Mitigating experimental challenges in using pileup for physics

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

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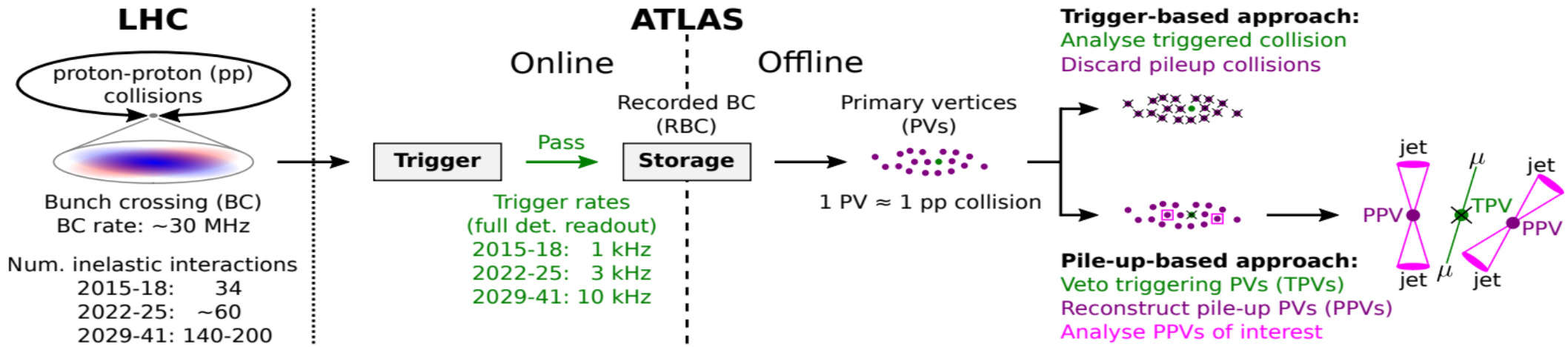
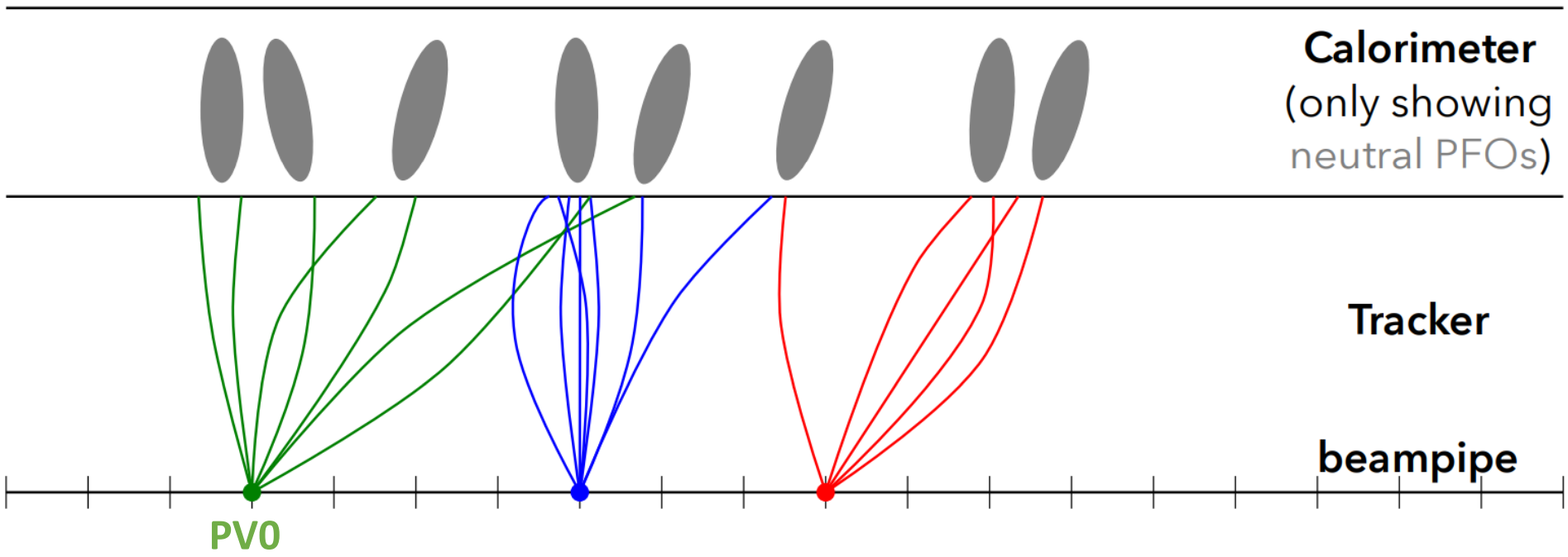
Turning noise into data: pileup collisions

- Each proton-proton (*pp*) collision is independent.
  - If we are able to reconstruct the pileup collisions separately and remove the triggering vertex, we can build trigger-unbiased data of low energy hadronic processes.
- Pileup data has superior statistics for $p_{\mathrm{T}} \lesssim 60\ \mathrm{GeV}$ compared to single-jet triggers



Pileup data reconstruction

- Standard reconstruction technique:
  - Mitigate all other vertices keeping a single Primary Vertex (PV)
  - Match charged components (tracks) and calorimeter clusters to TPV
  - Cluster jets from tracks and calorimeter clusters



