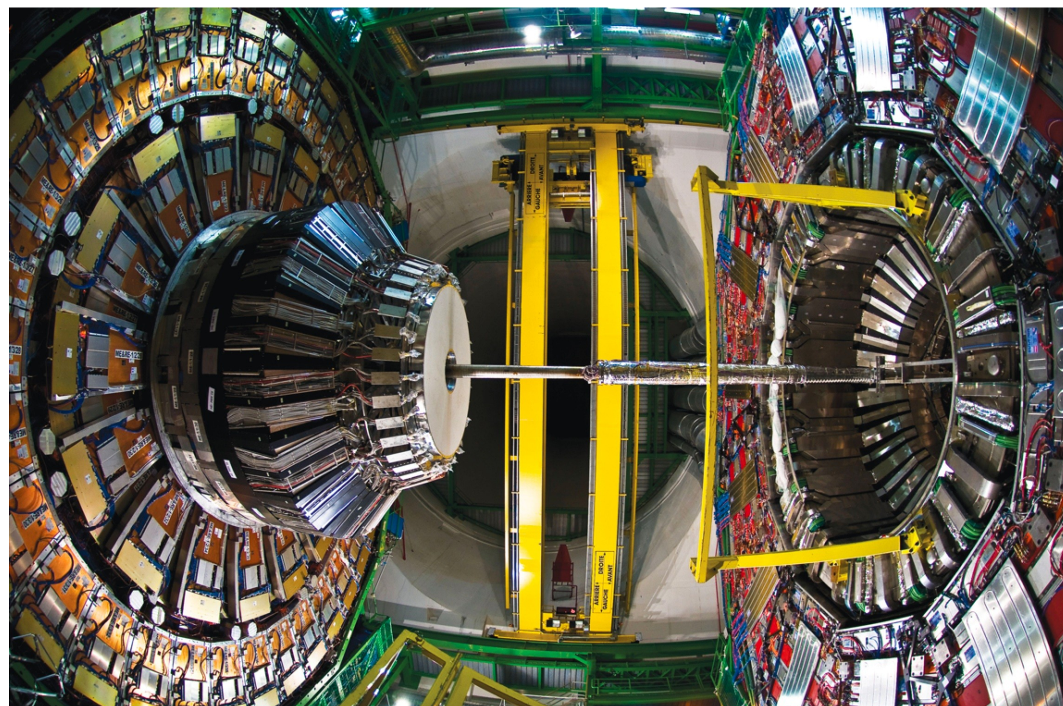
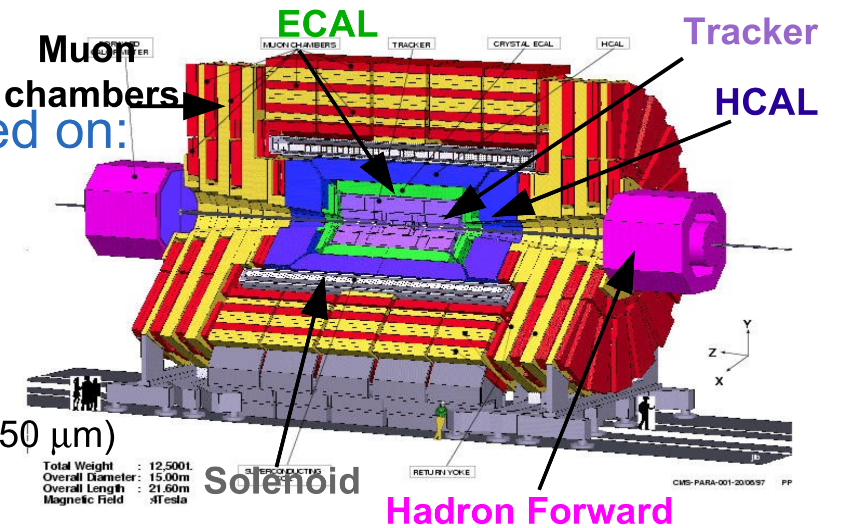
EPS-HEP 2011, July 22nd, 2011 - Grenoble

Alignment and Calibration of the CMS detector at the LHC

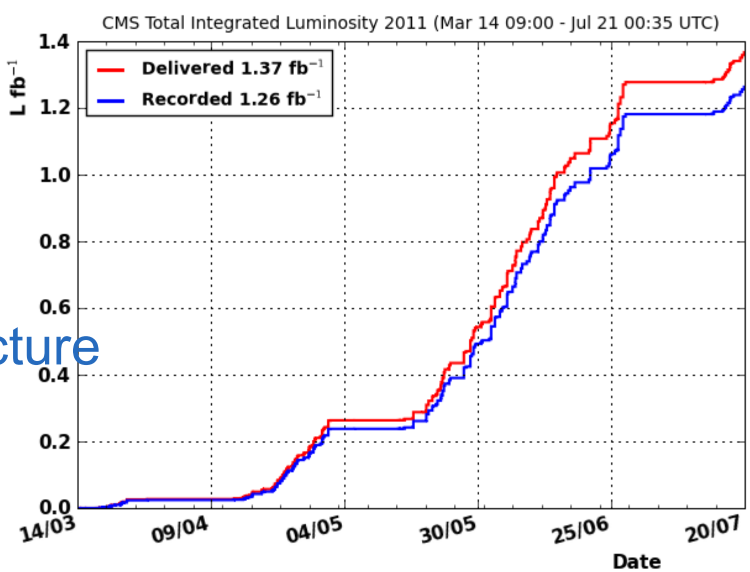


Gianluca Cerminara (CERN)
on behalf of the CMS Collaboration

The CMS Detector @ the LHC



- Compact Muon Solenoid (CMS):
  - compact 4π experiment → design based on:
    - high intensity B field
      (3.8T superconducting solenoid)
    - redundant muon spectrometer
    - high precision silicon tracker (σ_x = 15-50 μm)
      - ~ 76M channels (Pixel + SiStrip)
    - high precision homogeneous EM calorimeter (ECAL)
      - ~ 76k $PbWO_4$ scintillating crystals
    - hermetic calorimeter
- High level of complexity →
  very demanding in terms of calibration:
  - complex alignment&calibration infrastructure allows fast turn-around for analysis



