Missing Transverse Energy commissioning in CMS

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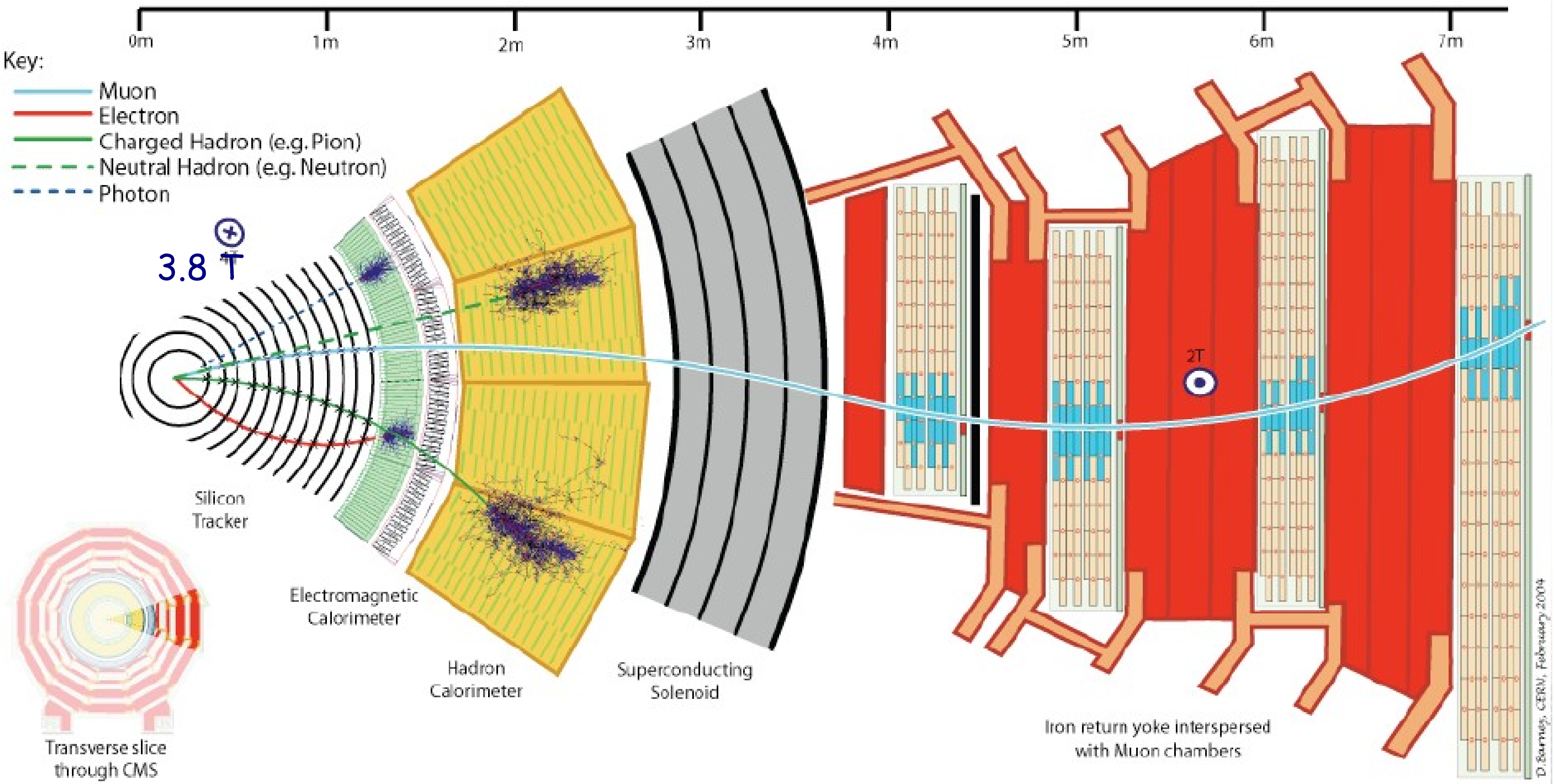
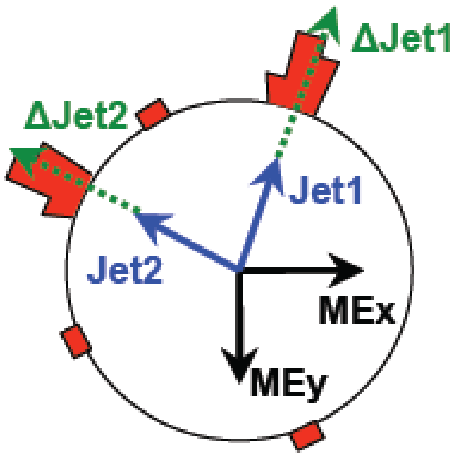
The Compact Muon Solenoid detector

- Nearly 4π, hermetic, redundant, Russian-doll design



The Missing Transverse Energy

- A very important variable for various analyses:
  - indirect detection of invisible particles
  - one of the most promising signatures of new physics
  - Allow to reduce QCD and other low MET backgrounds
- A **challenging** variable:
  - The degree of separation depends on the MET **resolution**
  - A good understanding of the **tails** is vital for physics searches
  - Easy to obtain fake MET
    - For example, jets tend to fluctuate wildly
      - Large shower fluctuation
      - Fluctuations in the e/h energy ratio
      - Non-linear calorimeter response
      - Non-compensation
    - Instrumental effects
      - Dead or « hot » calorimeter cells
      - Instrumental noise
      - Poorly instrumented area of the detector
      - Accelerator-induced MET



Calorimeter MET

- Calorimeter MET is computed from energy deposits in projective calorimeter towers:

$$\vec{\not{E}}_T = -\sum_n (E_n \sin\theta_n \cos\phi_n \hat{\mathbf{i}} + E_n \sin\theta_n \sin\phi_n \hat{\mathbf{j}}) = \not{E}_x \hat{\mathbf{i}} + \not{E}_y \hat{\mathbf{j}}$$

