中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

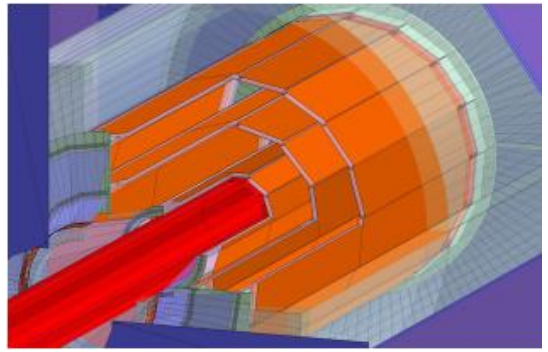
Update on CEPC Vertex Detector Optimization

Hao Zeng, Joao Guimaraes Costa, Quan Ji, Jinyu Fu, Gang Li,
Kewei Wu, Zhijun Liang, Mingyi Dong,
2021/01/13

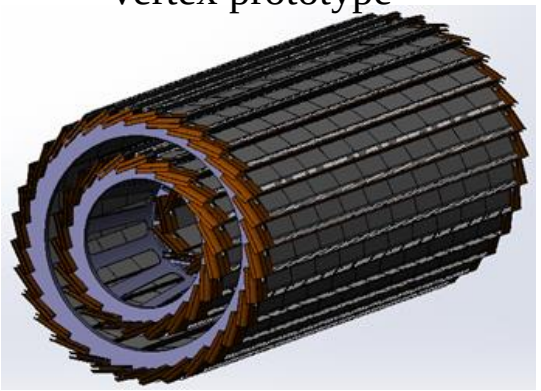
Background Review

- CDR vertex:
  - based on ILD
  - ideal concept vertex(Z. Wu et al 2018 JINST 13 T09002)
- Vertex prototype for MOST2:
  - realistic implementation of CDR vertex (barrel)
  - mechanics: ladder design, support structure, ladder arrangement
  - electronics: chips, read-out
  - cooling: air cooling
- Realistic vertex detector for CEPC:
  - based on vertex prototype (mechanics, electronics)
  - full-size vertex detector (barrel + endcap)
  - beam pipe, MDI, cooling

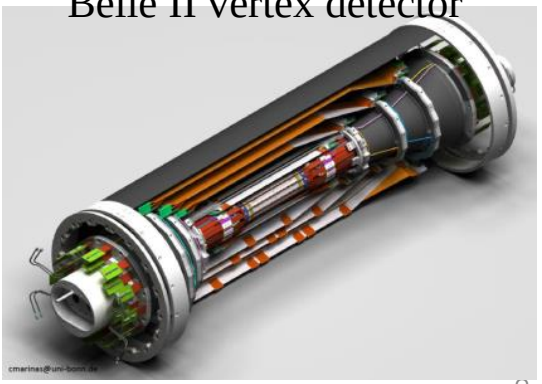
CDR baseline vertex



vertex prototype



Belle II vertex detector



Vertex layout optimization review

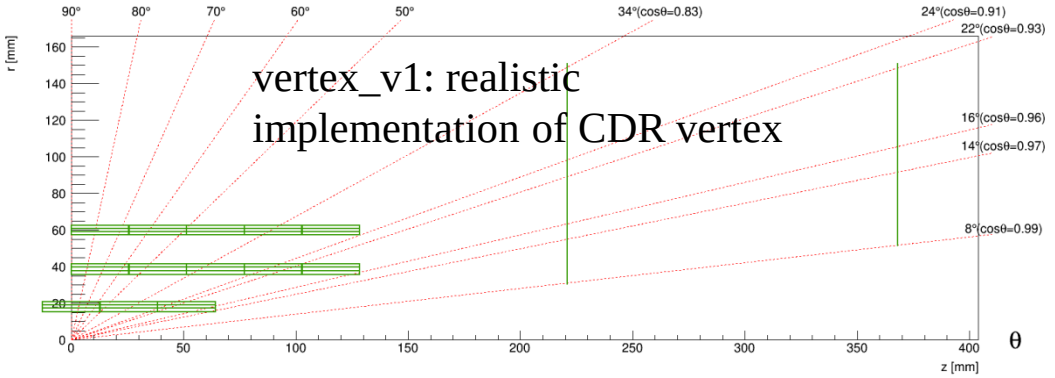
- Base on the design of vertex prototype (mechanics, electronics), we try to optimize the full-size vertex detector (d0 resolution as criteria):
  - Barrel optimization
    - The radius of vertex detector
    - The number of layers
    - The radius of second layer
    - Lengthen the innermost layer

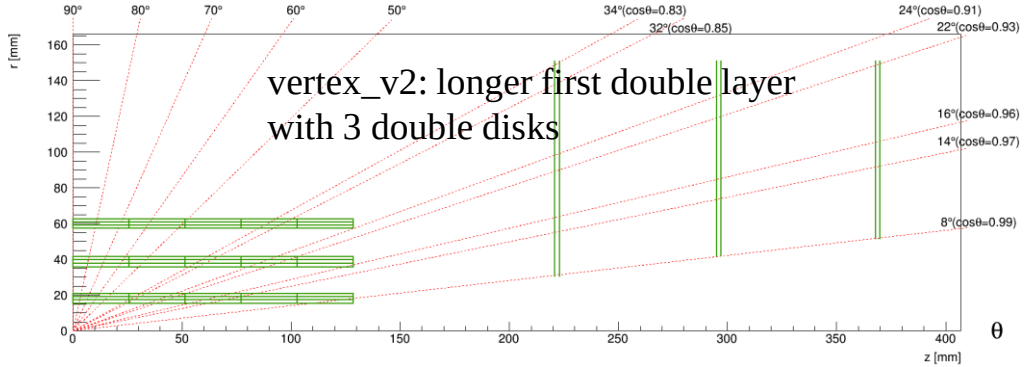
Layout with 3 equidistance double layers is best

  - Disk optimization
    - The number of disks
    - Single-disk or double-disk
    - The putting place of the disk

improve the d0 resolution in front region

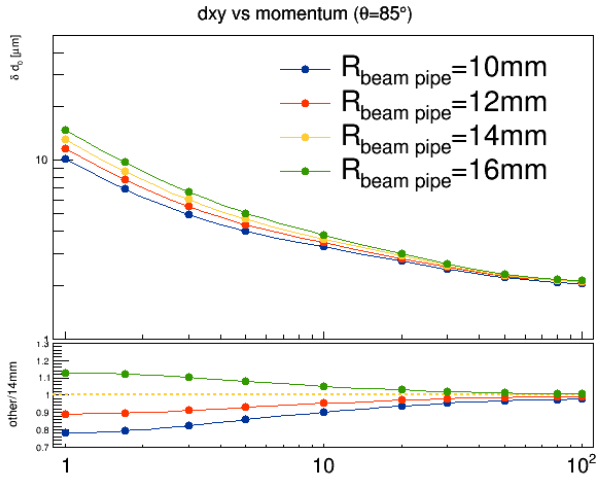
    - 3 double-disks in endcap is the best



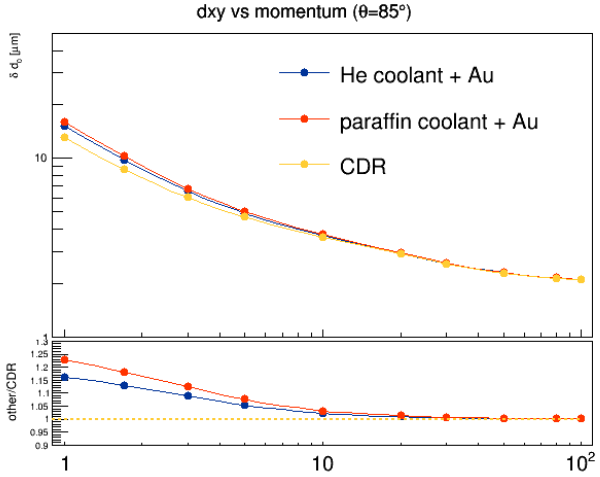


Beam pipe study review

- Beam pipe radius
  - Big effect on low momentum track
  - Beam pipe radius is smaller, resolution is better
  - Improve d0 resolution 21% if reduce beam pipe radius to 10 mm
- Beam pipe material
  - Beam pipe structure:
    - innermost Au: T=5 um
    - inner Beryllium layer: T= 0.5 mm
    - gap: T=0.5 mm (coolant)
    - outer Beryllium layer: T= 0.35 mm
  - 24% worse if use paraffin coolant +Au
  - might cancel the material effect if reduce beam pipe radius to 10mm



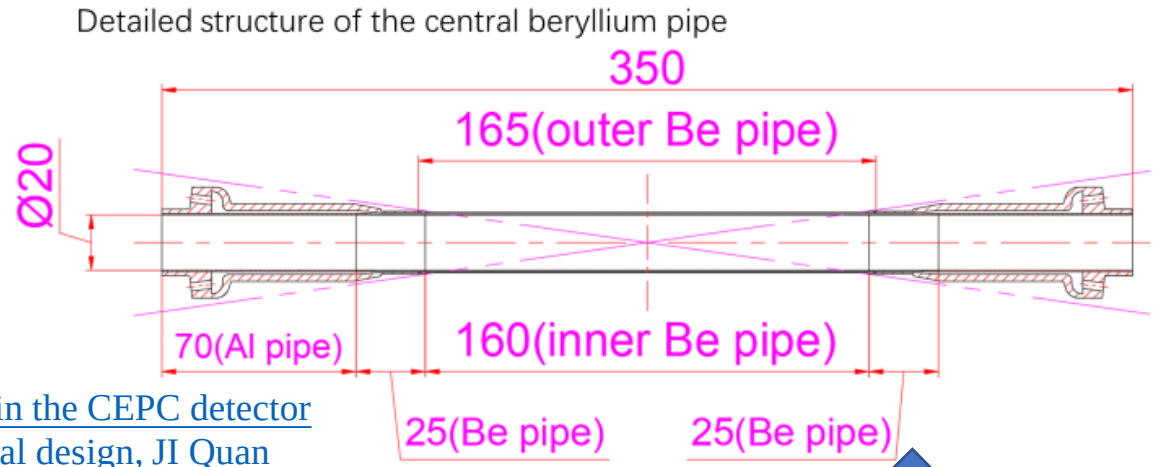
Reduce the beam pipe radius!!!



Reduce the beam pipe material!!!
Make the beam pipe thinner!!!

Radiation length	CDR	Helium gas coolant	Paraffin coolant
Au	0	0.001495	0.001495
Beryllium	0.001417	0.002409	0.002409
coolant	0	≈0	0.001037
total	0.001417	0.003905	0.004941

New beam pipe with diameter of 20 mm

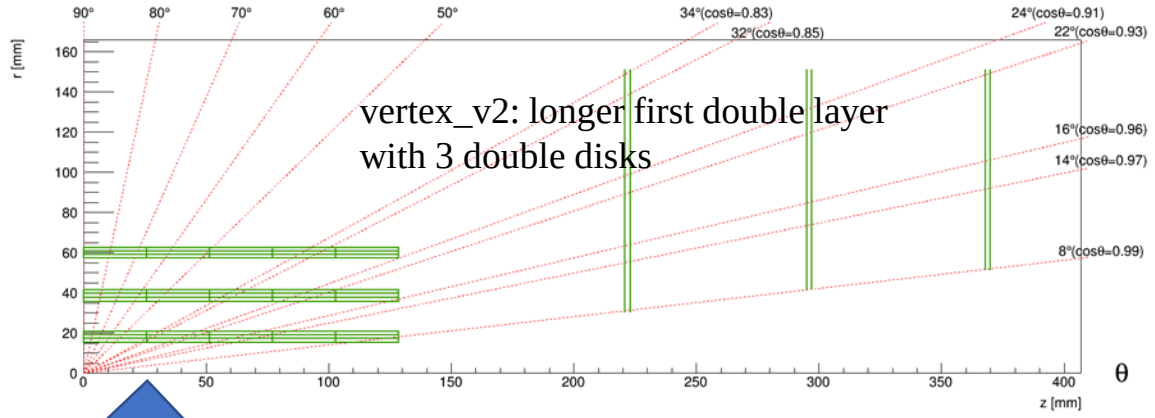


[Progress in the CEPC detector mechanical design, JI Quan]

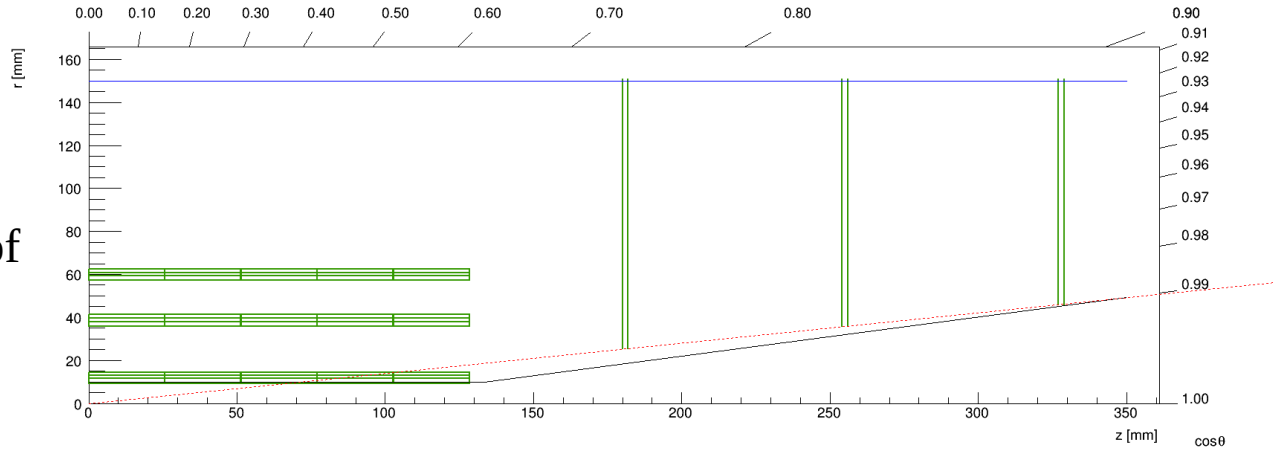
According to processing capacity:
Inner Be pipe: 0.20mm thick, 210(25+160+25)mm long
Outer Be pipe: 0.15mm thick, 165mm long

thinner

inner Beryllium layer: T= 0.5 mm
outer Beryllium layer: T= 0.35 mm



vertex_v2: longer first double layer with 3 double disks



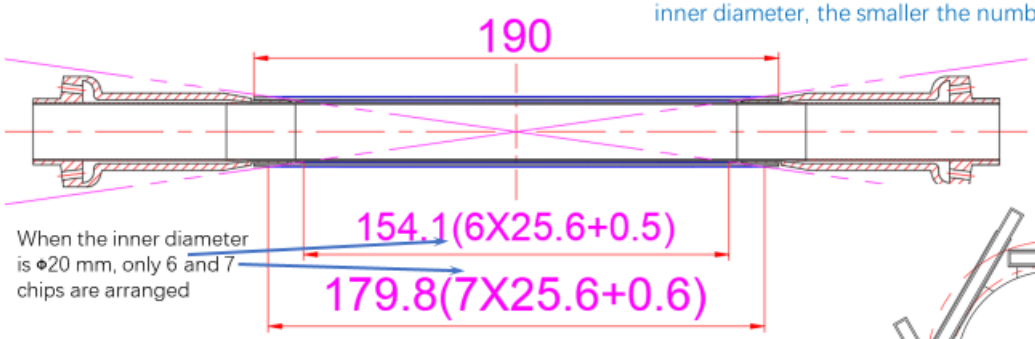
Innermost layer will be inside the border line, which is the limitation of vertex coverage.
Shorter innermost layer is required

7 ladders arrangement for innermost layer

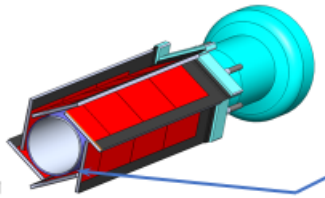
Comparison of air-cooled structures with different vertex arrangements

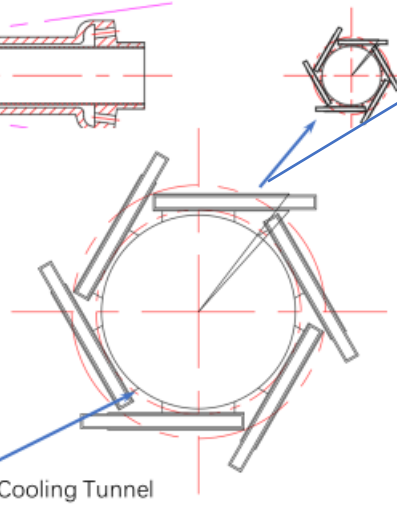
Single layer:

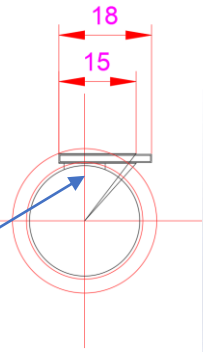
Due to the limitation of detection angle, the smaller the inner diameter, the smaller the number of chips



When the inner diameter is Φ20 mm, only 6 and 7 chips are arranged



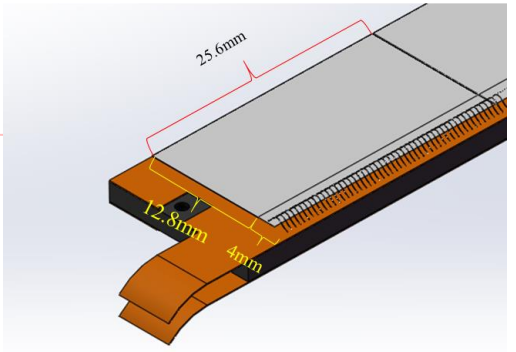




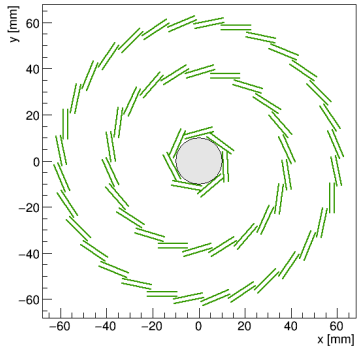
Pros:
All silicon chips are in same radius and close to the beam pipe.

