CEPC vertex detector/si tracker

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outline

- physics motivation
- CEPC vertex detector
    - requirement & preCDR
    - baseline solution
    - self-support & inside-beam layer
- chanllenge
- outlook

physics motivation

vertex

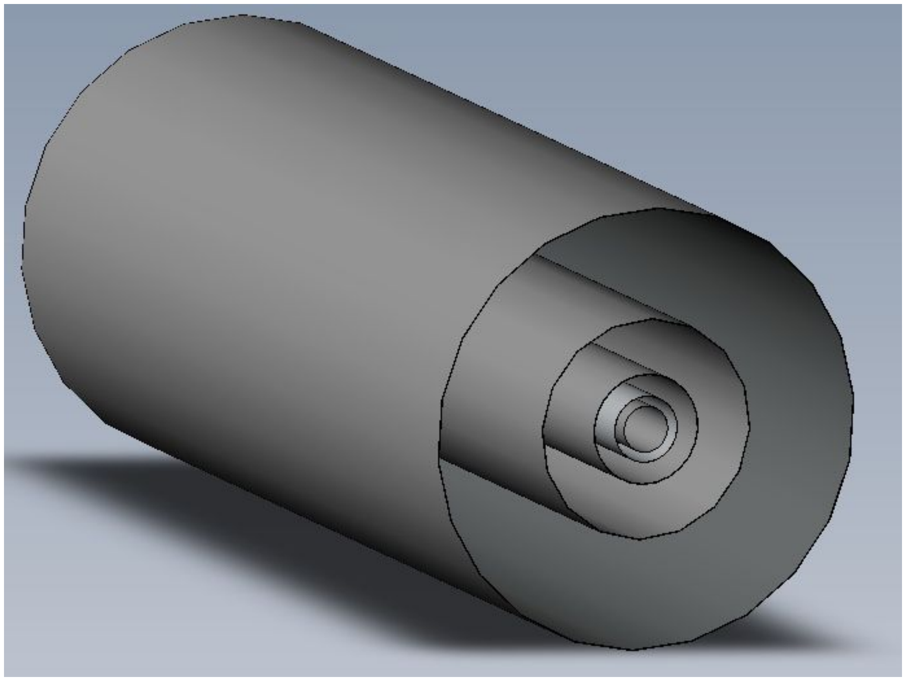
- distinguish short-lifetime particle from background; better measurement

- Higgs->b bbar；Higgs->tau taubar

silicon tracker

- connect TPC tracks to TOF hits, increase association efficiency

CEPC vertex detector



requirement & preCDR

baseline solution

self-support pixel detector

inside-beam layer

CEPC vertex requirement

High impact parameter resolution driven by flavor tagging

$$\sigma_{r\phi} = 5 \oplus 10/p \cdot \sin^{3/2}\theta \ \mu\mathrm{m}$$

Imposing stringent requirements on the Vertex detector, including

- Spatial resolution near the interaction point $\sigma_{SP} \leq 3\ \mu m$ → high granularity (small pixel size)
- Material budget $\leq 0.15\% X_0$/layer → monolithic pixel sensor (sensor + embedded electronics, thinned down to e.g. 50 μm) + air cooling (power dissipation ≤50mW/cm^2)
- Low detector occupancy below 0.5% → high granularity, short integration time
- Radiation tolerance (pre.): ~1 MRad (TID),10^{12} n_{eq}/cm^2 (NIEL)

Reminder: Detector requirements

Vertex detector specifications:

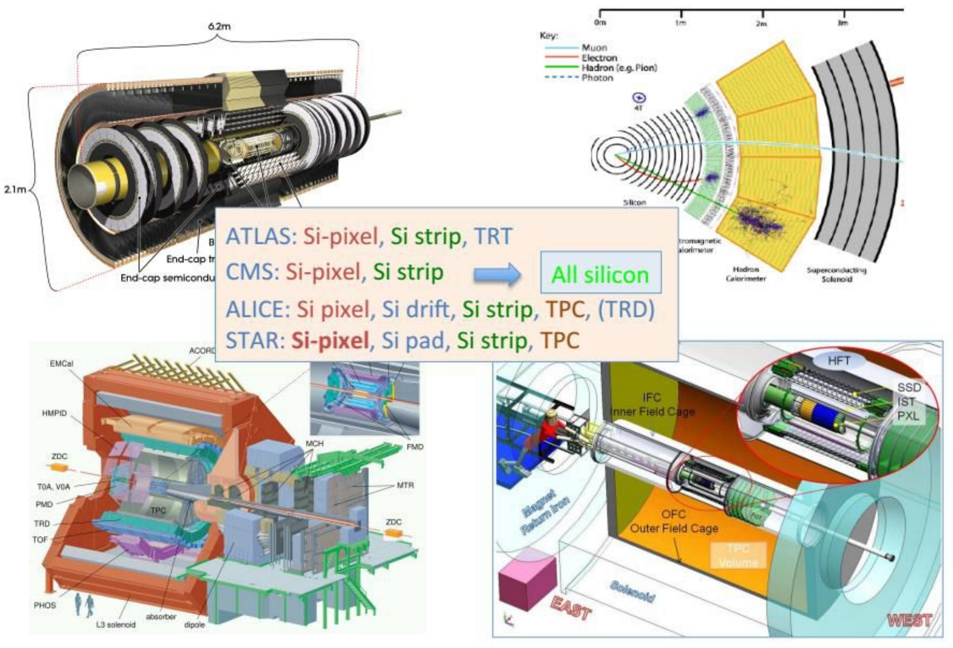
Parameter	Inner layers	Outer layers
Single point resolution	2.8μm	4μm
Integration time	20μs	
Power consumption	50 mW/cm² (air cooling)	
Material budget	0.15%X_0/layer	
TID radiation tolerance*	1M krad/ year	?
NIEL radiation tolerance*	$10^{12} n_{eq}$/ (cm^2 year)	?

