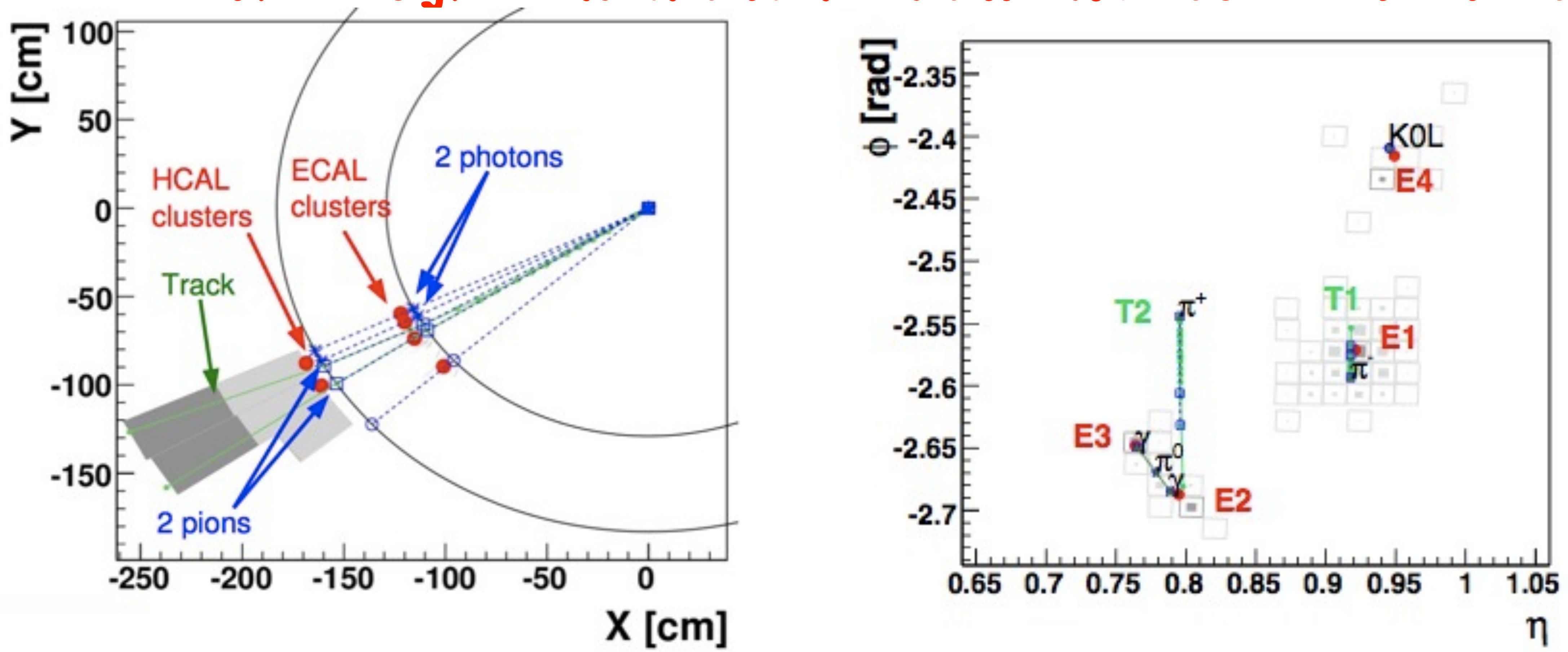
# Jets and MET reconstruction with the Particle Flow technique

Simone Gennai,
on behalf of the Particle Flow and Tau Id group

# Index

# Particle Flow in few words

The particle-flow event reconstruction aims at reconstructing and identifying all stable particles in the event, with a thorough combination of all CMS sub-detectors.



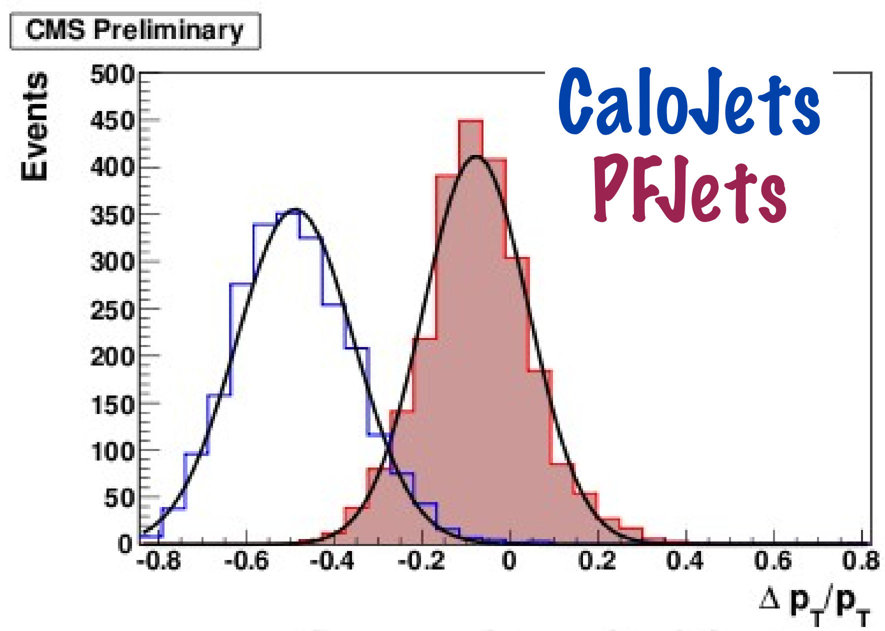

Simple Jet event

# Jet Reconstruction steps

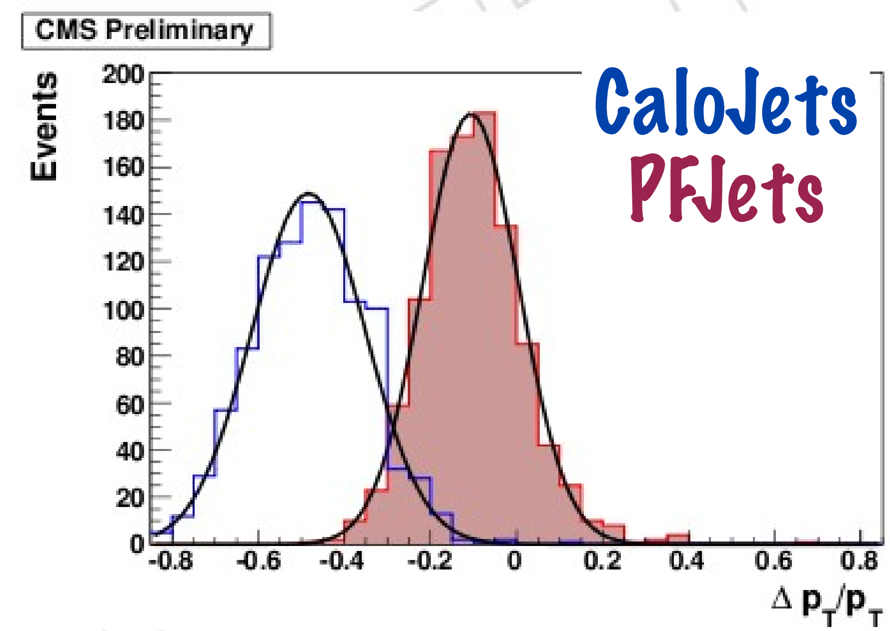
* The particles are reconstructed and identified
    * isolated leptons can be removed from the list of the particles to be considered in the jet clustering
        * see the tutorial for more informations
* N.B.: charged particle momentum is taken at production vertex!
    * no spead due to magnetic field will affect the jet reconstruction
* Are then passed to the clustering algorithm
    * the same used for CaloJet
        * in the next slides the IterativeCone 0.5 is used
* Once the jets are reconstructed a residual calibration can be applied

# Jet pT reconstruction

40-50 GeV/c

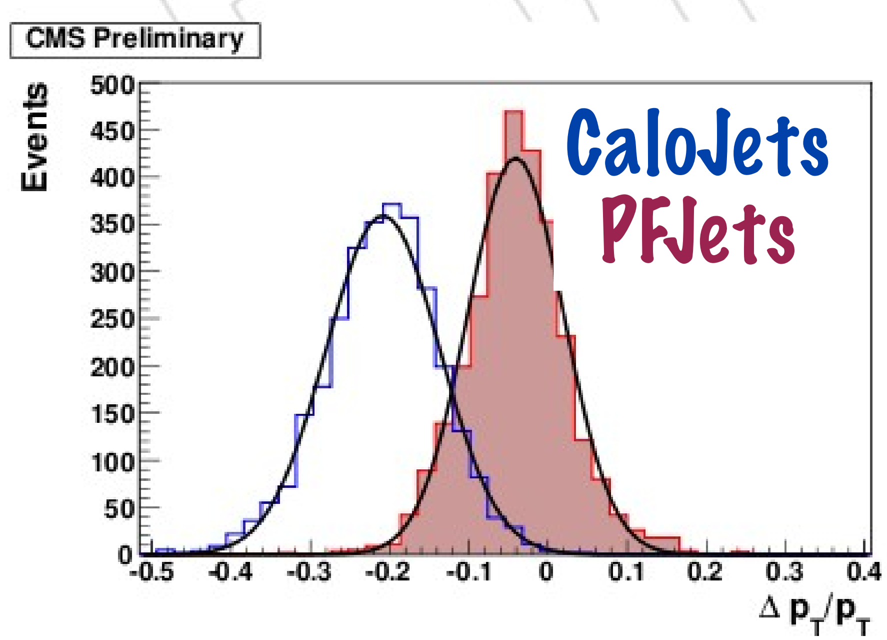



(a) $-1.5 < \eta < 1.5$

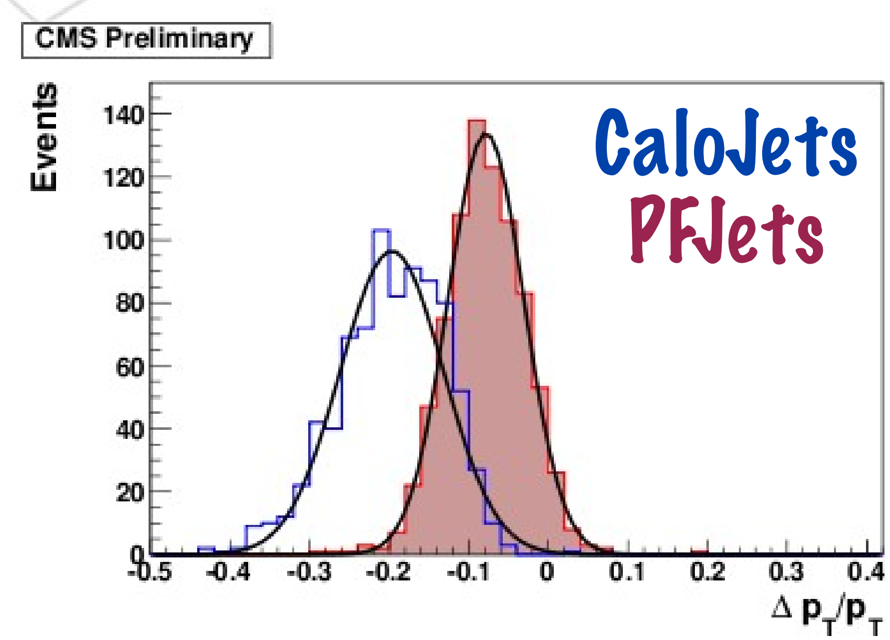



(b) $1.5 < |\eta| < 2.5$

300-400 GeV/c



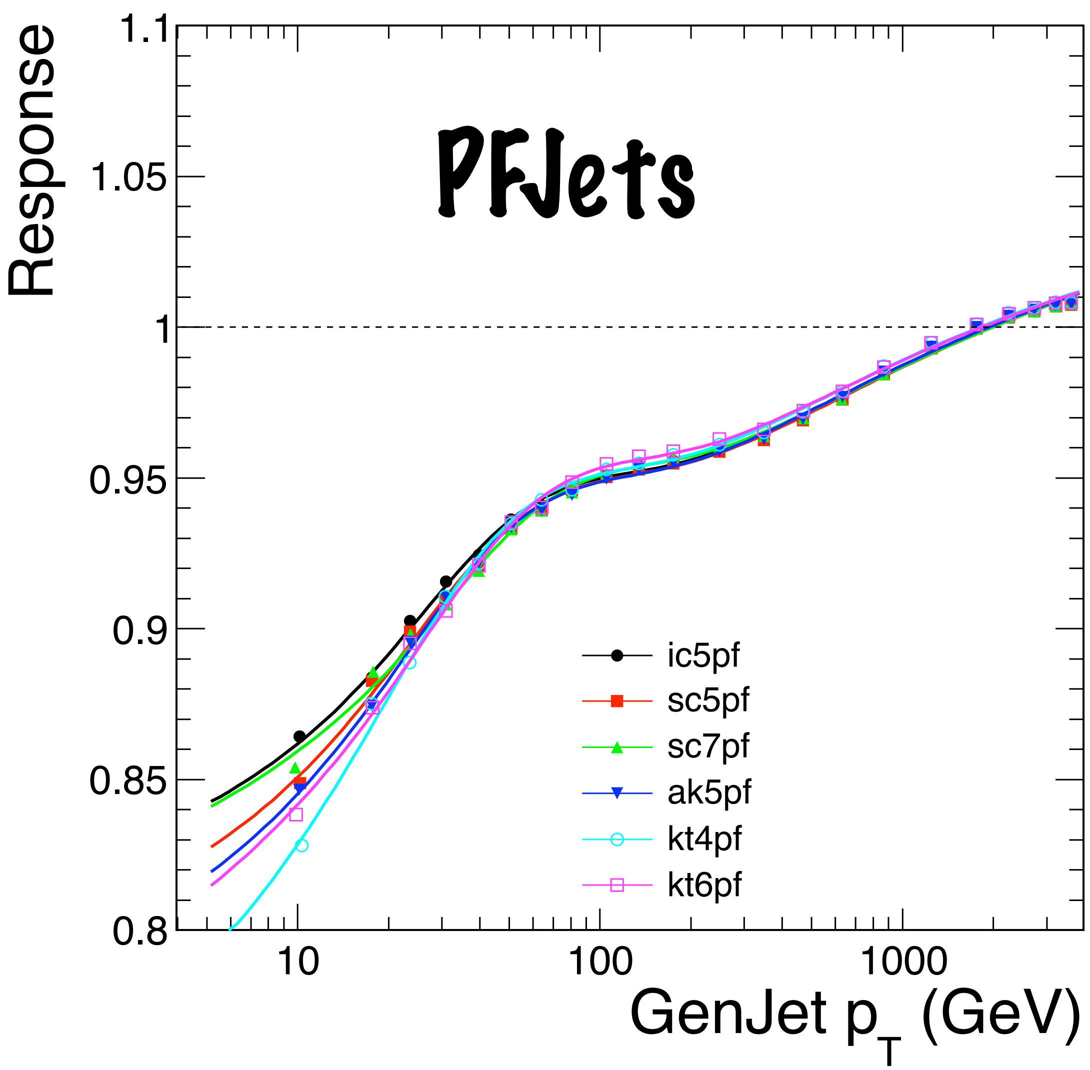

(c) $-1.5 < \eta < 1.5$

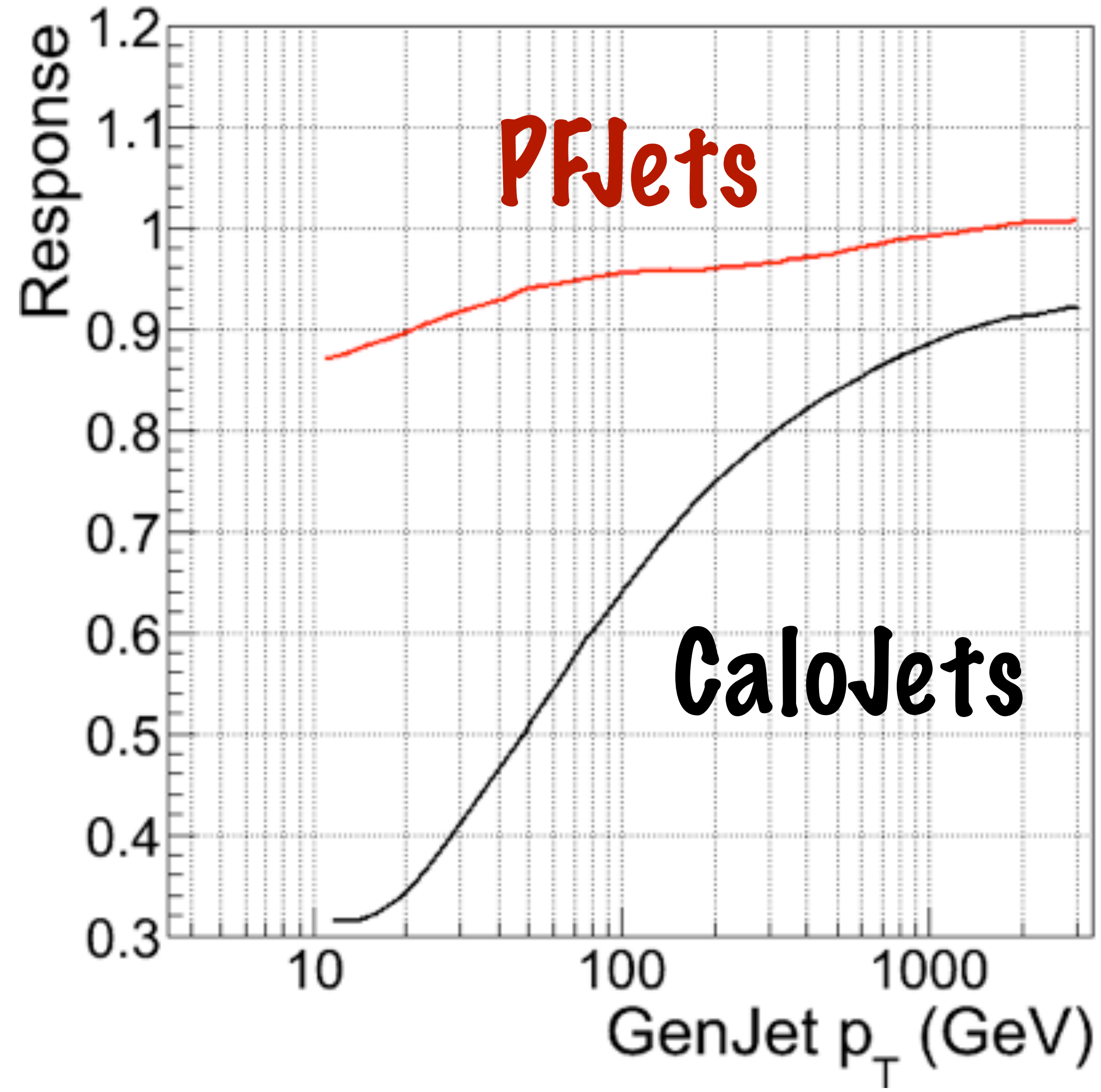



(d) $1.5 < |\eta| < 2.5$

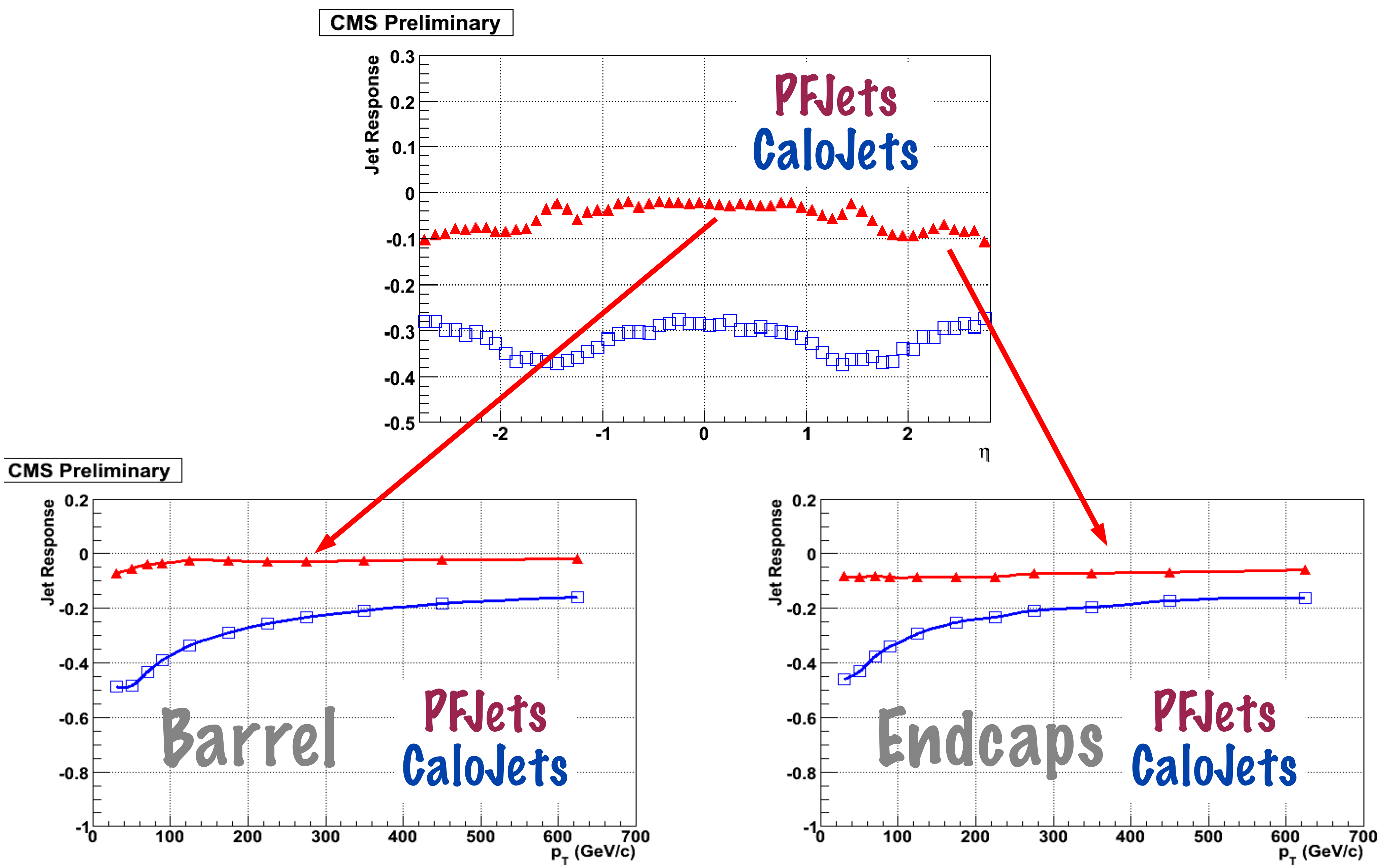
# Jet pT response

* At 10 GeV the dependence on the jet algorithm is:
  * < 4% for PFJets
  * < 10 % for CaloJets



