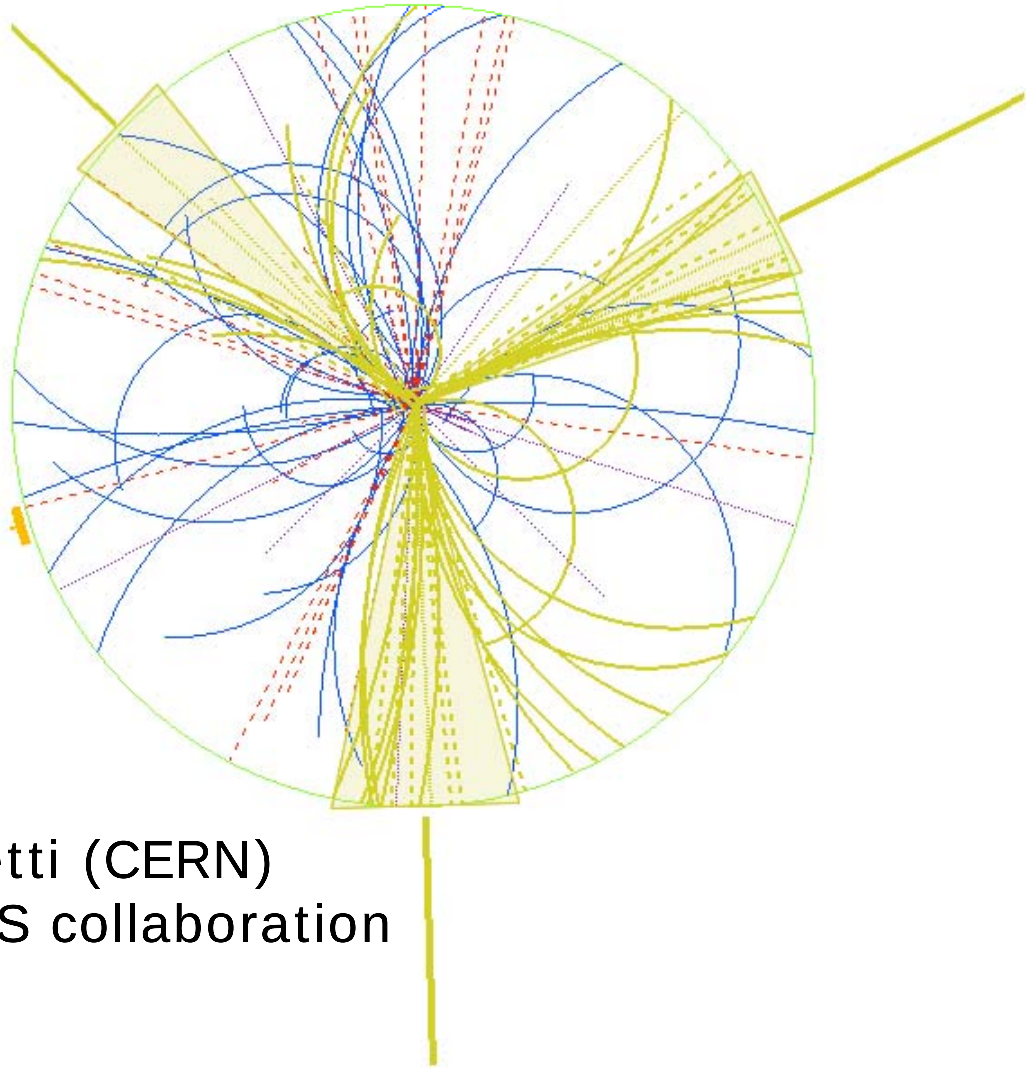
Performance of the particle flow algorithm in CMS



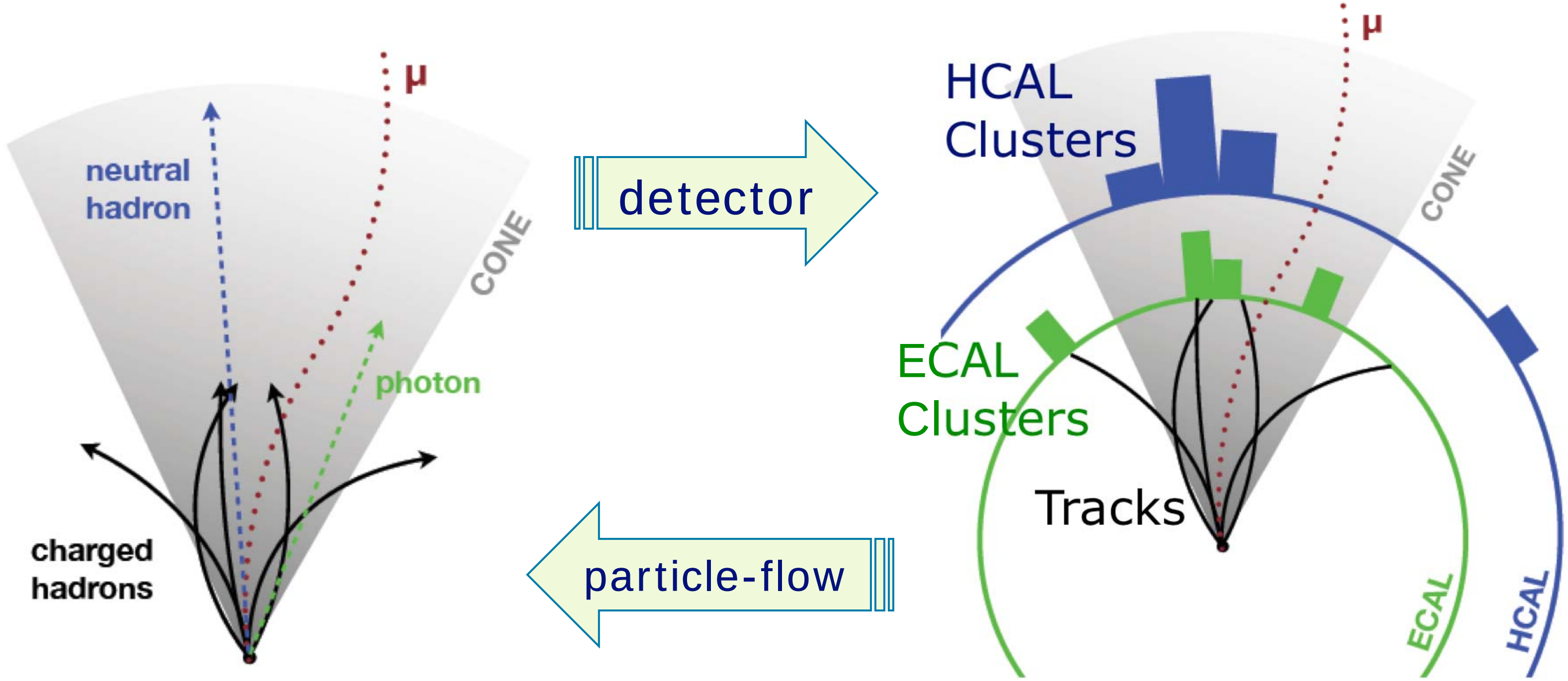
Outline

- *The particle-flow algorithm: overview*
- *The CMS experiment and particle-flow*
- *Performance on simulated data*
- *Commissioning*
- *Conclusion*

Daniele Benedetti (CERN)
on behalf of the CMS collaboration

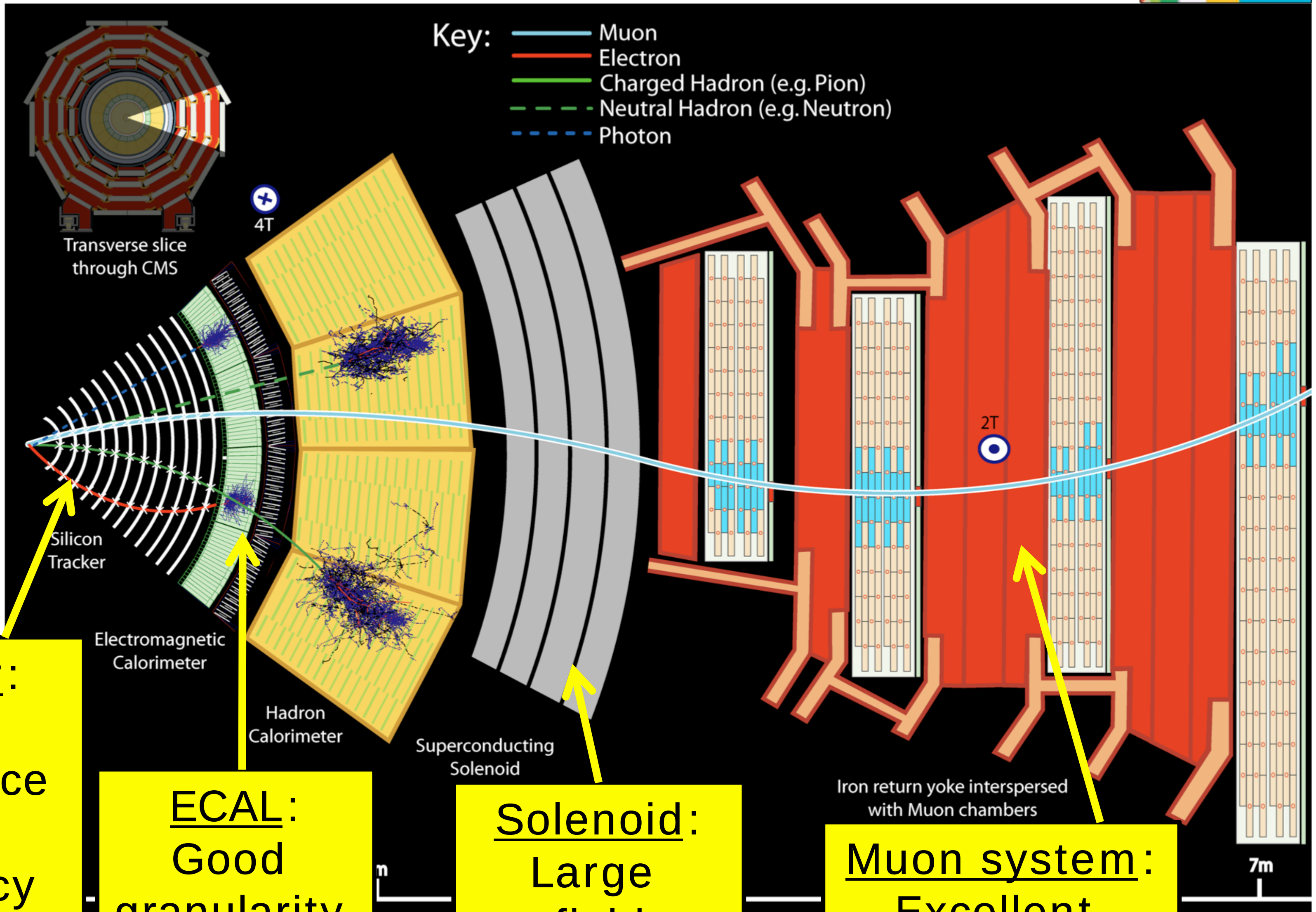
Overview: the particle-flow algorithm

Particles <-> clusters and tracks



The list of individual particles is then used to build jets, to determine the missing transverse energy, to reconstruct and identify taus from their decay products, to tag b jets …

Why particle-flow with CMS?



