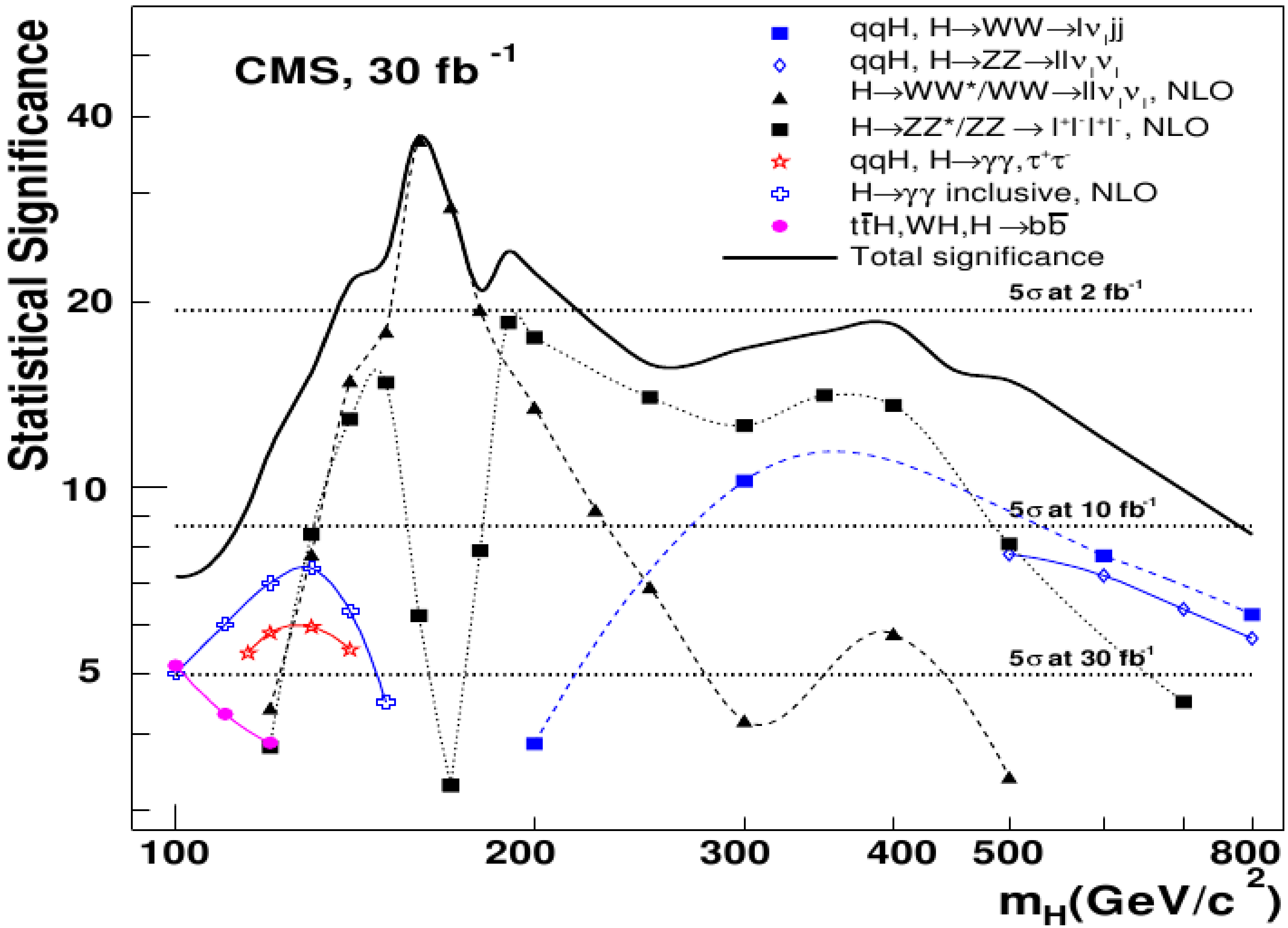
Particle Flow in CMS

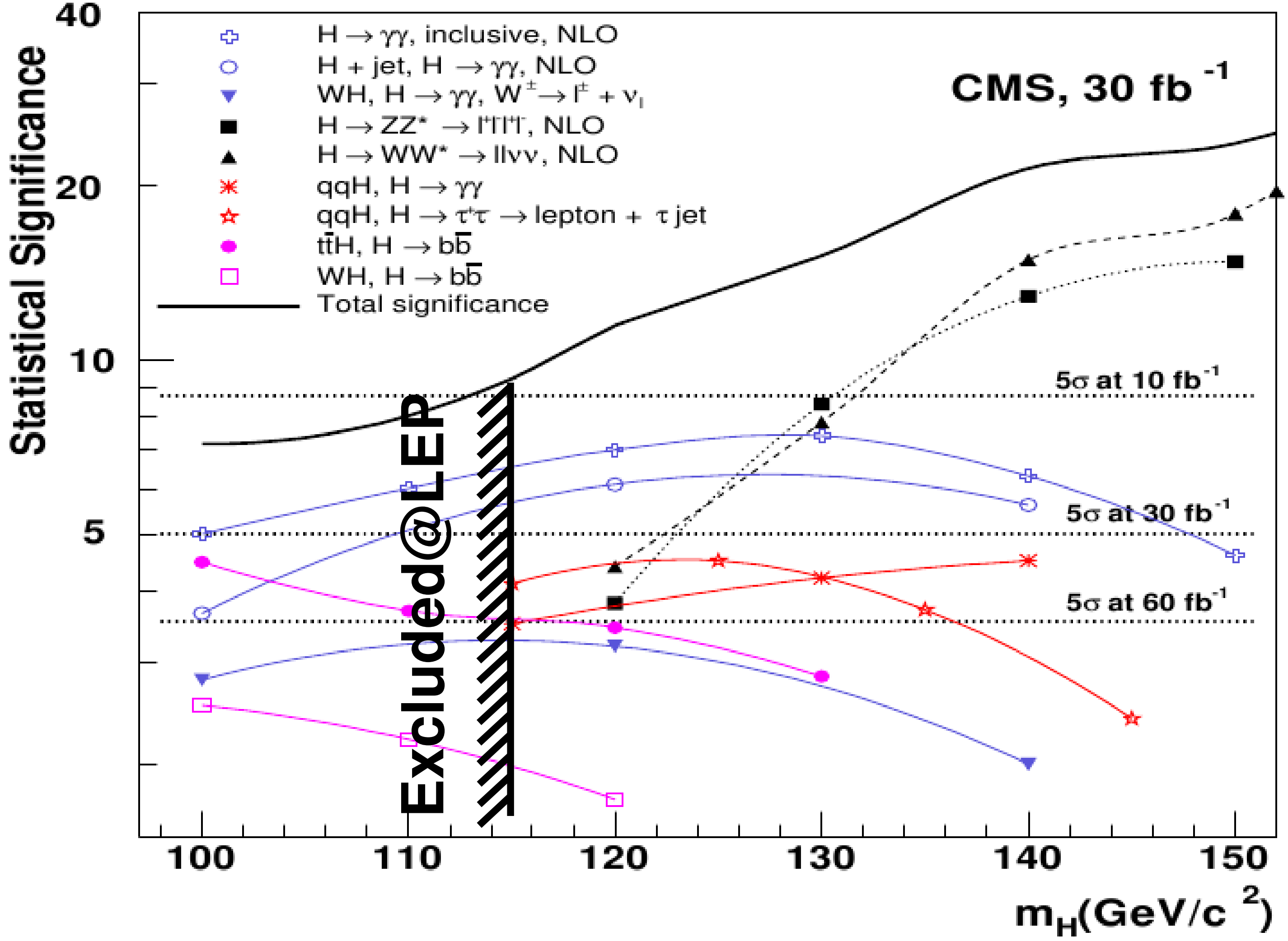
Colin Bernet (CNRS/LLR)

CMS reach for the Higgs



- CMSJET
- Crude simulation:
  - Smearing of the generator information
- Outdated !

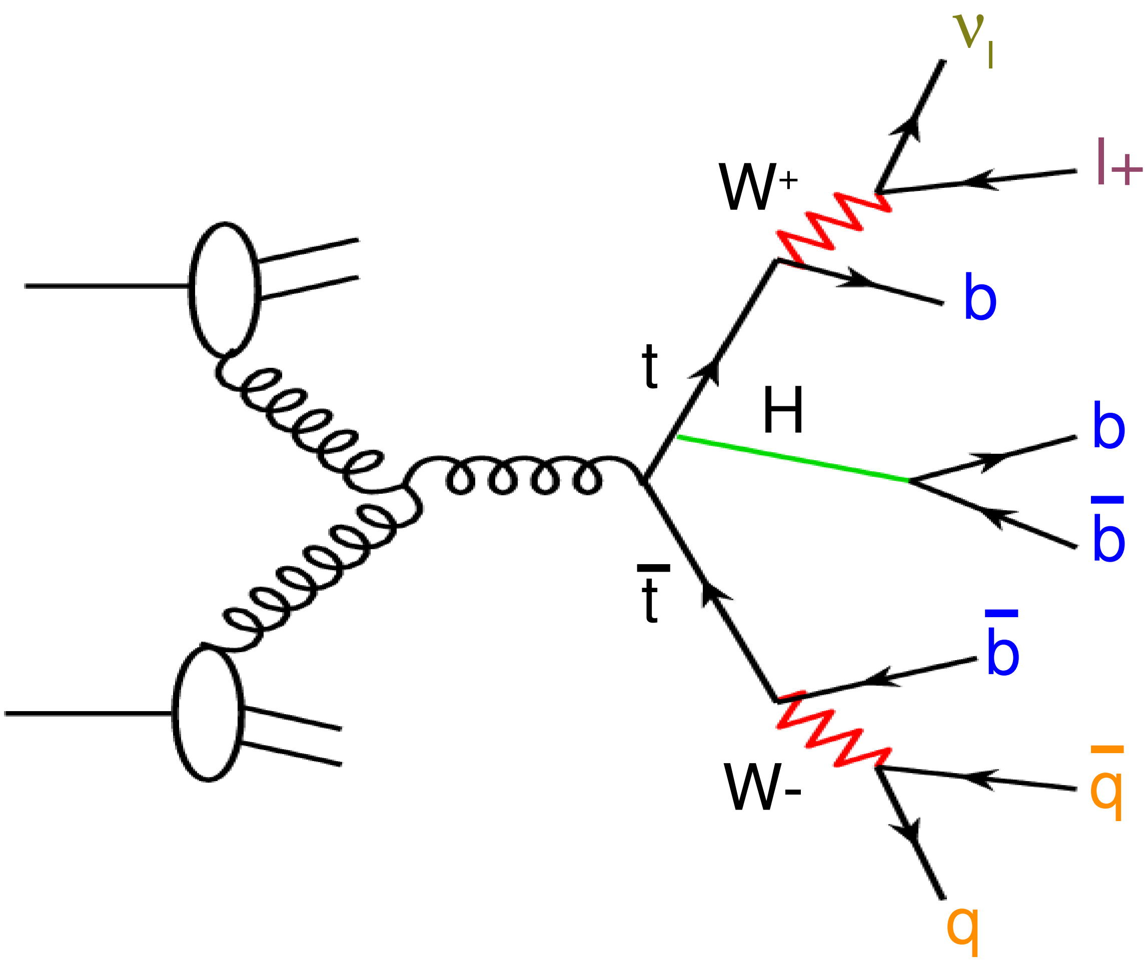
CMS reach for the Higgs



Low mass region

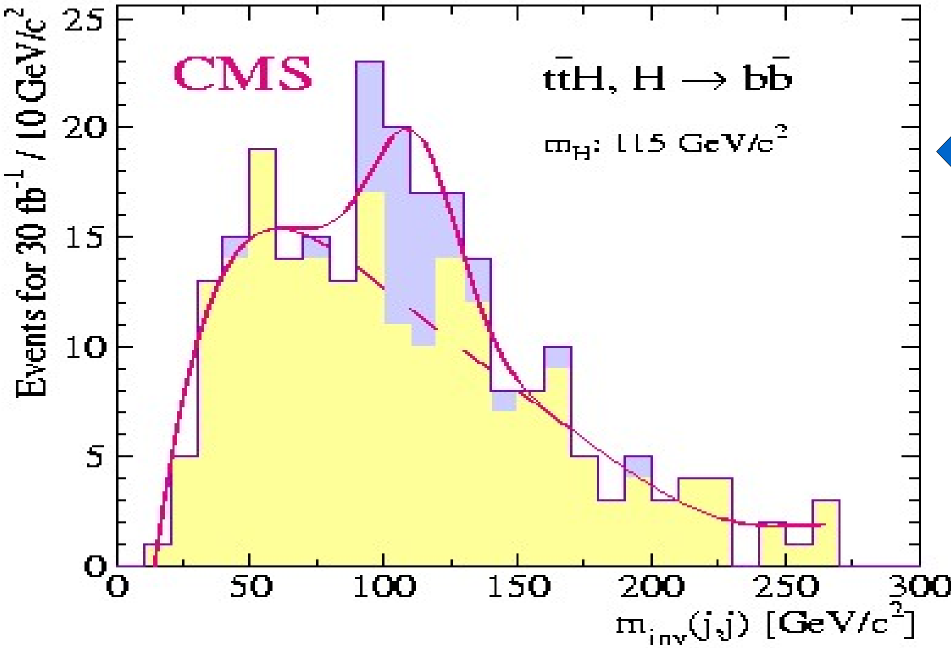
- CMSJET
- Crude simulation:
  - Smearing of the generator information
- Outdated !

$t\bar{t}H, H \rightarrow b\bar{b}$

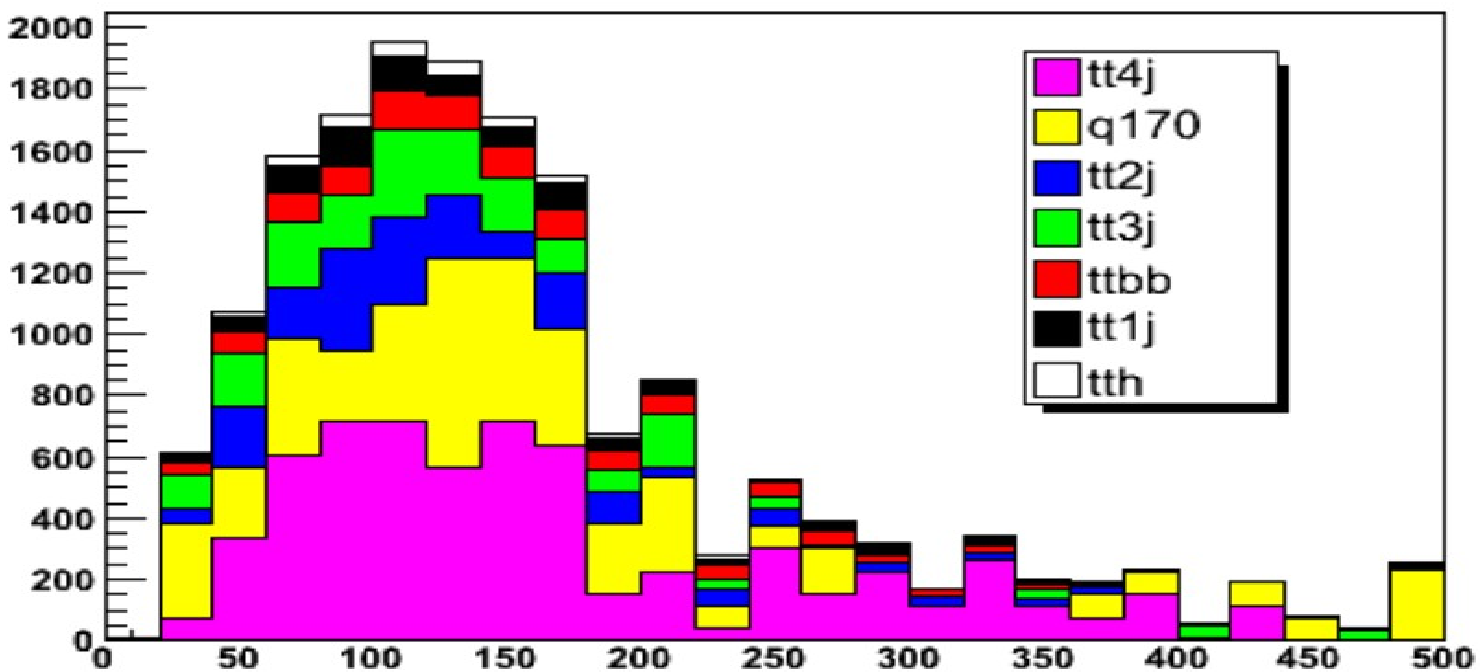


- In this example:
  - 1 high pT lepton
  - MET
  - 4 b jets
  - 2 light jets
- Challenging...