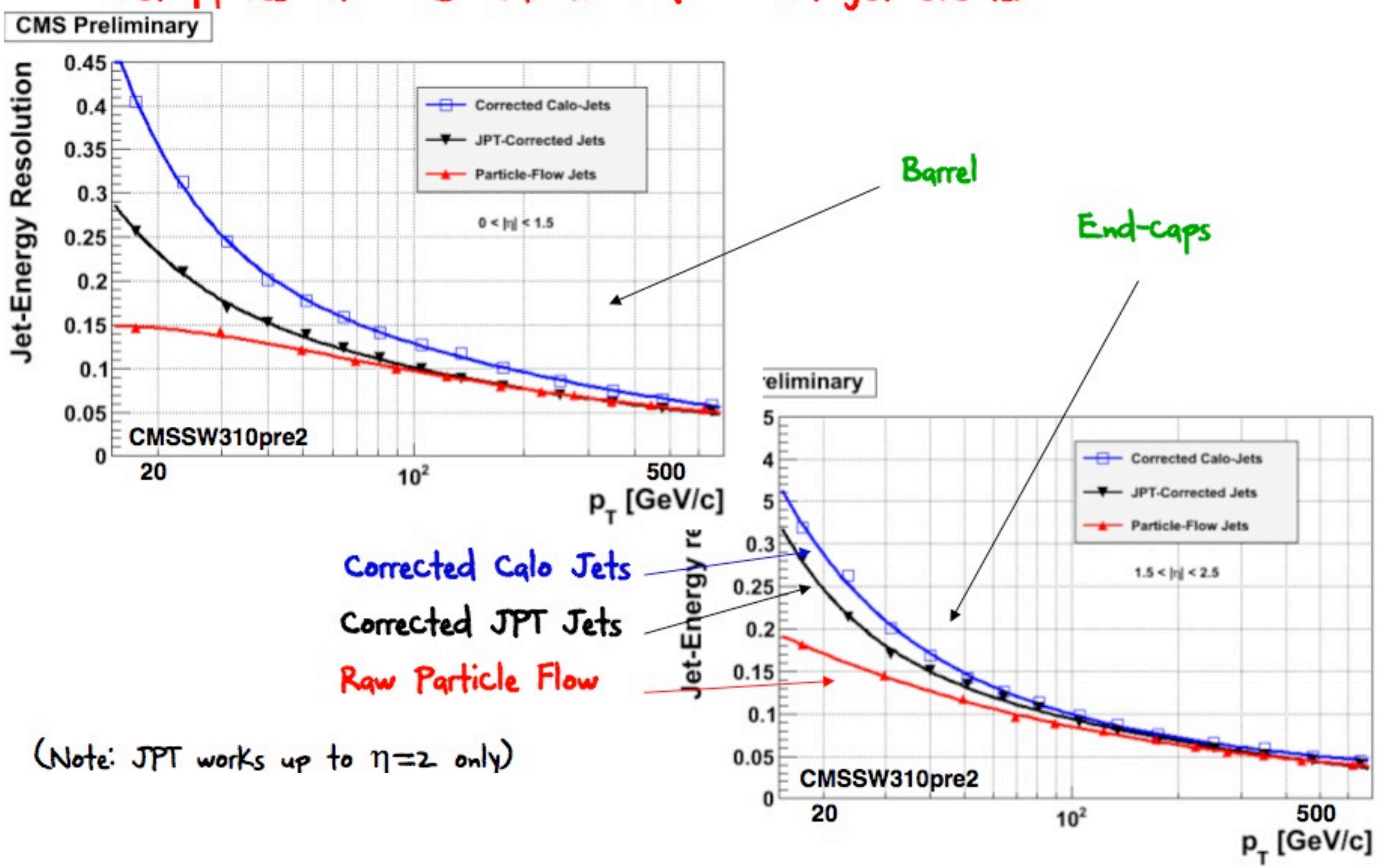



# Jet pT response in



# Jet pT resolution: PFlow Vs other techniques

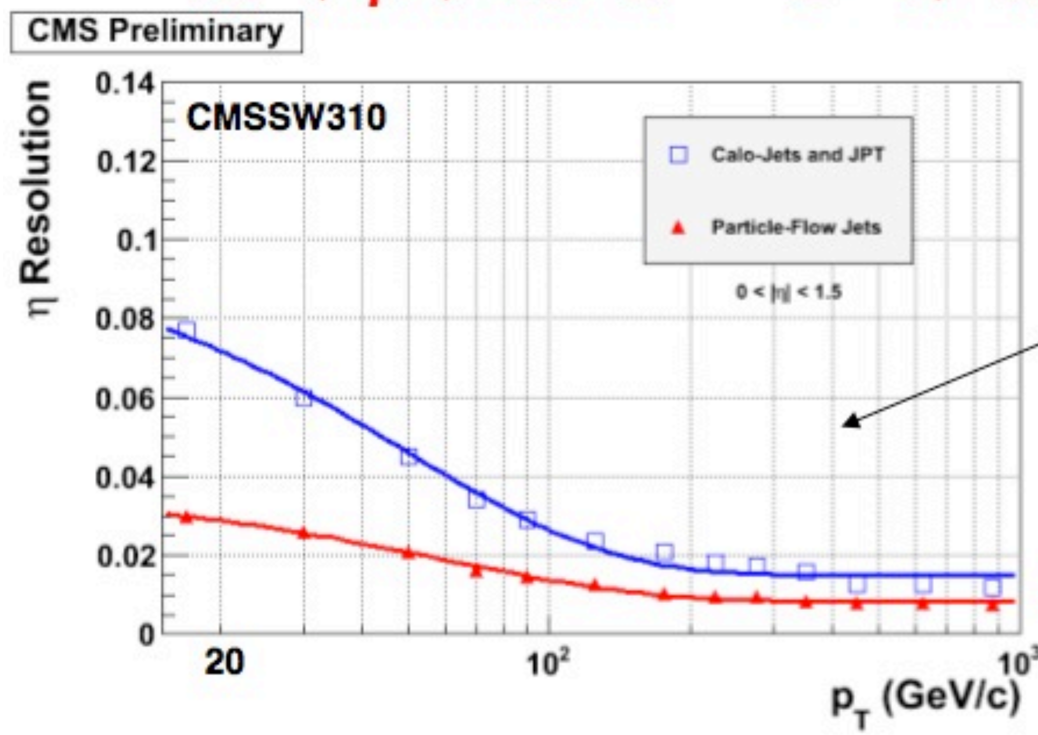
- Jet $p_T$ resolution (so far from QCD multi-jet events)




(Note: JPT works up to $\eta$=2 only)

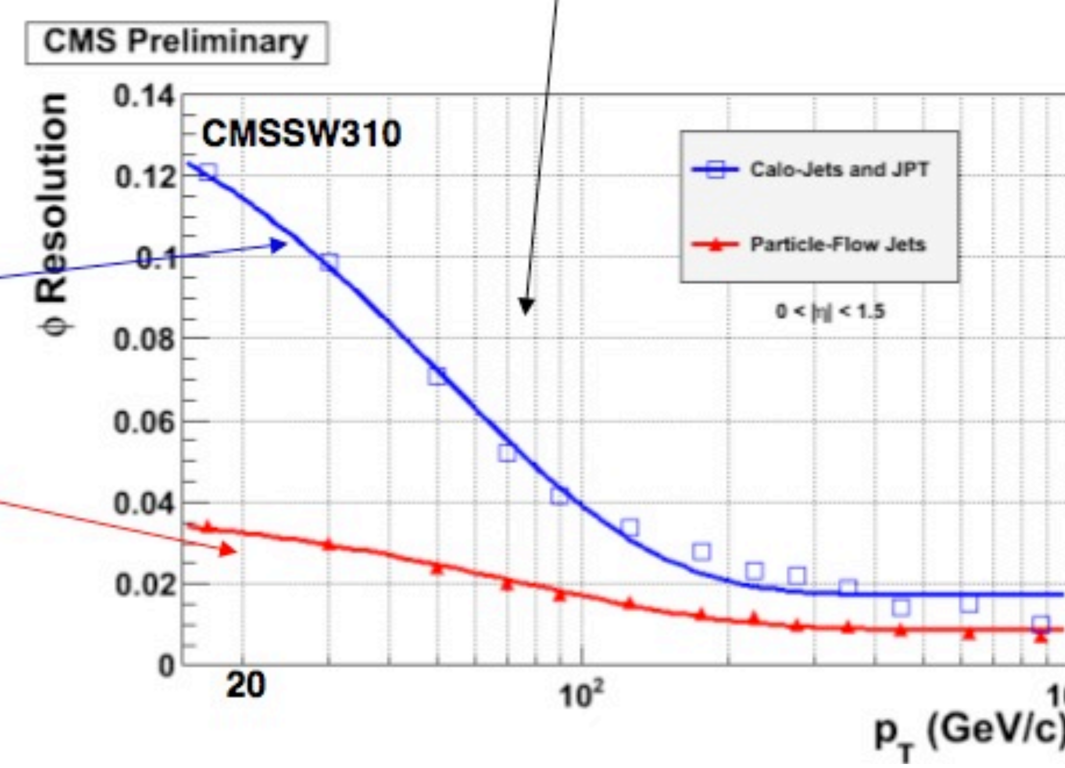
# Jet angular resolution: PFlow Vs other techniques

- Jet angular resolution (so far from QCD multijet events)




η resolution

ϕ Resolution



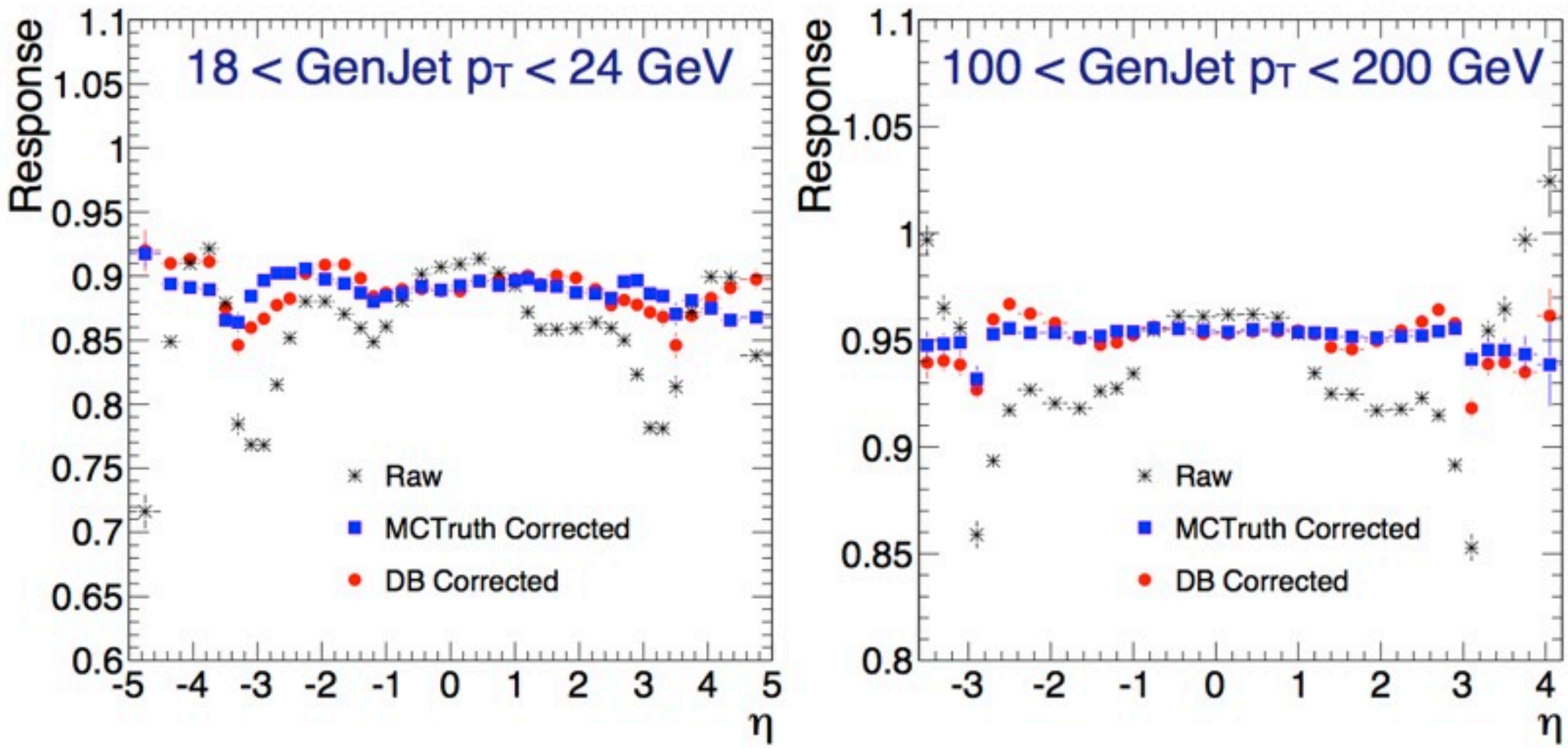

Calo Jets and JPT

Particle Flow

**PFlow is more than a factor of 2 better at low pT**

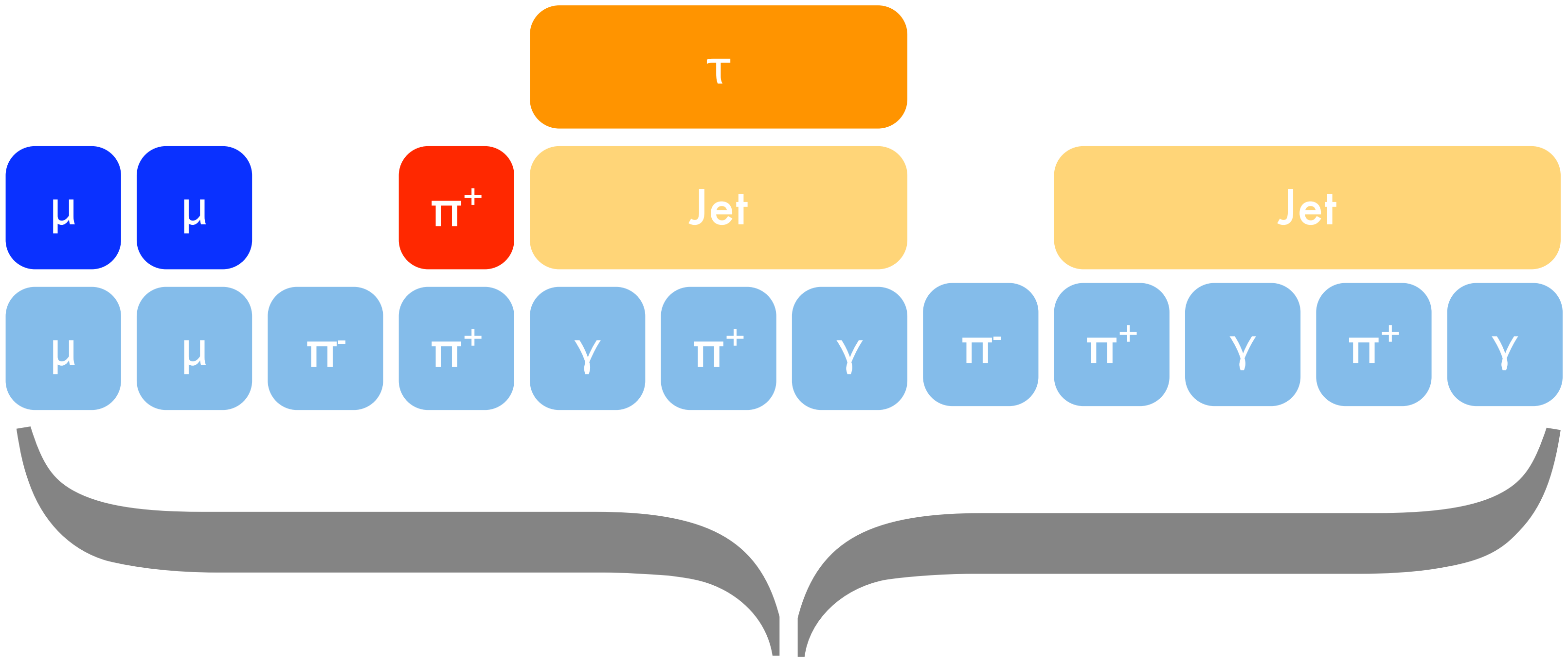
# Jet energy correction

- A 1st level correction can be applied to the PFJets in order to equalize the response in eta
- A residual correction can be applied to bring the response to 1
  - Only PFJets are shown in this plot
  - See Richard Cavanaugh's talk for more details



# PFMET

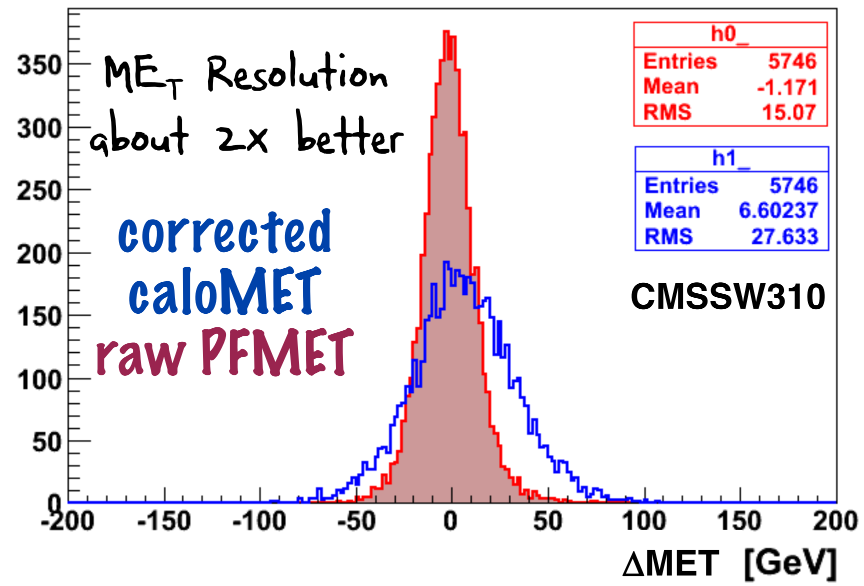
* With the Particle Flow technique the MET can be easily computed summing up the momentum of the reconstructed particles in the transverse plane
    * it would be more adequate to speak about missing momentum more than missing energy in this case!