Cons:
It's hard to cool the inner silicon chips which close to the beam pipe using air-forced cooling

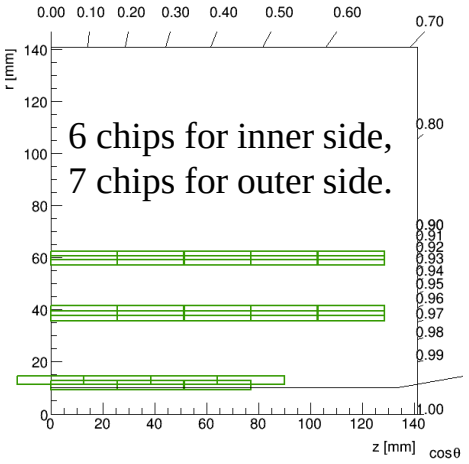
Our present ladder design:

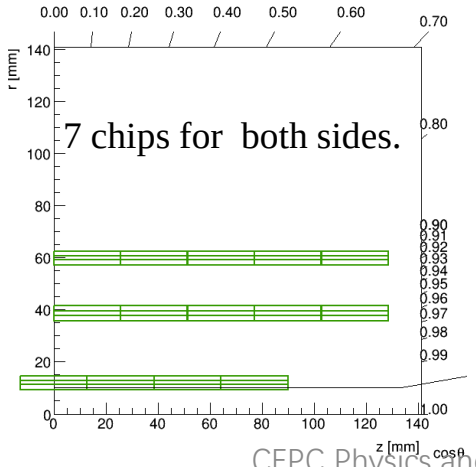


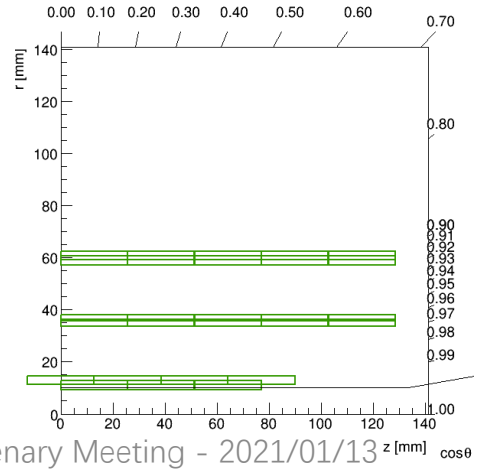
At least 7 ladders for innermost layer

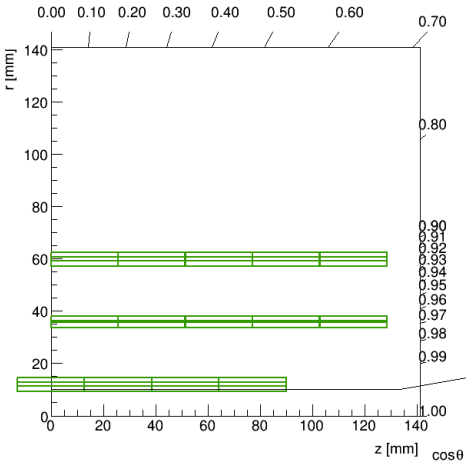


Second layer in the middle:

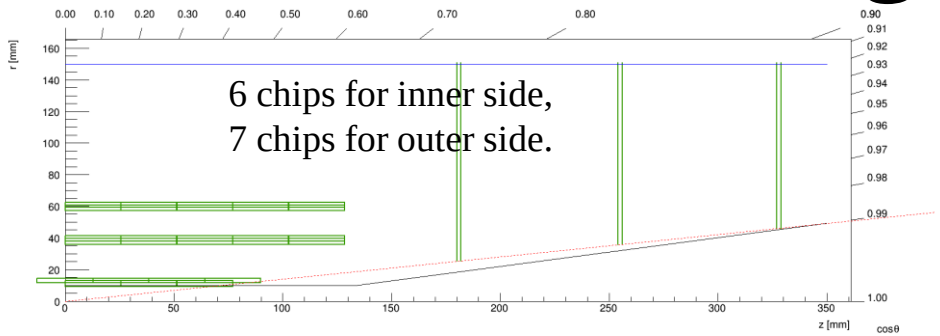




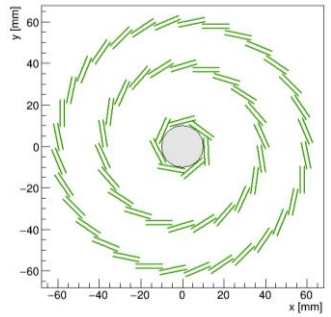




7 ladders arrangement for innermost layer

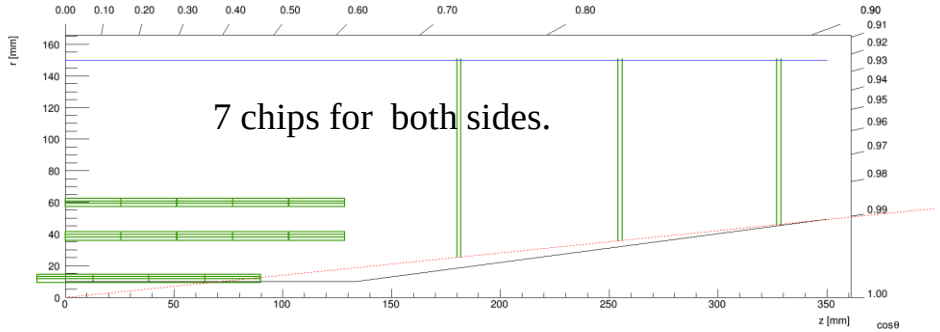


6 chips for inner side,
7 chips for outer side.

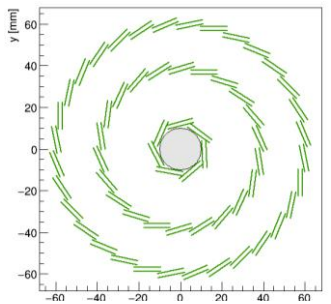


Barrel modular parameters:

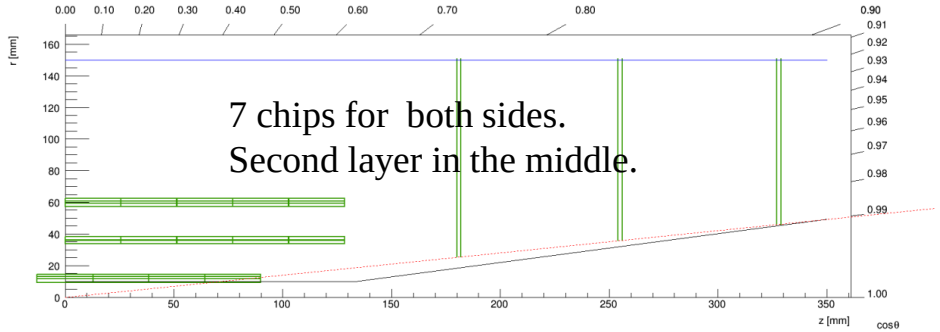
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	11.037	12.969	37.667	39.577	58.914	60.842	
z_max	77.050	89.900	128.450	128.450	128.450	128.450	
# rods	7	7	22	22	32	32	
# mods	42	49	220	220	320	320	1171



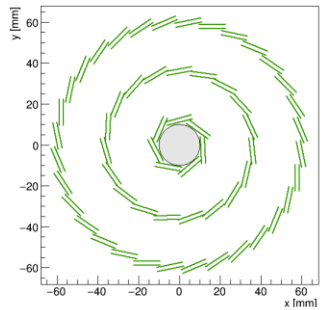
7 chips for both sides.



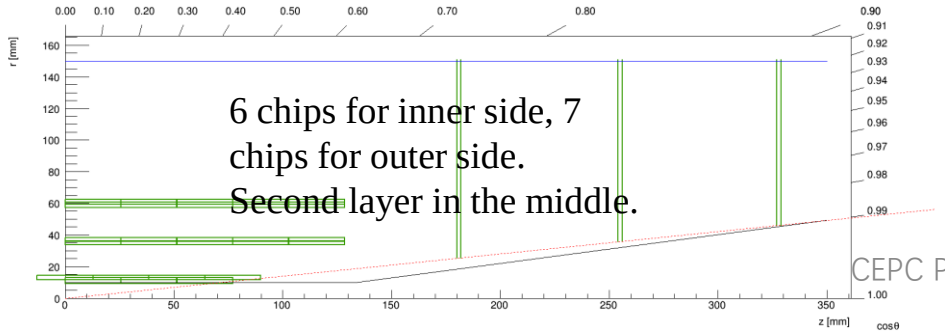
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	11.037	12.969	37.667	39.577	58.914	60.842	
z_max	89.900	89.900	128.450	128.450	128.450	128.450	
# rods	7	7	22	22	32	32	
# mods	49	49	220	220	320	320	1178



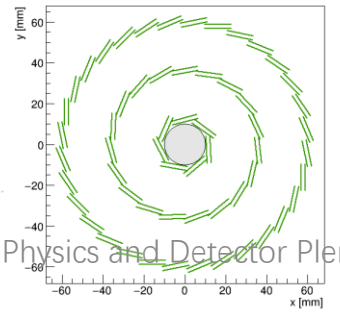
7 chips for both sides.
Second layer in the middle.



Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	11.037	12.969	35.019	36.982	58.914	60.842	
z_max	77.050	89.900	128.450	128.450	128.450	128.450	
# rods	7	7	19	19	32	32	
# mods	42	49	190	190	320	320	1111



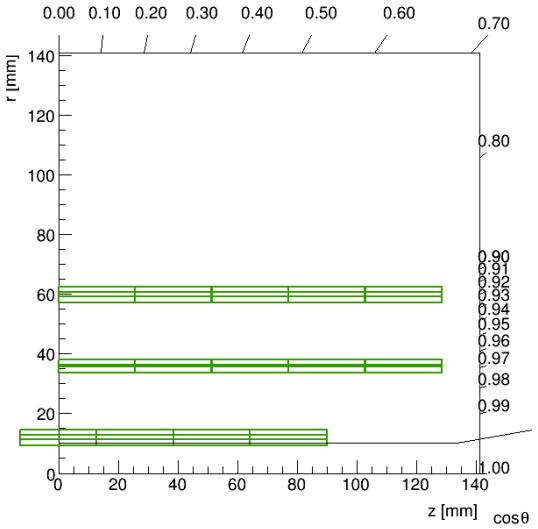
6 chips for inner side, 7 chips for outer side.
Second layer in the middle.

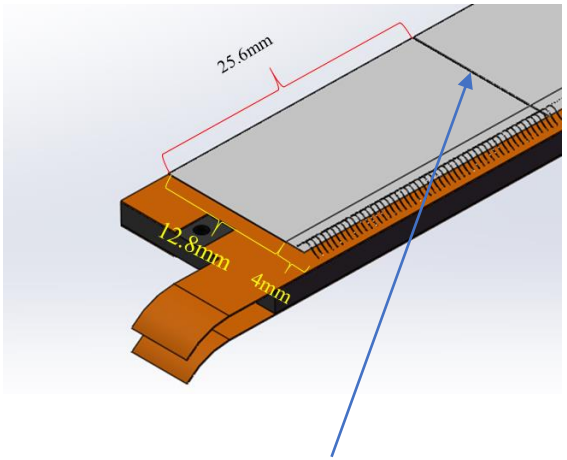


Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	11.037	12.969	35.019	36.982	58.914	60.842	
z_max	89.900	89.900	128.450	128.450	128.450	128.450	
# rods	7	7	19	19	32	32	
# mods	49	49	190	190	320	320	1118

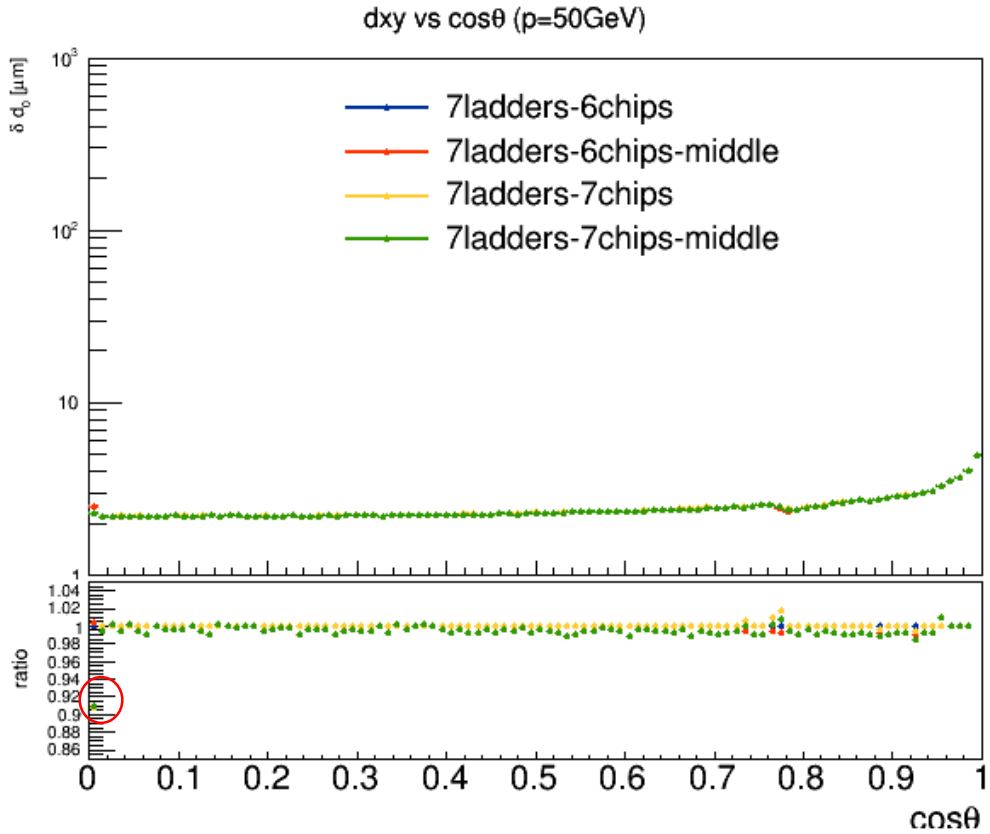
7 ladders arrangement for innermost layer

The effect of whether placing second layer in the middle or not on d0 resolution is very small.
Using 7 ladders for the innermost layer improves d0 resolution a lot at cosθ=0.
For mechanical consideration, I prefer placing second layer in the middle.

