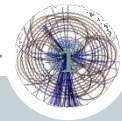


# Particle Flow Event Reconstruction



MARTYN JARVIS

# Introduction

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- Example Higgs analyses
- What is particle flow?
- How does it work?
- Example reconstruction of an event
- Performance
- Commissioning of the algorithm



# Motivation

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- In general, signatures of New Physics appear in final states containing:
  - Charged leptons including hadronic taus
  - High  $P_T$  jets
  - b-quarks
  - Missing transverse energy due to weakly interacting neutral particles.
- To study these signatures need a method to reconstruct and identify all particles in events as accurately as possible.
- Particle Flow techniques...

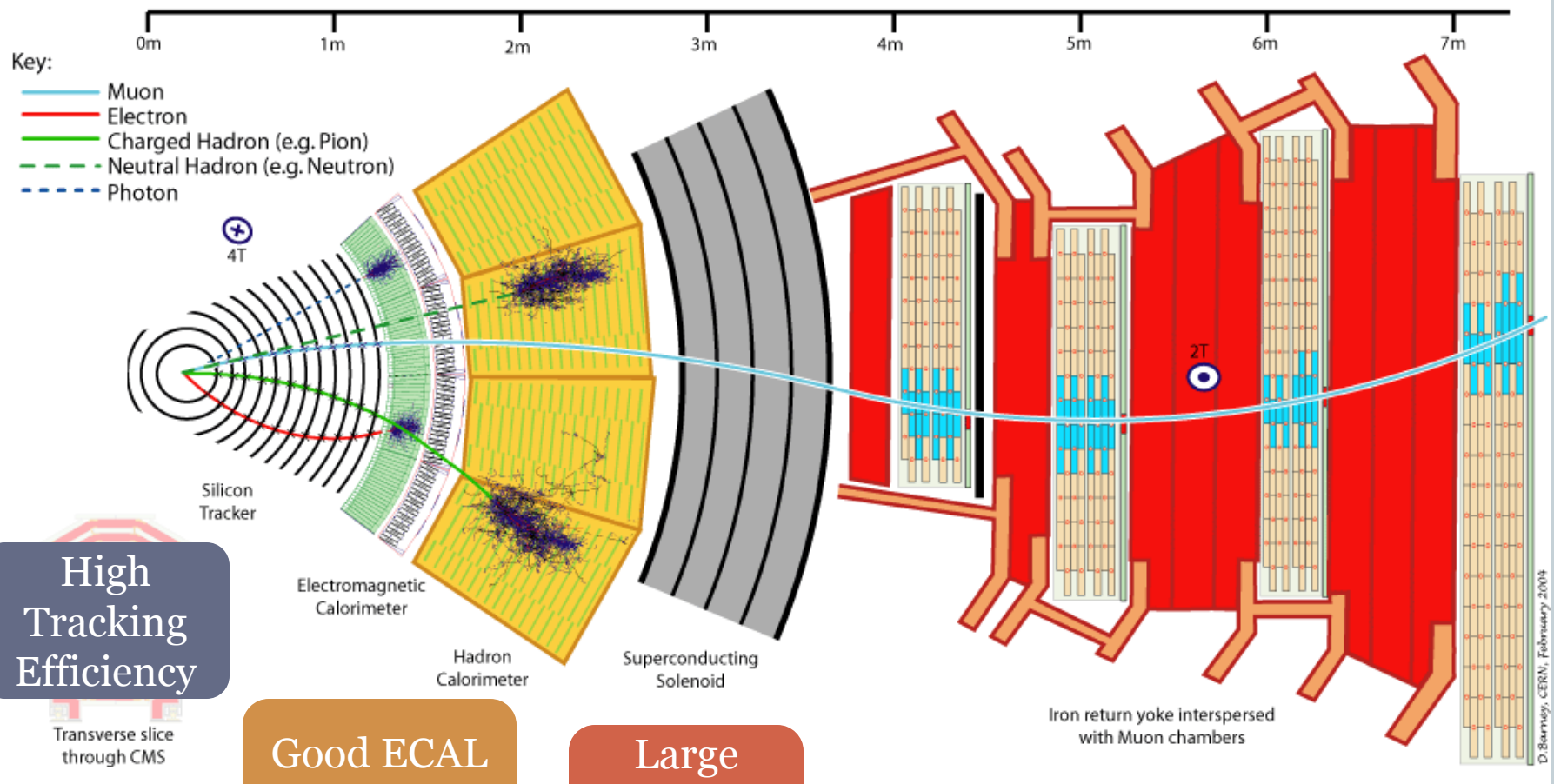
# What is Particle Flow?

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- Attempt to reconstruct all stable particles in an event.
  - Photons, charged and neutral hadrons, electrons, muons.
- Information from sub-detectors is combined in best possible way.
- List of particles is returned, as if it came from a MC generator.
- Higher level physics objects can be built from list of particles.
  - hadronic taus
  - jets
  - b-tagged jets
  - Missing transverse energy

# CMS detector

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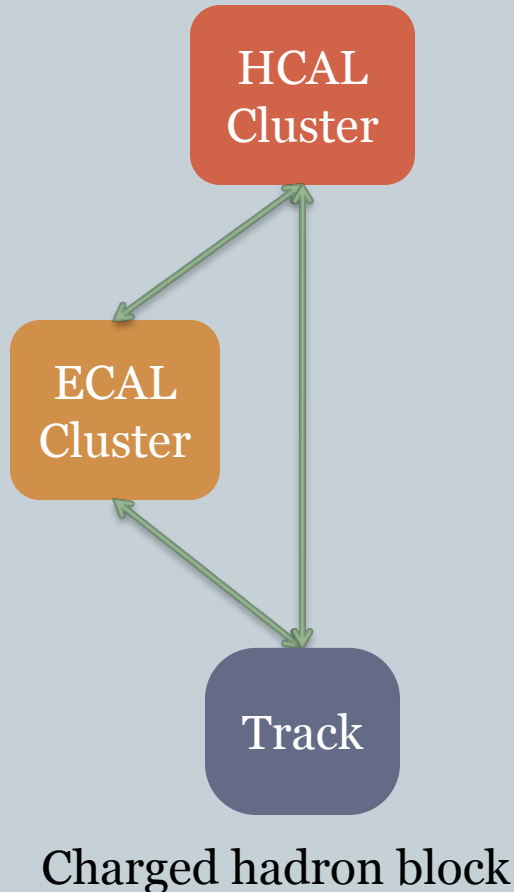
High Tracking Efficiency

Good ECAL granularity

Large Magnetic Field

# Overview of Particle Flow

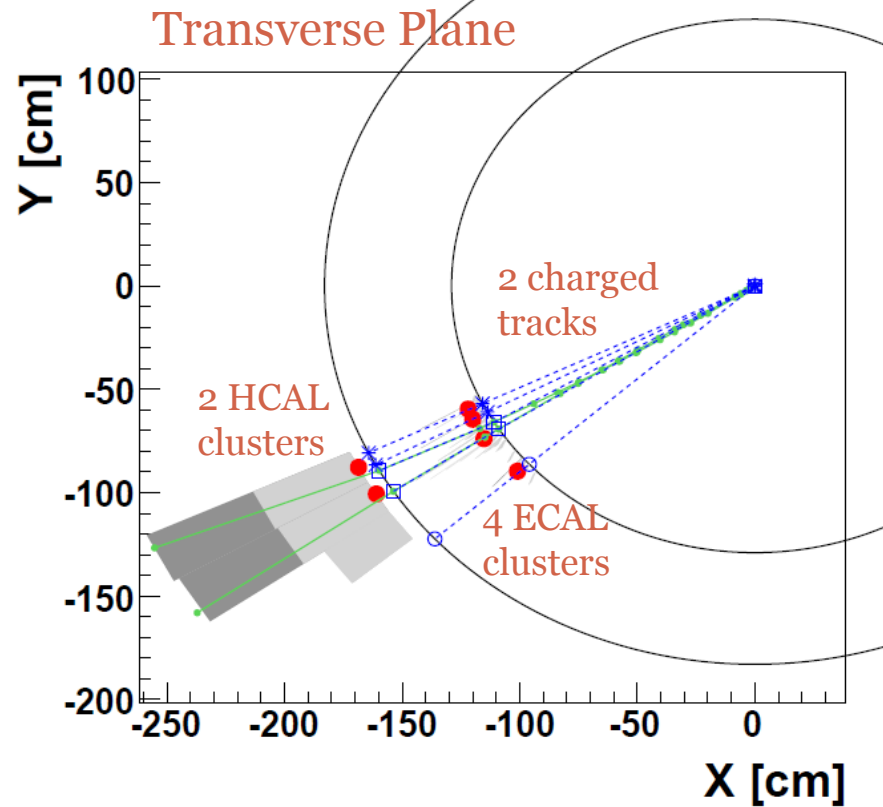
7



- Reconstruct elements.
  - Charged tracks, energy deposits in calo, muon tracks
- Link elements to blocks.
- Blocks interpreted as particles.
  - Example: charged hadron
- Higher level physics objects are built from particles
- Physics analyses...

