First Alignment of the CMS Tracker and its Implications for the First Collisions Data

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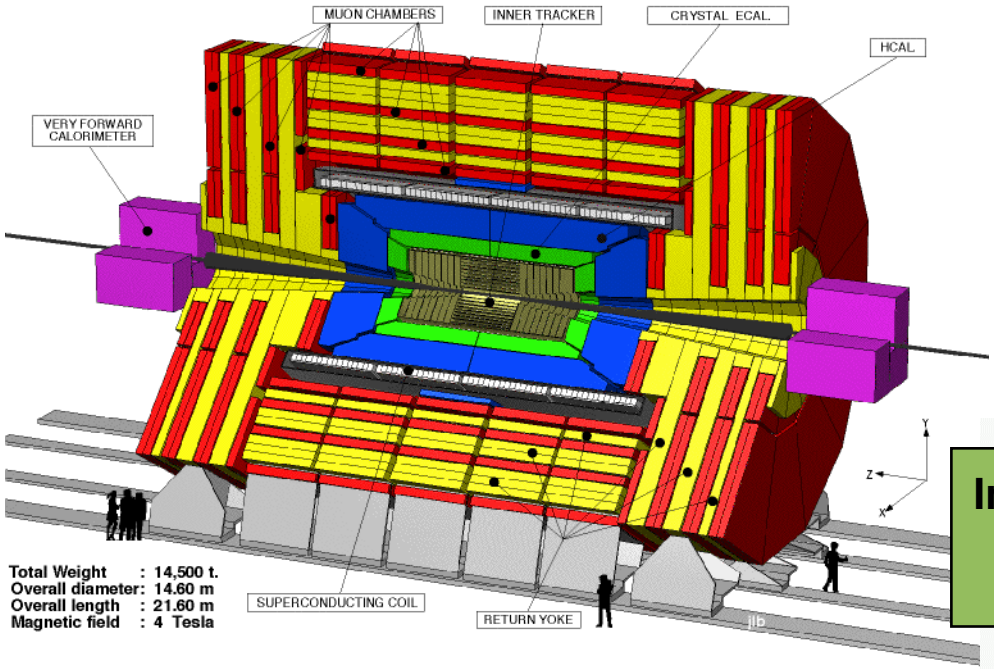
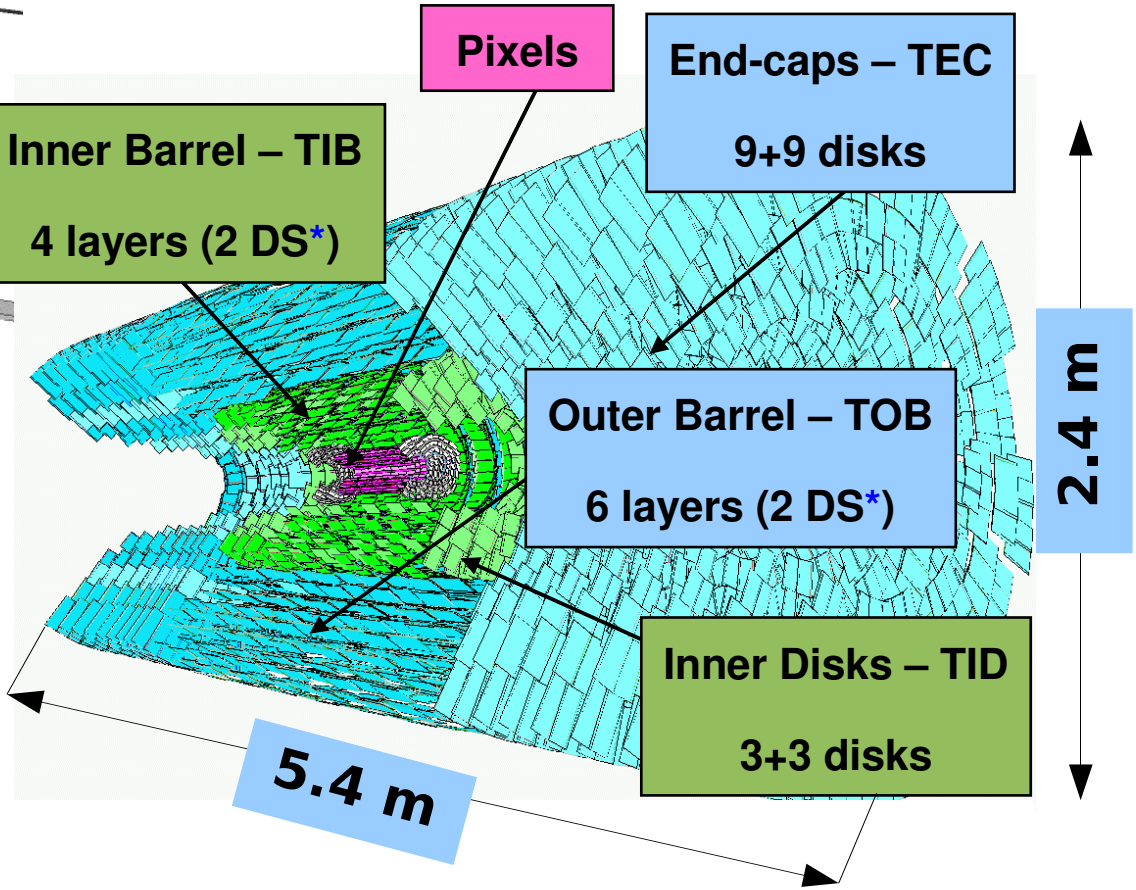
– on behalf of the CMS Collaboration –