* *safety factor of 5*

Silicon tracker specifications:

Parameter	Inner layers	Outer layers
Single point resolution	7μm	
Power consumption	50 mW/cm² (air cooling?)	
Material budget	0.65%X_0/layer	

baseline solution



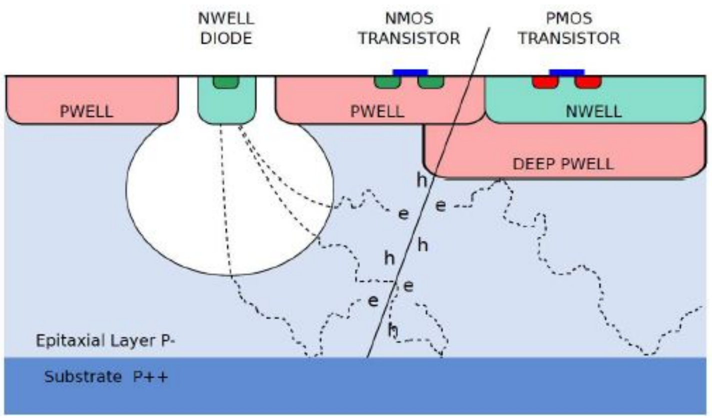
MAPS (CMOS pixel)
carbon fiber structure
lvds + optical link

example applications：

STAR HFT
ALICE ITS upgrade

task:
design chip matching CEPC requirement

CMOS MAPS



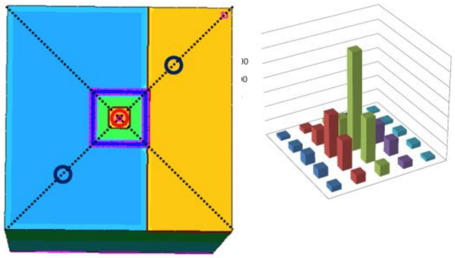
Integrated sensor and readout electronics on the same silicon bulk with "standard" CMOS process → low material budget, low power consumption, low cost …

Ultimate (Mimosa 28) installed for STAR PXL, technology for ALICE ITS Upgrade

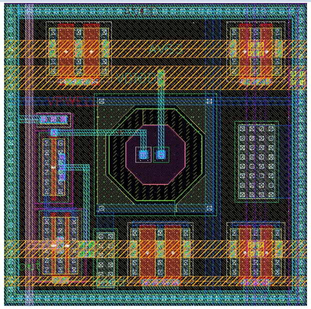
- Selected TowerJazz 0.18 μm CIS technology for R&D, featuring:
  - Quadruple well process: deep PWELL shields NWELL of PMOS transistors, allowing for full CMOS circuitry within active area
  - Feature size of 0.18 μm and 6 metal layers: high-density and low power
  - Thick (20 – 40 μm) and high resistivity (1 kΩ cm) epitaxial layer
  - Thin gate oxide (3 nm): radiation tolerance

R&D for CEPC

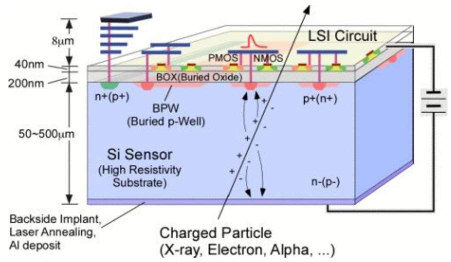
	3-year Project	Ultimate
Resolution (μm)	10	3
Detection Efficiency	99%	≥99%
Integration Time (μs)	100	20
Power Consumption (mW/cm^2)	150	50
Radiation Tolerance	/	1 Mrad/y (TID) &10^{12} $n_{eq}/cm^2/y$ (NIEL)



- TCAD simulation to guide the diode optimization and to be verified with future measurements (radiation damage being implemented …)



- TowerJazz CIS 0.18 μm Engineering Run expected mid of October

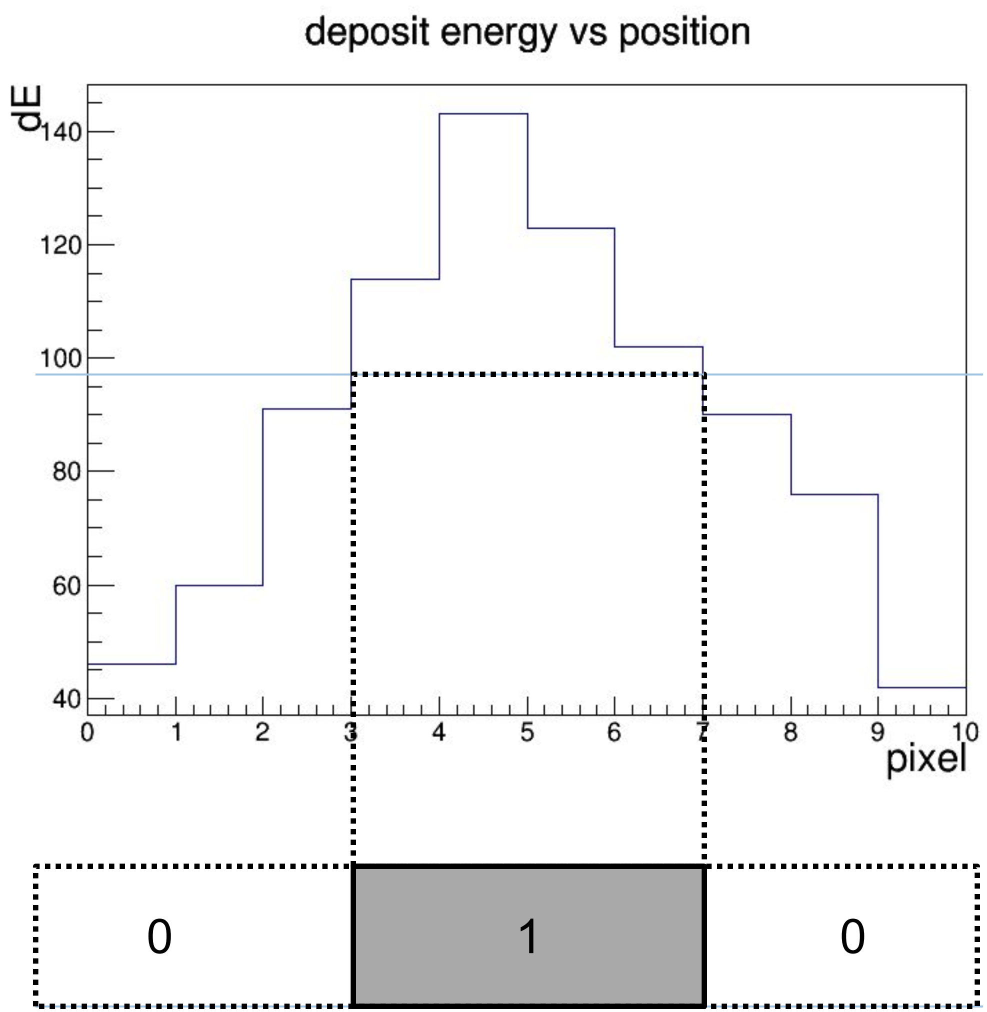


Other Options/Ideas

Monolithic pixel sensors based on the SOI technology: fully depleted sensor (large signal) and existing design experience with SOI detectors for X-ray detection

better position resolution
solution

postion resolution-weighting method



increase postion resolution to 1/10

position resolution

- pixel size 10um
- ADC bits 9
- threshold 3 σ
- ENC 10 e^-
- diffusion 10um
- signal charge 2000

