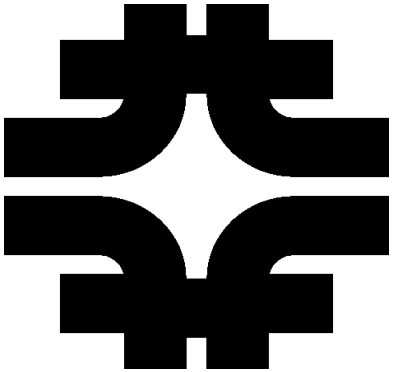
arxiv hep-ph/1407.6013

PileUp Per Particle Id

Philip Harris (CERN) Nhan Tran(FNAL),
Daniele Bertolini(MIT), Matthew Low(Chicago)



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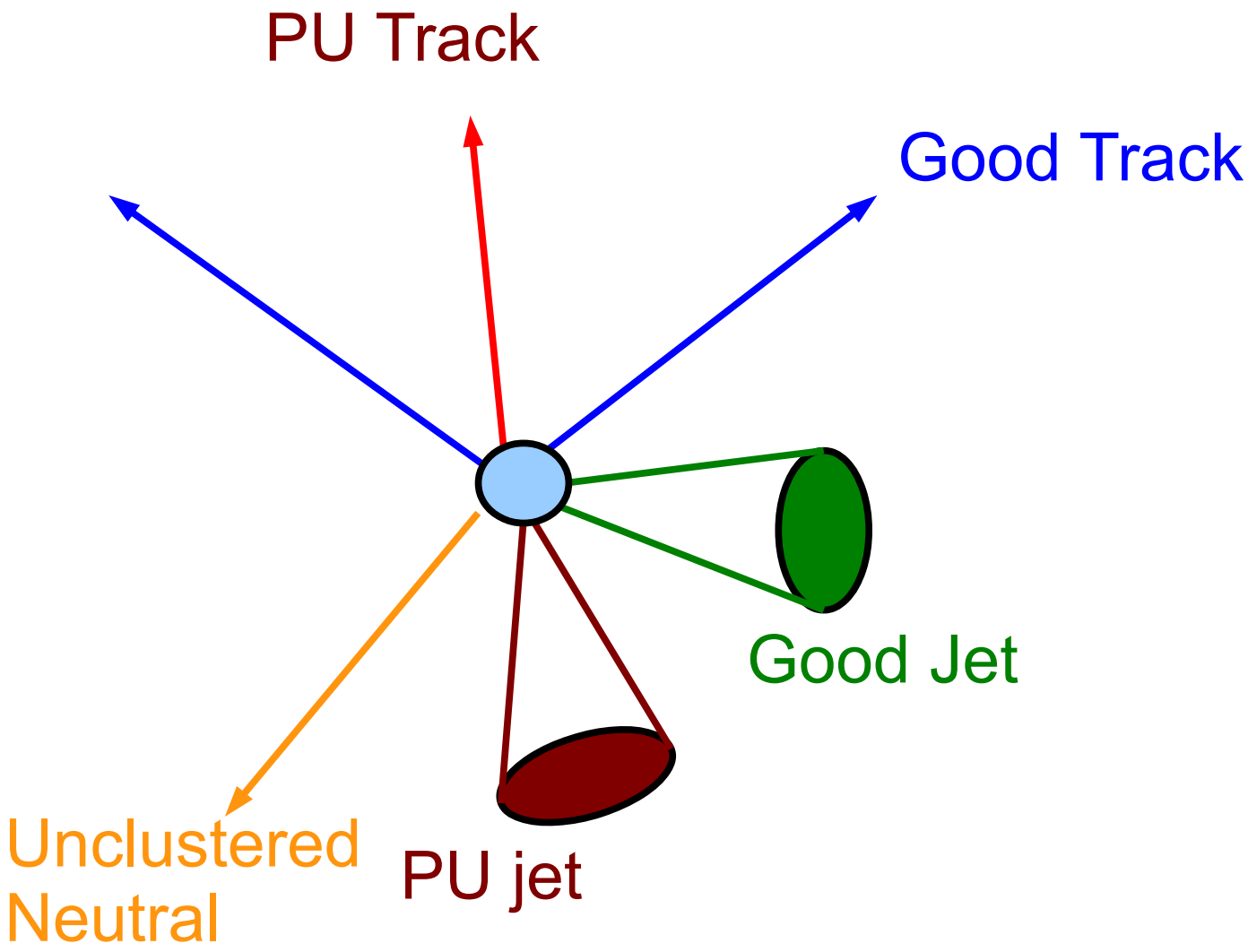
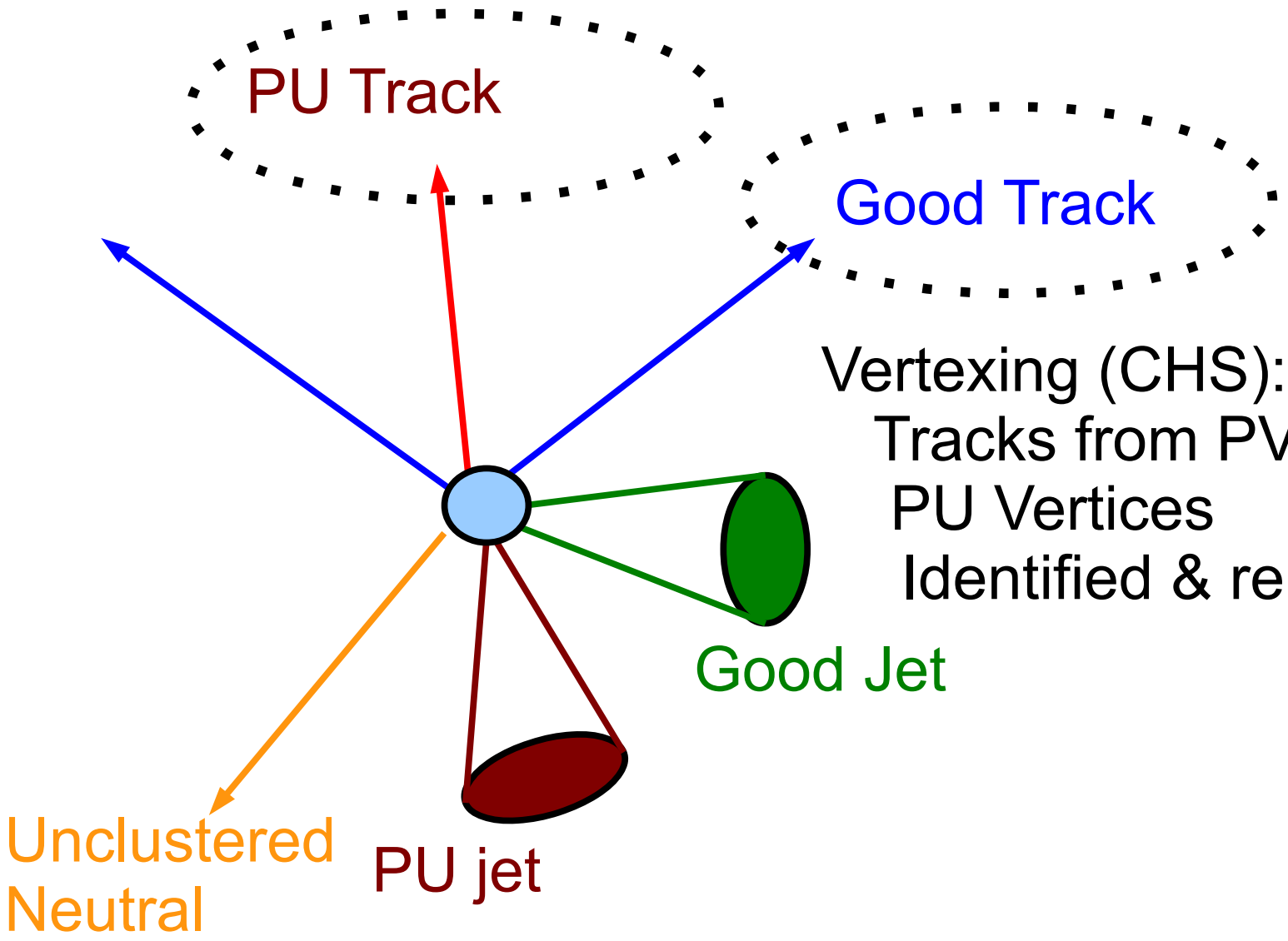
Whats the deal with Pileup?



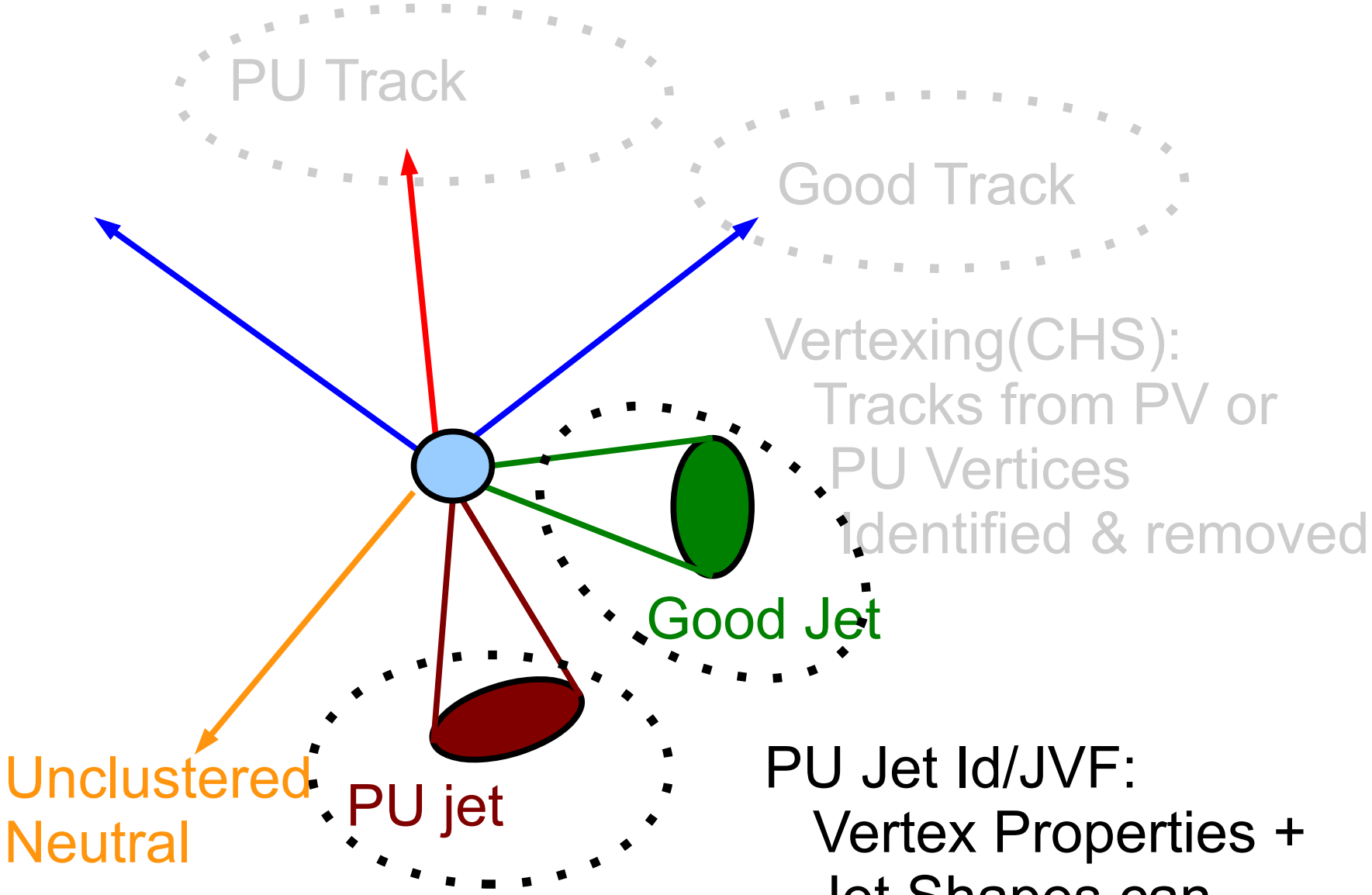
Simplified event can be decomposed into 5 different objects

We have tools to go after all

Whats the deal with Pileup?

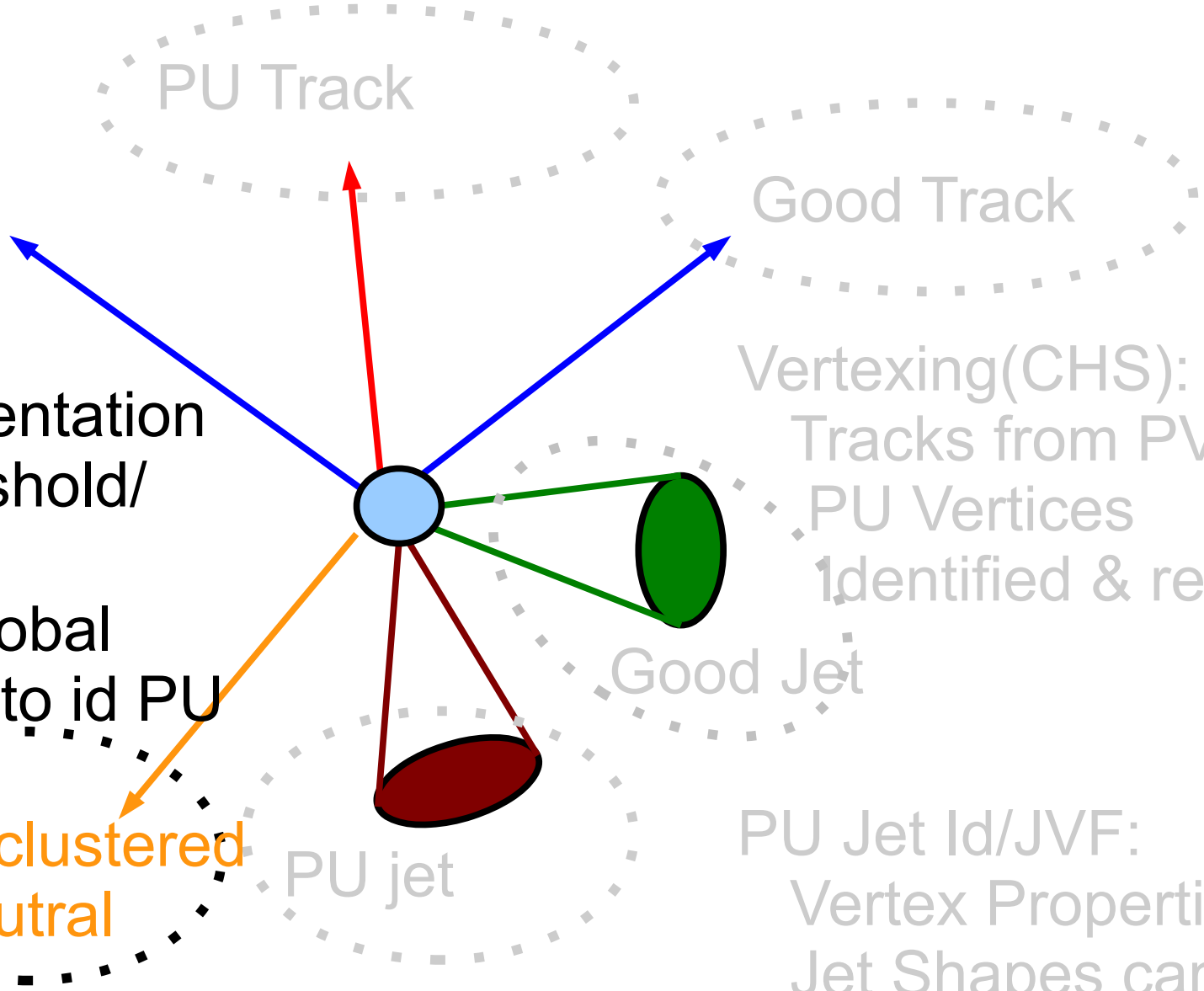


Whats the deal with Pileup?



PU Jet Id/JVF:
Vertex Properties +
Jet Shapes can
Infer jet is PU or not

Whats the deal with Pileup?

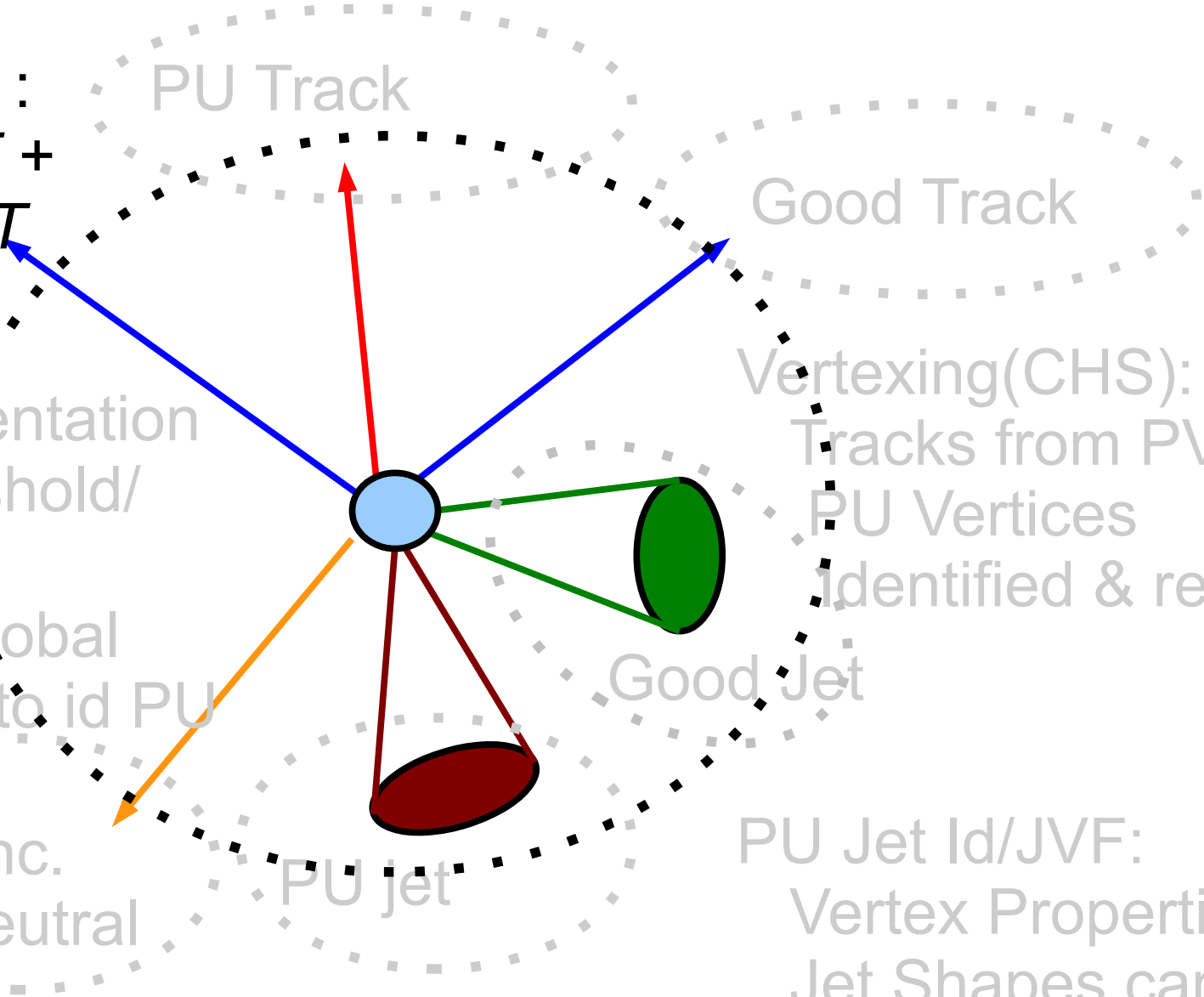


Depth segmentation
Neut. E threshold/
Global ρ*:
Rely on global
Properties to id PU

*Fast calorimeter timing may also be possible

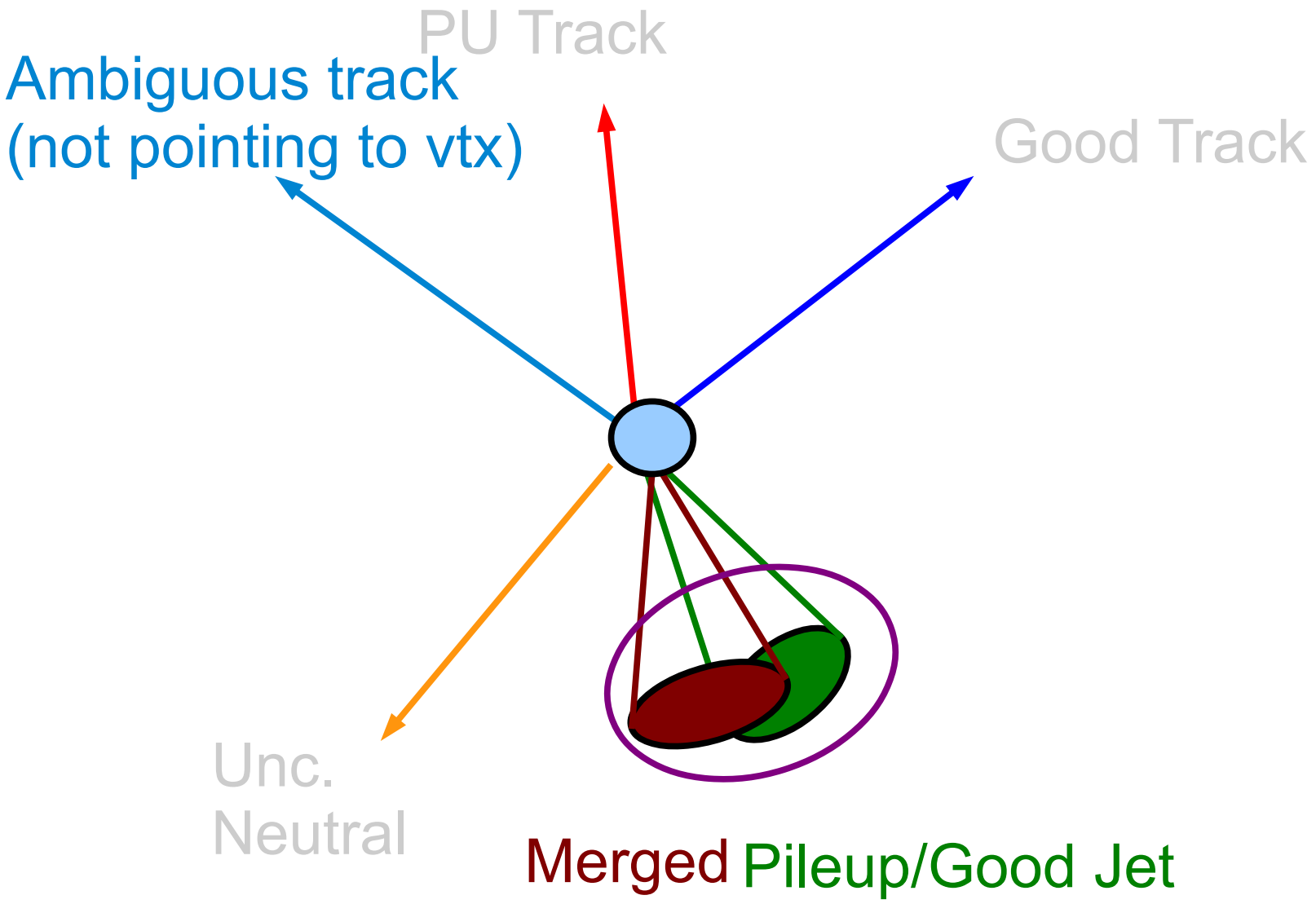
Whats the deal with Pileup?

