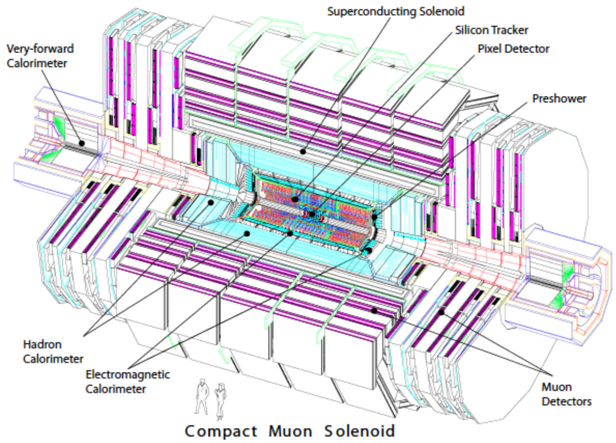
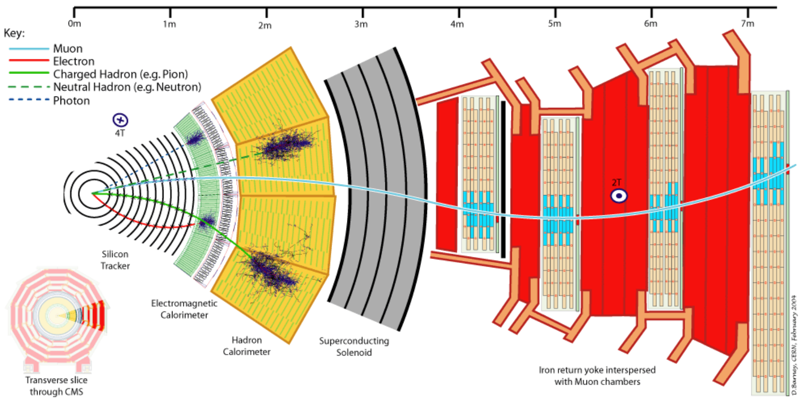
20th International Conference on Computing in High Energy and Nuclear Physics (CHEP 2013)
14-18th October 2013, Amsterdam, The Netherlands

Alignment and calibration of CMS detector during collisions at LHC

Roberto Castello (UC Louvain - FNRS, Belgium)
on behalf of CMS collaboration

- From particle identification (muons, electrons, charged and neutral hadrons, photons) to reconstruction of physics objects (muons, electrons, jets ...)