# Particle Flow Elements

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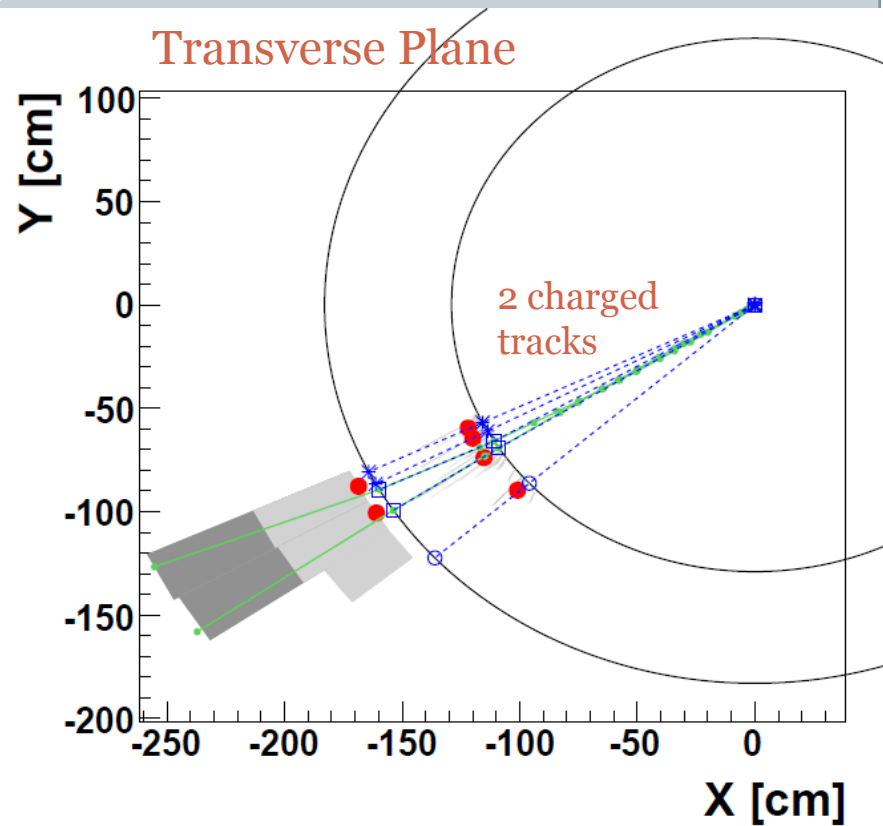
$(\pi^+, \pi^-, \pi^0, K_L^0)$