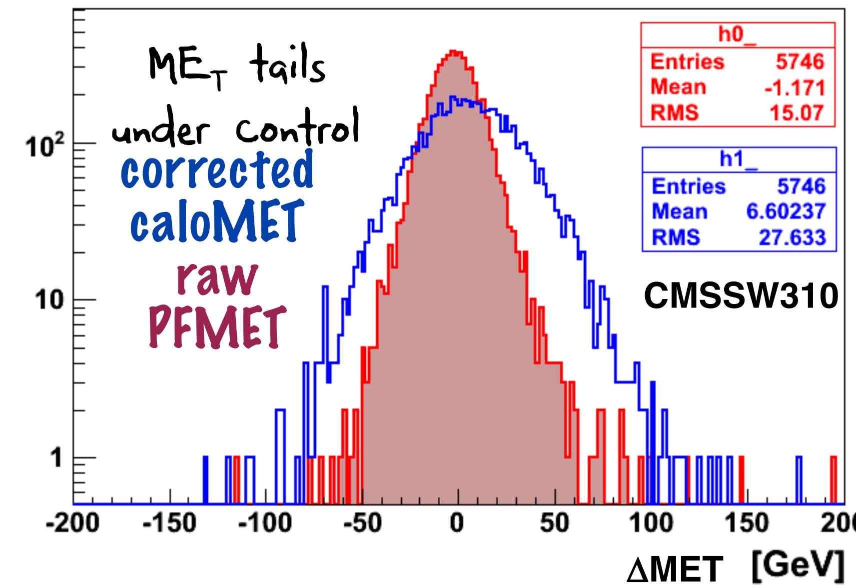


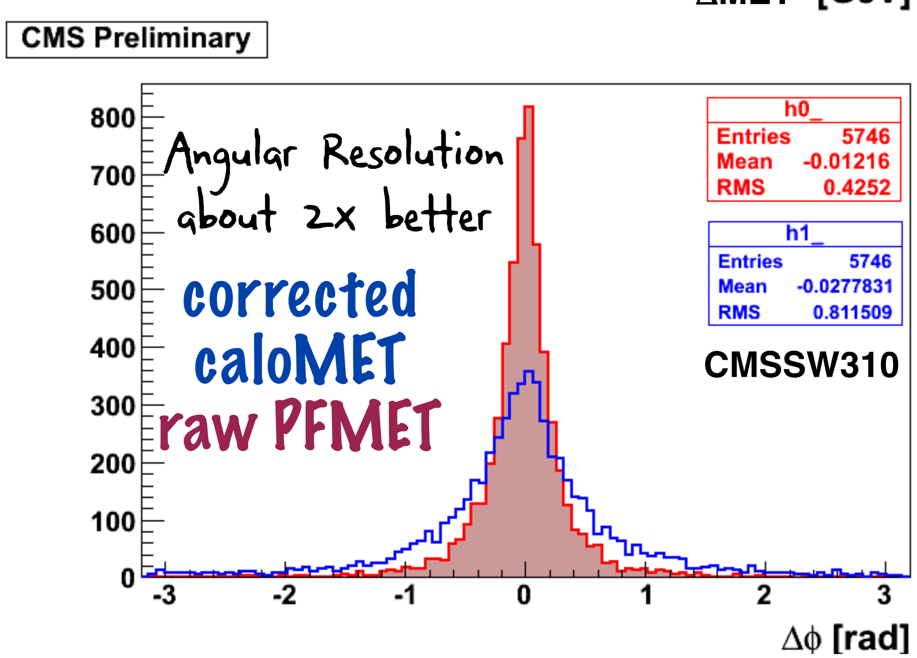

the MET can be computed before the other level objects are reconstructed

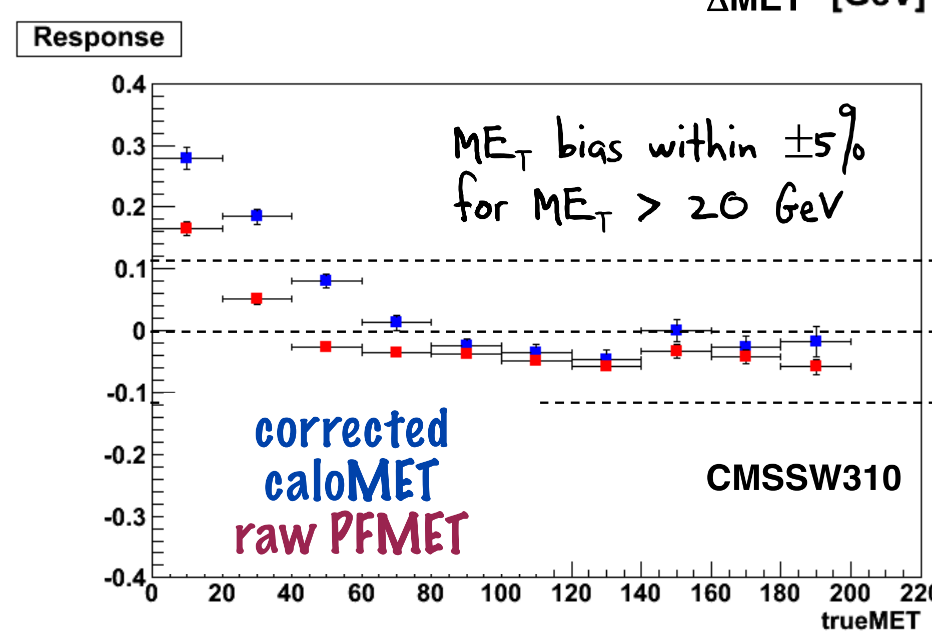
# PFMET vs CaloMET

* ttbar events
* CaloMET has Type-1 + muon correction applied



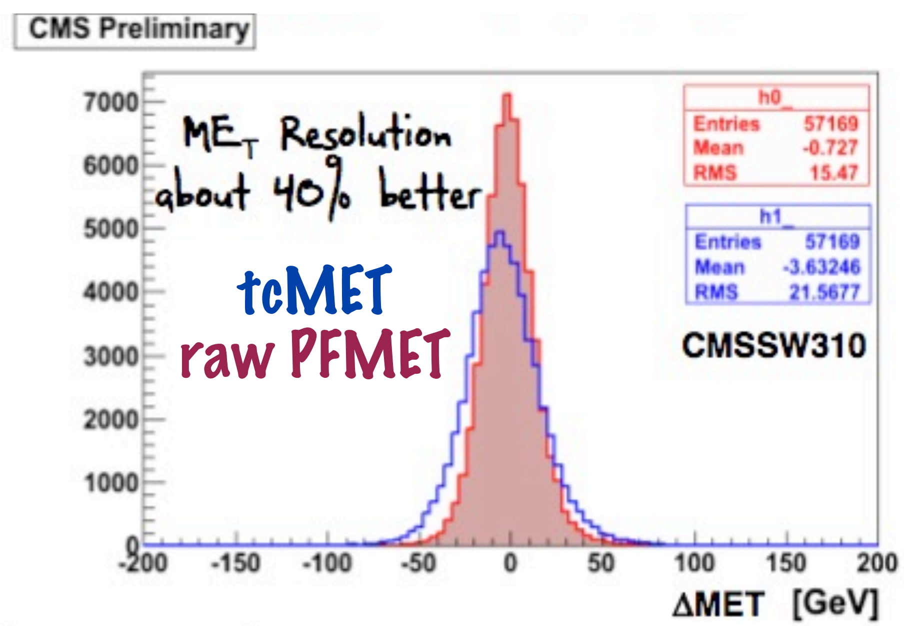



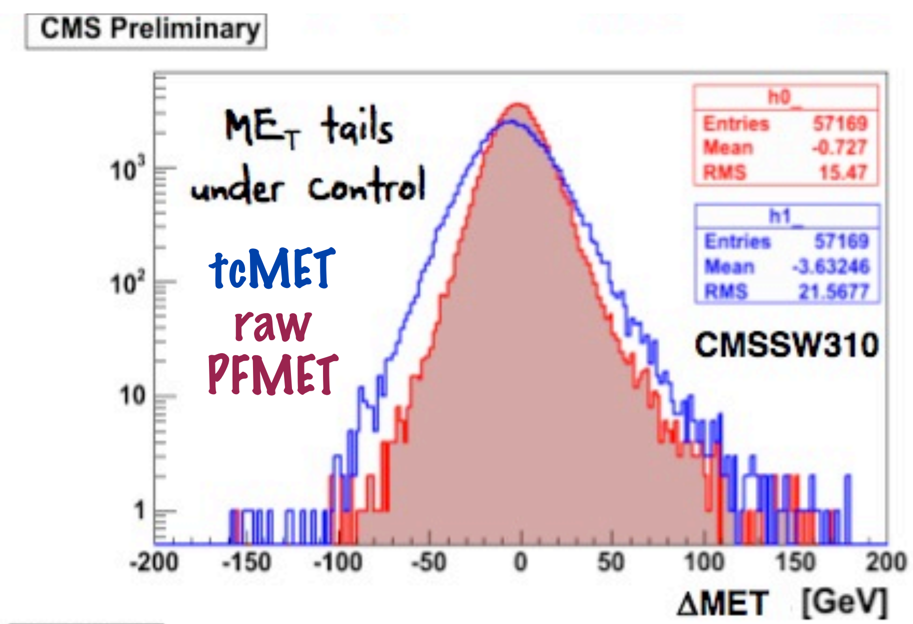



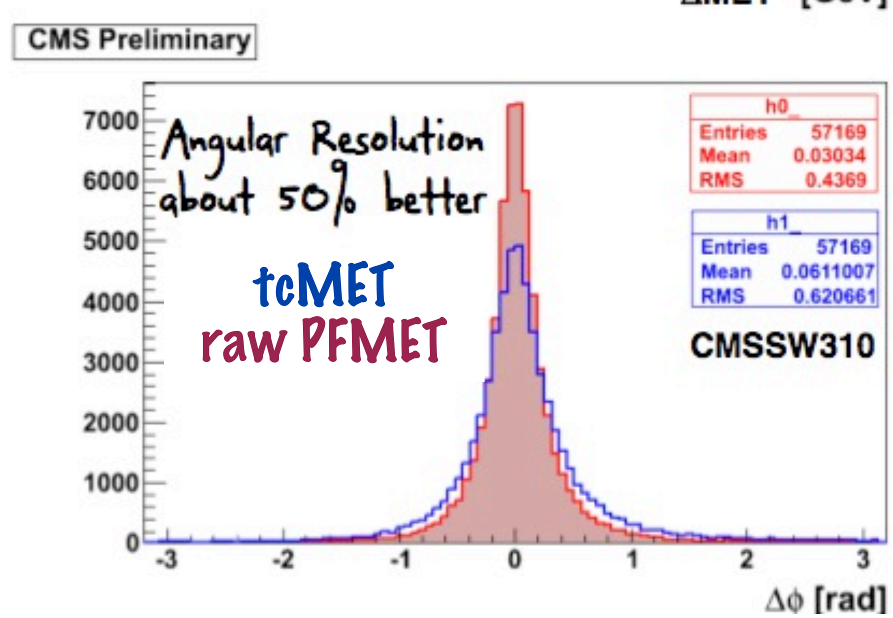



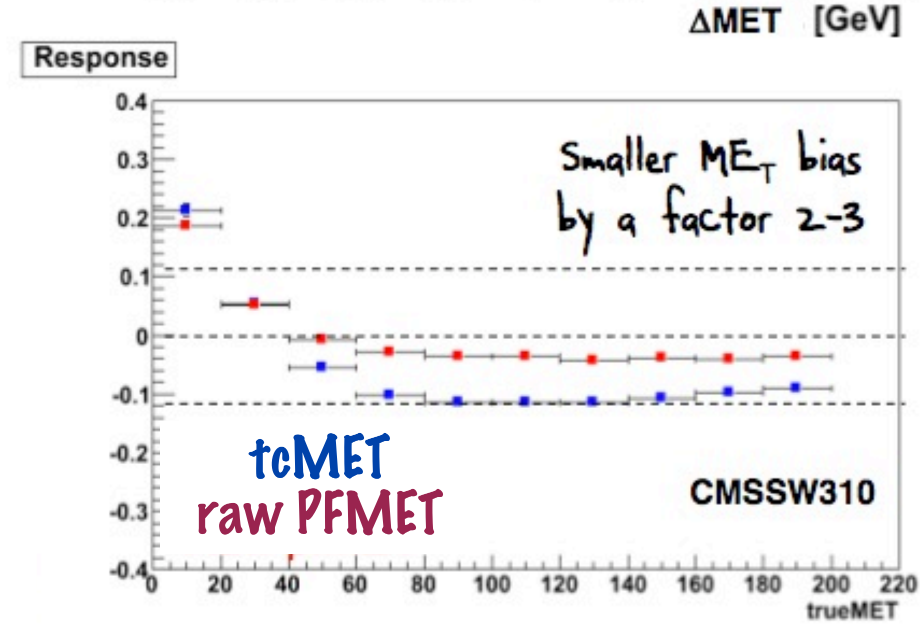
# PFMET Vs tcMET

* TTbar events
* tcMET = track corrected MET



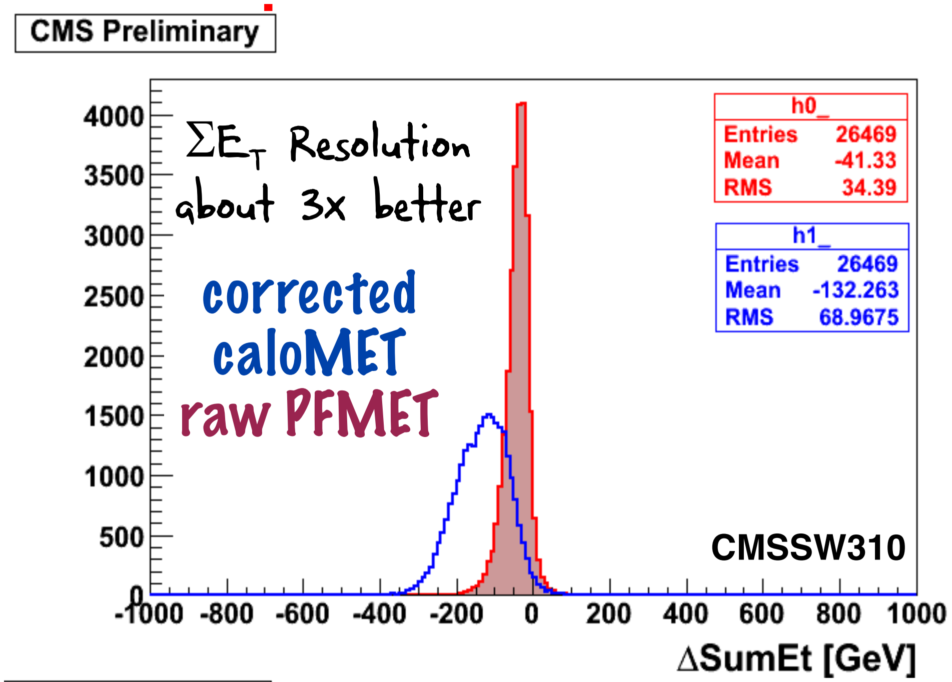



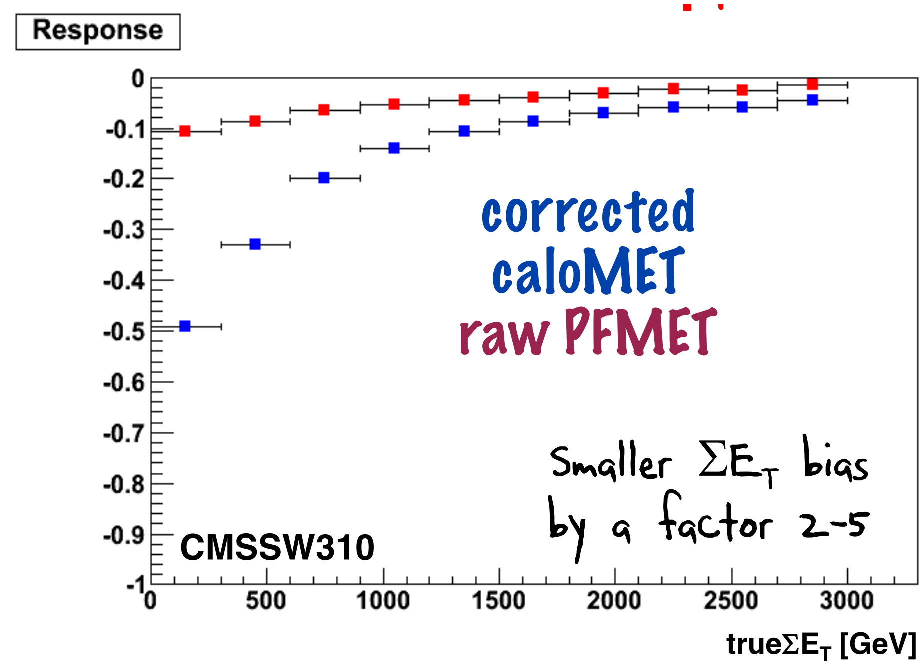



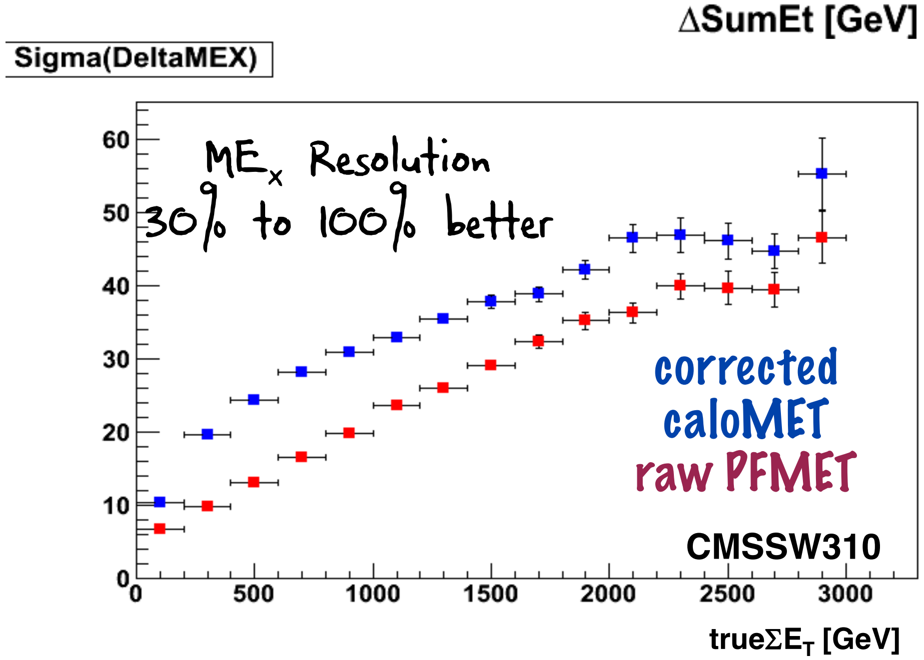



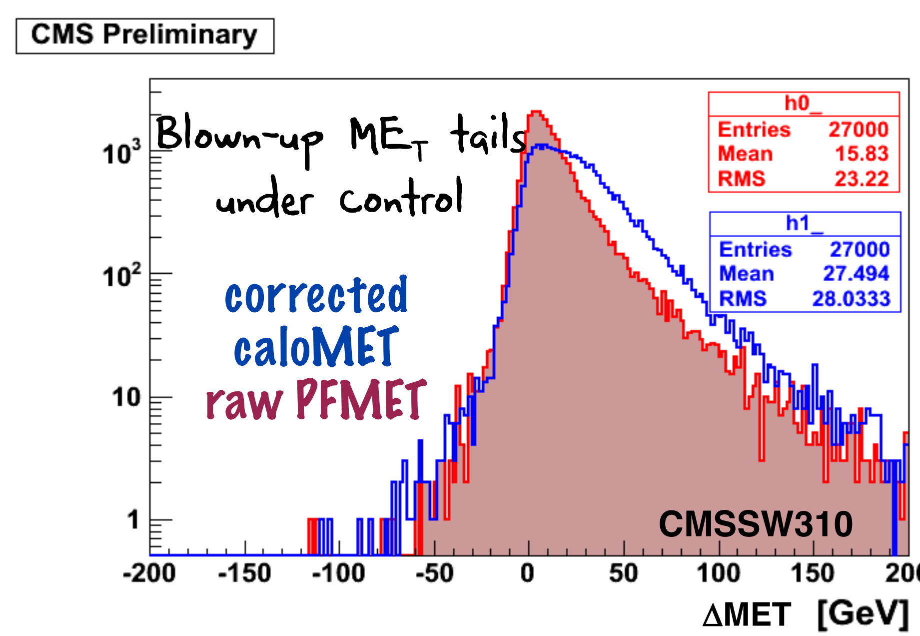
# PFMET Vs CaloMET

* Events without real MET



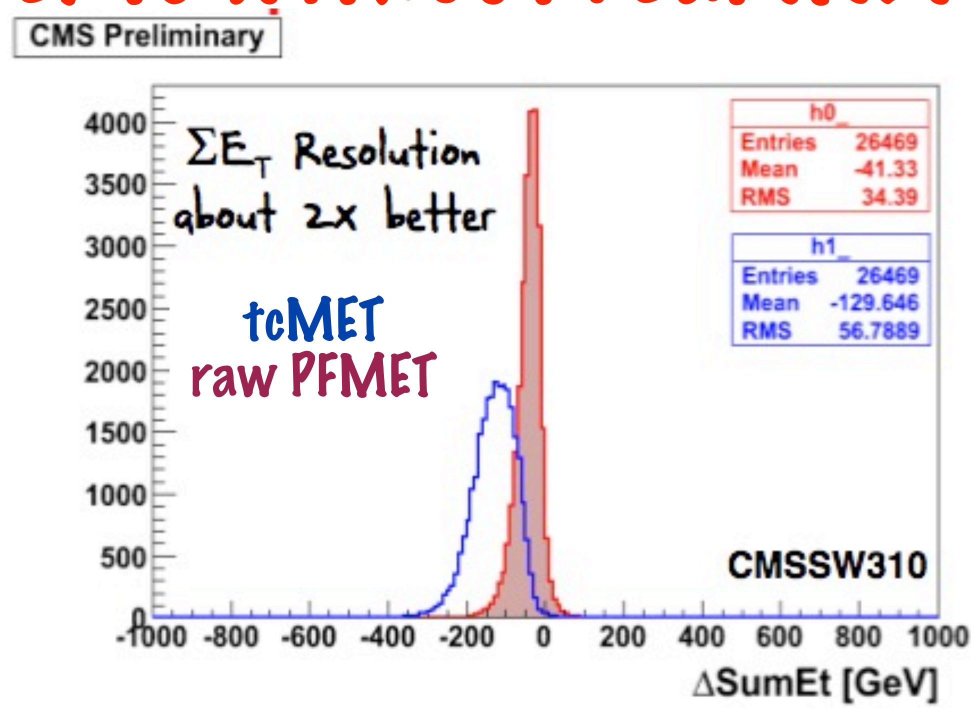



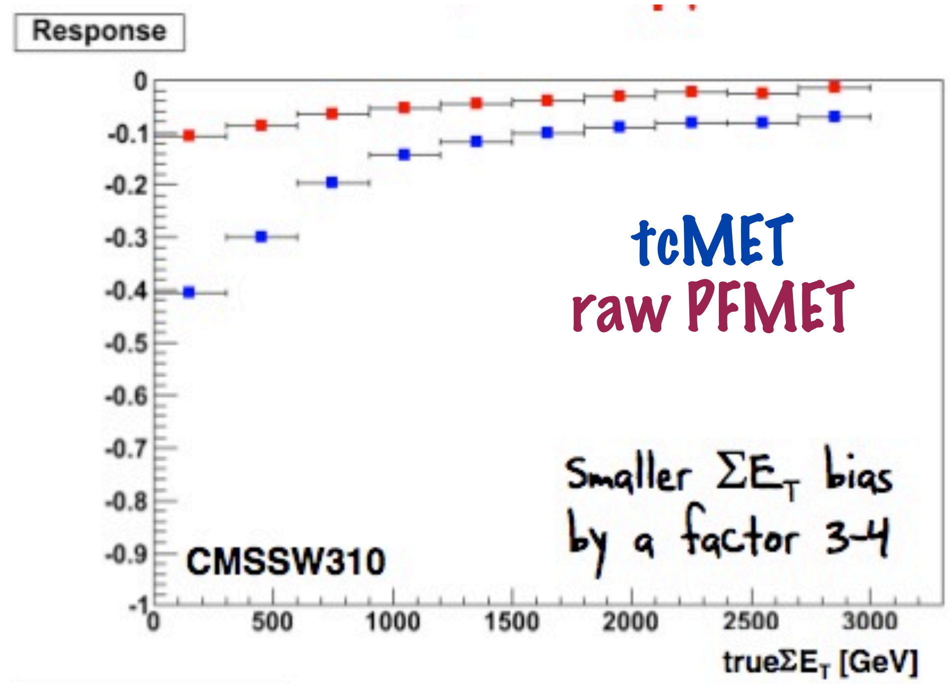



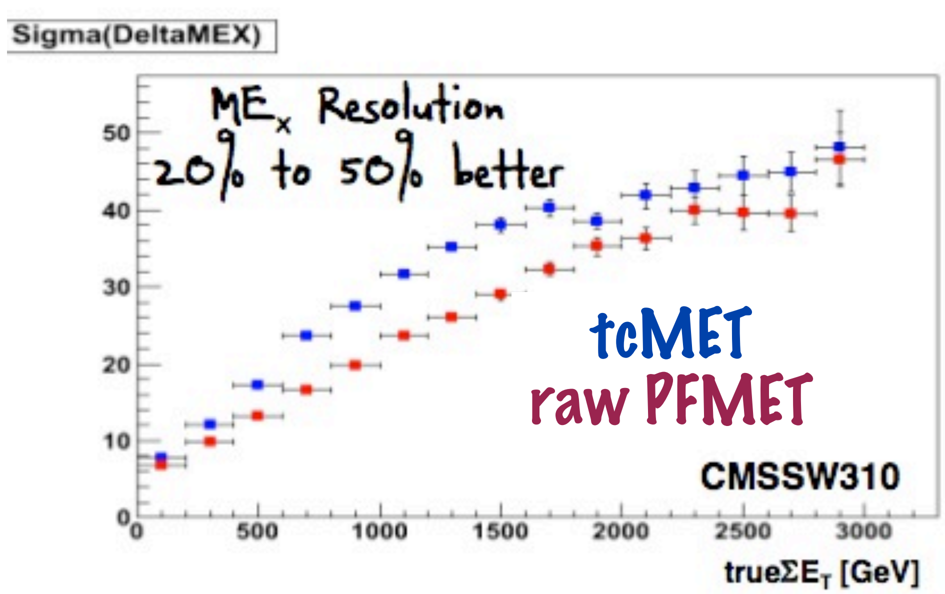



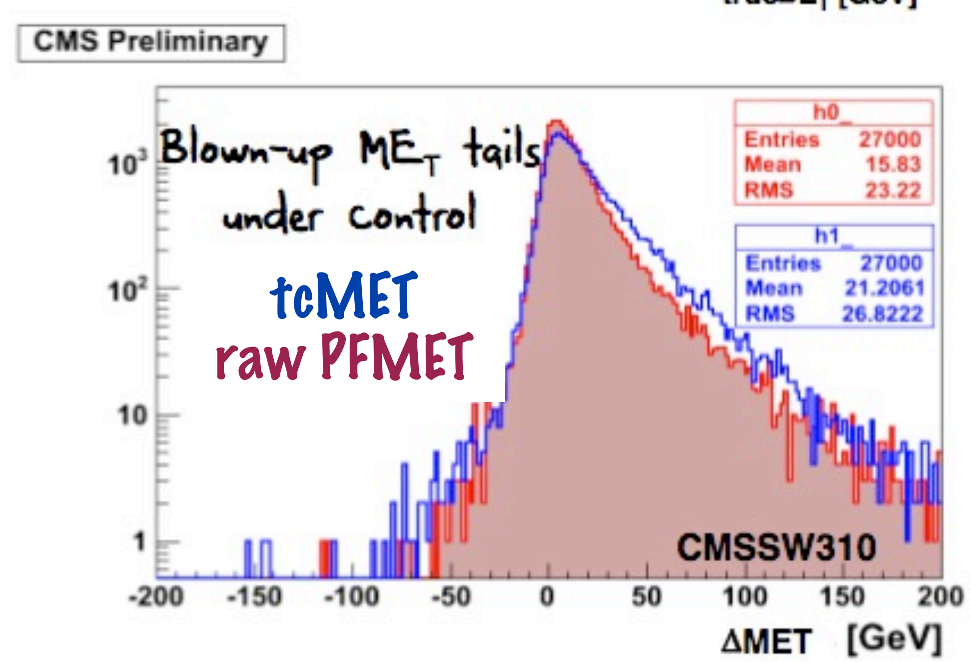
# PFMET Vs tcMET

* Events without real MET



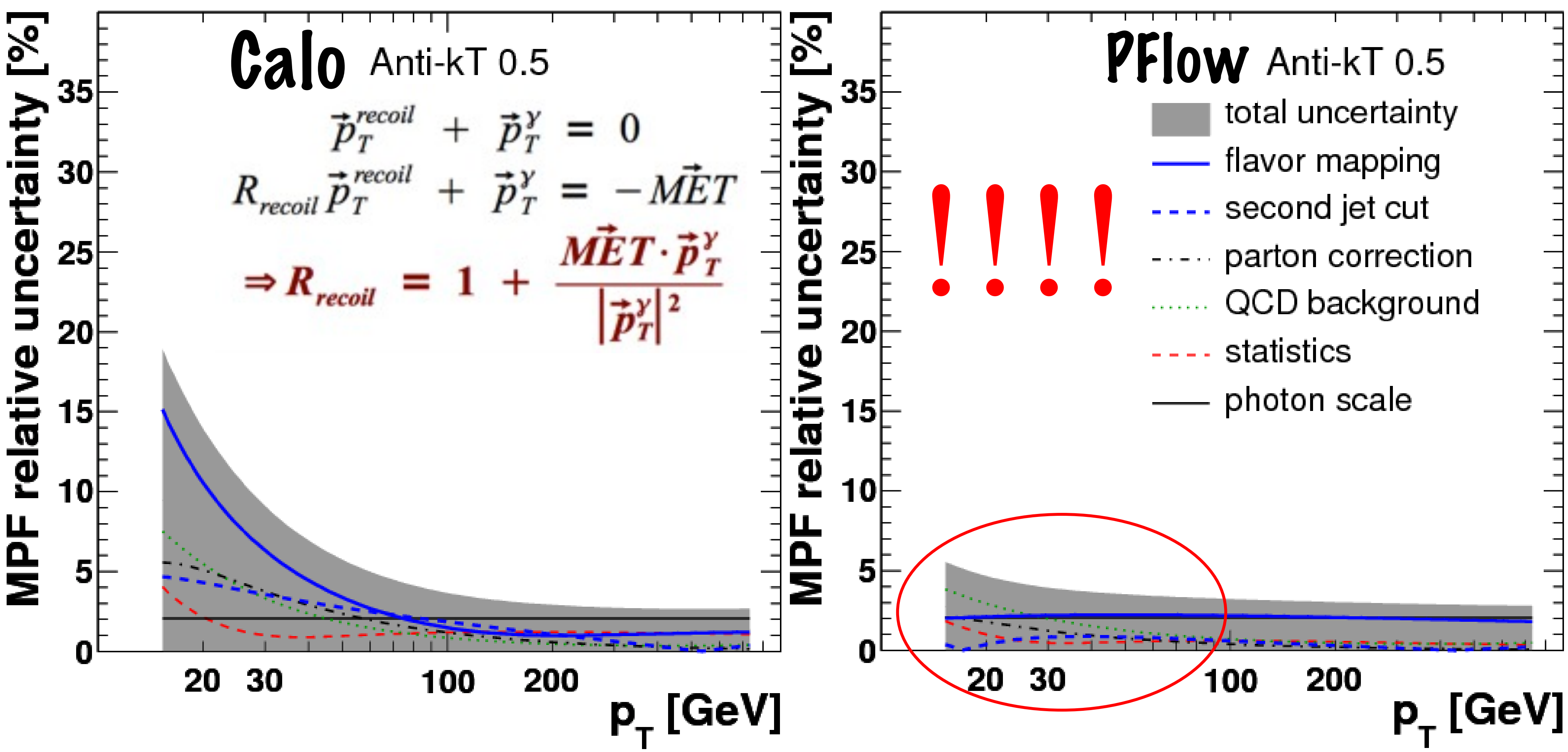



# Use of the PFMET to measure PFJets energy response

* the Missing ET projection Fraction method allows a dramatic reduction of uncertainties when is applied to PFJets

