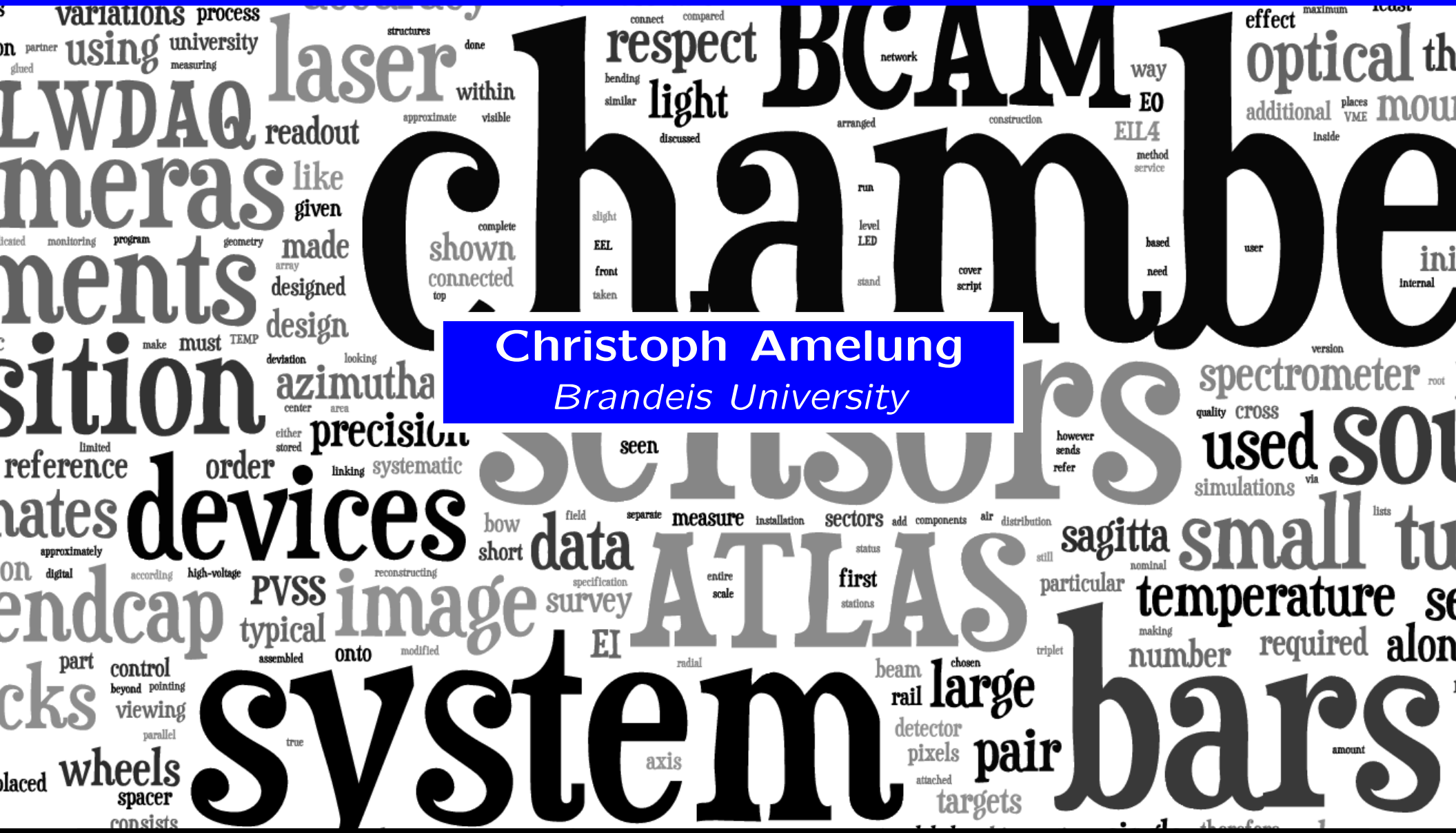
Performance of the
Muon Spectrometer Alignment



Christoph Amelung

Brandeis University

Contents

- How we aligned the muon spectrometer

  ... is an extremely interesting topic that I could keep talking about for hours – but it is not the main subject of this talk, and you will get little more than the executive summary

- How we checked the alignment performance

  ... is what I will discuss for most of the time

- How you can get hold of alignment corrections

  ... is covered at the end

- In case you feel you have seen this talk before

  ... you are (nearly) right

The State of Affairs

- **2008/2009 cosmics:**

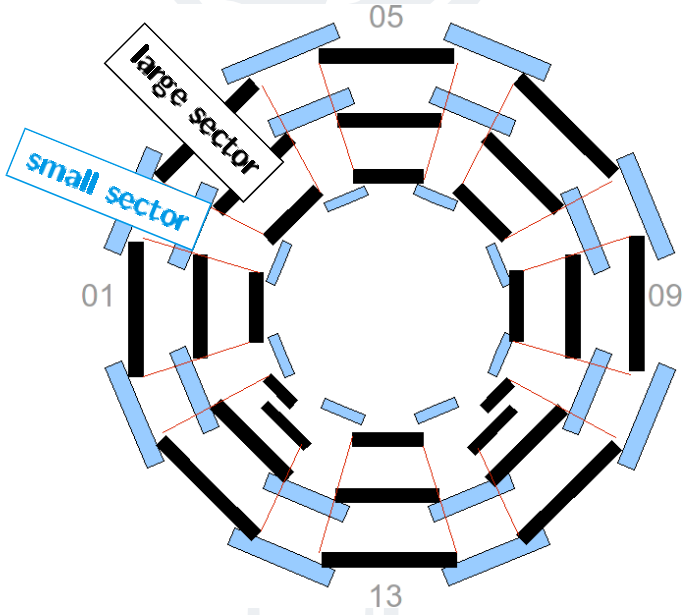
  μ mostly in the barrel, $\mathcal{O}(100\,\mathrm{M})$ events, $p \approx p_T$

  magnets on and off

- **2010 collisions:**

  μ mostly in the endcaps, $p_T < p$ or even $p_T \ll p$

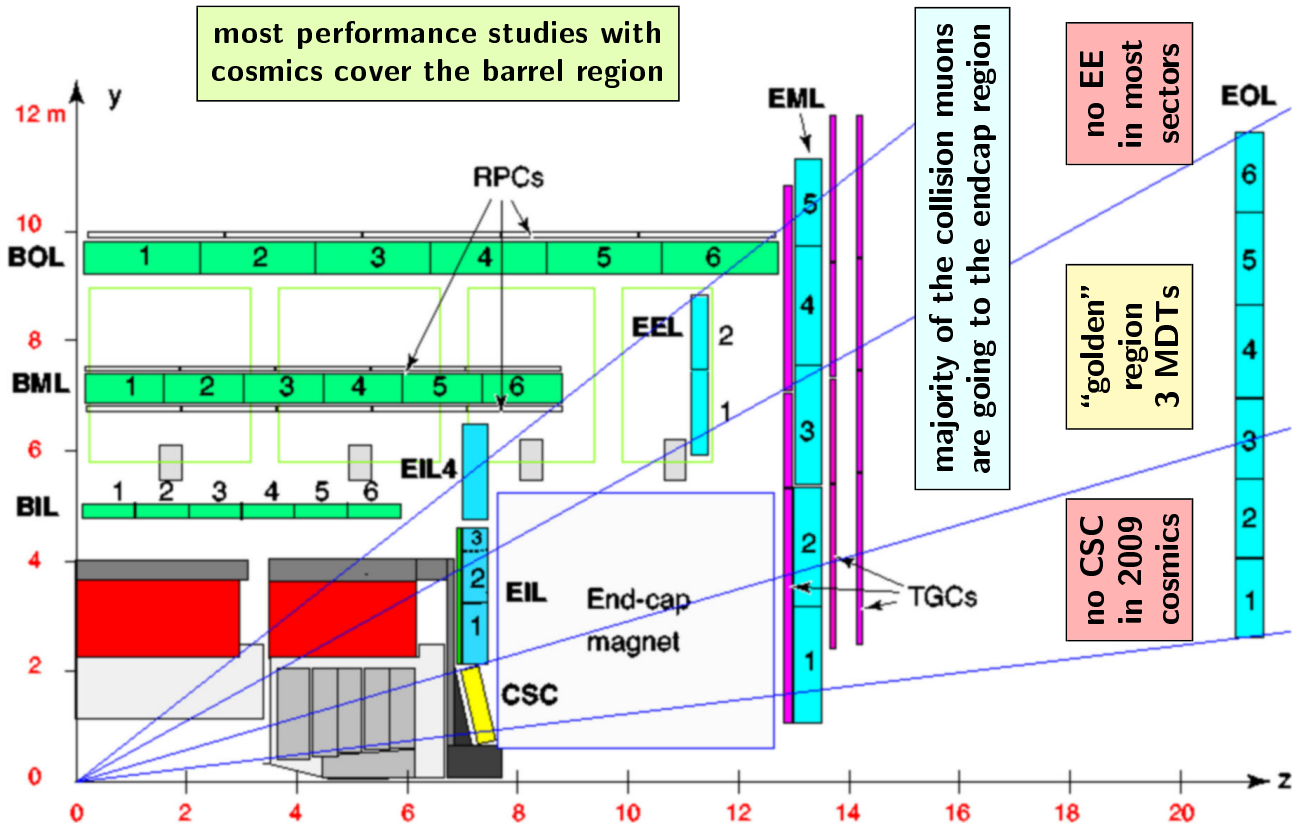
  two short magnet-off periods this year, only $30\,\mathrm{nb}^{-1}$ and $450\,\mathrm{nb}^{-1}$



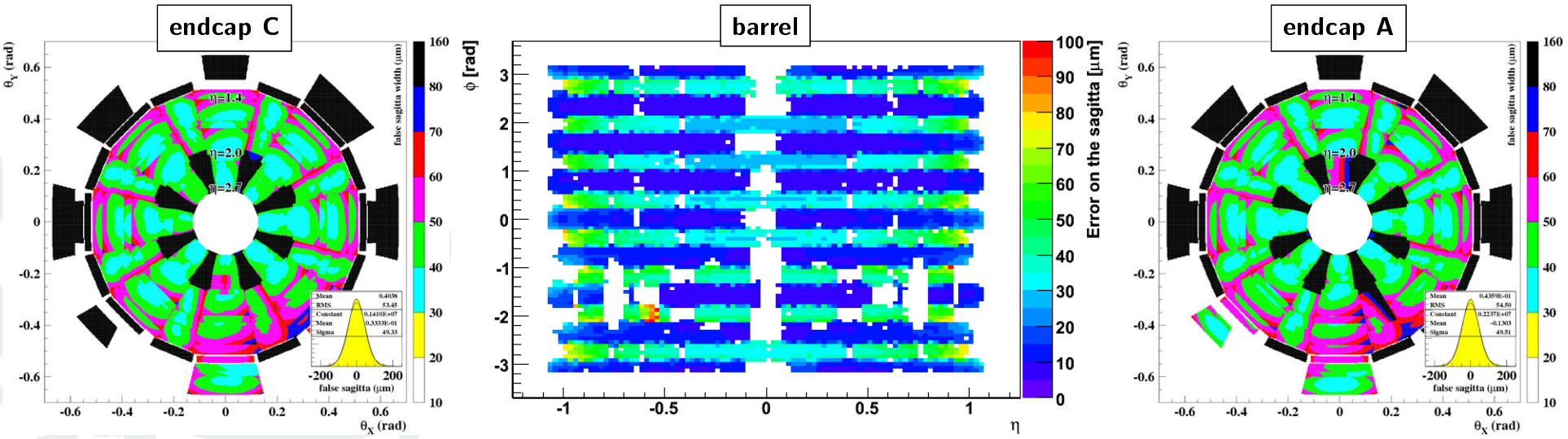
- **Endcap issues:**

  EEL/EES MDT chambers not yet installed: in region $1.0 < |\eta| < 1.4$ a muon traverses only 2 (not 3) MDT chambers

