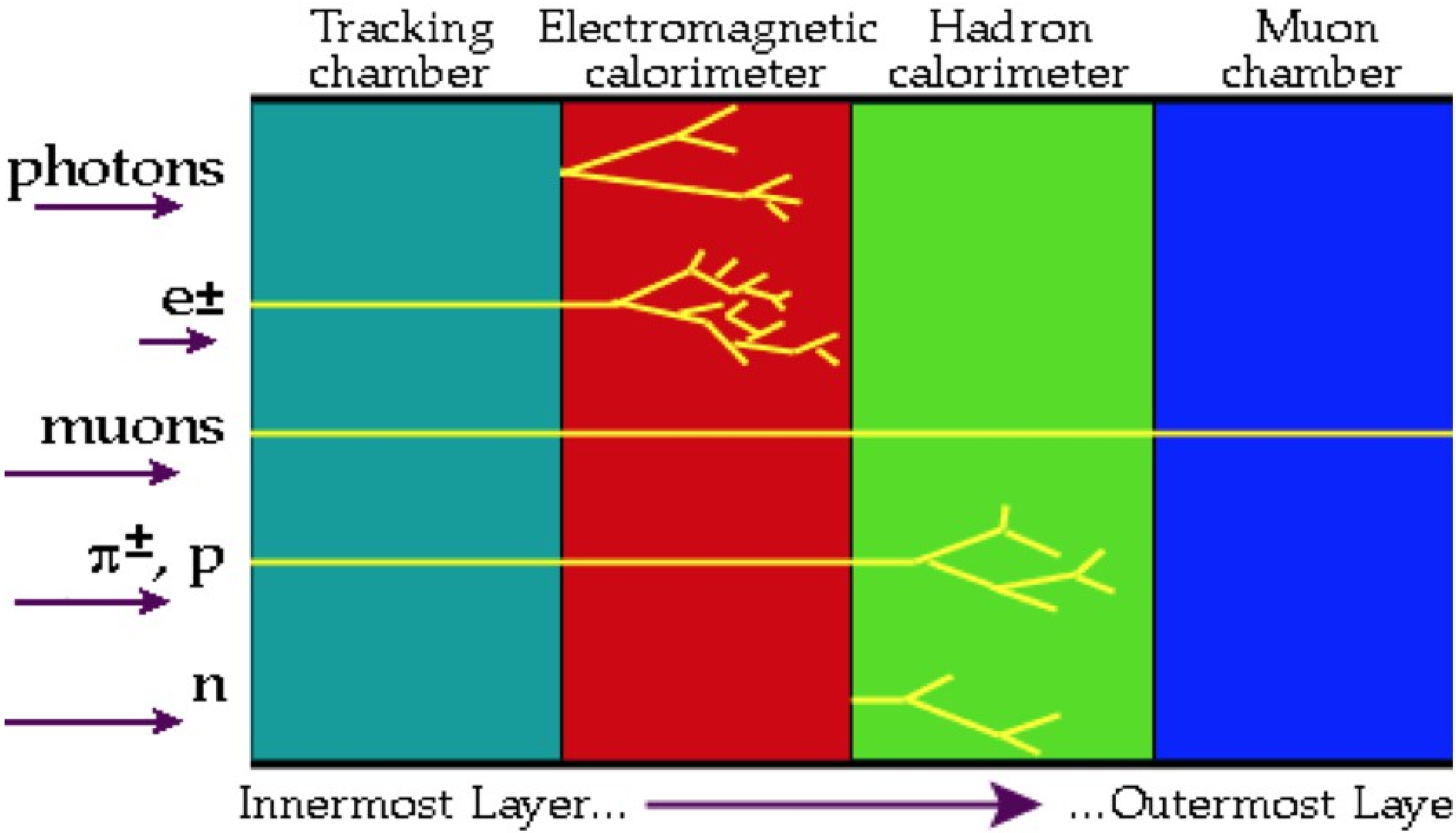
Reconstruction

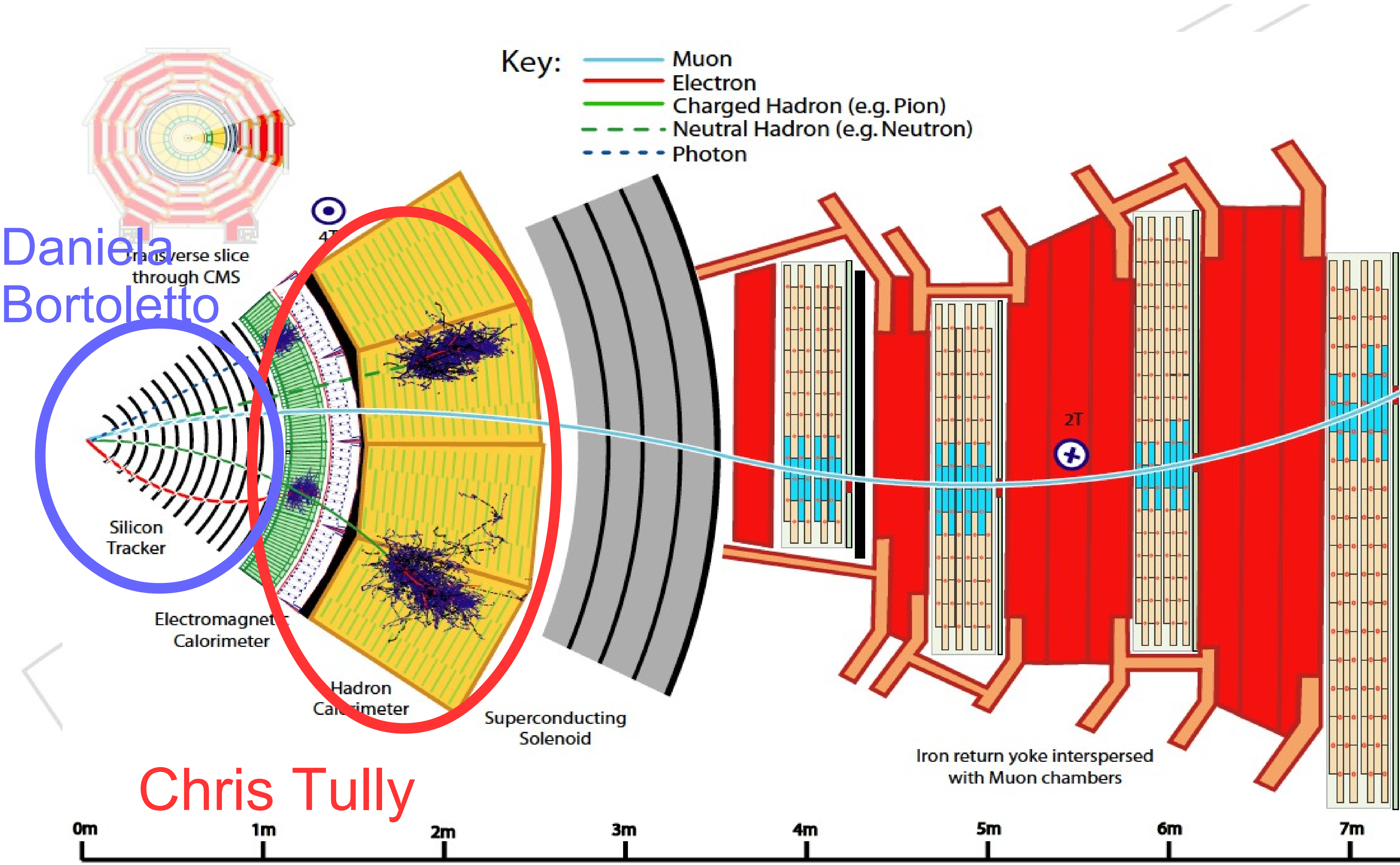
P. Harris

Particle Identification Basics



Credit: Particle Data Group (LBNL)

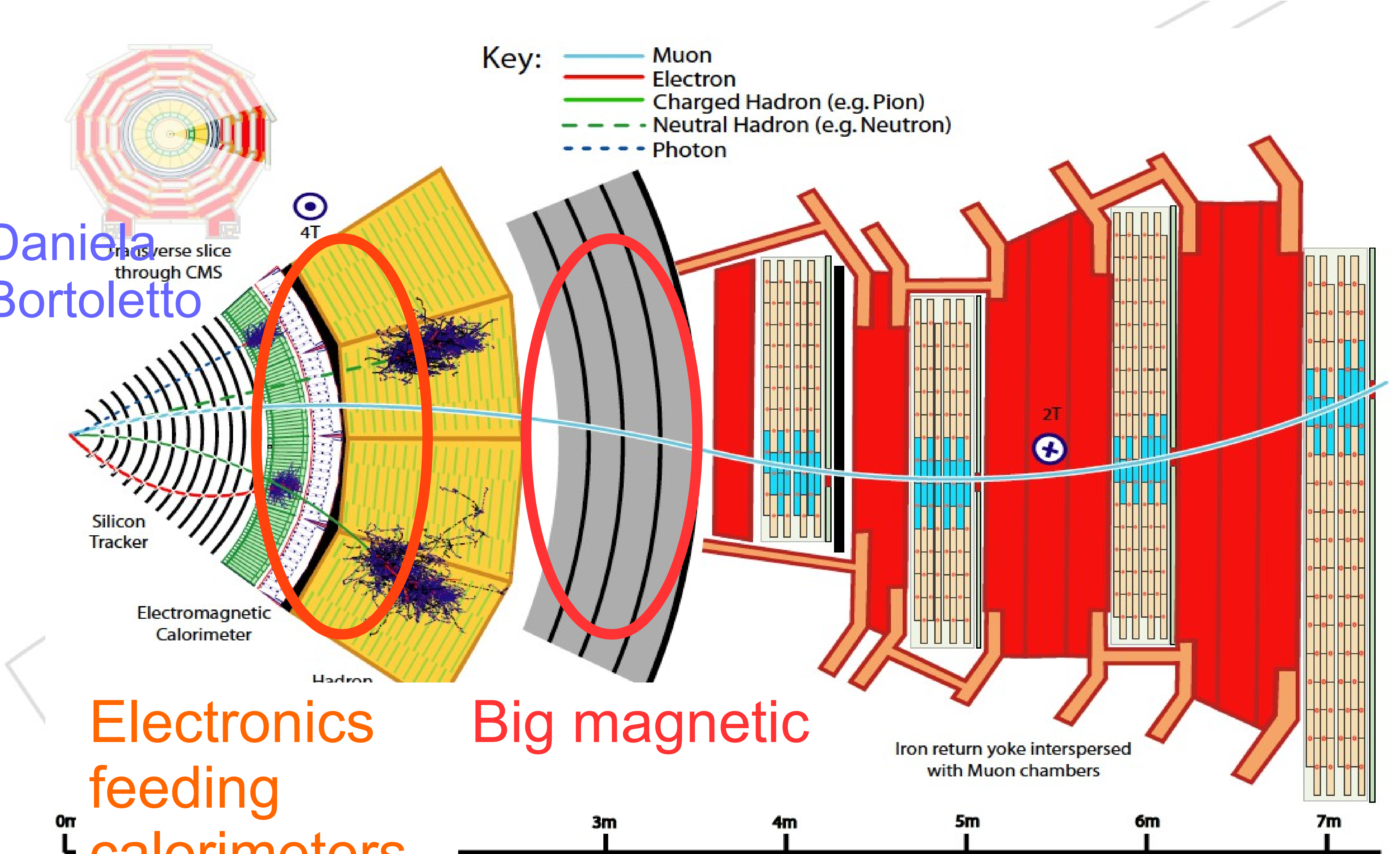
Over the past week you have seen the individual components



What if we start to link things together?

We have to account for the other detectors

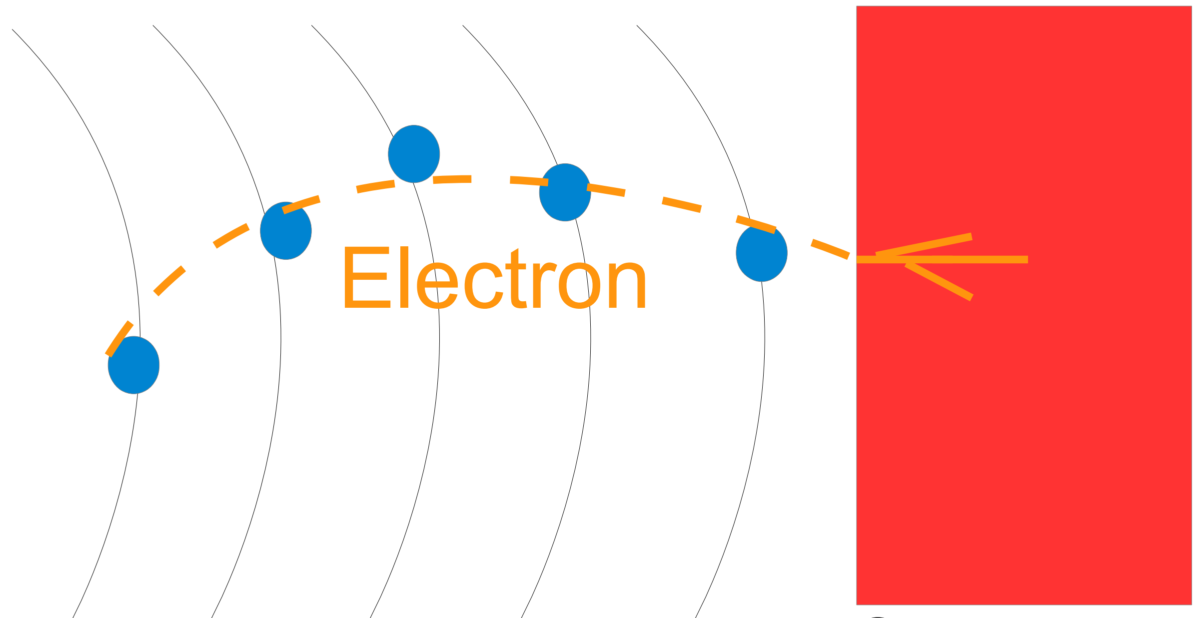
Daniela Bortoletto

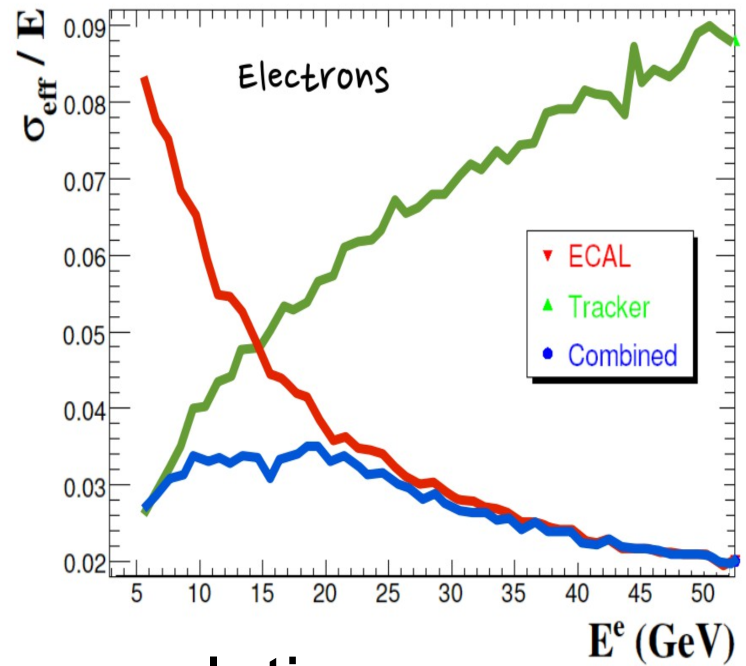


Electronics feeding calorimeters

Big magnetic

What if we link our components





Track resolution

$$\frac{\sigma(p_T)}{p_T} = \frac{\sigma_x p_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}$$

Calorimeter resolution

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.8\%}{\sqrt{E}}\right)^2 + \left(\frac{12\%}{E}\right)^2 + (0.3\%)$$

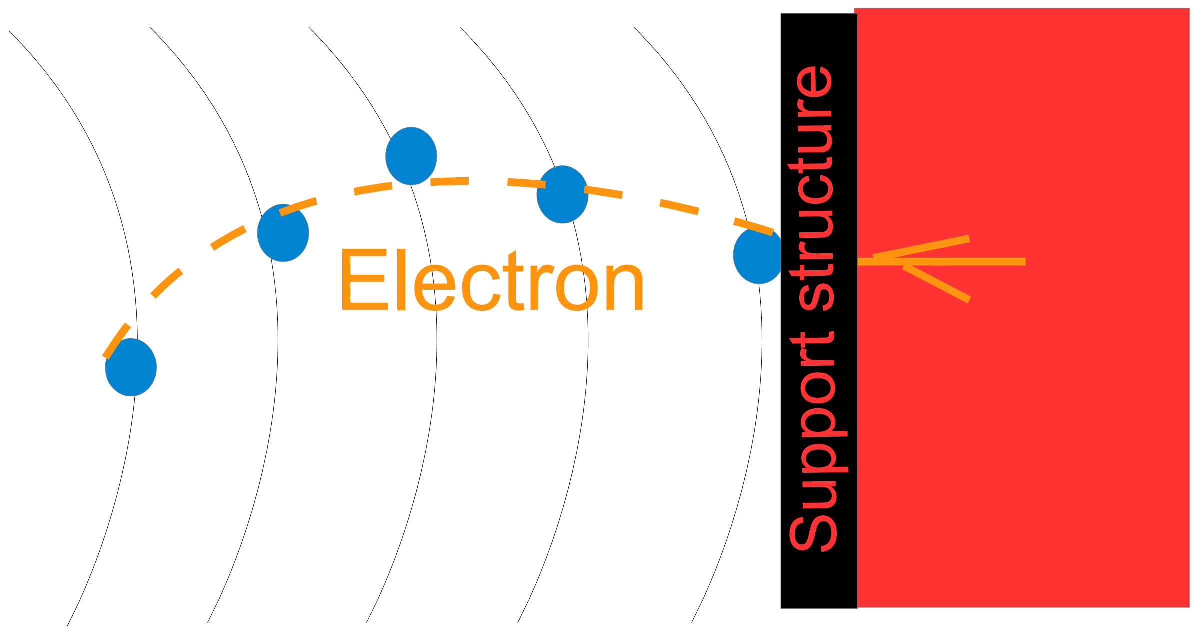
Measurement #1

Measurement #2

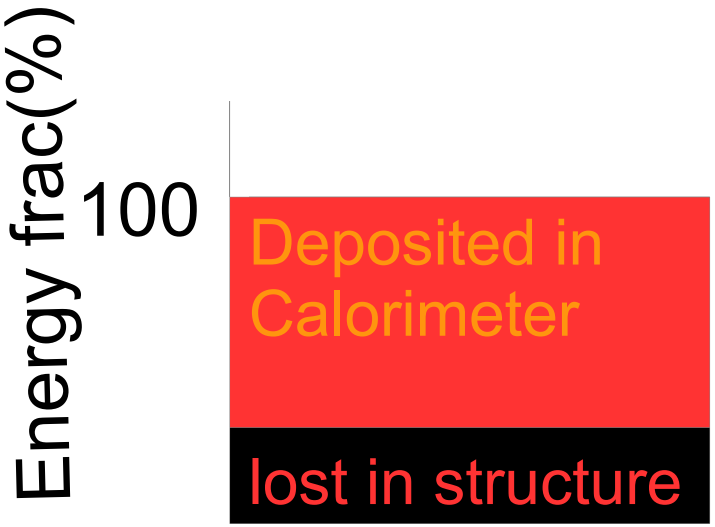
The combined “best” measurement

Particle flow concept

- Linking however requires us to be realistic

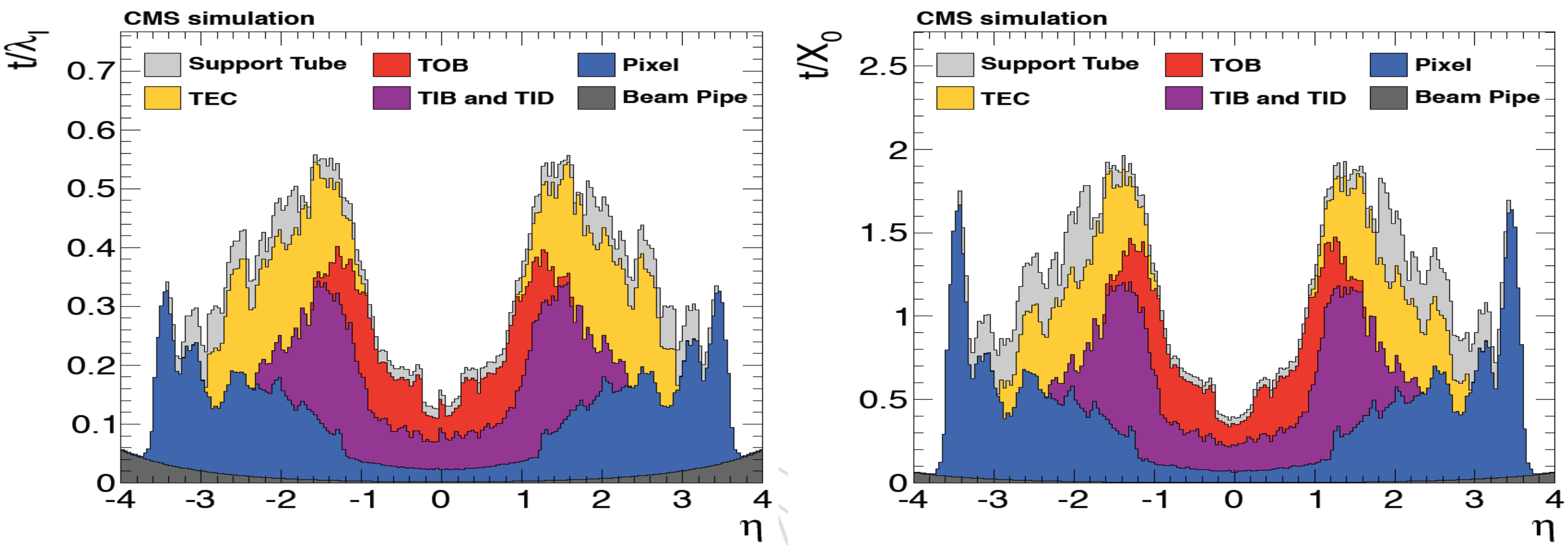


Electron Track p_T =

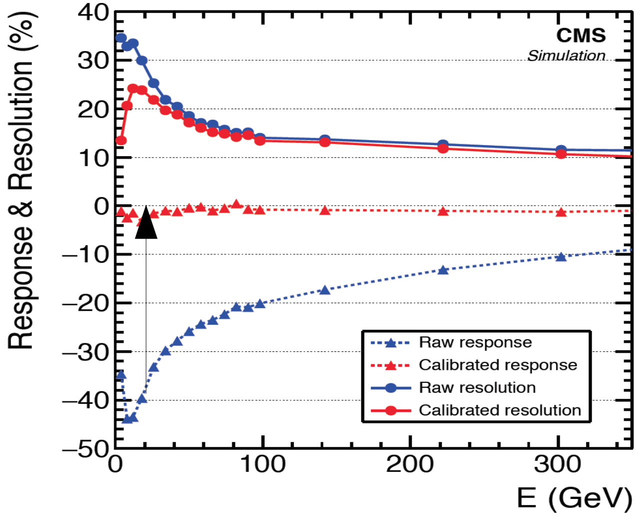


Calibrating for Missing informaiton

- Step 1: Measure your electronics material

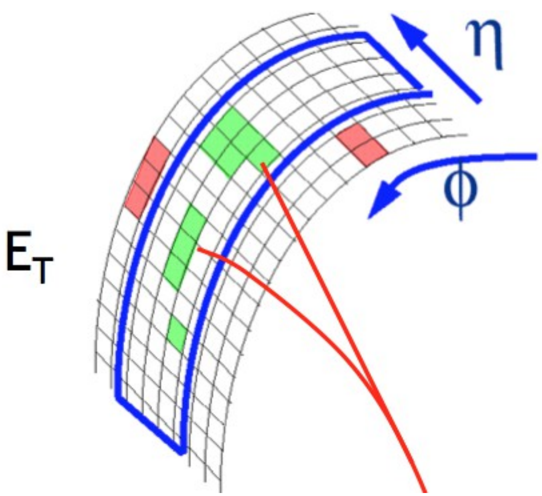


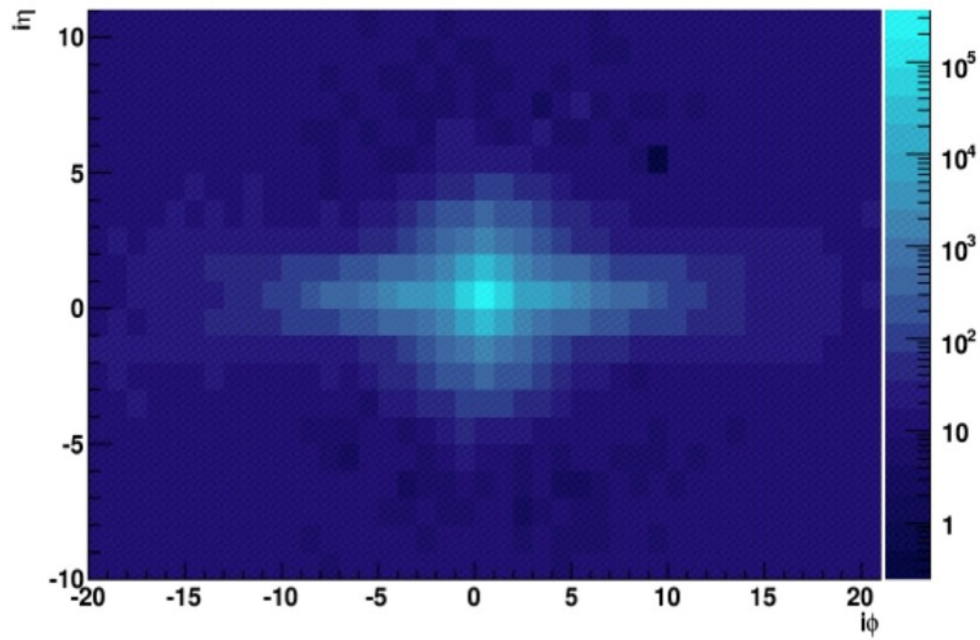
- Step 2 : Add this into your simulation
- Step 3 : Compute the average loss
- Step 4 : Correct it

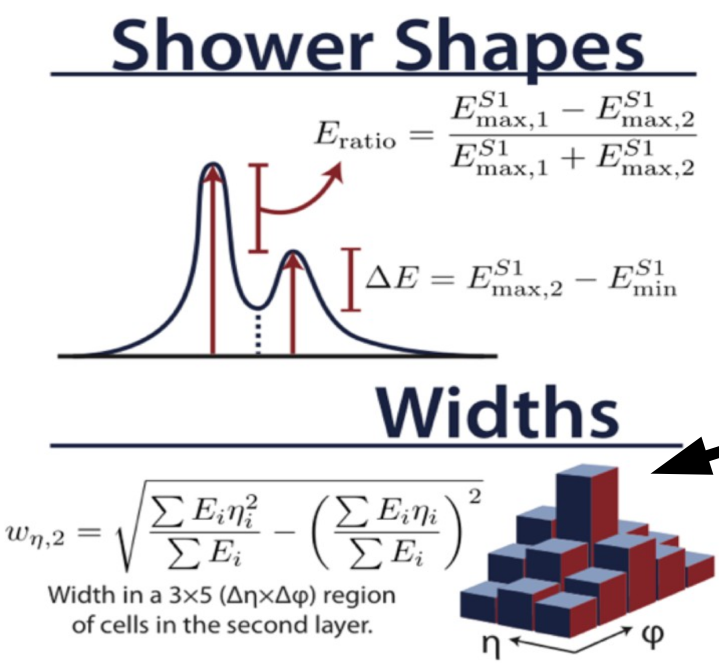


Can we use more info?

- What if we take the full info of the Ecal cluster

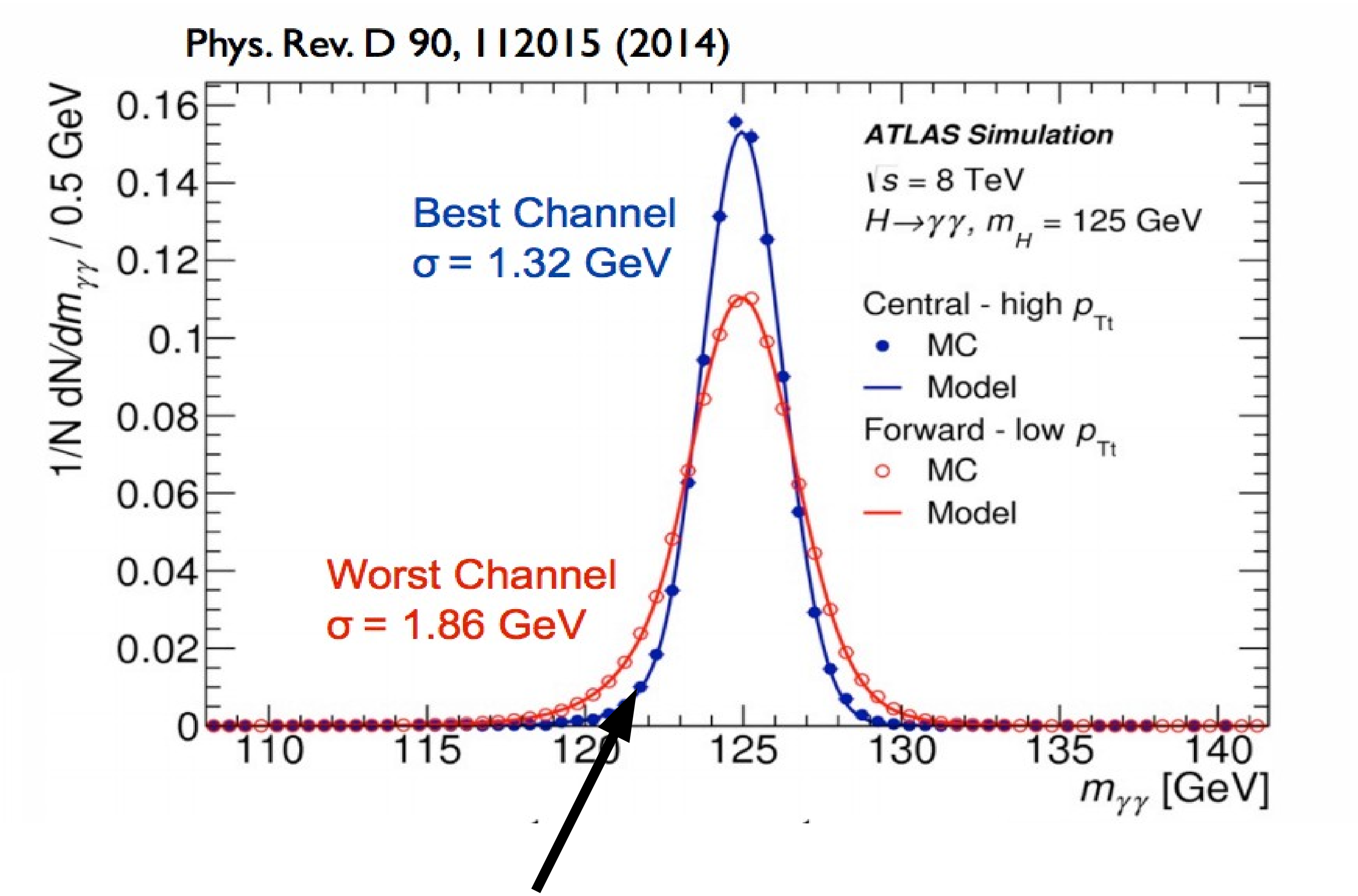






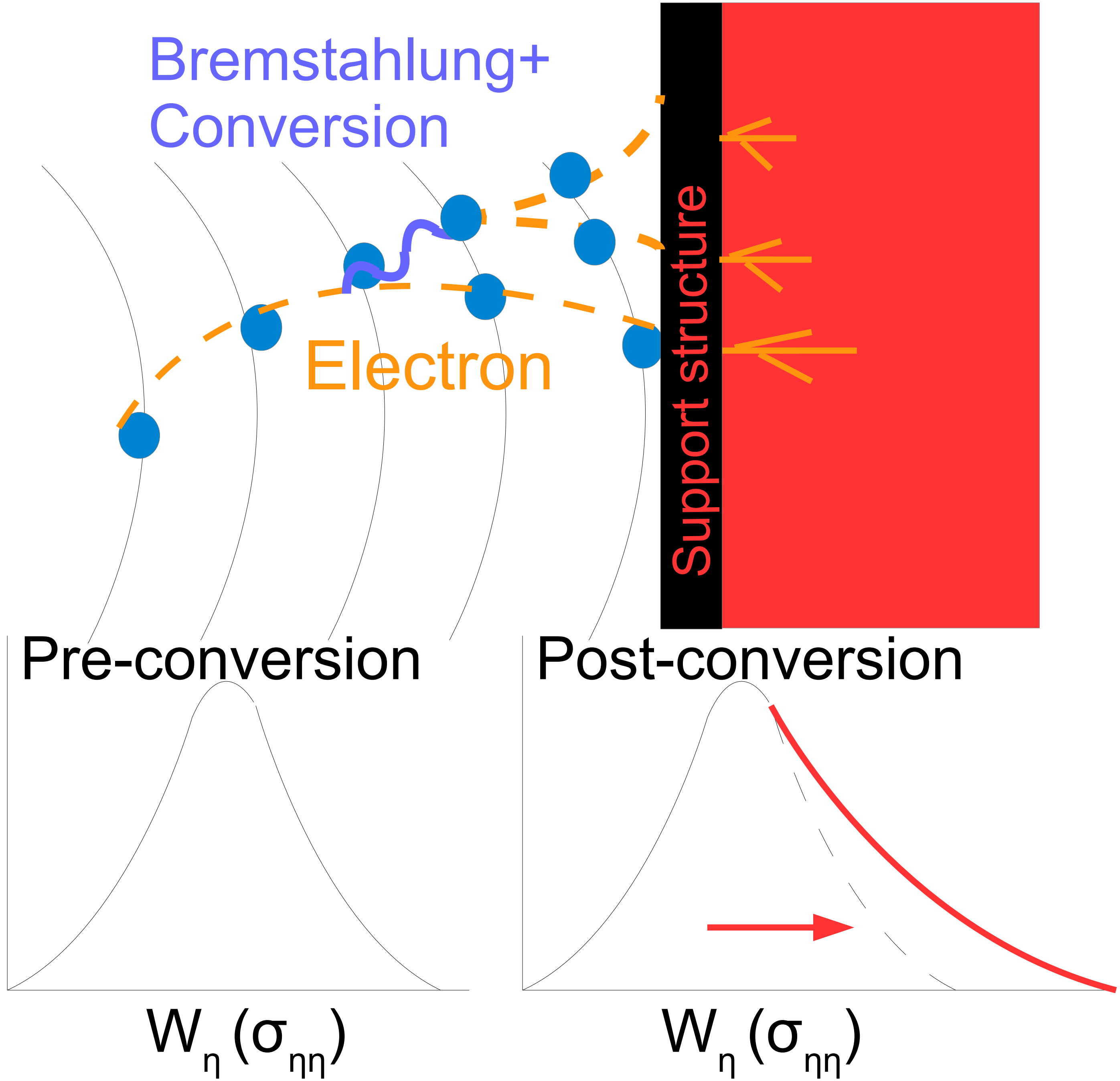
Consider the width of an Ecal shower (aka RMS of ECAL shower)

One Encouranging View



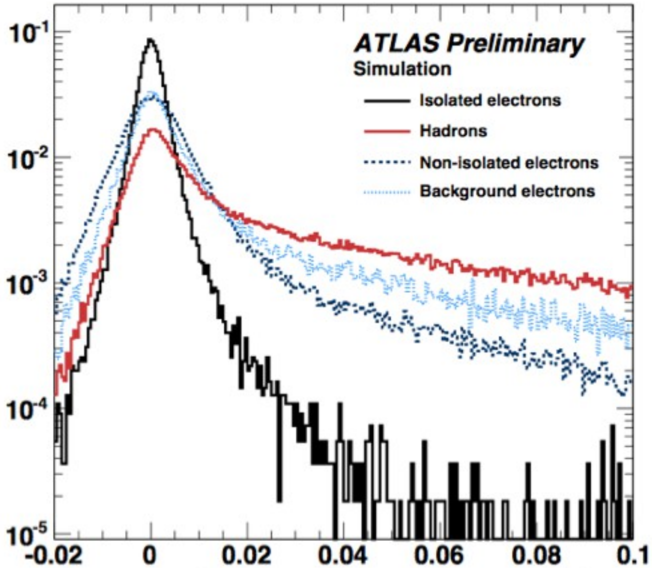
If we adjust the cuts on the shower parameters
Can improve the photon shower performance

More complicated effects

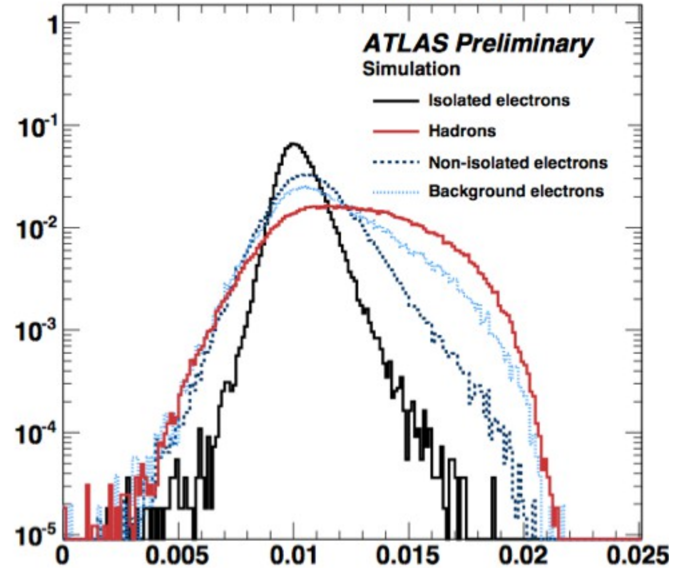


More Sophisticated Calibration

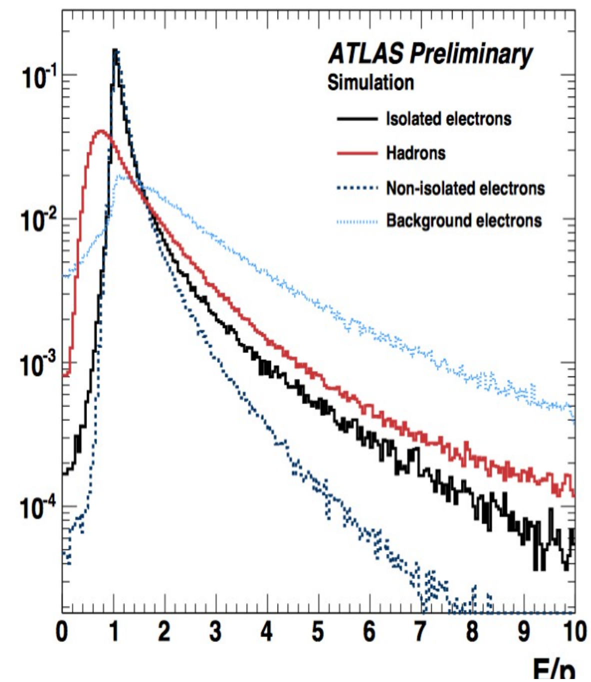
From J. Alison

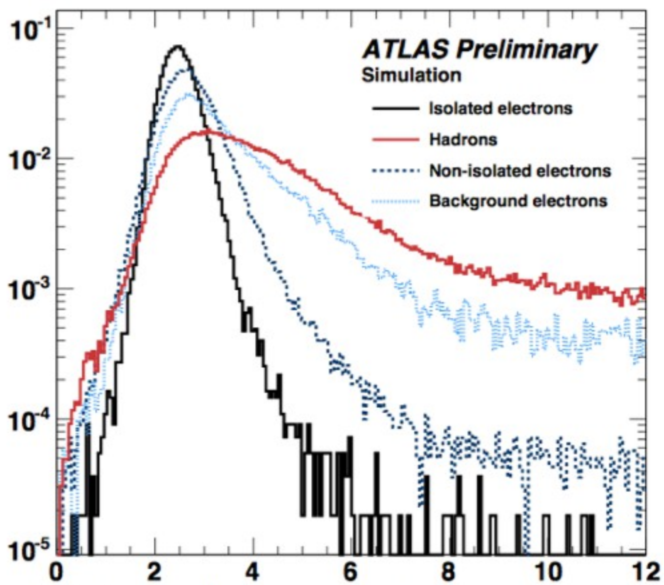


leakage fraction into HCAL R_{had1}

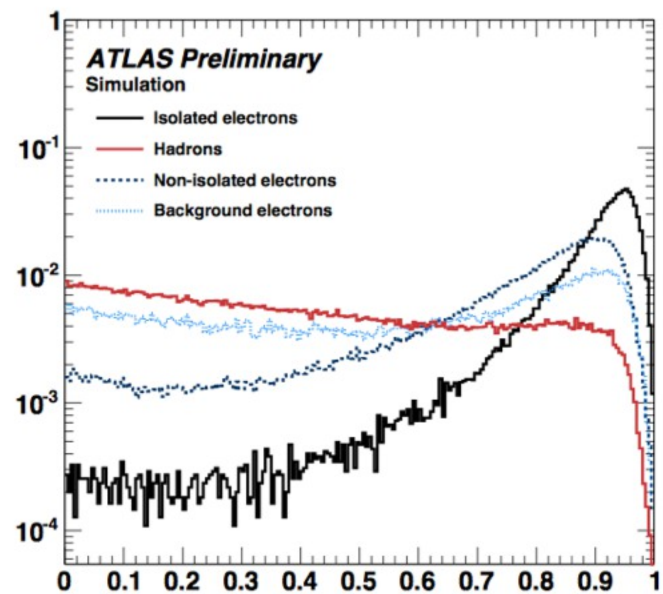


shower width $w_{\eta 2}$



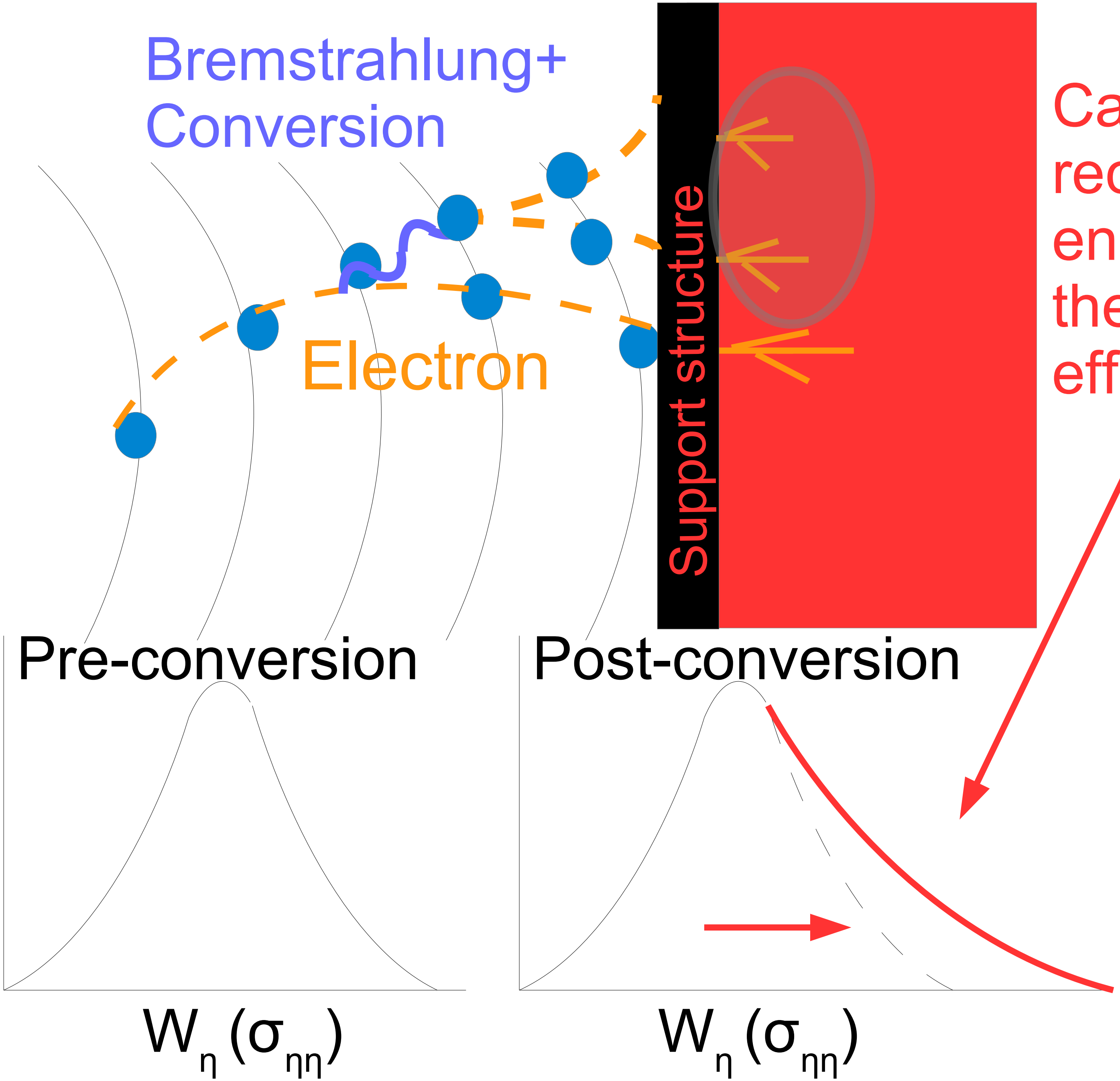


Width (2nd moment) in strips w_{stot}

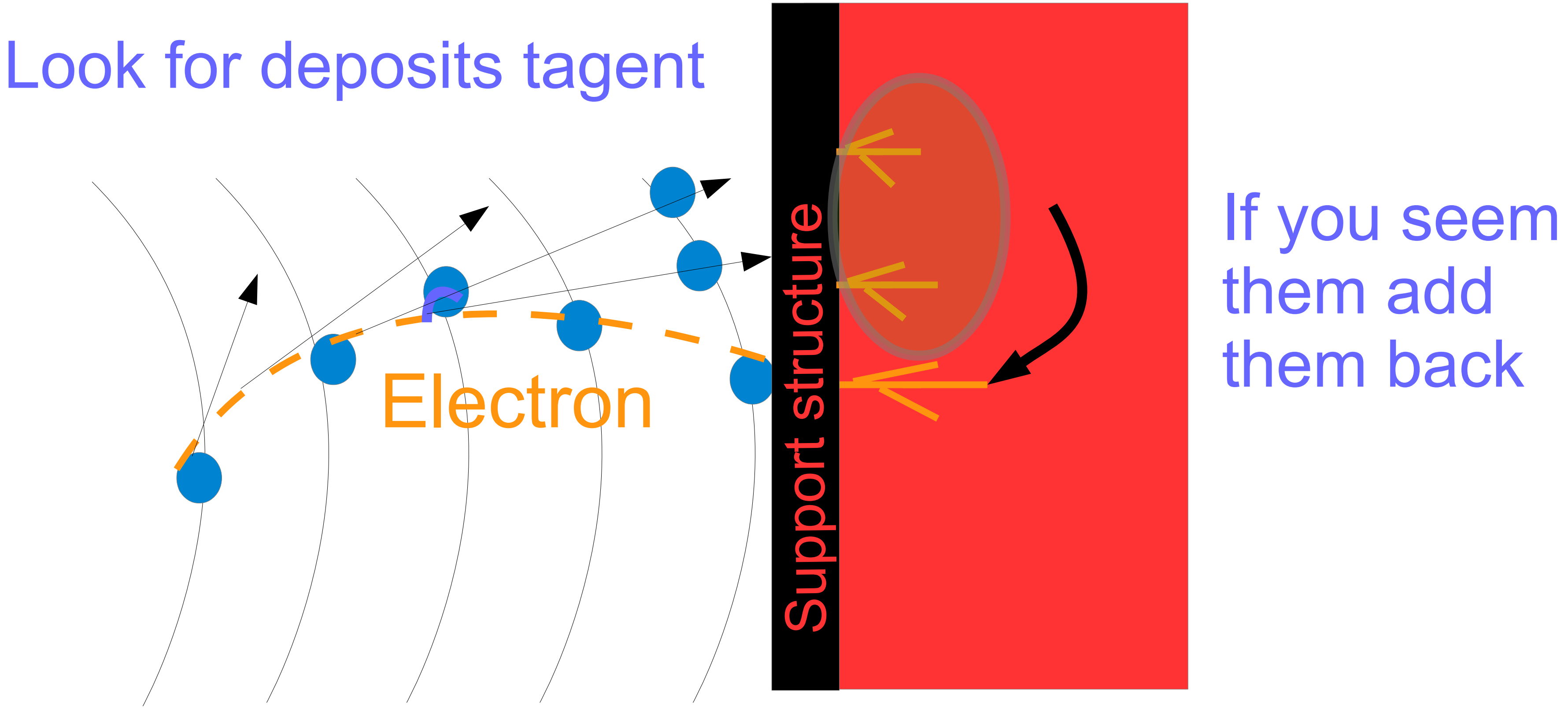


Difference in 2 highest E strips E_{ratio}

More complicated effects



Simplest Approach

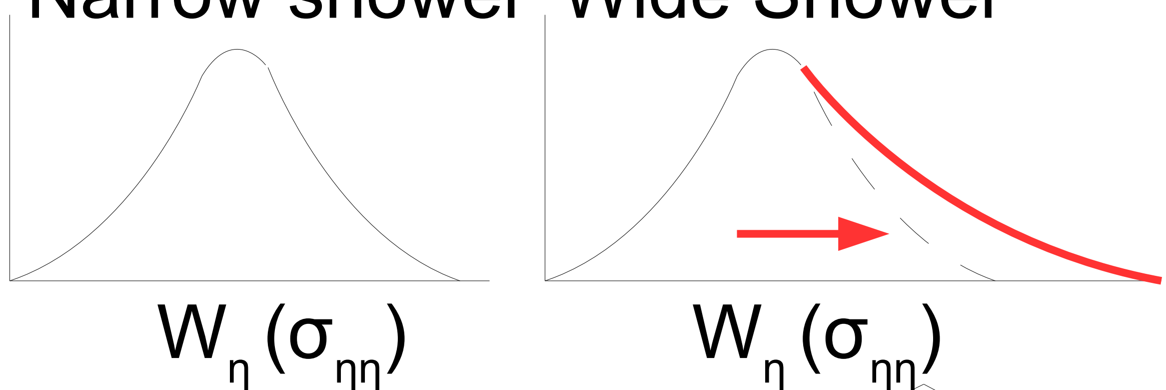


Write down a few scenarios and modify reconstruction to accomodate

Sophisticated approach

- Generate a large set of events : split by categories

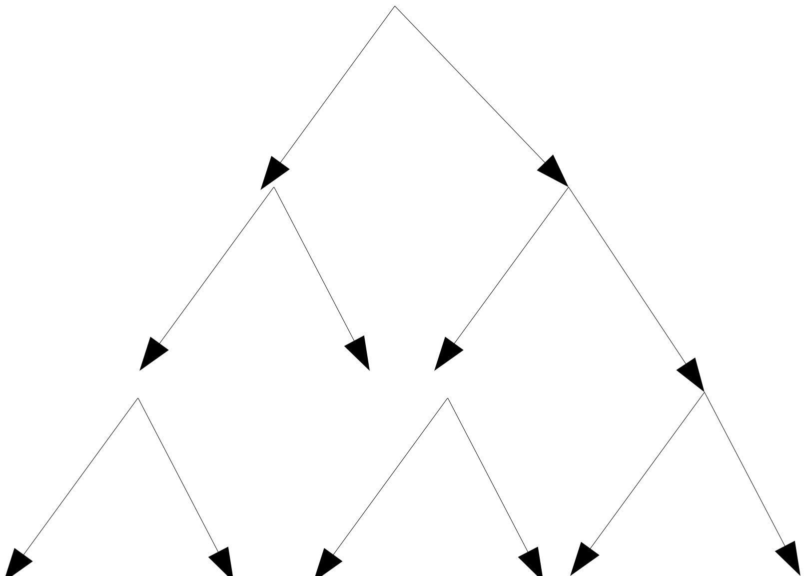
Narrow shower | Wide Shower



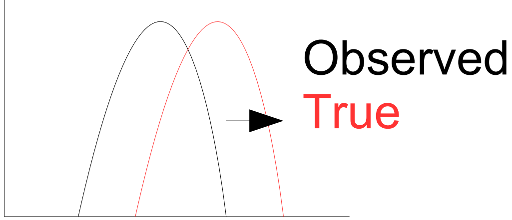
Large tangential energy | Small tangential energy | Large tangential energy | Small tangential energy

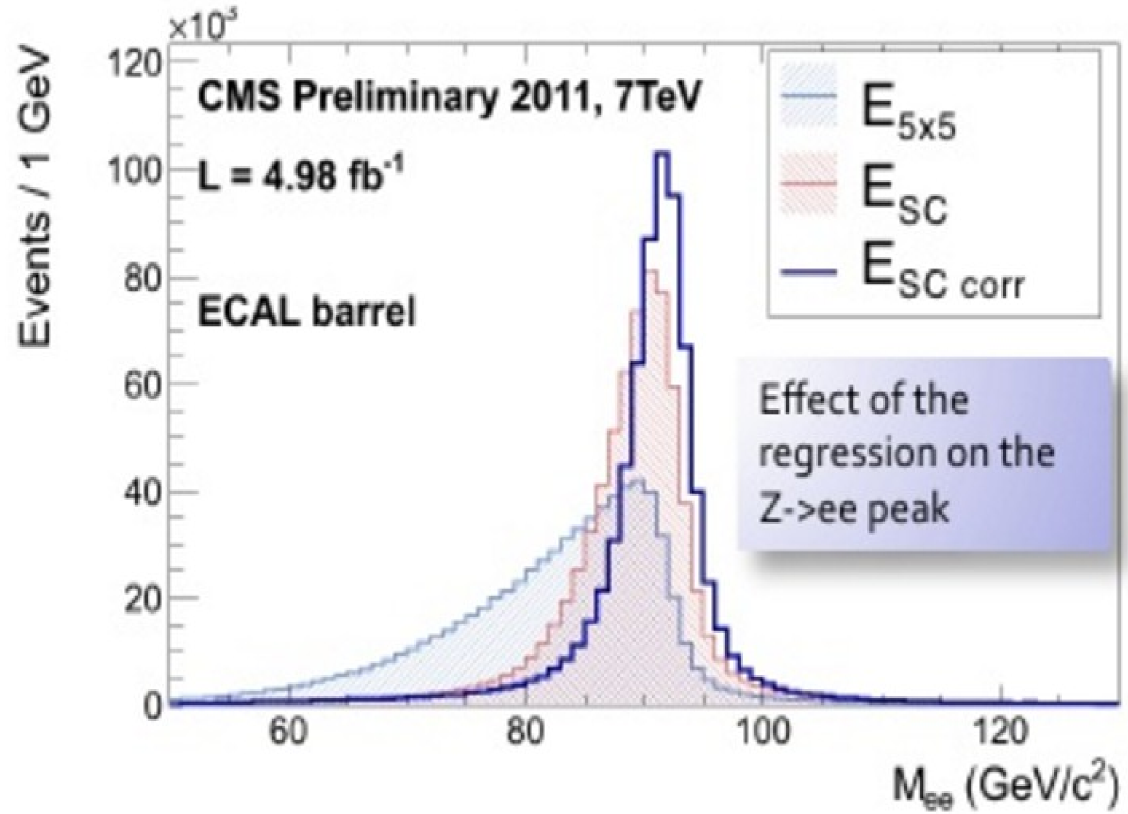
MVA Regression

- Keeps on splitting events by properties



Match observed to true

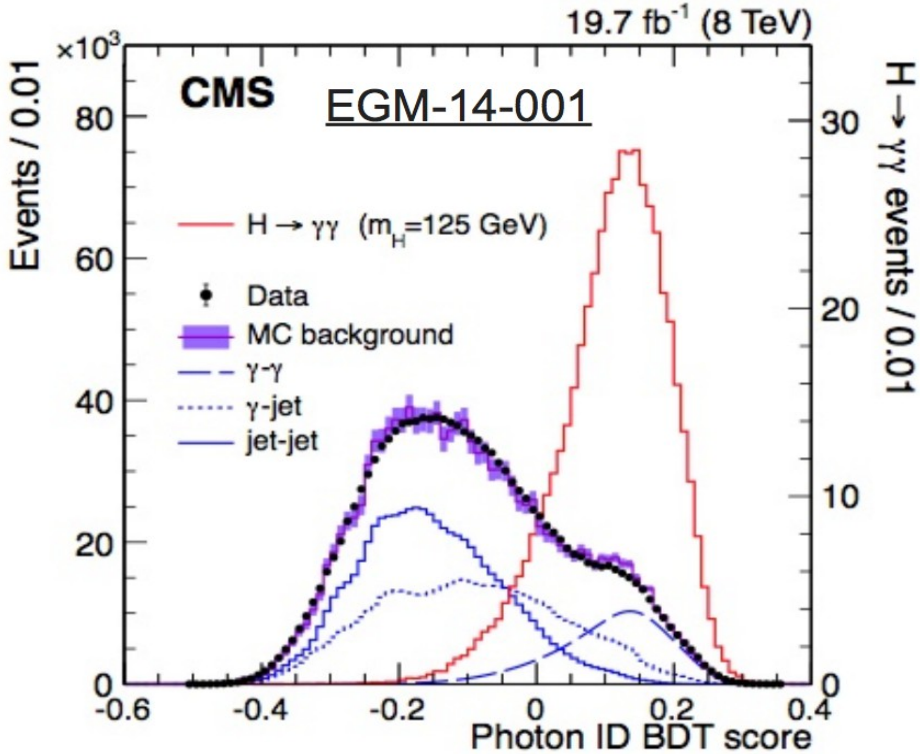


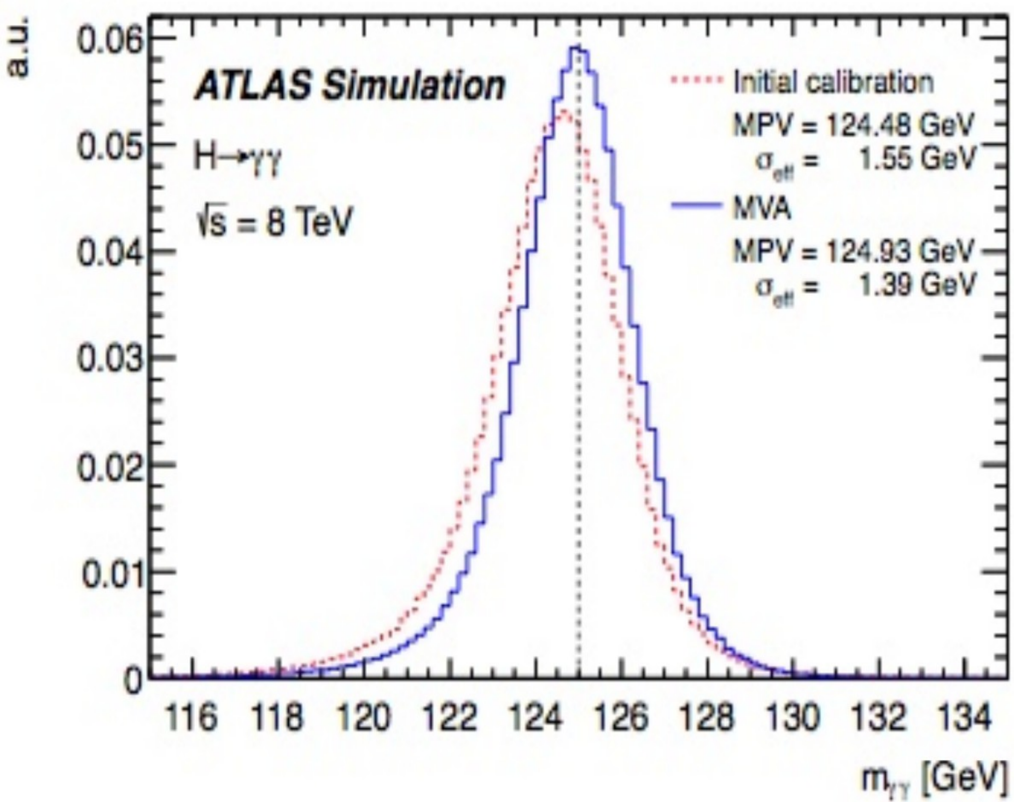


$P_T^{True}=p_T^{Reco}\text{Correction}(w_1,p_T,\ldots,\text{All variables you split on })$

Impact of MVA regression

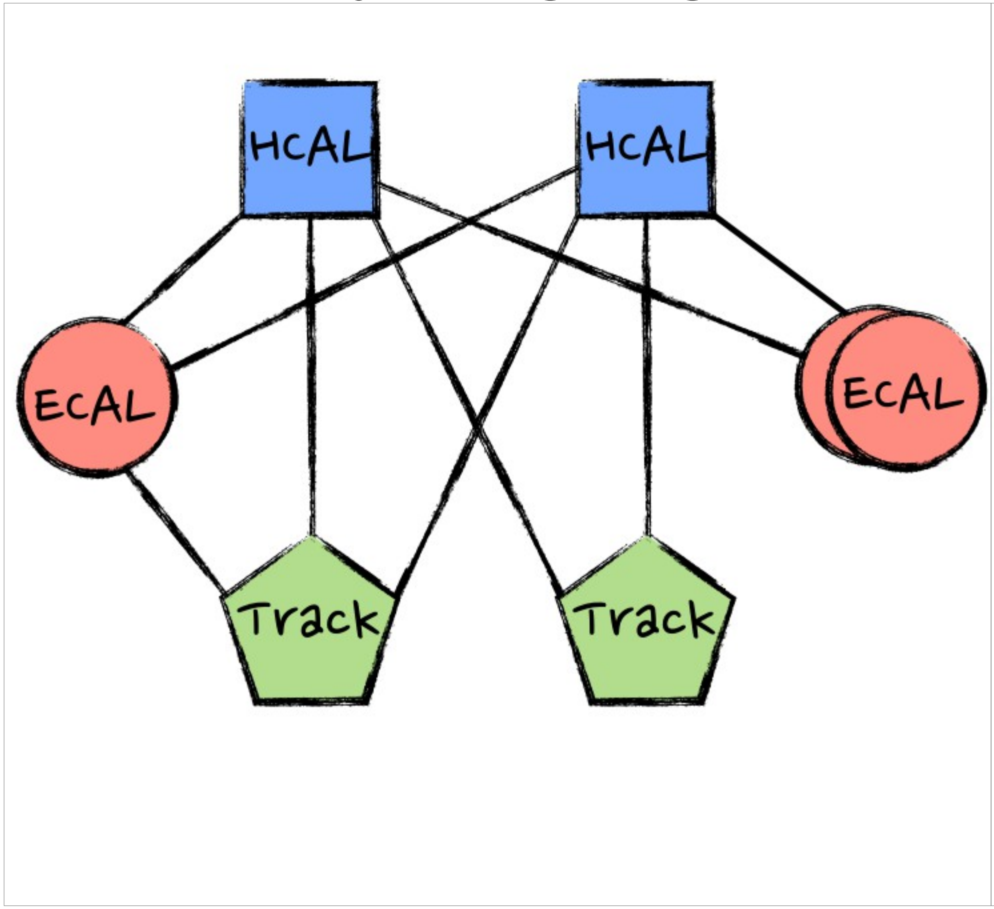
- MVA regression was used for a number of objects
  - A big part of the ATLAS/CMS Higgs searches
  - MVA used for classification



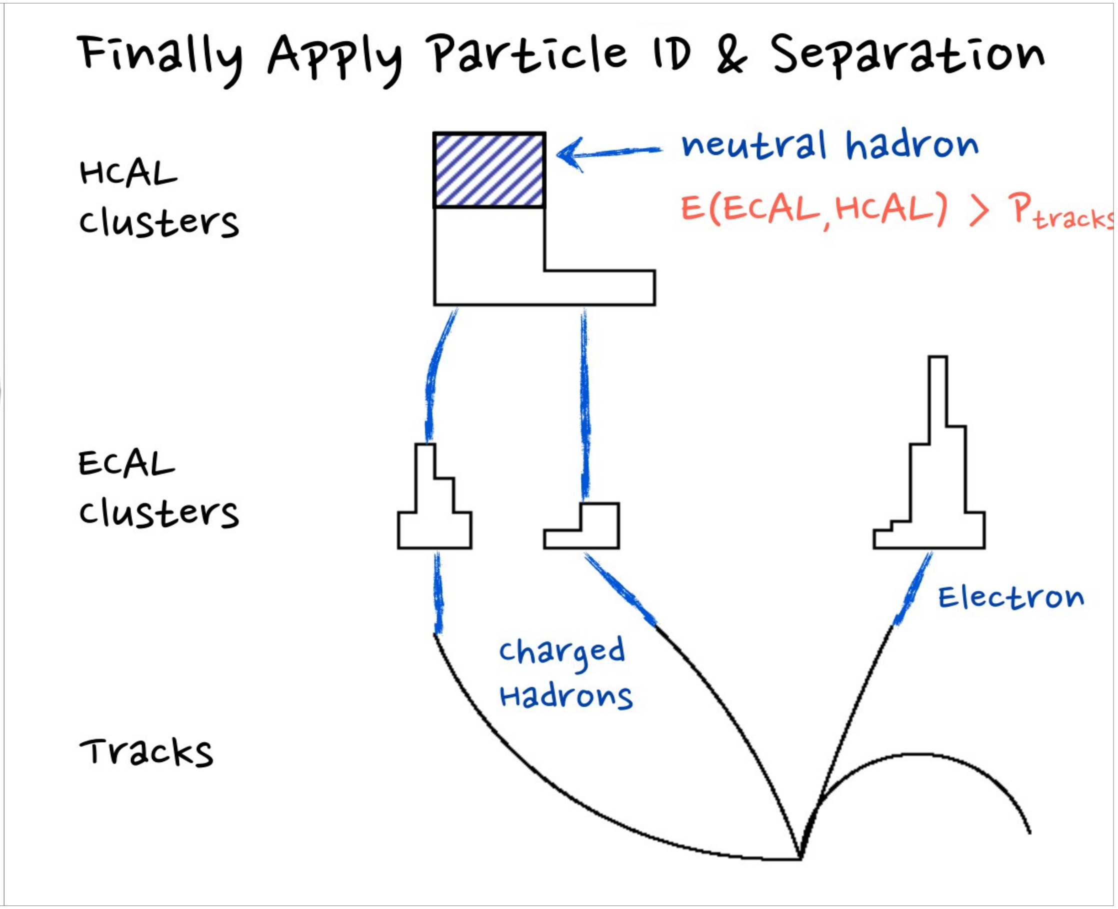


Particle Flow

Link everything together



Make Particles



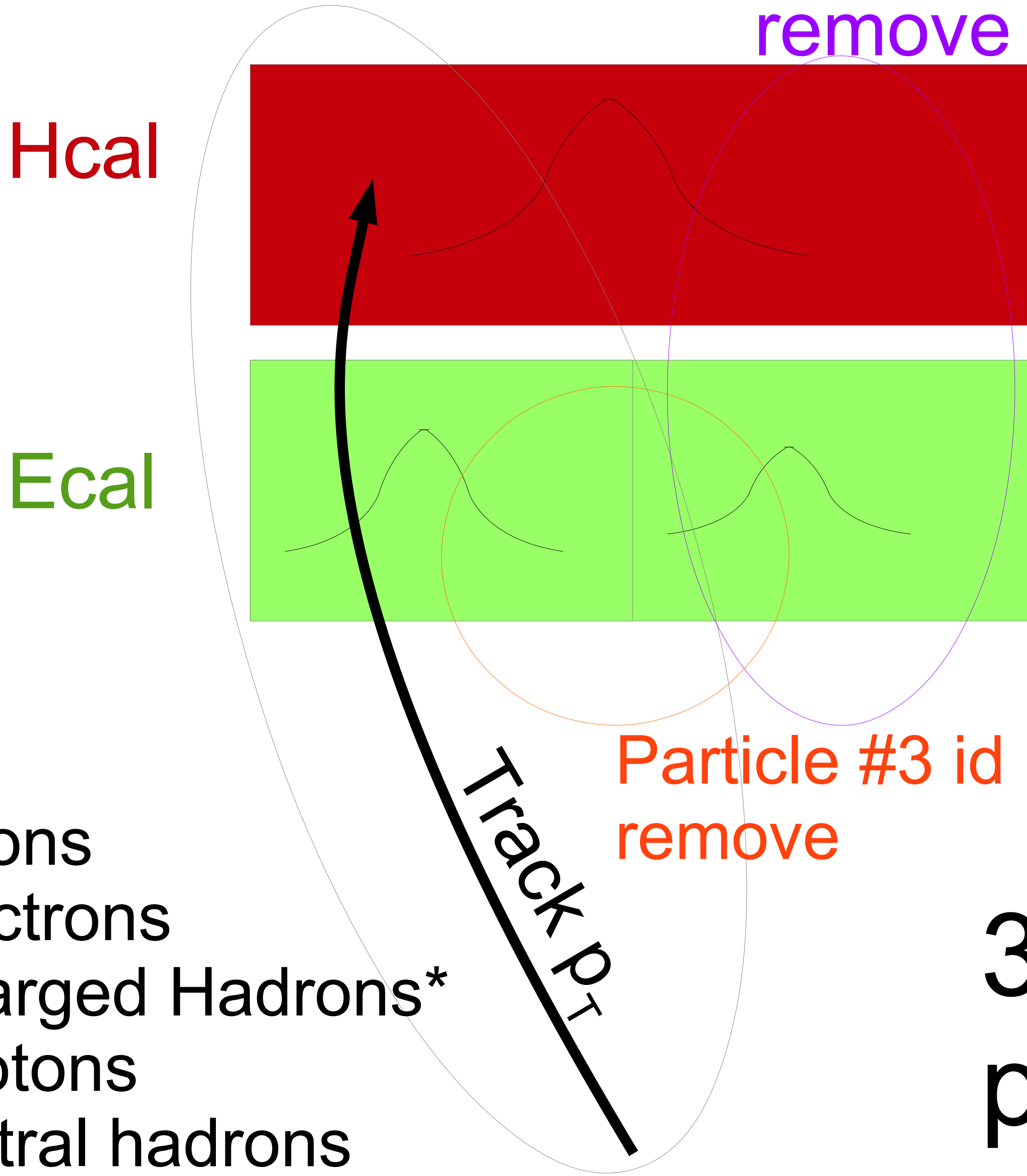
We get 5 classes of particles

Are we missing any?

Particle #1 (Id) & remove (expected)deposit

Ordering is key

Particle #2 (Id) & remove



Particle #3 id & remove

1. Muons
2. Electrons
3. Charged Hadrons*
4. Photons
5. Neutral hadrons

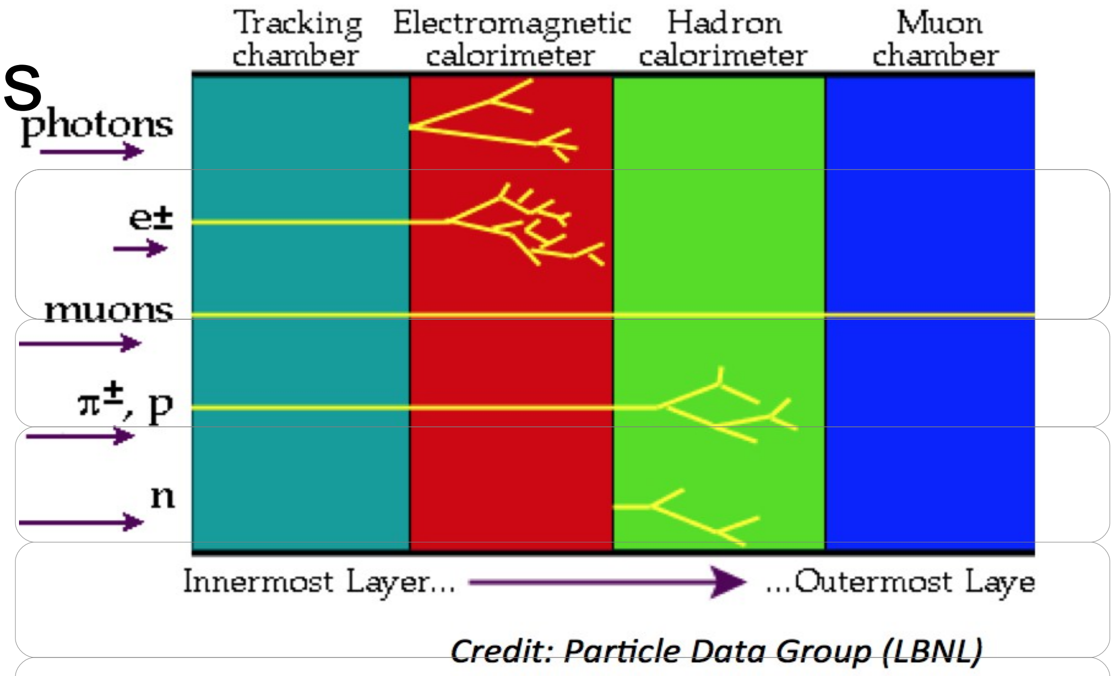
3 overlapping particle event

Resulting Componnets

- Std::vector<ParticleFlowCandidates>

- ParticleFlowCandate :
  - Particle id
  - Mass
  - p_T
  - Eta
  - Phi

5 types

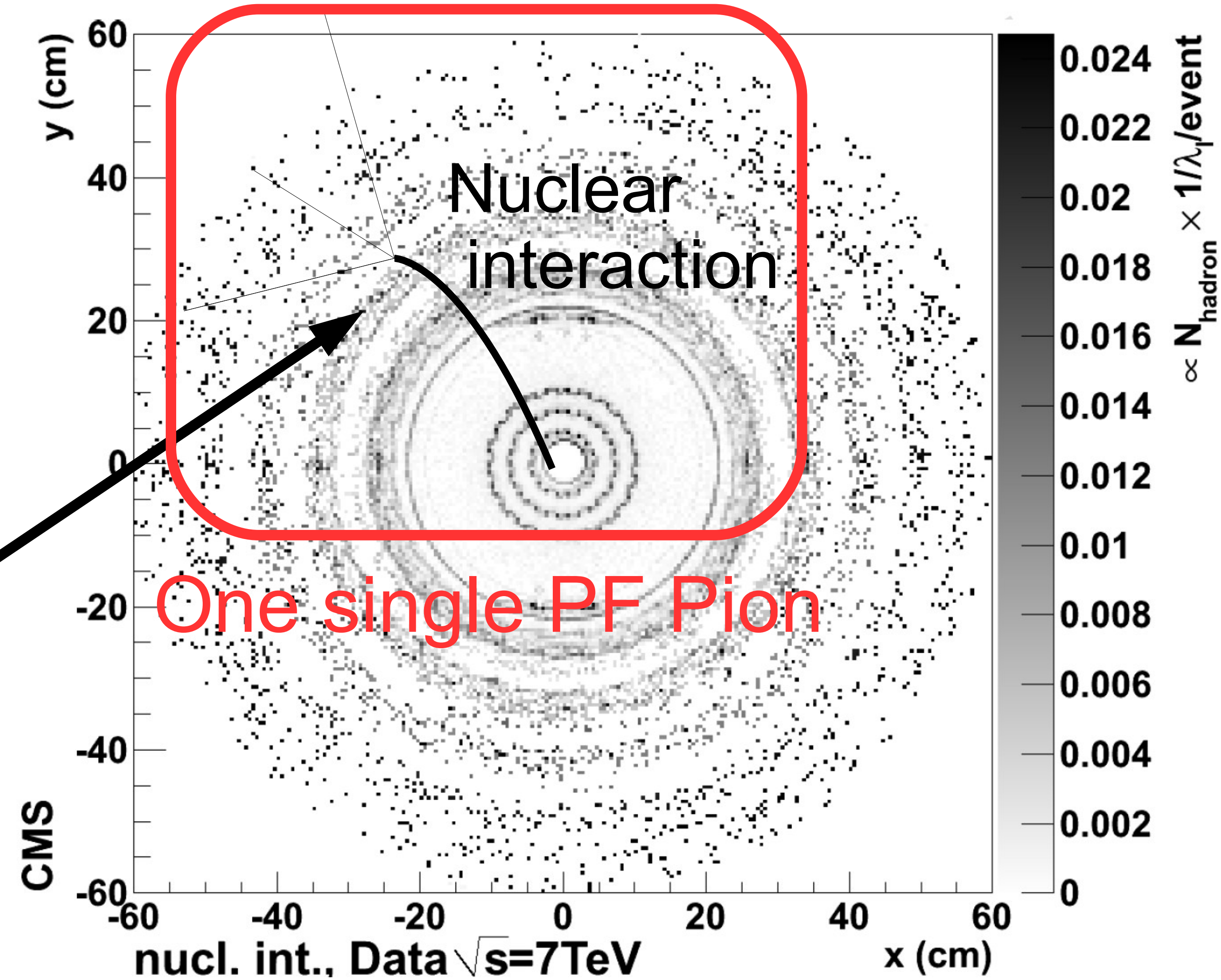


ATLAS does not (yet) link charged particles w/calo

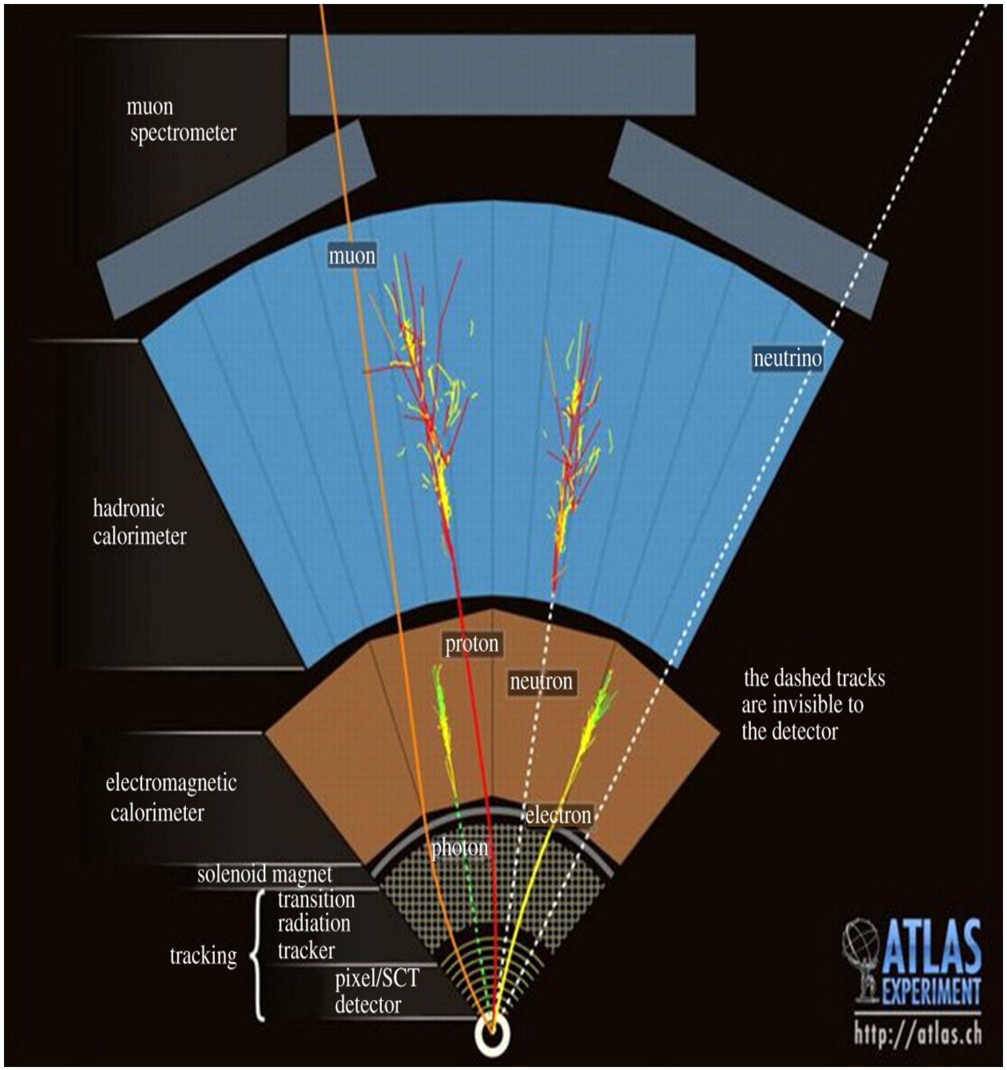
A lesser known point

- Embedded in particle flow are nuclear interaction

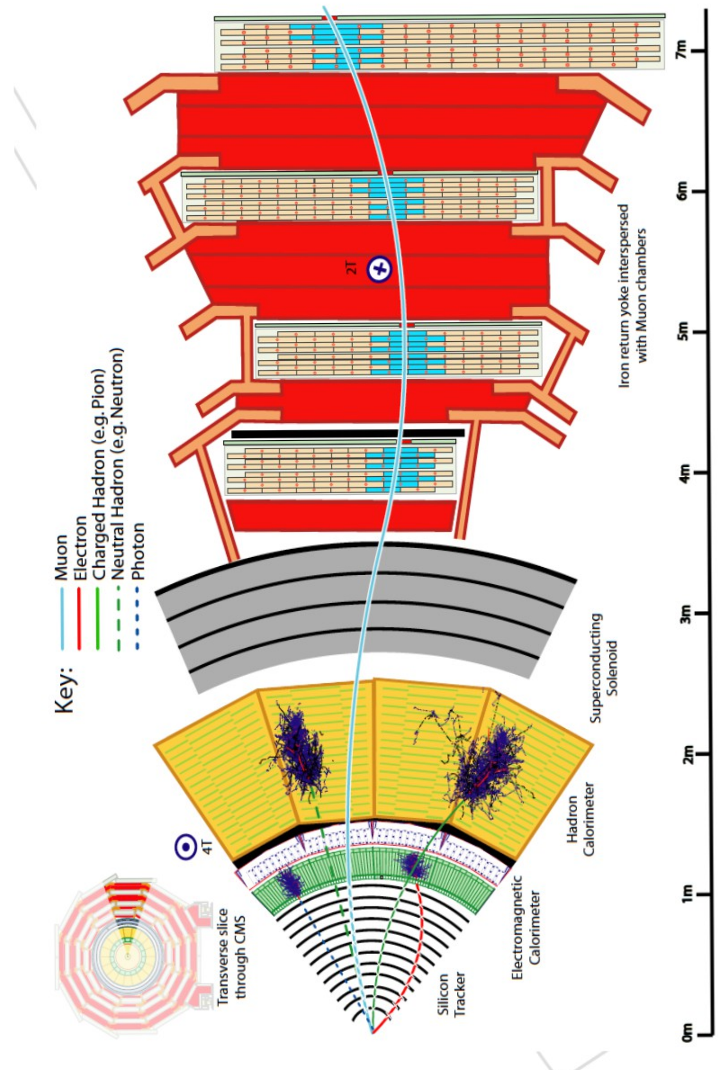
Particle flow looks for displaced secondary vertices and merges tracks into 1 particle



Any complication for PF in ATLAS?

