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Muon Reconstruction in CMS

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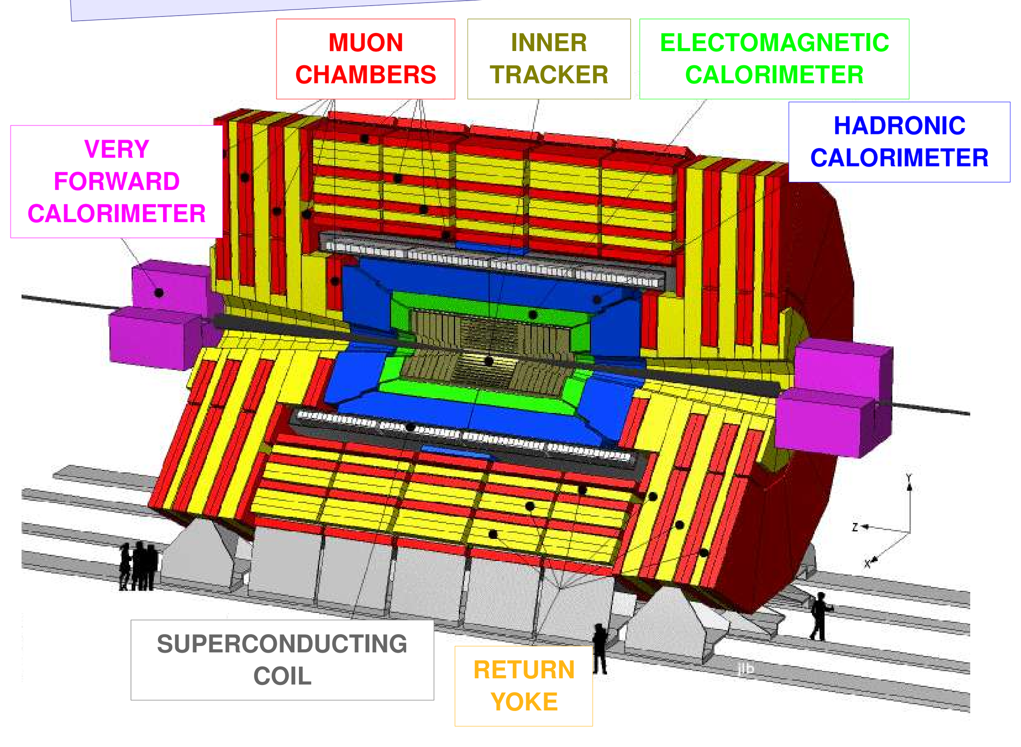
on behalf of the CMS Collaboration

The Compact Muon Solenoid

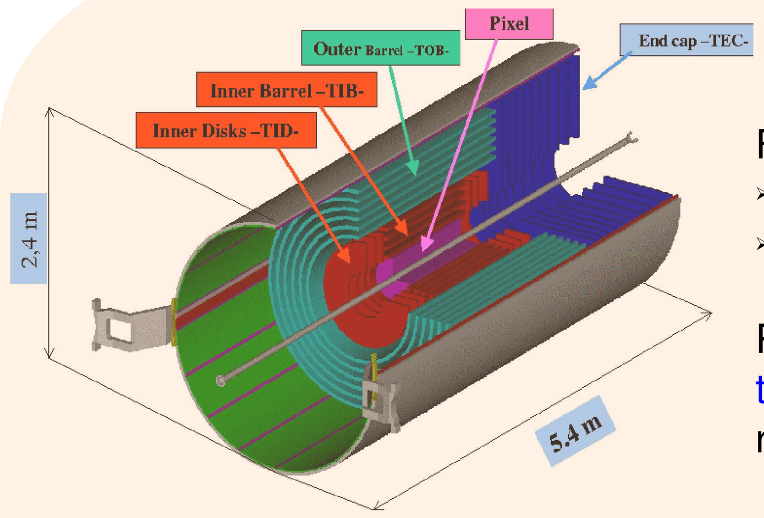
Weight: 12,000 t.
Diameter: 15 m
Length: 21.6 m
Magnetic field: 3.8 T in the Inner Barrel
~1.8 T in the return yoke (Muon System)