Alignment & Calibration: Outline

Optimal alignment & calibration of each sub-detector/component
→ full resolution and physics performance of the CMS detector

A complex architecture for a complex task:

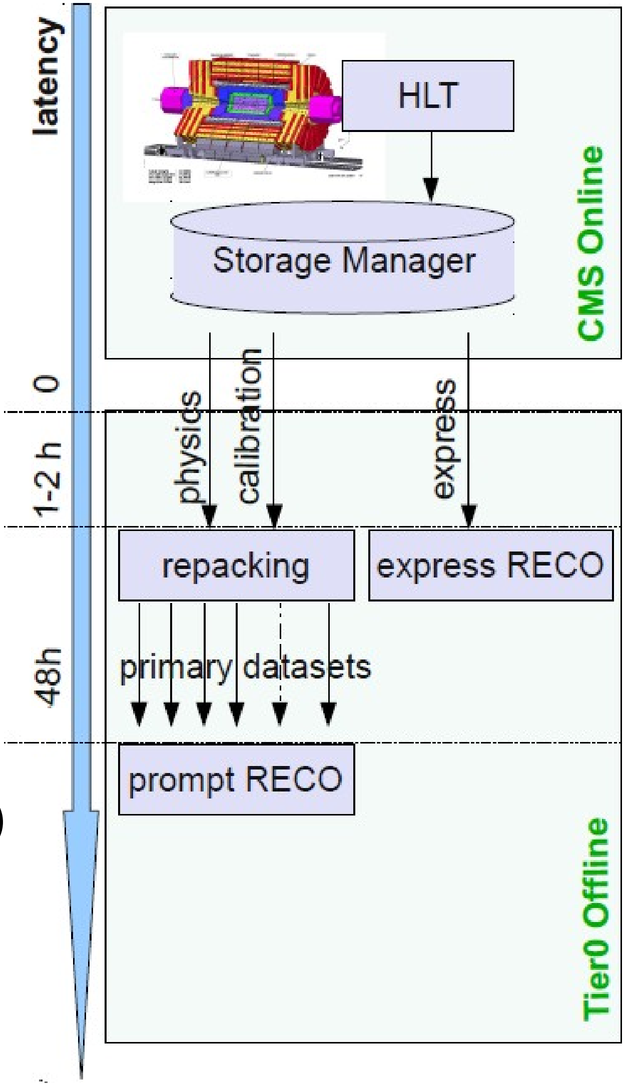
- prompt-calibration concept:
  - provide offline level conditions with very short latency
  - limited # of reprocessing per year → ensure data “analysis ready”
- infrastructure for calibration workflows
  - dedicated datasets and streams for calibration purposes
  - dedicated CPU resources
- performance and status of the calibrations:
  - CAVEAT: just a few workflows covered → not a complete review

Complementary talks:

- Ia Iashvili (State Univ. of New York)
  Jet Energy Calibration and Transverse Momentum Resolution in CMS
- Jean-Roch Vlimant (UC Santa Barbara)
  Experience with CMS Offline and Computing in LHC Runs 2010-2011

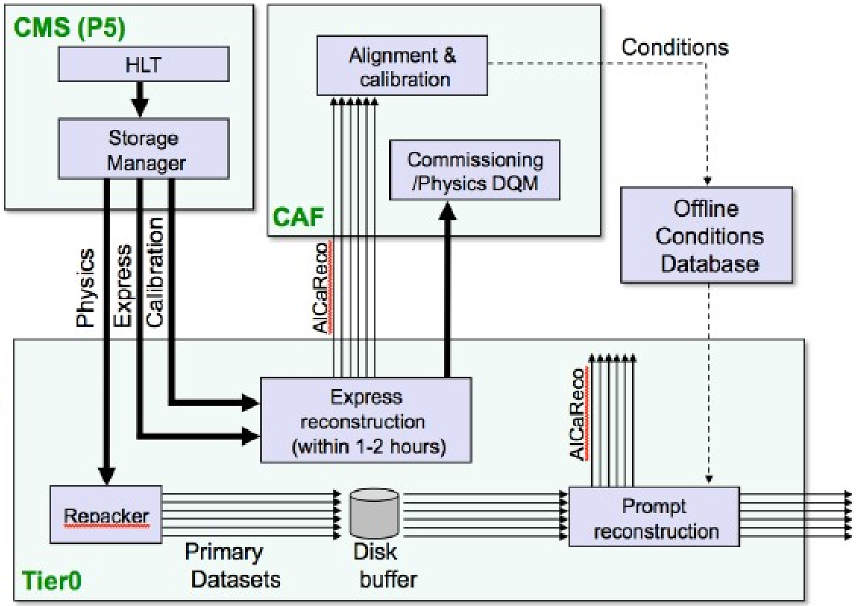
Data Streams & Tier0 processing

- Data streams & Tier0 workflows → specialized for different tasks
- Depending on the latency
  - express → prompt feedback & calibrations
    - short latency: 1-2 hours
    - ~40Hz bandwidth shared by:
      - calibration (½)
      - detector monitoring (¼)
      - physics monitoring (¼)
  - Alignment & Calibration (AlCa) streams
  - bulk data → sample for physics analysis (prompt reconstruction)
    - split in Primary Datasets (using High Level Trigger (HLT) decision)
    - reconstruction starts after 48h → get latest calibrations
    - writing ~300Hz



