Muon Reconstruction and Identification in CMS

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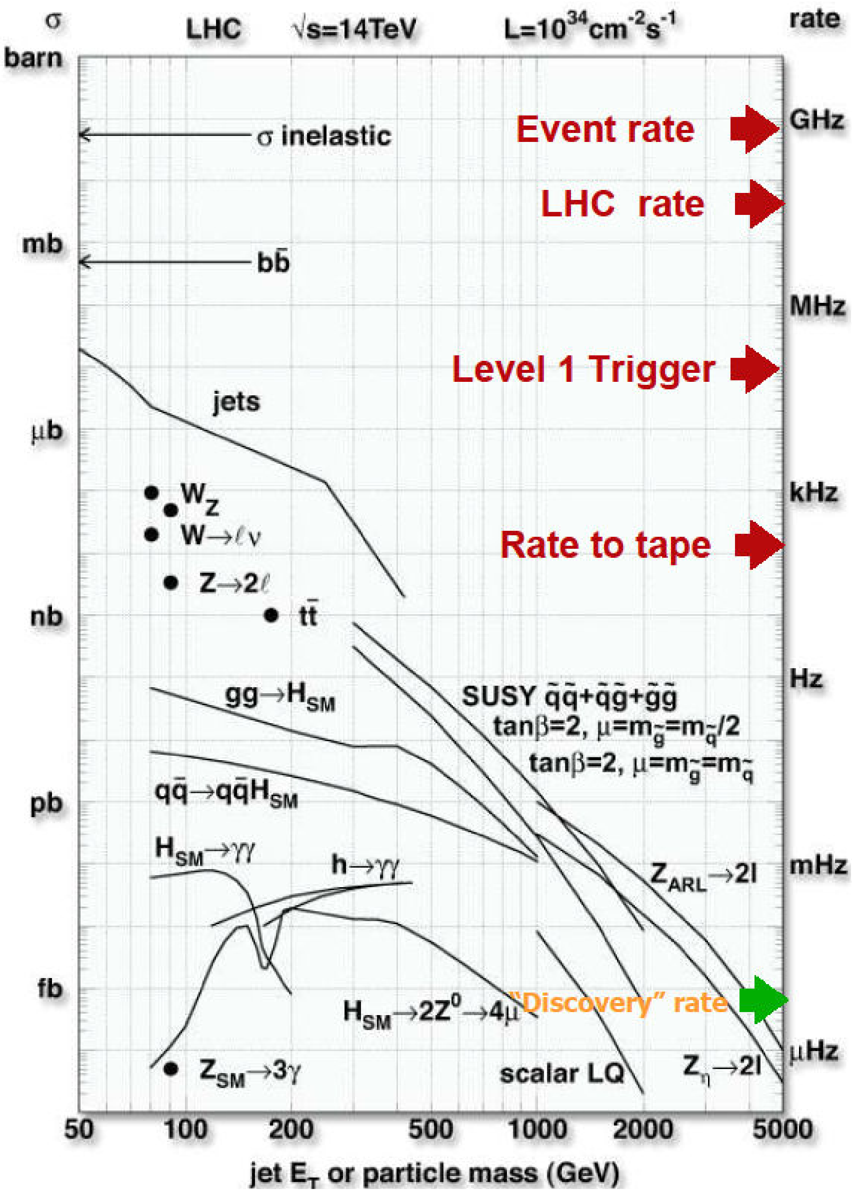
on behalf of the CMS collaboration

1. CMS Muon System
2. Muon Reconstruction
3. Preparation for LHC data

Challenge: physics at LHC



- LHC designed to investigate the Electroweak Symmetry Breaking scenarios
- High energy, 40MHz collision rate, high multiplicity
- Interesting events may be hidden in a enormous QCD background
- Triggering with leptons is of key importance

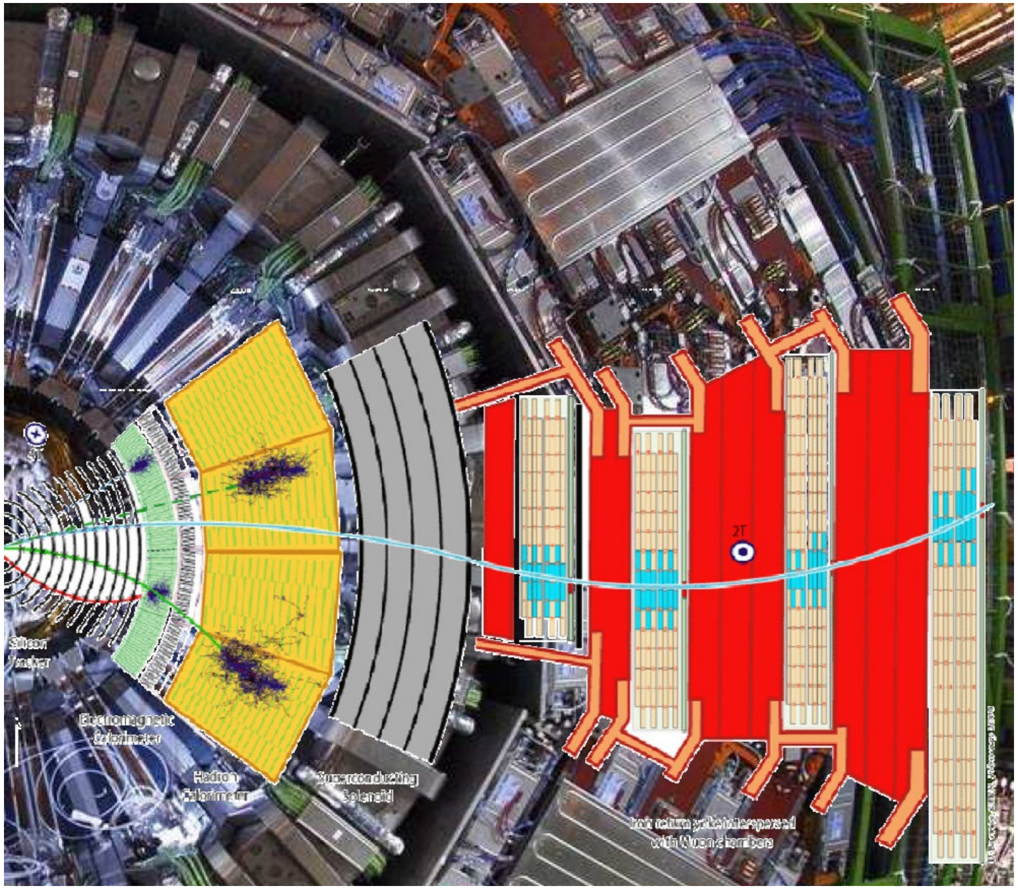
Challenge: CMS

Compact Muon Solenoid

The design goals of CMS:

1. A very good and redundant muon system
2. The best possible ECAL consistent with 1)
3. A high quality central tracking to achieve 1) and 2)
4. A financially affordable detector

