EicC Tracking System

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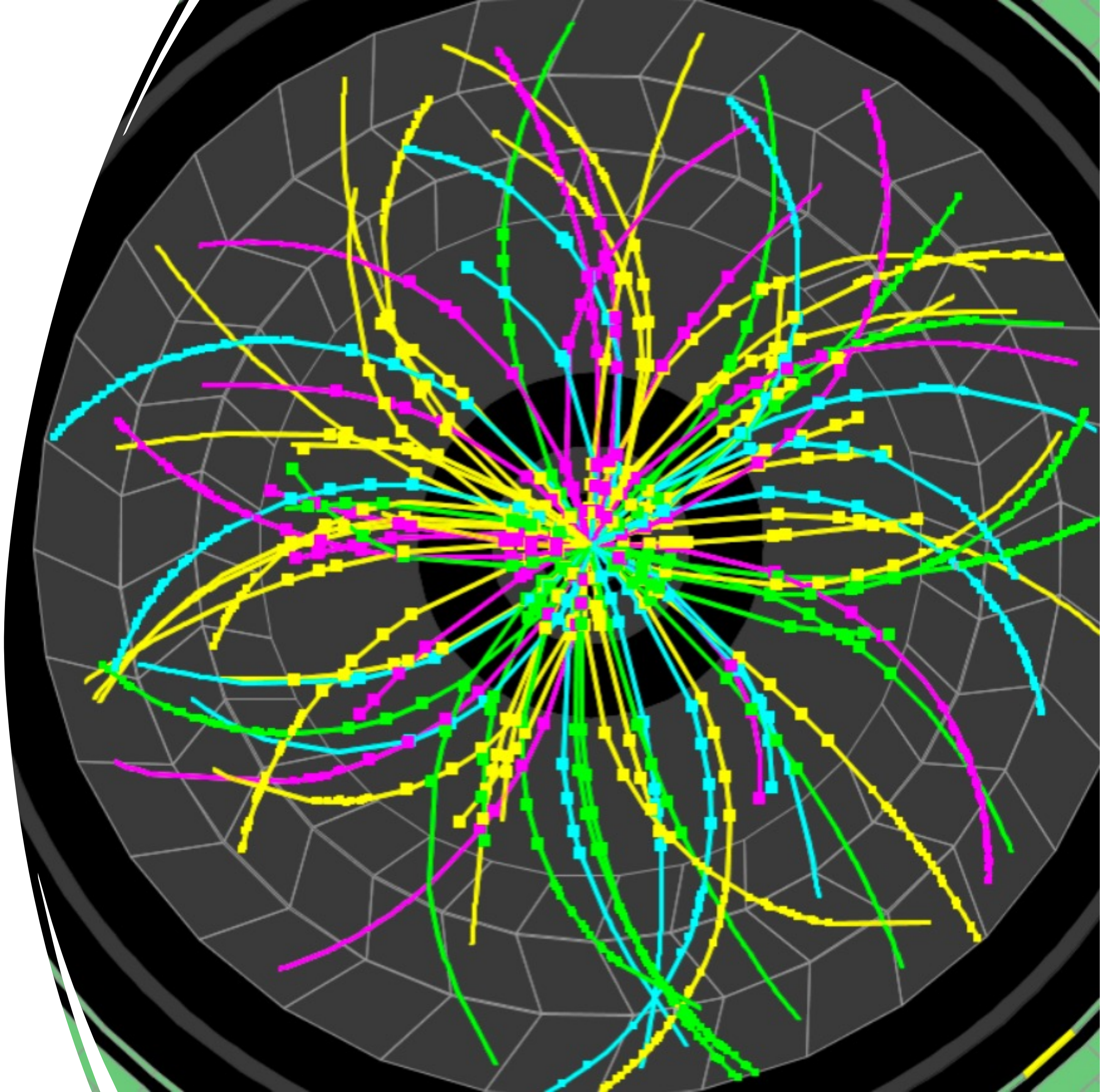
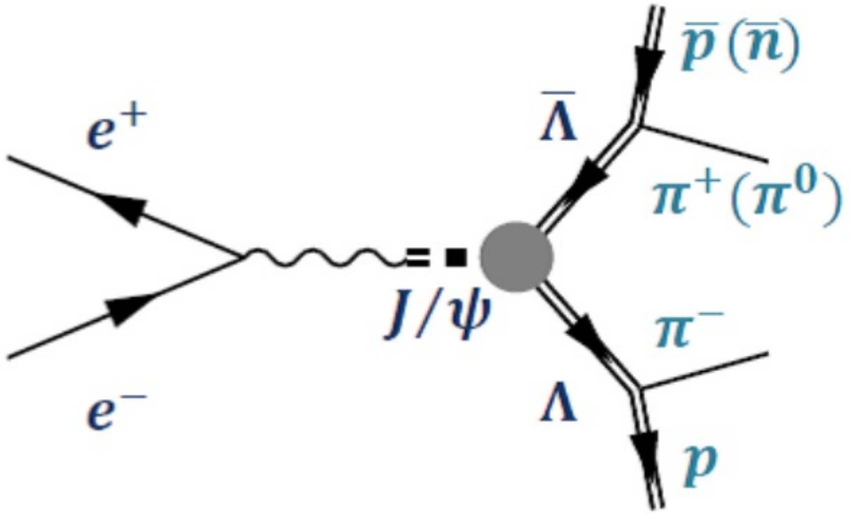
The 6th EicC CDR workshop - Huizhou



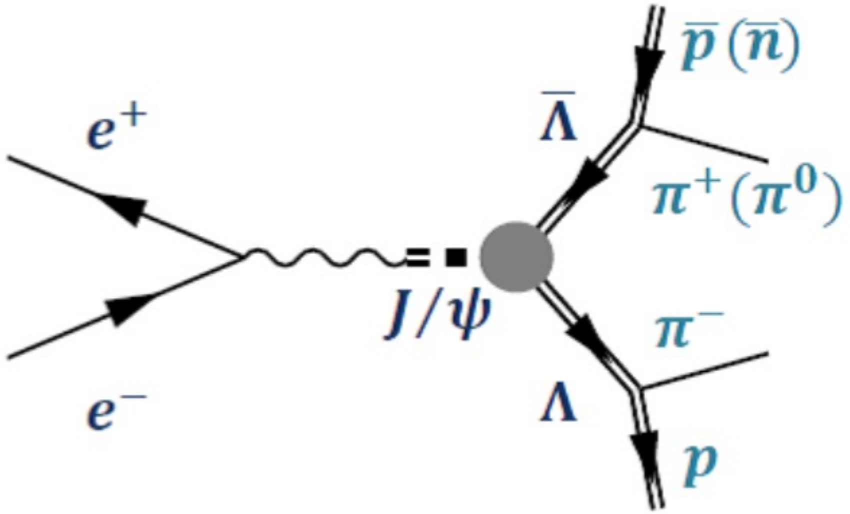
Introduction of tracking system

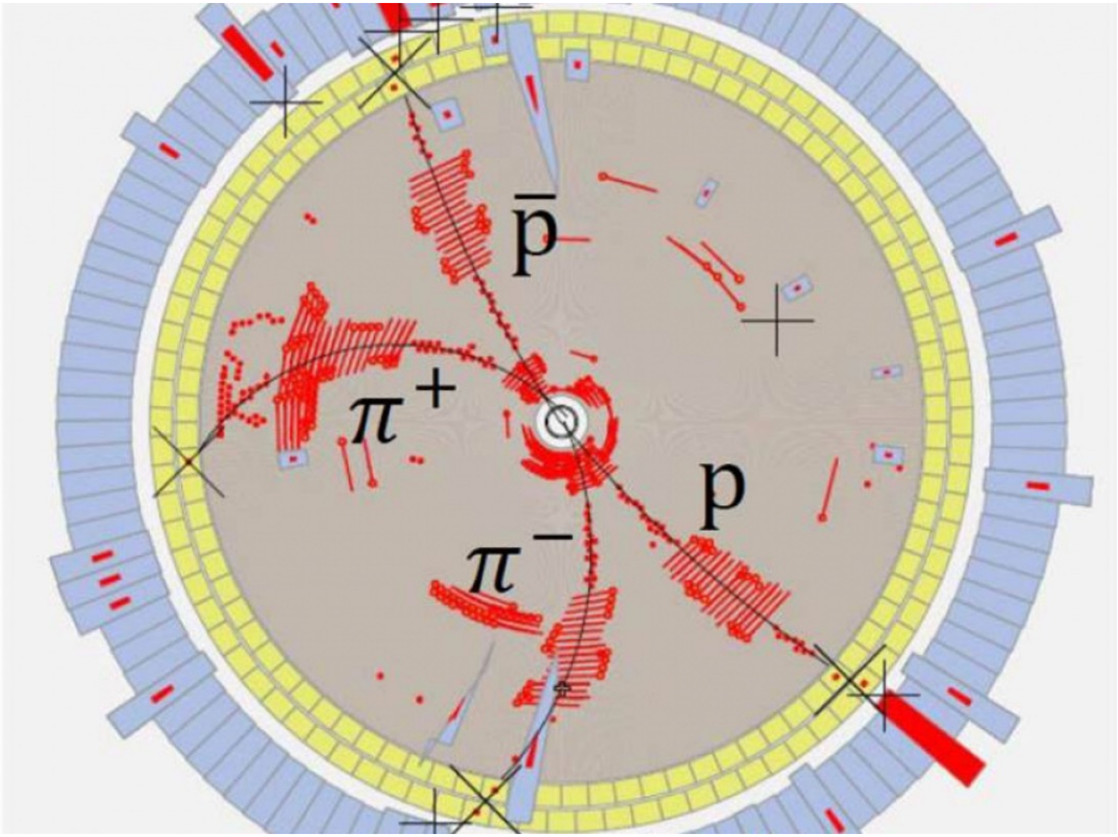
To study a physics process



Introduction of tracking system

To study a physics process





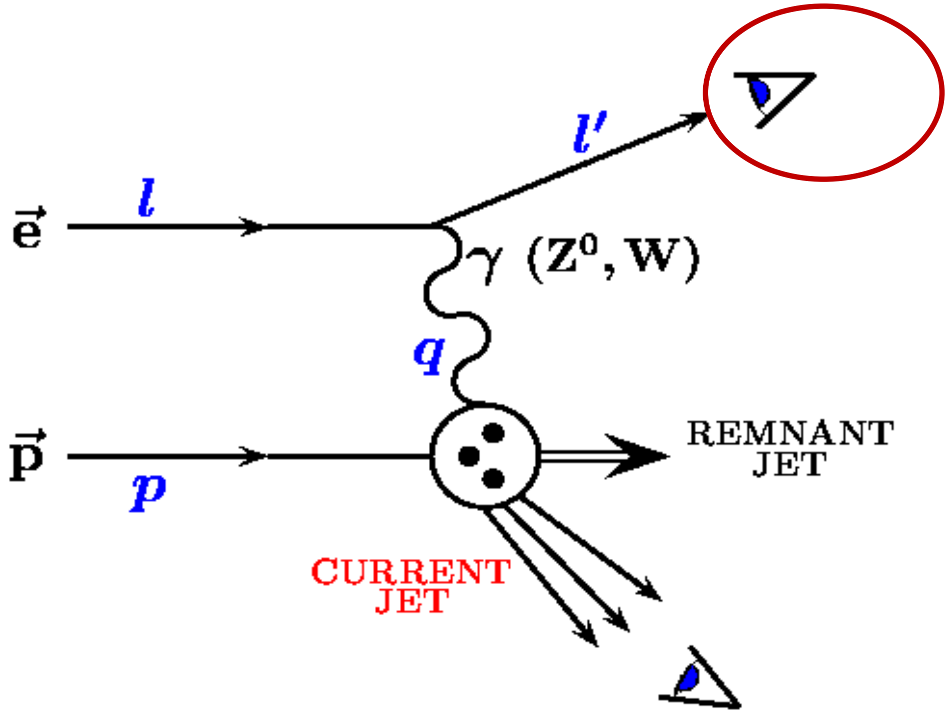
Tracking is all about building an image of the particle interactions with detector

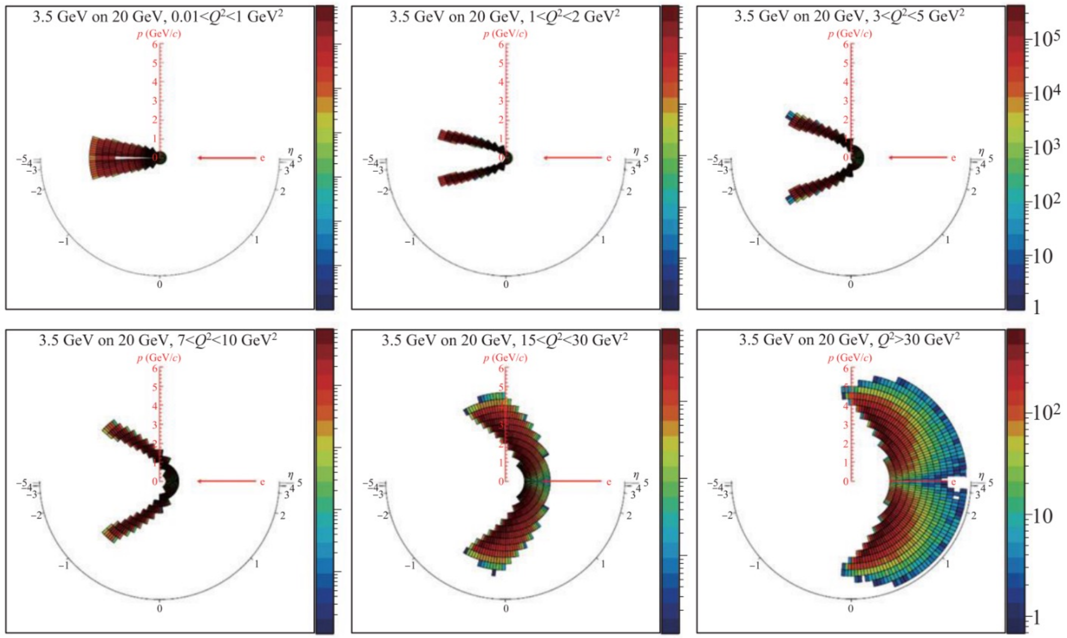
The talk will last about half an hour…

Requirements

The primary physics topic is spin physics, we need to explore the DIS, SIDIS, DVCS etc.

- the scattered electrons provide crucial information to most of processes



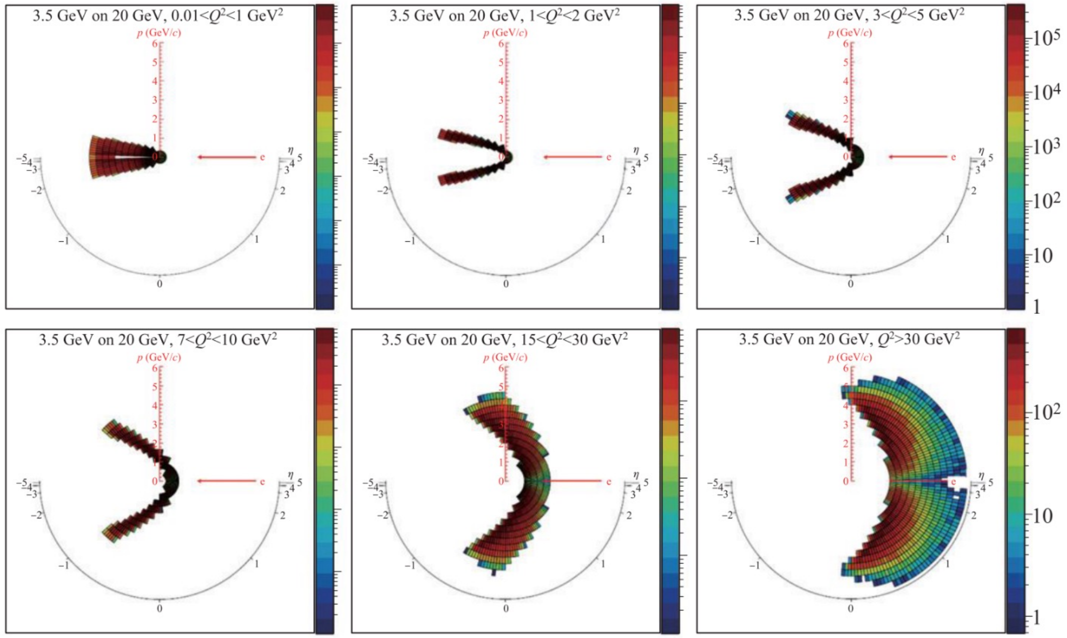


Kinematics of the scattered electron at various Q^2

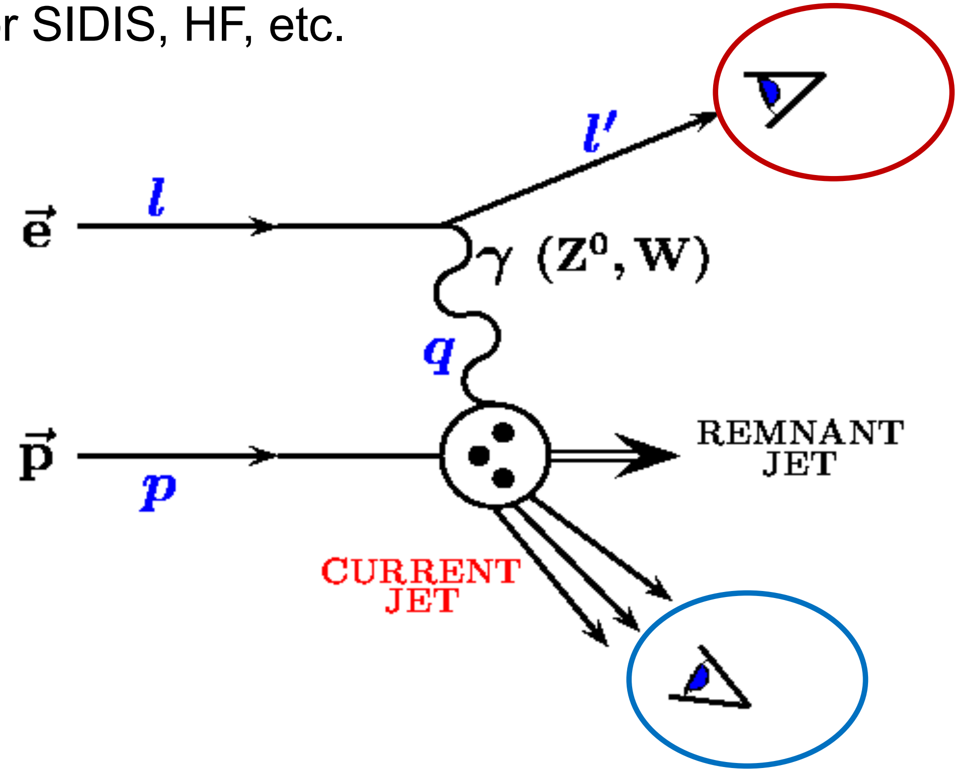
Requirements

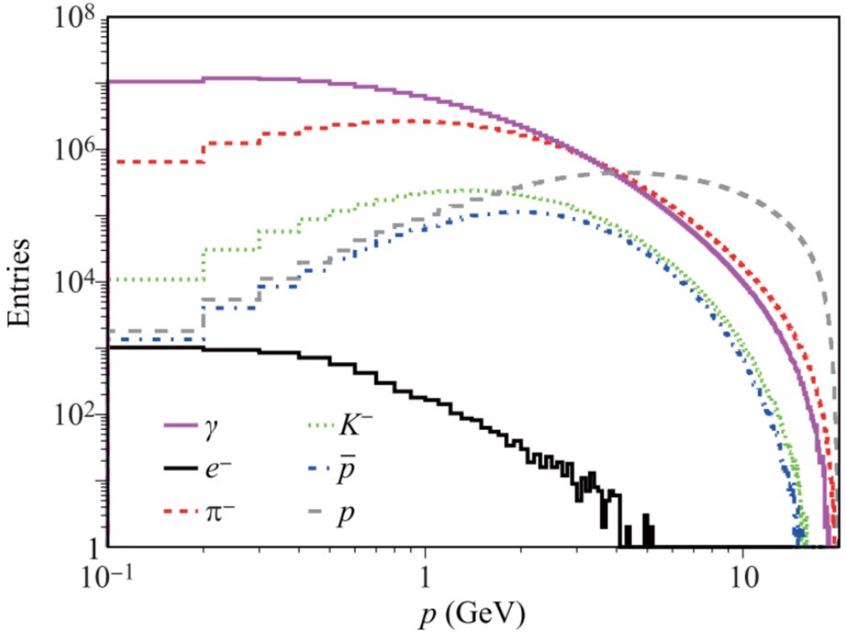
The primary physics topic is spin physics, we need to explore the DIS, SIDIS, DVCS etc.

- the scattered electrons provide crucial information to most of processes
- The hadrons in the final states are essential for SIDIS, HF, etc.



Kinematics of the scattered electron at various Q^2

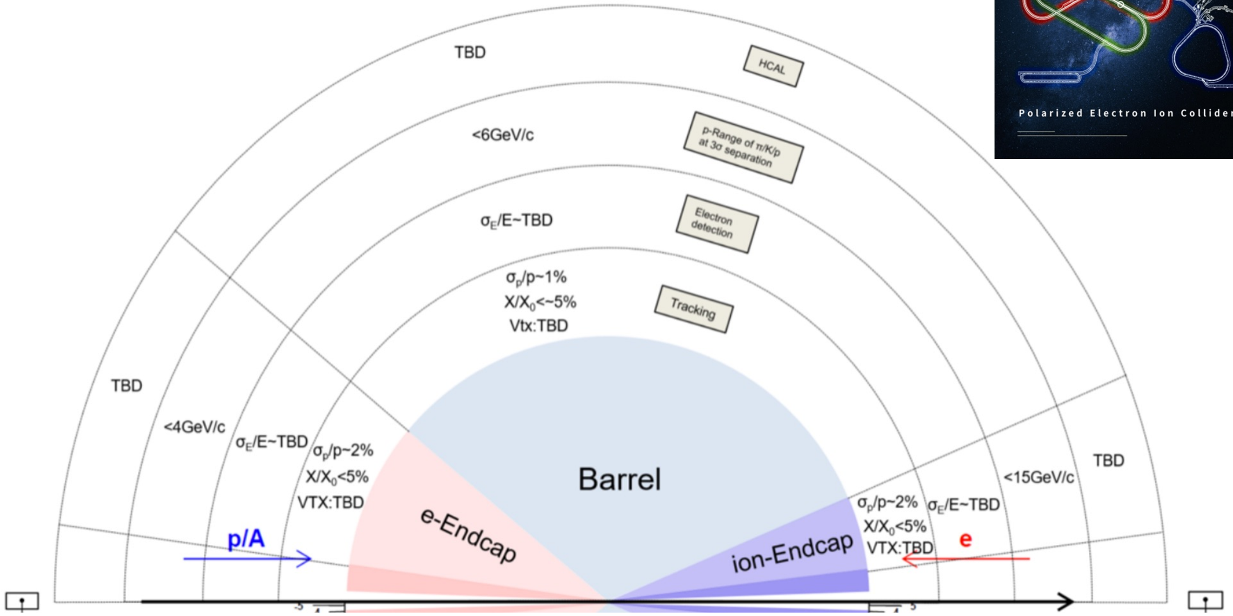




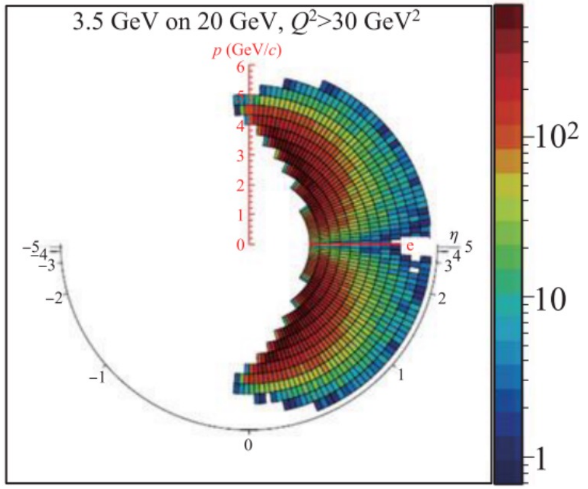
Requirements

The primary physics topic is spin physics, we need to explore the DIS, SIDIS, DVCS etc.

- the scattered electrons provide crucial information to most of processes
- The hadrons in the final states are essential for SIDIS, HF, etc.
- A rough requirement is set →
- More efforts are needed to draw a **crystally clear conclusion** !



Region	η	δp	δDCA	Material Budget (X/X_0)	Physics Program
Barrel	[-1,0]	<1%	Cell 2,4	<5%	Exotics, etc.
	[0,1]	<1%	Cell 3,4	<5%	Cell 3,6
Ion-going	[1,2]	<2%	Cell 4,4	<5%	Gluon PDF, etc.
	[2,3.5]	<5%	Cell 5,4	<5%	Cell 5,6
Electron-going	[-1,-2]	<2%	Cell 6,4	<5%	Cell 6,6
	[-2,-3.5]	<5%	Cell 7,4	<5%	DIS, etc.



