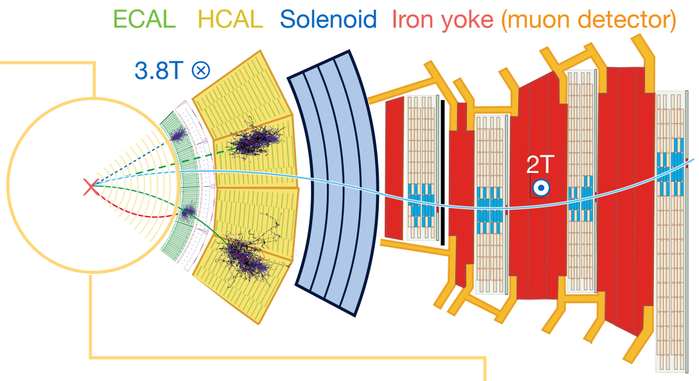
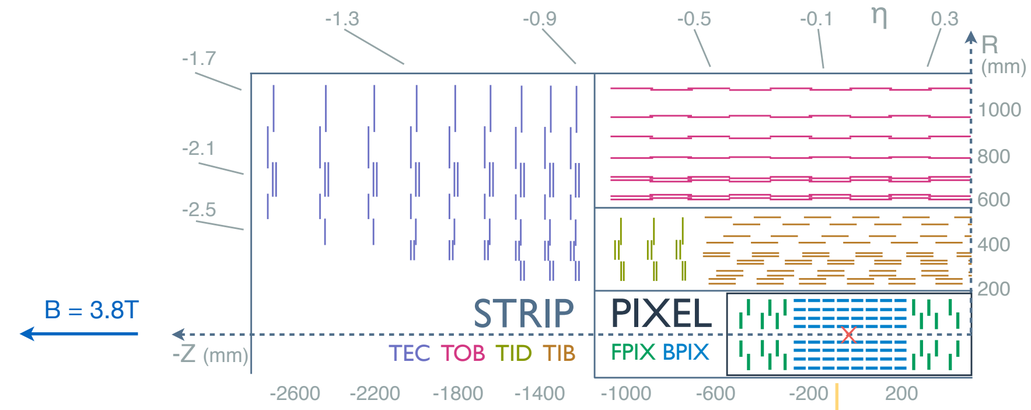
Tracker alignment of the CMS detector

Nazar Bartosik on behalf of the CMS Collaboration
Istituto Nazionale di Fisica Nucleare (INFN), Torino, Italy

PSD12 | 12-17 September, 2021 | Birmingham, UK
12th International Conference on Position Sensitive Detectors

CMS tracker





The innermost detector
- highest spatial resolution
- largest irradiation dose

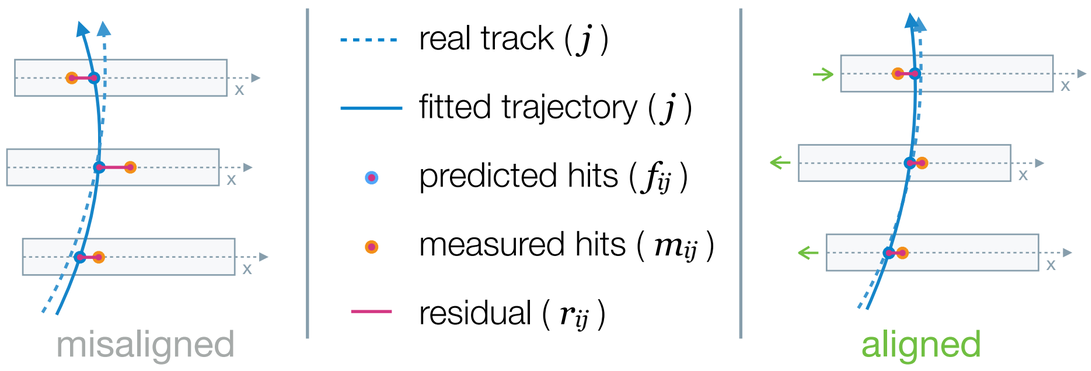
Crucial component of event reconstruction:
- p_T measurement (track curvature)
- particle identification (charged vs neutral vs photon)
- vertex reconstruction (combining multiple tracks)
- heavy-flavour jet tagging (jet-vertex matching)

Consists of up to 1 856 PIXEL + 15 148 STRIP individual Si detector modules with spatial resolution of $\mathcal{O}$(10μm) vs $\mathcal{O}$(100μm) mounting precision
$\mathcal{O}$(1mm) large-structure movements

