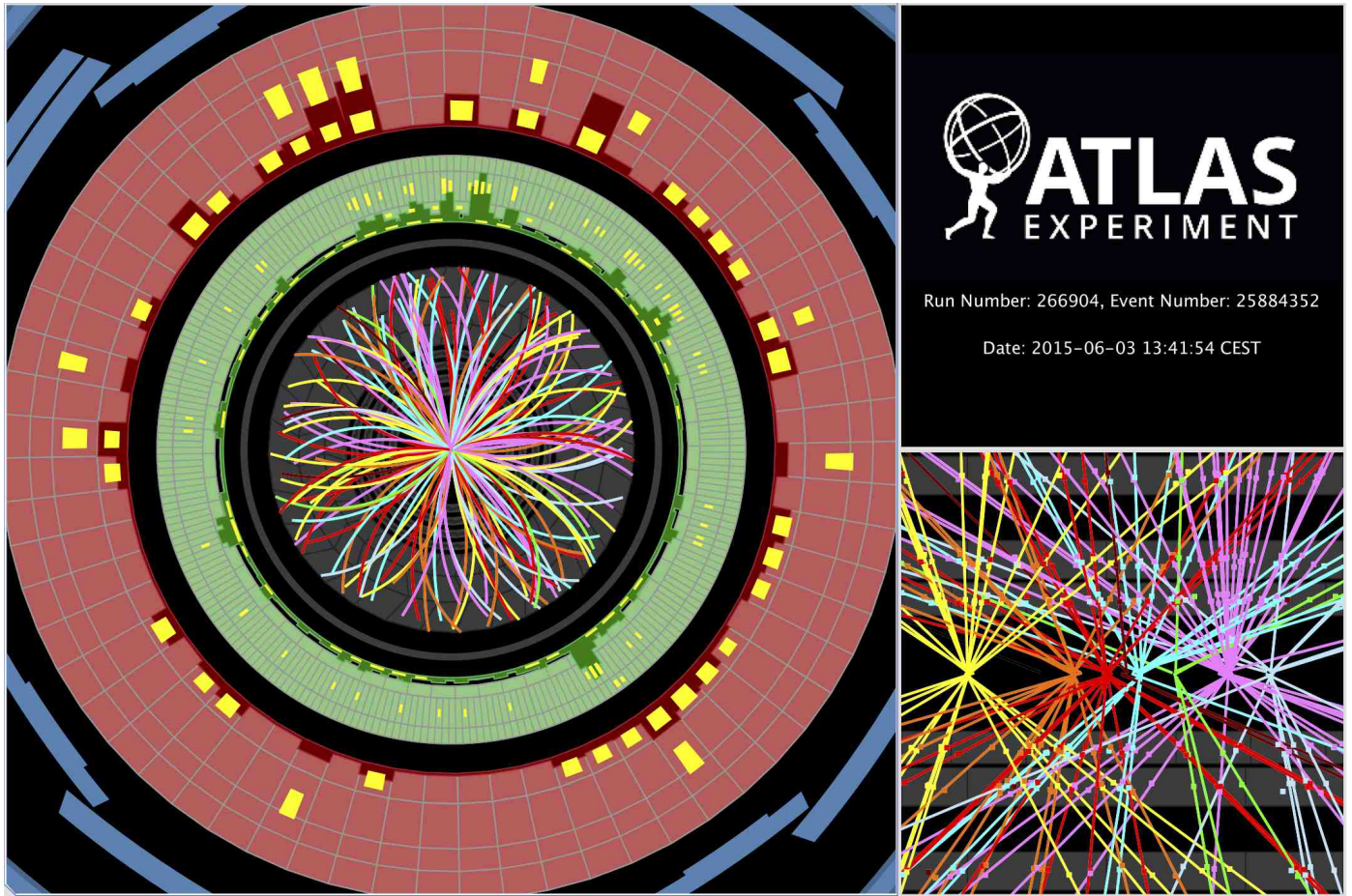
Jet Pileup Mitigation Techniques

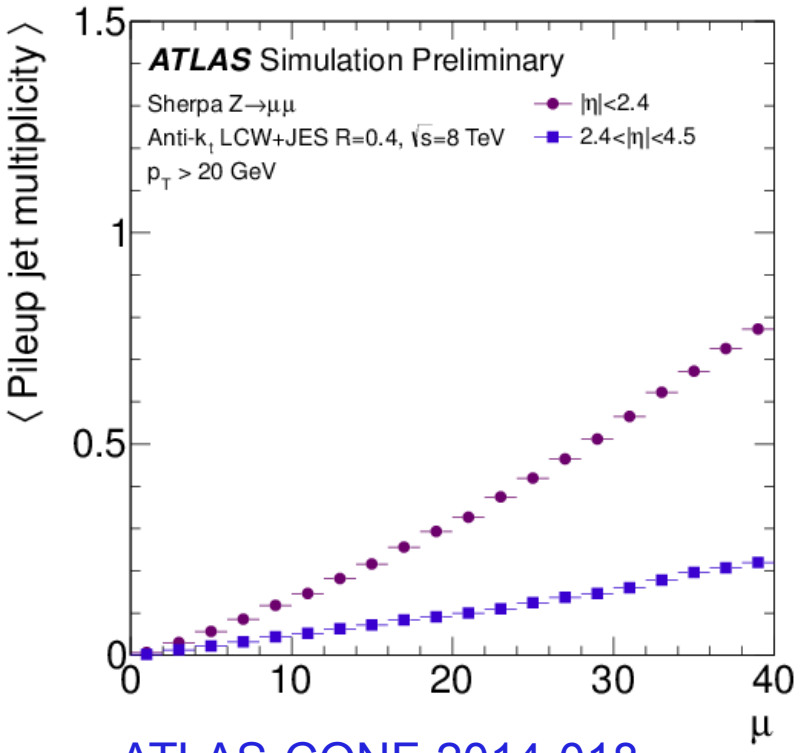
BOOST2016 – University of Zurich

Matthew Klein, on behalf of the ATLAS Collaboration

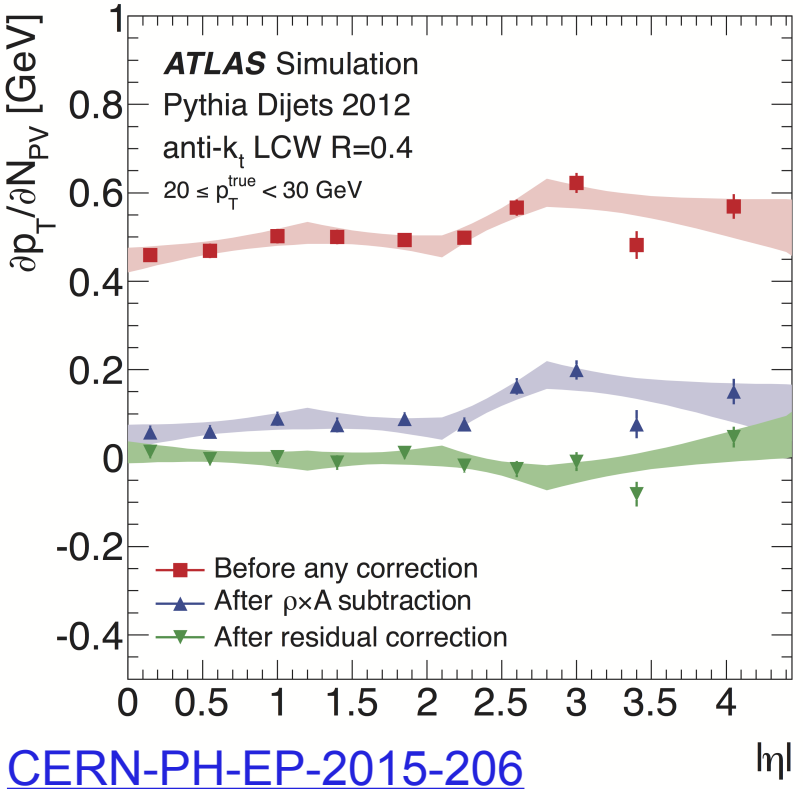


The Challenge of Pileup

- Affects hard-scatter jets, adding energy from pileup interactions to reconstructed hard-scatter jets.
- Produces pileup jets – jets produced from either single or multiple pileup interactions.
- One of the most important challenges for the reconstruction of jets and the LHC



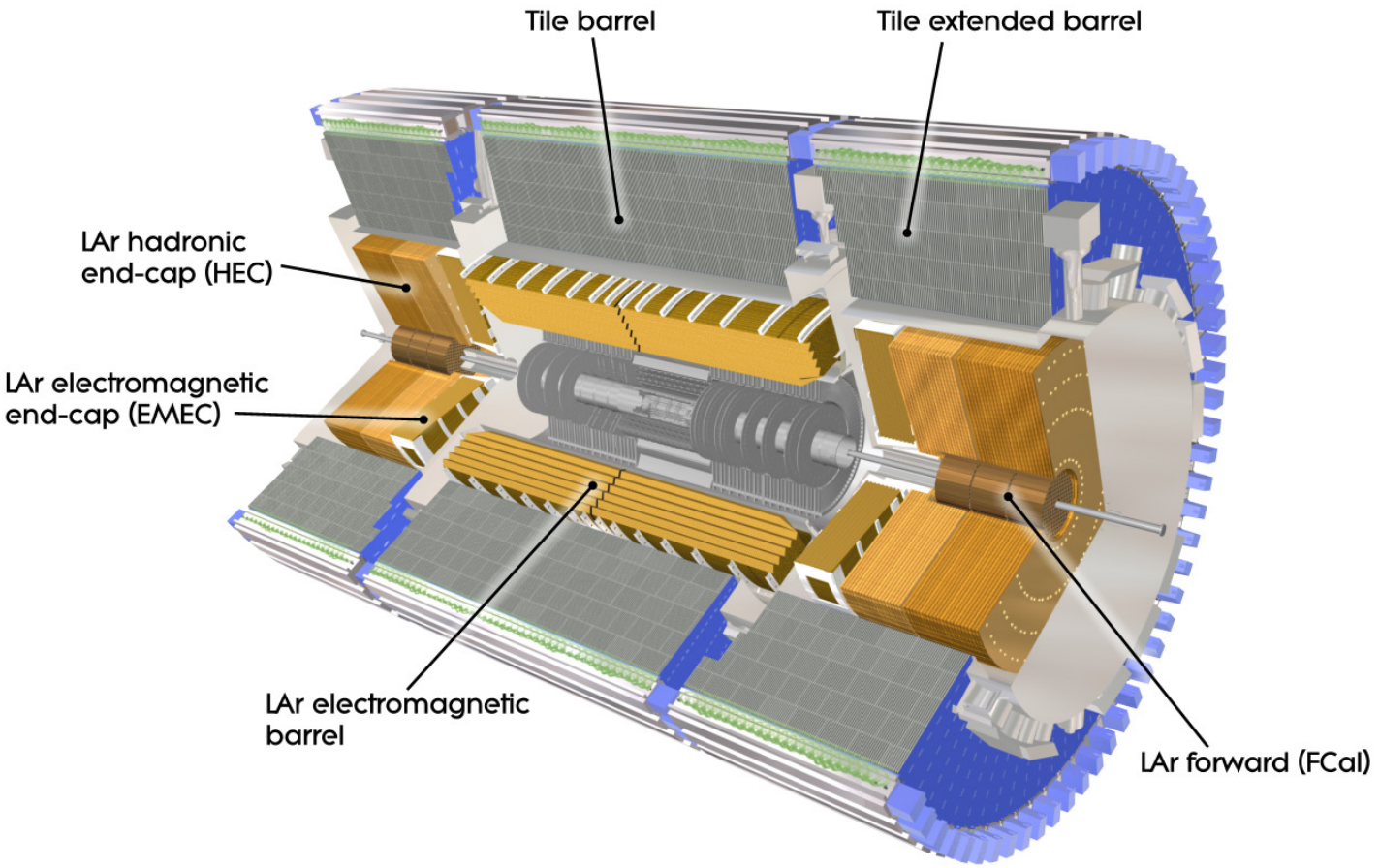
ATLAS-CONF-2014-018



CERN-PH-EP-2015-206

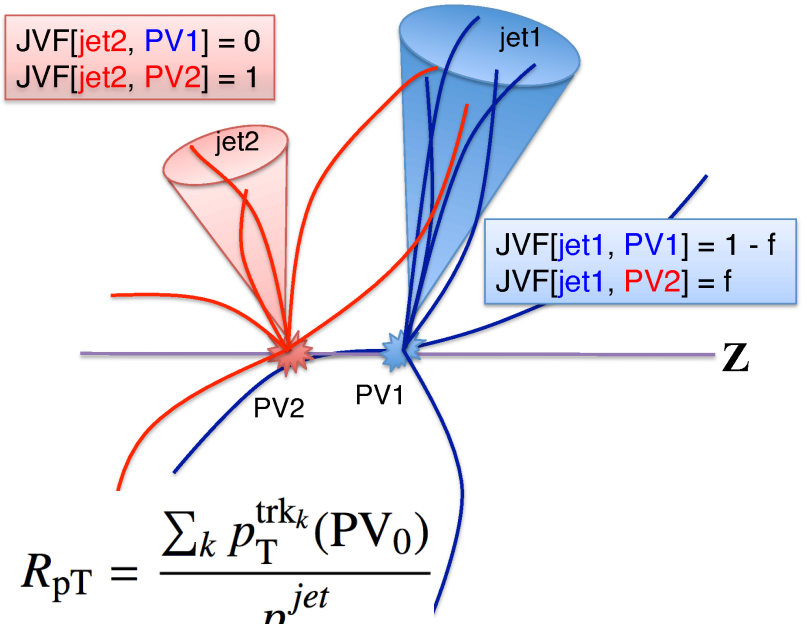
ATLAS Detector

- Calorimeters allow jet reconstruction up to $|\eta|=4.9$
- Tracker allows for track-based pileup suppression up to 2.5