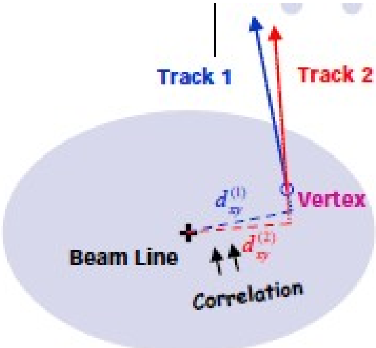
Prompt-Calibration Concept

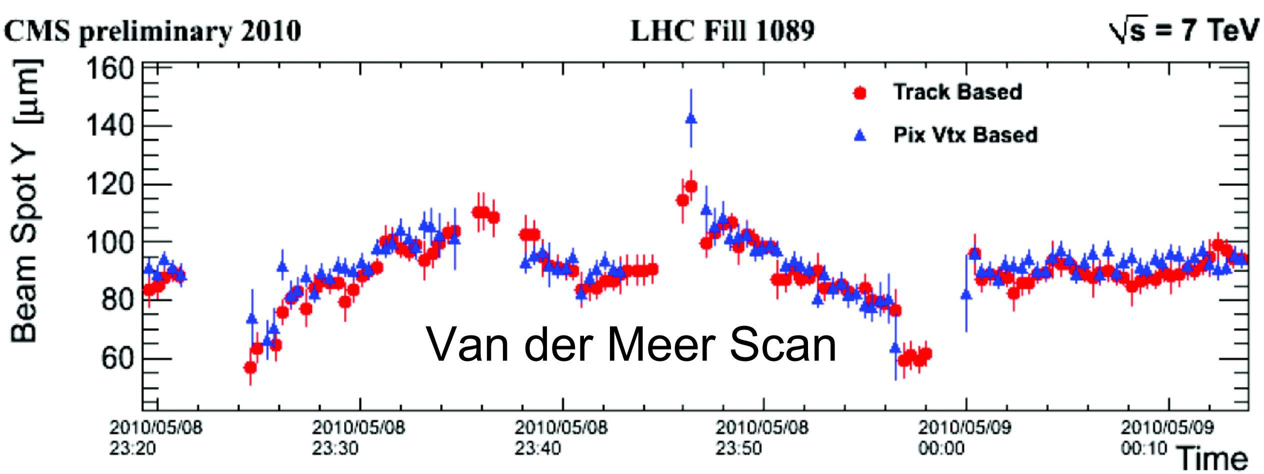
- Low latency workflows run immediately after the data-taking:
  - conditions which need continuous updates:
    - beam-spot position → measured every 23s (= 1 Lumi Section)
    - tracker problematic channels → respond to HV trips/noise
    - ECAL transparency corrections → measured with laser pulses
  - conditions which need monitoring
    - calorimeter problematic channels → mask hot channels
    - tracker alignment → monitor movements of large structures
- Update strategy based on delay between express and prompt reco
  - AlCa streams out of express used for calibration
    - compute conditions in time for prompt-reco
      → start 48h later
- Reduce need for offline re-reco
- Dedicated resources @ CERN: CMS Analysis Facility (CAF)



Example: Beam-Spot Measurement

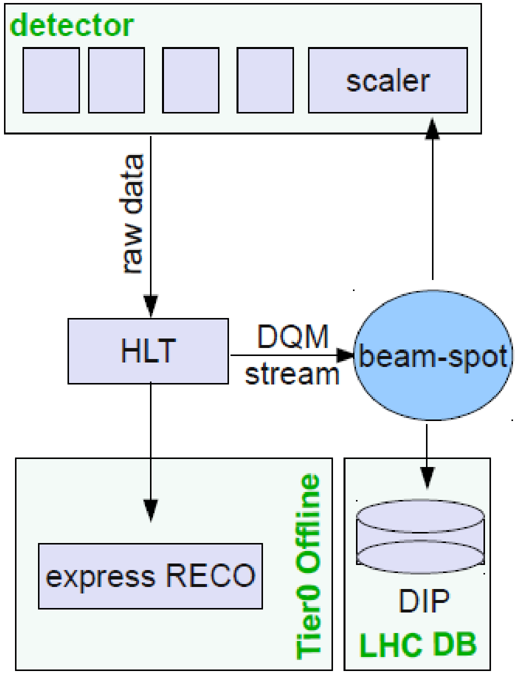
- Track beam-spot 3D position and width as a function of time.
- Two independent methods with complementary systematics
  - track based →correlation of impact parameter and azimuthal angle (d_0-ϕ) (no unfolding of resolution required)
  - vertex based → 3D fit to distribution of primary-vertexes
- Can deliver one measurement every 23s