Main issues in muon reconstruction
- high density → energy loss, multiple scattering
- inhomogeneous magnetic field (in the Muon System)

The CMS Tracking System

Inner Tracking System



Fully made of silicon
- Pixels (inner)
- Micro-strips (outer)

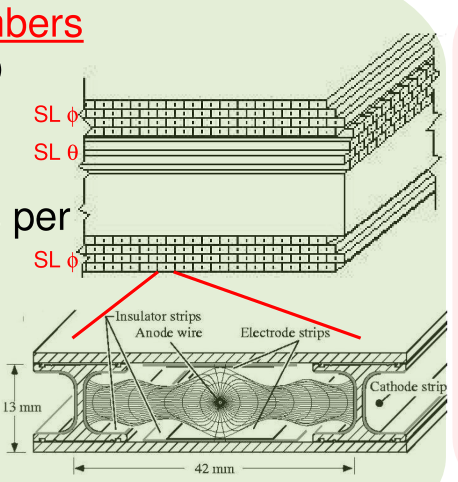
Precise hit, track and vertex reconstruction

Pixel detector
r = 4.4÷10.2 cm, |z| < 26.5 cm (barr.)
r = 6÷15 cm, |z| < 46.5 cm (endc.)
- 3 barrel layers
- 2 disks in each endcap
- 100 × 150 μm² each pixel
- totally 66 million pixels
- 3D measurements

Micro-strip detector
r = 20 cm÷1.1 m, |z| < 1.1 m (barr.)
r = 20 cm÷1.1 m, |z| < 2.75 m (endc.)
- 10 barrel layers
- 12 disks in each endcap
- 80÷183 μm pitch, 320÷500 μm thickness
- totally 9.3 million pixels
- 40% *double-sided* layers

Muon System

Drift Tube chambers
barrel (0 < |η| < 1.2)
- 4 DT stations
- 3/2 SuperLayers per station (2 φ, 1 θ)
- 4 layers of DT's per SL



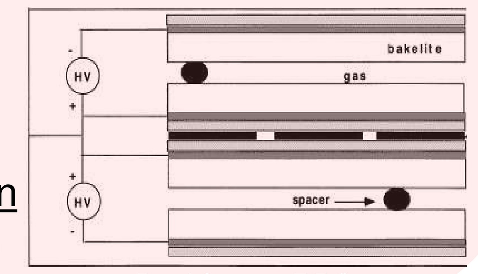
Spatial resolution (single hit) ~ 200 μm

Resistive Plate Chambers
both barrel and endcaps (0 < |η| < 1.6)

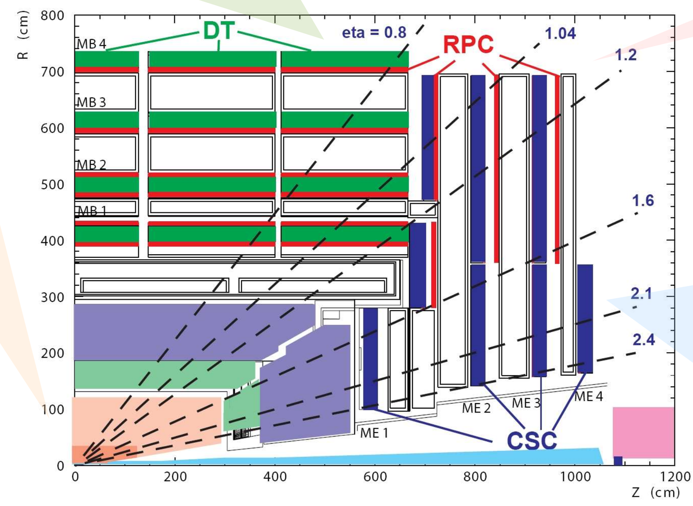
Barrel: 2 RPC's per DT (stations 1-2)
1 RPC per DT (stations 3-4)
Endcap: 1 RPC per CSC station (|η| < 1.6)