Whole Event :
MVA *MET* +
JA(F) *MET*



*Fast calorimeter timing may also be possible

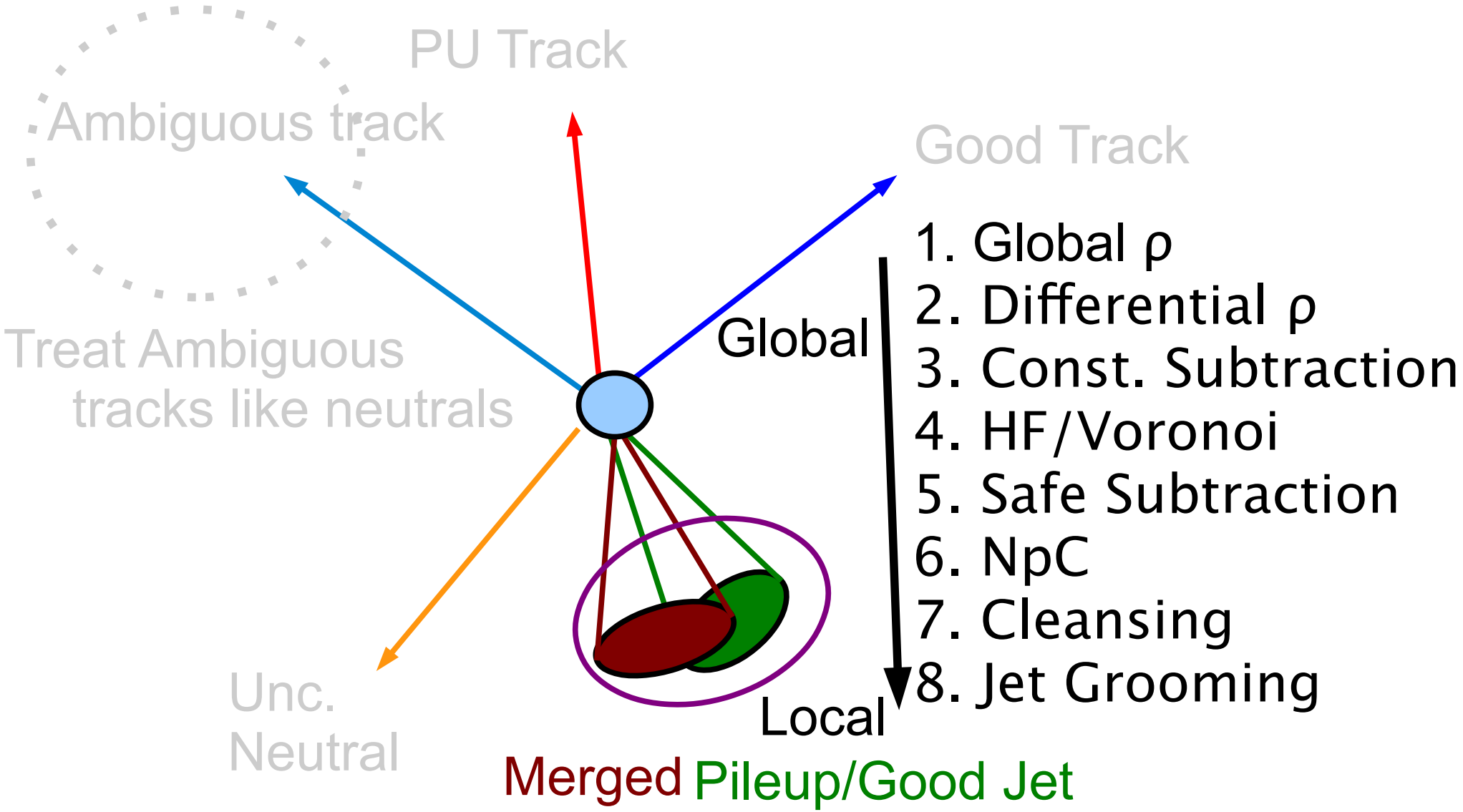
More Realistic Pileup



Tackling the ambiguous cases is just as critical

A large amount of methods exist on the market

More Realistic Pileup



Challenge of isolating PU from a jet garnered much interest

Builds on the building blocks outlined before

Inside of a Jet

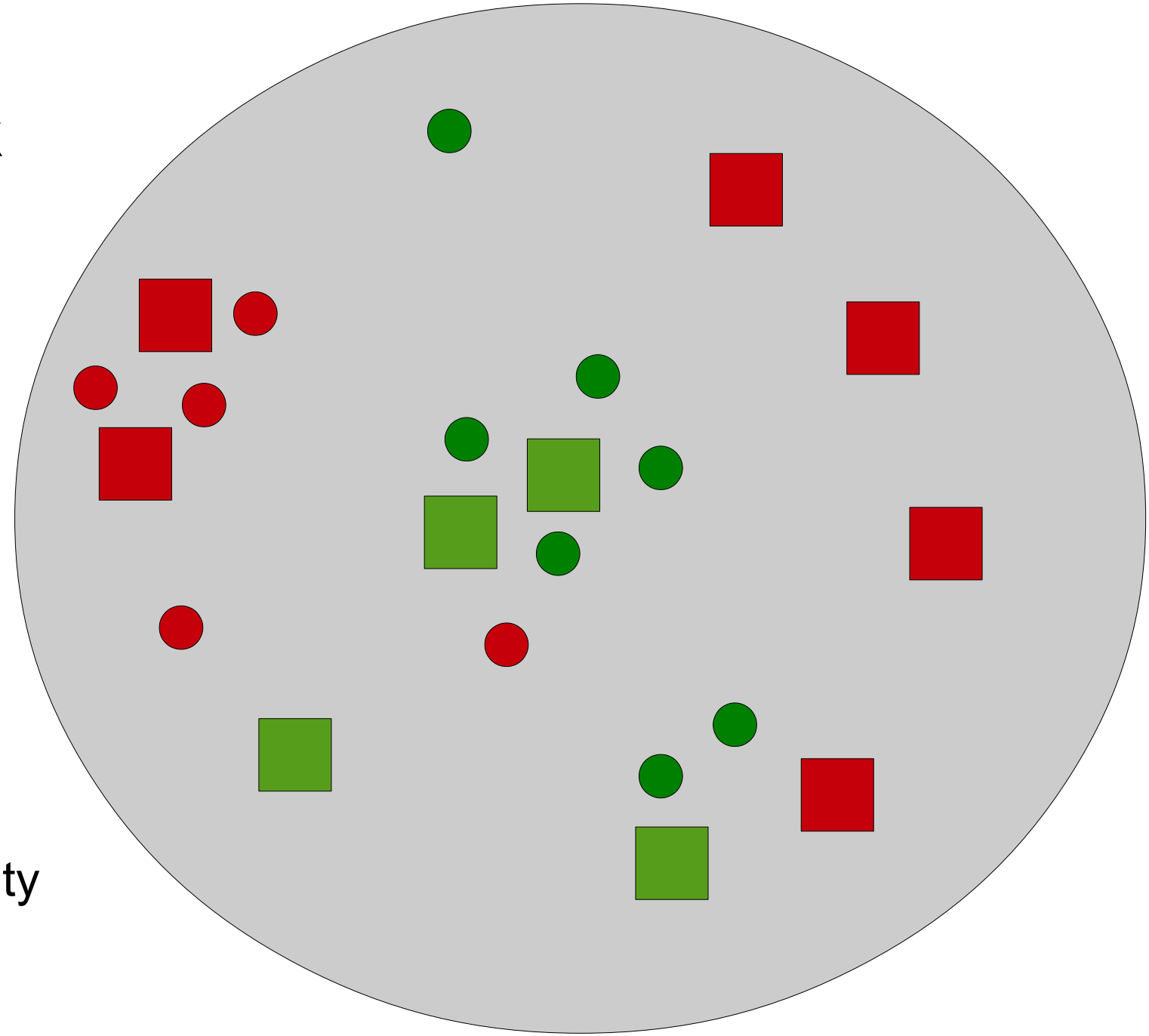
Key

- Good Track
- PU Track
- Good Neut
- PU Neut

Hard scatter is clumpy

Methods take advantage of its clumpiness

Per Particle density subtraction



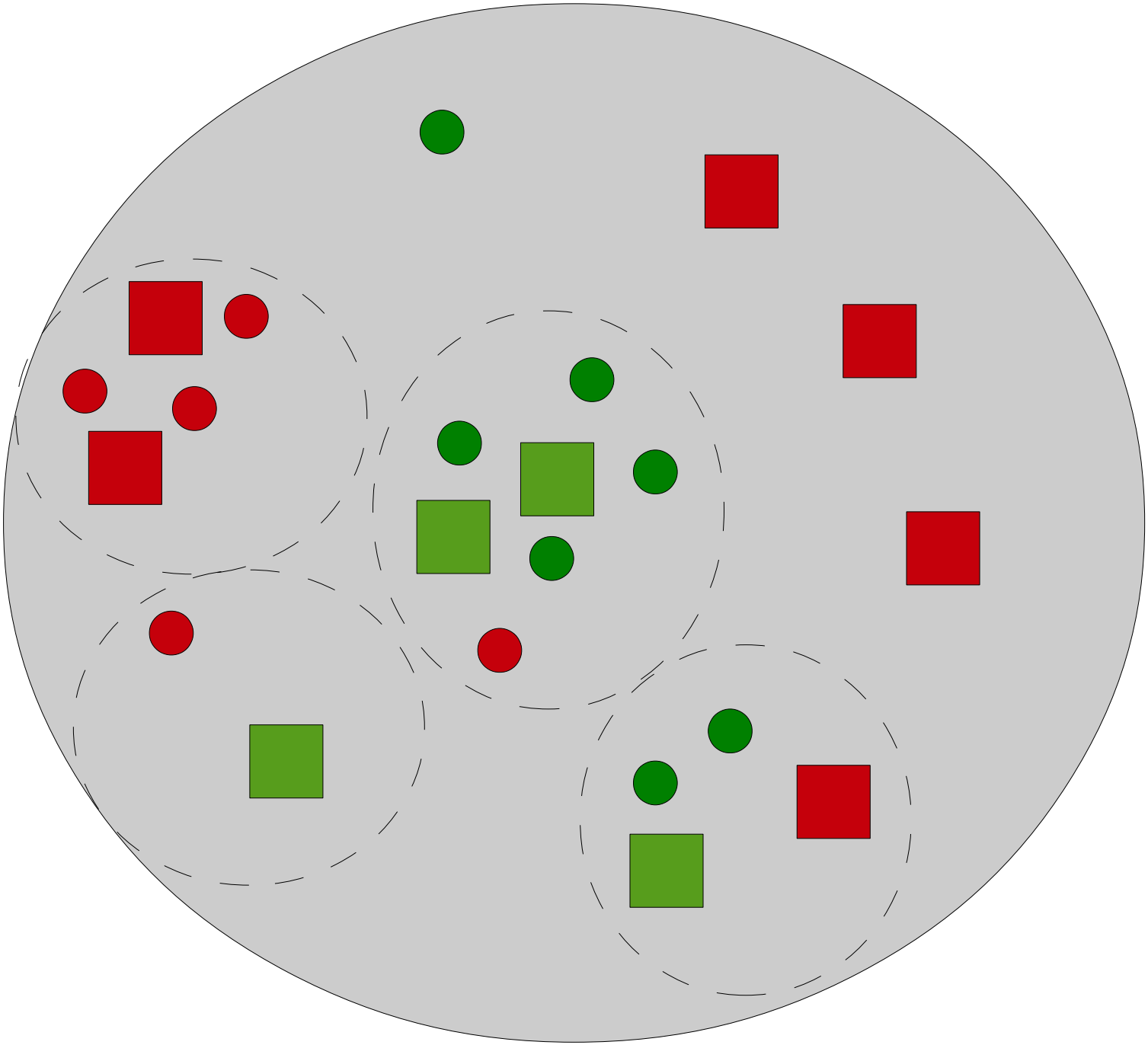
Inside of a Jet

Key

- Good Track
- PU Track
- Good Neut
- PU Neut

Shape of a jet

Contains info about PU



Pileup Subtraction Swiss Army Knife

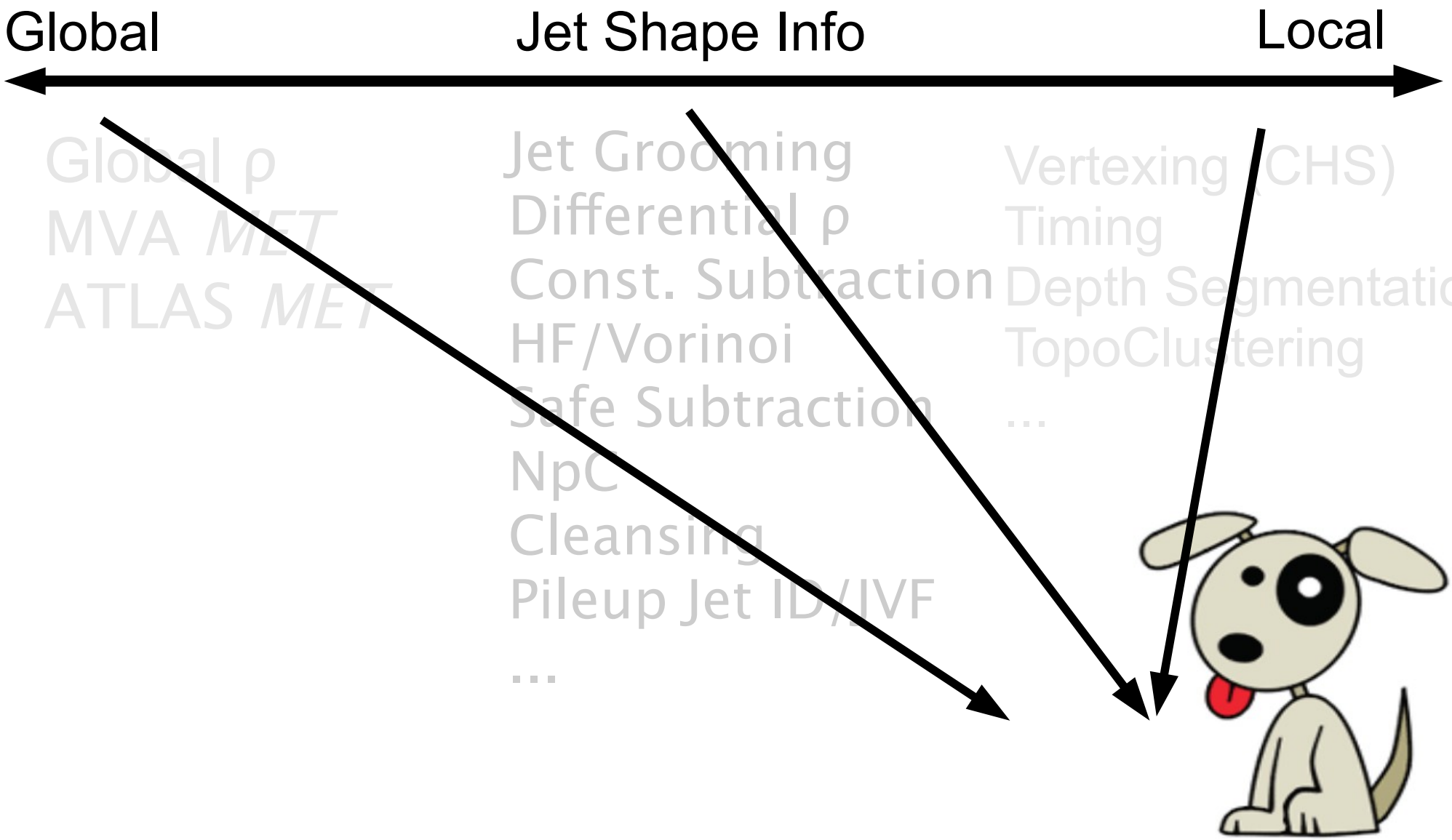
Global — Jet Shape Info — Local

Global ρ
MVA *MET*
JA(F) *MET*

Jet Grooming
Differential ρ
Const. Subtraction
HF/Vorinoi
Safe Subtraction
NpC
Cleansing
Pileup Jet ID
...

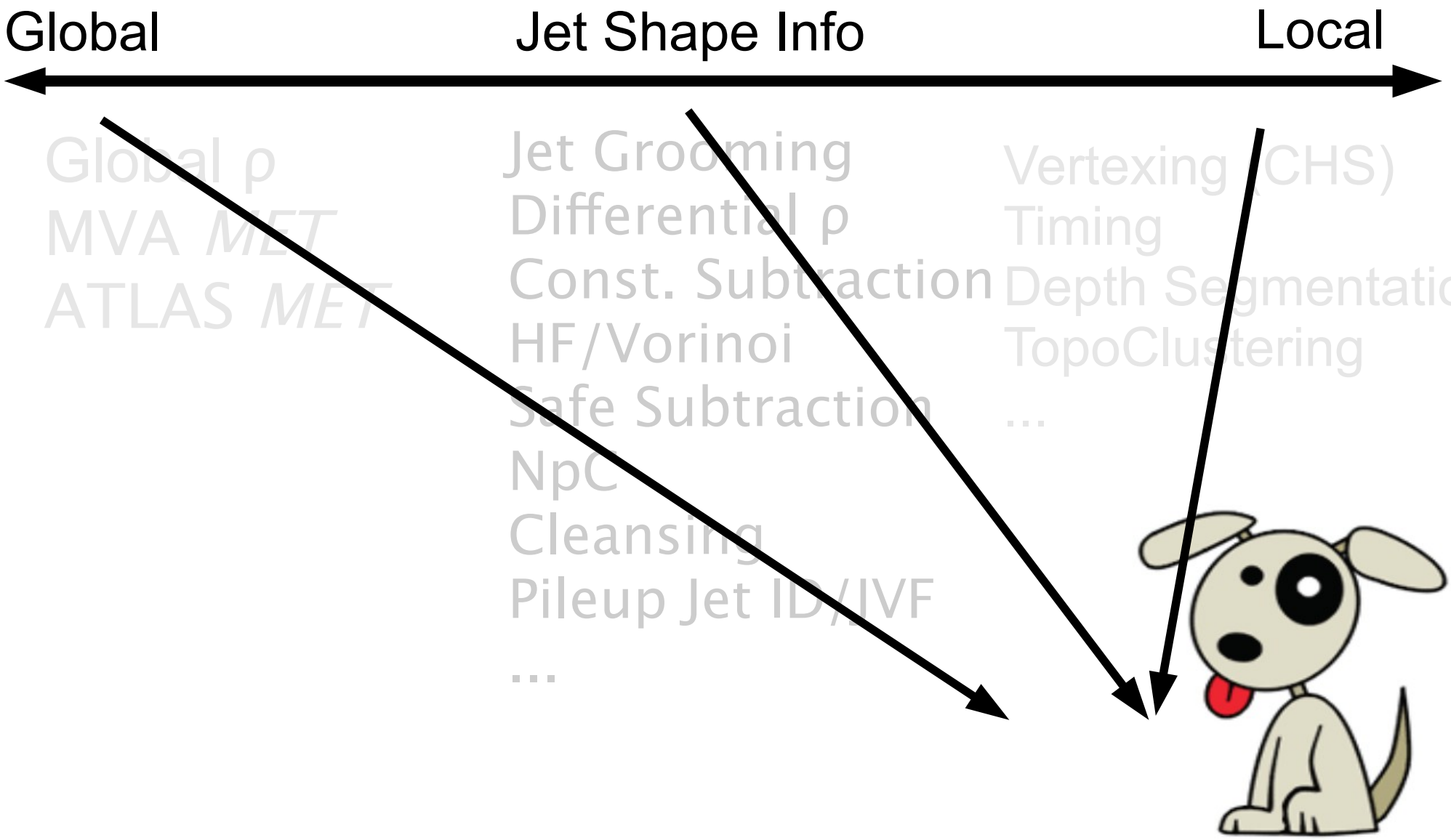
Vertexing (CHS)
Timing
Depth Segmentation
TopoClustering
...