Track-based alignment

Incorporating alignment constants as free parameters in the track fit
performing least-squares minimisation of normalised track-hit residuals

$$\chi^2(p,q) = \sum_{j}^{tracks} \sum_{i}^{hits} \left(\frac{m_{ij} - f_{ij}(p,q_j)}{\sigma_{ij}^m} \right)^2$$



Up to 9 parameters/module
↳ **~200K parameters in total**
- translation [along 3 axes]
- rotation [around 3 axes]
- surface deformation [3 parameters]

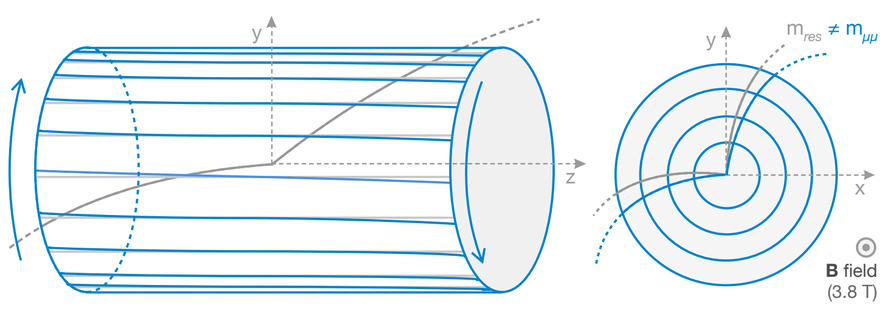
- $m_{ij} \pm \sigma_{ij}$ - measured hits
- f_{ij} - predicted hits
- p - alignment parameters
- q_j - track parameters

Primary algorithm implementation → **MILLE PEDE - II**

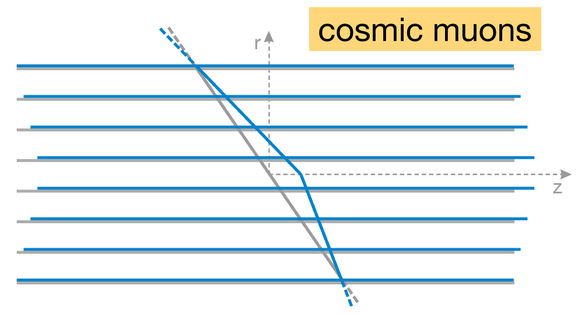
Systematic distortions

Cylindrical symmetry of the Tracker makes the raw minimisation of residuals insensitive to certain systematic misalignments

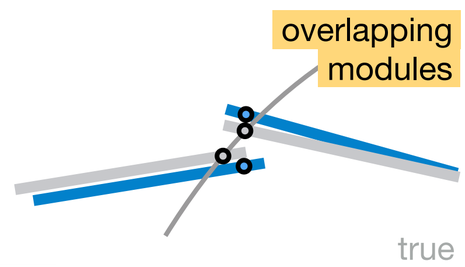
↳ additional constraints provided by **special track topologies** + usual isolated-muon tracks from the *pp* collision data



