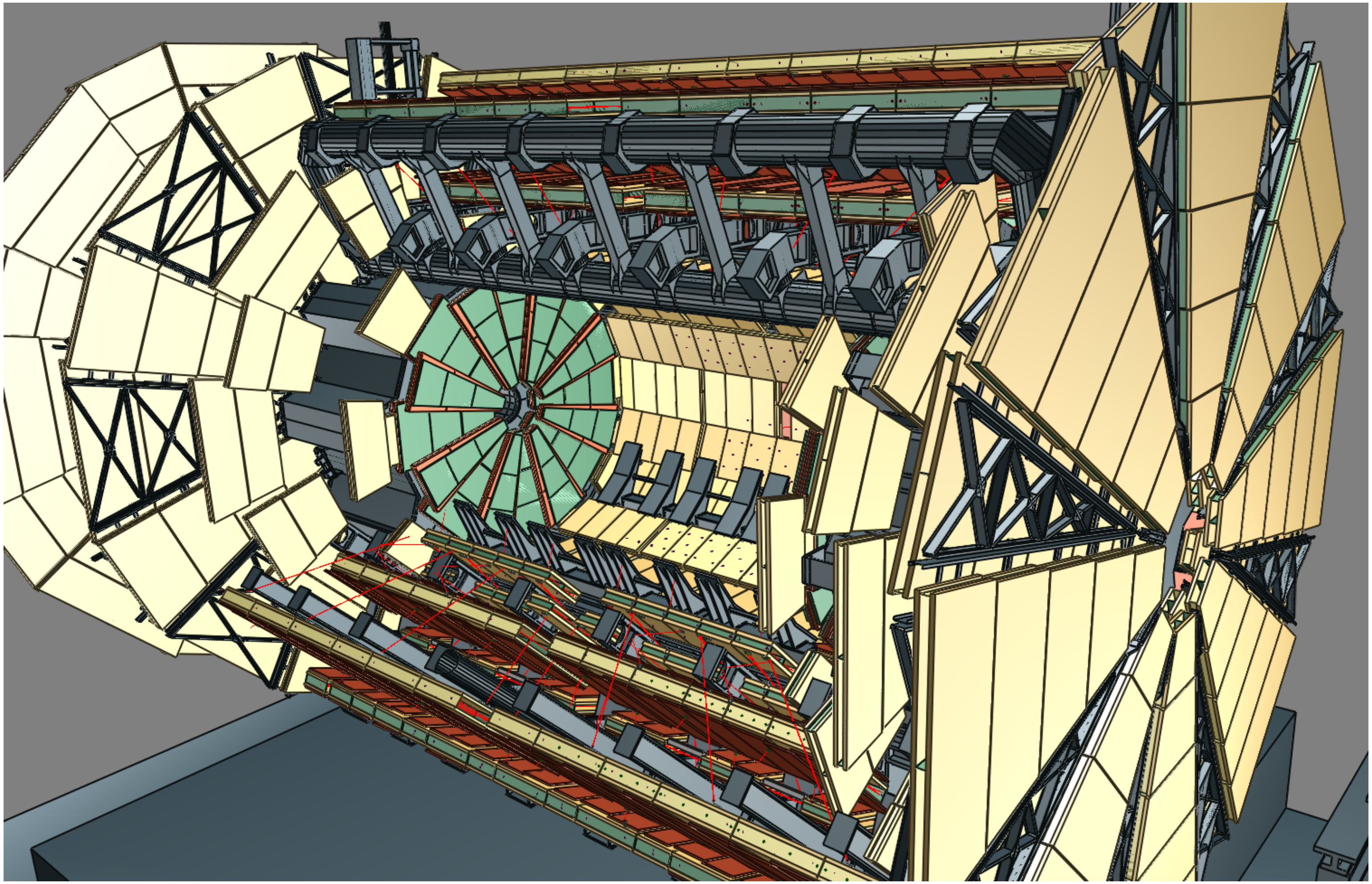
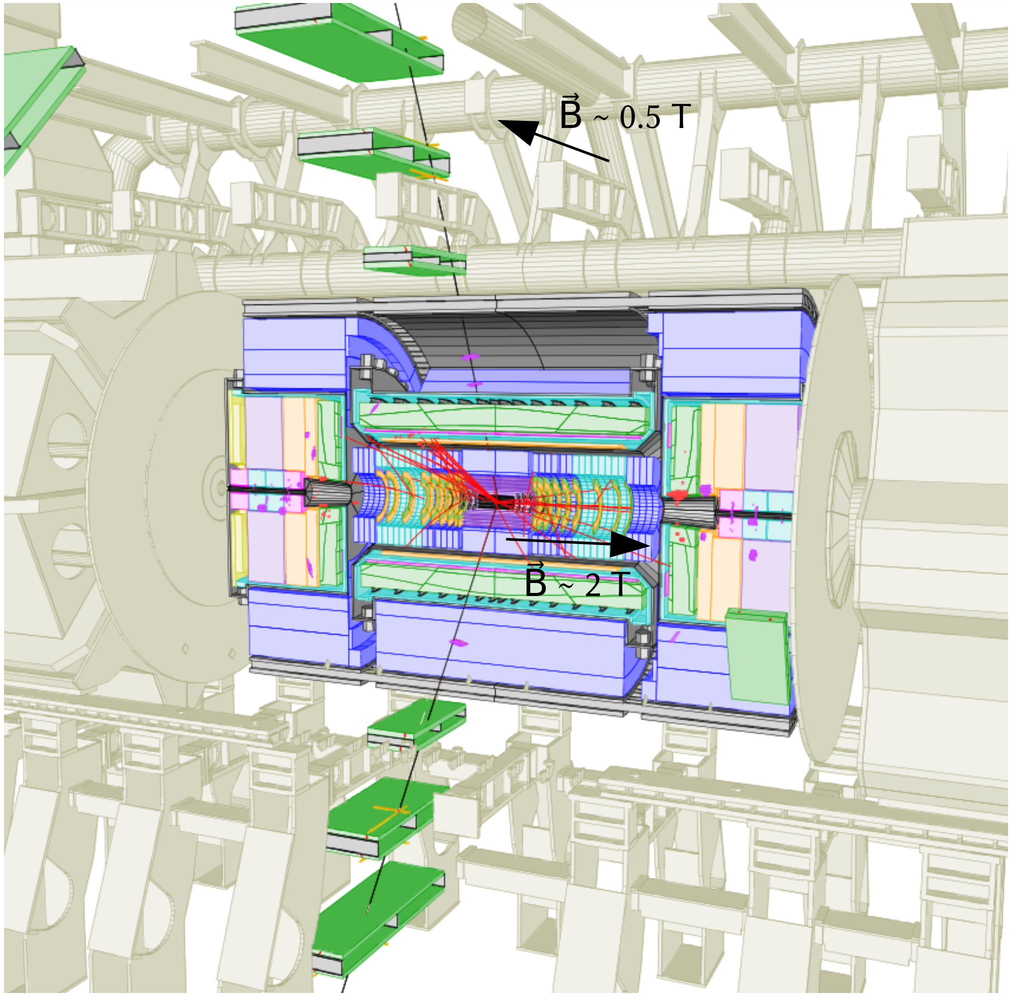