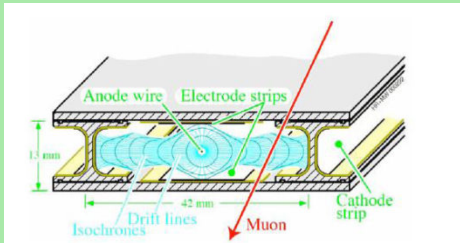
-Three types of muon detectors |η| <2.4
-4T solenoid 13m long, 6m diameter
-Powerful inner tracking system
supplementing μ reconstruction



Muon Spectrometer

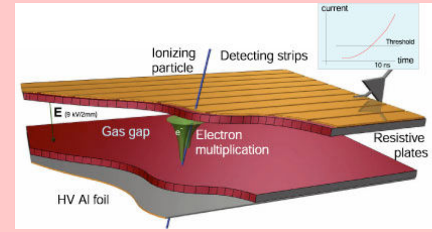
Muon detectors

DT
(Drift Tubes)

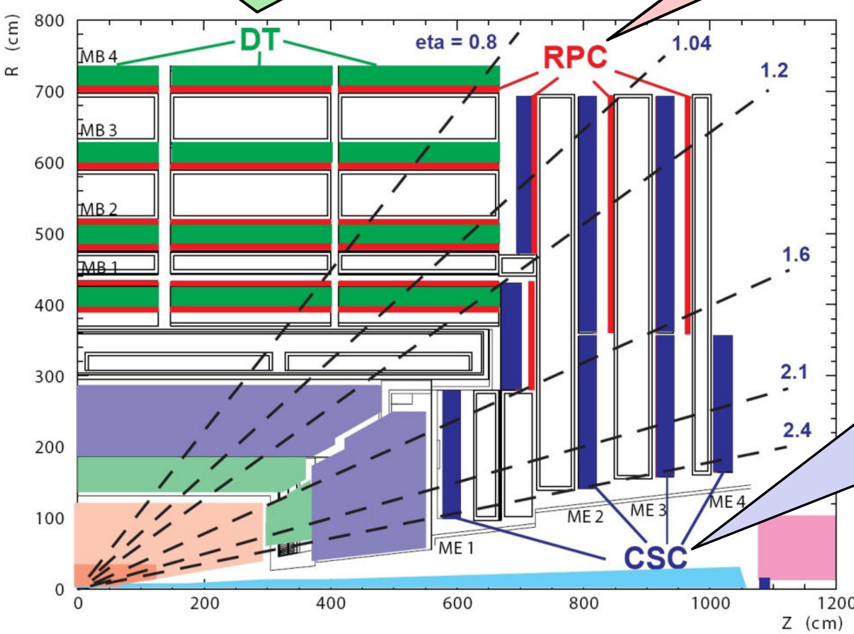


long drift time (380ns) – low rate reg.,
wire pitch 4.2cm
resolution (per chmber) rφ:100 µm, rθ:150 µm
8φ+4θ layers in station (only φ in MB4)

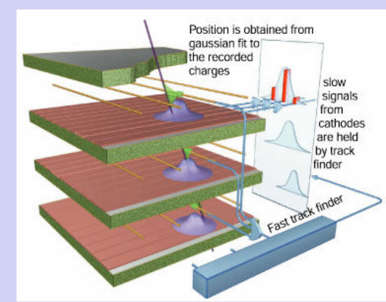
RPC
(Resistive Plate Chambers)



Fast gaseous det. (~2ns), dedicated for L1
Efficiency >95% @ 1KHz
Low noise (<5Hz/cm2),
meas. Φ (strip Pitch 0.5-4cm)



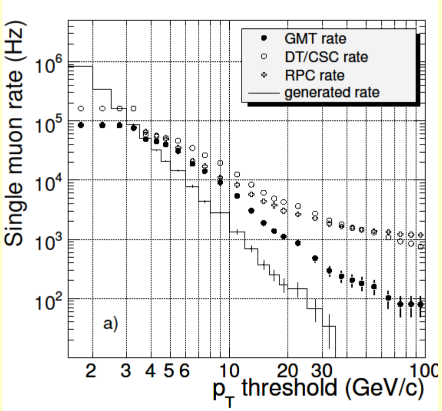
CSC
(Cathode Strip Chambers)



fast response,
high rate
close wire spacing (res. R75-150 µm)
strips 6.7-16mm (res. Φ 150 µm)

Muon Reconstruction in CMS

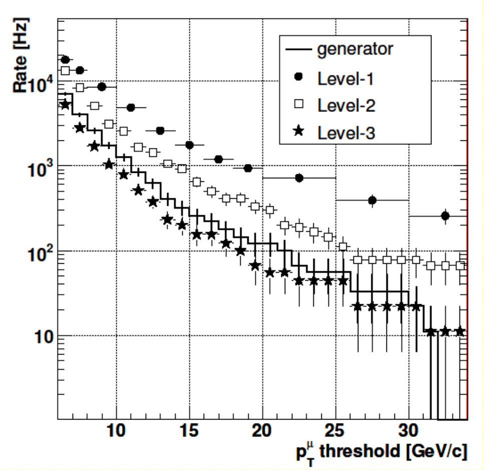
CMS Muon System
Muon Reconstruction
Preparation for LHC data



Algorithms implemented in programmable hardware logic
Combination of independent information from L1 muon detectors (DT,CSC,RPC)

The Level-1 Trigger (L1)

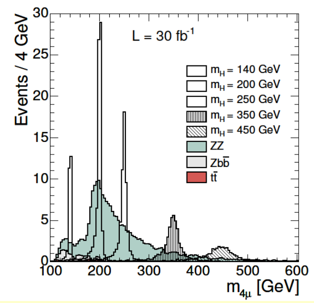
The High-Level Trigger (HLT)



Online rec. of ev. accepted by L1; computer farm in PT5
Level-2: Gathers information from muon detector
(Local reconstruction and L2 Stand-Alone Muon)
Level-3: Access information from Tracker sub-detector
(exploring Stand-Alone Muon)

Offline Reconstruction

(events accepted by HLT; offline analysis at Tier-0 and satelites)
Stand-Alone Muons: Global muon reconstruction in limited to Muon System
Global Muons: Tracker tracks combined with Stand-Alone muons
Tracker Muons: Tracker tracks identified as muons



Algorithms in Muon Detectors

Local Reconstruction: Find **Track Segments** which held information about position and direction of muon crossing one chamber. Track Segments are formed by straight line fit using multi-hit measurements in stations.