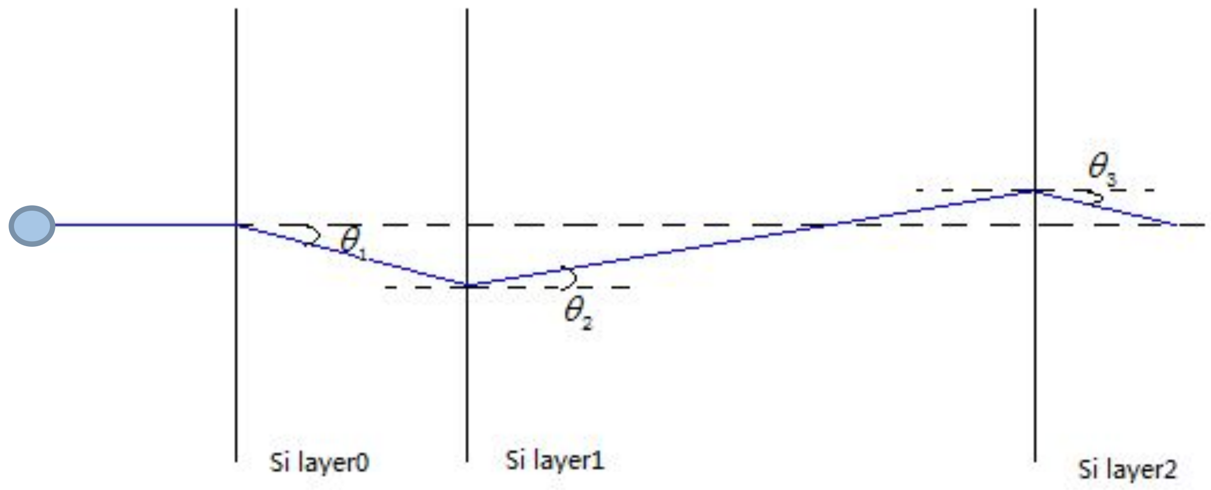
position resolution simulated

0.2um

position resolution from delta electron from IPHC small pixel measurement

1um

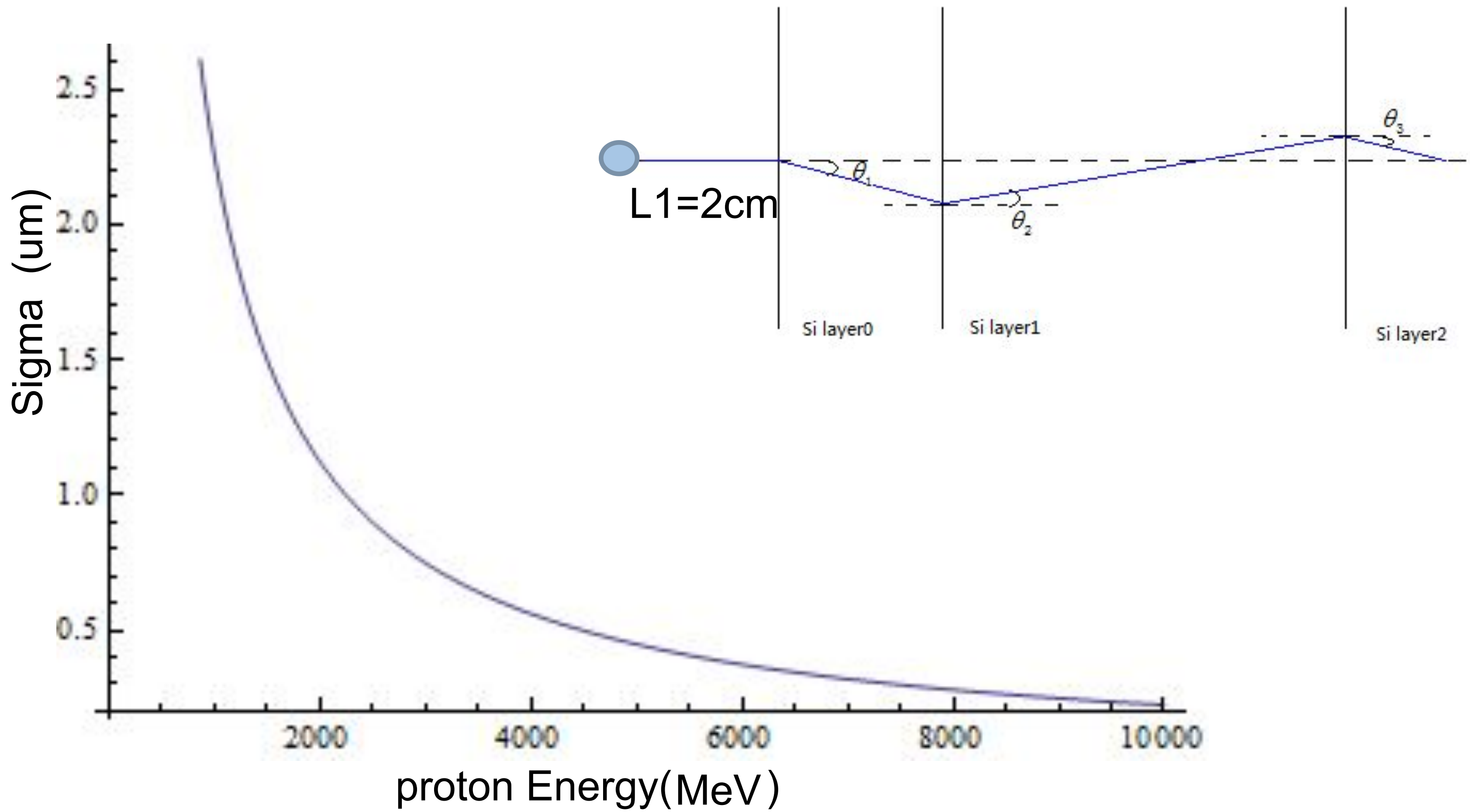
vertex resolution



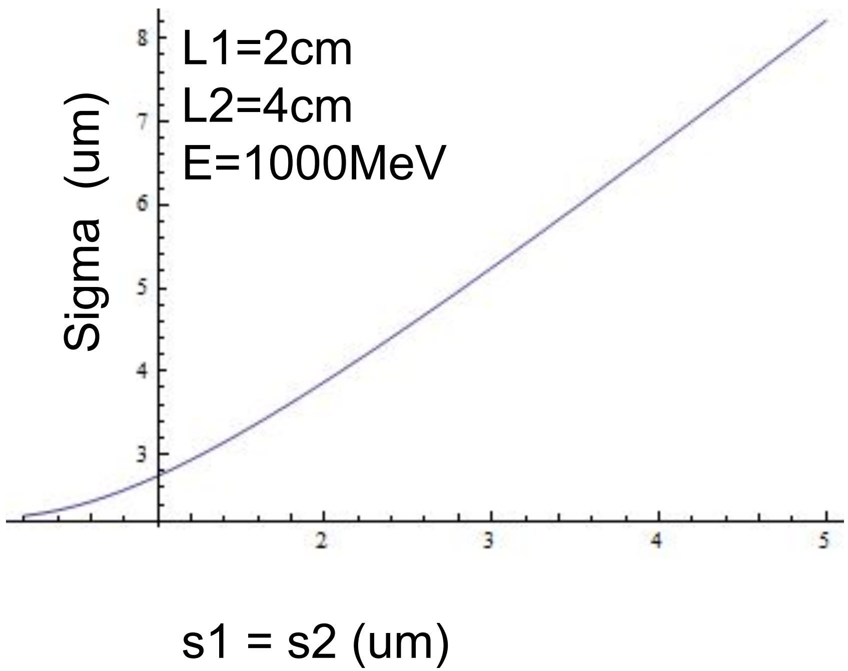
vertex resolution：
sigma= ((sita*L1)^2 + (s1*(L1 + L2)/L2)^2 + (s2*L1/L2)^2)^0.5