Muon reconstruction and performance: list of topics of interest

P.-F. Giraud

Introduction



Muons are detected and measured by:

- Inner Detector (ID)
  - Solenoid magnetic field
  - Si pixels and strips (SCT), and straw tubes (TRT)
  - (No trigger)
- Muon Spectrometer (MS)
  - Toroidal magnetic field
  - MDT: precision coordinate (η)
  - RPC,TGC: trigger, and second coordinate (ϕ)

LArg and Tile calorimeters do not measure the muons, but affect the muon trajectory and momentum

Several muon tracks can be reconstructed:

- ID track
- MS track
- Combined (CB) track of ID and MS information

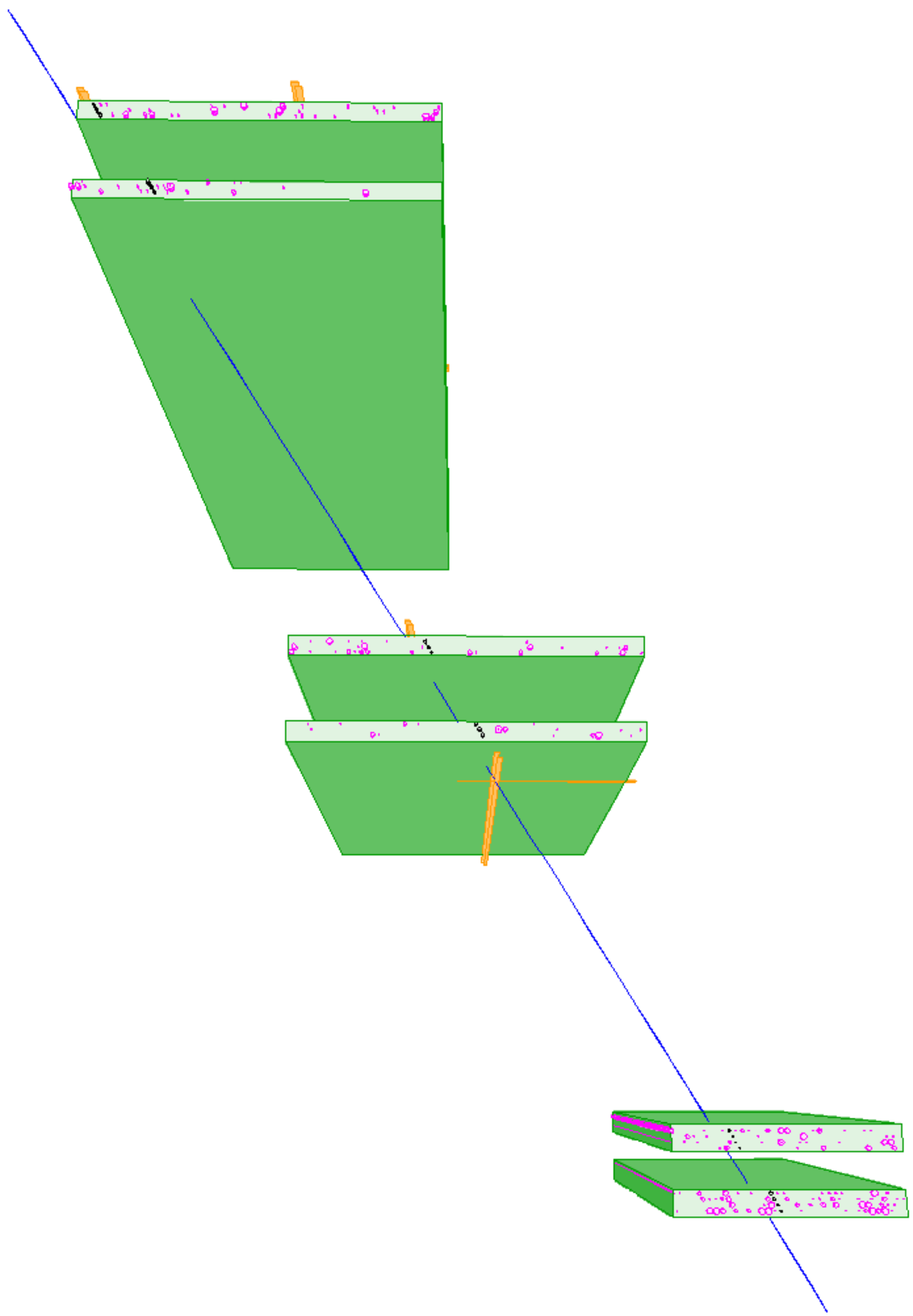
Ingredients affecting the muon reconstruction:

- Interaction of muons with material:
  - Multiple Coulomb scattering
  - Energy loss
- Magnetic field determination
- Detector hit intrinsic resolution
- Alignment

ID and MS have very different systematics:

- Precision EW measurements up to now use ID tracks only
- Idea of Maarten:
  - Work plan to improve the precision of the MS track
  - Use CB tracks in EW precision measurements: increase acceptance in η, extend EW measurements to high energy

What is a muon track?

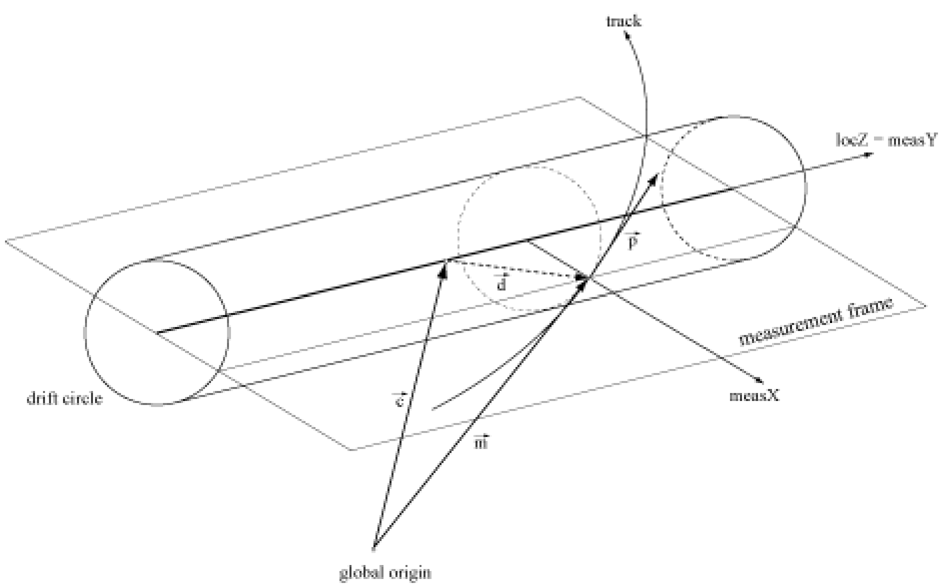


A reconstructed track is (very roughly) made of:

- a collection of detector hits associated together by the muon reconstruction algorithm
- the resulting 5 track parameters **θ**, e.g. perigee representation:
  - 2 direction parameters: polar and azimuthal angles
  - 2 position parameters: d_0, z_0
  - the charge weighted inverse momentum: q/p
- the 5x5 error matrix on the fitted parameters: **V**

The muon reconstruction generally go in the following steps:

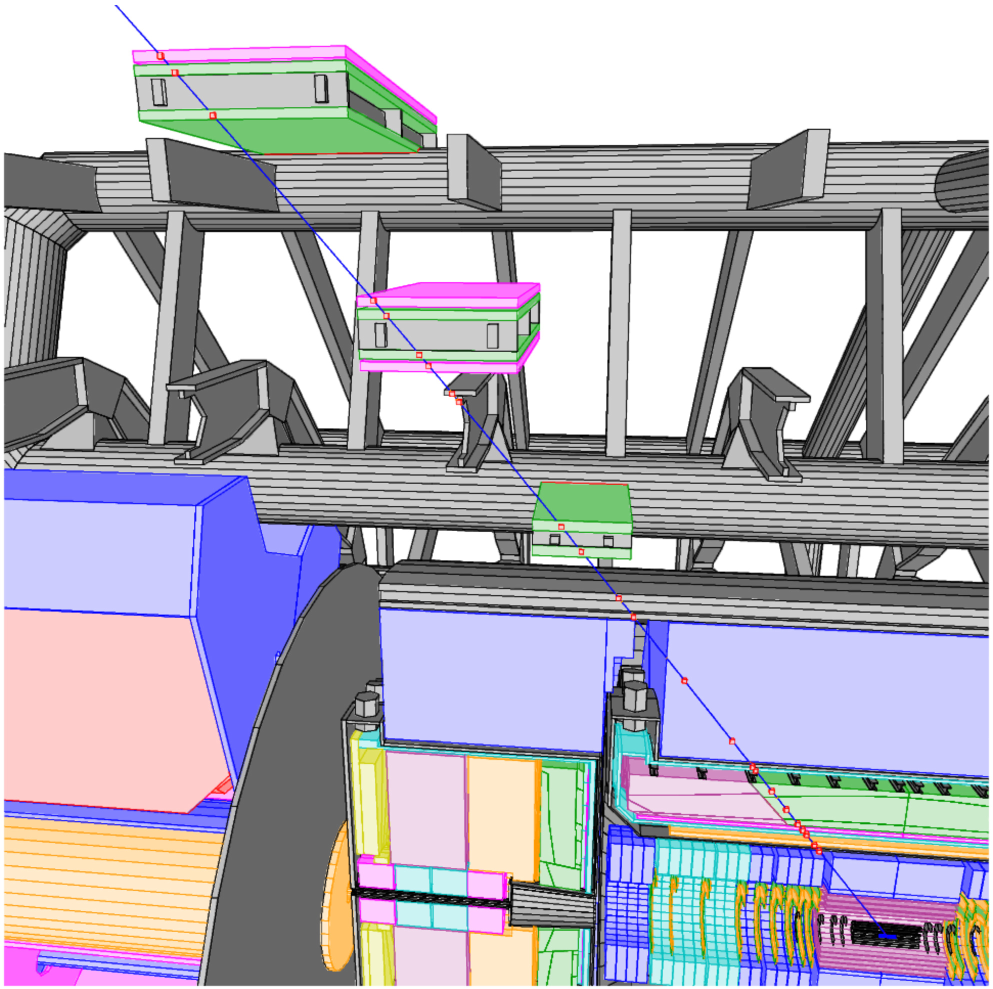
- Reconstruct tracks in the ID: $\boldsymbol{\theta}_{ID}$, $\mathbf{V}_{ID}$
- Reconstruct tracks in the MS: $\boldsymbol{\theta}_{MS}$, $\mathbf{V}_{MS}$ at MS volume entry, and extrapolate to the interation point: $\boldsymbol{\theta}_{ME}$, $\mathbf{V}_{ME}$
- Combine the two tracks: $\boldsymbol{\theta}_{CB}$, $\mathbf{V}_{CB}$
- (Reconstruction algs can proceed differently, but nevertheless define isolated ID and MS tracks)



