



EicC Detector

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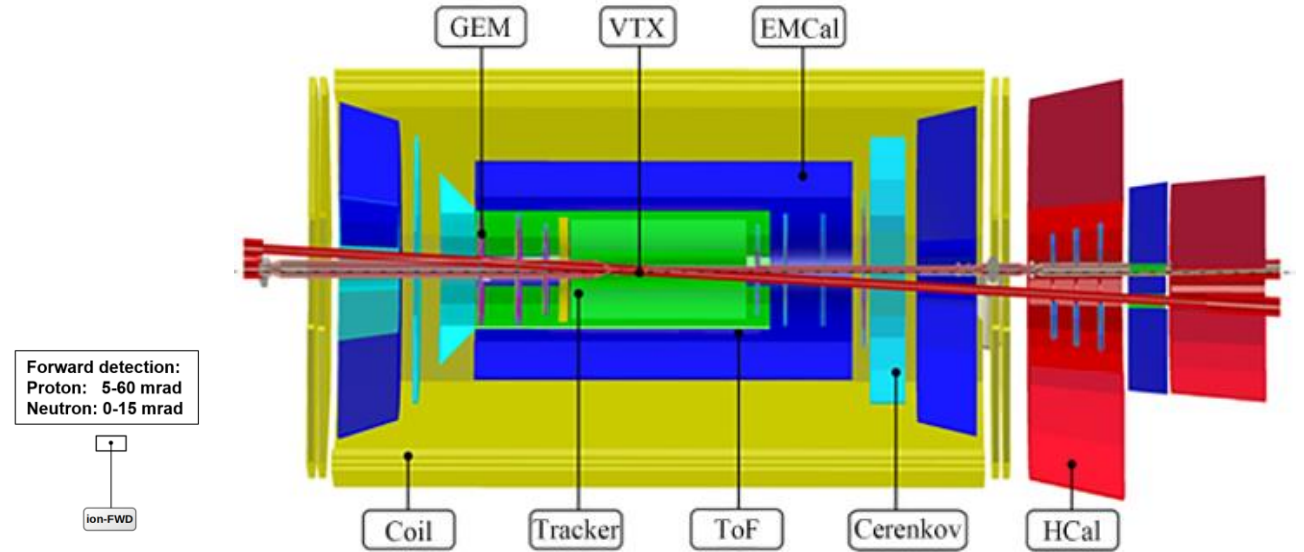
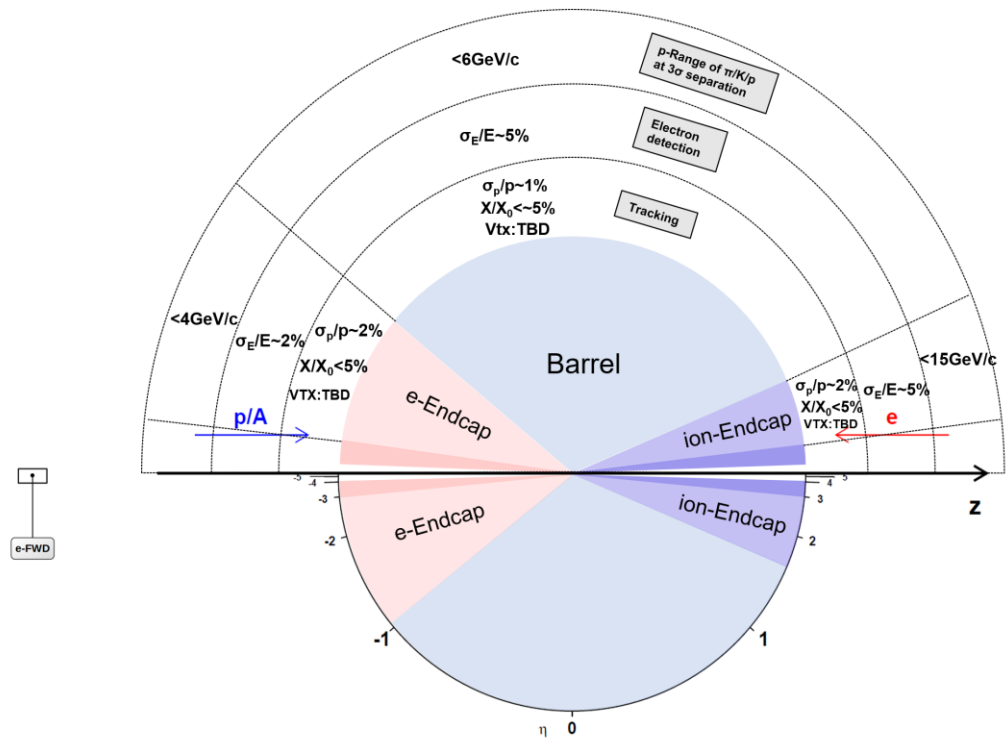
EicC 8th CDR Workshop

2024.08.18-20 Shandong University

Outline

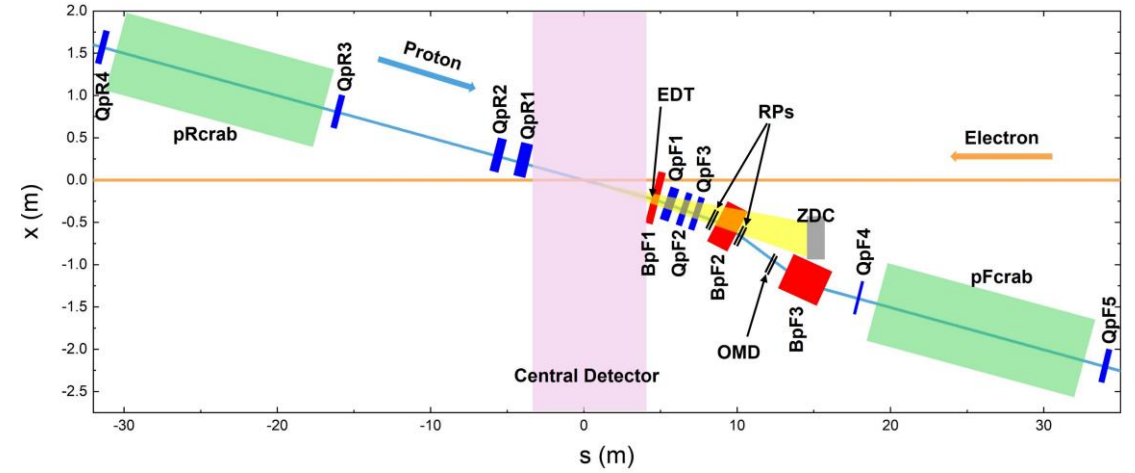
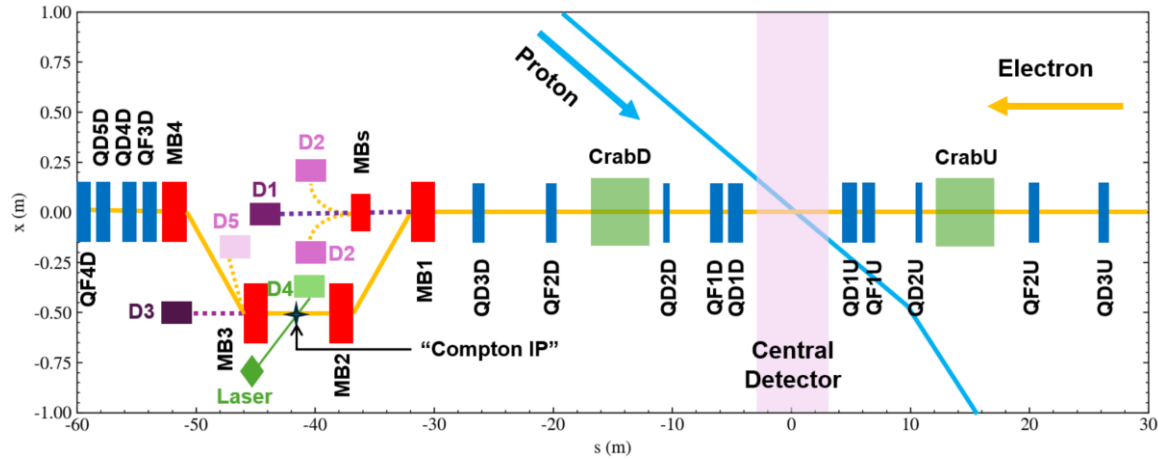
- **Central detector: Tracking, PID, ECal**
- **Forward detector: EDT, RPs, ZDC, OMD**
- **Beam polarimetry and luminosity measurement**
- **Readout and DAQ**
- **Summary**

Preliminary detector design at WP



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

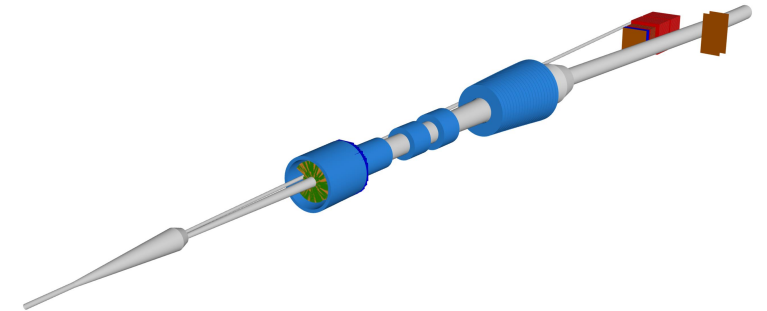
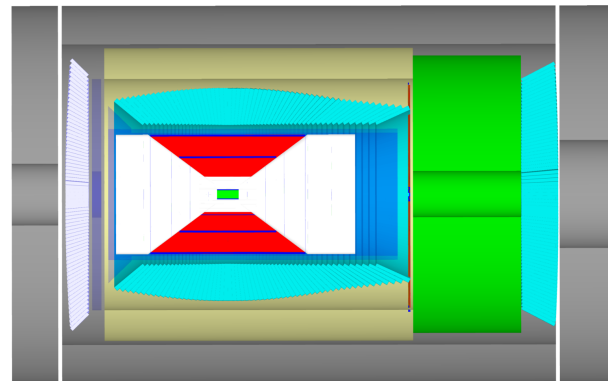
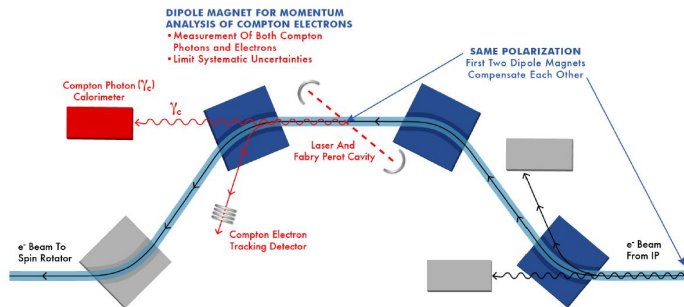
EicC IR layout and detector at CDR



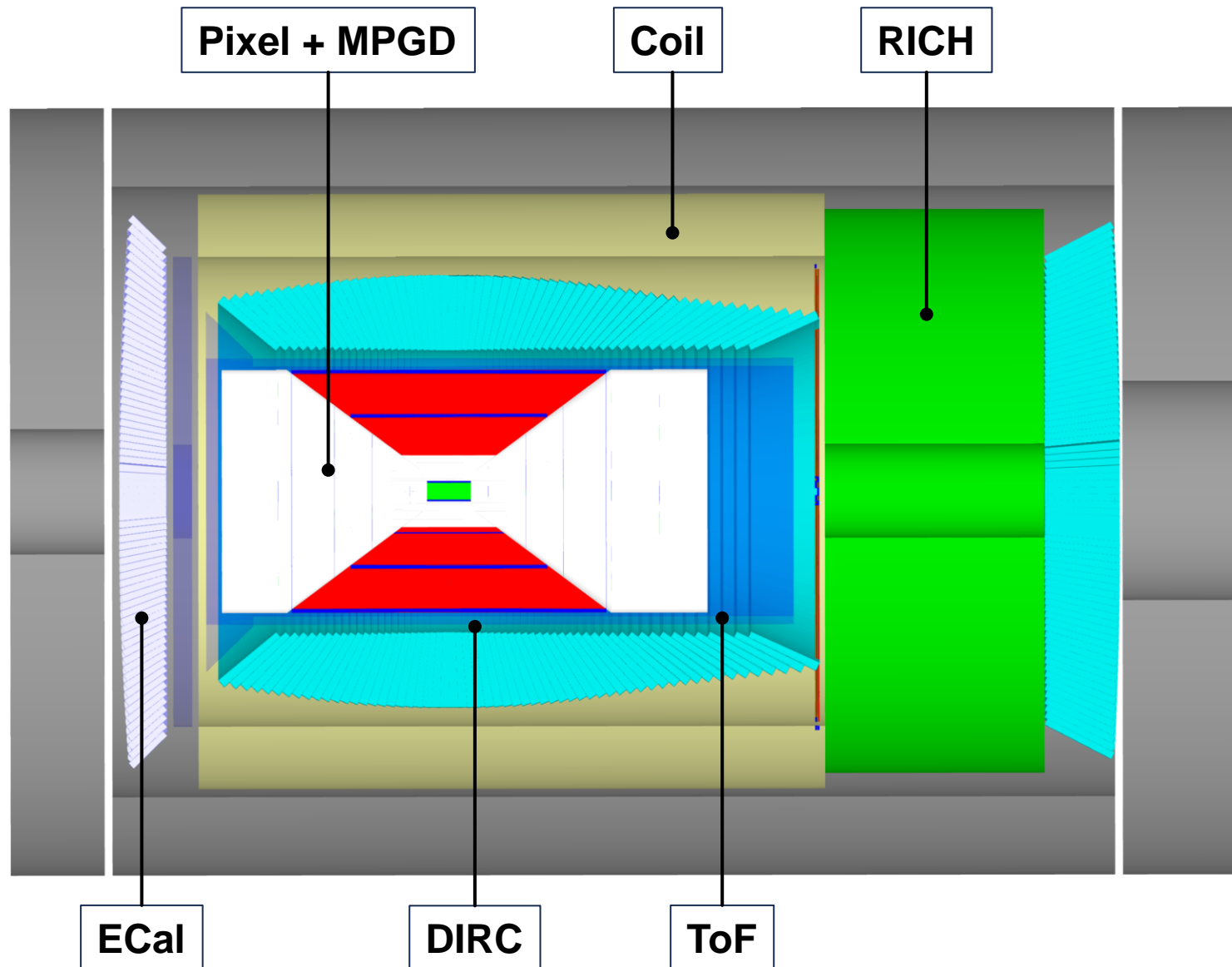
e far-forward detectors

Central detector

Ion far-forward detectors

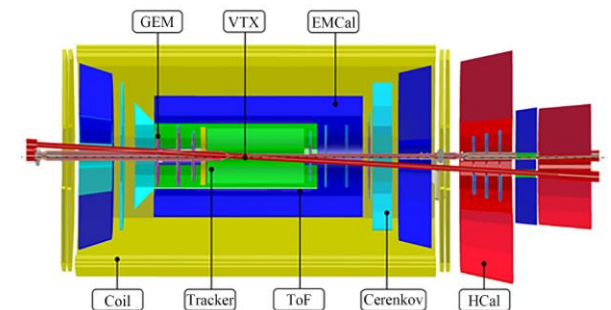


Central Detector

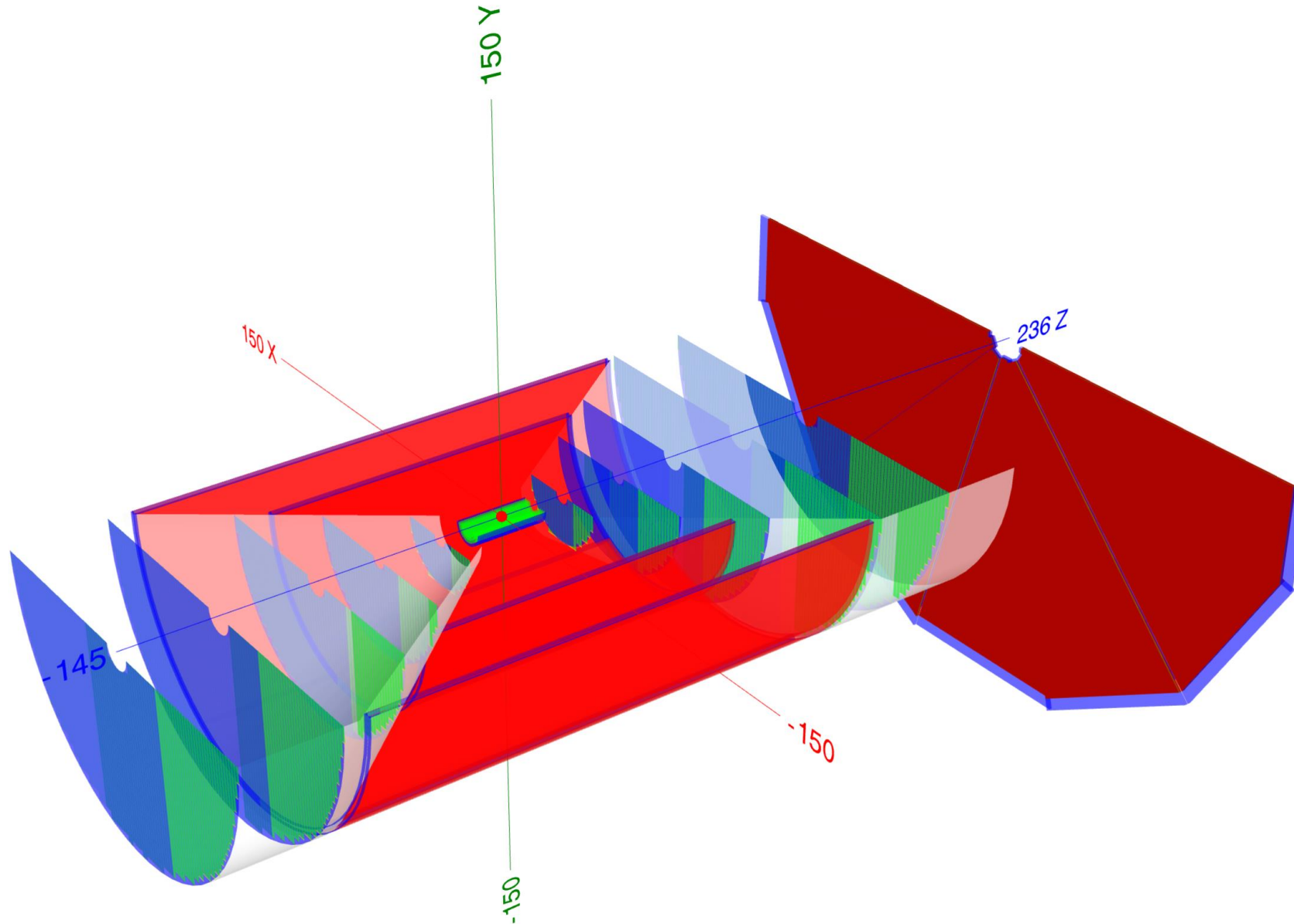


- Tracking
- PID
- ECal

Compare to the design (WP)

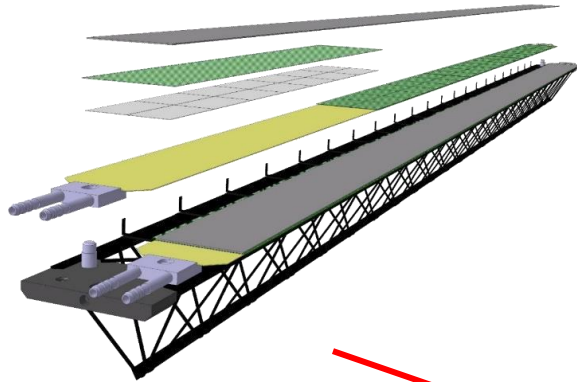


Tracking system

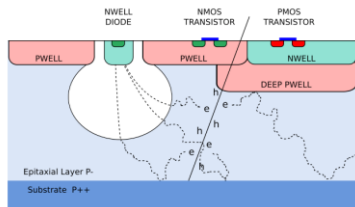


Technology choices

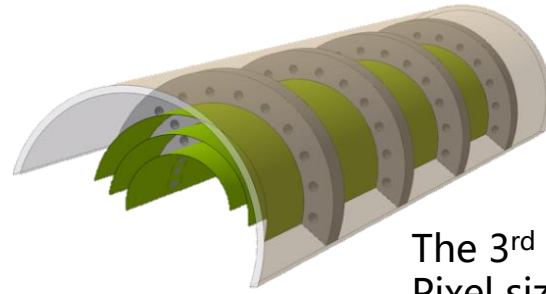
Tracker



The 1st generation MAPS
Pixel size : $\sim 30 \times 30 \mu\text{m}$
Material budget: 0.85%



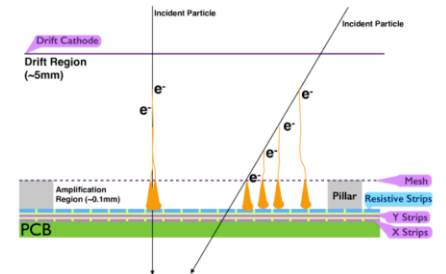
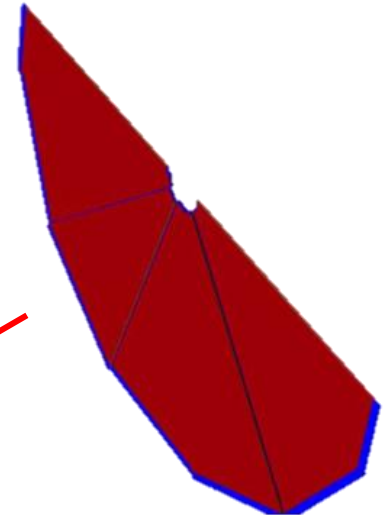
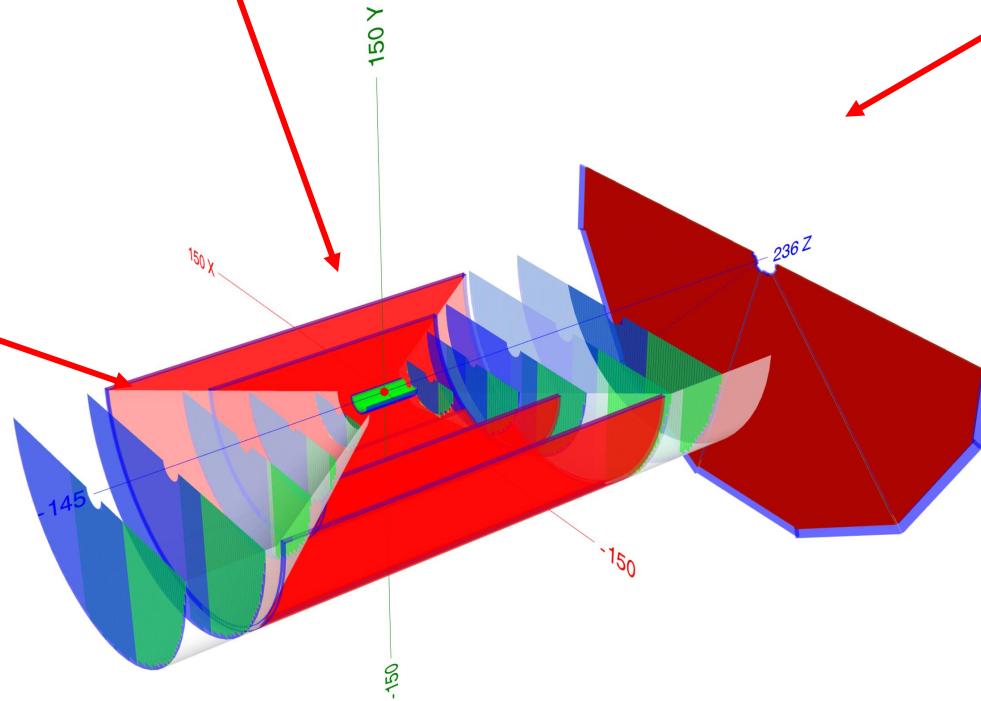
MIC6