... very challenging indeed !



- CMSJET (2001)
- Geant simulation (2007)
  - ORCA, PTDR vol 2



The particle flow miracle

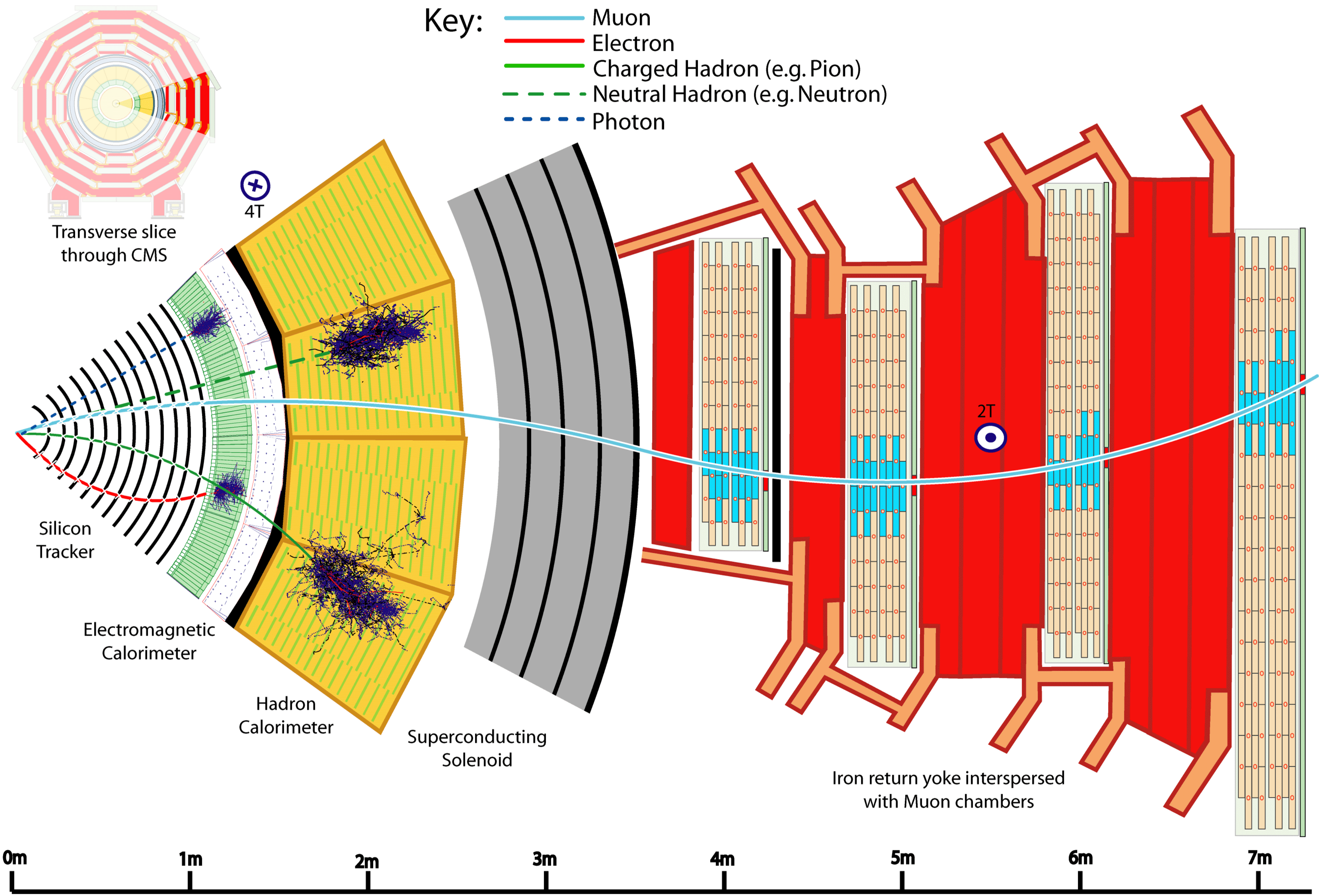
- Will benefit all channels with:
  - Jets
  - Tau jets
  - b jets
  - MET
- Our only hope for ttbar H, H->bbar

- **Overview of this talk**
  - An introduction to particle flow
  - A selection of hot topics
    - Detection of neutral particles
    - Material effects
    - Analysis with particle flow

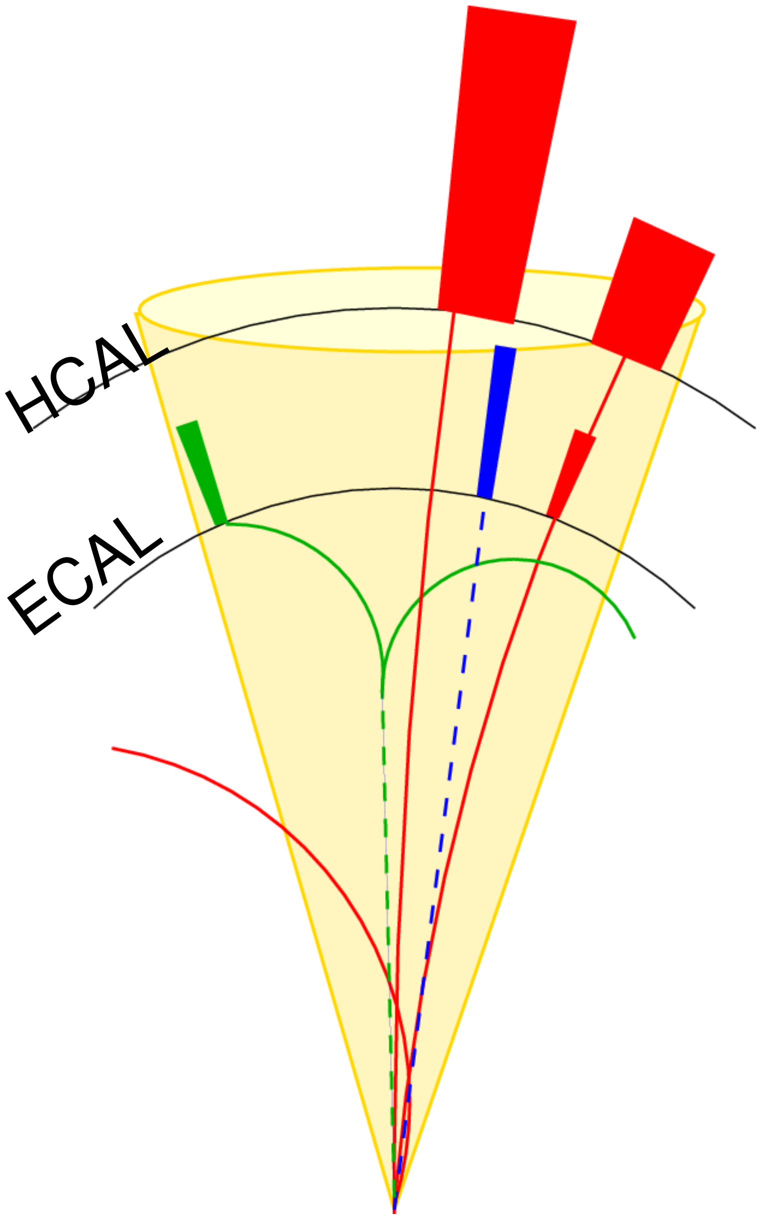
The father of particle flow in CMS walking on the lac de Geneve

By Jingwen

A slice of CMS



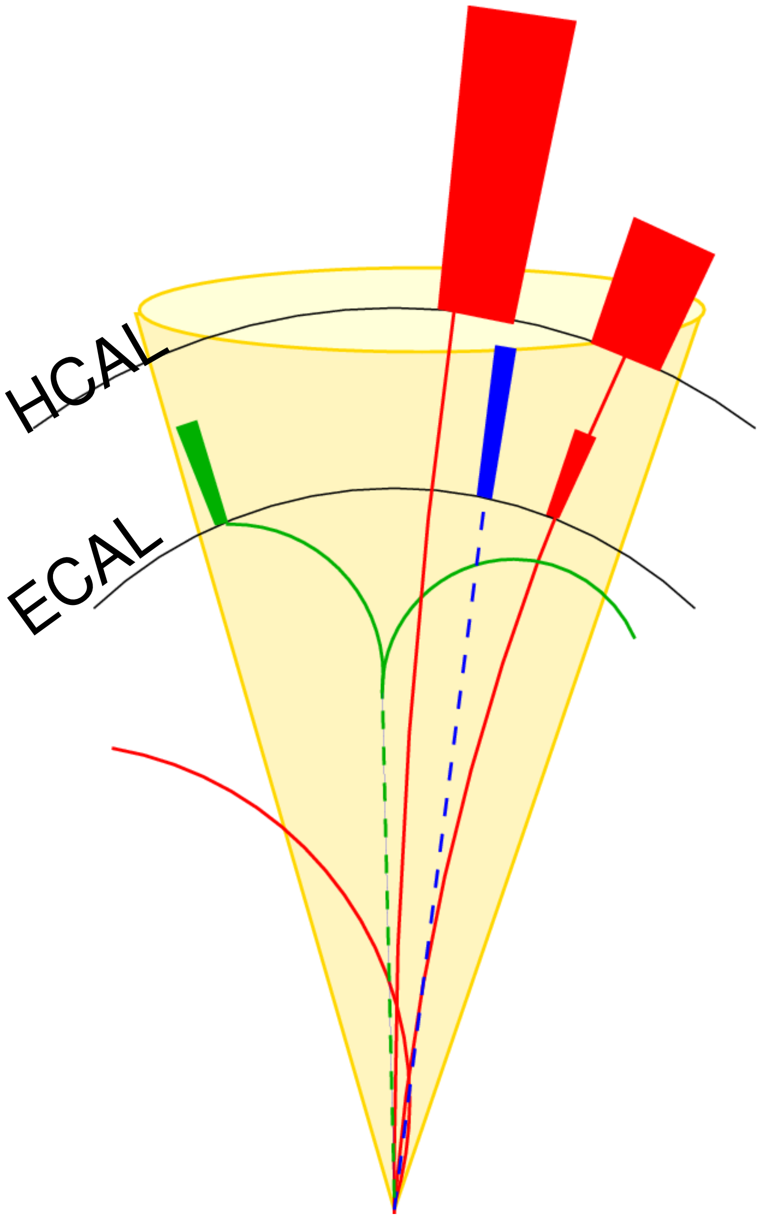
Traditional jet reconstruction



- Jets from calorimeter cells

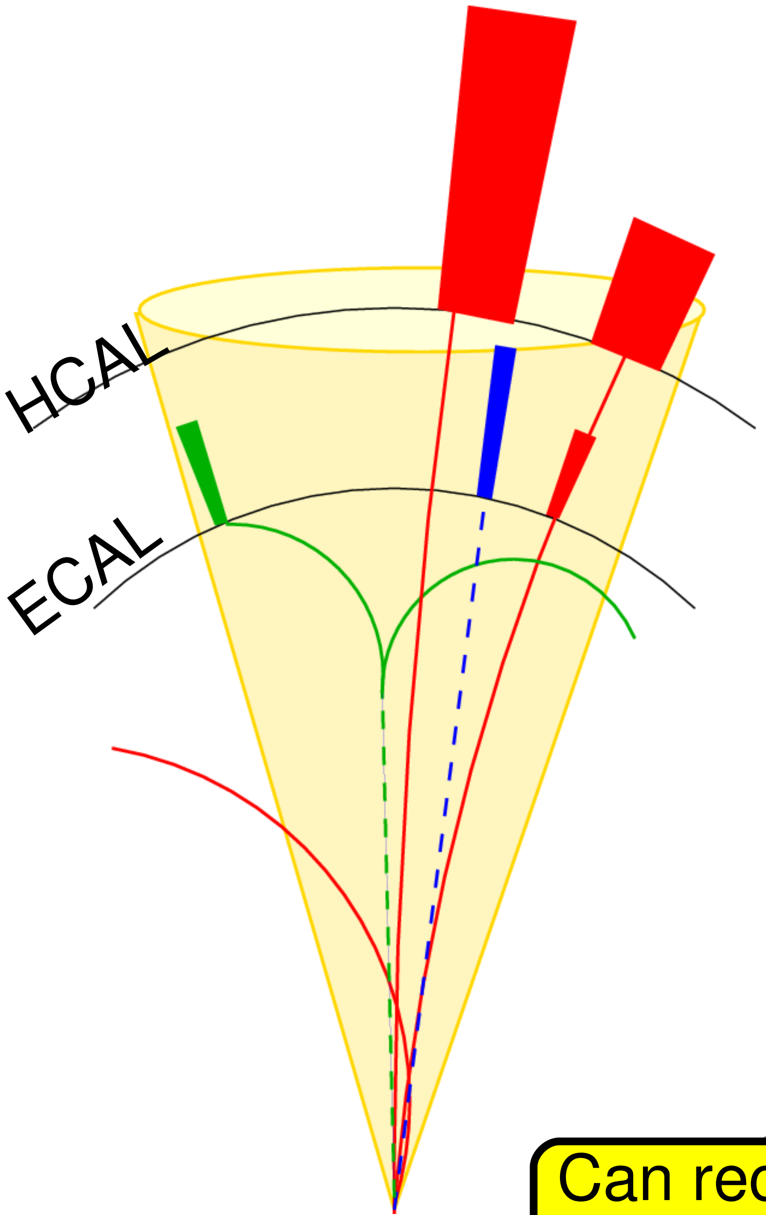
- **<u>Hadrons</u>** (75% of the energy)
  Measured with a 130%/√E relative energy resolution
  → Bad energy resolution.
- **<u>Photons</u>** (25% of the energy)
  Calibrated as hadrons
  → Bias on the energy.
- **<u>All charged particles:</u>**
  Bent by the magnetic field
  → Bad angular resolution,
  → Bias on the direction (τ),
  → Creates fake invariant mass,
  → Energy lost (escape jet cone).
- **<u>Unstable neutral particles</u>** (converted γ, V^0)
  Suffer from most problems.

What is particle Flow ?