The momentum resolution

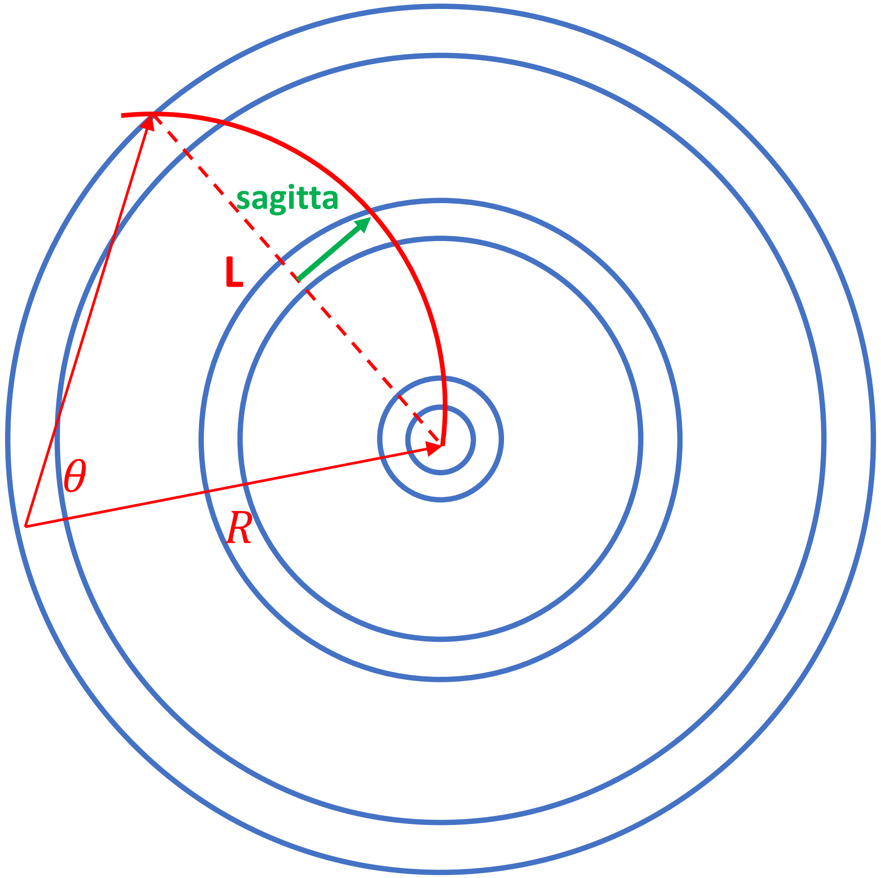
The momentum of a charged track is determined by its trajectory (curvature)

- The formula: **p = 0.3 RB**, R is the radius of the track, B is the intensity of the magnetic field
- Practically, we measure the sagitta to determine the R:

$$s = R\left(1 - \cos\frac{\theta}{2}\right) = 0.3BL^2/8p$$

- The relative momentum resolution is:

$$\frac{\sigma_p}{p} = \frac{\sigma_s}{s} = \frac{8p}{0.3BL^2}\sigma_s$$



To improve the momentum resolution:

- Reduce σ_s:
  - **Reduce Multiple-scattering effect**
  - Better detector spatial resolution
- Increase intensity of B field. Downside → lower tracking efficiency (low p)
- **Increase scale of detector L**. Downside → higher cost
- The momentum resolution is proportional to p

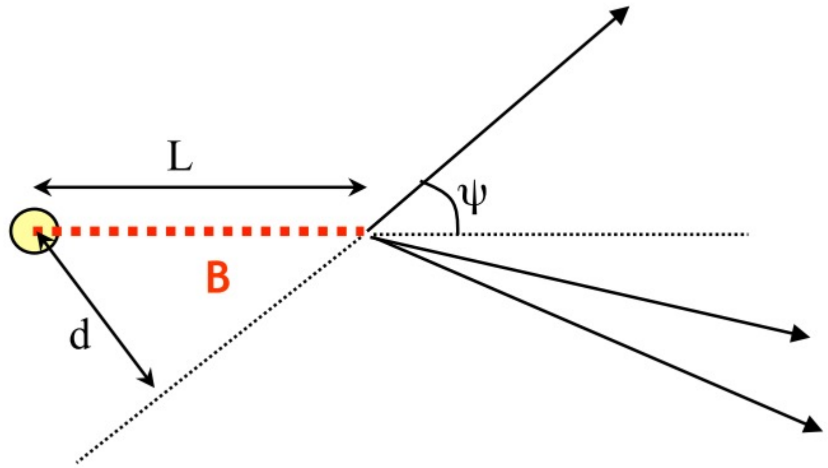
Vertex resolution

The impact parameter d：

- $d = L sin\psi$
- ψ is due to multiple-scattering and detector resolution

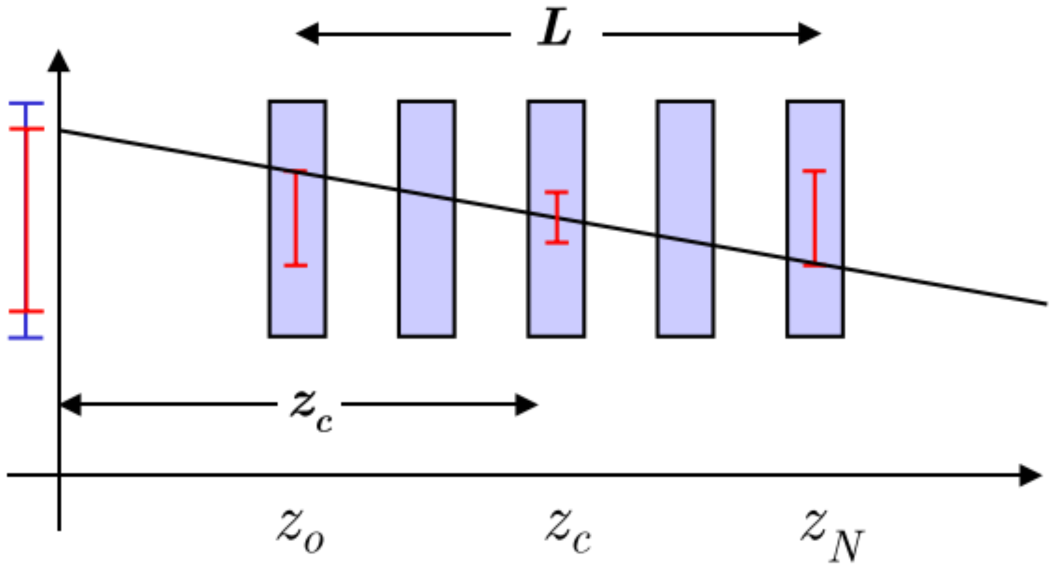
- In the case of equal spacing detector and equal errors σ
- The uncertainty of measurement on vertex (details in backup):

$$\sigma_{vertex}^2 = \frac{\sigma^2}{N+1} + \frac{\sigma^2}{N+1}\frac{12N}{N+2}\frac{Z_c^2}{L^2}$$



To improve the vertex resolution:

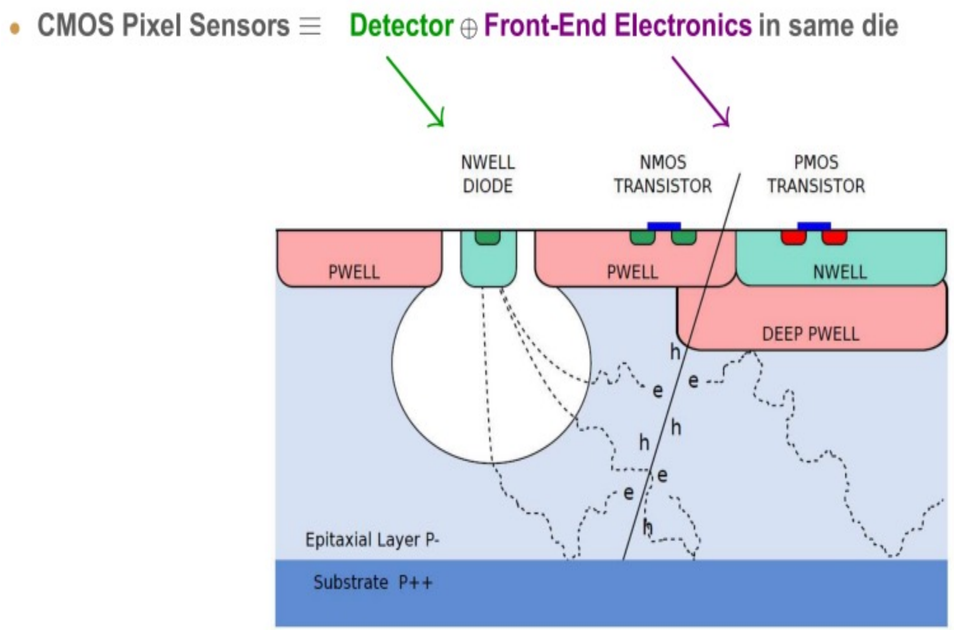
- Reduce σ:
  - **Reduce Multiple-scattering effect**
  - Better detector spatial resolution
- **Increase scale of detector L.**
- **Reduce Z_c : Place the first plane as near as possible to the IP**
- Increase the number of points, only as $\sqrt{N+1}$

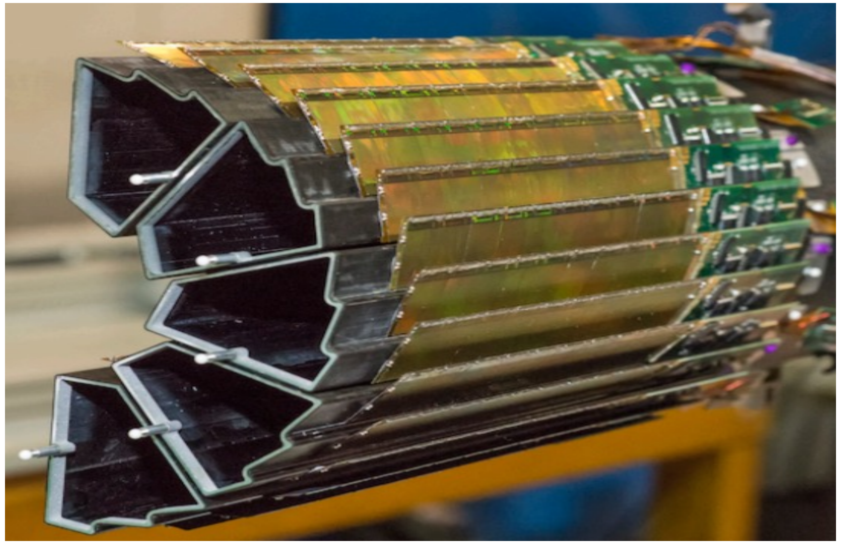


Technologies

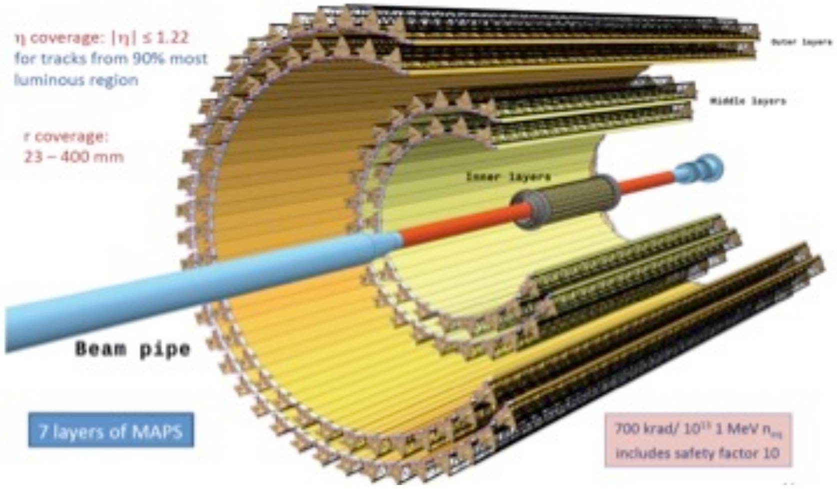
- **Vertex + inner tracker**
  - Exellent spatial resolution
  - Low material
  - Raidation hardness

The Monolithic Active Pixel Sensor (MAPS)





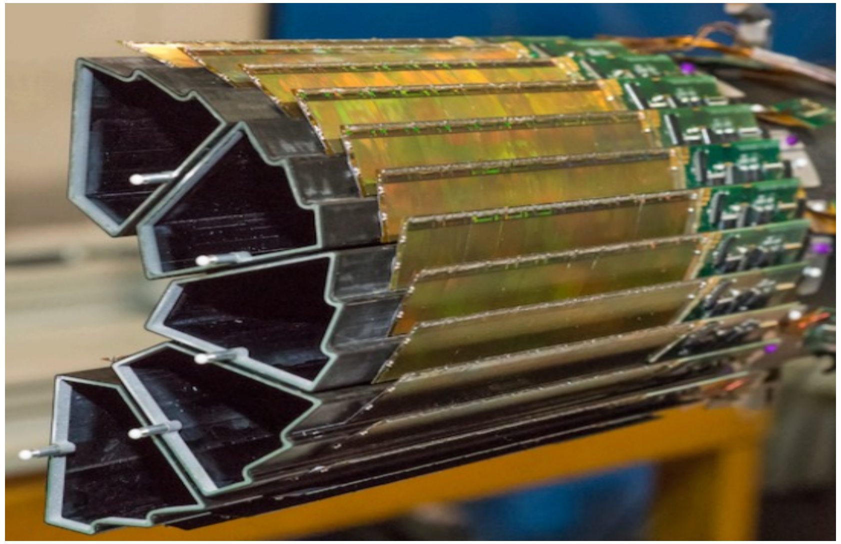
STAR HFT（世界上首个像素探测器）
400片MAPS, 360M pixels



ALICE ITS 探测器 （目前最大规模像素探测器）
24142块MAPS, ~10㎡，12.5G pixels

Technologies

- **Vertex + inner tracker**
  - Exellent spatial resolution
  - Low material
  - Raidation hardness



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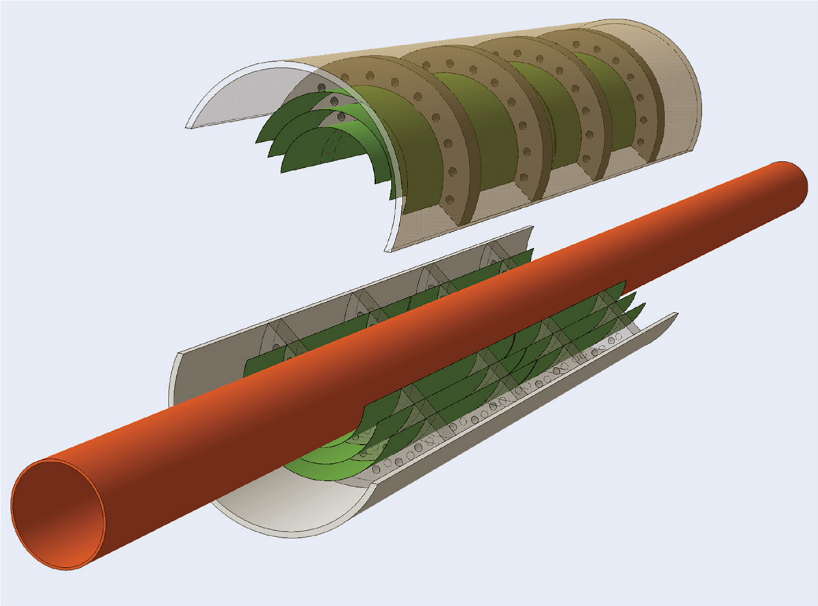
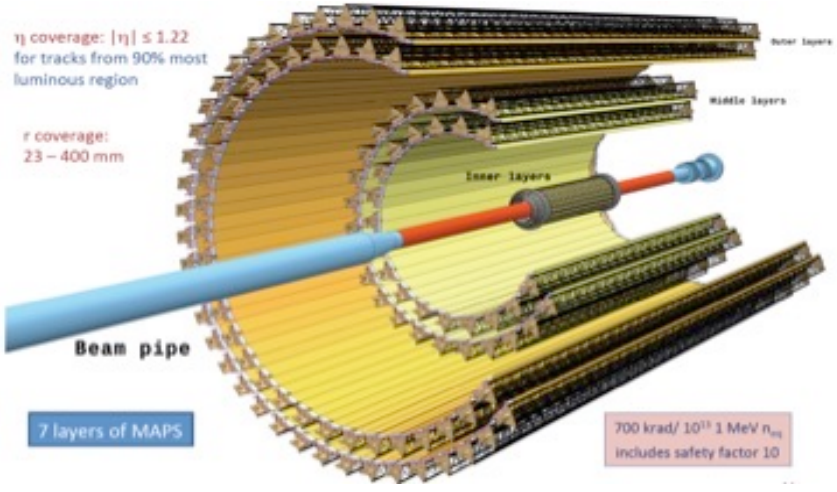


ITS3 (MIC7)

Pixel size: 10 μm

Material: 0.05% X/X0



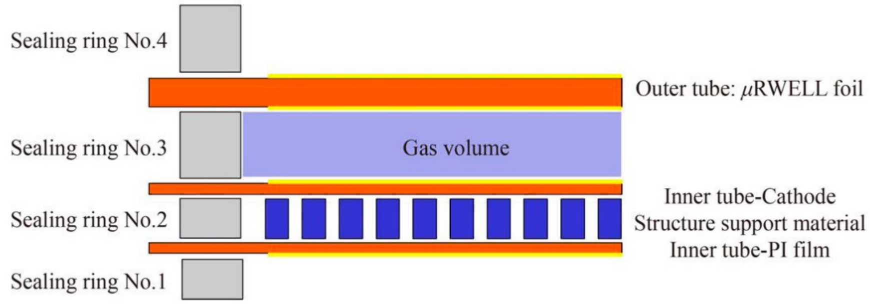
ALICE ITS 探测器 （目前最大规模像素探测器）

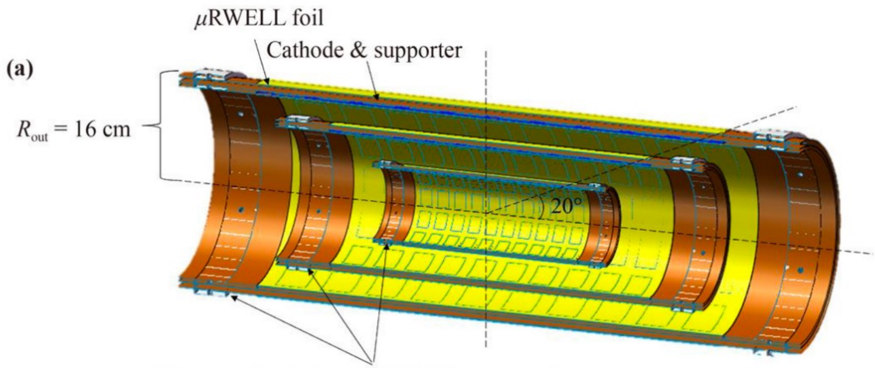
24142块MAPS, ~10㎡，12.5G pixels

Technologies

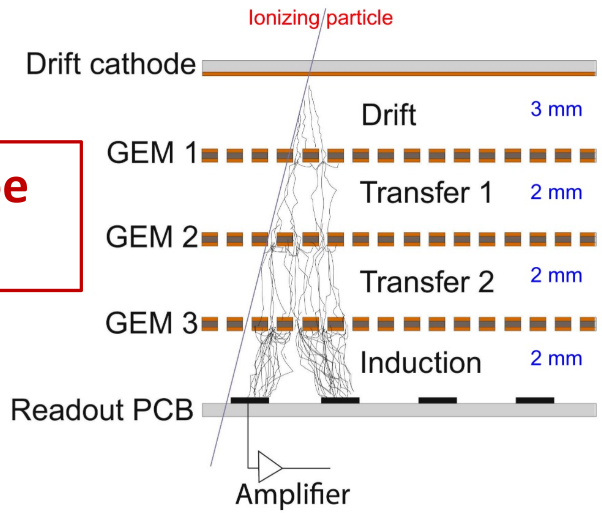
- **Outter tracker**
  - Large area
  - Good spatial resolution

More details can be found in YP's Talk

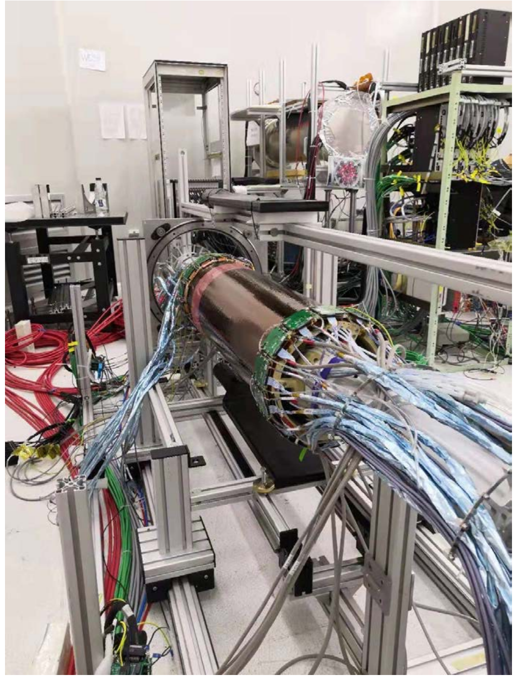




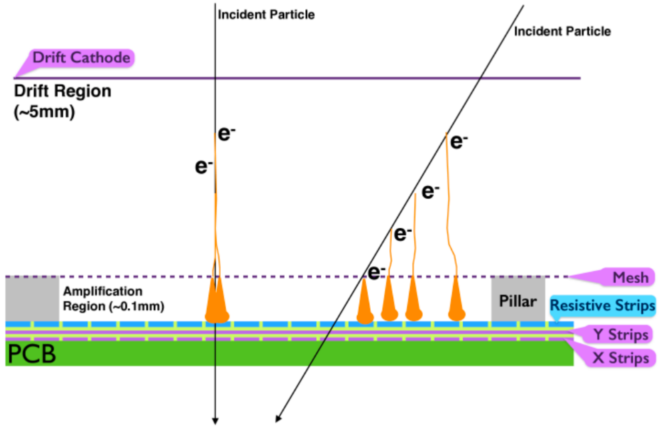
μRWELL for STCF



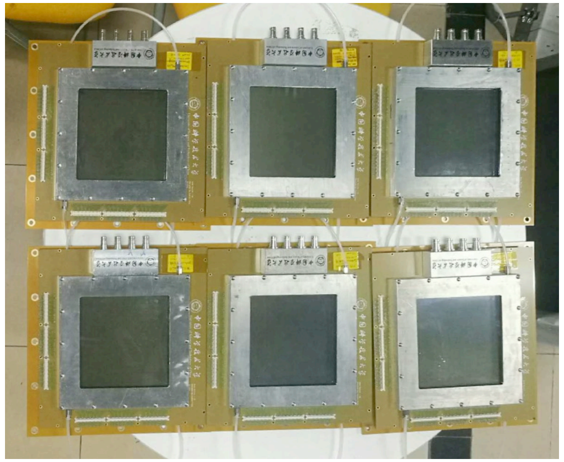
Gas Electron Multiplier (GEM)



CGEM for BESIII



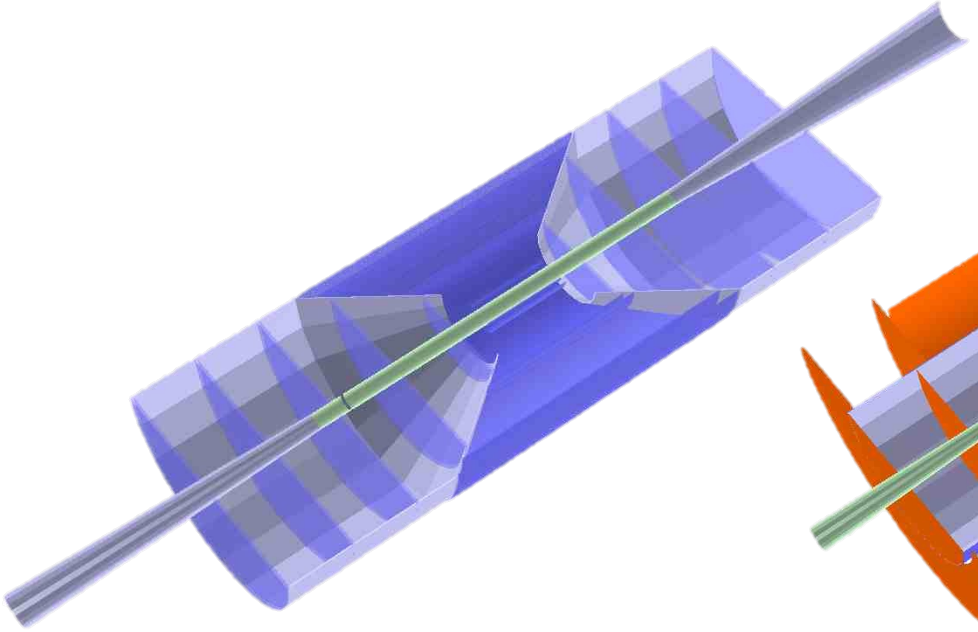
Micromegas



25cm x 25 cm Micromegas

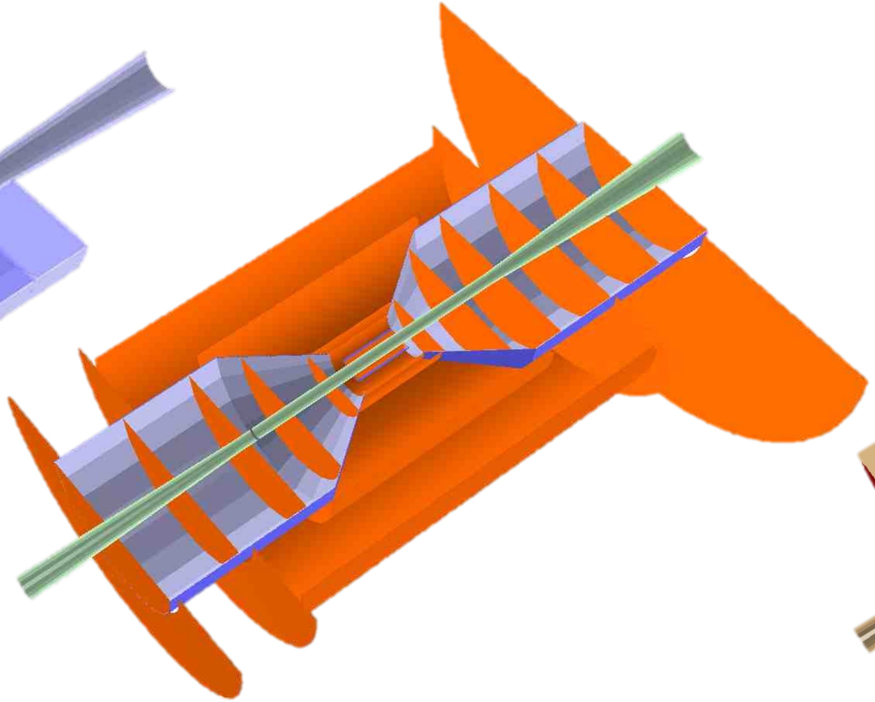
The evolution of the EicC tracker design

Det_v0



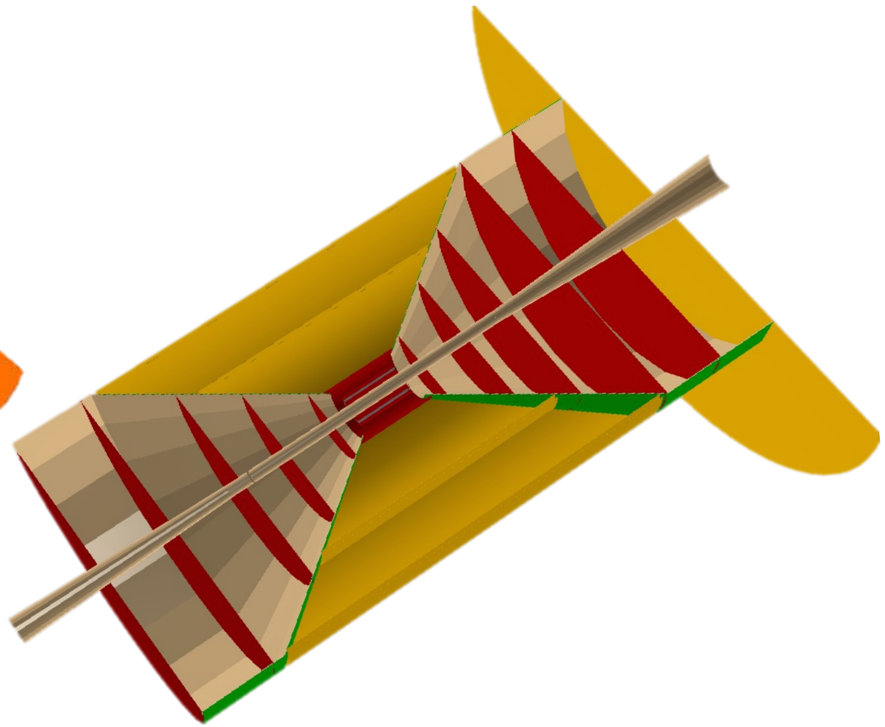
- ➢ All-silicon based on ITS2

Det_v1/2



- ➢ Silicon+MPGD Hybrid design
- ➢ Silicon: vertex ITS3 + tracker ITS2
- ➢ Only the pixel size is different for v1/v2