- Apply corrections **a posteriori**:
  - Jet energy scale $$\mathbf{E}_{\mathbf{T}}^{\mathbf{miss}} = -\sum_i \mathbf{E}_{\mathbf{T},i}^{\mathbf{tower}} - \sum_j \left(\mathbf{p}_{\mathbf{T},j}^{\mathbf{corr},jet} - \mathbf{p}_{\mathbf{T},j}^{\mathbf{raw},jet}\right)$$
  - Muons corrections $$\vec{\not{E}}_T = -\sum_{i=1}^{\text{towers}} \vec{E}_T^i - \sum^{\text{muons}} \vec{p}_T^{\mu} + \sum_{i=1}^{\text{deposit towers}} \vec{E}_T^i$$
  - Hadronic tau energy scale, unclustered energy correction, etc

track-corrected MET

- Basic idea: Use well measured tracks to correct the imperfect response of the calorimeter to charged hadrons (⇒lower tail, better resolution)
  - Add track momenta (Important to separate μ's from π's)
  - Substract average single-particle response for each track
- First step: Compute muon corrected caloMET

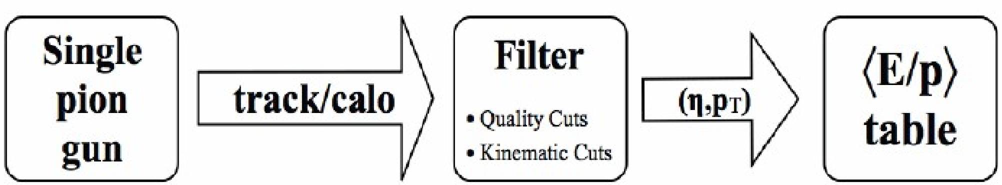
$$\not\!\!E_T^{\mu} = \not\!\!E_T^{\text{calo}} + \delta\not\!\!E_T^{\mu}, \\ = -\sum_{\text{towers}} \vec{E}_T - \sum_{\substack{\text{good}\\\text{muons}}} \vec{p}_T + \sum_{\substack{\text{good}\\\text{muons}}} \vec{E}_T^{\text{MIP}}$$

Tracker muon p_T — Calo E deposit (~2 GeV)

- Second step: Compute tcMET using hadron tracks

$$\not\!\!E_T^{\text{tc}} = \not\!\!E_T^{\mu} + \delta\not\!\!E_T^{\text{tc}}, \\ = \not\!\!E_T^{\mu} + \sum_{\substack{\text{good}\\\text{tracks}}} \langle\vec{E}_T\rangle - \sum_{\substack{\text{good}\\\text{tracks}}} \vec{p}_T$$

Expected energy deposited (RF) — Track momentum at vertex



Particle flow MET

- The particle flow reconstruction aims at reconstructing all stable particles in the event:
    - $\mu^{\pm}$, $e^{\pm}$, γ, charged hadrons and neutral hadrons

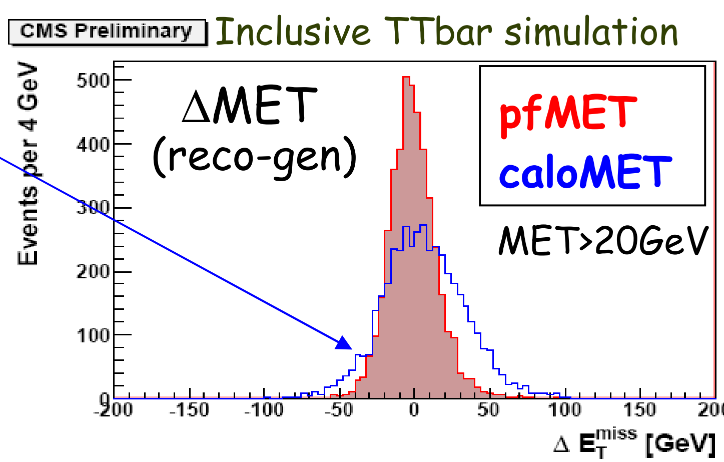
using full ensemble & redundancy of all CMS detectors:

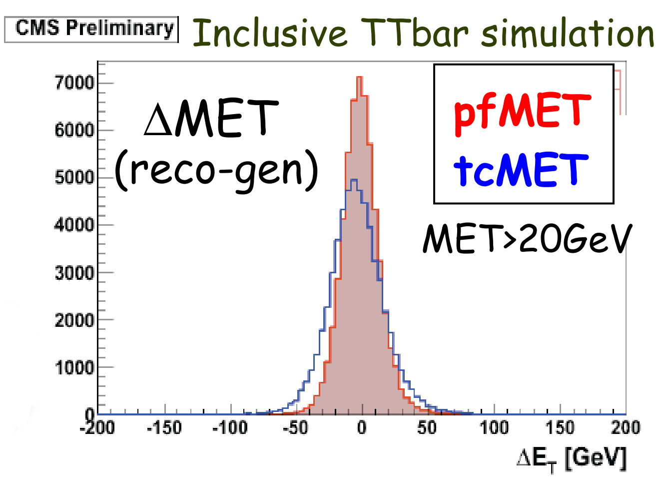
- Tracker, ECAL, HCAL, muon system

- PfMET is the transverse momentum vector sum over all reconstructed particles:

$$\vec{E\!\!\!/}_T = - \sum_{\text{particles}} (p_x \hat{\mathbf{i}} + p_y \hat{\mathbf{j}})$$

caloMET is corrected from muons and jet energy scale here, but in the following only raw quantities will be compared

