UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

ePIC

Geometry Benchmarking Comparison of the Outer Barrel in epic/main (before and after October)

https://github.com/eic/epic

Oxford SVT meeting
17/12/2025

By Athavan Ramalingam

epic/main Outer Barrel Changes

- Merged flat_OB branch into main
  - Made by Sam Henry & Aditya
  - **Initial attempt for a simple stave design close to the CAD design**
  - Prev presentation from Sam of the July CAD design - https://indico.bnl.gov/event/29542/

- Purpose
  - Give a more appropriate estimate of material and geometry based on CAD designs of the staves
  - Based on the September CAD design of the staves

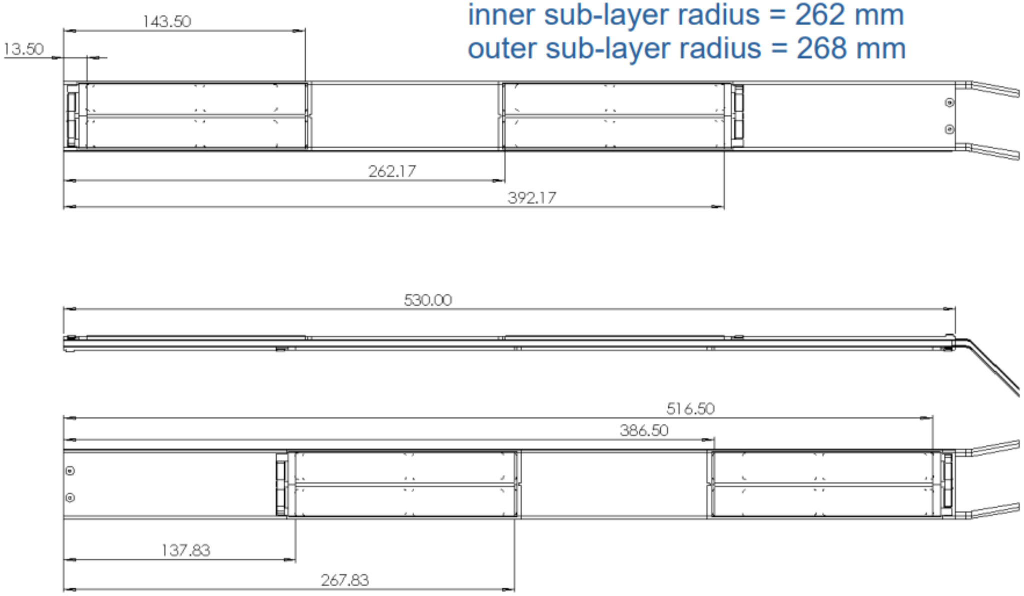
- This study
  - **Pre-merge OB**
    - Before flat_OB was merged (in eic shell 25.08.0 stable)
  - **Post-merge OB**
    - After flat_OB was merged (in eic shell 25.10.0-stable)

  - **July CAD OB (no simulation for Sep CAD yet)**

Sep CAD design:

OB L3

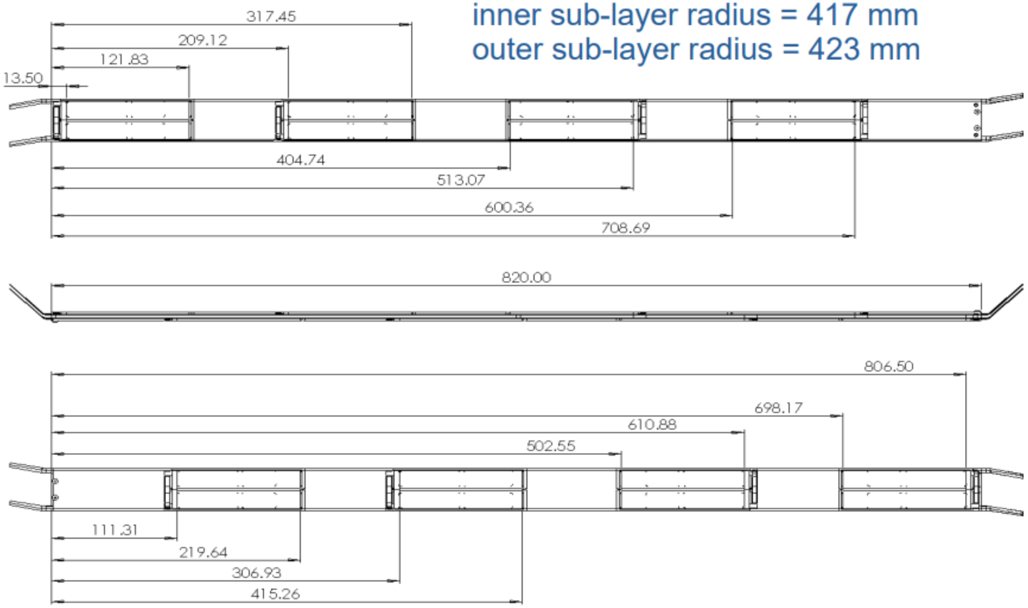
(Module = 2 × 6RSU-LAS, side-by-side)
44 staves per L3
inner sub-layer radius = 262 mm
outer sub-layer radius = 268 mm



Total active length = 503 mm

OB L4

(Module = 2 × 5RSU-LAS, side-by-side)
70 staves per L4
inner sub-layer radius = 417 mm
outer sub-layer radius = 423 mm



Total active length = 793 mm

From ePIC SVT WP4 & WP6 joint meeting:
https://indico.bnl.gov/event/29758/

epic/main Outer Barrel Changes

- Merged flat_OB branch into main
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  - **<u>Initial attempt for a simple stave design close to the CAD design</u>**

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Post-merge OB →
(23rd Oct 2025)

Pre-merge OB →
(8th Oct 2025)

```
d66f231b8 (HEAD -> main, origin/main, origin/HEAD) Fixes stuck particles in far backward hadron beampipe (#903)
83aeabee6 Moved BTOF forward by 2.5 cm. (#965)
97e36e573 Change segmentation for the RP, and add LUTs for the RP polynomial re… (#966)
5fc9ff41c (tag: 25.10.1, tag: 25.10.0, origin/25.10) Update material map for 25.09.0 (#952)
d7053fb25 ForwardServiceGap_length increased by 2.8cm to move calo endcap (#960)
3e1ad24e8 SVT support/service update (#961)
dfc8b03a3 fix: tighter overlap tolerances (10 um) (#917)
b06e84c13 Flat ob (#933)
c42b63382 Add LightGuide and EndOfSectorBox lengths (#956)
c6439ab6d Add .github/release.yml (#949)
bbb53813e Implement curved RSU structure for the three layers of vertex barrel trackers  (#803)
3188d2f5c Aerogel refractive index changed to 1.026 (#957)
5cc51e788 Updated-drich.lut (#958)
fc2eb7a5f (tag: 25.09.0) [pre-commit.ci] pre-commit autoupdate (#950)
```

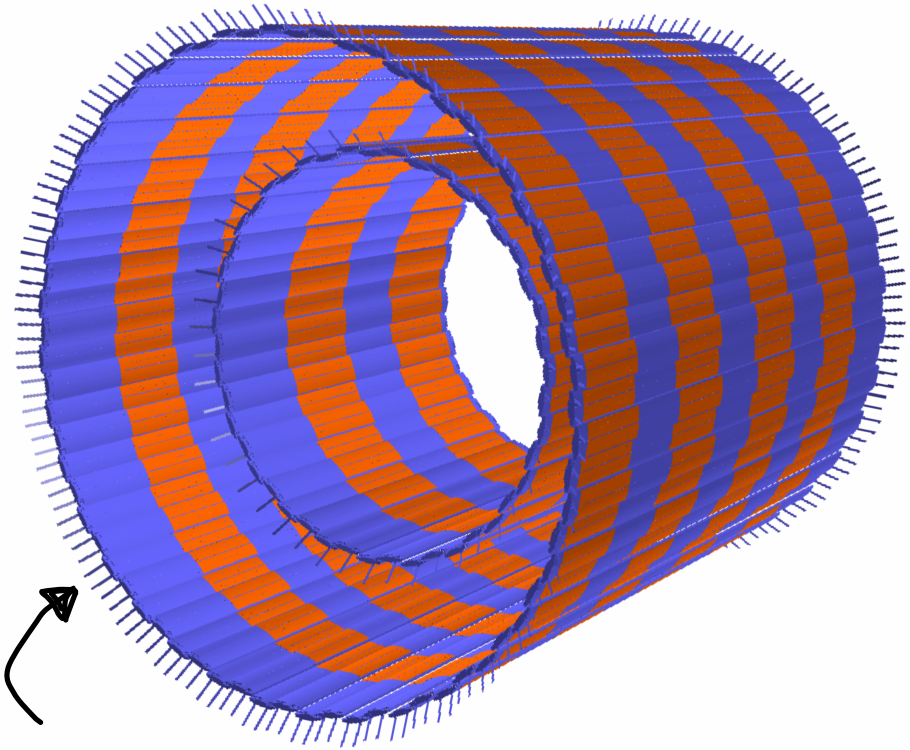
Overview

- Visualisation of the outer barrel in geoviewer
  - Material
  - Layer geometry
- Hitmaps
  - Barrel region (sensitive material)
- Material scans
  - Barrel
  - Staves
- Resoluton plots
  - Updated material map
  - Momentum resolution
  - DCA_T resoluton
- Hitmatching

OB visualisation

OB visualisation

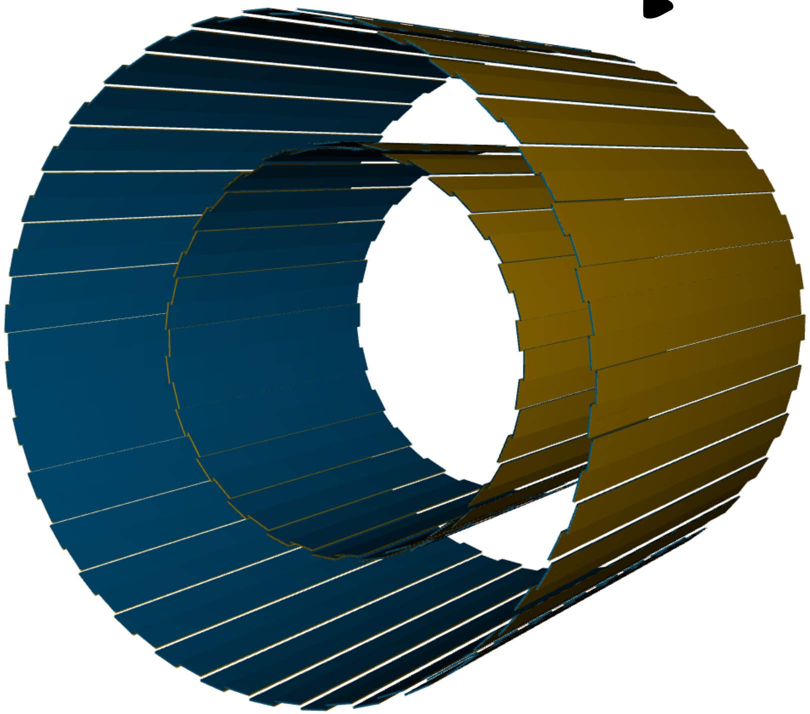
July CAD design



Realistic CAD model

Post-merge

Castellated single sided flat staves (based on Sep CAD design)

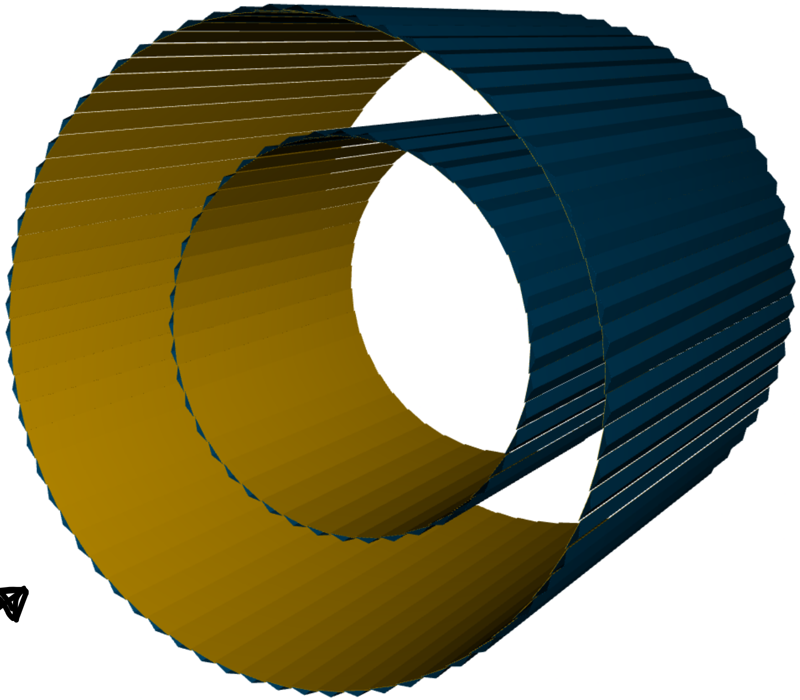


https://eic.phy.anl.gov/geoviewer/

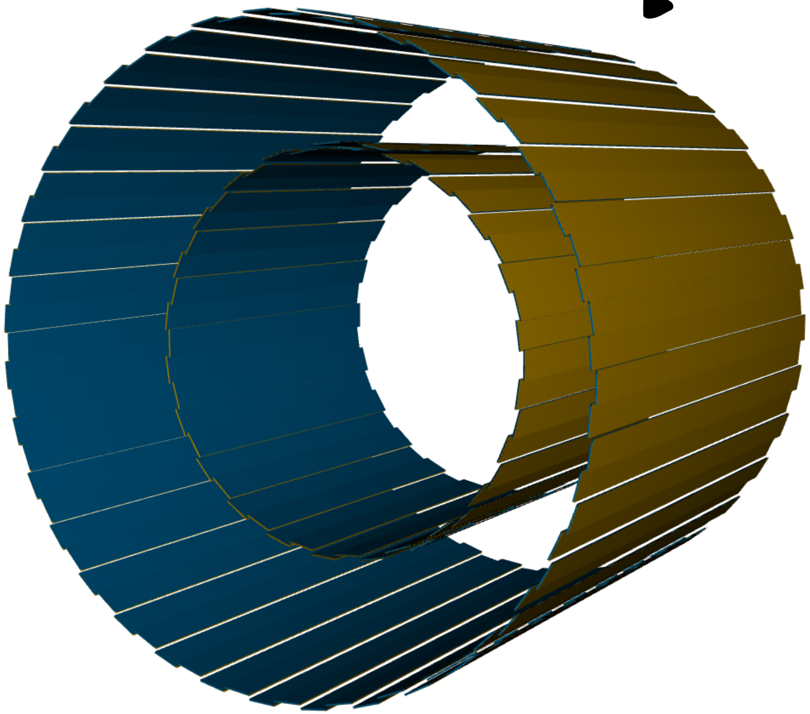
Geoviewer visualisation

Castellated single sided flat staves (based on Sep CAD design)

Pre-merge



Post-merge

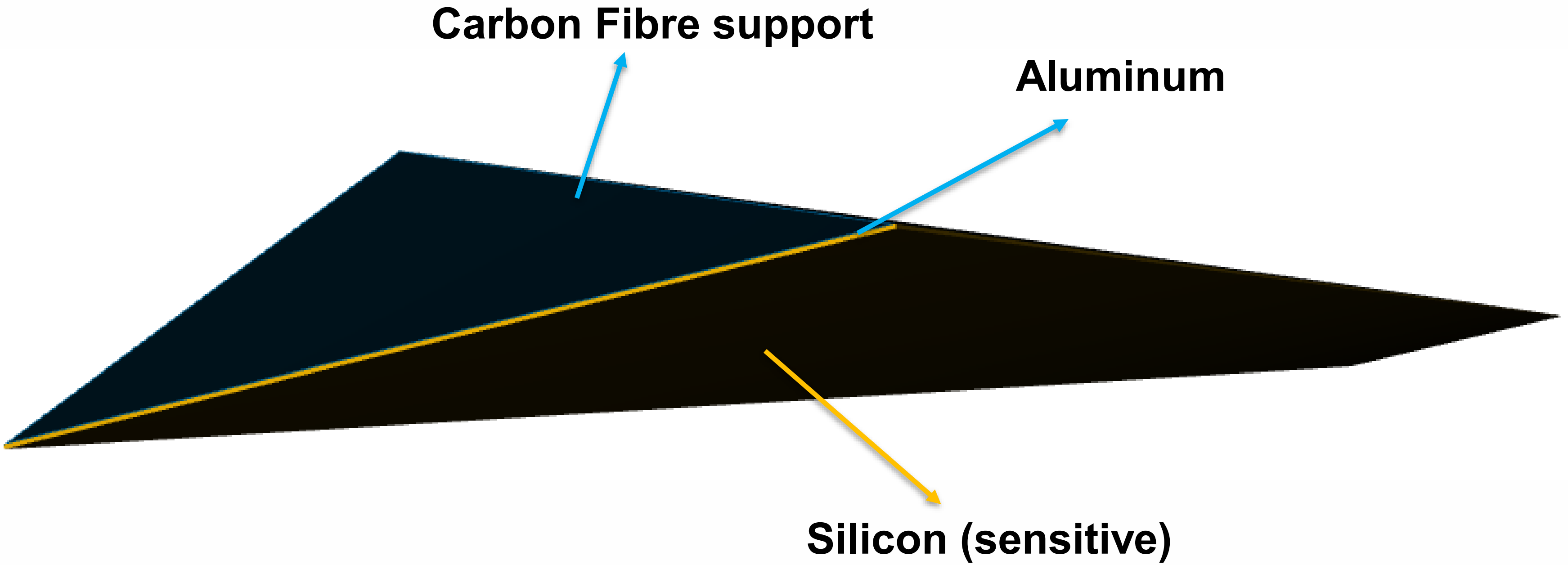


Tilted its2 like staves

https://eic.phy.anl.gov/geoviewer/

Geoviewer visualisation Stave

Pre-merge



L3 stave

Pre Merge - Stave structure L3

Silicon
Component: 0_1
Material: Si

L: 52cm, W: 4cm, D: 0.005cm (50μm)