Tracker: large acceptance and efficiency

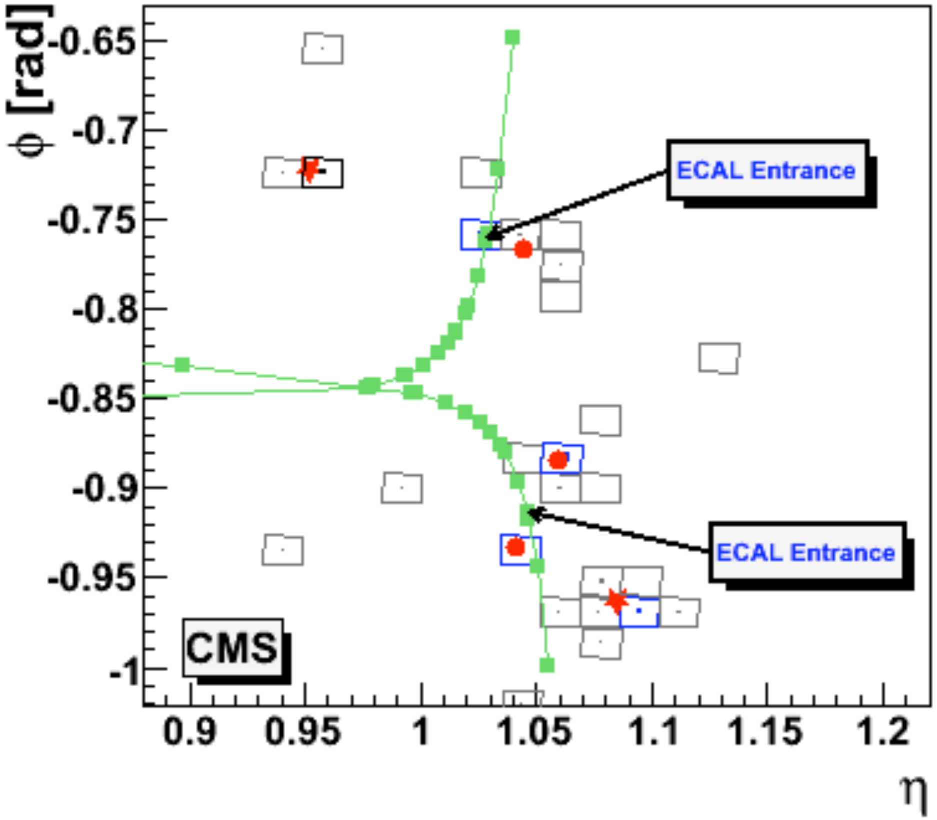
ECAL: Good granularity

Solenoid: Large field

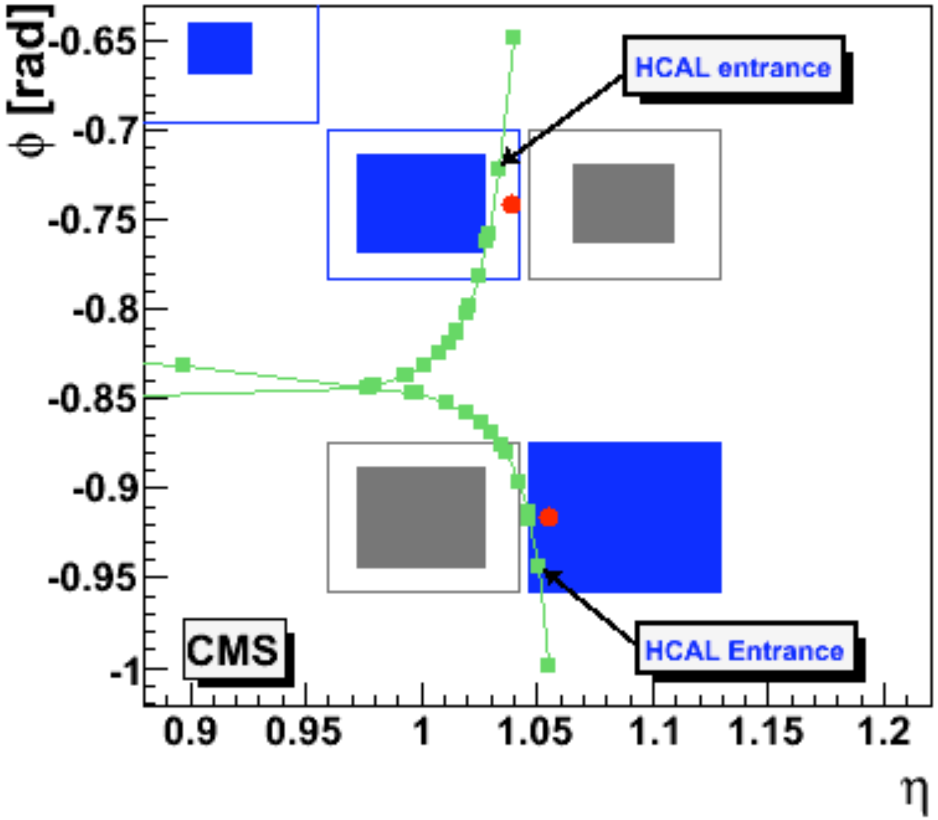
Muon system: Excellent efficiency

How does it work: the track-cluster link

ECAL – Track link

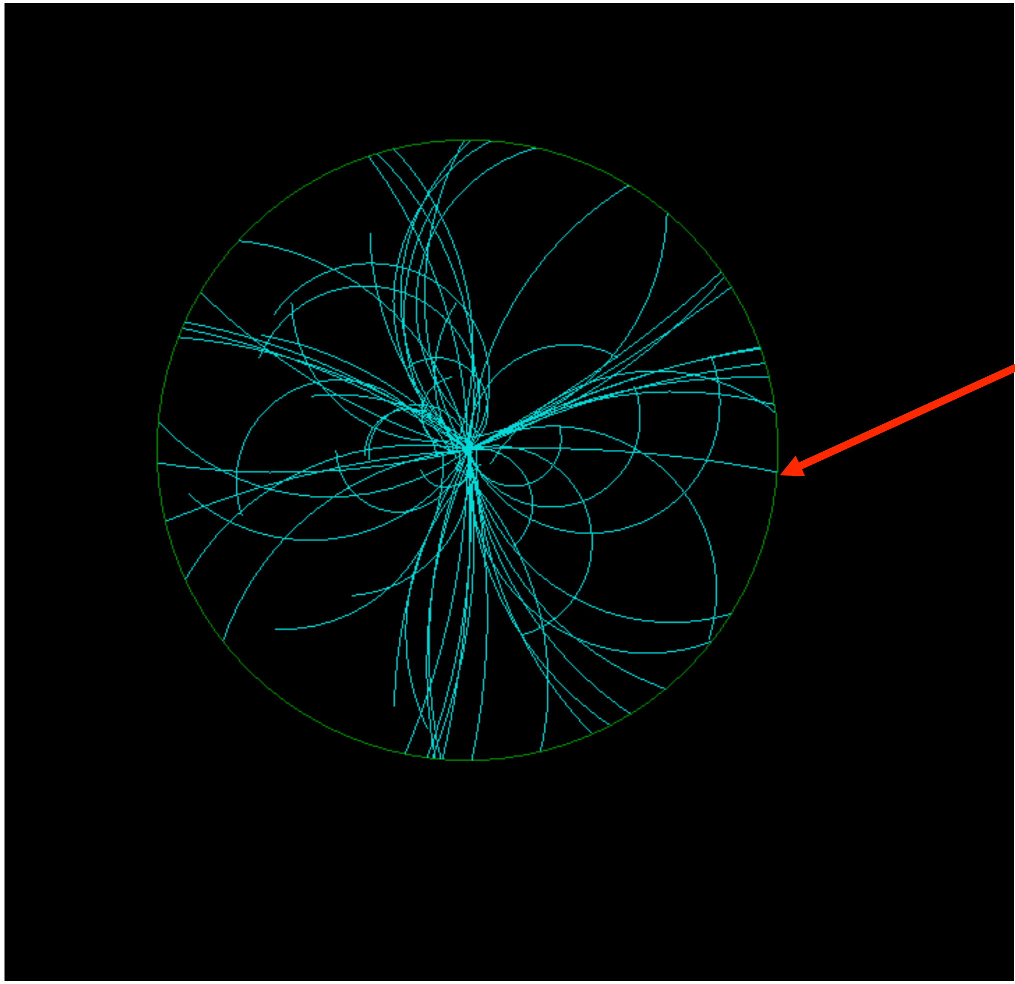


HCAL – Track link



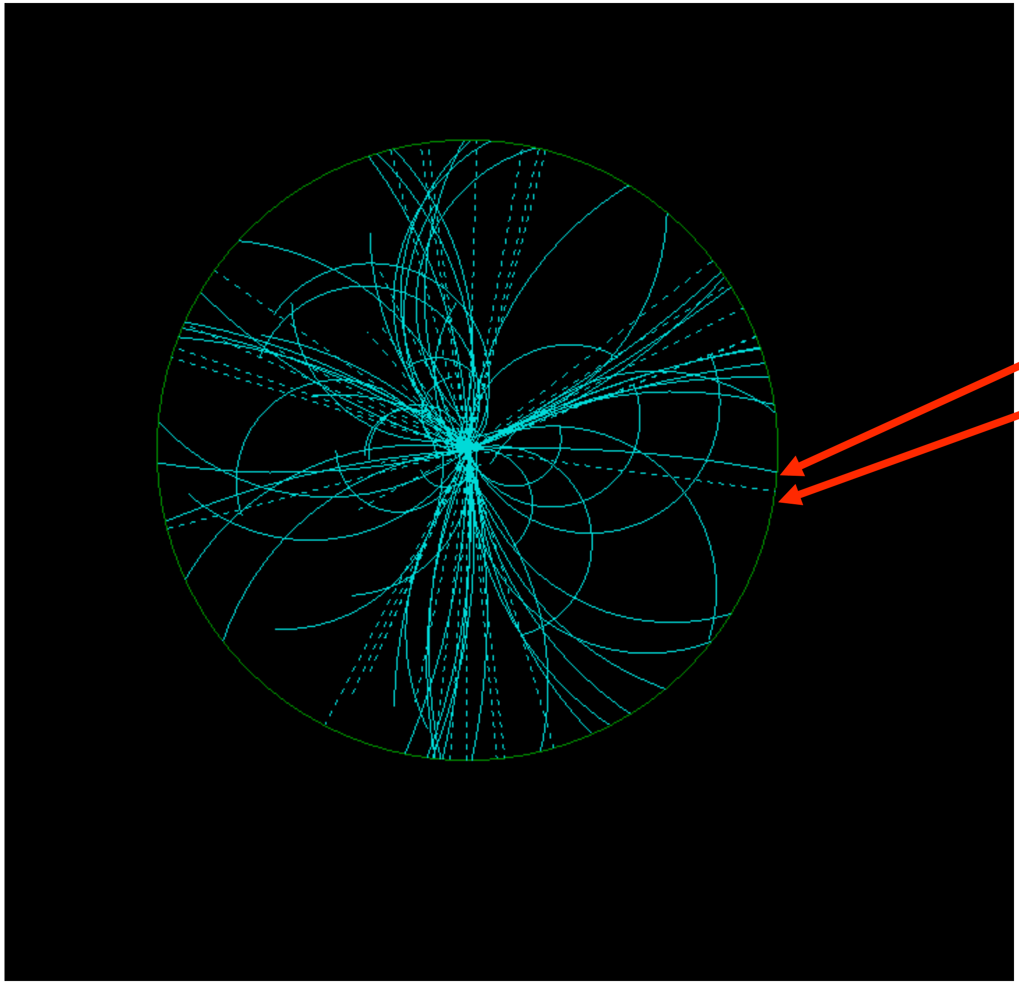
2 photons (★ ECAL clusters not linked to any track)