Vertex Detector

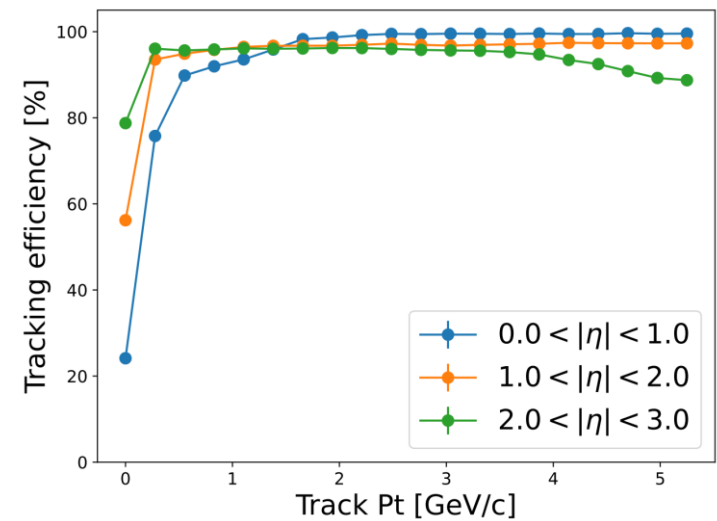
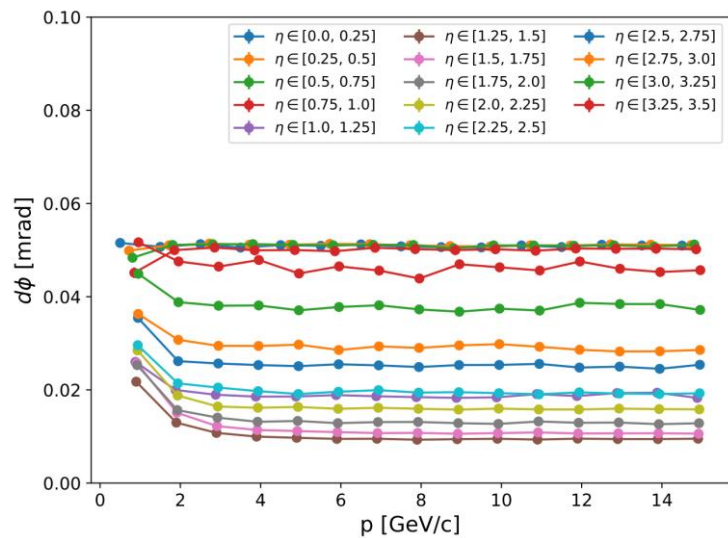
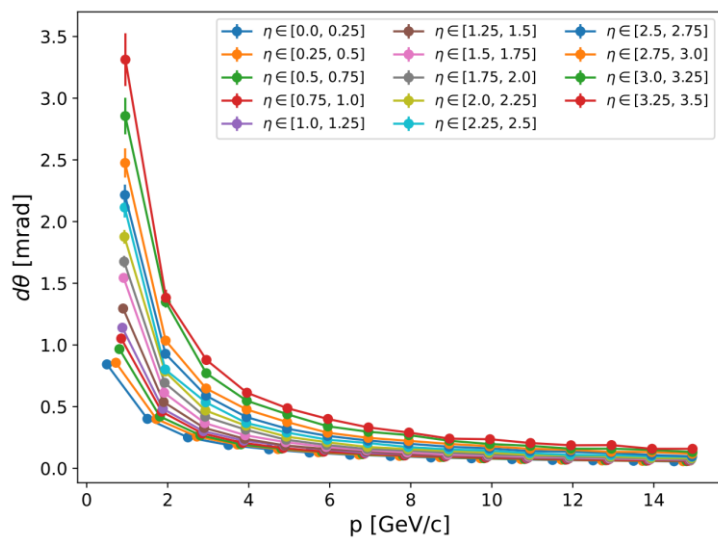
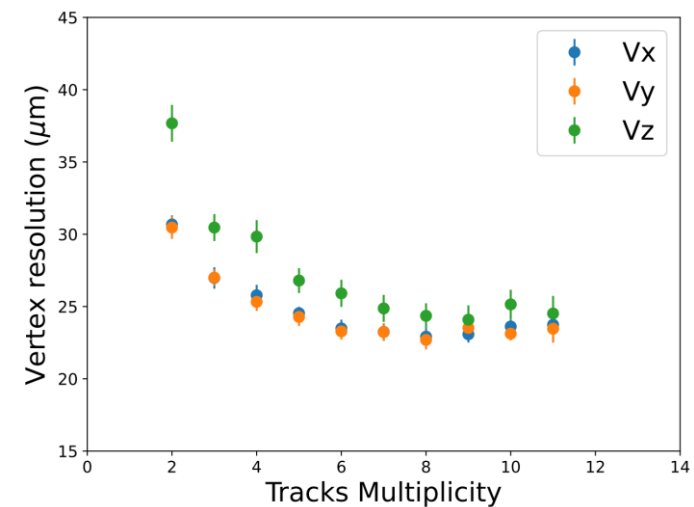
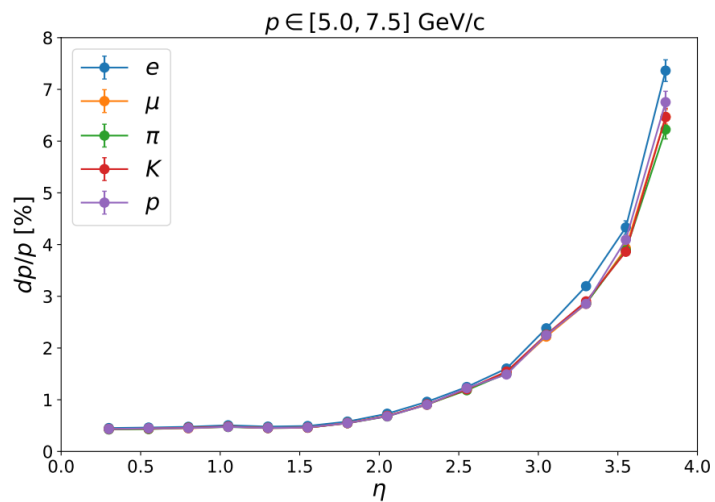
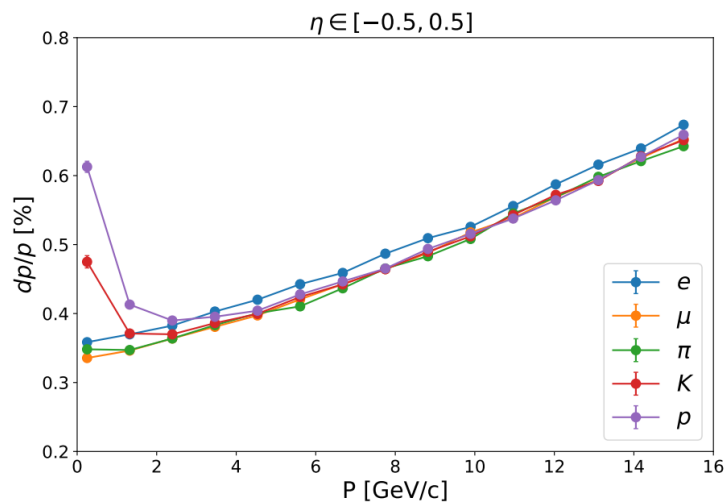
The 3rd generation MAPS
Pixel size: $\sim 20 \times 20 \mu\text{m}$
Material budget: 0.05%

MIC7

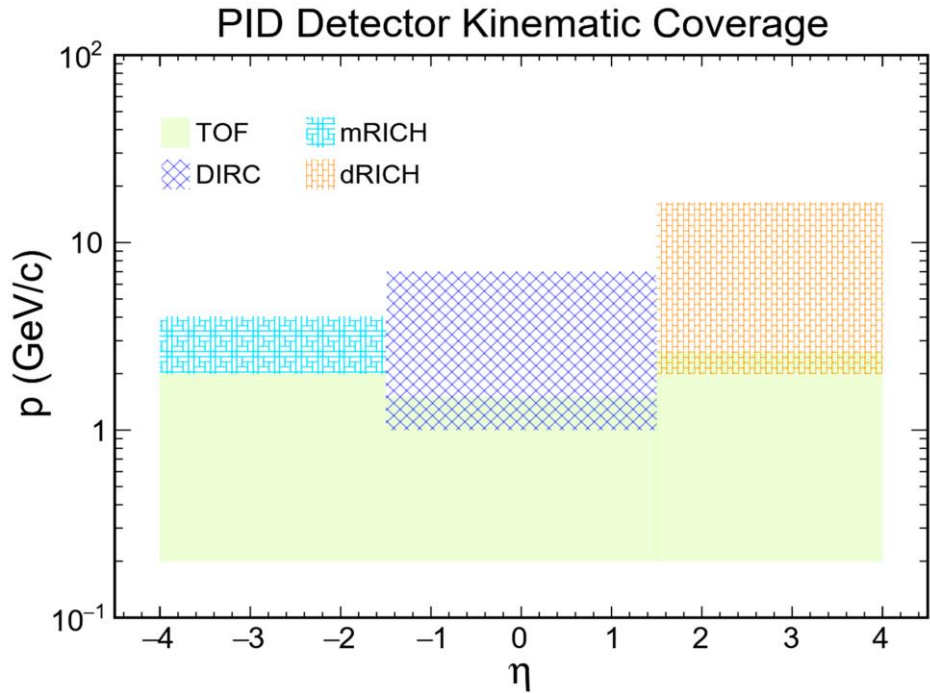


MPGD
Pitch size: $50 \times 250 \mu\text{m}$
Or $\sim 150 \times 150 \mu\text{m}$
Material budget: 1%

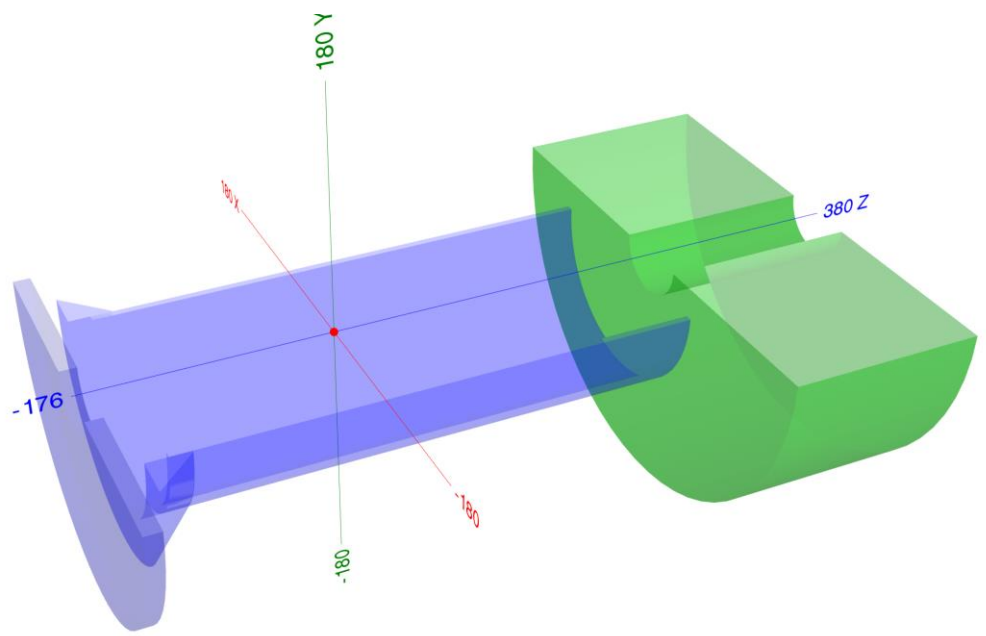
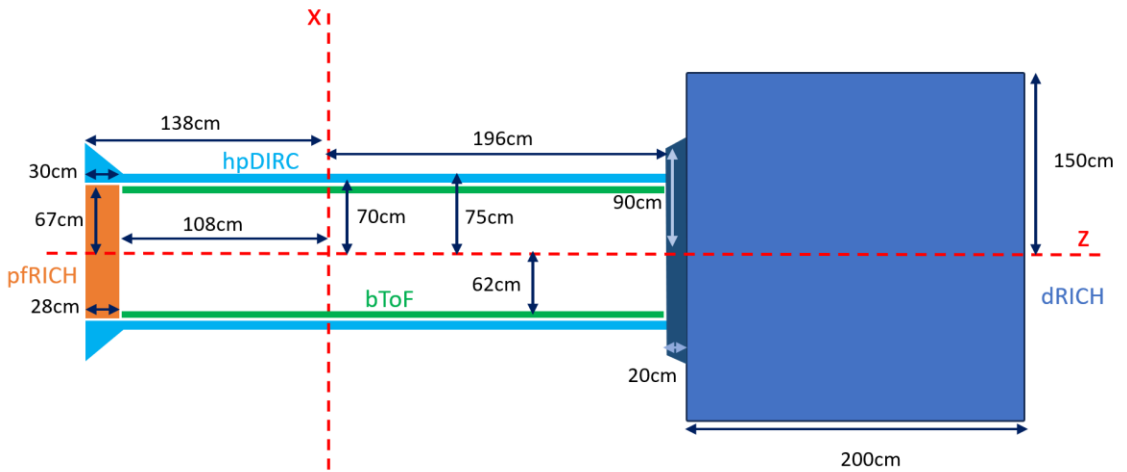
Performance



PID detectors

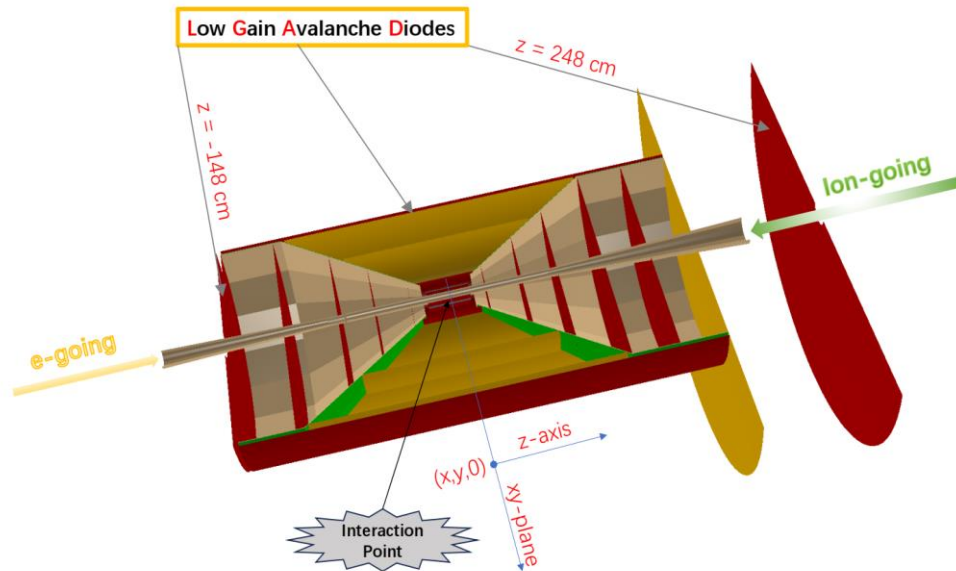


- TOF based (low p)
 - MRPC
 - LGAD
- Cherenkov based (high p)
 - DIRC
 - RICH

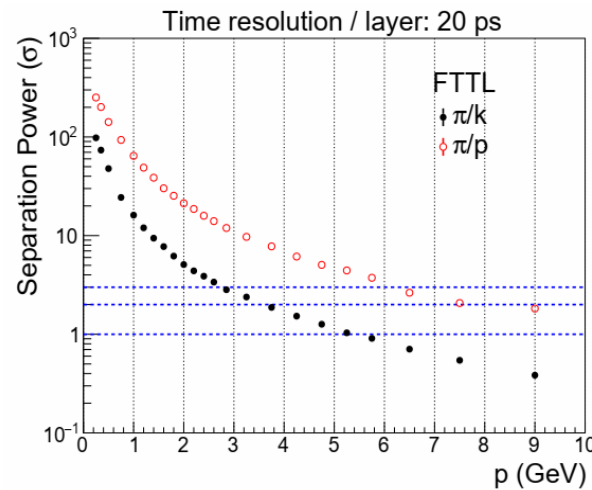
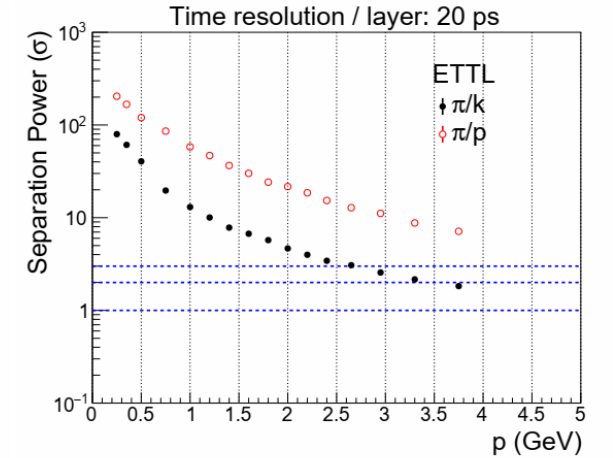
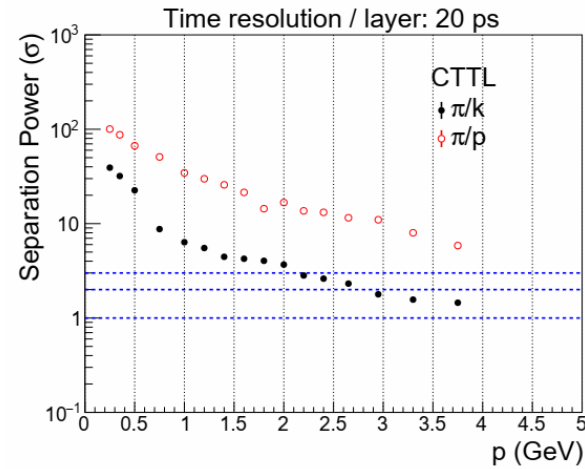


LGAD

Low Gain Avalanche Diodes (LGAD)

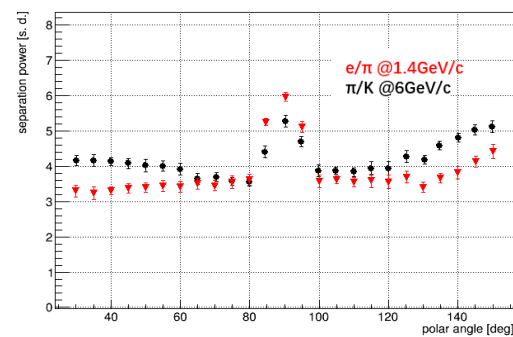
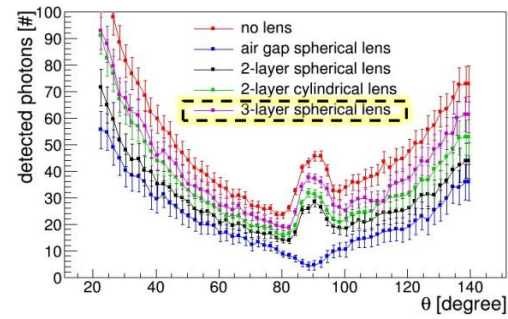
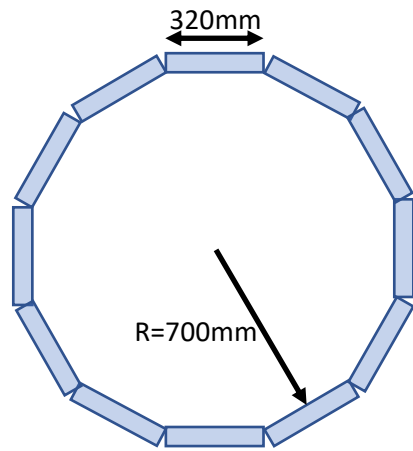
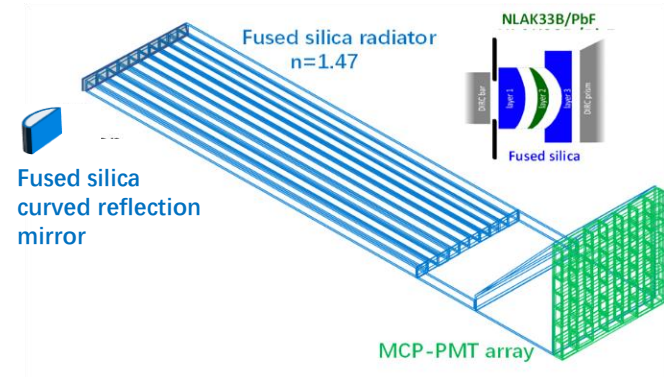
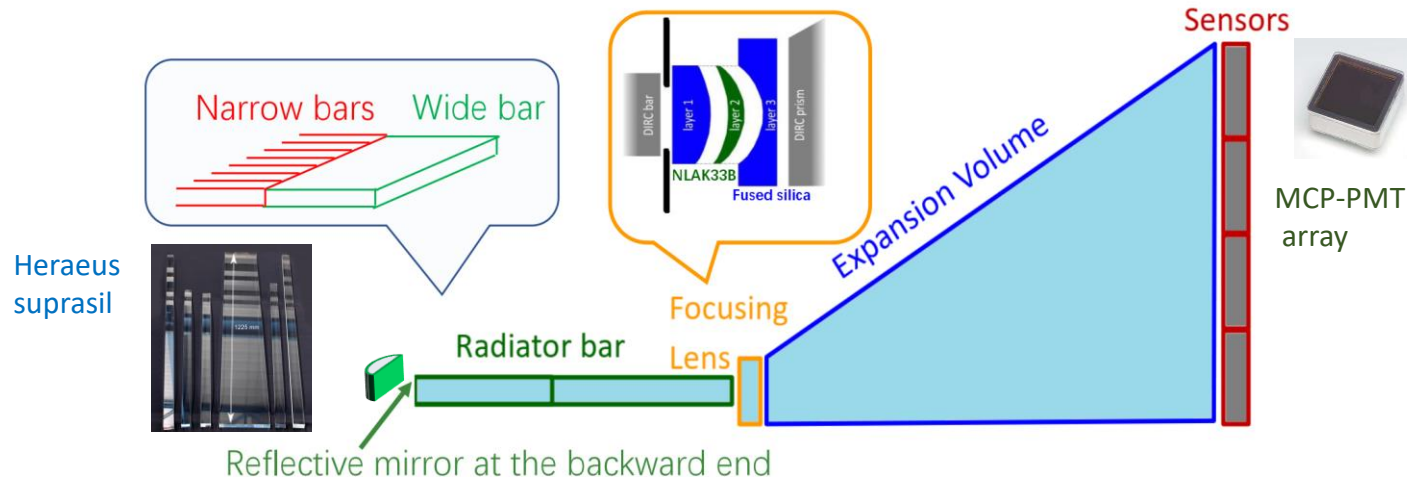


- Current configuration fits to the tracker system well
- Timing resolution: 20-30 ps / layer
- Spatial resolution: $\sim 30 \mu\text{m}$



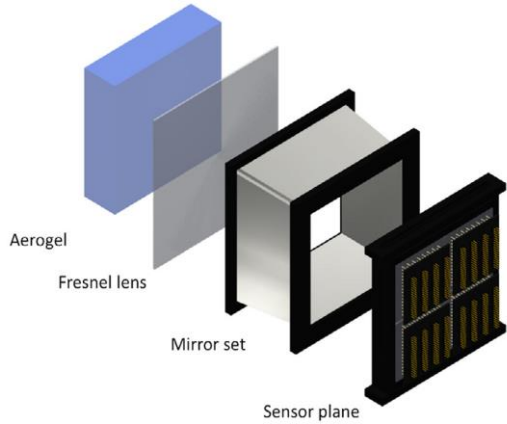
The detector geometry was reconfigured.
 π/K separation of 2-3 GeV/c achieved.