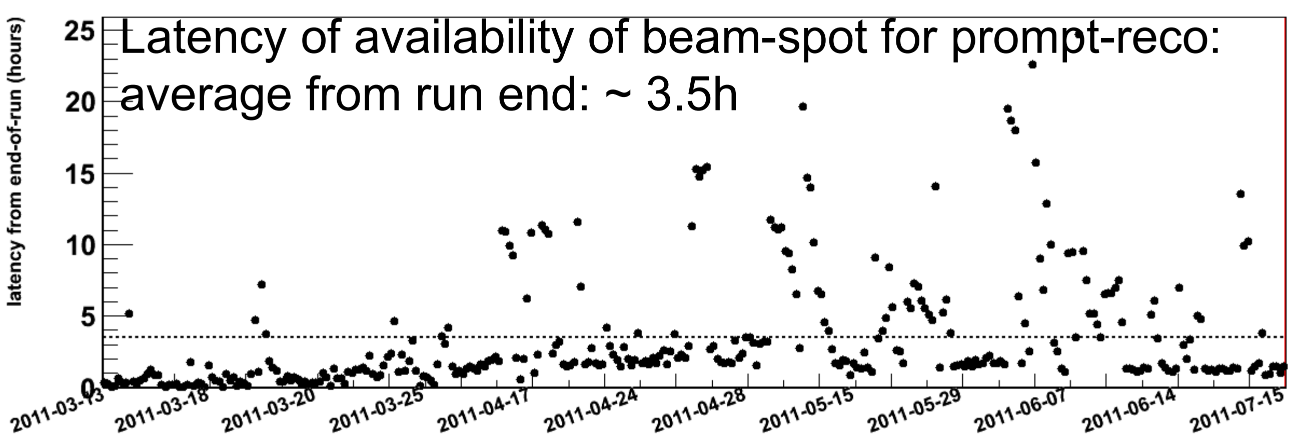




Beam-spot workflows

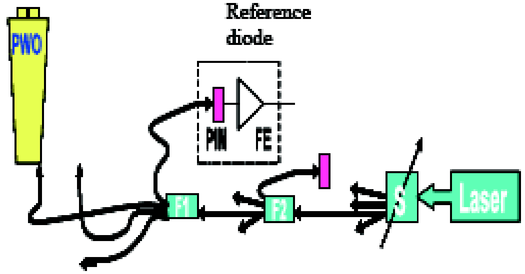
- Quasi-online workflow for HLT (and express) reconstruction
  - using DQM-dedicated stream (sampling @ ~ 100Hz max)
  - using track based and pixel-only vertexing → very fast
    - 1 value every 5 Lumi-Section (~2 min)
- Runs also in prompt-calibration loop using tracks selected on Express stream
  - full statistics and tracking capabilities
    - 1 value every LS (=23s)

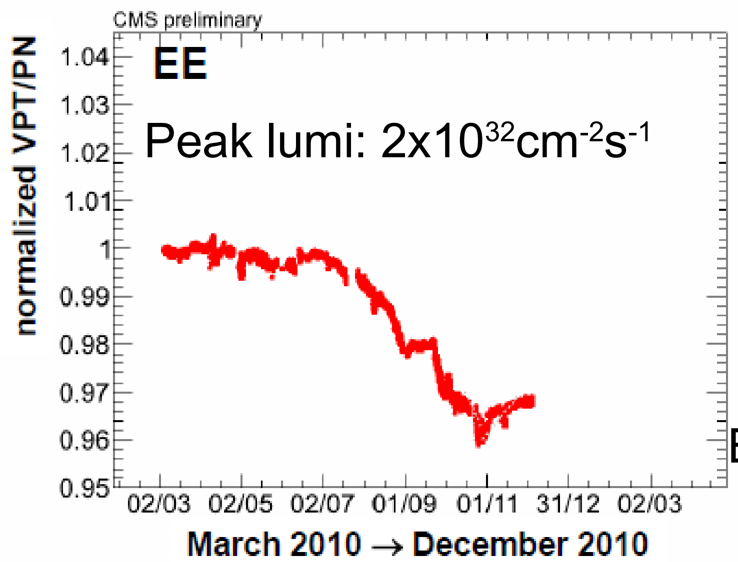




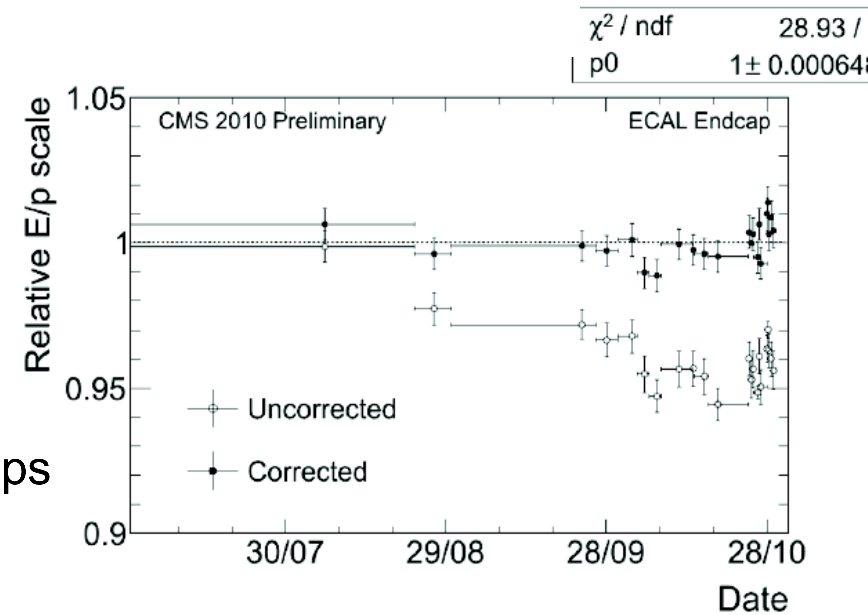
ECAL Transparency corrections

- ECAL $PbWO_4$ crystals temporary lose transparency due to irradiation (O(1%) in barrel ~10% in endcaps)
  - formation of colour centers → partially recovered without beam
- Damage/recovery cycles monitored by laser:
  - 2 wavelengths: 440 nm and 796 nm
  - pulsed @ 80Hz (LHC abort gaps) → dedicated stream @ HLT level
  - small online farm → corrections within 48h → applied in prompt-reco