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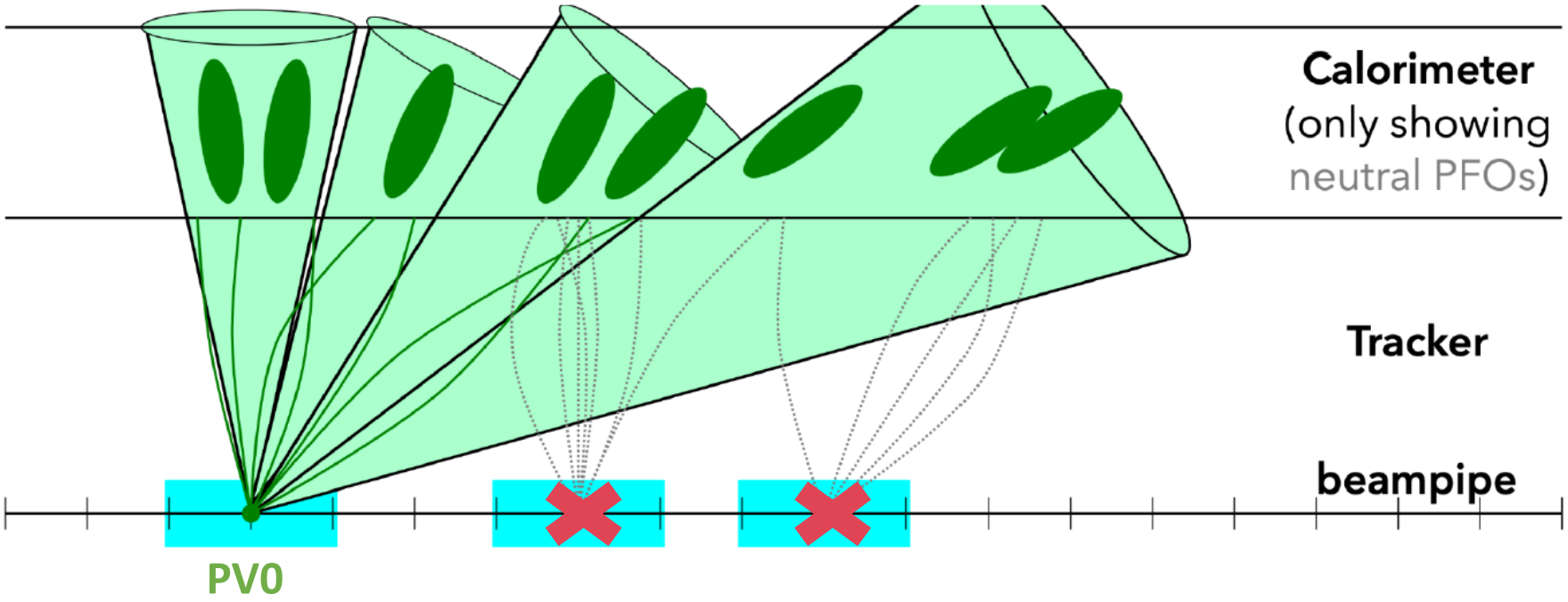
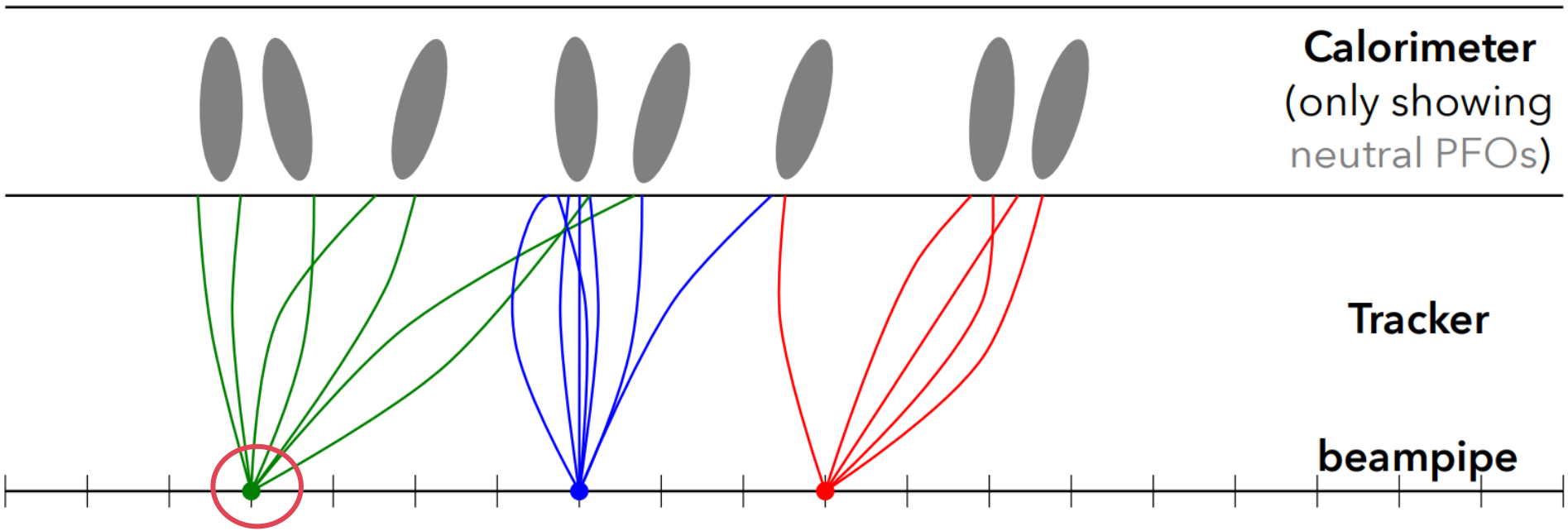


Pileup data reconstruction

- **Goal**: Adapt the standard jet reconstruction for multiple Primary Vertices (PVs) within a single bunch crossing.

- **Procedure**:

1. Select the current PV for jet reconstruction.

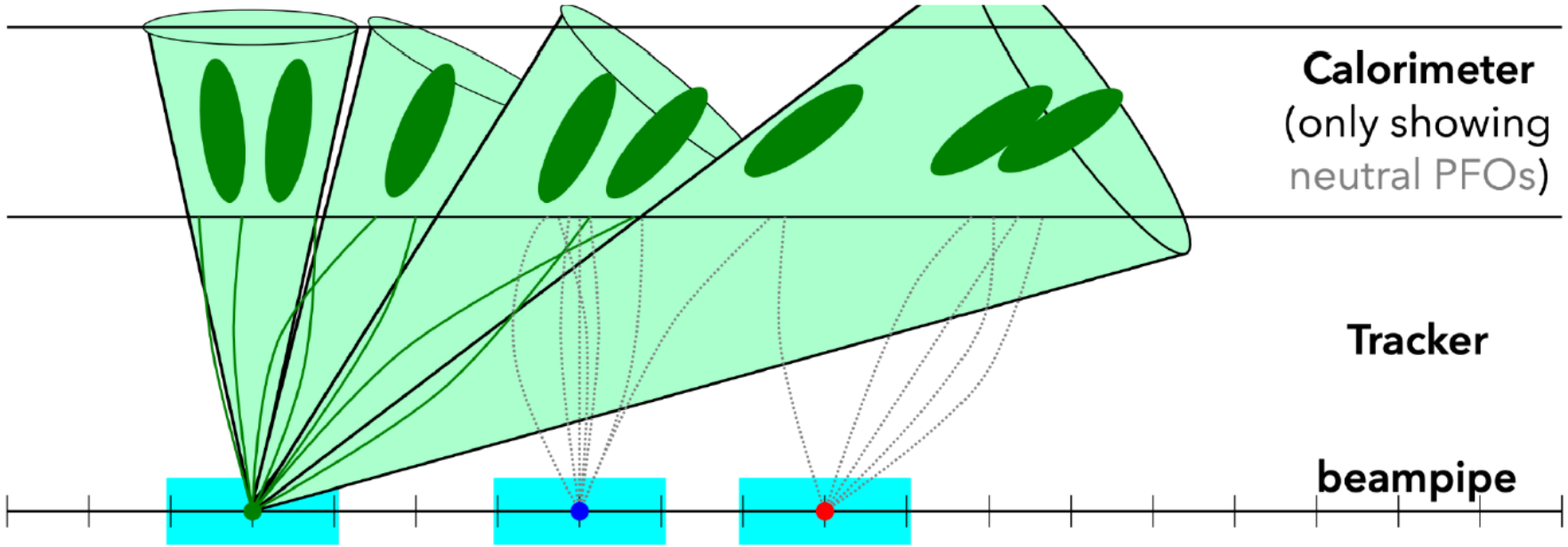


Pileup data reconstruction

- **Procedure**:

1. Select the current PV for jet reconstruction.

2. Cluster jets from tracks and calorimeter clusters consistent with current vertex. Loop this step for all vertices.



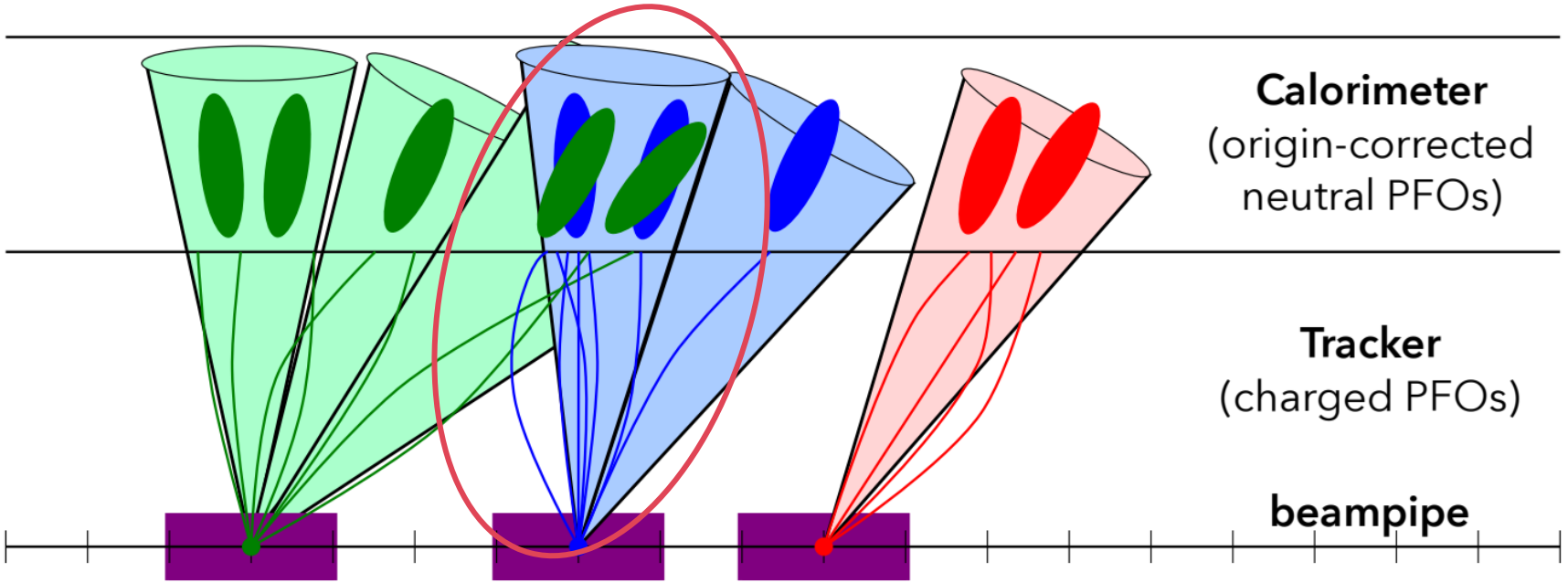
Pileup data reconstruction

- **Procedure**:

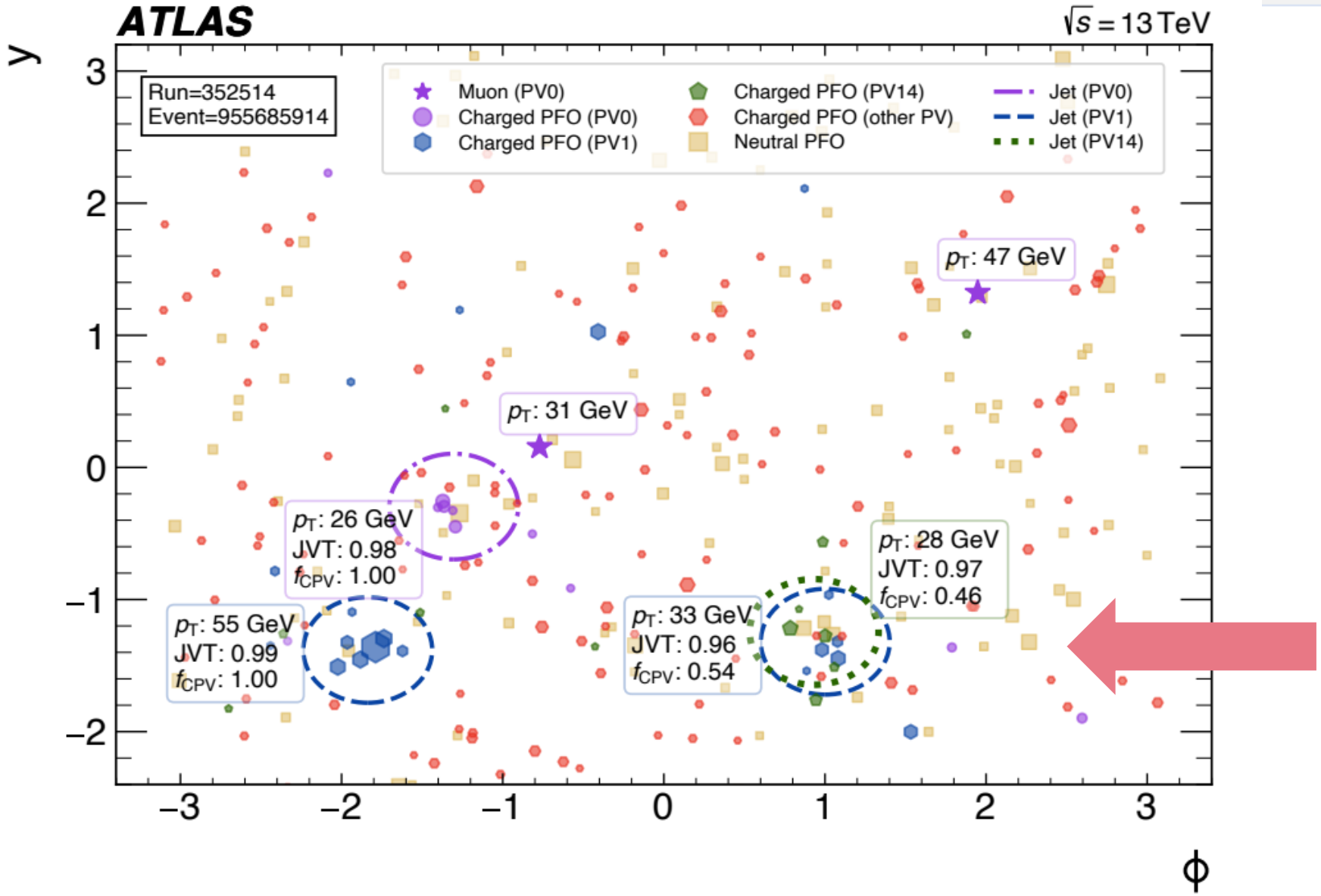
1. Select the current PV for jet reconstruction.

2. Identify the charged components (tracks) and correct neutral clusters to point to the vertex chosen.

3. Remove jets that don’t pass a threshold of charged activity encompassed within it (Jet Vertex Tagger)



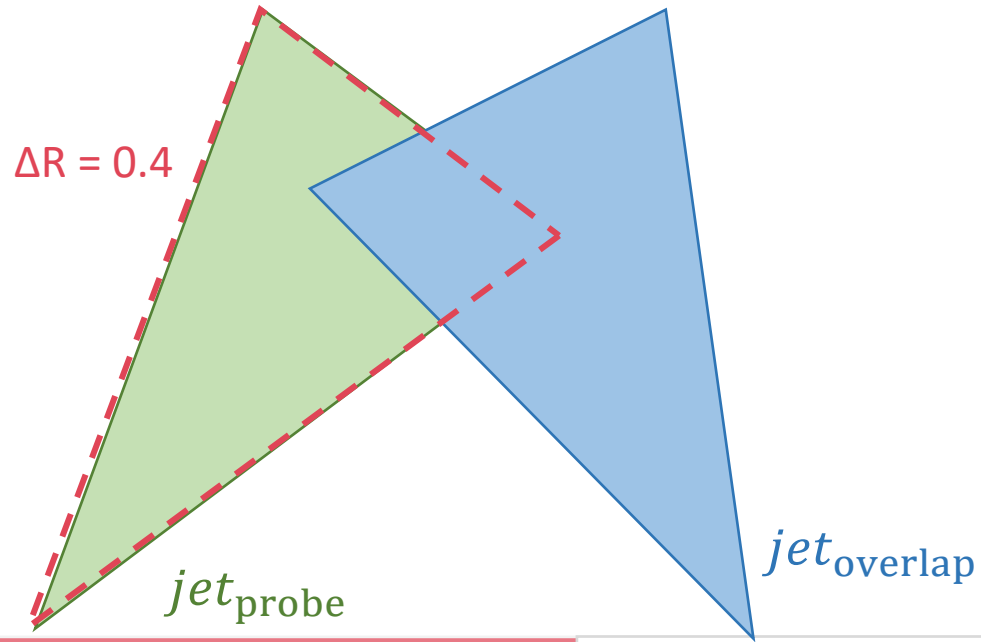
Pileup data reconstruction: overlapped jets