Fast response
σ_t ~ 2 ns

Spatial resolution
~1 cm (only φ)

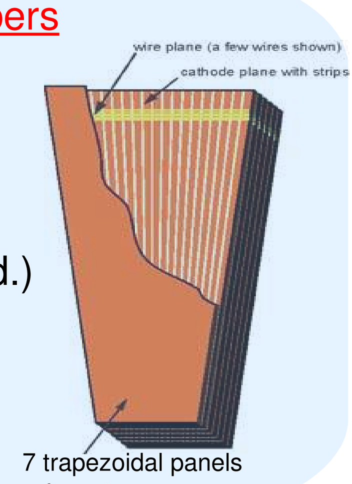


Double-gap RPC



Cathode Strip Chambers
endcaps (0.8 < |η| < 2.4)
- 4 CSC stations
- 6 gaps per station
- per gap:
  - 1 wire plane (*R* coord.)
  - 1 strip plane (φ)

Spatial resolution
100-250 μm



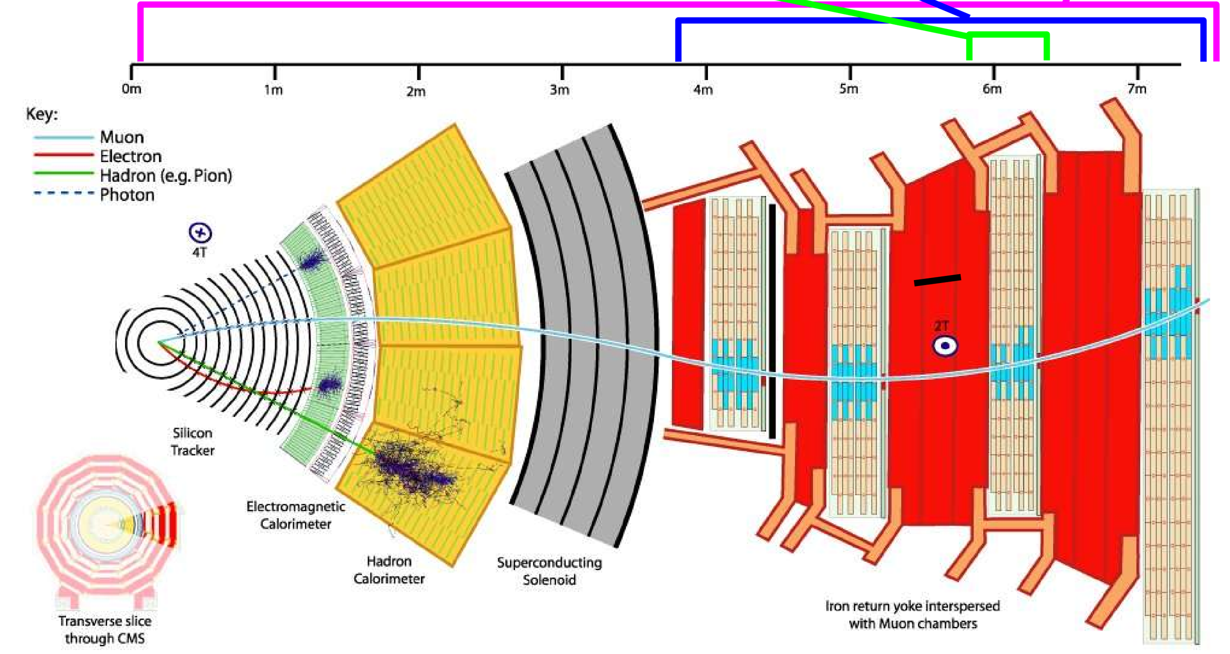
7 trapezoidal panels form 6 gas gaps

The Muon Reconstruction

1. Local Reconstruction
Reconstruction of hits and track segments inside a chamber

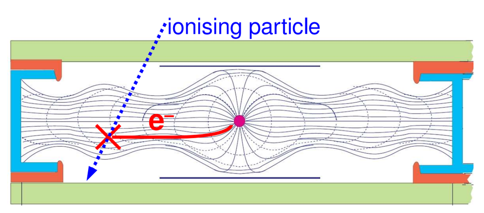
2. Stand-alone Reconstruction
Reconstruction of the track inside the Muon System

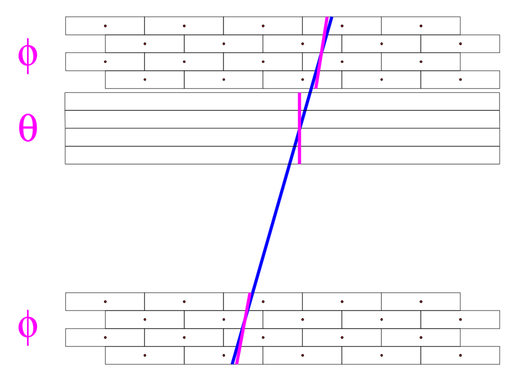
3. Global Reconstruction
Reconstruction of the track combining the information from Tracker and Muon System



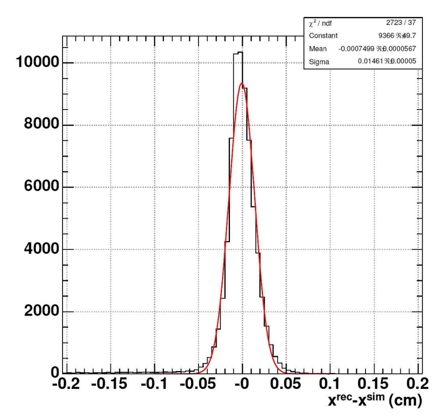