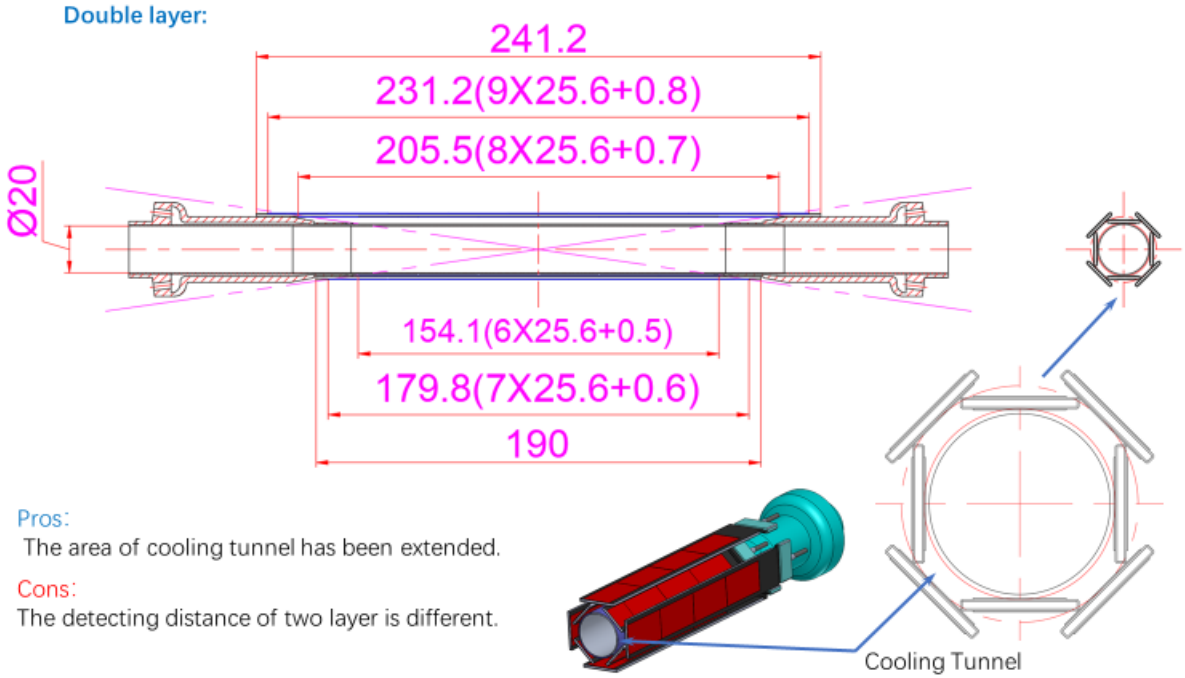


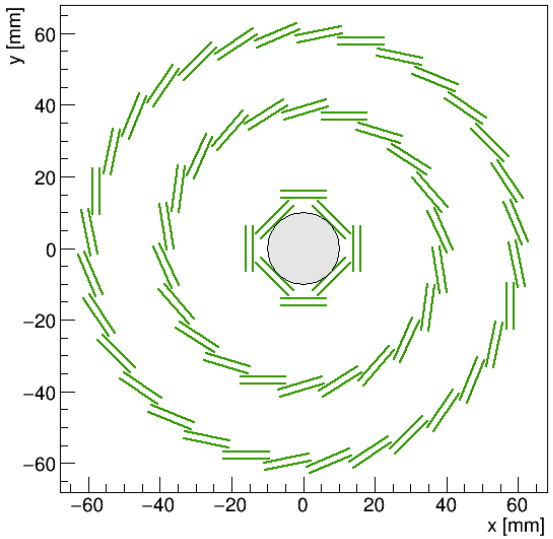


0.1 mm gap between two adjacent chips



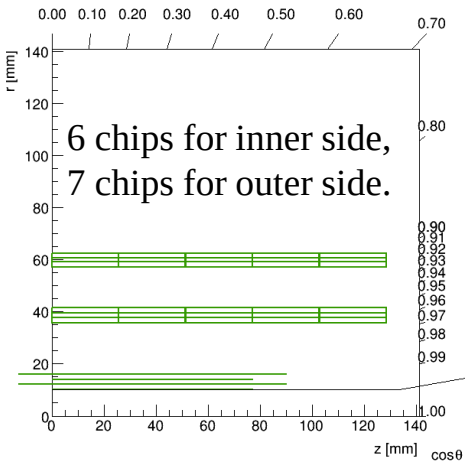
8 ladders arrangement for innermost layer

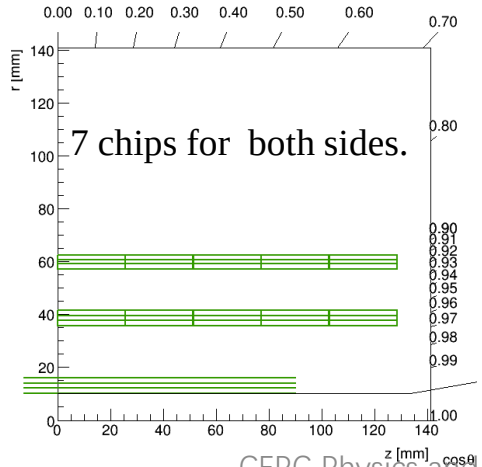


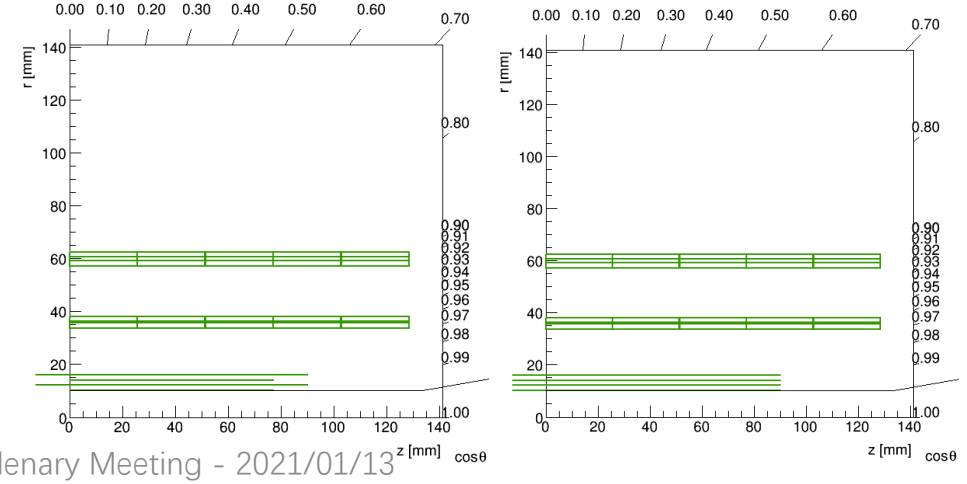


ideal condition excluding dead area of the ladders

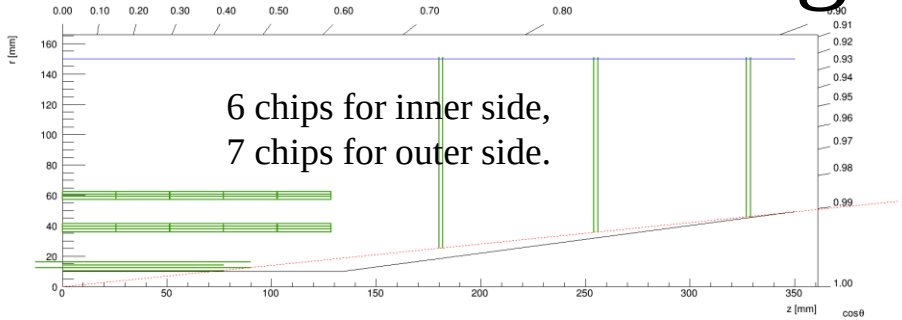
Second layer in the middle:

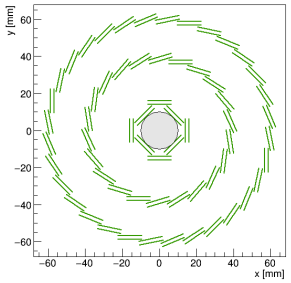






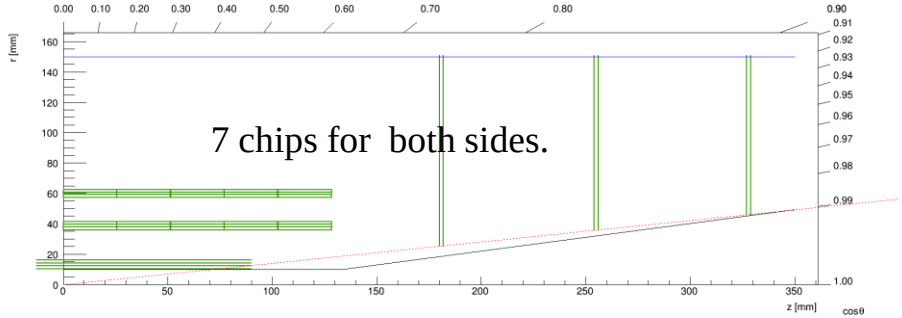
8 ladders arrangement for innermost layer

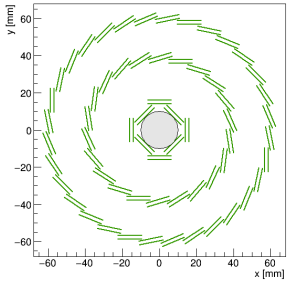




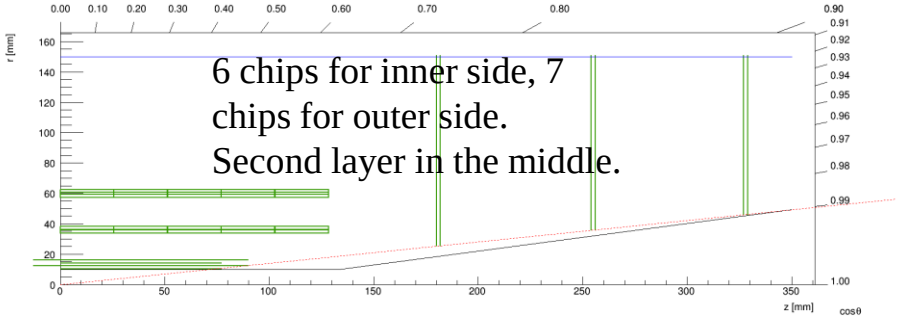
Barrel modular parameters:

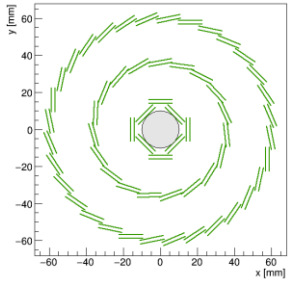
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	12.100	14.100	37.667	39.577	58.914	60.842	
z_max	77.050	89.900	128.450	128.450	128.450	128.450	
# rods	8	8	22	22	32	32	
# mods	48	56	220	220	320	320	1184



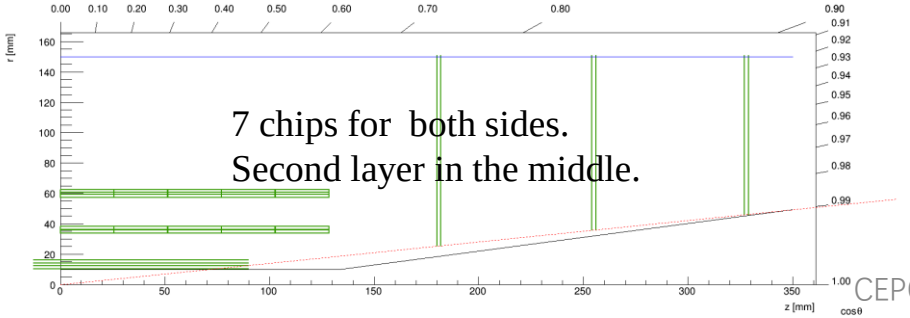


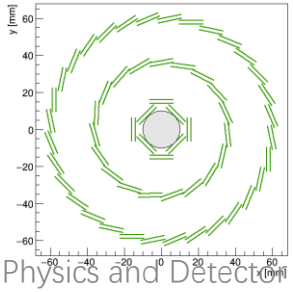
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	12.100	14.100	37.667	39.577	58.914	60.842	
z_max	89.900	89.900	128.450	128.450	128.450	128.450	
# rods	8	8	22	22	32	32	
# mods	56	56	220	220	320	320	1192





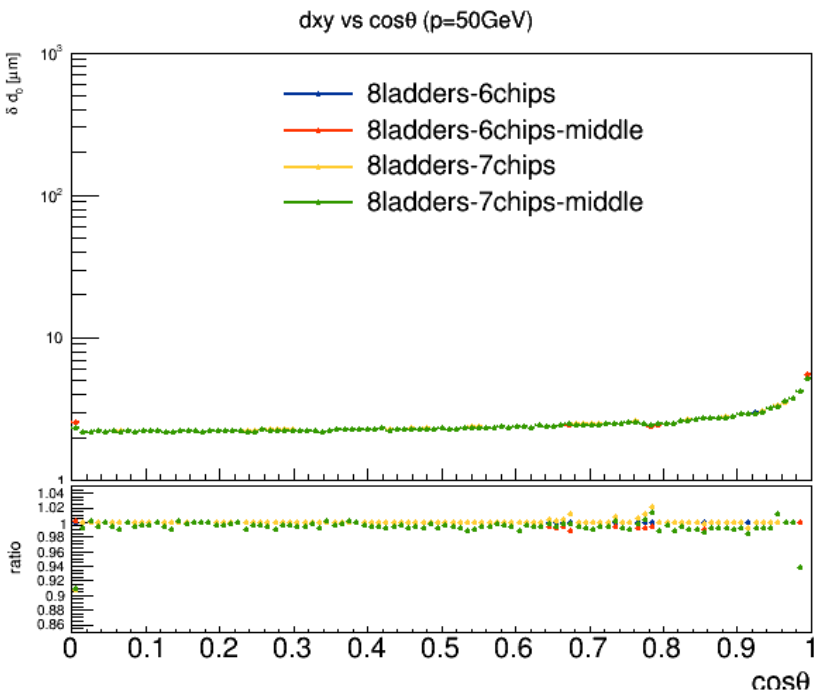
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	12.100	14.100	35.019	36.982	58.914	60.842	
z_max	77.050	89.900	128.450	128.450	128.450	128.450	
# rods	8	8	19	19	32	32	
# mods	48	56	190	190	320	320	1124





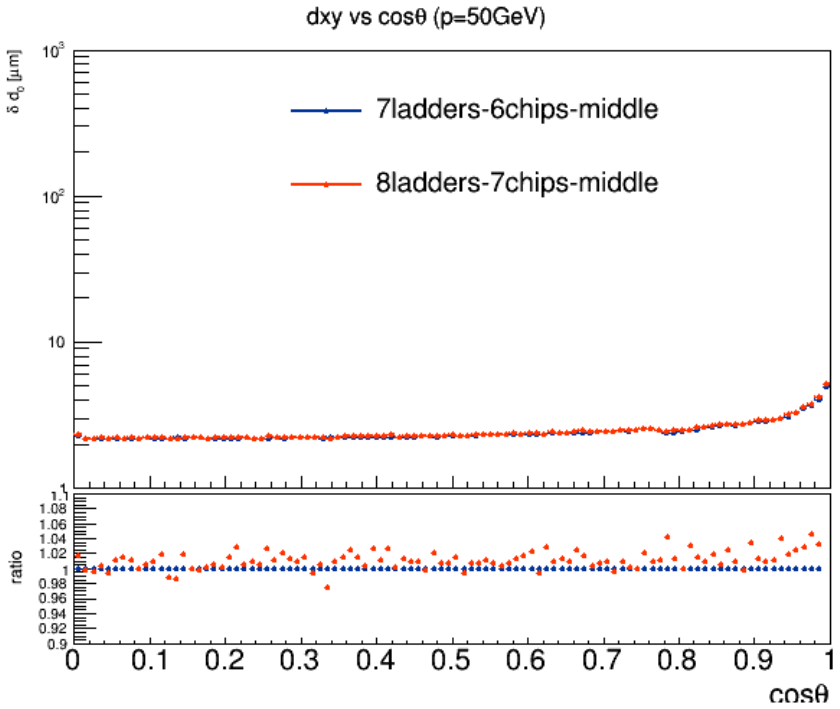
Barrel : PXB1							Total
Layer	1	2	3	4	5	6	
r	12.100	14.100	35.019	36.982	58.914	60.842	
z_max	89.900	89.900	128.450	128.450	128.450	128.450	
# rods	8	8	19	19	32	32	
# mods	56	56	190	190	320	320	1132

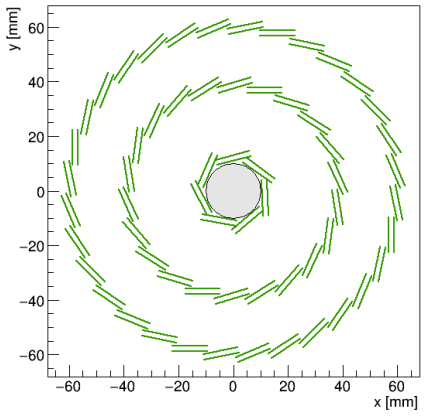
8 ladders arrangement for innermost layer

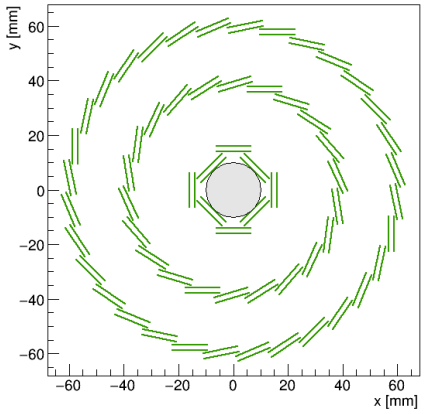


7 chips on both sides for innermost layer and second layer in the middle is better.

