the CMS muon reconstruction

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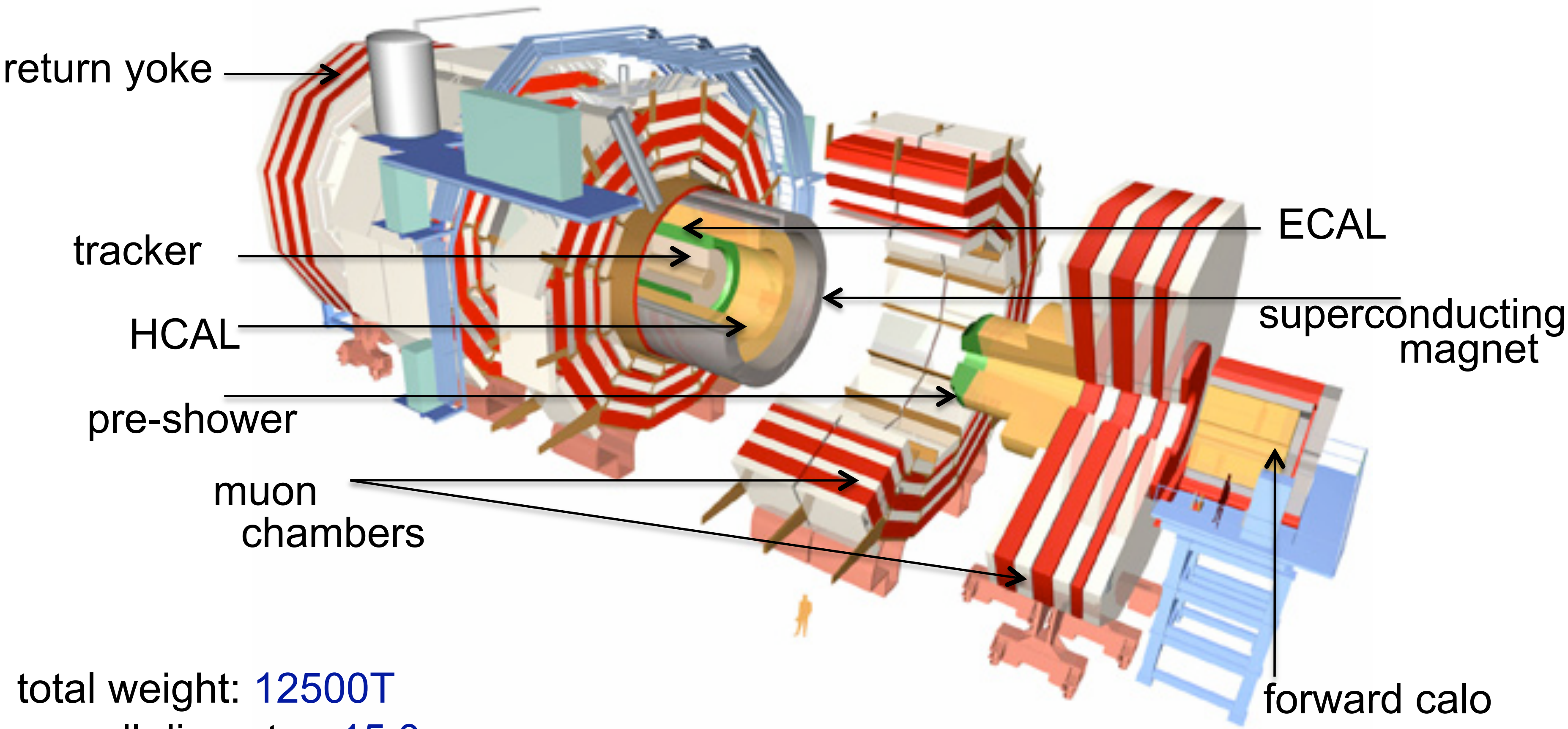
Young Researchers Workshop

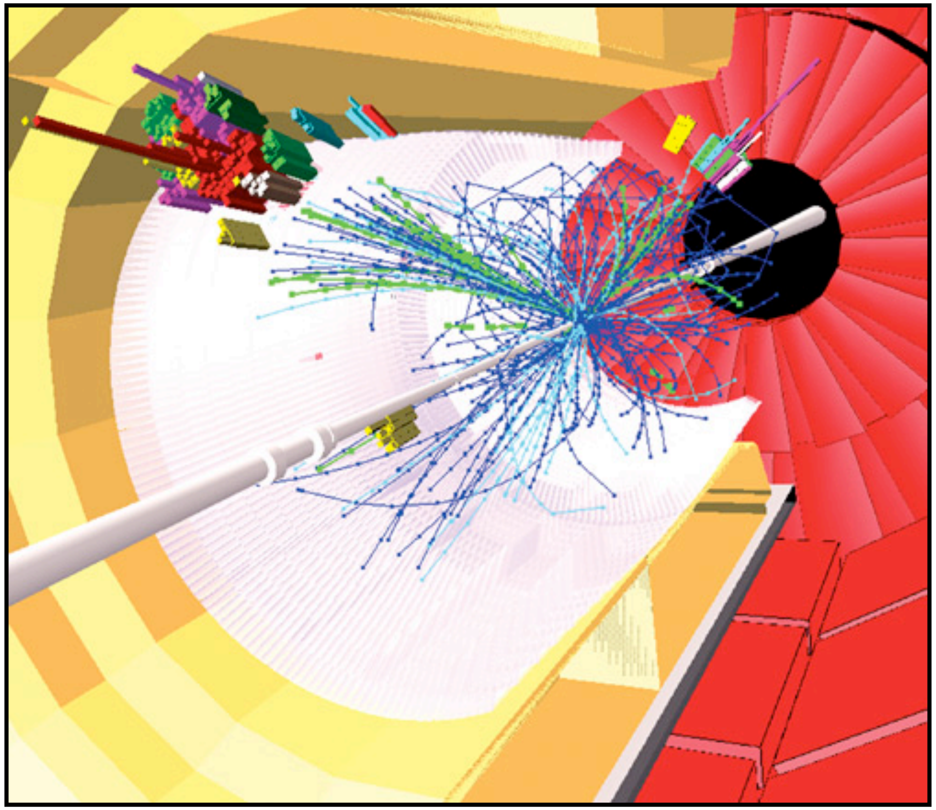
OVERVIEW

- The CMS detector
- Tracking charged particles
  - ✓ main concept
  - ✓ parameters
  - ✓ fitting methods
    - iterative mode: the Kalman Filter
- The muon reconstruction
  - ✓ local muon track segments
  - ✓ high-level tracks
    - Stand-Alone muon
    - Tracker muon
    - Global muon
- The muon reco offline monitoring
  - main aims and operations -
- Conclusions

the CMS detector



total weight: 12500T
overall diameter: 15.0m
overall length: 12.5m
magnetic field: 4tesla