Pileup Subtraction Swiss Army Knife



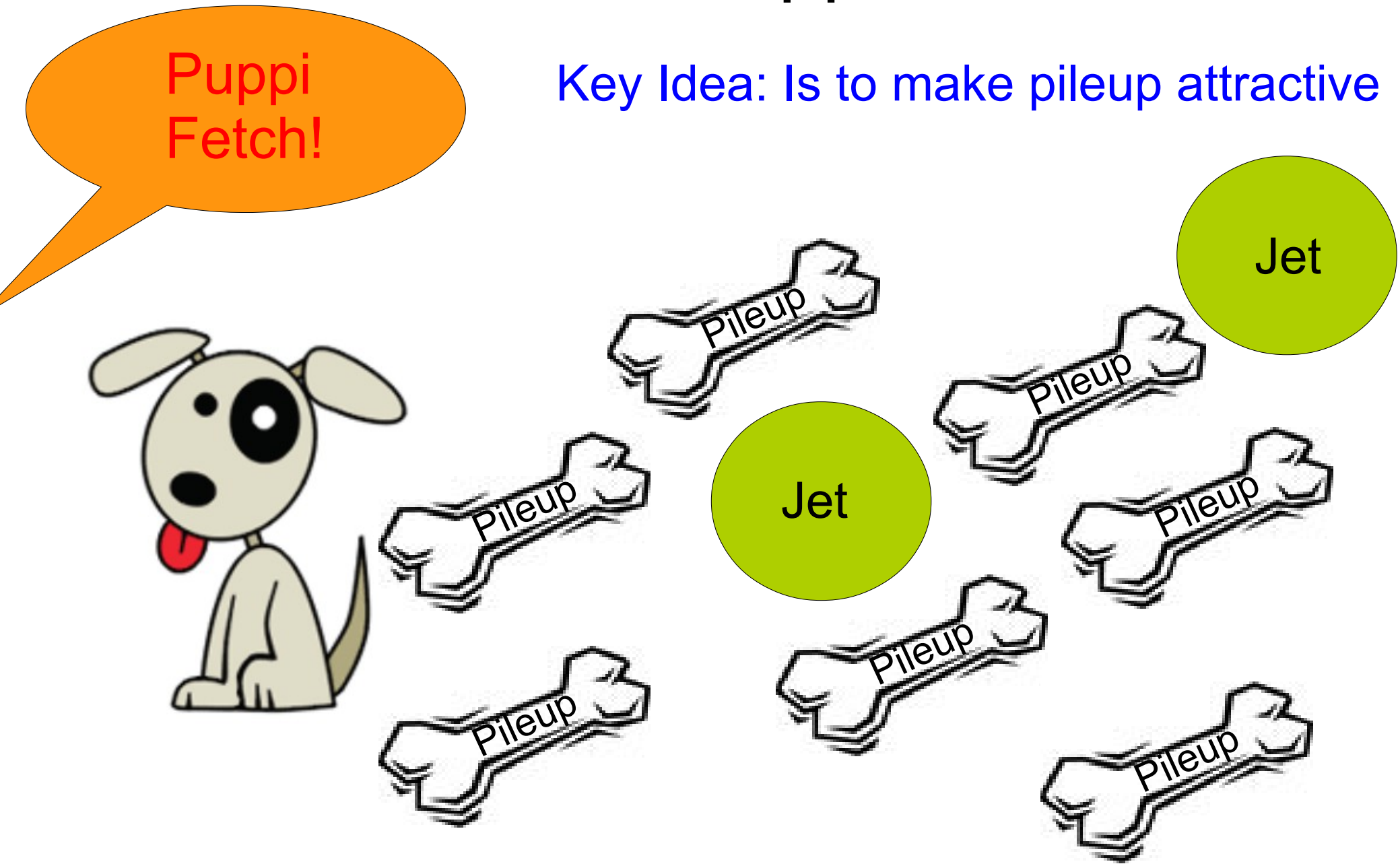
Jets without Jets Paradigm

Pileup Subtraction Swiss Army Knife



per particle weight pre-clustering

How does Puppi work?



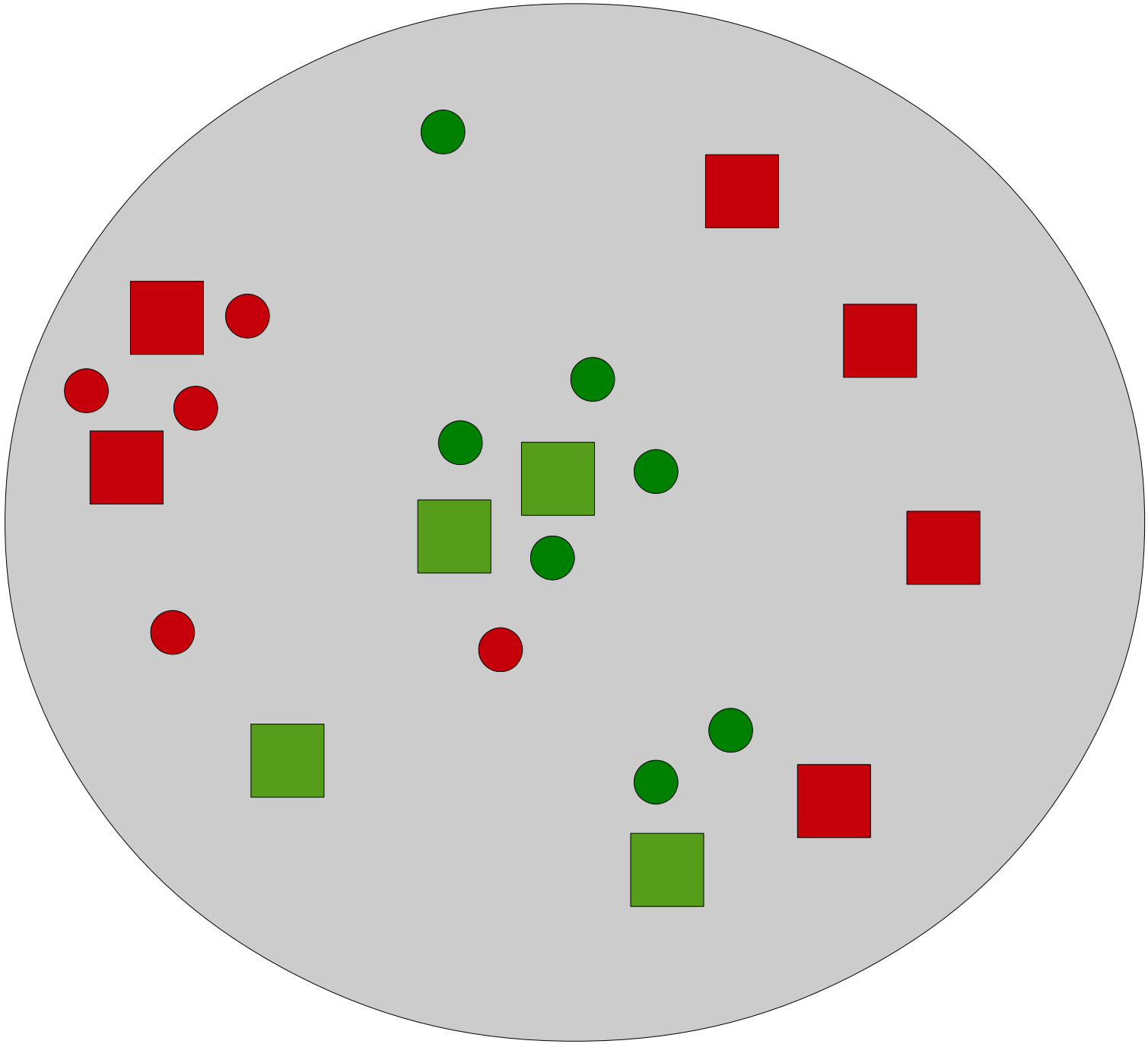
General Idea of the Algorithm

- Use the Jets without Jets paradigm
  - For each particle draw a cone around it
- In each particle cone
  - Compute metric α
    - Distinguishes particle from hard scatter from PU
  - Calculate median α and α_{RMS} over an event for PU
    - Average over all particles associated to another vertex
- Compute a weight that a particle is from pileup
- Reweight particles and re-interpret the event

Puppi Algorithm

Key

- Good Track
- PU Track
- Good Neut
- PU Neut
- Chosen
- Removed

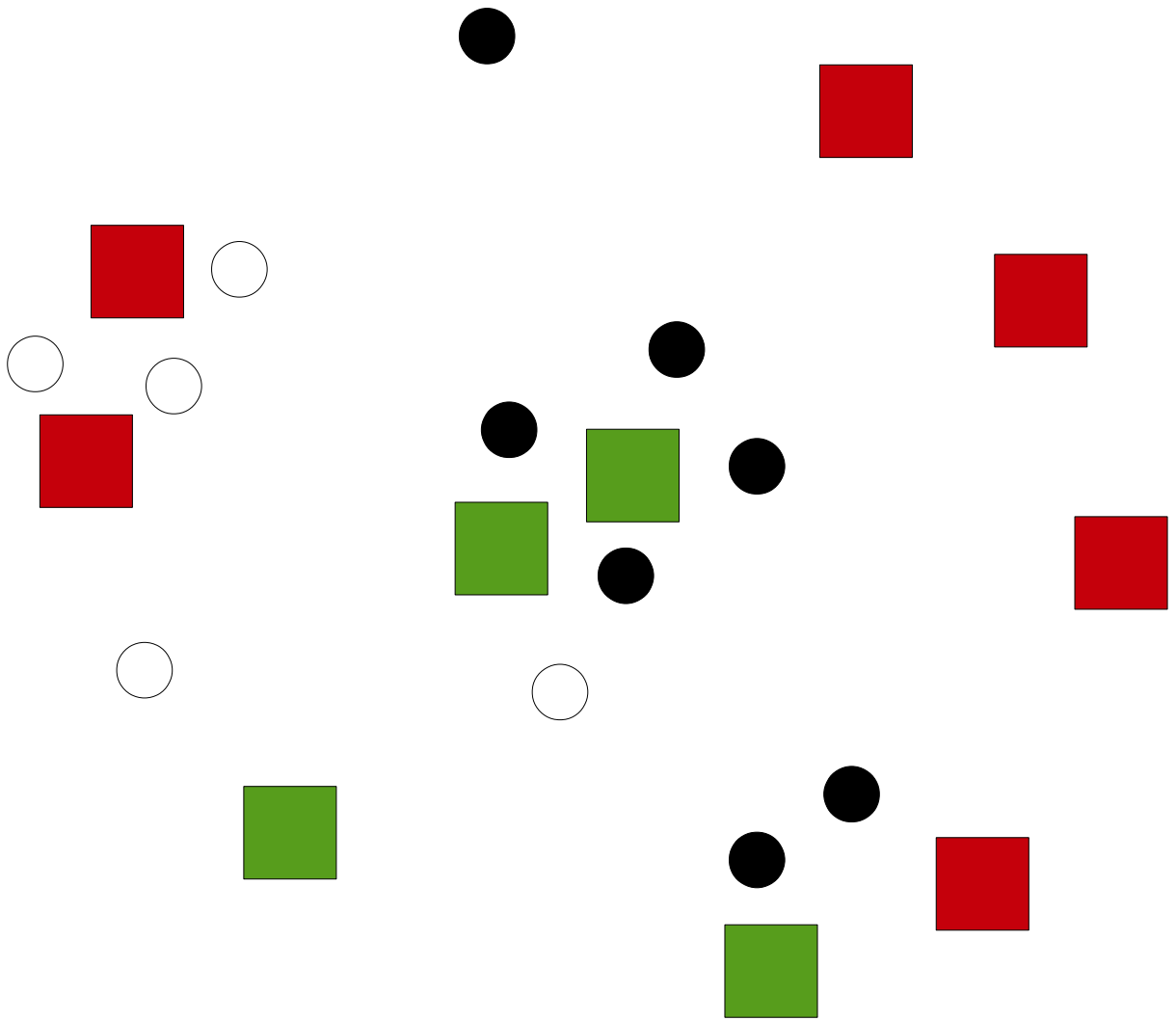


Puppi Algorithm

Key

- Good Track
- PU Track
- Good Neut
- PU Neut
- Chosen
- Removed

Step 1
Run CHS



Puppi Algorithm

Key

- Good Track
- PU Track
- Good Neut
- PU Neut
- Chosen
- Removed

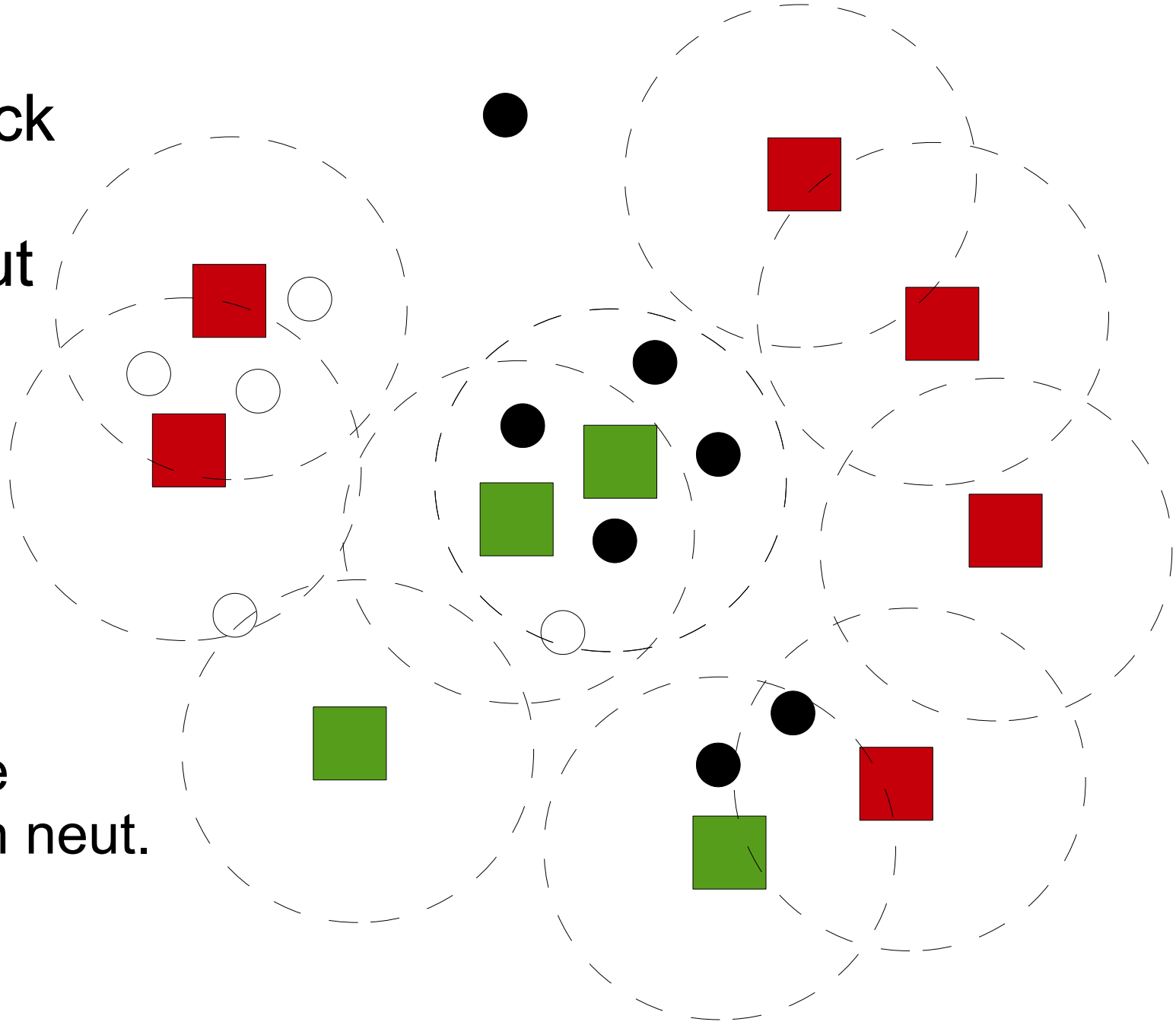
Step 1

Run CHS

Step 2

Draw a cone

About each neut.