Comparison of different ladder arrangements for innermost layer:

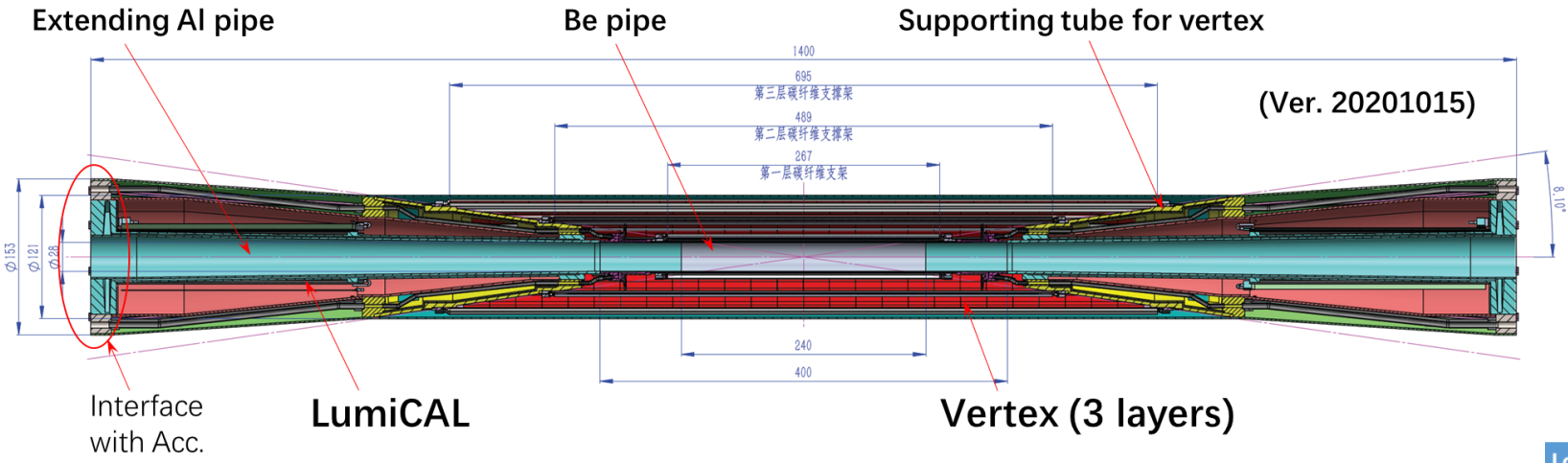






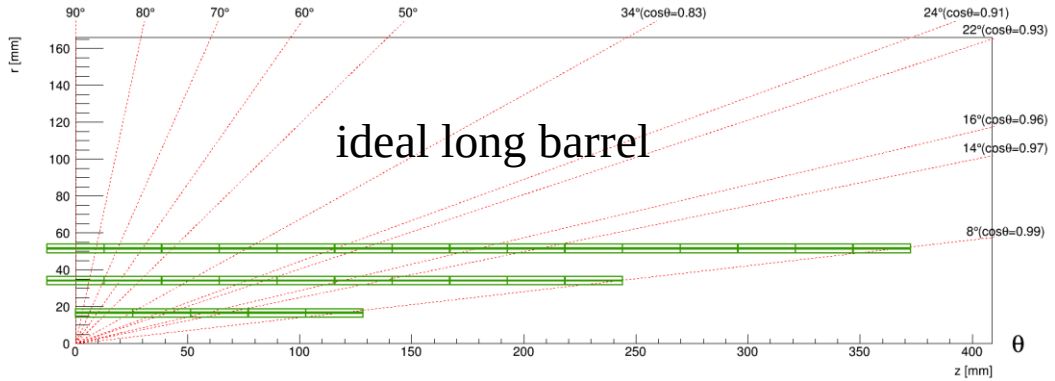
- 7-ladders arrangement is better than 8-ladders arrangement.
  - less material
  - 7 ladders are close to beam pipe.

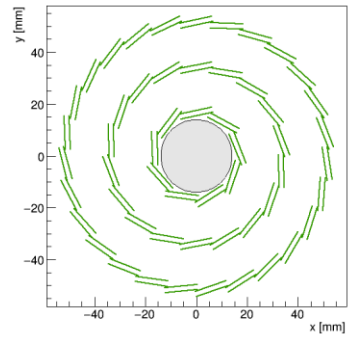
Realistic long barrel vertex



- Feasible solution for air cooling
- Realistic long barrel vertex:
  - stiffer carbon fiber ladder support
  - more cable for read-out

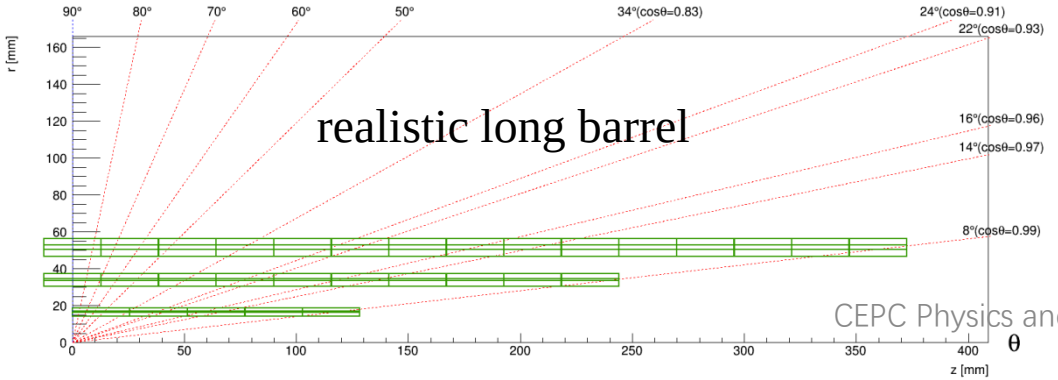
Long barrel design	Length of ladder	Chips / ladder	Readout mode	No. of flex Layers
layer1	250	10	Single end	2
layer2	500	20	double ends	2
layer3	750	30	double ends	4

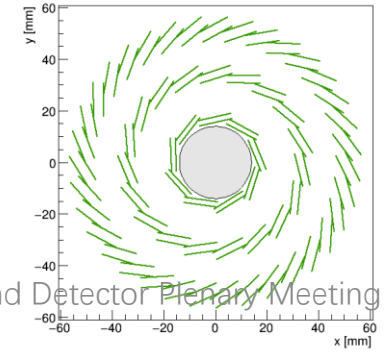




2 flex layers

	Thickness	Optimization goal
Polyimide	25um	12
Adhesive	28um	15
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
Adhesive	28um	15
Polyimide	25um	12

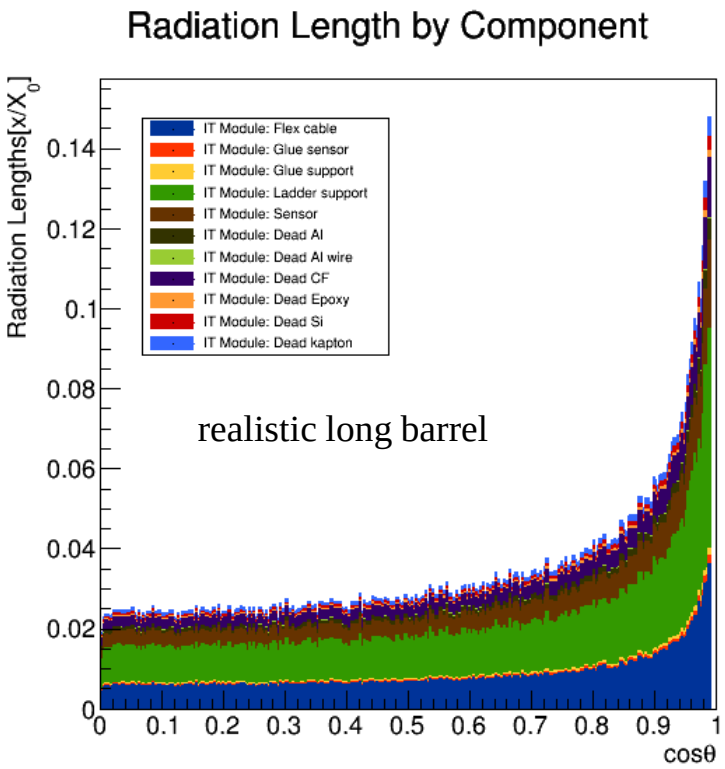


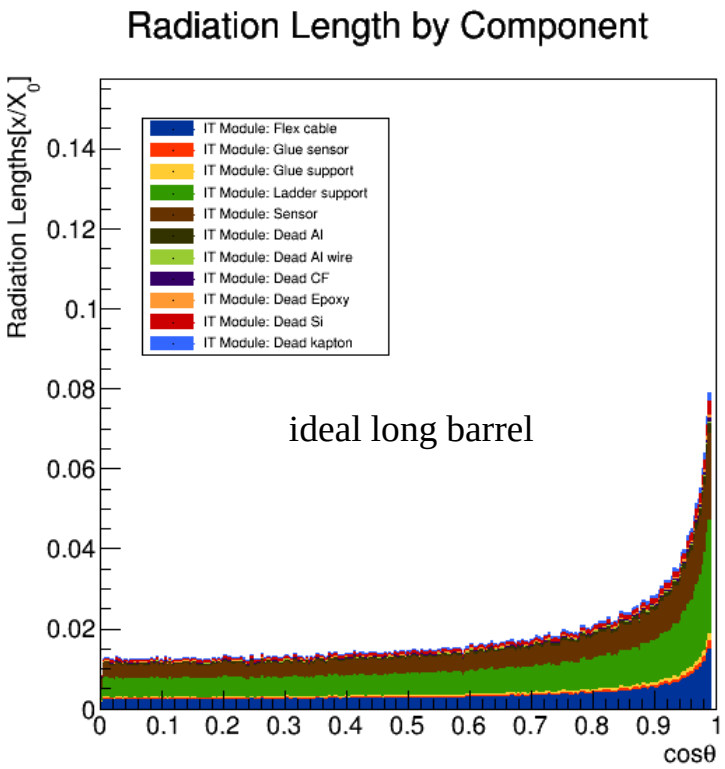


4 flex layers

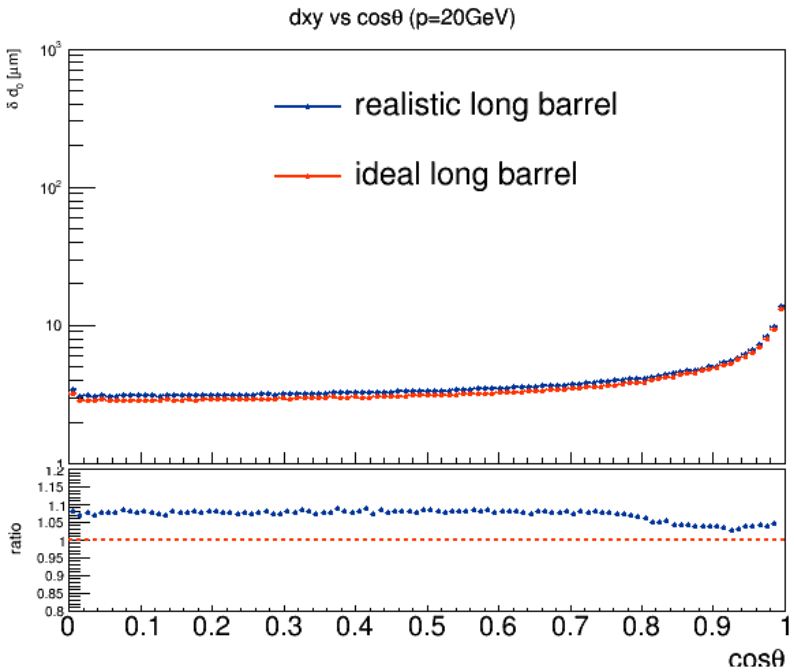
	thickness	Optimization goal
Polyimide	25um	12
Adhesive	28um	15
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
kapton+adhesive	50um	50
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
Adhesive	28um	15
Polyimide	25um	12

Realistic long barrel vertex





The material budget of realistic long barrel vertex is about twice as much as the ideal long barrel vertex.



The d0 resolution of realistic long barrel vertex is worse about 7% than ideal long barrel vertex.

Optimal vertex layout

vertex_v1

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

Disk	1	2
z	221.000	368.000

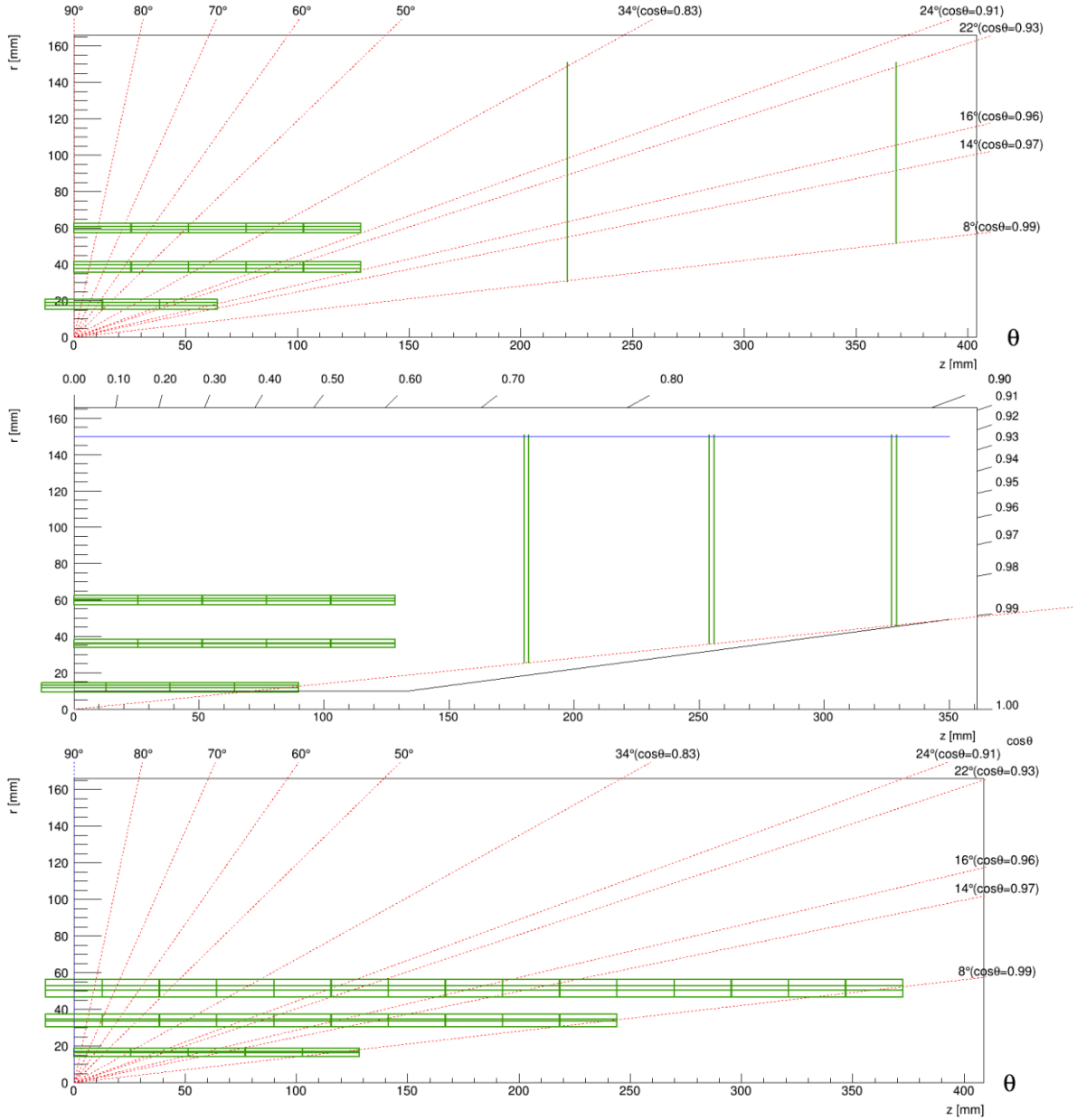
Optimal vertex

Layer	1	2	3	4	5	6
r	11.037	12.969	35.019	36.982	58.914	60.842
z_max	89.900	89.900	128.450	128.450	128.450	128.450

