Status of alignment

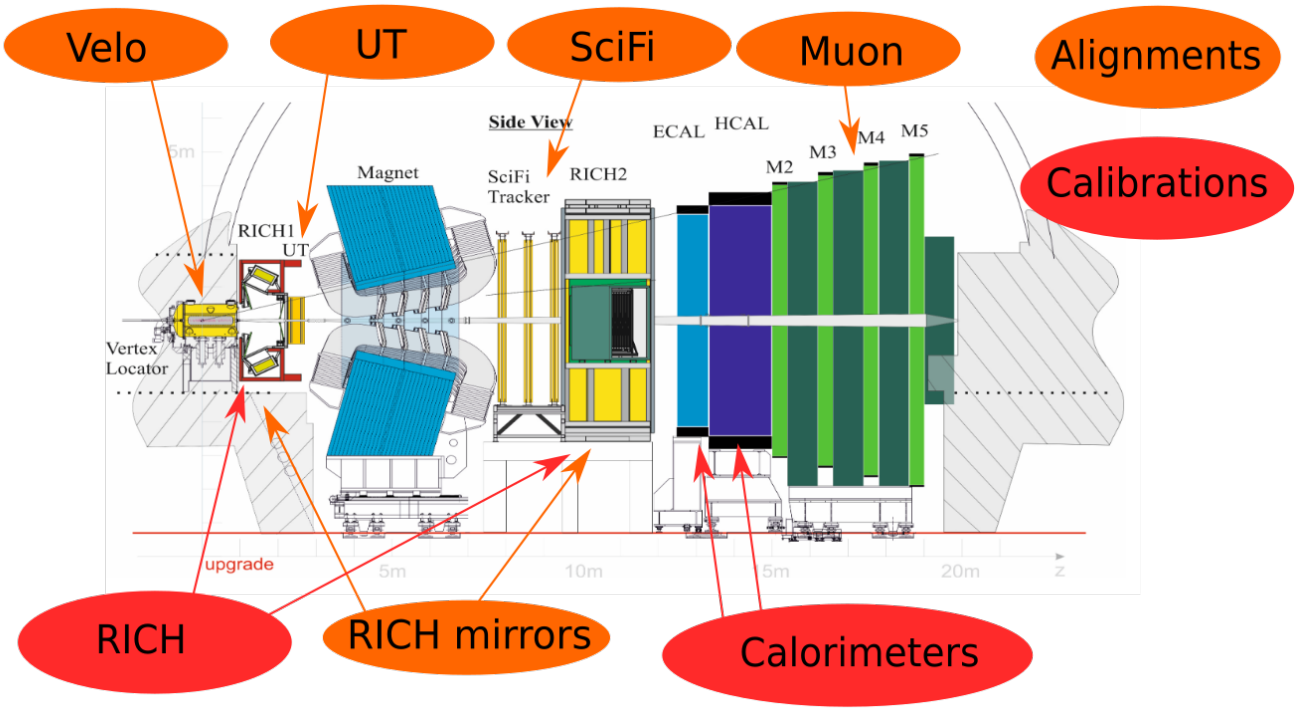
84th Analysis and Software Week

Florian Reiss
on behalf of RTA-WP4

04.05.2023

Introduction

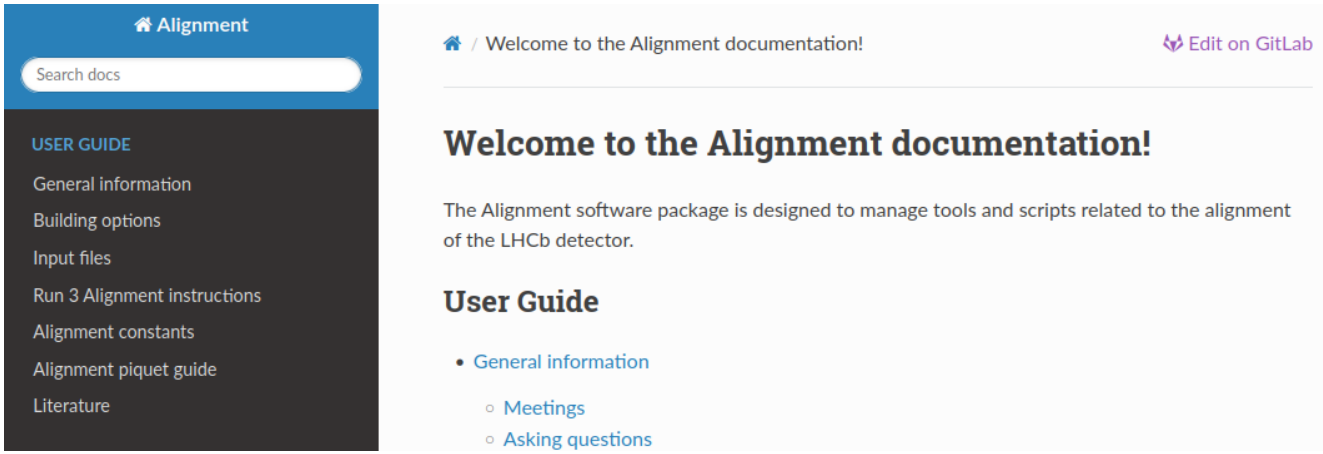
What we need to align and calibrate?



Focus here on the alignment tasks

Introduction

New alignment documentation



Alignment tags for 2022 data [docu]

sub-system	v2	v4	2022_12_HLT2
VELO module and sensor	X		X
VELO half	two runs	more runs	fills 8489, 8491, 8496
Scifi module	X		X
Muon			
RICH mirror			X
RICH panel	X		X
RICH calibration			for some runs
Other			
Magnet	MagUp wrong	MagUp wrong	MagUp wrong

v5	v6	v7	v9
for 4 runs of VdM			
	X		
for other runs			
		Scifi mat contraction	Tell40 conditions
MagUp wrong	MagUp wrong	MagUp wrong	MagUp correct

Introduction

To use constants with DD4hep

```
options.conditions_version = TAGNAME
options.simulation = False
```

Latest tag `AlignmentV9_2023_03_16_VPSciFiRich`

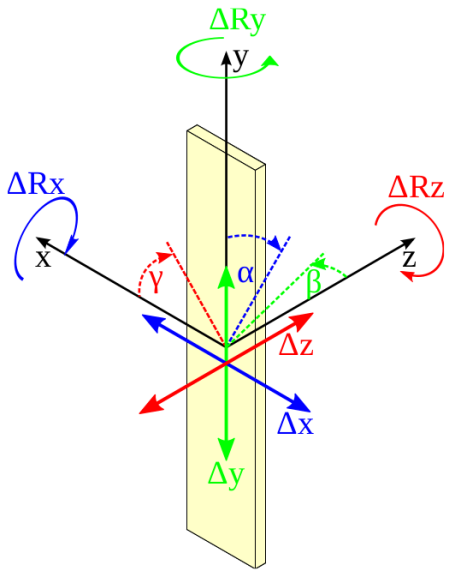
- dedicated VELO right half alignment for number of runs
- VELO module and sensor alignment
- SciFi half module alignment
- RICH panel alignment
- RICH1 +RICH2 central mirror alignment
- RICH calibration

Next version:

- updated SciFi alignment "v3"
- RICH1 full mirror alignment

Tracker alignment

Align VELO, UT, SciFi, Muon system



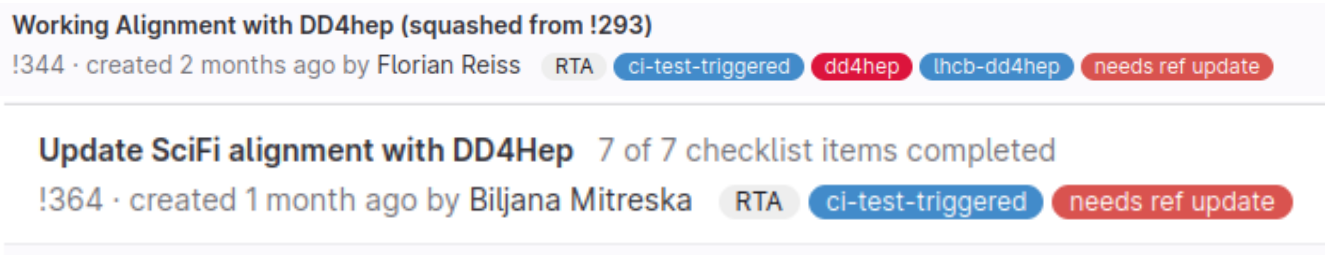
Degrees of freedom α for tracker alignment (alignment constants)

- 3 translations T_x, T_y, T_z
- 3 rotations R_x, R_y, R_z

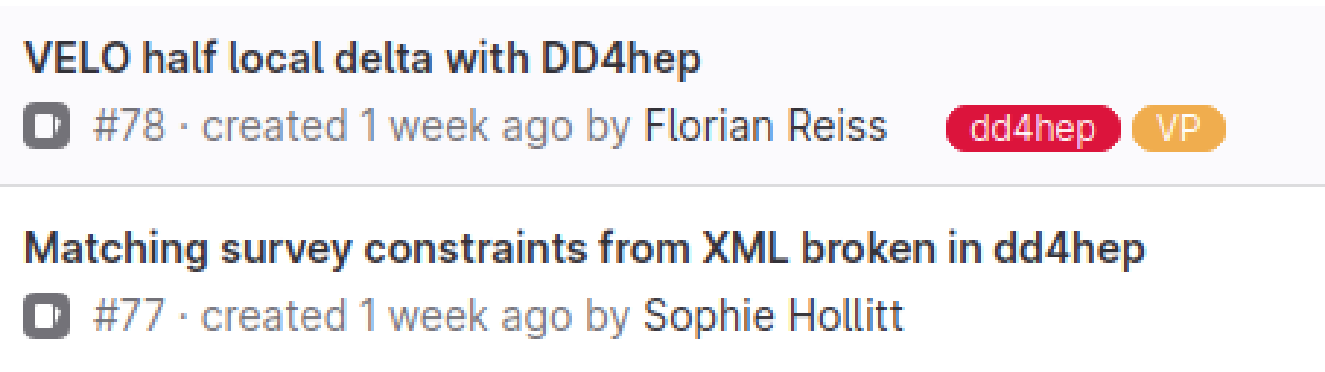
for each 'alignable' element
$\rightarrow$ alignment 'moves' and 'rotates' detector elements in software

Tracker alignment

Tracking alignment working with DD4hep



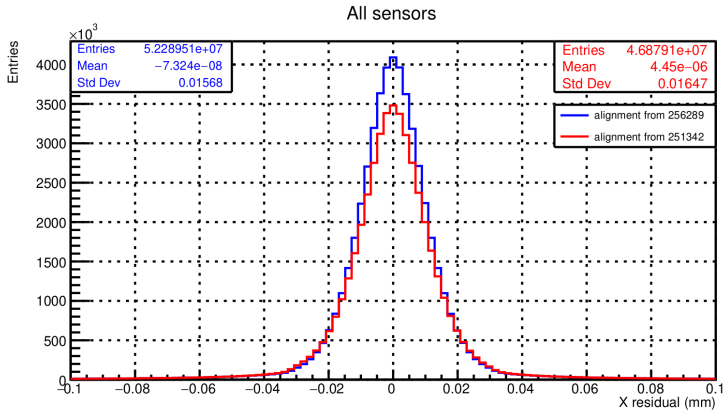
Some DD4hep-specific issues seen and being addressed