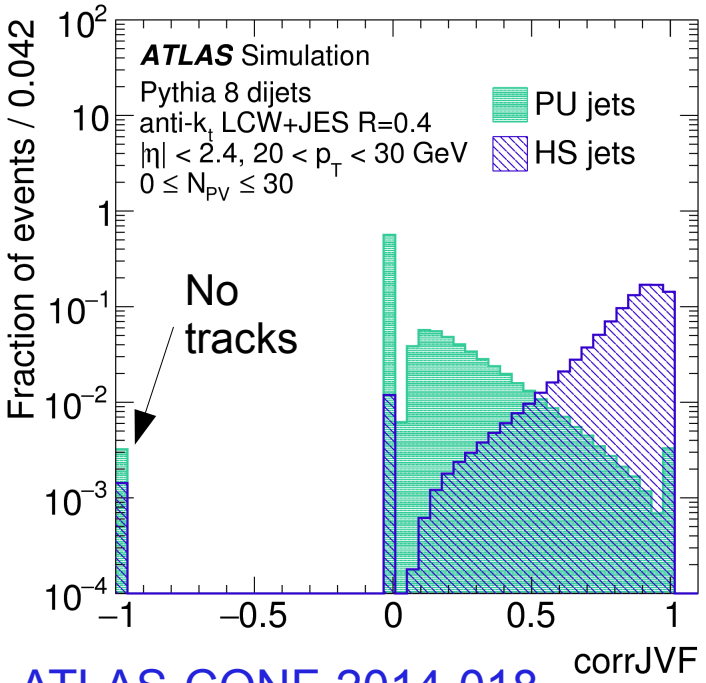
Central Pileup Jet Suppression

- Tracks allow for precise association of jets to vertices
- Two primary variables are
  - corrJVF: measure of relative amount of pileup vs. hard-scatter tracks
  - R_{pT}: measure of consistency between hard-scatter tracks and calibrated jet p_T

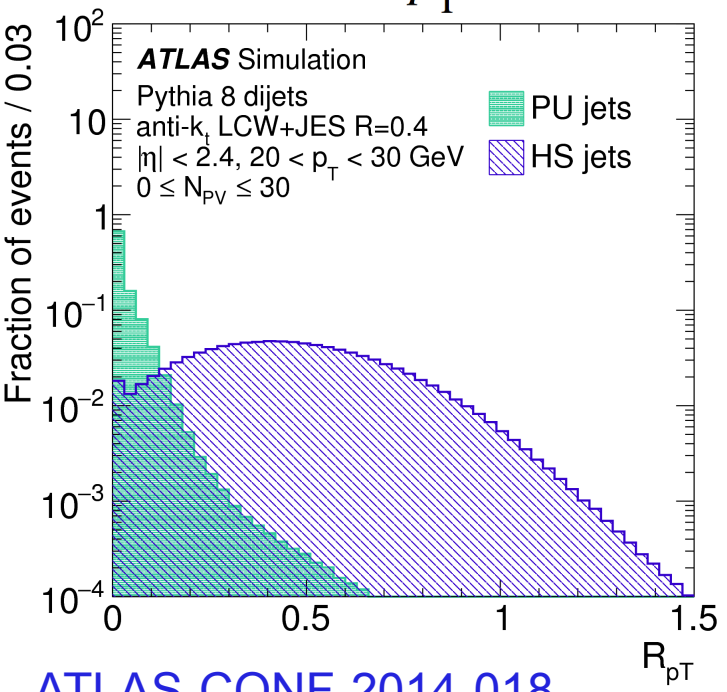


$$\text{corrJVF} = \frac{\sum_k p_{\mathrm{T}}^{\mathrm{trk}_k}(\mathrm{PV}_0)}{\sum_l p_{\mathrm{T}}^{\mathrm{trk}_l}(\mathrm{PV}_0) + \frac{\sum_{n\geq 1}\sum_l p_{\mathrm{T}}^{\mathrm{trk}_l}(\mathrm{PV}_n)}{(k\cdot n_{\mathrm{trk}}^{\mathrm{PU}})}}$$

$$R_{\mathrm{pT}} = \frac{\sum_k p_{\mathrm{T}}^{\mathrm{trk}_k}(\mathrm{PV}_0)}{p_{\mathrm{T}}^{jet}}$$



ATLAS-CONF-2014-018



ATLAS-CONF-2014-018

Central Pileup Jet Suppression

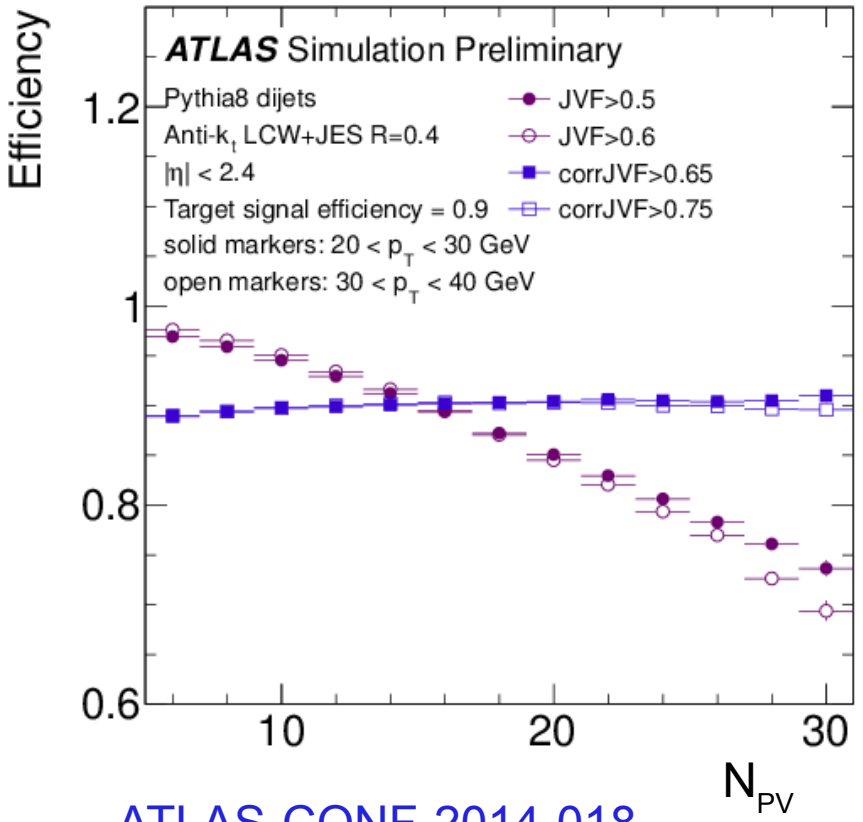
No NPV dependence

$$\text{corrJVF} = \frac{\sum_k p_{\mathrm{T}}^{\mathrm{trk}_k}(\mathrm{PV}_0)}{\sum_l p_{\mathrm{T}}^{\mathrm{trk}_l}(\mathrm{PV}_0) + \frac{\sum_{n\geq 1}\sum_l p_{\mathrm{T}}^{\mathrm{trk}_l}(\mathrm{PV}_n)}{(k\cdot n_{\mathrm{trk}}^{\mathrm{PU}})}}$$

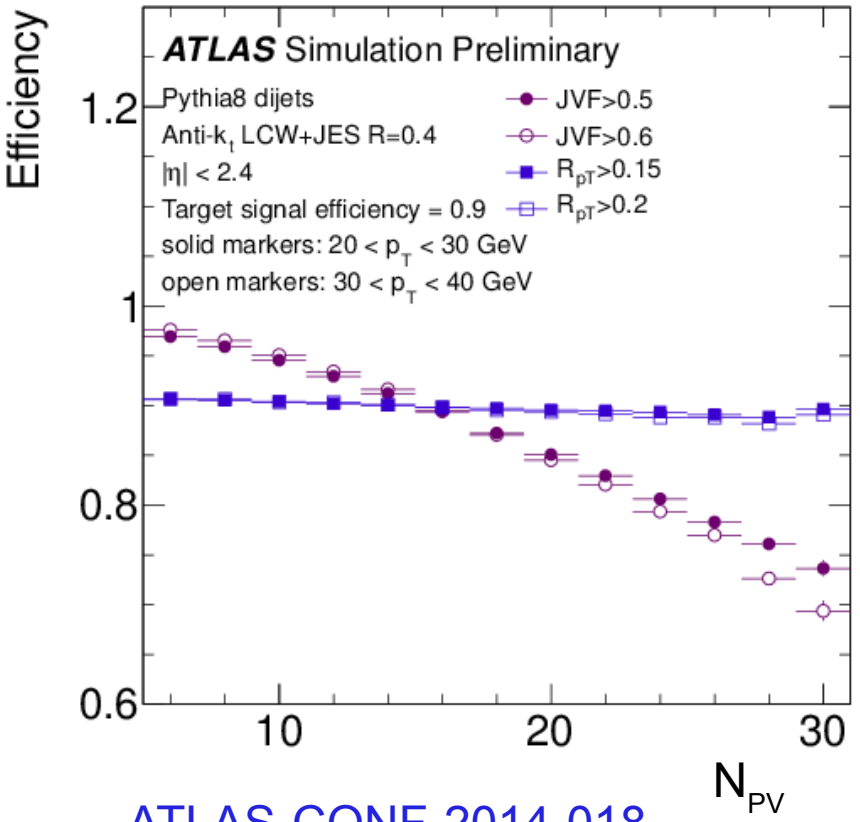
$$R_{\mathrm{pT}} = \frac{\sum_k p_{\mathrm{T}}^{\mathrm{trk}_k}(\mathrm{PV}_0)}{p_{\mathrm{T}}^{jet}}$$

Proportional to N_{PV}

- RpT and corrJVF both NPV independent!



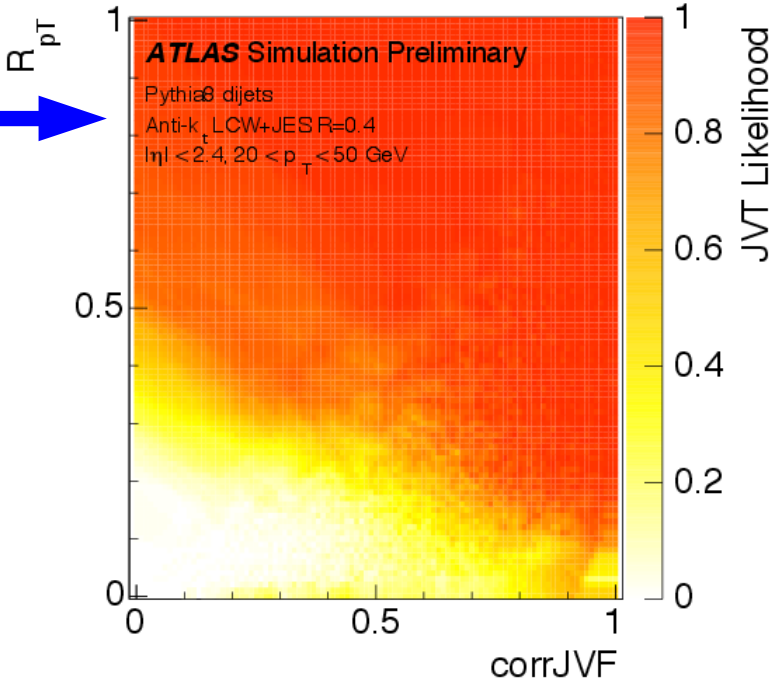
ATLAS-CONF-2014-018



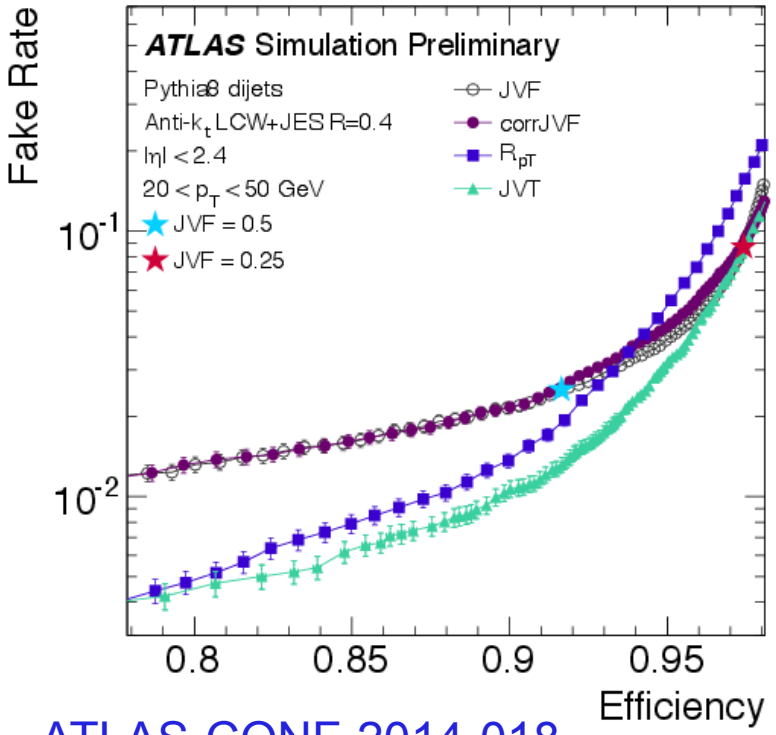
ATLAS-CONF-2014-018

Central Pileup Jet Suppression: Performance

- Combine corrJVF and R_{pT} into likelihood to get best performance
- Final tagging variable, JVT (Jet vertex tagging), rejects 99% of pileup jets at a 90% hard-scatter efficiency