- Reconstruct/identify all stable particles in the event:
  - Photons, charged and neutral hadrons, electrons, muons
- By combining all subdetectors in the best possible way
  - Tracker, preshower, ECAL, HCAL, muon chambers
- The resulting list of particles is the input of
  - Jet clustering
  - Tau and b ID
  - MET reconstruction

Particle flow jet reconstruction



- Jets from particle flow particles

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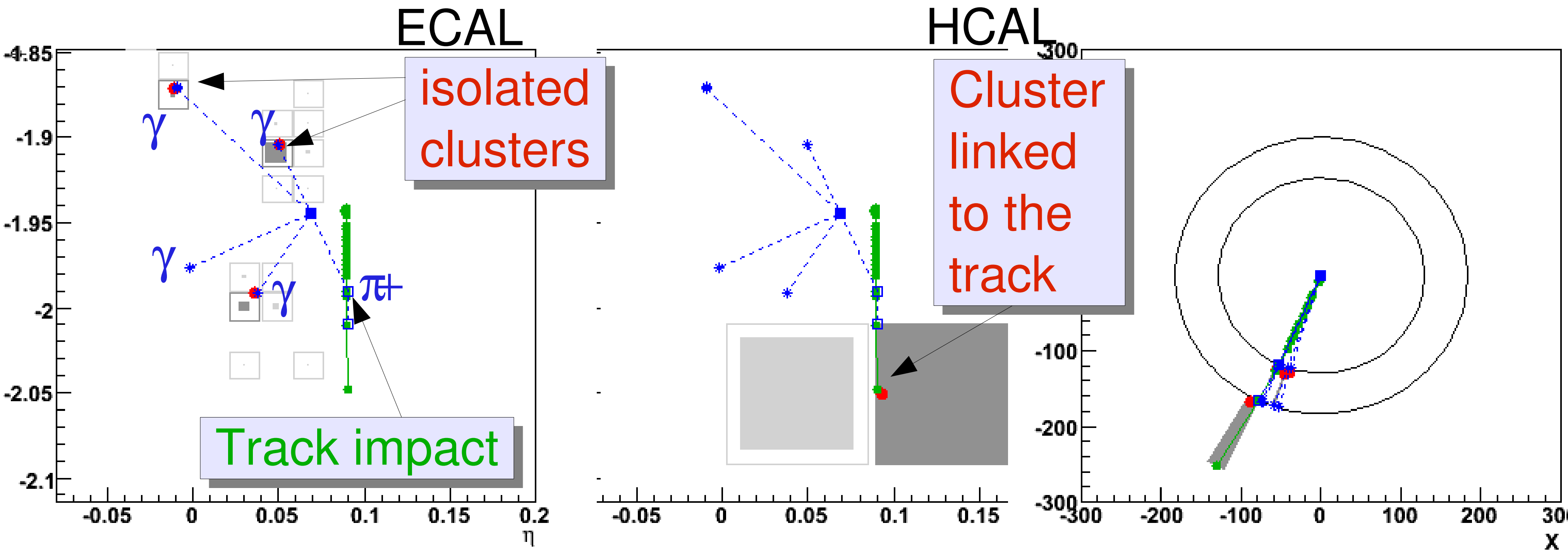
80% charged hadrons

charged particles from the tracker

Can reconstruct them

A simple example



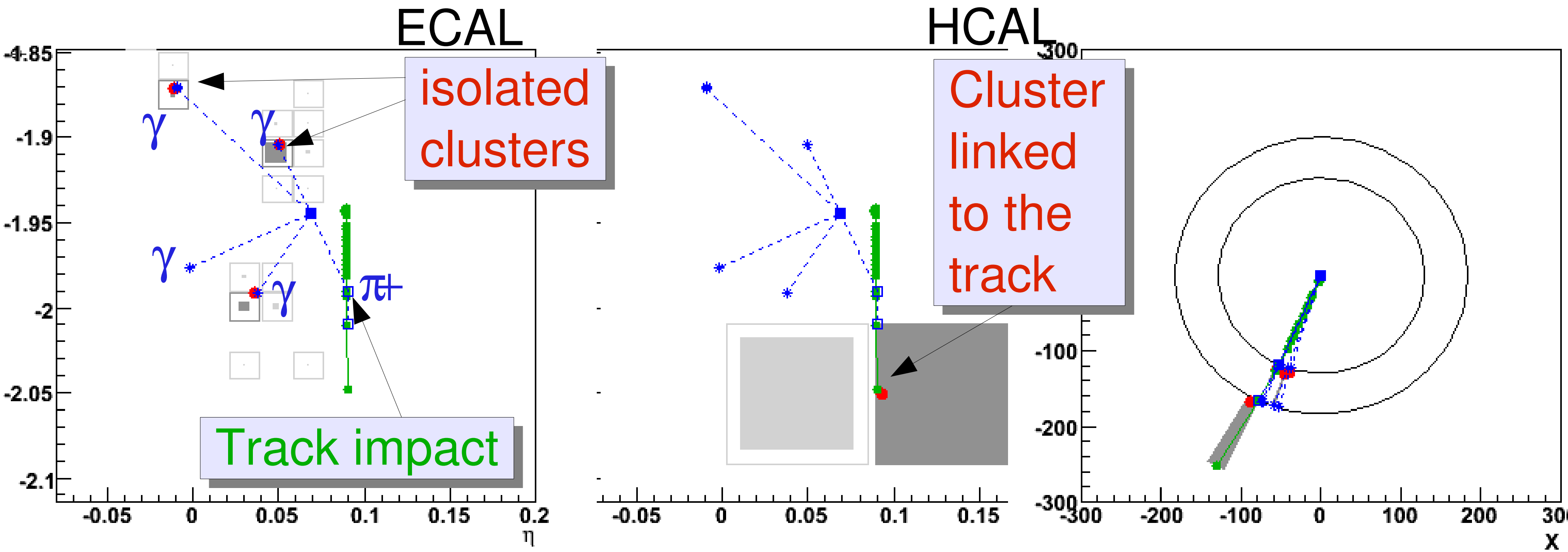
- Reconstruct blocks of interconnected tracks and clusters
  - 3 blocks with 1 single ECAL cluster
  - 1 block with
    - 1 track
    - 1 ECAL cluster

Single tau jet

p_T=40 GeV

π^+, 2 π^0

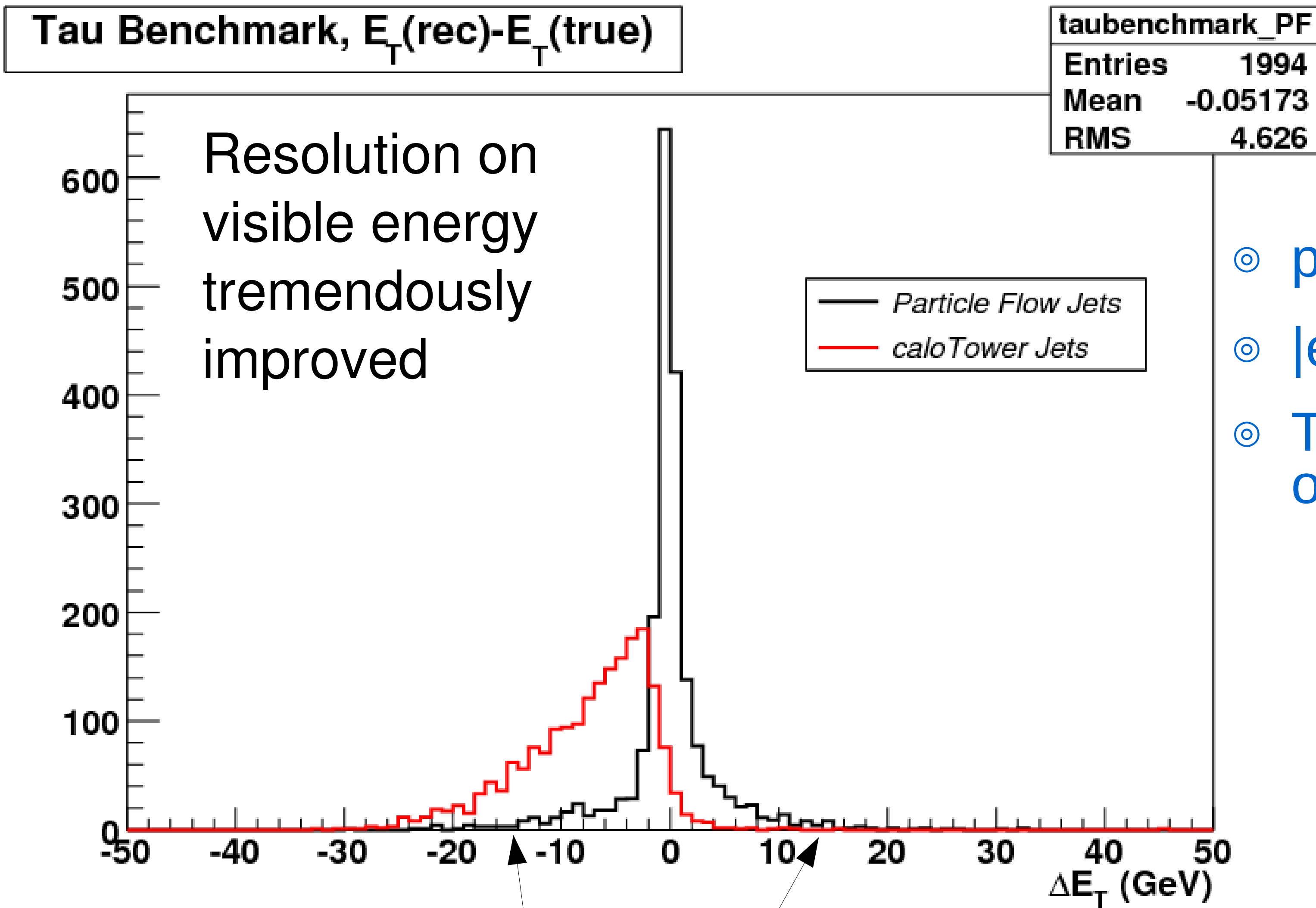
A simple example



- Reconstruct blocks of interconnected tracks and clusters
  - 3 blocks with 1 single ECAL cluster
  - 1 block with
    - 1 track
    - 1 HCAL cluster
- Interpret the blocks in terms of particles
  - 3 photons
    - ECAL e/gamma calibration
  - 1 charged hadron
    - Weighted average of the track and cluster energies

Single taus at low energy

Resolution on visible energy tremendously improved

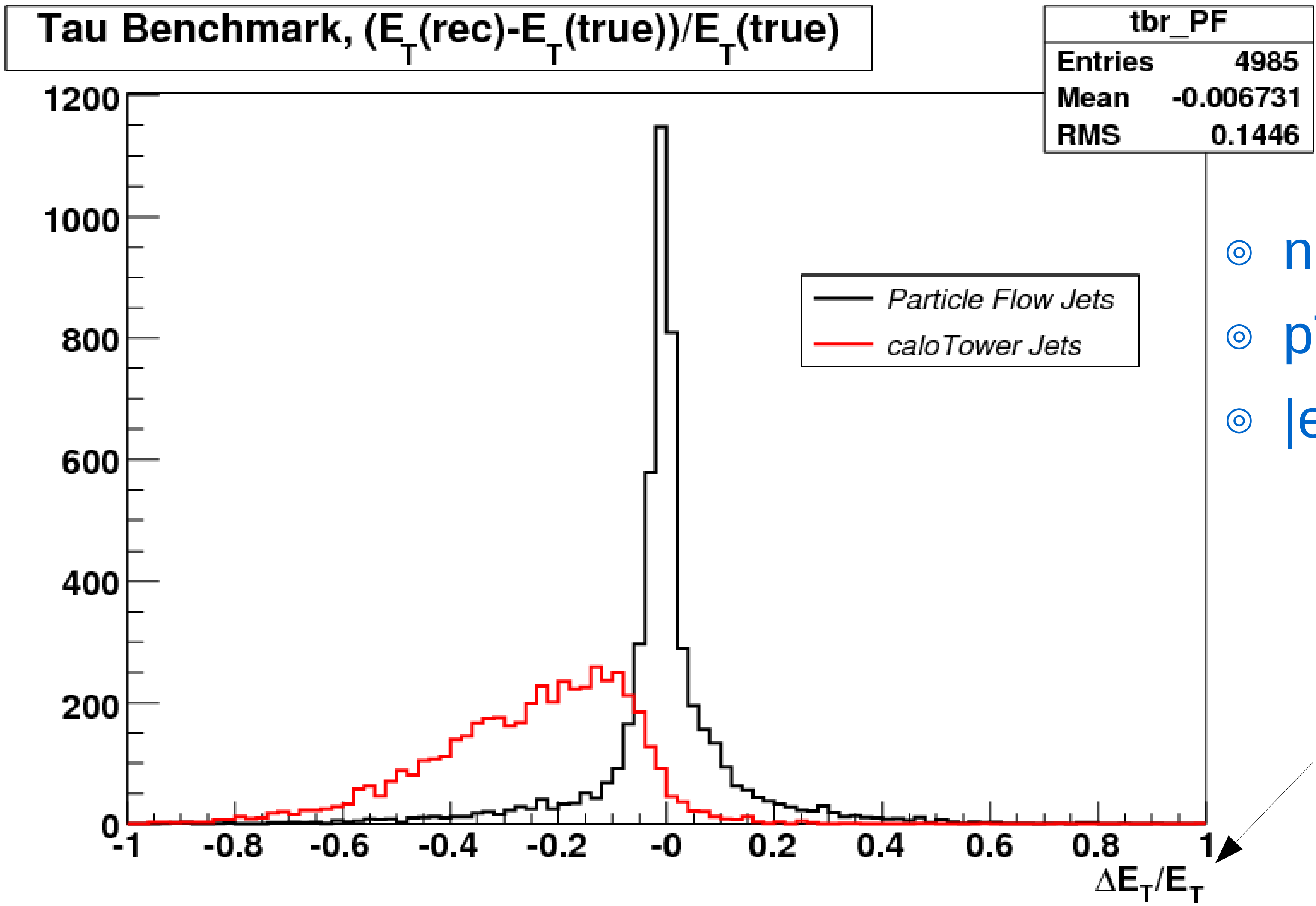


- pT (τ + ν) = 50 GeV
- |eta|<1
- Tau hadronic decays only

Still room for improvements

Hot topic 1: Neutrals

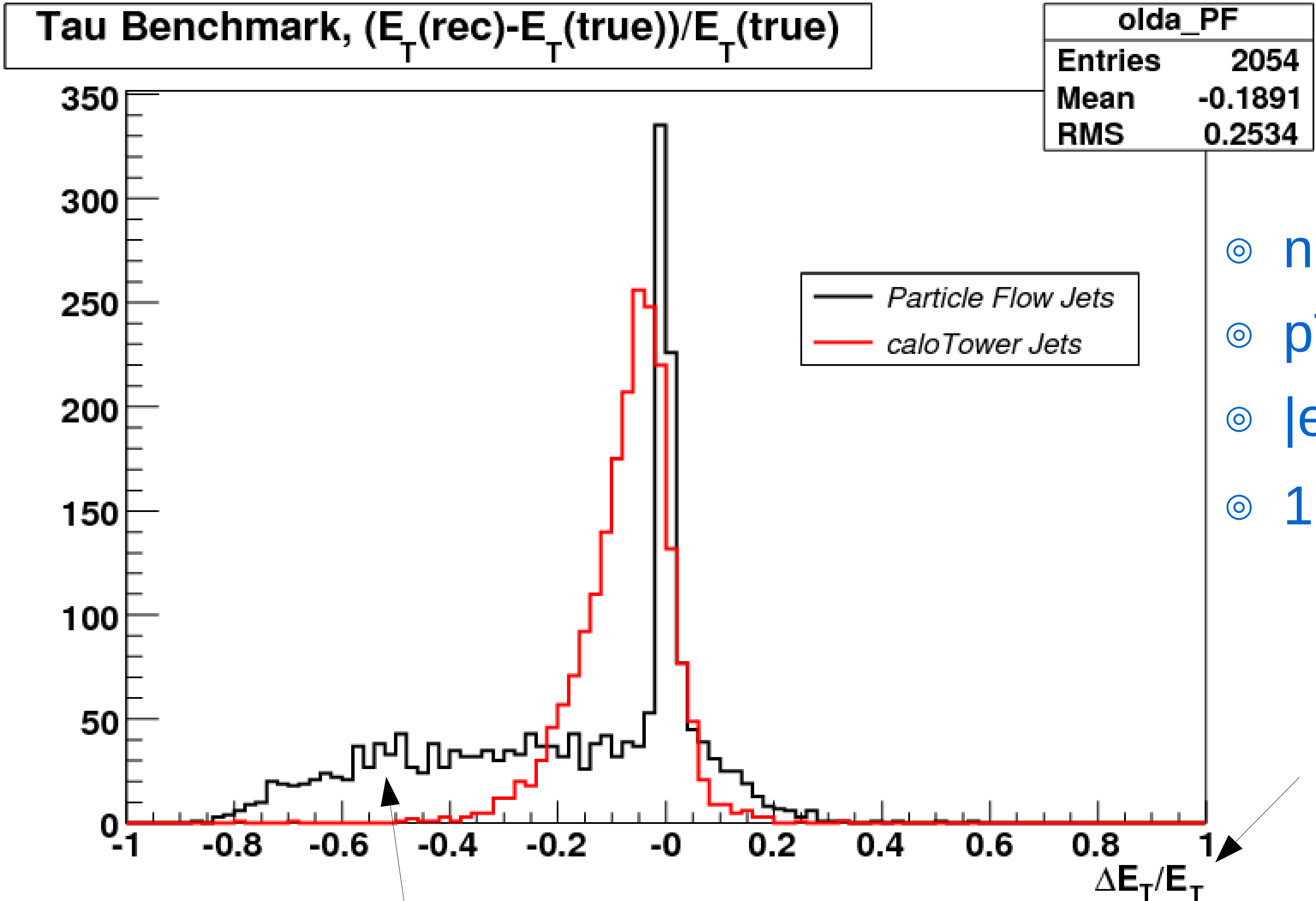
Single taus at low pT



- no material effects
- pT 50 GeV
- |eta|<1

Now plotting the Relative resolution

Single taus at high pT, June07



- no material effects
- pT 200-500 GeV
- |eta|<1
- 1 π^+, 1π^0

Now plotting the Relative resolution

- A huge amount of energy can be lost in high pt taus!