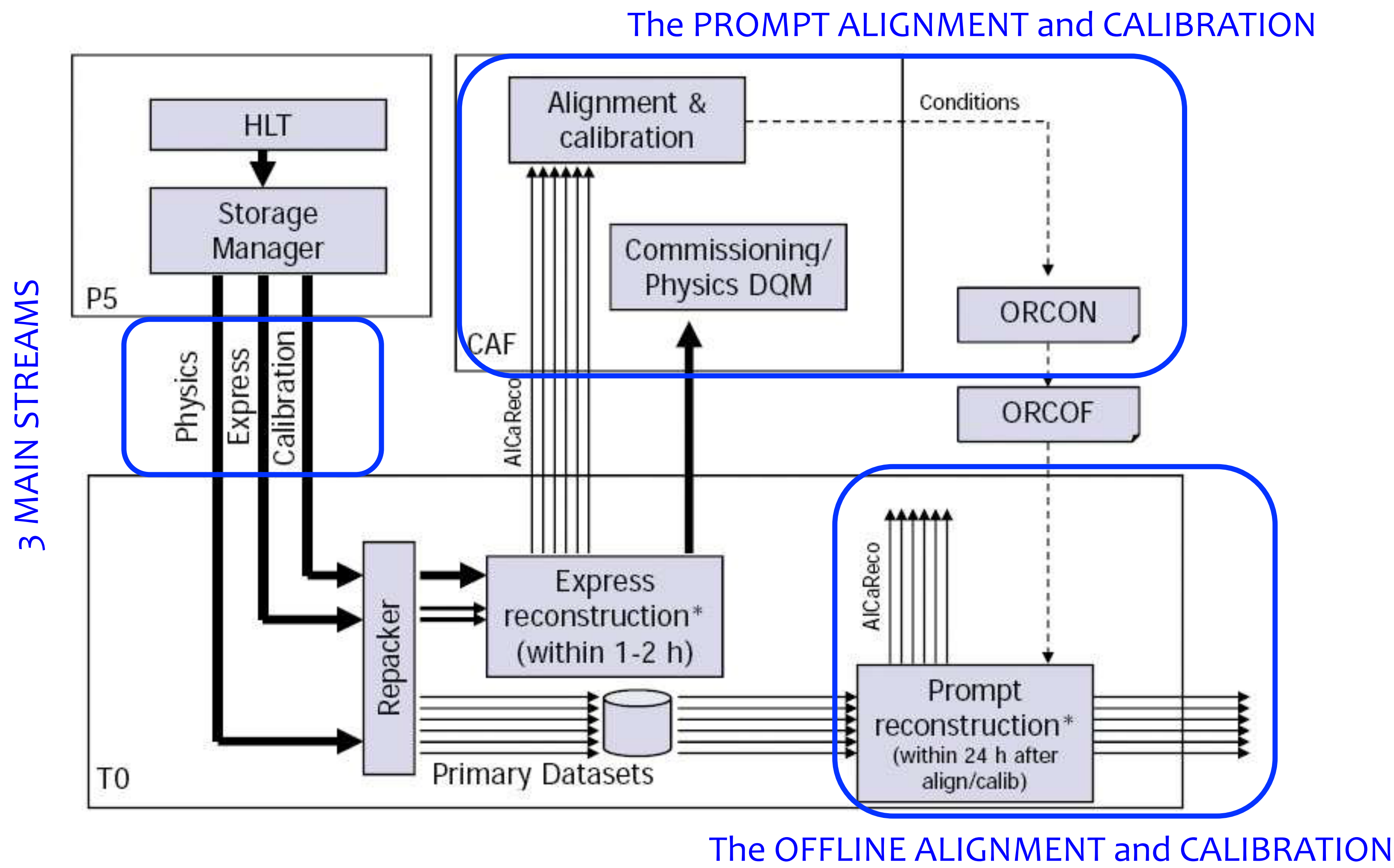




- Very demanding and complex detector:
  - Largest Tracker (76M channels), homogeneous calorimeter (76k cristals)
  - Transverse momentum resolution: $\sigma(p_T)/p_T$= 1.5 - 3% for tracks of p_T ~ 100 GeV
  - Energy resolution for electrons and photons: $\sigma(E)/E$~ 1 %

A solid alignment calibration infrastructure has been set up to allow physics analysis fast turn-around

The structure of alignment and calibration workflow



The QUASI ON-LINE CALIBRATION

- For high-level Trigger and express stream calibration, using dedicated stream (100 Hz)
- Beam-spot measurement using track based and pixel-only vertexing: very fast, 1 value every 5 LS (~2 min)

The PROMPT ALIGNMENT and CALIBRATION

- For calibration of physics stream: designed to allow updates with short latency
- Based on the delay between express and prompt reco at Tier-0 (48h): updated conditions for a given run while the bulk of the data is buffered on disk

The OFFLINE ALIGNMENT and CALIBRATION

- Aiming to provide more stable and improved conditions
- Workflows run on dedicated calibration stream, outputs stored on ORACLE DB
- Event selection tuned according to needs and event content reduced to optimize bandwidth/disk space usage (special *AlCaReco* format)
- Alignment geometry determined together with inter-dependencies and calorimeter (inter-)calibrations

The *prompt* Calibration and Alignment workflow

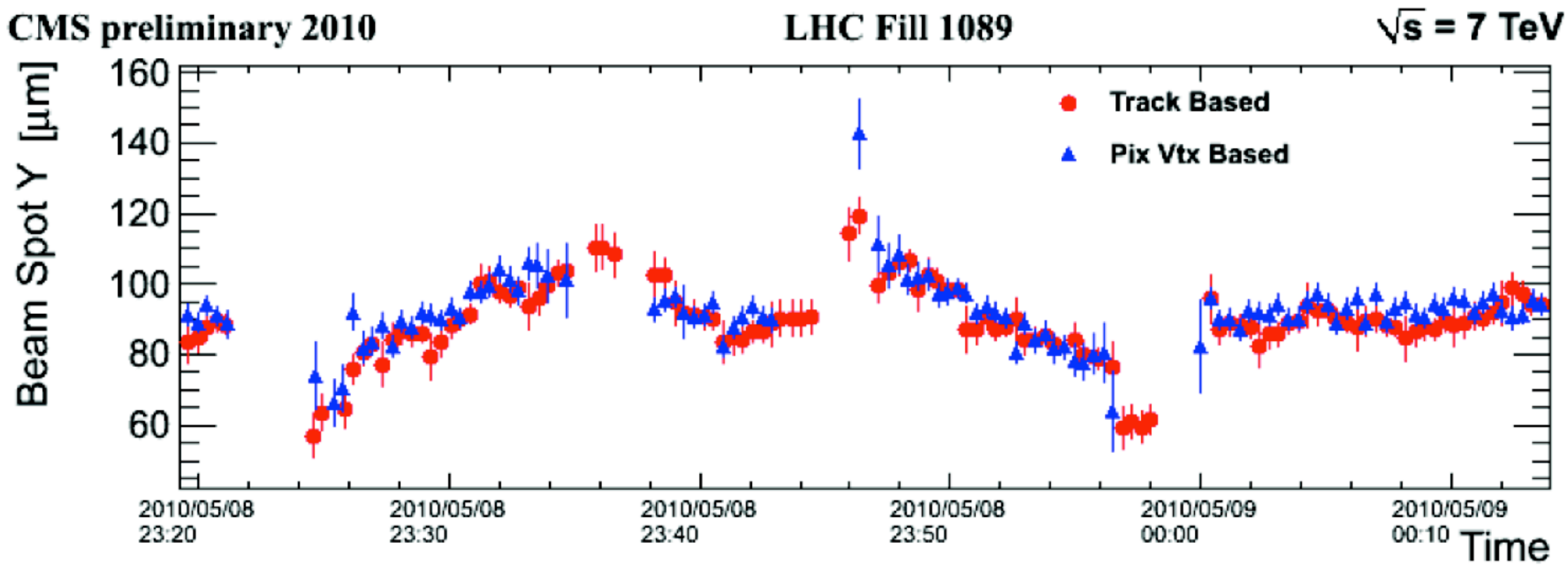
- Low latency workflows run immediately after the data-taking:
  - beam-spot position → measured frequently (every Lumi Section)
  - ECAL transparency corrections → measured with laser pulses