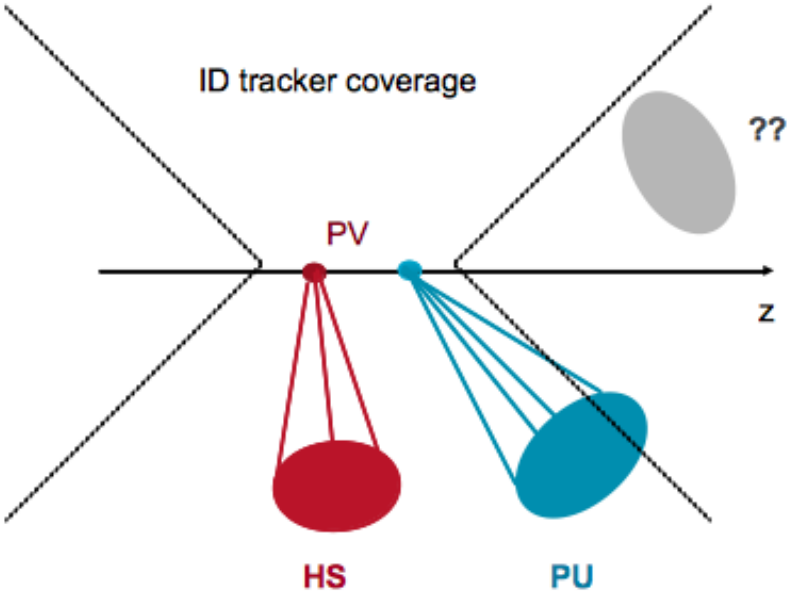


ATLAS-CONF-2014-018

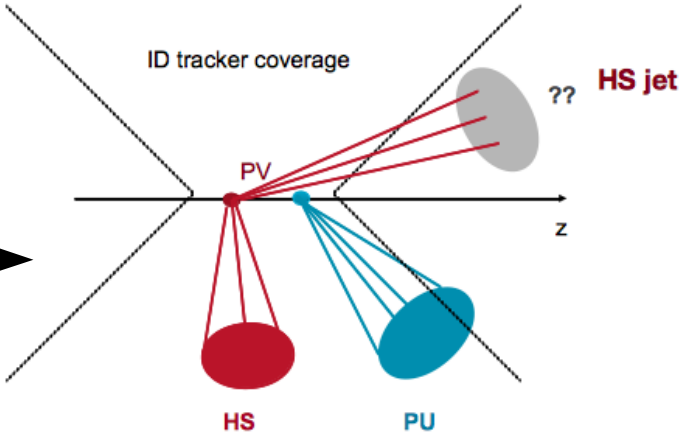


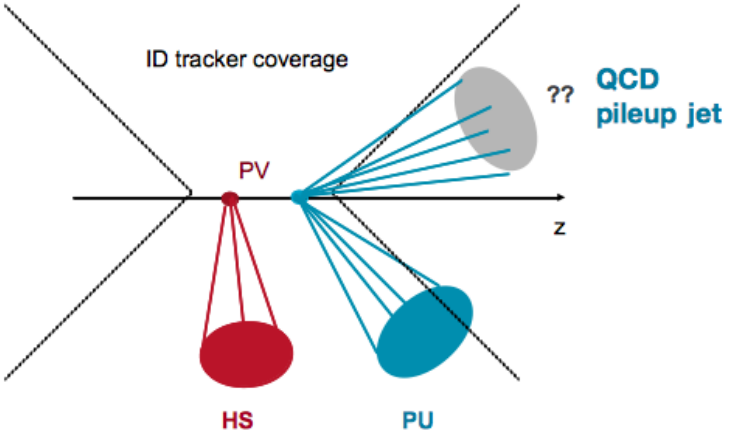
ATLAS-CONF-2014-018

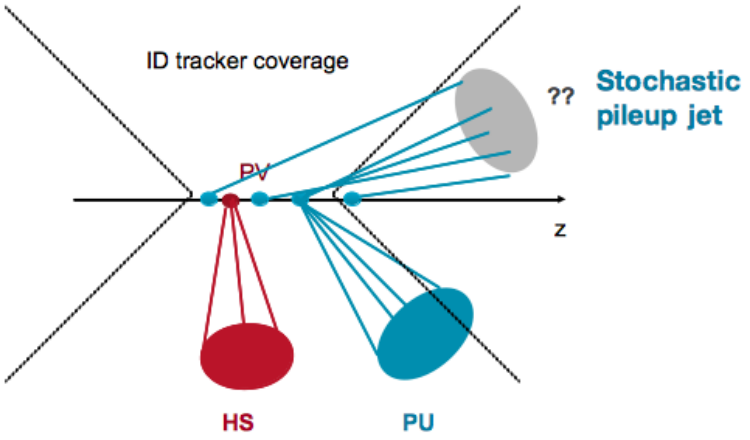
Forward Pileup Jets



Ambiguous!



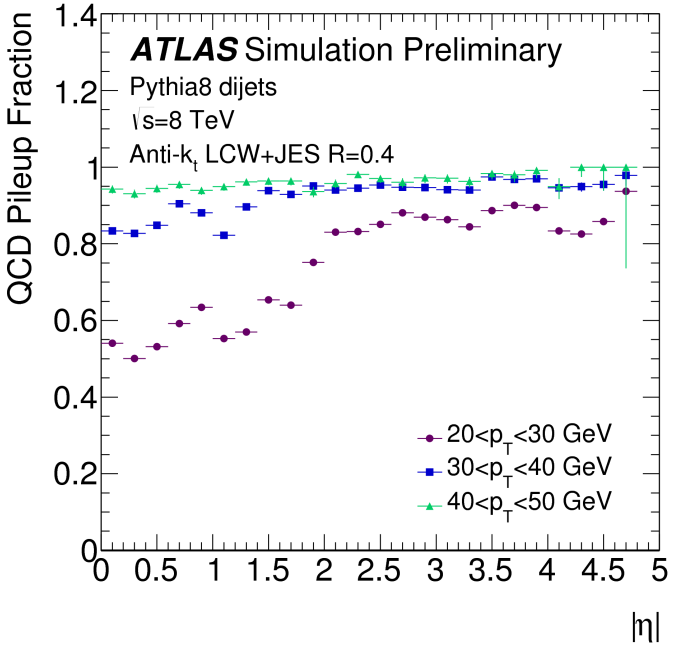


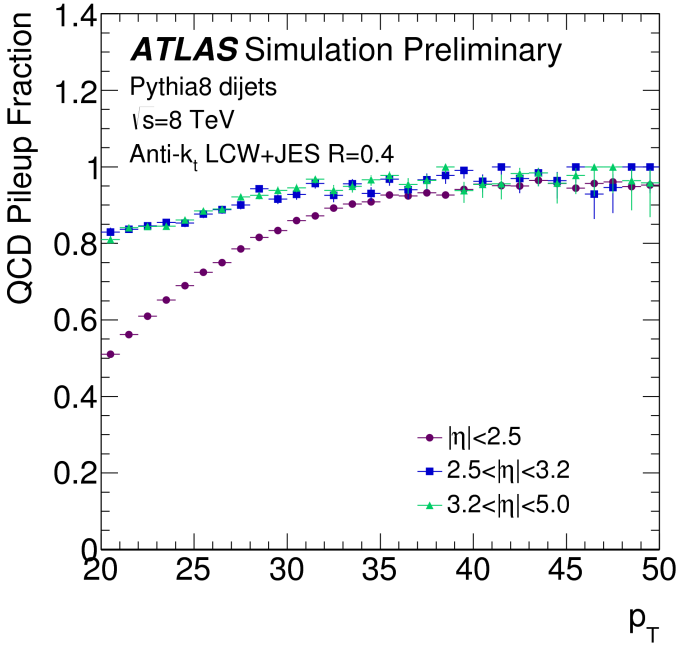


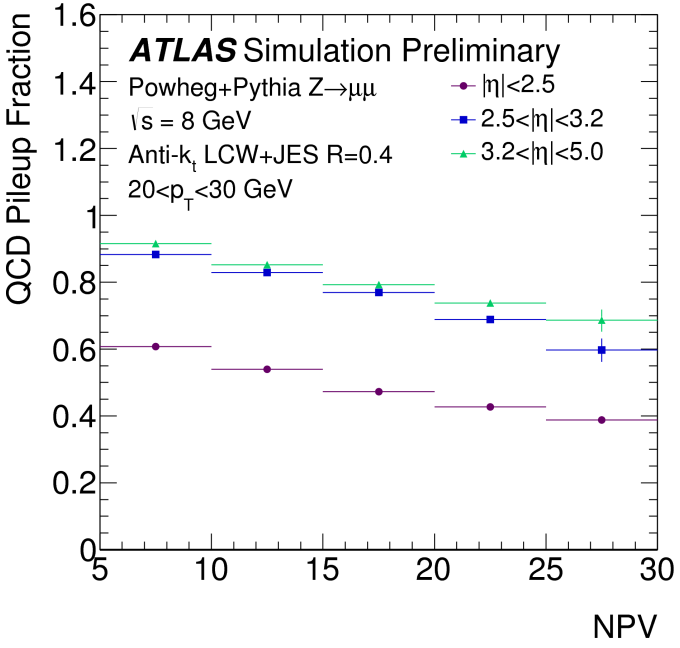
- Without tracking, difficult to determine source of forward jet
- Instead, exploit properties of QCD and Stochastic pileup jets (event topology and shape)

Types of Pileup Jets

- QCD (stochastic) pileup jets produced from single (multiple) vertices
- Stochastic pileup in forward region only relevant at higher pileup conditions – at 2015 data conditions, only QCD rejection important