(first seen by S. Lehti and R. Kinnunen, spring 07)

Merged photons

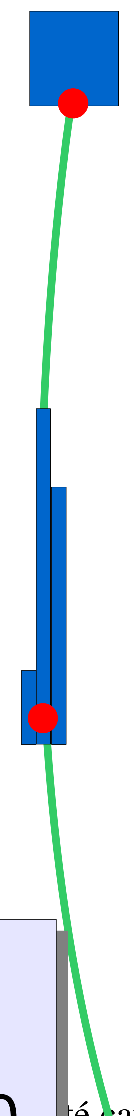
HCAL cluster: E_{HCAL} = 12 GeV

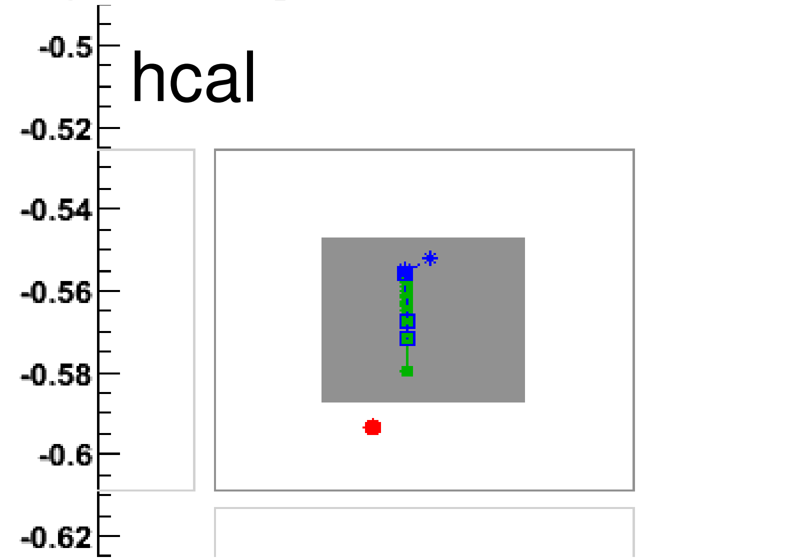
ECAL cluster: E_{ECAL} =160 GeV

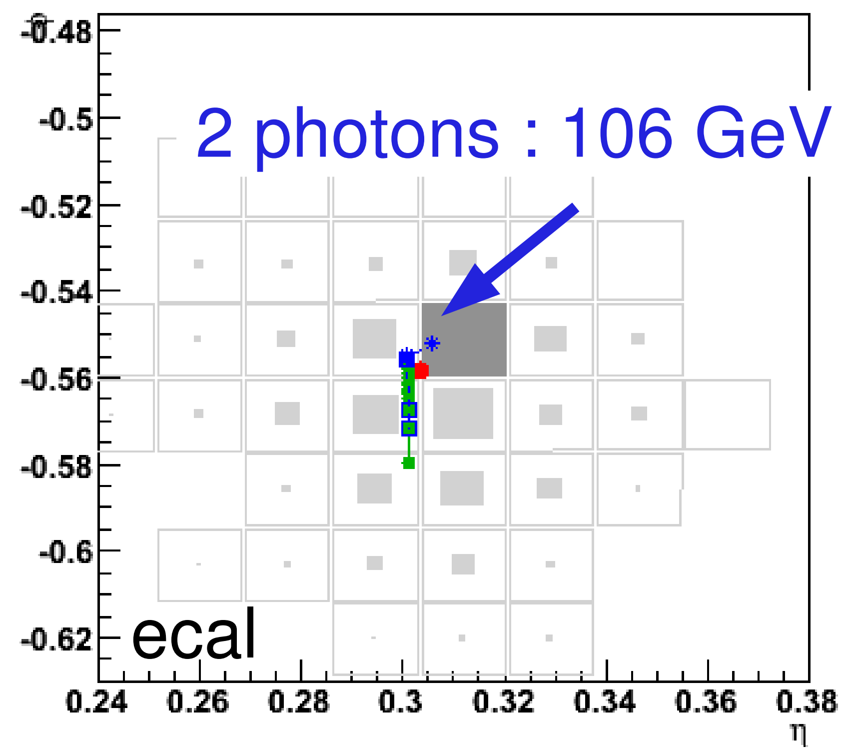
locked away

-> 106 GeV is lost ...

Track: p_{Track} = 80 GeV/c







High pT
single tau
1prong, 1pi0

Merged photon detection

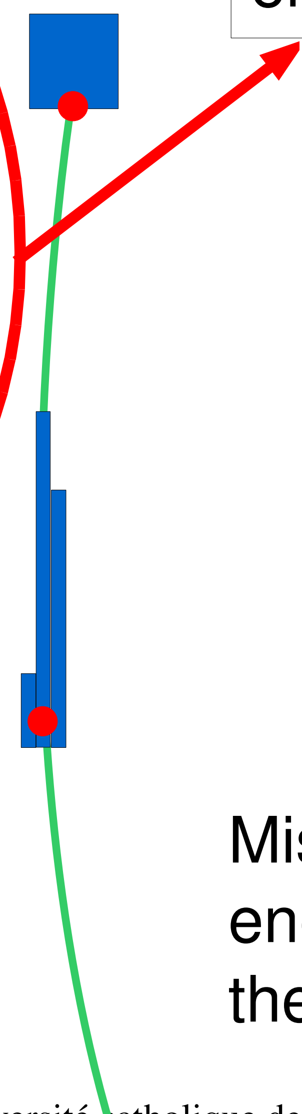
HCAL cluster: E_{HCAL} = 12 GeV

ECAL cluster: E_{ECAL} =160 GeV

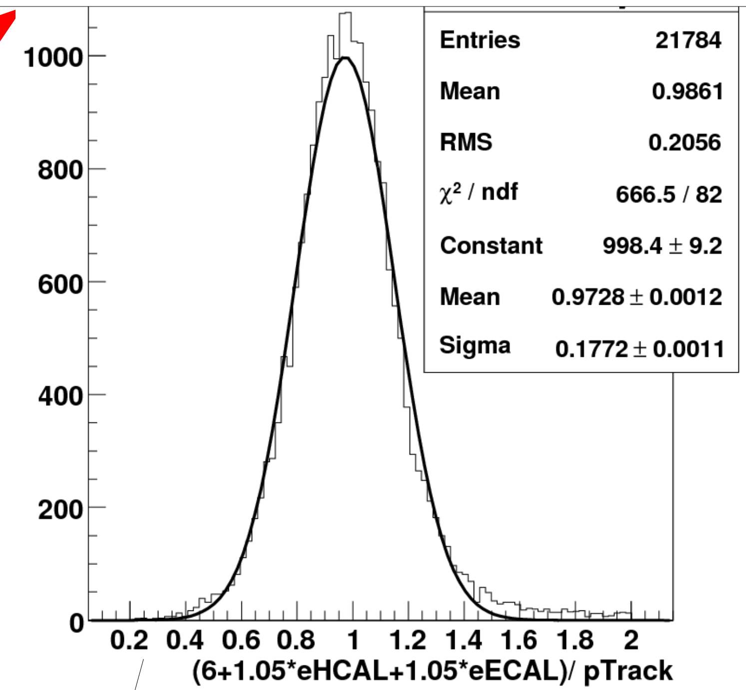
locked away

-> 106 GeV is lost ...

Track: p_{Track} = 80 GeV



Calibrated calorimeter energy over p_{Track} (single π)



Missing energy in the calos

Compatible

Too much energy in the calos

Too much energy in the calorimeters

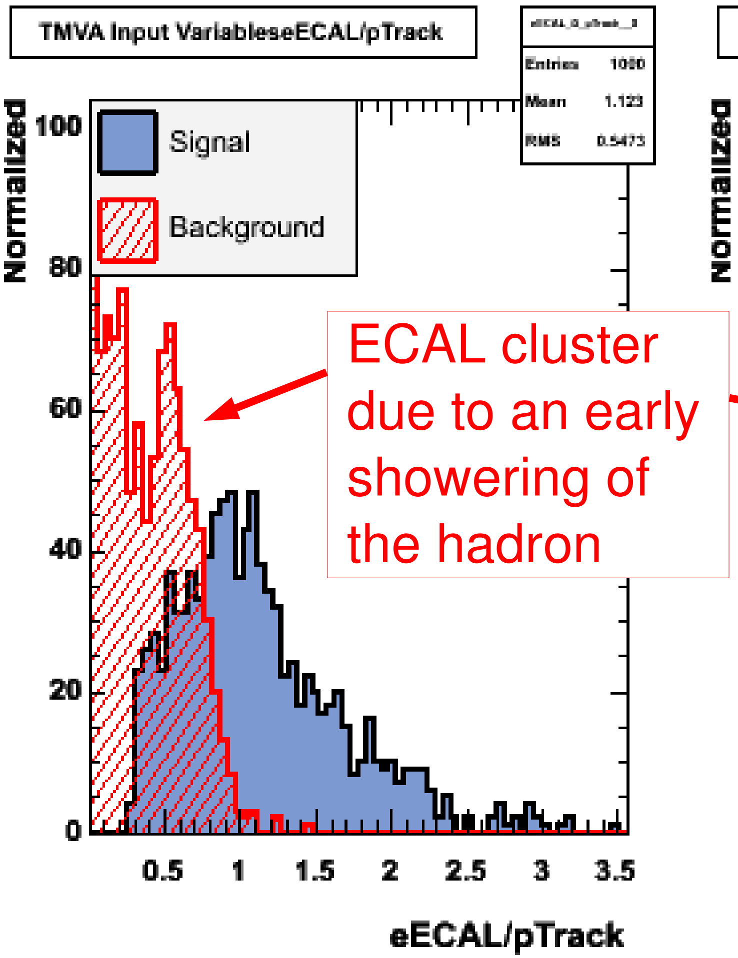
- Excess of energy:
  - Calibrated E_{calo} – track momentum
- Neutral hadron or photon ?
  Important to know this for 2 reasons:
  - To apply the correct calibration (~5% effect)
  - To identify particles correctly

    taus: neutral hadrons mostly come from nuclear interactions

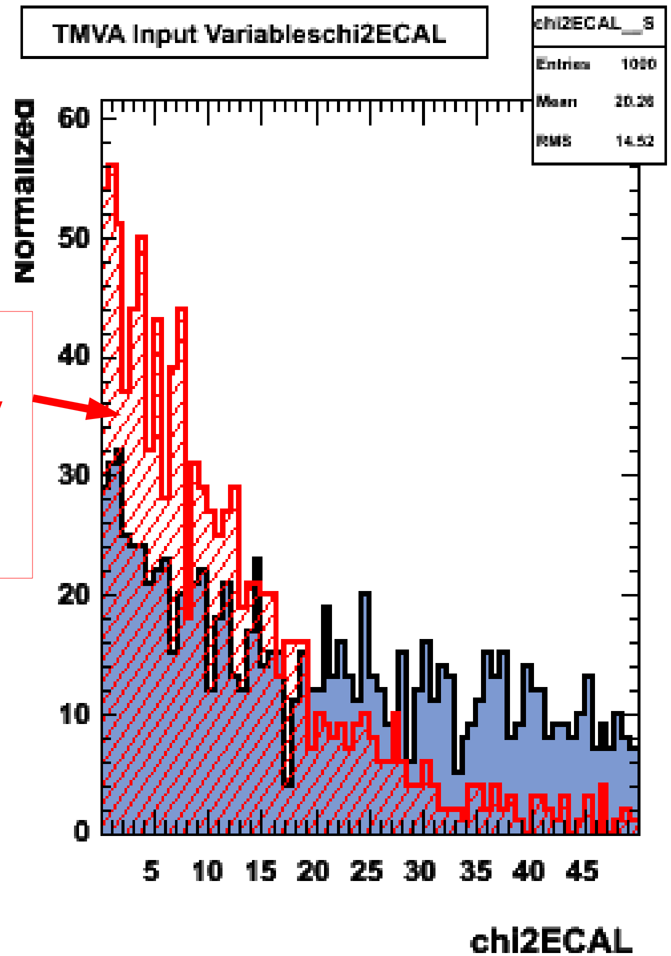
    -> tau ID does not consider neutral hadrons in the tau jets.