MAIN CONCEPT

a particle travels through the material of the detector

⇓

its signal is recorded as individual points in space known as recHits

⇓

the recHits are associated together to determine points on the particle trajectory

⇓

the trajectory's characteristics are used to define its momentum, charge and particle identification

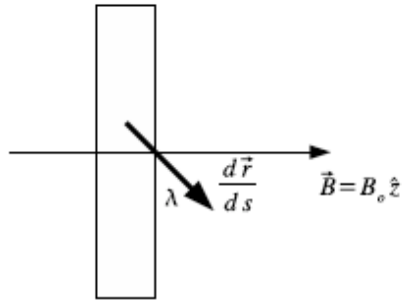
Track parameters (1)

The trajectory of a charged particle which cross through a magnetic field is described by the Lorentz force:

$$\frac{d^2\vec{r}}{ds^2} = \frac{q}{p}\frac{d\vec{r}}{ds}B(\vec{r})$$

trajectory's curvature (measured)

tangent to the trajectory (measured)



For known B, the momentum at a point (x,y,z) is determined solving this equation

→ the parameters are 5: **x,y,z,λ**(angle between B and the trajectory),**q/p**

BUT in a "real" detector we have also to take into account of:

1- inhomogeneous B field
2- the multiple scattering which deflects the trajectory
3- the energy loss as the particle travels through the detector

Track parameters (2)

Solution to the inhomogeneous B field+ multiple scattering : method of Runge-Kutta

- magnetic field function of the coordinates B(x,y,z) included into the parameterisation
  [parameters {x,y,x',y',q/|p|} computed at each reference surface $z=z_r$]
- at each step
  - scaling with the effects of multiple scattering
  - trajectory localized to a plane region where the B field can be expanded as a perturbation to a good approximation

Solution to the material effects:
loss of energy incorporated in the equations of motion in an iterative manner

- information given by the Bethe-Bloch formula

density effect

$$-\frac{dE}{dx}=\frac{const}{\beta^2}\times[\ln(\frac{2m_e c^2\beta^2\gamma}{I})-\beta^2-\delta(\beta)]$$

mean eccitation E

- 0.35 GeV/c<E_μ<100GeV/c → slight rise of ≈10%
- E_μ>100GeV/c radiation losses become significant

Track Algorithm

The CMS track reconstruction and parameterisation occur in 4 stages:

- seeding

Search for initial points for the track reconstruction

- trajectory building

Starts at the seed position and proceeds in its direction to locate compatible hits in the subsequent detector layers using an iterative approach to update the trajectory estimate momentum and its covariance matrix

- trajectory cleaning

Trajectory ambiguity resolved and a maximum number of track candidates kept

- trajectory smoothing

Backward (layer iterative) fit which use all the covariance matrices applying them to all the intermediate points based on all the measurements used so far

Iterative fit - the Kalman Filter method (1)

Filtering

- estimation of the "present" state vector, based up all the "past" measurements

Prediction

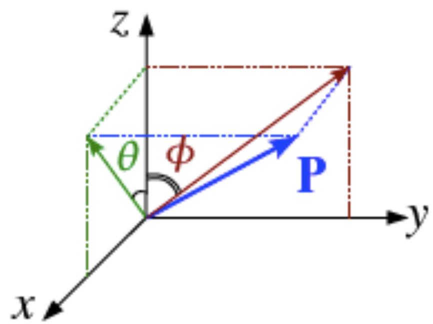
- estimation of the "future" state vector at a future time

Smoothing

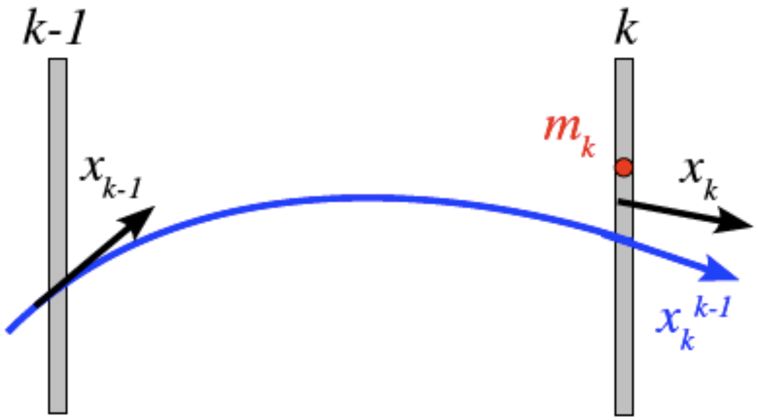
- estimation of the state vector at some time in the "past" based on all the measurements taken up to the "present" time

NOTE: For the tracking of the charged particles the state vector is often parameterised as

$$x = \begin{pmatrix} q/p \\ \tan\theta \\ \tan\varphi \\ x \\ y \end{pmatrix}$$



Iterative fit - the Kalman Filter method (2)



Propagation of the state on the (k-1)th layer (black arrow) on the kth layer

predicted state: $x_k^{k-1} = F_{k-1} x_{k-1}$

Thus, taking into account of the relation between the state and the measurement space: $m_k = H_k x_{k,true} + \varepsilon_k$

and minimizing the χ^2, the filtering updated state (back arrow on k) is:

$$x_k = x_k^{k-1} + K_k (m_k - H_k x_k^{k-1})$$

takes into account the covariance matrix of both the layers k, k-1

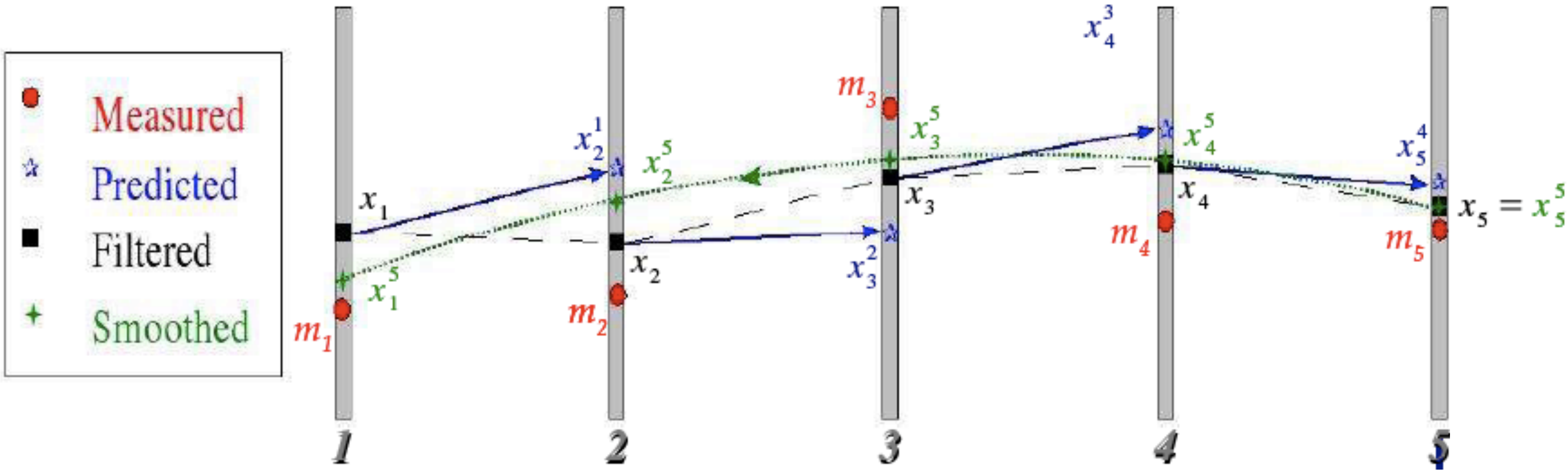
Iterative fitting methods : the Kalman Filter (3)

Once all the measurements have been filtered, the smoothing can be performed.
As the filetring it's an iterative process.

smoothed state: $x_k^n = x_k + A_k(x_{k+1}^n - x_{k+1}^k)$

covariance matrix: $C_k^n = C_k + A_k(C_{k+1}^n - C_{k+1}^k)A_k^T$

with: $A_k = C_k F_k^T (C_{k+1}^k)^{-1}$



the muon reconstruction

Muon tracks into the CMS detector are reconstructed at different levels

first:

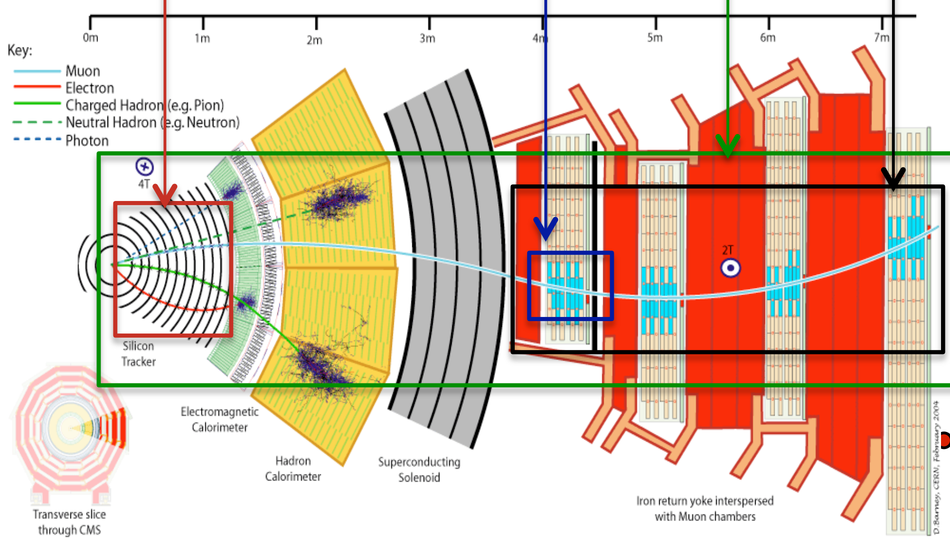
Local reconstruction

• performed separately by the muon spectrometer CSC, DT detectors
• hits → track segments used for high-level fit

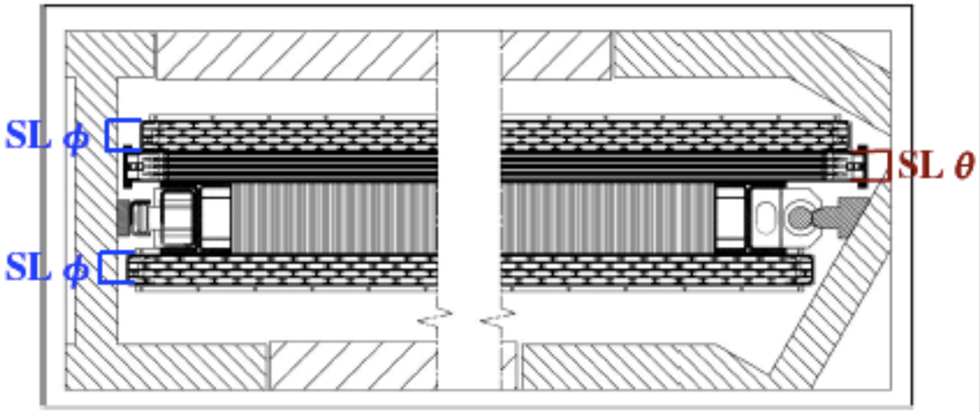
then:

High-level reconstruction

• using information from different sub-detectors
• 3 types:
- **Stand-Alone reco**
  this just use hits in the mu system
- **Global reco**
  starts with muon segments then adds tkr info
- **Tracker Mu reco**
  starts with tracks found in the inner tracker and identifies them as a muon by matching expected info from the calorimeters

