Status of Vertex Prototype Mechanics and Layout Optimization

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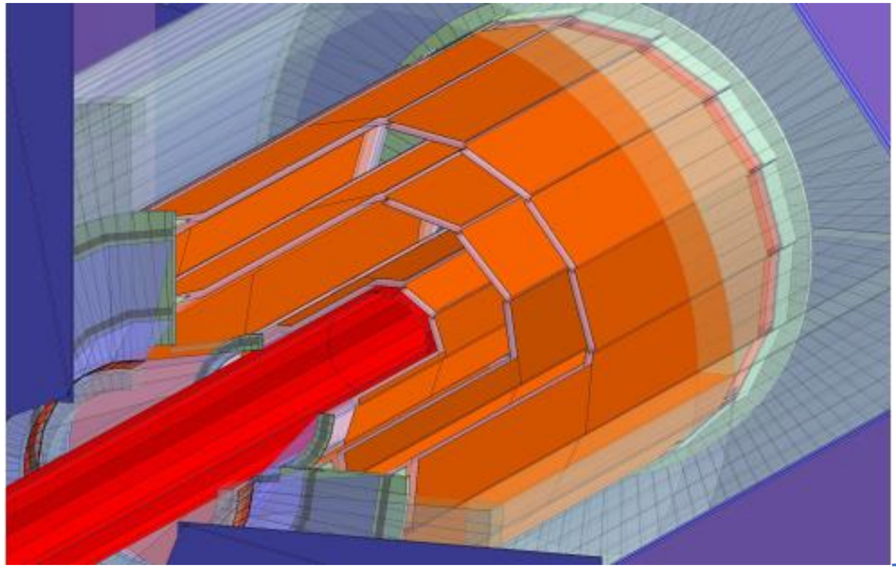
2019/12/18

Motivation

CDR vertex detector concept



	R (mm)	$\|z\|$ (mm)	$\|\cos\theta\|$	σ(μm)
Layer 1	16	62.5	0.97	2.8
Layer 2	18	62.5	0.96	6
Layer 3	37	125.0	0.96	4
Layer 4	39	125.0	0.95	4
Layer 5	58	125.0	0.91	4
Layer 6	60	125.0	0.90	4

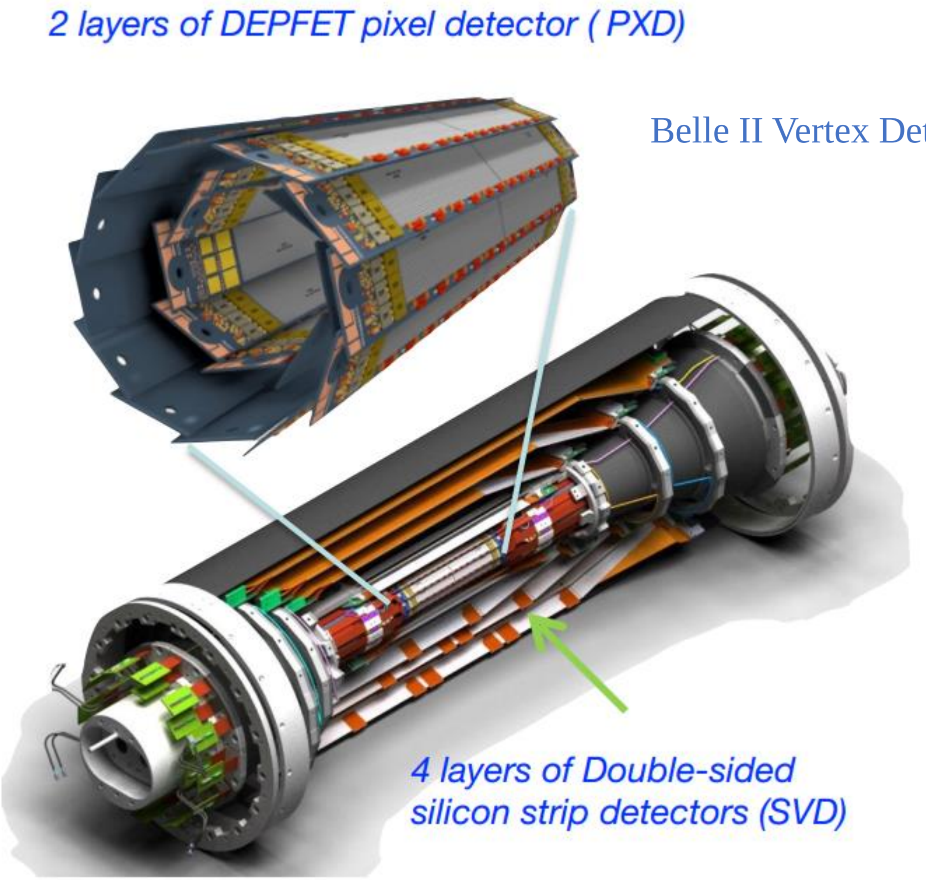
+ mechanics

+ electronics

+ cooling system

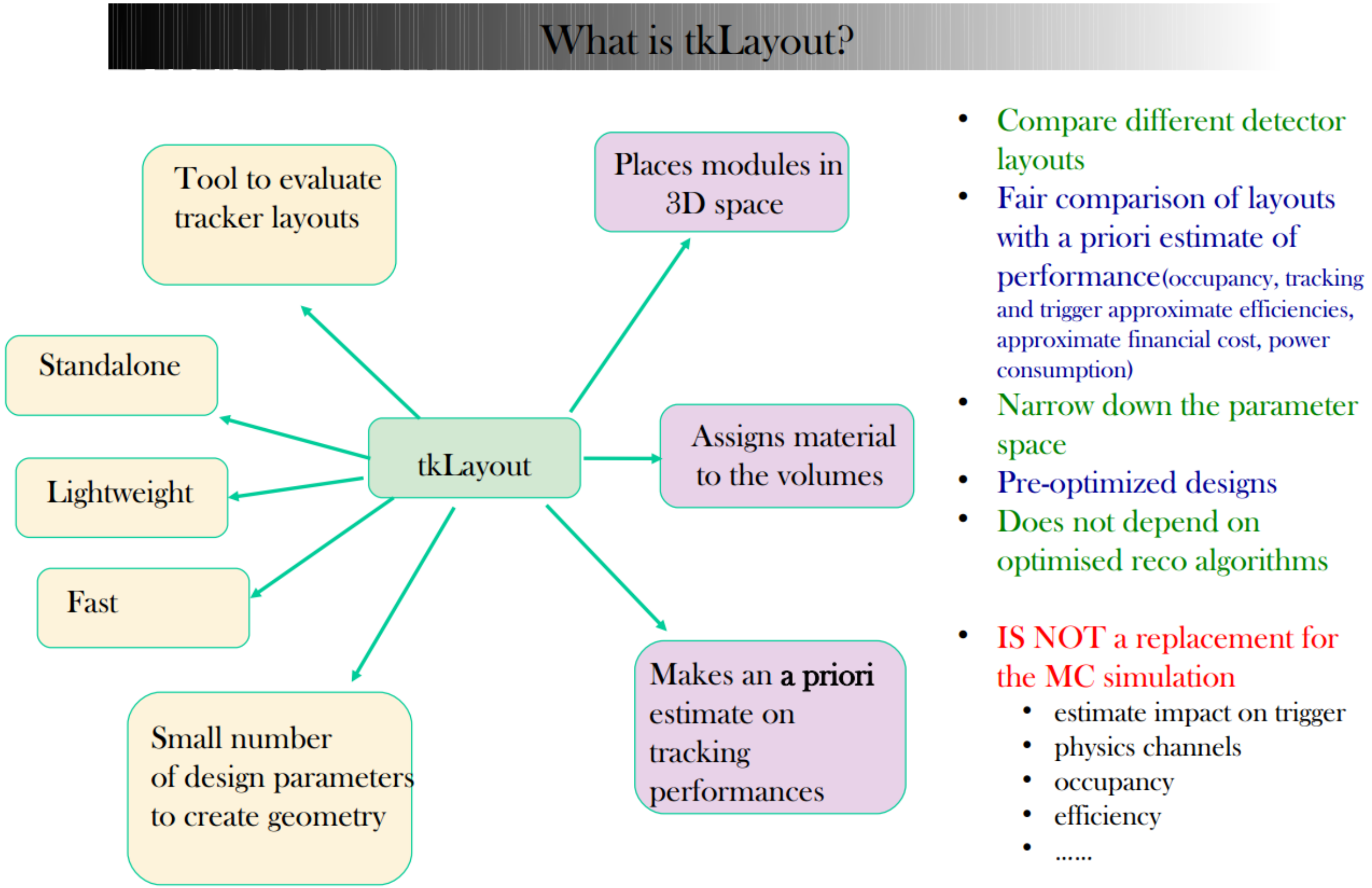
+ cable

Vertex detector prototype



Belle II Vertex Detector

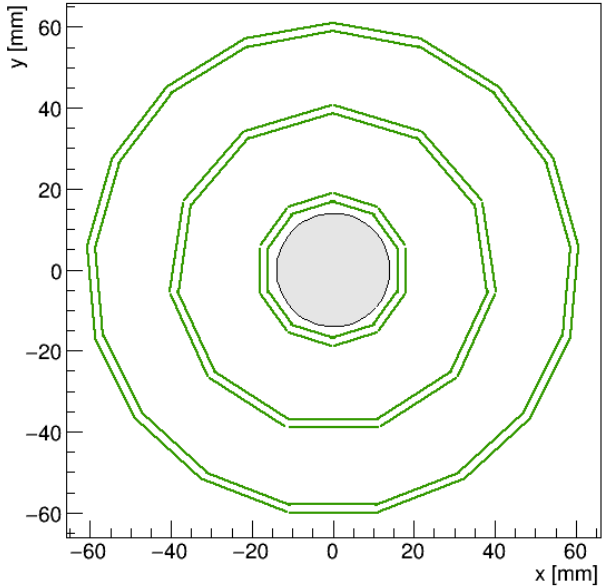
Fast simulation tool - tkLayout



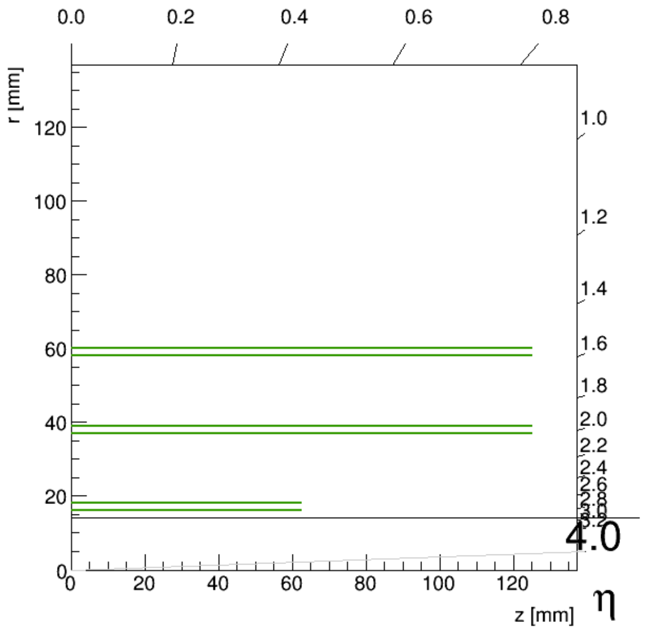
- Comparing radically different layout options
- Optimizing given layouts
- Generating a realistic material description
- Preparing detector description for full simulation
- Key tool for the design of two large detectors(different level of development stage):
  - – CMS Tracker for HL-LHC
  - – Tracker for FCC-hh proposal
- Useful tool for CEPC vertex prototype layout optimization

Vertex geometry simulation results

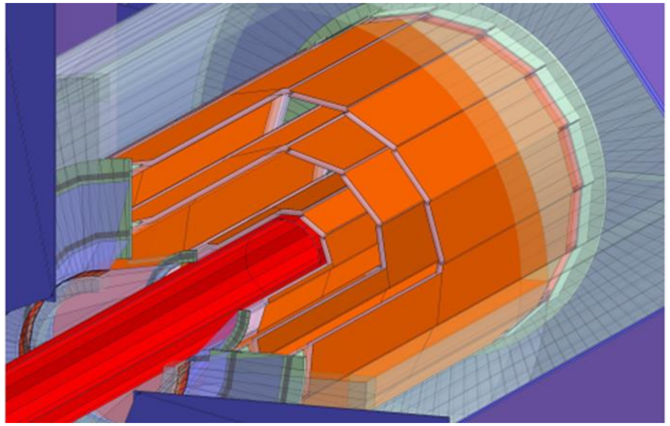
- CDR vertex detector geometry



XY Section of the tracker barrel. - (png) - (pdf) - (root)



RZ positions of the barrel modules. - (png) - (pdf) - (root)

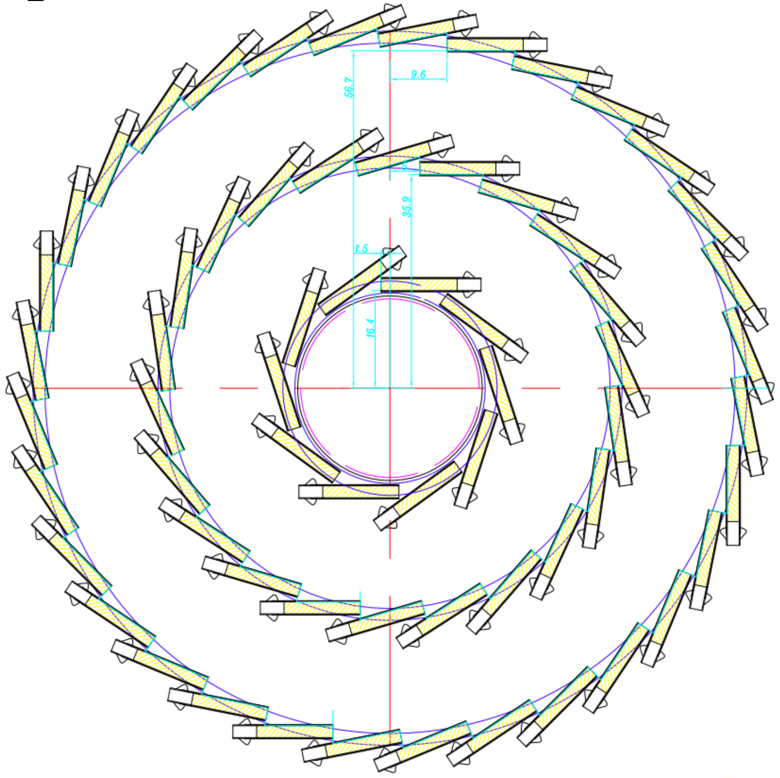


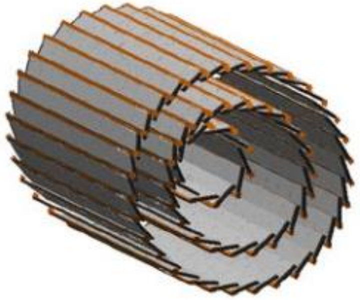
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	16.004	18.004	37.003	38.995	57.989	59.995	
z_max	62.500	62.500	125.000	125.000	125.000	125.000	
# rods	10	10	11	11	17	17	
# mods	40	40	88	88	136	136	528

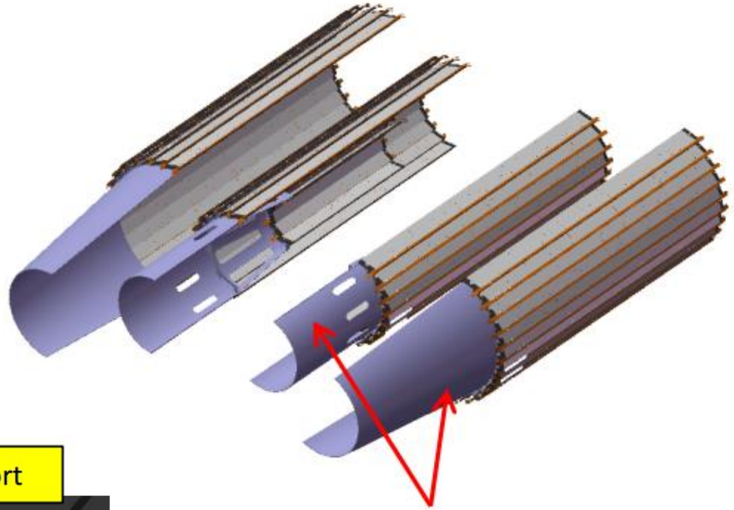
	R (mm)	$\|z\|$ (mm)	$\|\cos\theta\|$	σ(μm)
Layer 1	16	62.5	0.97	2.8
Layer 2	18	62.5	0.96	6
Layer 3	37	125.0	0.96	4
Layer 4	39	125.0	0.95	4
Layer 5	58	125.0	0.91	4
Layer 6	60	125.0	0.90	4

Vertex geometry simulation results

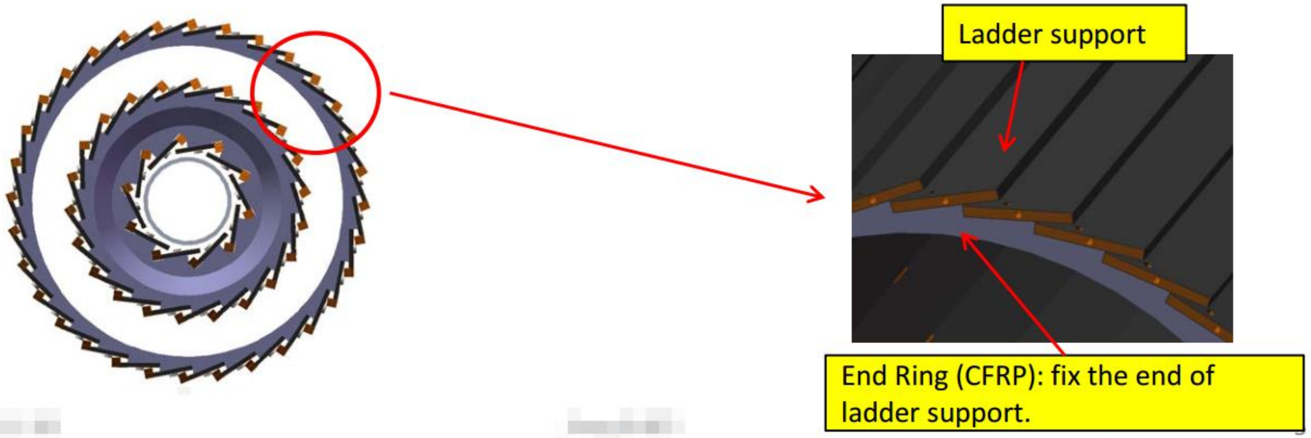
- Prototype V1 design:
  - Designed by Fu Jinyu
  - three layers with double-sided ladder
  - Only need to rotate one ladder around Z axis at a fixed angle to cover the whole barrel
  - Sensors are on both sides of the yellow slash region





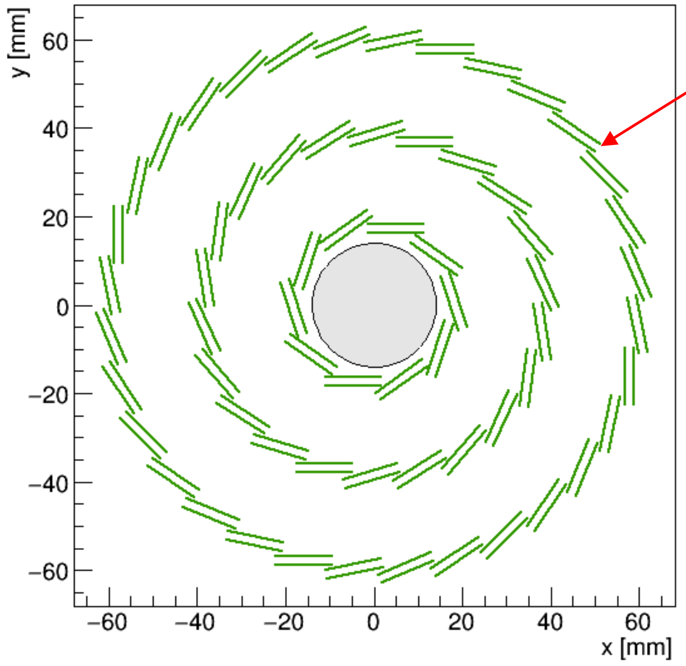


Half support barrel



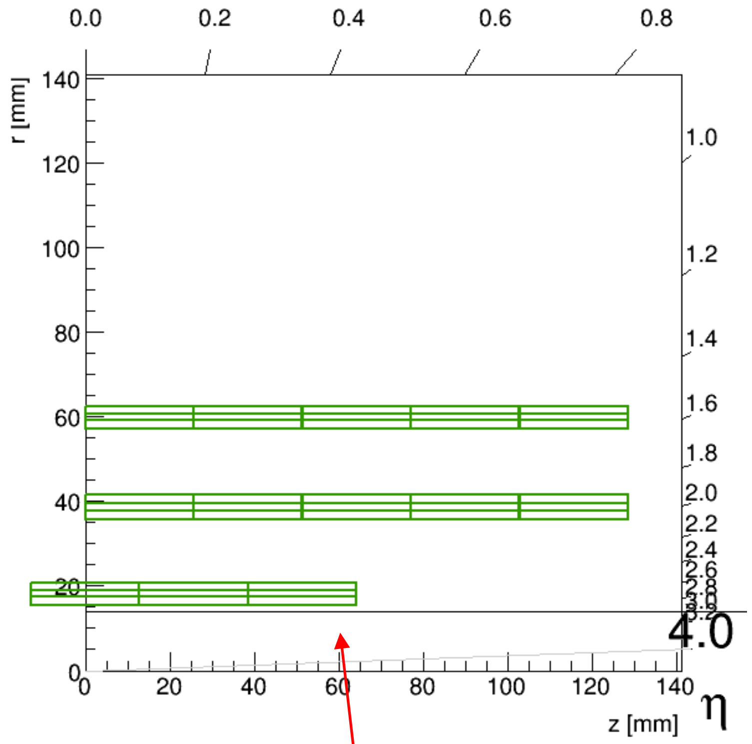
Vertex geometry simulation results

- Prototype V1 geometry



XY Section of the tracker barrel. - (png) - (pdf) - (root)