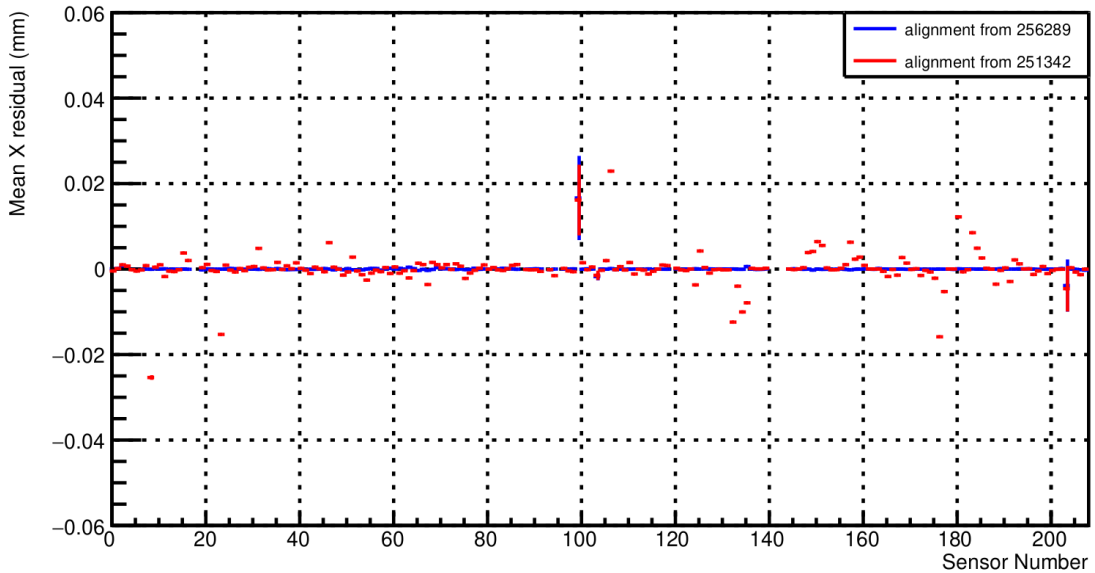


- consistent results between DetDesc and DD4hep builds

VELO alignment with 2022 data

Align VELO halves, modules and sensors



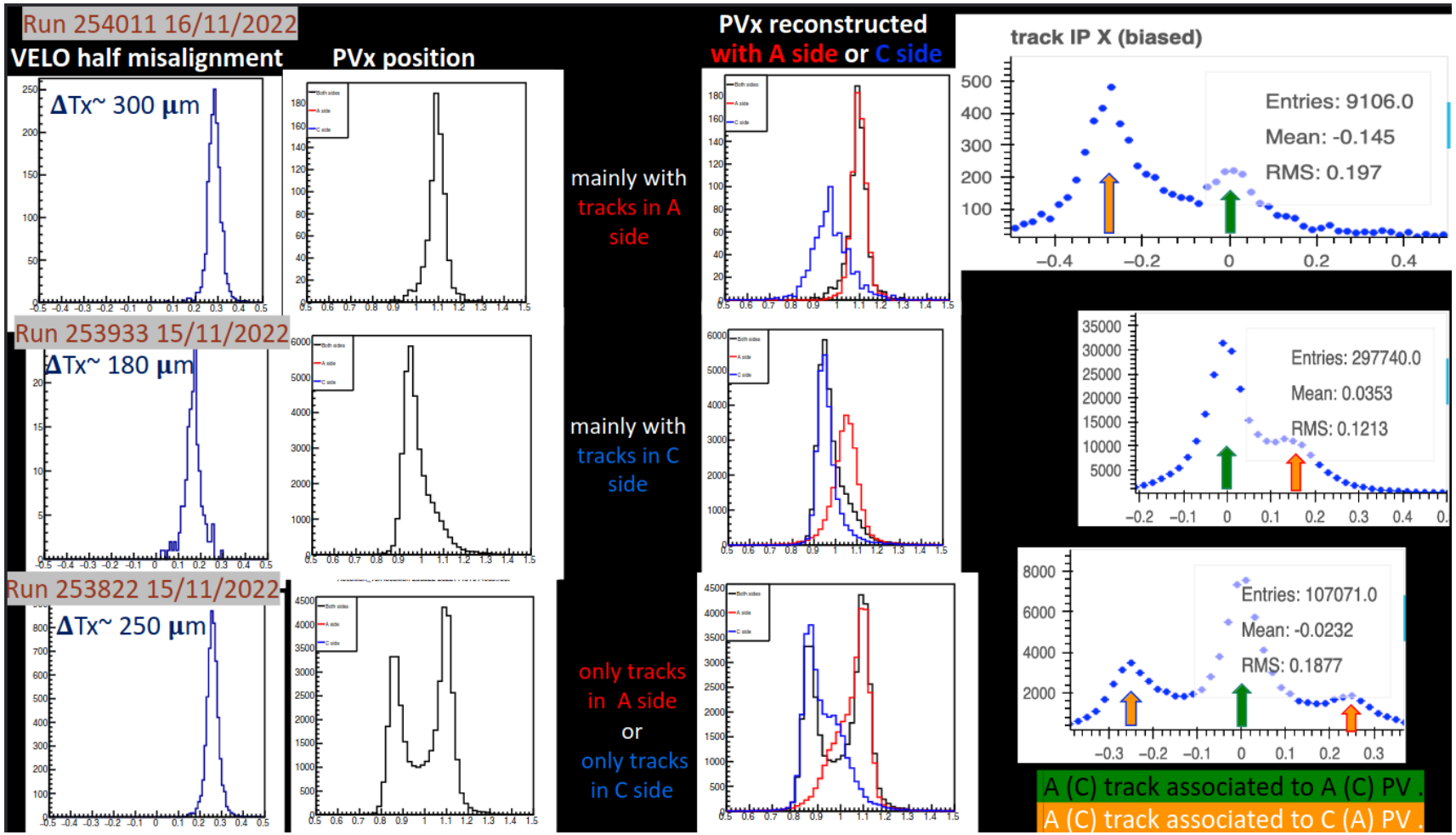


from FR's slides

- updated VELO module and sensor alignment with data from last fill
  - profit from improved detector conditions
  - good quality seen

VELO alignment with 2022 data

VELO right half drift unexpected issue last year

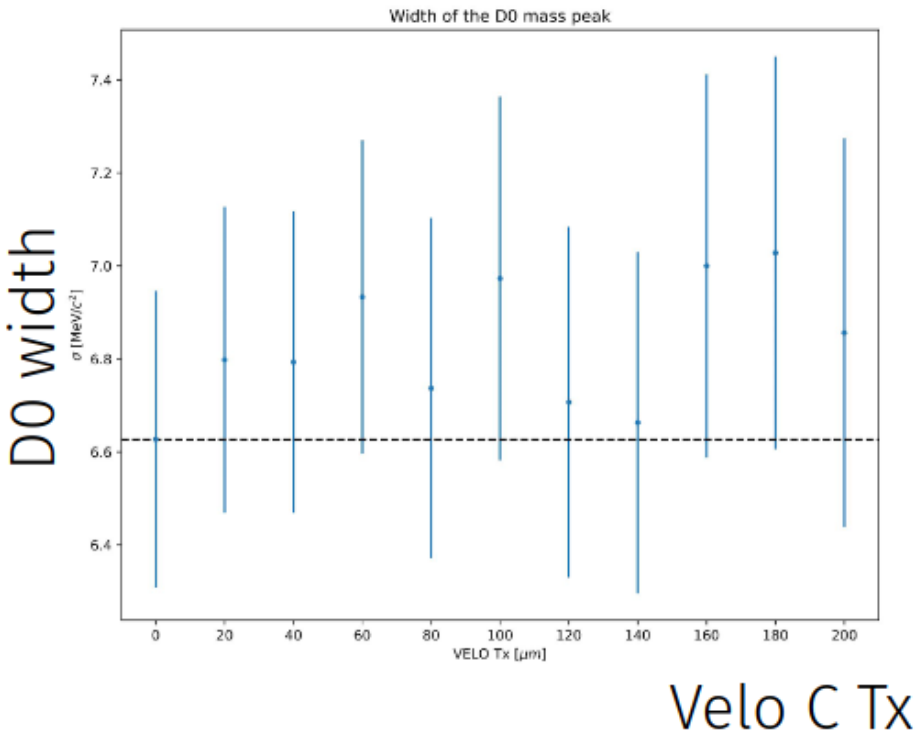


from Silvia's and FR's slides

- impacts PV reconstruction and related variables (e.g. IP)
- small impact on reconstructed mass

VELO alignment with 2022 data

Effect on the mass resolution

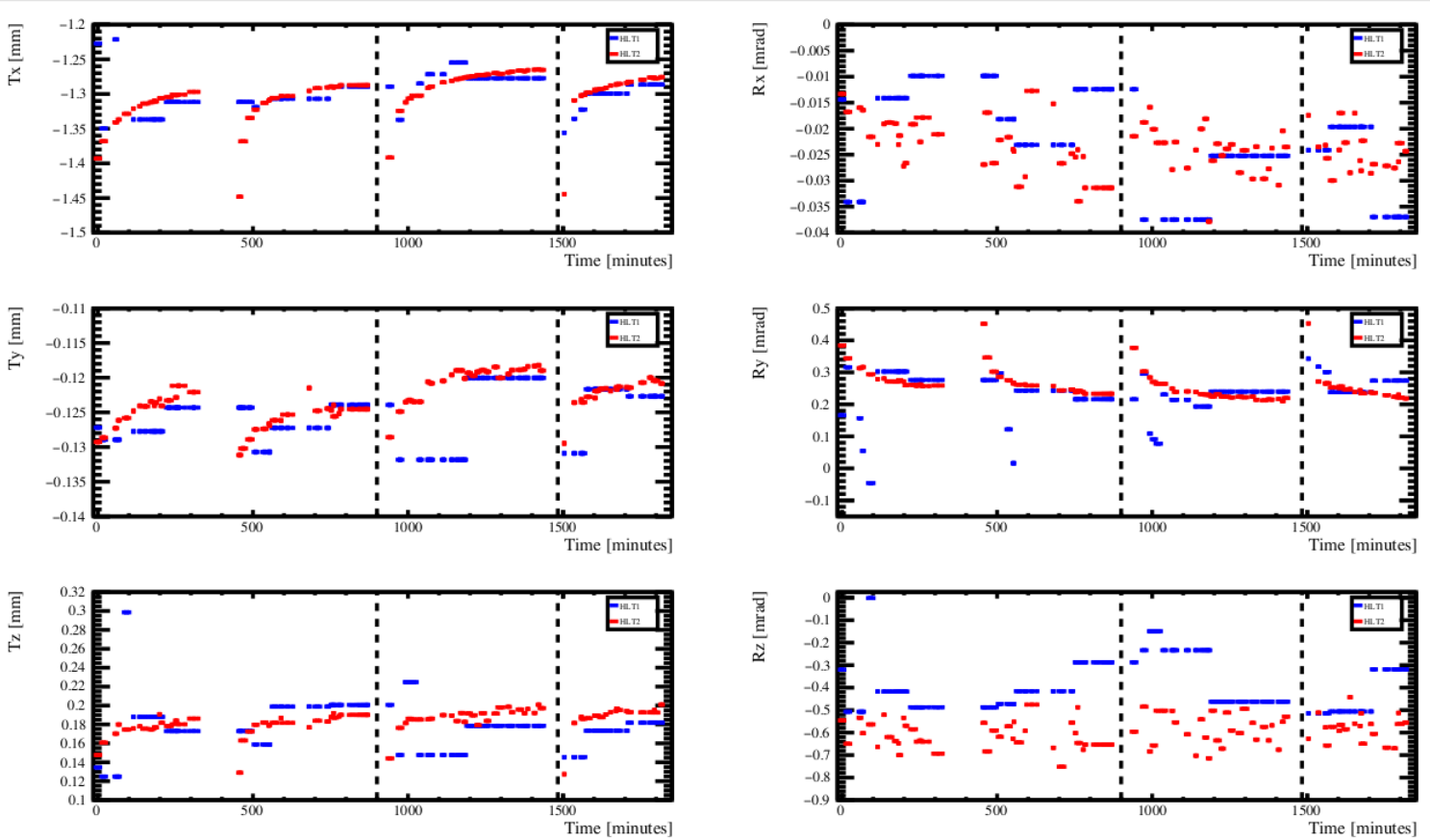


from Sophie's slides

- impacts PV reconstruction and related variables (e.g. IP)
- negligible impact on reconstructed mass