Aluminum
Component: 1_2
Material: Al

L: 52cm, W: 4cm, D:0.014 cm (140μm)

Carbon Fibre support
Module:1_0
Material: Carbon Fibre
Left/right

L: 52cm, W: 4cm, D: 0.801cm (8010 μm)

Total material ~0.25% X_0

https://eic.phy.anl.gov/geoviewer/

Pre Merge - Stave structure L4

Silicon
Component: 0_1
Material: Si

L: 84cm, W: 4cm, D: 0.005cm (50μm)

Aluminum
Component: 1_2
Material: Al

L: 84cm, W: 4cm, D: 0.038cm (380μm)

Carbon Fibre support
Module:1_0
Material: Carbon Fibre
Left/right

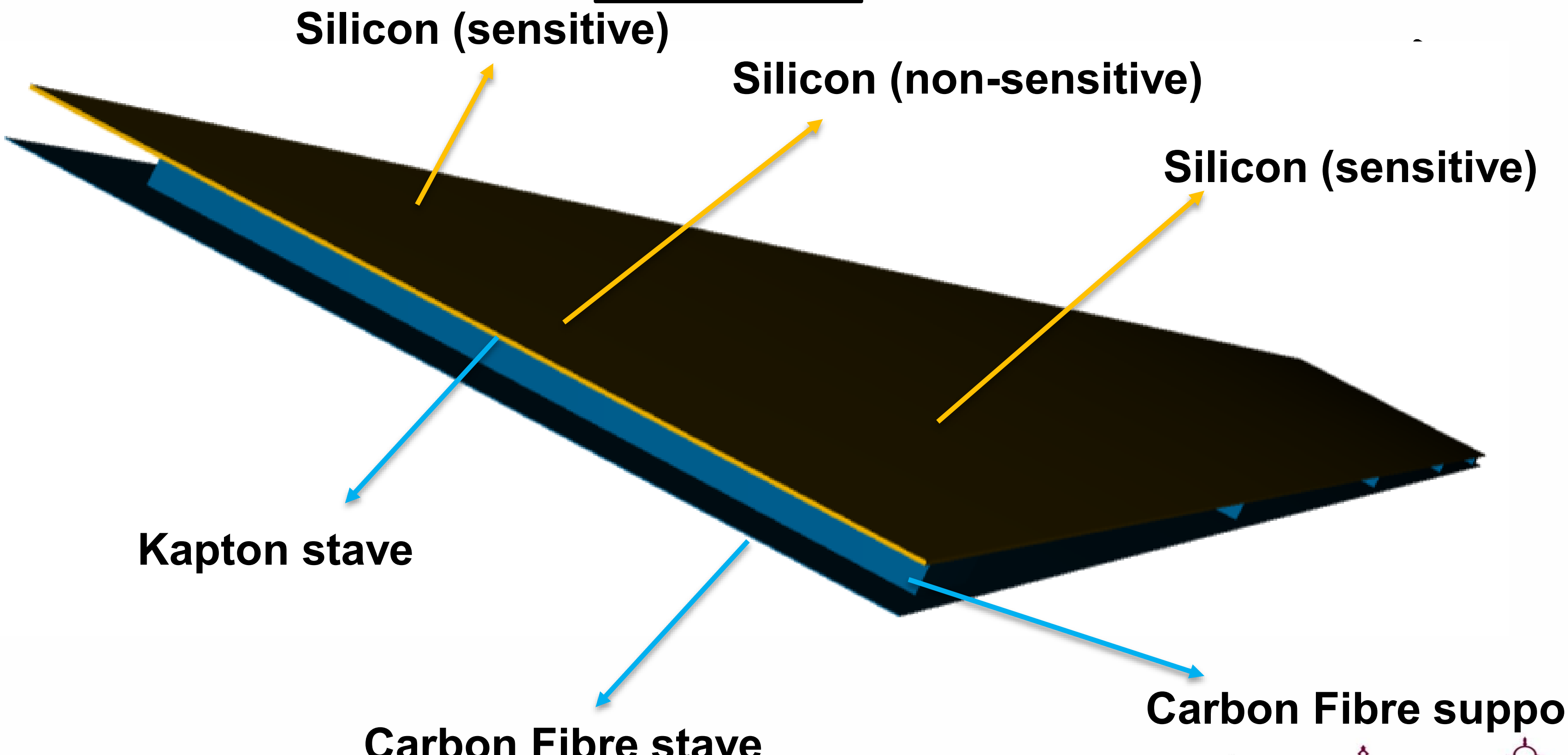
L: 84cm, W: 4cm, D: 0.801cm (8010μm)

Total material ~0.55% X_0

https://eic.phy.anl.gov/geoviewer/

Geoviewer visualisation Stave

Post-merge



L3 stave

https://eic.phy.anl.gov/geoviewer/

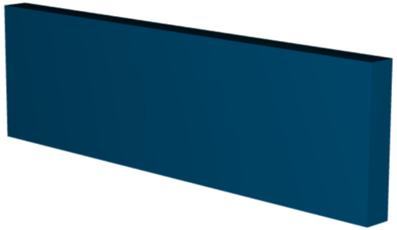
Post Merge - Stave Structure L3

Carbon Fibre stave
Components:0
Material: CHO

L: 50cm, W: 4cm, D: 0.006cm (60μm)

L: 1cm, W: 4cm, D: 0.2cm (2000μm)

Carbon Fibre support
Components:1-5
Material: CHO



Kapton stave
Components:6
Material: CHNO

L: 50cm, W: 4cm, D: 0.008cm (80μm)

https://eic.phy.anl.gov/geoviewer/

Post Merge - Stave structure L3

L: 50cm, W: 1.85cm, D: 0.01cm (100μm)

Sensitive (7)

Silicon
Components:7-9
Material: Si

L: 50cm, W: 0.1cm, D: 0.01cm (100μm)

Non-sensitive (8)

L: 50cm, W: 1.85cm, D: 0.01cm (100μm)

Sensitive (9)

Total average material at ~0.25% X_0 (with hotspots of ~0.8% X_0)

https://eic.phy.anl.gov/geoviewer/

Total active length = 503 mm

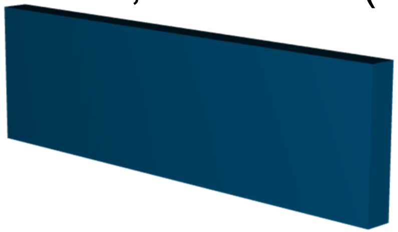
Post Merge - Stave structure L4

Carbon Fibre stave
Components:0
Material: CHO

L: 80cm, W: 4cm, D: 0.012cm (120μm)

Carbon Fibre support
Components:1-9
Material: CHO

L: 1cm, W: 4cm, D: 0.2cm (2000μm)



Kapton Stave
Components:10
Material: CHNO

L: 80cm, W: 4cm, D: 0.007cm (70μm)

https://eic.phy.anl.gov/geoviewer/

Post Merge - Stave structure L4

L: 80cm, W: 1.85cm, D: 0.011cm (110μm)

Sensitive (11)

L: 80cm, W: 0.1cm, D: 0.011cm (110μm)

Non-sensitive (12)

Silicon stave
Components:11-13
Material: Si

L: 80cm, W: 1.85cm, D: 0.011cm (110μm)

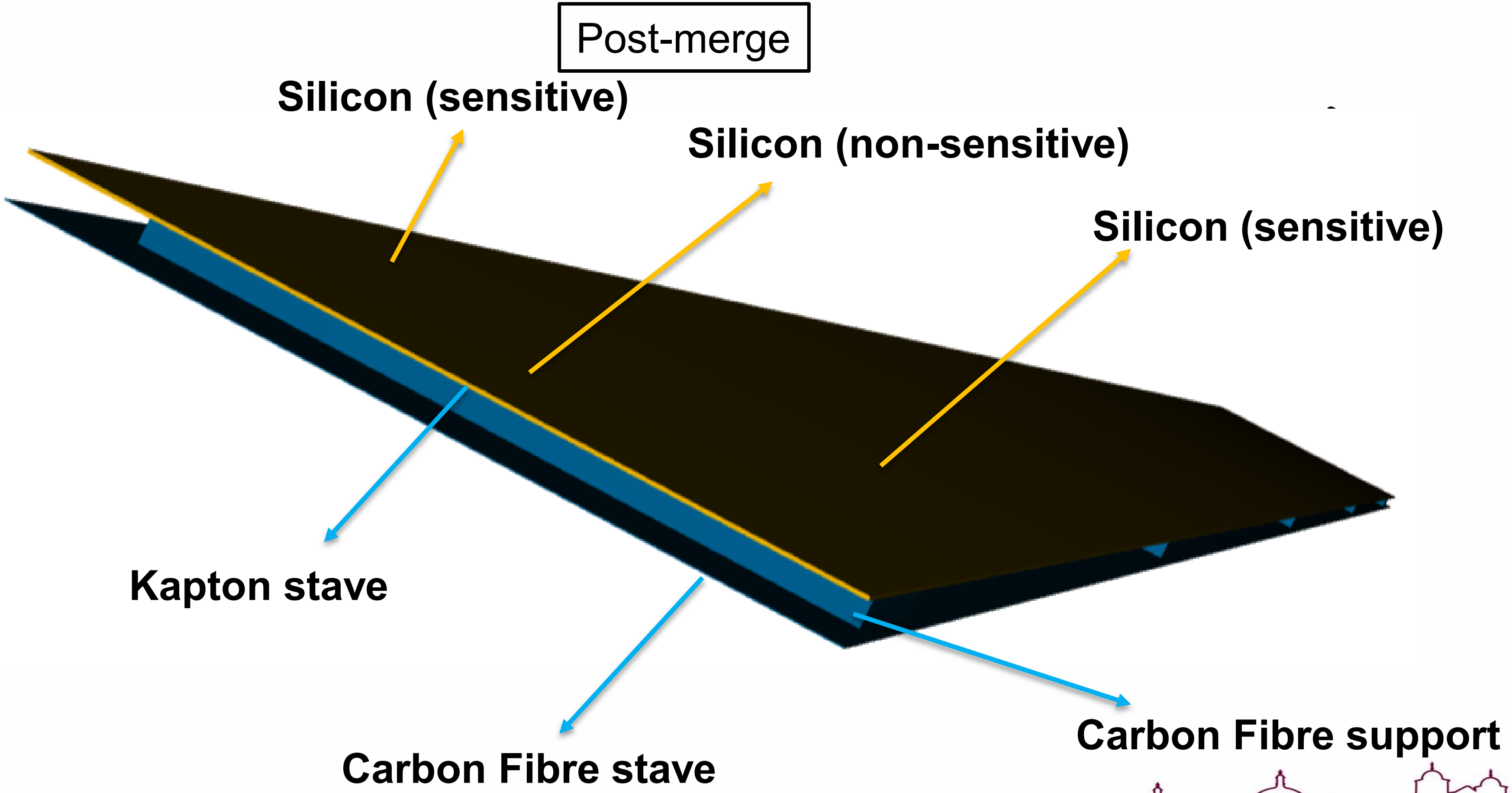
Sensitive (13)

Total average material at ~0.25% X_0(with hotspots of ~0.8% X_0)

Total active length = 793 mm

https://eic.phy.anl.gov/geoviewer/

Geoviewer visualisation Stave



L3 stave

https://eic.phy.anl.gov/geoviewer/

Hitmaps

Steering file for the hitmaps

Main focus is the barrel region ($|\eta| < 0.88$)

- π^- events
- 1 million single particle events
- Momentum $15 GeV/c$

steering.py

```
from DDSim.DD4hepSimulation import DD4hepSimulation
from g4units import mm, GeV, MeV, deg

SIM = DD4hepSimulation()

# Configure particle gun
SIM.enableGun = True
SIM.gun.particle = "pi-"
SIM.gun.multiplicity = 1
SIM.gun.thetaMin = 45 * deg  # Minimum angle
SIM.gun.thetaMax = 135 * deg  # Maximum angle
SIM.gun.distribution = "eta"  # Correct distribution type
SIM.gun.momentumMin = 15 * GeV  # Min momentum
SIM.gun.momentumMax = 15 * GeV  # Max momentum
```

ddsim
--steeringFile steering.py
--compactFile $DETECTOR_PATH/epic_craterlake_sb.xml
--numberOfEvents 1000000
--outputFile *name*.root

Only silicon barrel

```xml
<documentation level="5">
  ## Electric and magnetic fields
</documentation>
<include ref="${DETECTOR_PATH}/compact/fields/marco.xml"/>

<documentation level="10">
  ## Central tracking detectors
</documentation>

<include ref="${DETECTOR_PATH}/compact/tracking/definitions_craterlake.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/vertex_barrel.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/vertex_barrel_support.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/silicon_barrel.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/mpgd_barrel.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/support_service_craterlake.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/mpgd_outerbarrel.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/mpgd_forward_endcap.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/mpgd_backward_endcap.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/silicon_disks.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/tof_barrel.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/tof_endcap.xml"/>

<documentation level="11">
  ## Central beam pipe
</documentation>
<include ref="${DETECTOR_PATH}/compact/central_beampipe.xml"/>

<documentation level="11">
  ## Far foward detectors
</documentation>
<include ref="${DETECTOR_PATH}/compact/far_forward/default.xml"/>

<documentation level="11">
  ## Far backward detectors
</documentation>
<include ref="${DETECTOR_PATH}/compact/far_backward/default.xml"/>
</lccdd>
```

epic_craterlake_tracking_only.xml

```xml
<documentation level="5">
  ## Electric and magnetic fields
</documentation>
<include ref="${DETECTOR_PATH}/compact/fields/marco.xml"/>

<documentation level="10">
  ## Central tracking detectors
</documentation>

<include ref="${DETECTOR_PATH}/compact/tracking/definitions_craterlake.xml"/>
<include ref="${DETECTOR_PATH}/compact/tracking/silicon_barrel.xml"/>
</lccdd>
```

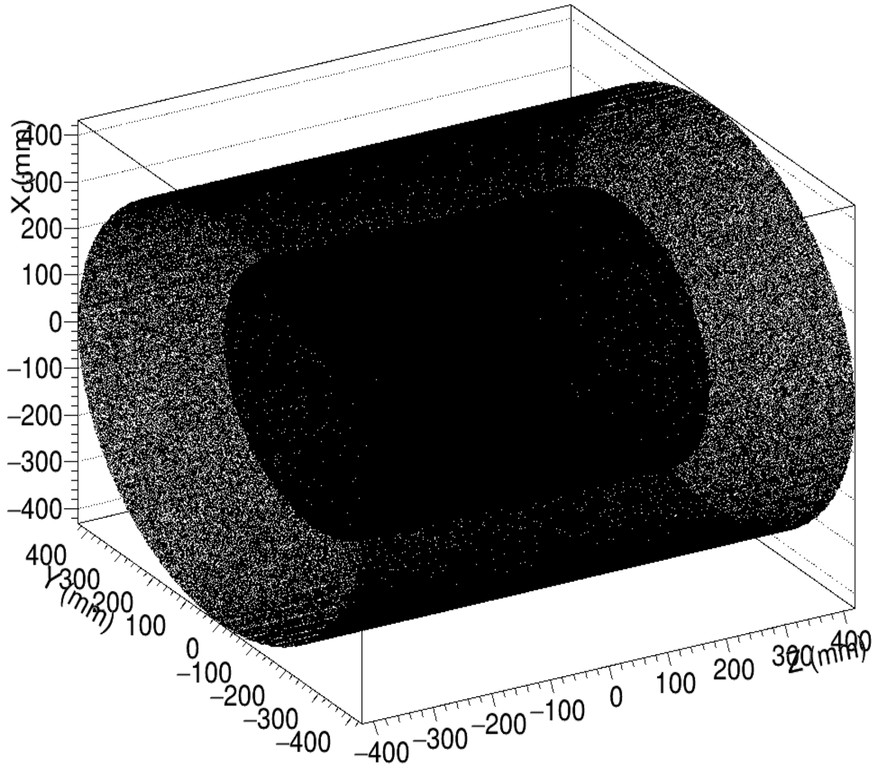
epic_craterlake_sb.xml

- **epic_craterlake_sb.xml** is a copy of **epic_craterlake_tracking_only.xml** with only the definitions and the silicon_barrel.xml as shown above.
- In install/share/epic/compact