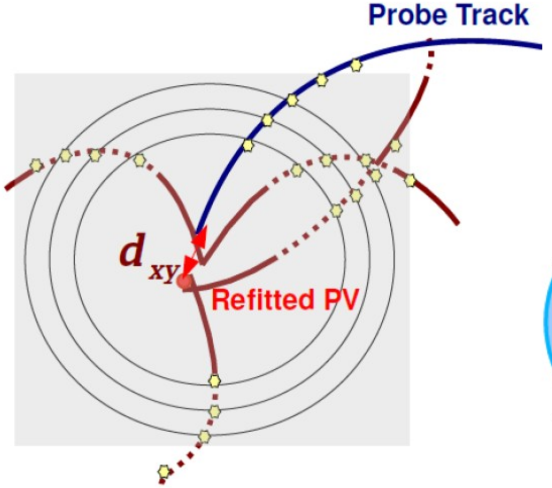


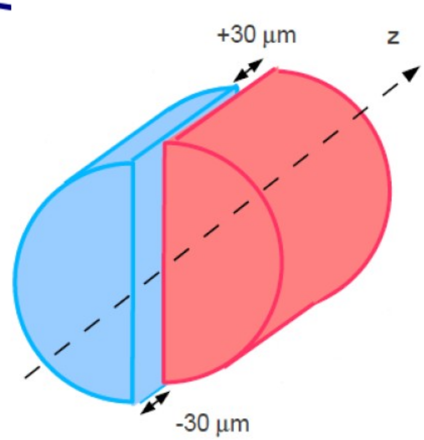
ECAL Endcaps

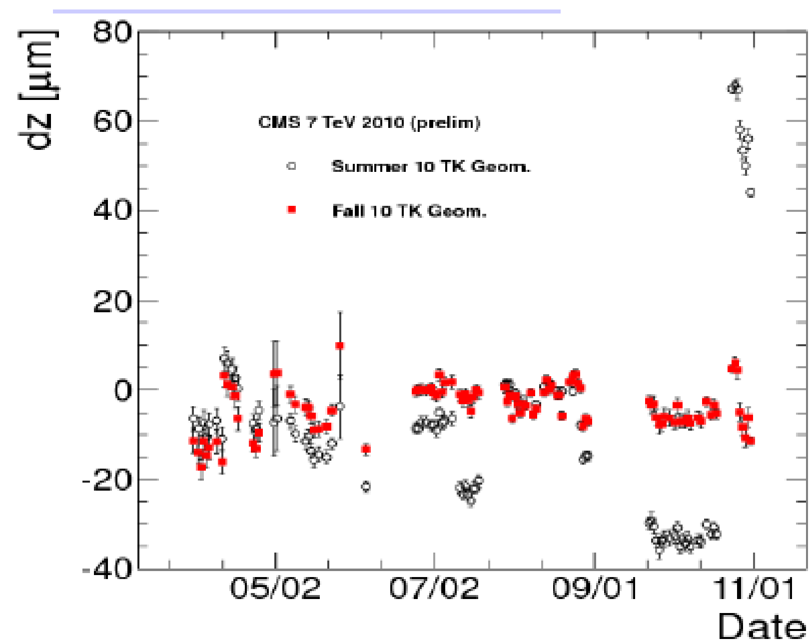


Monitoring of Tracker Structures

- Continuously use express data to monitor Tracker alignment
- Particularly critical for Pixel half-barrels:
  - changes in longitudinal separation mechanically allowed
- Monitoring systems: Primary-Vertex (PV) monitoring:
  - plot d_{xy} and d_z of track N^{th} wrt the PV computed with remaining N-1 tracks (as a function of ϕ-sector of probe track)
- Movements corrected by alignment geometry (up to 30μm)