  CSC chambers were not read out in the long 2008/2009 cosmic runs



MDT/CSC Alignment Status



- **Status of MDT/CSC alignment:**

alignment provided by optical systems (combined with cosmic tracks in the barrel) – works without collision tracks

see e.g. `http://cern.ch/amelung/talk-cern-detector-seminar-may10.pdf`

endcap: sagitta accuracy around $\boxed{50\,\mu\mathrm{m}}$

barrel: around $\boxed{50/100\,\mu\mathrm{m}}$ (large/small sectors)

global positions from survey: $\boxed{2\ \mathrm{mm}}$ level

values predicted from performance of optical alignment systems and checked with tracks → next slides

some known caveats – no alignment for BIS8, BEE1/2, EIL5, missing EEL/EES chambers, poorer quality for CSCs, tracks in barrel large-small sector overlaps, and for barrel-endcap overlaps, CSC alignment has never been cross-checked with cosmics

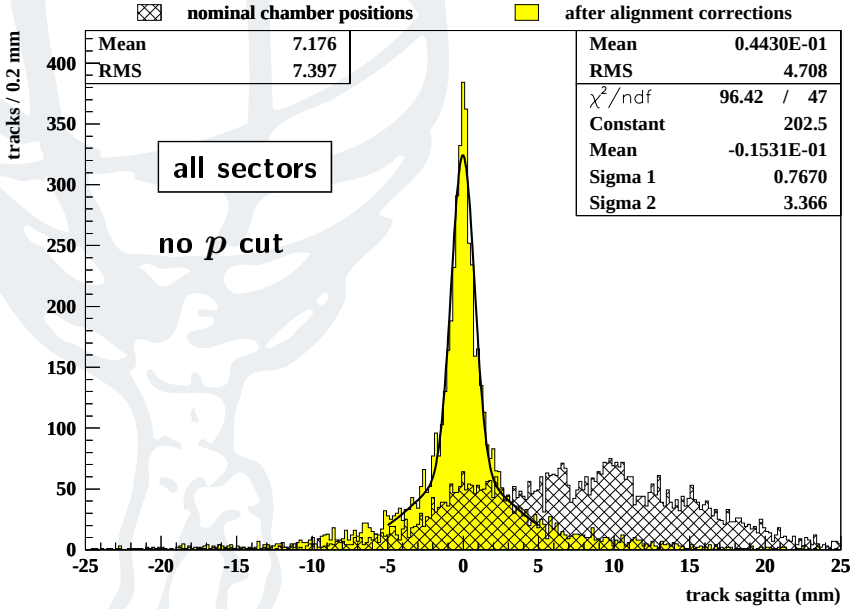
MDT Sagitta Studies

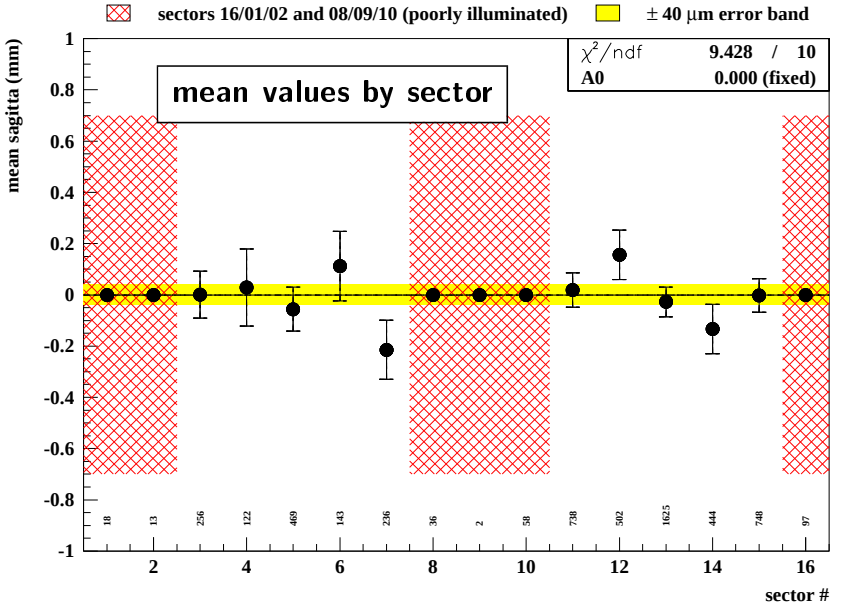
2009 Cosmics

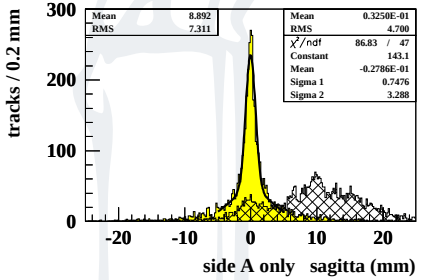
- **Endcap sagitta distributions of cosmic tracks:**

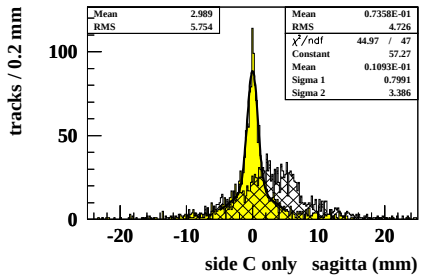
for toroids off, plot sagitta of segment triplets (≈ tracks), expect zero mean, and width dominated by multiple scattering

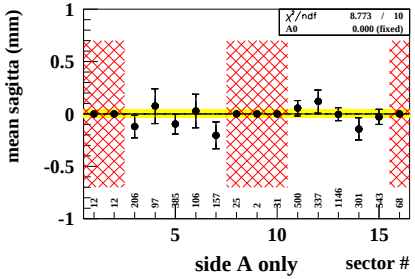
overall **mean value within ± 40 μm** – sector results statistics-limited

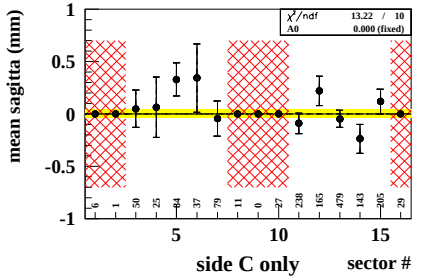












MDT Sagitta Studies

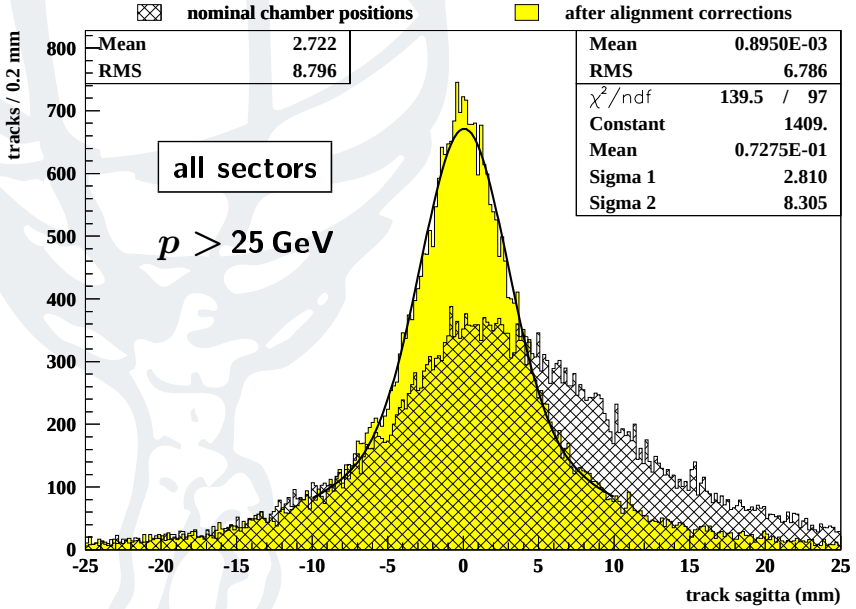
2010 Toroid-Off

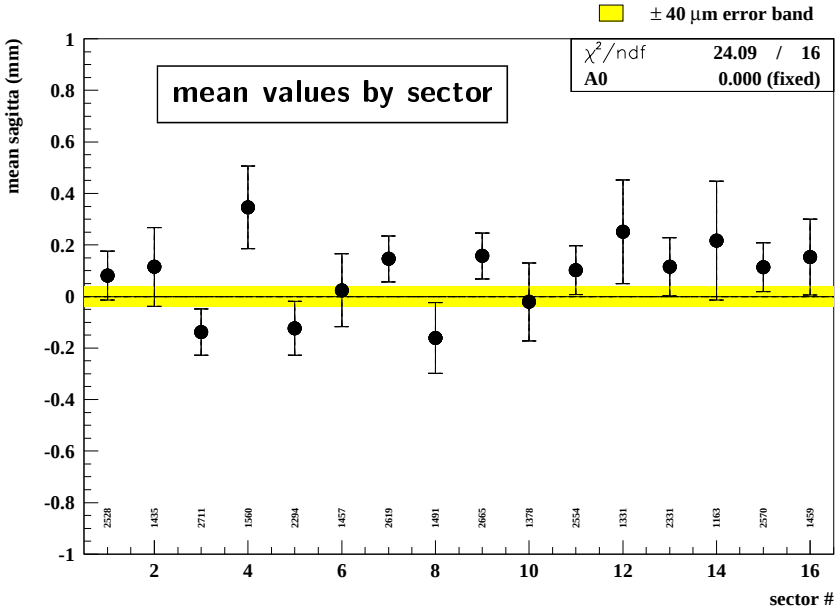
- **Endcap sagitta distributions from 2010 toroid-off runs:**

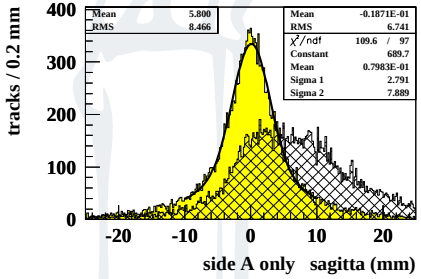
  for comparison: same analysis using collisions data

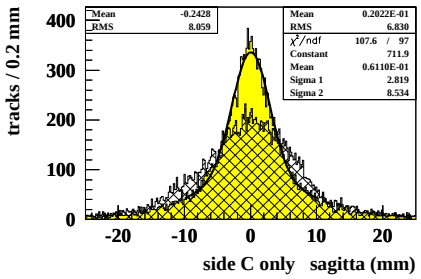
  still not competitive with cosmic results in bottom sectors, top sectors have similar quality, side sectors covered for the first time

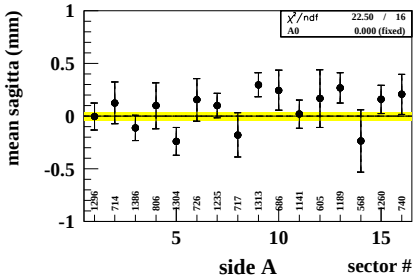
  overall mean value only marginally compatible with $\pm 40\,\mu\mathrm{m}$