DT: hit position w.r.t. wire computed from drift time; r-φ (8meas.) and r-θ (4meas.); direction reconstructed independently and combined into segment

CSC: 2D points from wire and strips meas. in plane
Build segment using hits from up to 6 planes

RPC: secondary importance in track reconstruction (measure 3d hit only)

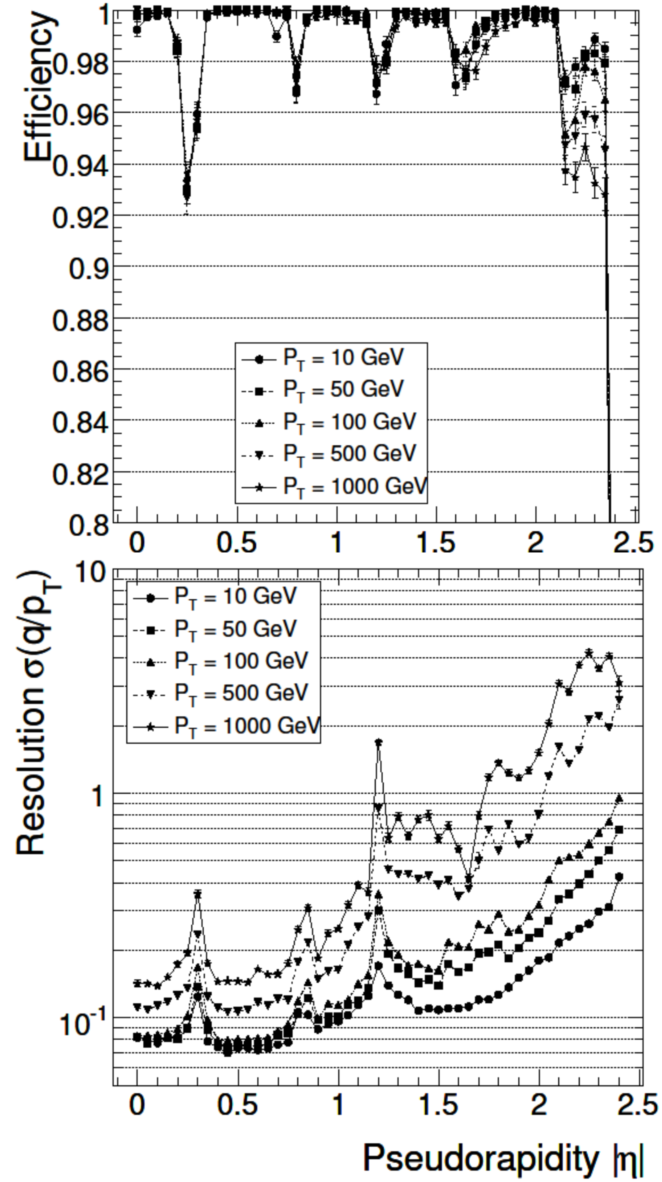
Stand-Alone Muon Reconstruction

Based on the Kalman Filter Technique
Propagation with energy losses, in non-constant magnetic field.

Seeding – definition of initial trajectory state.
Online: input (position, momentum) from L1 trigger
Offline: global analysis of segments. Seed kinematics is estimated by simple parametrisation of bending in/between segments.

Forward Patter Recognition (pre-filtering) goes from most inner to outer muon station. Segments compatible with trajectory (χ^2 based) are collected constraining trajectory state.

Backward Pattern Recognition: Trajectory Fitting: propagating outside-in update trajectory with individual hits from segments (χ^2 based).
Optionally update fit with **vertex constraint**



Algorithms in Tracker

Global Muon:

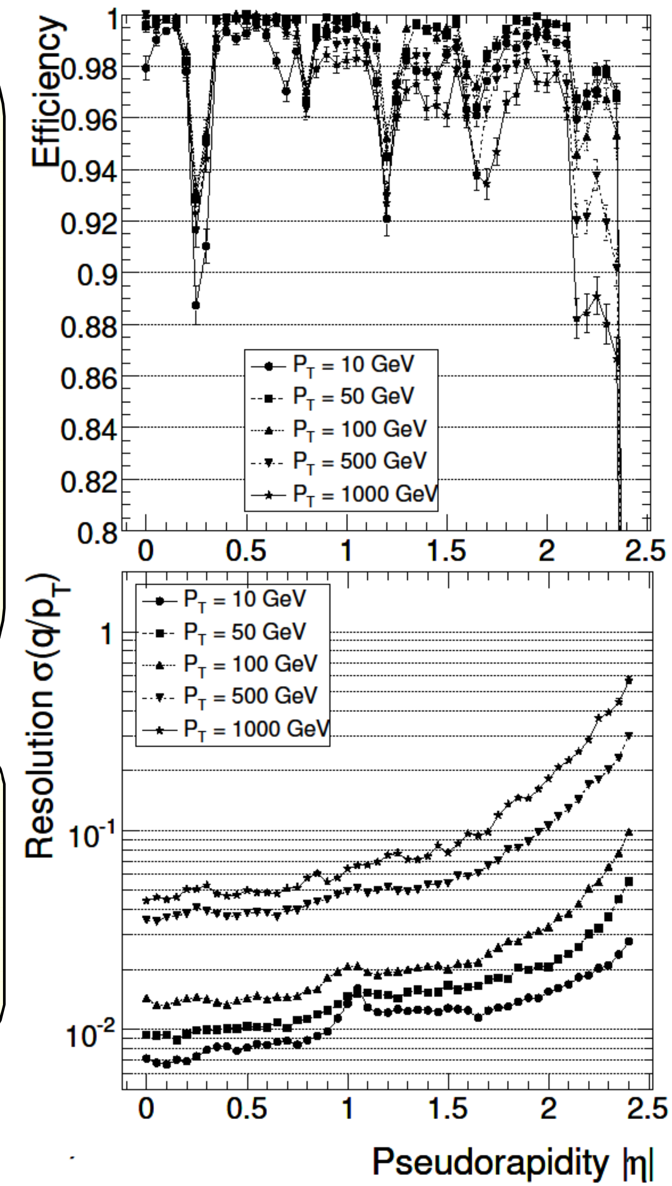
Define **Region of Interest (ROI)** which describes supposed track parameters at vertex (based on Stand-Alone Muon reconstruciton and assumed tolerances).

Offline: reuse Tracks from standard tracker reconstruction (done anyhow offline) Combinatorial Track Finder - Kalman Filter based algorithm consisting of global hit based seeding, inside-out pattern recognition, final cleaning, fitting and smoothing (backward fitting).) Select tracks compatible with ROI.
Online: run regional tracker track reconstruction in ROI (find pixel hit pairs or triplets which are compatible with ROI). Standard tracker CTF, customized cleaning.

Match tracker tracks to Stand-Alone Muon (check trajectory compatibility on intermediate surface). **Refit** track using hits from Tracker Track and Stand-Alone Muon.