plus a π^- and a π^+

Event Display (2.36 TeV data), transverse view



Charged hadron

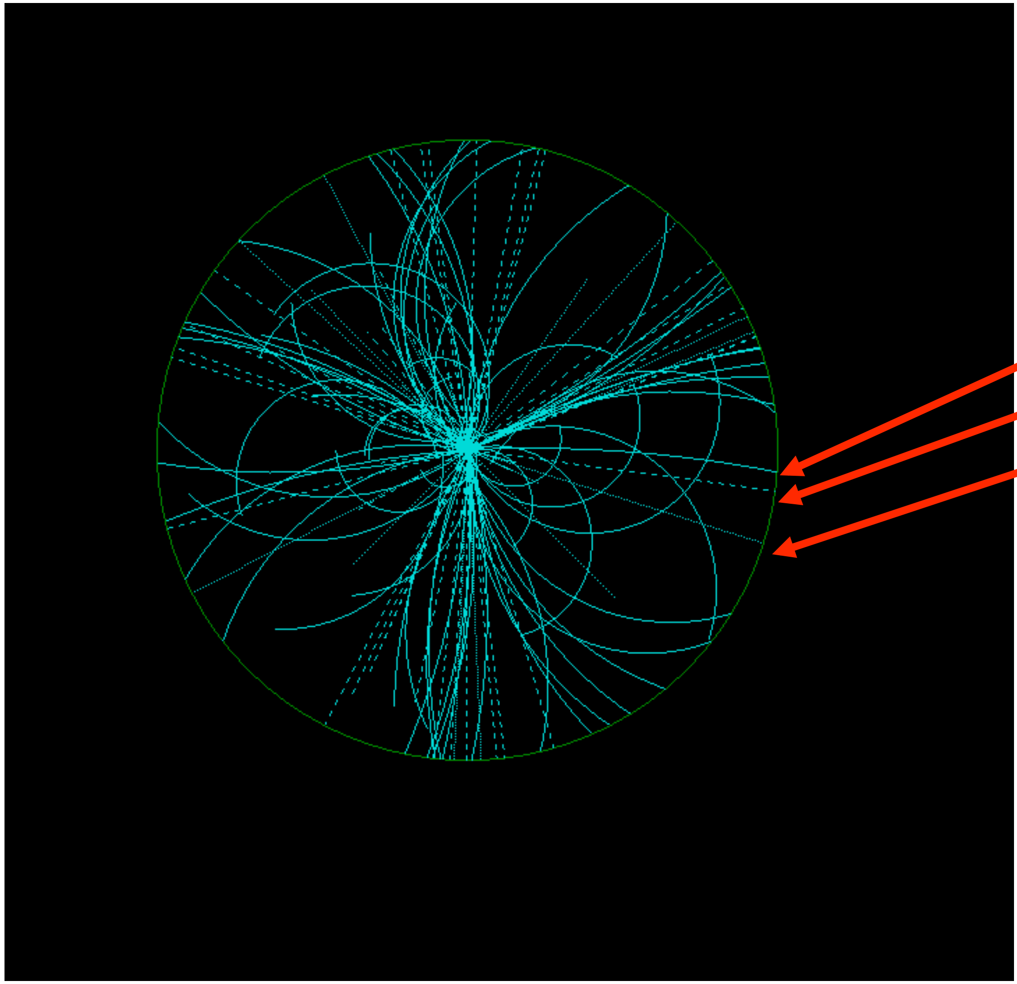
Event Display (2.36 TeV data), transverse view



Charged hadron

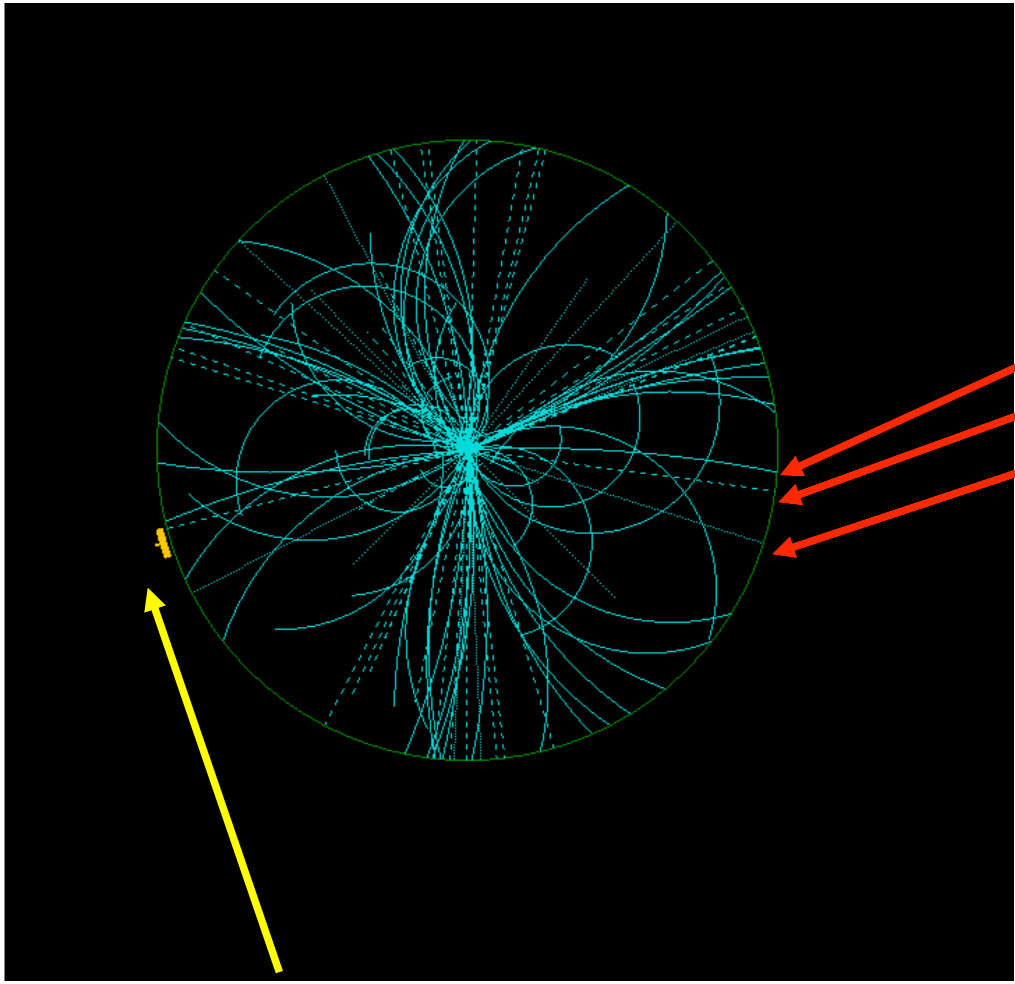
Photon (dashed line)

Event Display (2.36 TeV data), transverse view



Charged hadron
Photon (dashed line)
Neutral hadron (dotted line)

