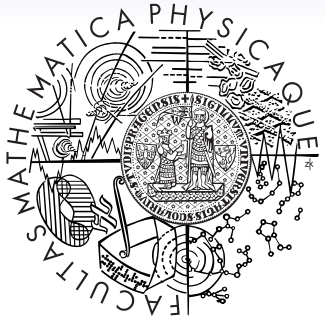

VXD Alignment: Phase II

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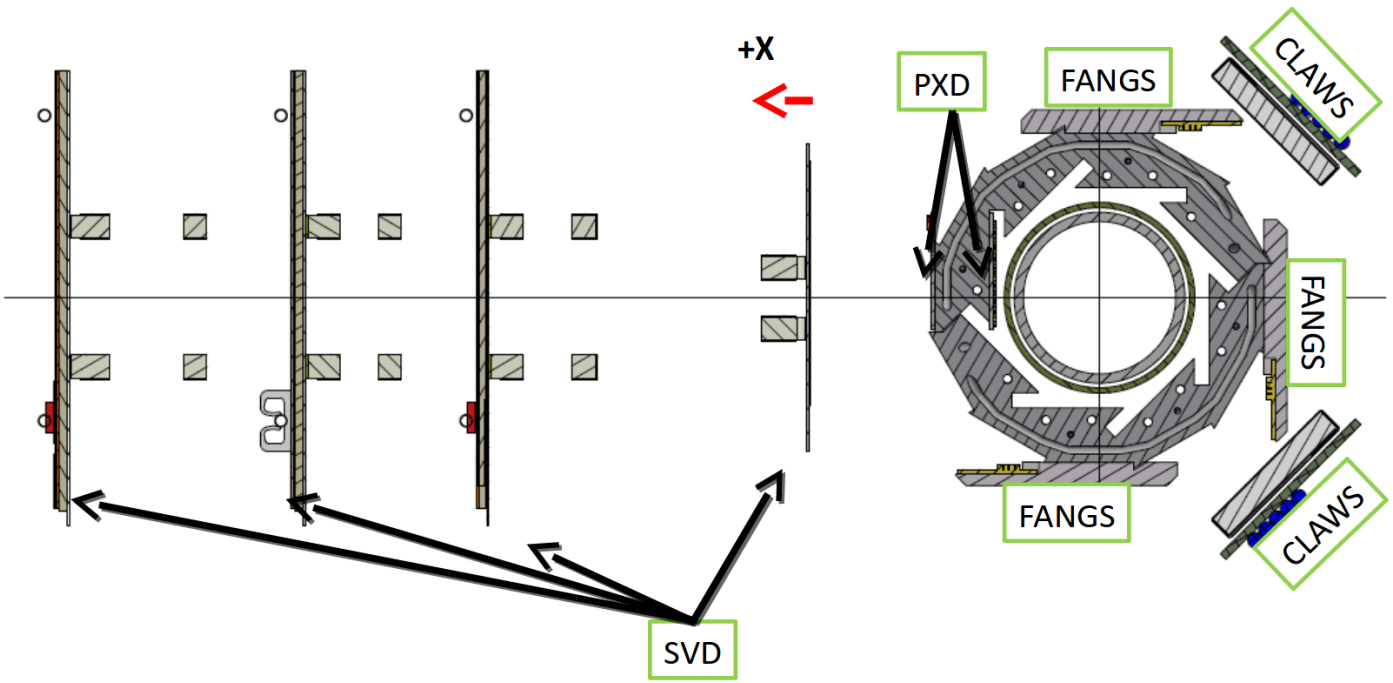
Outline

Geometry of Phase II

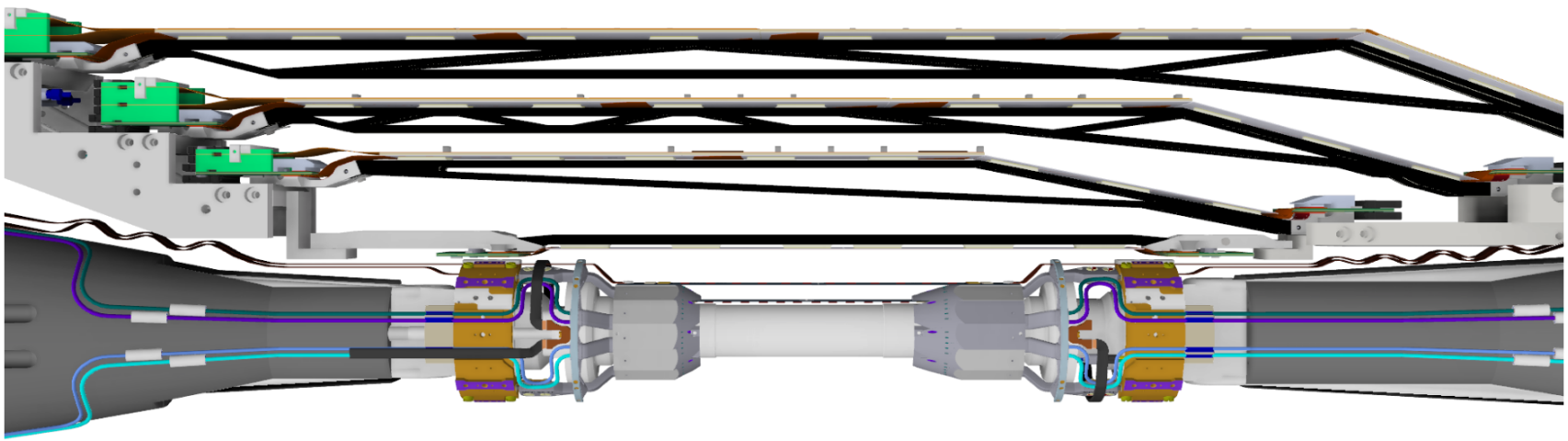
- EKLM, BKLM, CDC, VXD and Beast will be used.
- VXD: One ladder in each layer
- VXD: 4 sensors of PXD and 14 sensors of SVD
- Beast: Dedicated radiation monitors (FANGS, CLAWS, PLUME)
  - $\phi_{FANGS} = \{90°, 180°, 270°\}$
  - $\phi_{CLAWS} = \{135°, 225°\}$
  - $\phi_{PLUME} = \{135°, 225°\}$ (exchanged position of sensors)



VXD and Beast Geometry of VXD.