Contact with tkLayout authors to modify source code
Add skewed layer mode
Now it can build our geometry



RZ positions of the barrel modules. - (png) - (pdf) - (root)

	numRods	R(mm)	skewAngle(rad)	module width(mm)
Layer 1	10	17.11637	0.290338	12.8
Layer 2	10	19.04127	0.260264	12.8
Layer 3	22	37.66656	0.307478	12.8
Layer 4	22	39.57739	0.292183	12.8
Layer 5	32	58.91426	0.275036	12.8
Layer 6	32	60.84152	0.266108	12.8

Calculated value

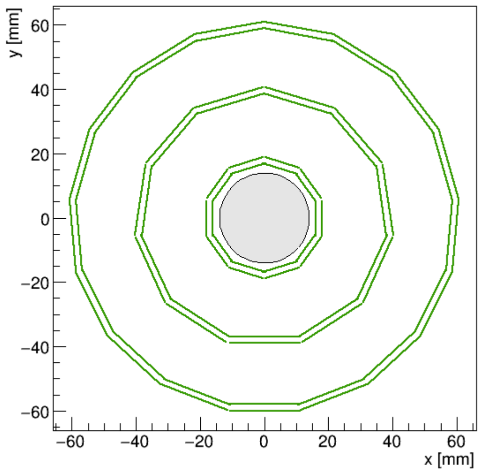
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	17.116	19.041	37.667	39.577	58.914	60.842	
z_max	64.200	64.200	128.450	128.450	128.450	128.450	
# rods	10	10	22	22	32	32	
# mods	50	50	220	220	320	320	1180

Output value of tkLayout

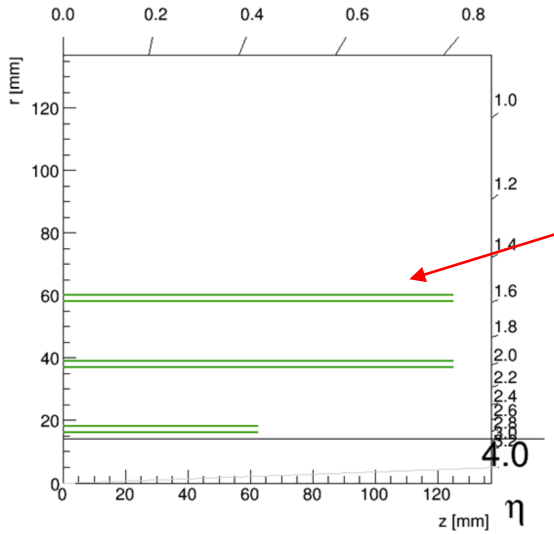
Vertex geometry simulation results

- Comparison

CDR



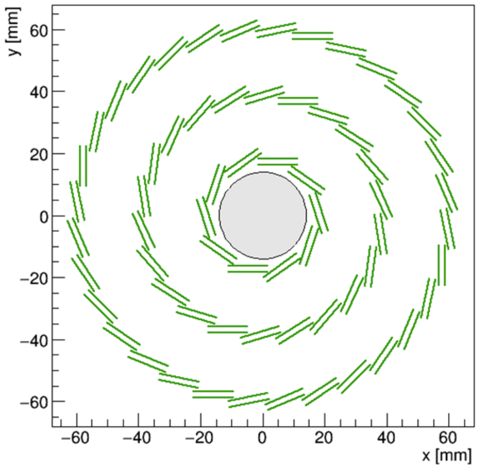
XY Section of the tracker barrel. - (png) - (pdf) - (root)



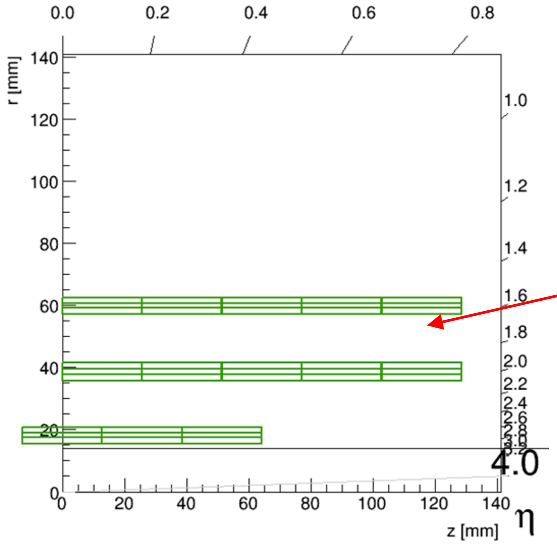
RZ positions of the barrel modules. - (png) - (pdf) - (root)

Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	16.004	18.004	37.003	38.995	57.989	59.995	
z_max	62.500	62.500	125.000	125.000	125.000	125.000	
# rods	10	10	11	11	17	17	
# mods	40	40	88	88	136	136	528

Prototype V1



XY Section of the tracker barrel. - (png) - (pdf) - (root)



RZ positions of the barrel modules. - (png) - (pdf) - (root)

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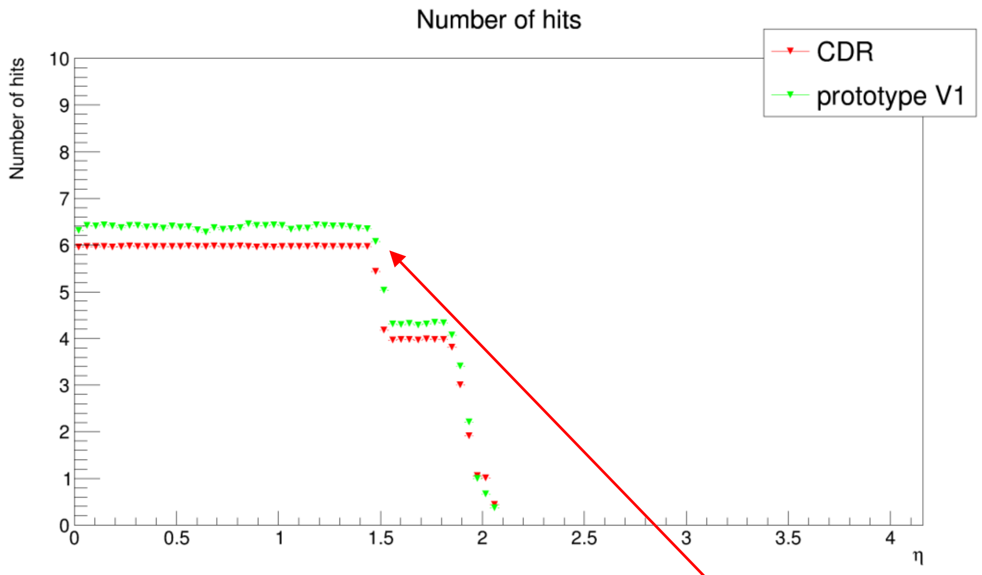
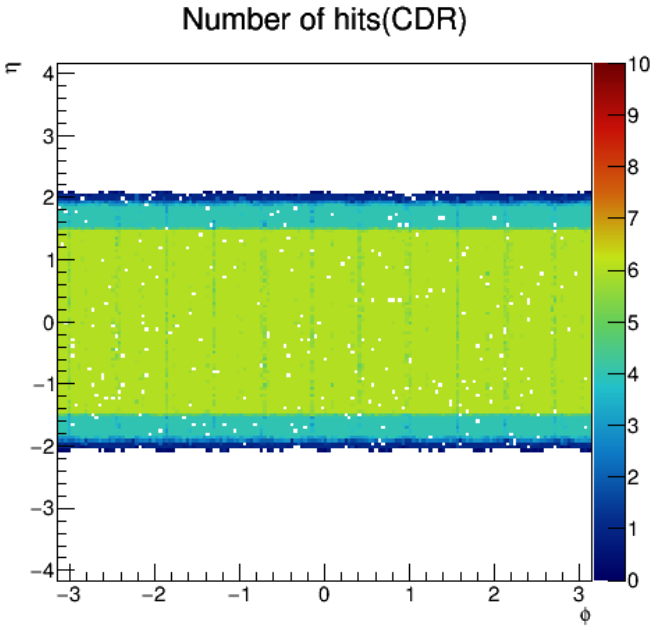
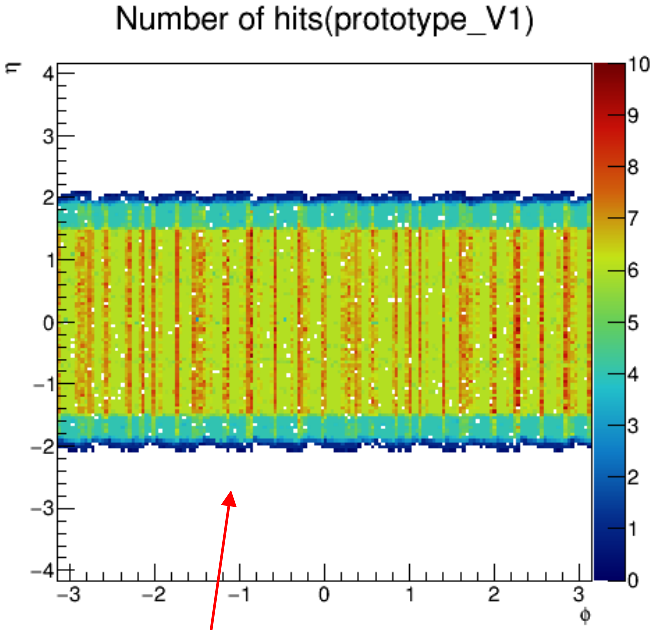
Layer	1	2	3	4	5	6	
r	17.116	19.041	37.667	39.577	58.914	60.842	
z_max	64.200	64.200	128.450	128.450	128.450	128.450	
# rods	10	10	22	22	32	32	
# mods	50	50	220	220	320	320	1180

Vertex geometry simulation results

- Hit coverage





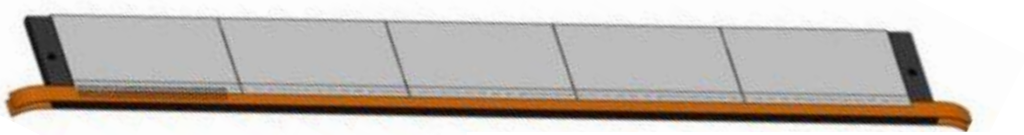


	R (mm)	$\lvert z \rvert$ (mm)	$\lvert\cos\theta\rvert$	σ(μm)	η
Layer 1	16	62.5	0.97	2.8	2.09
Layer 2	18	62.5	0.96	6	1.95
Layer 3	37	125.0	0.96	4	1.95
Layer 4	39	125.0	0.95	4	1.83
Layer 5	58	125.0	0.91	4	1.53
Layer 6	60	125.0	0.90	4	1.47

On average, more hits across η for prototype V1, that's because there are more overlaps in prototype V1.

More stripes in 2D hits distribution. At Φ direction, our prototype V1 is not so uniform.

PrototypeV1 material

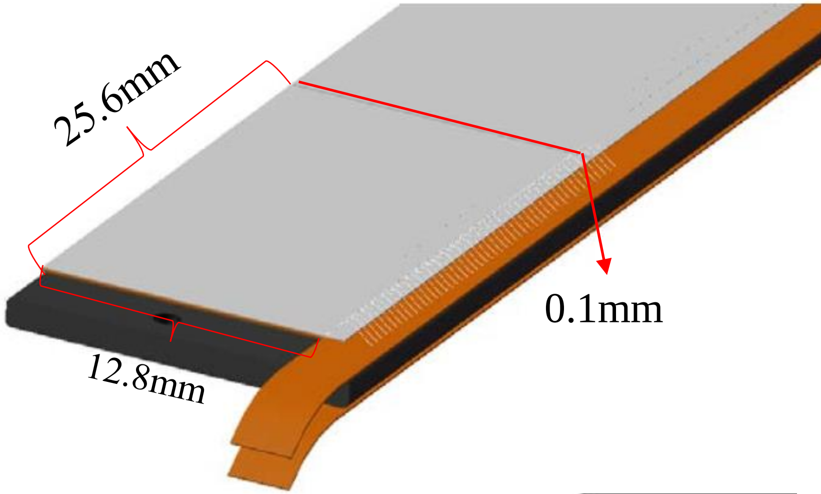


```
//                                    PIXEL MODULE
//
//  Top View
//
//     -------------------
//     |       (7)       |
//     -------------------          y
//     |  |           |  |          ^
//     |  |           |  |          |
//     |  |           |  |          |
//     |  |           |  |          |
//     |  |           |  |          |
//     |  |   Sensor  |  |          |
//     |(6)|   (2)    |(5)|         |
//     |  |           |  |          |
//     |  |           |  |          |
//     |  |           |  |          +----> x
//     -------------------
//     |       (8)       |
//     -------------------                       z
//                                               ^
//  Side View                                    |
//        ===============      Hybrid  (1)   +----> x
//    (6) --------------- (5)  Sensor  (2)
//    ======================    Chip    (3)
//
// Chip(3) volume can contain Bumps and any other material (supports, etc) for simplification.
```

deadAreaExtraLength

deadAreaExtraWidth

Top view:
Only consider the sensor area:
12.8mm × 25.6mm
Not consider the sensor dead area and electronics
Side view:
5 symmetric layer, gluing together.
From Jinyu(replace copper with aluminum)



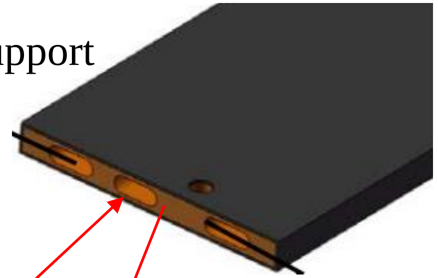
Outer pixel module:
Sensor (2)
Chip (3)

Carbon fiber with an equivalent thickness of 450 microns

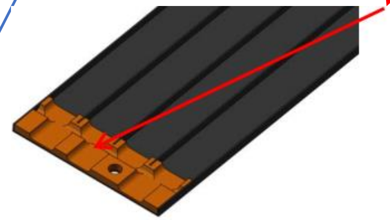
inner pixel module:
Hybrid (1)
Sensor (2)

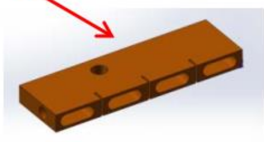
- Sensor(Si, 50um)
- glue(Epoxy, 15um)
- Al(12um)
- Adhesive(Epoxy, 15um)
- Kapton(50um)
- Adhesive(Epoxy, 15um)
- Al(12um)
- Glue(Epoxy, 15um)
- Ladder support(carbon fiber 450um)
- Glue(Epoxy,15um)
- Al(12um)
- Adhesive(Epoxy, 15um)
- Kapton(50um)
- Adhesive(Epoxy, 15um)
- Al(12um)
- Glue(Epoxy, 15um)
- Sensor(Si, 50um)

hollow support



(1) Sensor
(2) FPC
(3) Ladder support
(4) FPC
(5) sensor

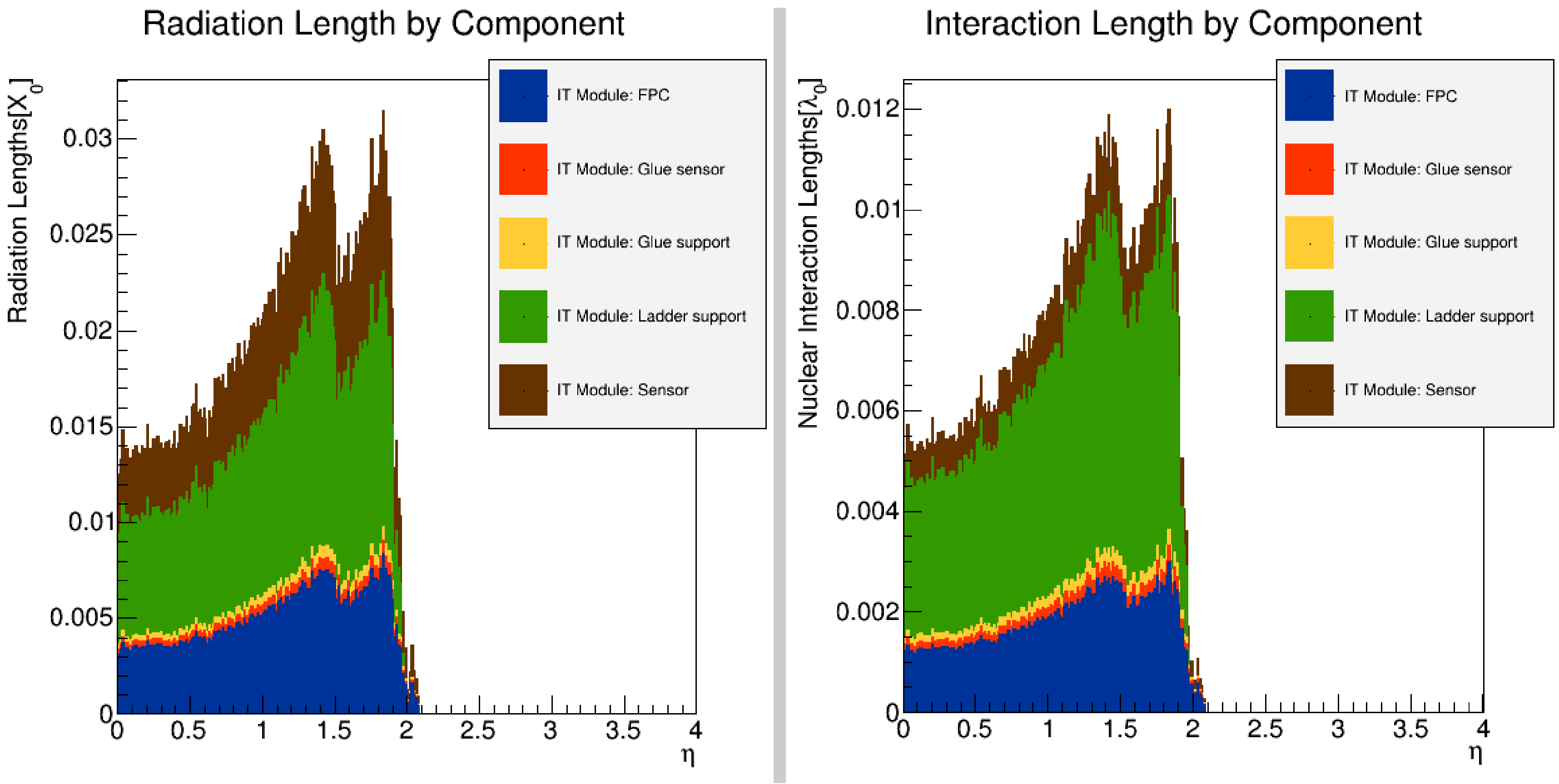




PrototypeV1 material budget

Components details:

Average (eta = [0, 4.0])	Radiation length	Interaction length
IT Module: FPC	0.00256	0.00092
IT Module: Glue sensor	0.00021	0.00010
IT Module: Glue support	0.00021	0.00010
IT Module: Ladder support	0.00444	0.00221
IT Module: Sensor	0.00256	0.00052
Services	0.00000	0.00000
Supports	0.00000	0.00000



CDR:

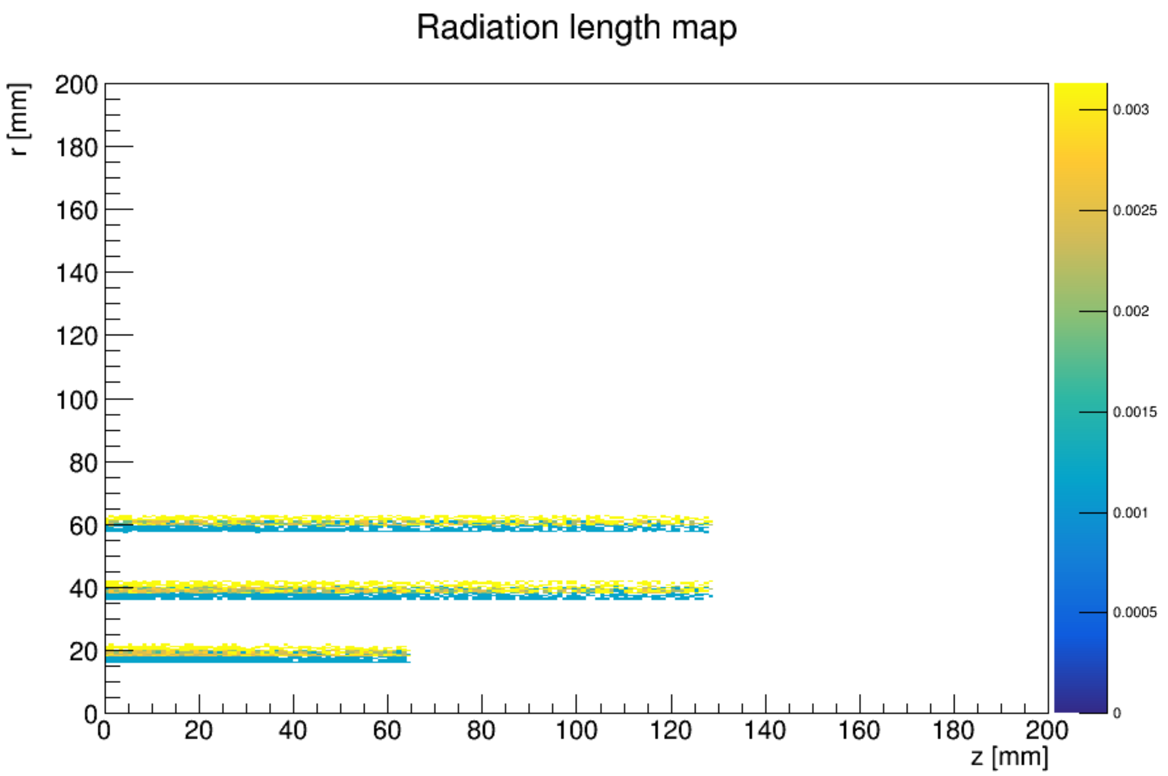
- Material budget below 0.15% X_0 per layer;

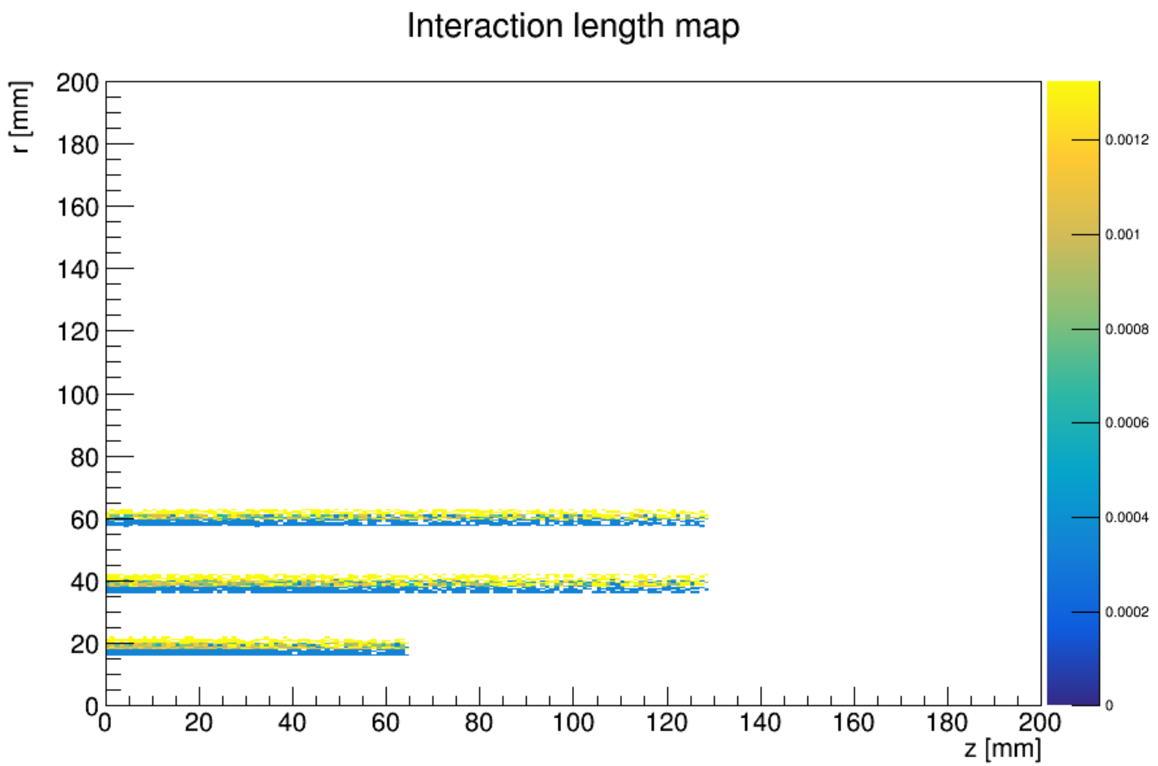
$0.15\% \times 6 = 0.9\% < 0.01$

We still have too much material!

PrototypeV1 material budget

Material distribution:





PrototypeV1 material budget

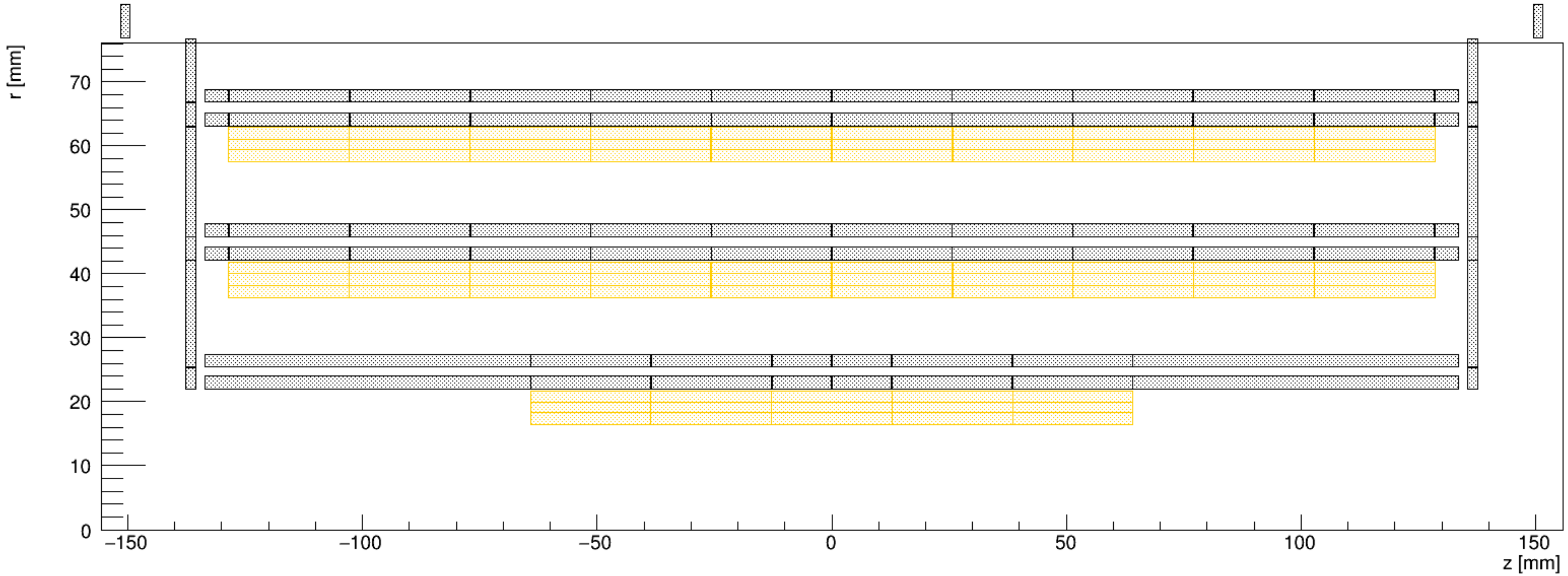
Weight(pixel):

pxb1

MODULE	mass (kg)
IT Module: FPC	0.1
IT Module: Glue sensor	0.0
IT Module: Glue support	0.0
IT Module: Ladder support	0.2
IT Module: Sensor	0.0
TOTAL MODULE	0.3
TOTAL PXB1	0.3

grand total (kg): 0.284519

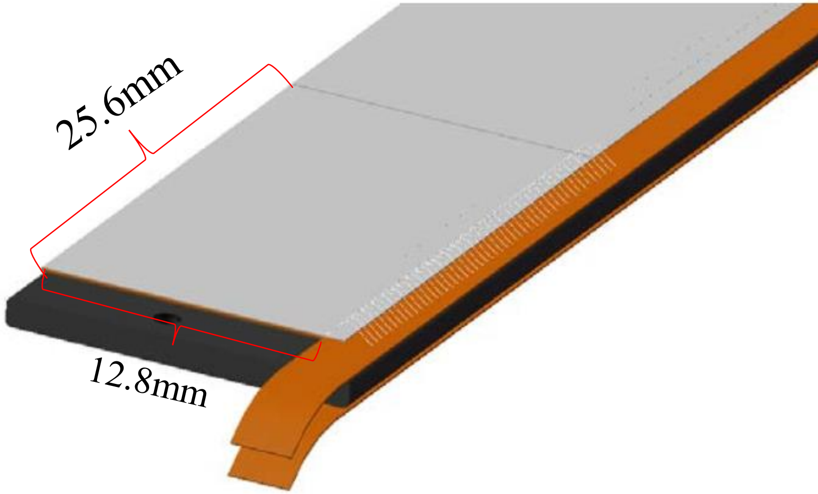
All material volumes, (RZ) view

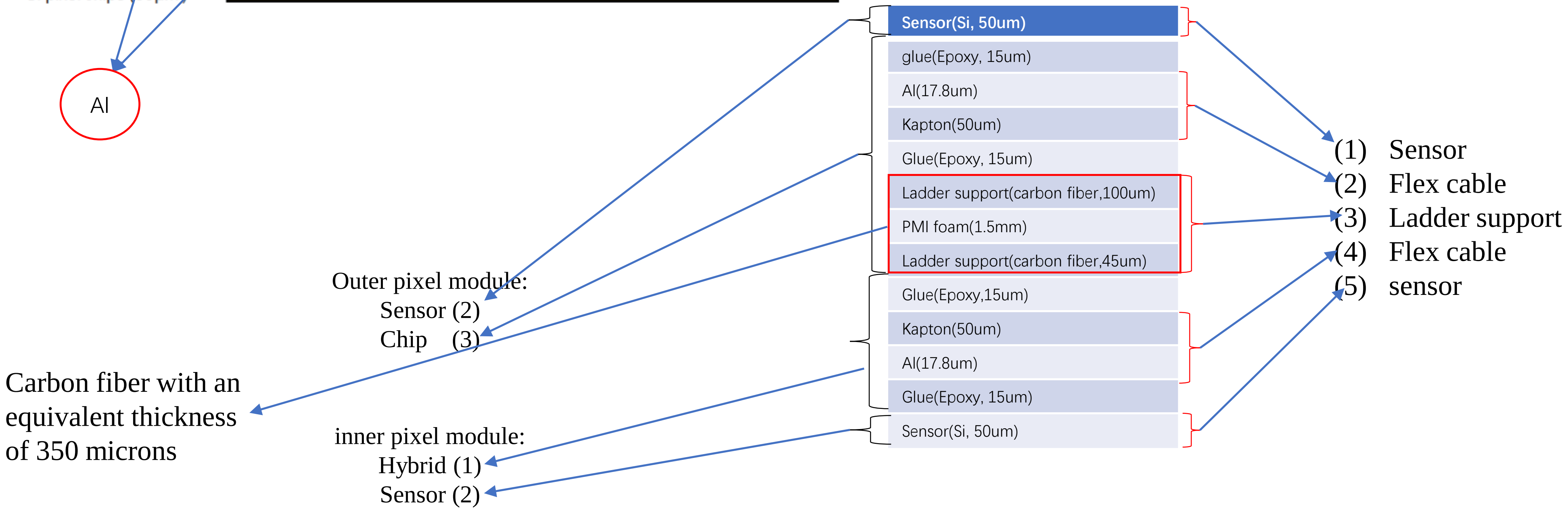


PrototypeV1 material

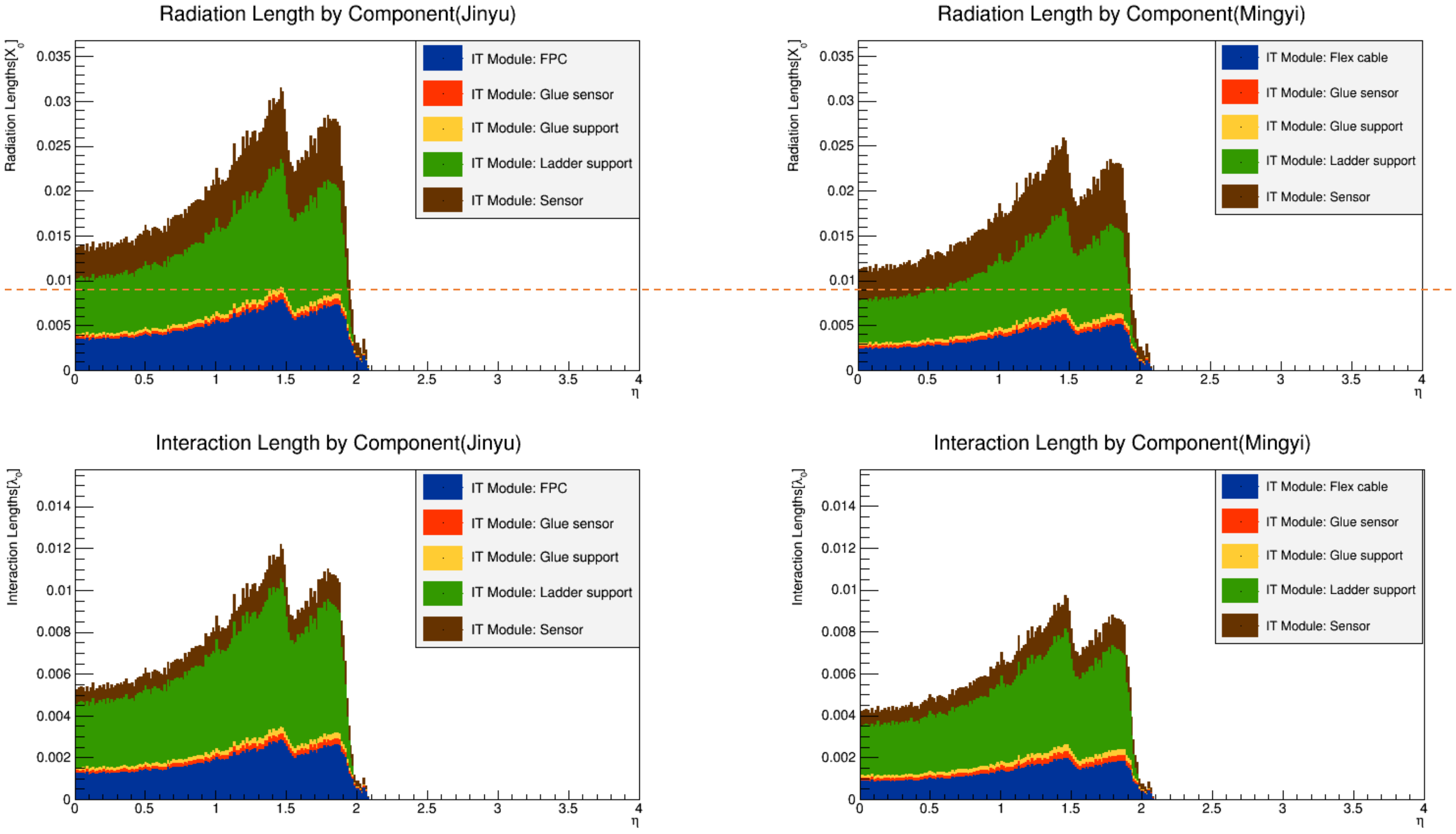
Another ladder design from Mingyi:

Top view:
Only consider the sensor area:
12.8mm × 25.6mm
Not consider the sensor dead area and electronics
Side view:
5 symmetric layer, gluing together.
From Mingyi(replace copper with aluminum)





Ladder material comparison



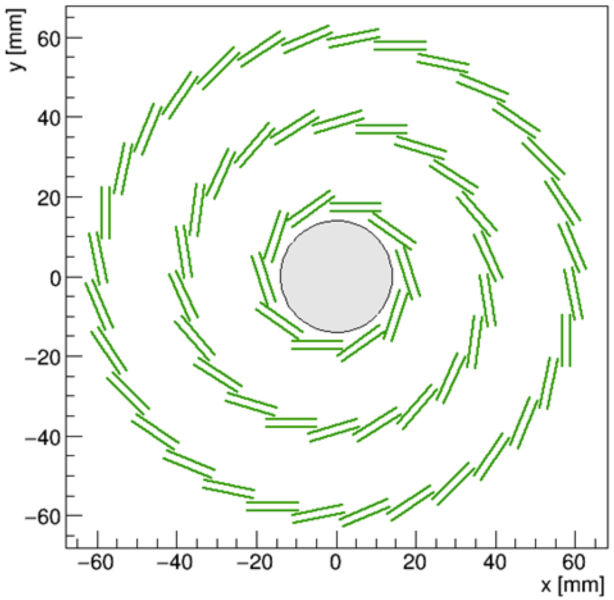
CDR:

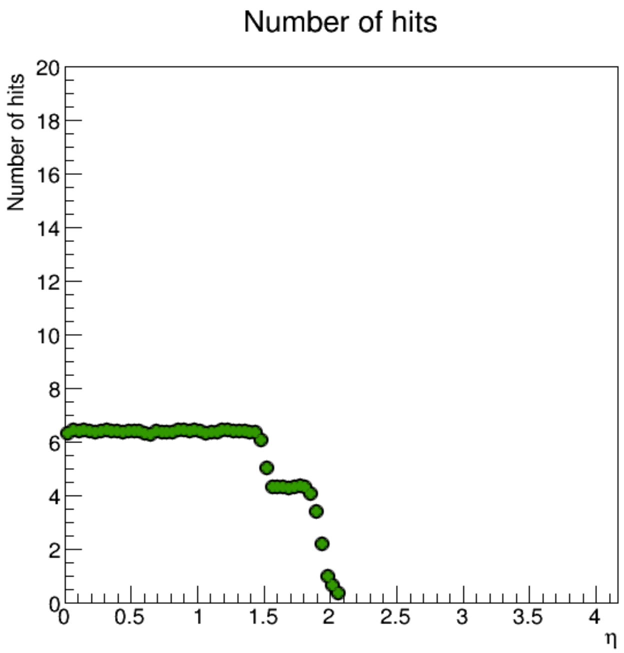
- Material budget below 0.15% X_0 per layer;

$0.15\% \times 6 = 0.9\%$

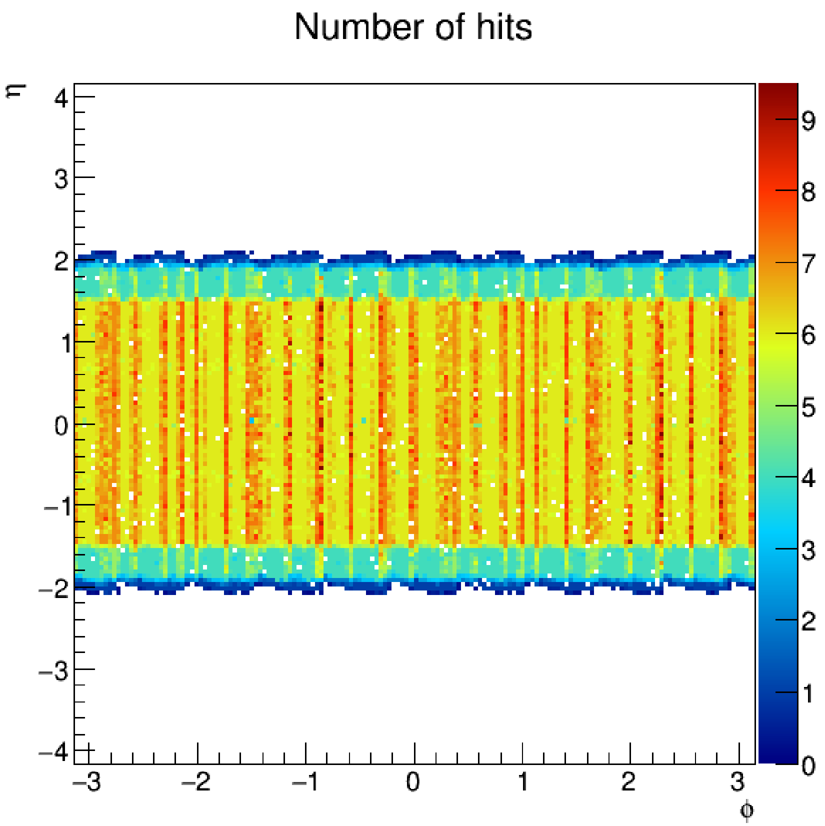
For Mingyi's new ladder design,
We still have too much material
even in the perpendicular direction!

