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CEPC Vertex Detector Optimization

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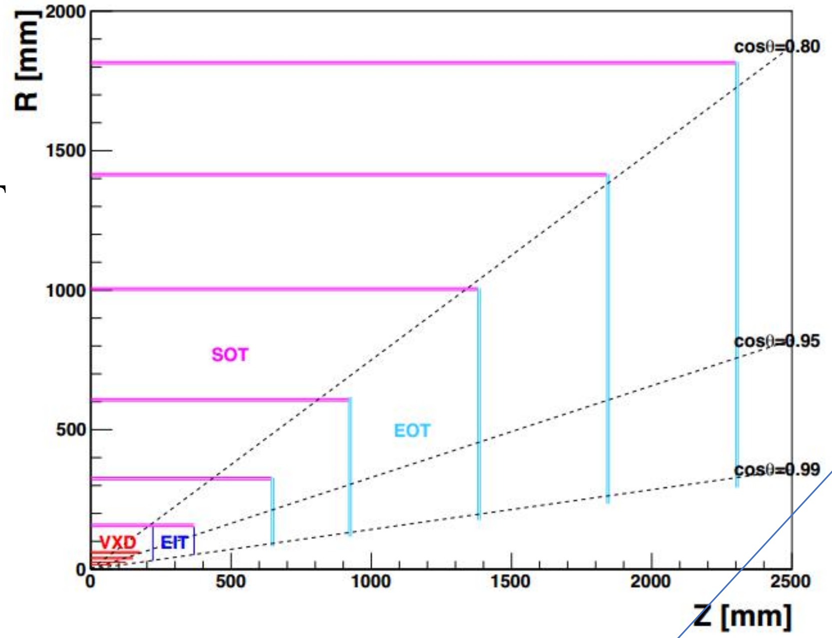
Outline

- Full silicon tracker
- Vertex layout optimization
  - Ladder material update
  - Barrel optimization
  - Disk optimization
- Air cooling → investigate new disk arrangements
- Beam pipe study
  - Beam pipe radius
  - Beam pipe material
- Summary & Plan

Full silicon tracker layout

FST

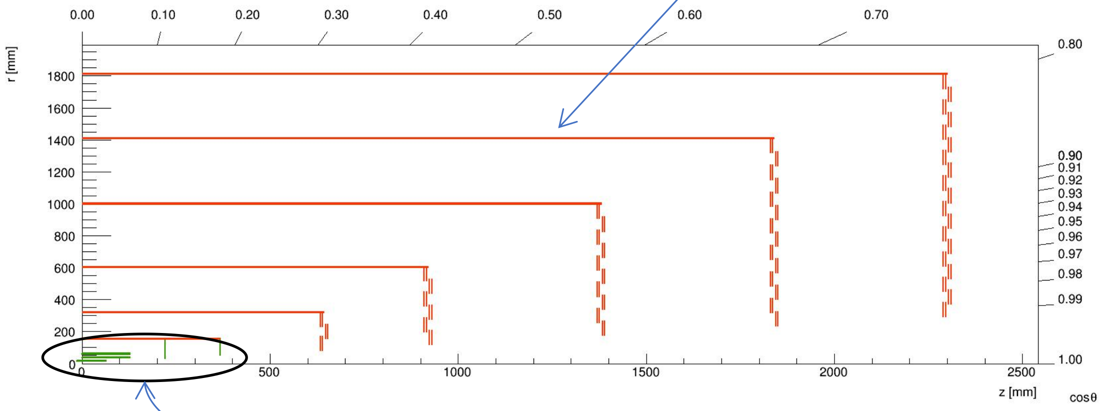


FST

SOT	R (m)		±z (m)	Type
Layer 1	0.153		0.368	D
Layer 2	0.321		0.644	D
Layer 3	0.603		0.920	D
Layer 4	1.000		1.380	D
Layer 5	1.410		1.840	D
Layer 6	1.811		2.300	D
EOT	R_{in} (m)	R_{out} (m)	±z (m)	Type
Disk 1	0.082	0.321	0.644	D
Disk 2	0.117	0.610	0.920	D
Disk 3	0.176	1.000	1.380	D
Disk 4	0.234	1.410	1.840	D
Disk 5	0.293	1.811	2.300	D

newFST

VXD	R(m)		z(m)
Layer 1	0.017		0.064
Layer 2	0.019		0.064
Layer 3	0.038		0.128
Layer 4	0.040		0.128
Layer 5	0.059		0.128
Layer 6	0.061		0.128
EIT	R_{in} (m)	R_{out} (m)	±z (m)
Disk 1	0.030	0.151	0.221
Disk 2	0.051	0.151	0.368
Disk 3			
Disk 4			
Disk 5			

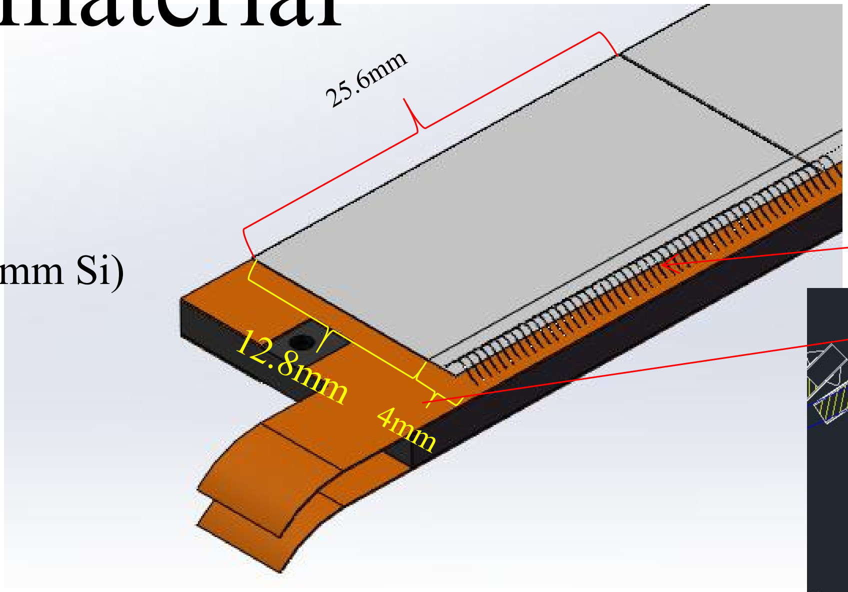


vertex layout optimization

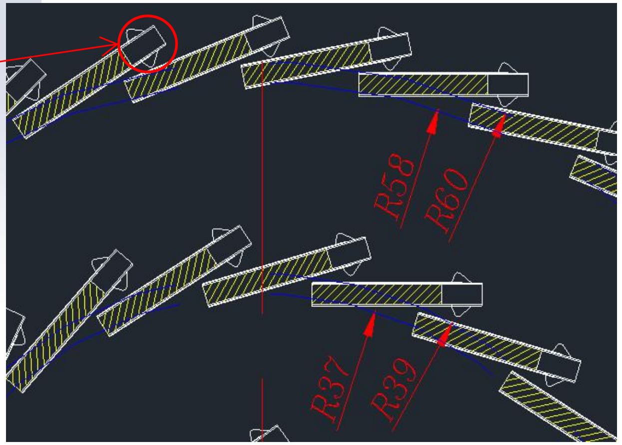
- 4 parts: VXD,EIT,SOT,EOT
- Outer tracker (SOT + EOT): from FST
- The coverage of the whole tracker is over cosθ=0.99
- Outer tracker disk has been adjusted for mechanics

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.

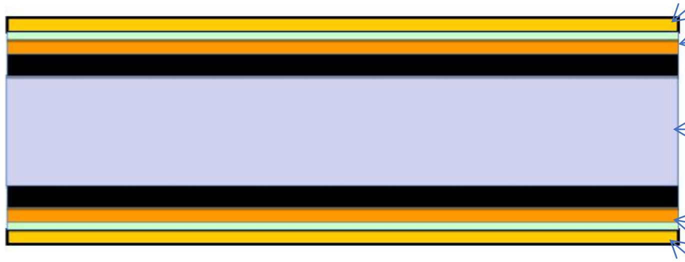


Al wire



One half dead area:

Sensor(Si, 25um)
Al wire
glue(Epoxy, 7.5um)
Al(17.8um)
Kapton(50um)
Glue(Epoxy, 15um)
Ladder support(carbon fiber,175um)



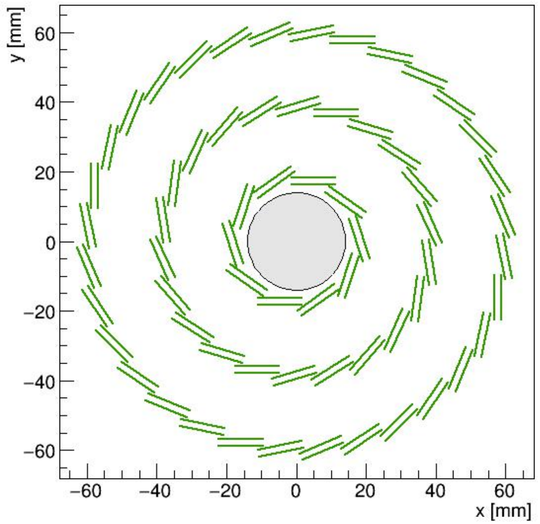
Sensor(Si, 50um)
glue(Epoxy, 15um)
Al(17.8um)
Kapton(50um)
Glue(Epoxy, 15um)
Ladder support(carbon fiber,350um)
Glue(Epoxy,15um)
Kapton(50um)
Al(17.8um)
Glue(Epoxy, 15um)
Sensor(Si, 50um)

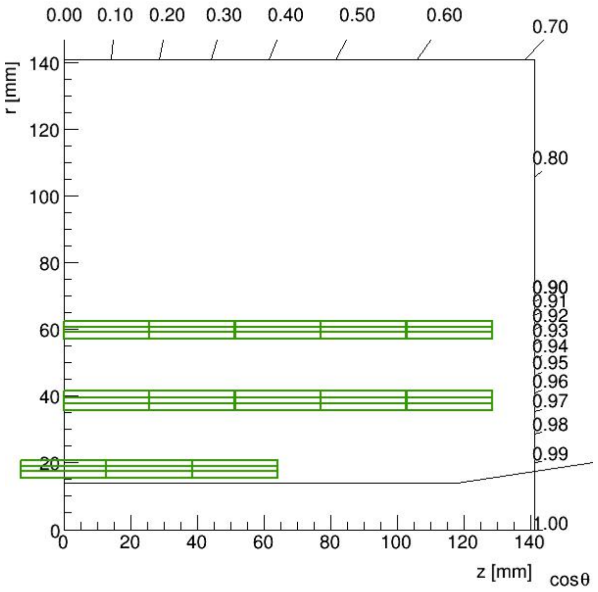
(1) Sensor
(2) Flex cable
(3) Ladder support
(4) Flex cable
(5) sensor

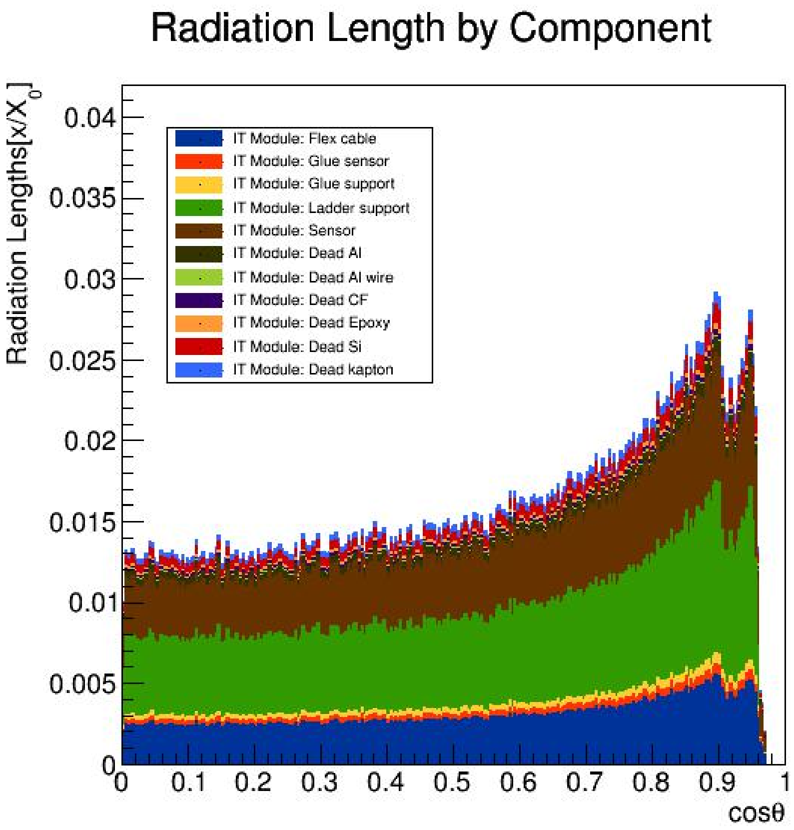
recent discussion shows that we need add more material into flex cable

Polyimide
Adhesive
Plating Al
kapton
Plating Al
Adhesive
Polyimide

Material budget vs cosθ



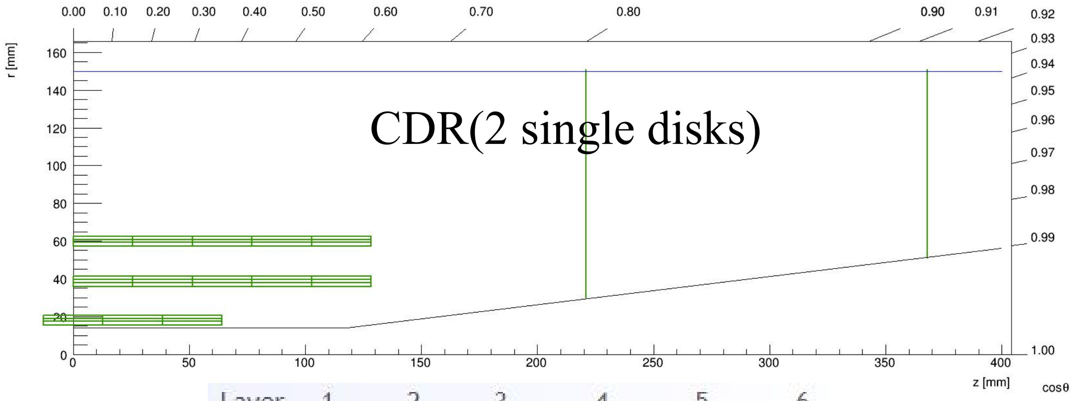




Average (cosθ = [0, 0.99])	Radiation length
IT Module: Flex cable	0.00299
IT Module: Glue sensor	0.00035
IT Module: Glue support	0.00035
IT Module: Ladder support	0.00591
IT Module: Sensor	0.00426
IT Module: Dead Al	0.00050
IT Module: Dead Al wire	0.00007
IT Module: Dead CF	0.00019
IT Module: Dead Epoxy	0.00017
IT Module: Dead Si	0.00066
IT Module: Dead kapton	0.00044
total	0.01589

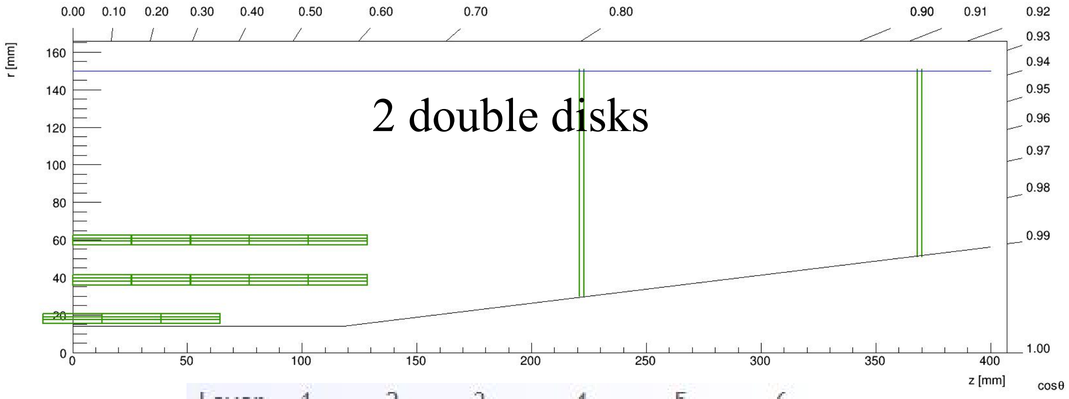
total average material budget is about 1.6% for vertex barrel, much more than CDR 0.9% (0.15% × 6)

CDR barrel with different disk



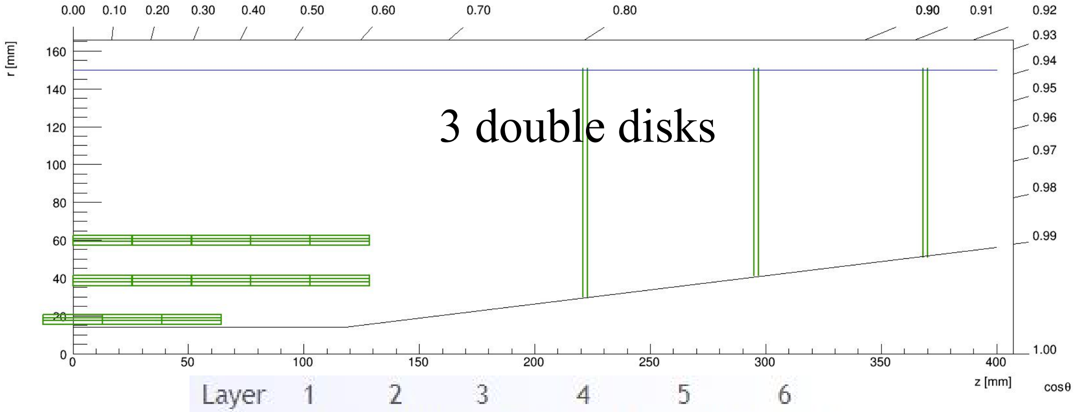
Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	64.200	64.200	128.450	128.450	128.450	128.450

Endcap :	FPIX_1	
Disk	1	2
z	221.000	368.000



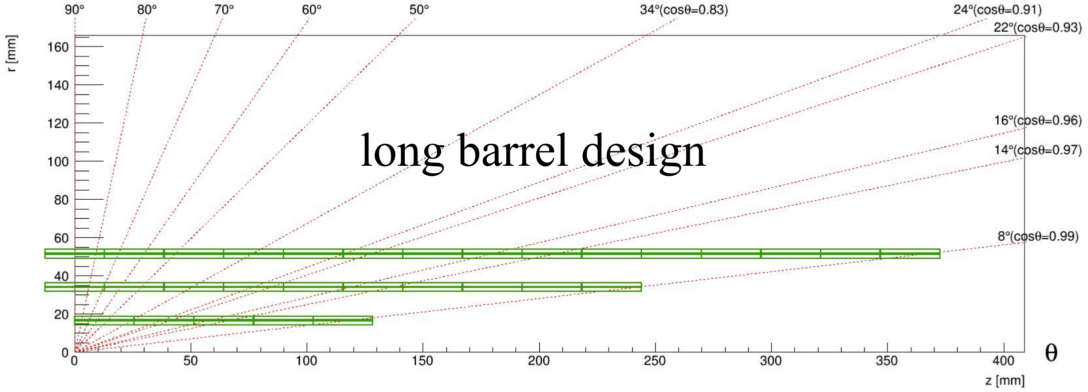
Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	64.200	64.200	128.450	128.450	128.450	128.450

Disk	1	2	3	4
z	221.000	223.000	368.000	370.000



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

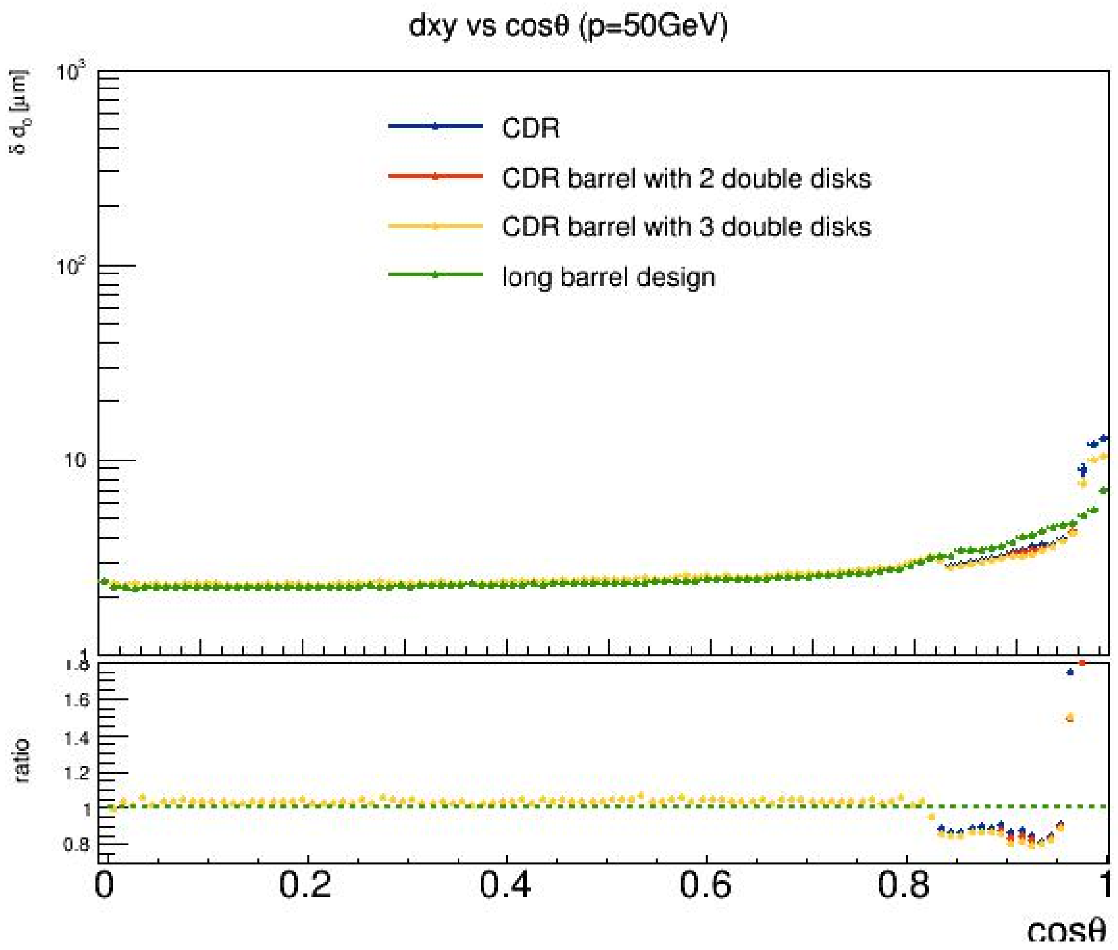
Endcap :	FPIX_1	FPIX_2	FPIX_3	FPIX_4	FPIX_5	FPIX_6
Disk	1	1	1	1	1	1
z	221.000	223.000	295.000	297.000	368.000	370.000
# rings	5	5	5	5	4	4



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

use ideal ladder, same as vertex prototype ladder

CDR barrel with different disk



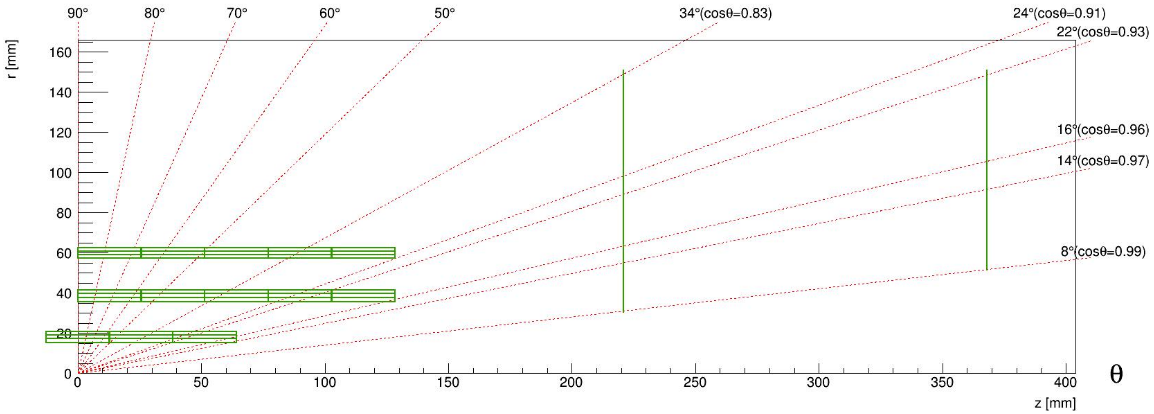
- cosθ: 0.82-0.96, disk version better than long barrel design
- cosθ> 0.96: long barrel design better CDR barrel with disk version, because innermost layer of long barrel provides closer first hit to IP

Longer first layer

CDR

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

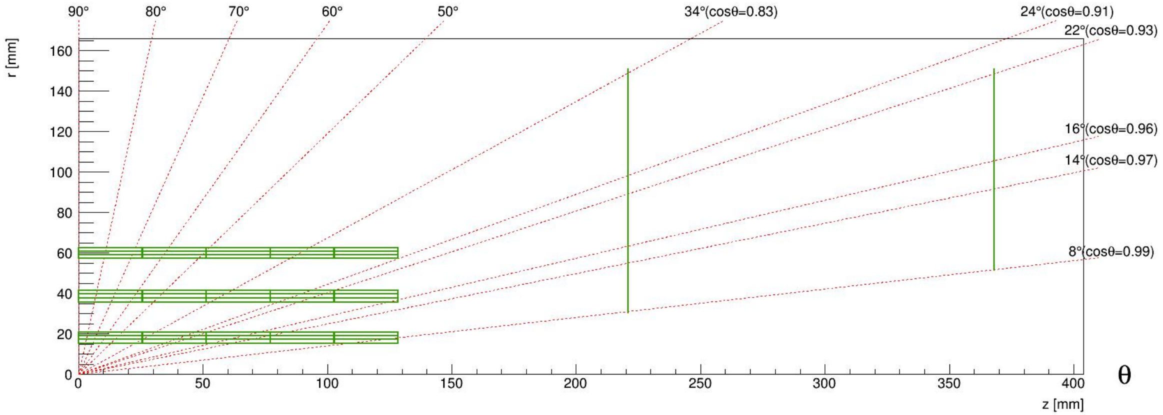
Disk	1	2
z	221.000	368.000



Longer first layer

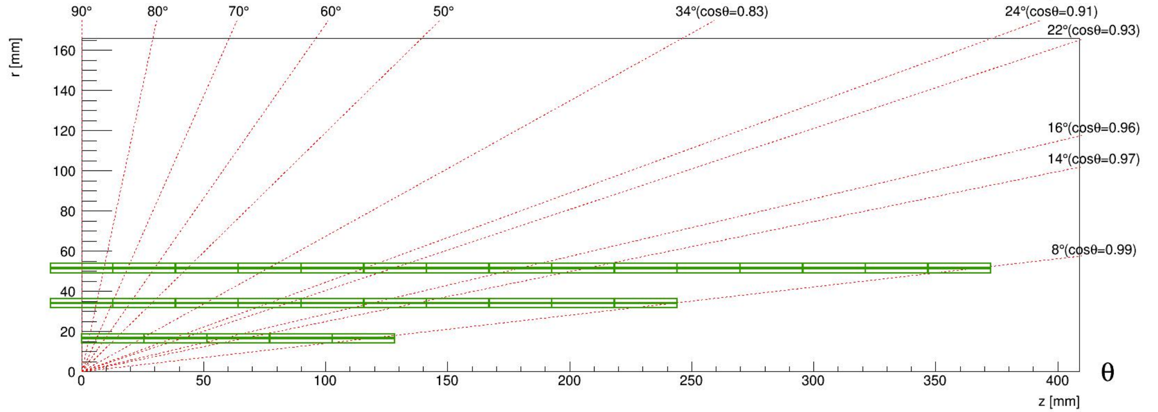
Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	128.450	128.450	128.450	128.450	128.450	128.450

Disk	1	2
z	221.000	368.000

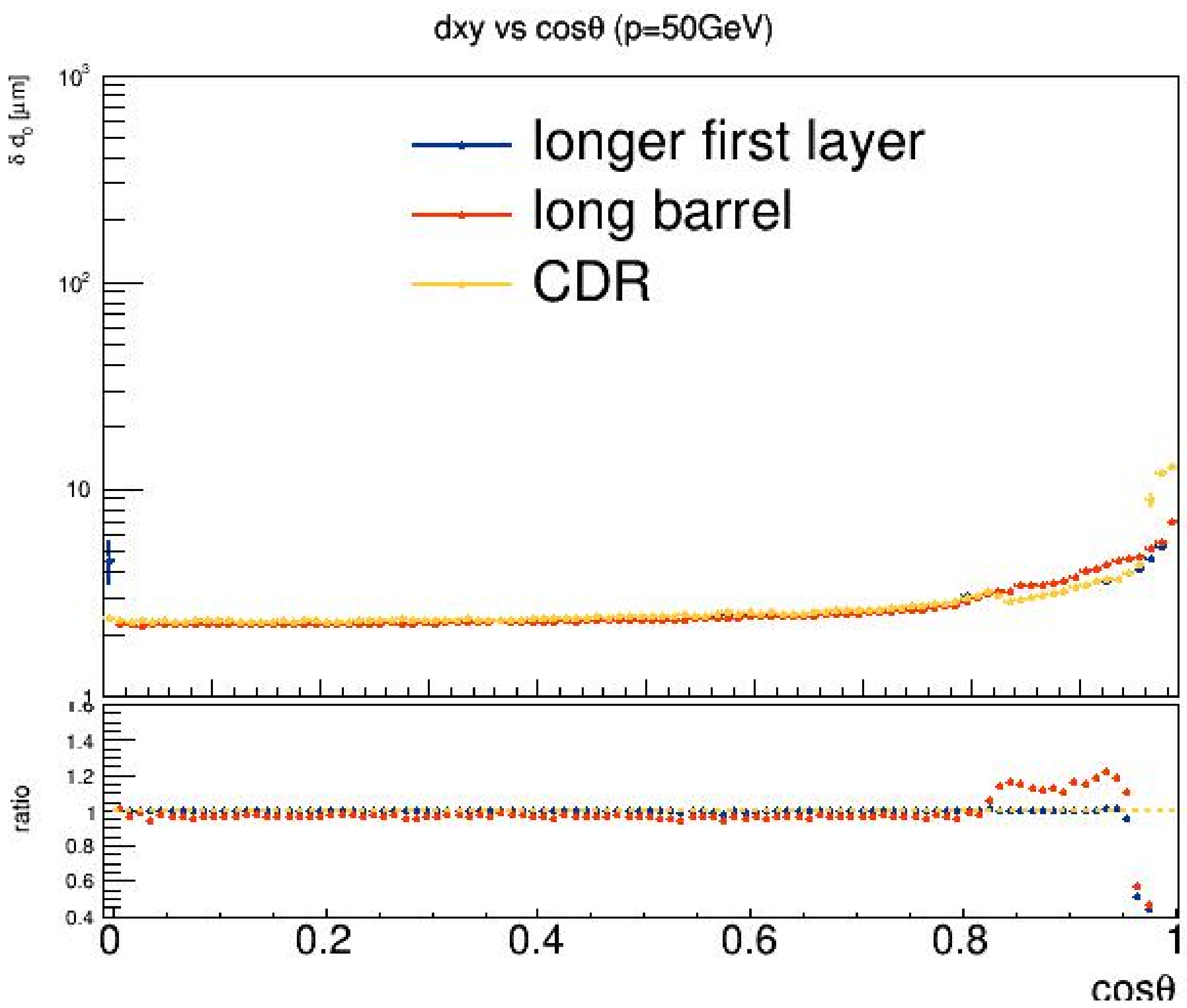


long barrel design

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

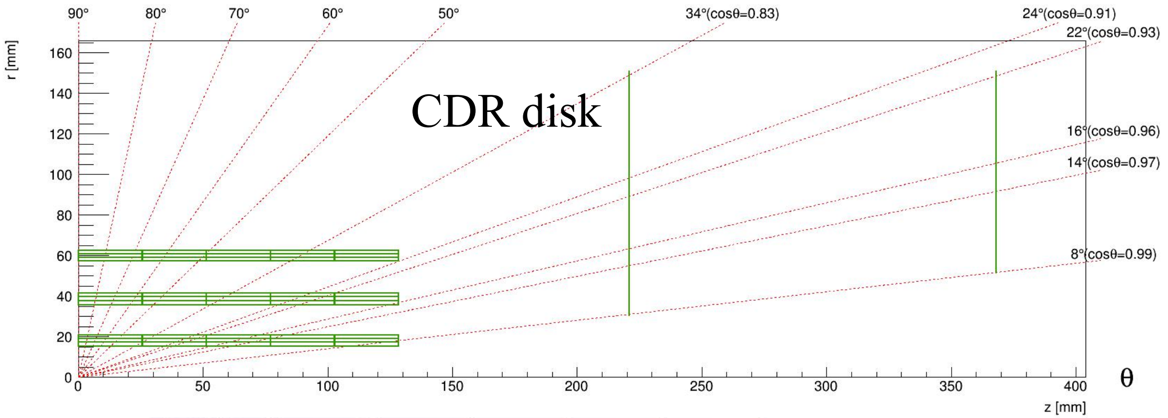


Longer first layer



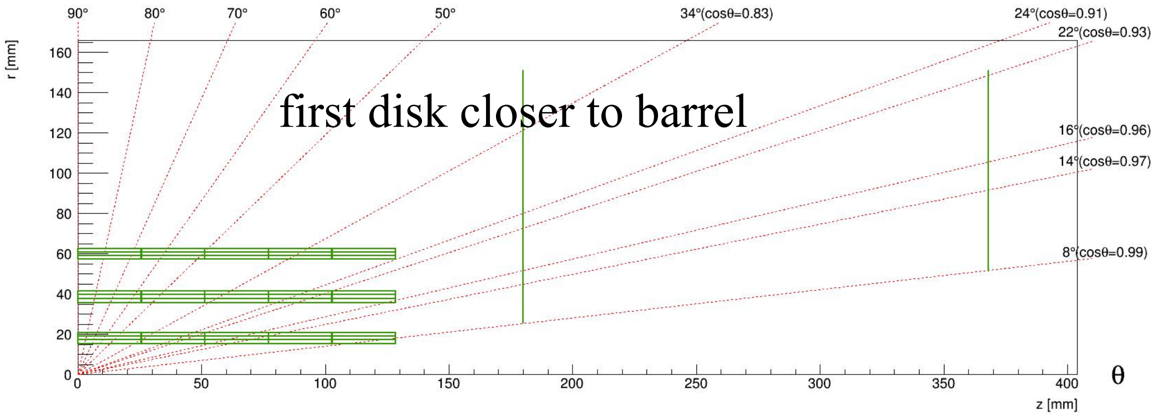
- longer first layer design has the advantages of long barrel design and disk design
- cosθ: 0.82-0.96, same as CDR
- cosθ> 0.96: similar to long barrel design (even a little better), better than CDR

Different position of 2 single-layer disks



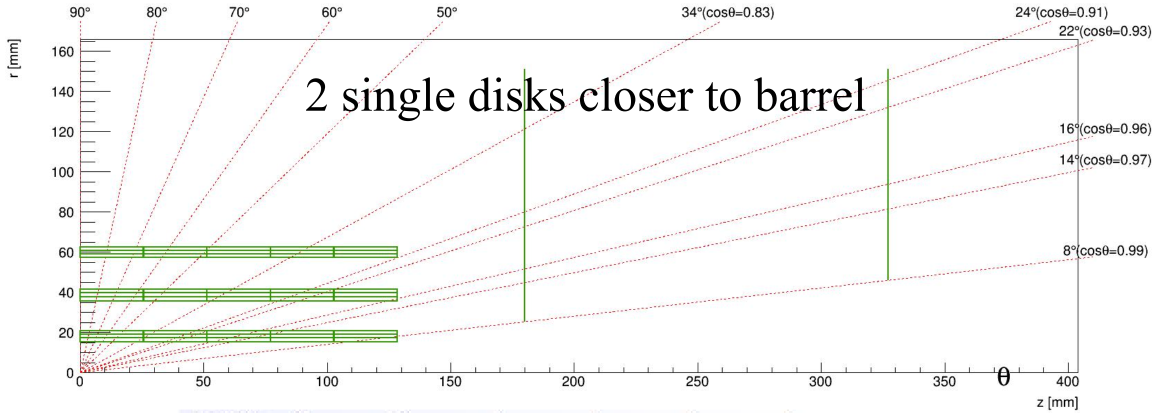
Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	128.450	128.450	128.450	128.450	128.450	128.450

Disk	1	2
z	221.000	368.000



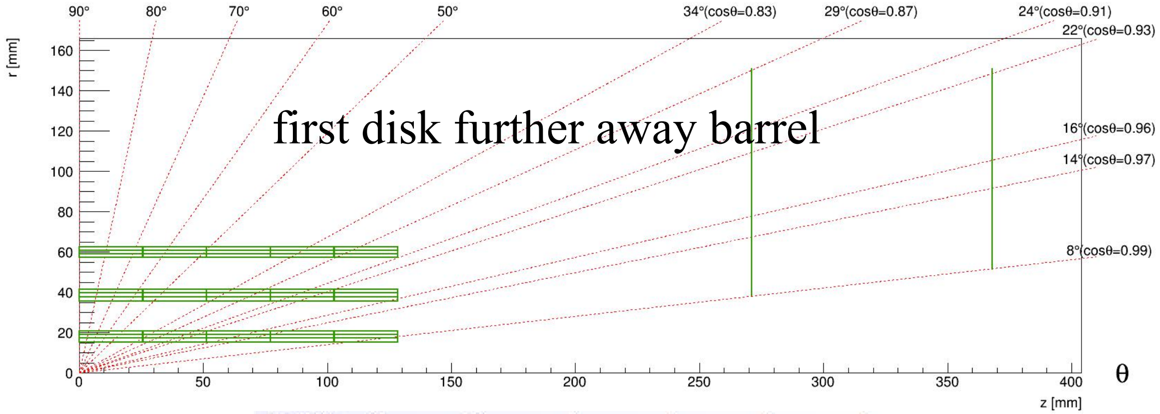
Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	128.450	128.450	128.450	128.450	128.450	128.450

Disk	1	2
z	180.000	368.000



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	128.450	128.450	128.450	128.450

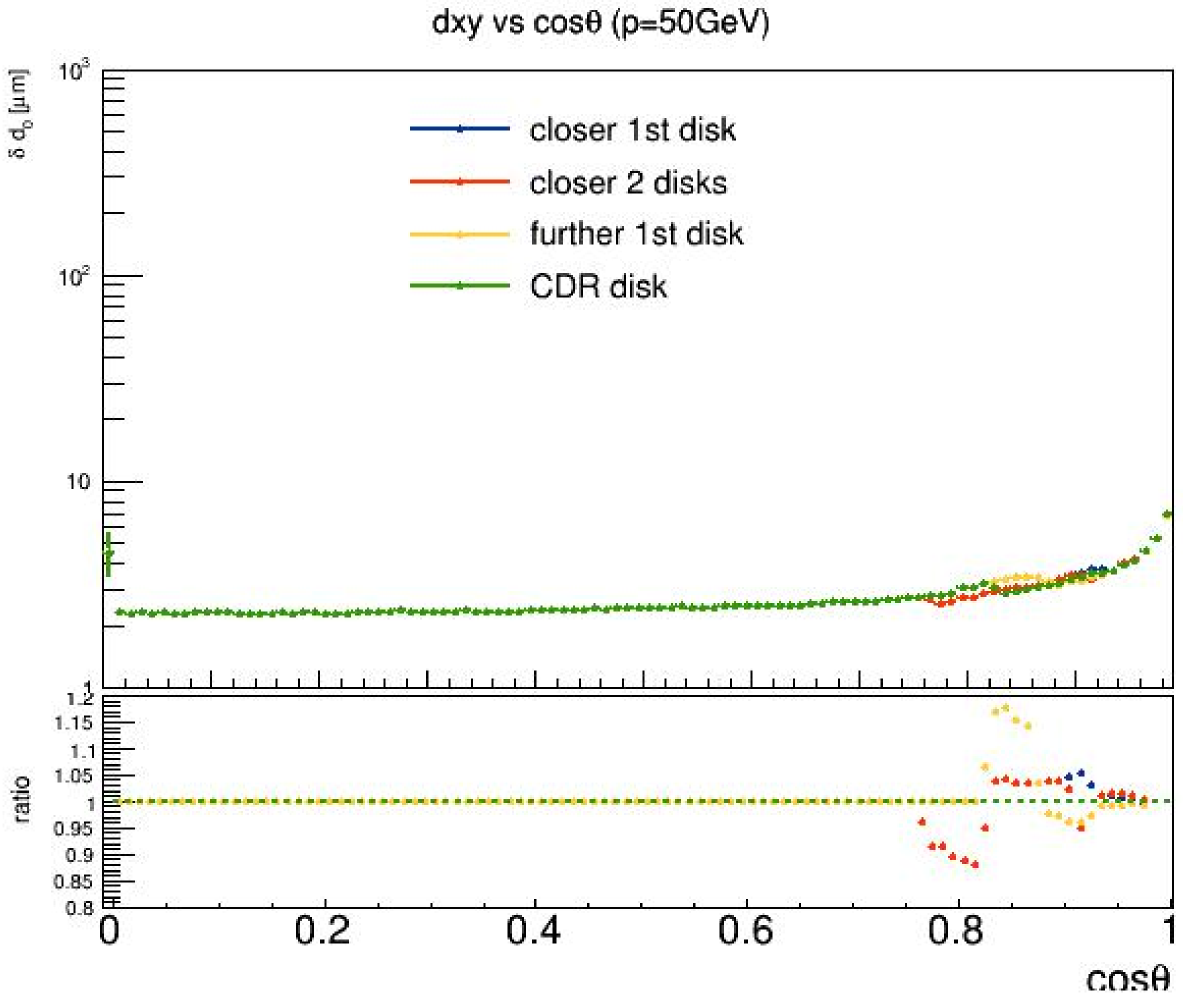
Disk	1	2
z	180.000	327.000



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	128.450	128.450	128.450	128.450

Disk	1	2
z	271.000	368.000

Different position of 2 single-layer disks



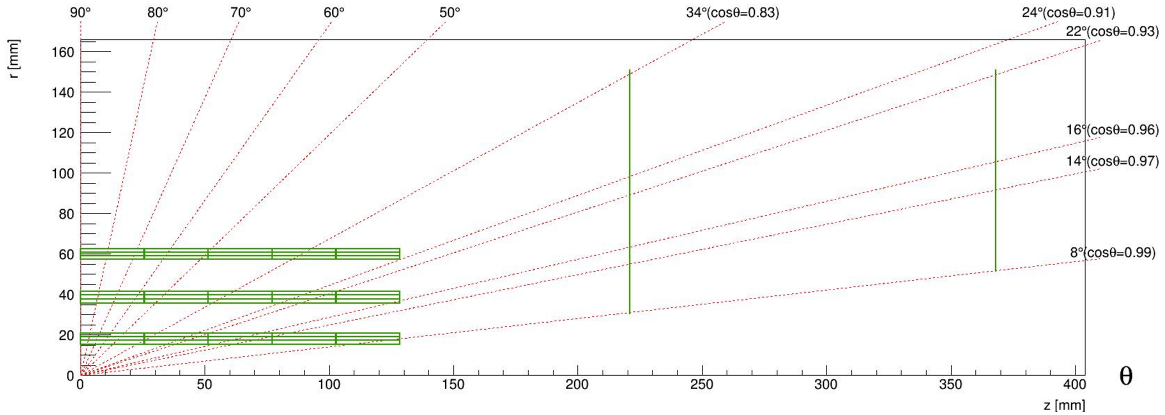
- ➢ not always improve resolution, some points better, some worse
- ➢ moving disk closer to barrel can improve resolution at cosθ ≈0.8 (more hits)

Longer first layer with different number of disk

2 single-layer disks

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	128.450	128.450	128.450	128.450

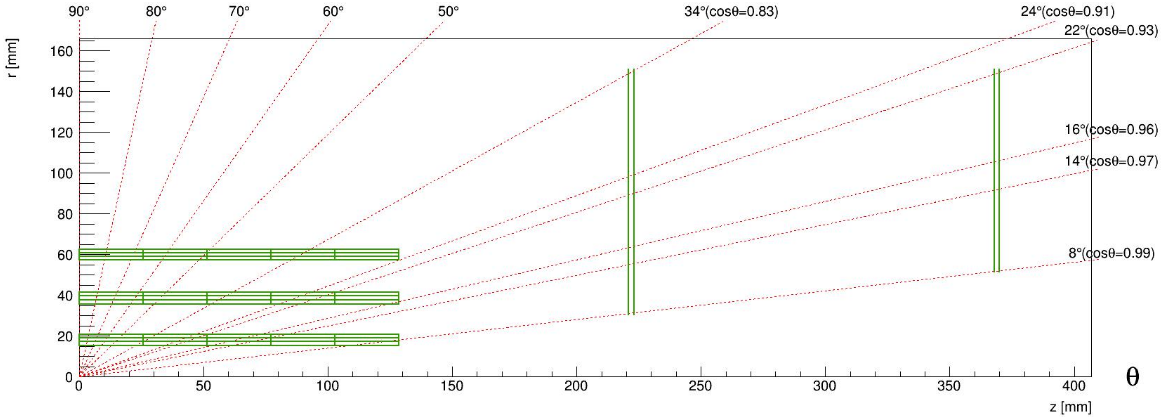
Disk	1	2
z	221.000	368.000



2 double-layer disks

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	128.450	128.450	128.450	128.450

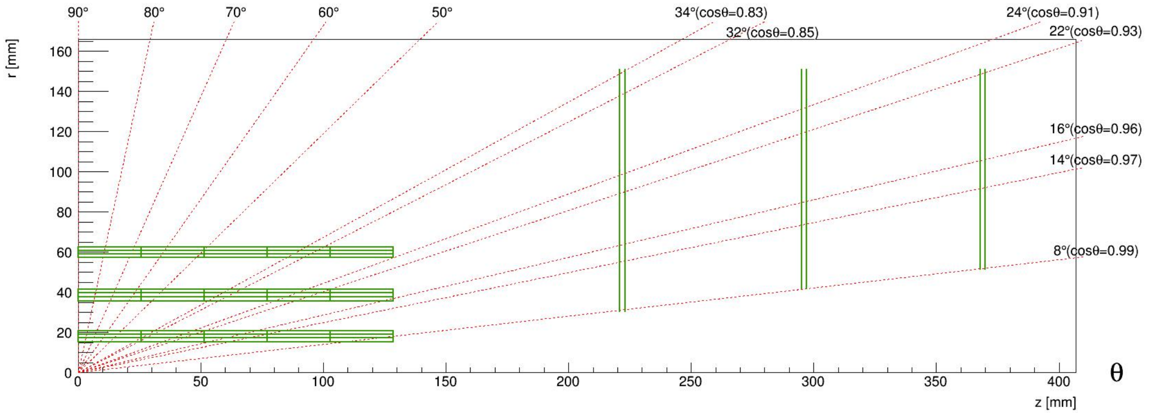
Endcap :	FPIX_1	FPIX_2	FPIX_3	FPIX_4
Disk	1	1	1	1
z	221.000	223.000	368.000	370.000



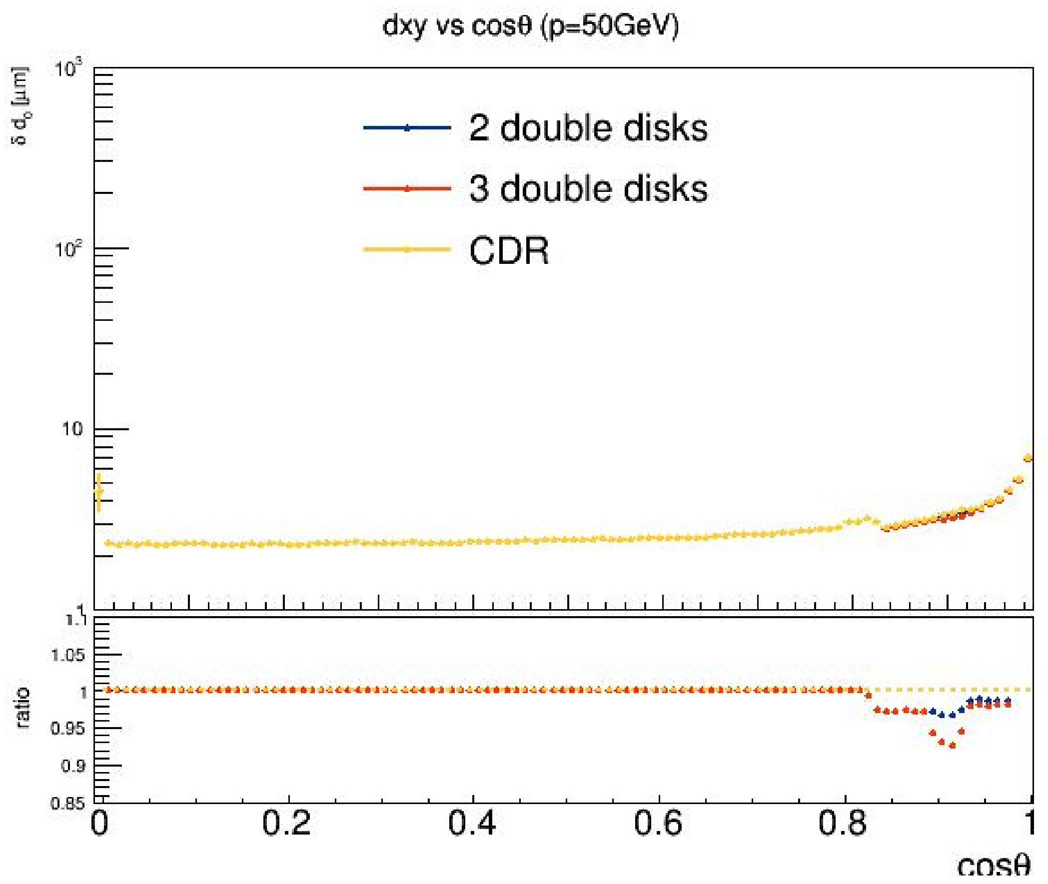
3 double-layer disks

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	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	221.000	223.000	295.000	297.000	368.000	370.000



Longer first layer with different number of disk



2 ways to improve resolution:

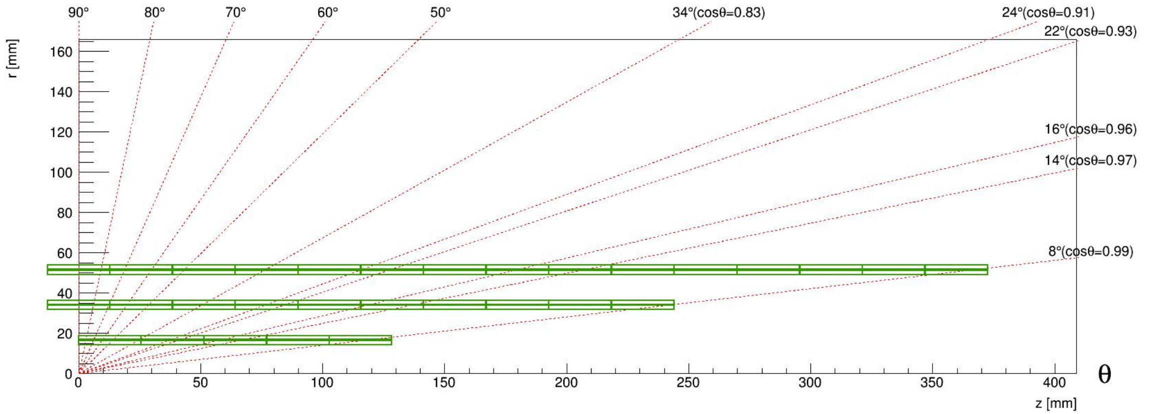
- ➢ increase the number of disk
- ➢ replace single disk with double disk

not have worse resolution points

3 double-layer disks closer to barrel

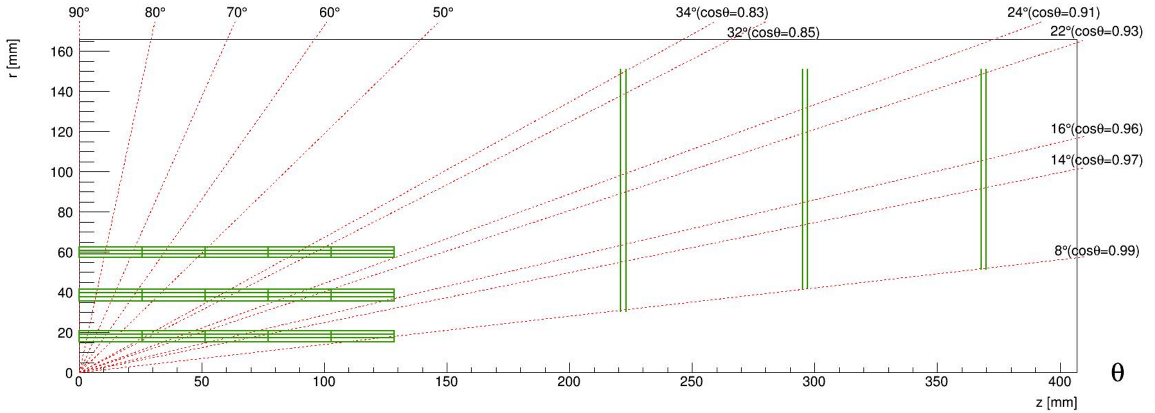
long barrel design

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



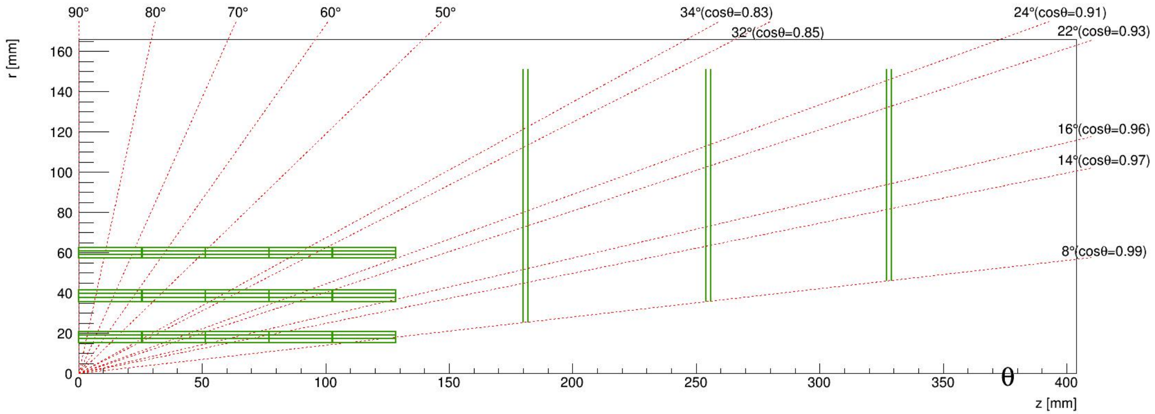
3 double-layer disks

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	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	221.000	223.000	295.000	297.000	368.000	370.000

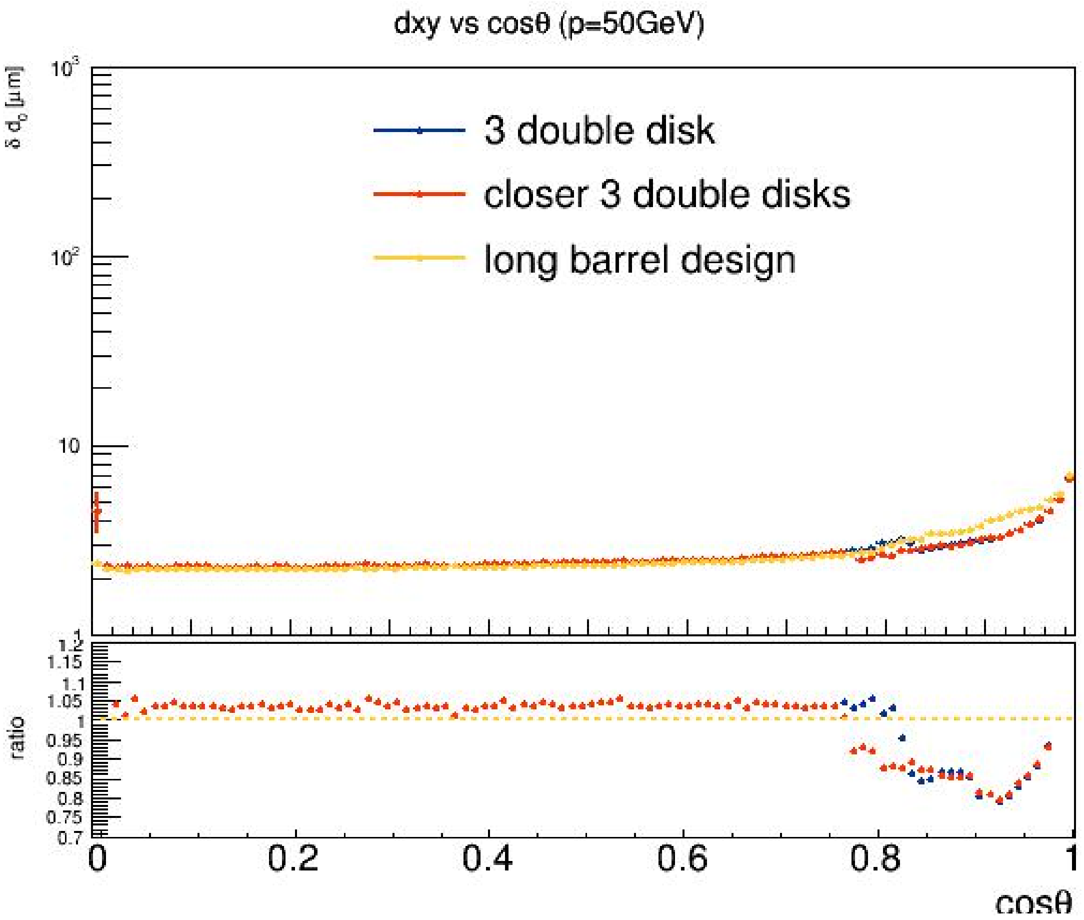


3 double-layer disks closer to barrel

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	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



3 double-layer disks closer to barrel



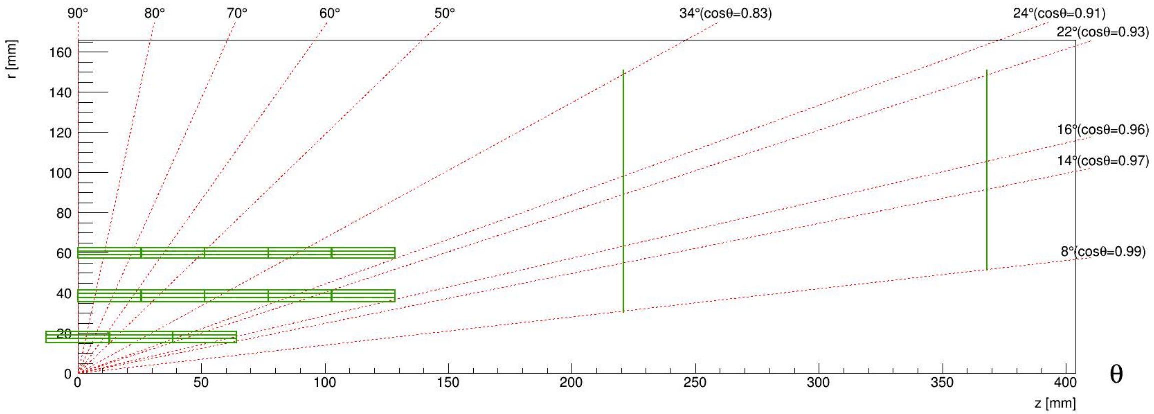
- ➢ longer innermost layer with disk has better resolution than full barrel design in front region
- ➢ moving disk closer to barrel will enlarge the improved region
- ➢ considering the mechanics, putting 3 double disk at CDR disk position is a better design.

Optimal layout

CDR

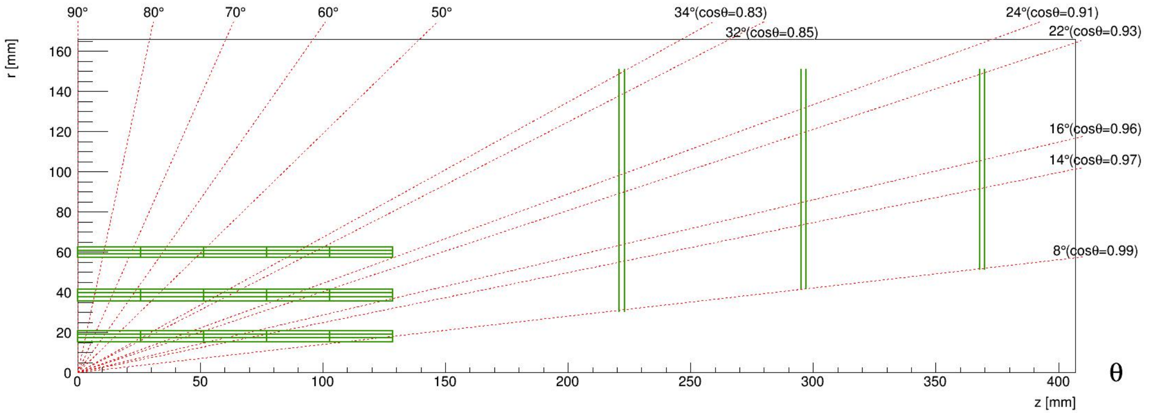
Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	64.200	64.200	128.450	128.450	128.450	128.450

Disk	1	2
z	221.000	368.000



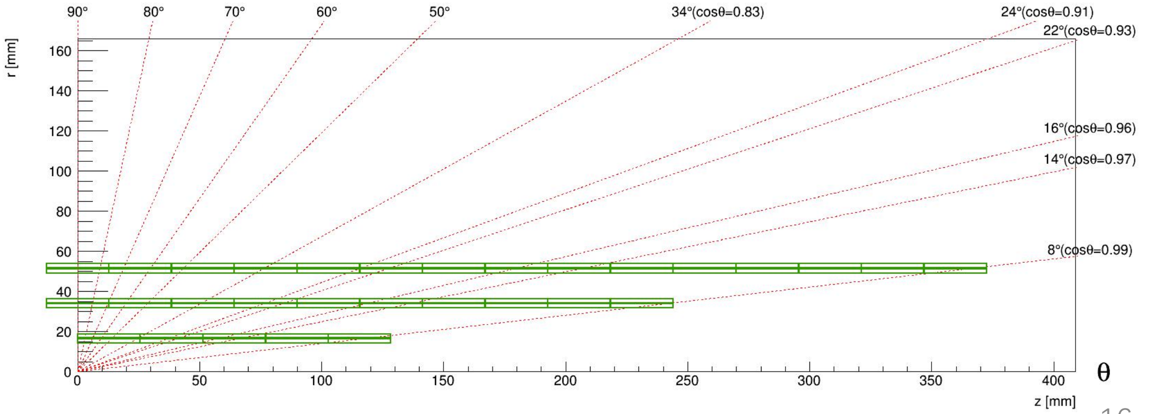
3 double disks(optimal)

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	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	221.000	223.000	295.000	297.000	368.000	370.000

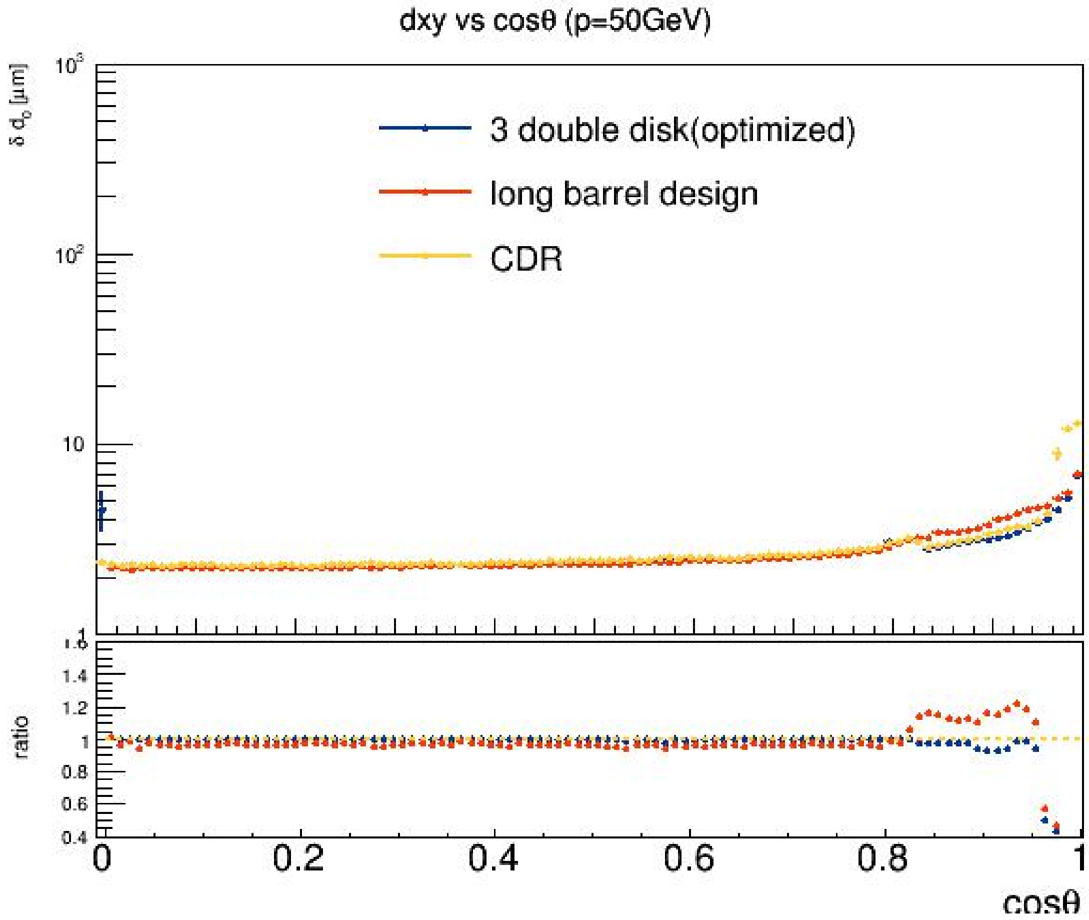


long barrel design

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

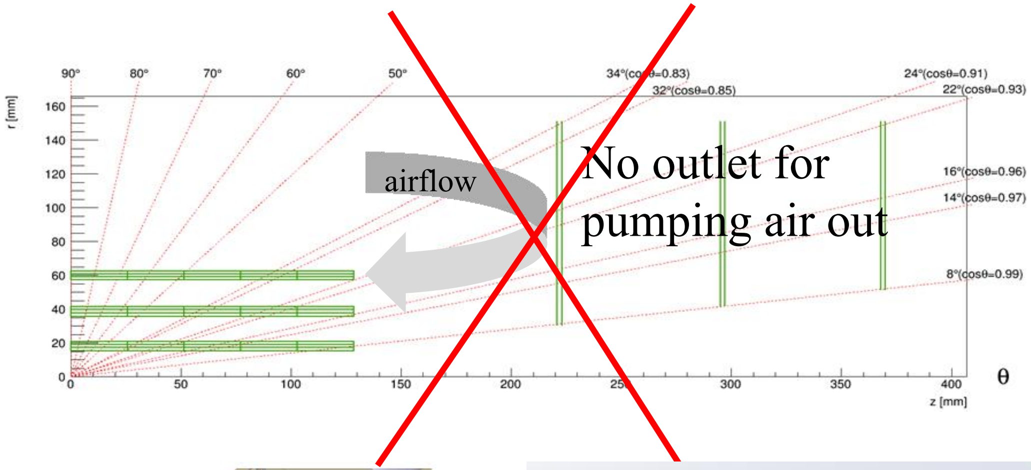


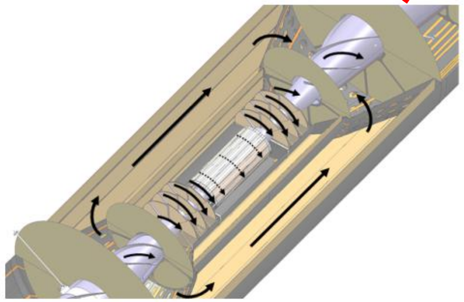
Optimal layout

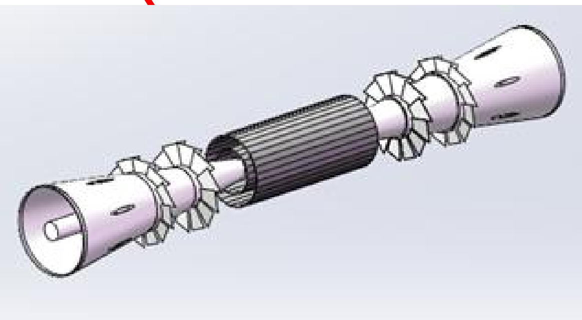


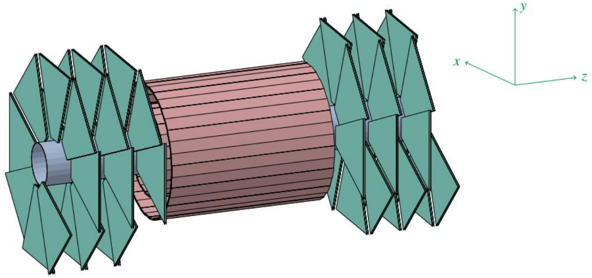
Optimal layout (longer first layer with 3 double disks) has better resolution than full barrel design and CDR design in front region

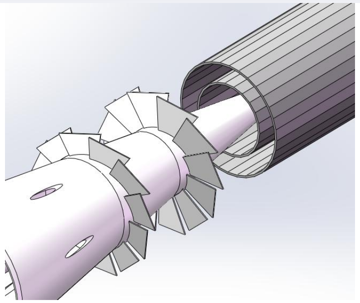
Vertex design including air cooling





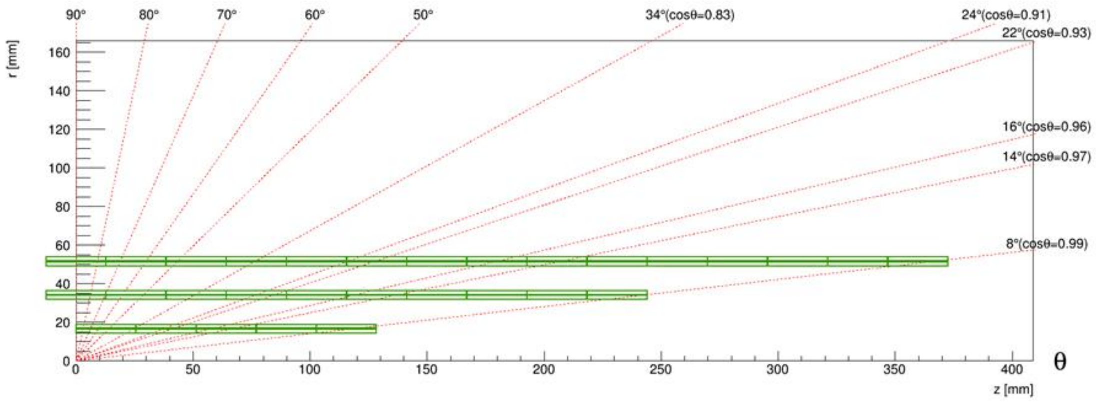




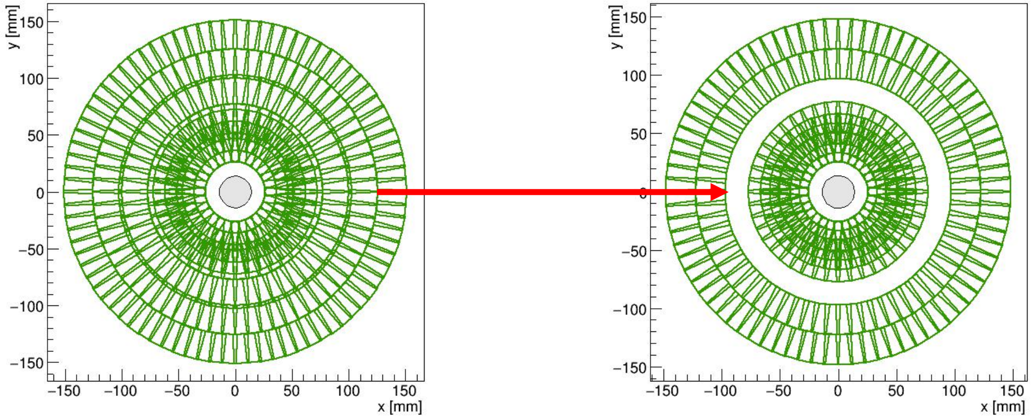


CLIC spiral disk concept

rotate the disk, from Jinyu



Long barrel design



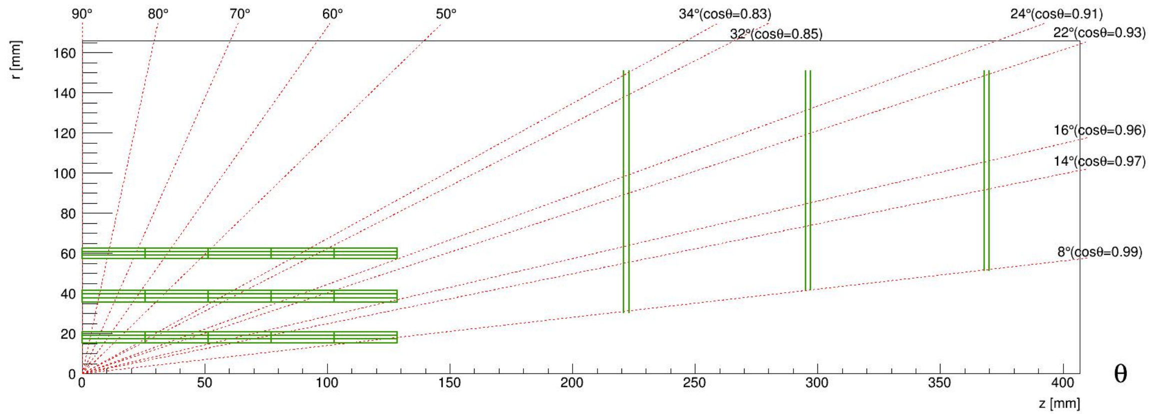
Make a hole in disk

New disk arrangements

3 double-layer disks

Barrel :	PXB1					
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	128.450	128.450	128.450	128.450

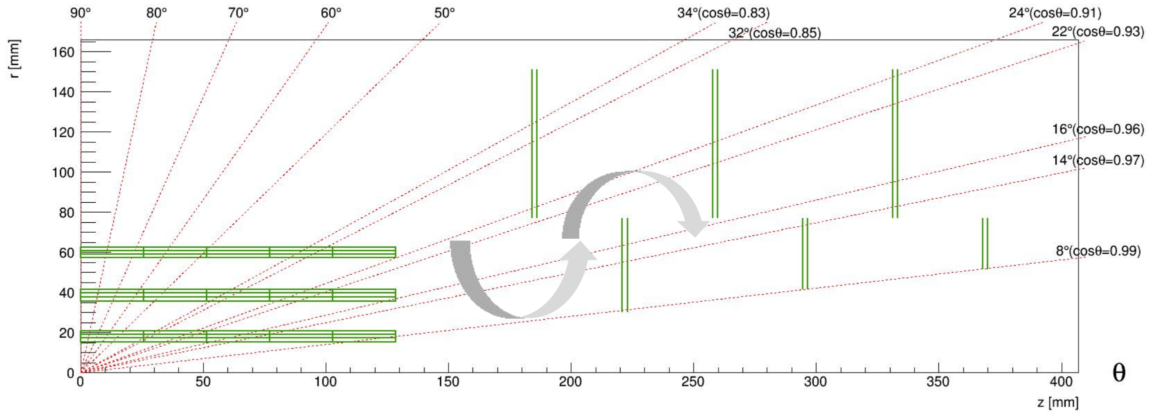
Endcap :	FPIX_1	FPIX_2	FPIX_3	FPIX_4	FPIX_5	FPIX_6
Disk	1	1	1	1	1	1
z	221.000	223.000	295.000	297.000	368.000	370.000



Upper ring set closer to barrel

Barrel :	PXB1					
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	128.450	128.450	128.450	128.450

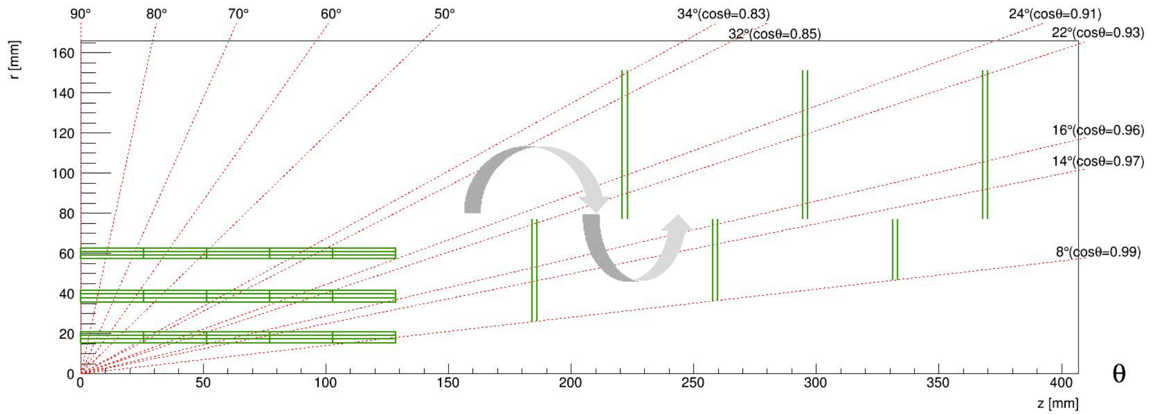
Endcap :	FPIX_inner					
Disk	1	2	3	4	5	6
z	184.250	221.000	257.750	294.500	331.250	368.000
	FPIX_outer					
	1	2	3	4	5	6
	186.250	223.000	259.750	296.500	333.250	370.000



lower ring set closer to barrel

Barrel :	PXB1					
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	128.450	128.450	128.450	128.450

Endcap :	FPIX_inner					
Disk	1	2	3	4	5	6
z	184.250	221.000	257.750	294.500	331.250	368.000
	FPIX_outer					
	1	2	3	4	5	6
	186.250	223.000	259.750	296.500	333.250	370.000

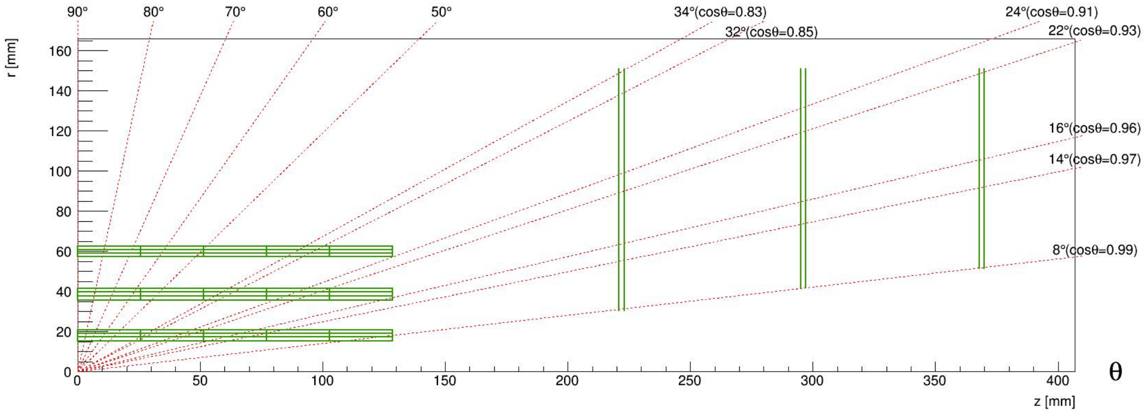


New disk arrangements

3 double-layer disks

Barrel :	PXB1					
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	128.450	128.450	128.450	128.450

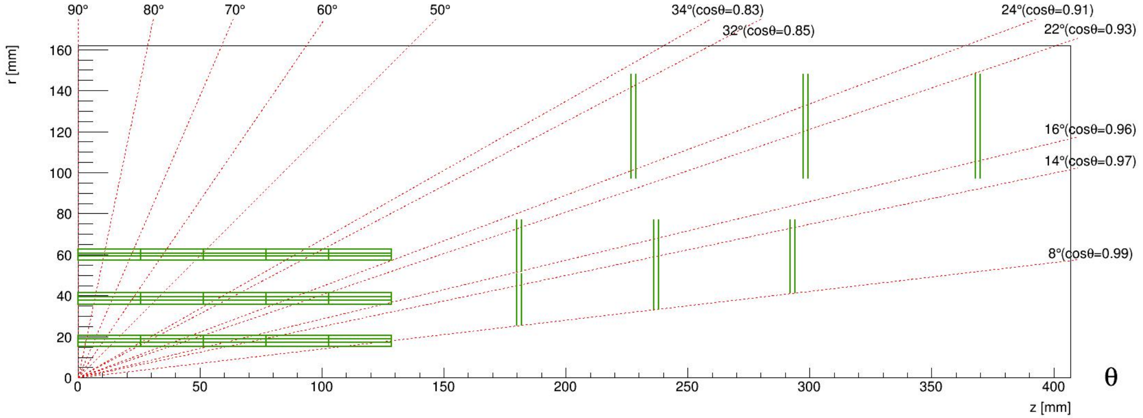
Endcap :	FPIX_1	FPIX_2	FPIX_3	FPIX_4	FPIX_5	FPIX_6
Disk	1	1	1	1	1	1
z	221.000	223.000	295.000	297.000	368.000	370.000

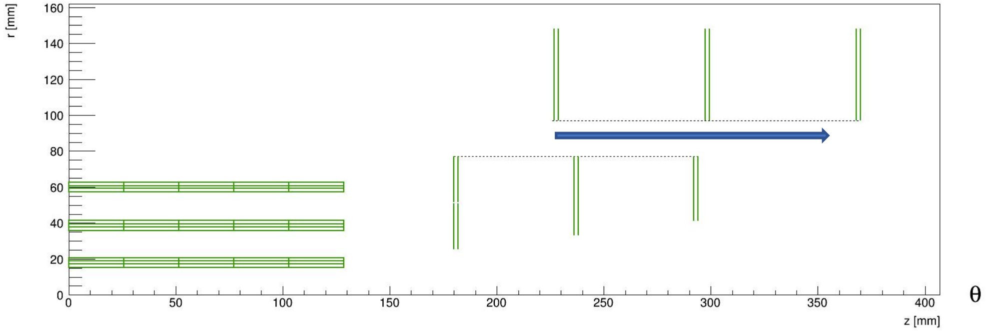


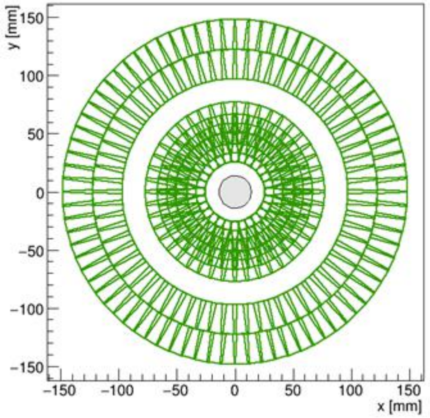
20mm ring hole

Barrel :	PXB1					
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	128.450	128.450	128.450	128.450

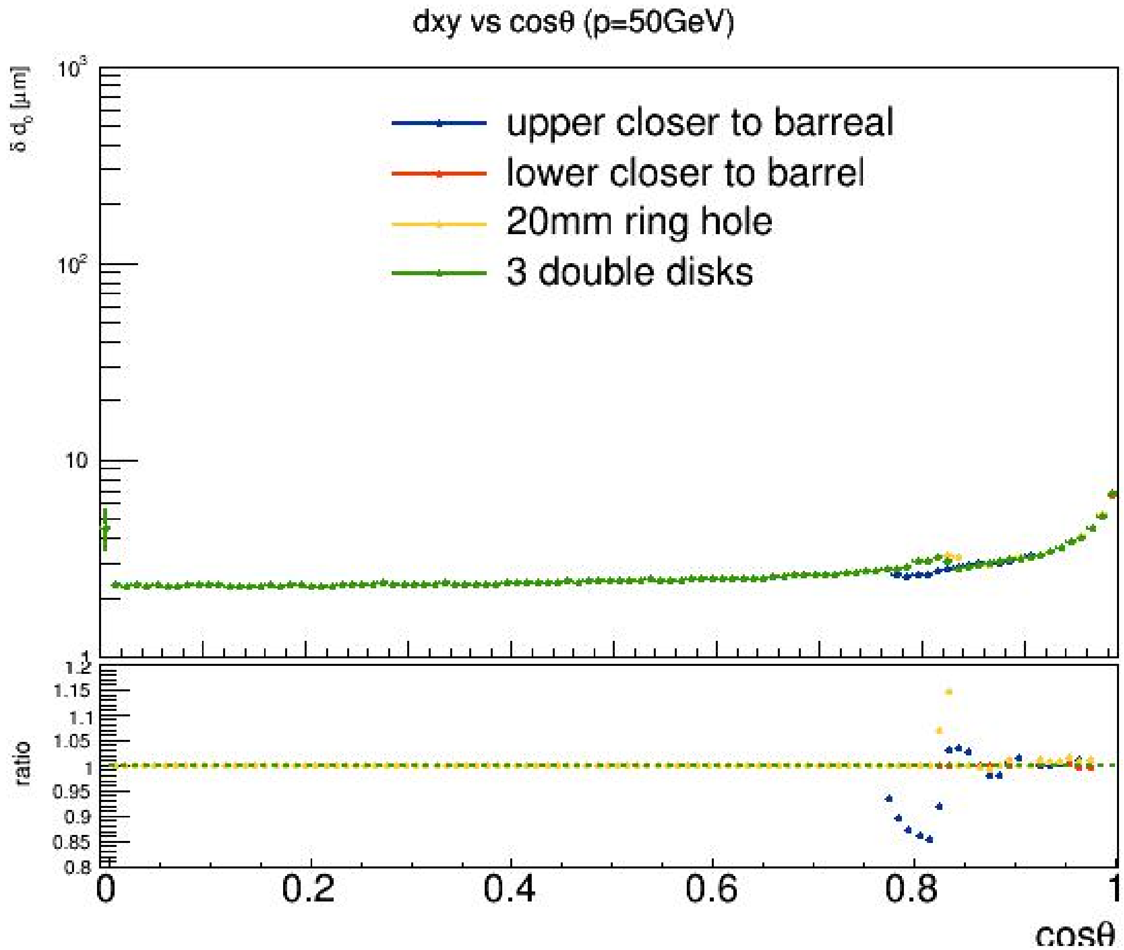
Endcap :	FPIX_inner					
Disk	1	2	3	4	5	6
z	180.000	226.800	236.050	292.100	297.400	368.000
	FPIX_outer					
	1	2	3	4	5	6
	182.000	228.800	238.050	294.100	299.400	370.000







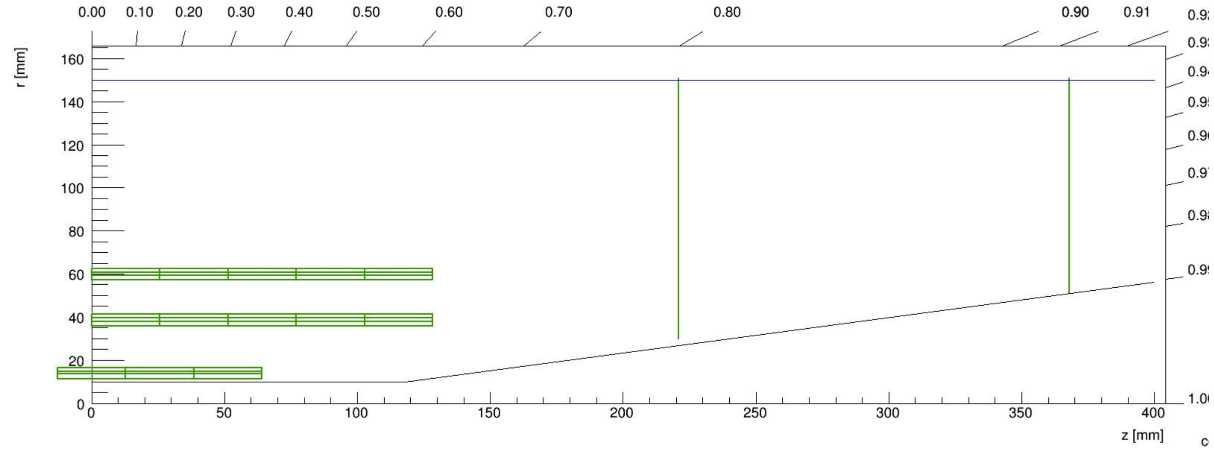
New disk arrangements



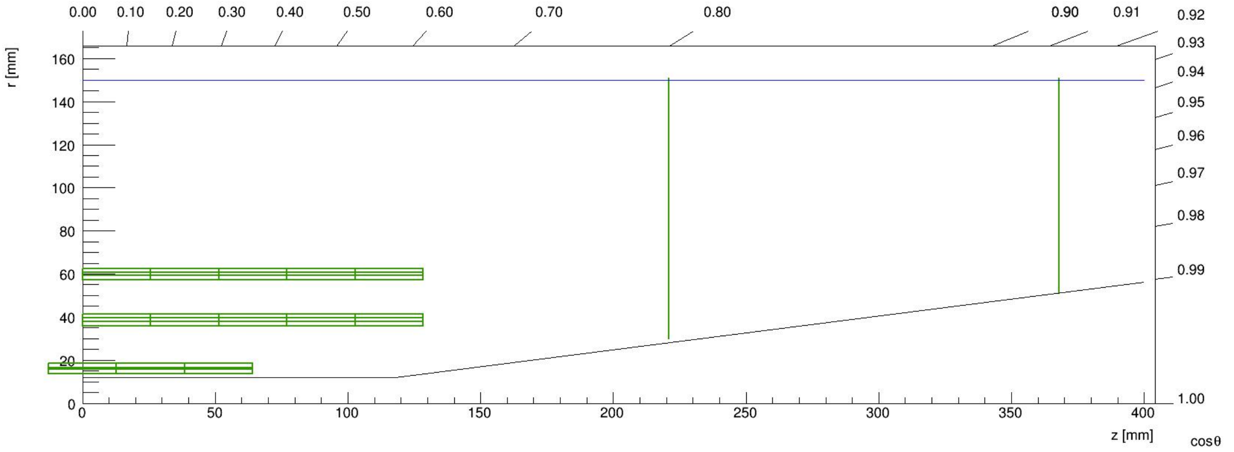
- not make resolution worse much, event improved in some region
- still need considering mechanics and cooling simulation

Beam pipe radius simulation

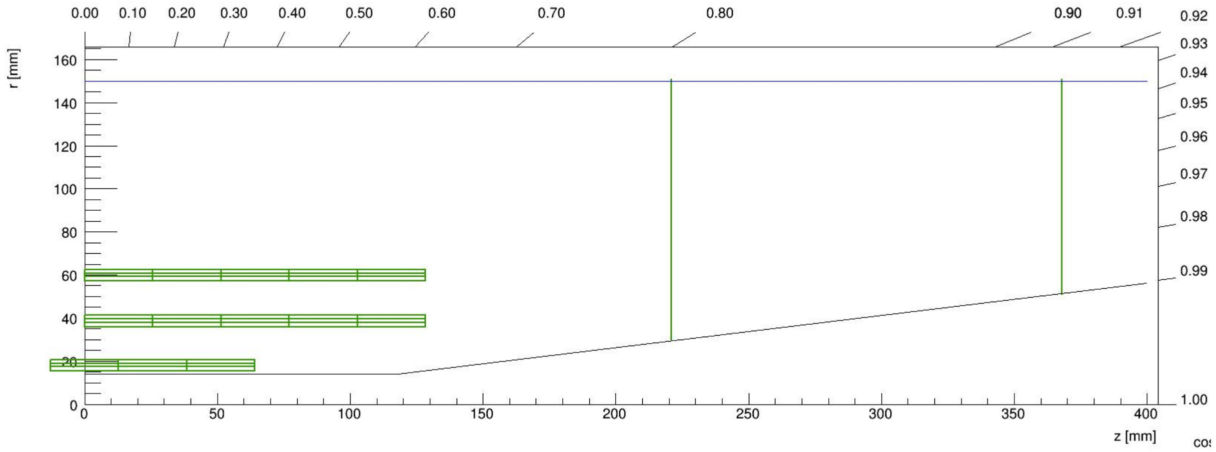
Beam pipe radius:10mm



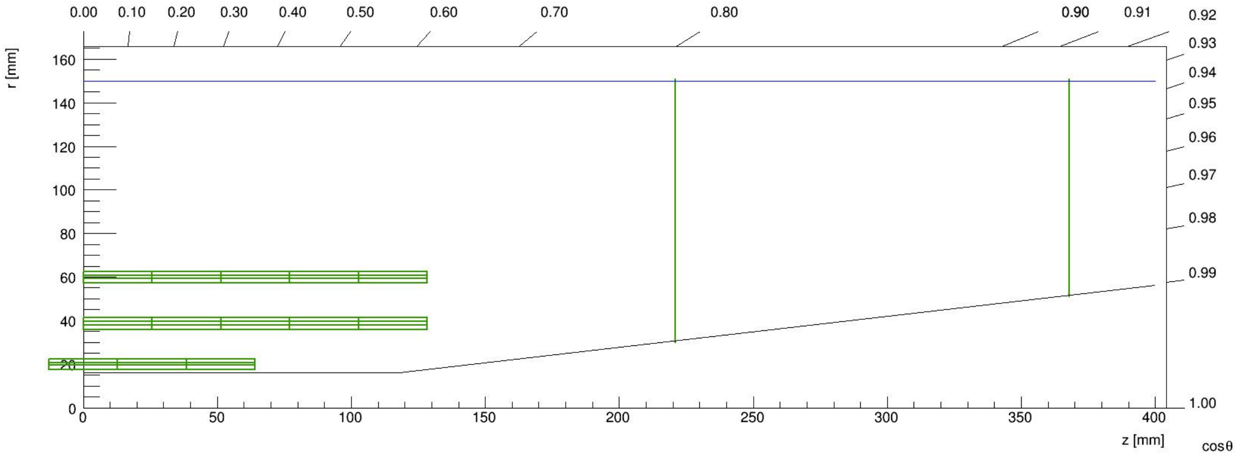
Beam pipe radius:12mm



Beam pipe radius:14mm(CDR)

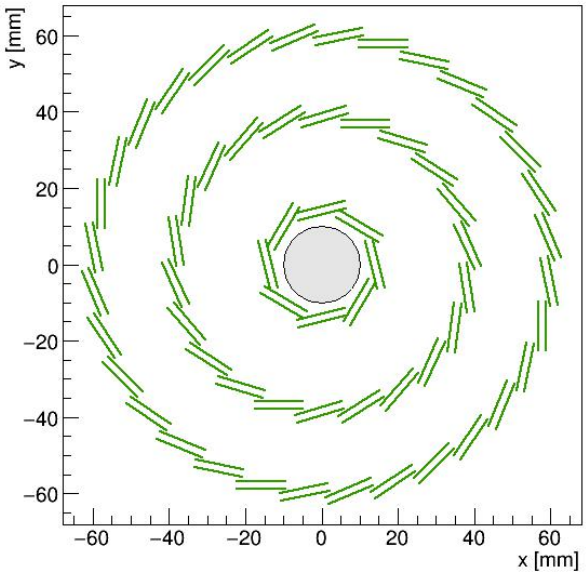


Beam pipe radius:16mm

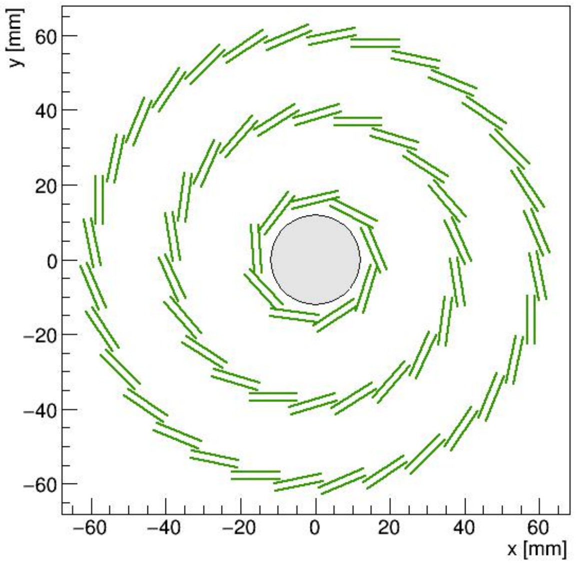


Beam pipe radius simulation

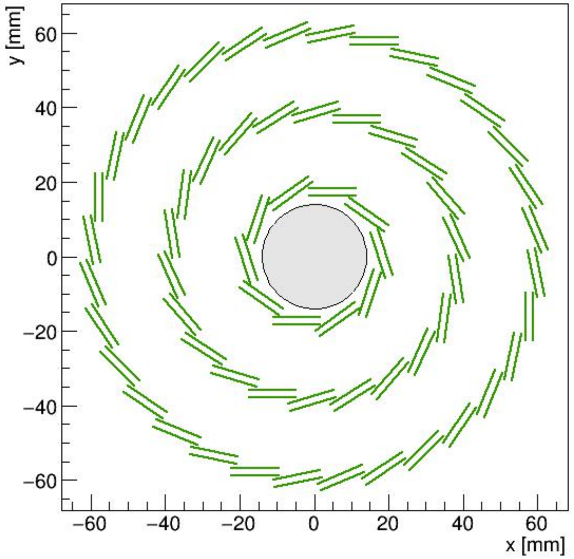
radius:10mm



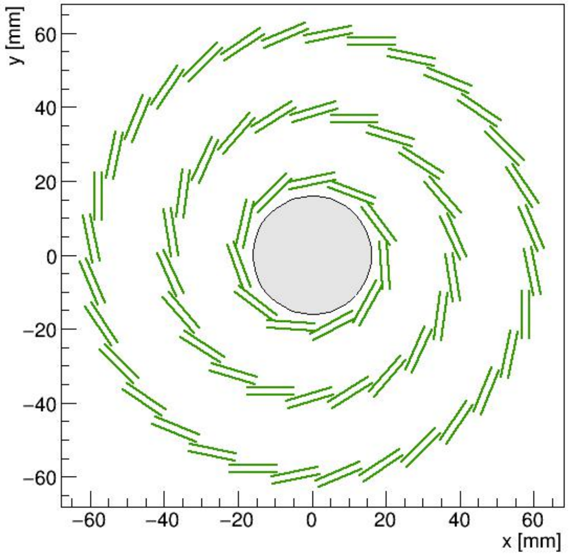
radius:12mm



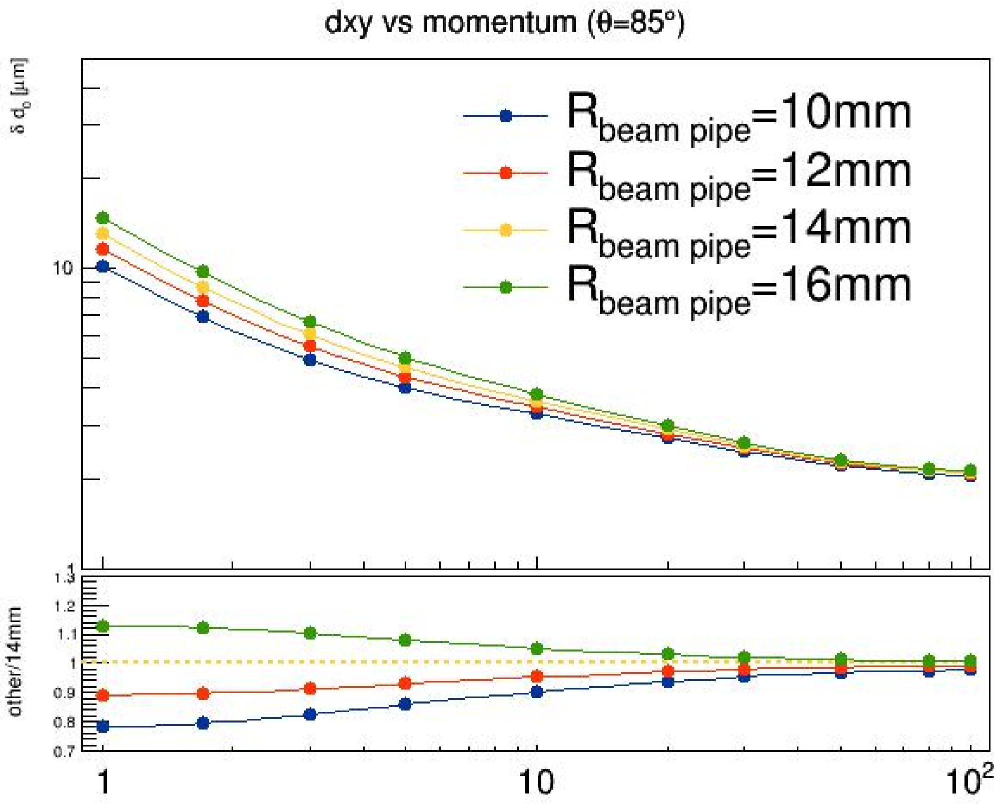
radius:14mm

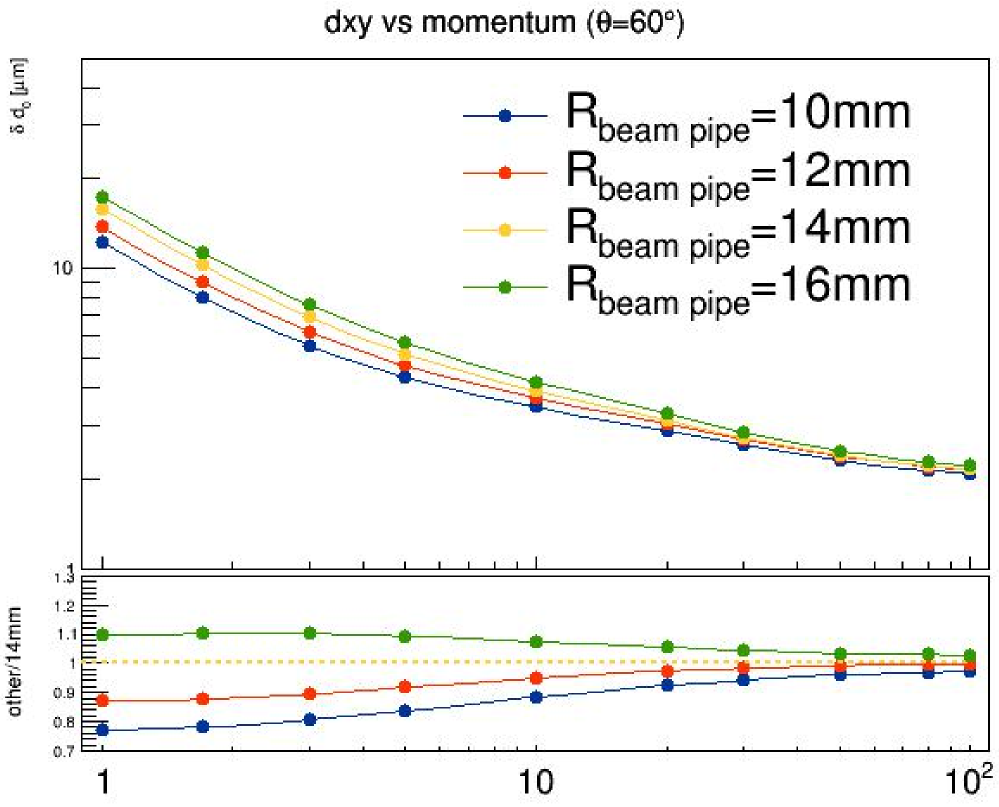


radius:16mm



Impact parameter resolution





Big effect on low momentum track
Beam pipe radius is smaller, resolution is better
Improve resolution 21% if reduce beam pipe radius to 10mm

Beam pipe material

Detail structure

备注：400+550+550=1500 mm

From Ji Quan

innermost Au: T=5um

inner Be: T=0.50mm L=400mm(240+80+80) D(inner)=Ø28mm

gap: T=0.50mm

outer Be: T=0.35mm L=230mm D(inner)=Ø30mm

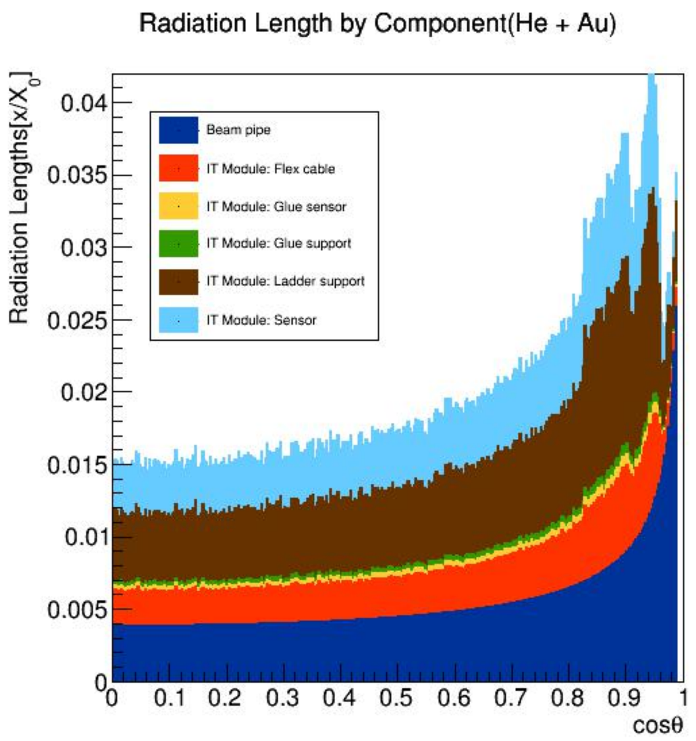
CDR beam pipe: 500um Beryllium

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

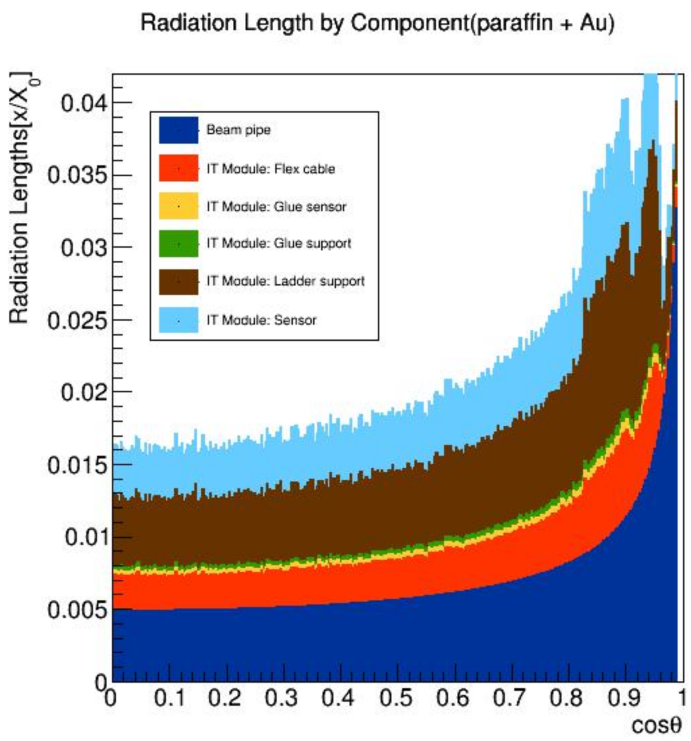
≈ 0.15%

- Paraffin coolant: $x/X_0 = 0.85mm/35.28cm + 0.50mm/48.22cm + 5um/0.3344cm = 0.004941$
- Helium gas coolant: $x/X_0 = 0.85mm/35.28cm + 0.50mm/5.671e{+}05cm + 5um/0.3344cm = 0.003905$
- CDR beam pipe: $x/X_0 = 500um/35.28cm = 0.001417$

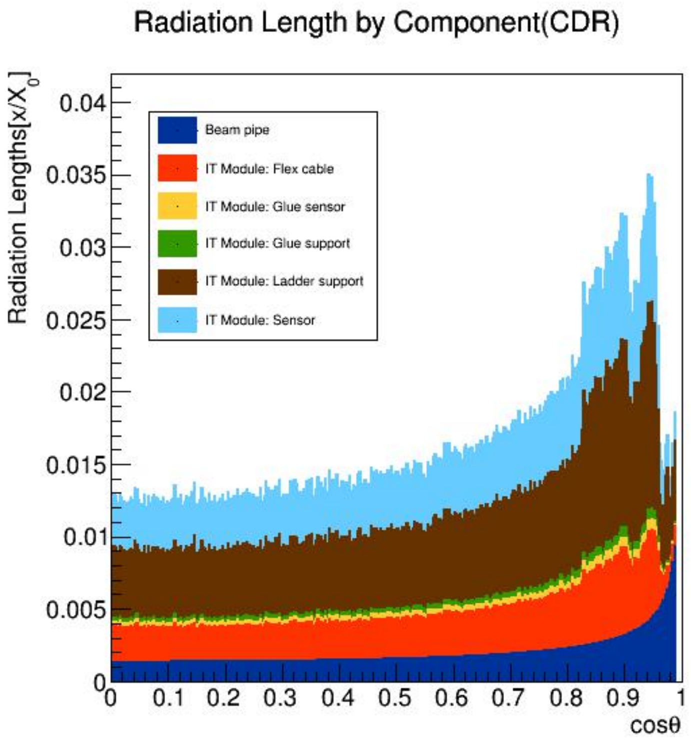
Material budget vs cosθ



Average (cosθ = [0, 0.99])	Radiation length
Beam pipe	0.00558
IT Module: Flex cable	0.00312
IT Module: Glue sensor	0.00037
IT Module: Glue support	0.00037
IT Module: Ladder support	0.00643
IT Module: Sensor	0.00444
total	0.02031

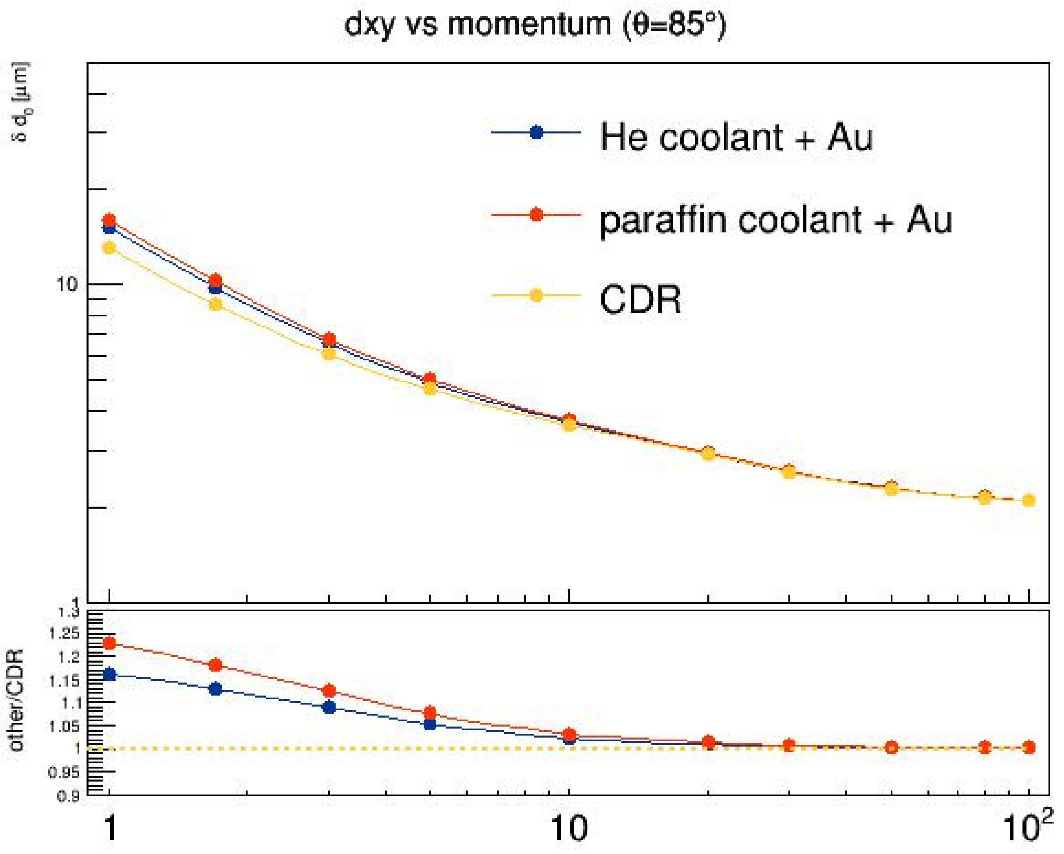


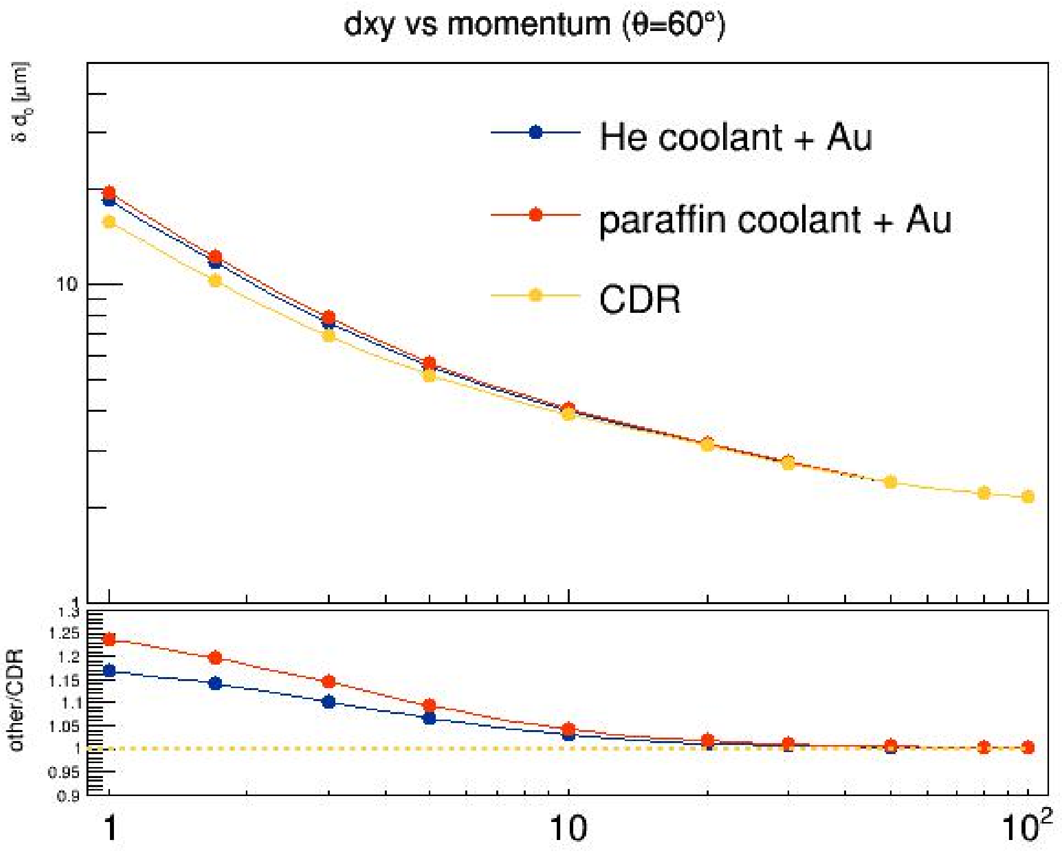
Average (cosθ = [0, 0.99])	Radiation length
Beam pipe	0.00707
IT Module: Flex cable	0.00312
IT Module: Glue sensor	0.00037
IT Module: Glue support	0.00037
IT Module: Ladder support	0.00643
IT Module: Sensor	0.00444
total	0.02180



Average (cosθ = [0, 0.99])	Radiation length
Beam pipe	0.00203
IT Module: Flex cable	0.00312
IT Module: Glue sensor	0.00037
IT Module: Glue support	0.00037
IT Module: Ladder support	0.00643
IT Module: Sensor	0.00444
Total	0.01676

Impact parameter resolution





24% worse if use paraffin coolant +Au

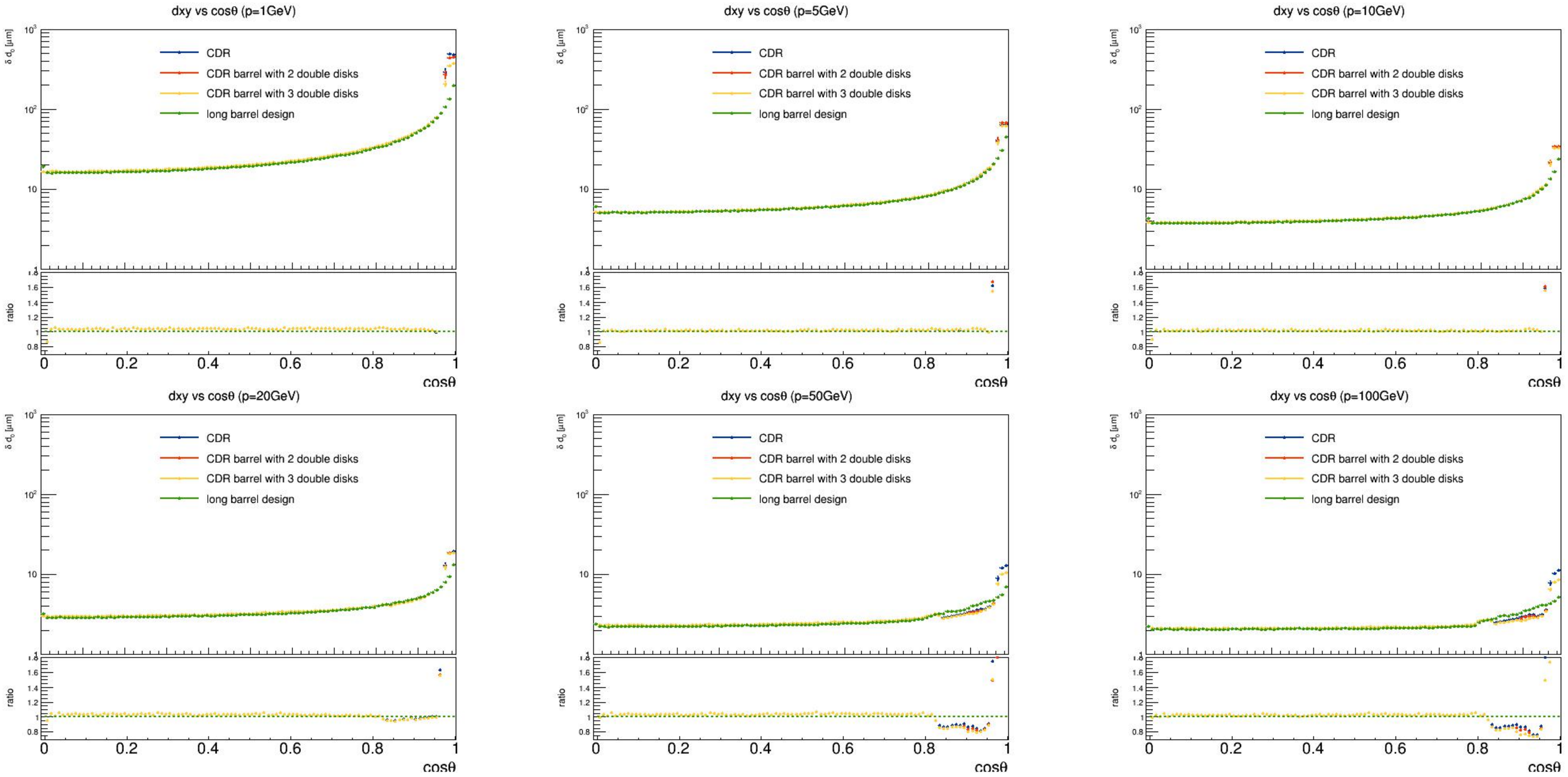
might cancel the material effect if reduce beam pipe radius to 10mm

Summary & Plan

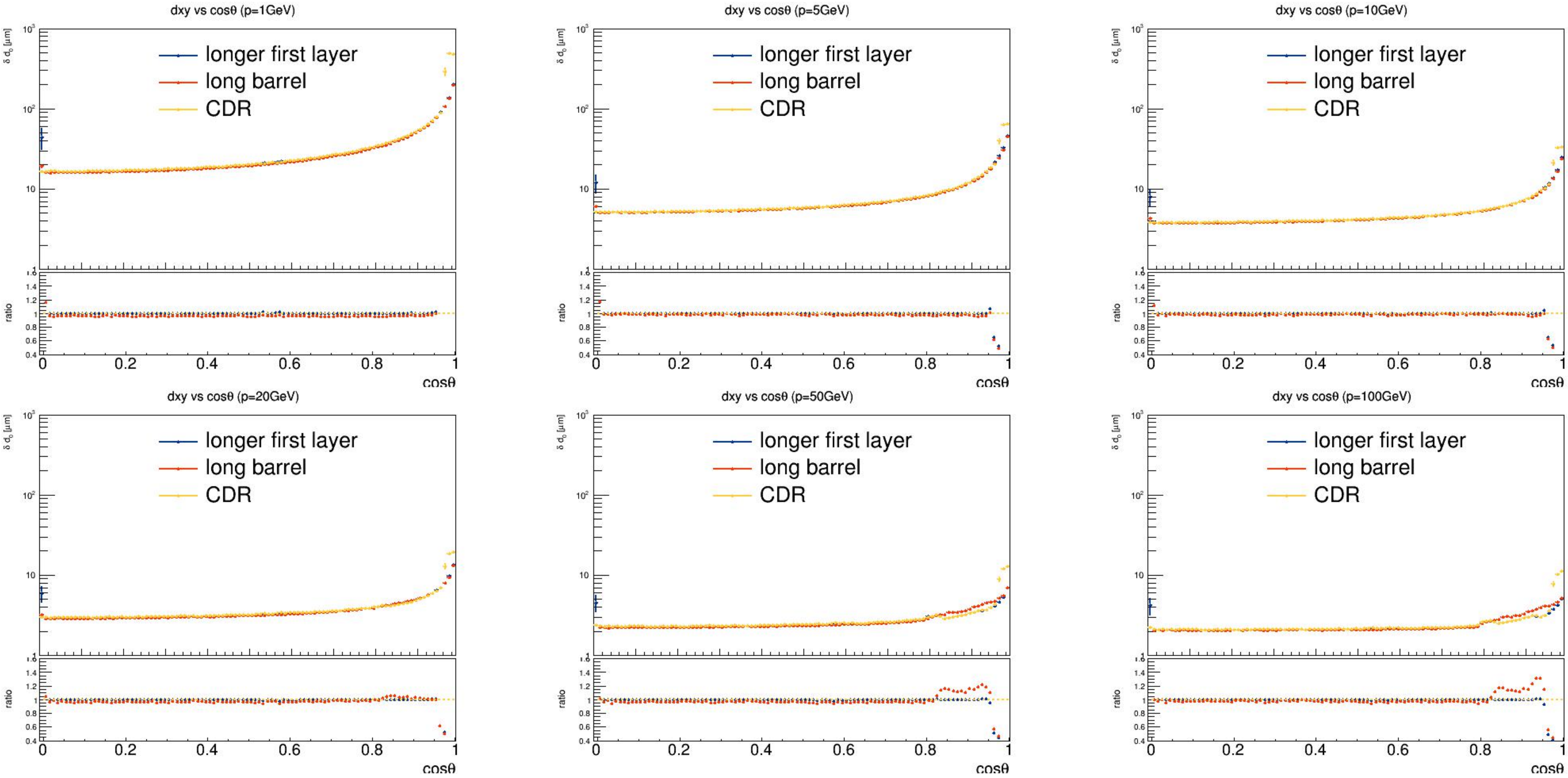
- An optimal vertex layout was got (longer innermost layer + 3 double disks), it has better resolution than CDR design and full barrel design.
- Some new disk arrangements for air cooling have been investigated, perhaps providing new choice for vertex air cooling.
- Beam pipe radius and beam pipe material have been studied, smaller beam pipe radius might cancel material effect.
- Next：
    - Investigate new arrangements
    - Fast simulation tool tkLayout customizing and cross-checking
    - Full simulation validation of optimal design

Backup

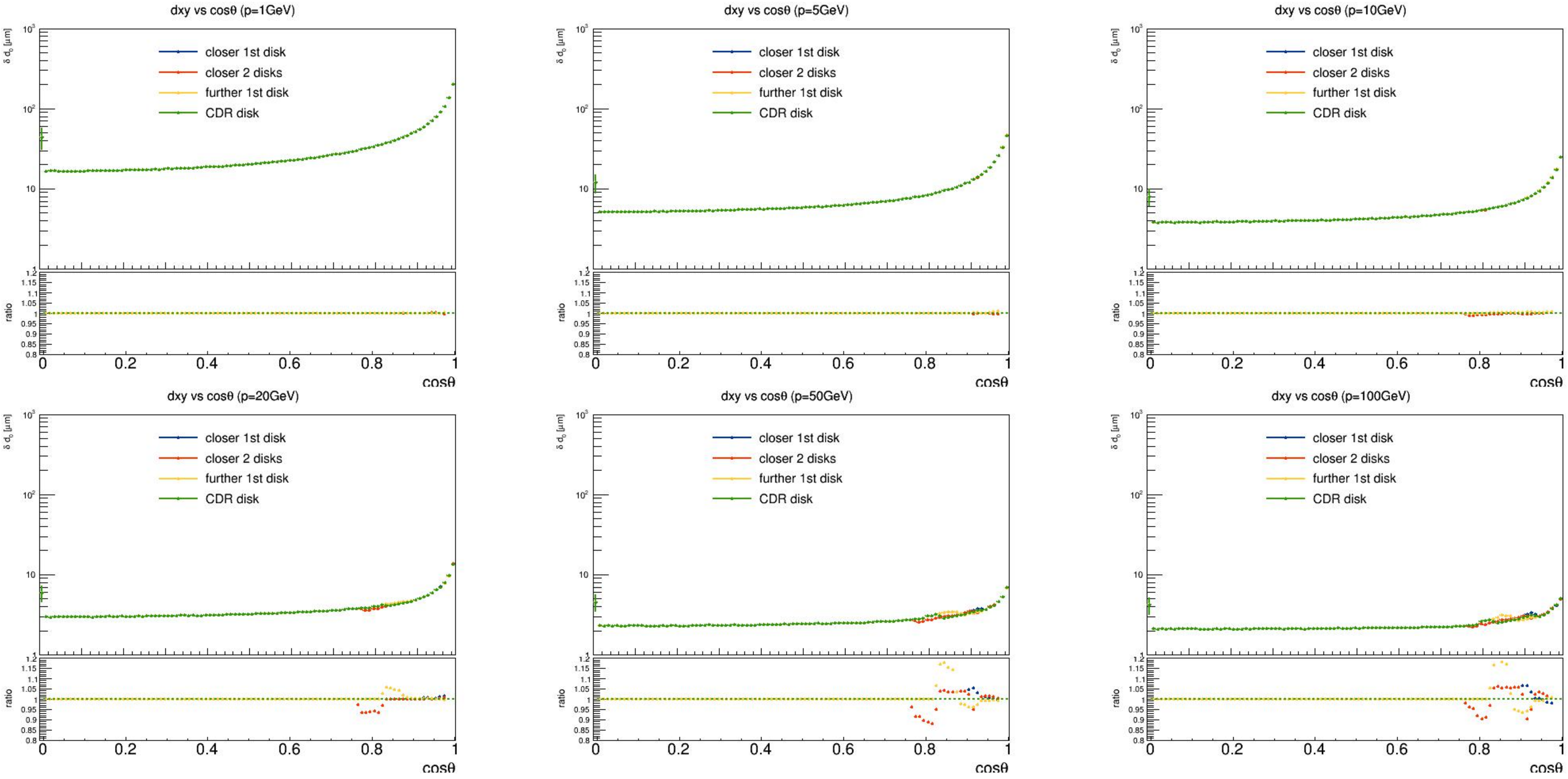
CDR barrel with different disk



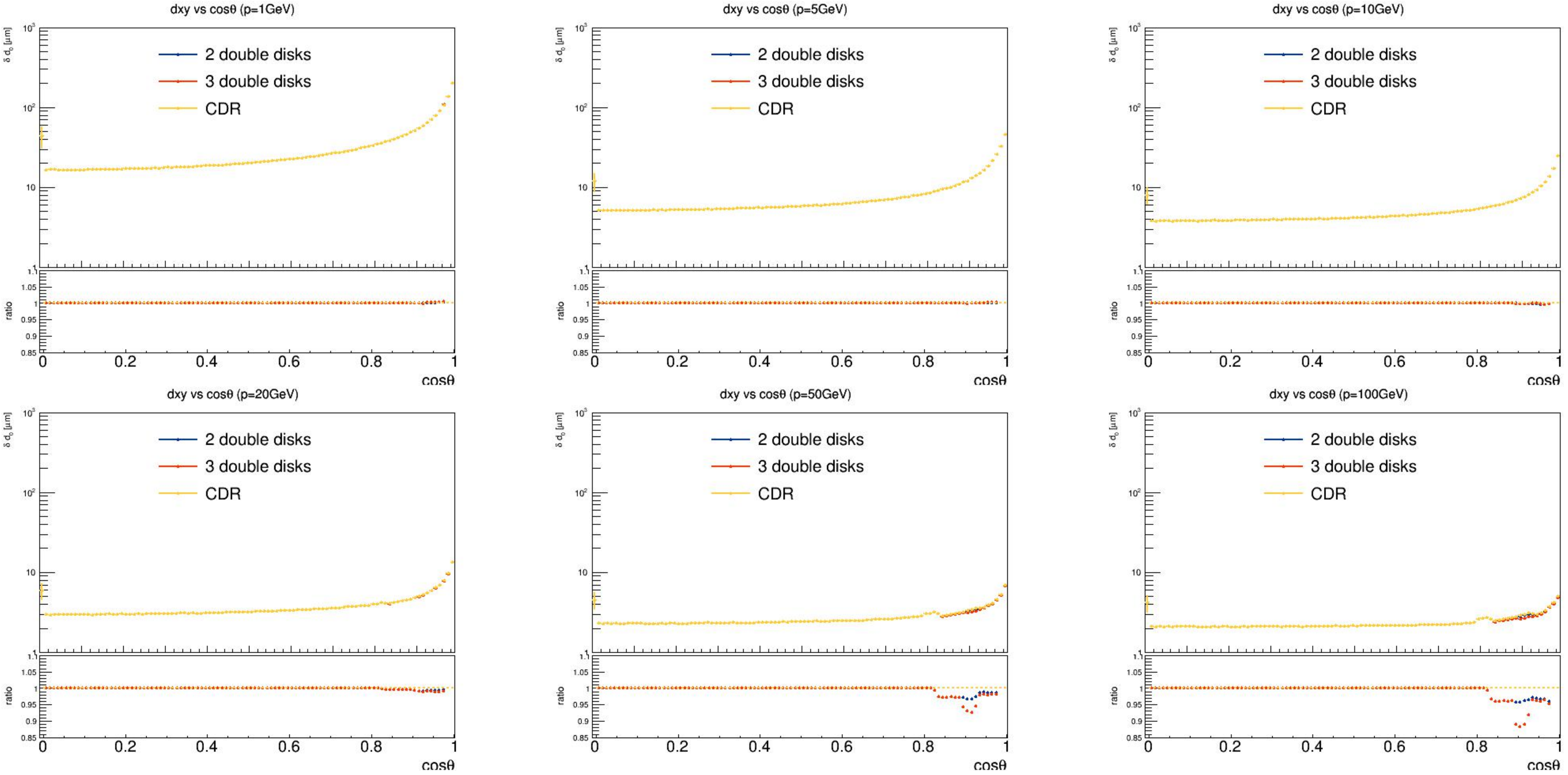
Longer first layer



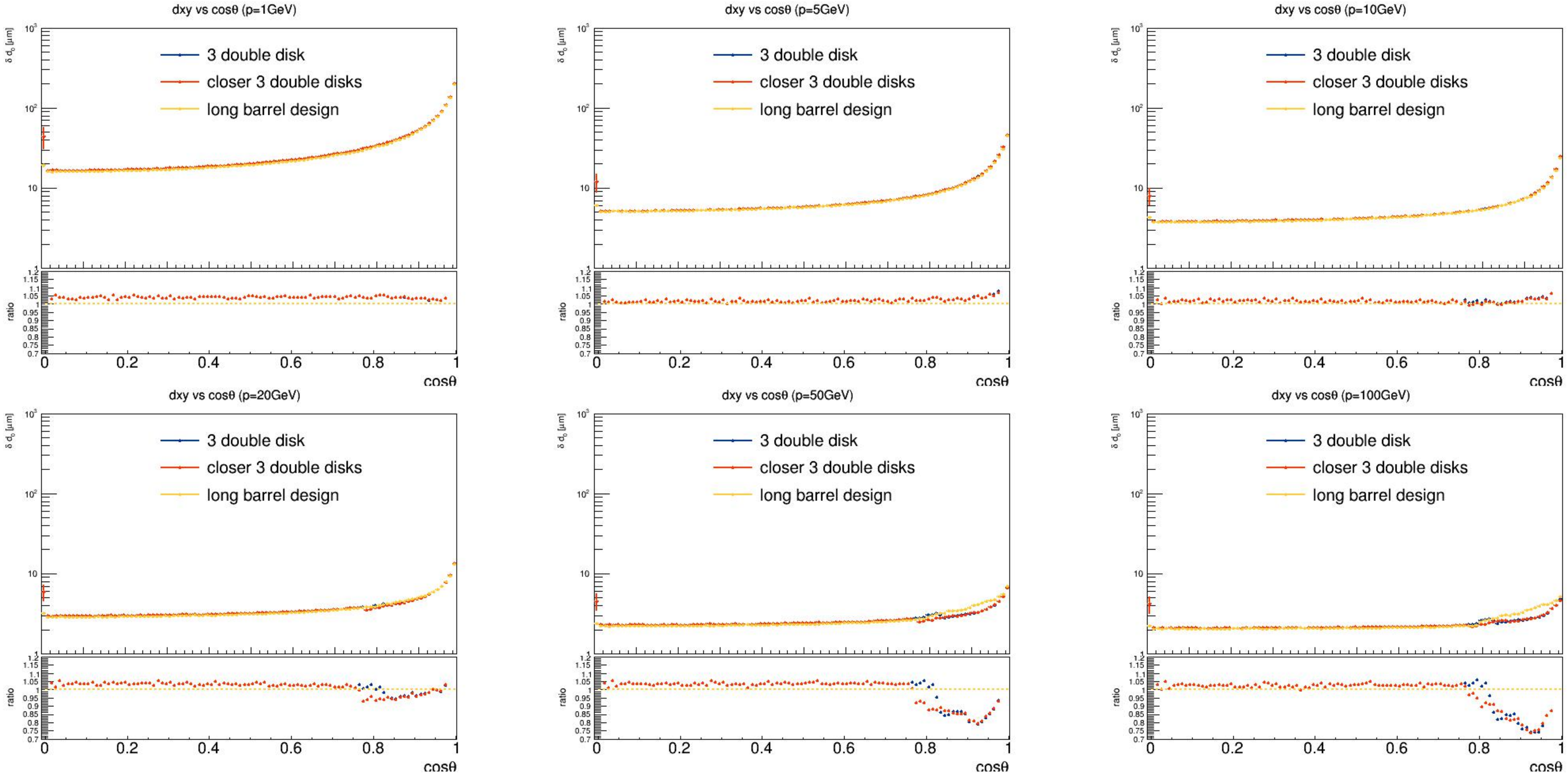
Different position of 2 single-layer disks



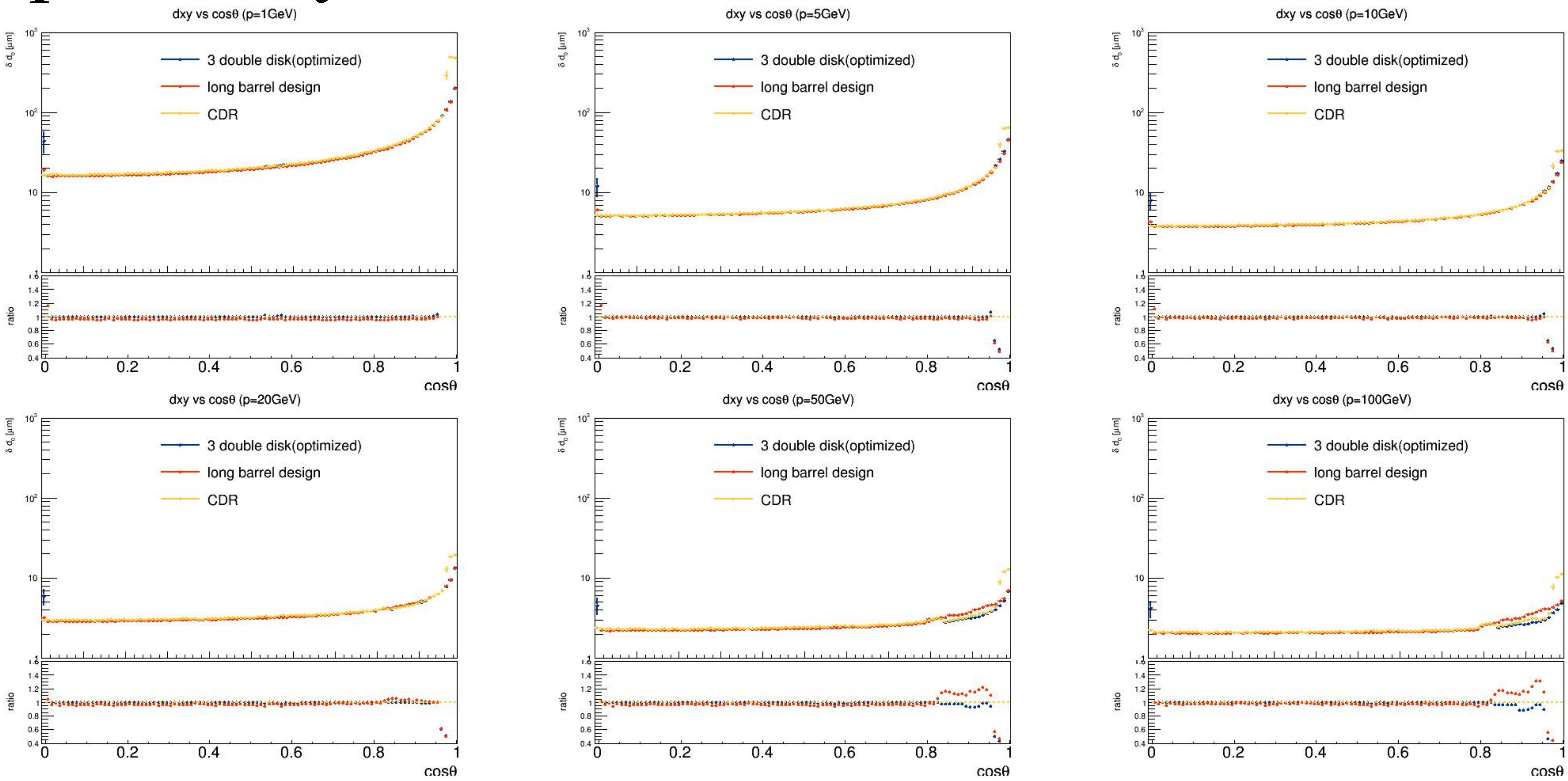
Longer first layer with different number of disk



3 double-layer disks closer to barrel



Optimal layout



New disk arrangements