Event Display (2.36 TeV data), transverse view

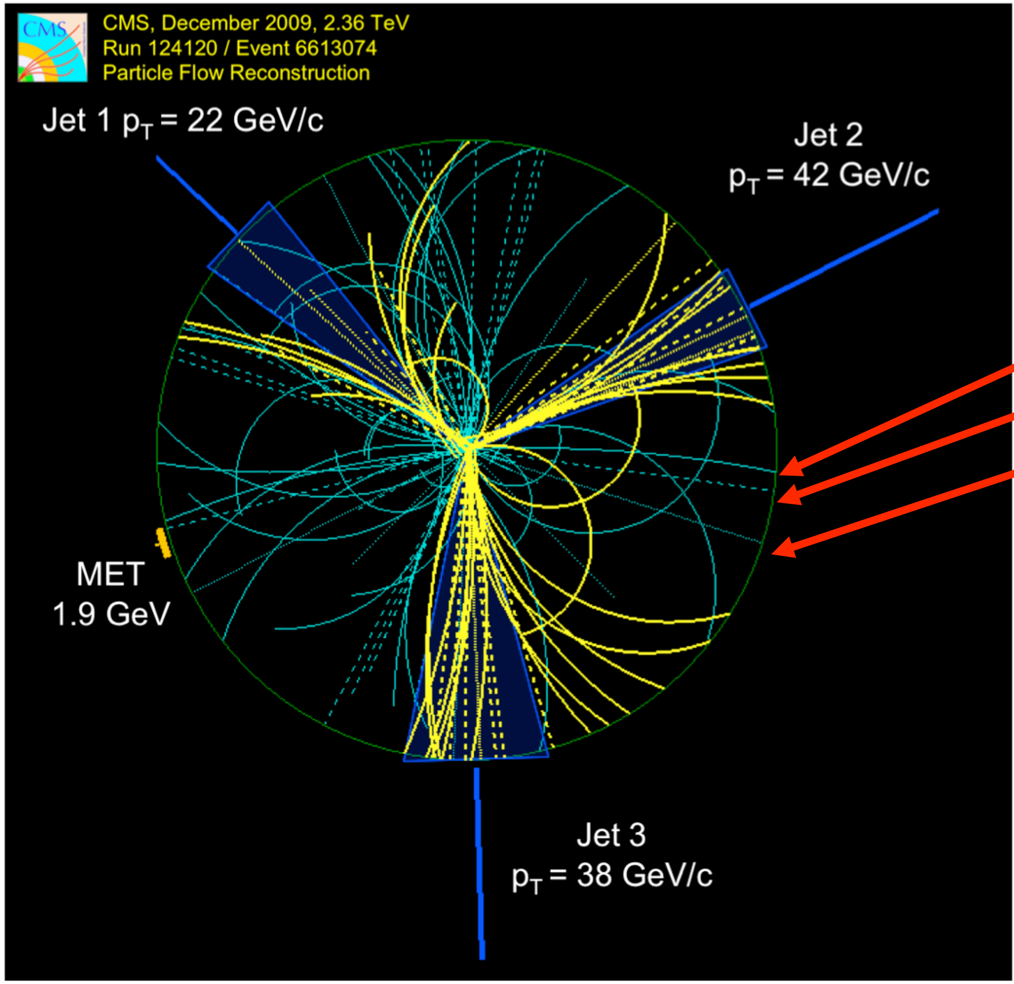


Charged hadron
Photon (dashed line)
Neutral hadron (dotted line)

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

SumE_T : 178 GeV
MET : 1.9 GeV

Event Display (2.36 TeV data), transverse view



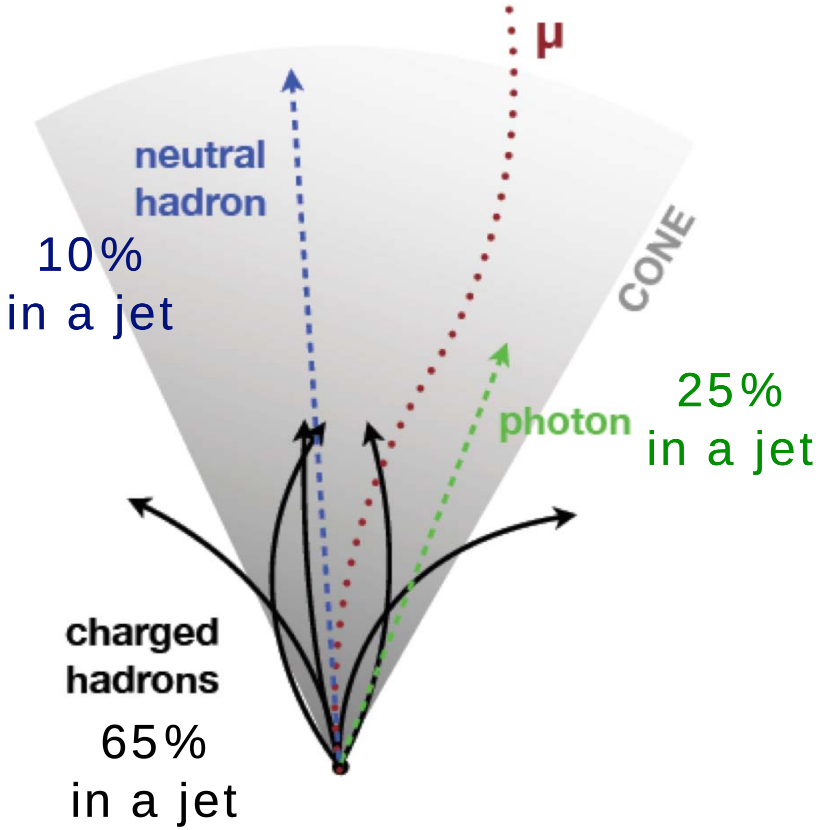
Particles clustered in jets

Jet

Charged hadron
Photon (dashed line)
Neutral hadron (dotted line)

- $SumE_T$: 178 GeV
- MET : 1.9 GeV
- Jet Algo: anti-Kt 5
- Three jets with p_T> 20 GeV/c

Expectations for the jet energy response and resolution

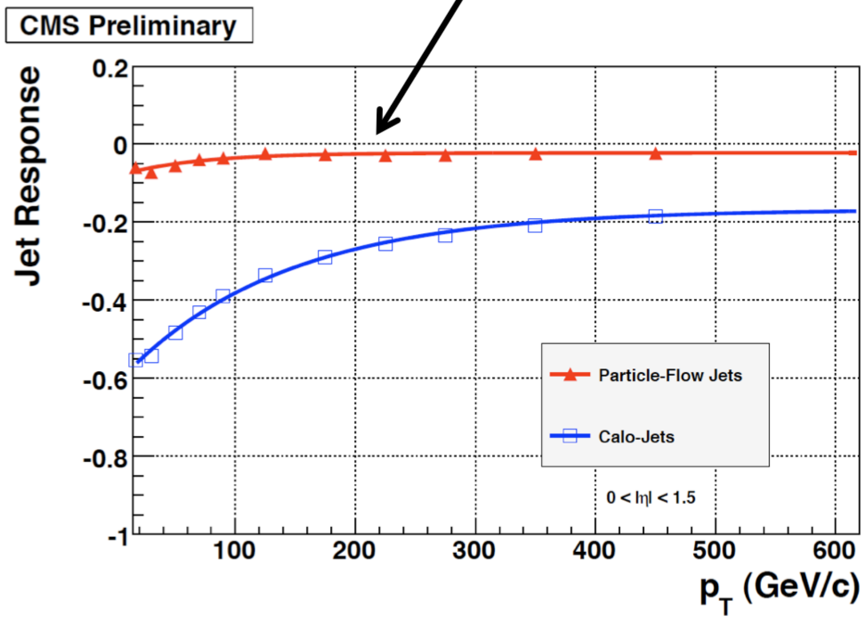


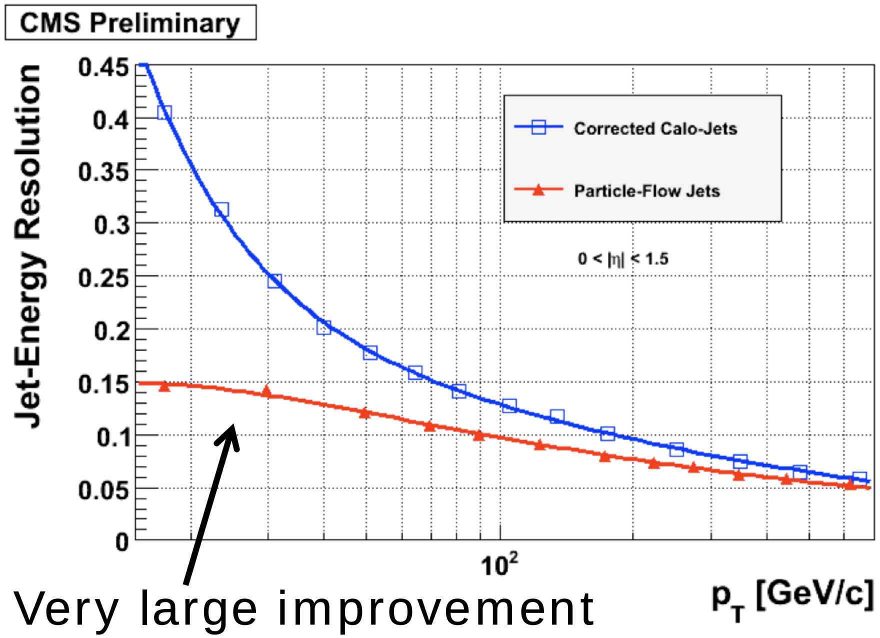
- ✓ Even for a jet of p_T = 500 GeV/c the average p_T of the stable particles is of around 10 GeV/c
- ✓ ~90% of the jet energy is carried out by charged-hadrons and photons

Jet energy response and resolution

simulated QCD-multijets events
barrel: |η| < 1.5

95-97%
of the p_T reconstructed,
over the whole range.