CMS Experiment and its Tracker



- The ***CMS Experiment*** is one of the 2 *multi-purpose experiments* at the p-p accelerator ***LHC*** at CERN
- It will provide insight in Higgs(es) physics / Super-symmetry / ***new physics at the high energy frontier***

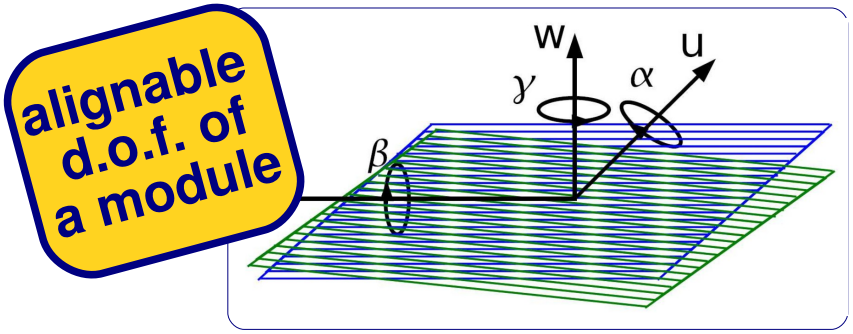


- The ***all-silicon design*** of the tracking system of the CMS experiment is expected to provide *1-2% resolution for 100 GeV* tracks and an *efficient tagging of b-jets.*
- The *alignment of the Silicon Tracker* is crucial to reach the design resolution of the CMS experiment for most physiscs channels

*Double Sided (2 modules mounted back-to-back tilted by 100 mrad)

Tracker Alignment

- Goal: nail down to a few μm the positions of all 16,588 (x 6 dof) silicon modules of CMS Tracker.



- Alignment strategy in CMS: use all available data sources:
  - Surveys (optical/mechanical/...)
  - Laser Alignment
  - *Track Based Alignment*

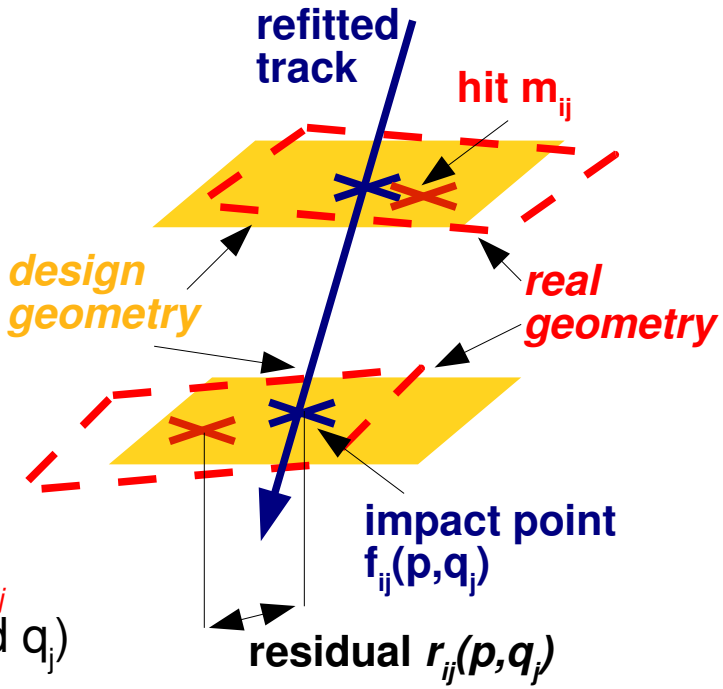
- From older experiments: ultimate precision is achieved using track based alignment, i.e. particles crossing *in situ* the Tracker volume