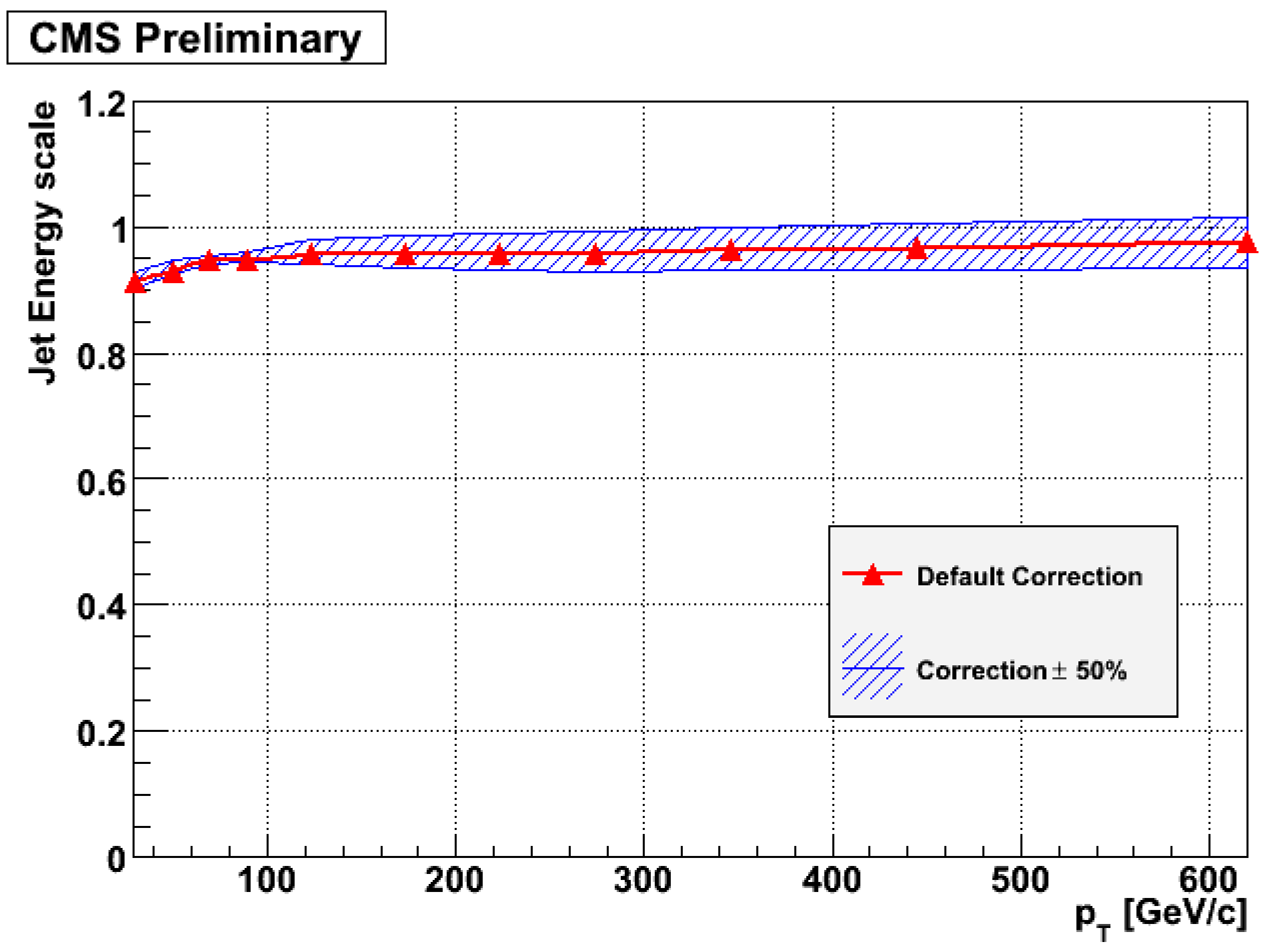


# robustness agains systematics

- Possible source of systematic effects
  - poor modeling of the calorimeter response to hadrons
  - poor modeling of the calorimeter energy resolution
    - used to remove bad measured tracks
  - poor modeling of the calorimeter energy thresholds
  - reduction in the track reconstruction efficiency
  - tracks reconstruction in jets
  - jet flavor energy response dependence
- PFJets response varies by less than 5% at low pT and less than 10% at high pT
  - Mostly driven by calorimeter response to hadrons

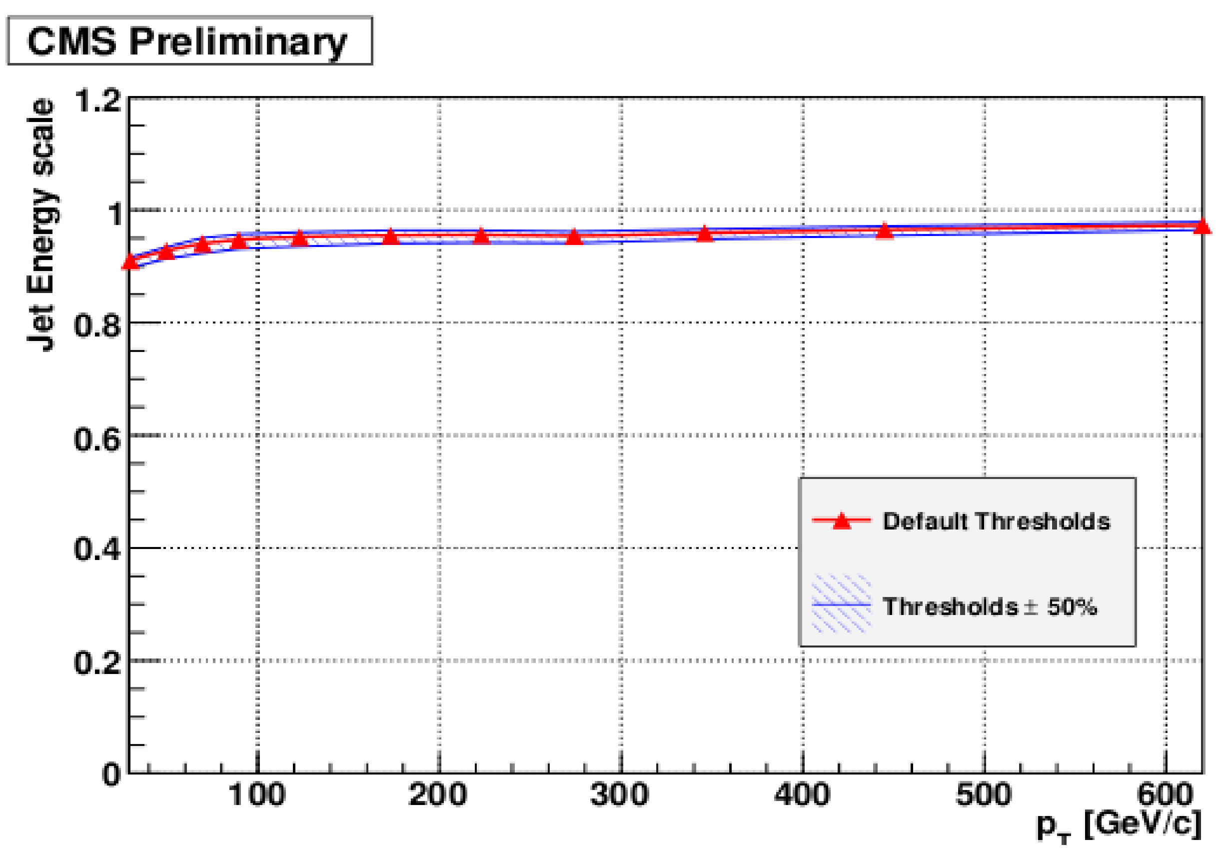
# Systematics: Calorimeter

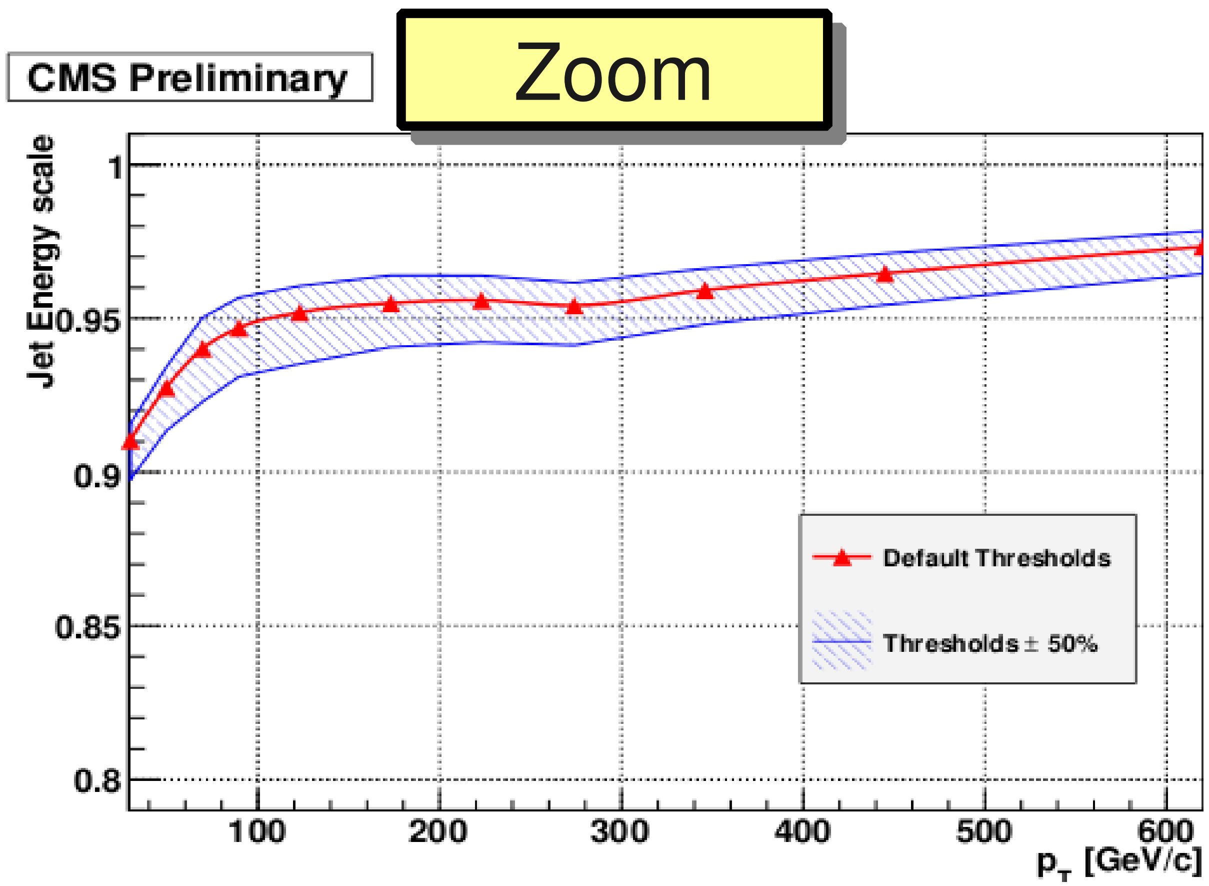
* Poor modeling of the response to the hadrons
  * Calibration factor varied by ~50%



# Systematics: Calorimeter

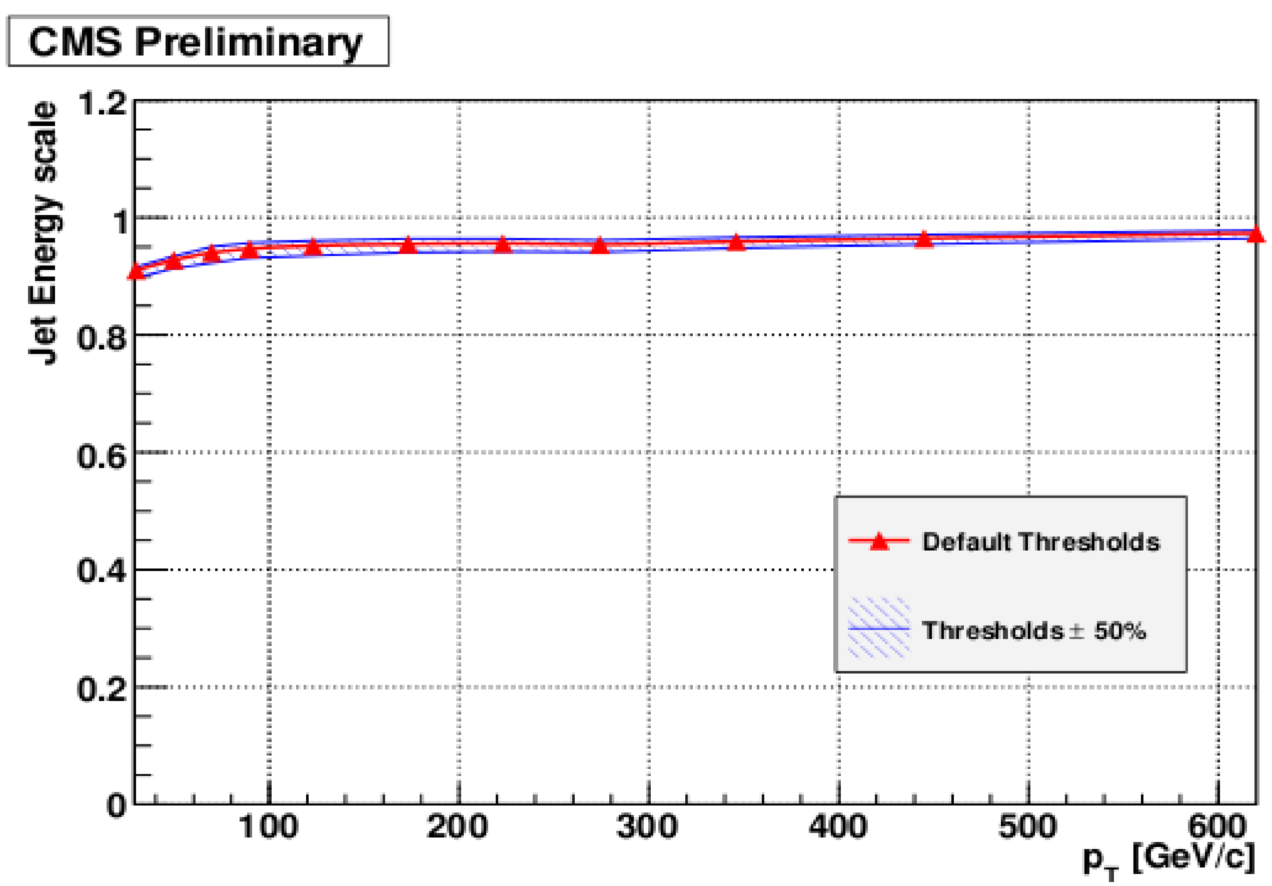
* Poor modeling of the calorimeter energy resolution
  * used to remove bad measured tracks
  * Resolution increased and reduced by ~50%

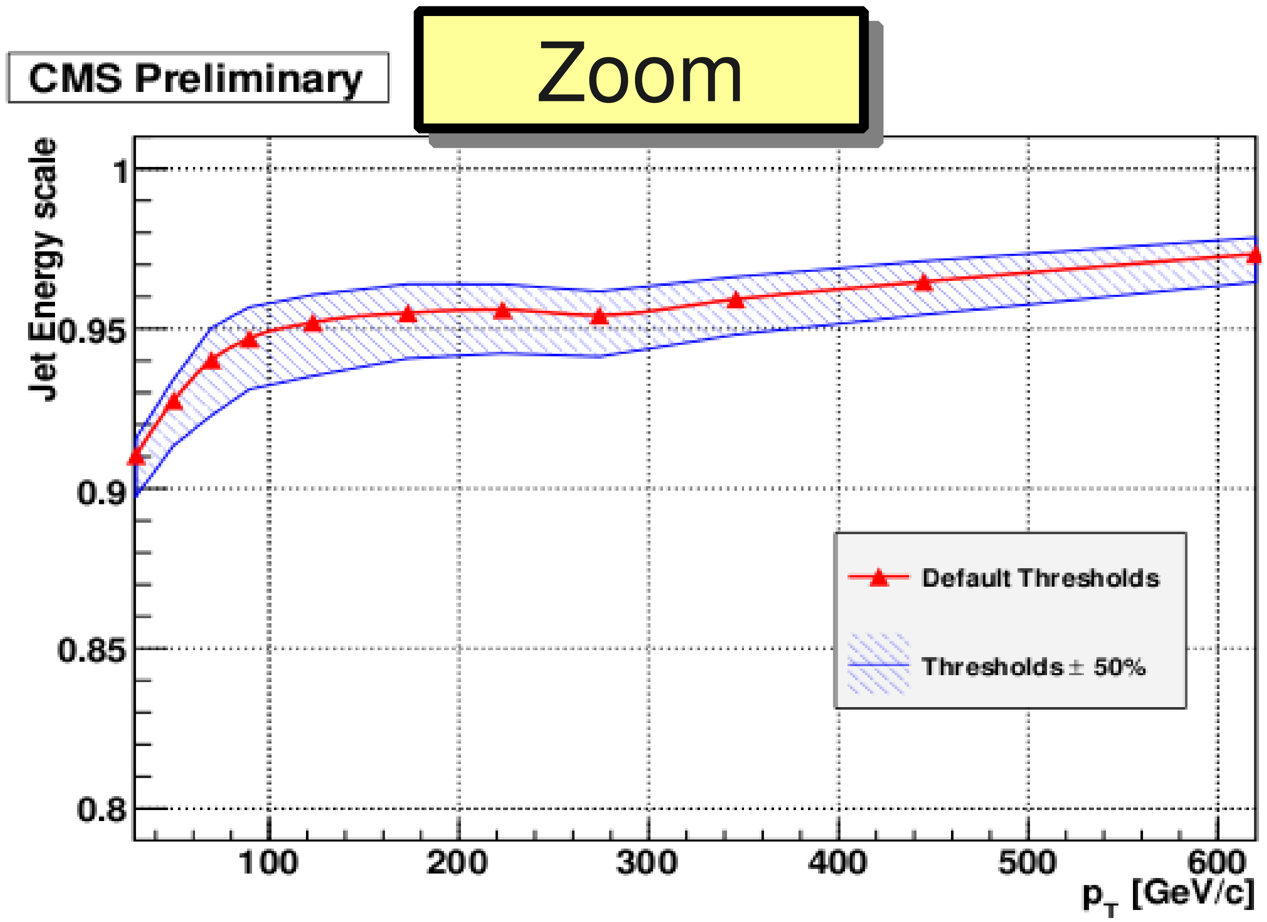


# Systematics: Calorimeter

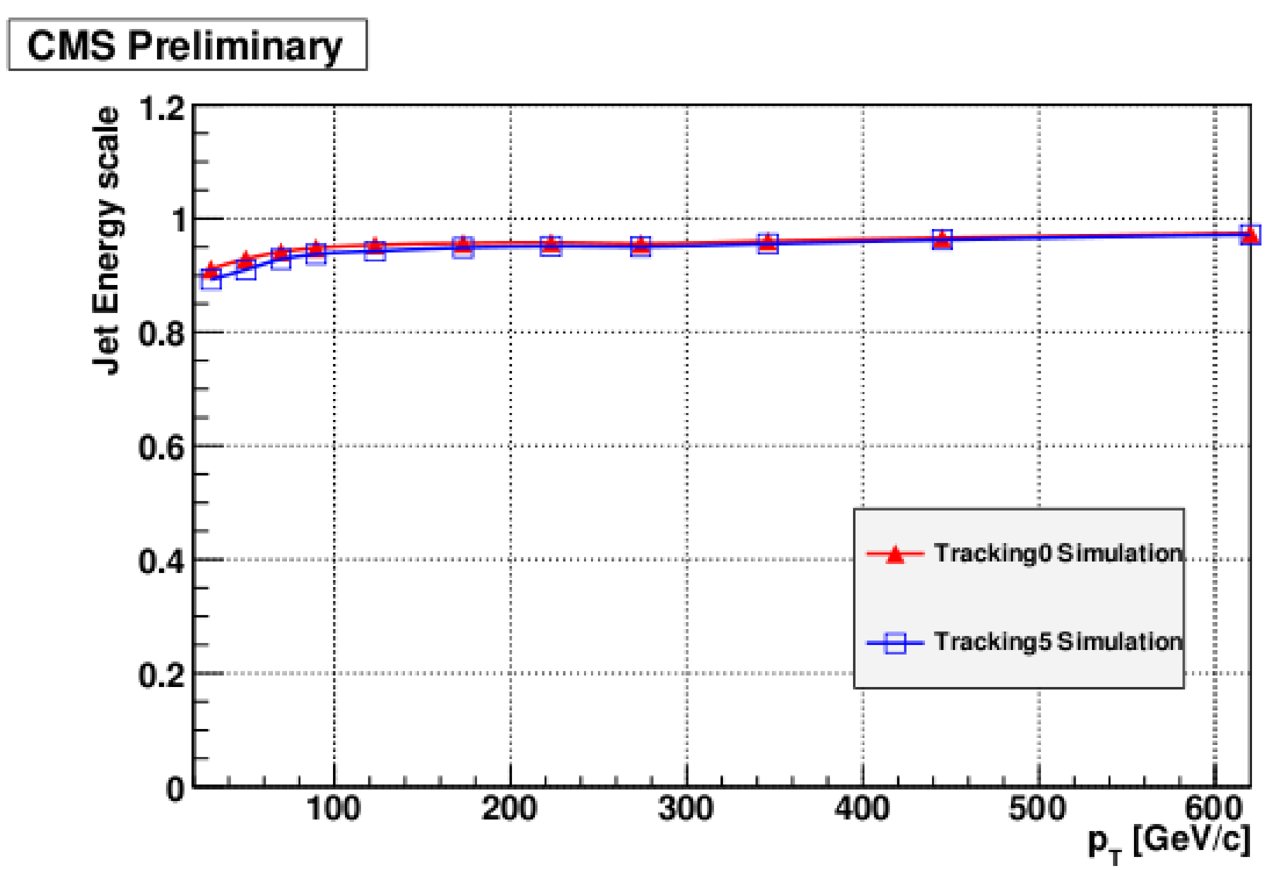
* Effect of calorimeter thresholds
  * Ecal: 40 --> 120 MeV
  * cHal: 400 --> 1.2 GeV