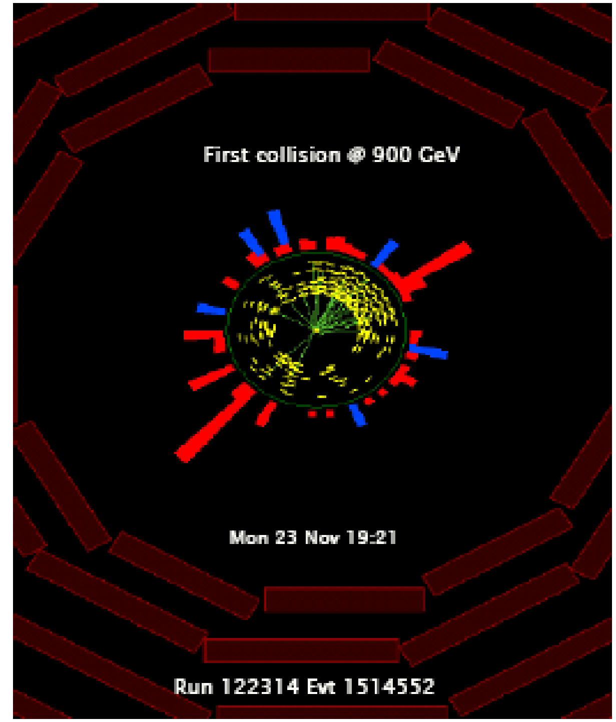




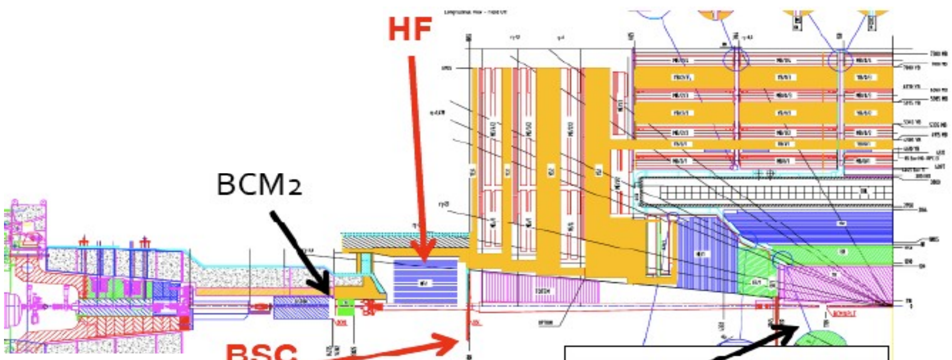
Factor ~2 improvement

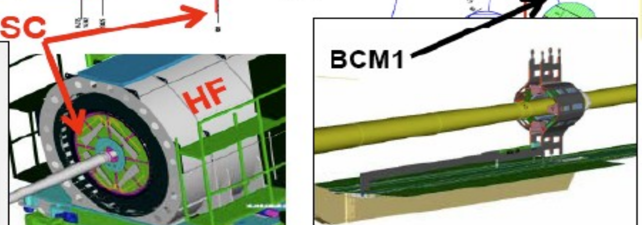
The 2009 p-p collisions

- First 900 GeV collision: 23 November
- First stable beams: 6 December
- First 2.36 TeV collision: 14 December
- Recorded luminosity (85% of delivered):
  - ~10 μb^{-1} @ 900 GeV
    - ~216k events after selection
  - ~0.4 μb^{-1} @ 2360 GeV
    - ~10k events after selection
- Trigger: coinciding trigger signal in each of the 2 beam scintillators counters (BSCs)



No magnetic field!
→ excluded in the following plots:
we consider only the data taken with all the CMS detectors fully operational

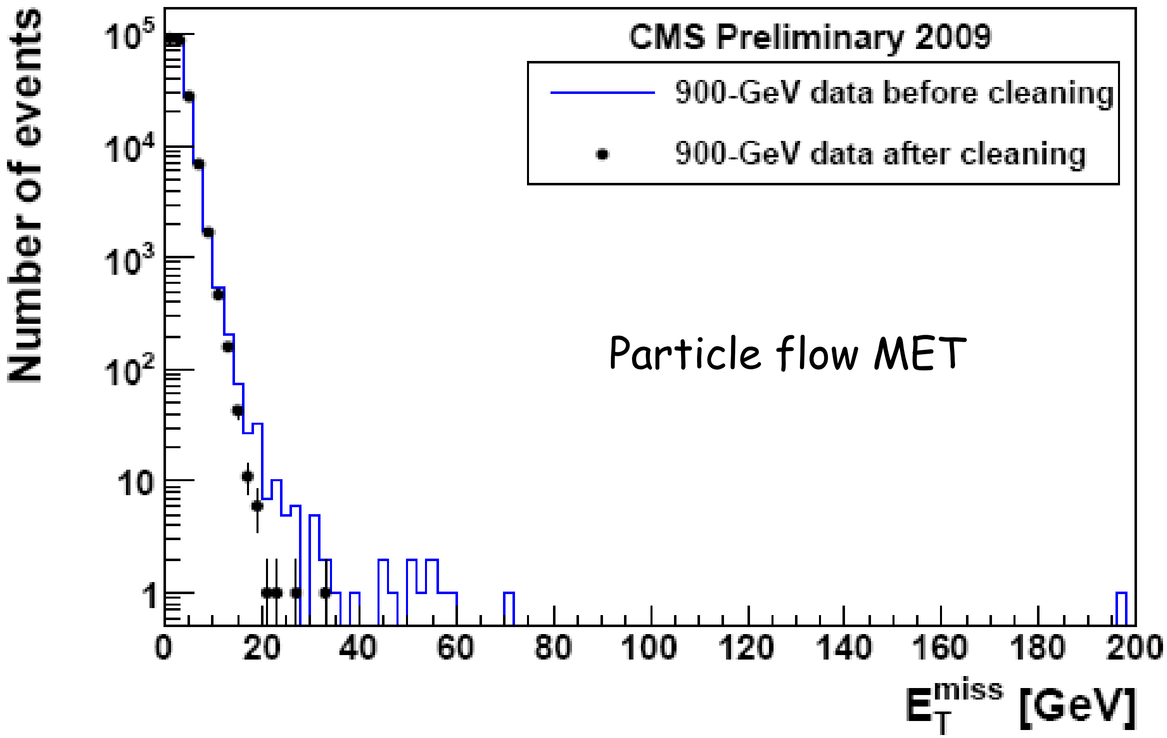




- Other selection cuts:
  - Veto BSC beam halo trigger (timing)
  - Remove scraping events (% bad tracks)