DIRC

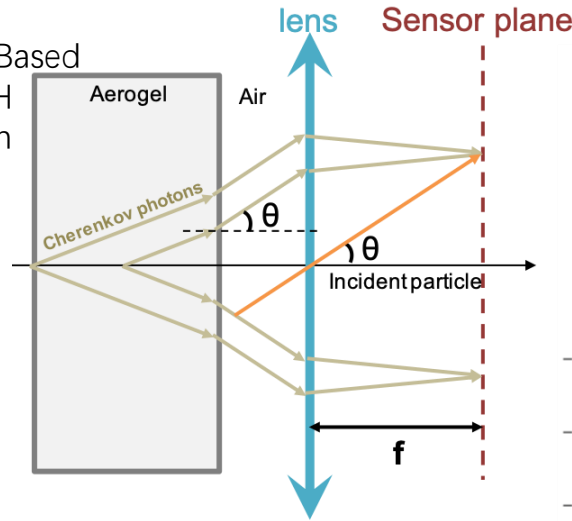


mRICH

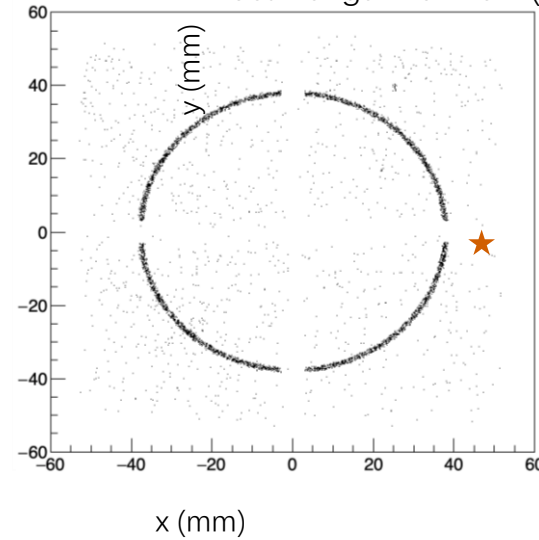
Smaller, but thinner ring improves PID performance and reduces length



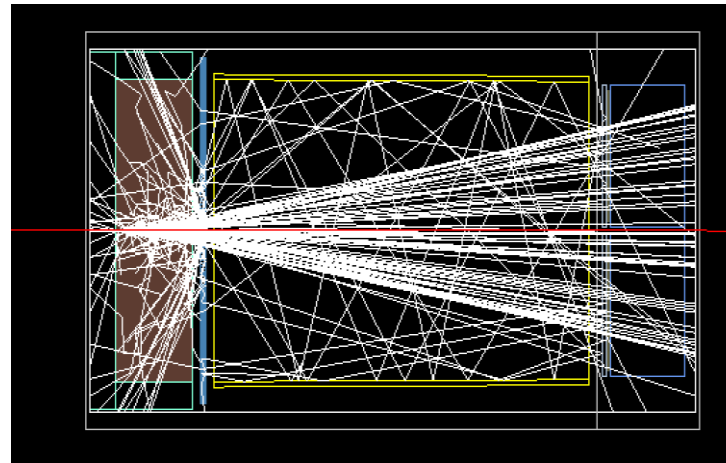
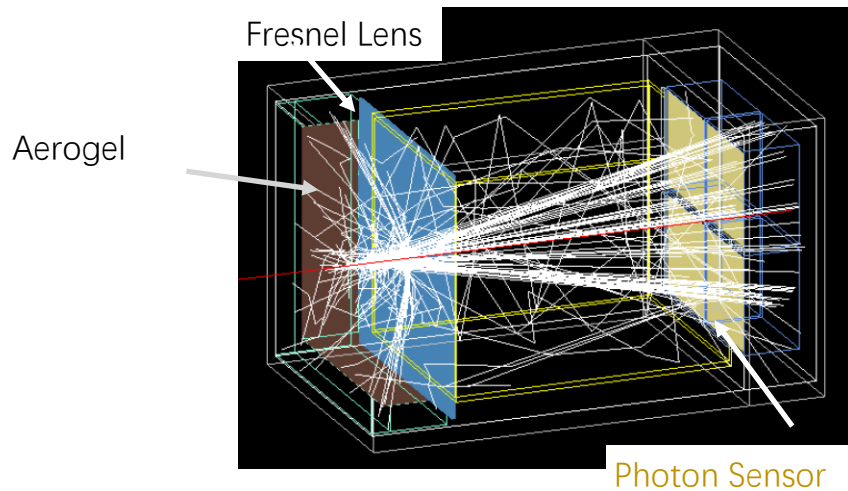
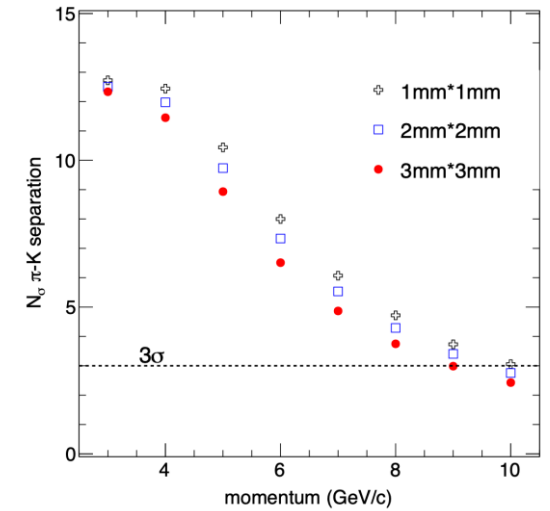
Lens-Based
mRICH
Design



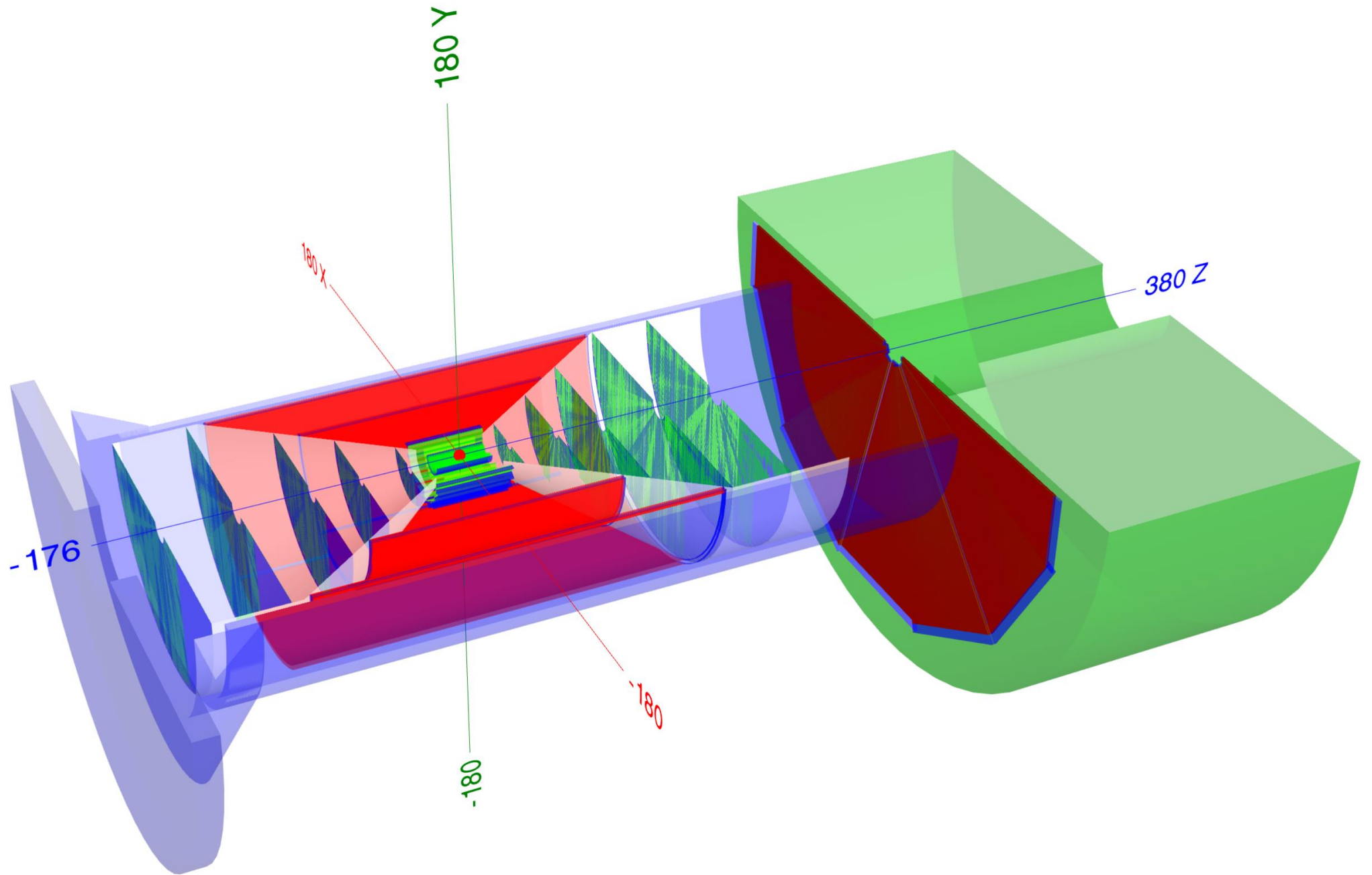
focal length 15.24cm (6")



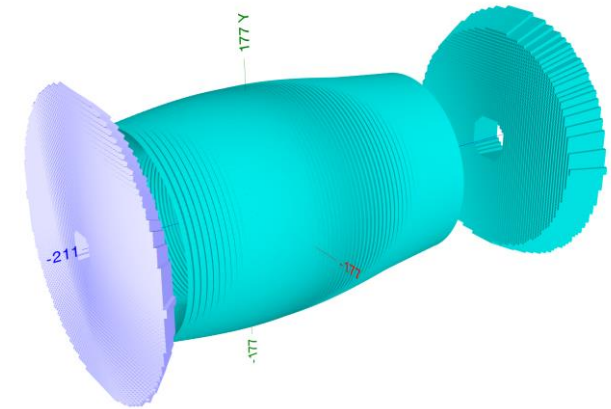
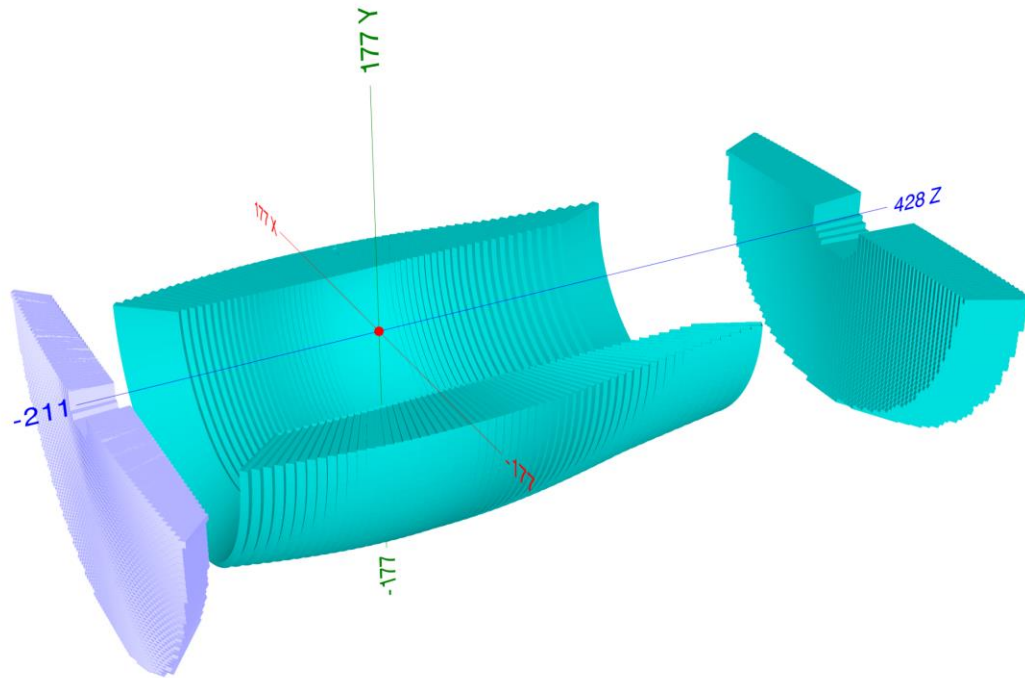
f: 7.62cm ~ 15.24cm (3"~6")



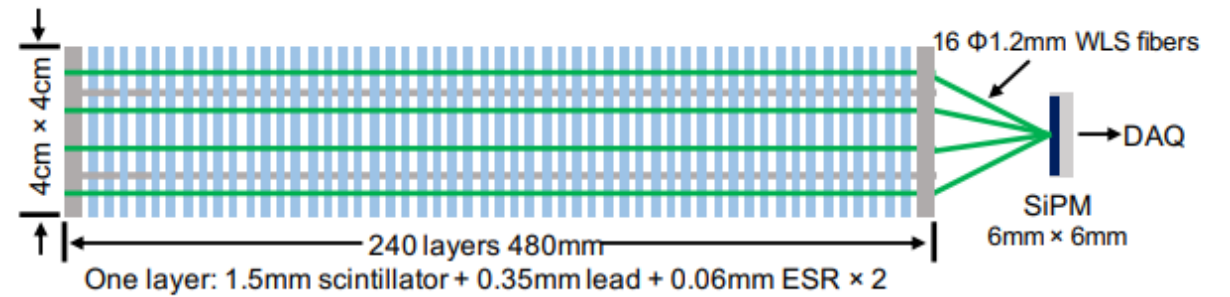
- pi/K separation up to 9 GeV/c
- e/pi separation up to 2 GeV/c
- Separation power decrease with increasing polar angle



ECal design

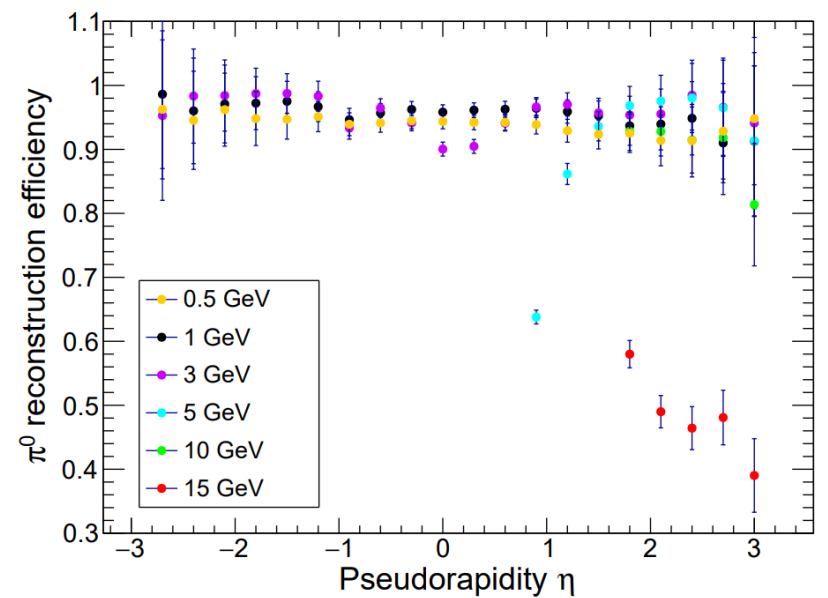
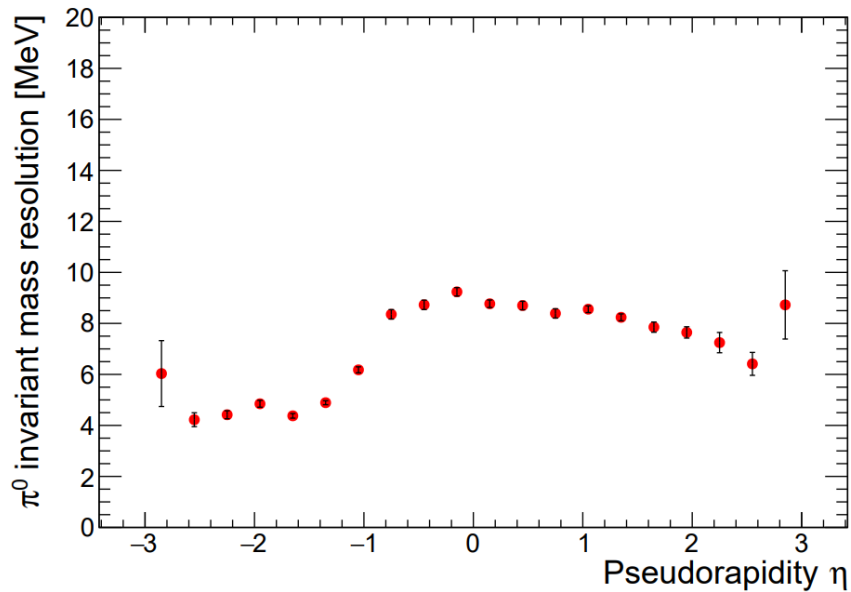
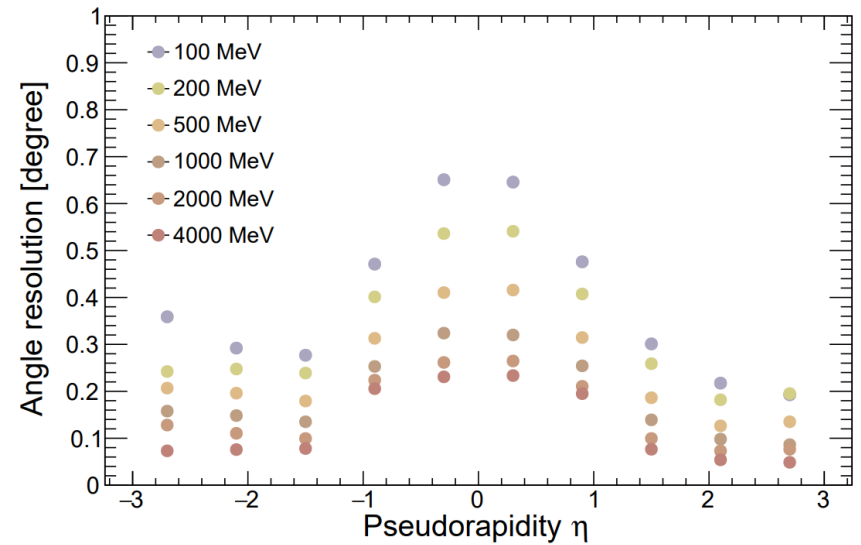
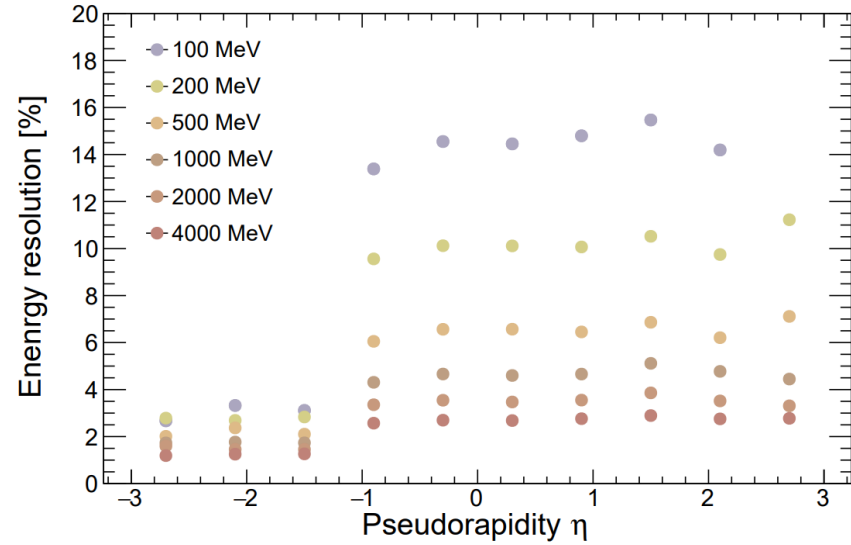