DT Local Reconstruction

1D hit
Inside a *single* cell, the electronics provides a drift time (TDC counts), converted at software level in a position w.r.t. the anodic wire



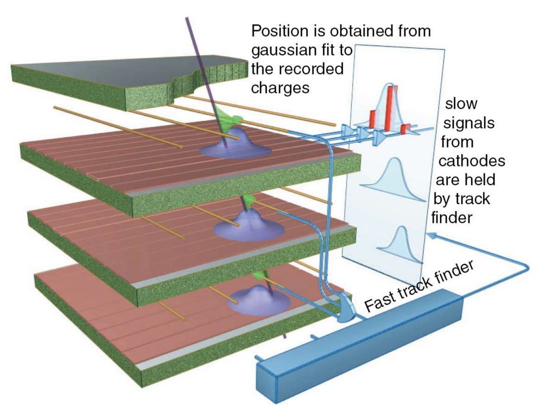


2D segments
The 1D hits are fitted to segments, independently in the R-φ (up to 8 hits) and R-θ (up to 4 hits)



3D segments
The two projections are eventually combined, giving a 3-dimensional track segment (σ ~ 150 μm)

CSC Local Reconstruction



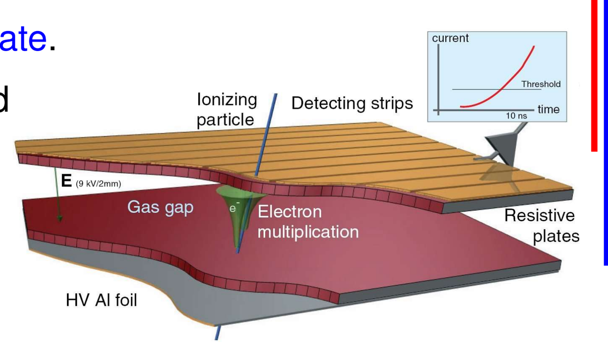
2D points
- φ coordinate measured by charge distribution on strips (fit with the Gatti function)
- R coordinate measured by wires

3D segments
Determined by fitting the 2D points from the 6 layers of each chamber

RPC Local Reconstruction

The strips measure the φ coordinate.