Cleaning of the instrumental noise

- Investigation of outliers → identification and cleaning of various type of noise:
  - HF (particle hits PMT windows)
  - Coherent HCAL noise (specific pattern)
  - Occasional ECAL single hot channel

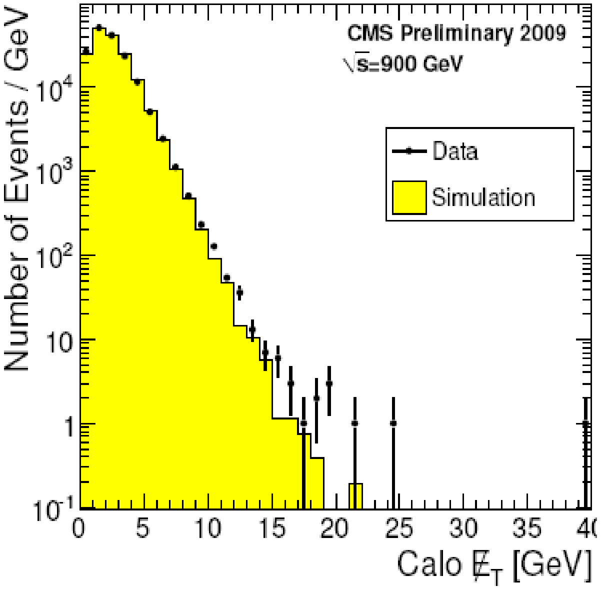


- No event has been killed!

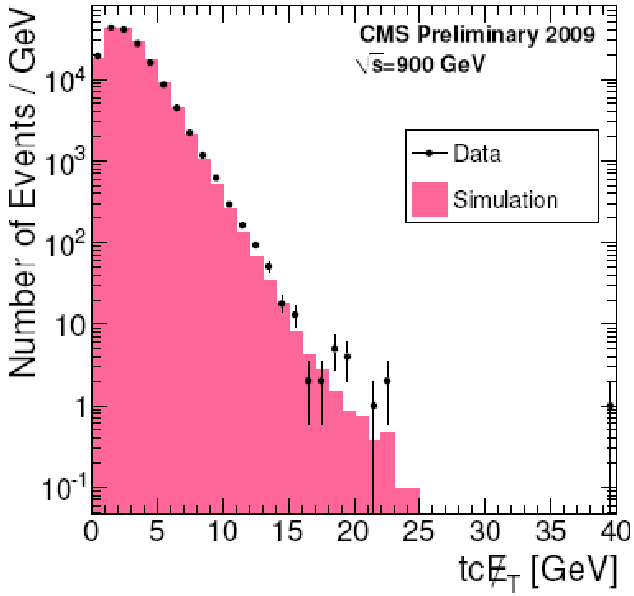
➢ We masked the crystals/towers/fibres identified as noisy

MET: Comparison, after cleaning, with the simulation

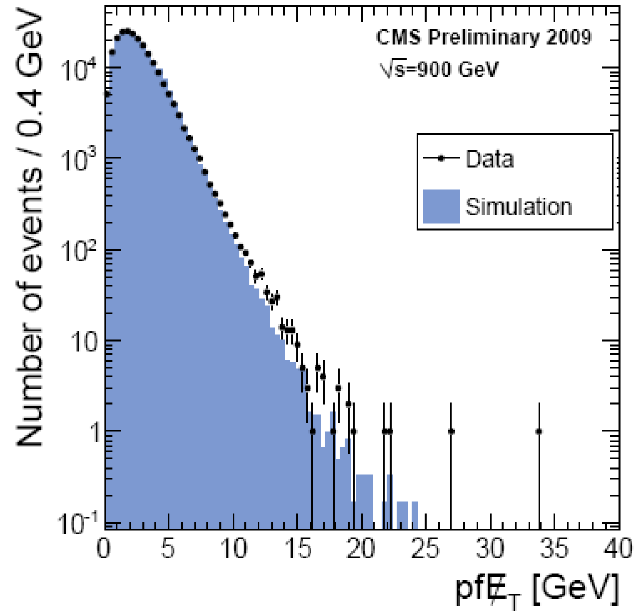
caloMET



tcMET



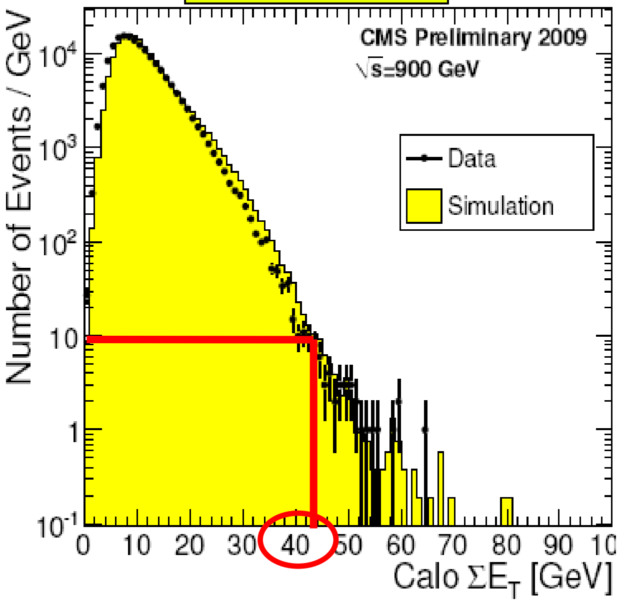
pfMET



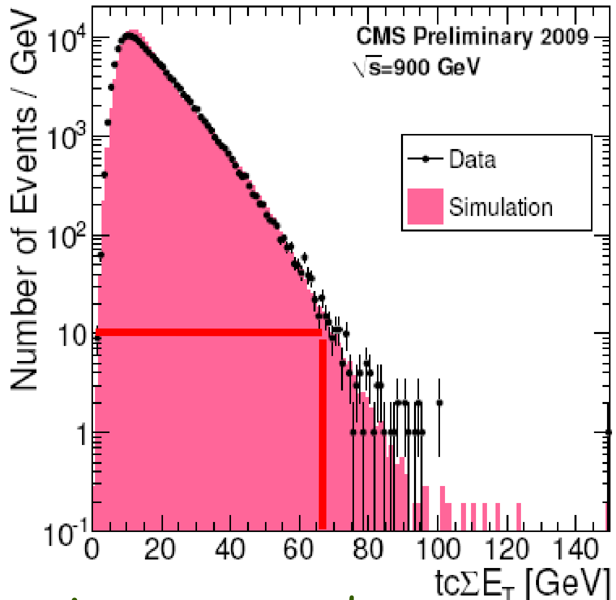
- 900 GeV data - No JES and muon corrections applied
- Good agreement between the data and the MinBias simulation