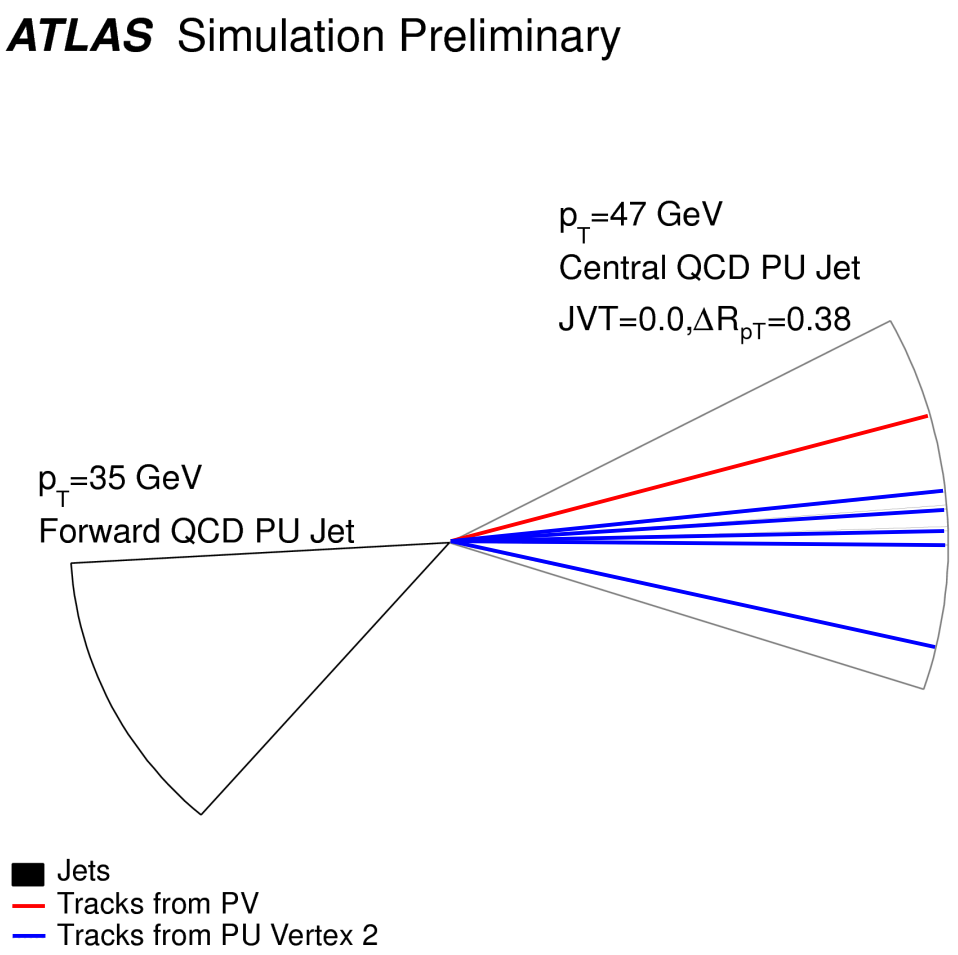


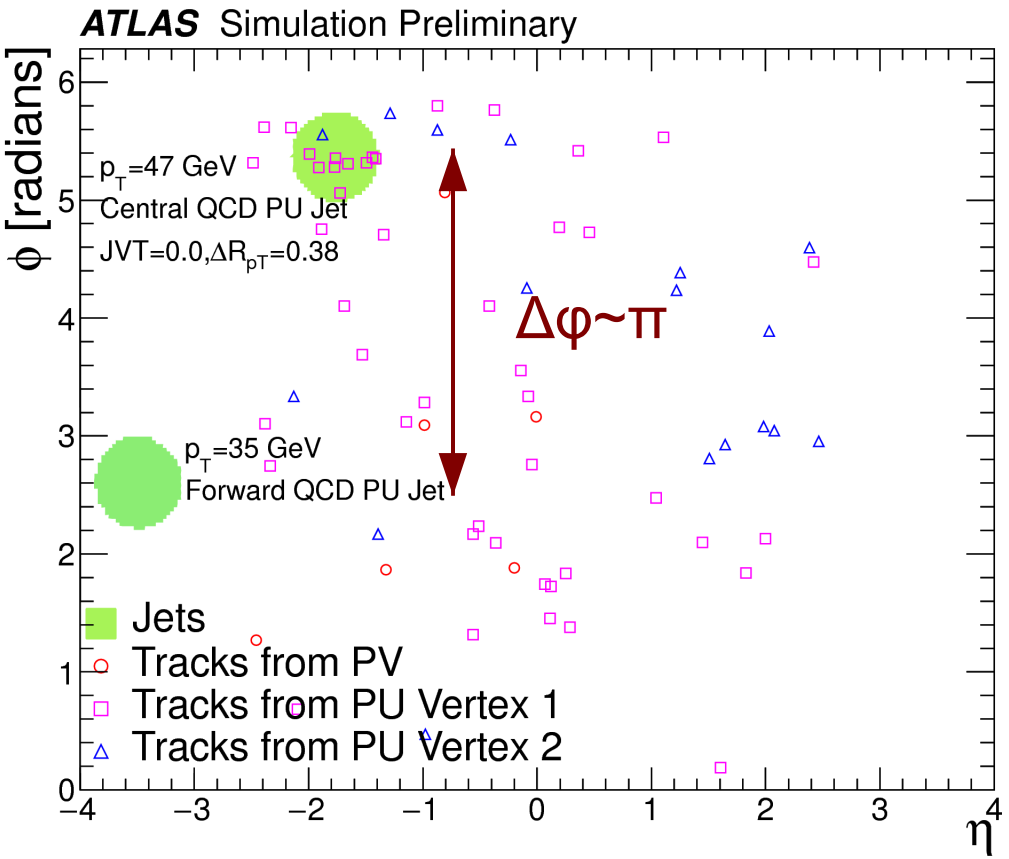


ATLAS-PUB-2015-034

Forward Pileup Jet Tagging: Step 2

- Exploit central tracking information and angular correlations between jets produced in QCD pileup interactions to indirectly tag forward jets