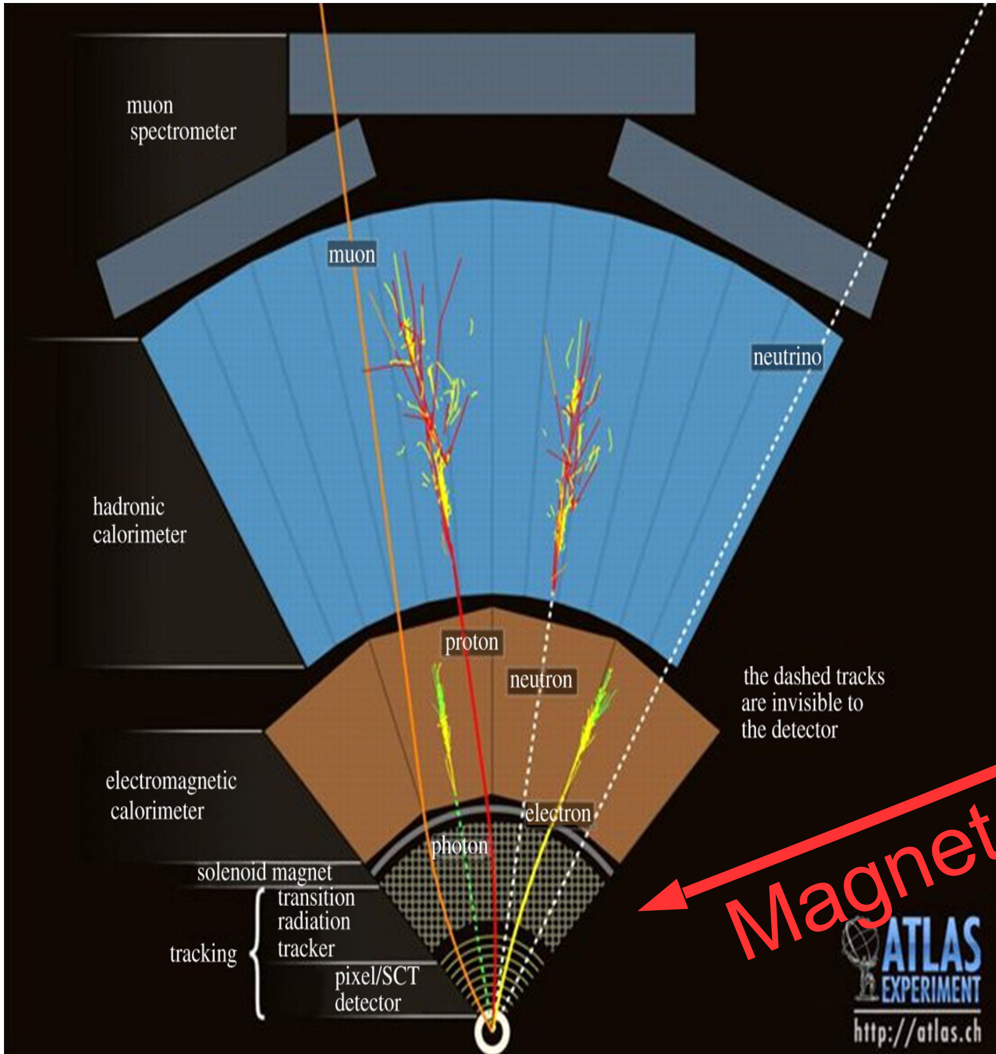


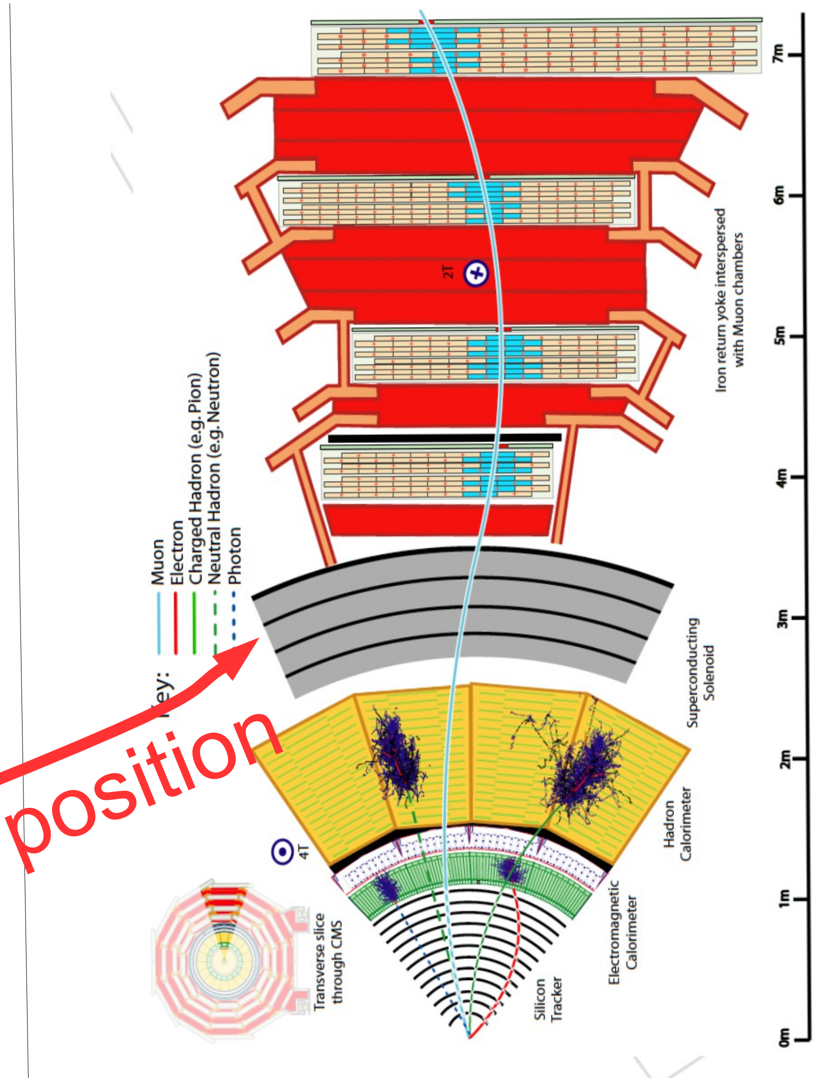
ATLAS



CMS

Any complication for PF in ATLAS?





Magnet position

ATLAS

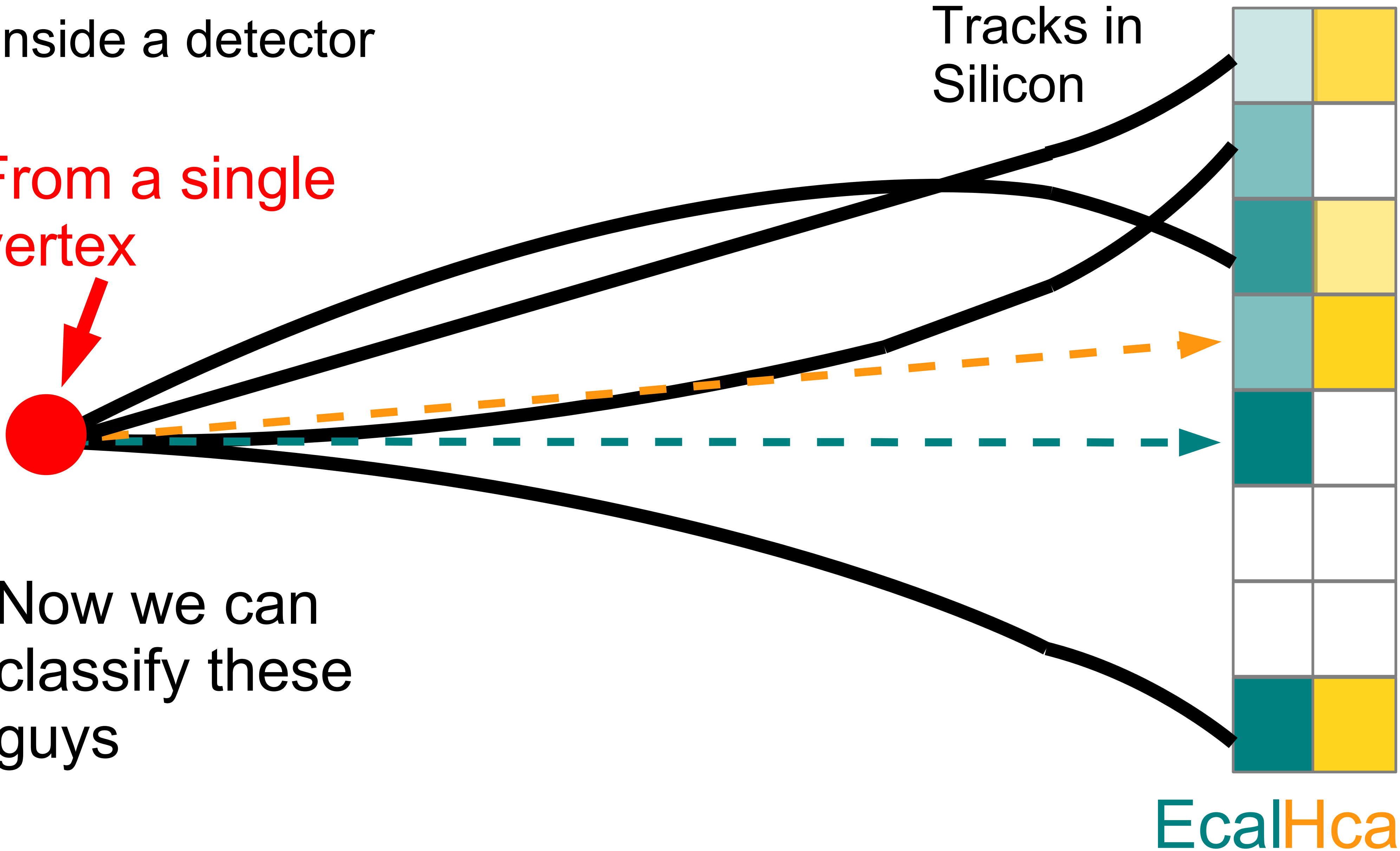
Need to correct for the energy loss

CMS

Using the particles

Inside a detector

From a single vertex

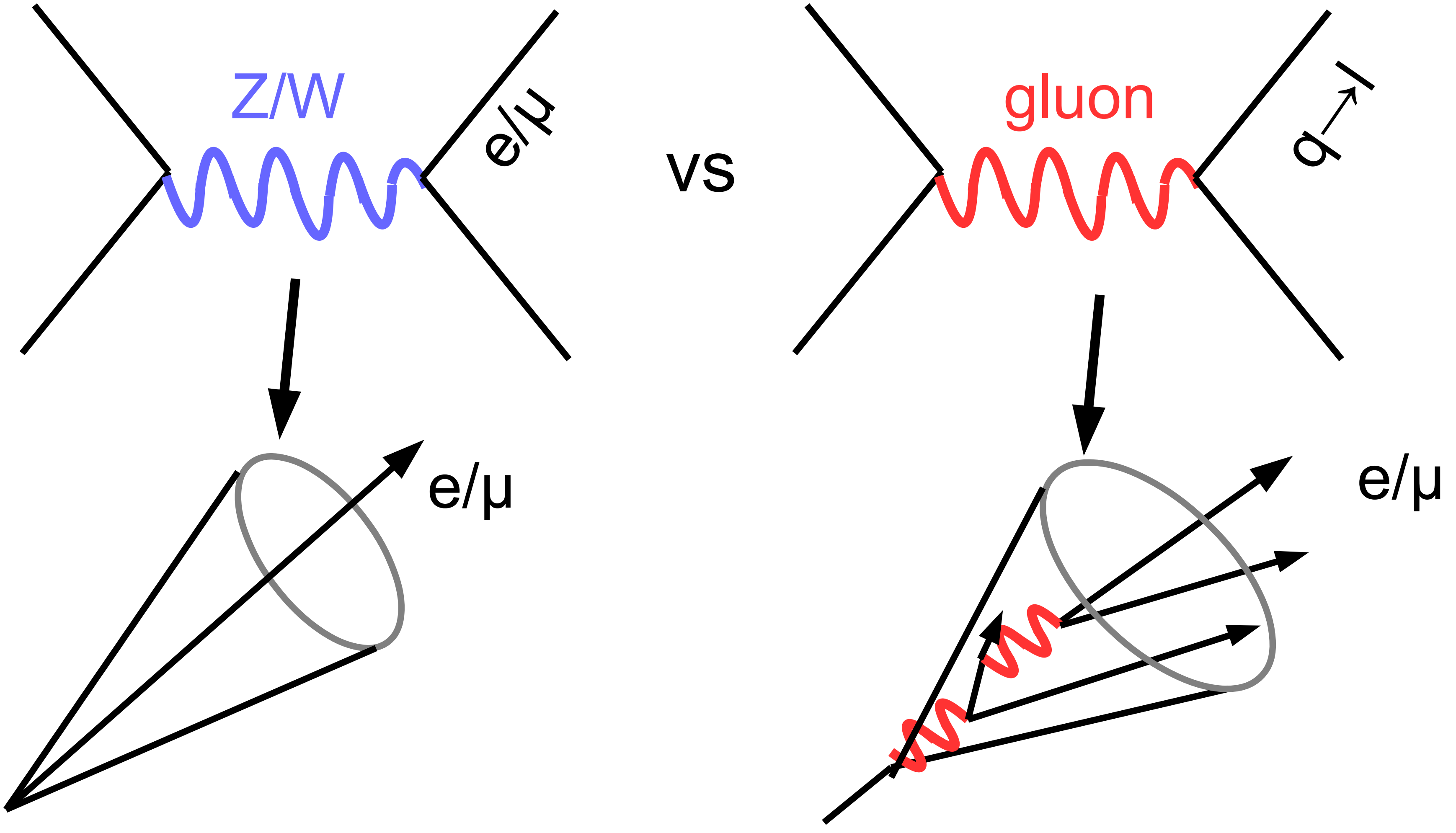


Now we can classify these guys

Building More Complicated Objects

Lepton Isolation

- Leptons from EWK decays are isolated



Lepton Isolation

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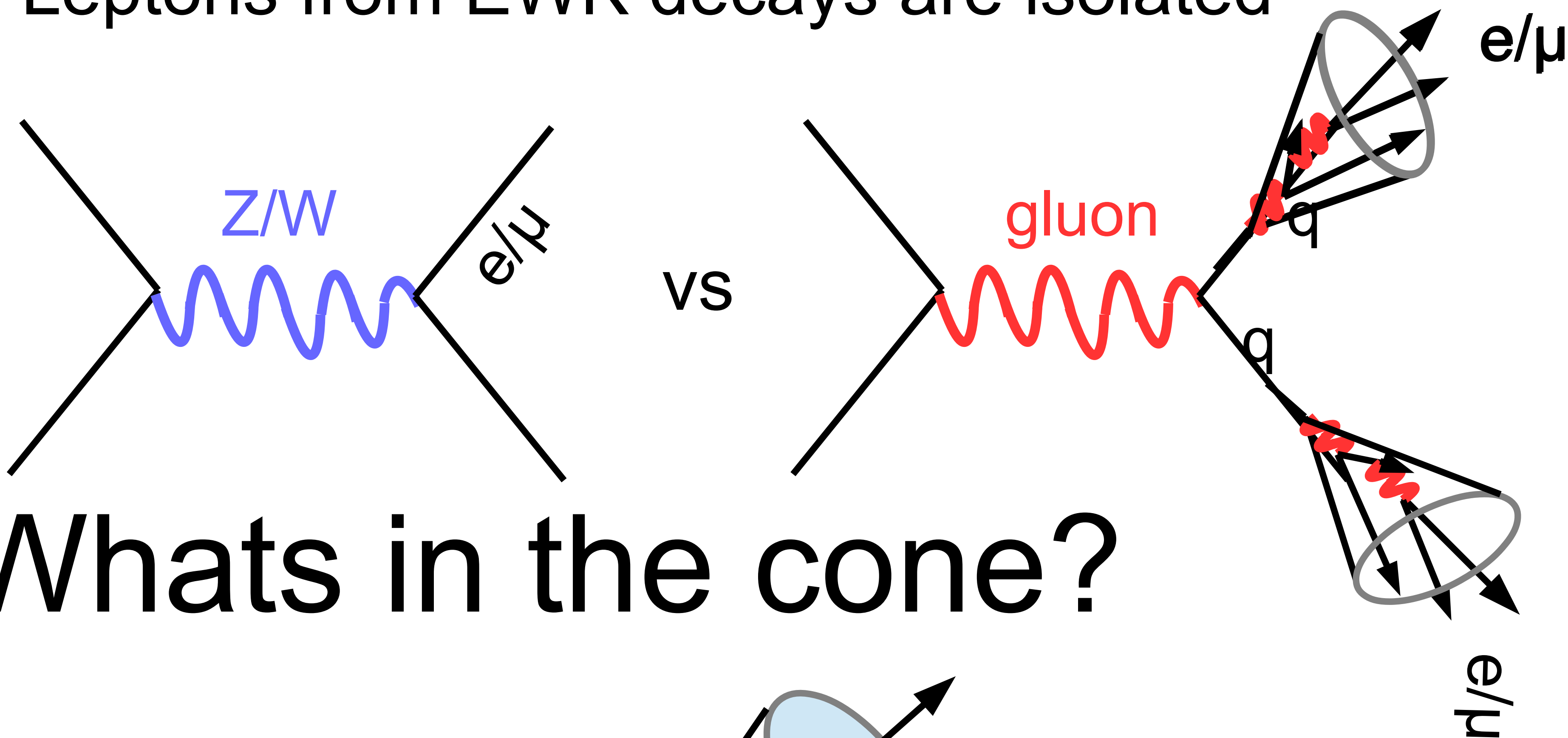
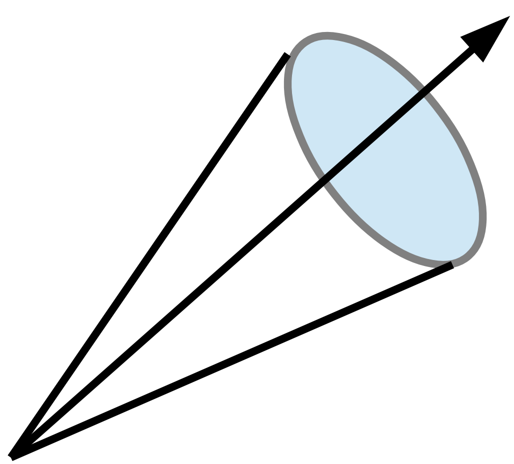


Whats in the cone?



Lepton Isolation

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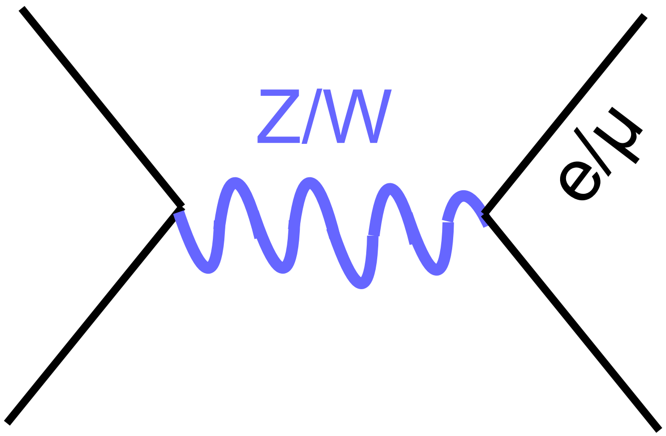
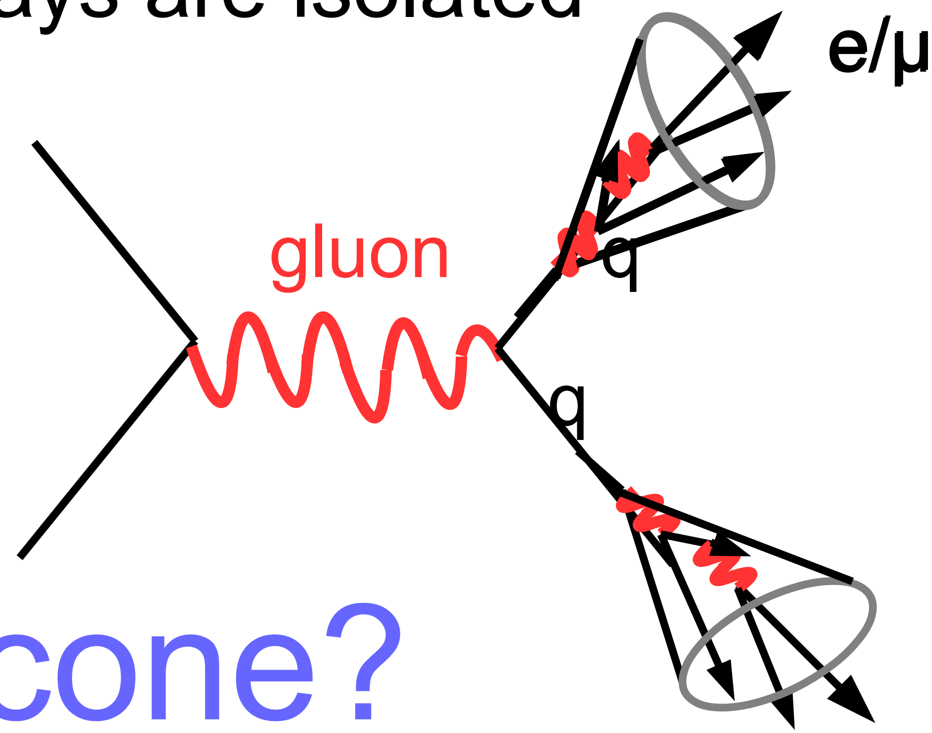


vs



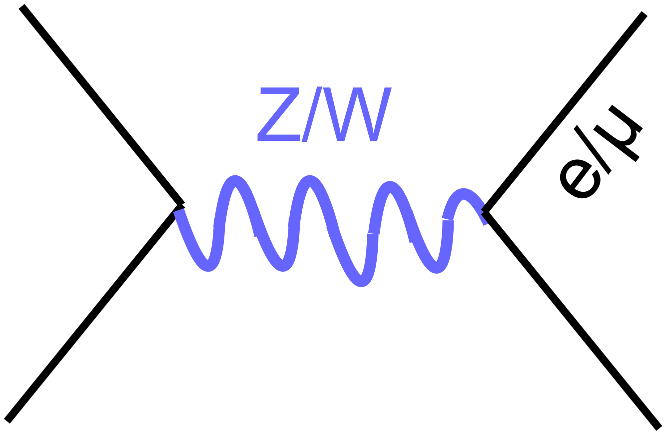
Whats in the cone?

Nothing

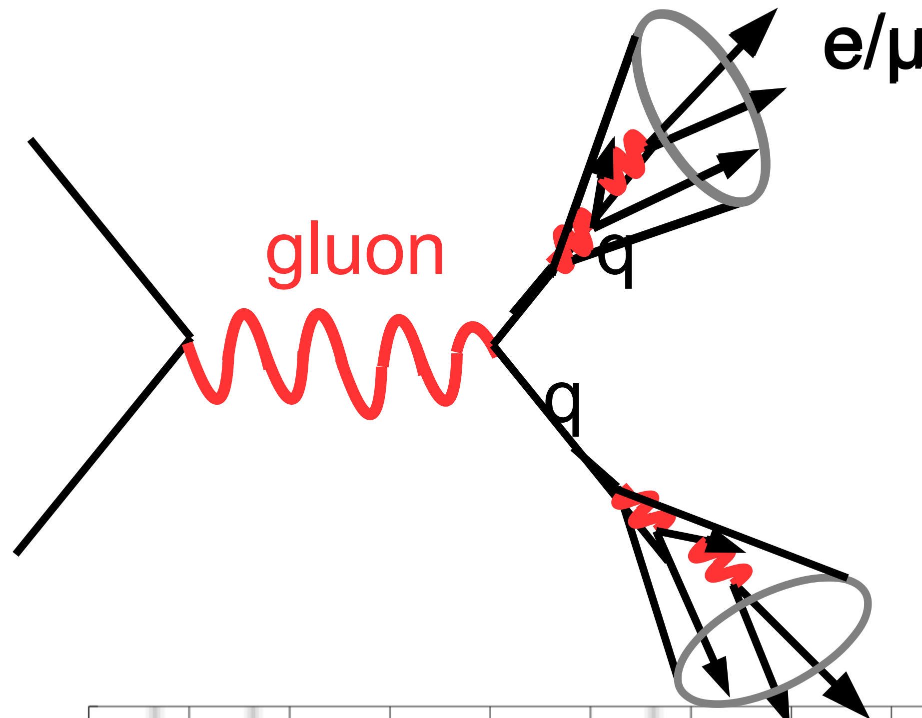
Something

Lepton Isolation

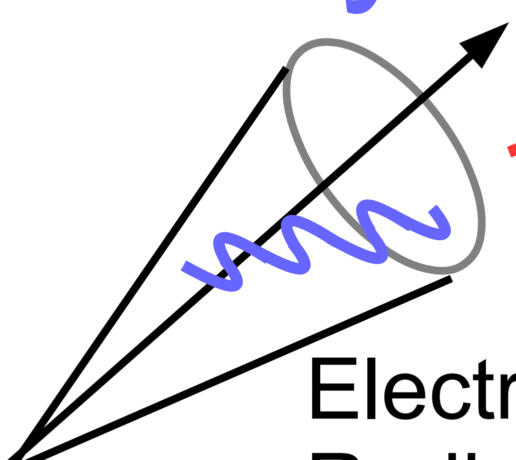
- Leptons from EWK decays are isolated



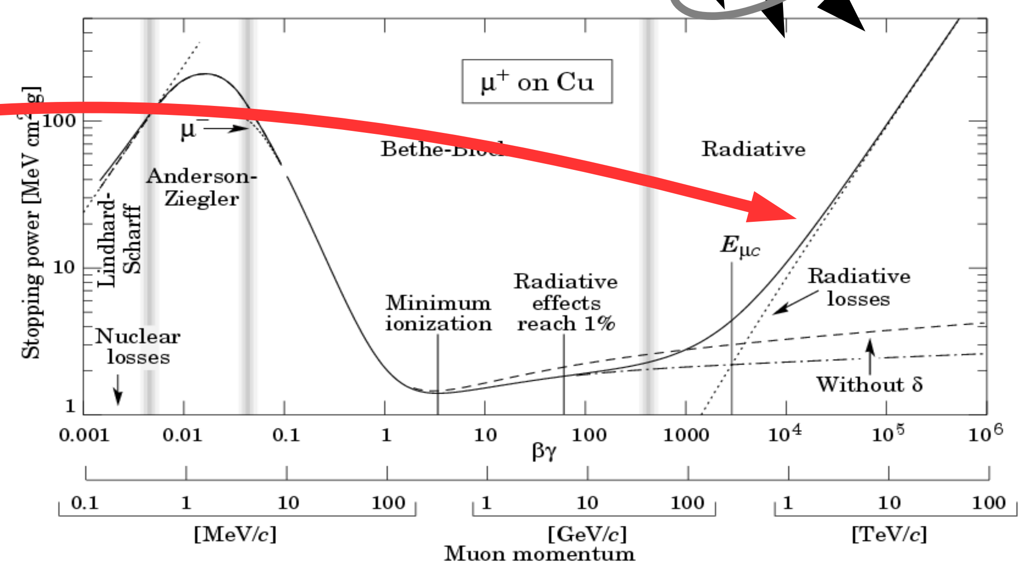
vs



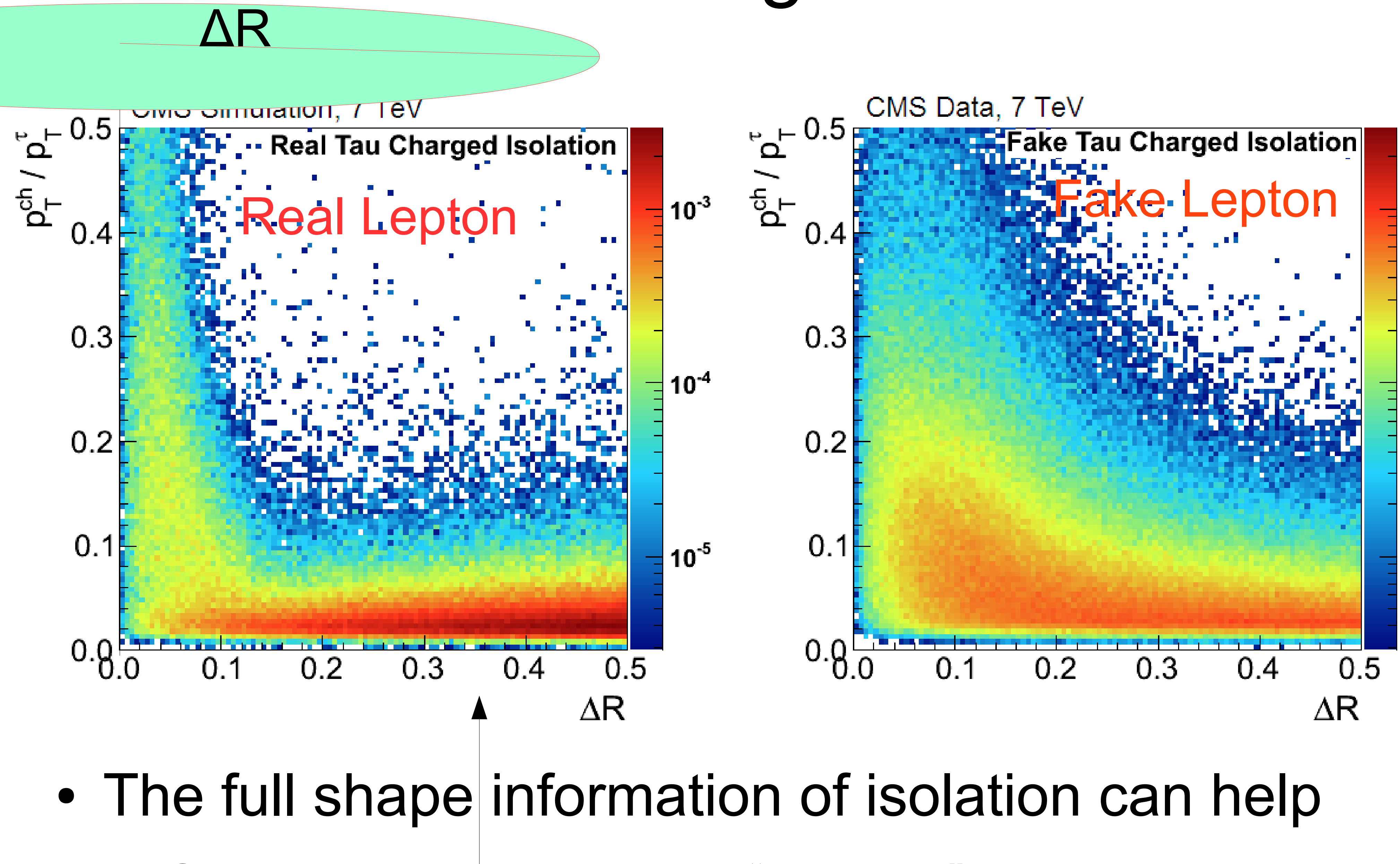
Really? No



Electrons/muons
Radiate photons

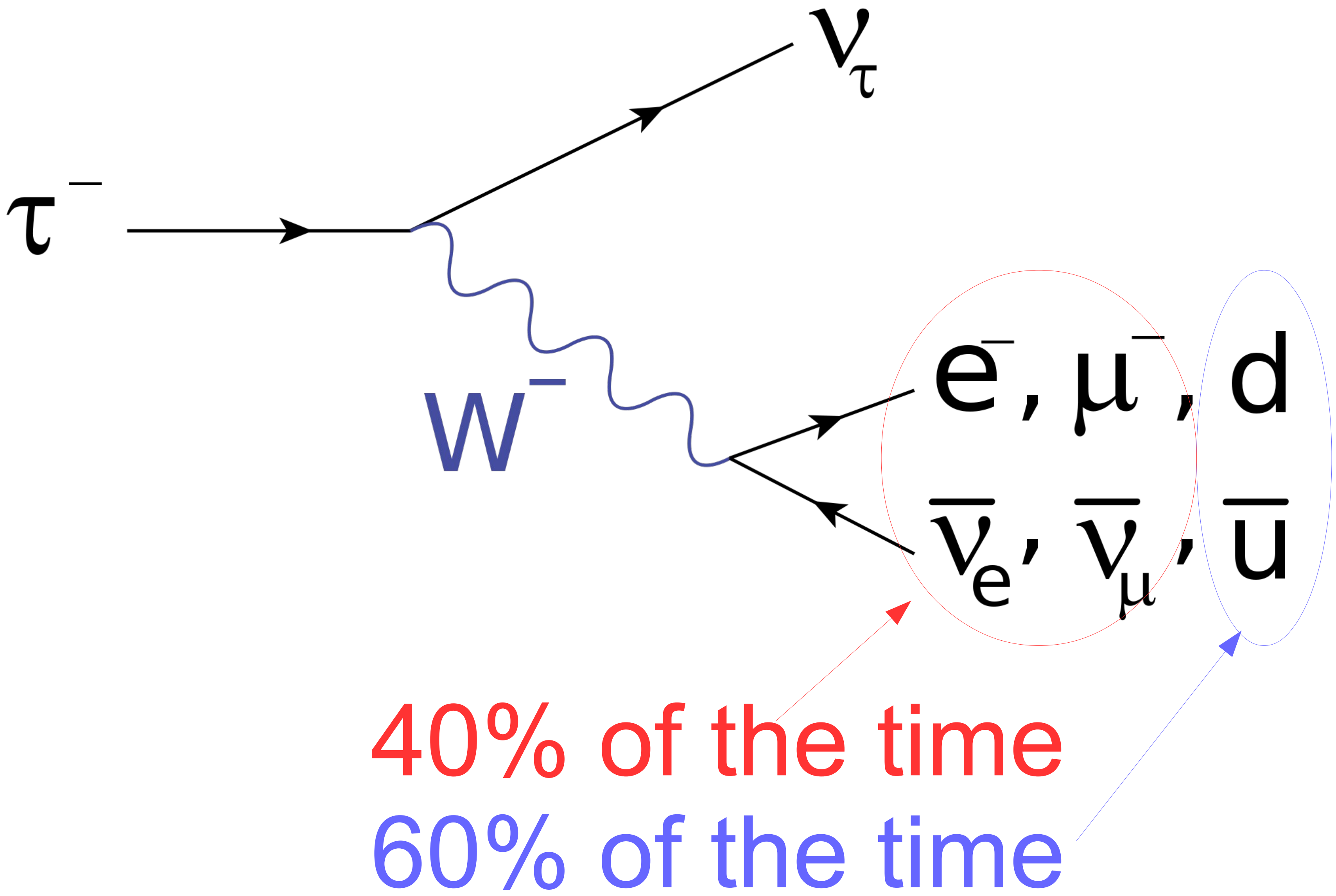


Using Isolation Profiles

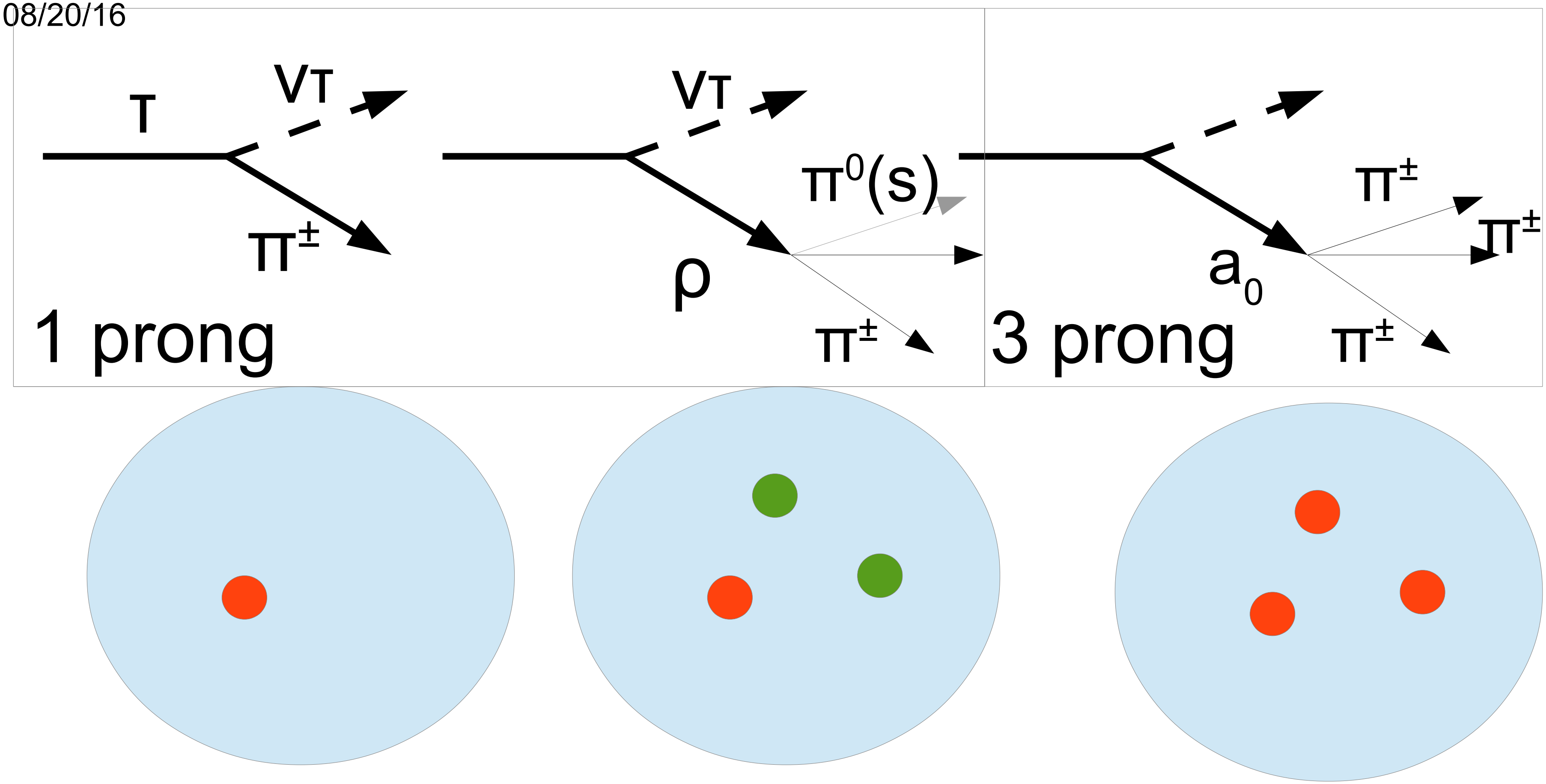


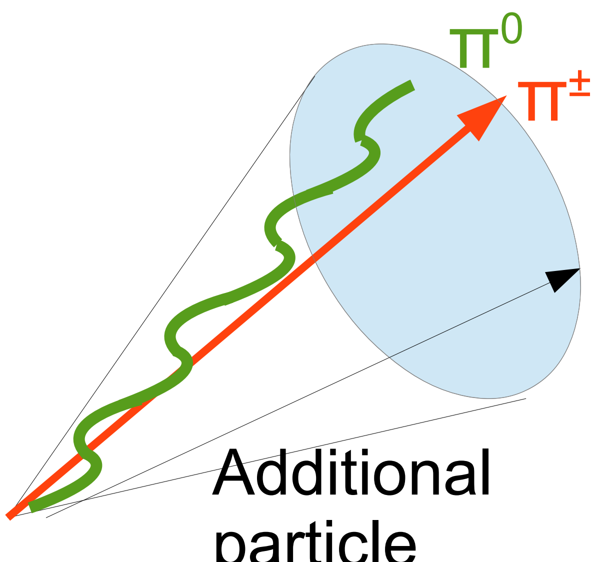
- The full shape information of isolation can help
  - Sometimes called the “Frixione” isolation
- Question : Why does this get so red for real leps?

Hadronic Tau decays



Taus

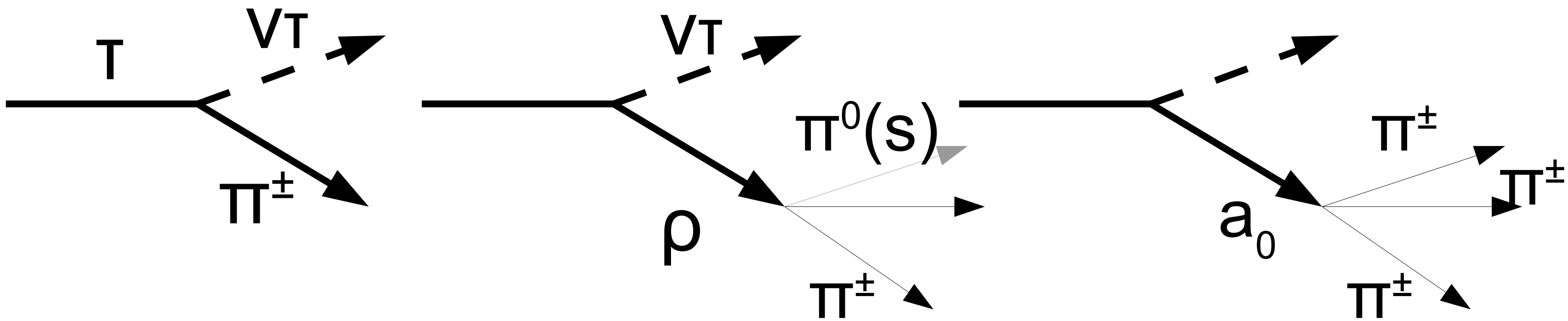


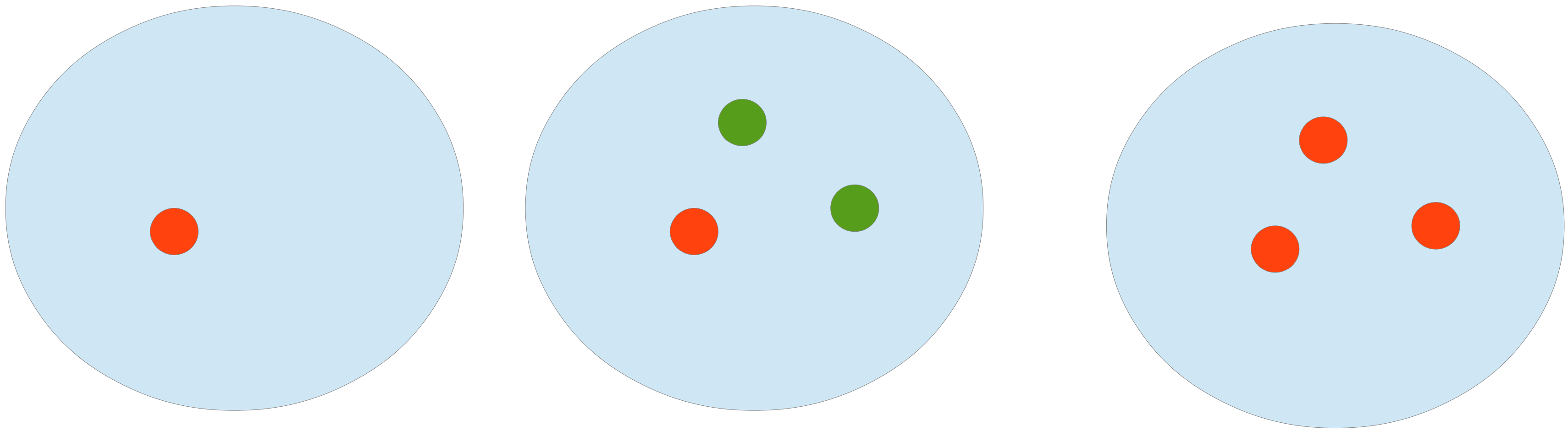


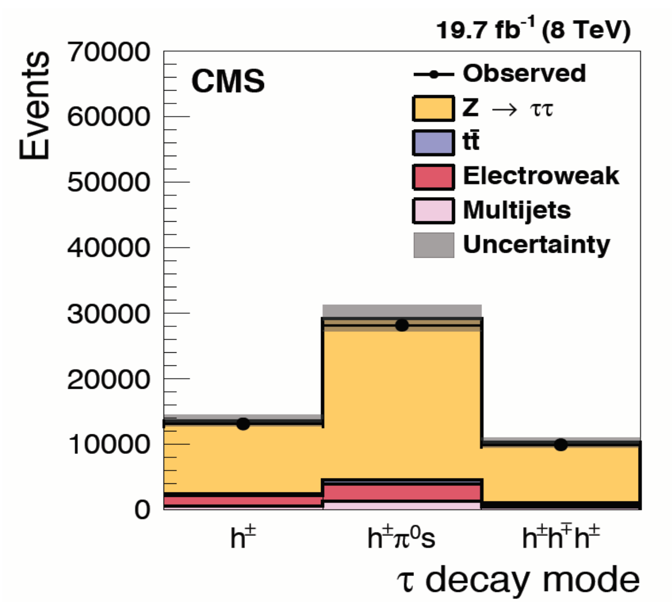
Look inside a cone for decays of a tau

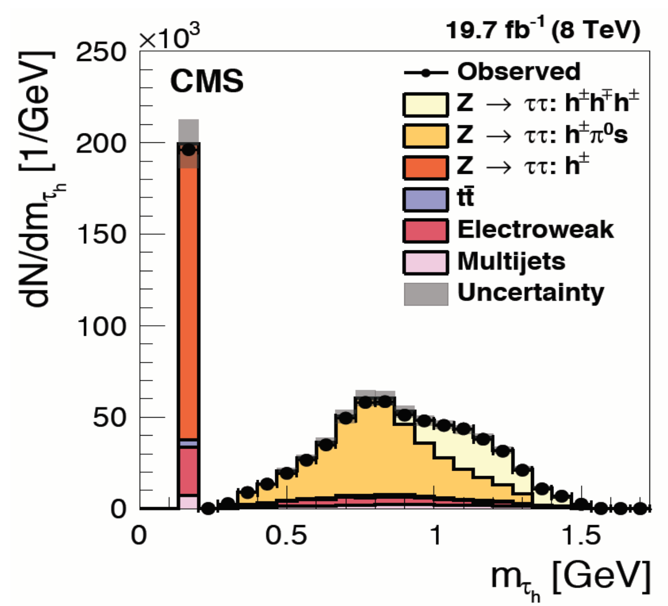
Take mass(π^0+$\pi^\pm$s)
Look for ρ or a_0

Taus


τ
ντ
π±
ντ
π0(s)
ρ
π±
a0
π±
π±
π±

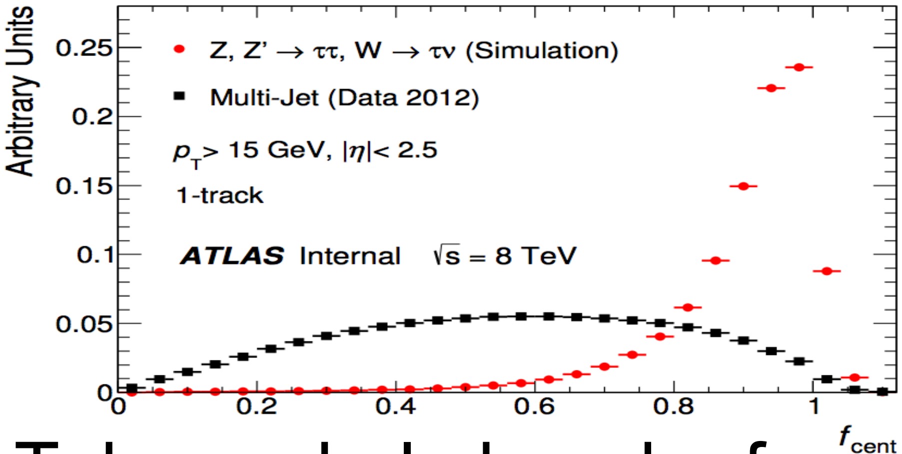



19.7 fb-1 (8 TeV)
CMS
Observed
Z → ττ
tt̄
Electroweak
Multijets
Uncertainty
Events
70000
60000
50000
40000
30000
20000
10000
0
h±
h±π0s
h±h∓h±
τ decay mode

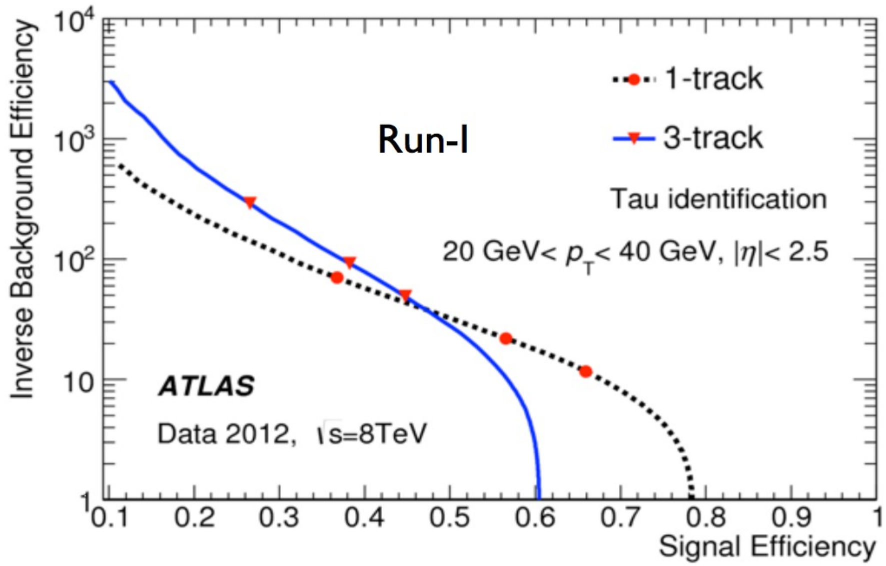

19.7 fb-1 (8 TeV)
×10³
CMS
Observed
Z → ττ: h±h∓h±
Z → ττ: h±π0s
Z → ττ: h±
tt̄
Electroweak
Multijets
Uncertainty
dN/dmτh [1/GeV]
250
200
150
100
50
0
0.5
1
1.5
mτh [GeV]

Approaches to Finding a Tau

ATLAS (1 step)

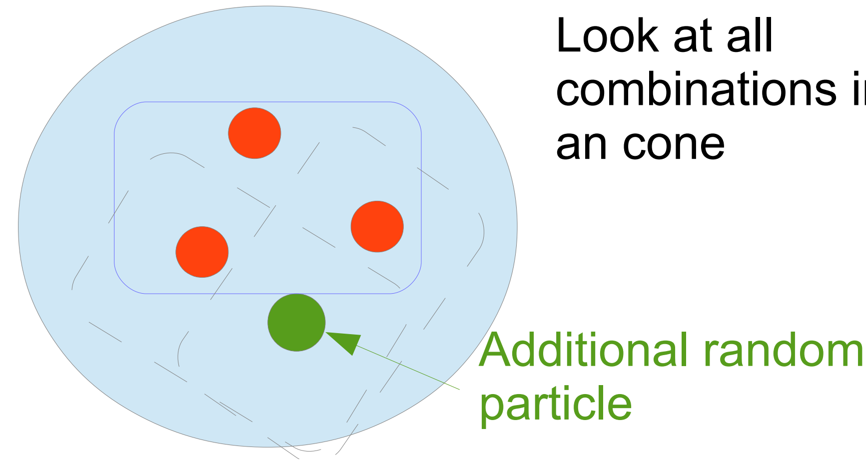


Take a whole bunch of variables and shove them into an MVA



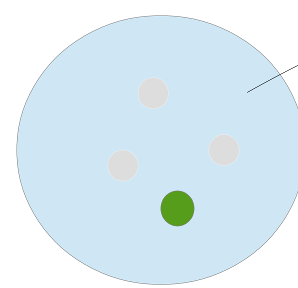
CMS (two step)

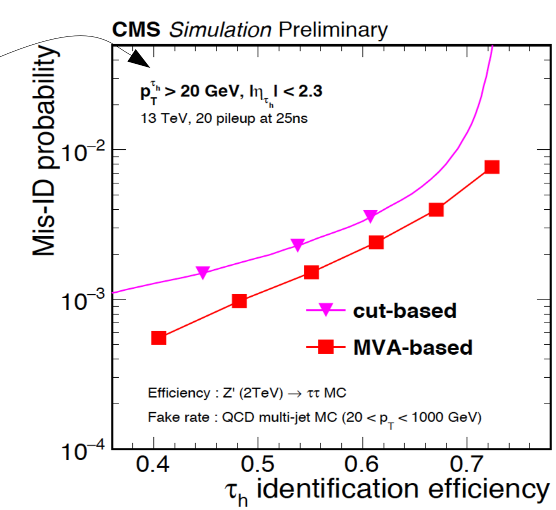
1. Identify tau decay



Look at all combinations in an cone

2. Remove decay particles
   Put rest in an MVA



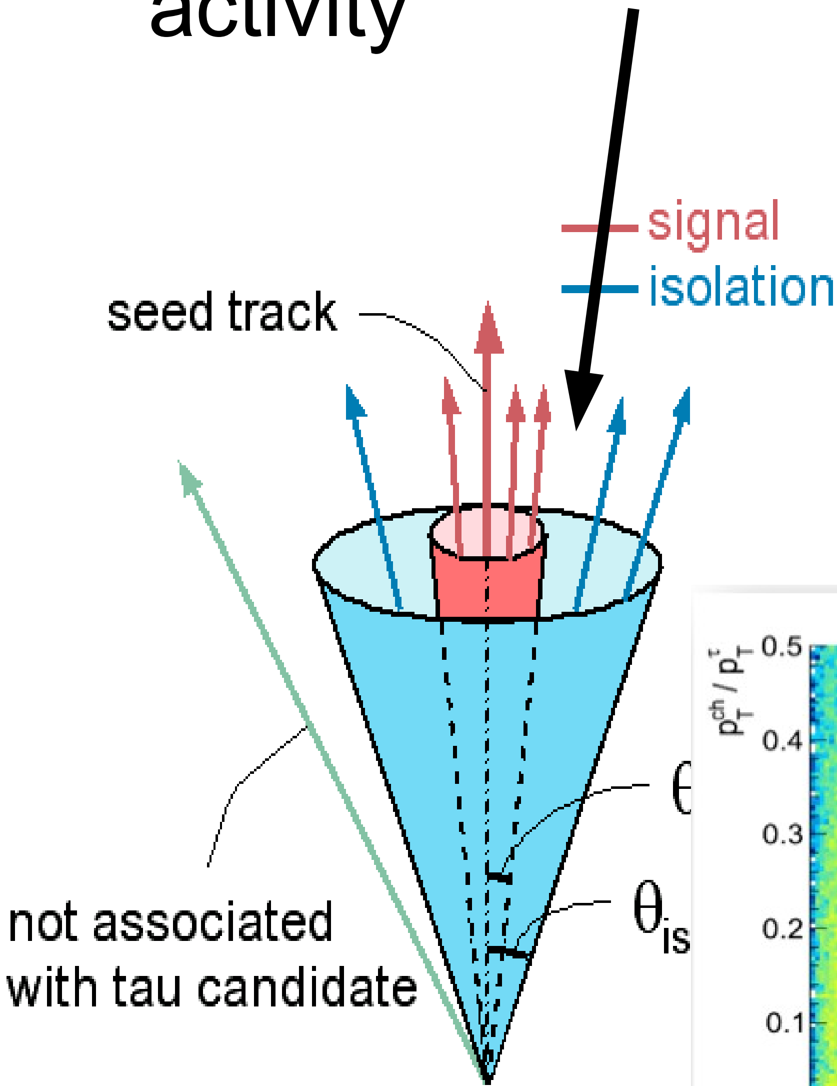


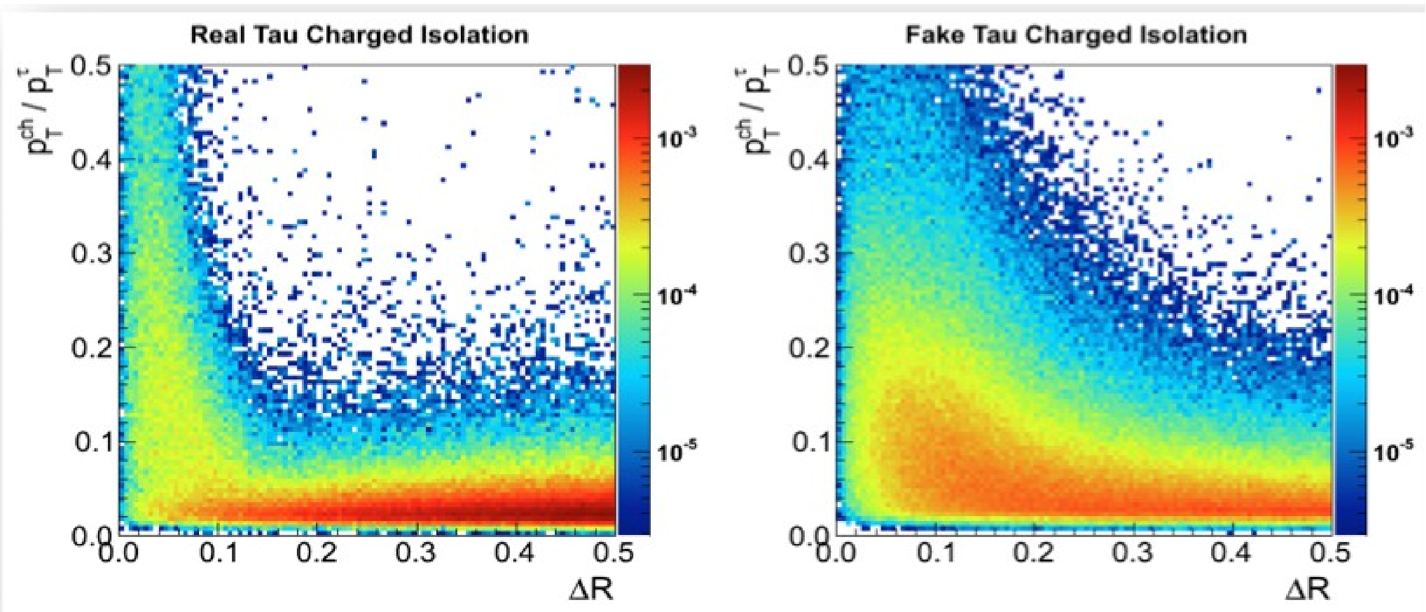
Tau isolation

Key component is isolation

- What distinguishes a tau from a jet is lack of activity

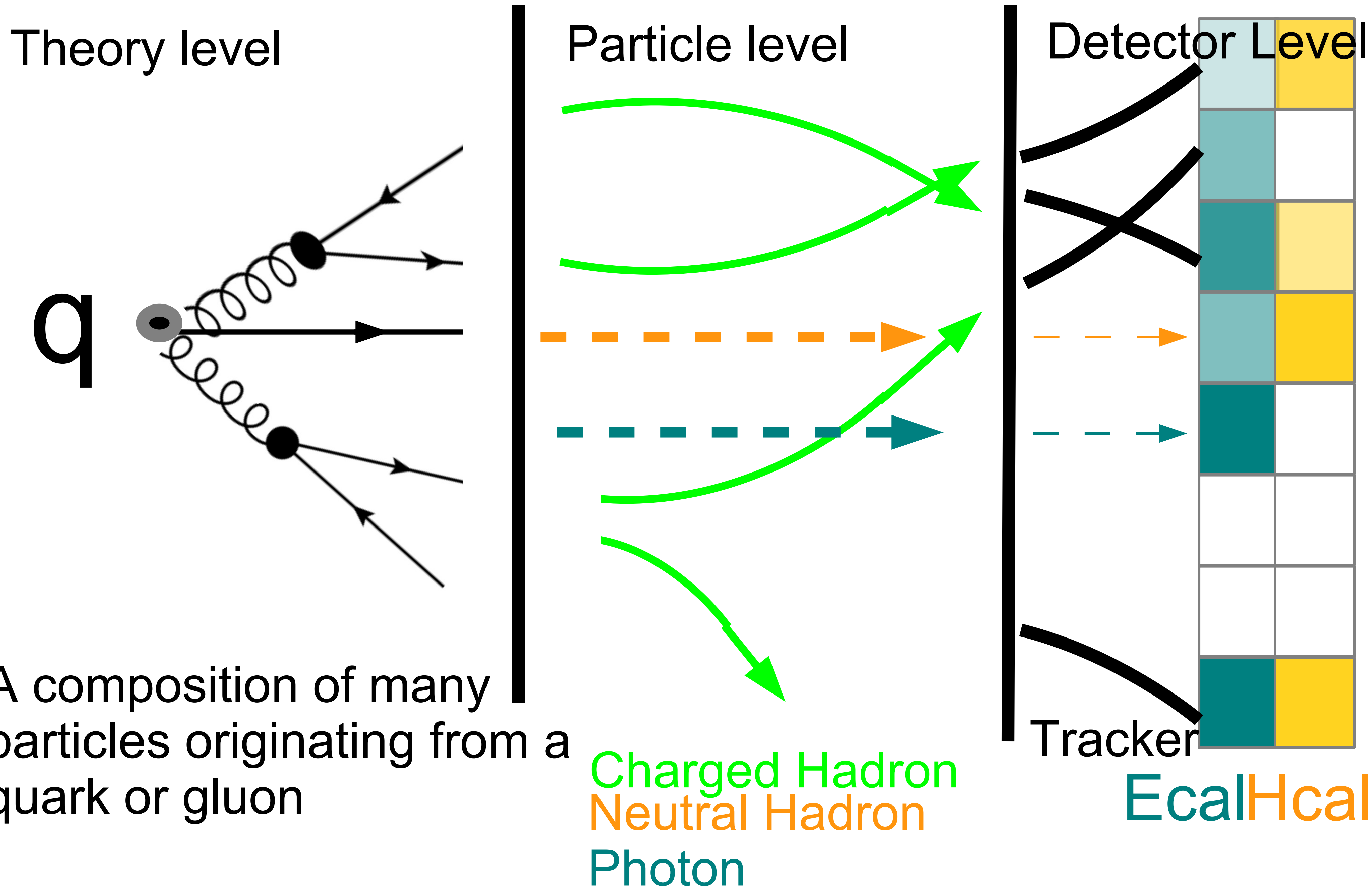
Isolation can reduce background by 95-99% for 70-50% Efficiency





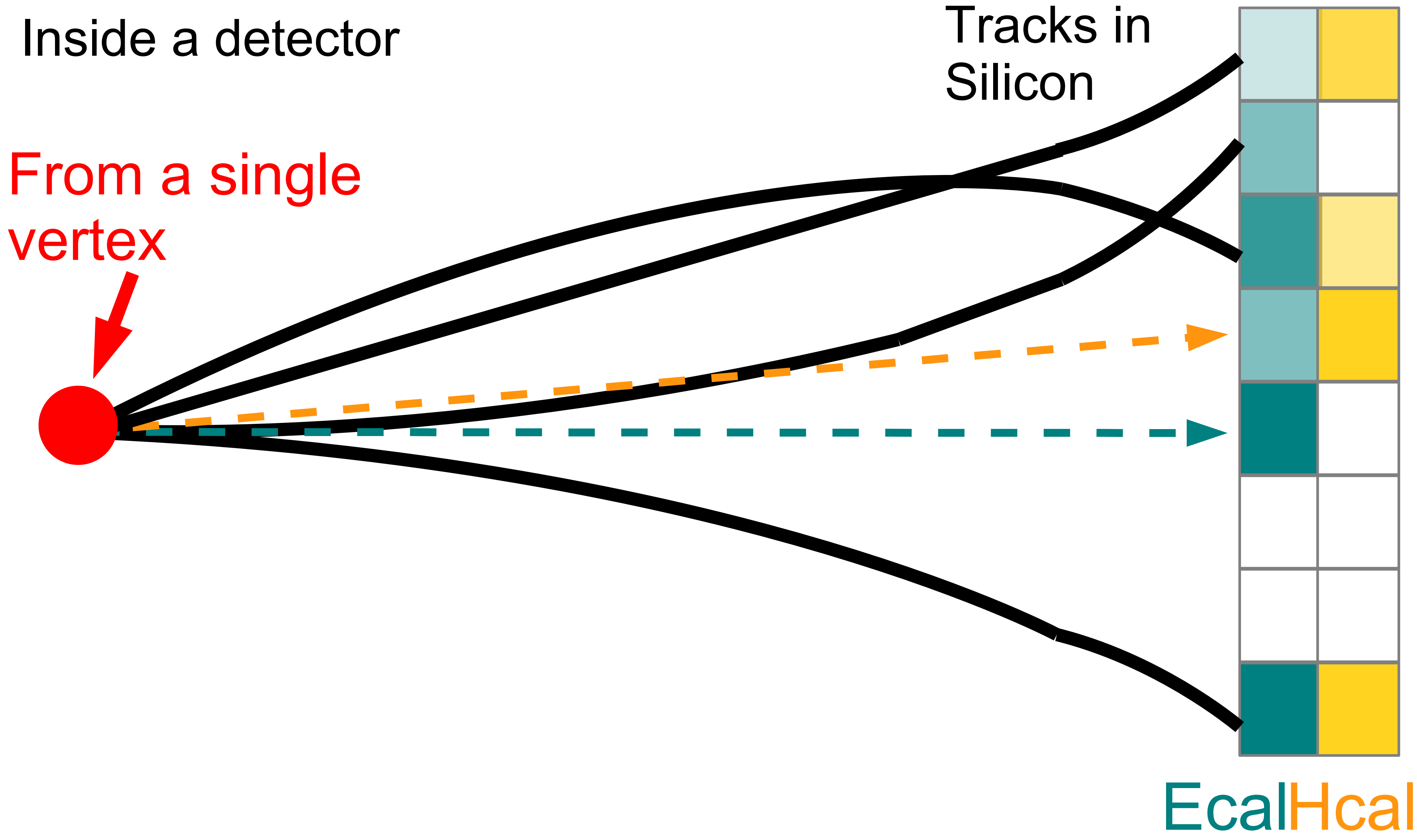
Jets

What is a jet?



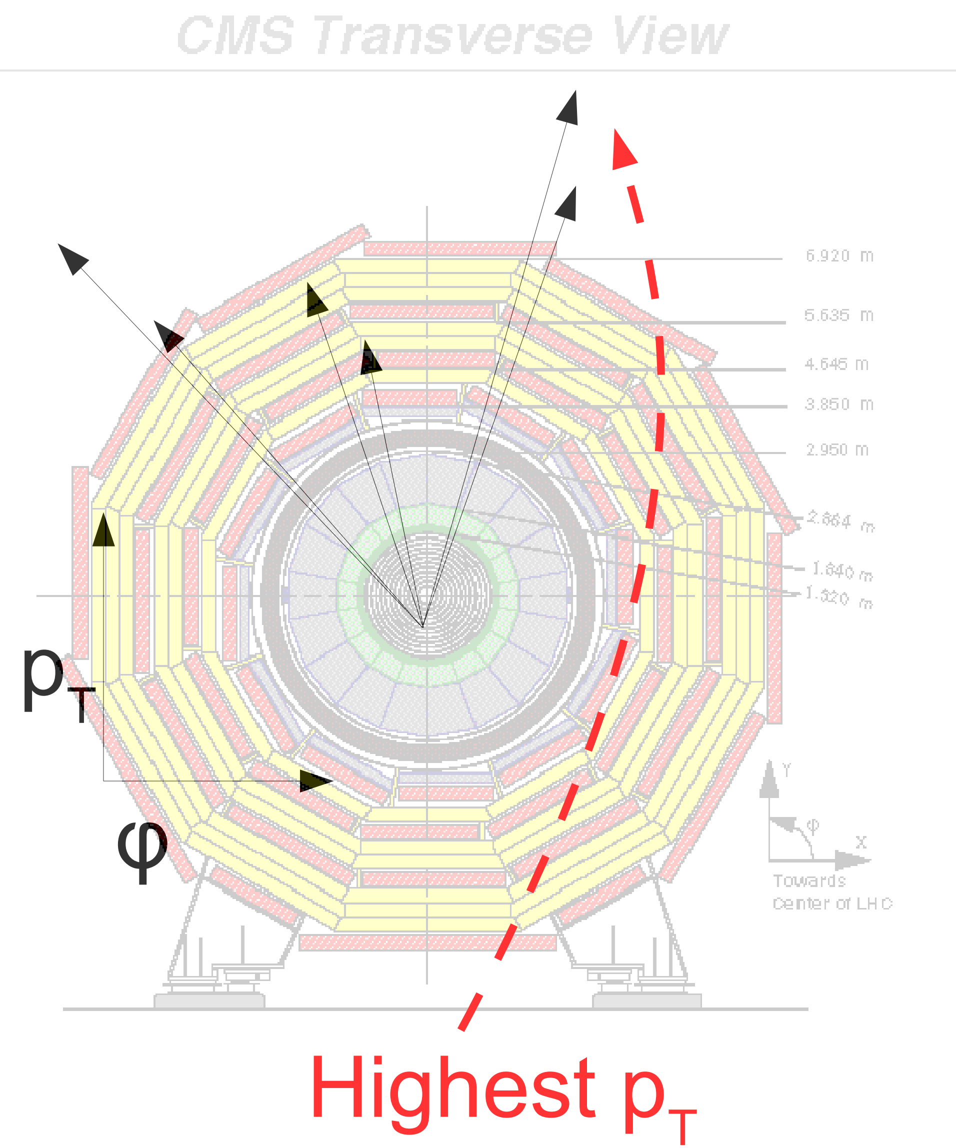
A composition of many particles originating from a quark or gluon

What is a jet?


Inside a detector
Tracks in Silicon
From a single vertex
Ecal
Hcal

Jet Reconstruction

- Itrerate over two



Take smallest

$$\Delta R \min(p_T^{\,1}, p_T^{\,2})^{\alpha}$$

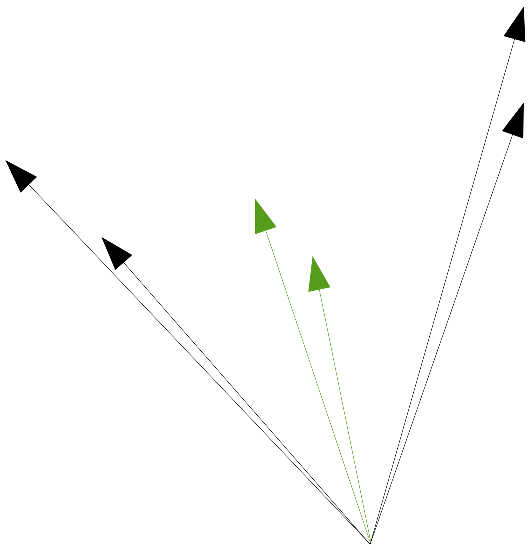
α=1 kT

α=0 Cambridge Aachen

α=-1 Anti-kT

Jet Reconstruction

- Itrerate over two



Start small

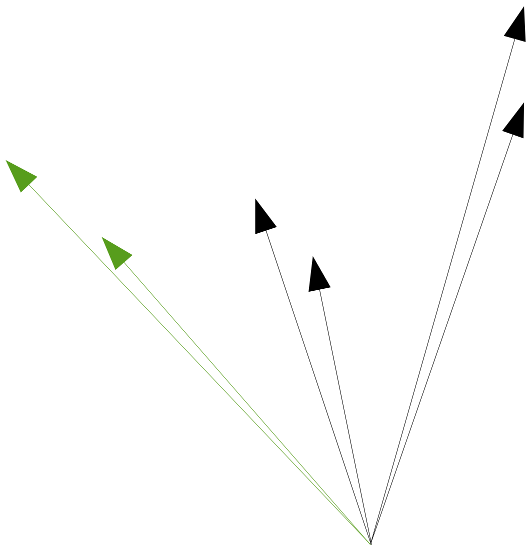
Take smallest

$$\Delta R \min(p_T^{\,1}, p_T^{\,2})^{\alpha}$$

α=1 kT
α=0 Cambridge Aachen
α=-1 Anti-kT

Jet Reconstruction

- Itrerate over two



Start Close

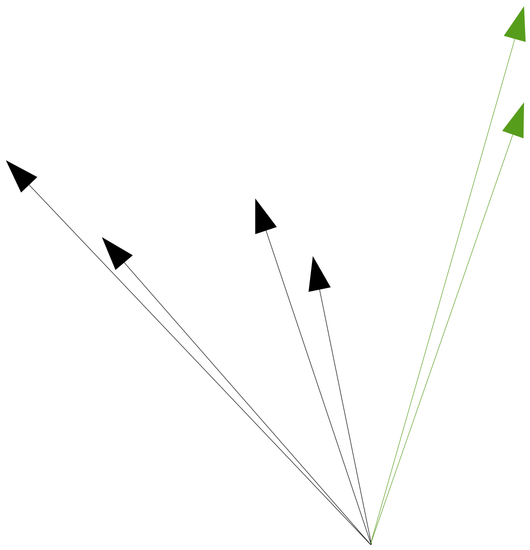
Take smallest

$$\Delta R \min(p_T^{1}, p_T^{2})^{\alpha}$$

$\alpha=1$ kT
$\alpha=0$ Cambridge Aachen
$\alpha=-1$ Anti-kT

Jet Reconstruction

- Itrerate over two



Start Big

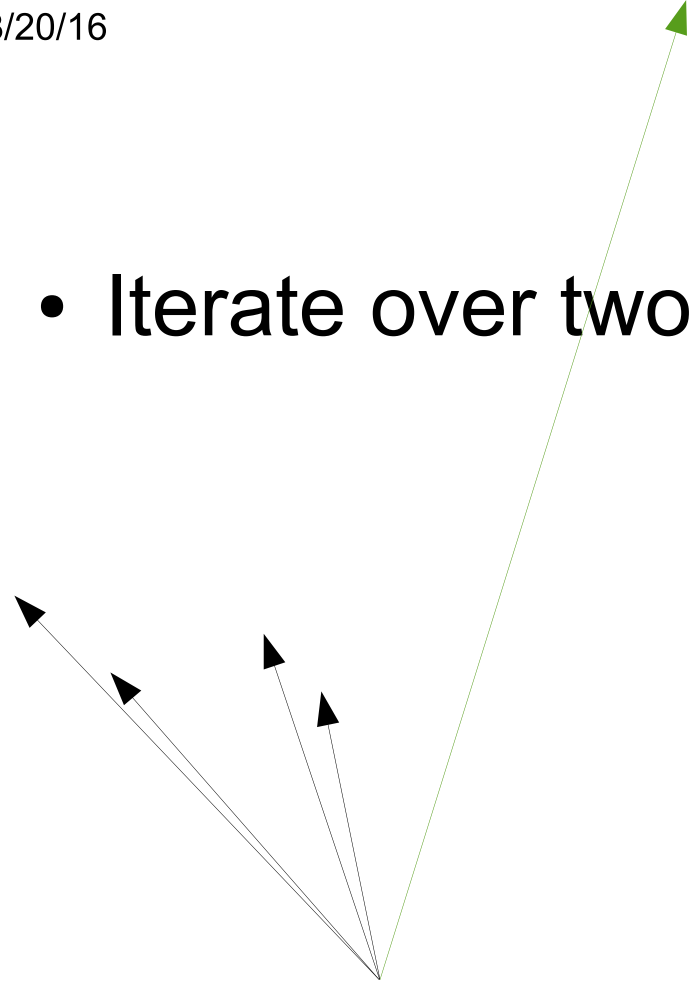
Take smallest

$$\Delta R \min(p_T^{1}, p_T^{2})^{\alpha}$$

α=1 kT
α=0 Cambridge Aachen
α=-1 Anti-kT

Jet Reconstruction

- Iterate over two



Take smallest

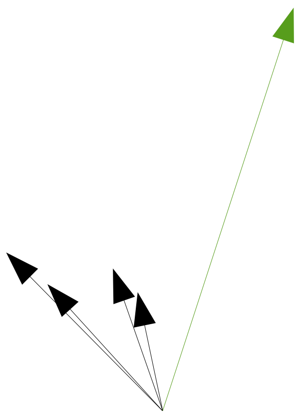
$$\Delta R \min(p_T^{1}, p_T^{2})^{\alpha}$$

$\alpha=1$ kT
$\alpha=0$ Cambridge Aachen
$\alpha=-1$ Anti-kT

Now merge initial into a particle

Jet Reconstruction

- Iterate over two



Zooming out

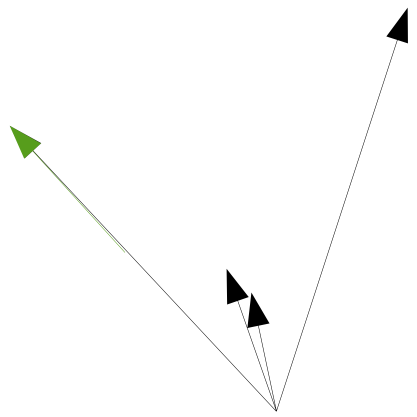
Take smallest

$$\Delta R \min(p_T^{1}, p_T^{2})^{\alpha}$$

α=1 kT
α=0 Cambridge Aachen
α=-1 Anti-kT

Jet Reconstruction

- Iterate over two



Merge next set

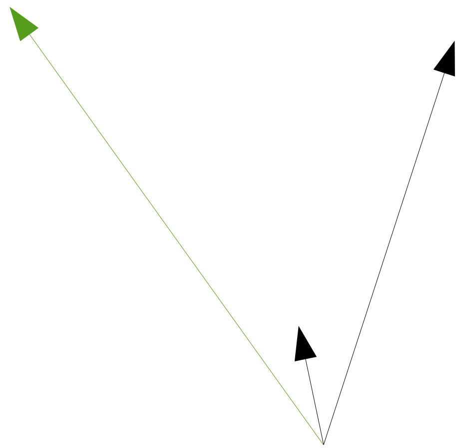
Take smallest

$$\Delta R \min(p_T^1, p_T^2)^{\alpha}$$

α=1 kT
α=0 Cambridge Aachen
α=-1 Anti-kT

Jet Reconstruction

- Iterate over two



Merge next set

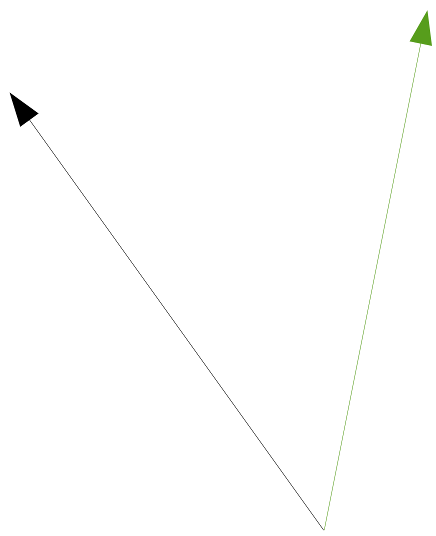
Take smallest

$$\Delta R \min(p_T^1, p_T^2)^\alpha$$

$\alpha=1$ kT
$\alpha=0$ Cambridge Aachen
$\alpha=-1$ Anti-kT

Jet Reconstruction

- Iterate over two



Merge next set

Take smallest

$$\Delta R \min(p_T^1, p_T^2)^\alpha$$

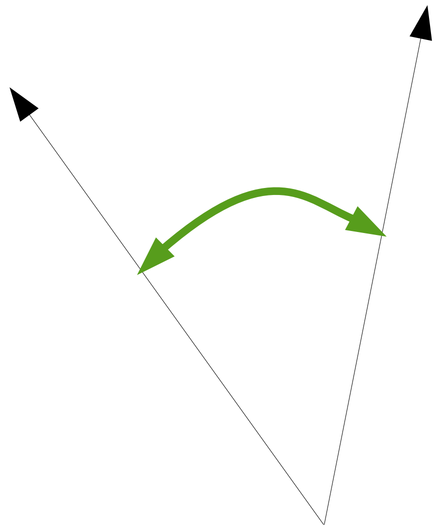
α=1 kT

α=0 Cambridge Aachen

α=-1 Anti-kT

Jet Reconstruction

- Iterate over two



If distance > X (stop)
X=0.4,0.8,...