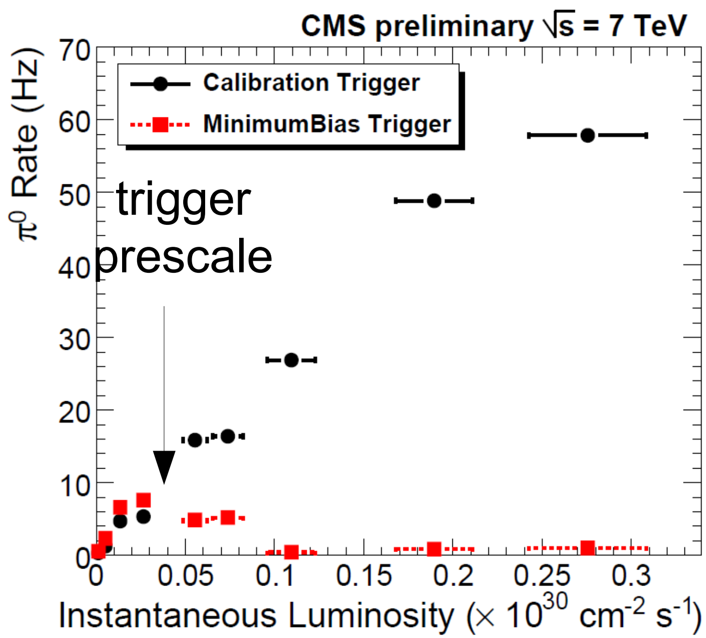


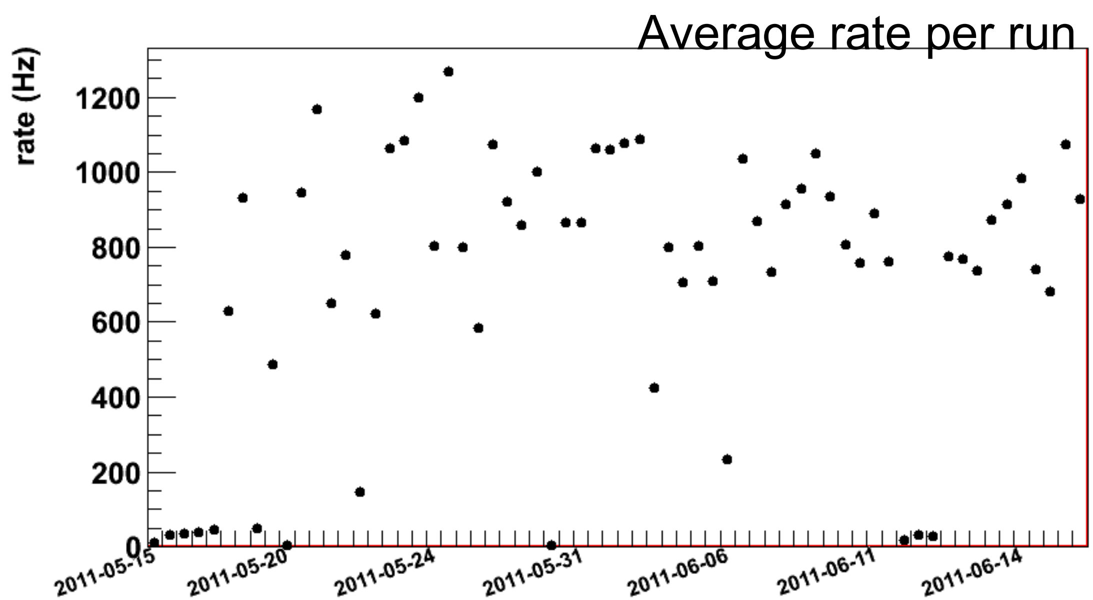
Alignment & Calibration Streams

- All workflows fed by dedicated skims or datasets:
  - event selection tuned on the needs of the workflow
  - event content reduced to optimize bandwidth/disk space usage
- 2 kind of calibration streams:
  - produced directly @ HLT level
    - select (low bias) events (otherwise discarded for physics needs)
    - workflows statistically limited or requiring dedicated selection:
      - e.g. ECAL π^0 stream and ϕ-symmetry....
    - profit from High Level Trigger flexibility → software based
  - produced offline during express and prompt reconstruction (and offline re-processing)
    - just skimming events dedicated to calibrations
      - tracker alignment → minimum-bias, muons and resonances
      - ECAL calibrations → electrons from W and Z
      - HCAL calibrations → di-jet events
      - muon chamber time pedestals and alignment

ECAL crystal inter-calibration

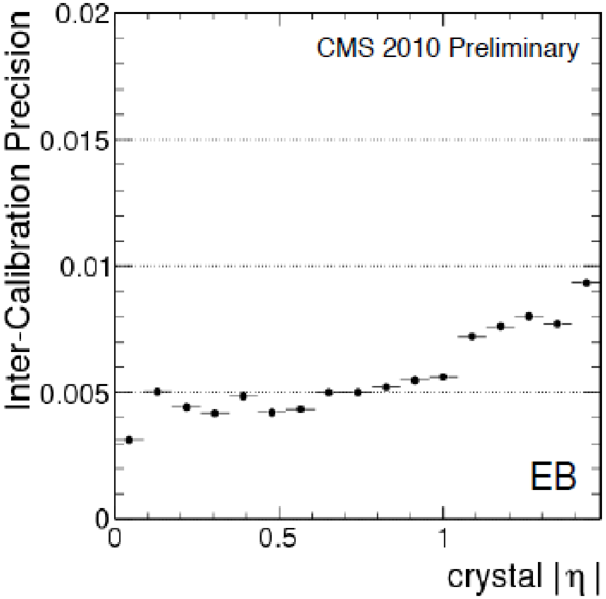
- Calibration stream produced @ HLT level: π^0 and η calibration events
  - low CPU usage @ HLT:
    - seeded by Level1 single-e/γ or single-Jet triggers
    - regional unpacking ($\Delta\eta$ x $\Delta\phi$ = 0.25 x 0.4 around the seed)
    - event selection based on info @ crystal-level only
  - high rate (O(1kHz)) but low bandwidth (~40MB/s)
    - store data only for interesting crystals (ROI)