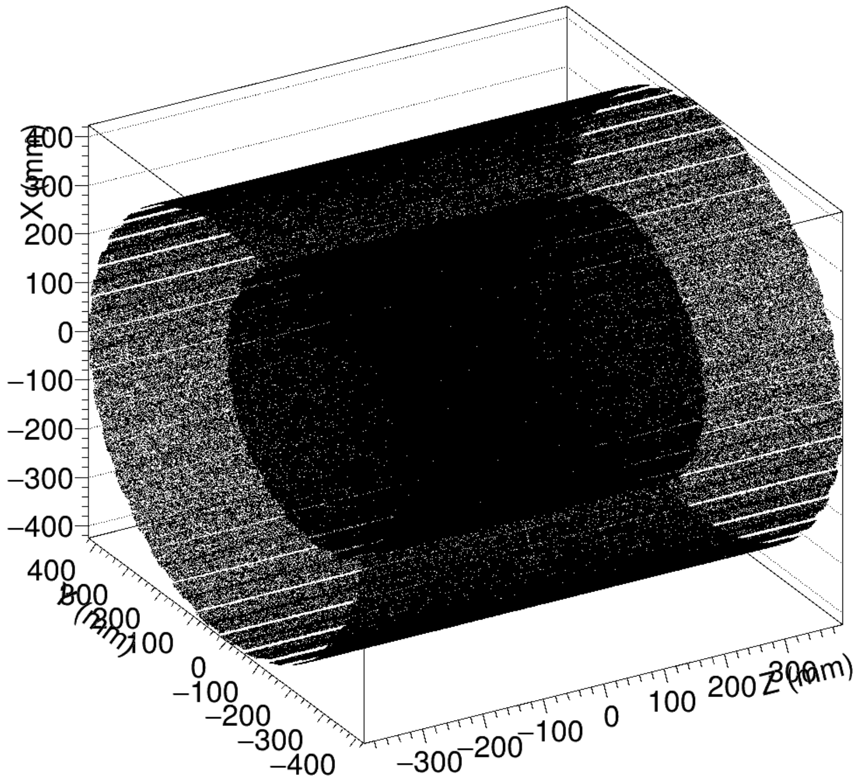
Outer Barrel Hitmaps

DDSIM
1 million events
$p = 15GeV/c$
SiBarrelHit.position

Pre-merge



Post-merge



Outer Barrel Hitmaps

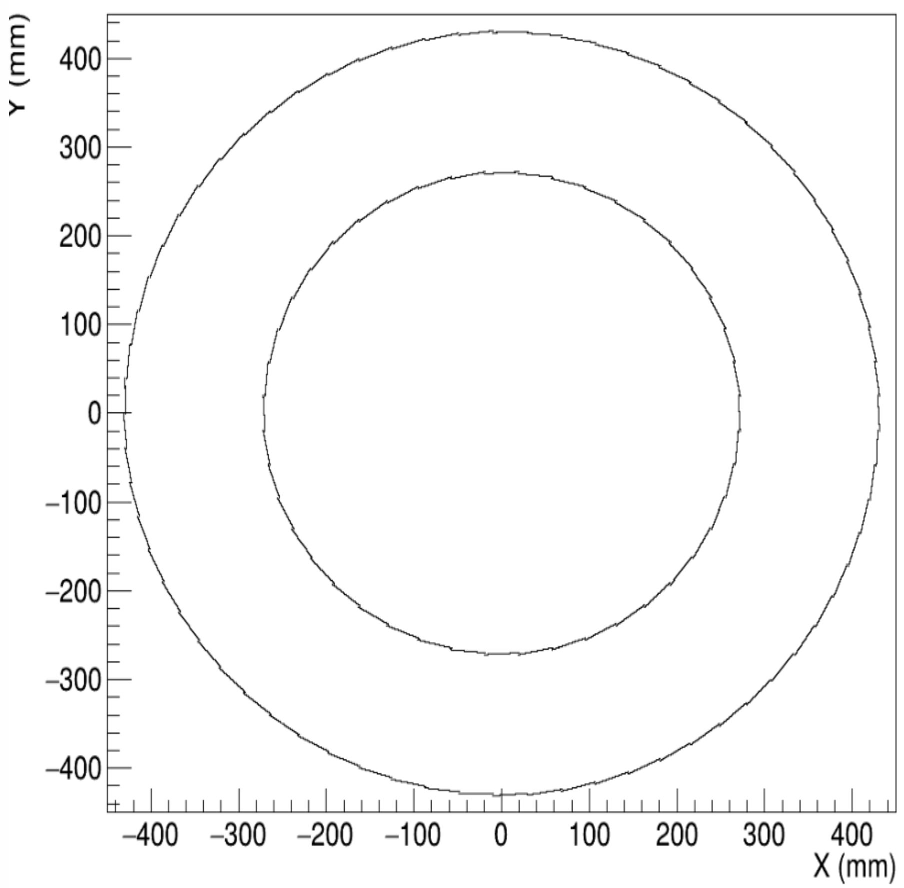
44 staves per L3

L3: 46 staves

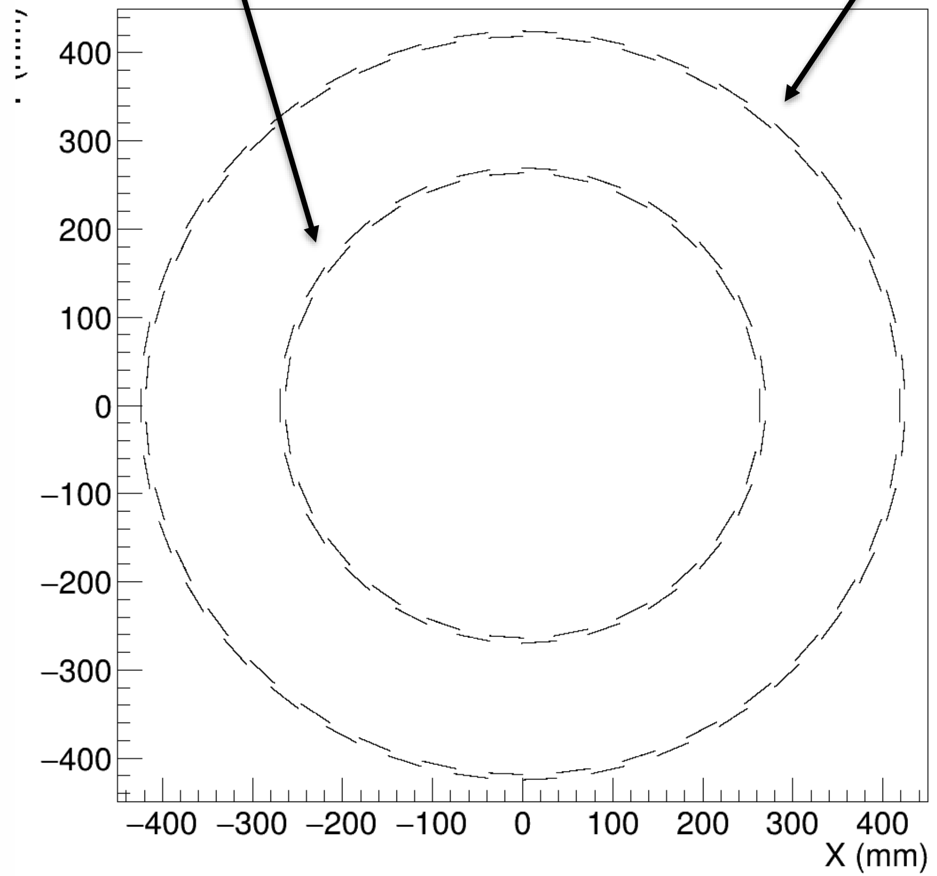
70 staves per L4

L4: 70 staves

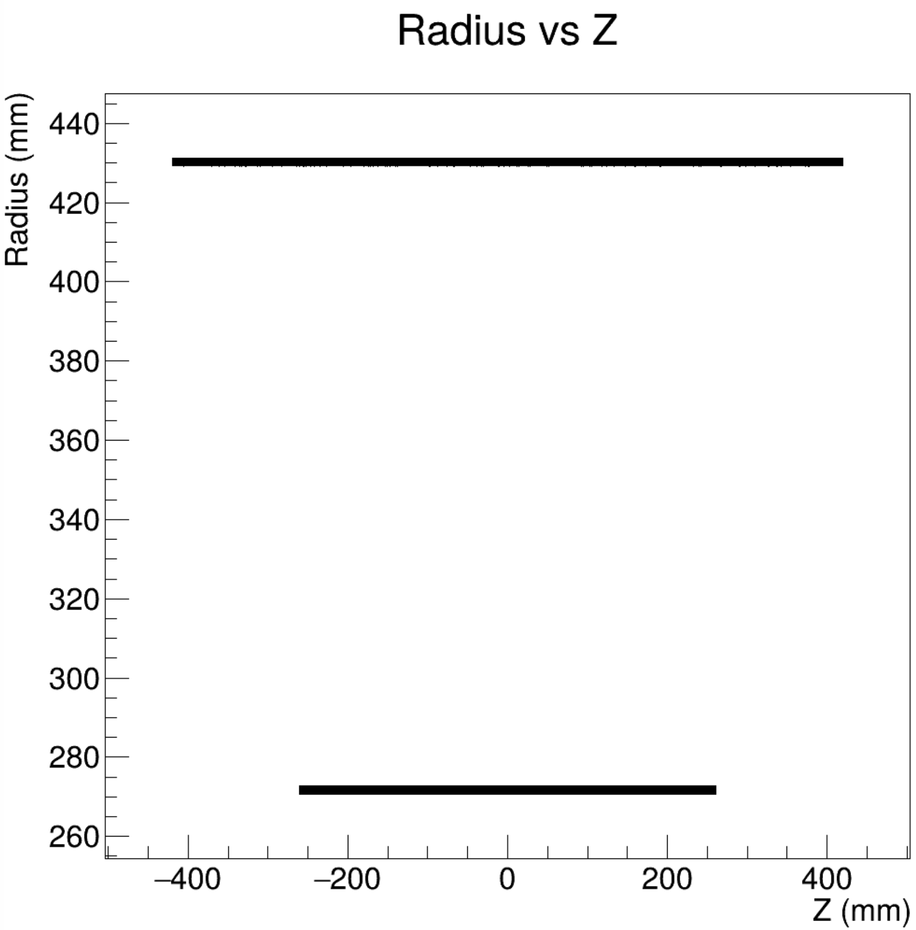
Pre-merge



Post-merge

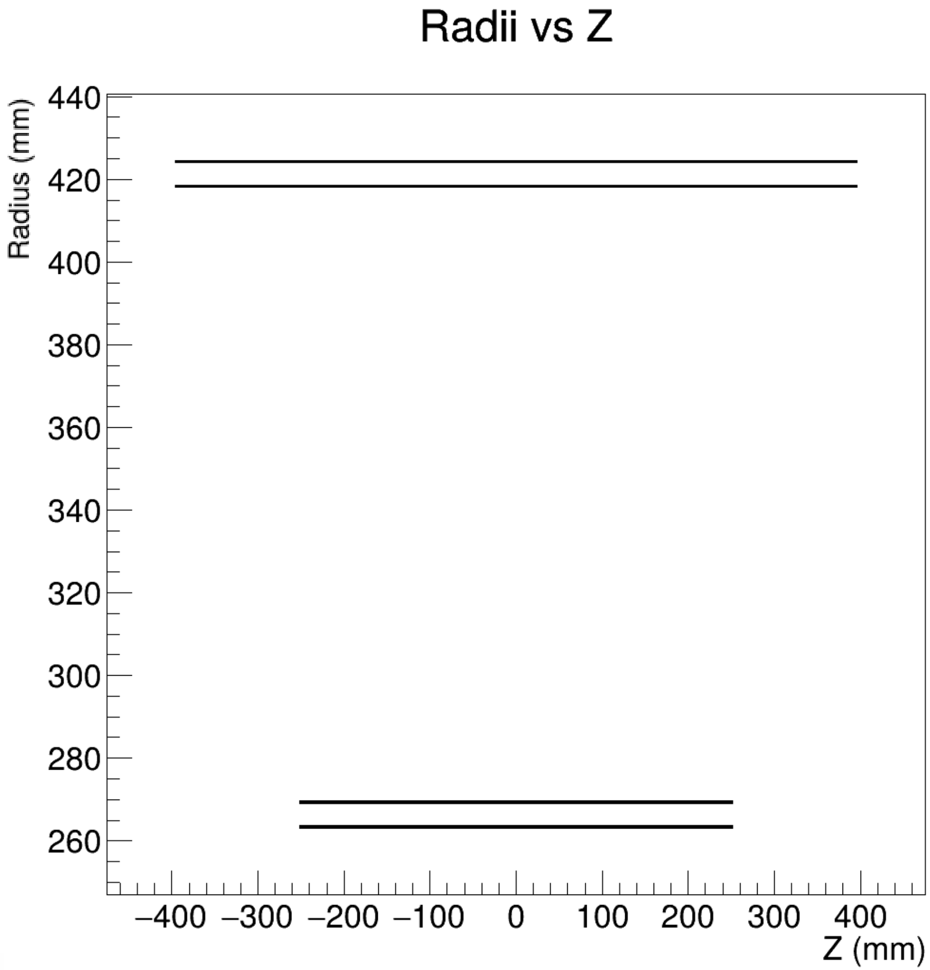


Outer Barrel Hitmaps

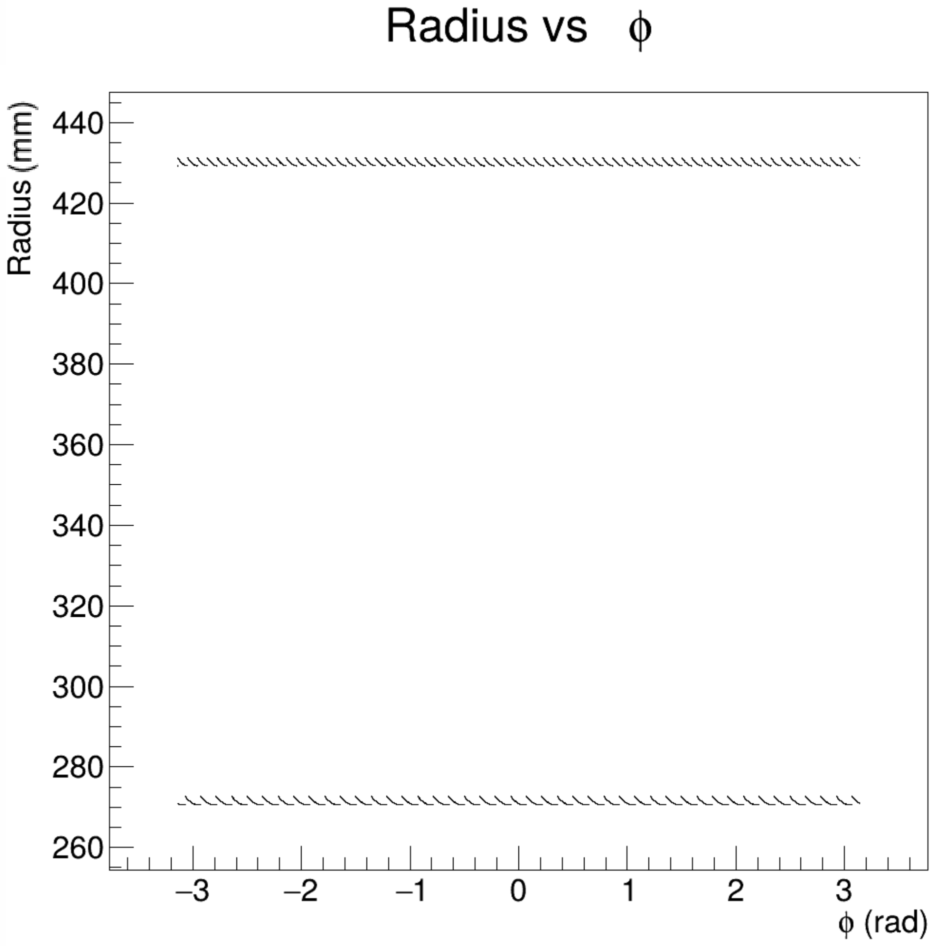


Pre-merge radii L3: ~27cm, L4: ~43cm

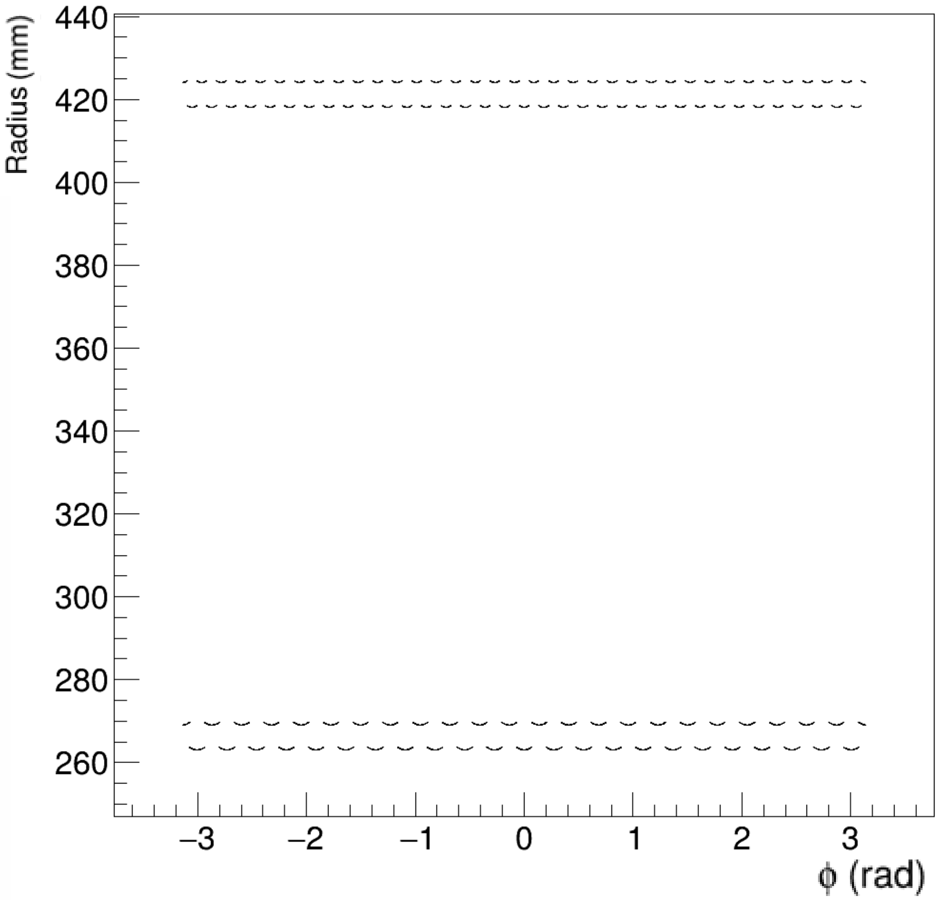
Post-merge L3: ~26.5 cm, L4: ~42cm



Outer Barrel Hitmaps



Post-merge L3: 26.5 cm, L4: 42cm



Pre-merge radii L3: 27cm, L4: 43cm

Outer Barrel Hitmaps

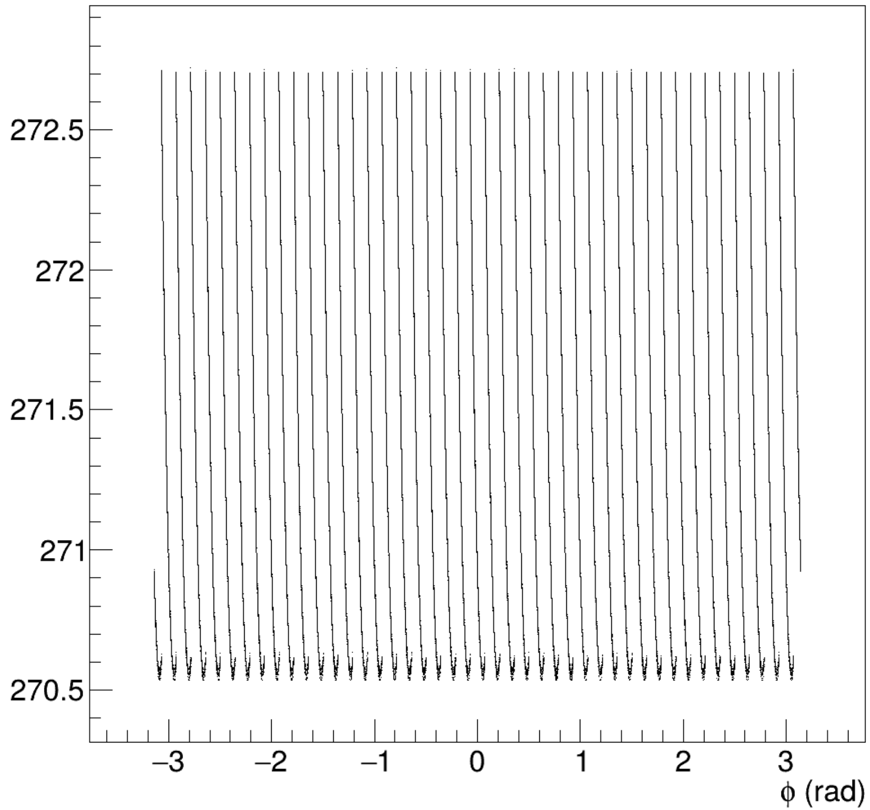
Inner sub-layer radius = ~270 mm
Outer sub-layer radius = ~273 mm

