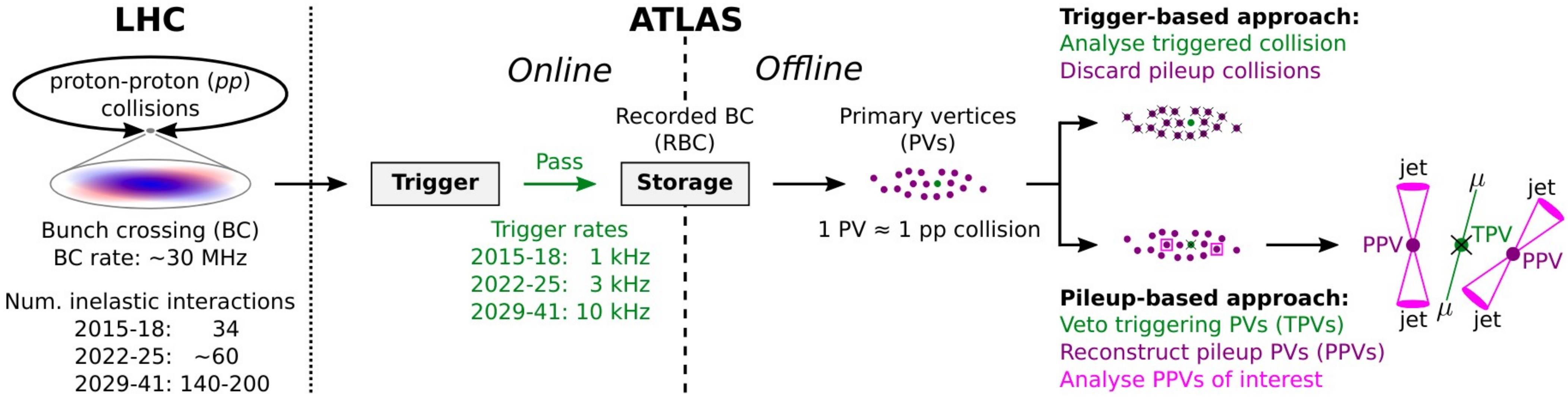
UNIVERSITÉ DE GENÈVE
FACULTY OF SCIENCE
Department of Nuclear and Particle Physics

This presentation is part of a project that has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 948254)