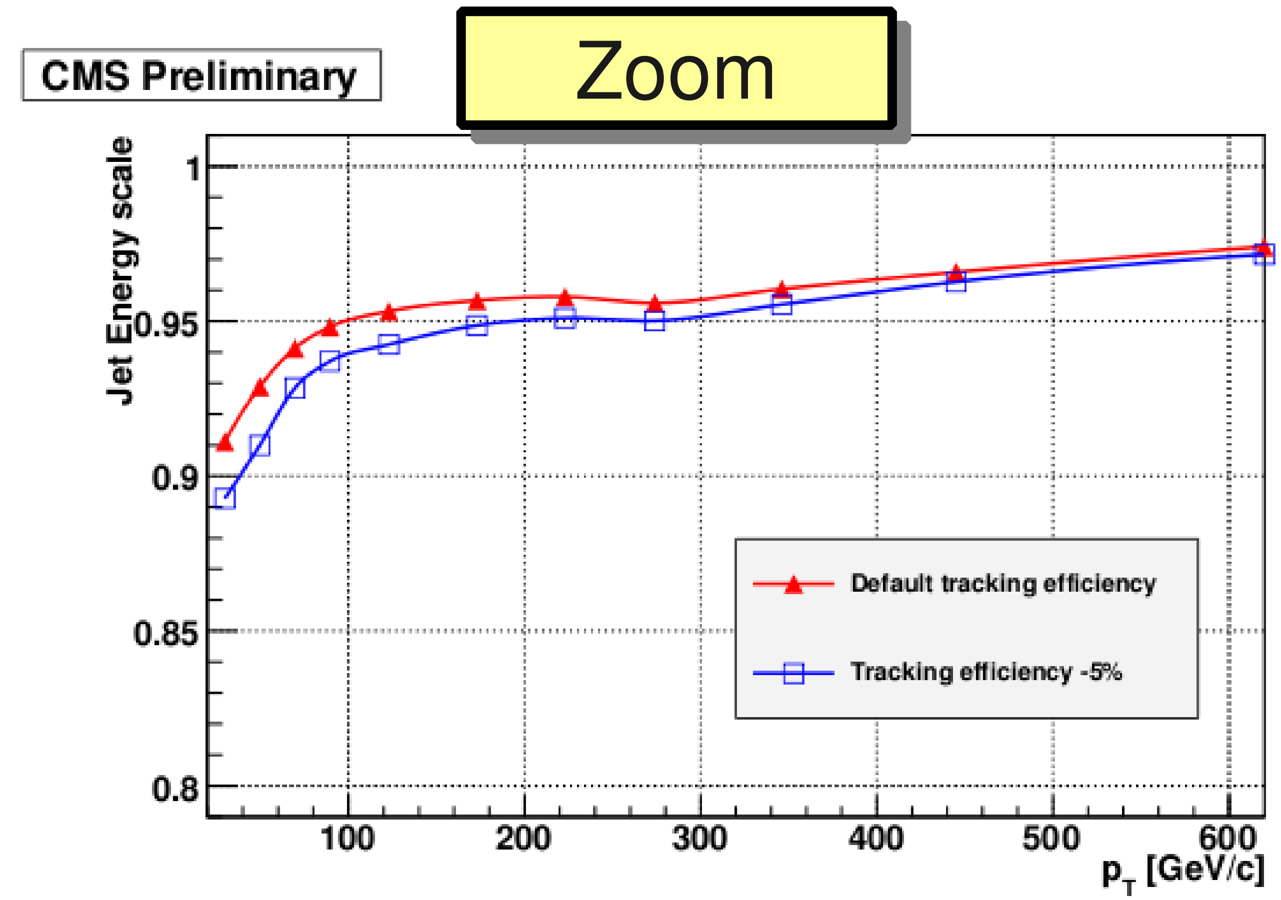


# Systematics: Tracking

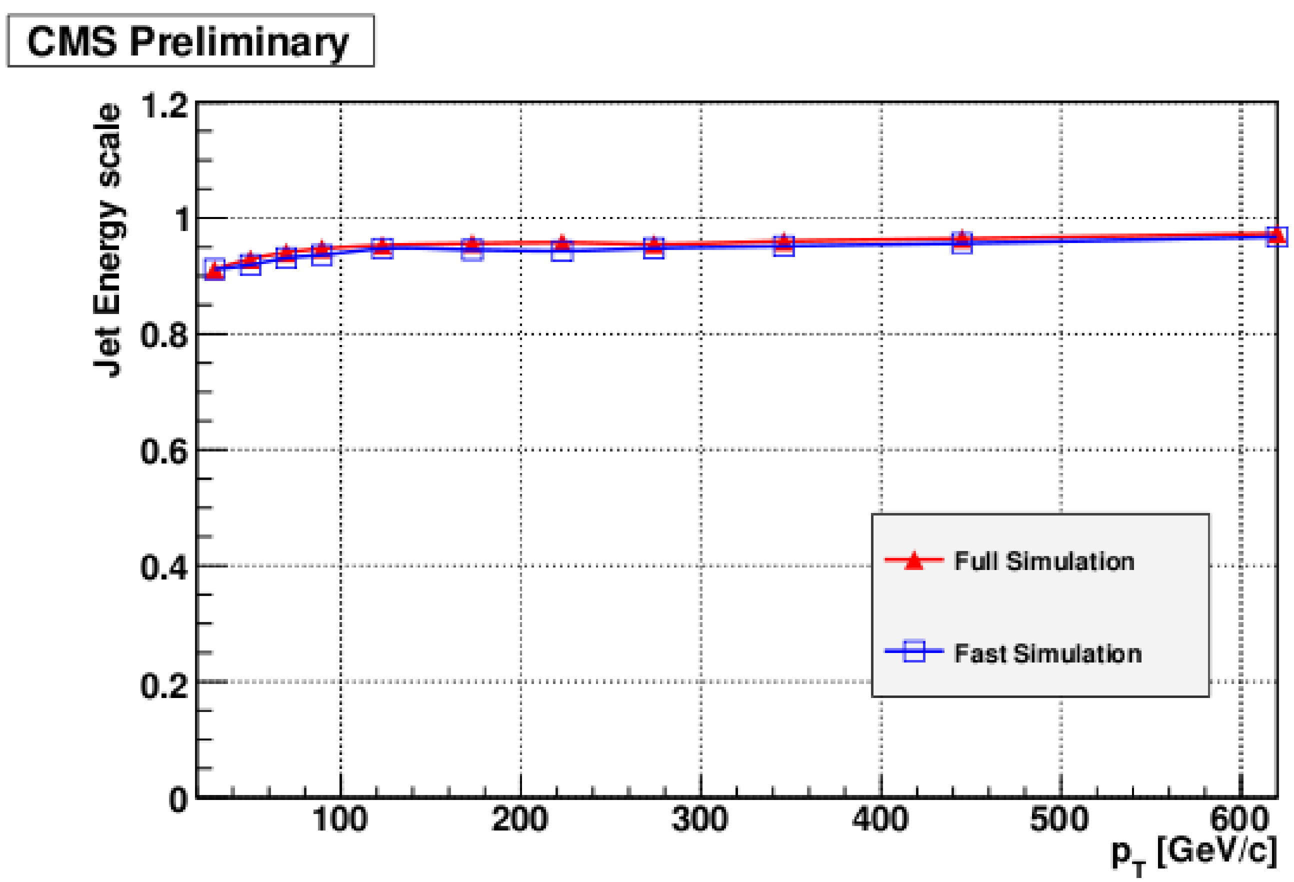
* Global reduction on track reconstruction efficiency by 5%

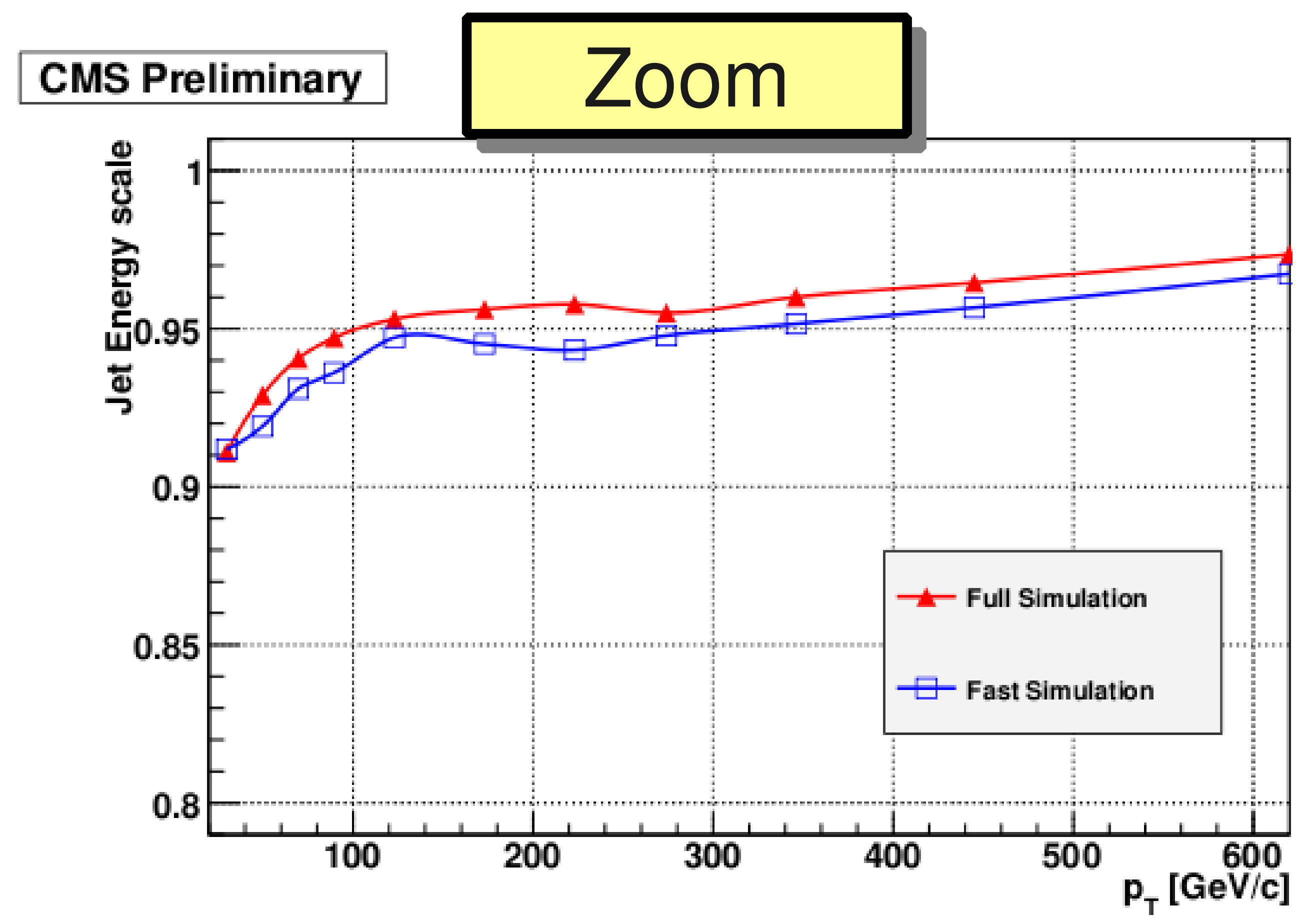


# Systematics: Tracking

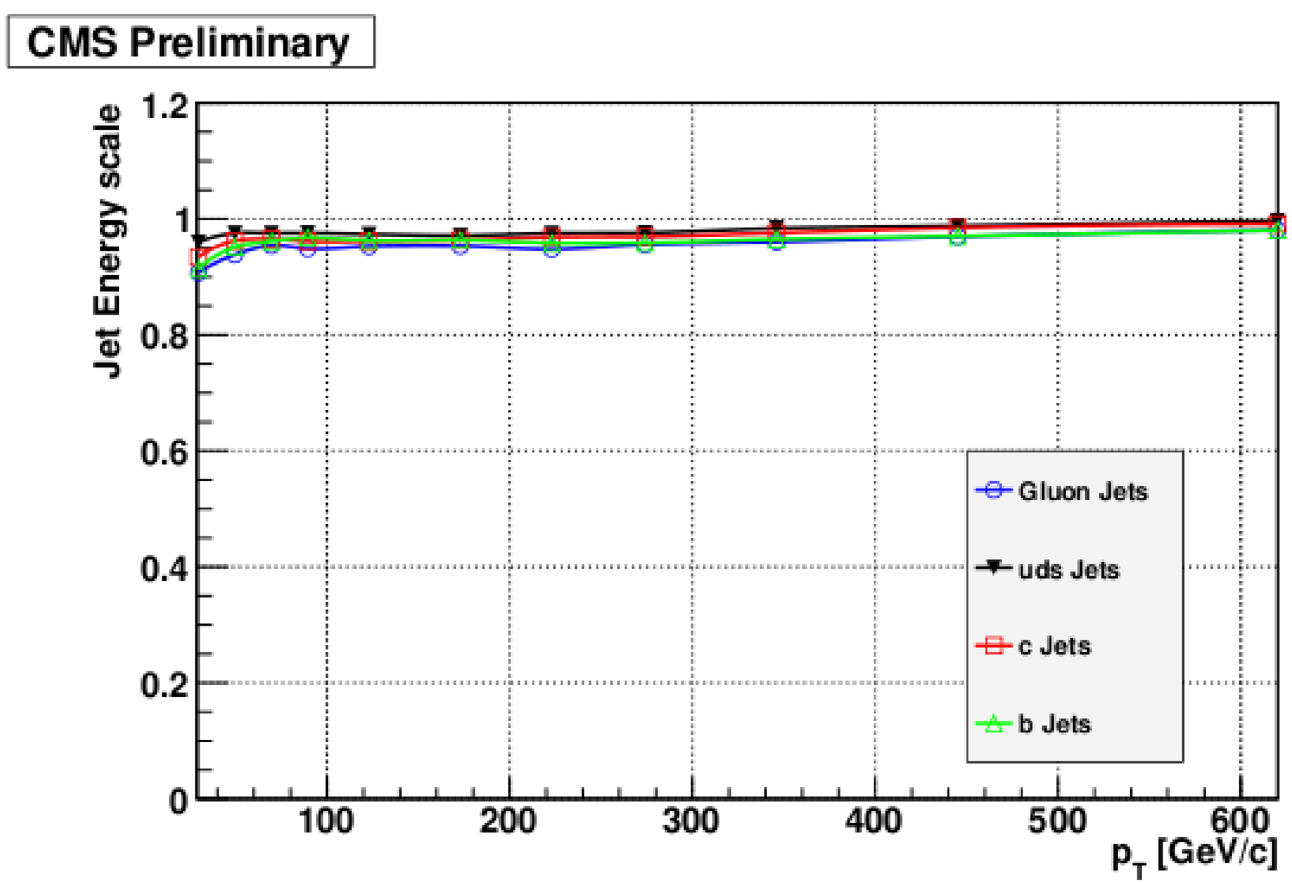
* Bad modeling of track reconstruction in dense environment
  * Taking as comparison the fast sim where effects due to dense environment are not considered

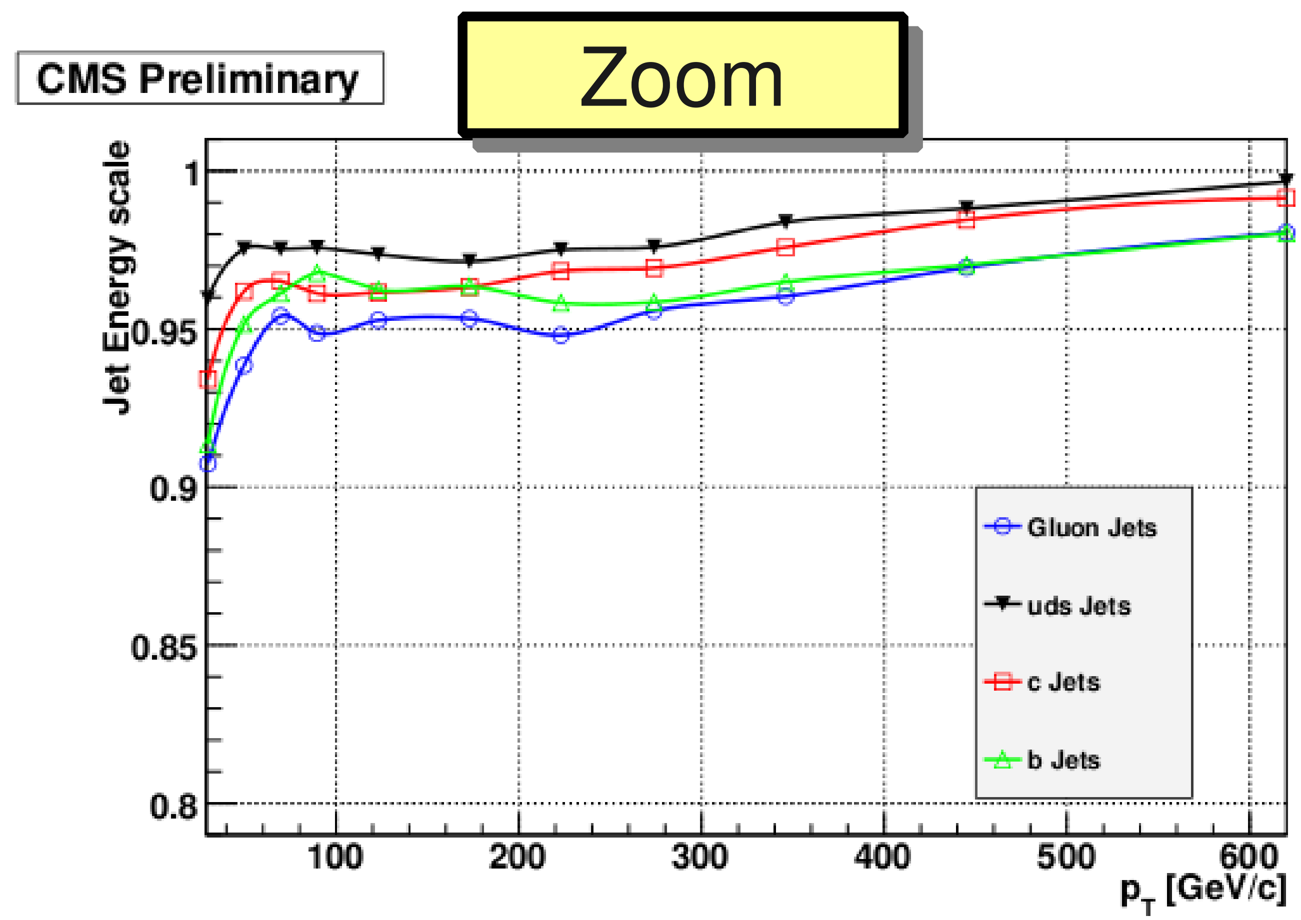


# Systematics: Parton Flavor

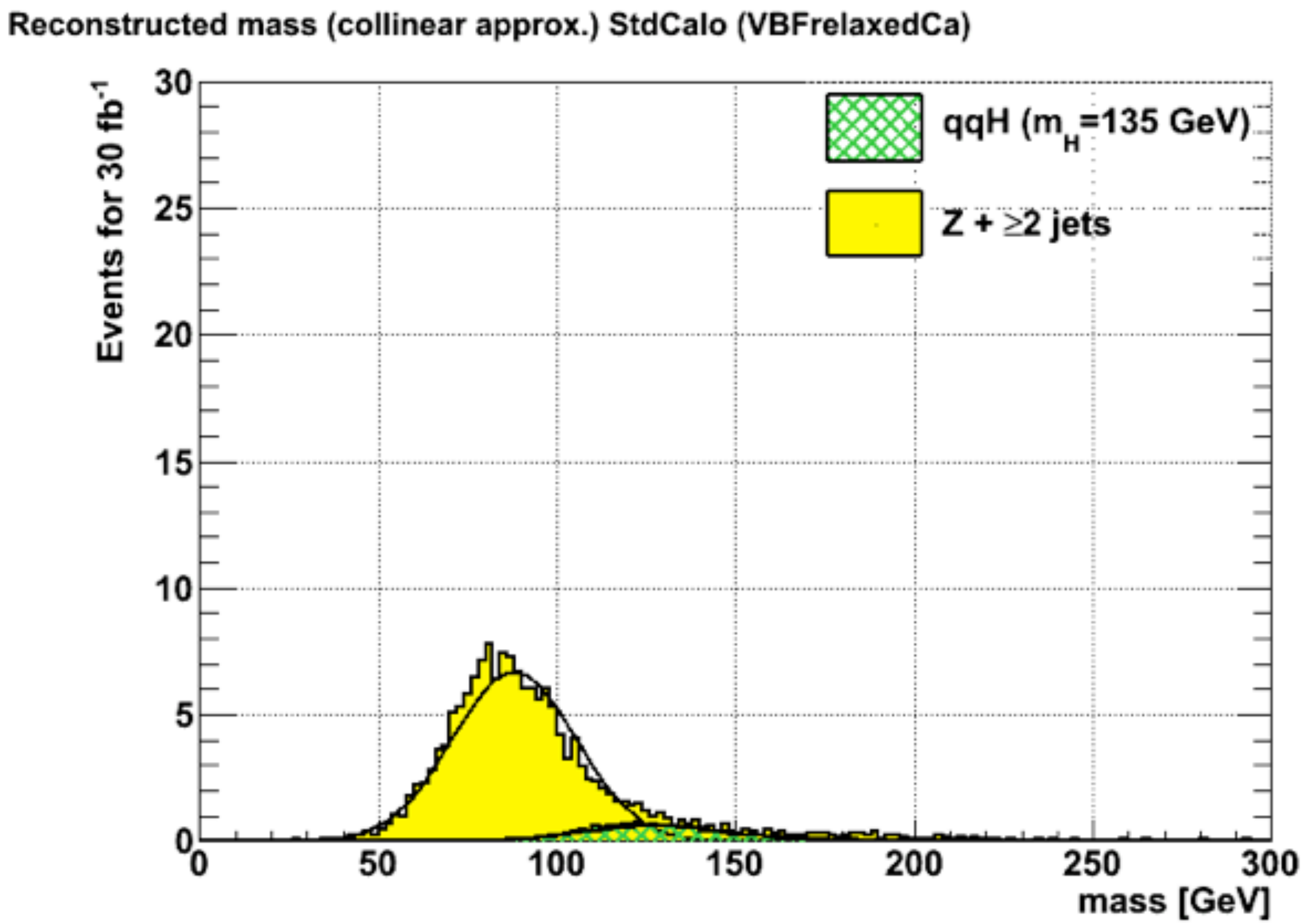
* Jet flavor: Gluon
  Light quark (u,d,s)
  c quark
  b quark