Prototype V1

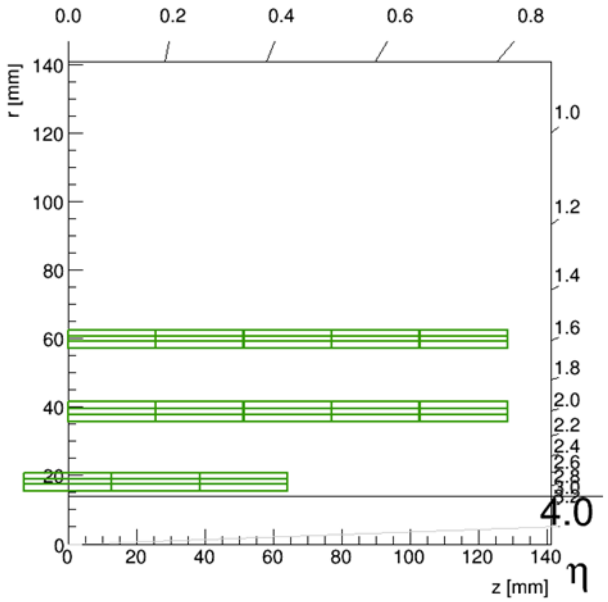




Hit coverage across eta. - (png) - (pdf) - (root)



Hit coverage in eta, phi - (png) - (pdf) - (root)



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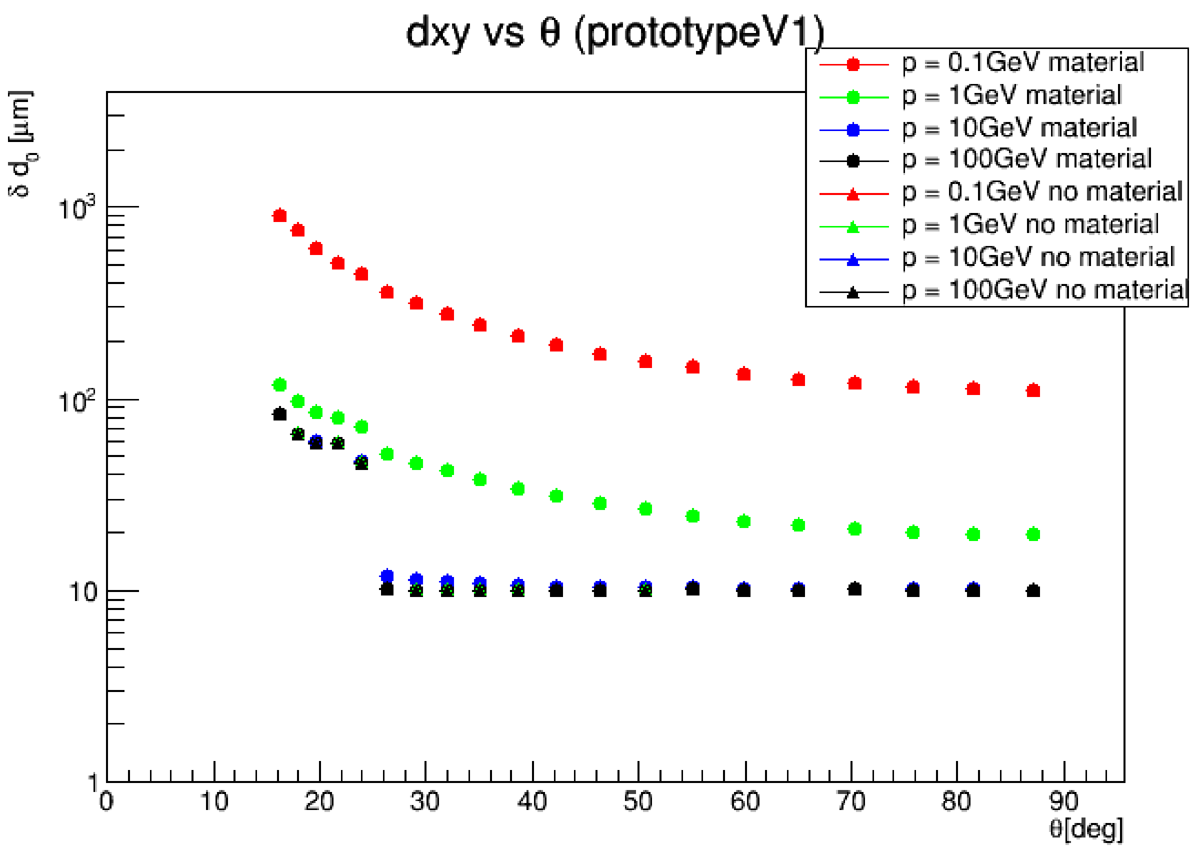
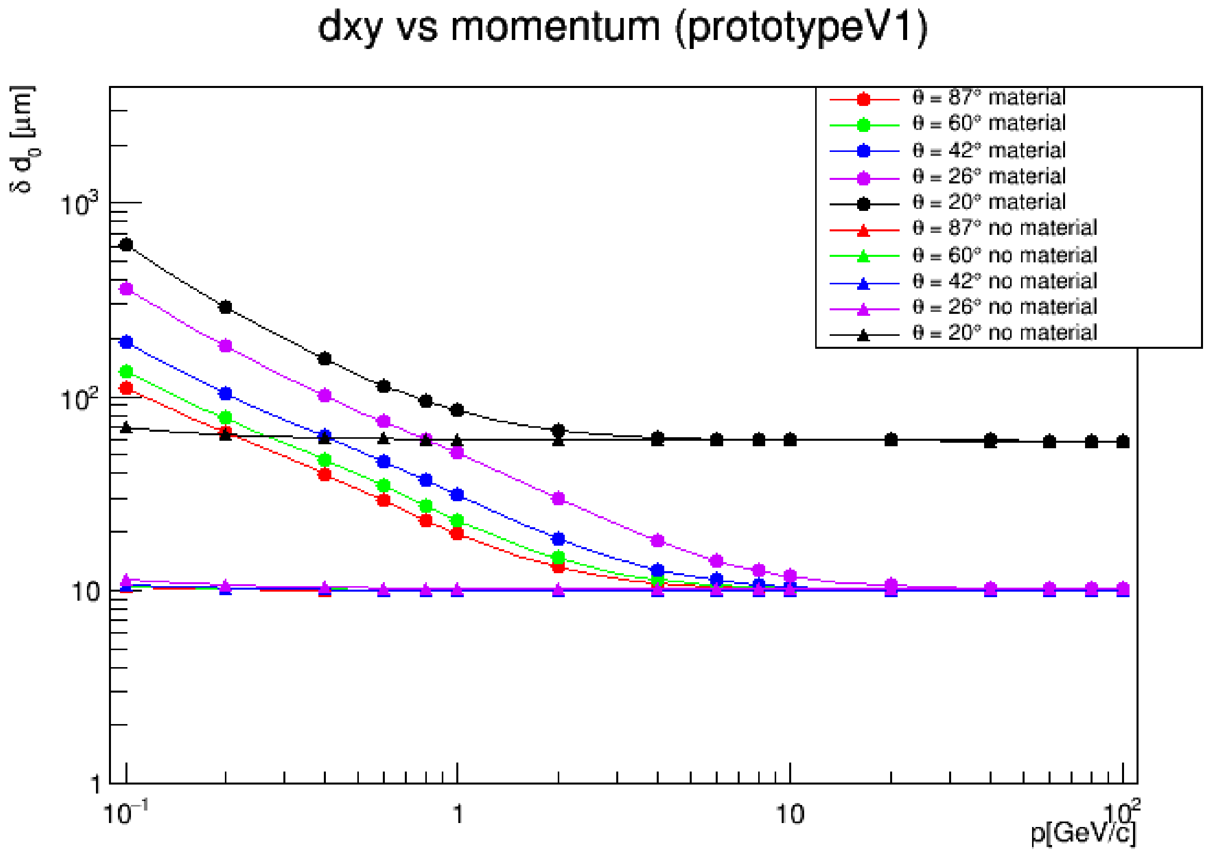
z_max	64.200	64.200	128.450	128.450	128.450	128.450	
# rods	10	10	22	22	32	32	
# mods	50	50	220	220	320	320	1180

Prototype V1

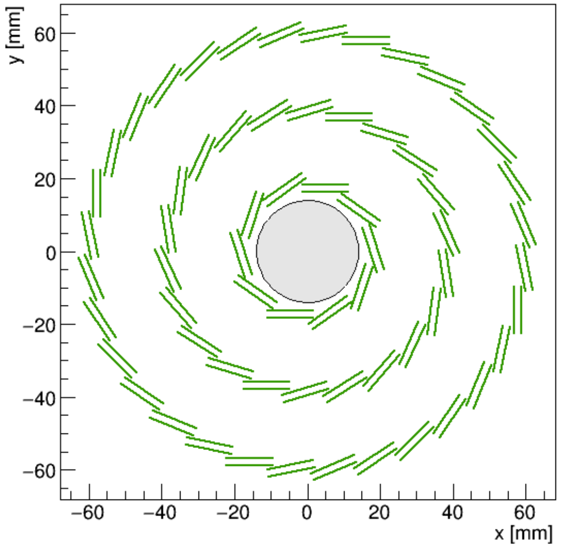
Impact parameter resolution plots:

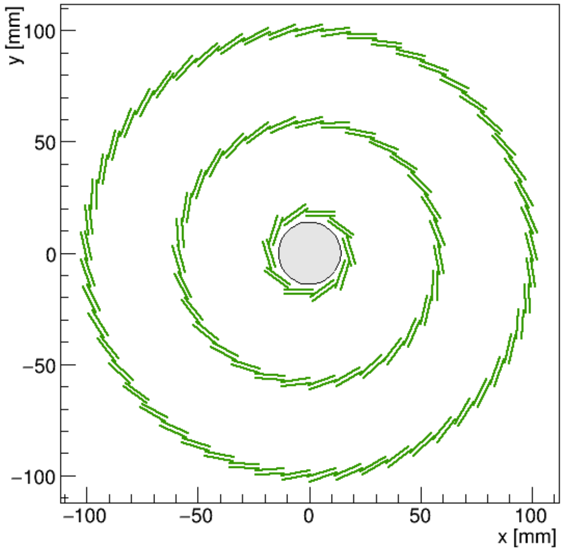


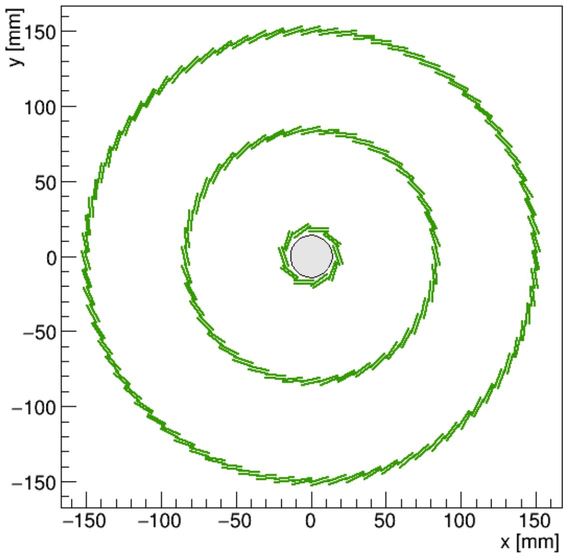


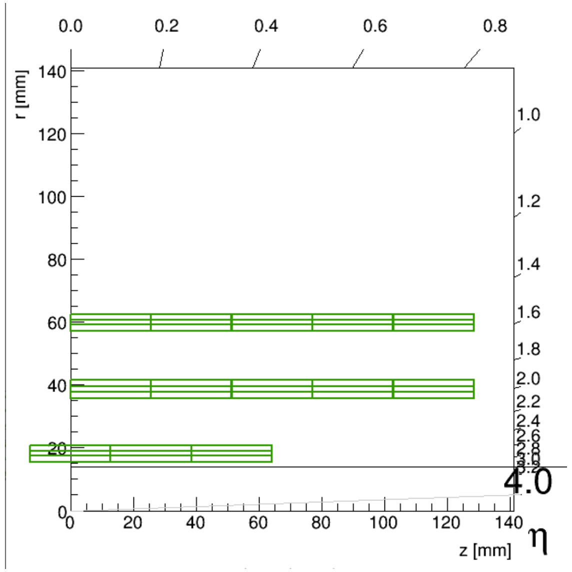
Layouts comparison

- Detector size

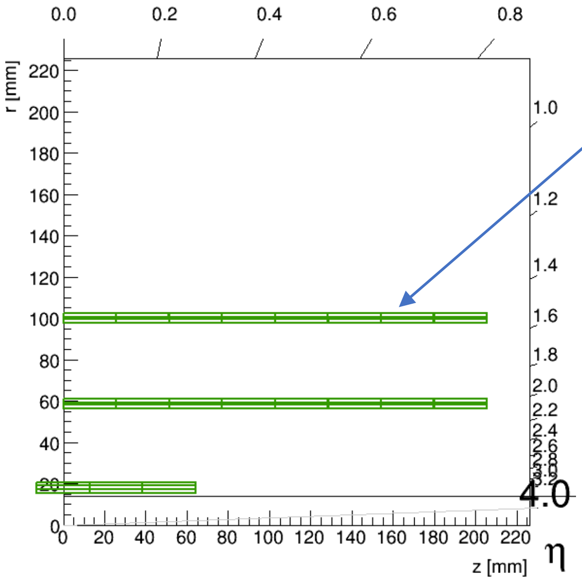






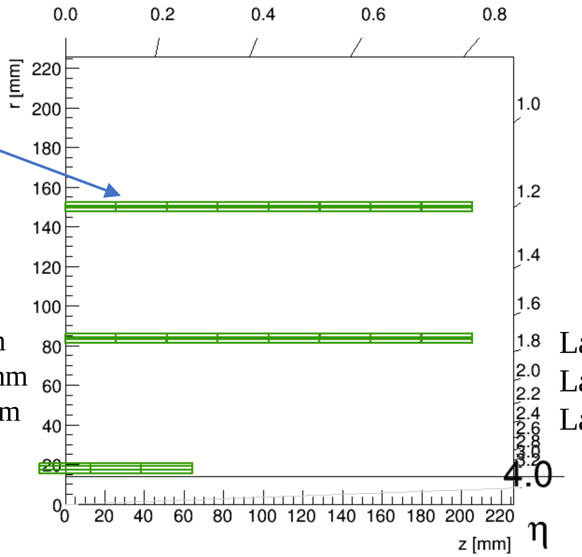


Layer 1: 18mm
Layer 2: 38mm
Layer 3: 60mm



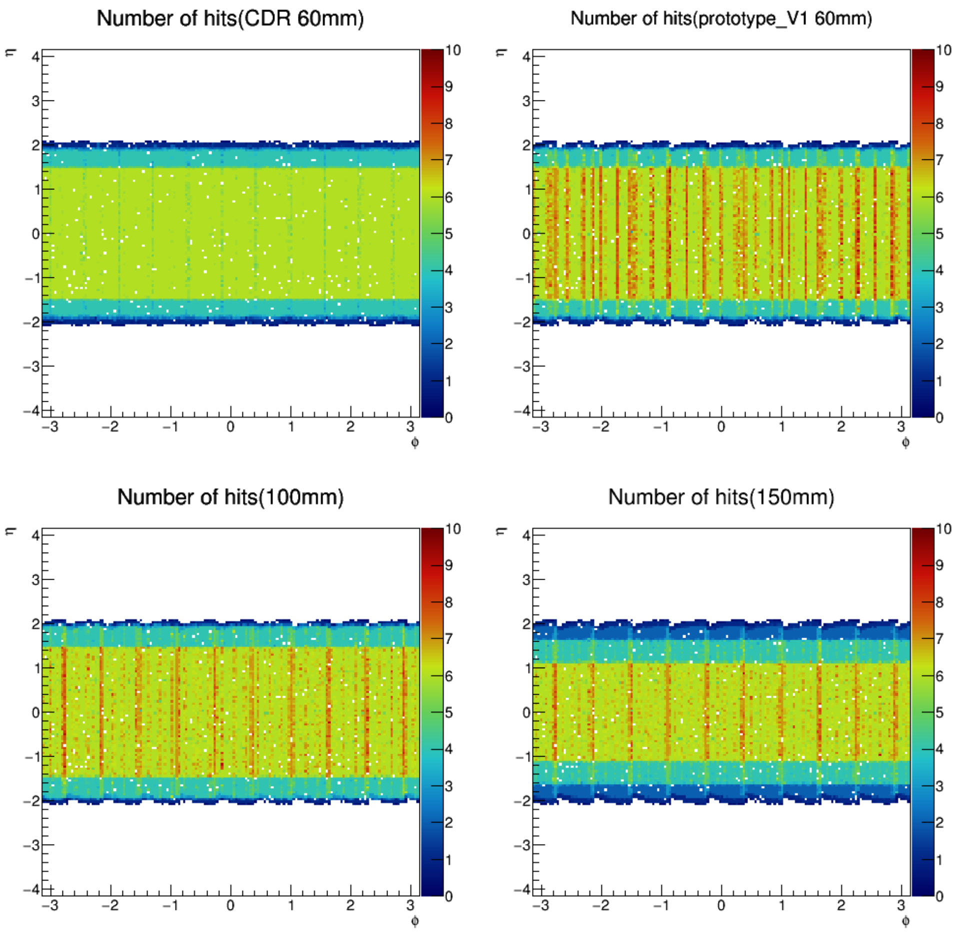
Z lengths are the same

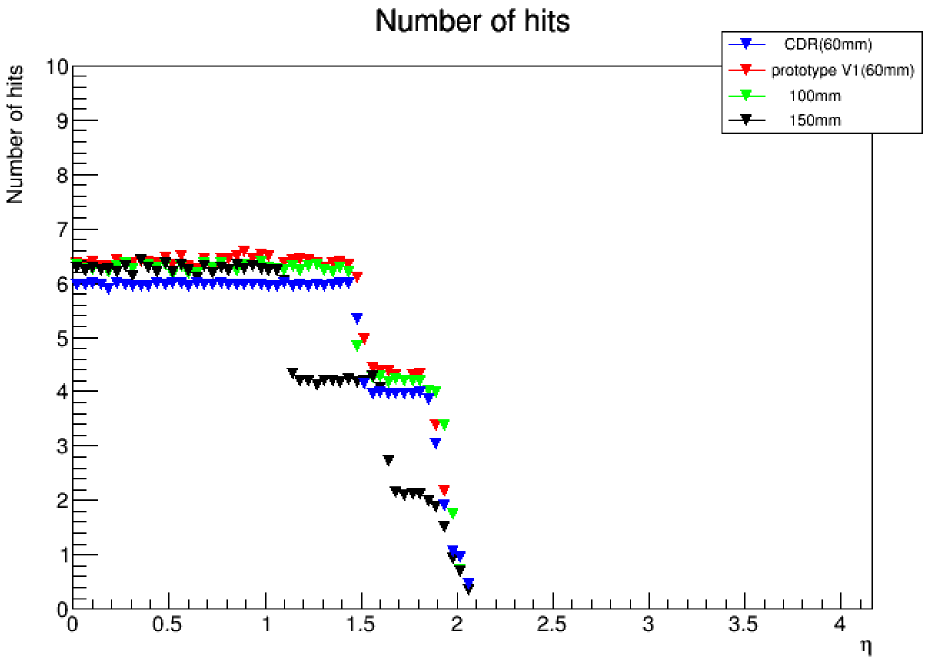
Layer 1: 18mm
Layer 2: 58.5mm
Layer 3: 100mm