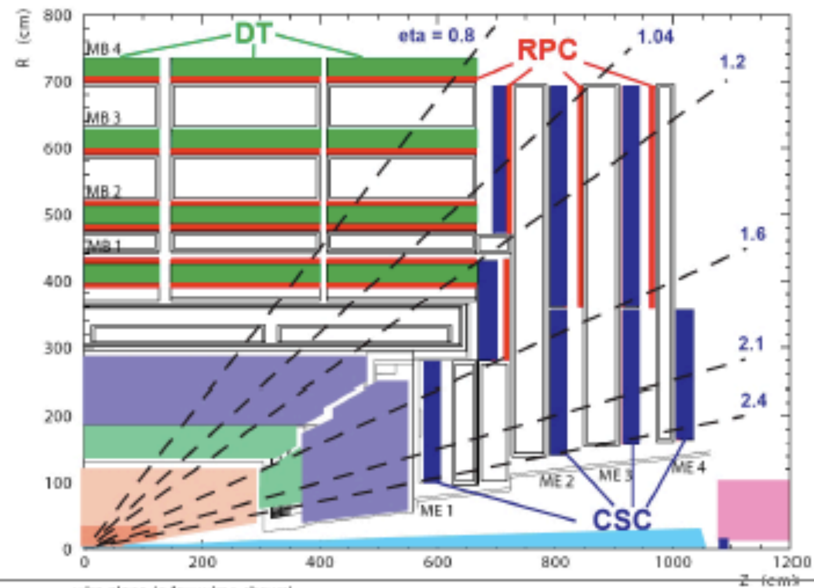


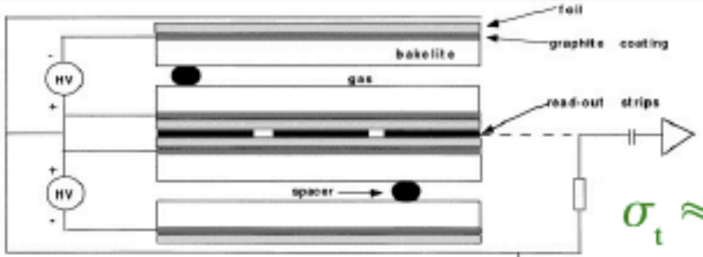
the local muon reconstruction



3 Super Layer (2ϕ and 1θ) for the first 3 stations
2 Super Layer (2ϕ) for the last station **DT**

4 Layer for each Super Layer $\sigma_x \approx 200\ \mu m$



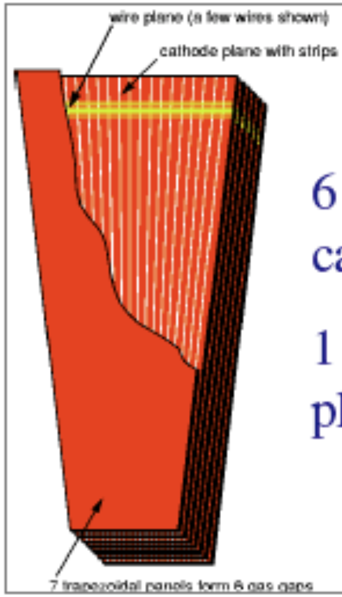


RPC

$\sigma_t \approx 2$ ns

2 RPC chamber for the first 2 DT stations

1 RPC chamber for the last 2 DT stations and for the CSC chamber till $|\eta|<1.6$



CSC

6 gaps (Layers) for each camber

1 wire plane and 1 cathode plane with strips

$\sigma_x \approx 100\text{-}240\ \mu m$

the Stand-Alone Muon reconstruction

Seed state estimation

- from the local segments reco for the offline reconstruction
- pattern of DT, CSC segments is searched for, using a rough geometrical criteria
- from the L1 trigger in the online reconstruction

Pre-filter from inside to outside using the DT/CSC segment granularity + RPC hits

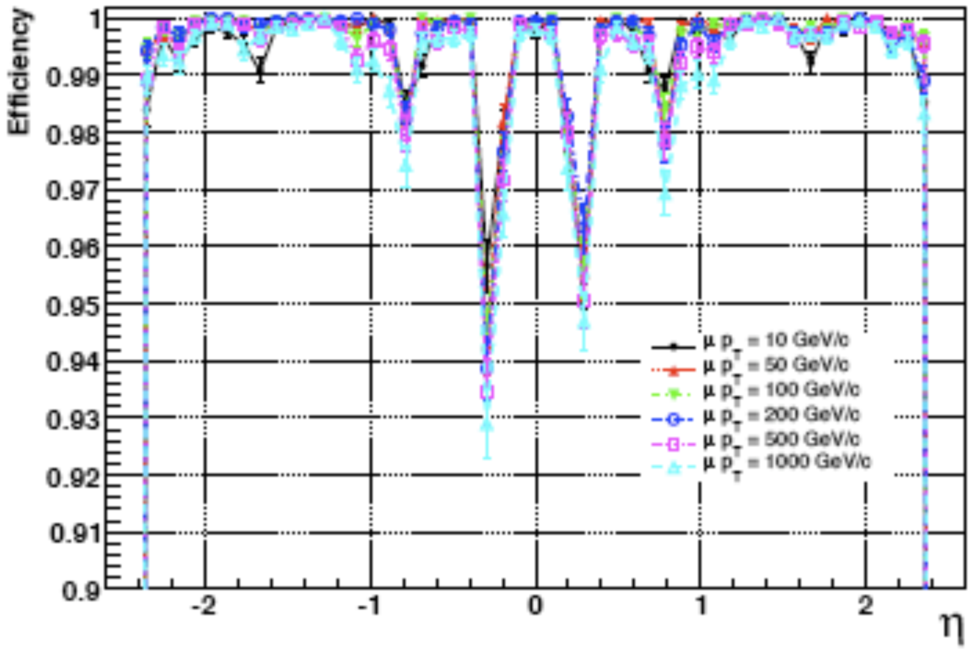
- "Pre"-filter needed to avoid possible bias from the seed
- Best estimate from the outermost (used) layer

Filter from outside to inside using the best state from the "Pre"-filter and:

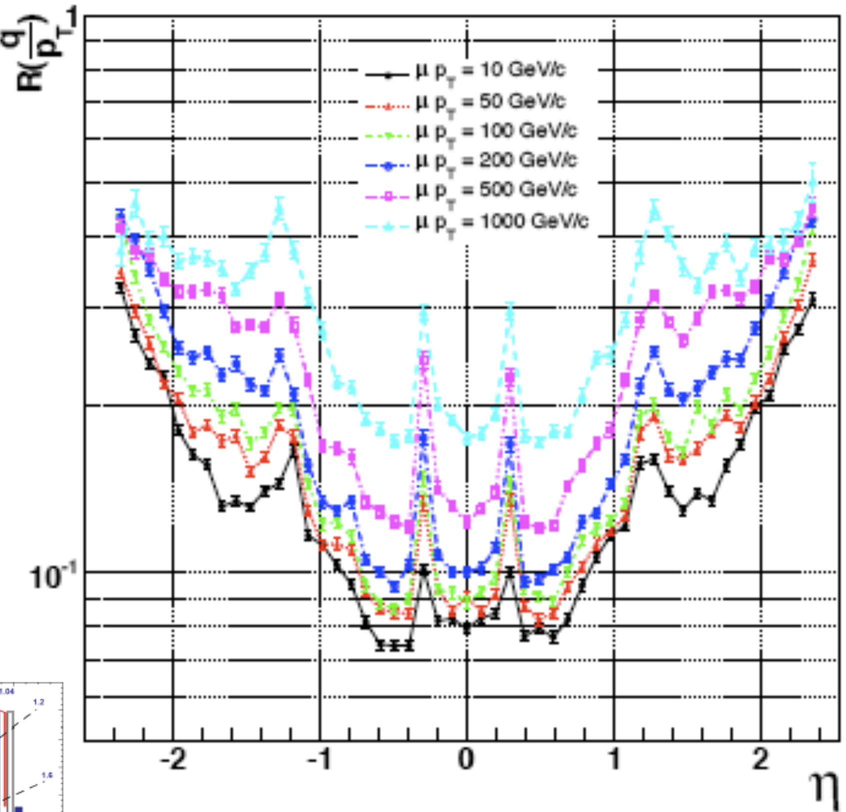
- the segment for the pattern recognition
- the 1D hit for the trajectory updating
- best state estimation from the innermost (used) layer

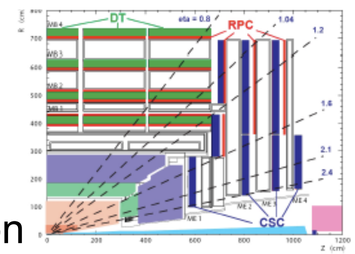
the Stand-Alone Muon reconstruction - performances

efficiency



resolution





$|\eta|\approx 0.3$ → gap between Wh0 and ±1
$|\eta|\approx 0.8$ → beginning of the overlap region
$|\eta|\approx 1.6$ → transition between 2 endcap rings

9% in the barrel for muons with p_T=50GeV

the Tracker Muon reconstruction

• general idea:

FIRST: reconstruct and identify muons in CMS starting from silicon tracker tracks
THEN: search for compatible segments in the muon detectors + energy deposition in the calorimeters

• no combined (silicon-hits+muon-hits) track fit is performed
→ the momentum of a Tracker Muon is the same as that of the silicon tracker track

• the algorithm starts from reconstructed silicon tracker tracks above a given p, p_T

• the propagator takes into account of :

magnetic fields, average expected dE/dX, multiple scattering (nearly crossed chamber)

and store:

distance between the nearest chamber edge, the position of the extrapolated track in local (X,Y) coordinate, the ChamberID, the 1σ uncertainties in position and slope, ...

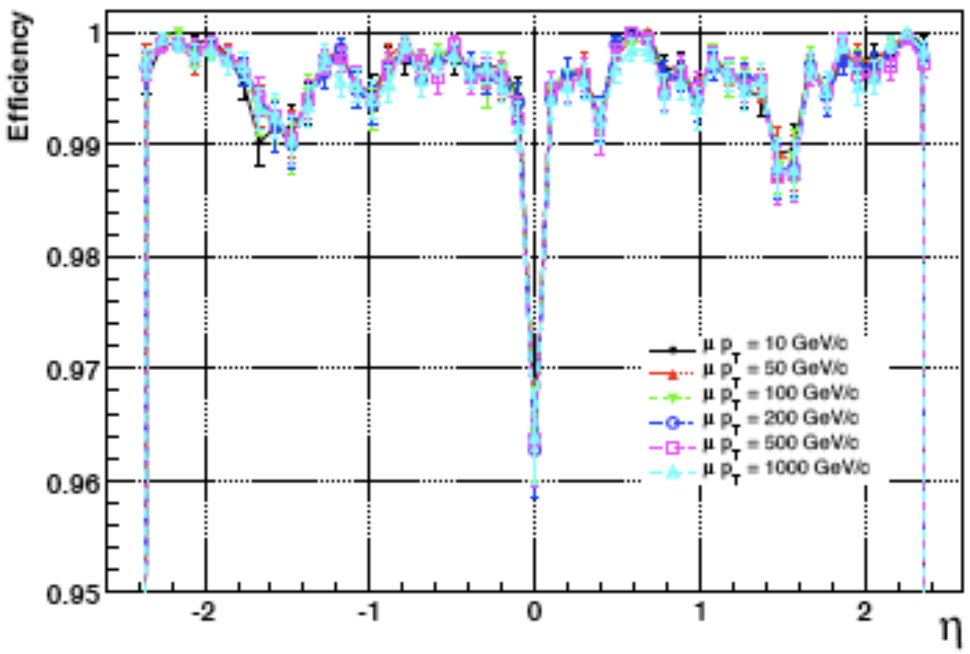
if:

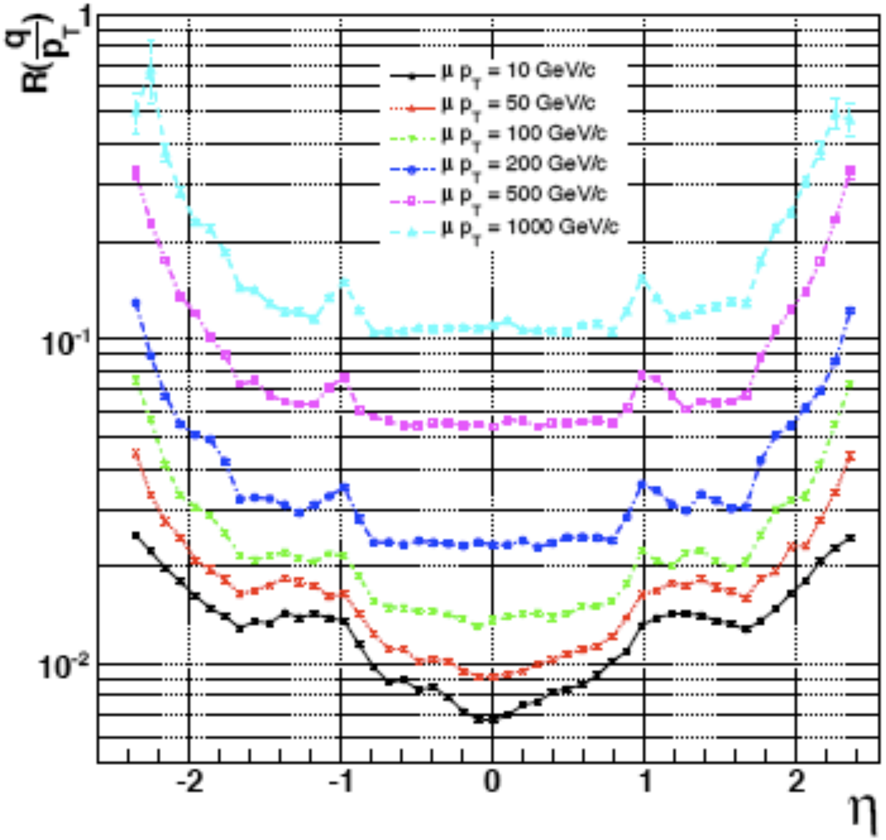
the track has a minimum number of associated segments