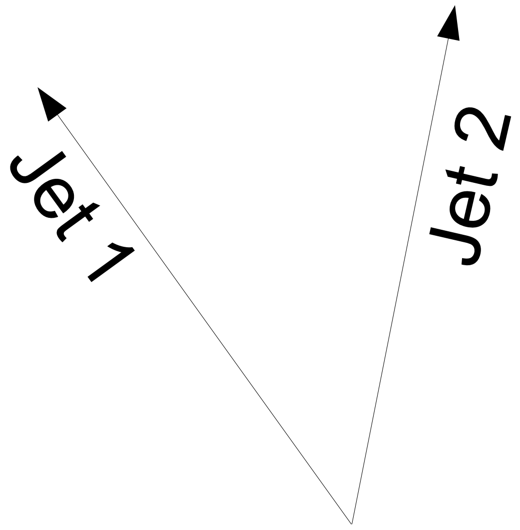
Take smallest

$$\Delta R \min(p_T^1, p_T^2)^\alpha$$

α=1 kT
α=0 Cambridge Aachen
α=-1 Anti-kT

Jet Reconstruction

- Iterate over two



Done

Take smallest

$$\Delta R \min(p_T^{1}, p_T^{2})^{\alpha}$$

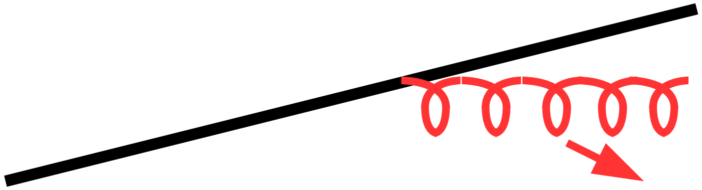
α=1 kT
α=0 Cambridge Aachen
α=-1 Anti-kT

Why do we use these algorithms?

$$\Delta R \min(p_T^1, p_T^2)^\alpha$$

Need to be able to calculate these with QCD

Collinear safety



Can Randomly happen? When $\Delta R \to 0$

$\Delta R \min(p_T^1, p_T^2)^\alpha \to 0$

When $\Delta R \to 0$

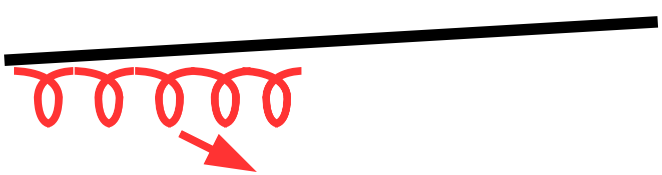
*Wesley Smith

Why do we use these algorithms?

$$\Delta R \min(p_T^1, p_T^2)^\alpha$$

Need to be able to calculate these with QCD

Infrared safety



Can Randomly happen? When $E \rightarrow 0$

$\Delta R \min(p_T^1, p_T^2)^\alpha \rightarrow 0$ ($p_T \rightarrow 0$)

For $\alpha=0$ gluon gets combined with nearest particle $p_T^i \rightarrow p_T^i + E(\rightarrow 0) = p_T^i$

*Wesley Smith

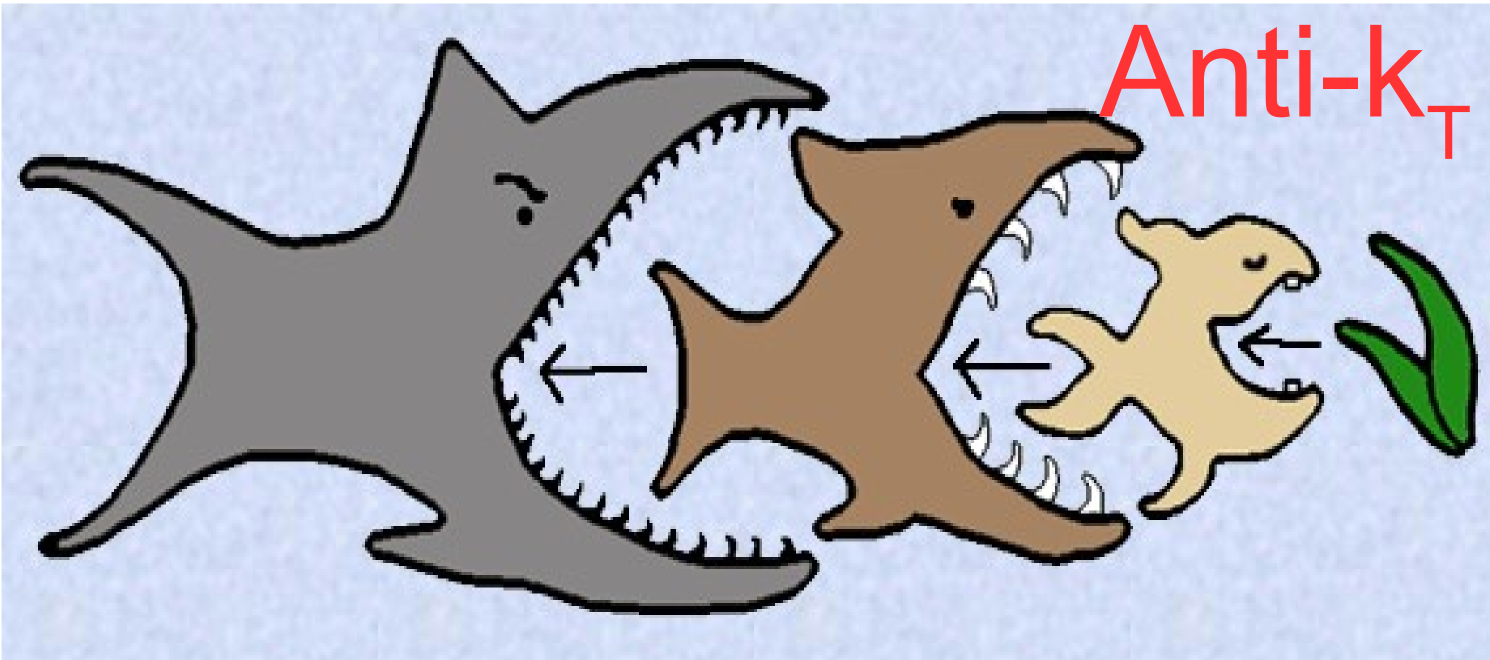
Why do we use these algorithms?

To calculate anything with a jet we need to observe :

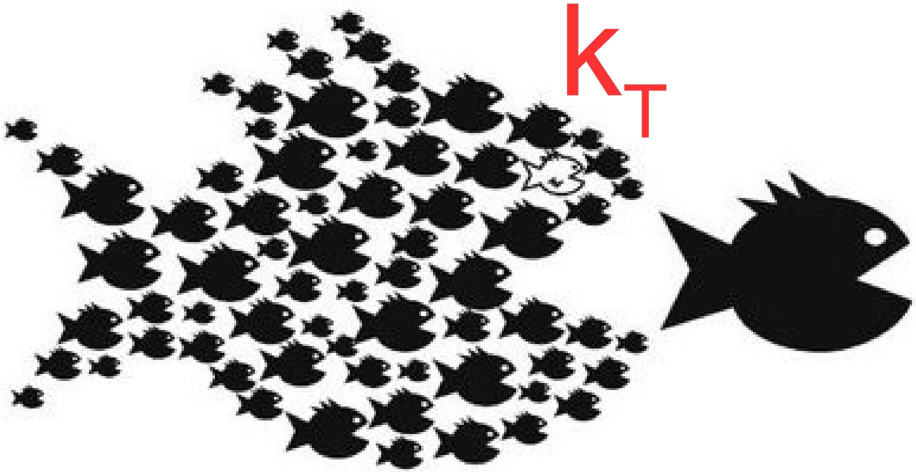
Infrared safety : invariance with random particle w/E→0
Collider safet : invariance with random split ΔR→0

This applies to jet substructure observables too!
…..Well maybe
can you think of a example that breaks IR safety?

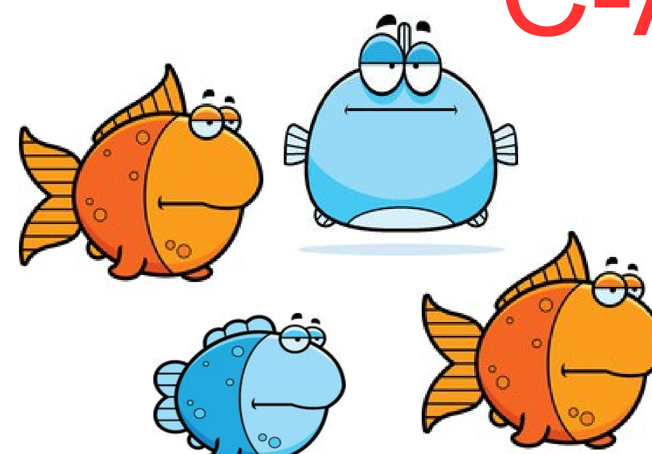
Recap



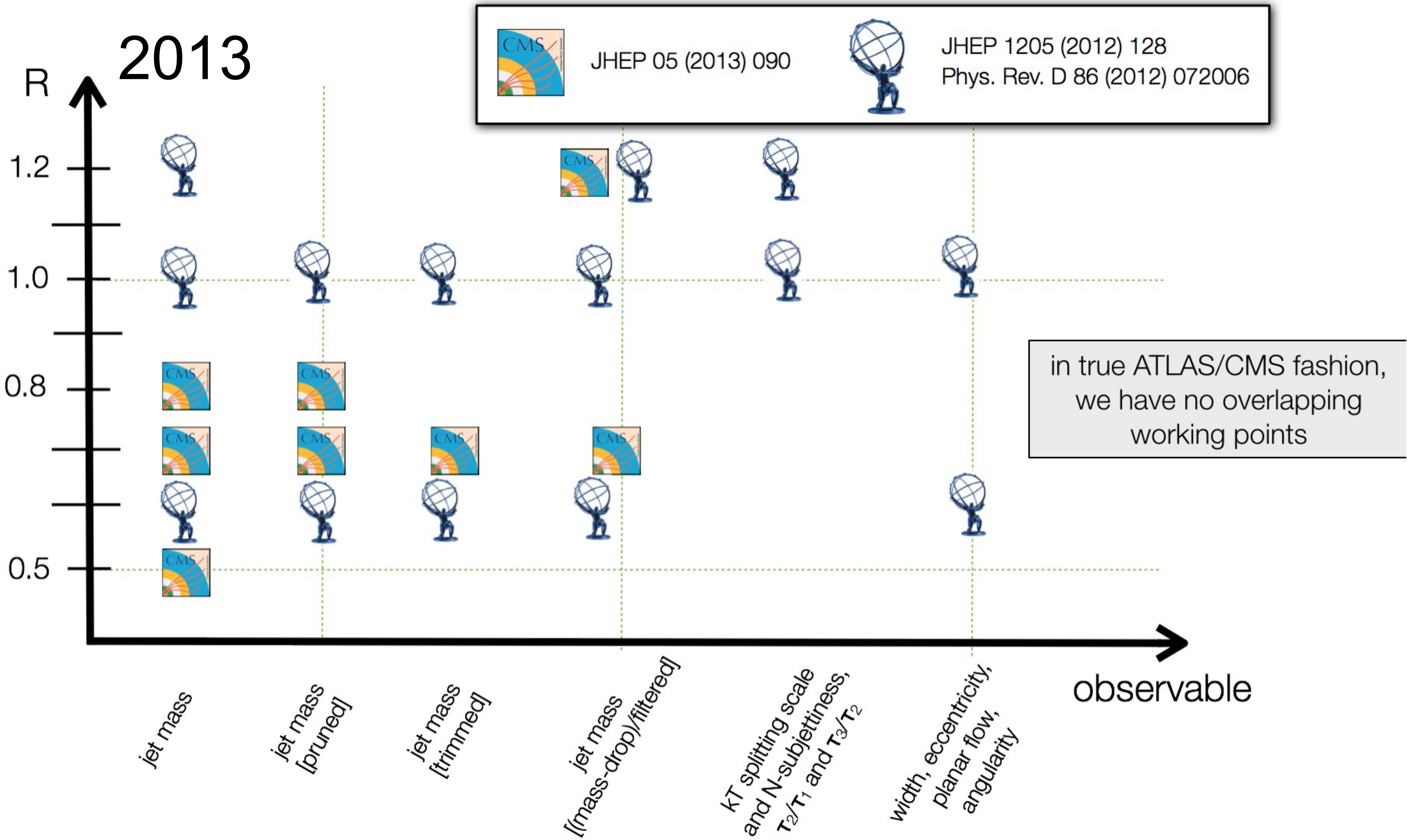
k_T



C-A

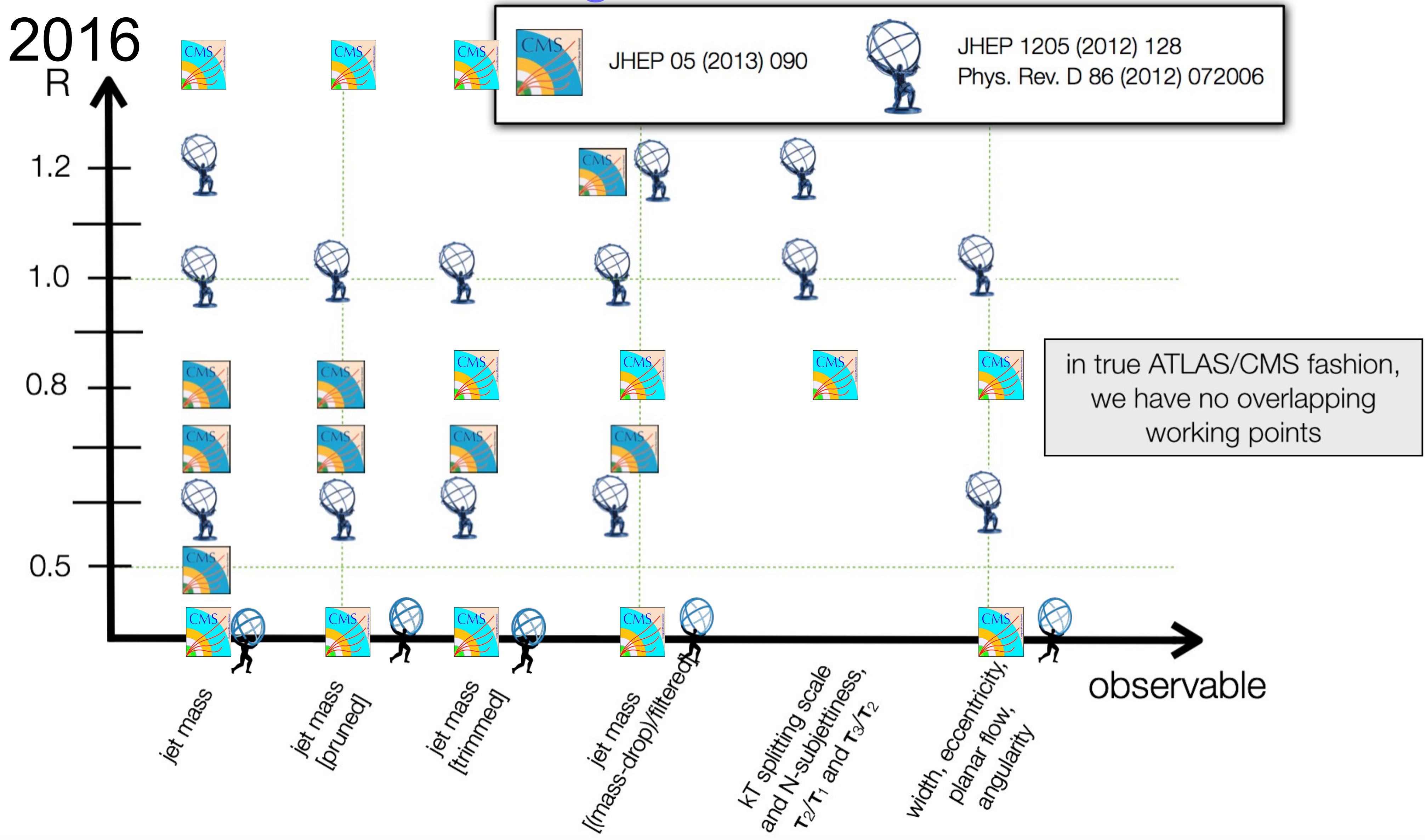


Whats the right cone size?

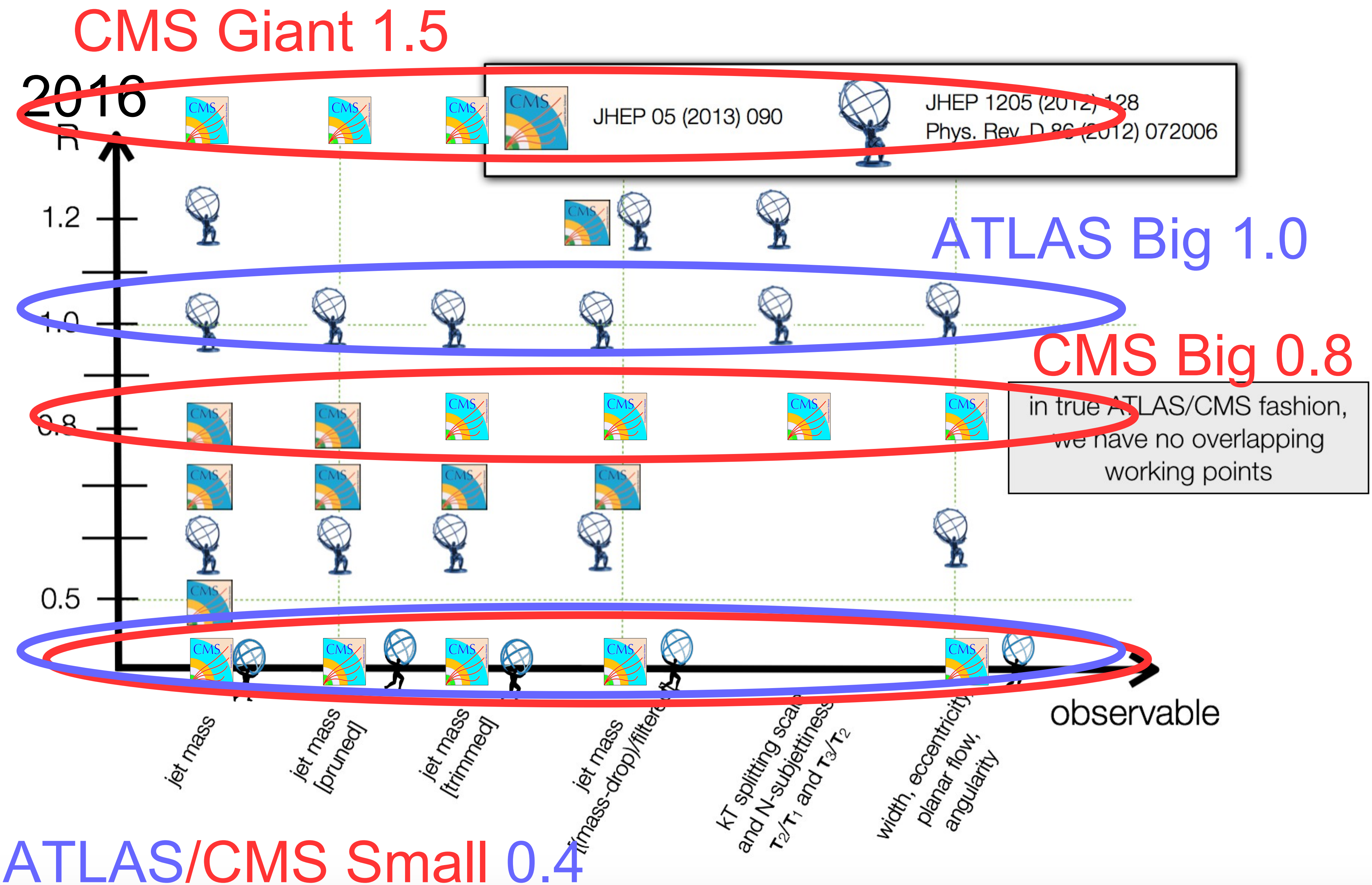


Whats the right cone size?

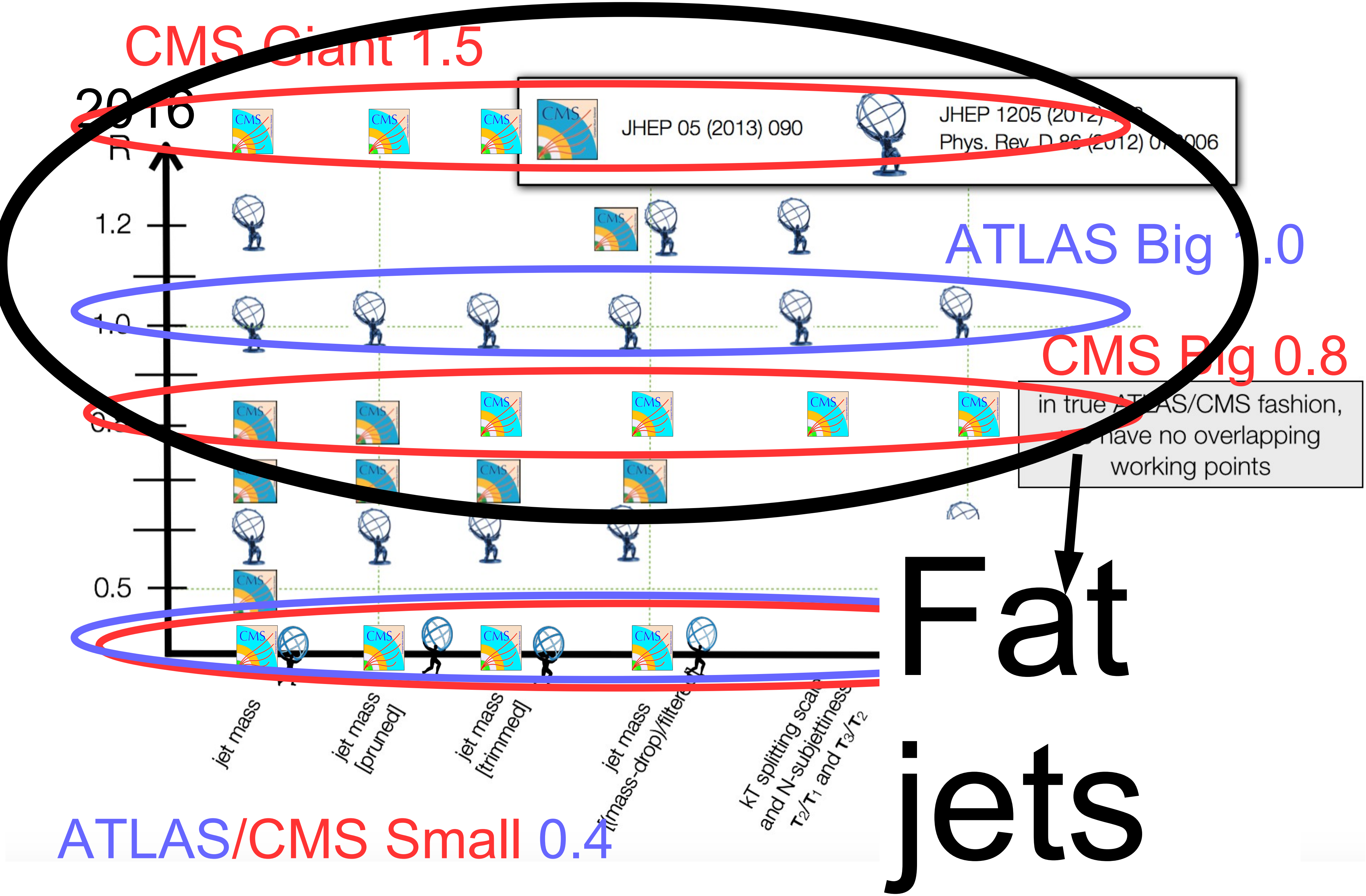
There is no right cone size



Current Defaults at LHC

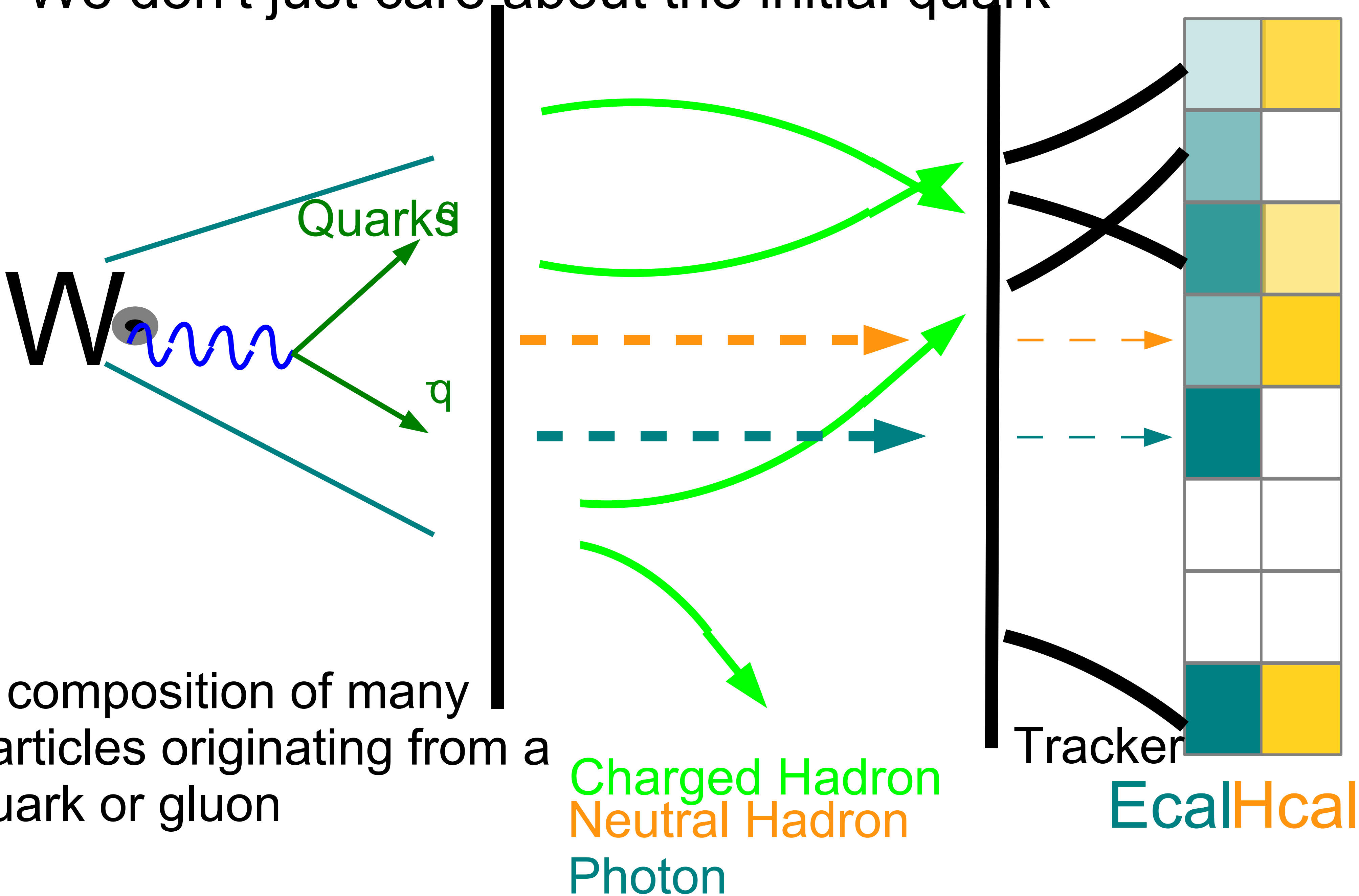


Current Defaults at LHC



Why do we have different defaults?

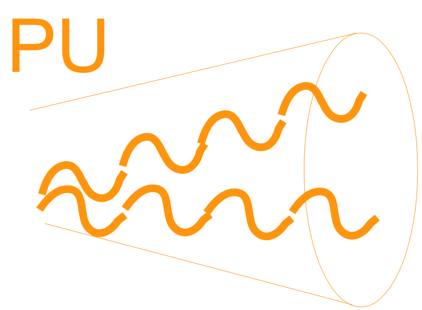
- We don't just care about the initial quark



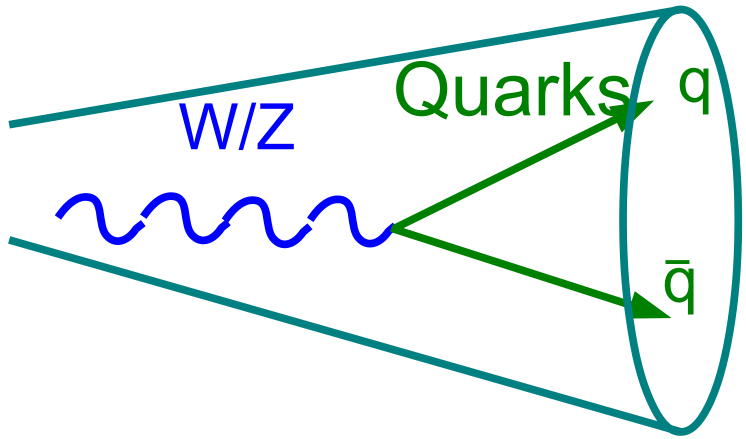
A composition of many particles originating from a quark or gluon

Many Phases of Jets

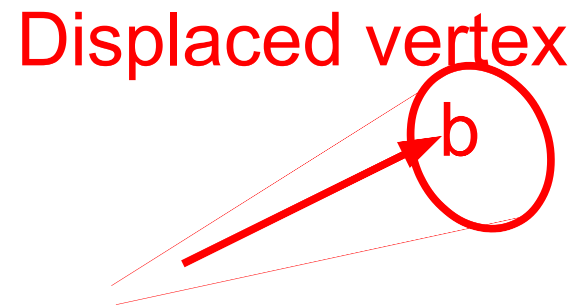
Pileup Jet



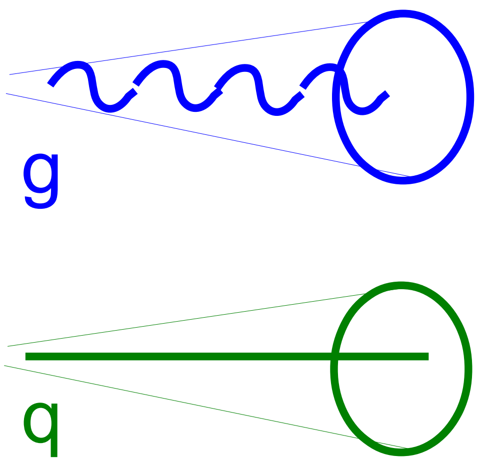
V Boson Jet



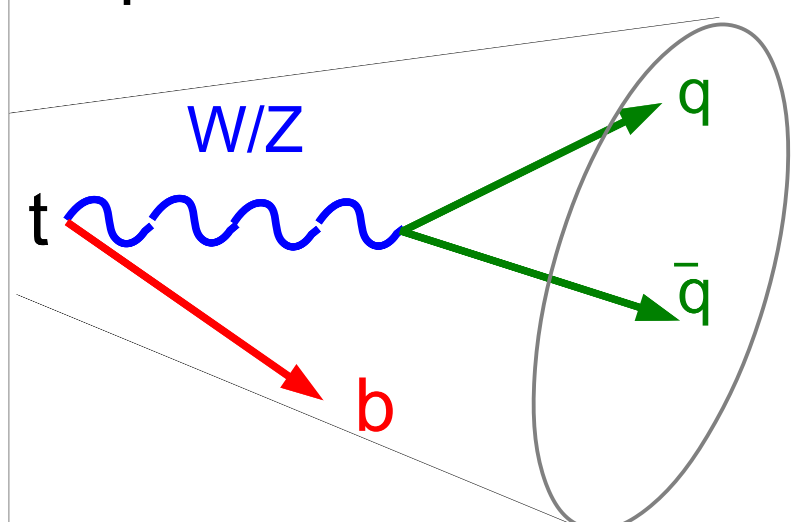
B-quark Jet



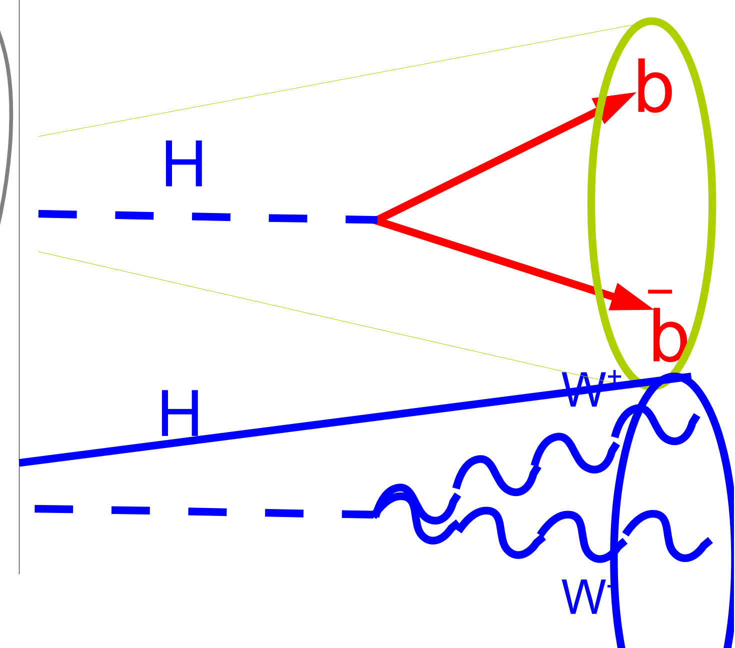
Quark/Gluon Jet



Top Jet

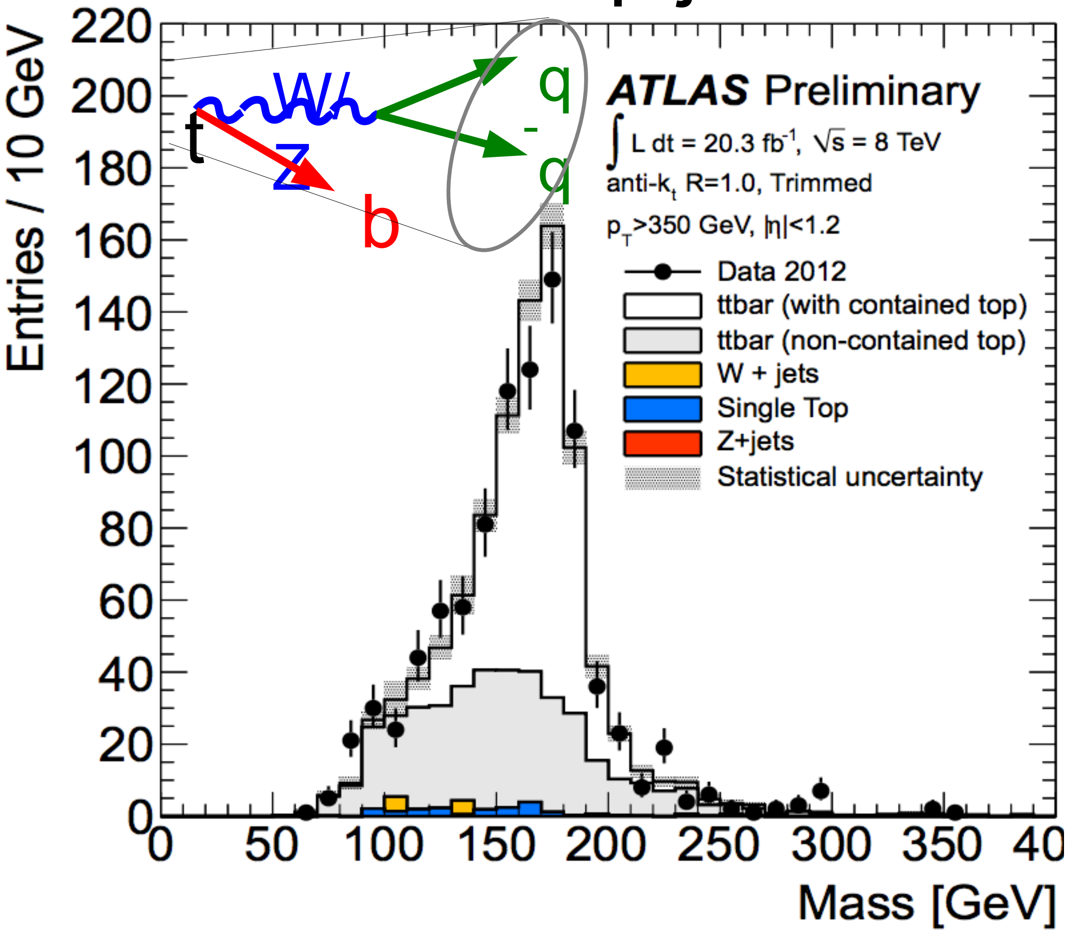


Higgs Jet

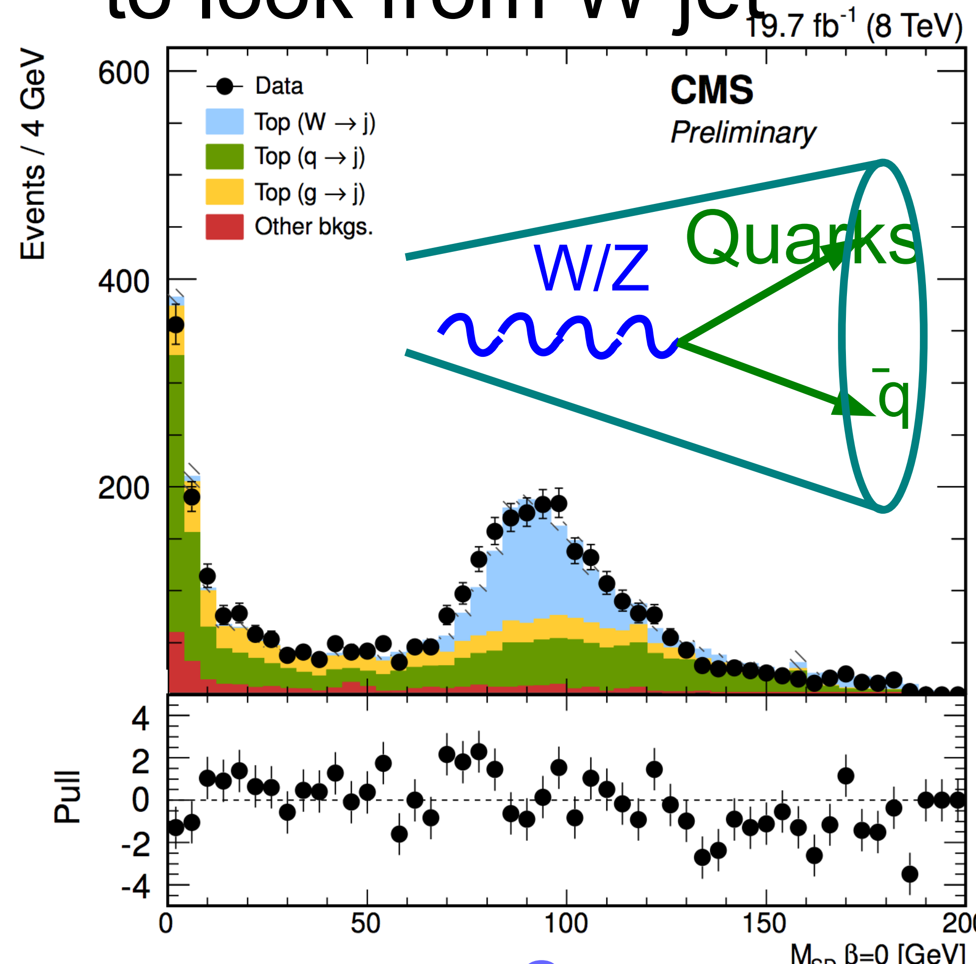


Each cone focus on a different object

Larger cone allows us to look from top jet



Smaller cone allows us to look from W jet

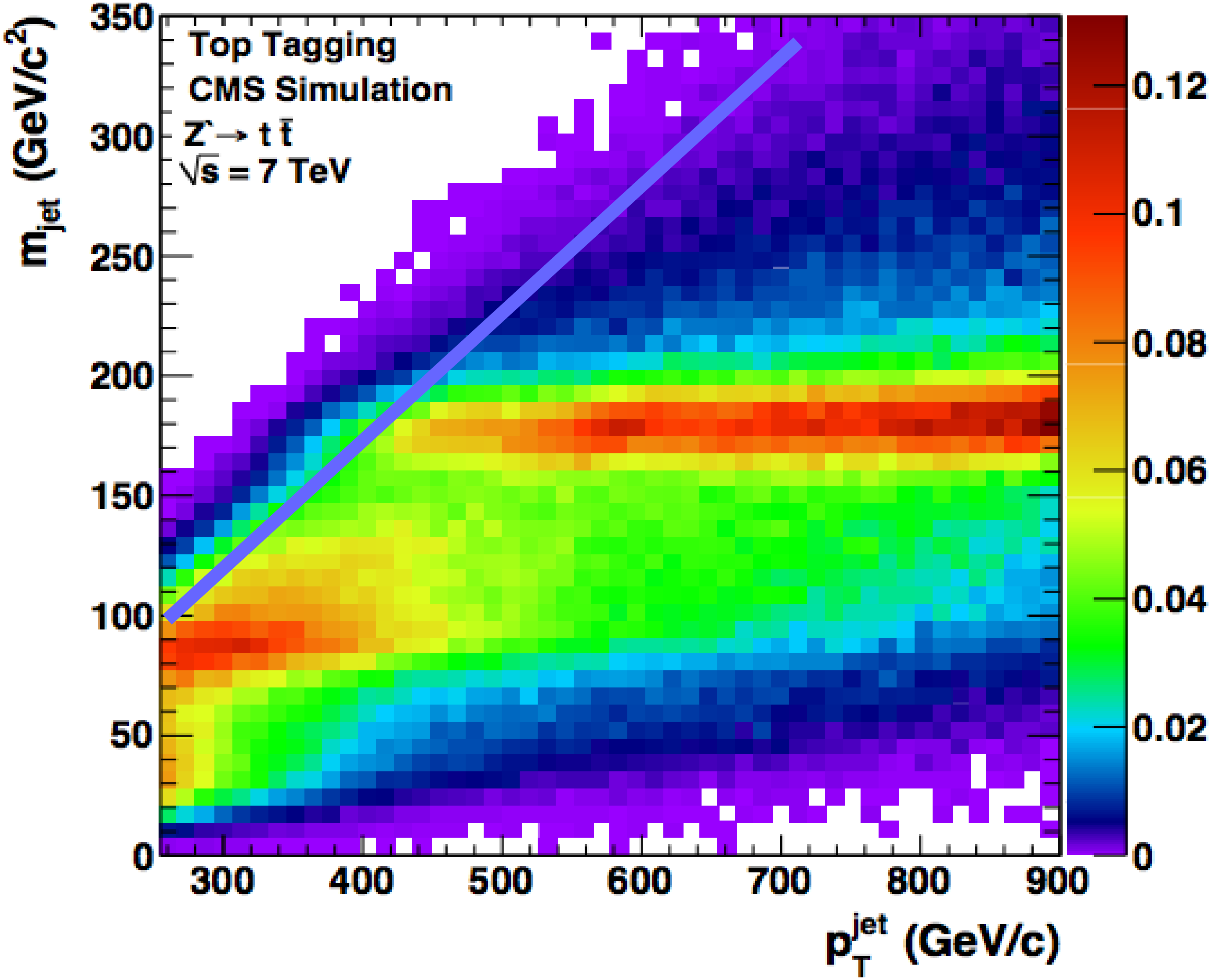


Master formula for heavy object : $\Delta R = \frac{2m}{p_T}$

Each cone focus on a different object

Larger cone allows us to look from top jet

Smaller cone allows us to look from W jet



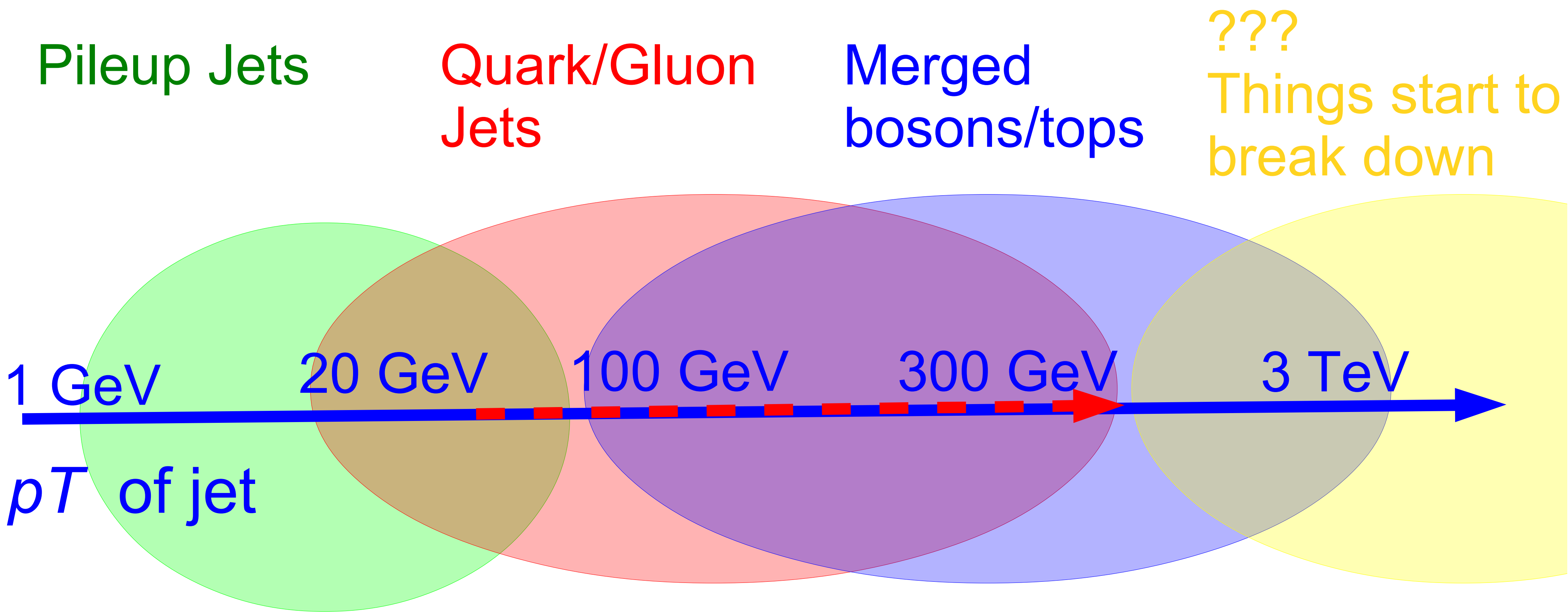
Fix $\Delta R \rightarrow 0.8$

$$\frac{2m}{p_T} = 0.8$$

$m = 0.4\ p_T$

Spectrum of Jet Substructure

Substructure has been leading to a change in how we view jets



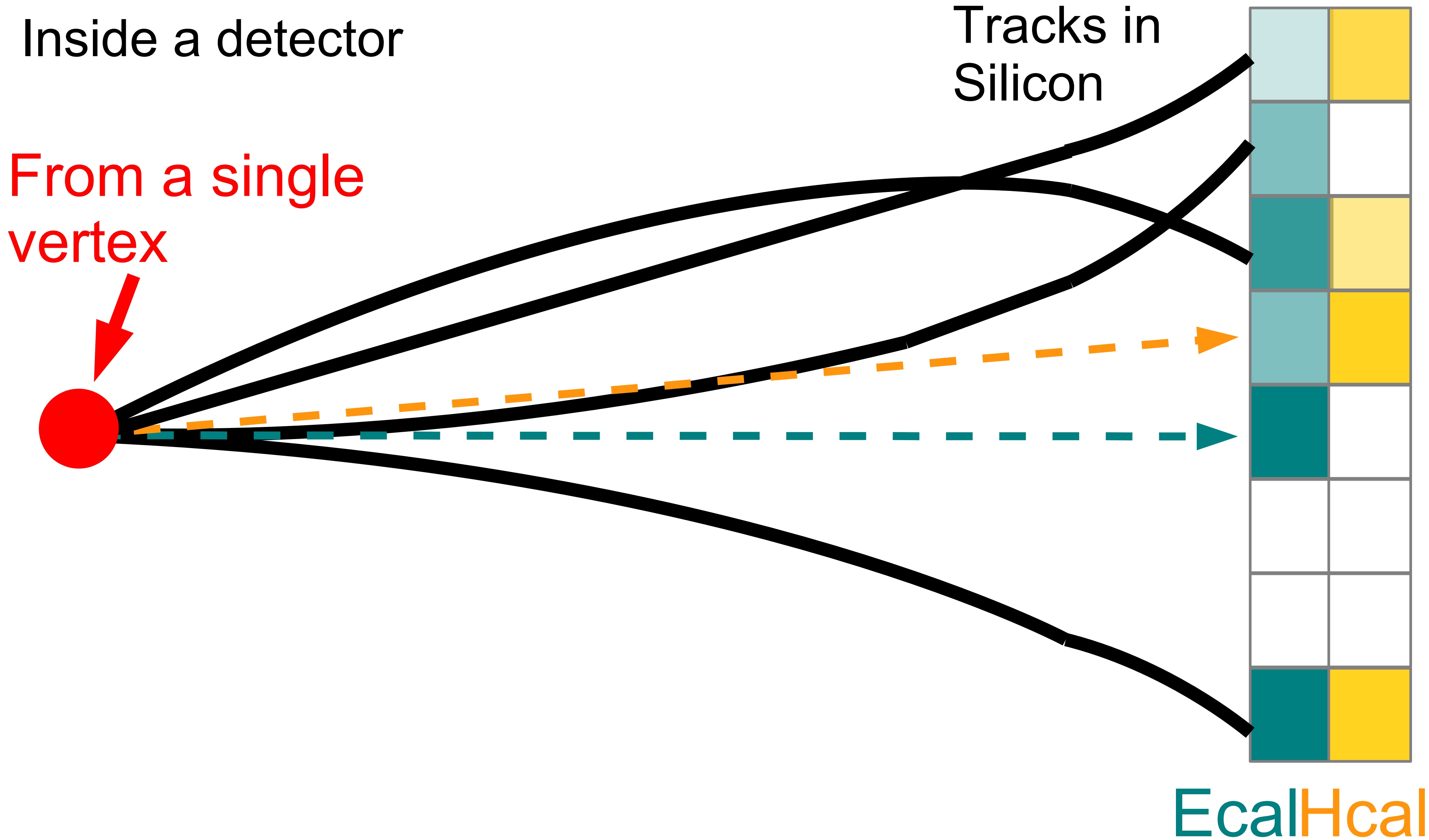
Pileup treated with Pileup Jet Id at low *pT*

At high *pT* Pileup subtraction the most important

At 1 TeV Reconstruction effects limit substructure

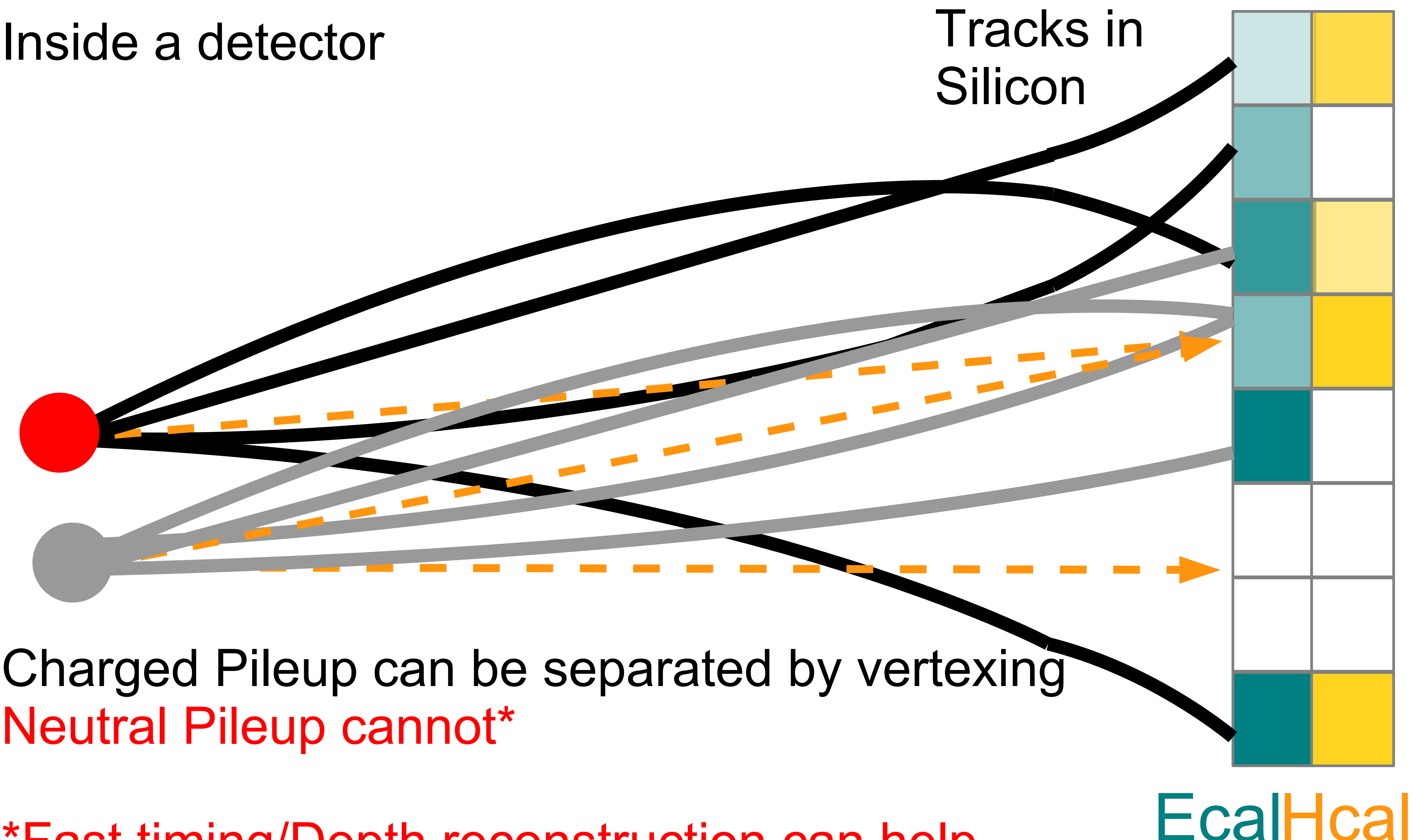
(we will not talk about this here)

What is a jet?


Inside a detector
Tracks in Silicon
From a single vertex
EcalHcal

What is a Jet?

Inside a detector

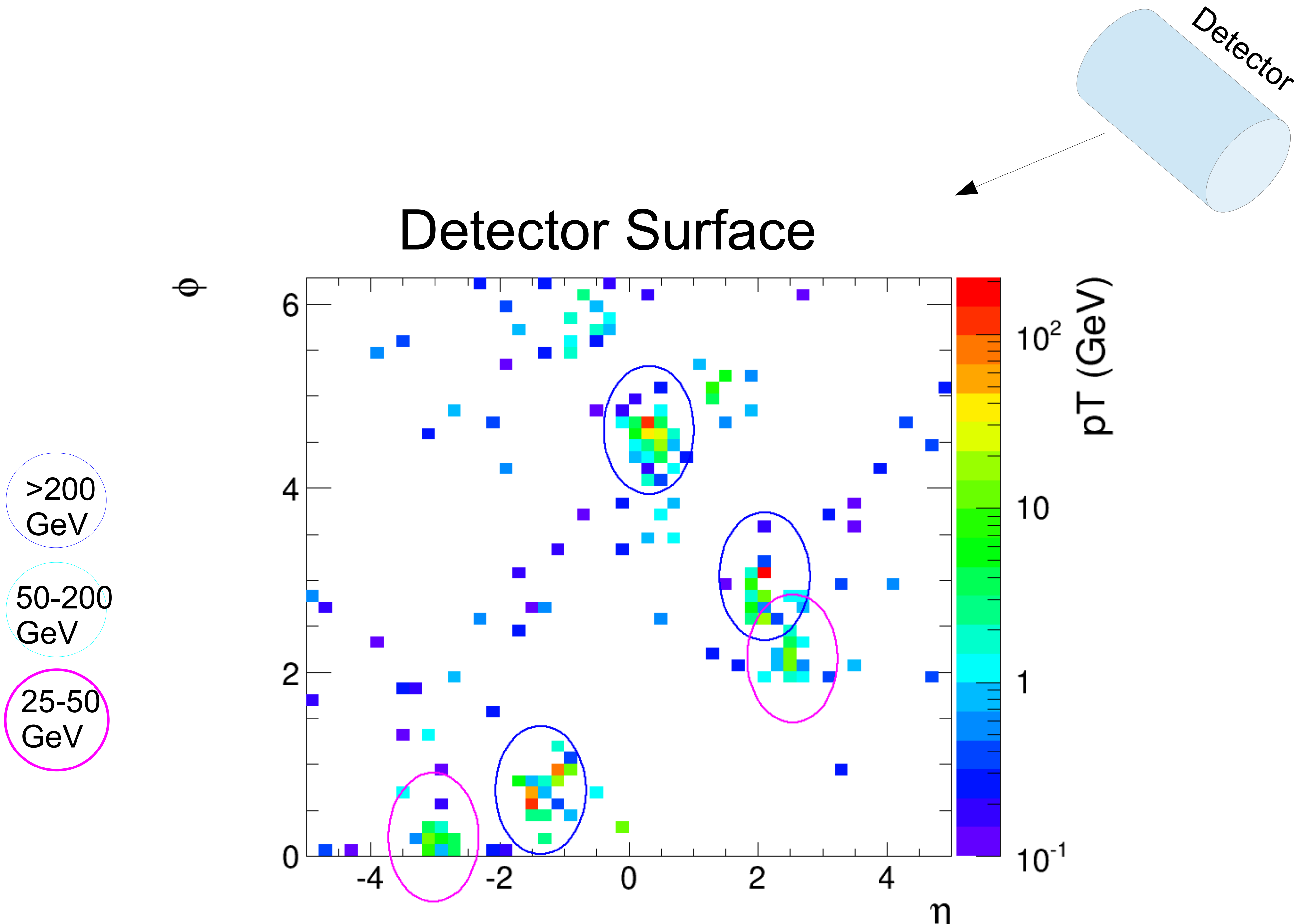


Charged Pileup can be separated by vertexing

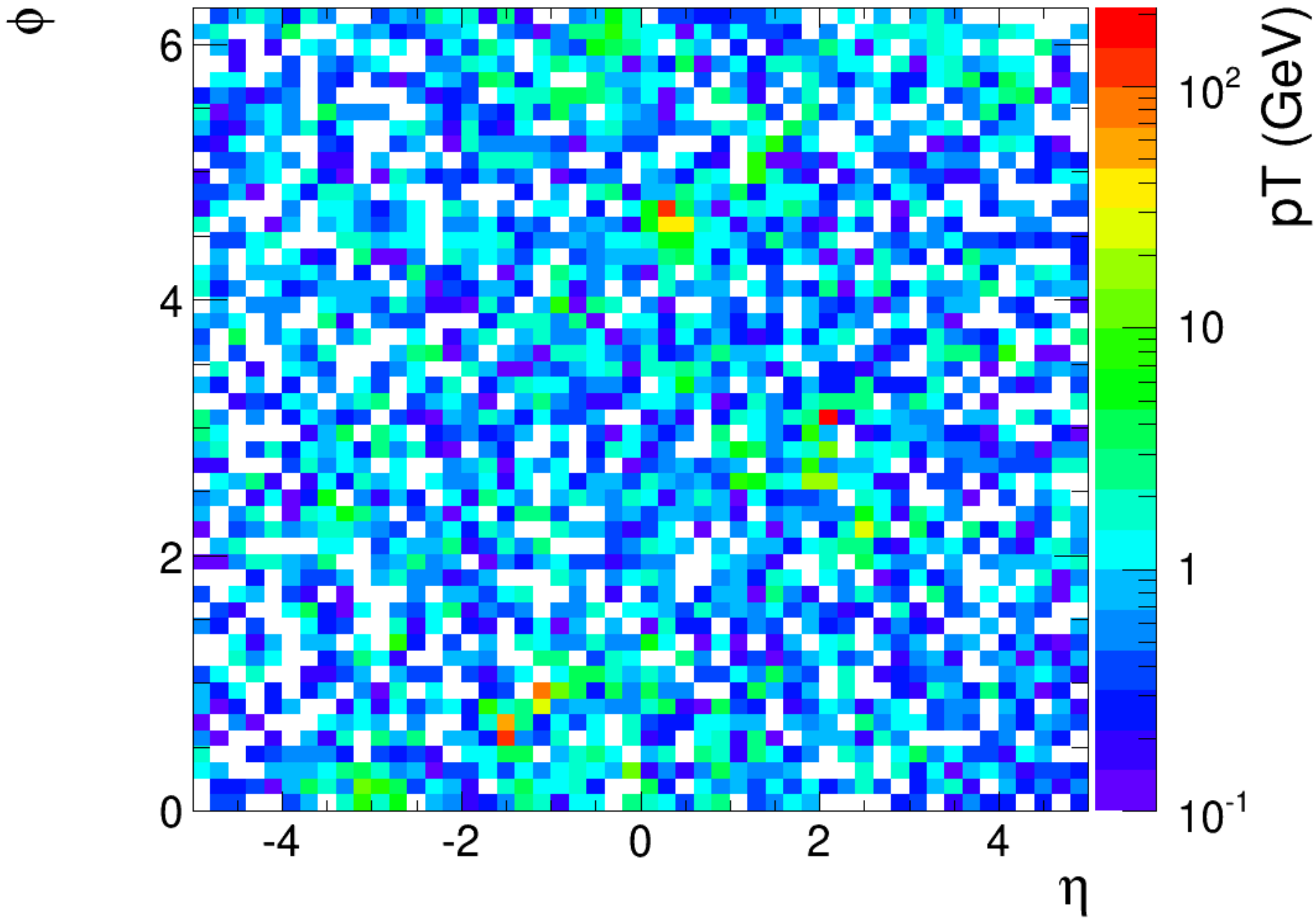
Neutral Pileup cannot*

*Fast timing/Depth reconstruction can help

Detector Surface



We also have pileup



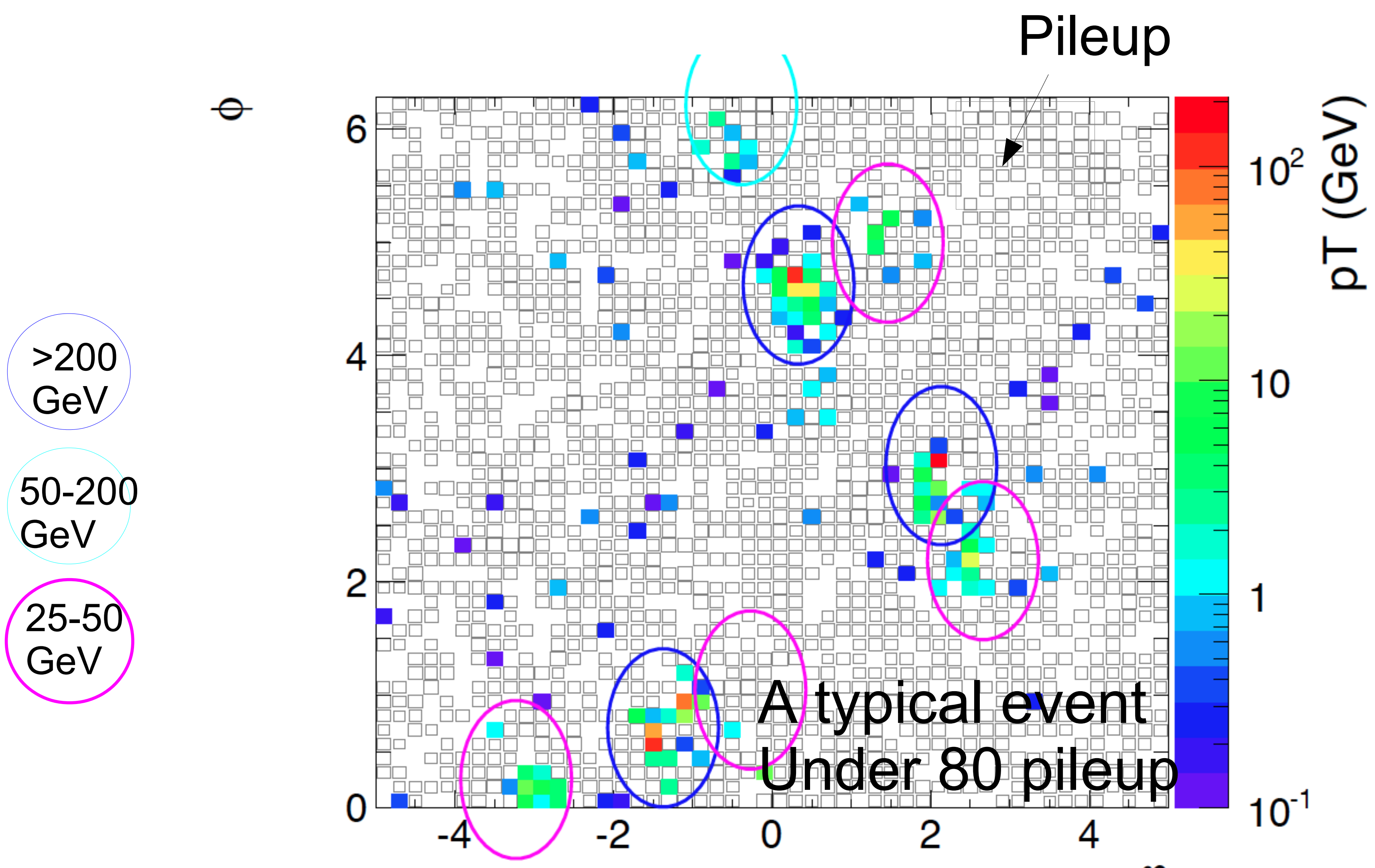
>200 GeV

50-200 GeV

25-50 GeV

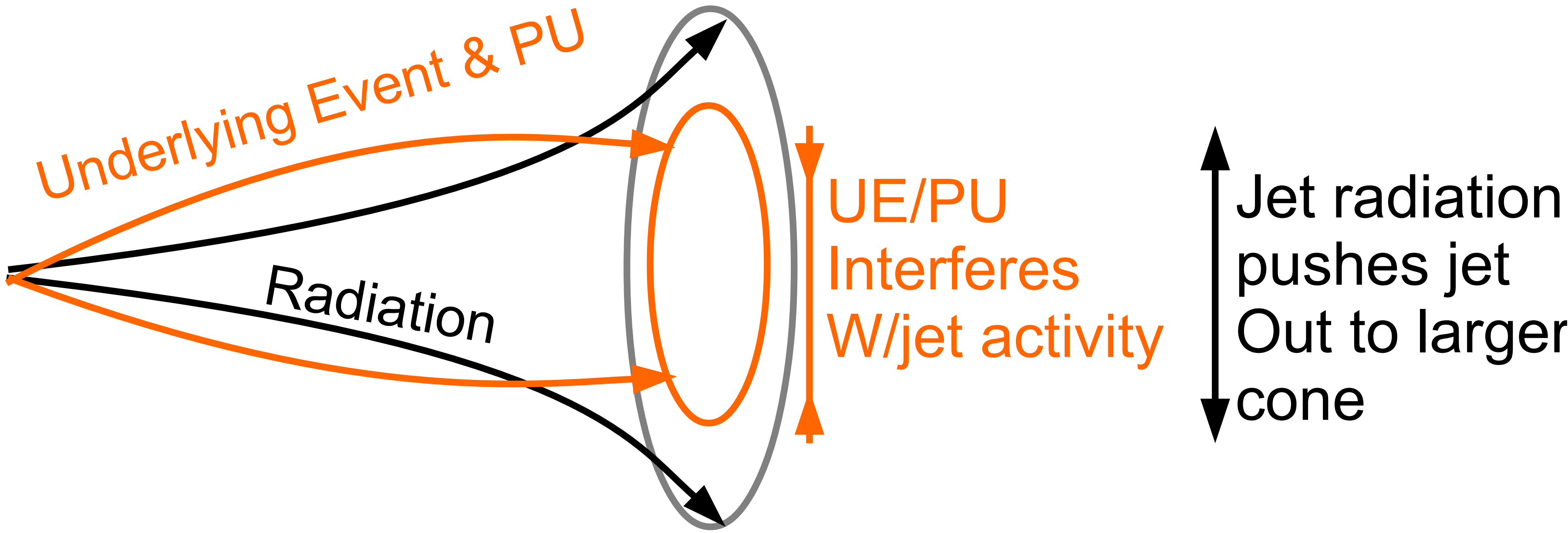
We also have pileup

- Filtering the interesting info



Jet Energy Correction

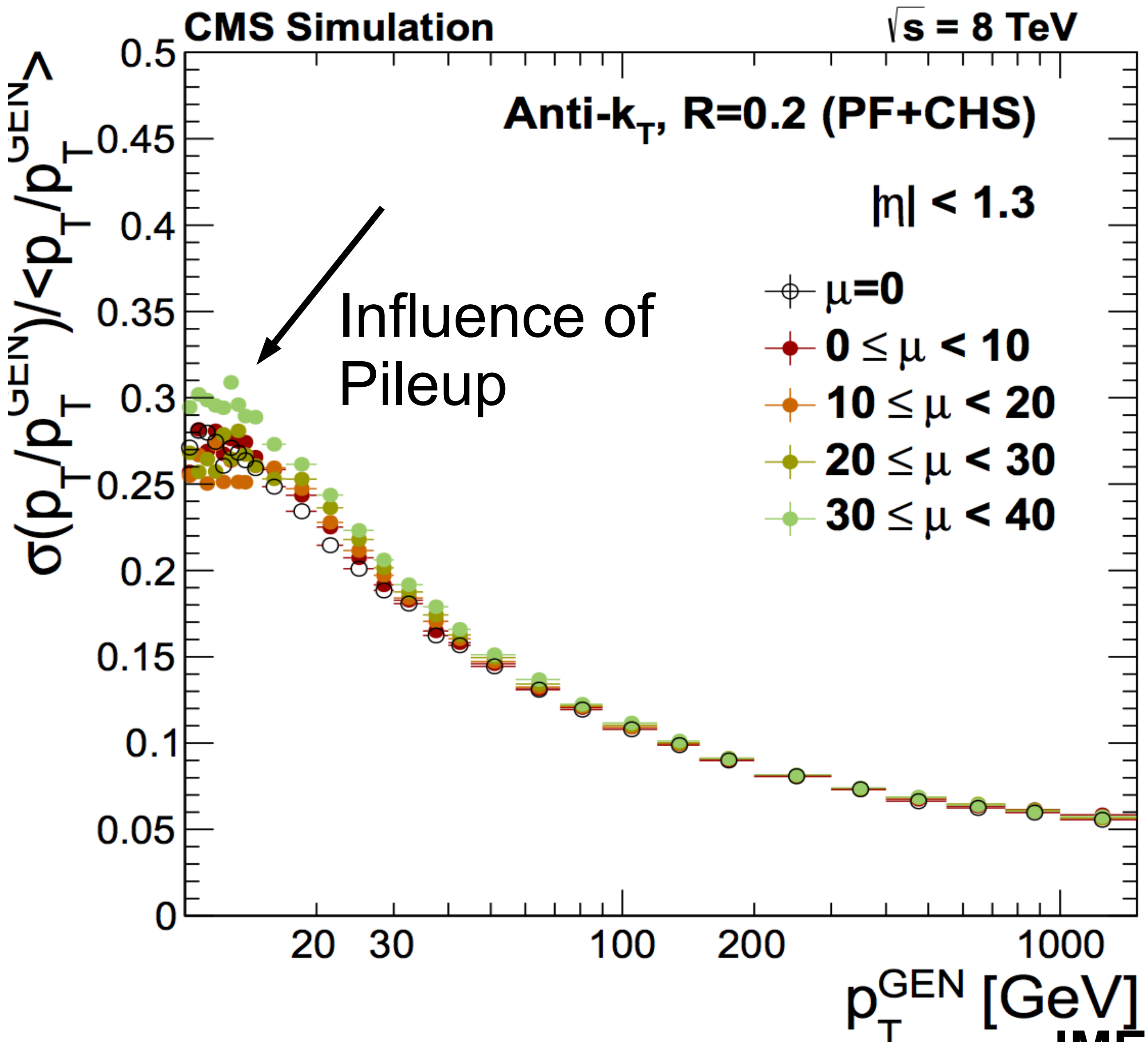
- Correcting to truth



How do we shape our jet against the UE?
Why did CMS switch to AK4?

