Vertex & tracking detector For EicC

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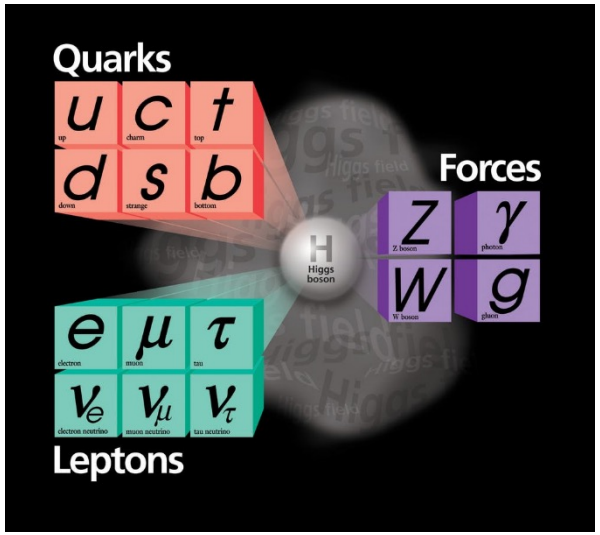
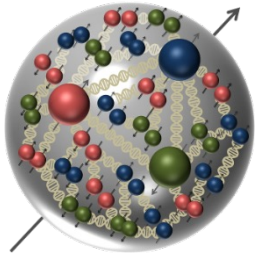
第三届半导体辐射探测器研讨会-2023-05

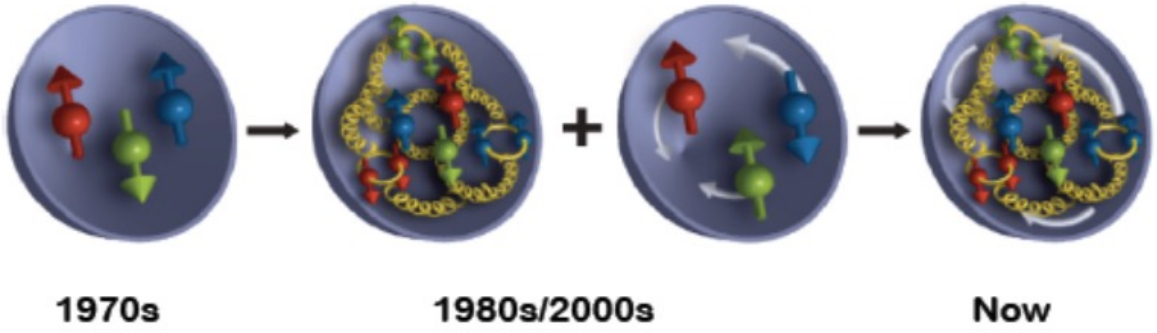
We know very little…





Origin of nucleon spin

Origin of nucleon mass

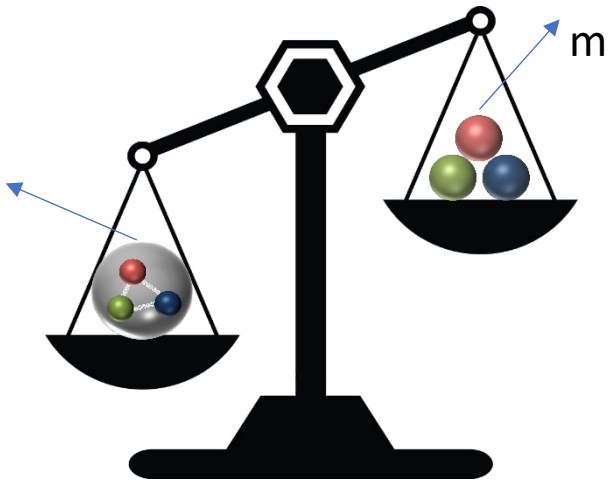


spin

mass

Proton mass

Higgs mechanism



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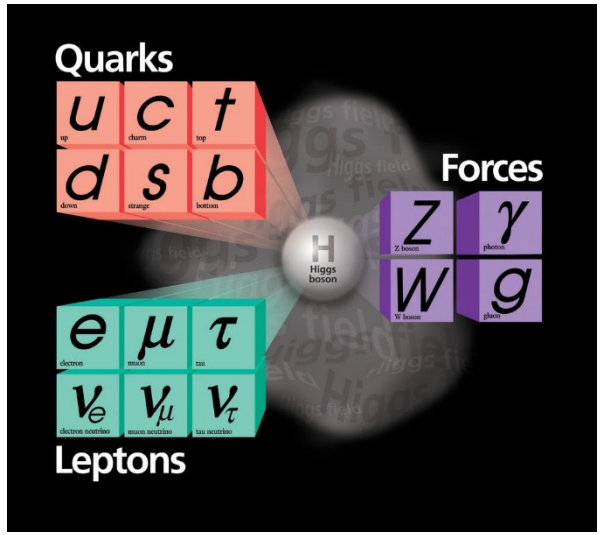

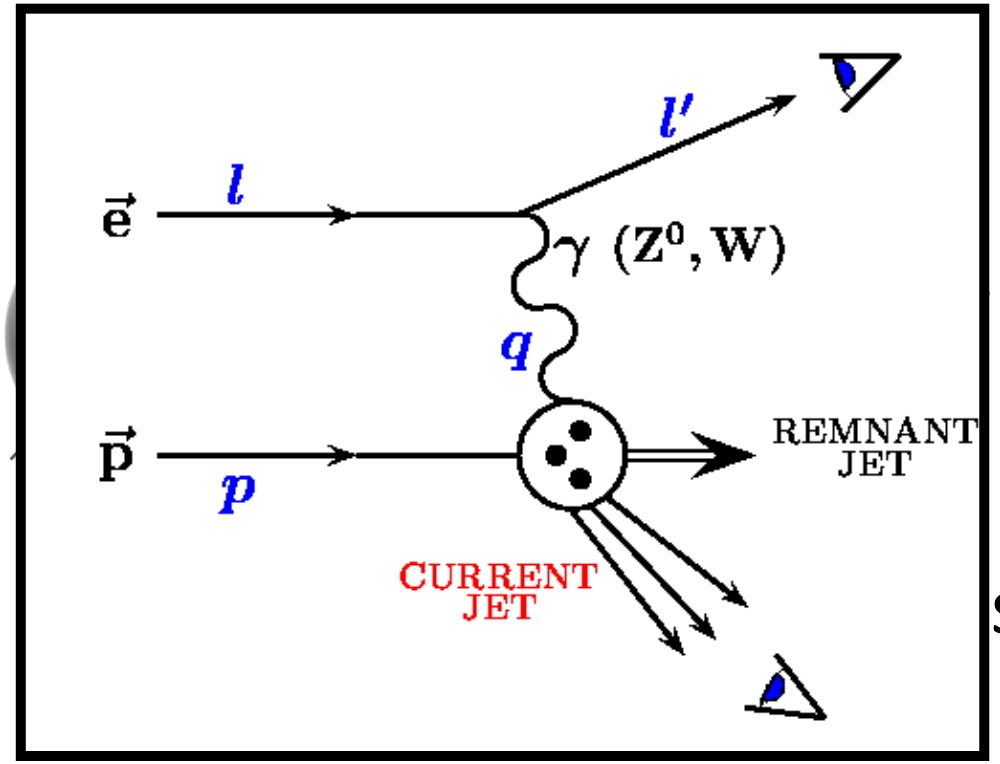

n

ss

spin

mass

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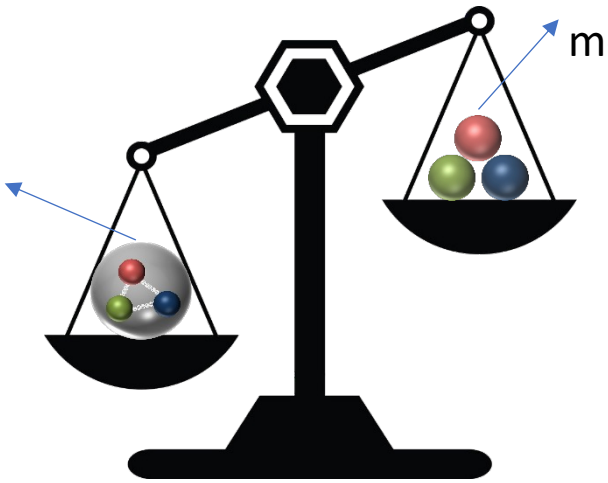
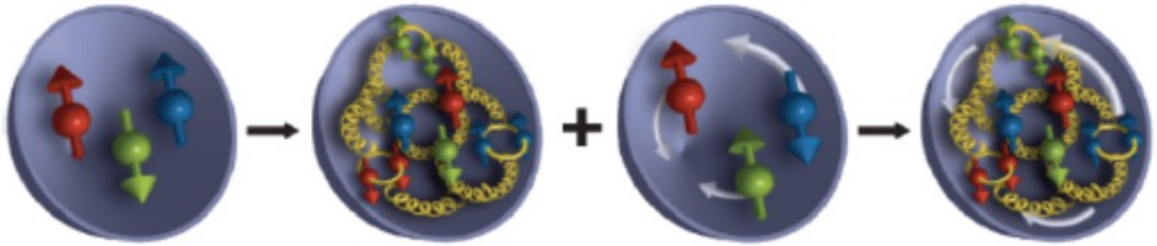
Proton mass





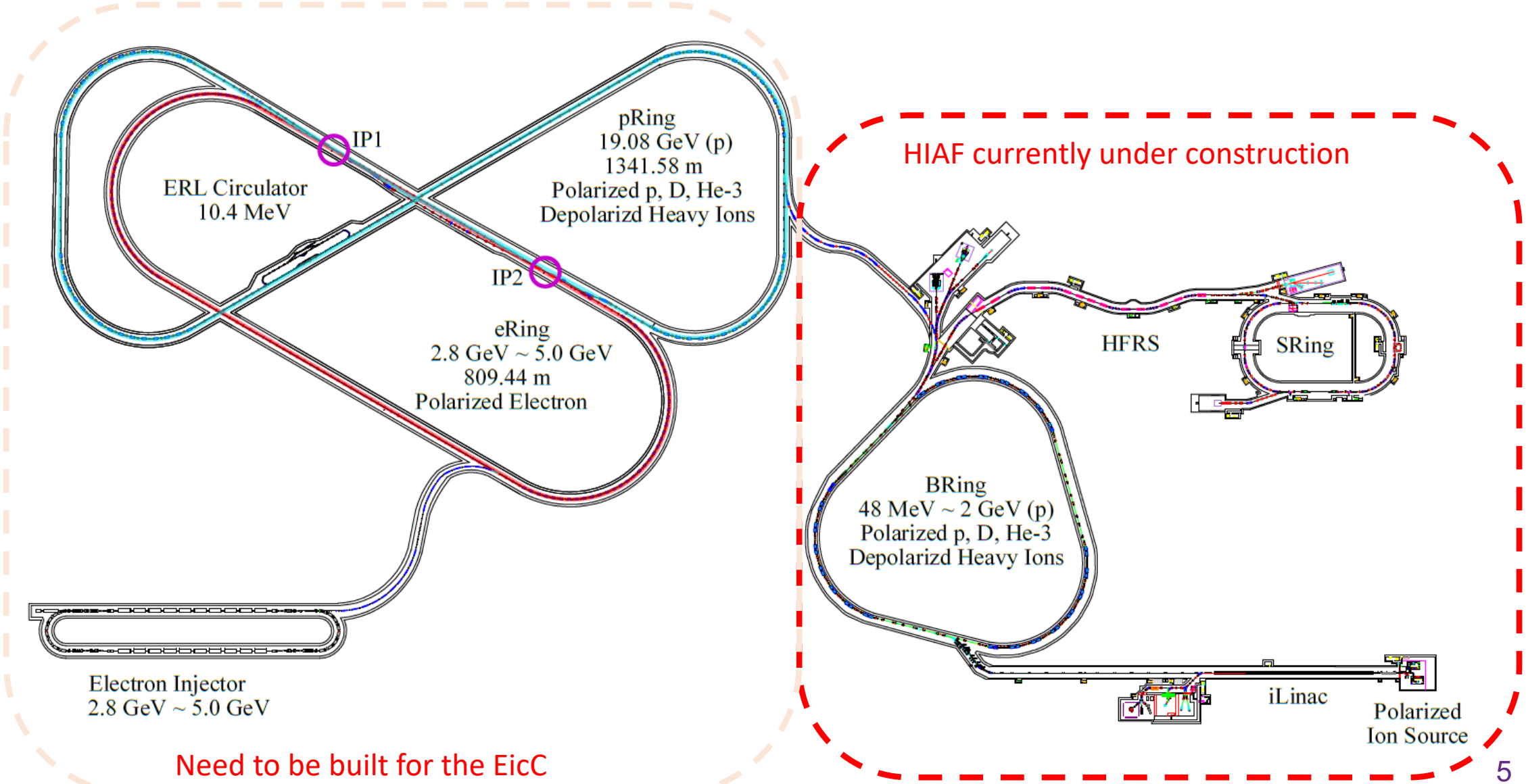
Electron Ion Collider in China…Huizhou(惠州) in Guangdong province

HIAF under construction

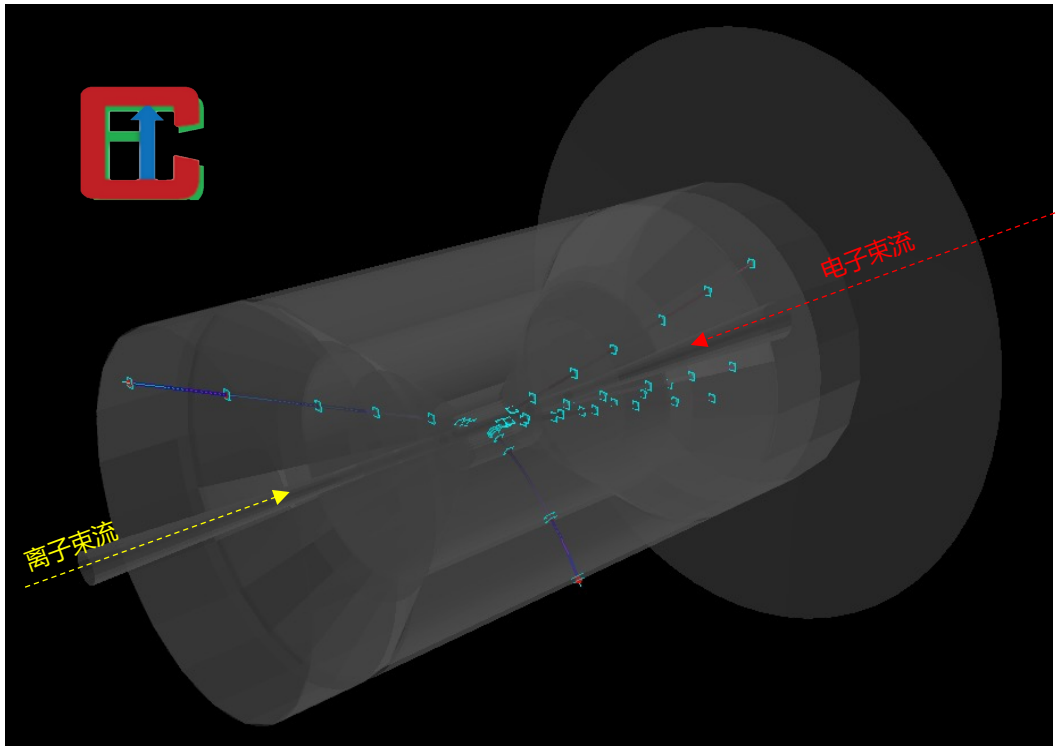
EIC in China

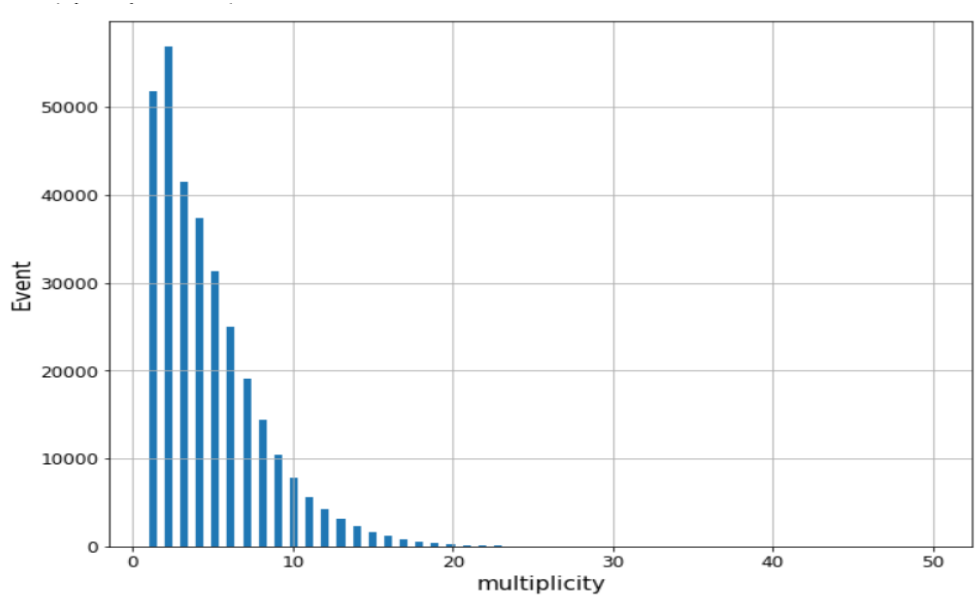
Electron **I**on **C**ollider in **C**hina, EicC

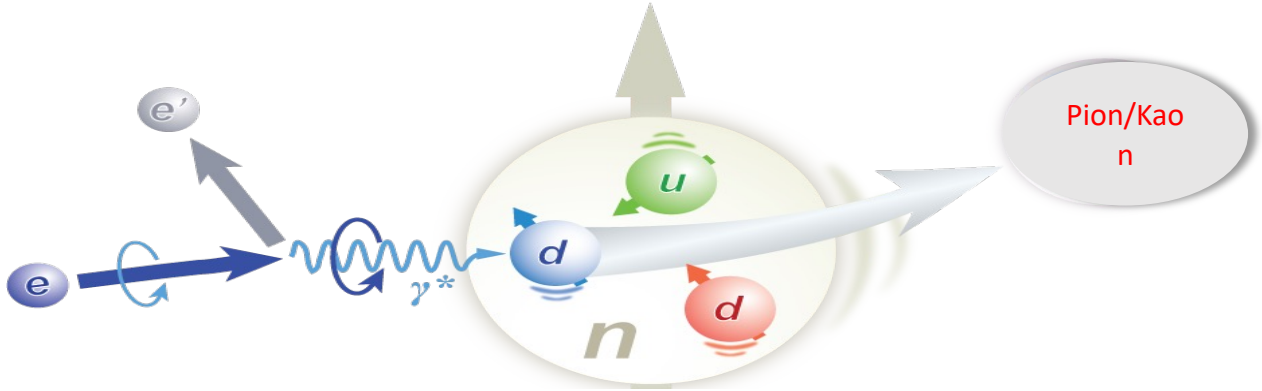
EicC Accelerator complex layout



Data sample @ EicC







- **3.5x20 GeV e-p collision with center of mass energy of 16.7 GeV**
- **A cross-section of 20.8 μb.**
- **The luminosity is L = 2×10^{33} $cm^{-2}s^{-1}$**
- **Expect to collect 50 fb^{-1} per year**