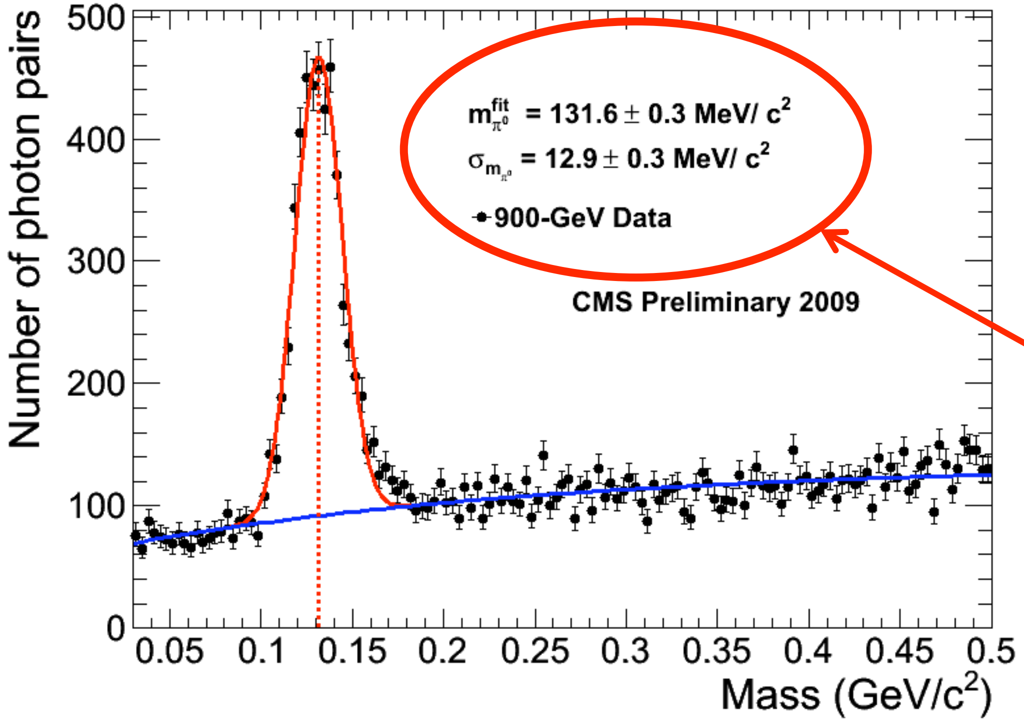




Very large improvement
at low pT, thanks to
Tracks

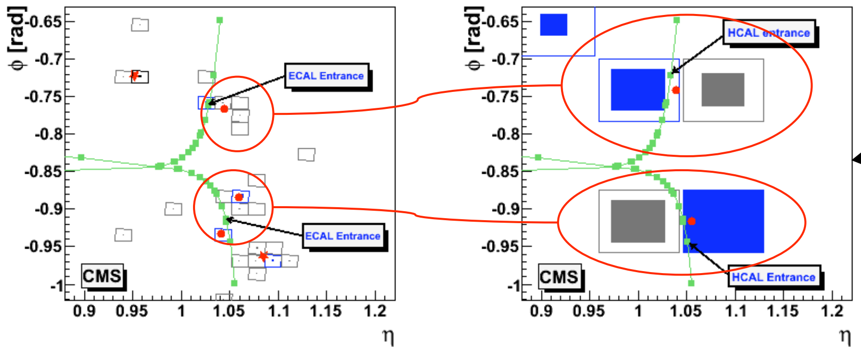
Commissioning …

Photon commissioning with π^0



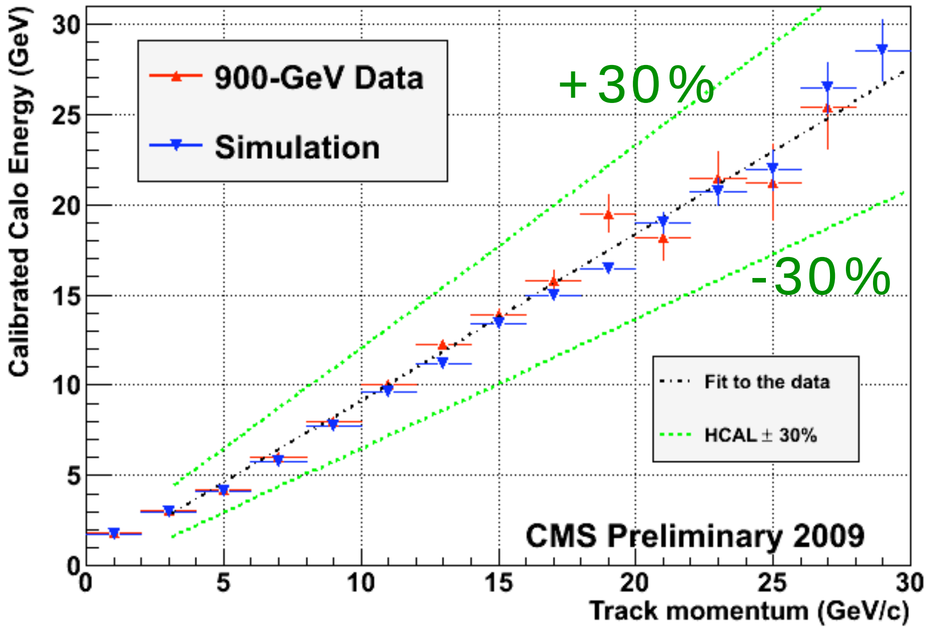
Agreement within ~2% of the PDG value in data

Calorimeter response for hadrons



Obtained with charged hadrons

Calorimeter response is important for neutral hadrons

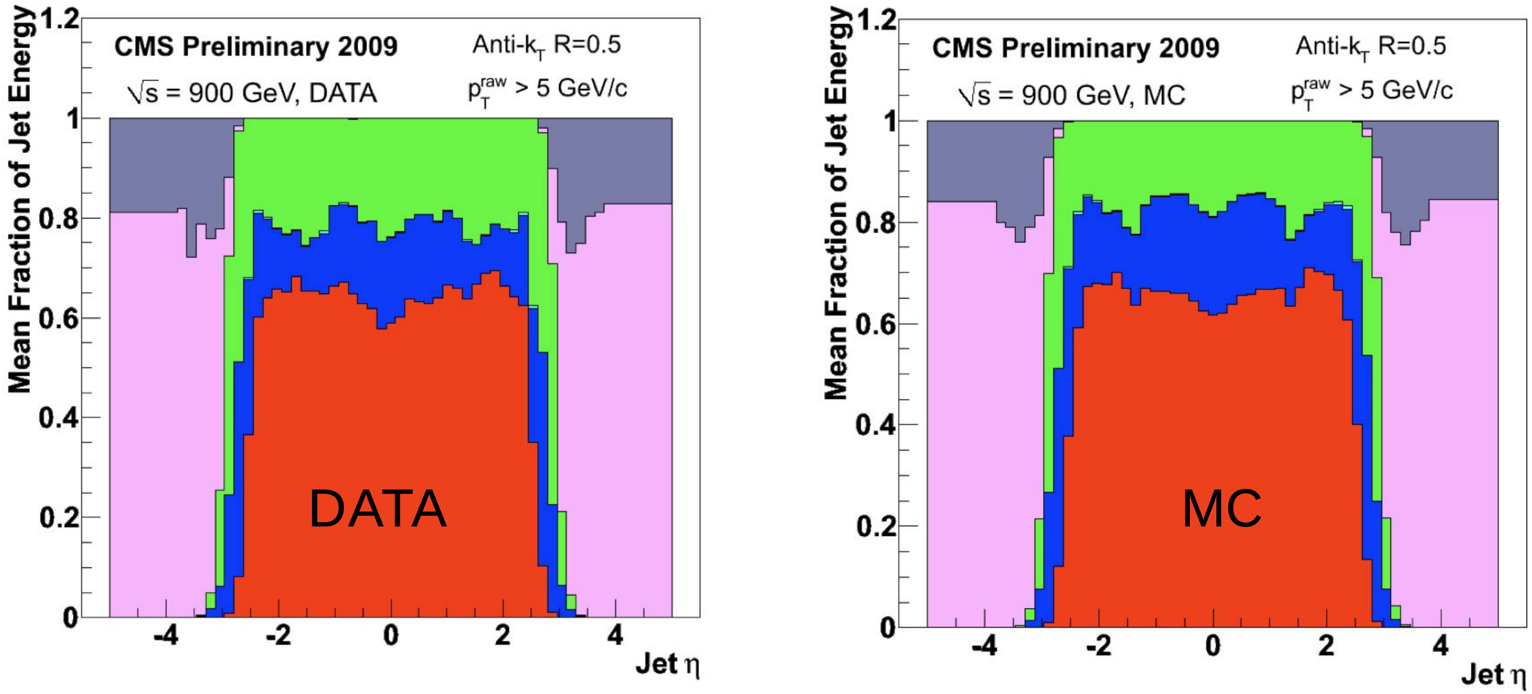


Calorimeter response to hadrons well simulated

Hadron response with calorimeters is adequate at the 5% level

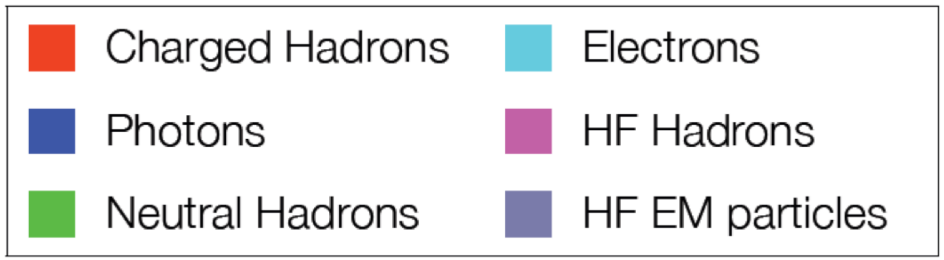
Jet composition

Jet energy fraction carried by particles within jets



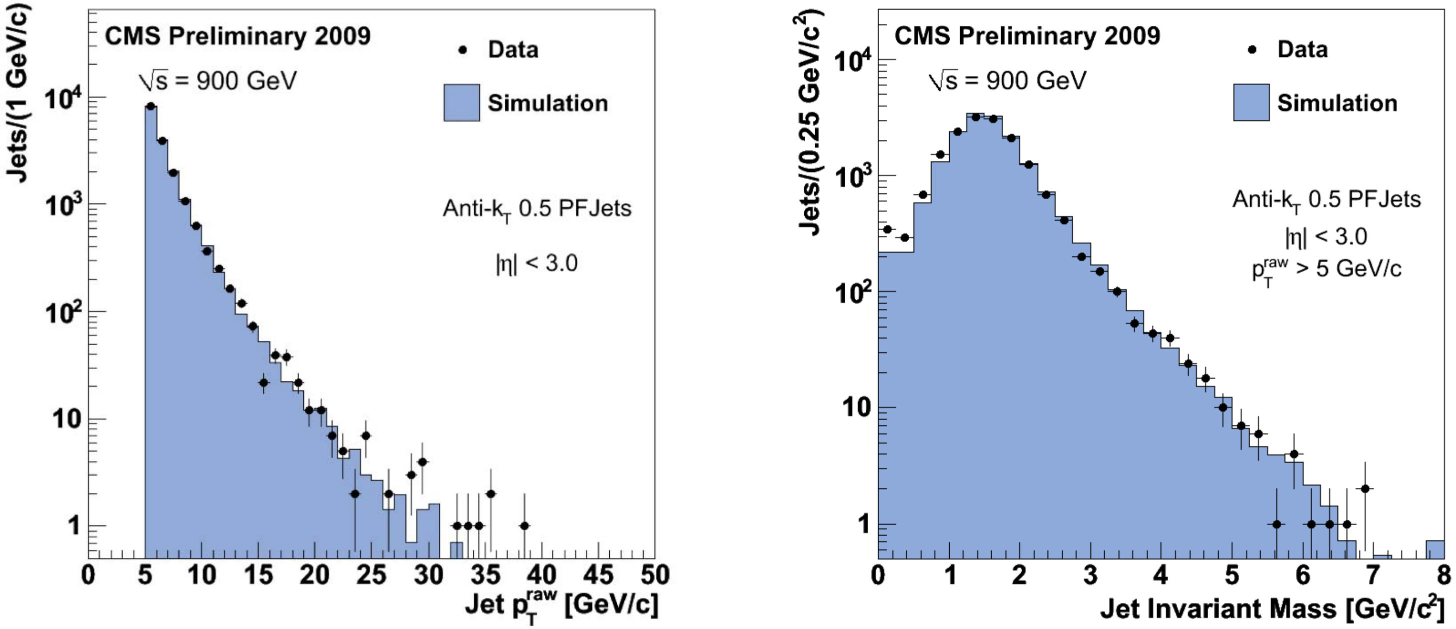
JES systematic uncertainty:
65% charged hadrons: 0
25% photons: 2%
10% neutral hadrons: 5%