VELO alignment with 2022 data

Studies of (residual) right half misalignment at HLT1 and HLT2 [EMTF meeting]



- HLT1 constants obtained in "real-time"
  - T_x and R_y parametrised in time
- HLT2 constants obtained offline

SciFi alignment with 2022 data

2022 alignment "version flow"

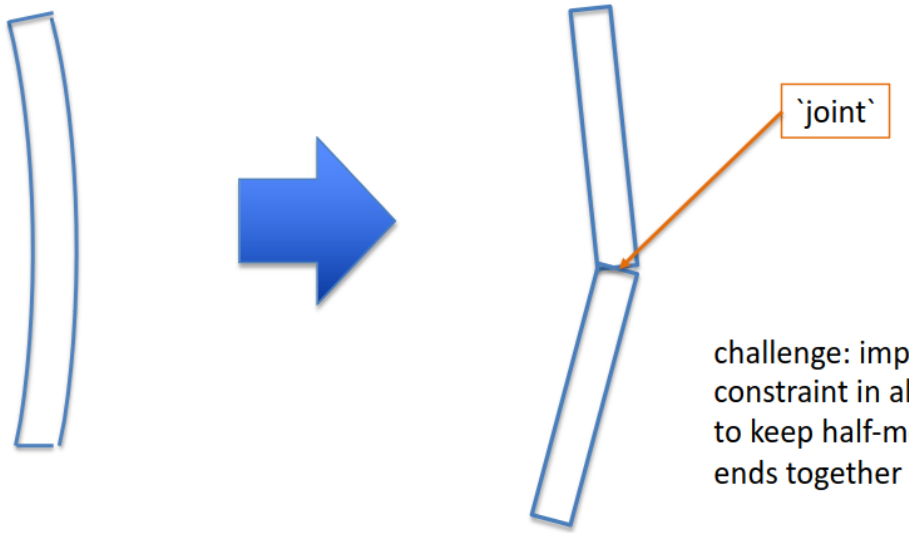
Initial positions from survey+photogrammetry	SciFi v0
Modules TxRz align (long tracks)	SciFi v1
Correct beam angle in survey Improvements to timing	
Modules TxRz align (long tracks)	SciFi v2
Cross check of VELO drift effect size Diagnose low efficiency: T2X2 C side starting position Ability to run in DD4HEP/master Mat adjustment needed to correct for SiPM position Module continuity constraint? Loose track matching/params on iteration 0-2?	
halflayers+ Modules TxRzTz align (long tracks + D0 particle) + Tx Mat alignment	SciFi v3

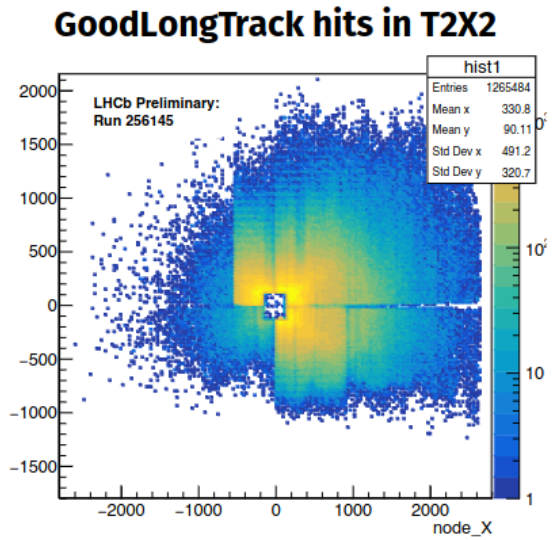
from Sophie's slides

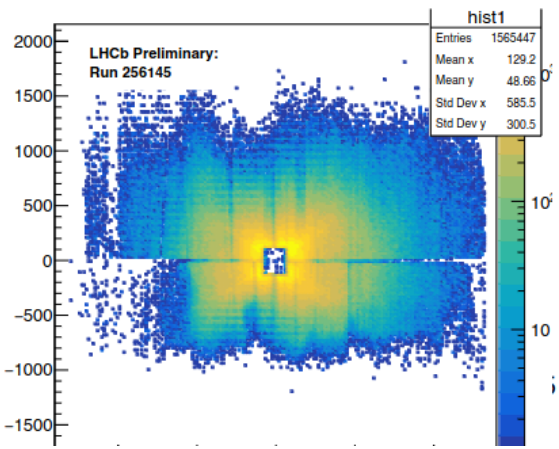
- many steps and considerations to refine SciFi alignment

SciFi alignment with 2022 data

Work ongoing to further refine SciFi alignment



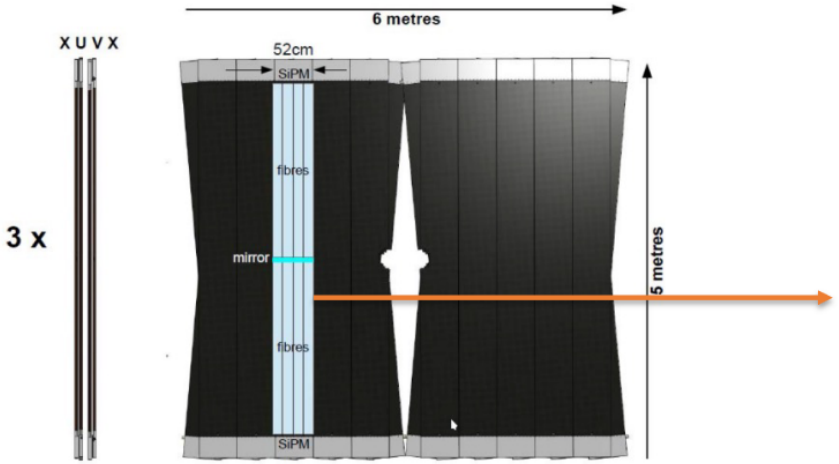




- improved "joint" survey constraints
- starting point adjustments
- inclusion of new survey
- input track selection
- mat alignment

SciFi alignment with 2022 data

Promising improvements from mat alignment



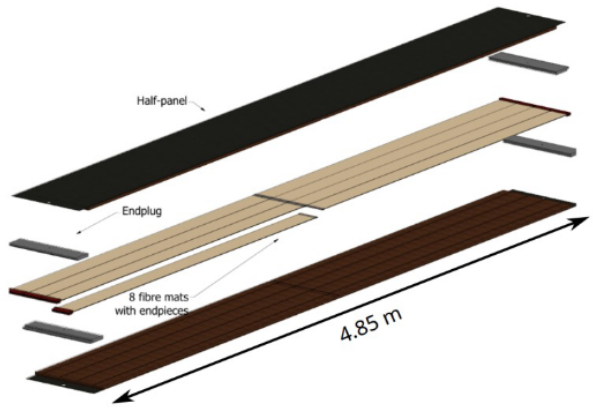
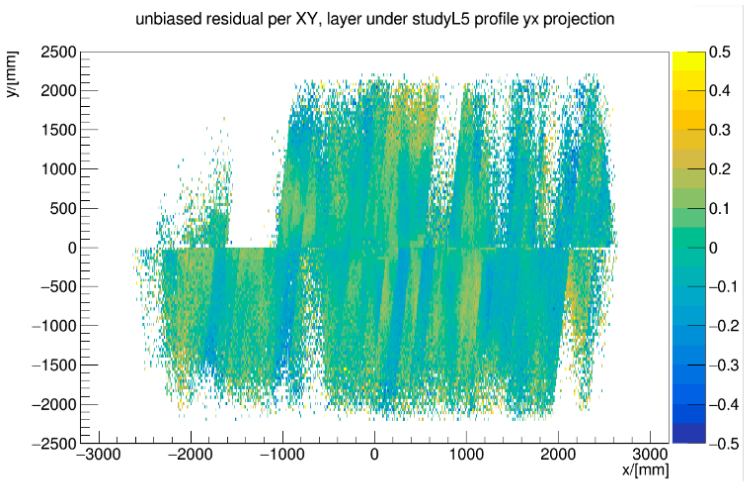
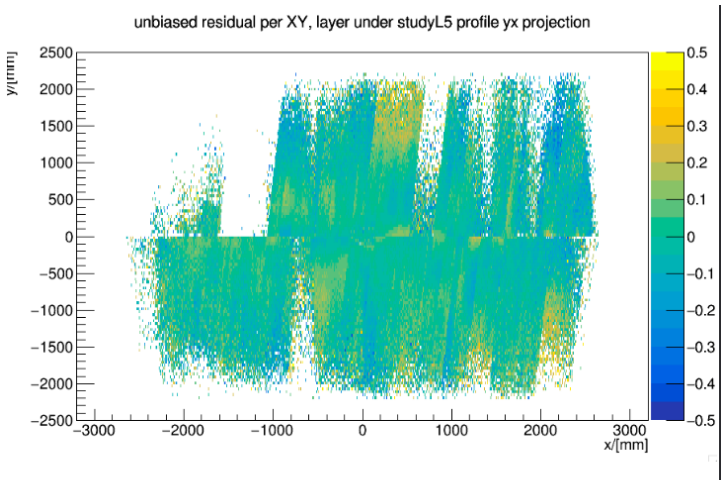


Figure 6: A schematic of a SciFi module.