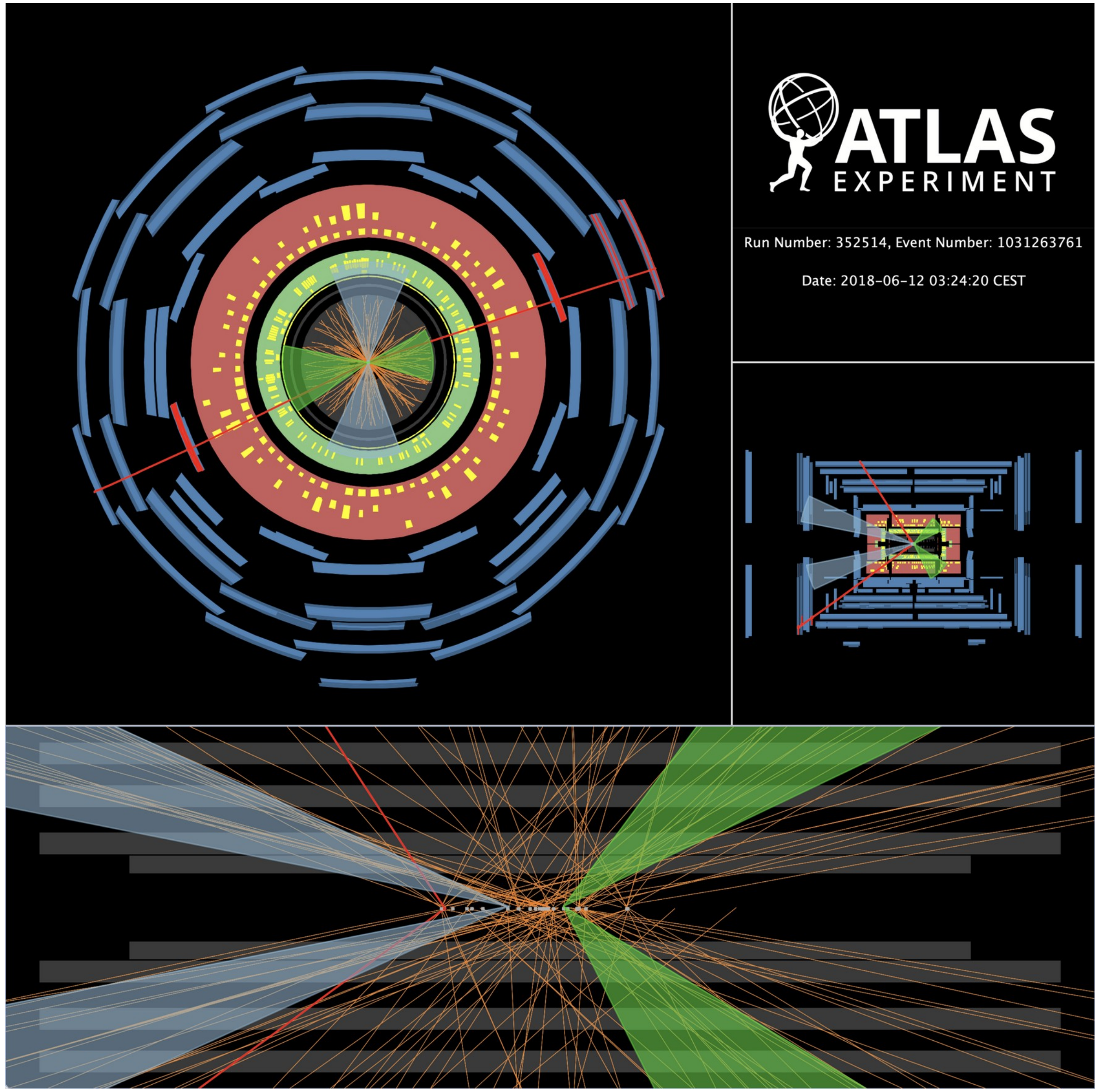
Introduction

- Novel approach to use data recorded in ATLAS
- Discard triggered collision and **reconstruct/analyse pileup collisions instead**
- Provides large trigger-unbiased dataset of low energy hadronic processes
- See the paper for more details about the reconstruction and validation of the dataset!
- So far you have heard how we can reconstruct and validate the dataset
  - **Now it is time to do some physics!**
  - Use pileup data to derive Jet Energy Resolution



Jet Energy Resolution (JER)

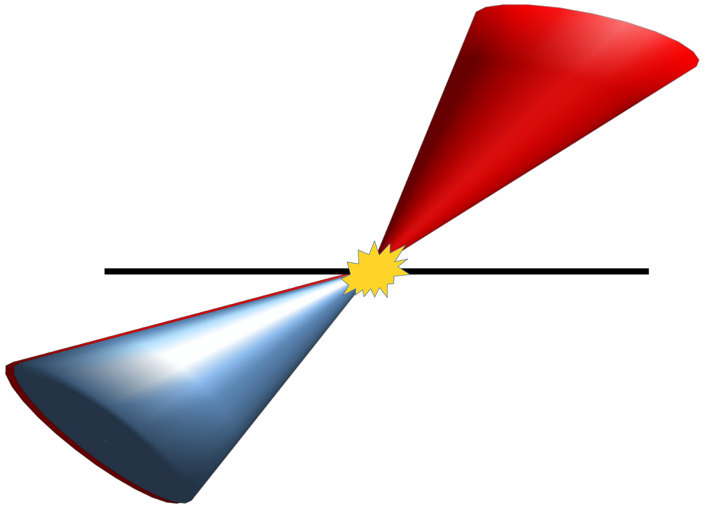
- Jet Energy Resolution (JER) measures the precision of which the energy of the hadronic showers (jets) can be known
- Important quantity in many Standard Model measurements and searches for new physics
- Part of so called "in-situ" calibration of jets
  - Final step in the jet calibration chain correcting the differences between data and simulation
  - Smear the simulated jets to match the data



Example event from the pileup dataset containing two pileup vertices which both produce two jets (blue and green cones), and the triggering vertex producing two muons (red lines)

Dijet balance technique

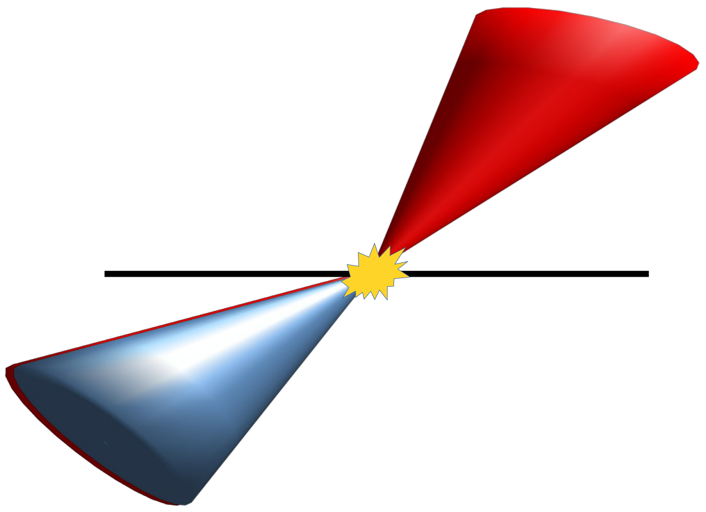
- The JER measurement is done using events with two jets (dijet)
  - One of the most abundant processes at the LHC
- The transverse momentum (p_T) is conserved in the collisions
  - Thus jets originating from same vertex should have equal p_T and “balance” each other



$$p_{T,1} = p_{T,2}$$

Dijet balance technique

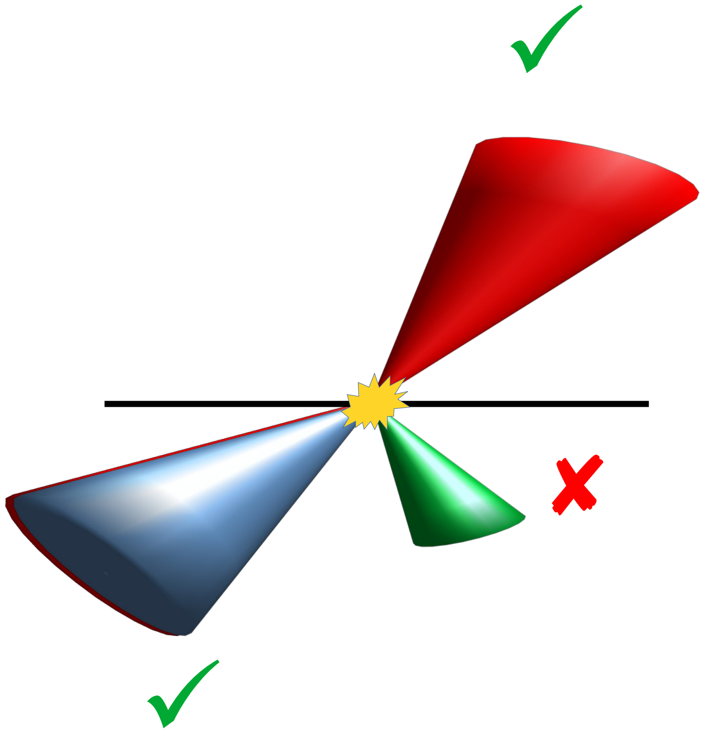
- The JER measurement is done using events with two jets (dijet)
  - One of the most abundant processes in LHC
- The transverse momentum (p_T) is conserved in the collisions
  - Thus jets originating from same vertex should have equal p_T and “balance” each other
  - However in practice, there is an imbalance in the p_T of the jets due to the detector resolution