inner sub-layer radius = 262 mm
outer sub-layer radius = 268 mm

Inner sub-layer radius = ~263mm
Outer sub-layer radius = ~270mm

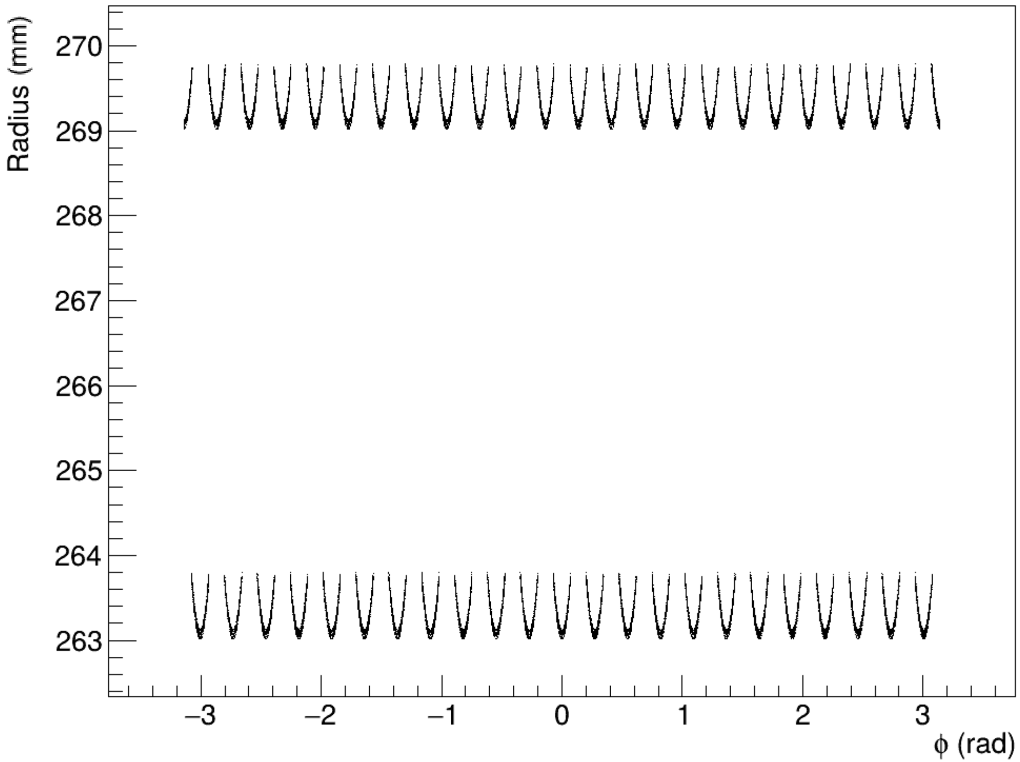
Pre-merge

L3 Radius vs ϕ



L3 Radius vs ϕ

Post-merge

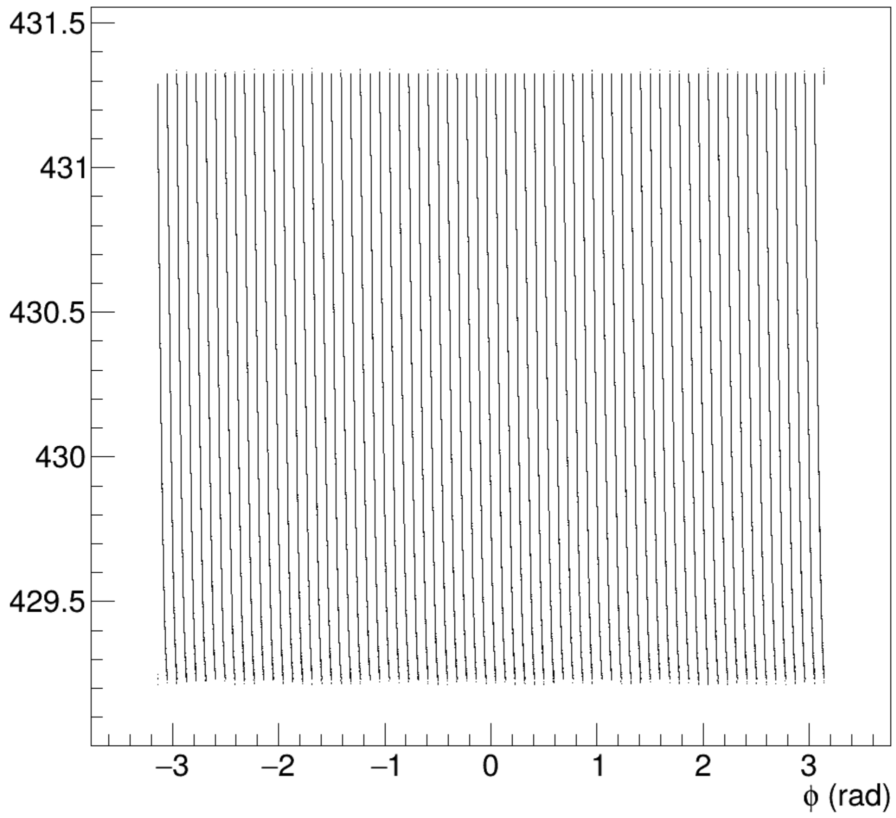


Outer Barrel Hitmaps

Inner sub-layer radius = ~429 mm
Outer sub-layer radius = ~432 mm

Pre-merge

L4 Radius vs ϕ

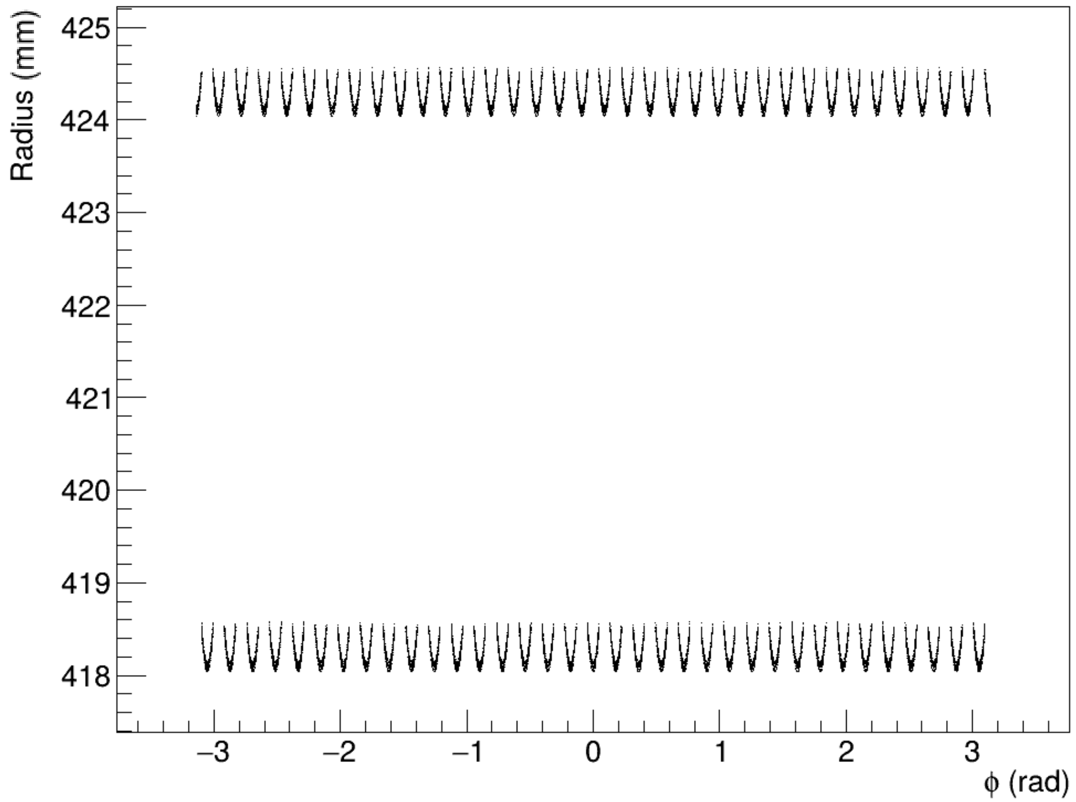


inner sub-layer radius = 417 mm
outer sub-layer radius = 423 mm

Inner sub-layer radius = ~418 mm
Outer sub-layer radius = ~425 mm

L4 Radius vs ϕ