# Particle Flow Elements

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Track

Track



$(\pi^+, \pi^-, \pi^0, K_L^0)$

# Particle Flow Elements

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ECAL  
Cluster

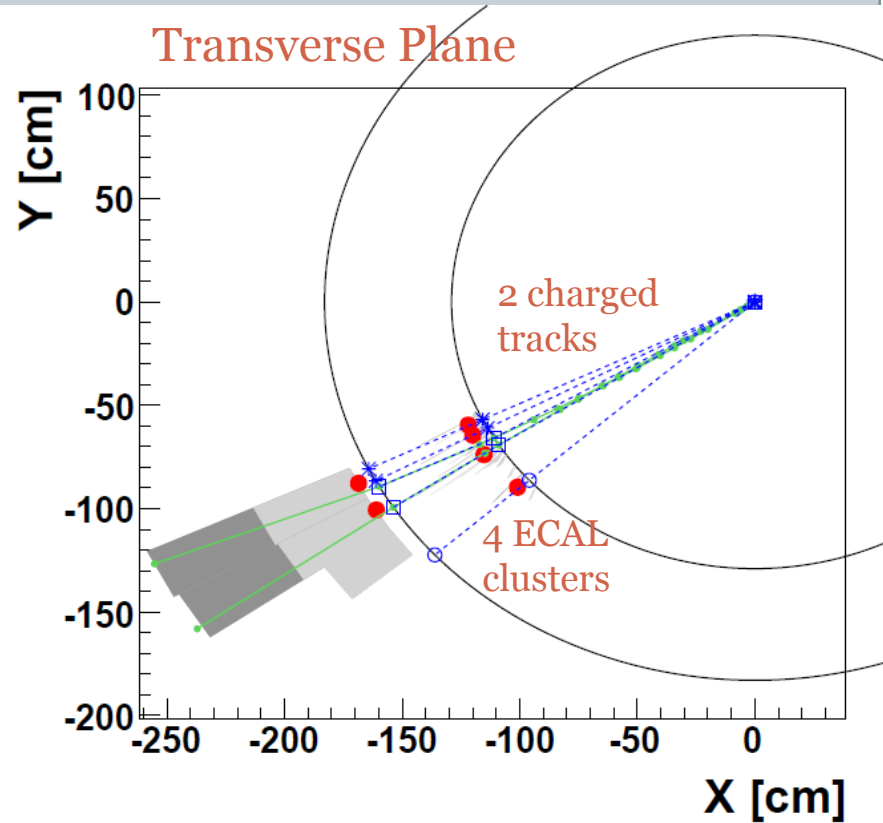
ECAL  
Cluster

ECAL  
Cluster

ECAL  
Cluster

Track

Track



$(\pi^+, \pi^-, \pi^0, K_L^0)$

# Particle Flow Elements

11

HCAL  
Cluster

HCAL  
Cluster

ECAL  
Cluster

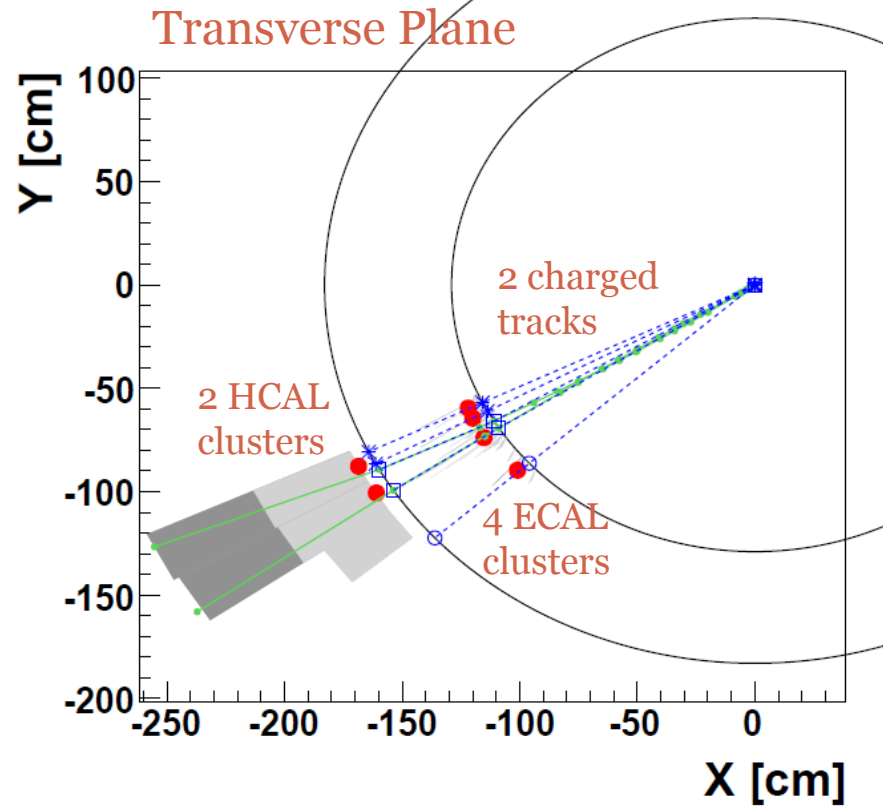
ECAL  
Cluster

ECAL  
Cluster

ECAL  
Cluster

Track

Track



$(\pi^+, \pi^-, \pi^0, K_L^0)$

# Linking Algorithm: Track-ECAL clusters

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HCAL Cluster