Though the RPC's were designed mainly for trigger, the 1D hits are used in track reconstruction:
- up to 6 hits in the barrel
- up to 4 hits in the endcaps

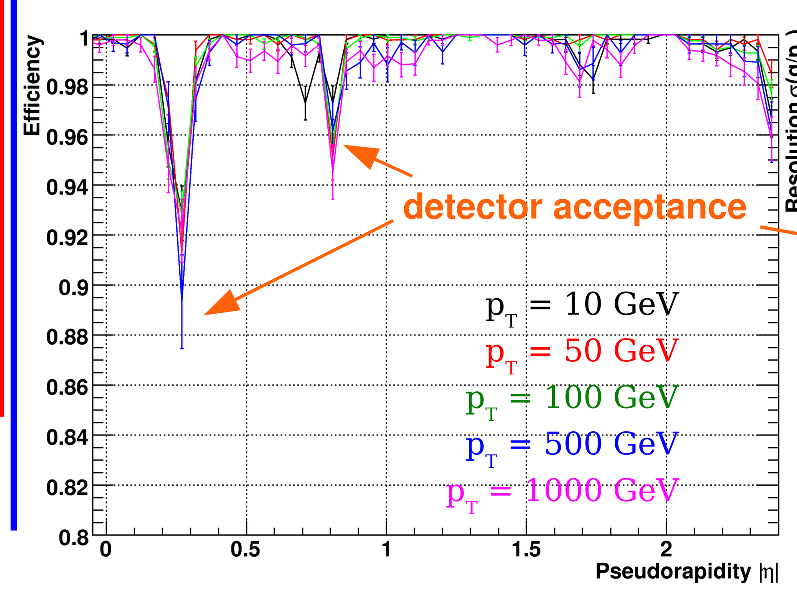


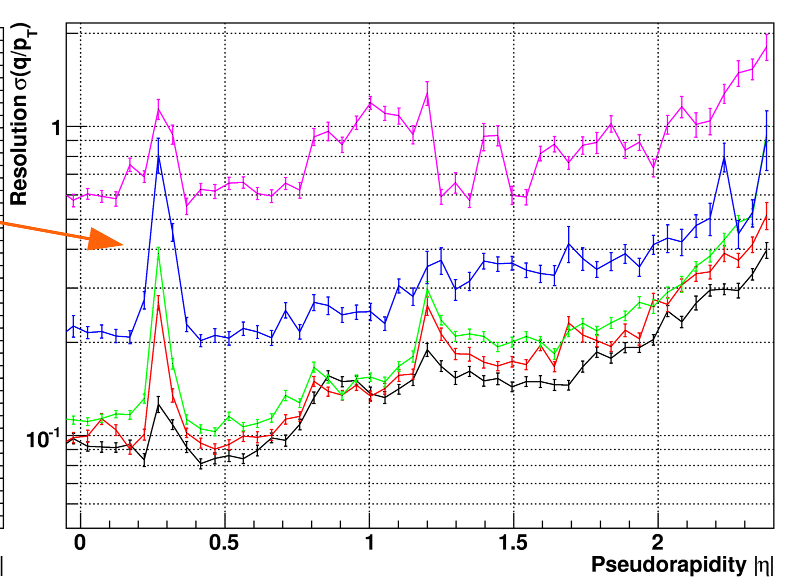
Stand-alone Reconstruction

Based on the *Kalman Filter* technique:
- State propagation to the next layer of chambers containing measurements (hits/segments)
- Pattern recognition: choose the most compatible measurement on a χ^2 basis and apply a χ^2 cut
- Filtering: update of the state vector with the new measurement