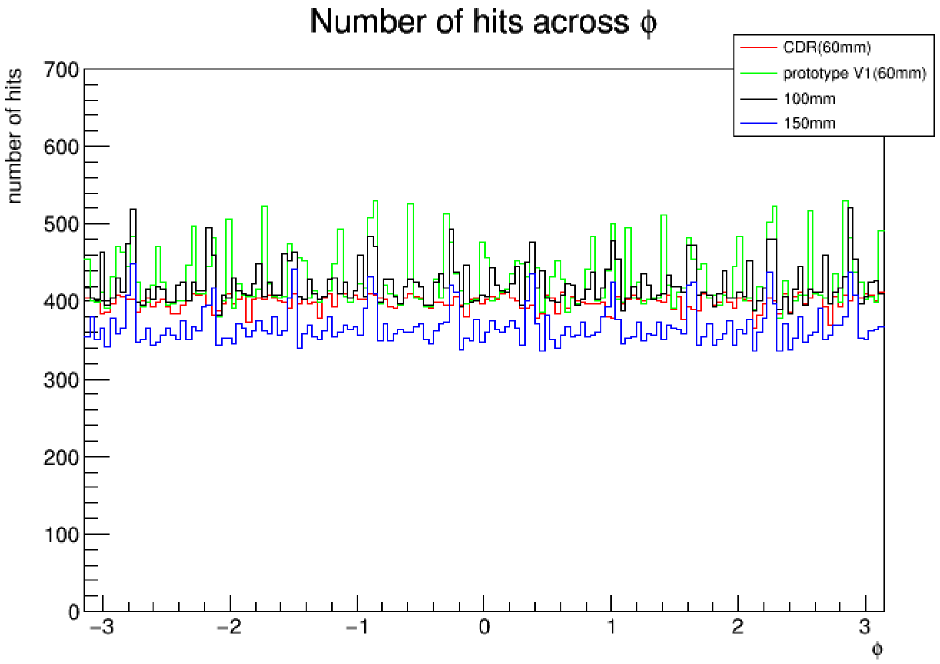


Layer 1: 18mm
Layer 2: 83.5mm
Layer 3: 150mm

Hit coverage comparison



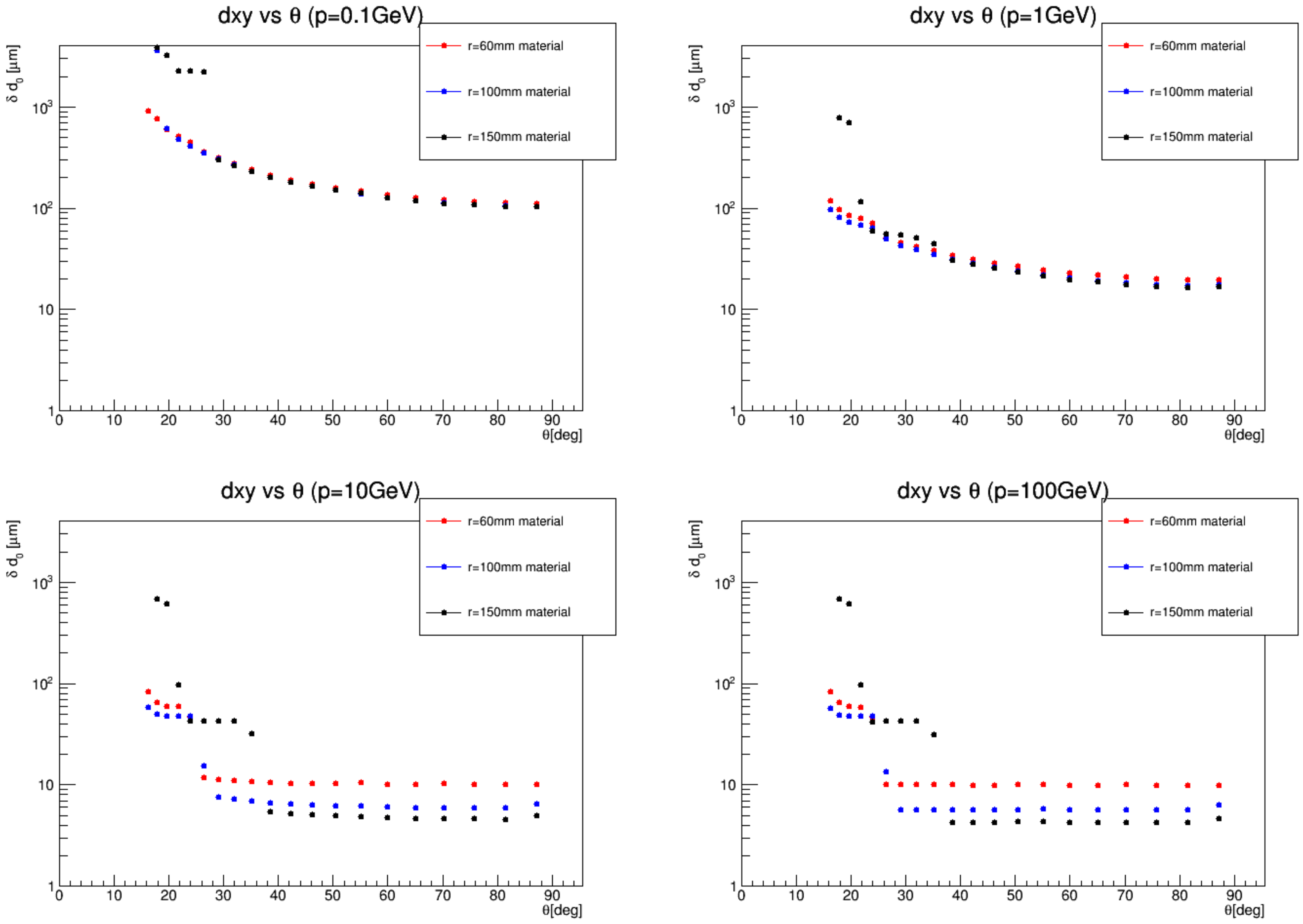




increase radius, number of stripes approaches 10.
Equal to the number of ladders of the first layer.

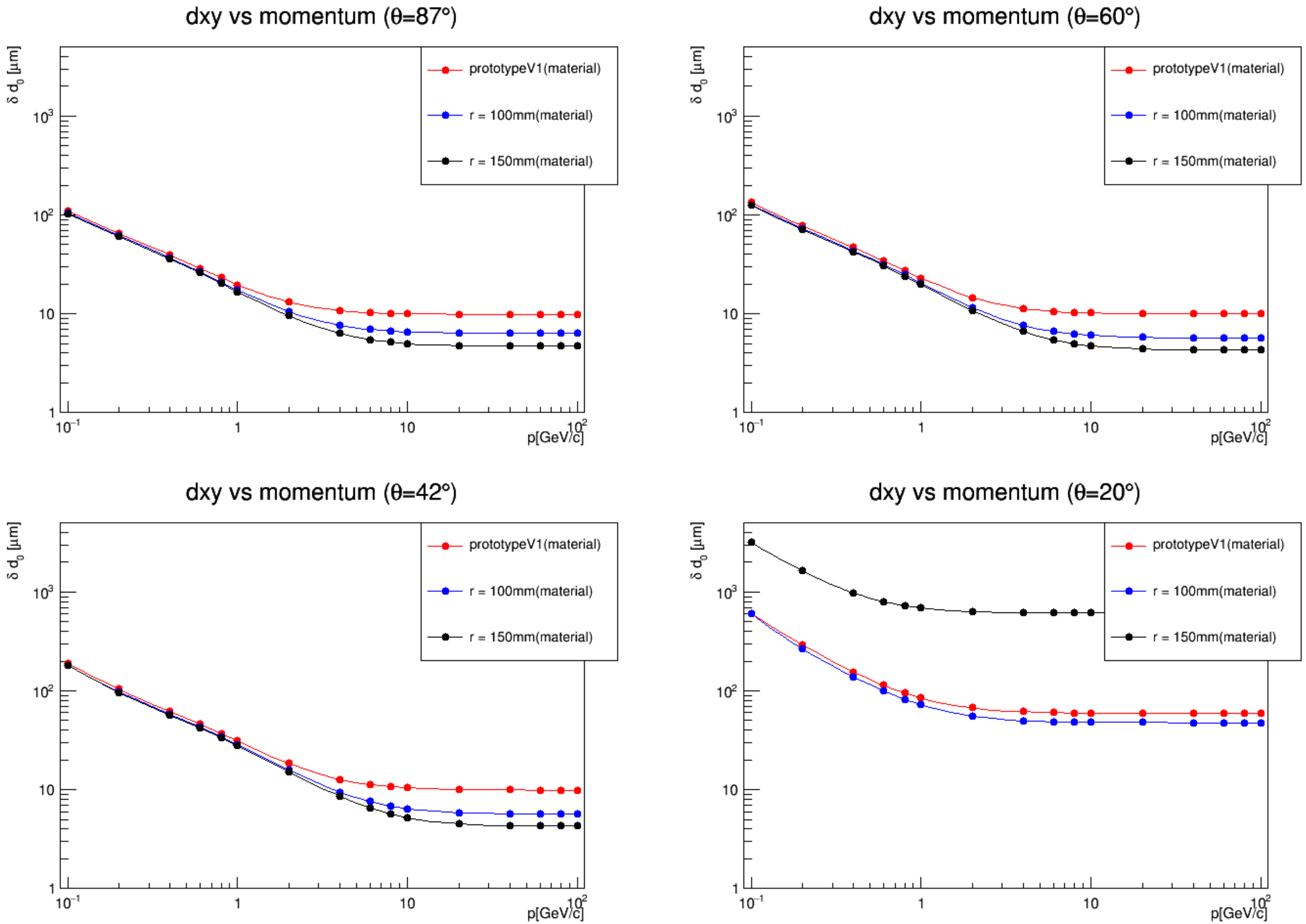
Layouts comparison

- Detector size(resolution across θ)



Layouts comparison

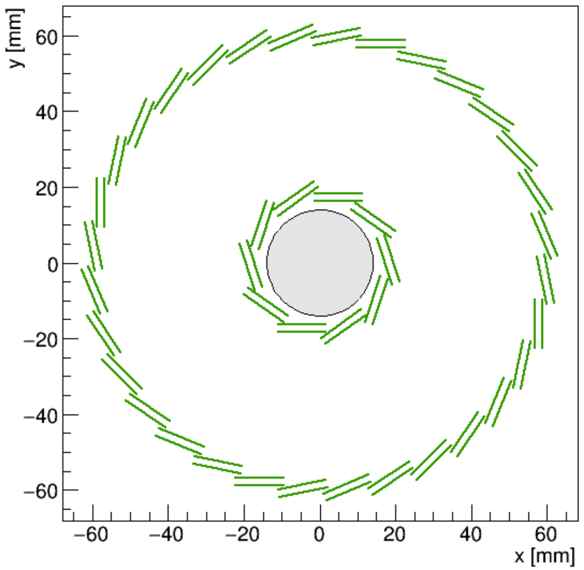
- Detector size(resolution across p)

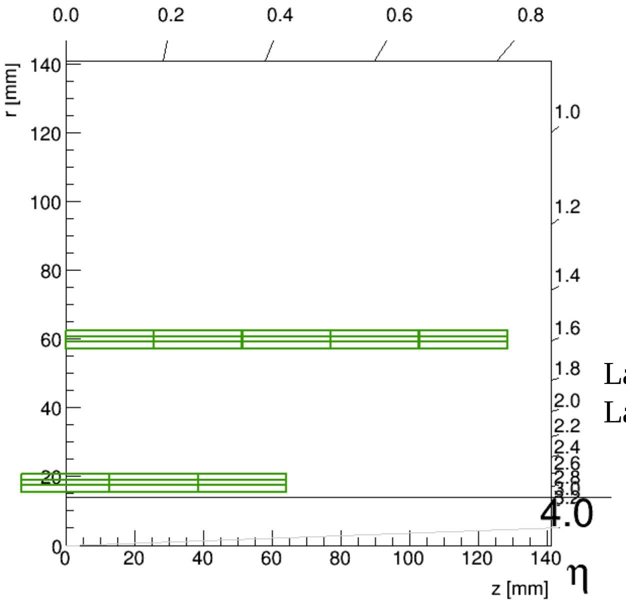


Detector become larger, resolution will be better.

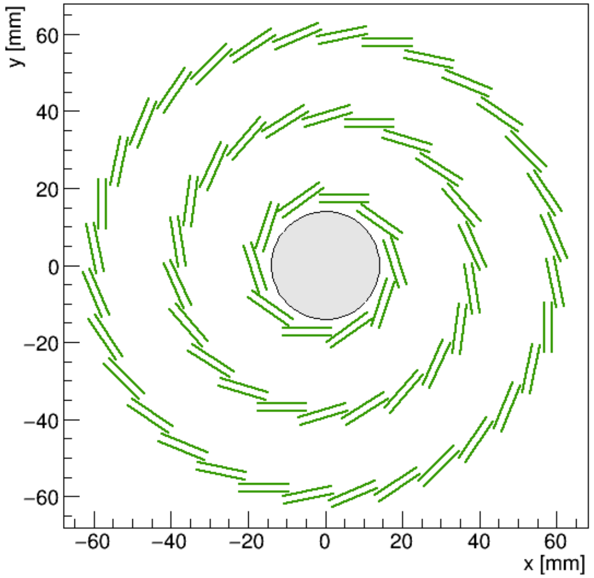
Layouts comparison

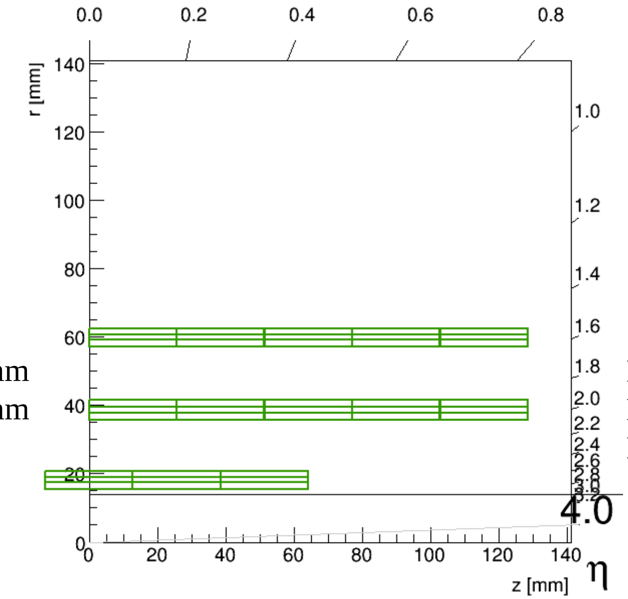
- Different number of layers



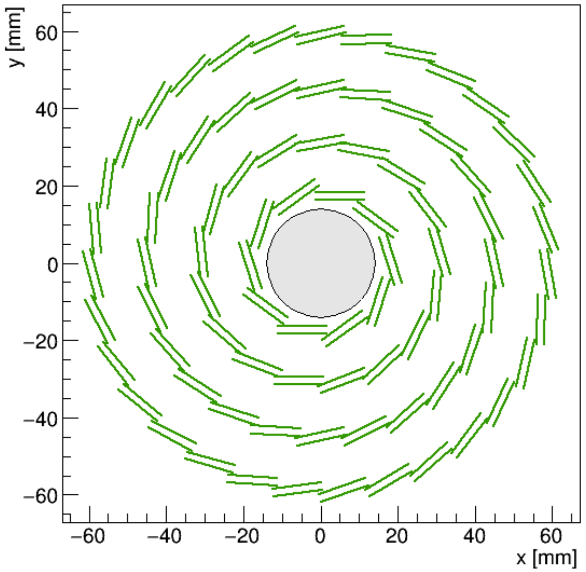


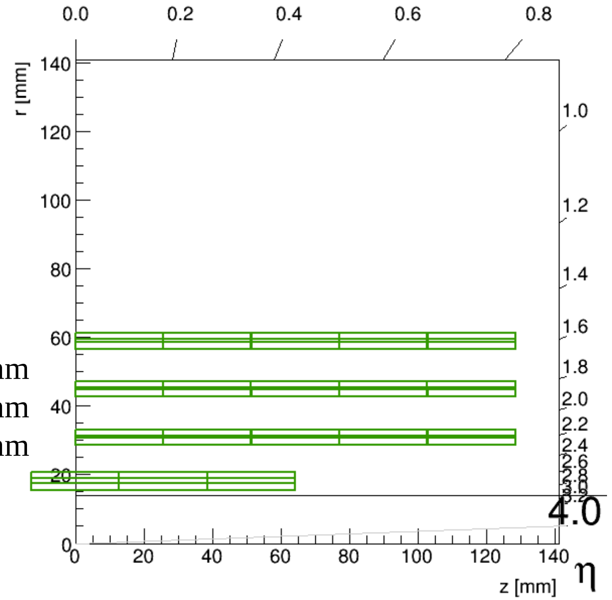
Layer 1: 18mm
Layer 3: 59mm





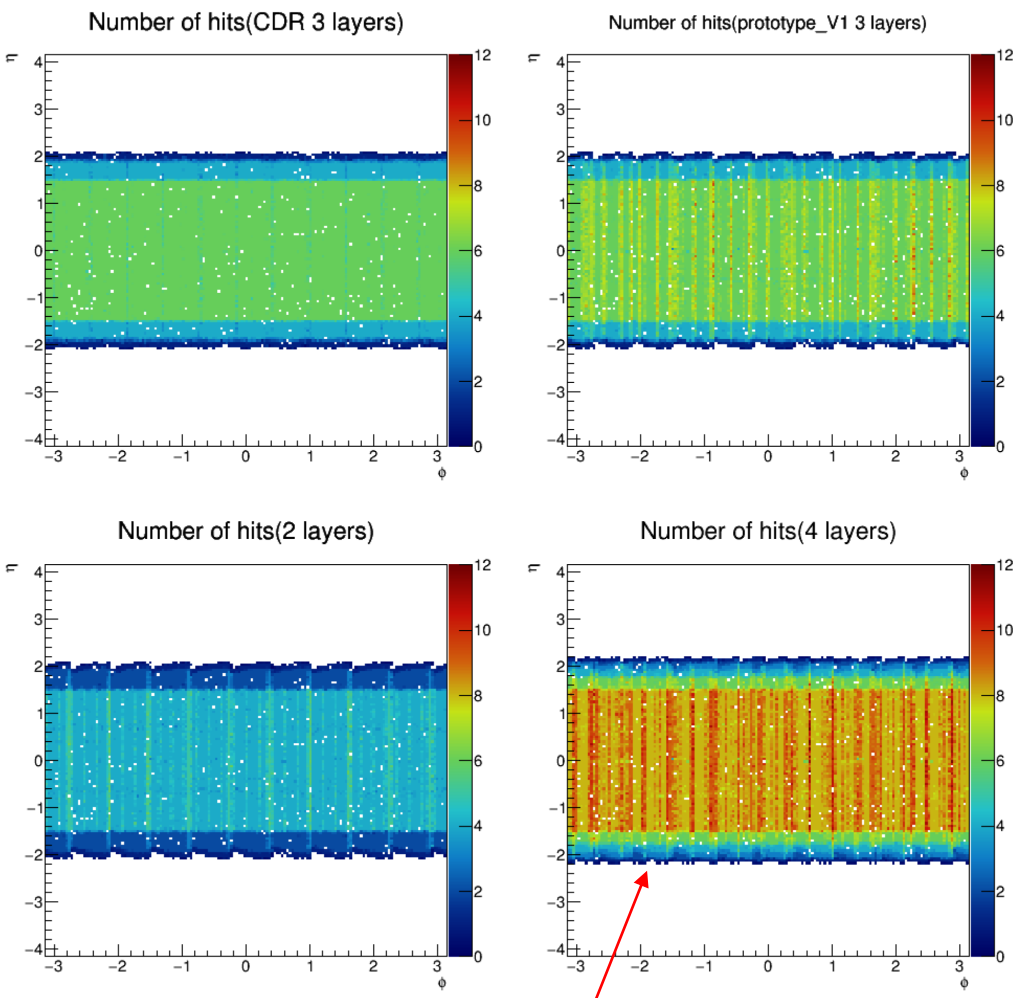
Layer 1: 18mm
Layer 2: 38mm
Layer 3: 60mm



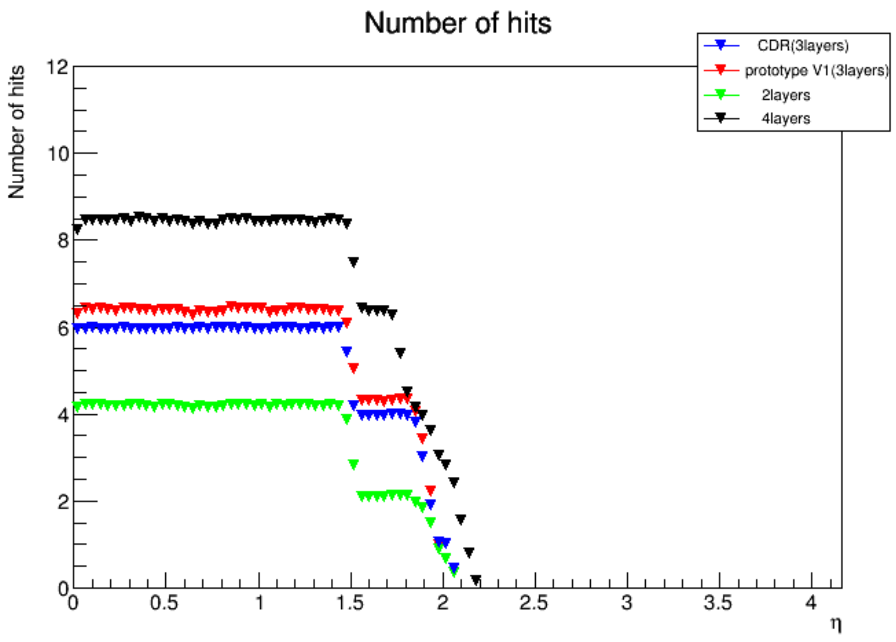


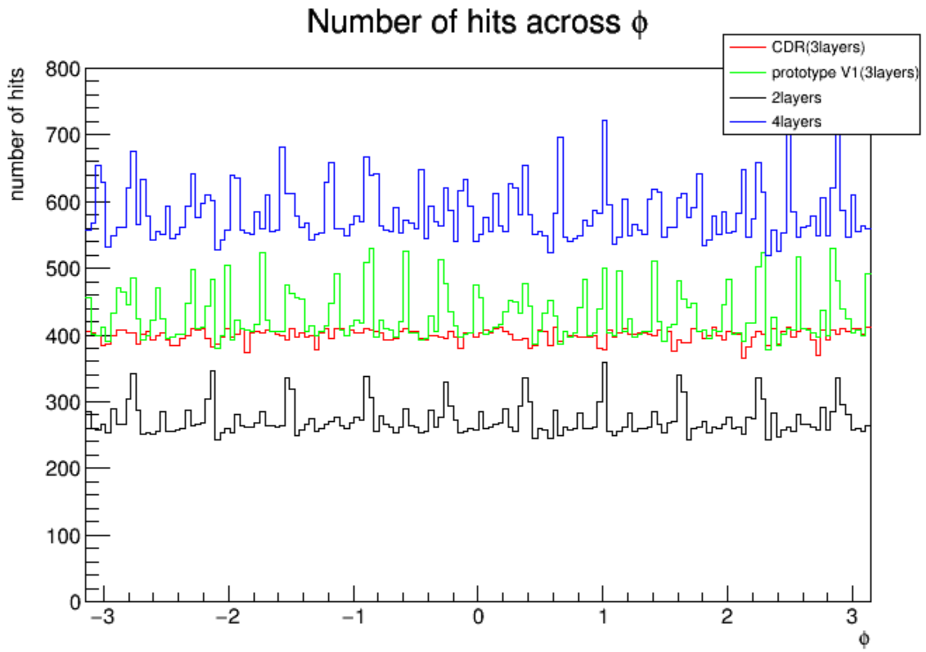
Layer 1: 18mm
Layer 2: 31mm
Layer 3: 45mm
Layer 4: 59mm