the Tracker Muon reconstruction - performances

efficiency

resolution





constant for all p_T values (≈99.5%)
η≈0 → dip due to the tracker geometry
(junction surface of the 2 half-barrels)

0.9% in the barrel for
muons with p_T=50GeV

the Global Muon reconstruction

• the concept is to combine info from multiple sub-detectors in order to obtain a more accurate description of the muon

✓ FIRST: track matching

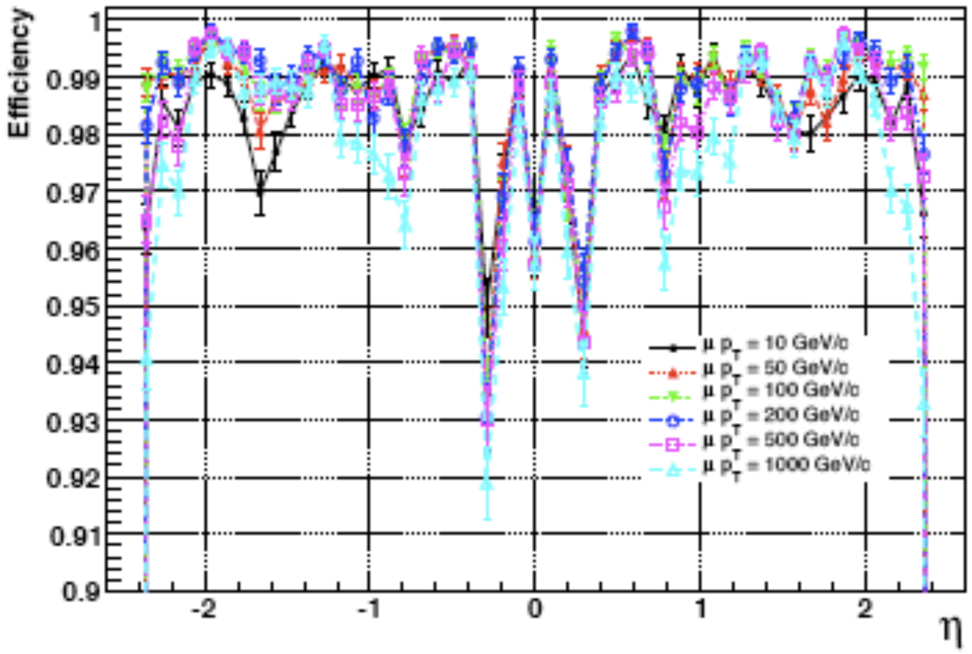
1. definition of a rectangular in η-Φ space, selection a subset of tracker tracks
2. iteration over the subset of tracks, applying more stringent spatial and momentum matching criteria to choose the best tracker track to combine with the stand-alone muon
   (extrapolation to a common surface of both the 2 types of tracks)

✓ THEN: global refit

1. no additional pattern recognition done
2. simple combination of the choosen tracker track hits with the muon hits from the sta-muon track
3. if there is more than 1 glb tracks, stored the one with the best X^2

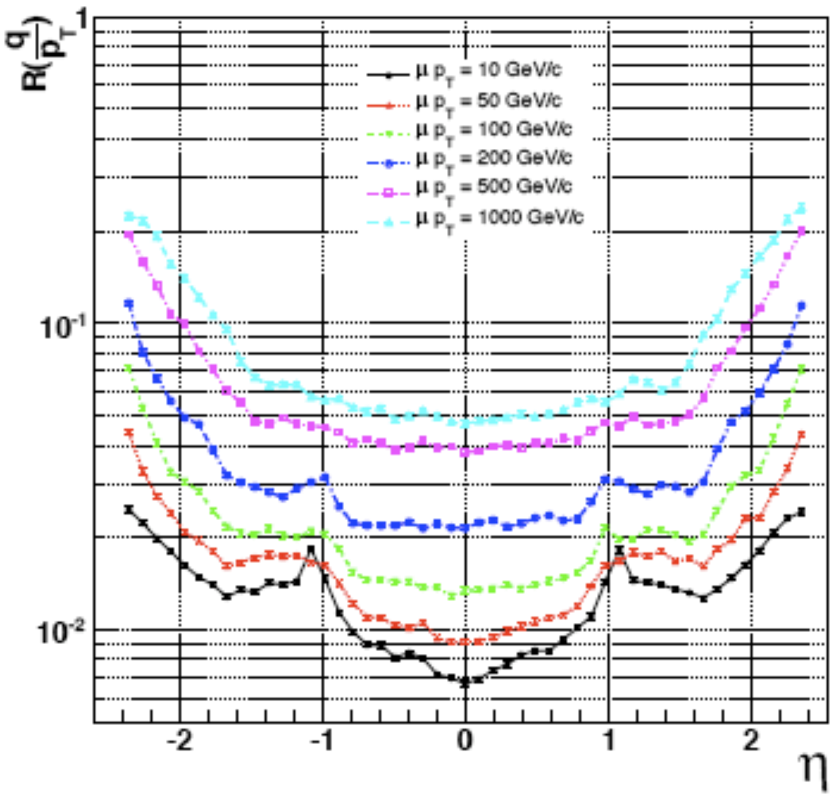
the Global Muon reconstruction - performances

efficiency



efficiency strongly depends on the Stand-Alone reconstruction

resolution



resolution strongly depends on the Tracker Muon reconstruction

the Off-line Muon Reco monitoring (1)