Ultimate uncertainty ~ 1%



Particle flow jets

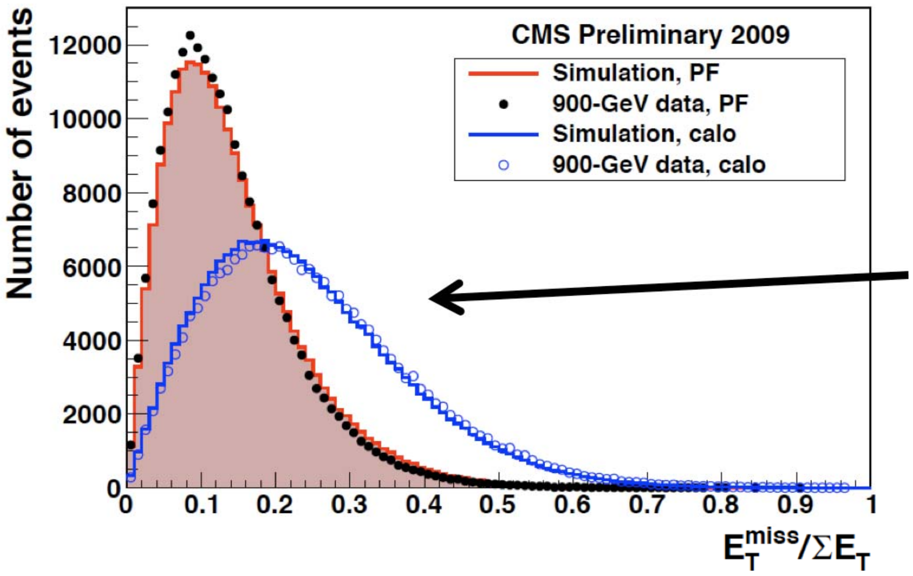
commissioning of the basic jet variables



Jet-constituent invariant mass

- Good agreement to simulation proof of accurate understanding of jet 4-vector properties

Missing transverse energy (MET)

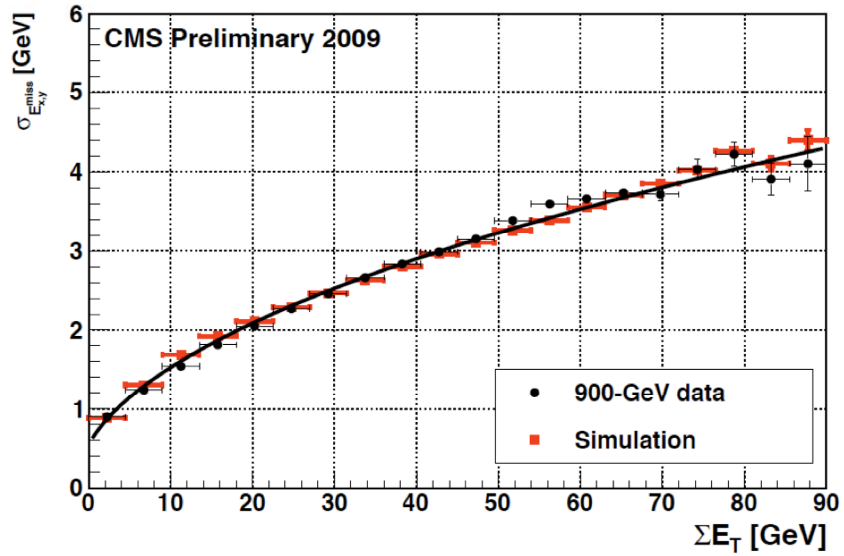


- For a given estimate of the ΣE_T the particle-based E_T^{miss} resolution is, on average, twice better than the calorimeter reconstruction

Resolution of the particle-based $E_{x,y}^{miss}$ vs ΣE_T:

$$\sigma(E_{x,y}^{\mathrm{miss}}) = a \oplus b\sqrt{\sum E_{\mathrm{T}}}.$$

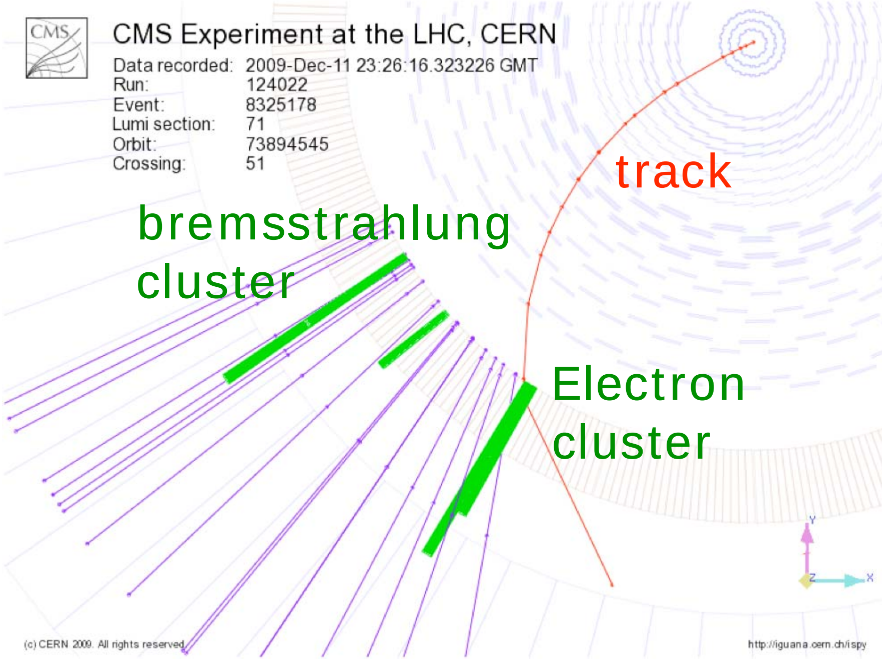
a = 0.55 GeV and b = 45%



Electrons in particle-flow (also within jets)

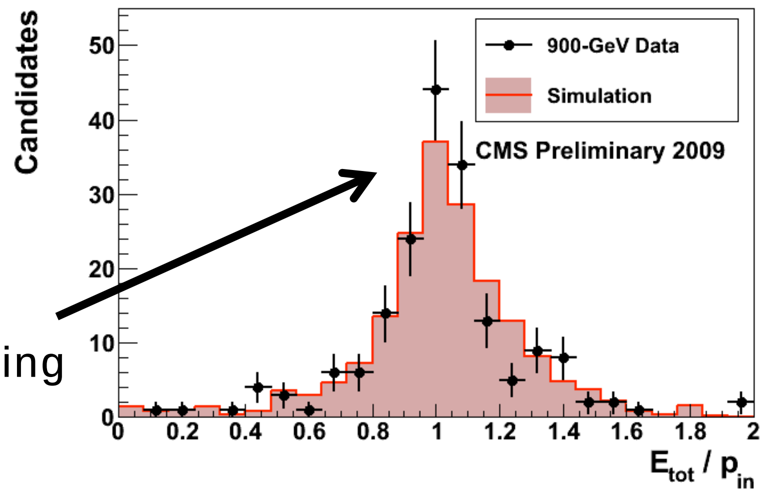
Only a few electrons in the 900 GeV data (mostly from photon conversions) and a very low p_T

p_T = 2.53 GeV/c



- The cluster-track link together with the large magnetic field and the good ECAL granularity play again the main role:
  - ✓ Electron reconstruction
    - electron track – ECAL cluster link
    - Bremsstrahlung recovery