Geometry of Phase II

- Similar geometry as in VXD DESY TestBeam 2017
- Difference between Phase II and VXD DESY TestBeam 2017:
  - VXD TB 2017: narrow beam of e^-
  - VXD TB 2017: beam is perpendicular to planes of sensors
  - VXD TB 2017: low beam background and no cosmic rays
  - Phase II: particles from collisions
  - Phase II: particles fly out from the IP to all θ directions
  - Phase II: realistic beam background and cosmic rays



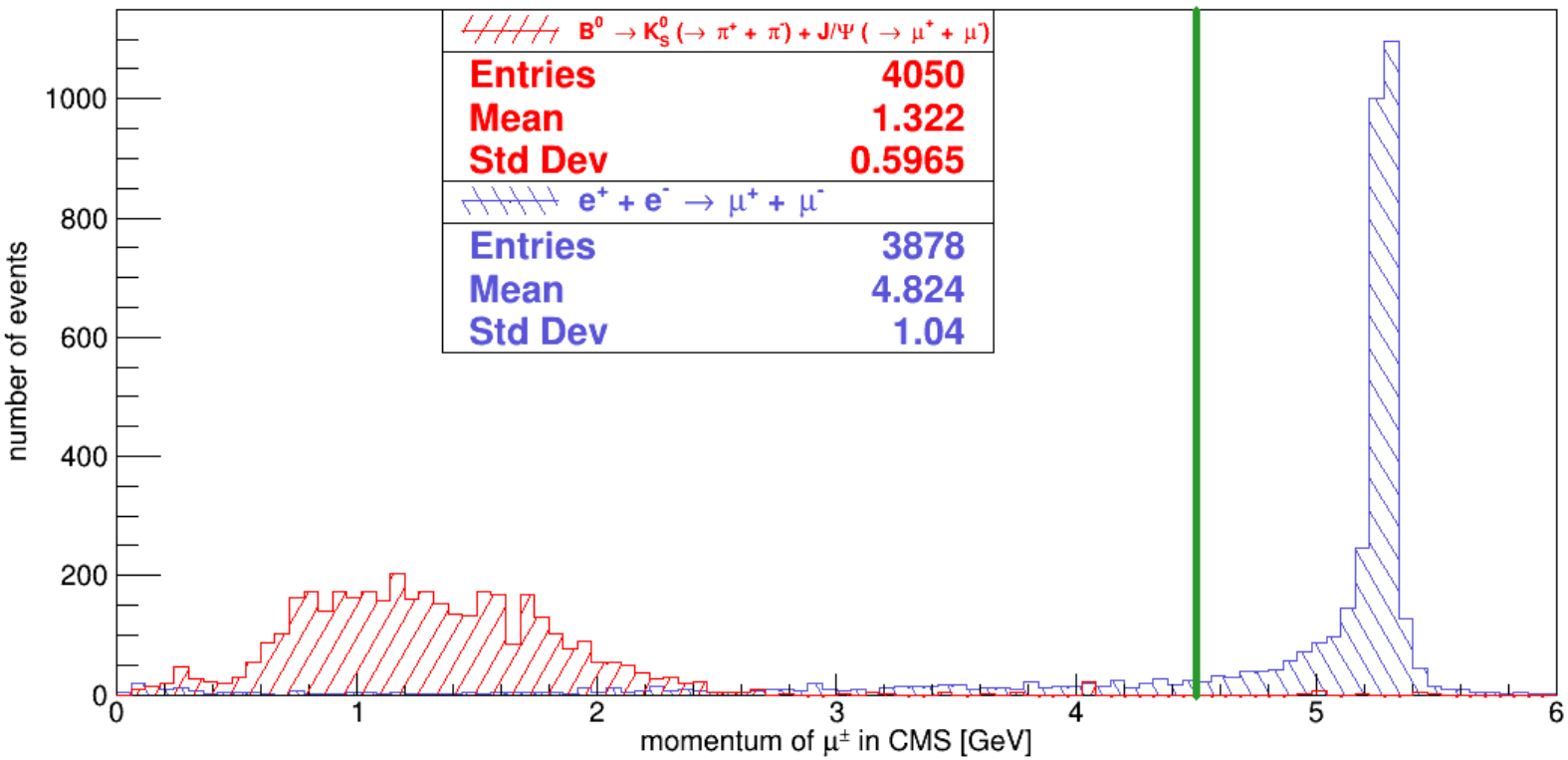
Geometry of Phase II in XZ direction.

Horizontal plane for highest background sensitivity (+X direction).

VXD Alignment of phase II

VXD alignment based on different datasets:

I) Vertex constraint decay: $e^+ + e^- \rightarrow \mu^+ + \mu^-$
II) Other $\mu^\pm$ from beam collisions
III) Cosmic rays
IV) Beam background



Explanation of analysis cut (green) for muons, because of alignment

Status of VXD alignment

Beam collision datasets

- Datasets of vertex constraint decay and $\mu^{\pm}$ from beam collisions are tested.
- Results are calculated ~ 10 μm, if we fix first and sixth layer as in TB VXD and some parameters for all sensors.
- We need tracks from outside of IP

Track of cosmic rays

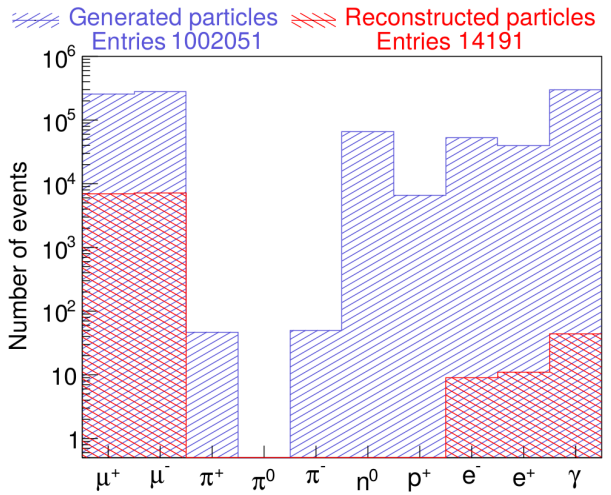
- Procedures for reconstruction and creation cosmic ray
- Inspiration in "CDCCosmicTrackMerger" by Dong Van Thanh.
- Is it possible used cosmic rays in alignment?