SumEt

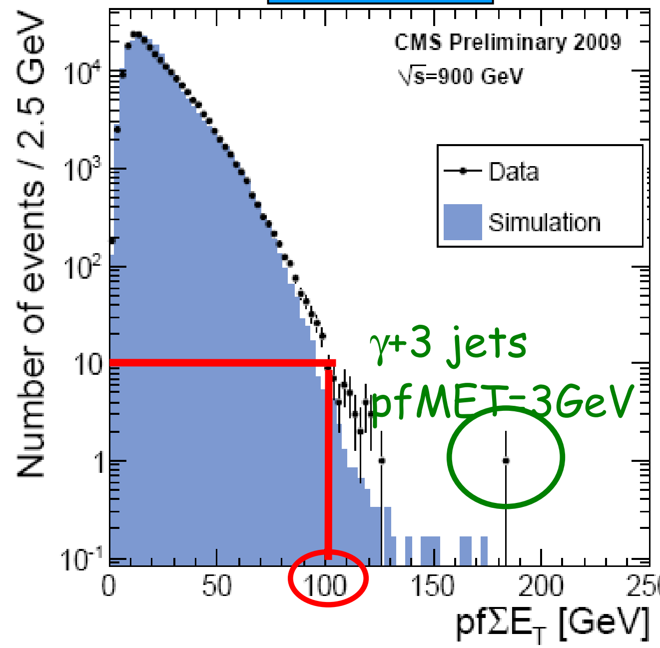
caloSumEt



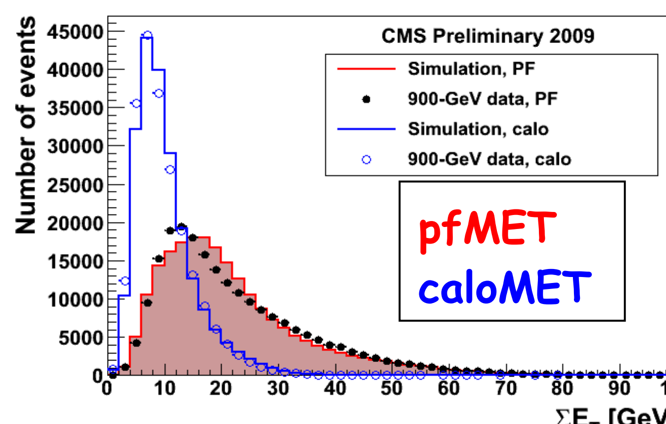
tcSumEt



pfSumEt



- SumEt is a challenging quantity to reproduce
  - no cancellation (in contrast with the MET)
- The MinBias simulation gives a quite good agreement with the data
- Discrepancies are mainly due to charged hadron multiplicity. Small discrepancy also due to not perfect noise modeling in ECAL endcaps
- The particle flow reconstructs much more energy than the other algorithms.



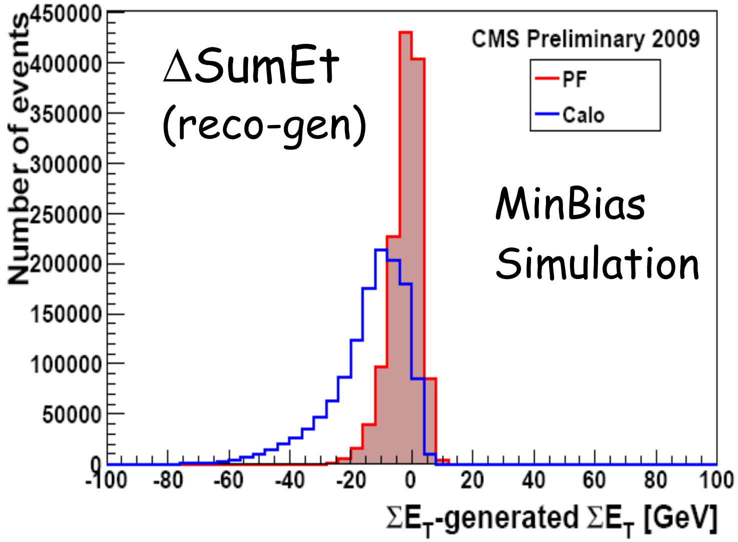
The particle-based SumEt is close to the true generated SumEt

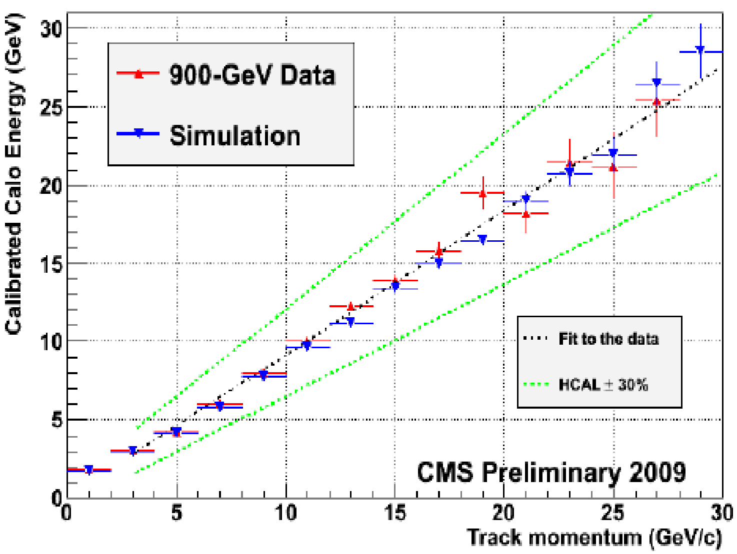
➢ Three reasons govern this observation:

▪ Charged hadrons (measured by the tracker) and photons (measured by the ECAL) are reconstructed at the correct energy scale and represent about 80% of the event energy.