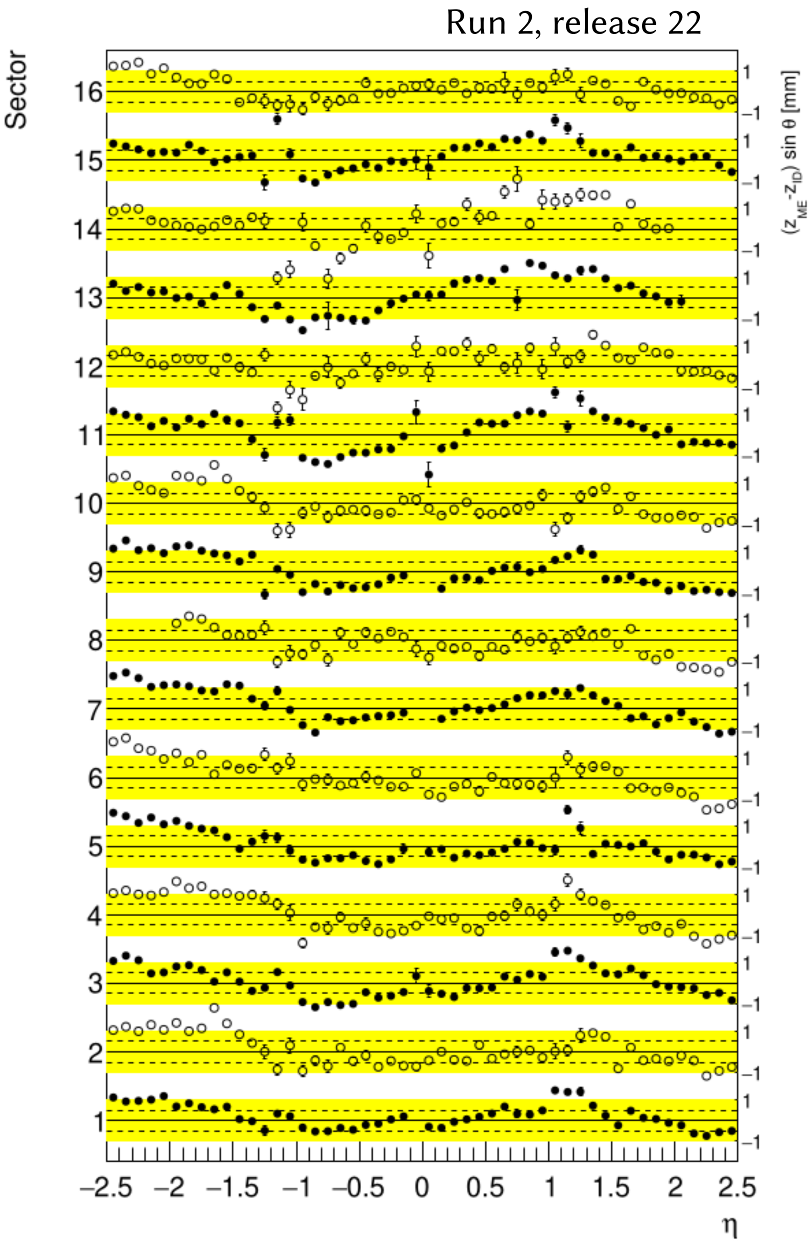
How to make a CB track

Strategies for making the CB track:

- Strategy 1: full refit
  - Merge the hit collections of ID and MS into one large hit collection
  - Refit the track with all the hits: $\boldsymbol{\theta}_{CB}$, $\mathbf{V}_{CB}$
  - This is presently done in the athena reconstruction
- Strategy 2: STACO
  - STAtistical COmbination of the two tracks
    - $\mathbf{V}_{CB} = (\mathbf{V}_{ID}^{-1} + \mathbf{V}_{ME}^{-1})^{-1}$
    - $\boldsymbol{\theta}_{CB} = \mathbf{V}_{CB}\,(\mathbf{V}_{ID}^{-1}\,\boldsymbol{\theta}_{ID} + \mathbf{V}_{ME}^{-1}\,\boldsymbol{\theta}_{ME})$
  - On paper, has the same performance as the combined fit
  - Appealing:
    - Can be performed at the analysis (ntuple) level
    - Can apply independent corrections to the ID or MS tracks, and re-compute the CB track afterwards
    - Variant: likelihood fit to model non-gaussian effects (Energy loss contribution)
  - But: technical complication presently preventing this (more on this later)



Agreement of the ID and MS tracks



Think of STACO:

- $\mathbf{V}_{CB} = (\mathbf{V}_{ID}^{-1} + \mathbf{V}_{ME}^{-1})^{-1}$
- $\boldsymbol{\theta}_{CB} = \mathbf{V}_{CB}\,(\mathbf{V}_{ID}^{-1}\,\boldsymbol{\theta}_{ID} + \mathbf{V}_{ME}^{-1}\,\boldsymbol{\theta}_{ME})$
- is not just a combination of $(q/p)_{ID}$ and $(q/p)_{MS}$
- $(q/p)_{CB}$ has improved resolution through:
  - the combination of the track position and direction parameters
  - the correlation between these parameters and q/p

For this to work: need to check the agreement of the position and direction parameters of the ID and MS tracks

Shown on the left: distance between ID and MS tracks expressed at the perigee, in the direction of the MS precision coordinate (release 22)

- O(mm) biases observed
- This is a difficult and long-standing issue: exists since run 1

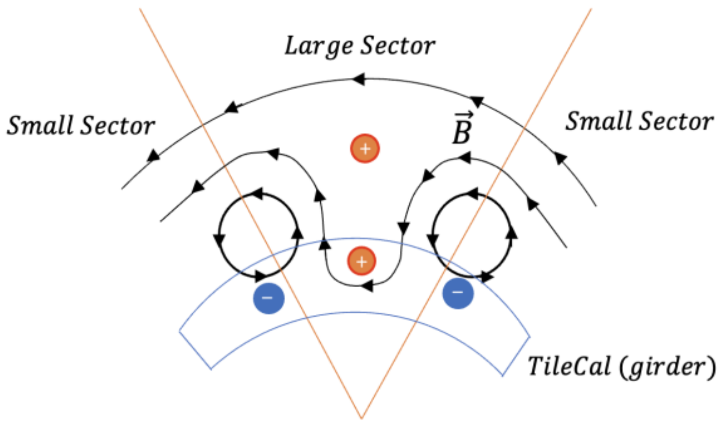
Strategy in athena to handle this disagreement:

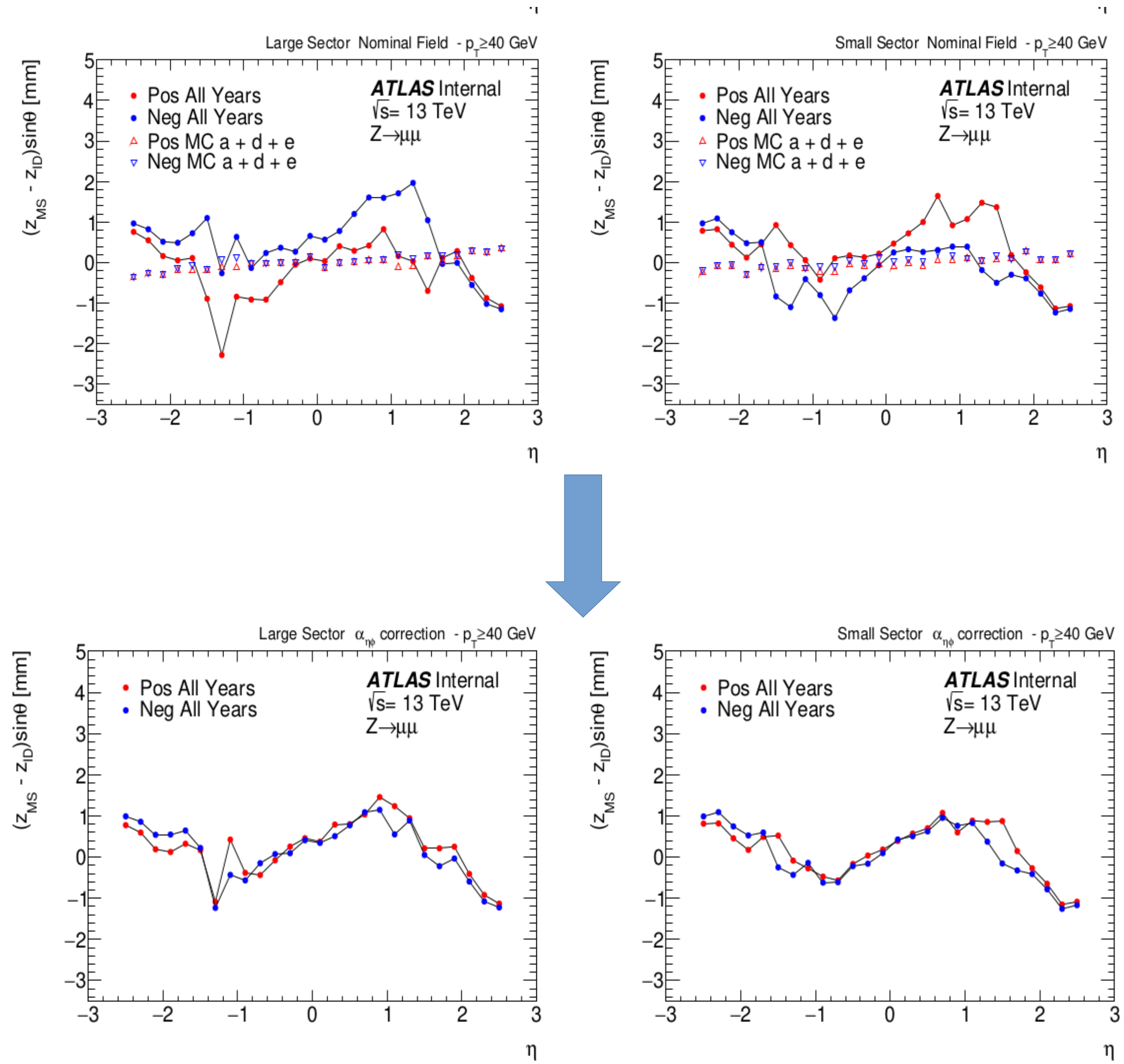
- Downweight the ME track position and direction information
- Technically done by introducing ad-hoc scattering planes in the back-tracking from the MS to the perigee
- $\boldsymbol{\theta}_{ME}$ and $\mathbf{V}_{ME}$ are affected by this procedure at first order
  - This is the reason preventing the use of STACO at the moment