Track Based Alignment

- Define a Global Track χ^2 function:

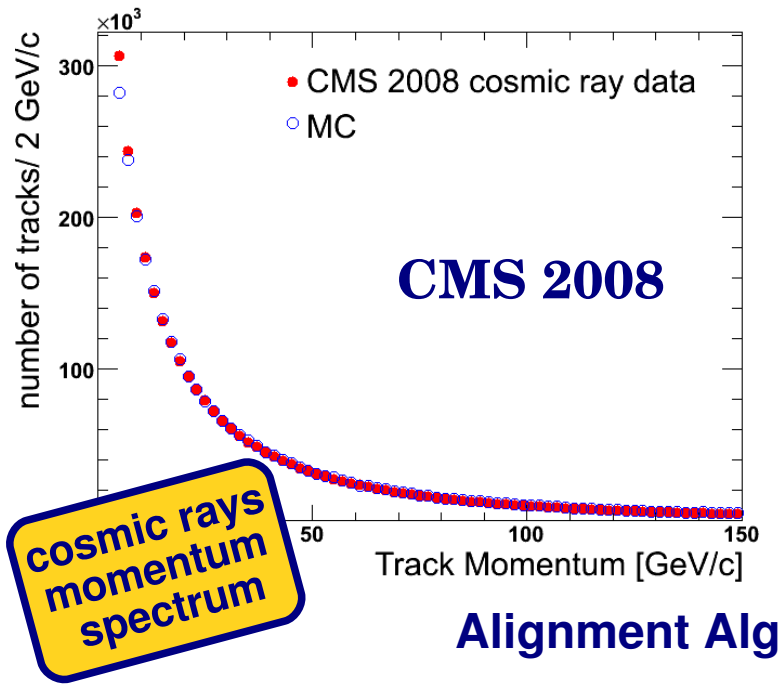
$$\chi^2 = \sum_{j=1}^{N_{tracks}} \sum_{i=1}^{n_{hits}} \boldsymbol{r}_{ij}^{T}(\boldsymbol{p},\boldsymbol{q}_j)\, \boldsymbol{V}_{ij}^{-1}\, \boldsymbol{r}_{ij}(\boldsymbol{p},\boldsymbol{q}_j)$$

- V_{ij} = covariance matrix from fit
- *p = alignment parameters (module position/orientation)*
- q_j = track parameters
- $r_{ij}(p,q_j)$ = residual: difference between measured position m_{ij} and position extrapolated from fit $f_{ij}(p,q_j)$ (depending on p and q_j)



- *Aligment algorithms attempt to minimize this χ^2 function and therefore track residuals*

Track Based Alignment with cosmic rays



- First complete alignment of the CMS Traker performed at the Cosmic Run at Four Tesla (CRAFT)
- A "*global run*": all CMS subdetectors participating to the data taking
- Major milestone demonstrating CMS capability of running over long periods
- 300 Million cosmic muon triggers collected @ 3.8 T
- Chance of performing alignment and calibration as an input to collision data taking

Alignment Algorithms used during cosmic data taking:

- minimizing the χ^2 with millions of tracks requires sophisticated algorithms, two complementary methods were used:

"Hits and Impact Points HIP" *(local method)*:

- Estimates alignment parameters per module, **iterates** due to correlations.
- Stabilizes minimization **by including survey**.

☺ Uses same track model as reconstruction.

☹ Needs many iterations to include correlation

"MillePede II" *(global method):*

- **Fits** track and alignment parameters simultaneously **in one step**.

☺ All correlations considered, no need for iterations.