Hit coverage comparison



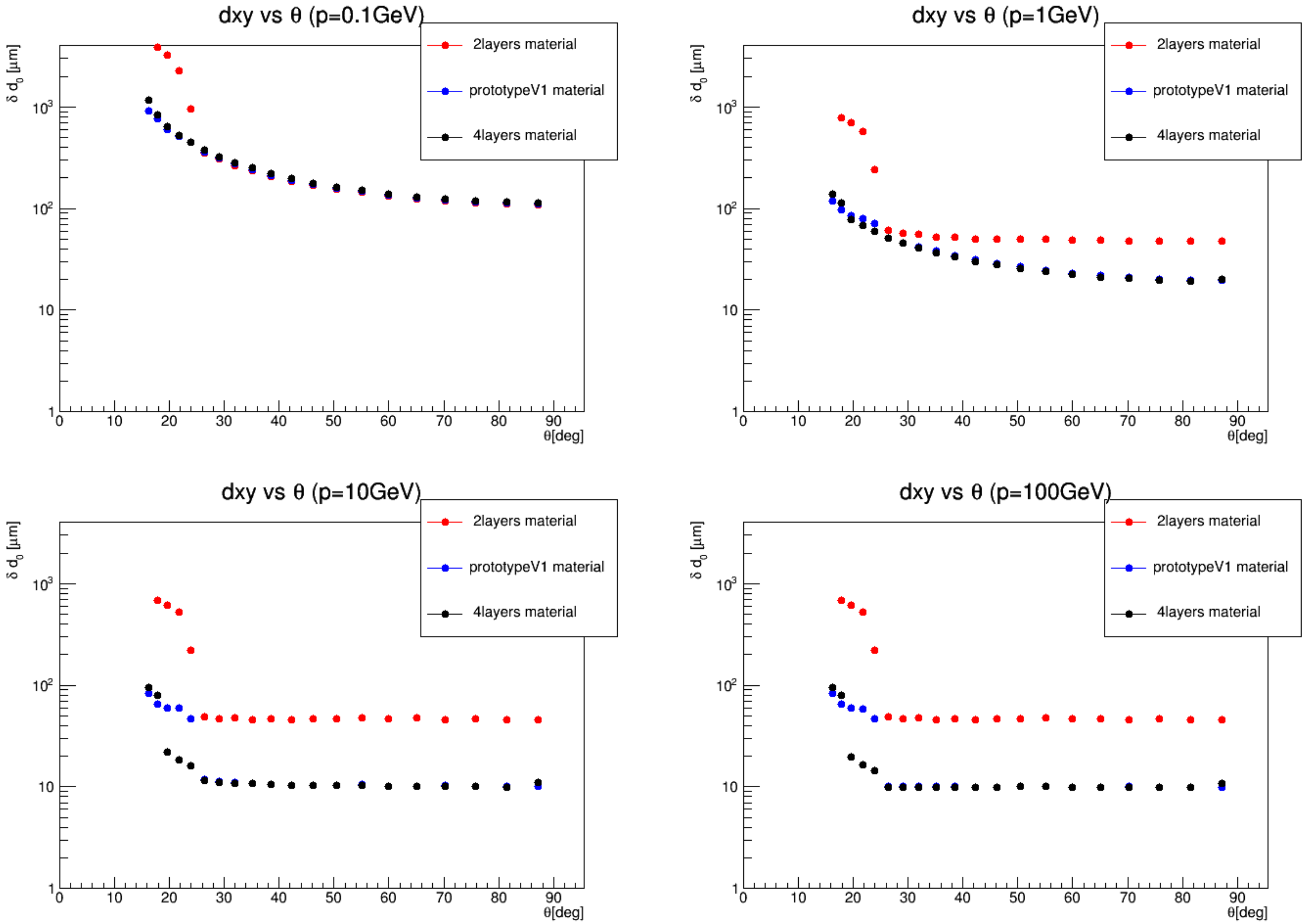
More layers, more stripes.





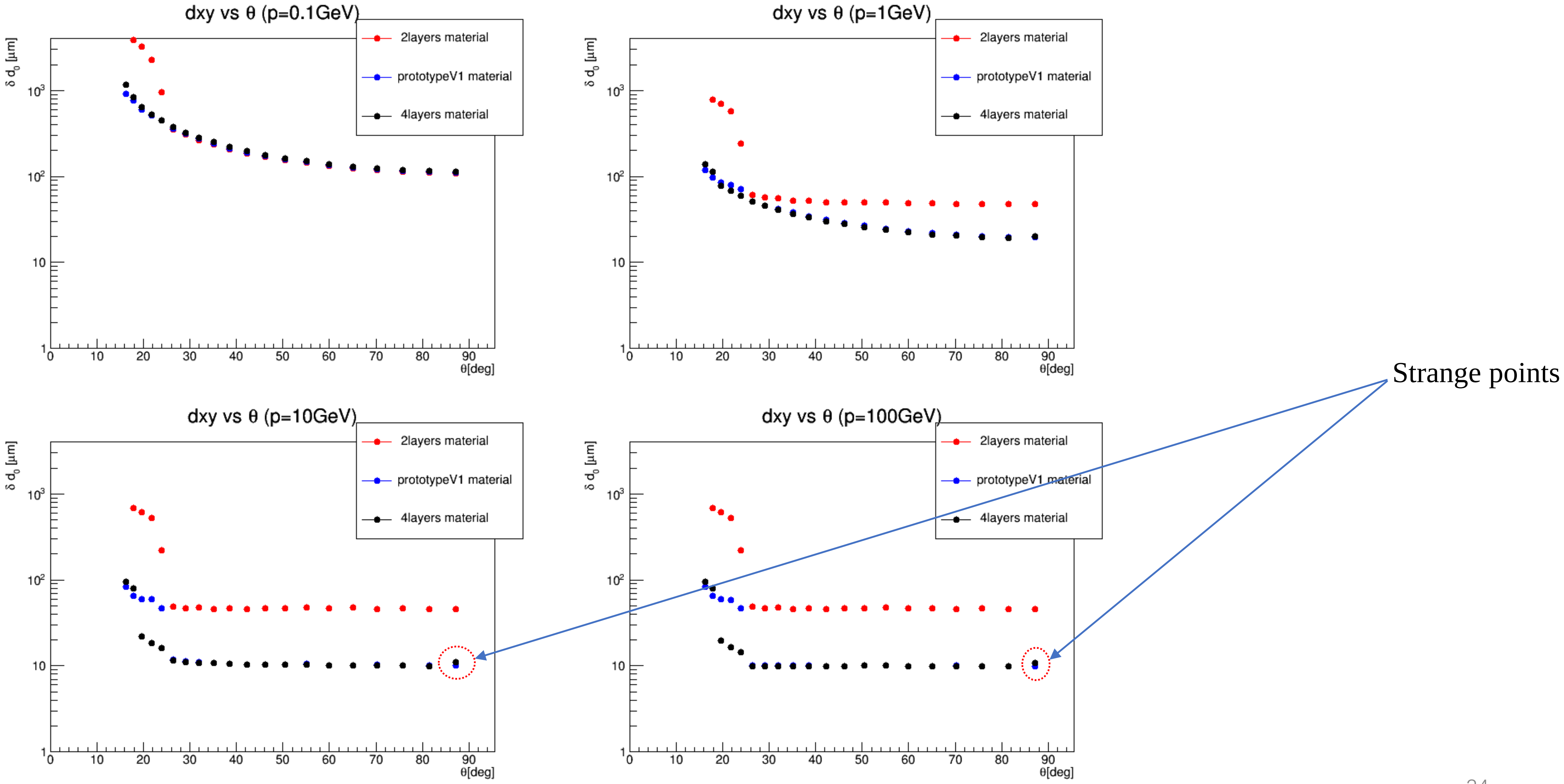
Layouts comparison

- Different number of layers(resolution across θ)



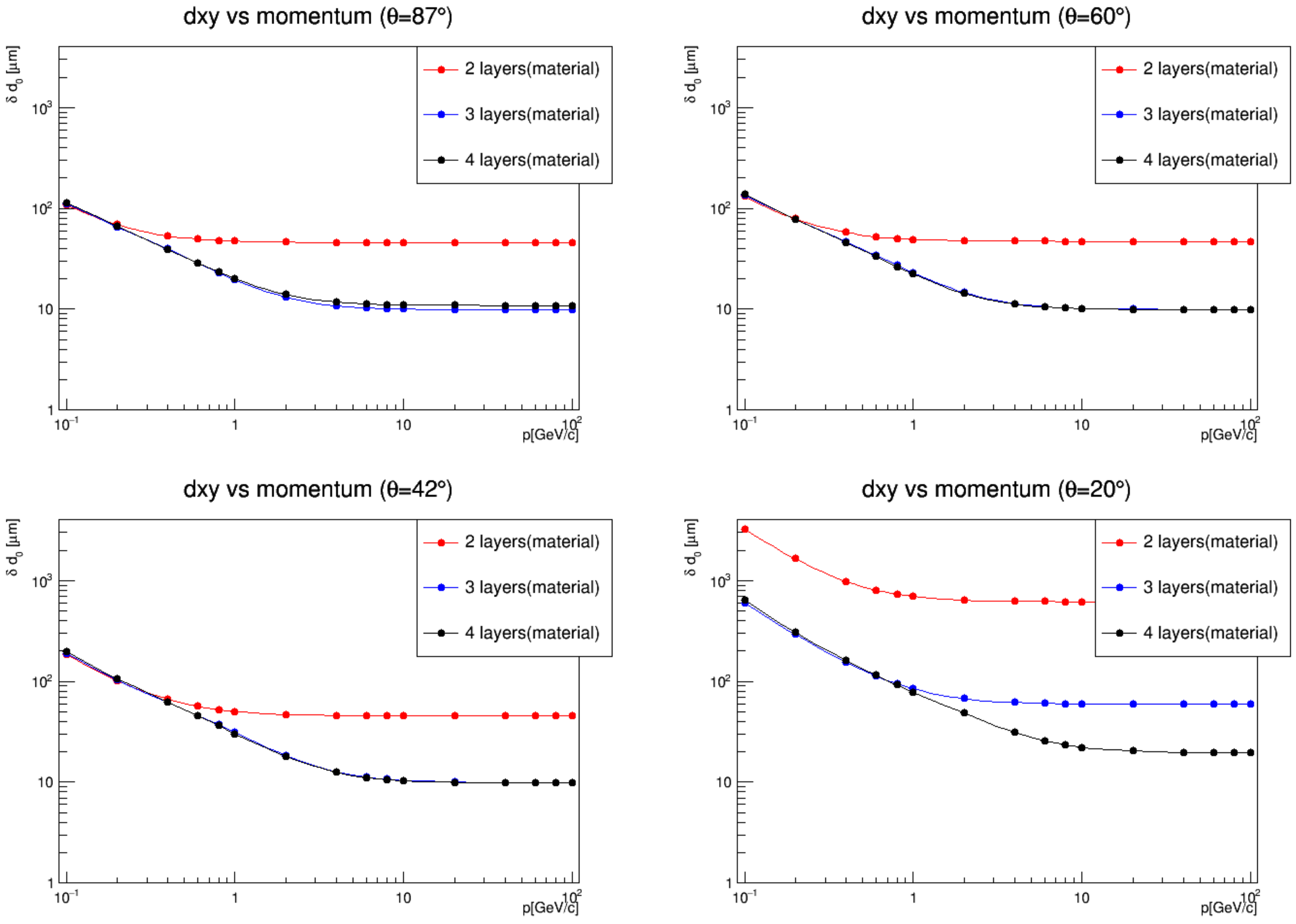
Layouts comparison

- Different number of layers(resolution across θ)



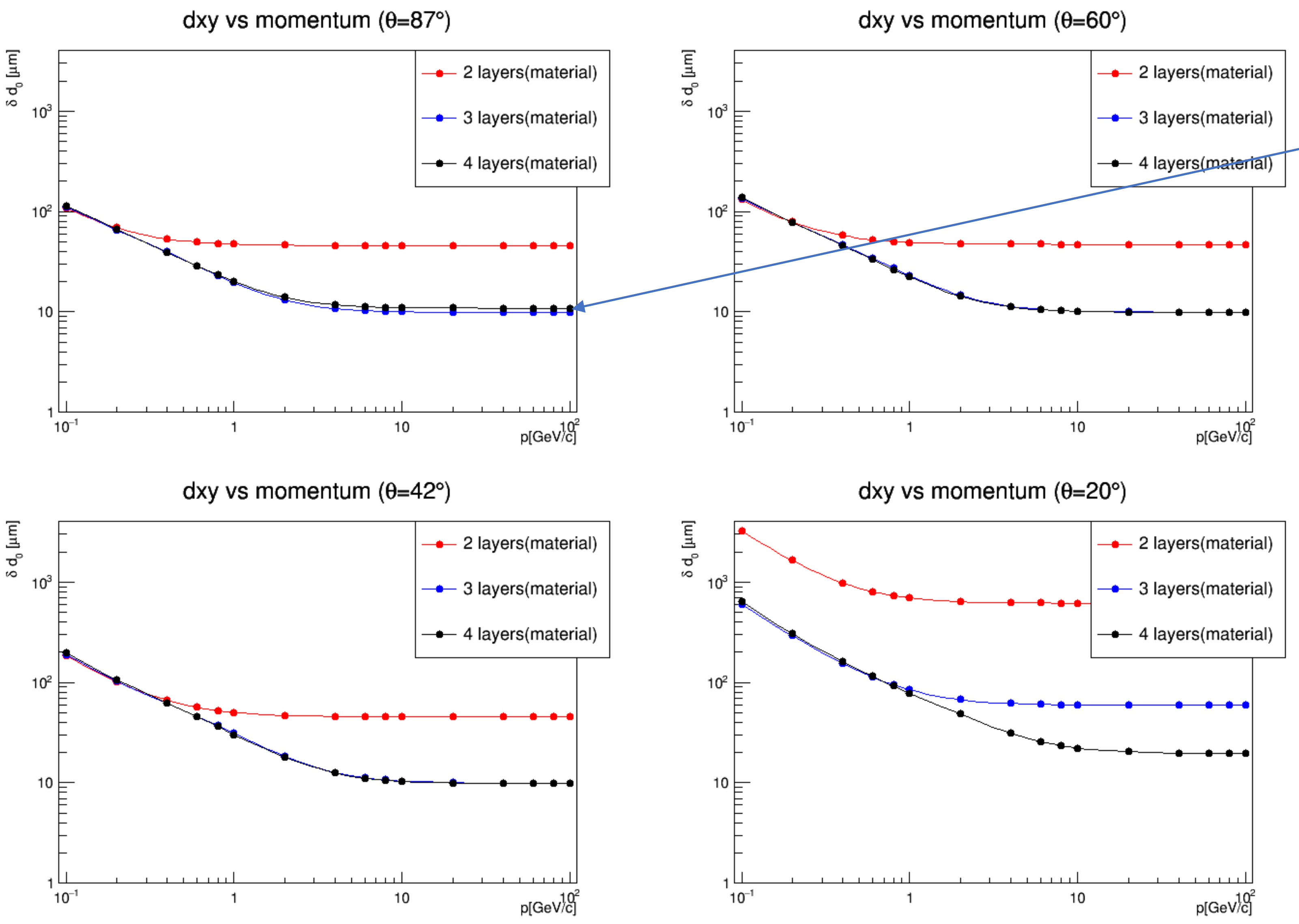
Layouts comparison

- Different number of layers(resolution across p)



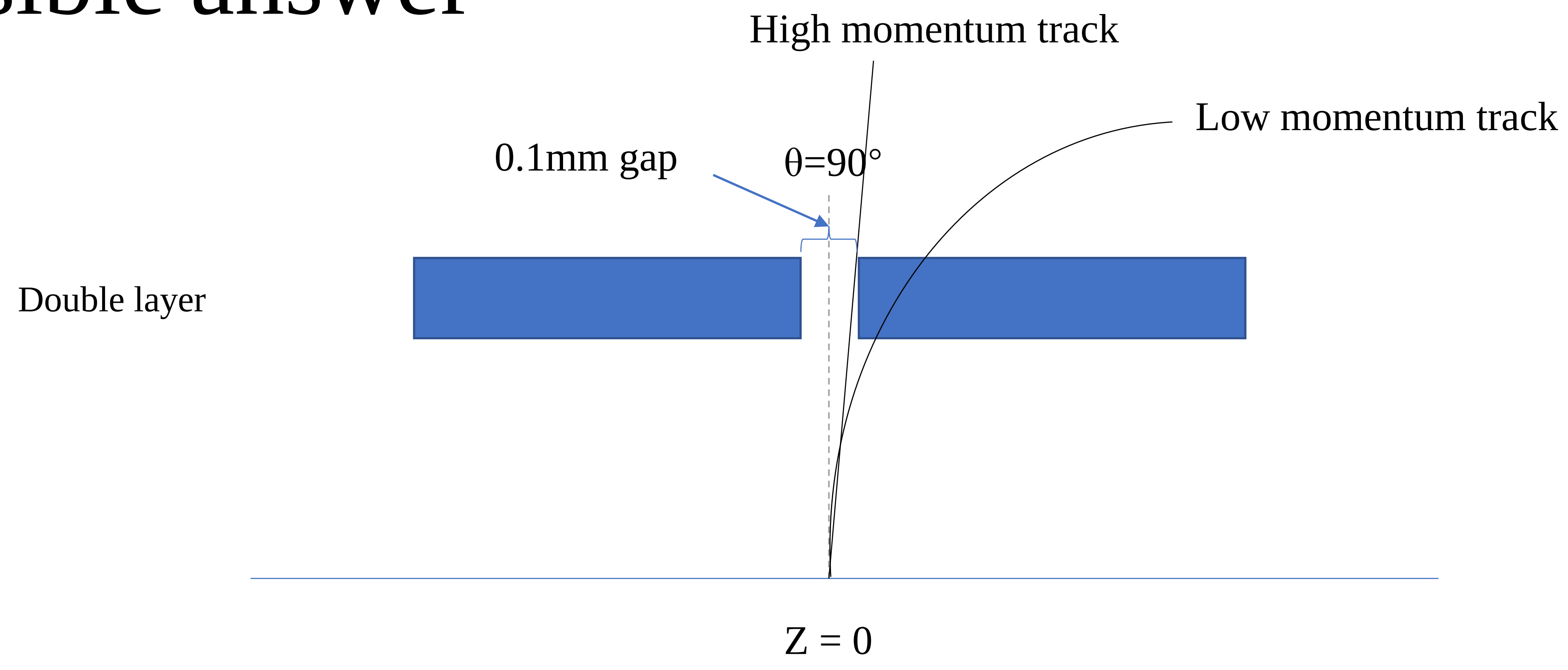
Layouts comparison

- Different number of layers(resolution across p)



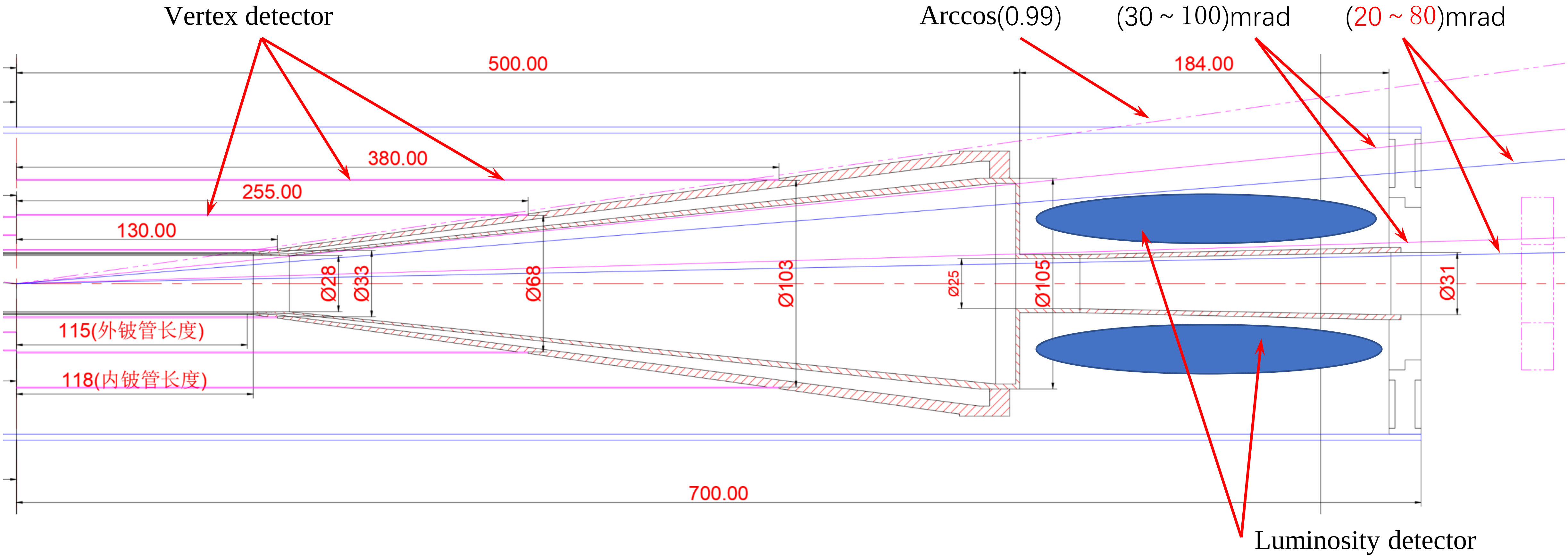
3 layers better than 4 layers???