HCAL Cluster

ECAL Cluster

ECAL Cluster

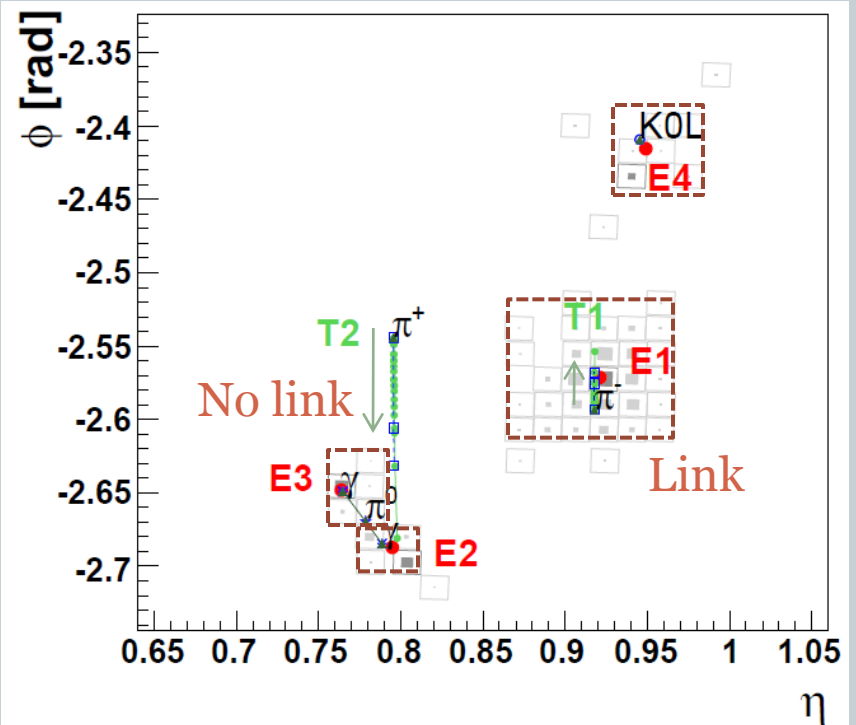
ECAL Cluster

ECAL Cluster

Track

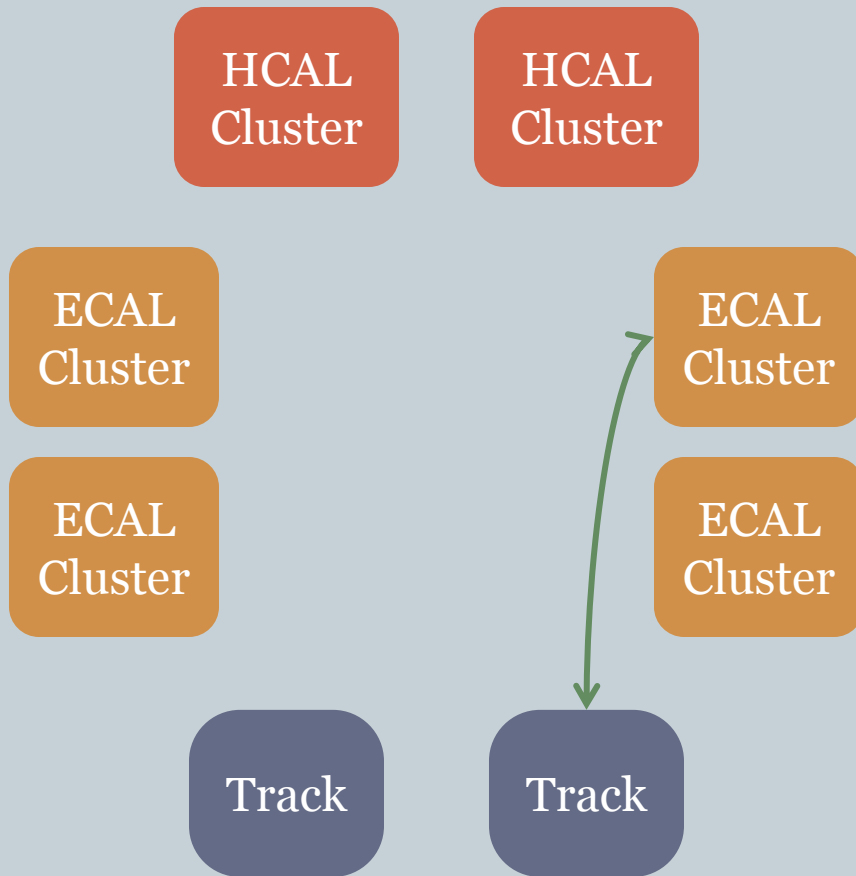
Track

ECAL,  $(\eta, \phi)$  plane

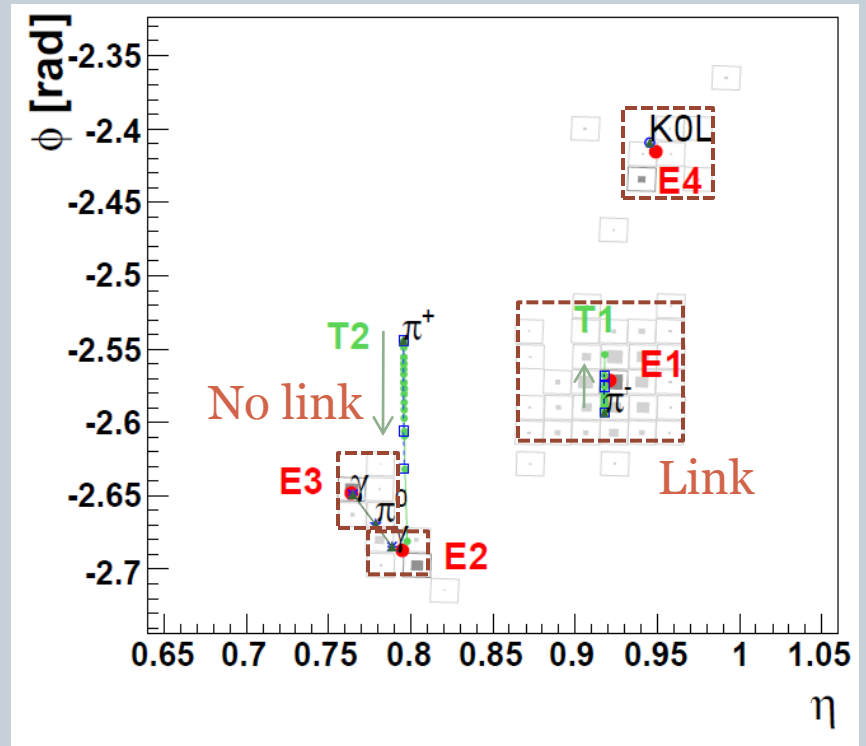


# Linking Algorithm: Track-ECAL clusters

13



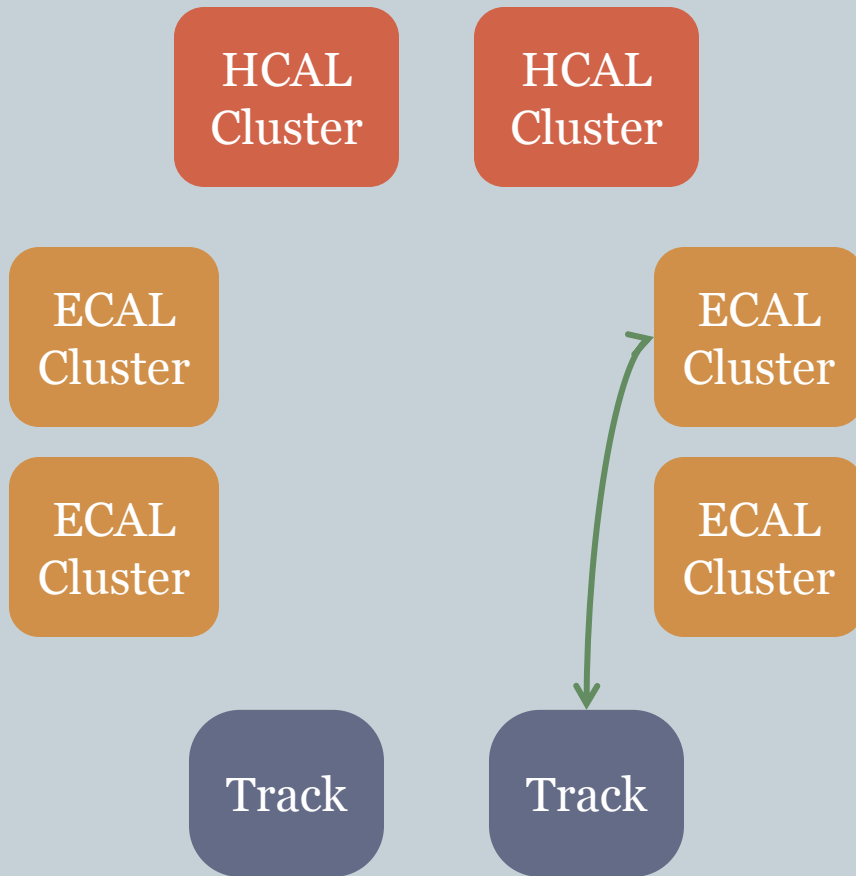
ECAL,  $(\eta, \phi)$  plane



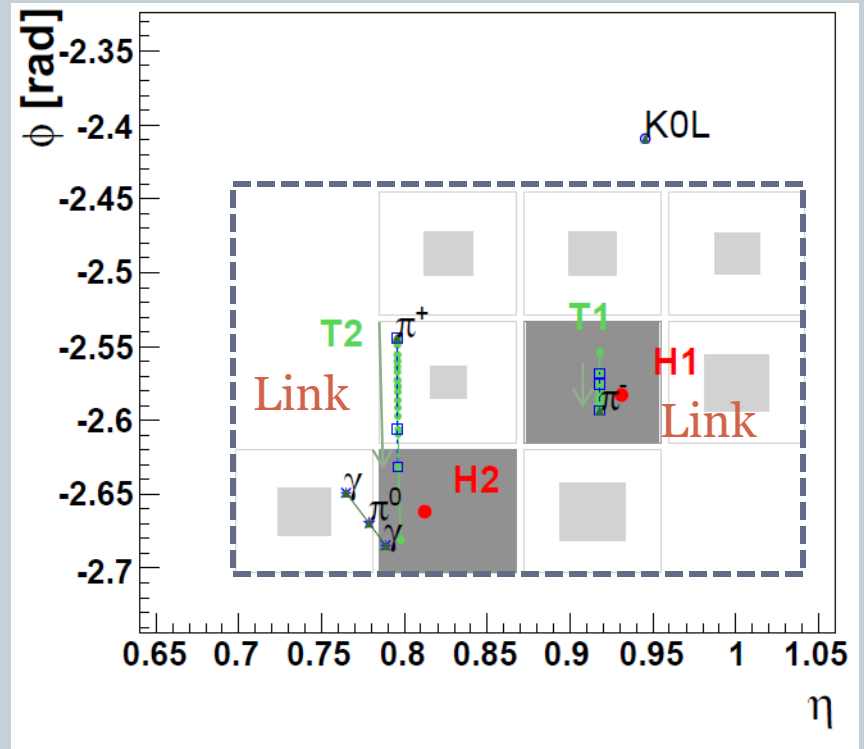
CMS PAS PFT-09-001

# Linking Algorithm: Track-HCAL clusters

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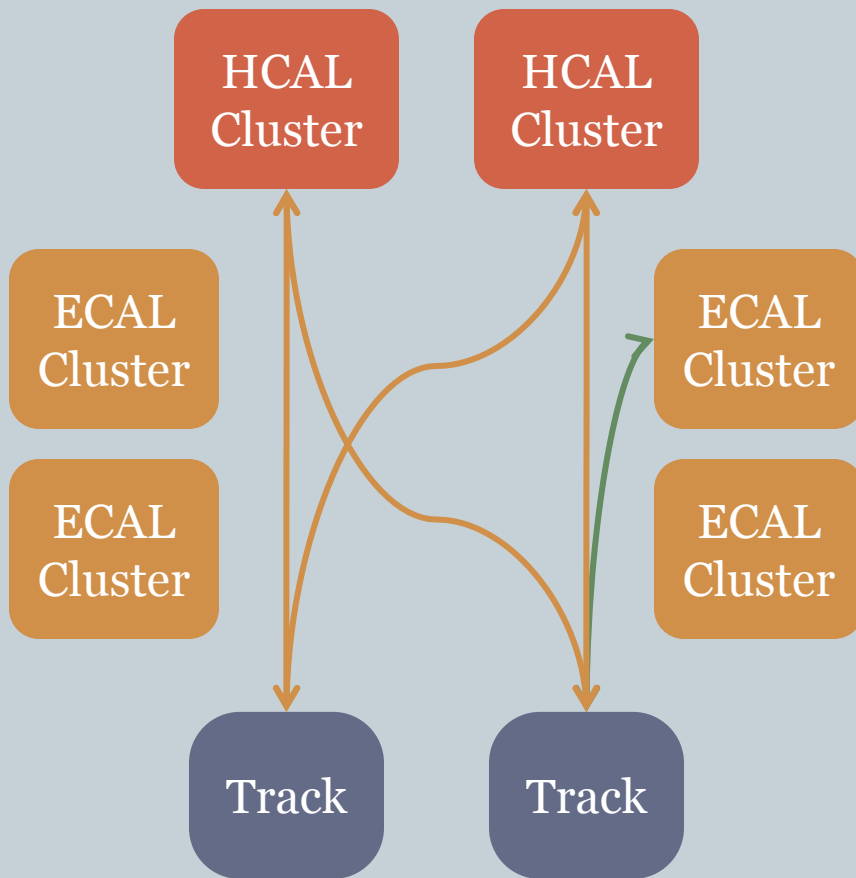
HCAL,  $(\eta, \phi)$  plane