Tracks outside from IP

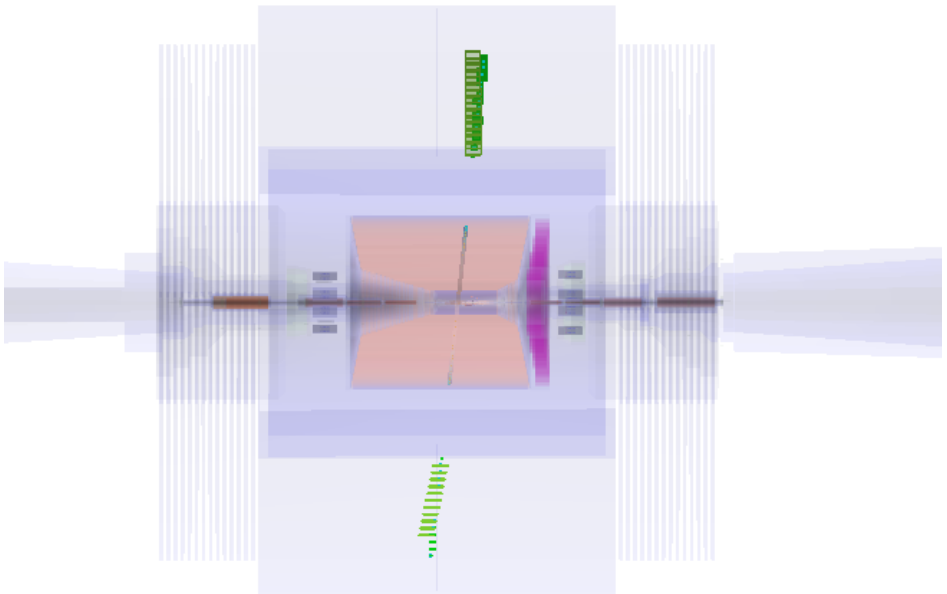
- Different way is using tracks outside of IP for alignment.

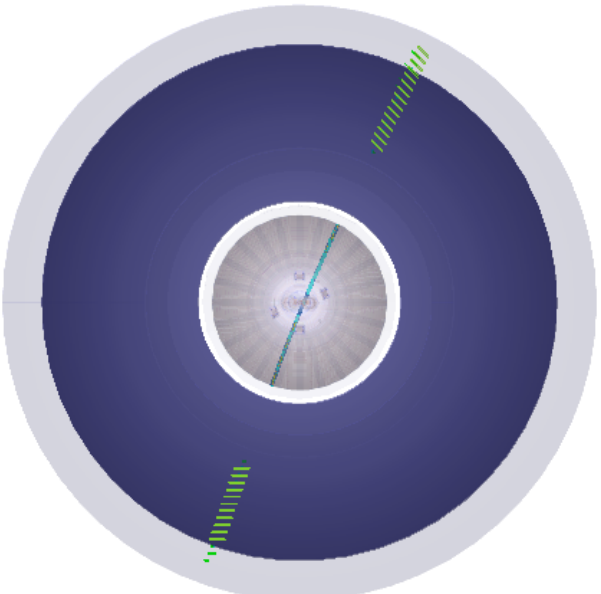
Cosmic rays: what is it?

- The cosmic rays are particles, are 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 Belle 2 tracking system

Simulation of cosmic muons

For simulation we are used 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",
  fileName='/geometry/Beast2_phase2.xml',
  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
latitude 36.0
altitude 0
subboxLength 300
```

- 1k events with 10^6 maxTrials parameter are using 12 GB RAM memory.
- 1k events are 20s (real time) with 20 cosmic tracks in VXD phase II.
- 33k cosmic tracks (11.5 hod real time) are simulated at `https://www.dropbox.com/s/n6i7rmj0ki0e8q0/withMagneticField.root?dl=0`

Reconstruction of cosmic rays

It is using reconstruction of simulated PXD and SVD hits.

```
add_svd_reconstruction(main)
add_pxd_reconstruction(main)
```

Track finding is based on combinatorial kalman filter (CKF).

```
tracking.add_geometry_modules(main, components=components)
tracking.add_ckf_based_track_finding(main,
  components=components, reco_tracks="RecoTracks")
main.add_module("TrackCreator", recoTrackColName="RecoTracks",
  useClosestHitToIP=True)
```

It is using reconstruction of BKLM and EKLM hits and merging "KLMClusters" and tracks to "RecoTracks":

```
main.add_module('EKLMReconstructor')
main.add_module('BKLMReconstructor')
main.add_module('KLMK0LReconstructor')
main.add_module('Muid')
...
```

Reconstruction (creating) of cosmic rays

- Creating "CosmicRecoTrack" array composed by a track is based on comparison between "RecoTracks" and "KLMClusters".

RecoTracks (with KLMHits)	KLMClusters	CosmicRecoTrack
1 (1)	1	Create
1 (1)	2	Create
2 (1)	1	Create
2 (2)	2	Create
2 (2)	More than 2	Create
More than 2 (2)	2	Create

- Each "CosmicRecoTrack" is composed by 40 CDC hits.
- For more than 2 "RecoTracks" it is used cut for more than 3 KLM hits.
- For more than 2 "KLMClusters" it is used cut for more than 4 layers.
- Definition of beginning of track:
  1. All seeds from alone "RecoTrack" is used for "CosmicRecoTrack".
  2. If two "RecoTracks", we classify an upper and lower part according seed of time. All seeds are used from upper "RecoTrack".

Reconstruction (creating) of cosmic rays

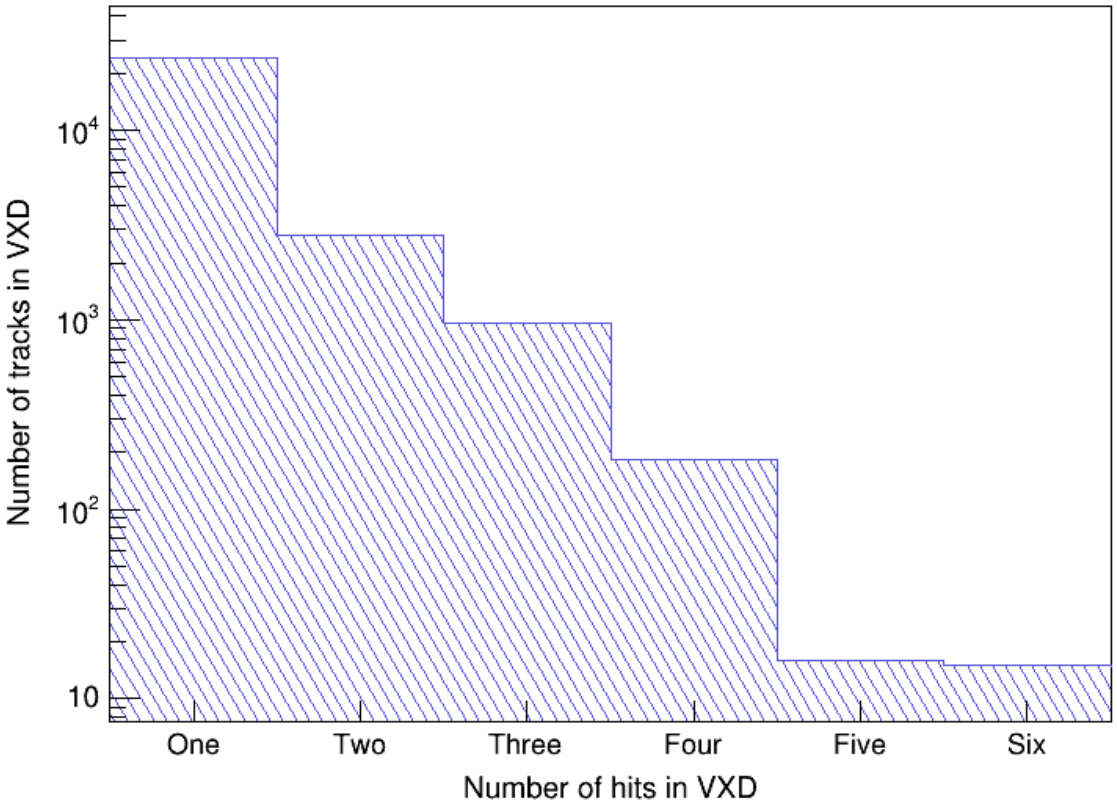
- "CosmicRecoTrack" is composed by all hits (PXD, SVD, CDC, EKLM, BKLM) from chosen "Recotracks".
- The algorithm of merging (creating) cosmic track is written in "CDCCosmicTrackModule".