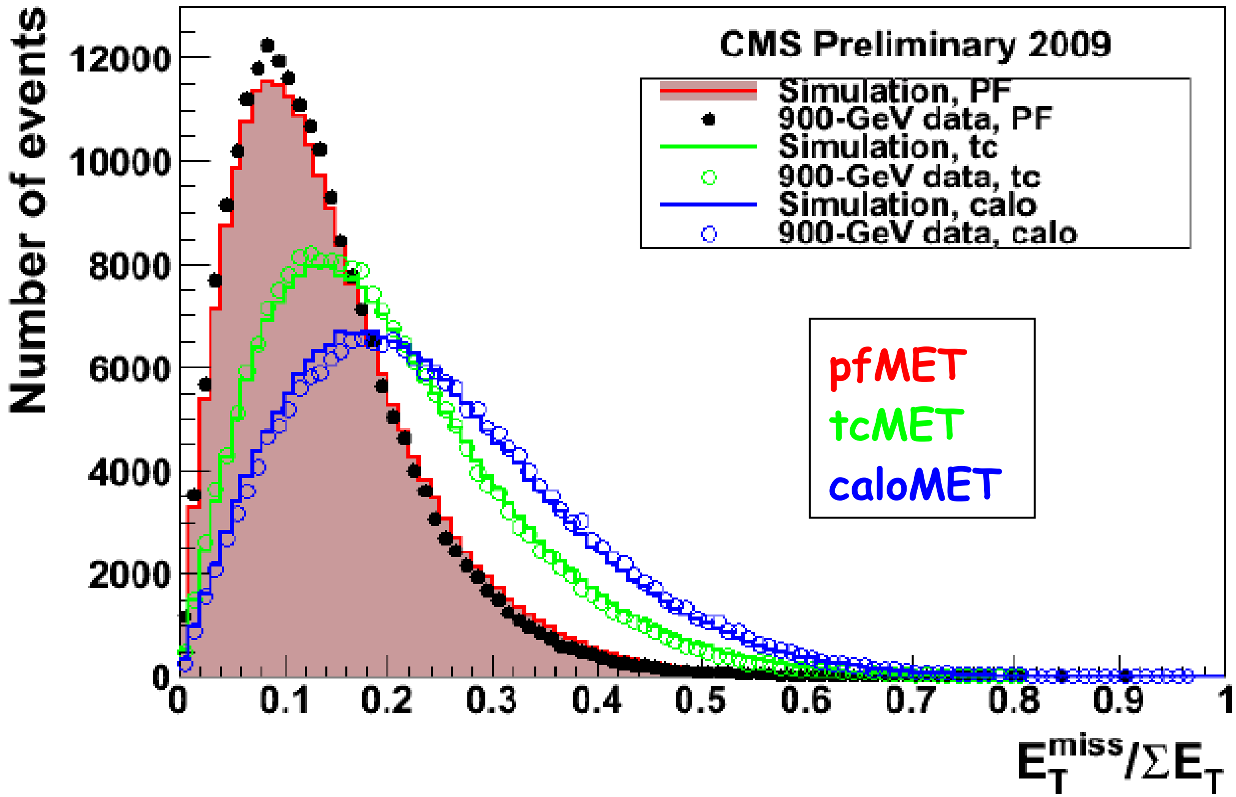
▪ The particle-flow algorithm is able to reconstruct very low-energy particles, down to a pT of 100 MeV/c for charged hadrons, and to an energy of 200 MeV for photons.

▪ The hadronic-cluster calibration brings the neutral hadron energy, which accounts for the remaining 20% of the event energy, to the proper scale as well.