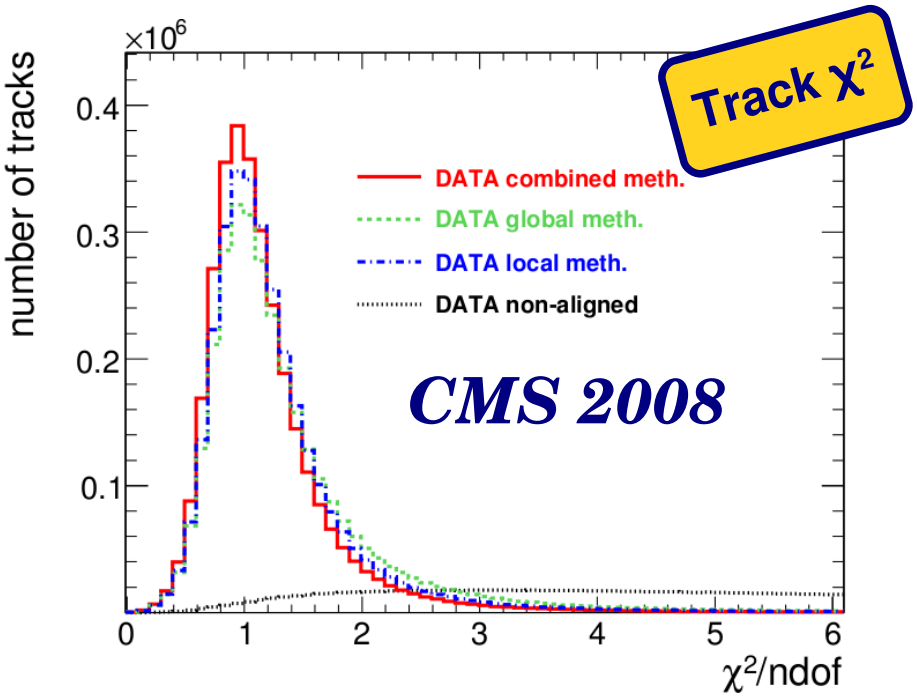
☹ Uses 5-parameter helix as track model.

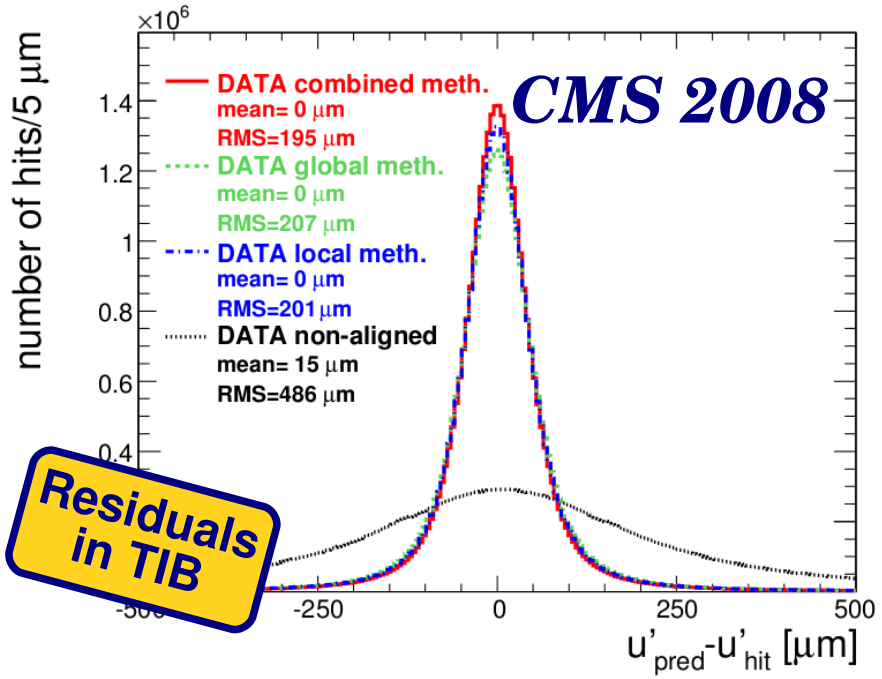
Alignment strategy and results

- Run a multi-step approach for both algorithms
  - *Large structure* movements (coherent ***v*** alignment of Single Sided modules)
  - Alignment of the two sides of the 2D strip *modules (units)* ***u,w,γ***
  - module-level alignment of strip and pixel modules