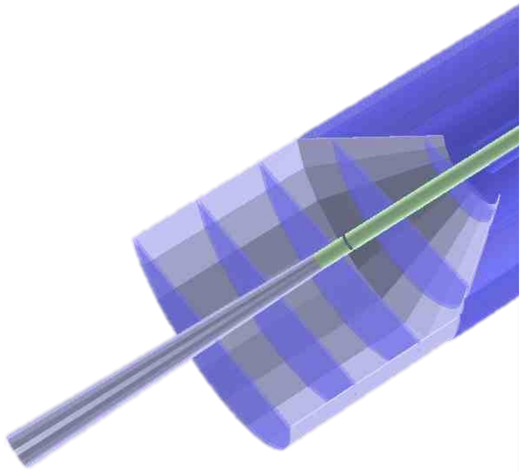
Det_v3

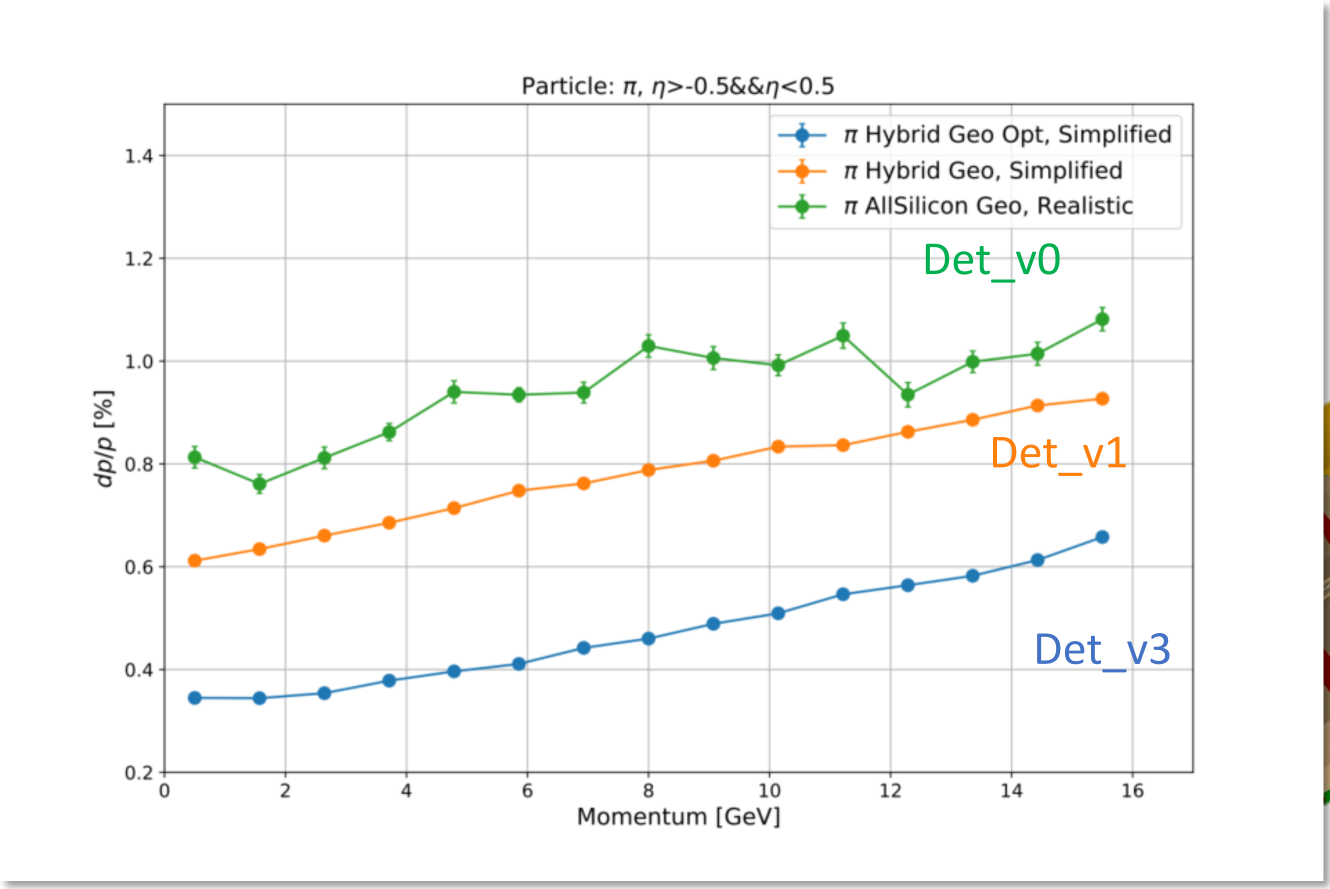


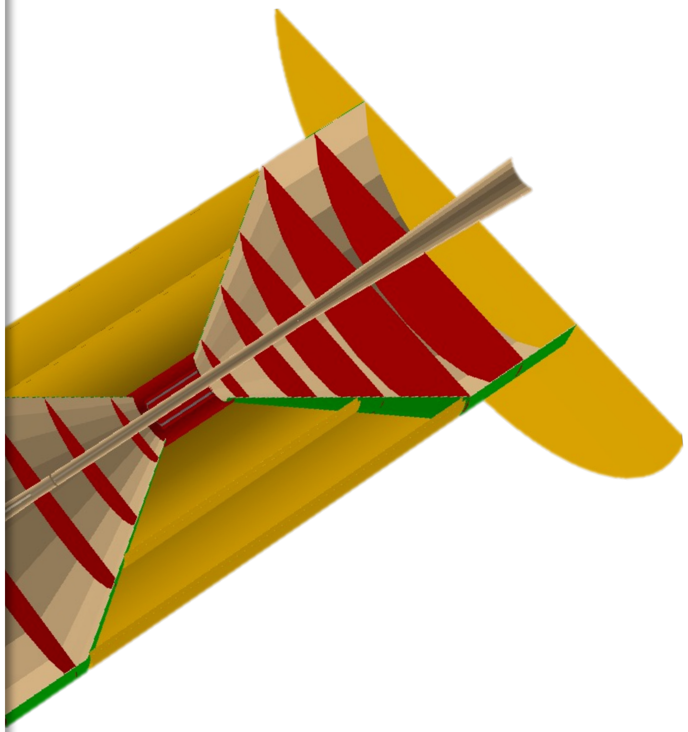
- ➢ Silicon+MPGD Hybrid design
- ➢ Silicon: ITS3
- ➢ Geometry is Optimized

The evolution of the EicC tracker design

Det_v0 **Det_v1/2** **Det_v3**





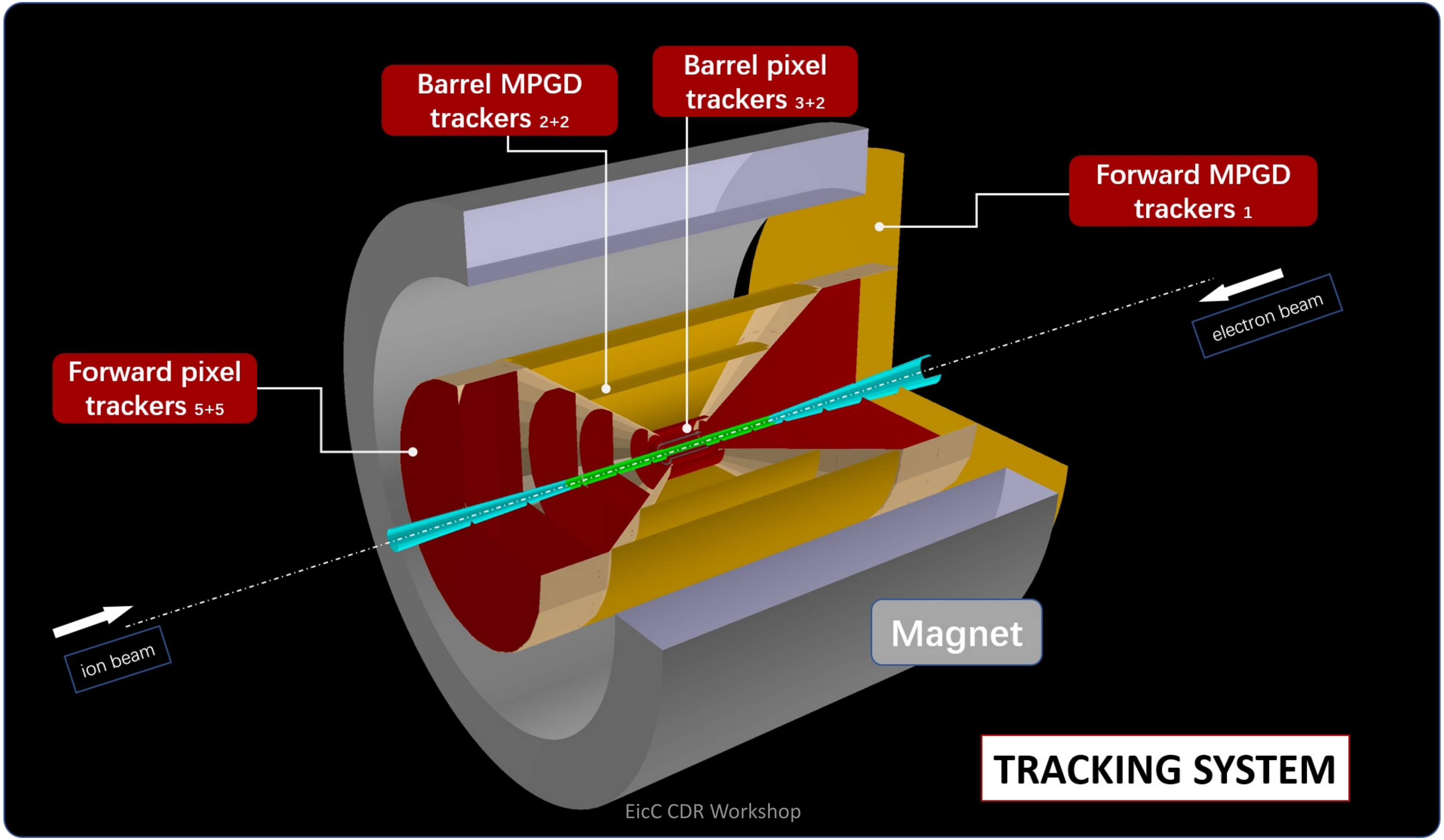


- All-silicon based on ITS2

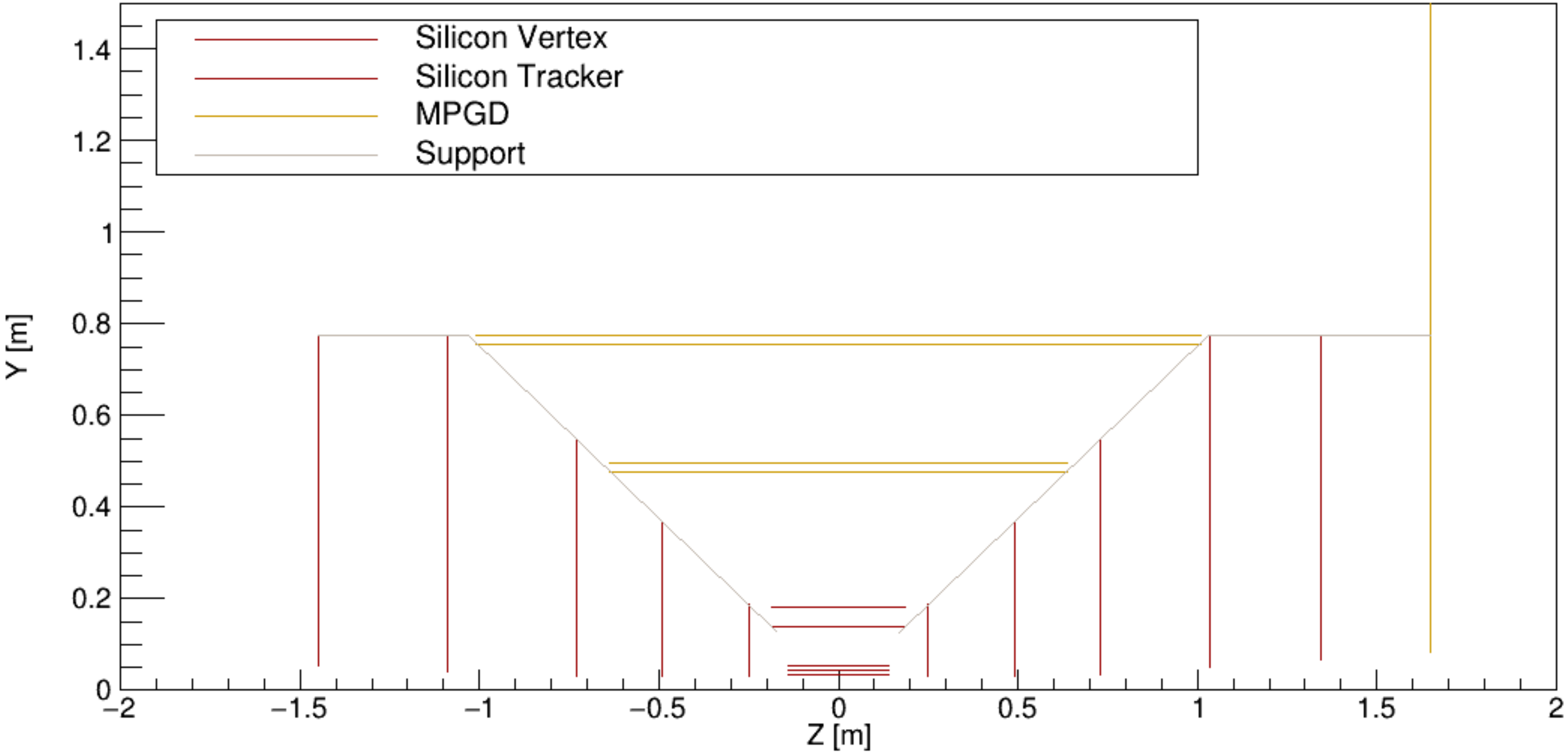
- Silicon+MPGD Hybrid design
- Silicon: vertex ITS3 + tracker ITS2
- Only the pixel size is different for v1/v2

- Silicon+MPGD Hybrid design
- Silicon: ITS3
- Geometry is Optimized

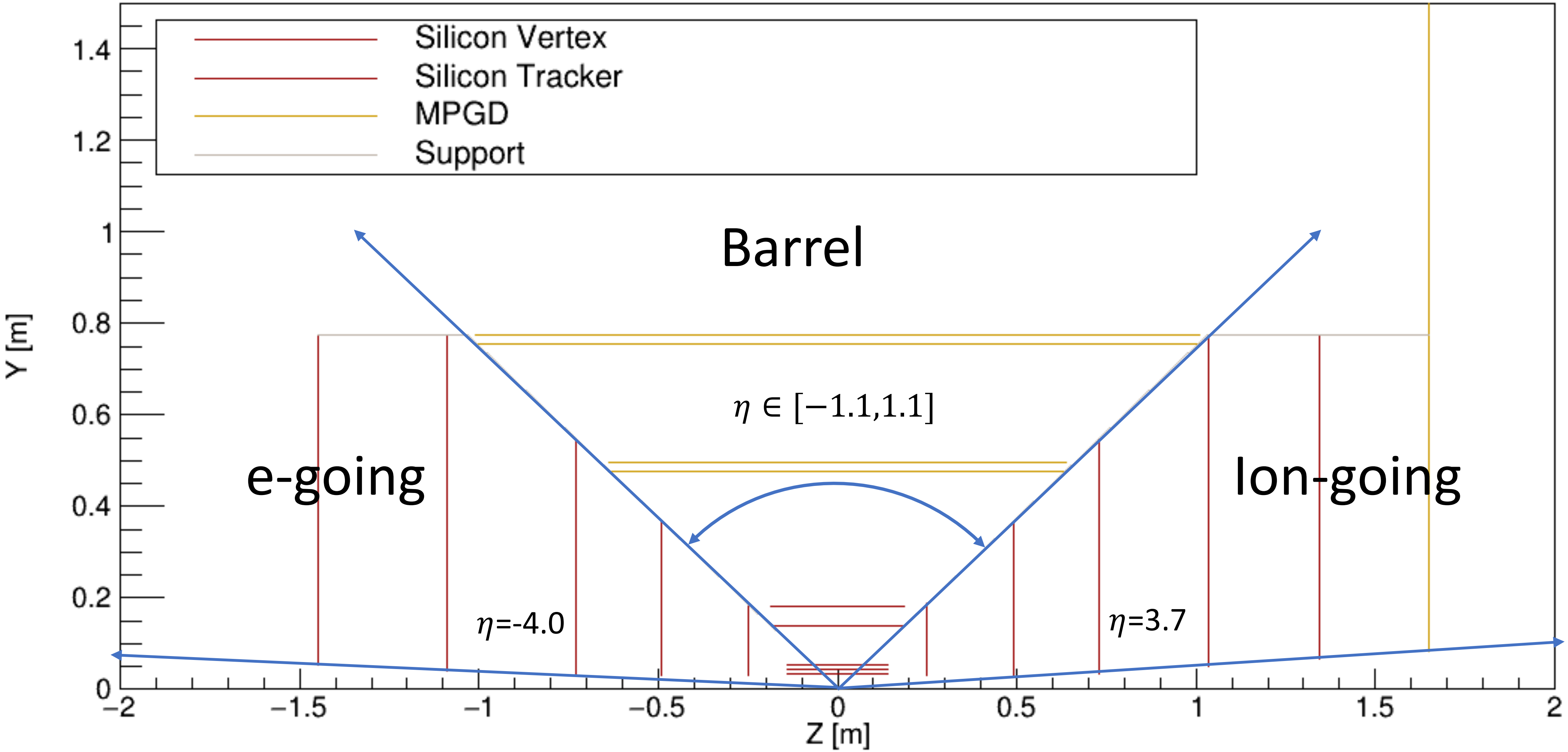
The latest design



The latest design

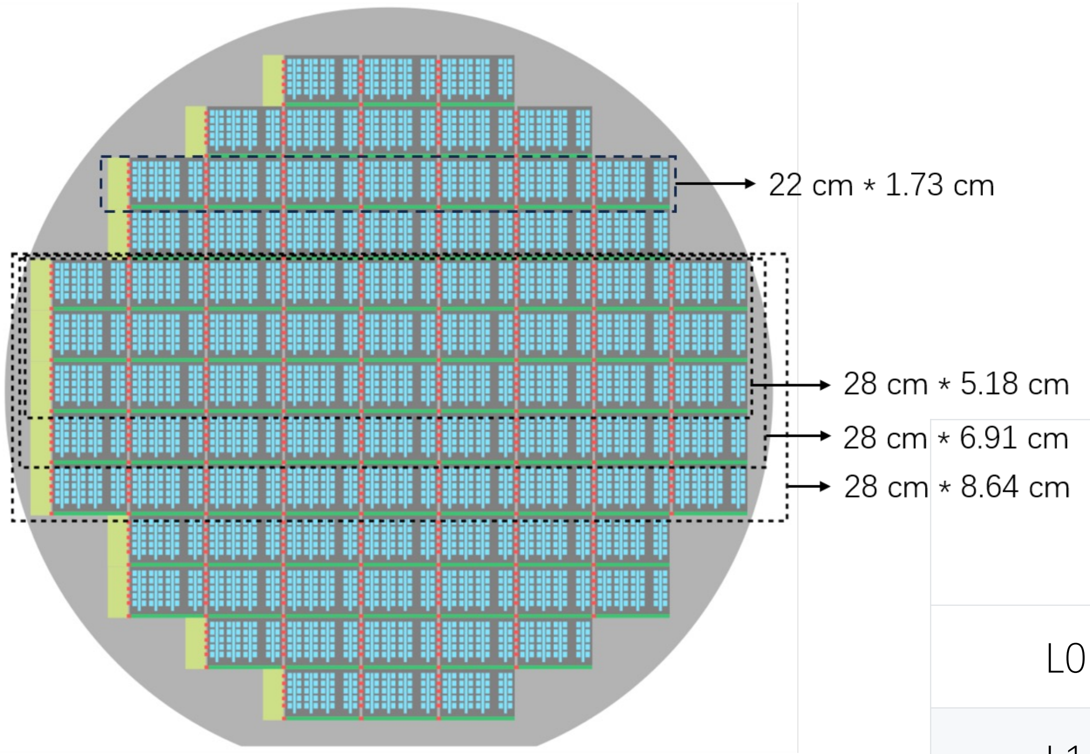


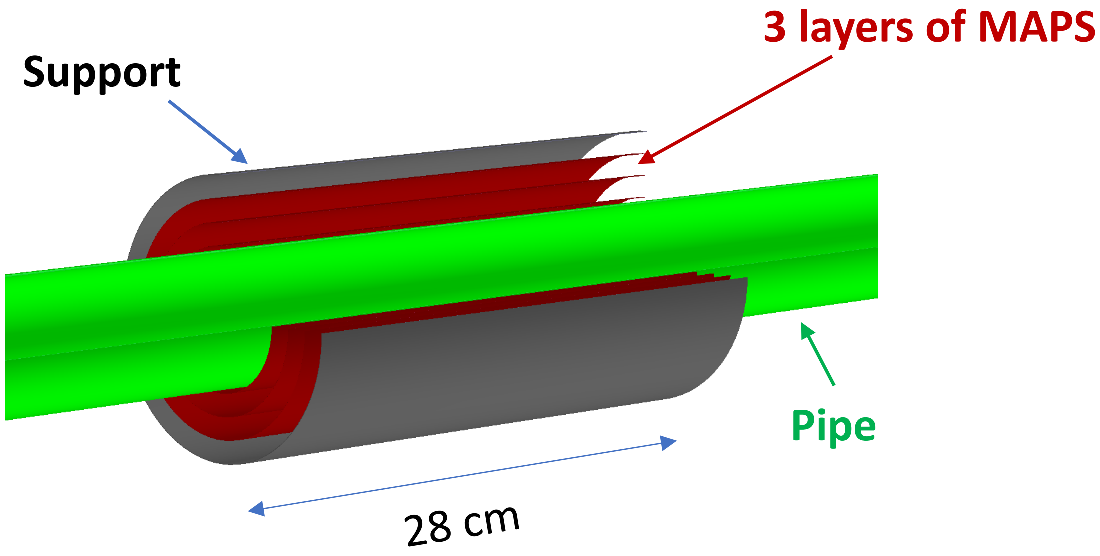
The latest design



Barrel: Vertex

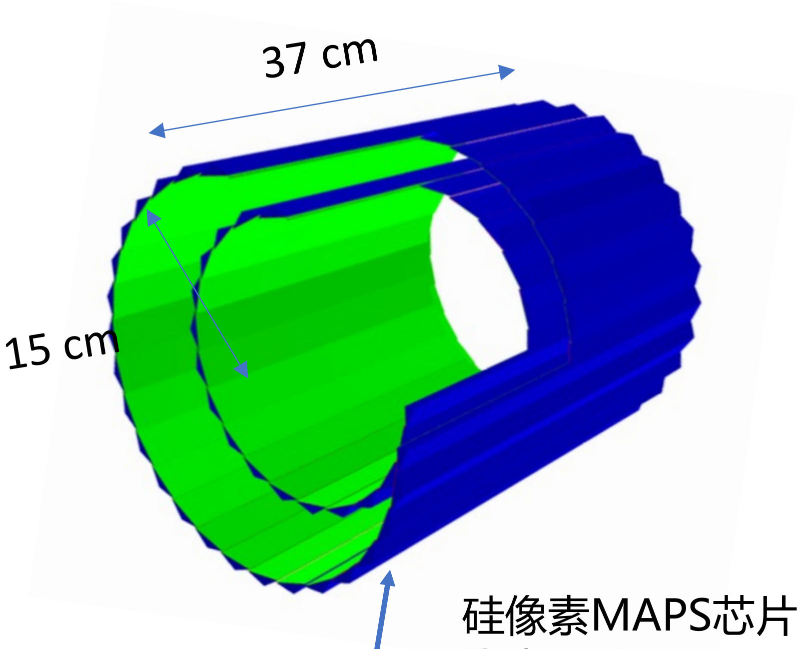
ITS3-based Vertex Detector



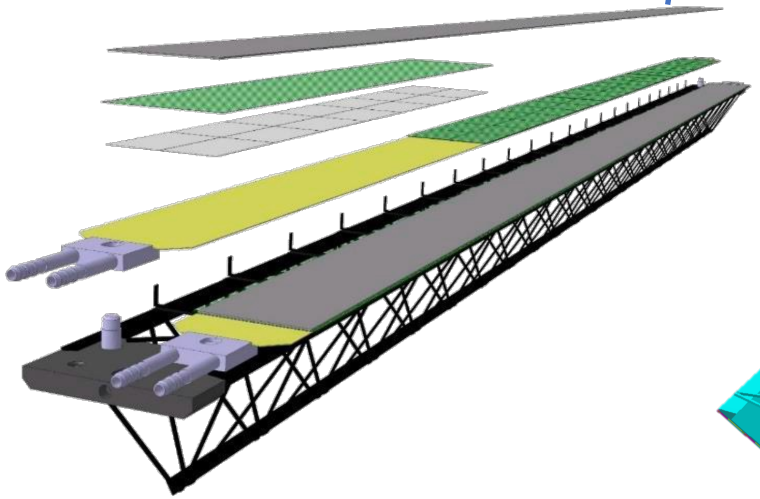


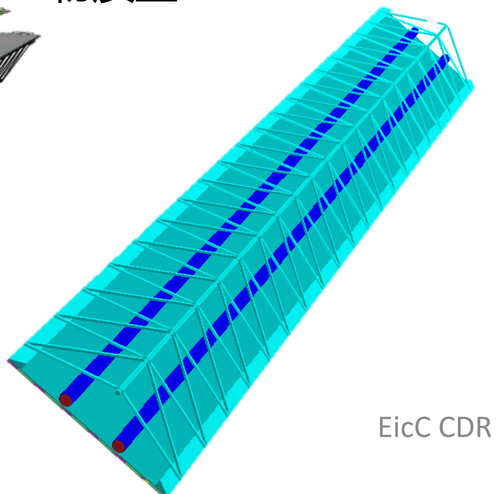
	R(cm)	Length(cm)	Pitch Size(μm)	Material Budget (X/X0 %)	Tech
L0	3.30	28.0	10	0.05	ITS3
L1	4.40	28.0	10	0.05	ITS3
L2	5.50	28.0	10	0.05	ITS3