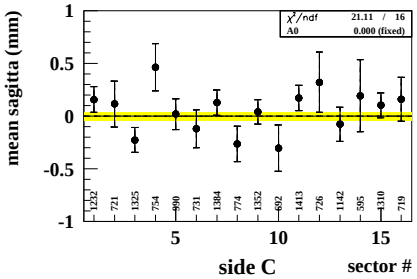












MDT Sagitta Studies

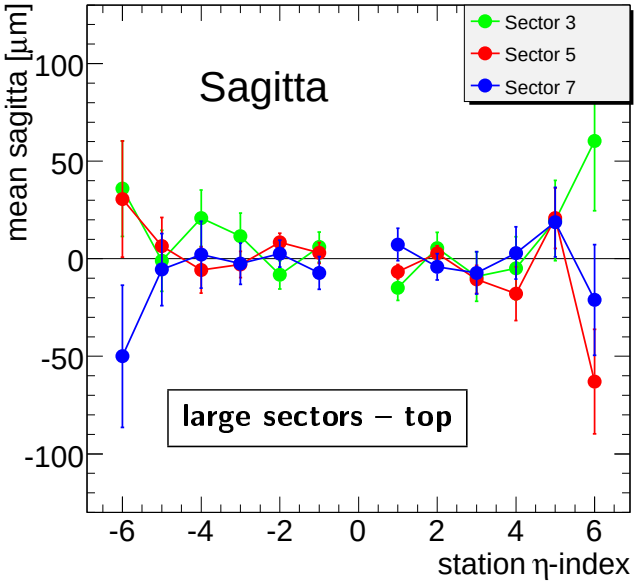
2009 Cosmics

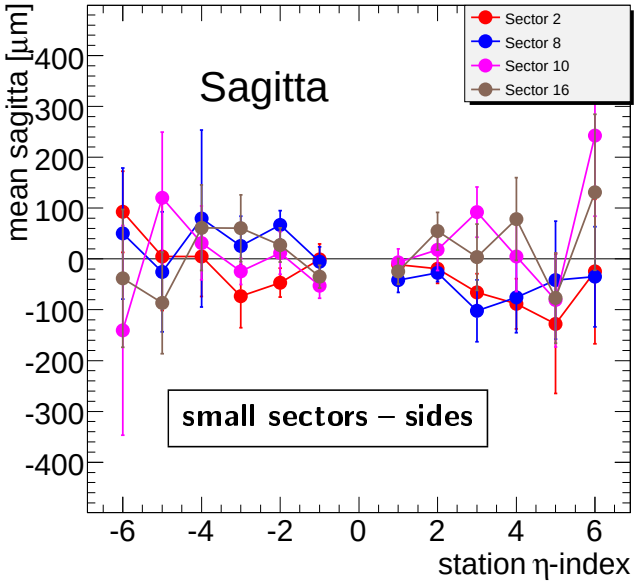
- **Barrel sagitta mean values:**

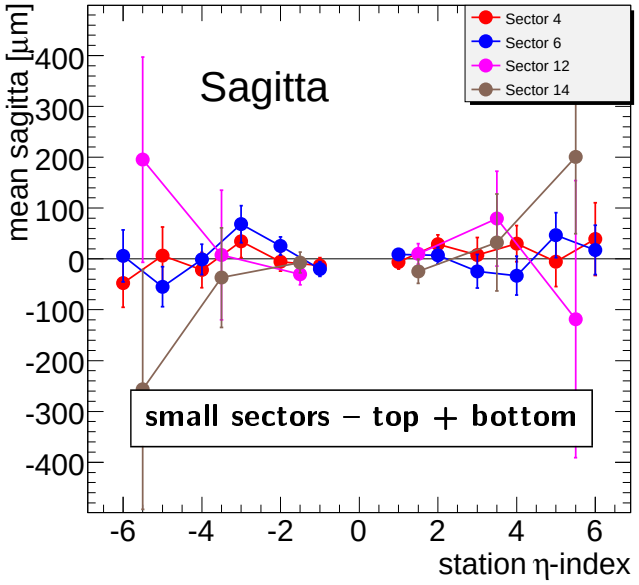
  nearly all (14 of 16) barrel sectors have sufficient statistics to break sagitta plot down by 2×6 towers ($=$ chamber triplets)

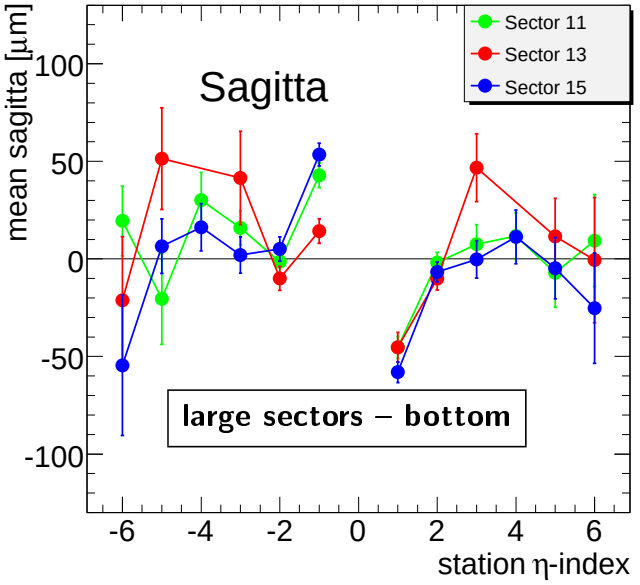
  plots show mean values of $2 \times 6 \times 14 = 168$ individual sagitta distributions

  large sectors: $\approx \pm 30\,\mu\text{m}$
  small sectors: $\approx \pm 70\,\mu\text{m}$ **typical mean value**







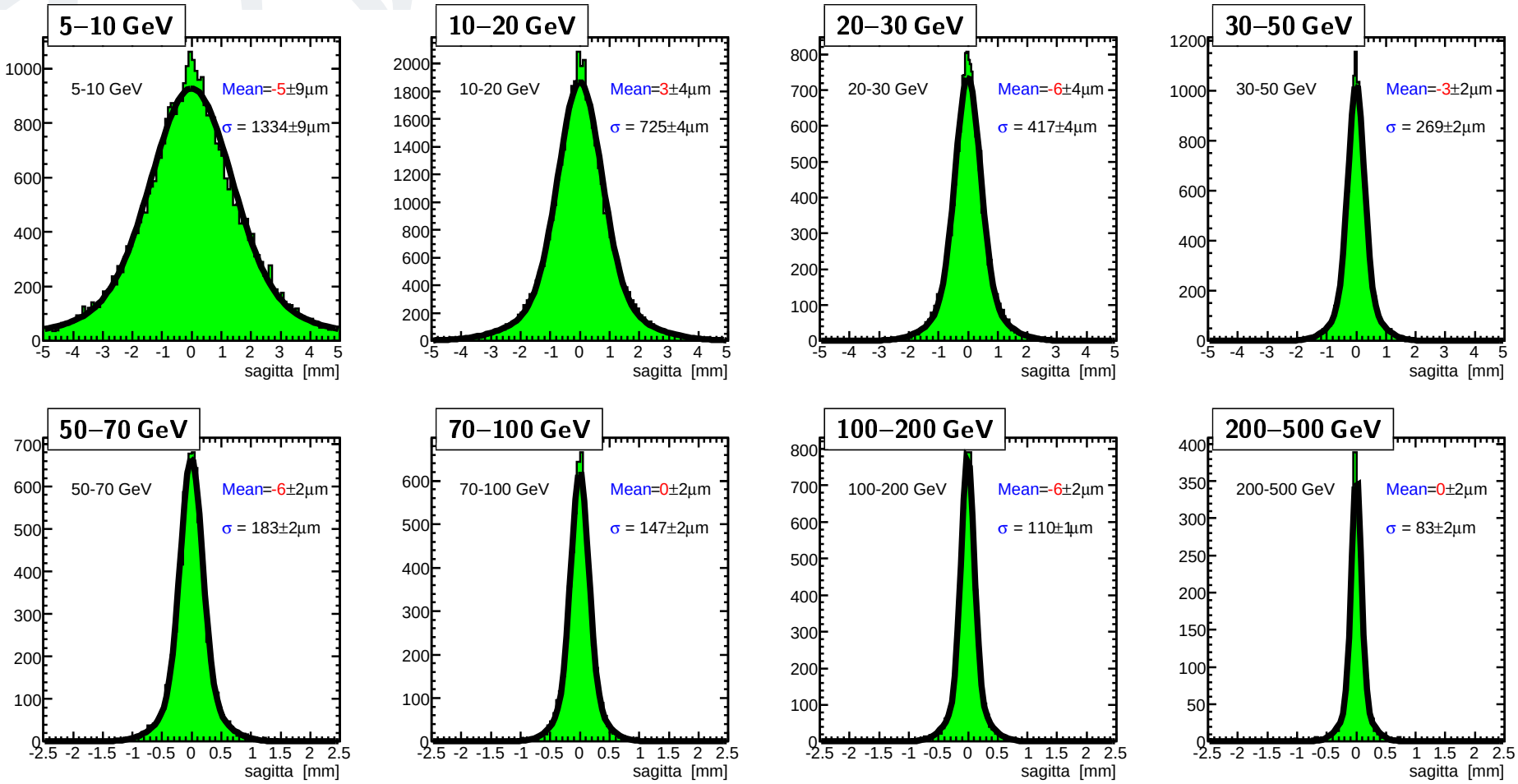


MDT Sagitta Studies

2009 Cosmics

- **Width of barrel sagitta distributions:**

solenoid on, toroid off: ID measures muon momentum,
observed non-zero sagitta of track in muon system due to
multiple scattering ($\propto 1/p$) and resolution + alignment ($\propto$ const.)