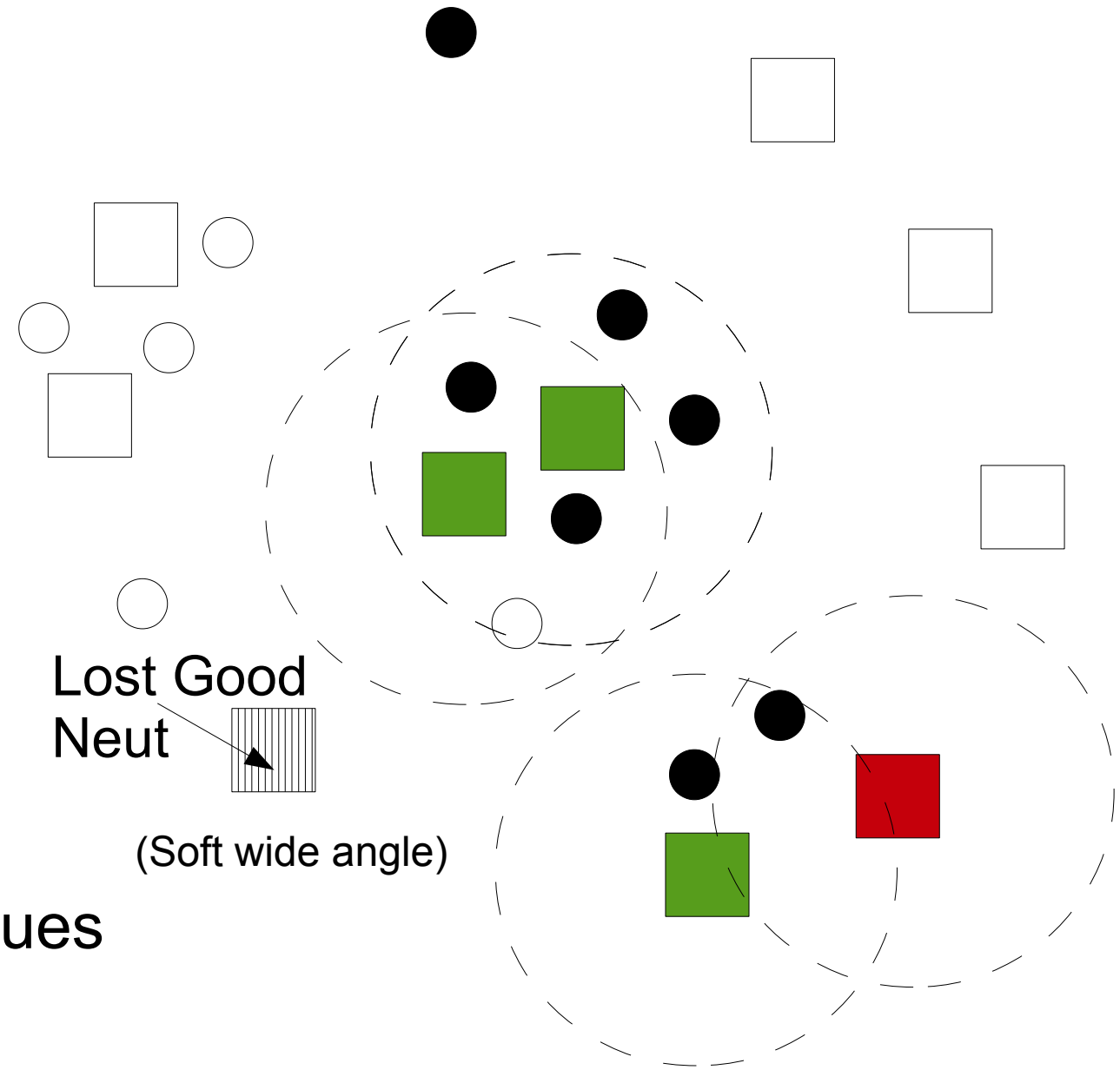


Puppi Algorithm

Key

- Good Track
- PU Track
- Good Neut
- PU Neut
- Chosen
- Removed

Step 1
Run CHS
Step 2
Draw a cone
Step 3
Remove all 0 values



Puppi Algorithm

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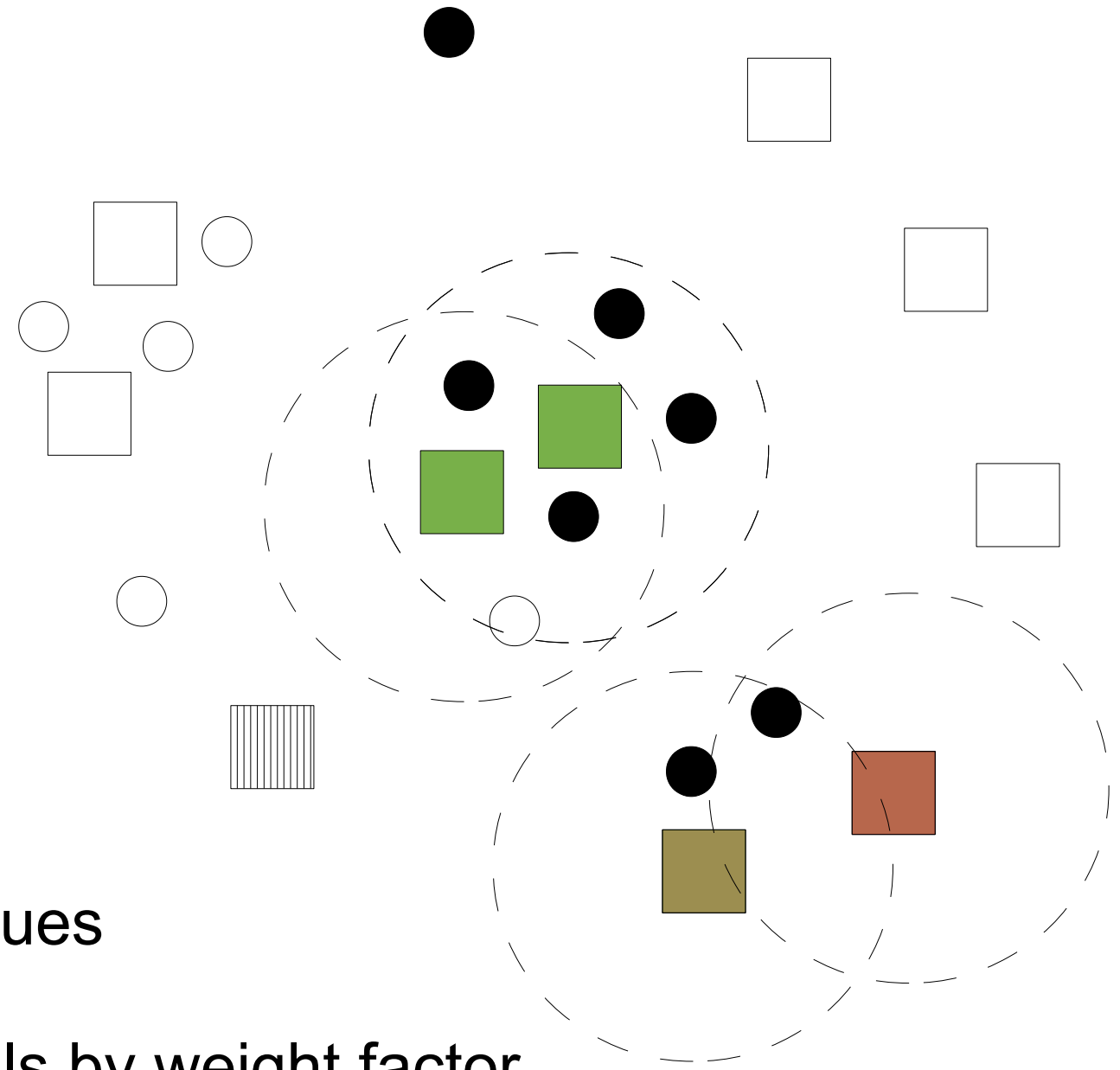


Step 1
Run CHS

Step 2
Draw a cone

Step 3
Remove all 0 values

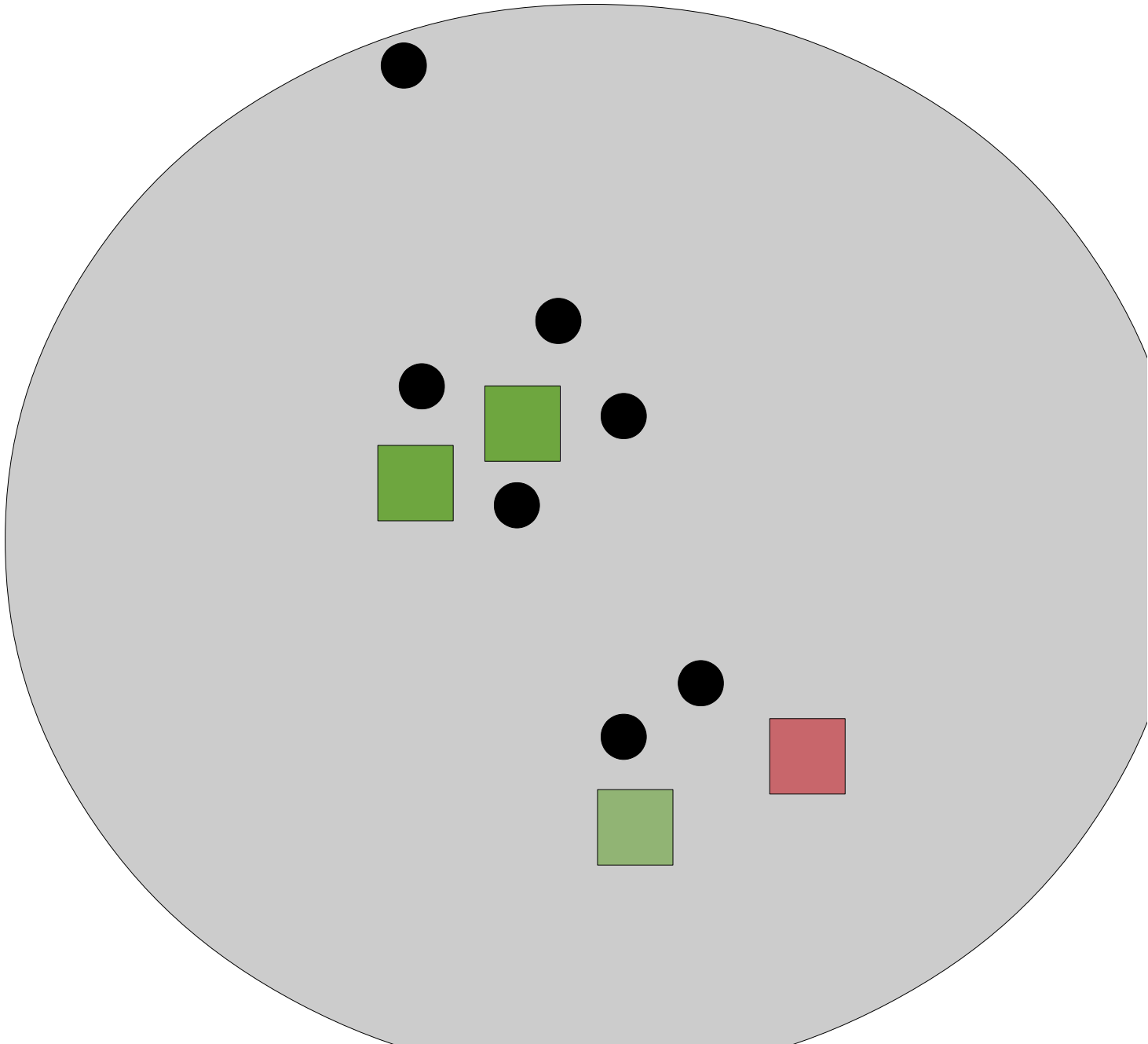
Step 4
Reweight Neutrals by weight factor

After Puppi

Key

- Good Track
- PU Track
- Good Neut
- PU Neut
- Chosen
- Removed

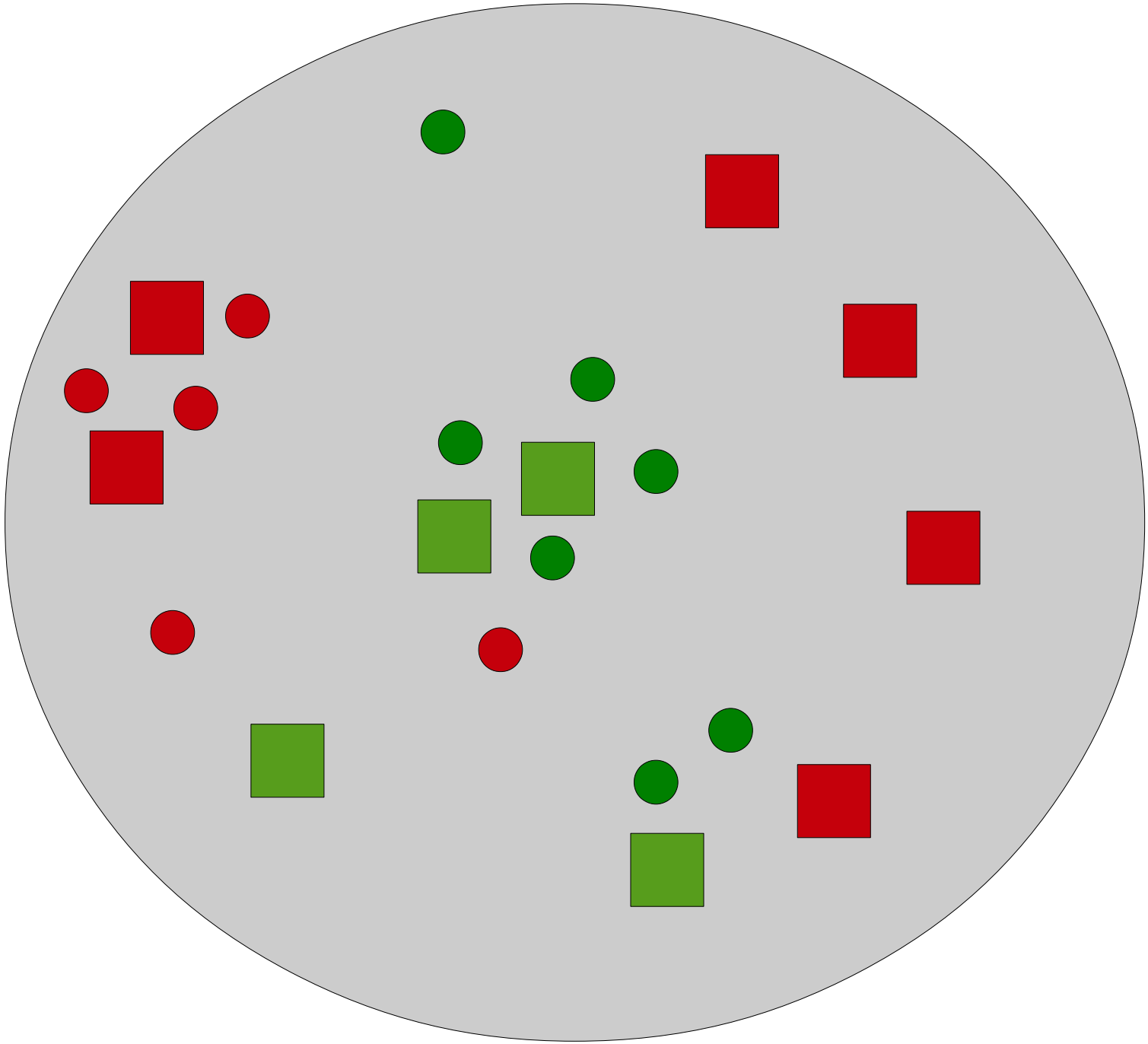
Step 5
Re-interpret evt
(Re-cluster)



Before Puppi

Key

- Good Track
- PU Track
- Good Neut
- PU Neut
- Chosen
- Removed



How to make pileup attractive?

- For each particle consider in a cone :

$$\log \sum_{j \in R_{\min} \leq \Delta R_{ij} \leq R_0} \frac{p_{Tj}}{\Delta R_{ij}}$$

Hard collinear particles

Soft wide angle particles

Regulate the scales

Cone size to sum over

2 free parameters R_{min} R_0 (R_{max})

What to Sum Over?

- For each particle consider in a cone :

$$\log \sum_{j \in \text{Charged Leading Vertex}} \frac{p_{Tj}}{\Delta R_{ij}}$$

When vertexing exists (Central Region)

Sum over charged particles from leading vertex :

α_C

What to Sum Over?

- For each particle consider in a cone :

$$\log \sum_{j \in \text{event}} \frac{p_{Tj}}{\Delta R_{ij}}$$

When no tracking + vertex exists (Forward Region)

Sum over all particles :

$$\alpha_F$$

Is this the Best Metric?

- For each particle consider in a cone :

There are many other options

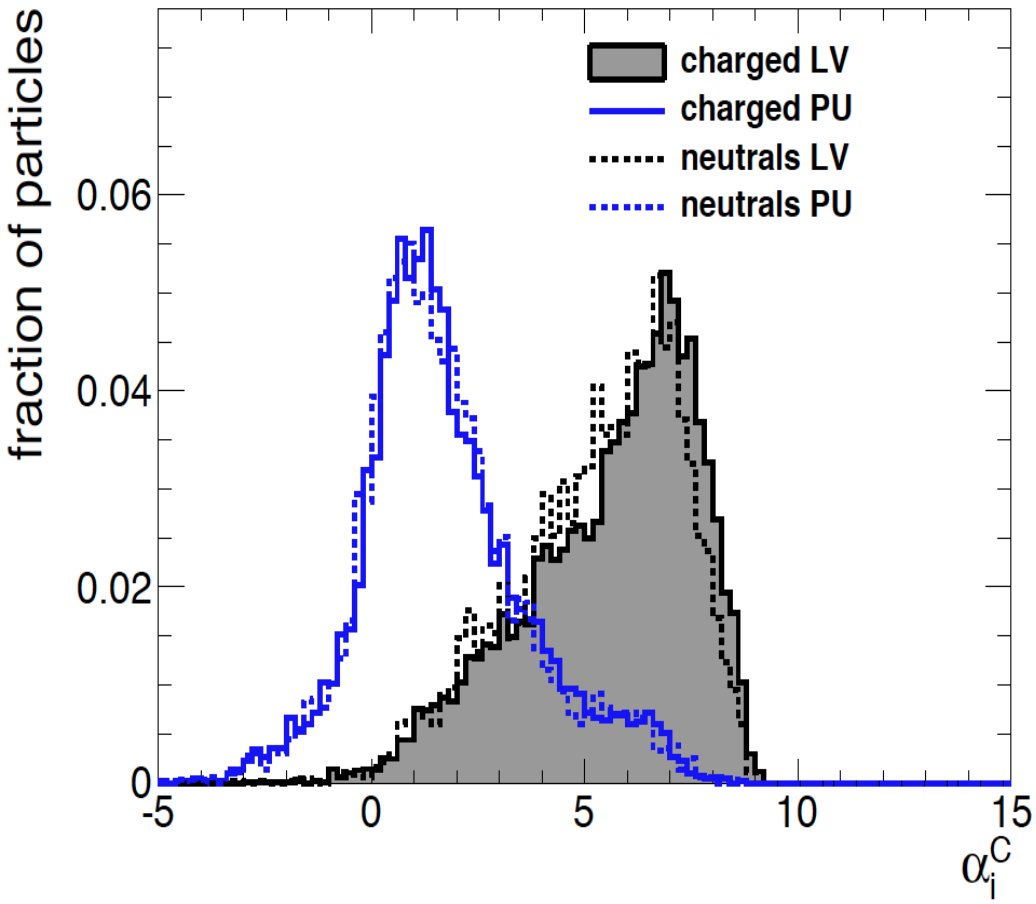
$$\log \sum_{j \in R'} \frac{p_{Tj}}{(\Delta R_{ij})^{\beta}}$$

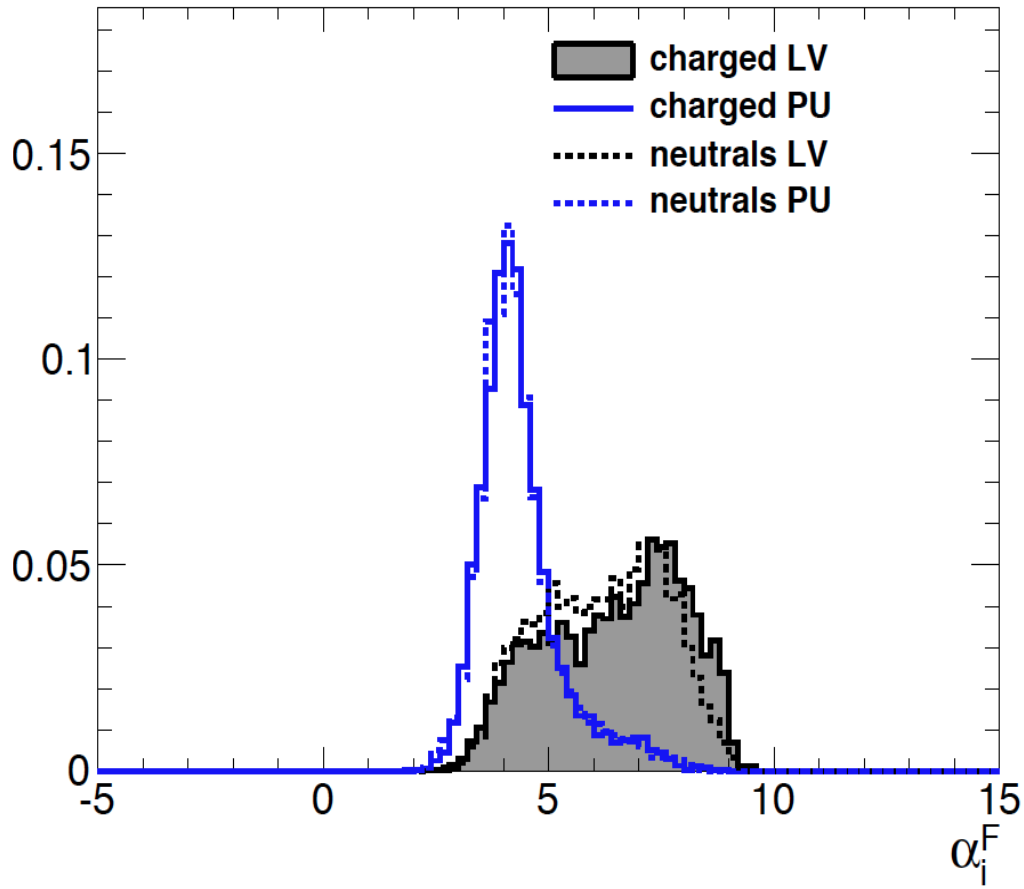
We sum over other stuff

We have considered many options

There are many more to consider

How does it look like?