ECAL- Tracker energy matching

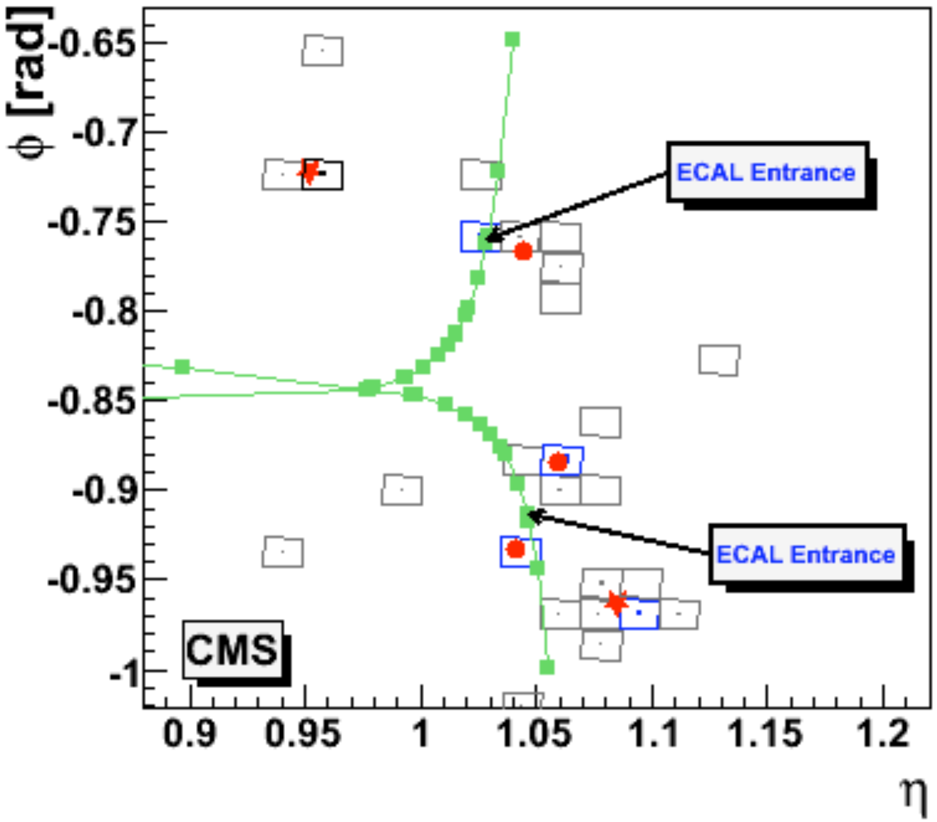


Conclusions

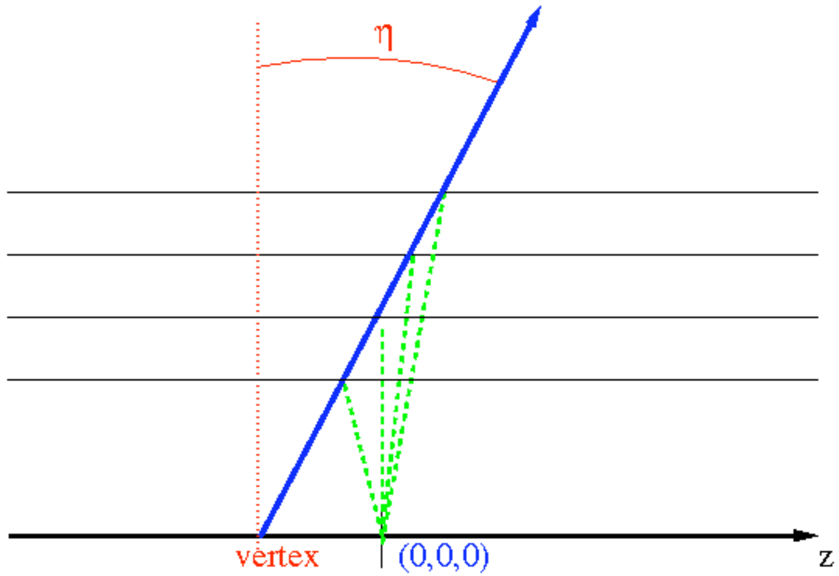
- Combining the various CMS sub-detectors, particle flow allows for a much better reconstruction of the jet, MET (and τ).
  - ✓ up to 3 times better resolution in jets
  - ✓ in average 2 times better resolution in E_T^{miss}
- Particle Flow commissioning is ongoing and going well
  - ✓ π^0 mass: agreement within 2% with the PDG value
  - ✓ hadron calorimeter response adequate at 5% level
  - ✓ Jets and missing energy performance as expected in simulation
  - ✓ JES, ultimate systematic uncertainty ~1%
- The Particle Flow event reconstruction is keeping up with the LHC challenge
  - ✓ The algorithm proves to be robust and reliable

backup

How does it work: the track-cluster link



- Clusters not linked to any track
  - photons



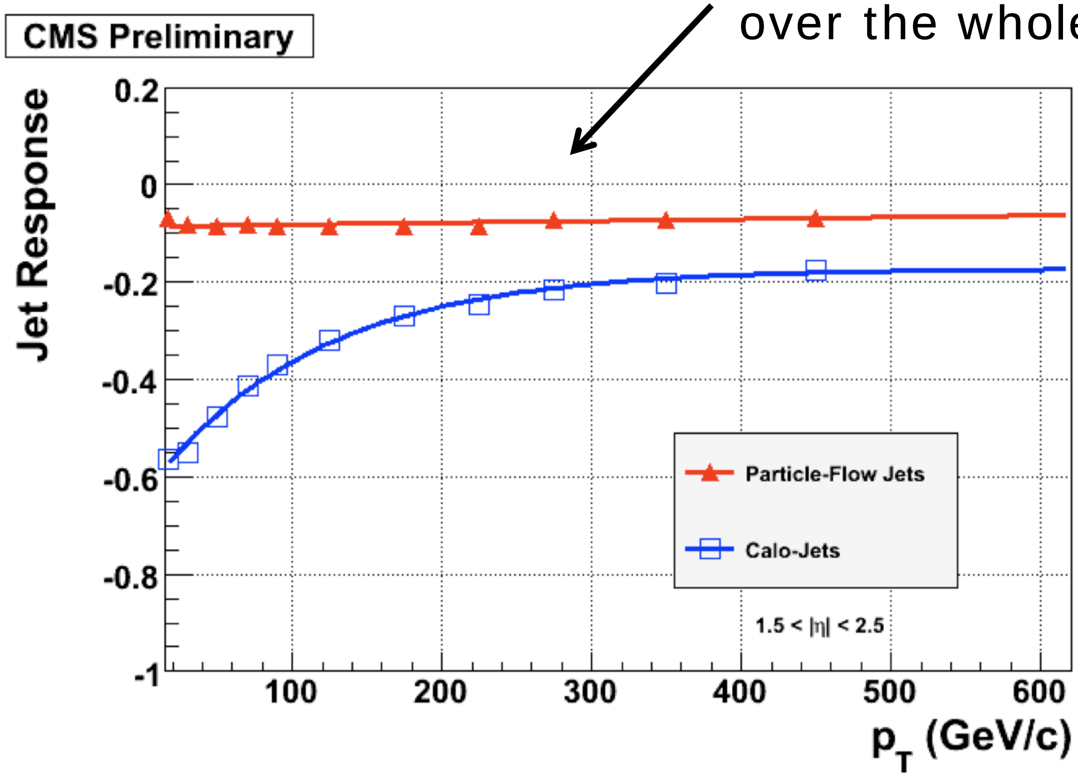
η as seen from (0,0,0)

The track is linked to a given cluster if the extrapolated position in the corresponding calorimeter is within the cluster boundaries

Reconstruction of the jet p_T

90%
of the p_T reconstructed,
over the whole range.