```
...
main.add_module("CDCCosmicTrackMerger",
recoTracksStoreArrayName="RecoTracks",
  MergedRecoTracksStoreArrayName="CosmicRecoTracks",
  deleteOtherRecoTracks=True)
main.add_module("TrackCreator",
  recoTrackColName="CosmicRecoTracks",
  trackColName="CosmicTracks",
  trackFitResultColName="CosmicTrackFitResult",
  useClosestHitToIP=True)
```

- All used scripts are published in feature/BII-2837-cosmic-tracks-in-vxd-phase-ii.

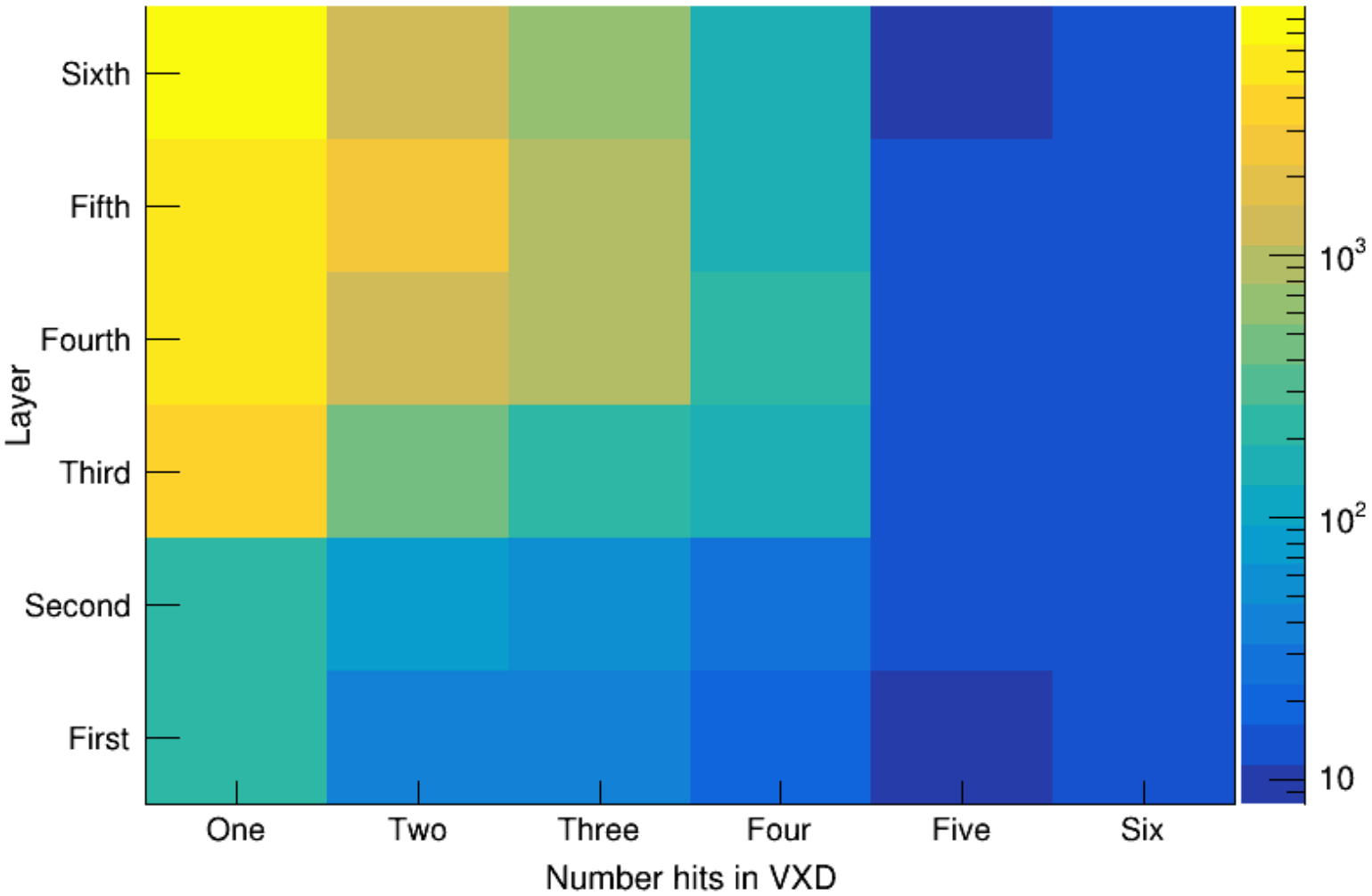
Analysis of VXD hits

- 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) hits.

Analysis of VXD hits

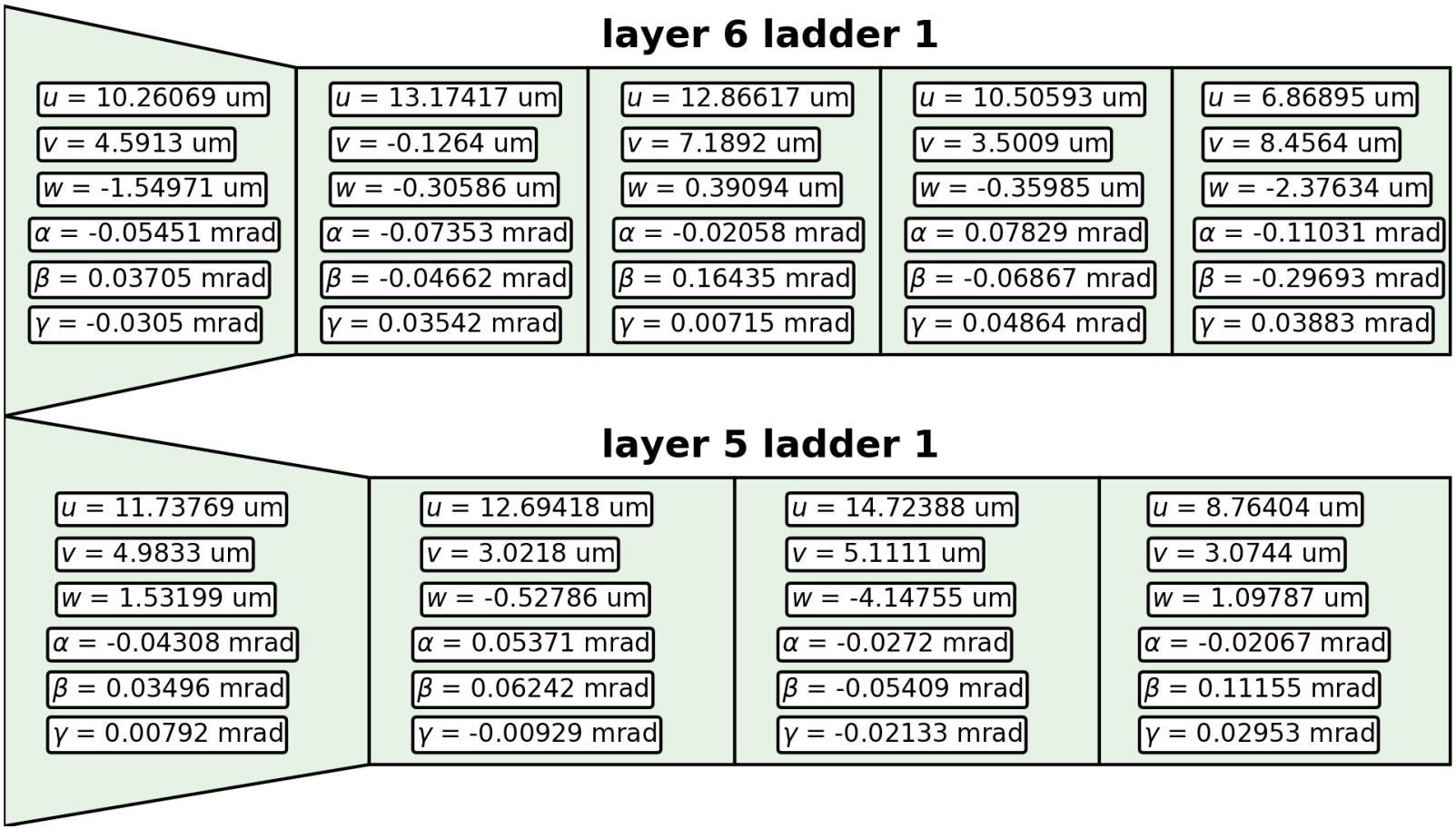


Occupancy of layers depended on number of hits in VXD

Conditions for alignment using cosmic rays

- We are fixing CDC.
- We are using magnetic field.
- The Millepede algorithm using 22 krecords for alignment.
- We are fixing all half-shells and ladders (in alignment hierarchy).