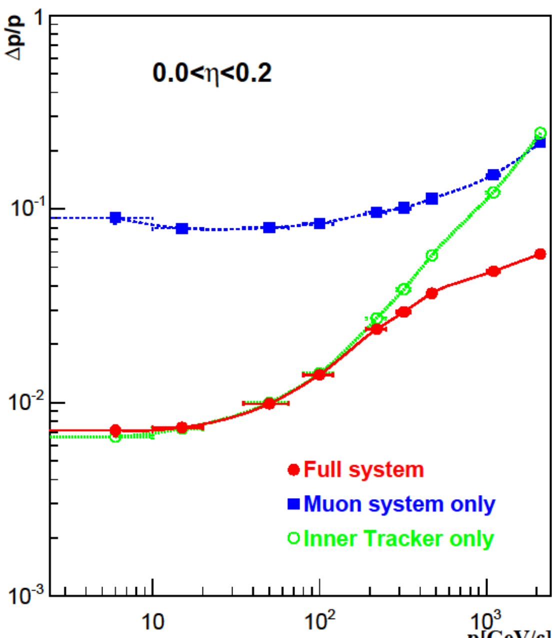
Tracker Muon

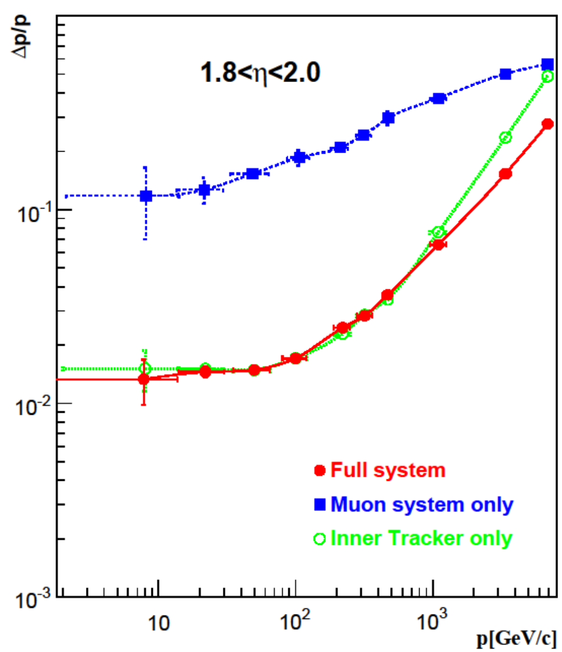
(offline only, alternative to start with Stand-Alone Muon)
Reuse tracks from standard tracker reconstruction
For each track combine muon signatures (energy in calorimeters, segment crossed by extrapolation, discance from chamber edges)
Flag track as Tracker Muon if track has MIP signal in calorimeter or at least one matched muon segment (do not refit)

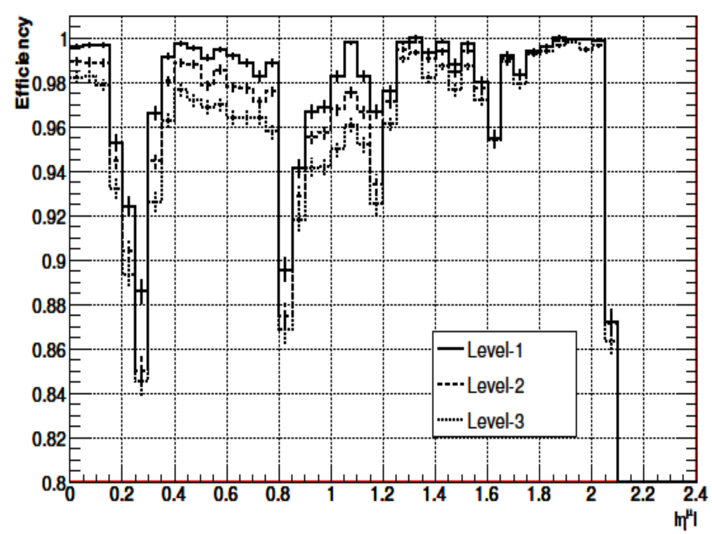


Muon Reco & Id

- A muon identification is based on reconstruction in outer spectrometer
- Momentum resolution is dominated by precise hits from tracker.
  For high p_T tracks (above a few hundred GeV) measurements from muon chambers are complementary (special algorithms developed for TeV muons).
- Muon track information is superimposed with calorimeter energy associated to track, track-segment matching information, track-calo compatibility with muon hypothesis, summary of muon isolation in two cones, timing







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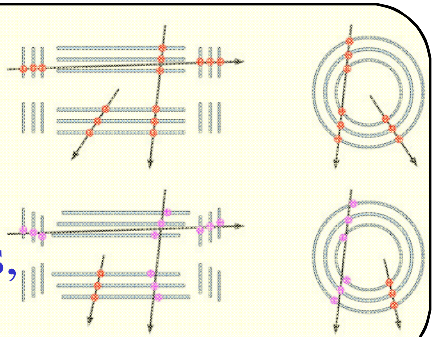
Alignment scenarios

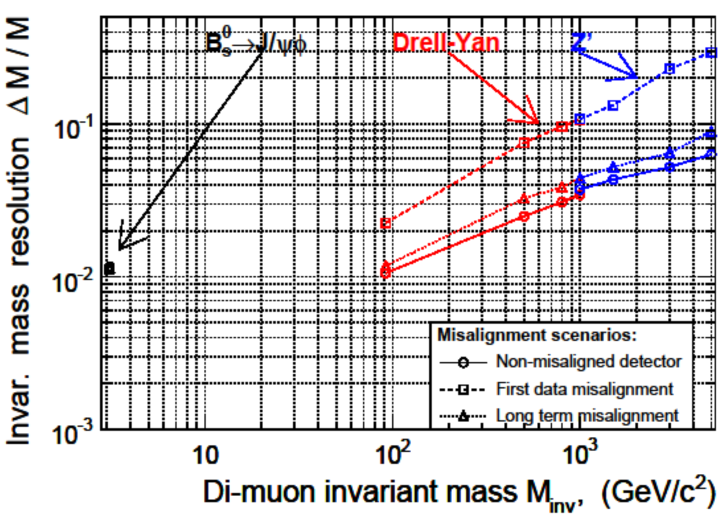
The structure of the CMS detector is not rigid:
- 1-3cm deformation due to magnetic field
- 5-15 mm due to gravity (weight)
- 500 μm due to changes in temperature and humidity

Reconstruction requires a precise knowledge of the location of the detector components
(ex. In order not to degrade momentum measurements in muon system: 200 μm in the r-φ).

CMS strategy for alignment is based on:
- Optical system
- Tracking (from collisions, cosmics, halo)



Alignment scenarios:
- Ideal: assumes a perfectly placed detector
- Startup: our best estimate of alignment at day one
- Long-term: our expectation of improved knowledge with data