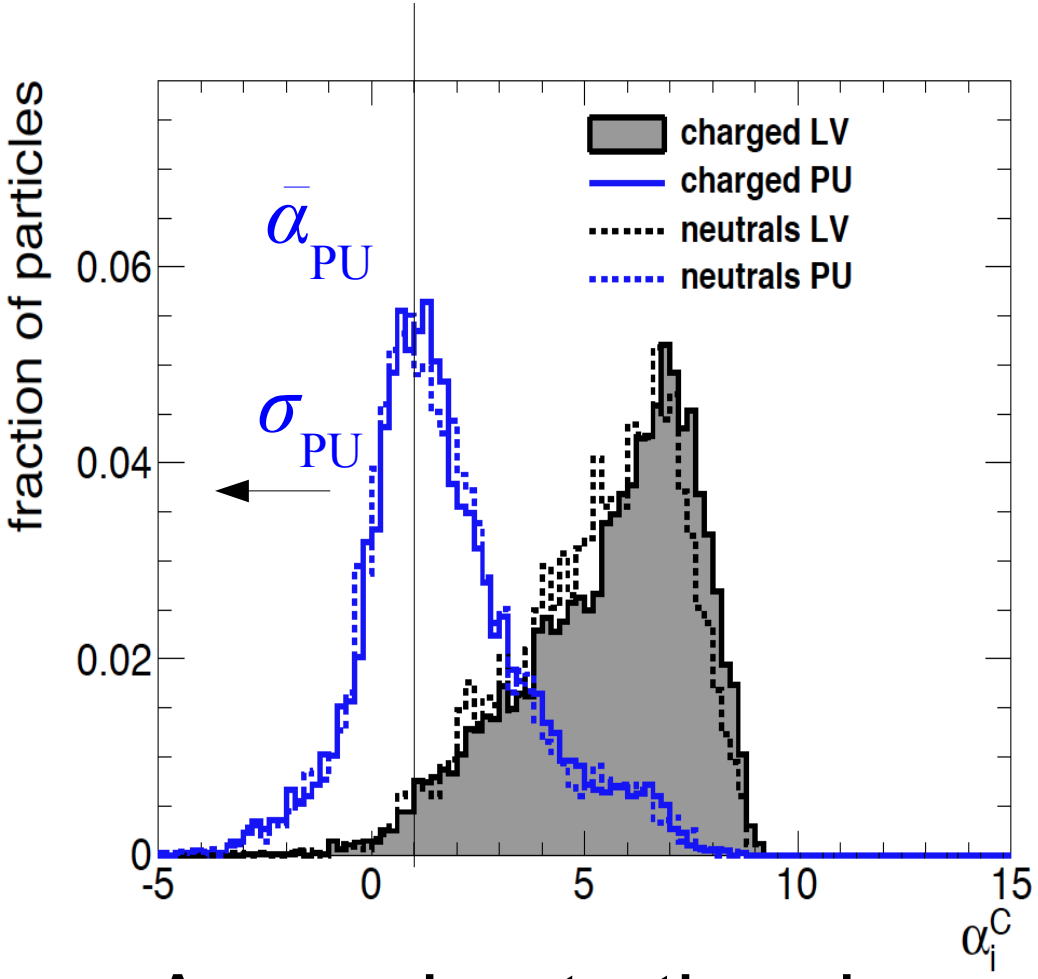


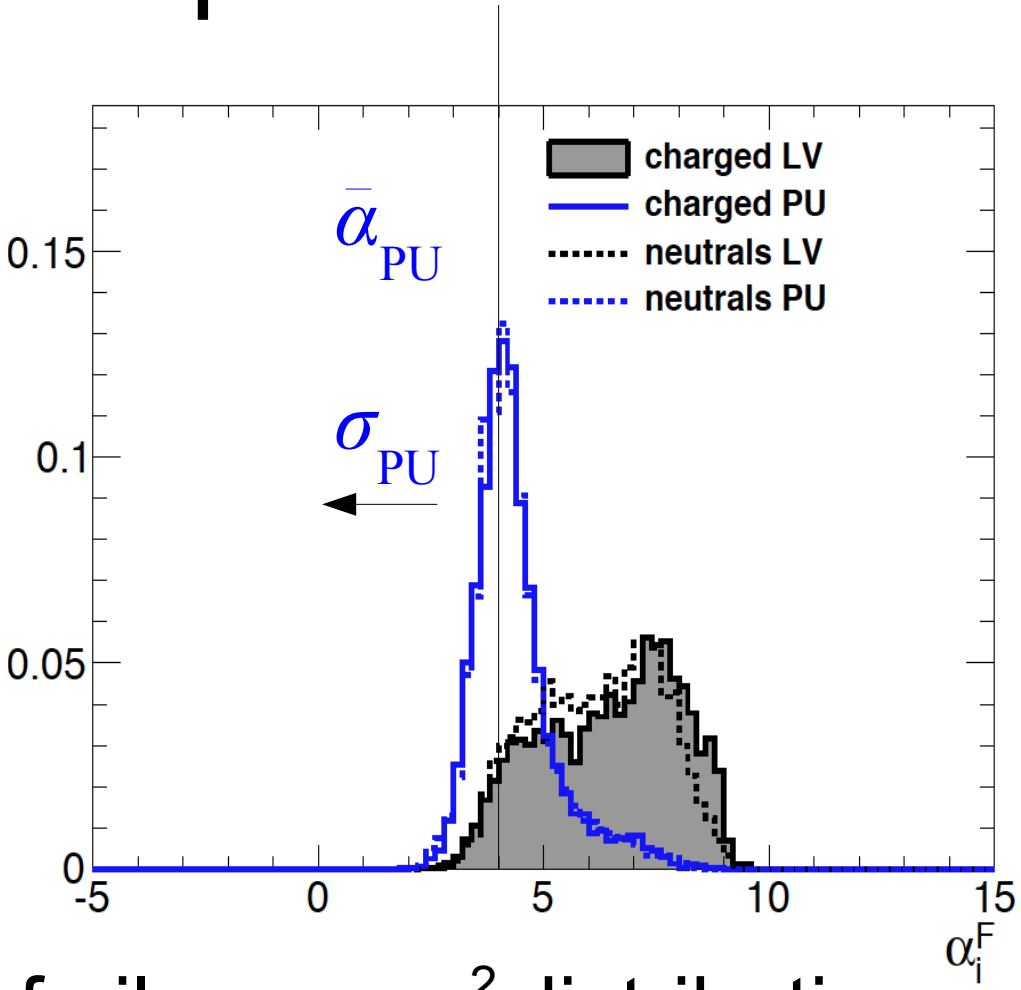
Metric gives a per particle separation of pileup

Take advantage of this distribution event by event

Use charged particles from other vertices as PU

Event Level Interpretation

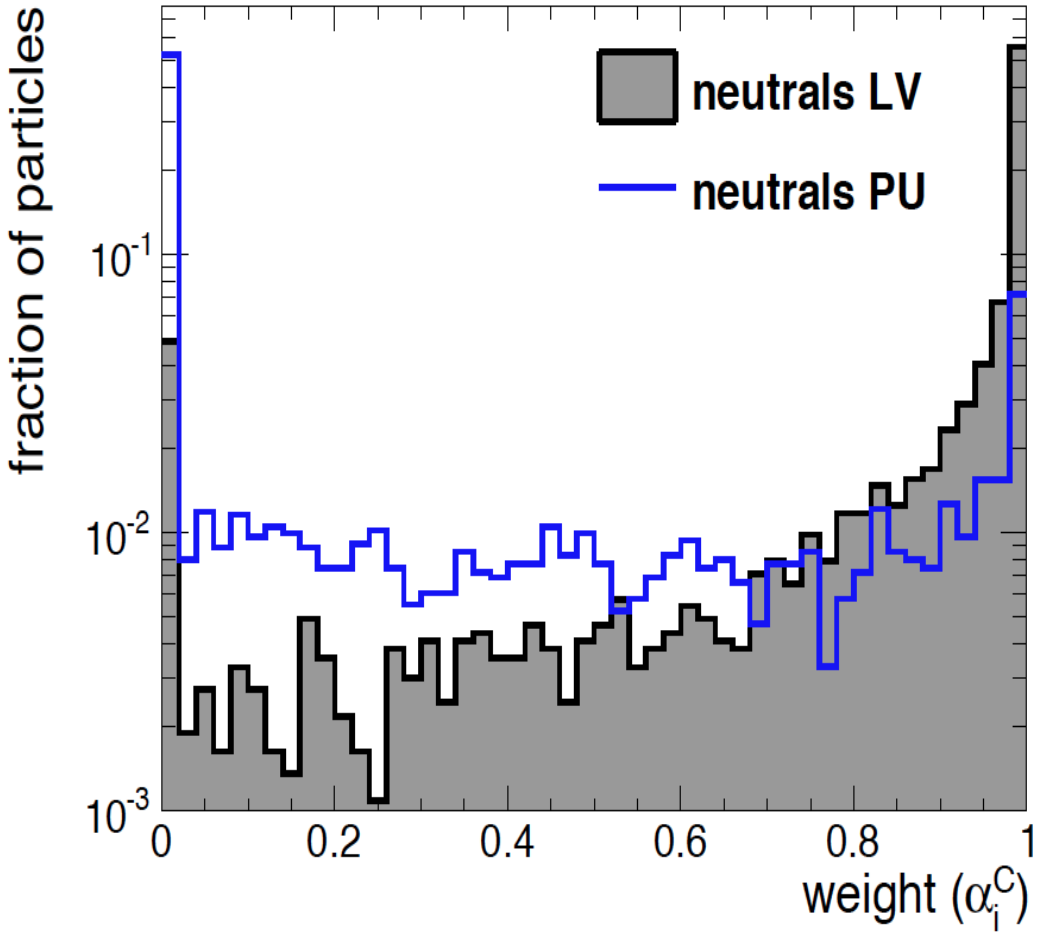


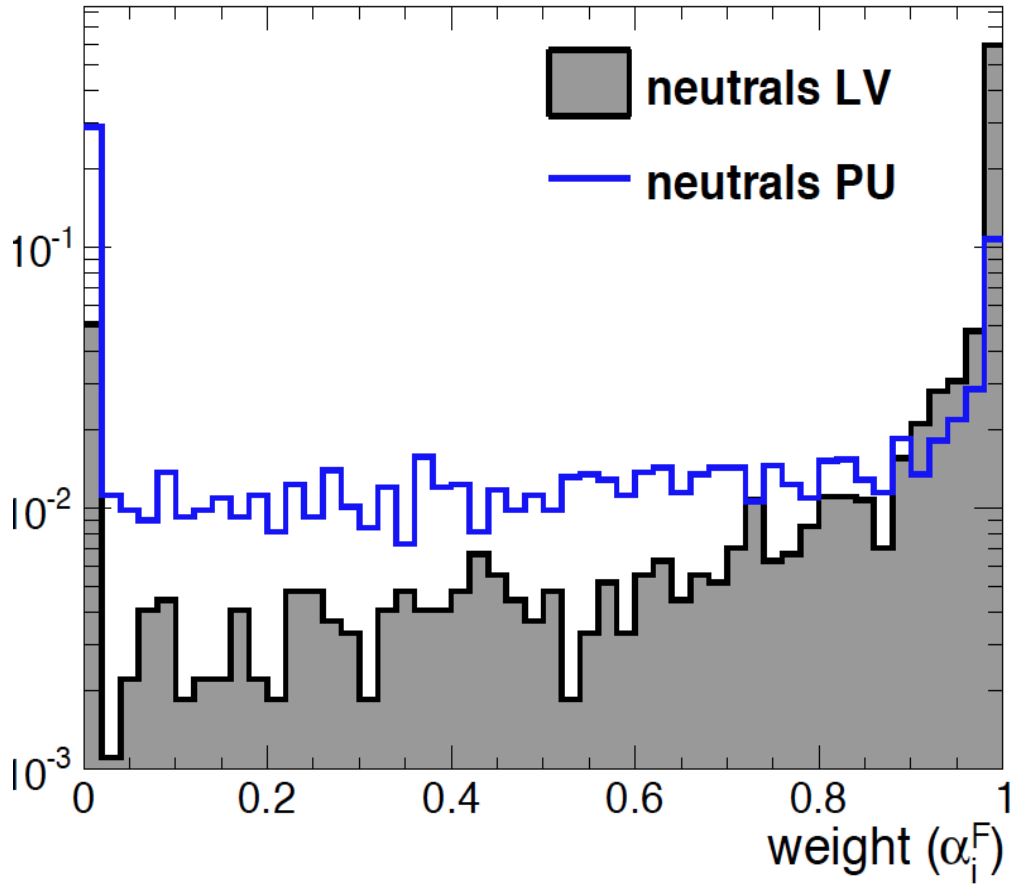


Approximate the shape of pileup as χ^2 distribution

$$\chi_i^2 = \Theta(\alpha_i - \bar{\alpha}_{\mathrm{PU}}) \times \frac{(\alpha_i - \bar{\alpha}_{\mathrm{PU}})^2}{\sigma_{\mathrm{PU}}^2}$$

Event Level Interpretation





Translate distribution into a weight*

$$w_i = F_{\chi^2,\mathrm{NDF}=1}(\chi_i^2) \longrightarrow p_i^{New} = w_i p_i$$

ie shower deconstruction*

How to make pileup attractive?

- For each particle consider in a cone :

  A test for guilt by Association

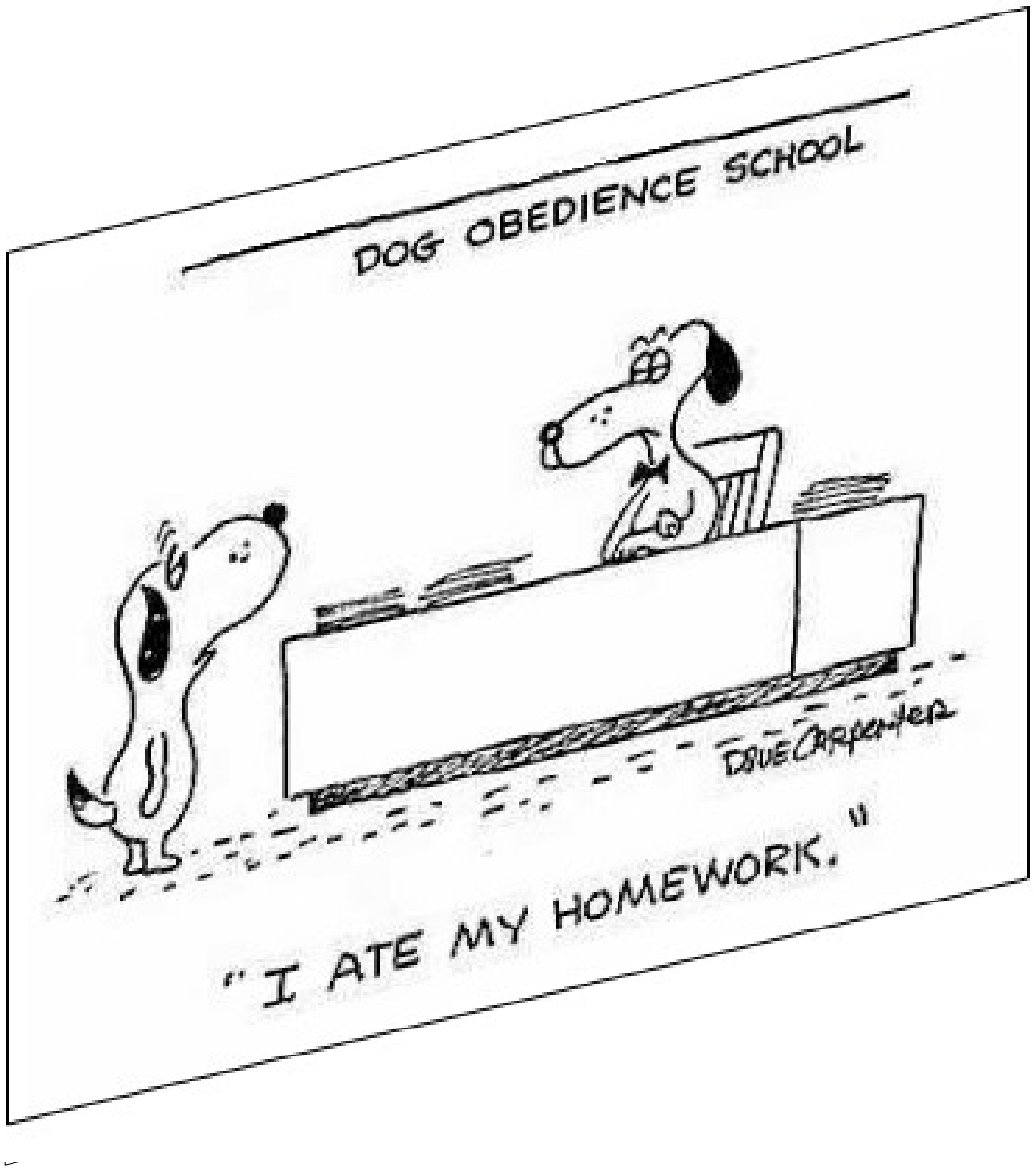
$$\log \sum_{j \in R_{\min} \leq \Delta R_{ij} \leq R_0} \frac{p_{Tj}}{\Delta R_{ij}}$$

Hard collinear particles

Soft wide angle particles

Is this the best metric?

Puppi Results



Understanding Puppi requires some real life experience

Setup For Studies

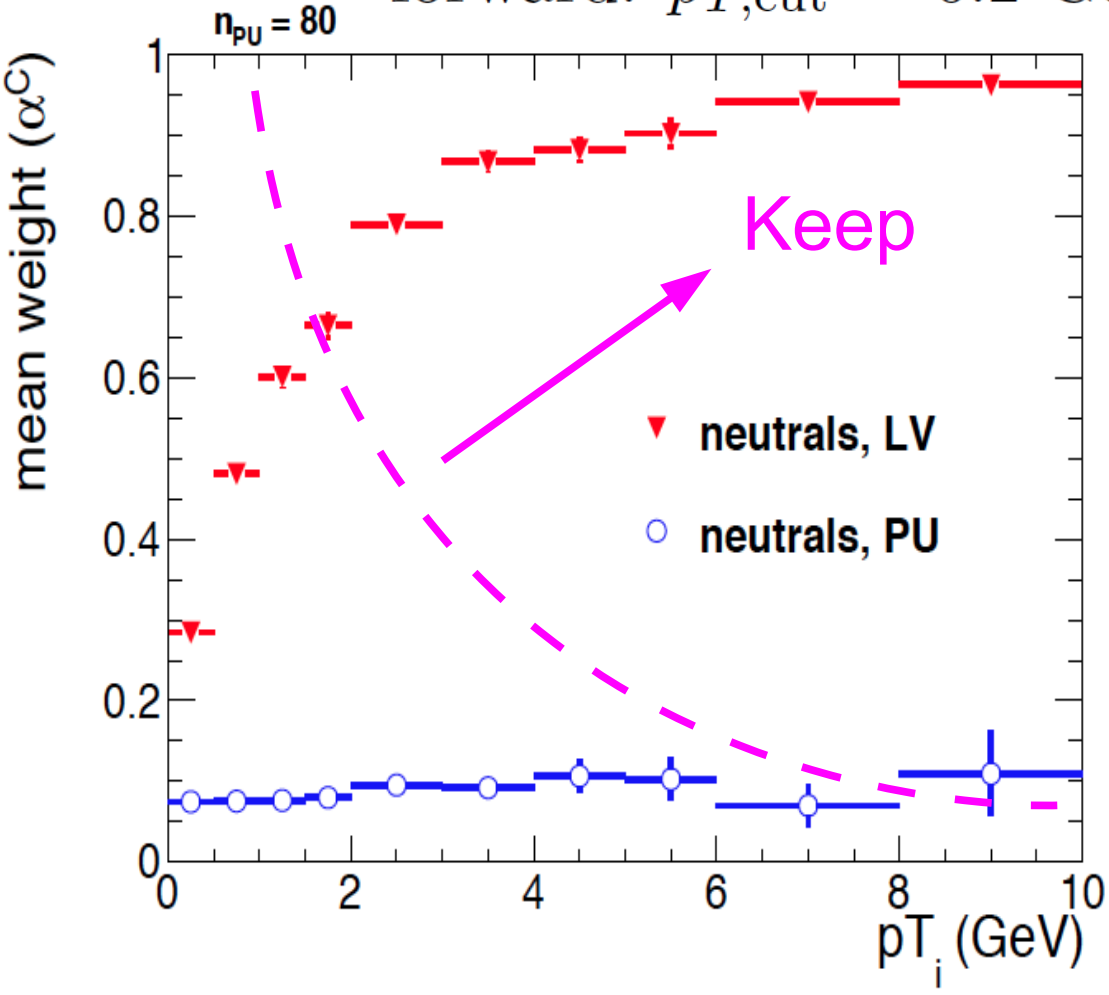
- MC :
  - Pythia 8.176 di-jet events float p_T 15-500 @ 14 TeV
  - PU 20-140 (in bins of 15)
- Detector :
  - Particle-flow like scenario
  - Tracking with $|\eta| < 2.5$
    - Perfect tracking
  - All particles with $|\eta| < 5$
  - Neutrals reconstructed in Cells
    - $\Delta\eta \times \Delta\varphi$ of 0.1x0.1
    - $p_T > 0.1$ GeV
  - AK7 Jets

Tunable Parameters

1. Cone size to sum over
2. Cut on the re-weighted p_T

$$\text{central: } p_{T,\text{cut}} = 0.1 \text{ GeV} + n_{\text{PU}} \times 0.007 \text{ GeV}$$

$$\text{forward: } p_{T,\text{cut}} = 0.2 \text{ GeV} + n_{\text{PU}} \times 0.011 \text{ GeV}$$