CsI Crystal



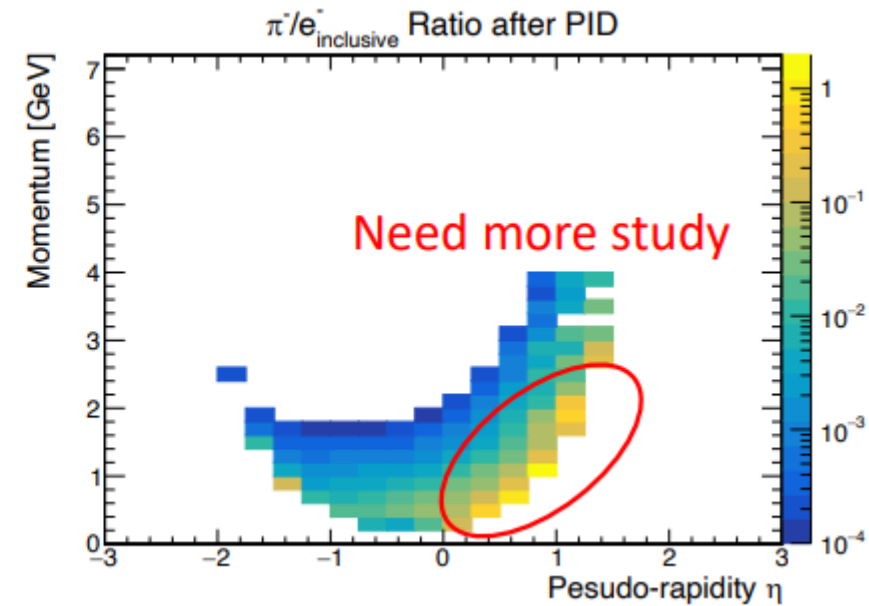
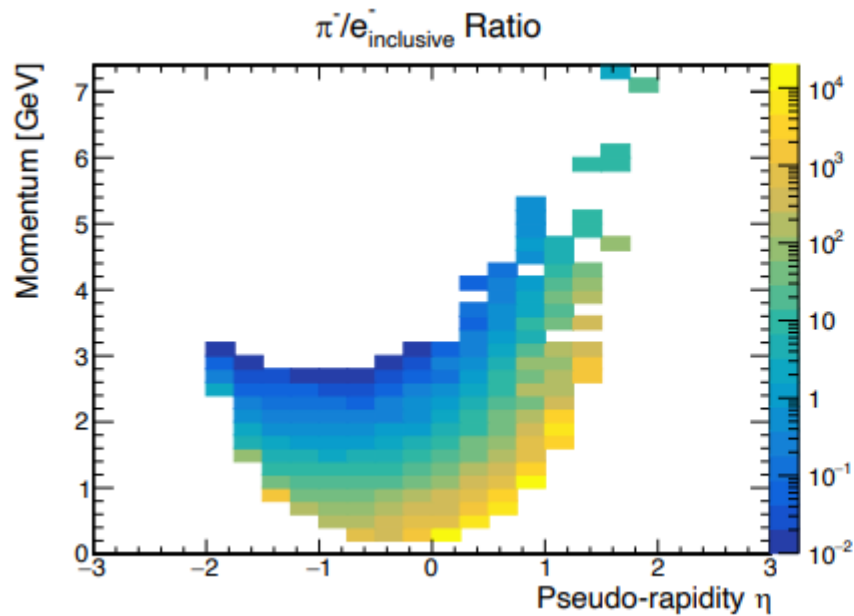
EicC Shashlik ECal

Performance

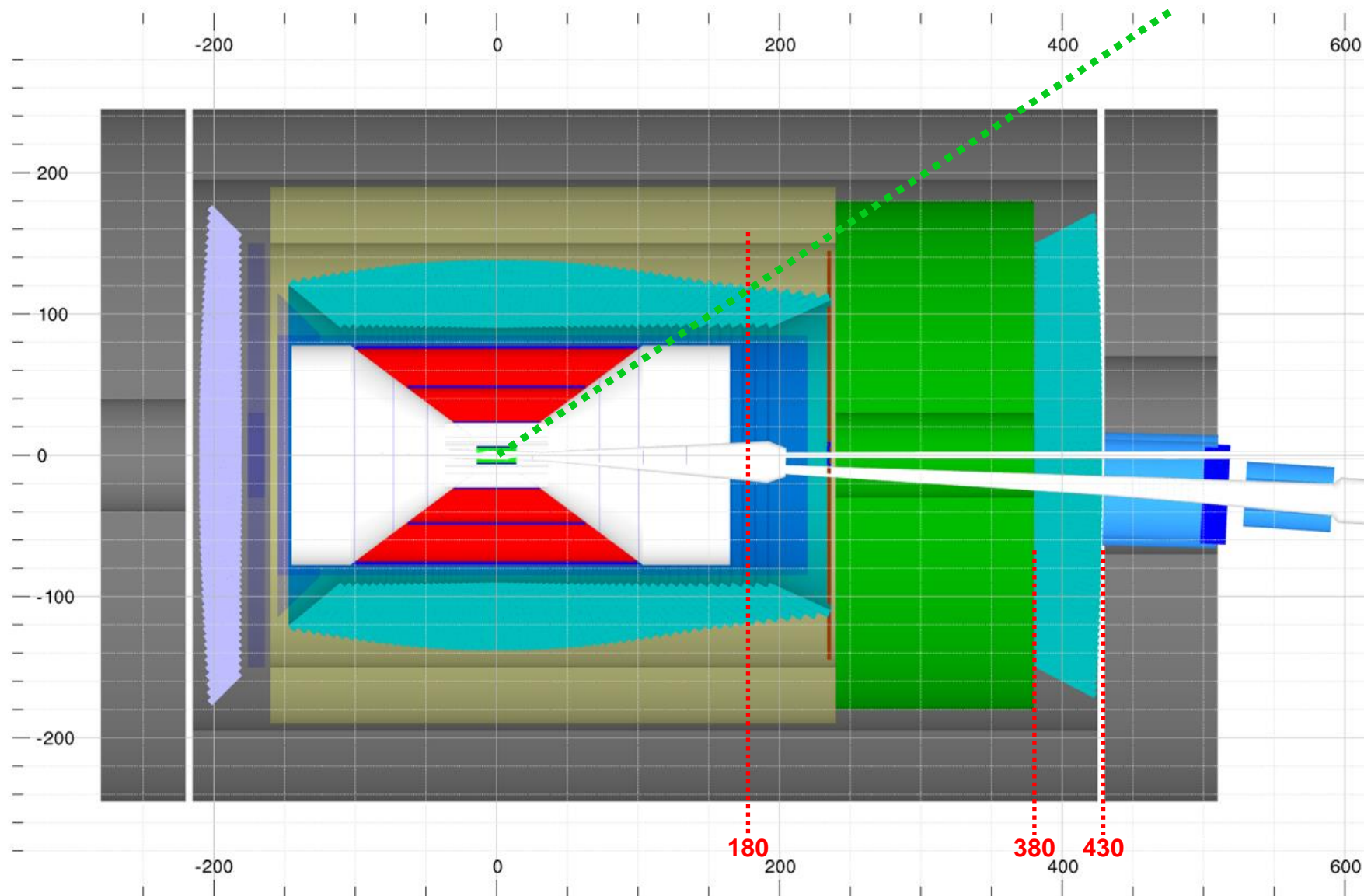


e/ π separation

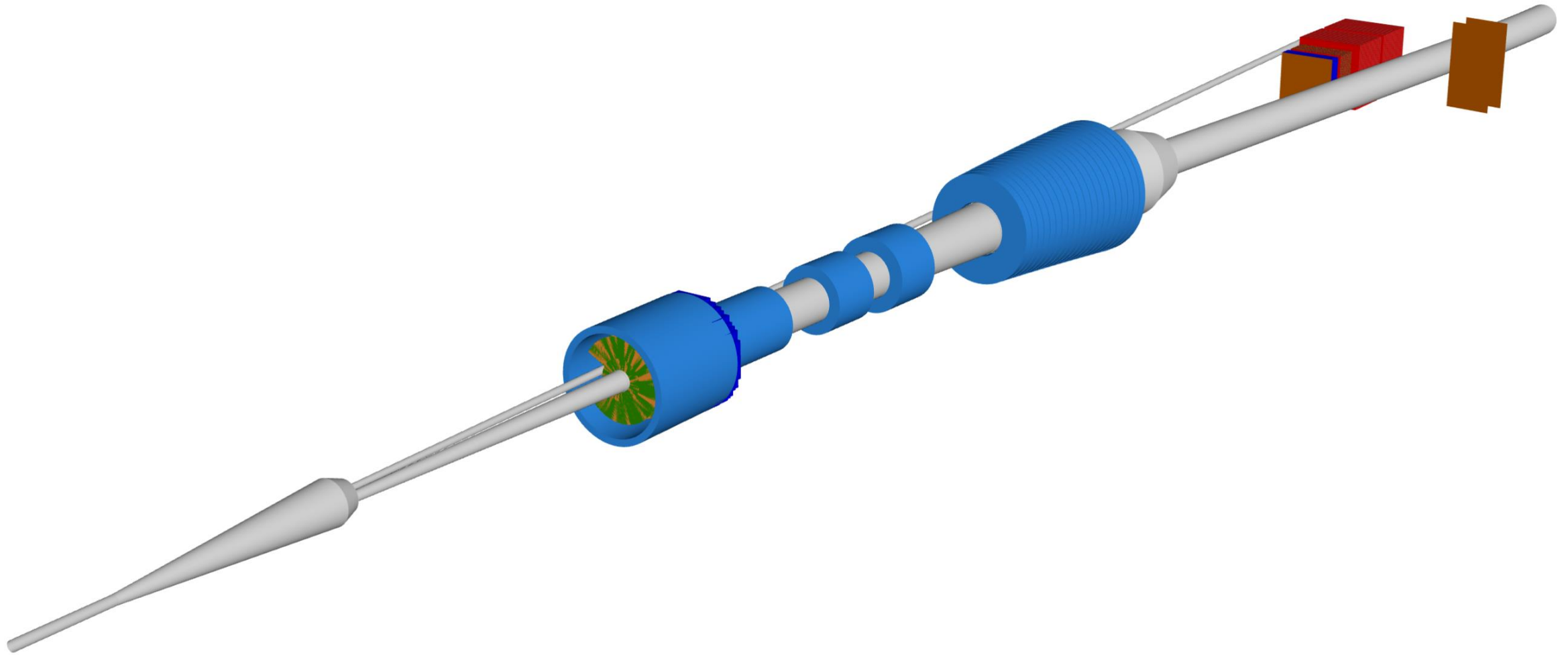
Momentum [GeV/c]	$ \eta $			π^- suppression ratio
[0, 0.1]	Tracking efficiency low, discard			-
[0.1, 0.2]	[0, 1]	[1, 2]	[2, 3]	-
	Long flight time + tracking efficiency low, discard		EMC no hit+ tracking efficiency low, discard	
[0.2, 0.5]	Excellent e/ π separation from TOF + below RICH π Cherenkov threshold			> 10⁵:1
[0.5, Cherenkov upper limit]	RICH / DIRC + ECal + TOF			10⁴:1
> Cherenkov upper limit	ECal			10³:1



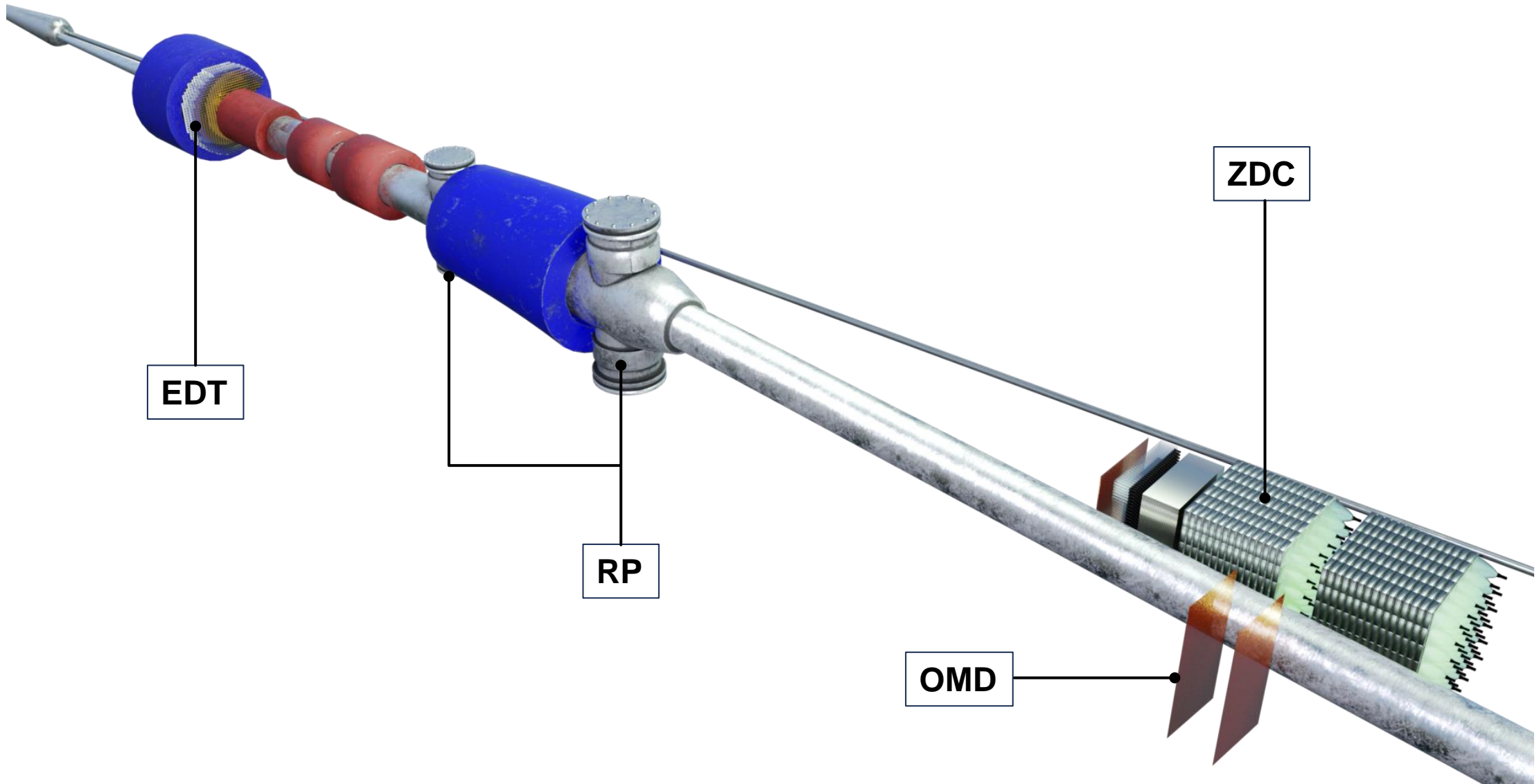
Central Detector



Ion Far-forward detectors

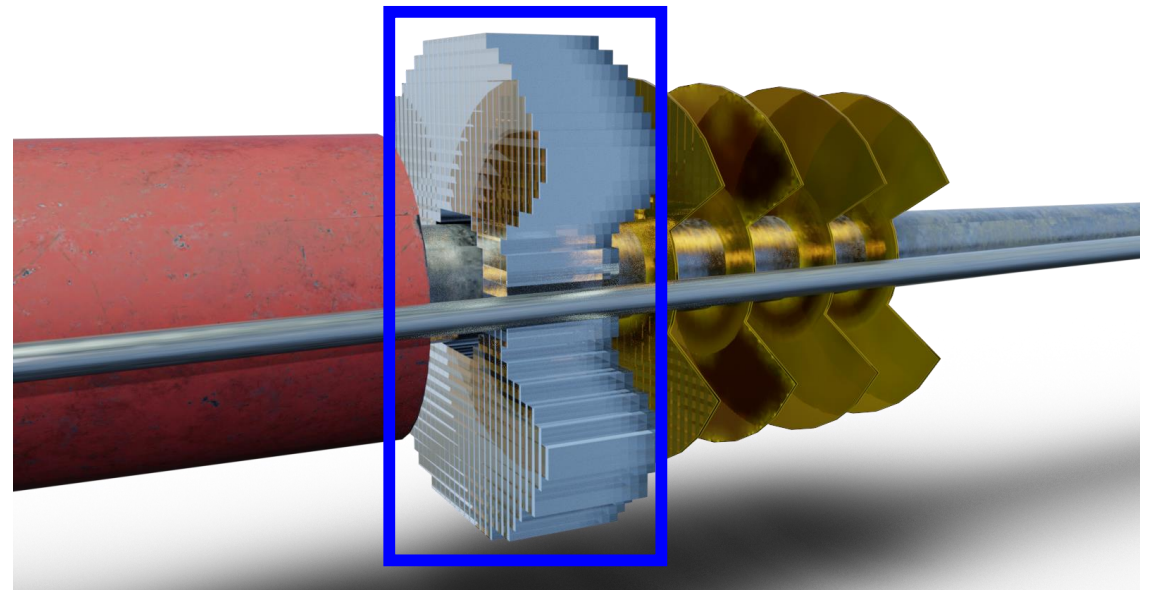
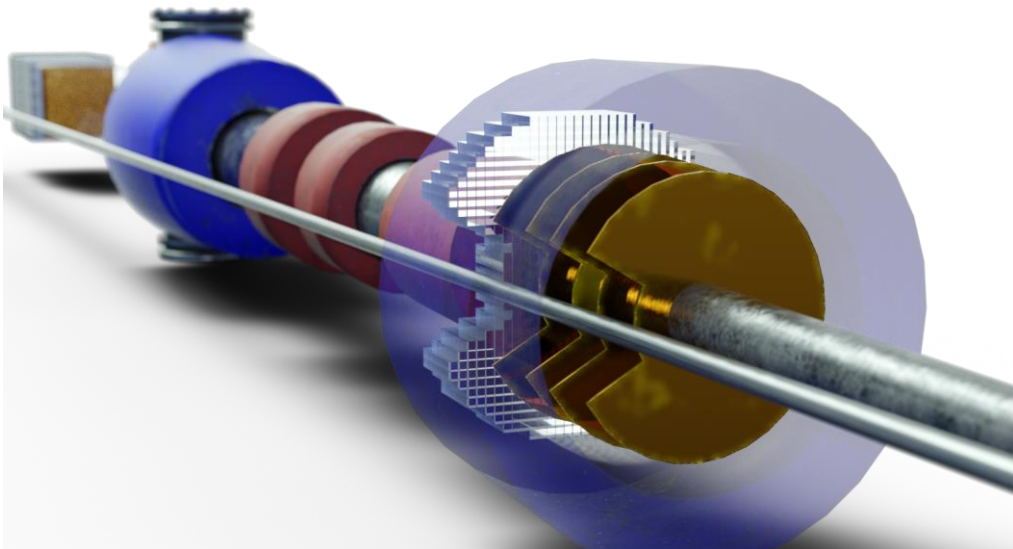


Ion Far-forward detectors



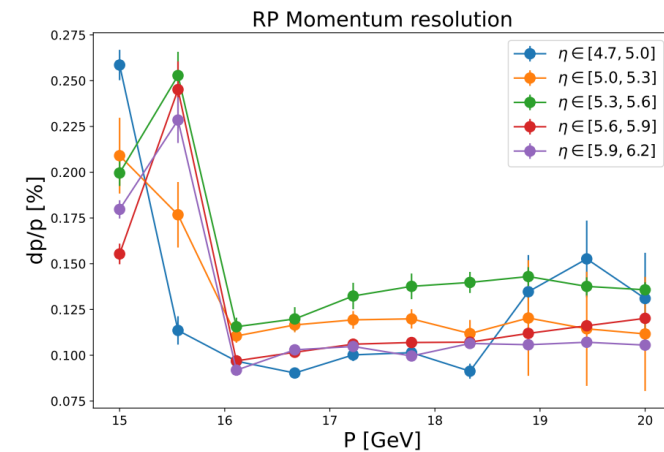
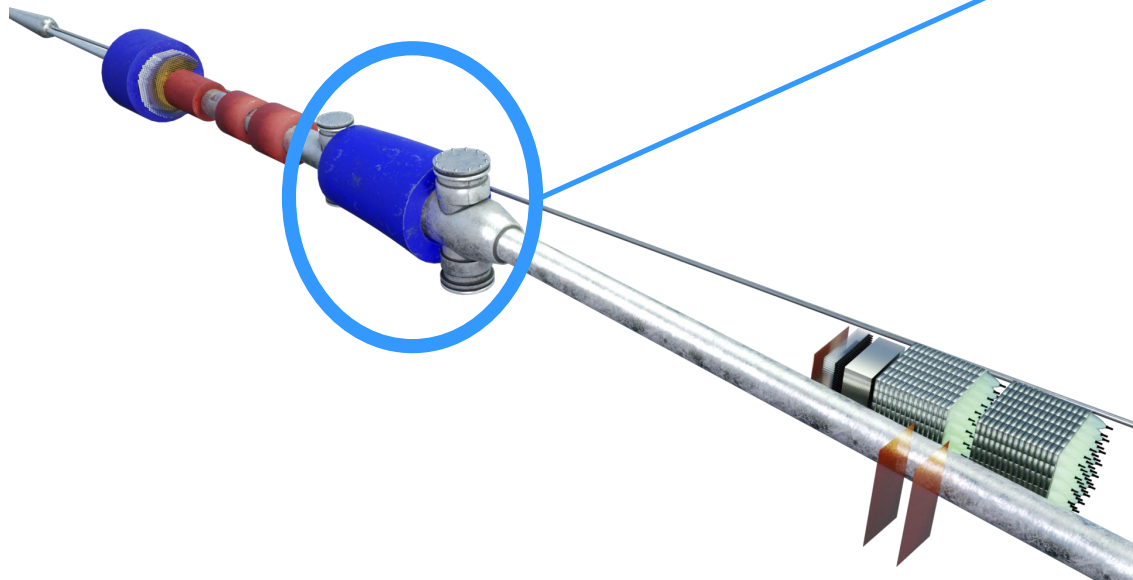
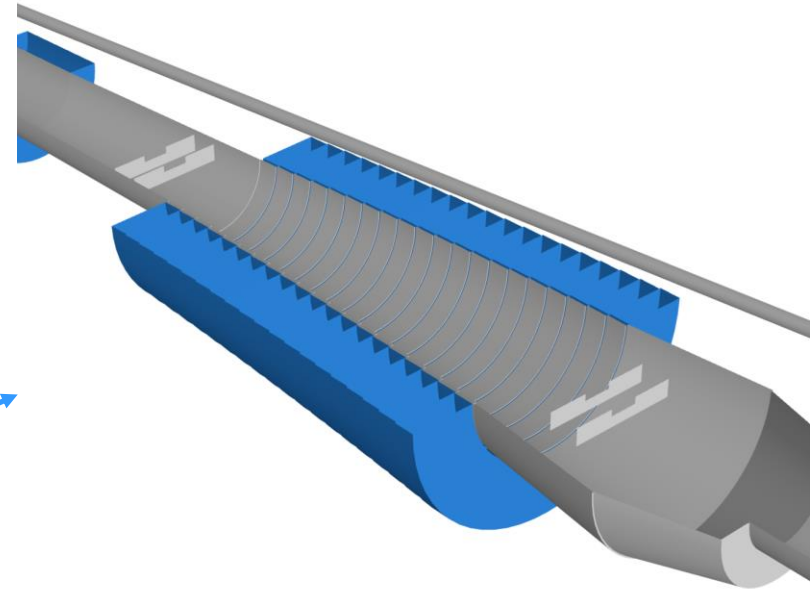
Endcap Dipole Trackers (EDT)