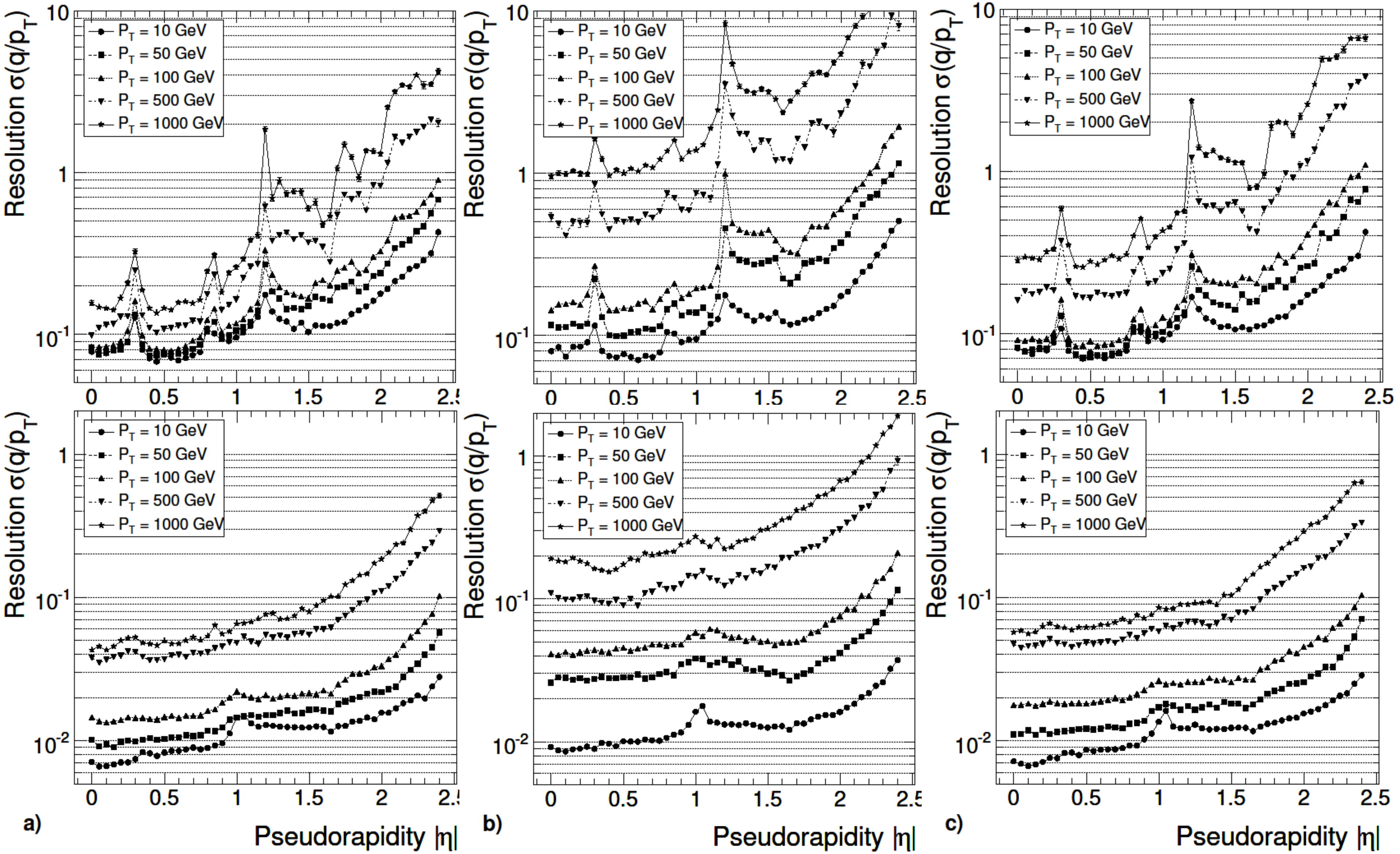


Alignment scenarios

CMS Muon System

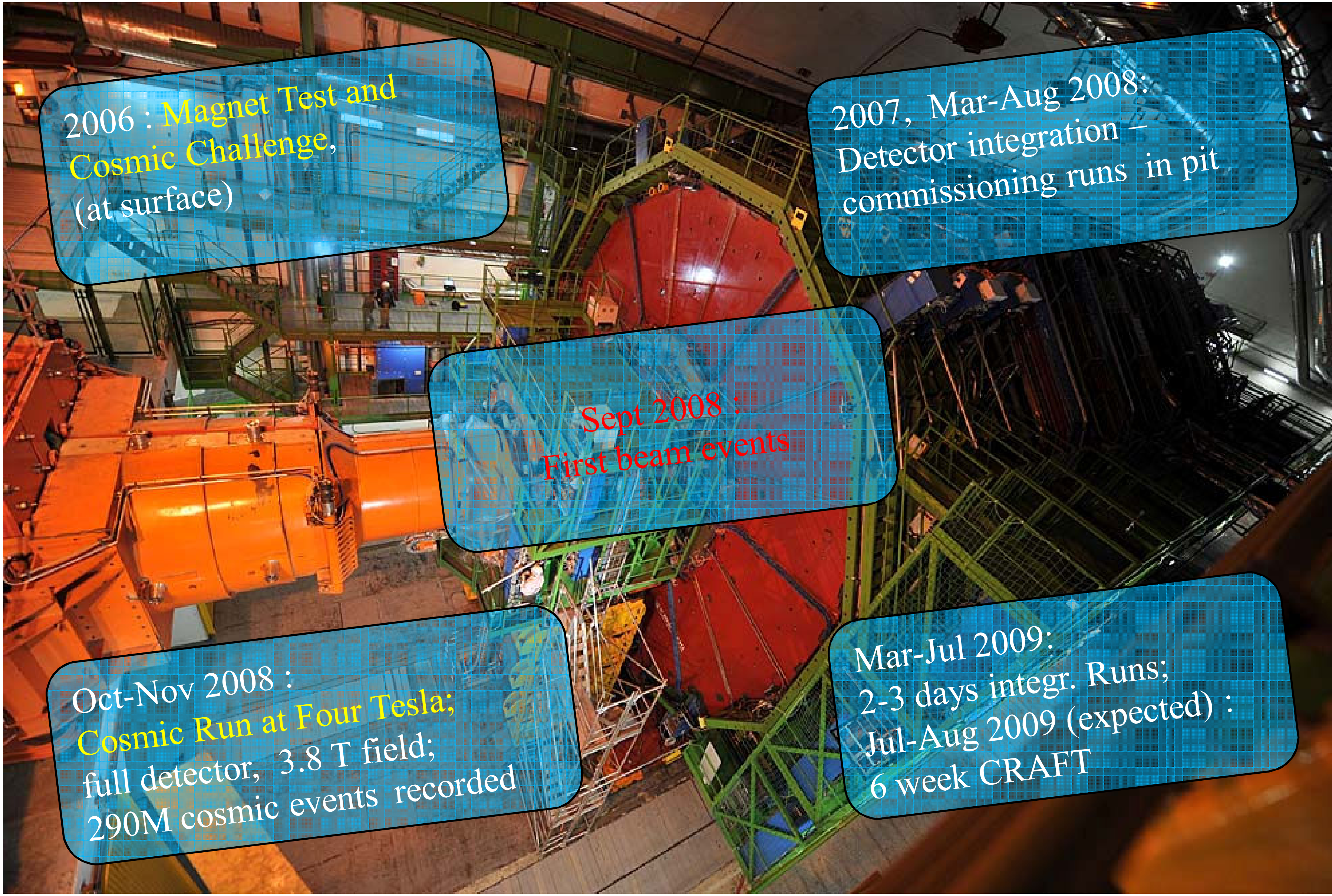
Muon Reconstruction

Preparation for LHC data



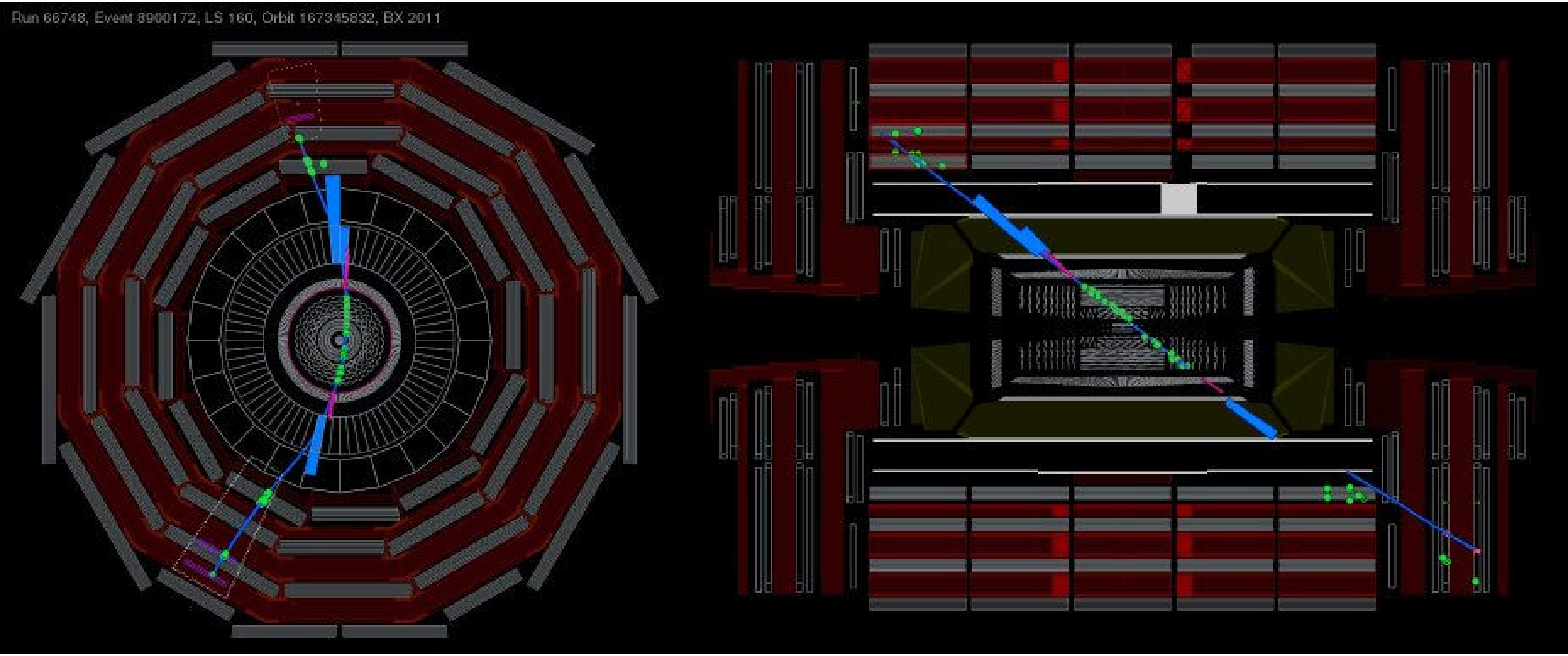
CMS preparation to LHC physics

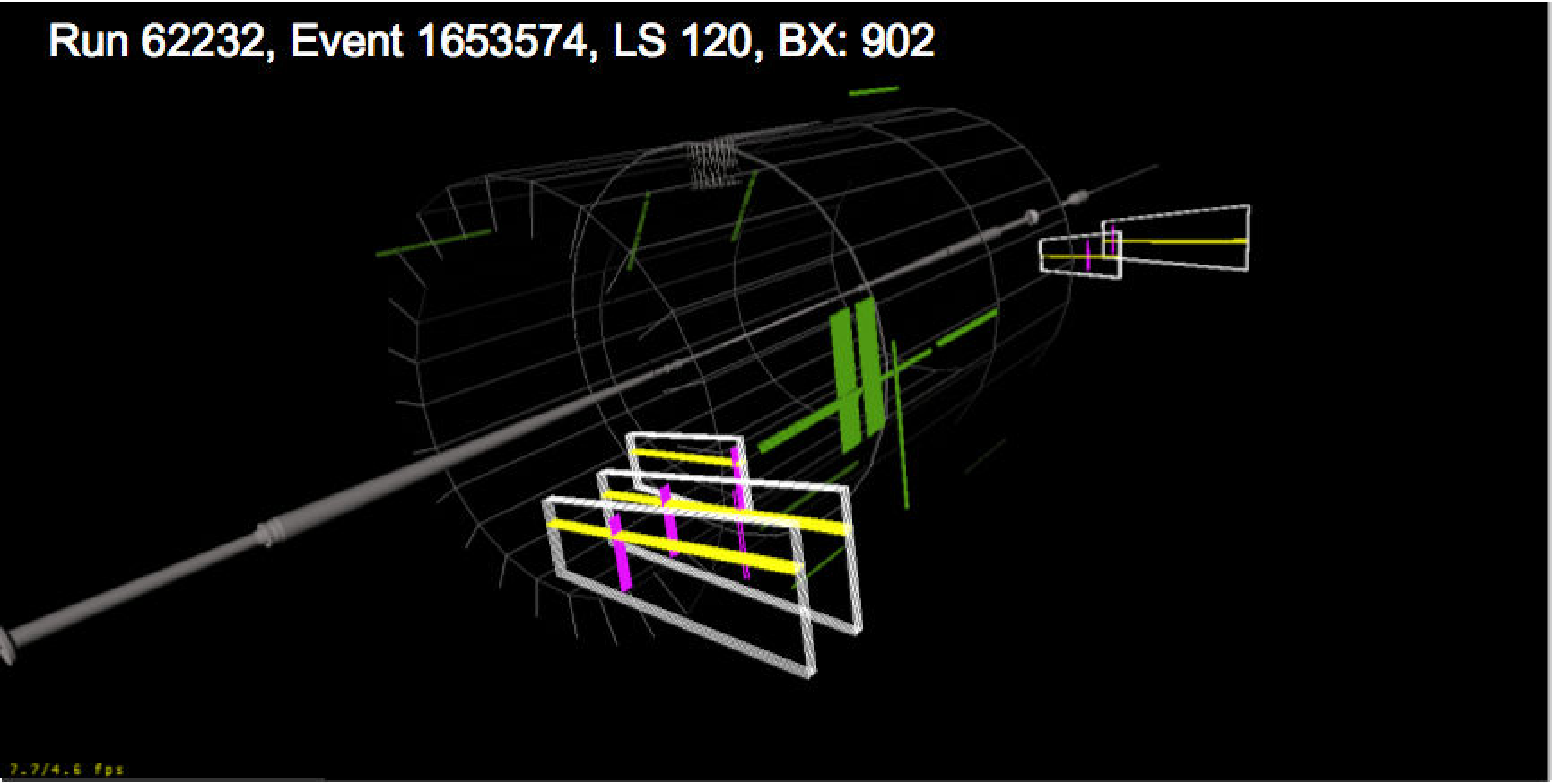
CMS Muon System
Muon Reconstruction
Preparation for LHC data



Global Run with B field 3.8Tesla

Since cosmic muons arrive from random direction muon local reconstruction (timing) and muon finding algorithm modified (seeding, navigation). Standard algorithms tested on "pointing" sub-sample.