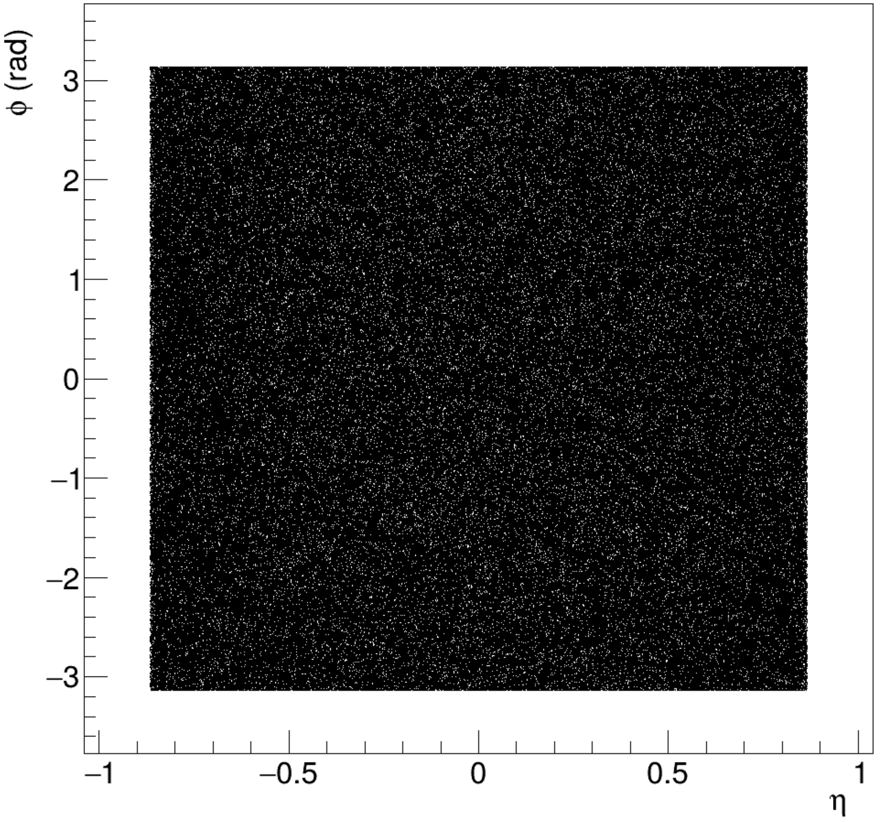
Post-merge



Hit map coverage

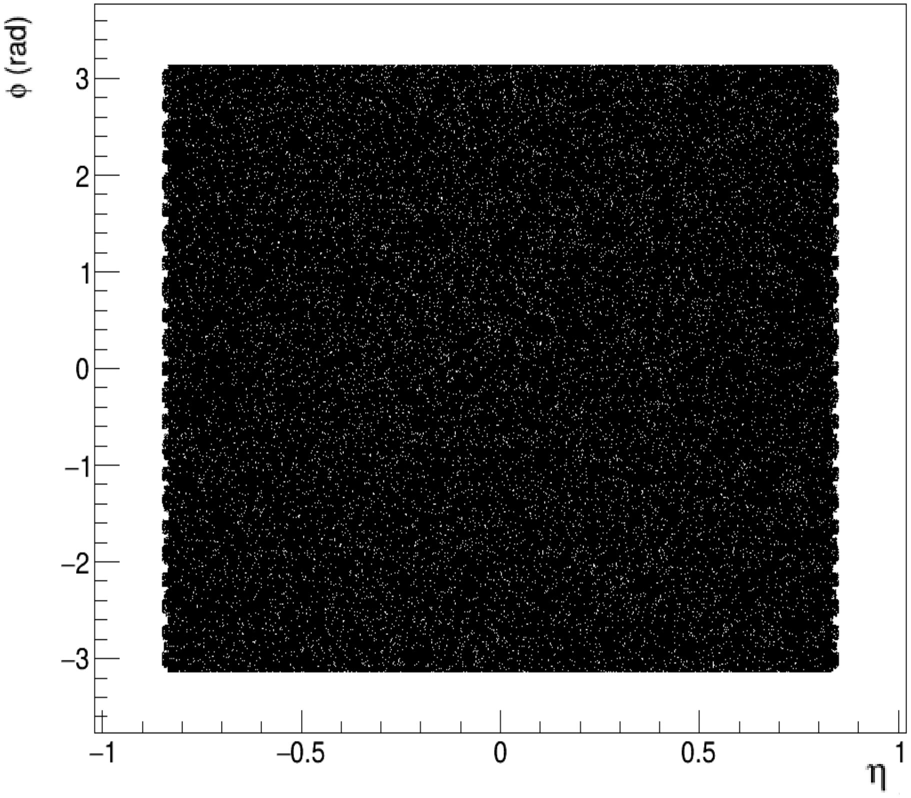
Pre-merge

ϕ vs η



ϕ vs η

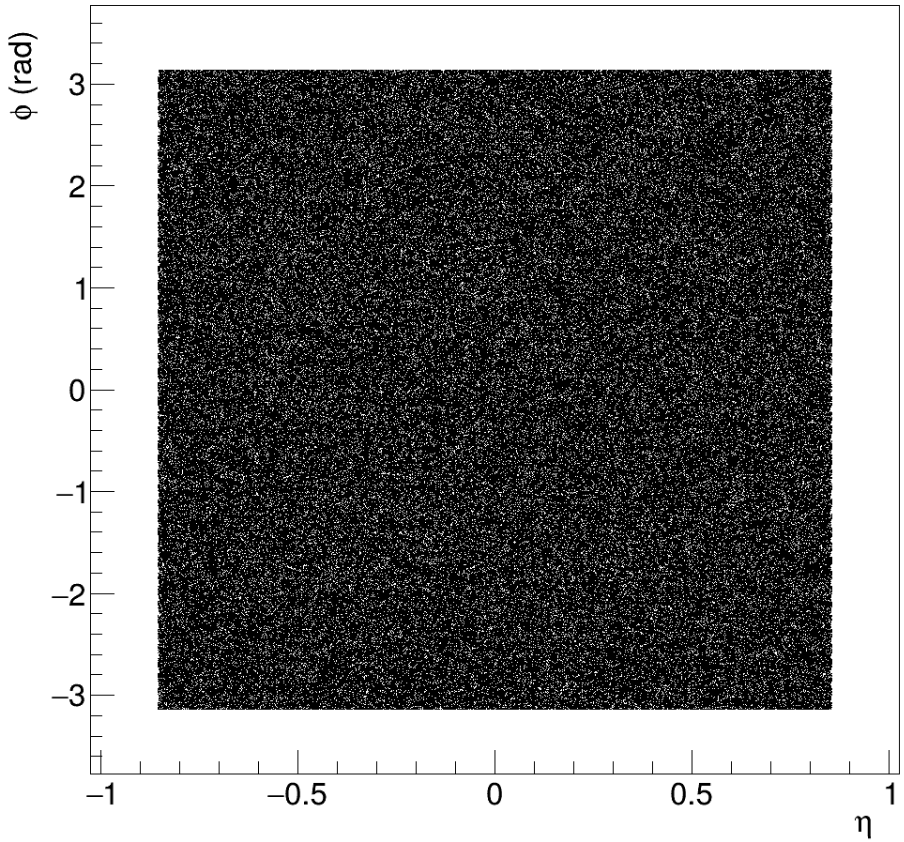
Post-merge



Hit map coverage

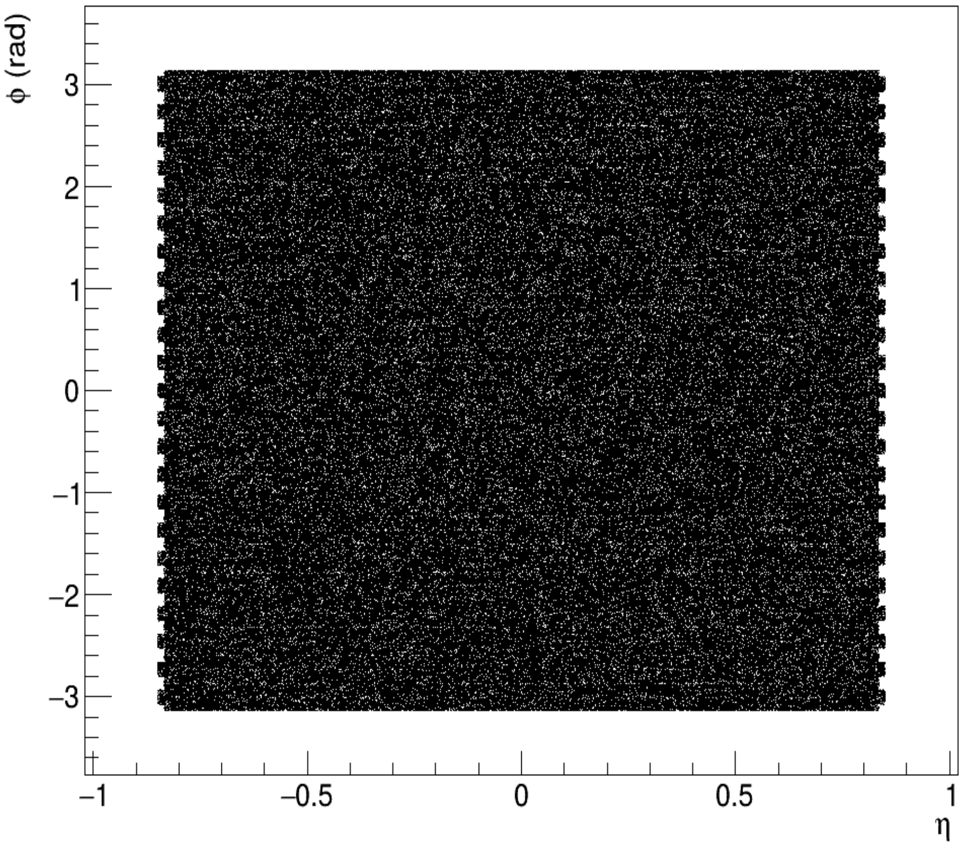
Pre-merge

L3 ϕ vs η



L3 ϕ vs η

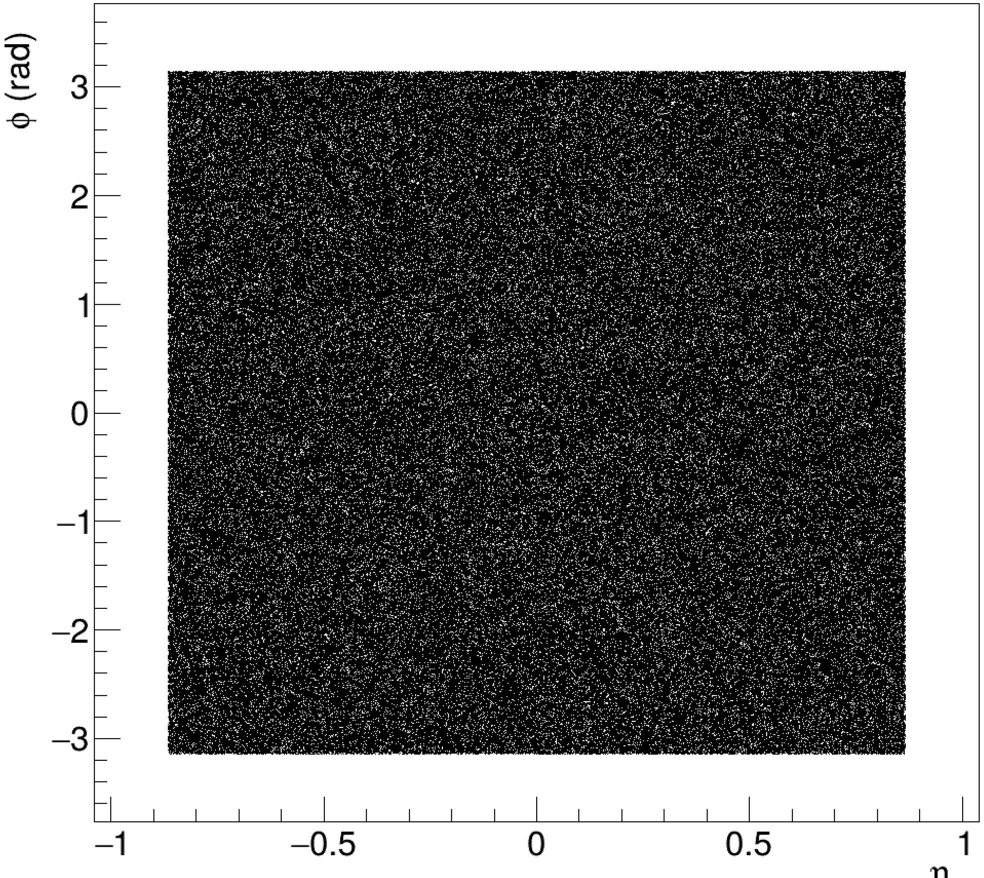
Post-merge



Hit map coverage

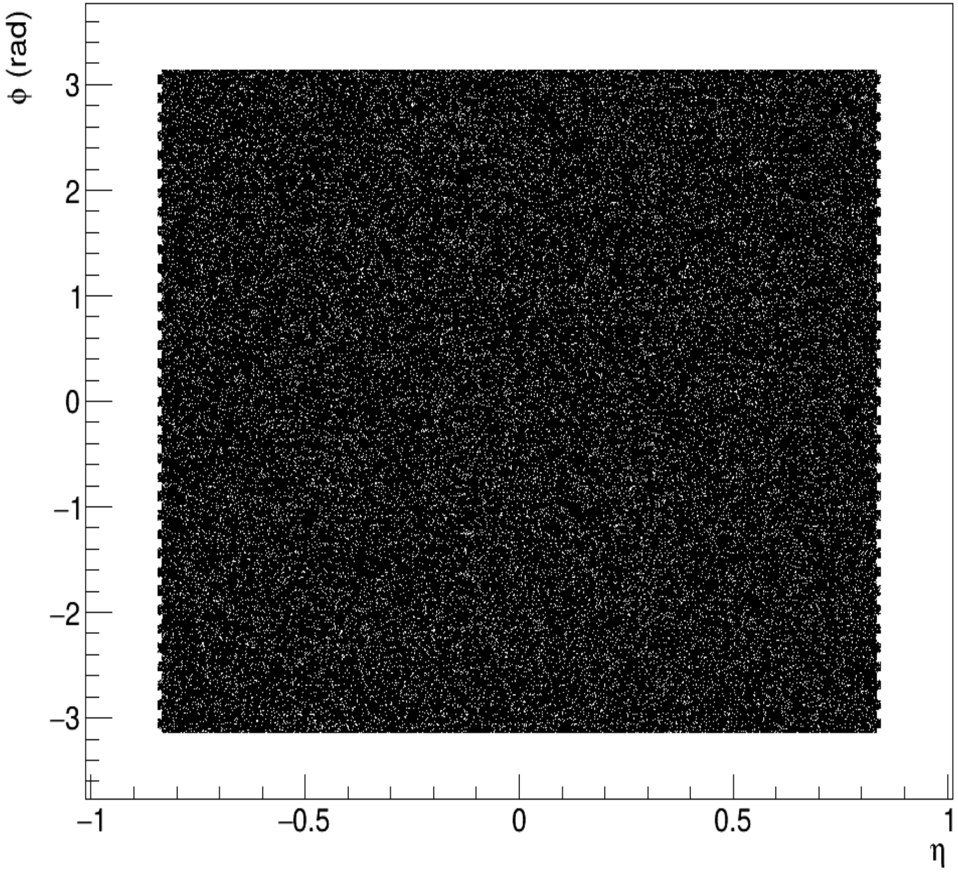
Pre-merge

L4 ϕ vs η



L4 ϕ vs η

Post-merge

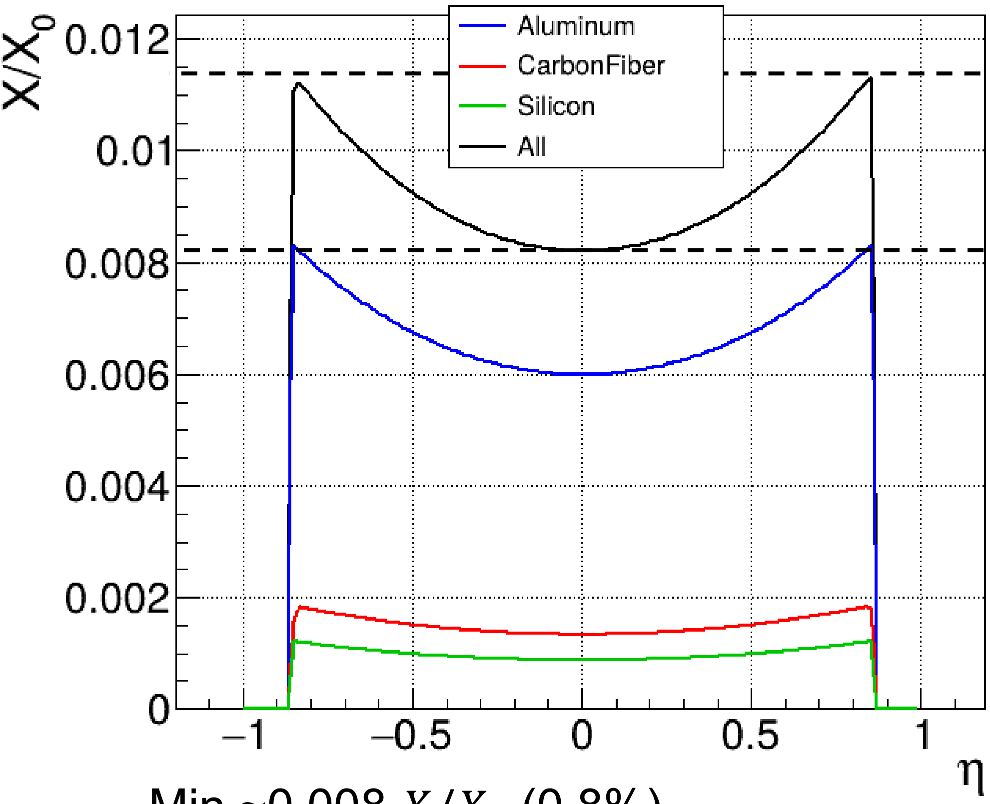


Material scans

Material Scan Barrel

Pre-merge

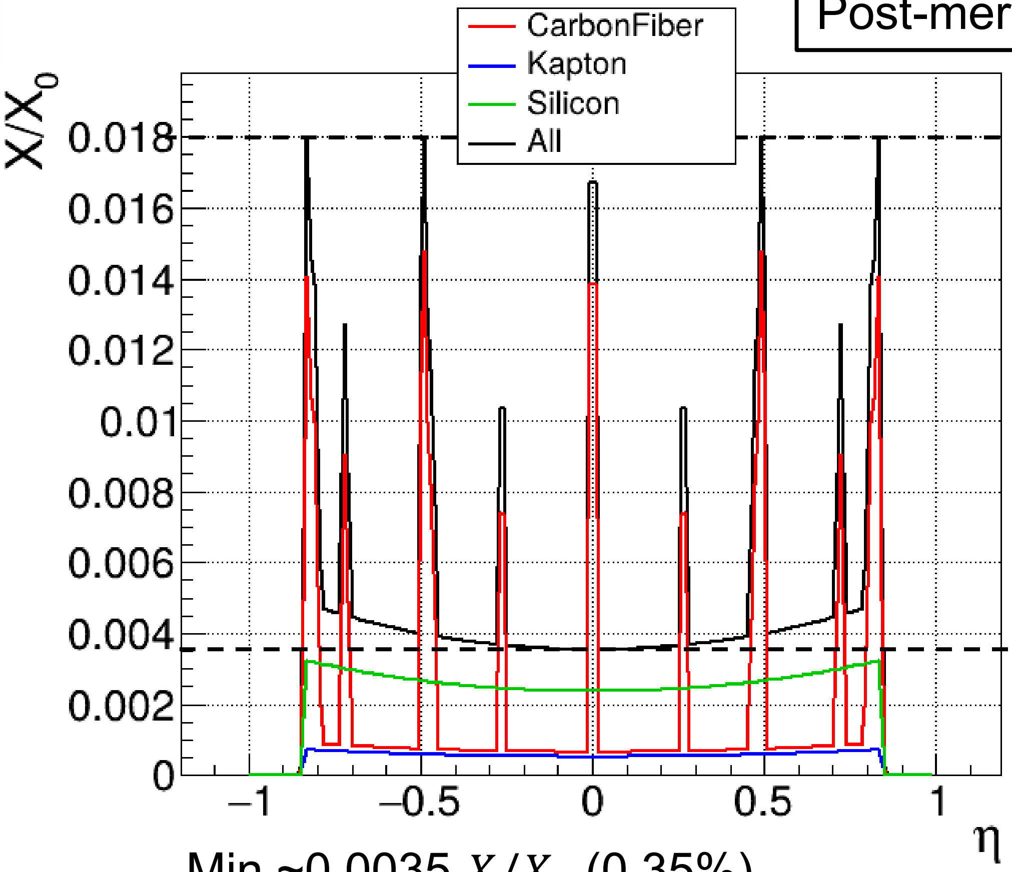
Max ~0.0115 X/X_0 (1.15%)



