EicC Detector

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EicC 8th CDR Workshop

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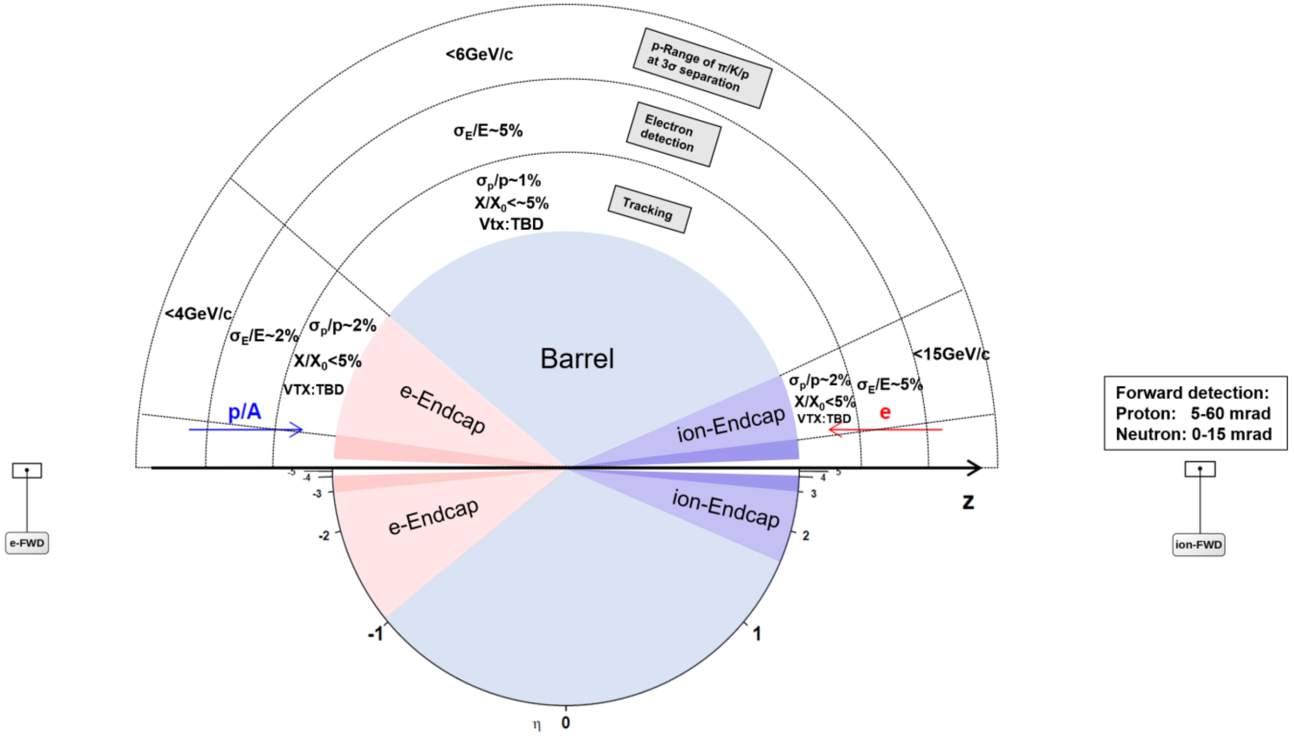
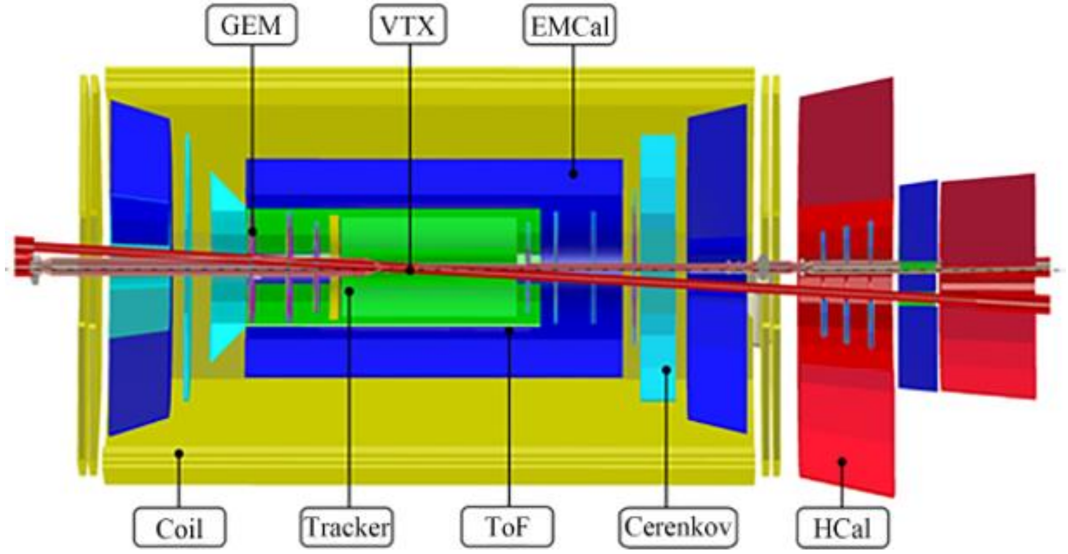
Outline

- **Central detector: Tracking, PID, ECal**
- **Forward detector: EDT, RPs, ZDC, OMD**
- **Beam polarimetry and luminosity measurement**
- **Readout and DAQ**
- **Summary**

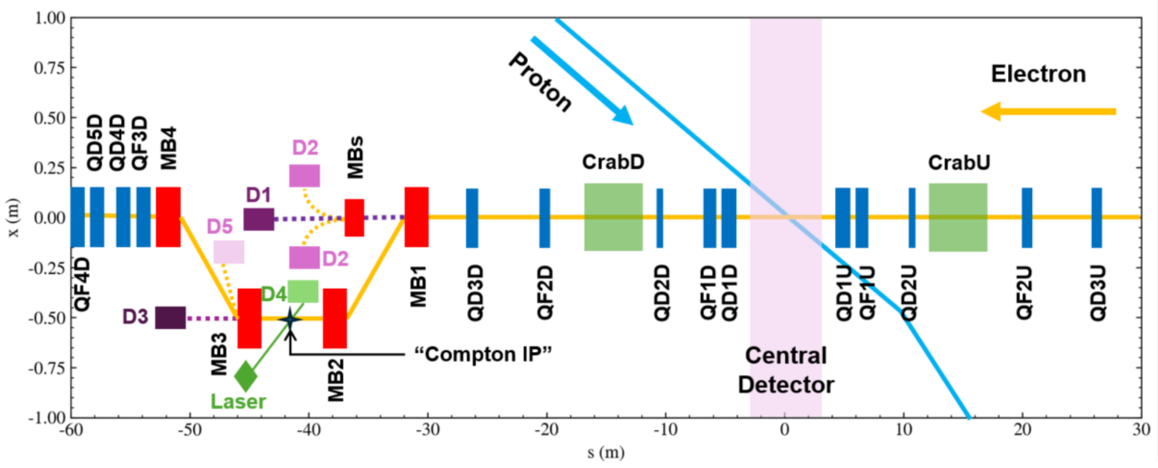
Preliminary detector design at WP

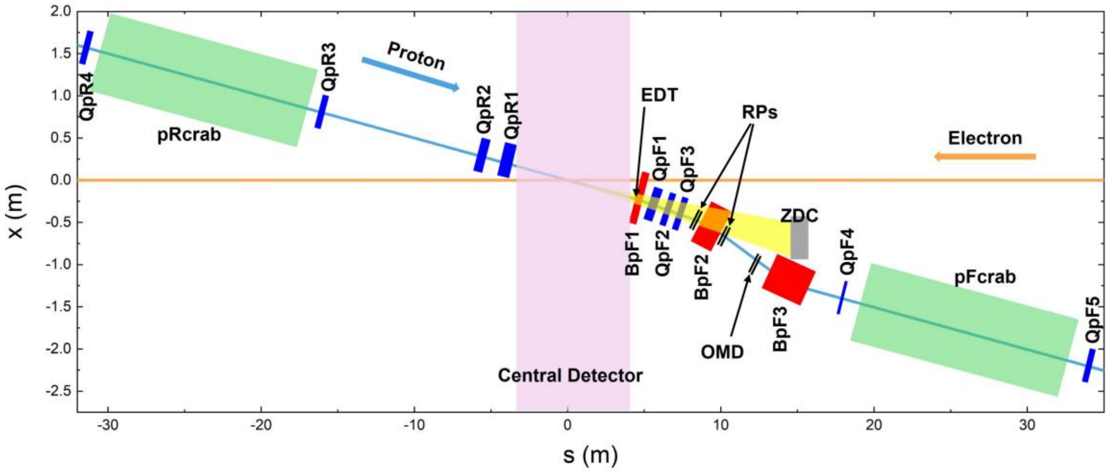




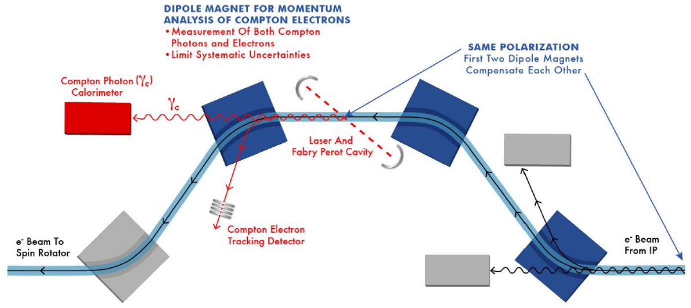
Beam background estimation is missing, which is critical to detector design.

EicC IR layout and detector at CDR

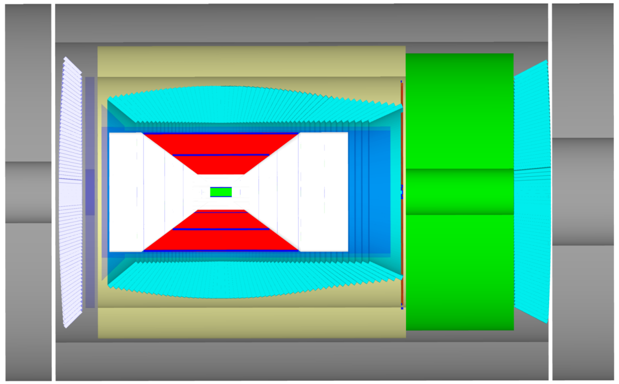




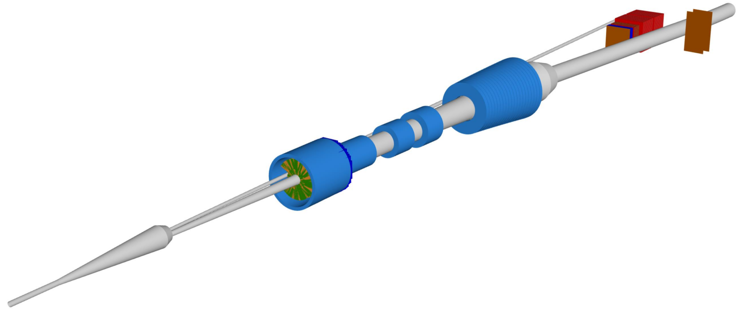
e far-forward detectors



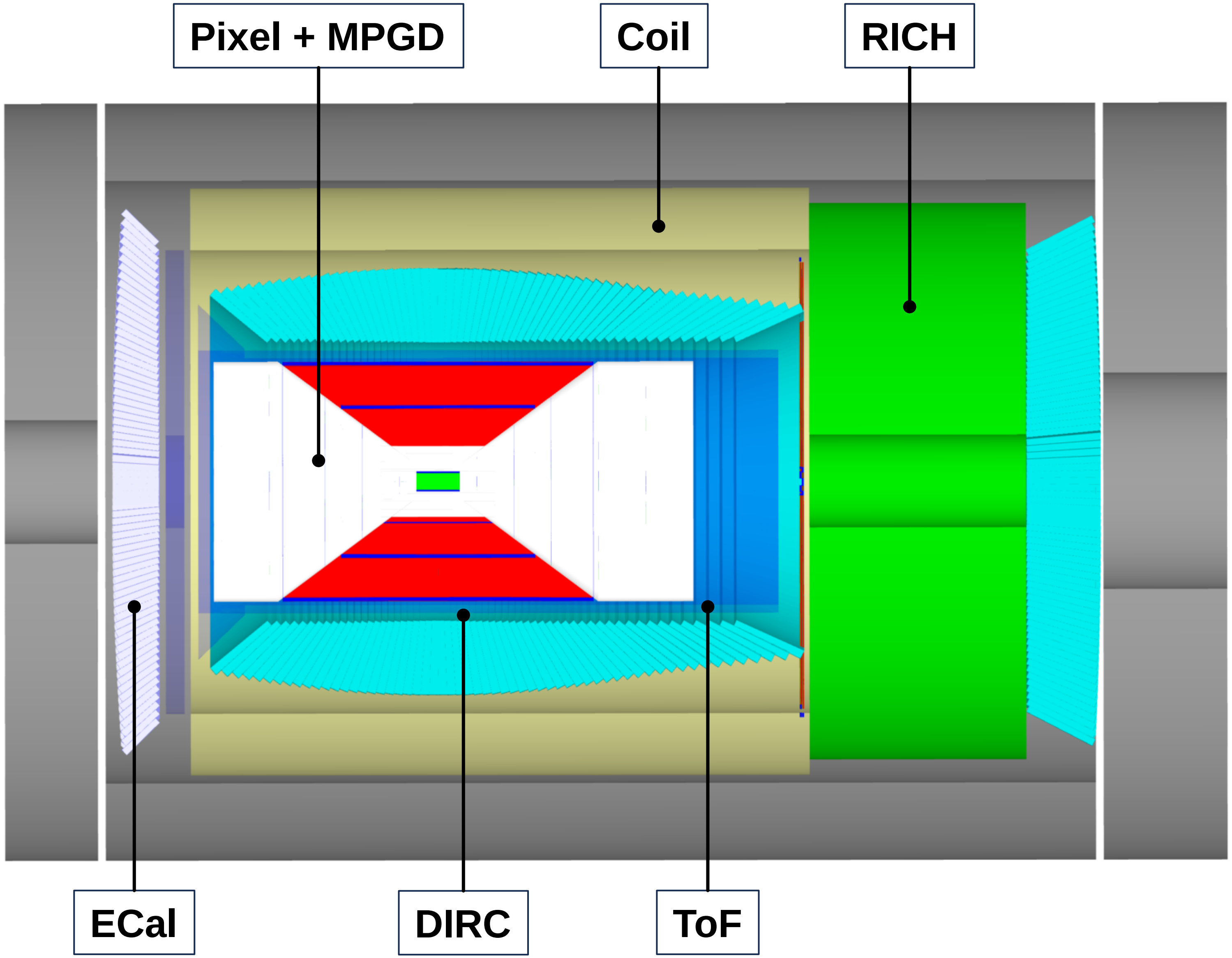
Central detector



Ion far-forward detectors

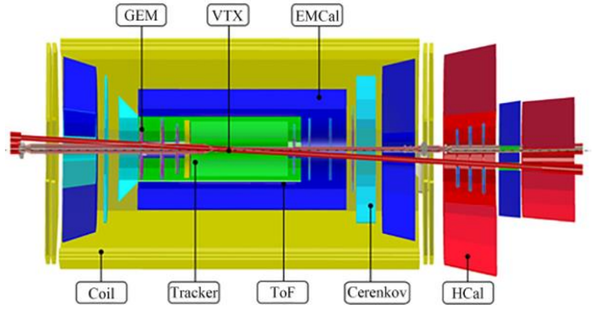


Central Detector

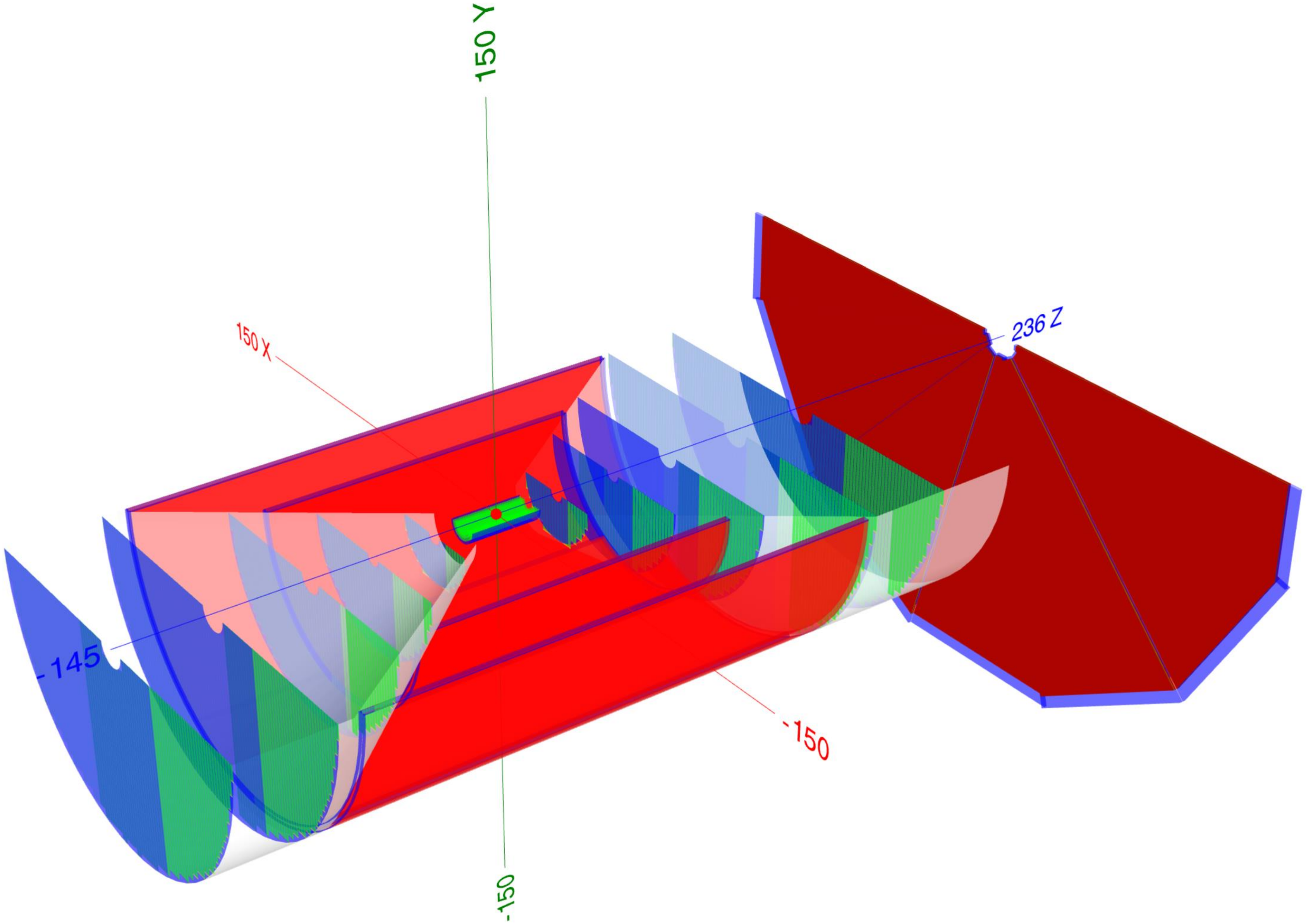


- Tracking
- PID
- ECal

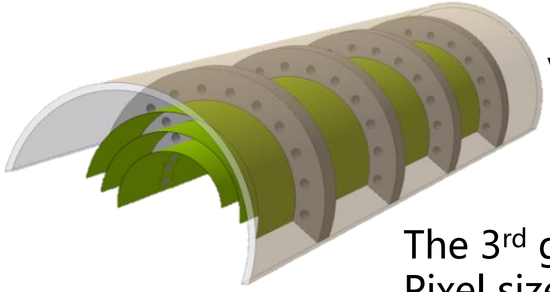
Compare to the design (WP)



Tracking system



Technology choices

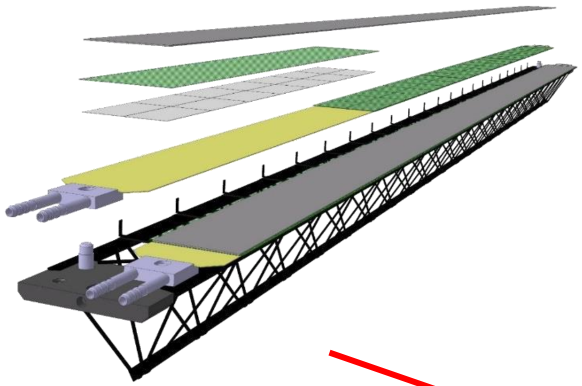


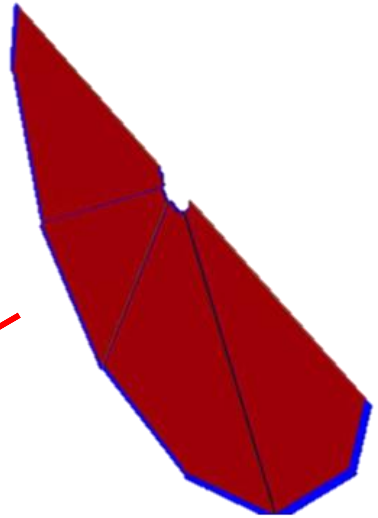
Vertex Detector

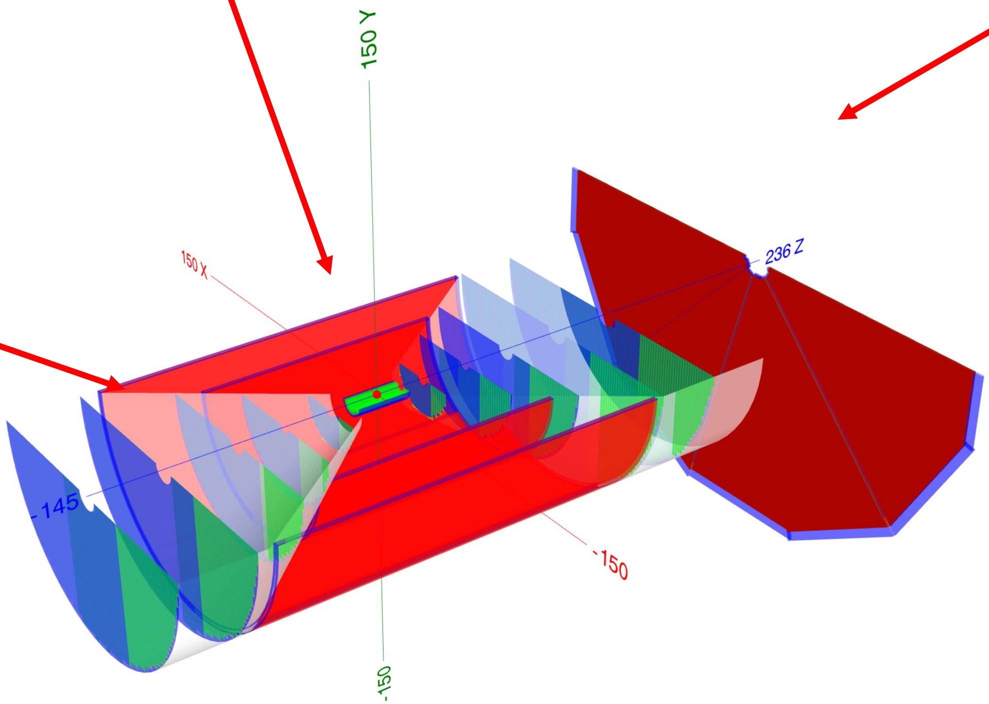
The 3rd generation MAPS
Pixel size: ~20x20 μm
Material budget: 0.05%

MIC7

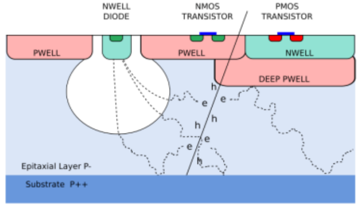
Tracker



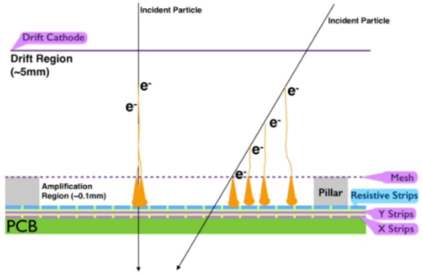




The 1st generation MAPS
Pixel size : ~30x30 μm
Material budget: 0.85%

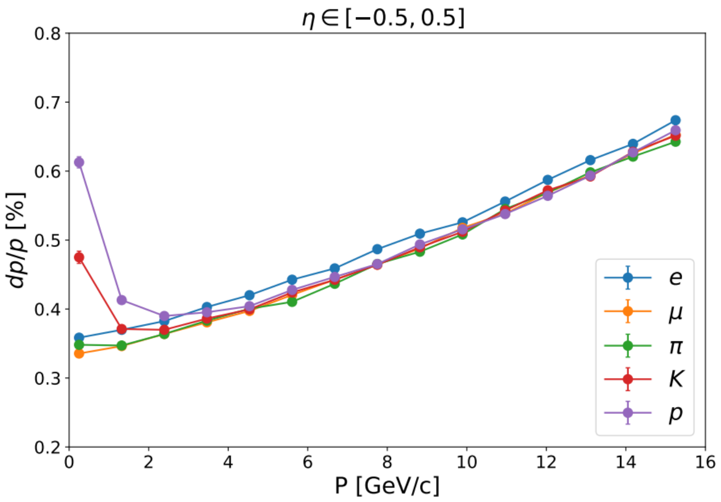


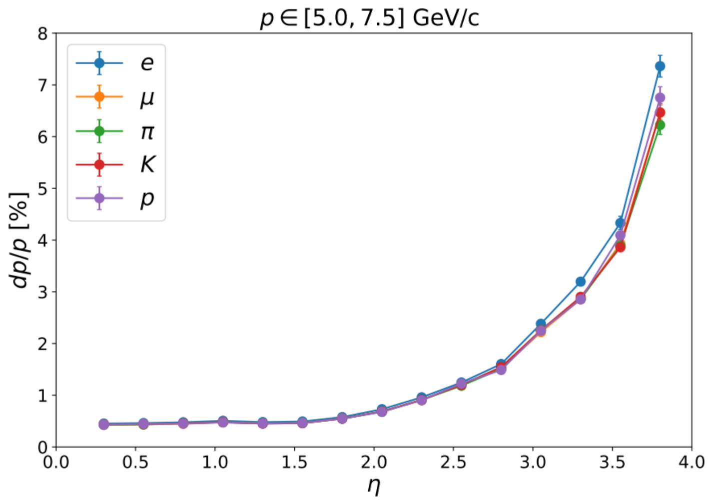
MIC6

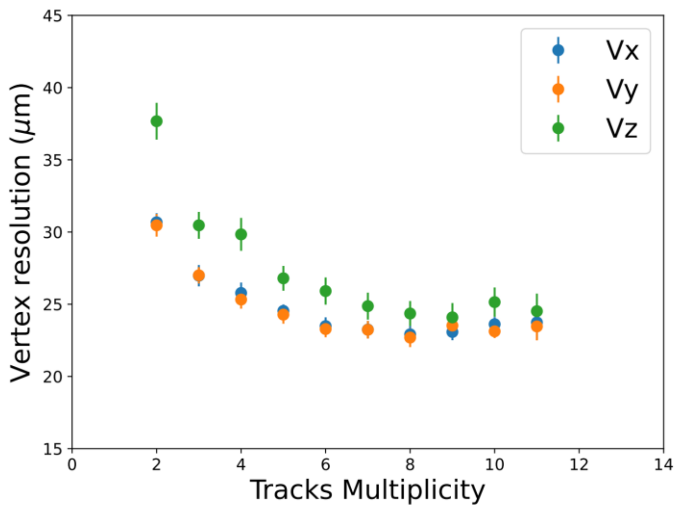


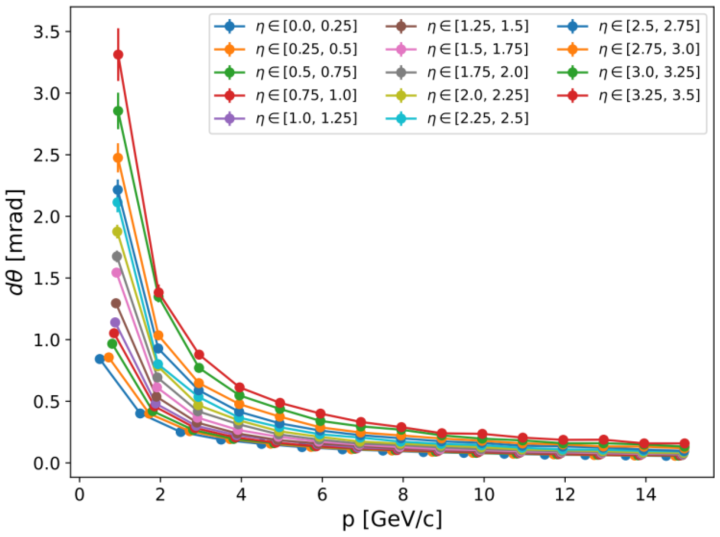
MPGD
Pitch size: 50X250 μm
Or ~150X150 μm
Material budget: 1%

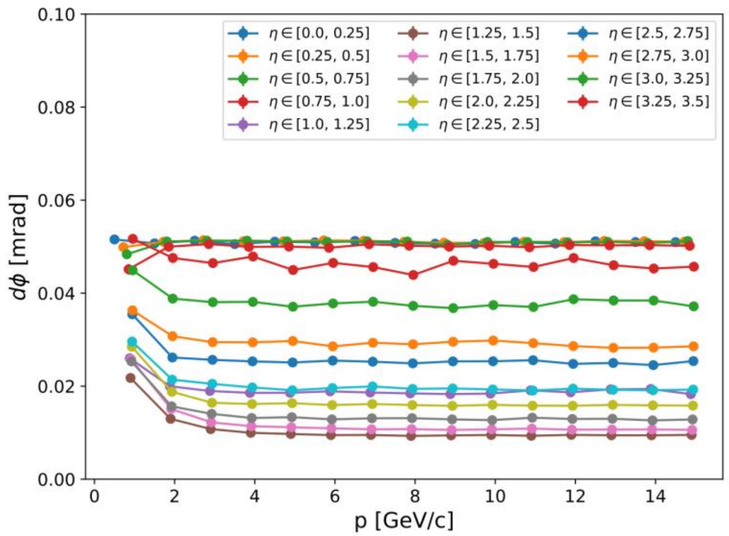
Performance

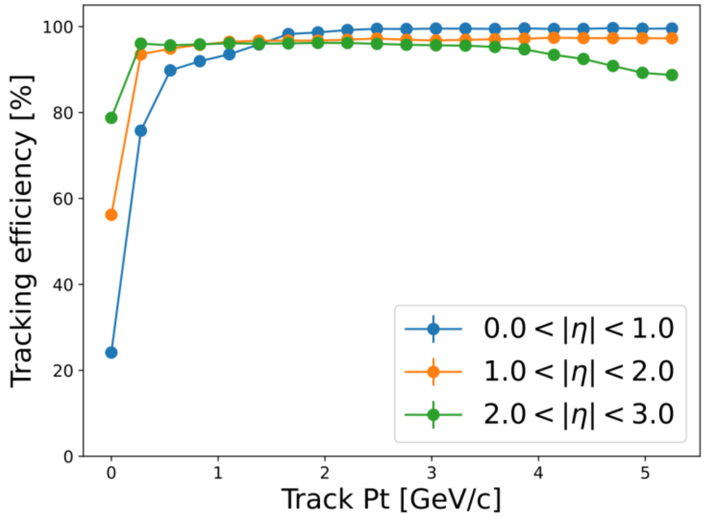




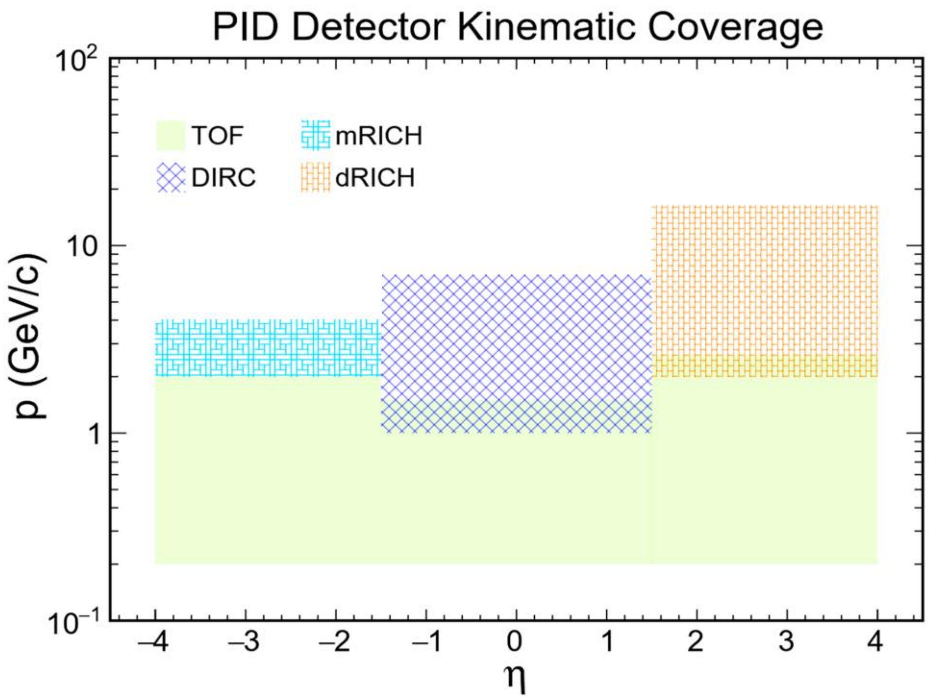


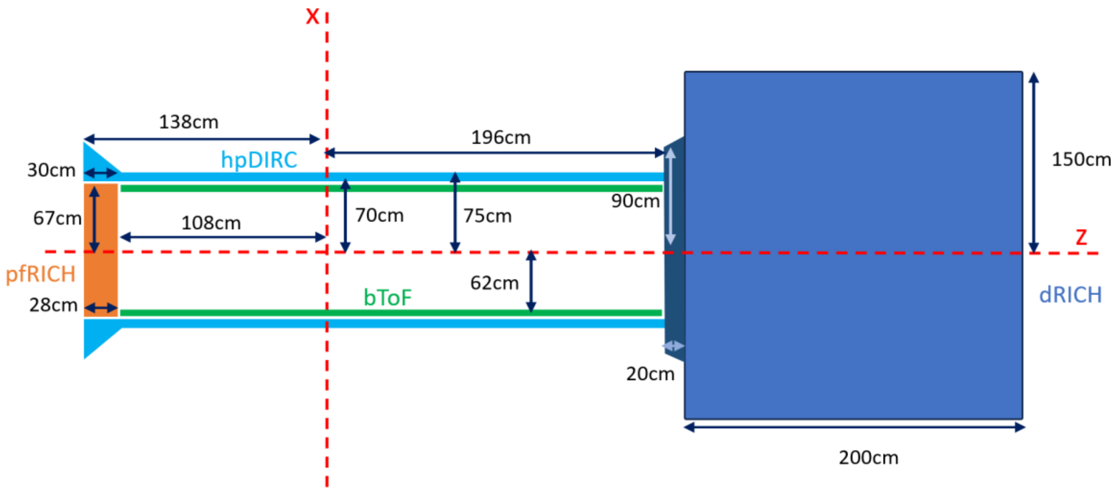


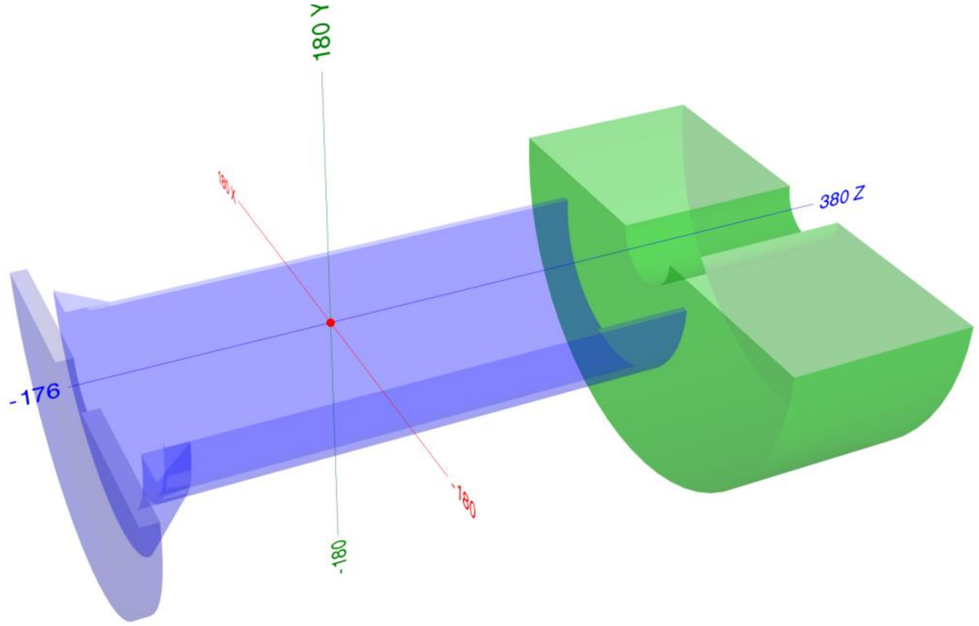




PID detectors



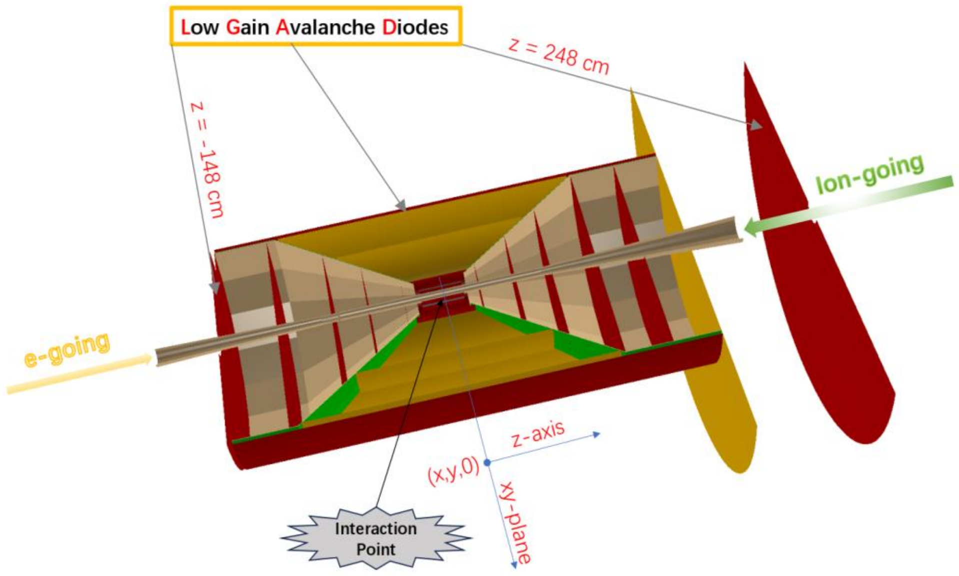


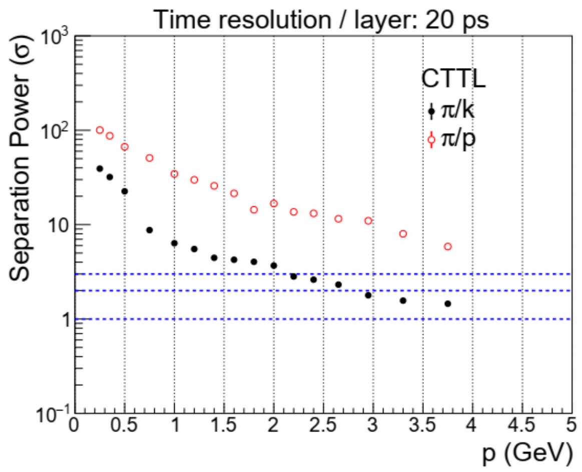


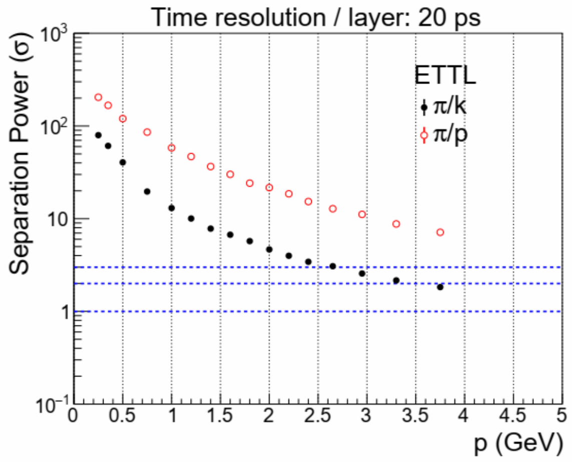
- TOF based (low p)
  - MRPC
  - LGAD
- Cherenkov based (high p)
  - DIRC
  - RICH

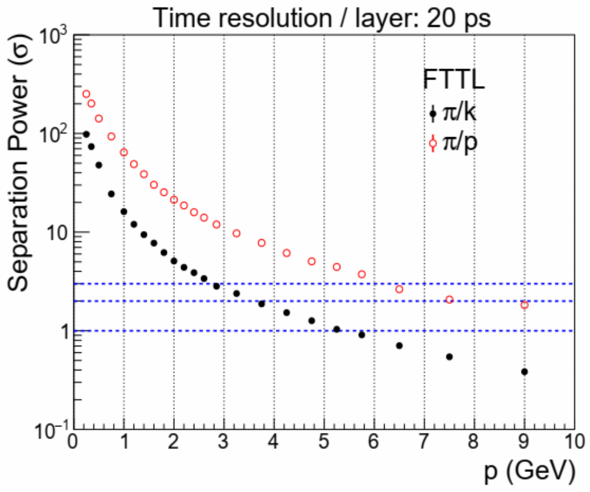
LGAD

Low Gain Avalanche Diodes (LGAD)





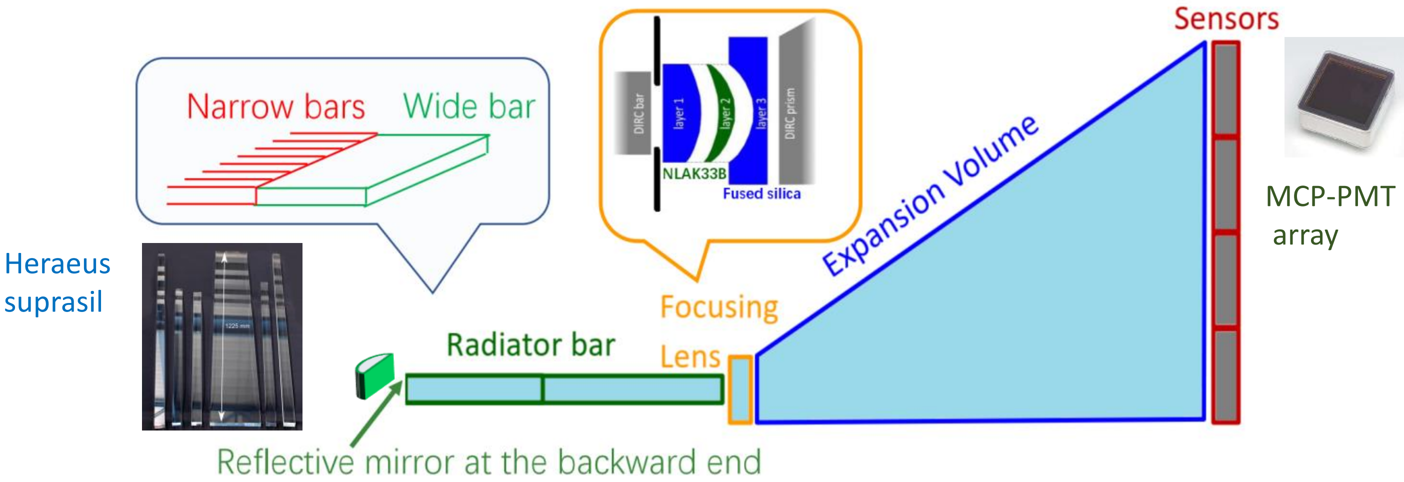


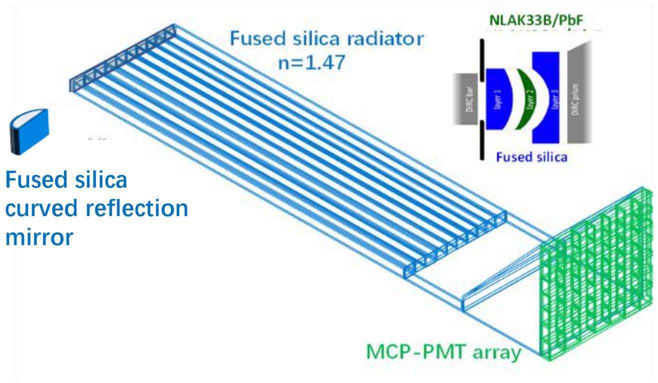


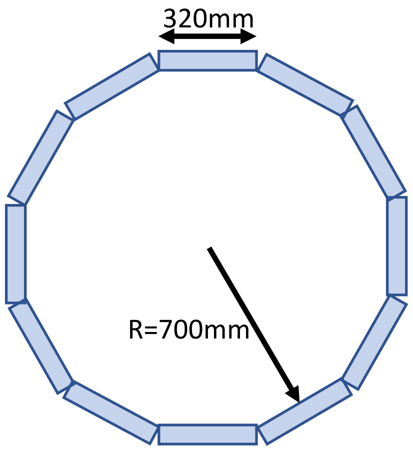
The detector geometry was reconfigured.
π/K separation of 2-3 GeV/c achieved.

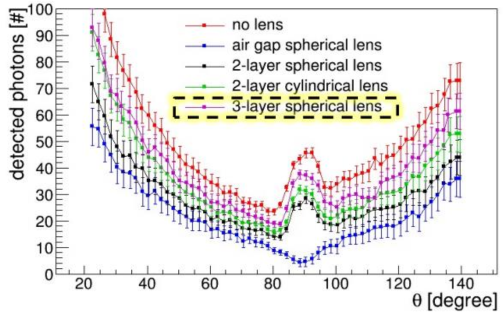
- Current configuration fits to the tracker system well
- Timing resolution: 20-30 ps / layer
- Spatial resolution: ~30 μm

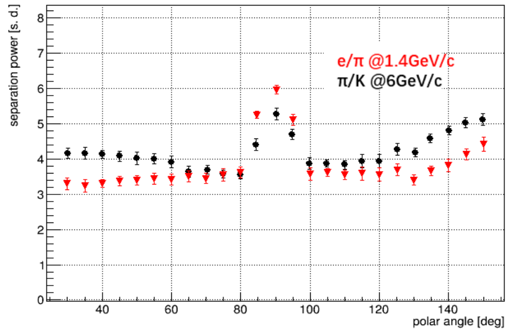
DIRC



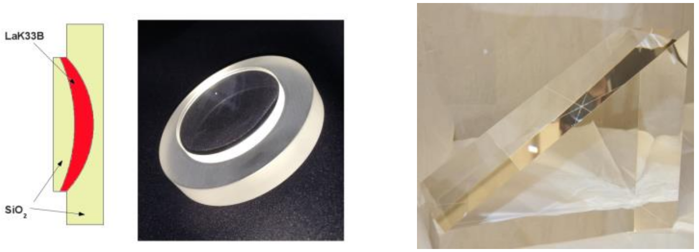








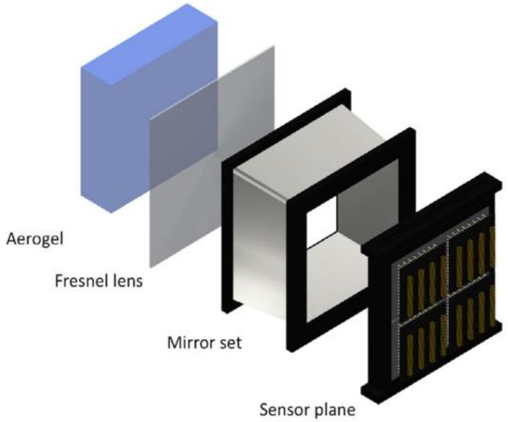
done

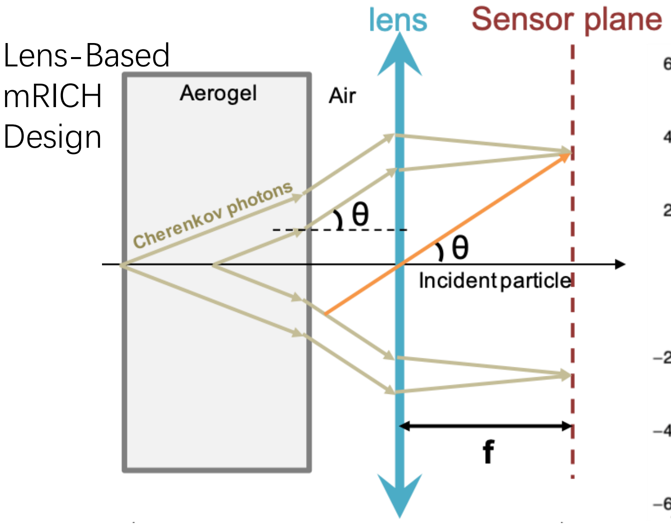


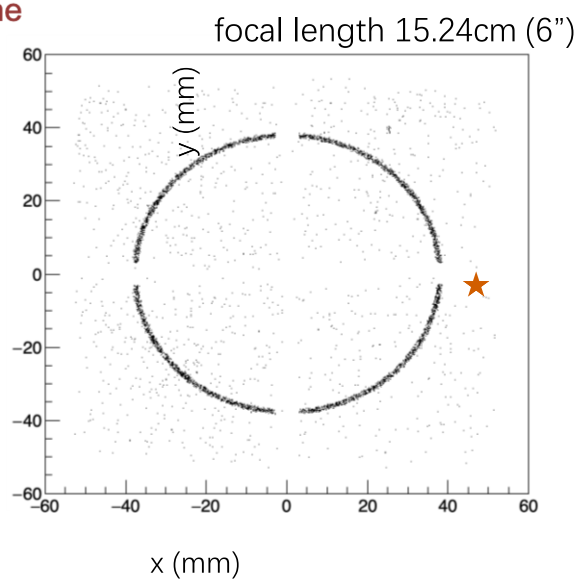
under processing

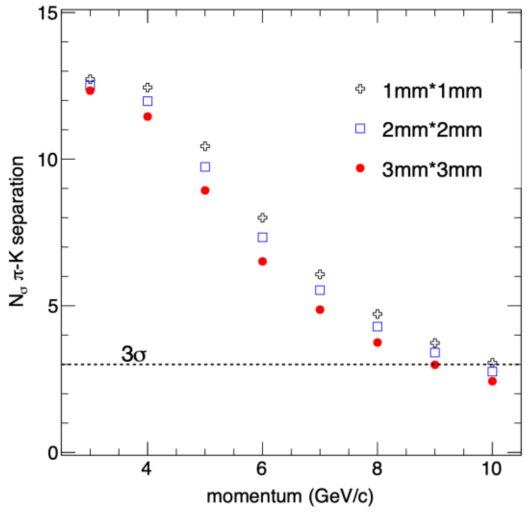
mRICH

Smaller, but thinner ring improves PID performance and reduces length

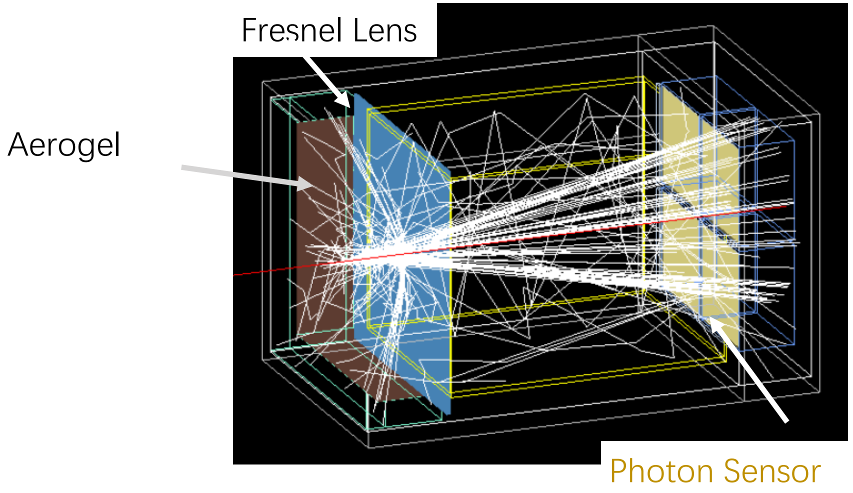


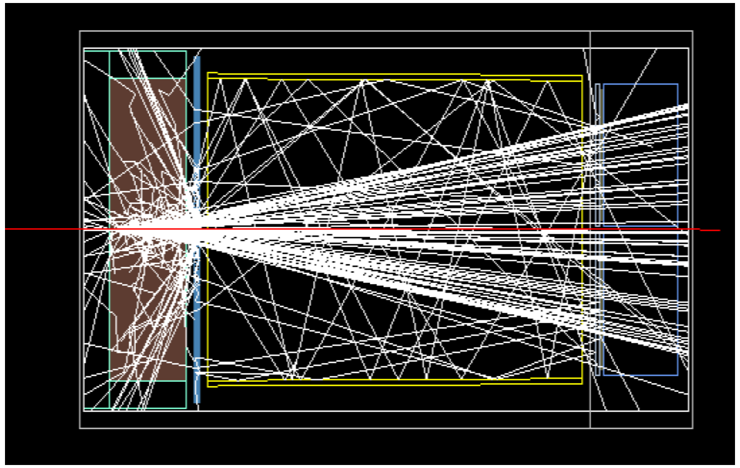




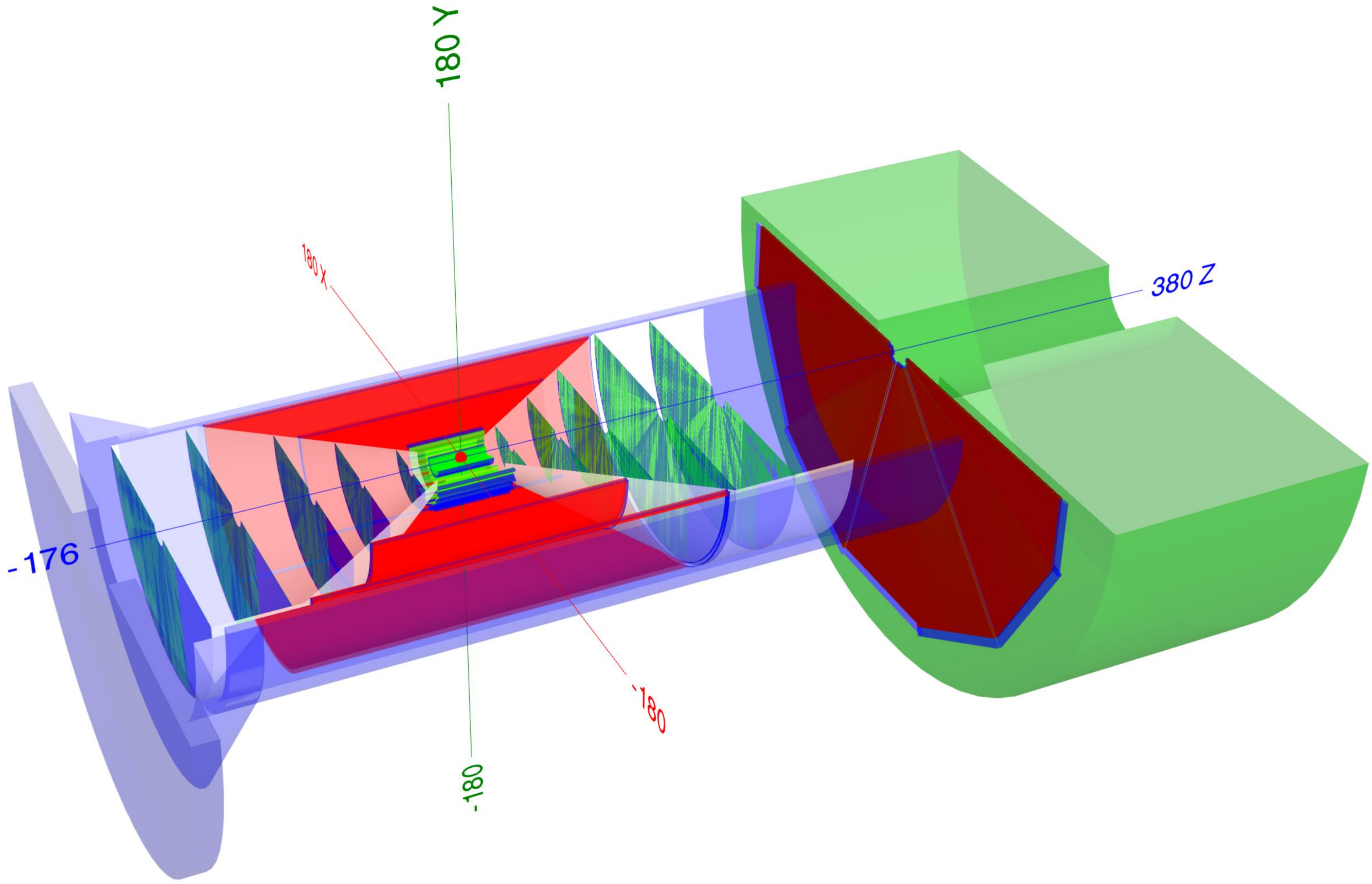


f: 7.62cm ~ 15.24cm (3"~6")

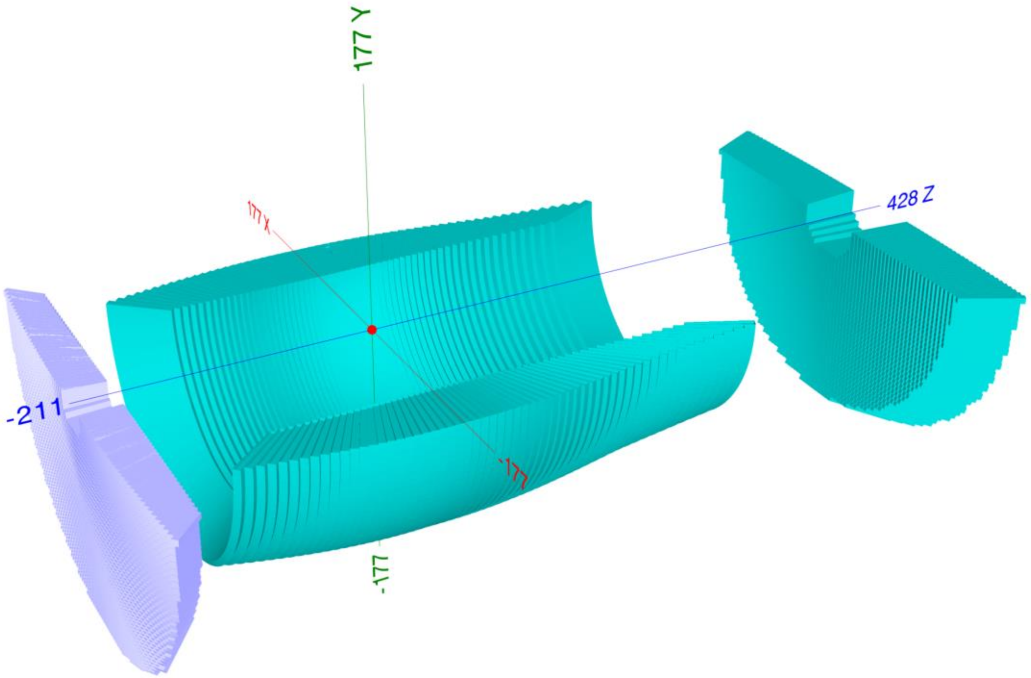


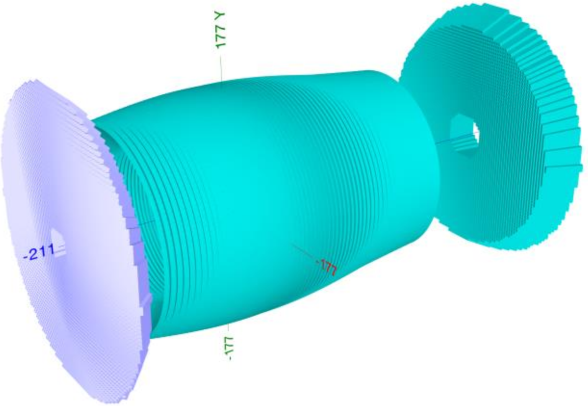


- pi/K separation up to 9 GeV/c
- e/pi separation up to 2 GeV/c
- Separation power decrease with increasing polar angle

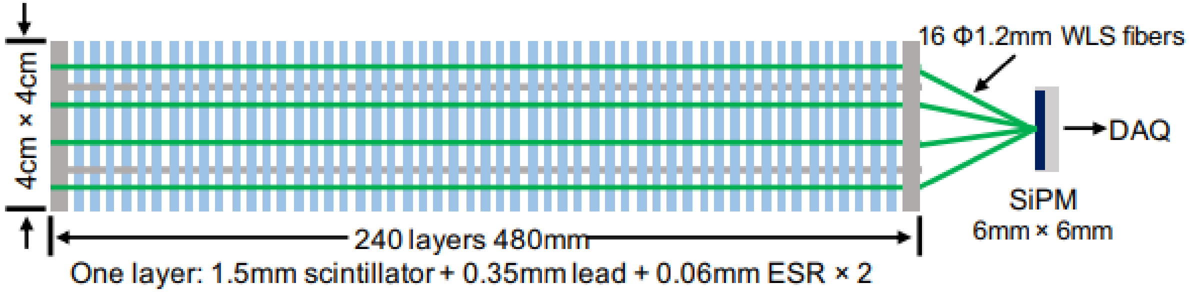

180 Y
180 X
380 Z
- 176
-180
-180

ECal design



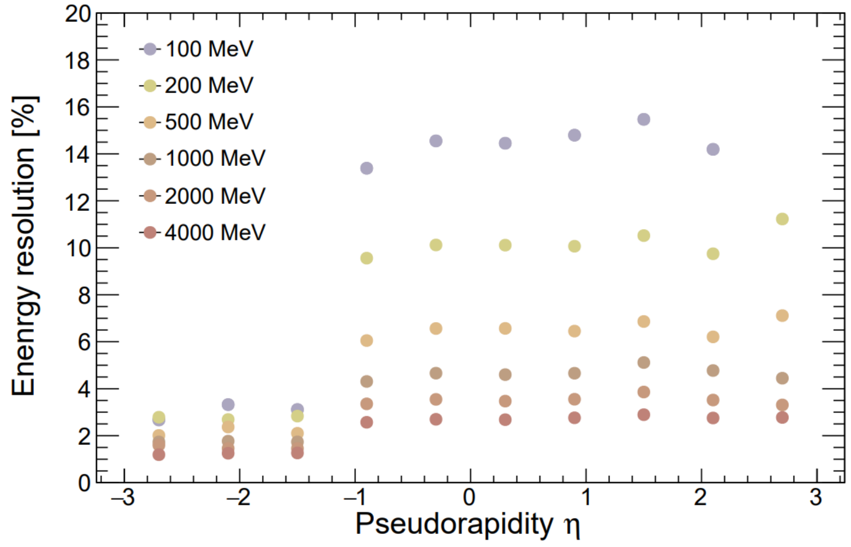


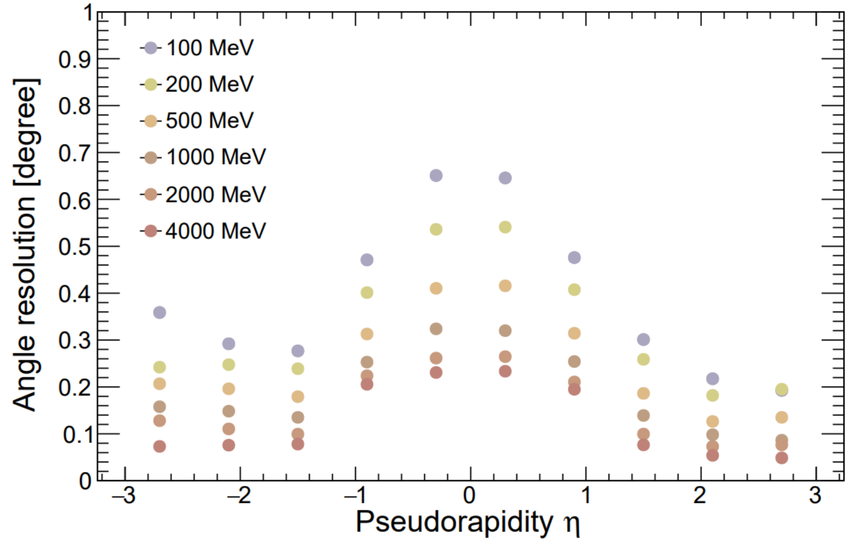
CsI Crystal

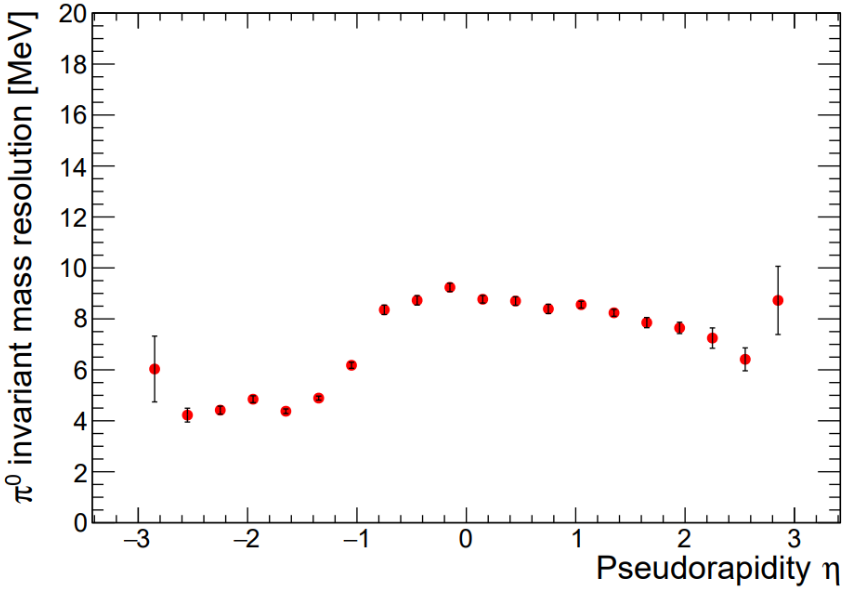


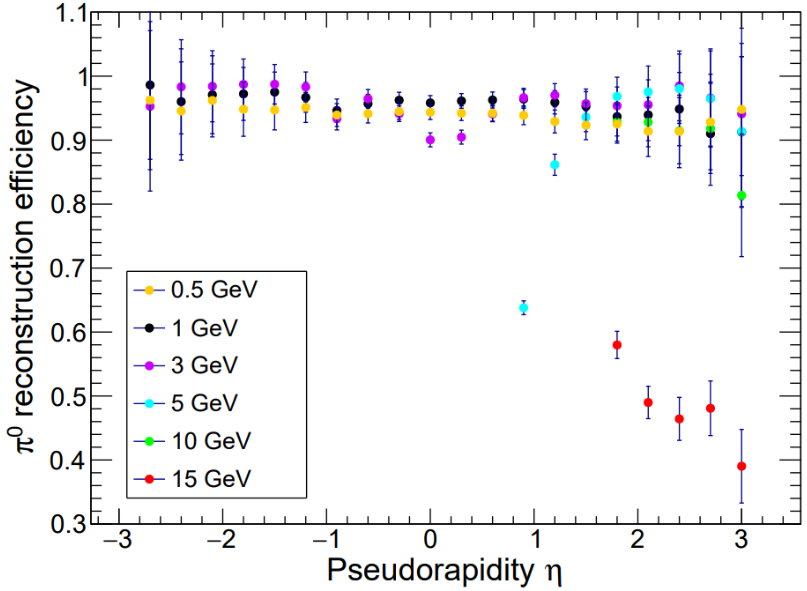
EicC Shashlik ECal

Performance



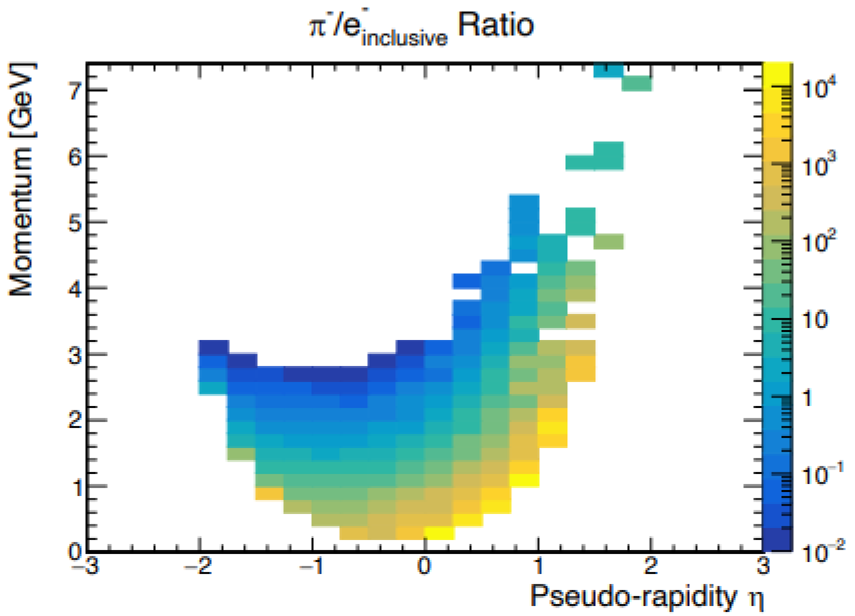


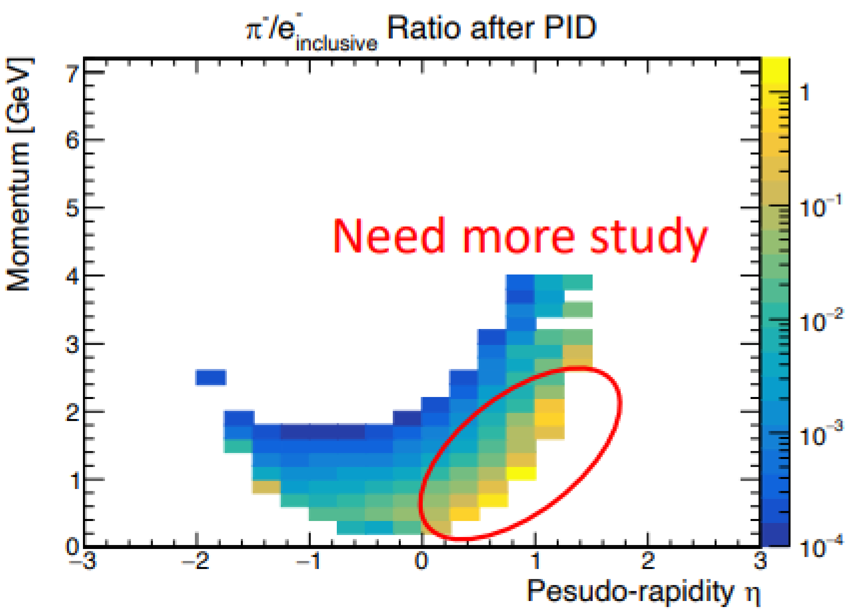




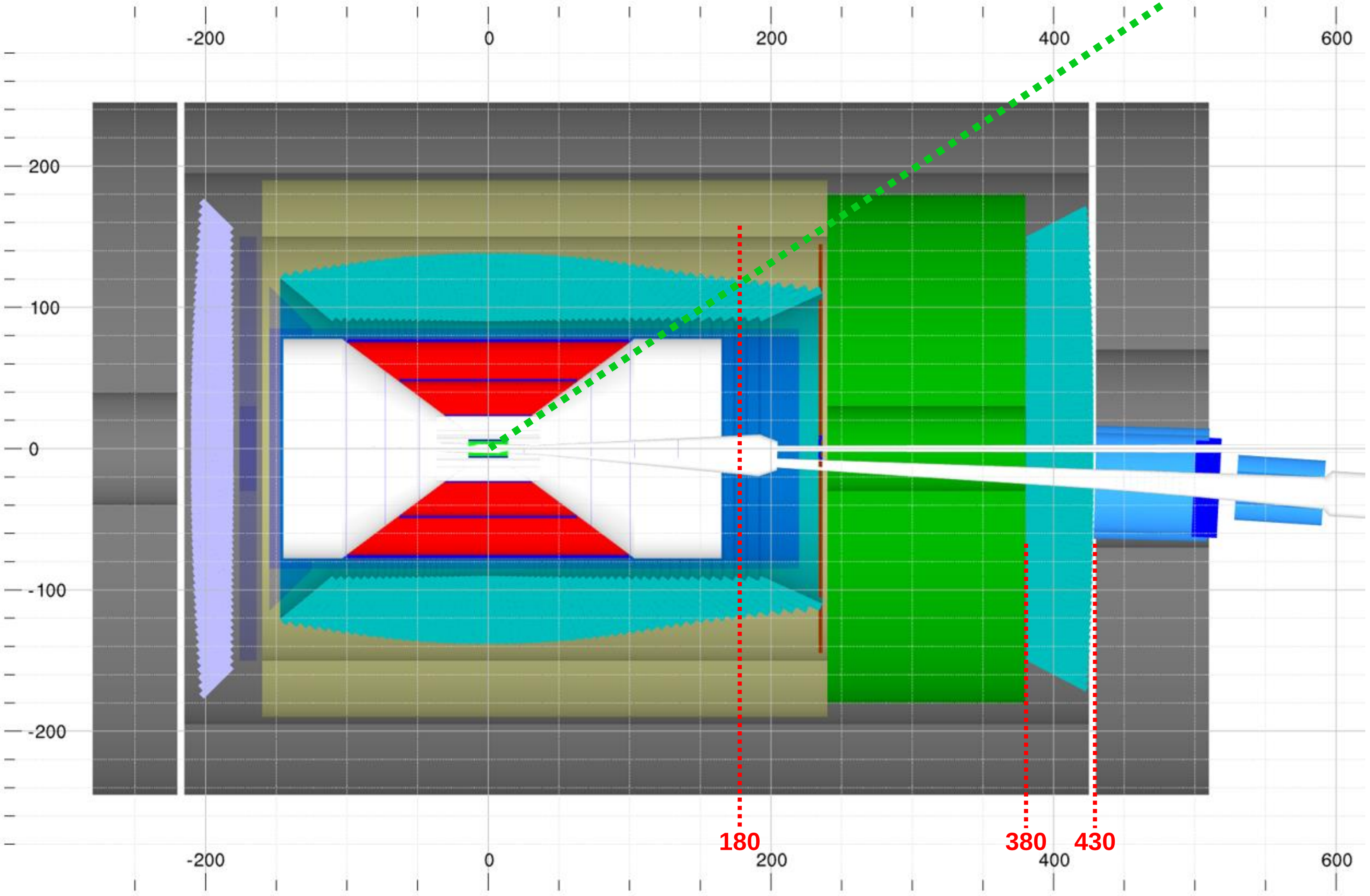
e/π separation

Momentum [GeV/c]	|η|			π^- suppresion ratio
[0, 0.1]	Tracking efficiency low, discard			-
[0.1, 0.2]	[0, 1]	[1, 2]	[2, 3]	
	Long flight time + tracking efficiency low, discard		EMC no hit+ tracking efficiency low, discard	-
[0.2, 0.5]	Excellent e/π separation from TOF + below RICH π Cherenkov threshold			**> 10^5:1**
[0.5, Cherenkov upper limit]	RICH / DIRC + ECal + TOF			**10^4:1**
> Cherenkov upper limit	ECal			**10^3:1**

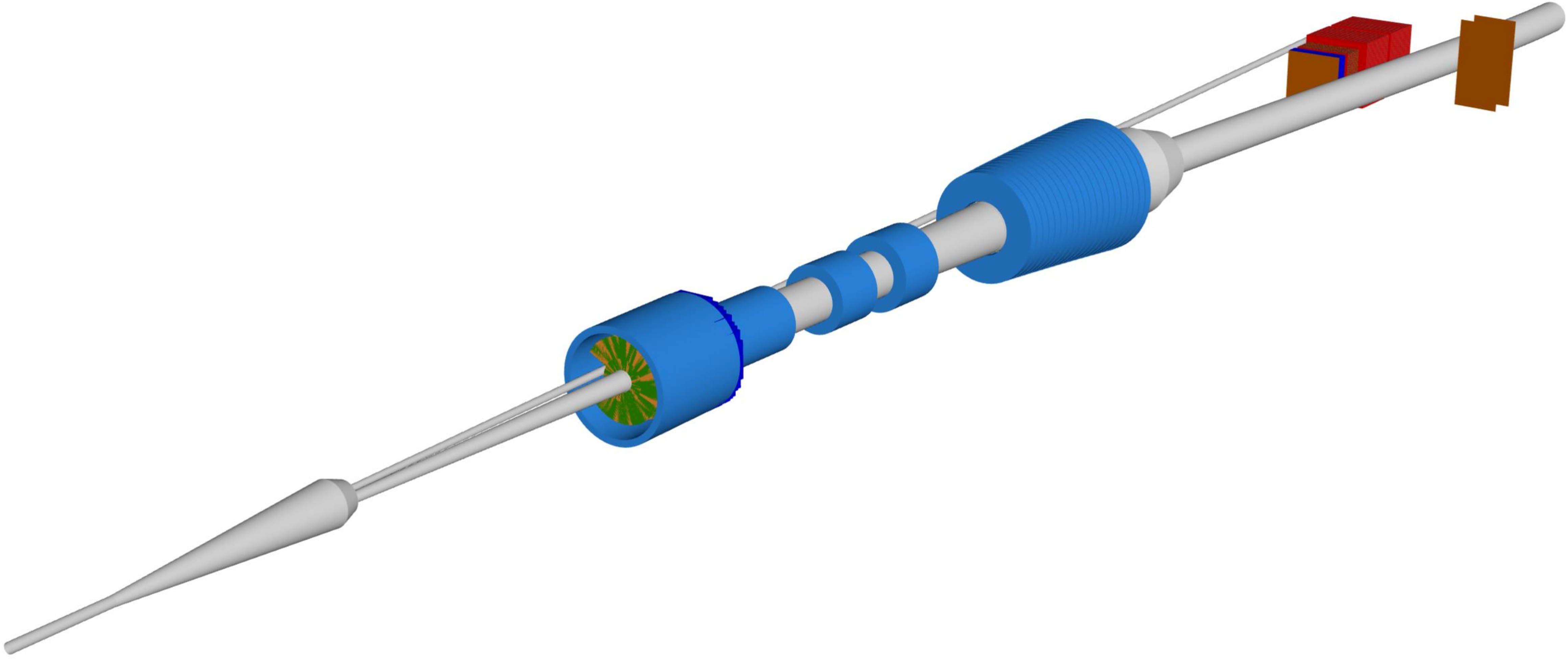




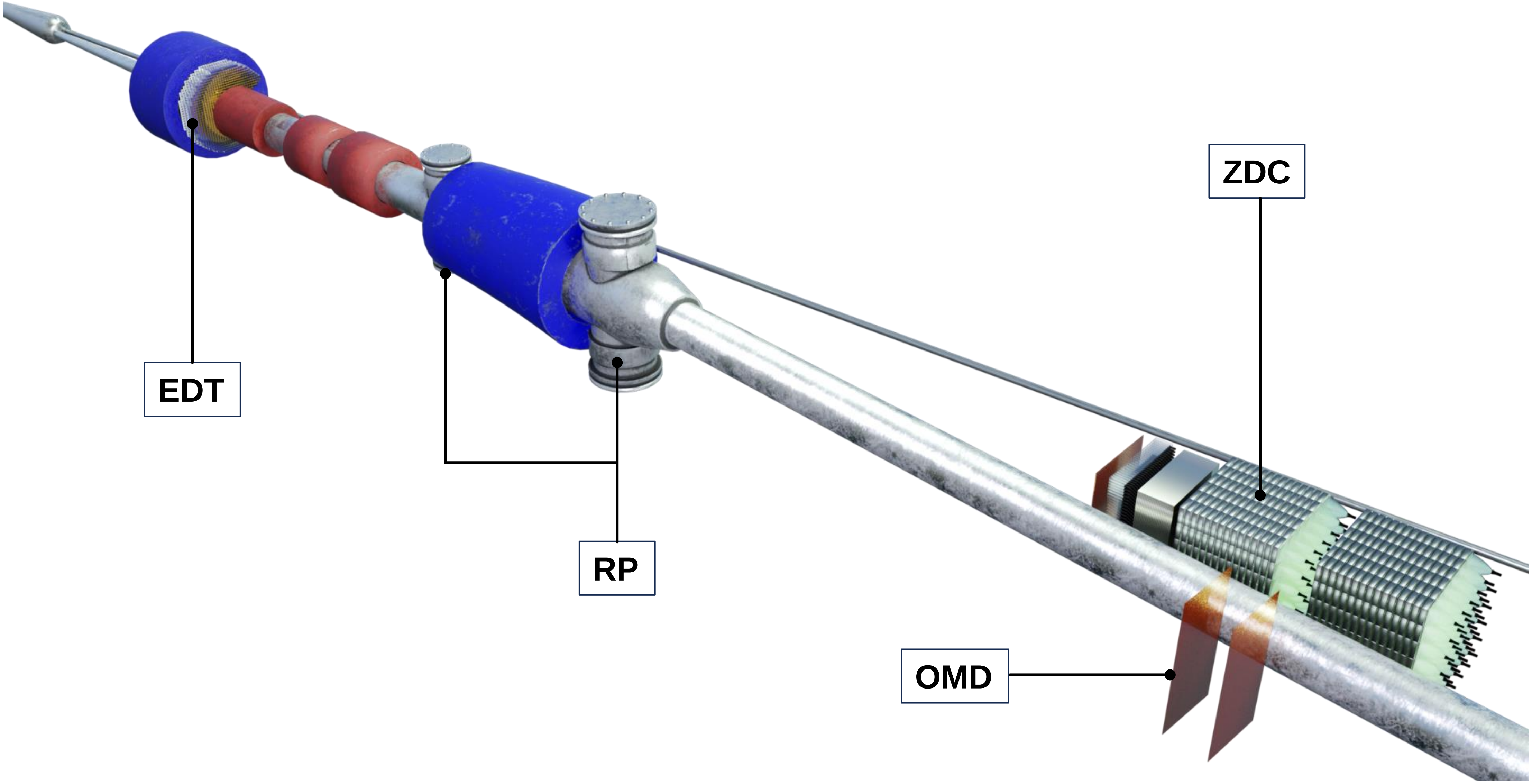
Central Detector



Ion Far-forward detectors



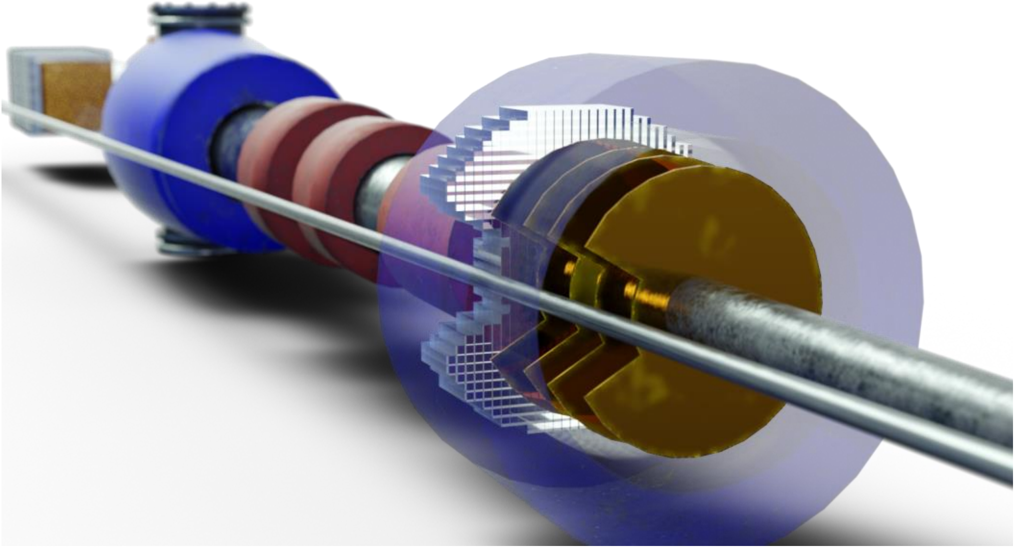
Ion Far-forward detectors

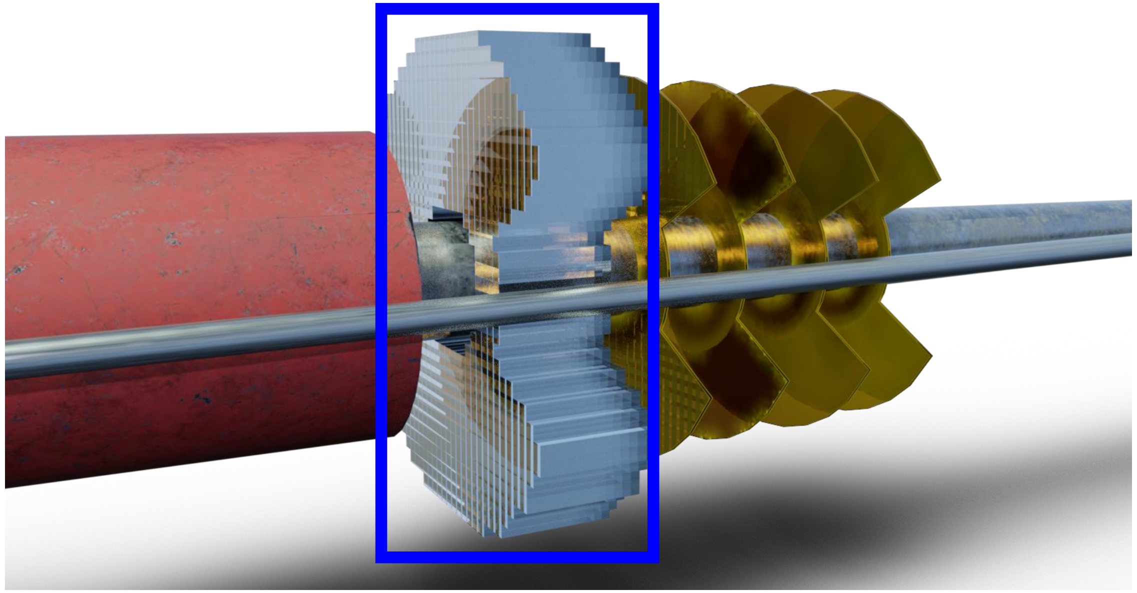


Endcap Dipole Trackers (EDT)

- Four silicon trackers (MAPS, AC-LGAD)
- Charged particle in 16 mr < θ < 60 mr
- Full ϕ coverage for θ < 35 mr
- gaps for θ > 35 mr and $-30^{o} < \phi < 30^{o}$ to allow electron beam pass through
- ~ 0.5% resolution

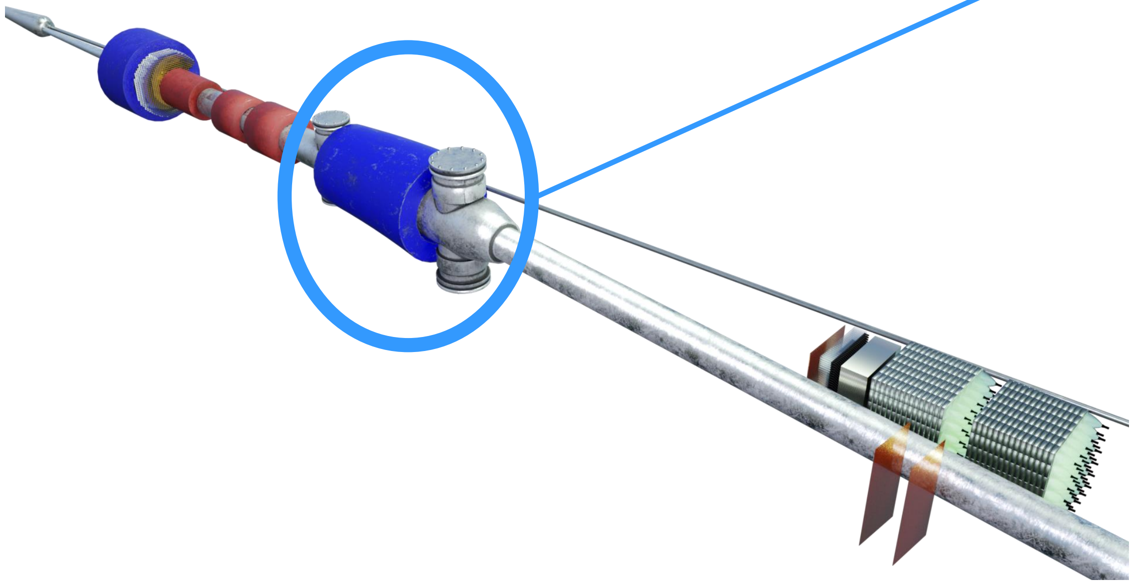
- Motivation: many meson decay photons peak in this range
- Compact EM calorimeter (only ~30cm available space in z due to quad. magnets)
- Reasonable candidate: $PbWO_4$
- Acceptance: 20 mr < θ < 60 mr

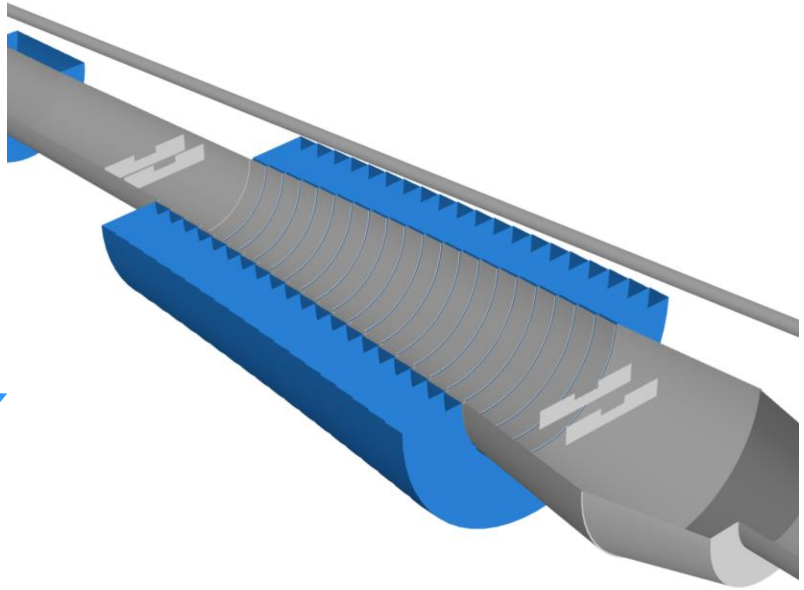


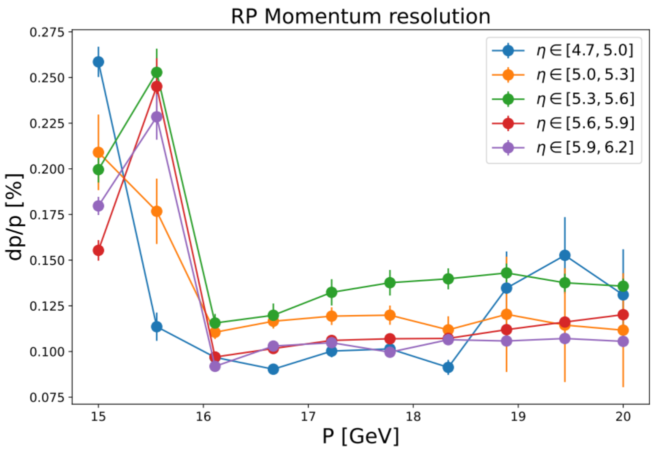


Roman Pot Stations (RPS)

- Roman pot station: 2 silicon trackers (MAPS + AC-LGAD) placed inside the ion beam pipe
- Small holes in the middie to allow ion beam passes through
- Each tracker made of two movable L-shape planes, making the hole size tunable
- ~ 0.3% resolution

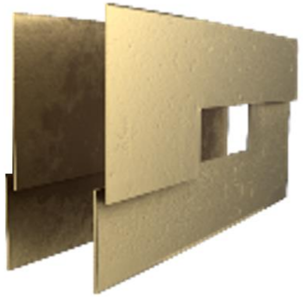


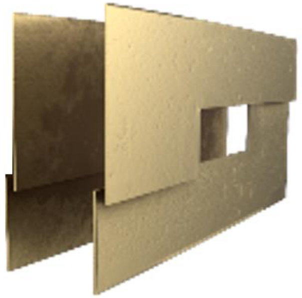




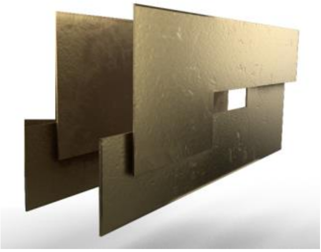
Roman Pot Stations (RPS)

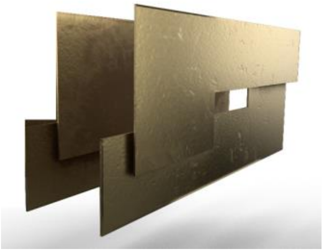
High lumi. configuration





Low lumi. configuration





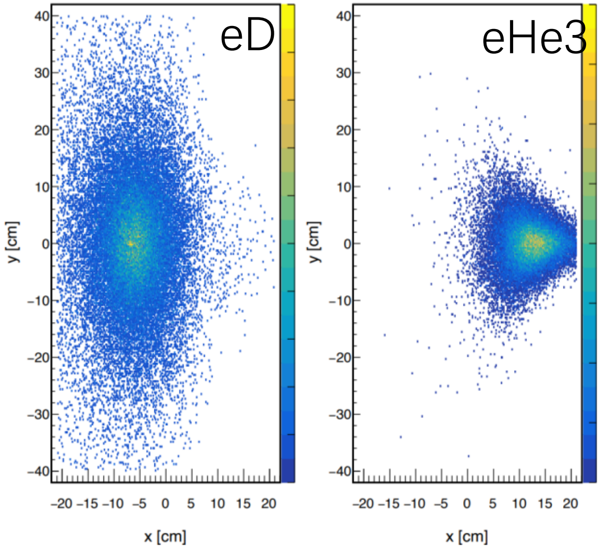
- With EicC high luminosity ~$4x10^{33}$ cm^{-2} s^{-1}
  - larger beam spot size at RPS
  - central hole needs minimum (18cm / 10cm in x / y)
  - Only cover down to ~10 mrad

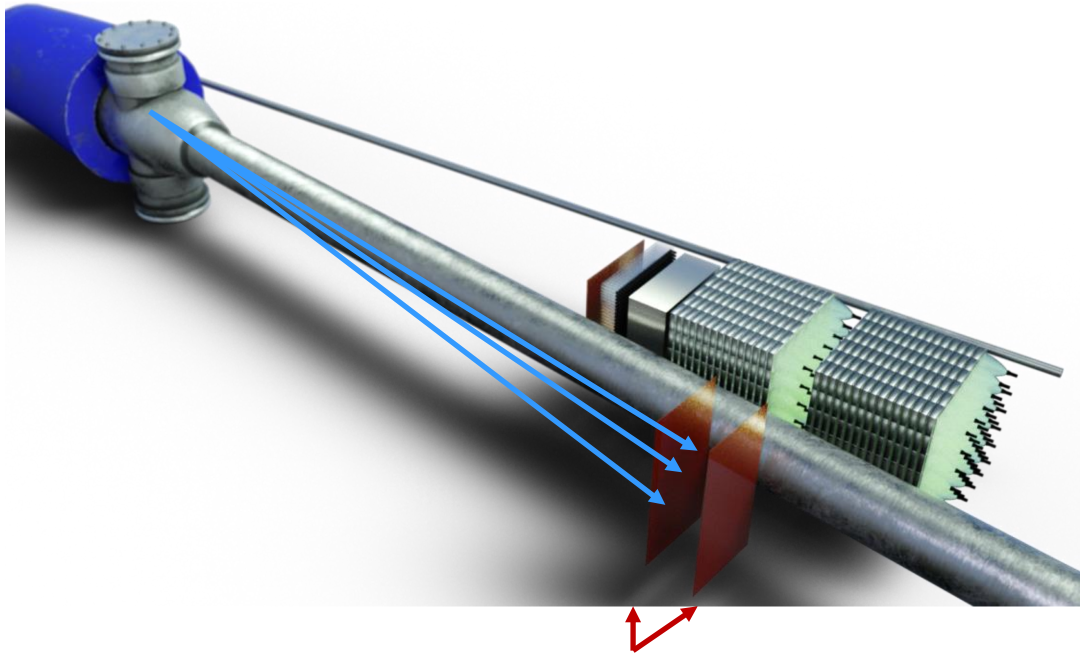
- With EicC high luminosity ~$1x10^{33}$ cm^{-2} s^{-1}
  - smaller beam spot size at RPS
  - central hole needs minimum (8cm / 4cm in x / y)
  - Can cover down to 5 mrad

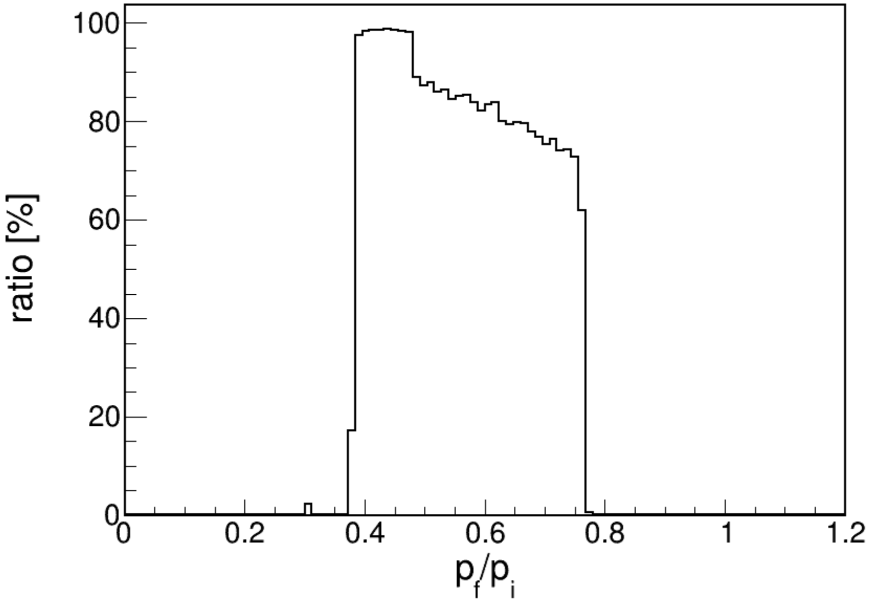
- Possible way to reach ultra-forward angles:
  - spend 10~20% of run time to run low-lumi. setting, reaching angles ~5 mrad

Off Momentum Detector (OMD)

- Purpose of OMD is for charged spectator tagging, which is essential for studies such as tagged DIS, SIDIS, SRC, etc.
- Envisioned technology: MAPS + AC-LGAD or MPGD + AC-LGAD
- Capable of detect charge particles with $0.4 < p_f / p_i < 0.75$







Zero Degree Calorimeter (ZDC)

2 PbSci detectors:

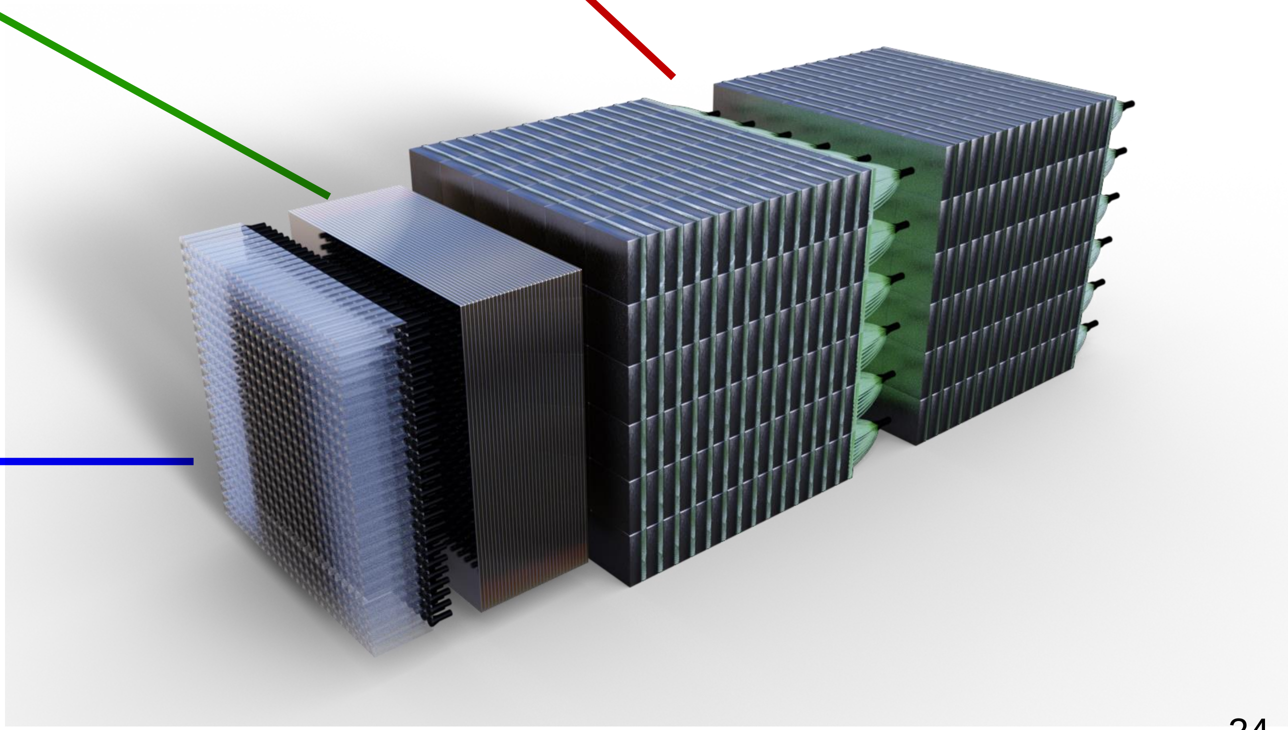
- **Energy measurement for neutron**
- each layer 25.6mm lead + 6.4mm scintillator
- 15 layers for each detector
- in total 60cm x 60cm x 48cm for each detector

WSi detectors:

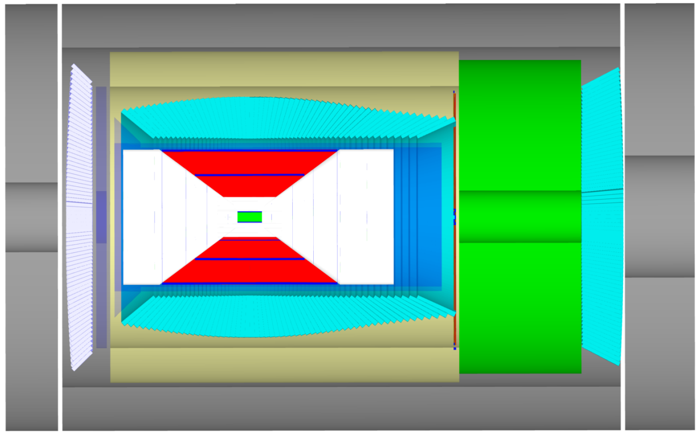
- **Imaging calo., pos recon., PID**
- each layer 3.5mm W + 320um Si
- in total 42 layers
- Si layer readout 1cm x 1cm for now
- in total 50.6 cm x 50.6 cm x 22.5cm

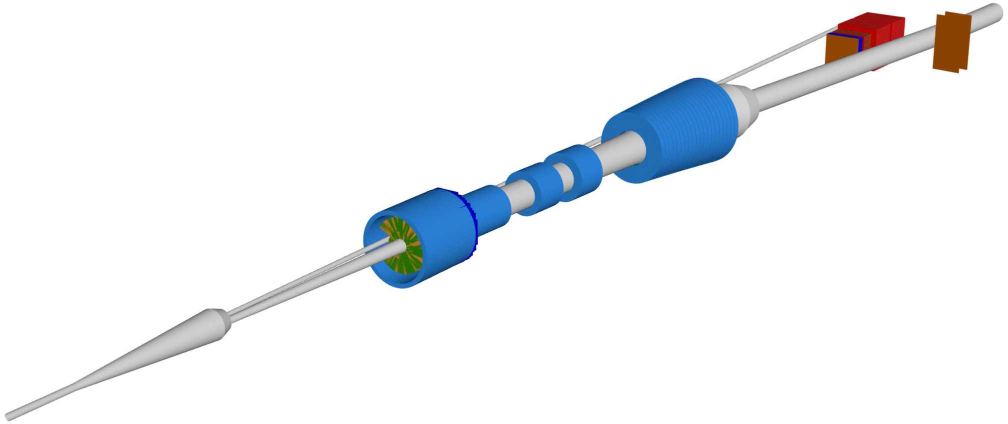
PbWO4 detectors:

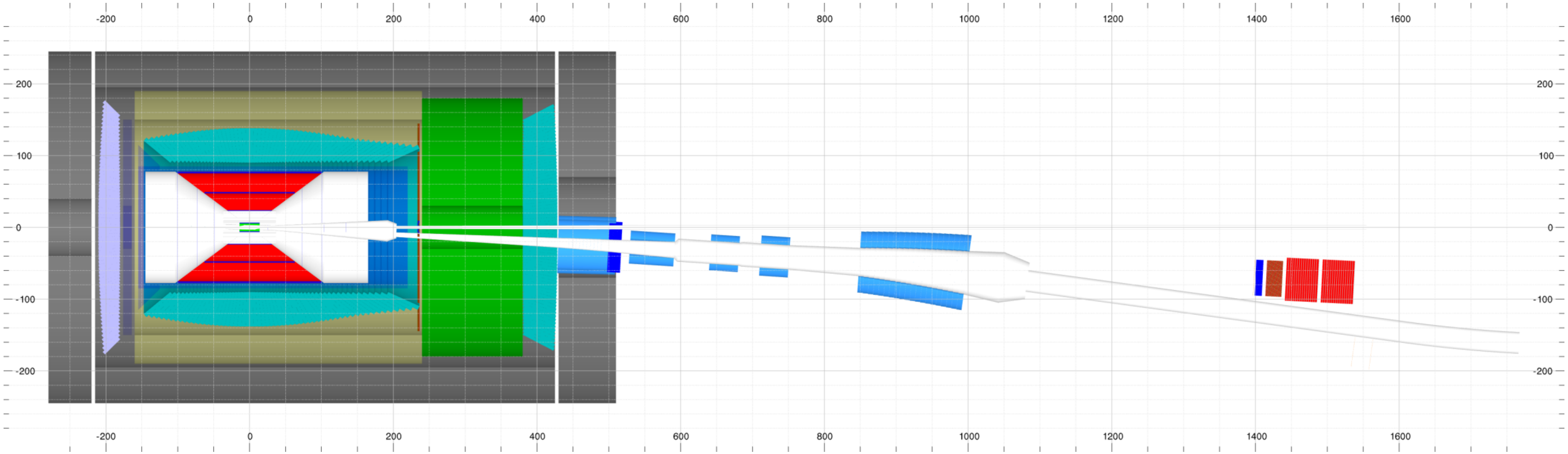
- **For photon detection**
- each module 2.2 cm x 2.2 cm x 10 cm
- in total 50.6 cm x 50.6 cm x 10.0 cm



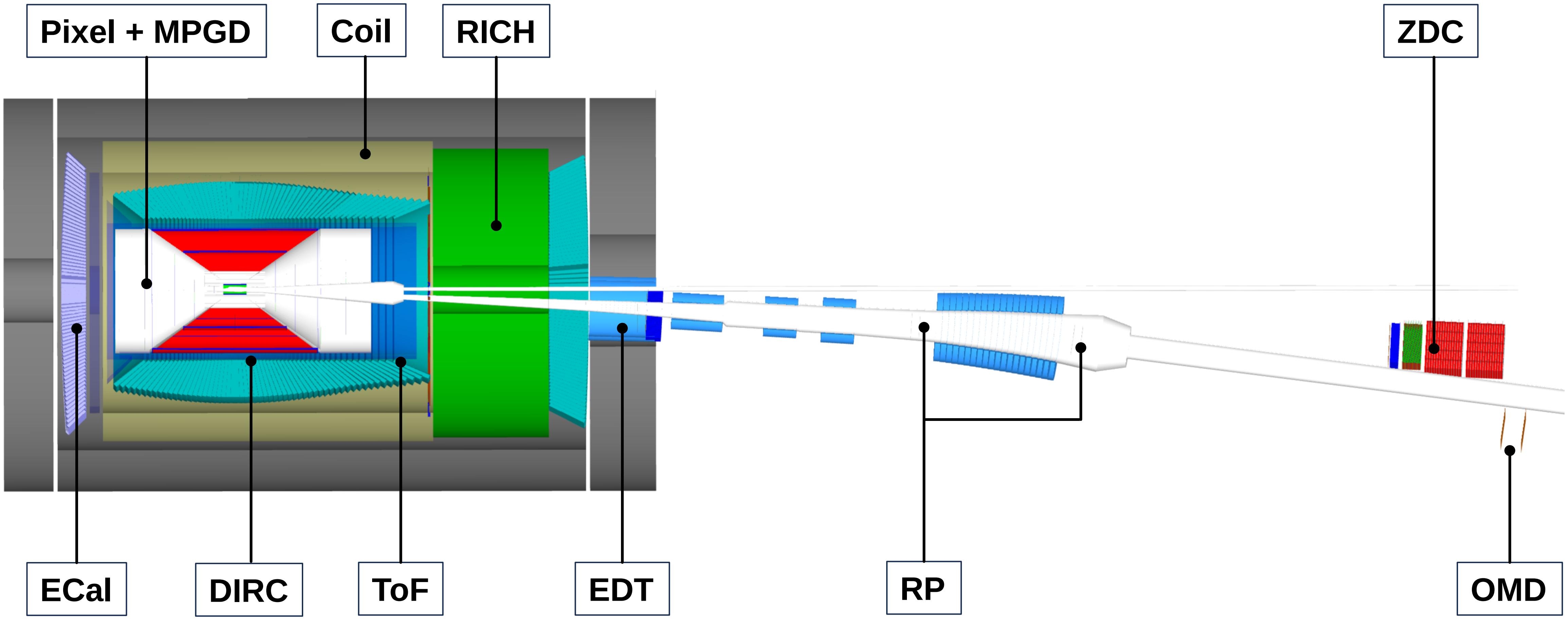
EicC detector at CDR



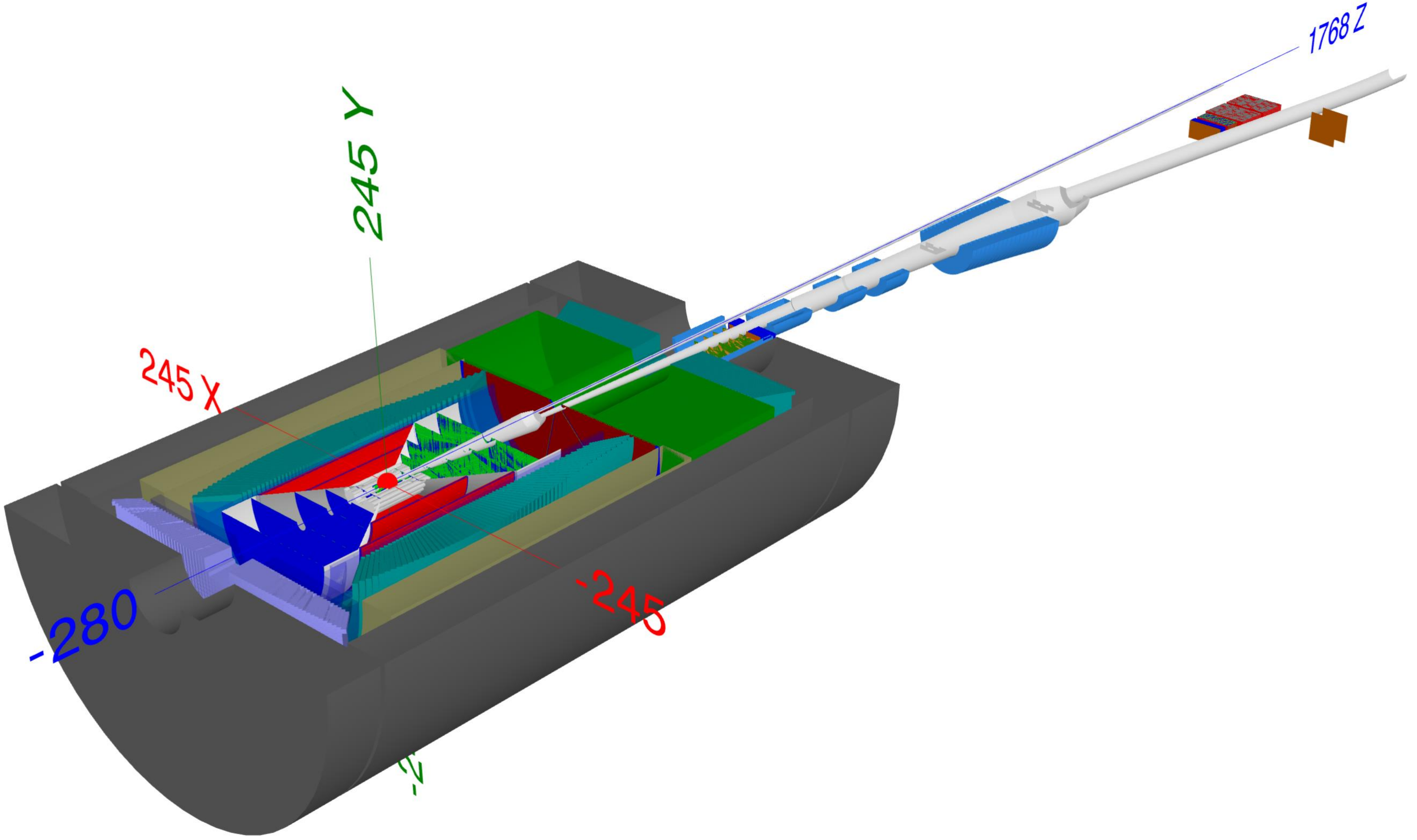




EicC detector at CDR

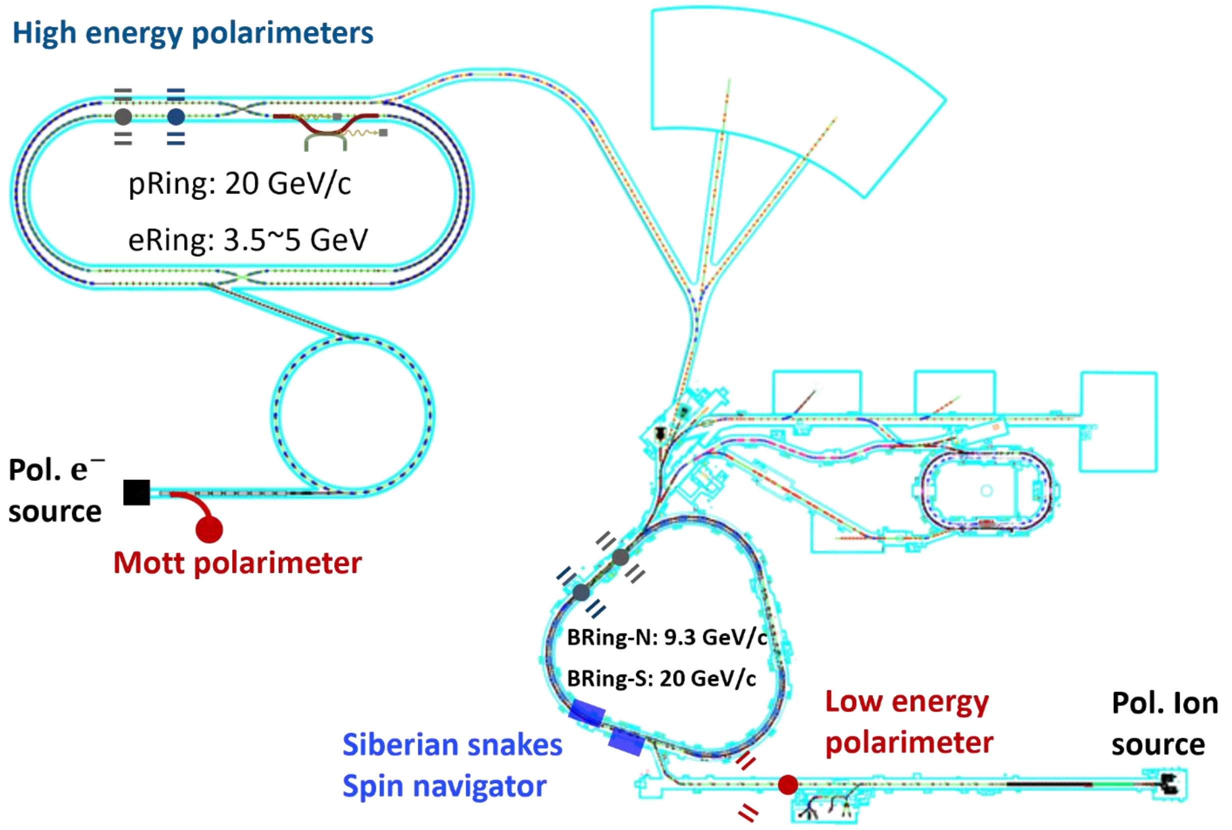


EicC detector at CDR



Polarimeters and Luminosity Monitors

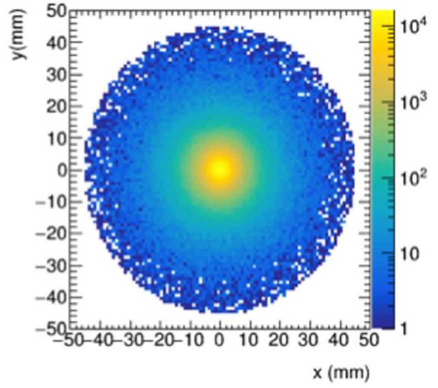
- **Luminosity measurement**
  - Bremsstrahlung luminosity monitor
- **Electron beam polarimetry**
  - Compton polarimeter
- **Proton beam polarimetry**
  - pp absolute
  - pC relative polarimeters

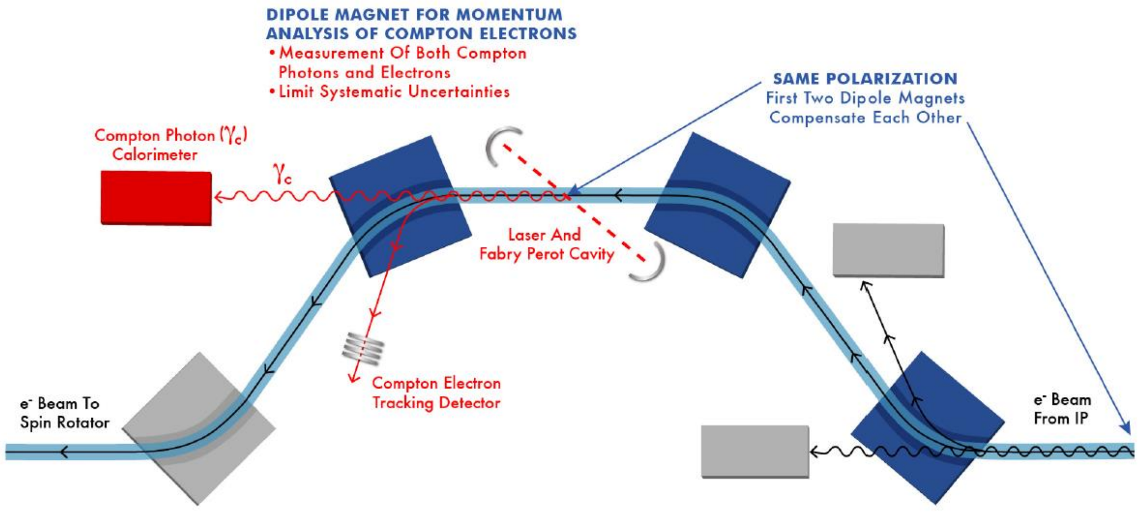


Luminosity Monitors

- via elastic bremsstrahlung off electrons; large and well-know cross section ~mb
- Detect bremsstrahlung photons downstream electron beam
  - Photon conversion to e+e- for precise luminosity calibration
  - Direct photon detection for instantaneous luminosity monitoring

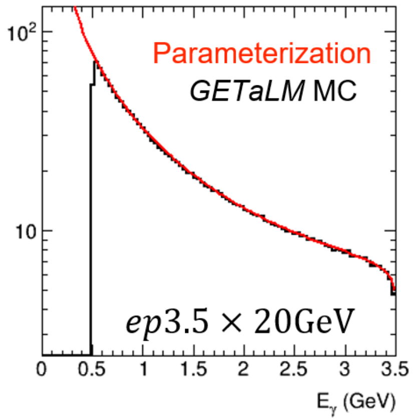
Photon spot at z=30m



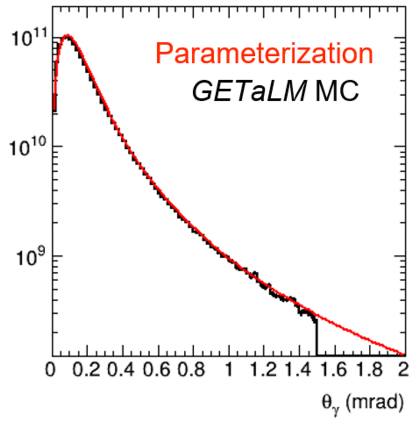


Luminosity monitor

Photon energy

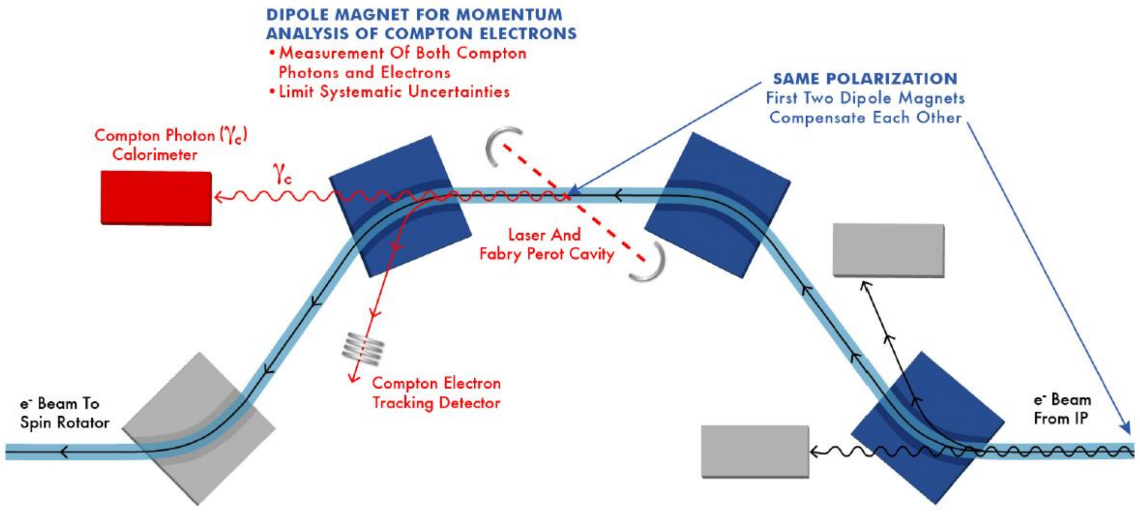


Photon angle



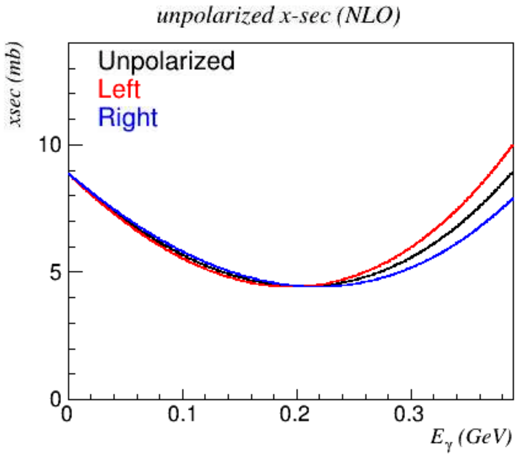
Electron Compton Polarimeter

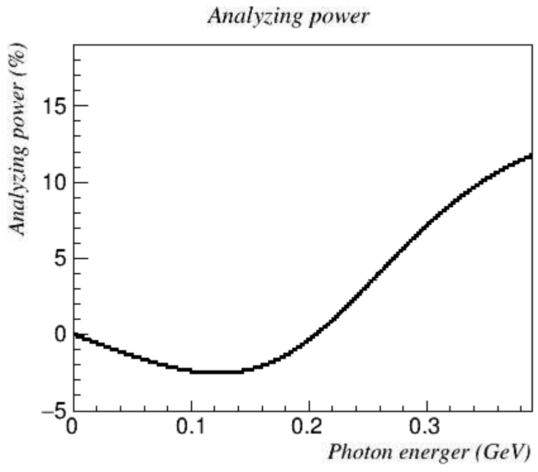
- Quasi-head-on collision with high-power 100% circularly polarized laser
- Independent detectors for electron and photon of $\vec{e}\vec{\gamma} \rightarrow e\gamma$
- Noninvasive and continuous measurement of asymmetries between left and right handed laser polarization states



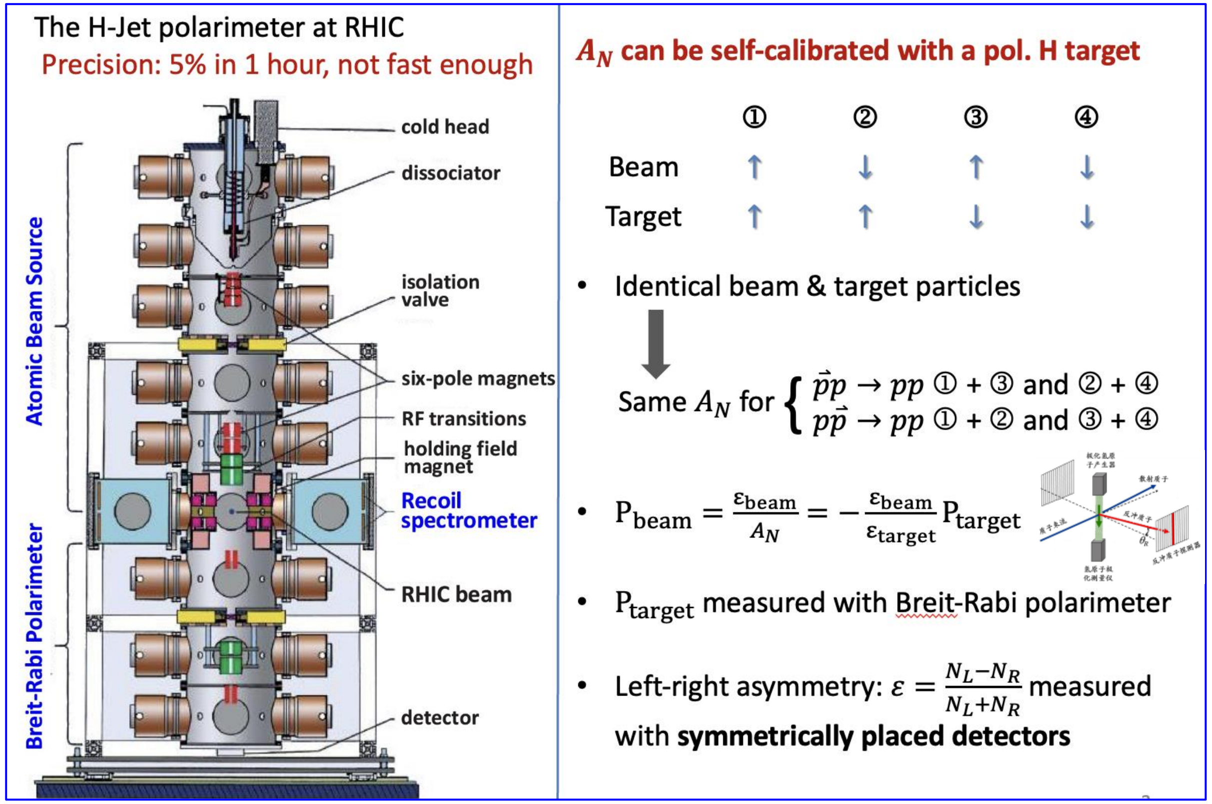
Luminosity monitor

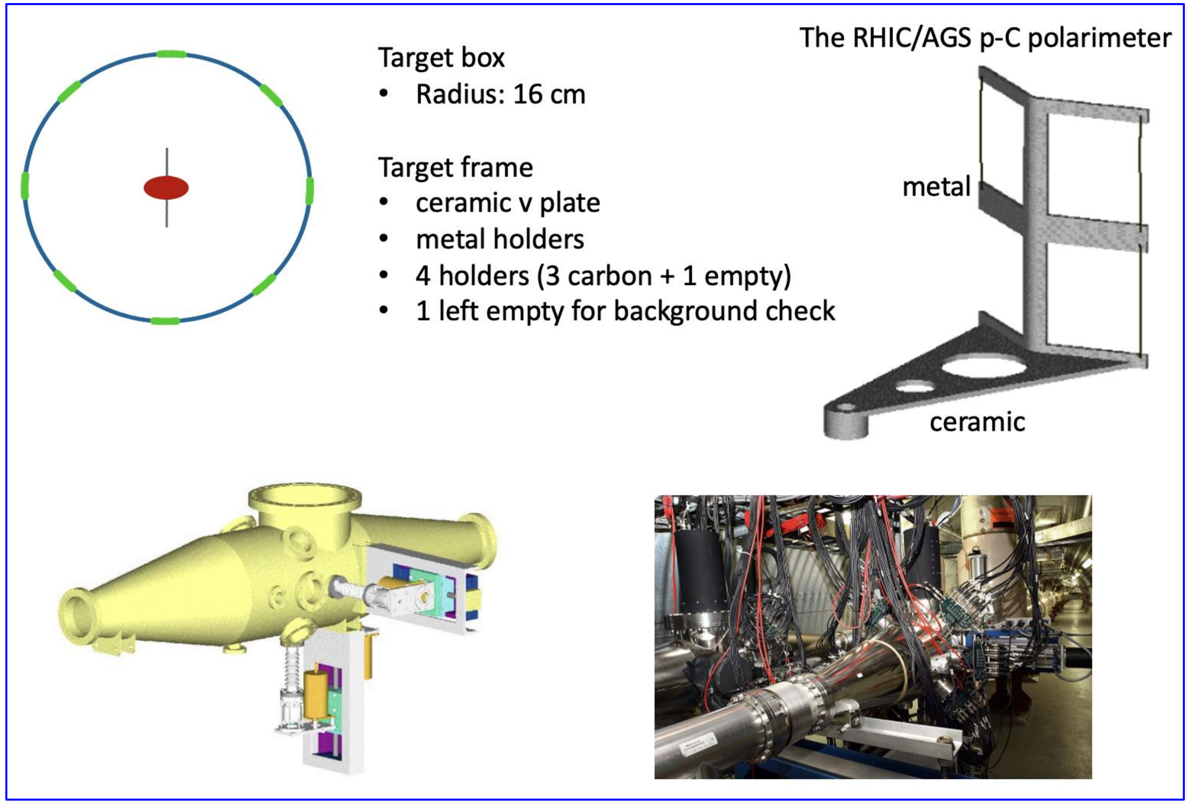
- Geant4 simulation is ongoing





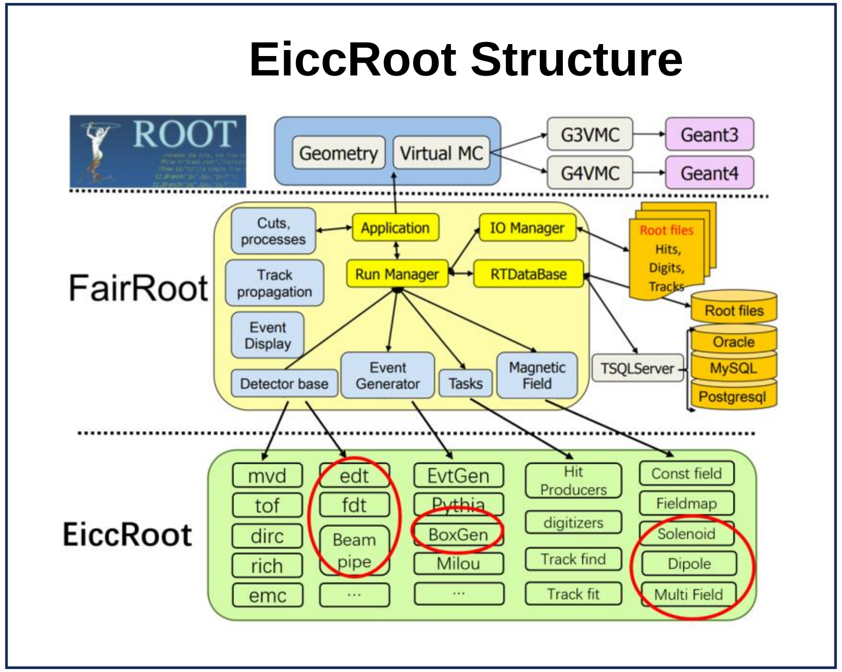
Proton polarimetry scheme





Technologies are rather mature in the world. However, critical R&D needs to be identified from our side.

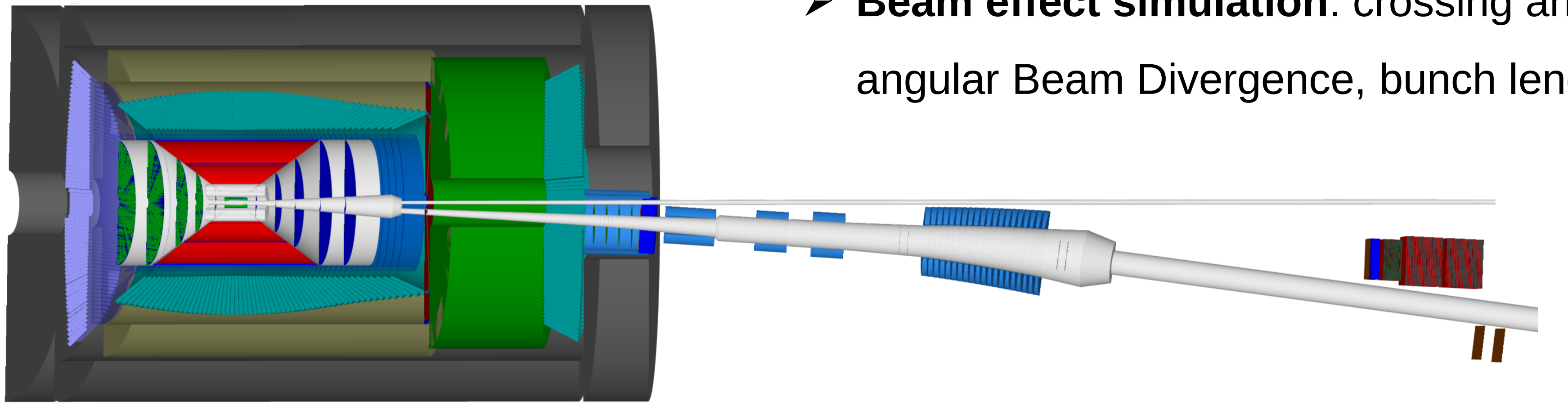
Simulation and Software



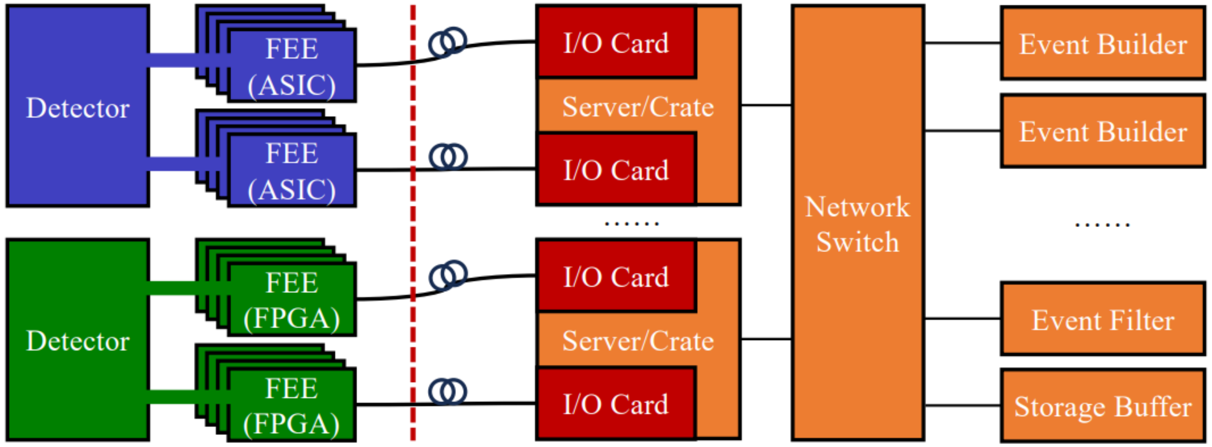
- **EiccRoot_3.0.0:**
- Full magnetic fields (16 field maps) in the IR region
- Complete beam pipe design from -40 to 20 meters
- Interface to event generators:

  EvtGen, Pythia, MILOU, eStarLight…
- Tracking, ECal, Forward detector, Polarimetry packages in good shape

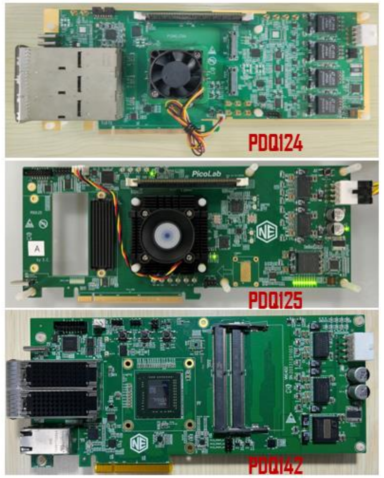
- **Beam effect simulation**: crossing angle, crab cavity, angular Beam Divergence, bunch length



Readout and data acquisition



PiDAQ: PCIe based hardware



R&D is in parallel with **STCF** & **NvDEx**.

Plan to integrate with front-ends in this summer.

Card	FPGA	Generation	Endpoint x Throughput	Server	Note
PDQ060	KU060	Gen3x8	1 x 7.48 GB/s	CHOU	MKU060 (Milianke)
PDQ016	KU5P	Gen3x8	1 x 7.38 GB/s	HSIA	KCU116 (Xilinx)
PDQ024/5	KU15P	Gen3x8	2 x 7.38 GB/s	HSIA	PDQ124 (CCNU)
		Gen3x16	1 x 14.76 GB/s		
PDQ124/5	KU15P	Gen4x8	2 x 14.76 GB/s	HSIA	PDQ124 (CCNU)
PDQ116	KU5P	Gen4x8	1 x 14.76 GB/s	HSIA	KCU116 (Xilinx)
PDQ128	VU37P	Gen4x8	2 x 14.76 GB/s	HSIA	VCU128 (Xilinx)
PDQ142	VM1402	Gen4x8	1 x 14.76 GB/s	HSIA	PDQ142 (CCNU)

```
Secs | Recvd[MB/s] | File[MB/s] | Total[(M)B] | Rec[(M)B] | Buf[%] | Wraps
-----|-------------|------------|-------------|-----------|--------|------
   1      14762.0         0.0        14762.0           0       27      13
### Blocks 14156858 Errors: header=14156858 trailer=0 (trunc=0 err=0 length=0 type=0 crc=0)
   2      14760.9         0.0        29522.9           0       18      27
### Blocks 28663488 Errors: header=28663488 trailer=0 (trunc=0 err=0 length=0 type=0 crc=0)
   3      14749.6         0.0        44272.5           0        7      41
```

Measured with **ATLAS FELIX** software

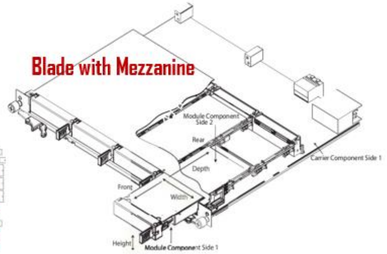
PDQ124: KU15P, 6x QSFP28
PDQ125: KU15P, 2x 12-ch module
PDQ142: VM1402, 2x QSFP28

VERO: ATCA based hardware

- Versatile Readout (**VERO**) system
  - **VAB23** (Versatile ATCA Blade): to be tested in June
  - **VRM24** (Versatile Rear Module): to be tested in July
  - AMC Mezzanine
- AMC cards to be supported
  - **LAM24** (Loopback AMC Mezzanine)
  - **SAM25** (SAMPA AMC Mezzanine)
  - **TAM24** (Trigger AMC Mezzanine): to be tested in Nov
  - **CAM24** (Converter AMC Mezzanine)

VAB23

Blade with Mezzanine



Status of CDR

Summary

- Big progress in various aspects for the past three years.
- Central detector: tracking, PID, ECal well studied.
- Ion forward detectors is in good shape.
- Electron forward detectors ongoing.
- Beam background need to be studied.

Thank You

PiDAQ: PCIe based hardware

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PDQ124/5	KU15P	Gen4x8	2 x 14.76 GB/s	HSIA	PDQ124 (CCNU)
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PDQ142	VM1402	Gen4x8	1 x 14.76 GB/s	HSIA	PDQ142 (CCNU)

```
 Secs | Recvd[MB/s] | File[MB/s] | Total[(M)B] | Rec[(M)B] | Buf[%] | Wraps
------|-------------|------------|-------------|-----------|--------|-------
    1       14762.0          0.0       14762.0           0       27      13
 ### Blocks 14156858 Errors: header=14156858 trailer=0 (trunc=0 err=0 length=0 type=0 crc=0)
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```
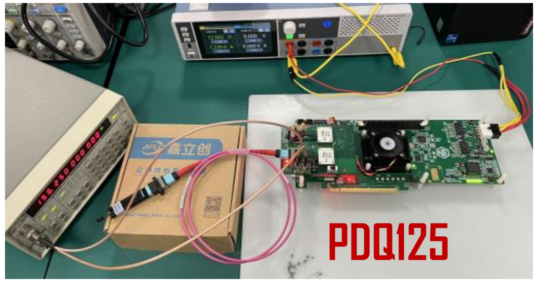

Measured with **ATLAS FELIX** software



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PDQ125: KU15P, 2x 12-ch module
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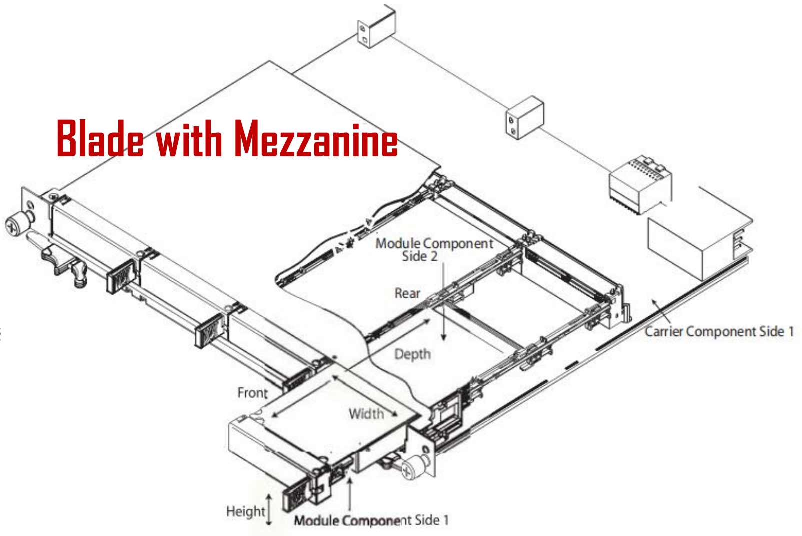
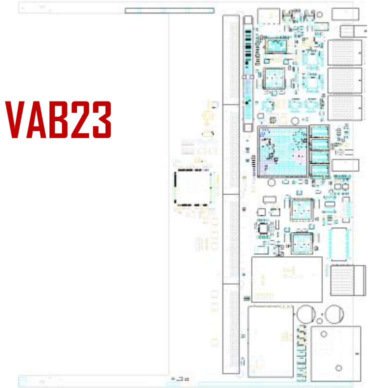


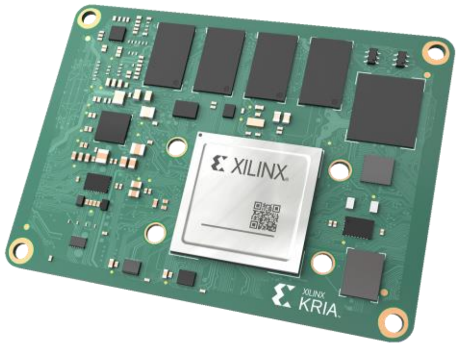
Blade with Mezzanine

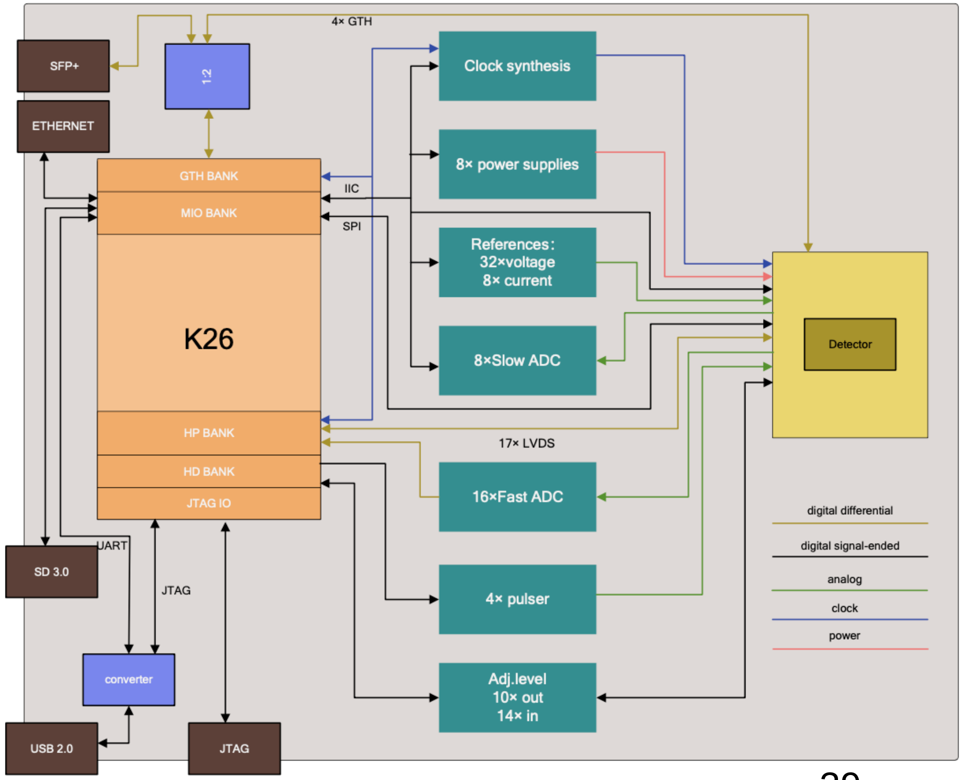

VAB23


ATLAS GCM & GRM

MAPS readout system: CARO

- Control and Readout system (**CARO**)
  - Flexible readout system for pixel chips
- Use the AMD **Kria K26 SOM** card
- Board is being deisgned to support **MIC6** & **ALPIDE**
  - May support other types of detector
- Modular design to support telescope readout in the future
- Prepare for on-stave electronics in the future
- **Schedule**
  - Schematics design (24/03-04)
  - PCB design (24/05-06)
  - PCB fabrication and assembly (24/07)
  - HW, FW, and SW (24/07-10)



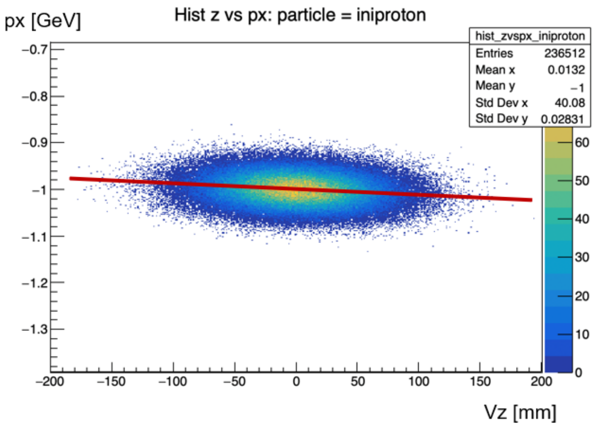


Beam effect study

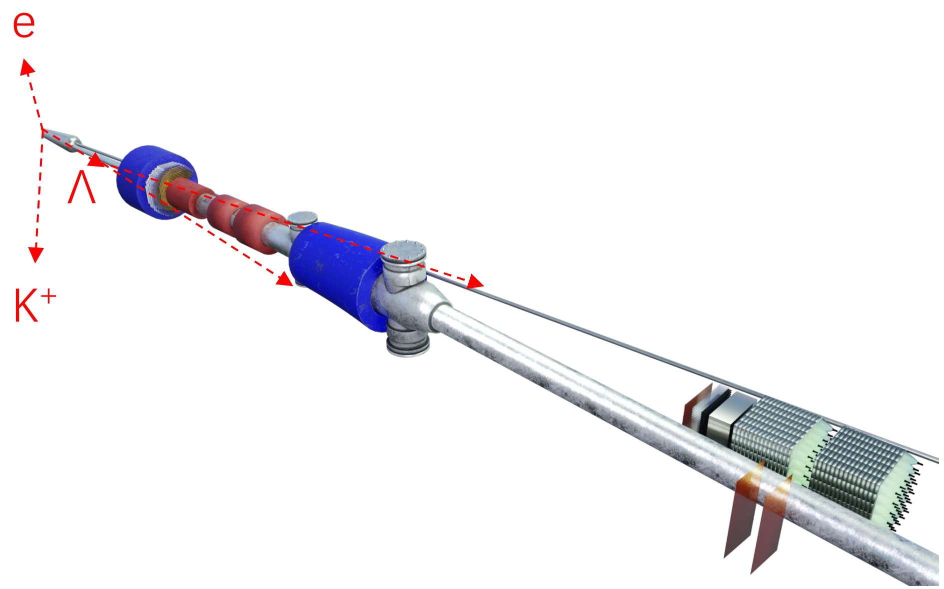
- Accelerator and beam conditions critical for physics and detector simulations for the Electron-Ion Collider
  - Document: https://zenodo.org/records/6514605
- Code: https://github.com/eic/afterburner
  1. Crossing angle
  2. Crab Cavity
  3. Angular Beam Divergence
  4. Bunch Length

With Bunch Length and Crab Cavity Effect

- Crab cavity will rotate the bunch, giving it a "kick" in the x-direction
- The "kick" is z-dependent, no kicking in the middle of the bunch
- Effect is at the level of 20 MeV from head to tail
  - Currently, effect in the program twice larger than expected, need to find out why



Forward Λ detection



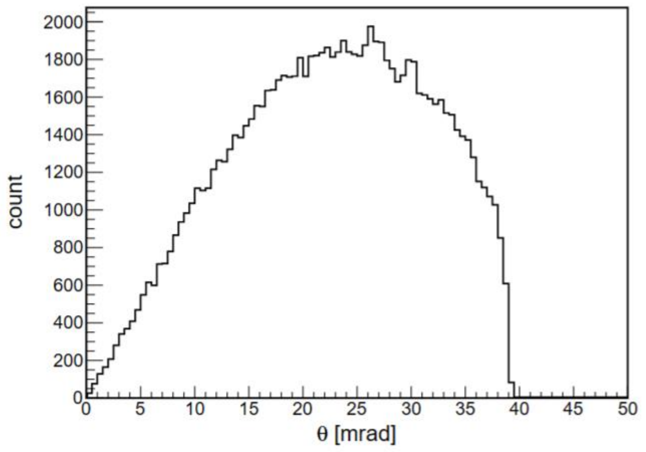
Detection of Λ is essential for measurement of the **kaon form factor** and **structure function using the Sullivan process.**

$e + p \rightarrow e' + K^+ + \Lambda$

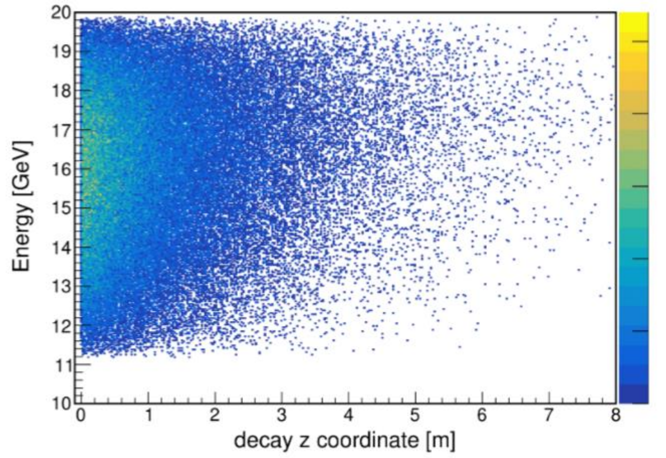
Obvious advantage for EicC, compared to EIC

Efficiency of Λ ~ 40% (EIC 1% ~ 20%)

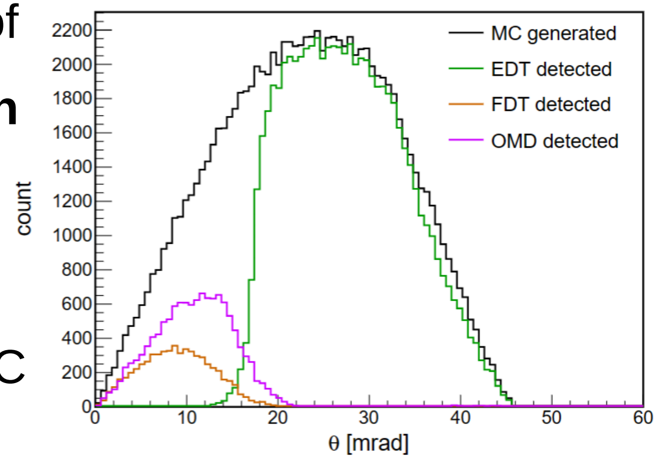
polar angle of Λ



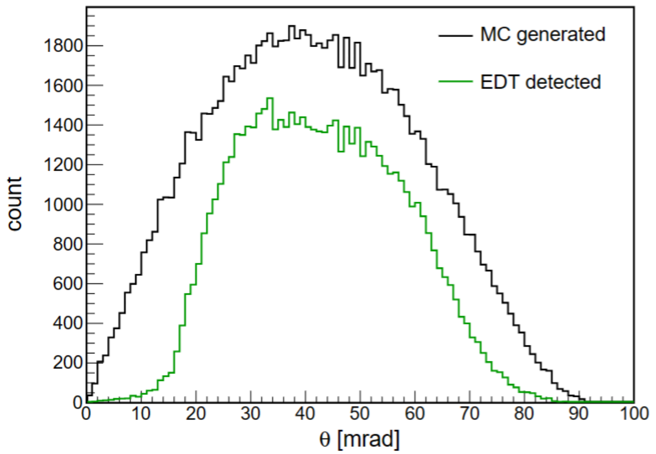
Energy vs decay z-vertex of Λ



polar angle of p from Λ

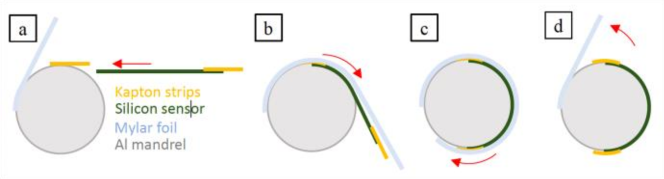


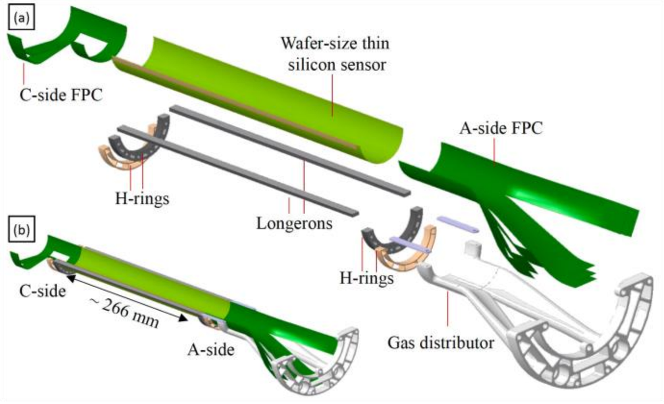
polar angle of π^- from Λ

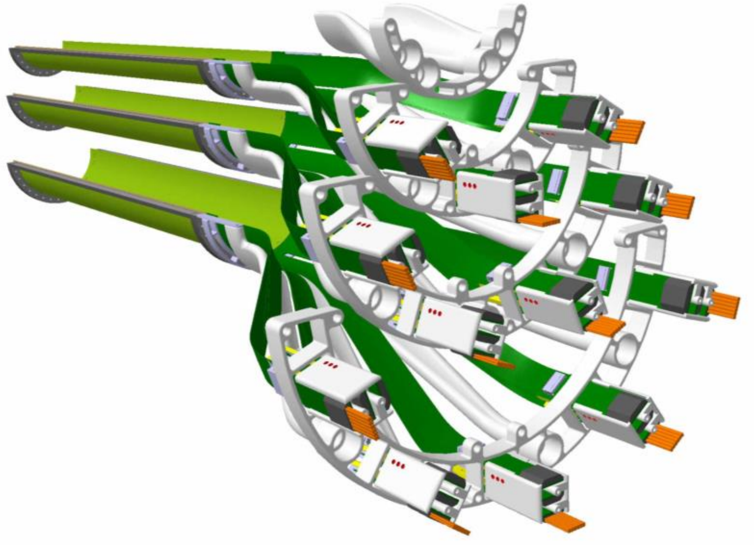


Structure of the EicC barrel silicon tracker

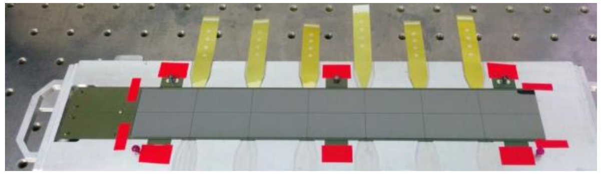
- **ITS3-based Vertexer (3 IB layers)**



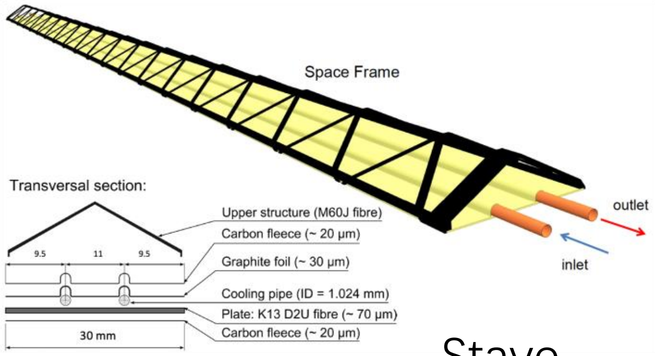




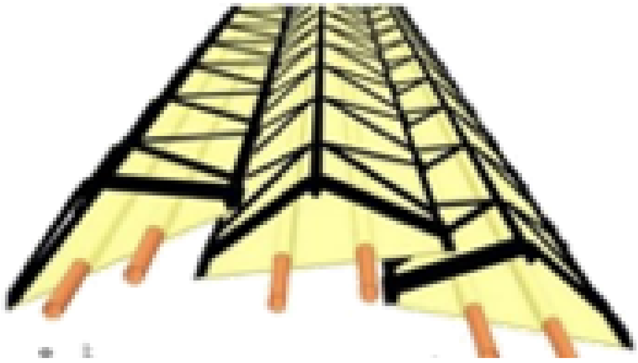
- **ITS2-based Silicon Tracker (2 OB layers)**



Hybrid Integrated Circuits (HIC)

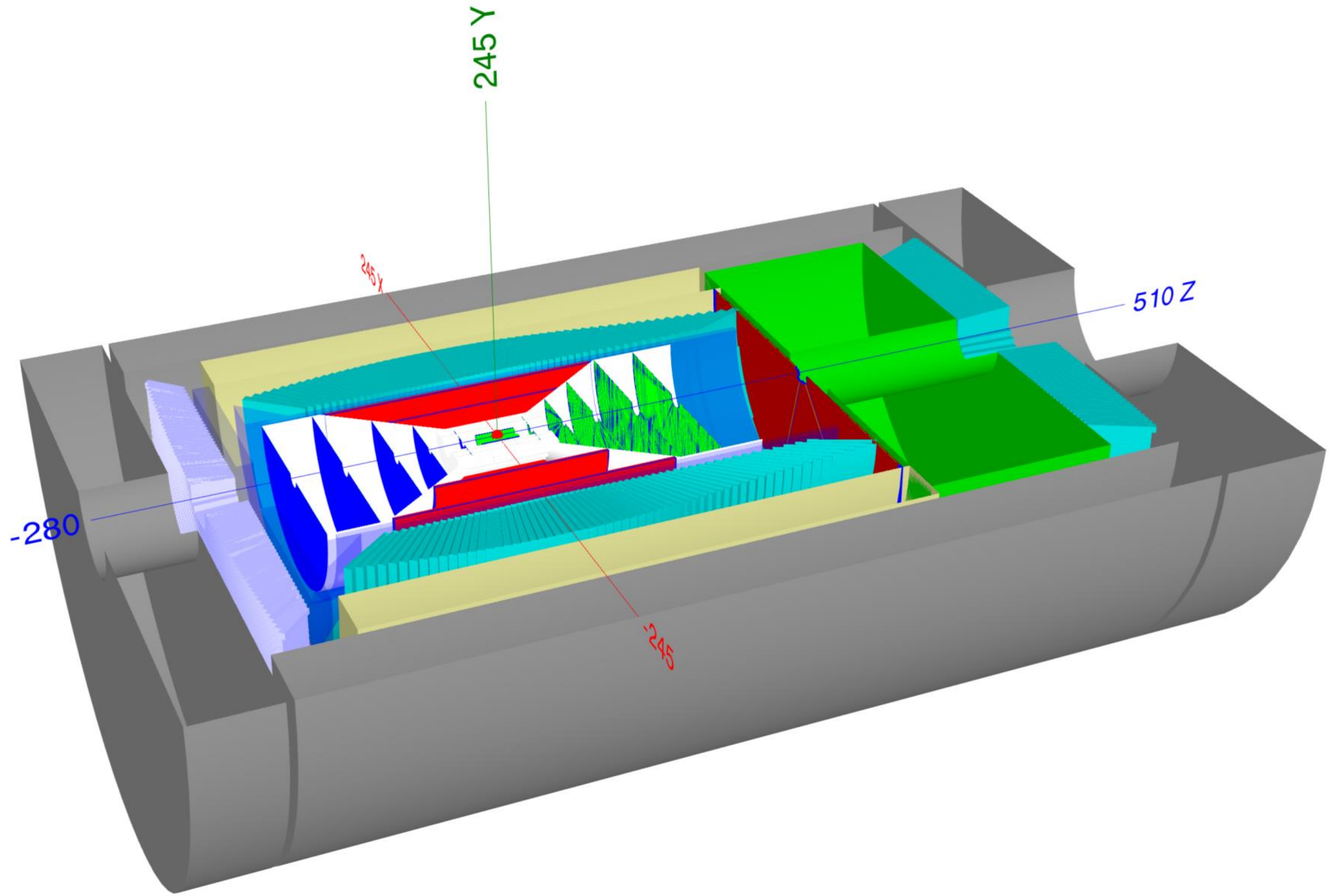


Stave

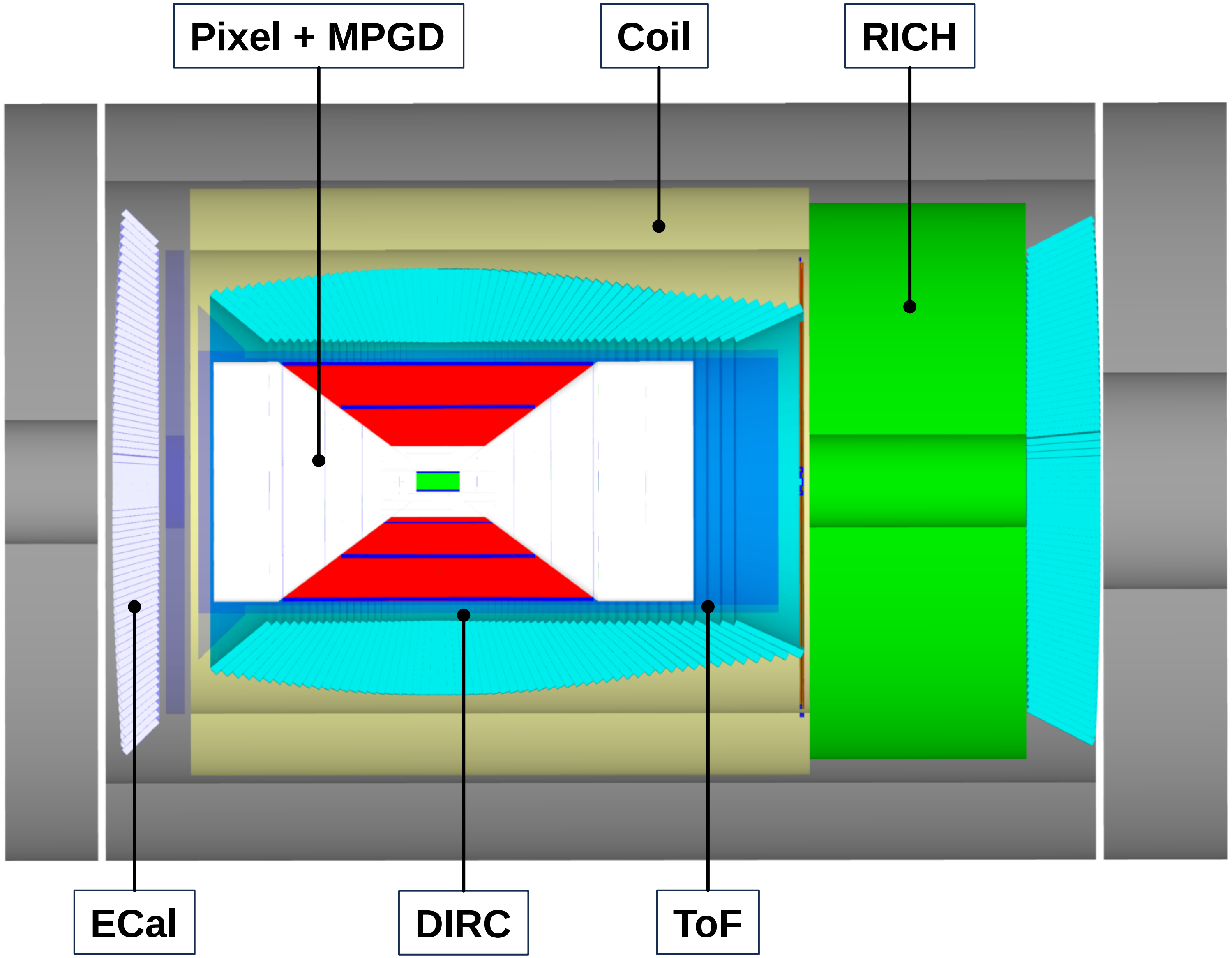


➢ 针对EicC，尽快启动MAPS探测器设计与仿真，开展柔性PCB、碳纤维机械支撑等关键器部件的市场调研

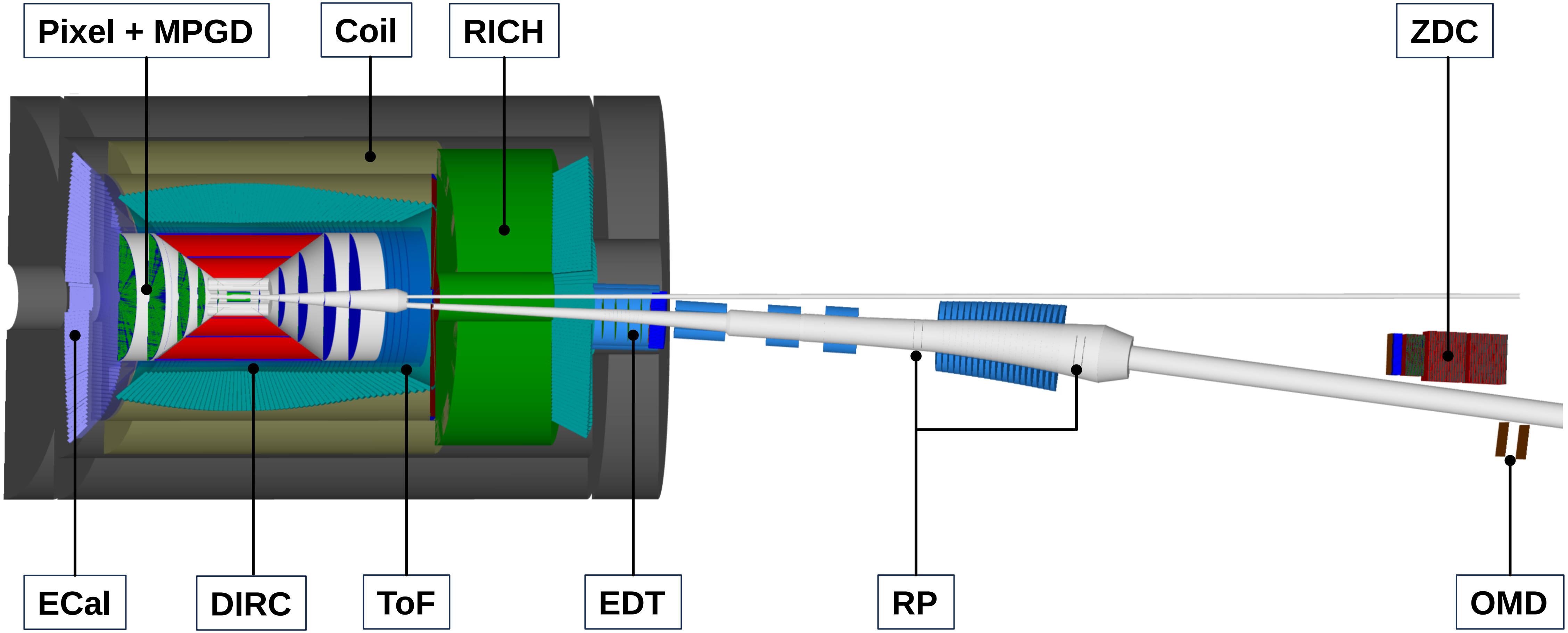
Central Detector



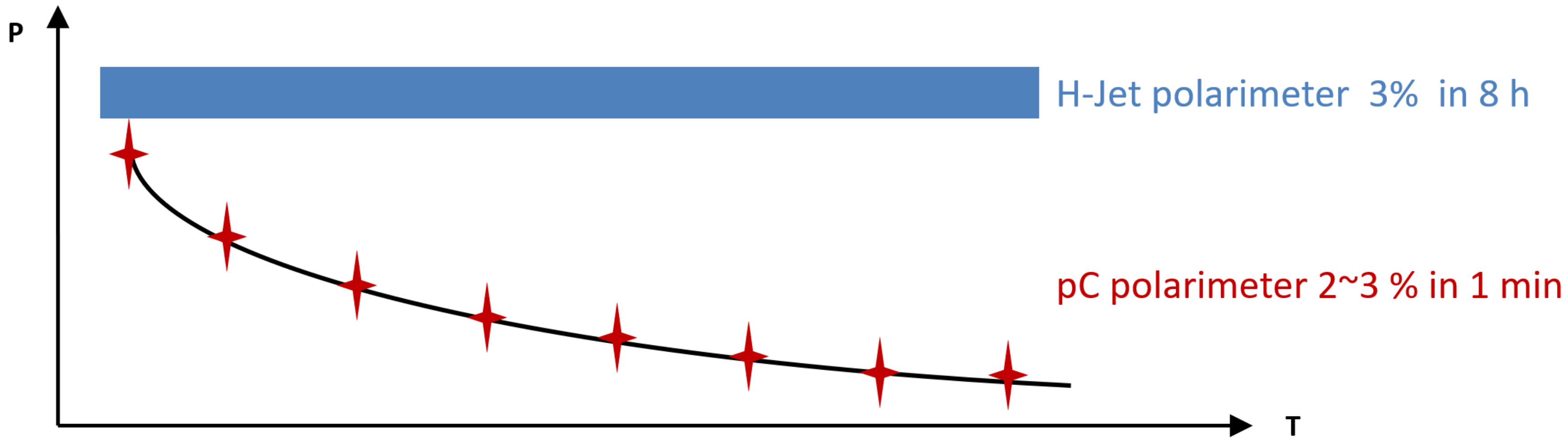
Central Detector



EicC Detector



Proton polarimetry scheme

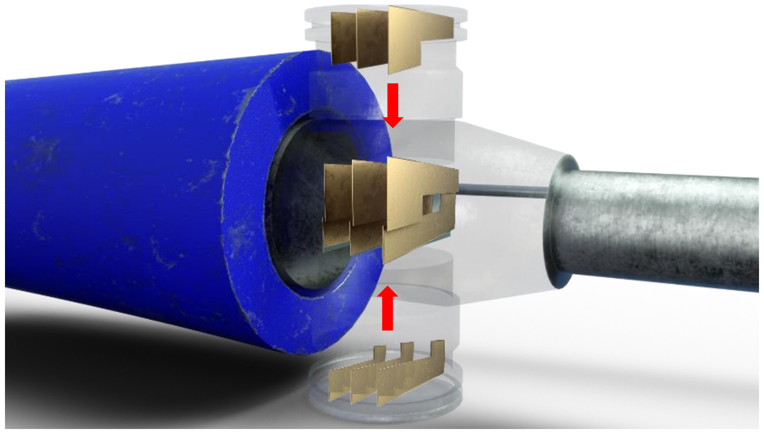


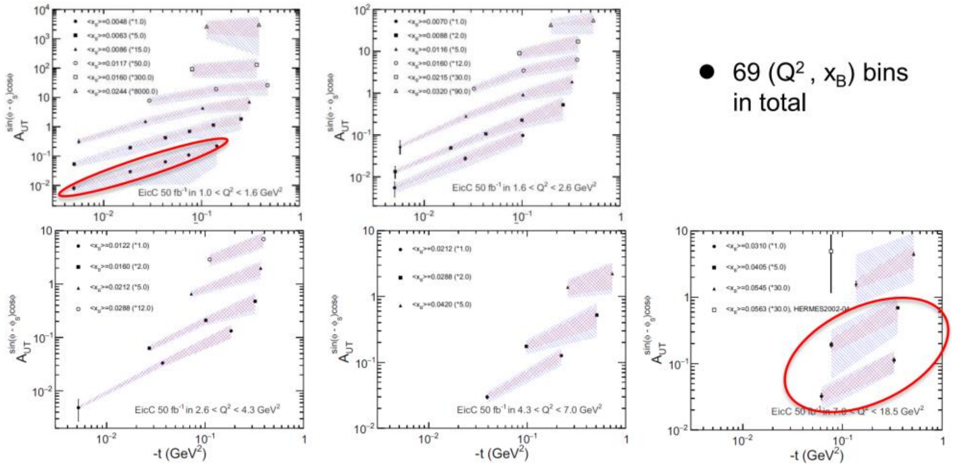
	H-Jet polarimeter	pC polarimeter
Target	Polarized H gas jet	Carbon fiber
Target thickness	$\sim 10^{12} atoms/cm^2$	$\sim 10^{16}\ atoms/cm^2$
Event rate	~ 60 Hz	~ 2 MHz
Operation	continuously	~ 1 min/h
Analyzing power	self-calibrated	unknown
Role	Absolute, slow Noninvasive	Fast, relative Polarization profile Feedback for machine tuning

FDT running at Low luminosity mode

	High Lumi.		Low Lumi.	
Designs	**HIAF-U-New, V0**		**V1**	
Particle	**e**	**p**	**e**	**p**
Circumference(m)	1151.20	1149.07	1151.20	1149.07
Kinetic energy (GeV)	3.5	19.08	3.5	19.08
Momentum (GeV)	3.5	20	3.5	20
Total energy (GeV)	3.5	20.02	3.5	20.02
CM energy (GeV)	16.76			
$f_{\text{collision}}$ (MHz)	100			
Polarization	80%	70%	80%	70%
$B\rho$ (T·m)	11.7	67.2	11.7	67.2
Bunch intensity($\times 10^{11}$)	1.7	1.05	0.44	0.27
$\varepsilon_x/\varepsilon_y$ (nm·rad, rms)	50/15	100/50	12.5/3.75	25/12.5
β_x^*/β_y^* (cm)	10/4	5/1.2	10/4	5/1.2
RMS divergence (mrad)		1.4/2.0		0.7/1.0
6×RMS size @ BpF2 (cm)		9.3/4.6		4.6/2.3
8×RMS size @ BpF2 (cm)		12.4/6.2		6.2/3.1
10×RMS size @ BpF2 (cm)		15.5/7.7		7.8/3.9
Bunch length (cm, rms)	0.75	8	0.75	8
BB parameter ξ_x/ξ_y	0.102/0.118	0.0144/0.01	0.105/0.121	0.015/0.010
Laslett tune shift	-	0.066/0.105		0.065/0.10
Energy loss (MeV/turn)	0.32	-		
Total SR power (MW)	0.86	-		
Average Current (A)	2.7	1.68		
Crossing angle (mrad)	50			
Luminosity ($cm^{-2}\cdot s^{-1}$)	4.25×10^{33} (H=0.52)		1.13×10^{33} (H=0.52)	

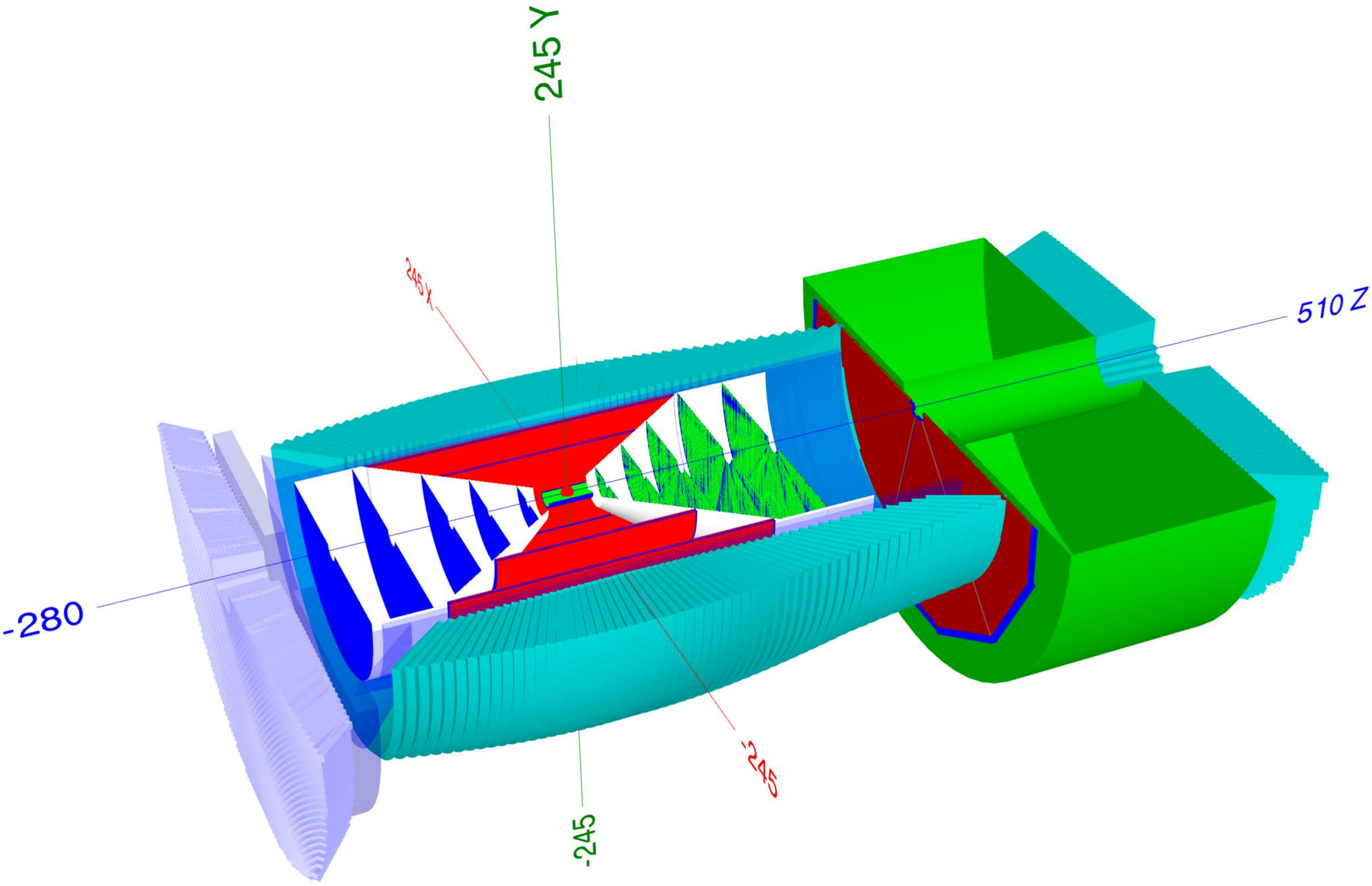
Assuming ¼ of data taking time running at low luminosity mode.

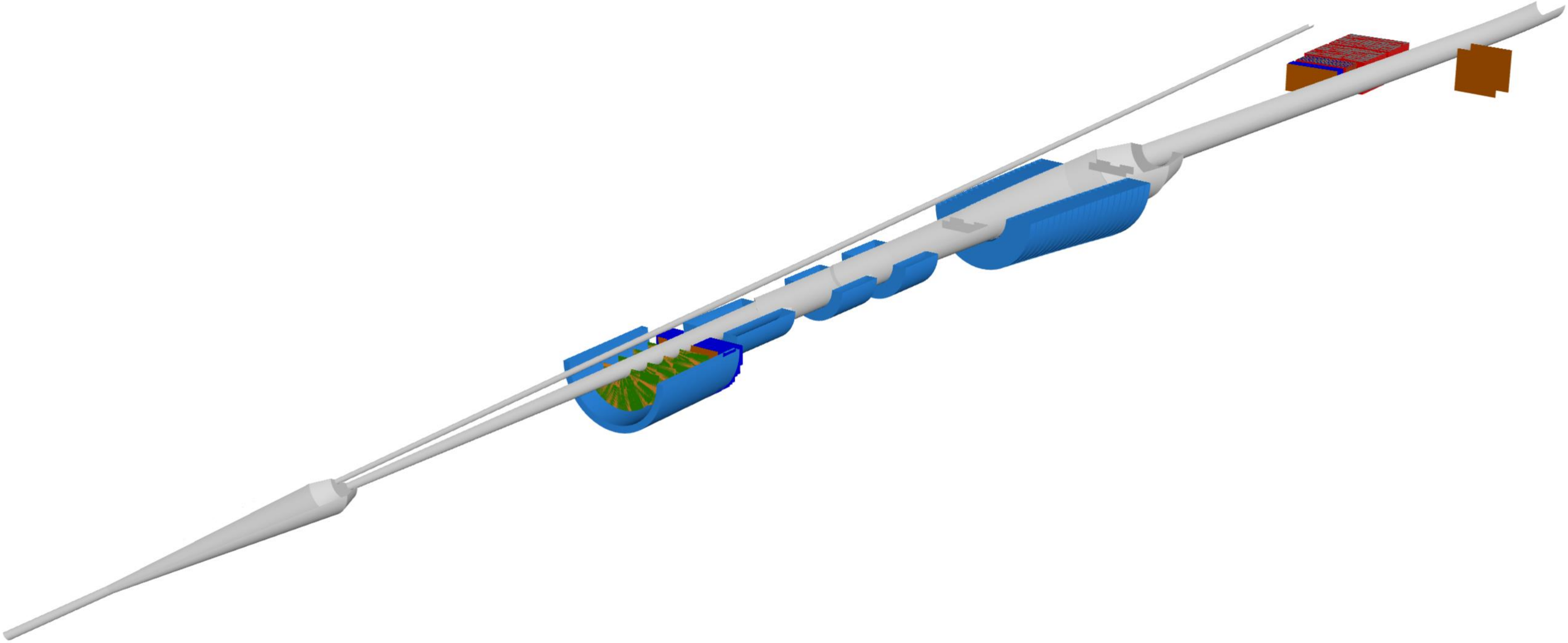




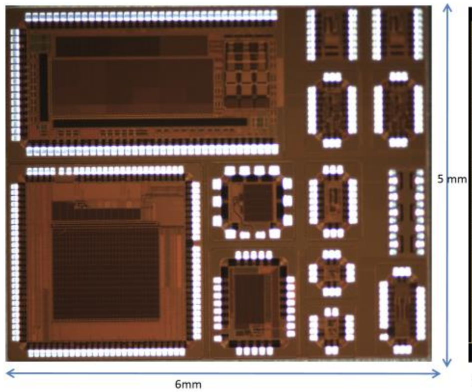
- 69 (Q^2, x_B) bins in total

50 fb^{-1} data→ ~1% stat. error on asymmetry

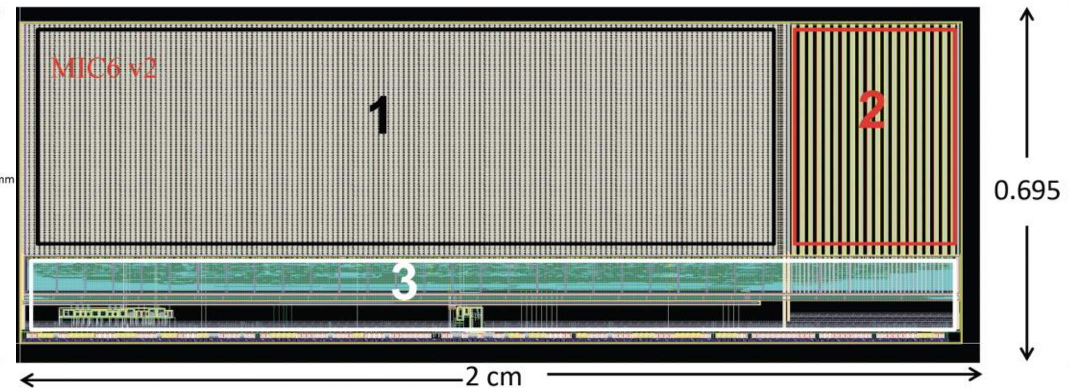

245 Y
245 X
510 Z
-280
-245
-245



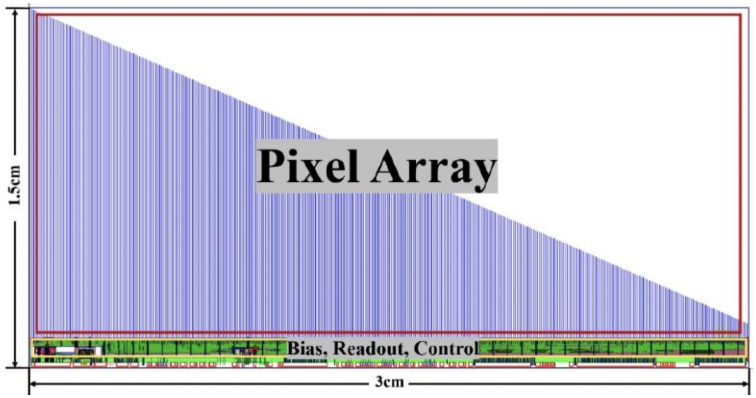
MAPS Chip Design – 基于国内工艺研发MIC6 -- 孙向明, 肖乐



MIC6_V1



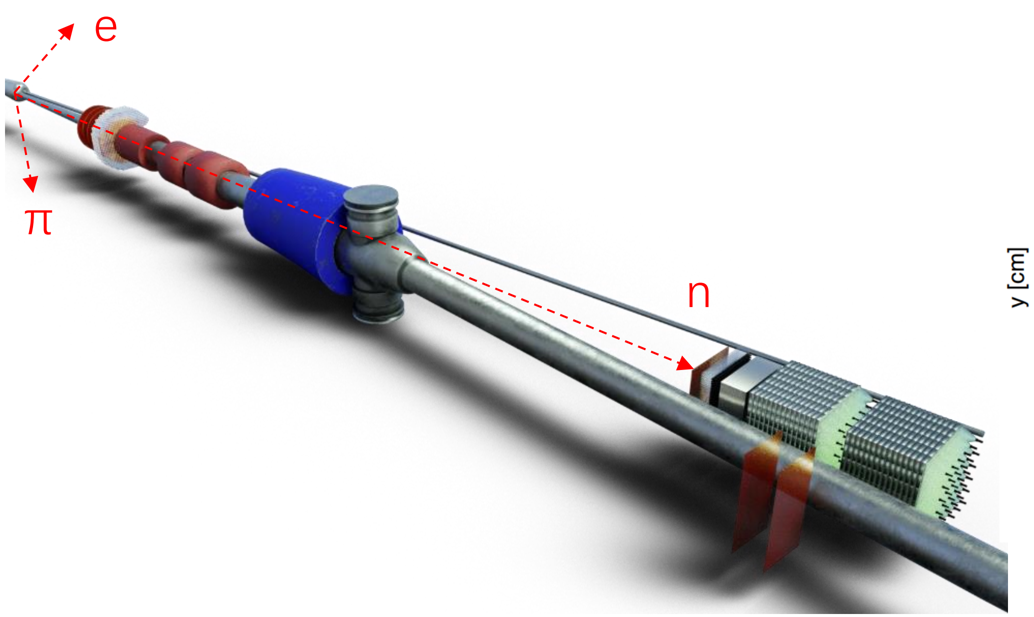
MIC6_V2

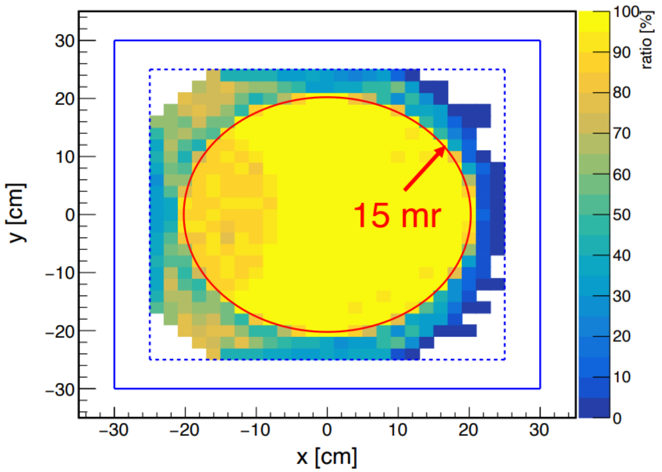


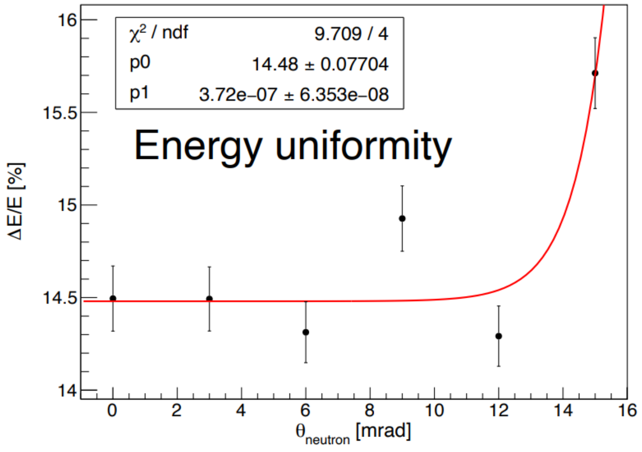
MIC6_V3

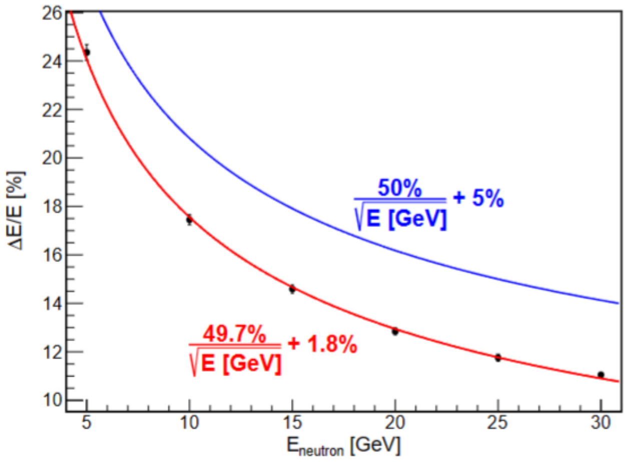
- ➢ 华力55nm CIS工艺:
- • 三阱（合作开发了第四阱Deep PW)
- • 进行了一次流片
- • 首次基于国产工艺设计的MAPS探测到^{55}Fe能谱，CCE > 93.5%，MAPS工艺国产化
- • 成功验证读出架构芯片MIC6_V1，每1.56ns读出8个像素(ALPIDE每25ns读出1个像素)
- ➢ 台积电180nm BCD工艺:
- • 四阱、高压70V
- • 第一次流片和测试：像素阵列测试芯片可以探测到^{90}Sr信号
- • 第二次流片：优化了diode结构，设计了MIC6_V2，已流片（2023年12月）
- ➢ 华虹宏力130nm工艺:
- • 三阱（合作开发了第四阱Deep PW ）、全高阻衬底
- • 第一次流片：完成像素阵列测试芯片的设计，已流片（2023年10月）
- • 第二次流片：已设计MIC6_V3（全功能MAPS芯片），已流片（2024年3月）

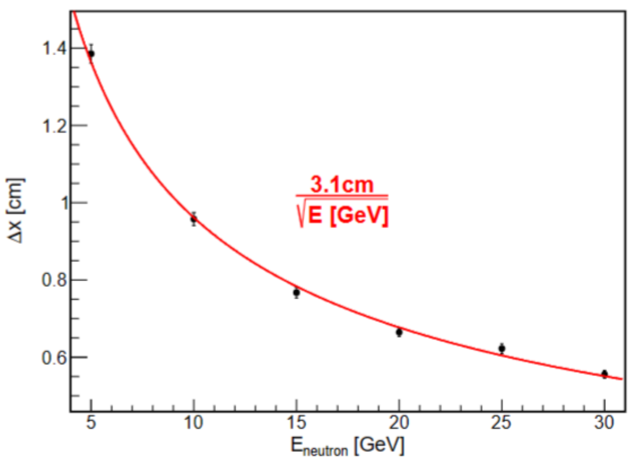
Zero Degree Calorimeter (ZDC)











ZDC is responsible for detecting forward-going neutrons and photons, essential for many physics topics, including meson structure, diffractive measurements, etc.

ZDC coverage: 0-15 mrad