The **track reconstruction** in the **Muon System** takes place in four steps:

1. Seed state estimation
   online: input from Level 1 trigger; *offline*: estimated from track segments
2. Pre-filter or forward filter (inside-out)
   needed to avoid possible biases from the seed.
   Segments (in DT/CSC) are used for pattern recognition and update of the track
3. Filter or backward filter (outside-in)
   starts from the last (and best) pre-filtered state.
   Segments are used for pattern recognition, single hits for the update of the track
4. Vertex constraint
   After the ghost suppression, the trajectory is extrapolated to the point of closest approach to the beam line and the beam spot is constrained to be a point of the track





Tracker Reconstruction

Two different algorithms are used to resolve the hit pattern. After the selection, the hits are fitted and the track is built.

Kalman Filter
Seeds are built with 2 or 3 consecutive hits. The tracks are propagated from one layer to the next and the compatible hits chosen.

Road Search
Starting from one hit in the innermost layer and one in the outermost layer, the hits are selected using pre-set roads.

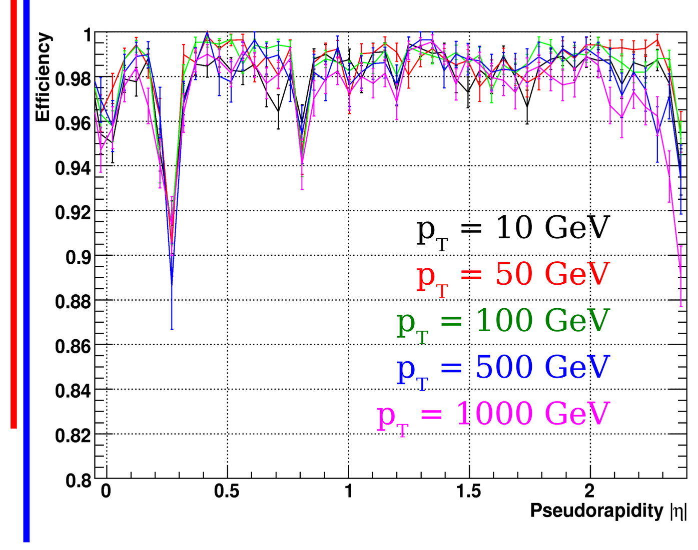
Global Reconstruction

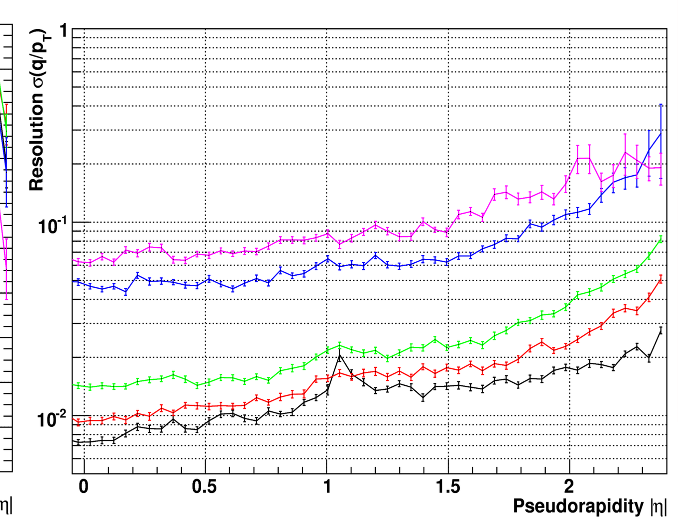
The stand-alone track defines a *region of interest* (ROI) in the Tracker. Then two different strategies are available.

Prompt reconstruction
Seeds and tracks are reconstructed *only* inside the ROI. It is used in the *online* (trigger) reconstruction for its rapidity.

Track matching
The tracks are already built in the *whole* Tracker and the ones in the ROI are selected. It is used in the *offline* reconstruction.