Details for this study

3. Cut on weight

$$w_i > 0.1$$

ΔR

$$0.02 < \Delta R < 0.3$$

3 tunable parameters

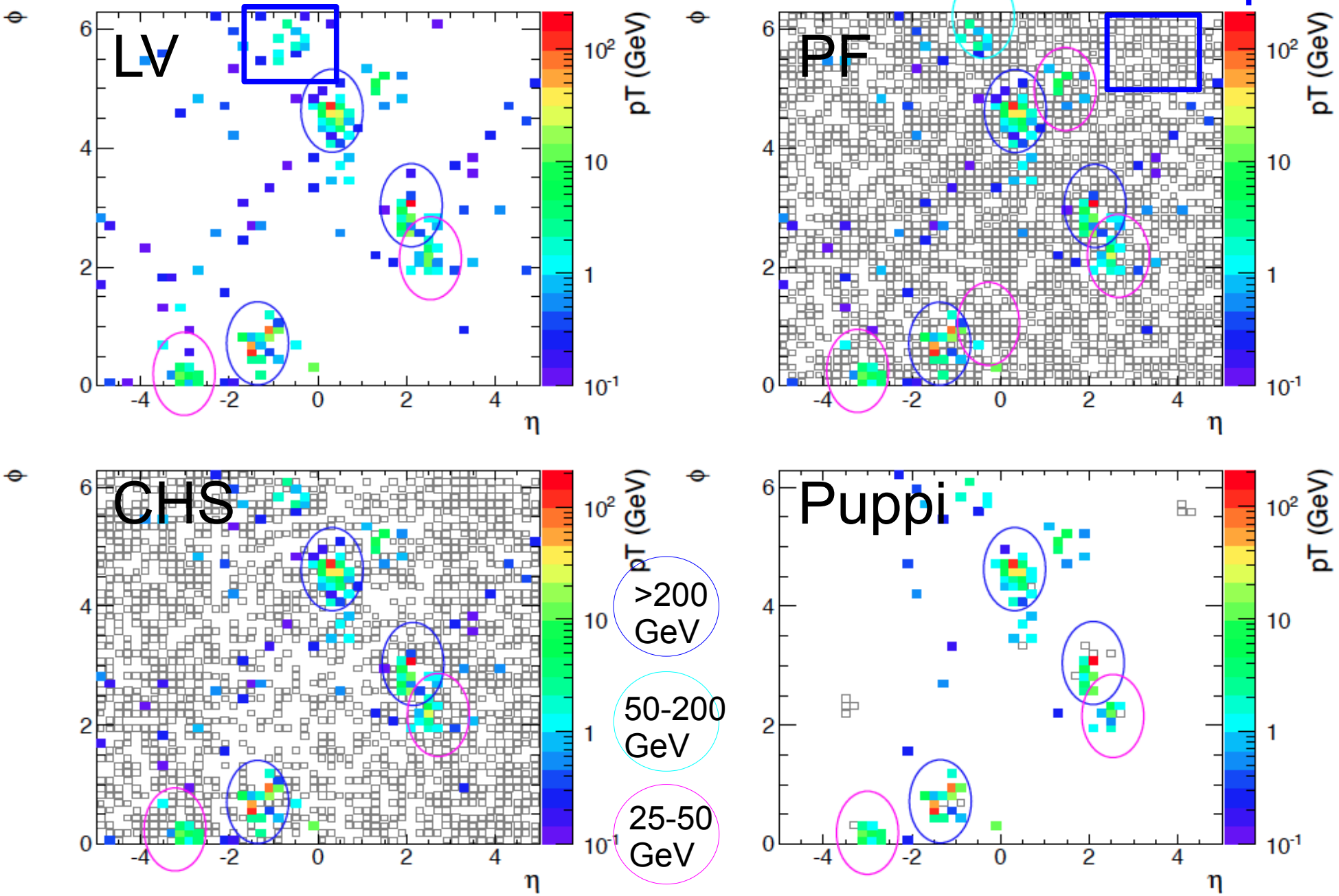
Setup Continued

- LV : Particles from the leading vertex
- PF : Take all particles in event
- PF+CHS : Removed charged PU w/$|\eta|<2.5$
- Puppi :
  - Particles with $|\eta| < 2.5$ apply α_C
  - Particles with $|\eta| > 2.5$ apply α_F
- For PF and PF+CHS
  - Apply 4 vector ρ x a safe subtraction
  - Recalculate ρ_{CHS} for CHS particles $|\eta| < 2.5$

An Example Event

Real Event

Pileup



Recap

- Draw a cone around each particle
- Compute

$$\alpha_i^C = \log \sum_{j \in \mathrm{Ch,LV}} \xi_{ij}\, \Theta(R_{\min} \le \Delta R_{ij} \le R_0), \qquad \xi_{ij} = \frac{p_{Tj}}{\Delta R_{ij}}$$

$$\alpha_i^F = \log \sum_{j \in \mathrm{event}} \xi_{ij}\, \Theta(R_{\min} \le \Delta R_{ij} \le R_0).$$

- For event compute median,RMS→weight

$$\bar{\alpha}^F_{\mathrm{PU}} = \mathrm{median}\{\alpha^F_{i\in \mathrm{Ch,PU}}\}, \qquad \sigma^F_{\mathrm{PU}} = \mathrm{RMS}\{\alpha^F_{i\in \mathrm{Ch,PU}}\}$$

$$\bar{\alpha}^C_{\mathrm{PU}} = \mathrm{median}\{\alpha^C_{i\in \mathrm{Ch,PU}}\}, \qquad \sigma^C_{\mathrm{PU}} = \mathrm{RMS}\{\alpha^C_{i\in \mathrm{Ch,PU}}\}$$

$$w_i = F_{\chi^2,\mathrm{NDF}=1}(\chi_i^2) \qquad \chi_i^2 = \Theta(\alpha_i - \bar{\alpha}_{\mathrm{PU}}) \times \frac{(\alpha_i - \bar{\alpha}_{\mathrm{PU}})^2}{\sigma^2_{\mathrm{PU}}}$$

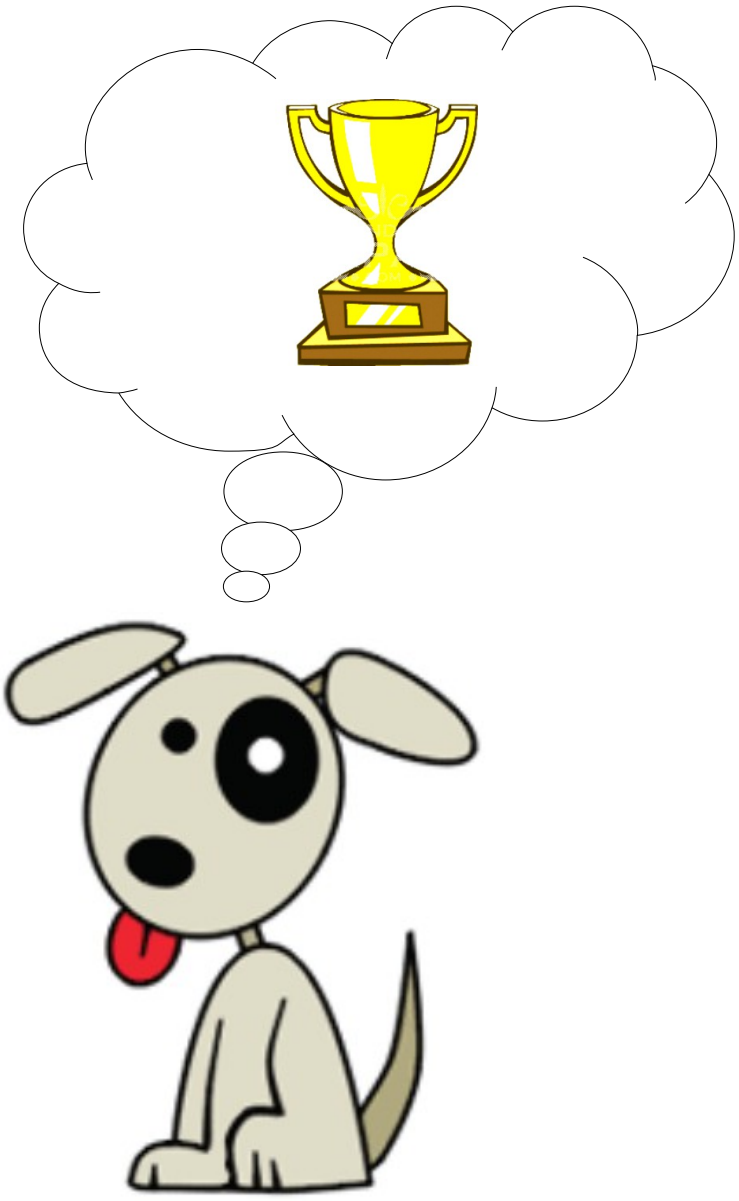
- Apply some cut on weight and re-weighted p_T

$$\text{central: } p_{T,\mathrm{cut}} = 0.1\ \mathrm{GeV} + n_{\mathrm{PU}} \times 0.007\ \mathrm{GeV}$$

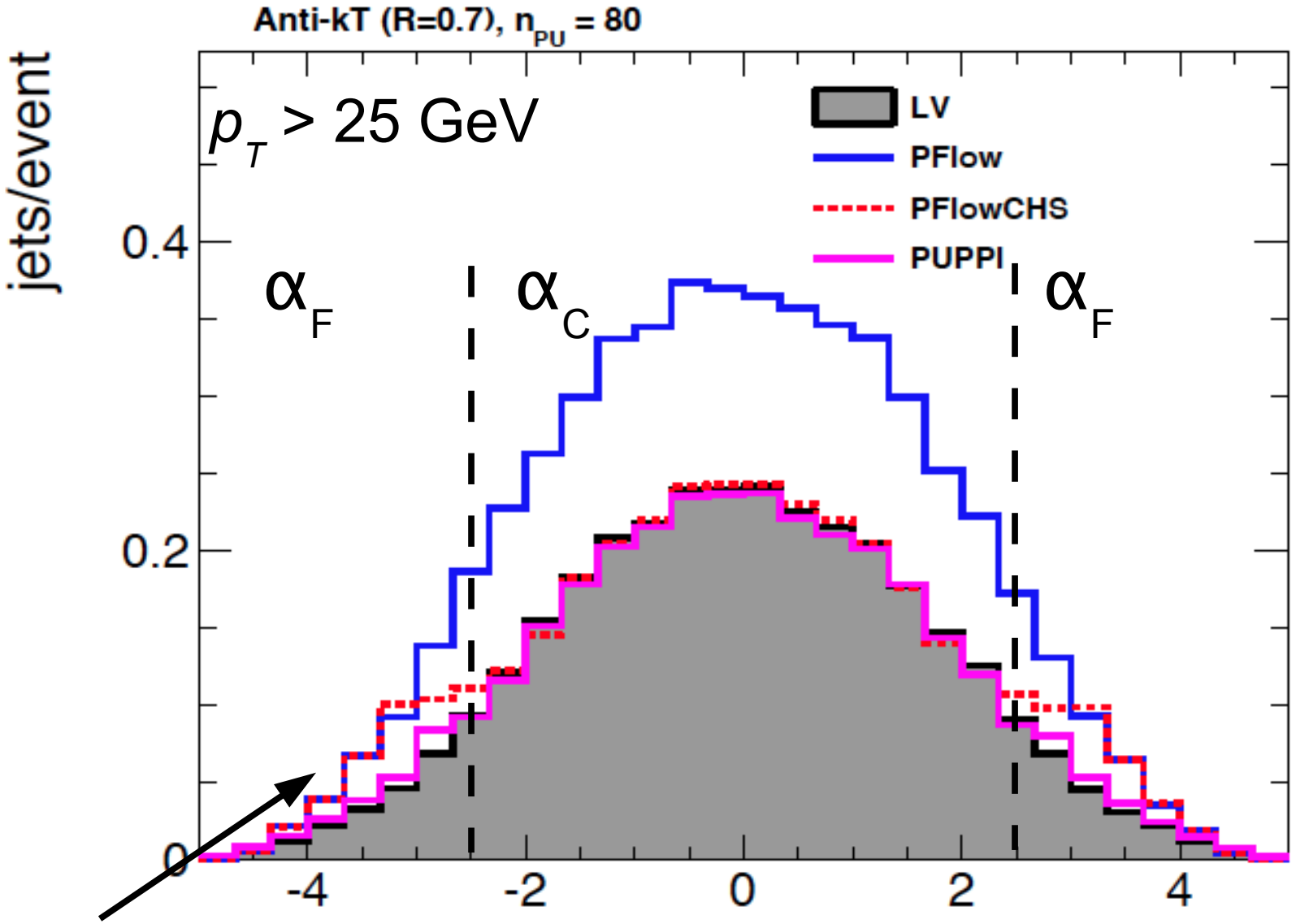
$$\text{forward: } p_{T,\mathrm{cut}} = 0.2\ \mathrm{GeV} + n_{\mathrm{PU}} \times 0.011\ \mathrm{GeV}$$