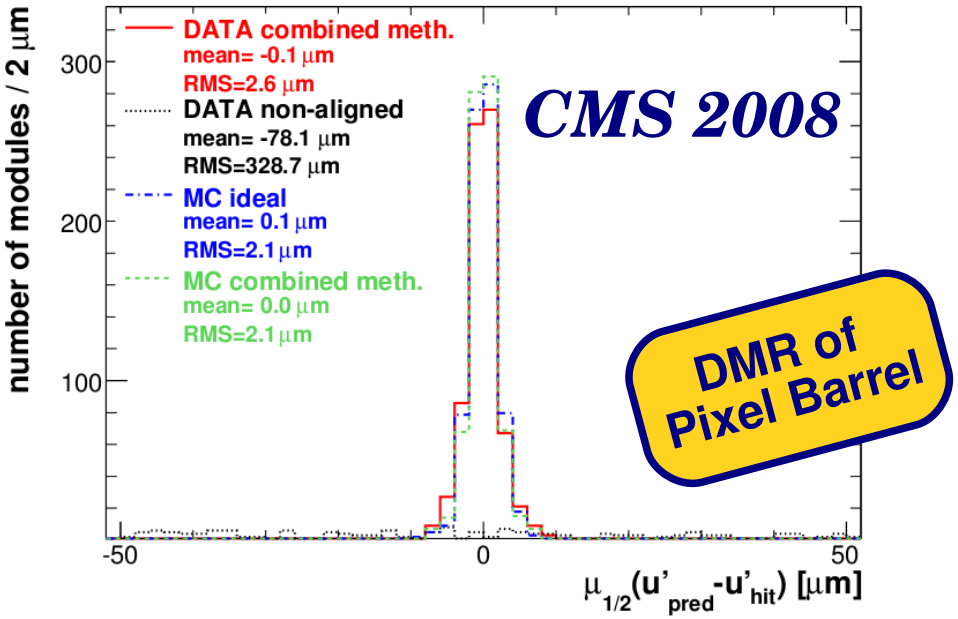
- Both showed clear improvements, **final strategy:**
  - Get the **best** from **both** algorithm, combining the two:
    I. run the ***global method***→ solves global correlations efficiently
    II. run the ***local method*** → solves locally to match track model in all degrees of freedom

- All the three results are compatible but the Combined shows the best performance