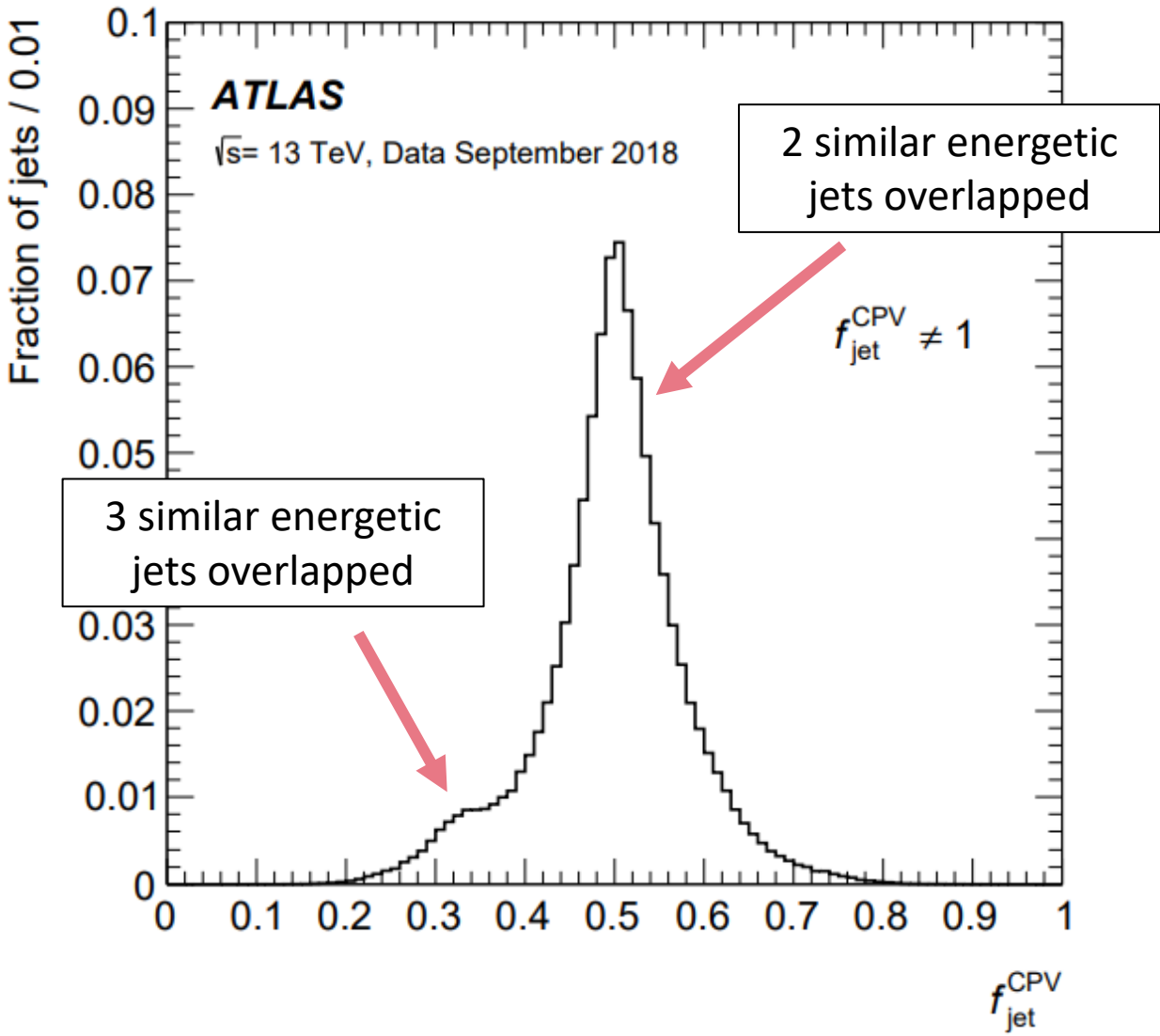


Mitigating overlapping signals

- A new quantity, $f_{\mathrm{jet}}^{\mathrm{CPV}}$, is defined to measure the fraction of p_{T} from the current PV (CPV) compared to the overlapping jets from other PVs within a distance of $\Delta R < 0.4$.

$$f_{\mathrm{jet}}^{\mathrm{CPV}} = \frac{p_{\mathrm{T}}^{\mathrm{probe}}}{p_{\mathrm{T}}^{\mathrm{probe}} + \sum p_{\mathrm{T}}^{\mathrm{overlap}}}.$$





Mitigating overlapping signals

- Mitigation strategy:
  - Imposing a strict requirement of $f_{\mathrm{jet}}^{\mathrm{CPV}} = 1$ ensures that only jets uniquely associated with their original PV are retained.
  - Jets failing this requirement are vetoed to avoid double-counting energy deposits.
- We only retain Pileup PV's (PPV's) where there is no double use of calorimeter energy deposits.

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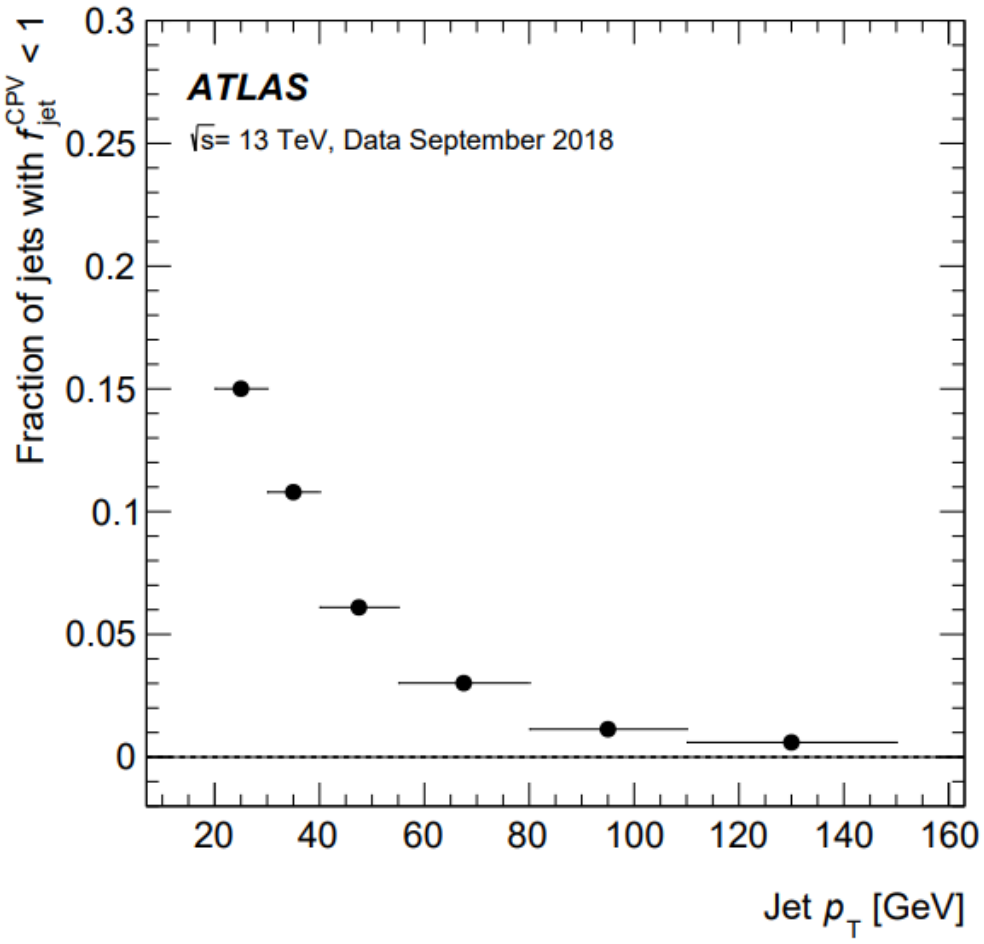
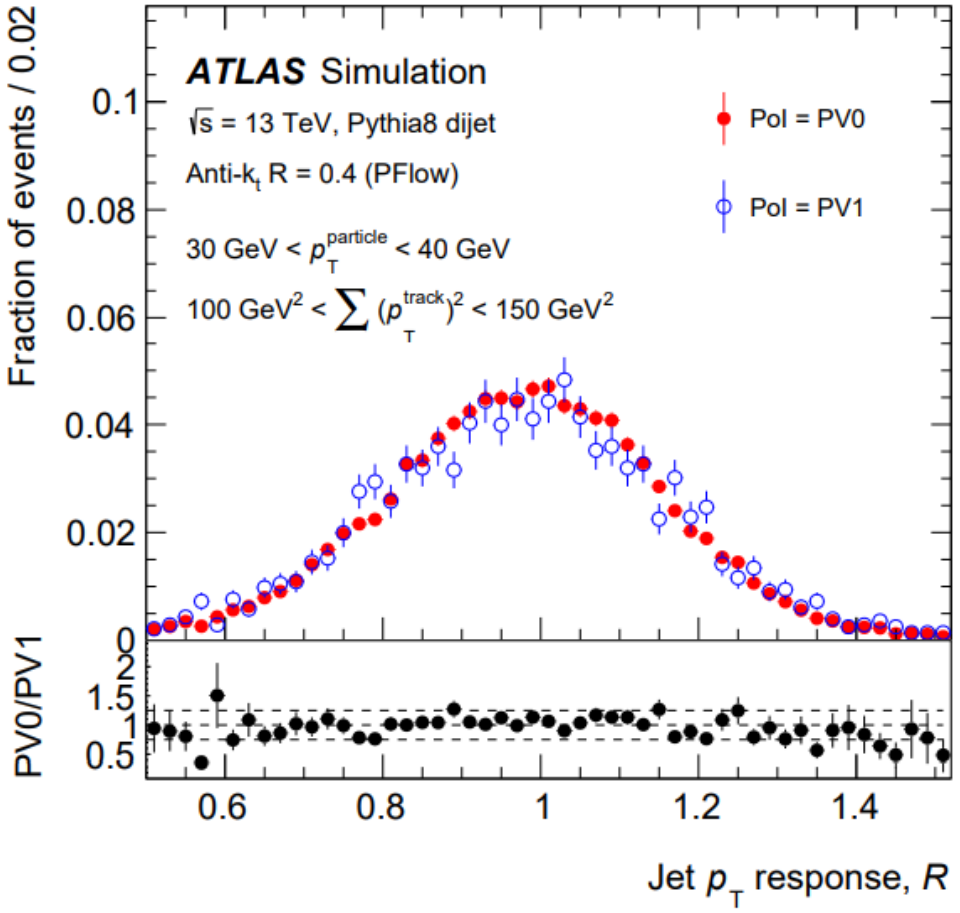