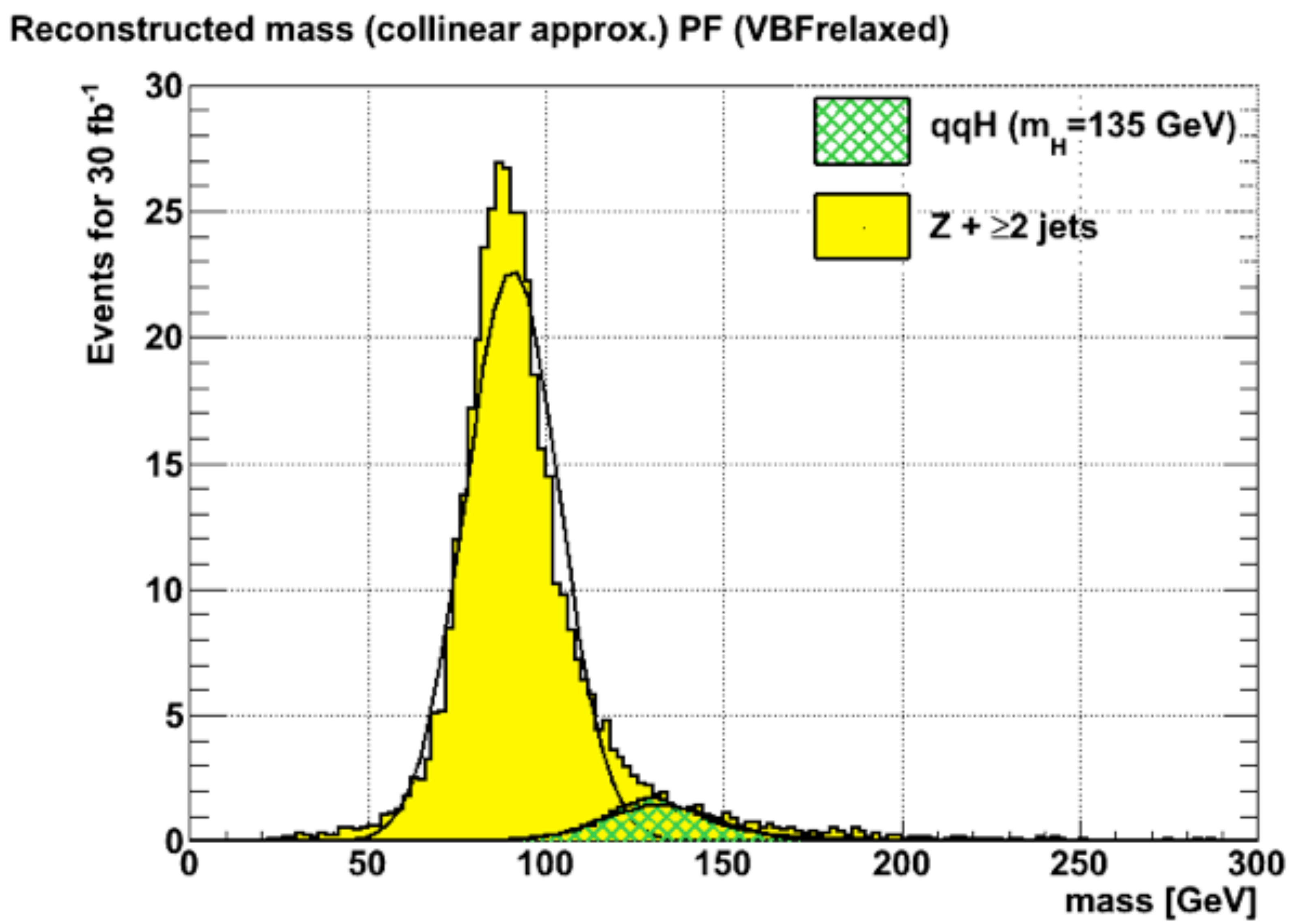
# Higgs invariant mass reconstruction

* qqH->tautau->muon+tau jet+ MET
* Here using Calorimeter based reconstruction



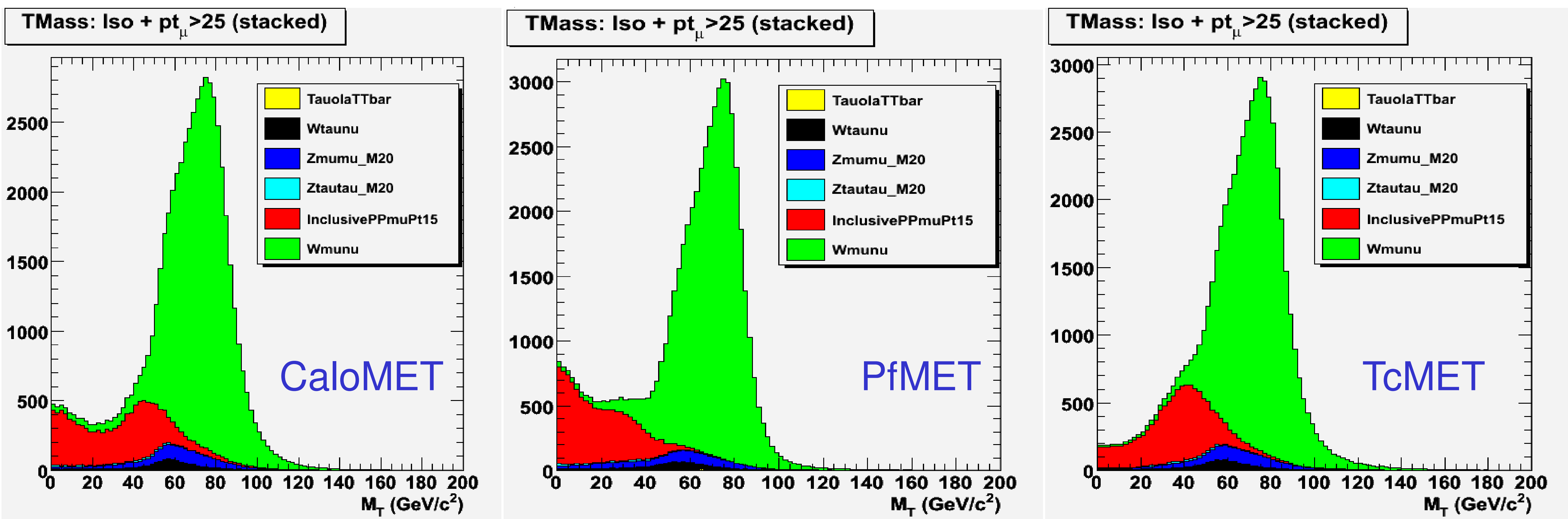
# Higgs invariant mass reconstruction

- qqH->tautau->muon+tau jet+ MET
- Here using Particle Flow based reconstruction

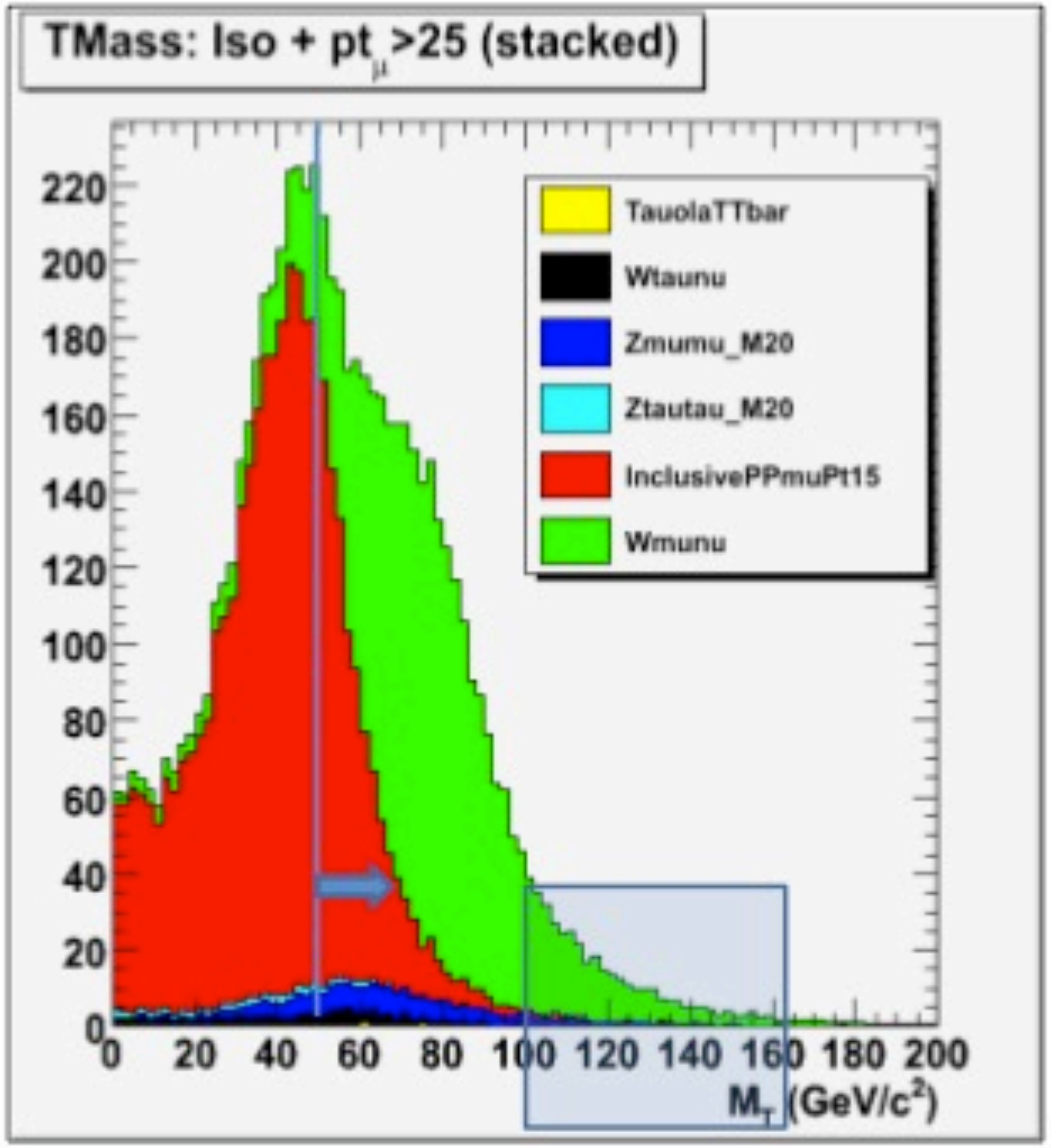


# Transverse invariant mass reconstruction

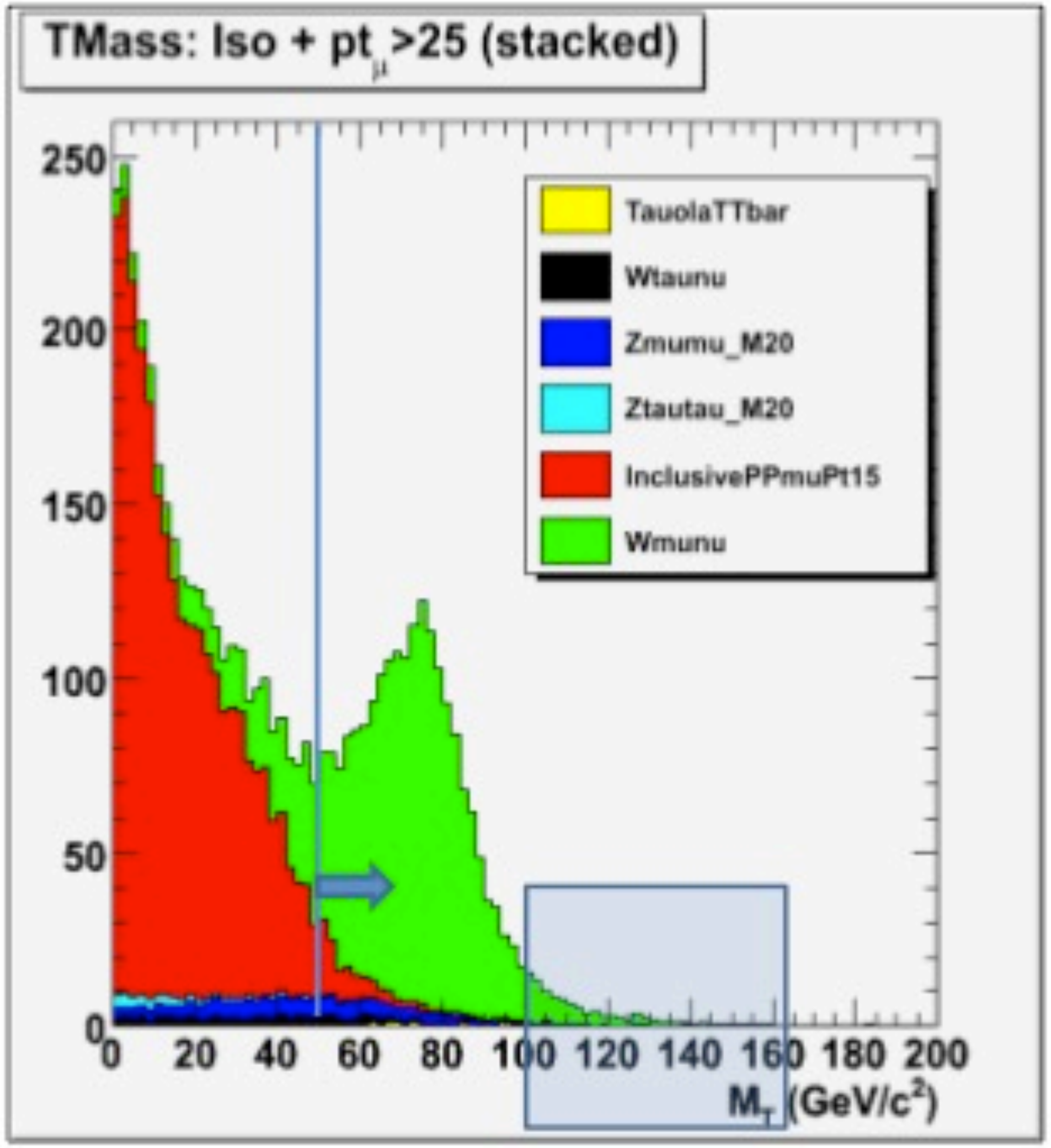
* W-> mu + neutrino sample
* PFMET gives the best performance in discriminating signal Vs background



# Transverse mass
## (requiring two extra jets)




CaloMET and CaloJets



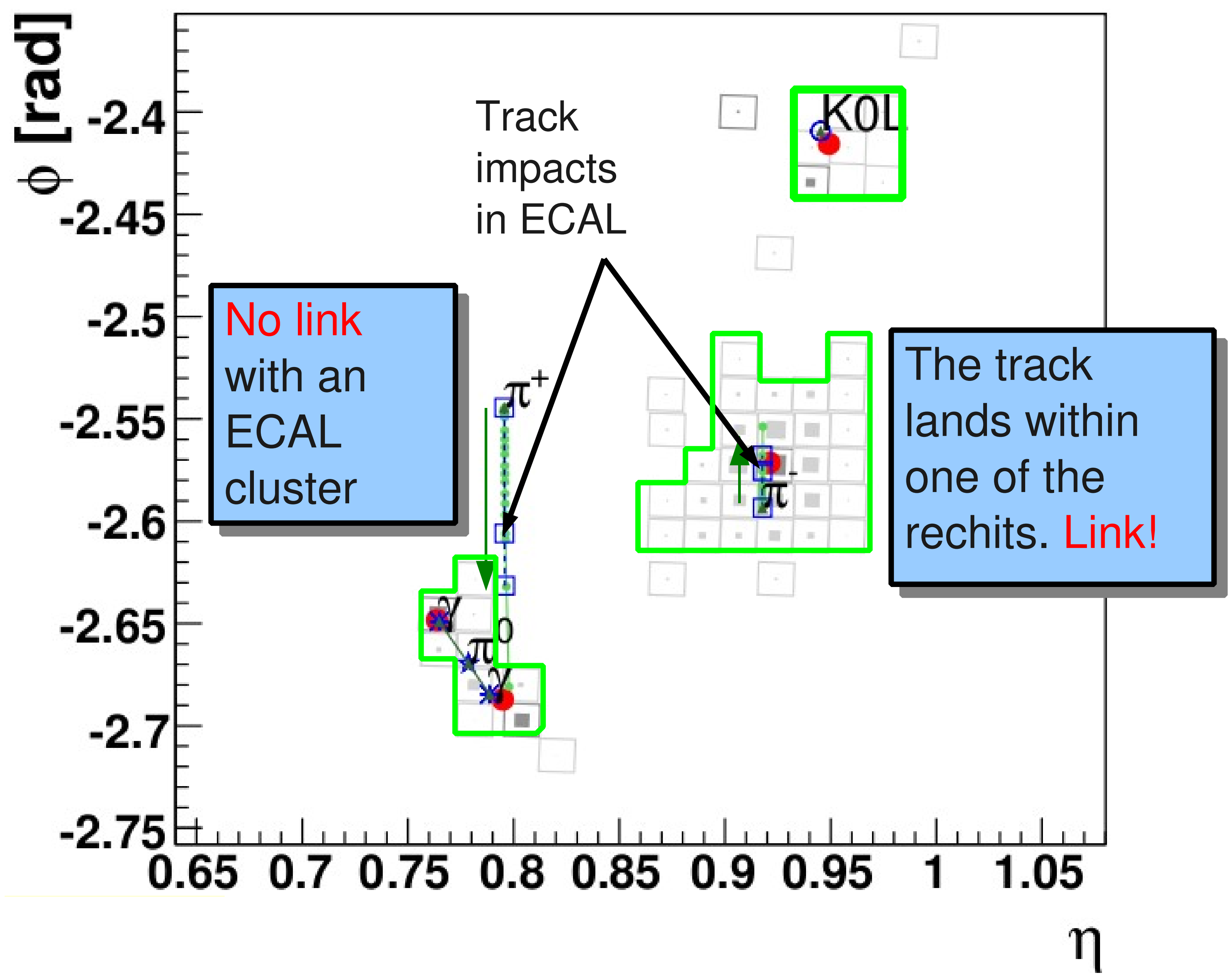

PFMET and PFJets

# Particle Reconstruction

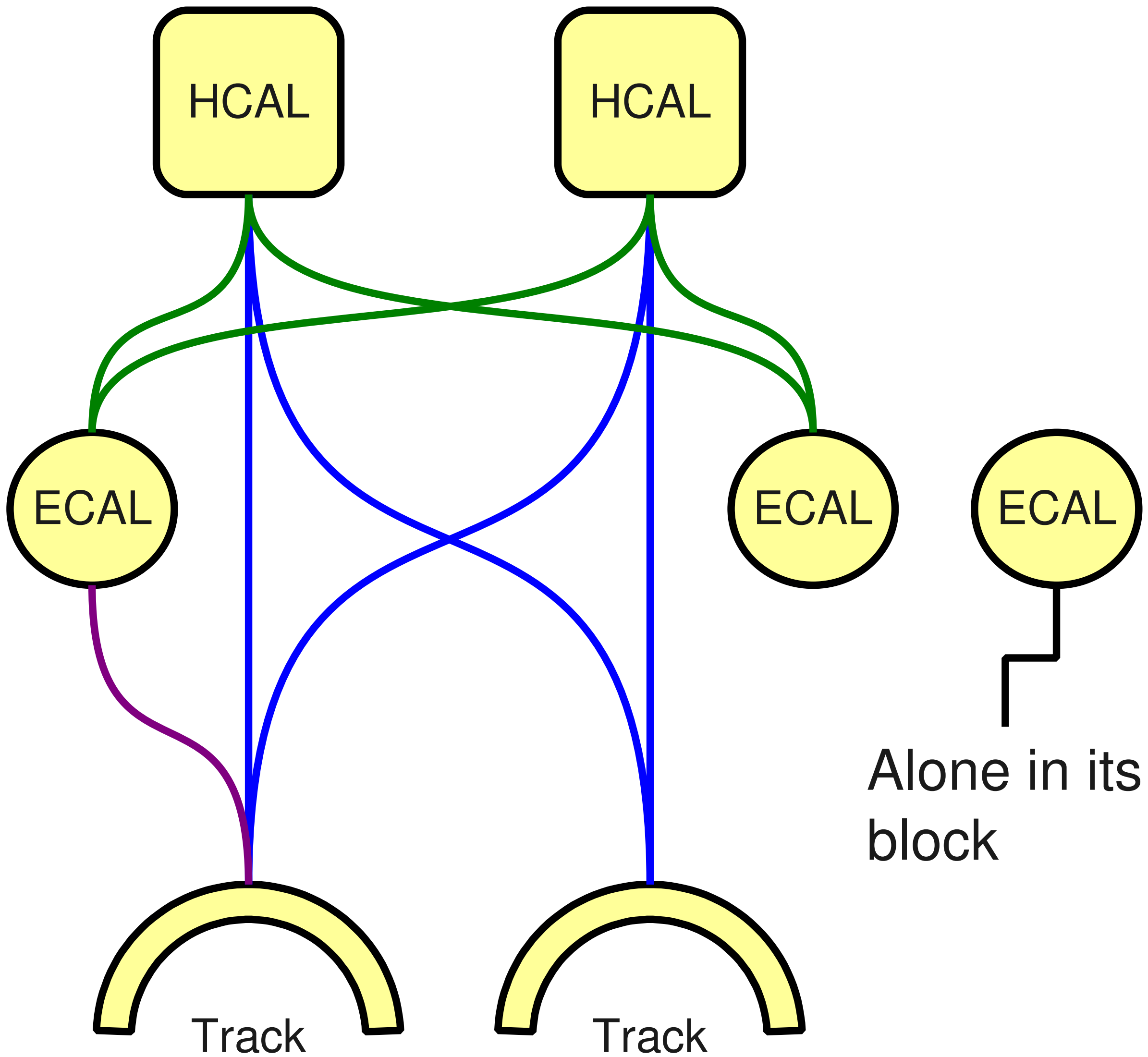
* Muons and electrons are reconstructed first
  * Muons are taken from the collections provided by the Muon POG
  * Electrons have a brand new reconstruction which will be documented soon
* Charged, neutral hadrons and photons are reconstructed from the blocks as follow:
  * A not-linked ecal cluster gives birth to a photon
  * A not-linked hcal cluster gives birth to a neutral hadron
  * A track (not already considered as a muon or an electron) gives birth to a charged hadron
  * Any other combination, i.e. blocks formed by more than one object, is analyzed in order to give the complete list of particles