The requirement on EicC

Goal of vertex and tracking system

- Reconstruct charged-particle trajectories
  - Join hits to form a track
  - measure momentum and charge (with magnetic field)
- Reconstruct vertices
  - “primary” vertex: collision point where most particle are produced
  - “secondary” vertices: decay of unstable particles

Physics requirements for EicC ➔

- Barrel ($-1 < \eta < 1.6$):
  - $\frac{\sigma_p}{p} < 1\%$ @ $1GeV$; $\frac{X}{X_0} < 5\%$;
- e-endcap ($-3 < \eta < -1$):
  - $\frac{\sigma_p}{p} < 2\%$ @ $1GeV$; $\frac{X}{X_0} < 5\%$;
- Ion-endcap ($1.6 < \eta < 3$):
  - $\frac{\sigma_p}{p} < 2\%$ @ $1GeV$; $\frac{X}{X_0} < 5\%$;
- Assume B ~ 1.5 T

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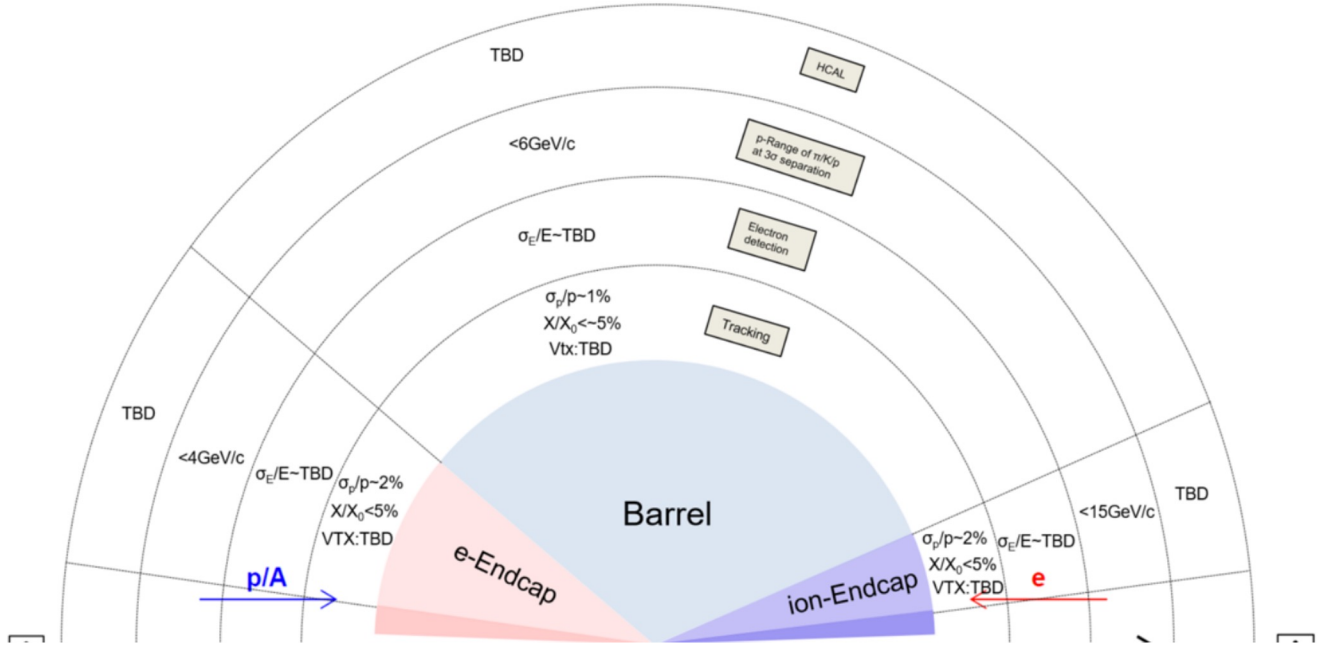
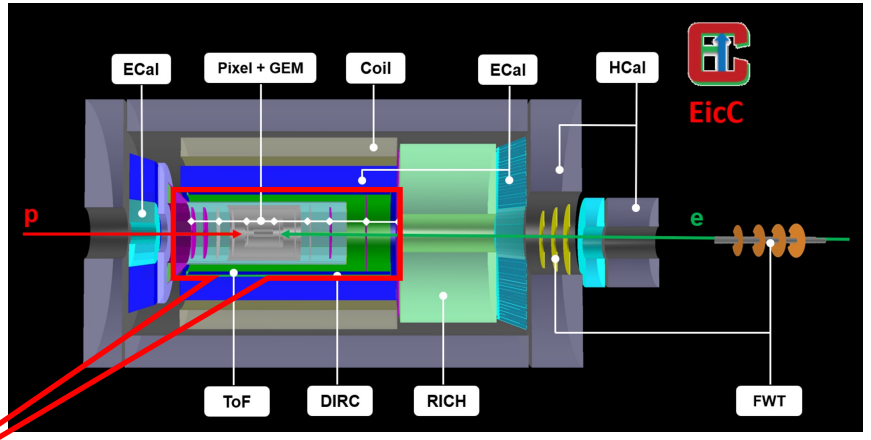


- The event rate of 83.2 kHz.
- the final state particles are concentrated near pseudo-rapidity η = 1, with a particle density rate of $dN/d\eta dt = 8 \times 10^4/s$.

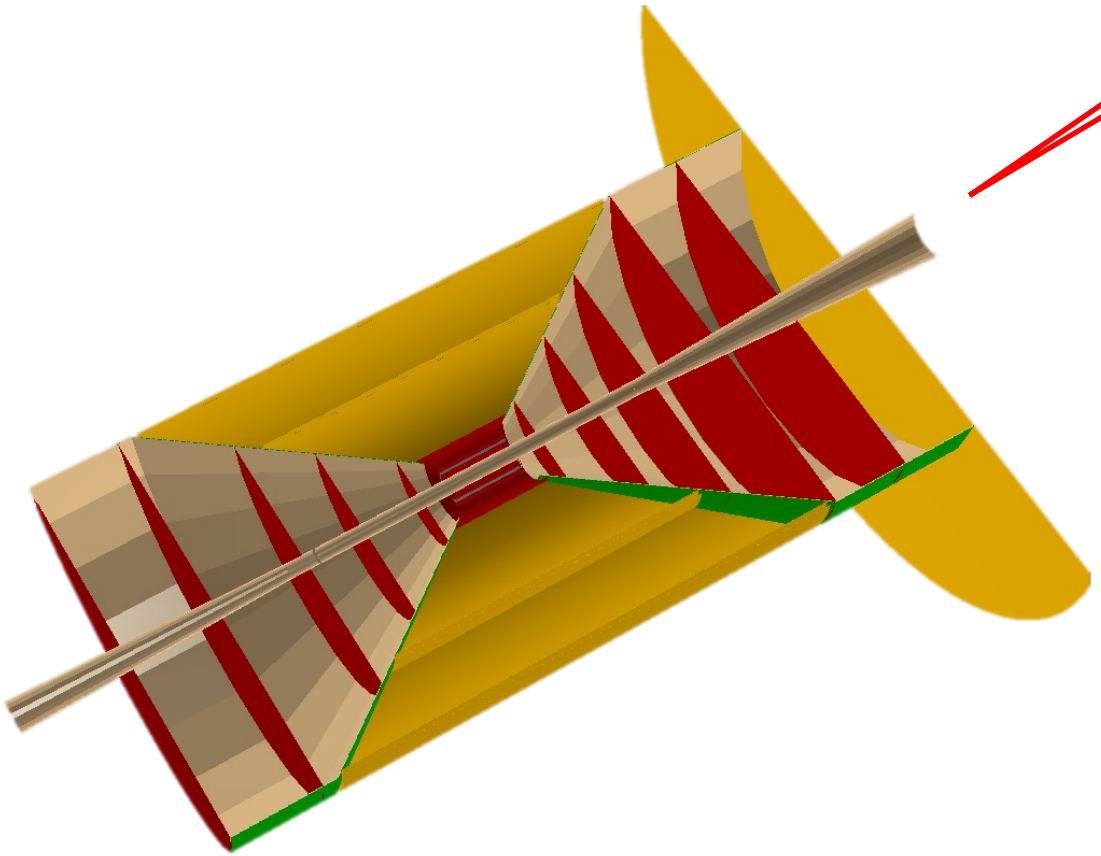
The vertex and tracking detector @ EicC

EicC vertex&tracking system:

- **The core detector of EicC**
- **Measure the vertex and momentum of charged tracks**



EicC conceptual design



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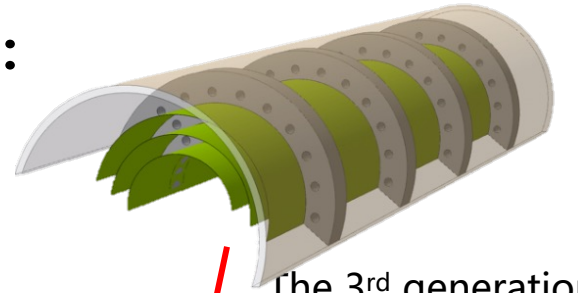
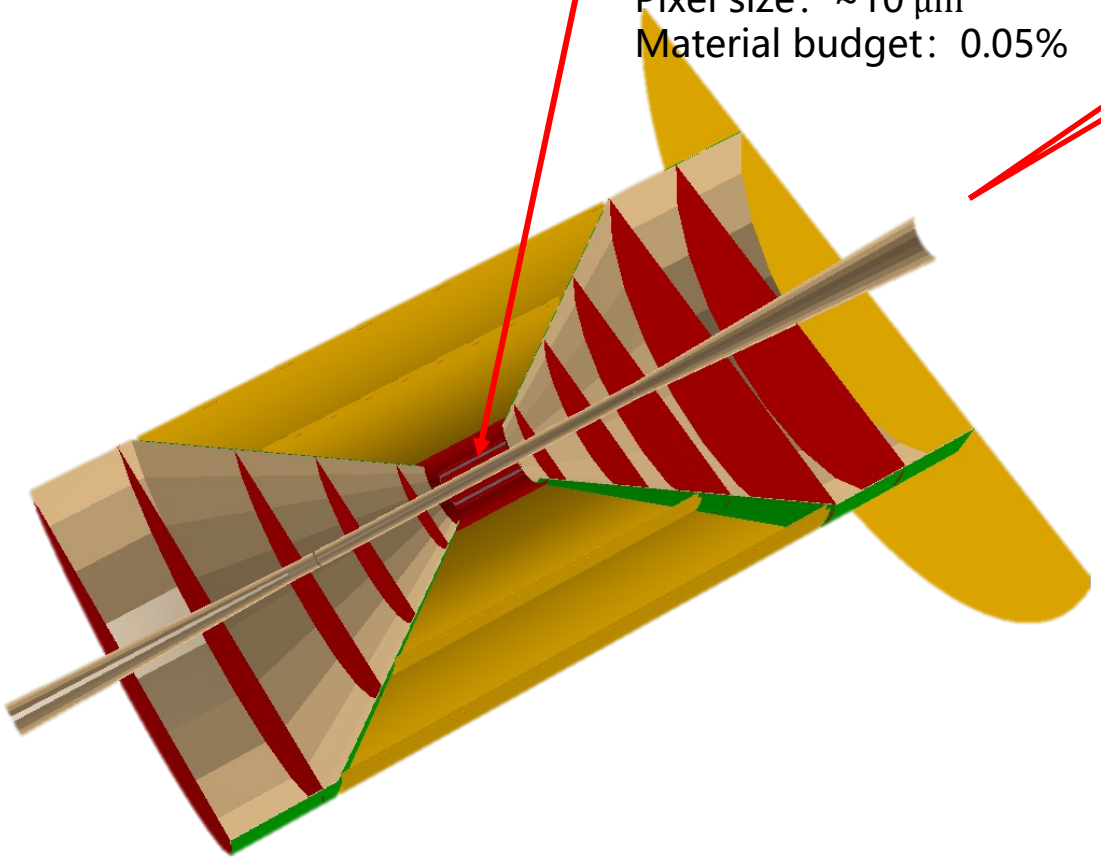
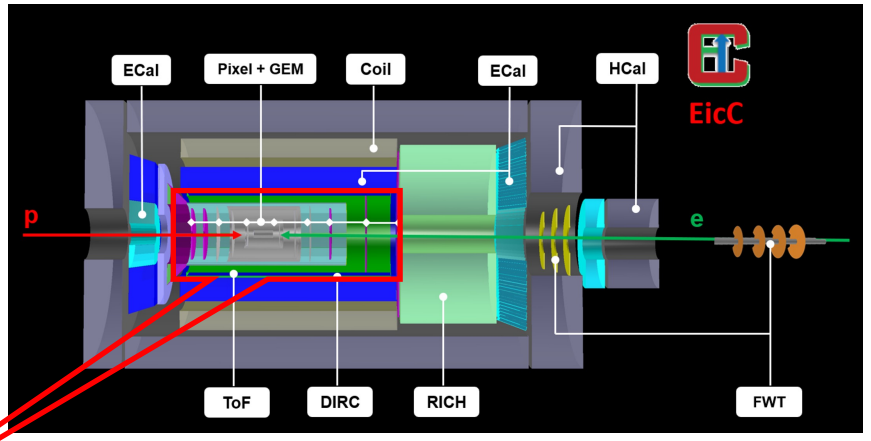


The 3rd generation MAPS
Pixel size: ~10 μm
Material budget: 0.05%





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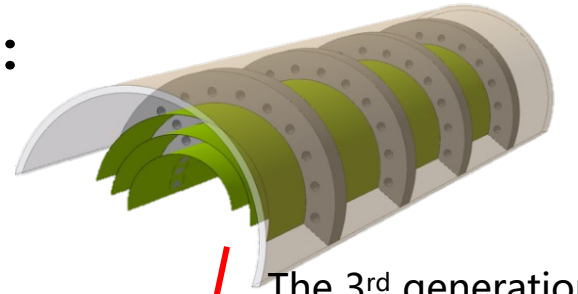

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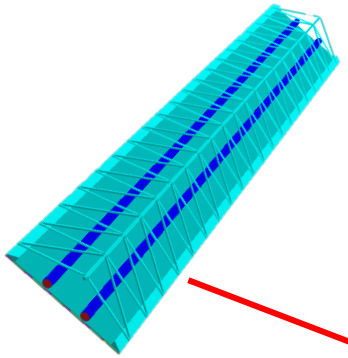

The 1st generation of MAPS
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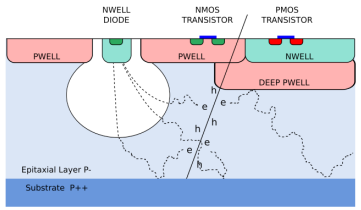

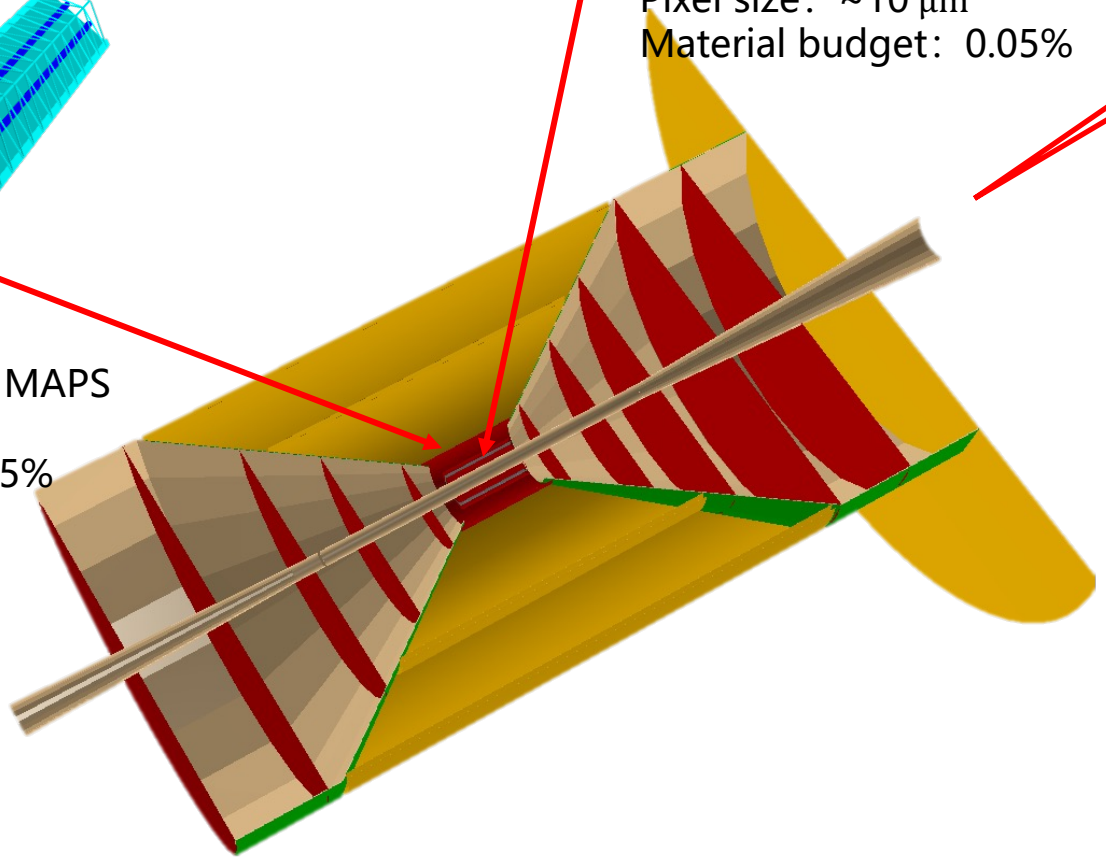

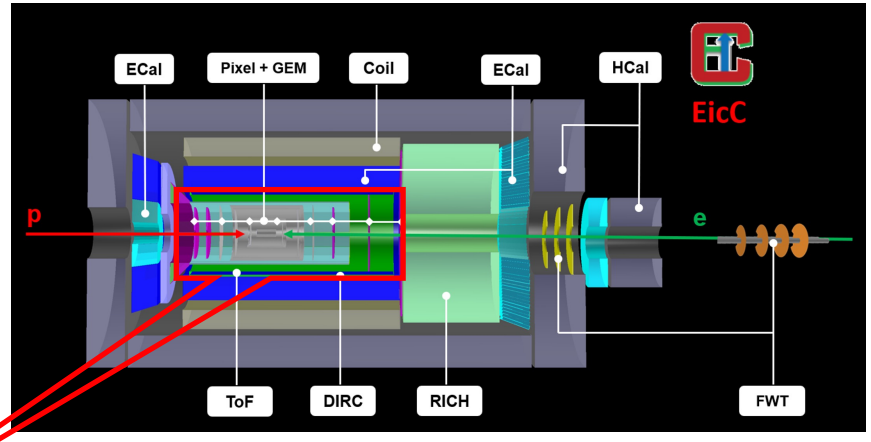

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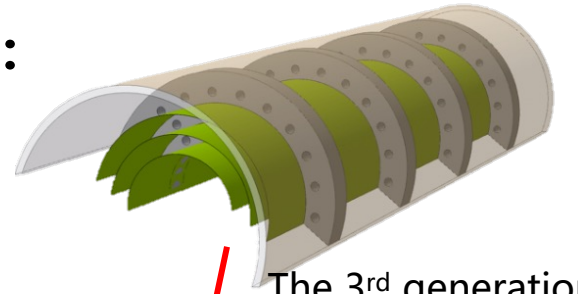