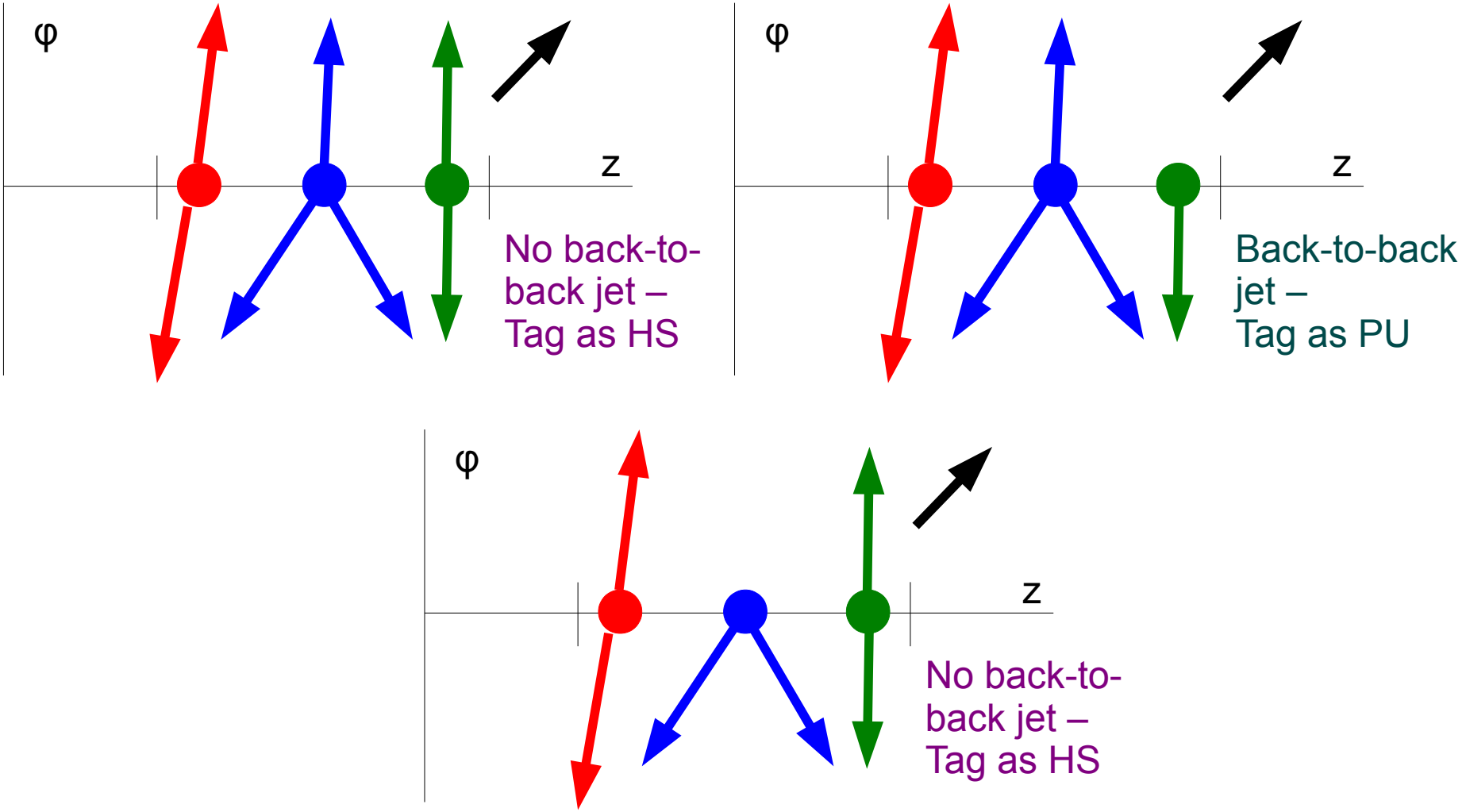




ATLAS-PUB-2015-034

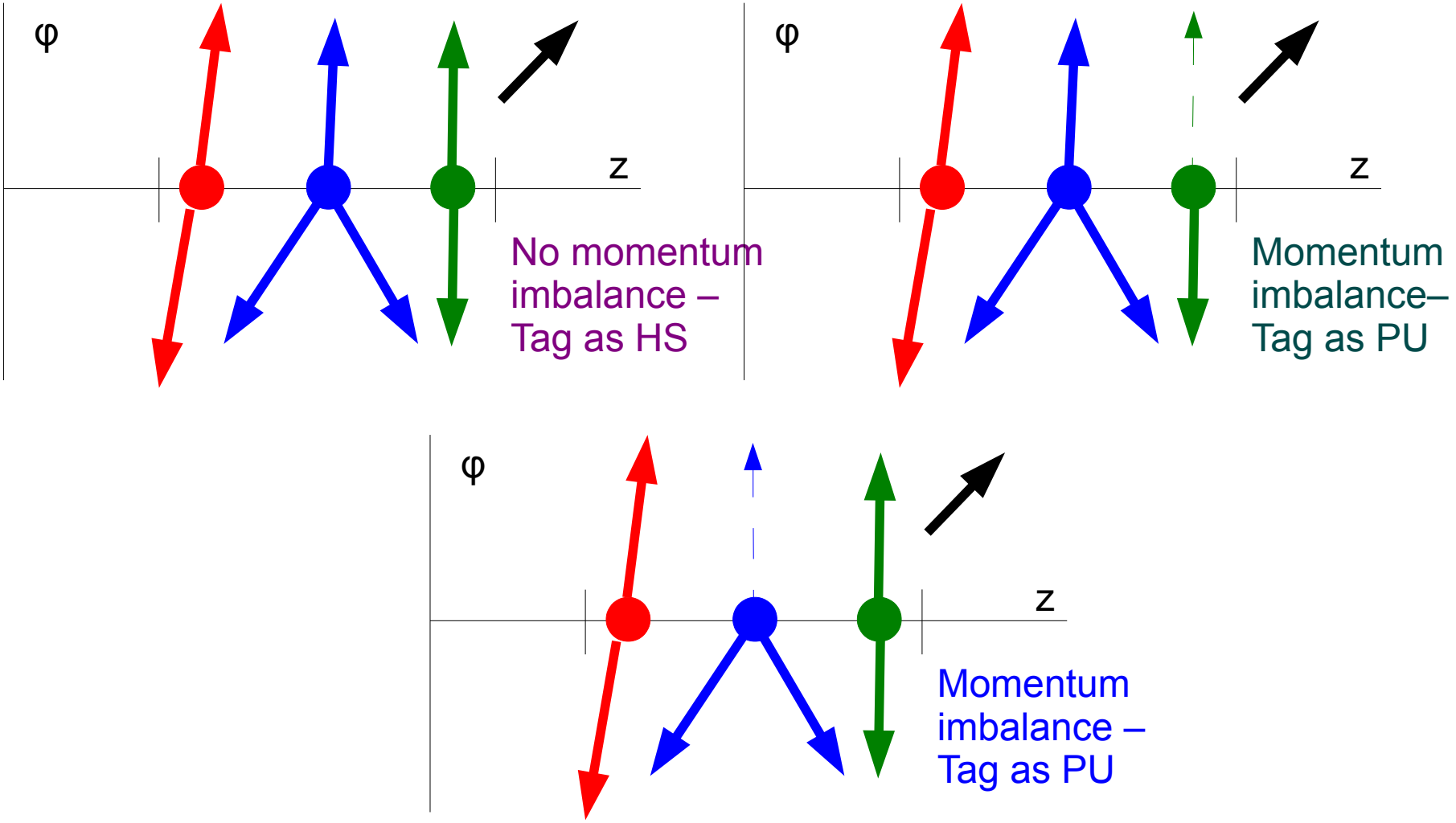
Limitation of Forward JVT

Not all interactions have two back-to-back jet final states

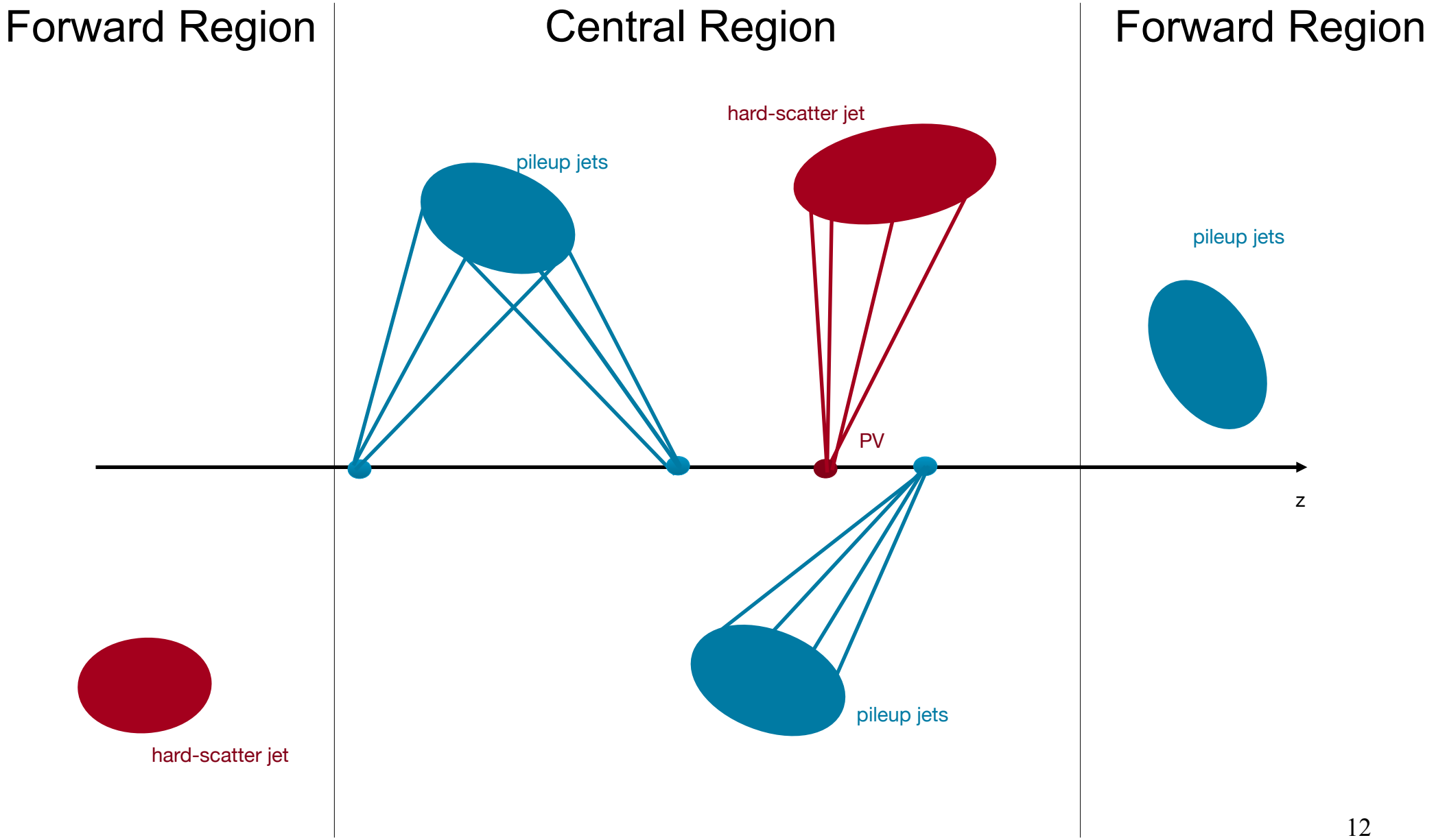


Improved Forward JVT

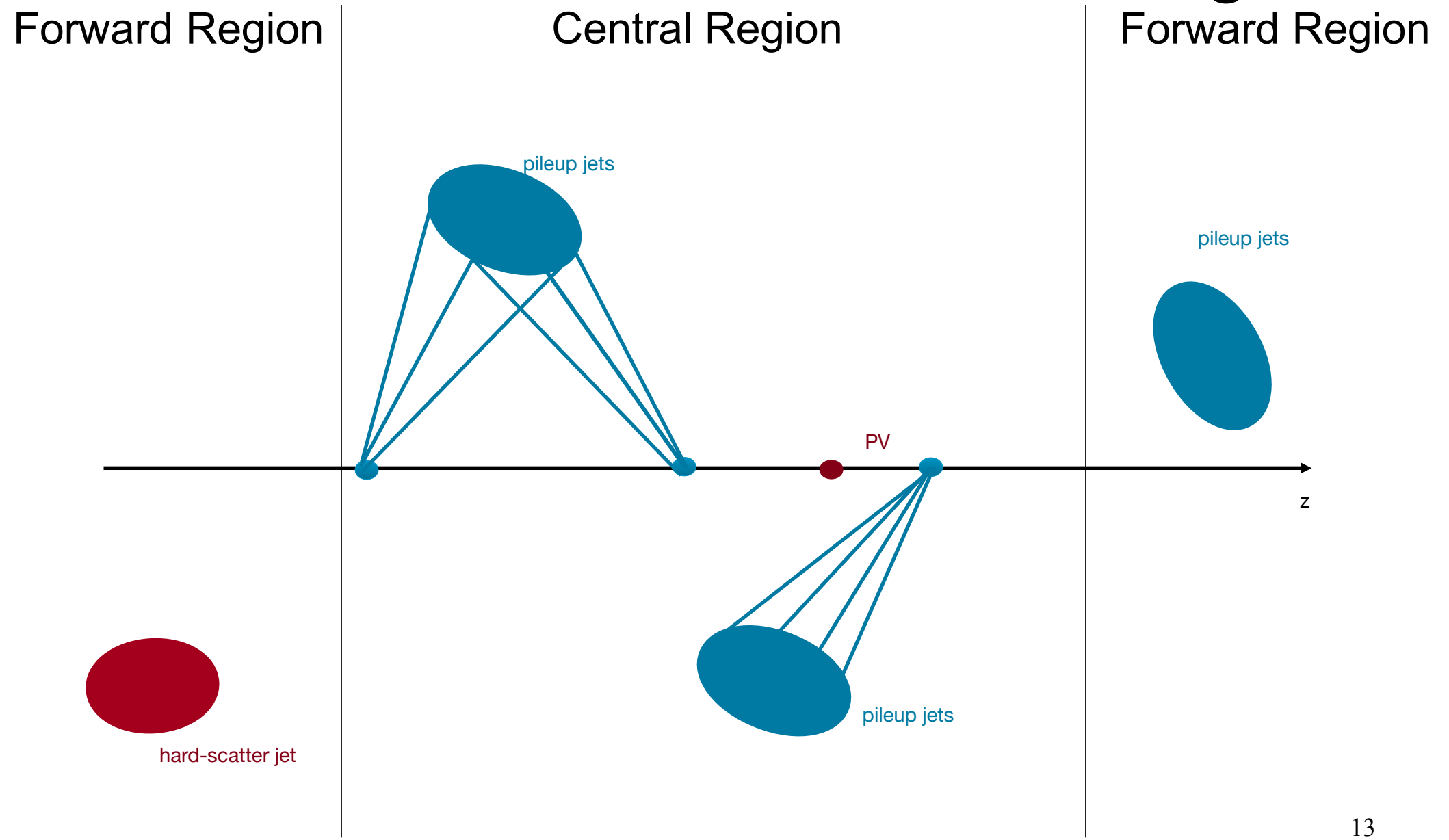
Tag based on vertex momentum imbalance instead of single back-to-back jet



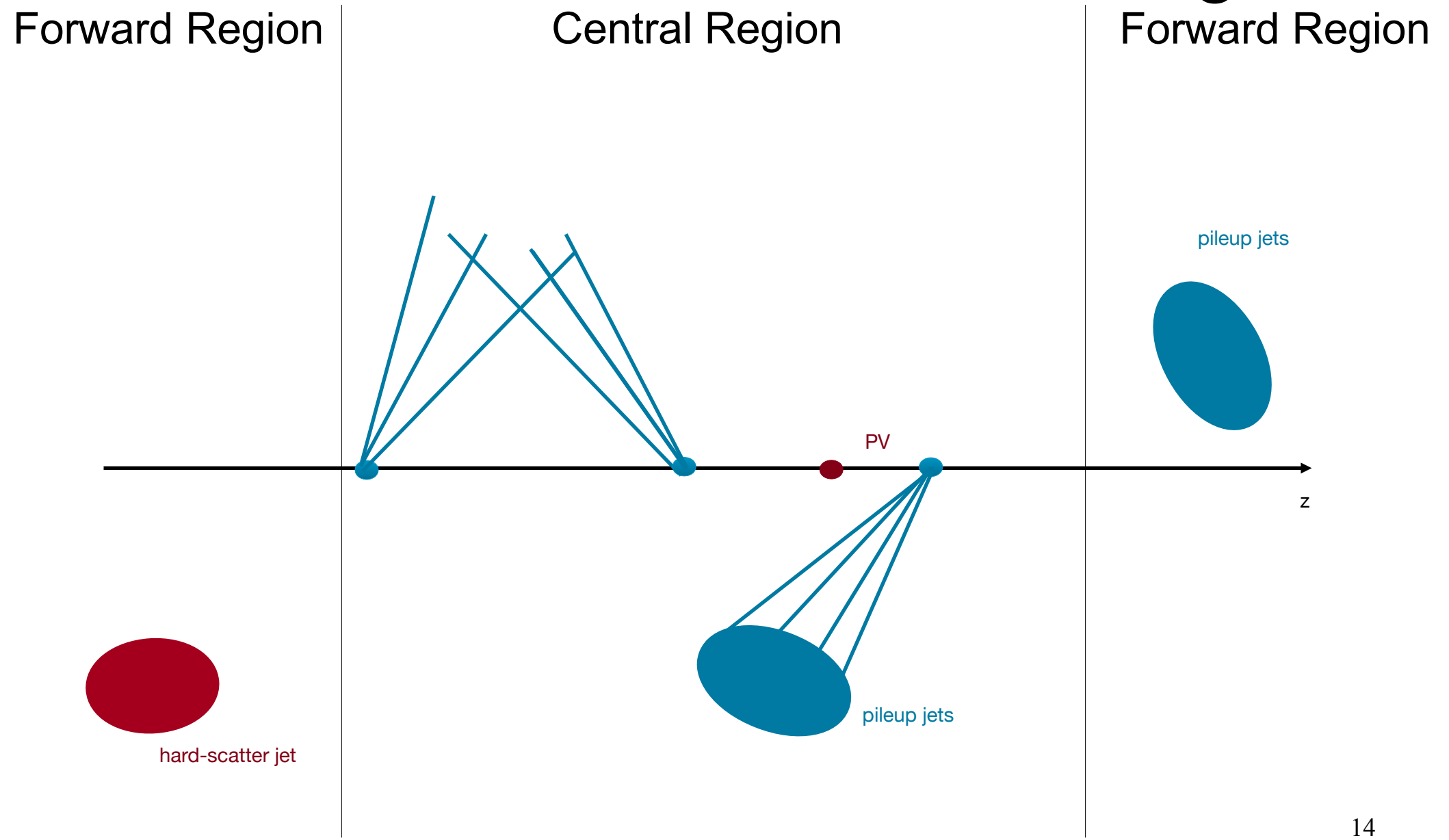
Building Forward JVT: Initial Event



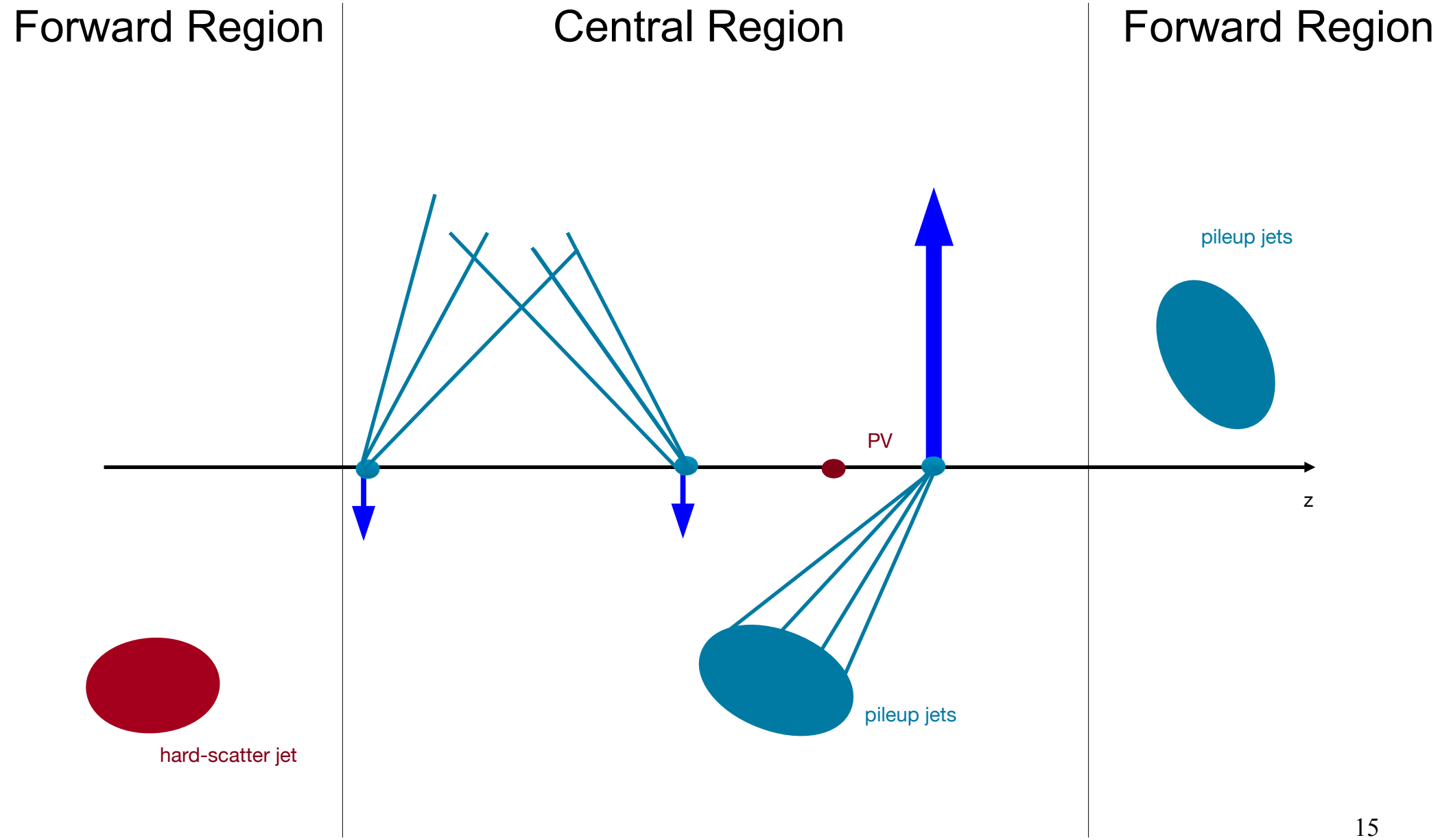
Building Forward JVT: Reject Central HS Jets with Tracking