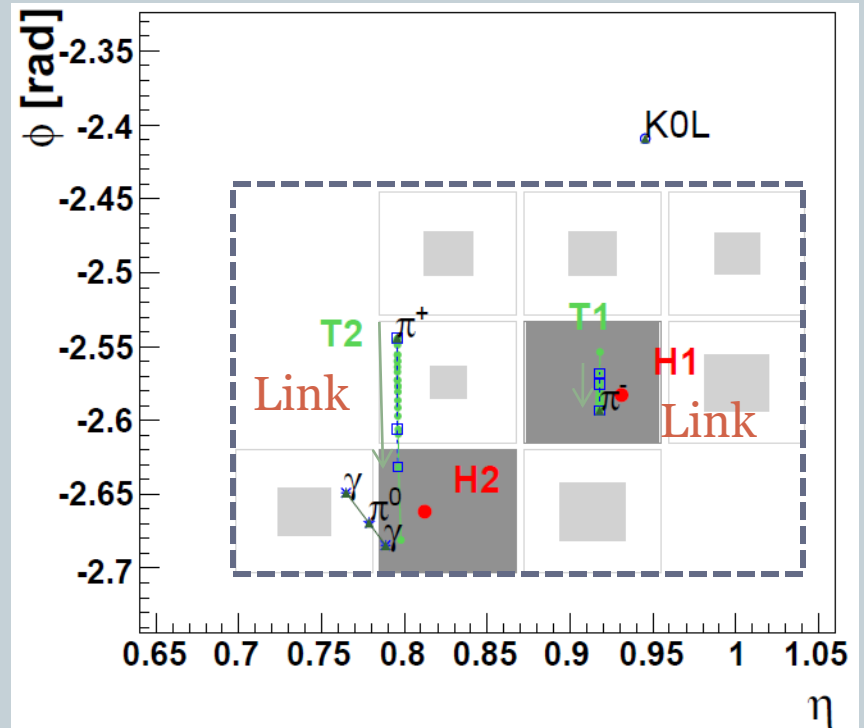
CMS PAS PFT-09-001

# Linking Algorithm: Track-HCAL clusters

15



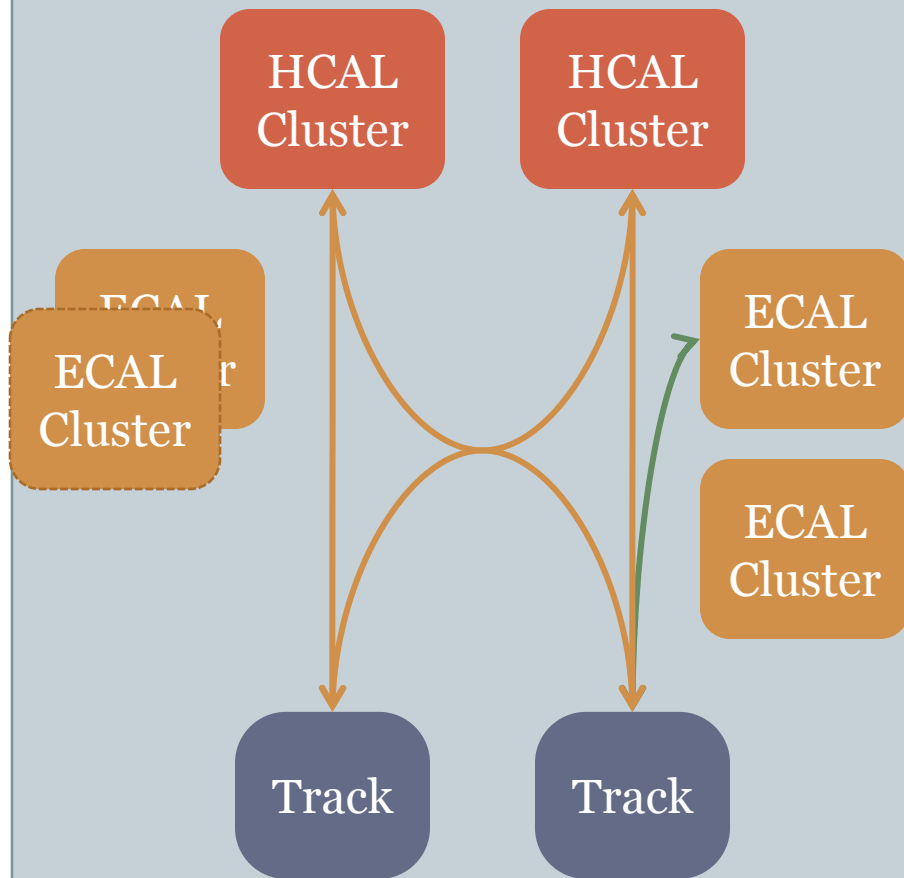
## HCAL, $(\eta, \phi)$ plane



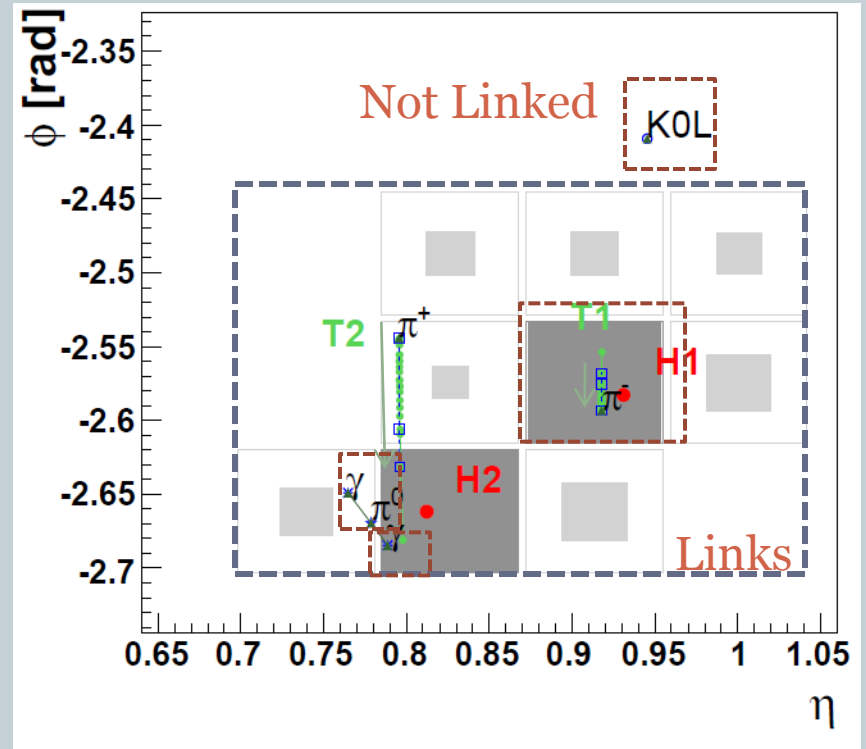
CMS PAS PFT-09-001

# Linking Algorithm: HCAL-ECAL clusters

16

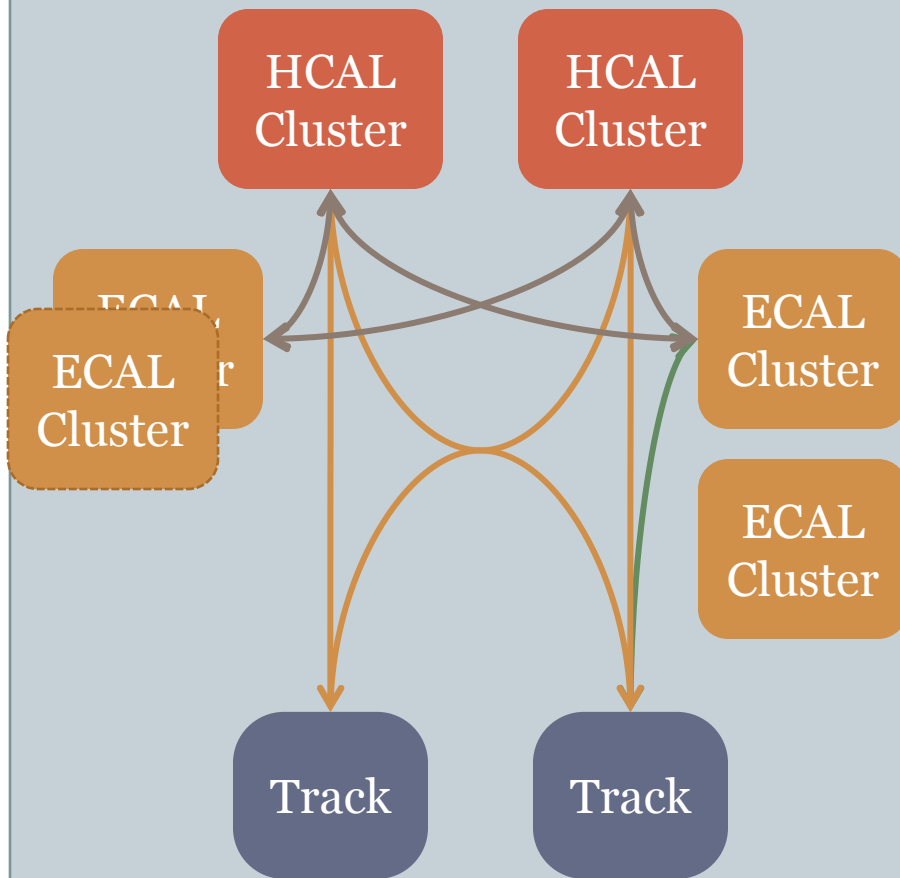


## HCAL, ( $\eta, \phi$ ) plane

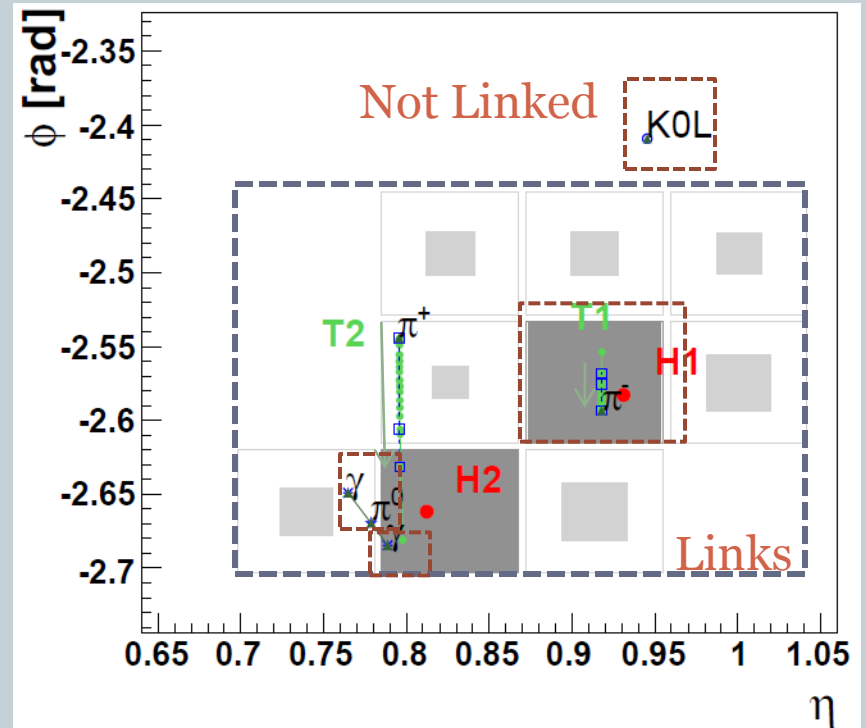


# Linking Algorithm: HCAL-ECAL clusters

17

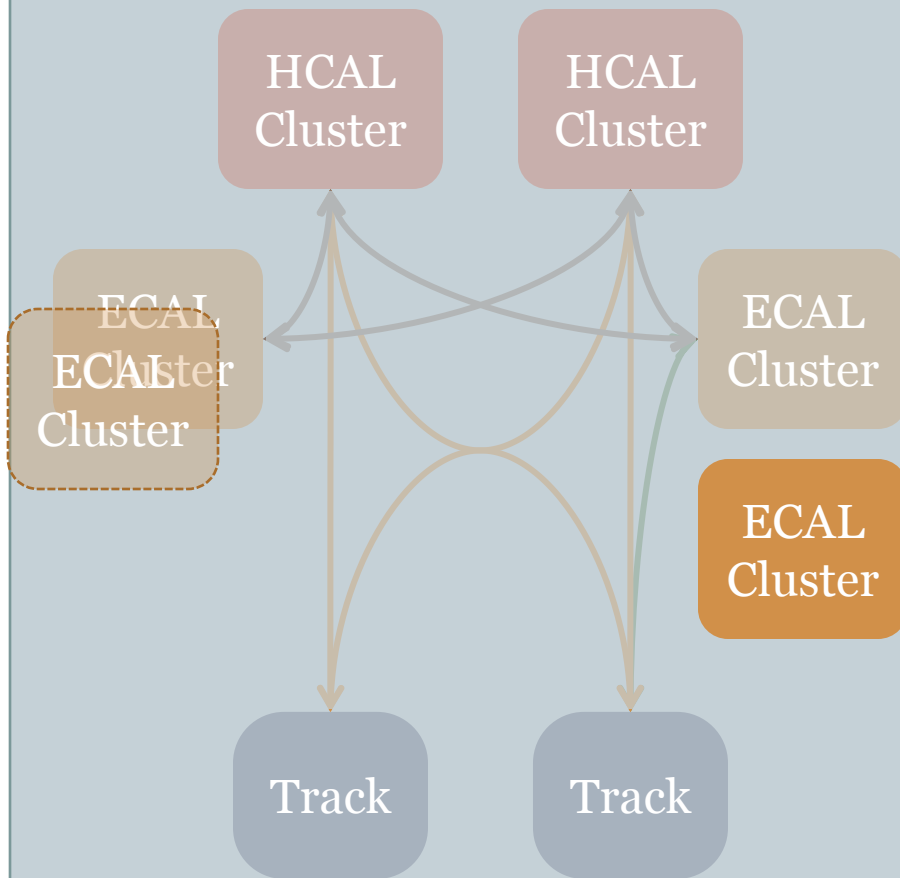


## HCAL, ( $\eta, \phi$ ) plane

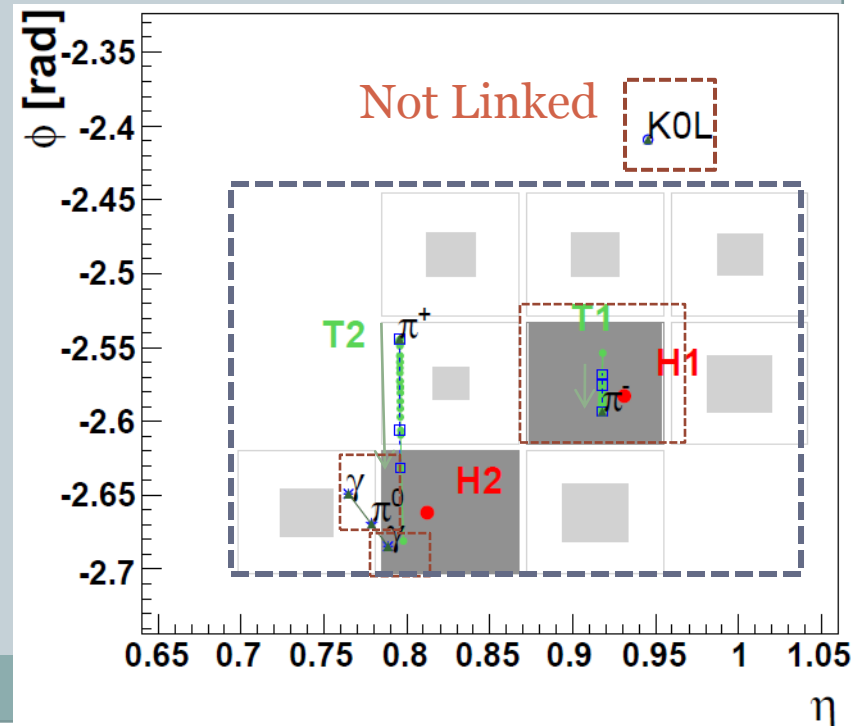


# Particle Identification

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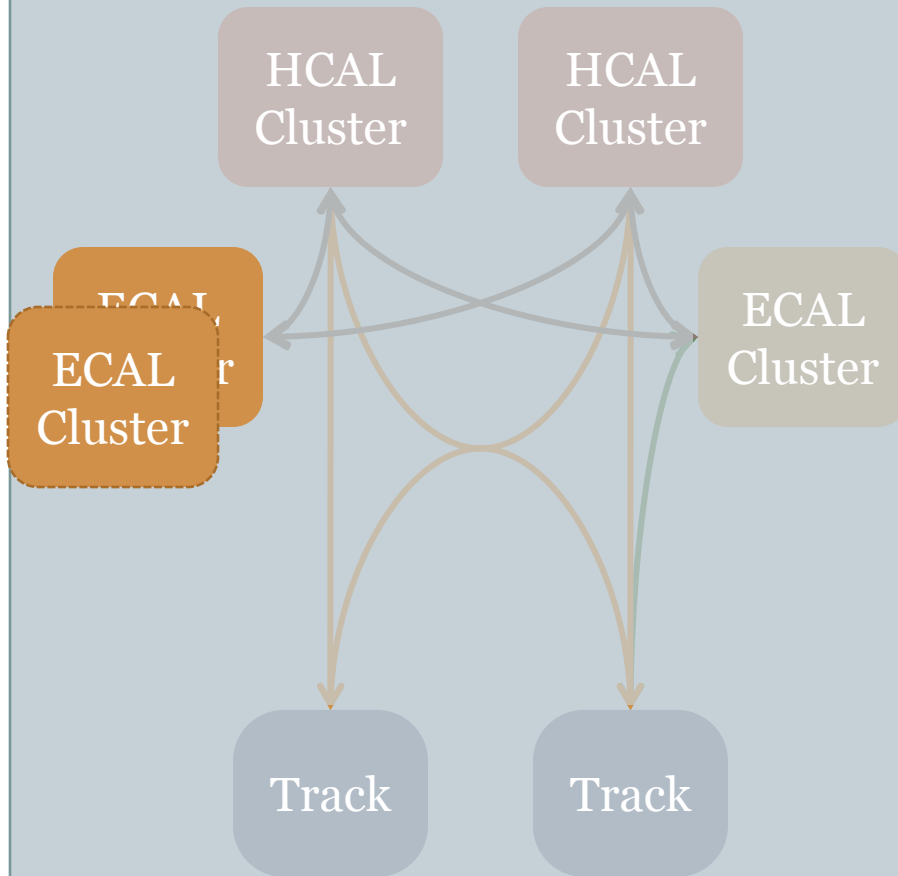


- Two Blocks
- Lone deposit in ECAL interpreted as a photon.
