Cosmic rays @ Phase 2, VXD CR, Phase 3

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Outline

Cosmic rays

Simulation of cosmic rays

Reconstruction of cosmic rays

Cosmic rays and magnetic field

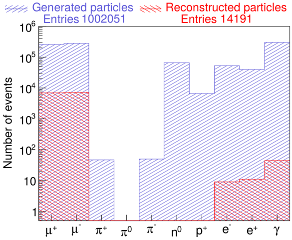
Cosmic rays in Phase 2

Alignment of phase 2 using cosmic rays

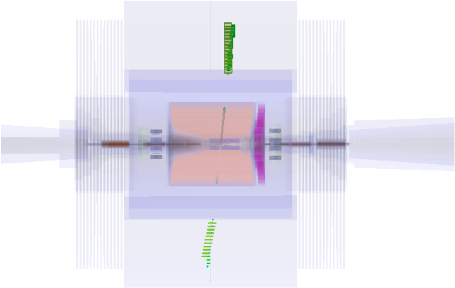
Summary

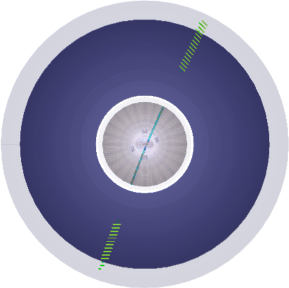
Cosmic rays: what is it?

- Cosmic rays are particles coming from outside of Belle II detector.
- The cosmic rays can be many types of particles, but only $\mu^{\pm}$ pass KLM system.



Efficiency of reconstructed cosmic rays





Reconstructed cosmic muon in the Belle 2 tracking system

Cosmic rays

Simulation of cosmic rays

Reconstruction of cosmic rays

Cosmic rays and magnetic field

Cosmic rays in Phase 2

Alignment of phase 2 using cosmic rays

Summary

Standard simulation of cosmic rays

For simulation we use cosmic generator CRY.

```
cry.param('acceptLength', 0.45)
cry.param('acceptWidth', 0.45)
cry.param('acceptHeight', 0.45)
cry.param('maxTrials', 1000000)
cry.param('keepLength', 0.45)
cry.param('keepWidth', 0.45)
cry.param('keepHeight', 0.45)
cry.param('kineticEnergyThreshold', 0.01)
add_module("Gearbox", override=[
    ("/Global/length", "300.0", "m"),
    ("/Global/width", "300.0", "m"),
    ("/Global/height", "300.0", "m")])
```

```
 "cry.setup":
returnGammas 0
returnKaons 0
returnPions 0
returnProtons 0
returnNeutrons 0
returnElectrons 0
returnMuons 1
date 2-1-2018
#(month-day-year)
latitude 36.0
altitude 0
subboxLength 300
```

- Simulation of cosmic rays spends a lot of time and RAM.
- Simulation estimates (realistic) collection time.

Cosmic reconstruction in different geometries

Hardware and datasets

- GCR 2017: ECL, EKLM, BKLM, CDC -> Cosmic data only
- Phase 2: ECL, CDC, VXD (ladder per layer), Beast -> Collision and cosmic data
- VXD CR: PXD, SVD (halfshells and full geometry) -> Cosmic data only
- Phase 3: PXD, SVD, CDC, EKLM, BKLM -> Collisions and cosmic data

Software

- GCR 2017: 'add_cosmic_reconstruction'
- Phase 2:
  - Collision: 'standard reconstruction'
  - Cosmics: 'add_cosmic_reconstruction' (not used for VXD), 'CKF' by Nils and 'CDC -> ROIs to VXD(SVD)' by Giulia
- VXD CR: 'VXD standalone track finder' by Felix
- Phase 3:
  - Collision: 'standard reconstruction'
  - Cosmics: 'add_cosmic_reconstruction', 'CKF' by Nils and 'CDC -> ROIs to VXD(SVD)' by Giulia

Creating reconstructed cosmic tracks

- Depends on used geometry and tool of reconstruction can be obtain:
  1) The 'RecoTracks' array is composed by one member:
     - 'add_cosmic_reconstruction', if merge_tracks is used (default).
     - 'VXD standalone track finder' in VXD CR.
  2) The 'RecoTracks' array is composed by two members or more. This situation is default issue of cosmic track finding methods.
     - How to create cosmic track, which is splitted?
     - 'RecoTracks' array is composed by one, two or more members dependent on direction, quality of tracking and energy loss.
     - Module will be publish in master soon.