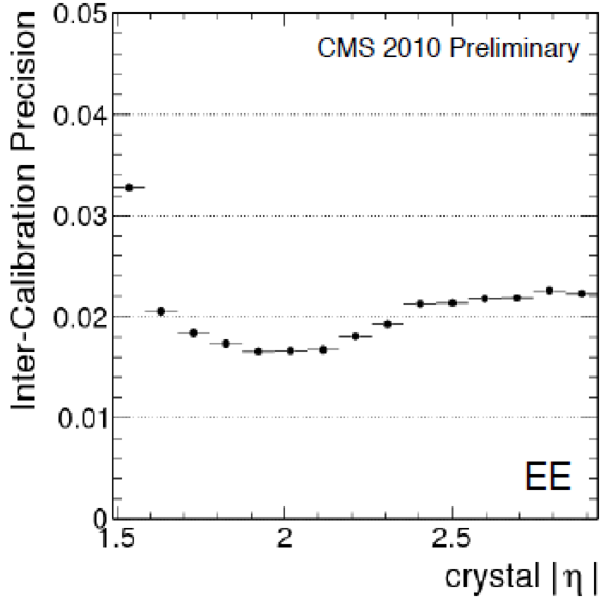




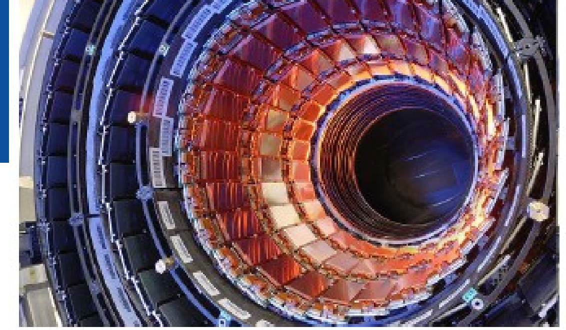
ECAL crystal inter-calibration

- Inter-calibration based on several (complementary) techniques:
  - pre-calibrations @ test-beam + cosmics
  - ϕ-symmetry → ϕ invariance of energy flow @ fixed pseudo-rapidity
    - dedicated stream (@ HLT) of minimum-bias events
  - π^0 and η calibration → photon pairs $\pi^0(\eta) \rightarrow \gamma\gamma$
- Combination allows to reach almost asymptotic precision in barrel
  - estimated comparing in-situ calib. against test-beam values (1/4 of the barrel crystals)

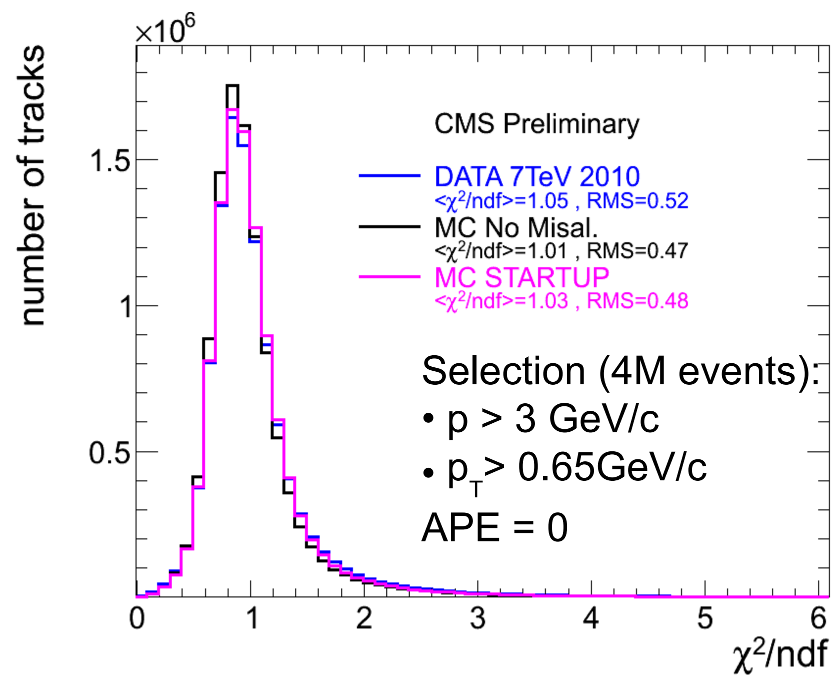




Tracker Alignment

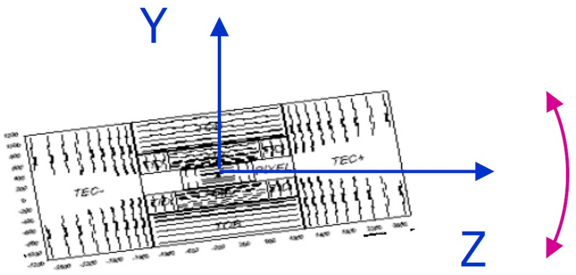


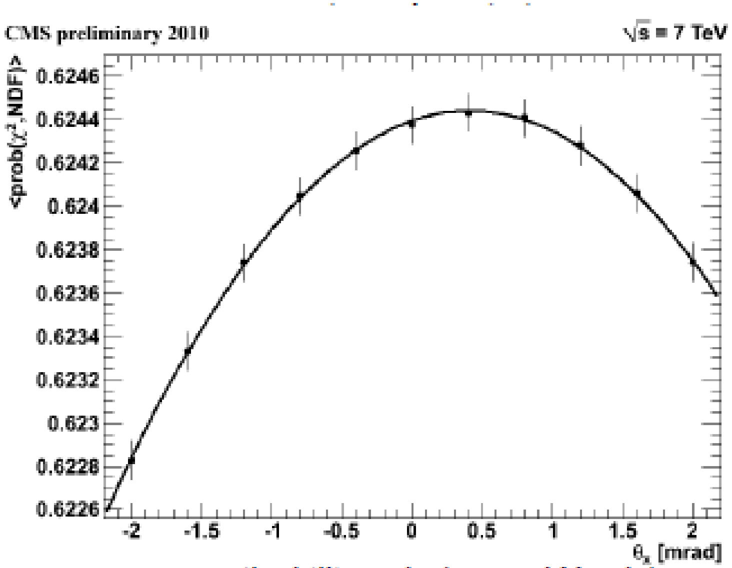
- Largest silicon tracker ever built ($\sim 200\ m^2$, 16588 modules)
  - alignment huge challenge methodically & computationally
- Track-based alignment combining two methods:
  - local method (HIP): alignment parameters from residuals of each alignable → iterative method
  - global method (Millepede-II): simultaneous fit of all alignment and track parameters
- Combine cosmics & collision data:
  - dedicated offline streams:
    - Minimum-Bias tracks
    - muons
    - resonances
- Performance are very close to “ideal” (=perfectly aligned) tracker