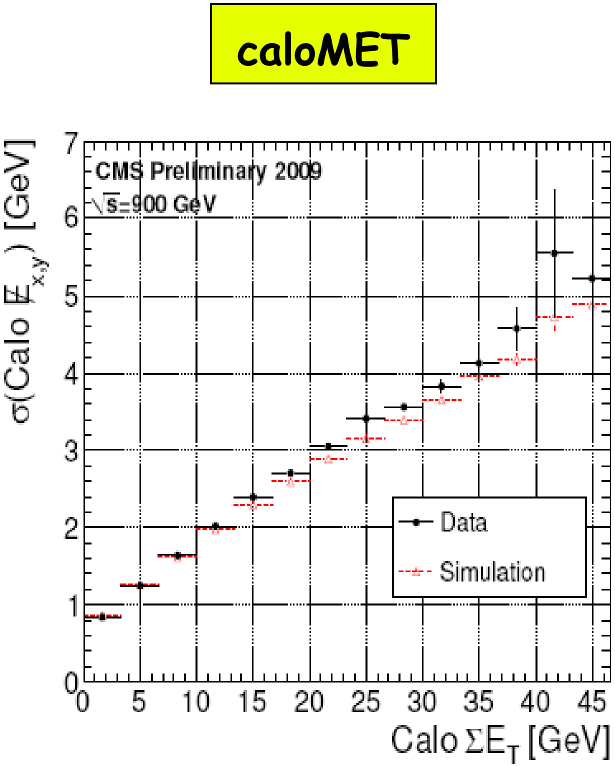
Poor-man MET significance

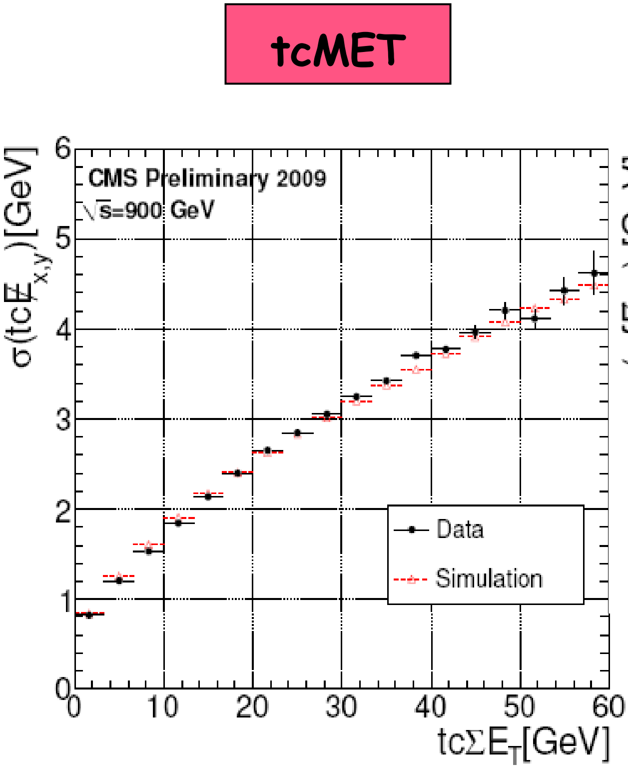


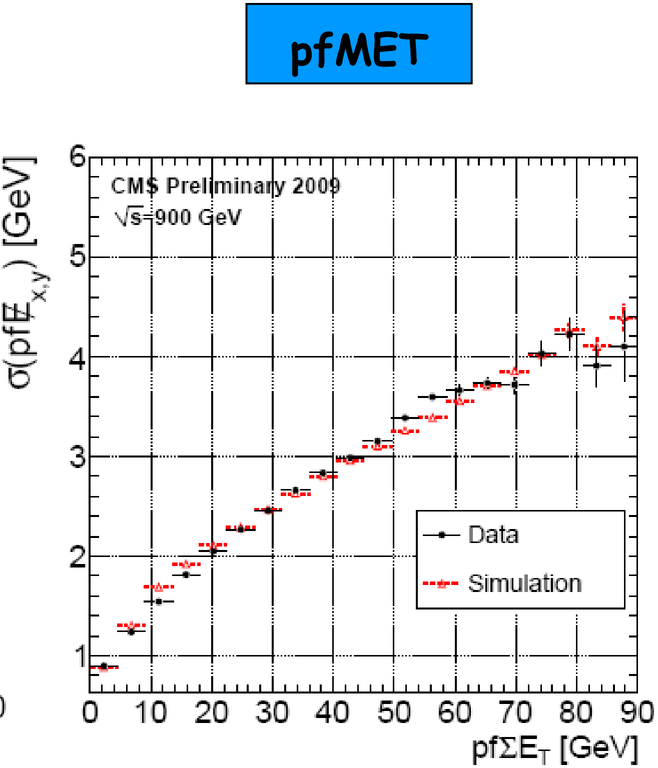
- SumEt > 3 GeV
- Particle-based MET relative resolution is about twice good as for the caloMET

$MET_{x,y}$ resolution

- Resolution of the MET components along the x- and y-axes:

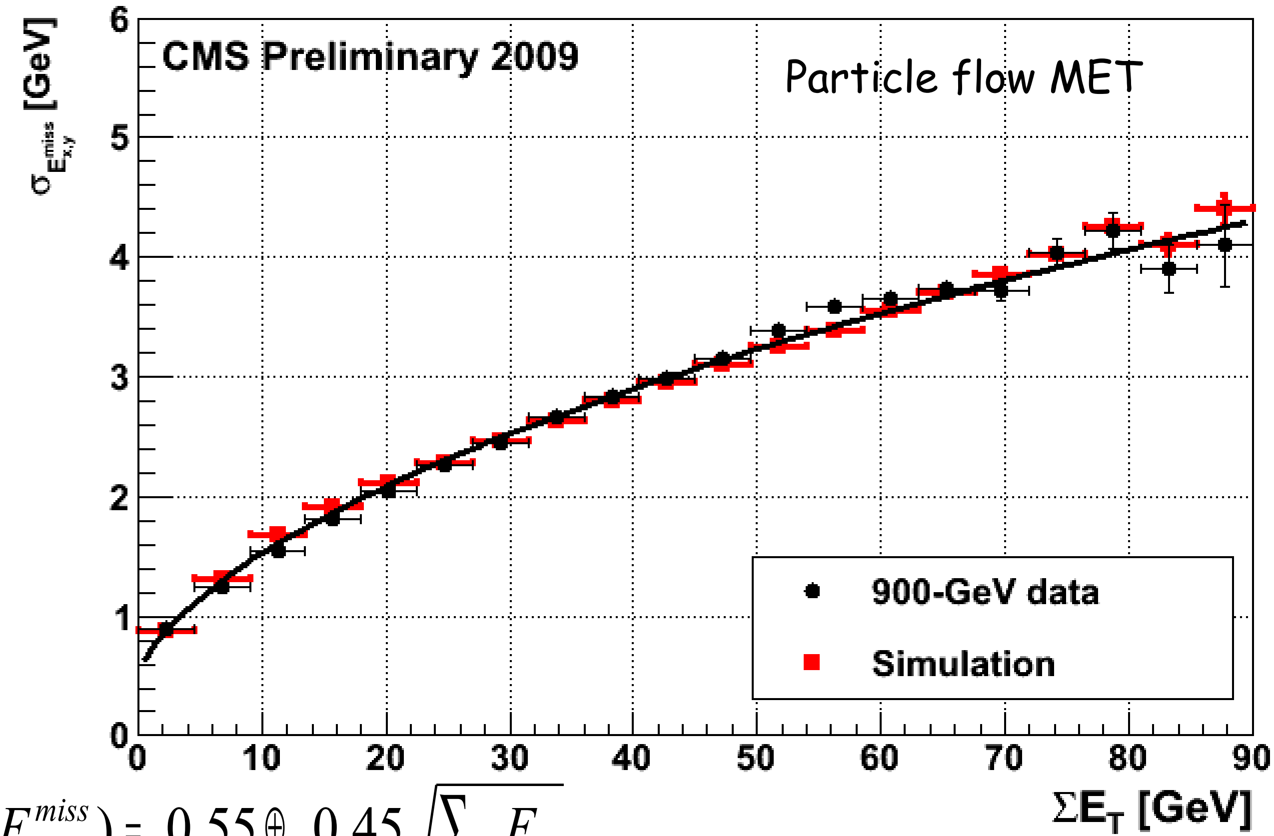






- *sigma is obtained with a Gaussian fit of the METx,y distribution*
- Good agreement between data and simulation for the 3 algorithms