- Conditions which need to be monitored (and updating if necessary):
  - Tracker problematic channels → HV trips/noise
  - Calorimeter problematic channels → mask hot channels
  - Pixel alignment → monitoring movements of large structure using tracks

- Update-strategy based on delay between express and prompt reco:
  - Pre-defined data streams out of express used for calibration
  - Conditions derived in time for being delivered to prompt-reco → within 48h

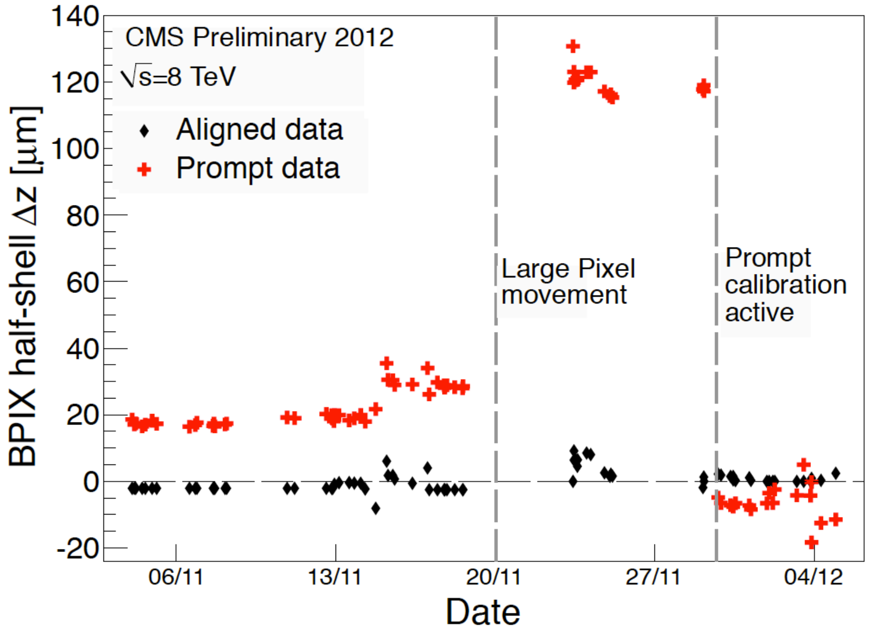
Updating the Beamspot position

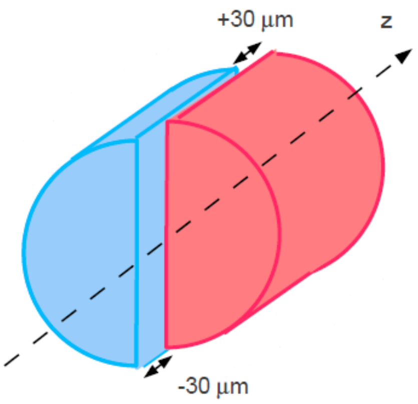
- Measurement delivered every LS, i.e. 23 s (tracks from Express stream)
- x, y position of the beam, along with slopes determined from d-ϕ fit with reconstructed (minimum bias) tracks
- Beam width along with z and $\sigma(z)$ come from fit to primary vertices
- Highly dependent from Pixel alignment (BS is recomputed offline whenever alignment is updated)



Monitoring the Pixel macro structures movements

- Correcting vs time relative pixel half barrels displacements along z
- Monitoring longitudinal separation, mechanically allowed, on a run basis (> 20k events) using unbiased track-to-vertex residuals