Possible answer



High momentum track can pass through this small gap at θ around 90°, there will be no hits in this double layer.
So the resolution of high p will be worse if there are gaps at z=0.

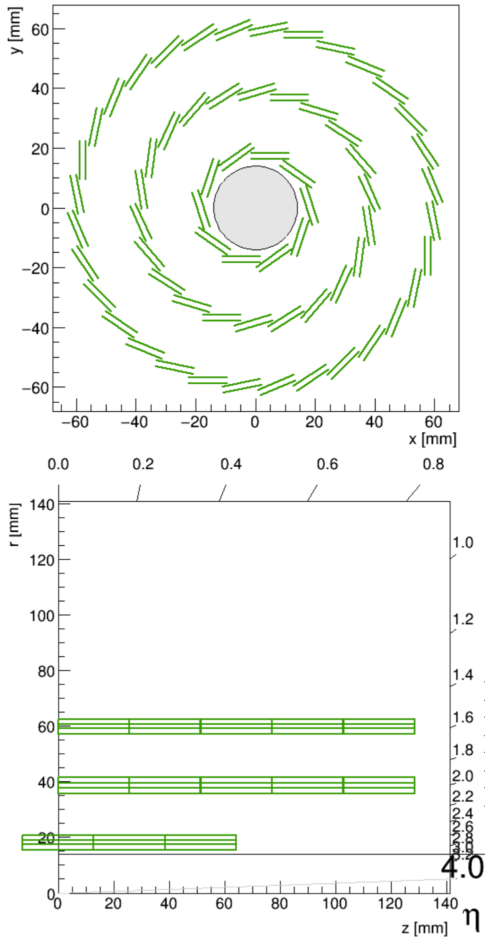
New beam pipe design



Design by Ji Quan

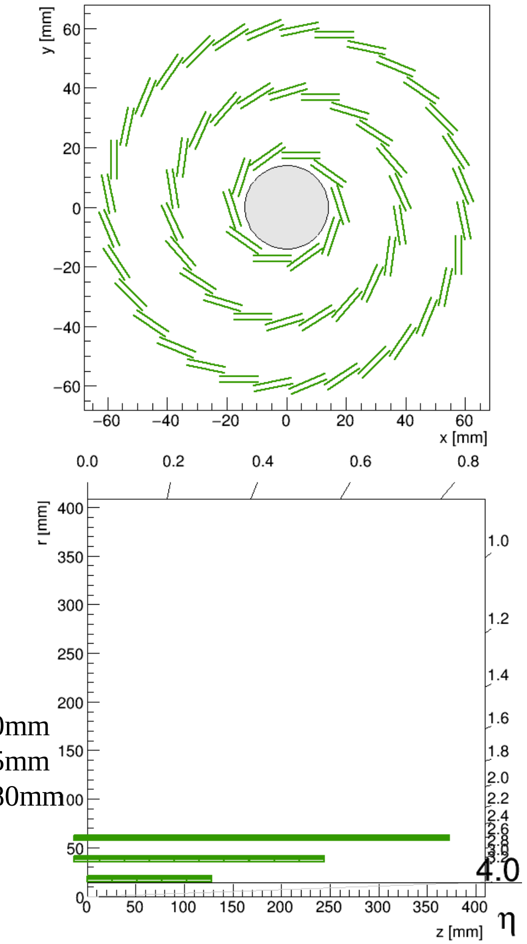
first layer: Ø33mm, +z=130mm
second layer: Ø68mm, +z=255mm
third layer: Ø103mm, +z=380mm

Layouts comparison

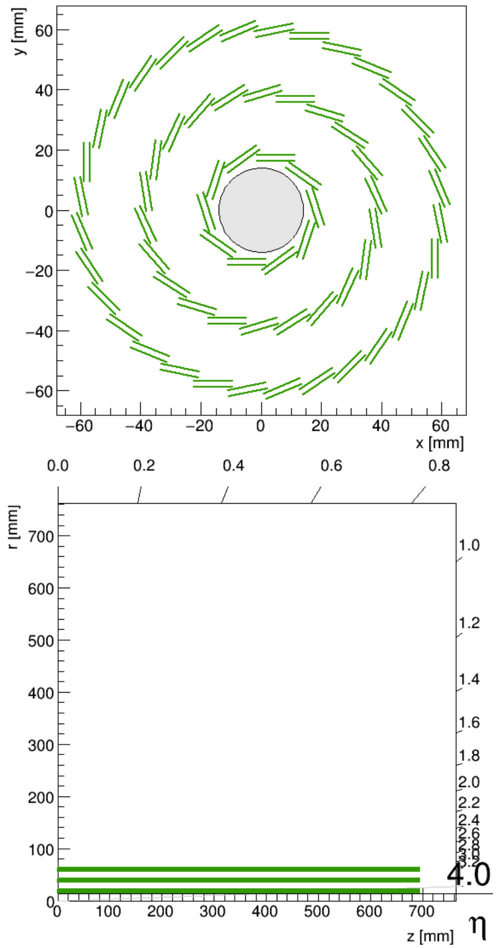


New beam pipe:
Layer 1: Ø33mm, +z=130mm
Layer 2: Ø68mm, +z=255mm
Layer 3: Ø103mm, +z=380mm

Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	17.116	19.041	37.667	39.577	58.914	60.842	
z_max	64.200	64.200	128.450	128.450	128.450	128.450	
# rods	10	10	22	22	32	32	
# mods	50	50	220	220	320	320	1180



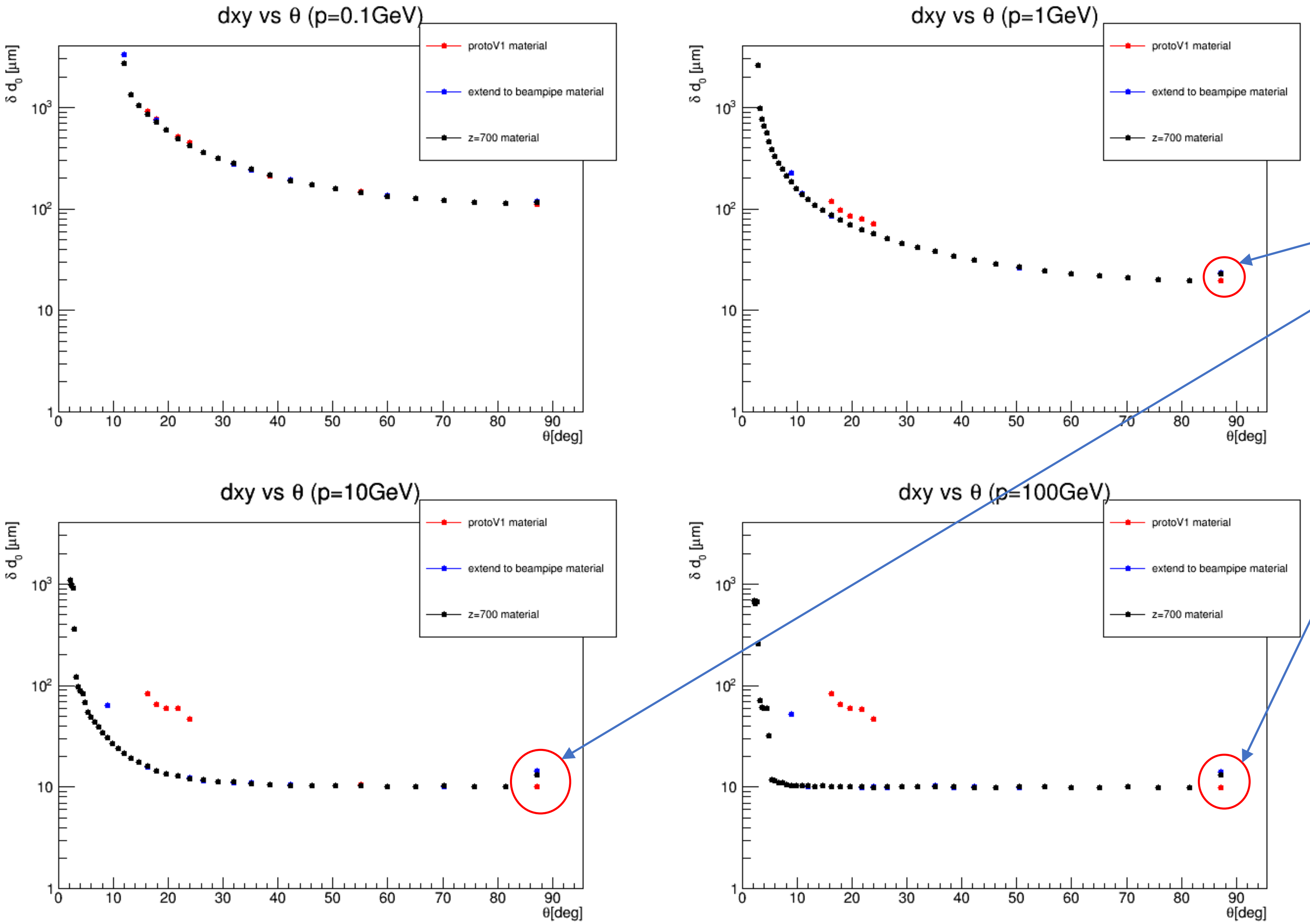
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	17.116	19.041	37.667	39.577	58.914	60.842	
z_max	128.450	128.450	244.100	244.100	372.600	372.600	
# rods	10	10	22	22	32	32	
# mods	100	100	418	418	928	928	2892



Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	17.116	19.041	37.667	39.577	58.914	60.842	
z_max	693.850	693.850	693.850	693.850	693.850	693.850	
# rods	10	10	22	22	32	32	
# mods	540	540	1188	1188	1728	1728	6912

Layouts comparison

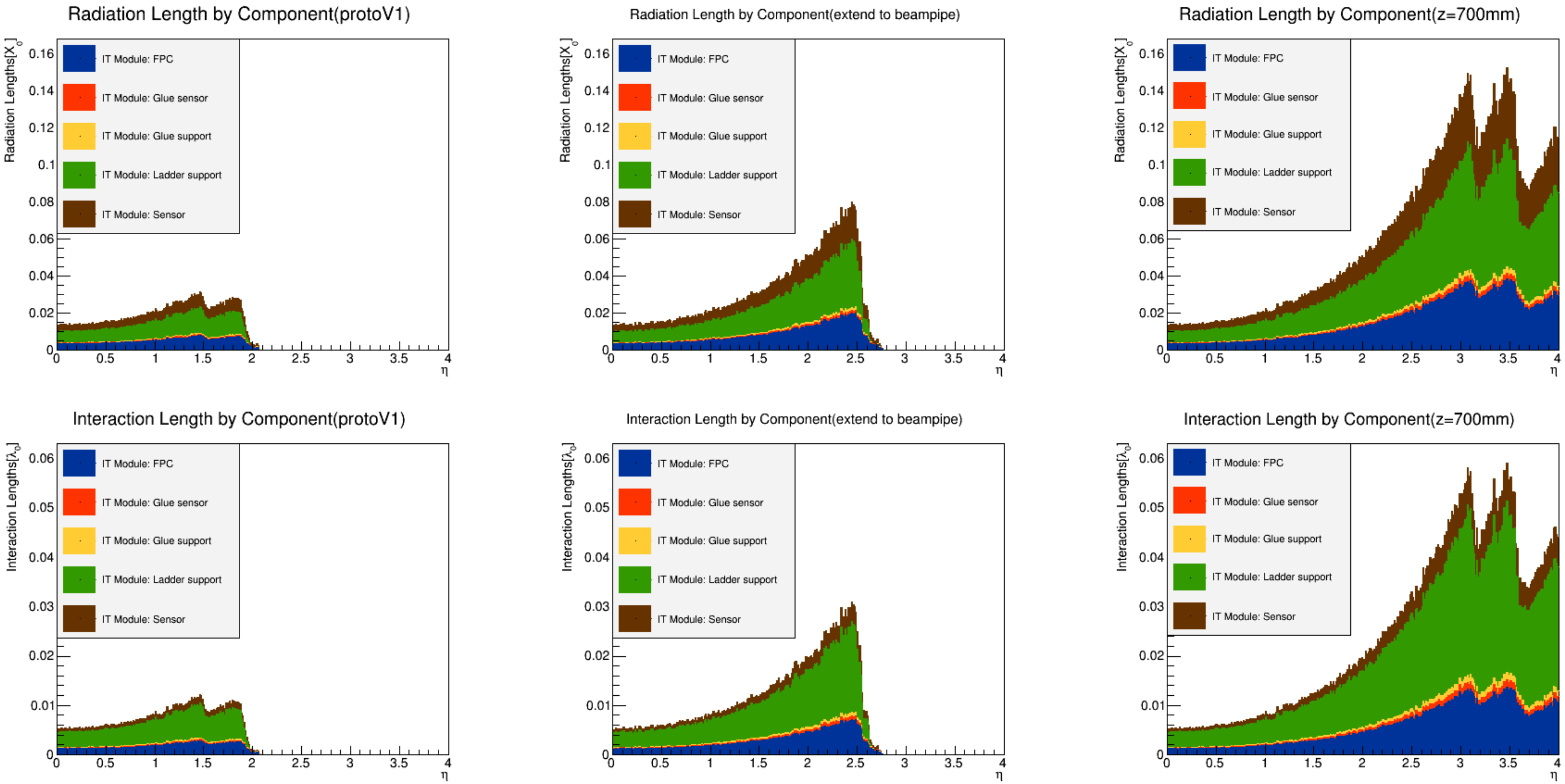
- Resolution for different z length:



No gap at z=0 for protoV1 first layer barrel

Layouts comparison

- Material comparison



Summary

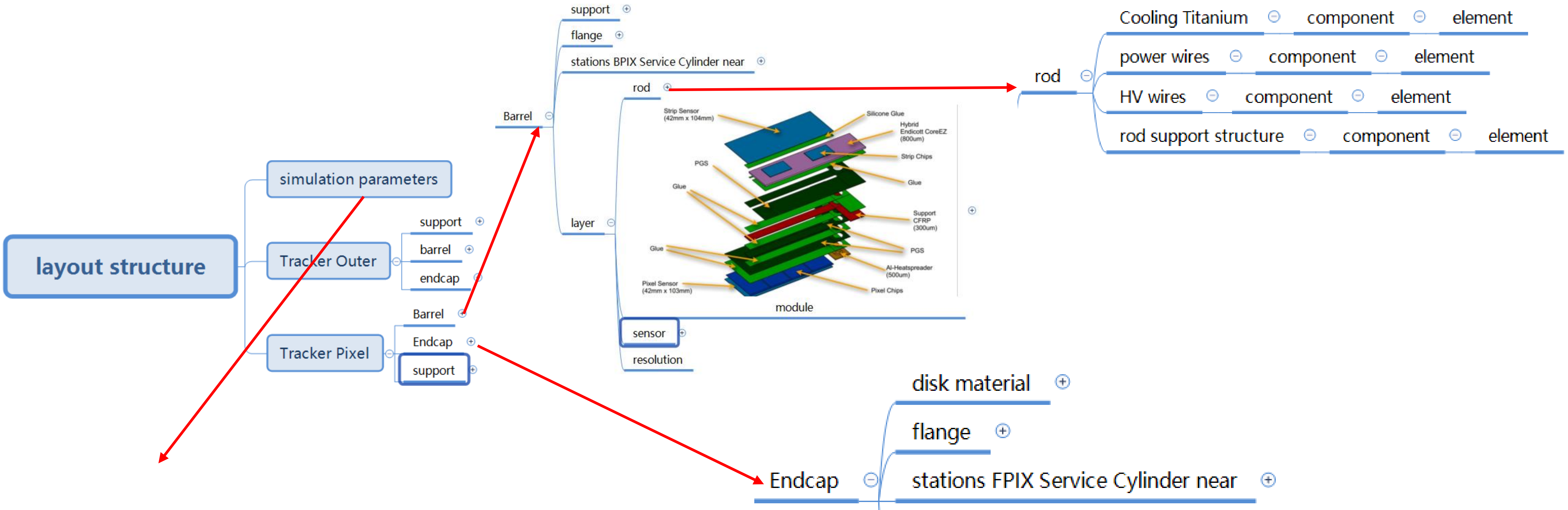
- Prototype V1 layout geometry has been studied
- Material budget simulation has been done for 2 ladder design, we still need to reduce our ladder material.
- Layout comparison with different size, layers and barrel length has been done.

Thank you!

Backup

Introduction of tkLayout

- Layout Configuration Structure




```
numMinBiasEvents 1      // Number of pile-up events
bunchSpacingNs 25

// Luminous region used in analysis (IP always on (Z) axis, with Z centered around 0)
lumiRegZError                    12     // mm
lumiRegShape                     spot   // Choose among { spot, flat, gaussian }
lumiRegShapeInMatBudgetAnalysis spot
```

Introduction of tkLayout

- Output webpage:

OT_V4_100_IT_V4_0_0_0
layouts

info | geometry | geometry (pixel) | bandwidth | trigger cpus | irradiation (outer) | irradiation (pixels) | material (outer) | material (pixel) | material (total) | weights (outer) | weights (pixel) | resolution (pixel) | resolution (tracker) | resolution (trigger) | patternreco | trigger | log page

layers and disks

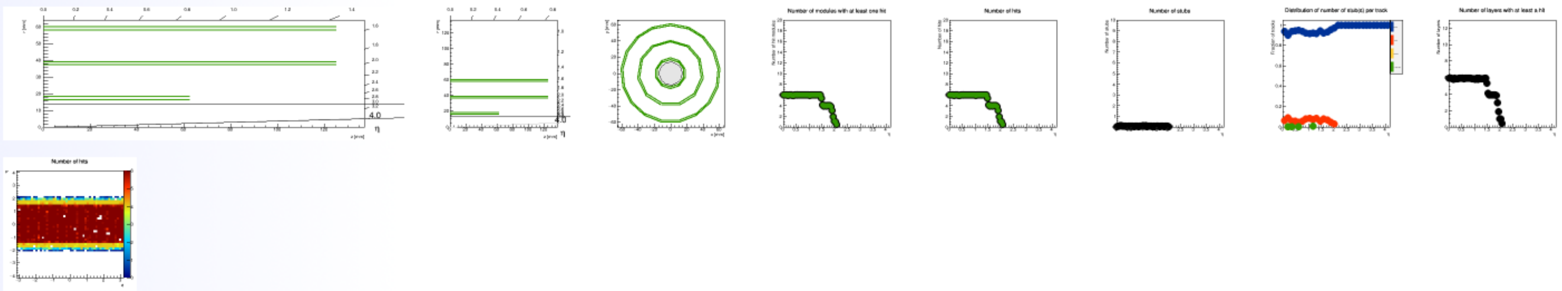
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	16.004	18.004	37.003	38.995	57.989	59.995	
z_max	62.500	62.500	125.000	125.000	125.000	125.000	
# rods	10	10	11	11	17	17	
# mods	40	40	88	88	136	136	528

Endcap :	Total
Disk	
z	
# rings	
# mods	0

endcaps : additional info

modules

plots



layer coverage (hit)

layer coverage (1 stub <-> (>= 2 hits))