    So we'd better not reconstruct photons as neutral hadrons!
- Multivariate analysis based on a neural network
  - Signal sample: high pT single taus, 1 prong, 1 pi0 (merged photons)
  - Background sample: same, pi0 removed after generation before simulation

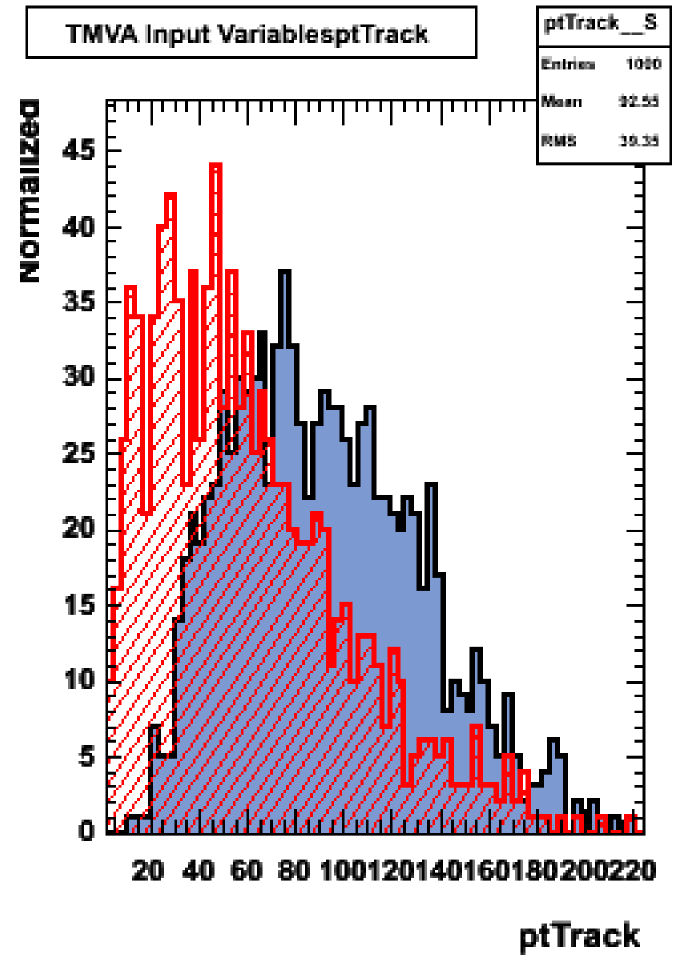
Discriminating variables



E_{ECAL} / p_{Track}

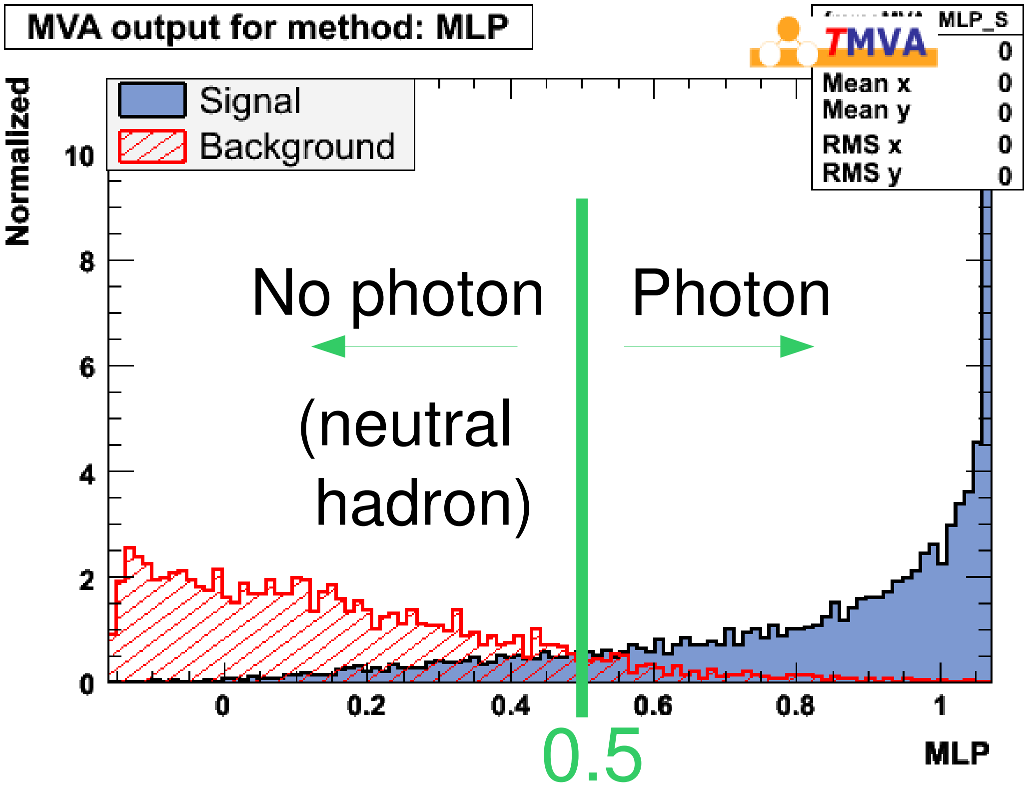


Chi2 between track impact and ECAL cluster (~normalized distance)



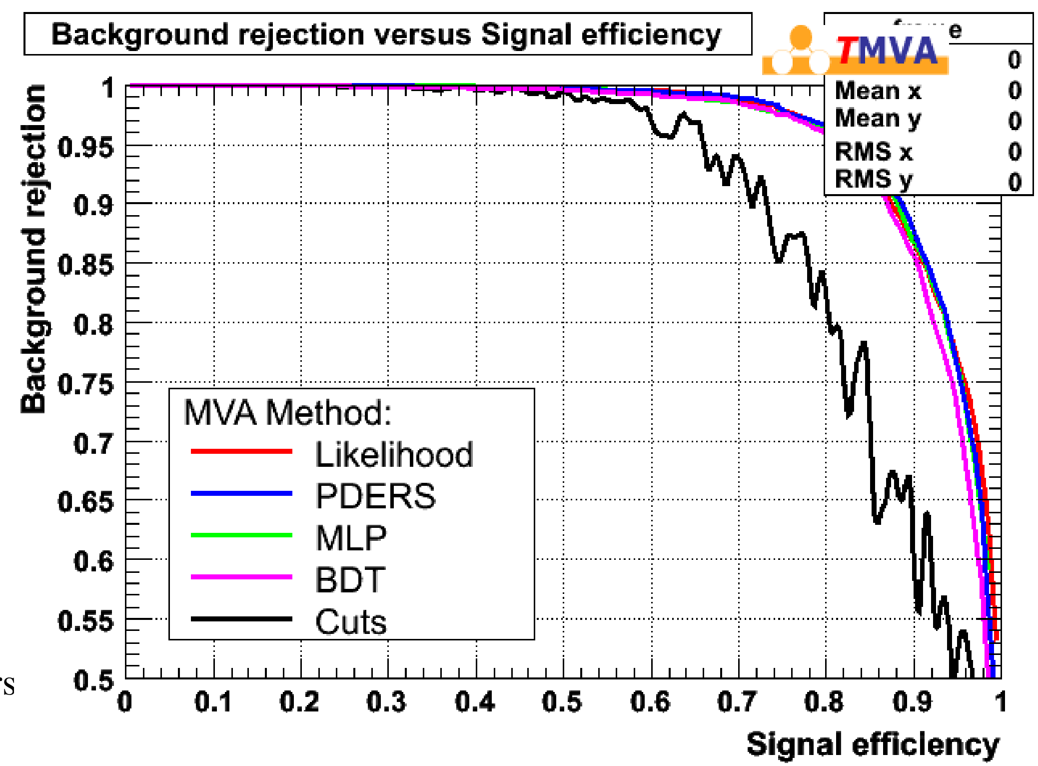
p_T of the track

MVA output and performance



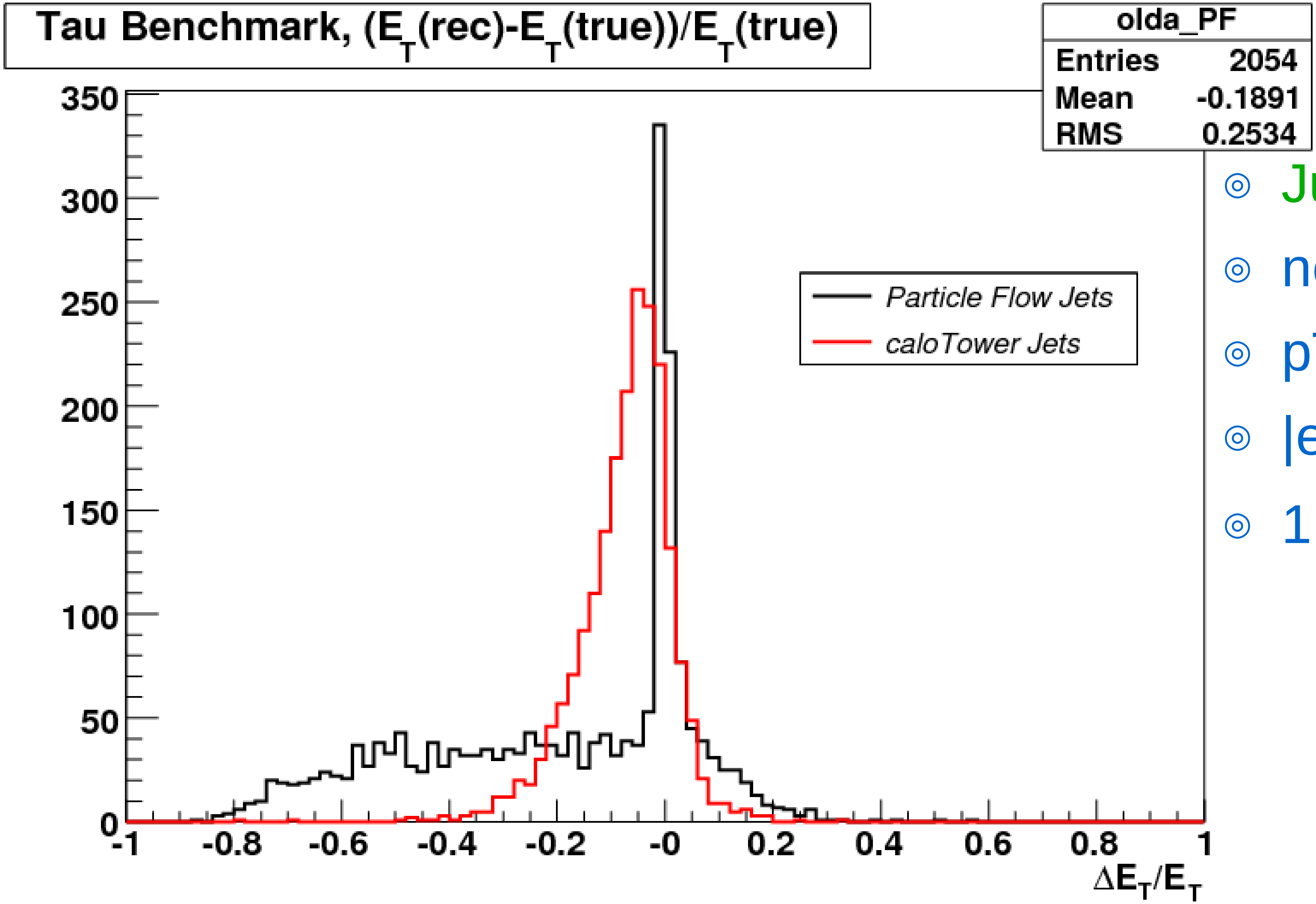
MVA output value

Efficiency vs purity



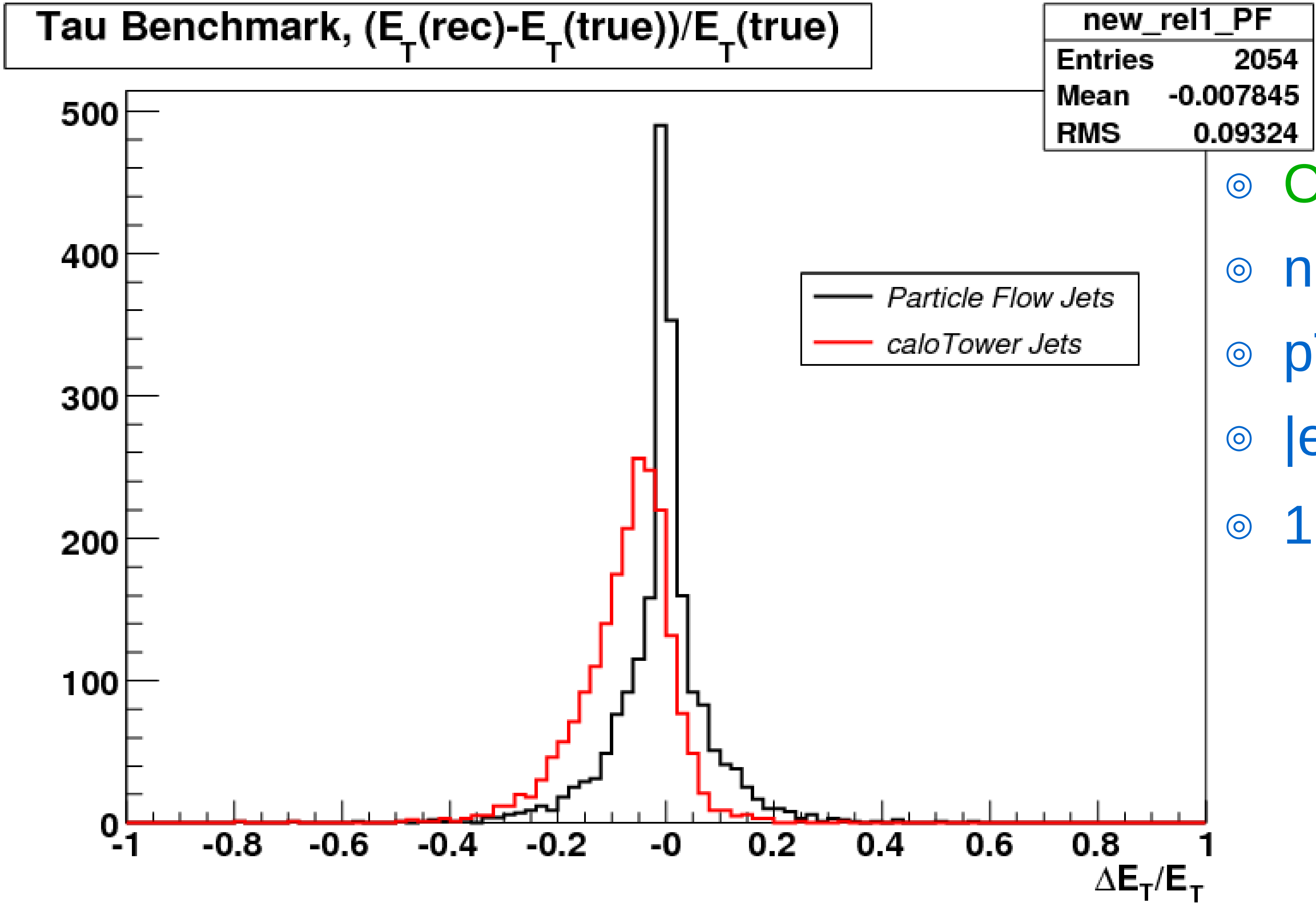
Univers

Single taus at high energy, June07



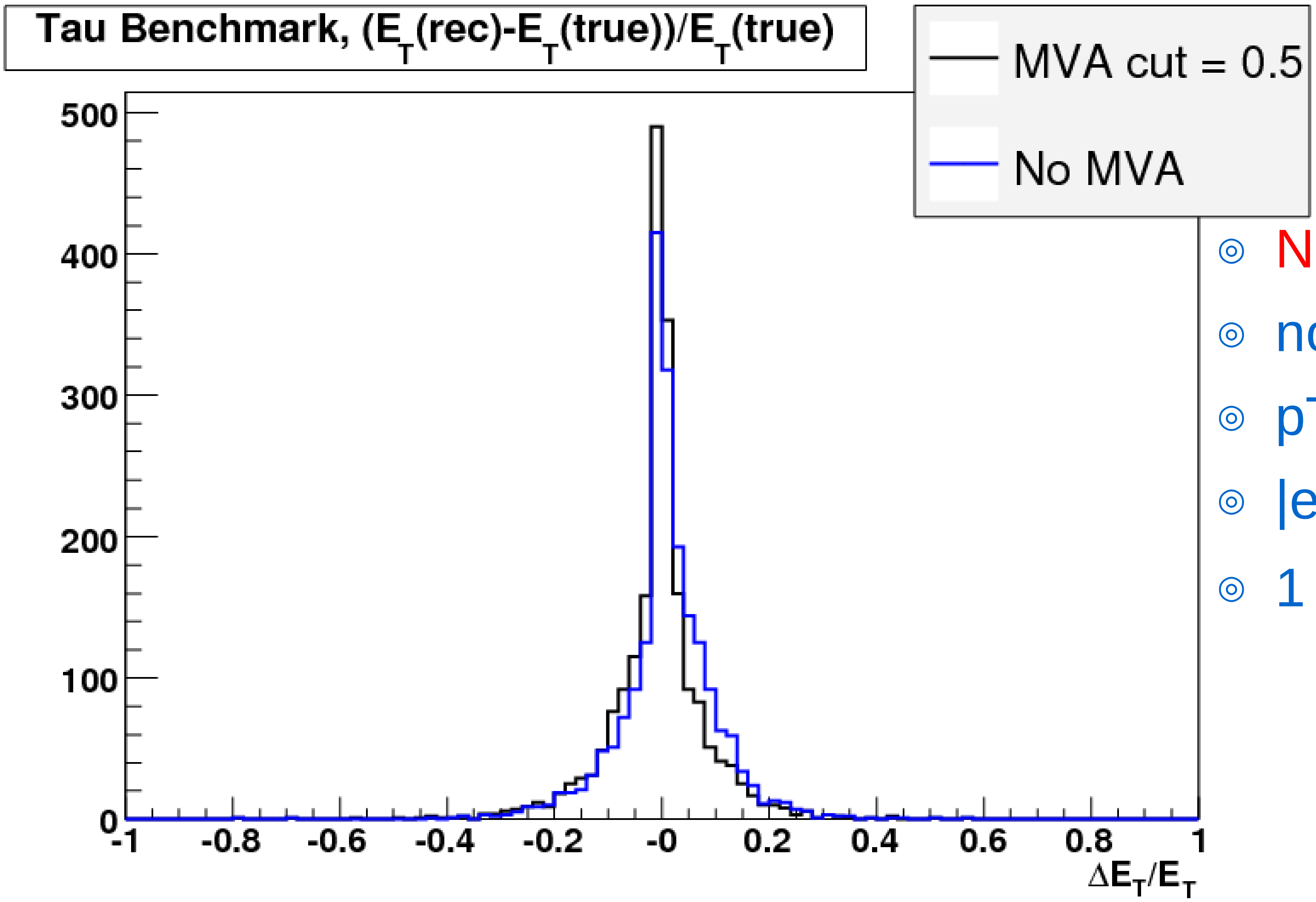
- June07
- no material effects
- pT 200-500 GeV
- |eta|<1
- 1 π^+, 1π^0