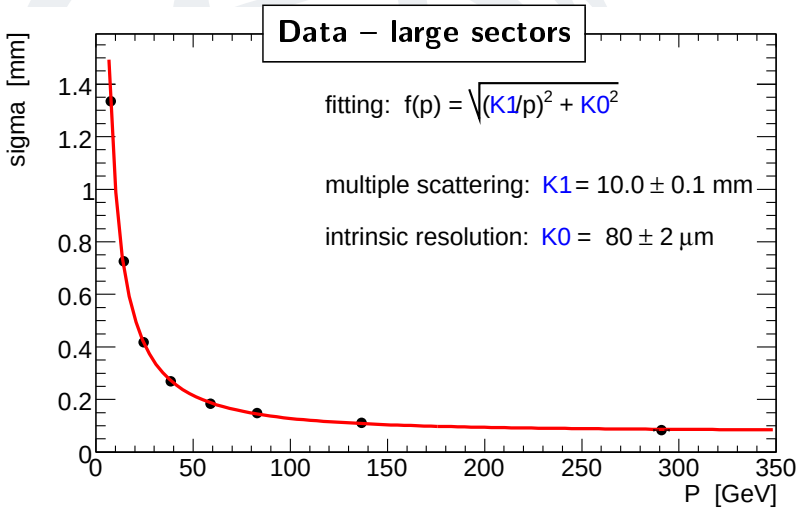


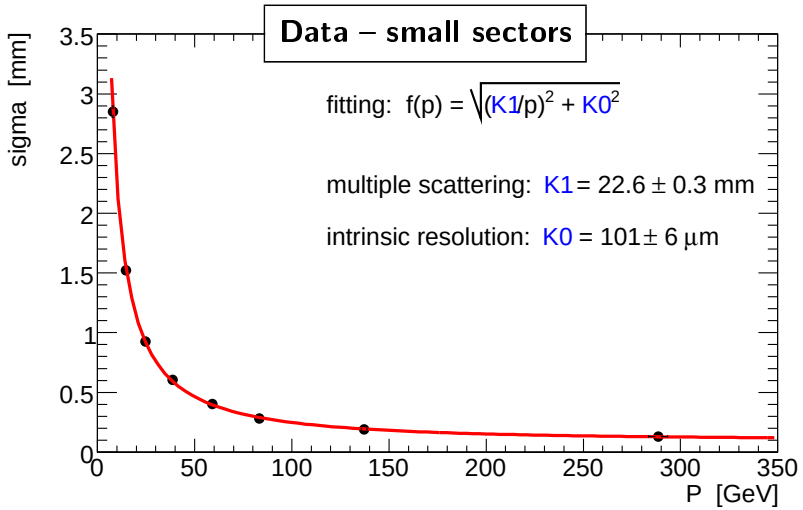
MDT Sagitta Studies

2009 Cosmics

- **Barrel sagitta width vs momentum:**

  differences large–small sectors due to geometry and amount of material;
  differences data–MC due to imperfections of alignment (perfect in MC)

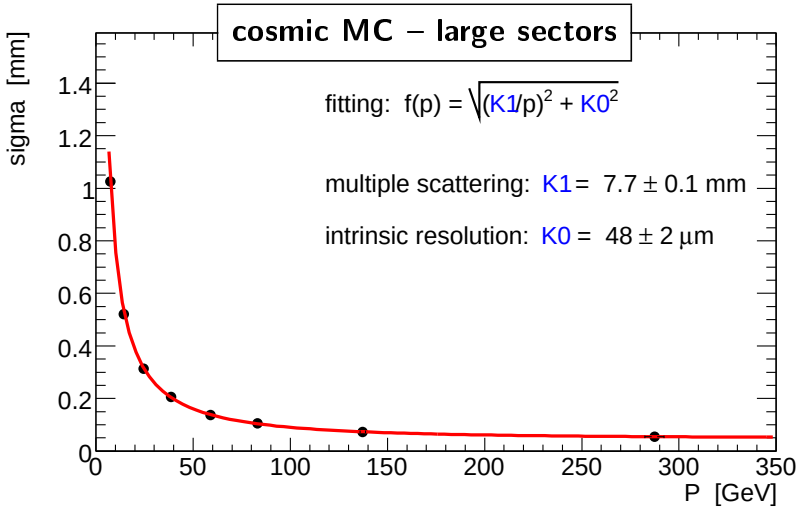


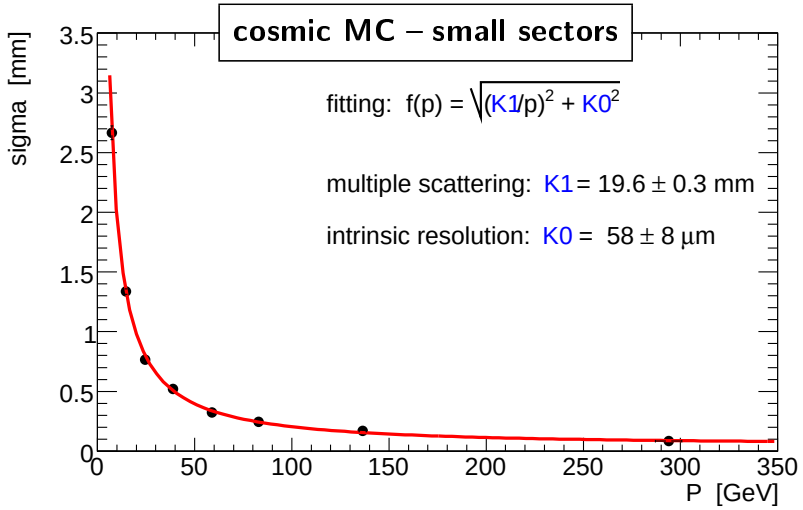


	K_1 mm ×GeV	K_0 µm
L	10.0	80
S	22.6	101

alignment contribution in data below 60/90 µm

multiple scattering larger in data by 30/15%





	K_1 mm ×GeV	K_0 µm
L	7.7	48
S	19.6	58

Alternative: Large-Small Overlaps

2010 Collisions

- **Overlap tracks:**

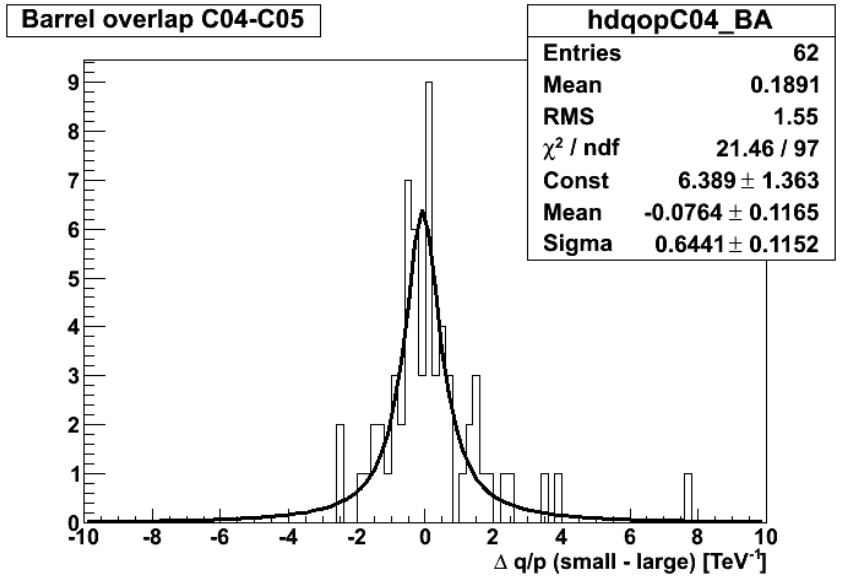
  select tracks traversing 6 stations (3 large, 3 small MDT)

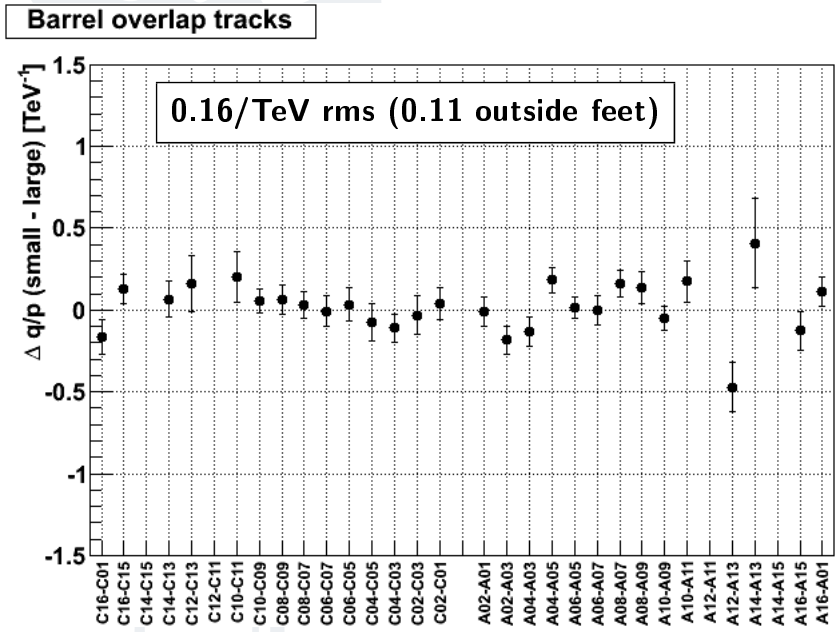
  reconstruct p using only large or only small chambers, compare q/p

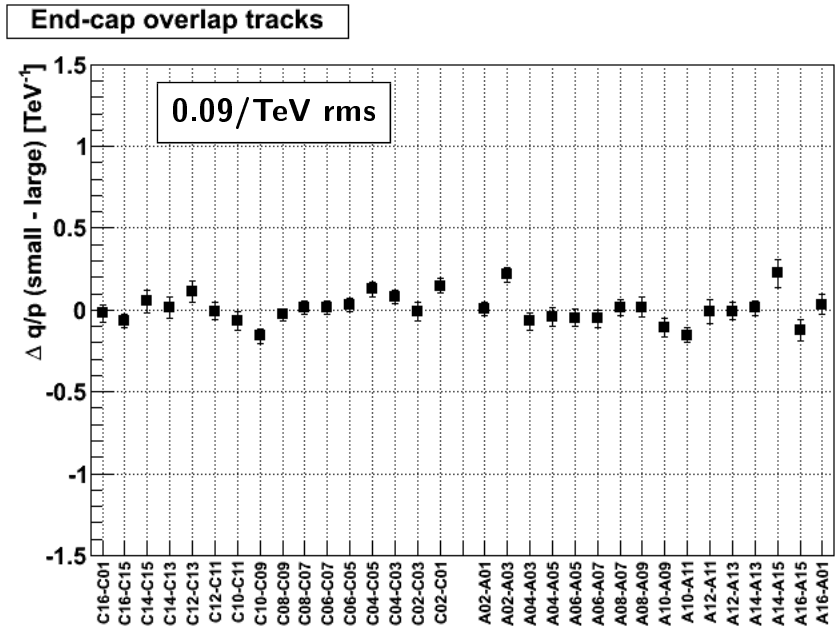
  conversion factor: $1\,\text{TeV}^{-1} \approx 500\,\mu\text{m}$

  trick: "small track" and "large track" are identical particle, have experienced same amount of multiple scattering

  does not require toroids to be off







CSC Alignment Bugs

2010 Collisions

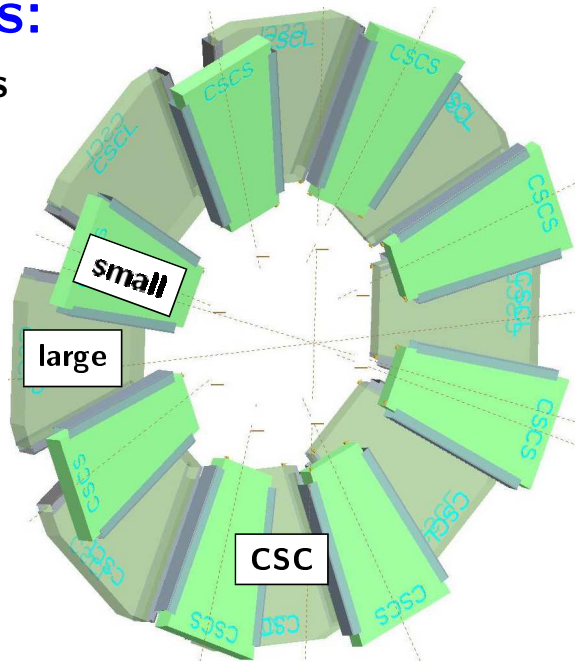
- **CSC alignment checks with curved tracks:**