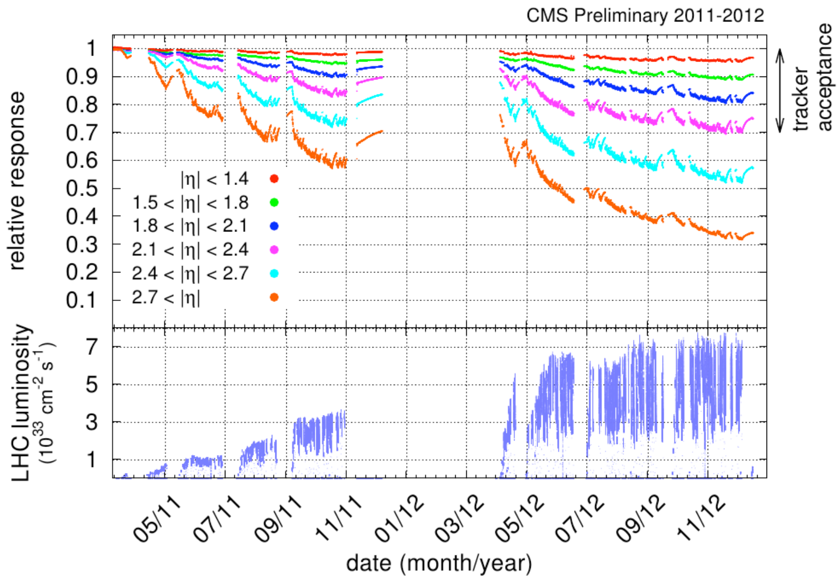


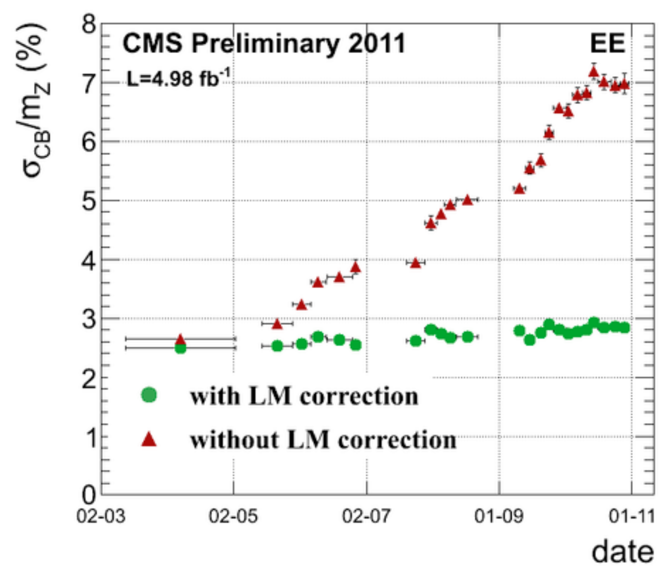


- Time dependence of pixel structure alignment accounts for separation as function of time: b-tagging algorithms insensitive to remaining 10 μm effect

Updating transparency corrections for EM calorimeter

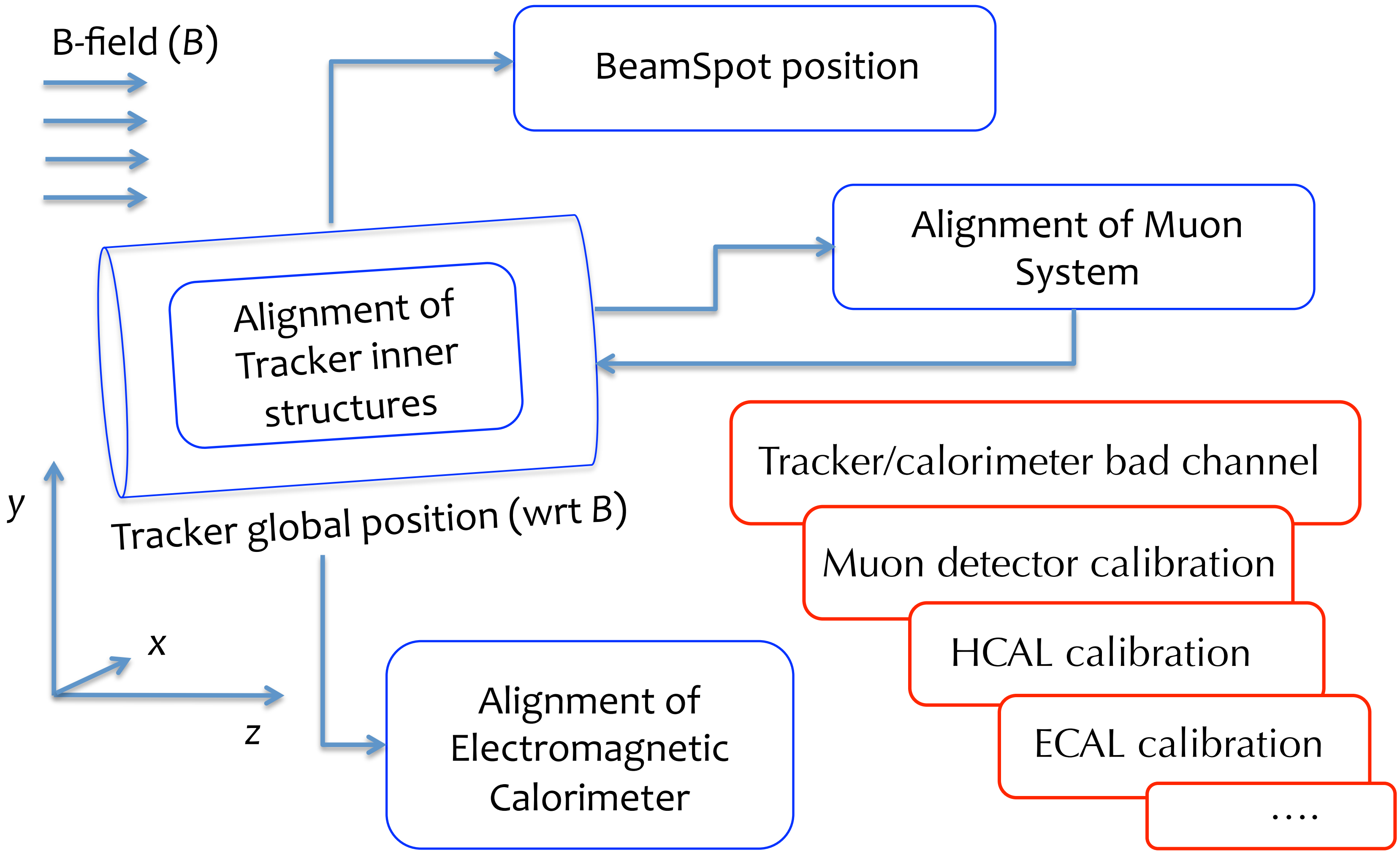
- ECAL PbWO4 crystals can temporary loose transparency due to irradiation: less significative in barrel, more pronounced in the endcaps
- Damage/recovery cycles monitored by laser pulsed @ 80Hz (LHC abort gaps) measuring the response (R) variation to the laser light (R/R0)→ dedicated stream @ HLT level
- Corrections derived within 48h → applied in prompt-reco