Work plan to use CB track for EW precision measurement:

- Understand and/or resolve the MS/ID disagreements (QT of Andres)
- Extract from athena a version of $\boldsymbol{\theta}_{ME}$ and $\mathbf{V}_{ME}$ unbiased by the downweighting procedure
- Apply STACO, possibly including some corrections or systematic variations

Magnetic field map





Work of Andres:

- Bias is charge asymmetric
- Origin of the charge asymmetric component is in the volume of the tile calorimeter
- Tile calorimeter:
  - Ferromagnetic material, large uncertainty on the magnetic field determination (~25%)
  - A bias in the tile magnetic field affects the back-tracking from the MS to the interaction point

Andres provides:

- A correction map to the magnetic field in the tile volume
- A recipe to correct the ME track at the ntuple level

Magnetic field map reconstruction

Magnetic field map is the sum of two components:

- A linear component: Biot-Savart integration of the current along the conductors
- A non linear component: the ferromagnetic contribution, estimated with a finite element reconstruction software (TOSCA)

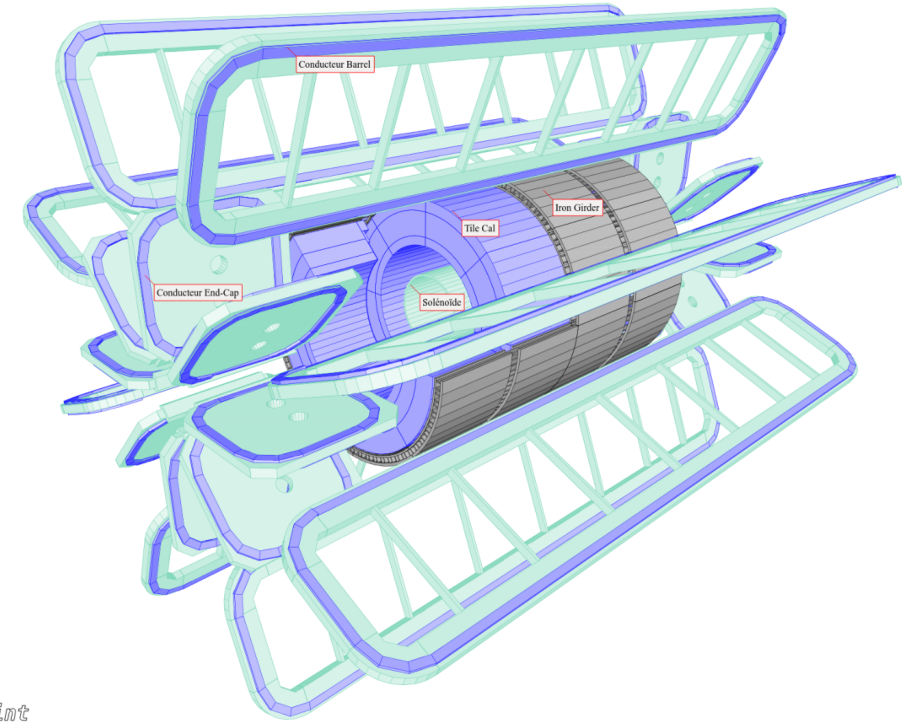
Several thousand magnetic field sensors are installed in the MS volume, and they are used to reconstruct the magnetic field map:

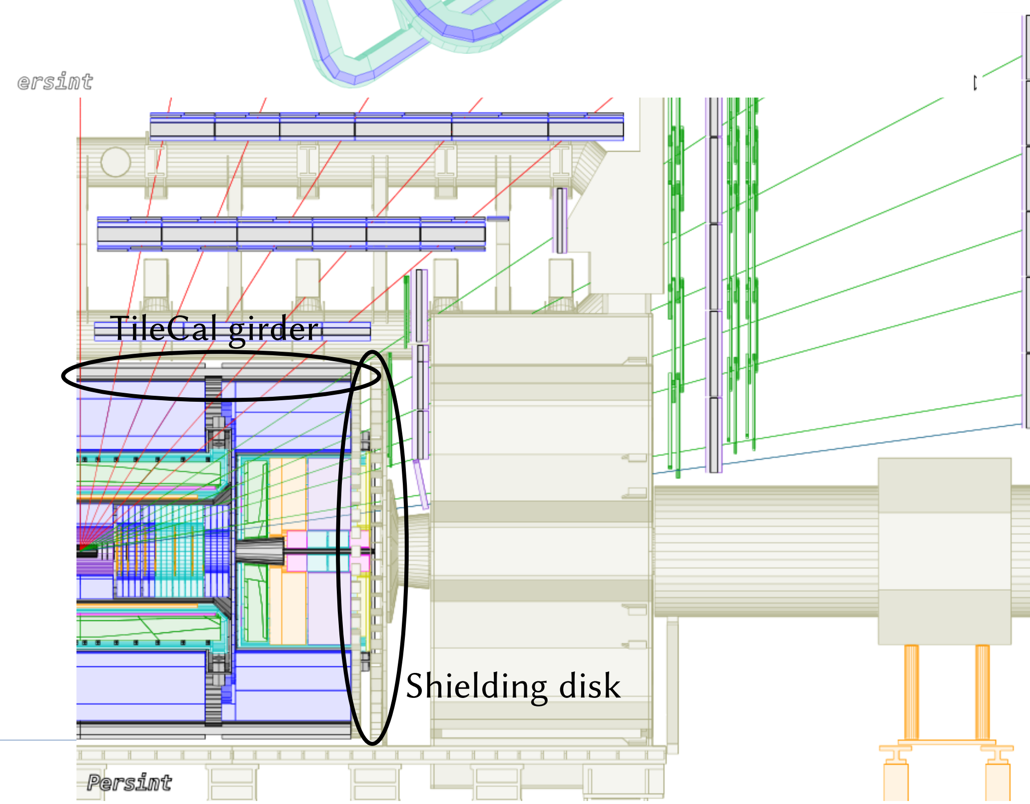
- A χ^2 is built comparing the magnetic field sensor readings to the estimated magnetic field map
- The positions and deformations of the conductors are minimized, with the non-linear component remaining fixed.