Jet Energy Correction

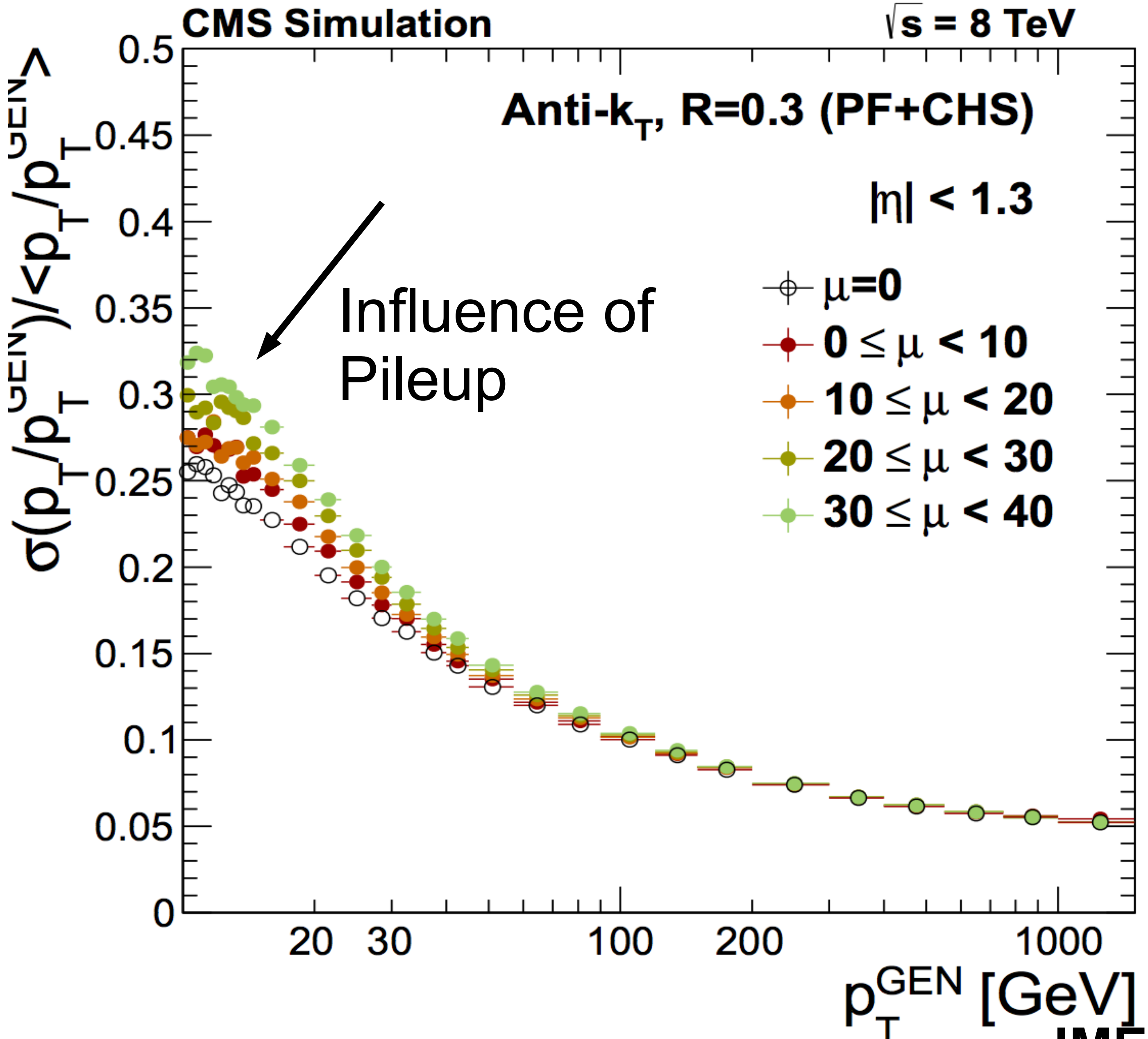
- AK2



JME-DP-14/037

Jet Energy Correction

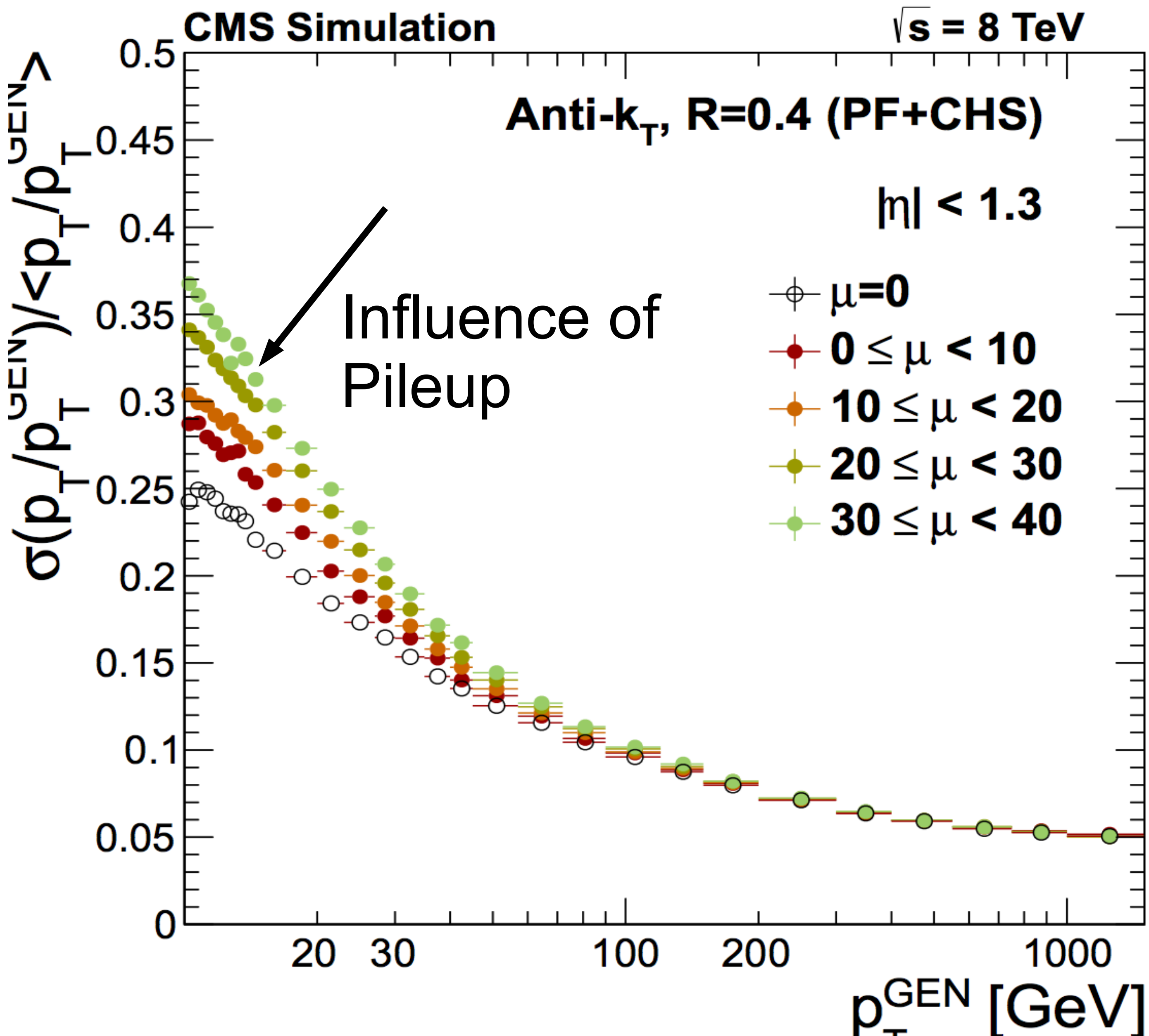
- AK3



JME-DP-14/037

Jet Energy Correction

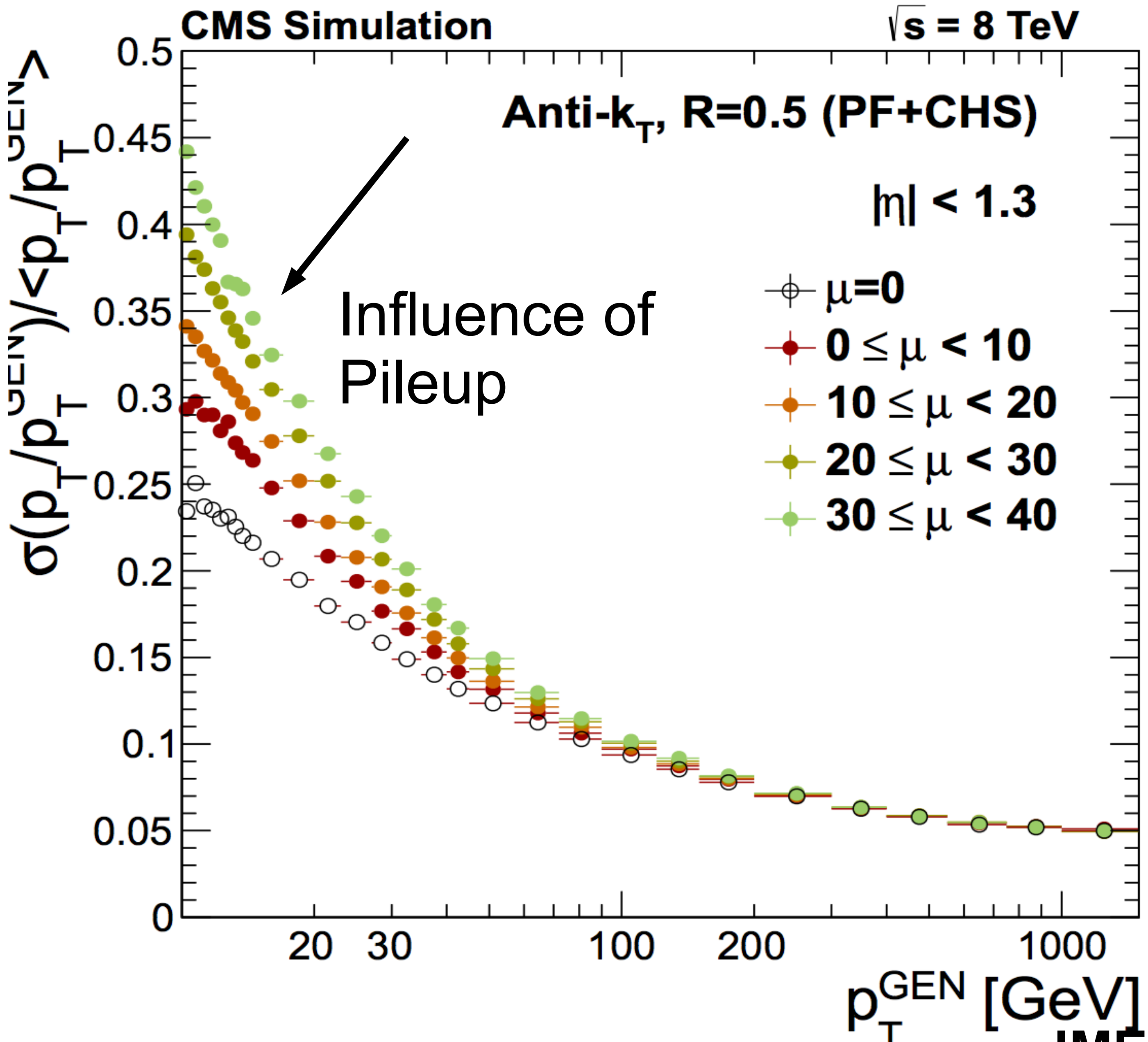
- AK4



JME-DP-14/037

Jet Energy Correction

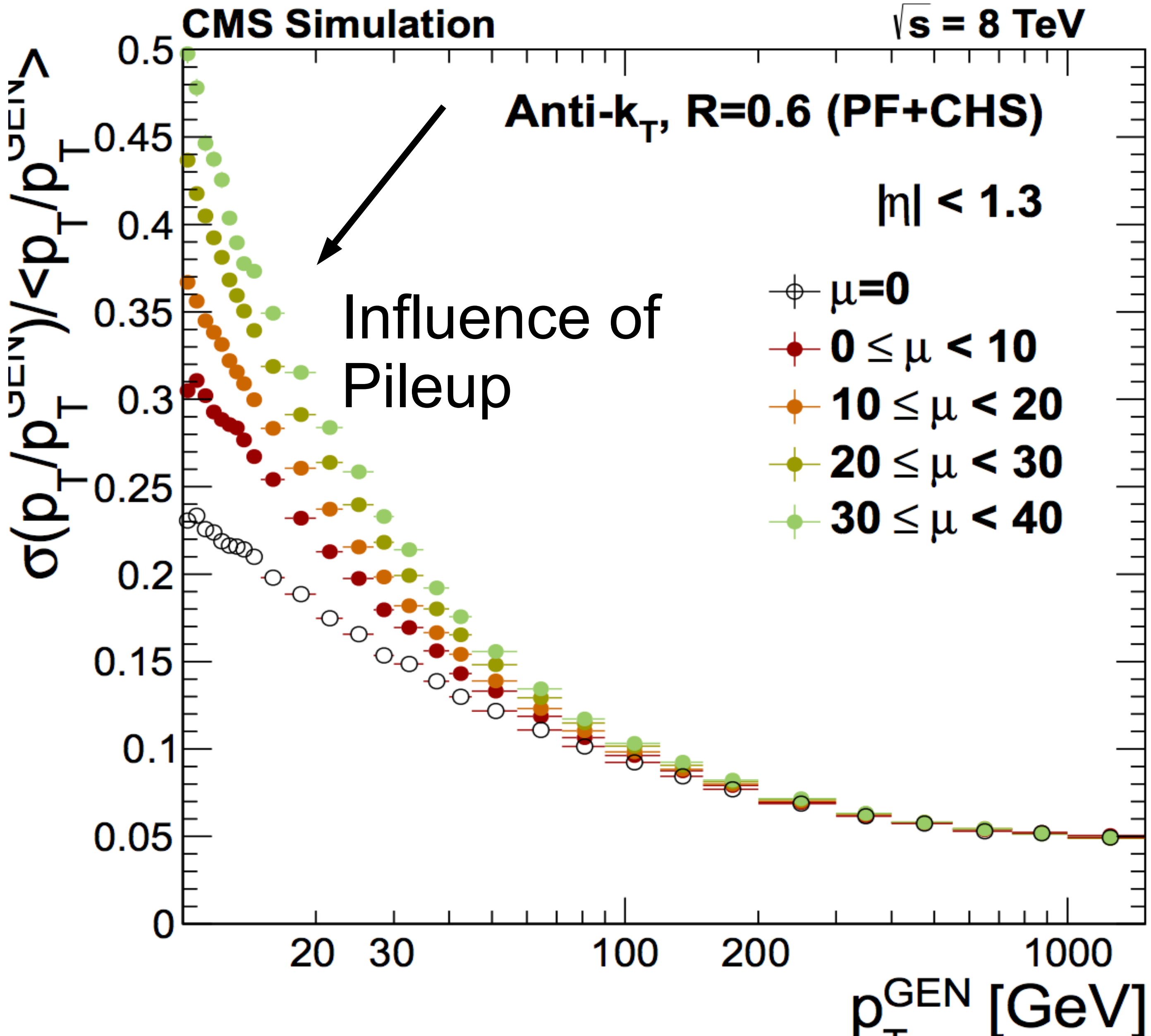
- AK5



JME-DP-14/037

Jet Energy Correction

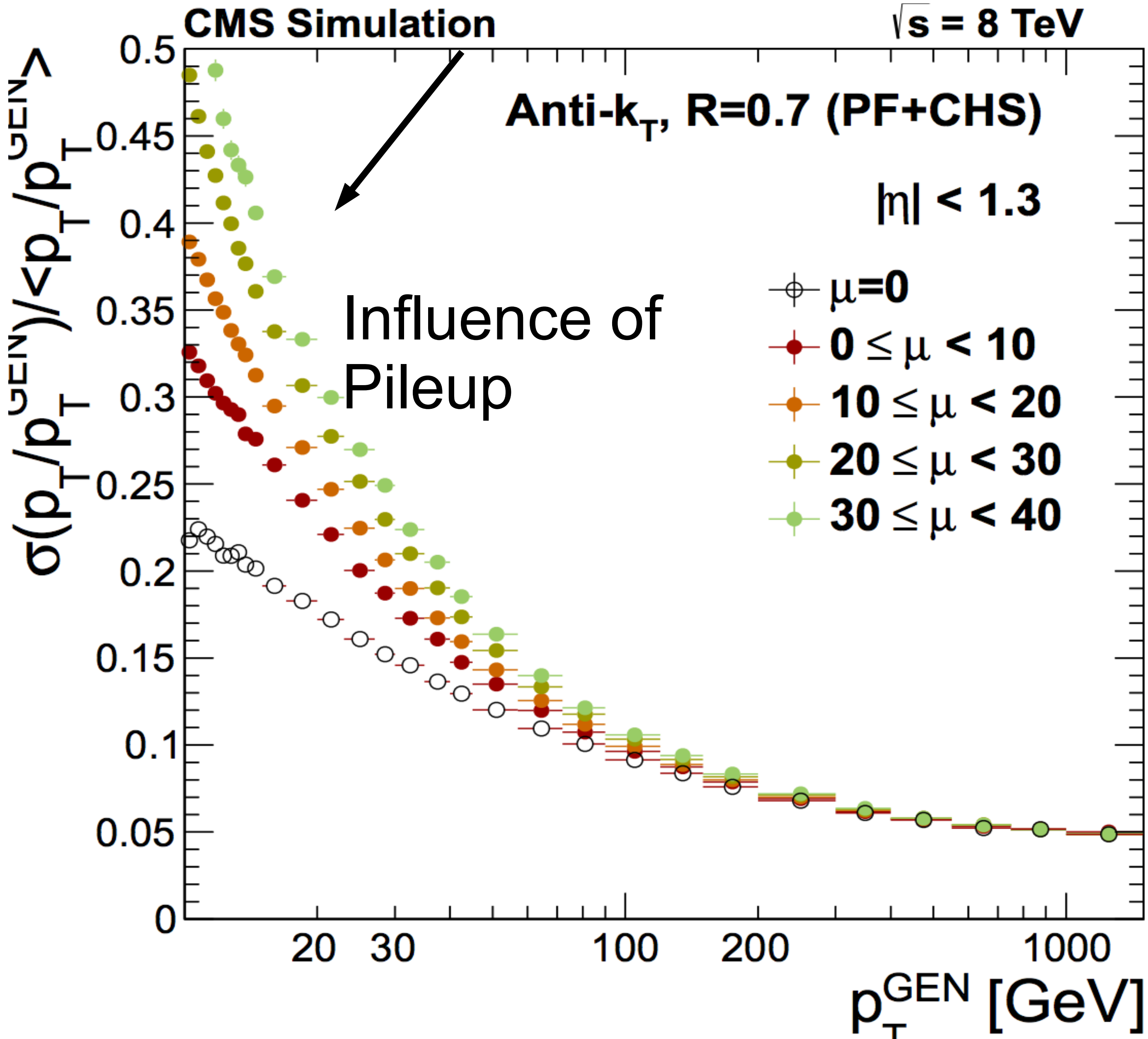
- AK6



JME-DP-14/037

Jet Energy Correction

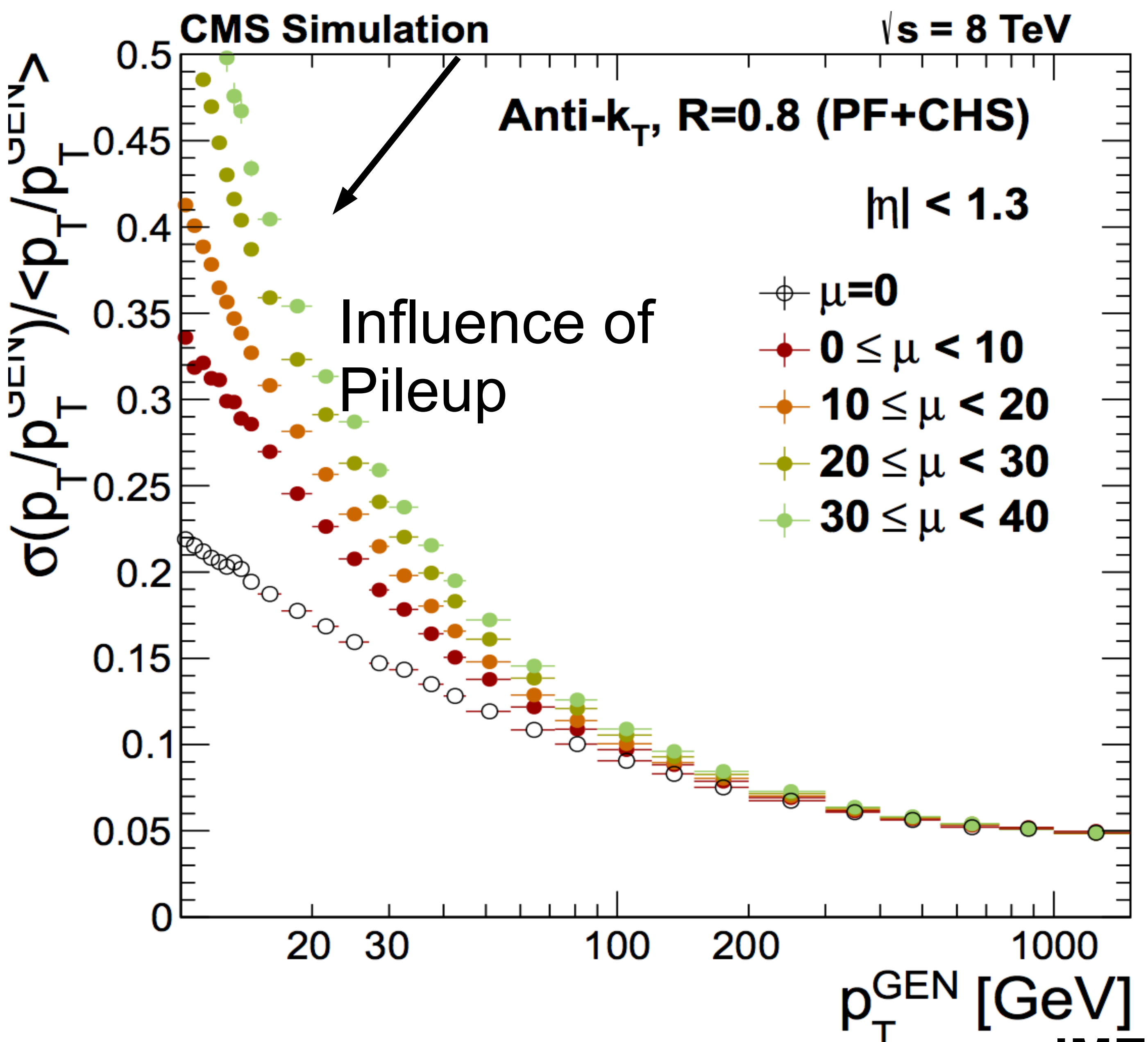
- AK7



JME-DP-14/037

Jet Energy Correction

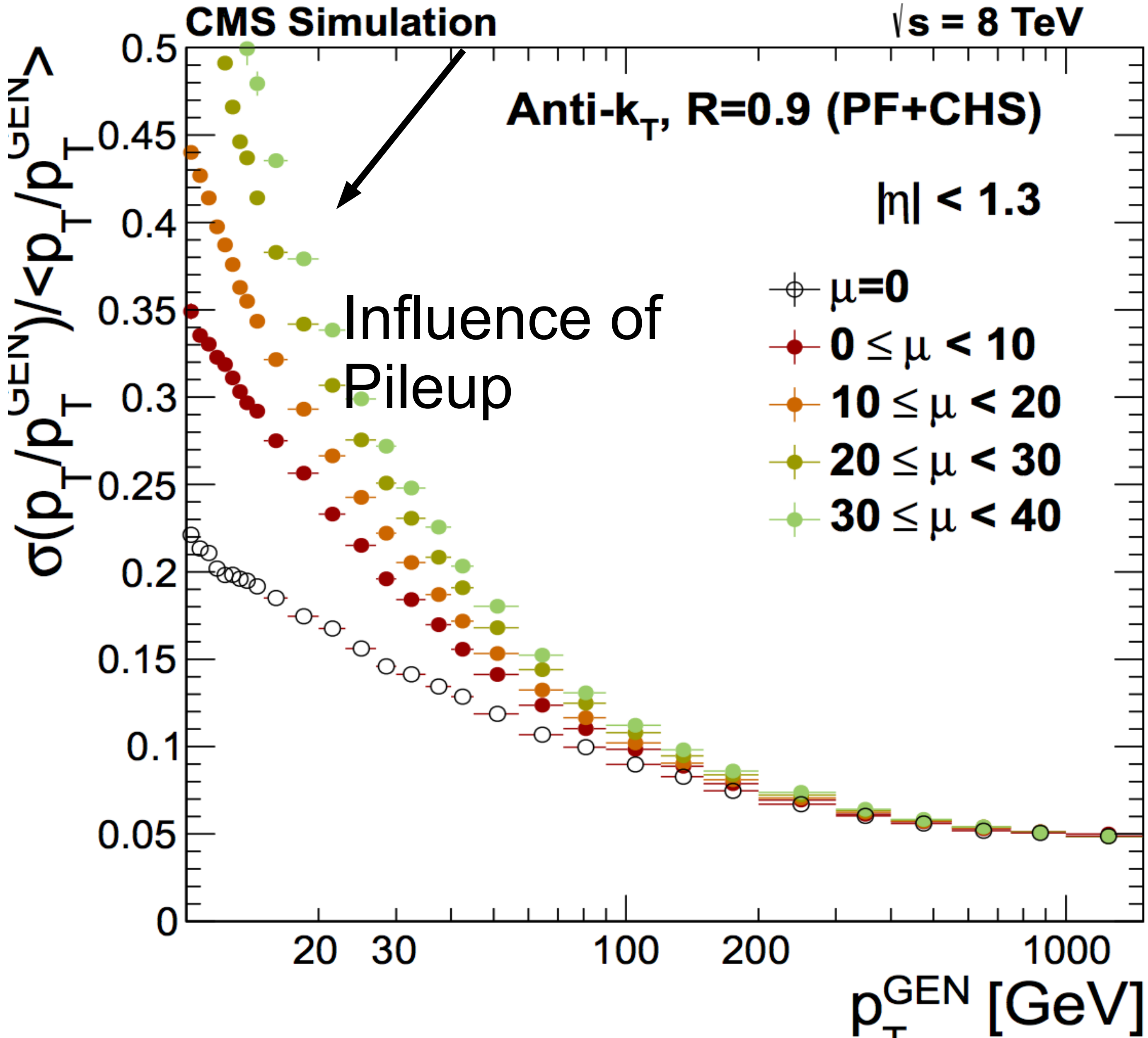
- AK8



JME-DP-14/037

Jet Energy Correction

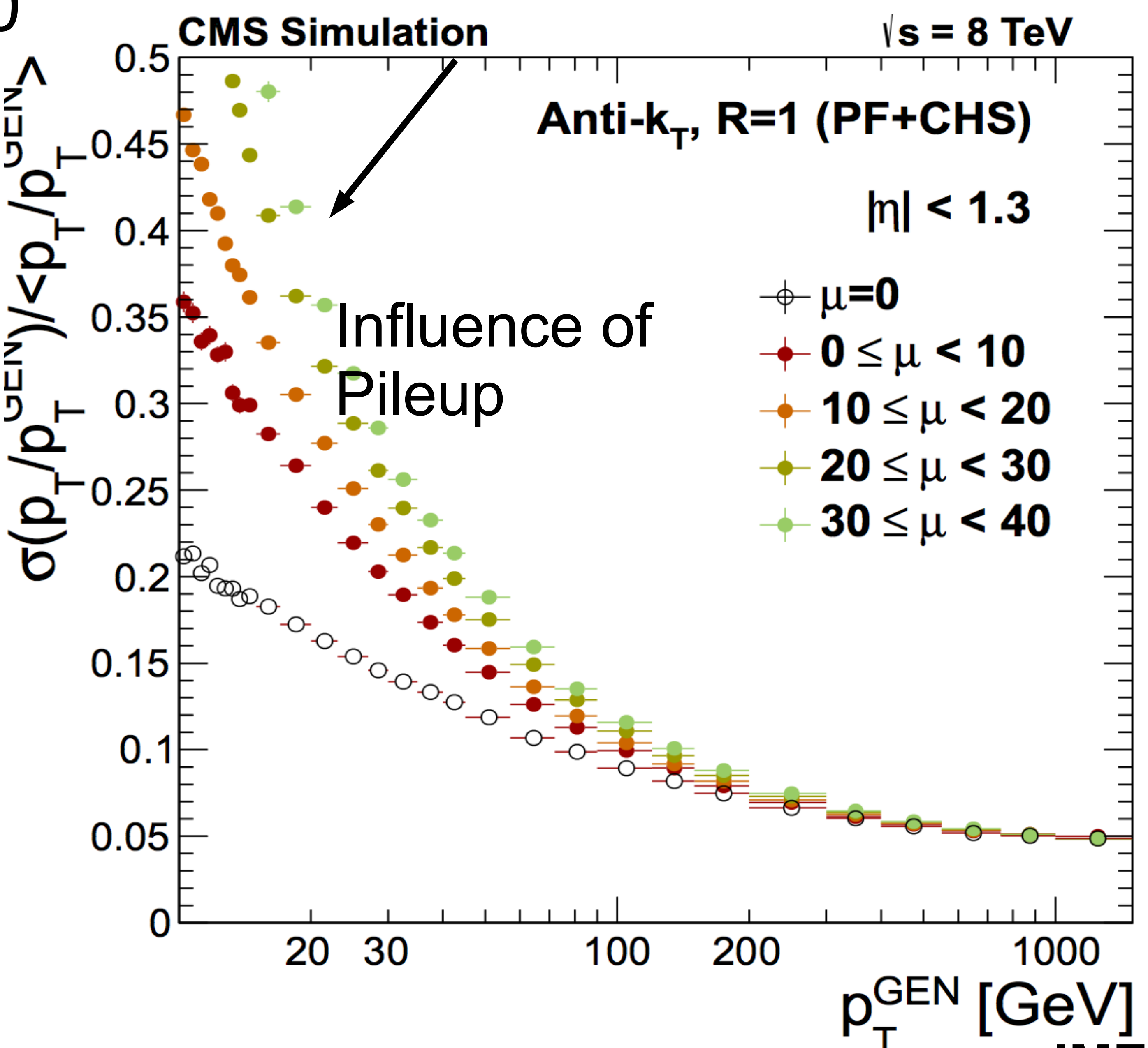
- AK9



JME-DP-14/037

Jet Energy Correction

- AK1.0



JME-DP-14/037

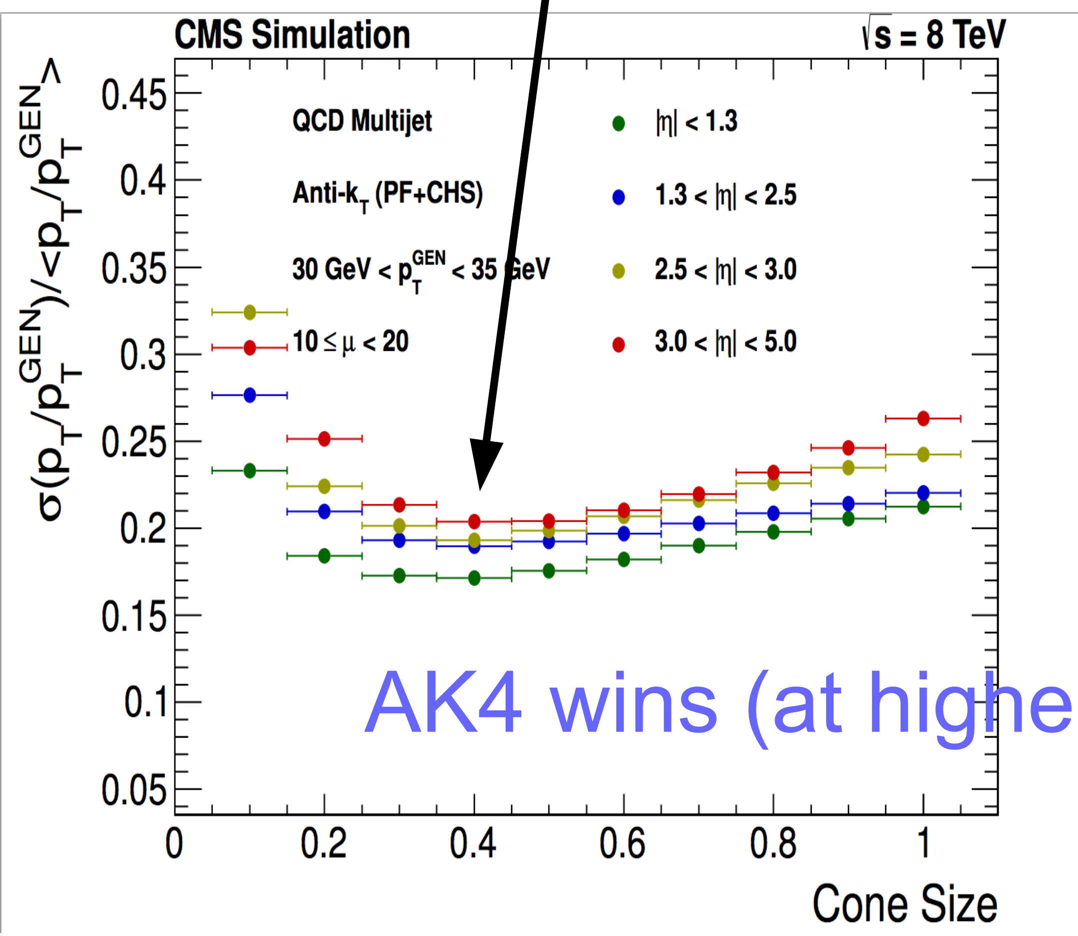
Jet Energy Correction

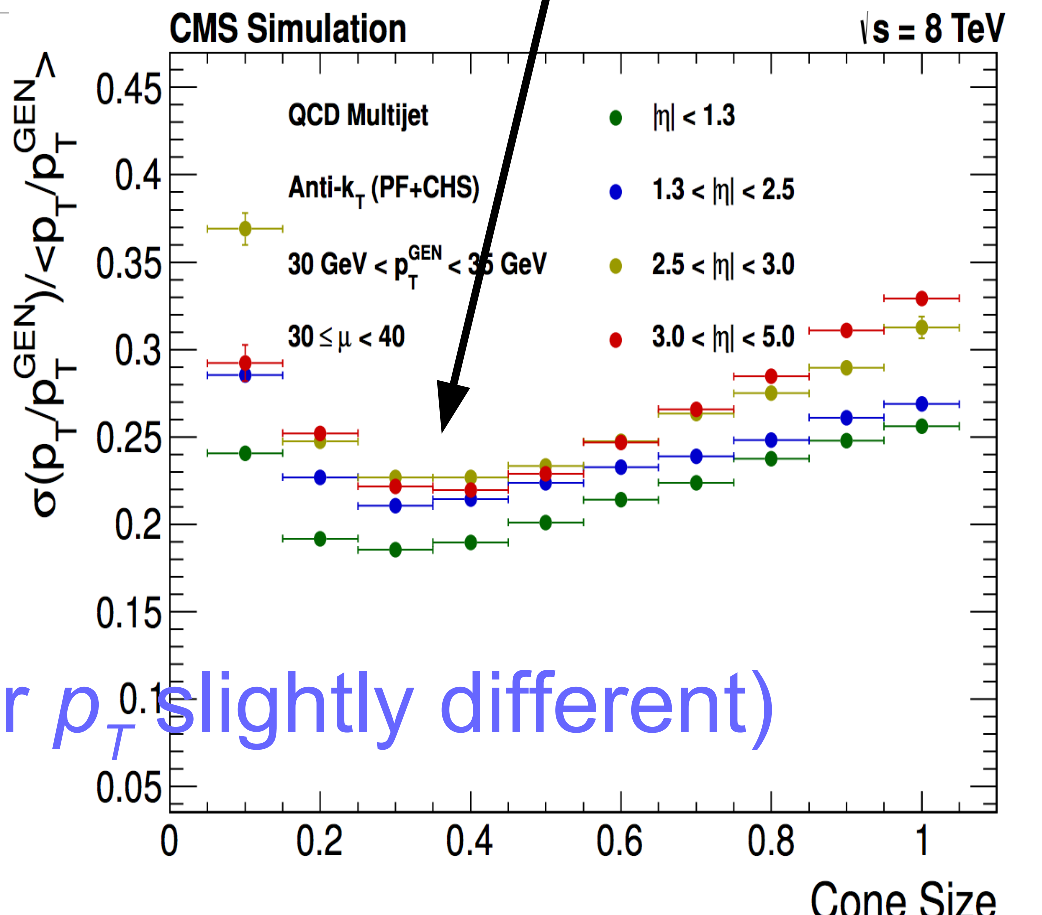
- Executive Summary :

We switch to AK4

Run I PU

Run II PU





AK4 wins (at higher p_T slightly different)

JME-DP-14/037

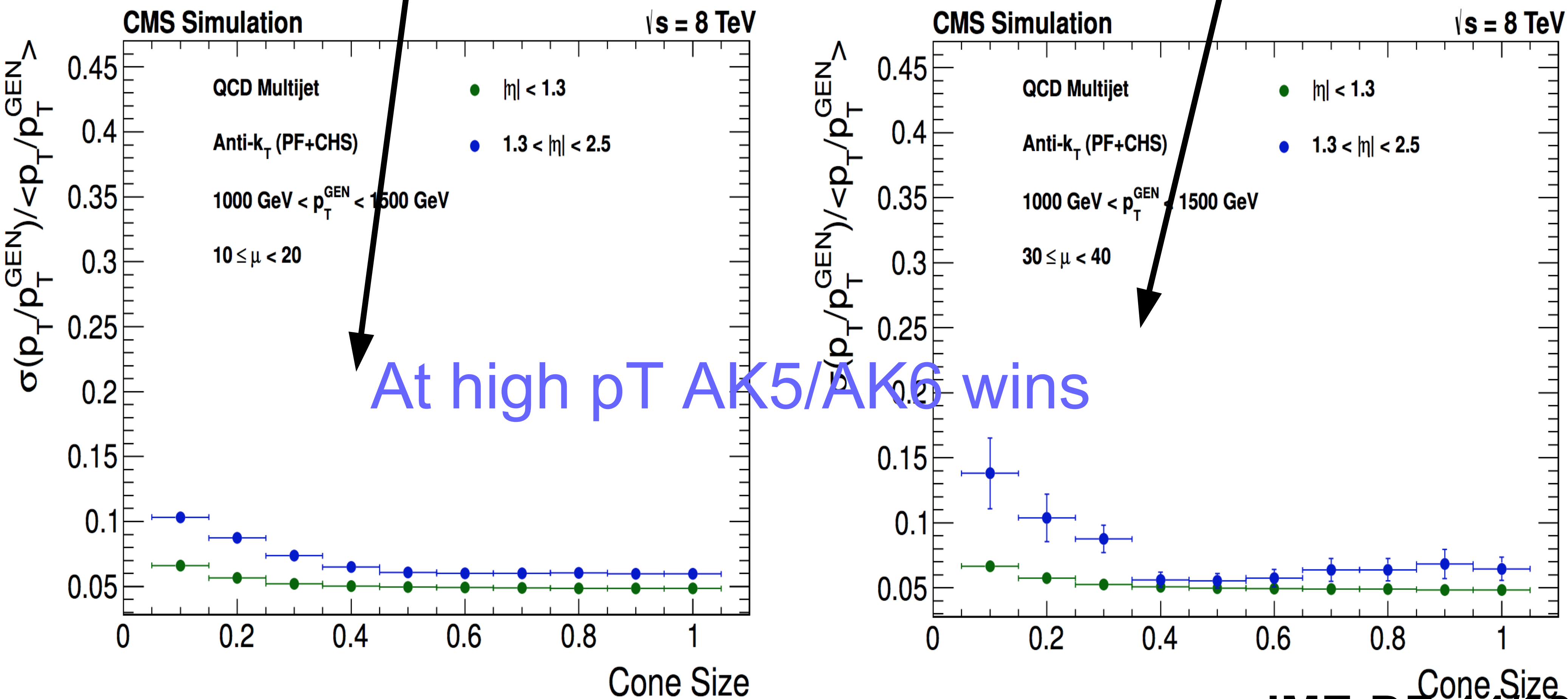
Jet Energy Correction

- Executive Summary :

We switch to AK4

Run I PU

Run II PU

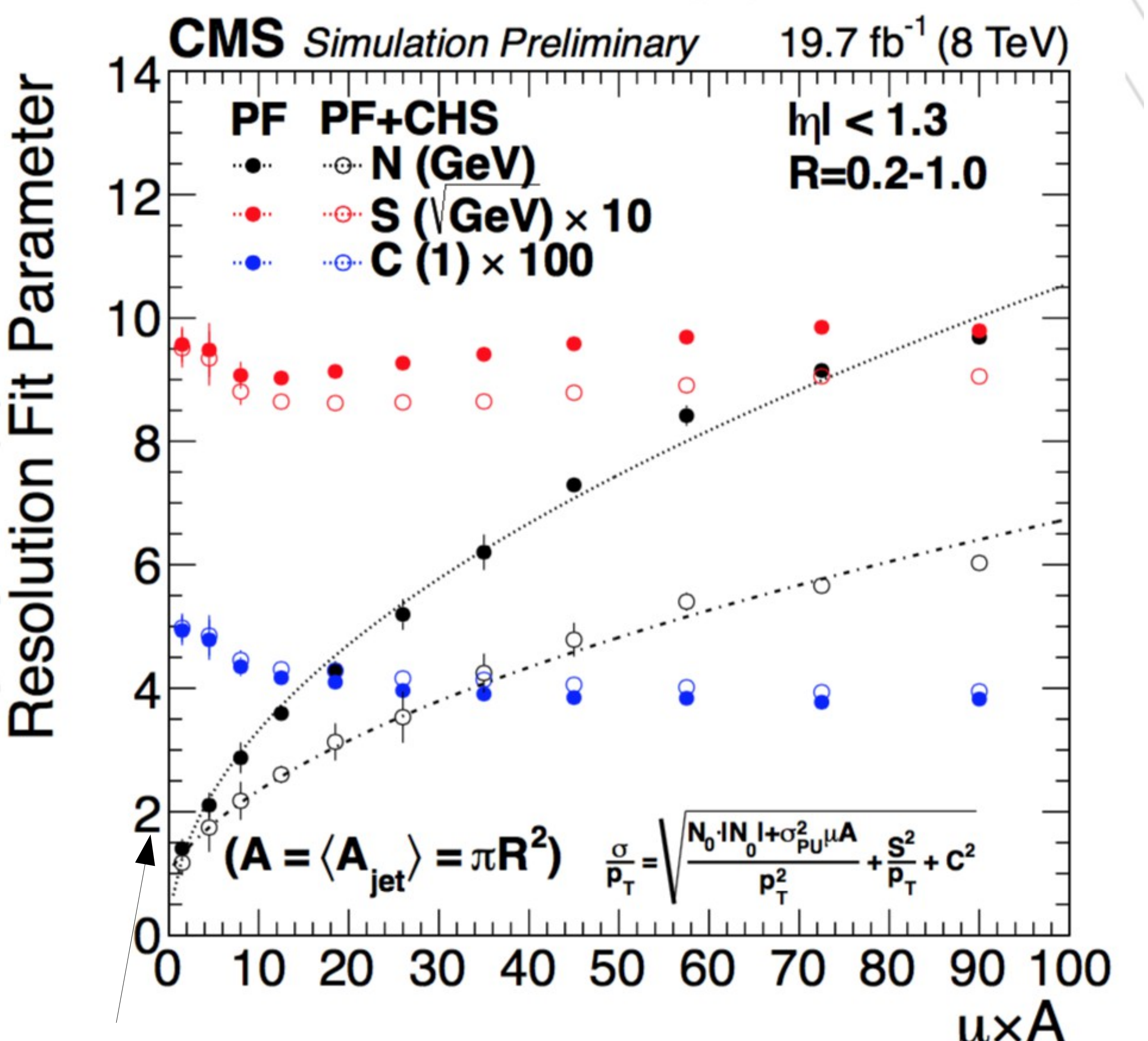


At high pT AK5/AK6 wins

JME-DP-14/037

Stability of our detector

- Using all the jet cones allows plots like this:



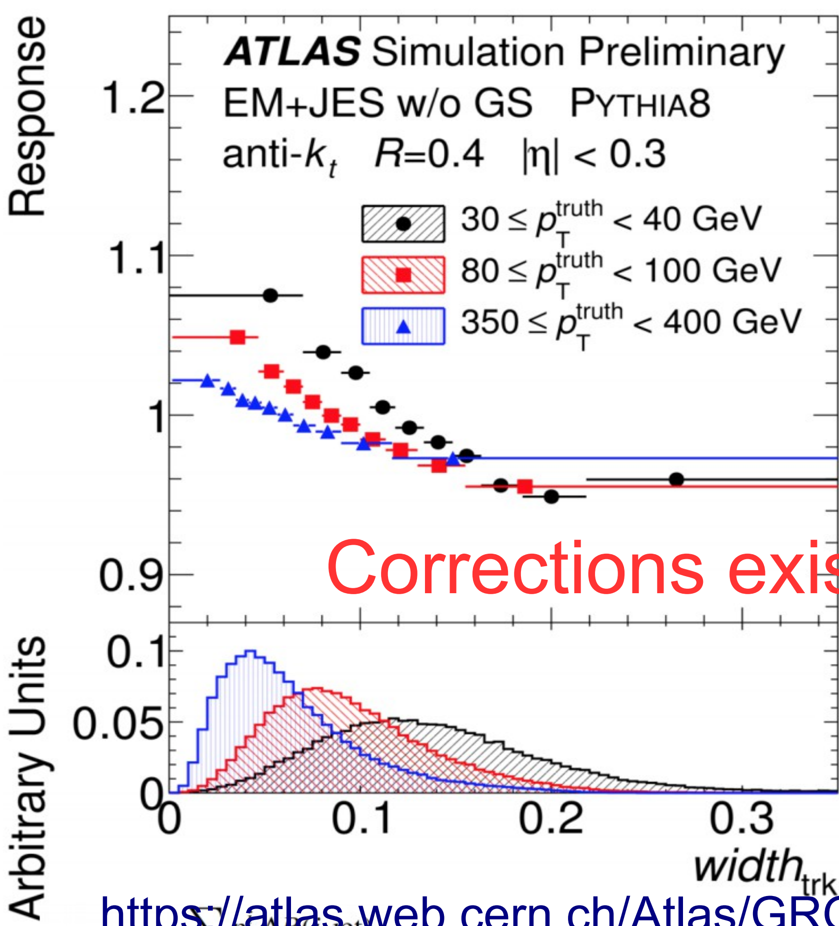
Generically ATLAS doesn't have this scaling

JME-DP-14/037

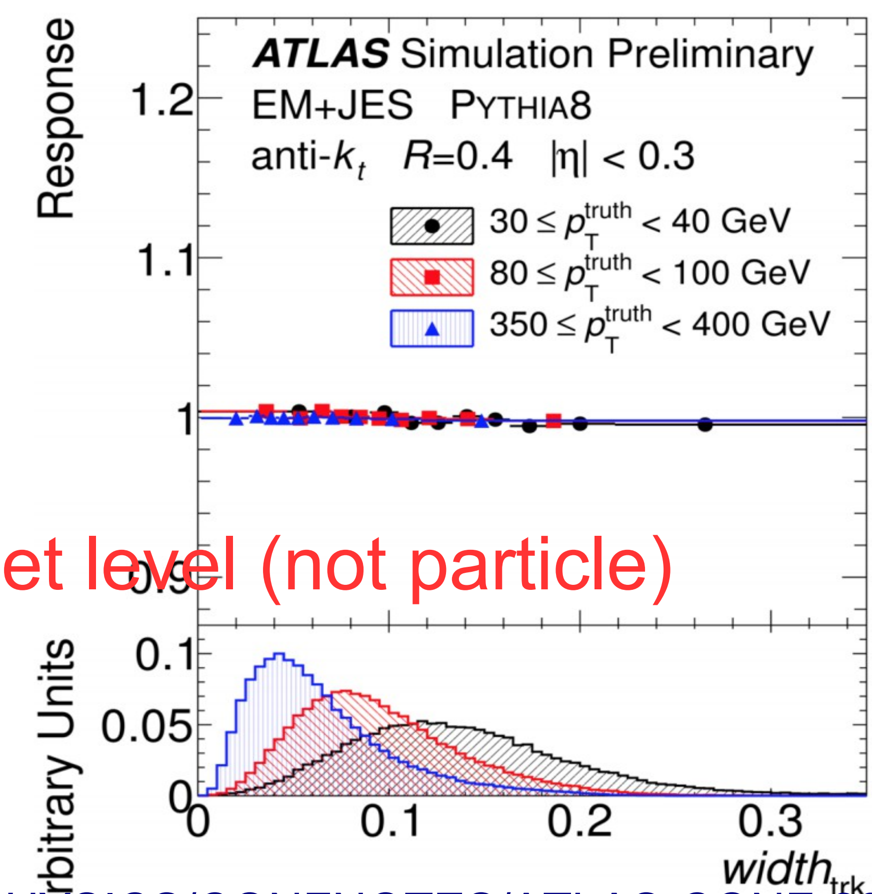
Improvements form ATLAS

- While ATLAS does not use pflow
  - Yields resol. loss(Charged parts)+worse granularity
  - Compensates w/improved granularity through GSC

Before GSC



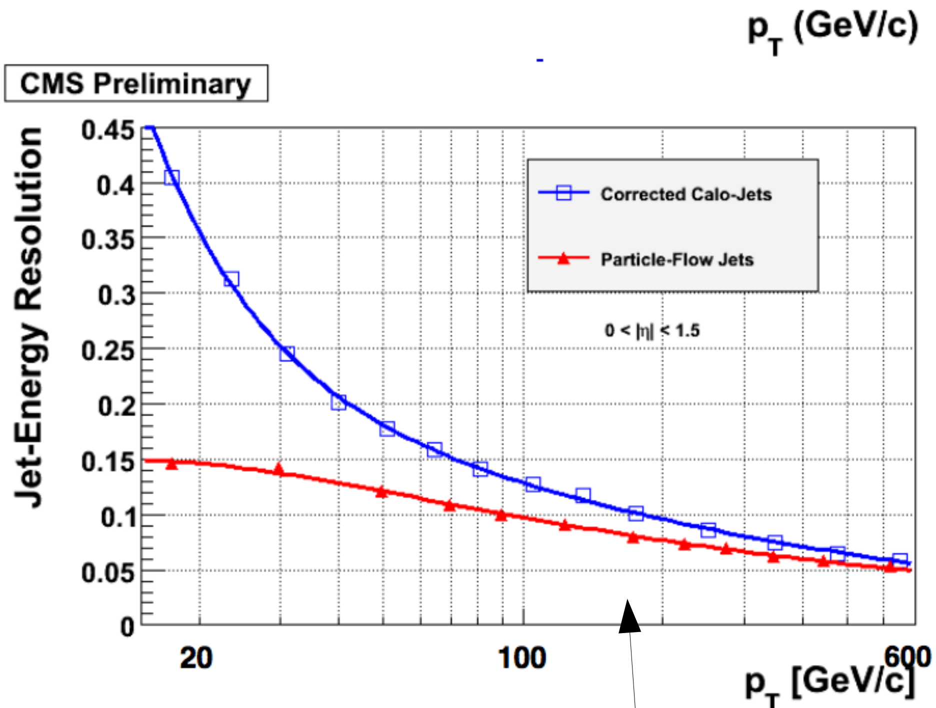
After GSC

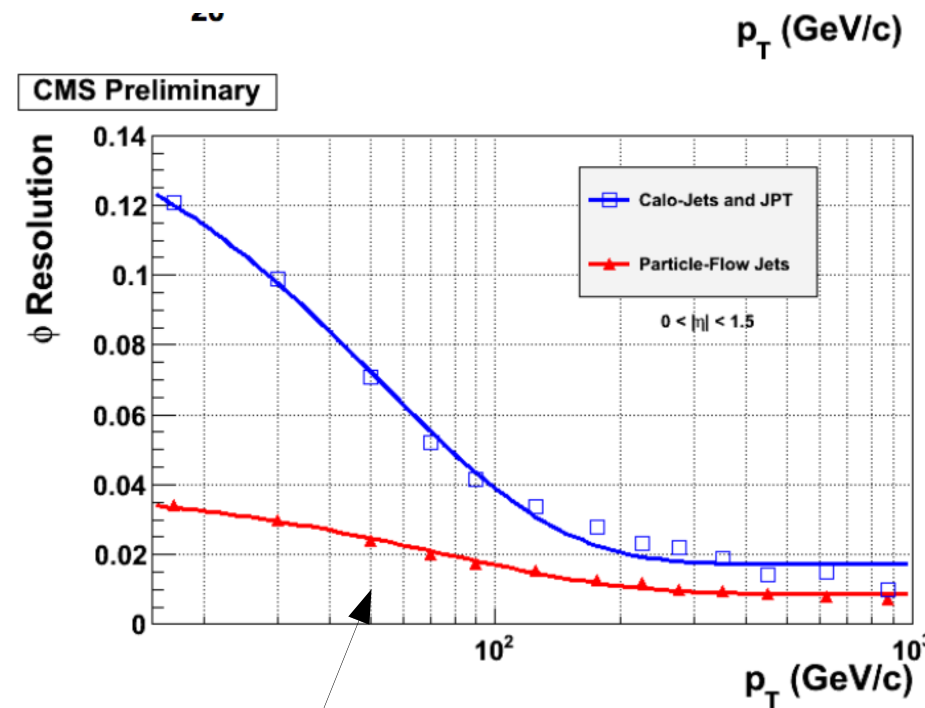


Corrections exist at jet level (not particle)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-00

Visualizing the PF impact

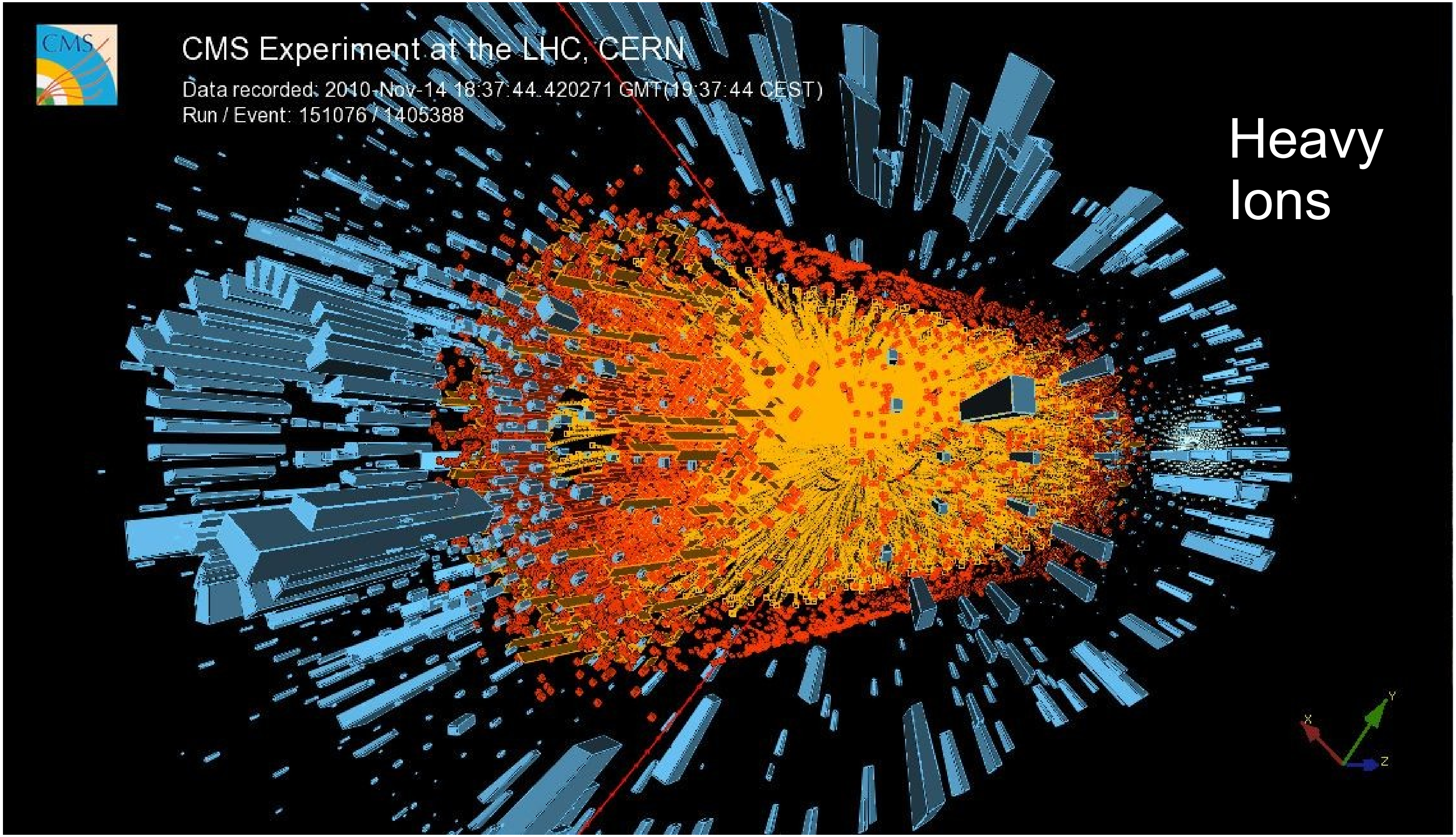




Angular information from the tracks improves the resolution of the jet shape internals

(Don't need to correct for jet shape aposteriori)

Dense Environment

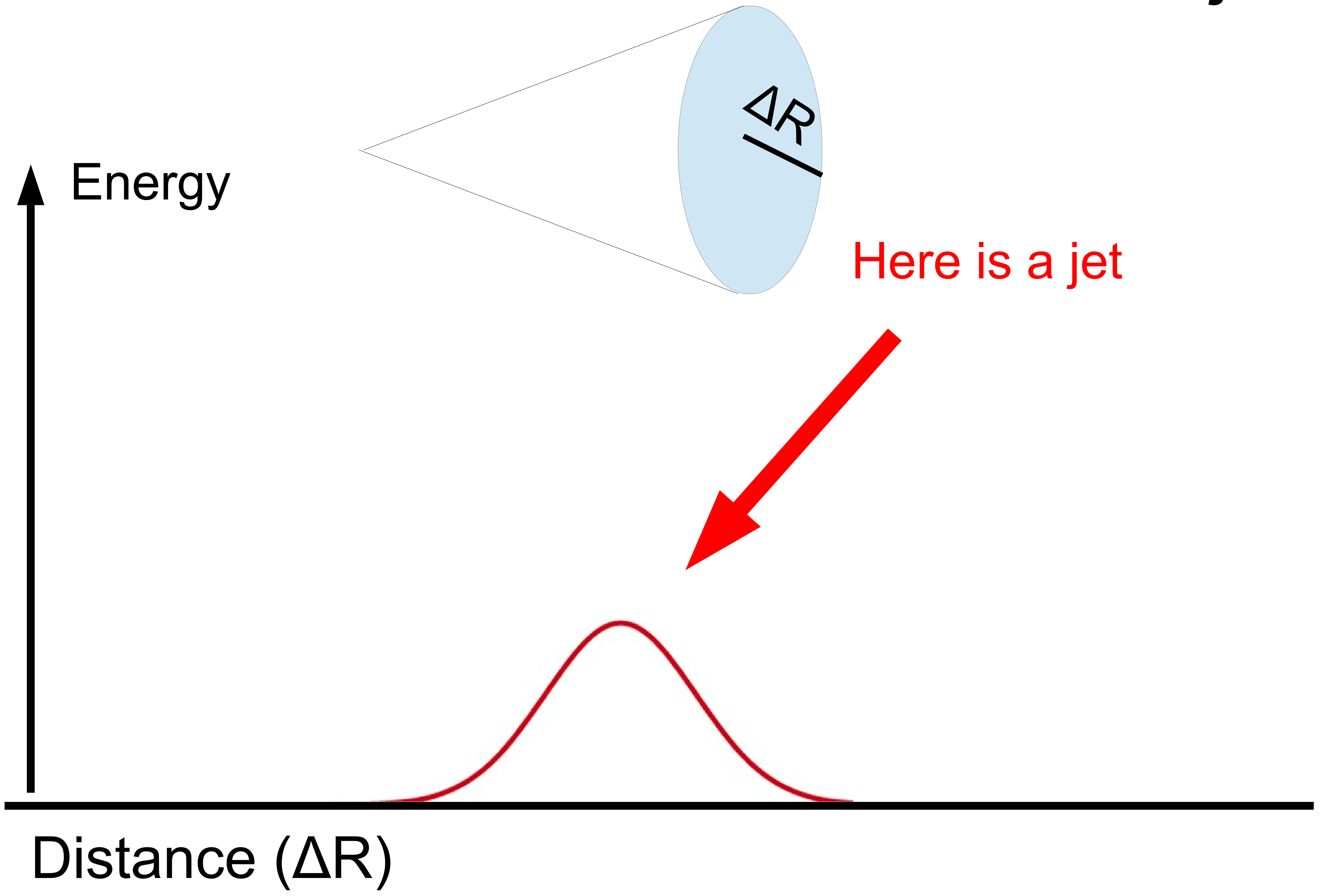


Dealing w/PU :

Key questions :

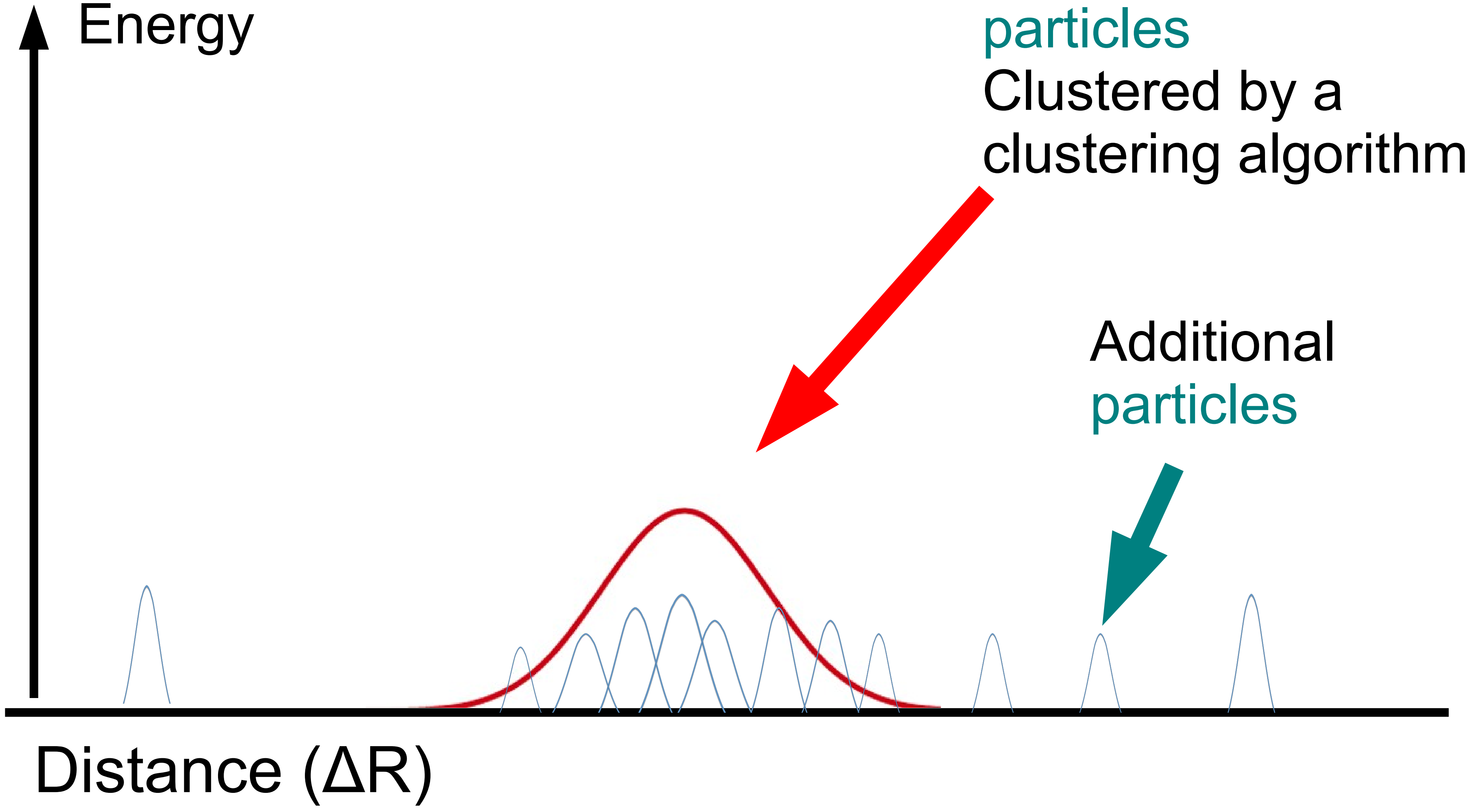
What happens to a jet in pileup?
What is the composition of pileup?

Consider a jet

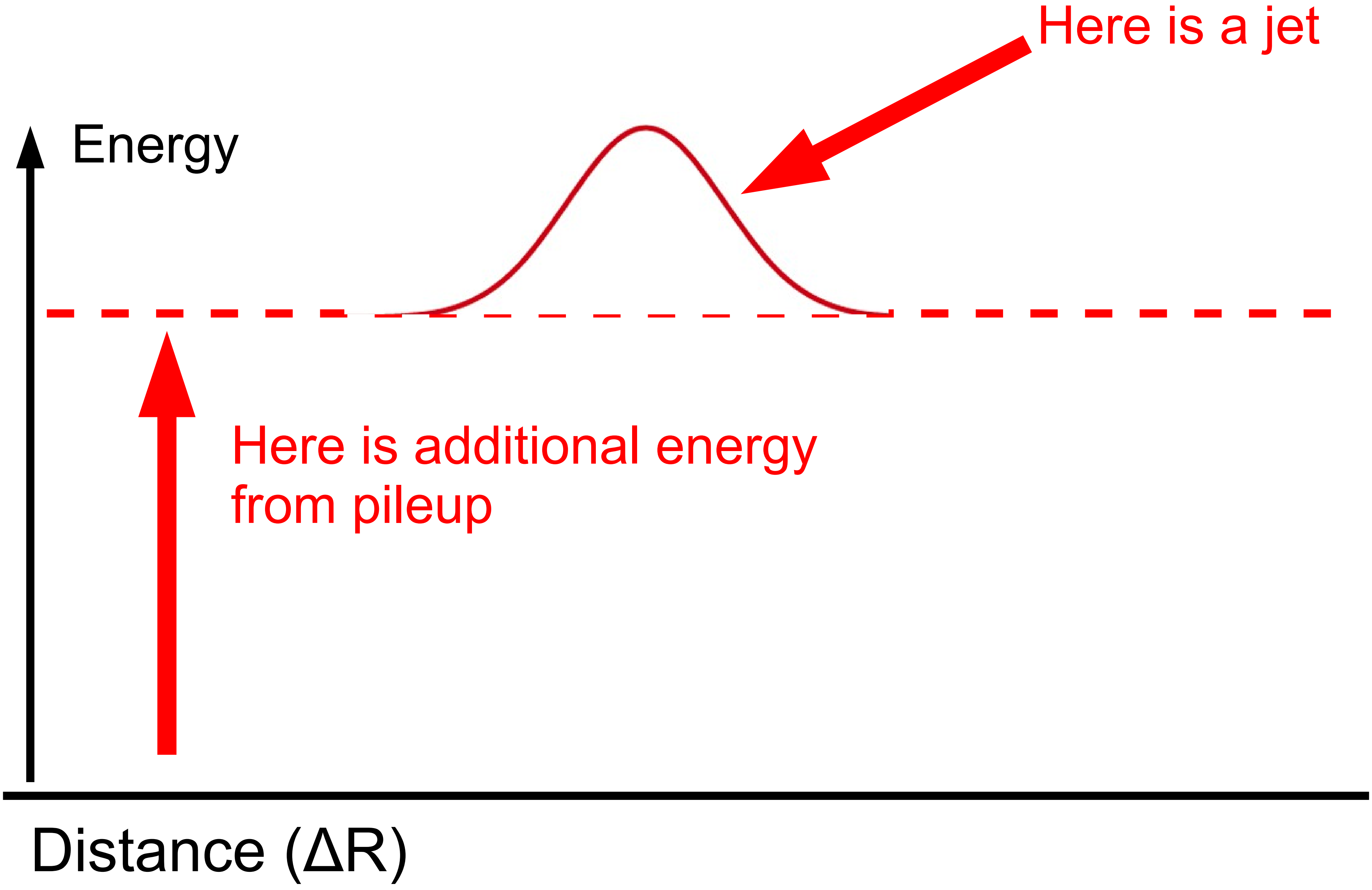


Consider a jet

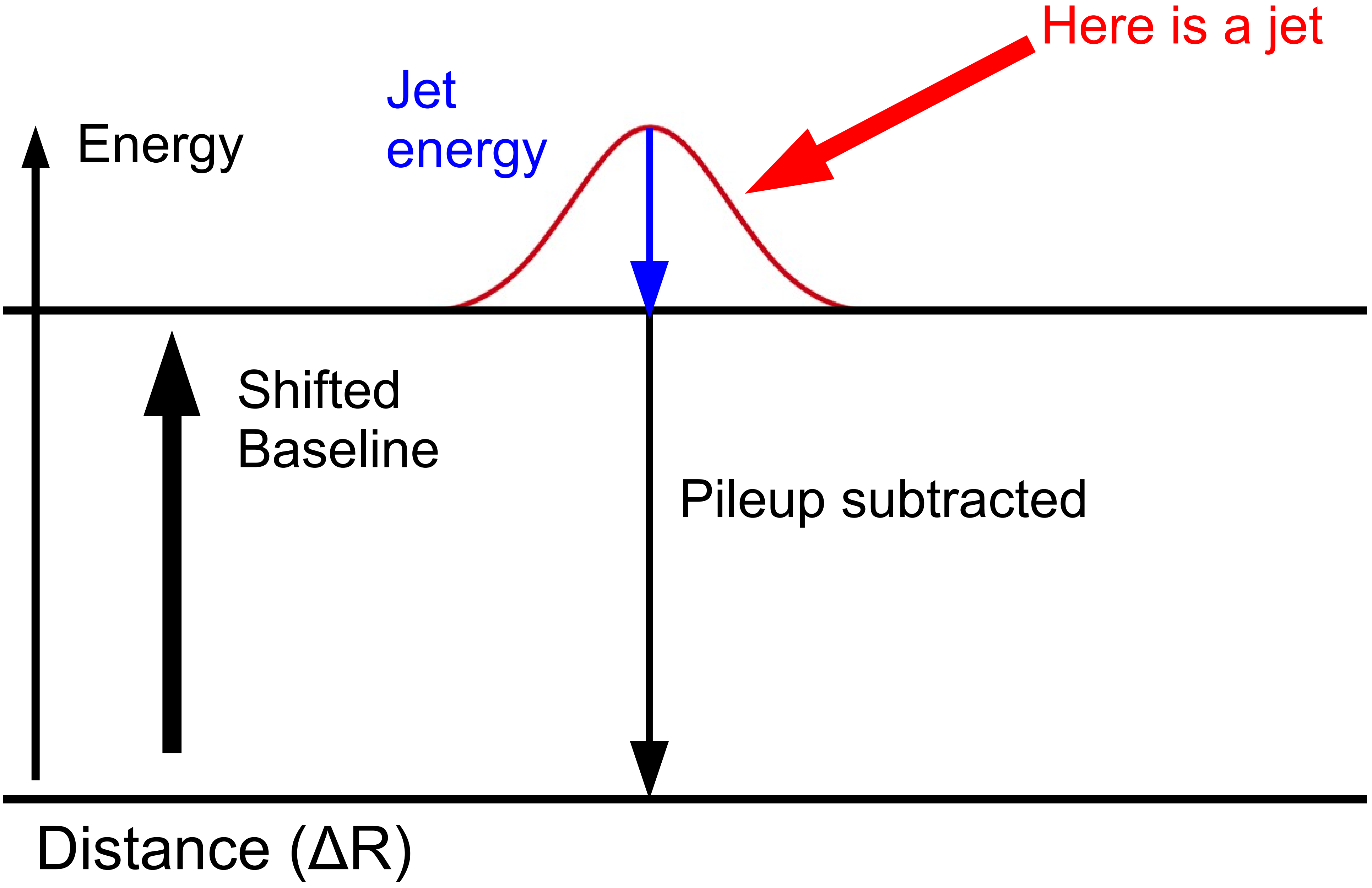
It is made of many particles
Clustered by a clustering algorithm



Consider a jet in high pileup

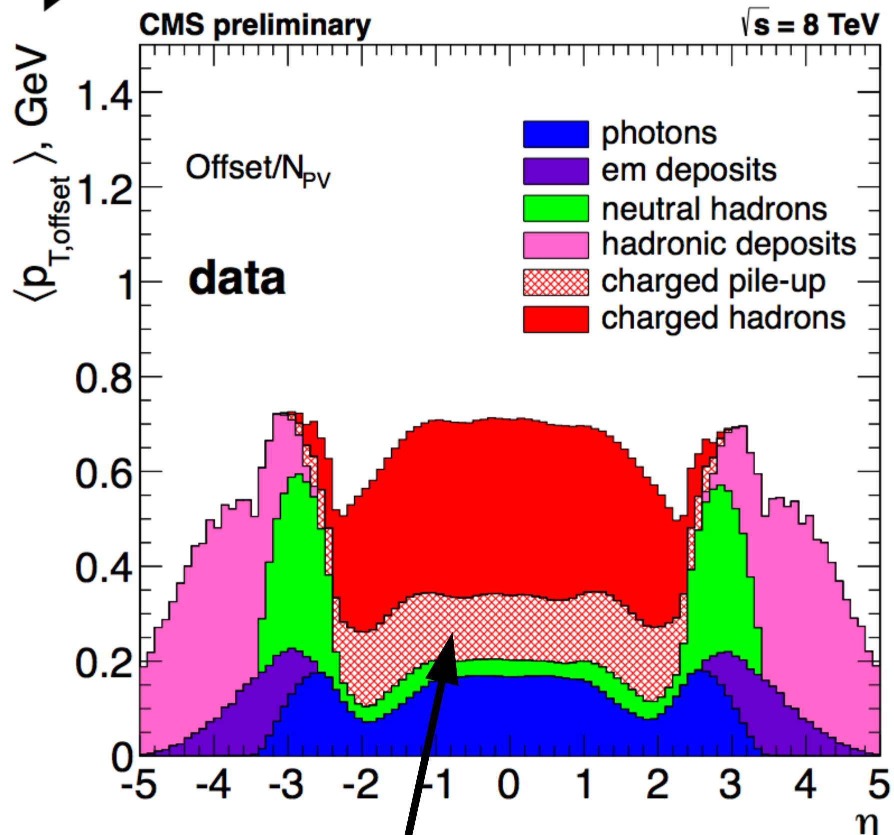


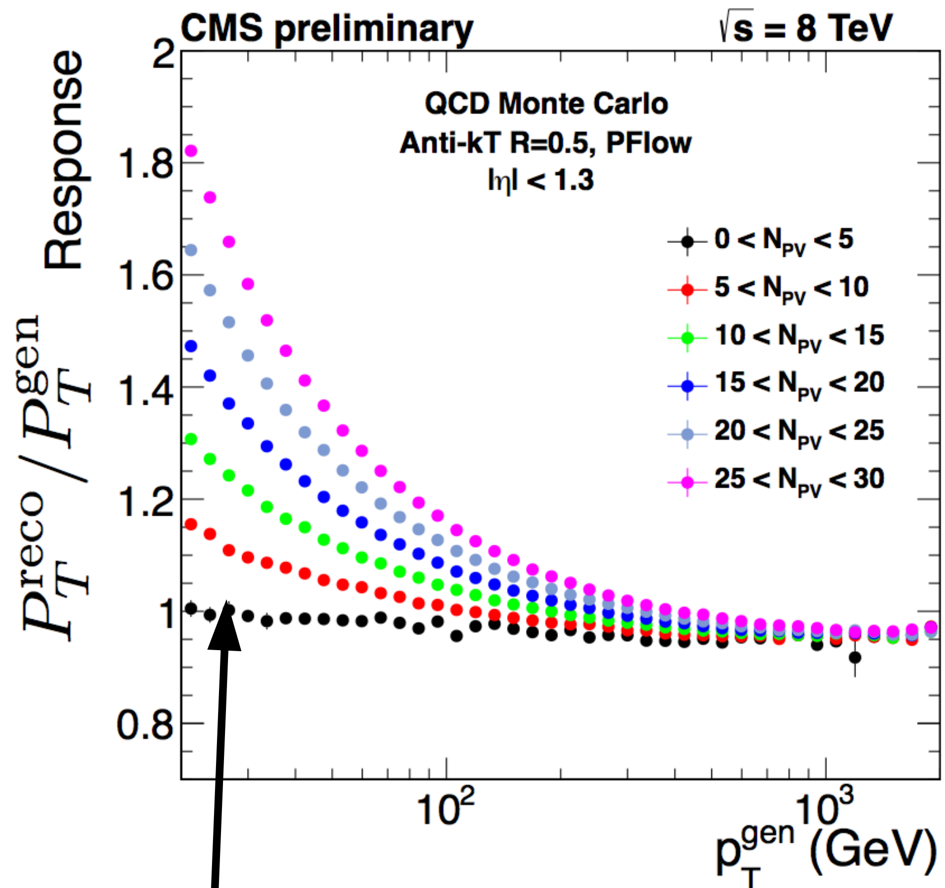
Consider a jet in high pileup



Pileup removal in action

PT offset / unit area / # of vertices

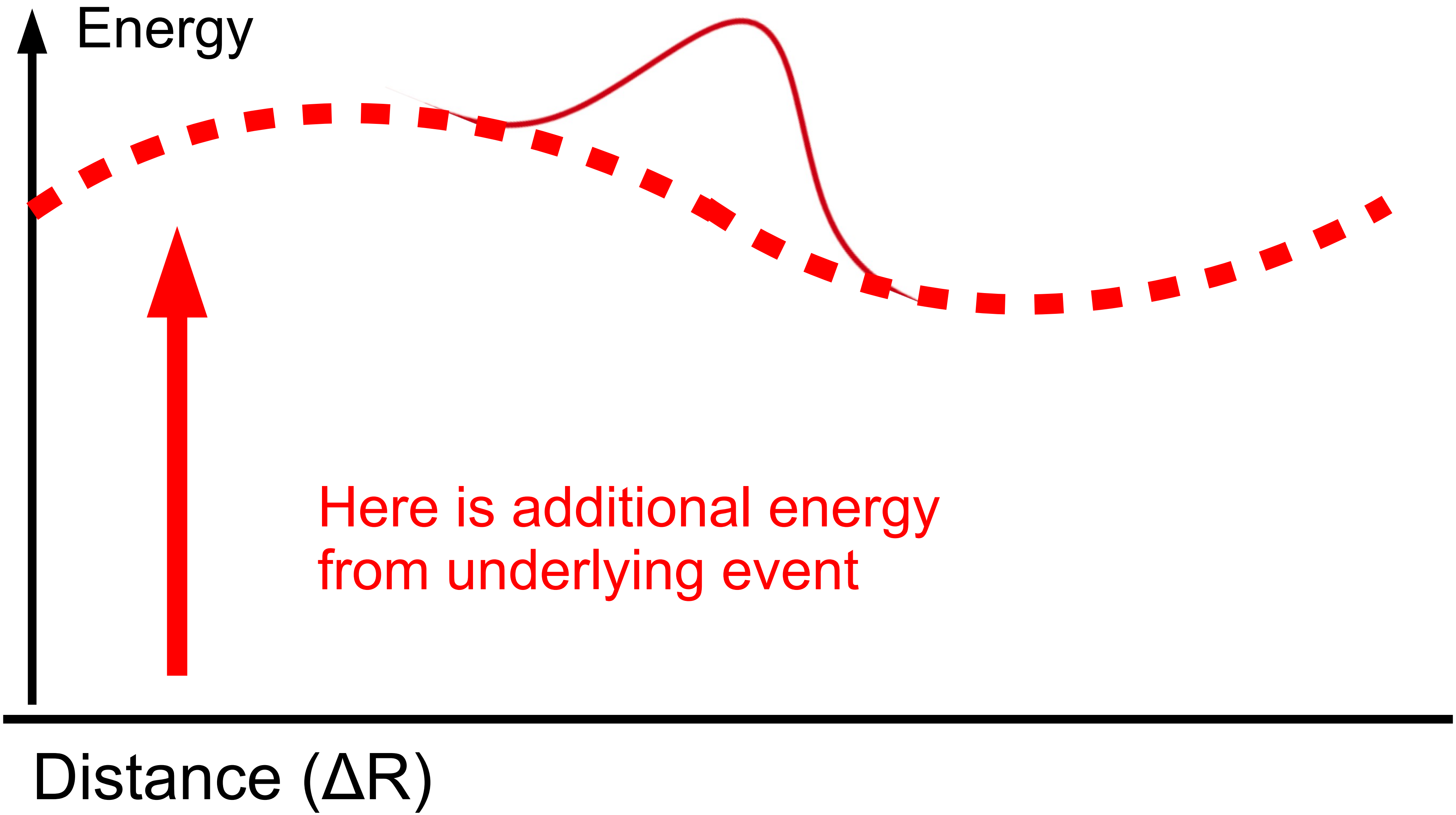




Average subtraction/Pileup

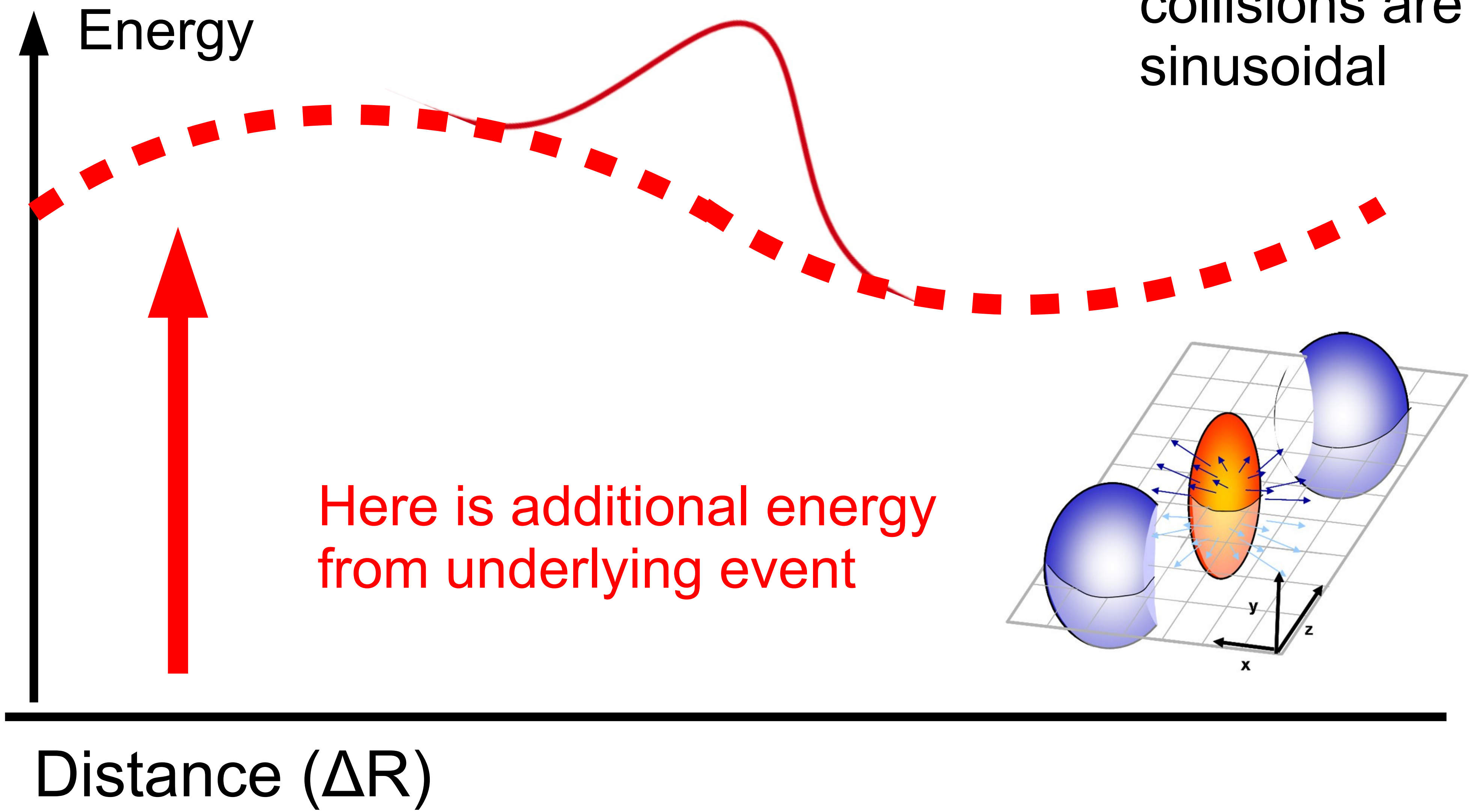
Change in response post subtraction

Consider a jet in Heavy Ions



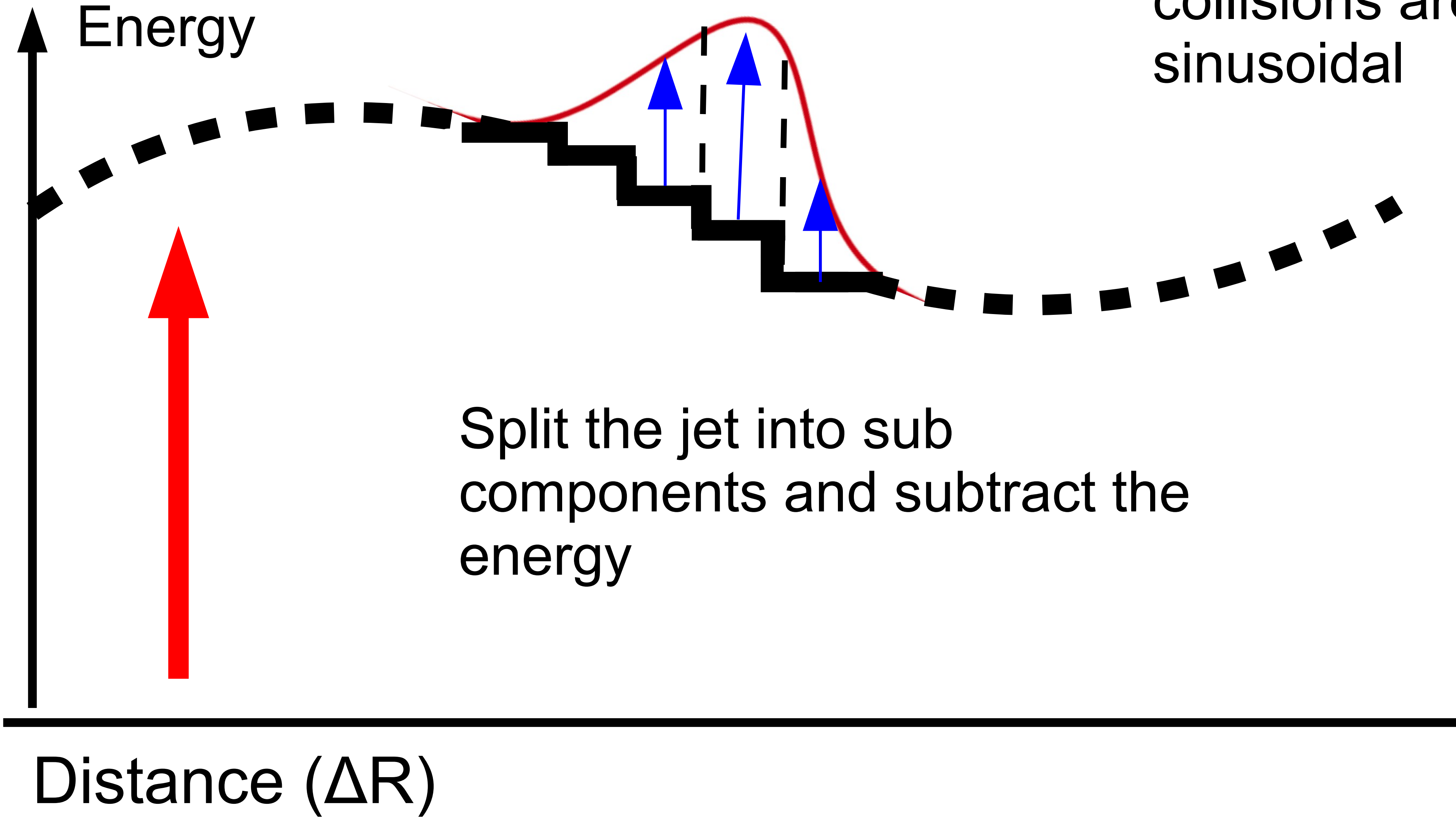
Consider a jet in Heavy Ions

Heavy Ion collisions are sinusoidal



Consider a jet in Heavy Ions

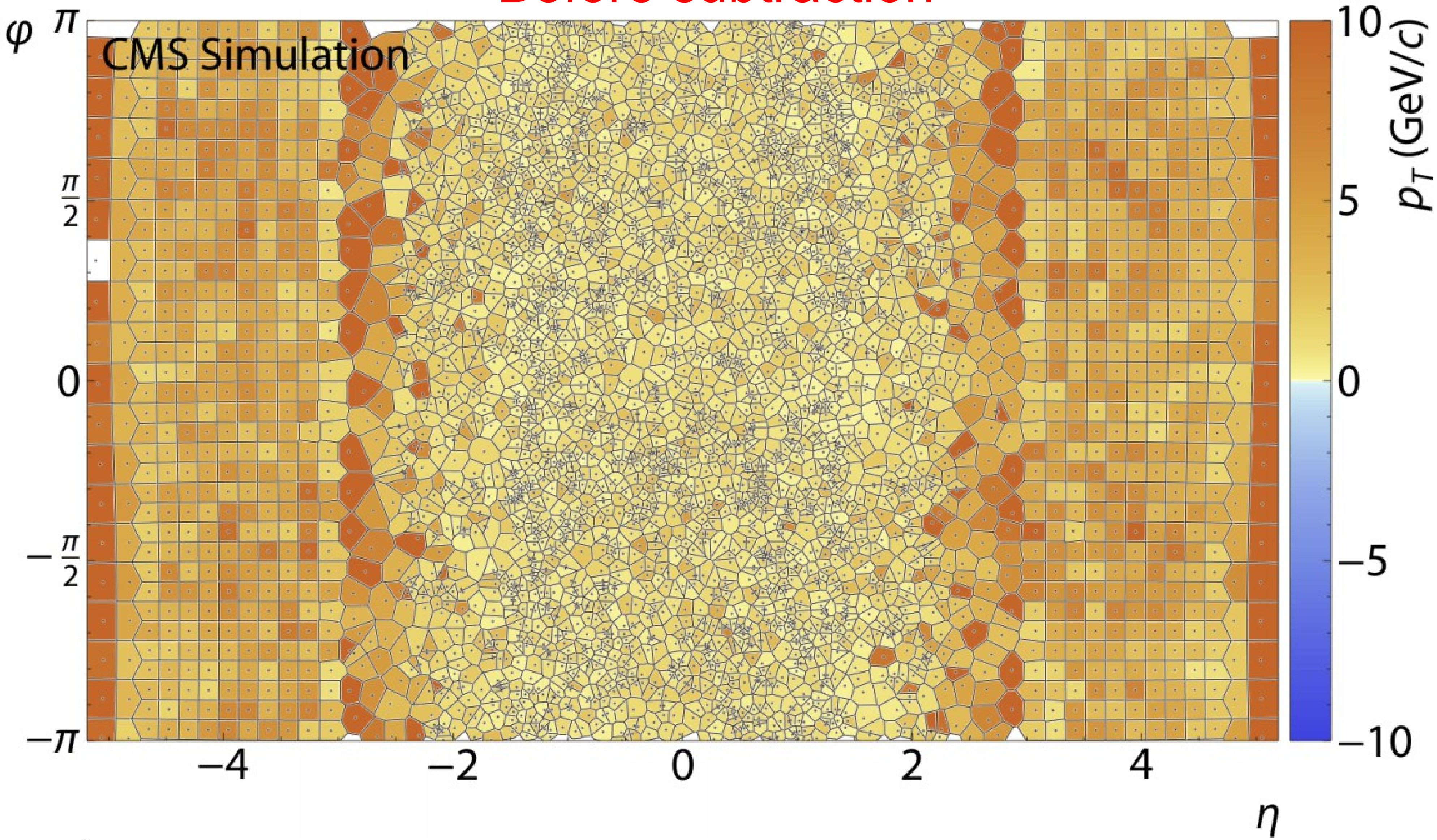
Heavy Ion collisions are sinusoidal



Split the jet into sub components and subtract the energy

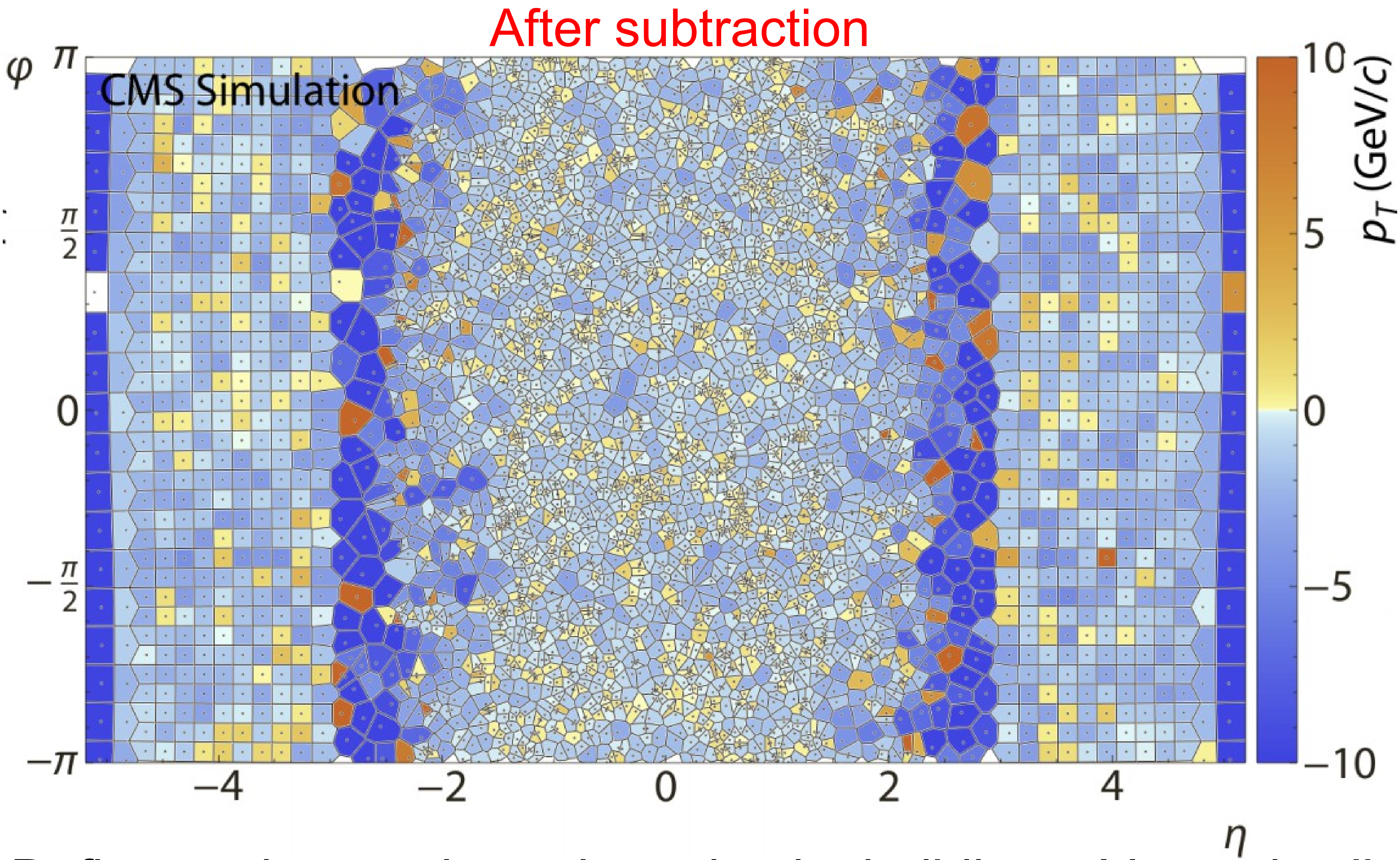
Led to HF/Voronoi Method

Before subtraction



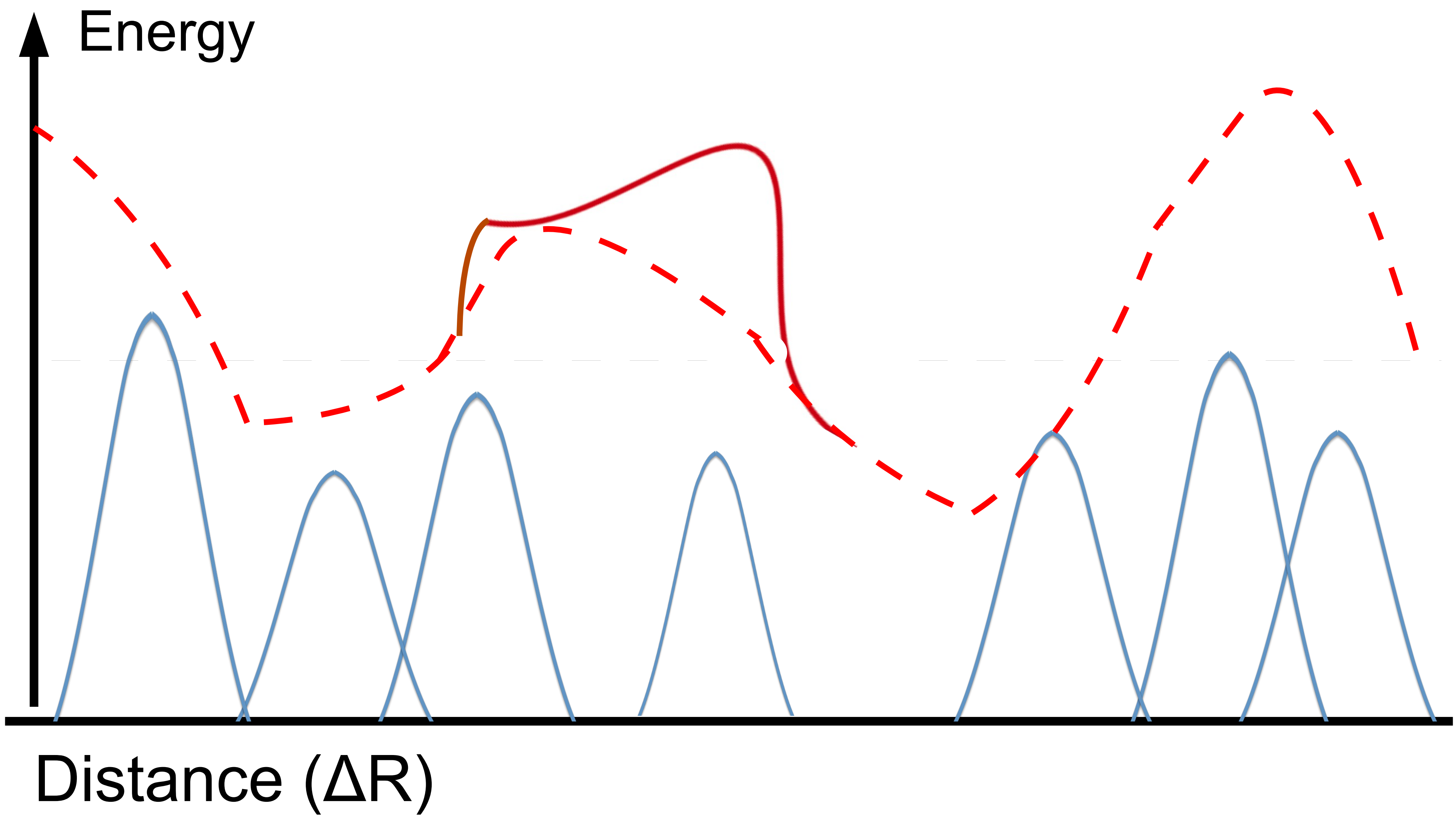
Define each stepwise subtraction by building a Voronoi cell