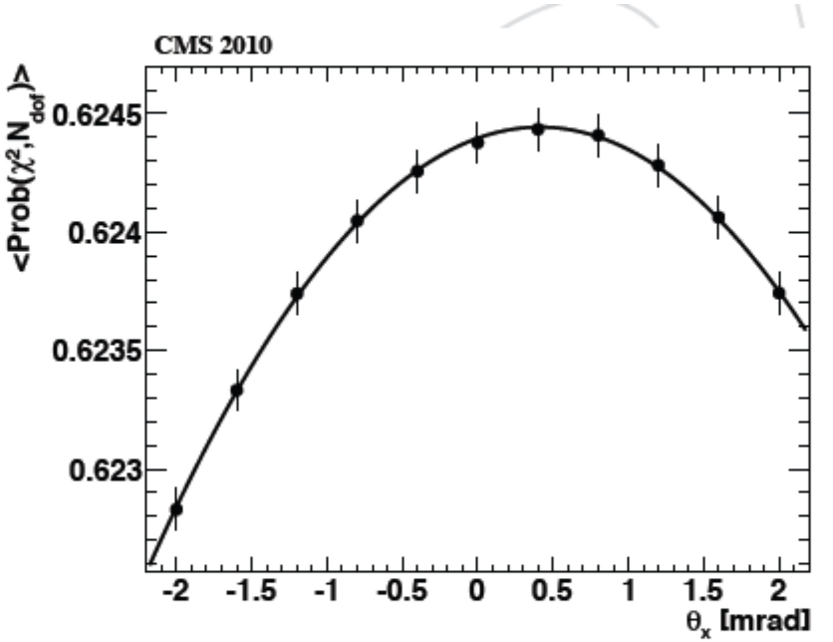
Z(ee) mass resolution already quite stable

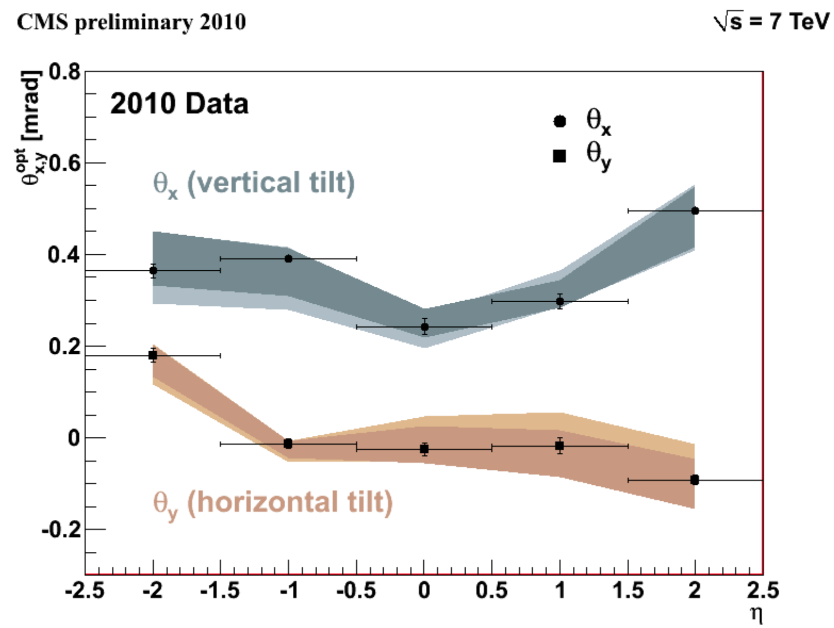
The offline alignment and calibration challenge



Tracker orientation with respect to magnetic field

- Uncorrected overall tilts of the Tracker relative to magnetic field (flux along global *z*) could result in biases of the reconstructed track parameters
- The global Tracker orientation is described by the angles θ_x / θ_y , corresponding to rotations around global *x*/*y* CMS axis
- Goodness of track fit scans for various tilt angles: $\theta y = 0$, $\theta x = 0.3$ mrad