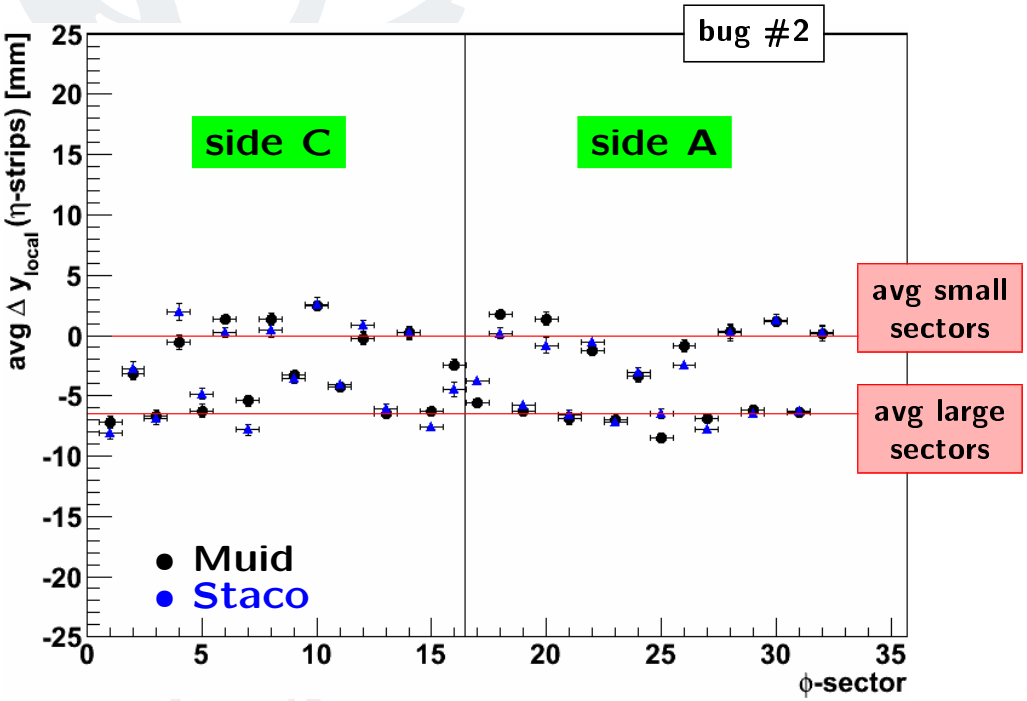
  use alignment from optical system, cross-check with tracks

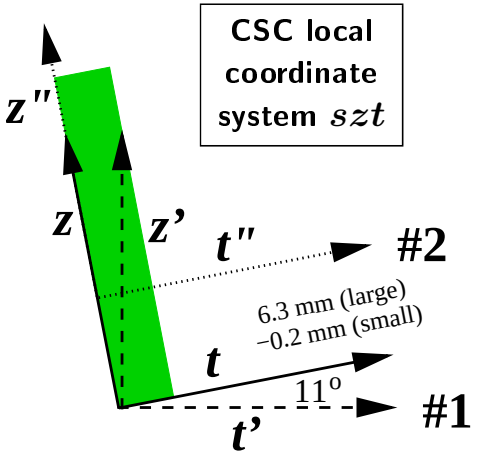
  combined tracks: remove CSC hits, refit track
  → unbiased residuals, plot average per chamber

  residuals in precision coordinate: large chambers systematically shifted by 6–7 mm, small ≈ ok

  due to a bug (#2) in local coordinate system position for optical alignment – another bug (#1) in coordinate system orientation found & fixed earlier (alignment corrections applied incorrectly in track reconstruction)







remaining deviations from zero (few mm)

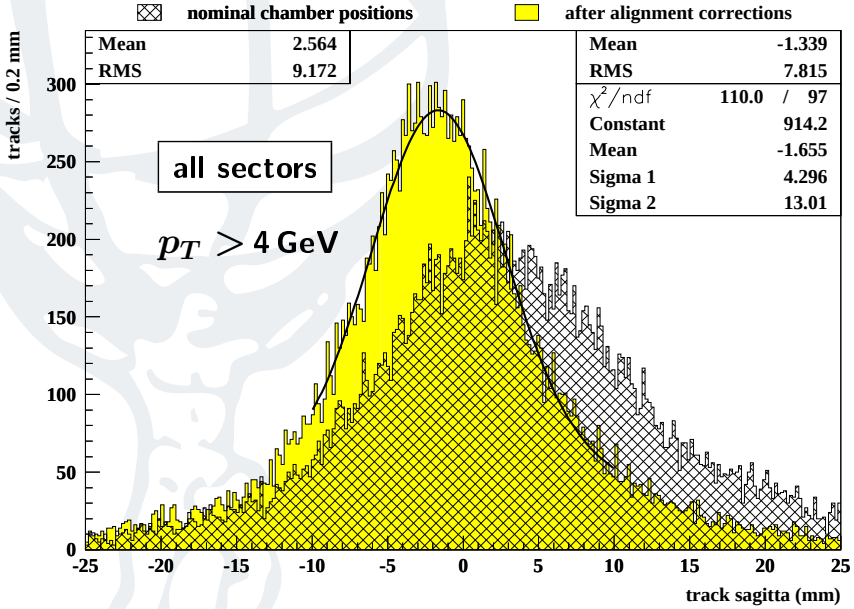
- MS-ID alignment ?
- wire sag ?

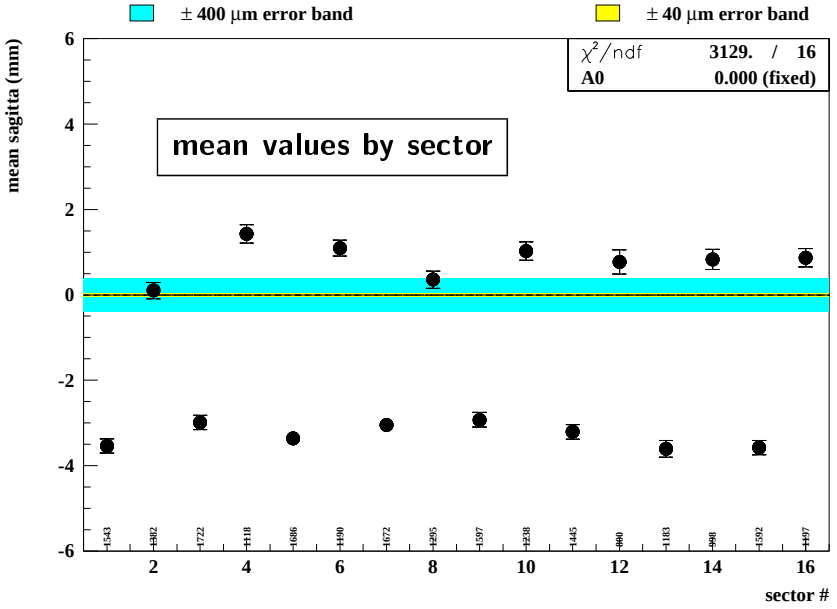
2010 Toroid-Off

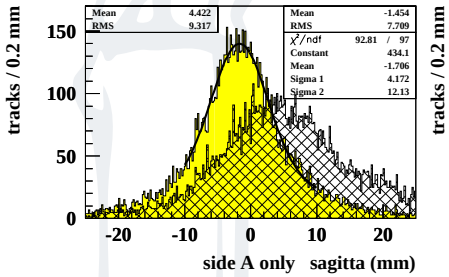
CSC Alignment Bug Confirmed

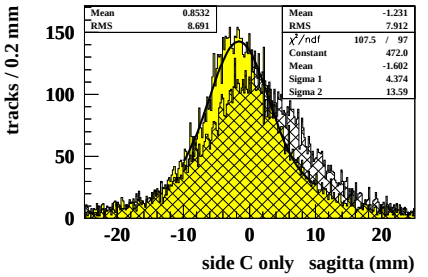
- CSC alignment checks with straight tracks:

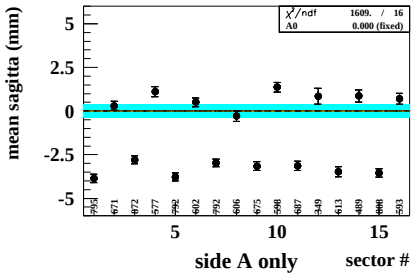
confirms the CSC alignment bug (sagitta $\approx$ residual/2) – important differences to plot on previous slide: no assumptions made about MS-ID alignment and quality of ID alignment (except for p_T cut on ID track), wire sag and MDT deformations taken into account

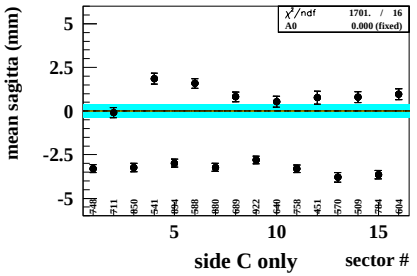












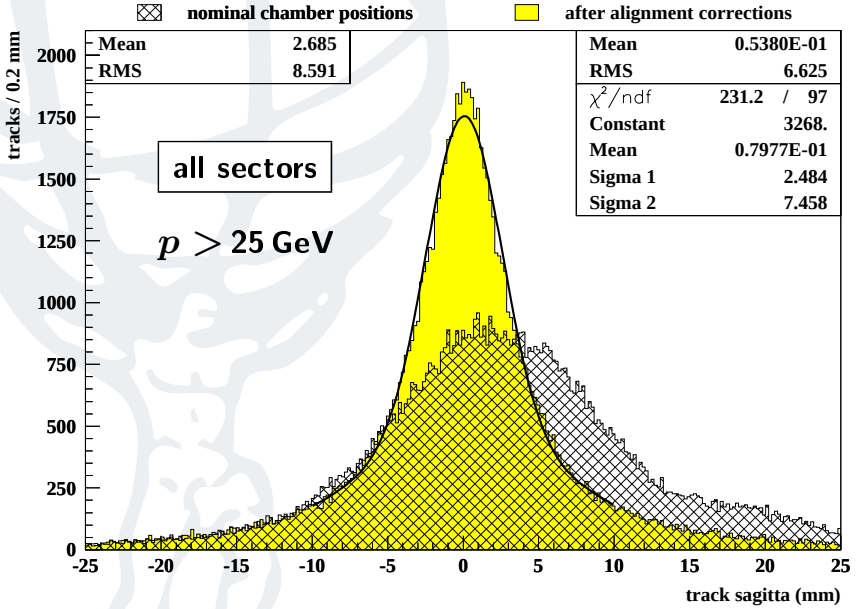
CSC Alignment Bug Fixed

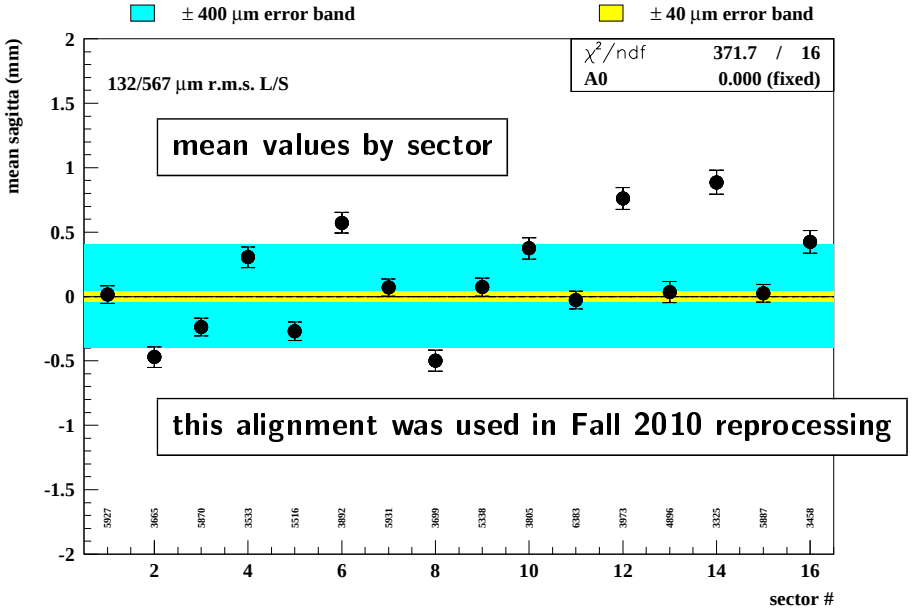
2010 Toroid-Off

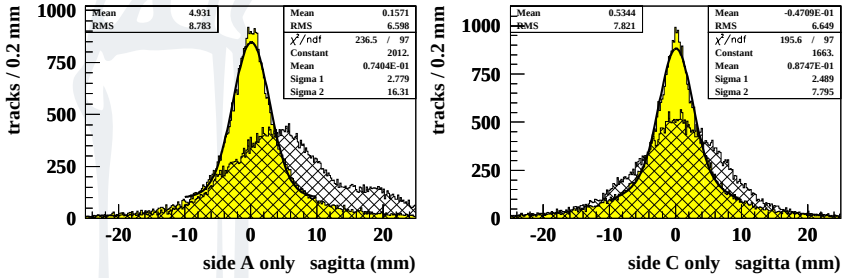
- **CSC alignment checks with straight tracks:**