L1 : distance between vertex and layer1;
L2 : distance between layer1 and layer2 ;
sita : multiple coulomb scattering angle for layer1=1.12*10^-4 for 50um Si 1GeV proton
s1 : position resolution of layer1;
s2 : position resolution of layer2;

multiple Coulomb scattering

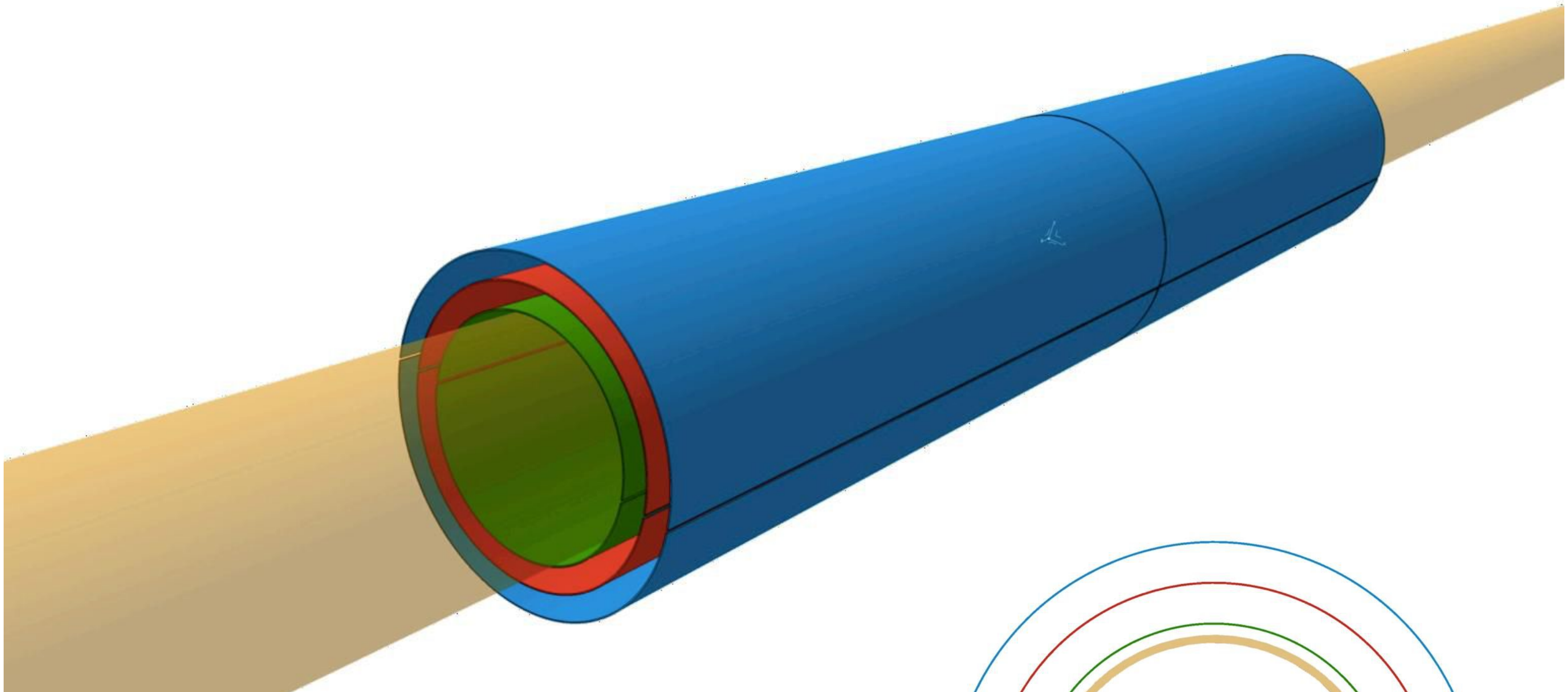


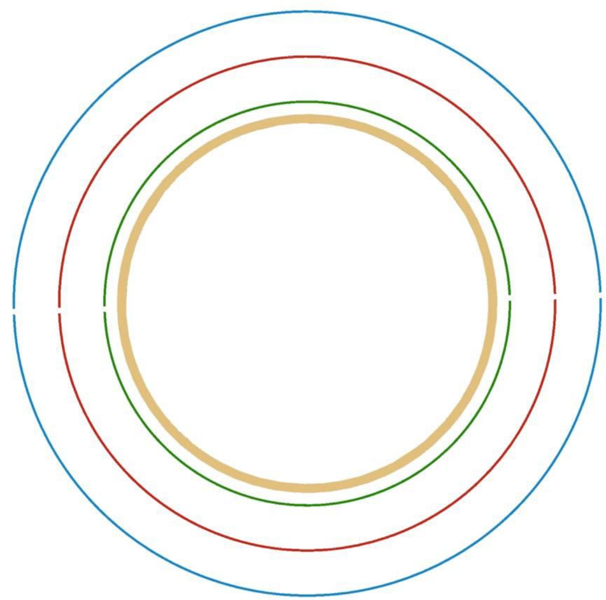
vertex resolution



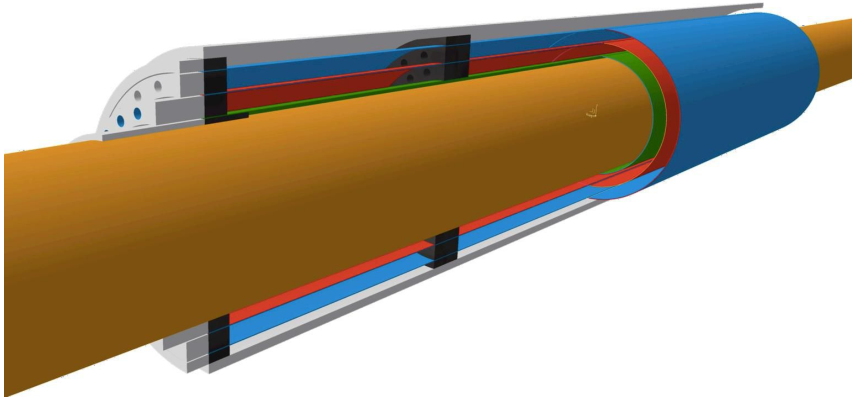
sigma= ((sita*L1)^2 + (s1*(L1 + L2)/L2)^2 + (s2*L1/L2)^2)^0.5