V9 alignment



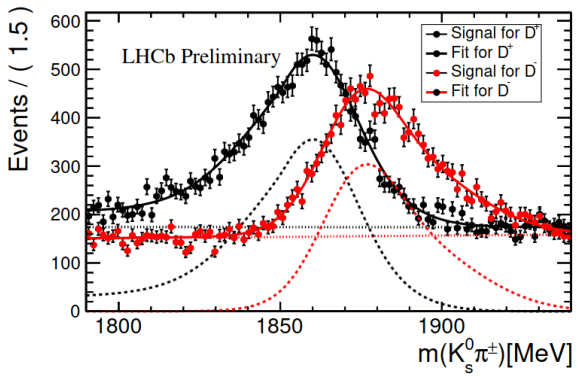
V9 + FTMat alignment

from Zehua's slides

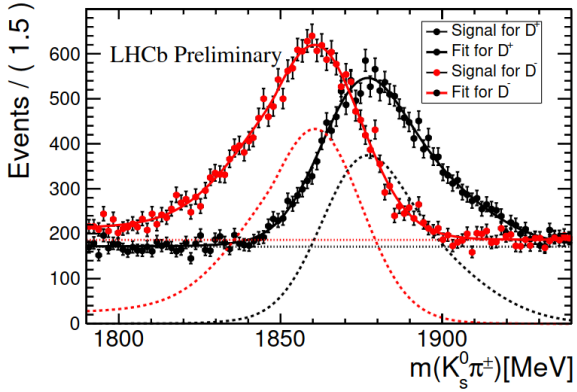
SciFi alignment with 2022 data

Many people trying out preliminary mat alignment [EMTF] [RTA-WP4/5]

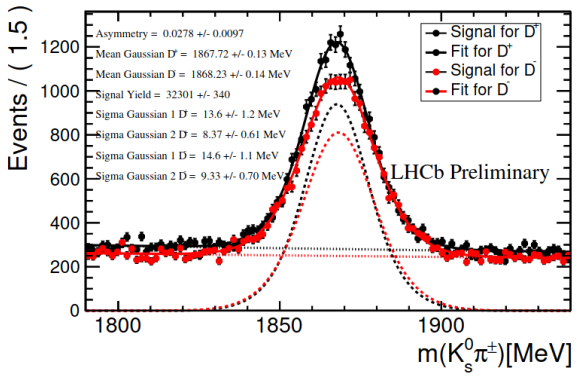
Magnet Down ∼ 75k entries



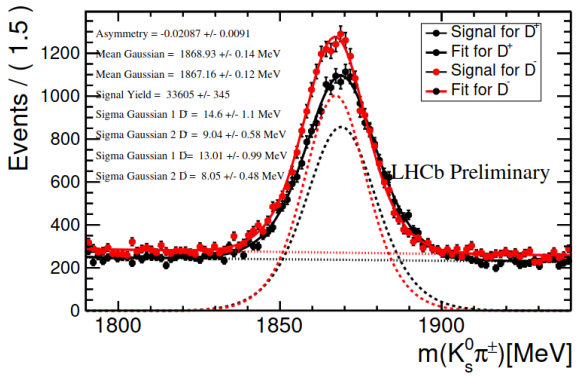
Magnet Up ∼ 107k entries



Magnet Down ∼ 160k entries



Magnet Up ∼ 156k entries

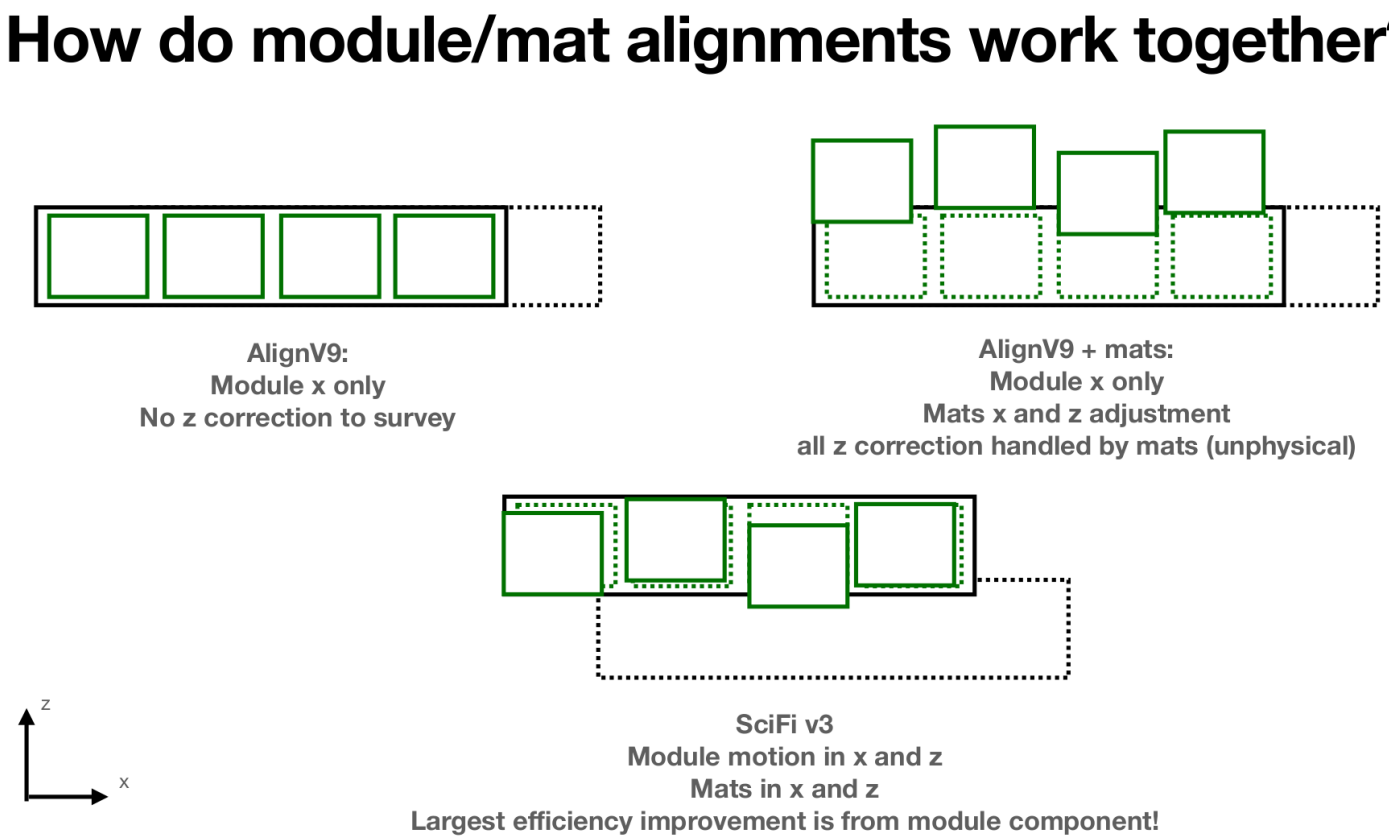


from Francesco's slides

- improved mass resolution
- mass difference between charged-conjugated particles much reduced

SciFi alignment with 2022 data

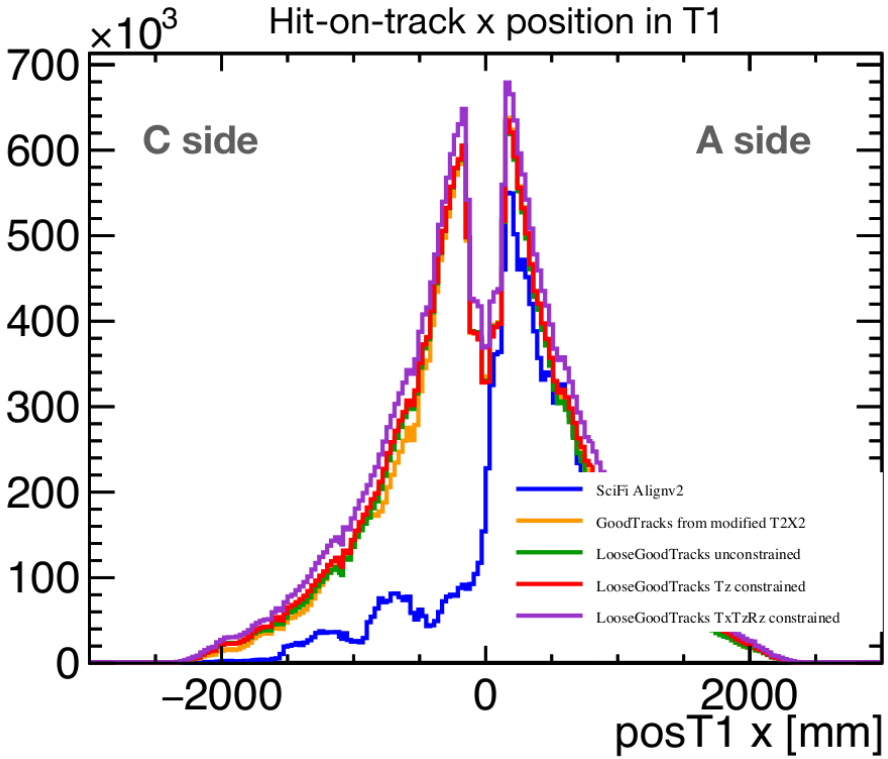
Mat alignment is not the only piece in the puzzle
Brand new update on v3 module alignment this morning by Sophie

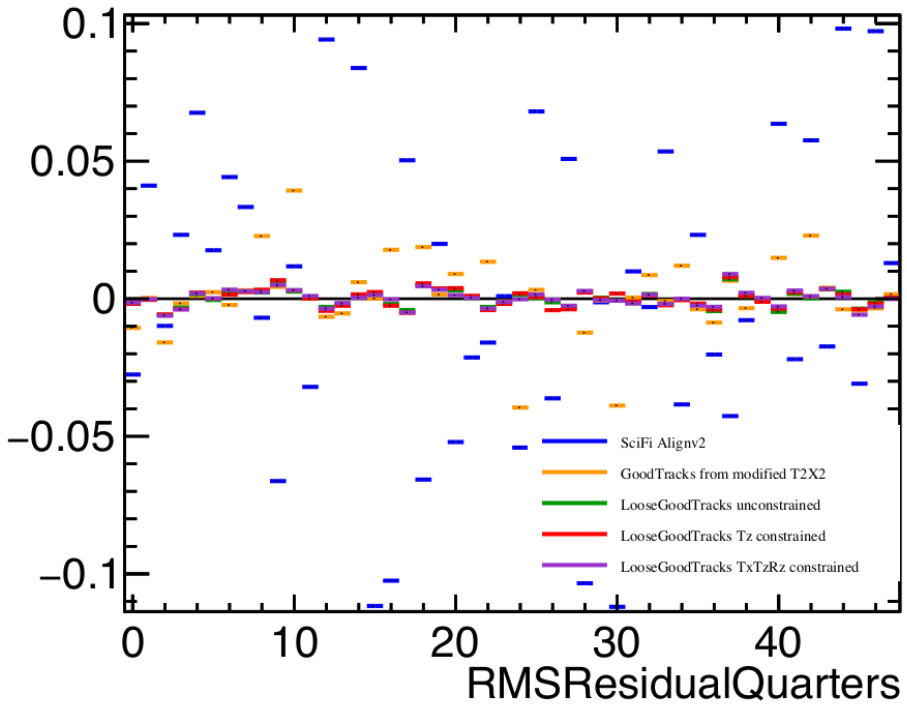


- need to avoid unphysical movements of mats

SciFi alignment with 2022 data

Big improvements from module alignment (without aligning mats)





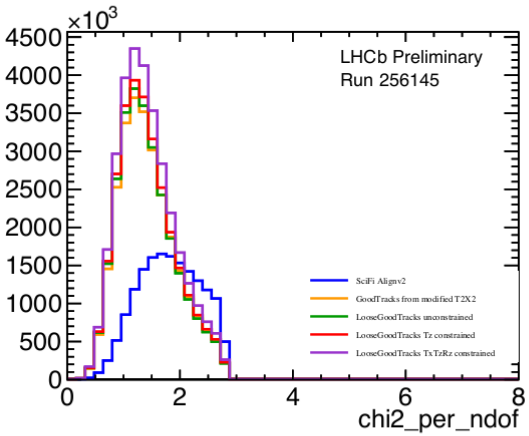
- larger input sample
- include translations in z (T_z)
- looser tracking
- D^0 mass constraint
- constrain average T_x, T_z in back layer