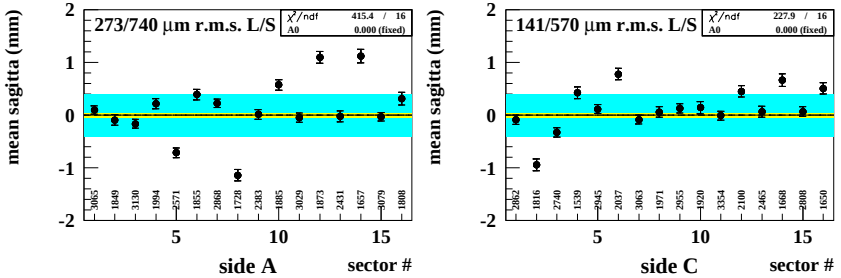
  bug was due to a mistake in relating the CSC chamber local coordinate system to the alignment sensor mounts on the chambers

  fixing the bug moves large/small chambers by $-5.85\,\text{mm}$ / $+0.75\,\text{mm}$ (some variation between chambers due to other small improvements)









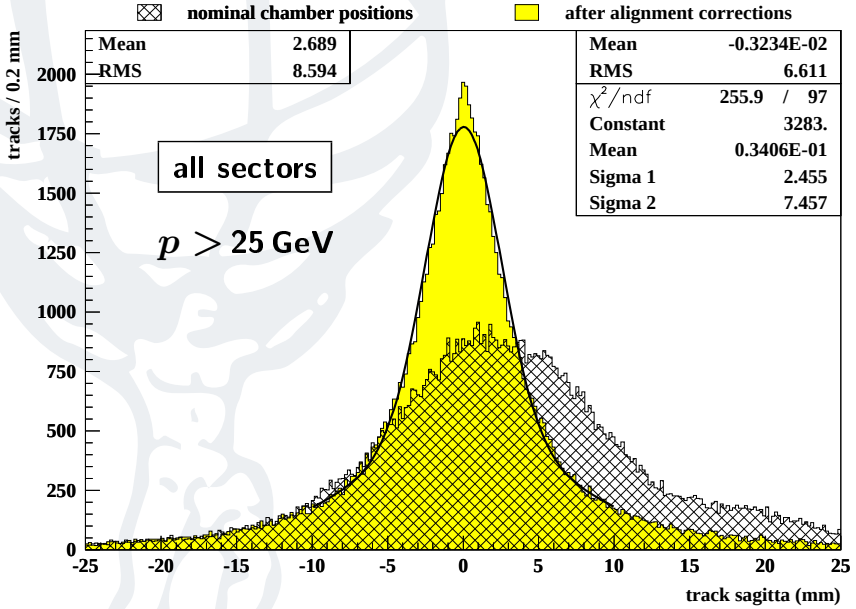
Towards Final CSC Alignment

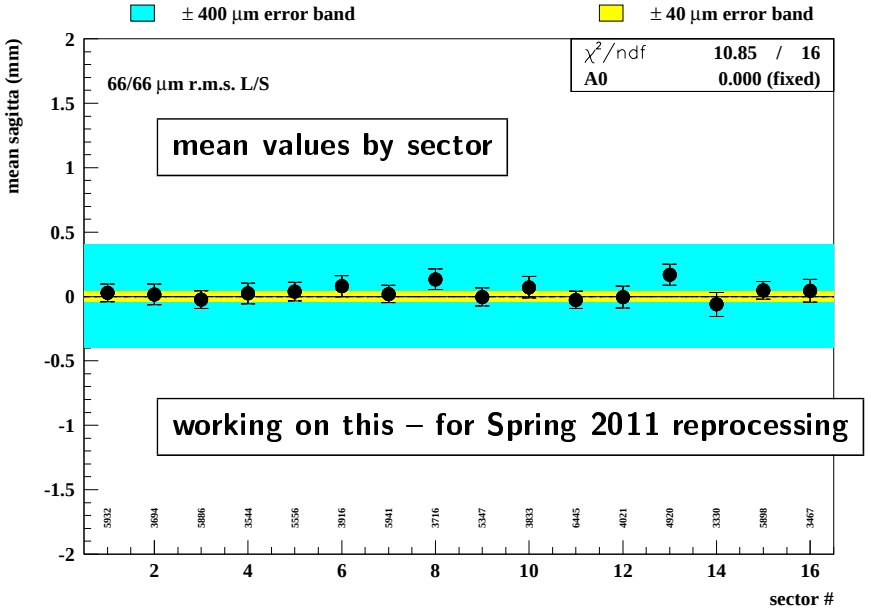
2010 Toroid-Off

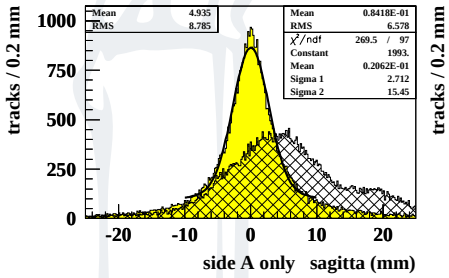
- **CSC alignment using tracks:**

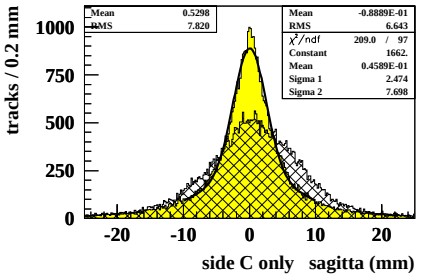
  re-fitting three of the six d.o.f. per chamber (shifts in local z, rotations around s and t) using track segments, keeping the remaining three d.o.f. at their values from optical alignment

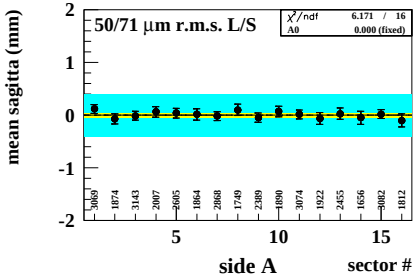
  yields sagitta mean values within 100 μm r.m.s. (note variations of mean value across a chamber may be larger – internal misalignment)

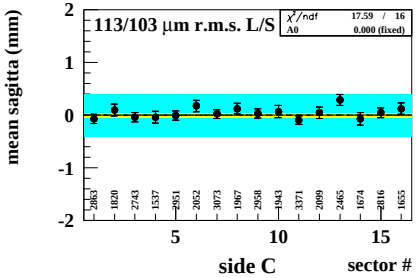












Interlude

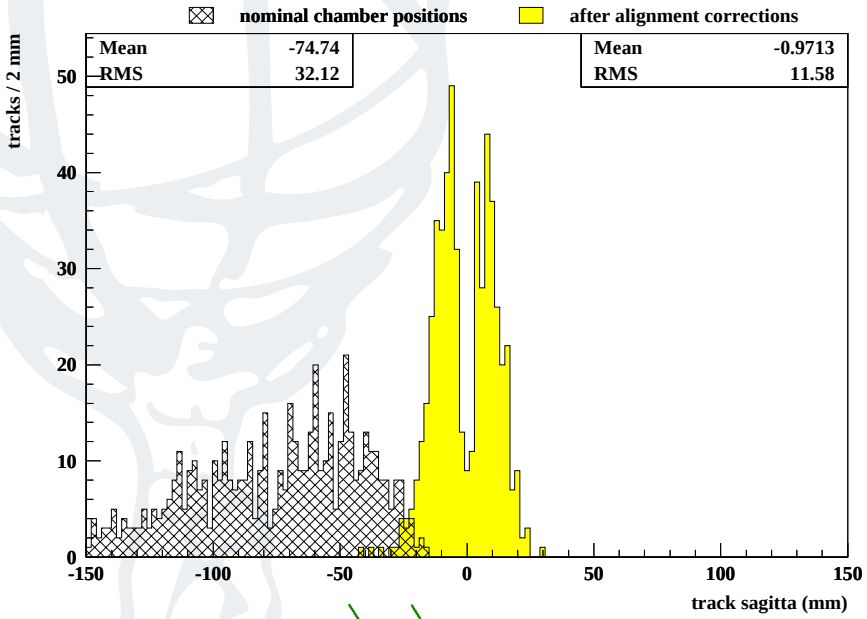
- so we think we have the MDT alignment about right for the bulk of the spectrometer: all the checks that we made are *compatible with the assumption* that the alignment is ok within the accuracy we have claimed
- we do not have enough statistics to check each measurement tower individually, especially in the endcap, so we have no *proof* the alignment is ok – watch out for special chambers and regions
- there are errors (uncertainties) and mistakes (bugs) – we can quantify our errors quite well, but our mistakes may be 10 or 10,000 times larger, and we will not know until we find them – see CSC bug
- not everything that manifests itself as a resolution problem is necessarily an alignment problem: see next slides for one (not the only one) example

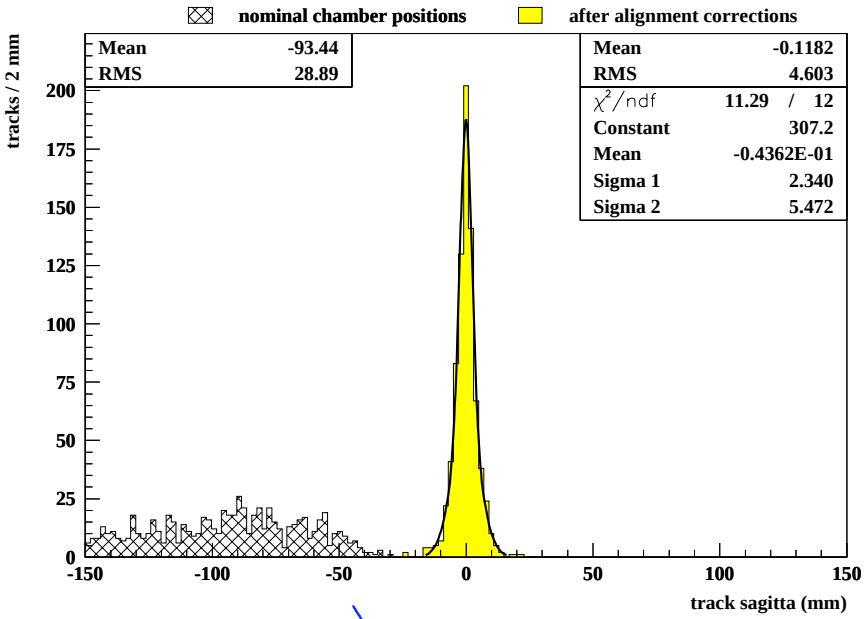
BEE Geometry Bug

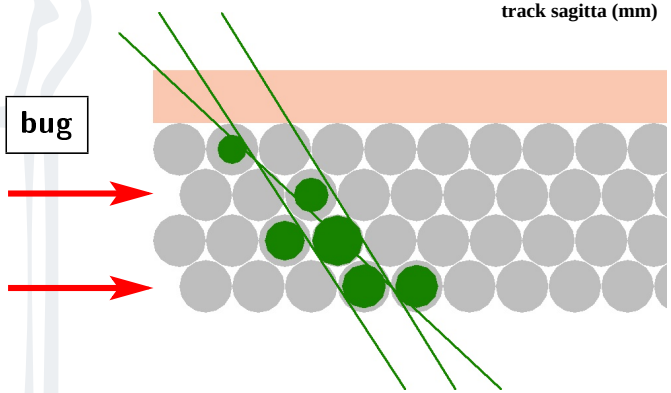
2009 Cosmics

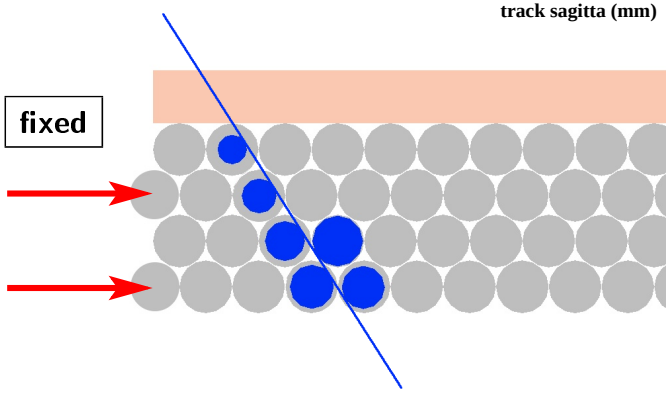
- **Sagitta distribution of tracks through BEE chambers:**

bizarre double-peak structure after alignment corrections (from survey; BEE have no alignment sensors) – traced back to a bug in the chamber geometry description (tube staggering inverted)









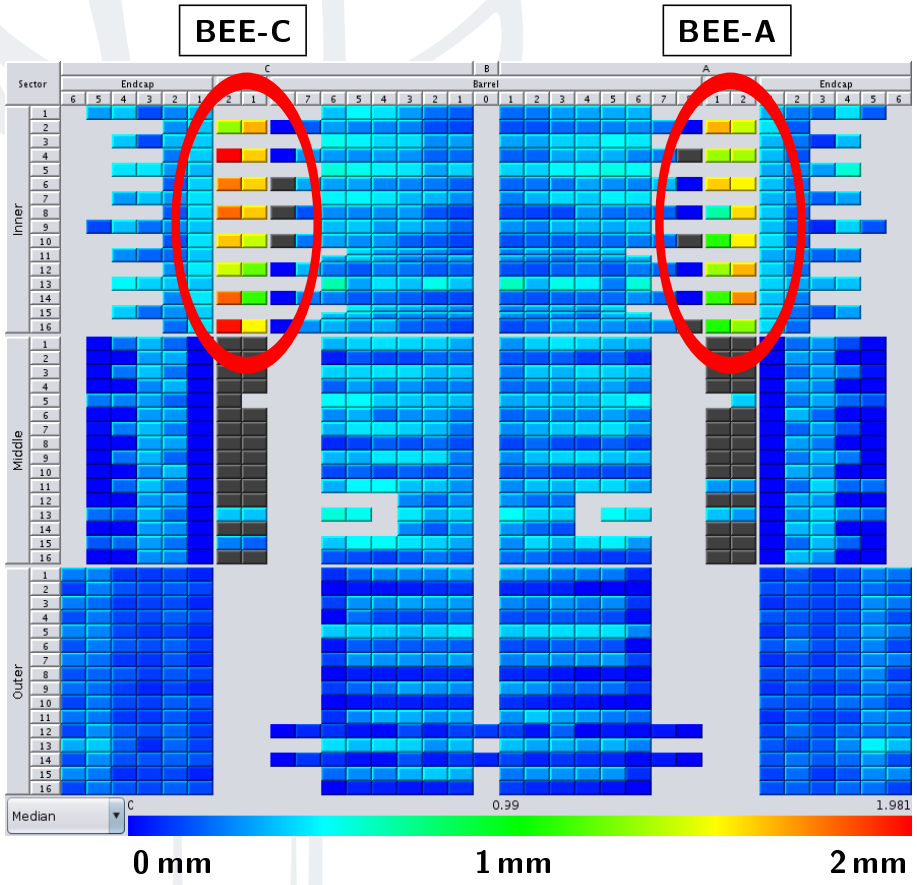
BEE Geometry Bug

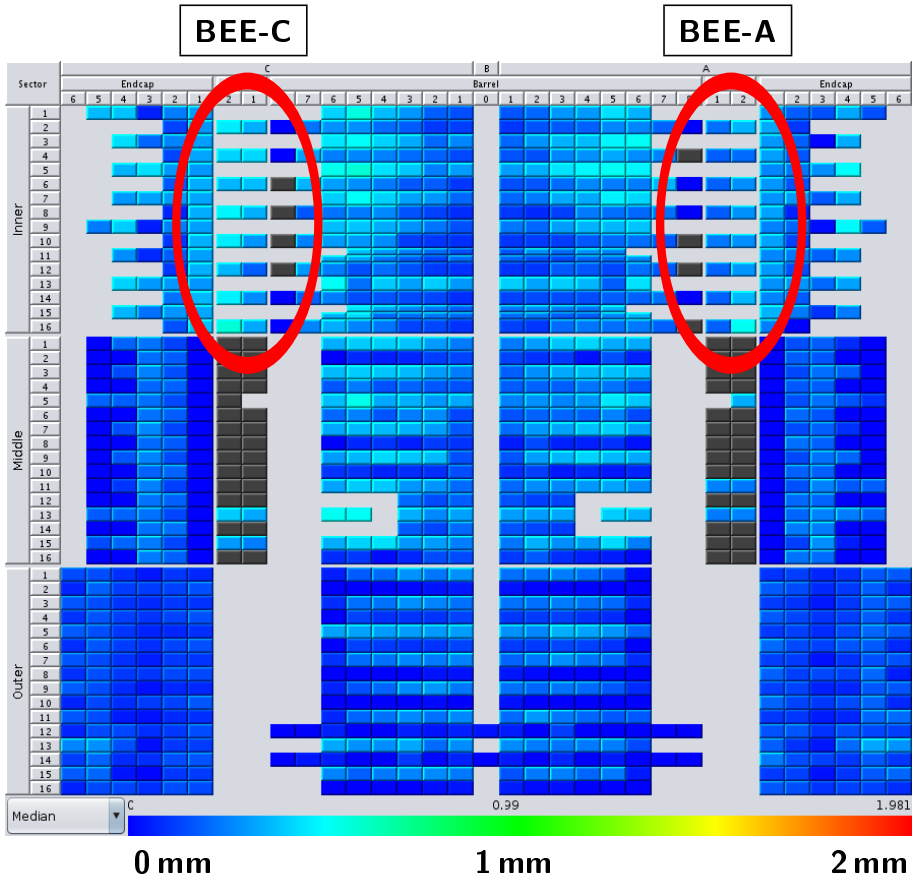
2010 Collisions

- **Another way to find the same bug:**

monitoring plots of average unsigned track residuals, $|r_{\text{hit}} - r_{\text{track}}|$, before and after BEE geometry bugfix

confirms the bug affected only BEE chambers





Tags, IoVs, and All That

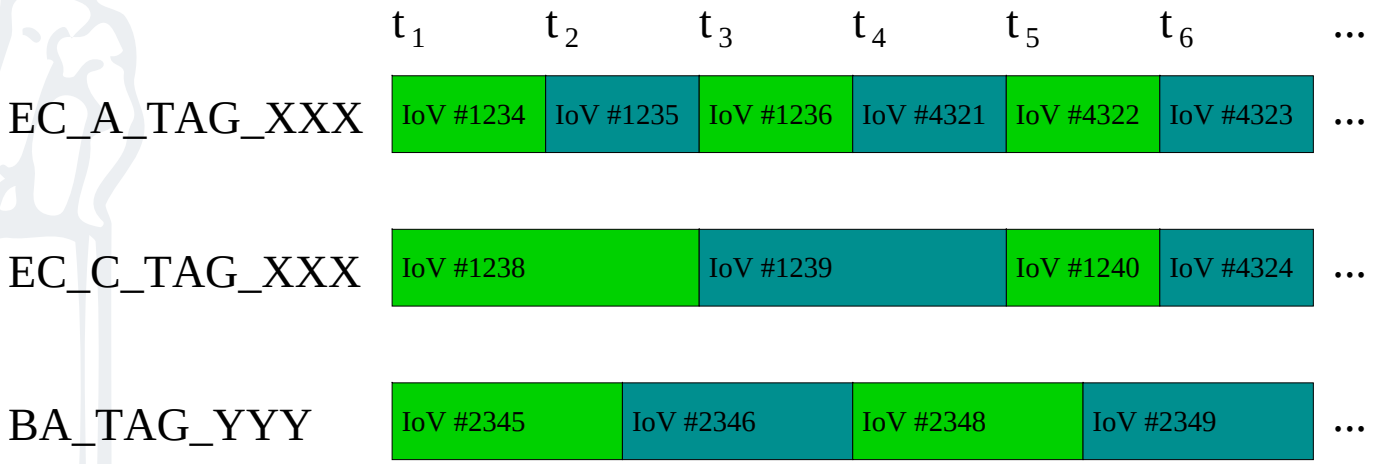
- **Tags and IoVs:**

  an IoV (interval of validity) is the range in time for which the set of alignment data associated to it is supposed to be used

  a tag is an identifier describing the part of a detector (barrel/EC-A/EC-C) which a set of alignment data is for, plus information about the source of the data (optical, tracks, combined) and the configuration of the reconstruction program

  usually many IoVs are associated to the same tag, covering a sequence of time ranges; for a given time t, there may exist several IoVs in different tags (no more than one IoV in each)

  think of tags and IoVs as folders and subfolders in a filesystem; alignment data then are files in the subfolders



Tags, IoVs, and All That

- **A fundamental complication:**

  once alignment data have been used for reconstruction, they must not be modified anymore (not even bugfixes), so that reconstruction results are reproducible forever – "tag is locked"

  once a tag has been used, cannot write to it anymore (worst case: prompt reconstruction would lock a tag instantaneously)

  incompatible with operation mode of alignment reconstruction: continuously keep adding new data to a tag, while old data should already be available for reconstruction

- **The solution(s):**

  UPD1 tags: locked at any given moment for the past, can be unlocked for the future → to be used for prompt reconstruction (note: alignment always "lagging behind", by construction)
  - updated regularly for barrel, not yet for endcap alignment