Jet Calibration in the Pileup Dataset

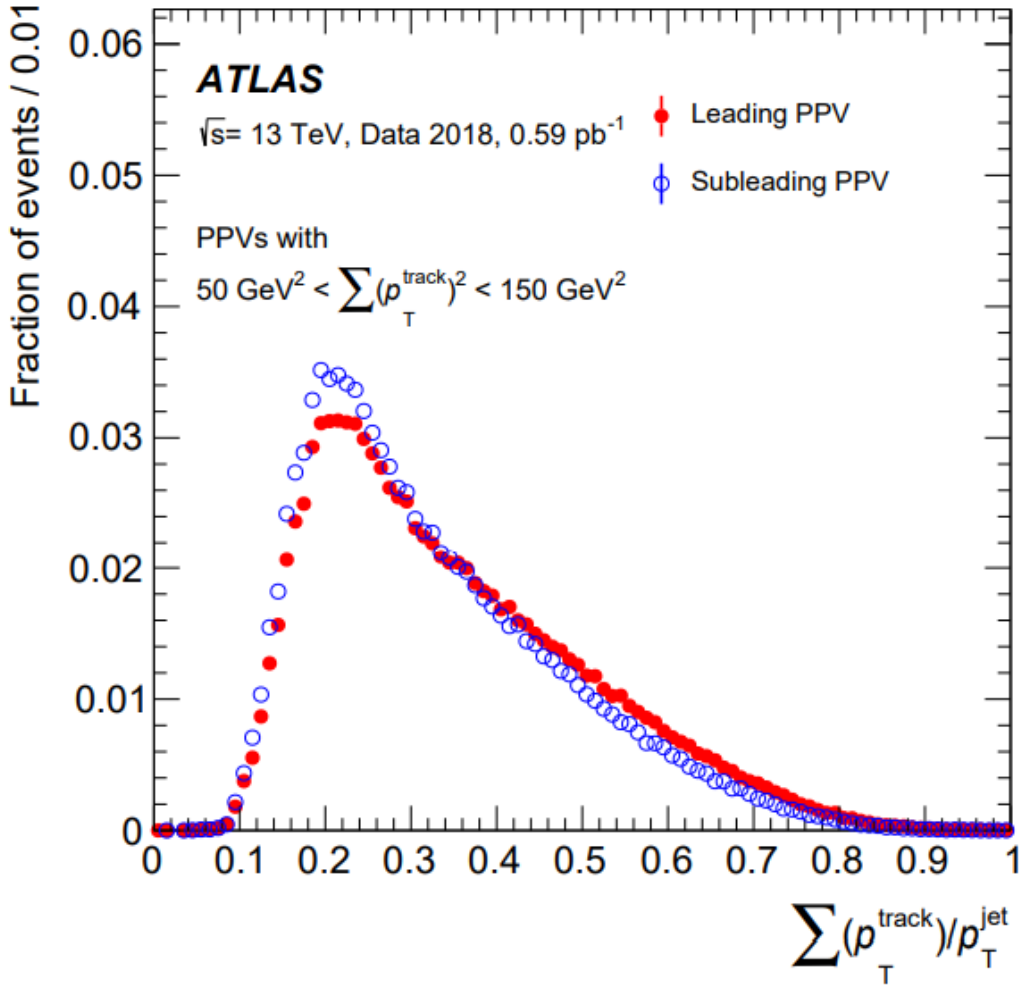
- We assume that all PPV's are independent from each other
  - We can validate this statement by verifying calibration consistency for jets from multiple PVs in MC.
- Studies show no significant differences in jet response for jets from different PVs.
- Standard calibration is valid for pileup jets.

$$\mathcal{R} = p_{\mathrm{T}}^{\mathrm{reco}} / p_{\mathrm{T}}^{\mathrm{true}}$$



Validation of Pileup dataset: comparing jets from different vertices

- A useful quantity for comparing jets belonging to different PPV's is the charged fraction.
  - It mixes both tracking and calorimeter information.
  - Is one of the variables used in the jet calibration procedure.
- Good agreement, which shows that reconstructed jets are independent from the *pp* collision from which they originate.