$$p_{T,1} \approx p_{T,2}$$

Dijet balance technique

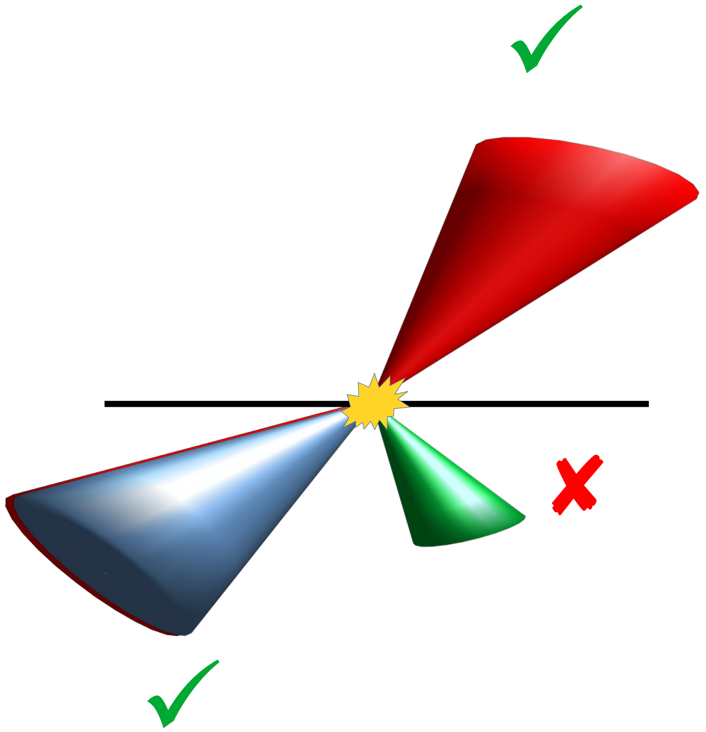
- The JER measurement is done using events with two jets (dijet)
  - One of the most abundant processes in LHC
- The transverse momentum (p_T) is conserved in the collisions
  - Thus jets originating from same vertex should have equal p_T and “balance” each other
  - However in practice, there is an imbalance in the p_T of the jets due to the detector resolution
  - Also additional radiation in the events affects to the p_T imbalance but this can be suppressed with appropriate event selections



Dijet balance technique

- The JER measurement is done using events with two jets (dijet)
  - One of the most abundant processes in LHC
- The transverse momentum (p_T) is conserved in the collisions
  - Thus jets originating from same vertex should have equal p_T and “balance” each other
  - However in practice, there is an imbalance in the p_T of the jets due to the detector resolution
  - Also additional radiation in event affects to the p_T imbalance but this can be suppressed with appropriate event selections
- This imbalance can be measured with ***dijet asymmetry***:

$$\mathcal{A} \equiv \frac{p_{\mathrm{T},1} - p_{\mathrm{T},2}}{p_{\mathrm{T}}^{\mathrm{avg}}}$$



Resolution from Asymmetry Distribution

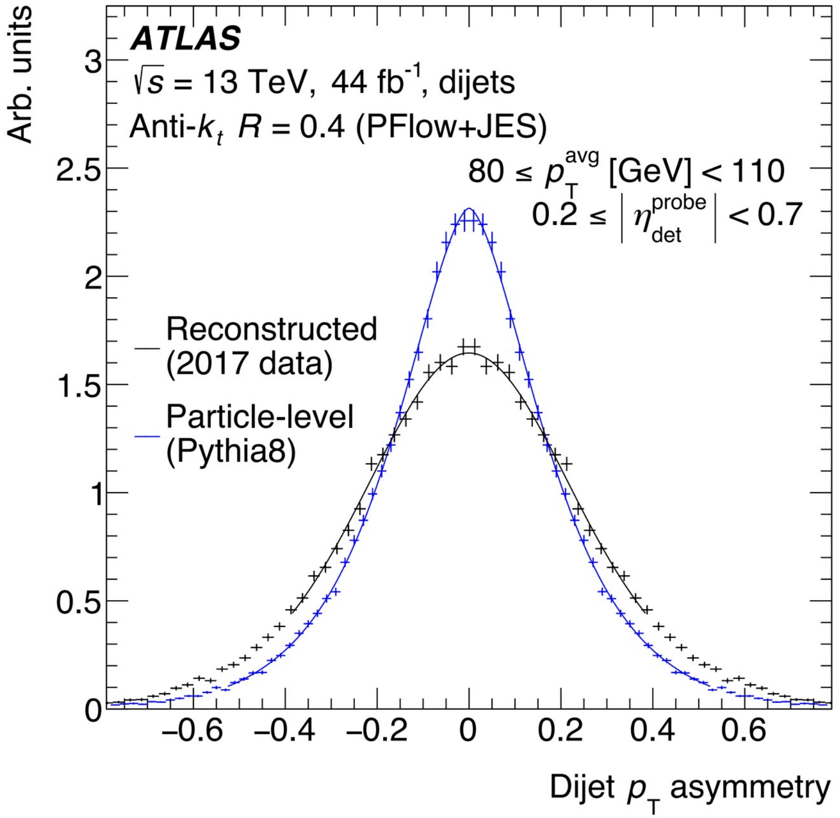
- The asymmetry distribution can be calculated at particle level using simulation (**blue markers**) or directly from data (**black markers**)
- The particle-level distribution is used to subtract the physics effects