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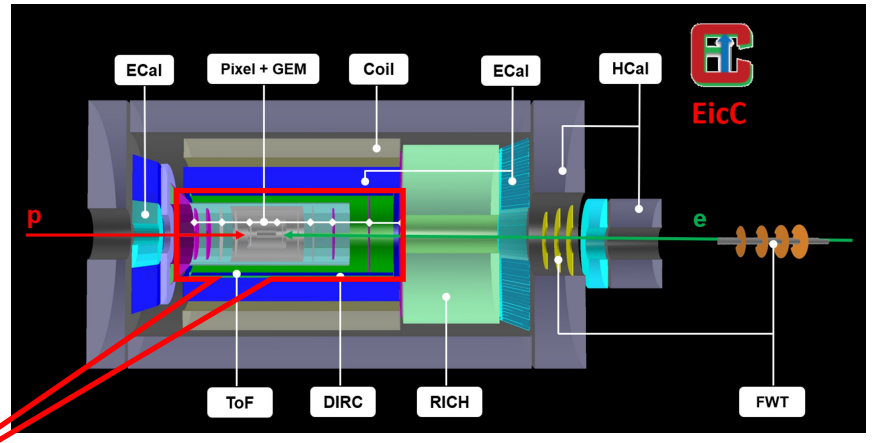

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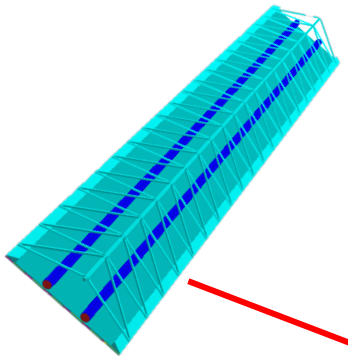

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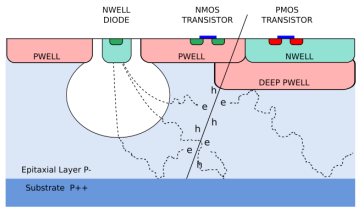
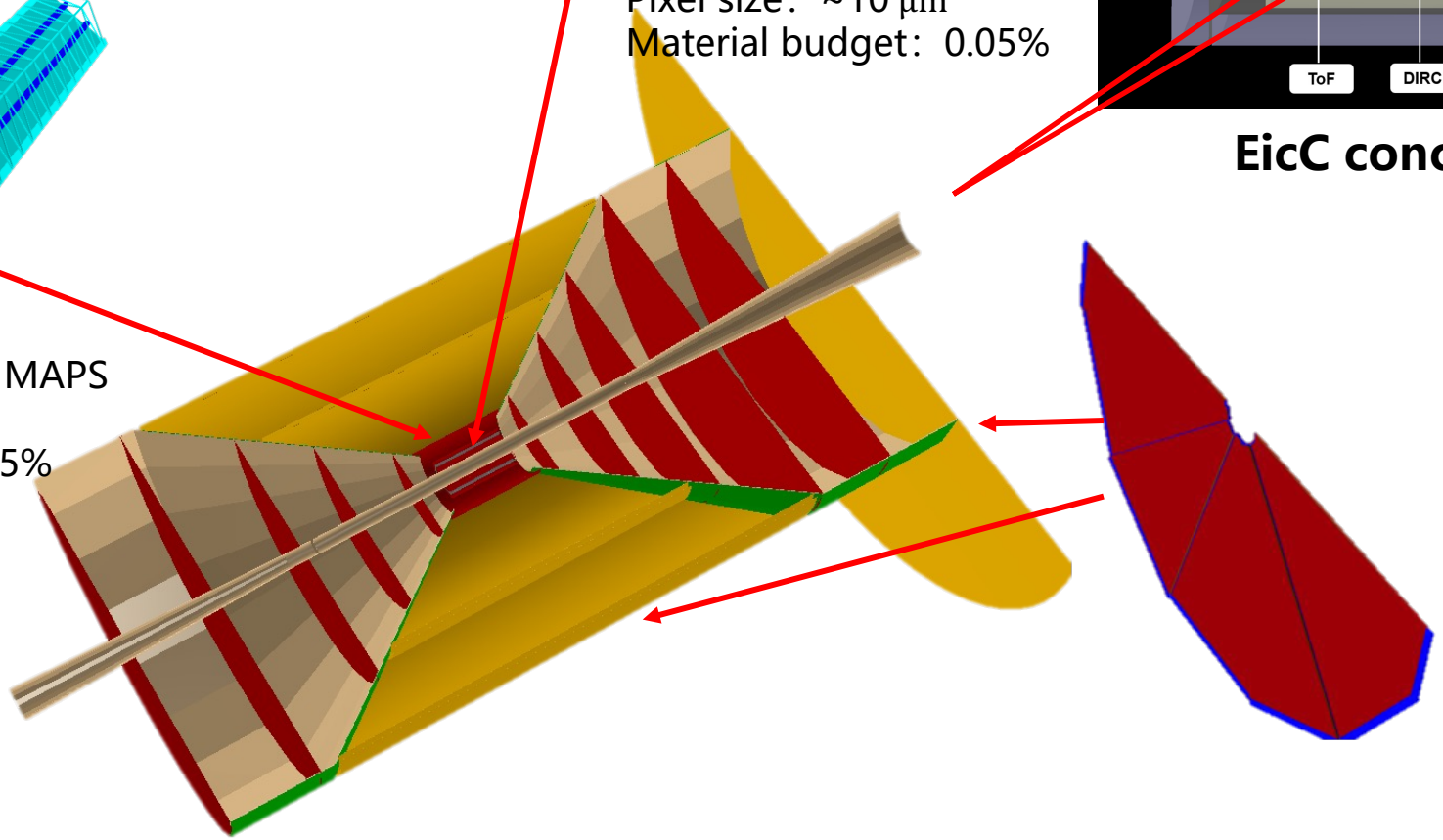
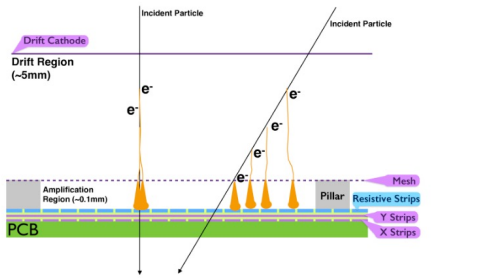


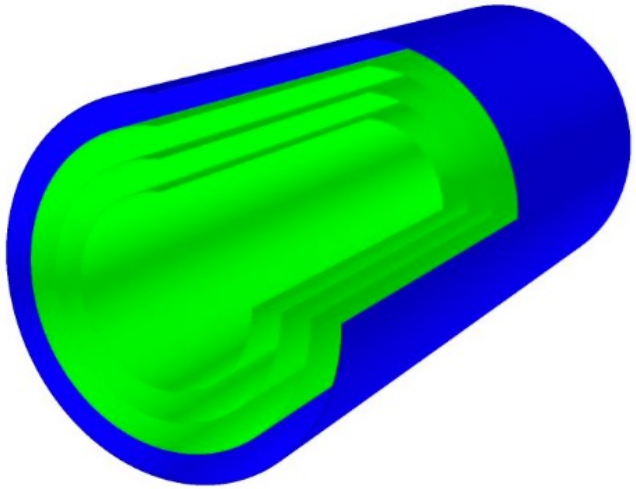




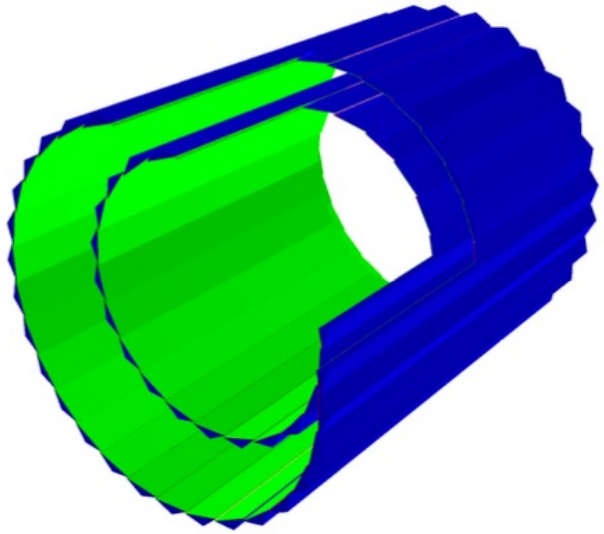
MPGD detector
Spatial resolution : ~150 μm
Material budget : 1%

The silicon components

3 ITS3 Layers + Support Layer



2 ITS2 Layers with Support Structure

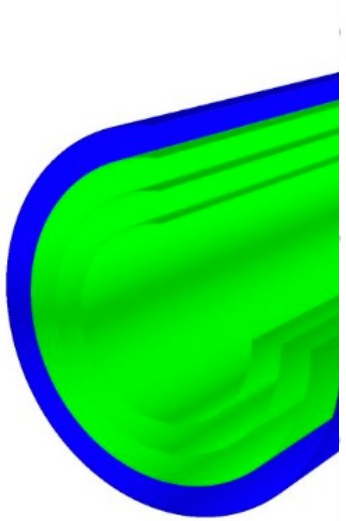


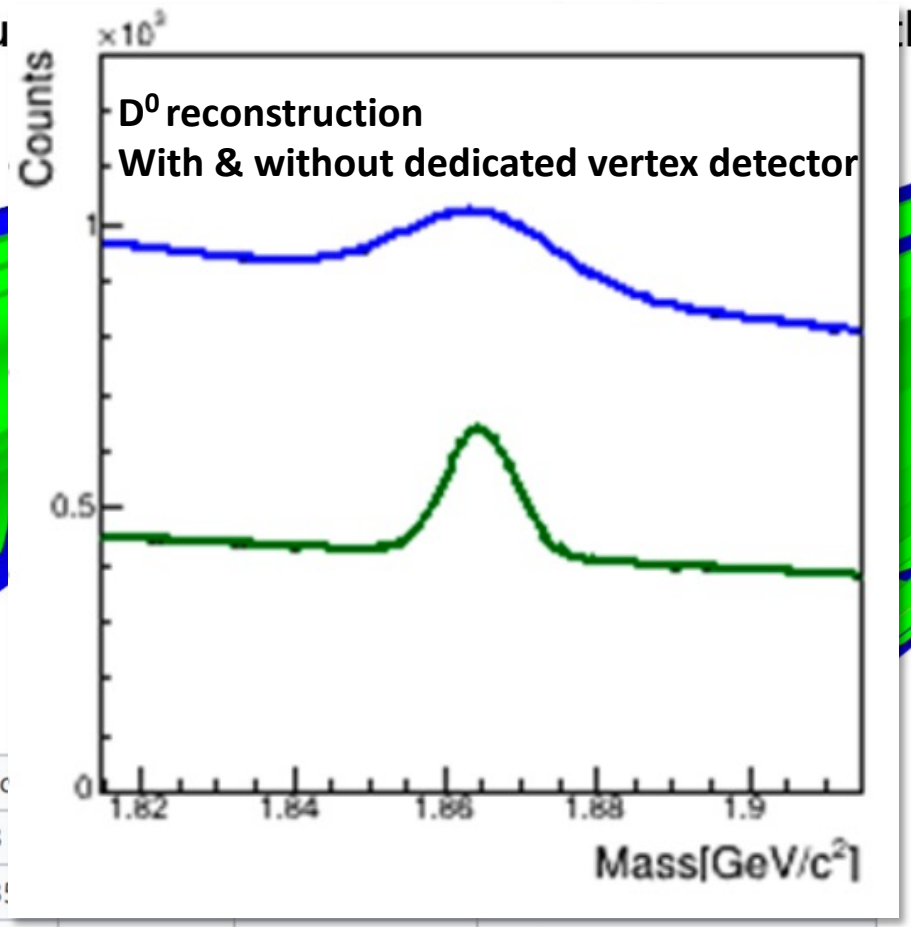
Silicon Tracker (3 Vertex + 2 Barrel Layers)

R (cm)	Length (cm)	Resolution	Active Area Material (X/X0 %)
3.3	28.0	10 um pixel pitch	0.05
4.35	28.0	10 um pixel pitch	0.05
5.4	28.0	10 um pixel pitch	0.05
13.34	34.34	10 um pixel pitch	0.55
17.96	46.68	10 um pixel pitch	0.55

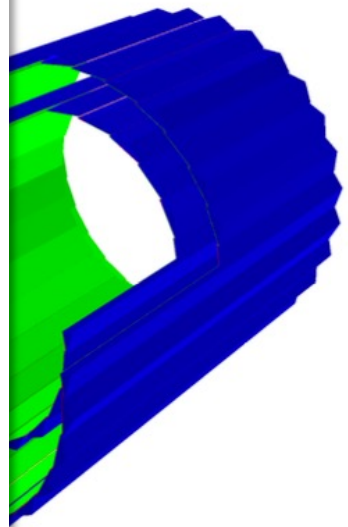
The silicon components

3 ITS3 Layers + Su





h Support Structure



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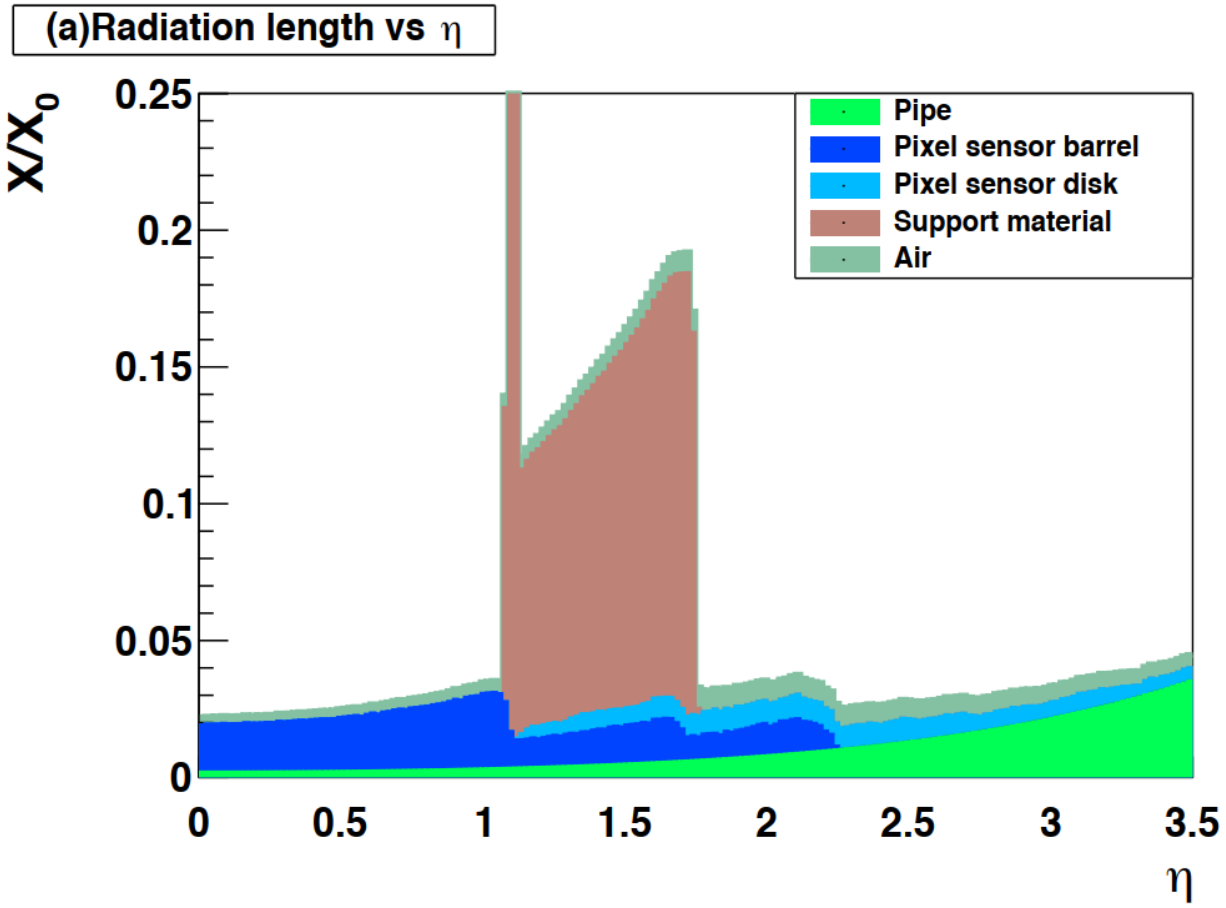
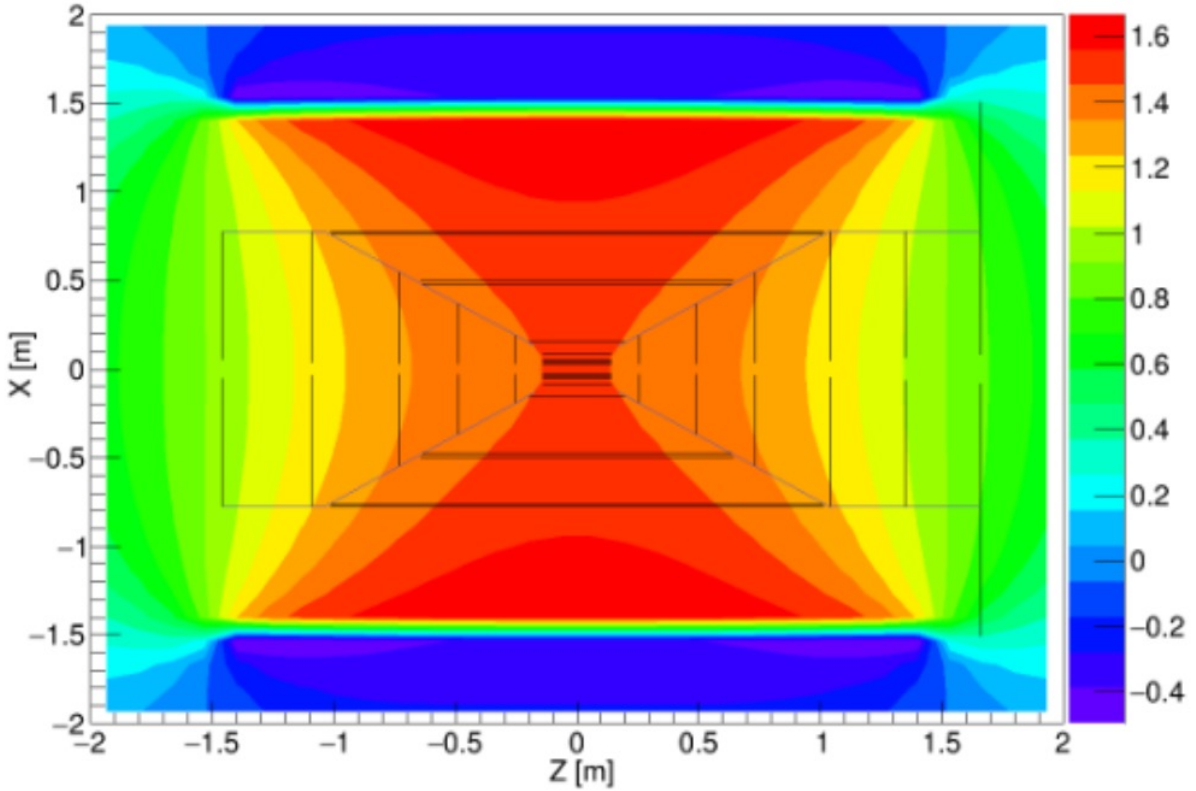
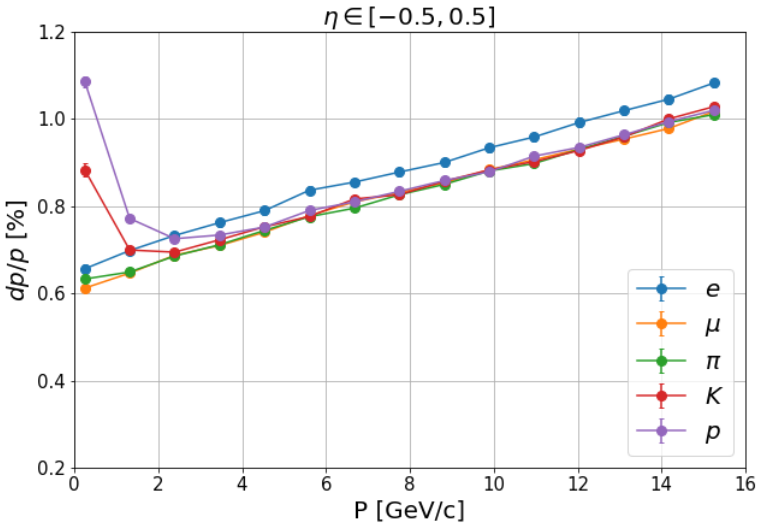
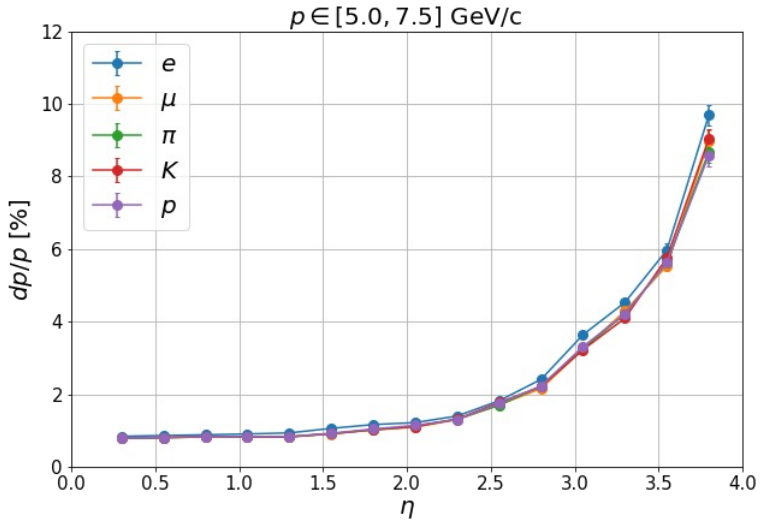
Material budget vs η and B field