Merging (creating) cosmic track

- We need some reference from outside of tracking system (e.g. KLM, ECL, TOP)
- The (Reco)Tracks should be associated with hits from outer detectors. (e.g. ECL shower, KLM hits, ...)
- The reference should require specific number of measurements in outer detectors (e.g. two 'KLMClusters', two 'ECLConnectedRegions', ...)

Cosmic rays and magnetic field

- For collision data it is necessary to use magnetic field.
- Cosmic rays are specific again, because we want use cosmic rays with/out magnetic field.
- For alignment we should know momentum of tracks.
- How to determine momentum without magnetic field?

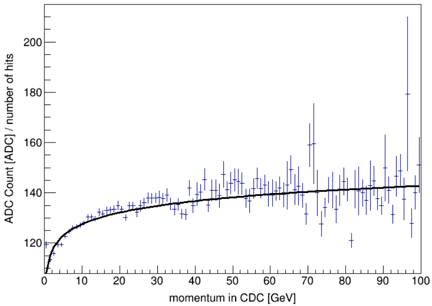
Alignment, magnetic field and momentum

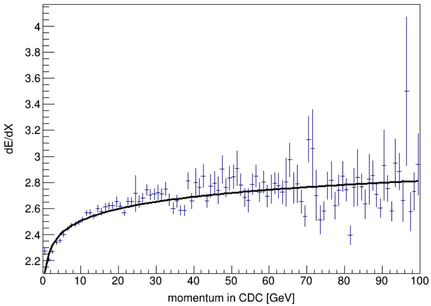
- In principle the alignment procedure does not depend on momentum of tracks, ...
- The method to determinates alignment parameters is based on Millepede and General Broken Lines (GBL).
- We need momentum of tracks for estimation of multiple scattering ('broken' lines).
- The energy loss in material (drift cell in CDC, sensors in VXD, ..) depends on momentum too.

Energy loss per distance travelled in CDC

- The energy loss of cosmic muons is small, but enough for measurement.
- The energy looses can be described by Bethe formula (for high energy regime):

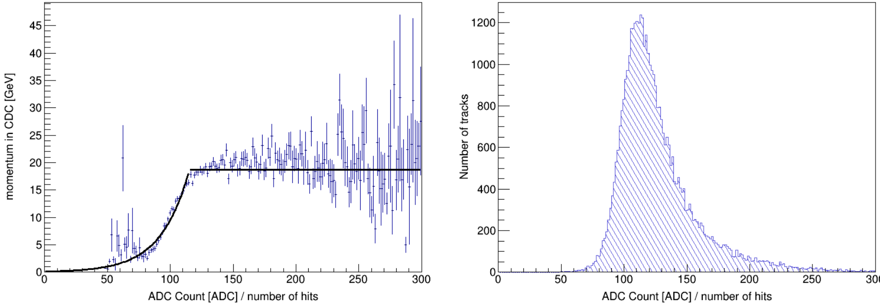
$$-\frac{dE}{dx} \sim \frac{\sum ADCCounts}{\#CDCHits} \sim \log \frac{p_\mu}{m_\mu}$$





Both TProfiles were fitted by function $p_0 + p_1 \log(x)$ and the result for left TProfile is $p_0 = 112.44 \pm 0.43$ and $p_1 = 6.59 \pm 0.17$.

Momentum estimation using energy loss in CDC

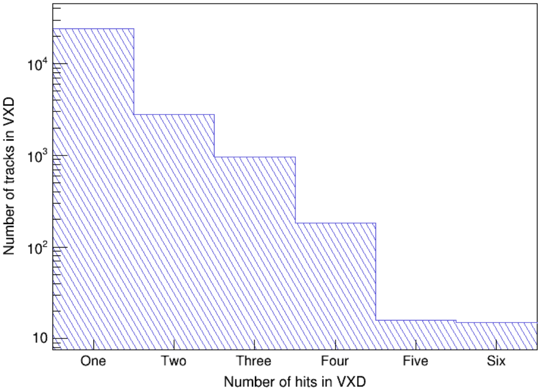


Left TProfile was fitted by function $exp(\frac{x-p_0}{p_1})$; $x \in (0, 115)$ & p_2; $x \in (115, 300)$, where $p_0 = 49.03 \pm 1.15$, $p_1 = 26.62 \pm 0.46$ and $p_2 = (18.75 \pm 0.12)\ \mathrm{GeV}$.

- This estimation can be used during phase 2 data taking.
- Can we do similar estimation using energy loss for VXD CR?
- Different idea, which can be used, is a constant momentum for all cosmic muons without magnetic field.