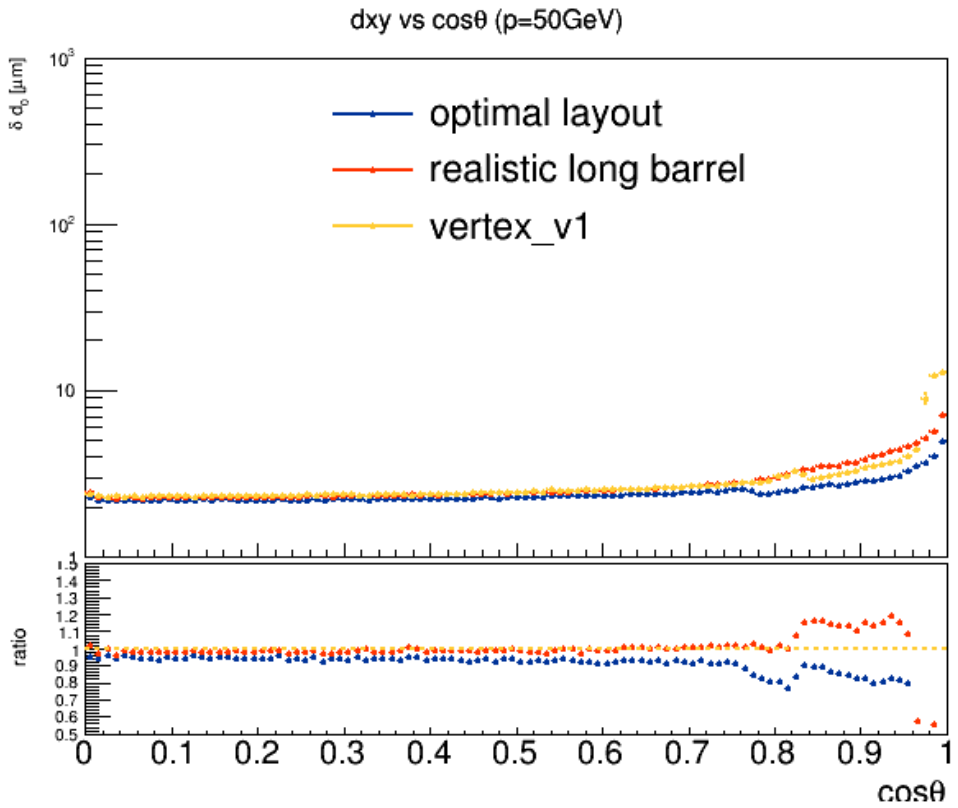
Endcap :	FPIX_1	FPIX_2	FPIX_3	FPIX_4	FPIX_5	FPIX_6
Disk	1	1	1	1	1	1
z	180.000	182.000	254.000	256.000	327.000	329.000

Realistic long barrel design

Layer	1	2	3	4	5	6
r	15.523	17.479	33.019	34.982	50.522	52.479
z_max	128.450	128.450	244.100	244.100	372.600	372.600



d0 resolution of optimal vertex layout



The d0 resolution of optimal vertex layout is much better than realistic long barrel vertex and vertex_v1 (realistic implementation of CDR vertex) layout, especially in the front region (20% and even more).

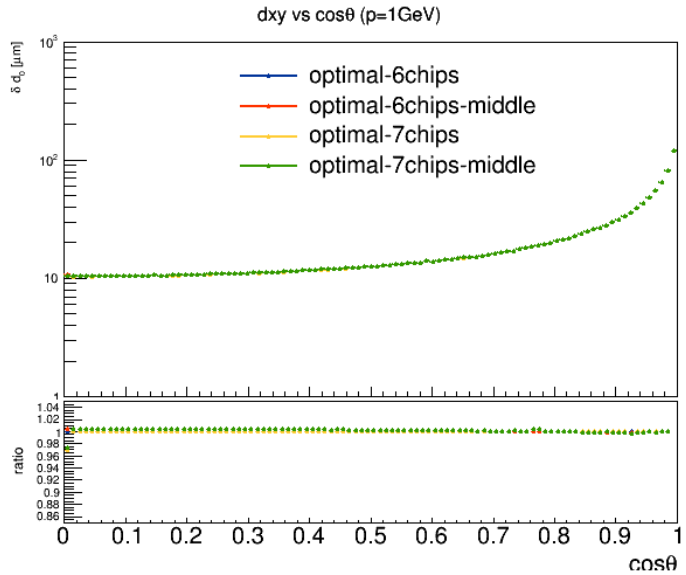
- smaller radius of beam pipe
- more disks
- longer innermost layer

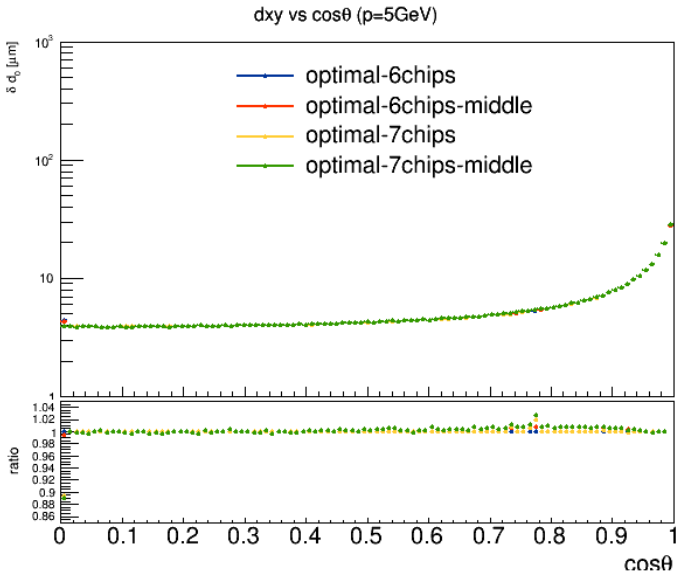
Summary

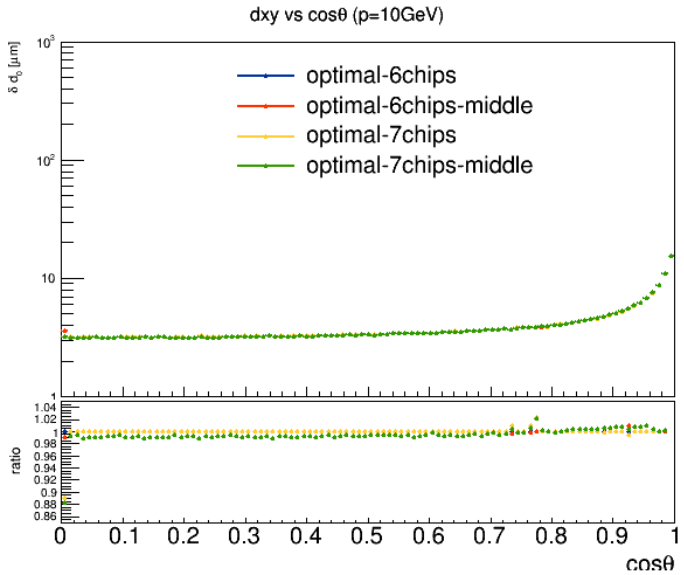
- New optimal vertex layout which combines the new beam pipe design and previous optimal vertex layout is studied.
  - The arrangement with 7 ladders and 7 chips on both sides of each ladder is a better choice for innermost layer.
  - Placing second layer in the middle is better considering both mechanics and performance.
  - The performance of this new optimal vertex is much better than the realistic implementation of CDR vertex and realistic long barrel vertex (20% and even more).

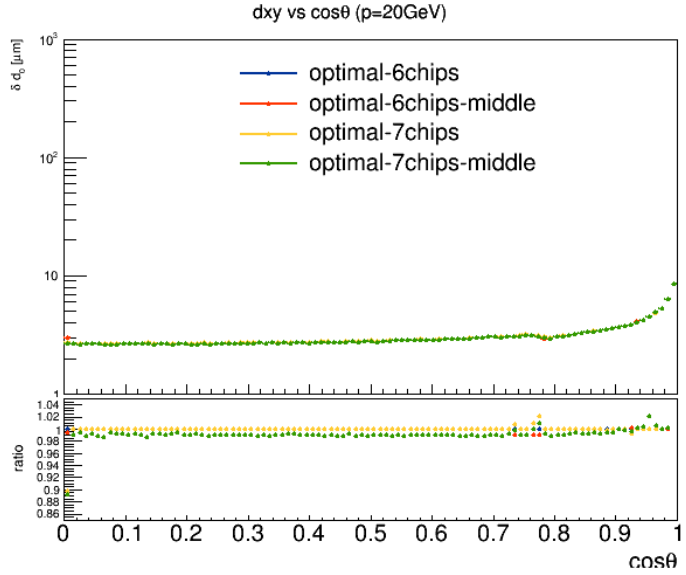
Backup

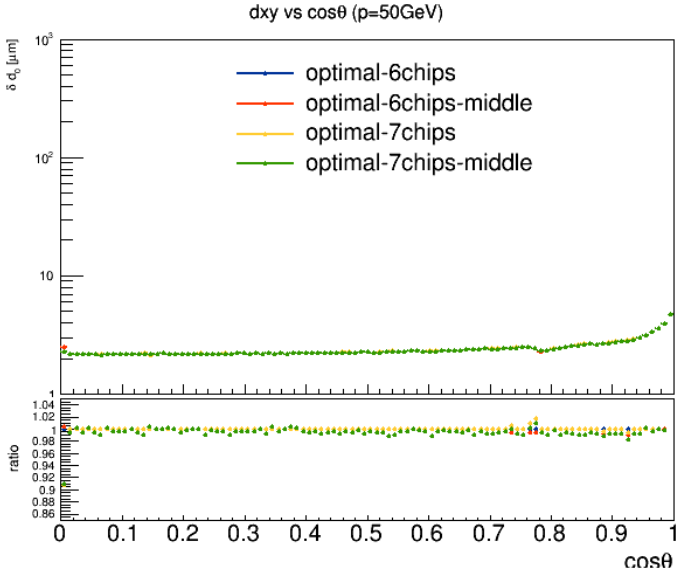
7 ladders arrangement for innermost layer