Led to HF/Voronoi Method

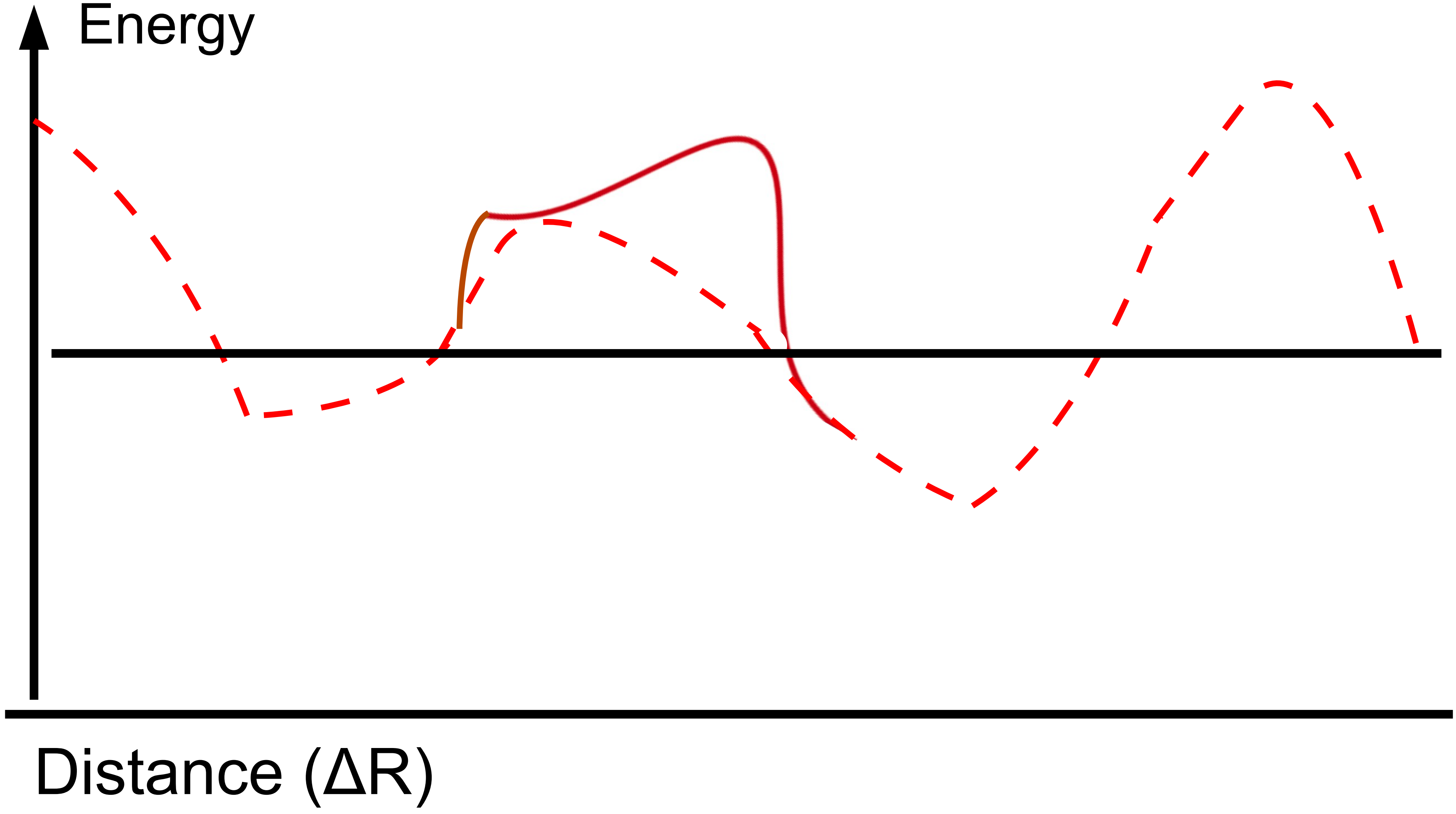


Define each stepwise subtraction by building a Voronoi cell

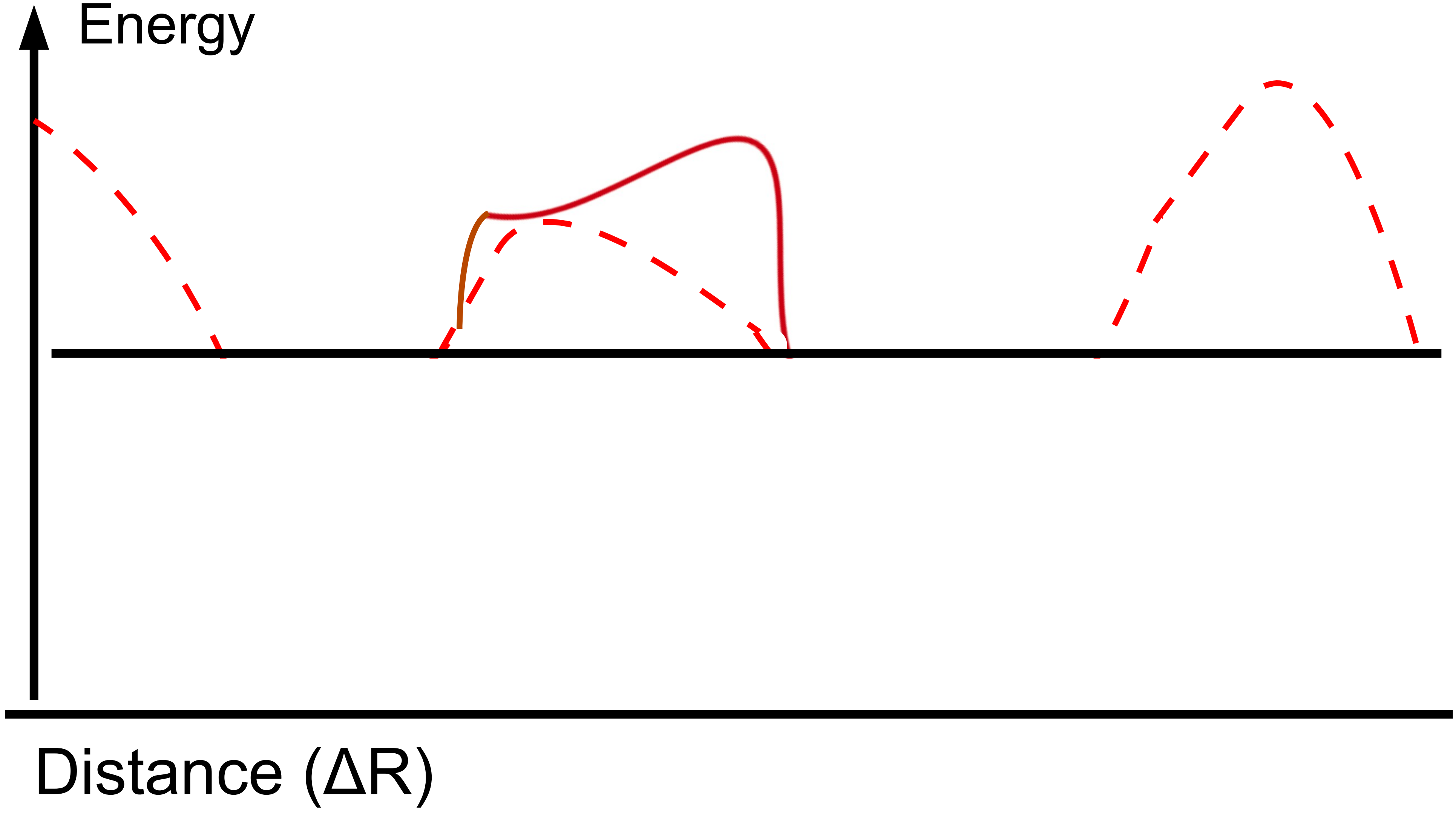
A jet in realistic pileup



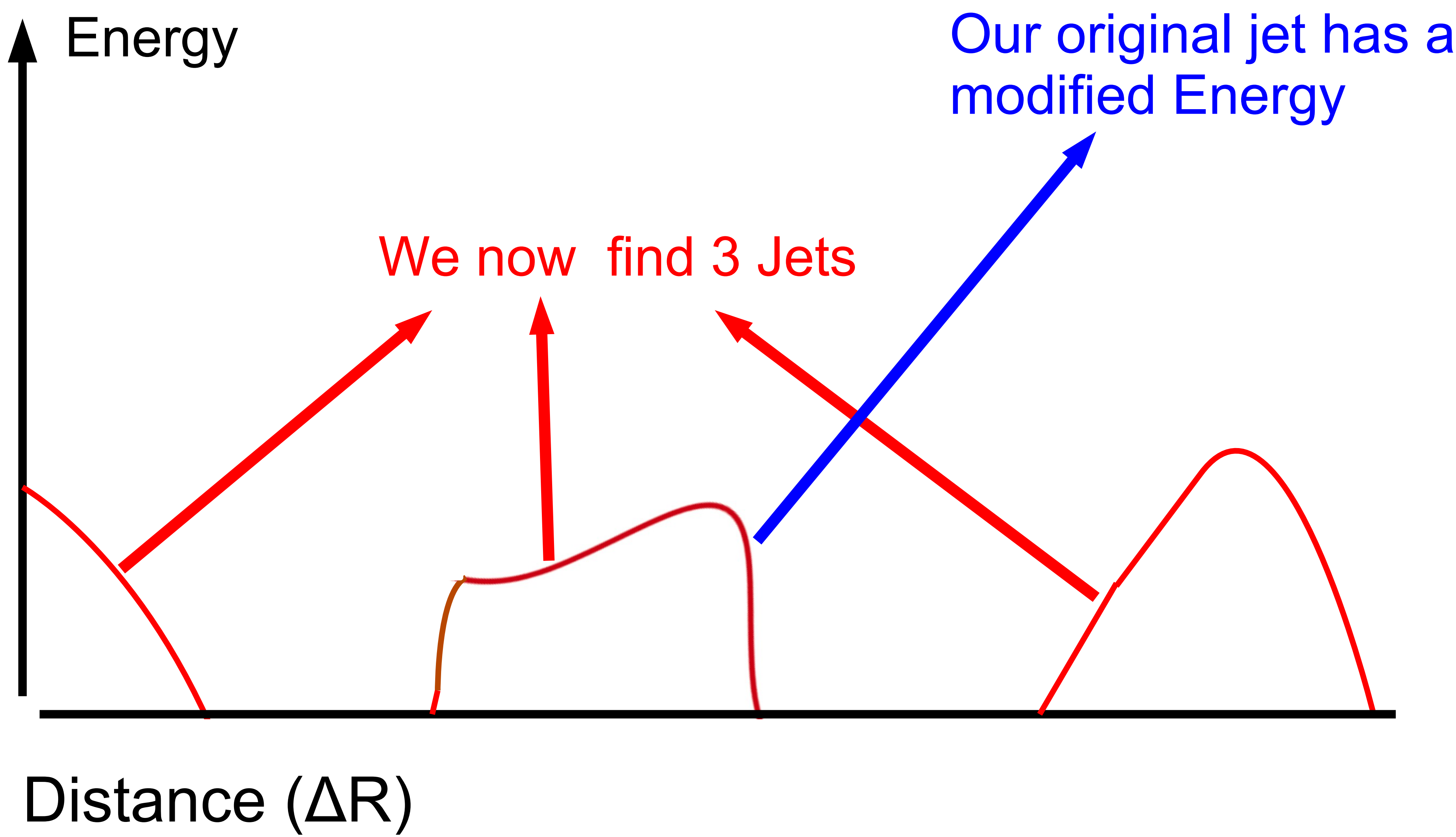
Conventional subtraction



Conventional subtraction



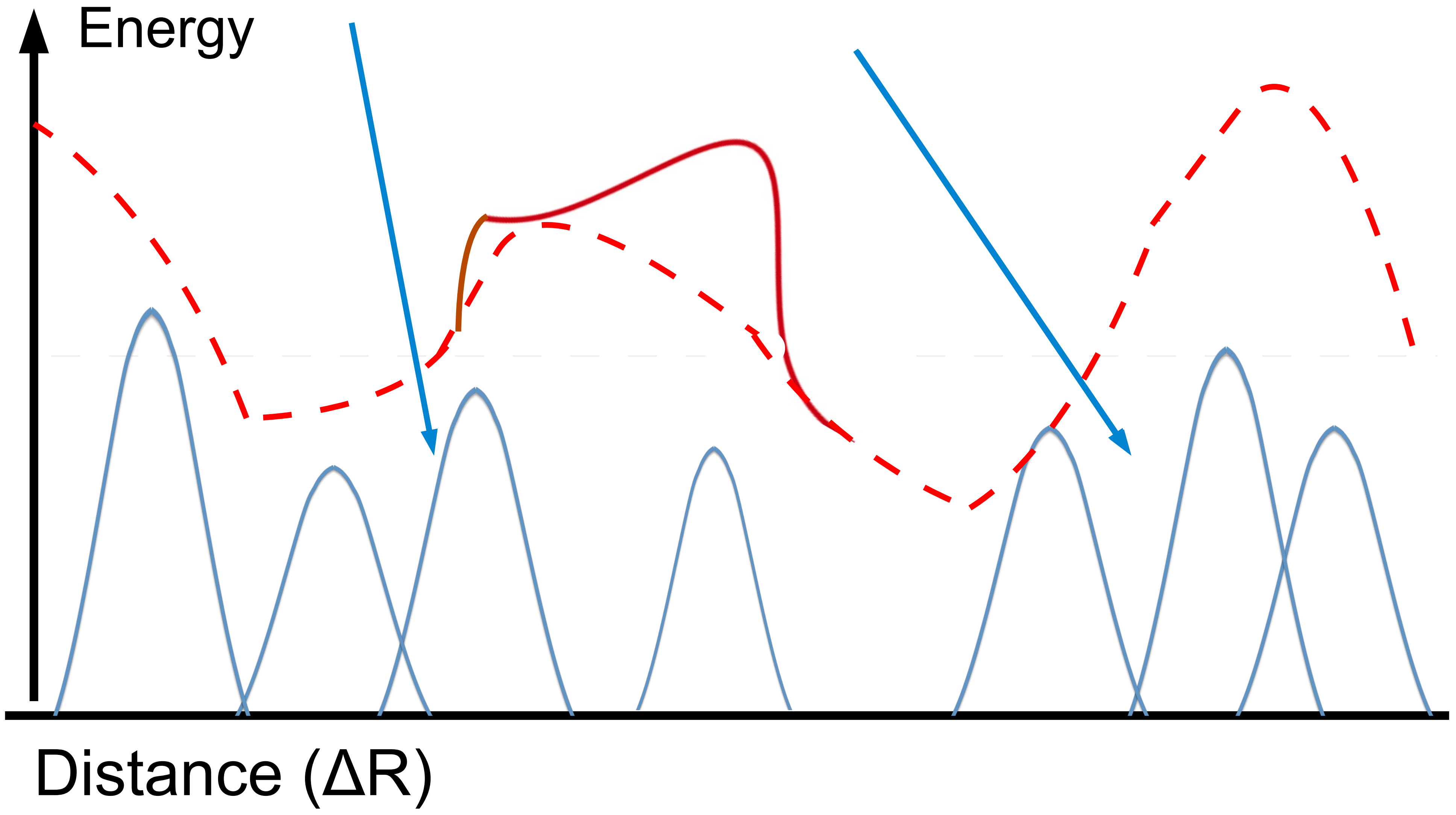
Conventional subtraction



Conventional subtraction

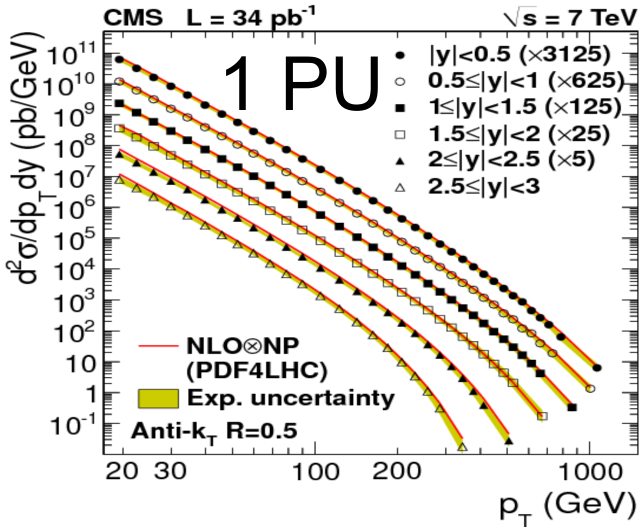
Lets back track

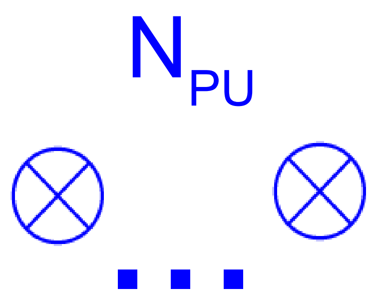
What is the composition of the pileup?

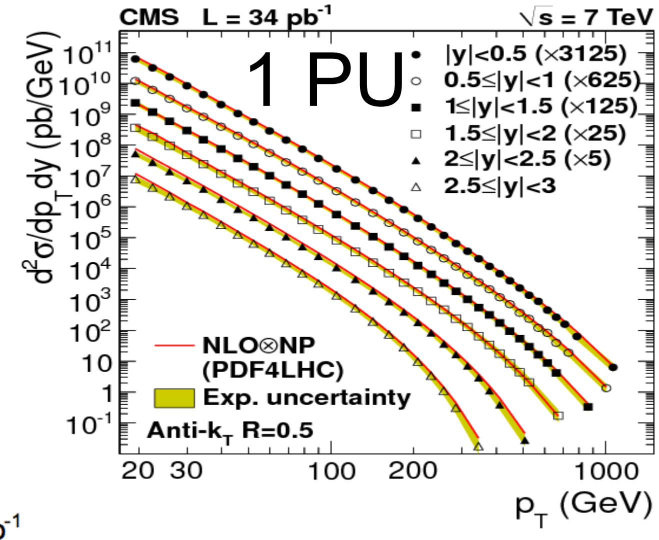


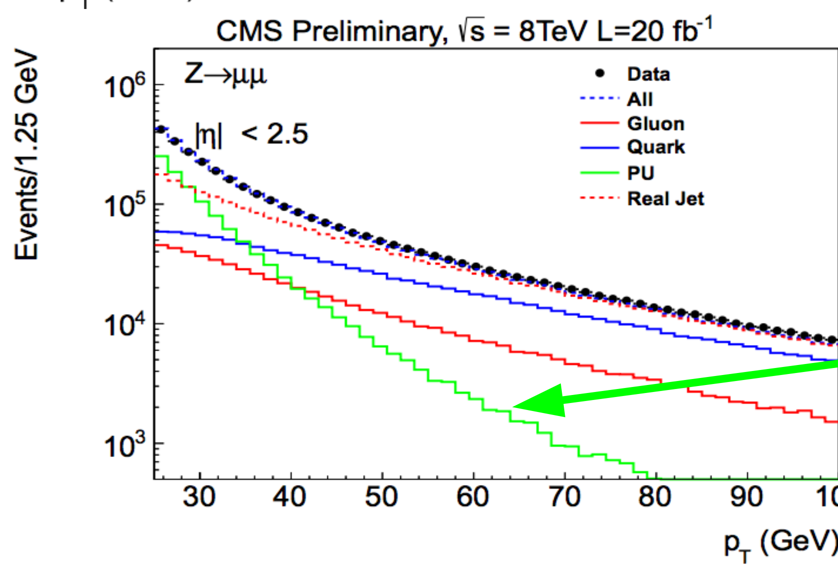
Composition of pileup

- Every collision starts with quarks
  - This leads to jets in the final state
  - Now combine many different collisions together







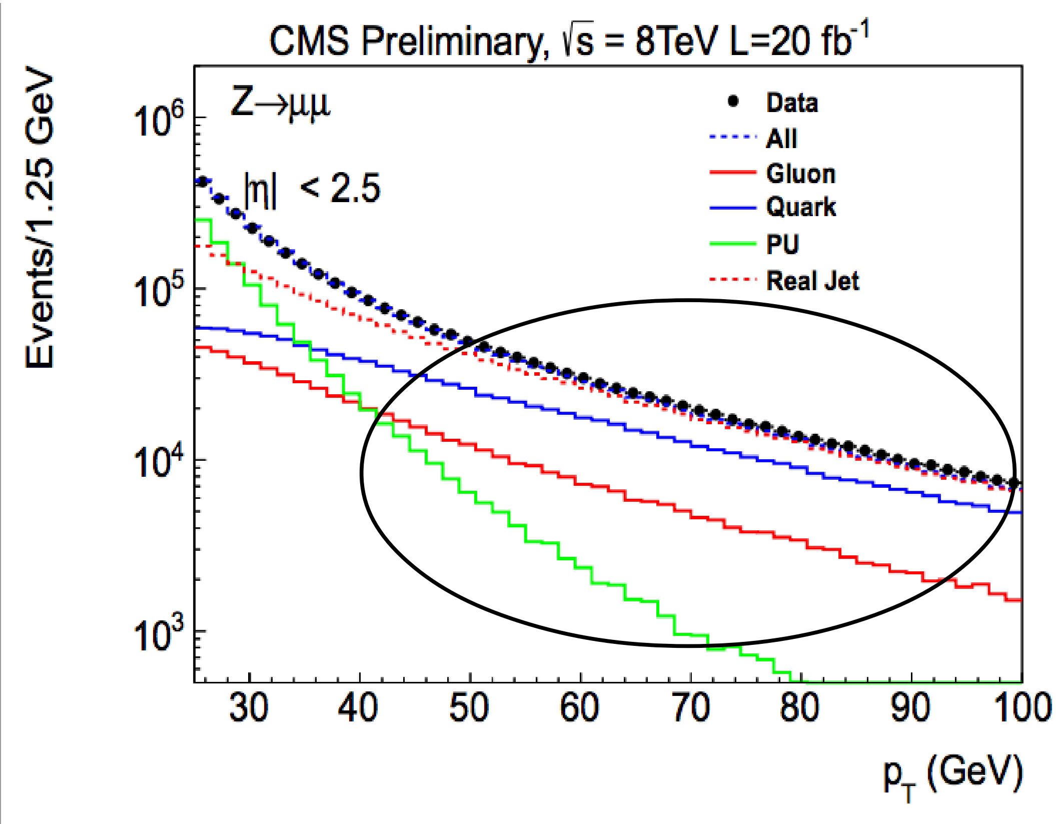


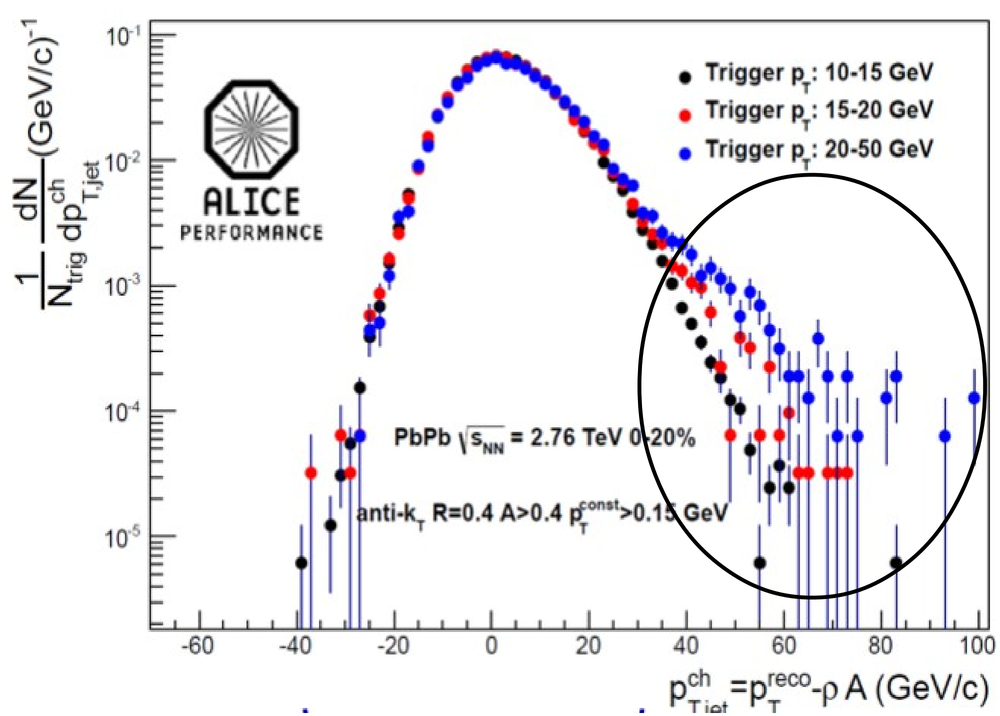
Jets overlapping
Gives up pileup jets

Pileup Jets or "Fake" Jets

- For all classical purposes
  - Pileup jet can be viewed as overlapping low p_T jets
    - **Consider the Jet substructure of such an object?**

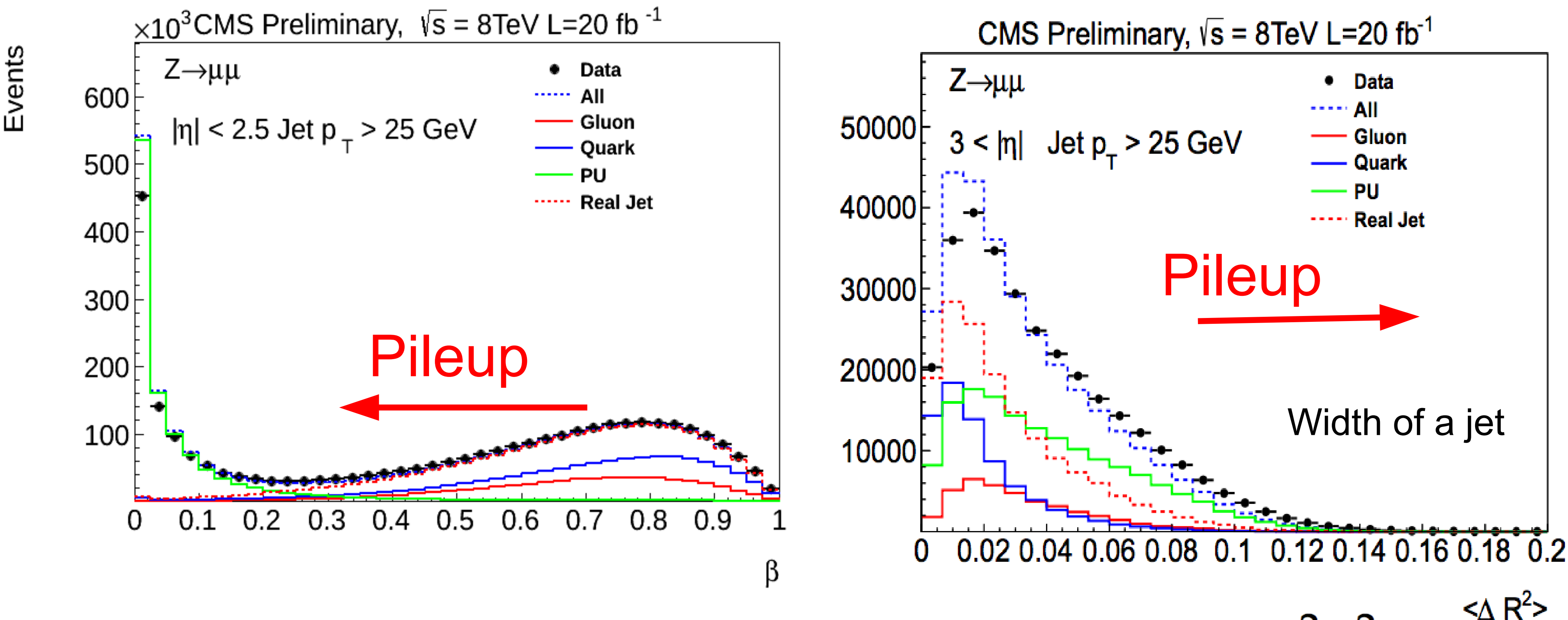
$P(\text{overlap}|pT) \approx C\, N^2_{pu}\, a^2_{jet}\, pT^{-6.2}$ Real Jets $\approx pT^{-5}$





Identifying pileup jets

- Can identify pileup jets by :
  - Jets that are associated to the primary vertex
  - Looking for objects that are wide(overlapping)

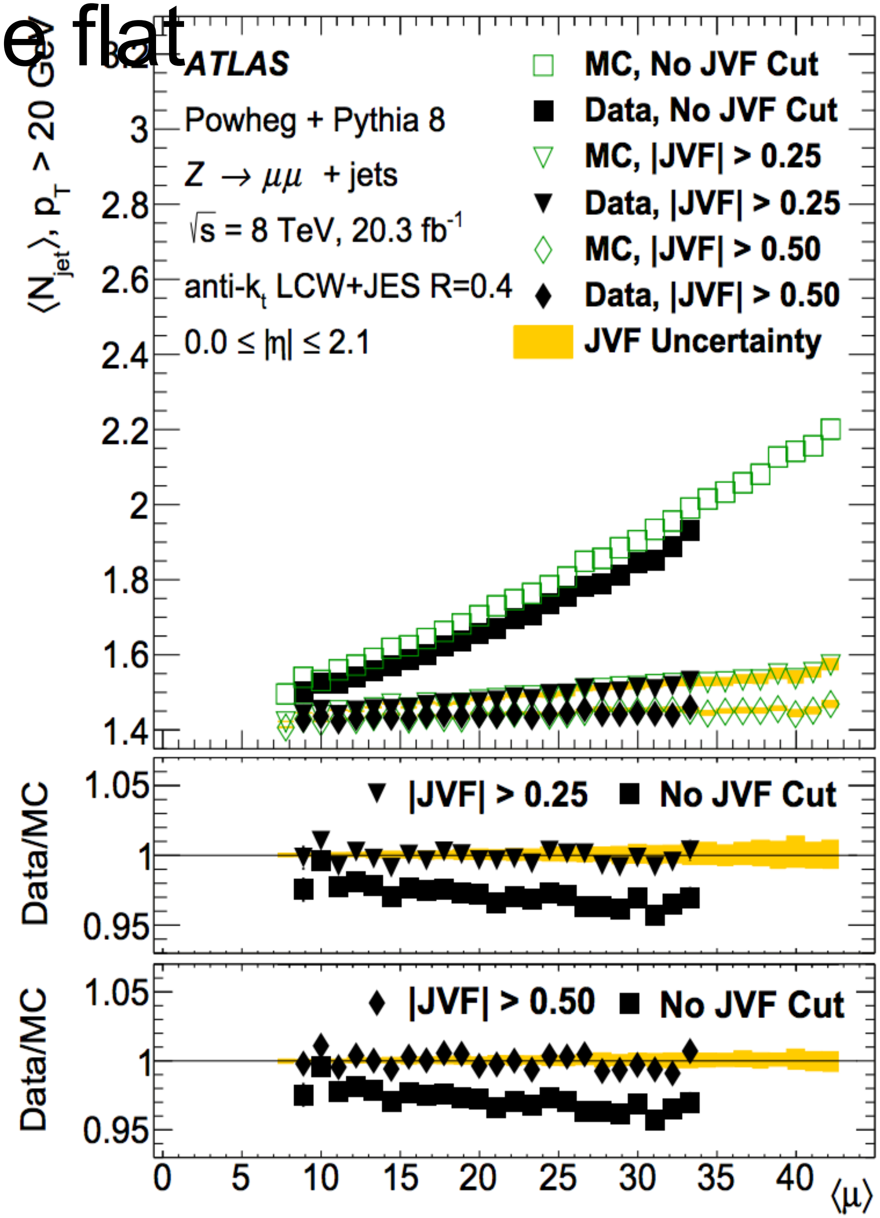


$$\beta = \frac{\sum_{i \in PV} p_{Ti}}{\sum_i p_{Ti}} \qquad \langle \Delta R^2 \rangle = \frac{\sum_i \Delta R_i^2 p_{Ti}^2}{\sum_i p_{Ti}^2}$$

Pileup Jet Id

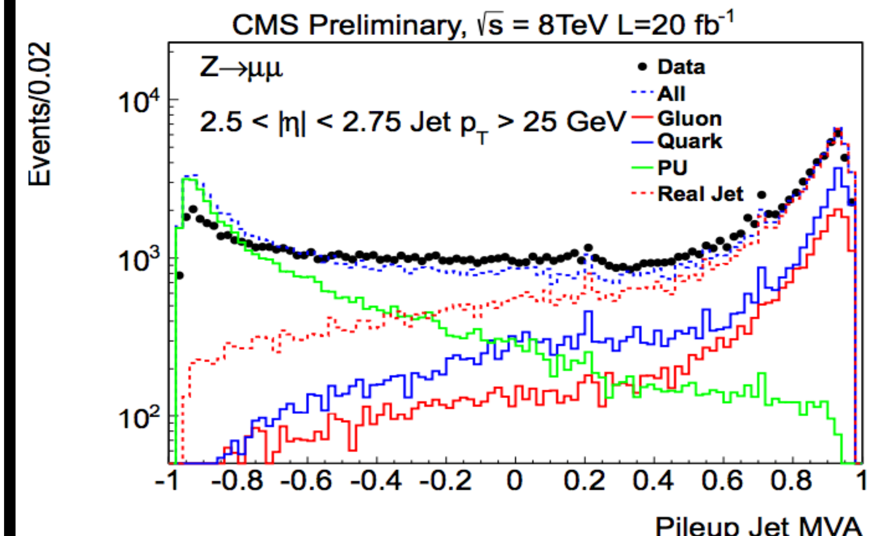
ATLAS

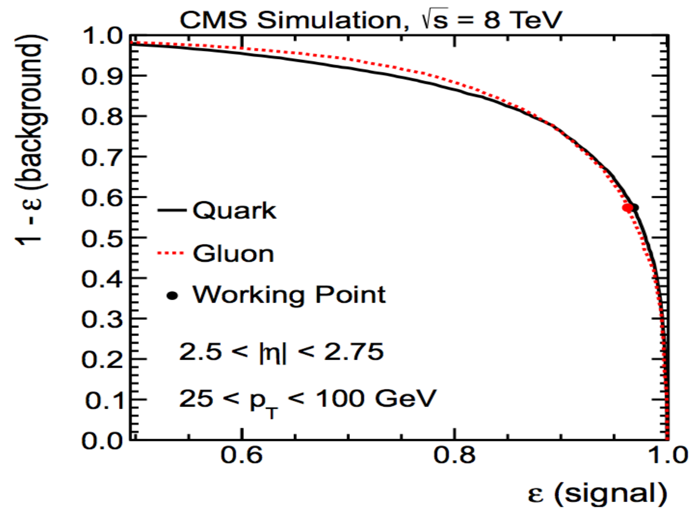
Cut on tracking tuned to be flat



CMS

Put 10 tracking/shape variables in an MVA



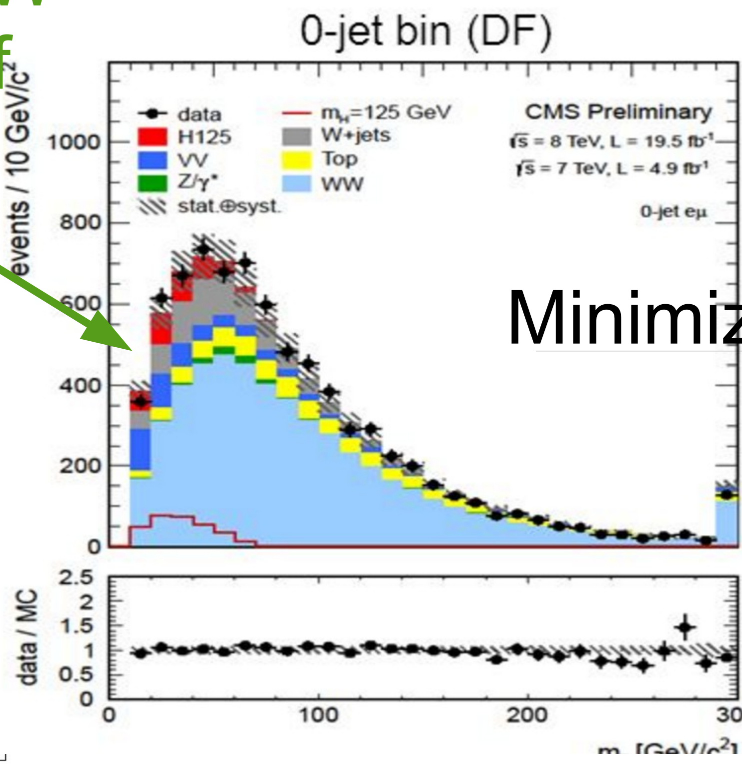


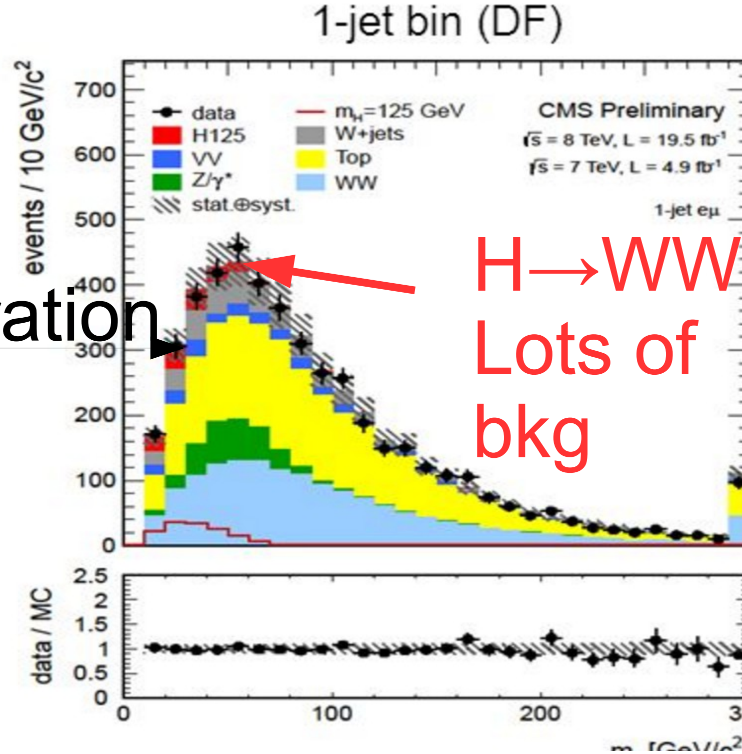
Why is it so important?

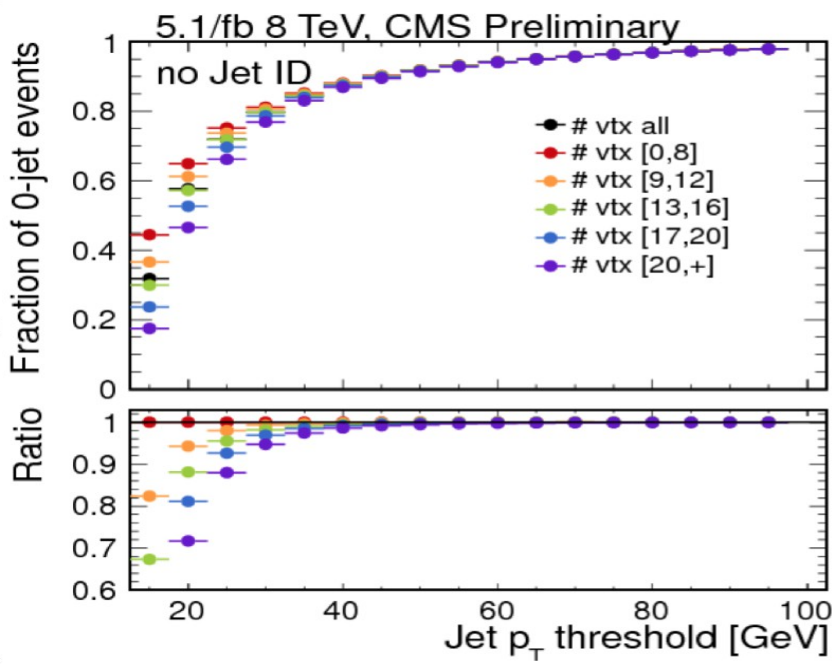
H→WW
Lots of higgs

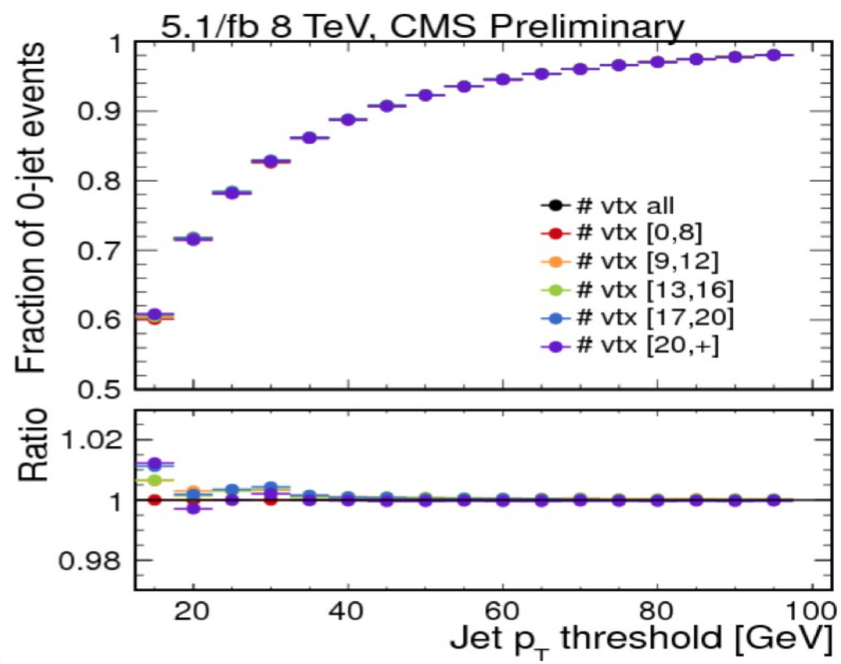
Minimize migration

H→WW
Lots of bkg

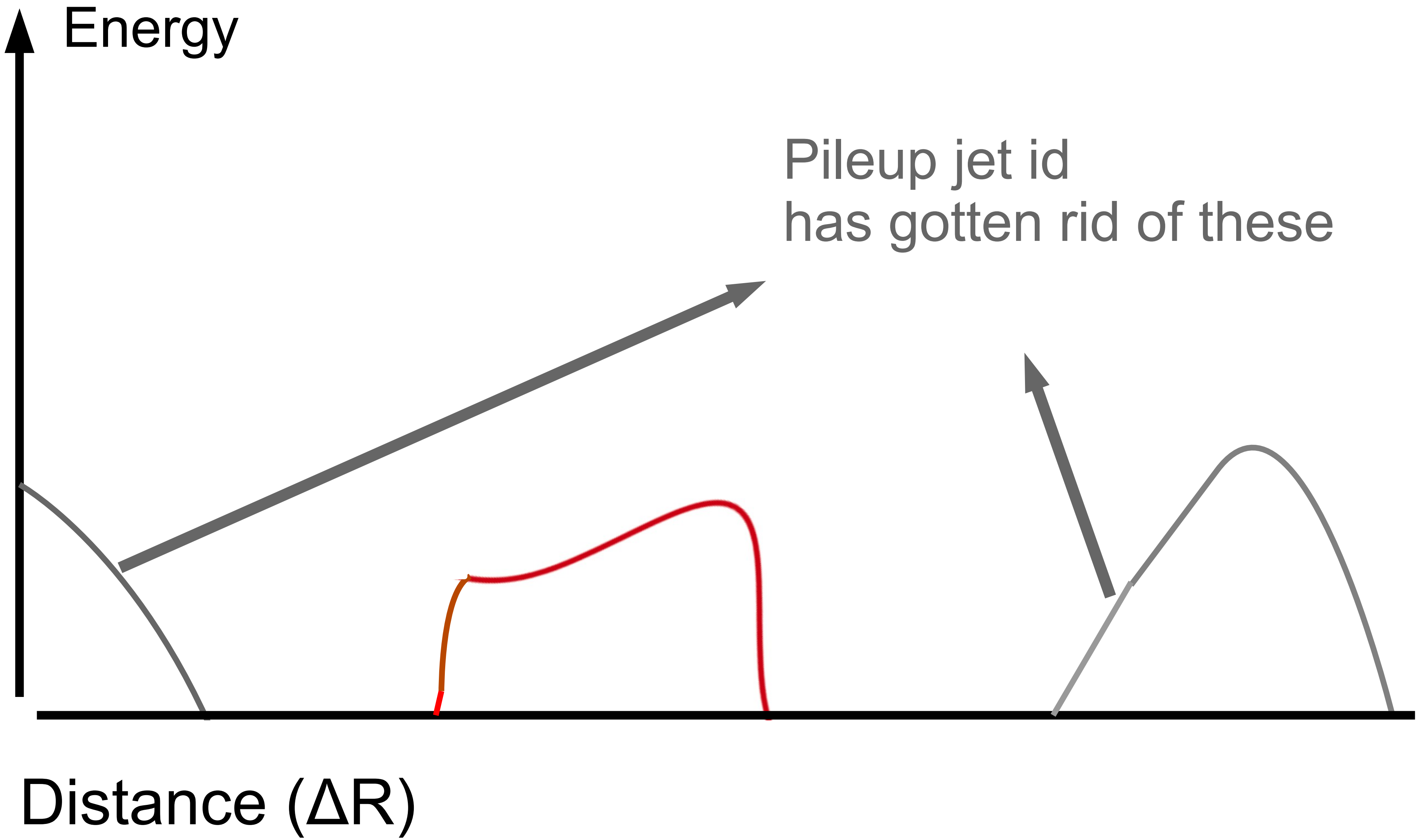




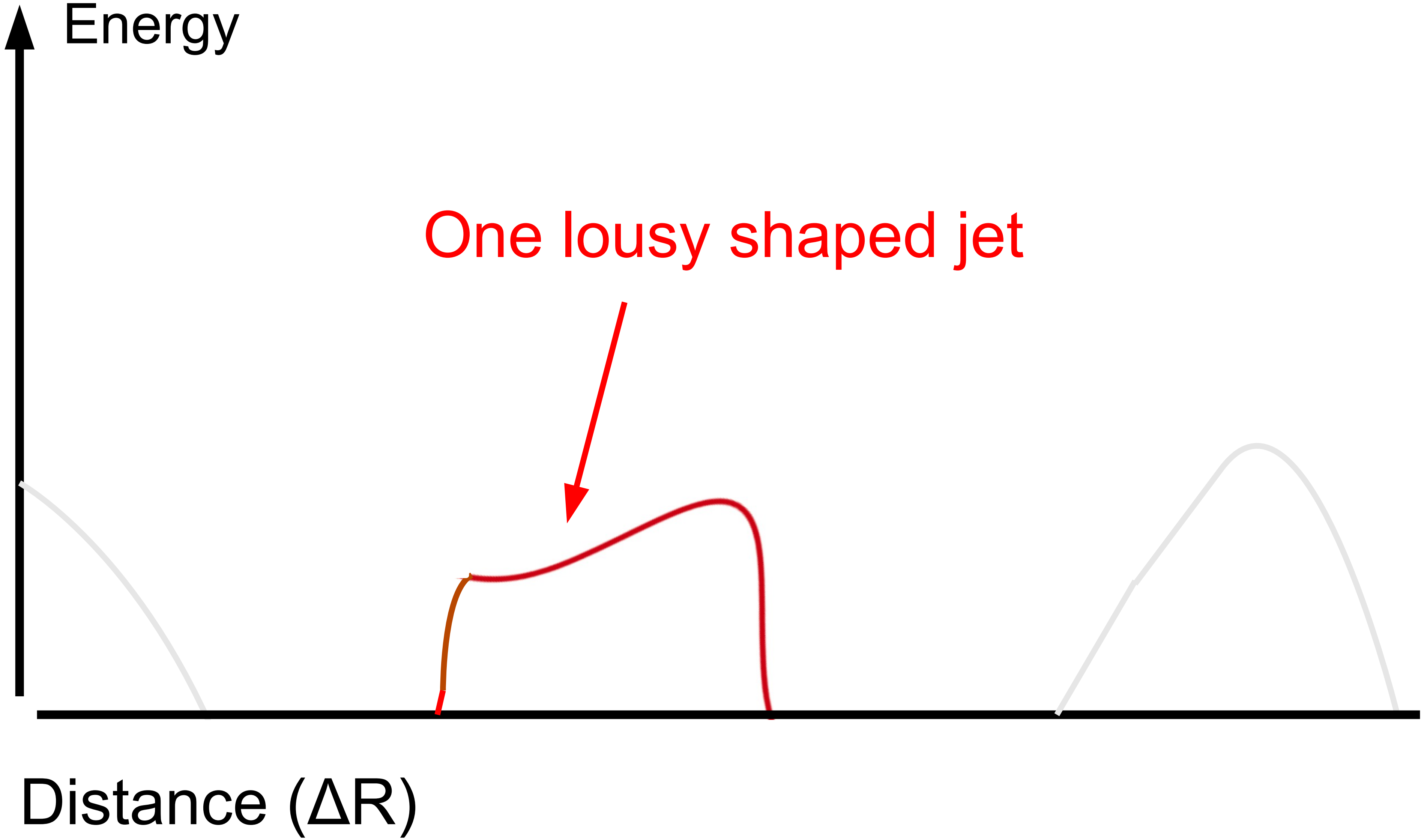




Pileup Jet Id Effect



State of the art 3 years ago



What if we could fix this?

- Consider merging two concepts together

HF/Voronoi
(Particle level subtraction)

Pileup Jet Id
(Discriminating against Pileup)

PileUp Per Particle Id
(Pileup discrimination per particle)

What if we could fix this?

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(Particle level subtraction)

Pileup Jet Id
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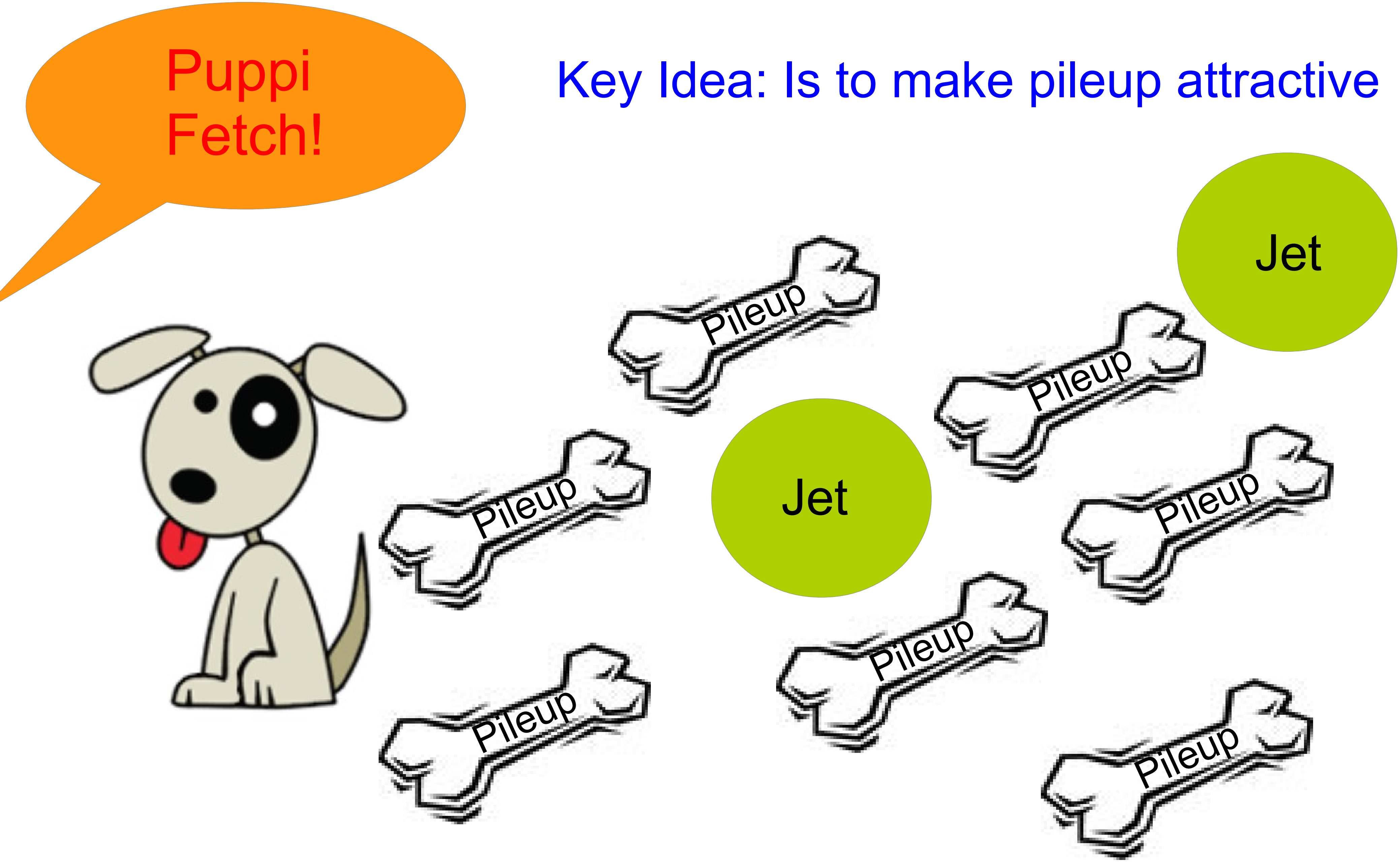
PileUp Per Particle Id
(Pileup discrimination per particle)

JHEP 1410 (2014) 59
http://arxiv.org/pdf/1407.6013.pdf

How does Puppi work?

Key Idea: Is to make pileup attractive

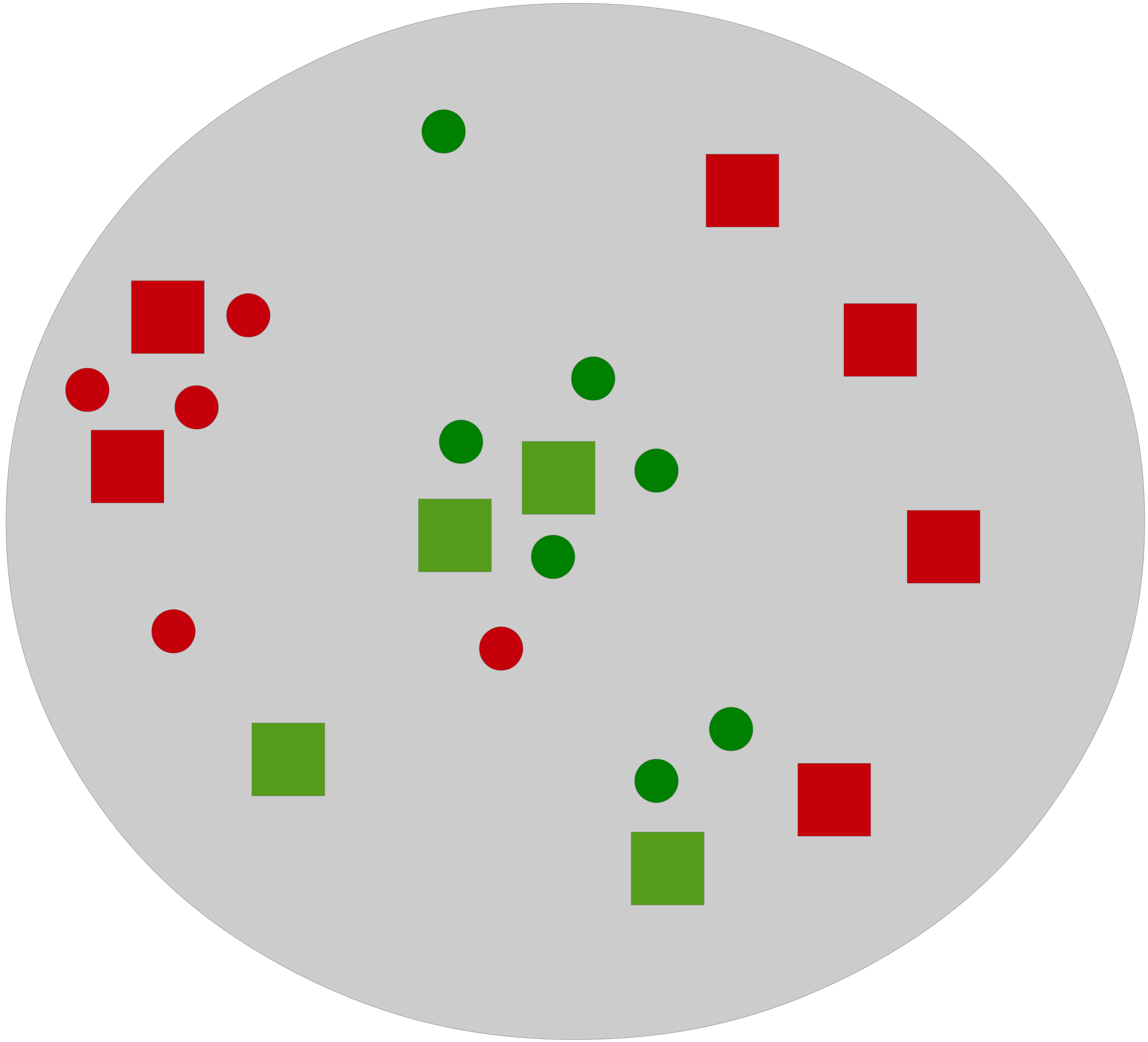


General Idea of the algorithm

- 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

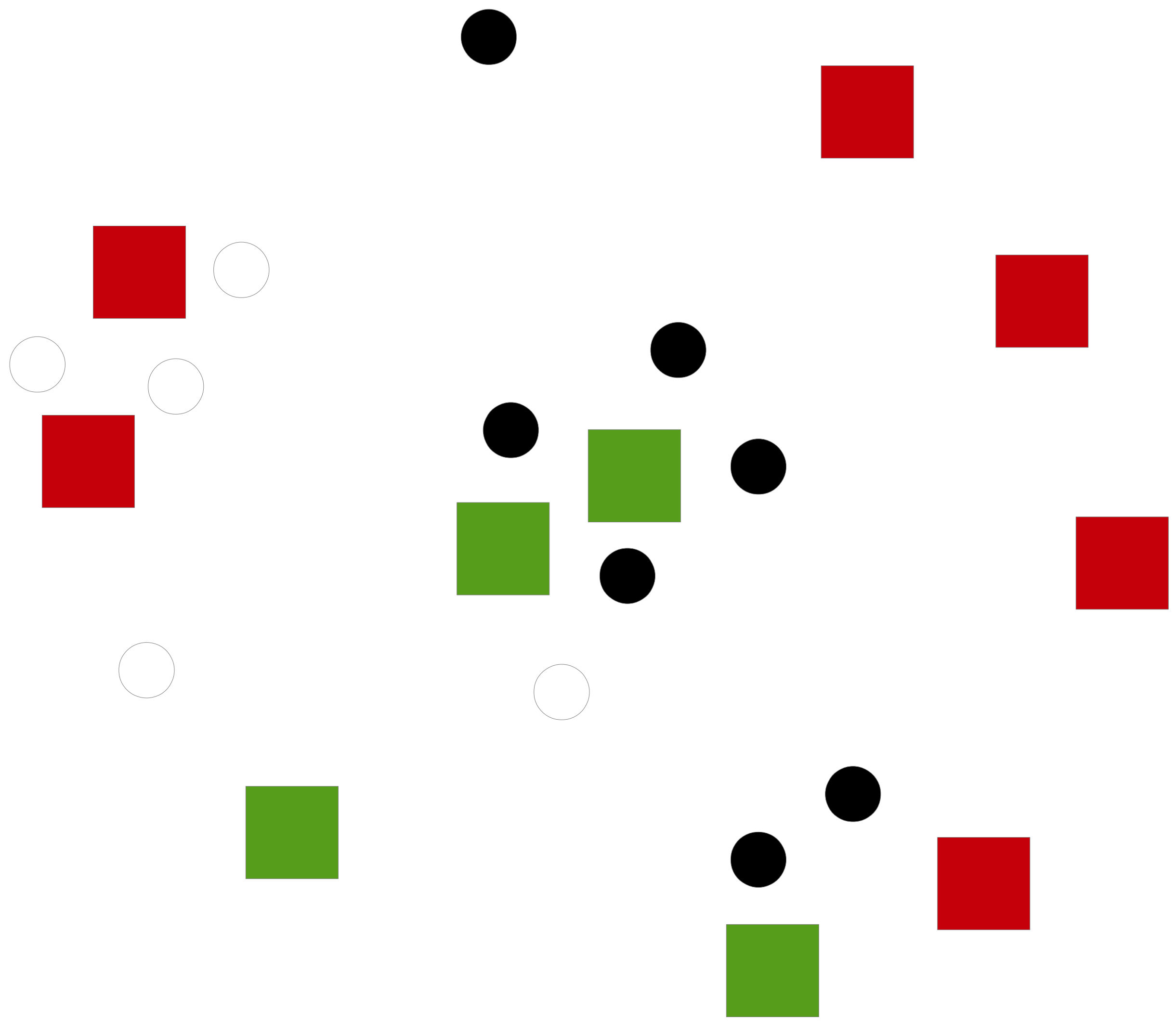
Key
- Good Track
- PU Track
- Good Neut
- PU Neut
- Chosen
- Removed



Puppi algorithm

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

Step 1
Tracks can point to PU vertices w/high efficiency

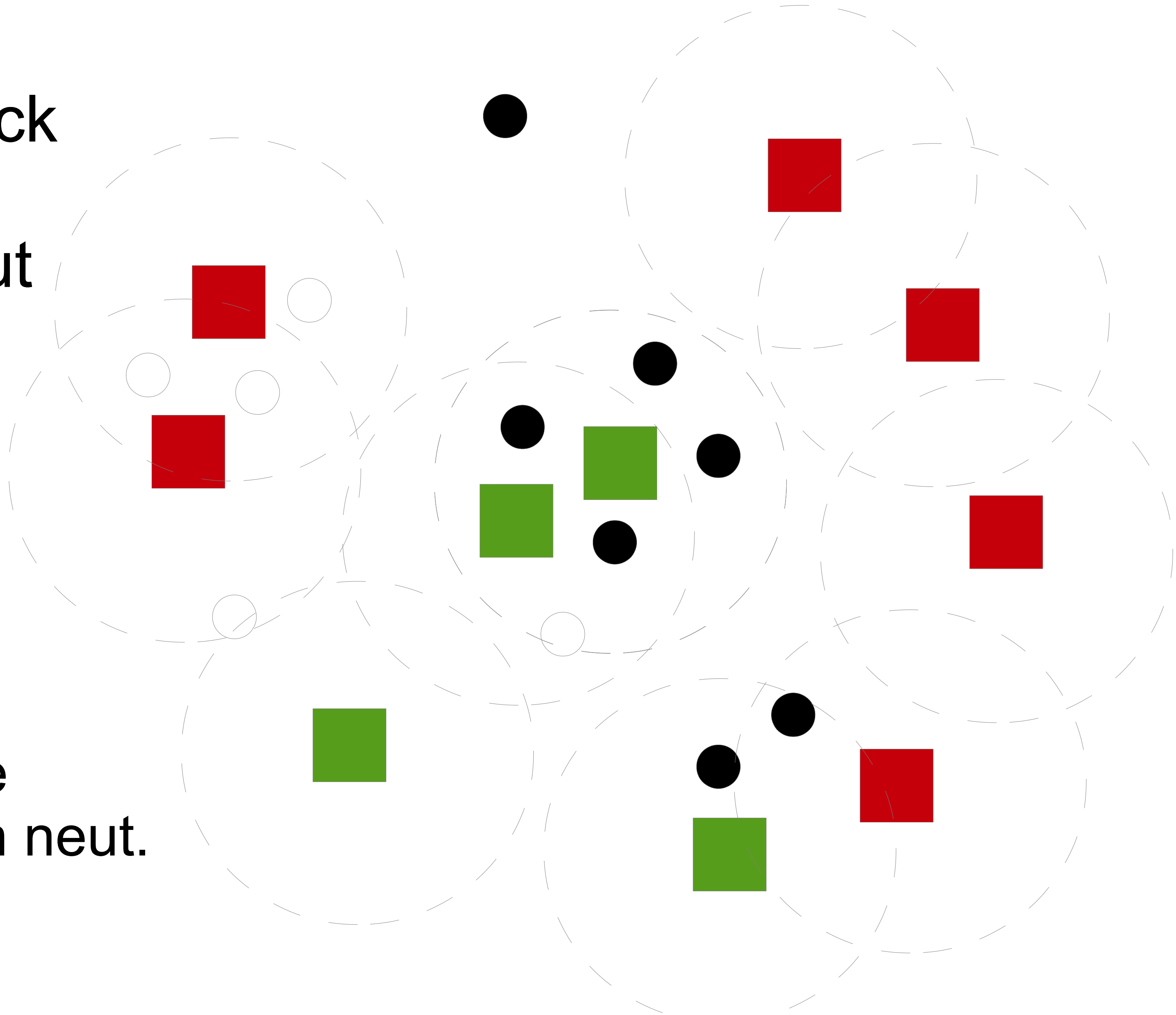


Puppi algorithm

Key

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

Step 1
 Vertexing
Step 2
 Draw a cone
 About each neut.



Puppi algorithm

Key

Good Track

PU Track

Good Neut

PU Neut

Chosen

Removed

Step 1

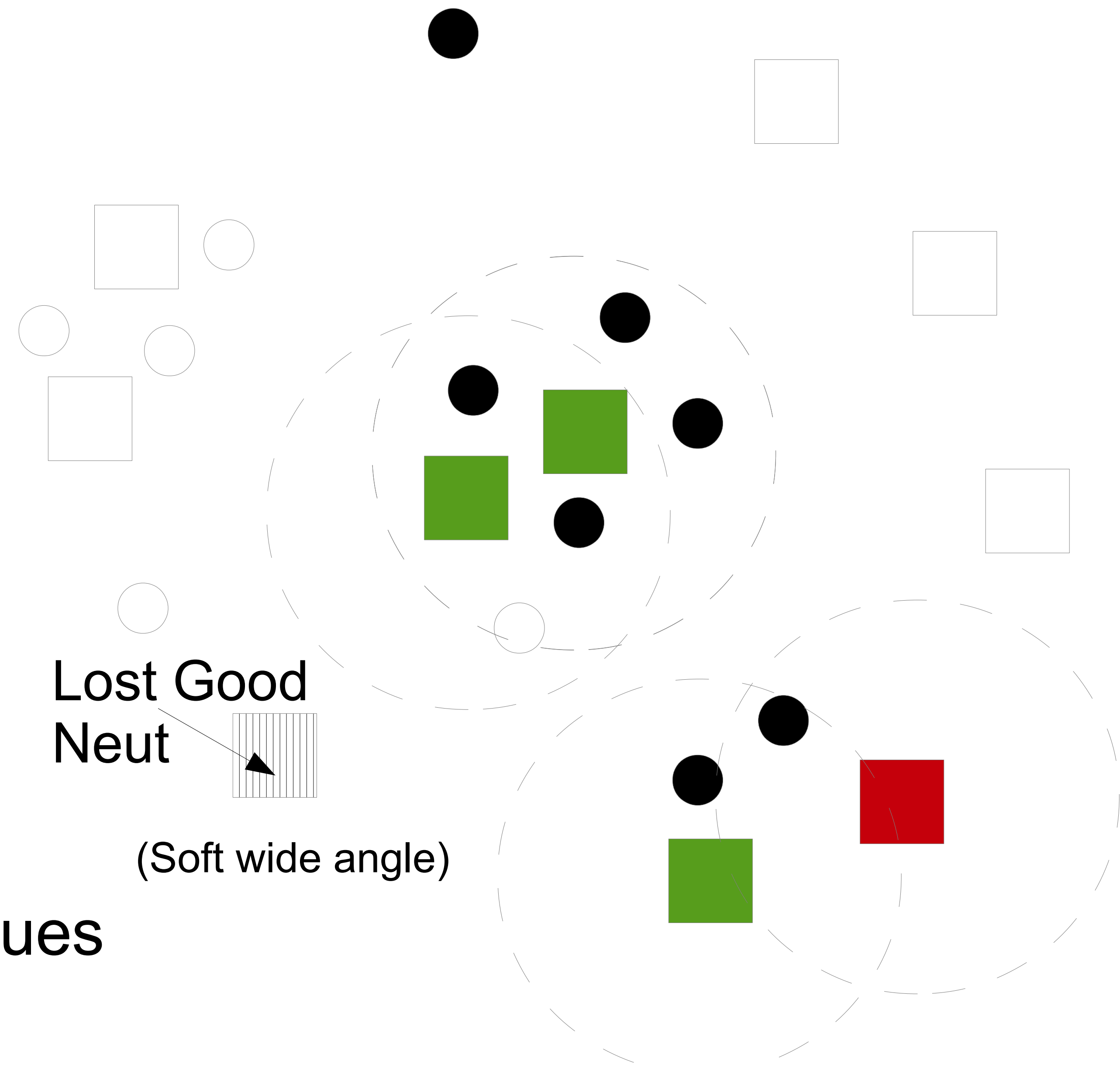
Run CHS

Step 2

Draw a cone

Step 3

Remove all 0 values



Puppi algorithm

Key

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

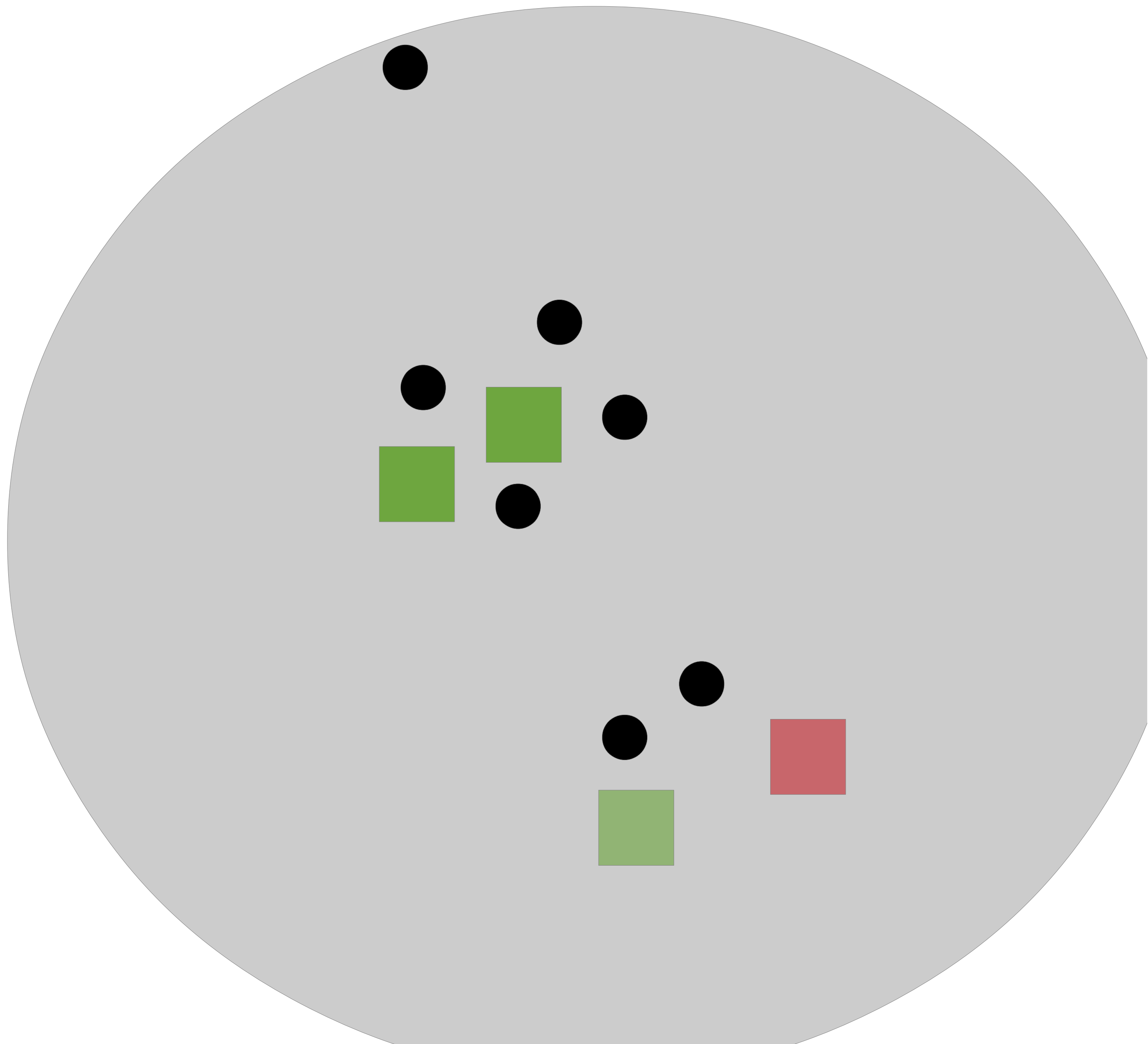
Step 1
 Vertexing
Step 2
 Draw a cone
Step 3
 Remove all 0 values
Step 4
 Reweight Neutrals by weight factor

After Puppi

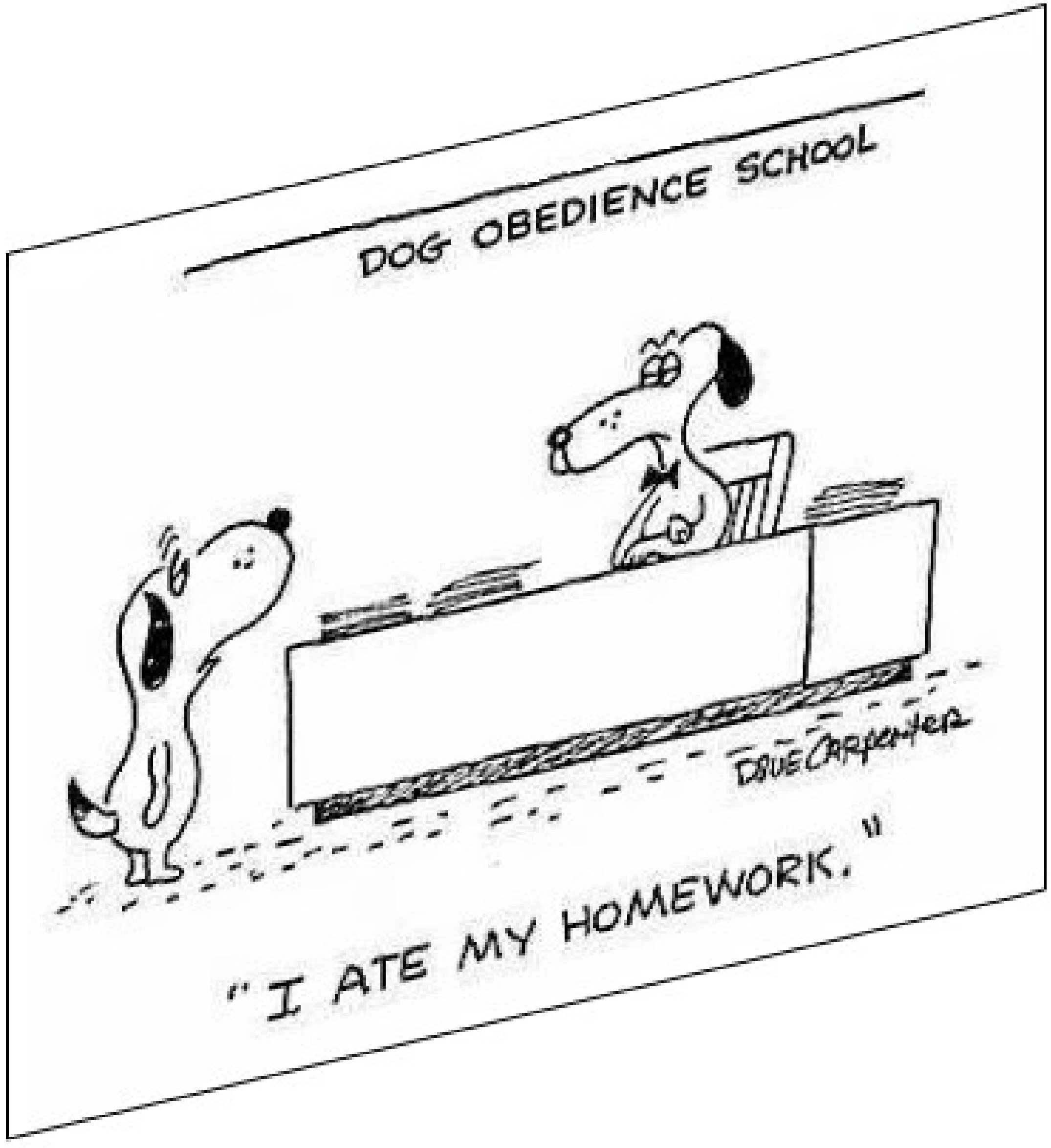
Key

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

Step 5
Re-interpret evt
(Re-cluster)



Understanding Puppi



Understanding Puppi requires some real life experience

The weight factor

- For each particle consider in a cone :