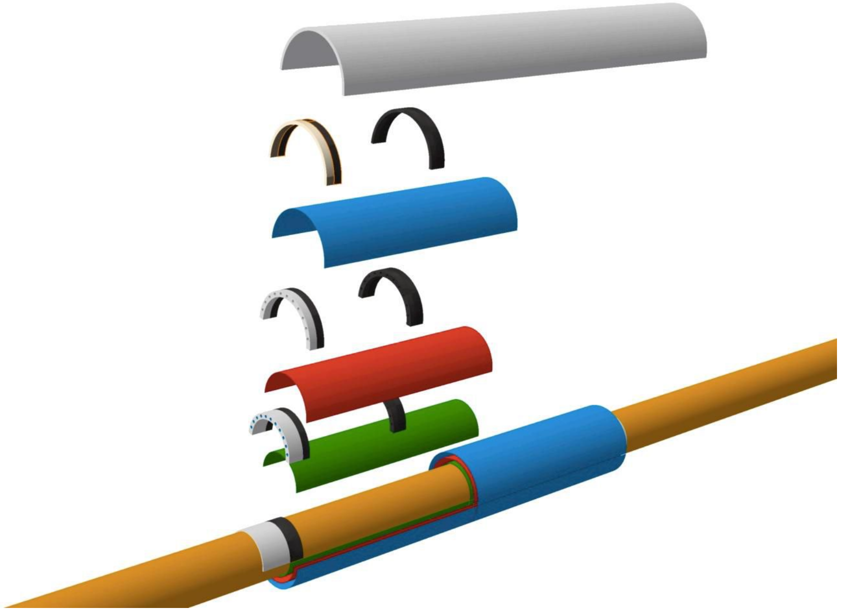
self-support



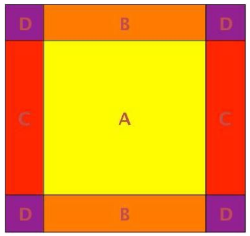


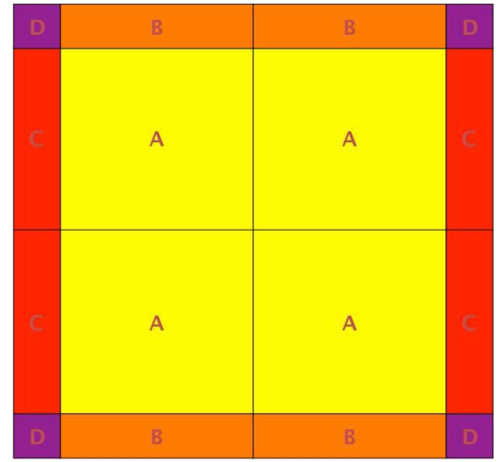
self-support

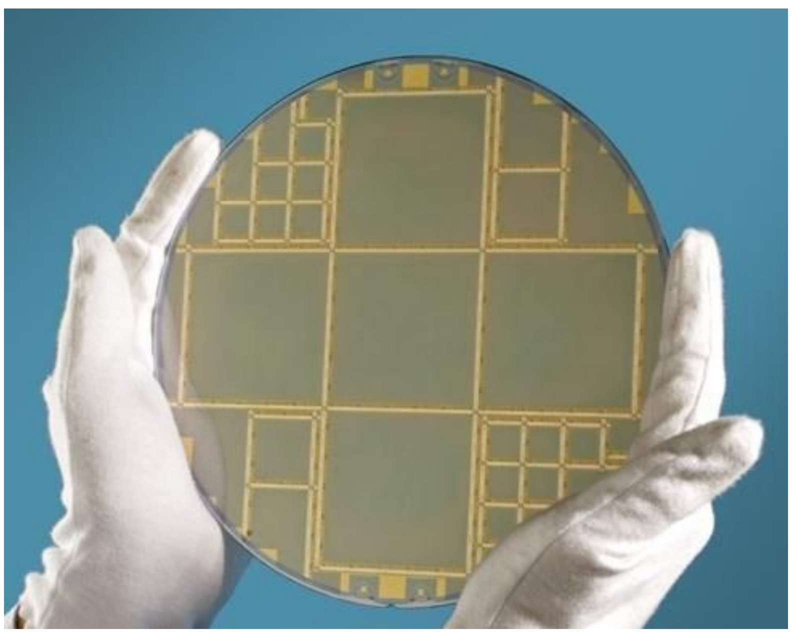


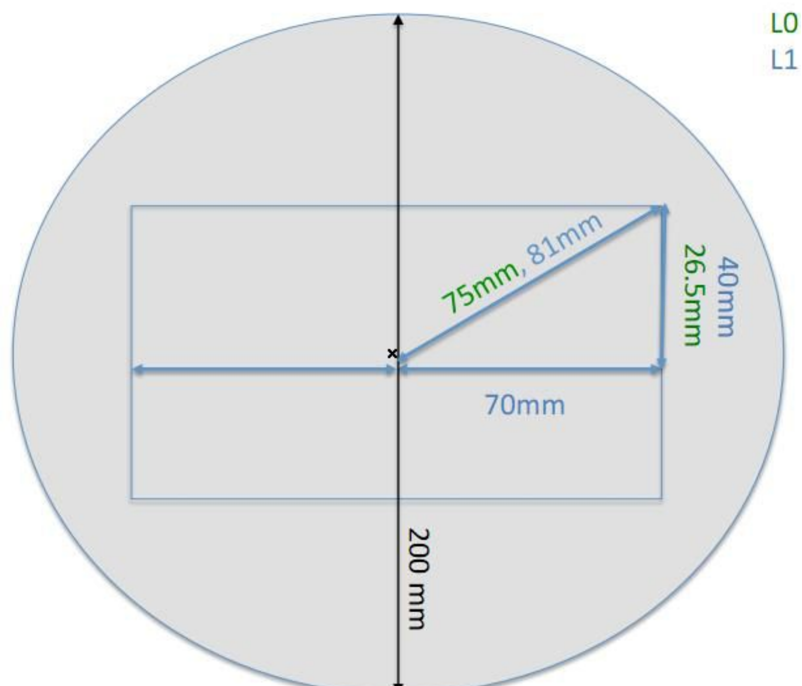


sensor design for selp-support

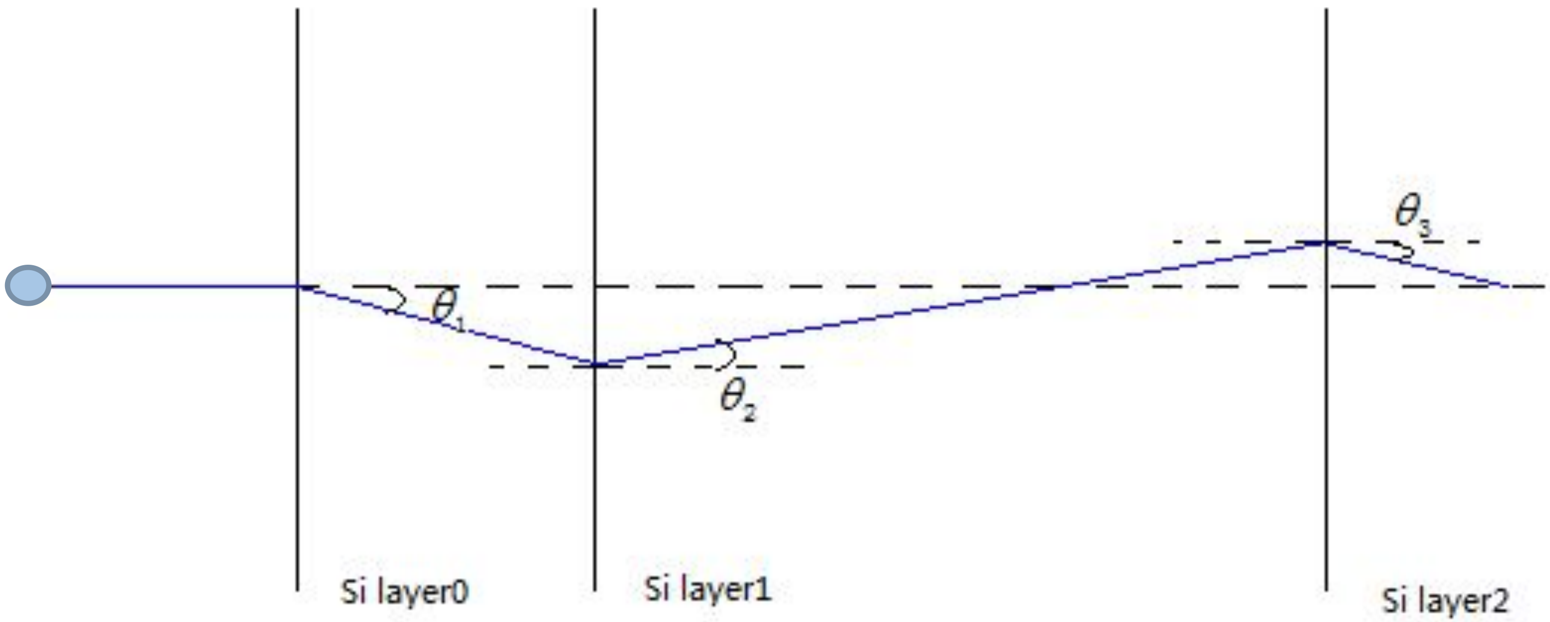








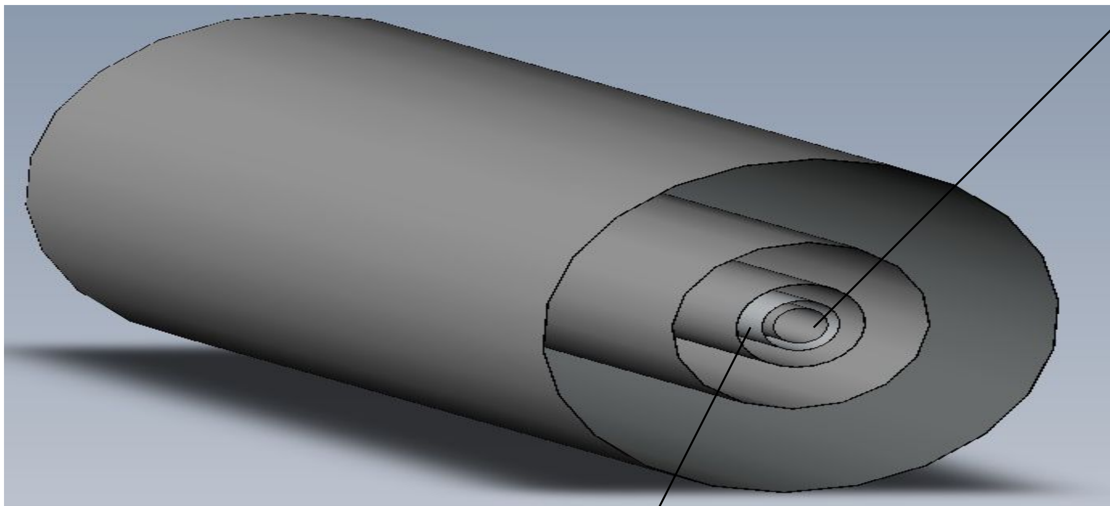
detector design requirement



only θ 1 matters
the first layer should be as thin as possible
vacuum between collision point to the first layer

inside-beam layer

the first layer is put inside
beam pipe



beam pipe

data rate

$$frameRate := 10^4 \cdot \frac{1}{s}$$

$$timeRes := 10^{-7} \cdot s$$

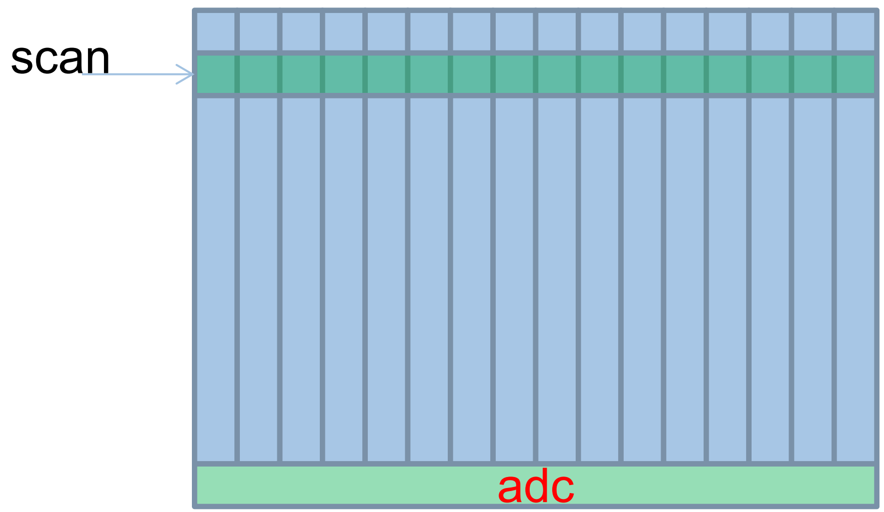
$$hitRate := 10^7 \cdot \frac{1}{s}$$

$$hitPerParticle := 3$$

$$chipSize := 3 \cdot cm$$

$$pixelSize := 20 \cdot \mu m$$

$$analogBit := 8$$



$$timeBit := \log\left(\frac{1}{frameRate \cdot timeRes}, 2\right) = 9.966$$

$$positionBit := \log\left(\frac{chipSize}{pixelSize}, 2\right) = 10.551$$

$$clkFre := frameRate \cdot \left(\frac{chipSize}{pixelSize}\right)^1 = 1.5 \times 10^7 \, s^{-1}$$

$$dataRate := [2 \cdot (positionBit) + timeBit + analogBit] \cdot hitRate \cdot hitPerParticle = 1.172 \times 10^9 \, s^{-1}$$

readout structure and power consumption added

- priority address encoding
- SCA on each column
- ADC is for each section

+SourceFollower+SwitchedCapacitorArray+ADC on each hits

other challenges for inside-beam layer

》 cooling and vibration

?