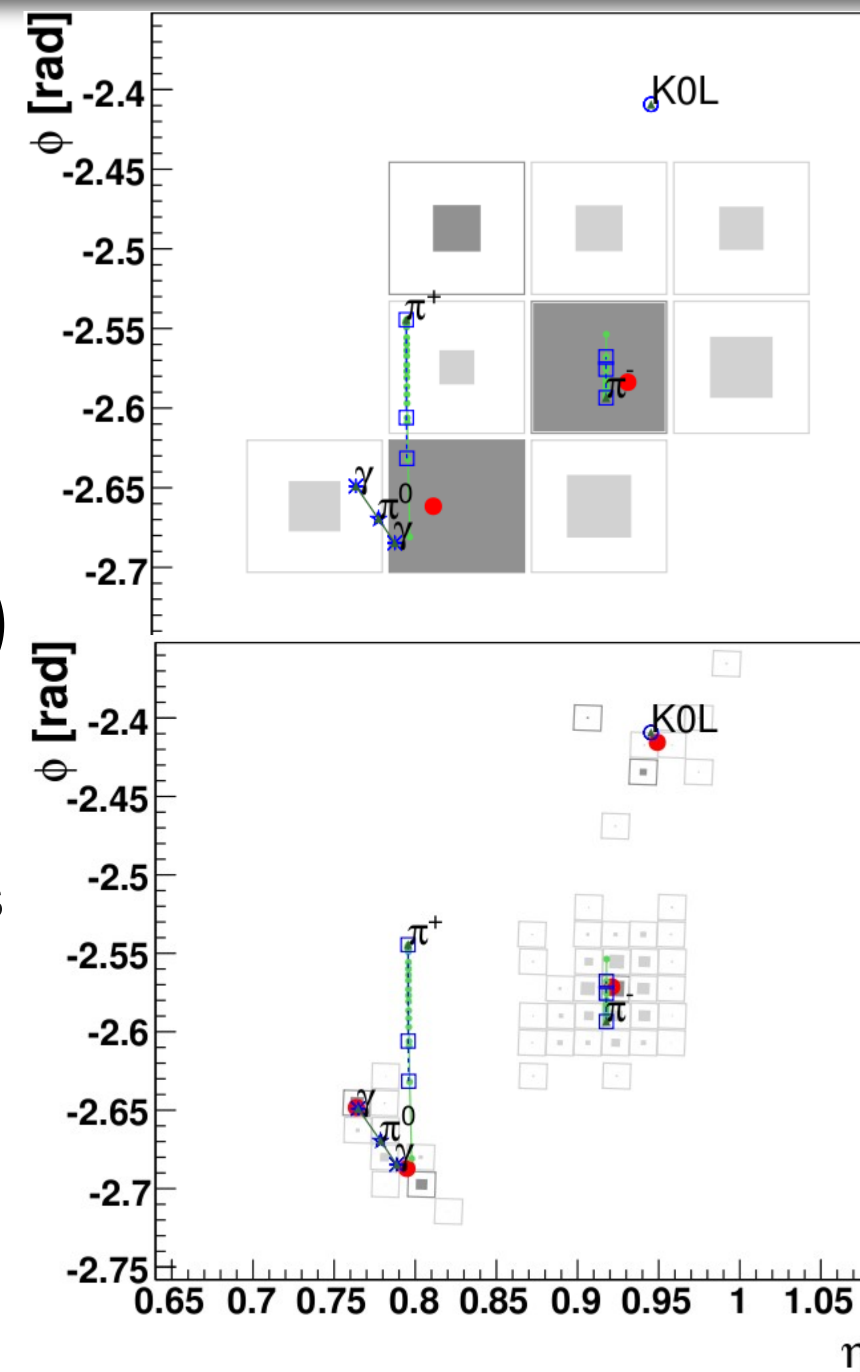
# A closer look at the algorithm

* Track-cluster link

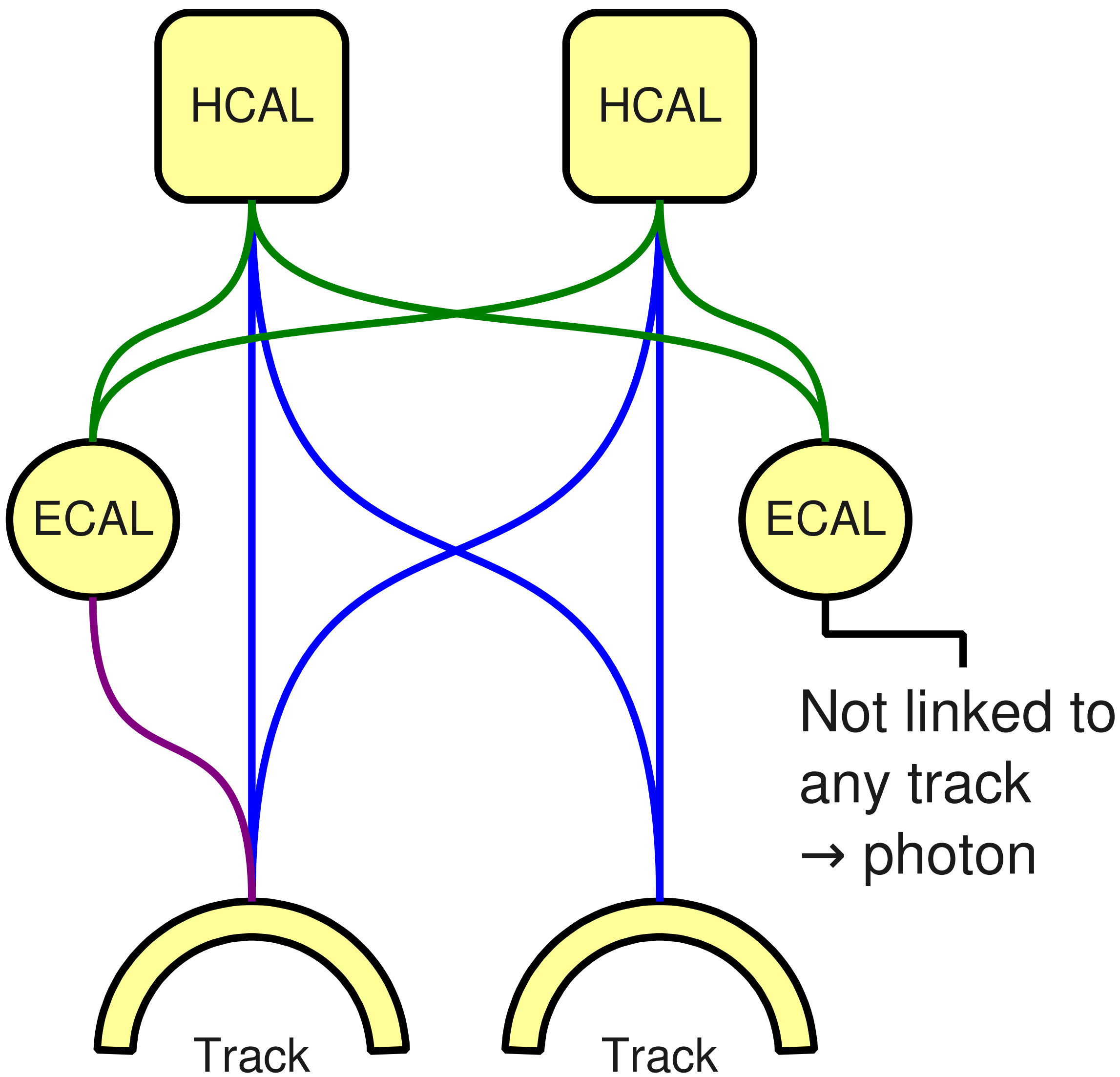


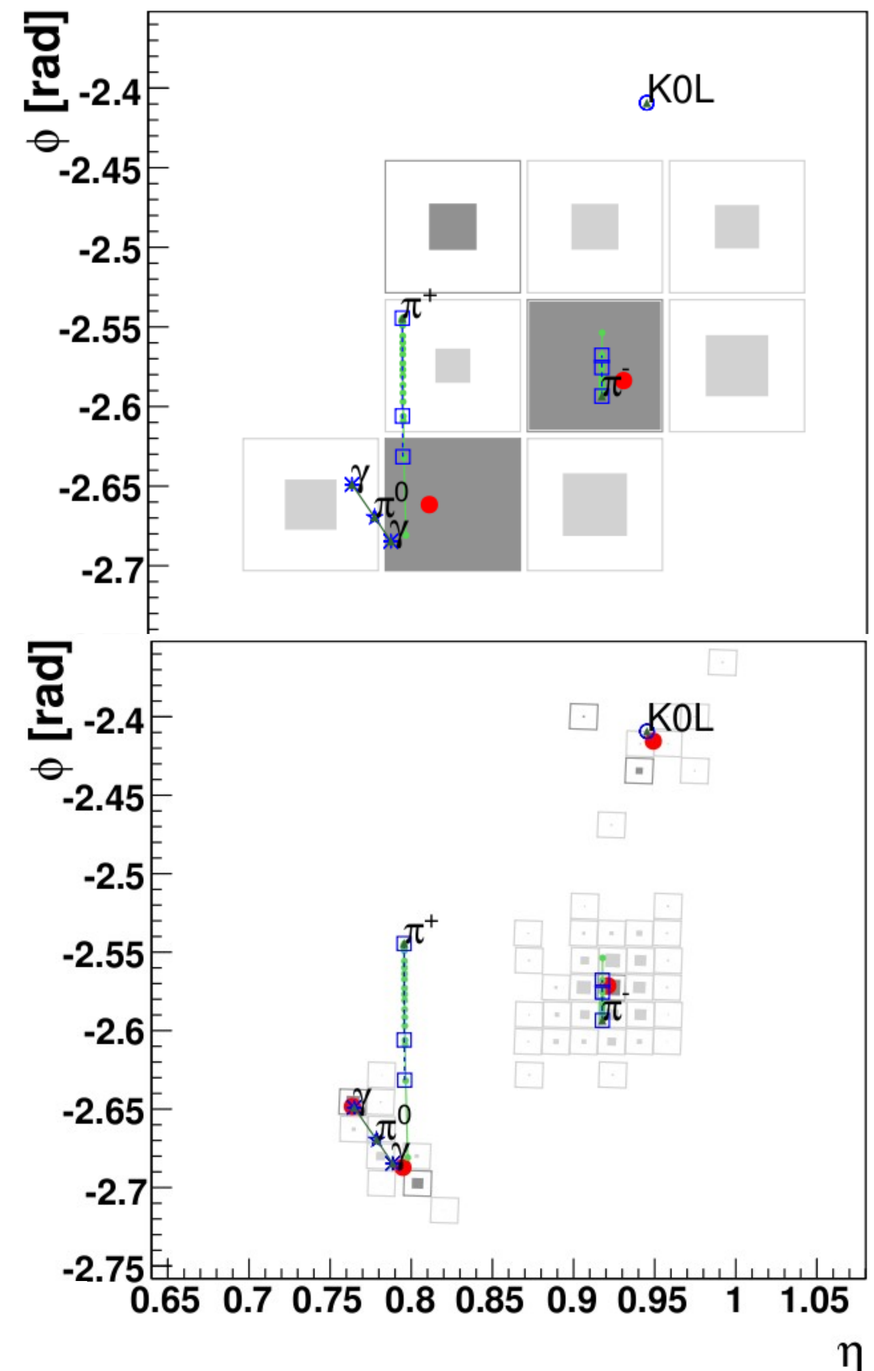
# Linking--> Blocks



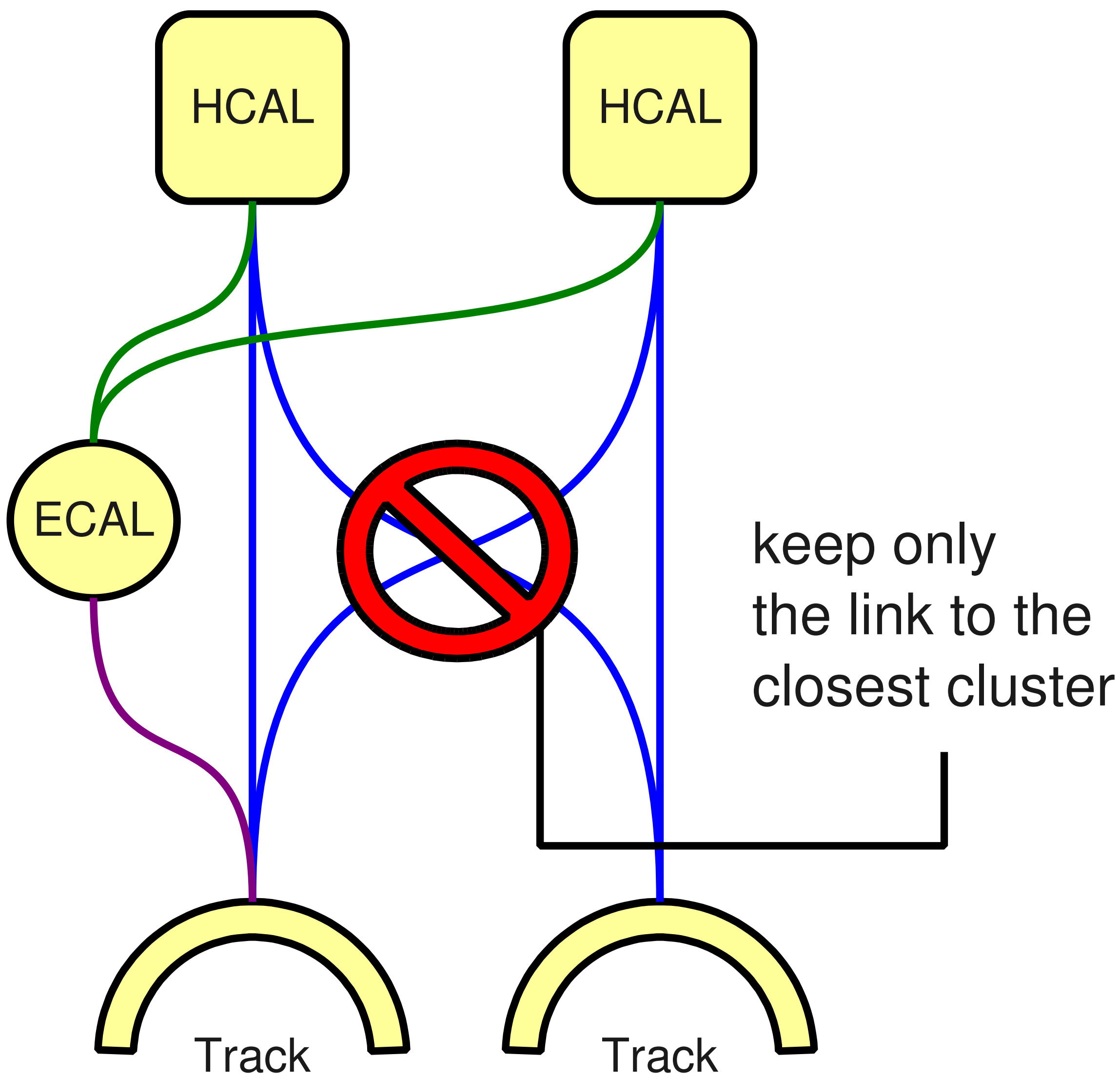



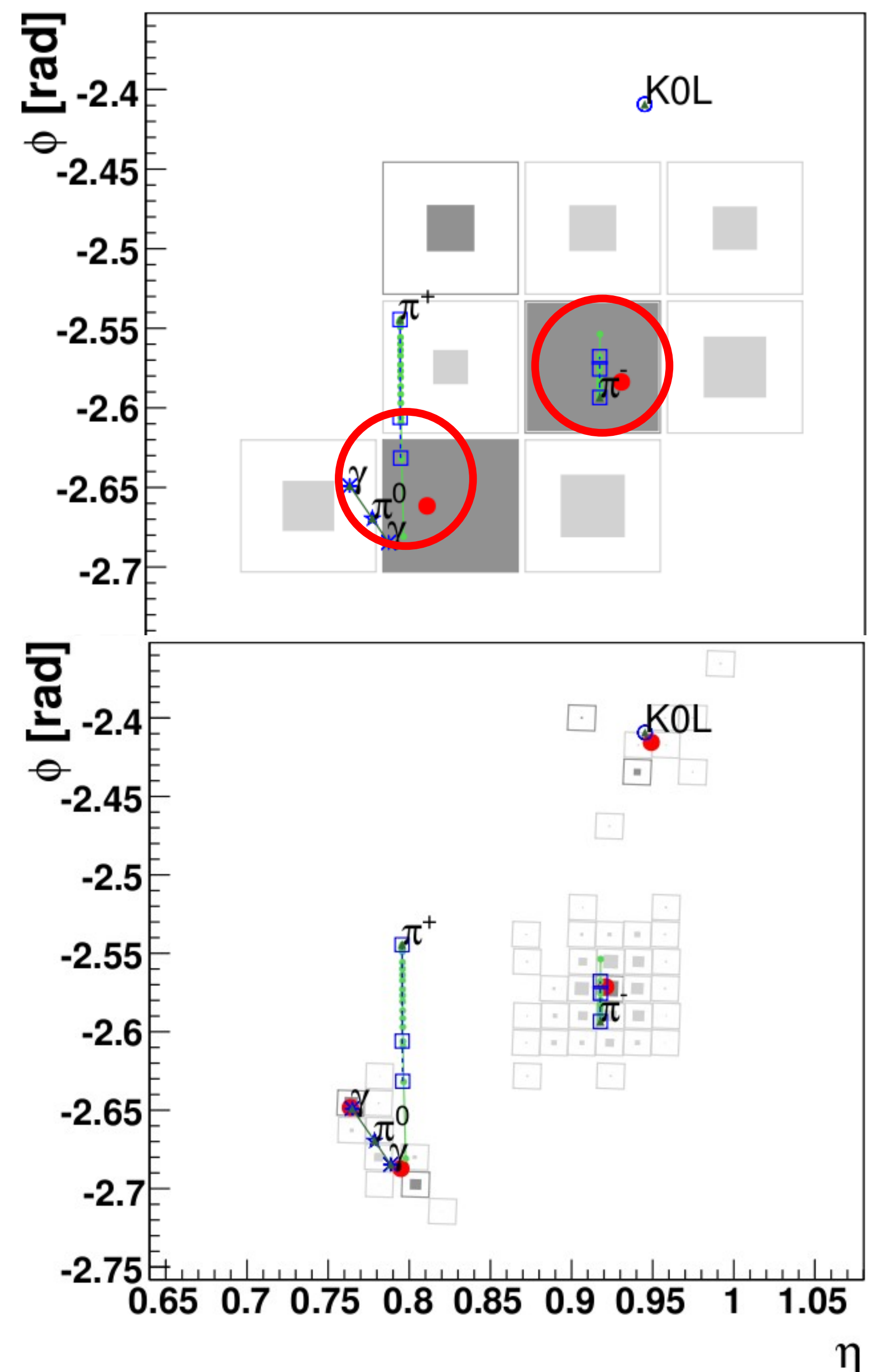
# Selecting photons



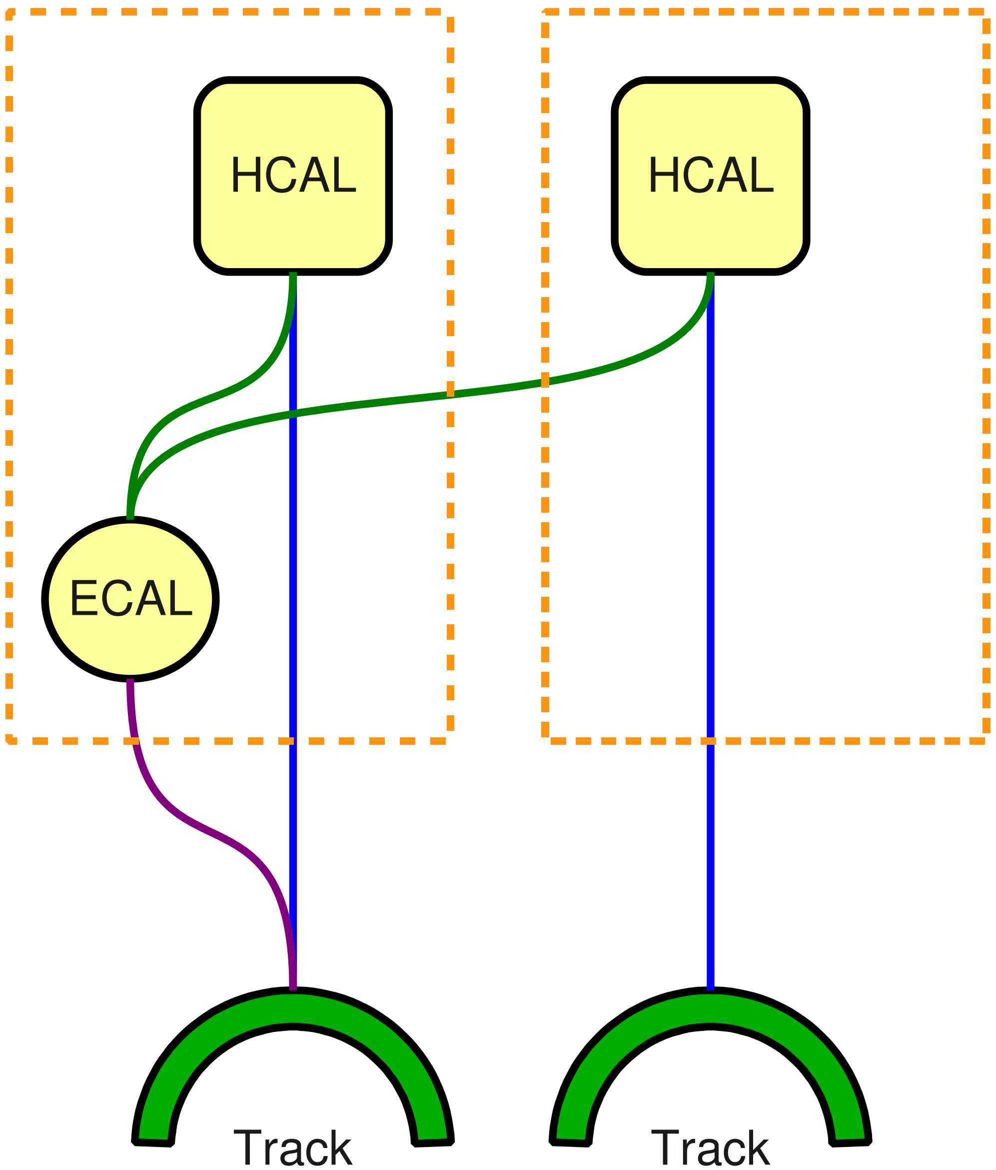



# Proceeding with the analysis of the blocks



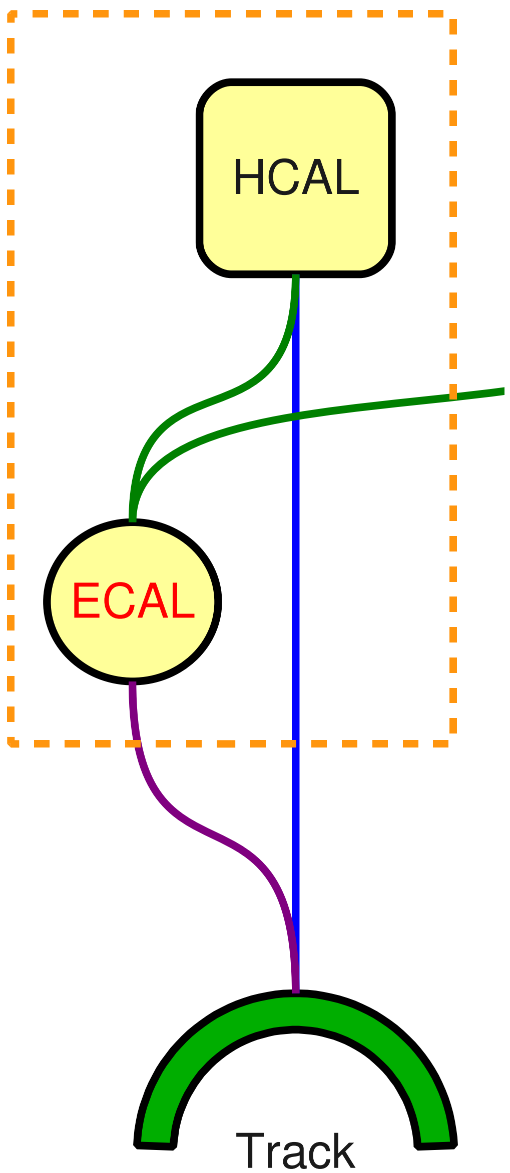



# From the blocks to the list of particles




* For each hcal:
  * compare reconstructed (and calibrated) calorimeter energy to the to the linked track momentum
  * if calorimeter energy is bigger than the track momentum:
    * create a charged hadron and one additional photon or neutral hadron
  * if not:
    * simply consider the calorimeter deposit as derived from the energy deposition of the charged hadron