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

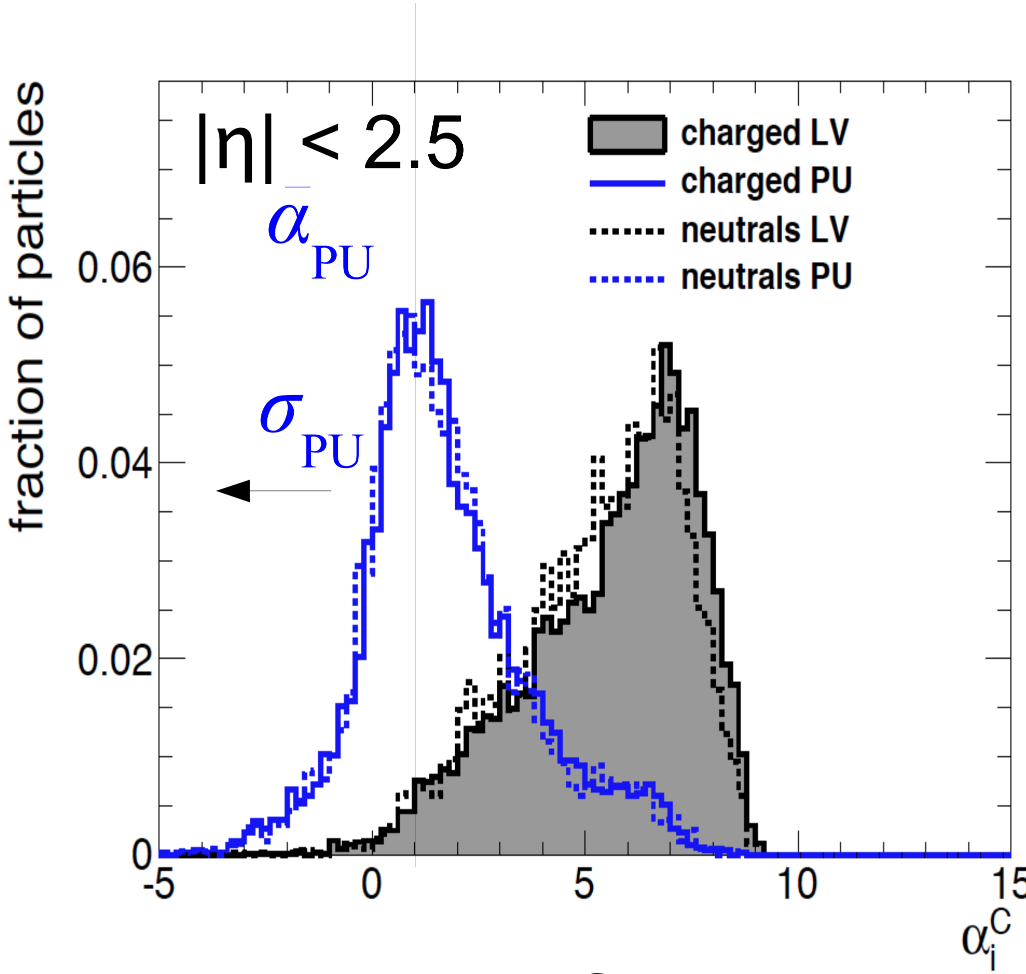
↑ Hard collinear particles

↓ Soft wide angle particles

Reminiscent of a P(scatter) α $1/(\Delta R)^2$

Number of particles increases with p_T

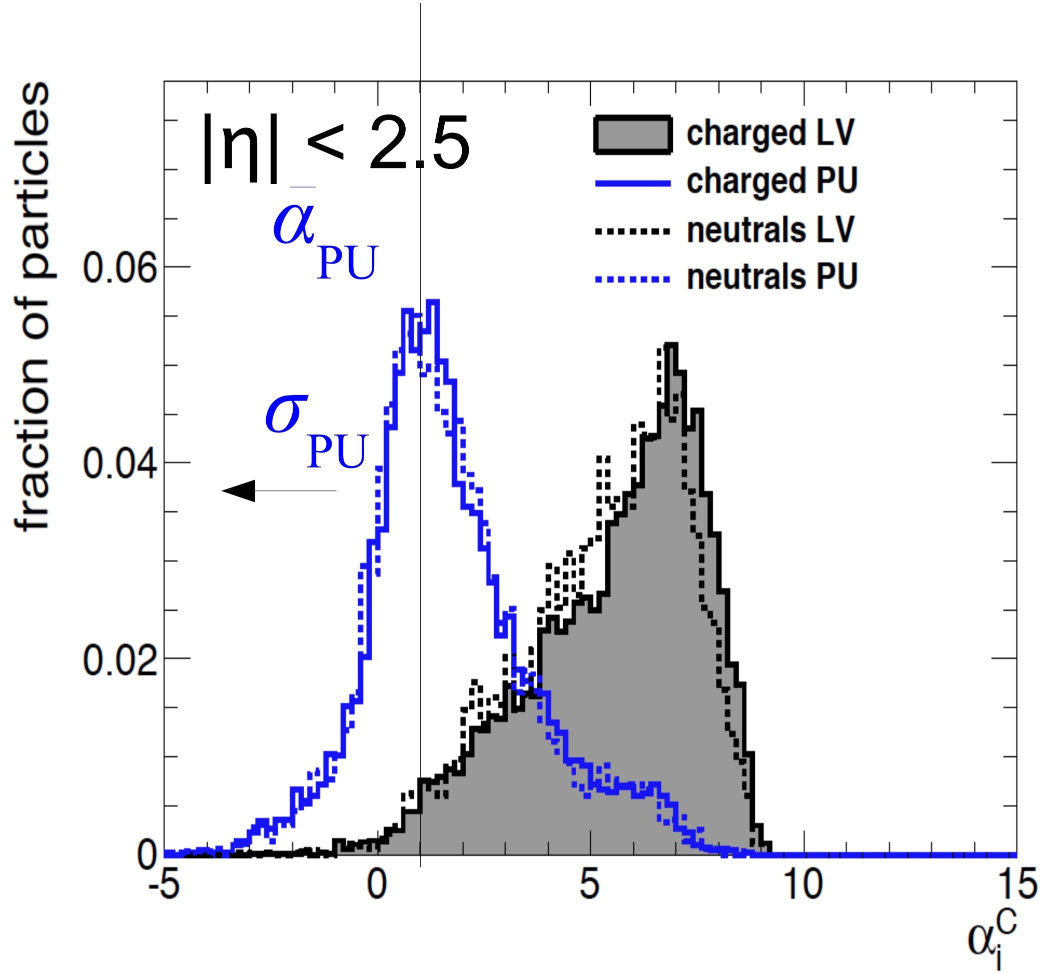
Event level interpretation



Approximate the shape of pileup as χ^2 distribution

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

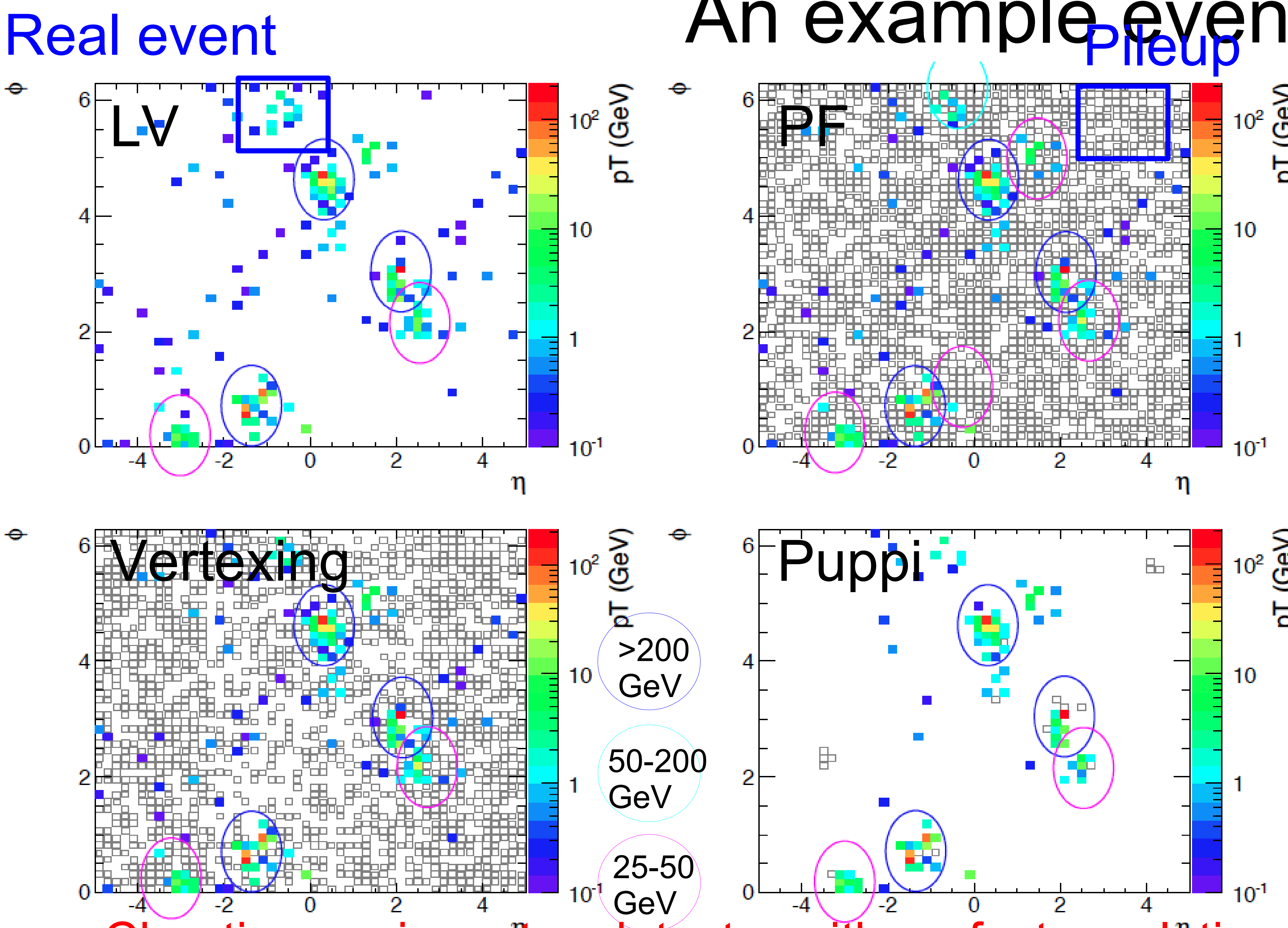
Event level interpretation



Translate distribution into a weight*

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

An example event

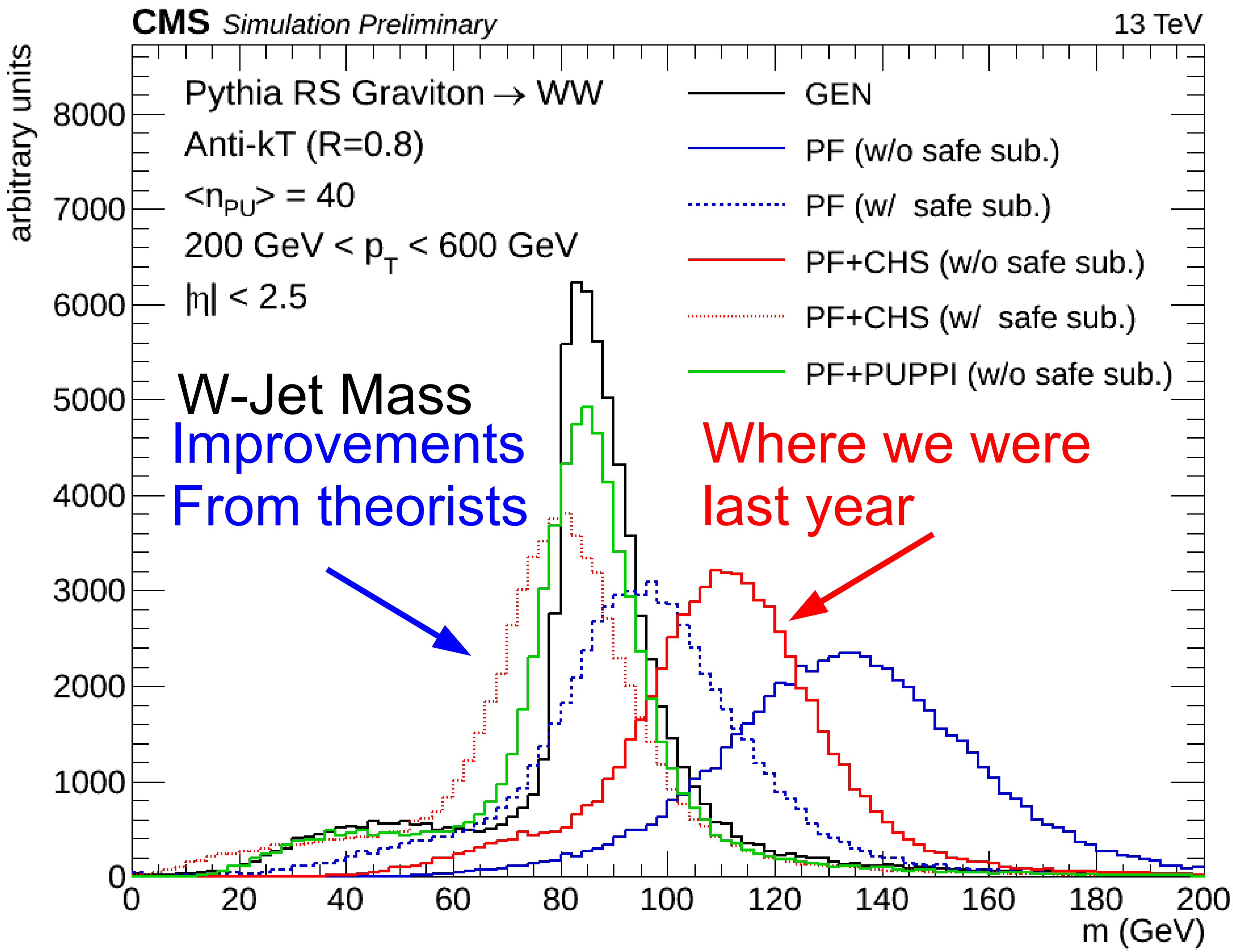


Cheating : using a toy detector with perfect resolution

Puppi performance on a detector

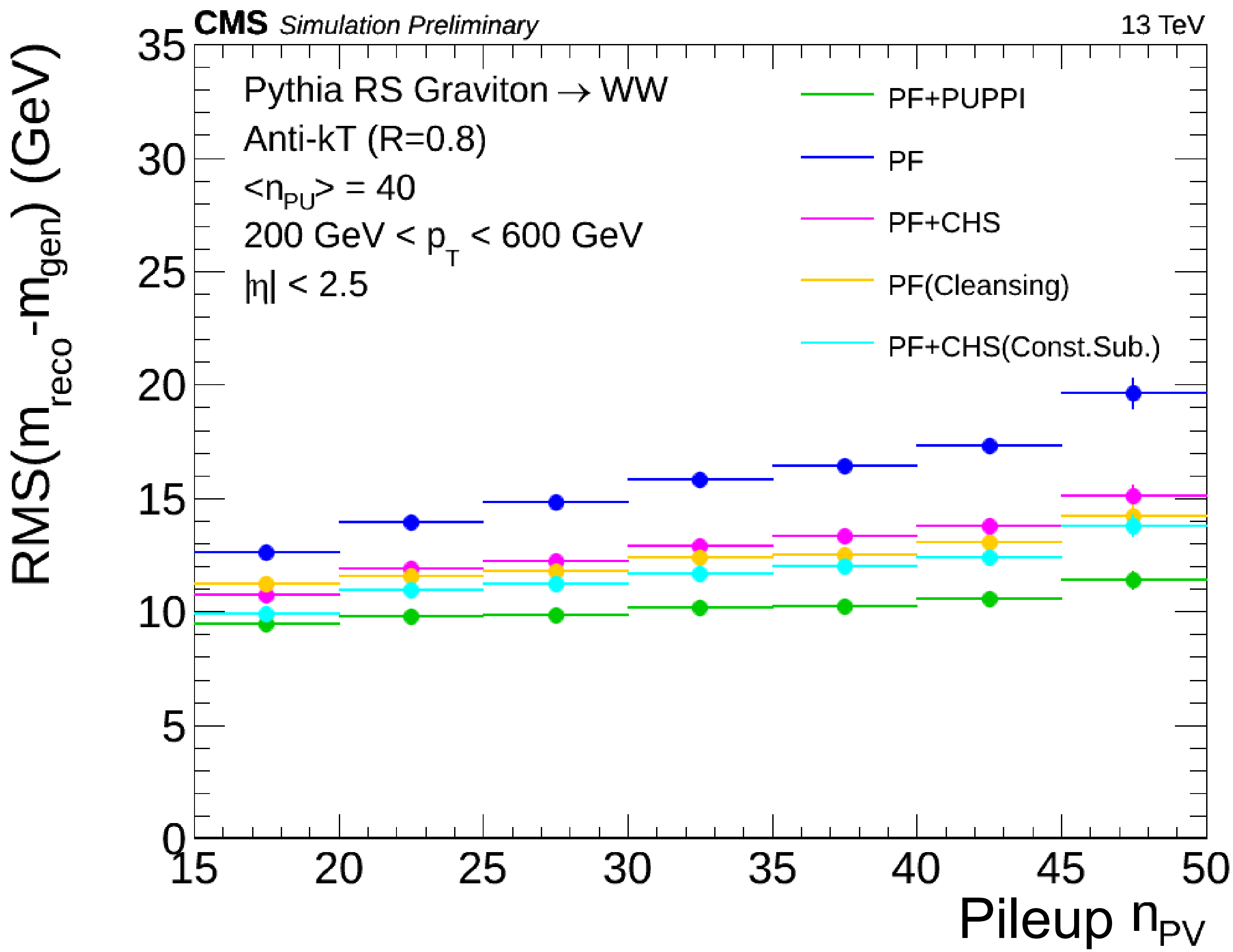
No cheating

Jets in CMS



Baseline comparison is state of the art ρ subtraction

Pileup performance

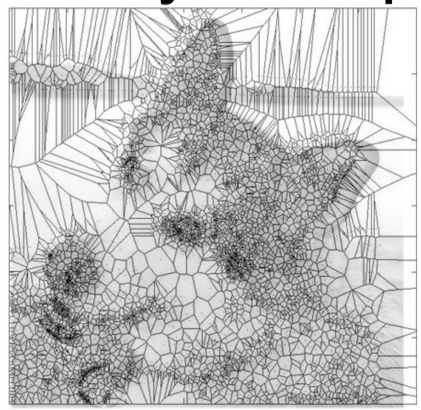


- Mass resolution is flat against pileup
  - Related trend observed in the data

Evolution of PU Subtraction

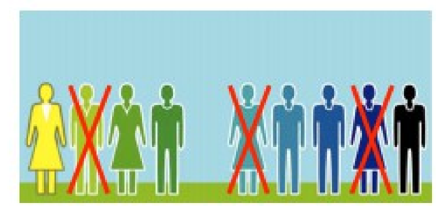
Aim is to remove pileup
at particle level

Heavy Ion approach



PUPPI
PU Jet id @particle level

HF Voronoi
Per-particle subtraction
Using voronoi cells



Constituent Subtraction
ρA correction per particle

Soft Killer
Median ρ removal
Per particle

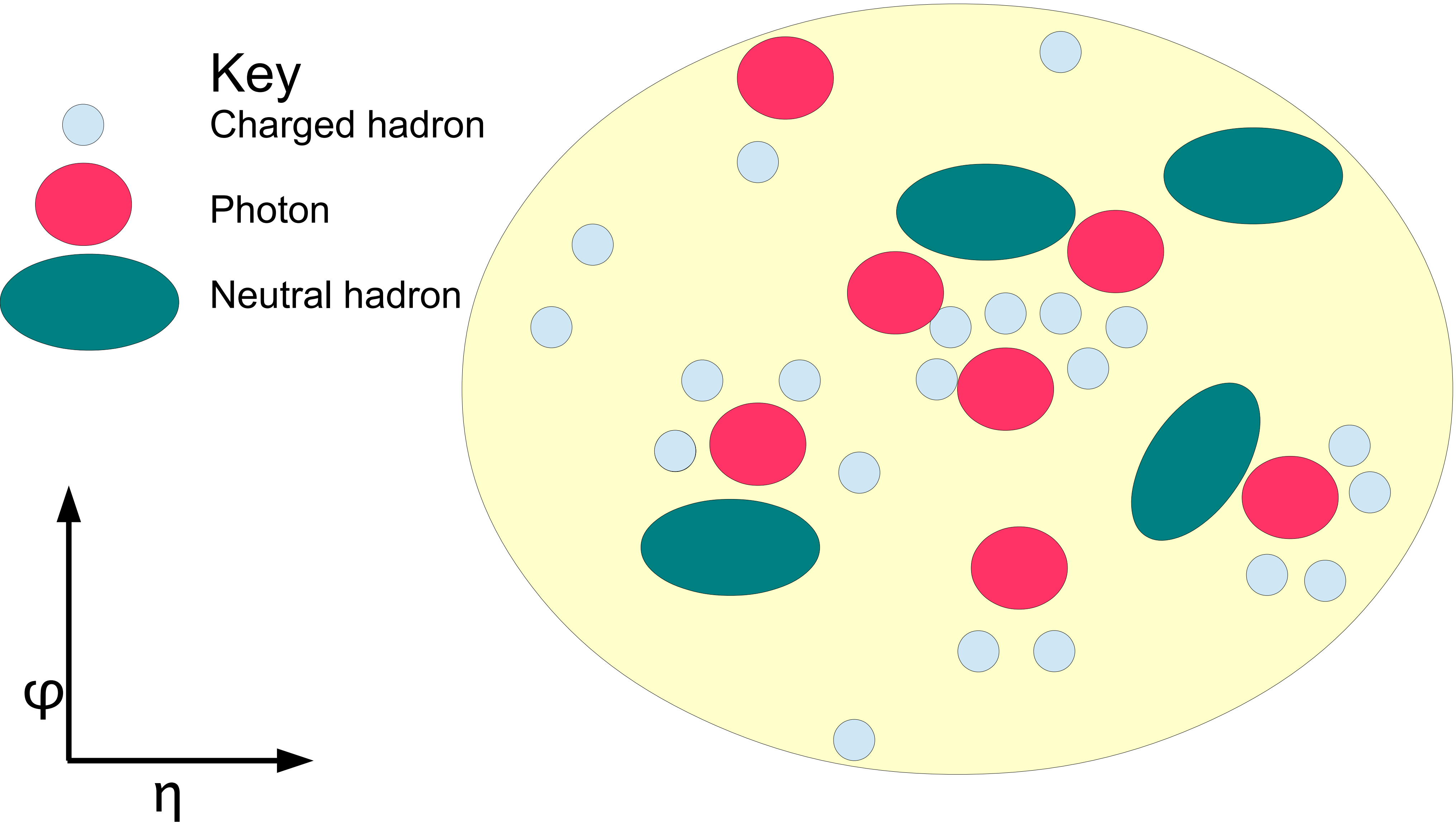
JME-DP-13-018
JME-14-001

A depiction of Jet Grooming :
0912.0033,1402.2657,0912.1342,/0802.2470

Jet Grooming

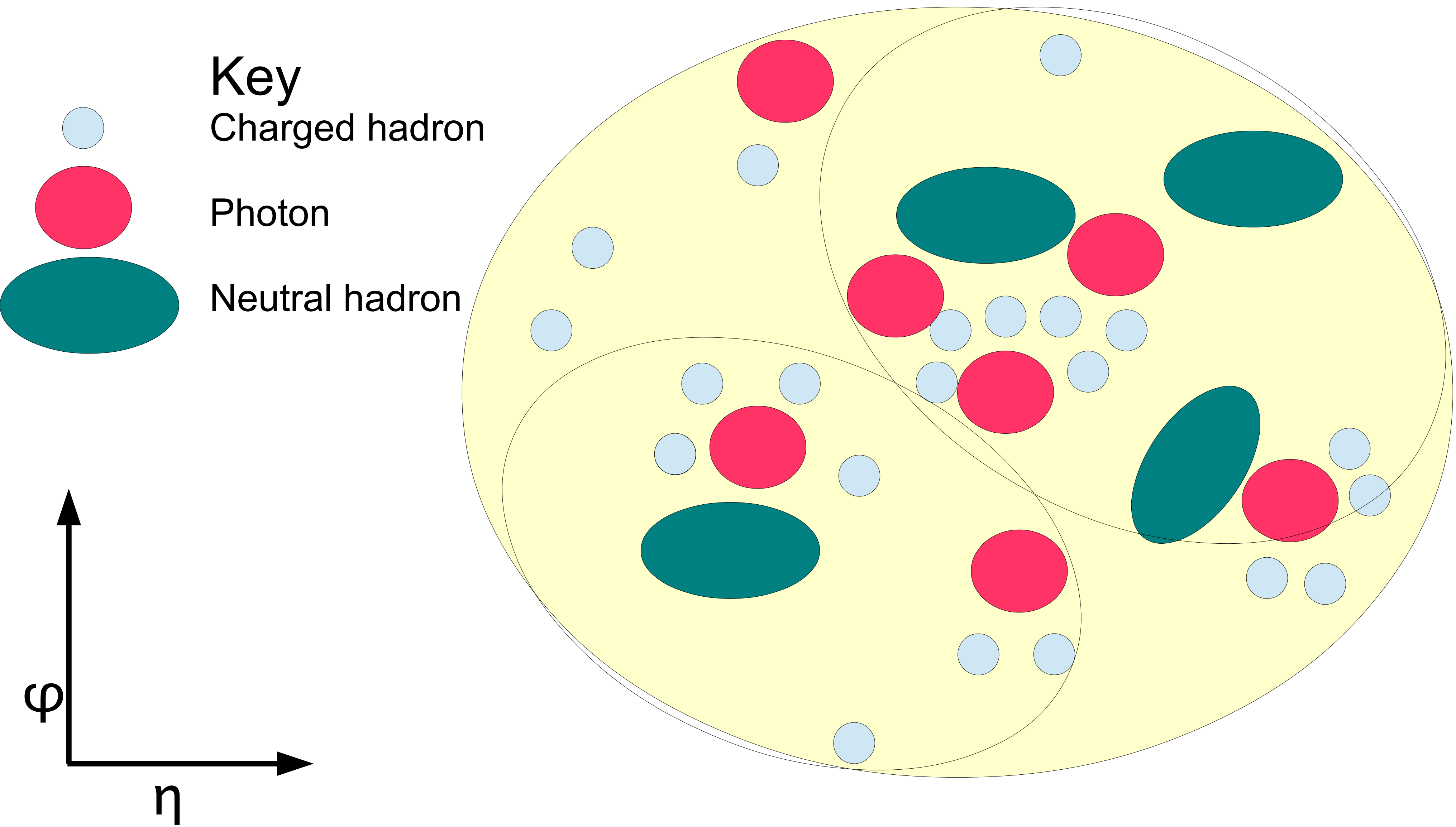
Jet Grooming

Imagine the surface of a jet



Jet Grooming

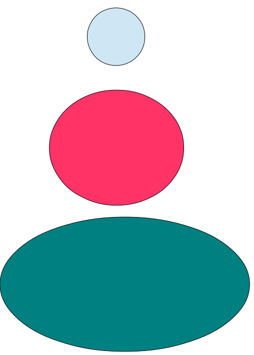
All Jet groom starts with de-clustering (using CA)



Jet Grooming : Pruning/Soft Drop

Iteratively decluster jet removing lowest p_T subjet failing pairwise condition

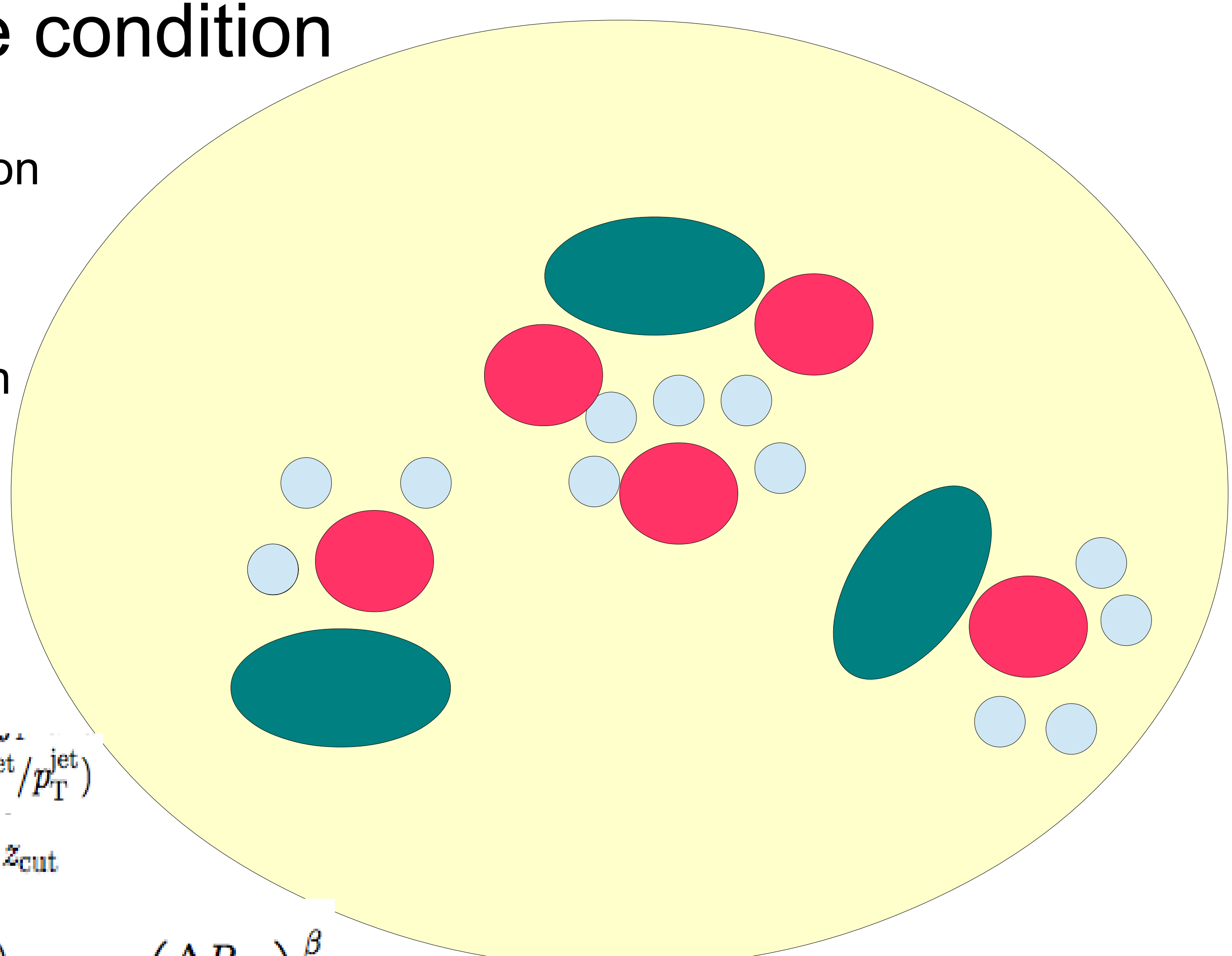
Key



Charged hadron

Photon

Neutral hadron



Approaches are generally more agressive

Pruning : $\Delta R_{j_1,j_2} < R_{\rm cut} \times (2m^{\rm jet}/p_{\rm T}^{\rm jet})$

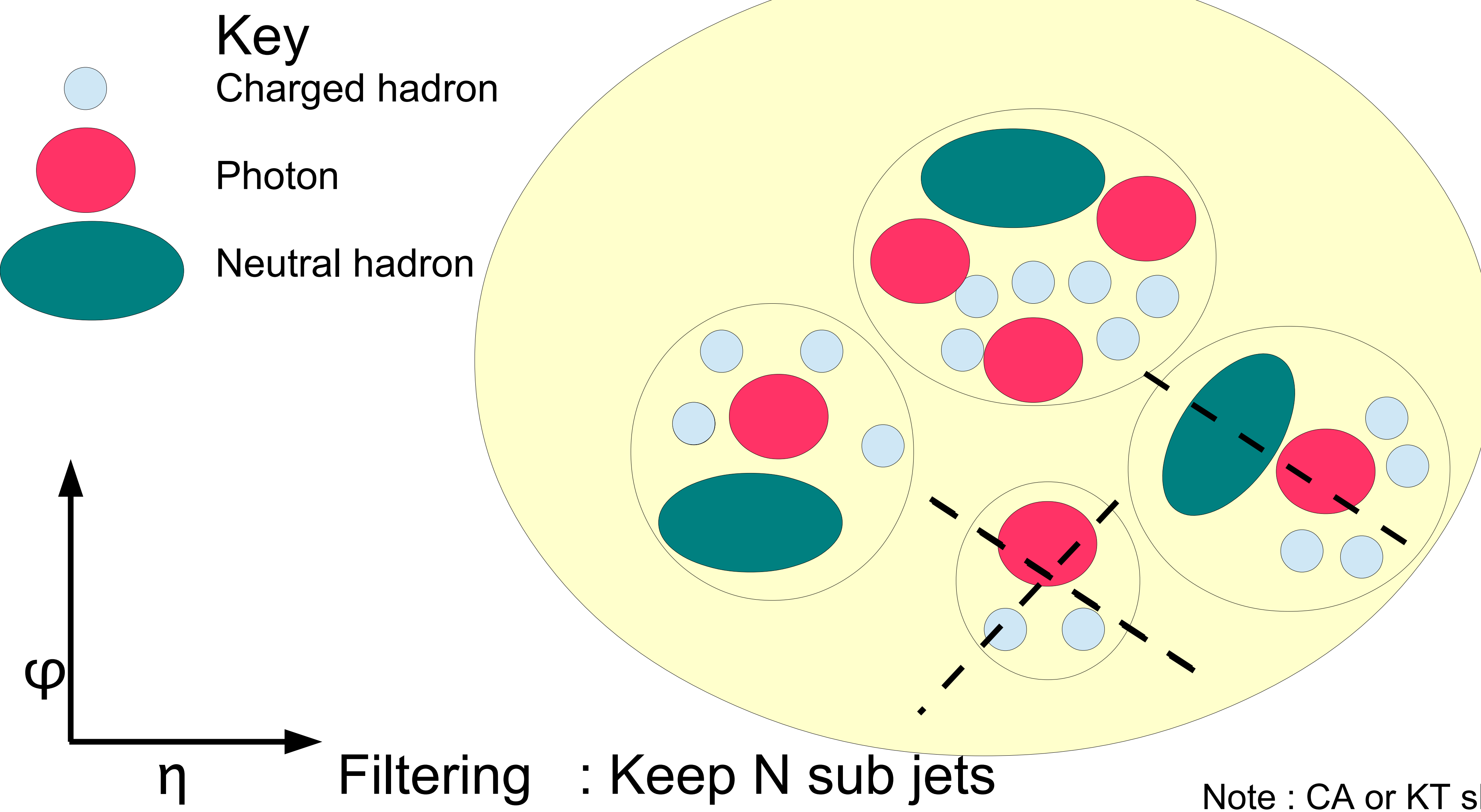
$p_{\rm T}^{j2}/p_{\rm T}^{j1+j2} > z_{\rm cut}$

Soft Drop: $\frac{\min(p_{T1},p_{T2})}{p_{T1}+p_{T2}} > z_{\rm cut}\left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$

Note : CA or KT shoul
be used to de-cluster

Jet Grooming : Filtering/Trim/SD

Decluster jet and take only subjets



Filtering : Keep N sub jets

Trimming : Keep pT_i/pT_{jet} jets

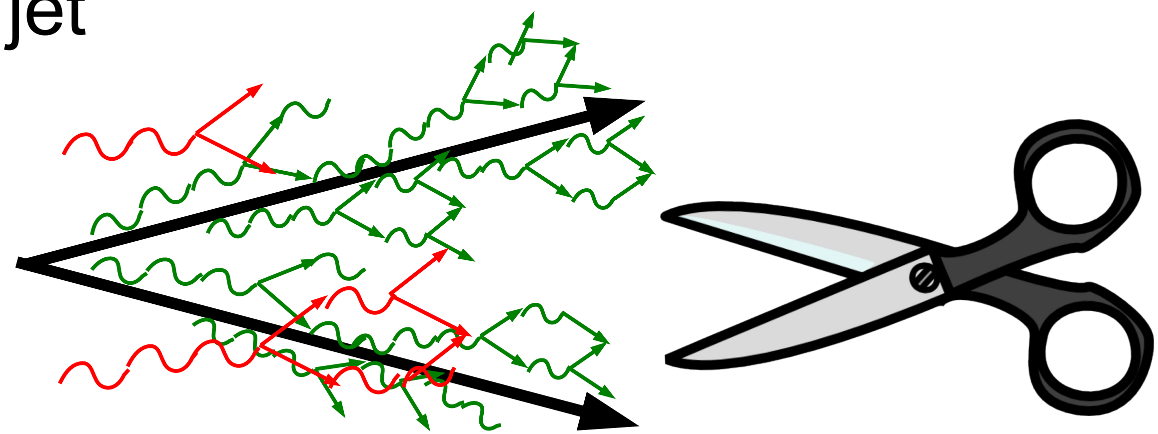
Note : CA or KT shoul
be used to de-cluster

Jet grooming : a highlight

- Improving the mass resolution on of a jet
  - Requires pruning/trimming away excess radiation

1 jet

$W \rightarrow qq$

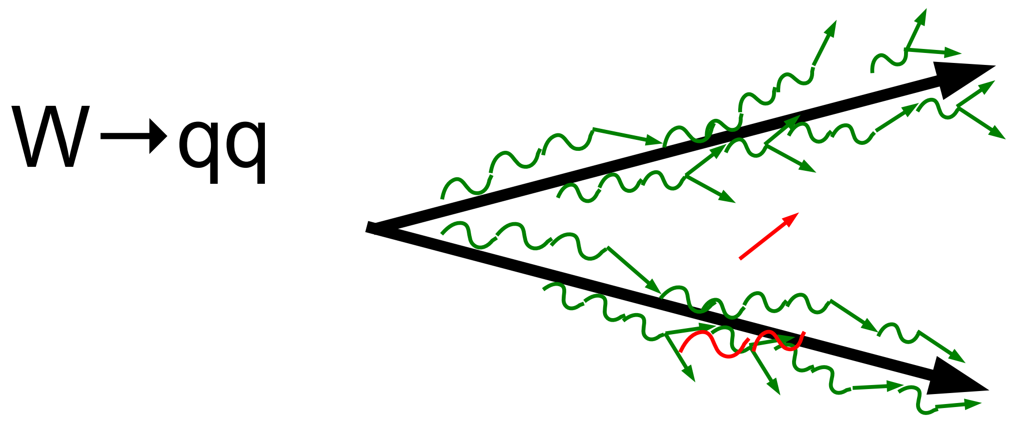


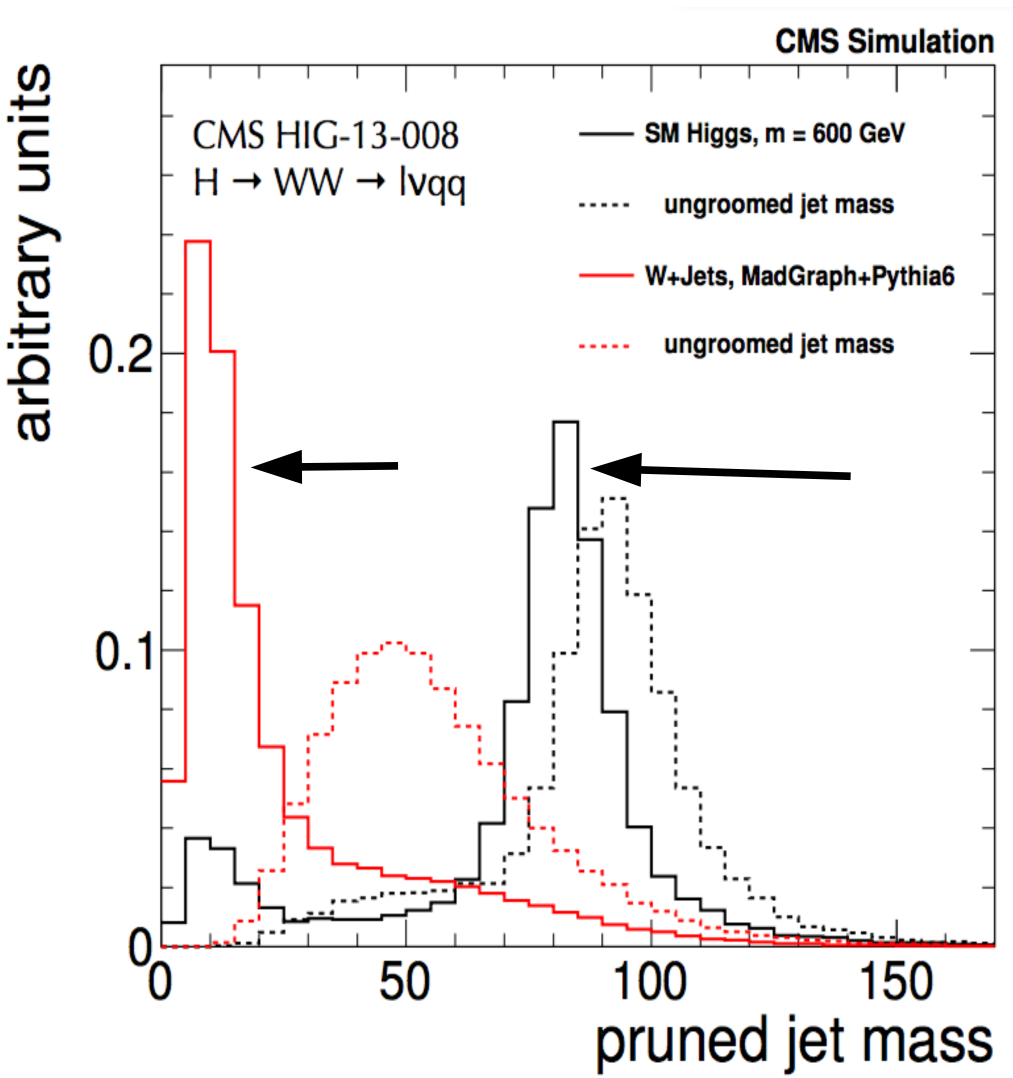
High W p_T

Pileup/QCD radiation

Jet Grooming : a Highlight

- Improving the mass resolution on of a jet
  - Requires pruning/trimming away excess radiation



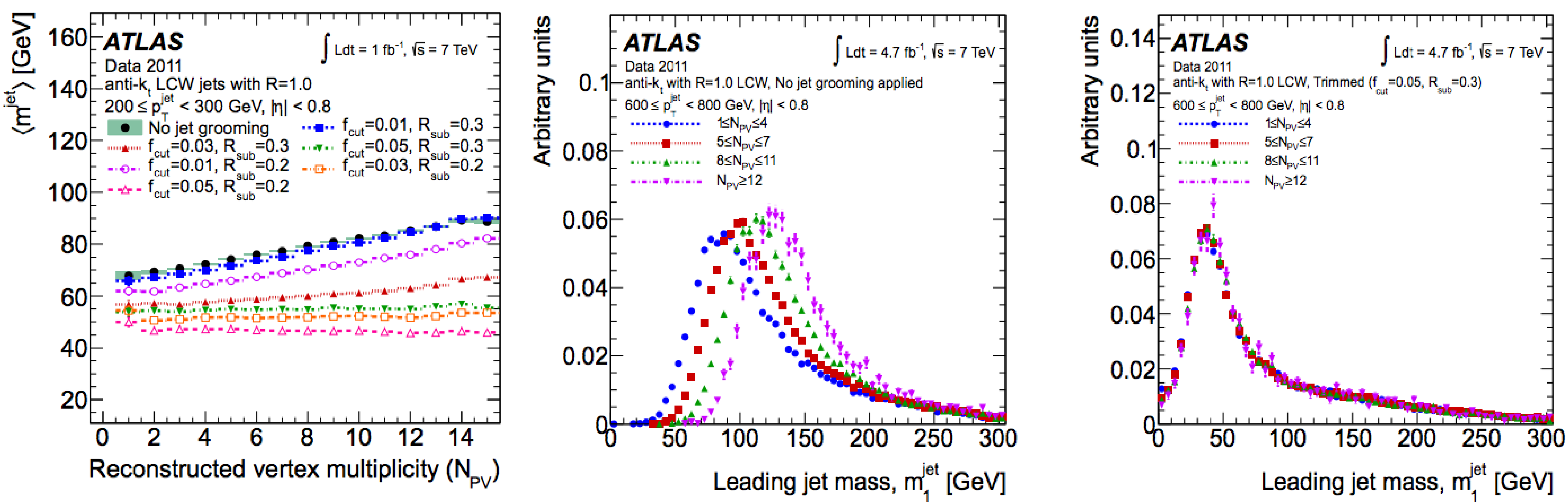


Jet grooming improves the resolution of jets

Pileup/QCD radiation

Grooming and PU

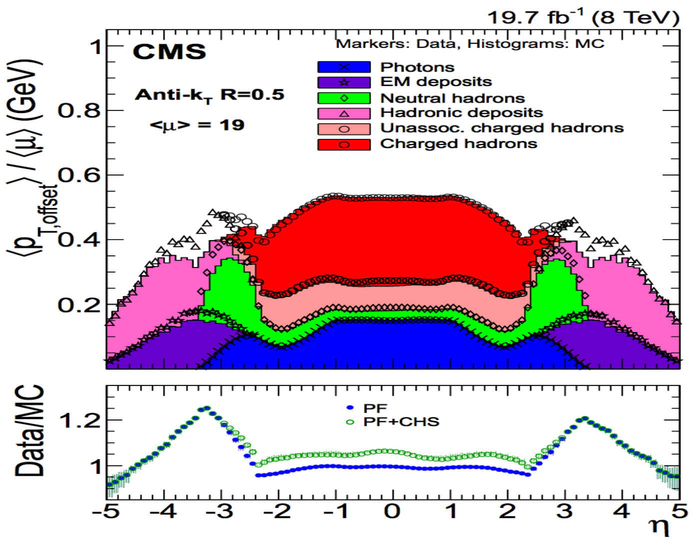
- Grooming makes jet reconstruction stable
  - Agains pileup and underlying event
- Allows for use of large jet cones
- Rapidly improves hadronic boson mass
- At its core is preserves theoretical robustness



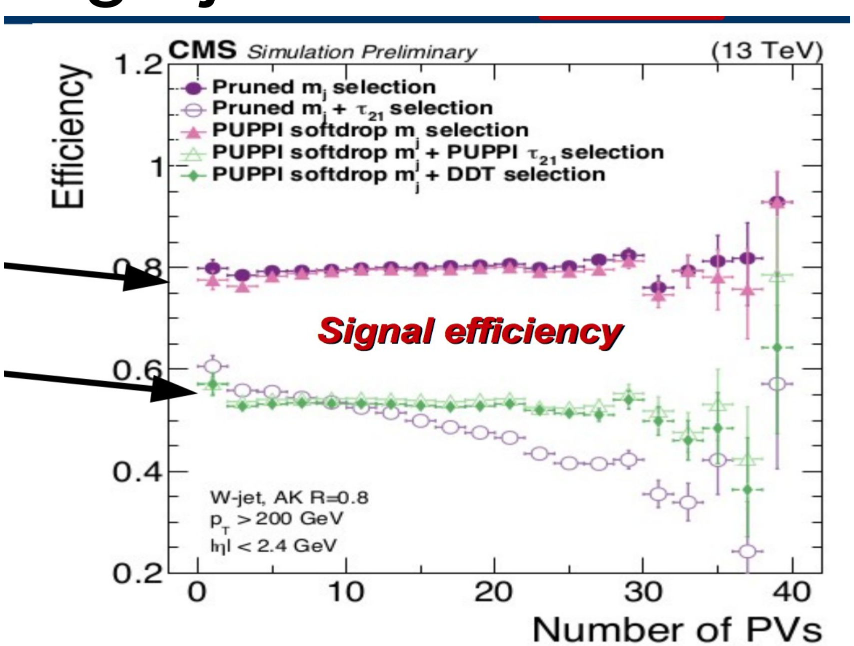
CMS

PU : ATLAS vs CMS

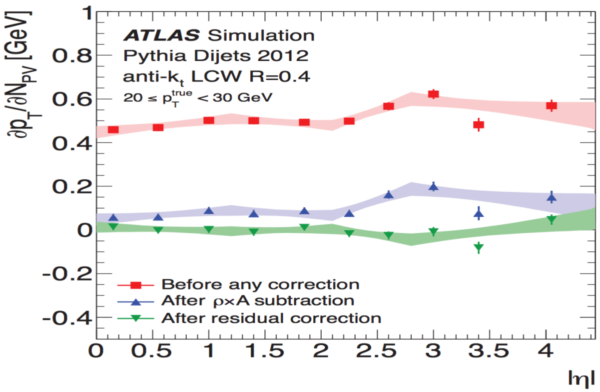
Small jets : Area sub



Large jets : PUPPI

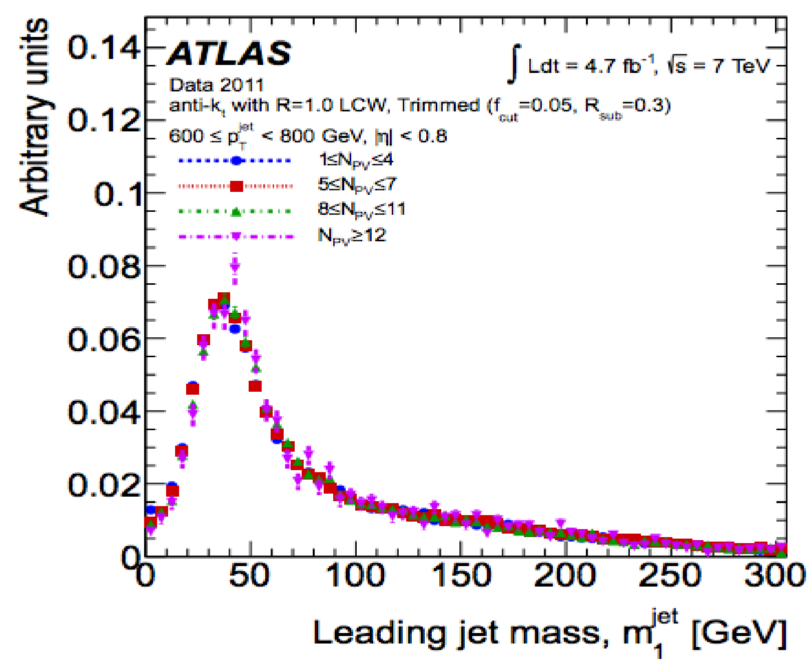


Small jets : Area subtraction



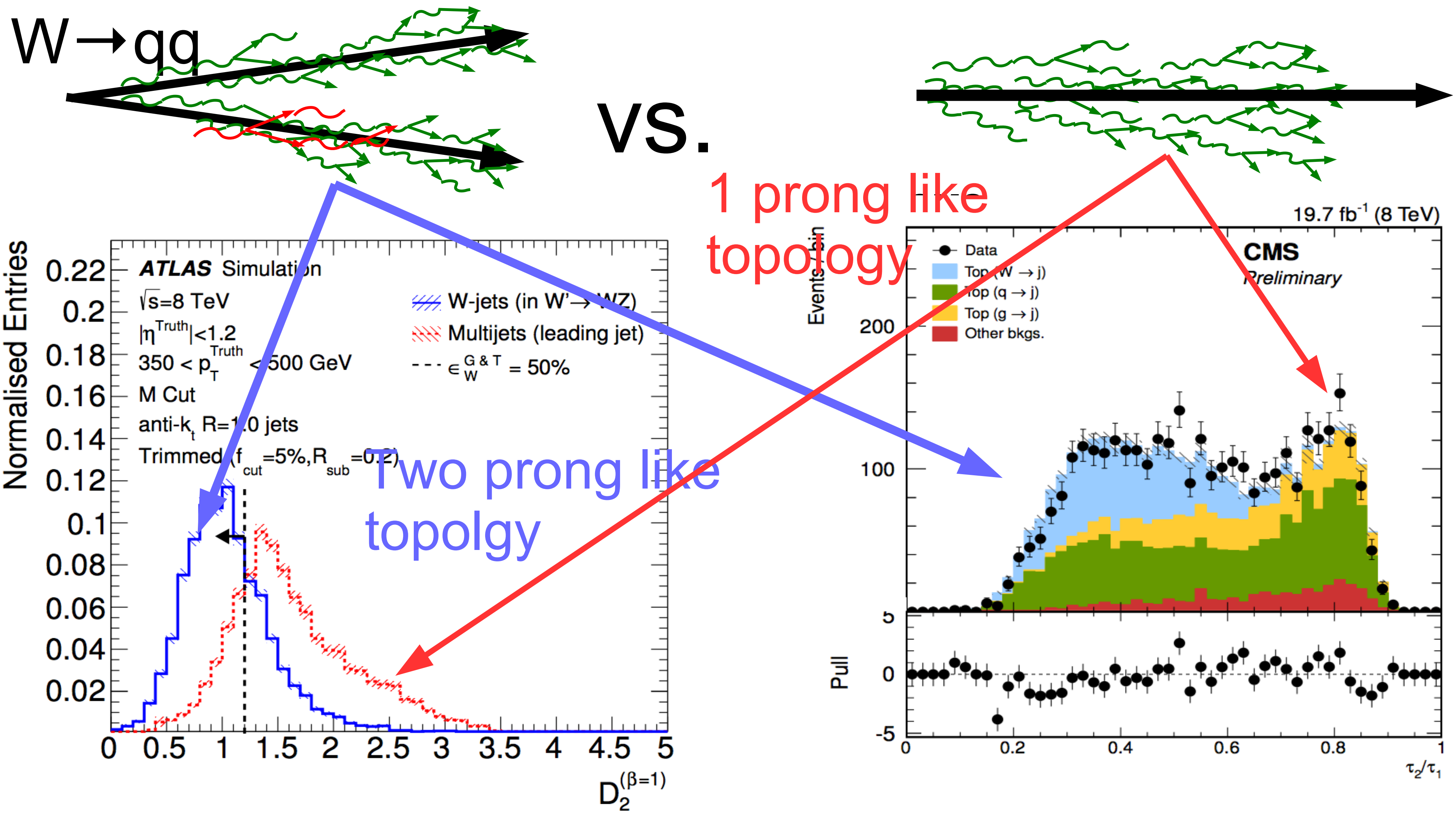
ATLAS

Fat jets : using trimming
On whole jet



Tagging

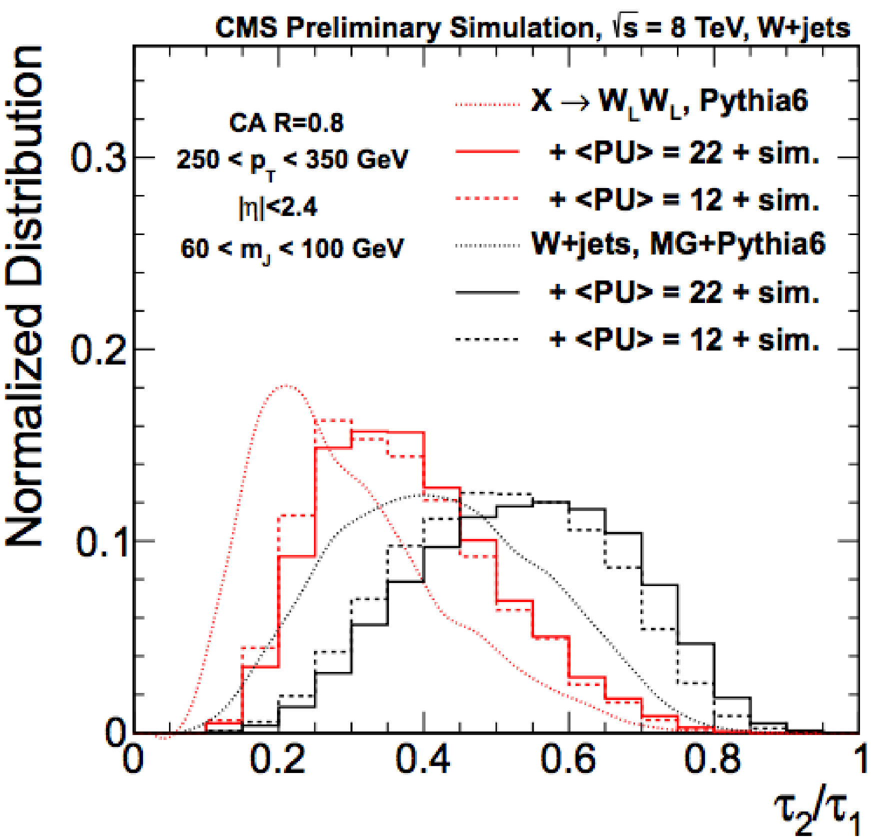
- In addition to grooming we use a tagger

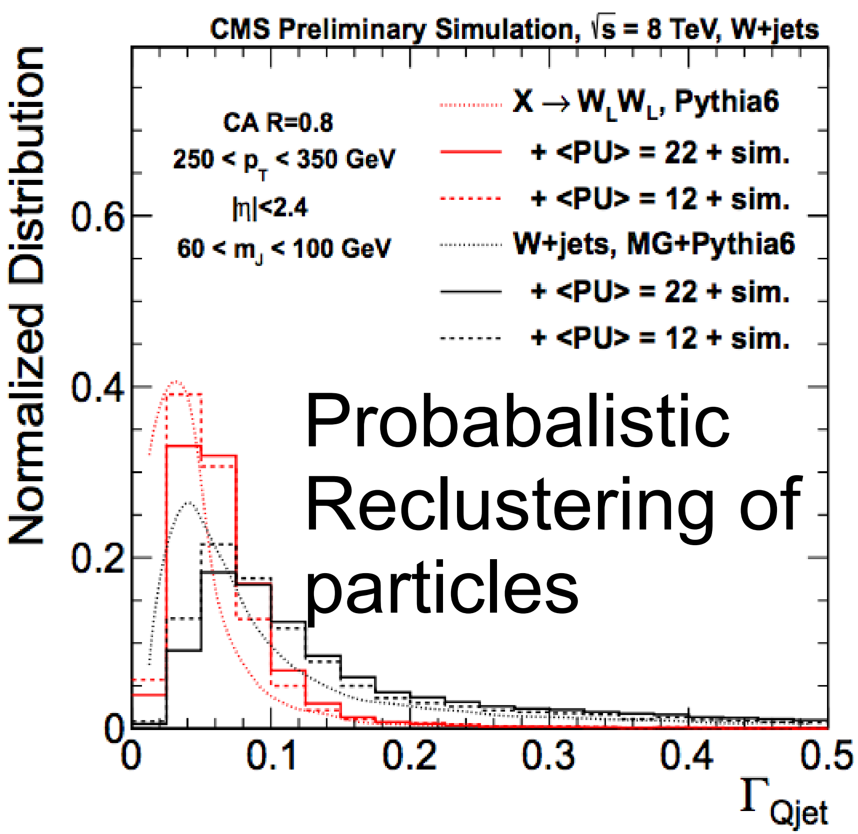


N-subjettiness/Q-Jets

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min\{\Delta R_{1,k}, \Delta R_{2,k}, \cdots, \Delta R_{N,k}\}$$

- Measures of number of prongs





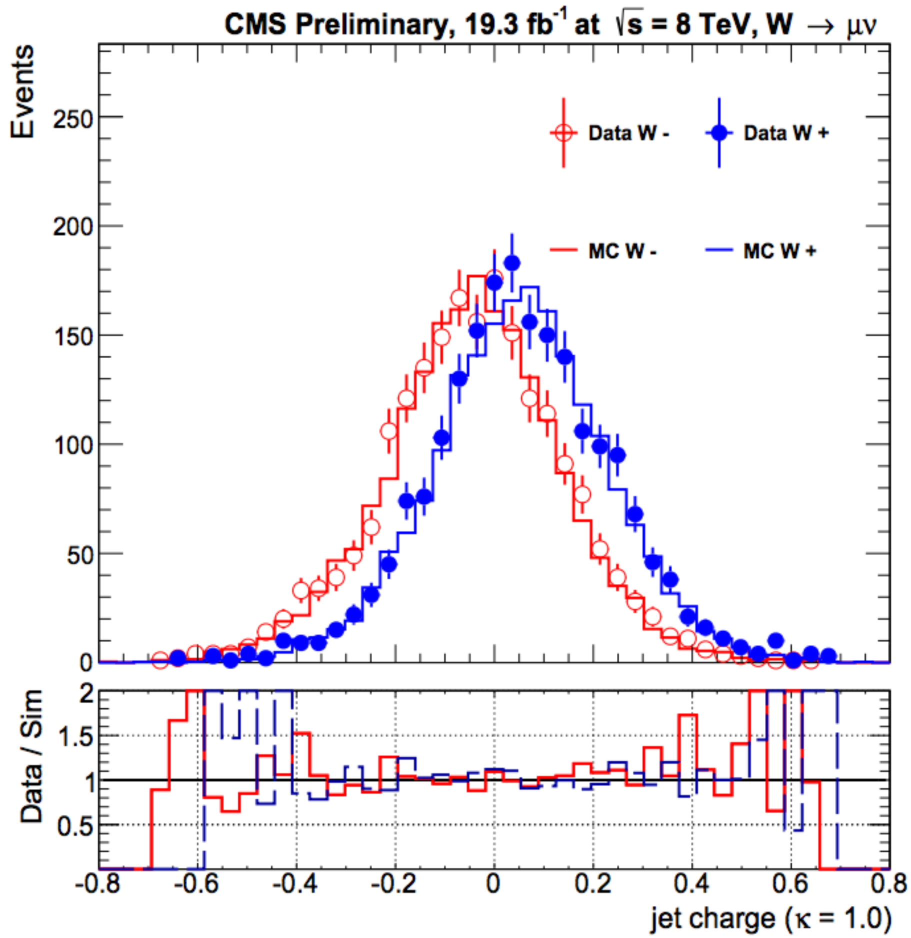
Probabalistic Reclustering of particles

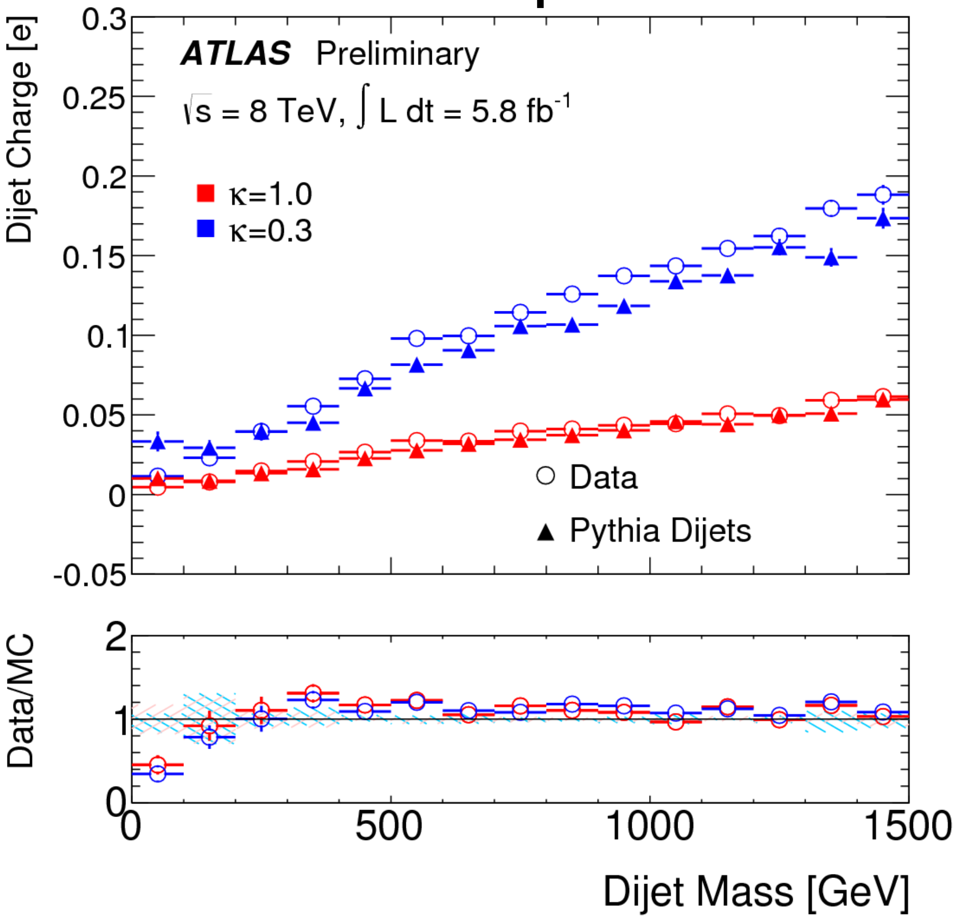
Jet Charge

$$Q^{\kappa} = \frac{\sum_i q_i (p_T^i)^{\kappa}}{(p_T^{jet})^{\kappa}}$$

- It works, but its not great :

Charge rise shows valence quarks

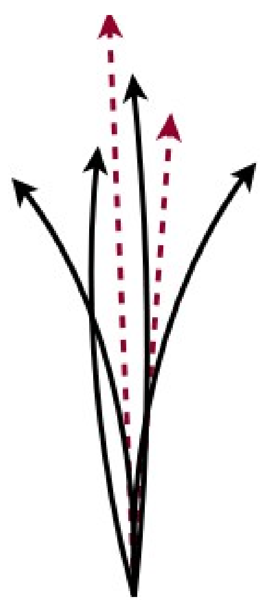




Quark Gluon Discrimination

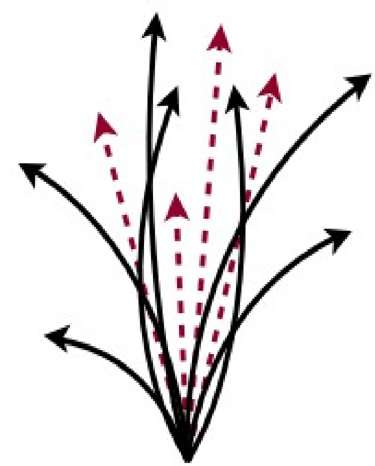
- Goal : Separate quarks and gluons
  - New technique for modeling of discriminant in data
  - Application : AK5 Jets
  - Potential application to many other approaches

Quark jets:



Narrow
Have less particles
High p_T core
Enhanced in Z/γ+jets

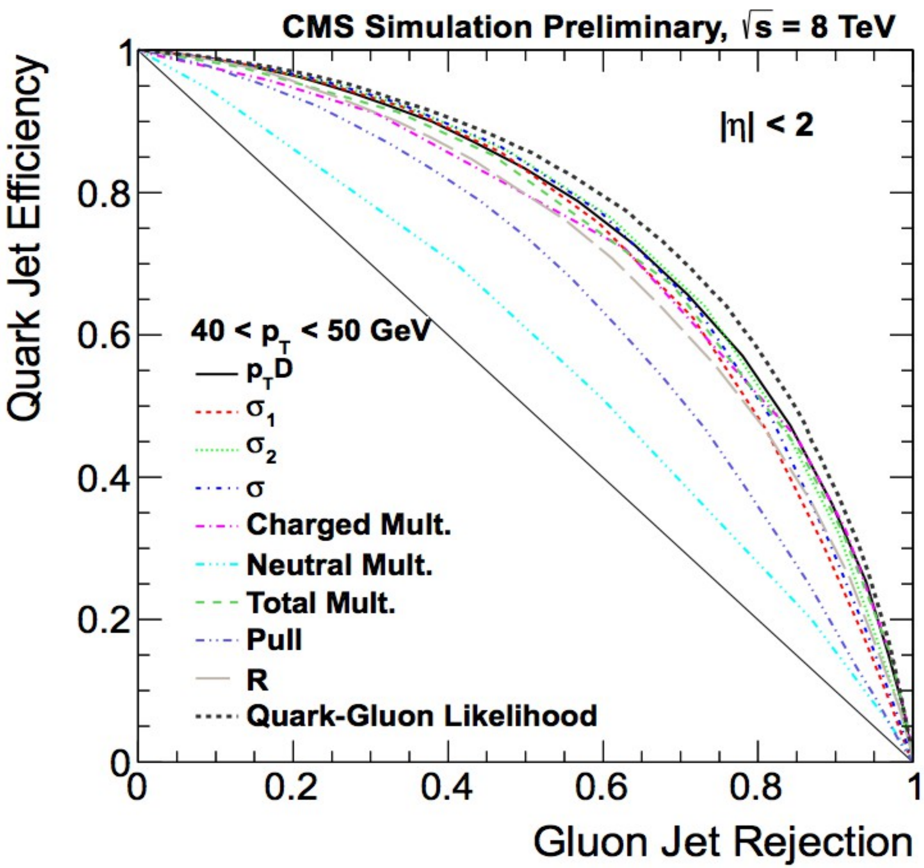
Gluon jets:

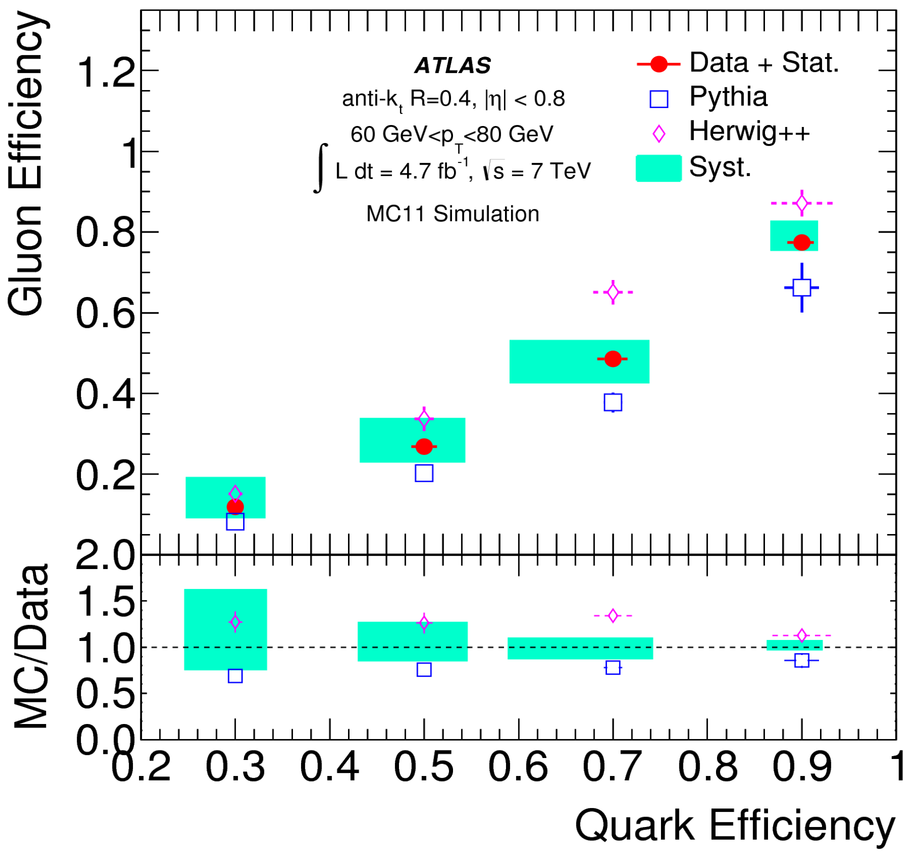


Wide
More particles
Lower p_T
Enhanced in dijet

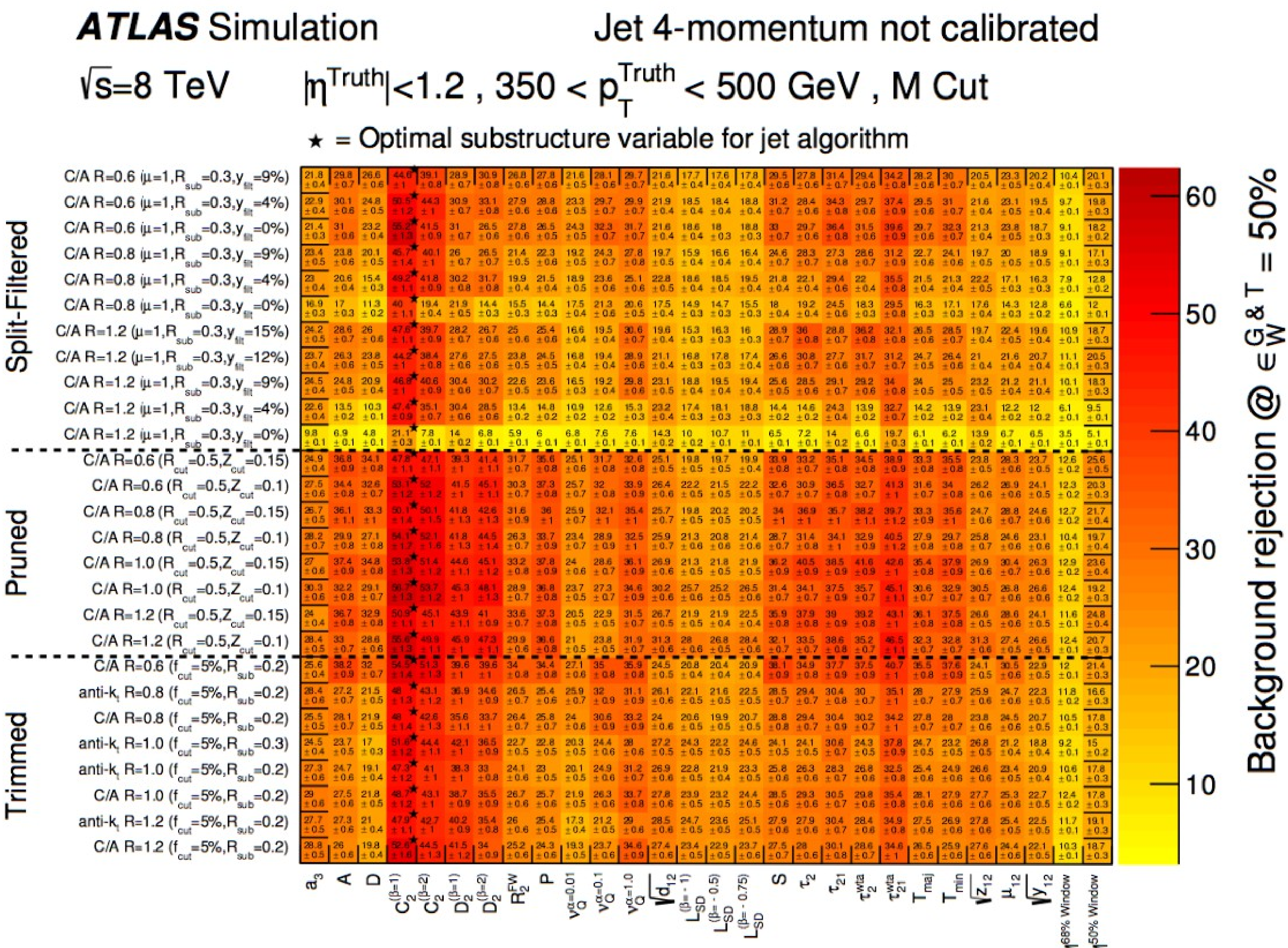
Quark Gluon Performance

- CMS has better performance
  - Gain from use of $p_T D$ variable (also not just using tracks)
  - ATLAS relies on tracks in place of all pf candidates
    - Also maintain large uncertainties from generator differences



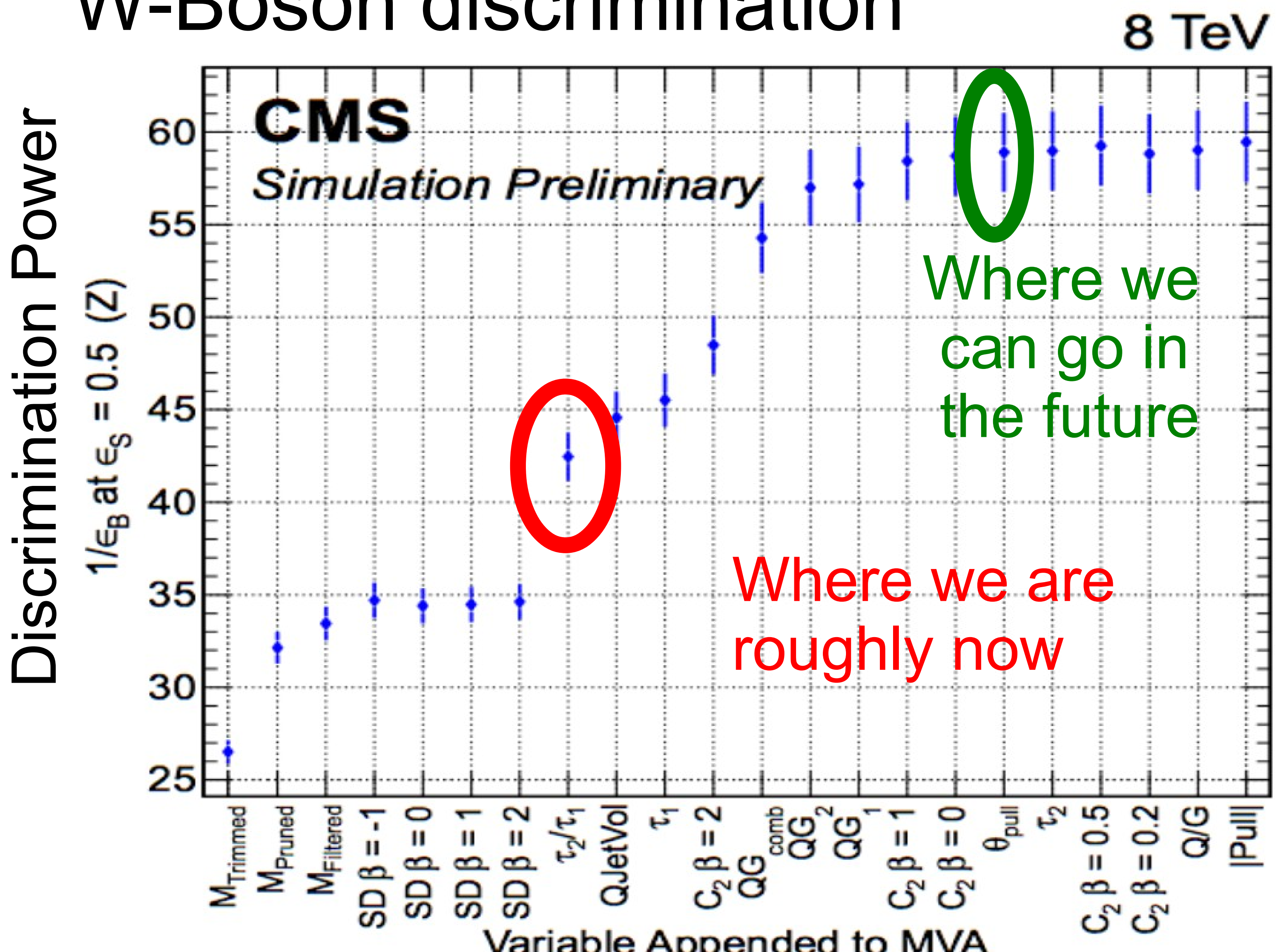


How did we scan these?



Pushing it to the Limits

W-Boson discrimination



We are not even done with ideas yet!

Executive Summary for W-tagging

- CMS :
  - Past : Pruning + τ_2/τ_1
  - Present : Soft Drop + PUPPI + $\tau_2/\tau_1^{(DDT)}$
- ATLAS :
  - Past : Trimmed Mass + $\sqrt{y_{12}}$
  - Present : Trimmed Mass + Smoothed D_2+Variable R
- Both are commissioned on data
  - Mass scale and efficiency

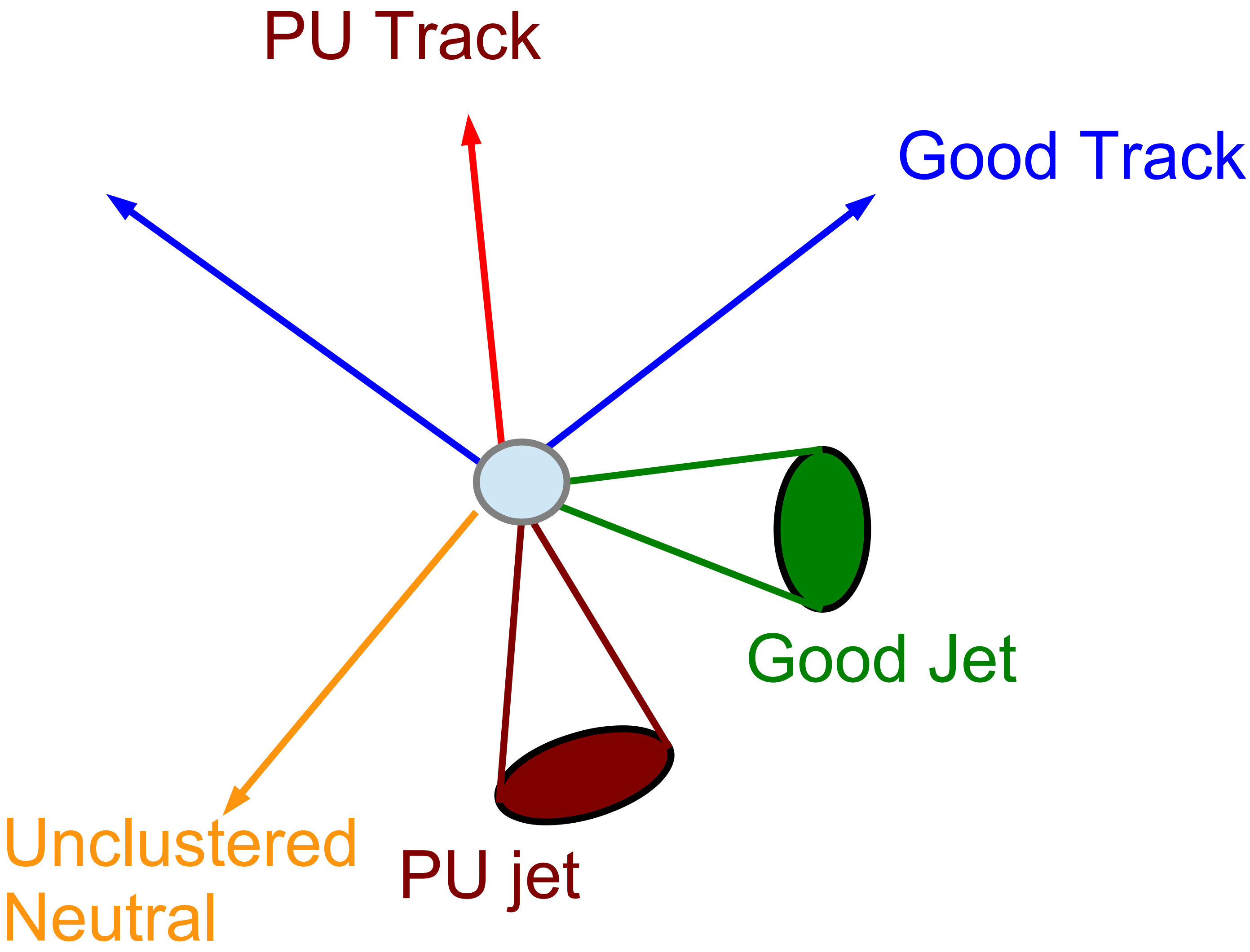
Executive Summary for Top tagging

- CMS :
  - Past : Mass + CMS/HEP Top Tagger
  - Present : Soft Drop + PUPPI + τ_3/τ_2 + subjet b-tag
- ATLAS :
  - Past : Trimmed Mass + $\sqrt{d_{12}}$
  - Present : Trimmed Mass +τ_3/τ_2 + b-tag (MV2C)
- Both are commissioned on data
  - Mass scale and resolution (ATLAS)

Pileup outside of jets

Lets look at objects outside of the jet!