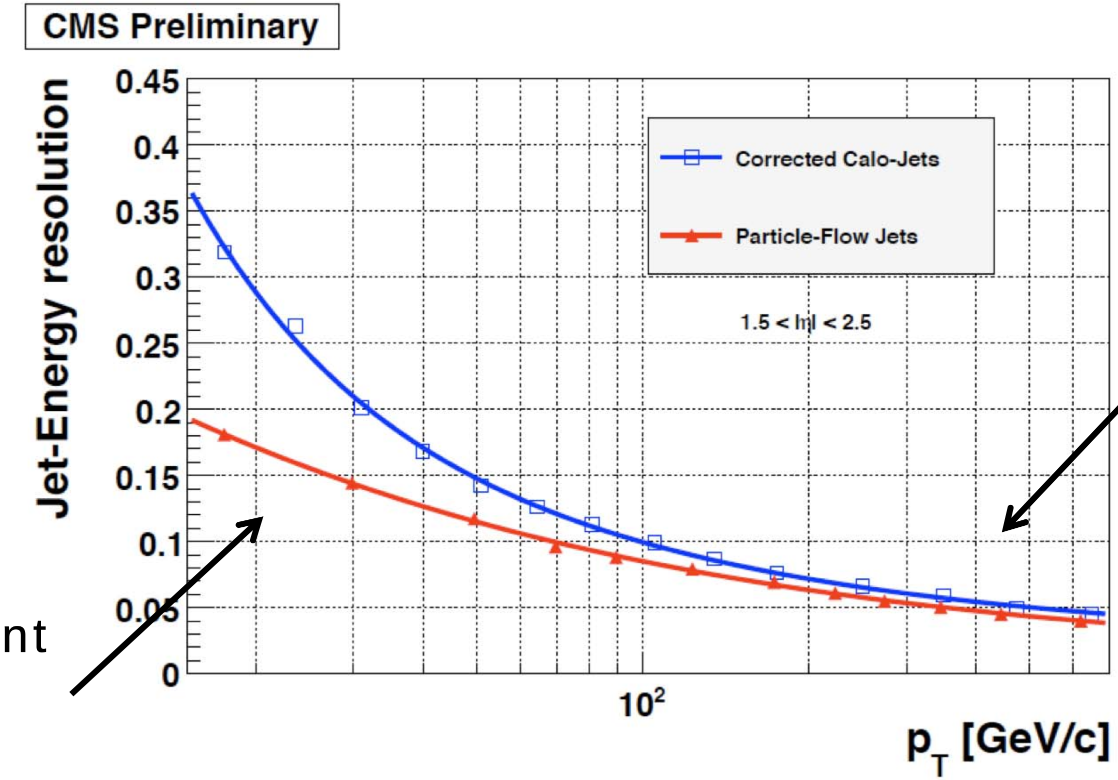
Mean of
the fitted
Gaussian



True jet p_T

- Endcap: $1.5 < |\eta| < 2.5$

Jet energy resolution



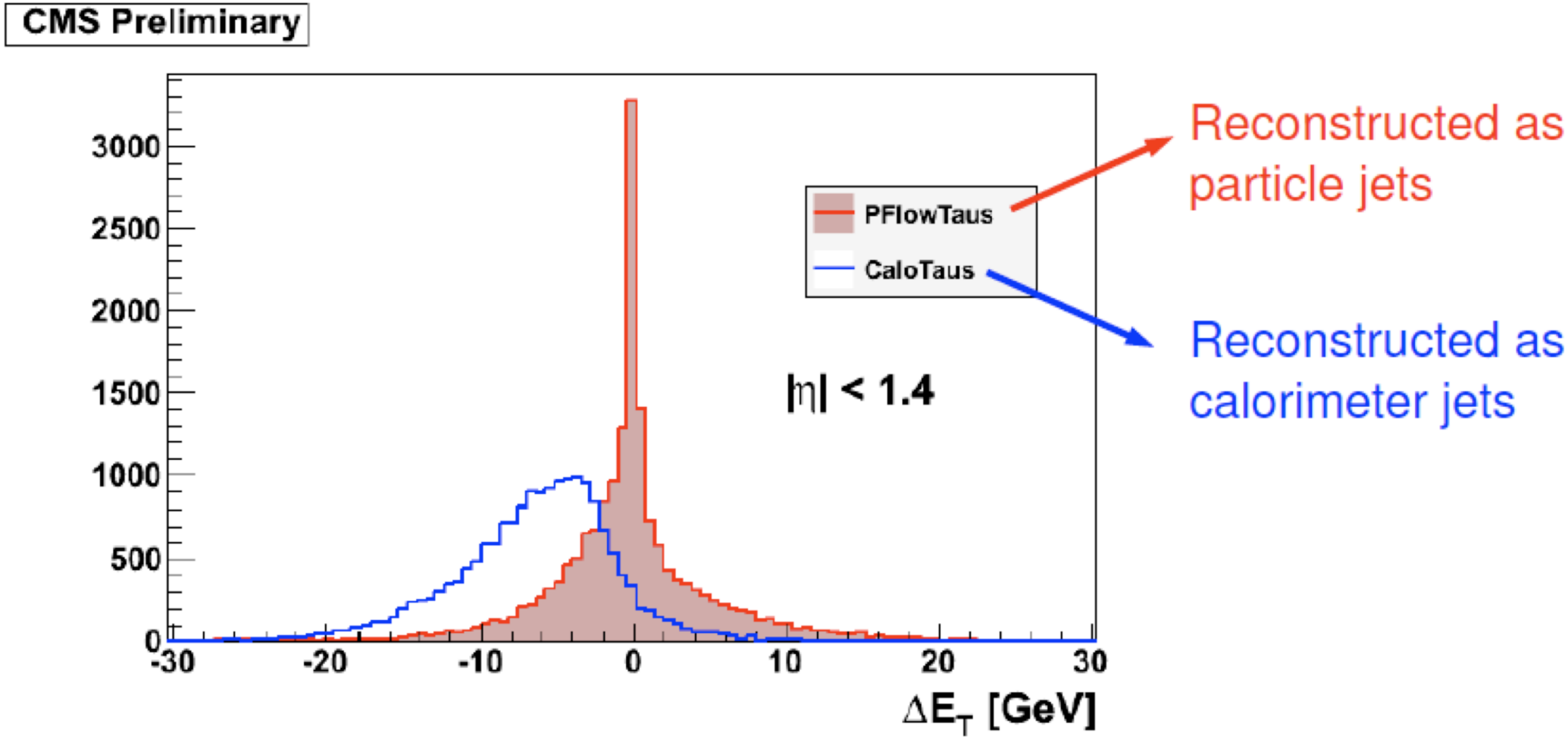
Very large improvement at low pT, thanks to Tracks

Good calorimeter resolution, Tracks → bring less

← True jet p_T

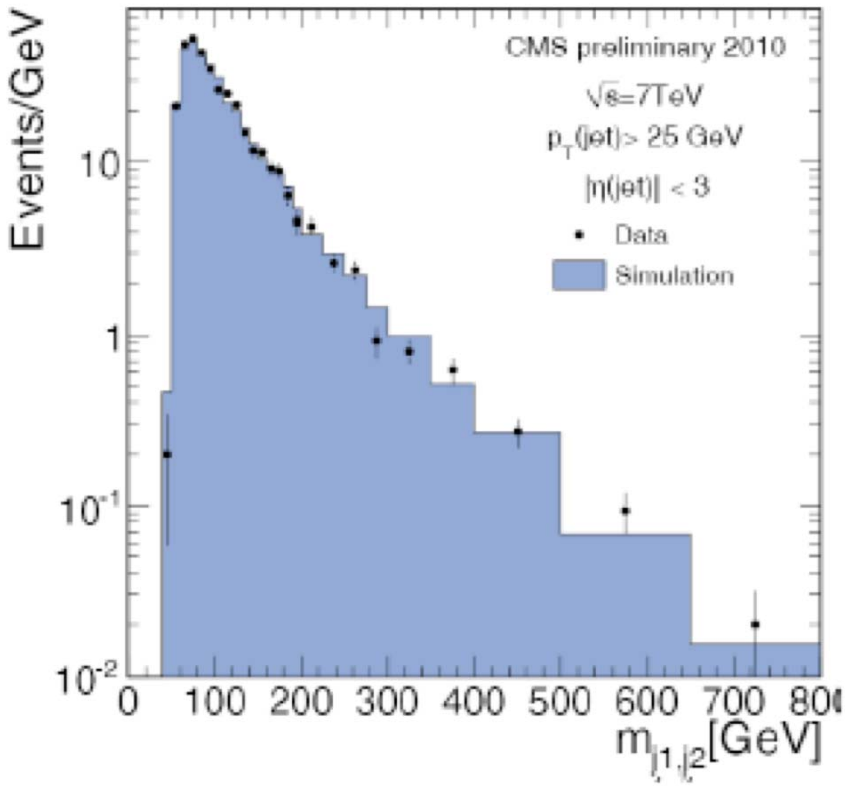
- Endcap: $1.5 < |\eta| > 2.5$

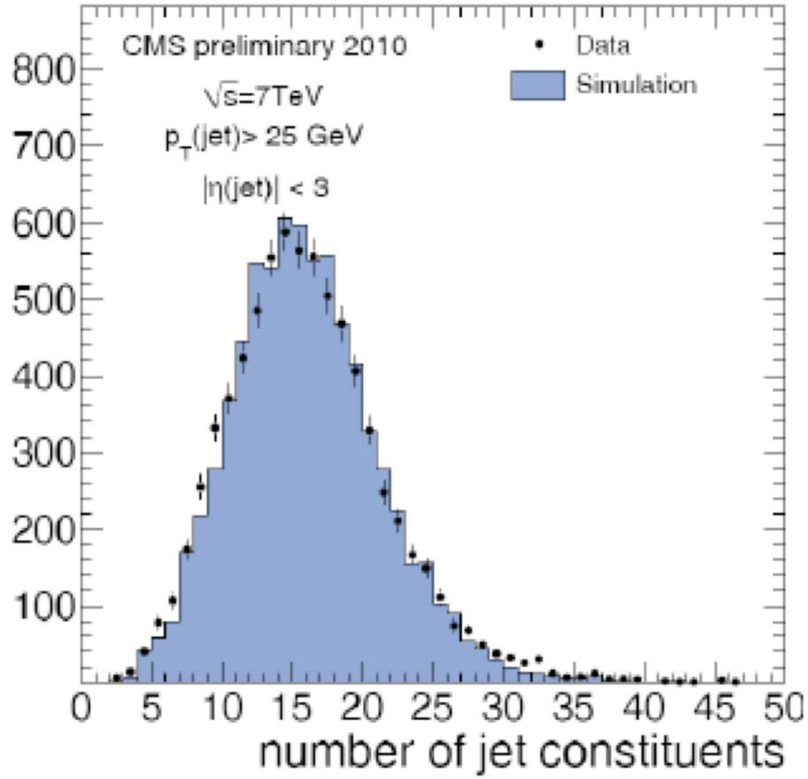
Performance with τ



- Even larger improvement than in the case of jets
  - because only 1% of the taus produce neutral hadrons in their decays.

Particle-flow jet commissioning: 7 TeV





Data vs simulation di-jet invariant mass and number of jets constituents

Particle-flow jet composition: 7 TeV

PF jets

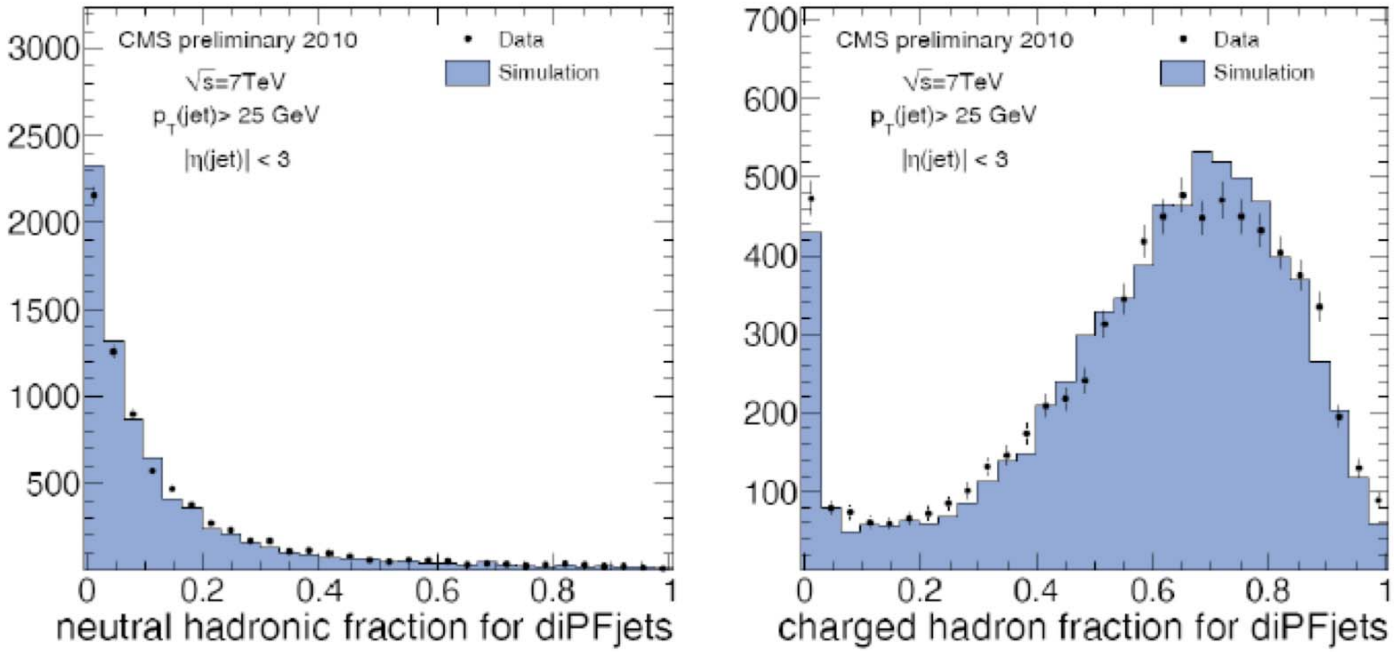


Figure: Data vs MC: Fraction of jet energy carried by neutral hadrons, *NHF* and the charged hadronic fraction *CHF*.