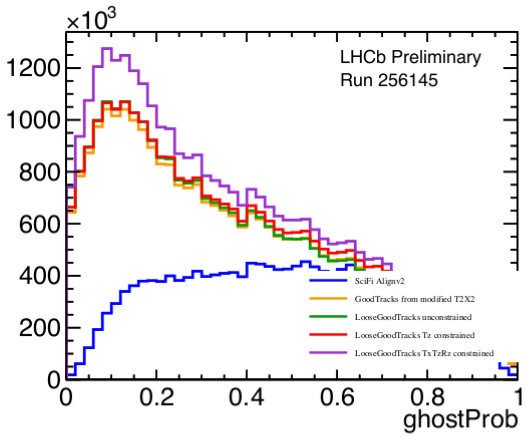
SciFi alignment with 2022 data

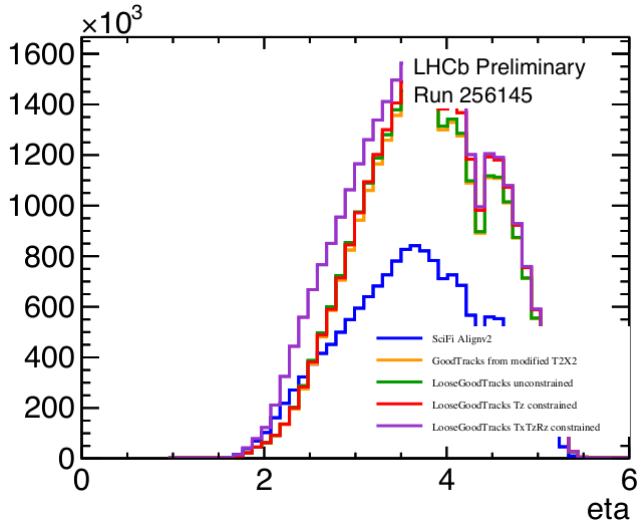
Big improvements from module alignment (without aligning mats)

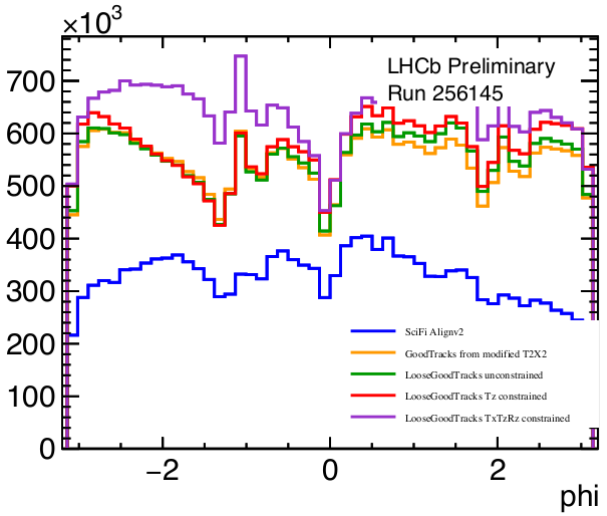
Long track properties

Plots for all (standard) long tracks









RICH alignment with 2022 data

- RICH1: all new optics, mechanics, photodetector panels
- RICH2: new photodetector panels

left: RICH1 (top view); right: RICH2 (side view)

Mirrors focus photons onto granular photodetector panels (two for each RICH)

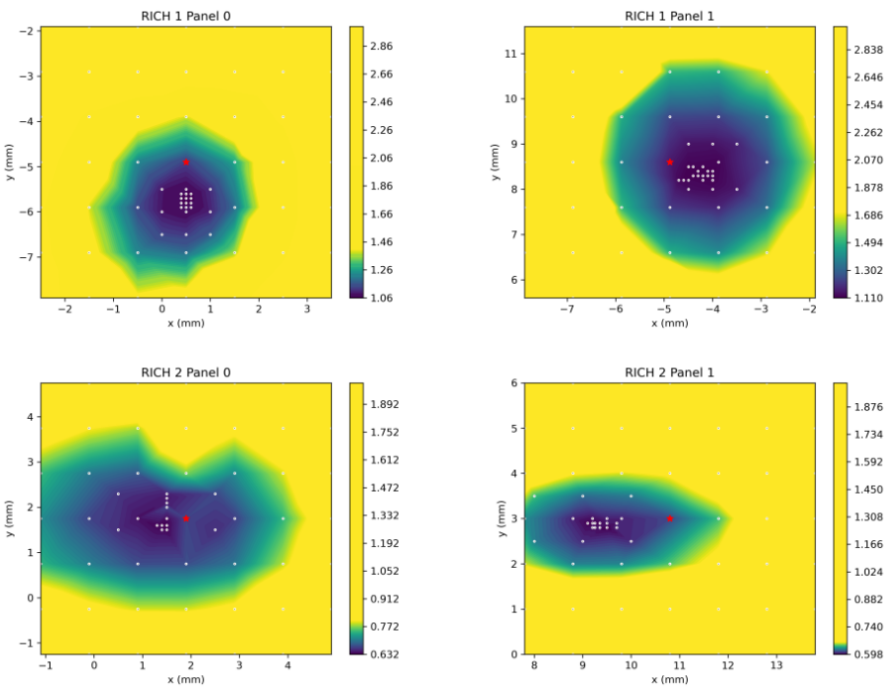
- need to align panels and mirrors
- quantity of interest: resolution per photon $\Delta\theta_{Cherenkov}$
  - difference measured and calculated $\theta_{Cherenkov}$
  - intrinsic optical precision

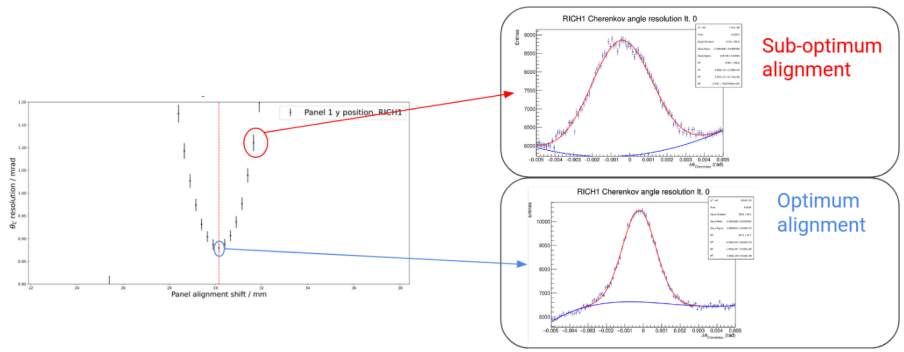
(see Jake's slides for more details)

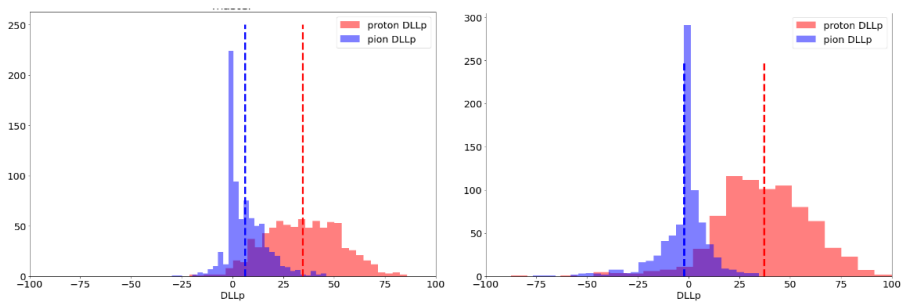
RICH alignment with 2022 data

Align all four RICH panels for 2D translations

- minimise $\sigma[\Delta\theta_{Cherenkov}]$





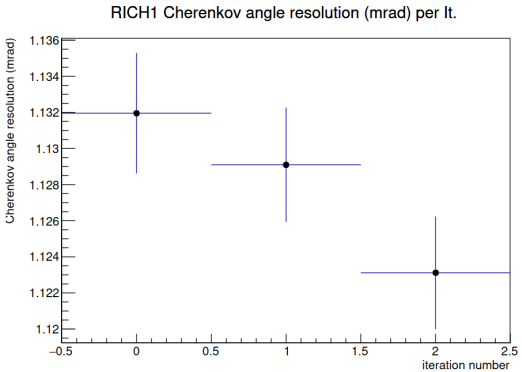


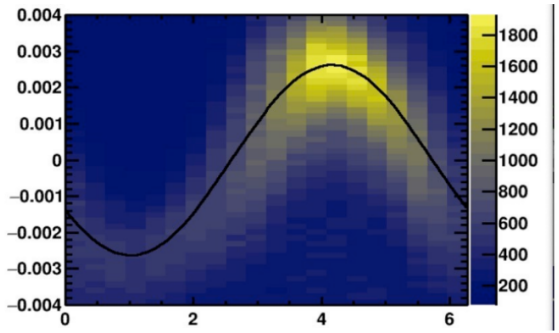
from Jake's slides

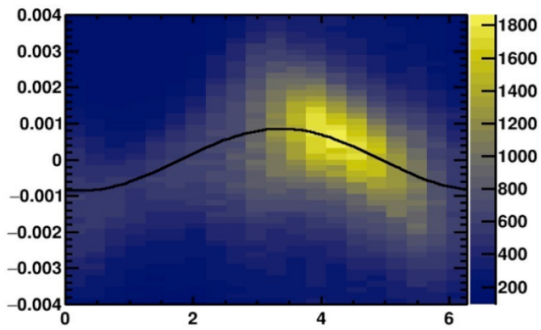
- clear minima obtained
- improvement in PID performance seen

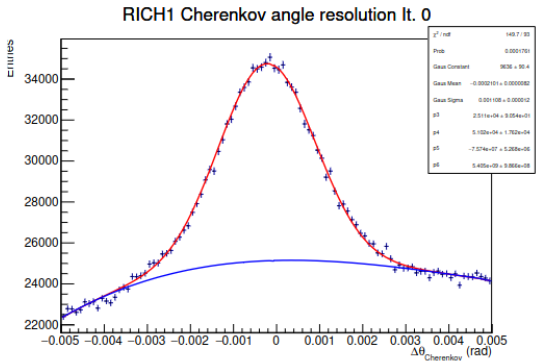
RICH alignment with 2022 data

Align sufficiently populated RICH mirrors (full RICH1, central RICH2)