$MET_{x,y}$ resolution: fit results



- $\sigma(E_{x,y}^{miss}) = 0.55 \oplus 0.45\sqrt{\sum E_T}$

~0.80 for caloMET

- Same results obtained with the 2.36 TeV events

Summary and future plans

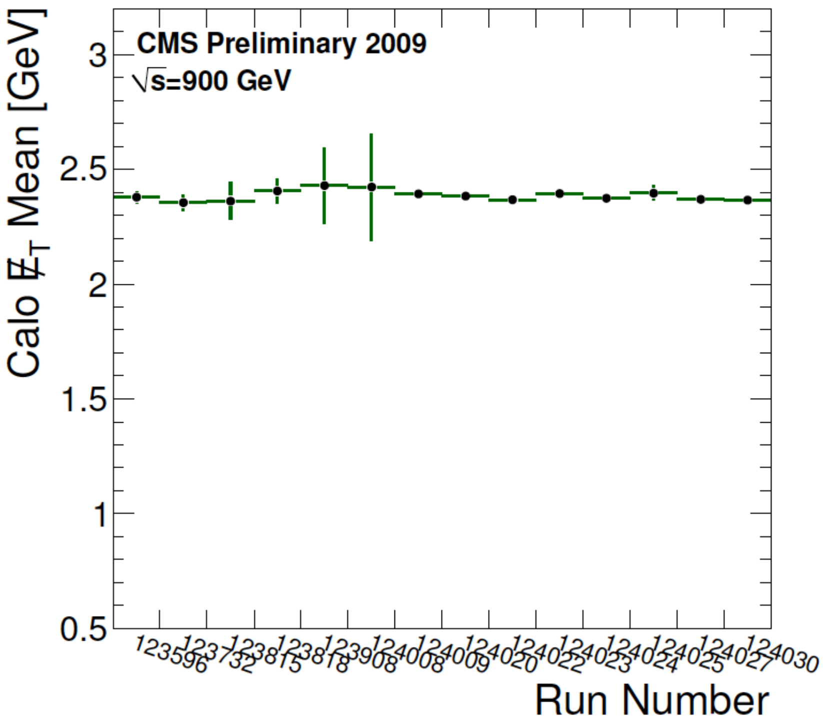
- MET variables are very important variables for physics analysis but most challenging variable to understand
  - Rely on good understanding of all the other objects

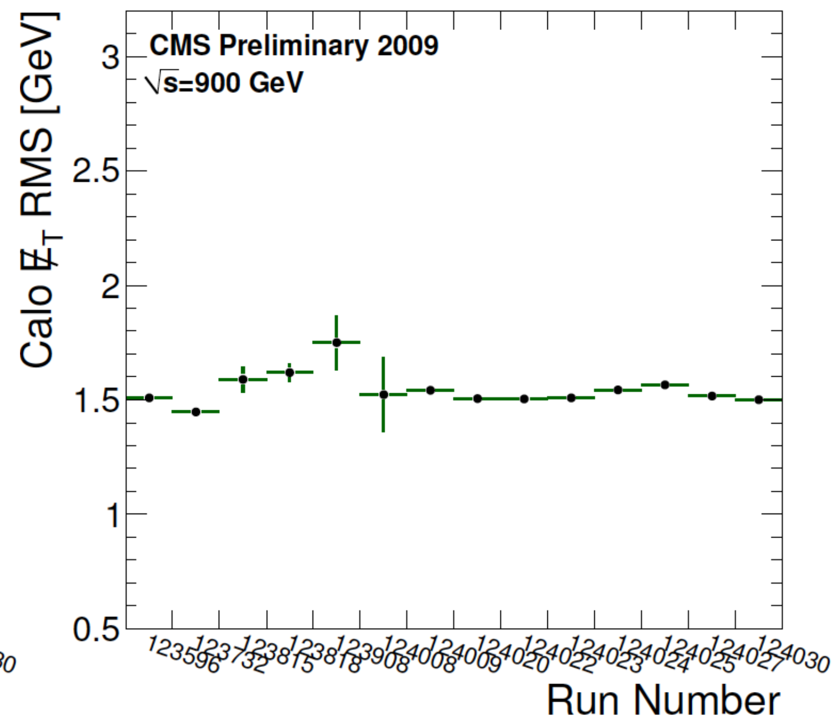
- Good agreement between data and simulation is observed for the calo/tc/pf MET distributions, even if calibrations of detectors are not final

- The commissioning confirms that the particle flow MET gives about x2 better resolution and performances than the caloMET and no additional tails for MinBias events.

- The MET commissioning will continue in the 7 TeV data, in particular with the study of W+jets and Z/γ^*+jets events
  - For example: in $Z\rightarrow\mu\mu$ events: comparison between the Z pt and the MET computed with all the particles excepts the 2 muons.
  - Many studies: noise cleaning, energy scale corrections, muons corrections, beam halo, met triggers, pile-up effects, etc.

BACK UP SLIDES


CMS Preliminary 2009
$\sqrt{s}$=900 GeV
Calo $\not\!\!E_T$ Mean [GeV]
Run Number
123596
123732
123815
123818
123908
124008
124009
124020
124022
124023
124024
124025
124027
124030


CMS Preliminary 2009
$\sqrt{s}$=900 GeV
Calo $\not\!\!E_T$ RMS [GeV]
Run Number
123596
123732
123815
123818
123908
124008
124009
124020
124022
124023
124024
124025
124027
124030