- Block is removed.



# Particle Identification

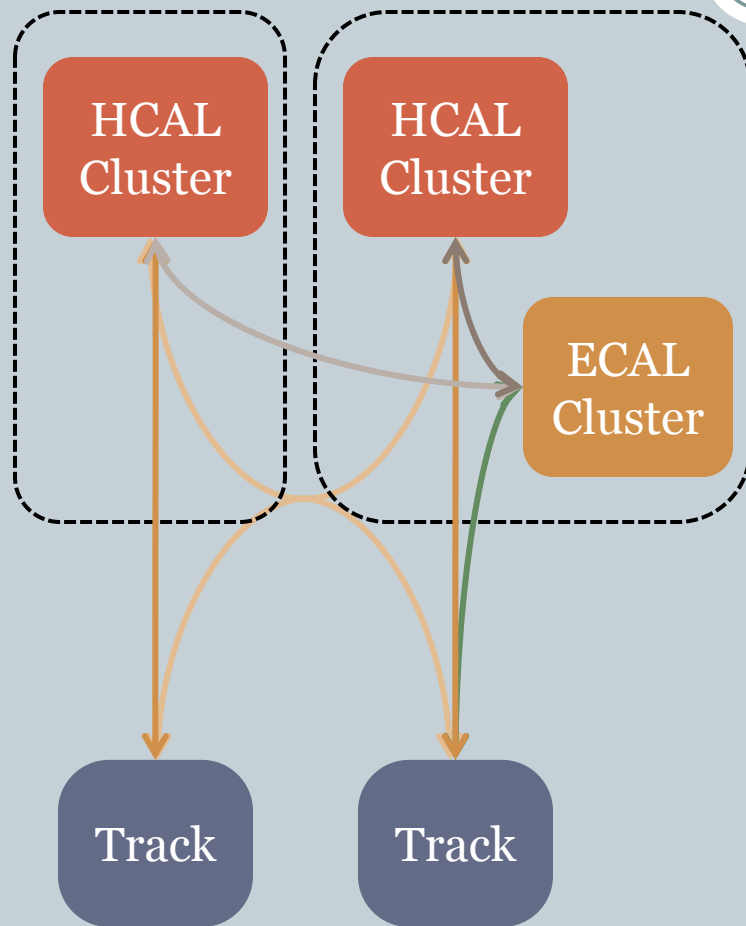
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- Two ECAL clusters without tracks
- Interpreted as two more photons.
- Elements are removed from the block.

# Particle Identification

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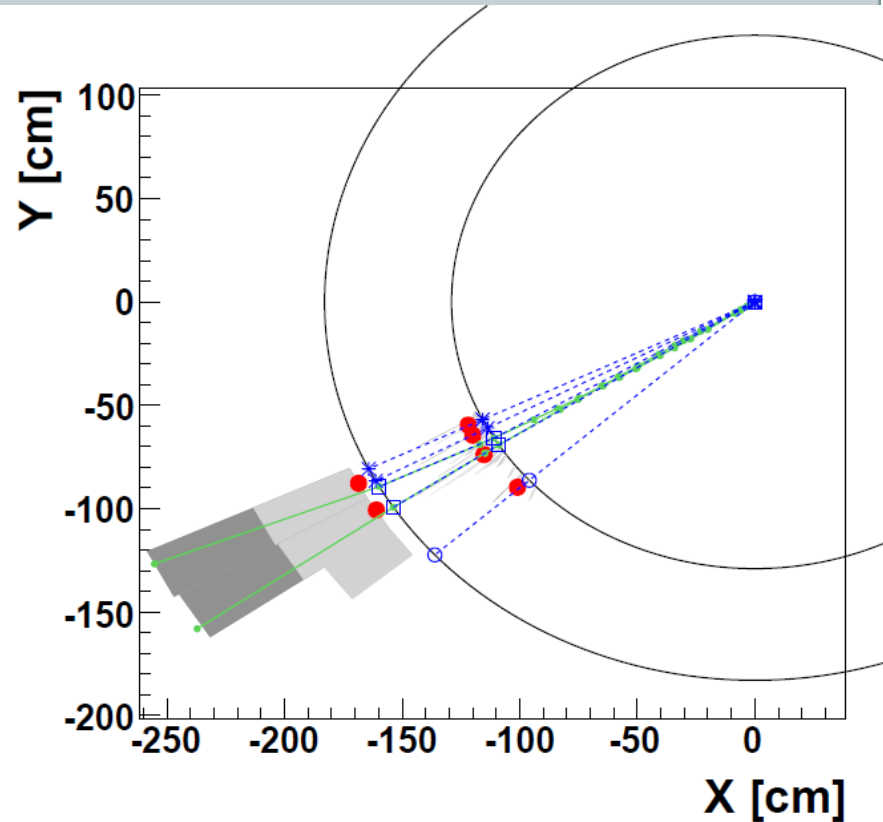


- Closest links are kept.
- Energy ( $E$ ) in calorimeters calculated.
  - HCAL + ECAL
- Track momentum ( $P$ ) calculated
- If  $E > P + \sigma_{\text{calo}}$ 
  - Charged Hadrons
  - Excess energy assigned to:
    - ✦ Neutral hadrons (excess HCAL)
    - ✦ Photons (ECAL)
- Else if  $E < P + \sigma_{\text{calo}}$ 
  - Look for mis-measured tracks or more muons.