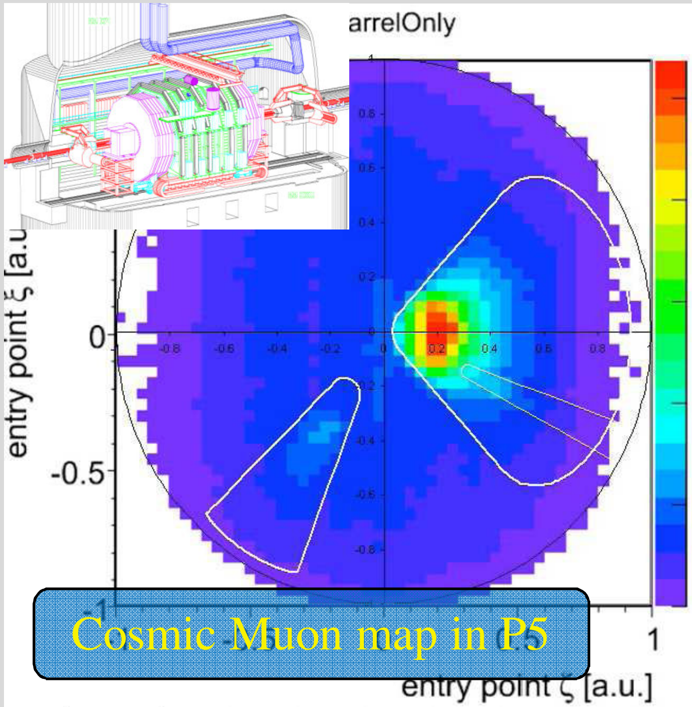

Run 62232, Event 1653574, LS 120, BX: 902

μ Results from commissioning runs

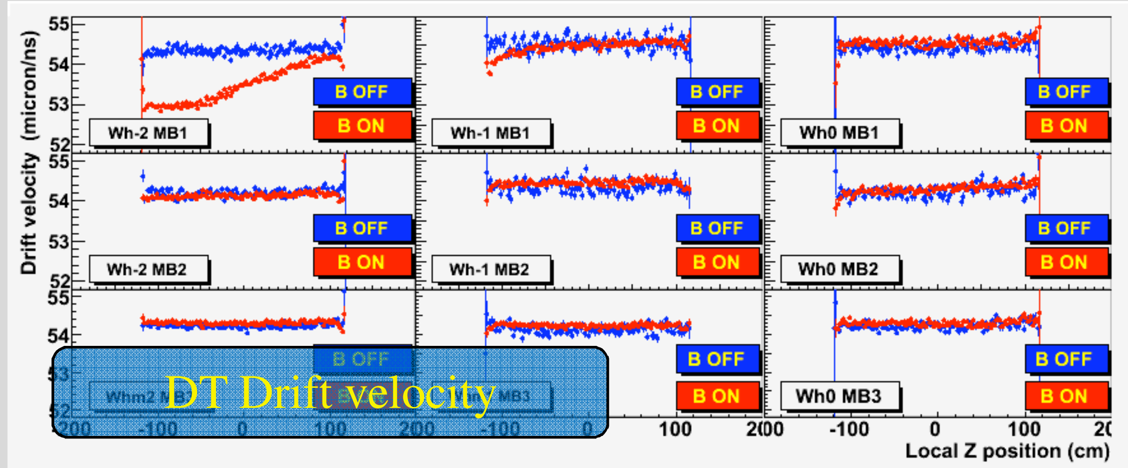
CMS Muon System

Muon Reconstruction

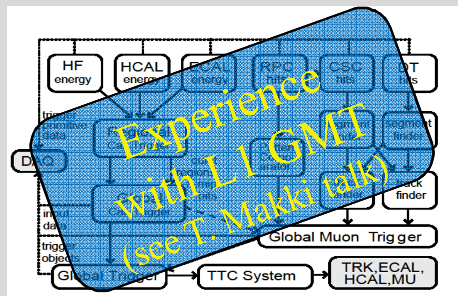
Preparation for LHC data



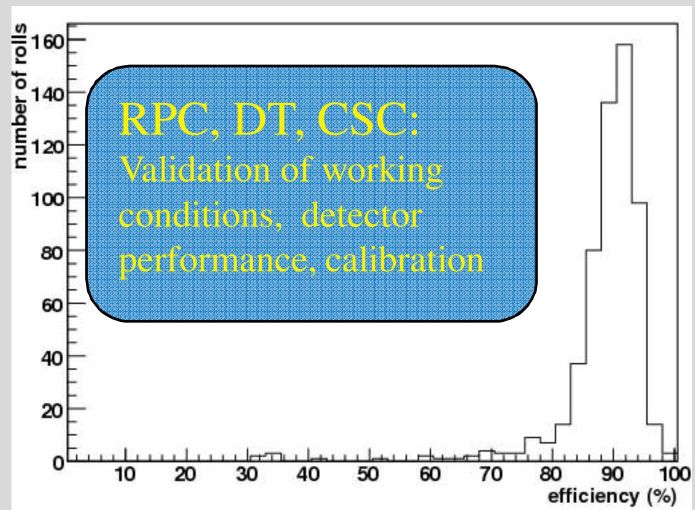
Cosmic Muon map in P5



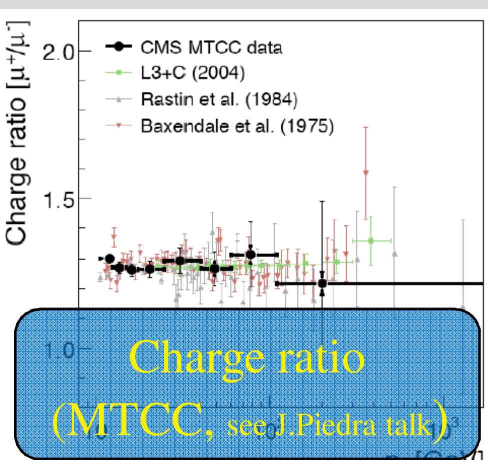
DT Drift velocity



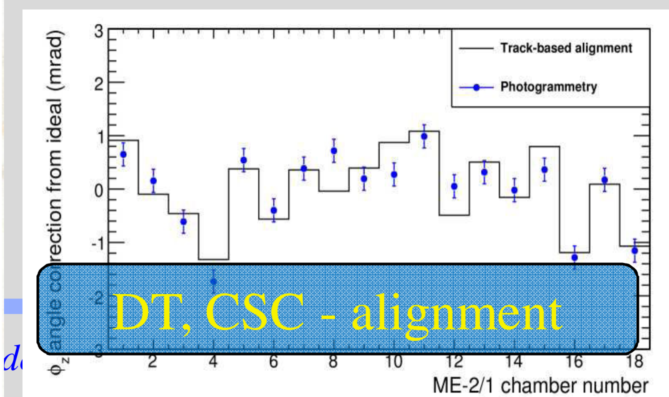
Experience with L1 GMT (see T. Makki talk)



RPC, DT, CSC: Validation of working conditions, detector performance, calibration



Charge ratio (MTCC, see J.Piedra talk)



DT, CSC - alignment

and more…..