Barrel: Outer tracker



硅像素MAPS芯片
像素尺寸：~20*20 μm
物质量：0.55%





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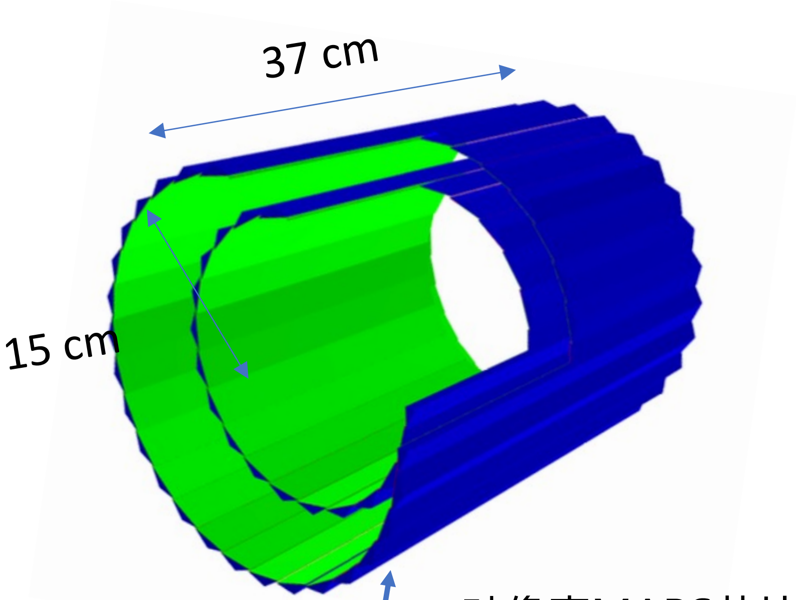

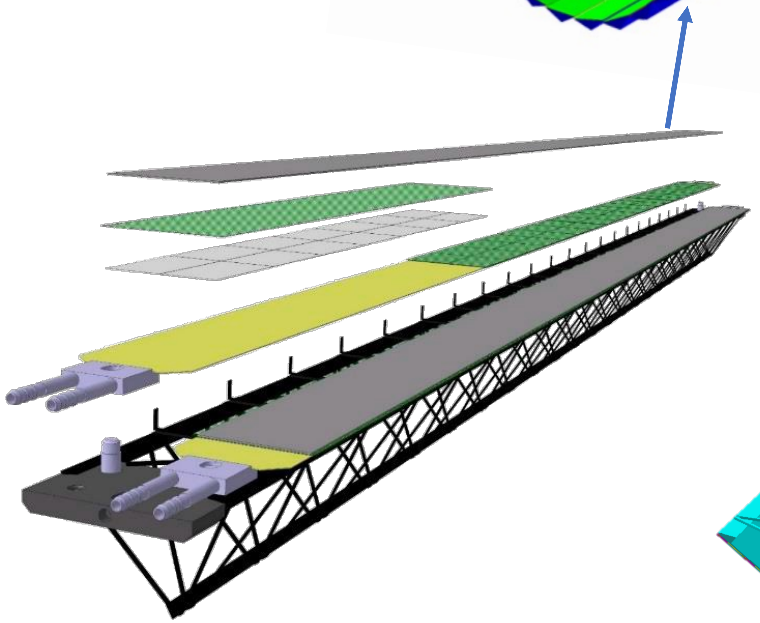

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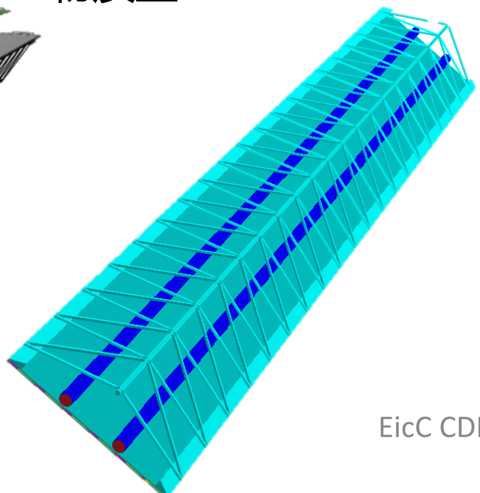
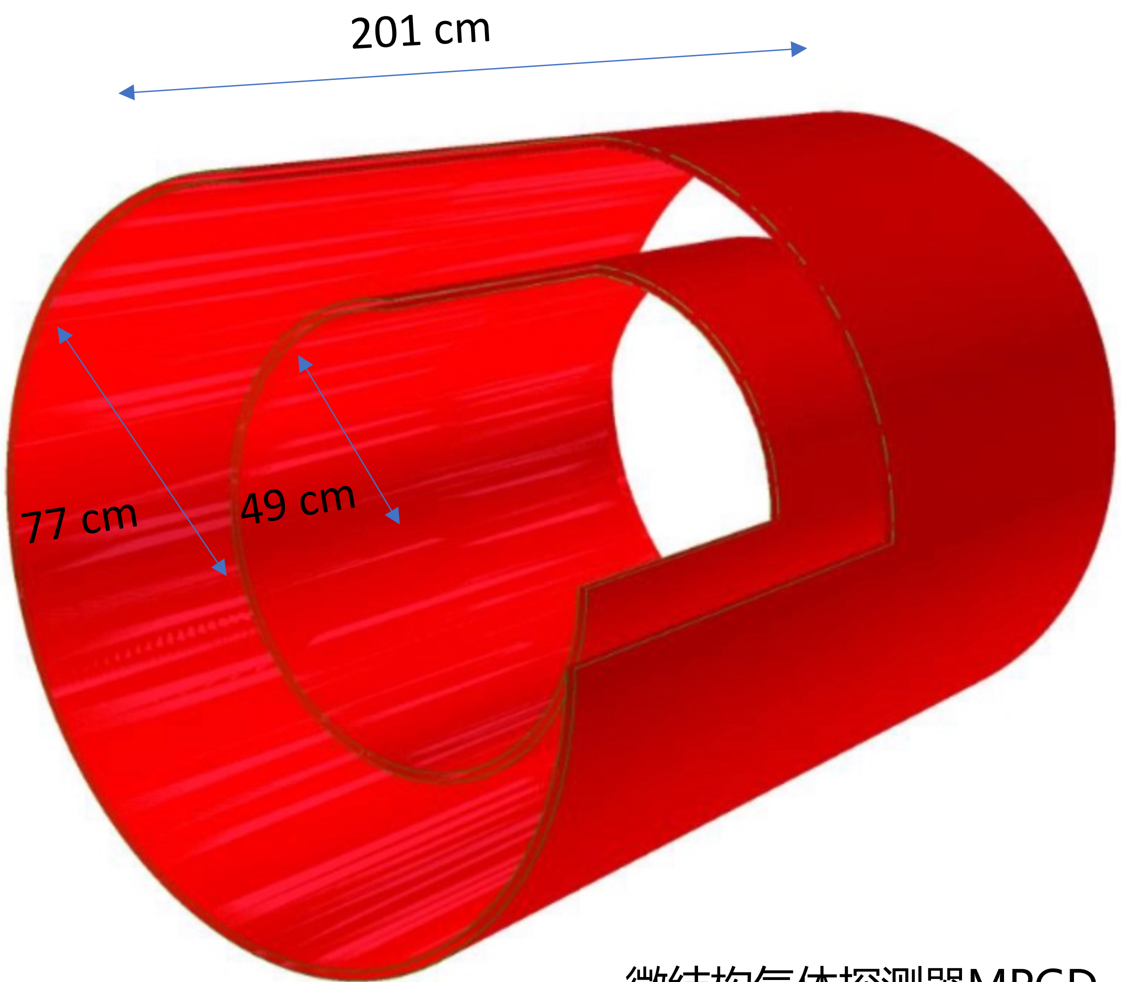
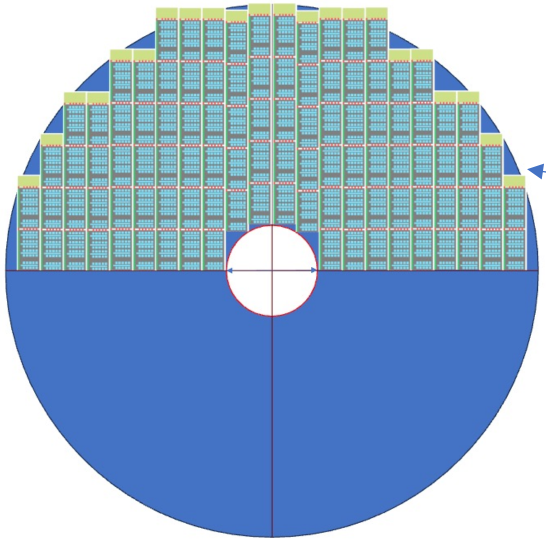
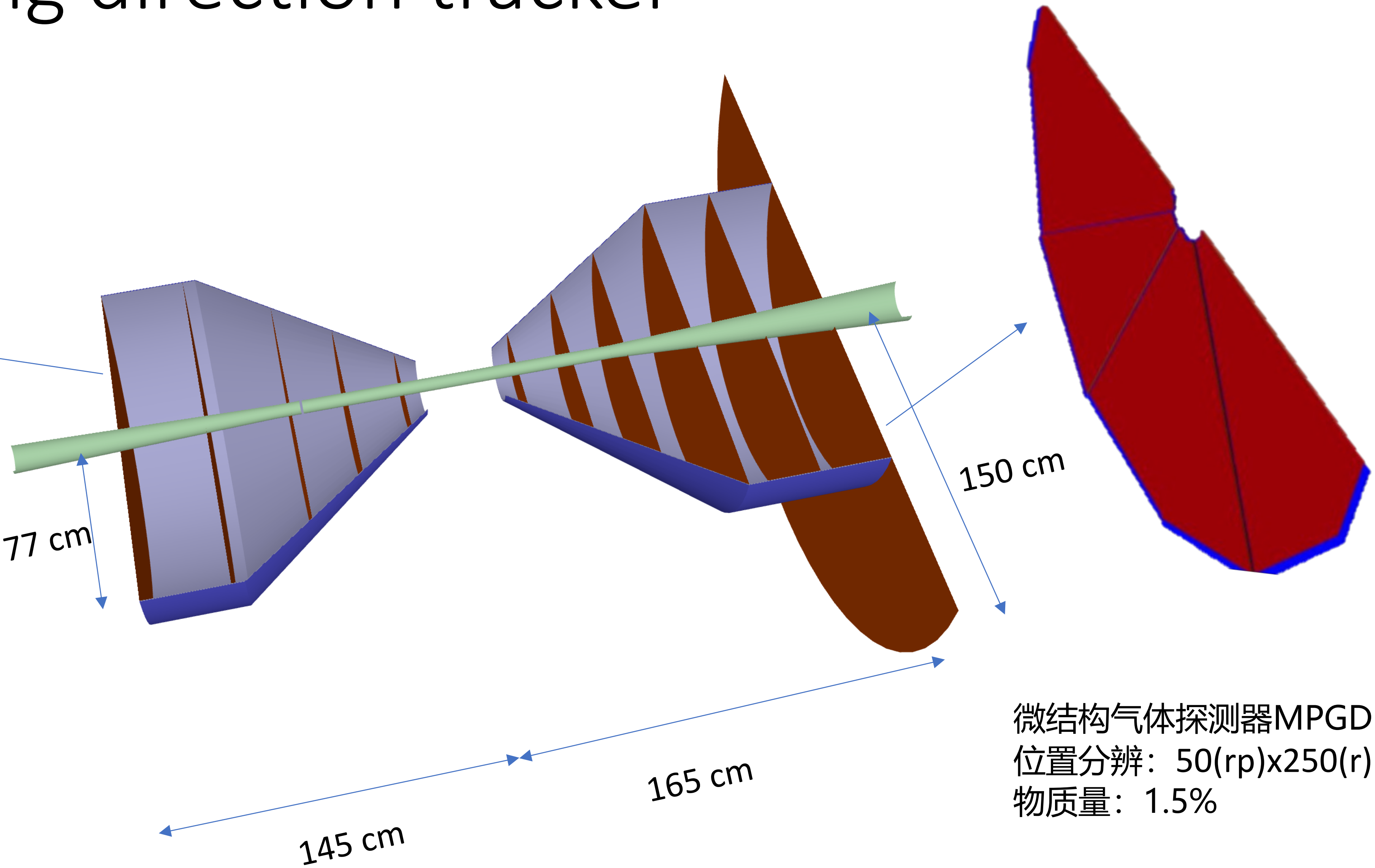




微结构气体探测器MPGD
位置分辨：~150 μm
物质量：<1.5%

Ion(e)-going direction tracker

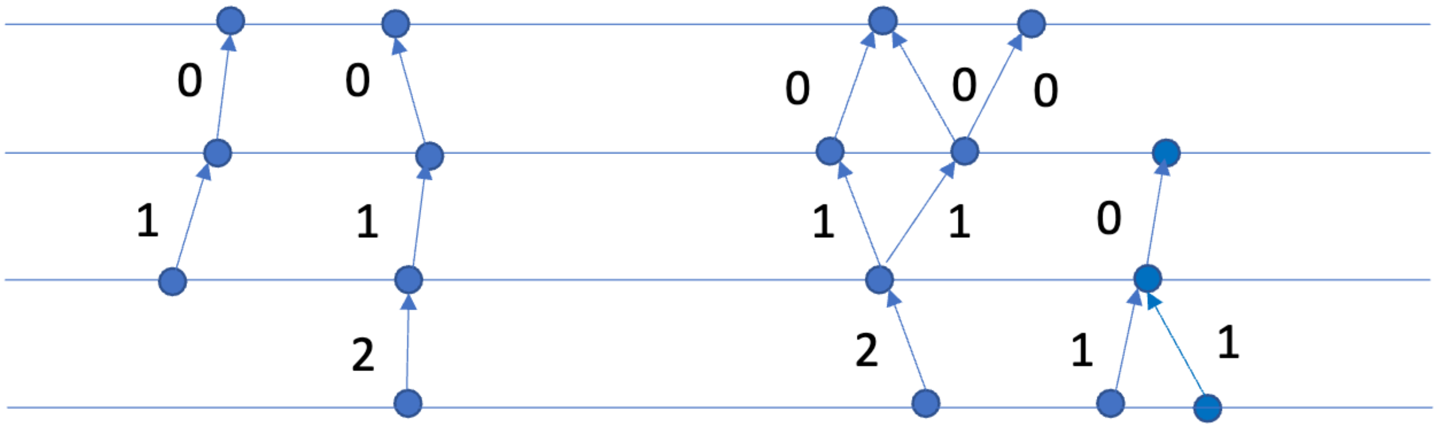




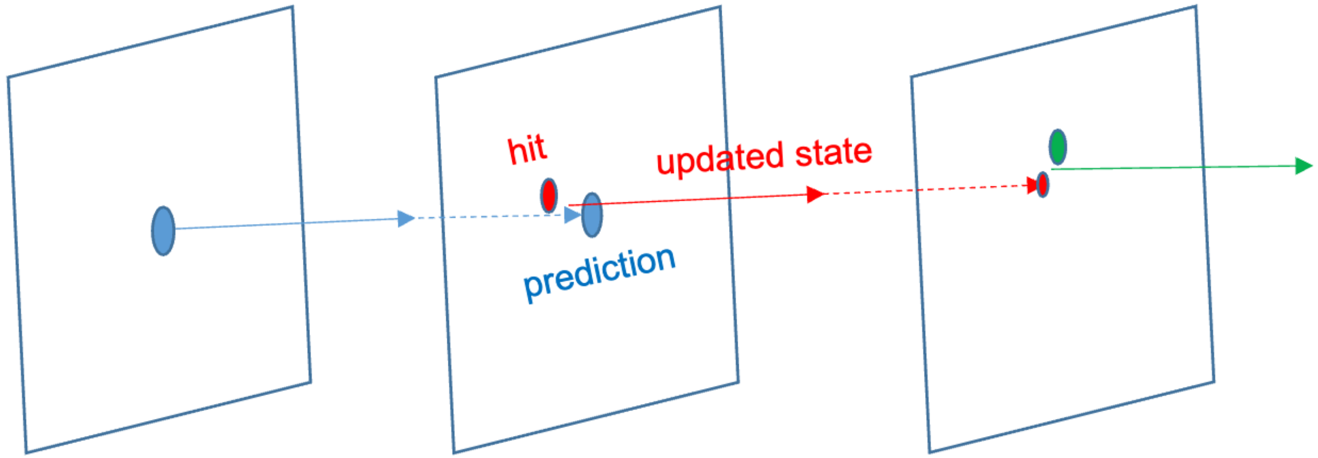
硅像素MAPS芯片
像素尺寸：~20*20 μm
物质量：0.55%

微结构气体探测器MPGD
位置分辨：50(rp)x250(r) μm
物质量：1.5%

Performance study – track finding/fitting



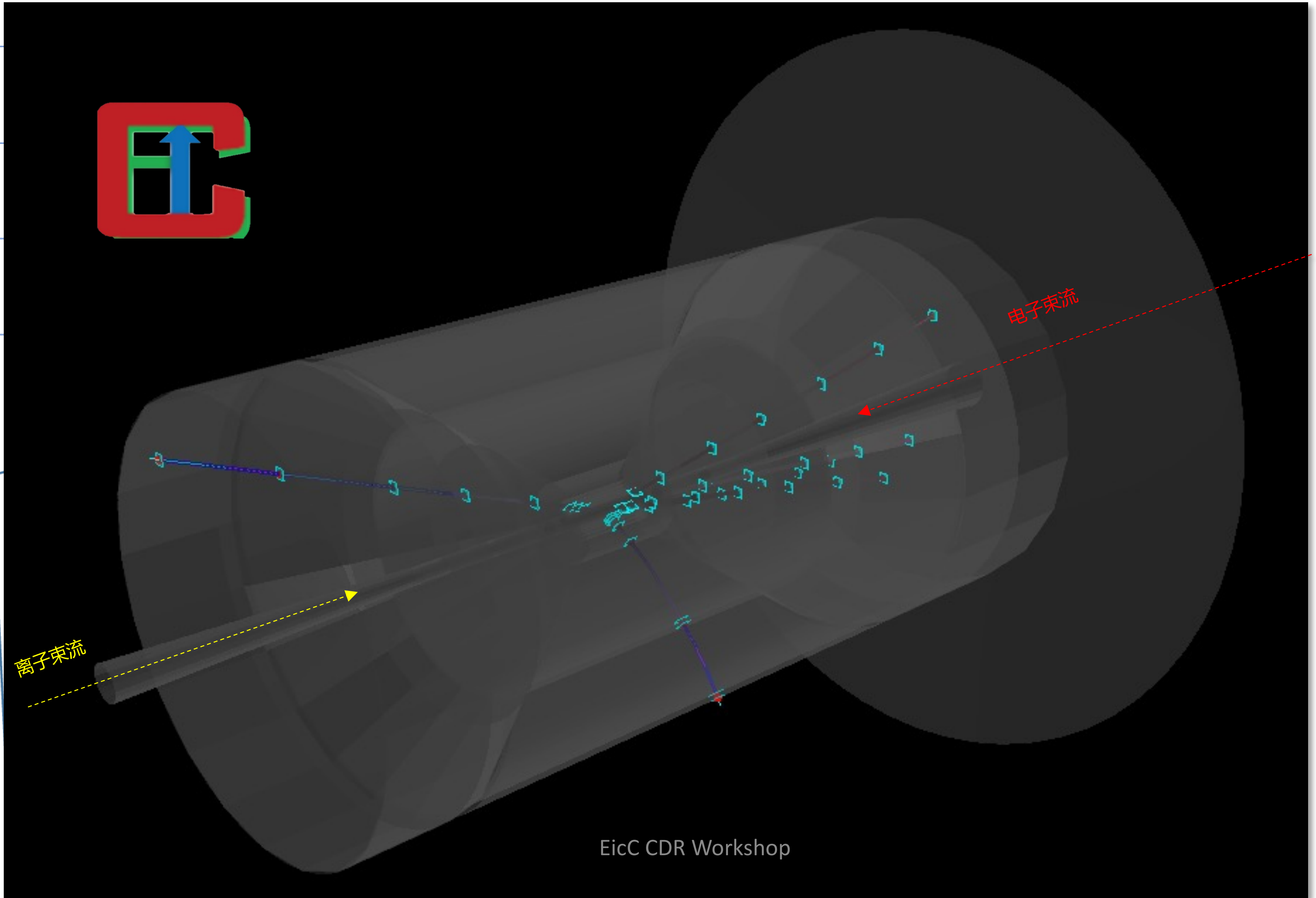
Track finding algorithm is based on Cellular Automaton (On going)



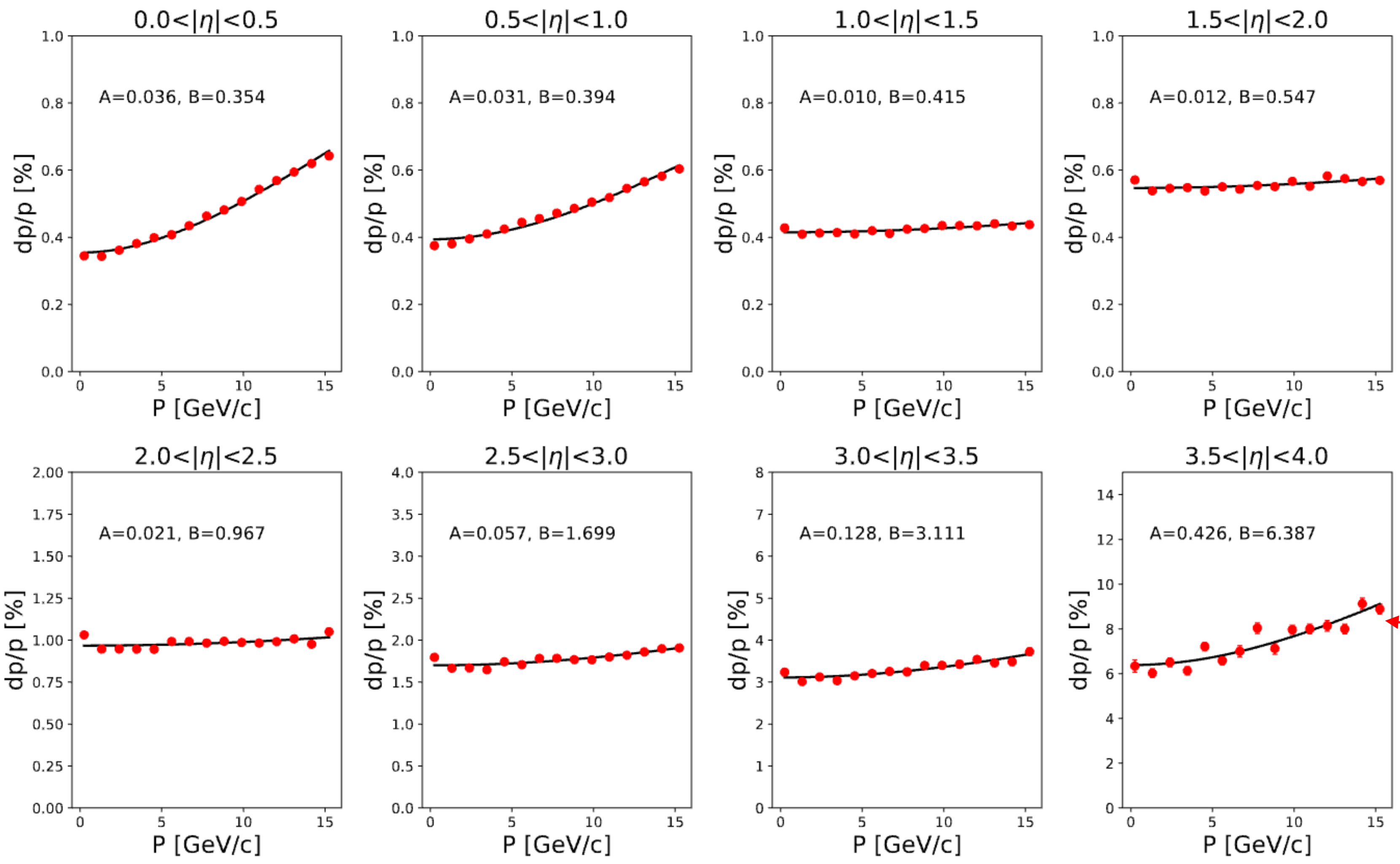
Initial state Detector plane 1 Detector plane 2

Track fitting algorithm is based on Kalman Filter (Finished)