# Particle Identification

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- List of particles is returned from the PFA.
  - Two oppositely charged hadrons ( $\pi^-\pi^+$ )
  - Two photons ( $\pi^0$ )
  - Additional photon ( $K_L^0$ )
- This list of particles can be passed to a jet clustering algorithm
- Energy of charged particles is measured more accurately.
  - Measurement of the jet energy will therefore be more accurate

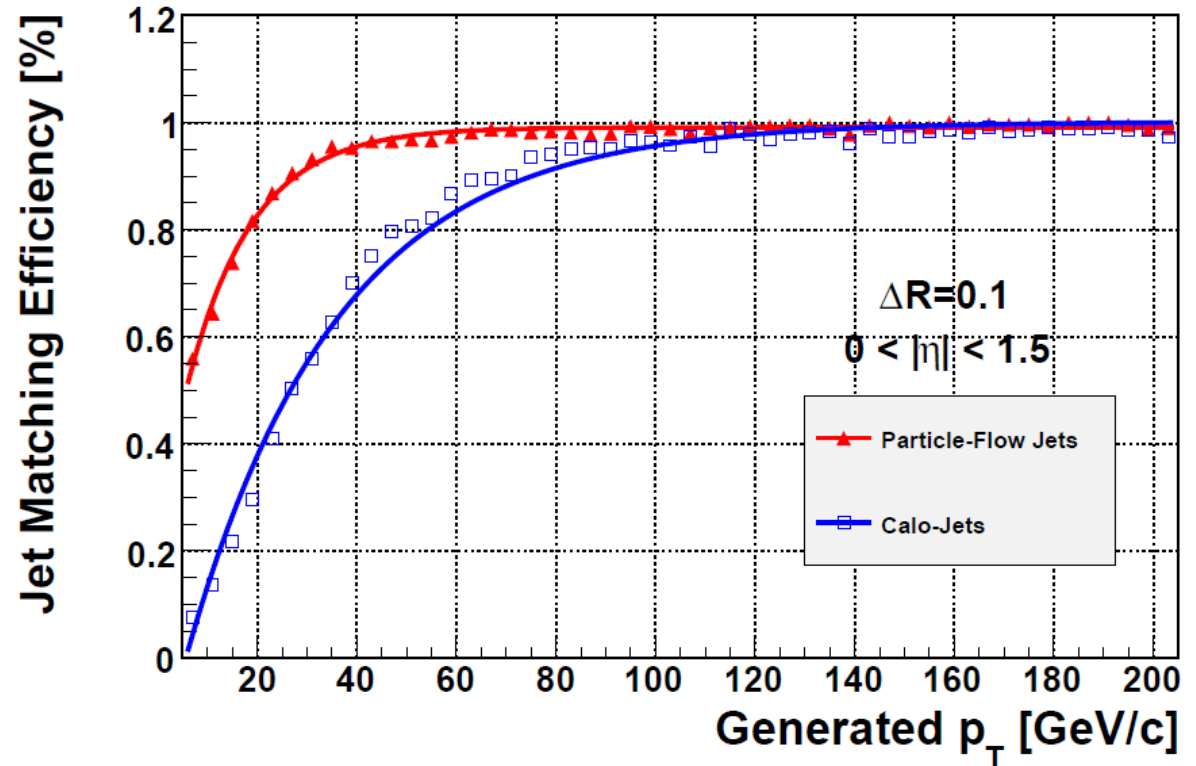


$(\pi^+, \pi^-, \pi^0, K_L^0)$

## Performance with Jets

- MC full sim
- Iterative cone algorithm
- Barrel Region
- Matching distance of 0.1

CMS Preliminary

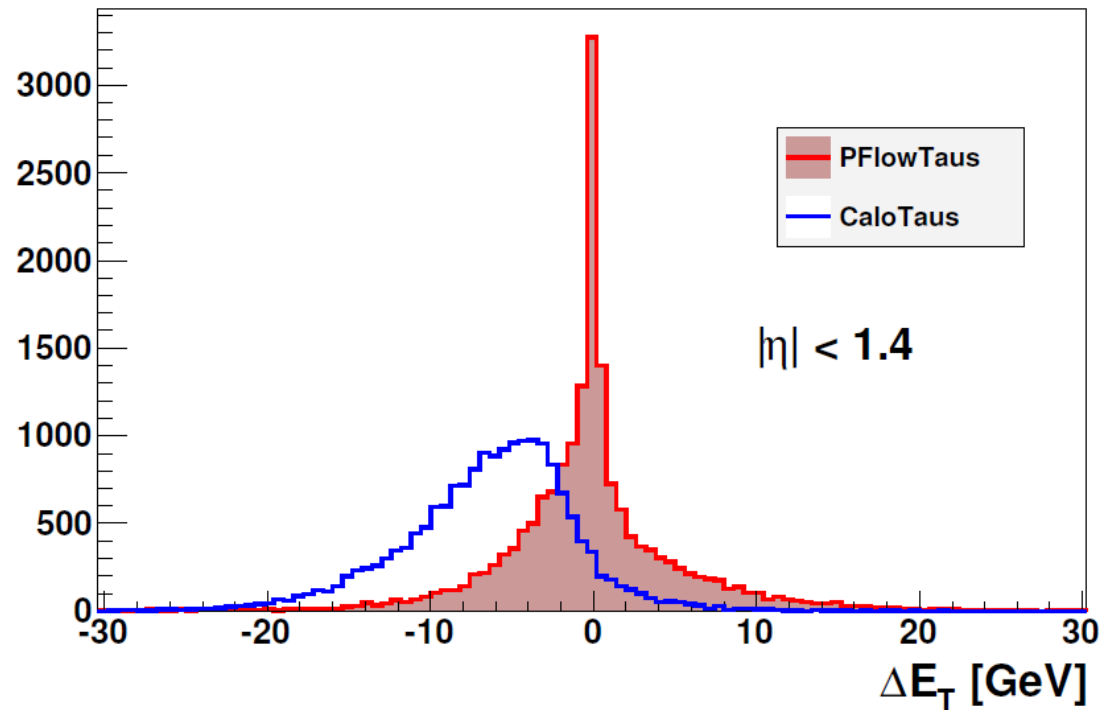


CMS PAS PFT-09-001

## Performance with Taus

- MC full sim Ztautau
- Barrel region
- Accurate measurement of energy and good resolution
- End caps not so good...
- Tau direction measurement also benefits from PF