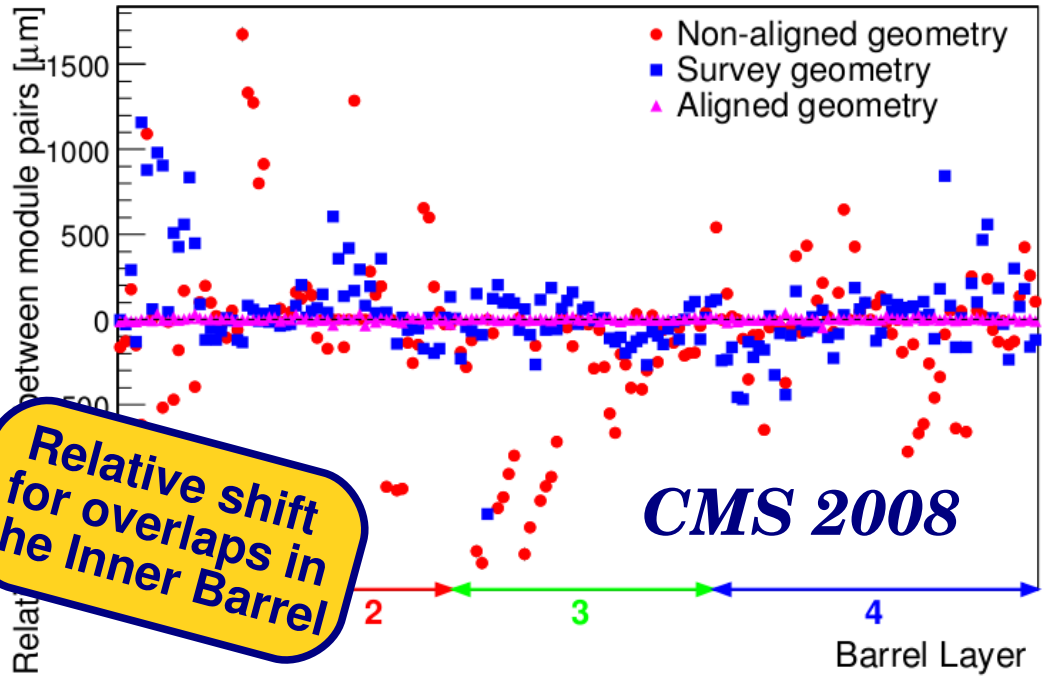


Validation Methods



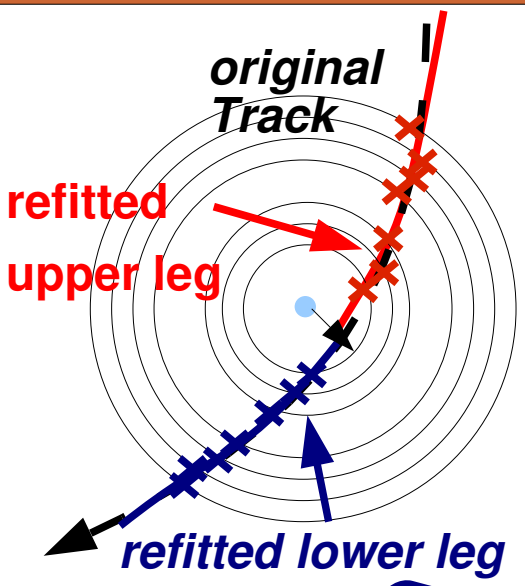
- **Overlapping modules** of *same layer* might have hits from same track.
- *Difference of their residuals* (overlap residuals): sensitive to relative misalignment within one layer. **Offsets indicate shifts**.
- Modules of TIB show significative improvement (RMS decreases)
- Same order of magnitude achieved in TPB and TOB

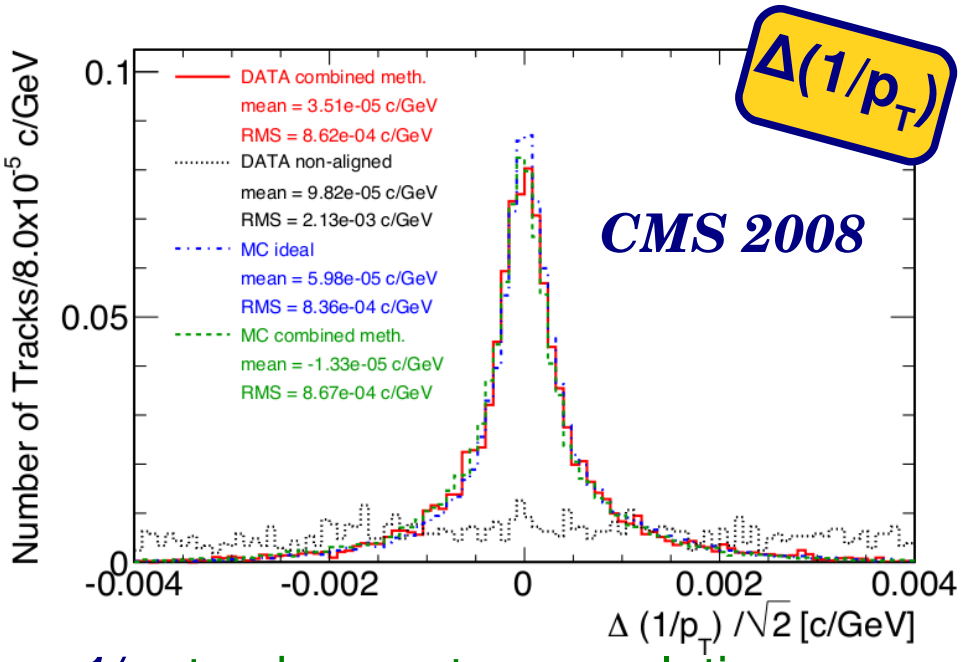
- **Measure for remaining misalignment:**
  - Module-wise informations: **D**istribution of **M**edian of **R**esiduals (**DMR**)
  - Spread gives the lower limit for misalignment (given sufficient statistics)
  - Sensitive to the ***incoherent displacements*** of the modules w.r.t each other in the *sensitive coordinate*
  - Used to estimate misalignment corrections to intrinsic hit errors