Performance study – track finding/fitting

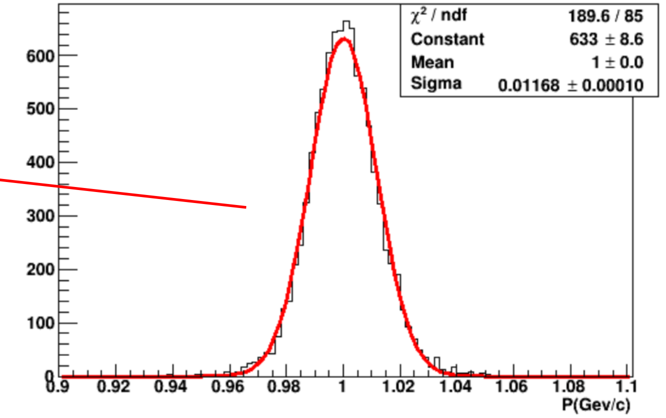


Performance study – momentum resolution

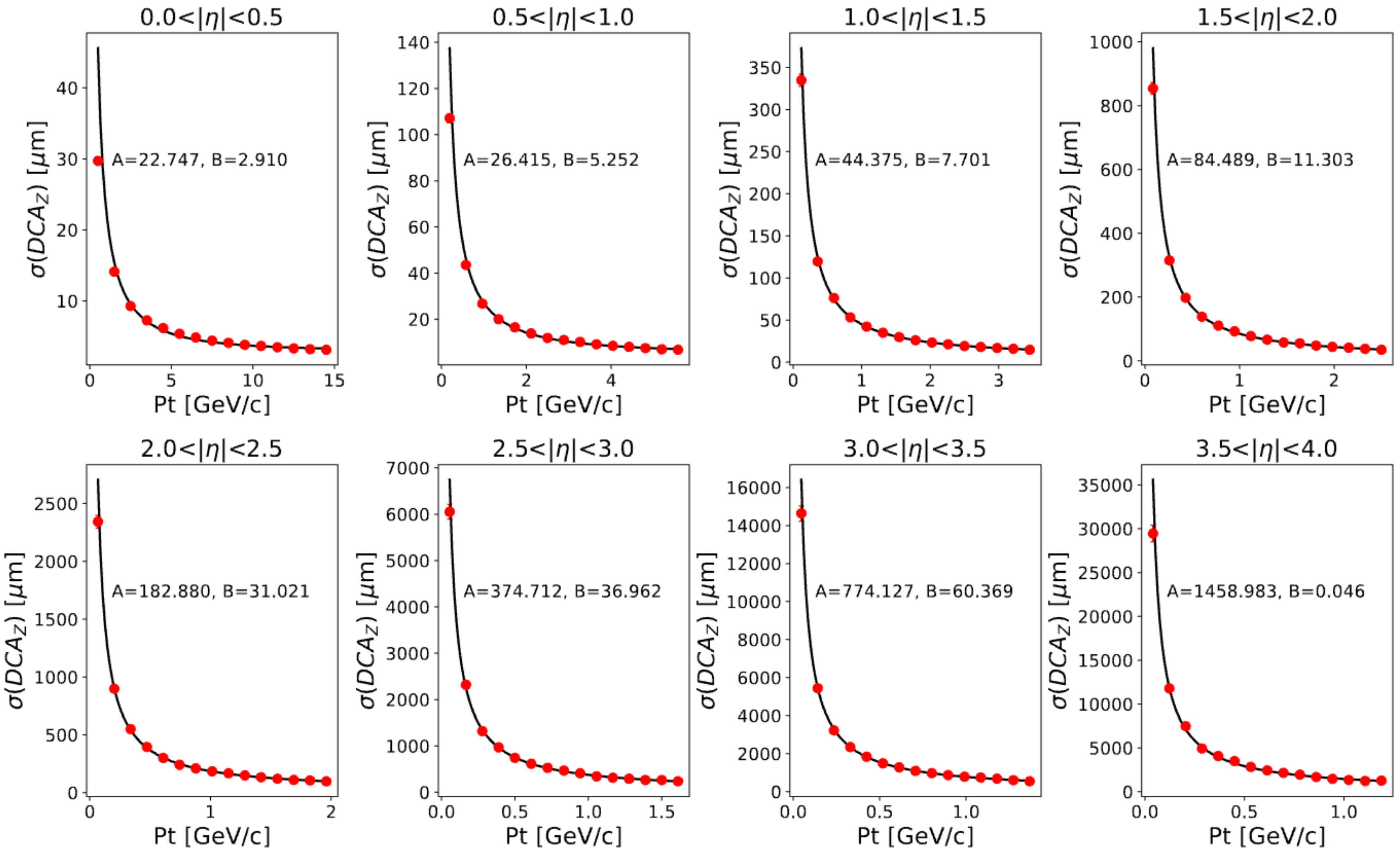


dp/p at different η, and parameterized as

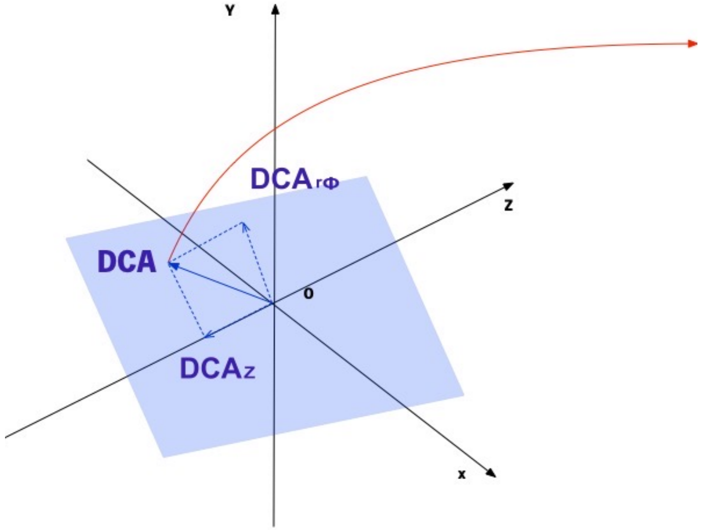
$$\mathrm{dp/p} = Ap \oplus B$$



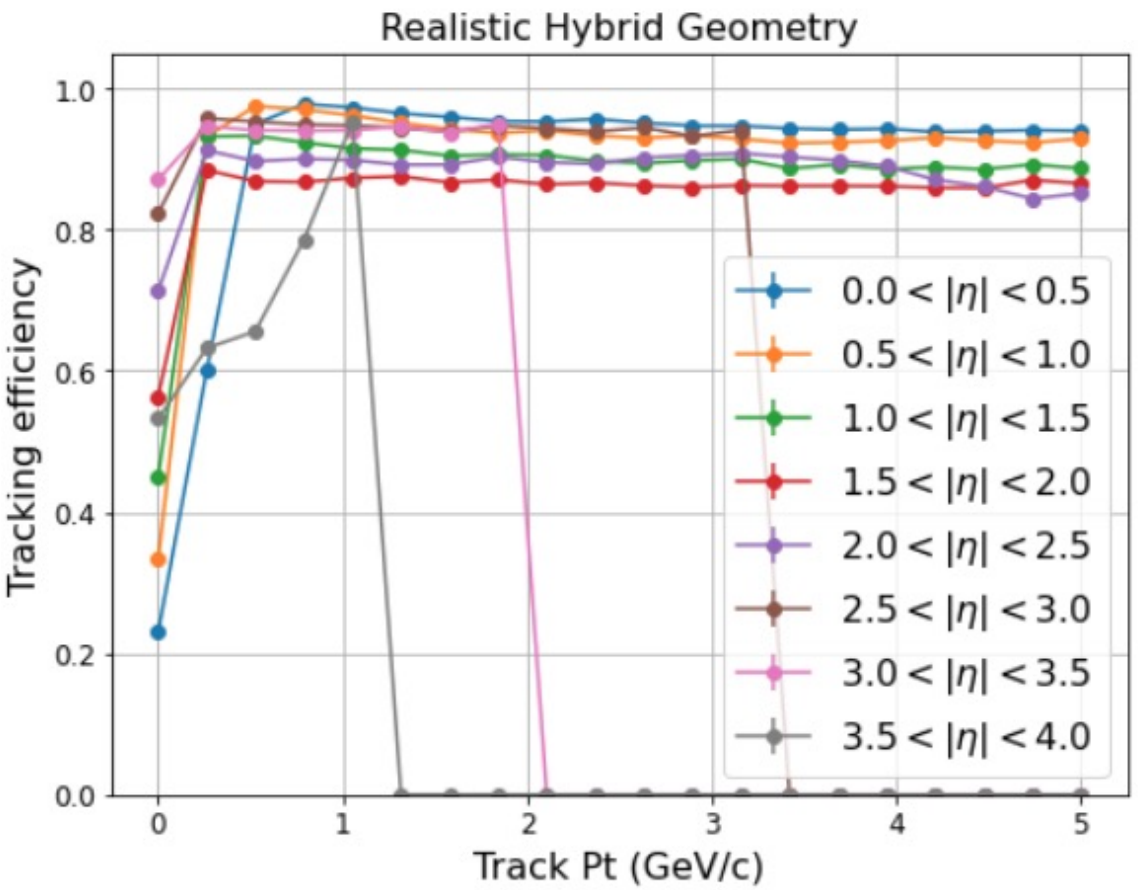
Performance study – DCA resolution

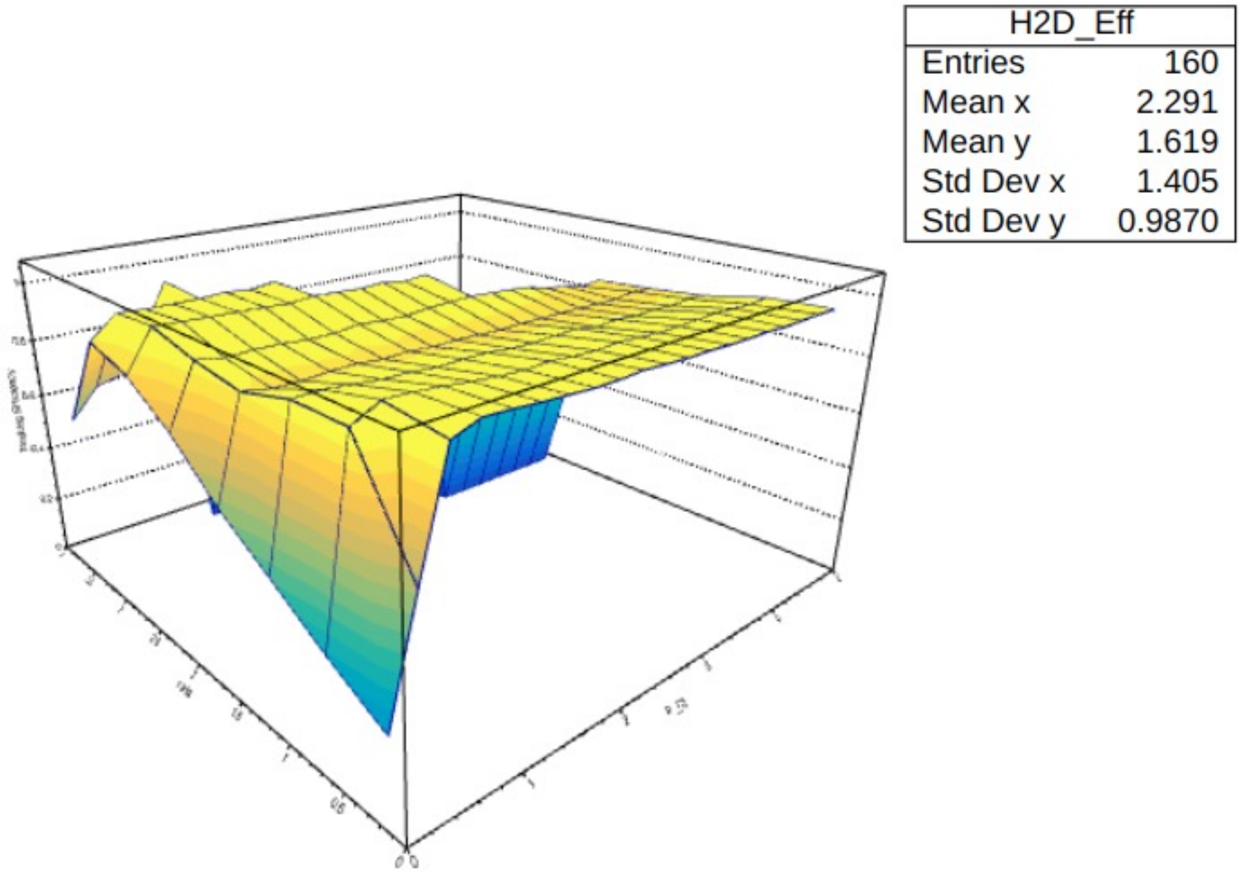


σ(DCA) at different η, and parameterized as σ(DCA)= $A/p_t \oplus B$



Tracking efficiency



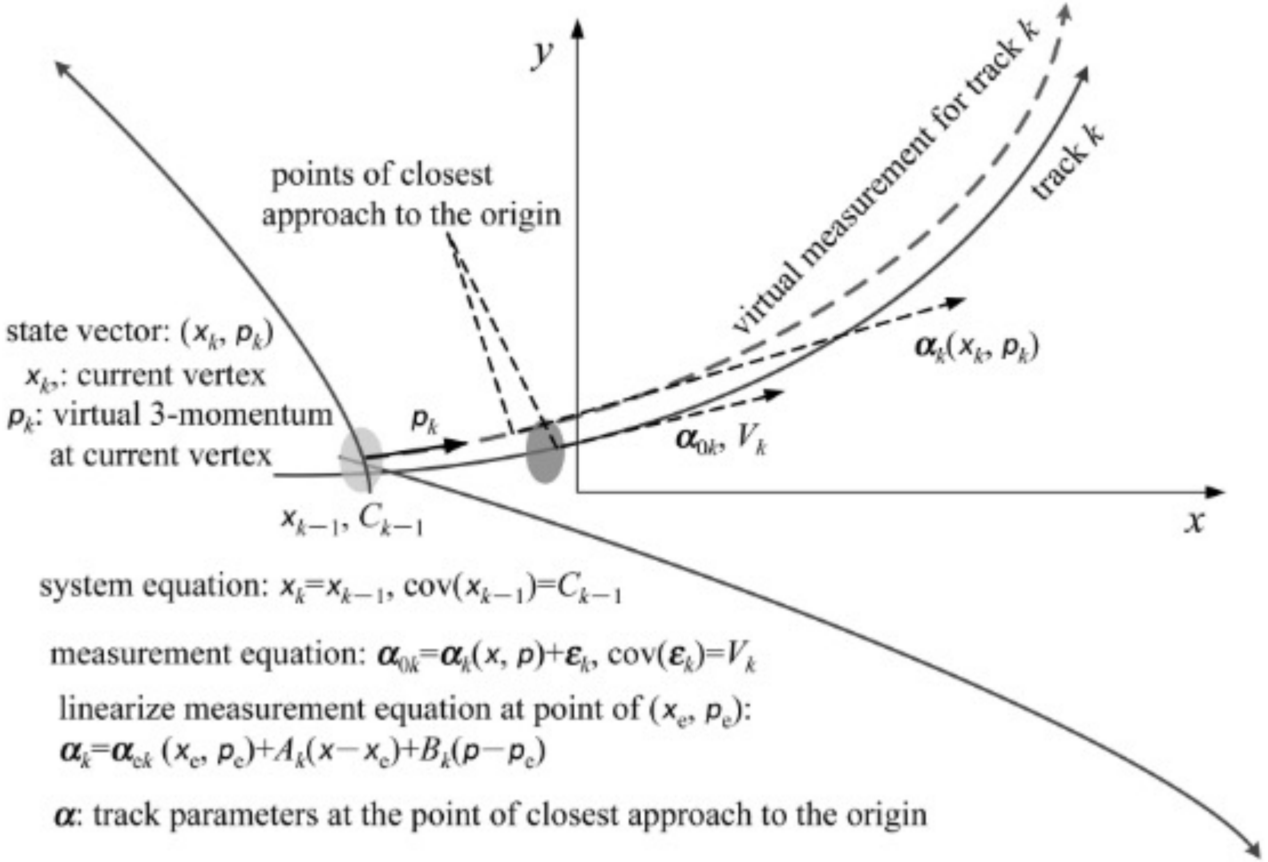


Performance study – vertex reconstruction

- **Strategy:** updating the vertex position and its covariance matrix step by step through adding a new track k
- For a track,
  - State vector (p_k, x_k)
  - Measurement equation: $q_k = \tilde{\alpha}(x, p_k) + \varepsilon_k$
  - Here, $\tilde{\alpha}(x, p_k) \approx \tilde{\alpha}_e(x_e, p_e) + A(x - x_e) + B(p - p_e)$
  - Usually (x_e, p_e) = (x_{k-1}, p_{0k})
  - Define χ^2_{KF}

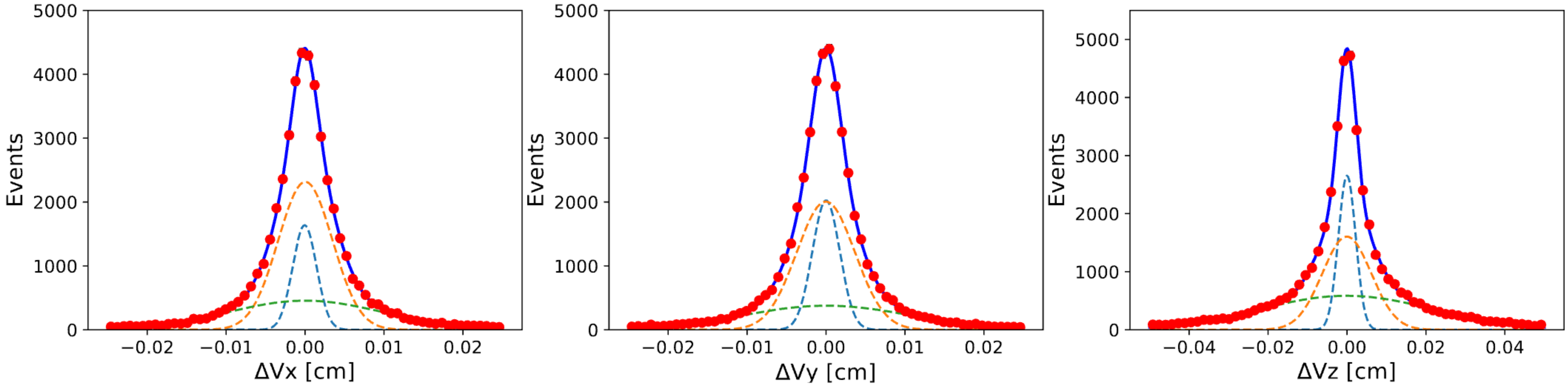
$$\chi^2_{\mathrm{KF}} = (\boldsymbol{x}_k - \boldsymbol{x}_{k-1})^{\mathrm{T}} C^{-1}_{k-1} (\boldsymbol{x}_k - \boldsymbol{x}_{k-1}) + (\boldsymbol{\alpha}_{0k} - \tilde{\boldsymbol{\alpha}}_k)^{\mathrm{T}} G_k (\boldsymbol{\alpha}_{0k} - \tilde{\boldsymbol{\alpha}}_k),$$

  - Minimize χ^2_{KF} and get solution of x_k and p_k



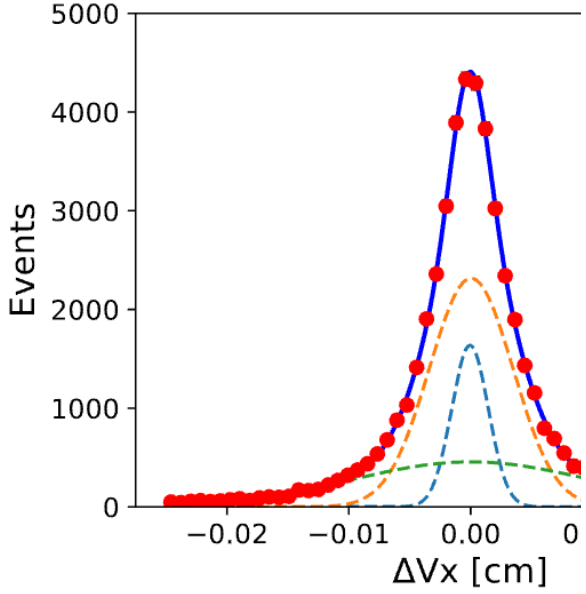
CPC(HEP & NP), 2010, 34(1): 92–98

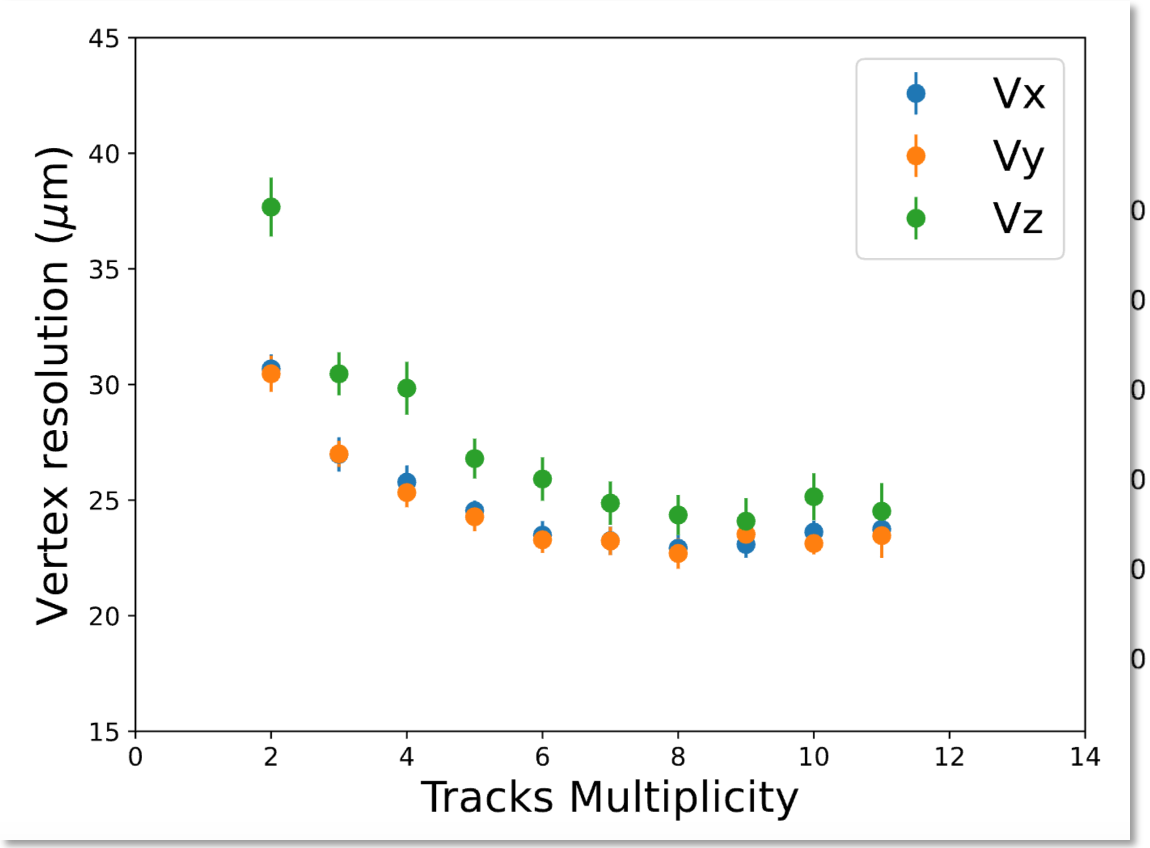
Performance study – vertex resolution

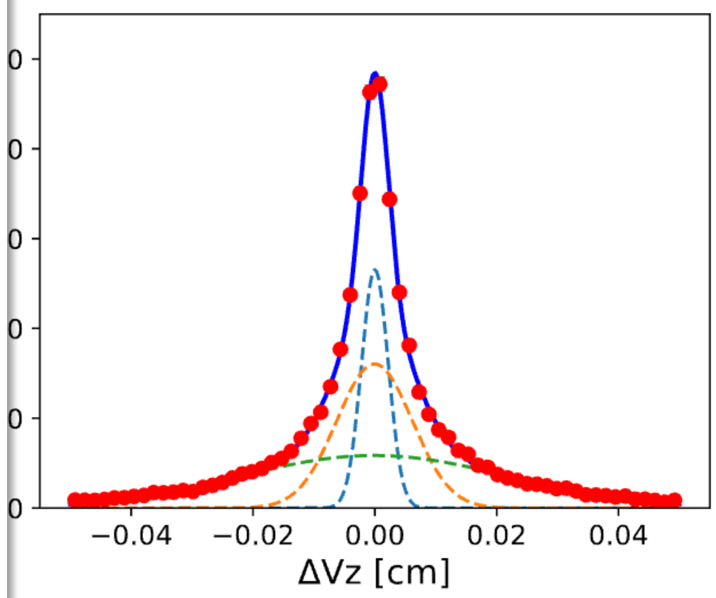


- The primary vertex is determined through a robust fitting process using the **RAVE** toolkit
- The primary vertex residual distributions contain non-Gaussian tails; Therefore, **three coherent Gaussian functions** are used to parameterize these residual

Performance study – vertex resolution







- The primary vertex is determined through a robust fitting process using the **RAVE** toolkit
- The primary vertex residual distributions contain non-Gaussian tails; Therefore, **three coherent Gaussian functions** are used to parameterize these residual
- The resolution will be improved with respected to track multiplicity

EicC Detector Performance Class

https://gitee.com/aiqiang-guo/EicC_Mvd_DP

AiqiangGu

代码

master ▾ 分

AiqiangGuo

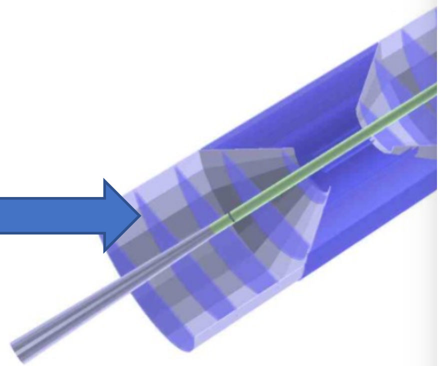
- database
- document
- include
- src
- .gitignore
- Eicc_MVD_DP
- LICENSE
- README.md

Det_v0:

Overall description:

All silicon design based on ITS2 technology.

The structure can be found below:



Barrel:

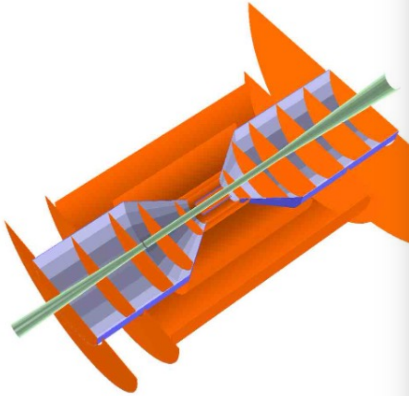
R(cm)	Length(cm)	Pitch Size(μm)	Material Bed
3.30	30	10	0.
5.70	30	10	0.
21.00	54	10	0.
22.68	60	10	0.
39.30	105	10	0.
43.23	114	10	0.

Det_v1:

Overall description:

Silicon+MPGD design. The vertex detector is based on ITS3 technology. Trac technology.