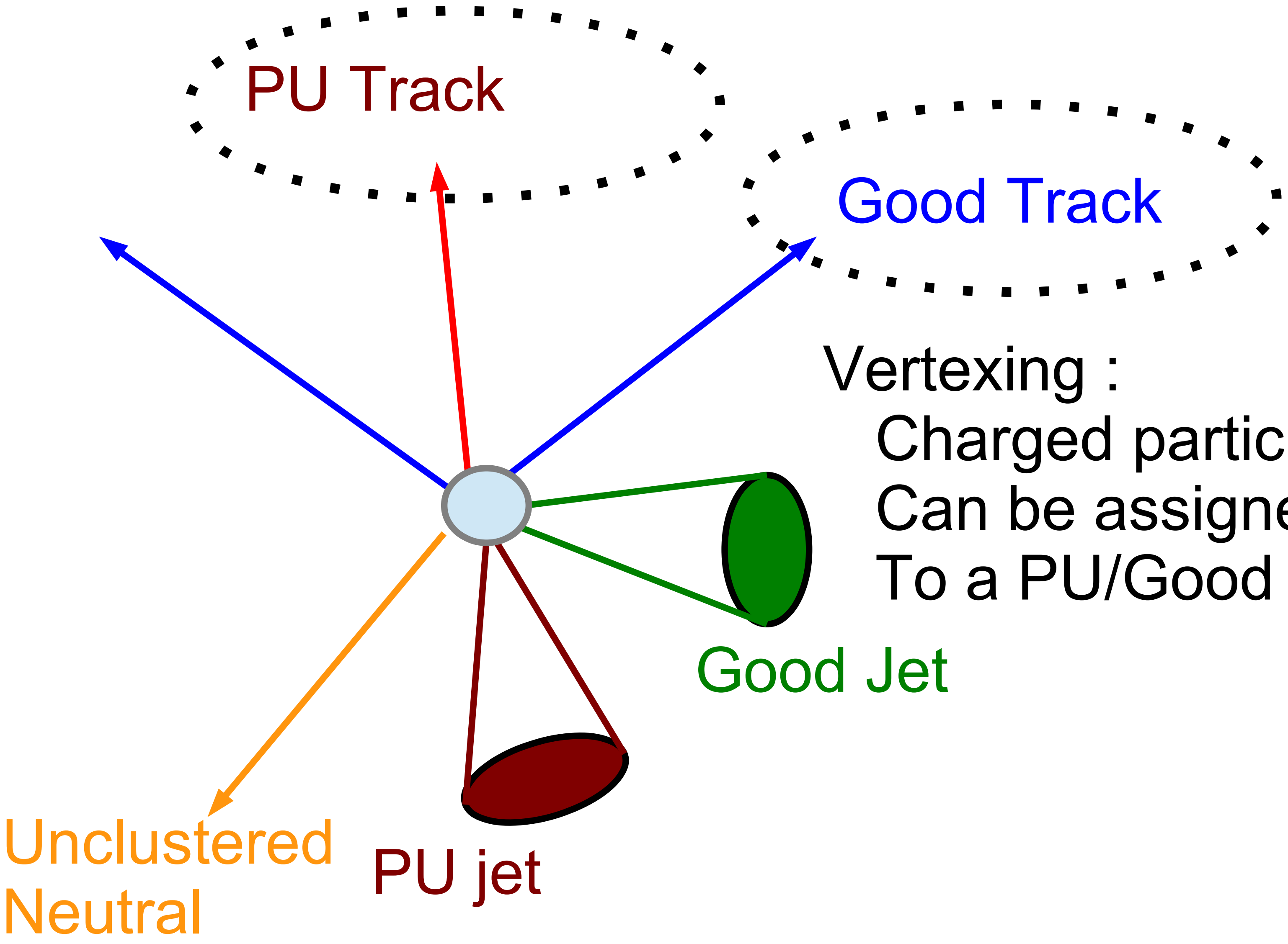
Pileup in the Event



Simplified event can be decomposed into 5 different objects

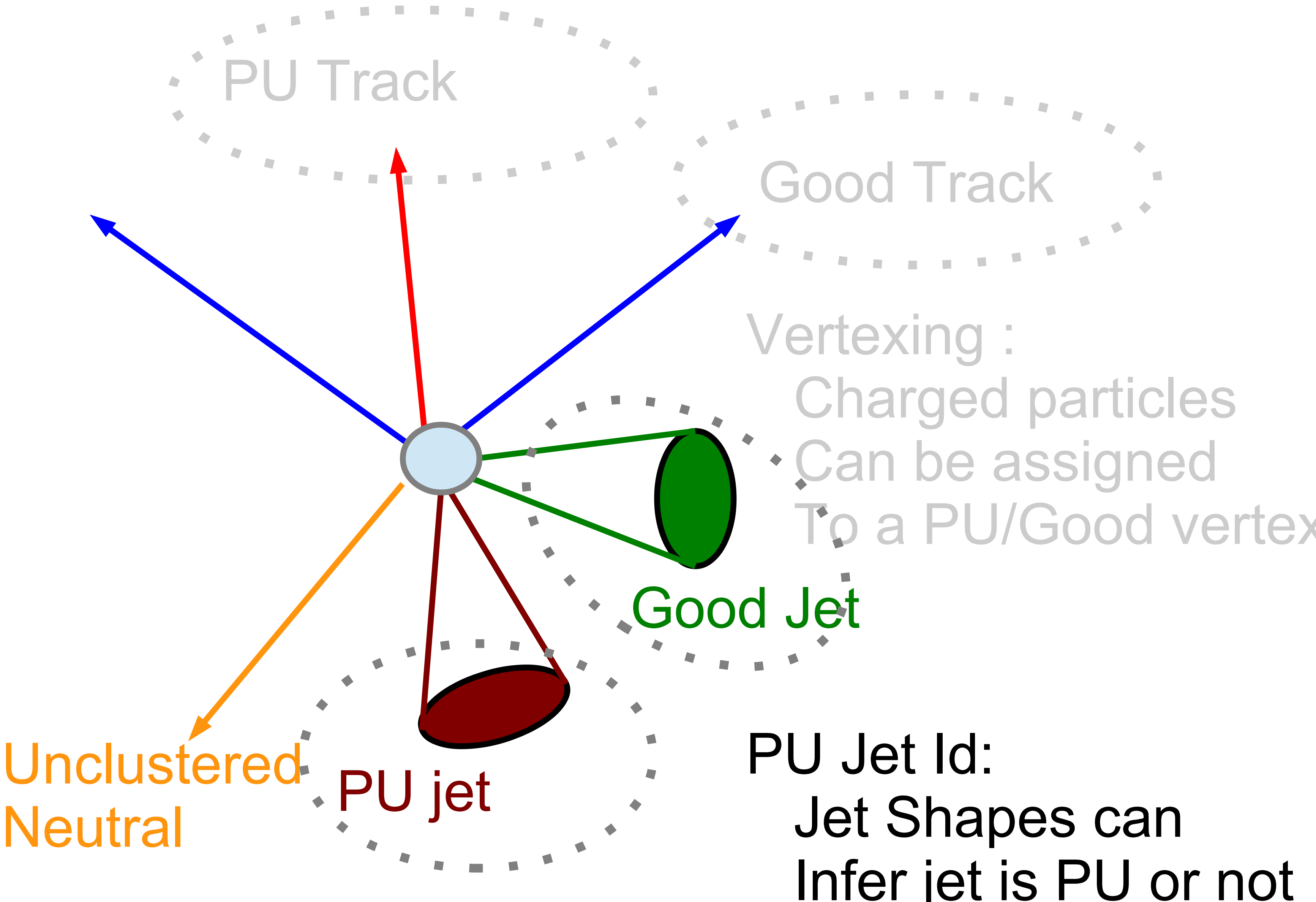
We have tools to go after all

Pileup in the Event



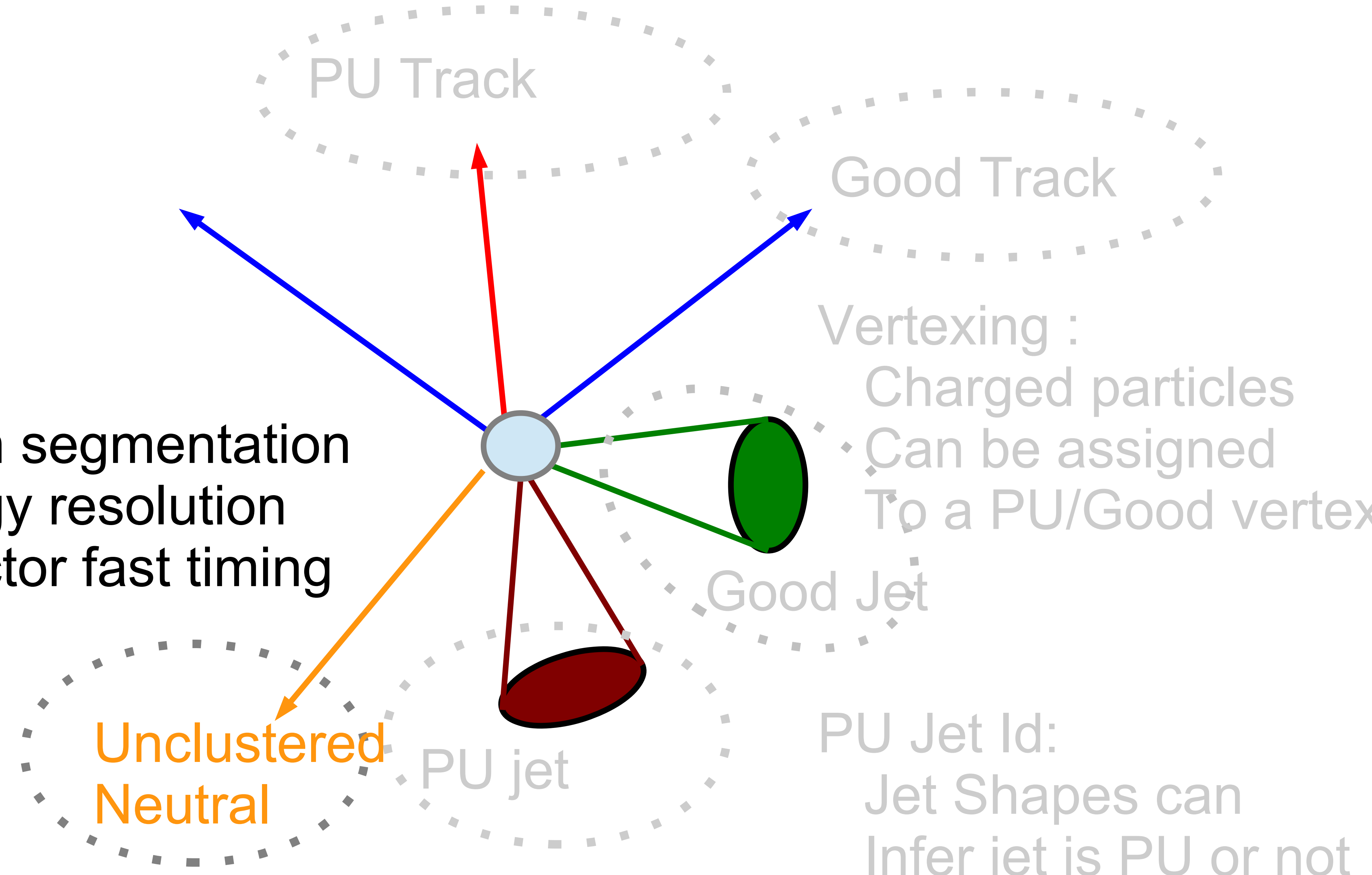
Vertexing :
Charged particles
Can be assigned
To a PU/Good vertex

Pileup in the Event



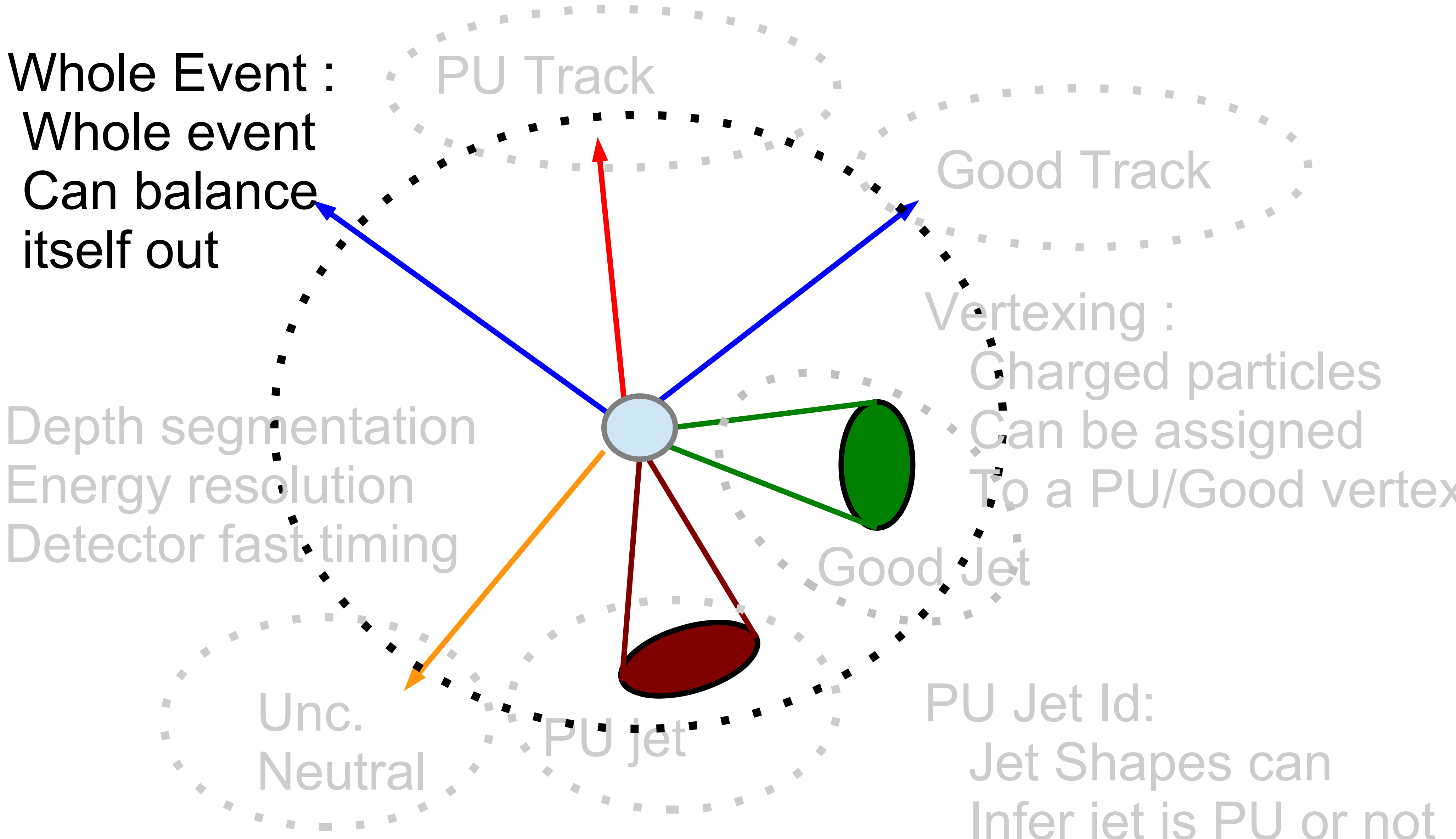
Pileup In the Event

Depth segmentation
Energy resolution
Detector fast timing



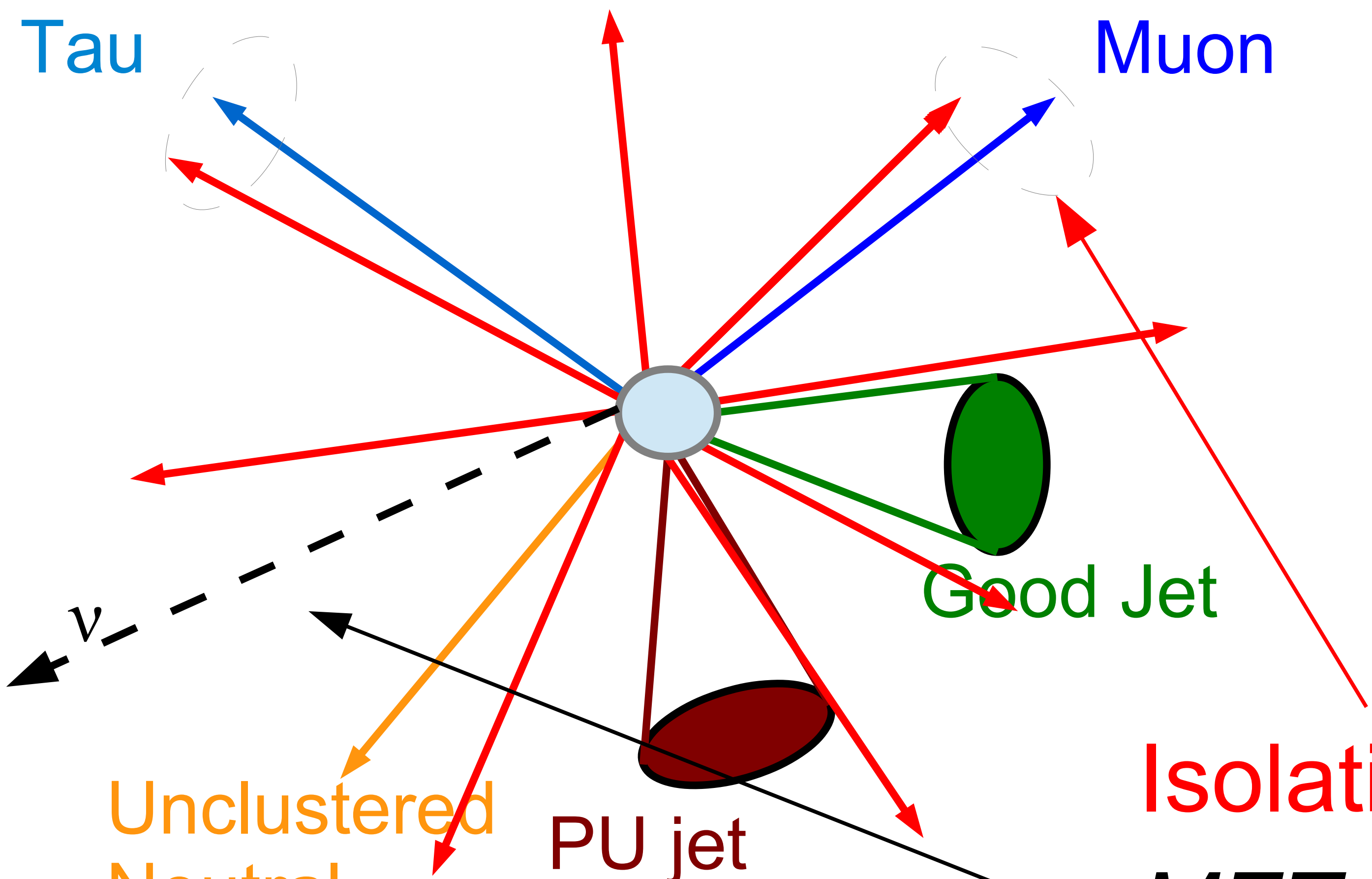
Pileup In the Event

Whole Event :
Whole event
Can balance
itself out



Puppi affects everything

- It does not just work on jets!



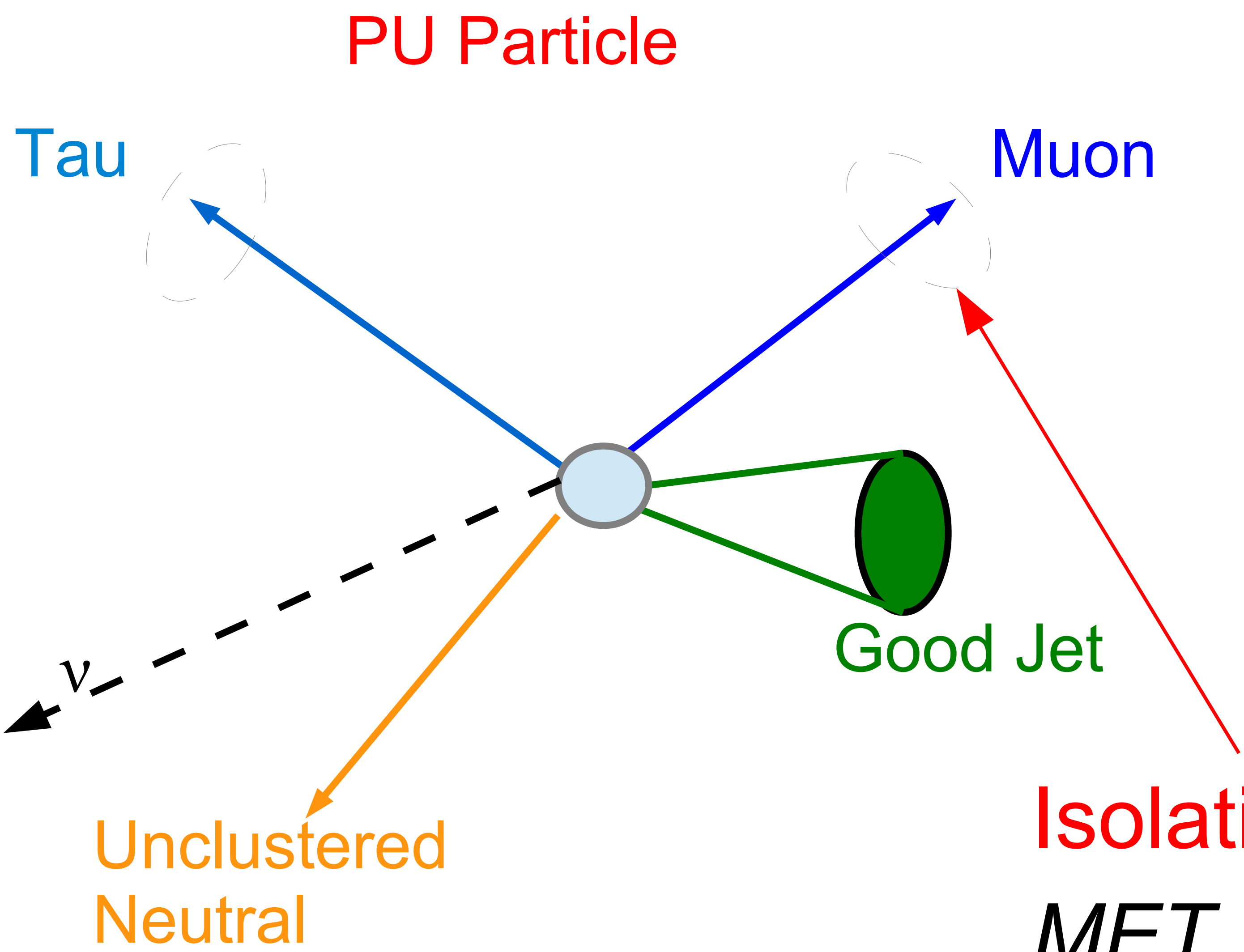
Isolation = $\Sigma_{\Delta R} p_T$

MET = $-\Sigma \vec{p}_T$

SUMET = Σp_T

Puppi affects everything

- It does not just work on jets!



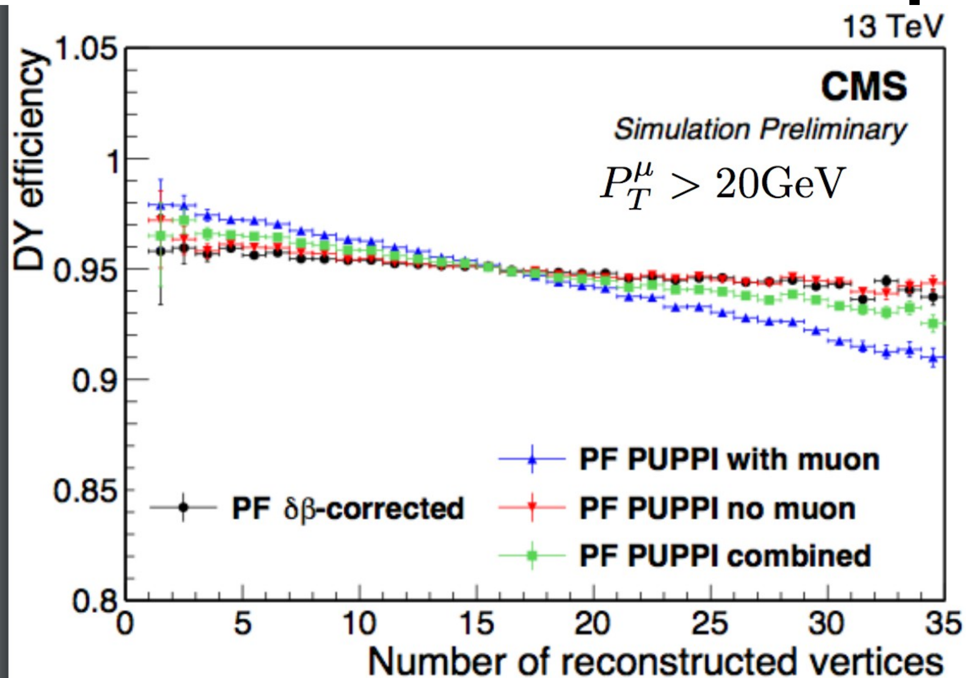
Apply the Puppi Weights w

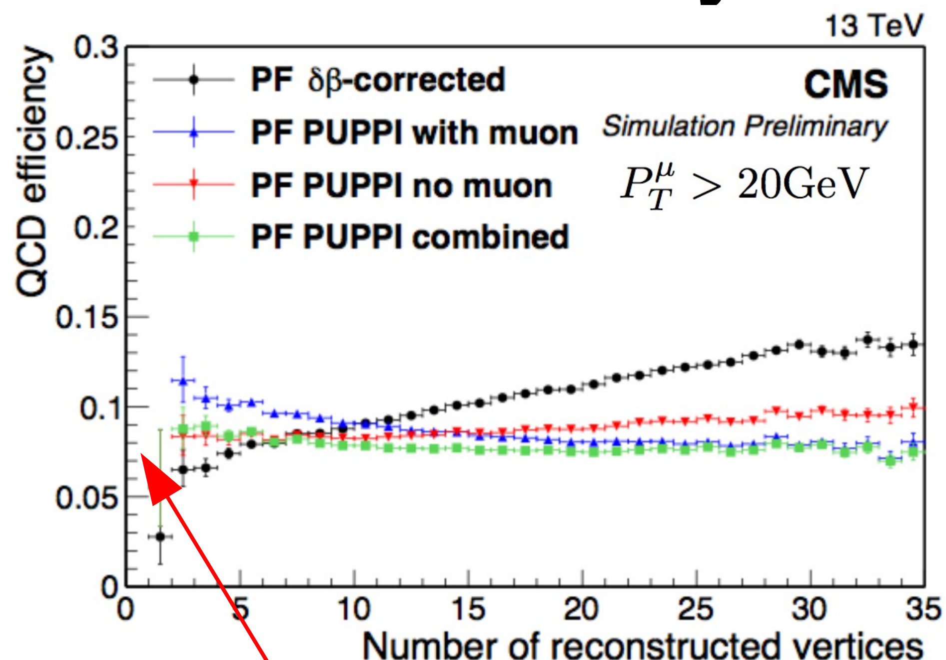
Isolation = $\Sigma_{\Delta R} p_T w$

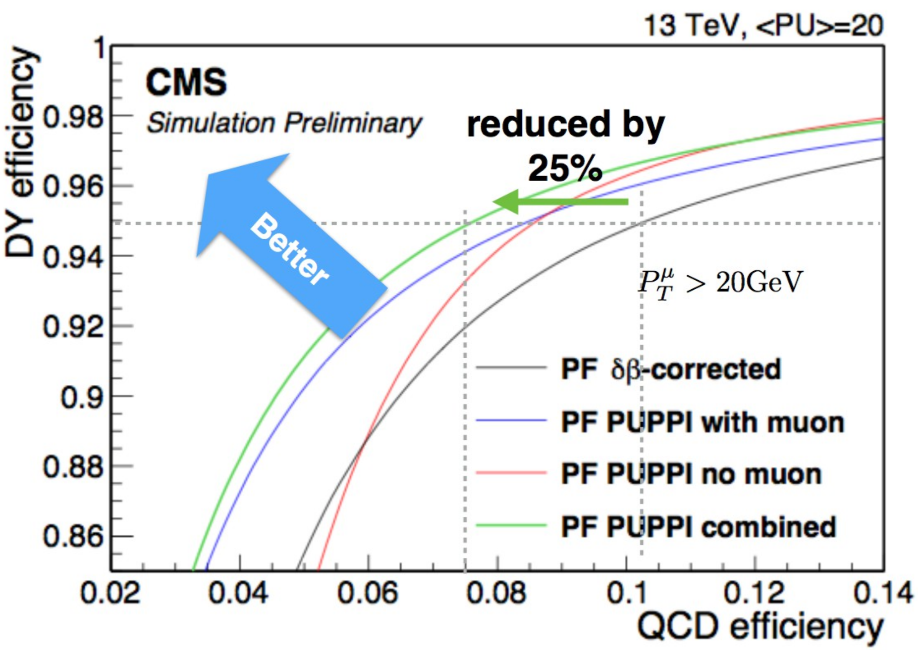
$MET = -\Sigma \vec{p}_T w$

$SUMET = \Sigma p_T w$

Puppi affects everything







Apply the Puppi Weights w

Isolation = $\Sigma_{\Delta R} p_T w$

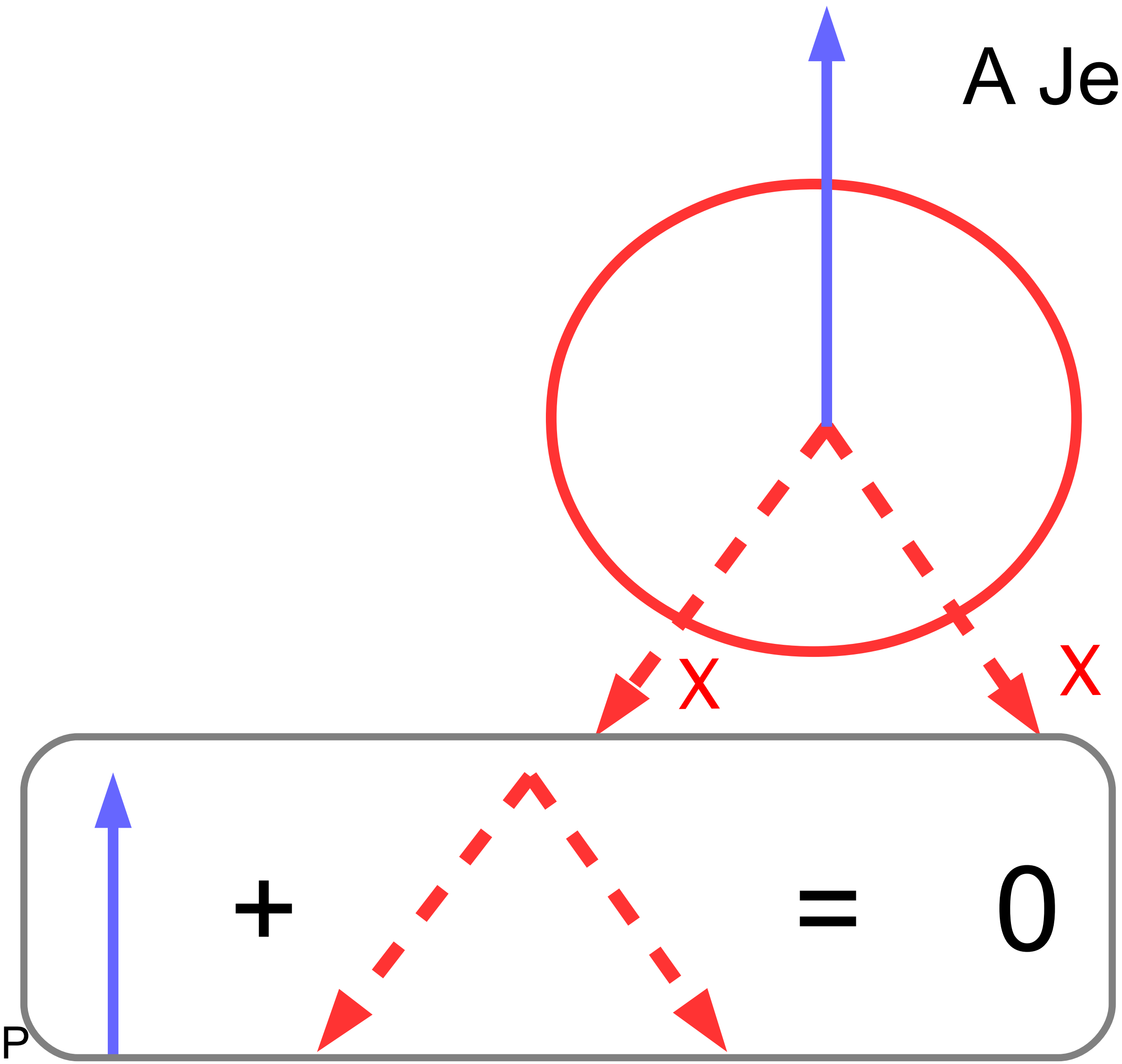
MET = $-\Sigma \vec{p}_T w$

SUMET = $\Sigma p_T w$

MET

To see nothing you have to reconstruct everything*

A Jet (+other particles)



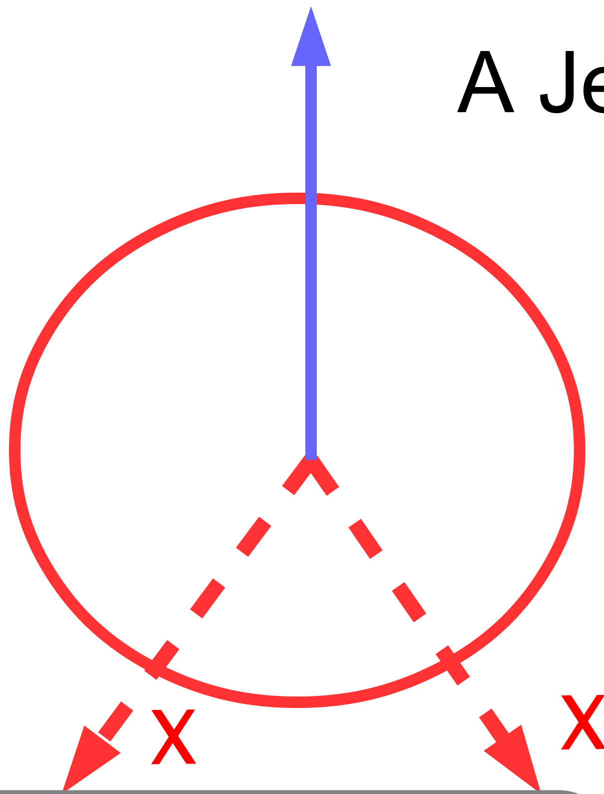
Invisible Particles

Conservation of transverse energy

*TDP

MET

To see nothing you have to reconstruct everything*



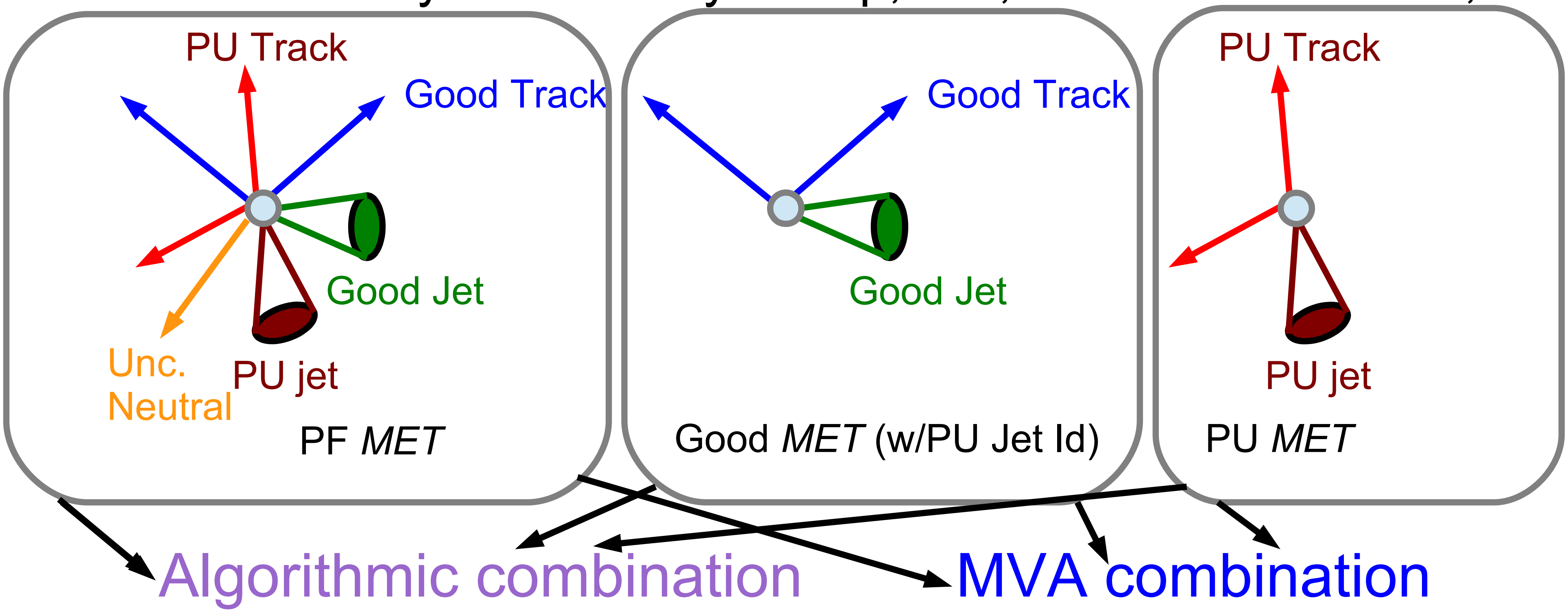
$$-\Sigma_{All\ particles}\ \vec{p}_T = \overrightarrow{MET}_{(E_T^{Miss})}$$

Conservation of transverse energy

*TDP

Garbage Collection: PU Reduced *METs*

- *MET* is effectively summing up all the trash
  - PU Reduced *METs* Equivalent to Recycling
    - Sorting your garbage by Metals/Plastics/Paper
    - Sort your event by Pileup,Jets,unclustered Neutral, tracks

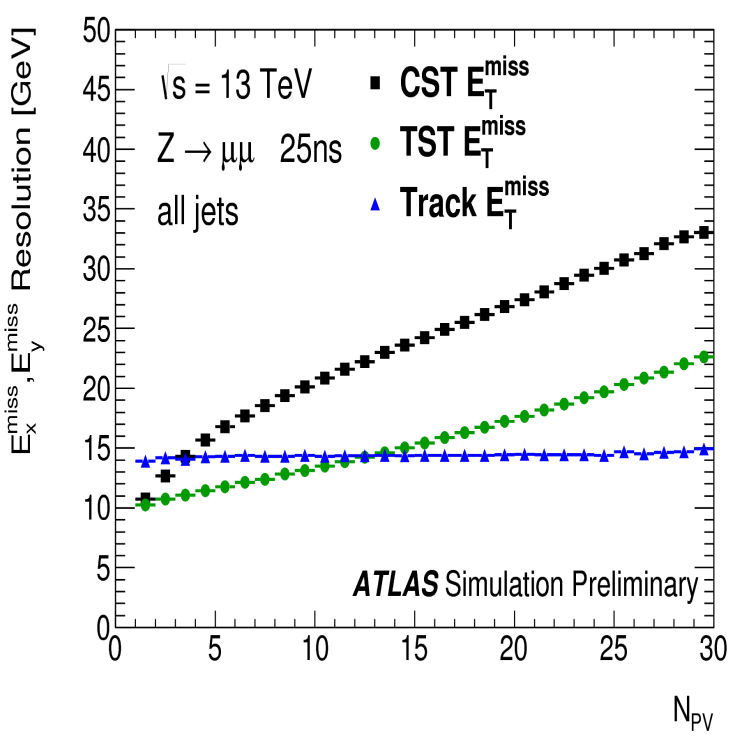


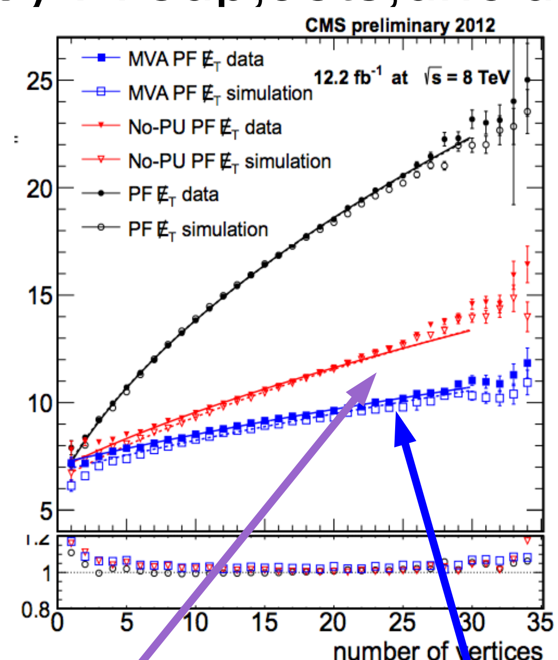
Combine all of the estimates into one best estimate

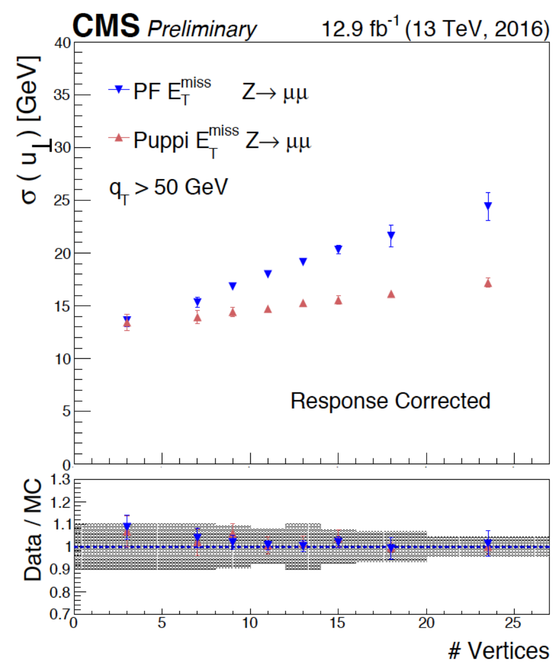
There is no perfect way to remove objects from the *MET*

Garbage Collection: PU Reduced *METs*

- *MET* is effectively summing up all the trash
  - PU Reduced *METs* Equivalent to Recycling
    - Sorting your garbage by Metals/Plastics/Paper
    - Sort your event by Pileup,Jets,unclustered Neutral, tracks







bination

MVA combination

Combine all of the estimates into one best estimate

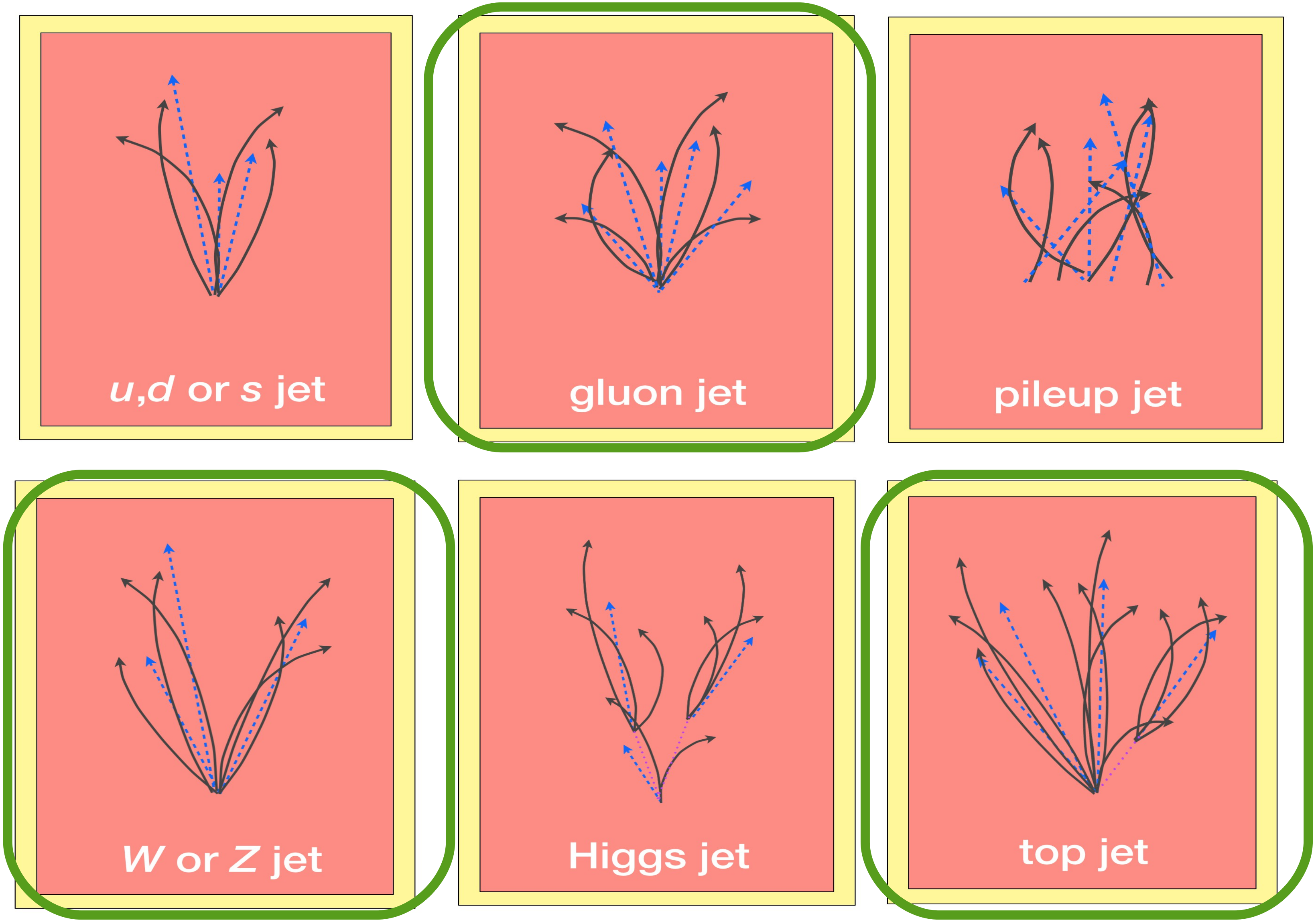
There is no perfect way to remove objects from the *MET*


THE MYSTERY FACE GAME • LE JEU DU PERSONNAGE MYSTERE
EL JUEGO DE LA CARA MISTERIOSA
6+
GUESS
WHO
?
GUESS WHO?

Guess the Jet by asking questions?*

*Concept by N. Tran

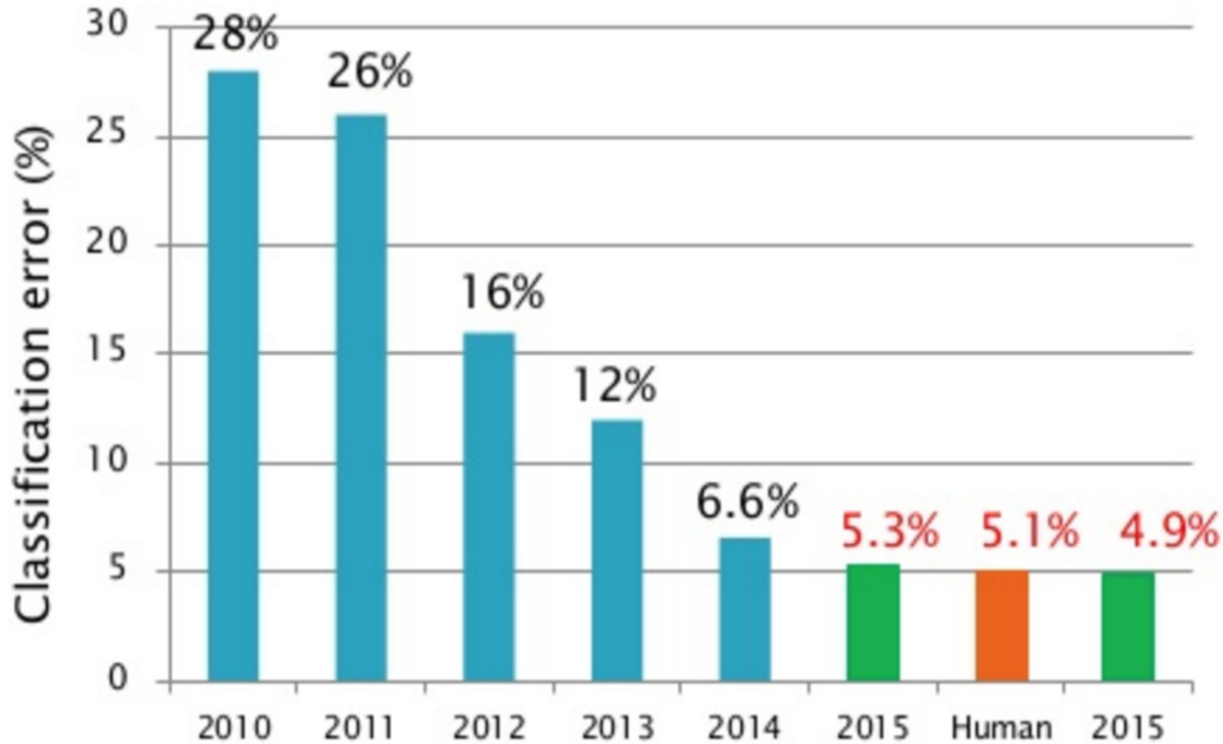
What are you options?



*Concept by N. Tran

We will just use the 3 in green

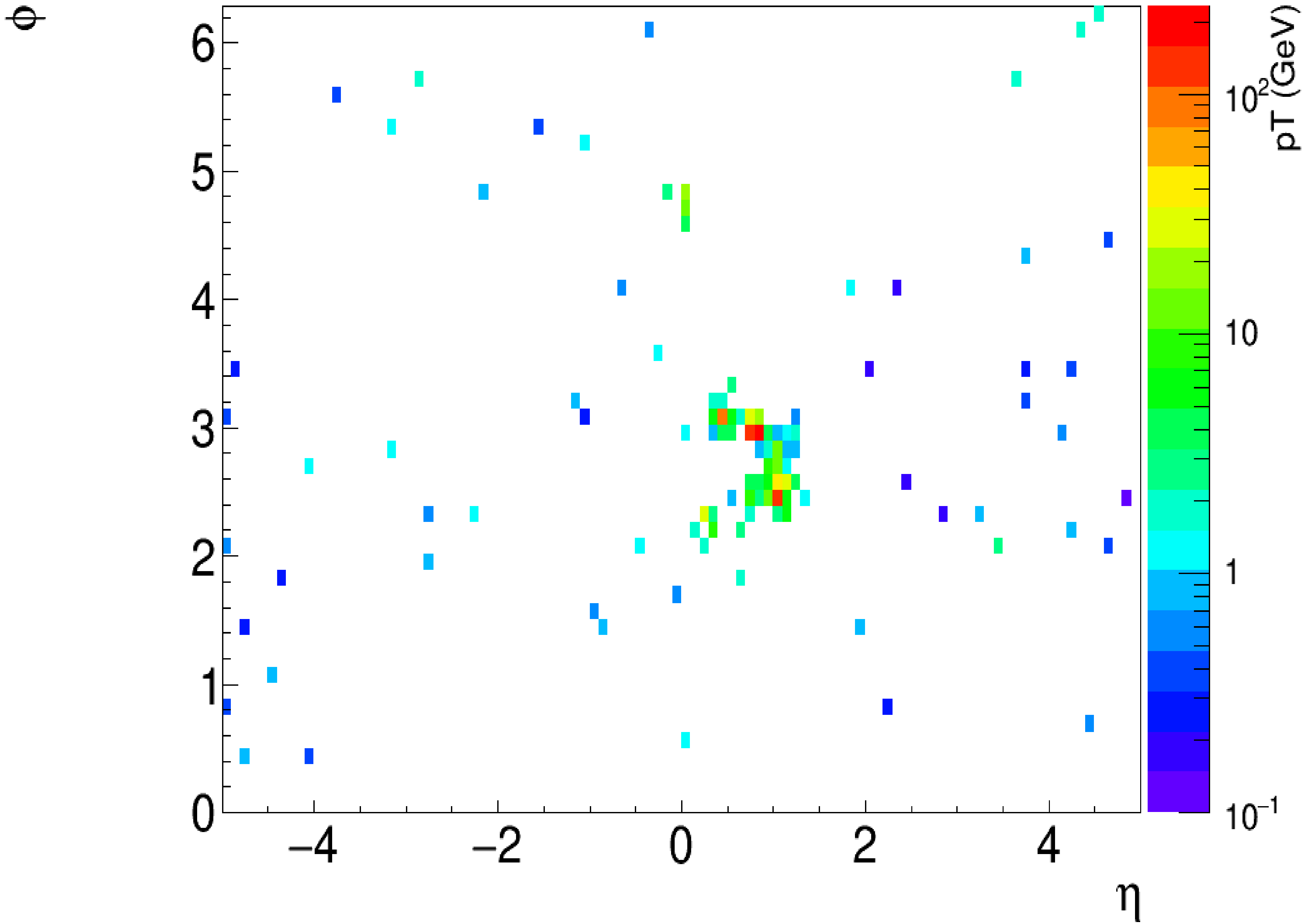
Deep Learning for Image Recognition

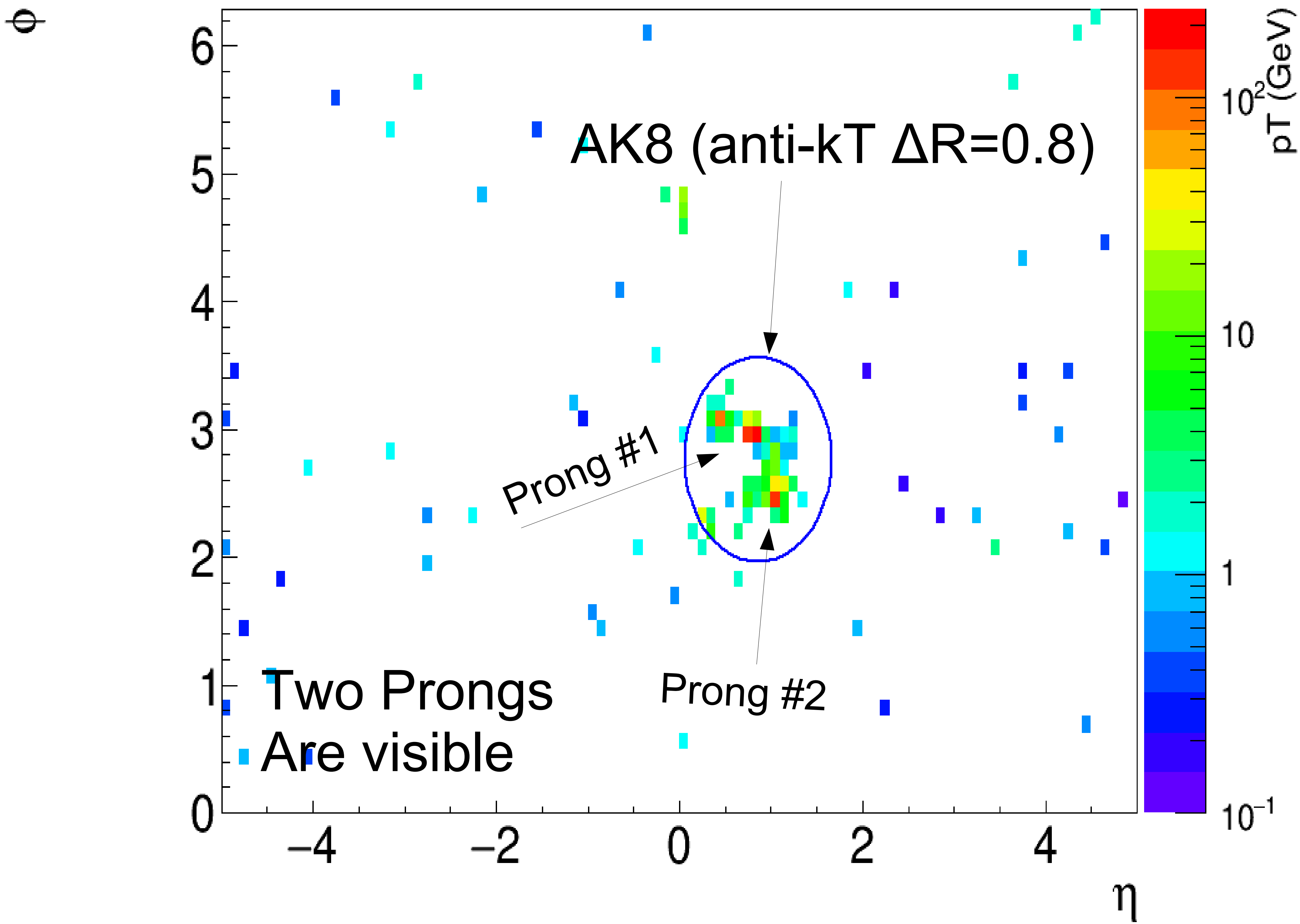


*Michael Kagan's slides (Yesterday)

Start @ 0 PU

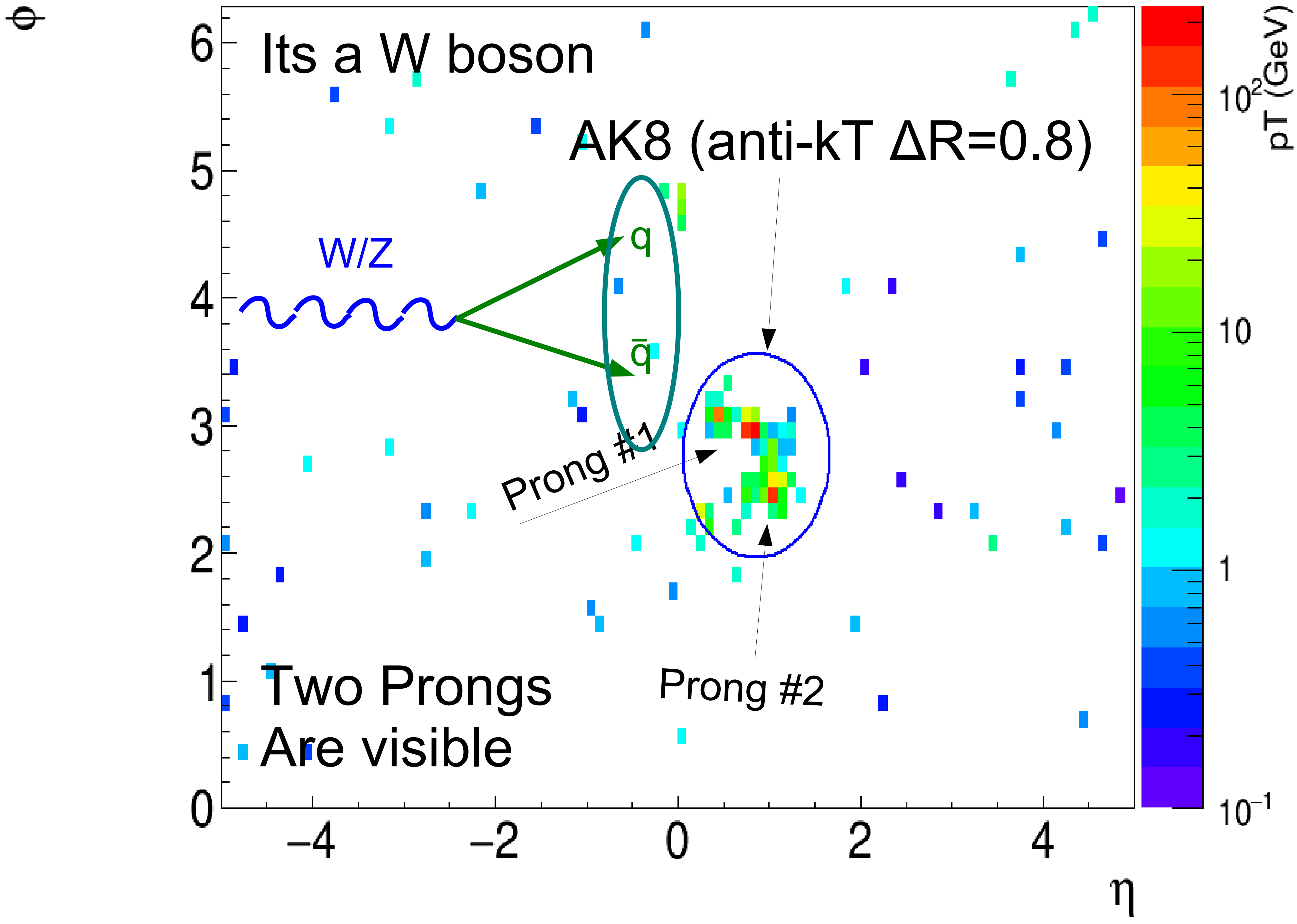
What is it?





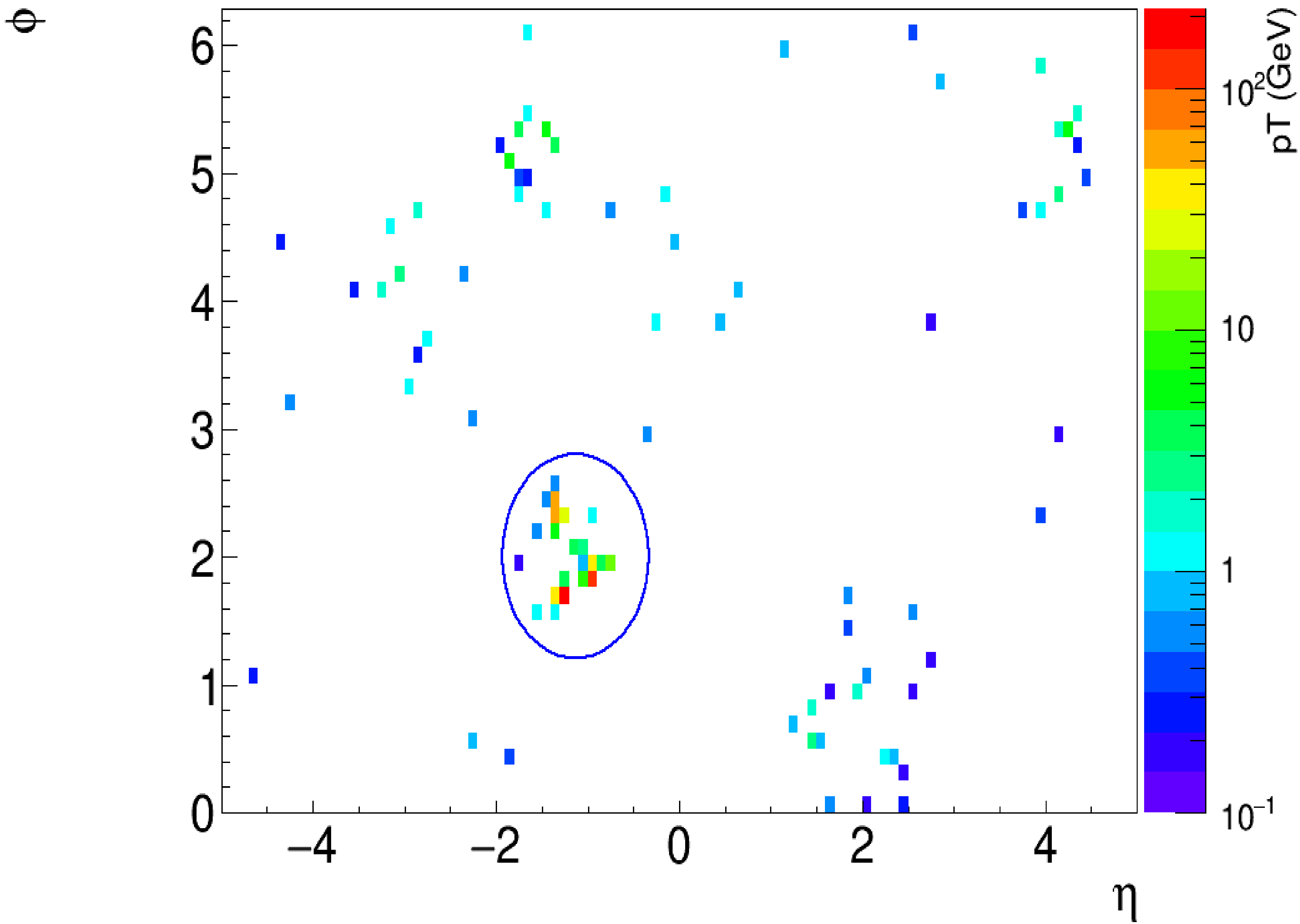
ϕ
AK8 (anti-kT ΔR=0.8)
Prong #1
Prong #2
Two Prongs
Are visible
η
pT (GeV)

What is it?

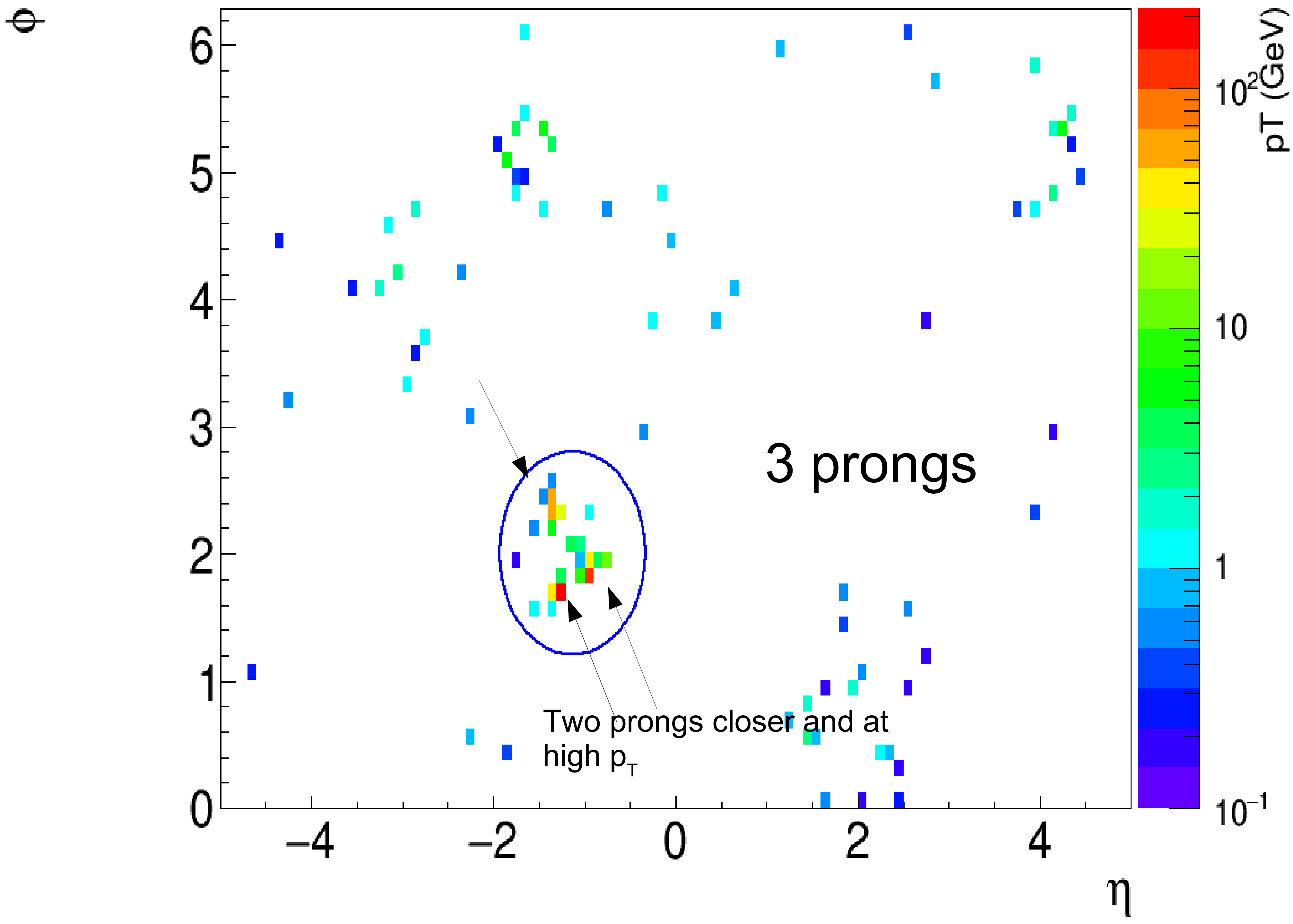


Its a W boson
AK8 (anti-kT ΔR=0.8)
W/Z
q
q̄
Prong #1
Prong #2
Two Prongs
Are visible
φ
η
pT (GeV)

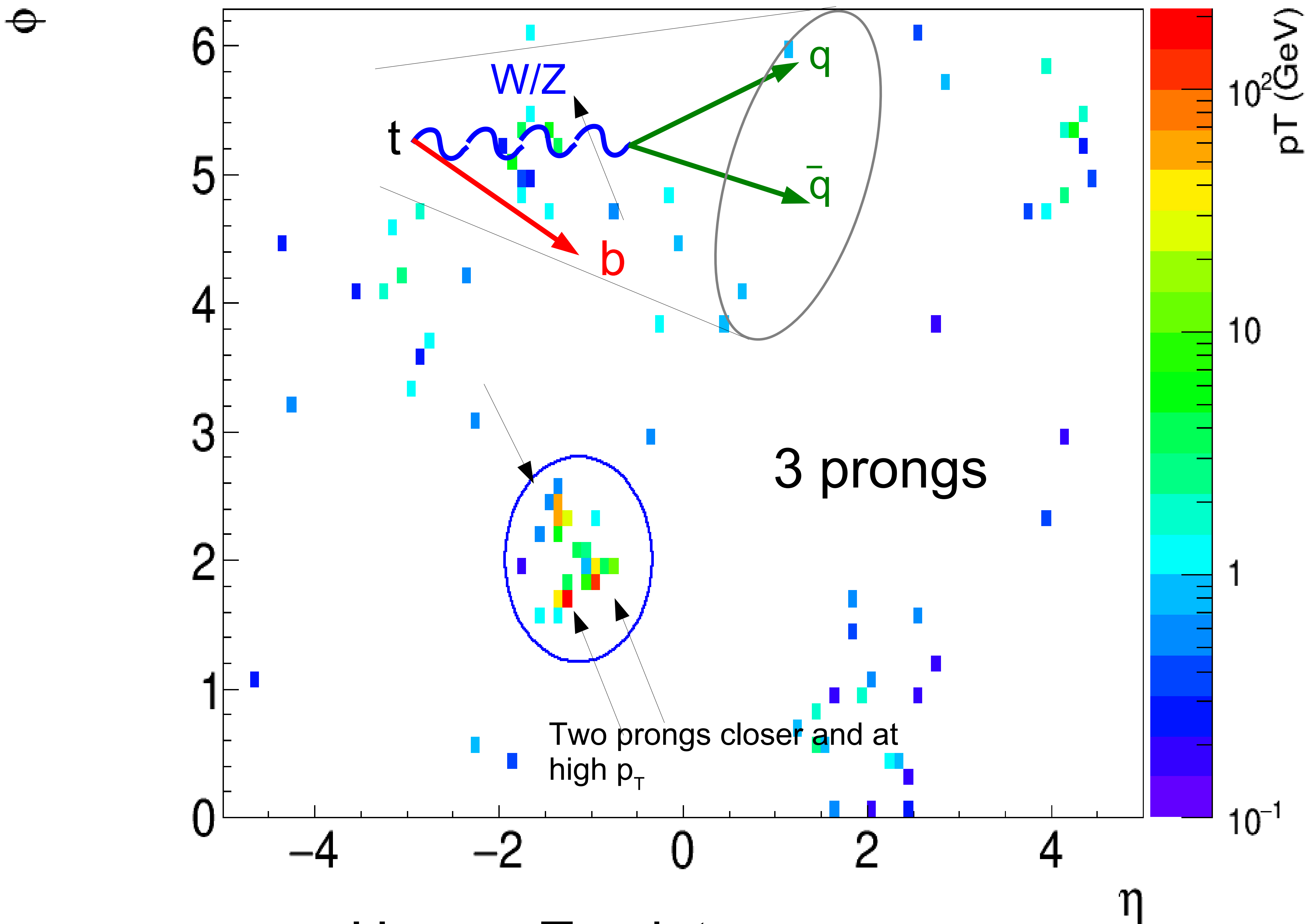
What is it?



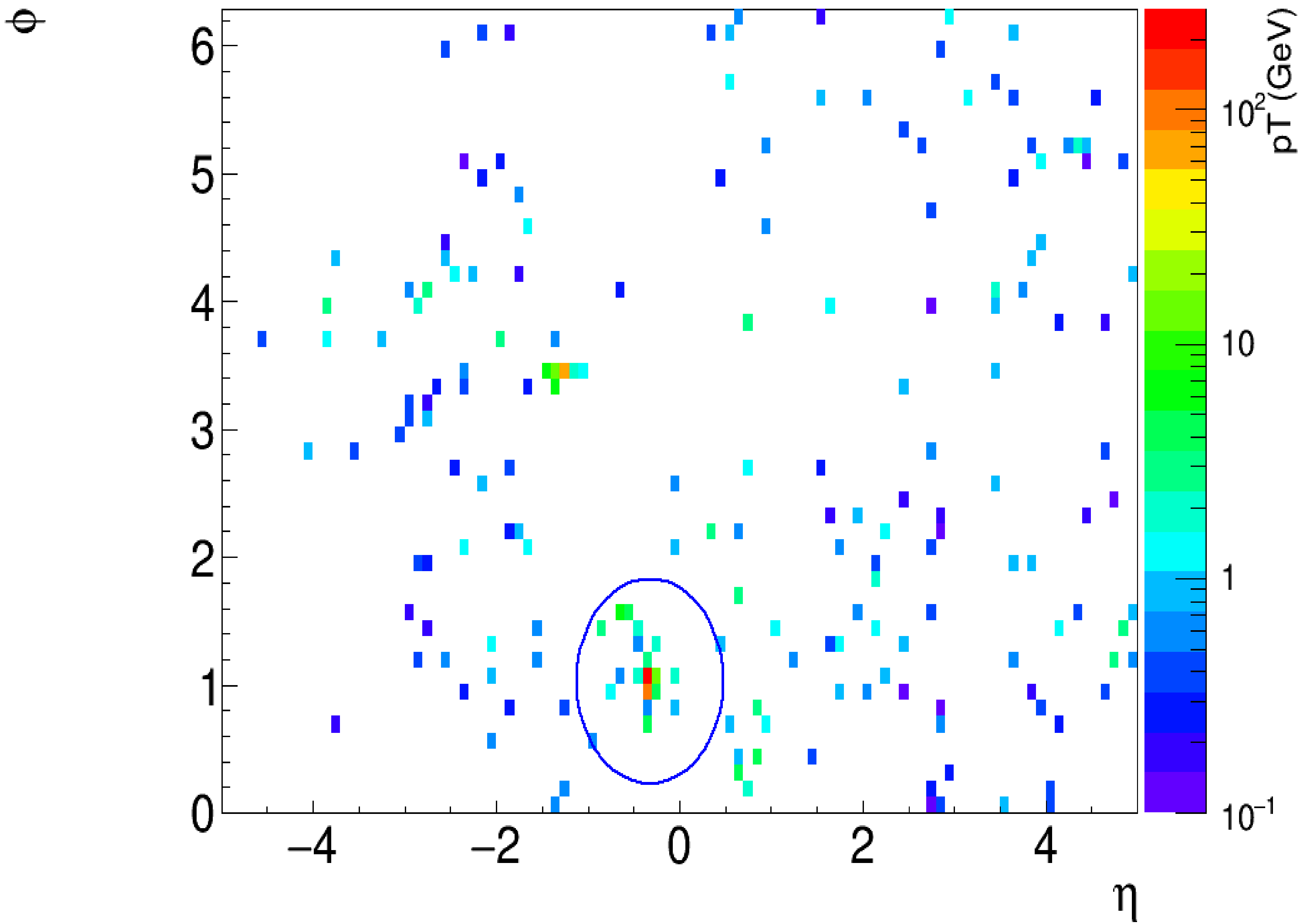
What is it?



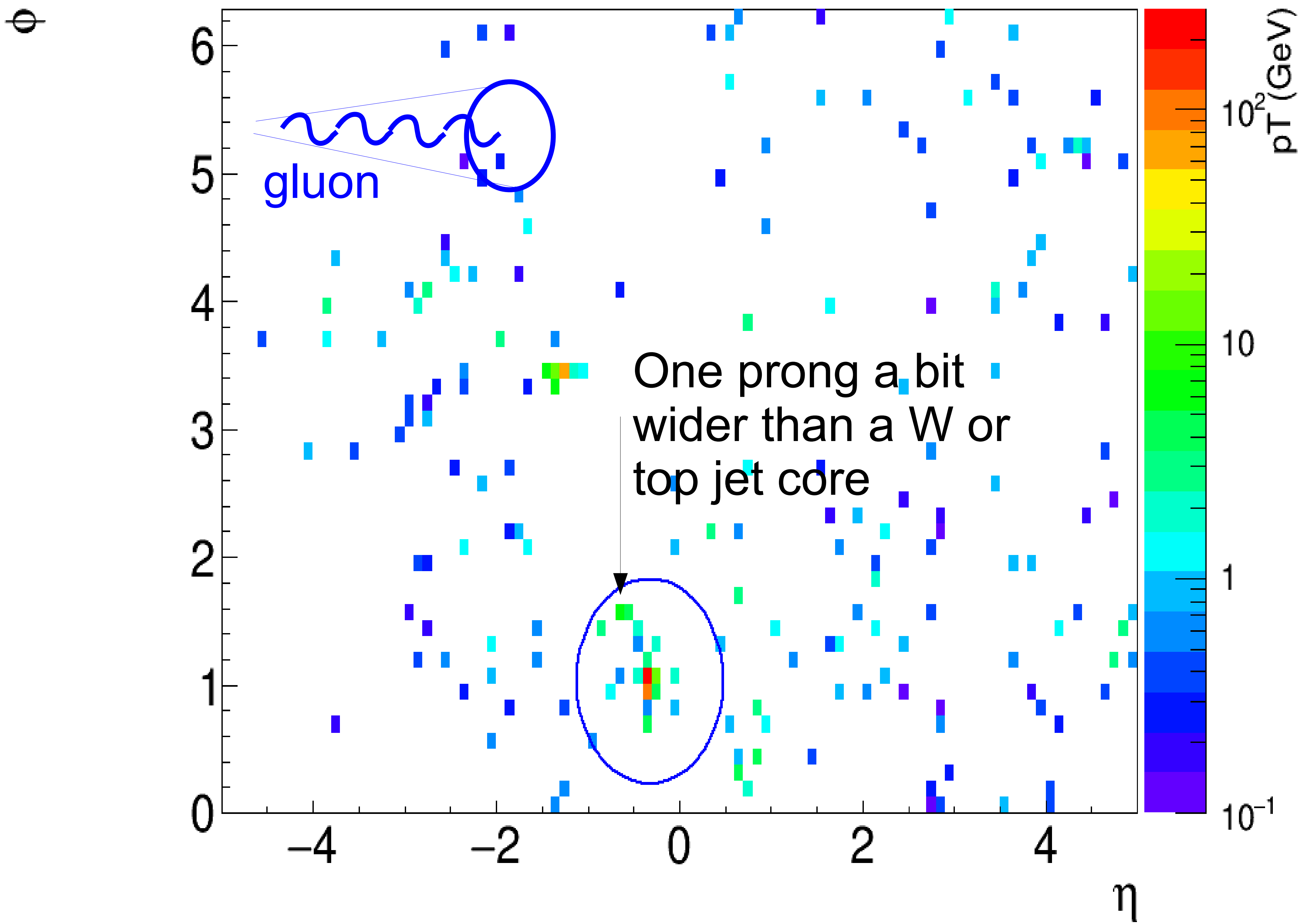
What is it?



Have a Top jet

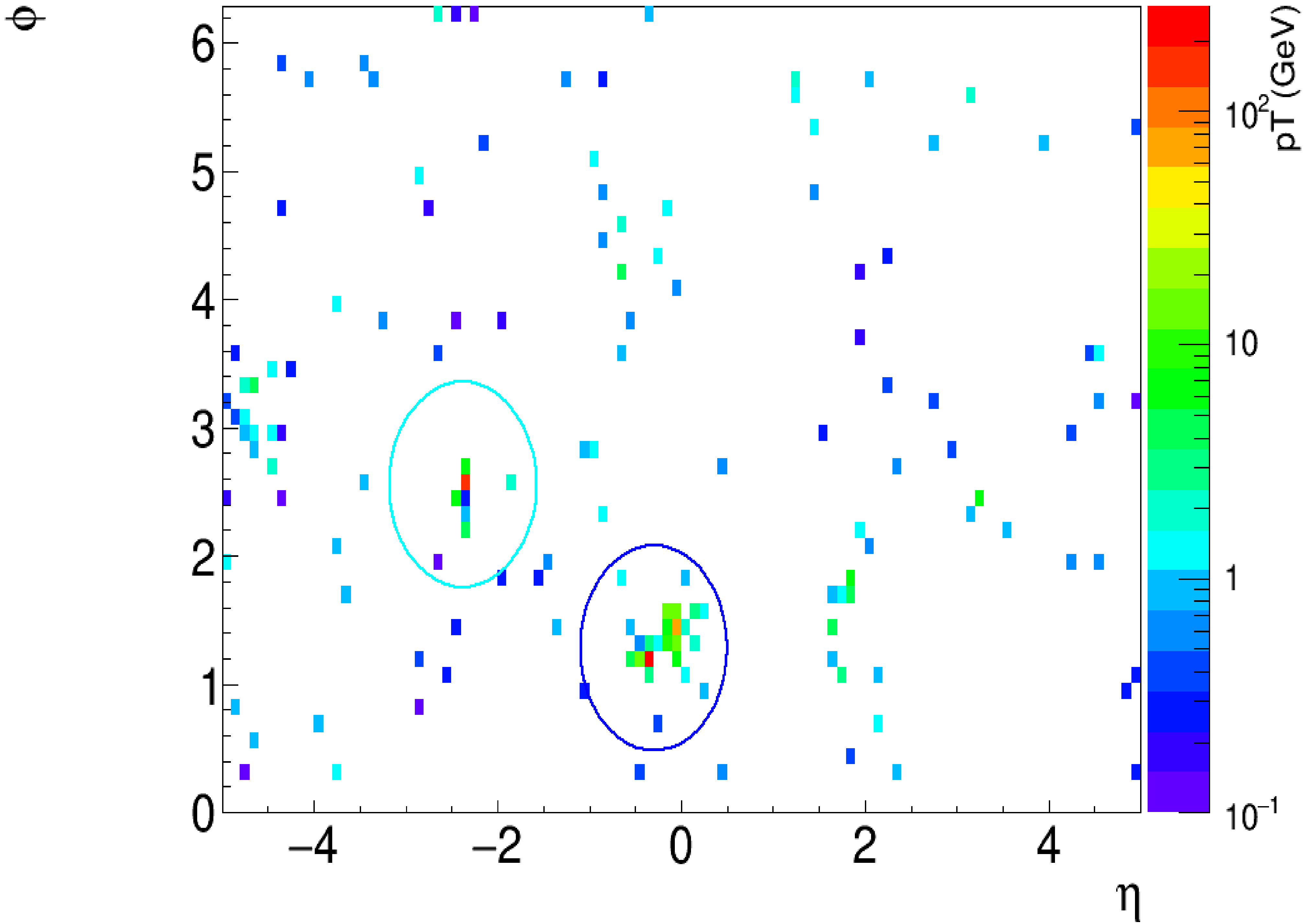


φ
6
5
4
3
2
1
0
−4
−2
0
2
4
η
pT (GeV)
10^2
10
1
10^{-1}

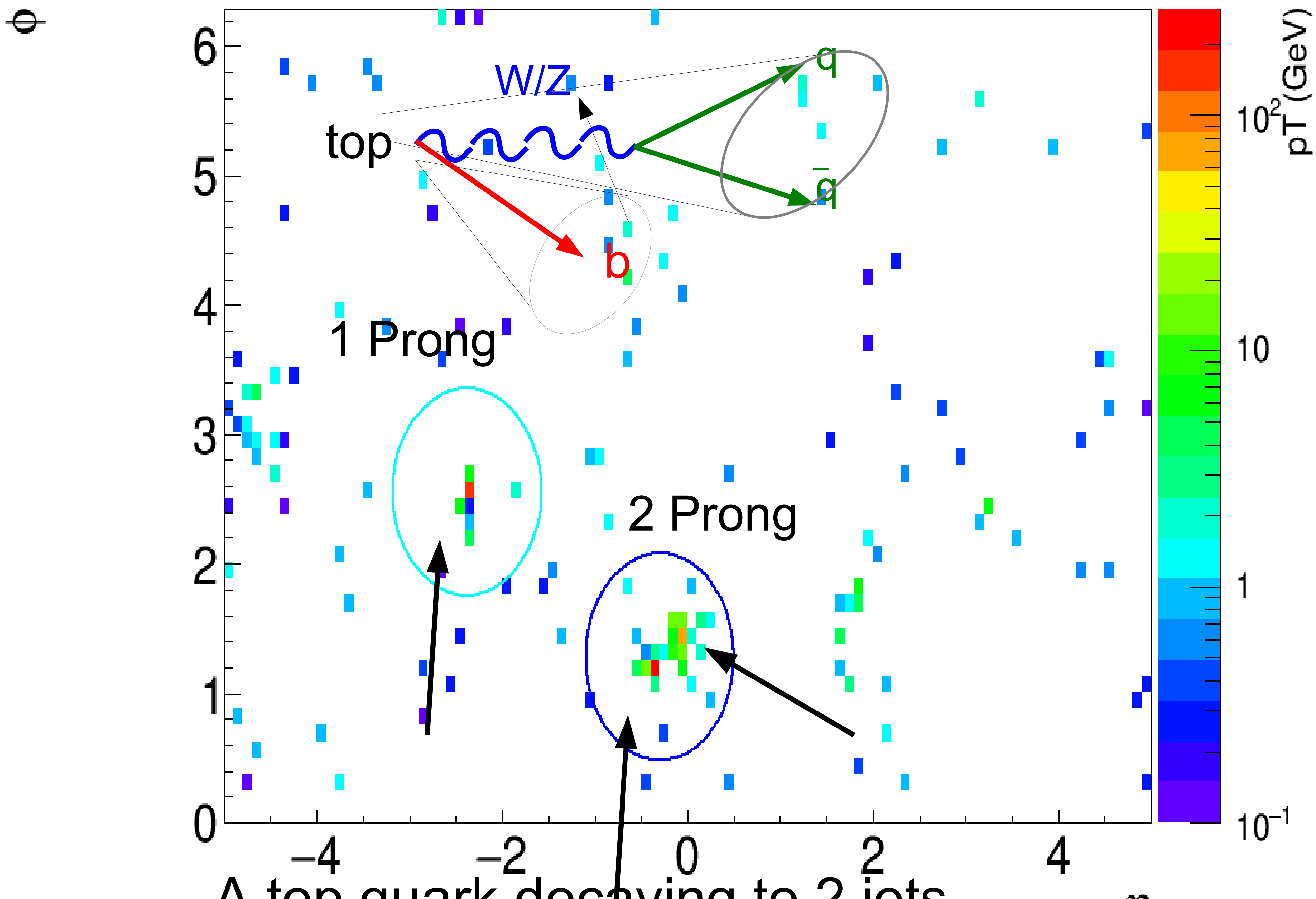


φ
6
5
4
3
2
1
0
−4
−2
0
2
4
η
gluon
One prong a bit wider than a W or top jet core
pT (GeV)
10²
10
1
10⁻¹

What is it?