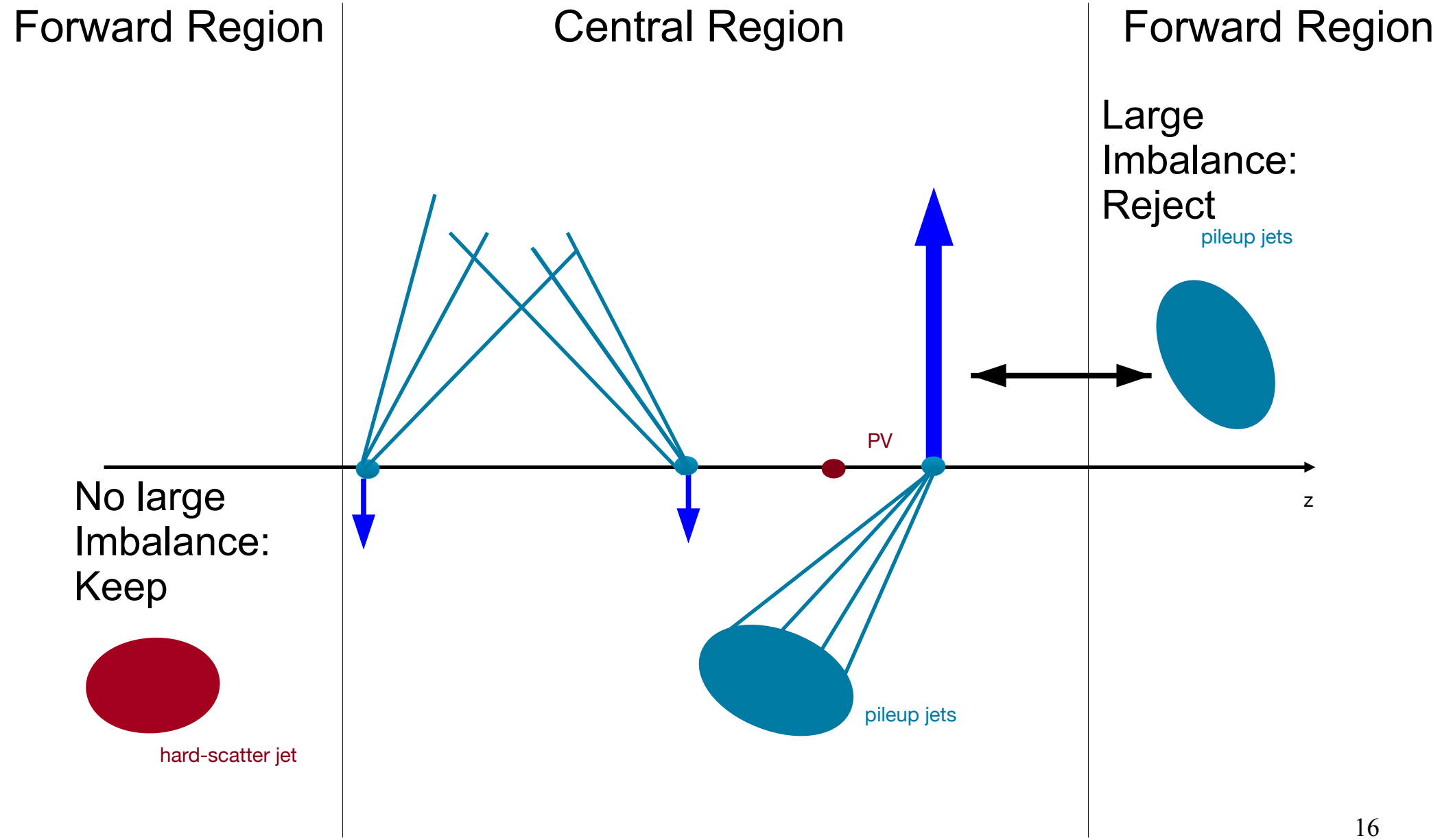
Building Forward JVT: Reject Central Stochastic Jets with Tracking



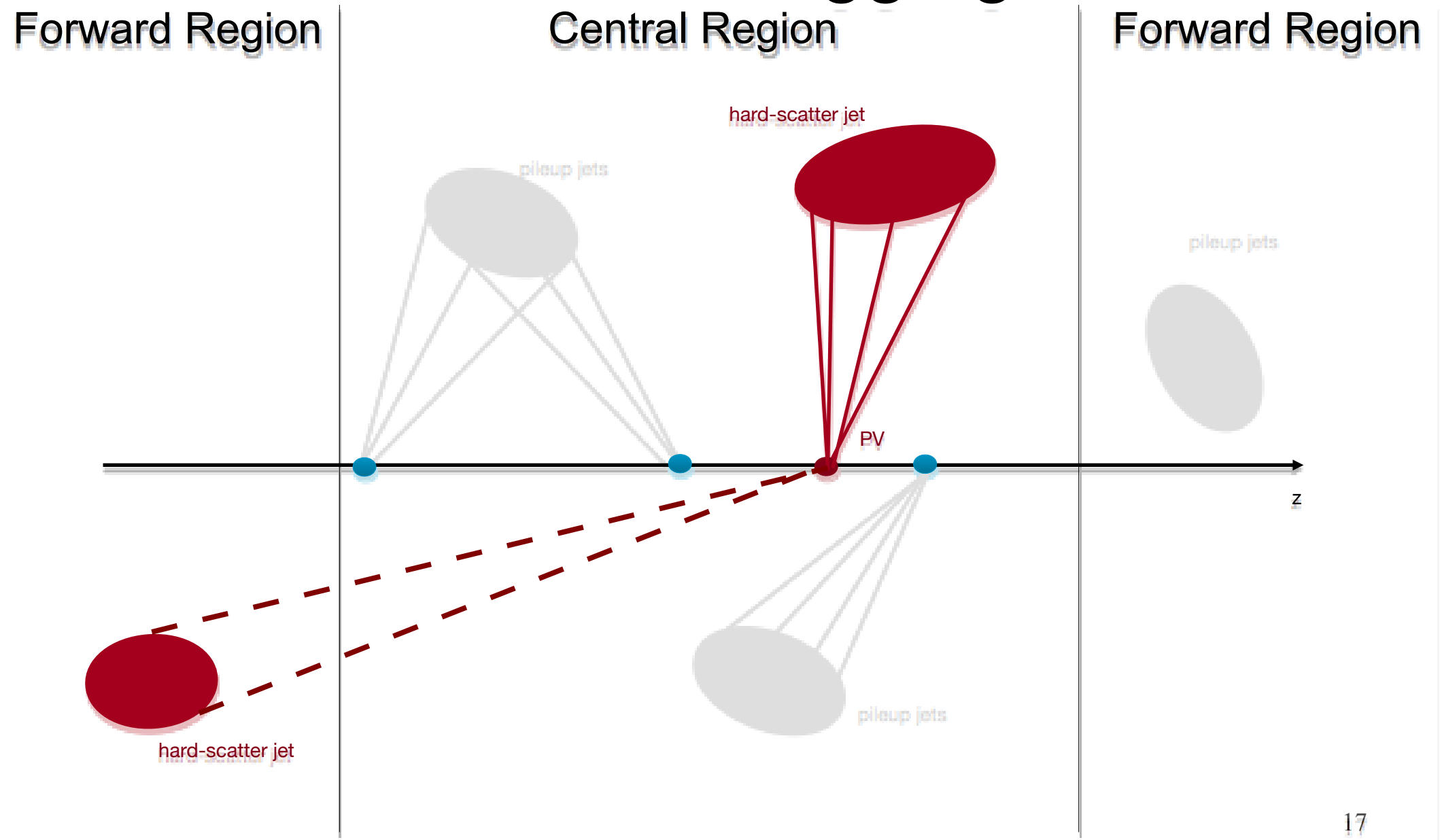
Building Forward JVT: Calculate Pileup Vertex Momentum Imbalances



Building Forward JVT: Reject Forward Jets with Imbalance in Jet Direction

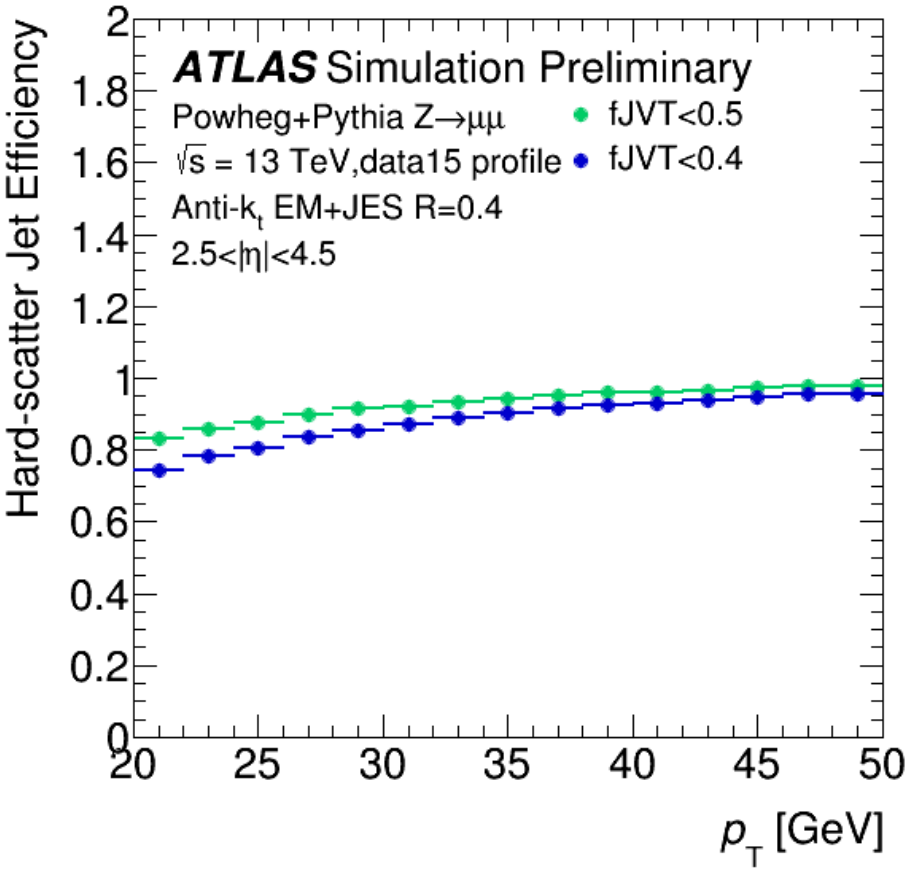


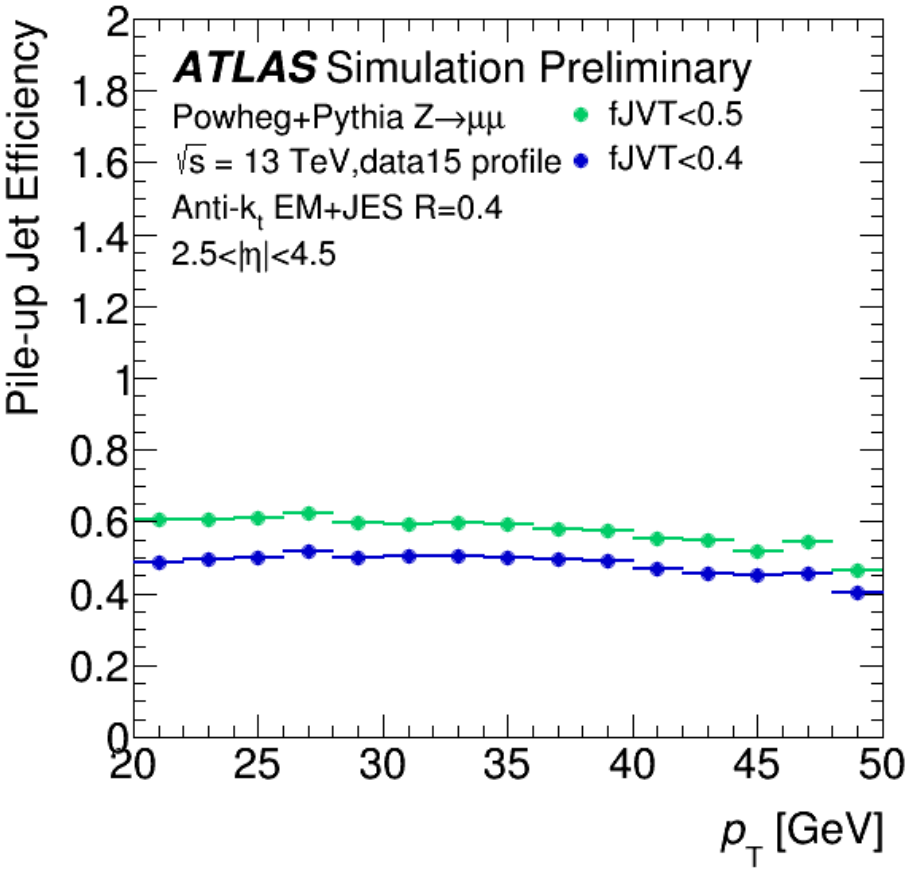
Final Event: Post Central and Forward Tagging



Forward Pileup Jets: Performance Without Stochastic Rejection – Low Pileup

- Measured in simulation, forward QCD pileup jet suppression rejects 40% of pileup jets and 8% of hard-scatter jets
- Simulation corresponds to the same pileup conditions as 2015 data