- Re-interpret the event

Puppi Performance

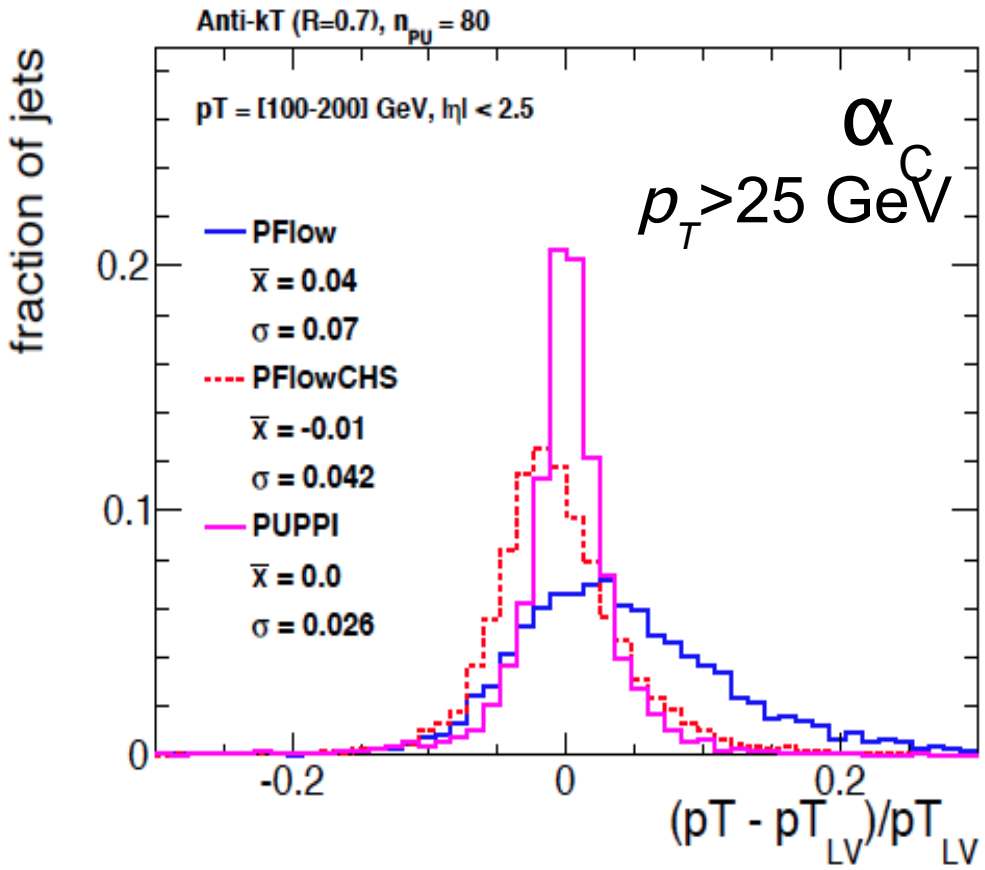


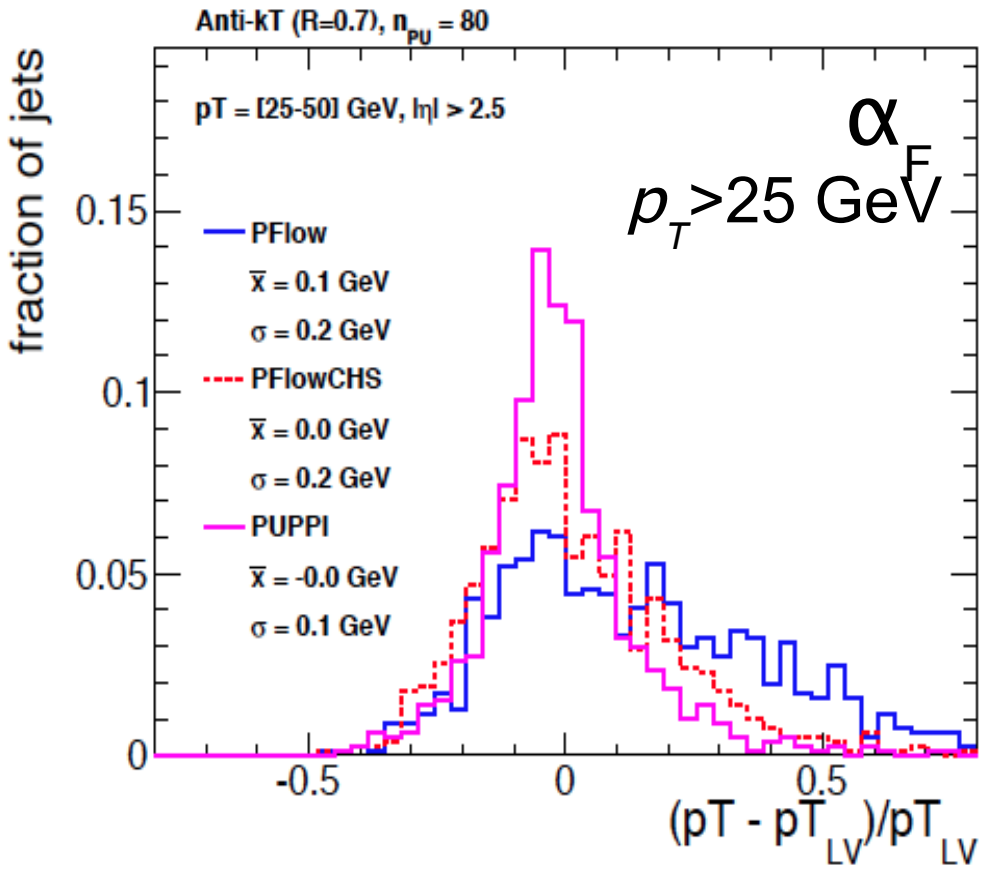
Performance of Pileup Jets



Pileup Jets are gone

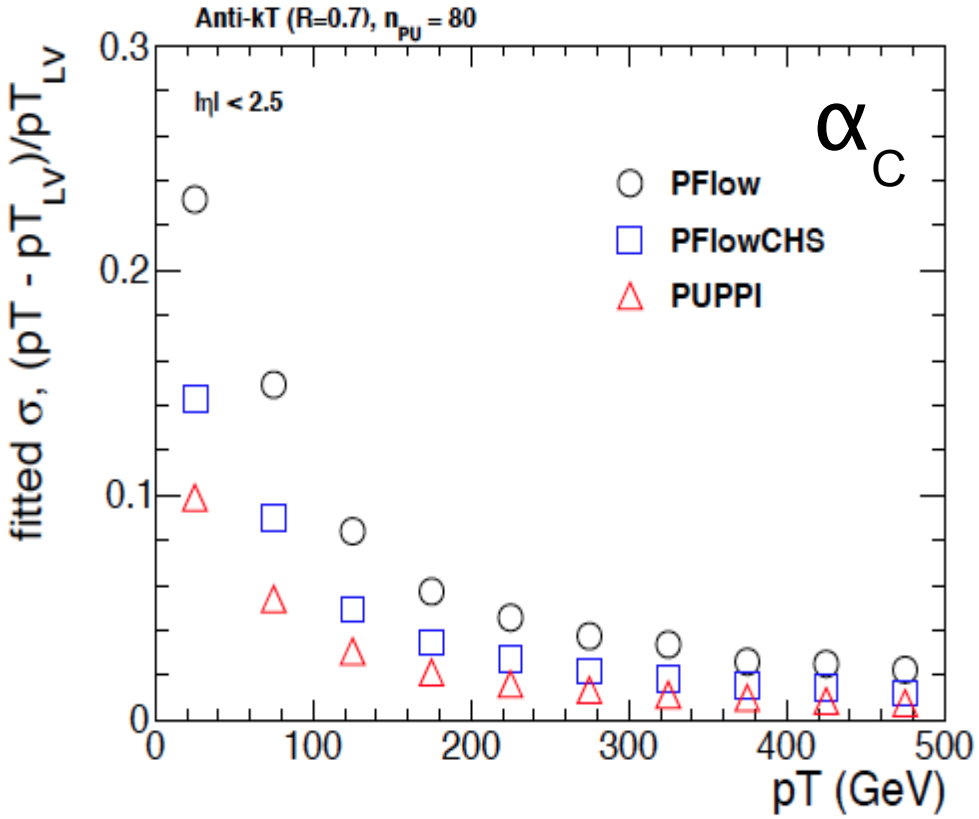
P_T Resolution From PU

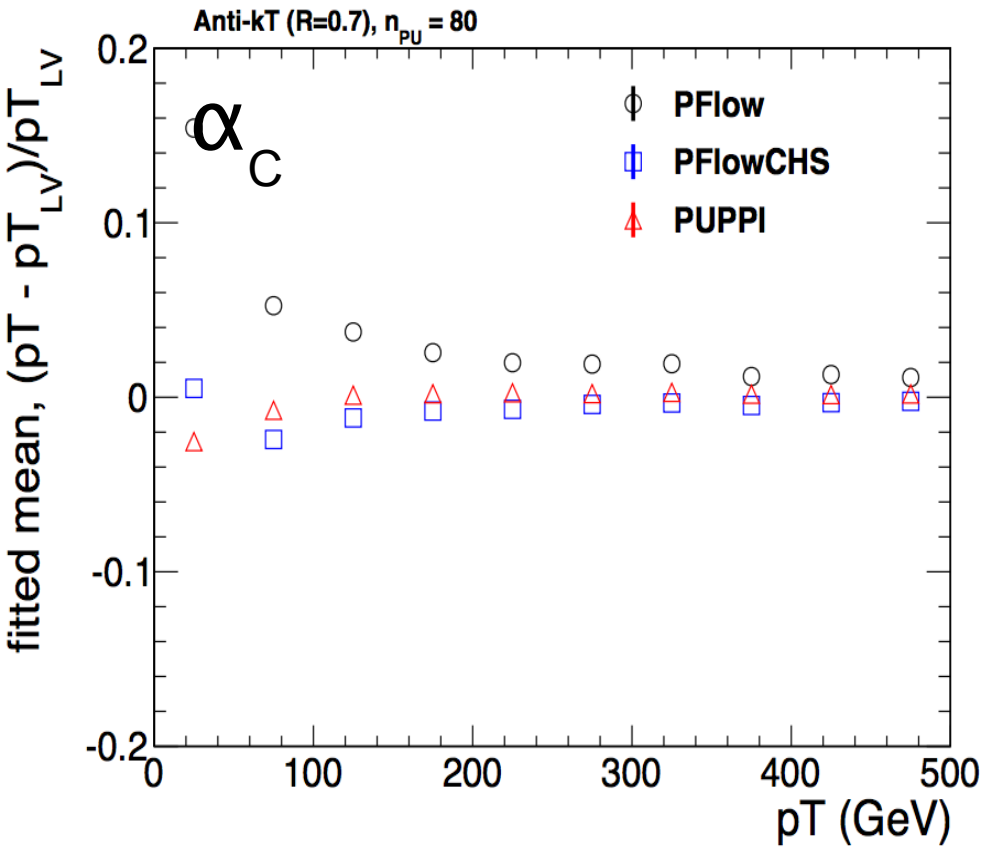




Impact of pileup on the pT resolution considerably reduced

P_T Performance From PU

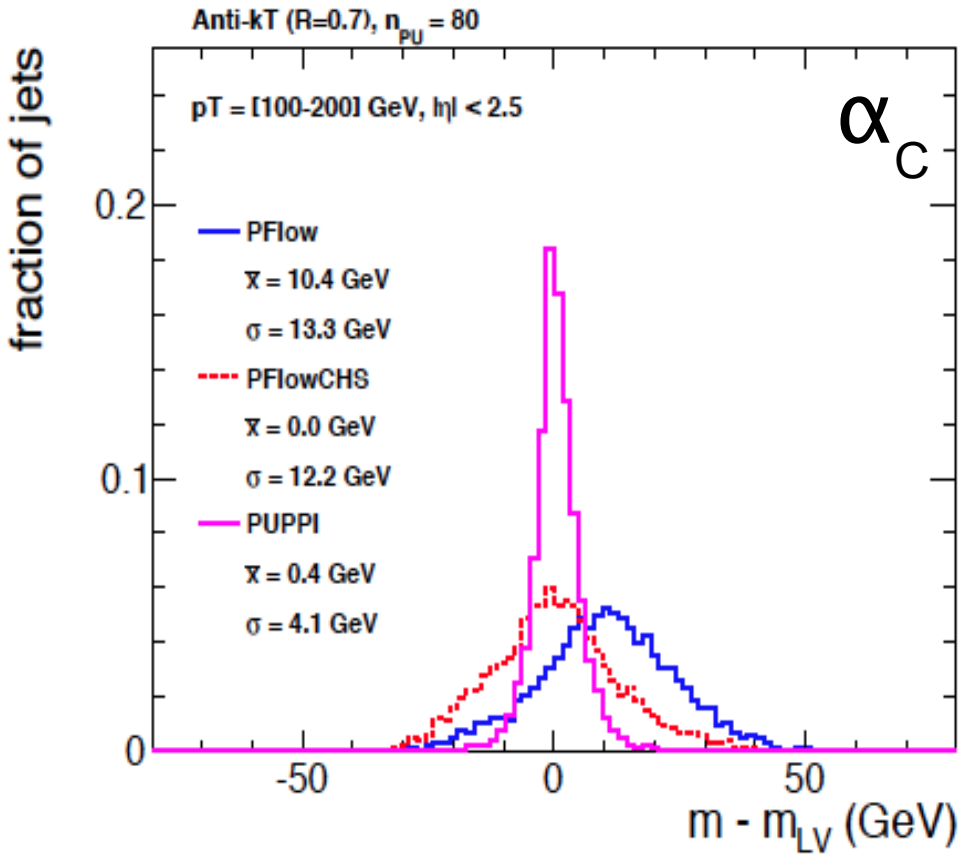


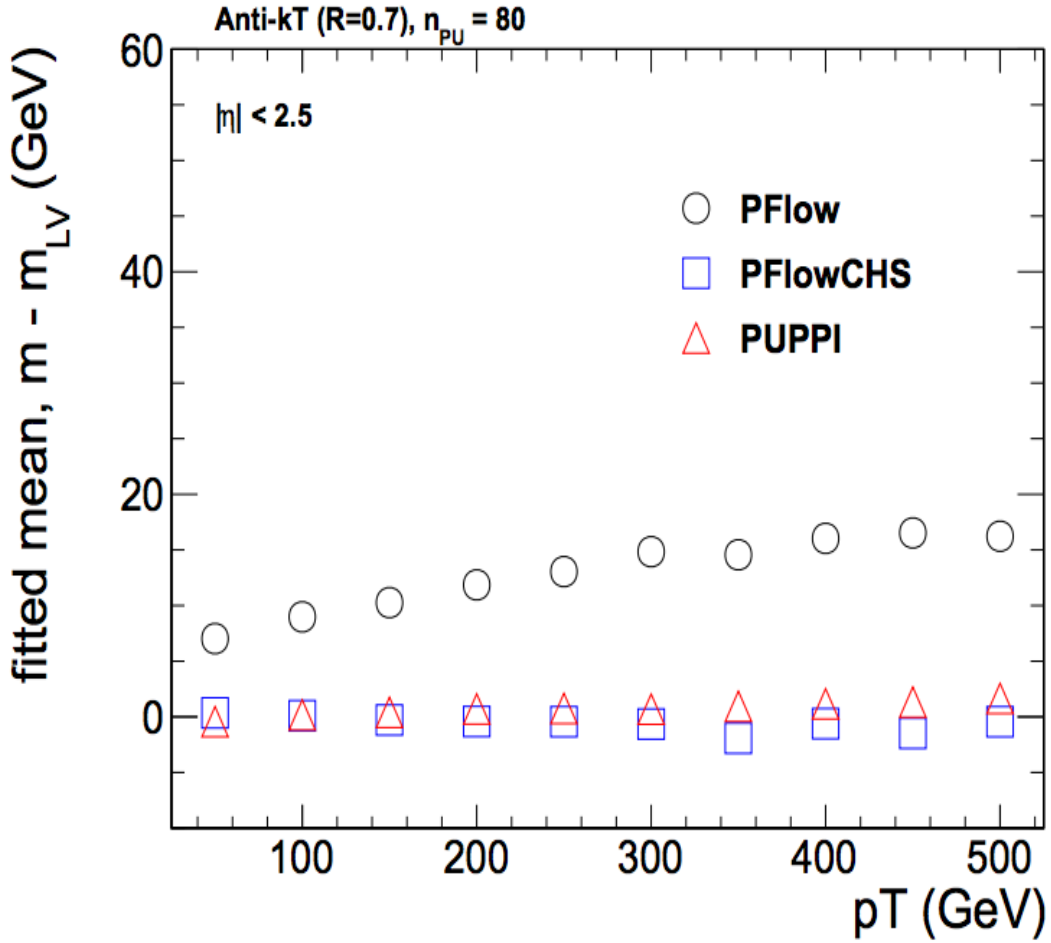


Response is flat over p_T

Resolution is better over p_T

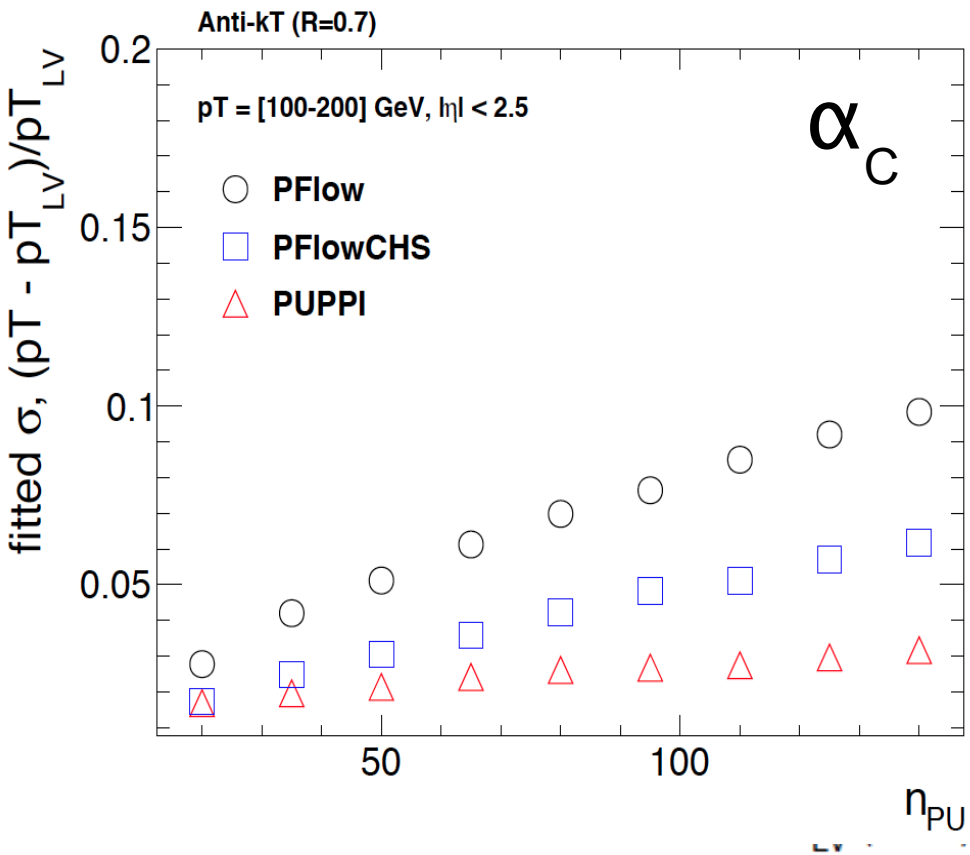
Mass Performance

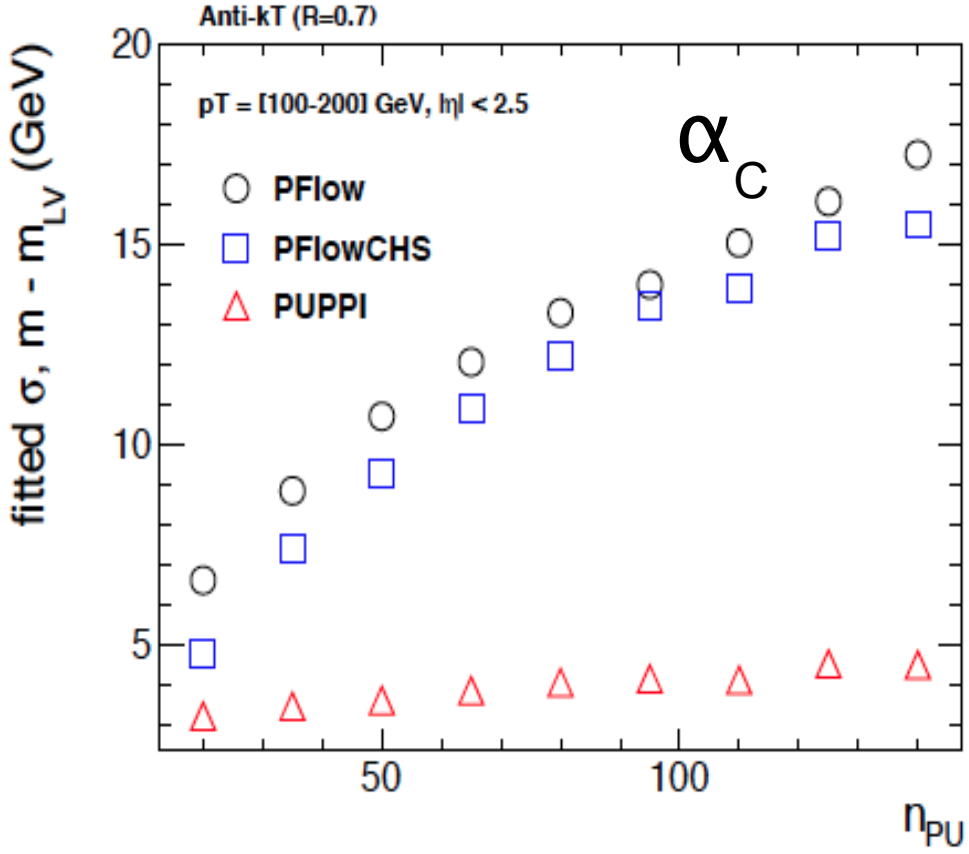




Mass Resolution is greatly improved
Mass Response is flat over pT

Performance Over Pileup





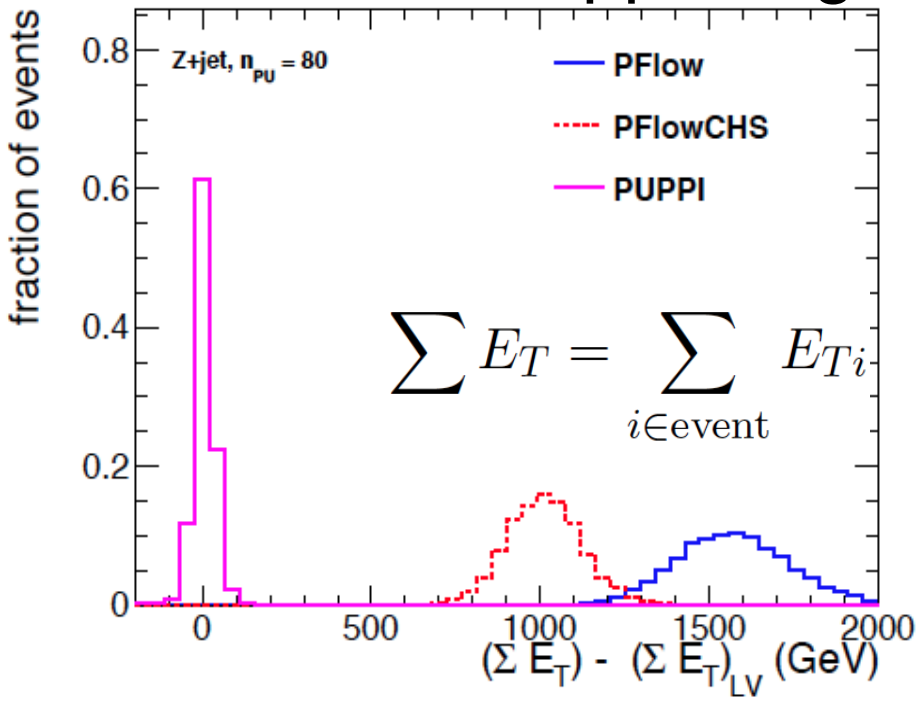
Performance over PU is reduced
Particularly strong for jet Mass

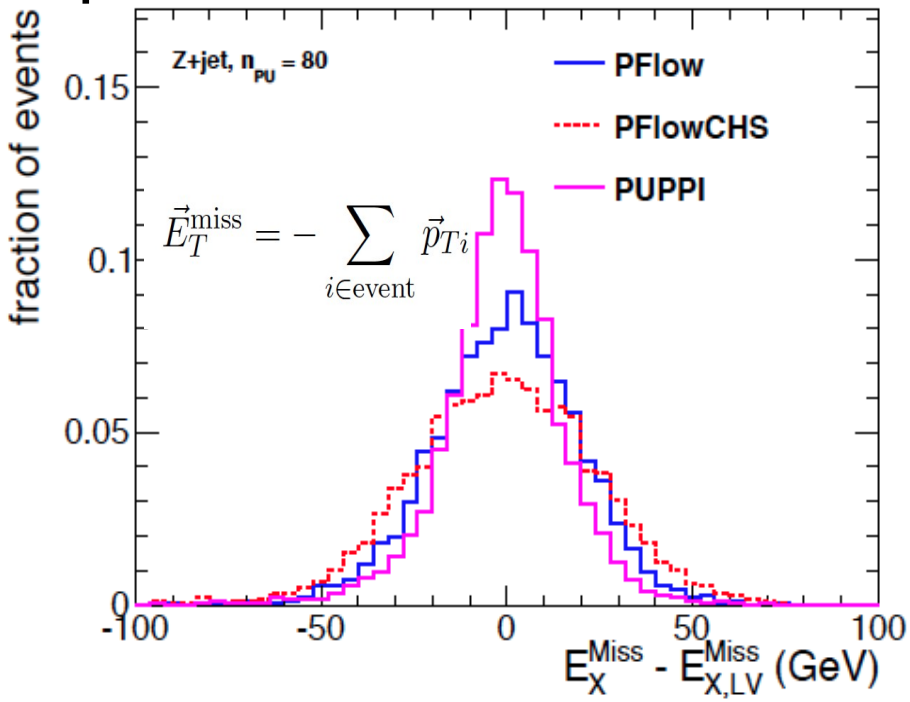
Puppi Usage Outside of Jets

- iPuppi :
  - Isolation w/puppi-weighted particles

    iPuppi= $\Sigma_{\Delta R}\, w_i p_{Ti}$

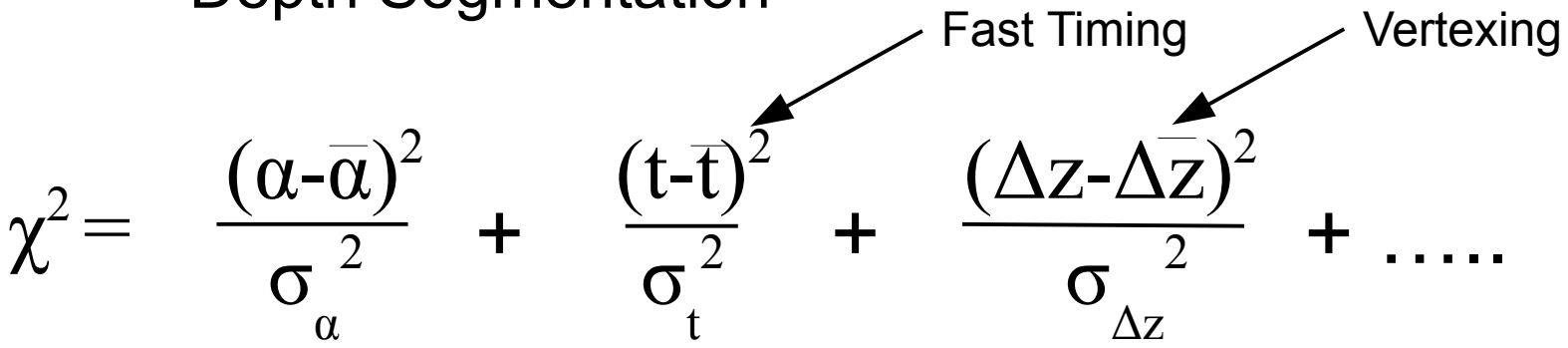
- Pupp$\not{E}_T$
  - *MET* with Puppi weighted particles





Further Extensions

- χ^2 to weight approach is very generic
  - Used to extend with experimental approaches
    - Fast Timing
    - Depth Segmentation



- A more complicated scheme MVA?!
  - aka Puppies
- An analytic understanding of best metric
  - IRC safety due to ΔR_{min}

Conclusions

- Demonstrated a new approach to pileup subtraction
  - Good performance on jet properties
    - Both Jet p_T and Jet Mass
- Works on the per-particle level
  - Clustering and event variables can be performed after
- Puppi is not set in stone
  - Framework for pileup approaches
- Give the puppi a bone!