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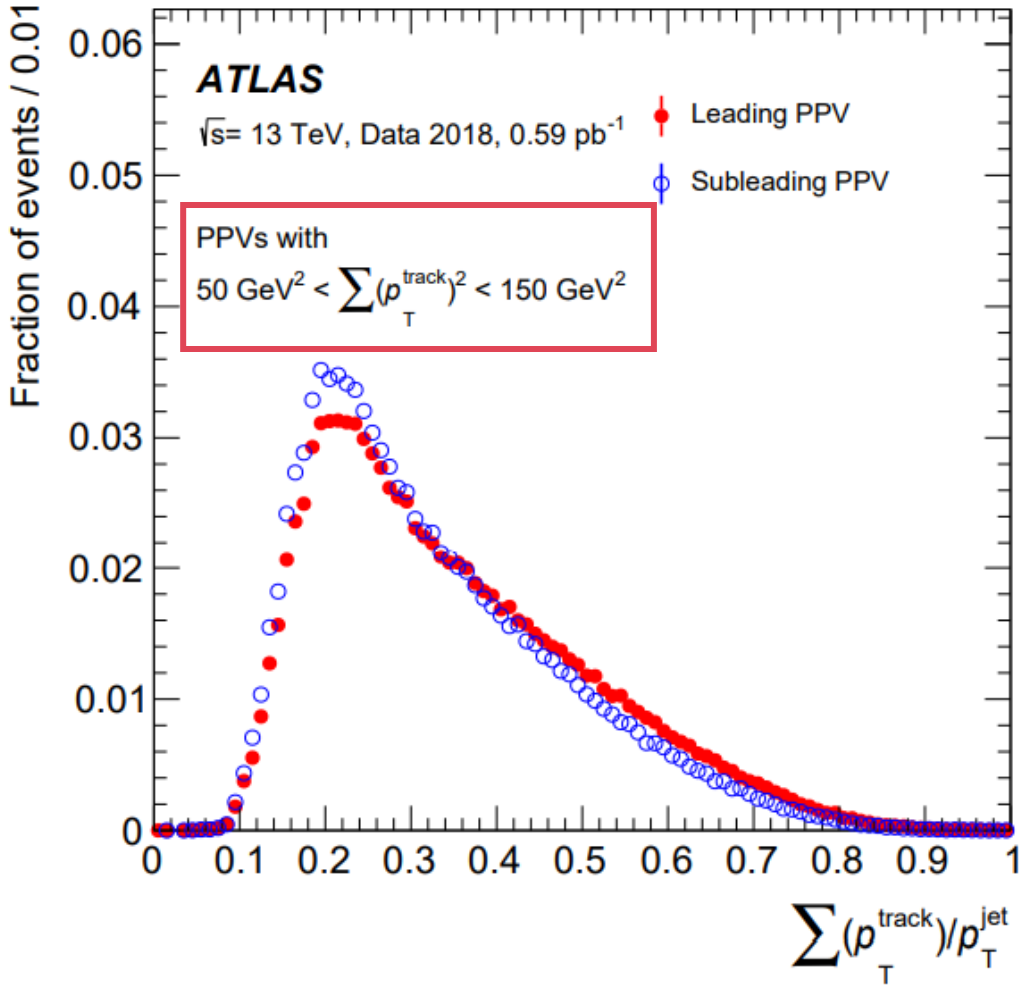
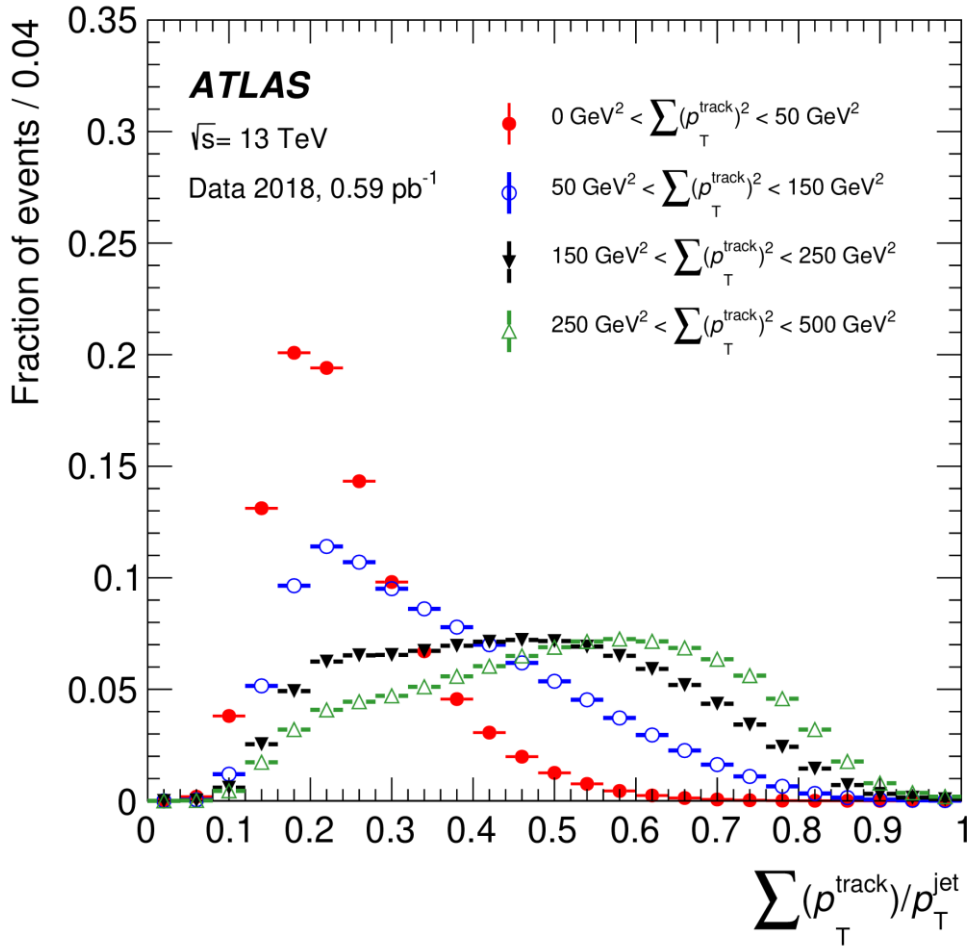
- Good agreement, which shows that reconstructed jets are independent from the *pp* collision from which they originate.
  - Tighter cuts on the $\sum\left(p_{\mathrm{T}}^{\mathrm{track}}\right)^2$ would further enforce agreement (more on the next slide).