  → We are only interested in the detector resolution related effects

- The JER can be then simply calculated from the width of the asymmetry distribution as:

$$\left\langle \frac{\sigma_{p_{\mathrm{T}}}}{p_{\mathrm{T}}} \right\rangle = \frac{\sigma_{\mathcal{A}}}{\sqrt{2}}$$

- Repeat the calculation for multiple p_{T} bins

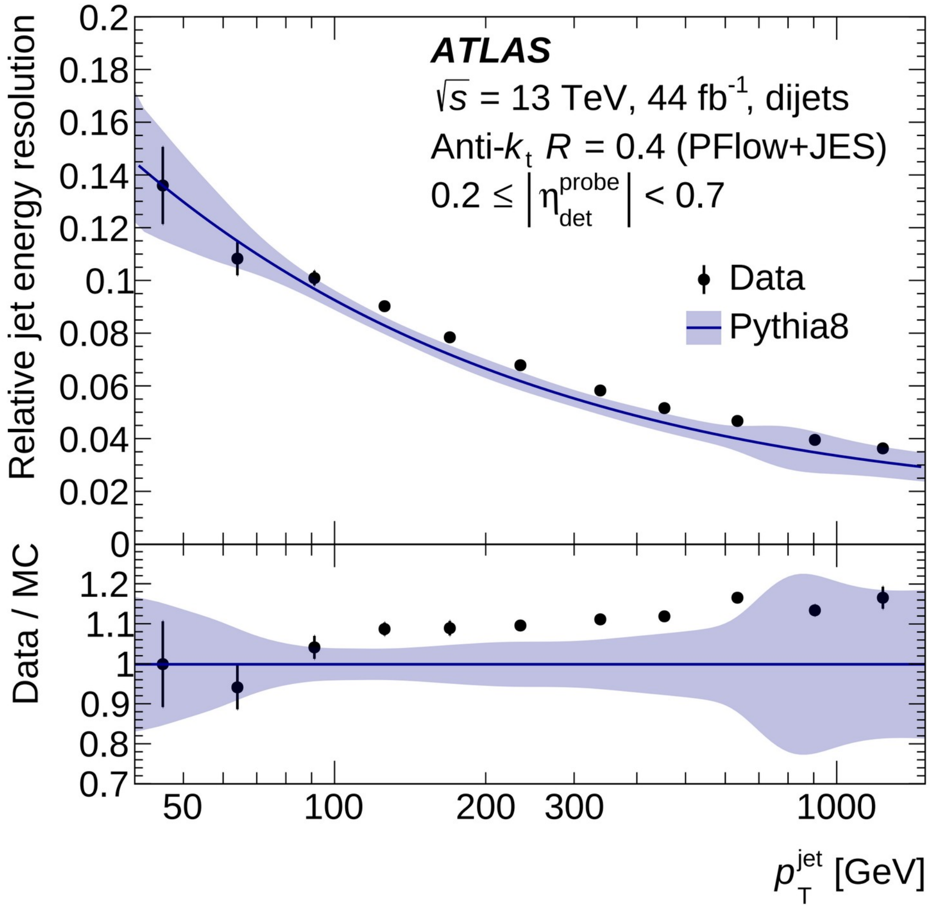


NSC-fit

- The JER can be then parameterized using knowledge of sampling calorimeters:

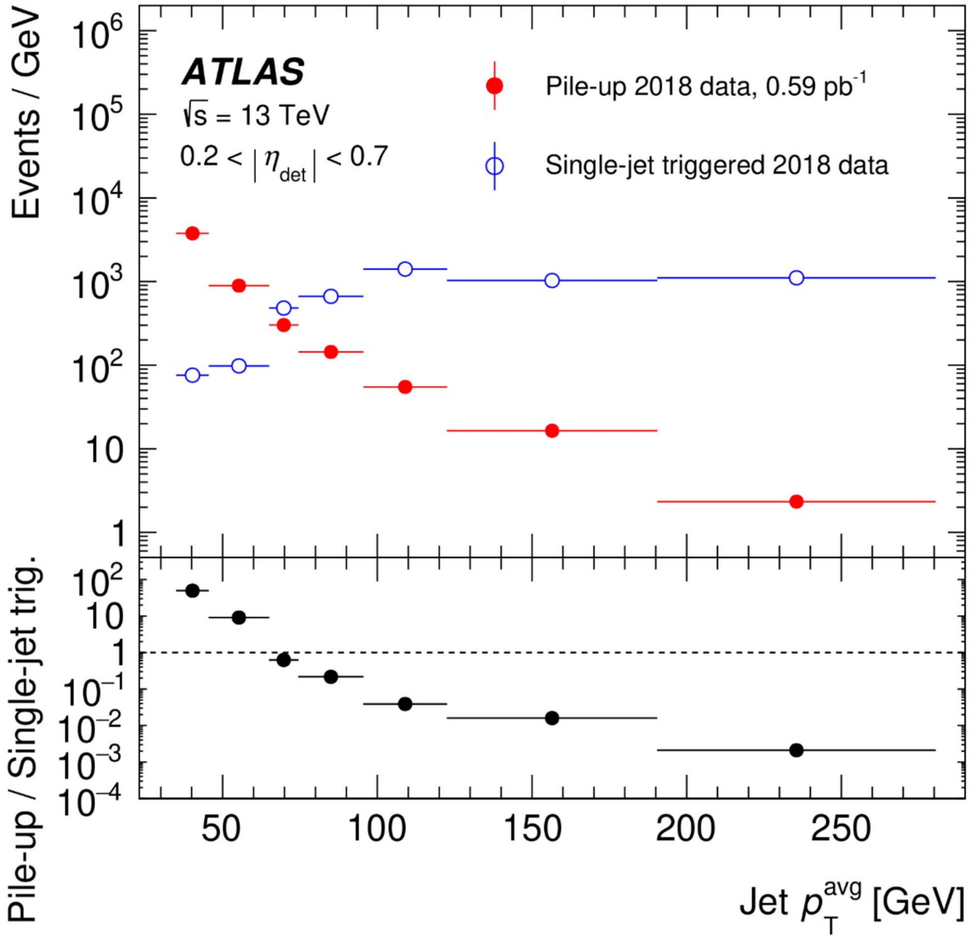
$$\frac{\sigma(p_{\mathrm{T}})}{p_{\mathrm{T}}} = \frac{N}{p_{\mathrm{T}}} \oplus \frac{S}{\sqrt{p_{\mathrm{T}}}} \oplus C$$