- The Millepede algorithm calculate 108 parameters (18 sensors $\times$ 6 parameters)

Alignment results for SVD (fixth and fifth layer)



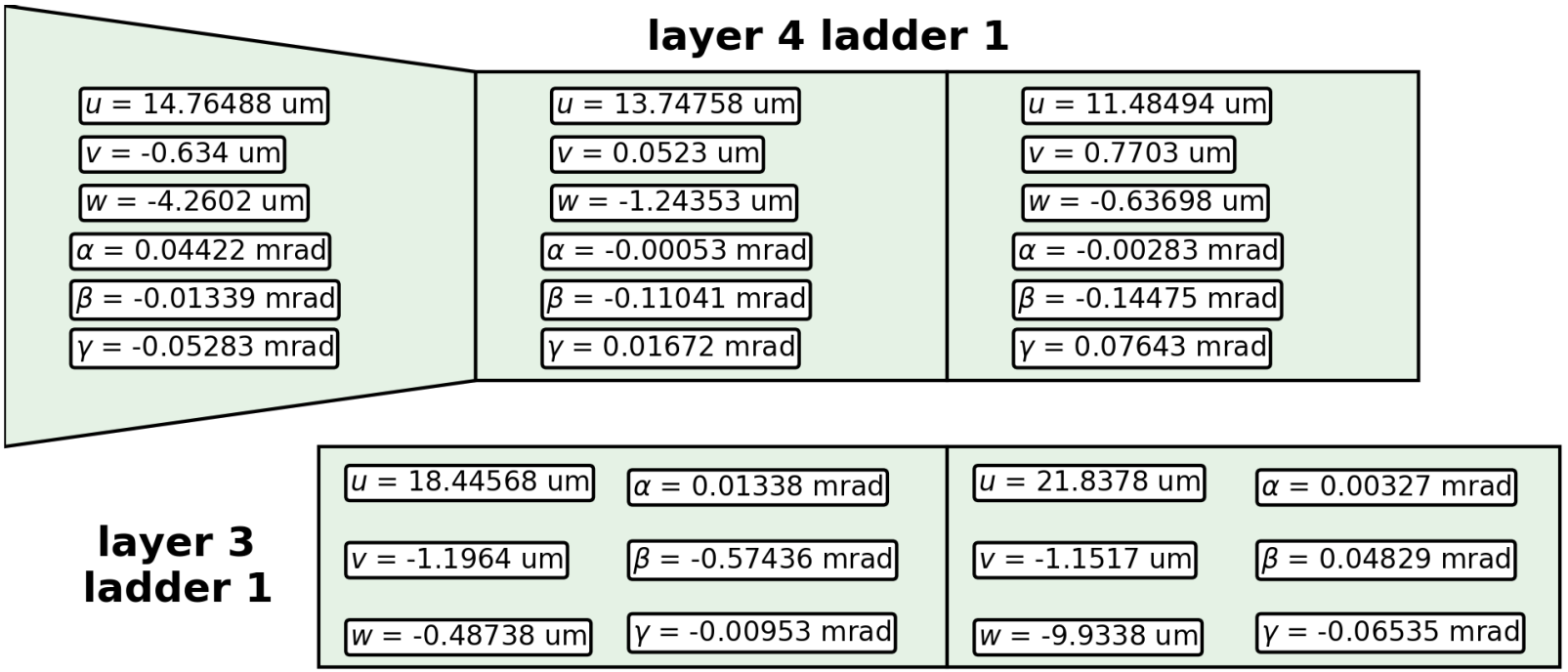
Results of alignment procedure using cosmic rays.

The worst results are for u alignment parameters.

The error for shifts in $u, w < 2$ um and $v < 2$ um.

The error for rotations in $\alpha, \gamma < 0.05$ mrad and $\beta < 0.1$ mrad.

Alignment results for SVD (fourth and third layer)



Results of alignment procedure using cosmic rays.

The worst results are for *u* alignment parameters.

The error for shifts in $u, w < 2$ um and $v < 2$ um.

The error for rotations in $\alpha, \gamma < 0.05$ mrad and $\beta < 0.1$ mrad.

More details for errors can be found in backup.

Alignment results for PXD (second and first layer)

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 error for shifts in $u < 2$ um, $v < 4$ um and $w < 3$ um.

The error for rotations in $\alpha, \gamma < 0.2$ mrad and $\beta < 0.9$ mrad.

More details for errors can be found in backup.

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 250 per sensor.

Summary

- In phase II we are able observed 33k cosmic events focused to VXD per 11.5 hours.
- According our analysis reconstruction of cosmic ray in VXD is efficient (93.74 %).
- More than half of reconstructed tracks has one hit in VXD only.
- The Millepede algorithm used 22 krecords for calculation alignment parameters.
- The Millepede are possible to calculate 108 alinment parameters.
- The worst results are in *u* alignment parameter.
- 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

Plans for next weeks

- Alignment studies using mixture of cosmic and beam collision data
- Alignment studies using cosmic rays without magnetic field, because reconstruction is not efficient. We should tune reconstruction firstly.
- Development monitoring tools for VXD alignment in phase 2

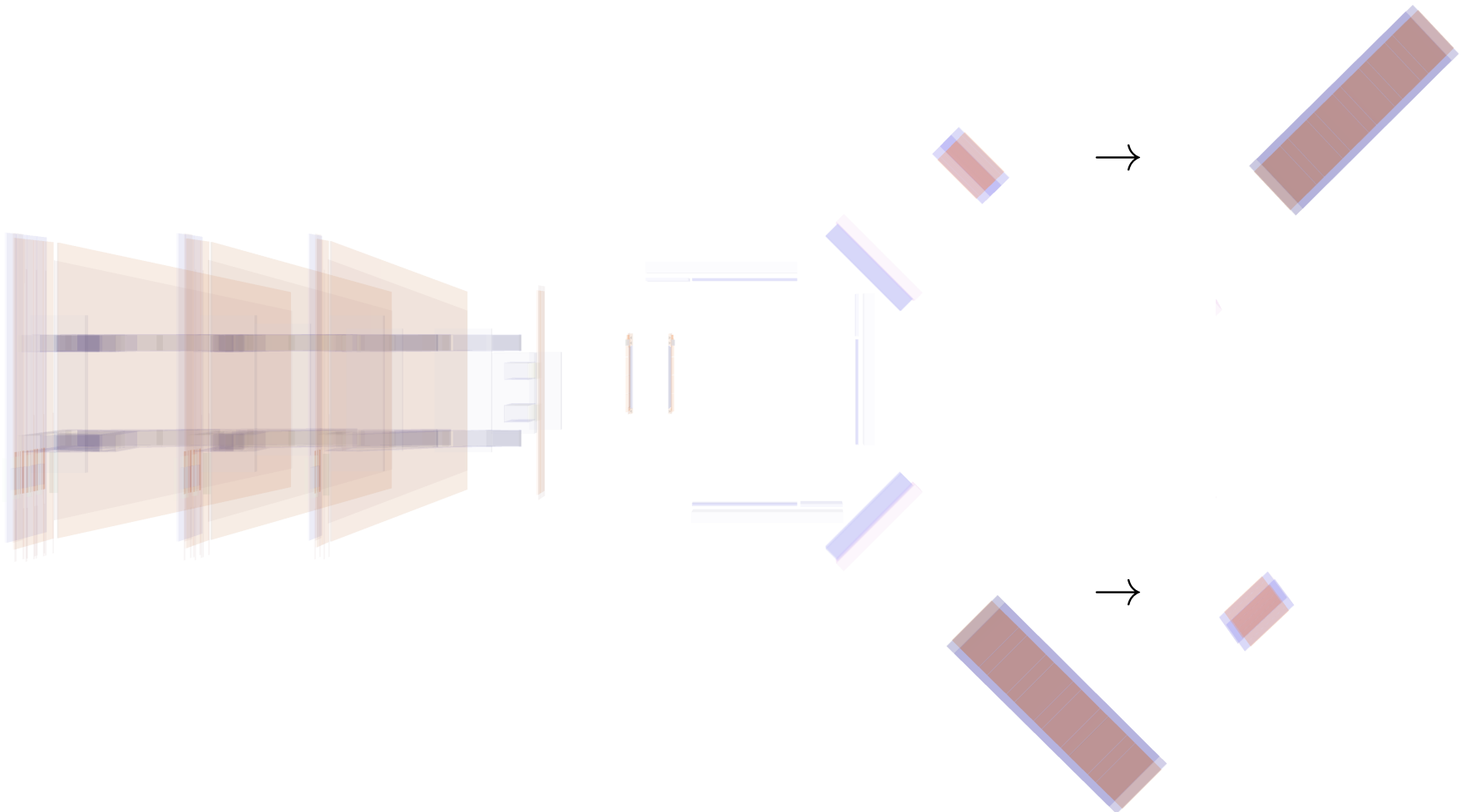
Open topics for phase 2

- At beginning of phase 2 (1. February), will we use general trigger for data?
- Will all subdetectors (PXD, SVD, CDC, ...) take synchronized data?
- Will we use them for alignment?
- What do you think about other data taking terms?
- Which type of trigger will be used in terms of phase 2?
- Will it be "easy" type of trigger, which will collect data and we should write pseudoanalysis tools for selection of the events like di-muons, off-IP tracks, bbbar or cosmic events?
- Or will we use some sophisticated type of trigger, which will separate events to di-muons, bbbar, ...

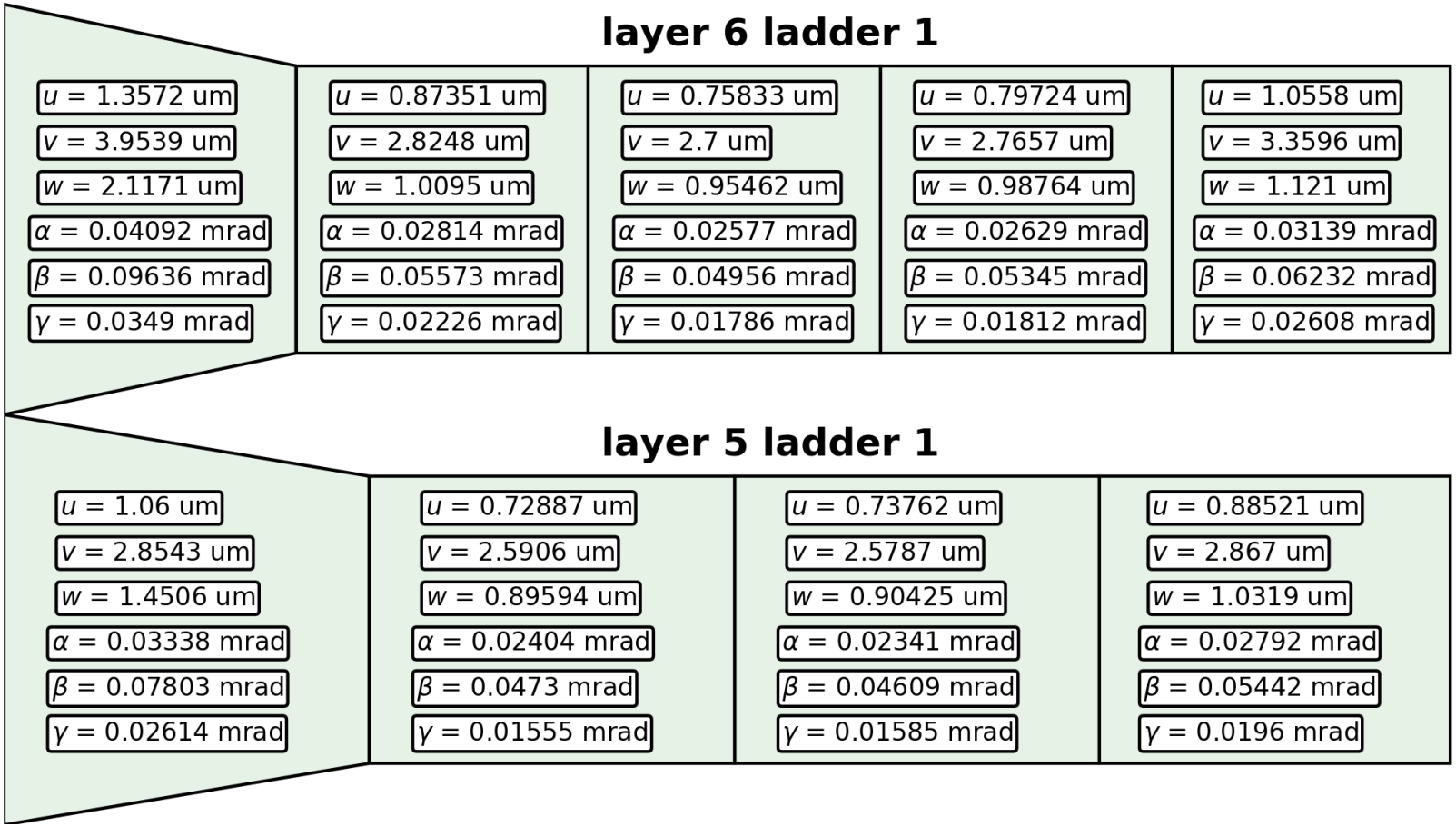
Backup

Exchange PLUME sensors in simulation

Plots show exchange of PLUME sensors in simulation according discussion with Carlos Marinas.



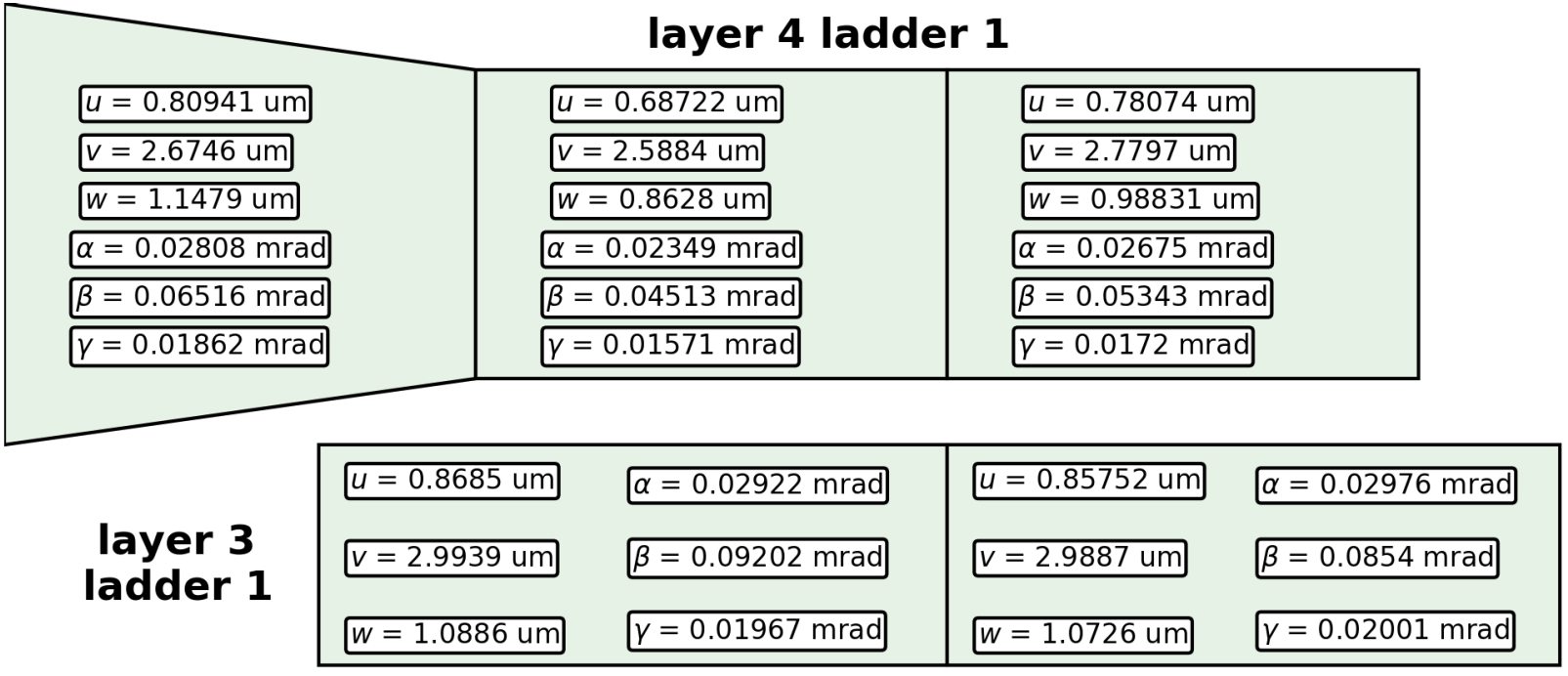