A new magnetic field map is in preparation by Aidan Chambers (Harvard): but only the Biot-Savart component will be updated

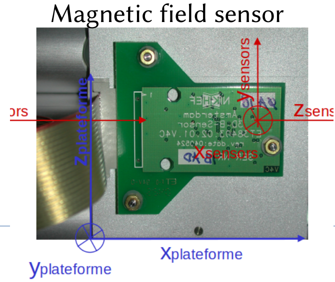
We need to also update the non-linear component:

- Results of Andres (previous slide) show the tile component is not well estimated
- As of run 3, the magnetic contribution has changed (new shielding disk)



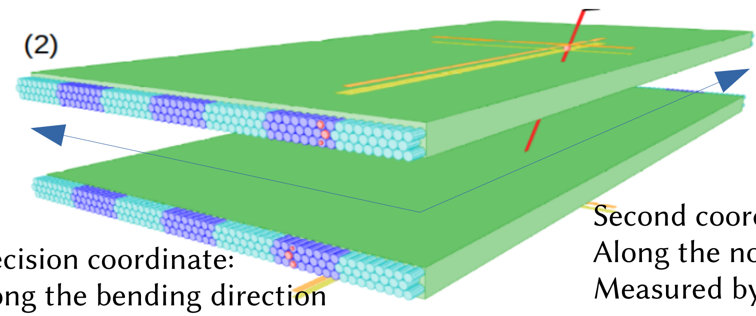


Magnetic field sensor

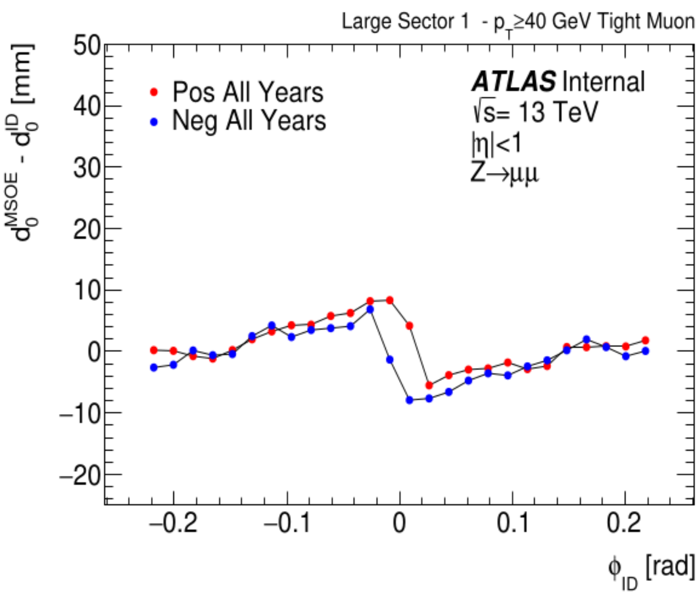


RPC second coordinate bias

Muon chamber: MDT + RPC



Andres: second coordinate expressed at perigee

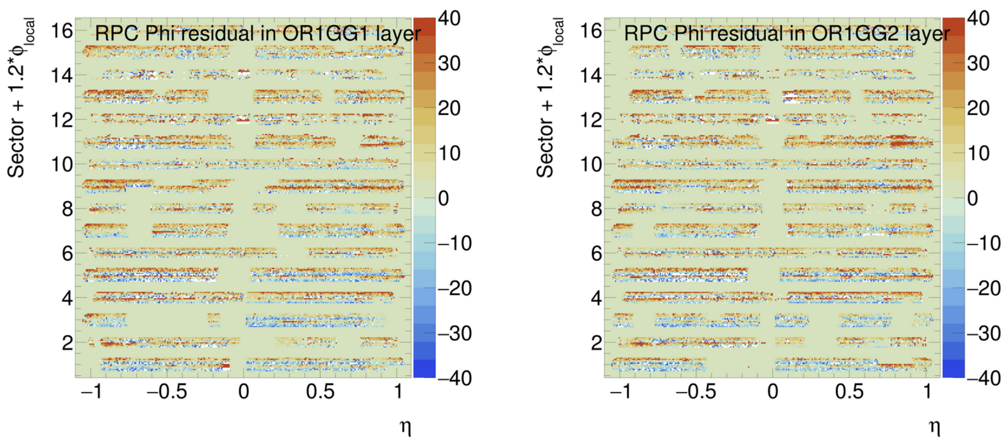


In comparison of MS and ID measurements: contribution of second coordinate

Andres: has shown O(cm) bias of the MS second coordinate information

Zirui: hit-level correction maps for the RPC second coordinate

Zirui: hit-level correction maps for RPC second coordinate



Alignment

MS alignment performance has two main components:

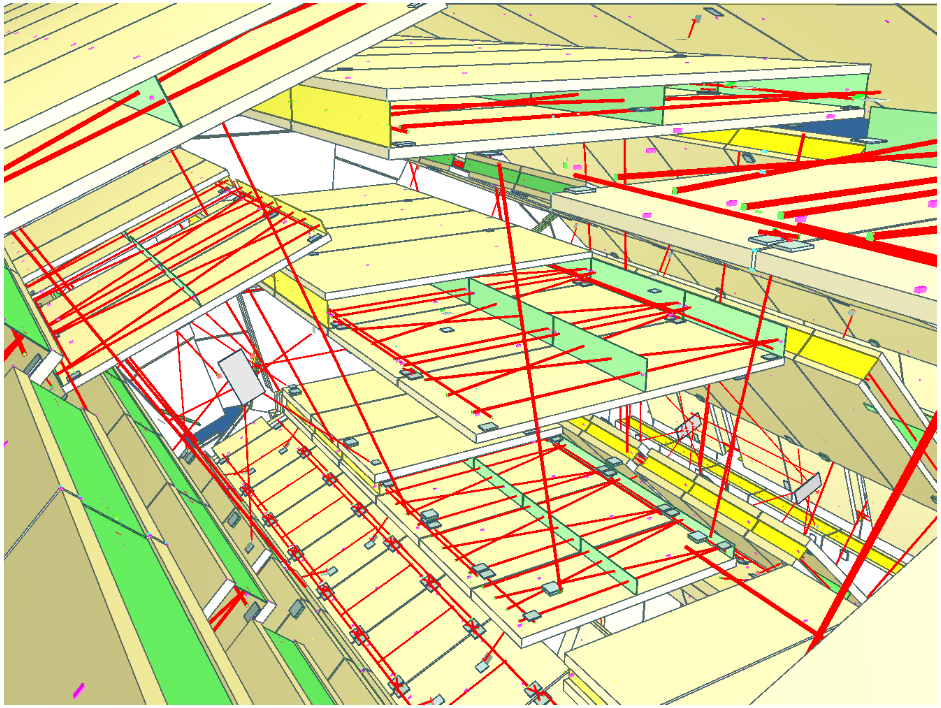
- Internal alignment: how well MS chambers are aligned with other MS chambers: 30 μm – 70 μm on the sagitta coordinate
- External alignment: how well MS is aligned with the ID: O(1mm)

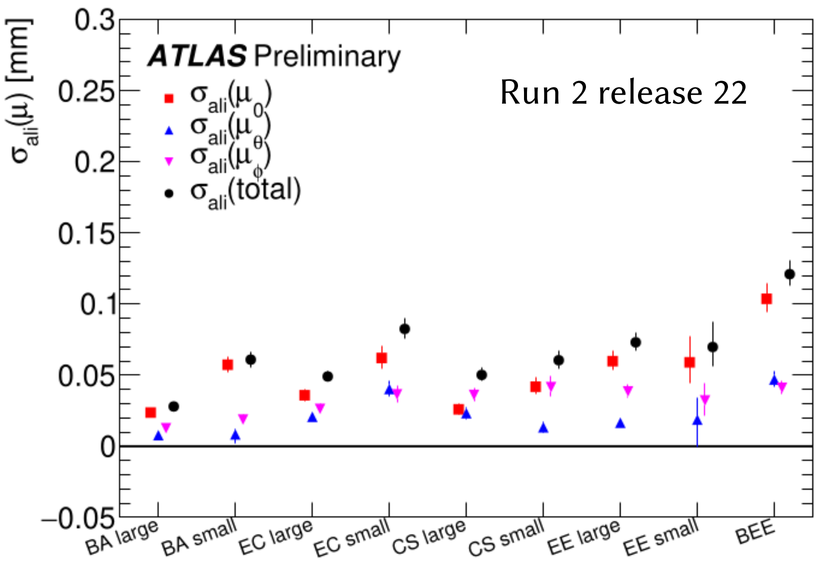
MS is equipped with an array of optical sensors:

- Monitor positions and deformations of the MS chambers continuously
- Alignment corrections are determined through χ^2 minimization
- Absolute reference alignment provided by tracks recorded:
  - in runs with toroid B=OFF (internal alignment)
  - in runs with toroid B=ON (external alignment)

Caveats to this procedure:

- Some of the biases to the track determination from the last slides influence the alignment
- Barrel and end-caps are treated as separate objects, with poor man strategy to minimize the biases for tracks crossing the two





Alignment: work in progress

ASAP = Atlas Spectrometer Alignment Program

Alignment program written for the barrel alignment: myself and Florian Bauer

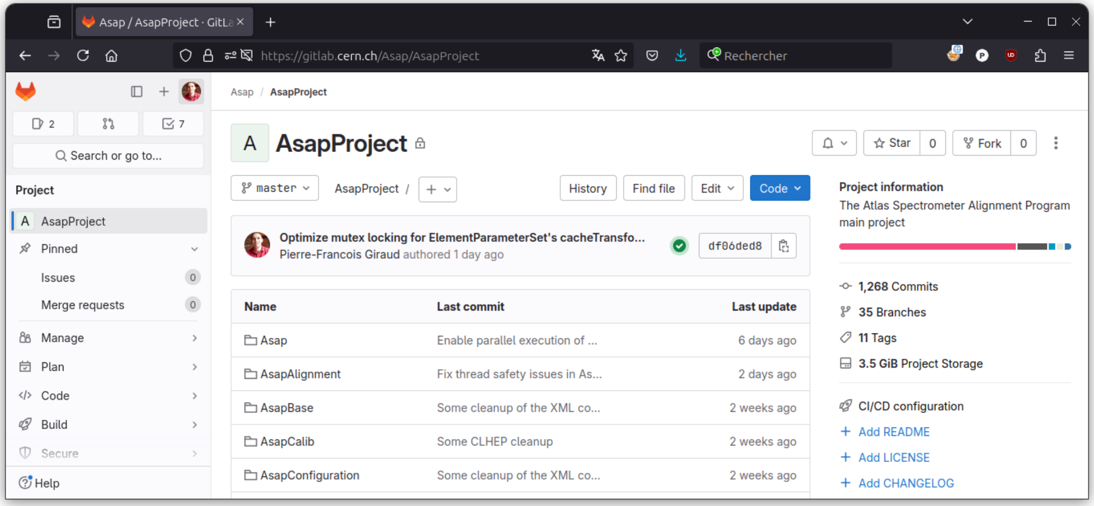
Since this summer: significant rewrite of ASAP
- Offer more safety to the sequence of operations
- Allow multi-threaded evaluation of alignment contributions
- Possibility to provide plugins with clean environment for externally defined geometry, sensors, χ^2 contributions

End-cap alignment software: Aramys, Christoph Amelung
- Agreement with Christoph: he provides dumps of the information inside Aramys
- ASAP plugin in development to align the end-cap based on these dumps

If successful, will have:
- Combined optical fits of the barrel and end-caps
- Combined track alignment of barrel and end-caps

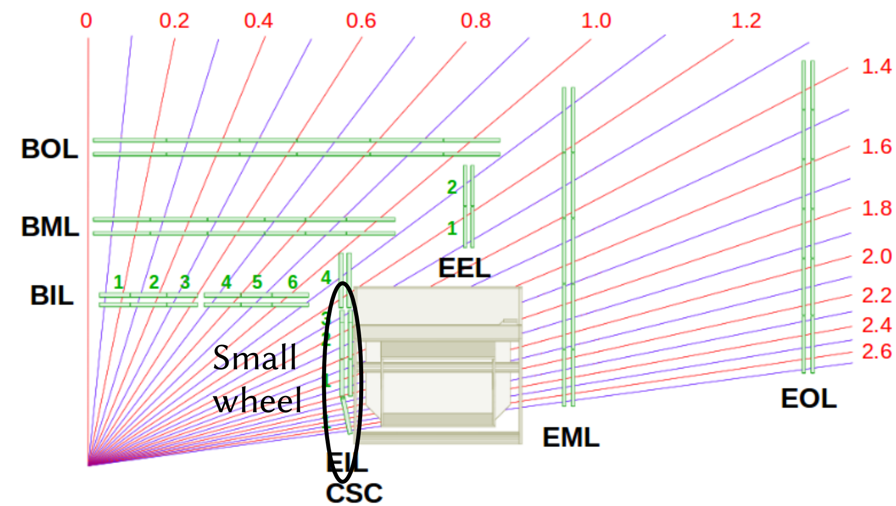
Expect to improve significantly the overall MS external alignment!

Note: the track alignment will also need a fix for the observed biases in the magnetic field and second coordinate



Related QT proposal: stream-line the track alignment monitoring, and improve precision of track alignment contribution
- Idea: define monitoring jobs executed automatically when each run is taken (similarly to MuonTester)
- In the context of MuonAlignTrk suite of tools
- Generate per-run track alignment histograms
  - Give us track-based validation of the alignment
  - Gather per-run information to build a track alignment χ^2 contribution
- Long term goal: Replace the rough track external alignment contribution used in ASAP with a more precise one

New Small Wheel



Run 3: MDT small wheel was replaced with New Small Wheel

- Sandwich of MicroMegas (MM) and sTGC chambers

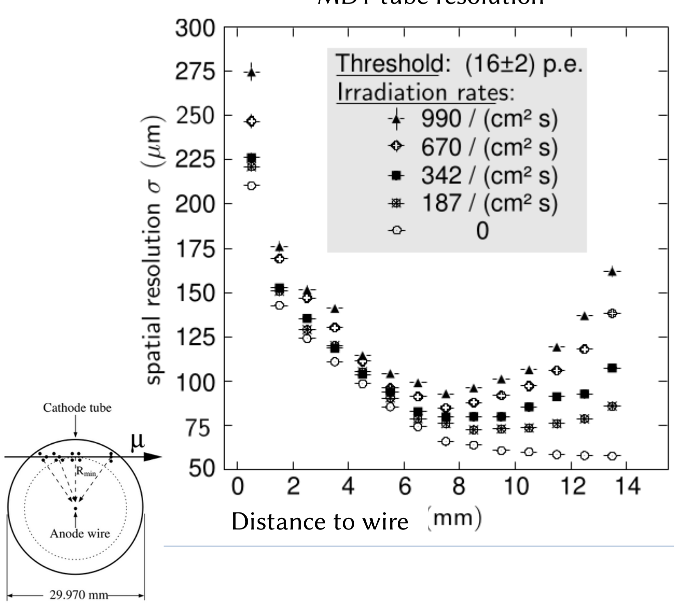
New Small Wheel performance still far from MDT small wheel

In particular MM detector resolution: 200 μm – 700 μm while MDT resolution ~ 100 μm

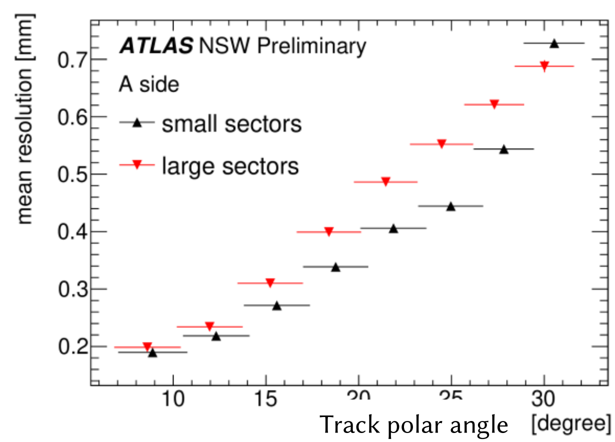
Identified issues under discussion:

- Electronic noise
- Electronic ADC, TDC resolution
- Detector gain
- Time correction calibration
- Zebra connector shift
- As-built geometry corrections
- Lorentz-angle correction

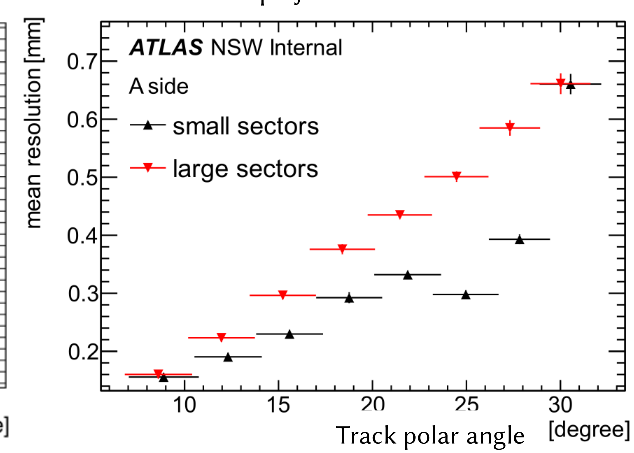
MDT tube resolution



MM resolution: centroid method



MM resolution: time projection method



Stefanie Goetz

EW analysis: Minimal work plan

Need a working version of STACO:

- Start from DESD_MCP samples
- Implement derivation for a new ME track, i.e. extrapolate MS track expressed at MS entry to the perigee, with the modifications:
  - Remove ad-hoc scatterers in calorimeter volume
  - Remove beam spot constraint
  - (Deep dive in athena!)
- Implement the statistical combination
  - Need a MC closure test, to ensure that STACO performance is compatible with the standard CB track

For data: implement a STACO fix, based on

- Magnetic field map correction of Andres
- Position and direction correction maps computed by Andres

In parallel: generate new xAOD derivations with the updated ME track

- Target sample: run 2, release 22
- (How to do that technically? Can start from event list?)
- Apply EW calibration performance with Z and J/Ψ on STACO-fixed tracks

Extended work plan

If new alignment or magnetic field is available:

- Derive ME correction maps from first principles, in (η,ϕ) binning
- Perform program above, with more precisely determined correction maps

If new alignment or magnetic field is made available for athena, could also consider asking for a partial data reprocessing

From Maarten

In parallel : finalize Release 21 muon calibration for mW

- MCP ntuples from high-statistics Jpsi MC samples? low-mu MC samples available?
- Low-mu Jpsi data sample
- Repeat ID distortions, scale and resolution fit as before