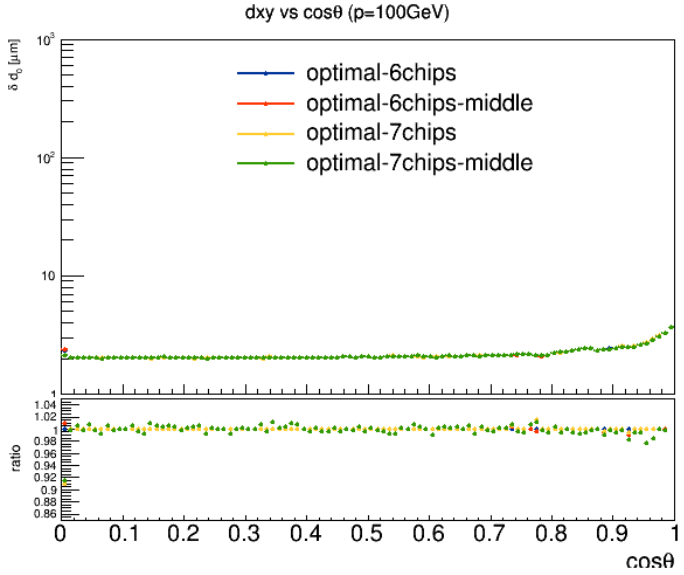




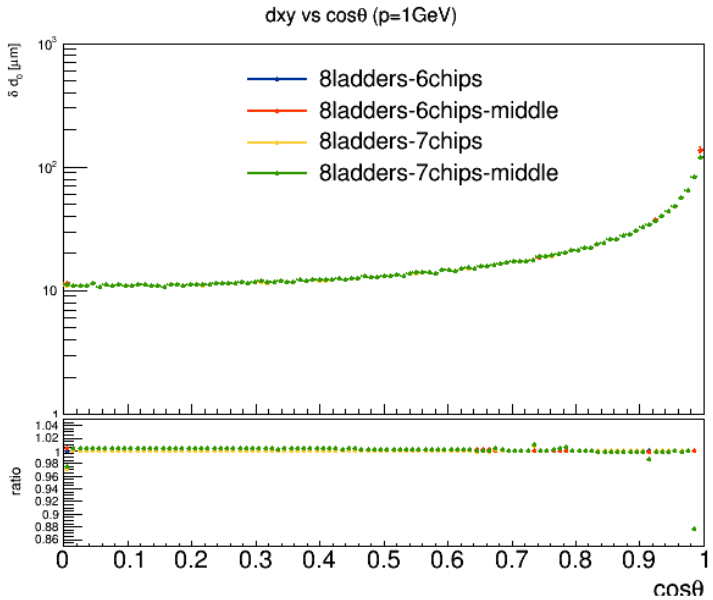


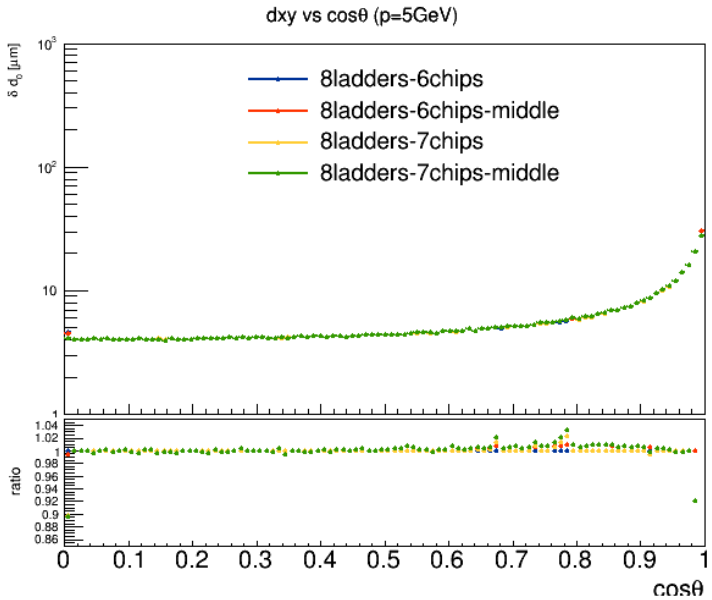


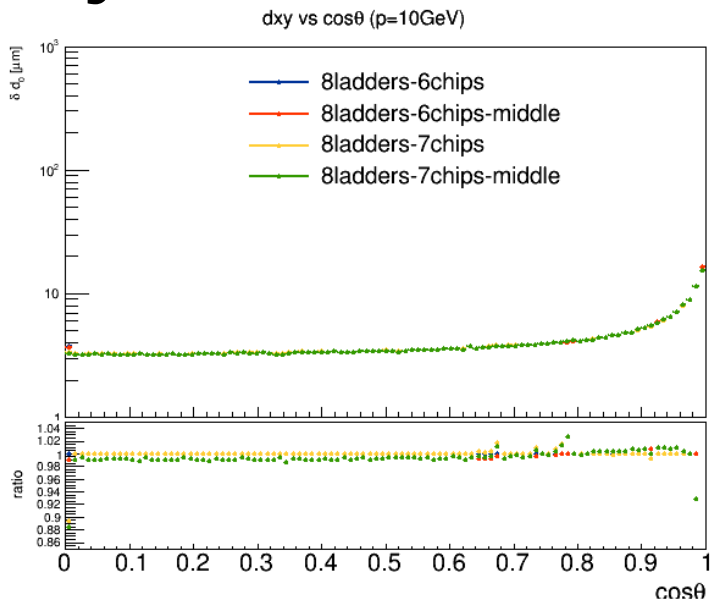


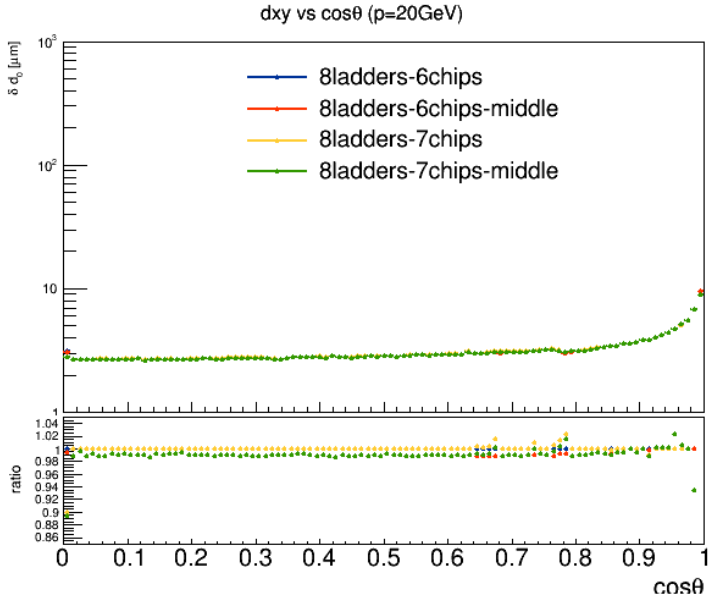


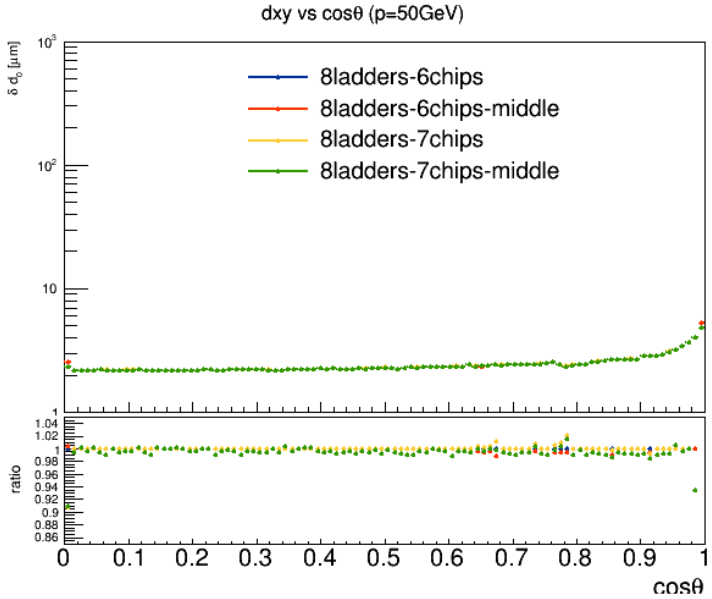
8 ladders arrangement for innermost layer

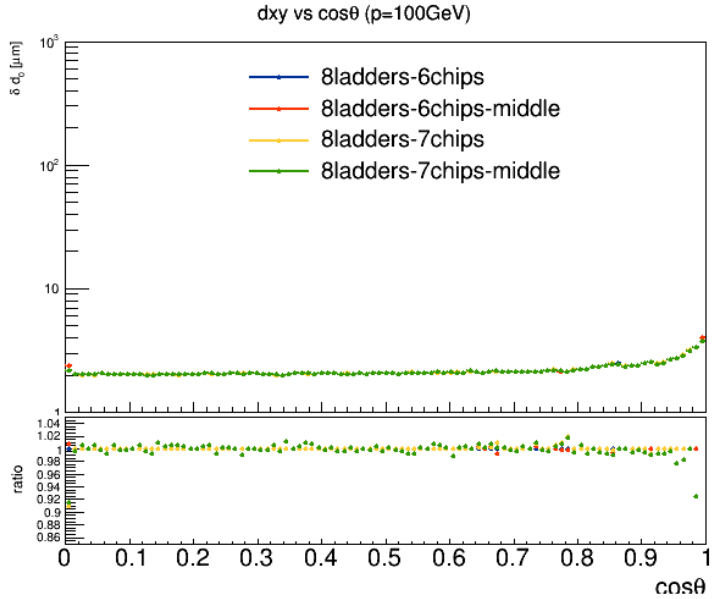




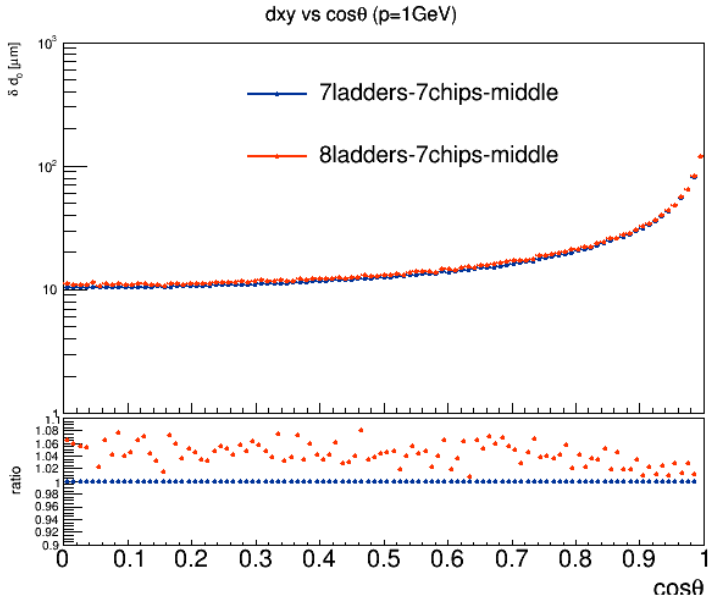


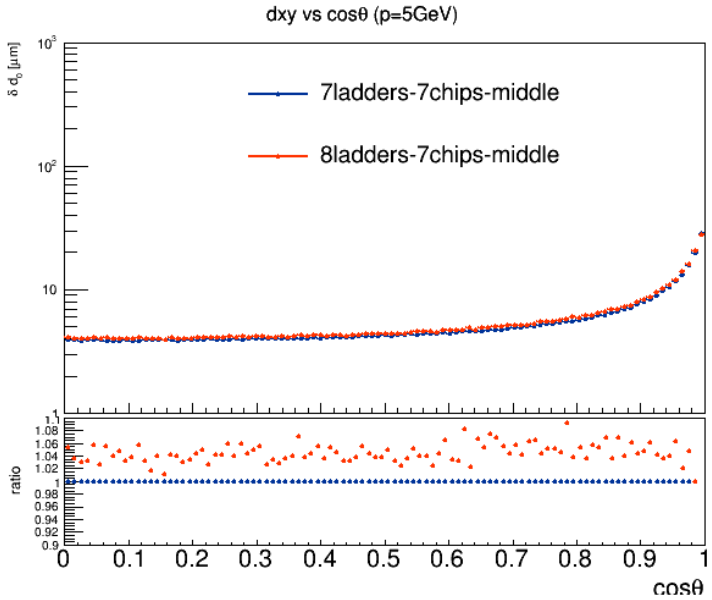


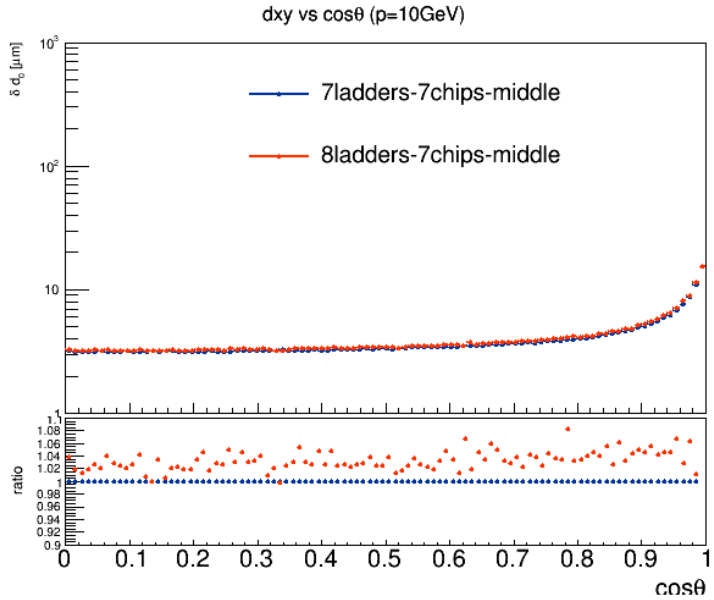


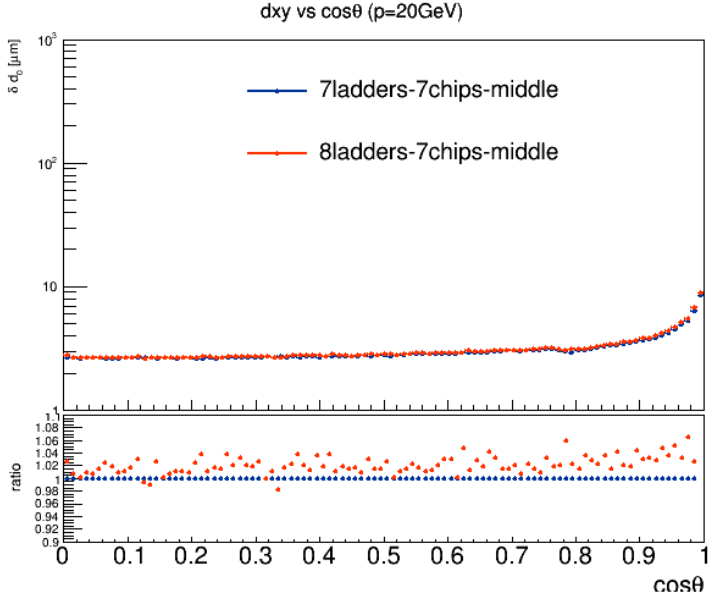


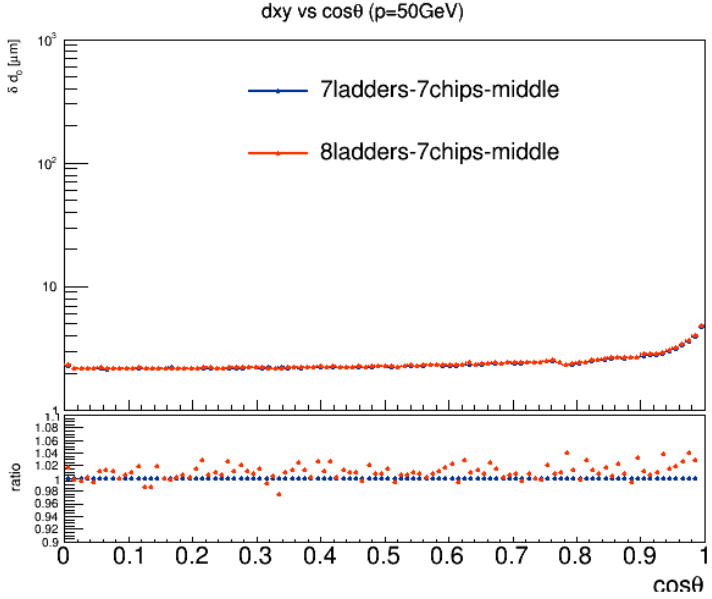
Comparison of different ladder arrangements for innermost layer