The momentum resolution

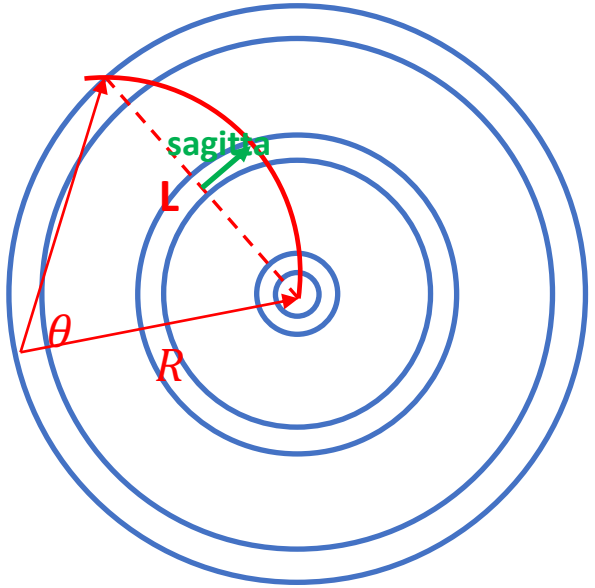




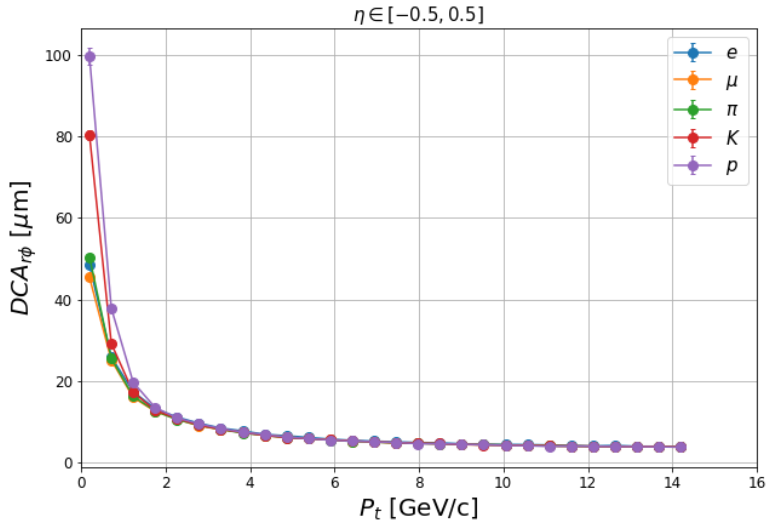
The momentum of a charged track is determined by its trajectory (curvature)

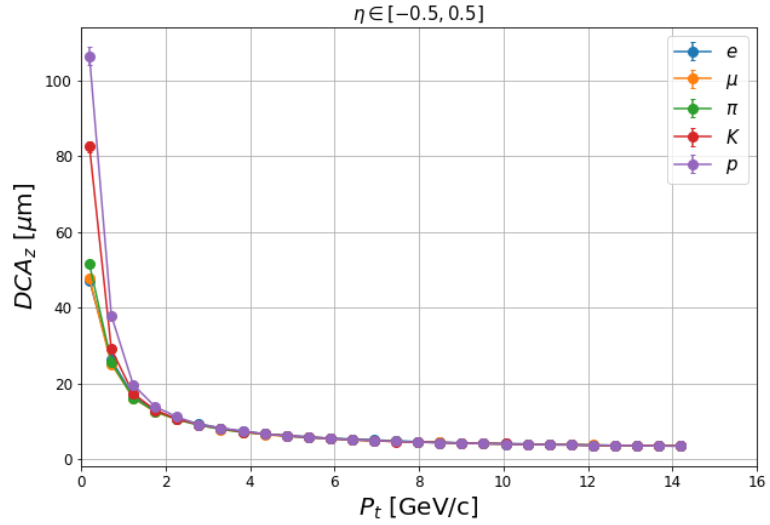
- The formula: **p = 0.3 RB**, R is the radius of the track, B is the intensity of the magnetic field
- Practically, we measure the sagitta to determine the R:
- The relative momentum resolution is:

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



The vertex resolution



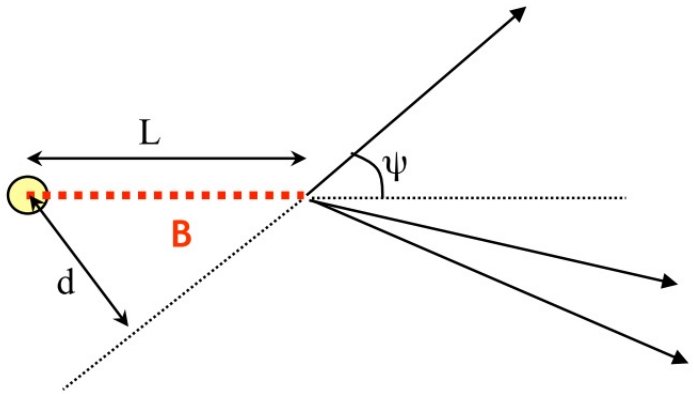


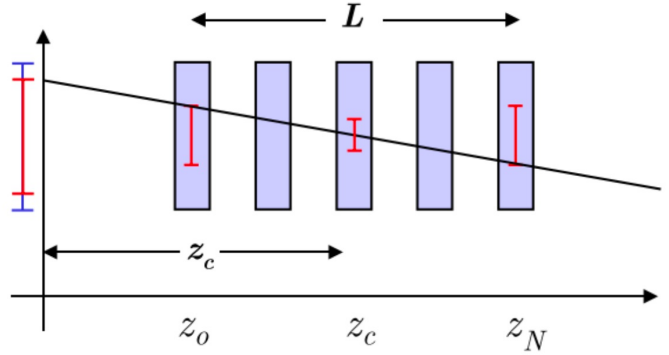
The impact parameter d :

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

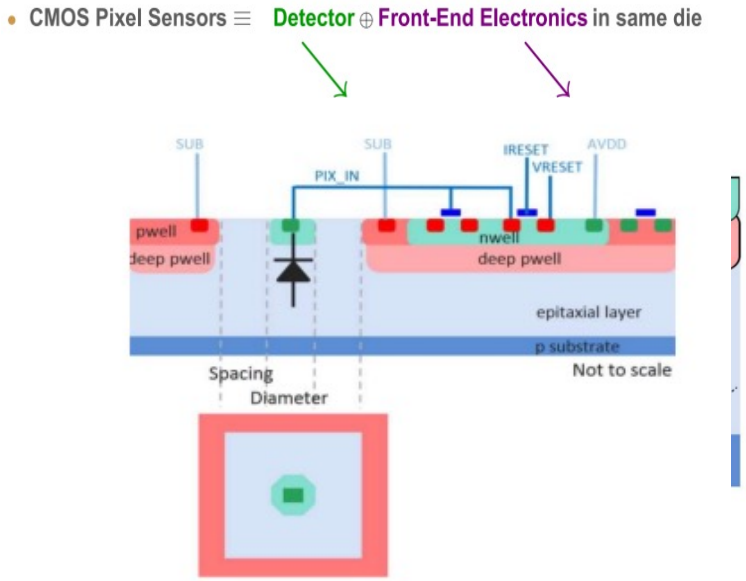
- In the case of equal spacing detector and equal errors σ
- The uncertainty of measurement on vertex (details in backup):

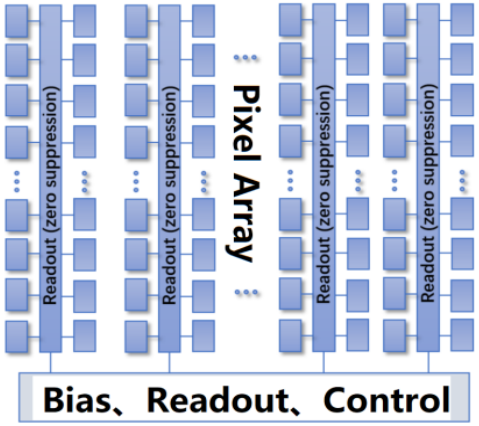
$$\sigma^2_{vertex} = \frac{\sigma^2}{N+1} + \frac{\sigma^2}{N+1}\frac{12N}{N+2}\frac{Z_c^2}{L^2}$$

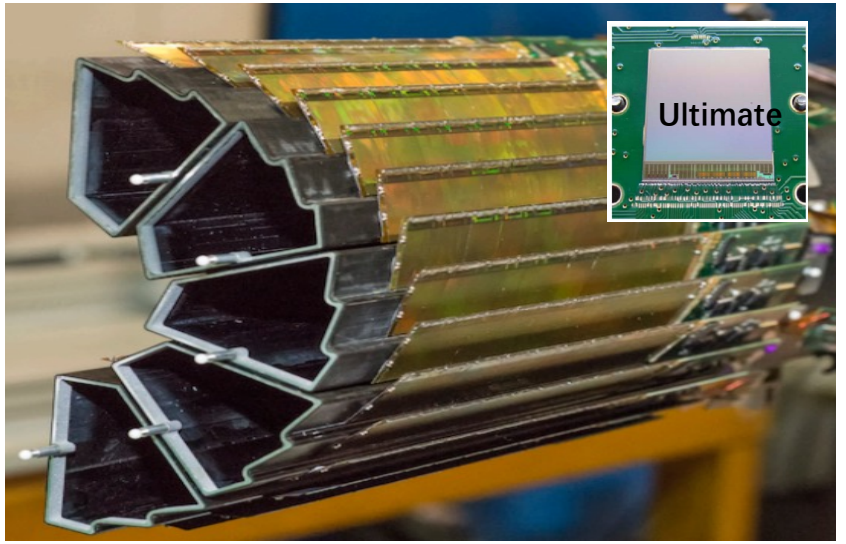




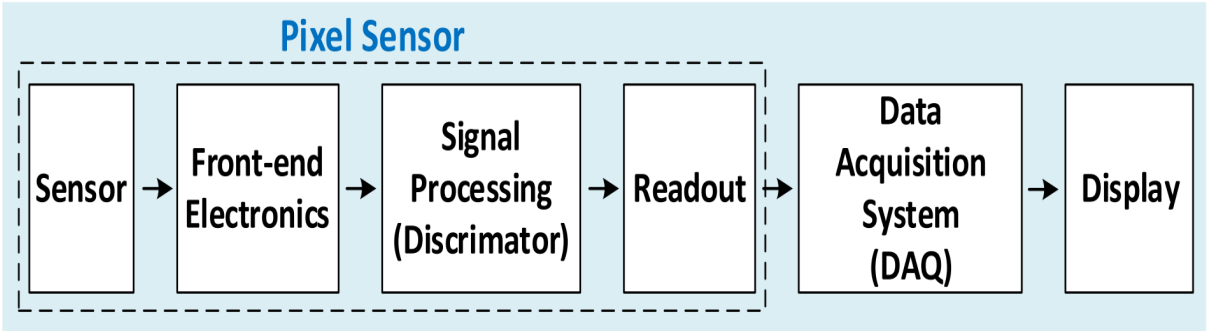
The Monolithic Active Pixel Sensor

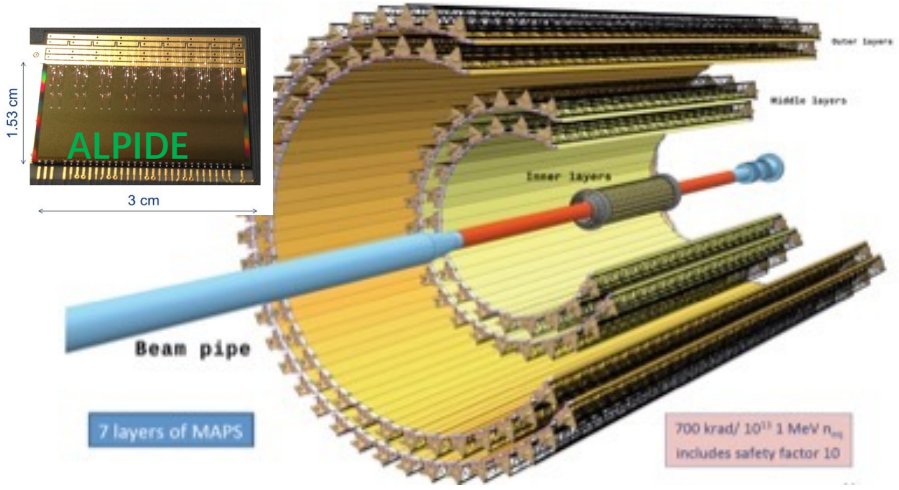






STAR HFT（世界上首个像素探测器）
400片MAPS, 360M pixels

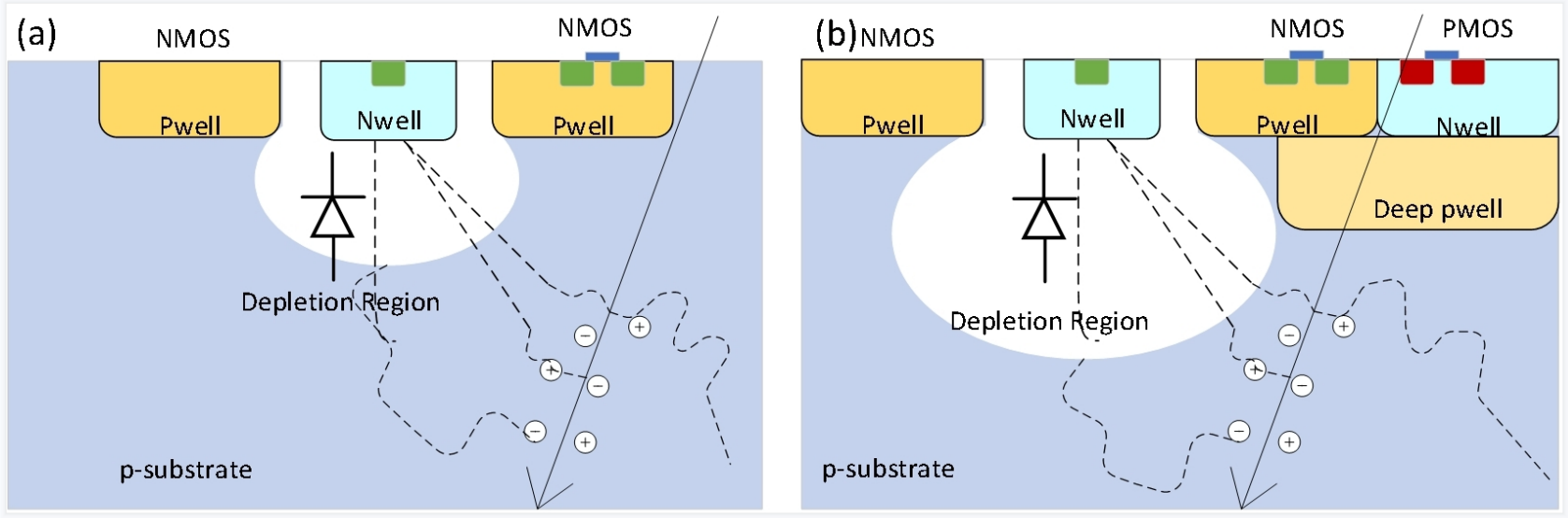




ALICE ITS 探测器 （目前最大规模像素探测器）
24142块MAPS, ~10㎡， 12.5G pixels

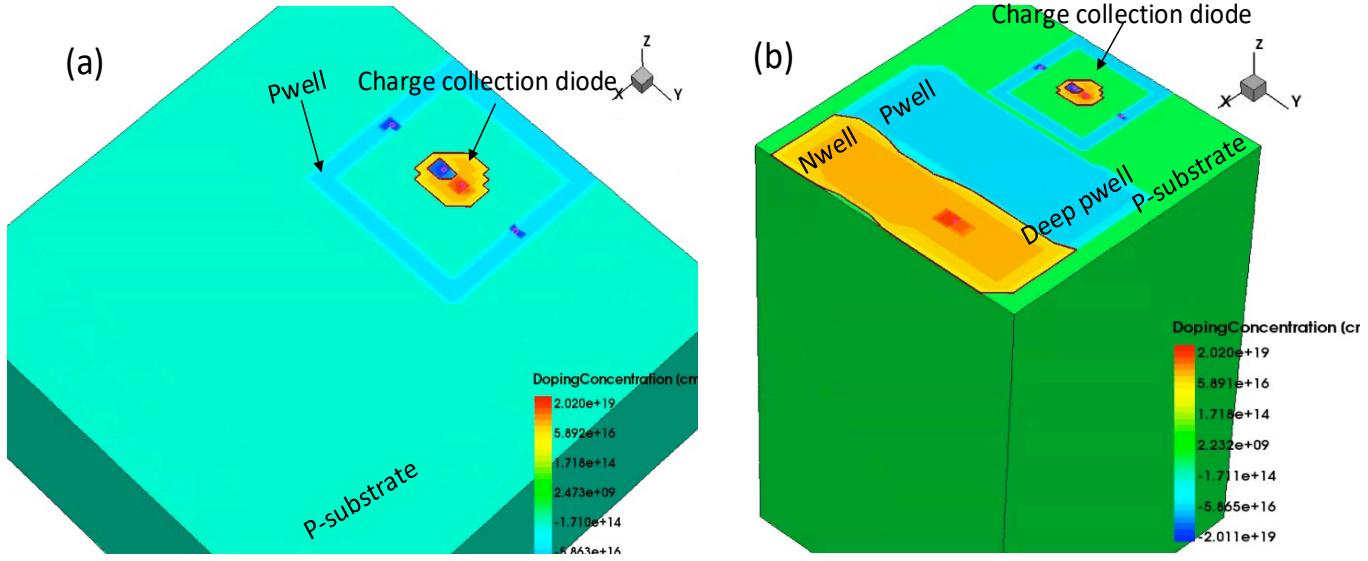
TCAD simulation

HFT tech.

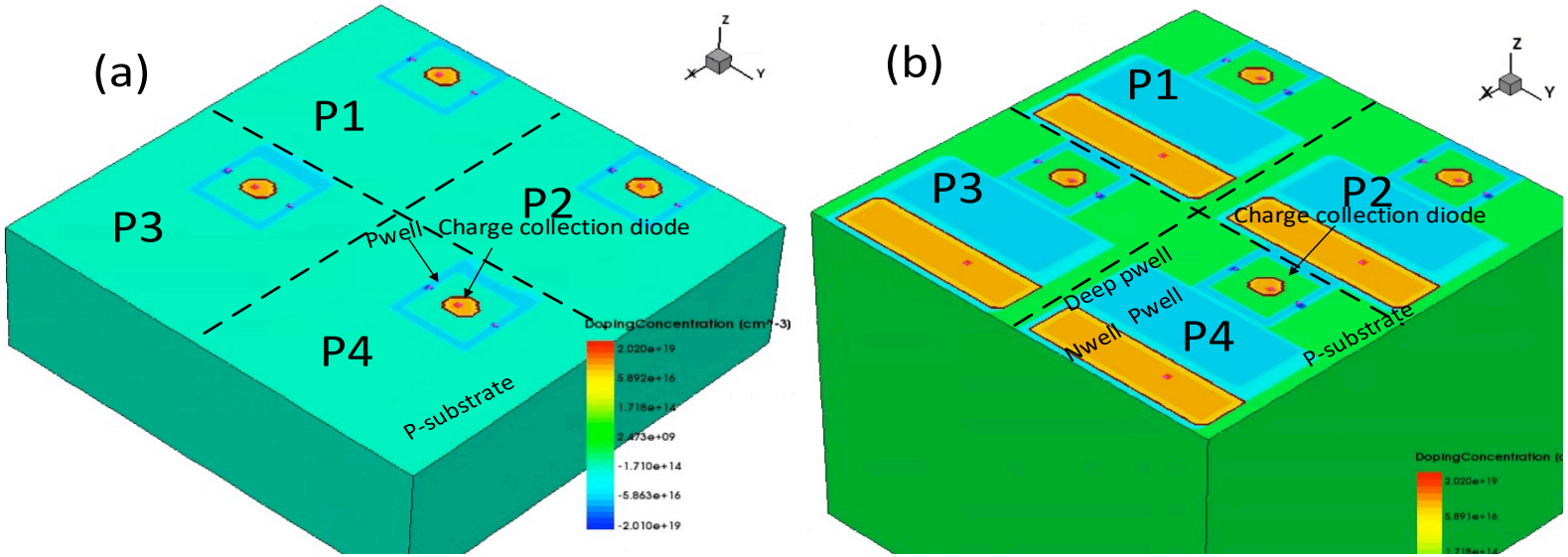


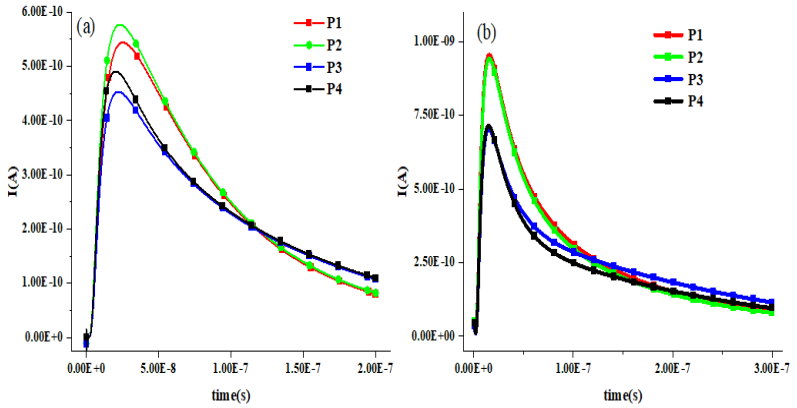
ITS tech.

工艺选择和比较：标准双阱工艺 vs 四阱工艺

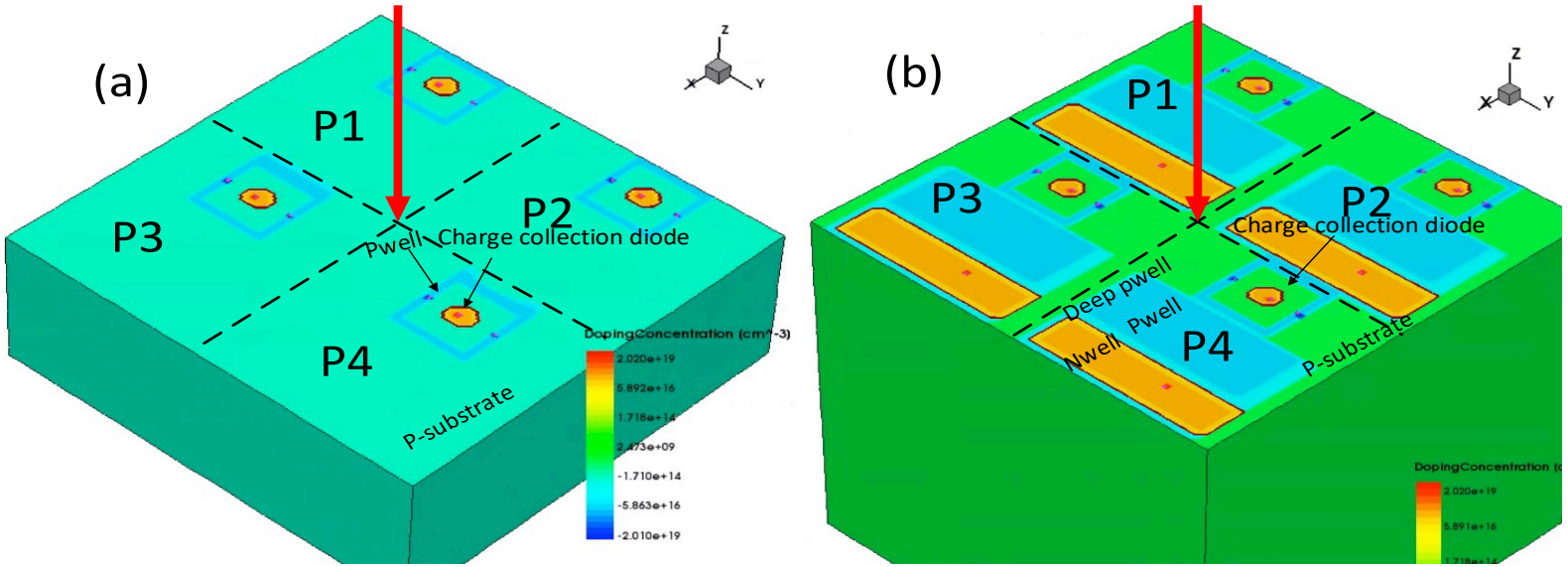


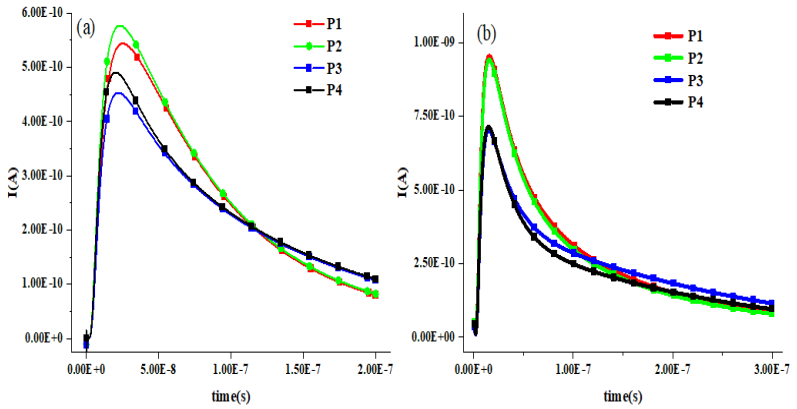
TCAD simulation





TCAD simulation

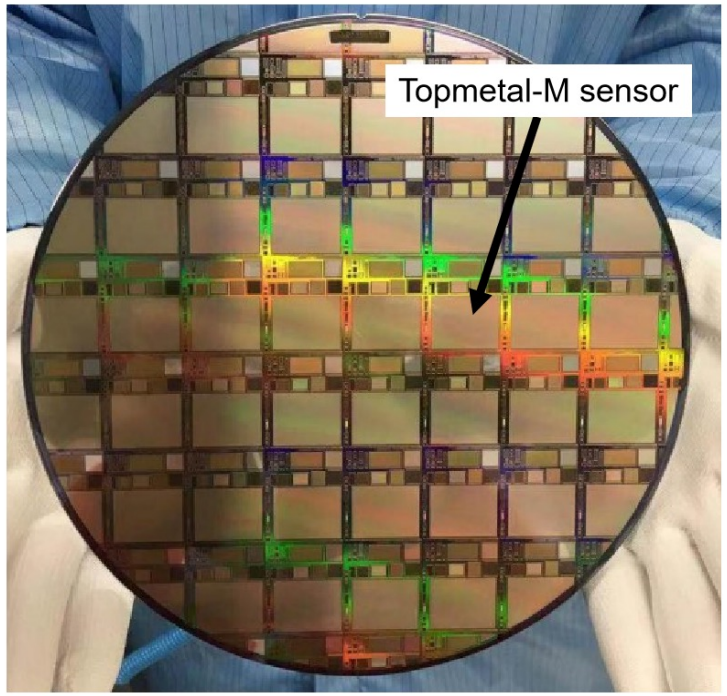


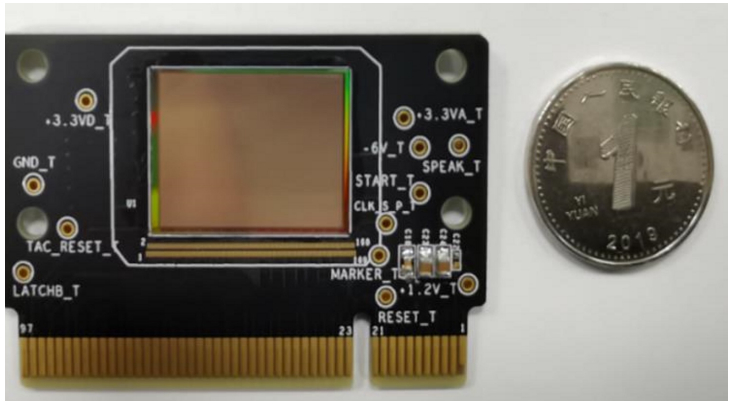


Pixel ID		P1	P2	P3	P4
Charge collection	Twin-wellLR process	329	340	300	308
	Quad-wellHR process	551	530	499	450

50~60% improvement

The first MAPS based on domestic technology - Topmetal-M





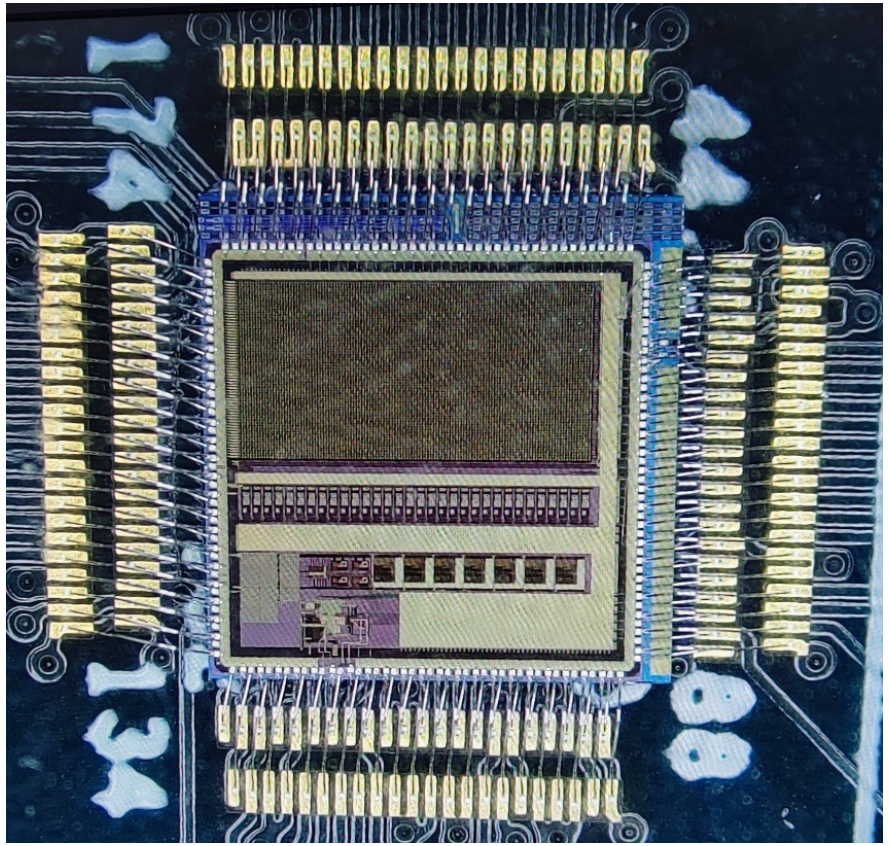
中科院战略先导B”核物质相结构与重元素合成研究”专项支持

- 近物所IMP SLIMP & 华师CCNU PLAC
- **基于国内四阱高阻衬底工艺**
- 2018.05 - 2019.12设计制造
- 2020.01 - 2021.12测试验证

Parameters:

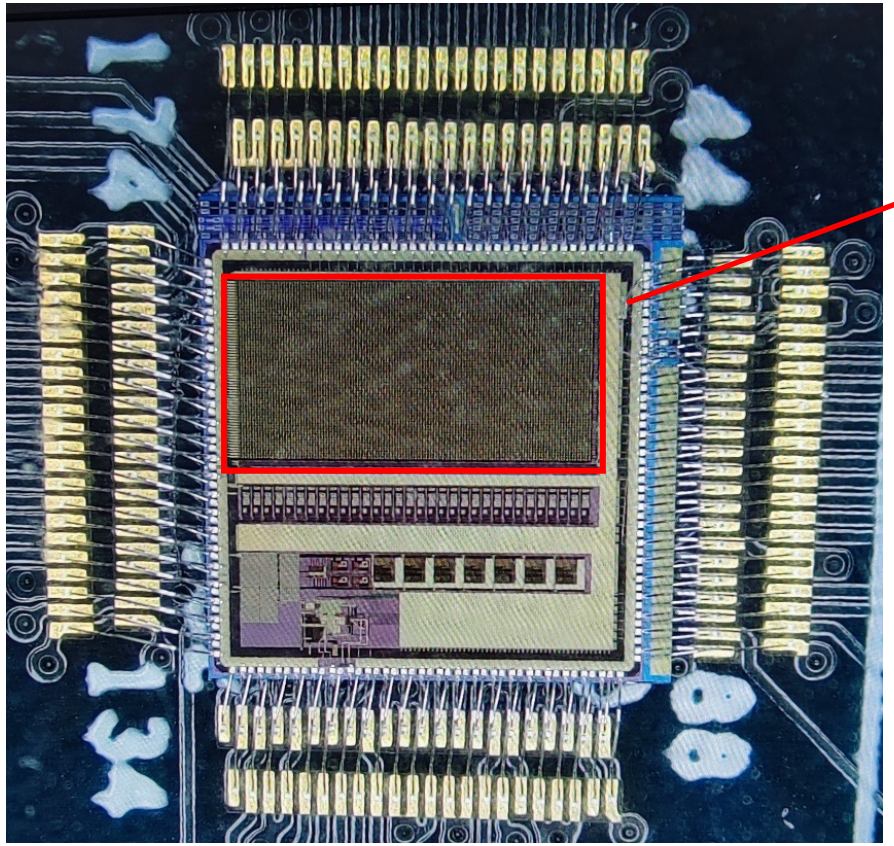
- 像素阵列 512 x 400 Pixels
- 40umx 40um
- Time, Energy and Position Measurement
- Thinned to 100um from backsid
- 兼具电荷搜集型Topmetal和MAPS

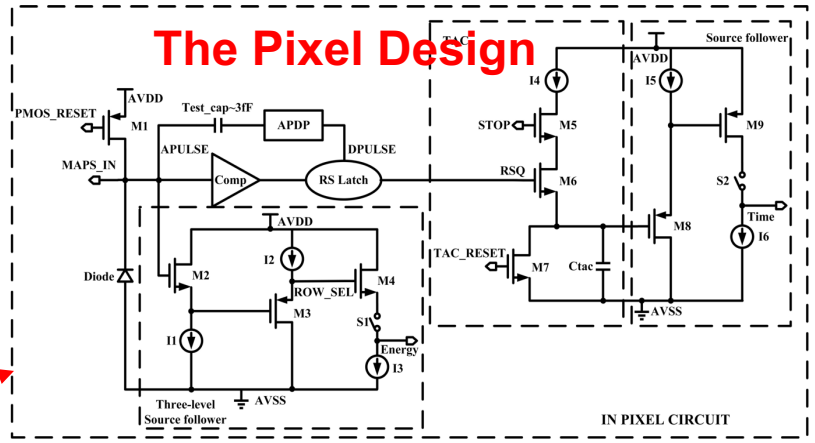
The full functional MAPS based on domestic technology - Nupix-A1



- 中科院战略先导B”核物质相结构与重元素合成研究”专项支持、EicC原型芯片
- 近物所像素研究室SLIMP牵头研发
- 位置、时间和能量测量
- 目的：验证基于国内工艺开发复杂度高的像素芯片

The full functional MAPS based on domestic technology - Nupix-A1





- Pixel Size 30μm x 30 μm
- Diode area is 10μm x 10 μm
- Octagon n-well is 3 μm x 3 μm

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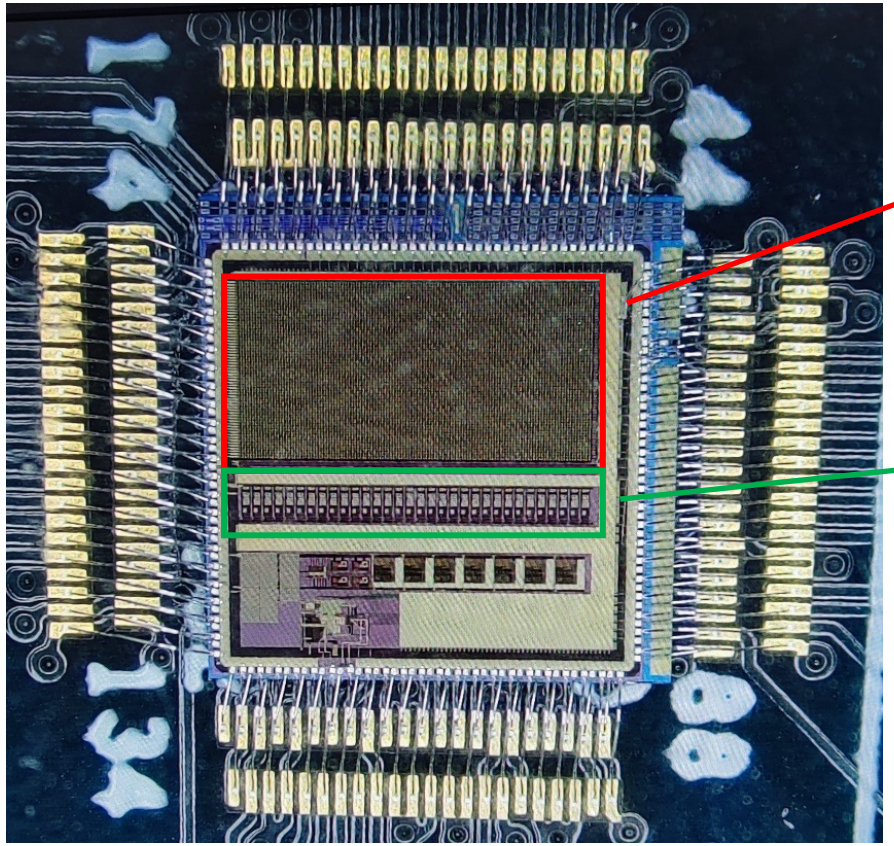
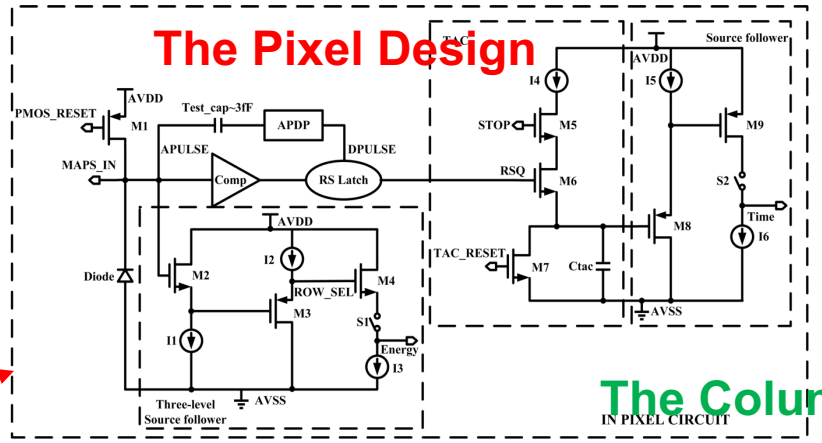


The Pixel Design



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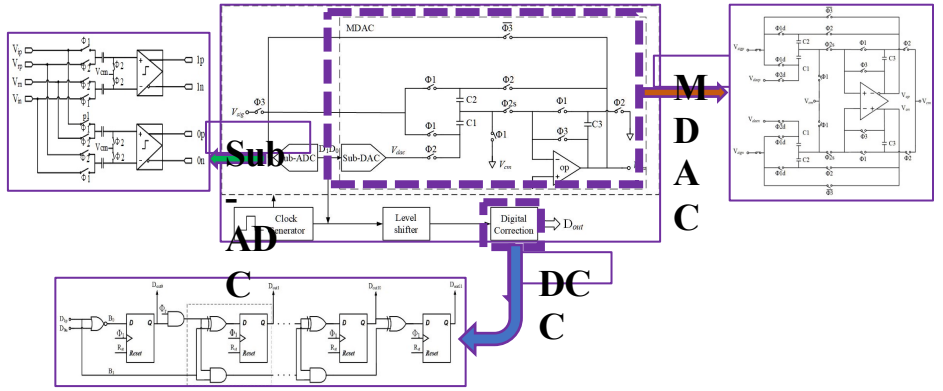
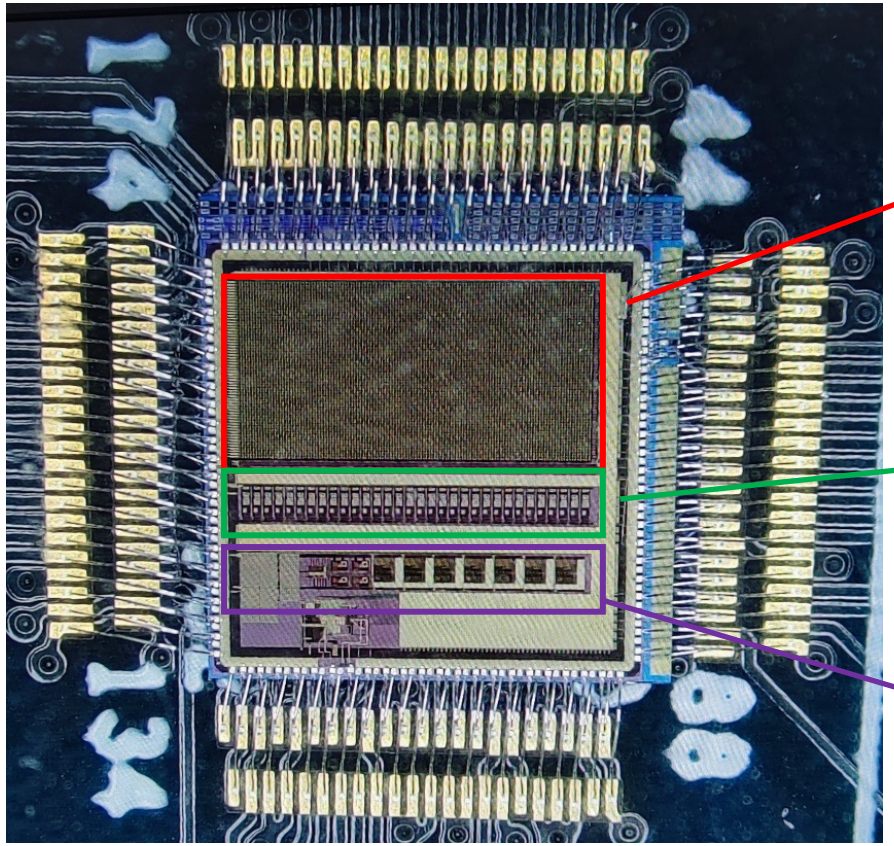
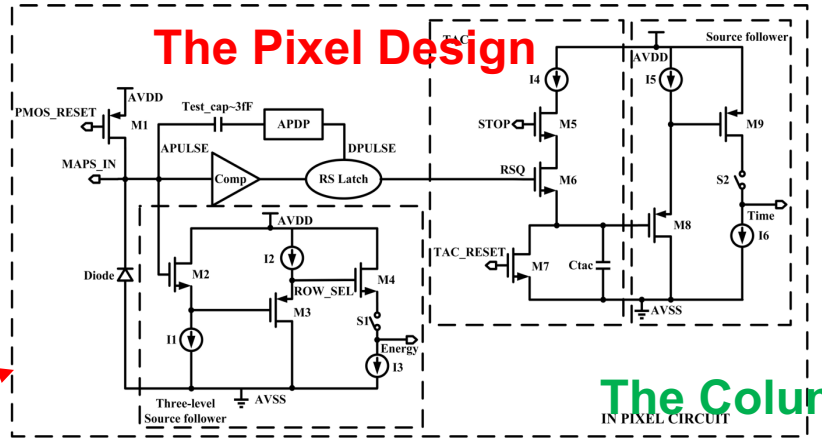
The Column-parallel ADC design



The full functional MAPS based on domestic technology - Nupix-A1



The Pixel Design



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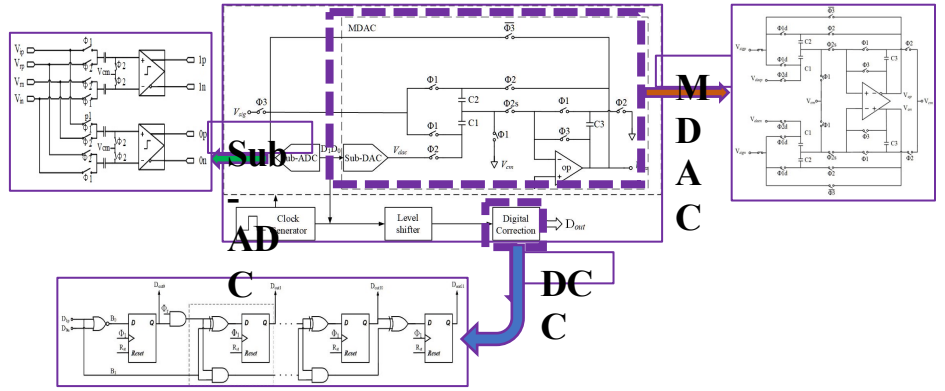
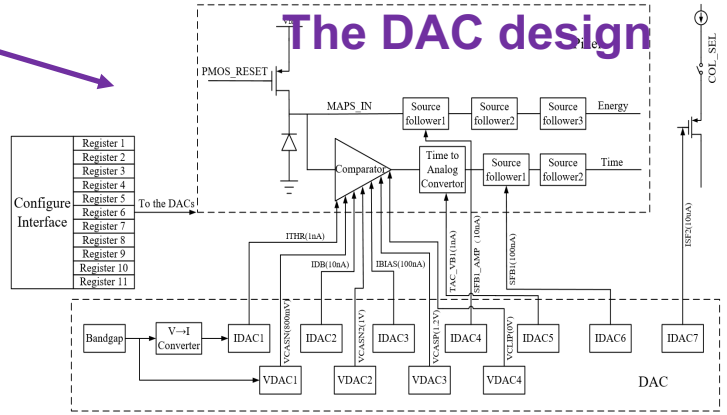


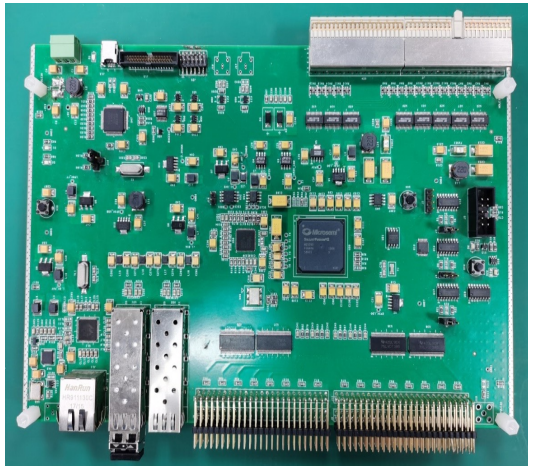
The DAC design



- 7 x 10bit VDAC + 4 x 8bit IDAC
- 3074μm×400μm. With a voltage supply of 3.3V, the power consumption is 46.2mW.

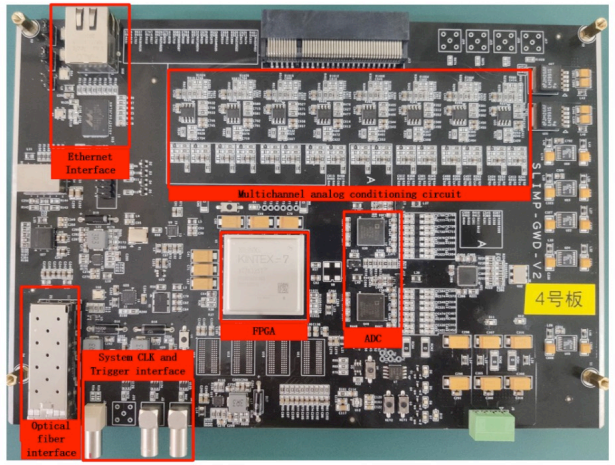
Radiation-hardened front-end electronics

Flash Based

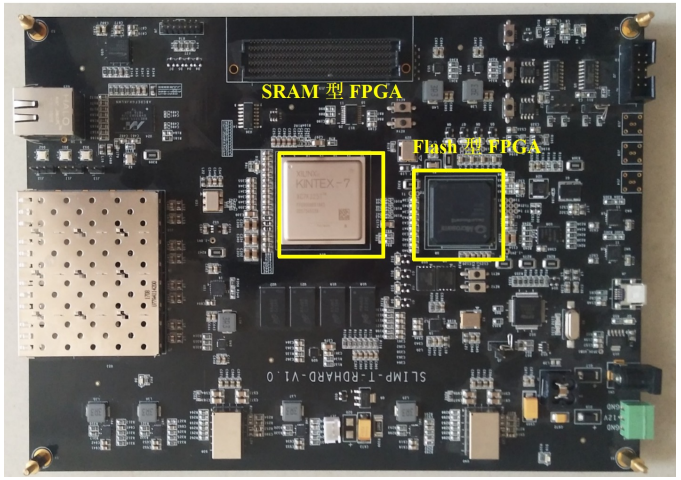


2.4Gbps

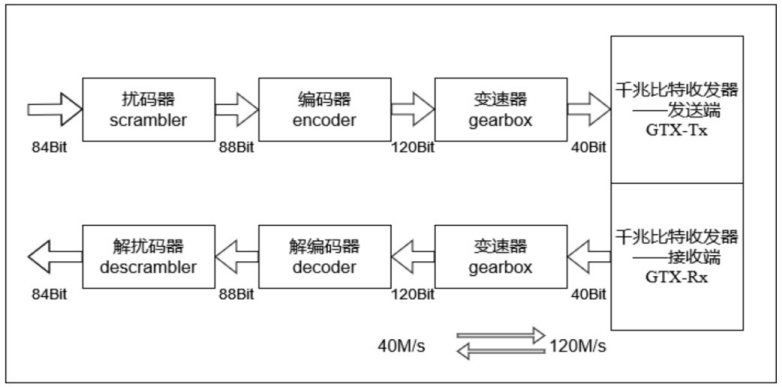
Sram Based



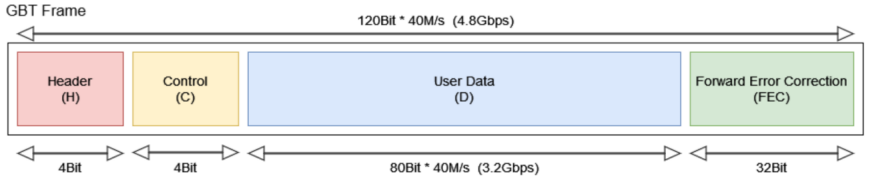
Sram based 三模重刷



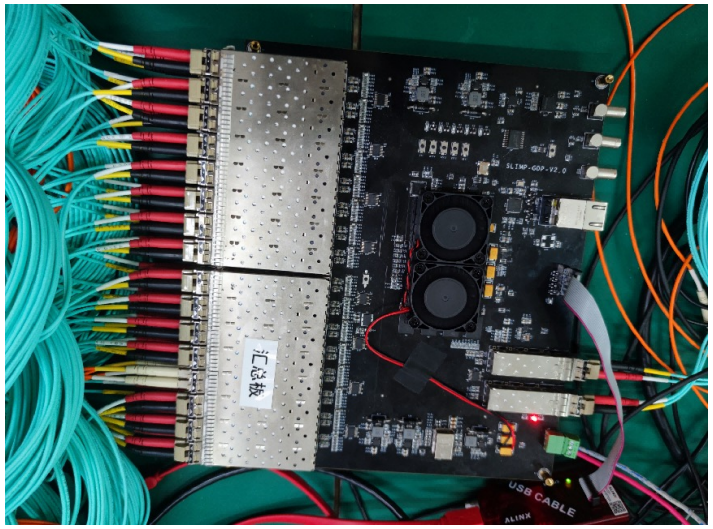
4.8Gbps



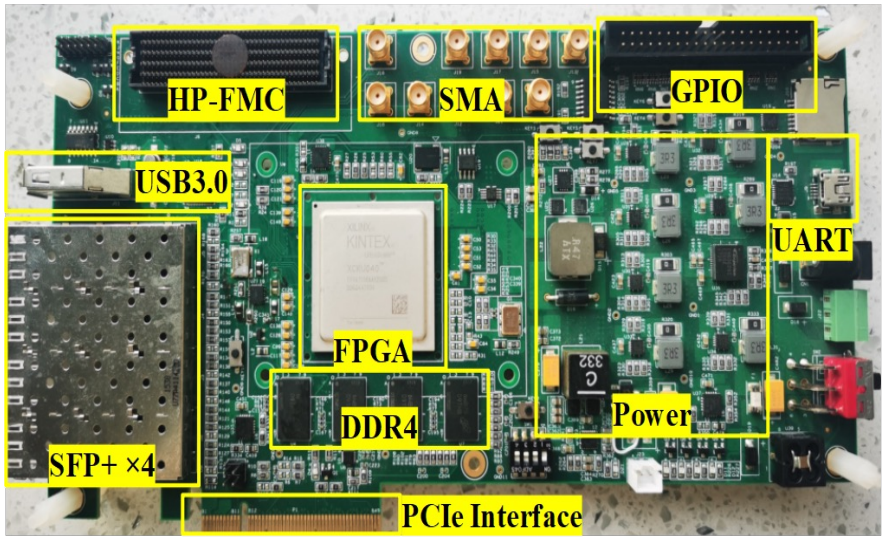
GBT-FPGA



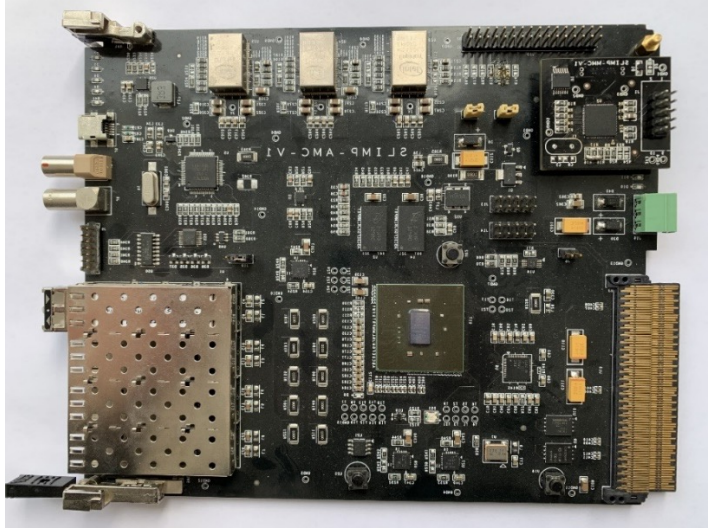
high speed back-end electronics



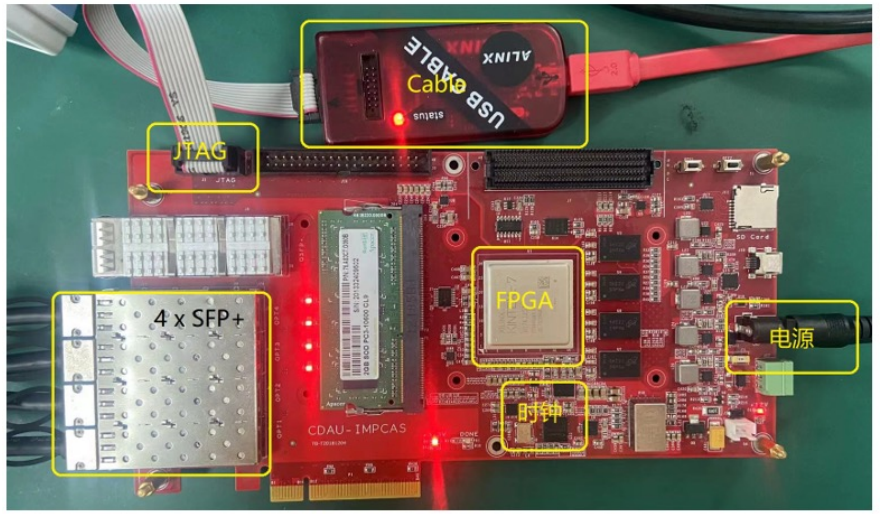
32路光纤汇总，两路万兆以太网数据汇总板。其中主要FPGA为Vertex-7.



ultra-scale的数据汇总板，其中PCIe提供了大于50gbps的数据通路



MircoTCA的数据汇总板



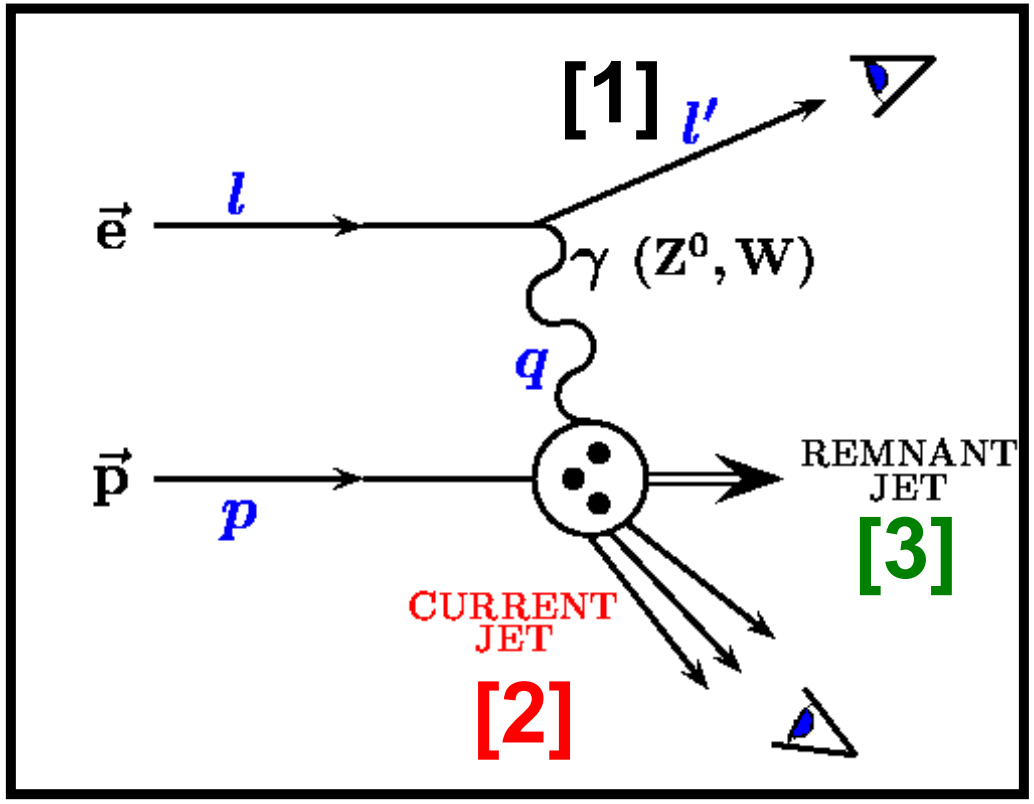
Summary

- Sillicon + MPGD vertexing and tracking detector is designed to fit the requirement of EicC
- The full simulation of the geometry design is done to validate the performance
- The full functional MAPS based on domestic technology - Nupix-A1 is developed by IMP SLIMP & CCNU PLAC
- More efforts are needed to improve the R&D

Thanks for your attention!!

Backup

Lepton-Nucleon Scatterings



QED tool to study QCD nature of the nucleon

$$Q^2 = -q^2 = sxy$$

$$x = \frac{Q^2}{2p \cdot q}$$

$$y = \frac{p \cdot q}{p \cdot l}$$

$$s = 4E_e E_p$$

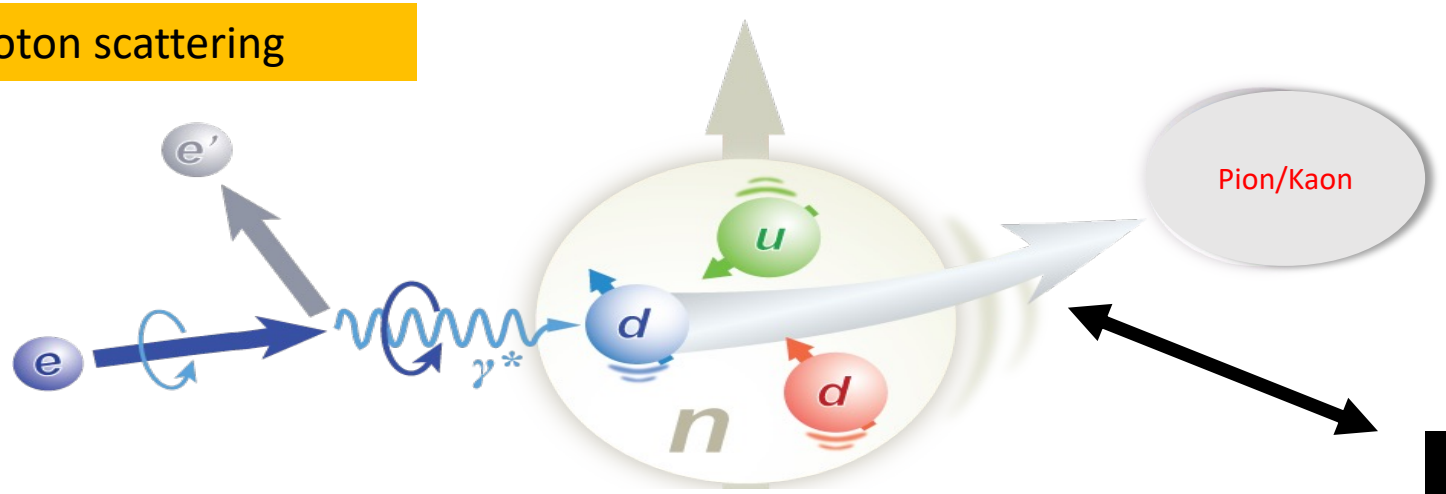
$$W = (q + p)^2$$

- QED probe is clean
- α_{EM} ~1/137 with broad Q coverage
- One-photon exchange approximation: ~1% accuracy
- Detection scale is determined by Q^2: $1GeV^2$ ~ nucleon size

Observe scattered electron/muon	**[1]**	**→ inclusive**
Observe current jet/hadron	**[1]+[2]**	**→ semi-inclusive**
Observe remnant jet/hadron as well	**[1]+[2]+[3]**	**→ exclusive**

SIDIS processes for flavor decompositions

Electron-proton scattering



Fragmentation Functions

input

input

Experimental observable: polarized structure functions g1

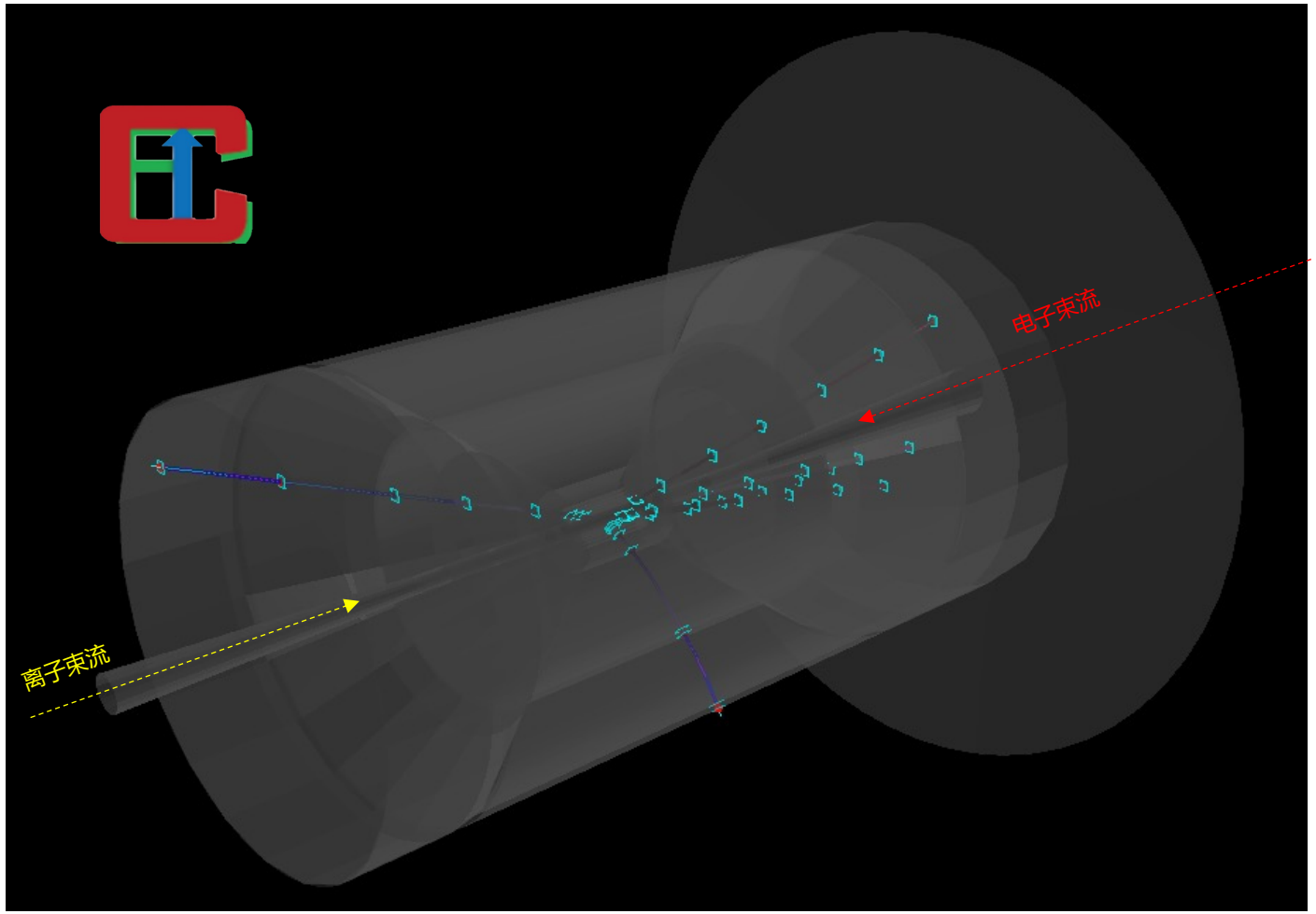
$$g_1^h(x,Q^2,z) = \frac{1}{2}\sum_q e_q^2 \left[\Delta q(x,Q^2) D_q^h(z,Q^2) + \Delta\bar{q}(x,Q^2) D_{\bar{q}}^h(z,Q^2)\right]$$

Leading Order picture

Extracted nucleon structure information: polarized PDFs (helicity distribution)

Track reconstruction

- No dedicate track finding algorithm is implemented
- Find track candidate according to the MC information
- Track candidates are fitted by Kalman fitter method



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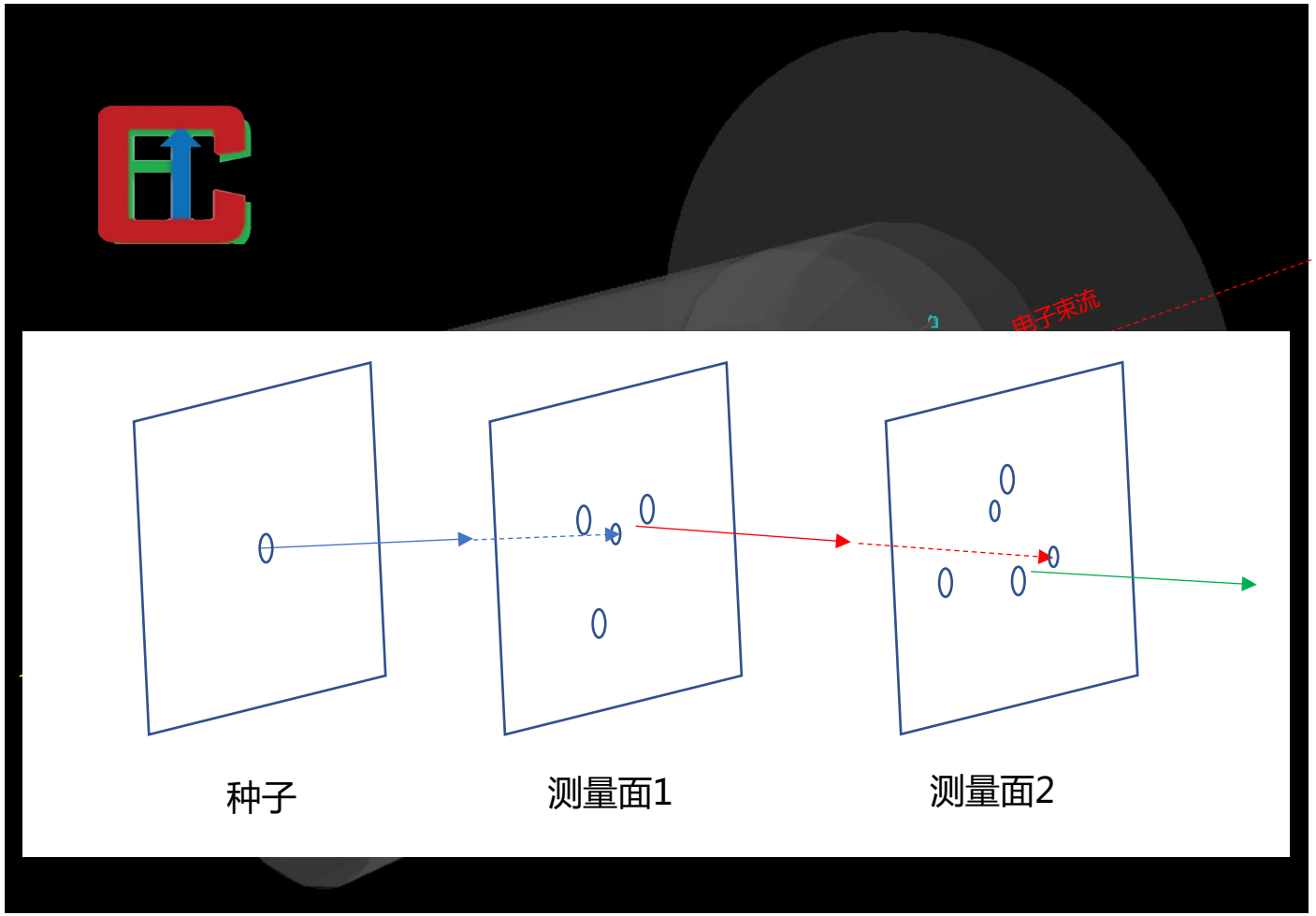
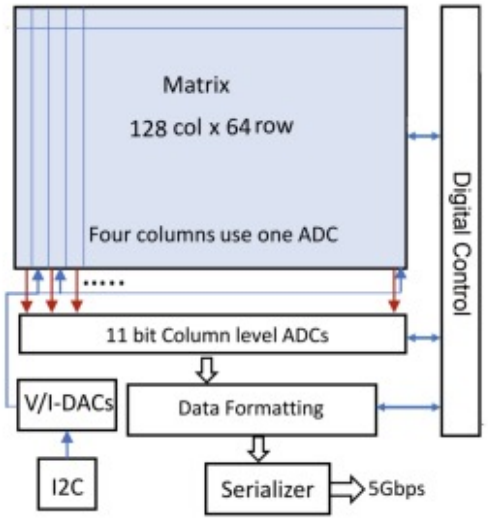
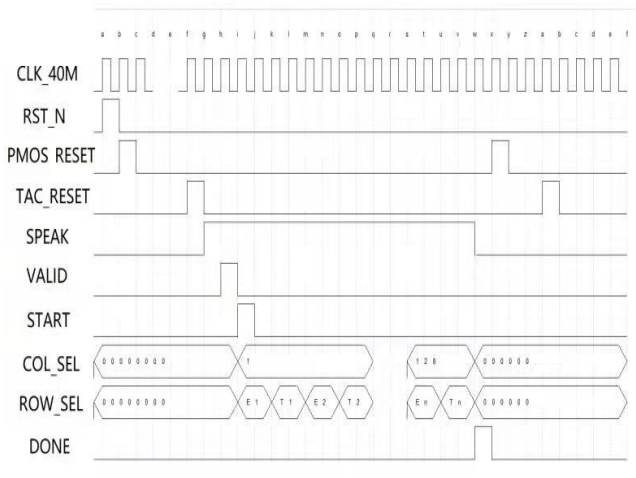


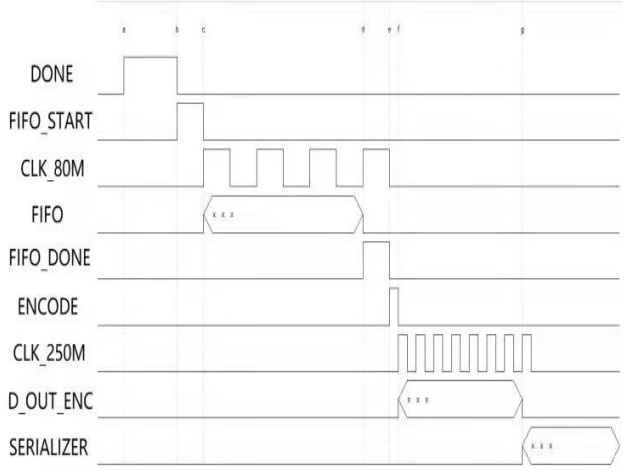
The Digital Control Design



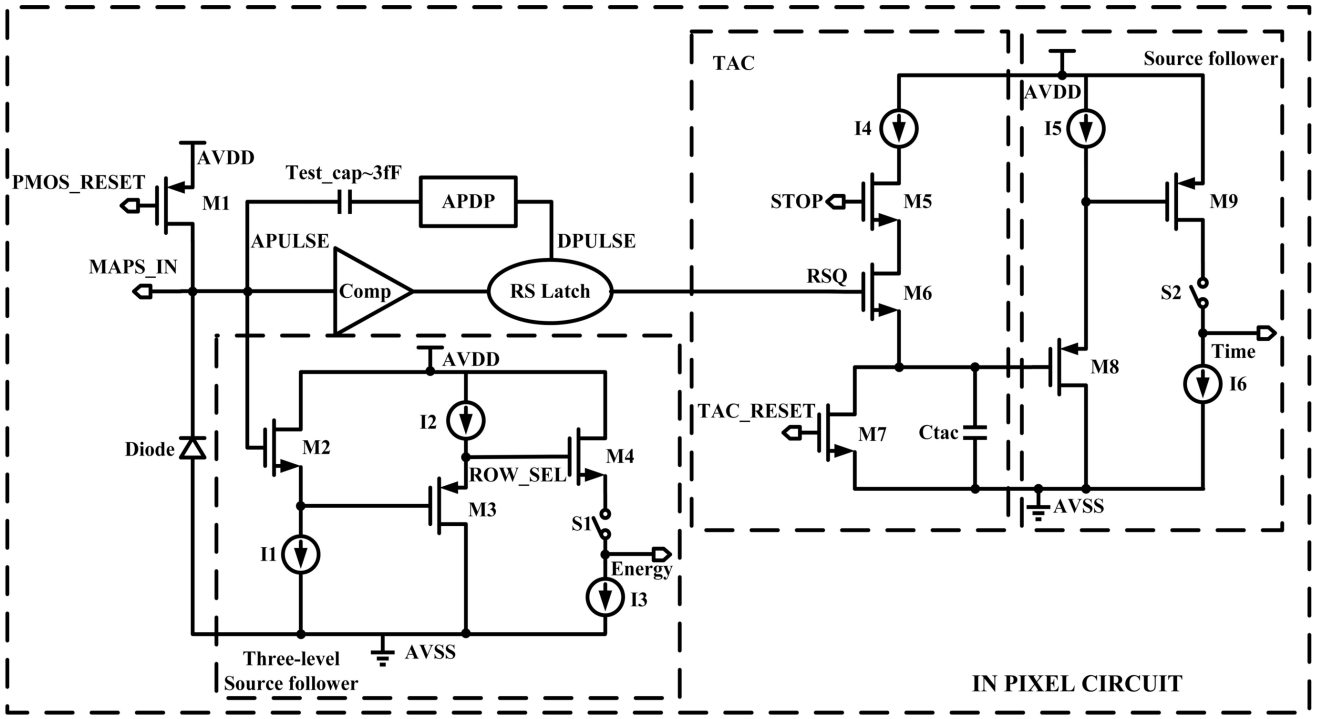
Pixel-to-pixel scan in each region

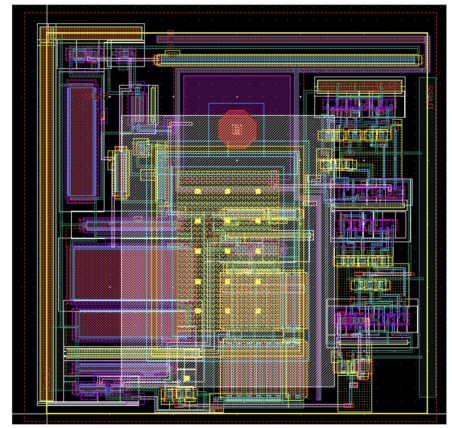


Chip-level data processing



The Pixel Design

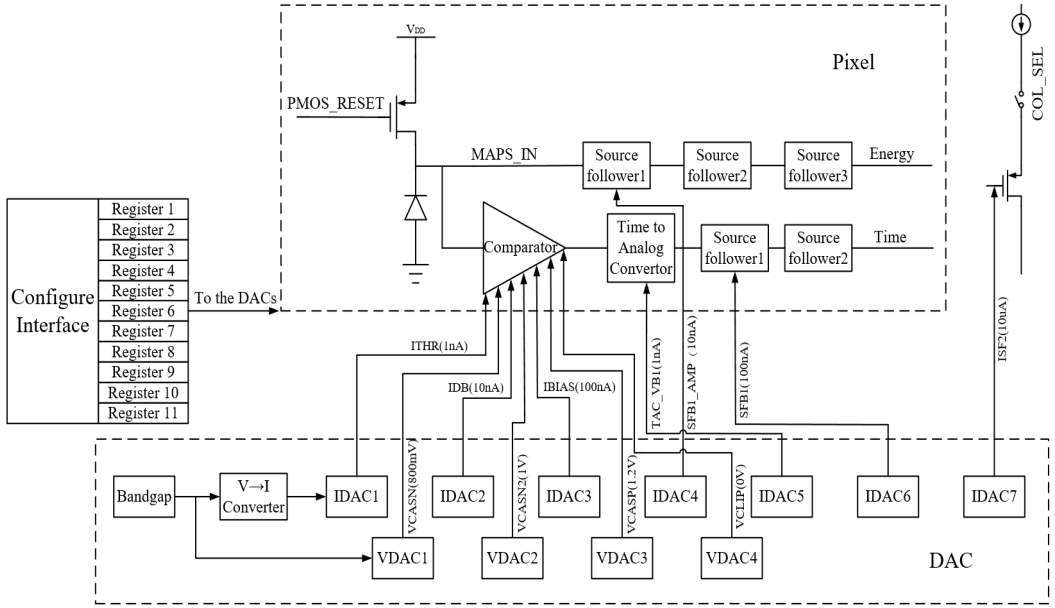


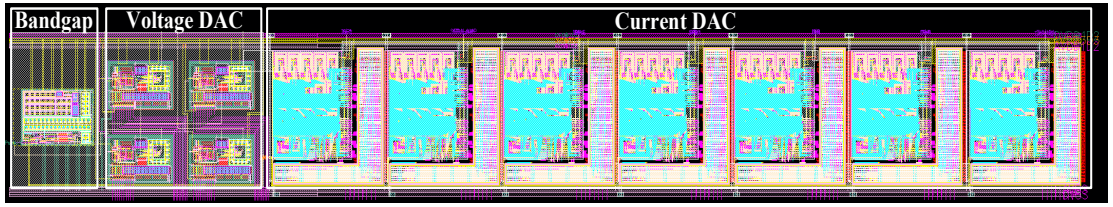


- Pixel Size 30μm x 30 μm
- Diode area is 10μm x 10 μm
- Octagon n-well is 3 μm x 3 μm

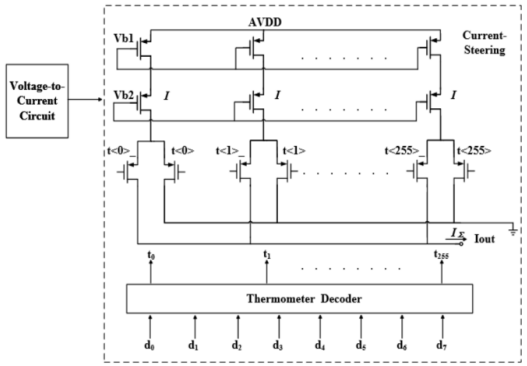
The DAC design

- 7 x 10bit VDAC + 4 x 8bit IDAC
- 3074μm×400μm. With a voltage supply of 3.3V, the power consumption is 46.2mW.

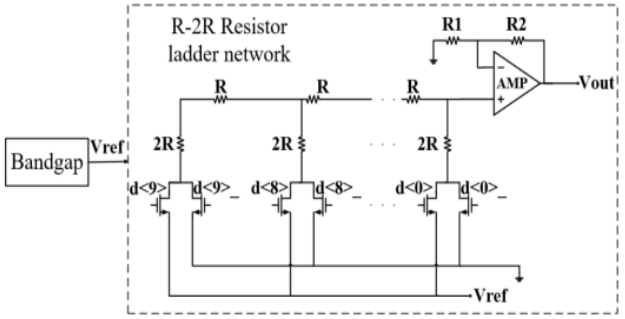




- **8-bit current-steering type DAC**

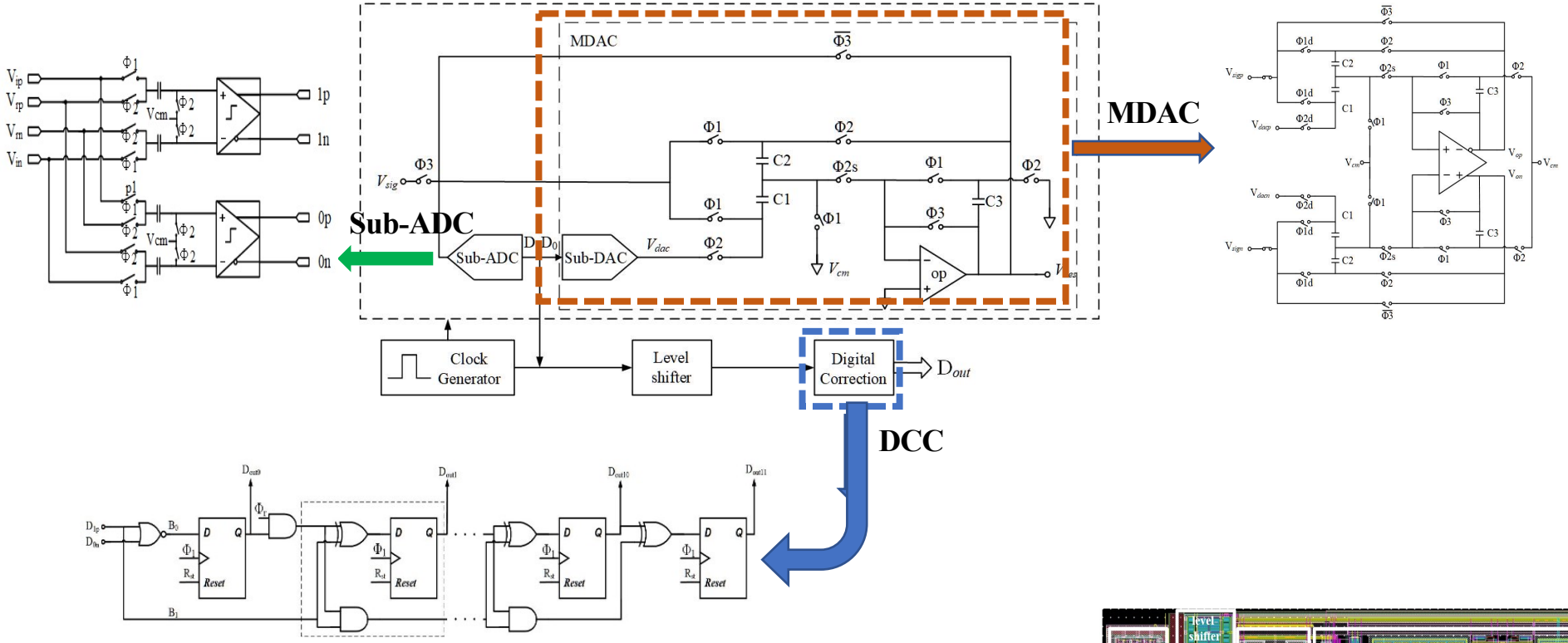


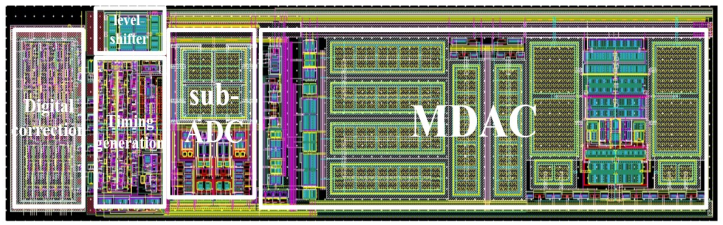
- **10-bit R-2R voltage DAC**



The Column-parallel ADC design

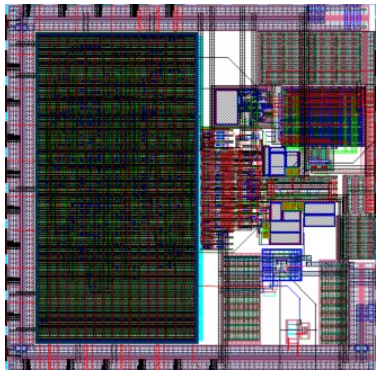
- Dsigned in a fully differential cyclic architecture and takes 11 clock cycles to to generate 12bit output
- 3.63Msps x 12bit, 380×100 μm^2 ,7.6mW@3.3V

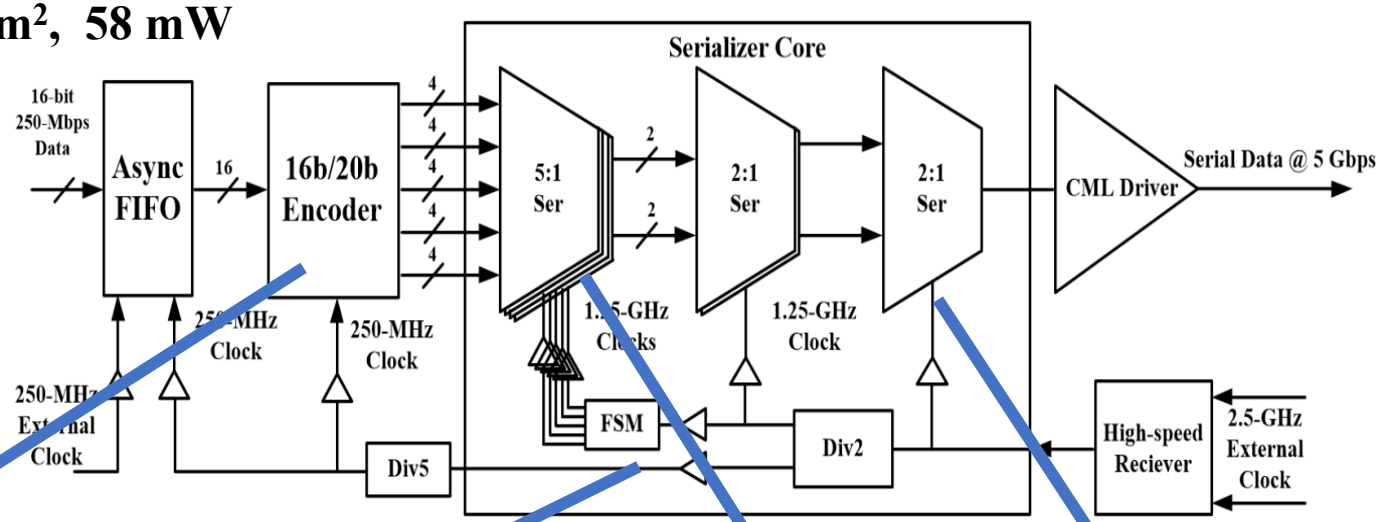


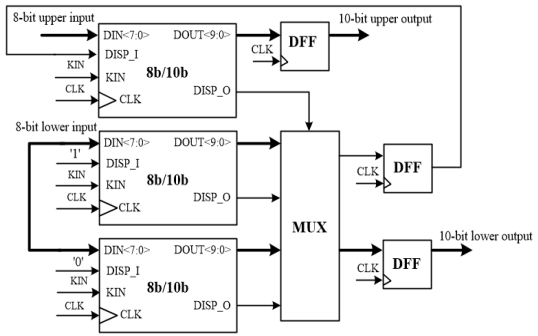


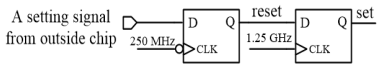
The Serializer Design

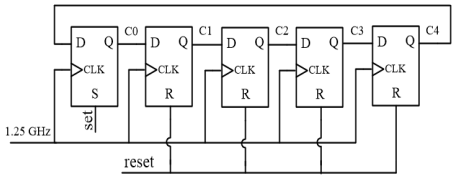
- 5Gbps, 1.96 mm^2, 58 mW

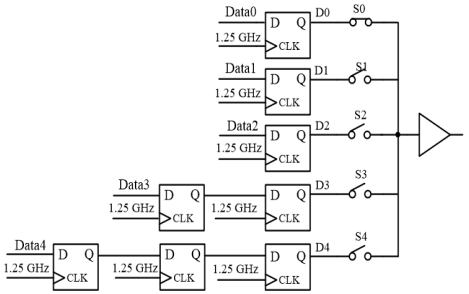


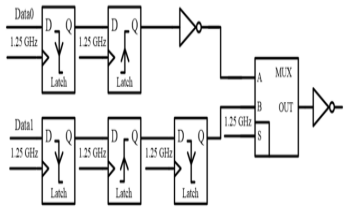






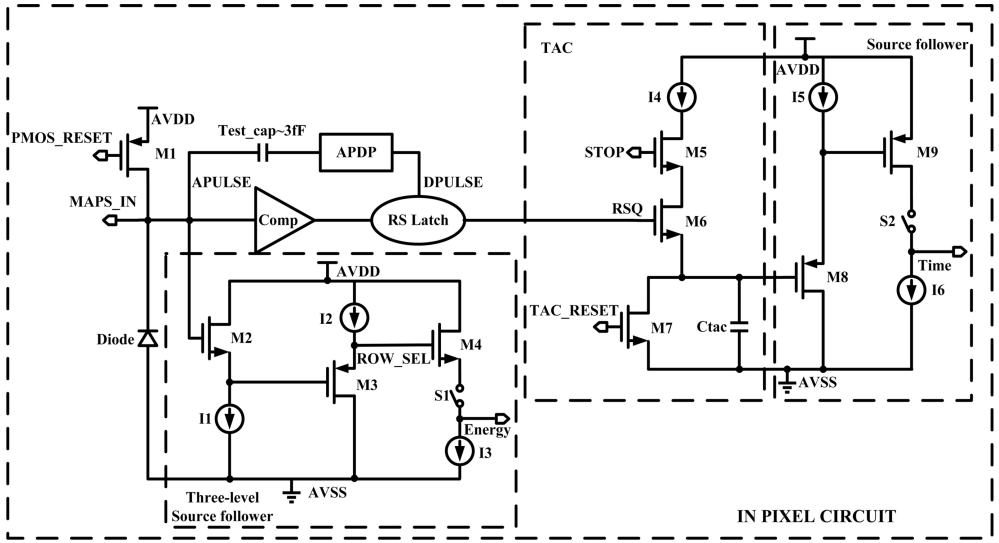


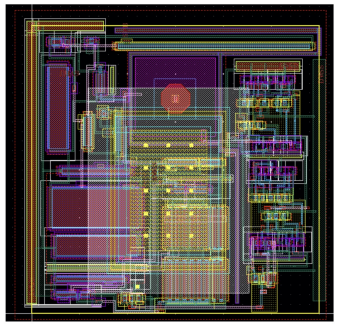




The Pixel and DAC design

The Pixel Design





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