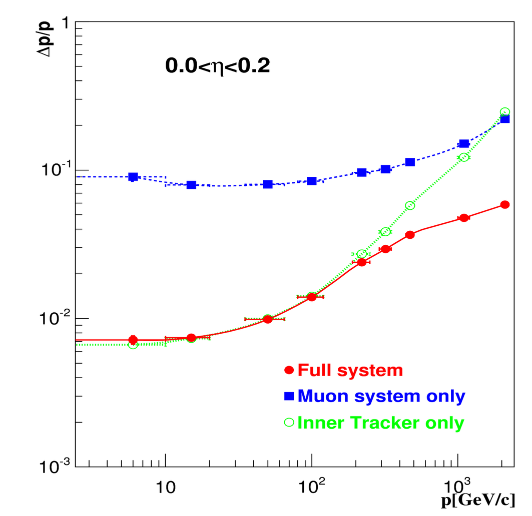
The most compatible Tracker track is chosen and the whole set of hits (Tracker + Muon hits) is fitted. Finally, the ghost suppression is applied.

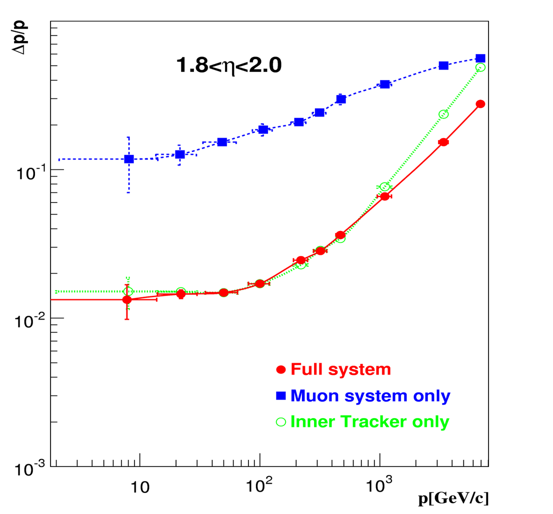




Tracker vs Global

At **low** p_T, the global resolution is dominated by the Tracker.
At **high** p_T, the Muon System improves the global resolution.

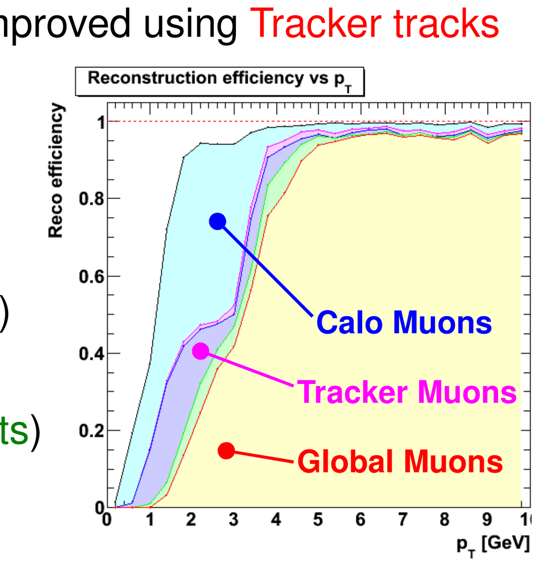




Muon Identification

At low p_T, the efficiency can be improved using Tracker tracks *alone* (no stand-alone tracks).

To *identify* them as *muon tracks*, muon signatures can be found:
- in the Muon System (segm./hits)
  → **"TrackerMuons"**
- in the Calorimeters (MIP deposits)
  → **"CaloMuons"**



References

1. CMS Collaboration, P-TDR, Vol. I "Detector Performance and Software", CERN/LHCC 2006-001
2. CMS Collaboration, Analysis Note 2008/097 "Muon Reconstruction in the CMS Detector"
3. CMS Collaboration, Analysis Note 2008/098 "Muon Identification in CMS"