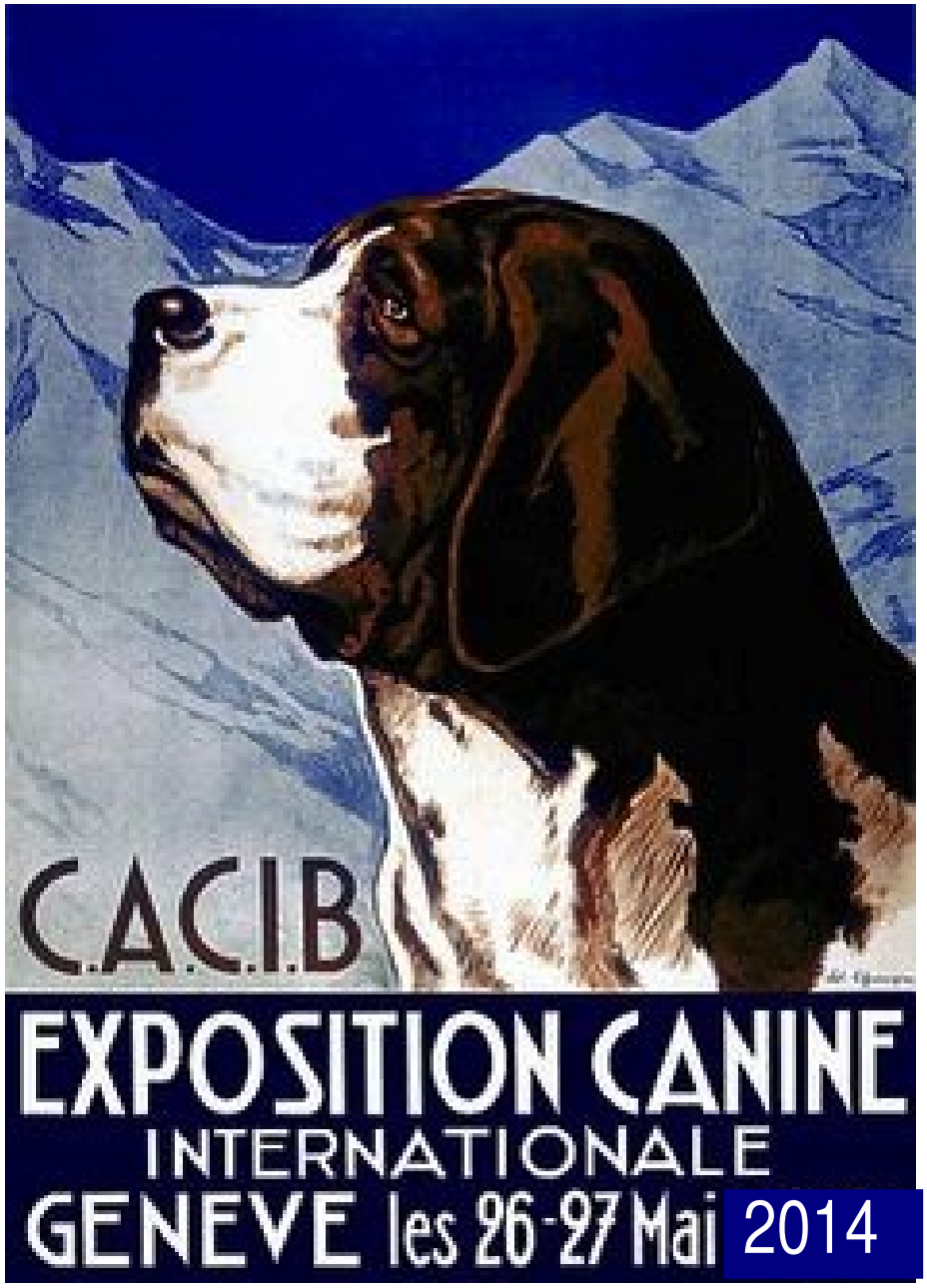
Thanks!

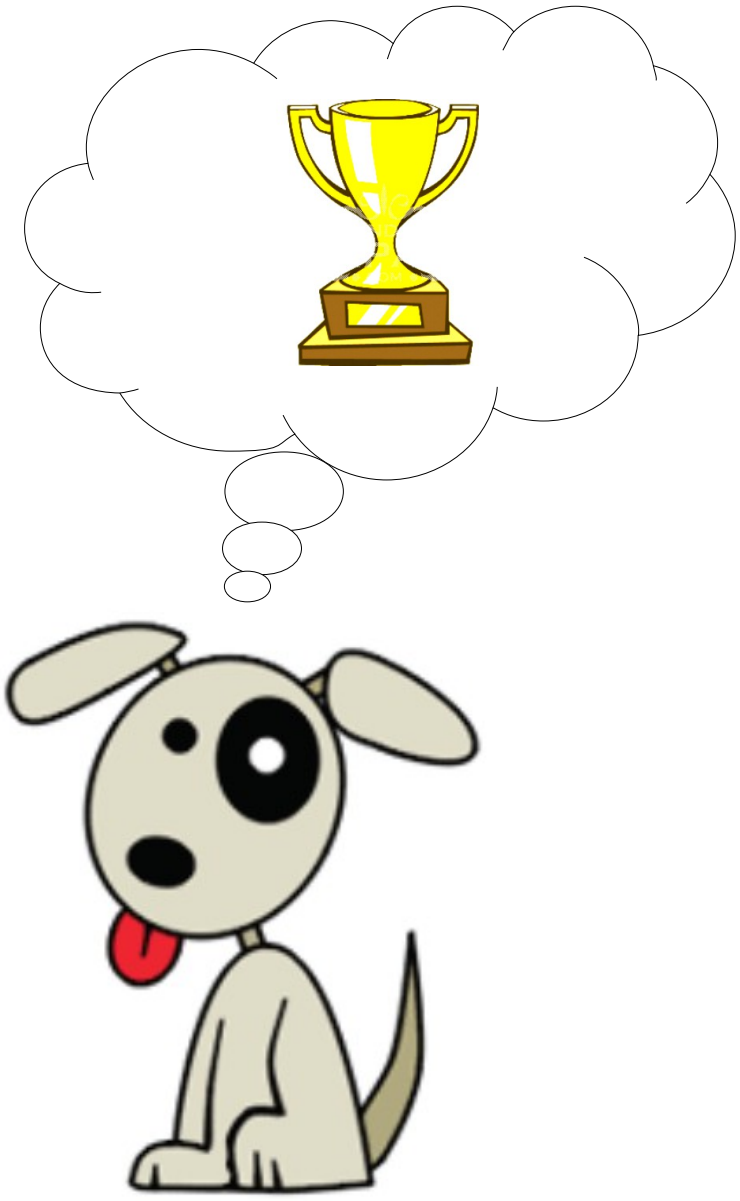
Jeff Berryhill, Matteo Cacciari, Dinko Ferencek, David Krohn, Andrew Larkoski, Filip Moortgat, Salvatore Rappoccio, Gavin Salam, Matthew Schwartz,Gregory Soyez, Jesse Thaler, and Lian-Tao Wang

Special thanks to PU Workshop

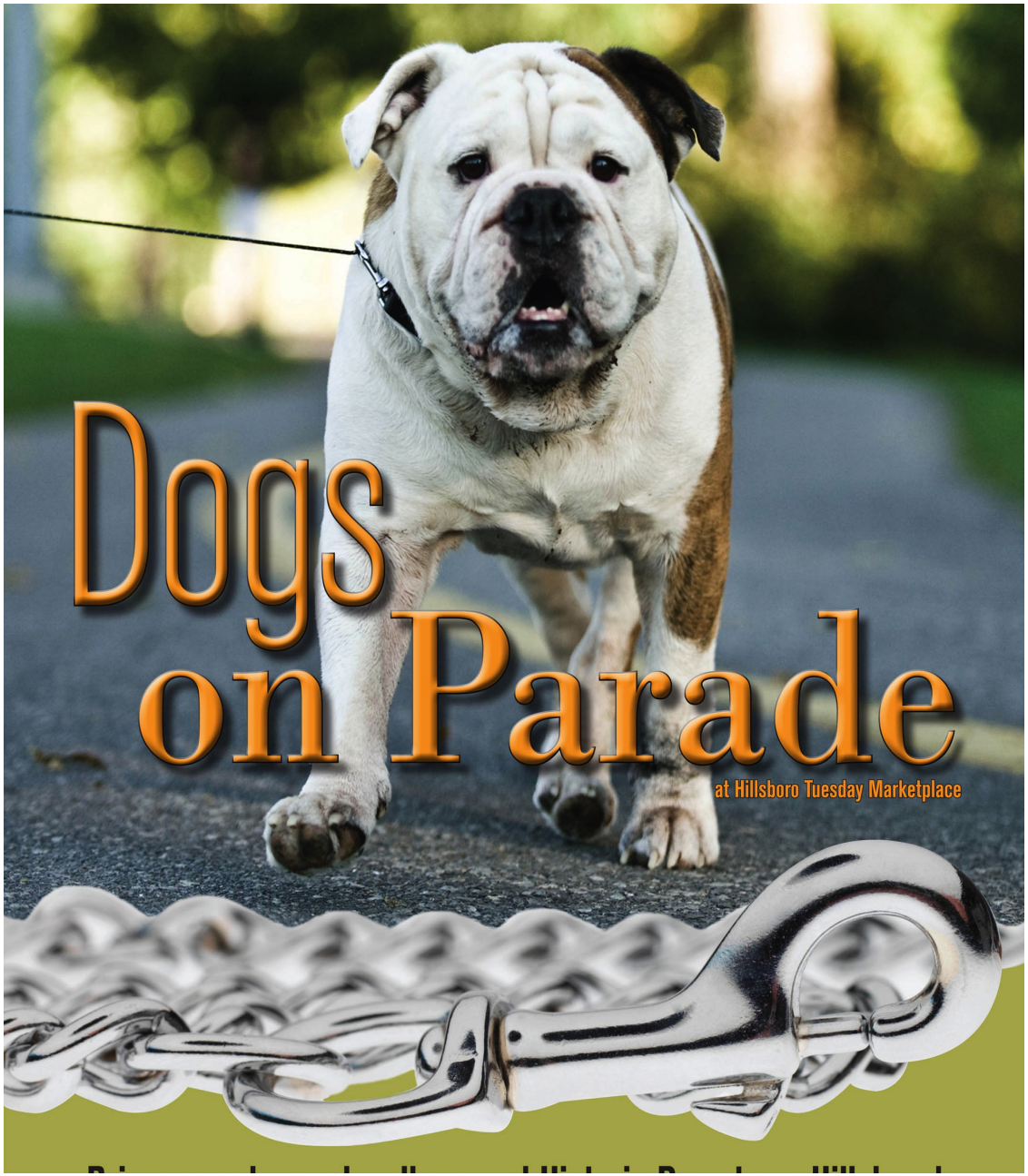
Ariel Schwartzmann,Filip Moortgat,Gavin Salam

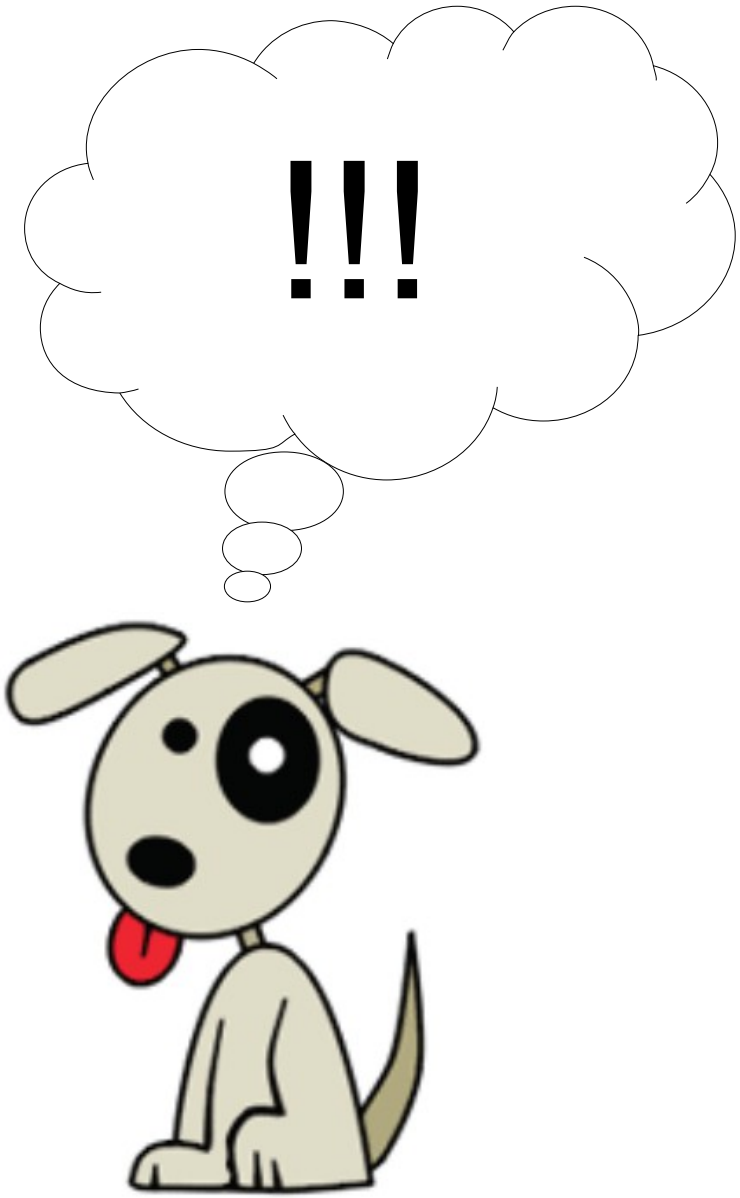
Puppi Performance



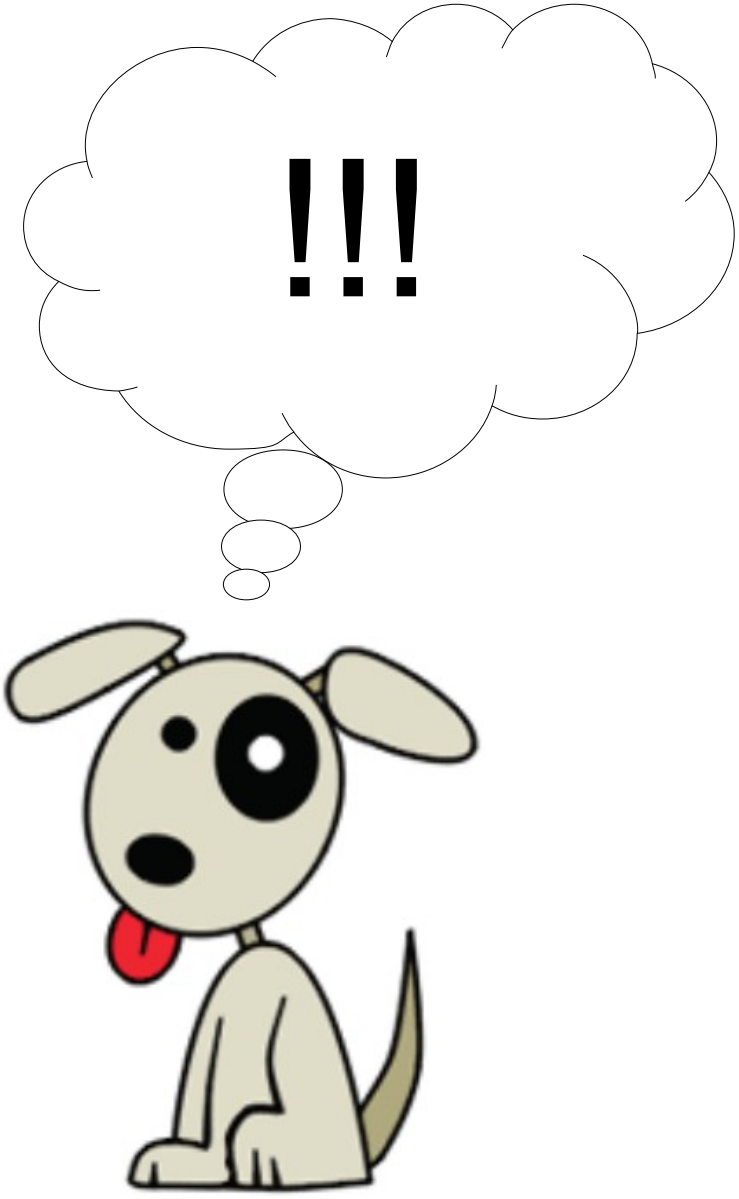


Puppi Performance





Puppi Performance



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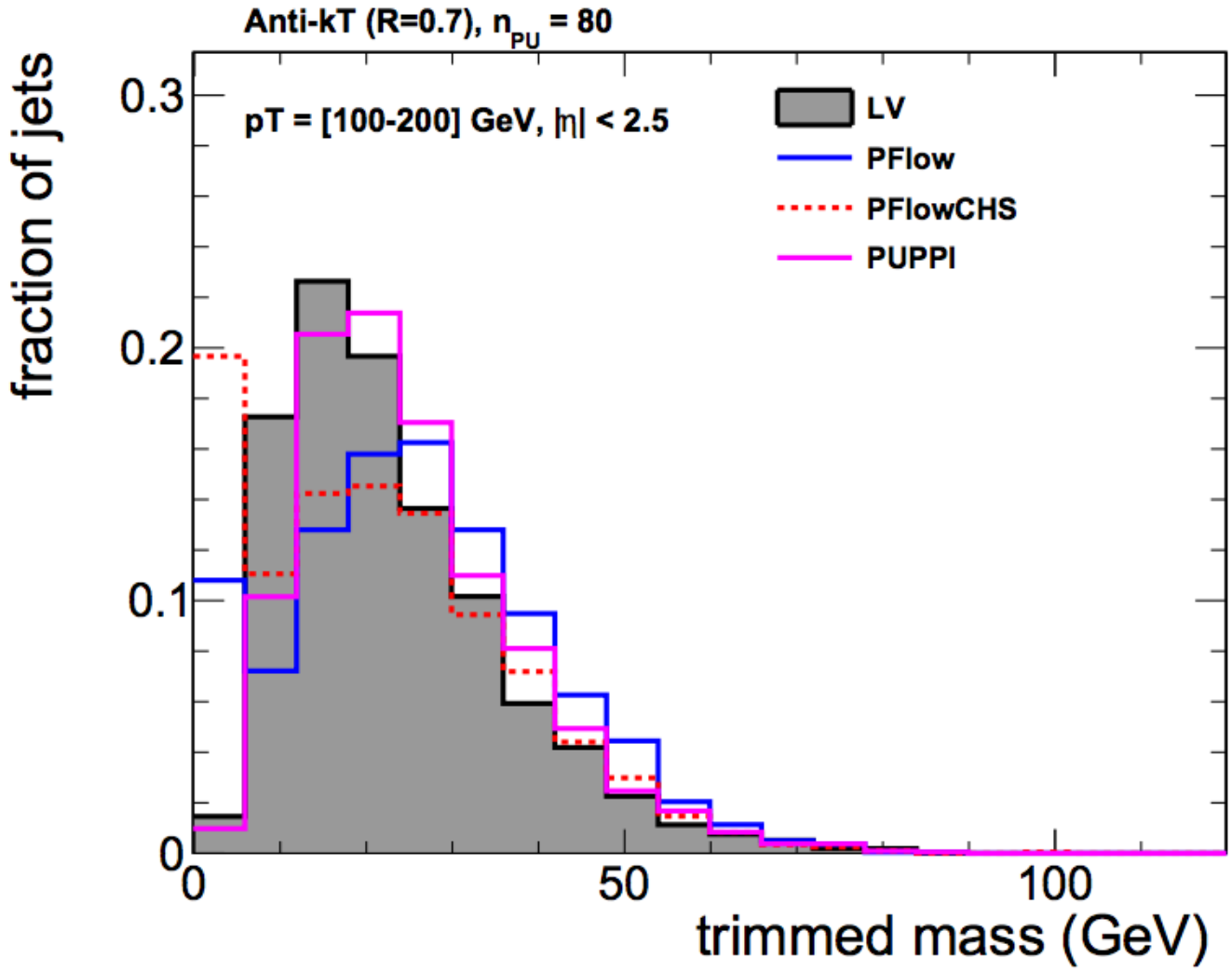
- Diffferential ρ : hep-ph/1211.2811
- JVF : ATLAS-CONF-2014-018
- PU Jet Id : CMS-PAS-13-005
- Cleansing : hep-ph/1309.4777
- HF/Voronoi : CMS-DP-2013-018
- NpC/Safe Subtractor : hep-ph/1404.7353
- Constituent subtraction : hep-ph/1403.3108

Jet Grooming and Puppi

- Puppi Grooming is possible and works well



More Realistic Pileup