Min ~0.008 X/X_0 (0.8%)

Max ~0.018 X/X_0 (1.18%)

Post-merge

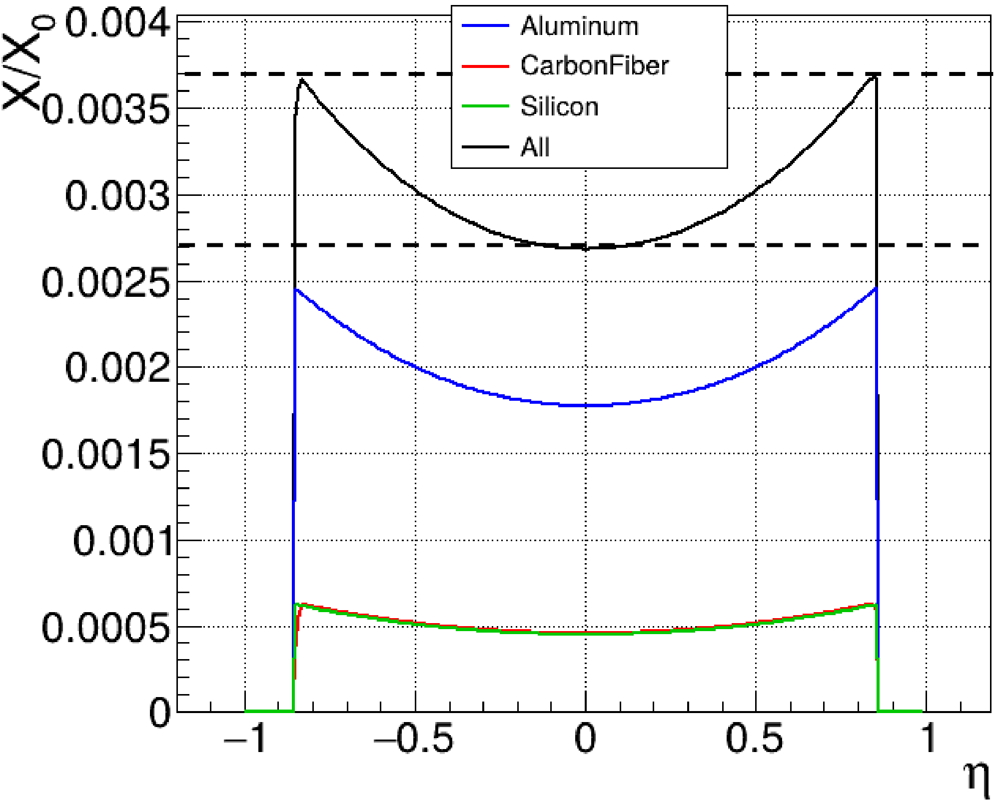


Min ~0.0035 X/X_0 (0.35%)

Material Scan Barrel – L3

Pre-merge

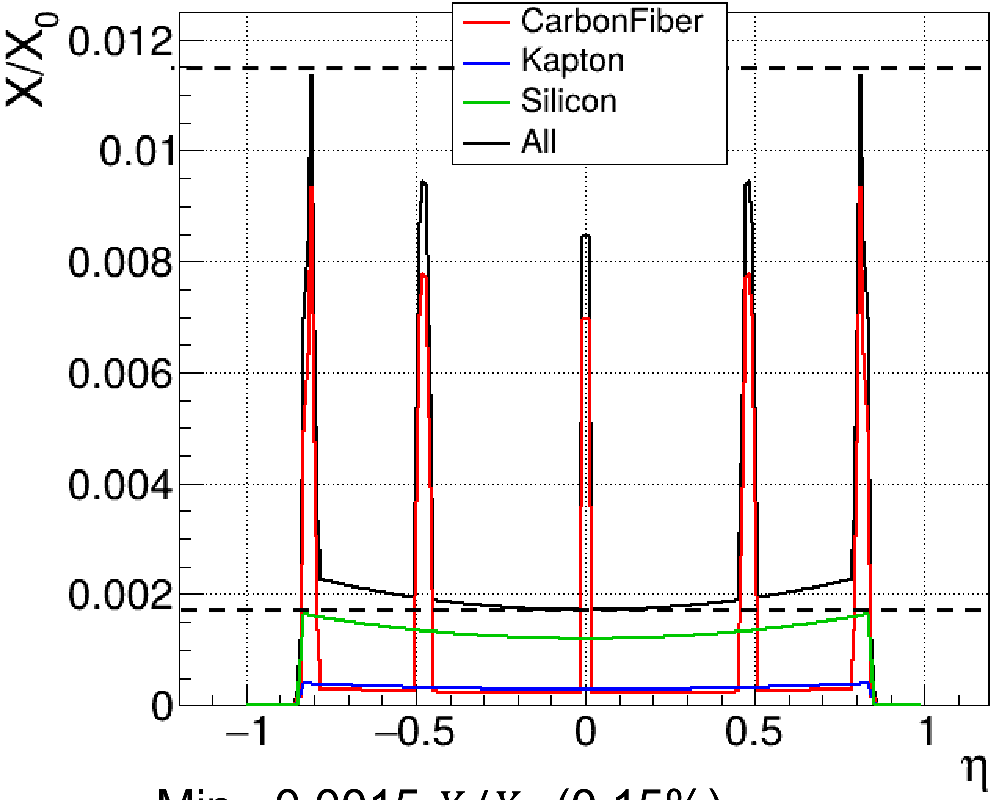
Max ~0.0037 X/X_0 (0.37%)



Min ~0.0027 X/X_0 (0.27%)

Max ~0.0115 X/X_0 (1.15%)

Post-merge

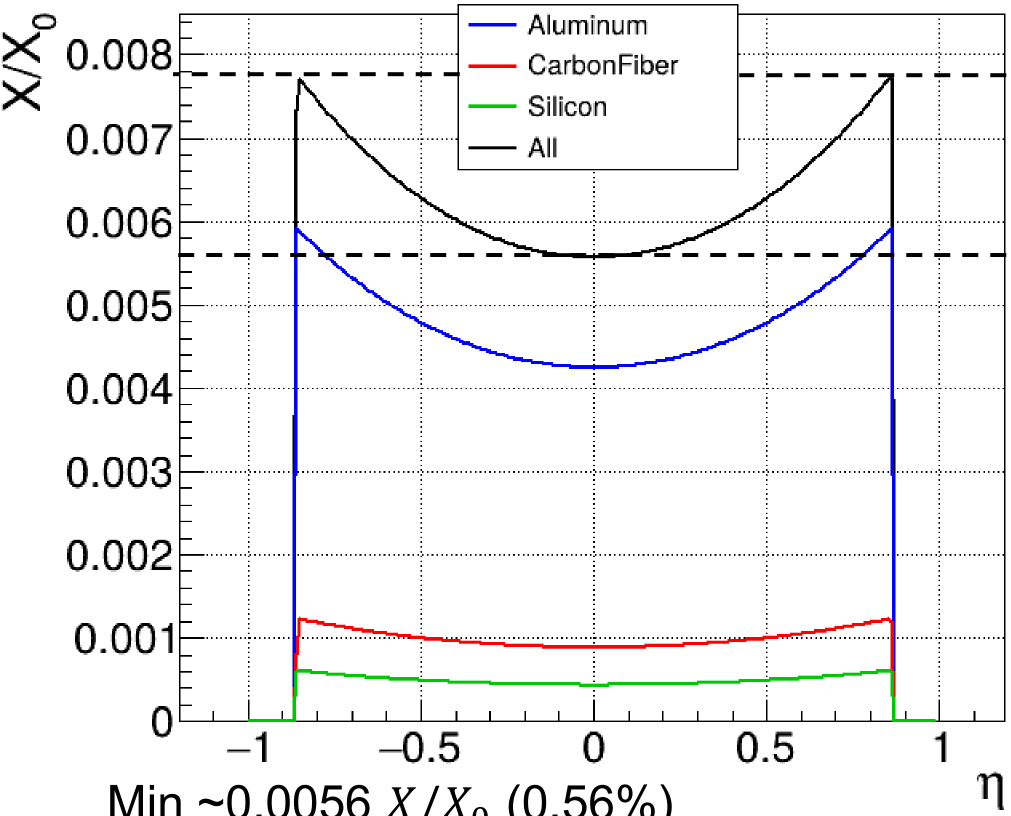


Min ~0.0015 X/X_0 (0.15%)

Material Scan Barrel – L4

Pre-merge

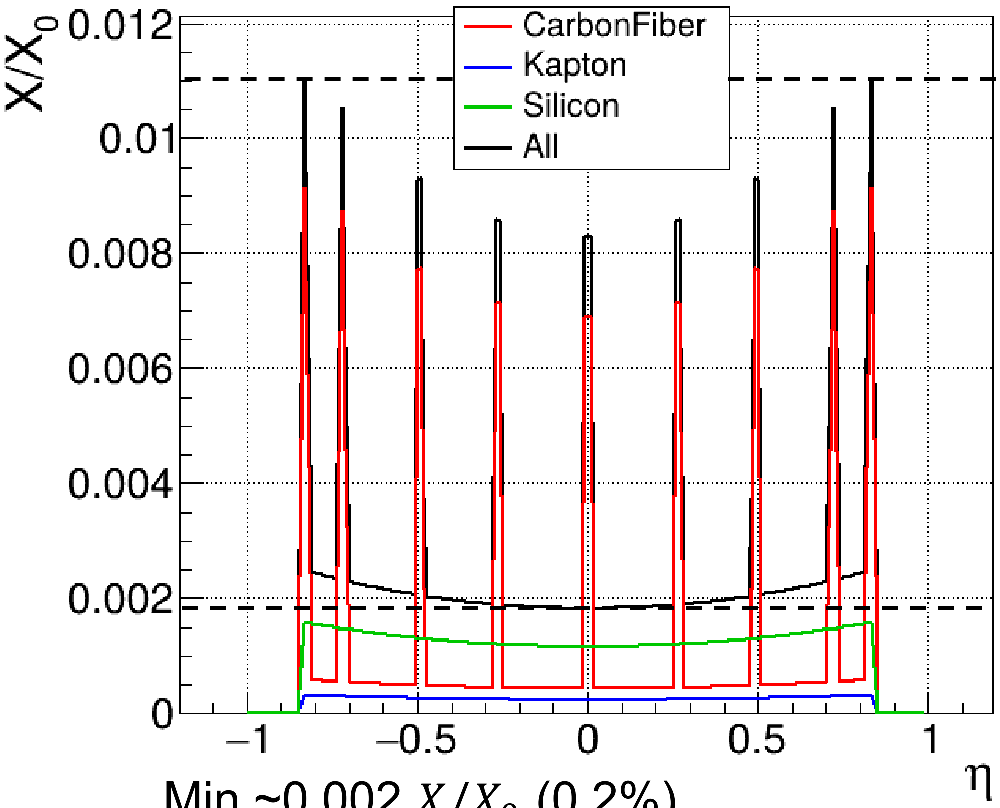
Max ~0.0078 X/X_0 (0.78%)



Min ~0.0056 X/X_0 (0.56%)

Post-merge

Max ~0.011 X/X_0 (1.1%)

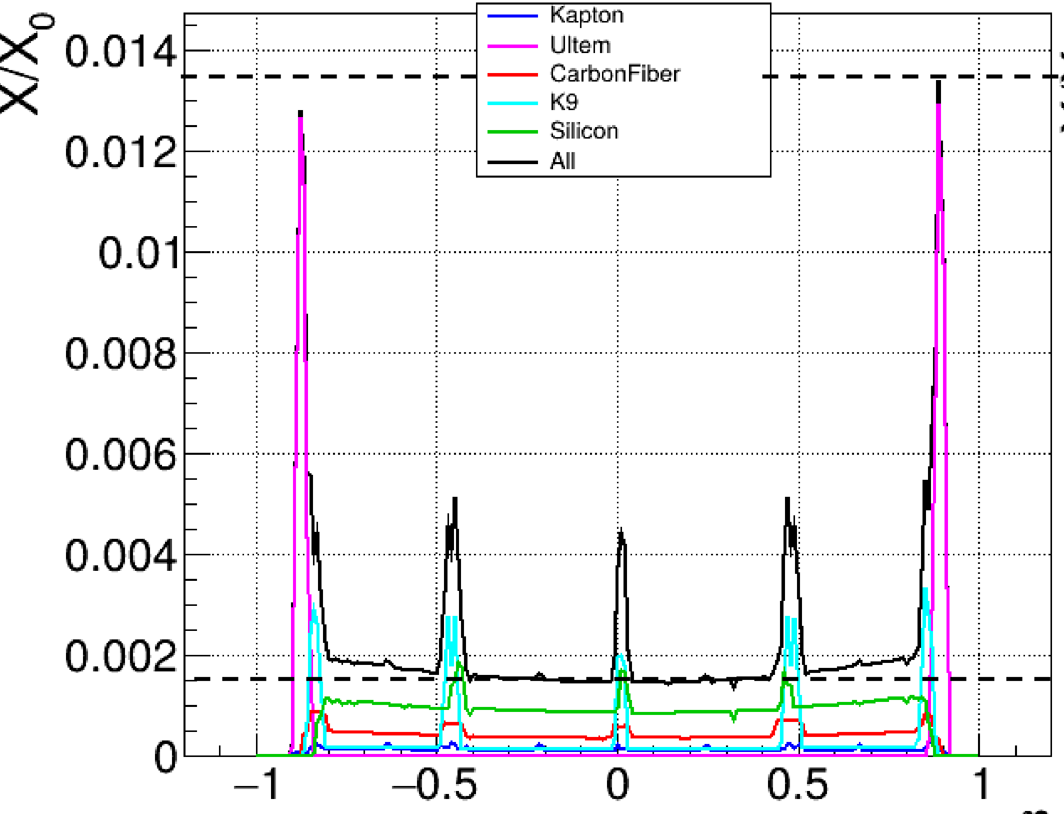


Min ~0.002 X/X_0 (0.2%)