CMS Preliminary

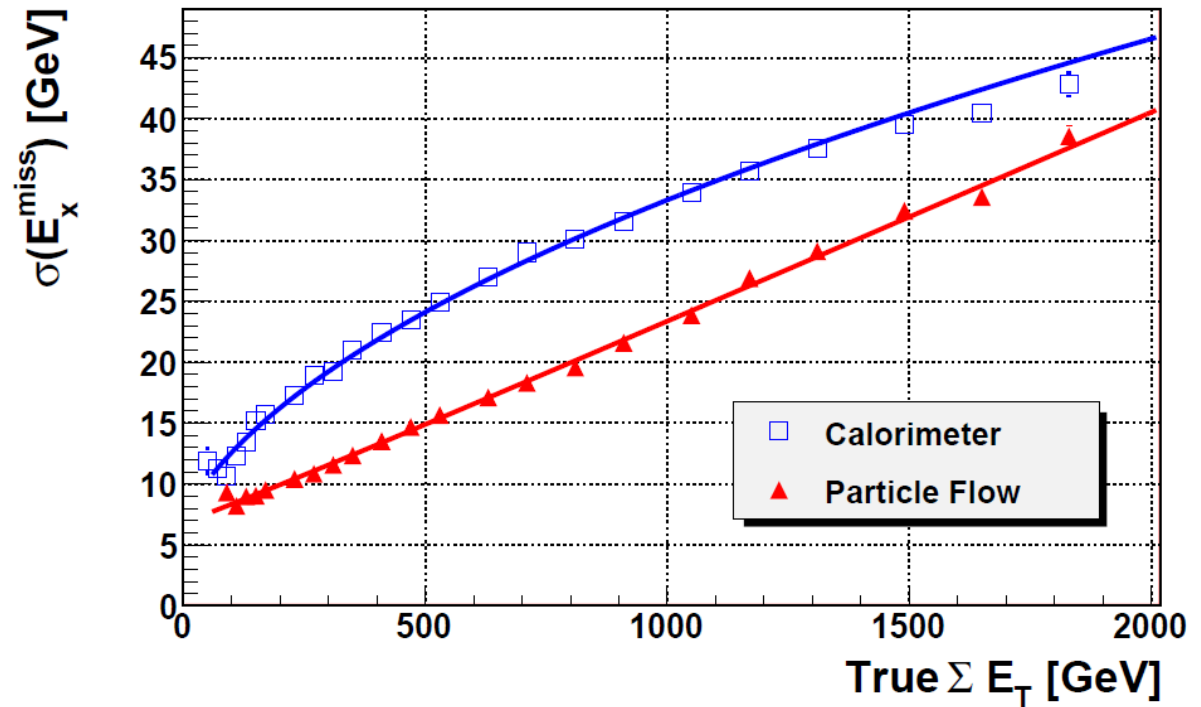


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## Performance with Missing Energy

- Data sample used should have zero missing energy.
- PF provides a better resolution of MET

CMS Preliminary



CMS PAS PFT-09-001

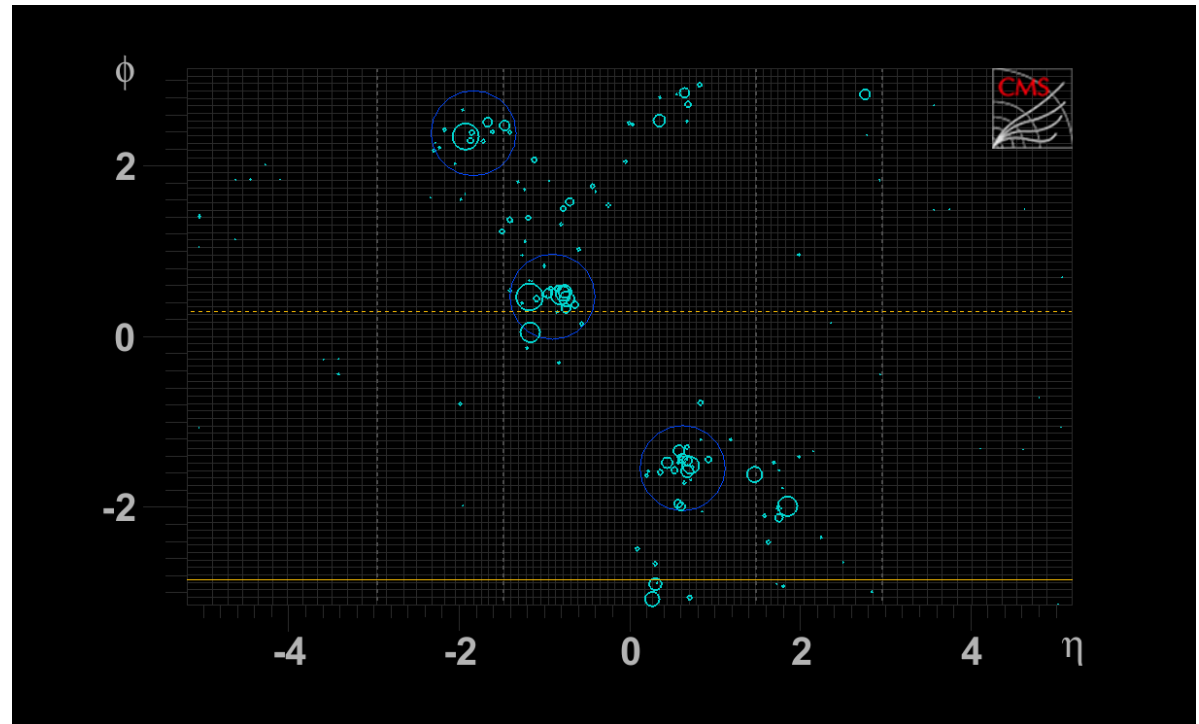
## Commissioning

In December 2009 CMS recorded 215 771 events at a centre-of-mass energy of 0.9 TeV. A few thousand events at 2.36 TeV were also recorded.

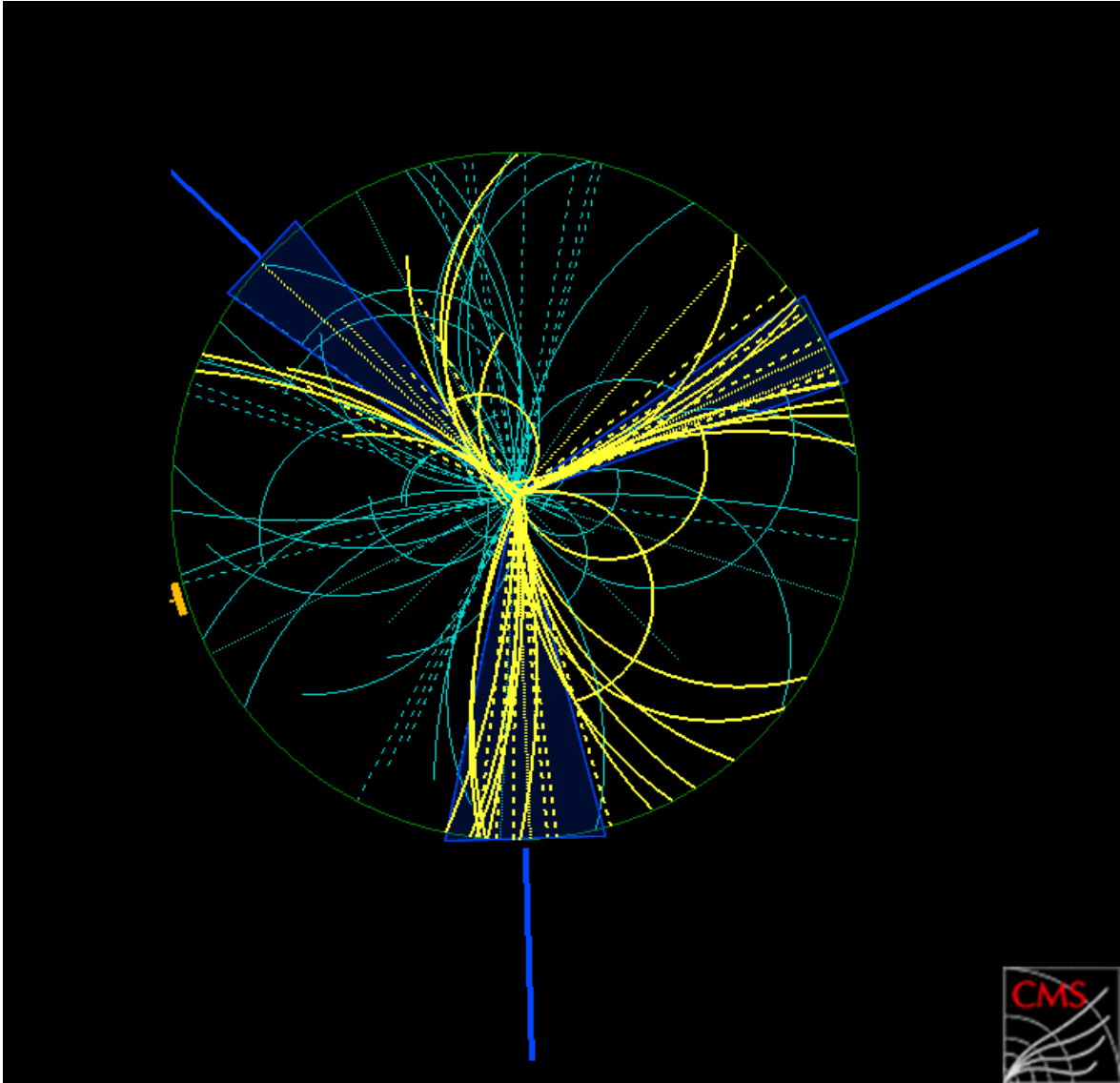
Reconstructed particles are indicated by small circles with radius proportional to  $P_T$ .

3 high  $P_T$  jets larger, thinner circles.

The missing transverse energy is estimated to be 1.9 GeV



**CMS PAS PFT-10-001**



**CMS PAS PFT-10-001**

# Conclusion

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- By combining the information from the various CMS sub-detectors the reconstruction of objects such as taus, jets and missing energy can be greatly improved.
- The energy and the direction measurements are improved by using more accurate information such as the tracker.
- This will benefit most CMS analyses.

# Motivation

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- Example:
- $ttH, H \rightarrow bb$
- For a good analysis we need:
  - Missing transverse energy measurement
  - Jet reconstruction
  - b-tagging