The structure can be found below:



Barrel:

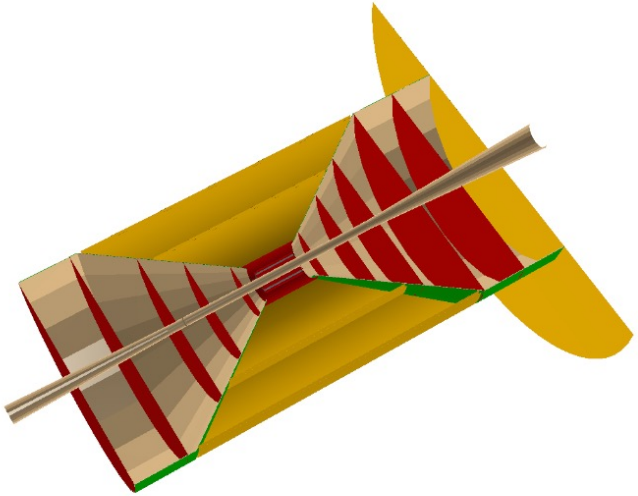
R(cm)	Length(cm)	Pitch Size(μm)	Material Bedget (X/X0 %)
3.30	28	10	0.05
4.35	28	10	0.05
5.40	28	10	0.05
13.34	34.34	10	0.55
17.96	46.68	10	0.55
47.72	127.47	150(rp)x150(z)	0.40
49.57	127.47	150(rp)x150(z)	0.40
75.61	201.98	150(rp)x150(z)	0.40
77.46	201.98	150(rp)x150(z)	0.40

Det_v3:

Overall description:

The optimized version of Hybrid design, all the sillicon part is based on ITS3 technology with pixel size of 10 μm

The structure can be found below:



Barrel:

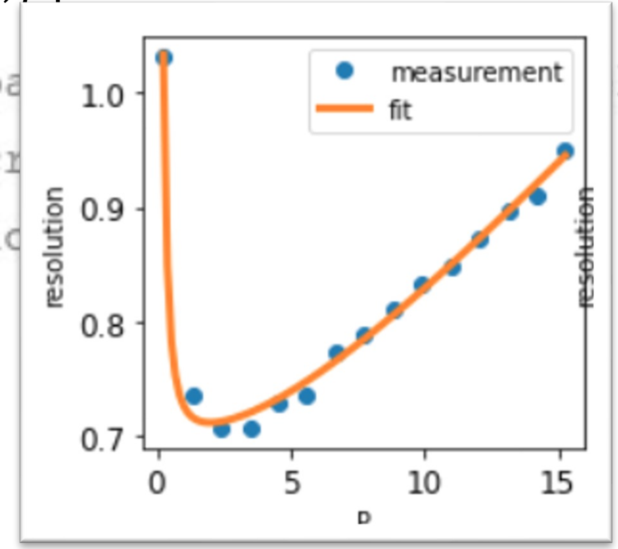
R(cm)	Length(cm)	Pitch Size(μm)	Material Bedget (X/X0 %)	Tech
3.30	28	10	0.08	ITS3
4.35	28	10	0.08	ITS3
5.40	28	10	0.08	ITS3
8.00	28	10	0.08	ITS3
15.00	38.70	10	0.08	ITS3
47.72	127.47	150(rp)x150(z)	0.40	MPGD
49.57	127.47	150(rp)x150(z)	0.40	MPGD
75.61	201.98	150(rp)x150(z)	0.40	MPGD
77.46	201.98	150(rp)x150(z)	0.40	MPGD

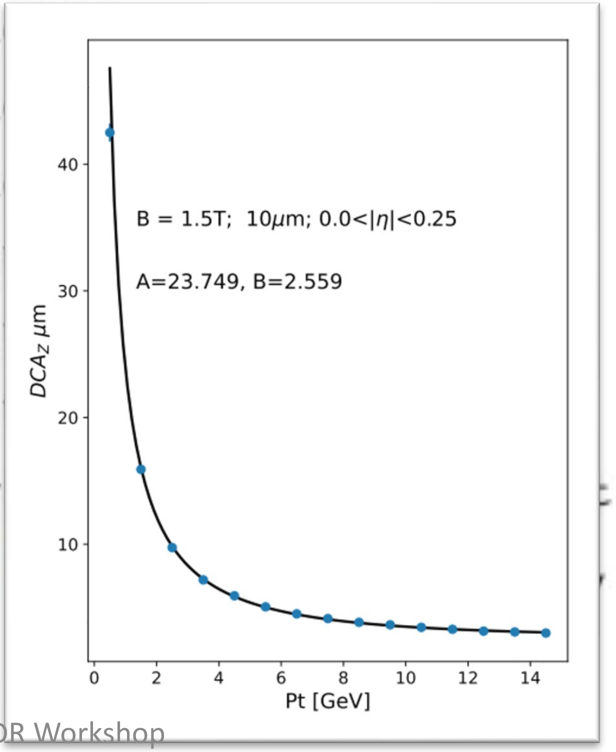
Parameterization of the performance

$[0,1,2,3,4] \Rightarrow [e, \mu, \pi, K, p]$

```
//Get the detector resolutions
double GetResP(double p, double eta, int par); // Unit: 1; pa
double GetResDCAz(double pt, double eta, int par); // Unit: micr
double GetResDCArp(double pt, double eta,int par); // Unit:: mic
double GetEff(double pt, double eta, int par); // Unit: 1
double GetRandomVx(int nTrk); // Unit: mi
dou                                        t: mi
double GetRandomVz(int nTrk); // Unit: mi
double GetLambdaRandomVx(double eta); //
double GetLambdaRandomVy(double eta); //
double GetLambdaRandomVz(double eta); //
double GetLambdaResP(double vx, double vy              t, double eta, int par);
double GetLambdaEff(double vx, double vy,              , double eta, int par);
```

Performance of track from IP





Publications

Published in NST

Lambda polarization at Electron-ion collider in China

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[3]*Southern Center for Nuclear-Science Theory (SCNT), Institute of Modern Physics, Chinese Academy of Sciences, Huizhou, China*

Lambda polarization can be measured through its self-analyzing weak decay, making it an ideal candidate for studying spin effects in high energy scatterings. In lepton-nucleon deeply inelastic scatterings (DIS), Lambda polarization measurements can probe the polarized parton distribution functions (PDFs) and the polarized fragmentation functions (FFs). One of the most promising facilities for high-energy nuclear physics research is the proposed Electron-ion collider in China (EicC). As a next-generation facility, EicC is set to propel our understandings of nuclear physics to new heights. In this article, we study the Lambda production in electron-proton collision at EicC energy, in particular Lambda's reconstruction based on the performance of the designed EicC detector. In addition, taking spontaneous transverse polarization as an example, we provide a theoretical prediction with statistical projection based on one month of EicC data taking, offering valuable insights into future research prospects.

Keywords: Electron-ion collider at China; Lambda polarization; polarizing fragmentation functions

Submitted to PRD

Probing gluon distributions with D^0 production at the EicC

Daniele Paolo Anderle,[1,2,3,*] Aiqiang Guo,[4,5,†] Felix Hekhorn,[6,‡] Yutie Liang,[4,5,7] Yuming Ma,[4] Lei Xia,[8] Hongxi Xing,[1,2,3,9] and Yuxiang Zhao[4,9,5,10]

[1]*Key Laboratory of Atomic and Subatomic Structure and Quantum Control (MOE), Institute of Quantum Matter, South China Normal University, Guangzhou 510006, China*
[2]*Guangdong Provincial Key Laboratory of Nuclear Science, Institute of Quantum Matter, South China Normal University, Guangzhou 510006, China*
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[5]*University of Chinese Academy of Sciences, Beijing 100049, China*
[6]*Tif Lab, Dipartimento di Fisica, Università di Milano and INFN, Sezione di Milano, Via Celoria 16, I-20133 Milano, Italy*
[7]*Guangdong Provincial Key Laboratory of Nuclear Science, Institute of Quantum Matter, South China Normal University, Guangzhou 510006, China*
[8]*University of Science and Technology of China, Hefei, Anhui Province 230026, China*
[9]*Southern Center for Nuclear-Science Theory (SCNT), Institute of Modern Physics, Chinese Academy of Sciences, Huizhou, Guangdong Province 516000, China*
[10]*Key Laboratory of Quark and Lepton Physics (MOE) and Institute of Particle Physics, Central China Normal University, Wuhan 430079, China*

(Dated: August 9, 2023)

Submitted to PRD

Studying charm in-medium modification and hadronization at the Electron-ion Collider in China*

Senjie Zhu, Xiao Huang, Lei Xia, and Yifei Zhang
University of Science and Technology of China, Hefei, Anhui Province 230026, China

Aiqiang Guo
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, Gansu Province 730000, China and University of Chinese Academy of Sciences, Beijing 100049, China

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Yuxiang Zhao
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Submitted to PRD

Exclusive Heavy Quarkonium Production at the Electron-ion collider in China

Xue Wang,[1,2,*] Xu Cao,[2,3,†] Aiqiang Guo,[2,3,‡] Feng-Kun Guo,[4,5,6,§] Xiao-Shen Kang,[1,¶] Yu-Tie Liang,[2,3,**] Peng Sun,[2,3,††] Jia-Jun Wu,[5,‡‡] and Ya-Ping Xie[2,3]

[1]*School of Physics, Liaoning University, Shenyang 110036, China*
[2]*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[3]*University of Chinese Academy of Sciences, Beijing 100049, China*
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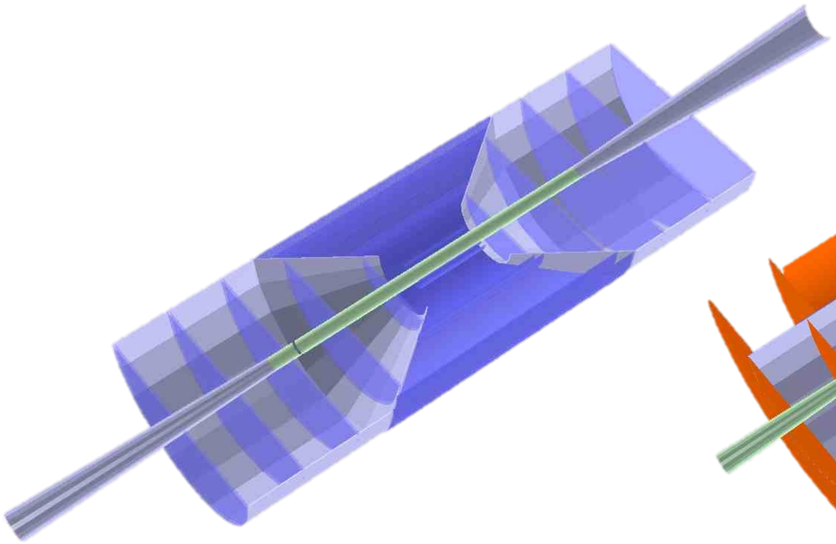
[5]*School of Physical Sciences, University of Chinese Academy of Sciences (UCAS), Beijing 100049, China*
[6]*Peng Huanwu Collaborative Center for Research and Education, Beihang University, Beijing 100191, China*

(Dated: September 15, 2023)

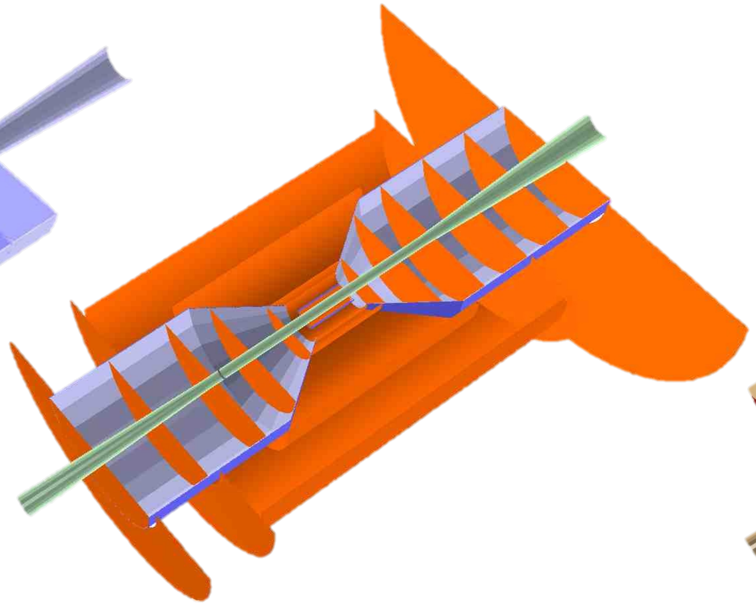
We investigate the exclusive production of heavy quarkonium and exotic states at the future Electron-ion collider in China by utilizing the eSTARlight event generator. We model the cross-section and kinematics by fitting to the world data of J/ψ photoproduction. Statistical uncertainties on J/ψ production are projected under the design of a central detector composed of a tracker and vertex subsystem. The precision of the pseudo-data allows us to probe the gravitational form factor, pentaquark states, rescattering effect and other selected physical quantities. The detector design and optimization enable the prospects for approaching near-threshold region and the domain of large four-momentum transfer squared.

The evolution of the EicC tracker design

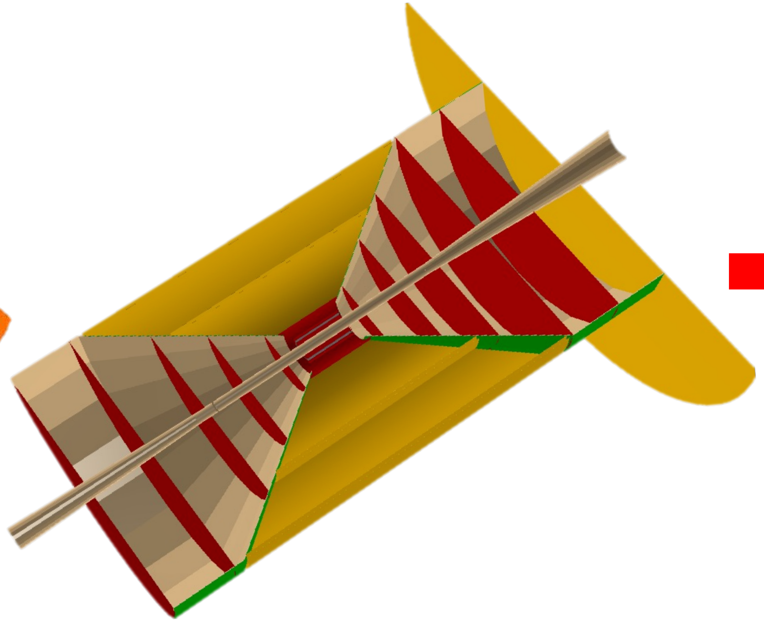
Det_v0



Det_v1/2



Det_v3



?

- All-silicon based on ITS2

- Silicon+MPGD Hybrid design
- Silicon: vertex ITS3 + tracker ITS2
- Only the pixel size is different for v1/v2

- Silicon+MPGD Hybrid design
- Silicon: ITS3
- Geometry is Optimized

The tools we have

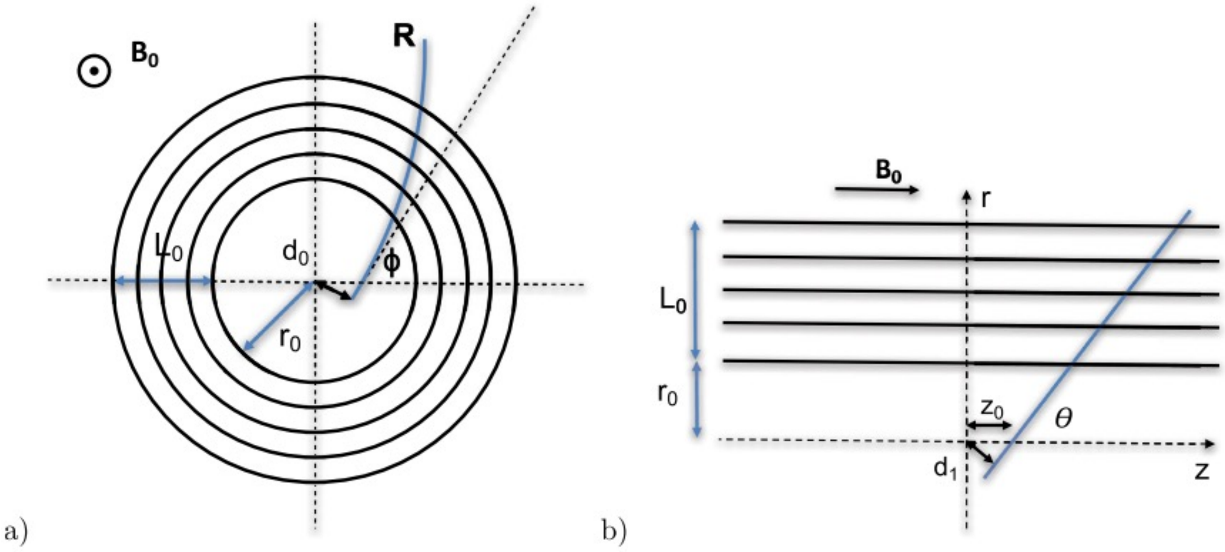
- By simulation
  - Very time consuming
- By analytic expressions
  - We need to know all the factors that affect the resolution
- Track model: $f(x) = \sum_i a_i g_i(x)$ with M unknow parameters
- N measurement y_n,
- The parameters a_i are estimated by minimize

$$\chi^2 = \sum_{m=0}^{N} \sum_{n=0}^{N} \left[y_m - \sum_{i=0}^{M} a_i g_i(x_m) \right] W_{mn} \left[y_n - \sum_{i=0}^{M} a_i g_i(x_n) \right]$$

Track parameter

$$\chi^2 = (\mathbf{y} - \mathbf{G}\mathbf{a})^T \mathbf{W} (\mathbf{y} - \mathbf{G}\mathbf{a})$$

measurement



To minimise χ^2 we have to solve $\frac{\partial \chi^2}{\partial a_i} = 0$ which gives

$$\mathbf{a} = (\mathbf{G}^T \mathbf{W} \mathbf{G})^{-1} \mathbf{G}^T \mathbf{W}\, \mathbf{y} = \mathbf{B}\, \mathbf{y}$$

The error of **a** can be determined by the errors of **y**

$$\mathbf{C}_a = (\mathbf{G}^T \mathbf{C}_y^{-1} \mathbf{G})^{-1}$$

$\mathbf{C}_y$ is the covariance matrix of **y**

The tools we have

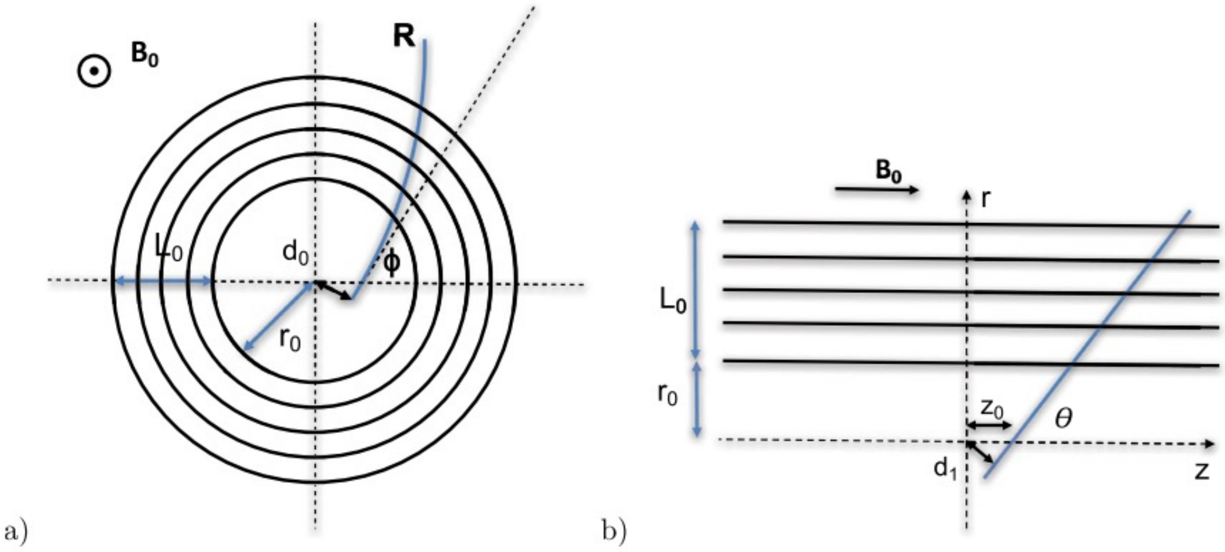
- By simulation
  - Very time consuming
- By analytic expressions
  - We need to know all the factors that affect the resolution
- Track model: $f(x) = \sum_i a_i g_i(x)$ with M unknow parameters
- N measurement y_n,
- The parameters a_i are estimated by minimize

$$\chi^2 = \sum_{m=0}^{N}\sum_{n=0}^{N}\left[y_m - \sum_{i=0}^{M} a_i g_i(x_m)\right] W_{mn} \left[y_n - \sum_{i=0}^{M} a_i g_i(x_n)\right]$$

Track parameter

$$\chi^2 = (\mathbf{y} - \mathbf{Ga})^T \mathbf{W} (\mathbf{y} - \mathbf{Ga})$$

measurement



To minimise χ^2 we have to solve $\frac{\partial \chi^2}{\partial a_i} = 0$ which gives

$$\mathbf{a} = (\mathbf{G}^T\mathbf{W}\mathbf{G})^{-1}\mathbf{G}^T\mathbf{W}\,\mathbf{y} = \mathbf{B}\,\mathbf{y}$$

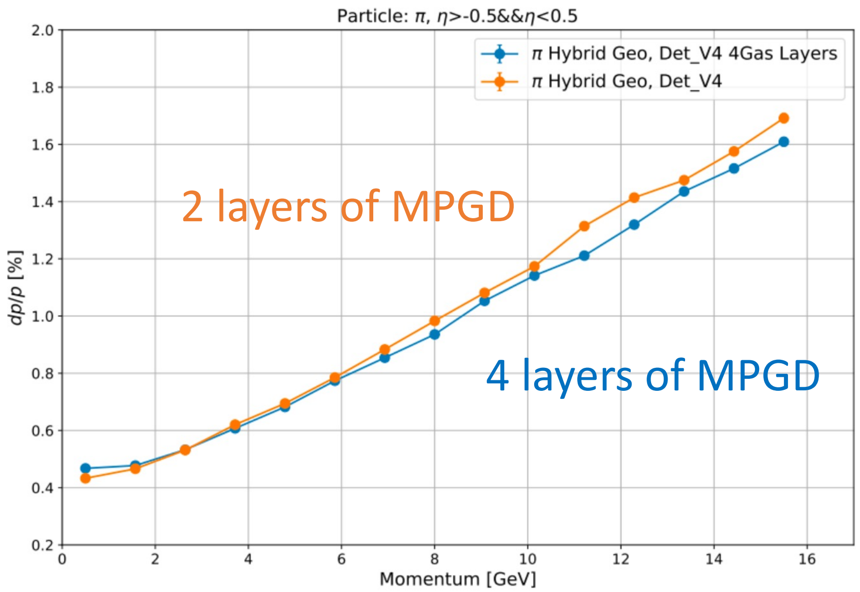
The error of **a** can be determined by the errors of **y**

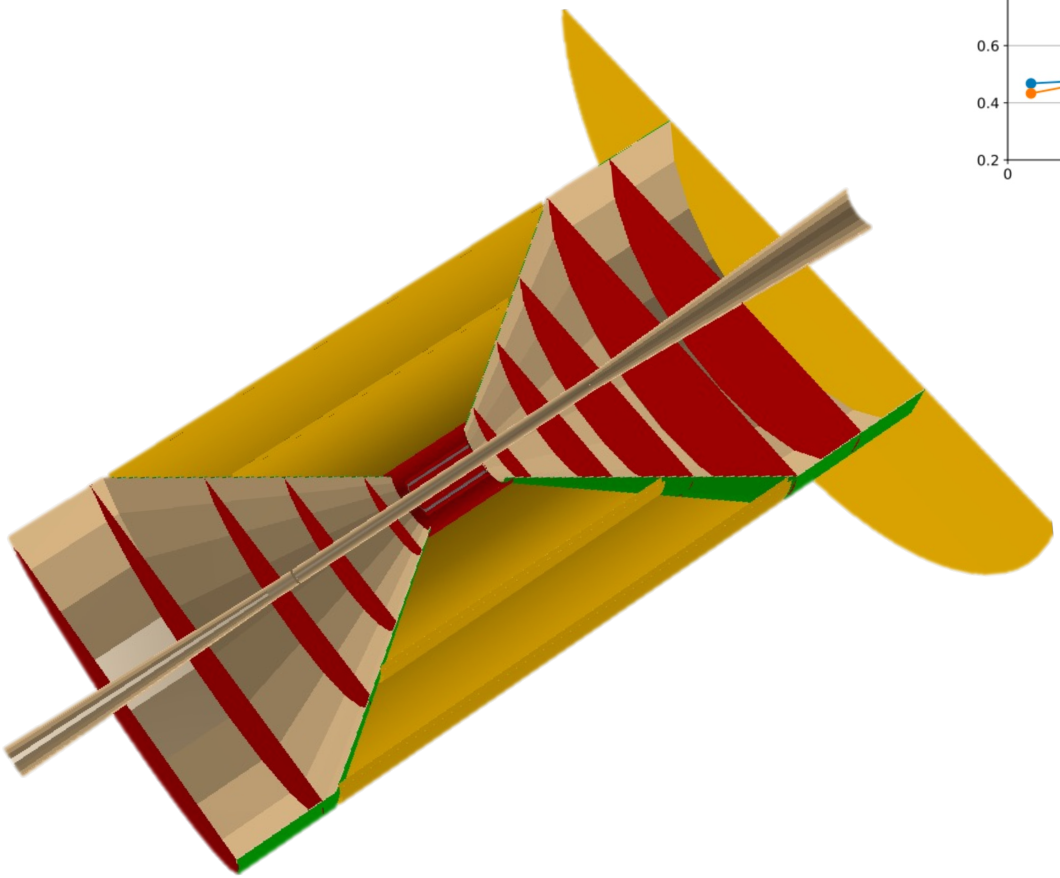
$$\mathbf{C}_a = (\mathbf{G}^T \mathbf{C}_y^{-1} \mathbf{G})^{-1}$$