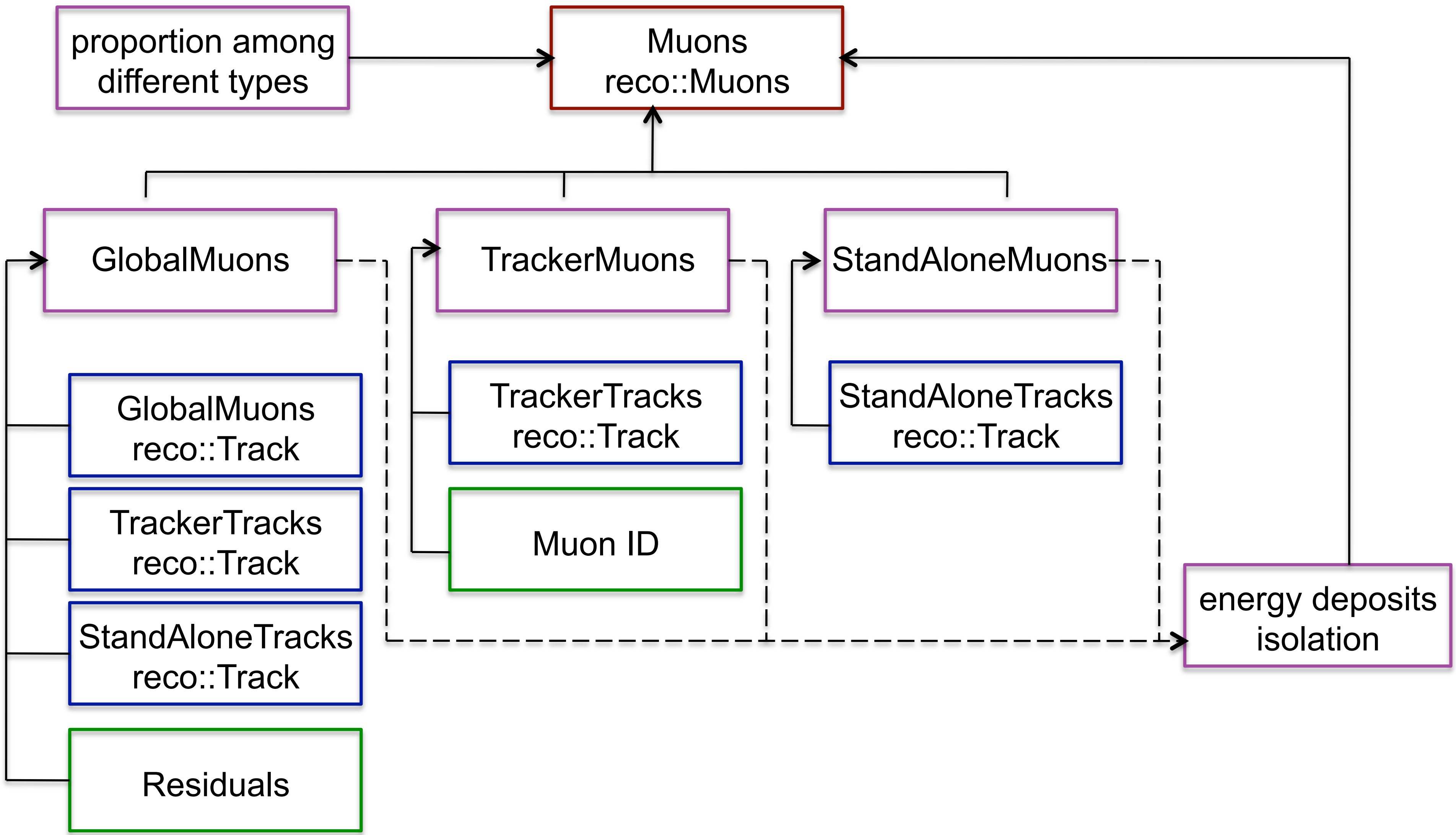
- Main Task: data certification for analysis usage

- it run on FULL statistics during prompt reconstruction (1 day delay from the online data taking – usage of the most updated calibration constants) and every data reprocessing

- Operations:
  - generate a list of plots to understand the status of the reconstruction
  - test the histograms
  - provide a list of flags which indicate the goodness of all the different components which take part to the muon reconstruction
  - put all the results on a web interface framework for shift usage

the Off-line Muon Reco monitoring (2)

NOTE that's a monitoring of a very complex object!
because a "recoMuon" is not only a track, but it contains many other information
→ need to test all these different parameters and to match the results together