- Three independent contributions affecting the JER:
  - **Noise (*N*)**, due to the pileup and electronics noise
  - **Stochastic (*S*)**, effects related to the intrinsically stochastic nature of hadronic showers
  - **Constant (*C*)**, fluctuations that are const. fraction of jet p_{T}, e.g. energy deposited to passive materials
- The single-jet triggered dijet balance can restrict the *S* and *C* terms, but has very limited sensitivity to the *N* term
- Instead another method called *random cones* is used to measure *N* term traditionally in ATLAS



Why to use pileup dataset for JER measurement?

- Contrary to single-jet triggered data, the size of the pileup dataset increases at low p_T
  - **x50 more data** compared to single-jet triggers at very low p_T!
- **Enhanced statistical precision** for noise and stochastic terms
- Can be used to complement the noise term value obtained from the random cones method
- Measuring JER is also another way to **demonstrate the validity of the pileup dataset**

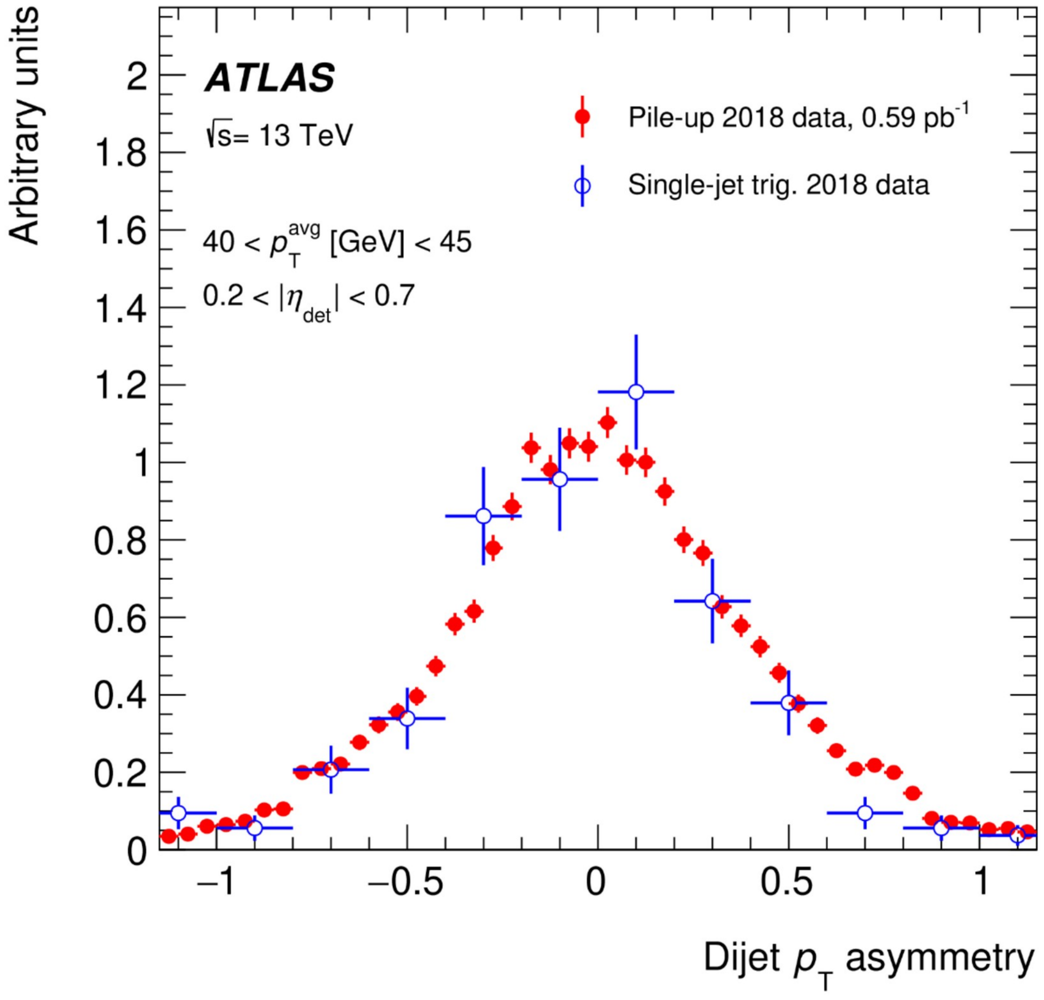


Asymmetry distribution comparison

- One example p_T bin showing the asymmetry distributions for pileup and single-jet triggered datasets

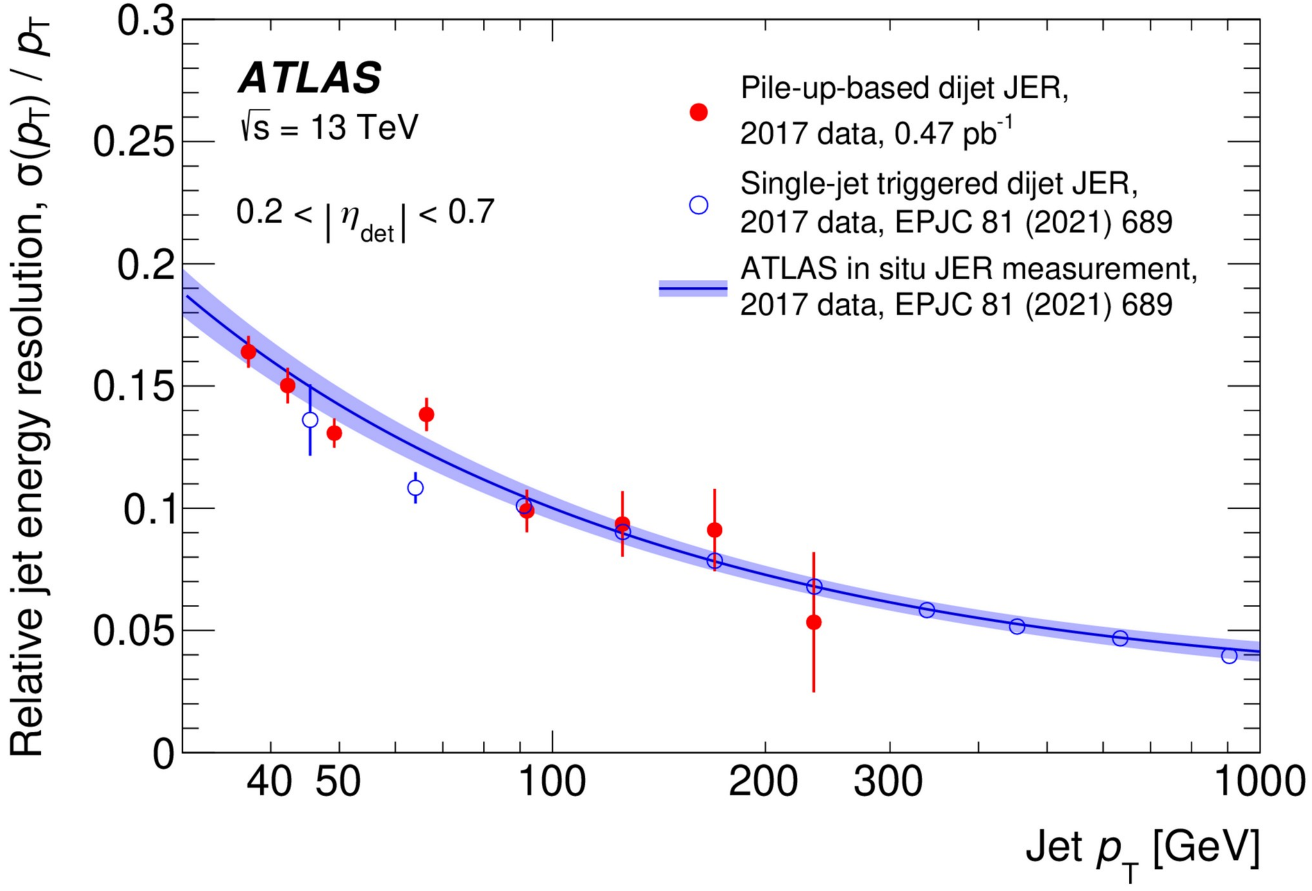
  → Looks promising

- The higher statistical power of the pileup dataset at low p_T is already evident



Pileup vs. single-jet triggered dijet balance JER in 2017

- Comparing the pileup measurement with the single-jet triggered result from the ATLAS Run 2 jet calibration paper
- **Good agreement** between the datasets and only one discrepant point at ~65 GeV
  - Studies suggest a statistical fluctuation
- Pileup dataset has excellent statistics at low p_T but runs out of stat. at high p_T while the opposite is true for the single-jet triggered data



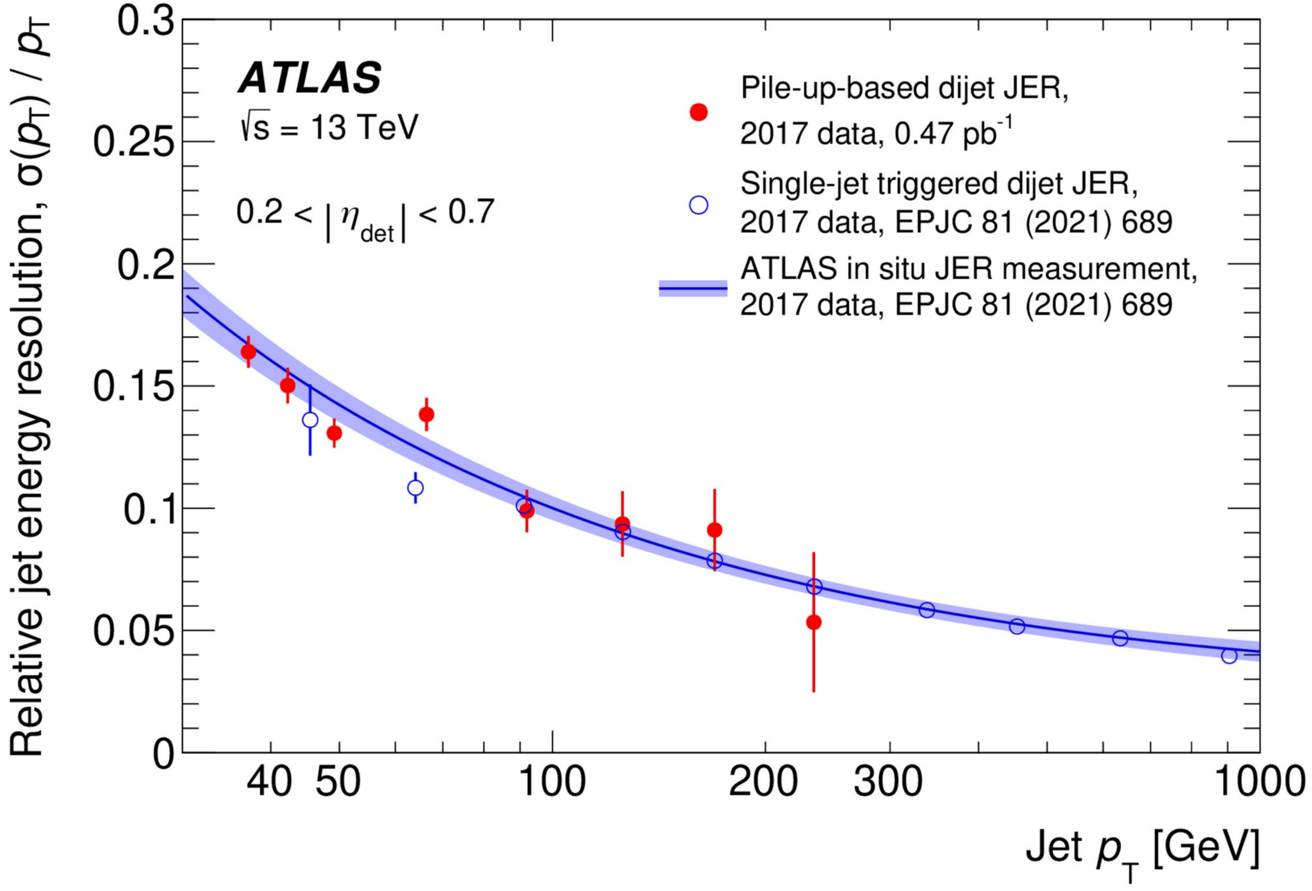
Pileup vs. single-jet triggered dijet balance JER in 2017

- Comparing the pileup measurement with the single-jet triggered result from the ATLAS Run 2 jet calibration paper
- **Good agreement** between the datasets and only one discrepant point at ~65 GeV
- Pileup dataset has excellent statistics at low p_T but runs out of stat. at high p_T while the opposite is true for the single-jet triggered data

  → **Simplified statistics-only combination** of the datasets was performed

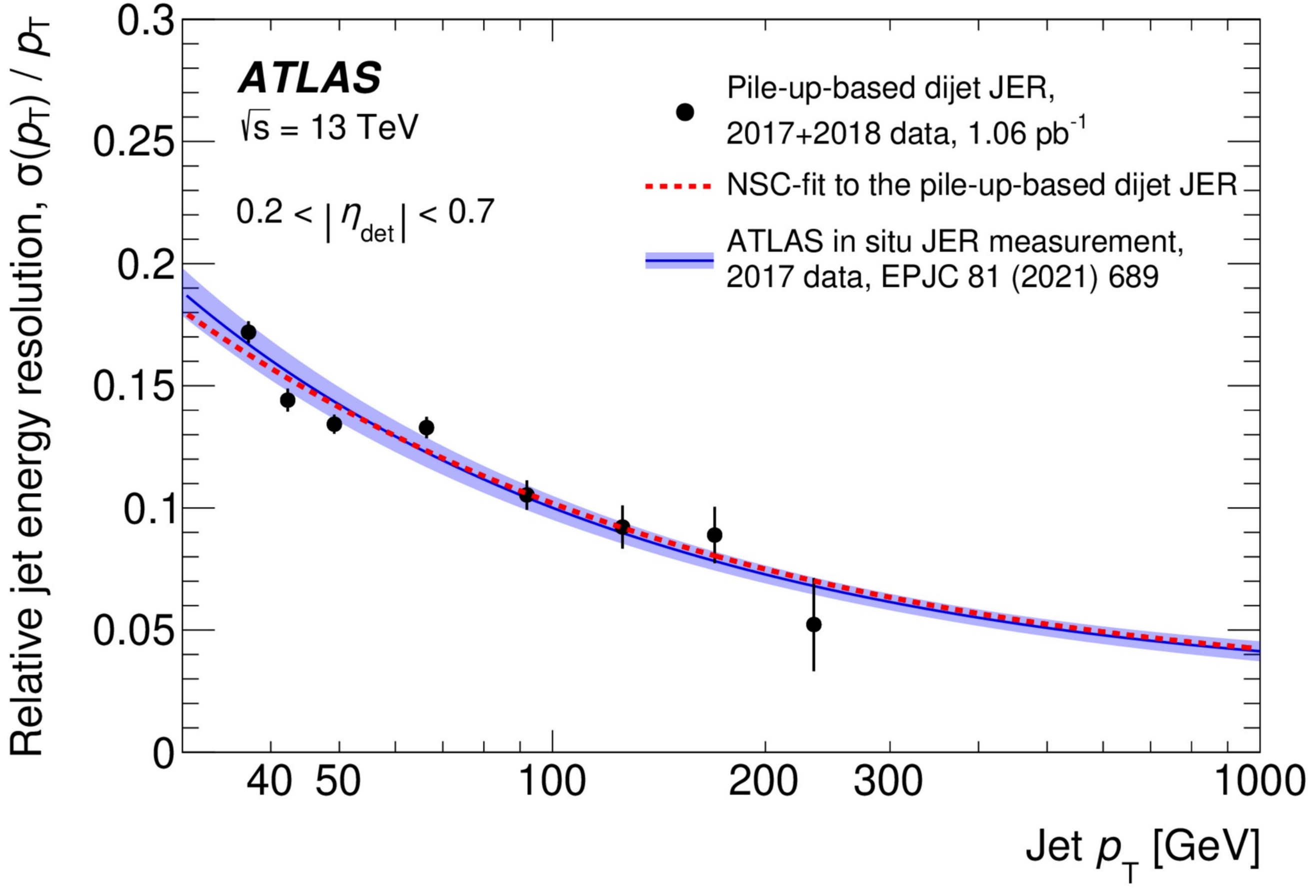
  - **Improved the stat. precision of *N* by 40% and *S* by 20%**