Single taus at high pT, Oct07



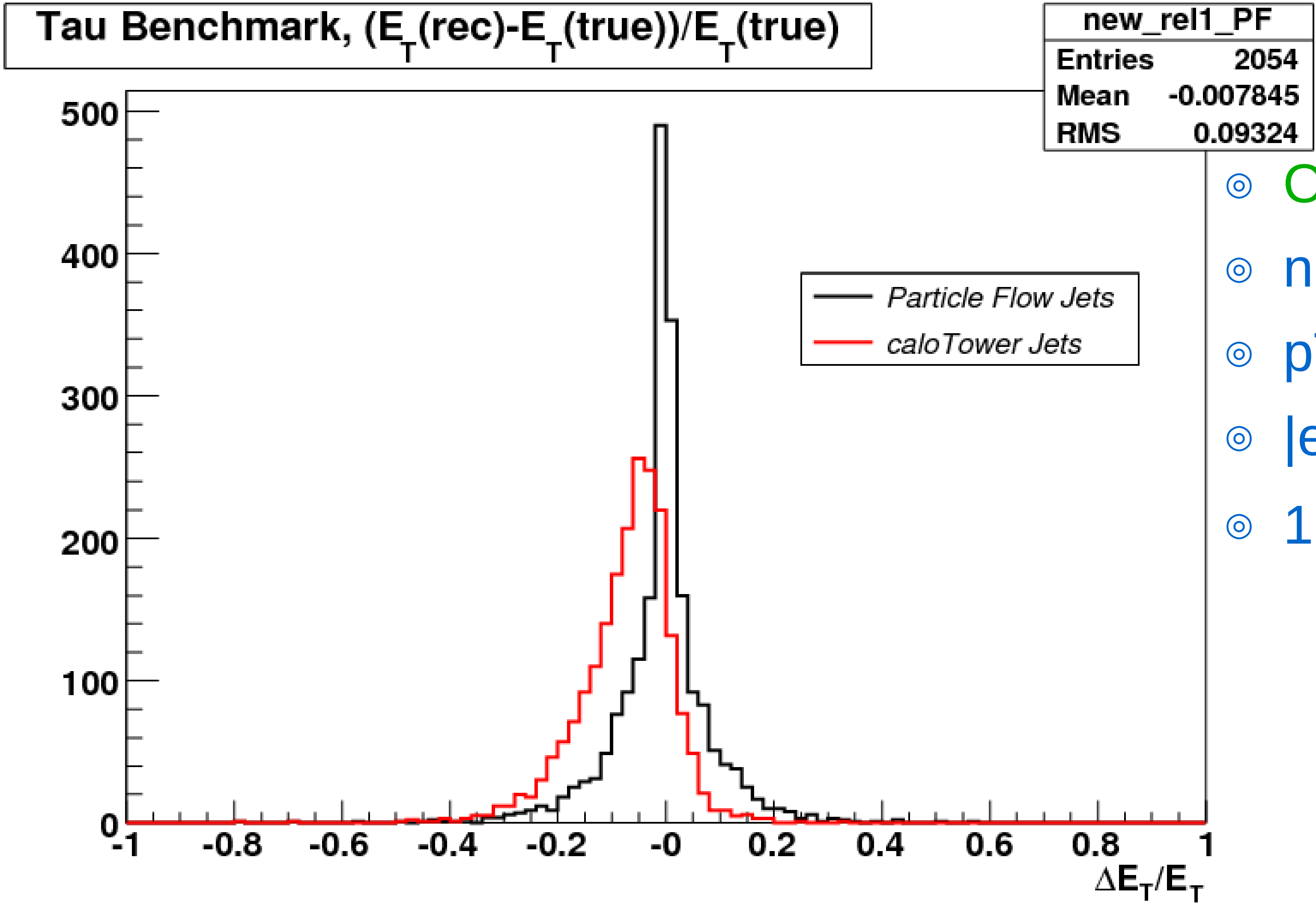
- Oct07
- no material effects
- pT 200-500 GeV
- |eta|<1
- 1 π^+, 1π^0

Identification is important



- New algorithm
- no material effects
- pT 200-500 GeV
- |eta|<1
- 1 π^+, 1π^0

Single taus at high pT, Oct07



- Oct07
- no material effects
- pT 200-500 GeV
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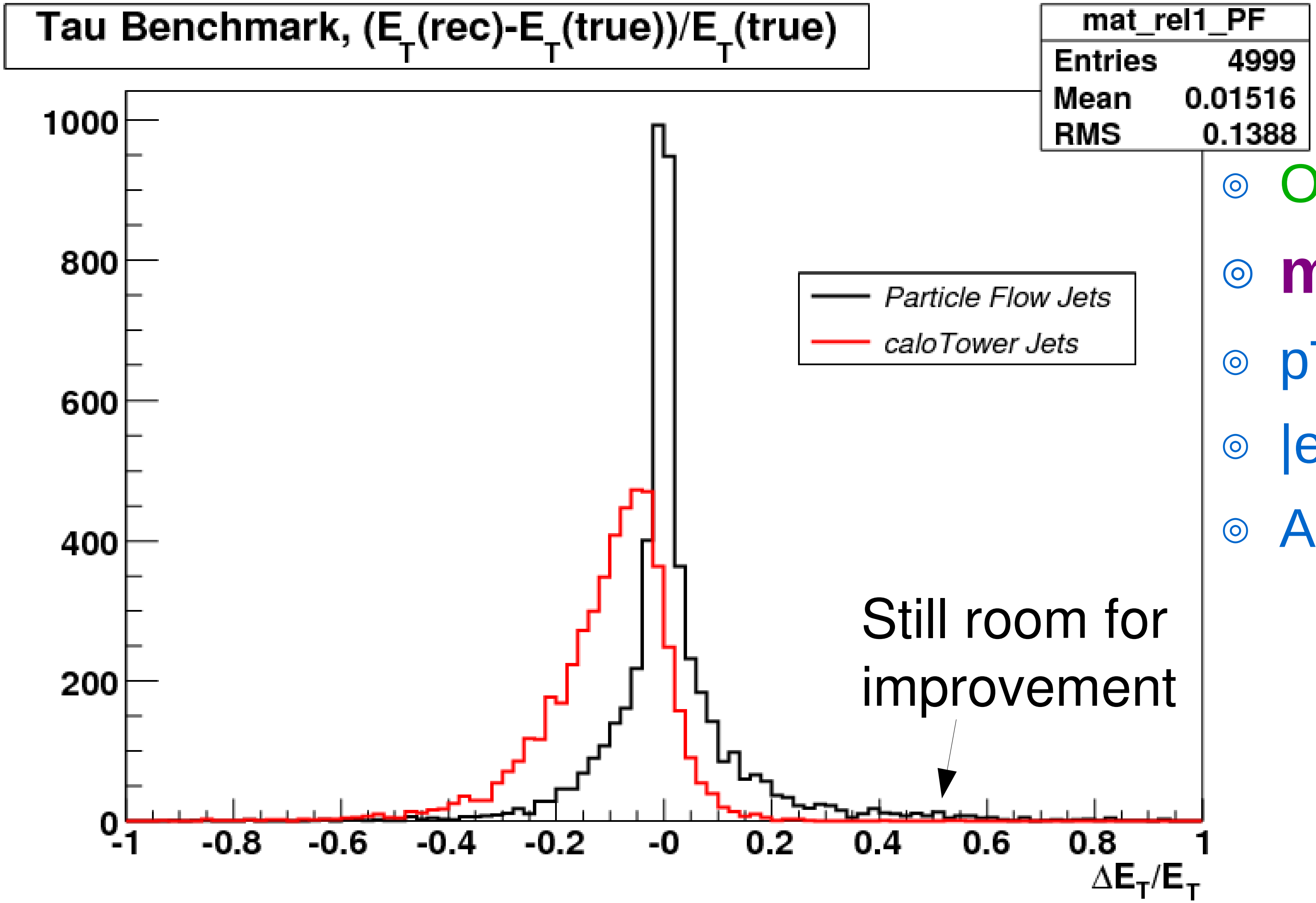
Single taus at high pT, Oct07



- Oct07
- **material effects**
- pT 200-500 GeV
- |eta|<1
- All hadronic taus

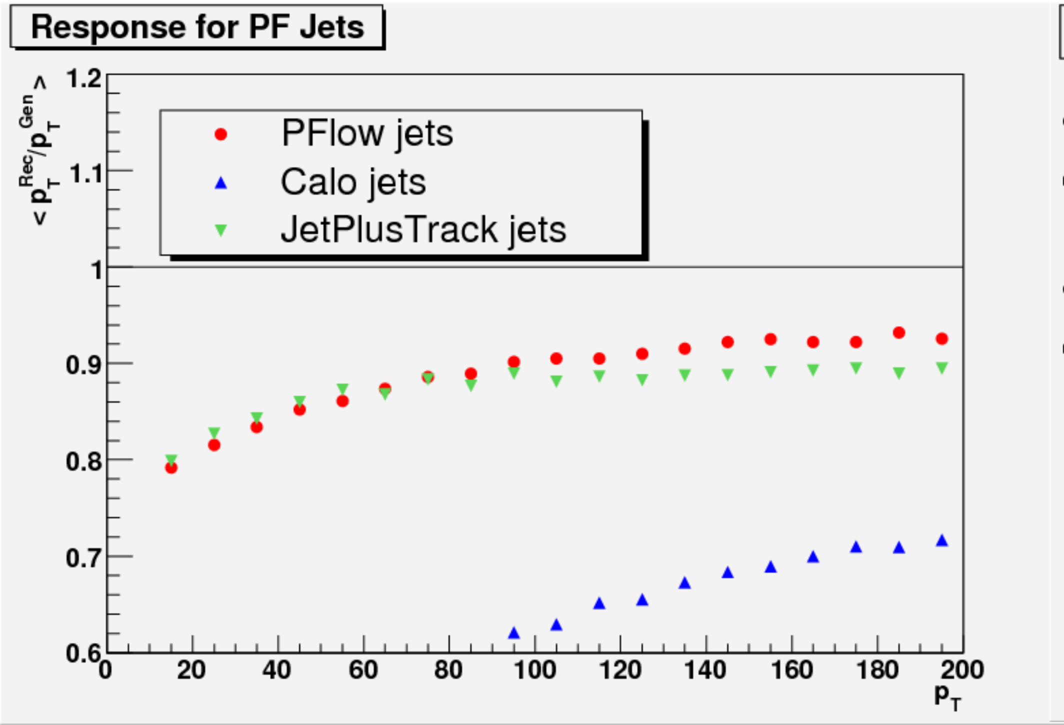
Possible improvements

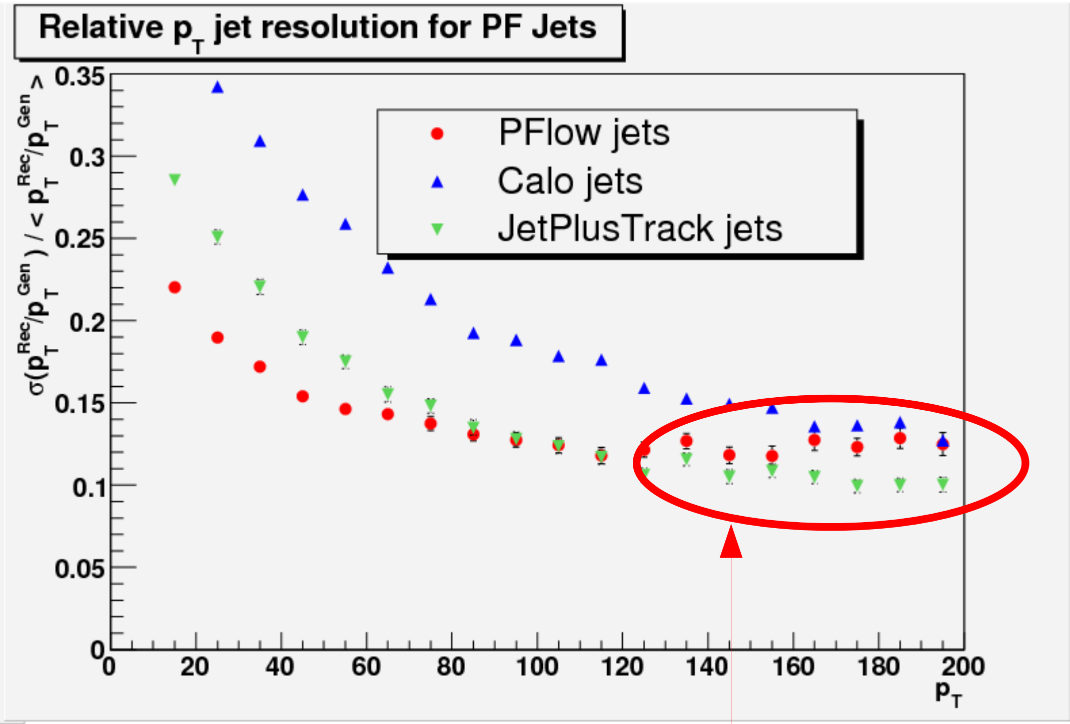
- Need a good single particle calibration for HCAL !
  - Current calibration: performed in FAMOS/ORCA,
    does not seem to be adapted to high E
- Determine the energy of the merged neutral:
  - We can do better than the difference:

    Calibrated E_{calo} – track momentum

  - Non-linear multivariate analysis, returning the energy of the merged neutral particle.
    - Input variables: the individual HCAL towers and ECAL crystals
- Identification of the neutral particle:
  3 multivariate analyses
  - Photon – nothing (already done)
  - Neutral hadron – nothing
  - Photon – neutral hadron