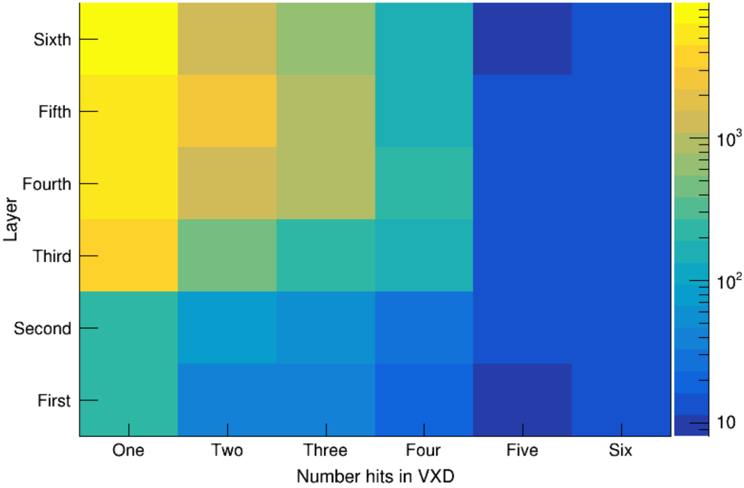
Analysis of VXD hits

- We simulated 32 838 cosmic events (11.5 hours of collecting data).
- We reconstructed 30 783 (93.74 %) cosmic muons.
- We choose 27 869 (84.87 %) "RecoTracks" with VXD hits.



The "CosmicRecoTrack" is composed by one (85.65 %), two (9.99 %), three (3.45 %), four (0.65 %), five (0.07 %) or six (0.05 %) VXD hits.

Analysis of VXD hits



Occupancy of layers depending on number of hits in VXD

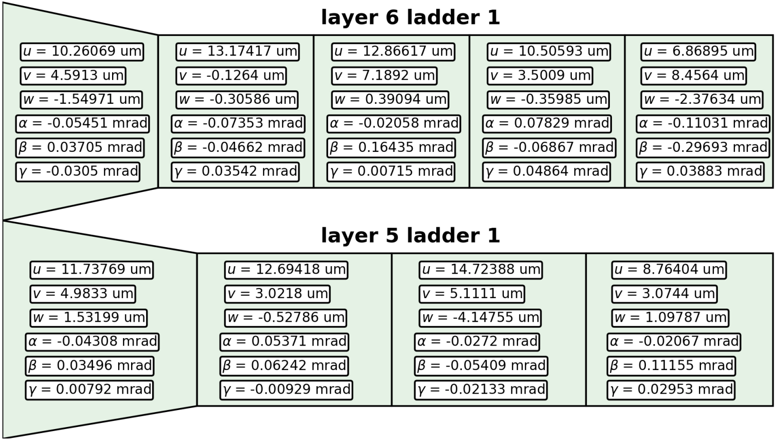
VXD alignment

- We are fixing CDC, but VXD alignment is dependent on CDC alignment
- We are using magnetic field
- We are fixing all half-shells and ladders (in alignment hierarchy).
- The Millepede algorithm calculates 108 parameters (18 sensors $\times$ 6 parameters)

Alignment using cosmic rays

- The Millepede algorithm is using 22 krecords for alignment.
- Cosmic tracks are composed by one (85.65 %), two (9.99 %), three (3.45 %), four (0.65 %), five (0.07 %) or six (0.05 %) VXD hits.

SVD alignment using cosmic data



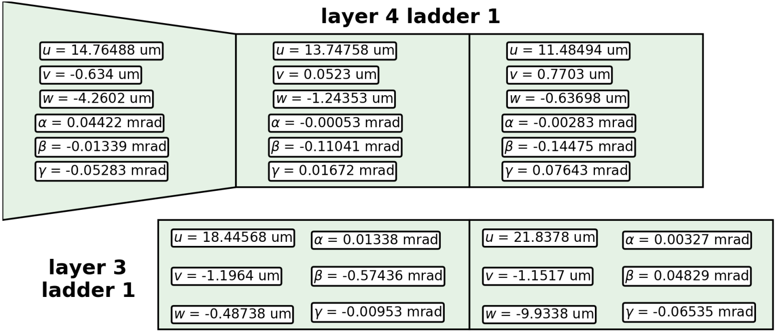
Results of alignment procedure using cosmic rays.

The worst results are for *u* alignment parameters.

The statistic errors for shifts are $u < 2$ um, $v < 4$ um and $w < 3$ um.

The statistic error for rotations are $\alpha < 0.2$ mrad, $\beta < 0.6$ mrad and $\gamma < 0.1$ mrad.