$\mathbf{C_y}$ is the covariance matrix of **y**

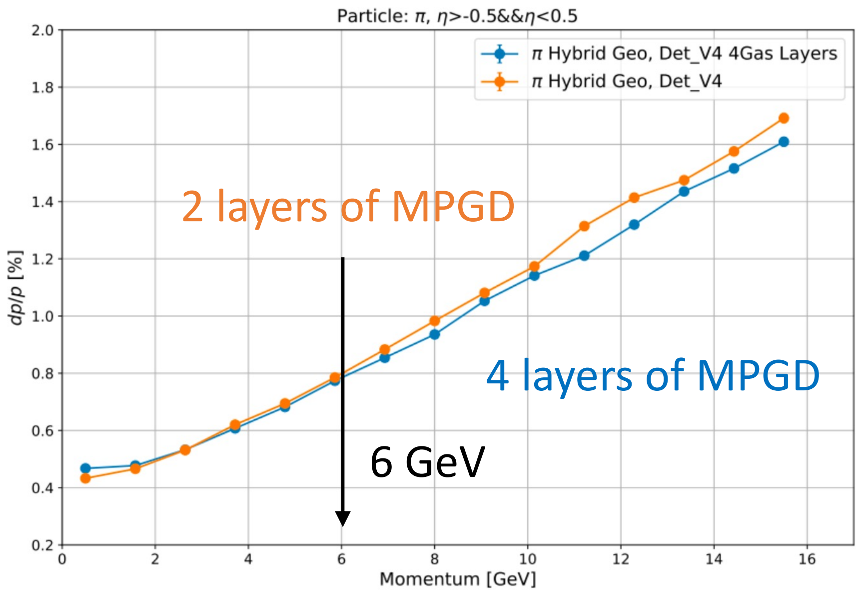
Track parameter   Measurement

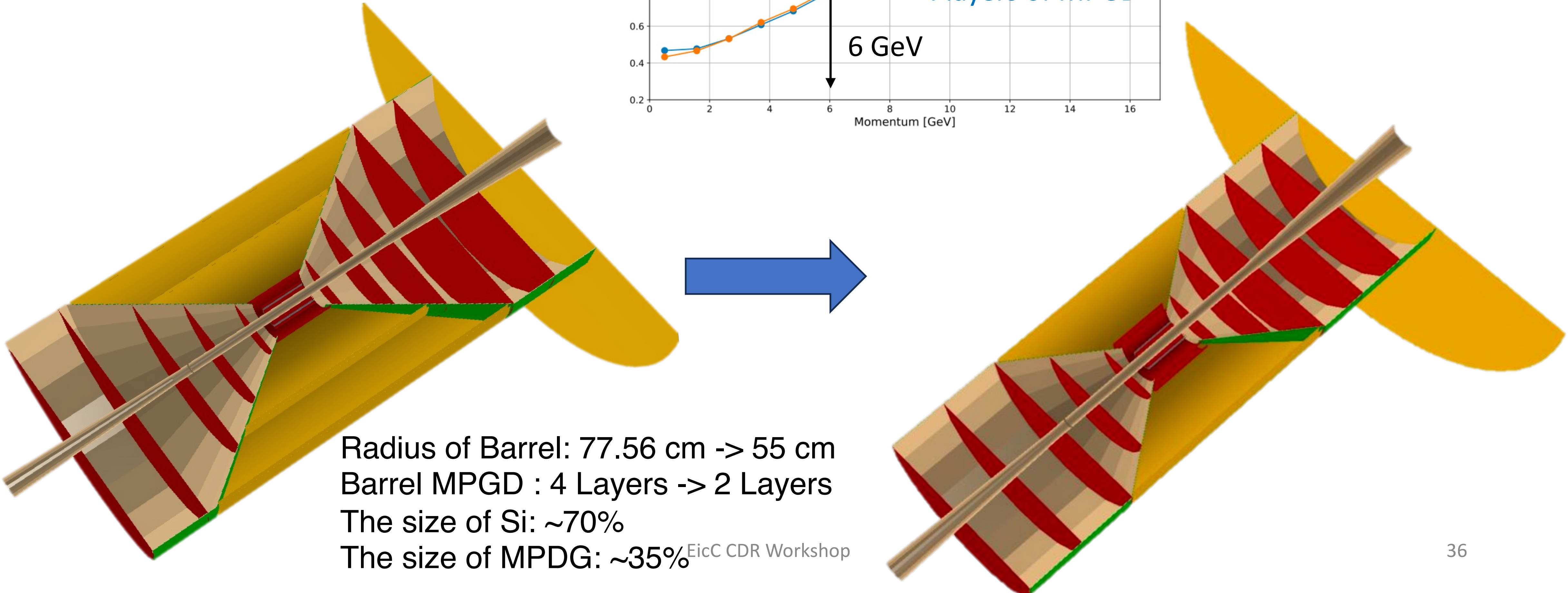
Number of layer





Number of layer

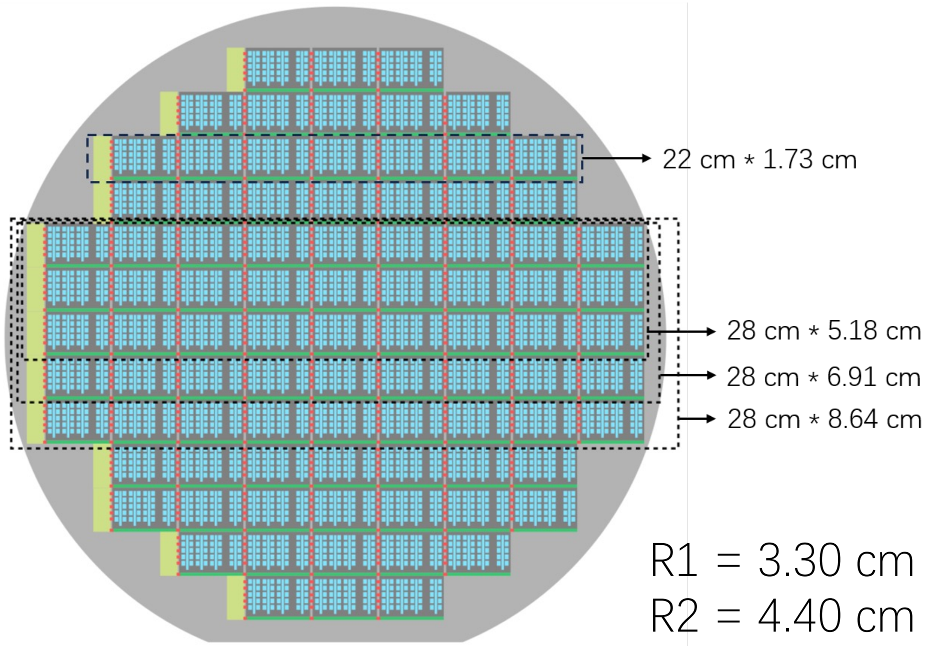




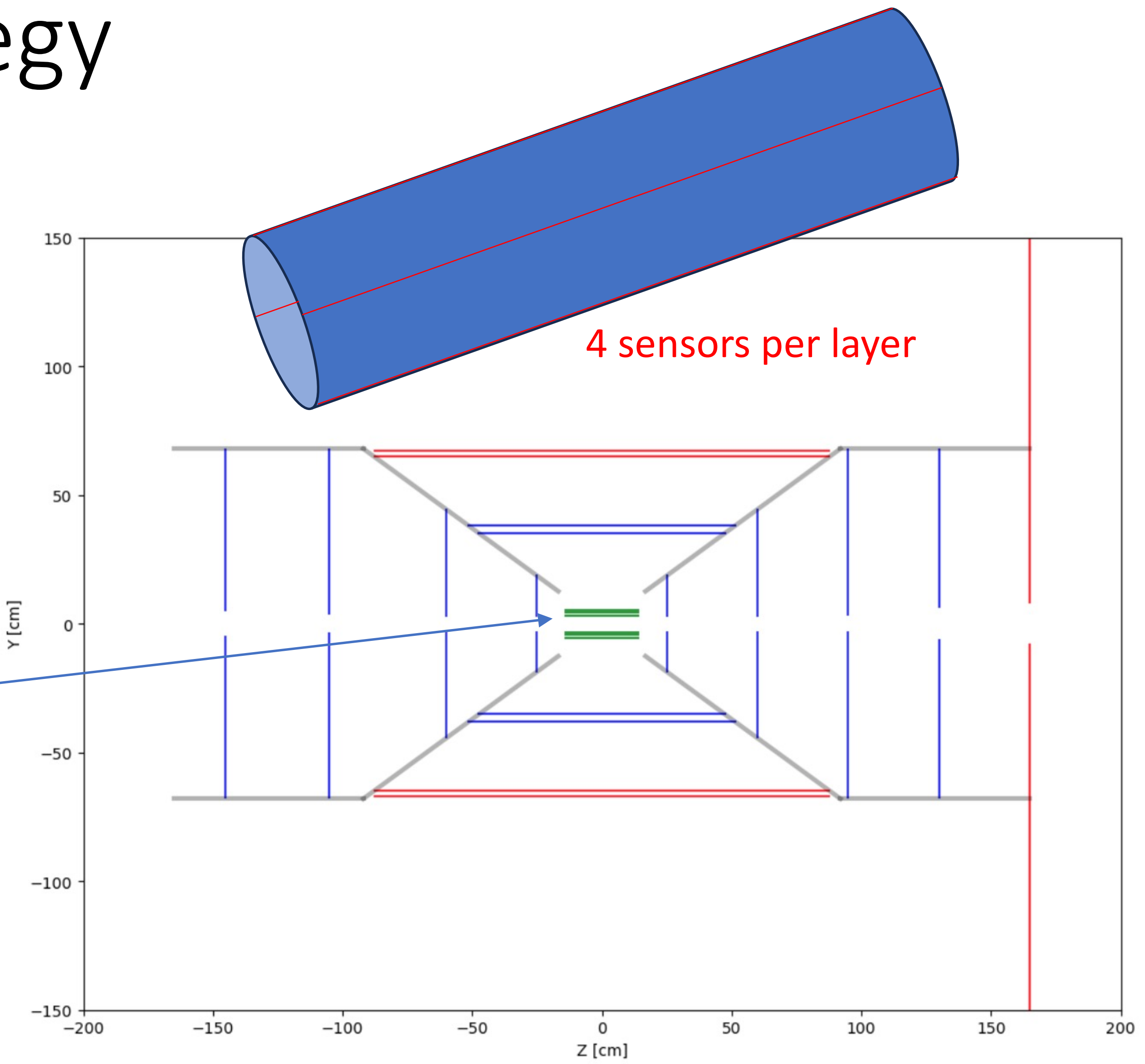
Radius of Barrel: 77.56 cm -> 55 cm
Barrel MPGD : 4 Layers -> 2 Layers
The size of Si: ~70%
The size of MPDG: ~35%

The optimization strategy

The geometry of vertex part is fixed due to the constrain of wafer size

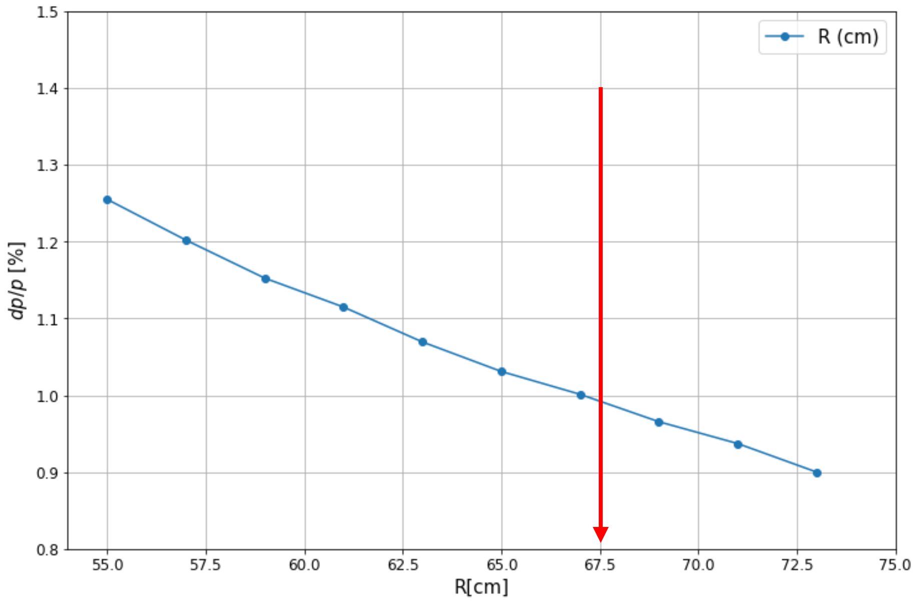


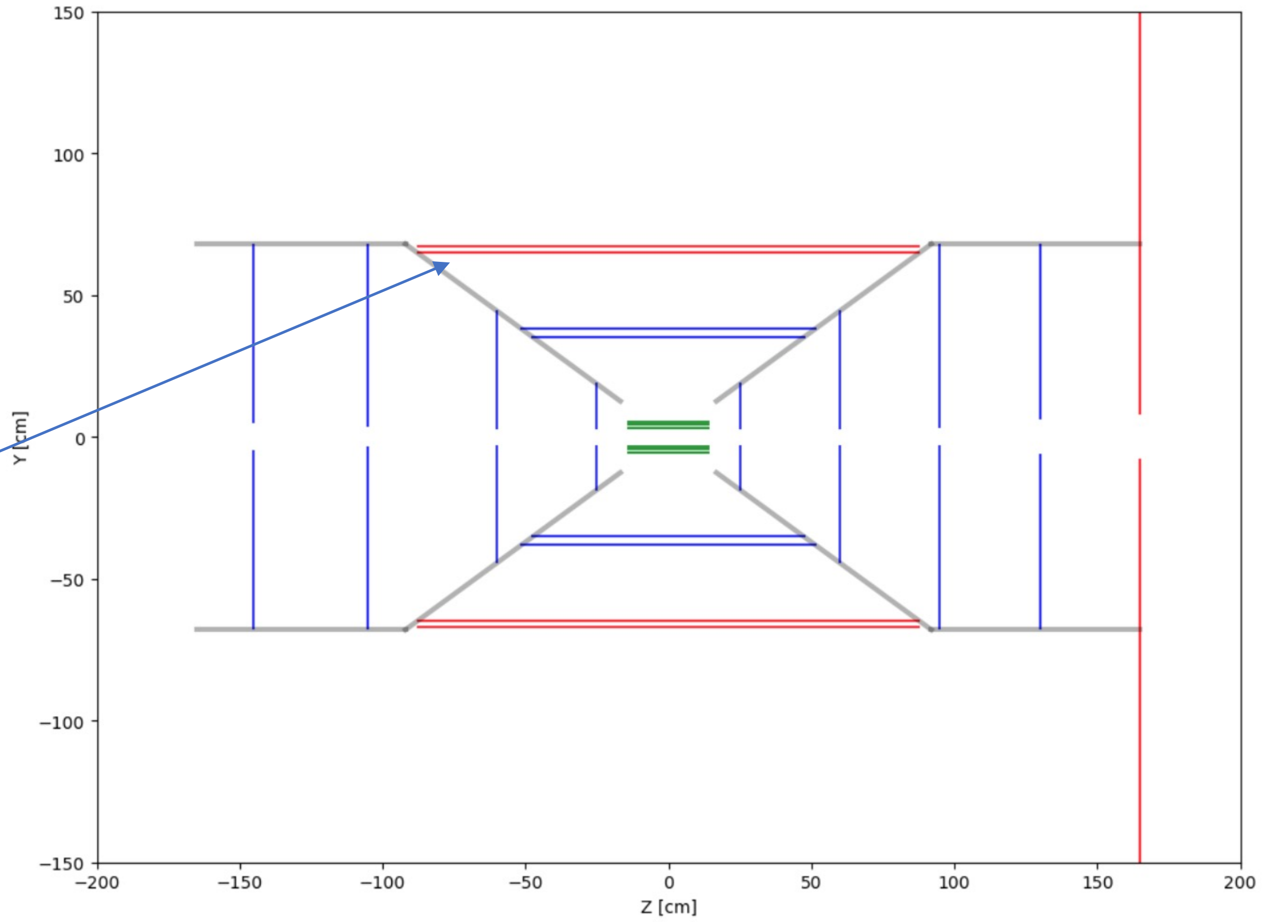
R1 = 3.30 cm
R2 = 4.40 cm
R3 = 5.50 cm



The optimization strategy

- The radius of the outmost layer is determined by physical requirement: **dp/p<1% @ 4GeV**
- **R = 67.5 cm**

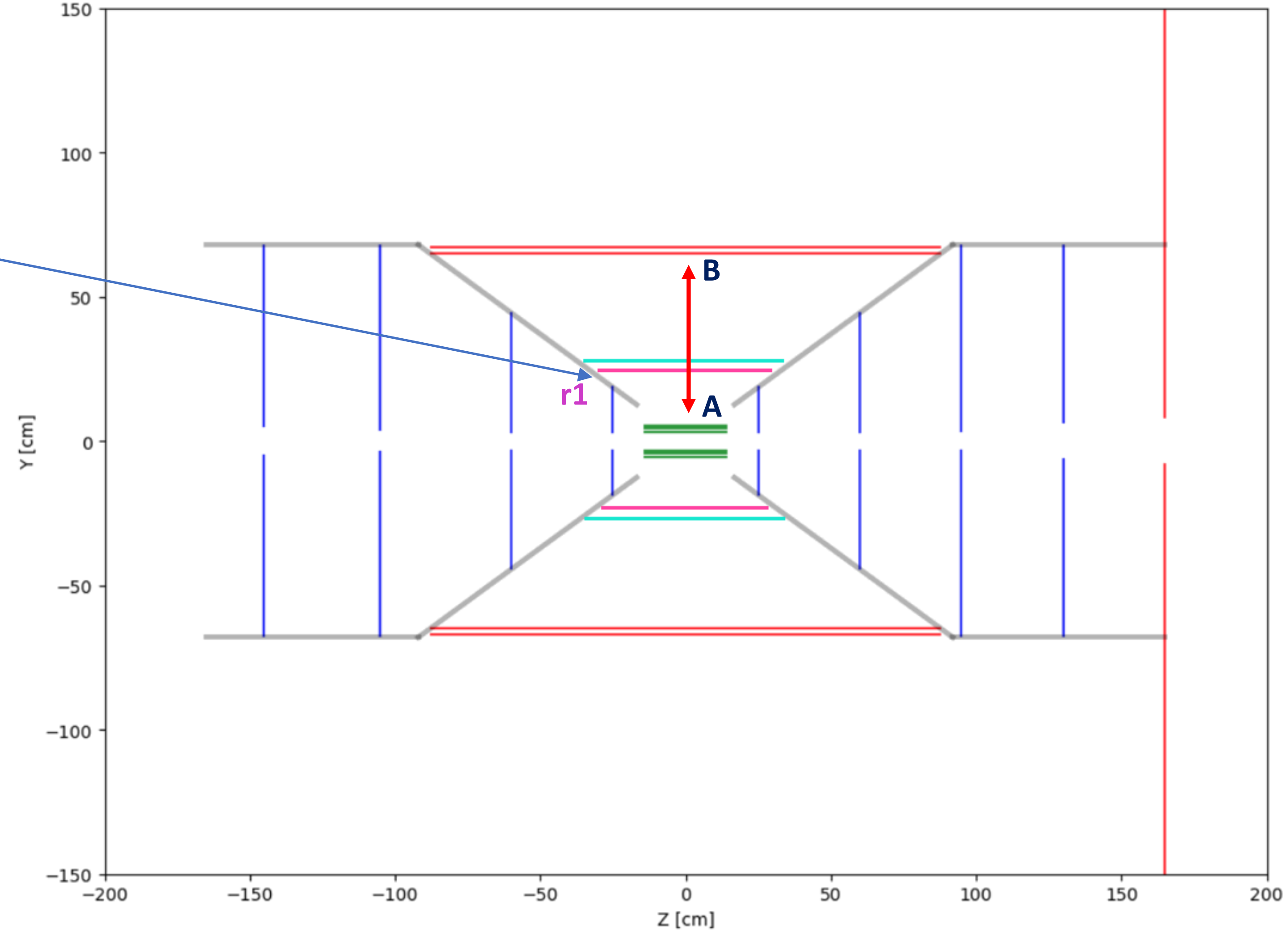




The optimization strategy

The radius of the middle two layers are optimized by a 2D scanning for **p = 1GeV**:

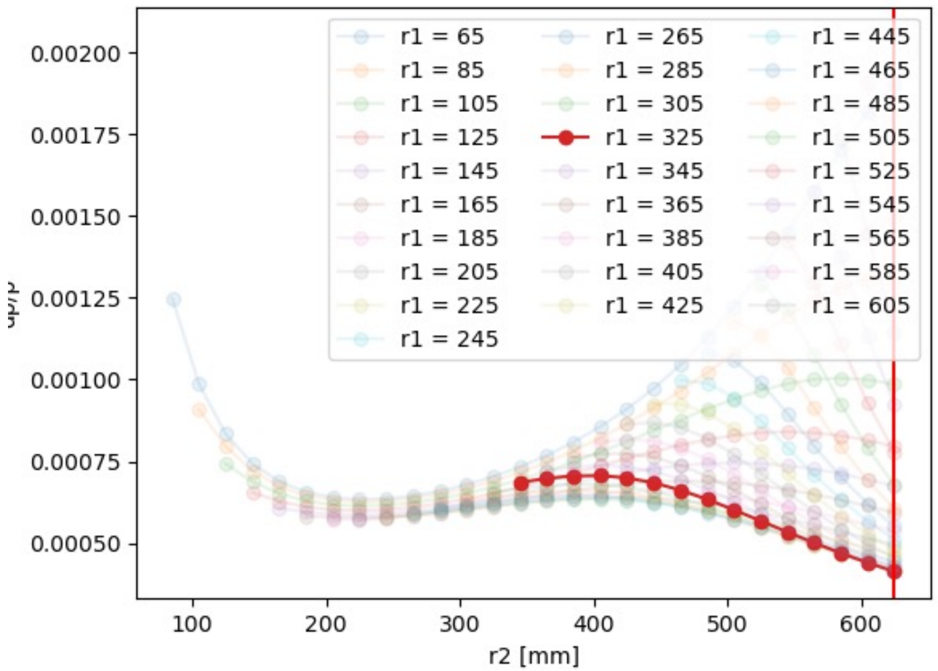
1. Scan r1 from A → B

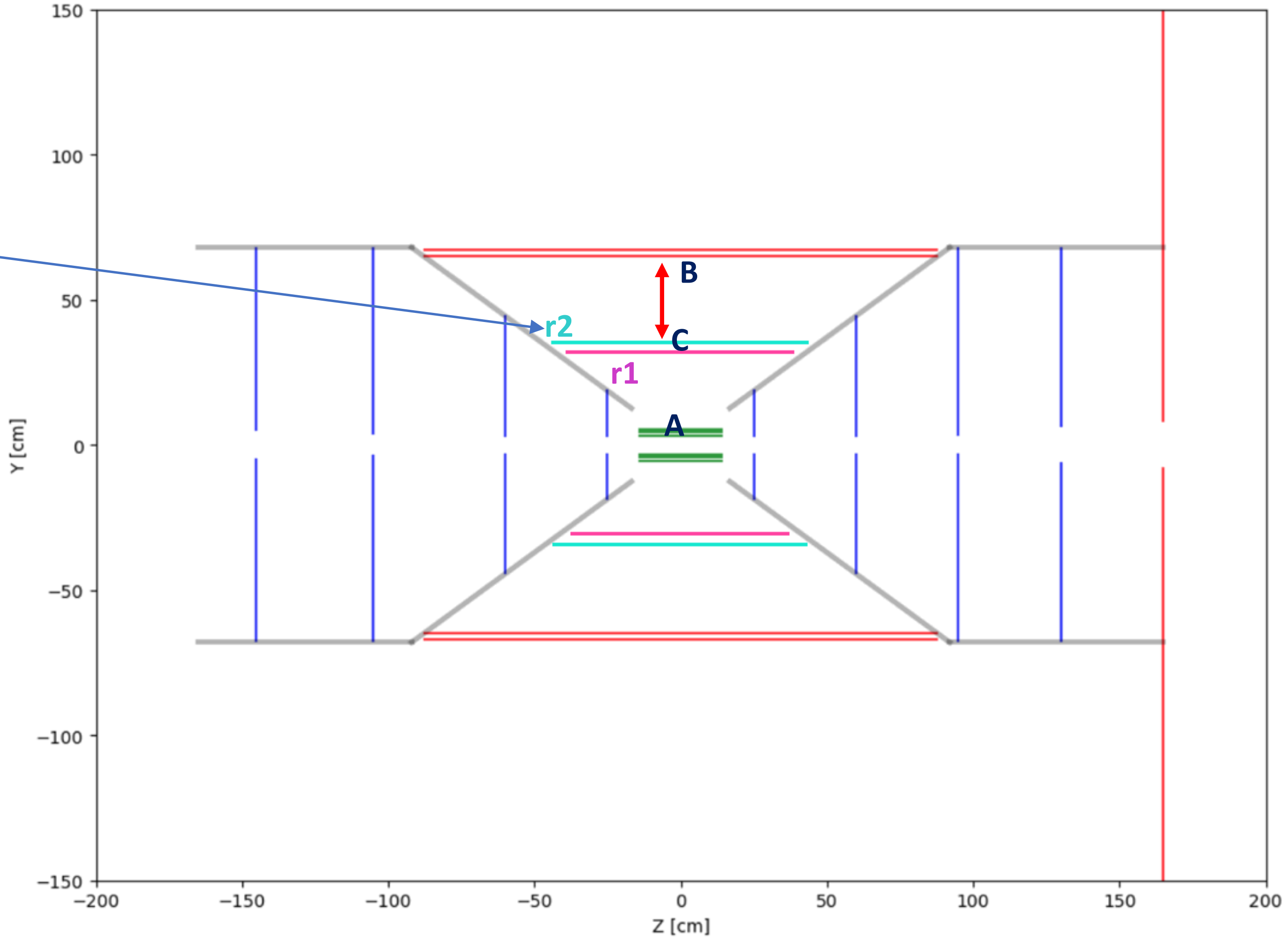


The optimization strategy

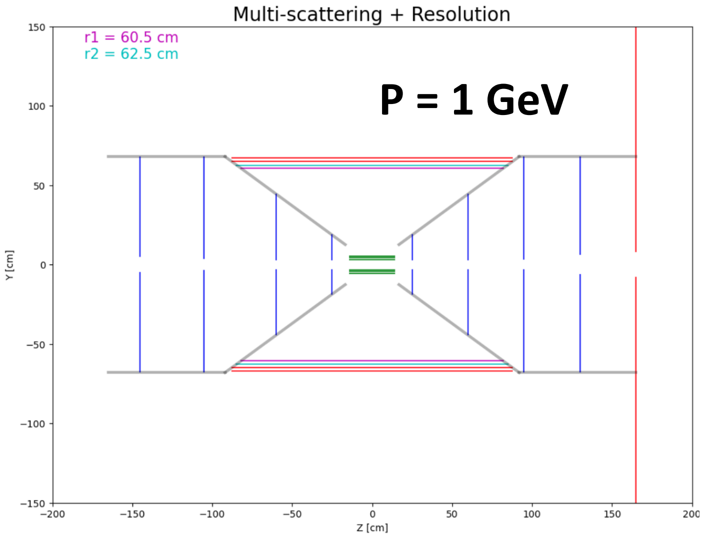
The radius of the middle two layers are optimized by a 2D scanning for **p = 1GeV** :

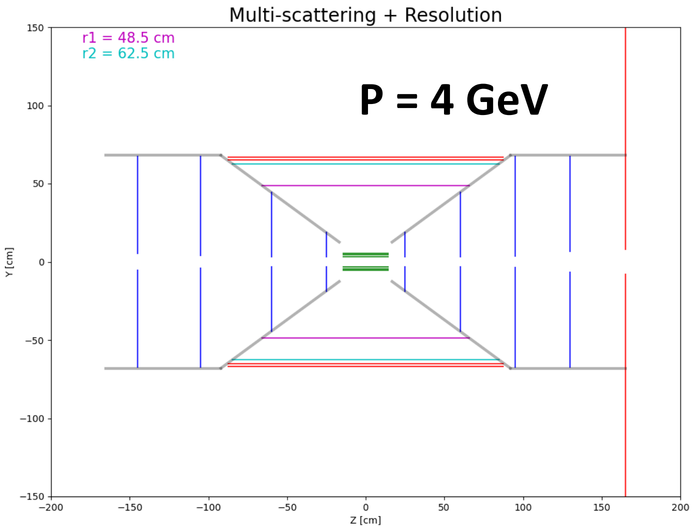
1. Scan r1 from A → B
2. For each r1 position, scan r2 from C → B