Jet Calibration in the Pileup Dataset

- **Implicit Vertex Ordering Bias:**
  - Vertices are sorted by $\sum\left(p_{\mathrm{T}}^{\mathrm{track}}\right)^2$ which favors higher-activity collisions.
  - Gives systematic differences in jet properties (ex: p_{T} response, charged fraction) based on the PV order.
  - Solution: impose a selection on $\sum\left(p_{\mathrm{T}}^{\mathrm{track}}\right)^2$ to remove this implicit bias and focus on whether there is a dependence originating from the presence of other higher-energy activity in the bunch crossing.
  - This bias is not present when looking at vertices inclusively, such as for physics results.
    - Bias only arises when selecting a specific vertex ordering.



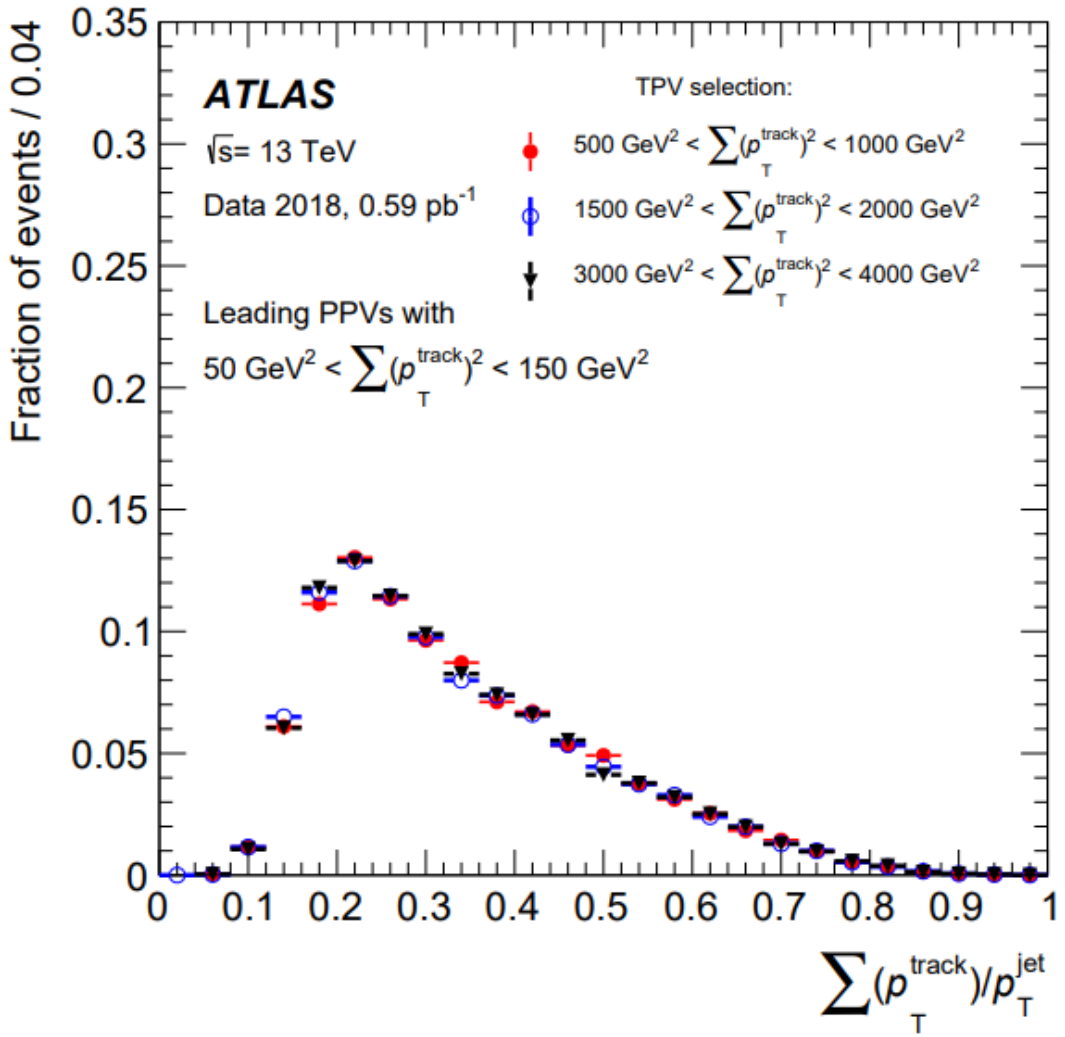
Validation of Pileup dataset: comparing vertices from different Bunch Crossings

- Do the PPVs belonging to Bunch Crossings (BC) containing the presence of other much higher energy collisions behave the same?

- We look into different BCs of varying energetic TPVs and compare the charged activity of the leading PPVs.

  - The highest energy bin represents a BC where its TPV is 20 times more energetic then its leading PPV.

- The charged fraction is independent to such additional energy in the detector, showing that the overlap removal and calibration procedures are working well.



Summary

- Most of ATLAS reconstruction is oriented around the single PV mentality.
  - We present an alternative: using pileup collisions.
  - For this we need a new event reconstruction strategies: vertex-by-vertex reconstruction.
- By comparing p_{T} response of different PVs in MonteCarlo we show that each PPV is independent from each other: trigger-unbiased dataset.
- Validation of the pileup dataset is given by the jet charged fraction between jets of different vertices.
  - We understand how to mitigate the vertex ordering bias that we impose when comparing individual vertices
- Pileup dataset shows improved statistical precision and promising studies for low-energy hadronic physics in ATLAS!
- For more info go check our **paper**!