- Four **silicon trackers (MAPS, AC-LGAD)**
 - Charged particle in $16 \text{ mr} < \theta < 60 \text{ mr}$
 - Full ϕ coverage for $\theta < 35 \text{ mr}$
 - gaps for $\theta > 35 \text{ mr}$ and $-30^\circ < \phi < 30^\circ$ to allow electron beam pass through
 - $\sim 0.5\%$ resolution
- Motivation: many meson decay photons peak in this range
 - Compact EM calorimeter (only $\sim 30\text{cm}$ available space in z due to quad. magnets)
 - Reasonable candidate: **PbWO₄**
 - Acceptance: $20 \text{ mr} < \theta < 60 \text{ mr}$



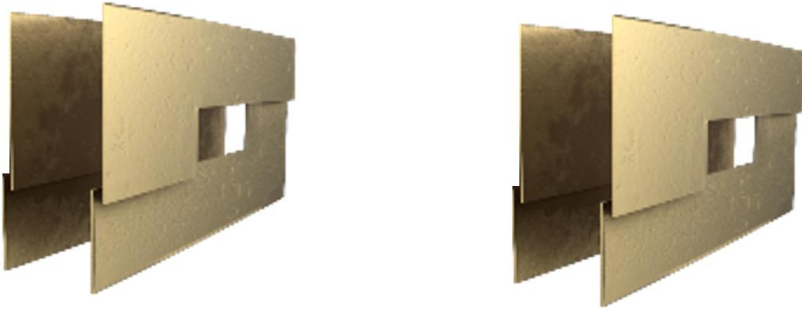
Roman Pot Stations (RPS)

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



Roman Pot Stations (RPS)

High lumi. configuration



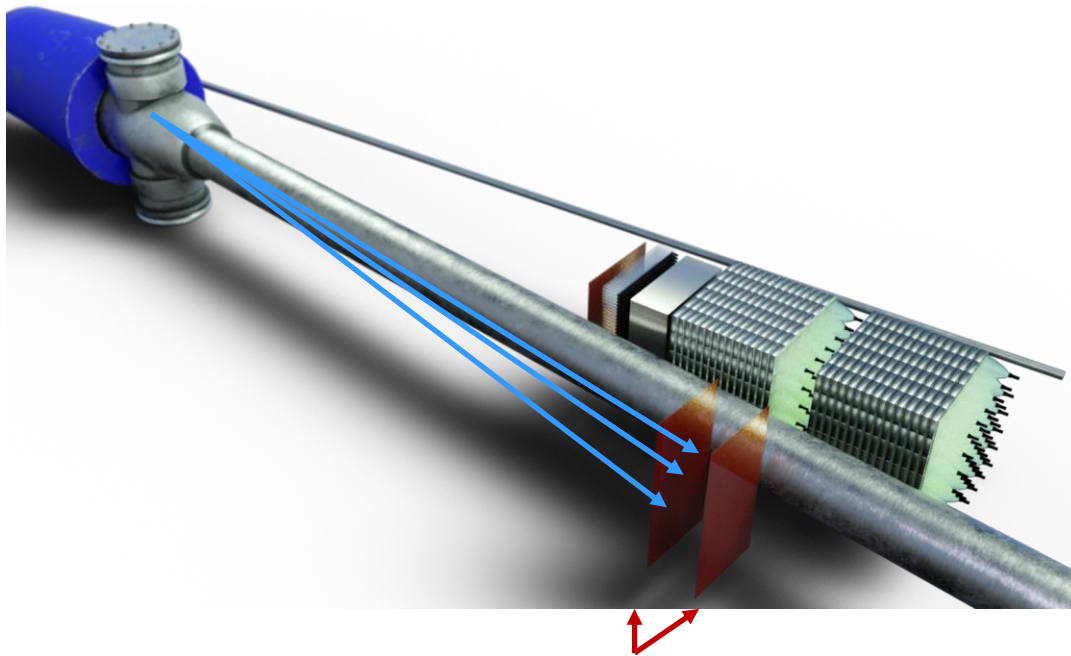
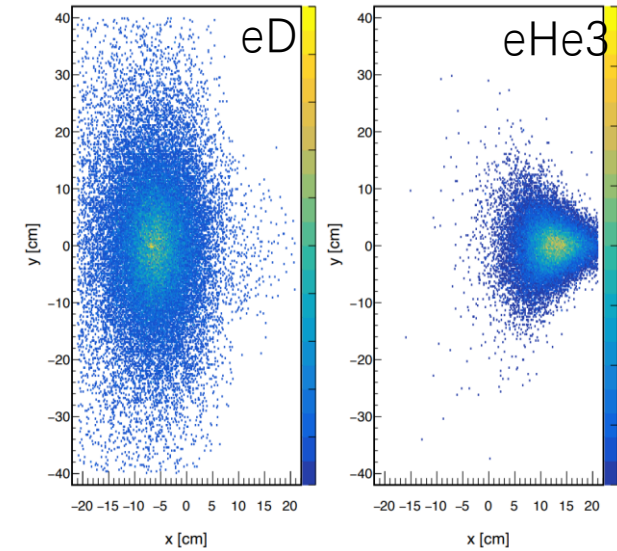
Low lumi. configuration



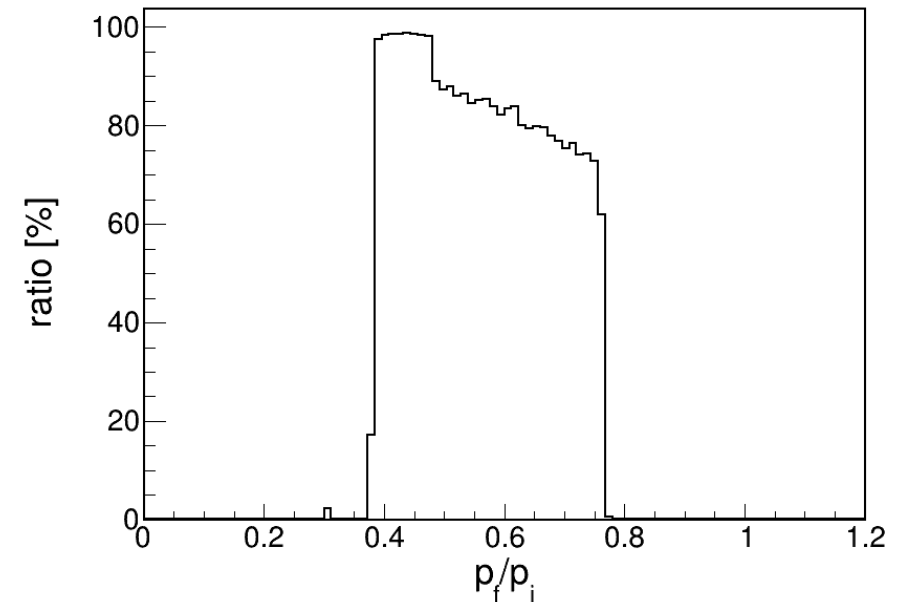
- With EicC high luminosity $\sim 4 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
 - larger beam spot size at RPS
 - central hole needs minimum (18cm / 10cm in x / y)
 - Only cover down to ~ 10 mrad
- With EicC high luminosity $\sim 1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
 - smaller beam spot 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 $0.4 < p_f / p_i < 0.75$



Off-momentum detectors



Zero Degree Calorimeter (ZDC)

WSi detectors:

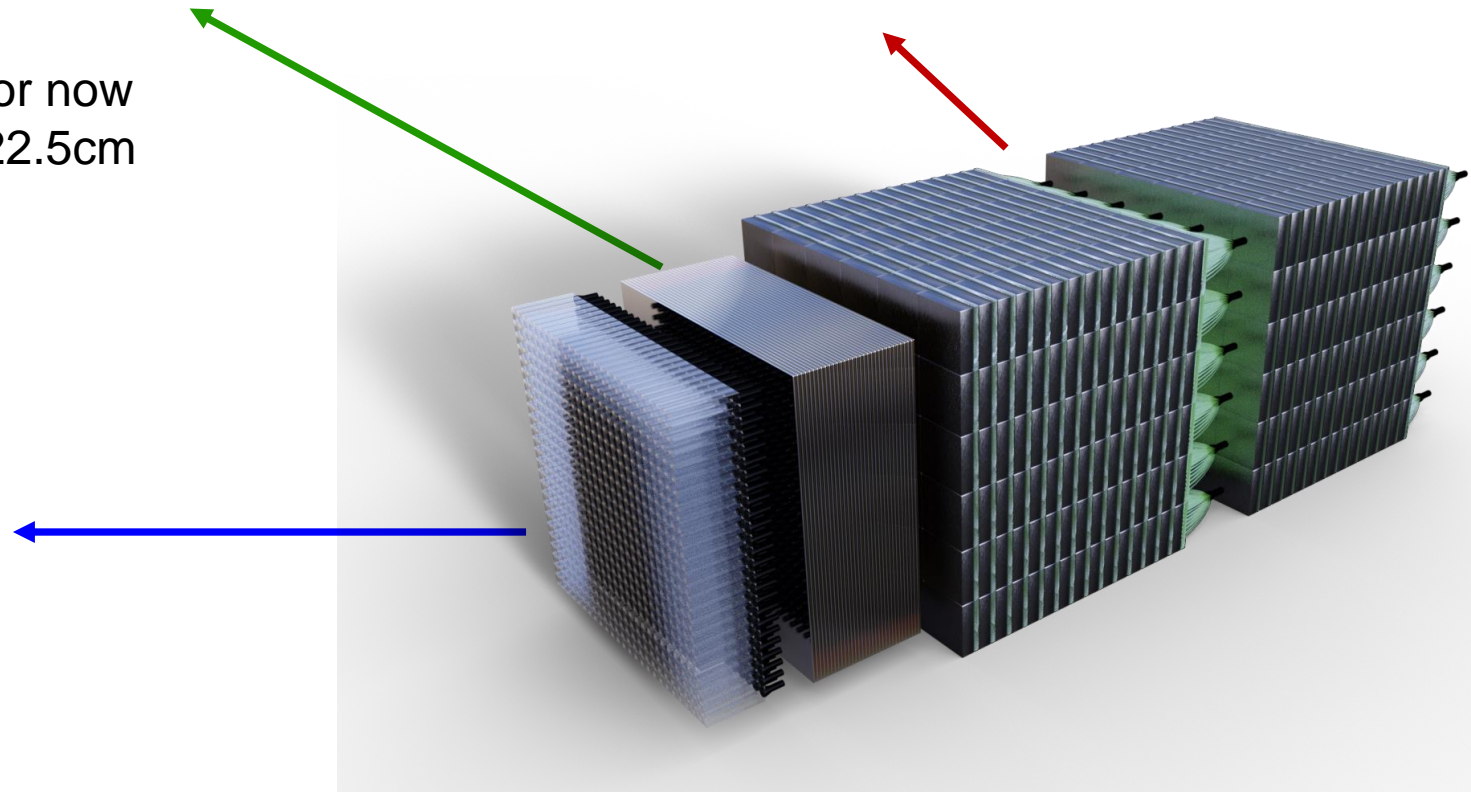
- **Imaging calo., pos recon., PID**
- each layer 3.5mm W + 320um Si
- in total 42 layers
- Si layer readout 1cm x 1cm for now
- in total 50.6 cm x 50.6 cm x 22.5cm

2 PbSci detectors:

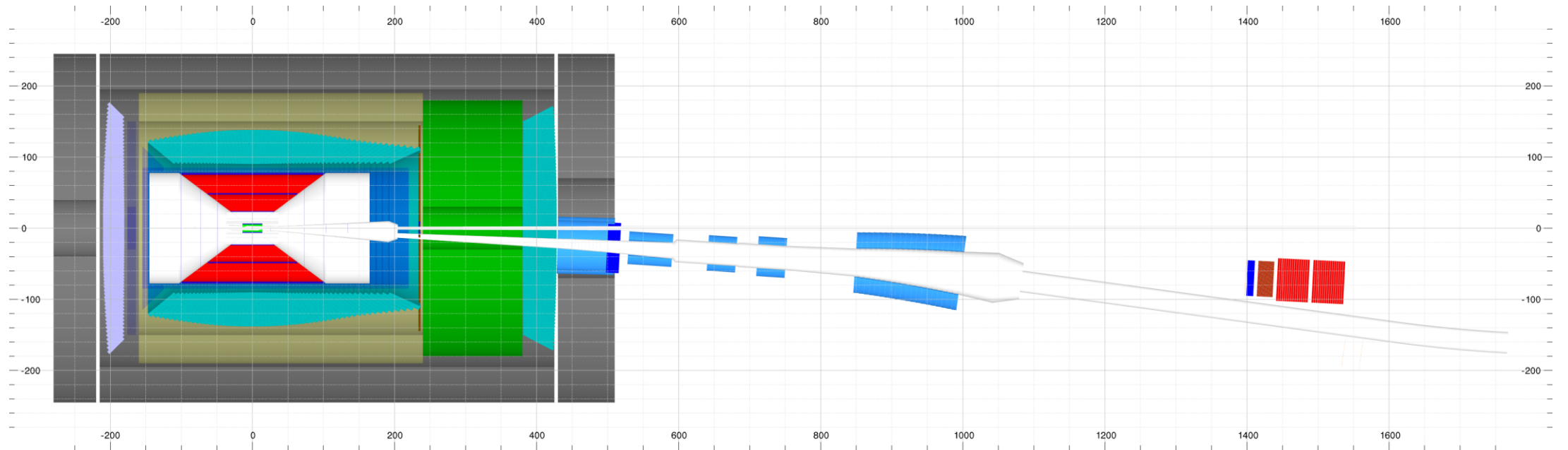
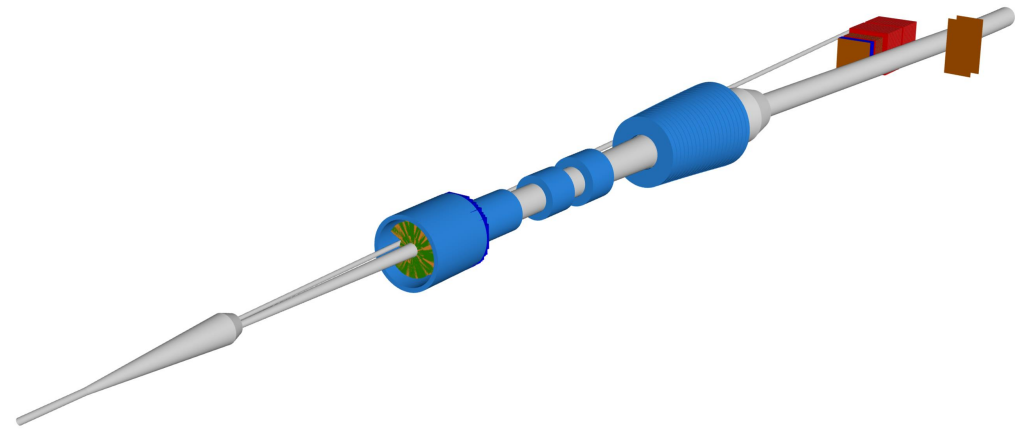
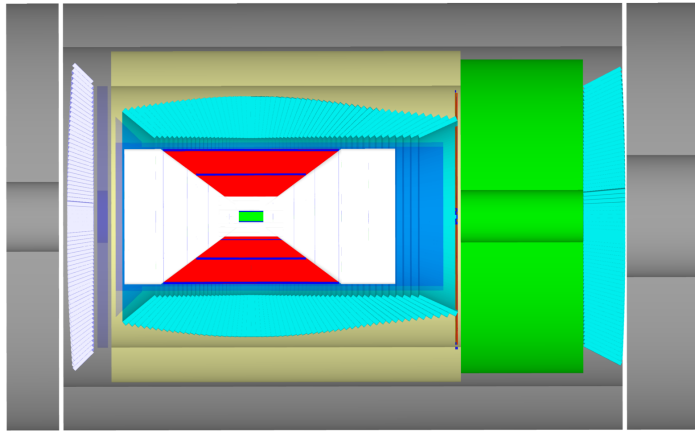
- **Energy measurement for neutron**
- each layer 25.6mm lead + 6.4mm scintillator
- 15 layers for each detector
- in total 60cm x 60cm x 48cm for each detector

PbWO4 detectors:

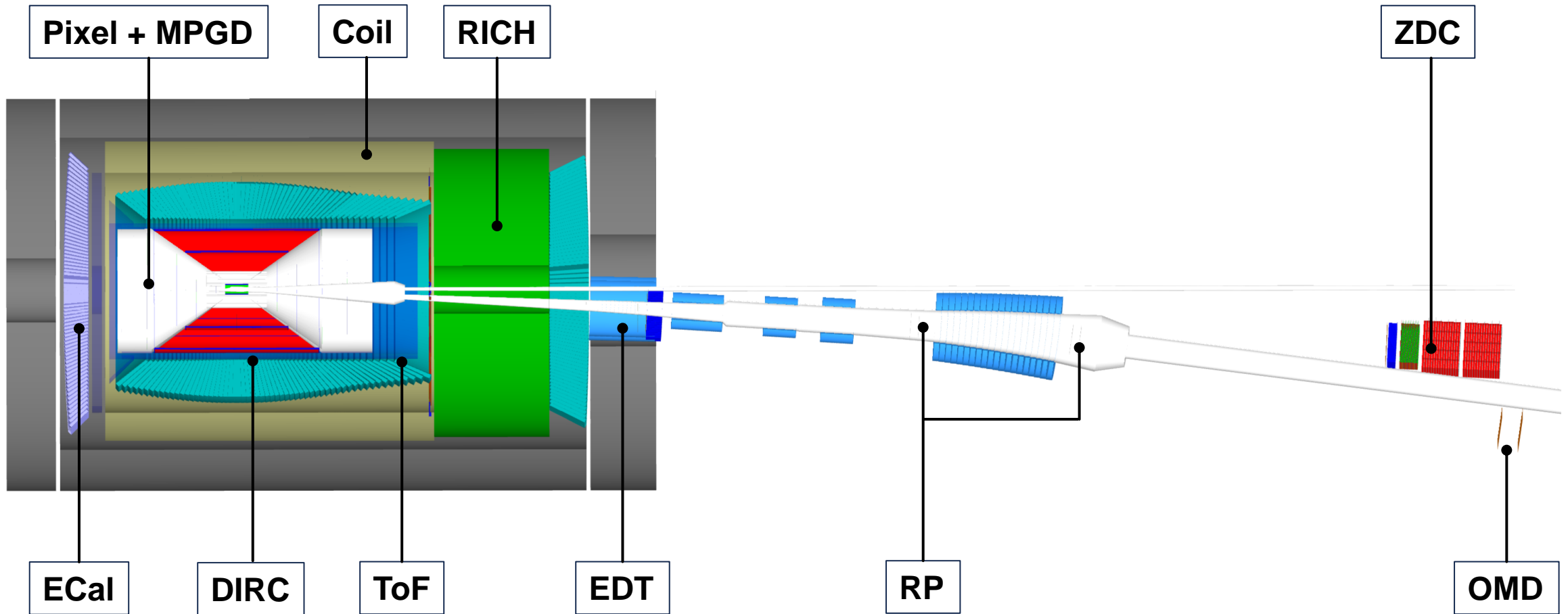
- **For photon detection**
- each module 2.2 cm x 2.2 cm x 10 cm
- in total 50.6 cm x 50.6 cm x 10.0 cm