》 data transmission

?

》 radiation hardness

?

》 outgasing

?

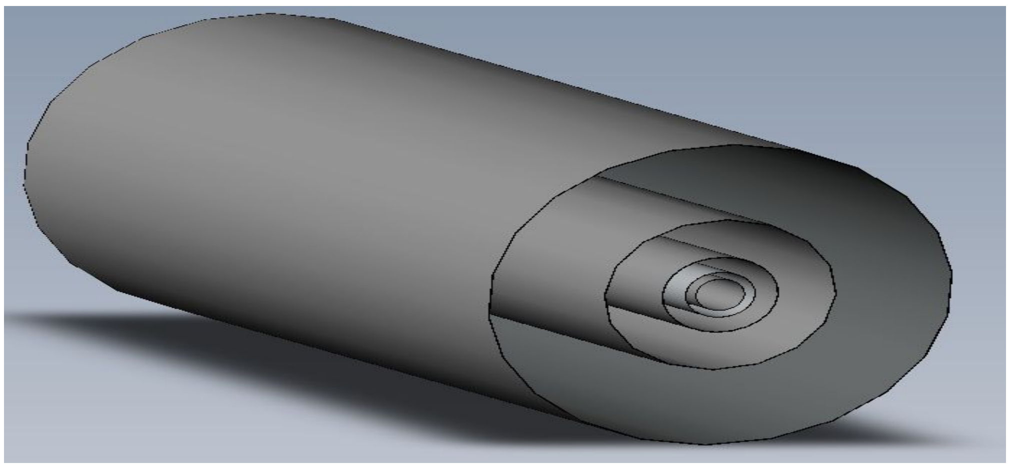
outlook

baseline R&D is ongoing

"new" ideas will be explored

Thank you for attention

自支撑结构仿真



探测器结构为五层，最内两层为50μm硅，100 μm铍束流管，外面三层为自支撑结构的硅探测器。

Geant4仿真中，除了上面这些部分设定材料外，其他空间填充的为空气。

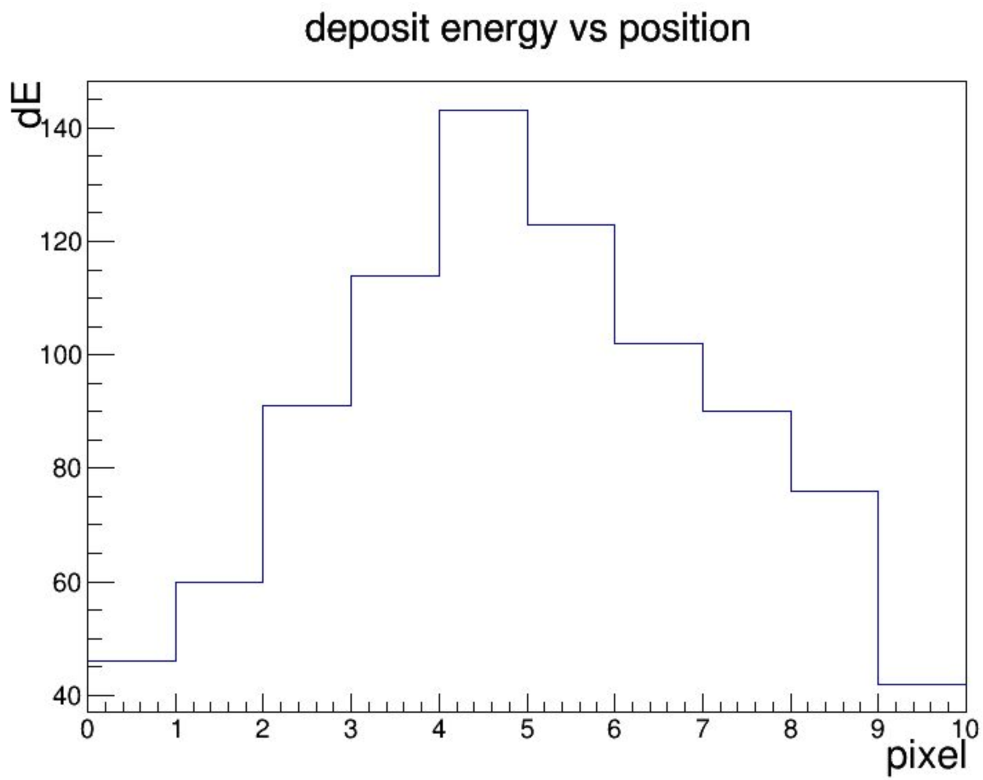
仿真中，由几何中心位置沿一定方向发射能量范围为1GeV到10GeV的质子。

进一步提高空间分辨能力

- 硅的厚度不可能无限减小下去，50um已接近目前工业极限。
- 像素的尺寸也有限制，分辨率无法突破1um