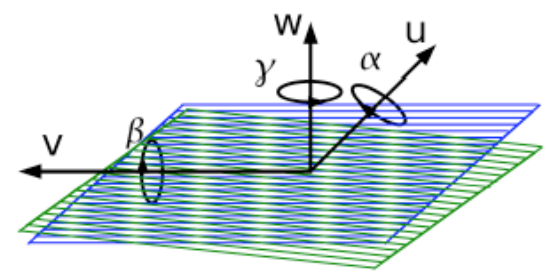


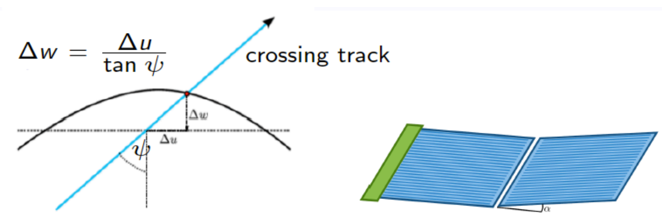


Alignment of Tracker module and structures

- CMS Tracker is a complex system:
  - The largest silicon detector ever built, 24k sensors in total
  - 5(6) rigid body-like + 3 bow parameters: O(200k) free parameters per sensor
- Survey measurement, but expected <10 μm precision using in situ track-based alignment with by means of minimization algorithms (MillePede II)

- Example: the 2011 alignment campaign (1 /fb)
  - Inputs: 15M loosely selected isolated muon tracks, 3M low momentum tracks, 3.6M cosmic ray tracks and 375k muon track pairs from Z
  - Z mass measurement as a constraint
  - Fitting sensor bows and kinks
  - Time dependent (9 intervals) rigid body alignment for large pixel structures
  - Total CPU 44.5 h, wall clock time 9:50 h