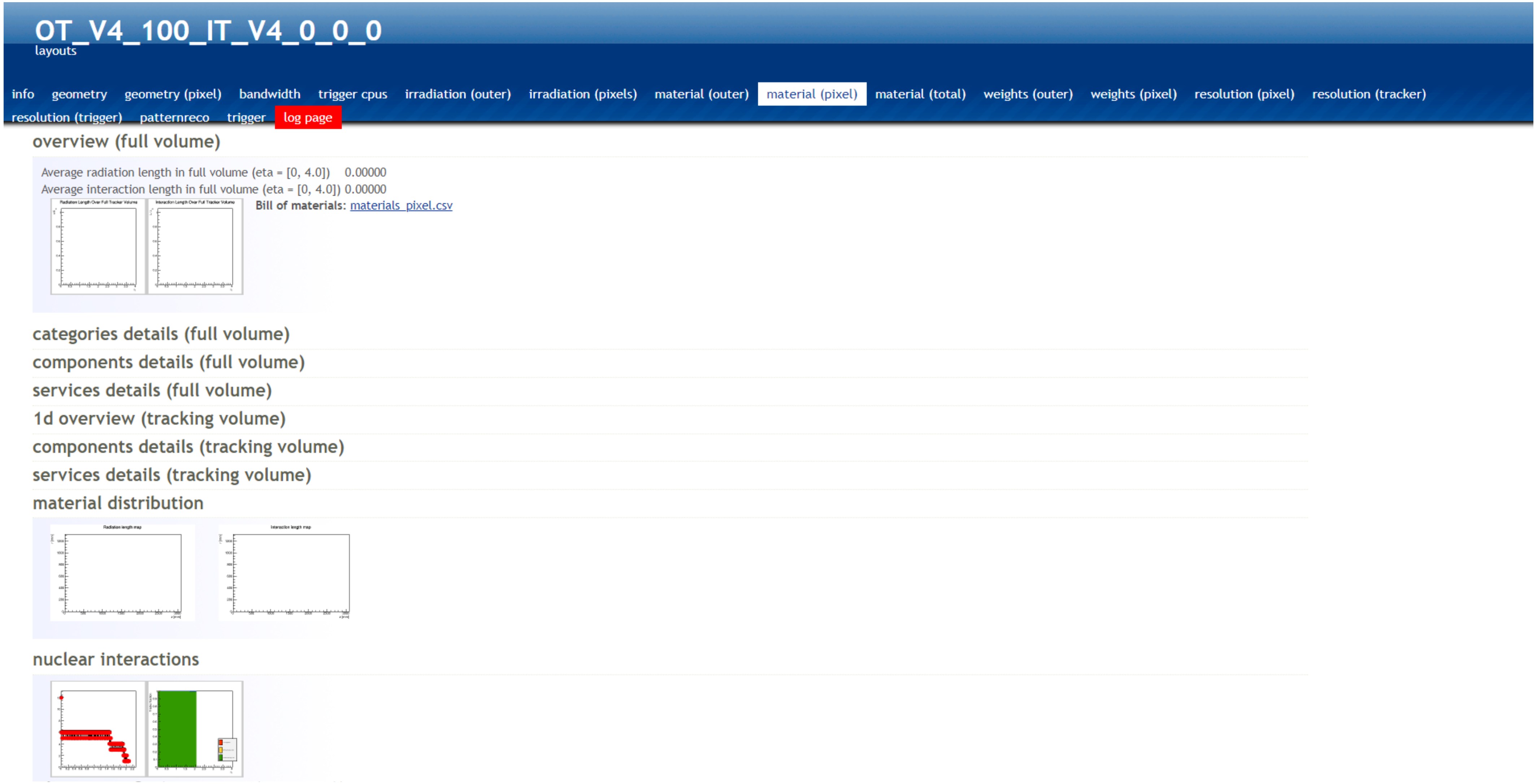
layer coverage (1 stub <-> (>= 3 hits))

Introduction of tkLayout

- Output webpage:

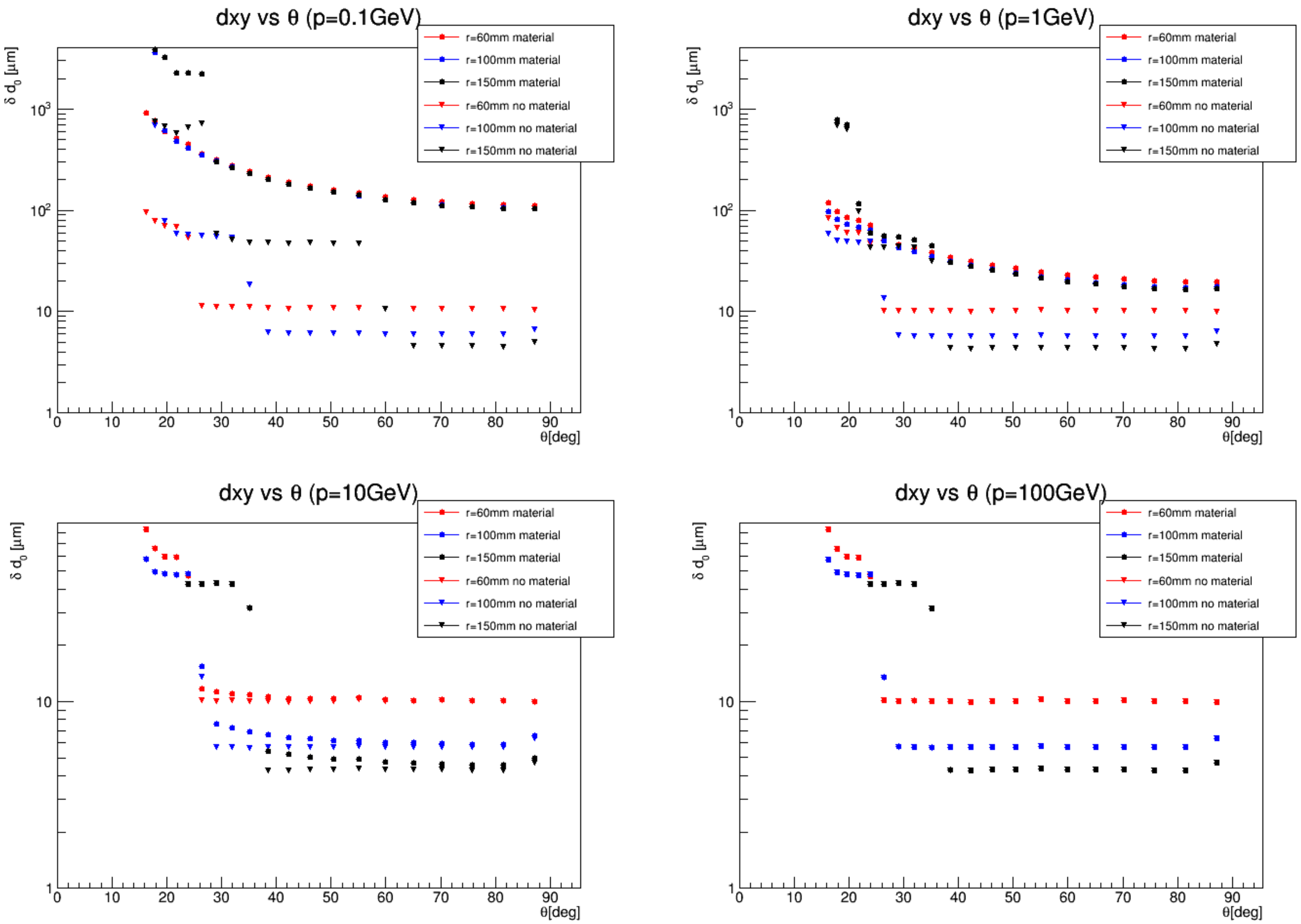
Introduction of tkLayout

- Output webpage:



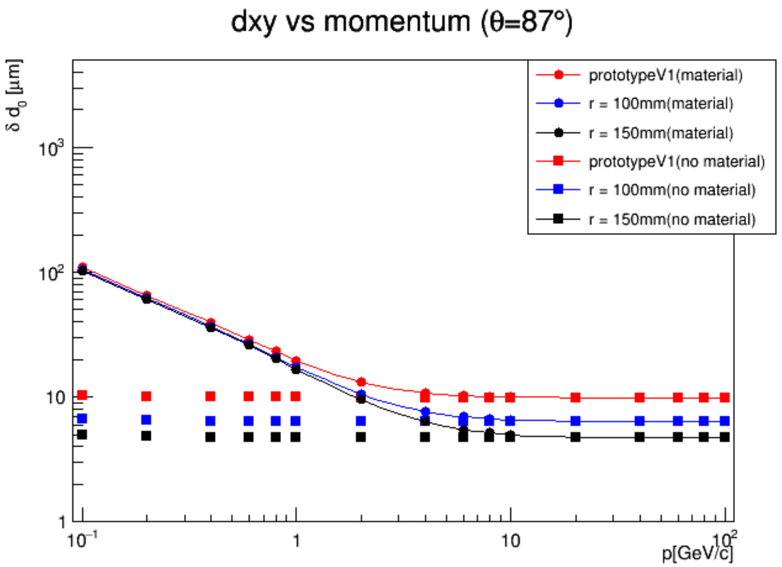
Material vs no material

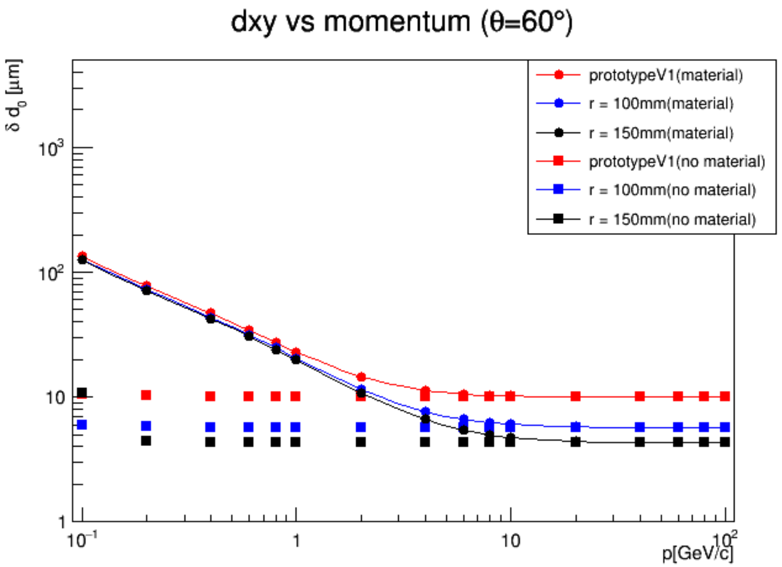
- Detector size(resolution across θ)

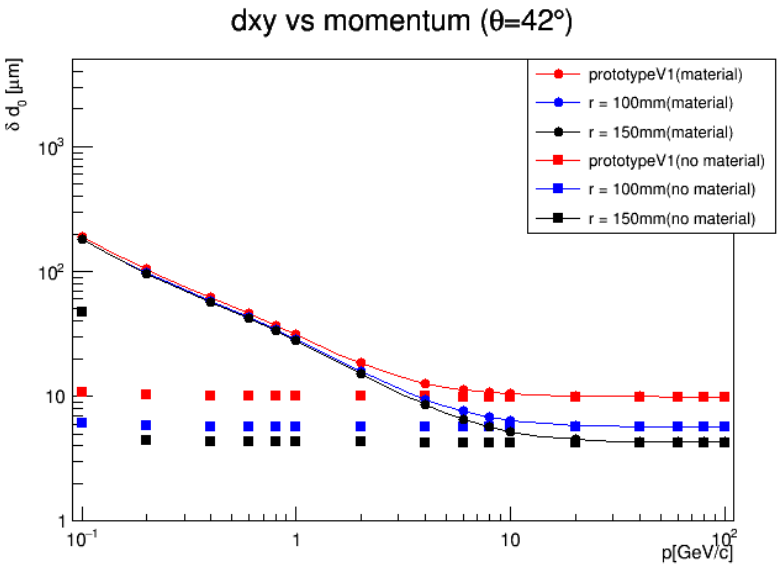


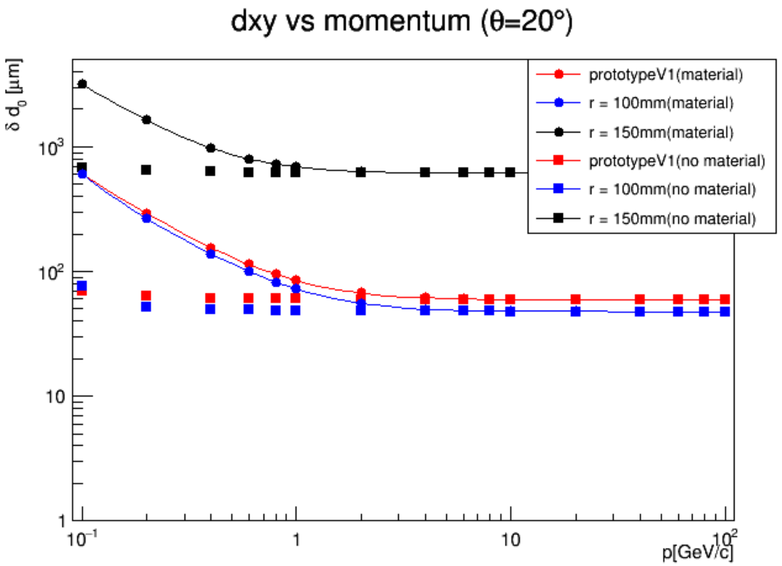
Material vs no material

- Detector size(resolution across p)



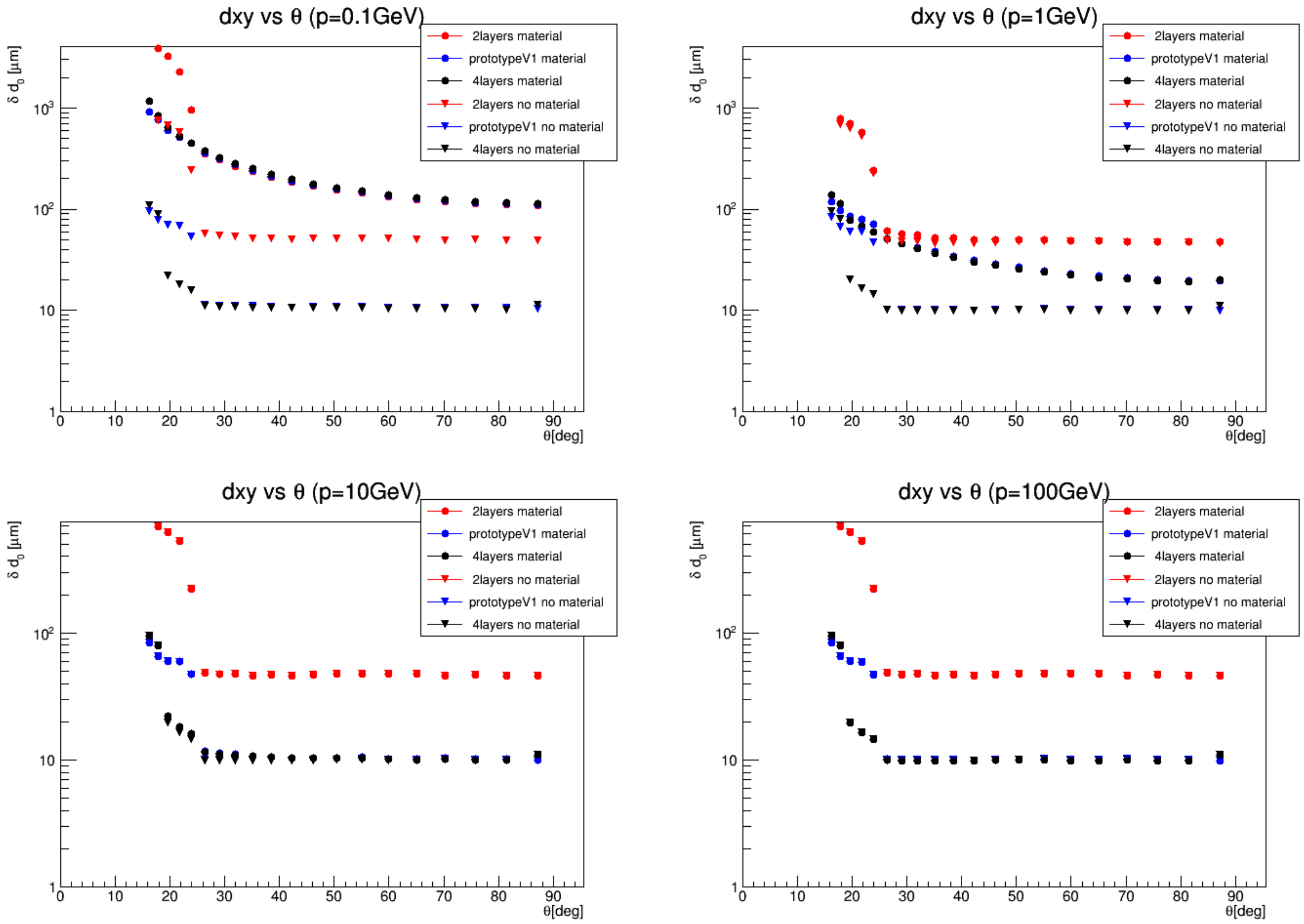






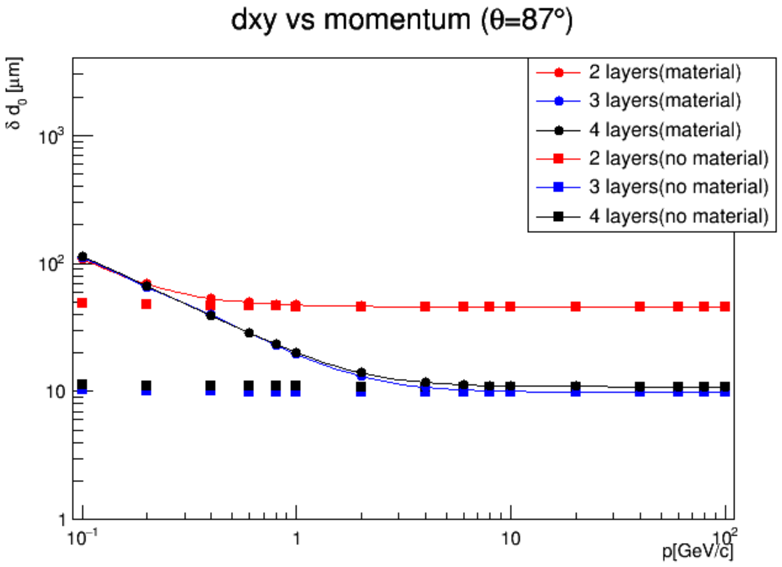
Material vs no material

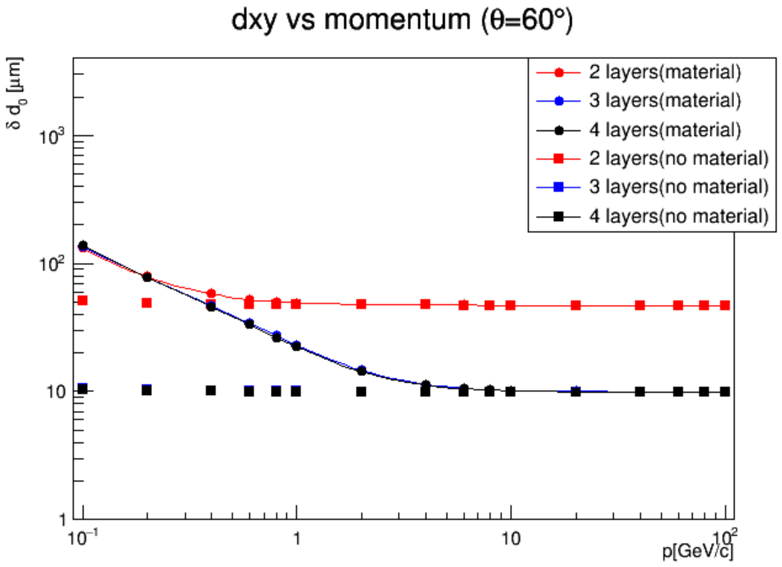
- Different number of layers(resolution across θ)

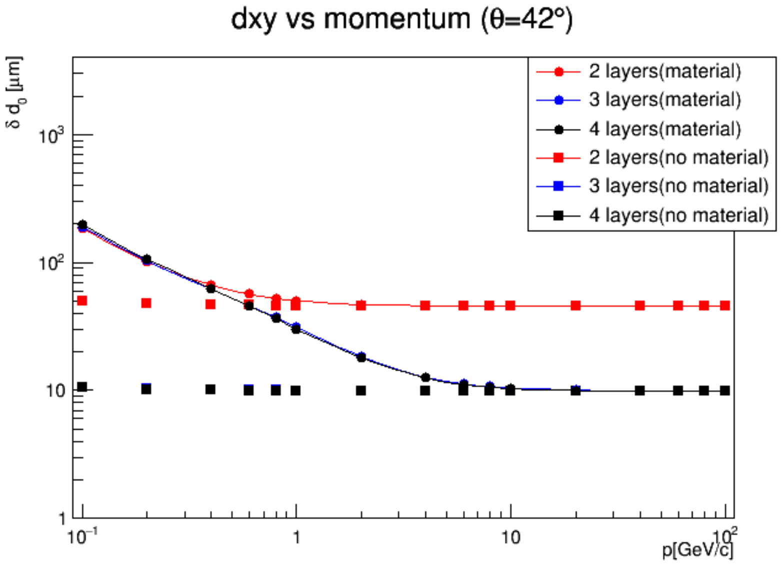


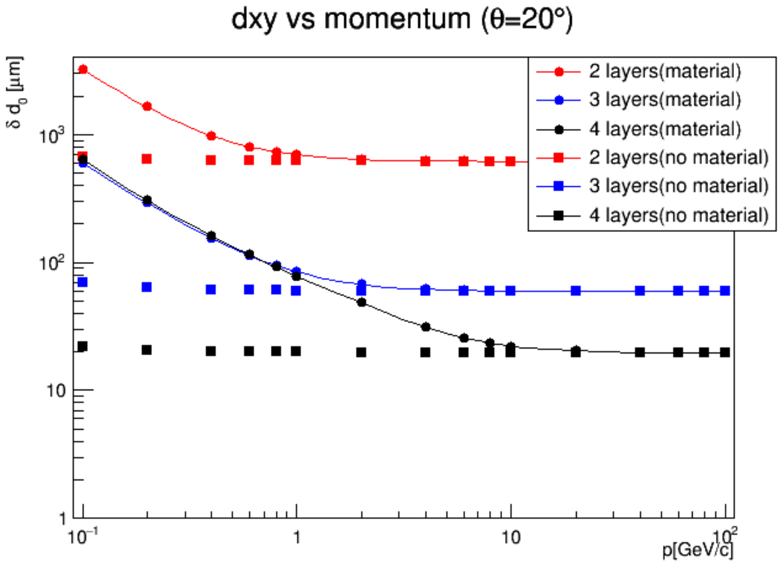
Material vs no material

- Different number of layers(resolution across θ)









Material budget

Nuclear interactions: