Simulation and Detector Geometry

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4th CEPC Physics and Software Workshop

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Outline

- Introduction
- Software for full simulation
- Detector geometry
- Discussion and Conclusion

Introduction

- A high energy **C**ircular **E**lectron **P**ositron **C**ollider (CEPC) is being planed as a Higgs and/or Z factory in future. The CEPC project is on the stage of CDR.

Pre-CDR 2015	CDR 2018	TDR 202?	…

- In order to study and optimize the CEPC detector, software as tools is necessary, which include simulation and reconstruction.

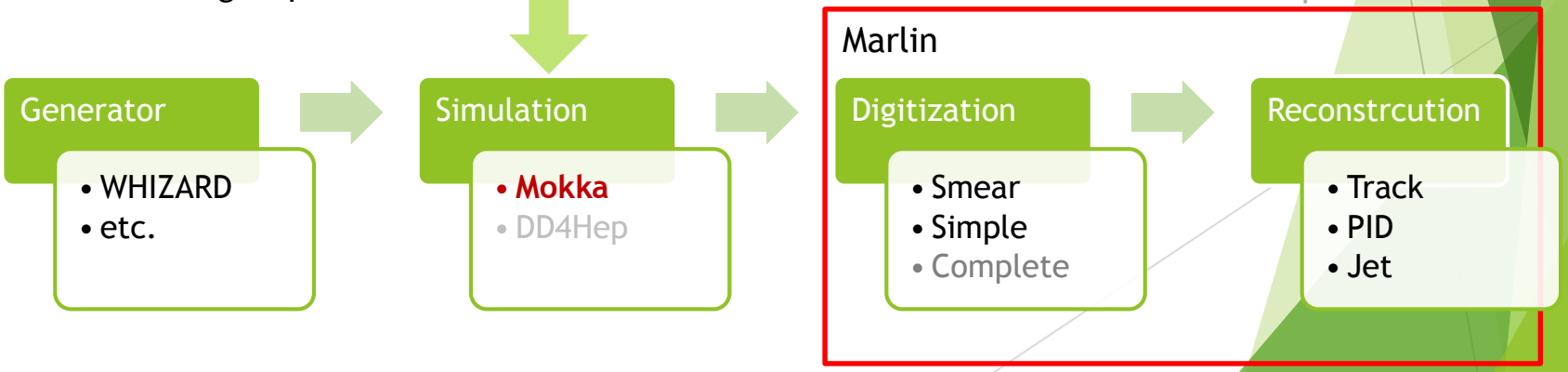
Man power:

Chengdong Fu (IHEP)
Gang Li (IHEP)
Manqi Ruan (IHEP)
Xianghu Zhao (IHEP)
Yin Xu (Nankai)
& other groups

Detector model

As quick starting, following ILC software is taken.

- Bug fix
- Algorithm develop
- Server for physical study and detector optimization
- Aim to software framework development



Simulation Tools—MokkaC

- Mokka at CEPC or Mokka for collider
- Code development
  - http://cepcgit.ihep.ac.cn/cepcsoft/Mokka
- Documents
  - Notes:
    - Full Simulation Software at CEPC (CEPC-SIMU-2017-001)
- How to use
  - Default ILCsoft environment has included Mokka. If use a developing version
    - export MOKKA="$WORKDIR/MokkaC/MokkaC-00-01"
    - export PATH="$MOKKA/bin:$PATH"
    - export LD_LIBRARY_PATH="$MOKKA/lib:$LD_LIBRARY_PATH"
  - Running MokkaC at foreground
    - Mokka [-option] <steering.macro>

Steering file

```
/Mokka/init/BatchMode true
/Mokka/init/printLevel 2
/Mokka/init/detectorModel CEPC_v4

/Mokka/init/dbHost 202.122.37.75
/Mokka/init/user consult
/Mokka/init/dbPasswd consult

/Mokka/init/randomSeed 1000

#Output lcio file
/Mokka/init/lcioFilename     cepc.slcio

#option file for generator
/Mokka/init/initialMacroFile ../event.macro

#Delete previous lcioFile and create a new file, if want to append to old lcioFile, use WRITE_APPEND
/Mokka/init/lcioWriteMode WRITE_NEW

#Option to save step information in a CalorimeterHit
#/Mokka/init/lcioDetailedShowerMode true
#/Mokka/init/lcioStoreCalHitPosition true

#Option to save momentum of particle to cause TrackerHit, user can choice one or more of these collec
#/Mokka/init/lcioDetailedTRKHitMode VXDCollection SITCollection TPCCollection SETCollection FTD PIXEL
```

/Mokka/init/lcioDetailedShowerMode true
/Mokka/init/lcioStoreCalHitPosition true

```
 collection name : HcalBarrelCollection
 parameters:

--------------- print out of SimCalorimeterHit collection ---------------

  flag:  0x80000300
 parameter CellIDEncoding [string]: M:3,S-1:3,I:9,J:9,K-1:6,
  -> LCIO::CHBIT_LONG   : 1
     LCIO::CHBIT_BARREL : 0
     LCIO::CHBIT_ID1    : 0
     LCIO::CHBIT_STEP   : 0

 [   id   ] |cellId0 |cellId1 |  energy  |        position (x,y,z)          | nMCParticles
          -> MC contribution: prim. PDG |  energy  |   time   | sec. PDG | stepPosition (x,y,
------------|--------|--------|----------|---------------------------------|--------------
 [00000088] |01114201|00000000|+9.649e-07|-2.044e+03, -8.989e+02, -1.994e+03|          +1
        id-fields: (M:1,S-1:3,I:1,J:34,K-1:0)
           ->                            +13|+9.649e-07|+9.991e+00| no PDG
 [00000089] |00994193|00000000|+1.666e-06|-2.081e+03, -9.203e+02, -2.034e+03|          +1
        id-fields: (M:1,S-1:2,I:174,J:30,K-1:0)
           ->                            +13|+1.666e-06|+1.019e+01| no PDG
 [00000090] |17673041|00000000|+7.049e-07|-2.108e+03, -9.370e+02, -2.064e+03|          +1
        id-fields: (M:1,S-1:2,I:173,J:27,K-1:1)
           ->                            +13|+7.049e-07|+1.033e+01| no PDG
 [00000091] |34384657|00000000|+1.202e-06|-2.134e+03, -9.537e+02, -2.084e+03|          +1
```

```
  flag:  0x90000300
 parameter CellIDEncoding [string]: M:3,S-1:3,I:9,J:9,K-1:6,
  -> LCIO::CHBIT_LONG   : 1
     LCIO::CHBIT_BARREL : 0
     LCIO::CHBIT_ID1    : 0
     LCIO::CHBIT_STEP   : 1

 [   id   ] |cellId0 |cellId1 |  energy  |        position (x,y,z)          | nMCParticles
          -> MC contribution: prim. PDG |  energy  |   time   | sec. PDG | stepPosition (x,y,z)
------------|--------|--------|----------|---------------------------------|--------------
 [00000088] |01114201|00000000|+9.649e-07|-2.044e+03, -8.989e+02, -1.994e+03|          +1
        id-fields: (M:1,S-1:3,I:1,J:34,K-1:0)
           ->                            +13|+9.649e-07|+9.991e+00|+13| (-2.042e+03, -9.013e+02, -1.993e+03)
 [00000089] |00994193|00000000|+1.666e-06|-2.081e+03, -9.203e+02, -2.034e+03|          +1
        id-fields: (M:1,S-1:2,I:174,J:30,K-1:0)
           ->                            +13|+1.666e-06|+1.019e+01|+13| (-2.081e+03, -9.233e+02, -2.034e+03)
 [00000090] |17673041|00000000|+7.049e-07|-2.108e+03, -9.370e+02, -2.064e+03|          +1
        id-fields: (M:1,S-1:2,I:173,J:27,K-1:1)
           ->                            +13|+7.049e-07|+1.033e+01|+13| (-2.108e+03, -9.381e+02, -2.061e+03)
 [00000091] |34384657|00000000|+1.202e-06|-2.134e+03, -9.537e+02, -2.084e+03|          +1
        id-fields: (M:1,S-1:2,I:172,J:25,K-1:2)
           ->                            +13|+1.202e-06|+1.047e+01|+13| (-2.134e+03, -9.531e+02, -2.088e+03)
 [00000092] |51063505|00000000|+3.189e-06|-2.161e+03, -9.705e+02, -2.114e+03|          +3
        id-fields: (M:1,S-1:2,I:171,J:22,K-1:3)
           ->                            +13|+1.199e-06|+1.060e+01|+11| (-2.161e+03, -9.679e+02, -2.115e+03)
           ->                            +13|+3.500e-07|+1.060e+01|+13| (-2.161e+03, -9.678e+02, -2.115e+03)
           ->                            +13|+1.641e-06|+1.060e+01|+13| (-2.161e+03, -9.682e+02, -2.116e+03)
```

/Mokka/init/lcioDetailedTRKHitMode VXDCollection SITCollection TPCCollection SETCollection

```
collection name : TPCCollection
parameters:

--------------- print out of SimTrackerHit collection ---------------

 flag:  0x20000600
parameter CellIDEncoding [string]: subdet:5,side:-2,layer:9,module:8,sensor:8,
    LCIO::THBIT_BARREL : 0
    LCIO::THBIT_MOMENTUM : 0

[   id    ] |cellId0 |cellId1 |  position (x,y,z)               |   EDep    |   time    |PDG of MCParticle|   (px,  py, pz)    | pathLength
------------|--------|--------|---------------------------------|-----------|-----------|-----------------|--------------------|-------------
[00000145] |00000001|00000000|(-3.65e+02, -1.30e+02, -3.45e+02)| 8.41e-06 | 1.73e+00 | 00000000000013  |   unknown          |
       id-fields: (subdet:1,side:0,layer:0,module:0,sensor:0)

[00000146] |00000002|00000000|(-3.70e+02, -1.32e+02, -3.50e+02)| 2.16e-06 | 1.76e+00 | 00000000000013  |   unknown          |
       id-fields: (subdet:2,side:0,layer:0,module:0,sensor:0)

[00000147] |00000003|00000000|(-3.76e+02, -1.34e+02, -3.56e+02)| 1.24e-06 | 1.78e+00 | 00000000000013  |   unknown          |
       id-fields: (subdet:3,side:0,layer:0,module:0,sensor:0)

[00000148] |00000004|00000000|(-3.81e+02, -1.36e+02, -3.61e+02)| 1.54e-06 | 1.81e+00 | 00000000000013  |   unknown          |
       id-fields: (subdet:4,side:0,layer:0,module:0,sensor:0)

[00000149] |00000005|00000000|(-3.87e+02, -1.38e+02, -3.66e+02)| 1.41e-06 | 1.84e+00 | 00000000000013  |   unknown          |
       id-fields: (subdet:5,side:0,layer:0,module:0,sensor:0)

[00000150] |00000006|00000000|(-3.93e+02, -1.40e+02, -3.72e+02)| 1.83e-06 | 1.86e+00 | 00000000000013  |   unknown          |
       id-fields: (subdet:6,side:0,layer:0,module:0,sensor:0)

[00000151] |00000007|00000000|(-3.98e+02, -1.43e+02, -3.77e+02)| 2.50e-06 | 1.89e+00 | 00000000000013  |   unknown          |
       id-fields: (subdet:7,side:0,layer:0,module:0,sensor:0)
```

```
collection name : TPCCollection
parameters:

--------------- print out of SimTrackerHit collection ---------------

 flag:  0x60000600
parameter CellIDEncoding [string]: subdet:5,side:-2,layer:9,module:8,sensor:8,
    LCIO::THBIT_BARREL : 0
    LCIO::THBIT_MOMENTUM : 1

[   id    ] |cellId0 |cellId1 |  position (x,y,z)               |   EDep    |   time    |PDG of MCParticle|   (px,  py, pz)    | pathLength
------------|--------|--------|---------------------------------|-----------|-----------|-----------------|--------------------|-------------
[00000145] |00000001|00000000|(-3.65e+02, -1.30e+02, -3.45e+02)| 8.41e-06 | 1.73e+00 | 00000000000013   | (-1.07e+01, -3.99e+00, -1.02e+01) | 8.04e+00
       id-fields: (subdet:1,side:0,layer:0,module:0,sensor:0)

[00000146] |00000002|00000000|(-3.70e+02, -1.32e+02, -3.50e+02)| 2.16e-06 | 1.76e+00 | 00000000000013   | (-1.07e+01, -4.00e+00, -1.02e+01) | 8.04e+00
       id-fields: (subdet:2,side:0,layer:0,module:0,sensor:0)

[00000147] |00000003|00000000|(-3.76e+02, -1.34e+02, -3.56e+02)| 1.24e-06 | 1.78e+00 | 00000000000013   | (-1.07e+01, -4.00e+00, -1.02e+01) | 8.04e+00
       id-fields: (subdet:3,side:0,layer:0,module:0,sensor:0)

[00000148] |00000004|00000000|(-3.81e+02, -1.36e+02, -3.61e+02)| 1.54e-06 | 1.81e+00 | 00000000000013   | (-1.07e+01, -4.01e+00, -1.02e+01) | 8.06e+00
       id-fields: (subdet:4,side:0,layer:0,module:0,sensor:0)

[00000149] |00000005|00000000|(-3.87e+02, -1.38e+02, -3.66e+02)| 1.41e-06 | 1.84e+00 | 00000000000013   | (-1.07e+01, -4.01e+00, -1.02e+01) | 8.04e+00
       id-fields: (subdet:5,side:0,layer:0,module:0,sensor:0)

[00000150] |00000006|00000000|(-3.93e+02, -1.40e+02, -3.72e+02)| 1.83e-06 | 1.86e+00 | 00000000000013   | (-1.07e+01, -4.02e+00, -1.02e+01) | 8.04e+00
       id-fields: (subdet:6,side:0,layer:0,module:0,sensor:0)

[00000151] |00000007|00000000|(-3.98e+02, -1.43e+02, -3.77e+02)| 2.50e-06 | 1.89e+00 | 00000000000013   | (-1.07e+01, -4.02e+00, -1.02e+01) | 8.04e+00
       id-fields: (subdet:7,side:0,layer:0,module:0,sensor:0)
```

Generator option

- /generator/generator events.stdhep
- /run/beamOn 100
- or

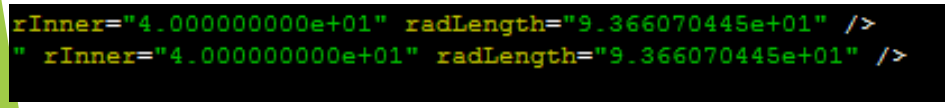
```
/generator/generator particleGun
/gun/position 0 0 0 mm
/gun/direction 1 0 0
/gun/directionSmearingMode uniform
/gun/thetaSmearing 89 deg
/gun/phiSmearing 180 deg
/gun/momentum 75 GeV
/gun/momentumSmearingMode uniform
/gun/momentumSmearing 74.9 GeV
/gun/particle mu-
/run/beamOn 10
```

Mokka VS MokkaC

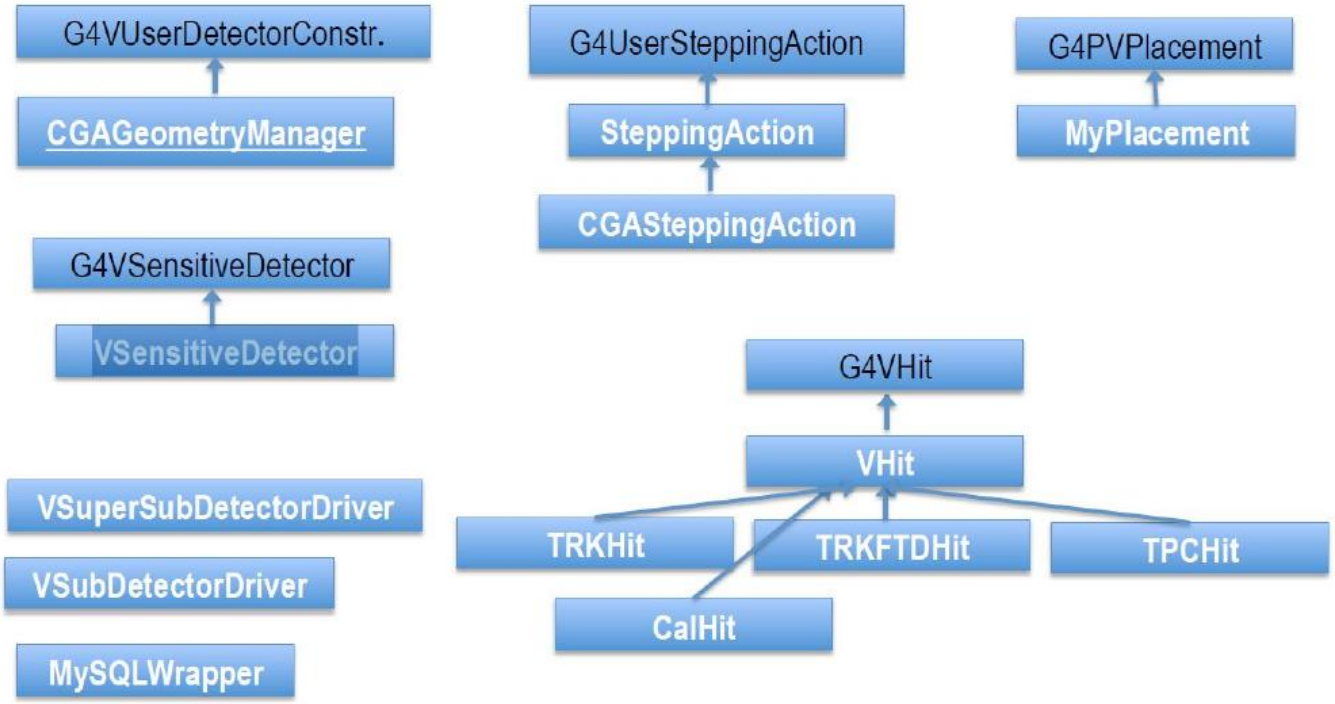
- **M**odellierung mit **O**bjekten eines **K**ompakten **Ka**lorimeters
- Object Modeling for compact calorimeters
- Mokka is a Geant4-based full simulation framework, in the original version, its detector data driven model is strongly based on MySQL
  - Store models information
  - Store geometry parameters
- It is modified to break away from database partly, in order to compact new sub-detectors quickly and modify them flexibly.
  - Add new sub-detector into CEPC model
  - Input parameters through steering file
- New more type of sub-detectors have been built.
  - A simple general calorimeter: silicon-based, BGO, LGO, Scintillator, THGEM, RPC, LYSO, BC420…
  - Silicon-based tracker: replace TPC
  - GeneralInterface: to intergrate sub-detector quickly

More update

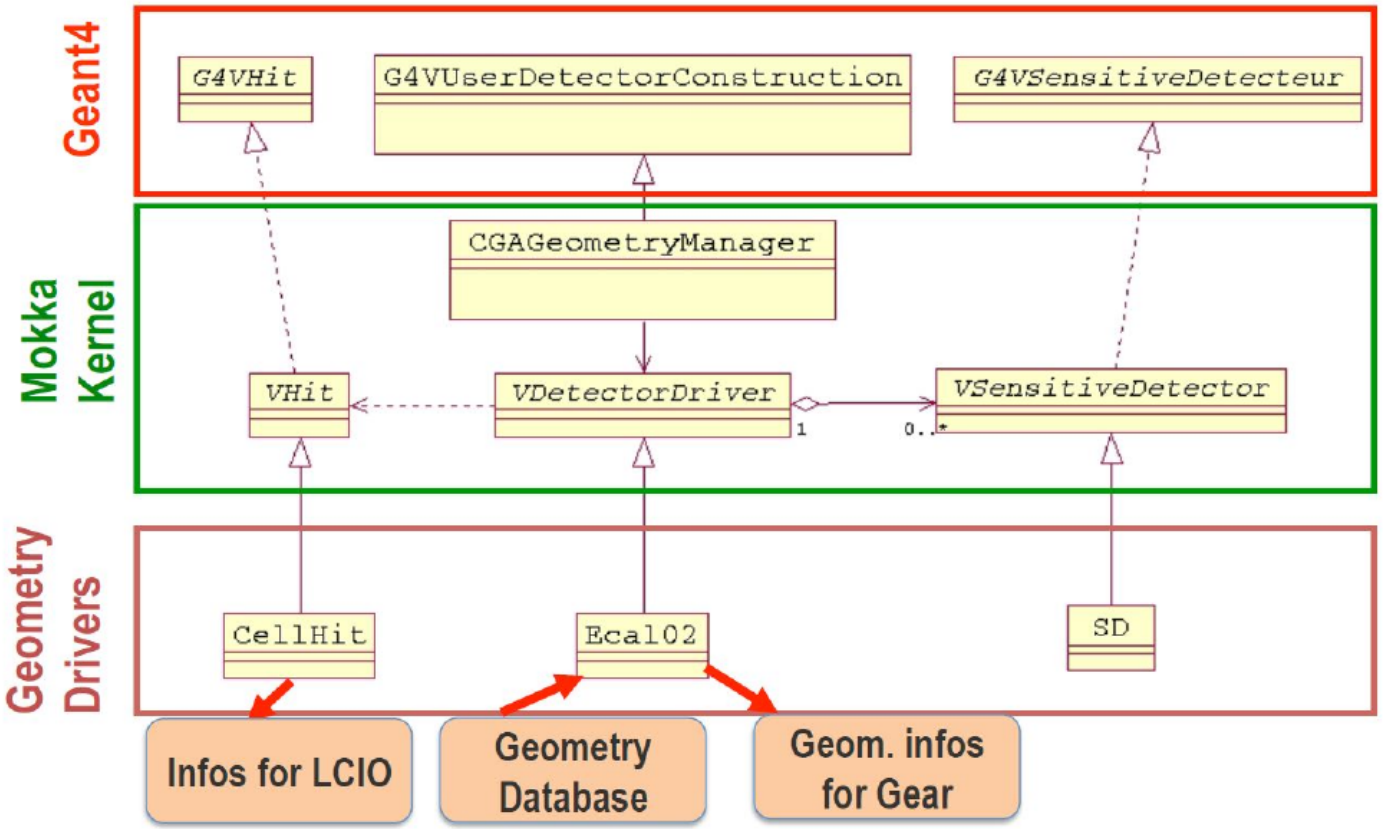
- Support to change database of driver in steering file
  - Previous:
    - /Mokka/init/EditGeometry/addSubDetector tube_cepc
    - /Mokka/init/EditGeometry/newSubDetector SiTracker01
  - Current:
    - /Mokka/init/EditGeometry/newSubDetector new_tube 150 Tube_cepc TMP_DB03_33_Cu
- Support scintillator for SHcalRpc01 driver
- Add optional parameters for VXD (scale of thickness) through steering file
- Add optional parameters for Yoke (layer number and thickness) through steering file
- Correct FTD Gear output for radiation length of support



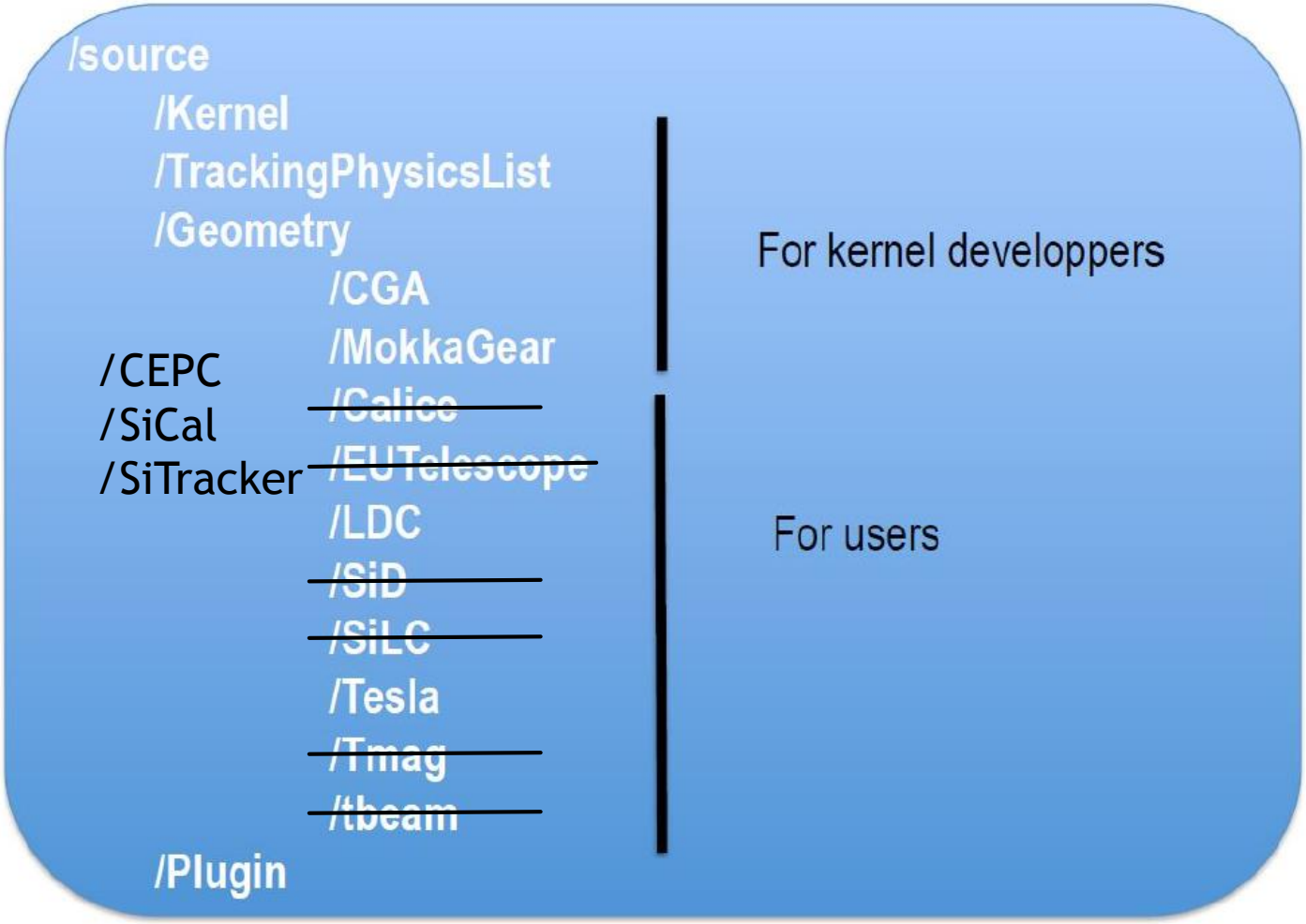
Mokka Kernel



Interface to Geant4



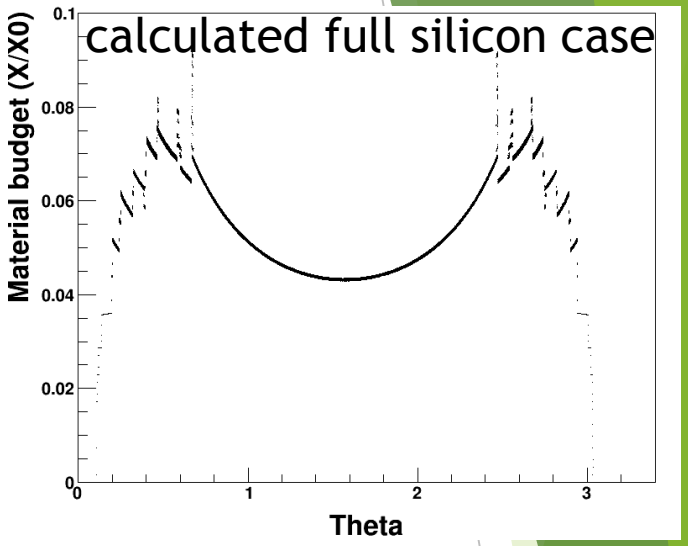
Codes

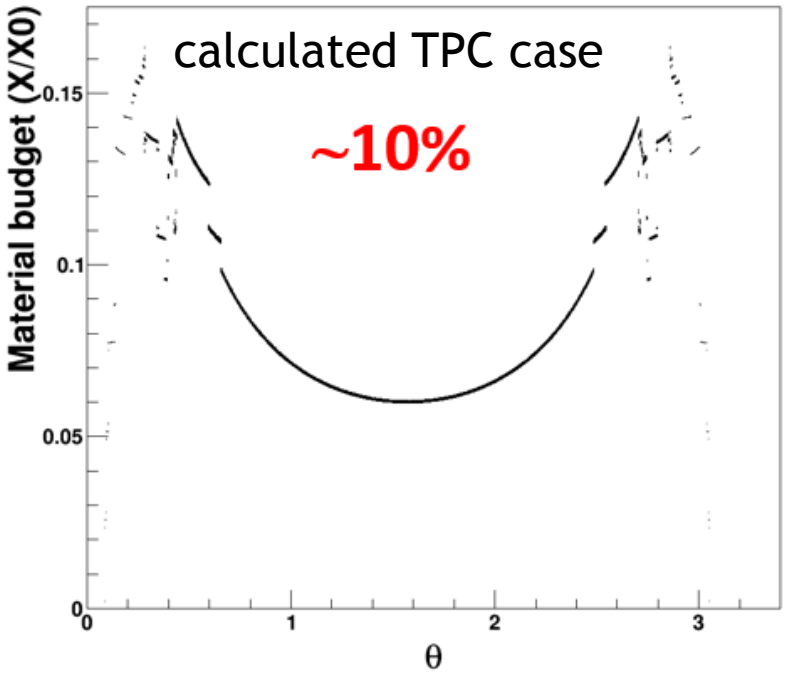

/source
/Kernel
/TrackingPhysicsList
/Geometry
/CGA
/MokkaGear
/CEPC
/SiCal
/SiTracker
/Calice
/EUTelescope
/LDC
/SiD
/SiLC
/Tesla
/Tmag
/tbeam
/Plugin
For kernel developpers
For users

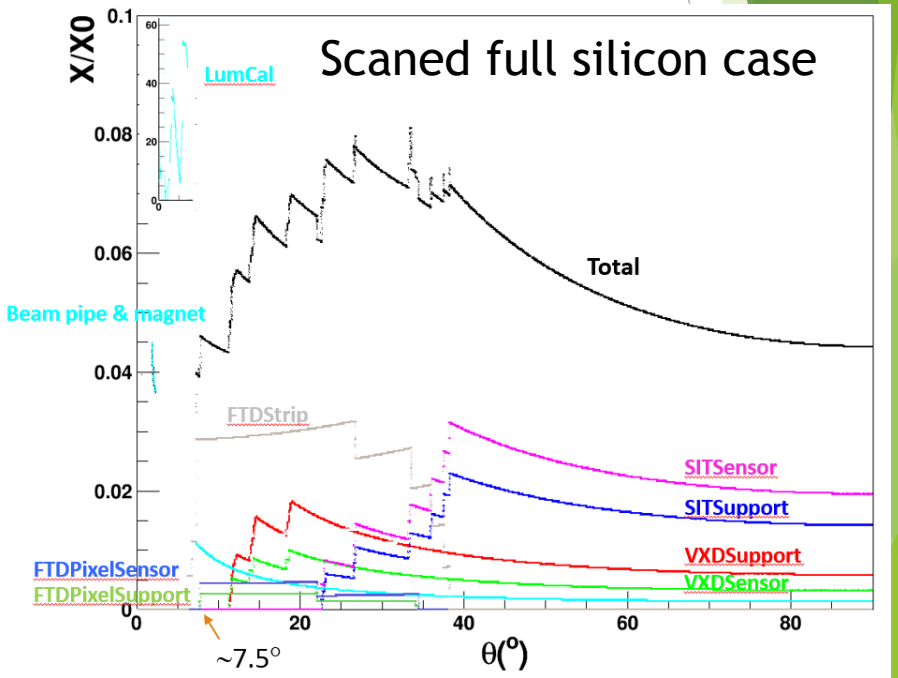
New tool—BudgetPlugin

- /Mokka/init/registerPlugin BudgetPlugin
- /Mokka/init/userInitString OutputFile budget.root
- /Mokka/init/userInitDouble zCut 2350
- /Mokka/init/userInitDouble rCut 1850

- /gun/particle geantino
- /run/beamOn 100000





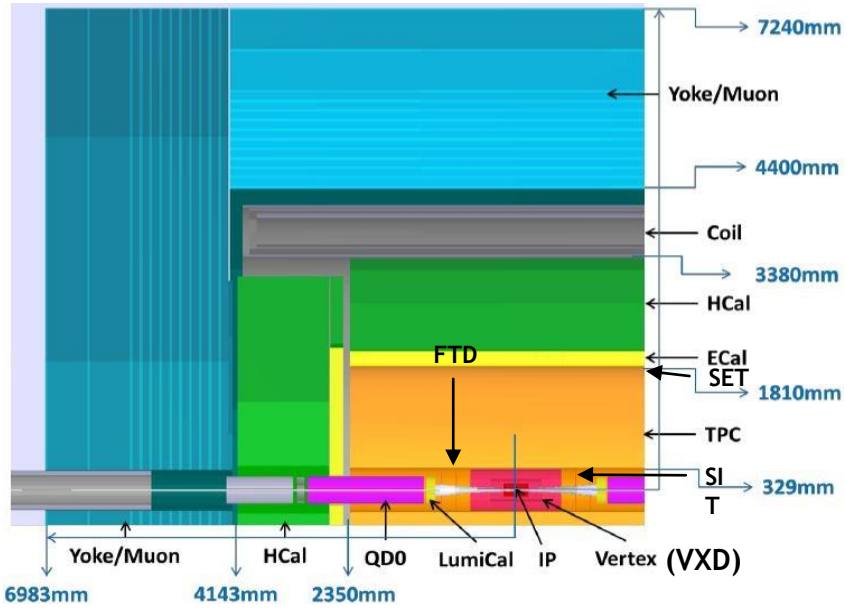


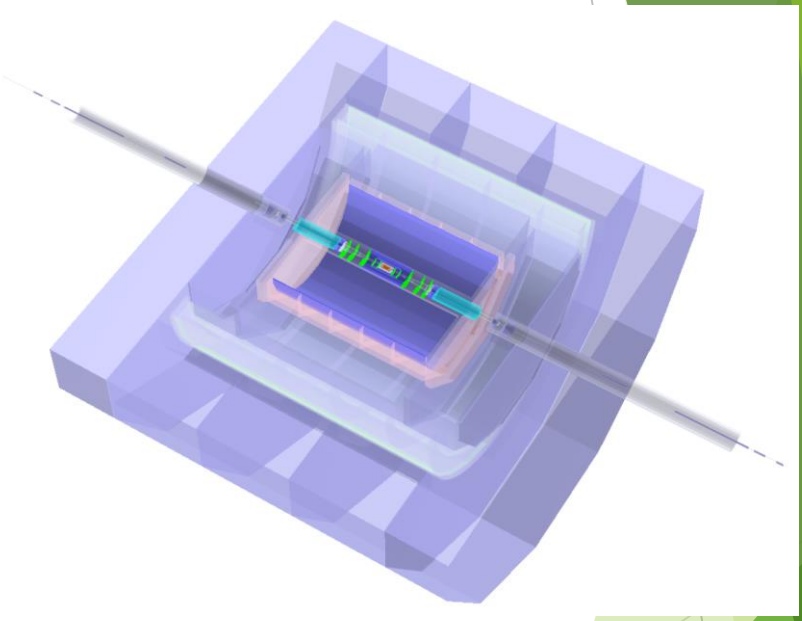
Detector models

- Dominant difference between CEPC_v1 and CEPC_v4 is MDI
- Model based on full silicon tracker: CEPC_v4 patch through steering file
- IDEA: wire chamber + dual-readout calorimeter
- CEPC_v5 is being considered

Sub-detector	CEPC_v1	CEPC_v4
Tube & Mask	Single pipe	New MDI design—doubly pipe
Lcal	R: 60 mm ~ 172 mm	R: 30 mm ~ 100 mm
VXD	16mm/62.5mm, 37mm/125mm, 58/125mm	Same as CEPC_v1
FTD	220mm, 371.3mm, 645mm, 846mm, 1057.5mm	220mm, 371.3mm, 643mm, 844mm, 925mm
SIT & SET	153mm, 300mm, 1811mm, 1813.5mm	Same as CEPC_v1
TPC	Sensitive Radius: 384mm ~ 1718mm	Same as CEPC_v1
Ecal	R: 1843mm ~ 2028mm; Z: 2450mm ~ 2635mm; Cell size: 5.0833mm Rin_endcap: 226.8 mm	Cell size: 10.1667mm Rin_endcap: 245 mm
Hcal	R: 2058mm ~ 3385.53mm; Cell size: 10.408 mm; 48 layers	R: 2058mm ~ 3143.43mm; Z: 2650mm ~ 3736.43mm; 40 layers
Yoke	Rin = 4415(barrel), 300(endcap)	Rin = 4174(barrel), 300(endcap) (240 for MDI)
Field	3.5 T	3.0 T

CEPC_v1


7240mm
Yoke/Muon
4400mm
Coil
3380mm
HCal
FTD
ECal
SET
1810mm
TPC
SI
T
329mm
Yoke/Muon
HCal
QD0
LumiCal
IP
Vertex
(VXD)
6983mm
4143mm
2350mm

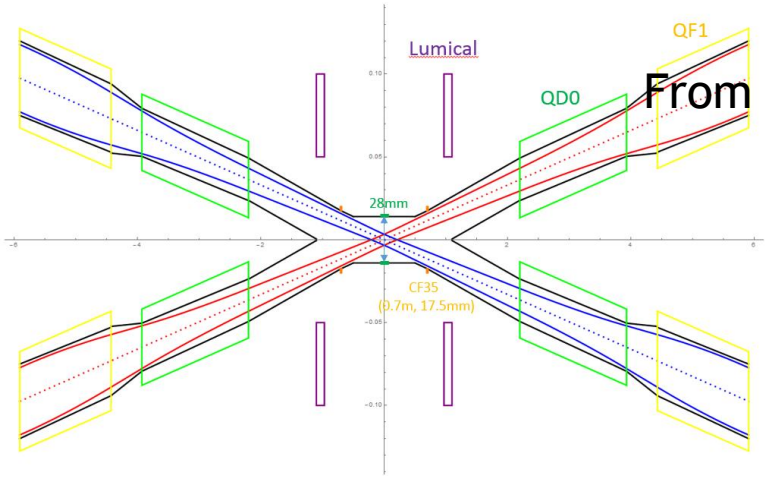


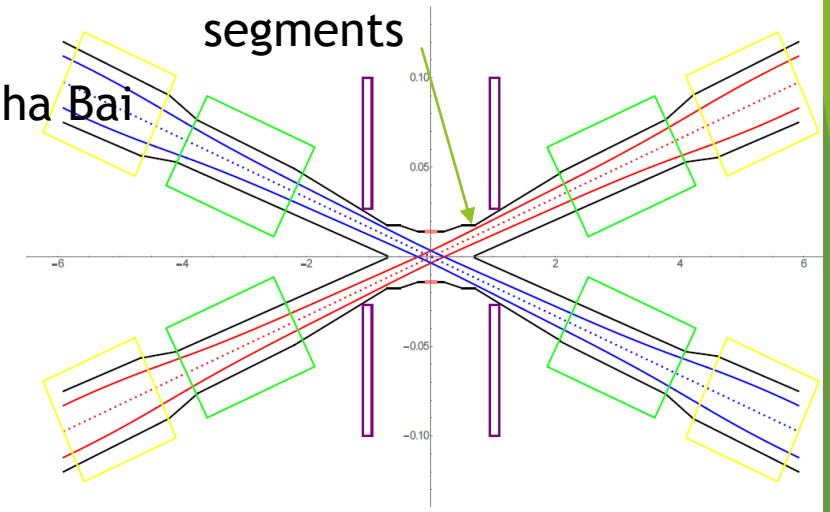
MDI in CEPC_v4

- There are two version of MDI with crossing angle now
  - First doubly-pipe: default in CEPC_v4
  - Sep.26

Designer is considering to use copper for these pipe segments

From Sha Bai

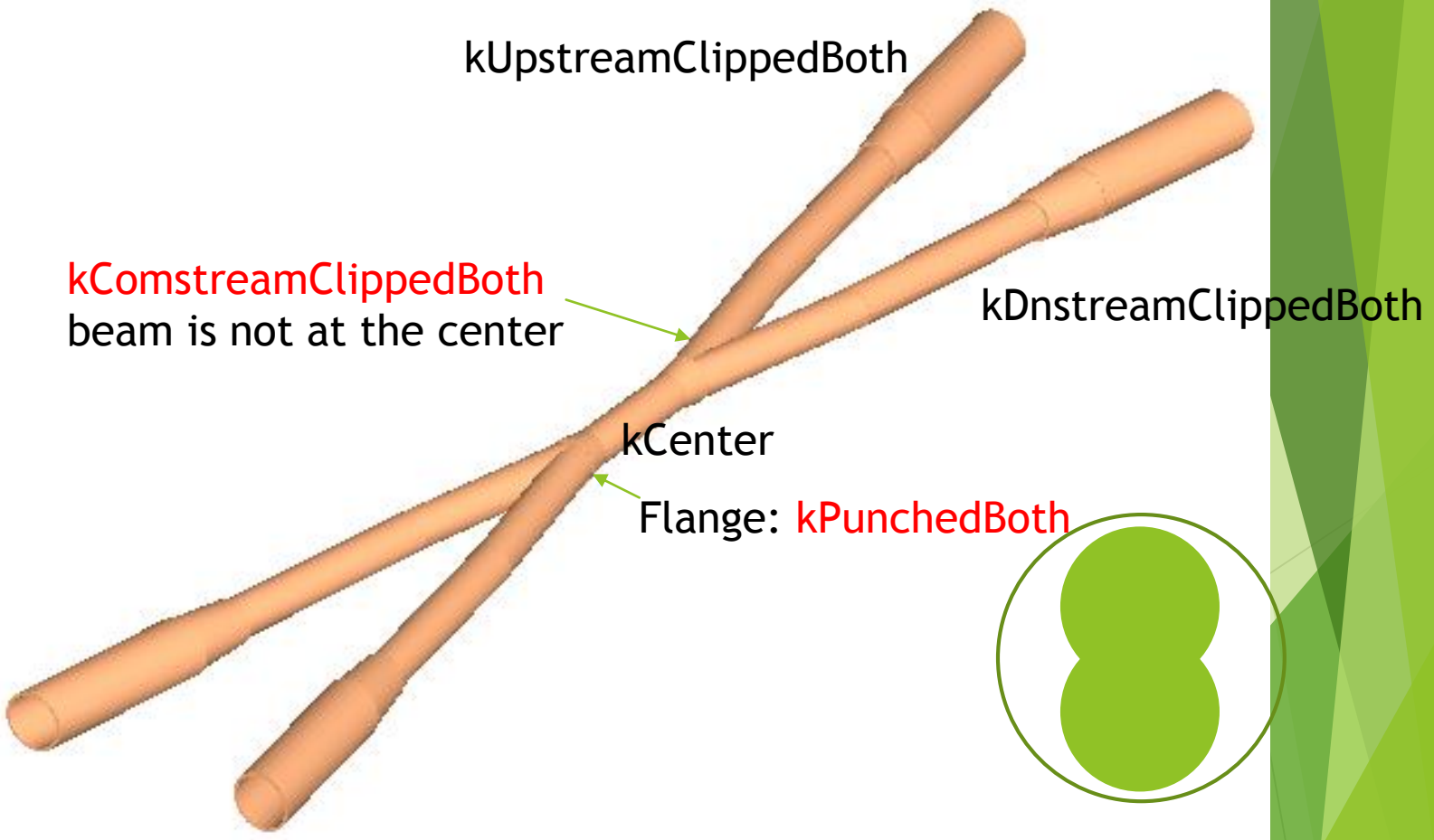




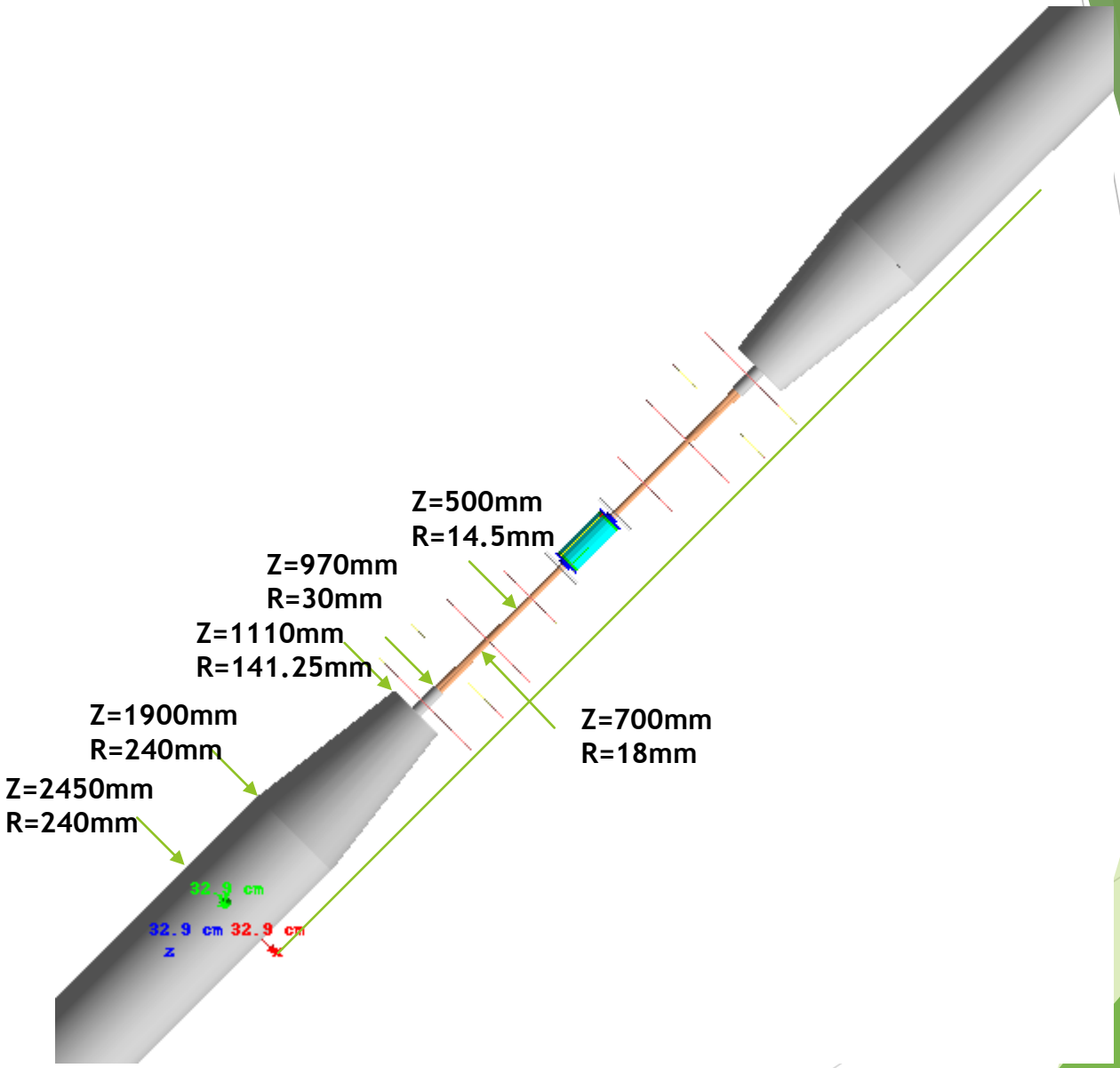
- How to use newer MDI
  - /Mokka/init/EditGeometry/rmSubDetector tube_cepc_v4
  - /Mokka/init/EditGeometry/rmSubDetector mask_cepc_v4
  - /Mokka/init/EditGeometry/newSubDetector new_tube 150 Tube_cepc **tube_cepc_MDI20171220pre**
  - /Mokka/init/EditGeometry/newSubDetector new_mask 160 Mask_cepc **mask_cepc_MDI20170508before**
- Plan:
  - support to change materials of Be-pipe: composited structure (Be+X1+X2+…)
  - Mask to absorb photon

pipe

- New type: kPunchedBoth, kComstreamClippedBoth

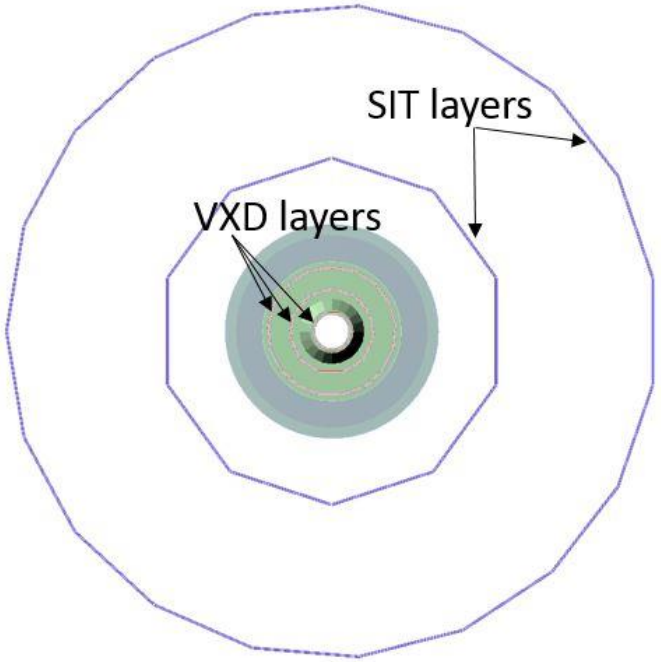


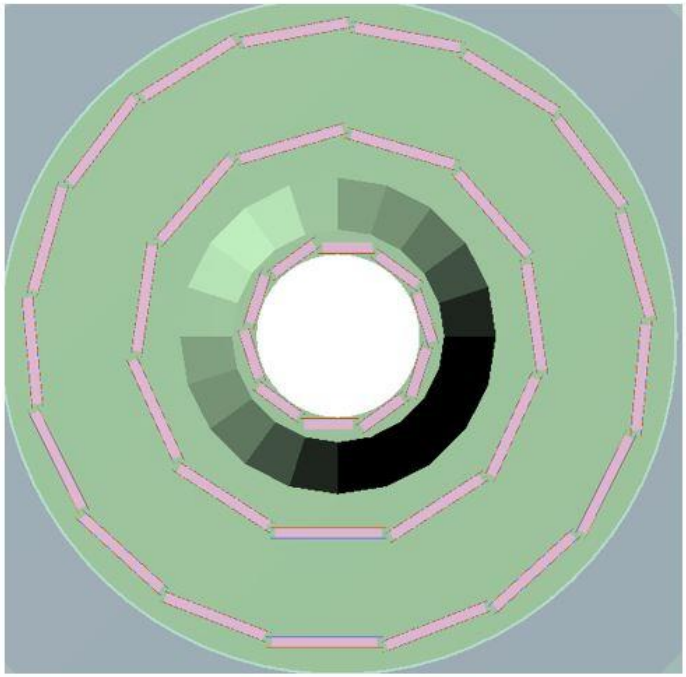
New MDI with old VXD and FTD



VXD

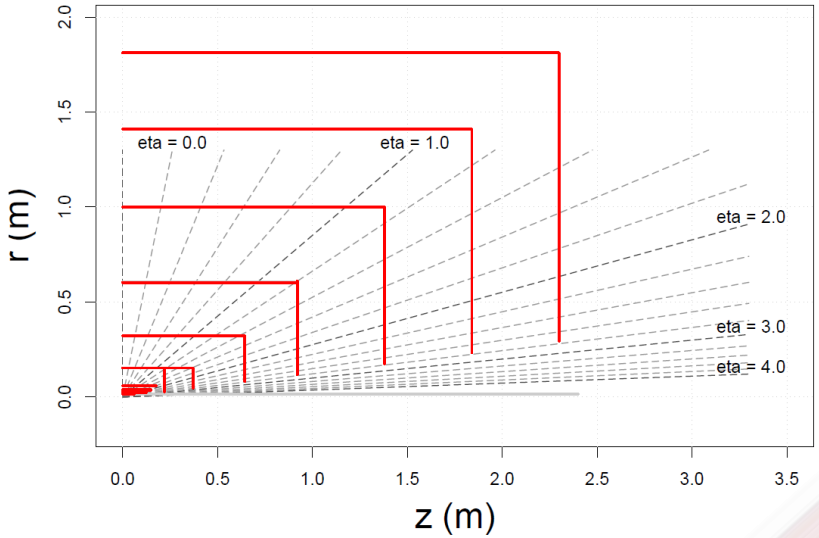
- Option for material budget through density
  - /Mokka/init/globalModelParameter VXDSupportScale 2
  - /Mokka/init/globalModelParameter VXDSiliconScale 1

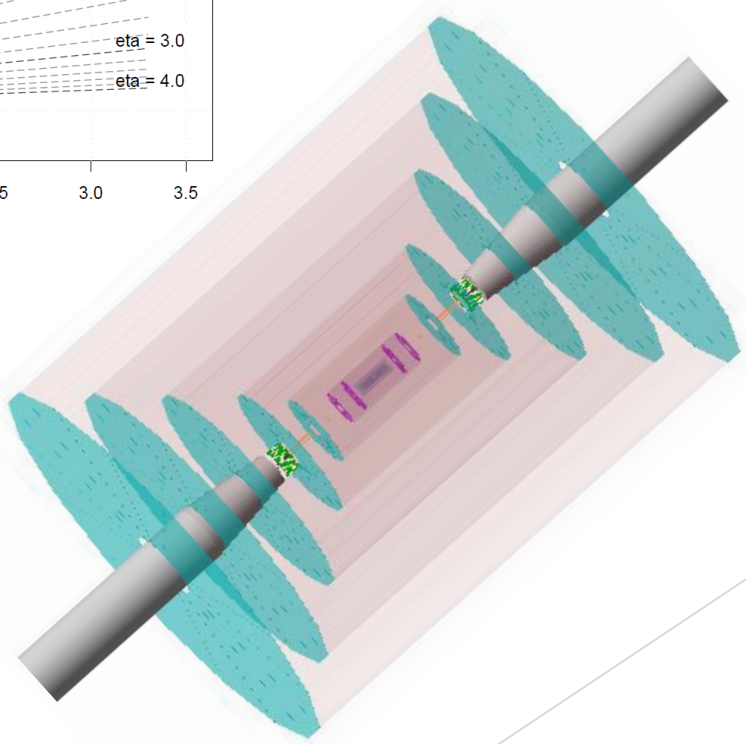




Full Silicon-based Tracker

- Preliminary designed by Weimin YAO (LBNL)
- Use sub-detector driver
  - /Mokka/init/EditGeometry/newSubDetector SiTracker01 100





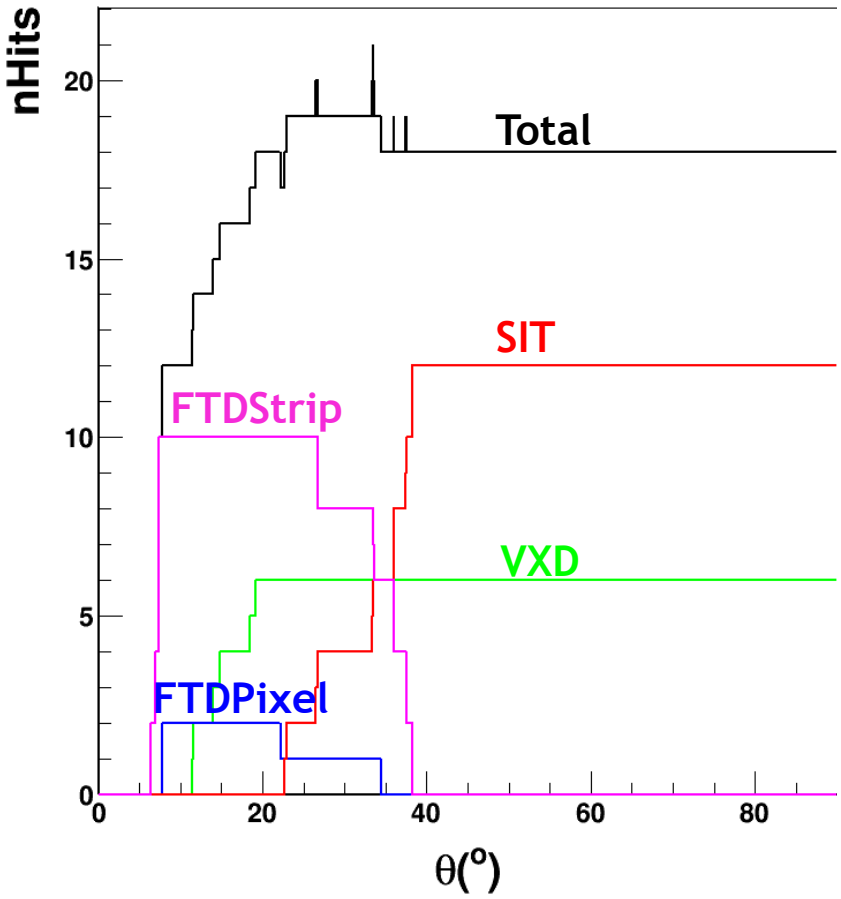
Geometry Size

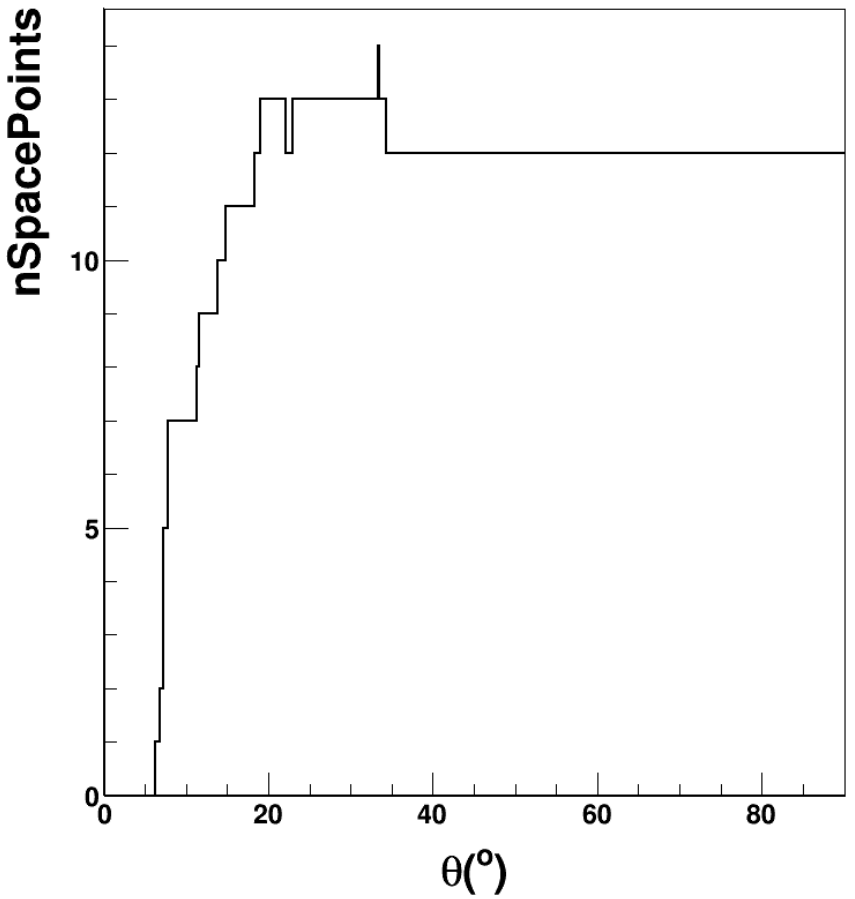
Barrel	R (m)	±Z (m)	Type	Ladders
VXD 0-1	0.016, 0.025	0.078, 0.125	Double pixel-C	10
VXD 2-3	0.037	0.150	Double pixel	11
VXD 4-5	0.058	0.175	Double pixel	17
SIT 0-1	0.153	0.368	Double strip	10
SIT 2-3	0.321	0.644	Double strip	19
SIT 4-5	0.603	0.920	Double strip	38
SIT 6-7	1.000	1.380	Double strip	62
SIT 8-9	1.410	1.840	Double strip	89
SIT 10-11	1.811	2.300	Double strip	115

Endcap	Rin (m)	Rout (m)	±Z (m)	Type
FTD_PIXEL 0	0.030	0.150	0.220	Single pixel
FTD_PIXEL 1	0.051	0.150	0.371	Single pixel
FTD_STRIP 0-1	0.082	0.321	0.644	Double strip
FTD_STRIP 2-3	0.117	0.610	0.920	Double strip
FTD_STRIP 4-5	0.176	1.000	1.380	Double strip
FTD_STRIP 6-7	0.234	1.410	1.840	Double strip
FTD_STRIP 8-9	0.293	1.811	2.300	Double strip

Expected Hit Number

- 7.8°<θ<11.5° (0.98<cosθ<0.99) >7
- 11.5° <θ<14° (0.97<cosθ<0.98) >9
- 14° <θ<18.5° (0.948<cosθ<0.97) >11
- 18.5°<θ<90° (cosθ<0.948) >12





Layer Materials

- Mechanical properties have not been studied in detail

VXD	silicon	kapton	aluminium	foam	Total support
Thickness(mm)	0.05	0.05	0.01	0.94	1

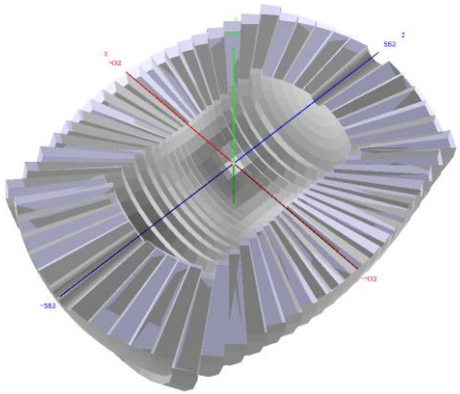
SIT(SiD-like)	silicon	peek	Carbon fiber	Rohacell 50D	epoxy	Carbon fiber	Total support
Thickness(mm)	0.15+0.0024	0.1	0.08	0.9	0.08	0.08	1.2424

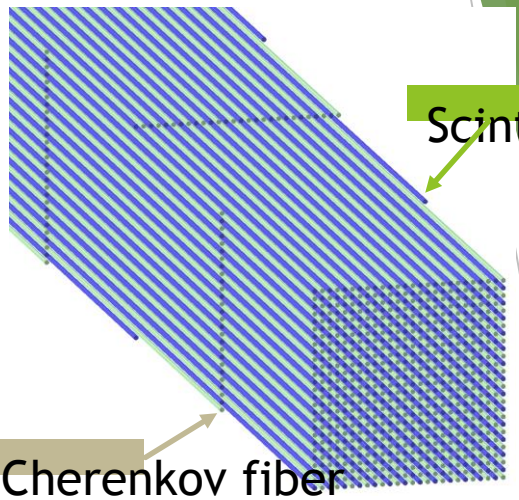
FTD_PIXEL	silicon	Carbon fiber	Rohacell50D	peek	Total support
Thickness(mm)	0.2+0.0048	0.16	1.8	0.2	2.1648

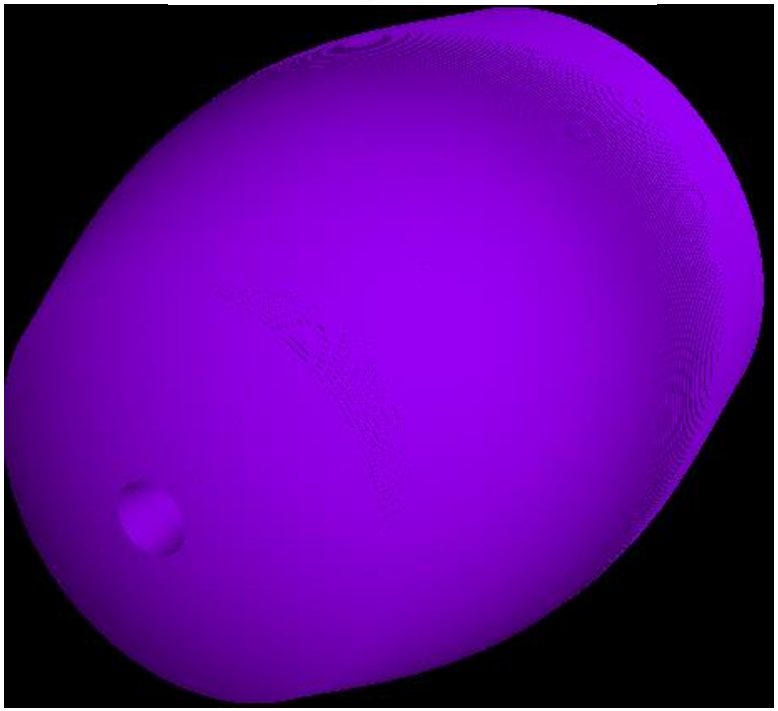
FTD_STRIP	silicon	peek	Carbon fiber	Rohacell 50D	epoxy	Carbon fiber	silicon	Total support
Thickness(mm)	0.15	0.2	0.16	1.8	0.175	0.16	0.15+0.0048	2.4998

IDEA Concept

- Preliminary version, but drivers have not been released



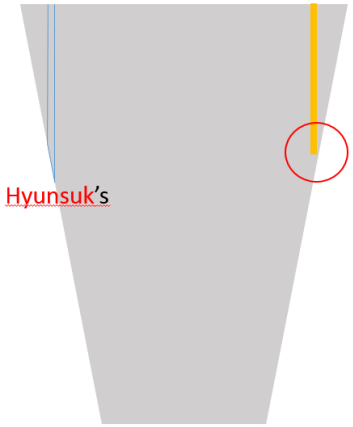


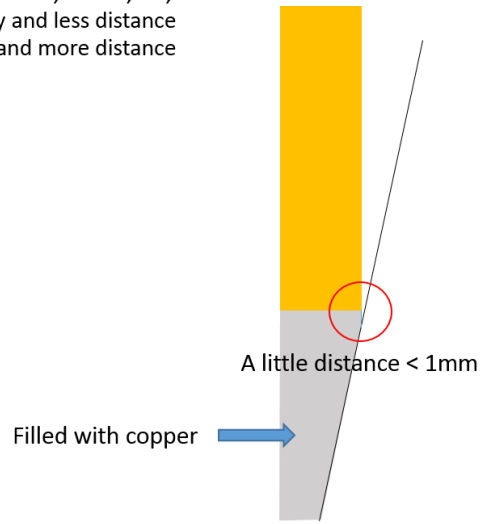


Simplified method

- Add fiber…
  - Ignore cut
  - 2500 length of fibers: 1mm, 2mm, … , 2500mm
    - >2500, more memory and less distance
    - <2500, less memory and more distance

This method need only 2500 volumes of class memory.

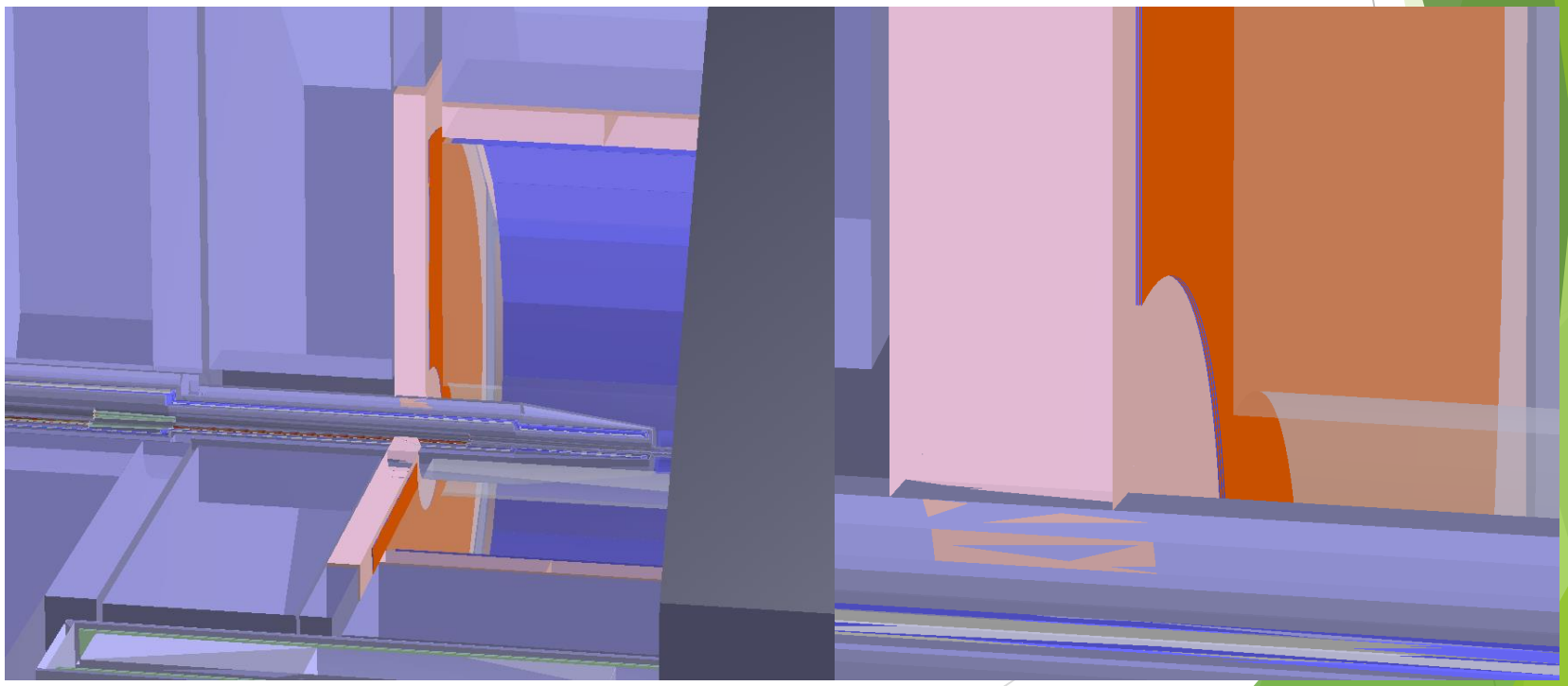




Geometry of ETD (not included in CEPC_v1 and CEPC_v4)

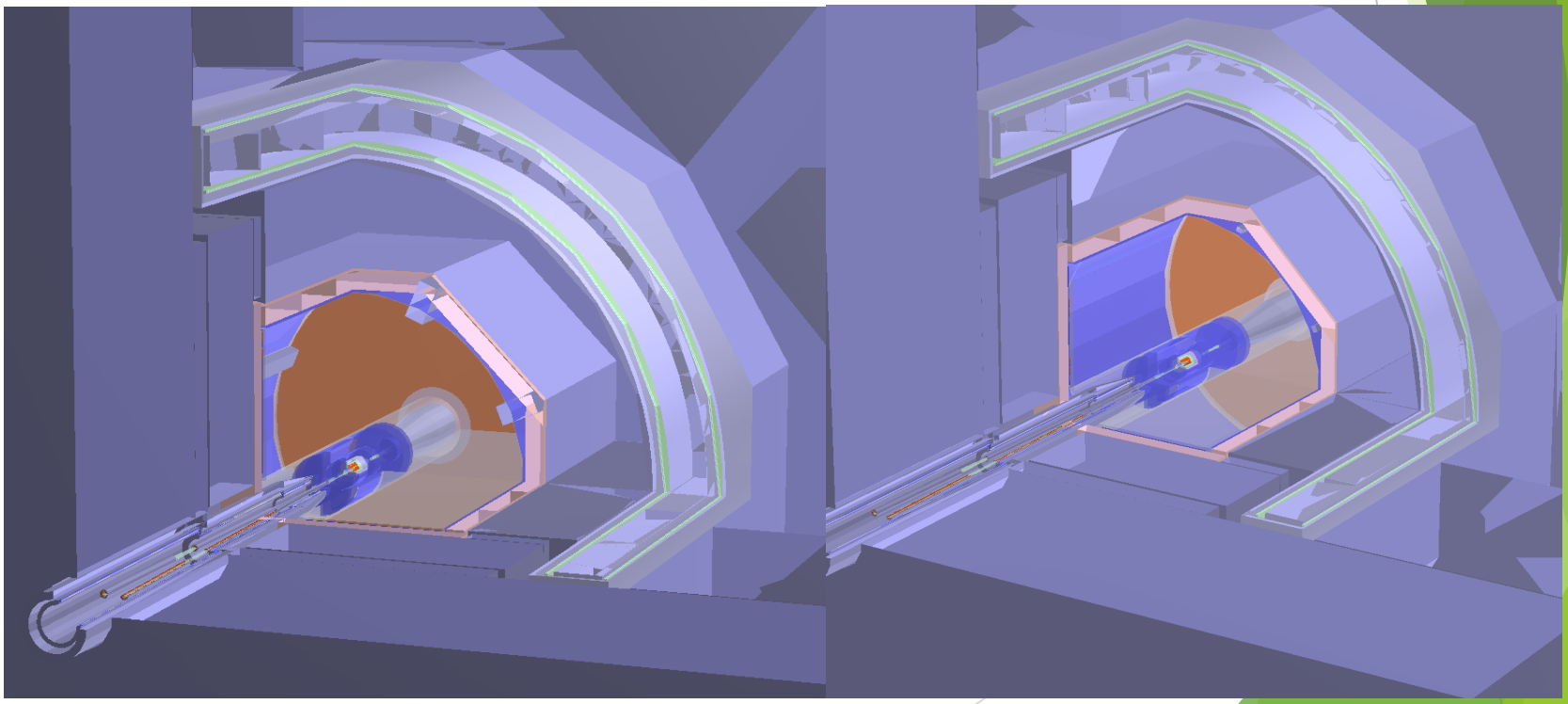
- Simplify
  - Disc: G4Tubs, sensitive + support
  - 3 layers? determined in future
- Usage
  - Driver: ETD_cepc
  - Mokka version: xx, currently /workfs/bes/fucd/MokkaC/
  - Add into steering file:
    - /Mokka/init/EditGeometry/newSubDetector MyETD 240 ETD_cepc etd03

database



Geometry of Laser Calibration System

- Simplify
  - No support and electronic: stainless_steel and TDR_gas (95.667%Ar+2.067%CH4+2.267%CO2)
  - Square tube： 4cm width and 5*mm thickness
- Usage
  - Driver: LaserCalibration
  - Mokka version: xx, currently /workfs/bes/fucd/MokkaC/
  - Add into steering file:
    - /Mokka/init/EditGeometry/newSubDetector LaserCalibration 250
    - /Mokka/init/userInitDouble LaserCalibrationPhi0 22.5

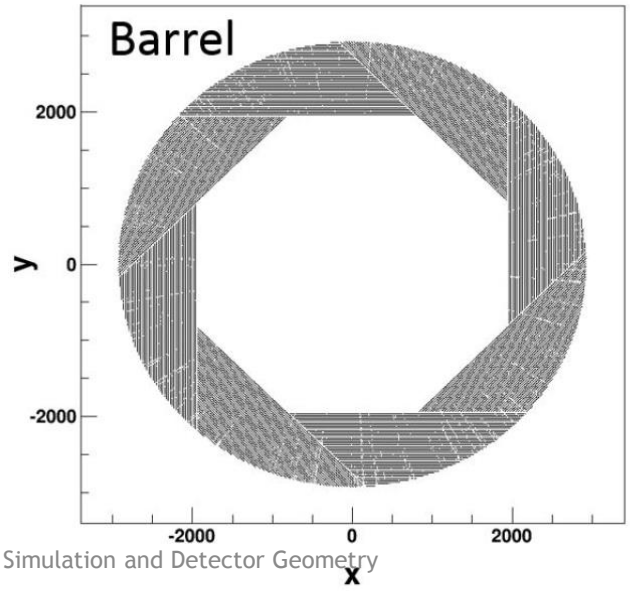


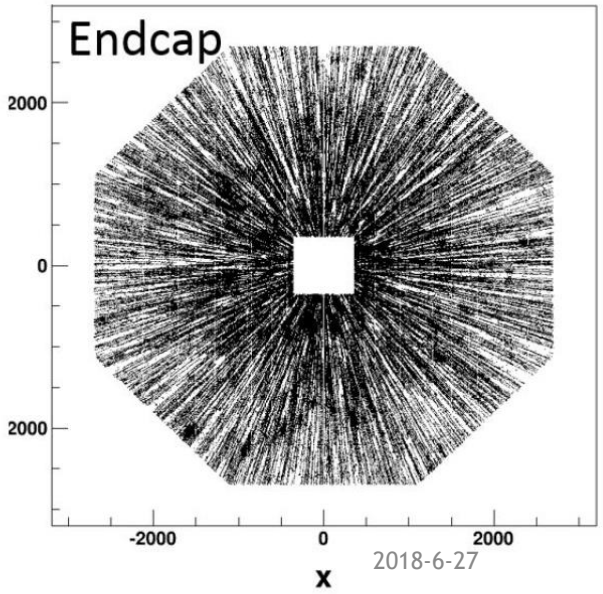
Ecal option

- Default
  - 20 layers + 10 layers
    - 0.5 mm silicon
    - 2.1 mm (4.2 mm) tungsten
  - cell size: 10 mm
- To change
  - /Mokka/init/globalModelParameter Ecal_Si_thickness 1
  - /Mokka/init/globalModelParameter Ecal_nlayers1 10
  - /Mokka/init/globalModelParameter Ecal_nlayers2 9
  - /Mokka/init/globalModelParameter Ecal_Sc_Si_mix 0000000000

Hcal option

- Default
  - 40 layers
    - 6.73 mm RPC chamber
    - 20 mm stainless steel
  - cell size: 10 mm
- To change
  - /Mokka/init/globalModelParameter Hcal_sensitive_model scintillator
  - /Mokka/init/globalModelParameter Hcal_scintillator_thickness 3
  - /Mokka/init/globalModelParameter Hcal_steel_cassette_thickness 0.5
  - /Mokka/init/globalModelParameter Hcal_Cu_thickness 0.1
  - /Mokka/init/globalModelParameter Hcal_PCB_thickness 0.7
  - /Mokka/init/globalModelParameter Hcal_radiator_thickness 25
  - /Mokka/init/globalModelParameter Hcal_nlayers 35





Yoke (muon detector) option

- Default
  - 1
- To change
  - **/Mokka/init/globalModelParameter YokeUserLayer 1**
  - /Mokka/init/globalModelParameter YokeGapThickness 25
  - /Mokka/init/globalModelParameter YokeIronThickness 100
  - /Mokka/init/globalModelParameter YokeLayerNumber 12
  - /Mokka/init/globalModelParameter YokeBarrelEndcapGap 5

Discussion and Conclusion

- Many options available for CDR study
- More options needed
  - beam pipe materials
  - mask option
  - digitization
  - mechanics structures
  - optimize sensitive thickness and radiator
- Problems
  - output lack information for detail study
  - between simulation and reconstruction

Thanks!