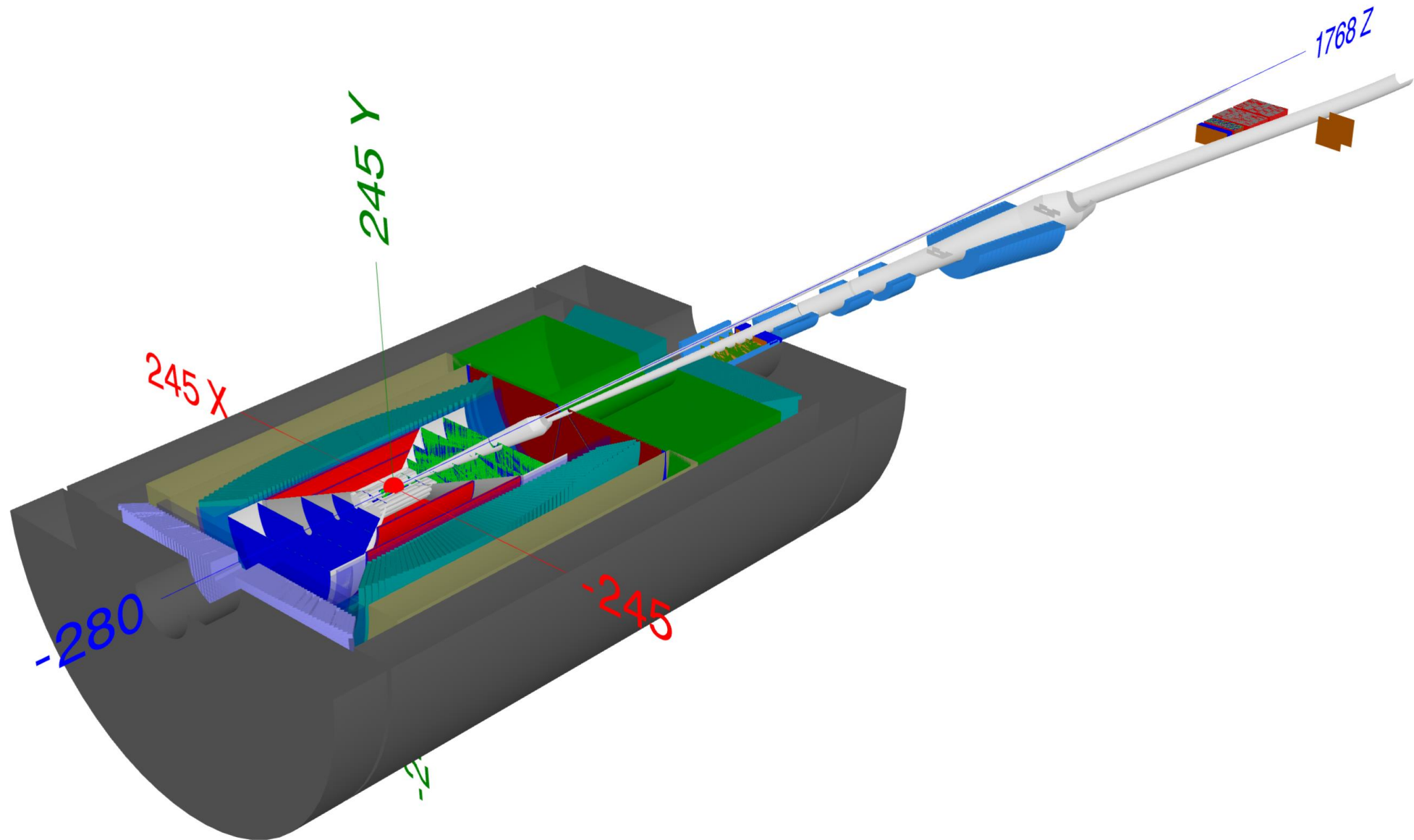
EicC detector at CDR



EicC detector at CDR



EicC detector at CDR



Polarimeters and Luminosity Monitors

➤ Luminosity measurement

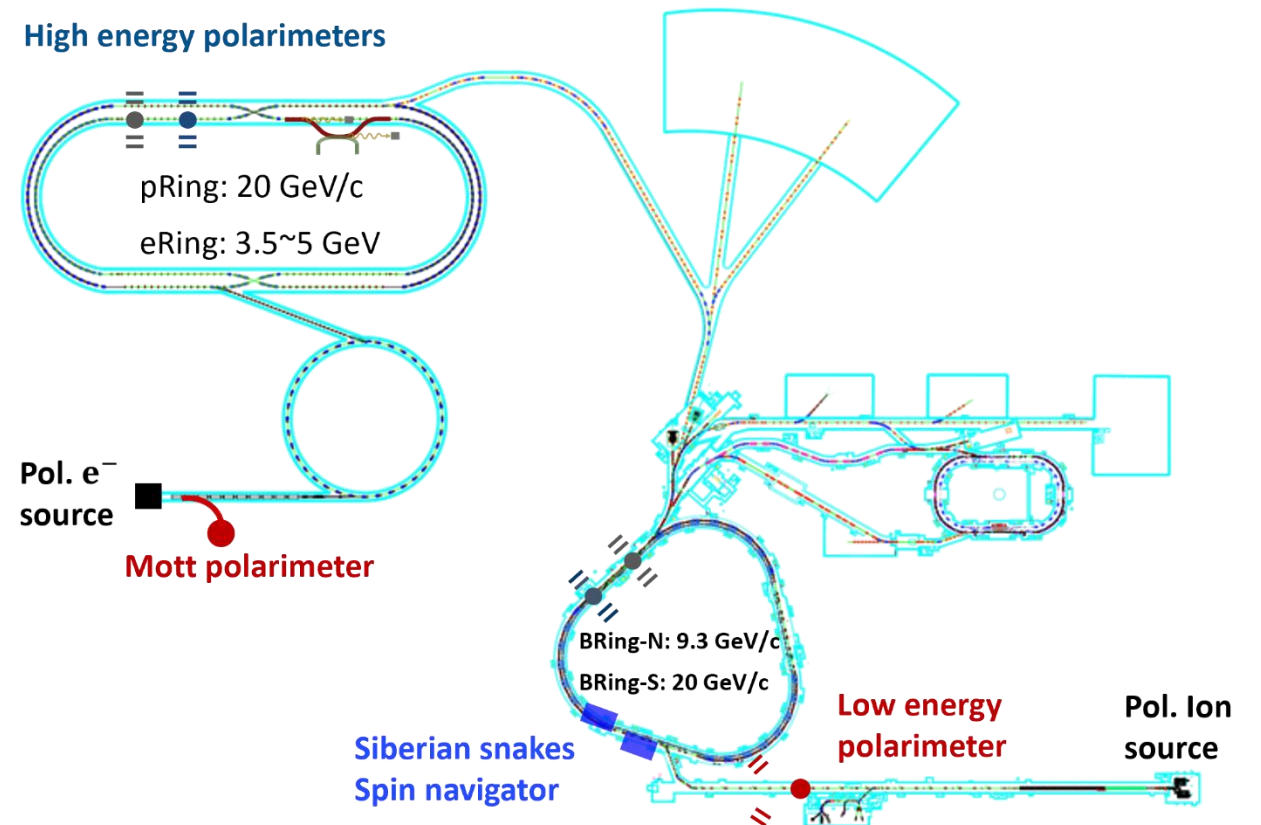
- Bremsstrahlung luminosity monitor

➤ Electron beam polarimetry

- Compton polarimeter

➤ Proton beam polarimetry

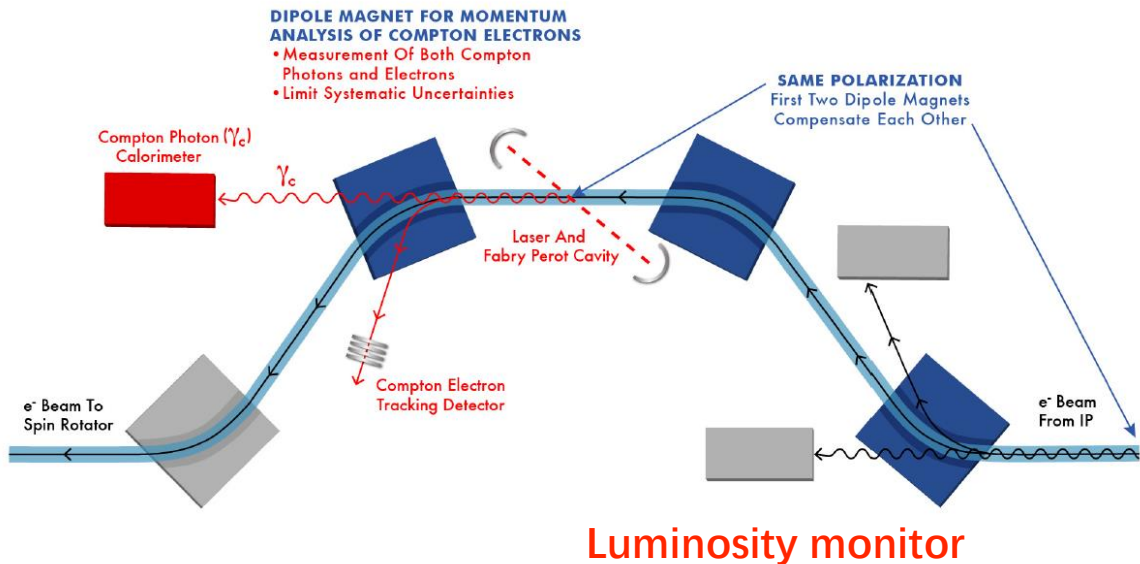
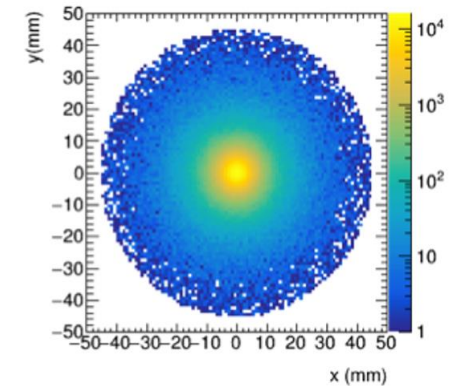
- pp absolute
- pC relative polarimeters



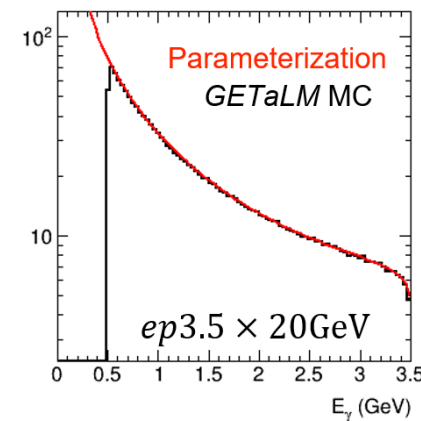
Luminosity Monitors

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

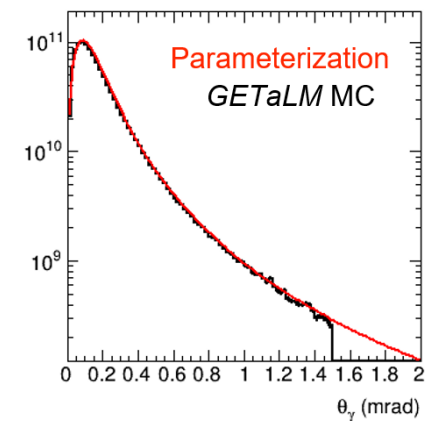
Photon spot at $z=30$ m



Photon energy



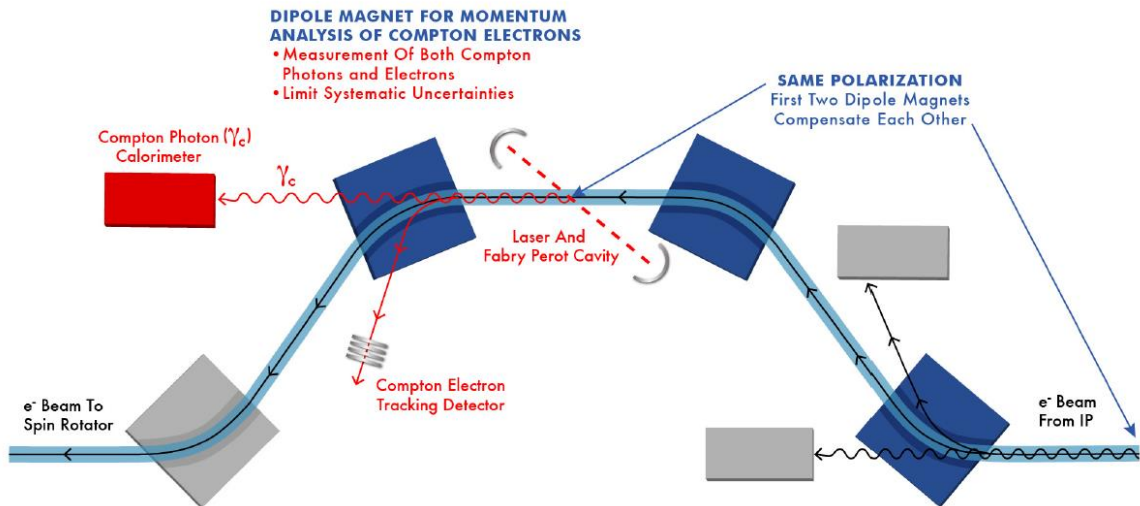
Photon angle



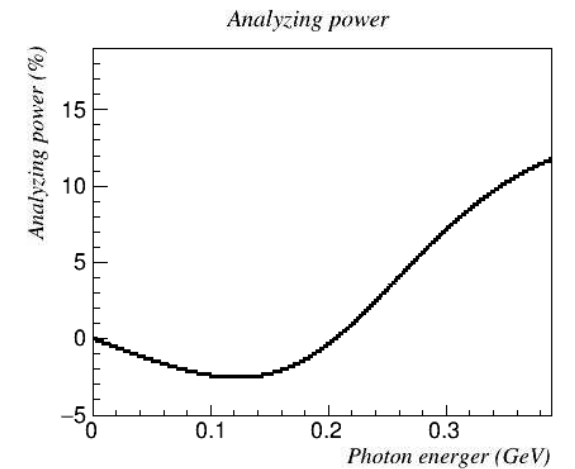
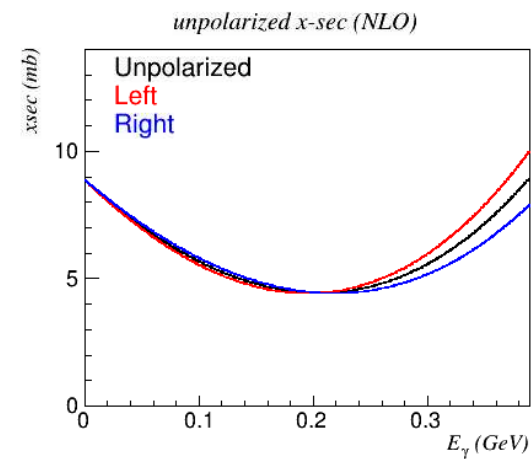
Electron Compton Polarimeter

- 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

- Geant4 simulation is ongoing



Luminosity monitor



Proton polarimetry scheme

The H-Jet polarimeter at RHIC
Precision: 5% in 1 hour, not fast enough

A_N can be self-calibrated with a pol. H target

	①	②	③	④
Beam	↑	↓	↑	↓
Target	↑	↑	↓	↓

- Identical beam & target particles

↓

Same A_N for $\begin{cases} \vec{p}p \rightarrow pp & \text{①} + \text{③} \text{ and } \text{②} + \text{④} \\ p\vec{p} \rightarrow pp & \text{①} + \text{②} \text{ and } \text{③} + \text{④} \end{cases}$

- $P_{\text{beam}} = \frac{\epsilon_{\text{beam}}}{A_N} = -\frac{\epsilon_{\text{beam}}}{\epsilon_{\text{target}}} P_{\text{target}}$
- P_{target} measured with Breit-Rabi polarimeter
- Left-right asymmetry: $\epsilon = \frac{N_L - N_R}{N_L + N_R}$ measured with symmetrically placed detectors

Target box

- Radius: 16 cm

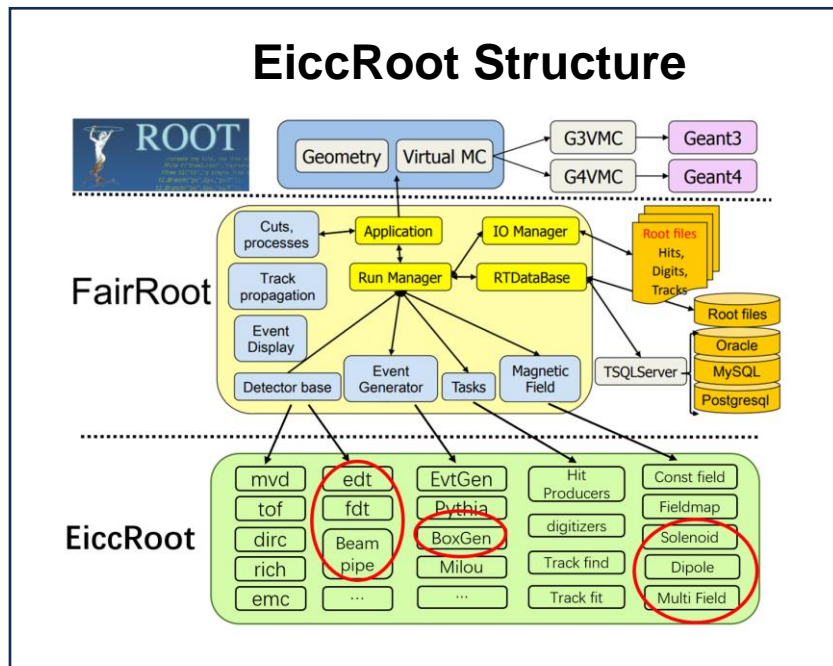
Target frame

- ceramic v plate
- metal holders
- 4 holders (3 carbon + 1 empty)
- 1 left empty for background check

The RHIC/AGS p-C polarimeter

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

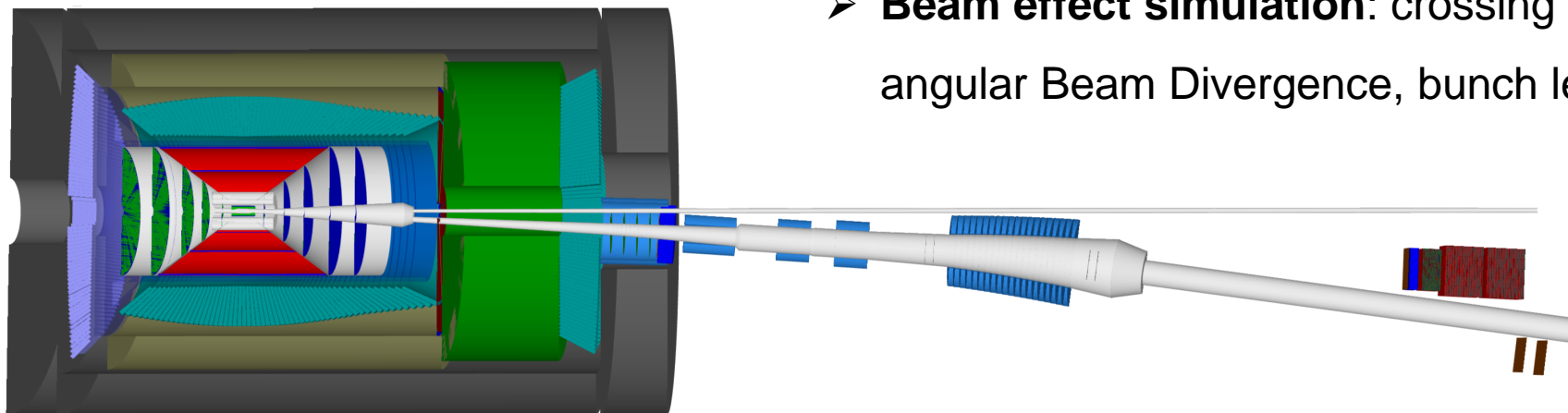
Simulation and Software



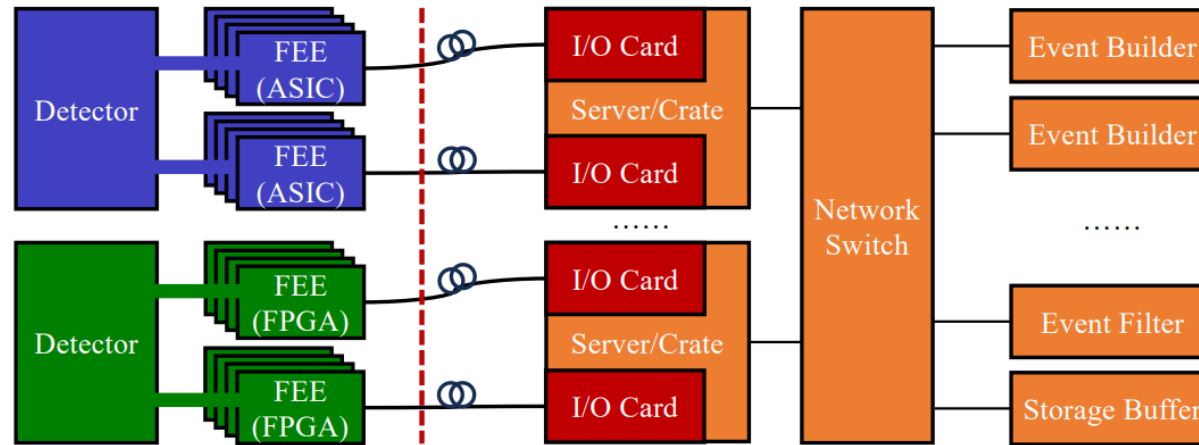
➤ EiccRoot_3.0.0:

- 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

VERO: ATCA based hardware



R&D is in parallel with STCF & NuDEx.
Plan to integrate with front-ends in this summer.

Card	FPGA	Generation	Endpoint x Throughput	Server	Note
PDQQ060	KU060	Gen3x8	1 x 7.48 GB/s	CHOU	MKU060 (Milanka)
PDQQ16	KU5P	Gen3x8	1 x 7.38 GB/s	HSIA	KCU11B (Xilinx)
PDQQ24/5	KU15P	Gen3x8	2 x 7.38 GB/s	HSIA	PDQ124 (CCNU)
		Gen3x16	1 x 14.76 GB/s	HSIA	
PDQ124/5	KU15P	Gen4x8	2 x 14.76 GB/s	HSIA	PDQ124 (CCNU)
PDQ116	KU5P	Gen4x8	1 x 14.76 GB/s	HSIA	KCU11B (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 | Recv2(HB/s) | F1e1(HB/s) | Tot1(HB) | Rec(HB) | Buf(S) | Wraps
3 | 0.0 | 0.0 | 34762.0 | 0 | 27 | 13
### Blocks: 1415858 Errors: header=1415858 trailer=0 (trunc=0 err=0 length=0 type=0 crc=0)
14760.0 | 0.0 | 29522.0 | 0 | 38 | 23
### Blocks: 2866348 Errors: header=2866348 trailer=0 (trunc=0 err=0 length=0 type=0 crc=0)
14740.0 | 0.0 | 44272.0 | 0 | 7 | 42
    
```

Measured with ATLAS FELIX software



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

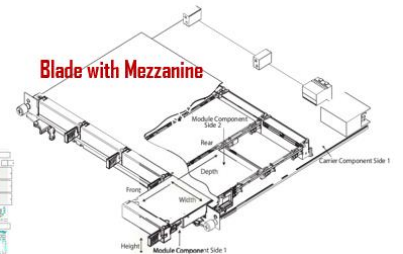
Versatile Readout (VERO) system

- 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



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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

R&D is in parallel with **STCF** & **NvDEx**.
 Plan to integrate with front-ends in this summer.



PDQ124



PDQ125



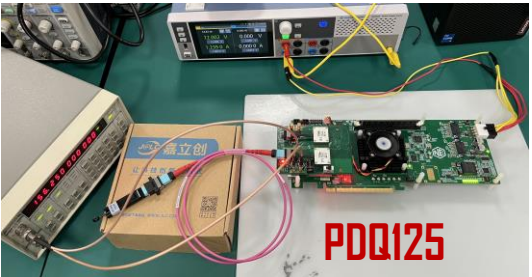
PDQ142

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



PDQ125

- PDQ124:** KU15P, 6x QSPF28
- PDQ125:** KU15P, 2x 12-ch module
- PDQ142:** VM1402, 2x QSPF28

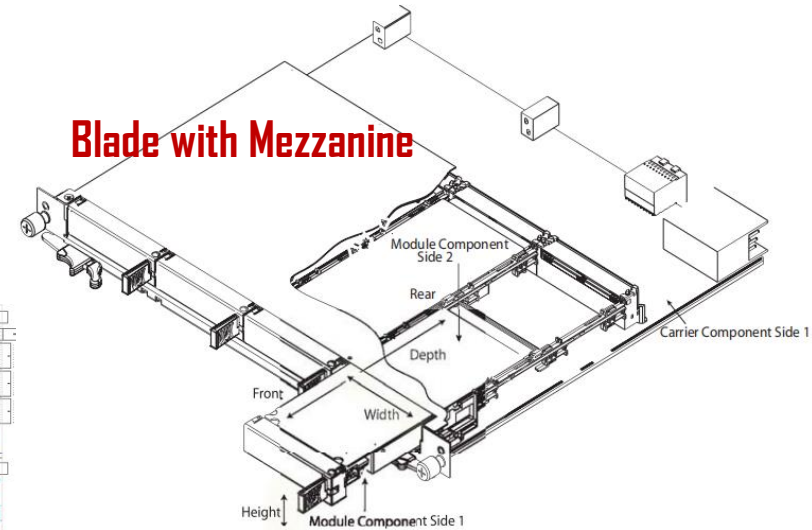
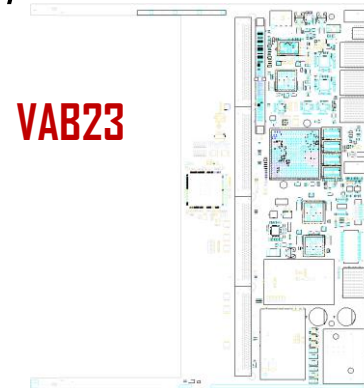
VERO: ATCA based hardware

❑ Versatile Readout (VERO) system

- **VAB23** (Versatile ATCA Blade): to be tested in June
- **VRM24** (Versatile Rear Module): to be tested in July
- AMC Mezzanine

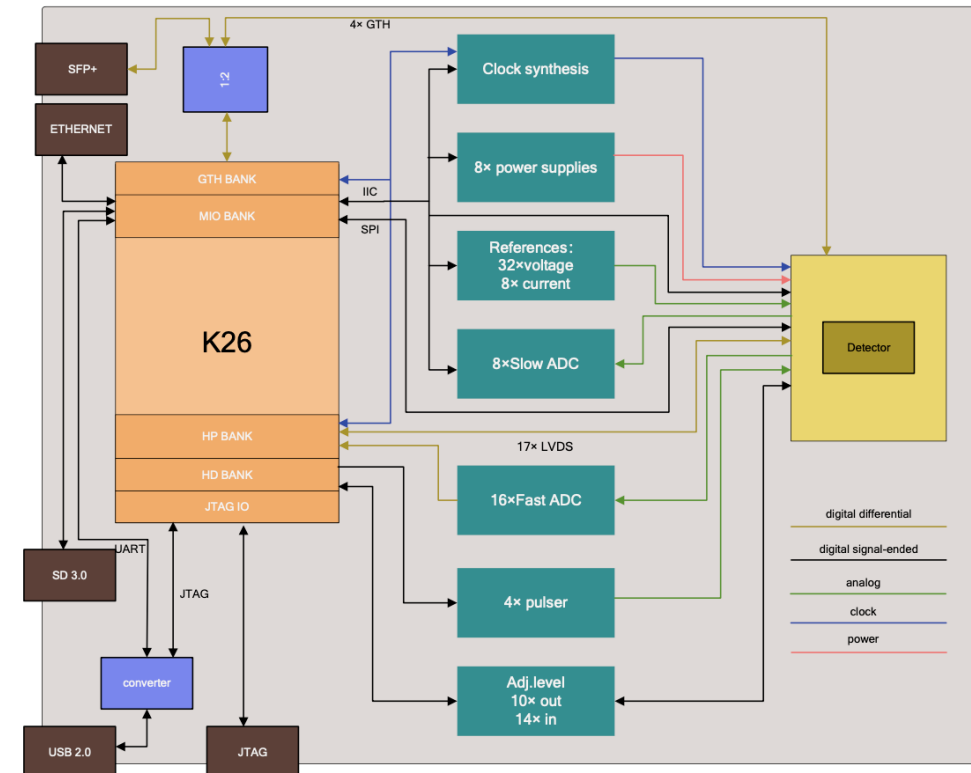
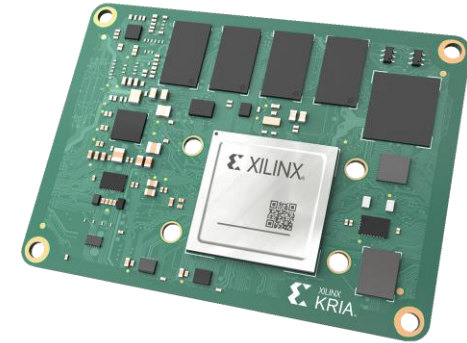
❑ AMC cards to be supported

- **LAM24** (Loopback AMC Mezzanine)
- **SAM25** (SAMPa AMC Mezzanine)
- **TAM24** (Trigger AMC Mezzanine): to be tested in Nov
- **CAM24** (Converter AMC Mezzanine)



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 designed 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)



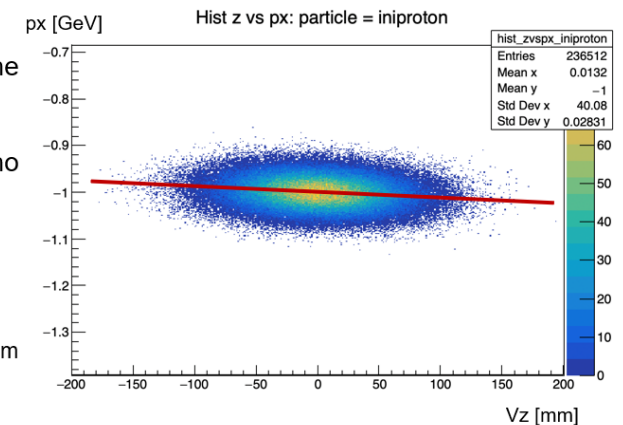
Beam effect study

- 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>

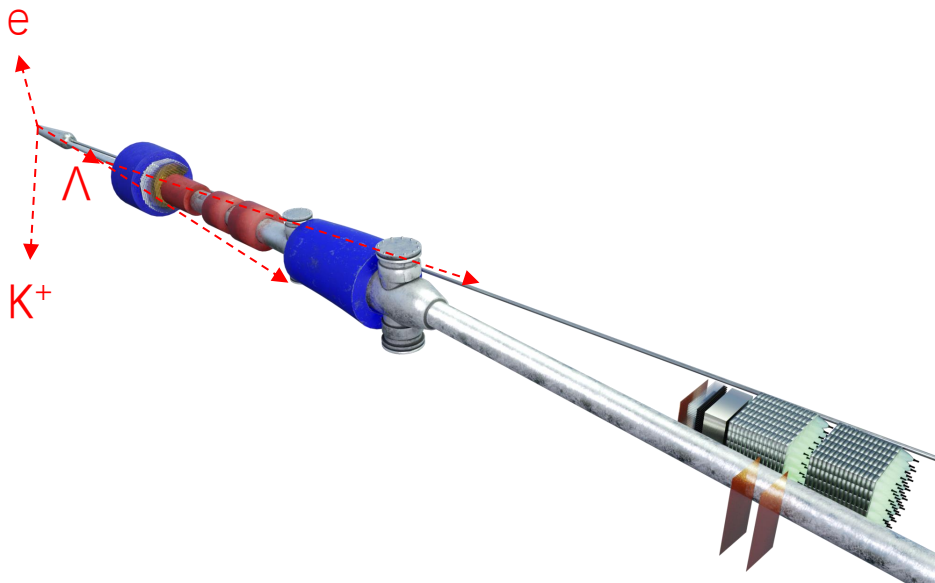
1. Crossing angle
2. Crab Cavity
3. Angular Beam Divergence
4. Bunch Length

With Bunch Length and Crab Cavity Effect

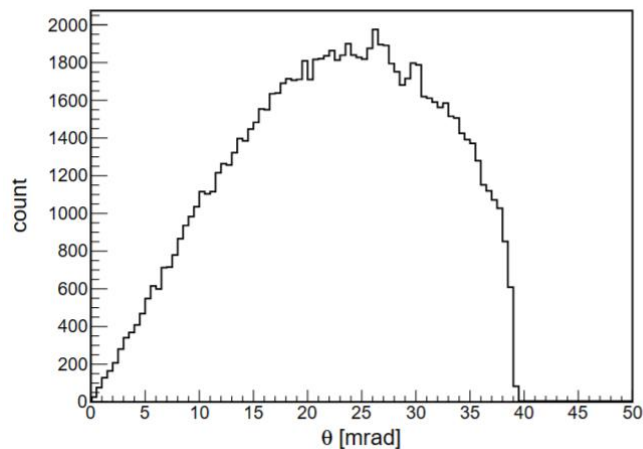
- Crab cavity will rotate the bunch, giving it a “kick” in the x-direction
- The “kick” is z-dependent, no kicking in the middle of the bunch
- Effect is at the level of 20 MeV from head to tail
 - Currently, effect in the program twice larger than expected, need to find out why



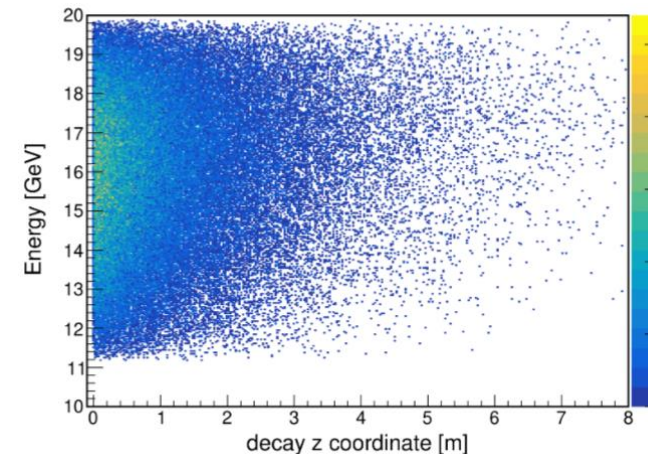
Forward Λ detection



polar angle of Λ



Energy vs decay z-vertex of Λ



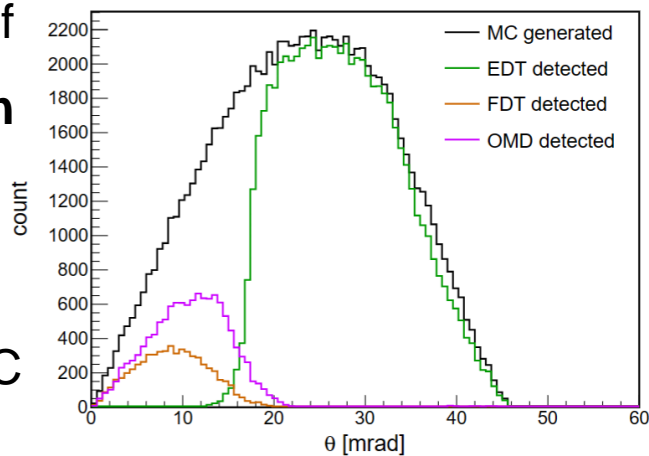
Detection of Λ is essential for measurement of the **kaon form factor** and **structure function** using the **Sullivan process**.



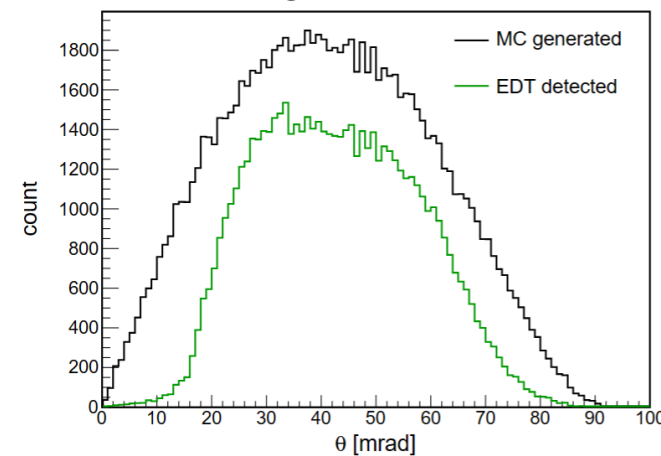
Obvious advantage for EicC, compared to EIC