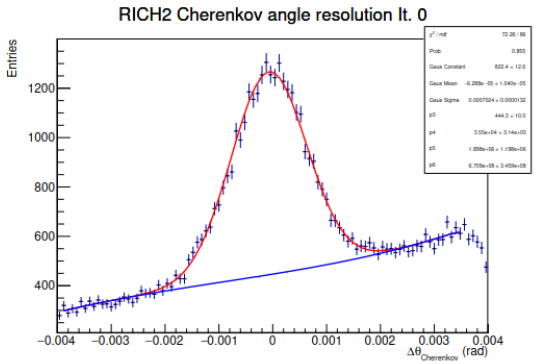




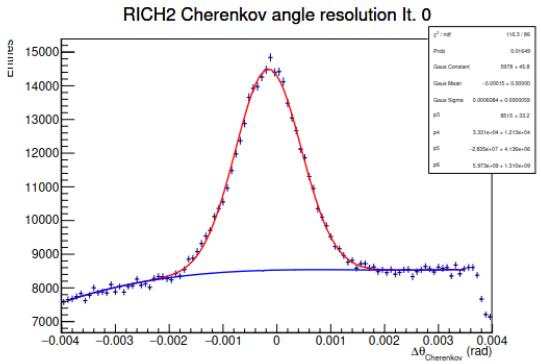




RICH 1 (all PMTs - only small)
$\sigma[\Delta\theta] = 1.108 \pm 0.012$ mrad



RICH 2 (large PMTs)
$\sigma[\Delta\theta] = 0.702 \pm 0.013$ mrad



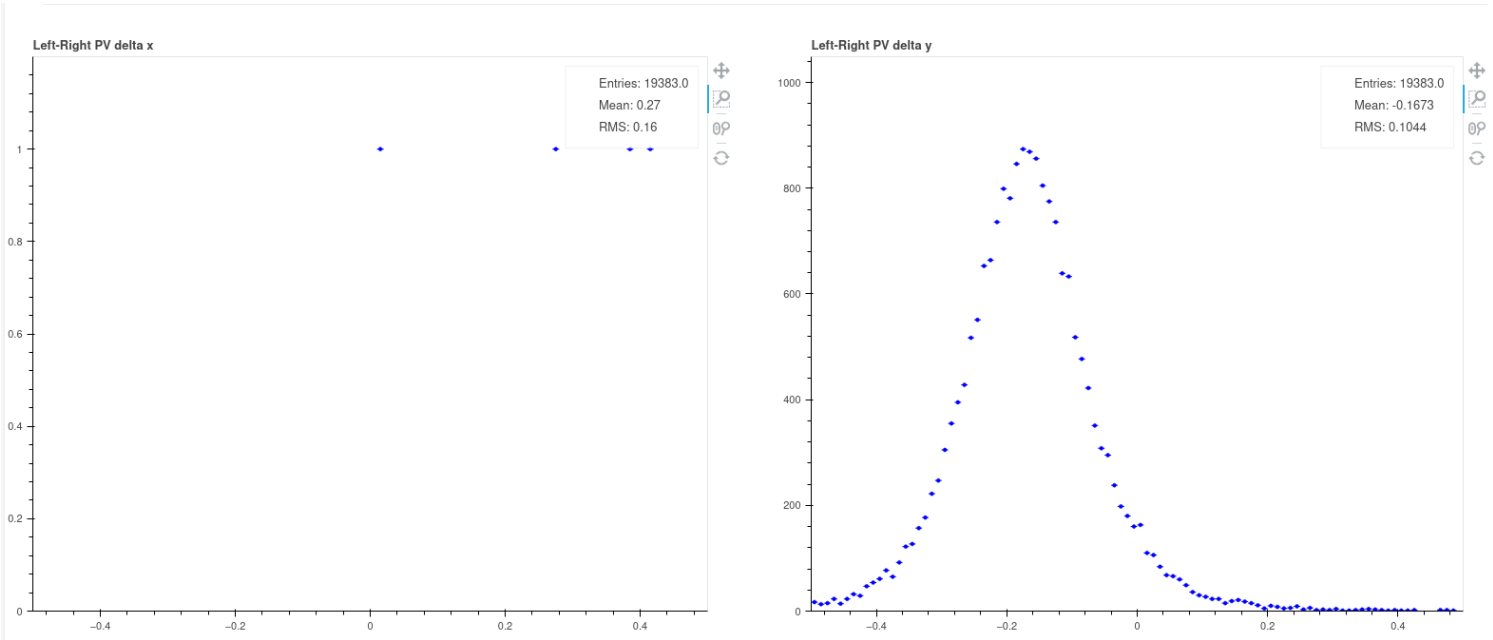
RICH 2 (small PMTs)
$\sigma[\Delta\theta] = 0.608 \pm 0.006$ mrad

- RICH1 resolutions better than Run 2 ($\approx 50\%$ improvement)
- RICH2 resolutions comparable with Run 3 simulation

2023 data

VELO alignment on 2023 data

After vacuum incident, need to check VELO half and module alignment



run 261695

Large half misalignment seen

- half constants from last year VELO open
- $\Delta x(PV_{left} - PV_{right}) \approx 2\,\text{mm}$
- $\Delta y(PV_{left} - PV_{right}) \approx -0.17\,\text{mm}$

Suspicion: rotation of VELO halves

VELO alignment on 2023 data

Possible explanation for misalignment: deformation of top flexible couplings of motion system

- top potentiometers show difference of 1-2 mm w.r.t bottom
- rotation R_z around bottom couplings of $\frac{1-2\,\text{mm}}{657\,\text{mm}} \approx 1.5 - 3\,\text{mrad}$ for each half

Run half alignment on 2023 data and compare with 2022:

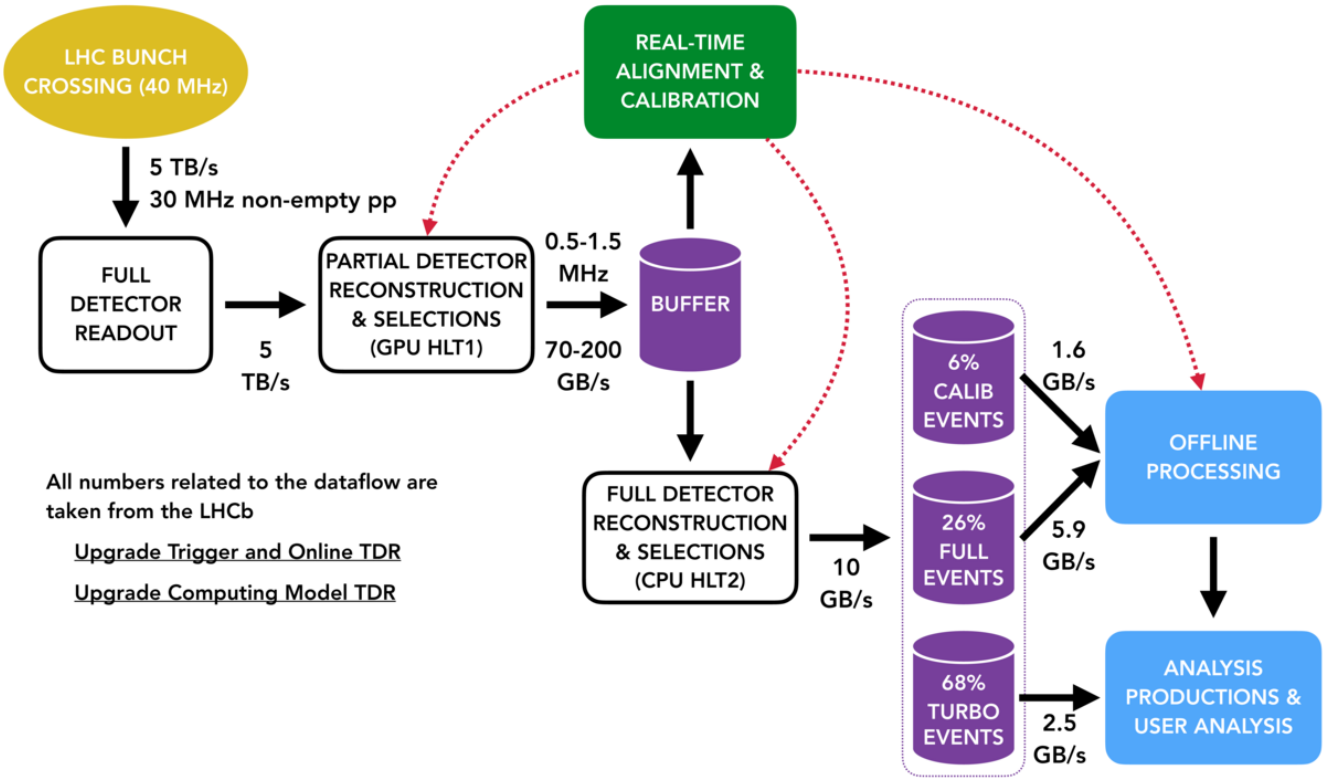
left half constants	T_X [µm]	T_Y [µm]	T_Z [µm]	R_X [mrad]	R_Y [mrad]	Rz [mrad]
design (shims)	1000	0	0	0	0	0
2022 VELO open	795.8	−1.4	−301.1	0.2041	0.0460	0.0016
2023 VELO open	−211.9	81.4	−369.0	0.166	−0.123	3.207
Δ(2023-2022) VELO open	−1007.7	82.8	−67.9	−0.0381	−0.169	3.2054

- total relative misalignment is twice the left half constant
- precision on R_z between $0.2 - 0.5\,\text{mrad}$

Flexible couplings can be inspected when VELO half is closed
New half alignment in place to account for this

Real-time alignment

Real-time alignment



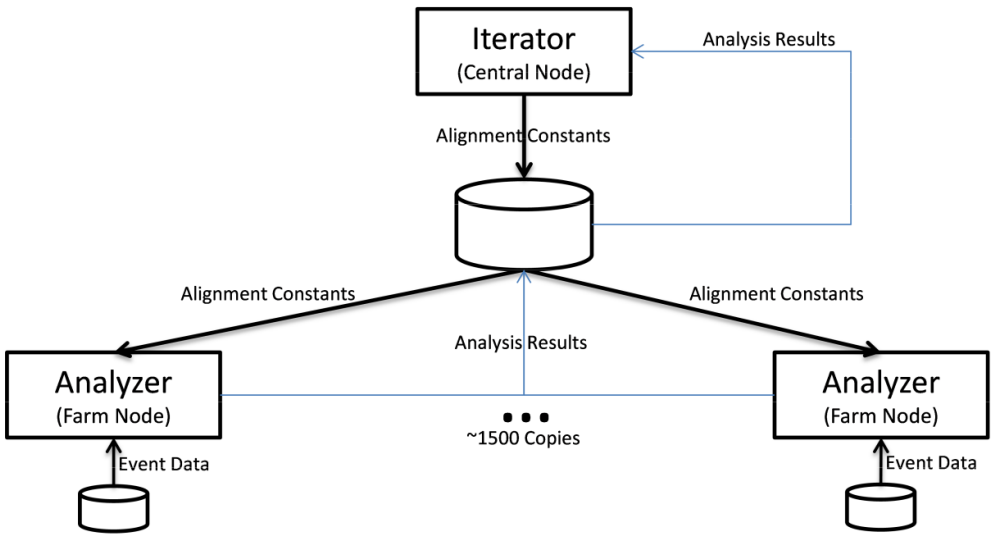
[LHCB-FIGURE-2020-016]

- alignment uses samples selected by HLT1 saved in the buffer
- alignment is executed at the start of each fill
- alignment&calibration used in the trigger $\rightarrow$ "real-time"