Material Scan Stave – L3

July CAD

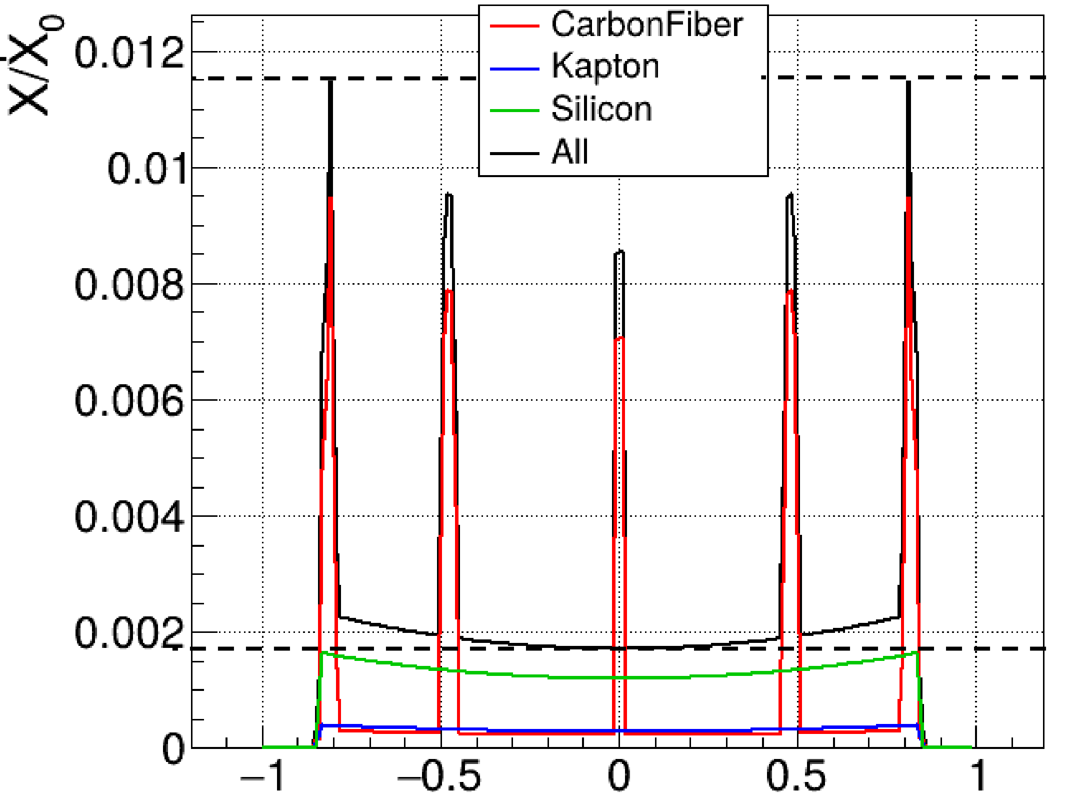
Max ~0.0135 X/X_0 (1.35%)



Min ~0.0015 X/X_0 (0.15%)

Post-merge

Max ~0.0115 X/X_0 (1.15%)

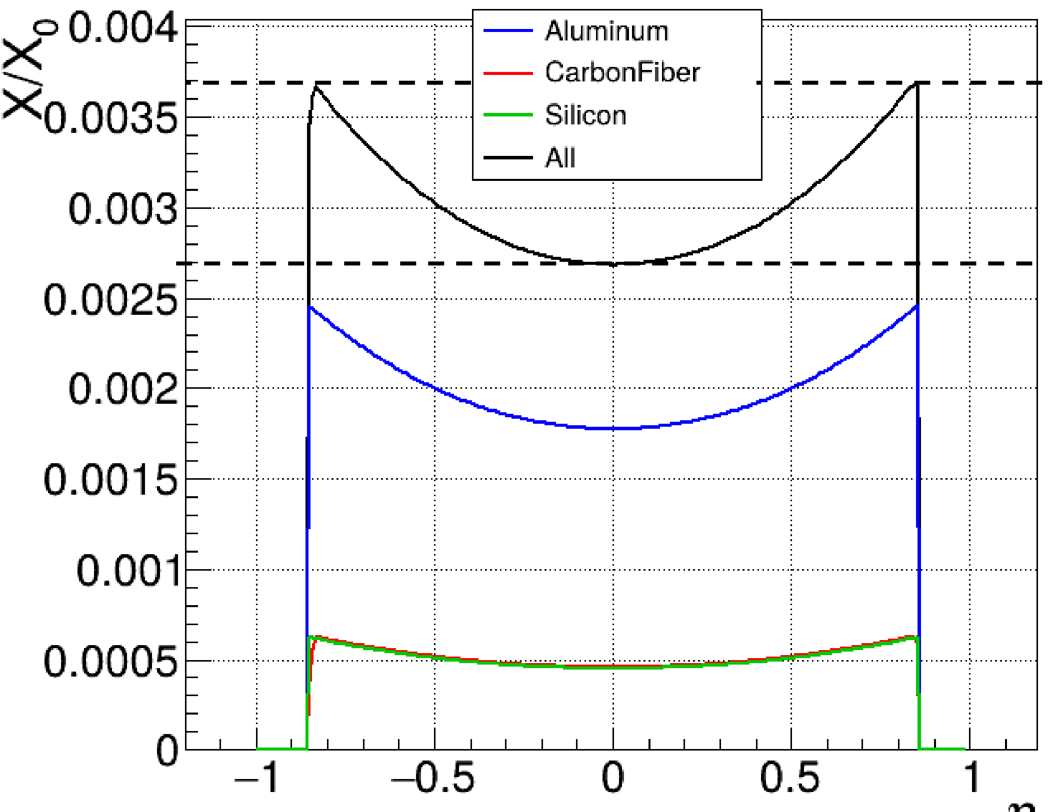


Min ~0.0015 X/X_0 (0.15%)

Material Scan Stave – L3

Pre-merge

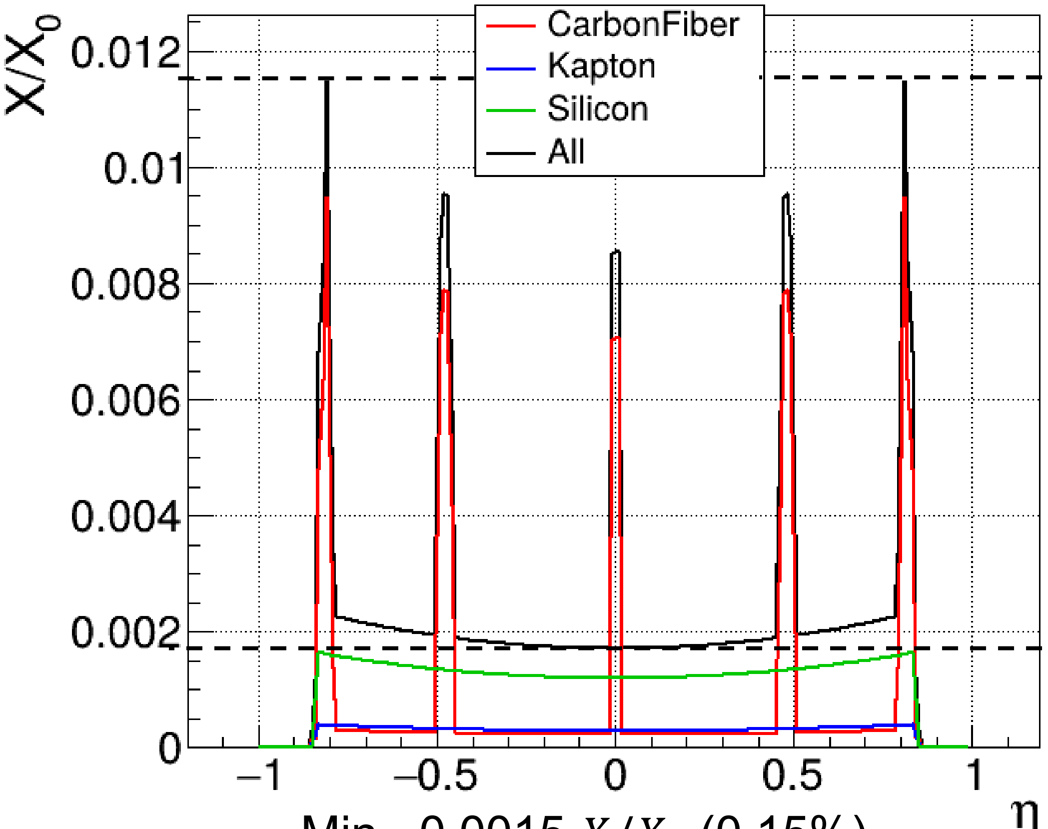
Max ~0.0037 X/X_0 (0.37%)



Min ~0.0027 X/X_0 (0.27%)

Post-merge

Max~0.0115 X/X_0 (1.15%)

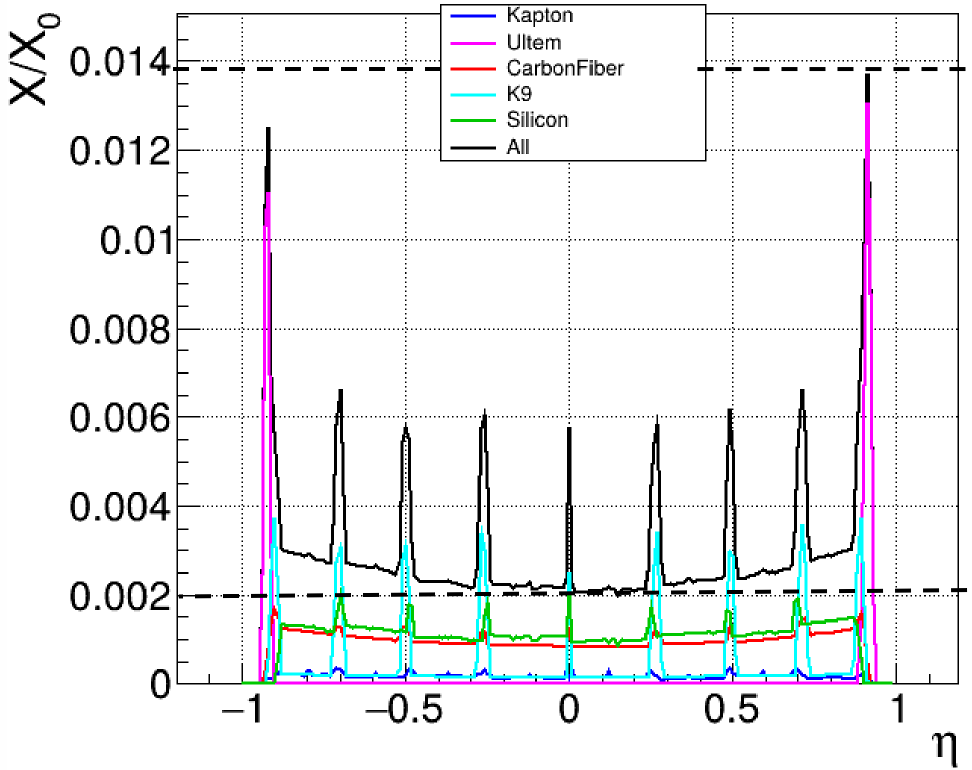


Min ~0.0015 X/X_0 (0.15%)

Material Scan Stave – L4

July CAD

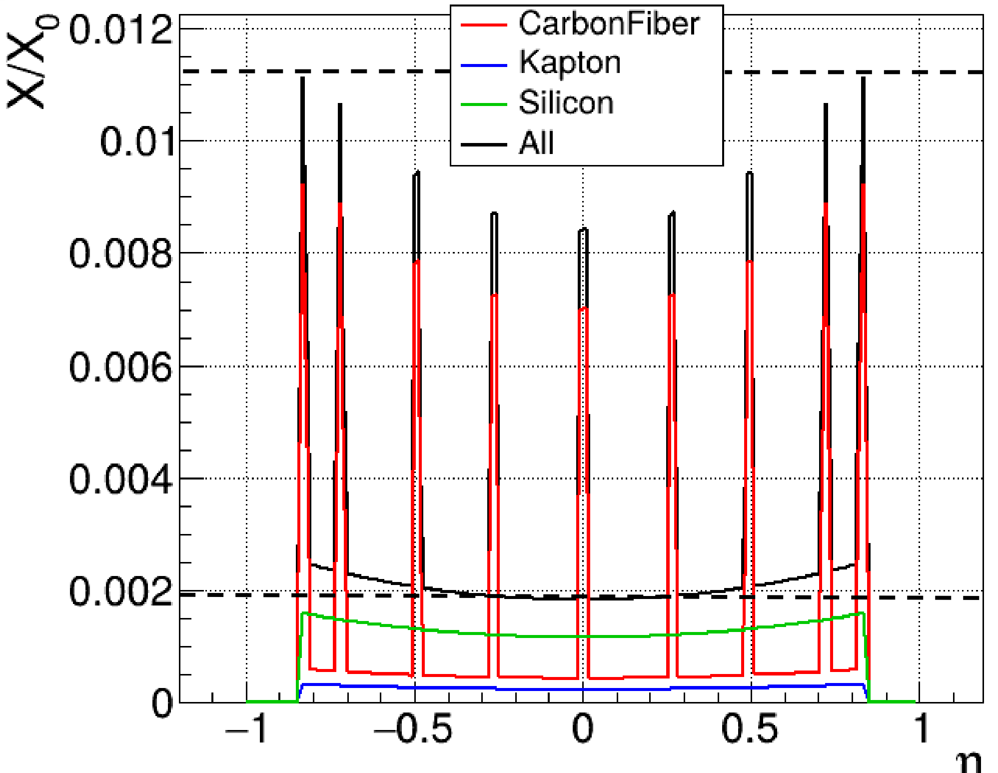
Max ~0.014 X/X_0 (1.4%)



Min ~0.002 X/X_0 (0.2%)

Post-merge

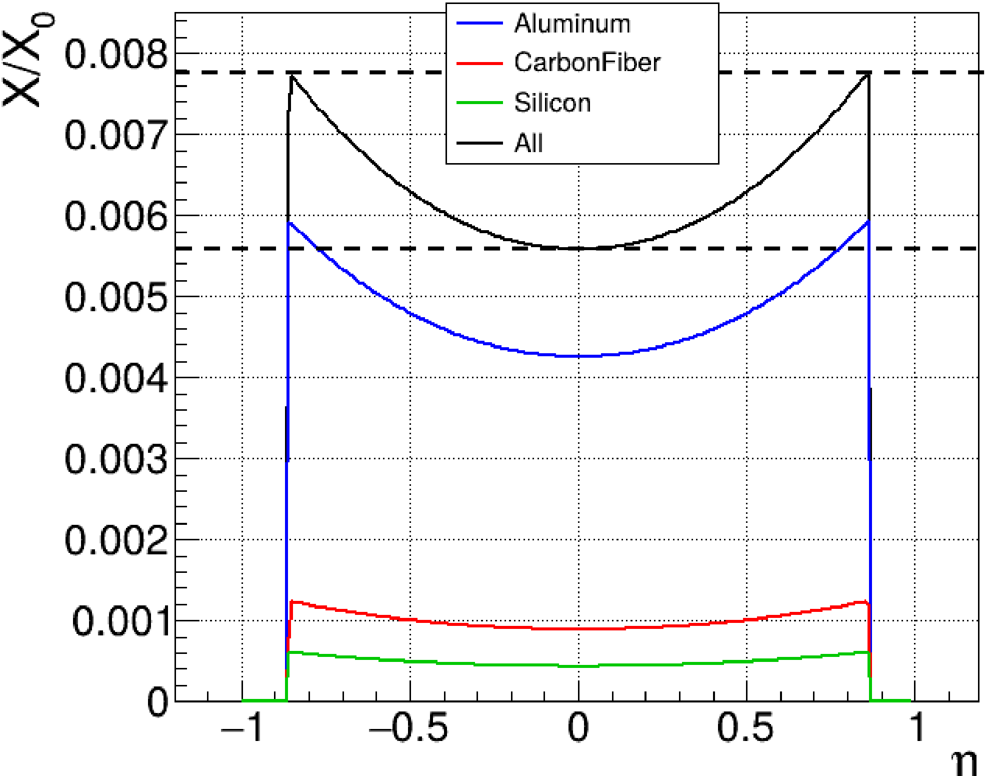
Max ~0.011 X/X_0 (1.1%)



Min ~0.002 X/X_0 (0.2%)

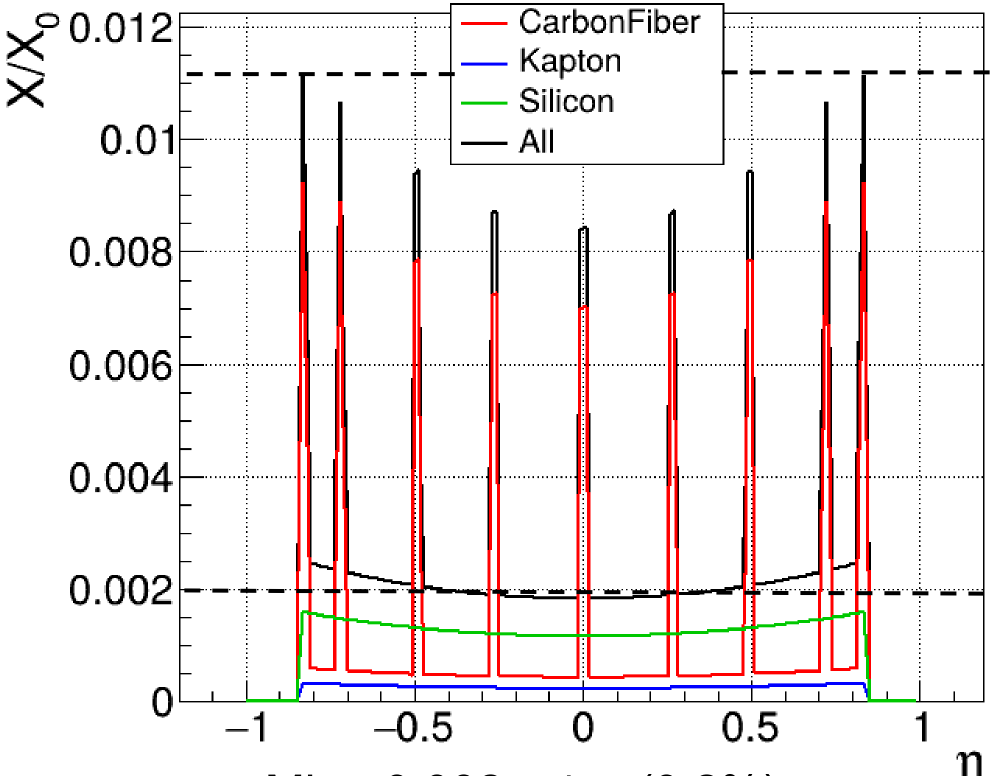
Material Scan Stave – L4

Pre-merge Max ~0.0078 X/X_0 (0.78%)



Min ~0.0056 X/X_0 (0.56%)

Max ~0.011 X/X_0 (1.1%) Post-merge



Min ~0.002 X/X_0 (0.2%)

Resolution Plots

Steering file for single particle simulations.