Alignment errors for SVD (fixth and fifth layer)



The error for shifts in $u, w < 2$ um and $v < 2$ um.

The error for rotations in $\alpha, \gamma < 0.05$ mrad and $\beta < 0.1$ mrad.

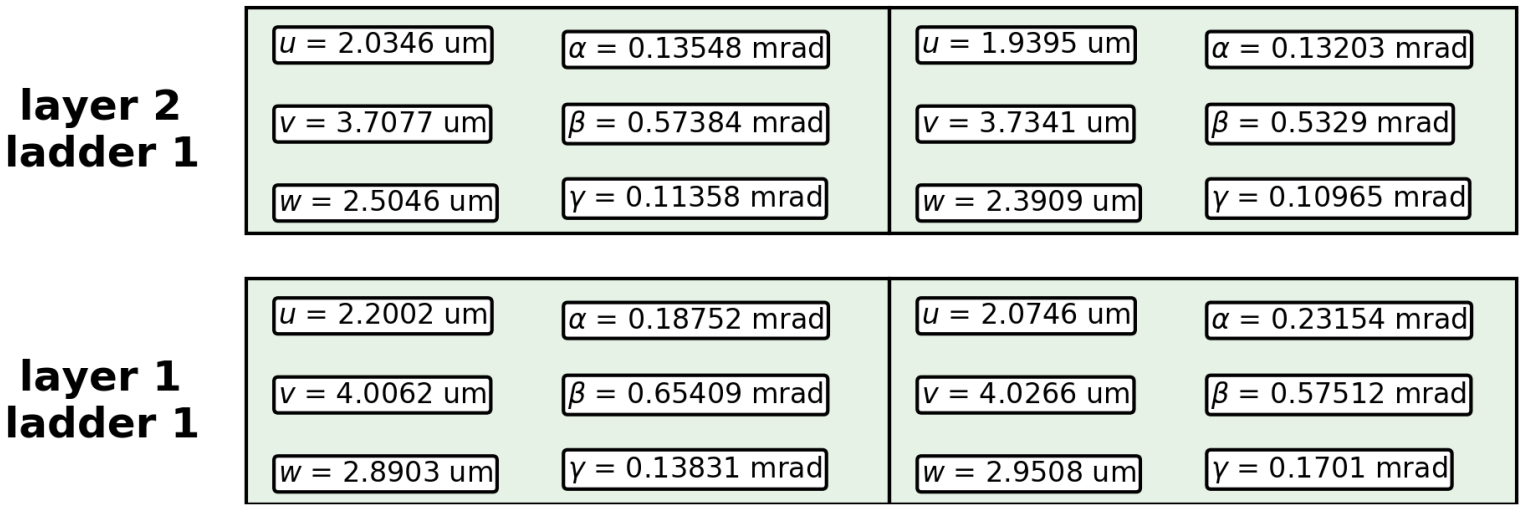
Alignment errors for SVD (fourth and third layer)



The error for shifts in $u, w < 2$ um and $v < 2$ um.

The error for rotations in $\alpha, \gamma < 0.05$ mrad and $\beta < 0.1$ mrad.

Alignment errors for PXD (second and first layer)



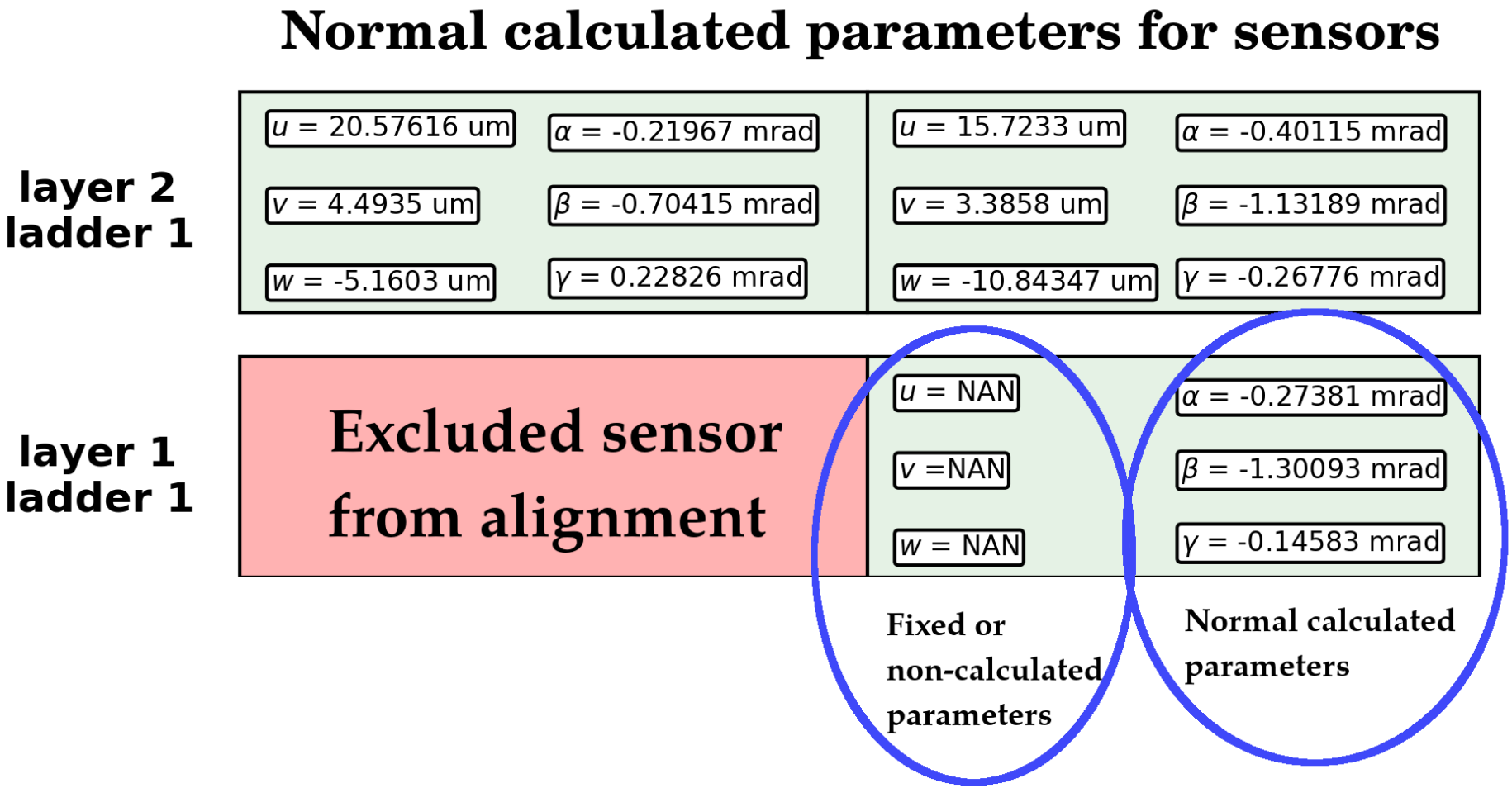
The error for shifts in $u < 2$ um, $v < 4$ um and $w < 3$ um.

The error for rotations in $\alpha, \gamma < 0.2$ mrad and $\beta < 0.9$ mrad.

More details for errors can be found in backup.

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 250 per sensor.

How to works script for plotting alignment result



The script is possible recognize 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.