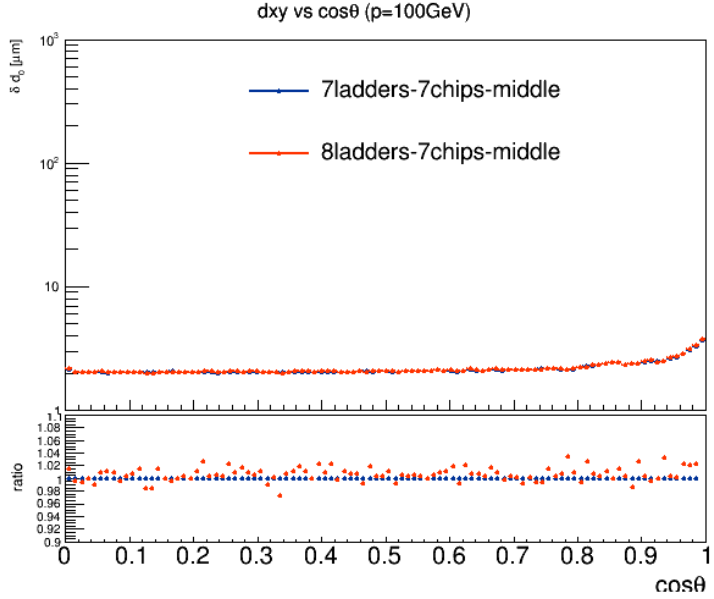




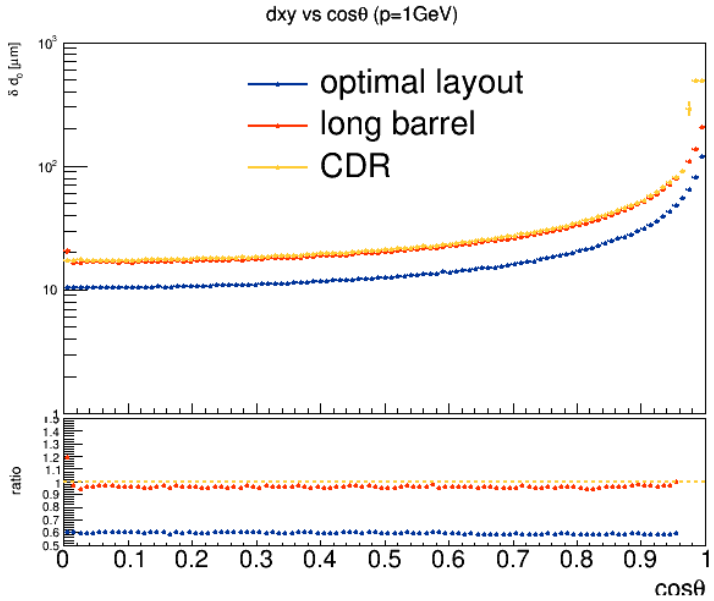


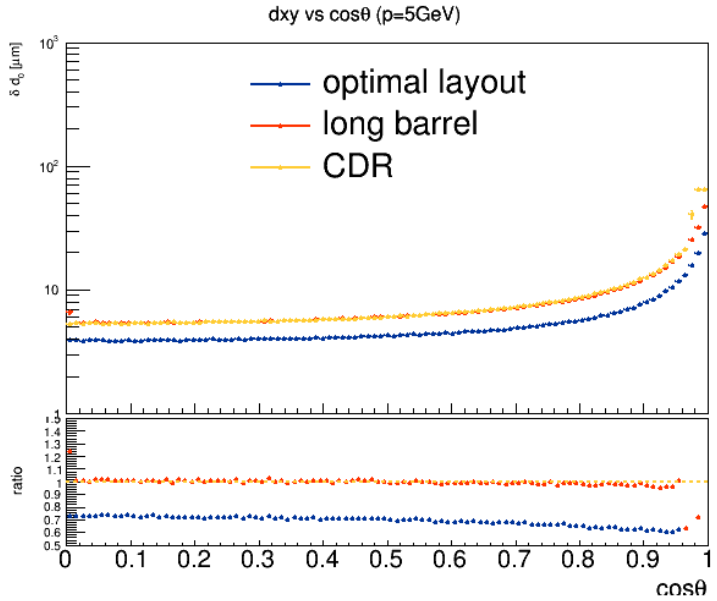


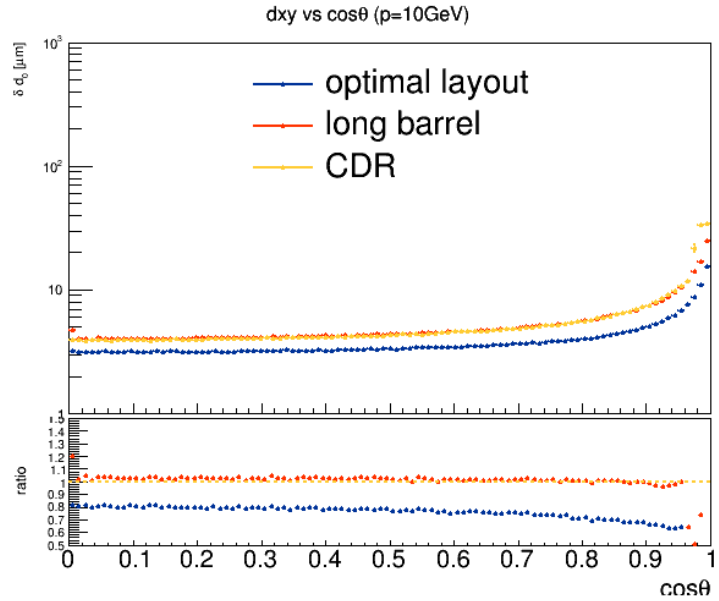


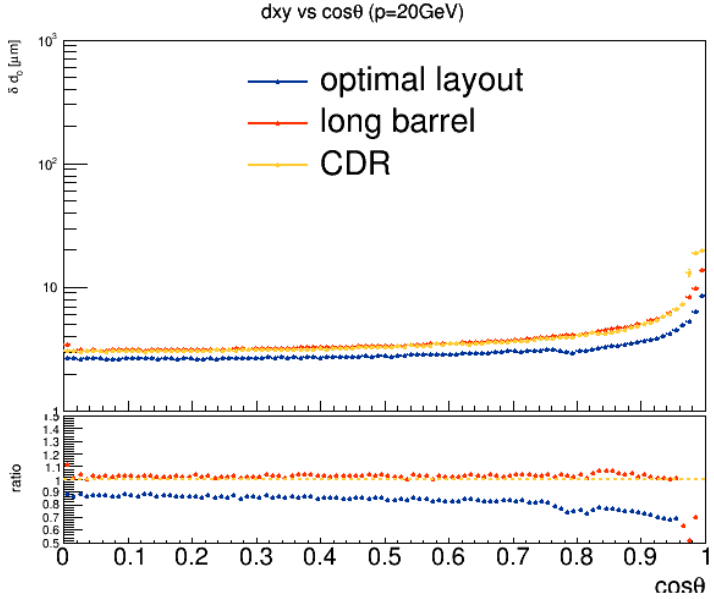


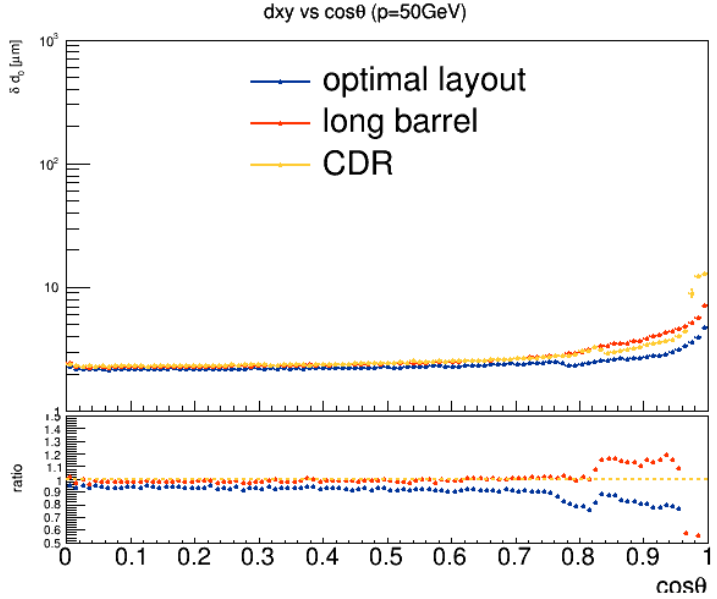
d0 resolution of optimal vertex layout

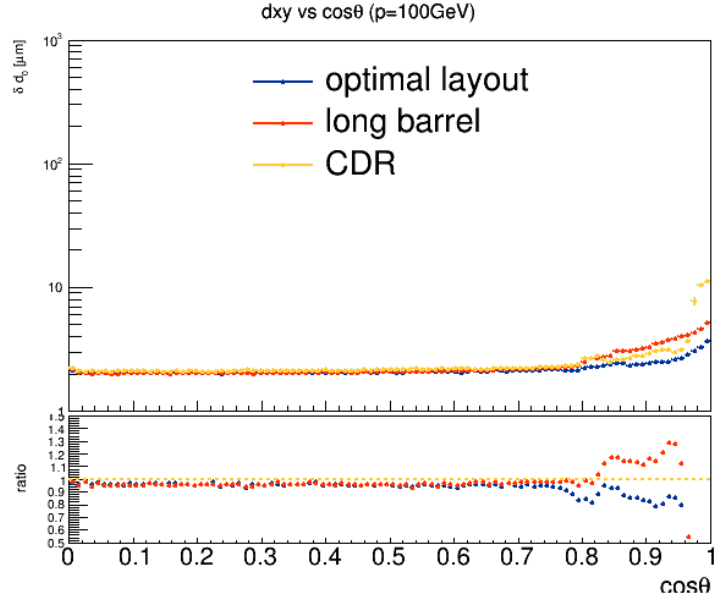




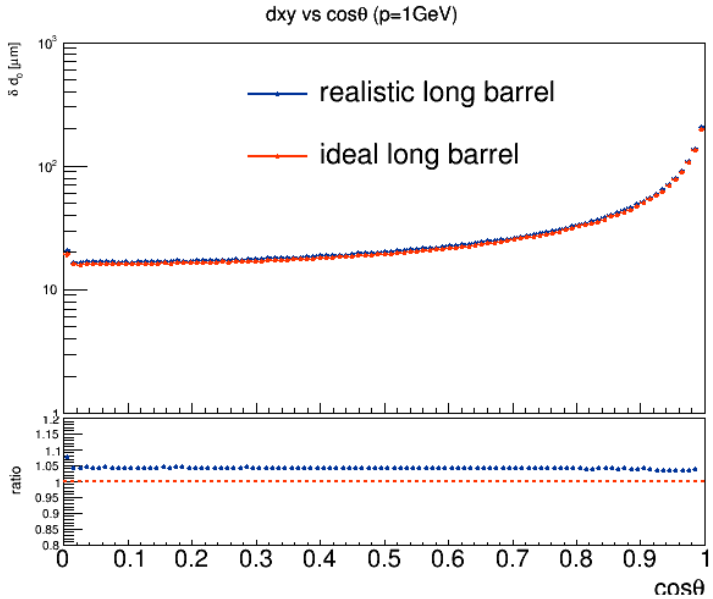


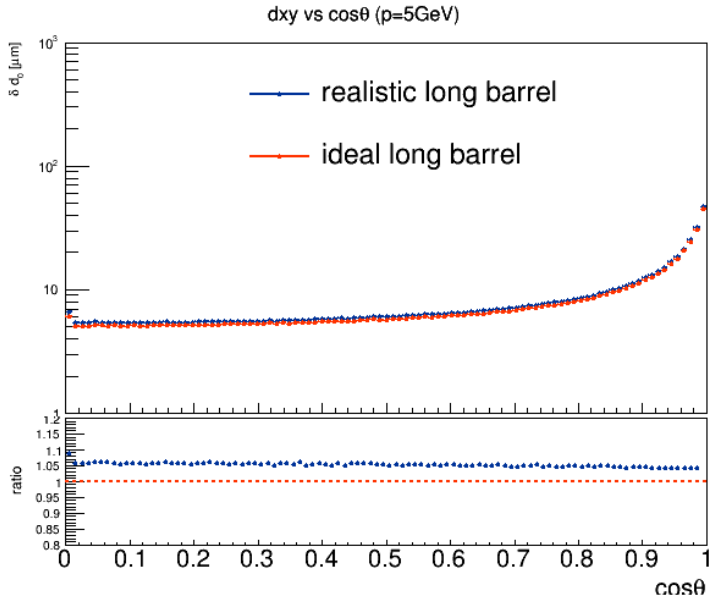


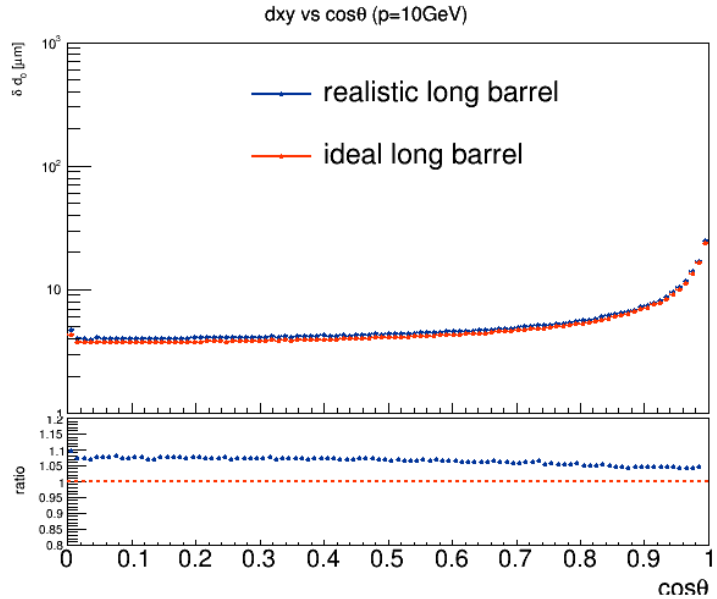


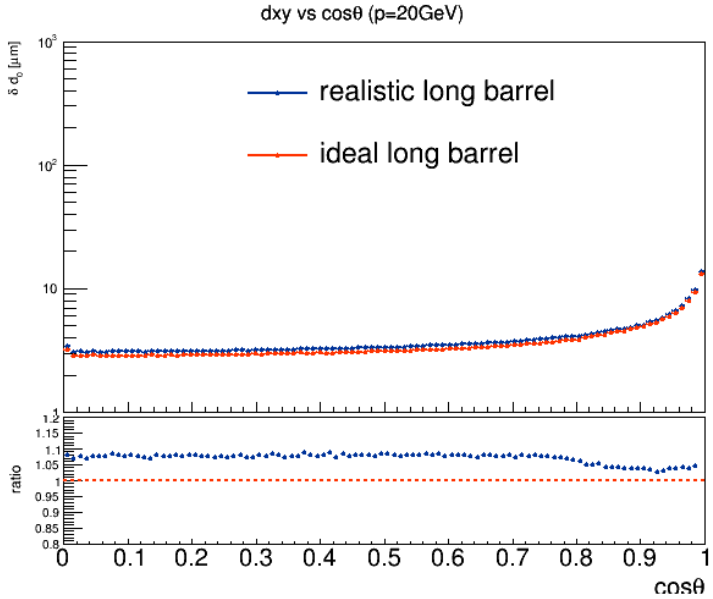


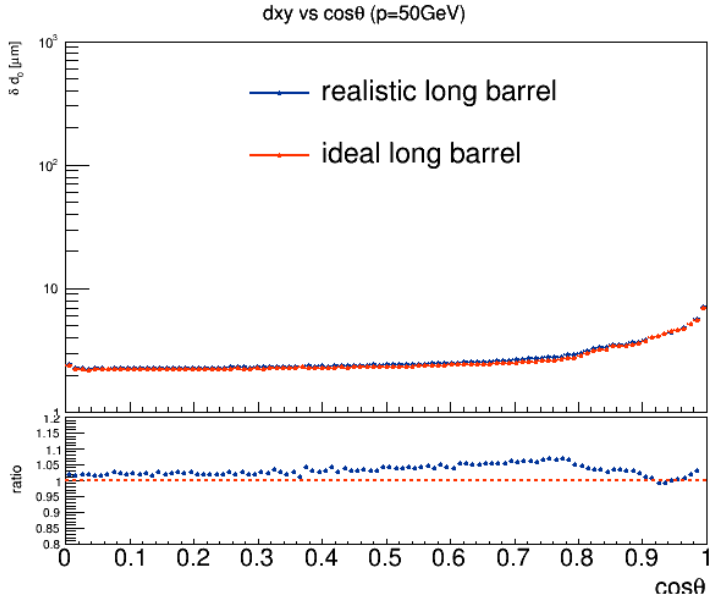
New long barrel

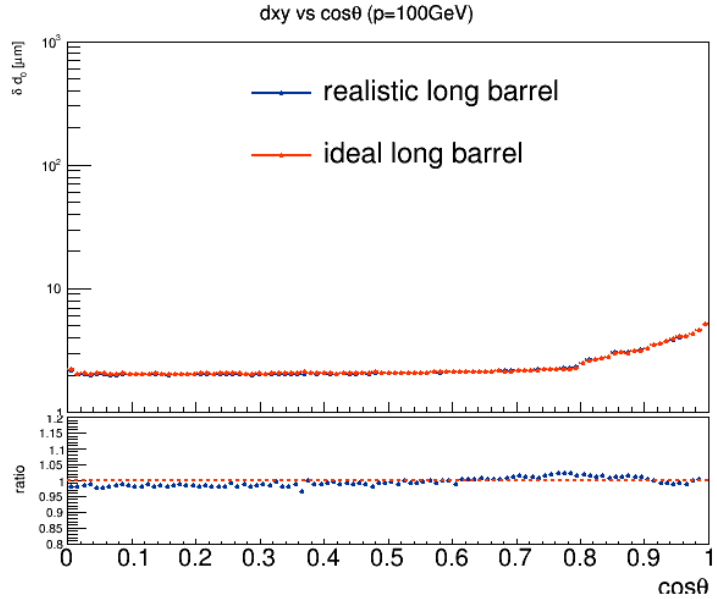




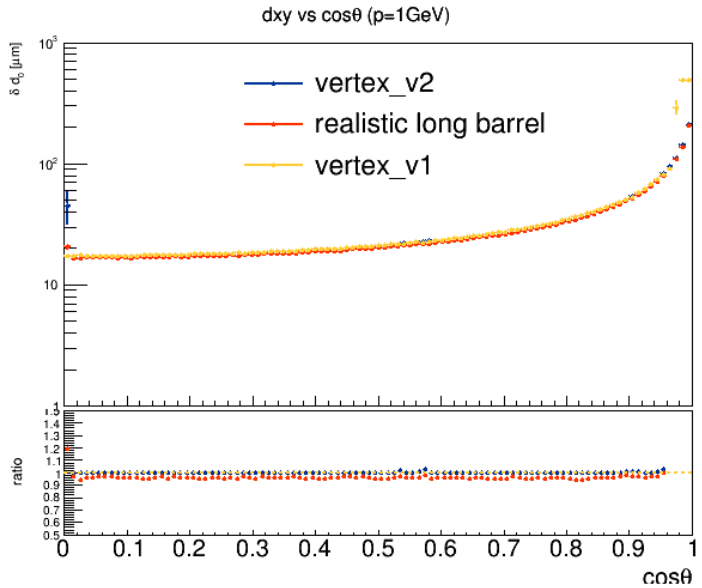


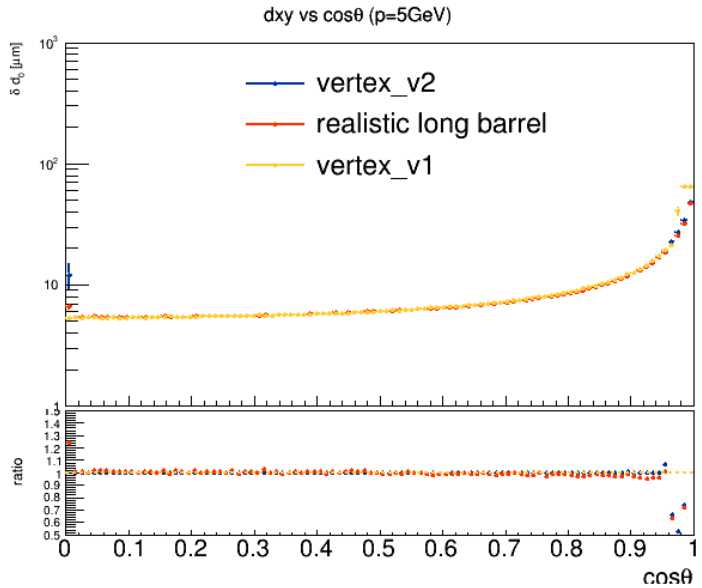


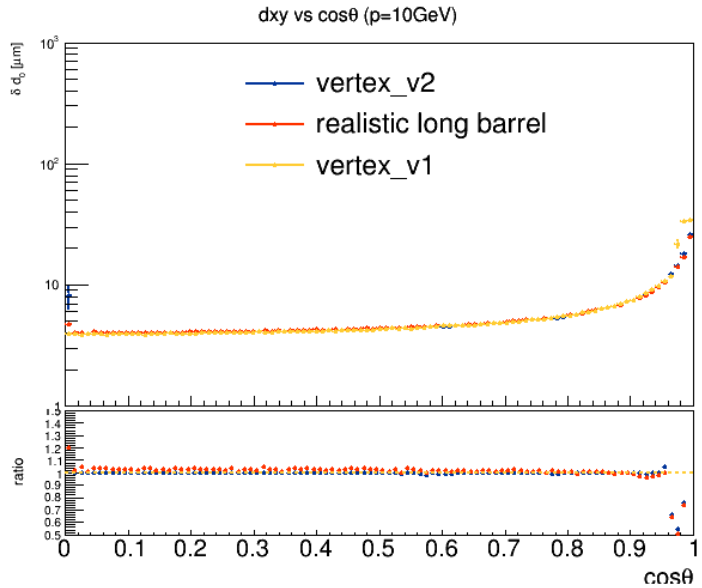


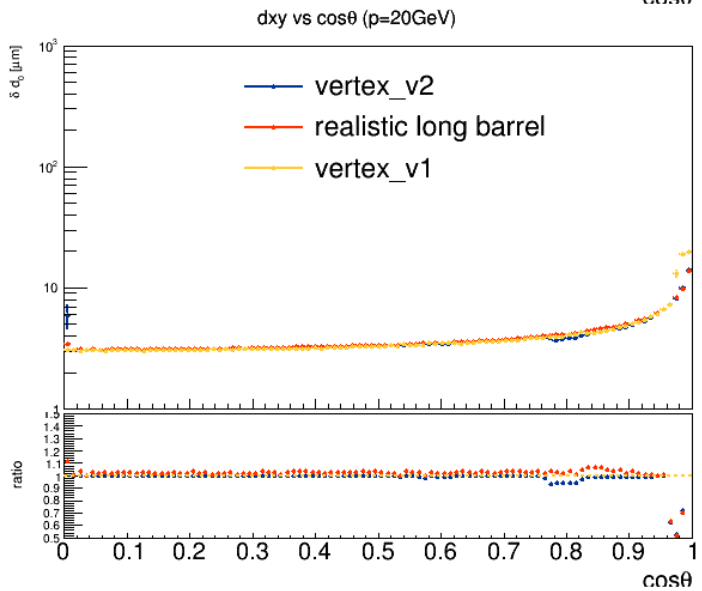


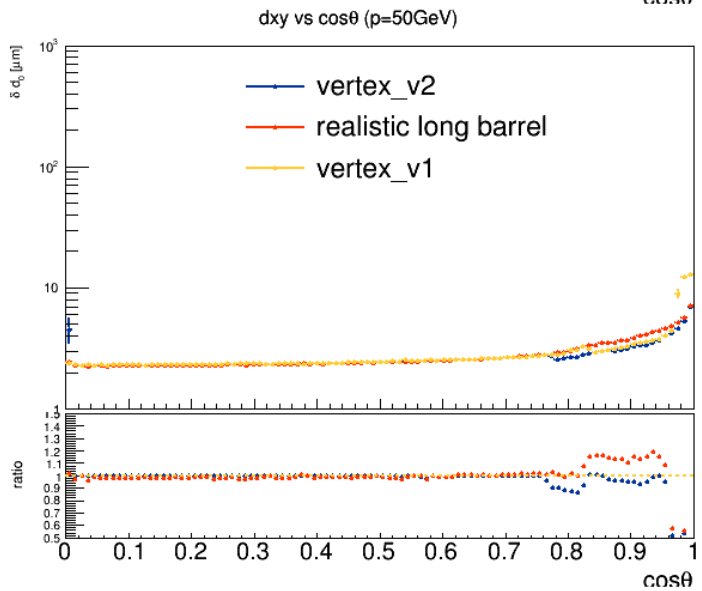
vertex_v2 performance

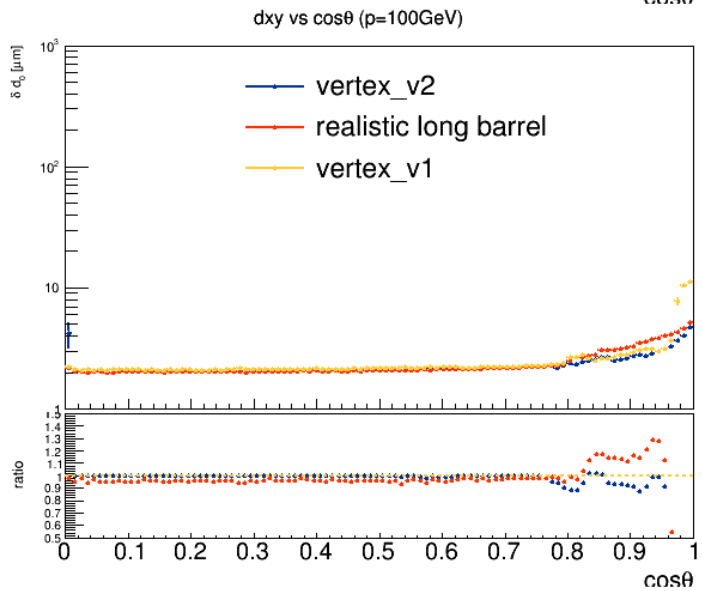






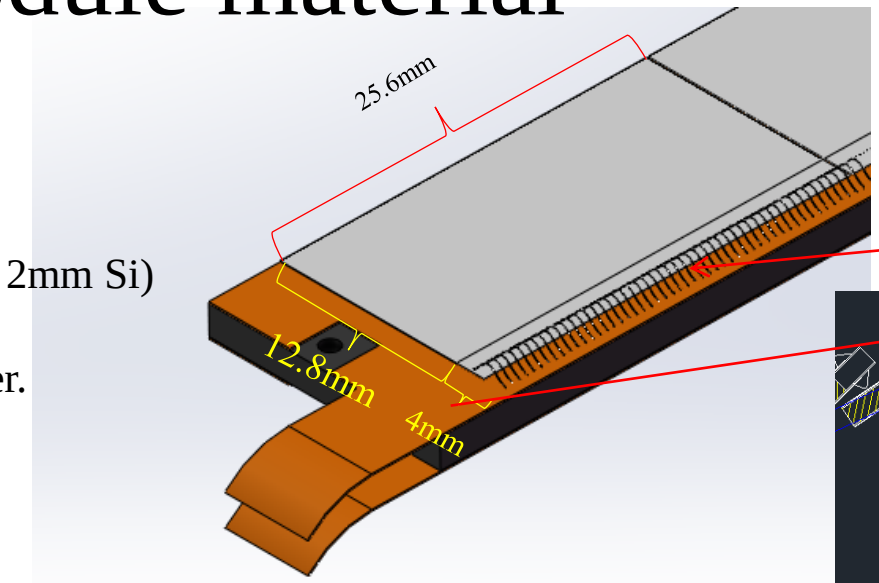




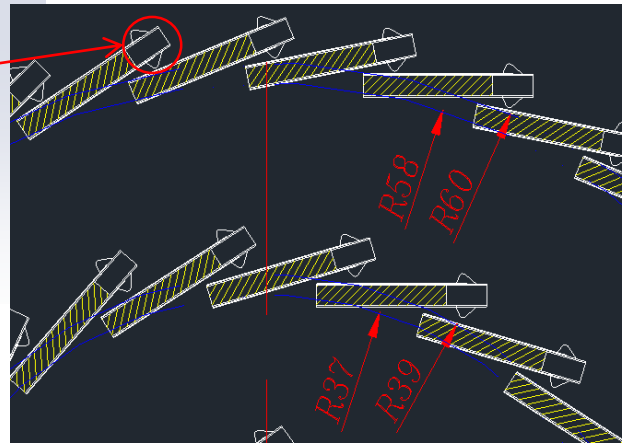


New pixel module material

Top view:
active area: 12.8mm × 25.6mm
dead area: 4mm × 25.6mm (only 2mm Si)
Side view:
5 symmetric layer, gluing together.



Al wire



One half dead area:

Sensor(Si, 25um)
Al wire
glue(Epoxy, 7.5um)
Al(26.7um)
Kapton(74um)
Glue(Epoxy, 52.5um)
Ladder support(carbon fiber,175um)