  UPD4 tags: similar, but some fraction of the recent past can be unlocked as well → to be used for bulk processing after 36h
  - barrel and endcap alignment will switch to this mode

  "normal" tags: unlocked until they are used for reconstruction; at that moment, create copy of "current" tag, lock and use copy → used for reprocessing (if improved alignment available)

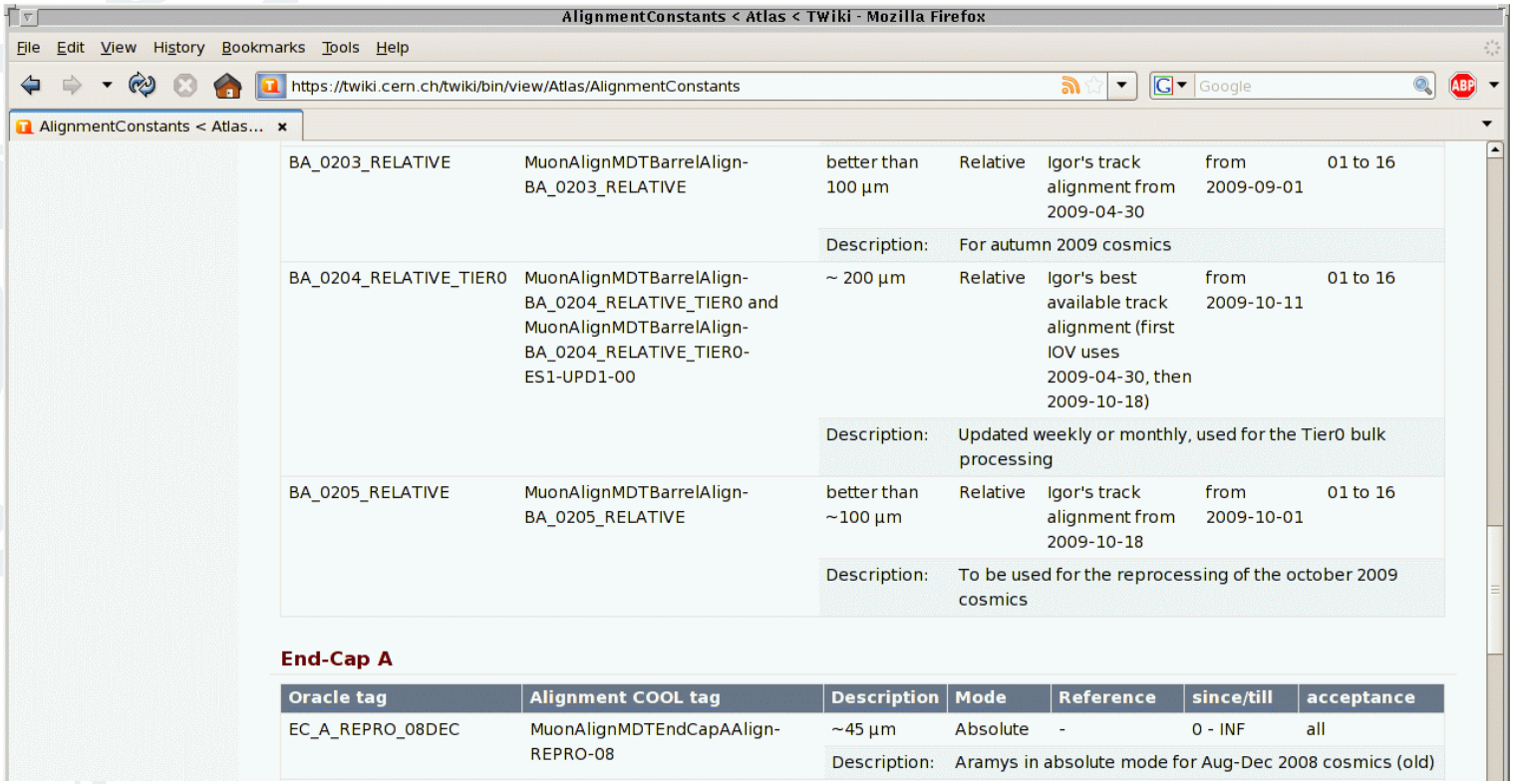
Which Tags to Use

- **Twiki page of available tags:**

  `https://twiki.cern.ch/twiki/bin/view/Atlas/AlignmentConstants`

  Oracle and COOL tag names, and description of what is inside (still advisable to talk with an expert to understand the details)

  (alignment corrections are stored in an intermediate Oracle DB, then migrated to the official ATLAS COOL DB)



What is Inside a Tag

- **Alignment data application server:**

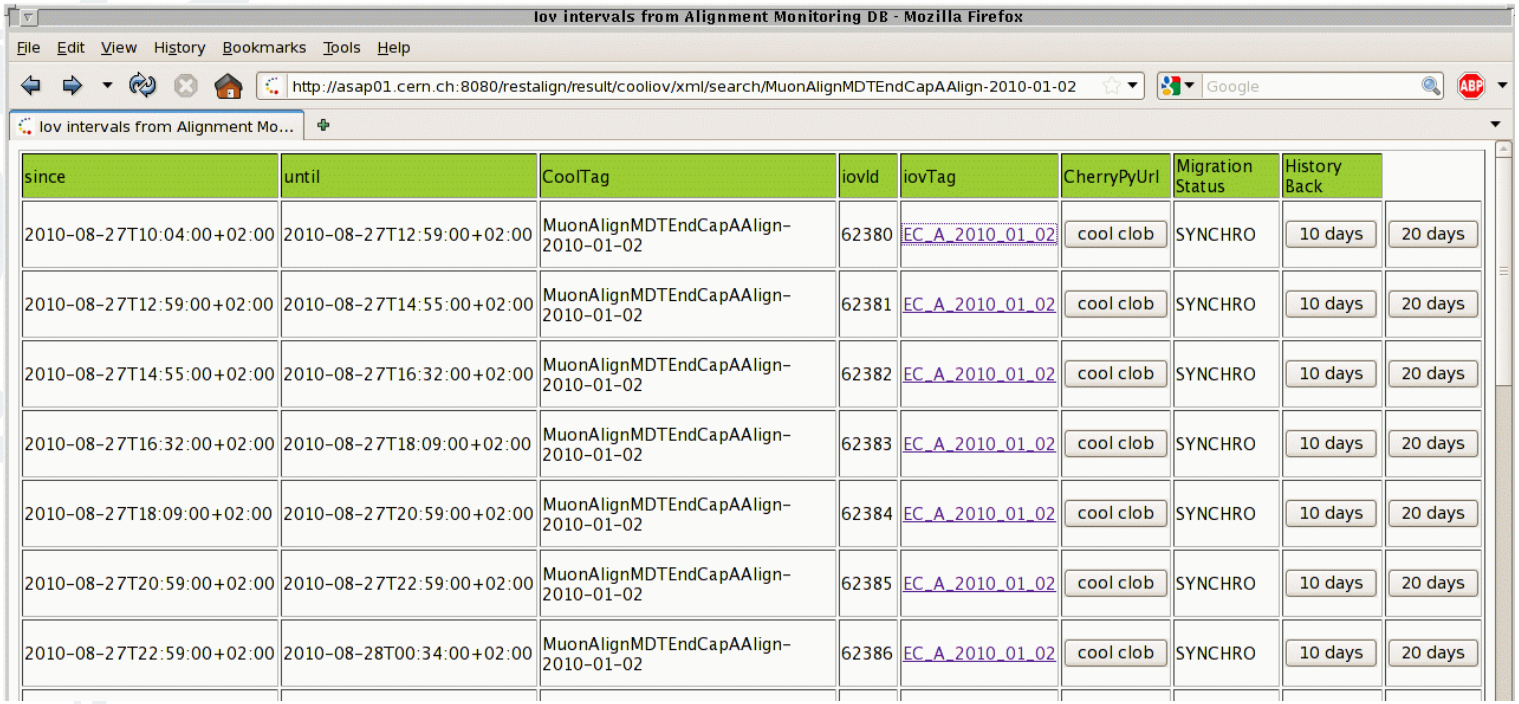
  Oracle tags:

  `http://asap01.cern.ch:8080/restalign/result/iov/xml/[TAGNAME]`

  COOL tags:

  `http://asap01.cern.ch:8080/restalign/result/cooliov/xml/search/[TAGNAME]`

  to list IoVs in a given tag, and read back the A-/B-lines and diagnostics (an ASCII version of this tool also exists – contact me if you are interested in using this)



since	until	CoolTag	iovId	iovTag	CherryPyUrl	Migration Status	History Back	
2010-08-27T10:04:00+02:00	2010-08-27T12:59:00+02:00	MuonAlignMDTEndCapAAlign-2010-01-02	62380	EC_A_2010_01_02	cool clob	SYNCHRO	10 days	20 days
2010-08-27T12:59:00+02:00	2010-08-27T14:55:00+02:00	MuonAlignMDTEndCapAAlign-2010-01-02	62381	EC_A_2010_01_02	cool clob	SYNCHRO	10 days	20 days
2010-08-27T14:55:00+02:00	2010-08-27T16:32:00+02:00	MuonAlignMDTEndCapAAlign-2010-01-02	62382	EC_A_2010_01_02	cool clob	SYNCHRO	10 days	20 days
2010-08-27T16:32:00+02:00	2010-08-27T18:09:00+02:00	MuonAlignMDTEndCapAAlign-2010-01-02	62383	EC_A_2010_01_02	cool clob	SYNCHRO	10 days	20 days
2010-08-27T18:09:00+02:00	2010-08-27T20:59:00+02:00	MuonAlignMDTEndCapAAlign-2010-01-02	62384	EC_A_2010_01_02	cool clob	SYNCHRO	10 days	20 days
2010-08-27T20:59:00+02:00	2010-08-27T22:59:00+02:00	MuonAlignMDTEndCapAAlign-2010-01-02	62385	EC_A_2010_01_02	cool clob	SYNCHRO	10 days	20 days
2010-08-27T22:59:00+02:00	2010-08-28T00:34:00+02:00	MuonAlignMDTEndCapAAlign-2010-01-02	62386	EC_A_2010_01_02	cool clob	SYNCHRO	10 days	20 days

Using Alignment Data in Reconstruction

- **How to use alignment data from a given tag in track reconstruction:**

  good question – ask it to a software/reconstruction expert (not an alignment expert)

- **How to make sure that alignment data from a given tag were used for track reconstruction:**

  several possibilities – start by checking job options and log files, look for (the COOL) tag names

  the ultimate check (probably the only absolutely safe one): download A-/B-lines for the tag and IoV that should have been used, have your ATHENA job print out the actual values $s\,z\,t$ that it uses – and compare for a few chambers

  PLEASE: before you present any results in any meetings, find out what alignment tags you have used, and check with an alignment expert whether they are the right ones

Summary

- To the best of our knowledge, the MDT alignment is good to about 50 μm (endcap) and 50/100 μm (barrel large/small sectors) sagitta accuracy
- Numerous caveats go with this statement, related to particular detector regions and track configurations – ask an expert when in doubt
- There was a 6 mm bug in the CSC positions, which has been fixed for the Fall 2010 reprocessing (and also for Tier-0); after the bugfix, CSC alignment should be good to about 700 μm sagitta accuracy
- Detector description bugs can affect the observed resolution in a way that is not always easy to distinguish from alignment problems