Jets in QCD events





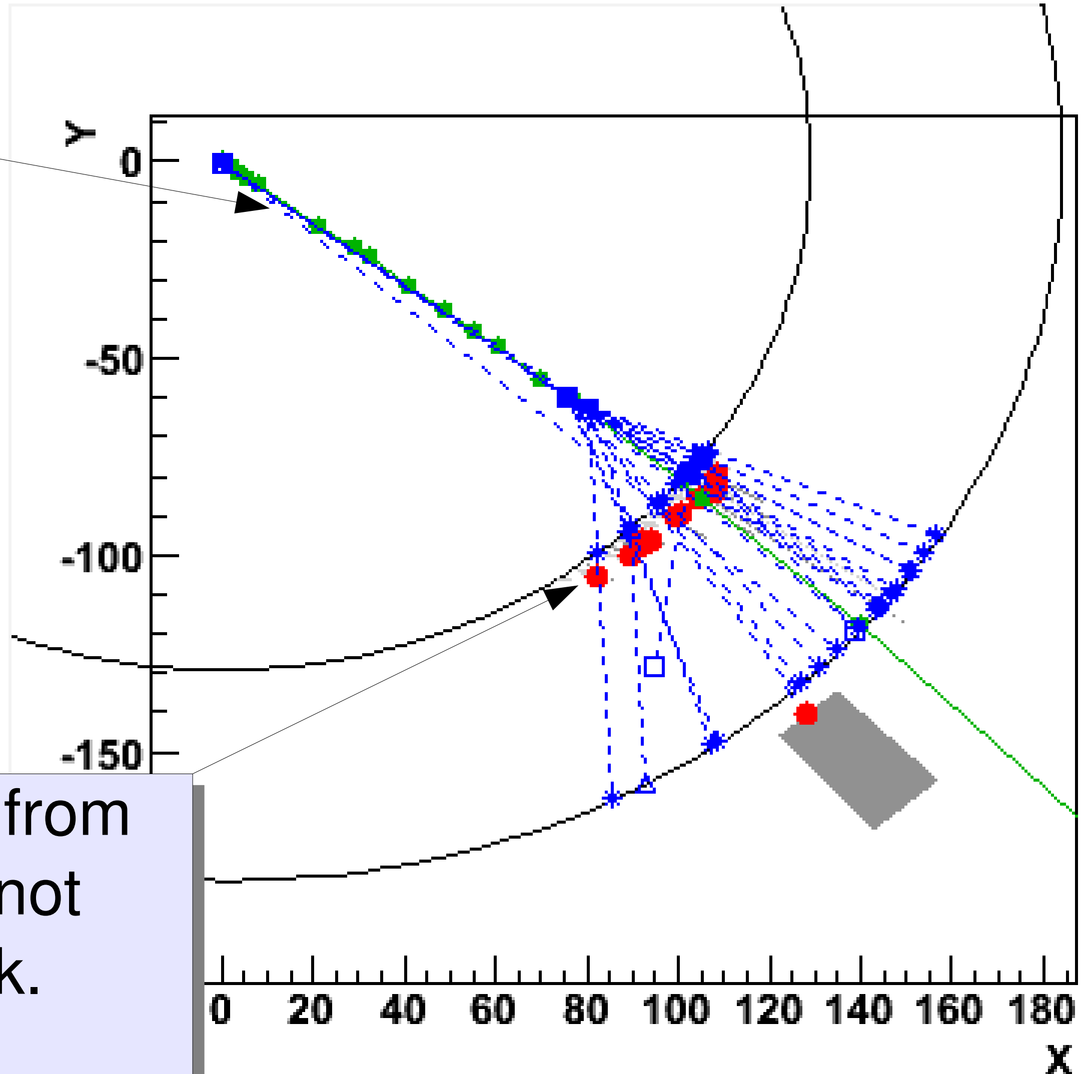
- We have concentrated on the low pT region until now
- Must have a look at high pT jets
- Very different input to jet algorithms
  - Review jet algorithms !

$|\eta| < 1$
matching $\Delta R < 0.2$

Hot topic 2: Material Effects

A nuclear interaction

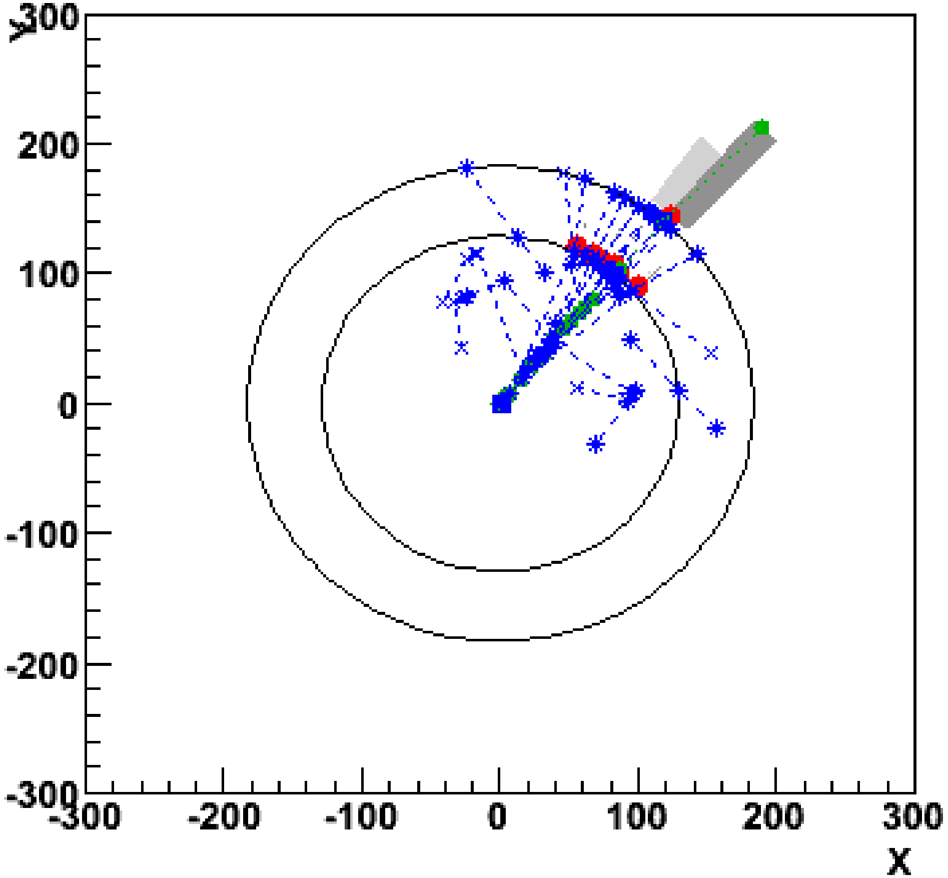
A charged hadron is reconstructed from the track momentum

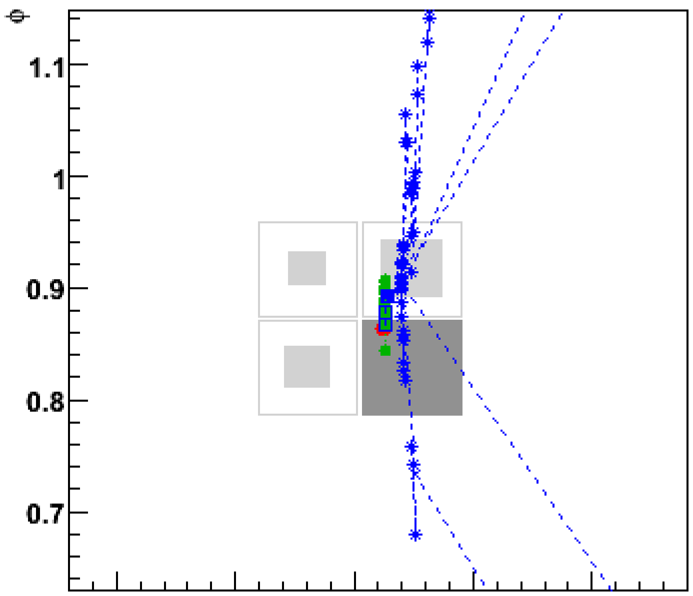


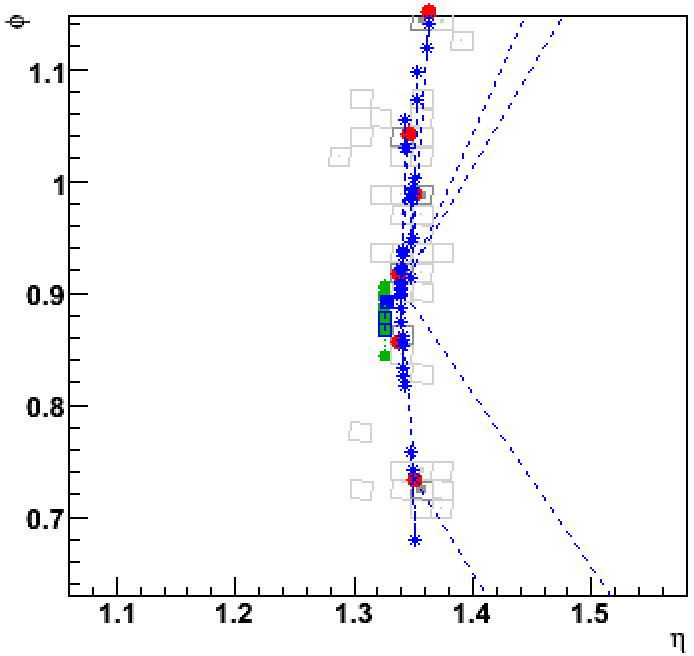
Isolated clusters from the secondaries not linked to the track.

Double-counting of the energy !