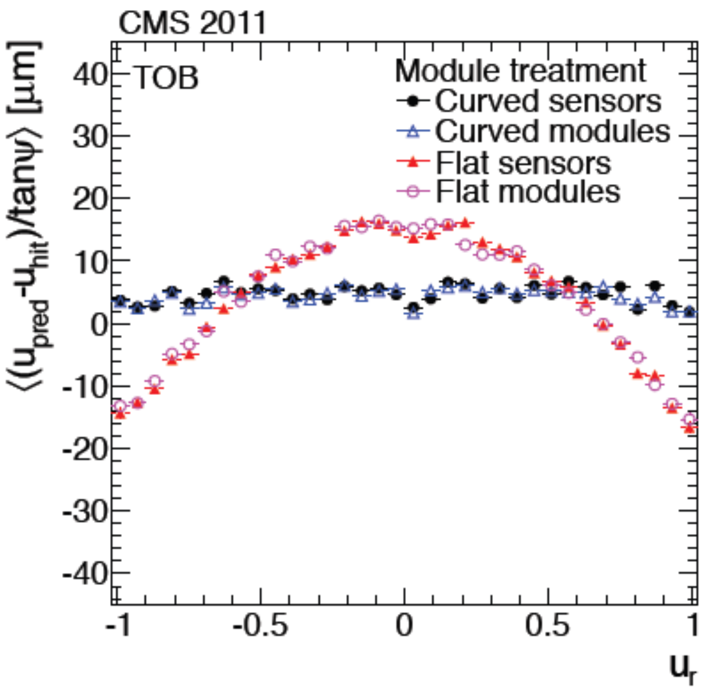


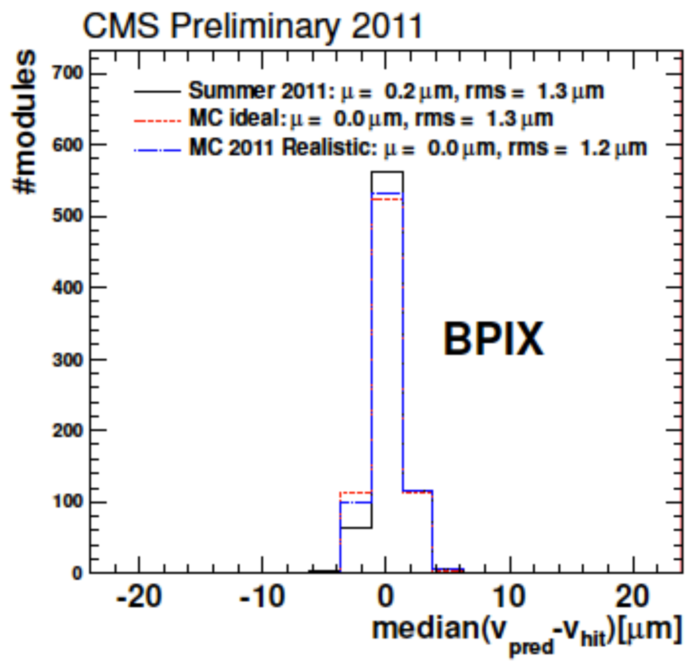


Visualization of bows and kinks

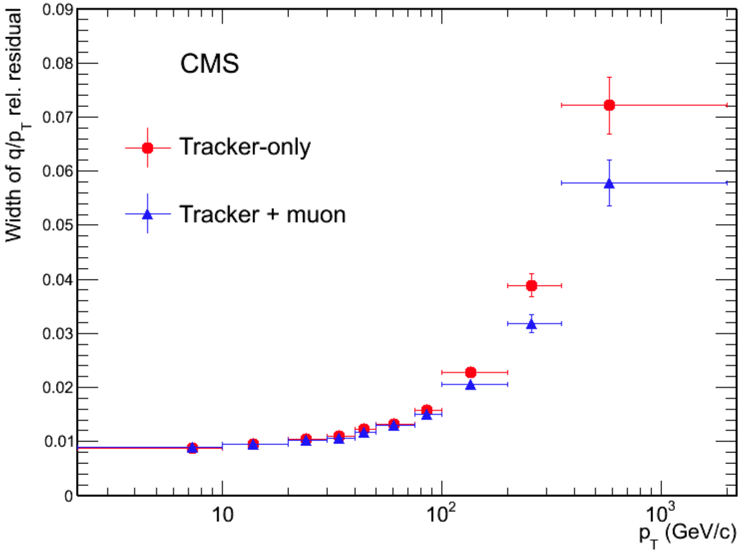
Local performance of Tracker alignment

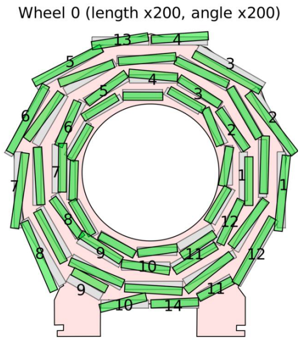
- Precision estimated from the RMS of the Distributions of the Medians of the Residuals (DMR) for each module (# hits>30): more robust against MS
- Collision tracks and module surface deformation improve local precision in the Pixels w.r.t. previous cosmic rays alignment (2008)

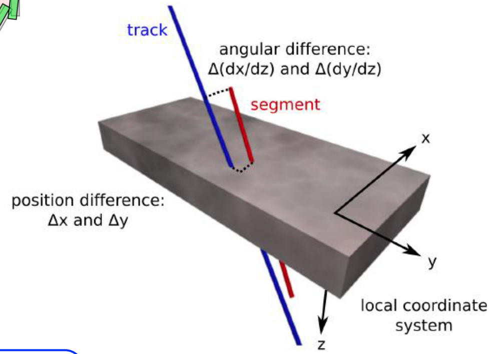




- Hardware based: measuring positions of all chambers with respect to a floating network of rigid reference structures ($\sigma_{x/y}$ < 0.1 cm)
- Track based: minimizing the *residuals* as the difference between measured (with segments) and predicted (i.e. propagated from Tracker) position of the muon in the chamber → r-ϕ precision: 100-150 μm
- Combination (and comparison) of the methods