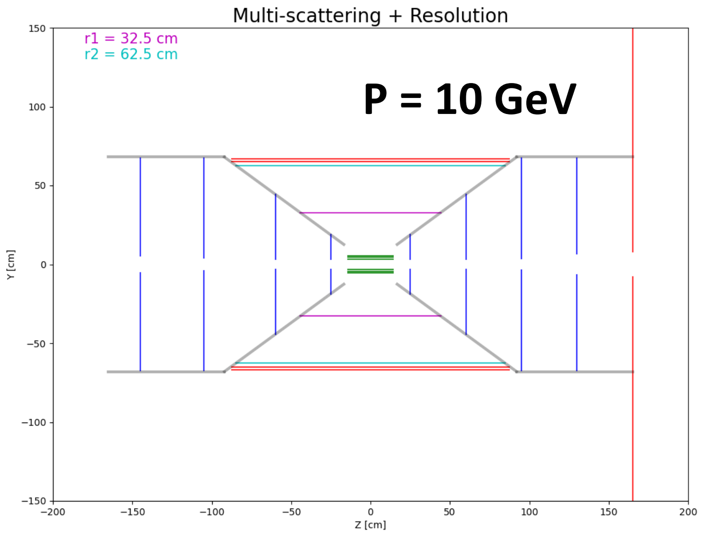




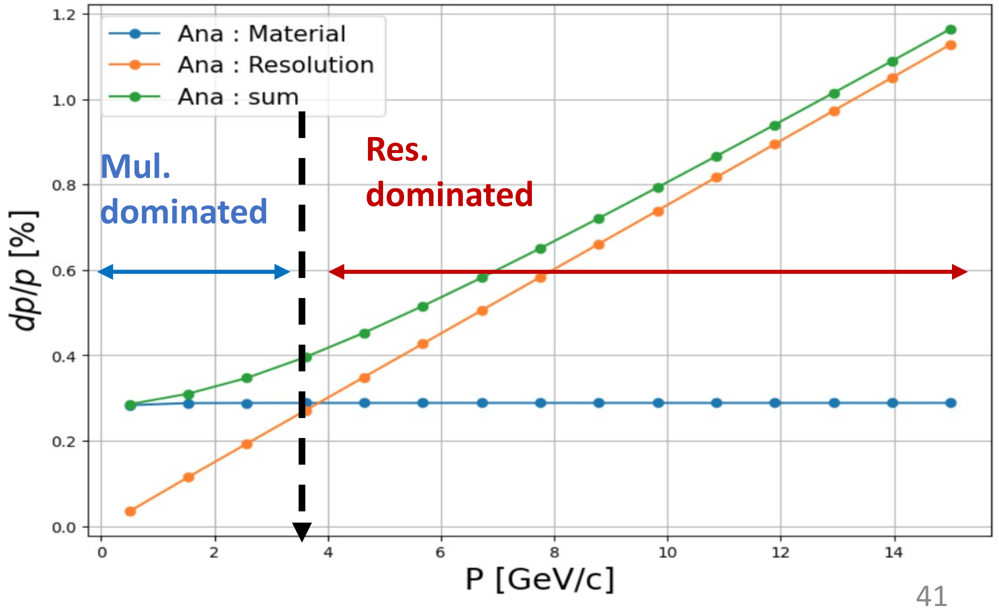
Conclusion



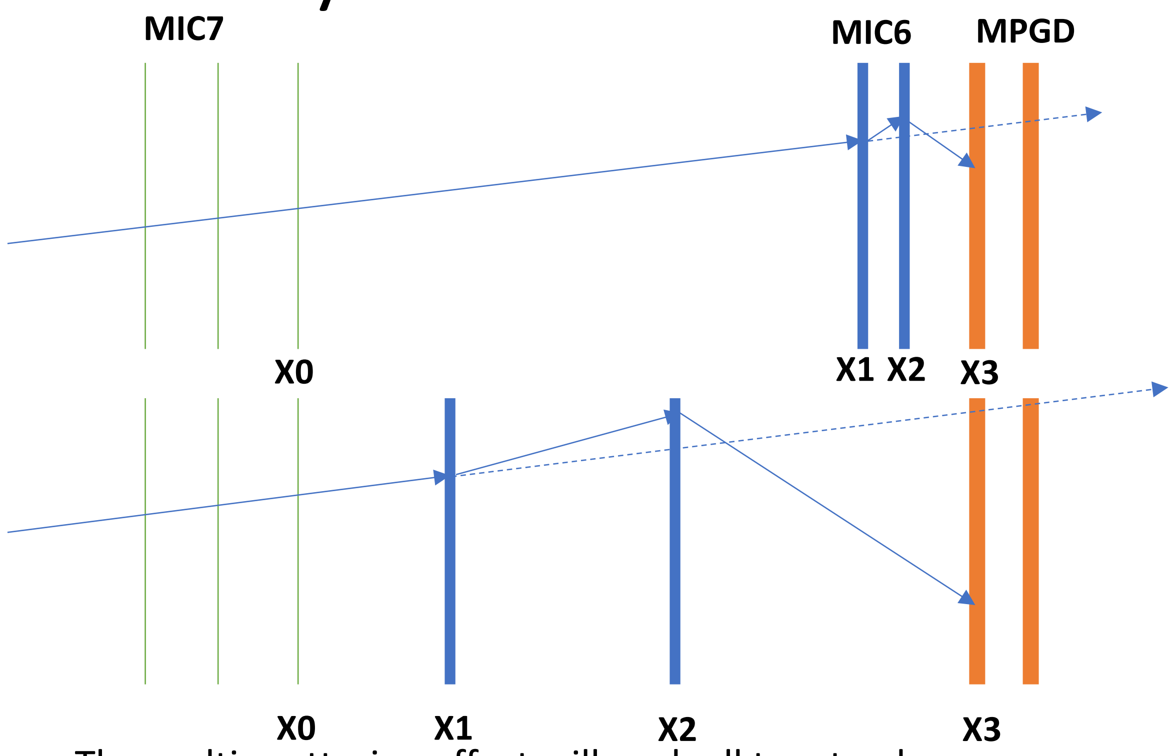




- The multi-scattering effect will push all two tracker layers to the outer-most layer
- The resolution effect will pull the inner tracker towards the middle of detector



But why ?



- The multi-scattering effect will push all two tracker layers to the outer-most layer
- The resolution effect will pull the inner tracker towards the middle of detector

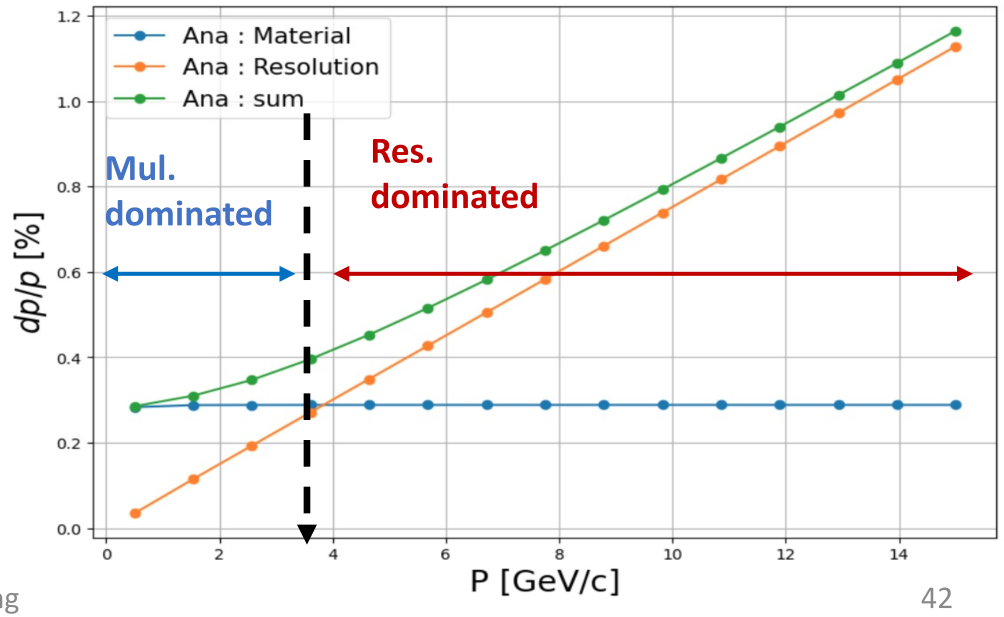
Due to resolution

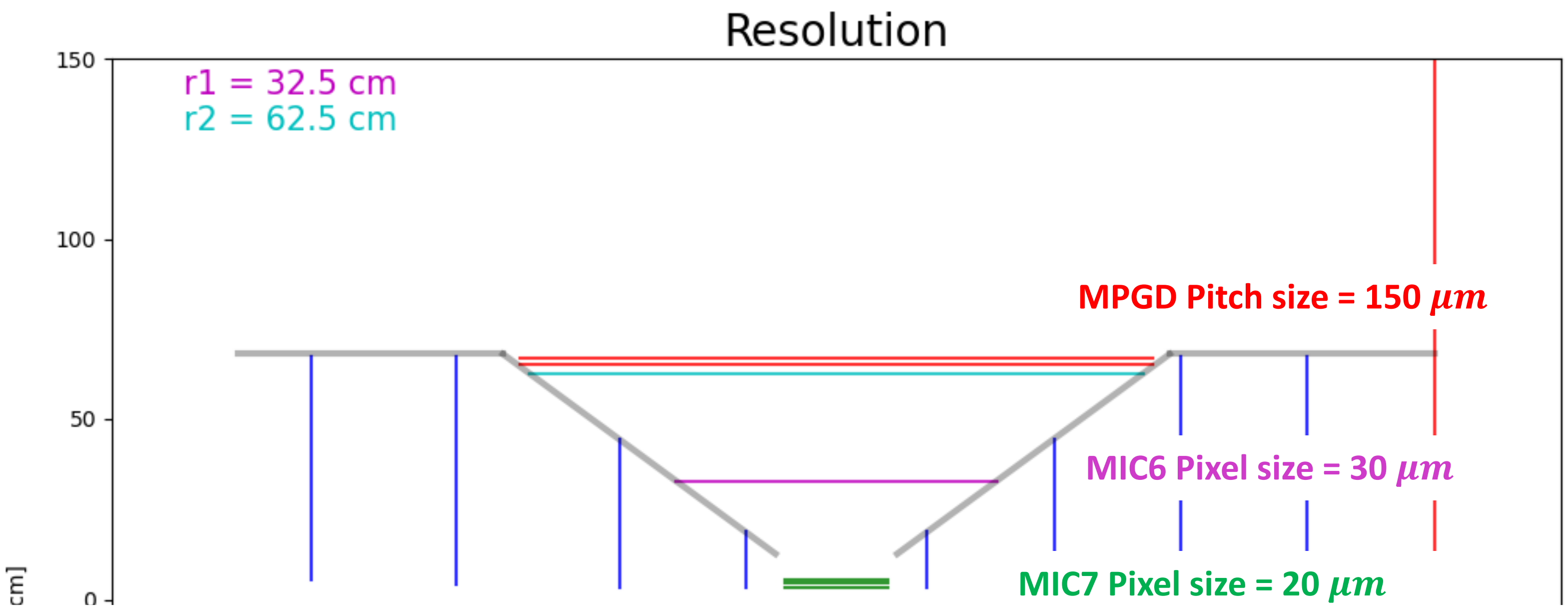
Determined by material budget

$$
\begin{aligned}
y_0 &= f(x_0) + u_0 \\
y_1 &= f(x_1) + u_1 + \alpha_0(x_1 - x_0) \\
y_2 &= f(x_2) + u_2 + \alpha_0(x_2 - x_0) + \alpha_1(x_2 - x_1) \\
&\vdots \\
y_n &= f(x_n) + u_n + \sum_{m=0}^{n-1} \alpha_m (x_n - x_m) \qquad n = 0, 1, \ldots, N
\end{aligned}
$$

The covariance matrix of y_n is therefore

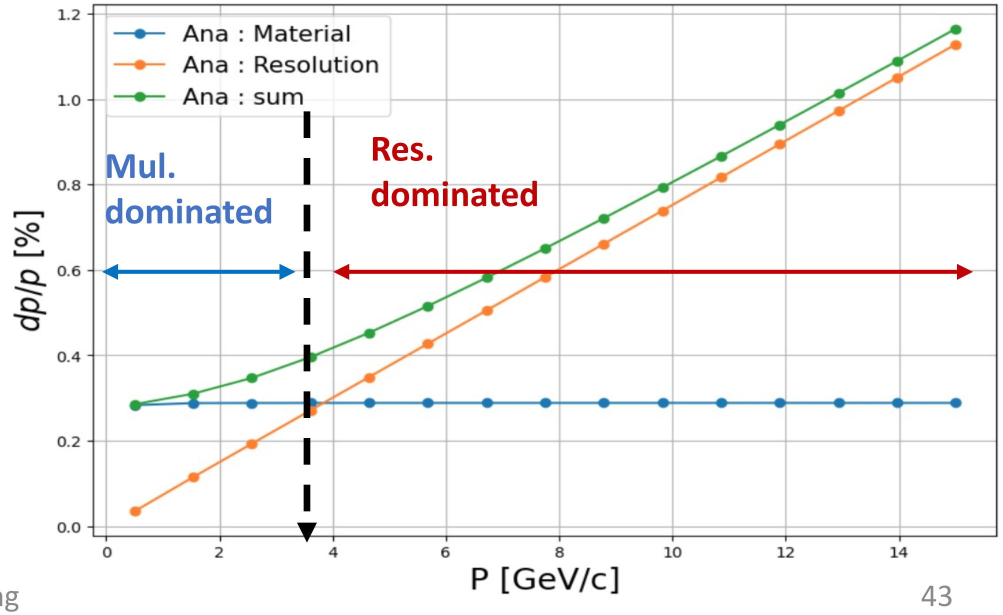
$$
(C_y)_{mn} = \sigma_n^2 \delta_{mn} + \sum_{j=0}^{\mathrm{Min}[m,n]-1} \sigma_{\alpha_j}^2 (x_m - x_j)(x_n - x_j)
$$





The resolution of MPGD is too bad compared to silicon layer !!

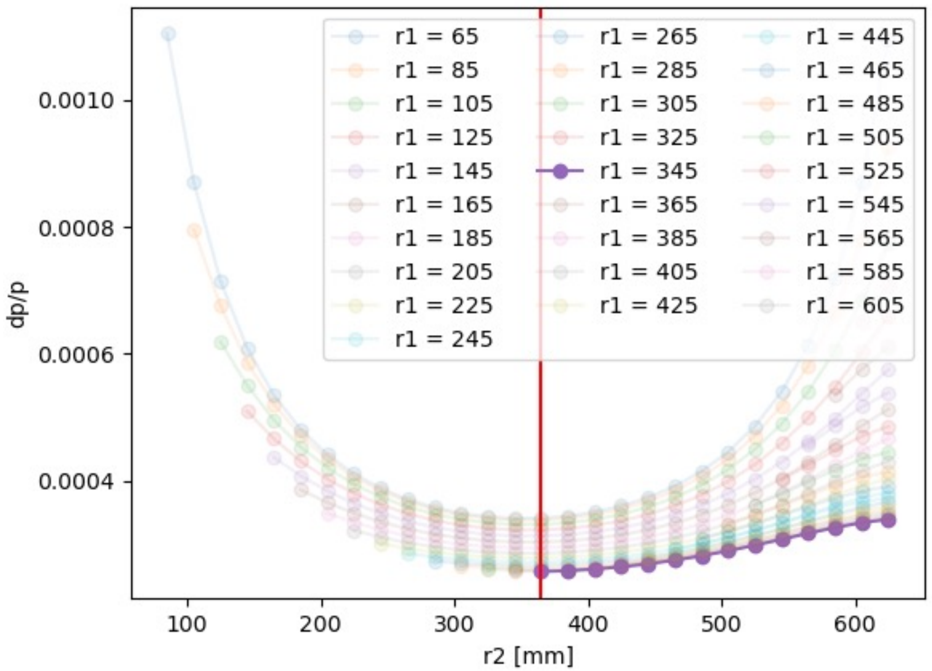
- The multi-scattering effect will push all two tracker layers to the outer-most layer
- The resolution effect will pull the inner tracker towards the middle of detector

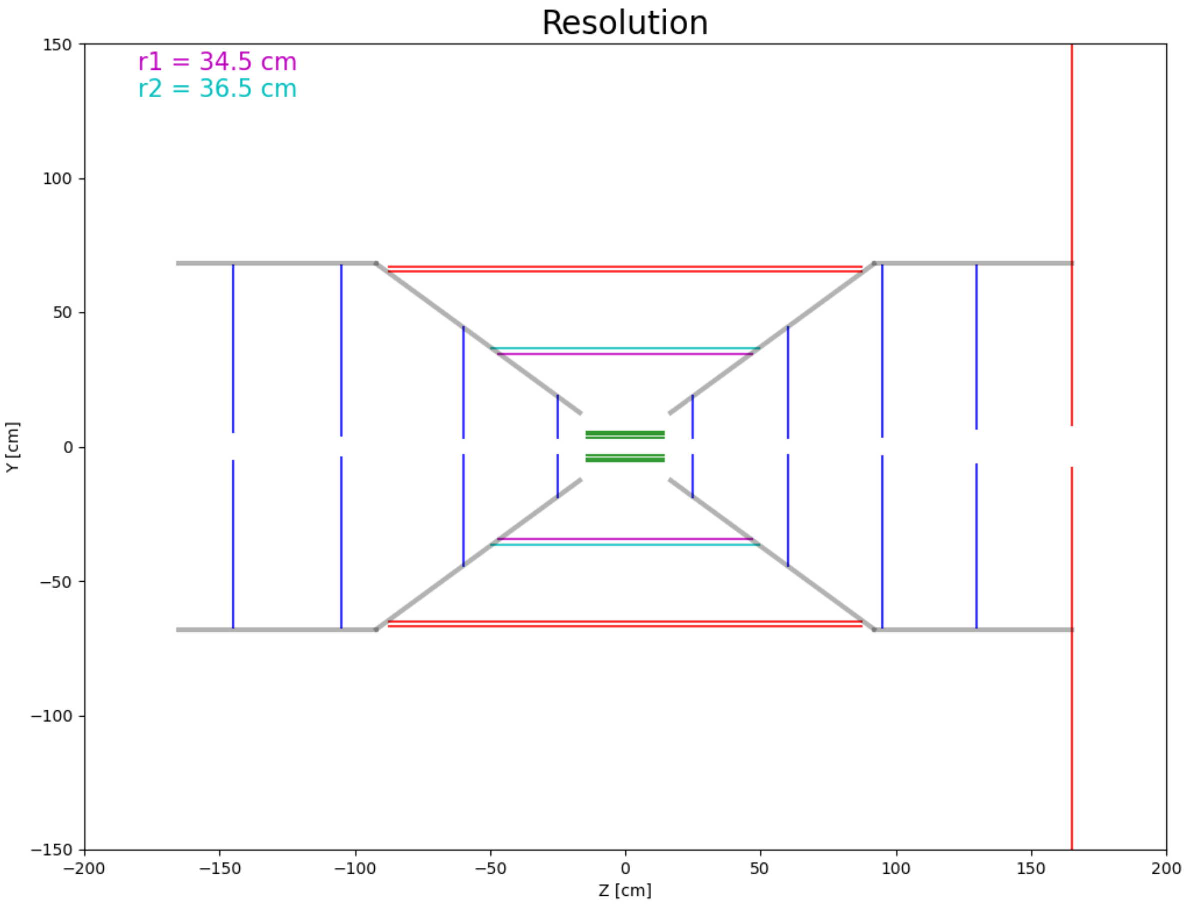


The optimized result with MPGD pitch size = 20 μm

The radius of the middle two layers are optimized by a 2D scanning for **p = 10GeV** :

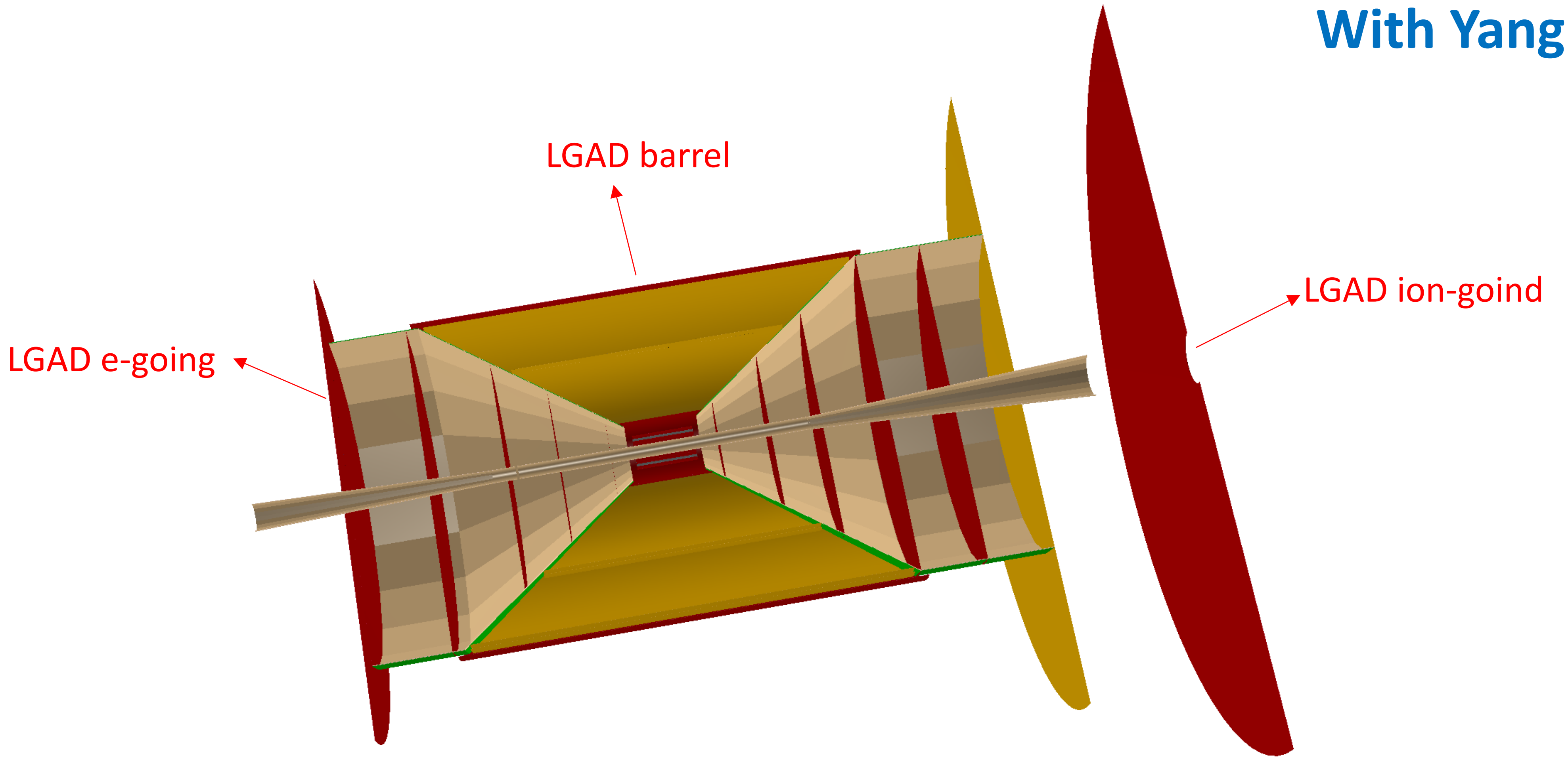
1. Scan r1 from A → B
2. For each r1 position, scan r2 from C → B



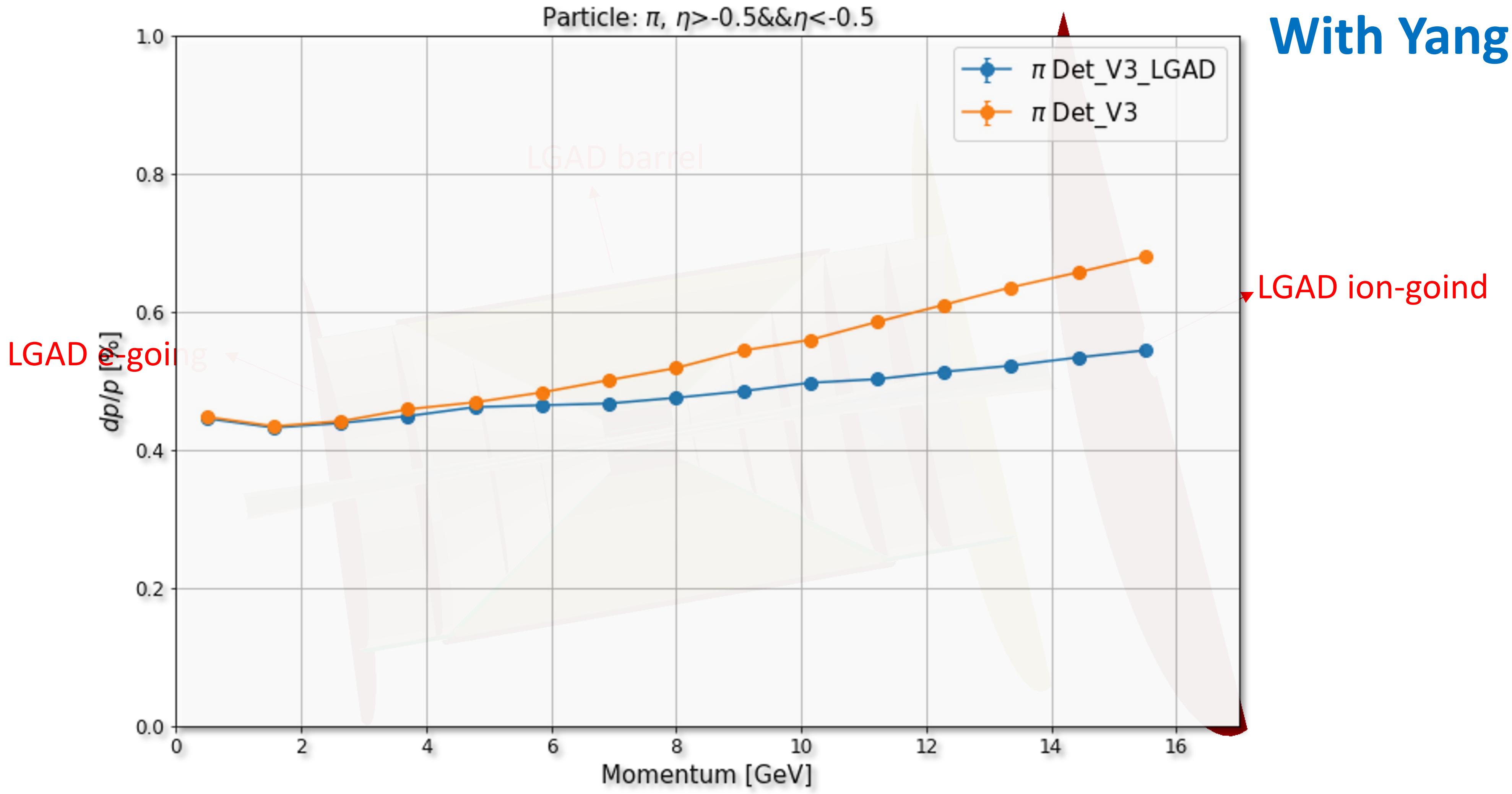


Tracking with TOF

With Yang shuai



Tracking with TOF



With Yang shuai

CDR preparation

Summary and outlook

Summary：

- A conceptual design for EicC traker, which consistes of MAPS and MPGD, is proposed
- The performance is studied with GEANT4 simulation
- CDR preparation is almostly done

Outlook:

- Need to figure out the physics requirement according to FAST simulation
- Optimize the geometry further for both barrel and endcap region
- Probably try new design: e.g. Silicon pixel + TPC

Thank you !

Backup