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Test of μ alignment procedure with CRAFT data

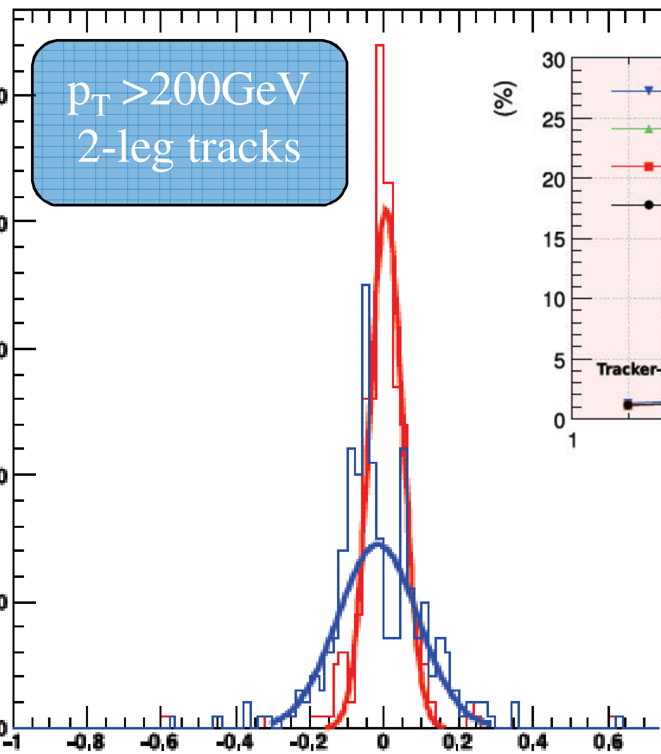
CMS Muon System

Muon Reconstruction

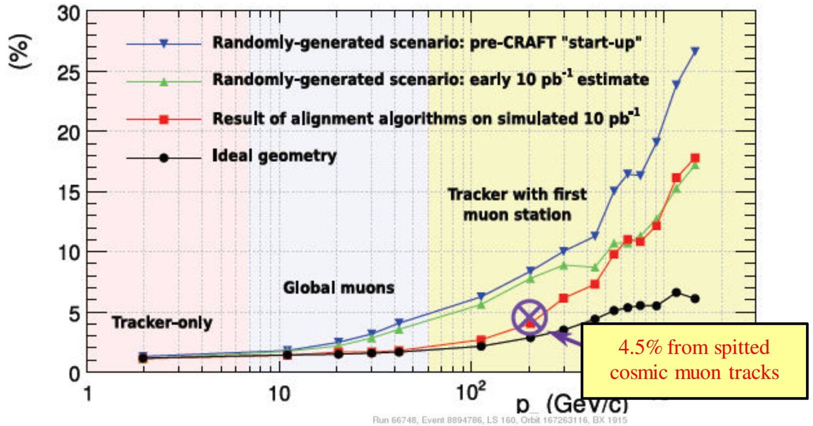
Preparation for LHC data

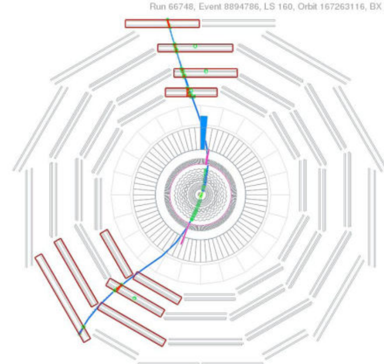
Before muon alignment

	mean	sigma
Tracker-only:	0.0040	0.044
With first muon station:	−0.0180	0.108



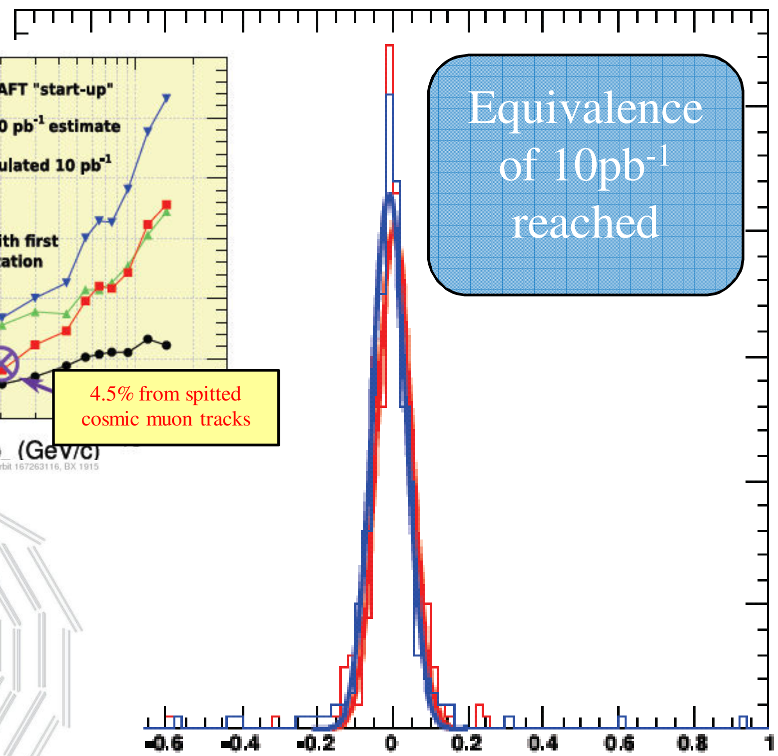
$$\frac{(1/p_T)_{\mathrm{upper}} - (1/p_T)_{\mathrm{lower}}}{\sqrt{2}\,(1/p_T)_{\mathrm{lower}}}$$





After muon alignment

	mean	sigma
Tracker-only:	0.0042	0.045
With first muon station:	−0.0097	0.045



$$\frac{(1/p_T)_{\mathrm{upper}} - (1/p_T)_{\mathrm{lower}}}{\sqrt{2}\,(1/p_T)_{\mathrm{lower}}}$$

More results: J. Piedra (EPS09)
+ coming CMS CRAFT publications

Summary

- Detection of muons is one of the main design points for CMS detector

  Robust and complementary muon system (DT,CSC,RPC)

- Several muon reconstruction algorithms provided

  Standalone muons, Global Muons, Tracker Muons

- Performance of muon reconstruction is verified with cosmic data.

  All distributions of basic quantities (numbers of hits, number of muons, direction of arrival, impact parameters and transverse momentum) in good agreement between data and MC