dimuon resonances
$Y \to \mu\mu$
$Z \to \mu\mu$

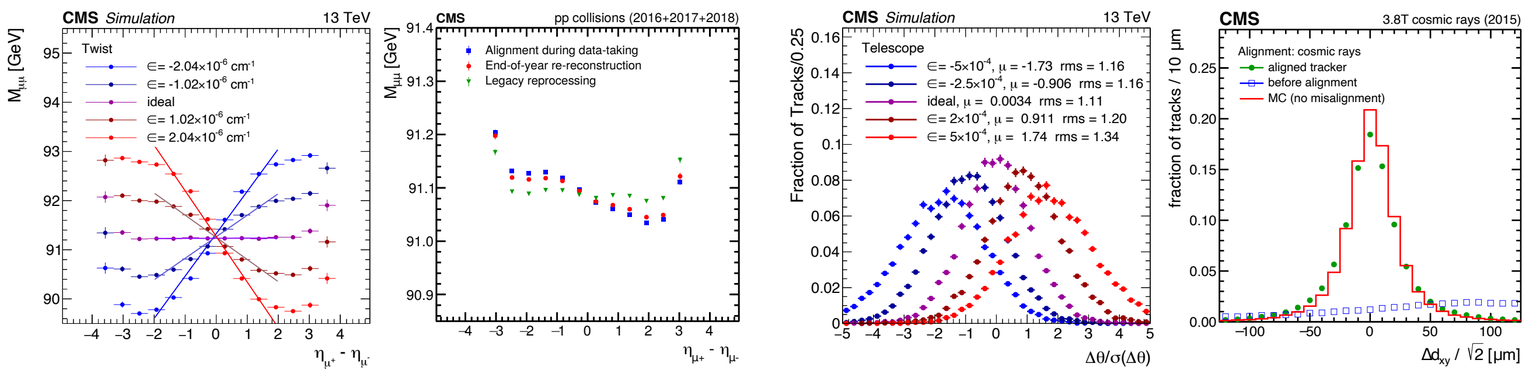


cosmic muons



Simple parameterisations of r/z/ϕ vs Δr/Δz/Δϕ used to generate data with distorted geometries
for validating the alignment procedure in simulation

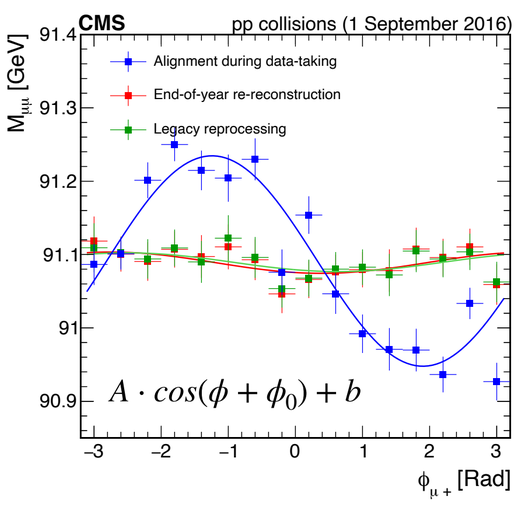
Track-hit residuals and track-parameter biases reduced in real data as expected



Time dependence

Combination of data from extended periods of time requires accounting for time-dependent changes in the detector conditions
assigning Intervals Of Validity (IOVs) to subsets of parameters
- movements of large structures (changes in temperature and magnetic field, upgrade activities)
- irradiation effects (changing Lorentz angle)

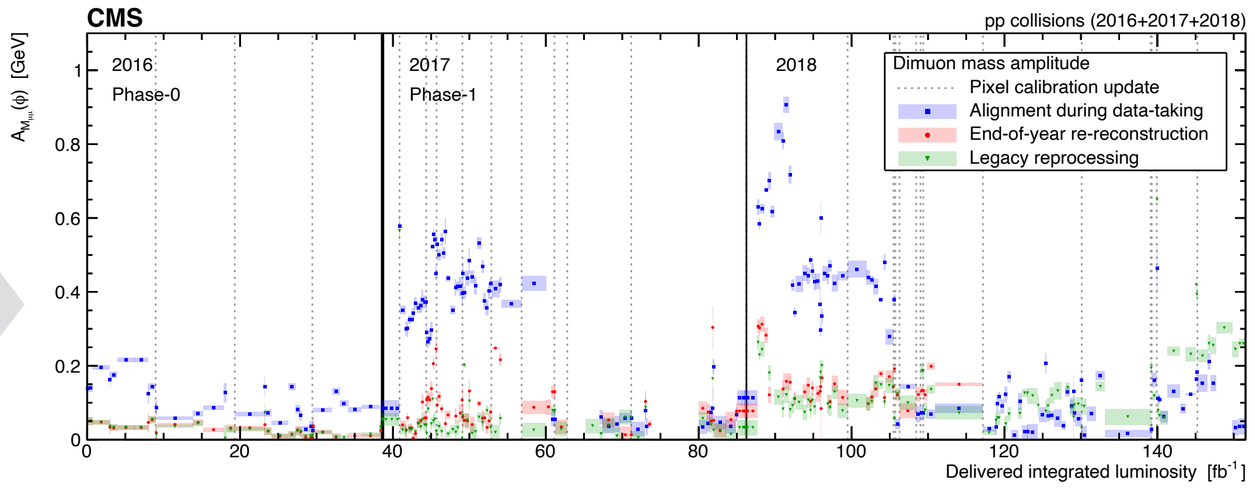
Significantly reduced bias of reconstructed $m_{\mu\mu}$ using fine time granularity and high statistics of tracks



$A_{M_{\mu\mu}}$

Automated alignment of large structures performed routinely
using the limited statistics available during data-taking (within 48h)

Ultimate precision obtained with finer IOVs and full statistics
available at the end-of-year and legacy reprocessing stage



+ other features

- **Alternative alignment algorithm: HIPPY**
- **Realistic misalignment for MC simulations**
- **Integrated Lorentz-angle calibration**