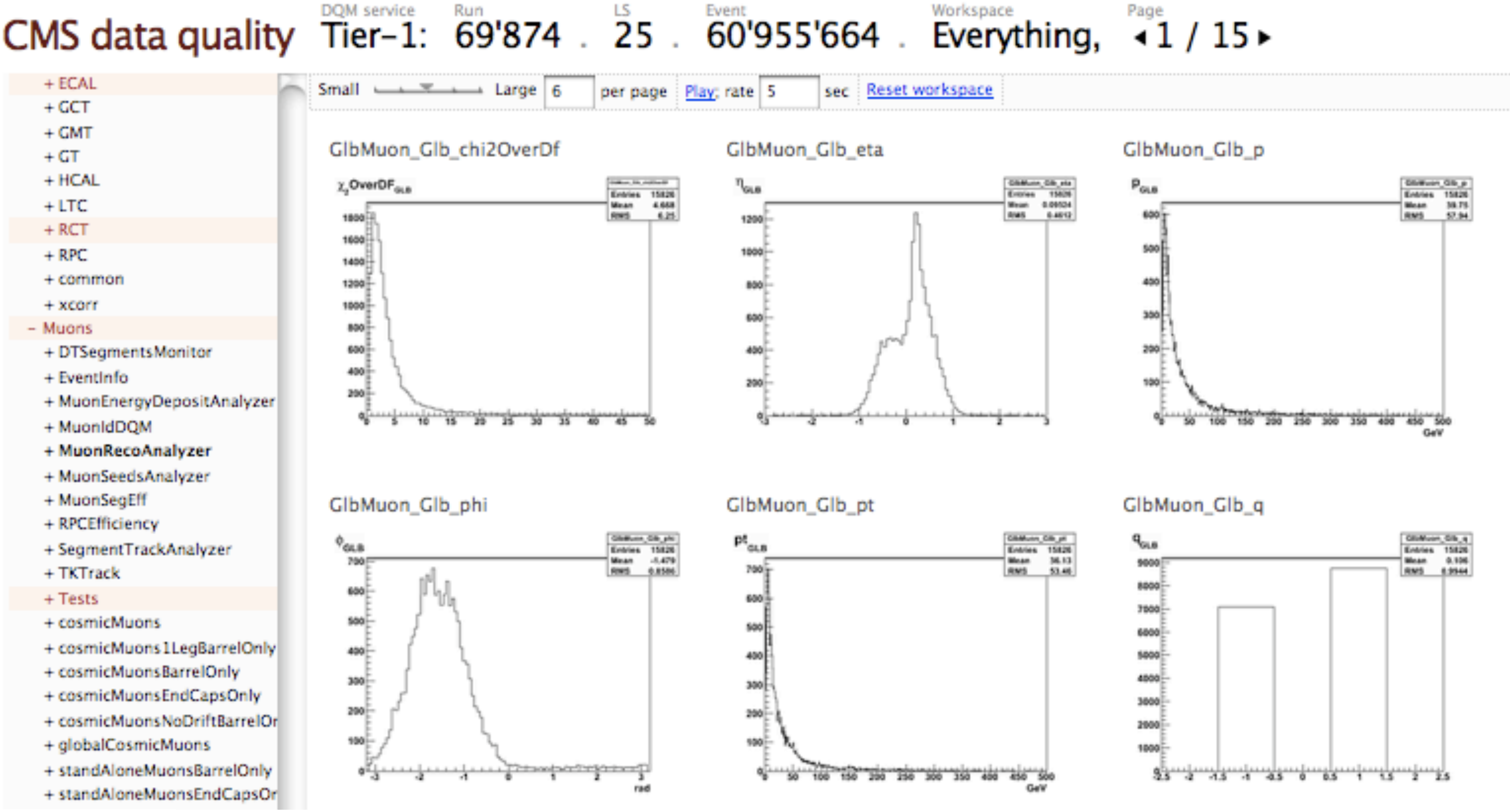


test histograms for Off-line muon certification (1)

- Track specific variables
  - track quality (X^2, number of RecHits ...) [also Vs (η, Φ, ϑ)]
  - distance of the closest approach [also Vs (η, Φ, ϑ)]
  - momentum: components + errors
- Comparison among the different Glb muon part (Glb/Sta_Glb/Tk_Glb)
  - charge comparison
  - residuals on η, $1/p_t$, $1/p$, Φ, q/p, q/p_t, ϑ and their correlations
- Track seeds
  - direction, number of RecHits, momentum also Vs (η, Φ, ϑ)
- RecHits
  - provenance
  - percentage notUsed/Used
- Muon energy deposits (single cells, 3×3 towers)
  - ecal, hcal, h0
  - barrel, endcap
- Tracker muId quantity
  - #chambers with matching segments/ #matching segments
  - residuals between segments/track + errors

test histograms for Off-line muon certification (2)

example from the web interface monitoring



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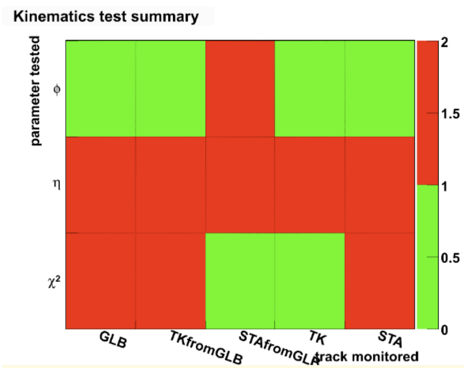
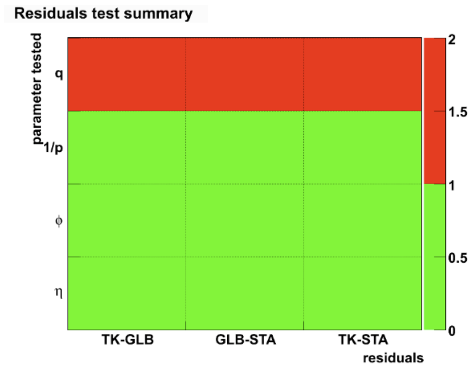
11-05-09

test summaries for Off-line muon certification

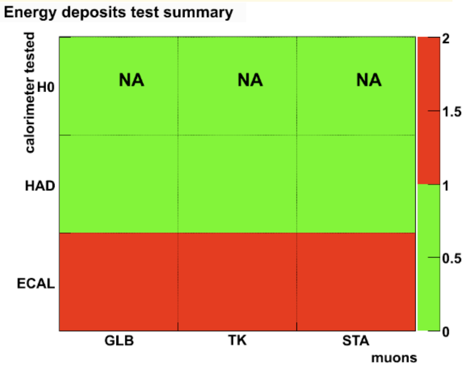
Summary plots with test results

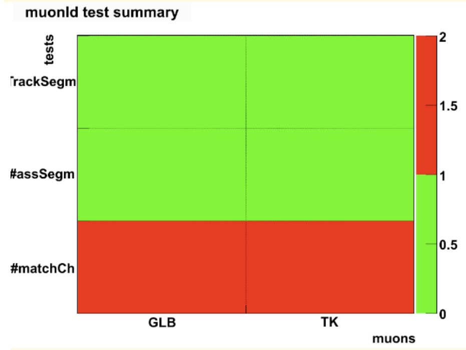
the tests on tracks produce 2 summary histograms



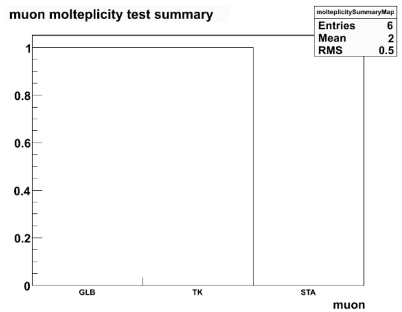


the tests on energy deposits and muonId parameters have both an associated summary





and finally, taking into account also of the proportion among the 3 different types of muons ....



... a final report histogram is provided for CMS central shifters

SUMMARY

- Strategies of tracking charged particles inside the CMS detector
  - ✓ track parameters
  - ✓ iterative fit method (Kalman Filter)

- Description of all the 3 types of muon reconstruction
  - ✓ information used for the fit
  - ✓ performance results on efficiency and resolution

- Offline monitoring of the muon reconstruction & Data Certification
  - ✓ main aims
  - ✓ observables
  - ✓ usage