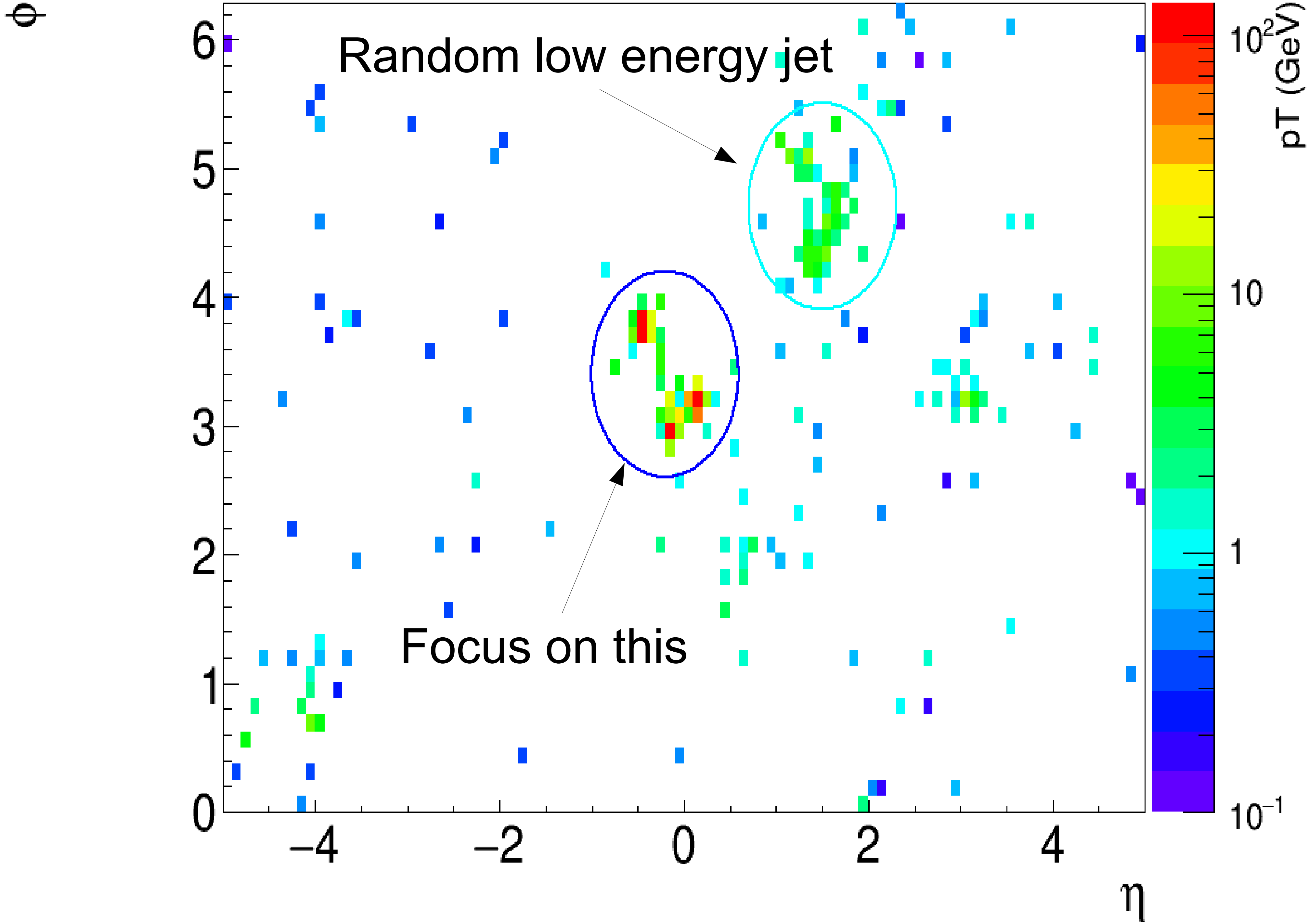


What is it?



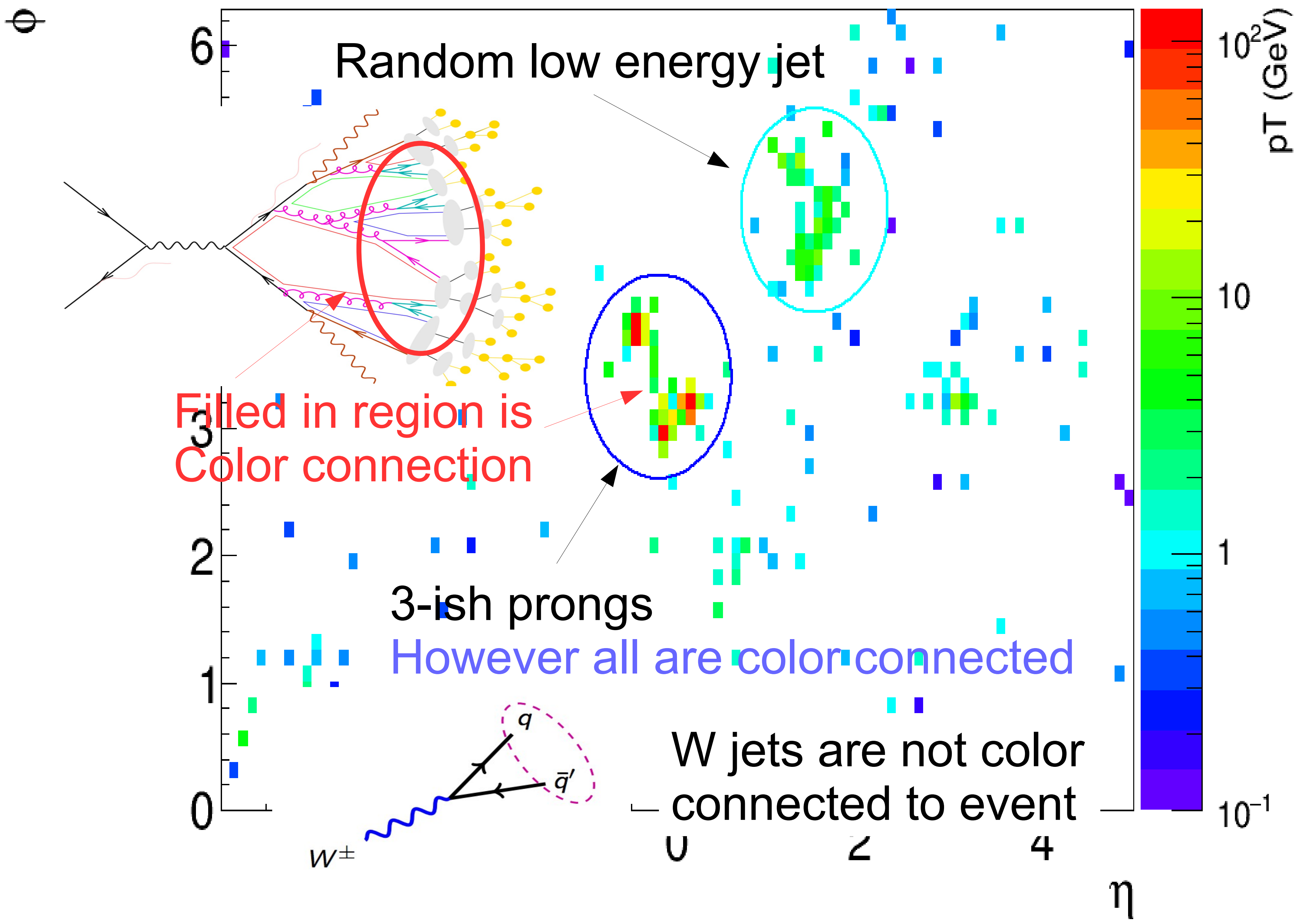
A top quark decaying to 2 jets

What is it?

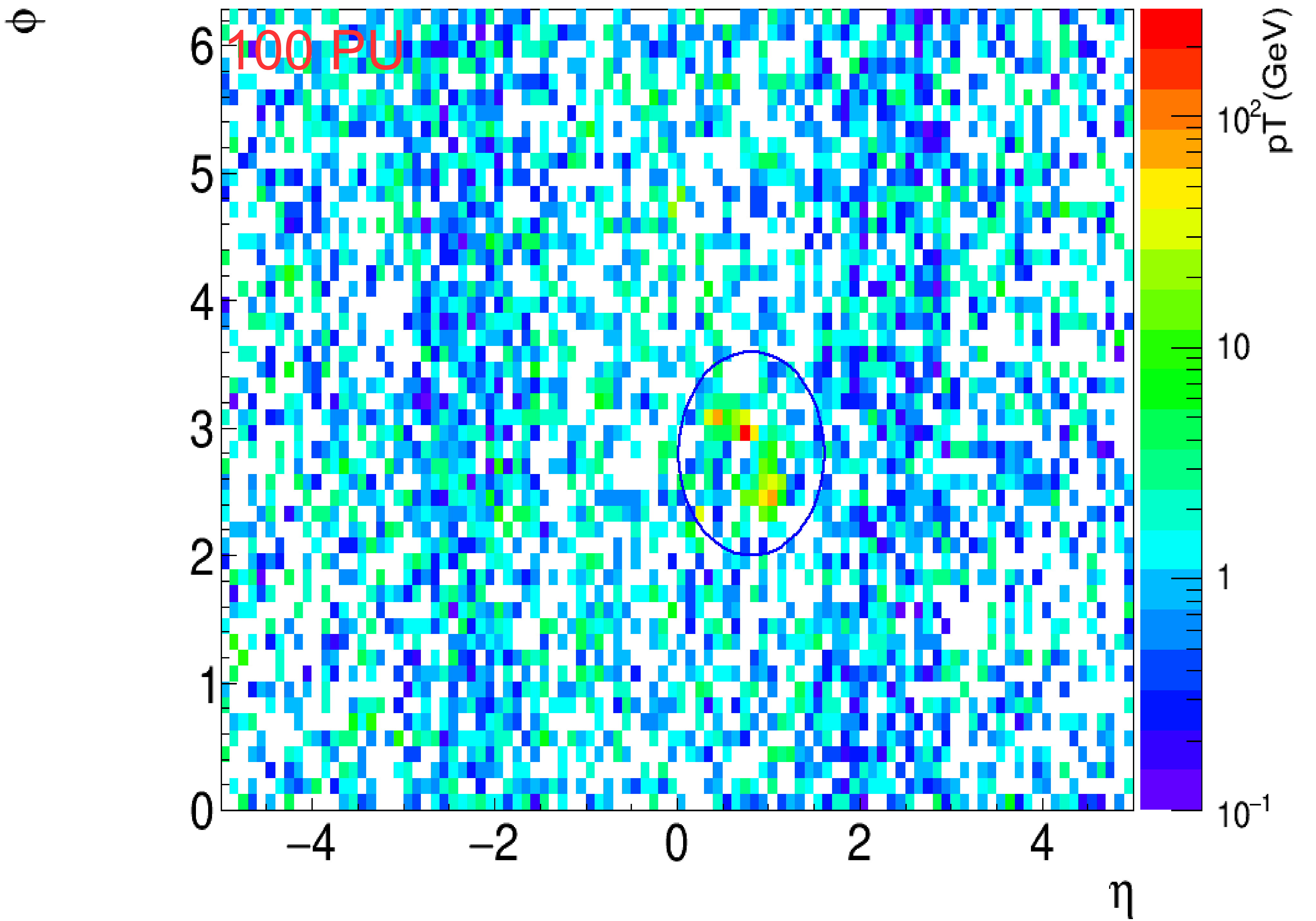


φ
6
5
4
3
2
1
0
−4
−2
0
2
4
η
Random low energy jet
Focus on this
10^2
10
1
10^−1
pT (GeV)

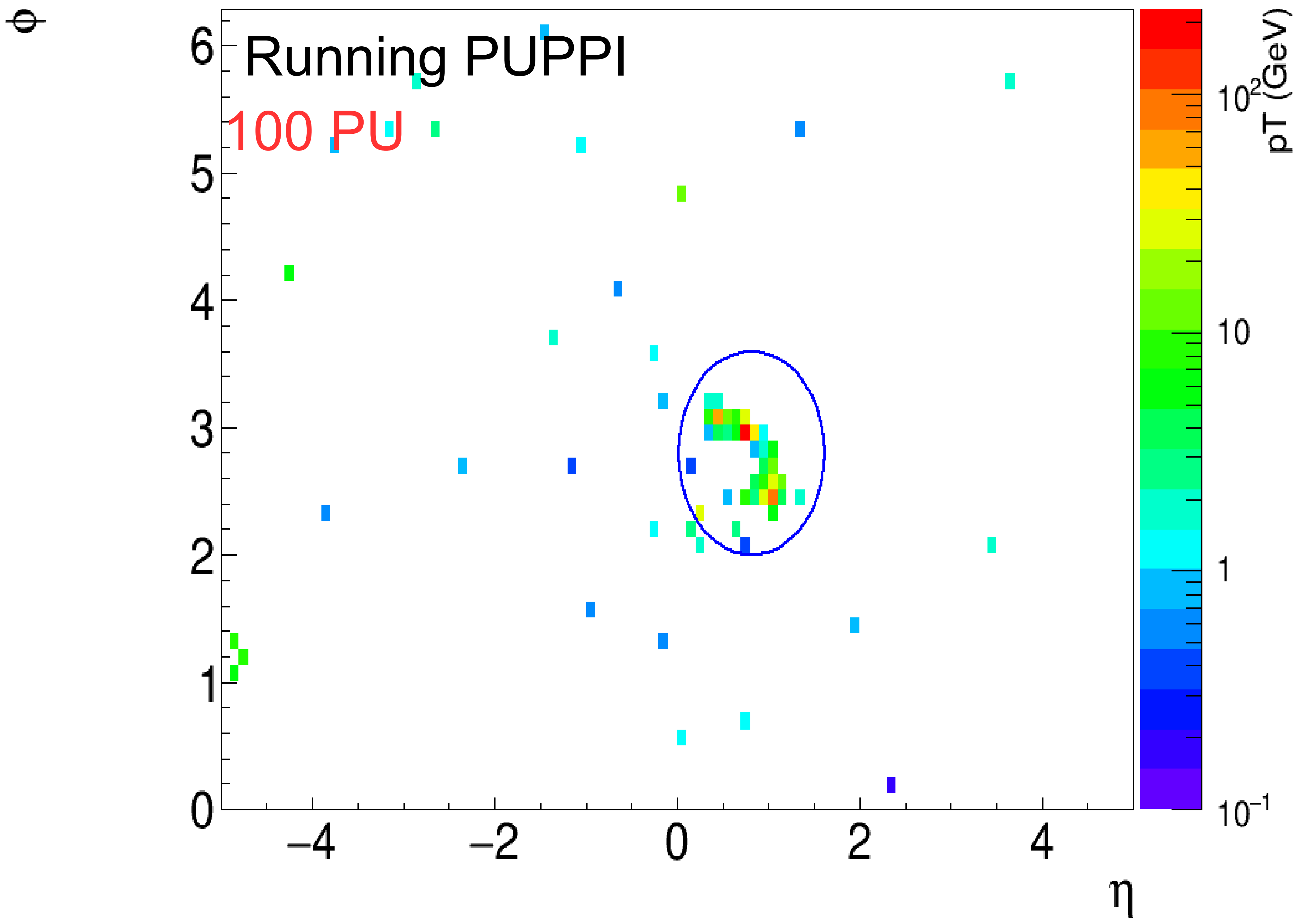
What is it?


φ
6
5
4
3
2
1
0
0
2
4
η
10^2
10
1
10^{-1}
pT (GeV)
Random low energy jet
Filled in region is
Color connection
3-ish prongs
However all are color connected
W jets are not color
connected to event
q
$\bar{q}'$
$W^{\pm}$

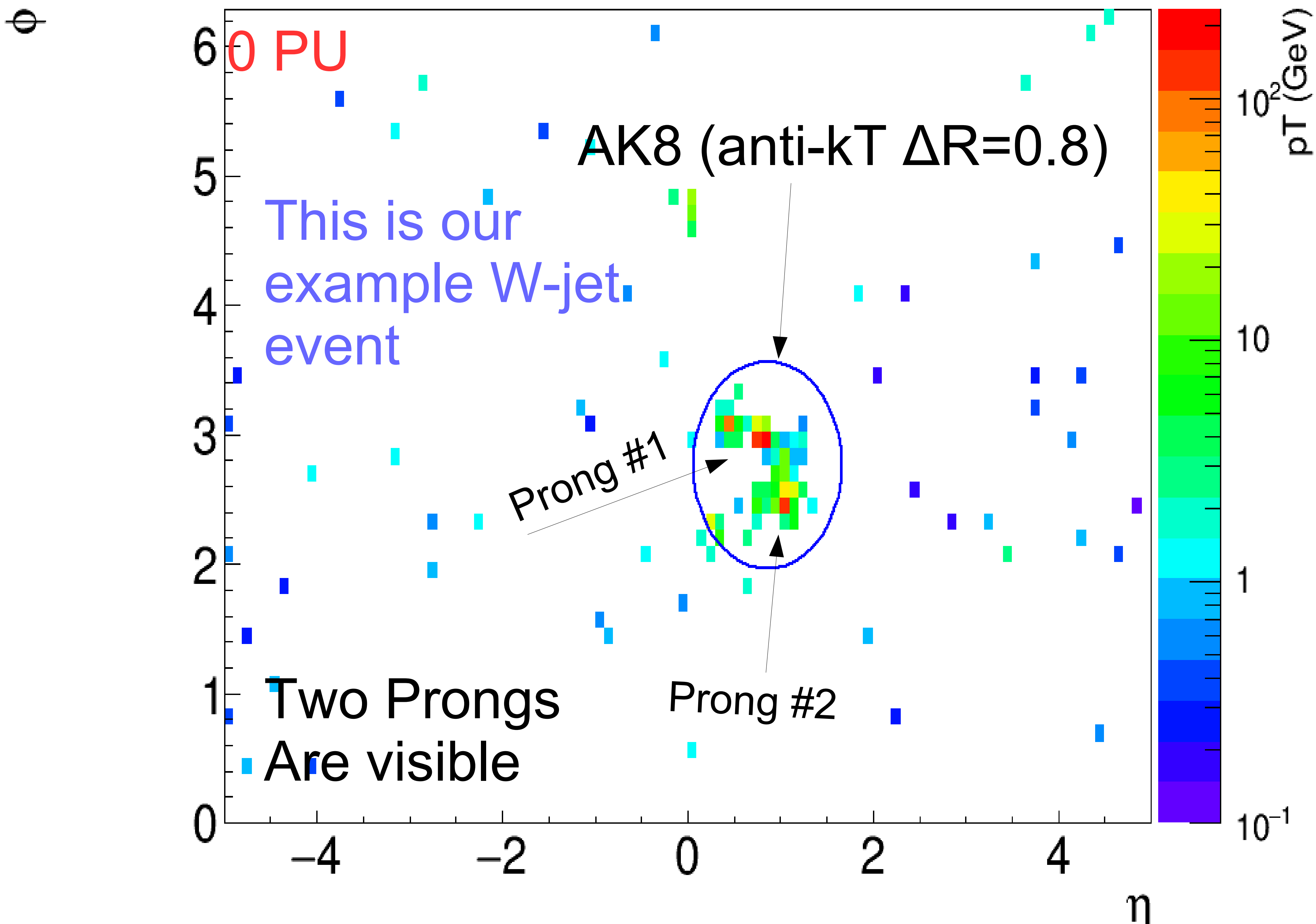
Now @ 100 PU (Next year)

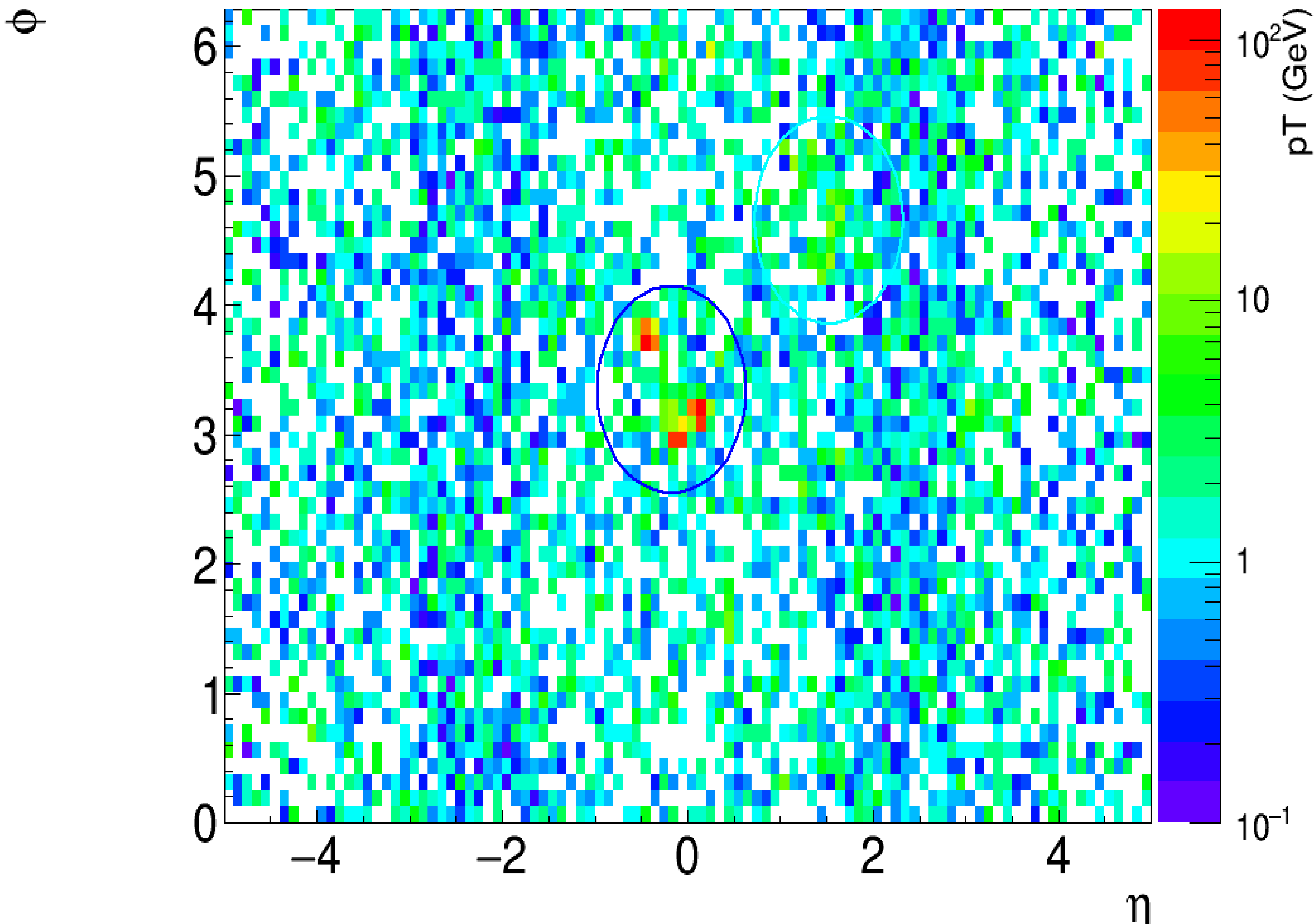


100 PU
φ
η
pT (GeV)

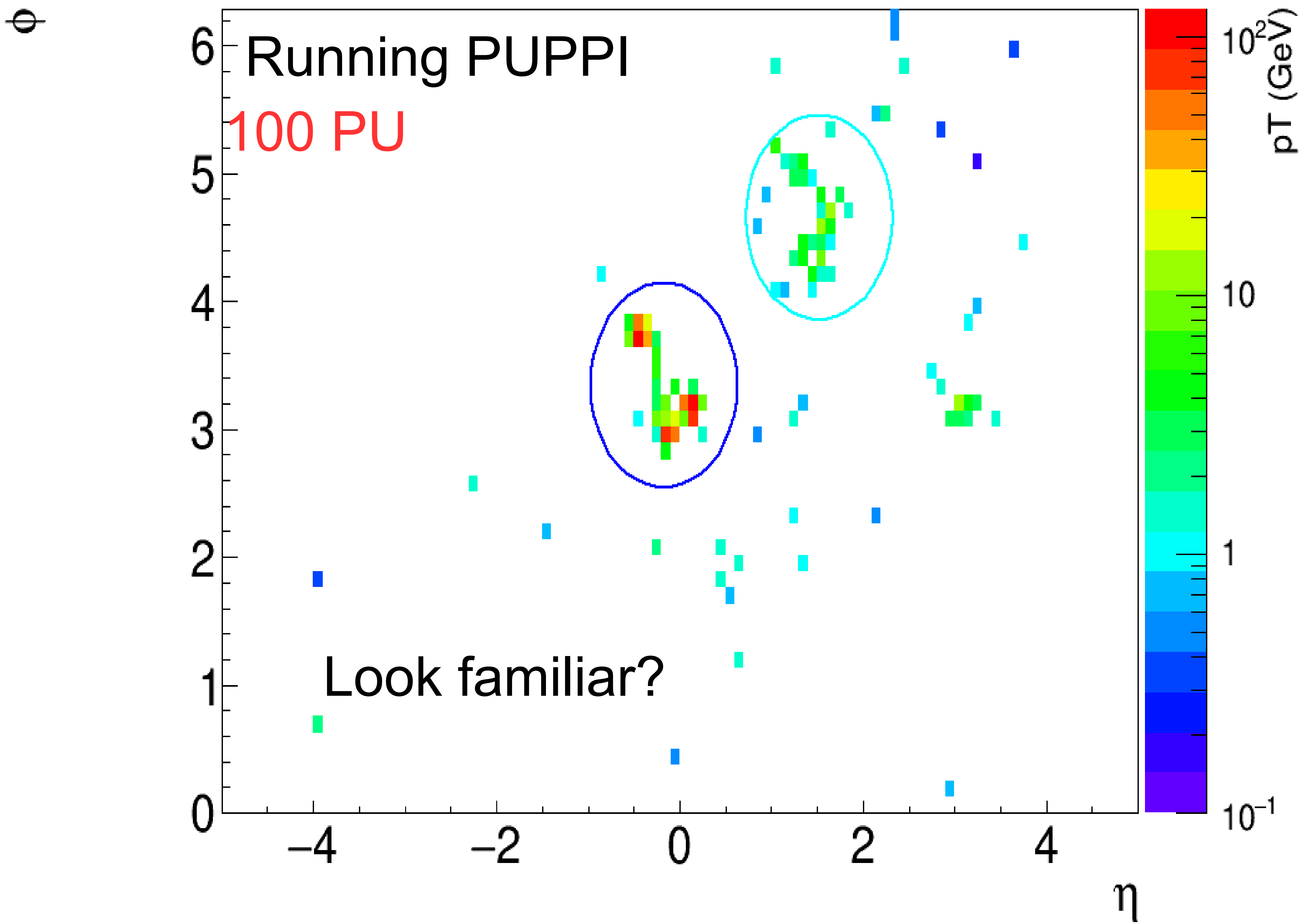


Running PUPPI
100 PU
φ
η
pT (GeV)
10^2
10
1
10^-1


0 PU
This is our example W-jet event
AK8 (anti-kT ΔR=0.8)
Prong #1
Prong #2
Two Prongs Are visible
φ
η
pT (GeV)
0
1
2
3
4
5
6
−4
−2
0
2
4
10^−1
1
10
10^2

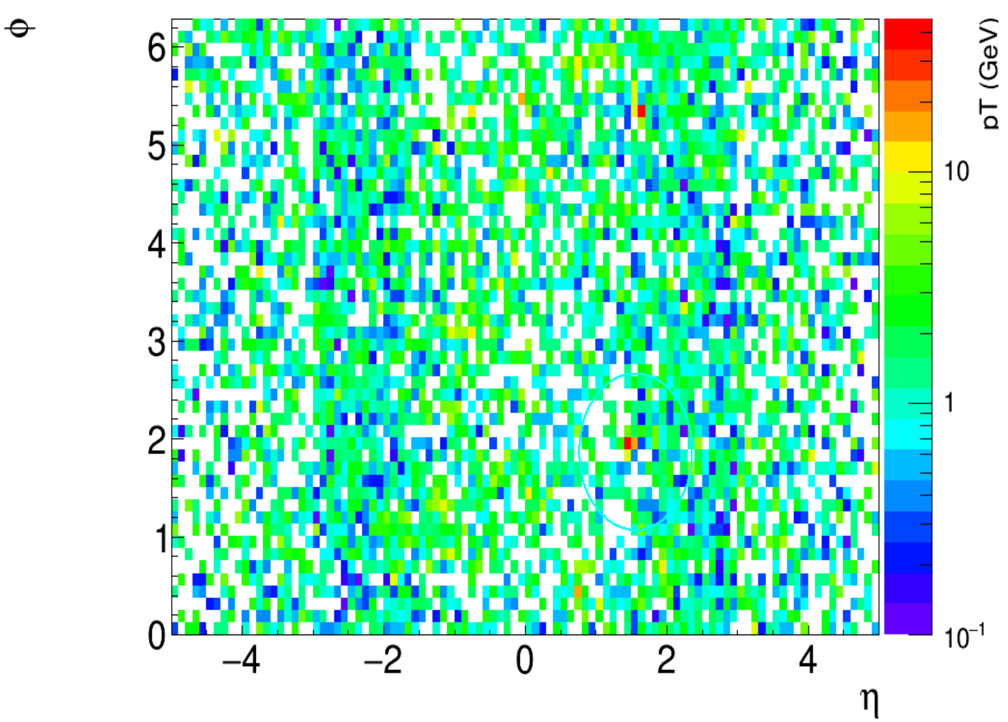


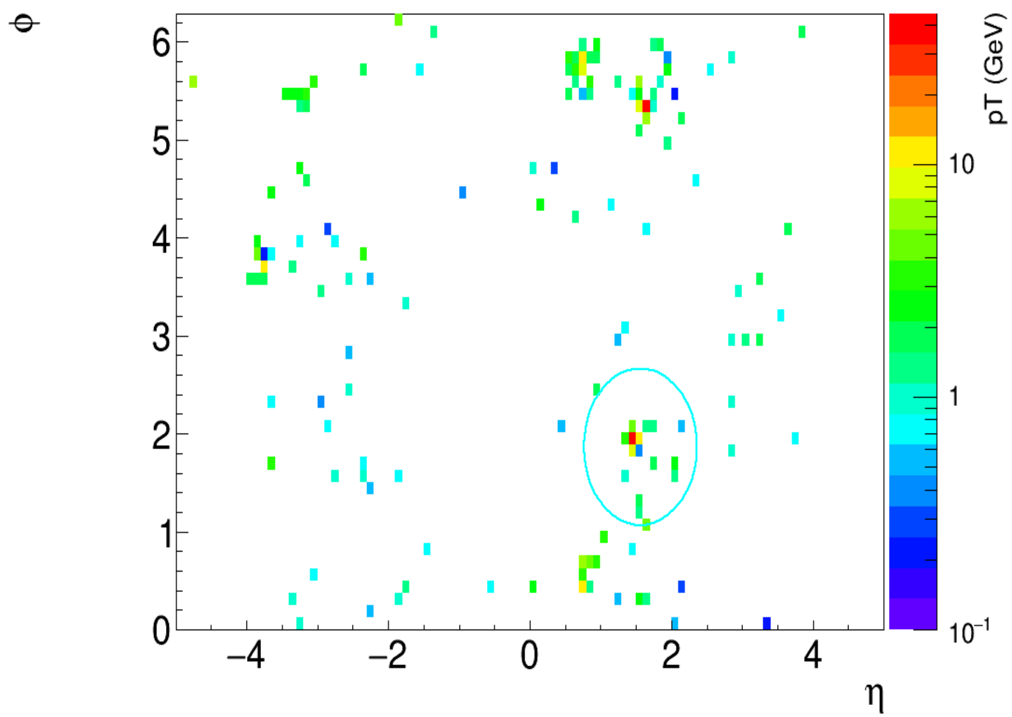
φ
6
5
4
3
2
1
0
−4
−2
0
2
4
η
pT (GeV)
10^2
10
1
10^{-1}



Running PUPPI
100 PU
Look familiar?
φ
η
pT (GeV)
0
1
2
3
4
5
6
−4
−2
0
2
4
10^{-1}
1
10
10^{2}

Any guesses?

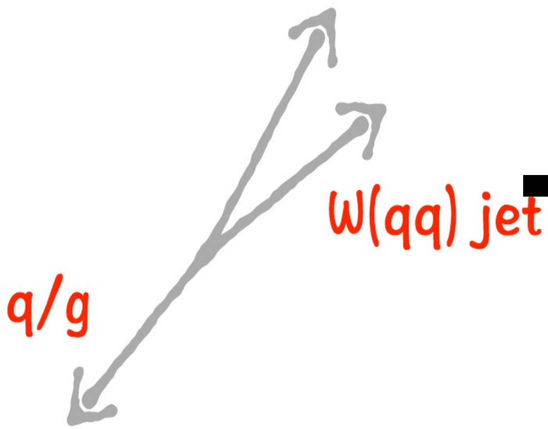




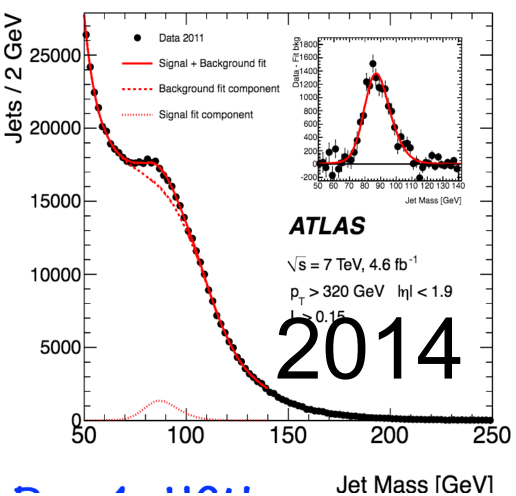
See backup

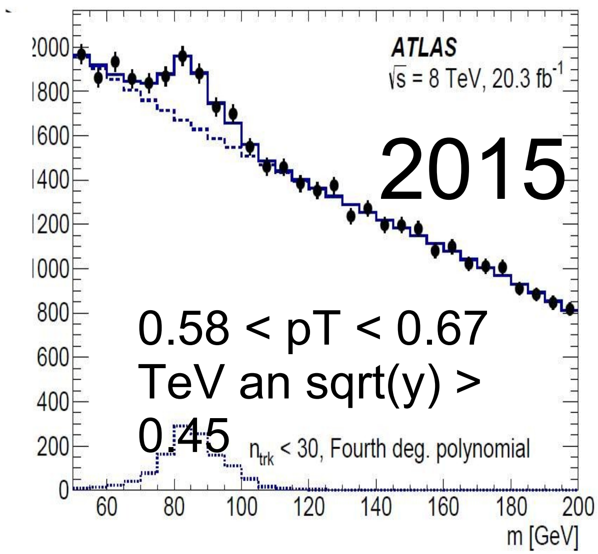
Recap

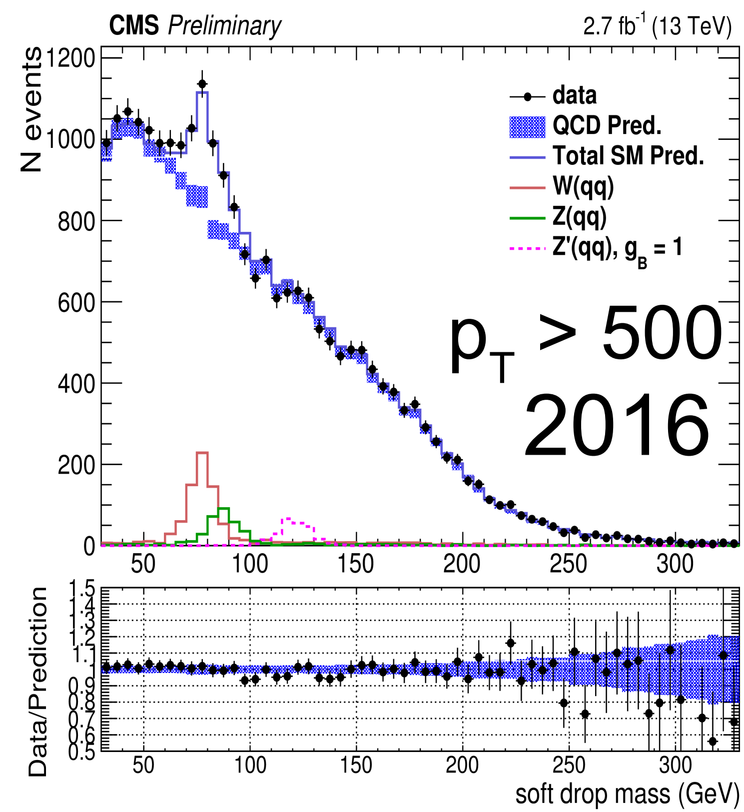
- Actual analyses are on objects combining deposits
- Particle flow combines the deposits to particles
  - Takes into account many features (Brem/Nuclear Int)
- Hadronic τ decays are composite “particle” objects
  - Find the decays and rely heavily on isolation
- Jets have rich & interesting identification features
  - Pileup an important aspect that needs to b addressed
- *MET* relies heavily on everything else
  - To reconstruct nothing you have to know everything



Thanks!



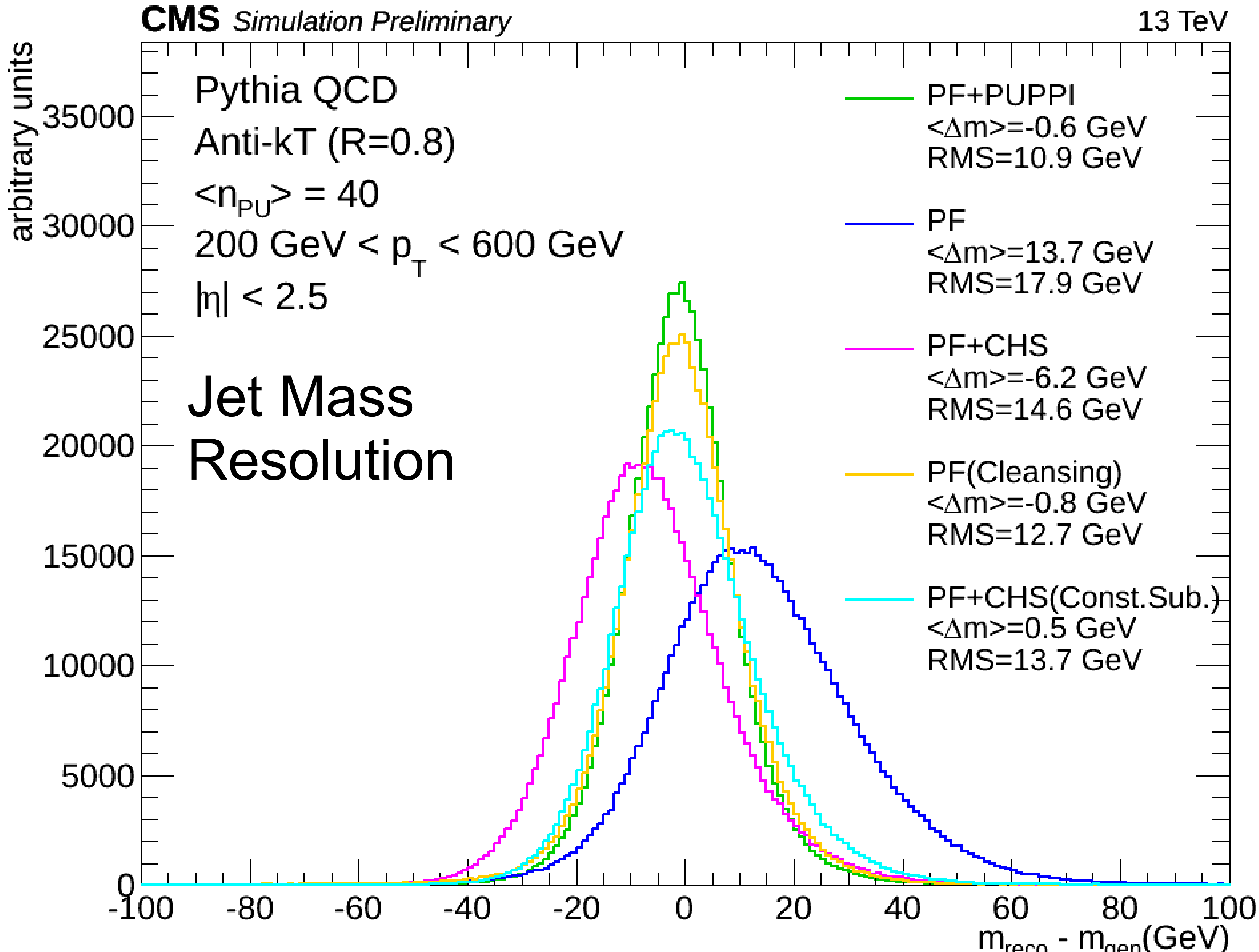




This peak has only been observed over past 2 year

Thanks to the Organizers! Have a good trip back

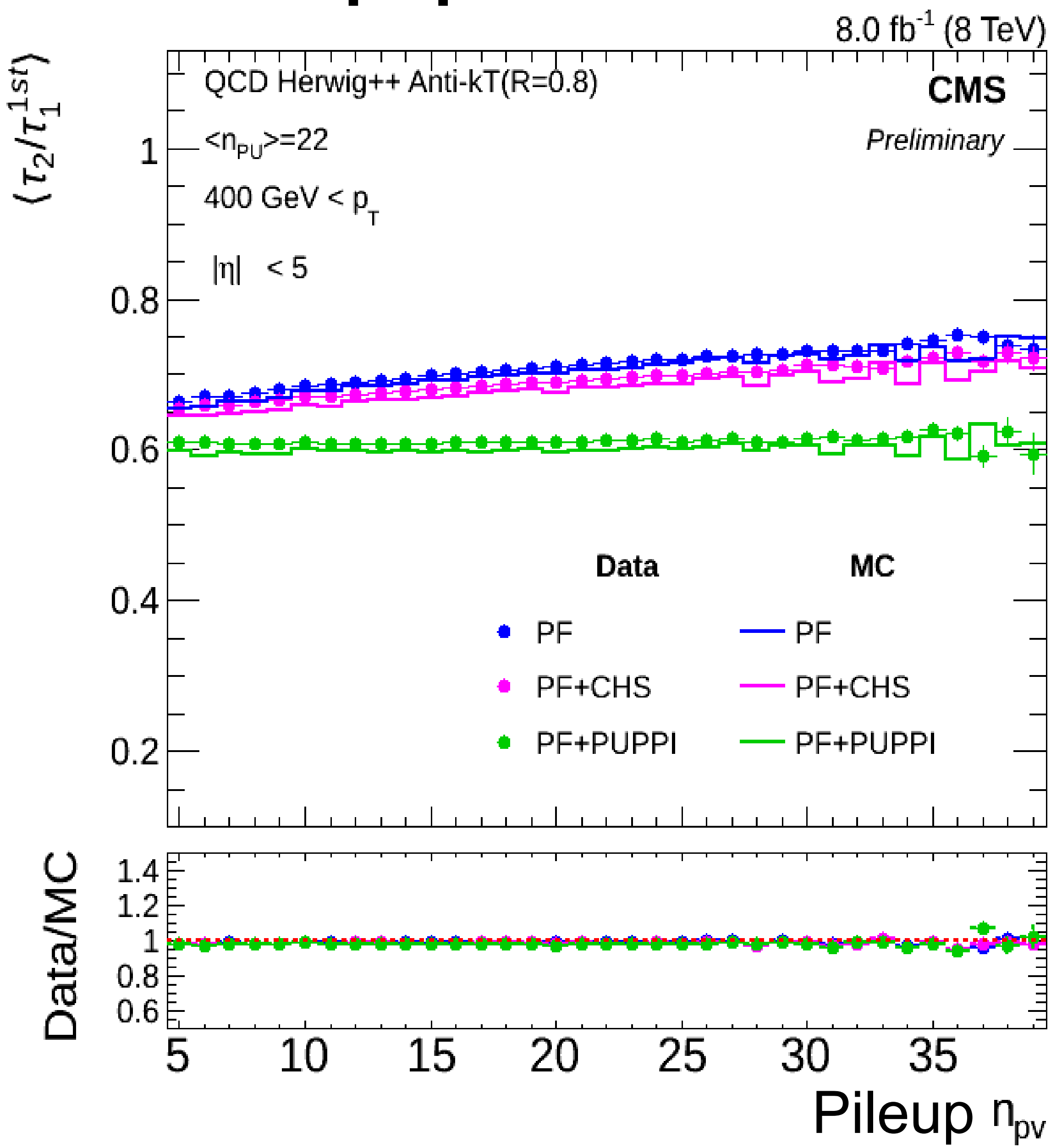
Jets in CMS



Mass resolution shows clear improvement (40 PU)

Pileup performance in data

Likelihood of two prongs



- No more trends in pileup with Puppi

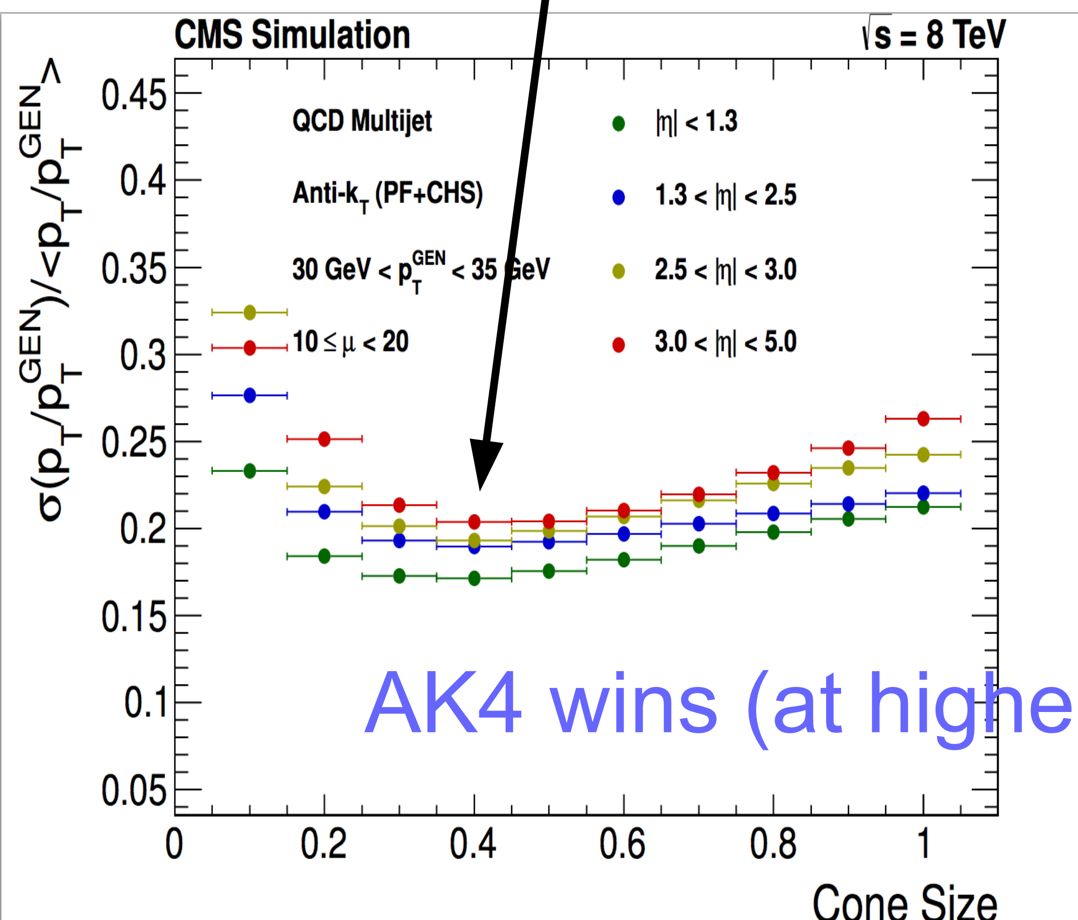
Jet Energy Correction

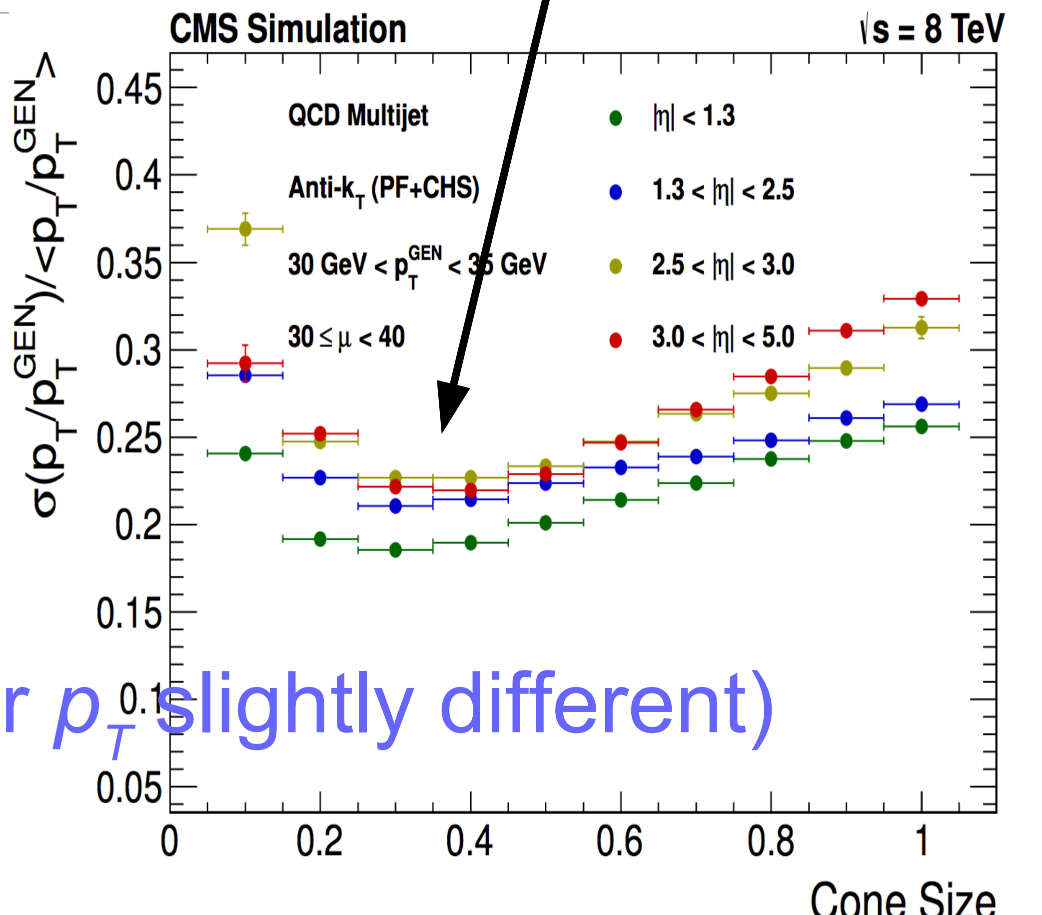
- Executive Summary :

We switch to AK4

Run I PU

Run II PU





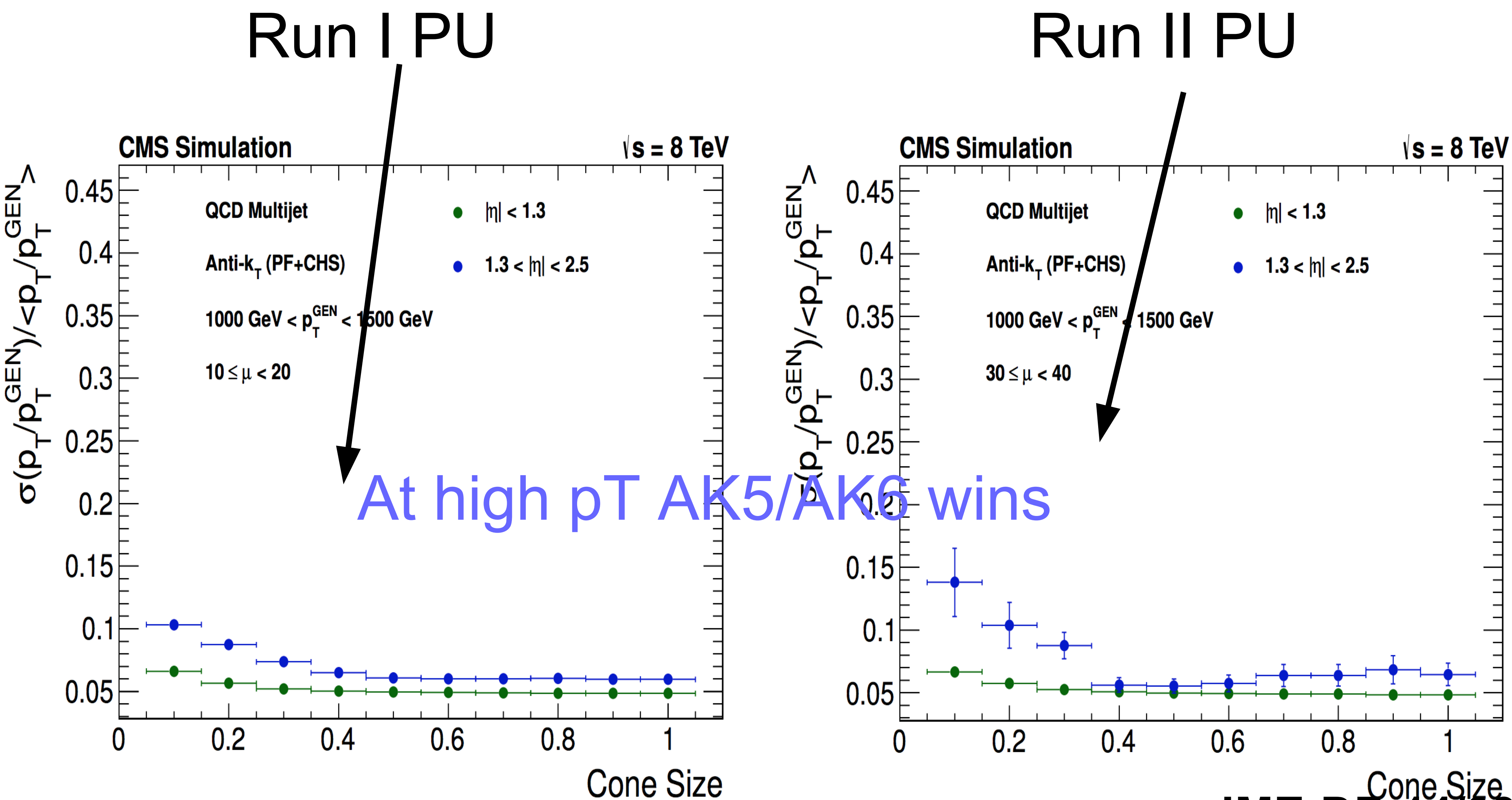
AK4 wins (at higher p_T slightly different)

JME-DP-14/037

Jet Energy Correction

- Executive Summary :

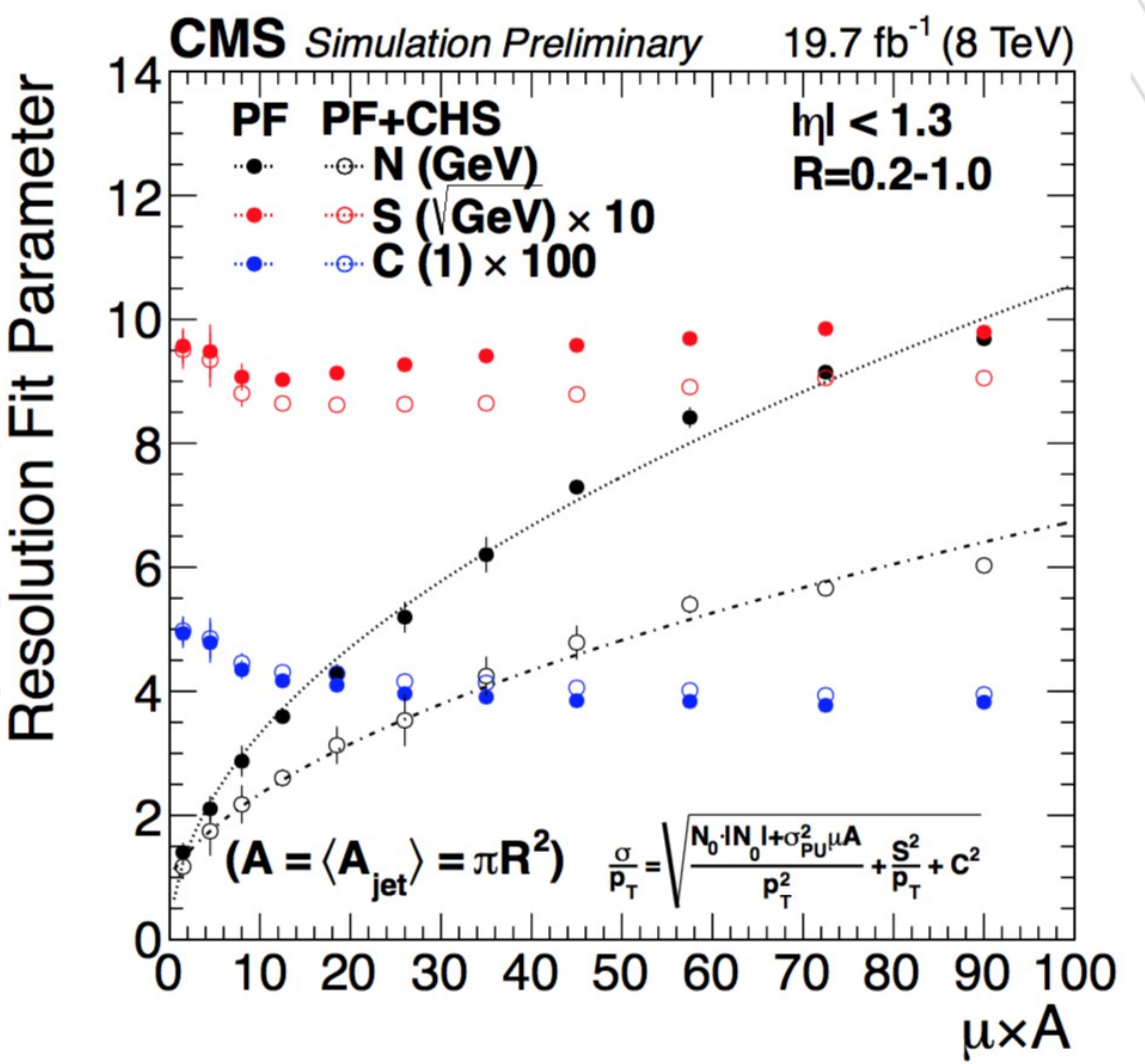
We switch to AK4



JME-DP-14/037

Stability of our detector

- Using all the jet cones allows plots like this:



JME-DP-14/037

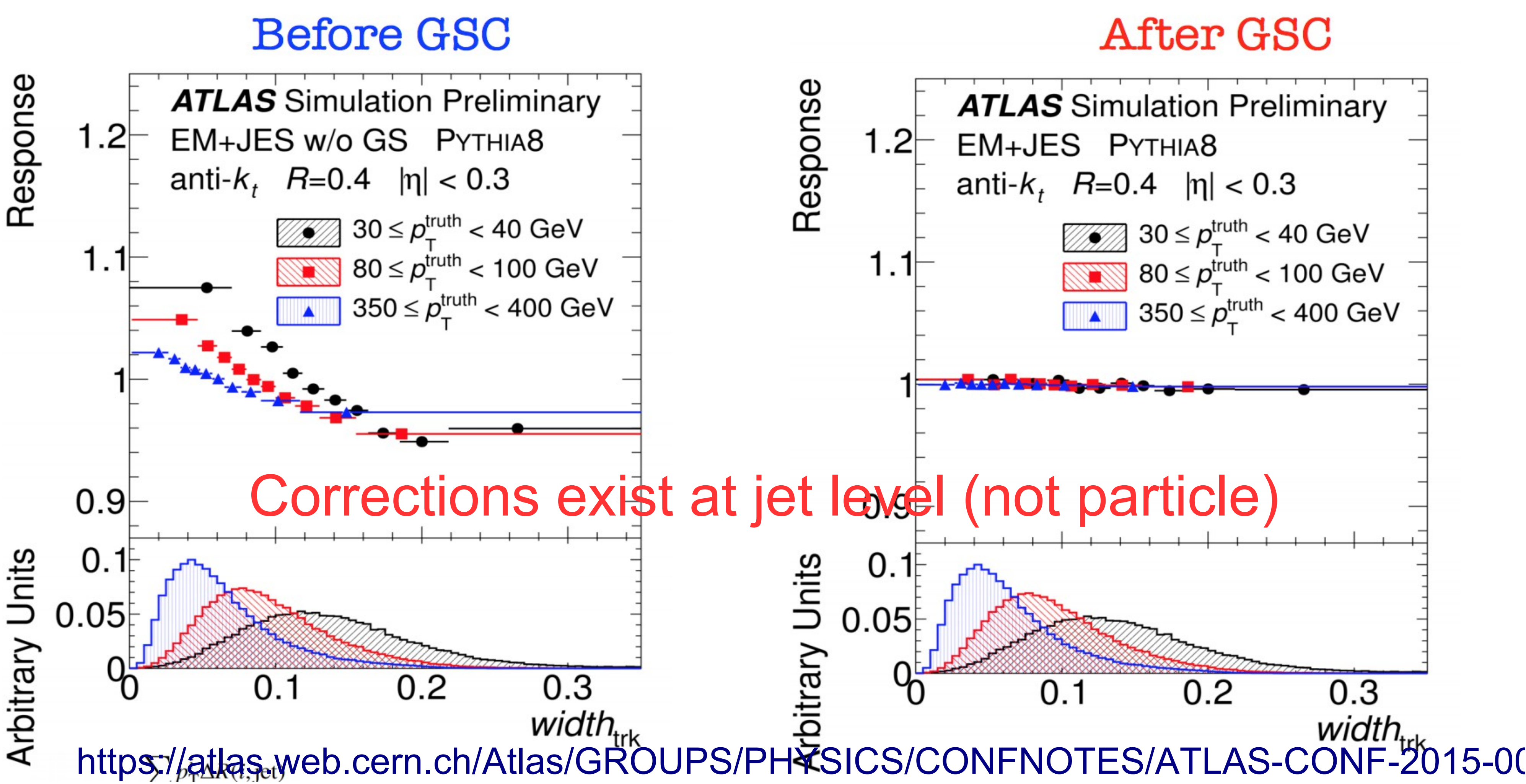
What does it take for E-flow?

- Need to reconstruct a jet and correct it

ATLAS Cluster+correct Calorimeter Cells (Topoclusters)	Cluster Topoclusters To jets	(ρ) PU Correction +Global Correction Of Jet (p_T+η)	Residual Correction of Jet (using width/tracks) GSC
CMS Cluster Calorimeter Cells (pf clustesr)	Link Tracks to Pfclusters (pf particles)	Correction Of PF Candidate (p_T+η)	(ρ) PU Correction + Global Correction of Jet (p_T+η)

Jet-Level in ATLAS

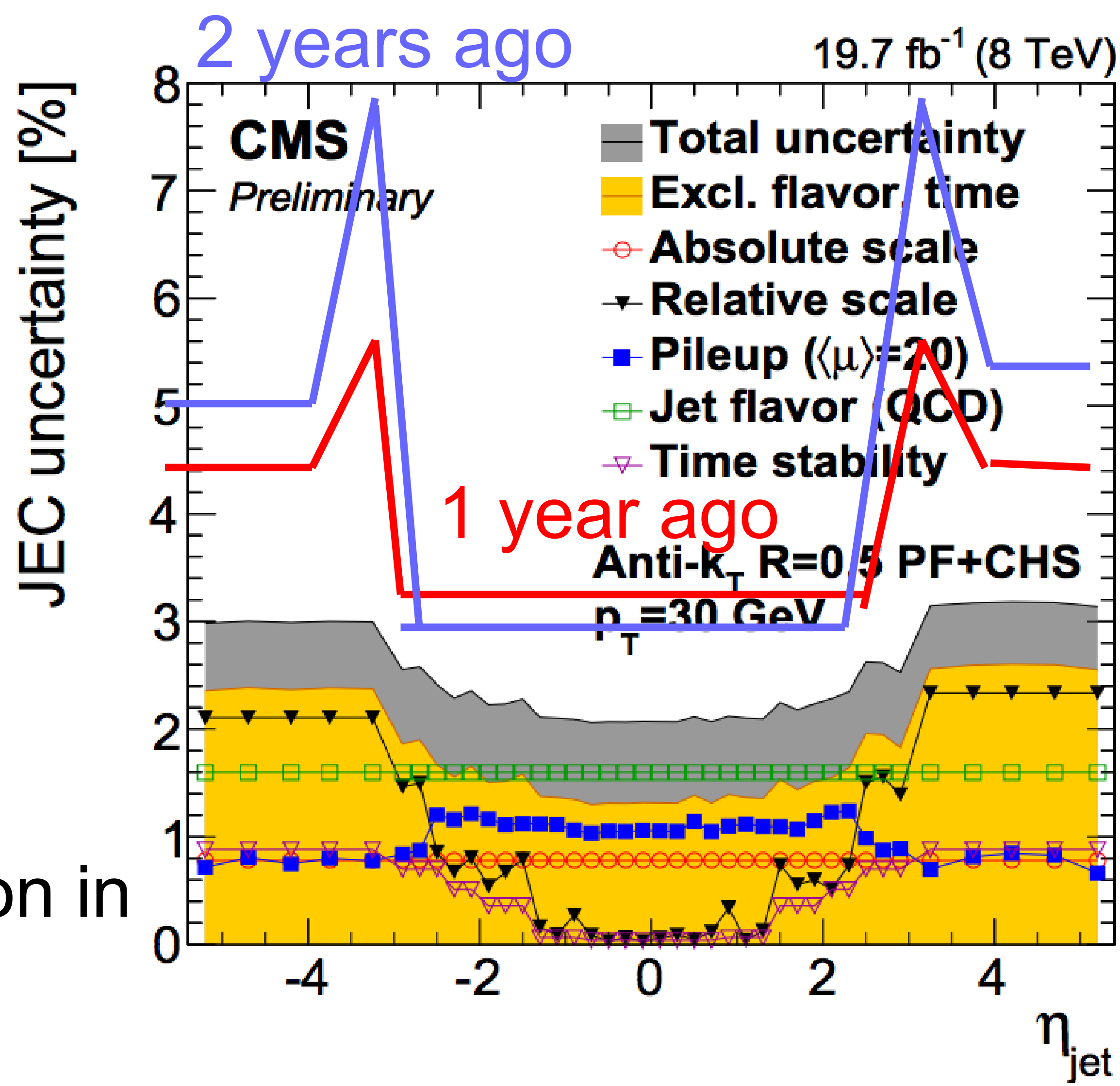
- While ATLAS does not use pflow
  - Yields resol. loss(Charged parts)+worse granularity
  - Compensates w/improved granularity through GSC



Corrections exist at jet level (not particle)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-00

Jet Energy Scale



Understanding of JEC Steadily improved

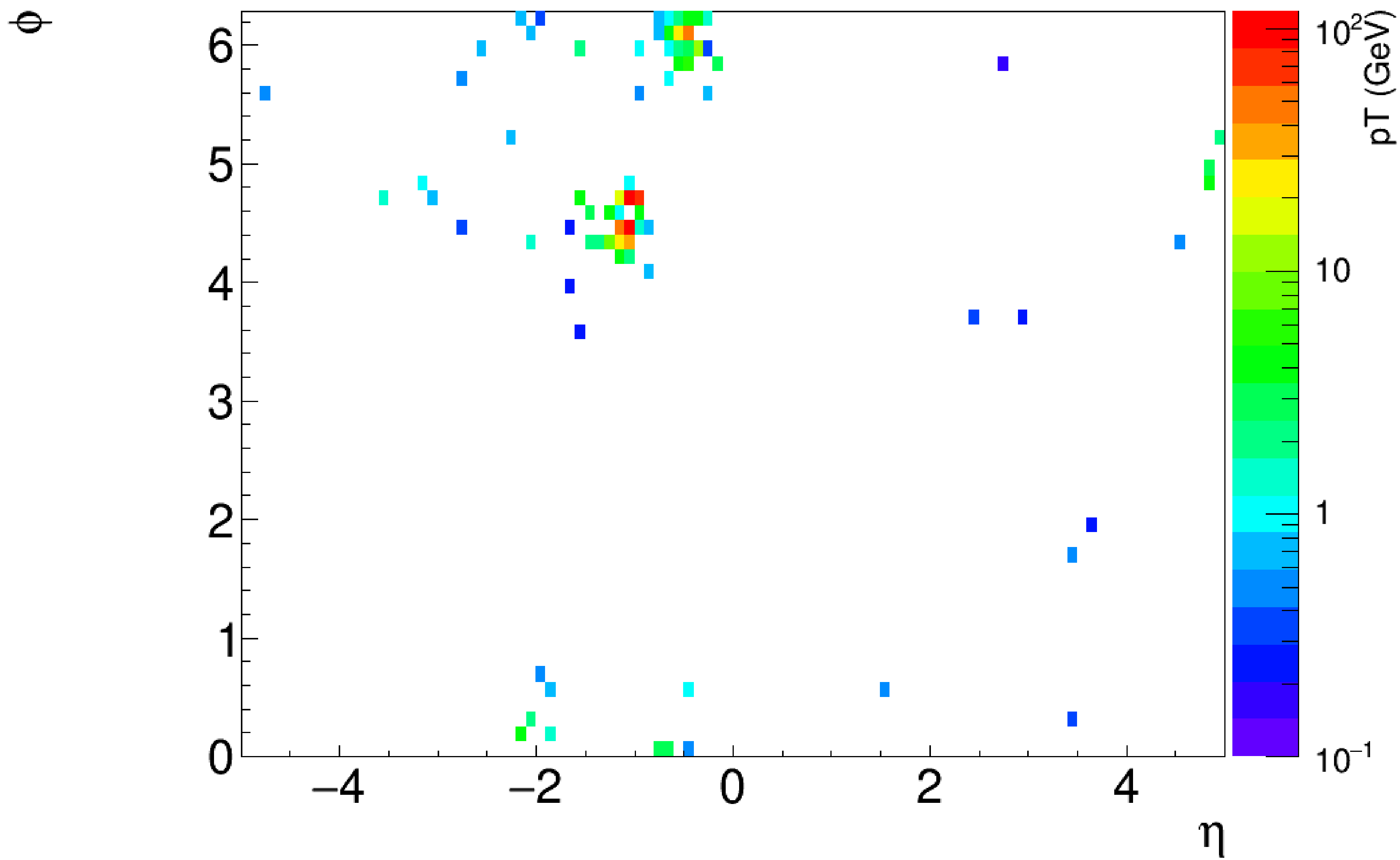
As we dealt with detector effects

Similar progression in ATLAS

- Run II: expect same trend with a faster timescale
- We are now down to 3% uncertainty a 30 GeV!

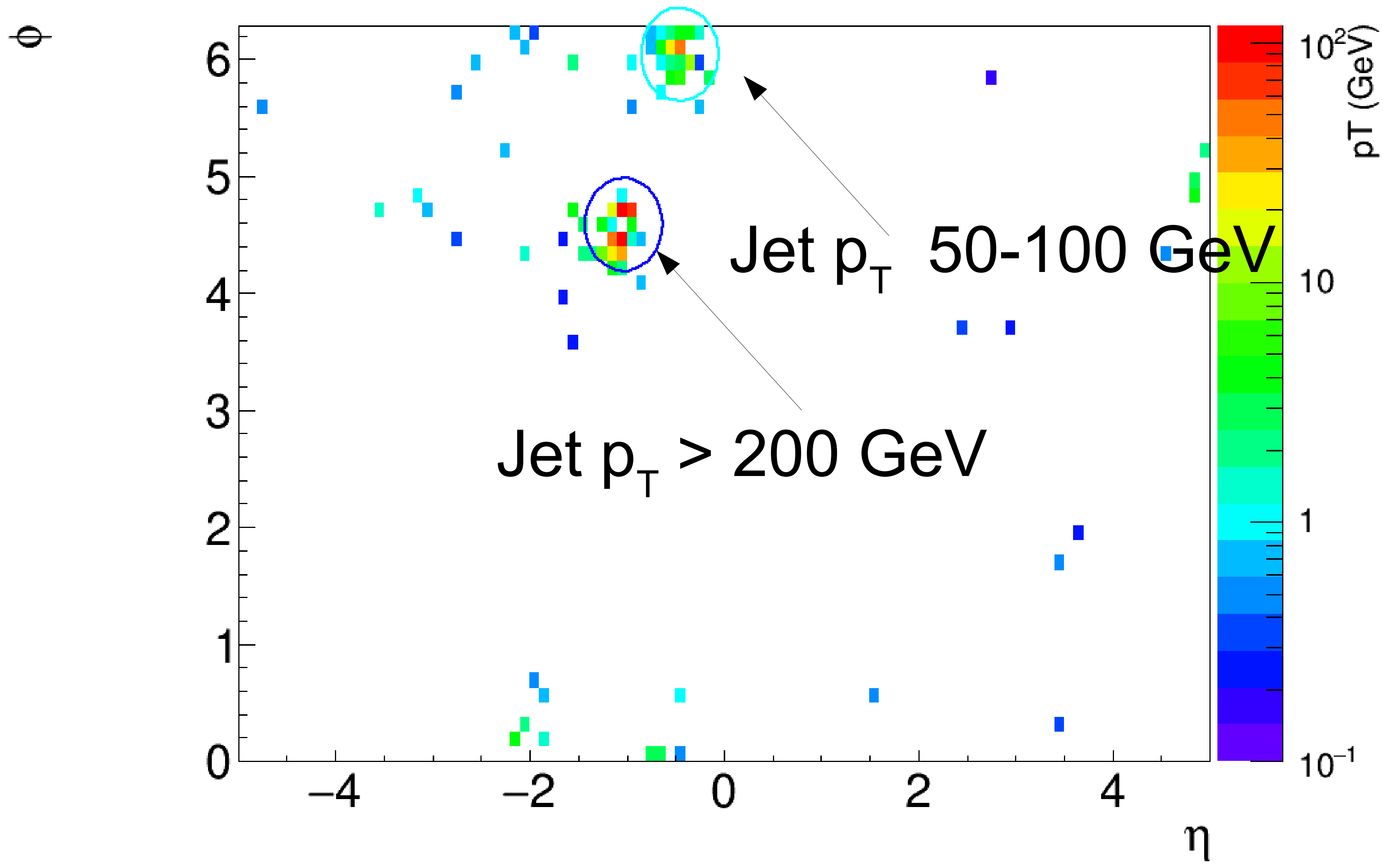
JME-13-004

What is it?

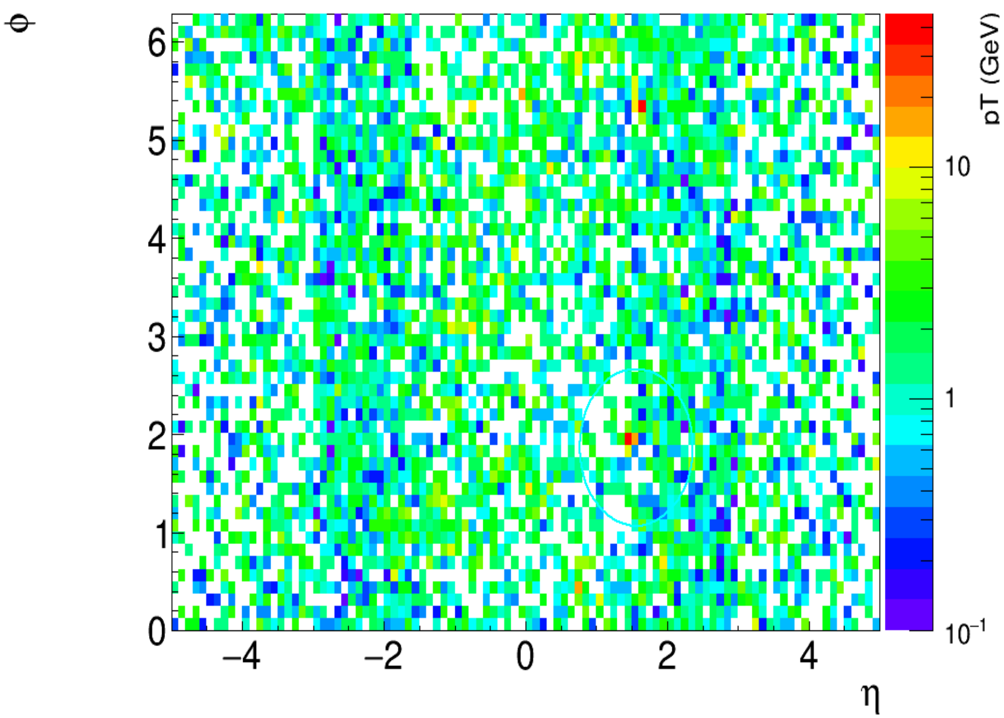


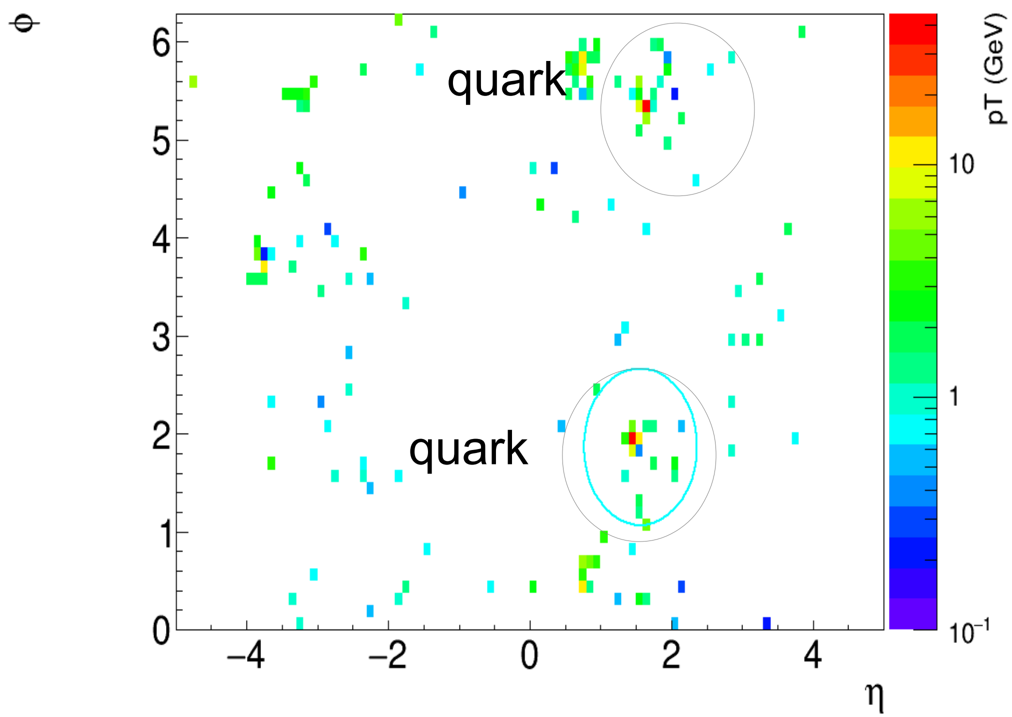
What is it?

Run Jet reco



Any guesses?





Its a low pT W boson