Sensor(Si, 50um)
glue(Epoxy, 15um)
Al(26.7um)
Kapton(74um)
Glue(Epoxy, 30um)
Ladder support(carbon fiber,350um)
Glue(Epoxy,30um)
Kapton(74um)
Al(26.7um)
Glue(Epoxy, 15um)
Sensor(Si, 50um)

(1) Sensor
(2) Flex cable
(3) Ladder support
(4) Flex cable
(5) sensor

recent discussion shows that we need at least 2 layer Al in flex cable

	Thickness	Optimization goal
Polyimide	25um	12
Adhesive	28um	15
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
Adhesive	28um	15
Polyimide	25um	12

Ladder of realistic long barrel vertex

detector layers 5-6: width 16.8 mm, high 4 mm

surface thickness: 0.25

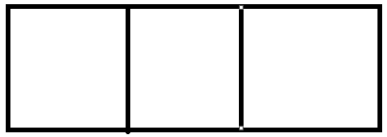
inside ribs thickness : 0.6 number: 2 intotal

detector layers 3-4: width 16.8 mm, high 3 mm

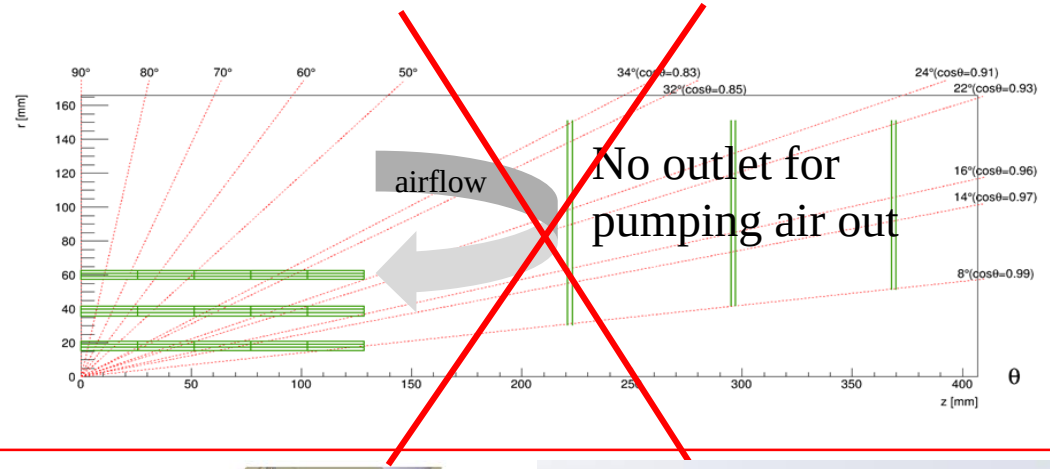
surface thickness: 0.2

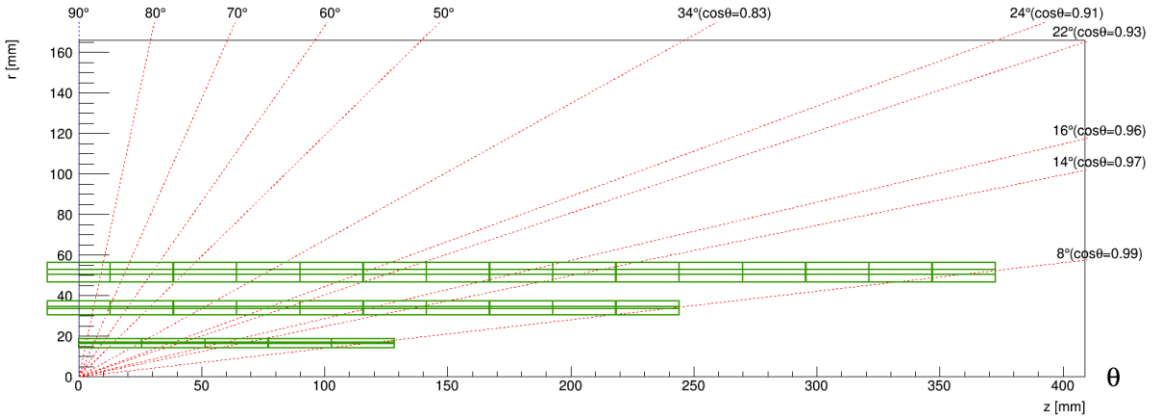
inside ribs thickness : 0.6 number: 2 intotal

Carbon fiber support:

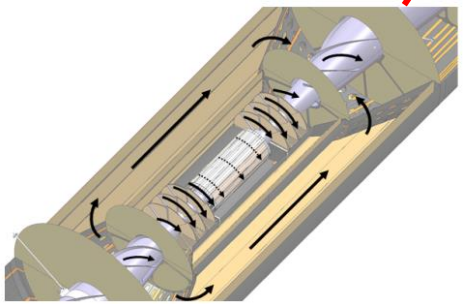


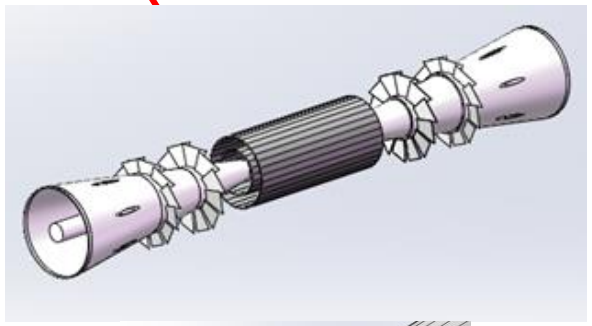
Vertex design including air cooling



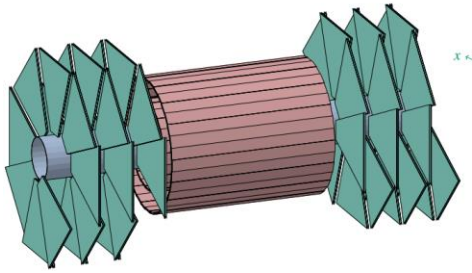


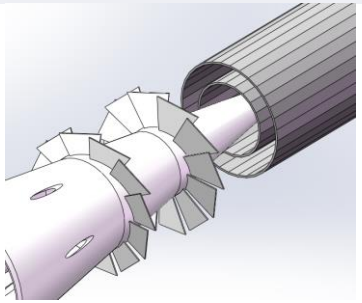
Long barrel design





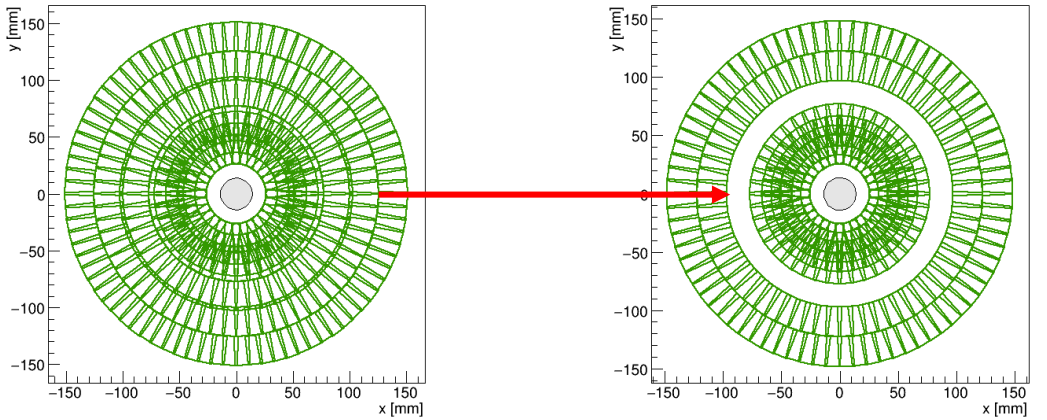
Solution?





CLIC spiral disk concept

rotate the disk, from Jinyu



Make a hole in disk