$$\frac{\sigma(p_T)}{p_T} = \frac{N}{p_T} \oplus \frac{S}{\sqrt{p_T}} \oplus C$$



Combined pileup vs. standard method

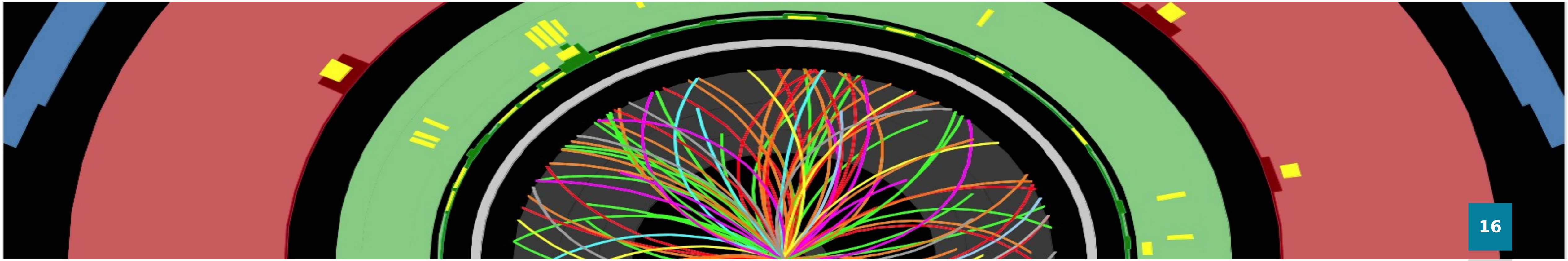
- Finally the 2017 and 2018 pileup datasets were combined and NSC-fit was performed to the points
- As a reference, the NSC-fit to the standard method with full systematic uncertainties is shown
- **NSC-fit to pileup agrees on the whole p_T range within the uncertainties to the reference!**



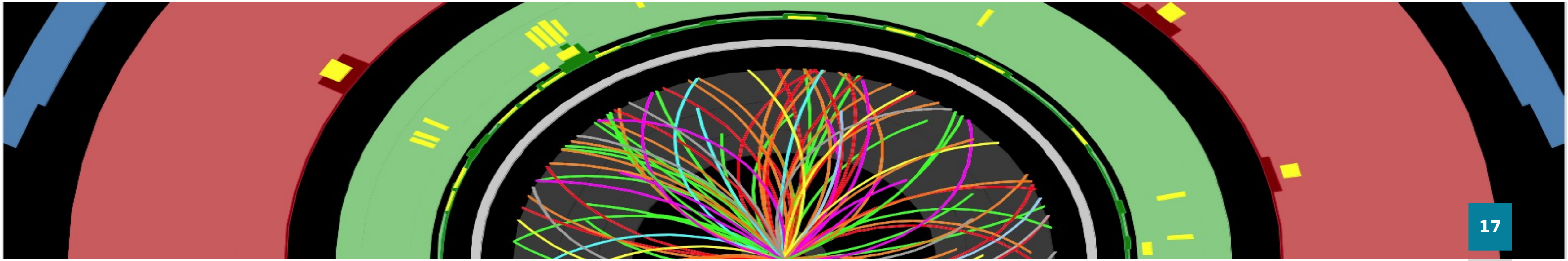
Summary and outlook

- Jet energy resolution is extracted from the novel pileup dataset and is found to be **consistent** with the traditional single-jet triggered result
- Provides strong evidence that pileup dataset is **unbiased** as results compatible with the normal approach
- The pileup JER measurement has much **higher sensitivity** than triggered dijet JER measurent at low p_T
  - Can provide much better precision for the noise and stochastic term measurements in the dijet NSC-fit
- Pileup dataset offers many interesting potential applications for low-energy hadronic physics processes!

Thank you!



Backup



Asymmetry distributions: different analysis selections for the pileup data