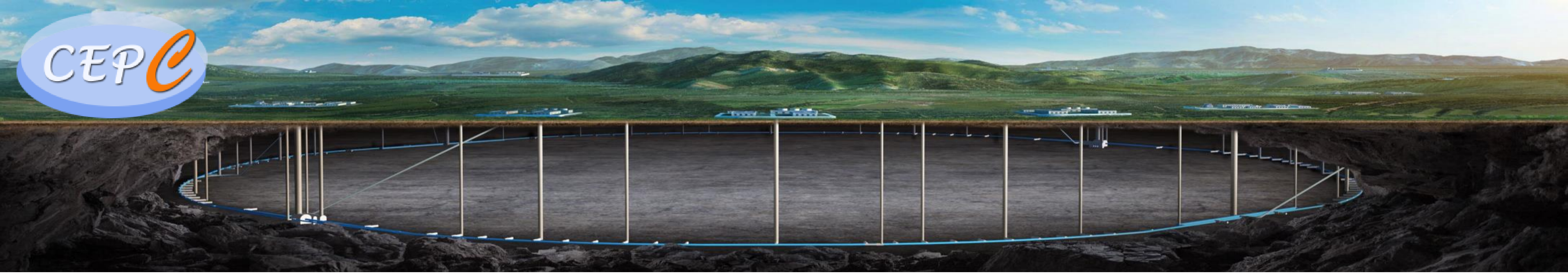

PID Performance of CEPC ToF and Outer Tracker

Yunyun Fan on behalf of ToF & Outer tracker detector group, fanyy@ihep.ac.cn

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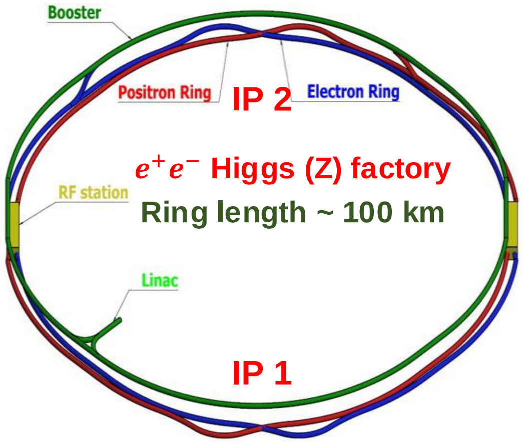
Institute of High Energy Physics
Chinese Academy of Sciences

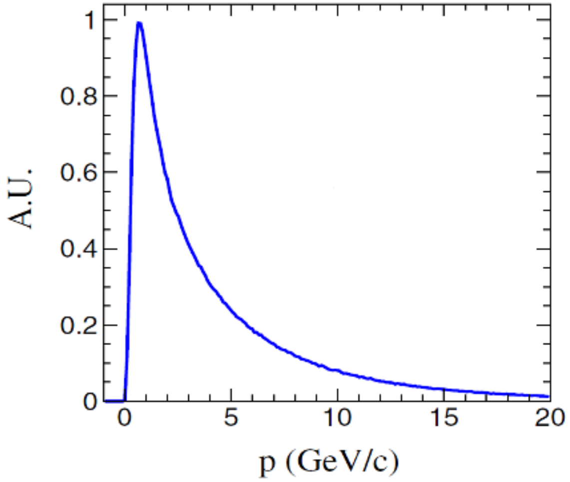
Introduction and requirement

- **CEPC: rich physics programs: Higgs, electroweak physics, flavor physics, QCD/Top**

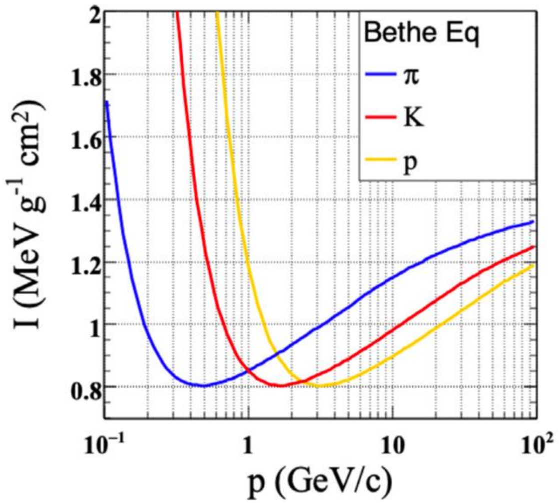


- **Particle identification(PID)** of Gas detector (dE/dx) : insensitive region
  - ✓ **0.5-2 GeV for K/pi separation, 1.5-2.5 GeV for K/p separation**
- PID is essential for flavor physics
- Precision timing detector is a matter of urgency (from IAC recommendation). **Timing detector is complementary to gas detector**

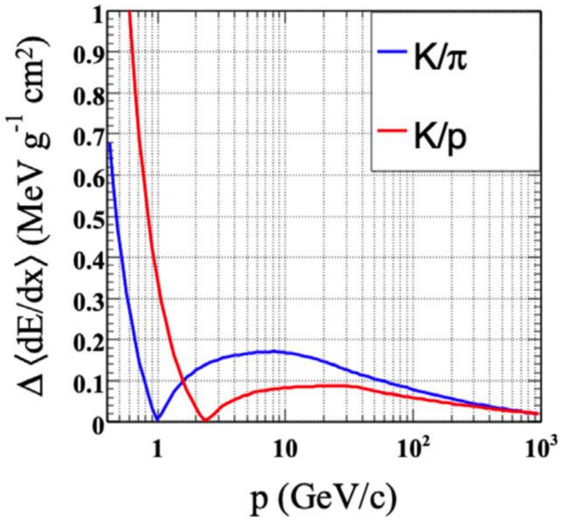
Momentum distribution



Average dE/dx for a track vs Momentum for K, pi, p



Absolute difference of the average dE/dx for a track vs Momentum for K, pi, p



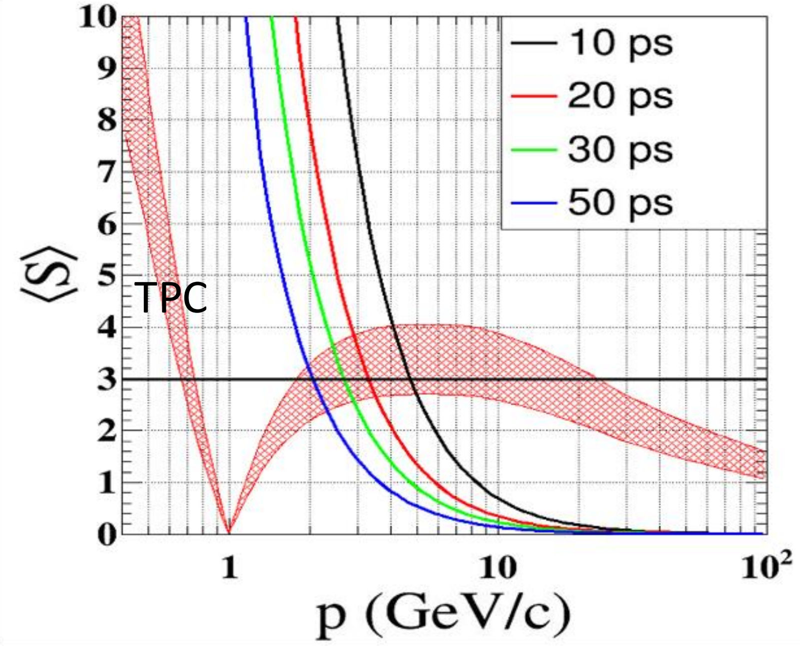
PID Ability with Different Time Resolutions

- Monte Carlo(MC) simulation with z-pole samples

Separation power

$$S_{A/B} = \frac{|t_A - t_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}} \qquad S_{A/B} = \frac{|dE/dx_A - dE/dx_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}}$$

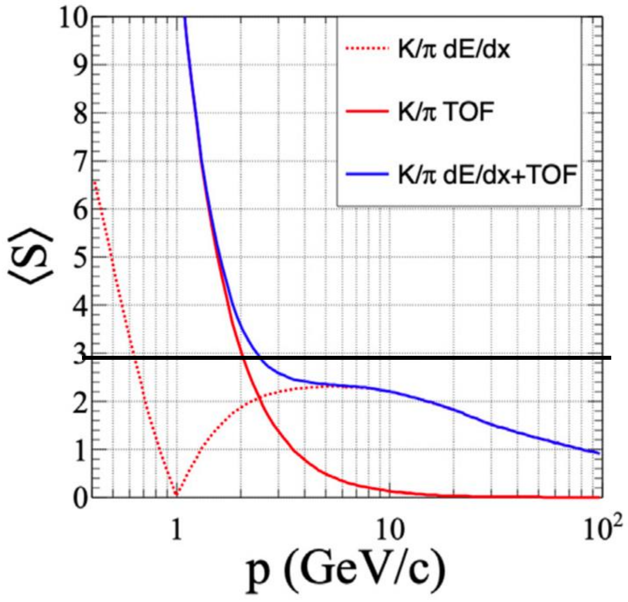
k/pi speration power of ToF with different time resolution, L=1.8m



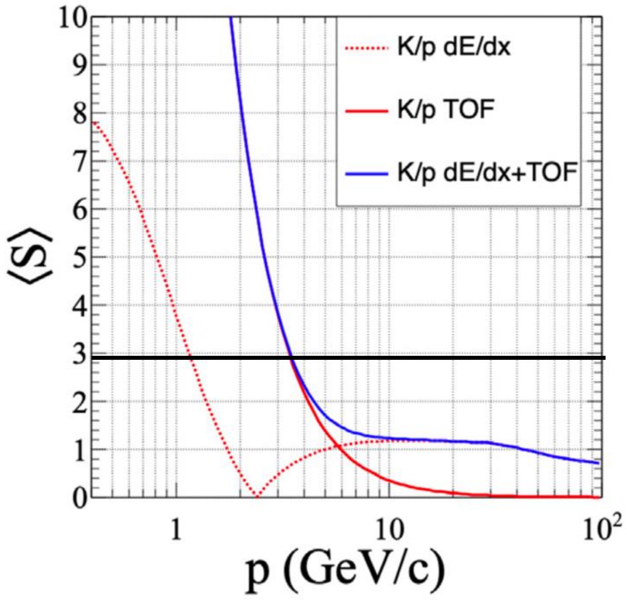
PID with 50 ps Time Resolution

- **Timing detector is complementary to gas detector: 50 ps** could improves the separation ability at the insensitive region of the gas detector
  - S > 3

K/pi separation



K/proton separation



Details in Yongfeng's paper

The efficiency and purity w/o ToF

- The $K\pm$ identification performance with ToF
  - A significant increase of purity effeciency when with ToF
  - Some increase of efficiency
  - The worse the dE/dx， the more important the ToF for PID

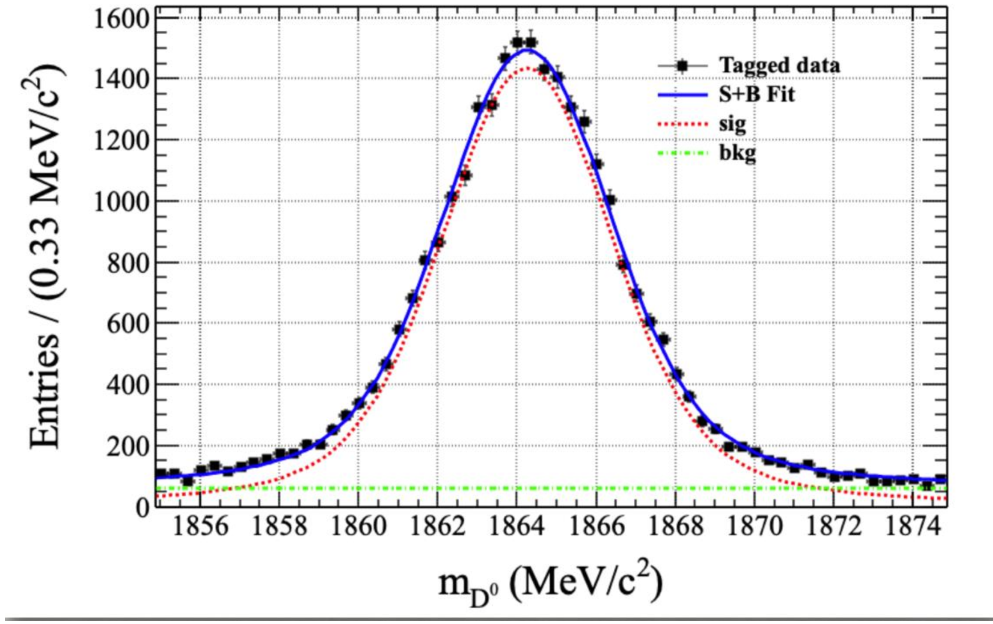
	Factor	1.	1.2	1.5	2.
dE/dx	ε_K (%)	95.97	94.09	91.19	87.09
	$purity_K$ (%)	81.56	78.17	71.85	61.28
dE/dx & TOF	ε_K (%)	98.43	97.41	95.52	92.3
	$purity_K$ (%)	97.89	96.31	93.25	87.33

$$\sigma_{actual} = factor \cdot \sigma_{intrinsic}$$

$D^0 \to \pi^+ K^-$ reconstruction with z-pole samples

- $D^0 \to \pi^+ K^-$ reconstruction with z-pole samples

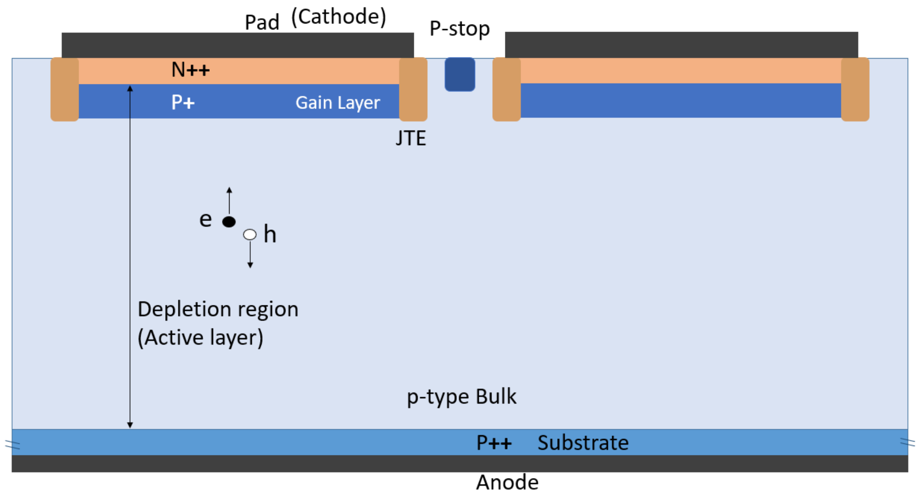
	ϵ (%)	p (%)
$\lvert mass - mass_{D0} \rvert < 0.01\,\mathrm{GeV/c^2}$	90.39 ± 0.24	2.16 ± 0.07
IMP $> 0.02\,\mathrm{mm}^2$	79.12 ± 0.21	5.04 ± 0.11
vertex fitted $\chi^2 < 5.15$	72.62 ± 0.23	15.36 ± 0.18
dis of vertex to IP $> 0.305\,\mathrm{mm}$	69.24 ± 0.24	28.41 ± 0.23
PID	68.19 ± 0.24	89.05 ± 0.16



Technology survey and our choices

LGAD (Low-Gain Avalanche Diode)

Segmented gain layer

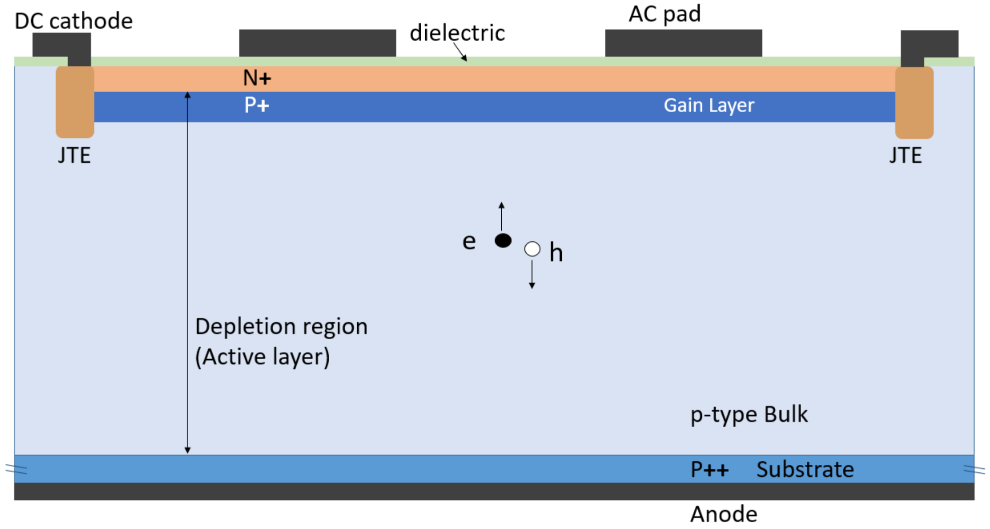


- The read-out electronics is connected to n++ layer
- Time resolution ~ 30ps
- Position resolution: pixel size/$\sqrt{12}$
- Radiation hardness: 10^{15} ~$10^{16} n_{eq}/cm^2$

AC-LGAD (AC-coupled LGAD)

Continuous gain layer

Less dead area，higher spatial resolution



- Metal AC-pads separated from the n+ layer by a thin dielectric (Si_3N_4, SiO_2)
- Time resolution ～30ps
- Position resolution: 5～10 um

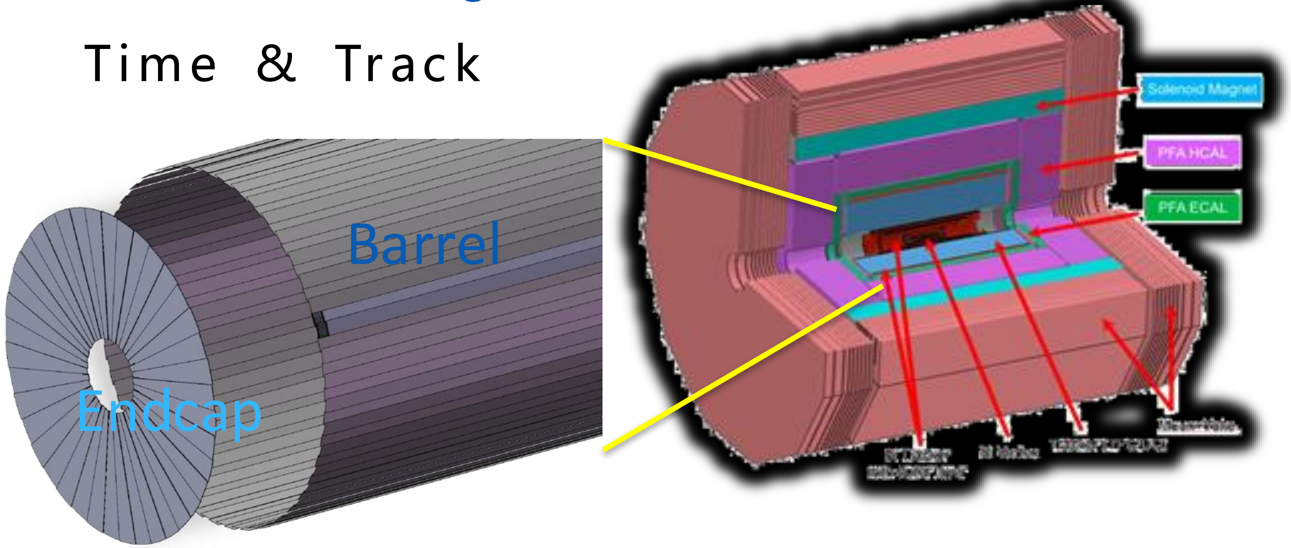
7

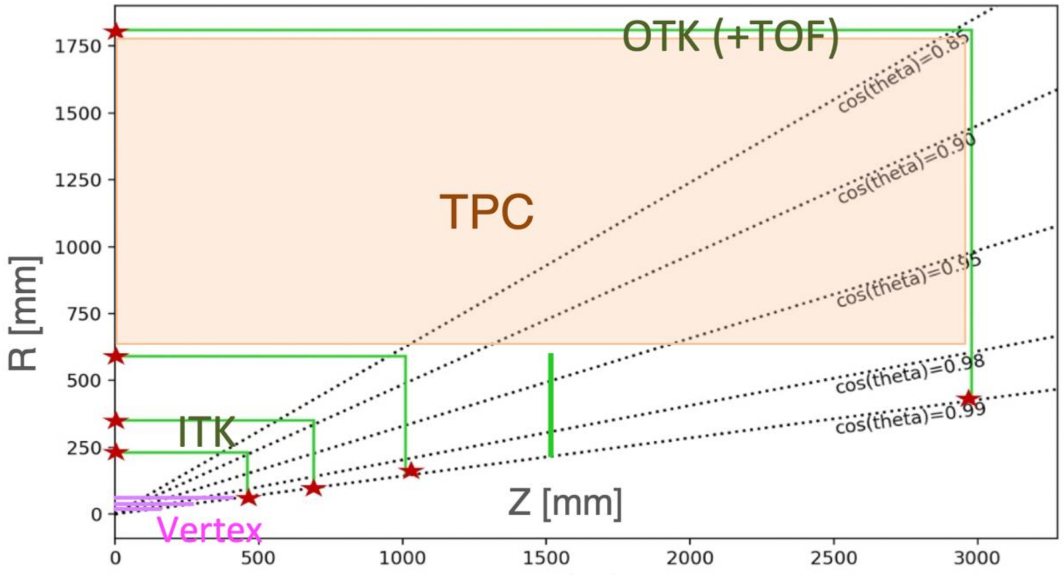
AC-LGAD Based ToF & Outer Tracker for CEPC

- Develop AC-LGAD strip silicon sensor for outer tracker
  - timing resolution **50 ps**
  - spatial resolution better than **10 μm** (Bending direction)
  - Between TPC and ECAL，R （400 mm – 1800 mm），L （5800 mm)

LGAD based 4D timing detector

Time & Track

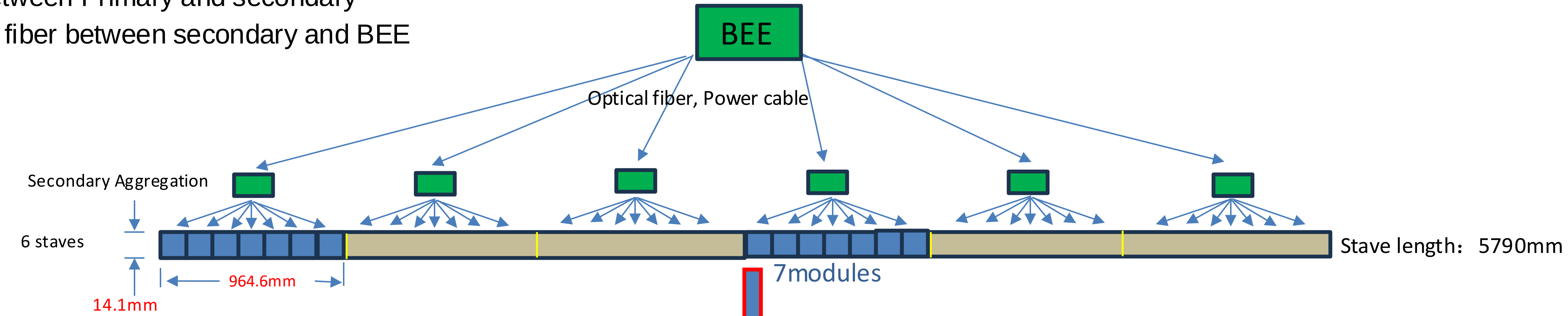




Reference TDR of CEPC

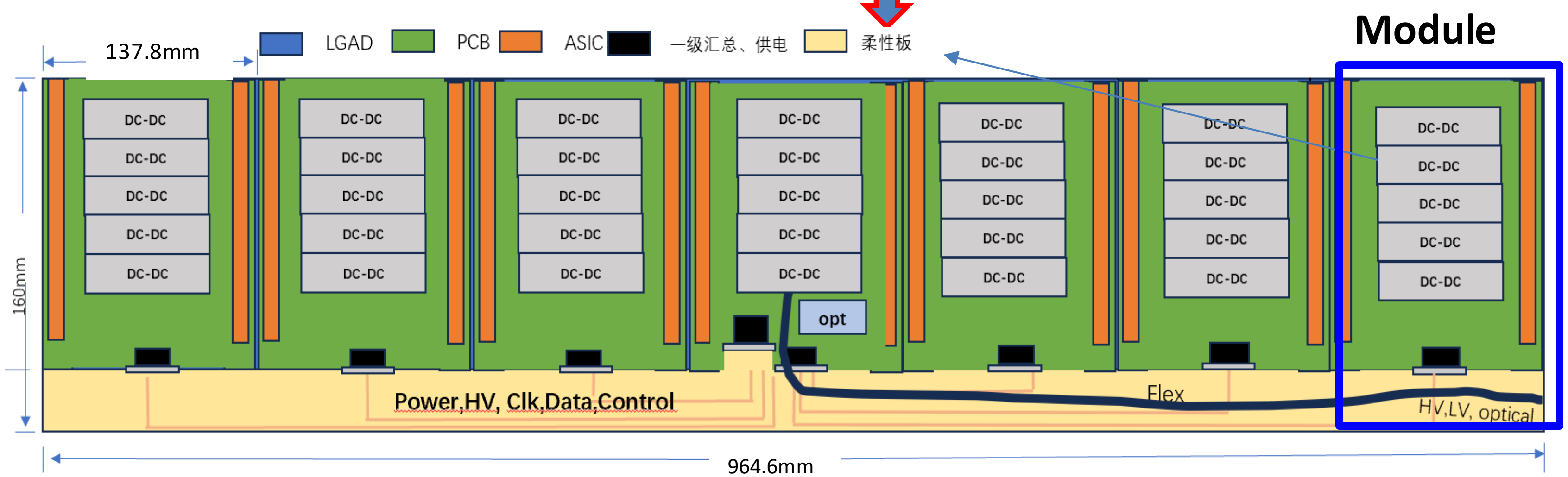
Electronics for ToF & Outer Tracker

- **Four parts：Readout ASICs，Data aggregation，Data Link，BEE**
  - Provide LV and HV for module independently
  - Primary Aggregation adapts Data rate between ASIC and Data Link
  - Flex between Primary and secondary
  - Optical fiber between secondary and BEE



Module

Ladder layout

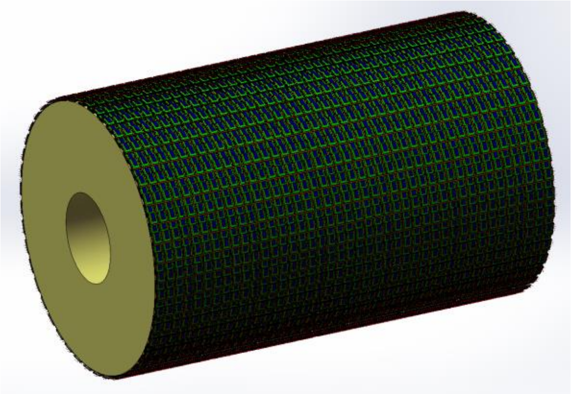


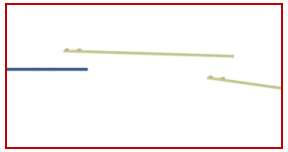
Design of the OTK with the strip AC-LGAD：Barrel

- one layer: 70 m^2, 3780 modules

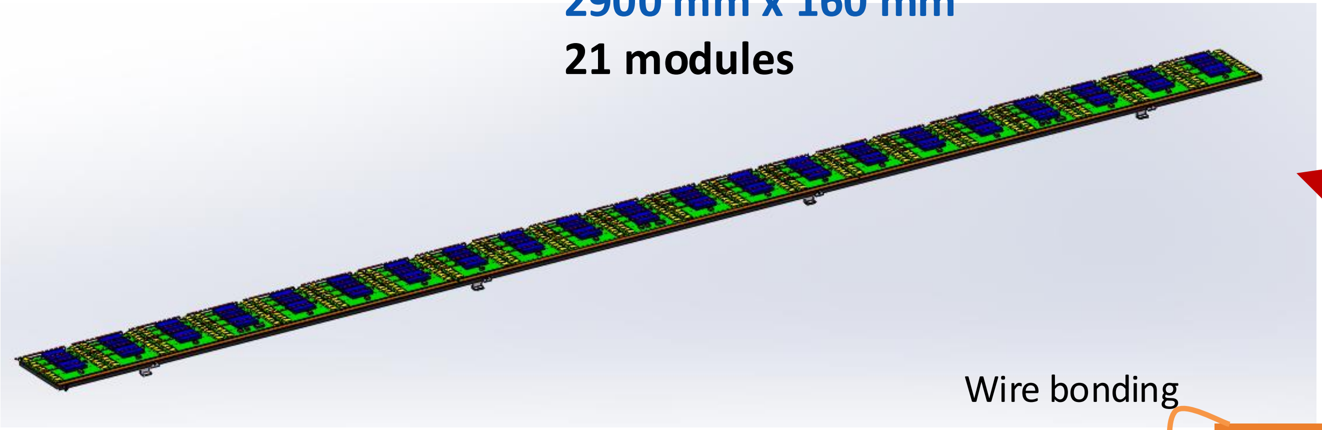
  R= 1800 mm ,H ~ 5800mm
  - overlap to decrease the dead area
  - 90 staves
  - 42 modules/stave

One layer ToF+OTK
R= 1800 mm , H～5800mm
90 staves

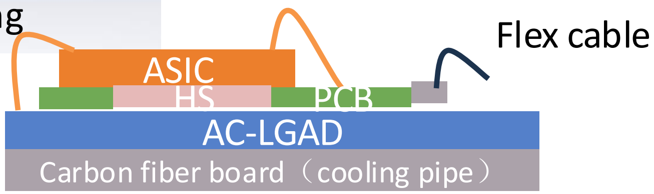




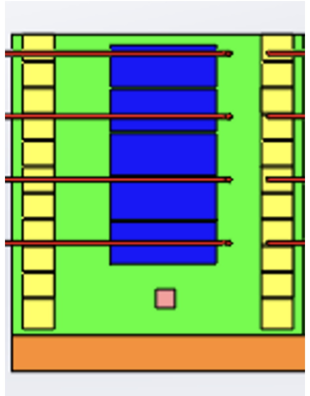
Long half stave
2900 mm x 160 mm
21 modules



Module
137.8 mm x 160mm
22 ASICs

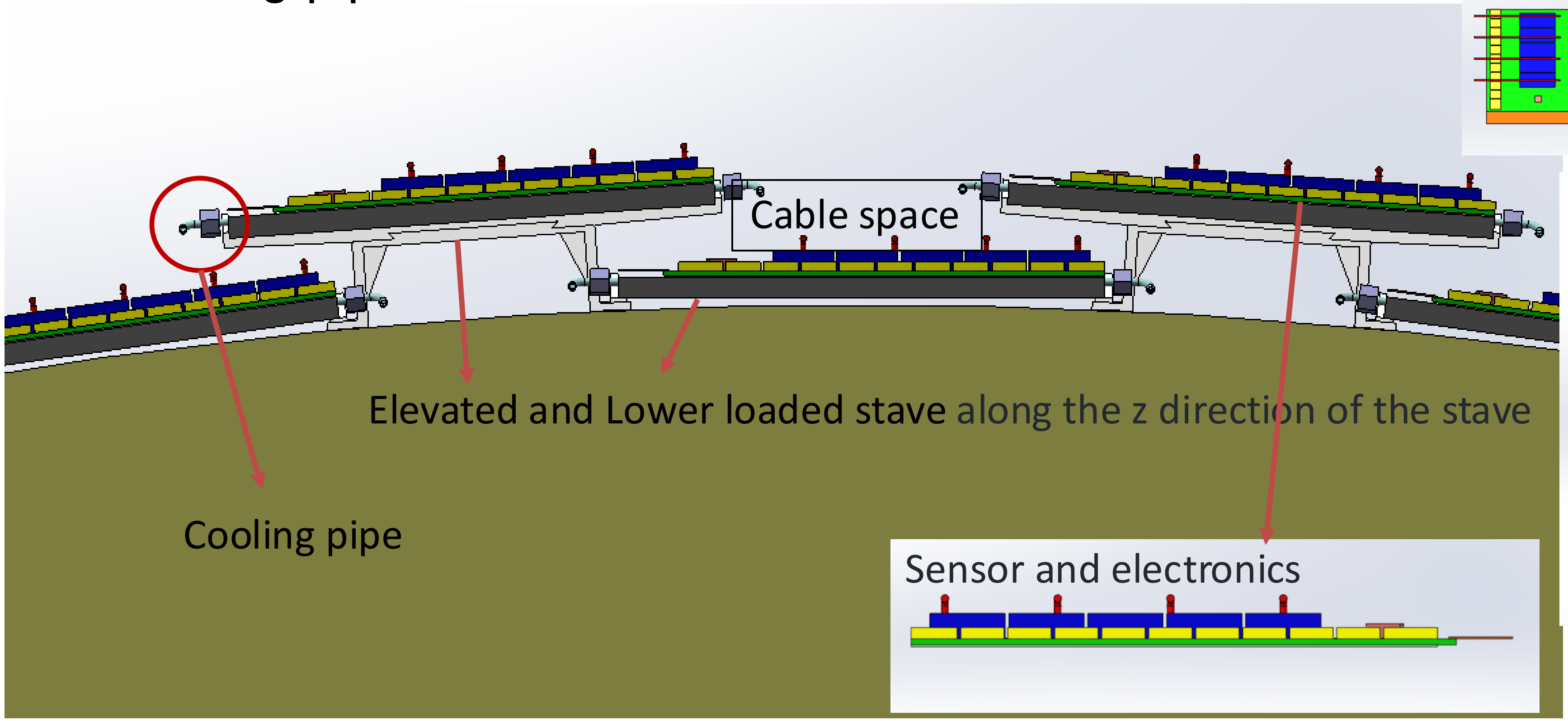


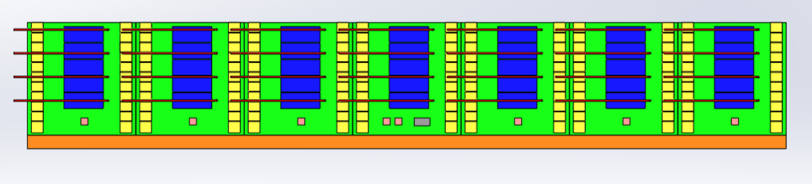
Heat sink(HS): Al;

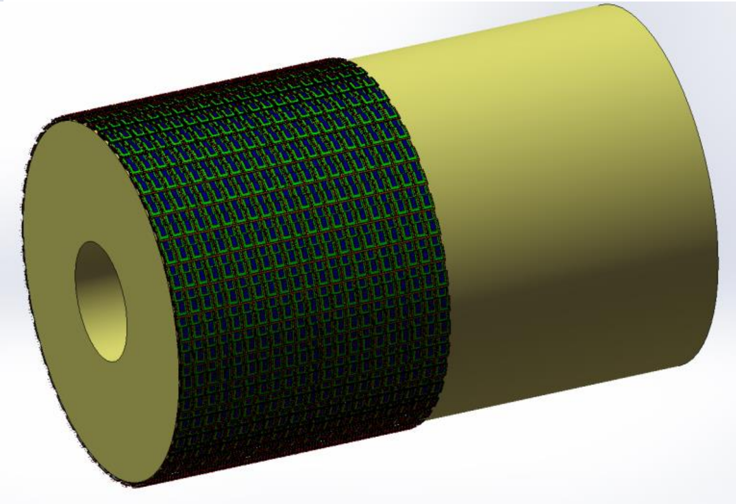


Mechanical Design for LGAD ToF & OTK

- Overlap staves for the barrel with detailed electronics design， cooling and installation
  - Sepcial support design to allow precise alignment of the AC-LGAD sensors
  - Extra space for cables
  - Cooling pipes

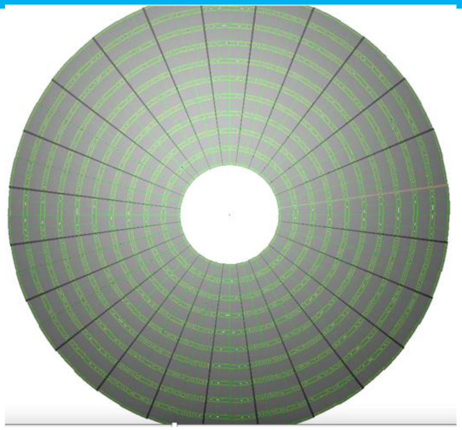




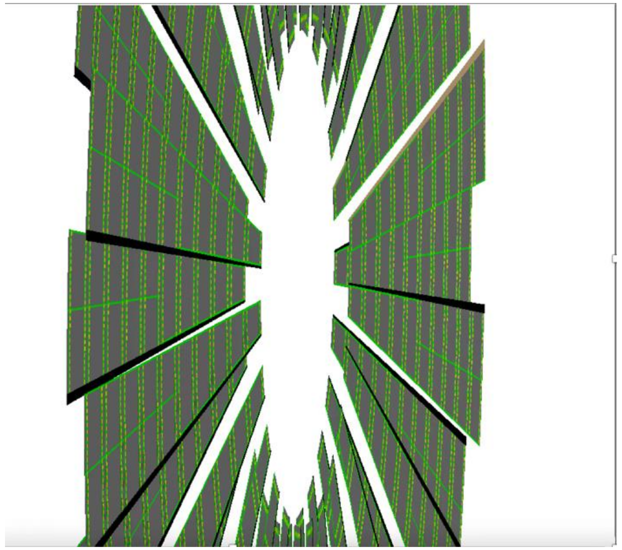


Endcap Design for ToF & OTK

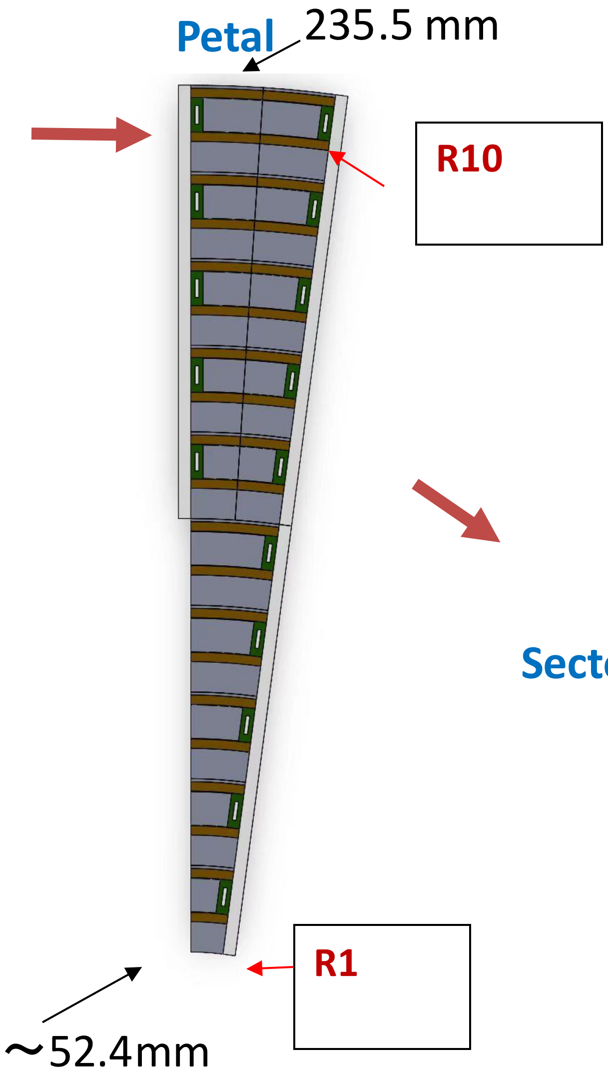
Disk



overlap petals to reduce the dead area

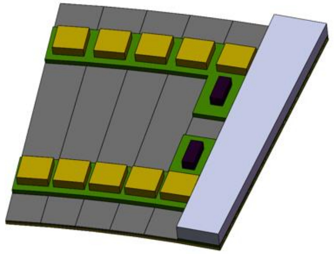


Petal



- One layer with 20 m^2
  - ✓ Radius from 400 mm to 1800 mm
  - ✓ Theta from 8^o to 30o
- Overlap to reduce the dead area
  - ✓ 48 petals/layer
  - ✓ 10 rows/petal,
  - ✓ 7.5^o per petal,
  - ✓ Overlap 0.5^o/petal
- 140 mm / row at R direction

Sector Module per row

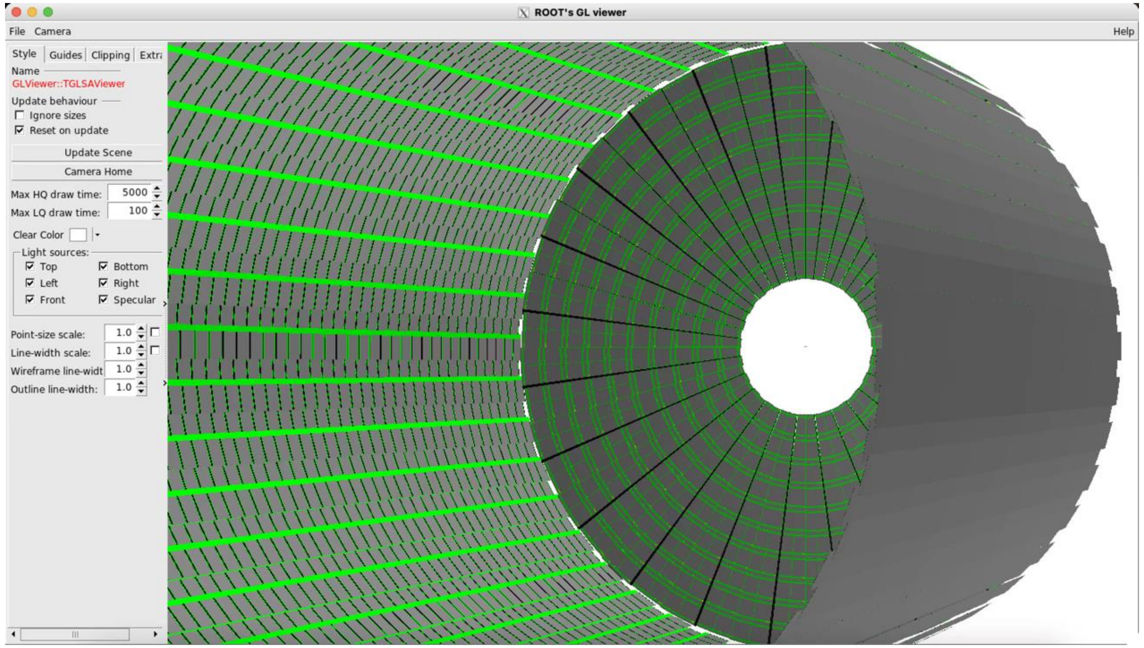


70 mm
R1: 52.36mm-70.69mm

CEPCSW Progress for ToF&out tracker

- Got the geometry of barrel and endcap into CEPCSW
  - Good for full simulation and future physics performance study

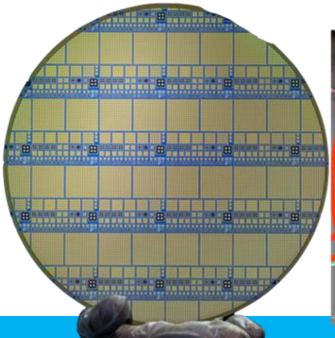
- Estimated the maximum occupancy: 0.35% at z pole, OK

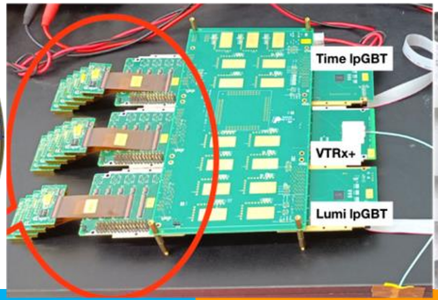


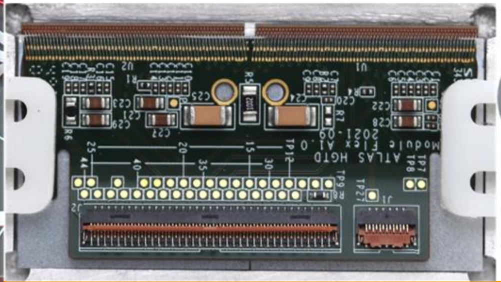
Details in Dian Yu's poster

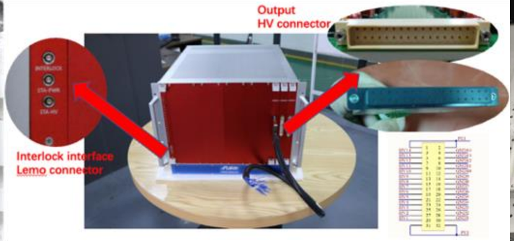
R&D Team

- ToF & OTK: 10 universities and institutes， ~ 18 staffs + ~ 22 postdocs & students
- **Joined the DRD3 group**
- **International cooperation experiences:** **ATLAS China team played a leading role in HGTD**
  - Joao (IHEP) is re-elected as Project leader (2021-2025)，L1 manager
  - 4 Level-2 conveners (Module, Sensor, Electronics, Risk, Simulation)
  - 3 Level-3 conveners (PEB, high-voltage, module flex)





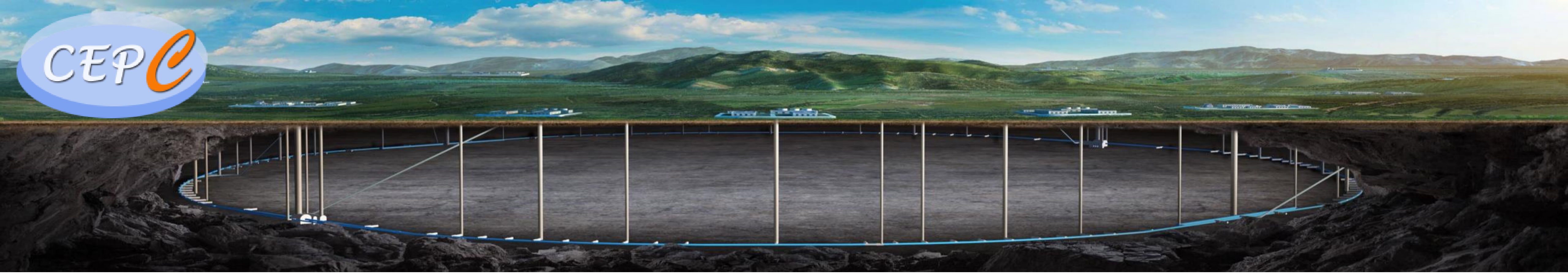




Summary and Working plan

- **PID**： ToF with 50 ps is complementary to gas detector （dE/dx） , which could improve the PID ability and essential for the flavor physics
- **Designed an AC-LGAD based detector as ToF + Outer Traker for CEPC**
  - **50 ps** time resolution and **10 μm** spatial resolution (4D detector)
  - aim to design **70 mm** long strip AC-LGAD with **100 μm** pitch
  - cover the barrel and endcap region： **～90 m^2**
- **Working plan for ToF & Outer Tracker**
  - Optimized the barrel and endcap design
  - High precision electronics optimization， such as the power consumption
  - Design and Optimize the cooling system (cooling pipe et. al.)
  - Physics performance study
  - **A lot to be done…**

Welcome to join us！



Thank you for your attention!

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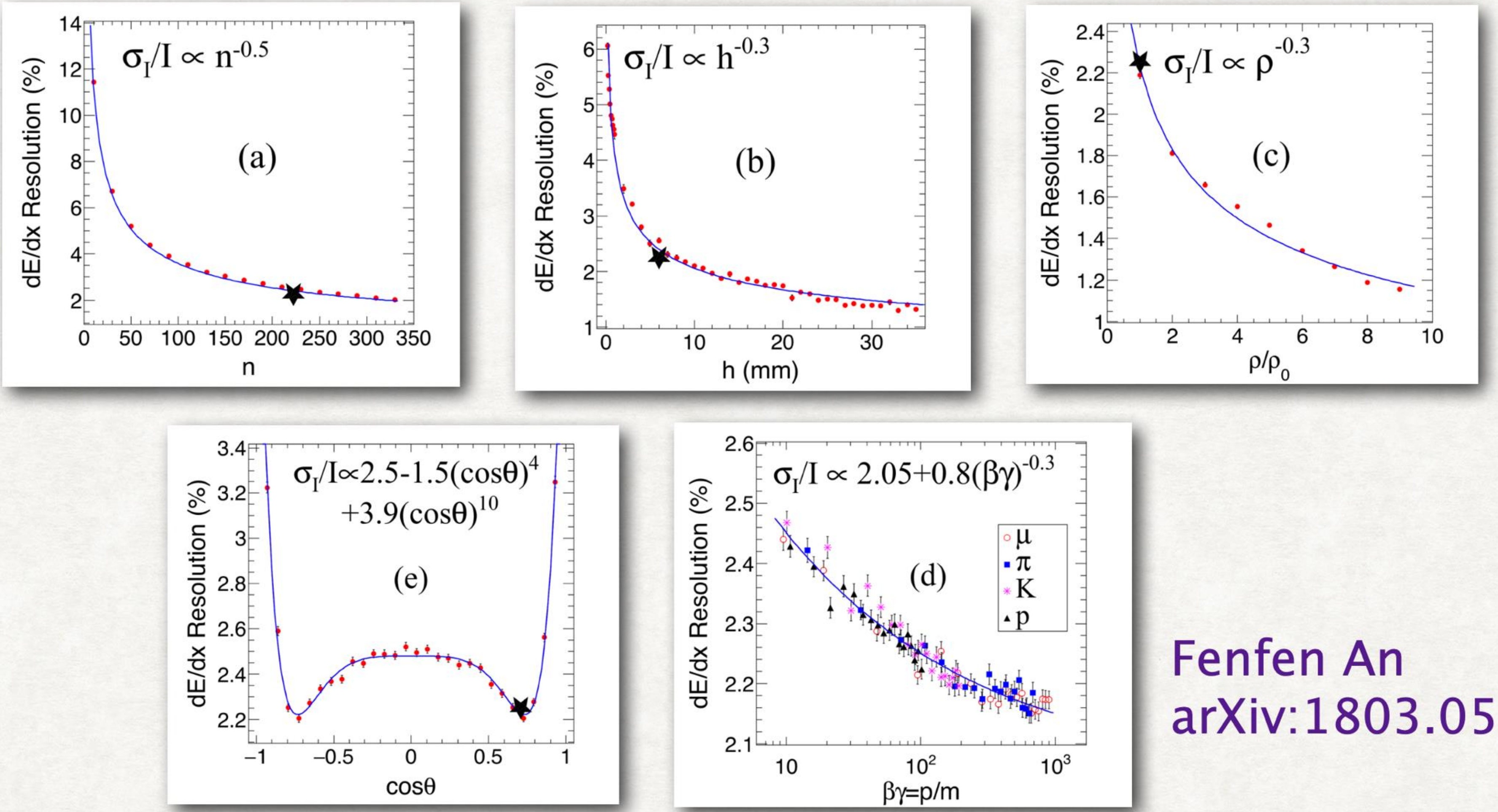
Backup

Table 2
The branching ratio and the number of simulated events of the Z-pole samples.

Process	$\mathcal{B}$	Sample used
$Z \to u\bar{u}$	11.17%	
$Z \to d\bar{d}$	15.84%	
$Z \to s\bar{s}$	15.84%	6.313×10^6
$Z \to c\bar{c}$	12.03%	
$Z \to b\bar{b}$	15.12%	

intrinsic dE/dx resolution

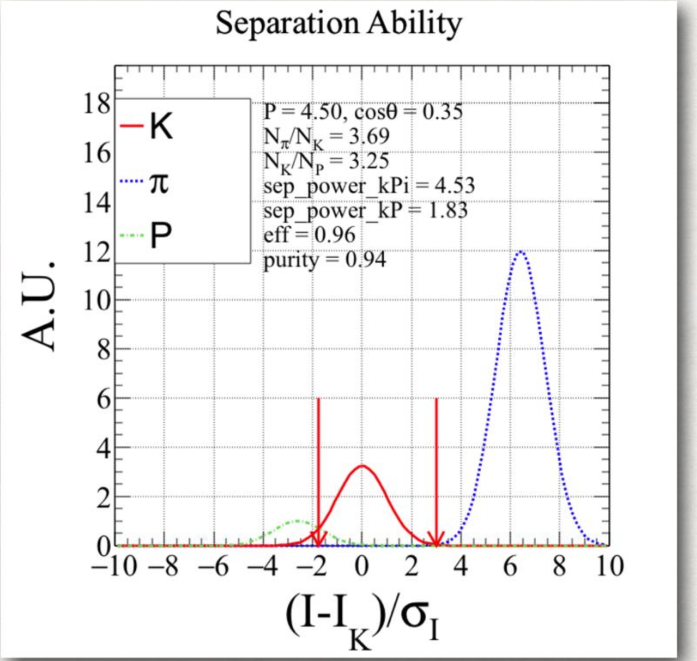


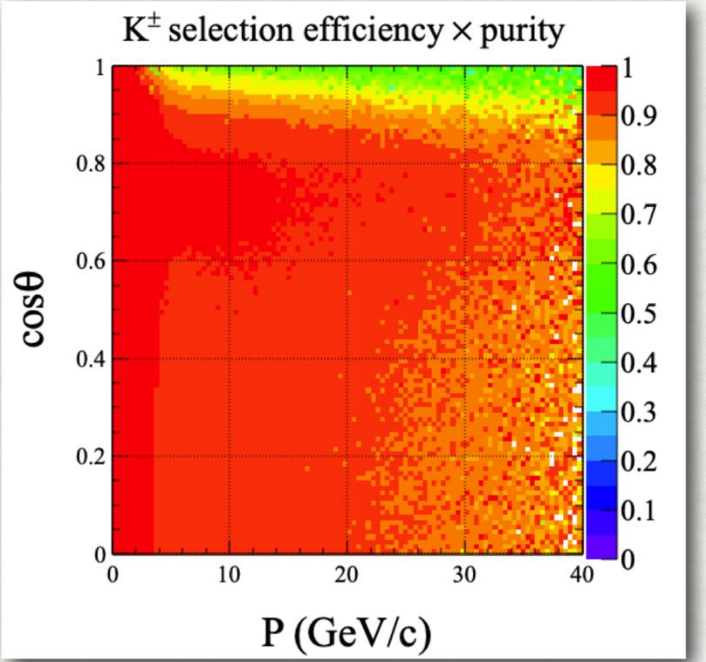
Fenfen An
arXiv:1803.05134

The dE/dx resolution could reach 2.5% in the barrel region with particle's energy ranges from 0.1 GeV to 100 GeV.

PID performance on Z-pole samples

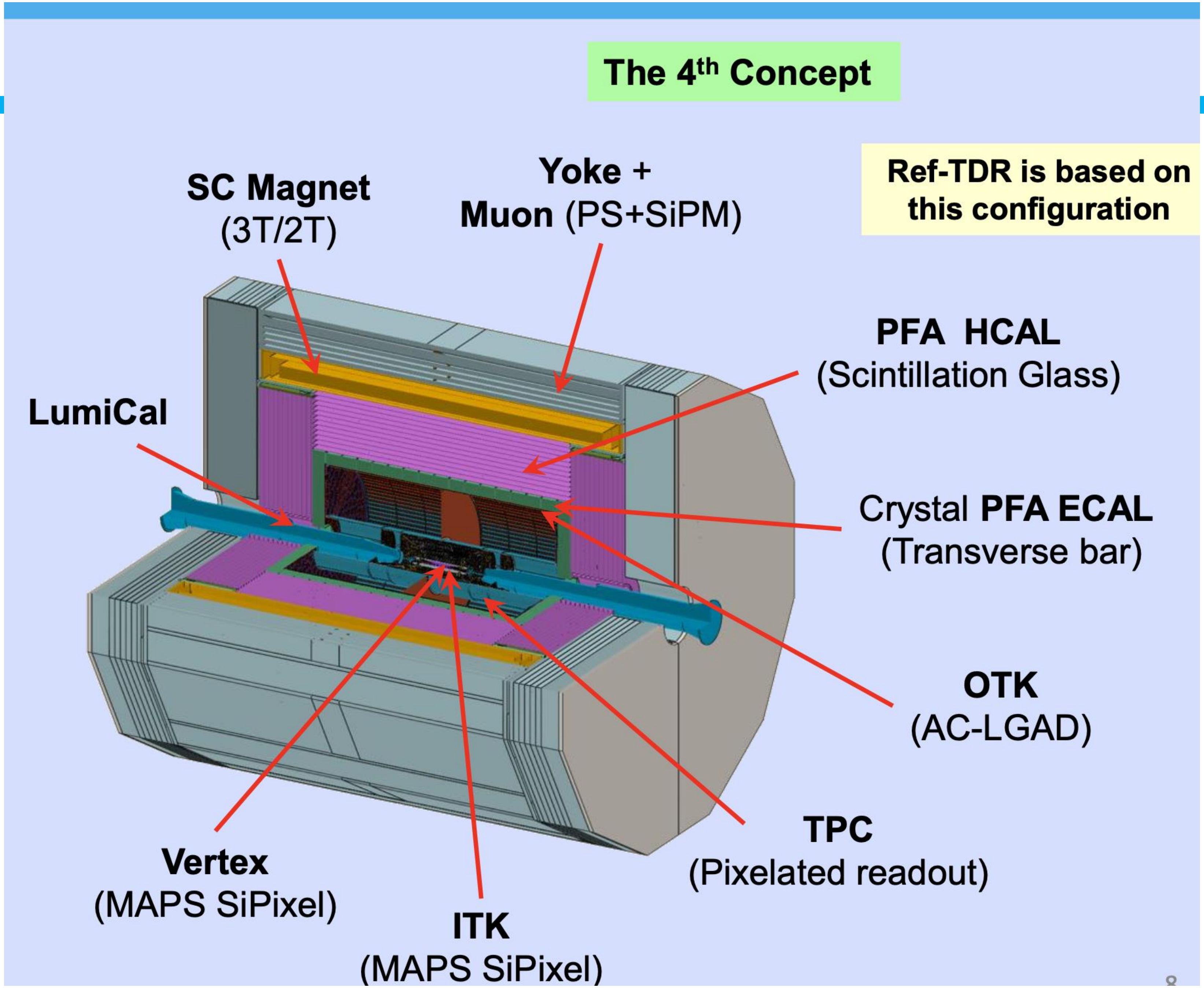
$K^{\pm}$ identification





$$\text{overall } efficiency = \frac{\sum_{bins} \epsilon_K * N_k}{\sum_{bins} N_k} \qquad 95.97\%$$

$$\text{overall } purity = \frac{\sum_{bins} p_K * N_k}{\sum_{bins} N_k} \qquad 81.56\%$$


The 4th Concept
Ref-TDR is based on this configuration
SC Magnet (3T/2T)
Yoke + Muon (PS+SiPM)
PFA HCAL (Scintillation Glass)
LumiCal
Crystal PFA ECAL (Transverse bar)
OTK (AC-LGAD)
TPC (Pixelated readout)
Vertex (MAPS SiPixel)
ITK (MAPS SiPixel)

Mechanism： Optimization of the Barrel Design

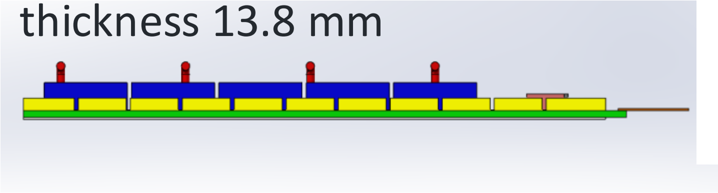
- Three arrangement of the ladder

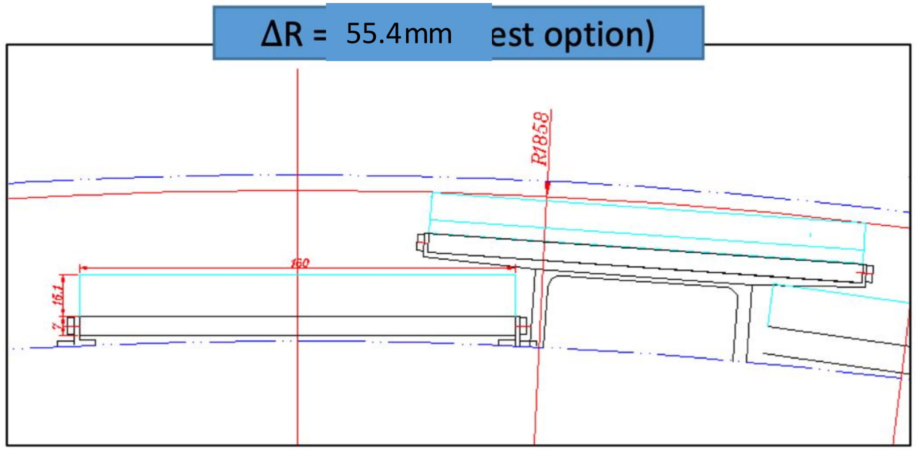
G1: ΔR = 55.4 mm （**The Best arrangement**）

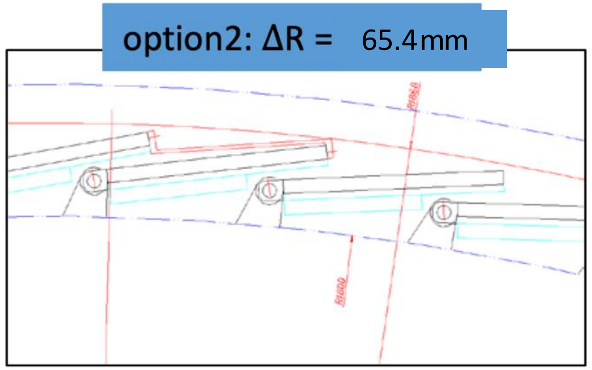
The best option:

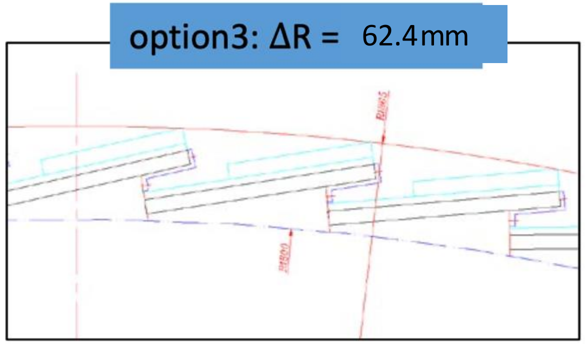
- minimum space required in R direction ΔR= 55.4 mm
- Sensors toward outside direction (update recently)

Sensor and electronics：
thickness 13.8 mm

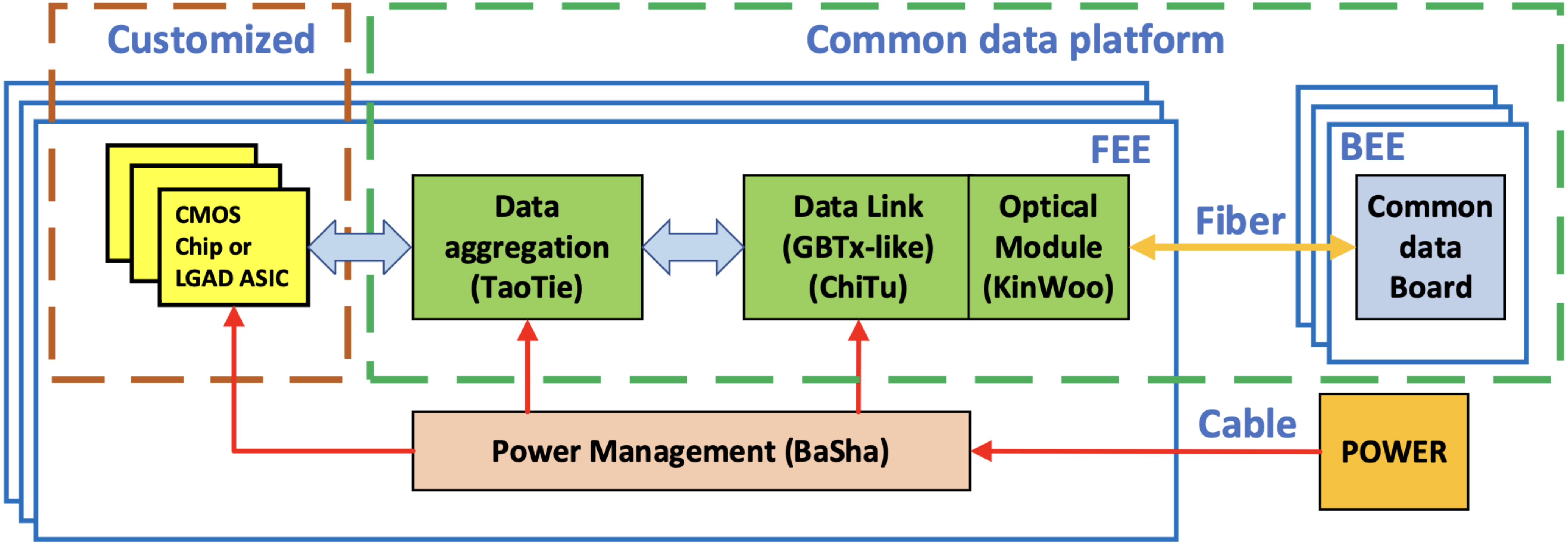




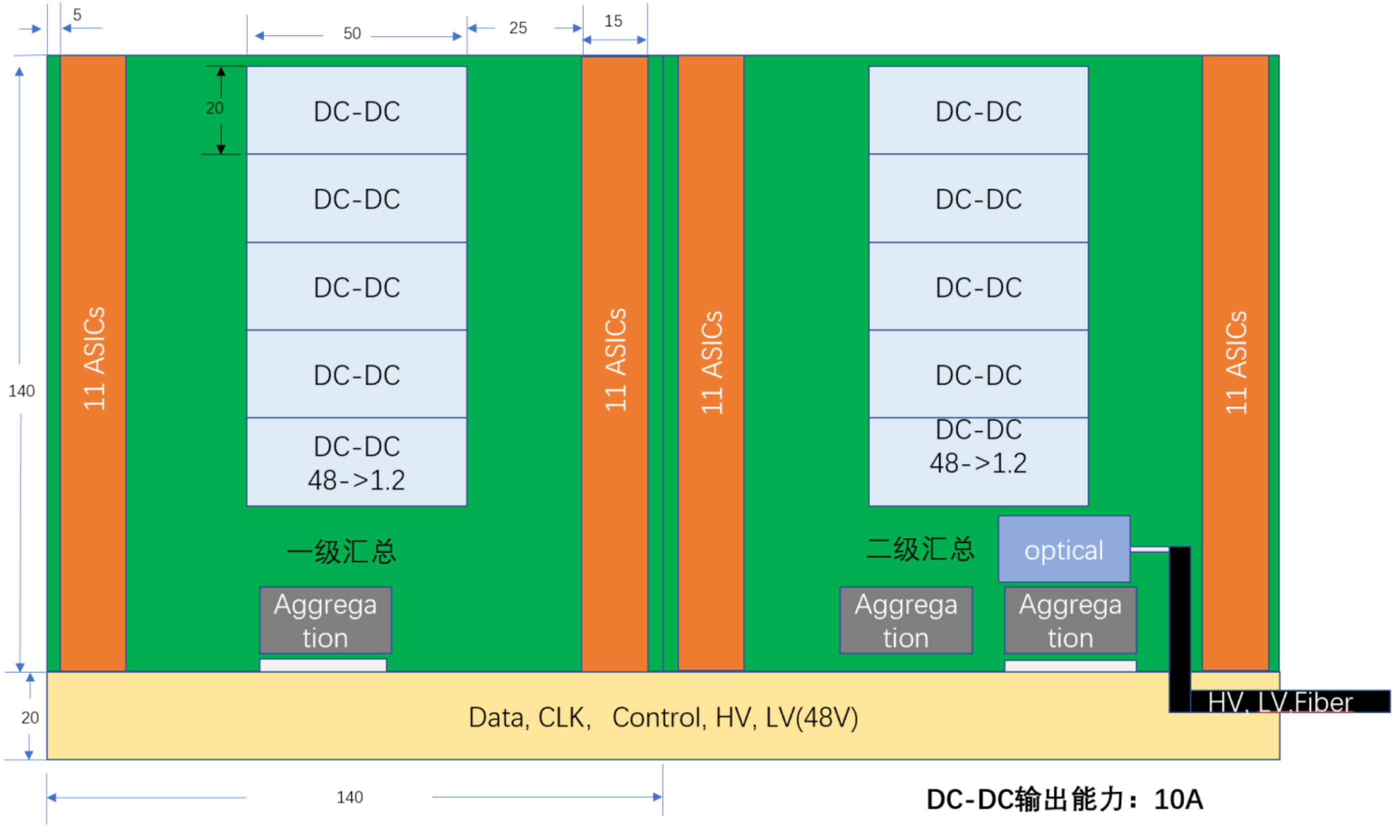




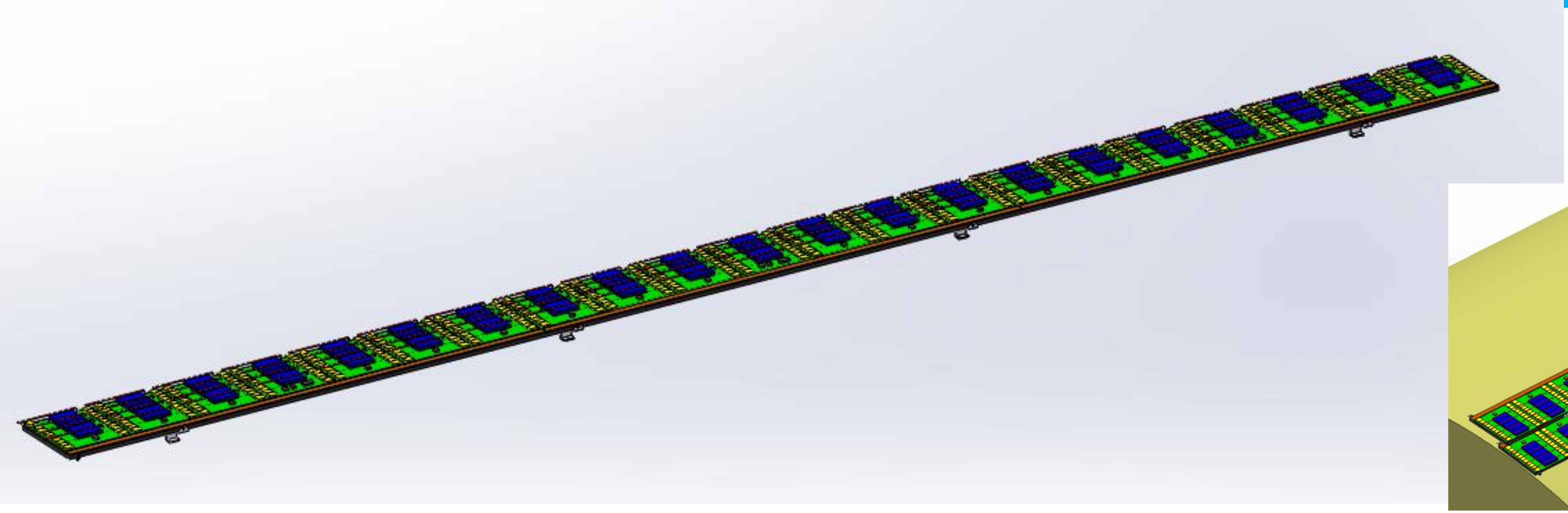
Silicon Tracker Common Electronics

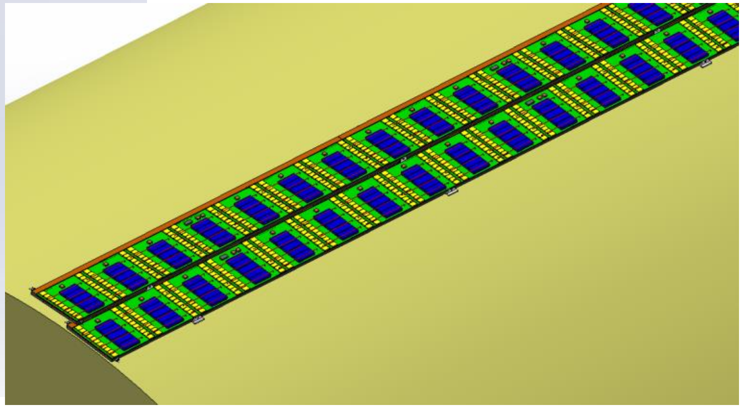


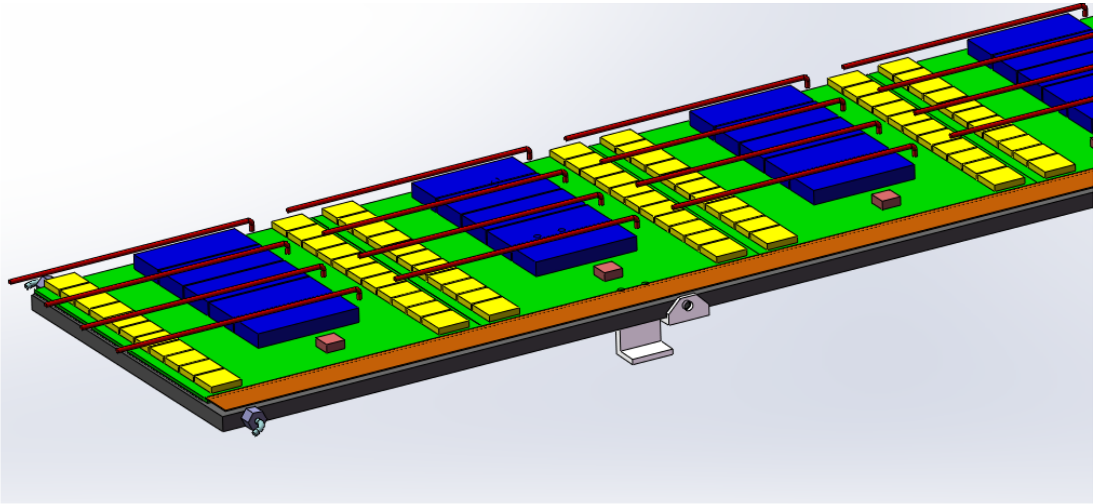
- Data transmission: common data platform
- Trigger mode: triggerless

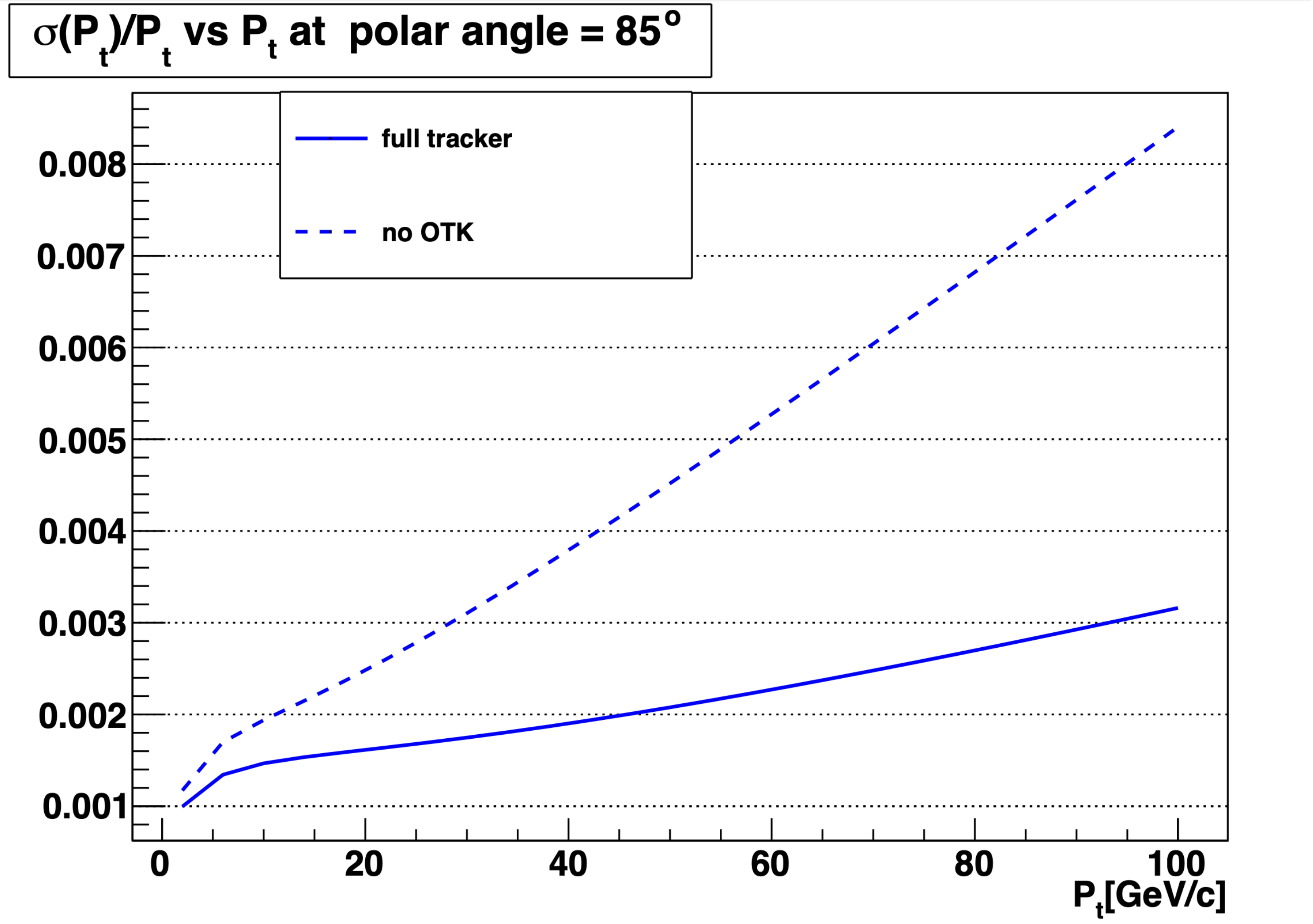


DC-DC输出能力：10A

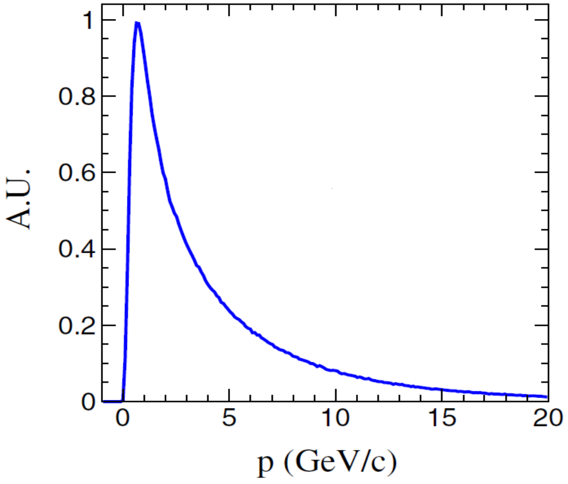




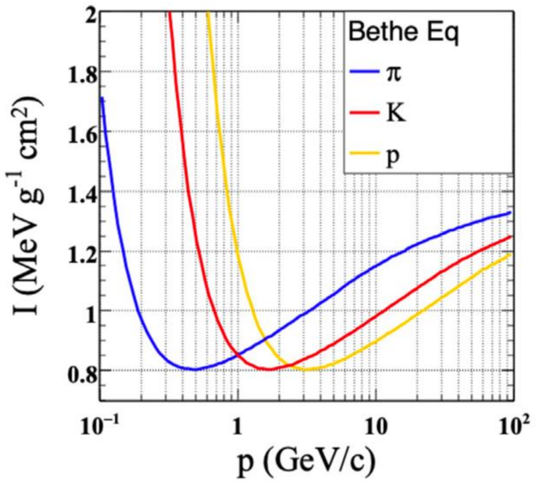



σ(Pt)/Pt vs Pt at polar angle = 85°
full tracker
no OTK
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
20
40
60
80
100
Pt[GeV/c]

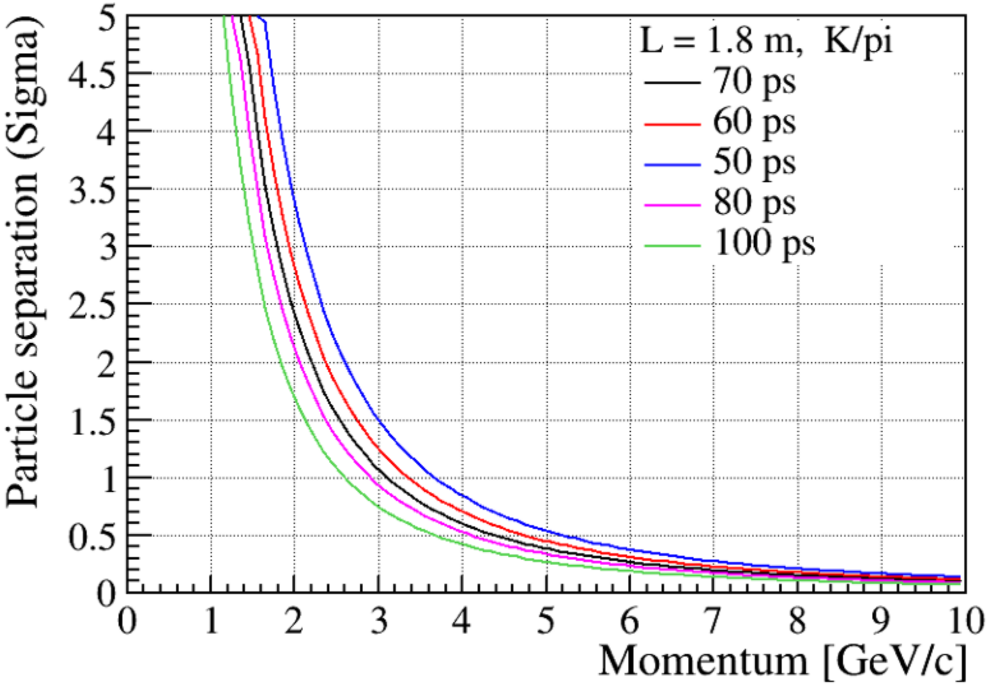
- TPC



A.U.
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
p (GeV/c)



I (MeV g^-1 cm^2)
Bethe Eq
π
K
p
10^-1
1
10
10^2
p (GeV/c)



Particle separation (Sigma)
L = 1.8 m, K/pi
70 ps
60 ps
50 ps
80 ps
100 ps
Momentum [GeV/c]