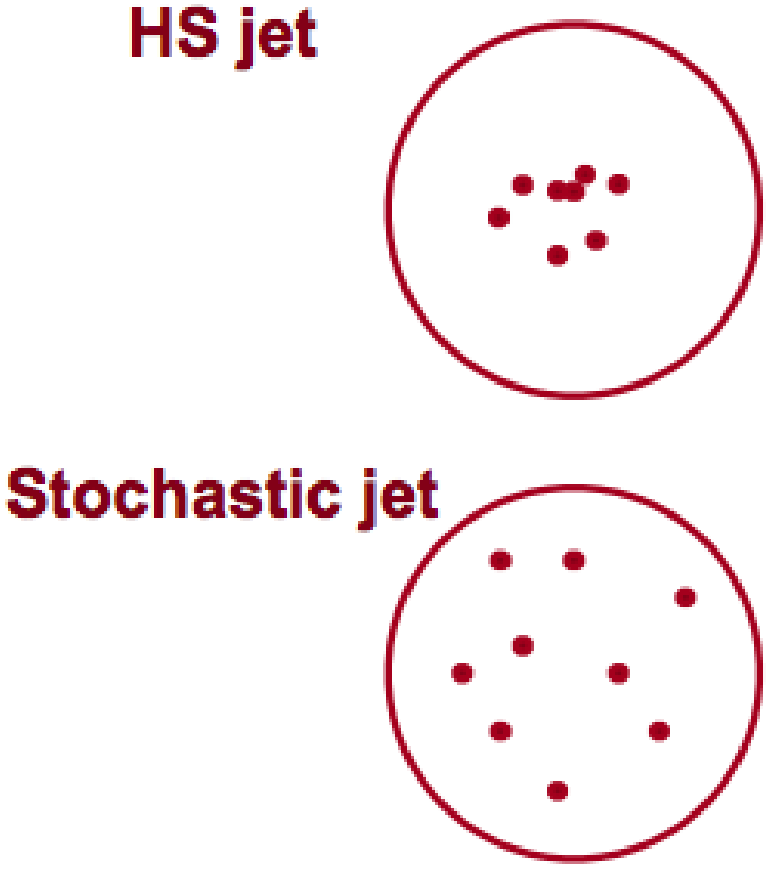
JETM-2016-006

Stochastic Pileup Jets: Composition

- Stochastic pileup jets do not have well defined core
- Can be tagged using shape information

Example variable:

$$w = \frac{\sum_k \Delta R(jet, k) p_{\mathrm{T}^k}}{\sum_k p_{\mathrm{T}^k}}$$

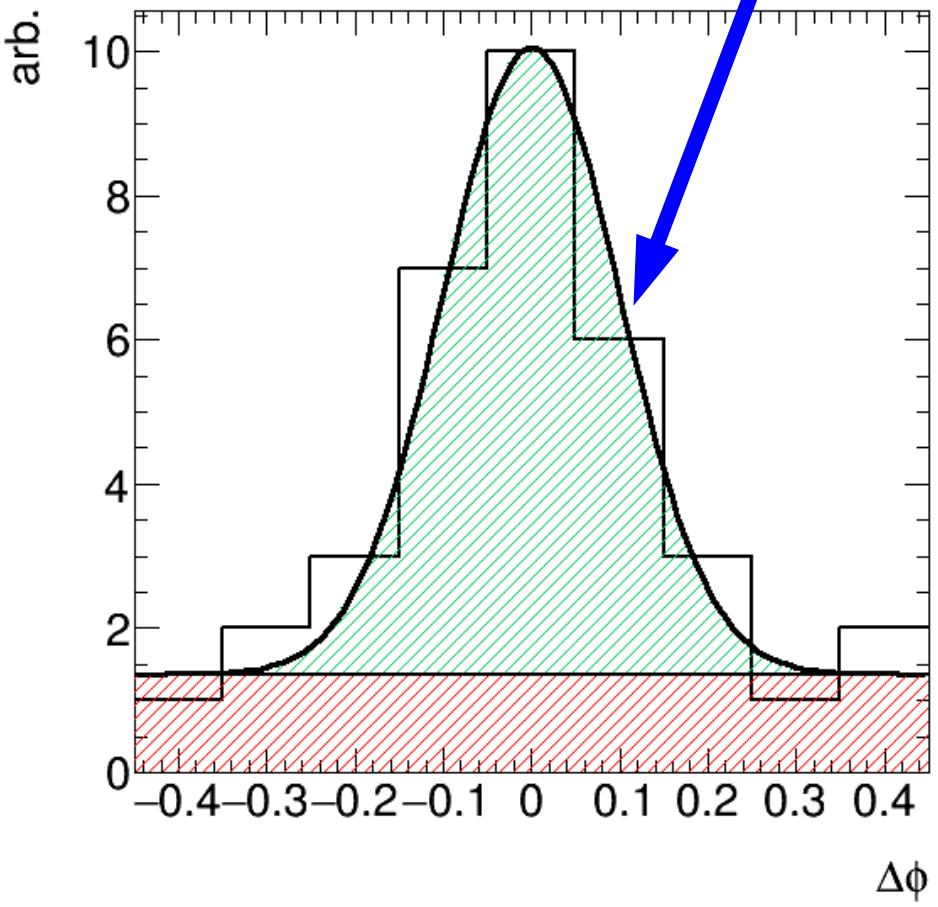


Forward Pileup Jet Tagging

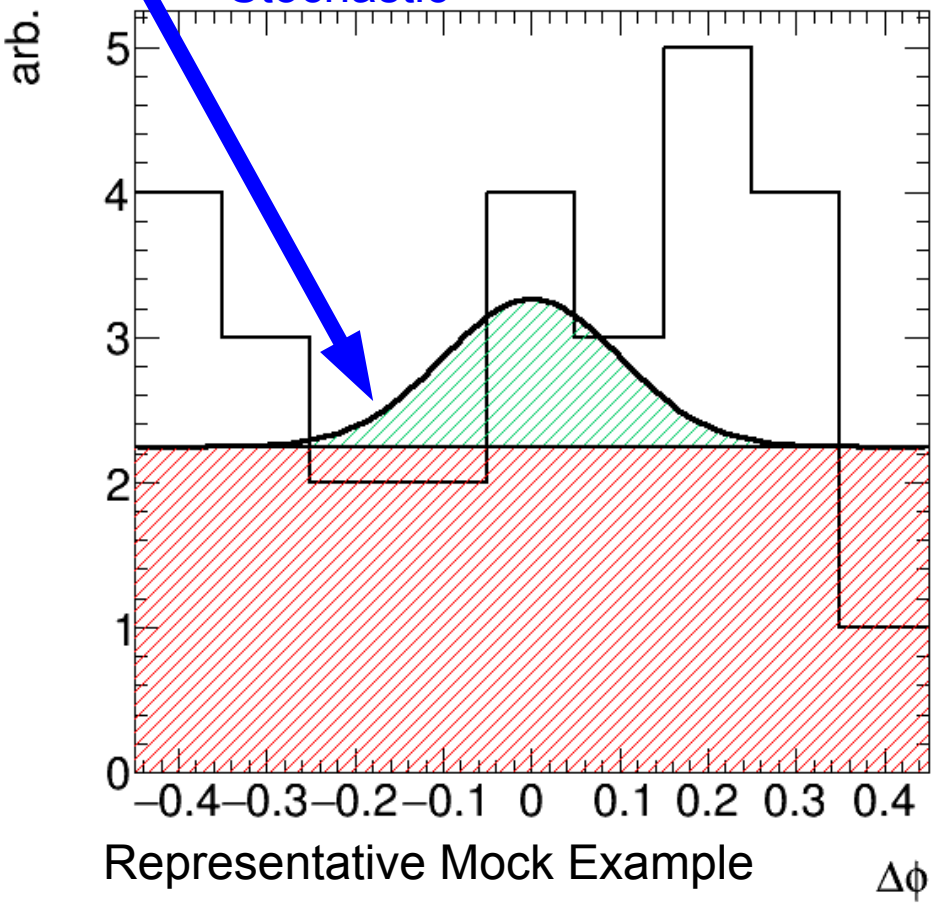
- Better method: extract QCD component (γ) of jet momentum with fit
- Pileup independent area large (small) for hard-scatter (stochastic pileup) jets.

$$f = \alpha + \beta\Delta\eta + \frac{\gamma}{10\,\mathrm{GeV}} e^{\frac{-1}{2}\frac{\Delta\eta}{0.1}^2} e^{\frac{-1}{2}\frac{|\Delta\phi|}{0.1}^2}$$

Representative Mock Example: Hard-Scatter



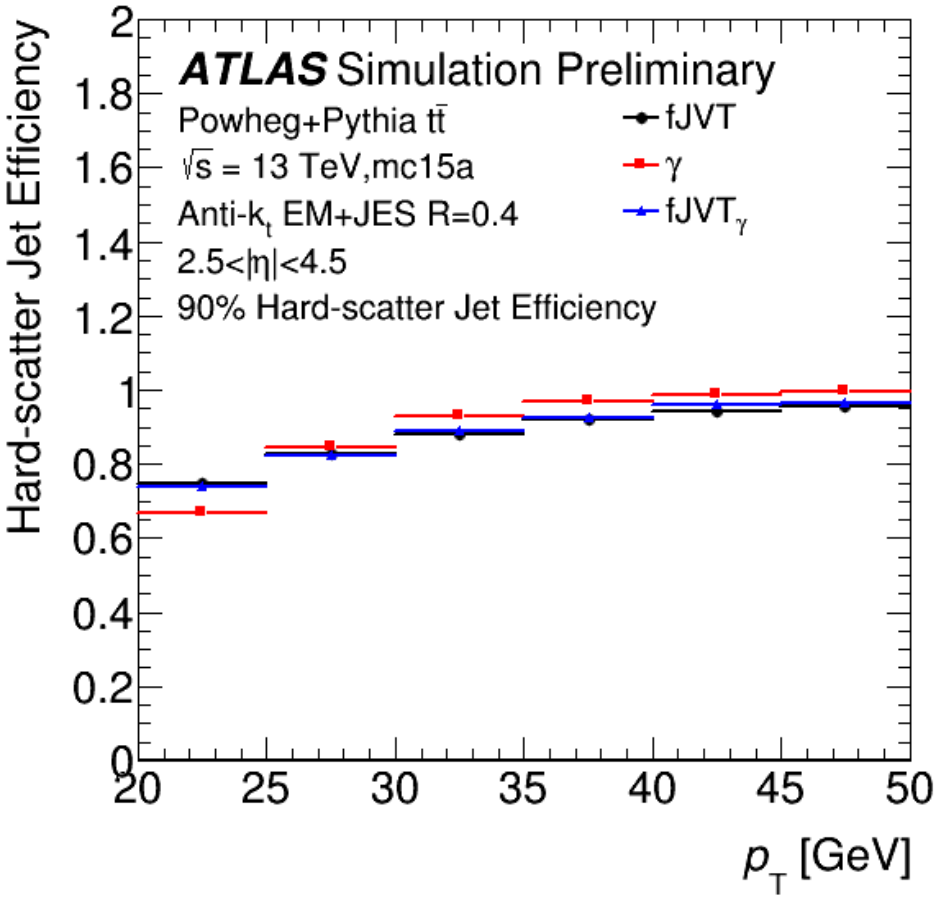
Representative Mock Example: Stochastic

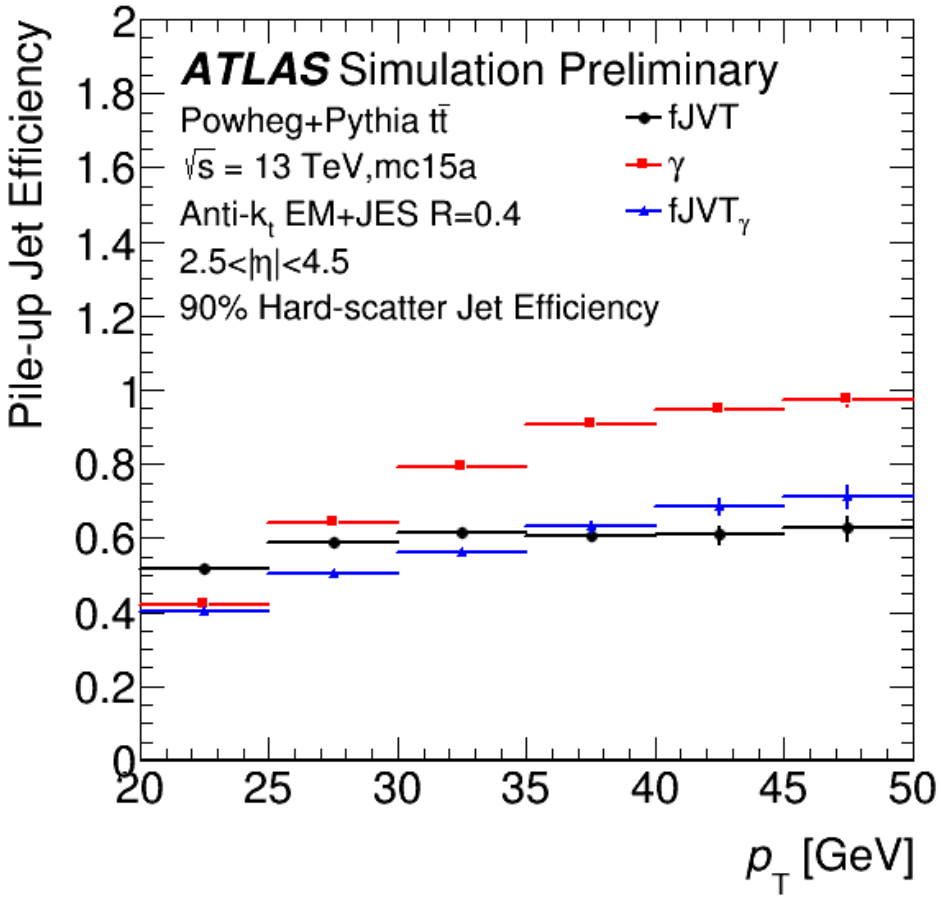


Representative Mock Example

Forward Pileup Jets: Performance With Stochastic Rejection – Higher Pileup

- Measured in simulation, full forward pileup jet suppression rejects 50% of pileup jets and 10% of hard-scatter jets
- Simulation corresponds to higher pileup conditions than 2015 data