Real-time alignment

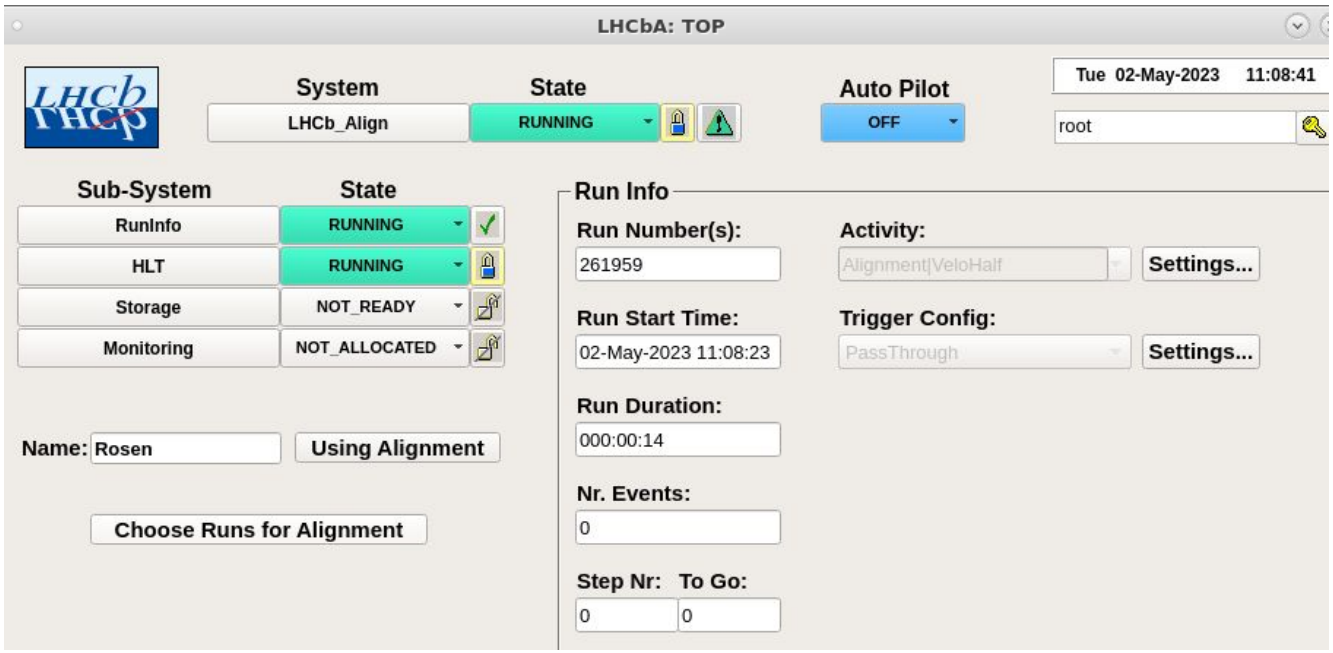
Tracker alignment (VELO, UT, SciFi, Muon) can be split in two parts:

- Analyzer
  - read current constants α_i
  - reconstruct tracks
  - calculate derivatives
  - write derivatives to file
- Iterator
  - read derivatives files
  - perform minimization
  - write out new constants α_{i+1}
  - update constants if necessary



$\rightarrow$ analyzer can be easily split over multiple processes/threads
The real-time alignment machinery is currently being set up
(RICH mirror alignment can be split up in a similar way)

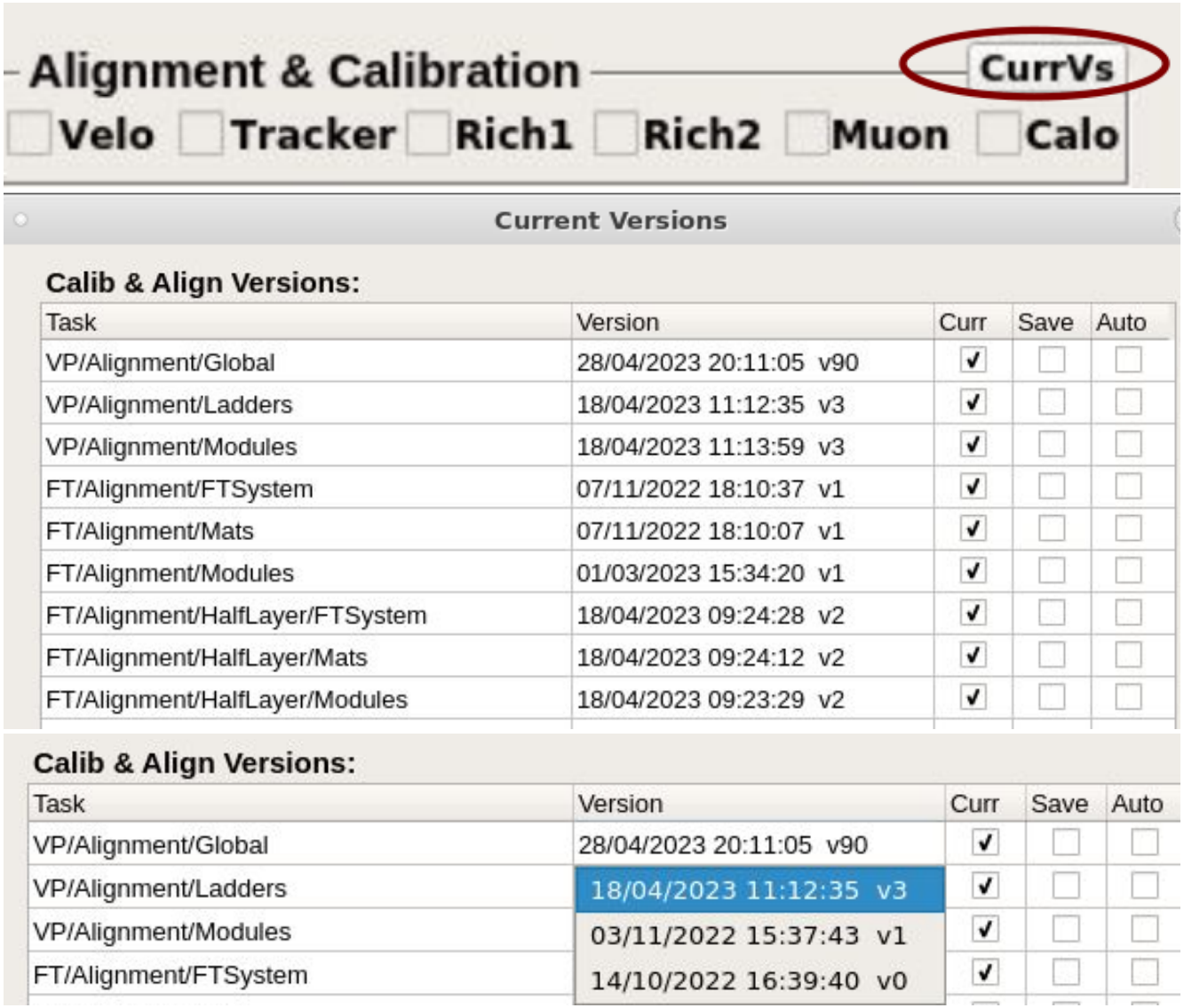
Real-time alignment



VELO half alignment as prototype configuration

- working job
  - interplay between Analyzer and Iterator working correctly
  - running with DD4hep and converging
  - allows further testing and development

Real-time alignment



- can select versions by hand

Real-time alignment

- for each run, create symbolic link pointing to version

```
3 Apr 18 16:09 260554 -> .pool/v1
3 Apr 18 17:10 260567 -> .pool/v1
3 Apr 18 17:58 260576 -> .pool/v2
3 Apr 18 18:05 260577 -> .pool/v2
```

- AlignWriters put samples selected by HLT1 in right location
- can select run(s) used as input
- communication with Online working

```
~$ cat /group/online/alignment/log/AlignVP.log
2023.04.26 18:41:23.532 - Received Version: VP/Alignment/Global=v62
2023.04.26 19:15:17.123 - Received Version: VP/Alignment/Global=v62
2023.04.27 14:16:40.700 - Received Version: VP/Alignment/Global=v66
2023.04.27 14:28:36.046 - Received Version: VP/Alignment/Global=v67
2023.04.28 16:38:48.272 - Received Version: VP/Alignment/Global=v68
```

- copy constants to database

Real-time alignment

Some parts kept manually for the moment

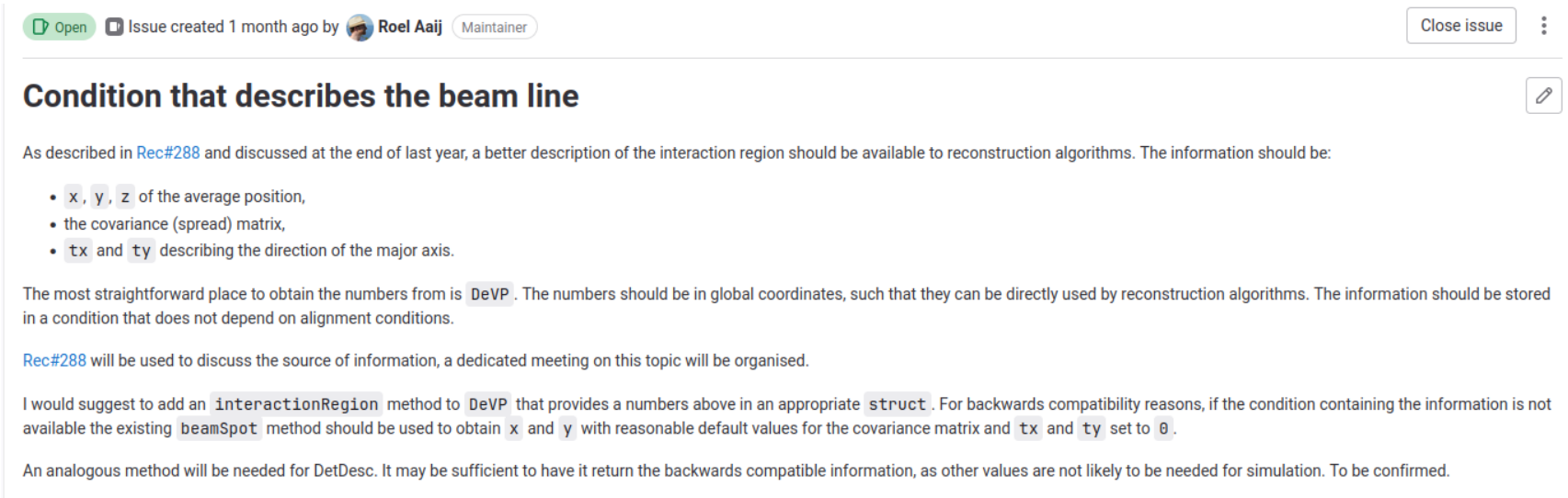
- alignment jobs are not launched automatically
- updated version not automatically picked up
  - avoid using non-optimal constants

To do:

- add more alignment configurations
  - e.g. VELO module alignment, SciFi alignment
- display histograms in Monet
- test automatic launching of alignment job

Hackathon tomorrow!

Other topics



Open · Issue created 1 month ago by **Roel Aaij** Maintainer · Close issue

Condition that describes the beam line

As described in Rec#288 and discussed at the end of last year, a better description of the interaction region should be available to reconstruction algorithms. The information should be:

- `x`, `y`, `z` of the average position,
- the covariance (spread) matrix,
- `tx` and `ty` describing the direction of the major axis.

The most straightforward place to obtain the numbers from is `DeVP`. The numbers should be in global coordinates, such that they can be directly used by reconstruction algorithms. The information should be stored in a condition that does not depend on alignment conditions.

Rec#288 will be used to discuss the source of information, a dedicated meeting on this topic will be organised.

I would suggest to add an `interactionRegion` method to `DeVP` that provides a numbers above in an appropriate `struct`. For backwards compatibility reasons, if the condition containing the information is not available the existing `beamSpot` method should be used to obtain `x` and `y` with reasonable default values for the covariance matrix and `tx` and `ty` set to `0`.