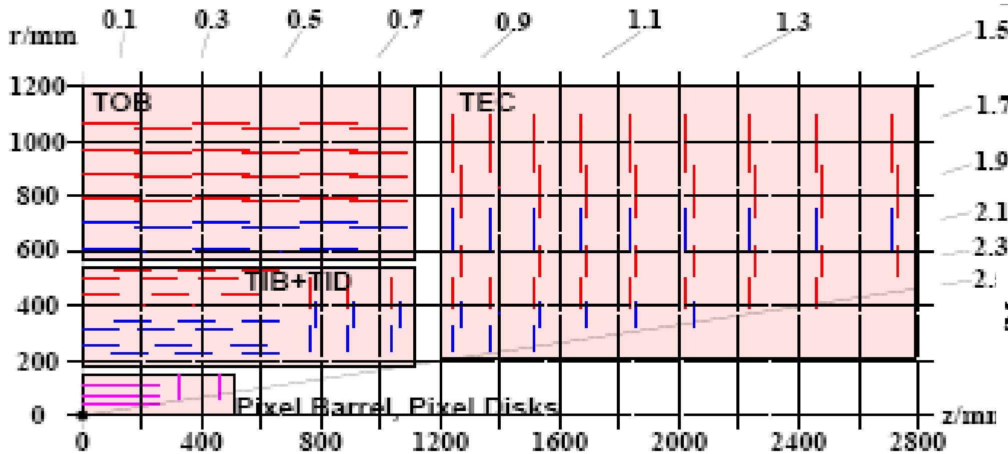
A conversion



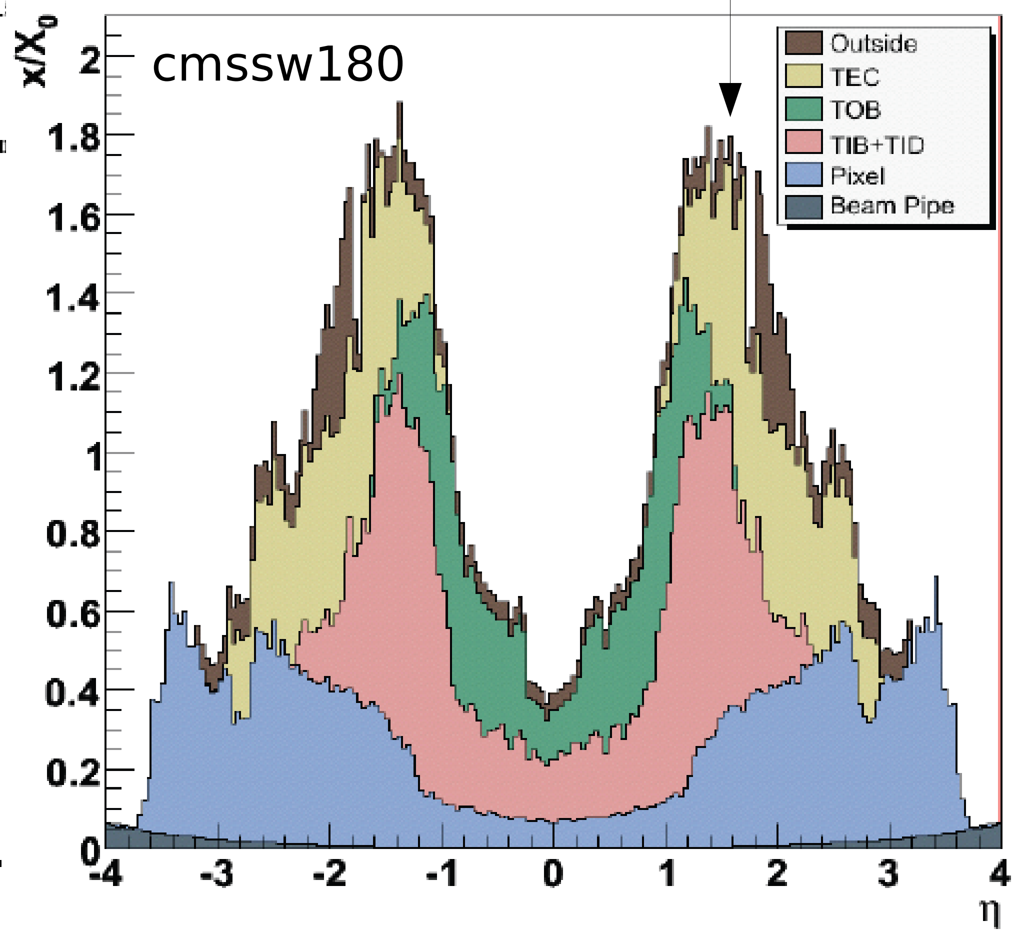




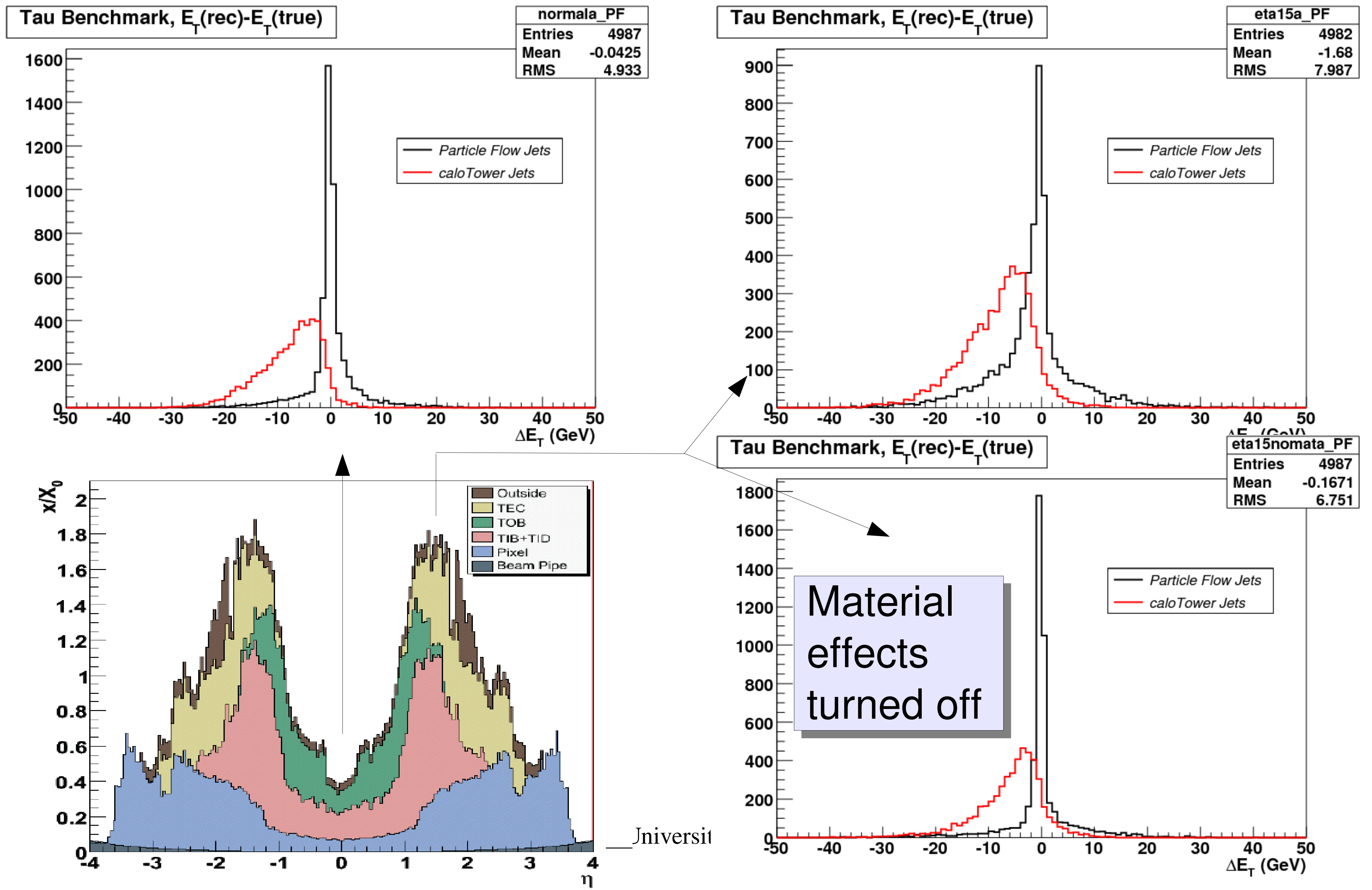
Tracker Material



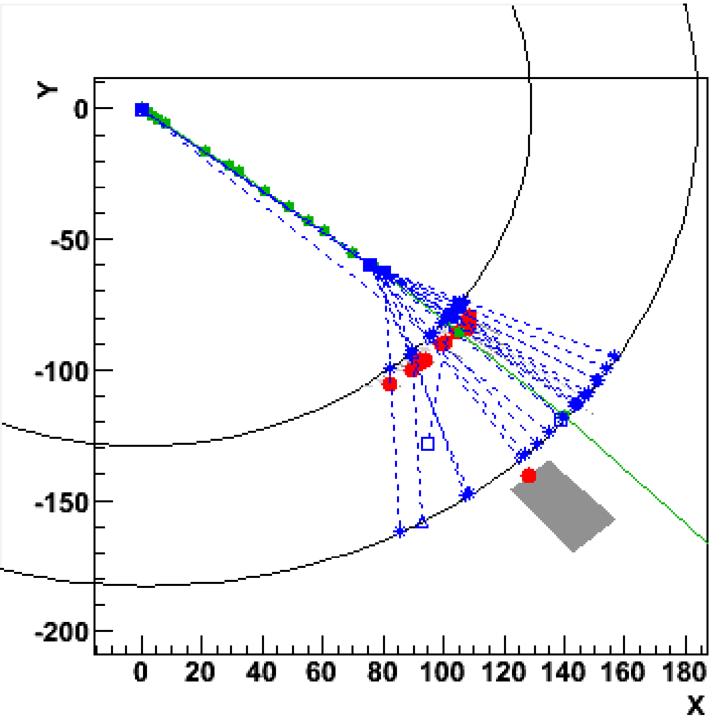
- Eta = 1.5 :
  - ~80 % of the photons convert
  - ~50 % of the pions do a nuclear interaction
- A nightmare for reconstruction
  - Tracking, photons, electrons..

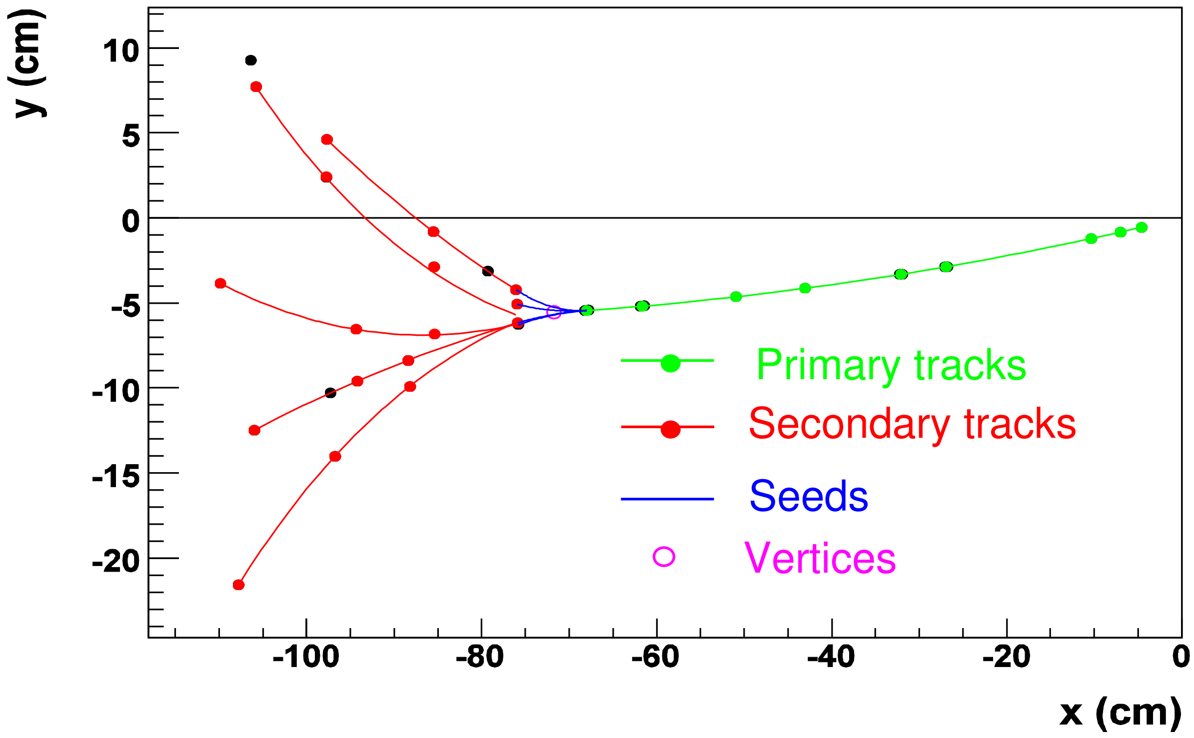


A nightmare for particle flow



Reconstructing nuclear interactions



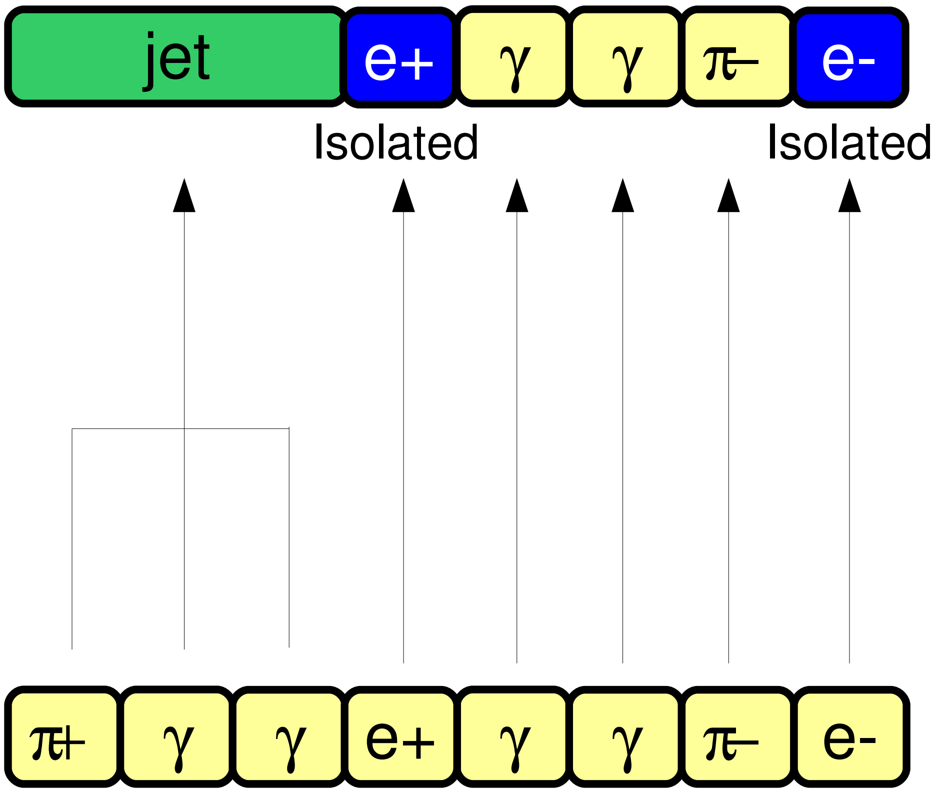


- The clusters from the secondary particles must be re-linked to the track
- Vincent:
  - Flag nuclear interactions
  - Seed and reconstruct secondary tracks

The integration to particle flow is on the way, stay tuned !

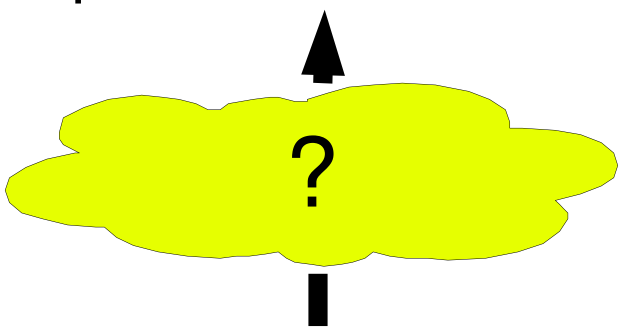
Hot topic 3: Analysis

From particle flow to analysis



The list of PFCandidates
(the reconstructed particles)

- A list of "particles":
  - Jets, taus, b-jets, isolated leptons...



- A list of "particles":
  - Charged/neutral hadrons, photons, electrons, muons
- Example: H->WW*
  - 2 high pt leptons, MET, jet veto

1st step: define analysis particles

PFCandidate

The new classes inherit from PFCandidate.
This is my choice here.
Could inherit from any candidate class

PileUpParticle

Just a new type

IsolatedPFCandidate

Add data members for isolation:

float SumPtCone5
float SumPtCone25
float deltaRPt2

- A set of classes for standard analysis particles will be provided
  - PileUpParticle and IsolatedLepton might be part of it.

2nd step: build the analysis wall

$\pi+$	γ	γ	e+	γ	γ	$\pi-$	e-

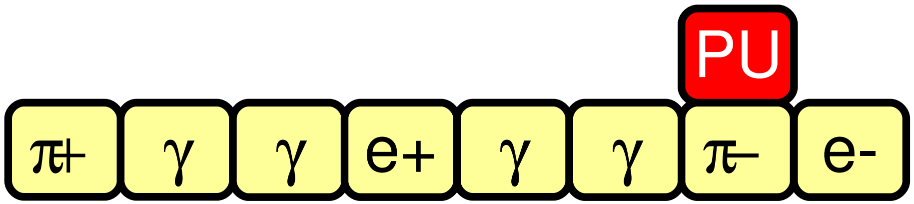
The list of PFCandidates

- Start from the list of particles and compute MET:

$$\overrightarrow{\mathrm{MET}} = -\sum_{i=0}^{N_{particles}} \vec{E}_T^i$$

2nd step: build the analysis wall

- Find pile-up particles, mask with PileUpParticles



The list of PFCandidates

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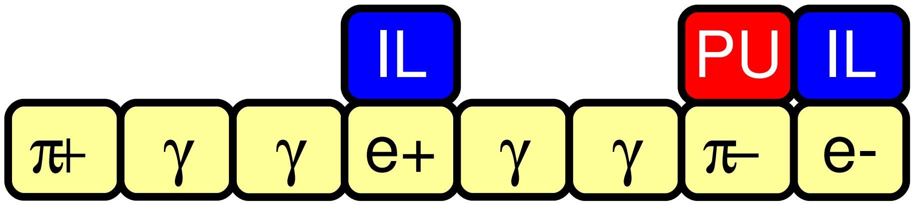
$$\overrightarrow{\mathrm{MET}} = -\sum_{i=0}^{N_{particles}} \vec{E}_T^{\,i}$$

2nd step: build the analysis wall

- Find pile-up particles, mask with PileUpParticles
- Find (loose) isolated leptons mask with IsolatedLeptons



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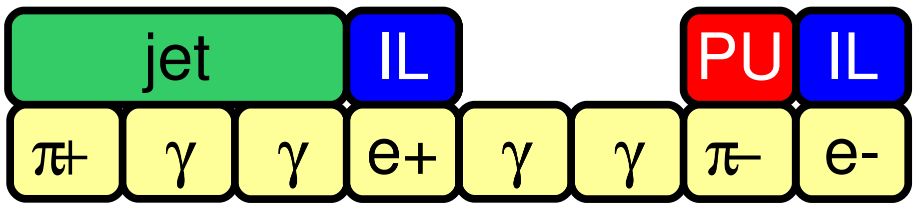

The list of PFCandidates

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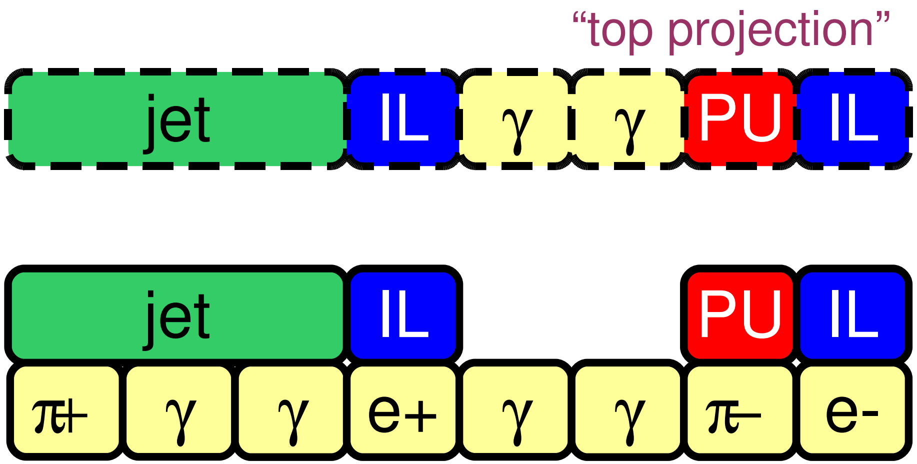
- Find (loose) isolated leptons mask with IsolatedLeptons
- Take all particles except pile-up and isolated leptons, and perform jet clustering

2^{nd} step: build the analysis wall



The list of PFCandidates

- Start from the list of particles and compute MET:

$$\overrightarrow{\mathrm{MET}} = -\sum_{i=0}^{N_{particles}} \vec{E}_T^i$$

- Find pile-up particles, mask with PileUpParticles
- Find (loose) isolated leptons mask with IsolatedLeptons
- Take all particles except pile-up and isolated leptons, and perform jet clustering
- Look at this wall from the top, you get a single list of particles, no double-counting
  - This action is a "***top projection***"
- Then, jet veto, MET cut, lepton pt cut, further isolation cuts.

Summary

- Particle flow already provides improved physics objects, and there is still a lot of room for improvements.
- Particle based analysis will be flexible and powerful
- Still a lot of interesting (and rewarding!) things to do, just contact us

<u>More Information:</u>

- Description and tutorial

  https://twiki.cern.ch/twiki/bin/view/CMS/EFlowTutorialVersion2
- Hypernews

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