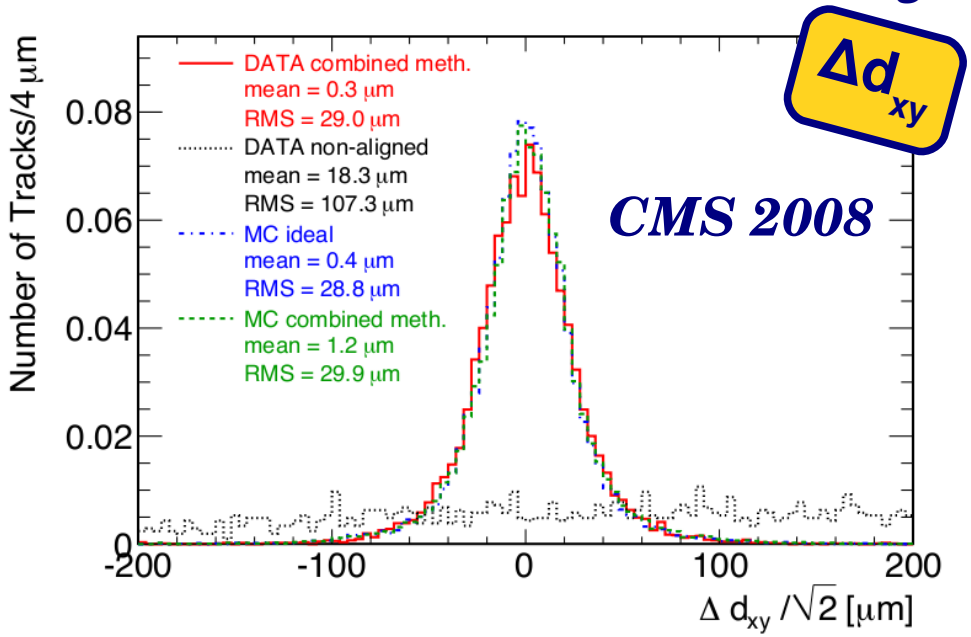
Implications for tracking

- Track parameter resolutions depend on alignment
- Idea: split the cosmic tracks along impact parameter and compare the five track parameters $X=(p_T, d_{xy}, d_z, \varphi_{tk}, \theta_{tk})$ of top and bottom halves independently reconstructed
- Define residuals as: $r = \frac{X_{top} - X_{bottom}}{\sqrt{2}}$
- Alignment has a dramatic impact on the resolutions





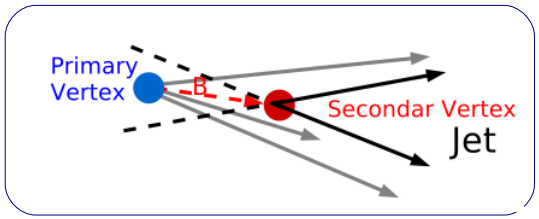
- $1/p_T$ track curvature resolution as good as in simulation



- d_{xy} transverse impact parameter resolution already good ($\sigma \simeq 30$ μm)

Implications for early physics

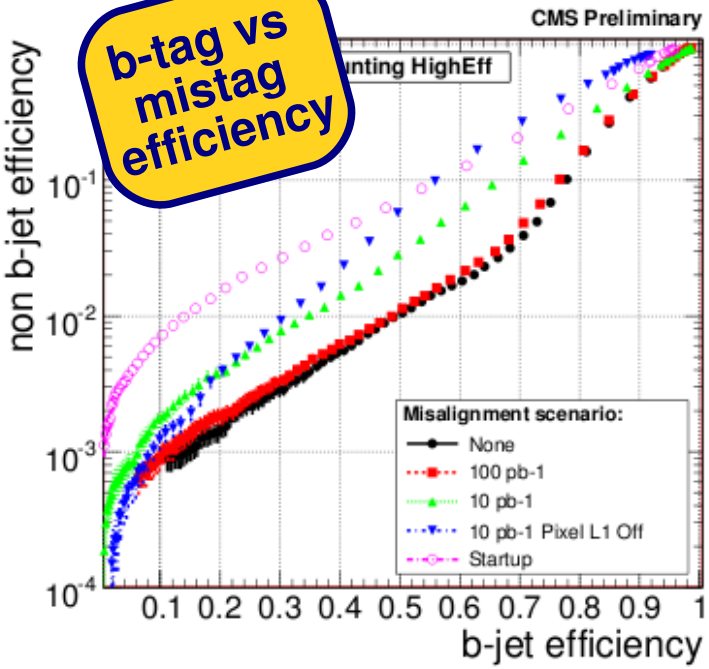
- B-tagging relies completely on tracking performance:



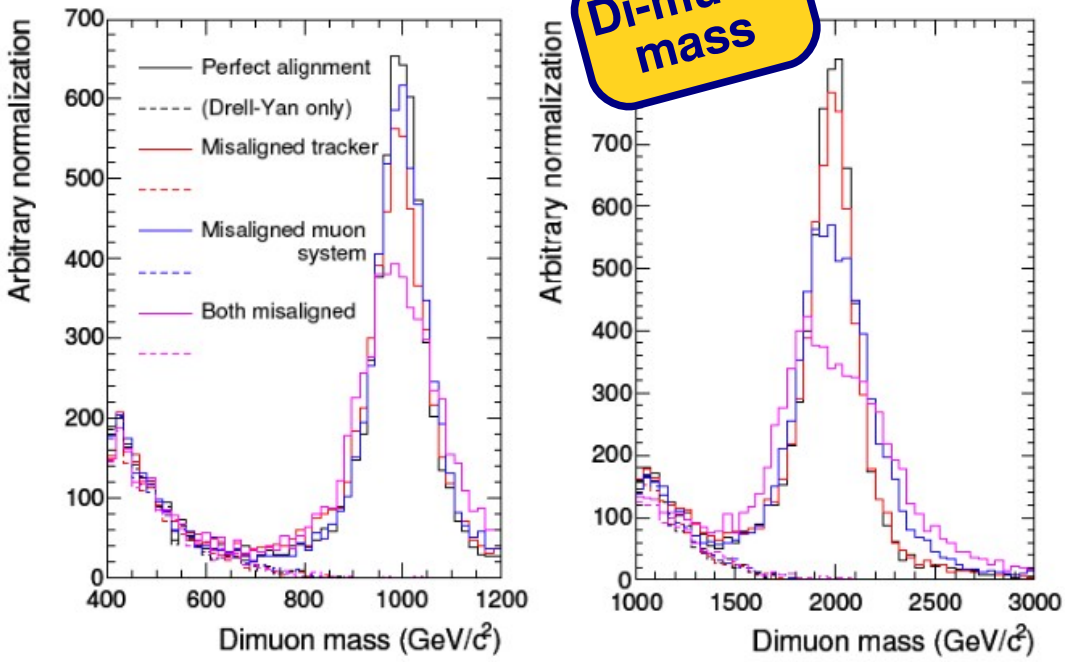
Needs clear separation between *primary* and *secondary vertices*

- all b-tag algorithm are sensitive to alignment
- Several misalignment scenarios considered
- b-tag efficiency improves with accumulation of statistics for alignment

b-tag vs mistag efficiency



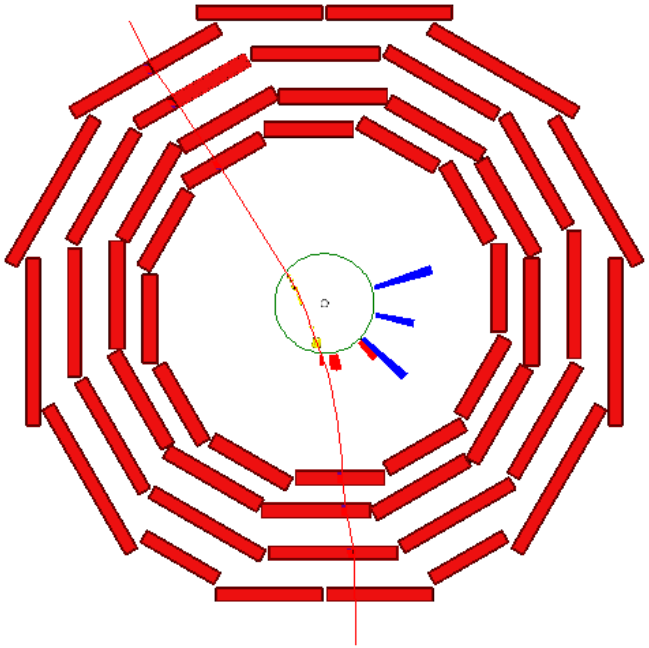
Di-muon mass



- Further MC studies check prospects of finding “new” physics, e. g. in dimuon resonances.
- Detectability and resonance width depend on both tracking systems.
- Alignment affects heavily high p_T muon resolution

Conclusions

- **First track based Alignment of full CMS Tracker** performed on *cosmic data*
- Similar results for *local* and *global* method: dramatic **improvement in alignment quality**. The combined method gives the best results
- *Residual misalgment predicted* and uncertaintes predicted accordingly
- The cosmic track splitting shows achievement of **excellent track parameter resolutions**.
- CMS Tracker Alignment is well advanced and prepared for collision data taking.



- **First year** of collision data-taking should already allow some *b-tagging* and “new physics” searches

Thanks for the attention