An analogous method will be needed for DetDesc. It may be sufficient to have it return the backwards compatible information, as other values are not likely to be needed for simulation. To be confirmed.

- dedicated condition for beam line
  - currently beam line is obtained from VELO motion system position
- determine global/relative position and rotation of subdetectors
  - e.g. is there a global rotation of the VELO?
- validation of new magnetic field map [presentations at WP4/5]

Summary

Status:

- 2022 data very useful to provide first alignments
  - important feedback to improve strategy and mechanisms
- good progress on tracker and RICH alignment
  - clear performance improvements seen
  - next version of SciFi alignment will further increase performance
- real-time alignment rapidly evolving
  - VELO half alignment as prototype job
  - SciFi and RICH making good progress to be included in run control

Plans:

- prepare new tag with new SciFi alignment
  - ideally re-run RICH mirror alignment
- check VELO module alignment for 2023
- add more (automatic) monitoring and quality checks
- finalise and test automatic alignment

Back-up

Tracker alignment

To align the tracking detectors

- reconstruct tracks with initial alignment parameters α_i
- fit tracks using Kalman filter
  [Nucl.Instrum.Meth.A 600 (2009) 471-477]
- new alignment parameters α_{i+1} obtained by χ^2 minimisation
- repeat until convergence is reached
- optionally include vertex and mass constraints
  [Nucl.Instrum.Meth.A 712 (2013) 48-55]

Input to the alignment

- tracks fitted with Kalman filter
- primary vertices
- particles (secondary vertices + mass)

Tracker alignment

Use states and covariance matrices from Kalman filter for alignment
[Nucl.Instrum.Meth.A 600 (2009) 471-477]

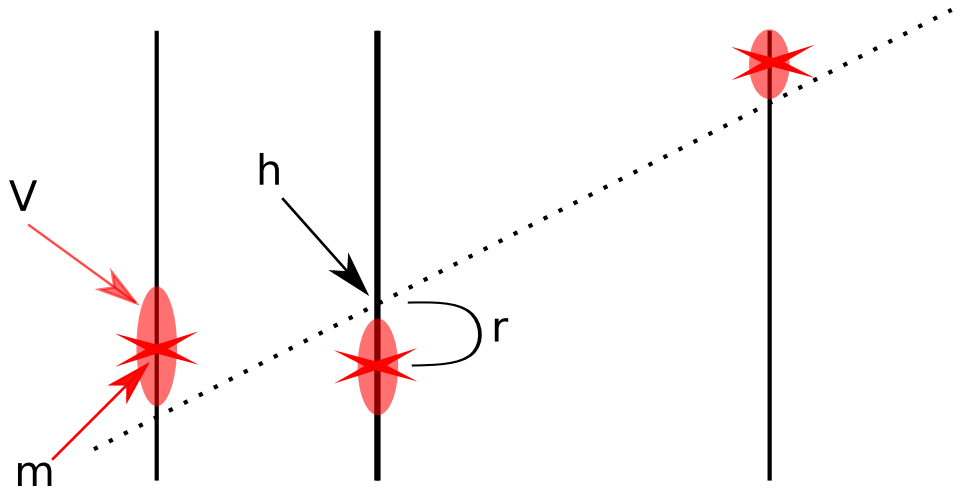
$$\chi^2 = r^T V^{-1} r$$

$$r = m - h(x, \alpha)$$

$$\frac{d\chi^2}{d\alpha} = 2 \sum_{tracks} \frac{dr}{d\alpha}^T V^{-1} r$$

$$\frac{d^2\chi^2}{d\alpha^2} = 2 \sum_{tracks} \frac{dr}{d\alpha}^T V^{-1} R V^{-1} \frac{dr}{d\alpha}$$

$$\alpha_1 = \alpha_0 - \left(\frac{d^2\chi^2}{d\alpha^2} \right)^{-1} \Bigg|_{\alpha_0} \frac{d\chi^2}{d\alpha} \Bigg|_{\alpha_0}$$



- r: track residuals
- m: measurement
- h: track model
- R: covariance matrix of residuals
- V: measurement covariance matrix

Tracker alignment

Iterative procedure until convergence
$\frac{\Delta\chi^2}{ndof} < 4$ and $\Delta\chi^2 < 25$ for each alignment degree of freedom

$$\Delta\chi^2 = -\Delta\alpha^T Cov(\alpha)^{-1}\Delta\alpha$$

If not converged, start next iteration from reconstruction with updated set of alignment constants

Tracker alignment

A difficulty:

- weak/unconstrained modes
  - little/no sensitivity
  - don't change residuals/χ^2

What might help:

- survey constraints
  - from survey measurements
  - Gaussian constraint in minimisation
- Lagrange/exact constraints
  - Lagrange multiplier in minimisation

Examples: global movement of VELO, shearing, scaling

VELO alignment on 2023 data

Hypothesis: Sensitivity to R_z depends on input sample, in particular distribution of vertices with tracks crossing both halves

left half constants	T_x [µm]	T_y [µm]	T_z [µm]	R_x [mrad]	R_y [mrad]	Rz [mrad]	comment
261033	-207.7	85.4	-253.3	0.102	-0.090	2.851	
261059	-204.7	88.1	-230.0	0.100	-0.013	2.530	
261228	-216.0	87.5	-368.1	0.107	-0.026	3.133	
261220	-216.0	87.4	-366.5	0.097	-0.011	3.218	
261219	-216.1	88.4	-368.1	0.102	0.001	2.695	
261208	-212.8	83.2	-371.6	0.190	-0.167	2.008	
259888	-224.8	94.9	-298.3	0.137	-0.132	1.515	

The alignment procedure provides an estimation of the uncertainty:
$\sigma(R_z) \approx 0.2 - 0.5\,\text{mrad}$
Currently trying to improve sensitivity to R_z. Idea: select sample enriched in vertices off-axis w.r.t z-axis, increase input sample size

VELO alignment on 2022 data

Estimated precision and remaining misalignment due to VELO drift for HLT1 and HLT2

Run Number	HLT1 precision						HLT2 precision					
	Tx [μm]	Ty [μm]	Tz [μm]	Rx [μrad]	Ry [μrad]	Rz [μrad]	Tx [μm]	Ty [μm]	Tz [μm]	Rx [μrad]	Ry [μrad]	Rz [μrad]
255941	166	2	-13	-1	-218	226	20	1	11	-3	-33	-84
255944	18	0	-36	-17	-28	143	22	1	11	-3	-35	-90
255949	120	-2	-45	-18	-156	27	7	0	2	0	-8	28
255950	198	-3	-55	-18	-262	95	3	1	8	0	3	-53
255956	533	127	124	-183	-340	562	6	0	-4	-4	-16	28
255958	-16	-3	12	9	23	247	1	0	0	0	-2	-13
255964	-19	-4	10	5	22	104	1	0	0	1	0	30
255970	-23	-4	13	5	30	202	4	0	-3	0	-10	-110
255971	-25	-4	13	5	32	220	1	0	0	0	-1	-9
255972	-27	-4	12	9	30	230	0	0	0	-1	0	-2
255974	-26	-4	11	7	27	282	-3	1	2	6	10	-171

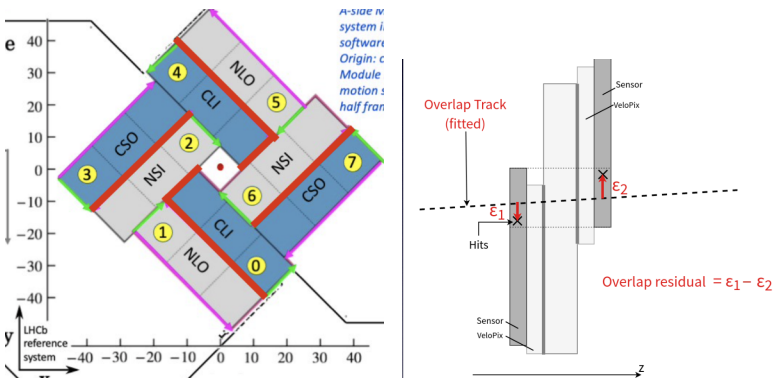
Legend
ΔTx > 20 μm or ΔTy > 20 μm
ΔTx > 50 μm or ΔTy > 50 μm

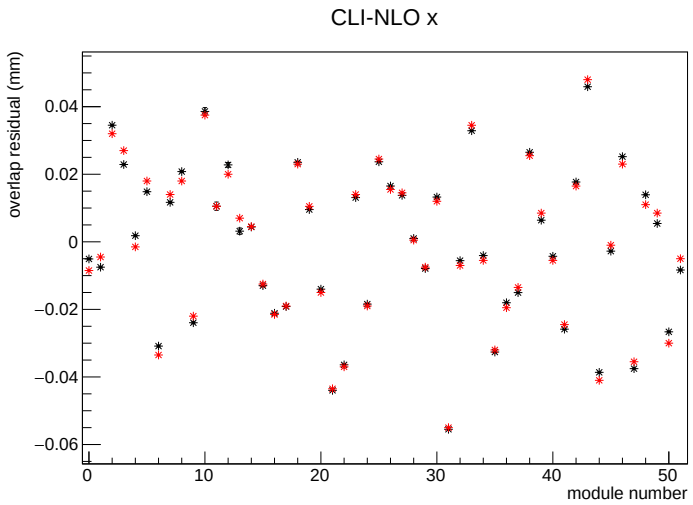
Run Number	HLT1 precision						HLT2 precision					
	Tx [μm]	Ty [μm]	Tz [μm]	Rx [μrad]	Ry [μrad]	Rz [μrad]	Tx [μm]	Ty [μm]	Tz [μm]	Rx [μrad]	Ry [μrad]	Rz [μrad]
256015	-12	-6	22	-8	-15	251	0	0	0	0	0	-13
256020	-15	-2	15	4	-1	336	3	-2	5	-8	-10	-60
256022	-16	-3	16	2	-4	140	0	0	0	1	1	53
256026	0	1	13	13	-22	314	1	0	2	0	-4	-20
256028	1	0	9	12	-22	200	-1	0	1	0	0	39
256029	0	2	14	22	-27	358	7	-9	-28	-58	29	-928
256030	-1	1	12	13	-22	388	0	0	0	2	-1	-9
256032	-2	1	11	19	-17	366	2	1	2	-8	-6	29
256035	-2	1	11	19	-17	366	0	0	0	0	0	0
256040	-2	1	11	19	-17	366	0	0	0	0	0	0
256045	-2	1	11	19	-17	366	0	0	0	0	0	0

Sensor overlap study

Ongoing study of sensor overlap residuals from Derek's slides @ RTA-WP4/5

- uses overlapping region between sensors
- check of relative sensor misalignment





Judge quality of sensor alignment from mean of overlap residuals

- Studies with MC with input sensor misalignment
  - black: mean of overlap residual
  - red: input misalignment

Input misalignment clearly reflected by mean of overlap residual

Mat alignment and the real SciFi

- Real mats are glued together with very fine tolerance/quality control (~50um), but prelim mat alignment sees movements up to 1.5mm
  - “mat alignment” moves the mats in software to match best hit position in tracking
    - Depends on module alignment quality
    - Depends on relative position of glued SiPM readouts relative to mats
  - Long term goal SciFi team: correct for hit positions in readout without moving mat material in simulation
    - Understand rotations in survey positions that may produce z movements in reconstruction
    - Understand true variations in SiPM positions
  - In the short term: offline mat alignment to improve reconstruction