# Photon or Neutral hadron?



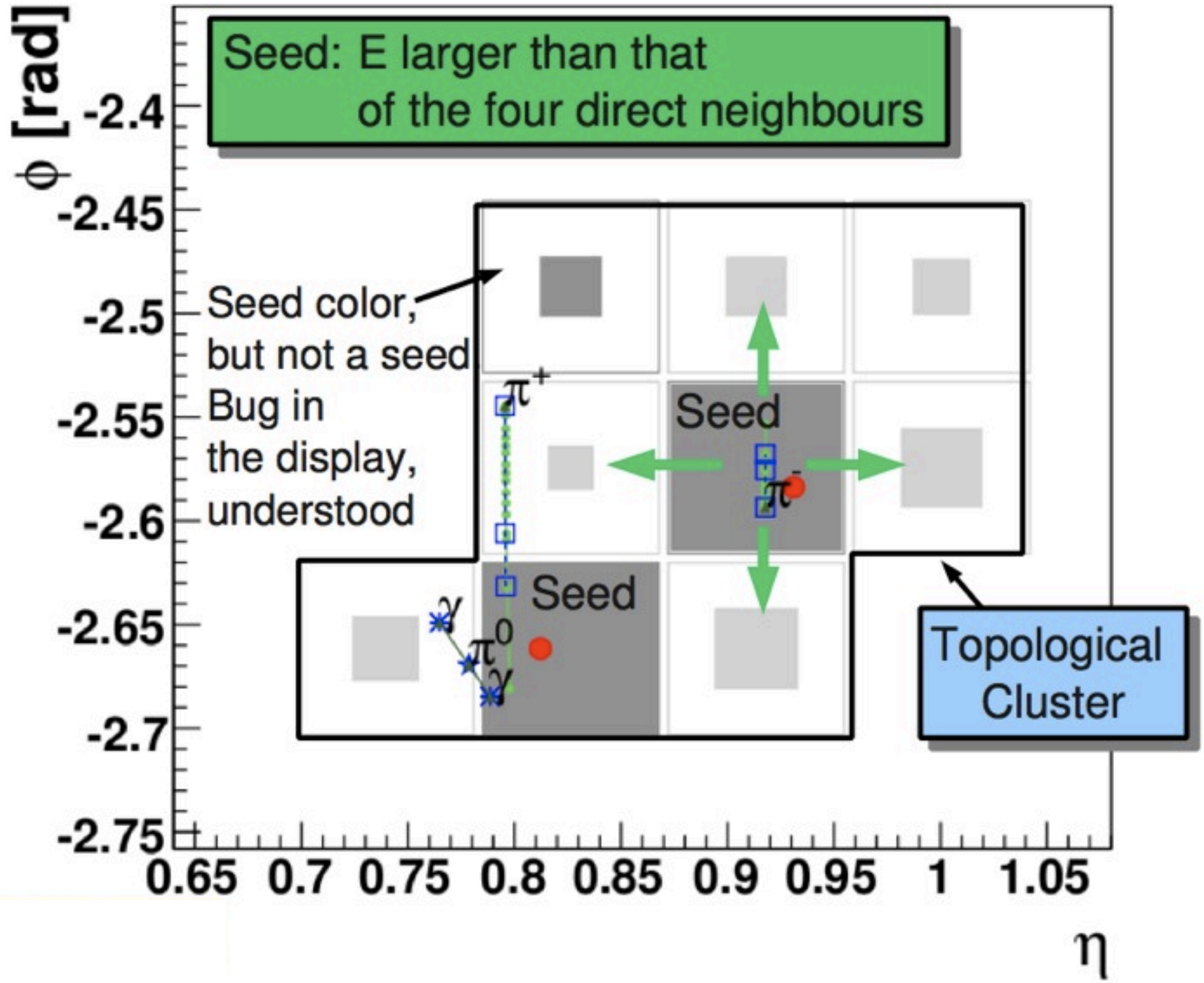

* In case an excess is found in the calorimeter energy wrt track momentum:
  * if the excess is bigger than the Ecal only energy:
    * both a photon (taking all the Ecal energy) and a neutral hadron (with the remaining excess) are created
      * each of them with the proper calibration applied
  * if the excess is less than the Ecal only energy:
    * only a photon is created

# Conclusions

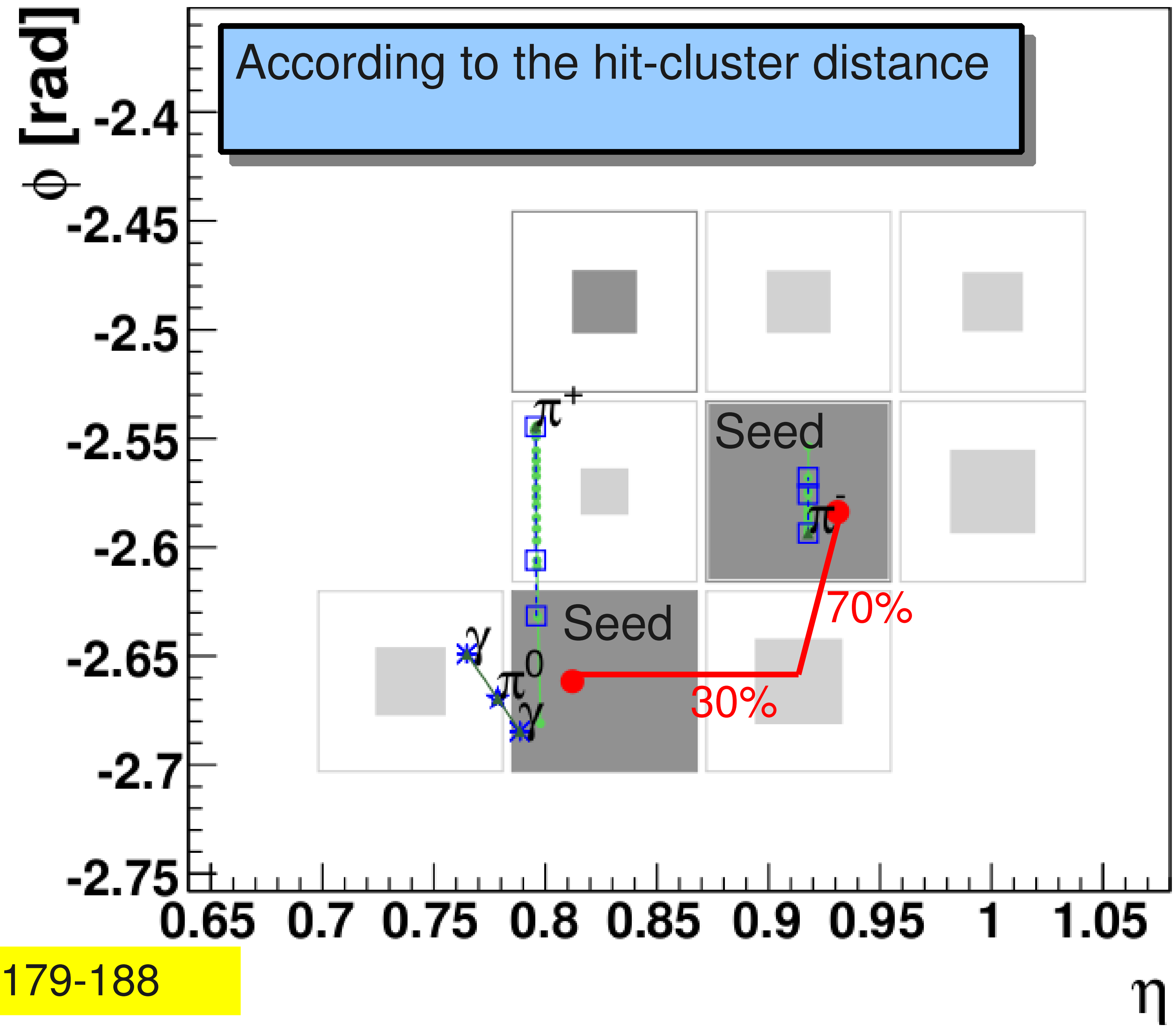
* the particle-flow technique aims at reconstructing and identifying all stable particles in the event
* The use of the PFlow in the jet and MET reconstruction shows superior performance wrt other techniques
    * Jet pT resolution up to a factor 2 better
    * MET Resolution up to 40%-50% better
* The use of redundancy among different sub-detectors ensure small sensitivity to mis-calibrations and other systematics
* Use it in your analysis! It will surely bring large improvements!
    * For more details follow the Tutorial on how to use the Particle Flow
* Special thanks to: Colin, Rick, Patrick and Kostas

# Back up

# Cluster Seeding (HCAL)

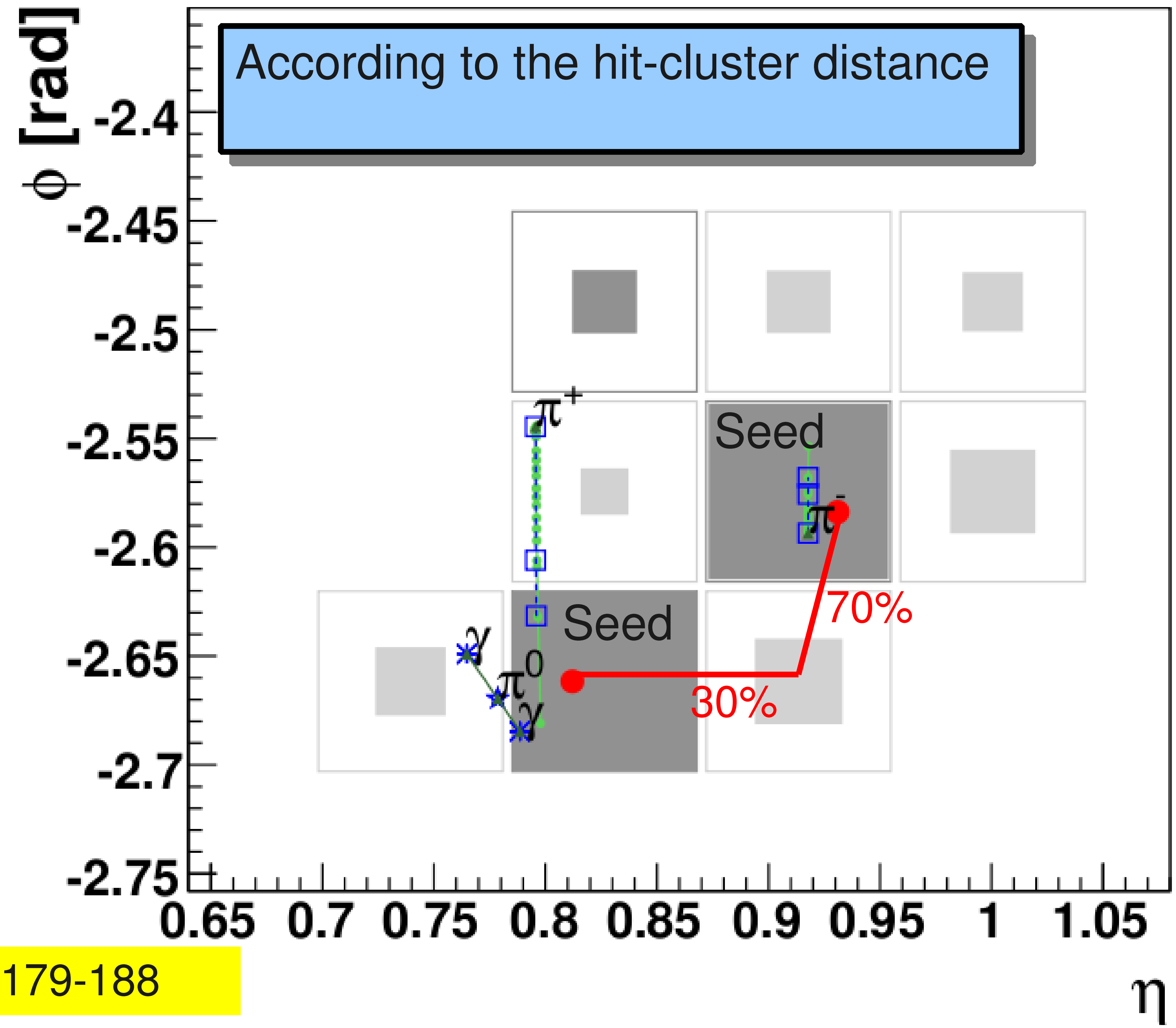


# Sharing the rechit energy



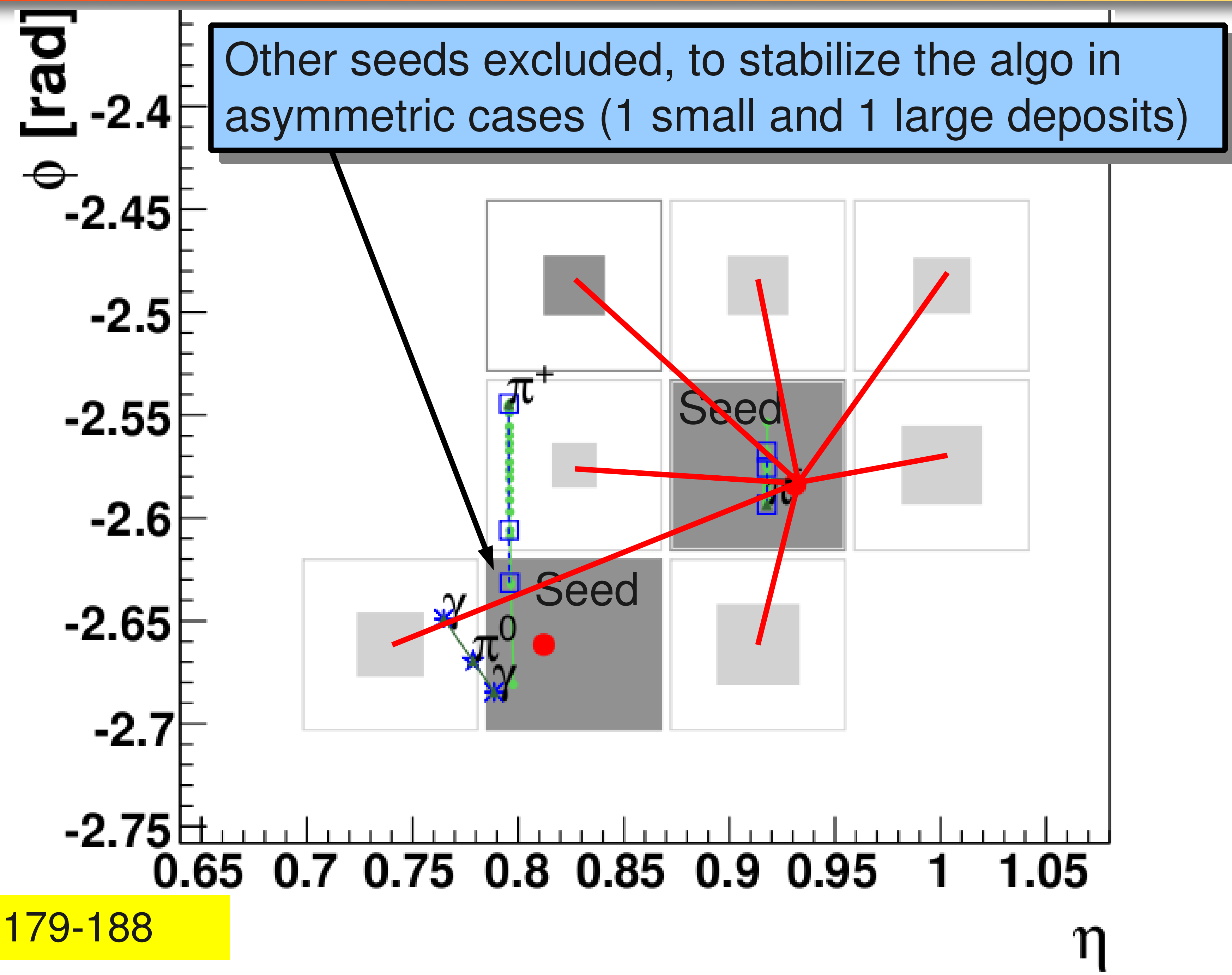

Lines 179-188

# Sharing the rechit energy



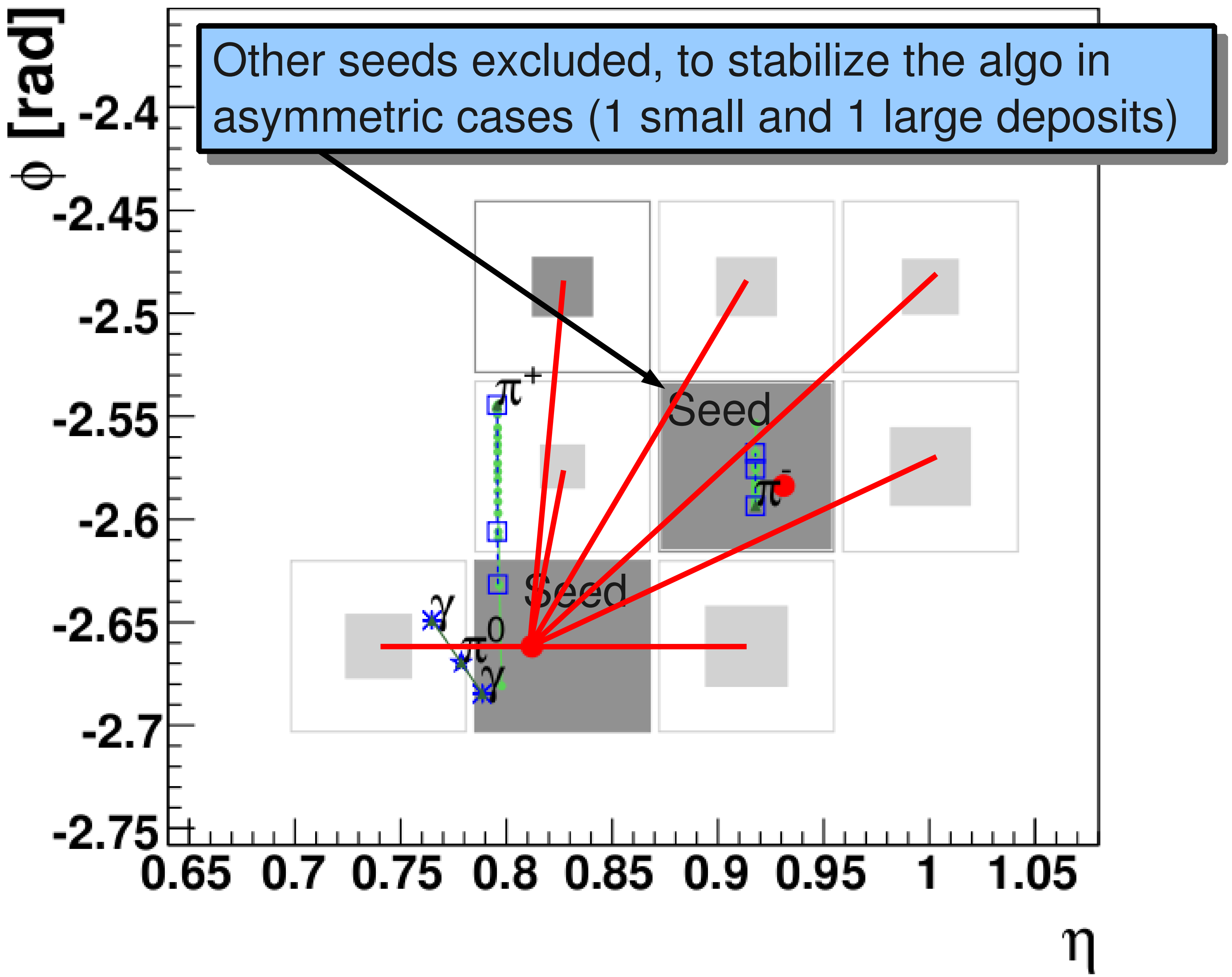

Lines 179-188

# Sharing the rechit energy

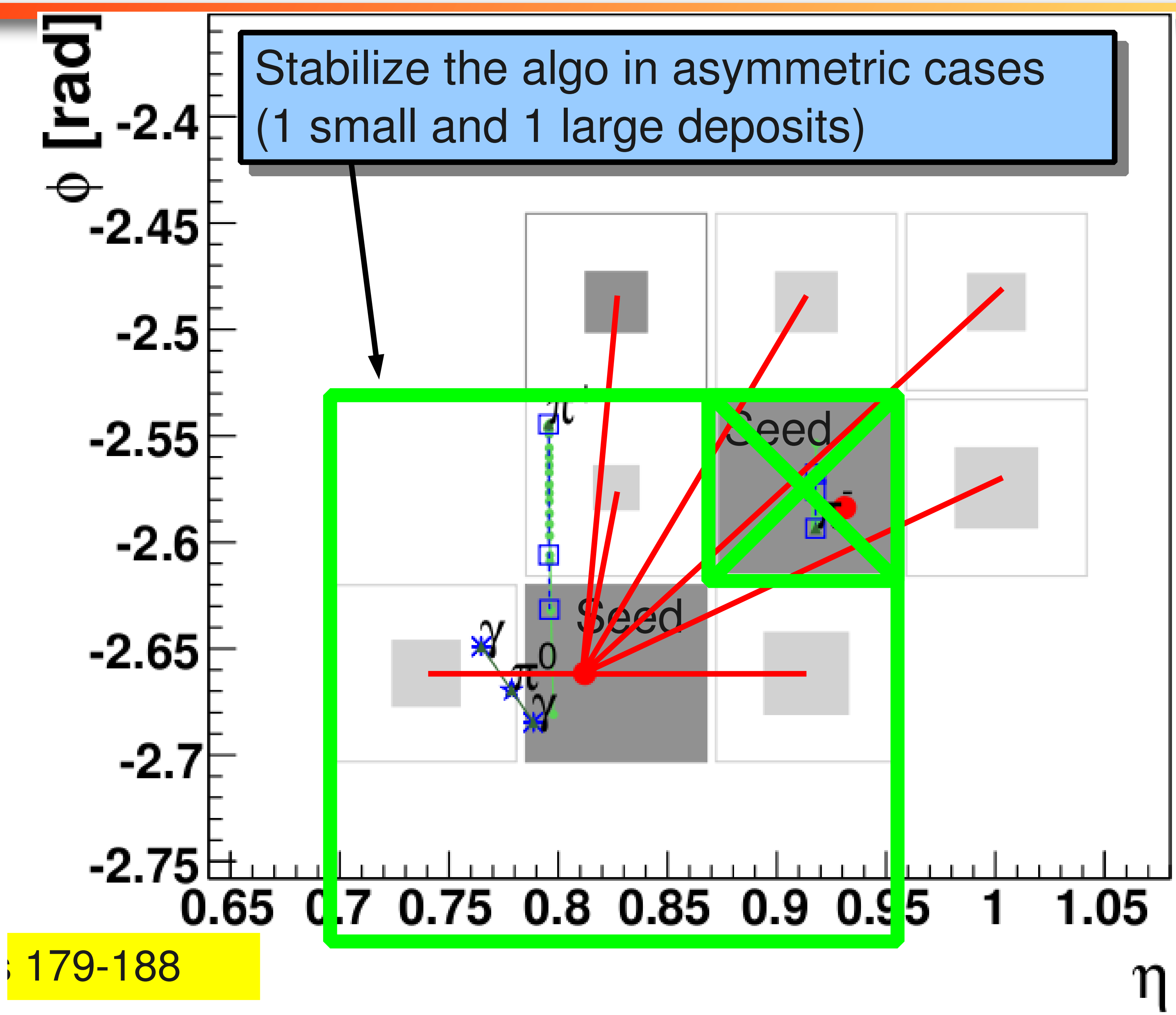



Lines 179-188

# Sharing the rechit energy



# Sharing the rechit energy



# Neutral hadron calibration

$$E_{\text{calib}} = a(E,\eta) + b(E,\eta)E_{\text{ECAL}} + c(E,\eta)E_{\text{HCAL}}$$

- In order to calibrate we need to estimate the real energy of the particle
- Estimator = max between
  - sum of track momentum
  - $E_{ecal} + E_{hcal}$
- Parameter estimation
  - "b" and "c" from the fit
  - "a" is chosen to minimize the Energy dependence of "b" and "c"