Efficiency of $\Lambda \sim 40\%$ (EIC 1% \sim 20%)

polar angle of p from Λ

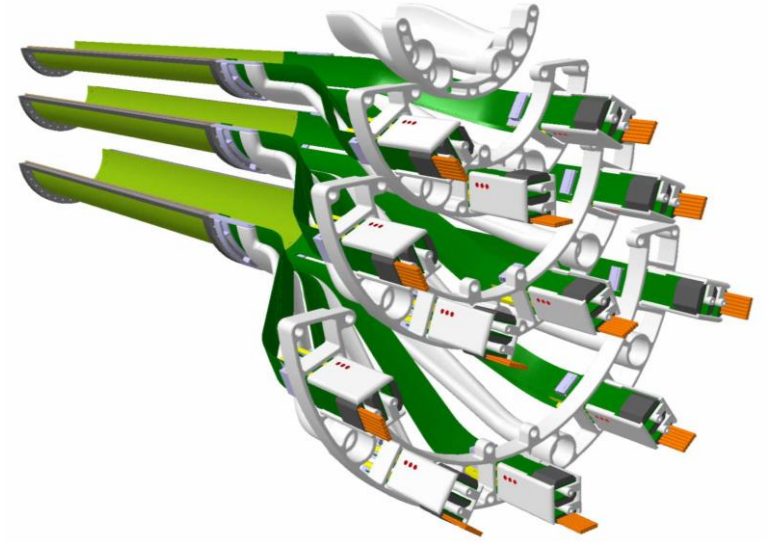
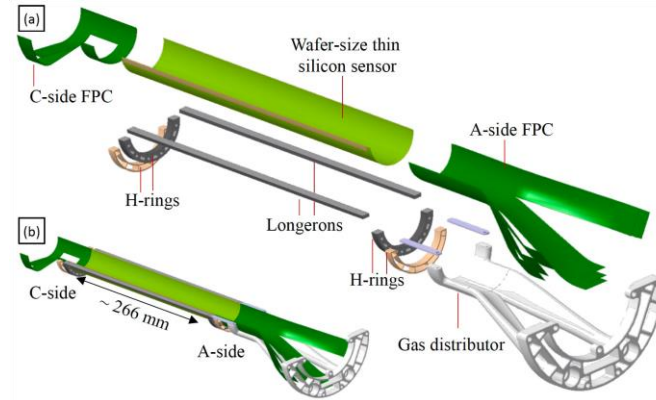
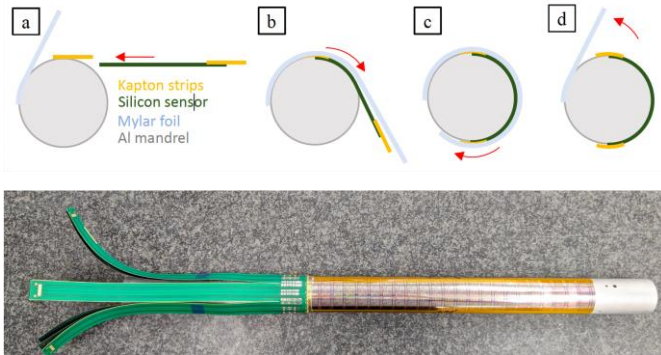


polar angle of π^- from Λ

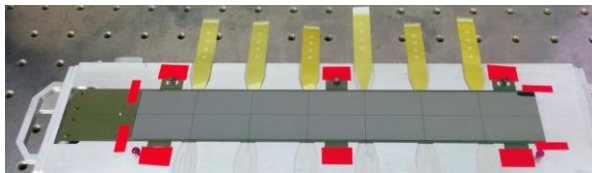


Structure of the EicC barrel silicon tracker

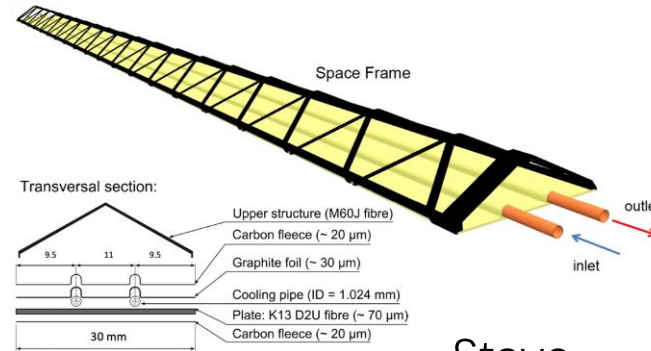
- ITS3-based Vertexer (3 IB layers)



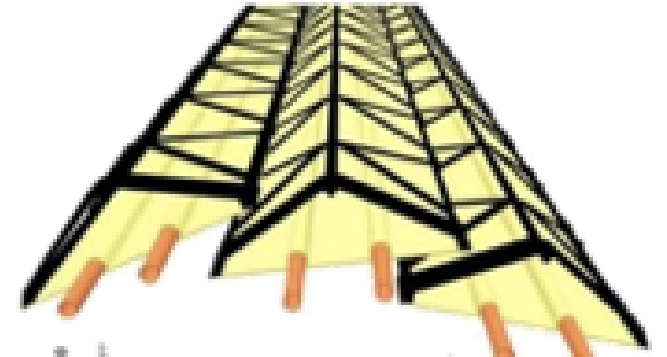
- ITS2-based Silicon Tracker (2 OB layers)



Hybrid Integrated Circuits (HIC)



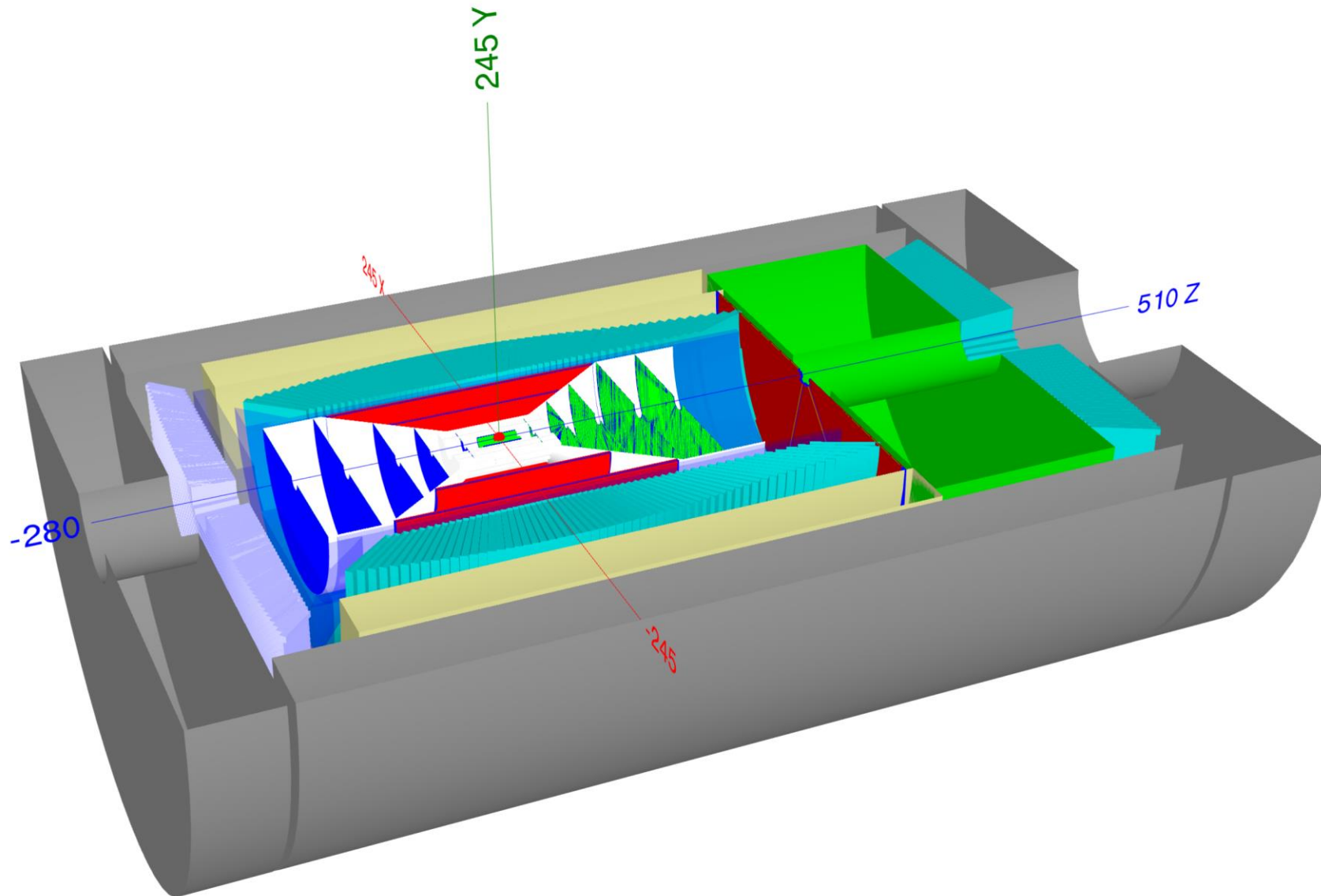
Stave



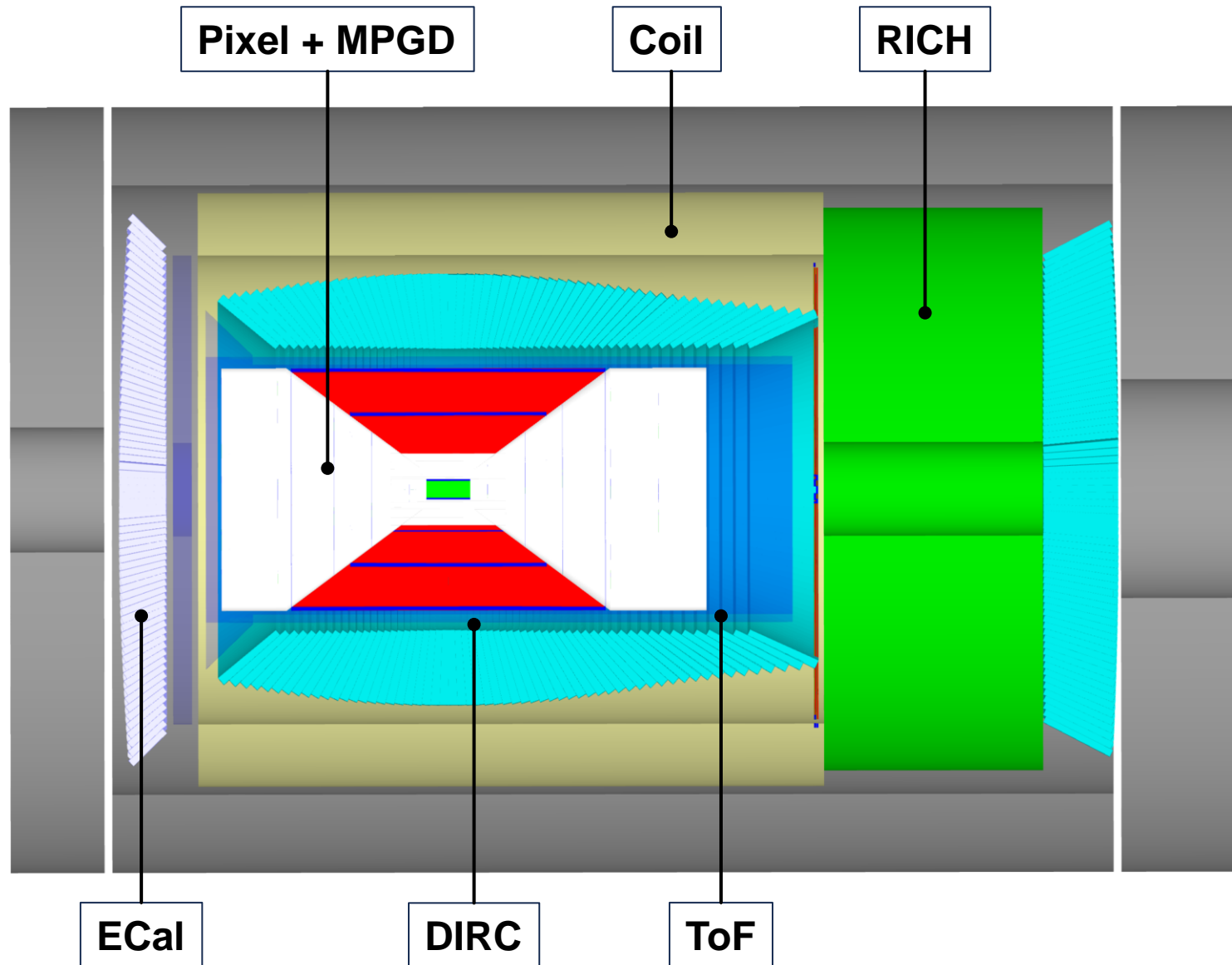
7th EicC CDR Meeting - Y.P. Wang

➤ 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

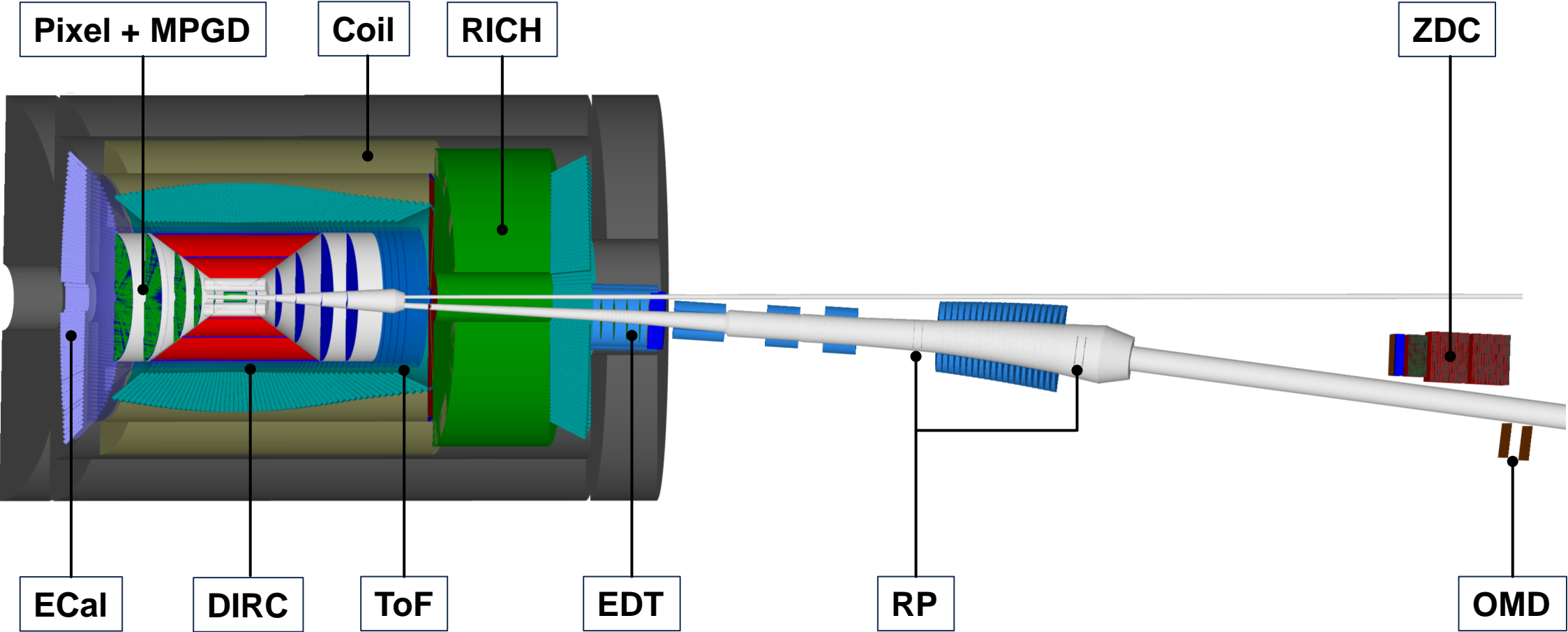
Central Detector



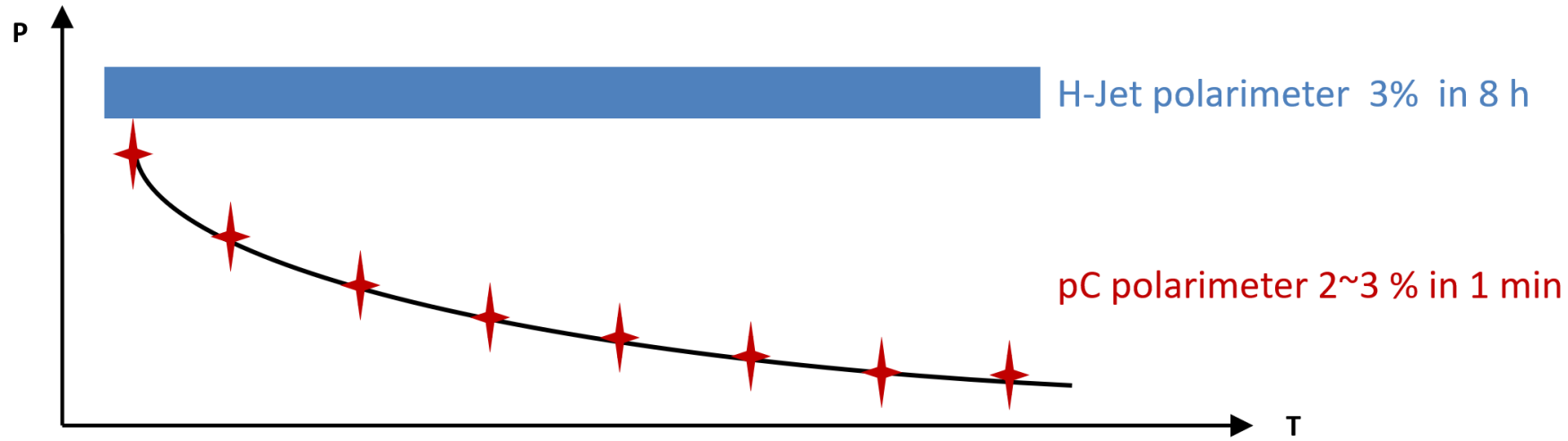
Central Detector



EicC Detector



Proton polarimetry scheme

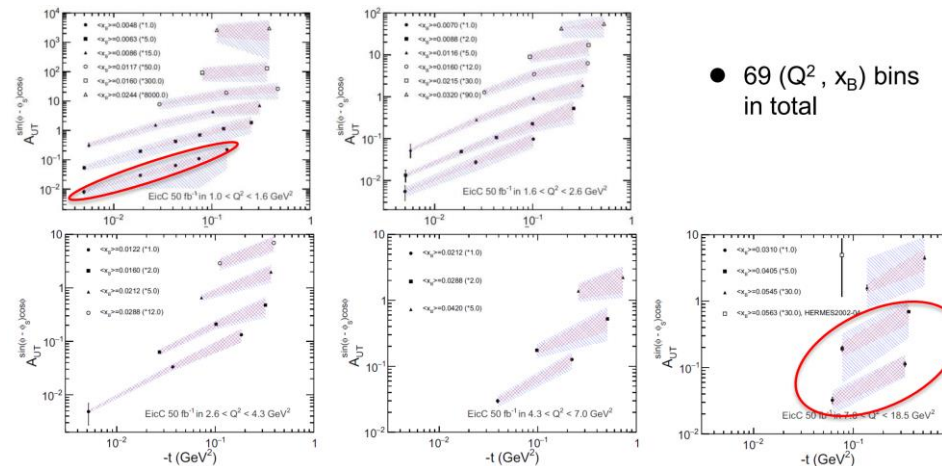
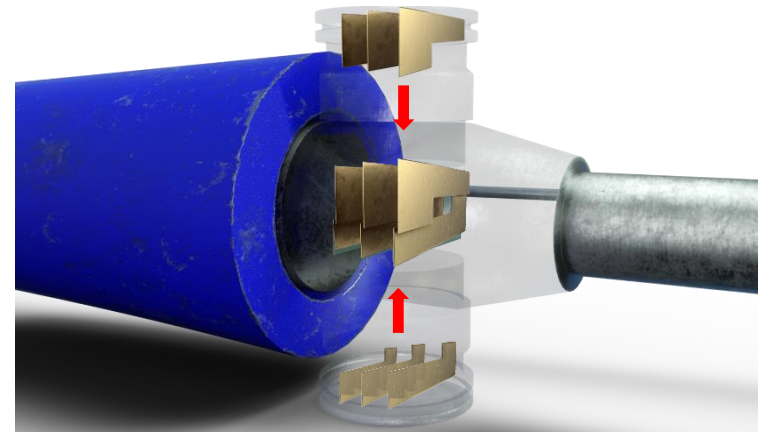


	H-Jet polarimeter	pC polarimeter
Target	Polarized H gas jet	Carbon fiber
Target thickness	$\sim 10^{12} \text{ atoms/cm}^2$	$\sim 10^{16} \text{ atoms/cm}^2$
Event rate	$\sim 60 \text{ Hz}$	$\sim 2 \text{ MHz}$
Operation	continuously	$\sim 1 \text{ min/h}$
Analyzing power	self-calibrated	unknown
Role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

FDT running at Low luminosity mode

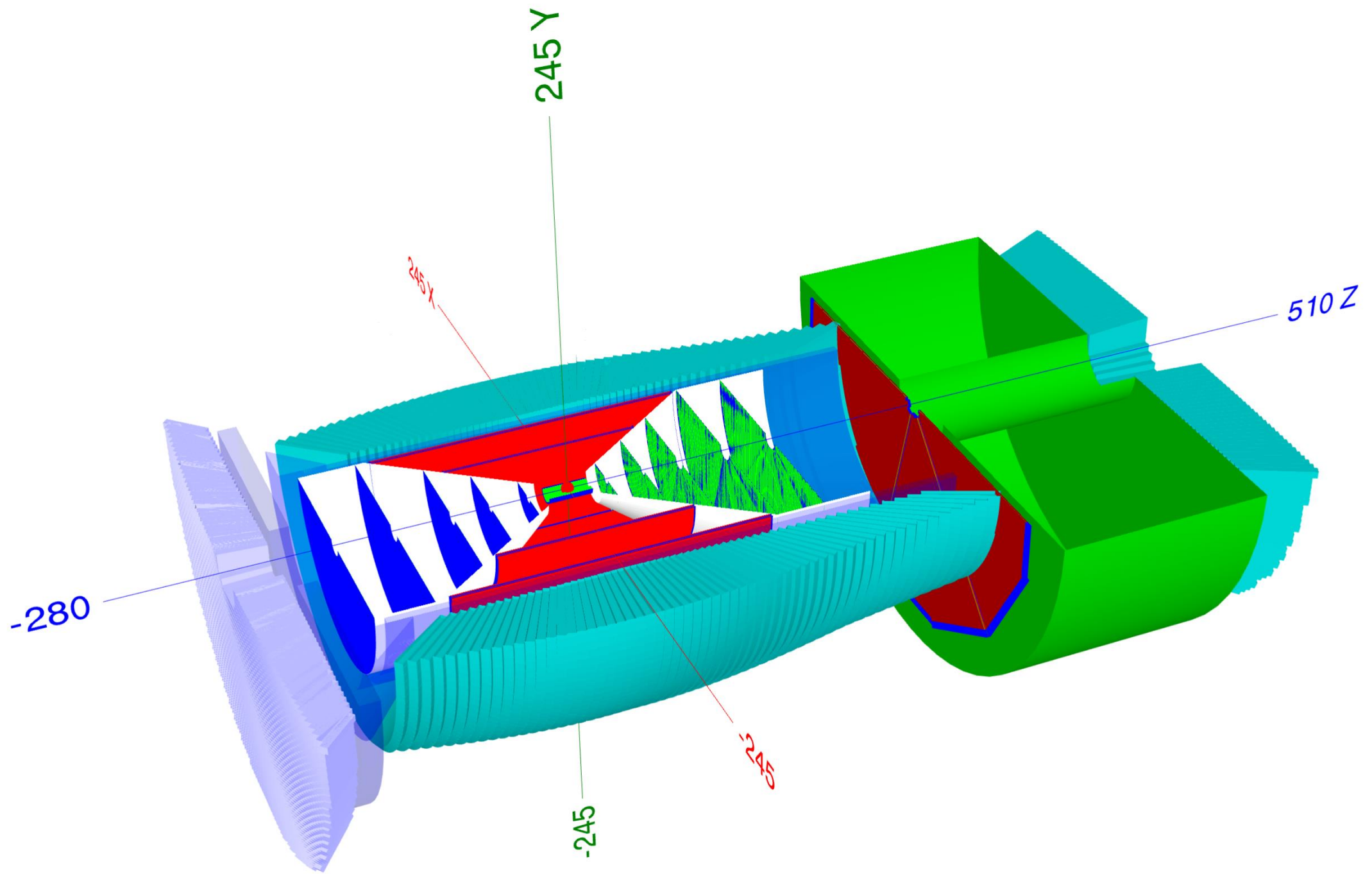
Designs	High Lumi.		Low Lumi.	
	HIAF-U-New, V0		V1	
Particle	e	p	e	p
Circumference(m)	1151.20	1149.07	1151.20	1149.07
Kinetic energy (GeV)	3.5	19.08	3.5	19.08
Momentum (GeV)	3.5	20	3.5	20
Total energy (GeV)	3.5	20.02	3.5	20.02
CM energy (GeV)	16.76			
$f_{\text{collision}}$ (MHZ)	100			
Polarization	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 ·s ⁻¹)	4.25×10 ³³ (H=0.52)		1.13×10 ³³ (H=0.52)	

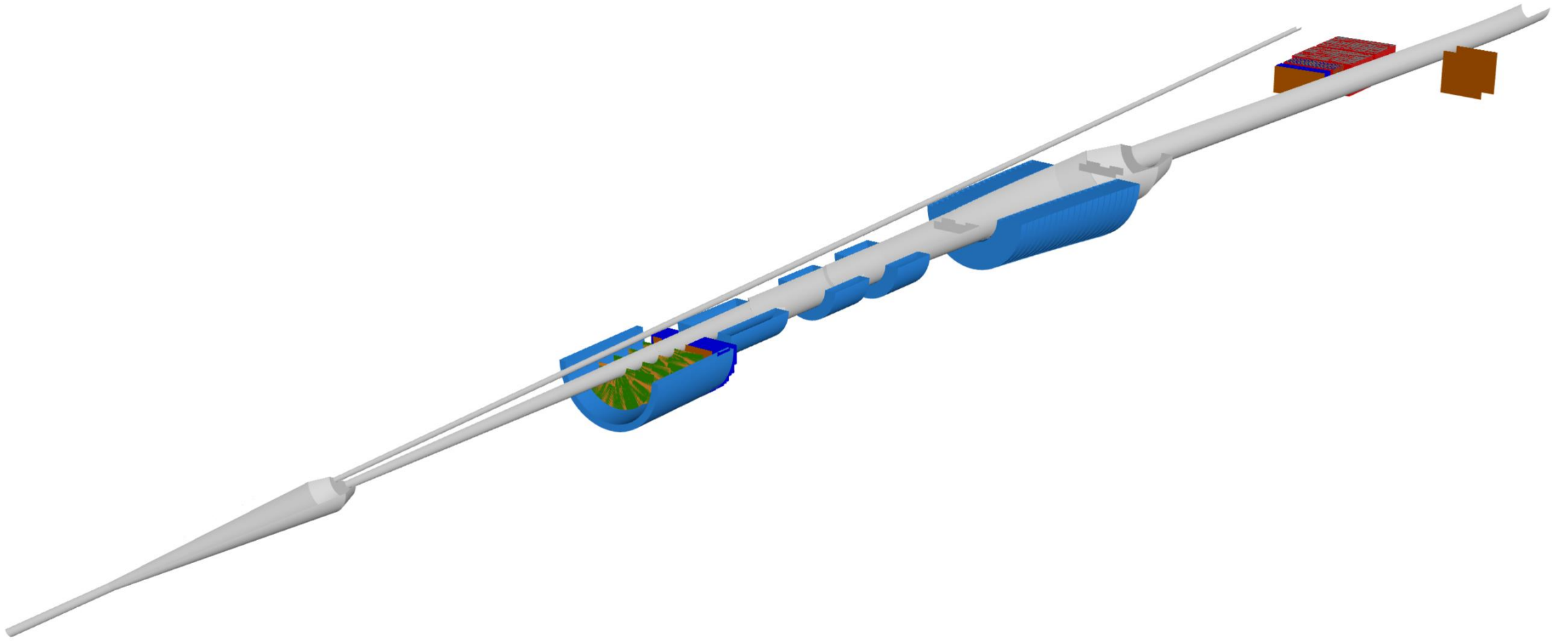
Assuming 1/4 of data taking time running at low luminosity mode.



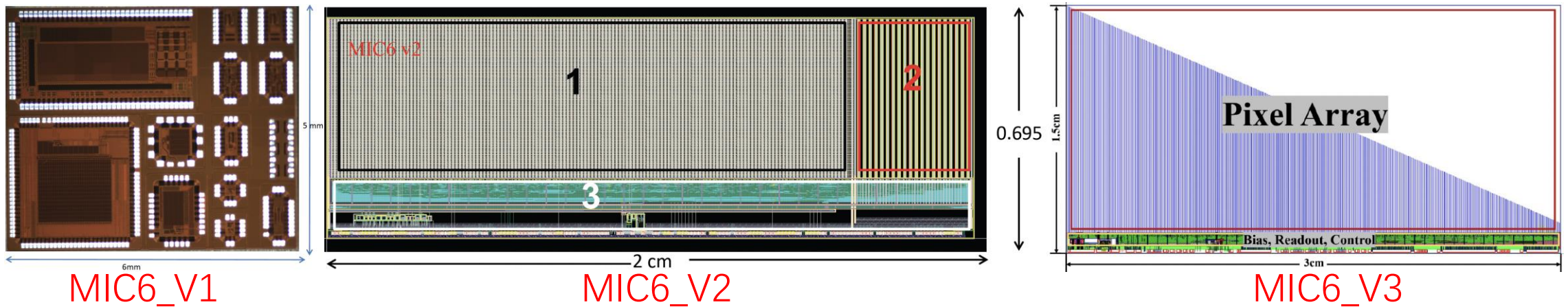
- 69 (Q^2, x_B) bins in total

50 fb⁻¹ data →
~1% stat. error
on asymmetry



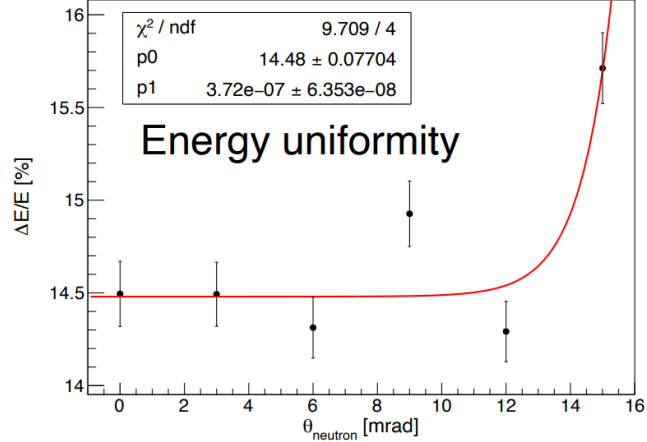
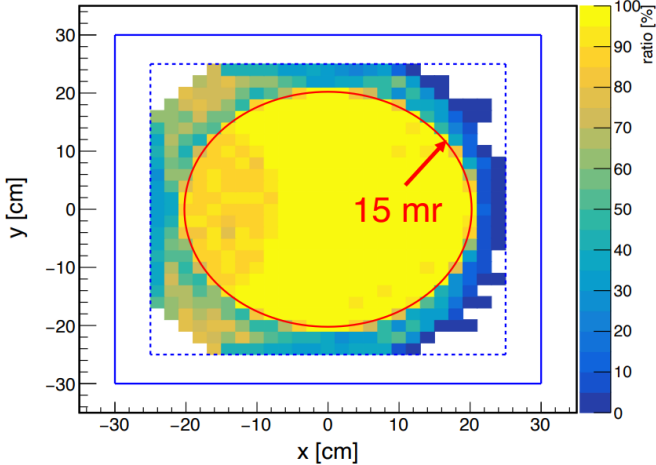
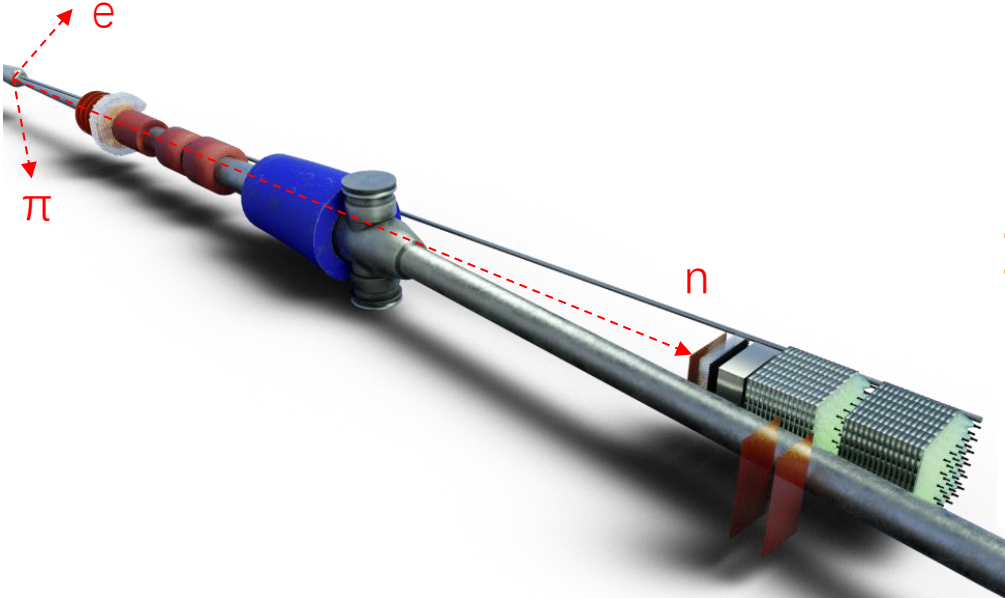


MAPS Chip Design – 基于国内工艺研发MIC6 -- 孙向明, 肖乐



- 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， $\text{CCE} > 93.5\%$ ，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