Main focus is the barrel region ($|\eta| < 0.88$)

π^- events
1000 events per momentum value
Particle distribution η

Momentum range $0.5GeV/c < p < 15GeV/c$

Steering.py

```
from DDSim.DD4hepSimulation import DD4hepSimulation
from g4units import mm, GeV, MeV, deg

SIM = DD4hepSimulation()

# Configure particle gun
SIM.enableGun = True
SIM.gun.particle = "pi-"
SIM.gun.multiplicity = 1
SIM.gun.thetaMin = 45 * deg  # Minimum angle
SIM.gun.thetaMax = 135 * deg  # Maximum angle
SIM.gun.distribution = "eta"  # Distribution type
#SIM.gun.momentumMin = 15 * GeV  # Min momentum
#SIM.gun.momentumMax = 15 * GeV  # Max momentum
```

Updating Material Map for EICrecon

Default run

- ./run_material_map_validation.sh --nevents 1000 --nparticles 5000
- Validation was failing

Instead:

- ./run_material_map_validation.sh --nevents 100 --nparticles 5000
- Increase seed by nevents.

- Hadd geant4_material_tracks.root file1.root file2.root … file10.root

Comment out the line, then run

- ./run_material_map_validation.sh --nevents 1000 --nparticles 5000

Result:

- A .cbor file of the updated material map for EICrecon

Examples/Scripts/Python/material_recording.py

```
    rnd = RandomNumbers(seed=228)
```

Examples/Scripts/Python/material_validation.py

```
    rnd = acts.examples.RandomNumbers(seed=42)
```

```

echo "::group::----GEANTINO SCAN------"
# output geant4_material_tracks.root
# The result of the geantino scan will be a root
# python material_recording_epic.py -i ${DETECTOR
echo "::endgroup::"

echo "::group::-----MAPPING Configuration-----"
# map geometry to geometry-map.json
```

Comparison of geometries (pre merge vs post merge)

- Fixed seed
- Barrel region
- 1000 events per momentum value

For the next slides:

- Black line – PWG requirement
- Blue line – best fit for momentum res.
- Green – multiple scattering term
- Orange – geometric/Sagitta term

preTDR_Version2.2

Central Barrel Region

Momentum resolution requirement:

$$\frac{\sigma(p)}{p} = 0.5 \oplus 0.05p$$

DCA_T resolution requirement:

$$DCA_T = 5 \oplus \frac{20}{p_T}$$

Taking results from TrackAnalysis.C based on the eic analysis tutorial: https://eic.github.io/tutorial-analysis/03-analysis/index.html

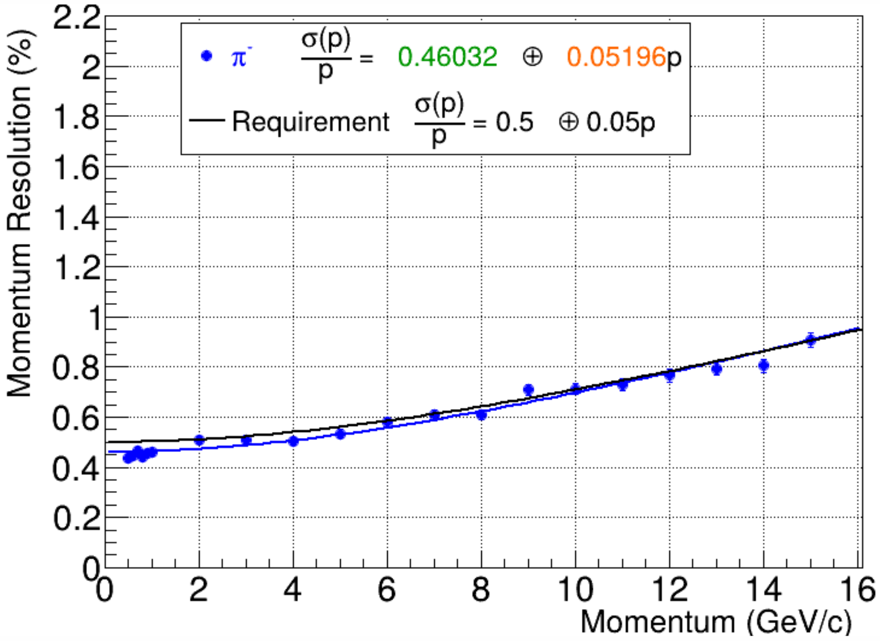
Average true transverse momentum:

$$< p_T > = \frac{1}{N} \sum_{n=1}^{N=1000} p_x \oplus p_y$$

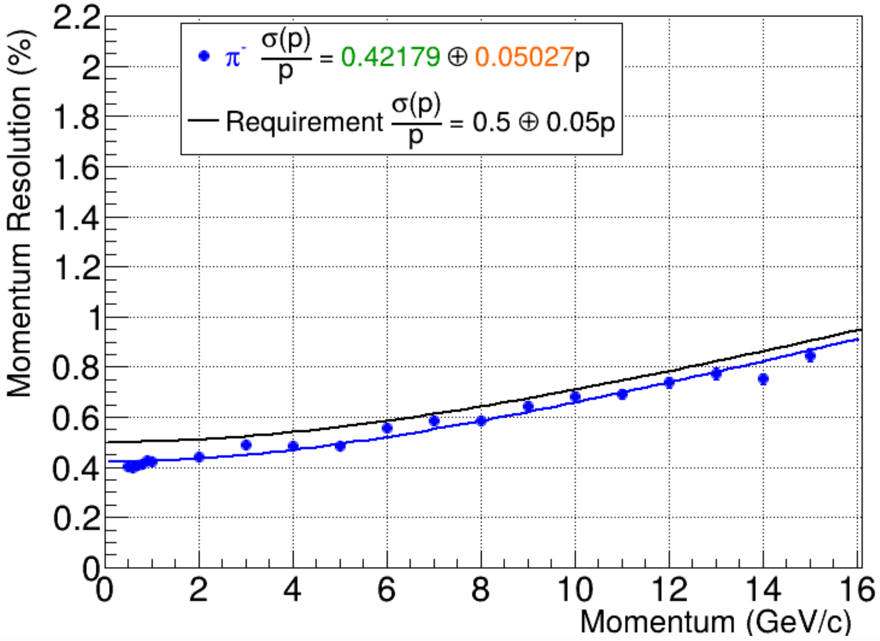
Total true momentum is set by the steering file.

Comparison of momentum resolutions

Pre-merge



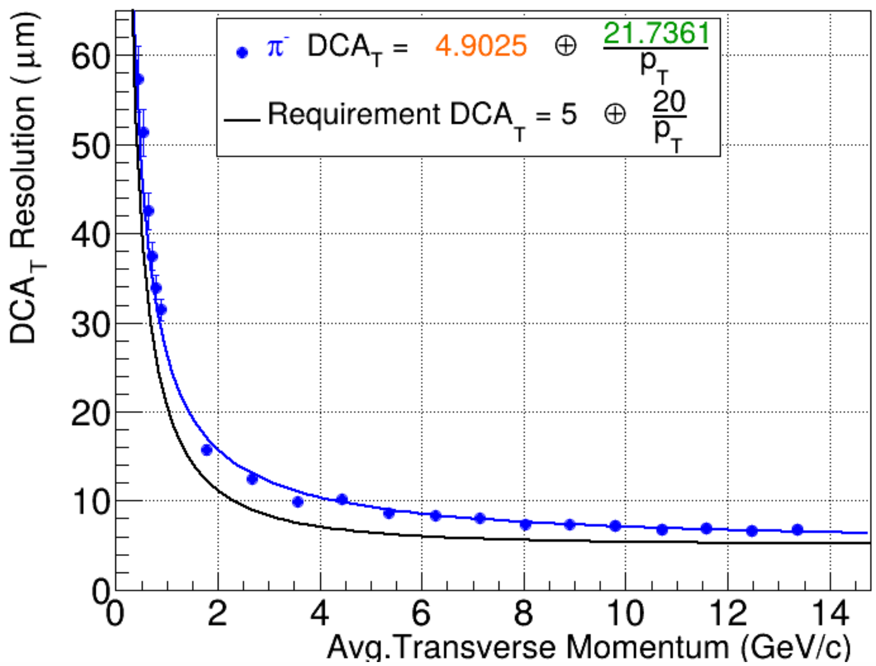
Post-merge



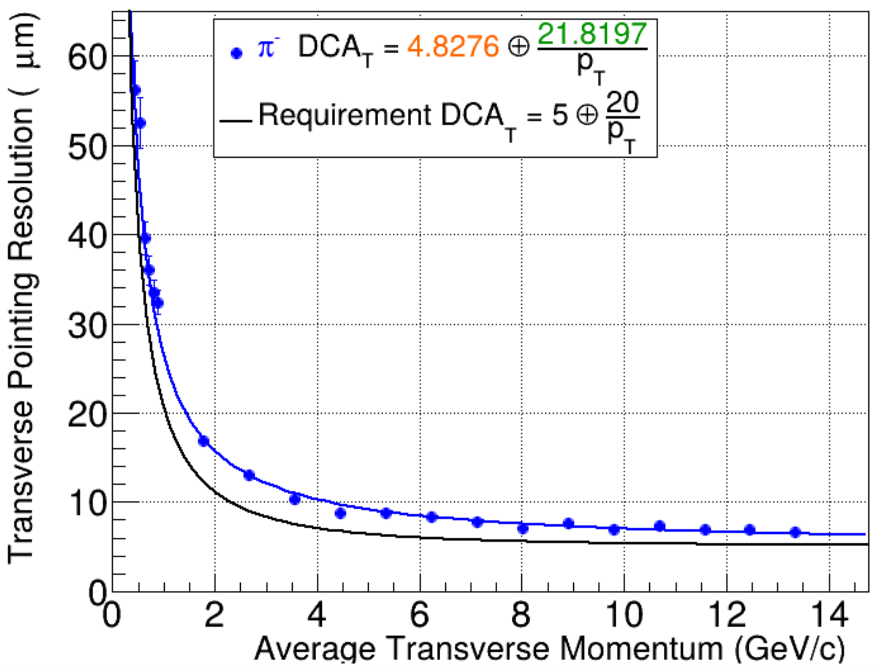
Pre merge has some momentum values above the requirement line.
Post merge has all the momentum values meet the physics set by WPG.

Comparison of momentum resolution

Pre-merge



Post-merge

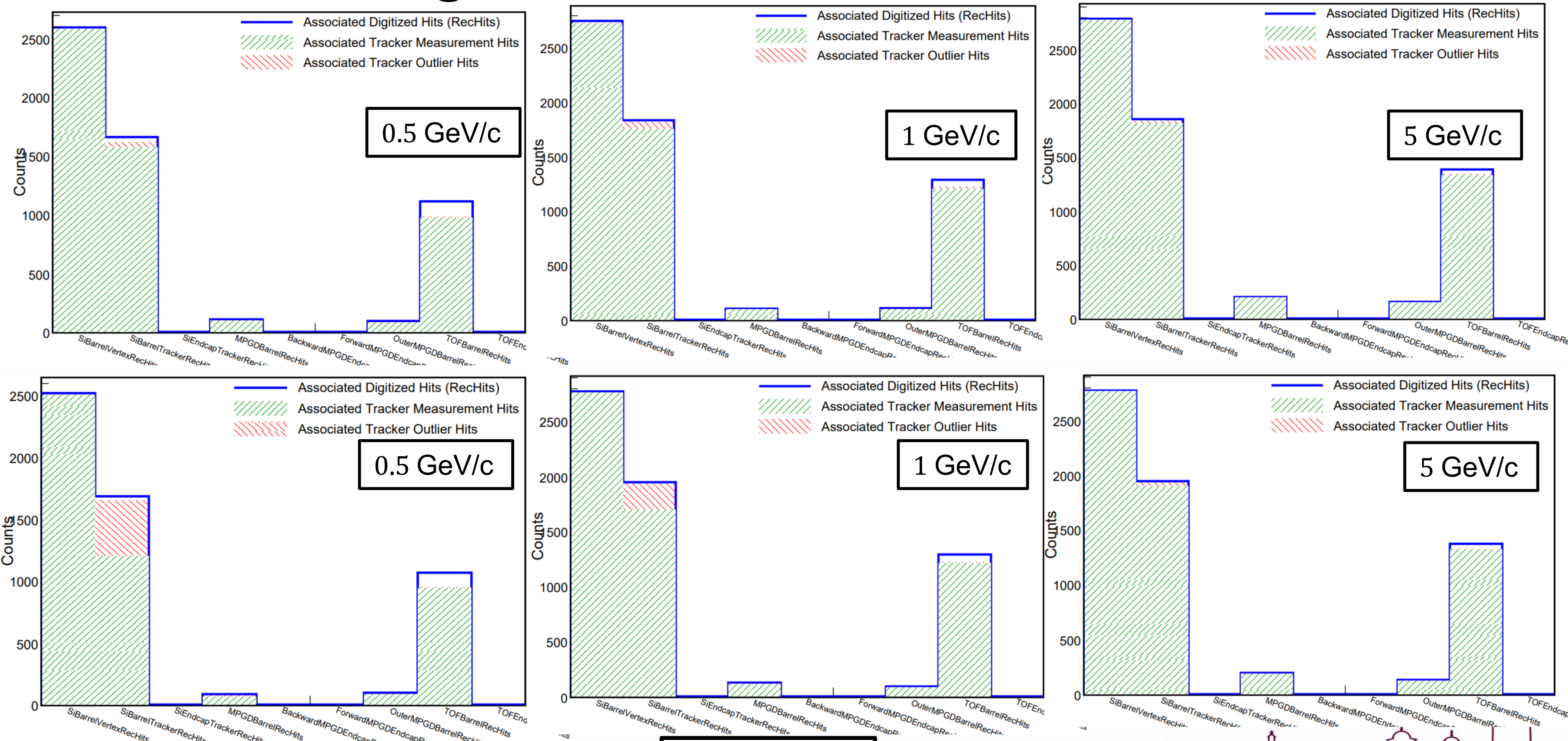


Minimal differences in the MS term and the geometric term.
Makes sense as only the OB was changed.

Hit matching

Hit matching

Post-merge



Pre-merge

End

More to do:

- ~~Efficiency comparison~~
- Bash file for material map
- Update material map in main to match current OB

Any further questions/feedback or benchmarking requests?

Example scripts

ddsim
--steeringFile steering.py
--compactFile $DETECTOR_PATH/epic_craterlake_tracking_only.xml
--numberOfEvents 1000
--outputFile ${filename.root}
--gun.momentumMin "${MOMENTUM}*GeV"
--gun.momentumMax "${MOMENTUM}*GeV"

eicrecon
-Pacts:MaterialMap=./scripts/material_map/material-map.cbor
-Ppodio:output_file="${EICRECON_FILE}" "${DDSIM_FILE}“

geoviewer
dd_web_display
-o *output.root*
--export $DETECTOR_PATH/epic_craterlake_sb.xml

Materialscan
python3 bin/g4MaterialScan_to_csv
--compact $DETECTOR_PATH/epic_craterlake_sb.xml
--eta="-1.0:1.0:0.2"
--phi="0:360:20"
--output *output.csv*

Hit matching code:
https://github.com/eic/snippets/blob/main/Tracking/TrackHitContributions/hit_matching.C