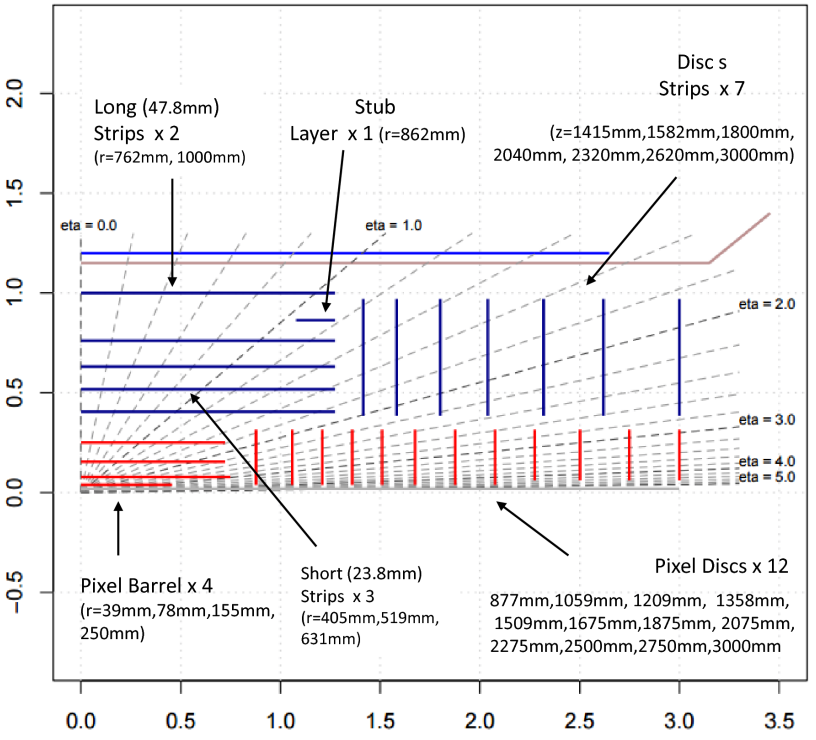


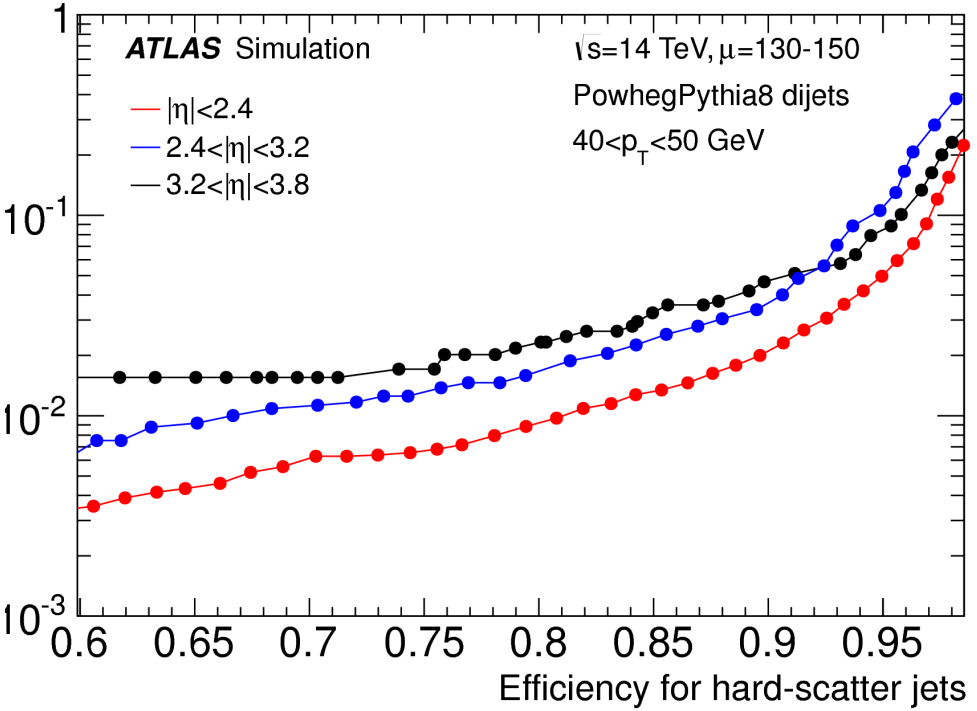


JETM-2016-006

Toward the Future

- Other methods under study include corrJVF-based grooming, constituent subtraction, particle-flow, and many more
- In Run 3 (μ~80) and particularly Run 4 (HL-LHC) conditions (μ~200), pileup jets will become even more important
- Stochastic pileup becomes dominant – in Run 4, new hardware dependent methods under investigation, such as an extended tracker and a precision timing detector.





CERN-LHCC-2015-020

Summary

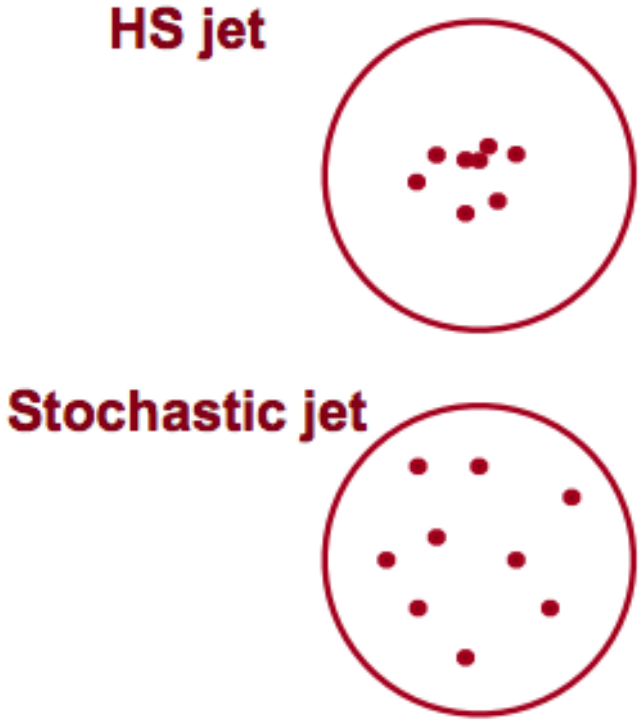
- Capability to tag central pileup jets with track-based variables
- Tag forward pileup jets using shape and central tracking and calorimeter information.
- In 2015 data conditions, forward pileup is QCD-like, and topological information alone performs best
- At higher pileup, can first remove stochastic part of jet and then use topological information

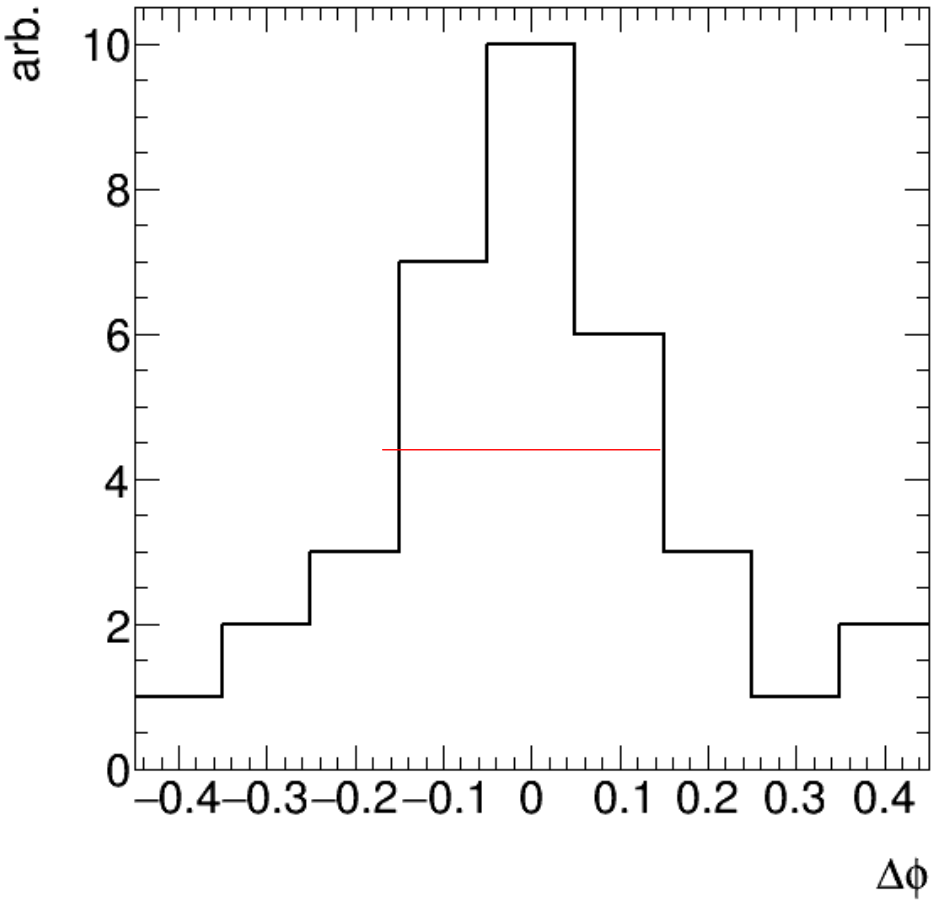
Backup

Stochastic Pileup Jets: Composition

- Stochastic pileup jets do not have well defined core
- Can be tagged using shape information
- Tend to have larger width

$$w = \frac{\sum_k \Delta R(jet, k) p_{\mathrm{T}^k}}{\sum_k p_{\mathrm{T}^k}}$$

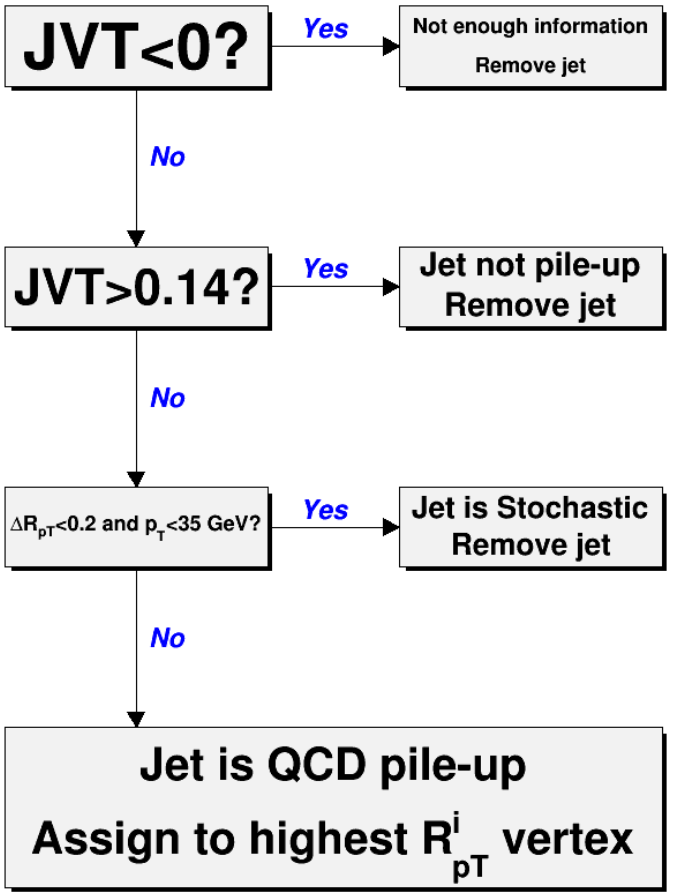
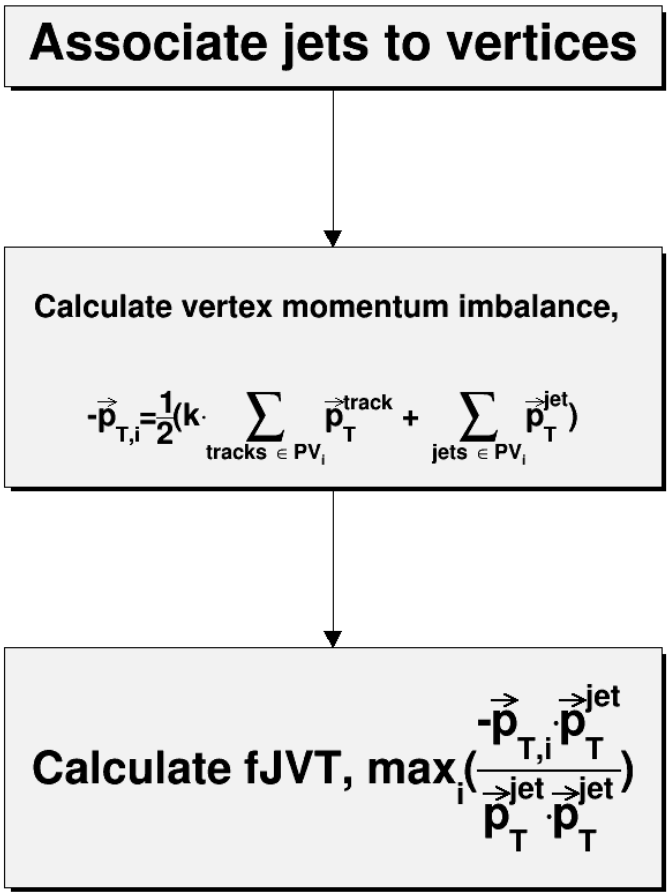




Forward JVT: Detailed

- QCD pileup jet tagging variable combines central jet and tracking information.

Associating central jets to vertices



Tagging forward jets