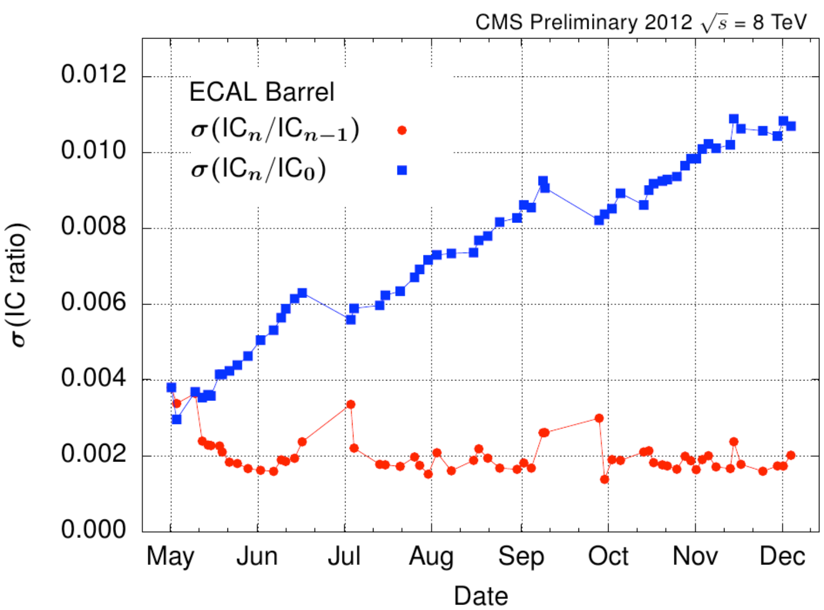


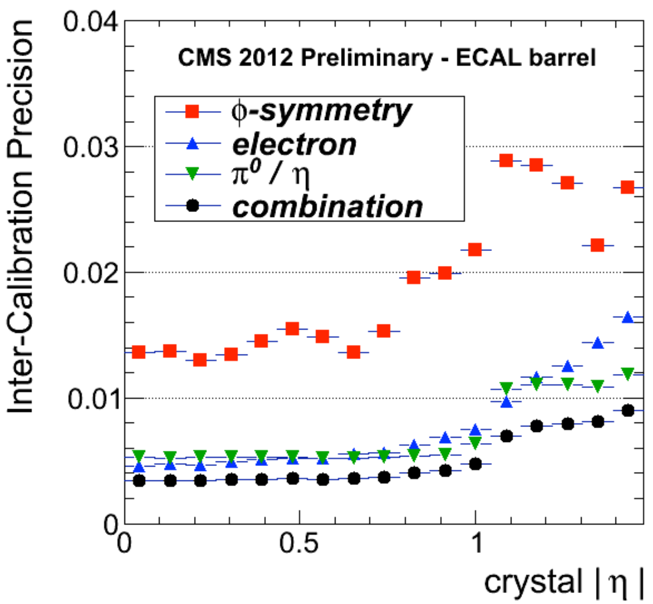




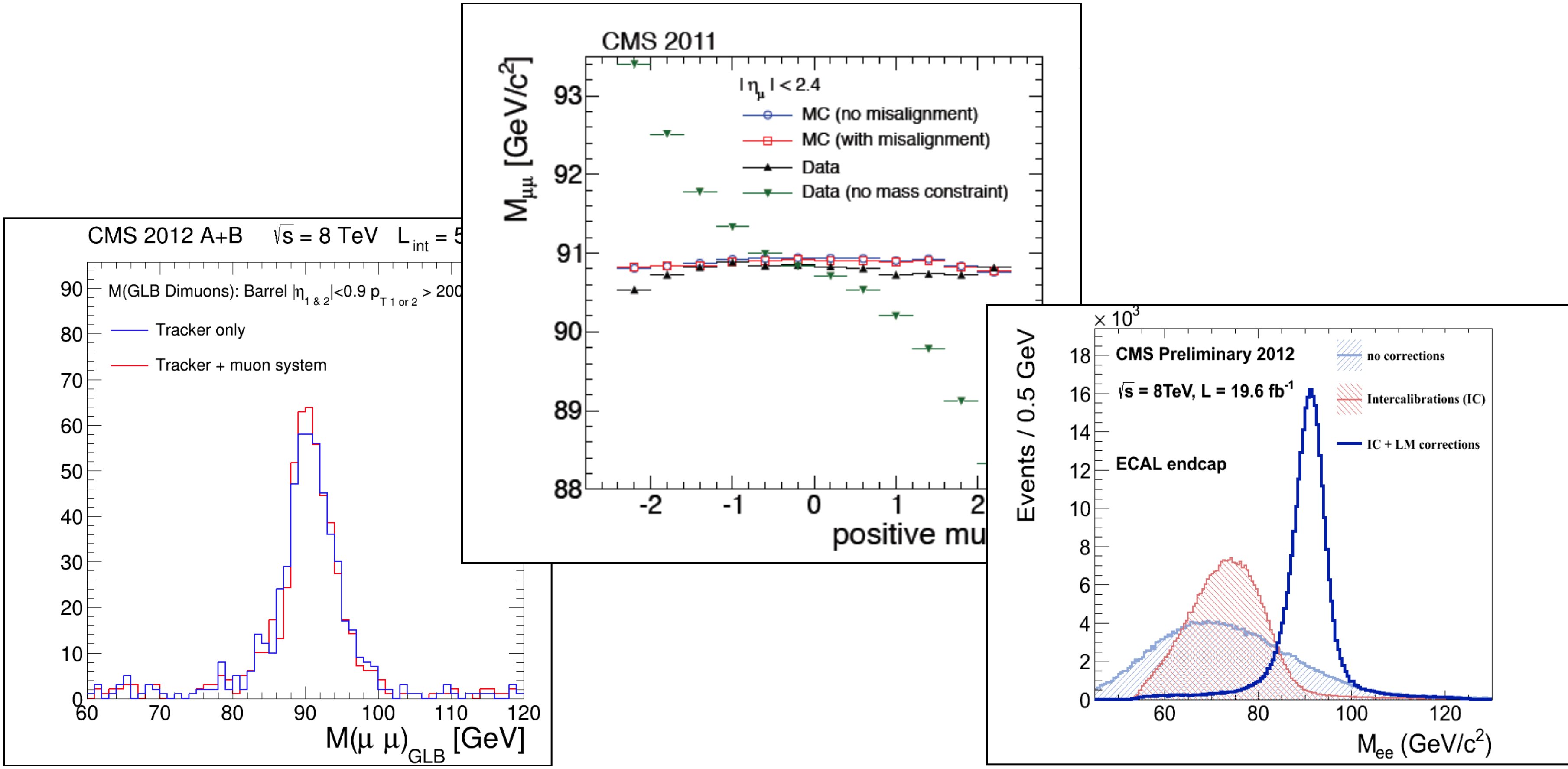
Improved muon momentum resolution for pT > 200 GeV

- Inter-calibration of crystals located within the same η ring:
  - φ-symmetry of the energy flow through the ECAL crystals (granularity of ~ 3-4 days)
  - π0/η → γγ invariant mass peak (granularity of ~ 2 months)
  - E(ECAL)/p(tracker) : high energy electrons from W(eν) and Z(ee) decays (once in the year)
  - Combination: weighted average of the 3 methods
- Also providing inter-calibration of the η rings (η scale) and determination of energy scale and resolution





Validation on physics performance



Remarkable CMS physics performance after alignment and calibration conditions are injected in the reconstruction

Outlook

- The alignment and calibration infrastructure proved to be efficient and effective for a fast analysis turnaround during CMS data taking
- The *prompt* alignment and calibration mechanism:
  - designed for low latency workflow run smoothly during Run1
  - better quality of physics reconstructed objects already during prompt reconstruction
- The *offline* calibration and alignment procedure:
  - Increasing time/space granularity of the calibrations and thus precision
  - Delivering to reconstruction the best knowledge of detector performance
  - Account for interdependencies among the different calibration and alignment workflow

- Calibration & alignment has been crucial step towards the successful physics program of CMS during 2010-2012
- Revision and amelioration of main workflow is under study

… aiming to keep the high standard at restart of data taking!