SVD alignment using cosmic data



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PXD alignment using cosmic rays

	Sensor 1		Sensor 2	
layer 2 ladder 1	u = 20.57616 um	α = -0.21967 mrad	u = 15.7233 um	α = -0.40115 mrad
	v = 4.4935 um	β = -0.70415 mrad	v = 3.3858 um	β = -1.13189 mrad
	w = -5.1603 um	γ = 0.22826 mrad	w = -10.84347 um	γ = -0.26776 mrad
layer 1 ladder 1	u = 10.61439 um	α = -0.06142 mrad	u = 14.50351 um	α = -0.27381 mrad
	v = -1.2214 um	β = -0.30374 mrad	v = -1.6432 um	β = -1.30093 mrad
	w = 1.98835 um	γ = 0.28571 mrad	w = 1.9125 um	γ = -0.14583 mrad

Results of alignment procedure using cosmic rays.

The worst results are for *u* alignment parameters.

The statistic errors for shifts are $u < 2$ um, $v < 4$ um and $w < 3$ um.

The statistic error for rotations are $\alpha < 0.2$ mrad, $\beta < 0.6$ mrad and $\gamma < 0.1$ mrad.

The reason for higher errors can be in statistic. Sensors are smaller, and it is difficult to hit them. Typically average for SVD sensors is 1200 hits per sensor and for PXD only 150 per sensor.

Status of VXD alignment

Beam collision datasets

- Datasets of vertex constraint decay and $\mu^{\pm}$ from beam collisions are tested.
- Alignment is possible, but the sensors should be fixed in some parameters for precise result.
- It is necessity to use tracks outside of IP, or cosmic ray.

Cosmic rays

- Software for reconstruction of cosmic rays in phase 2 is done.
- VXD alignment using cosmic rays is difficult, but it is worth.
- Cosmic rays is needed in VXD alignment procedure.

VXD misalignment of Phase 2

- The misalignment larger than 50 um and 0.5 mrad are determined using mixture of cosmic and collision data.
- **If collision data are used in alignment, cosmic data must be used too.**

Summary

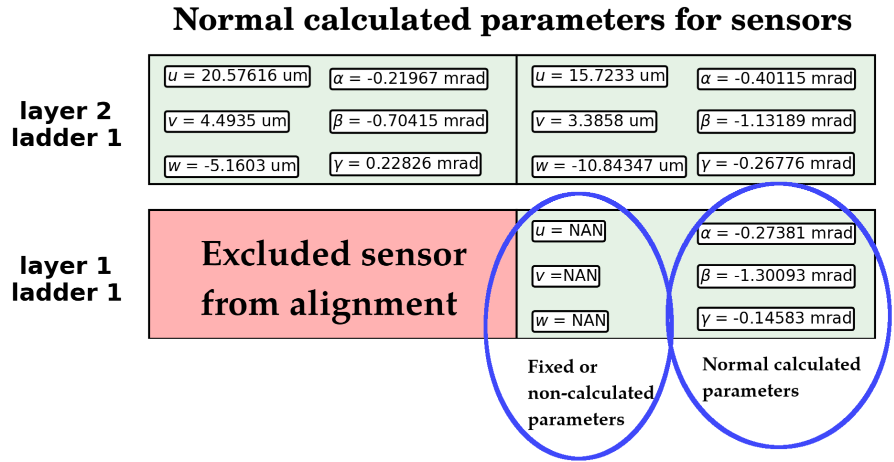
- VXD alignment sensor by sensor is working very well.
- During phase 2 the VXD alignment hierarchy will be determined.
- The worst results are in *u* alignment parameter (systematic shift).
- The alignment procedure is able to determined larger than 50 um and 0.5 mrad misalignment.
- **If collision data are used, cosmic data must be used too.**
- Monitoring tools (DQM) for Phase 2 is not necessary. We have DQM based on residuals (and p-Values, ...) in standard DQM from Peter.
- Scripts are published in feature/BII-2837-cosmic-tracks-in-vxd-phase-ii
- Status of our study is published in JIRA issue BII-2837-cosmic-tracks-in-vxd-phase-ii
- Alignment results with different datasets can be found in different presentation (*VXDAlignmentDatasets.pdf*).

Plans for next weeks

- Publishing official alignment procedure of phase 2 in master soon.
- Determination alignment constants during data taking phase 2.
- Creating short online documentation of alignment procedure for phase 2.
- Development reconstruction software for cosmic rays in different geometries (VXD CR, phase 3, ...)
- Development alignment procedure for different purpose (e.g. VXD CR)
- Development of analysis alignment procedure for selection the most important channel for alignment during phase 2/3.

Backup

How to works script for plotting alignment result



The script recognizes excluded sensor (red) from alignment.

If parameters are fixed or non-calculated, they are shown as "NAN".

The used sensor are shown green and all calculated parameters are in white boxes.