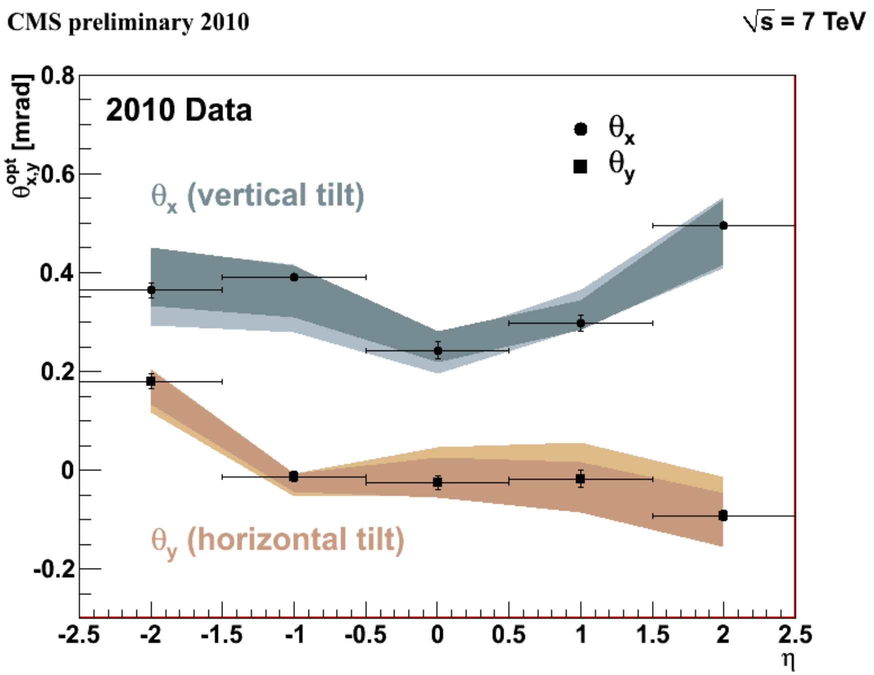
Tracker vs Magnetic Field

- Studied tilt angles of tracker w.r.t. magnetic field
  - goodness of fit (χ^2 prob.) scans for various tilt angles
    - vertical tilt (θ_x) ~300µrad
    - horizontal tilt (θ_y) ~zero





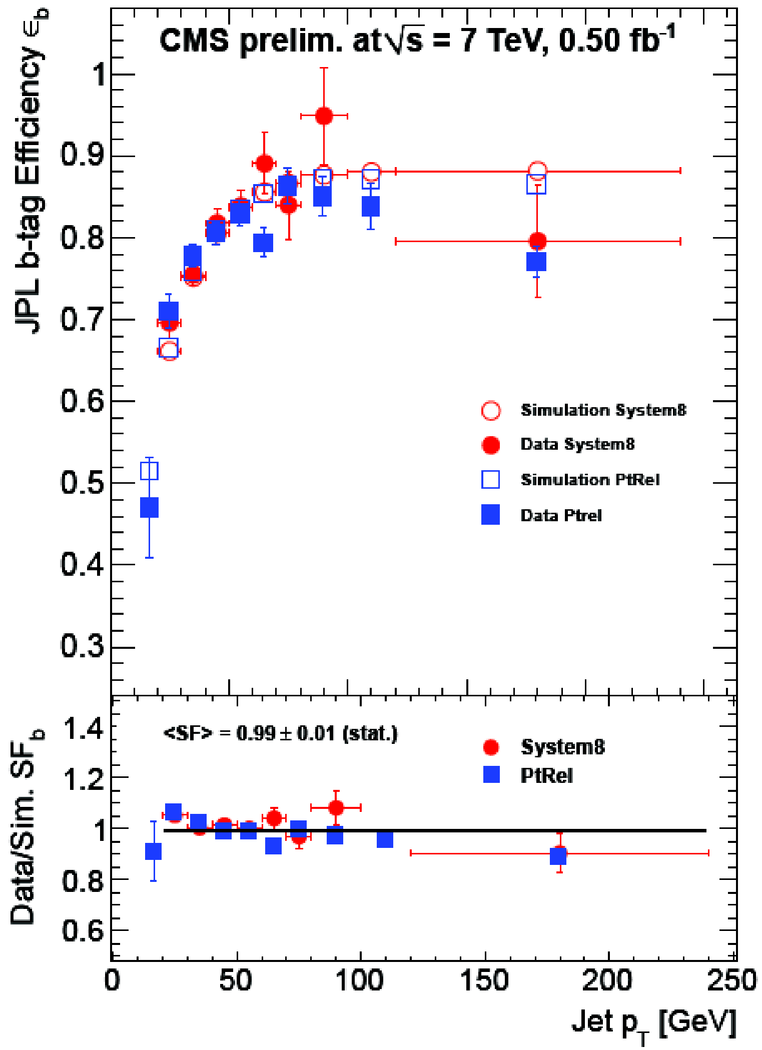
θ_X = vertical tilt angle (around X axis)



Performance

- Calibration workflows demonstrated needed robustness and flexibility:
  - can tune latency depending on needs
  - produce physics results very quickly: plots like this one →

    out of prompt-reconstruction
    (few hours after the data acquisition)
- Quality of prompt-reco → minimize need for offline re-reco
- Calibration & Alignment scenario in MC simulation:
  - decent data/MC agreement also on convoluted variables



Outlook

- The Alignment & Calibration infrastructure proved to be efficient and effective
  - fast analysis turnaround
  - prompt calibration → publication level data out of prompt-reco (48h after data-taking)
- The calibration challenge is still ongoing:
  - many conditions require continuous monitoring → automation is a key asset
  - still room for improvement for many aspects → not yet asymptotic in terms of performance
- Calibration & alignment tightly coupled to workflows for:
  - data-certification and validation
  - offline reconstruction