- 要进一步提高空间分辨能力，需要让出射粒子直接打到第一层探测器上，第一层探测器需放在束流管内。称为束流管层

束流管层+重心法



重心法可以达到小于单通道探测器大小1/10以上的精度

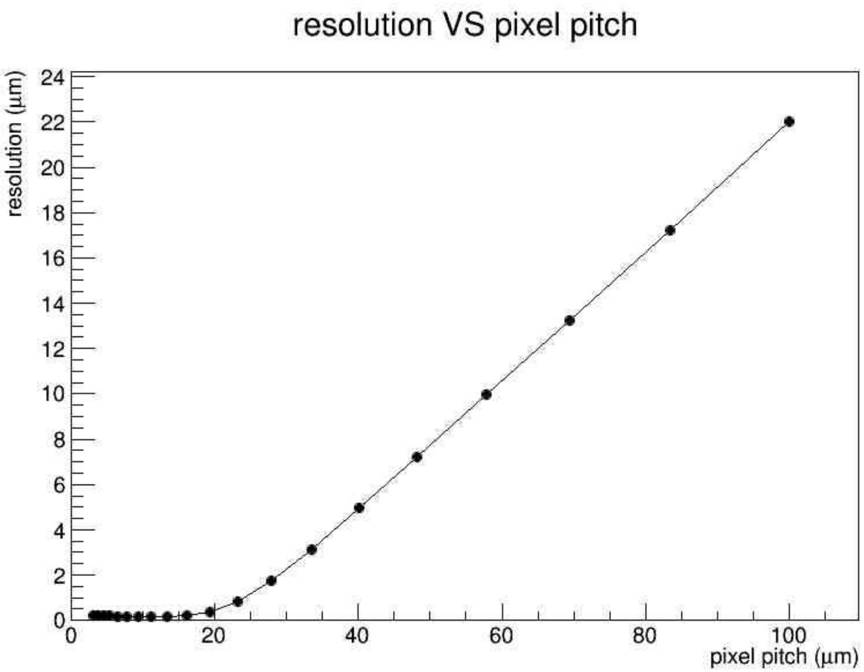
用在像素探测器上？

束流管层空间分辨的影响因素

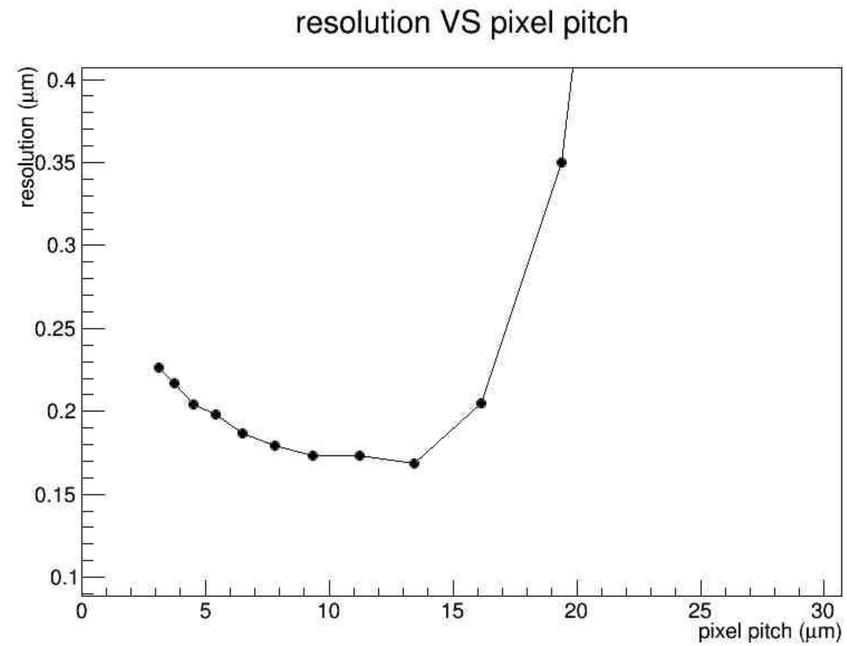
- 像素大小 10um
- ADC位数   9位
- 像素阈值   3 σ
- 像素噪声   10 e^-
- 信号扩散   10um
- 信号电荷   2000

能量沉积设为：
2000个电子~7.2KeV~8um耗尽层
信号的形状设为：
高斯分布

像素大小

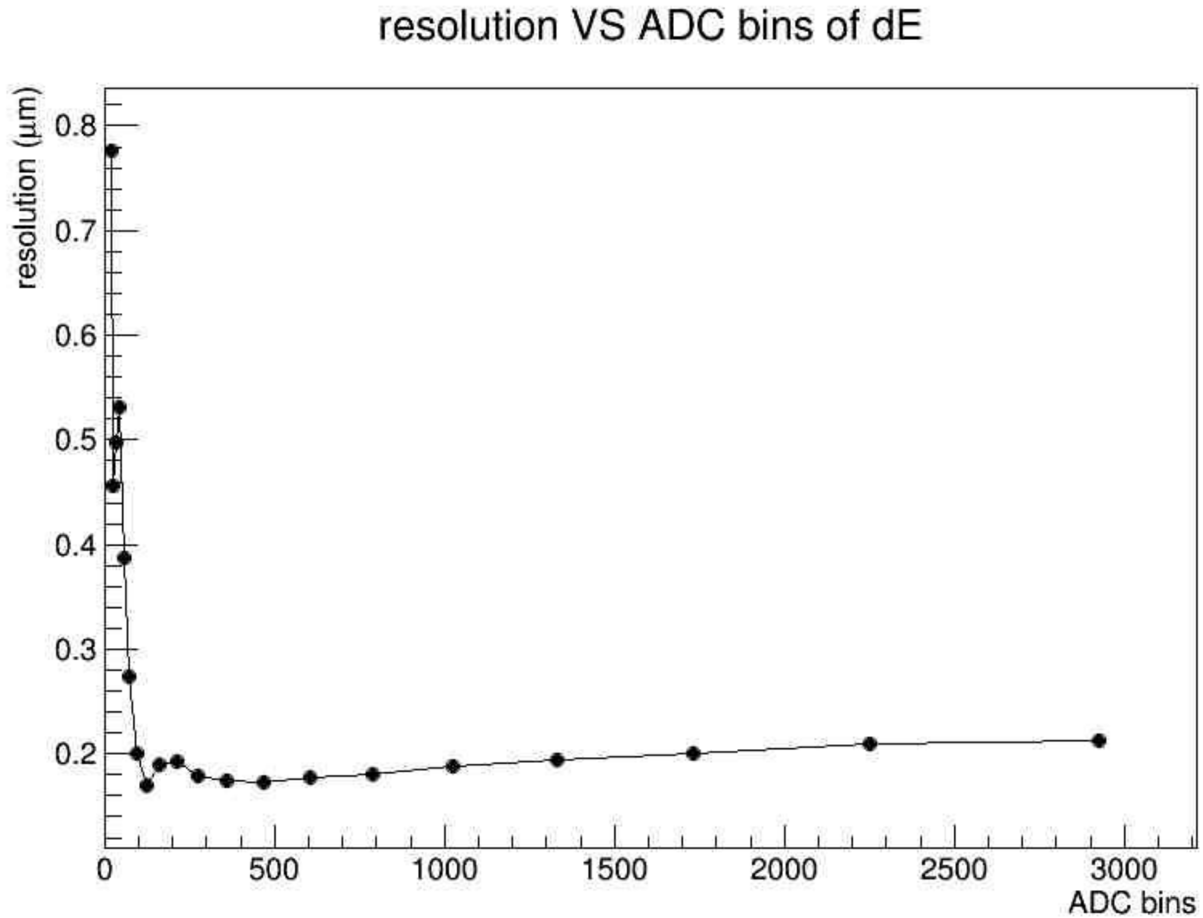


resolution VS pixel pitch
resolution (μm)
pixel pitch (μm)
0
2
4
6
8
10
12
14
16
18
20
22
24
0
20
40
60
80
100



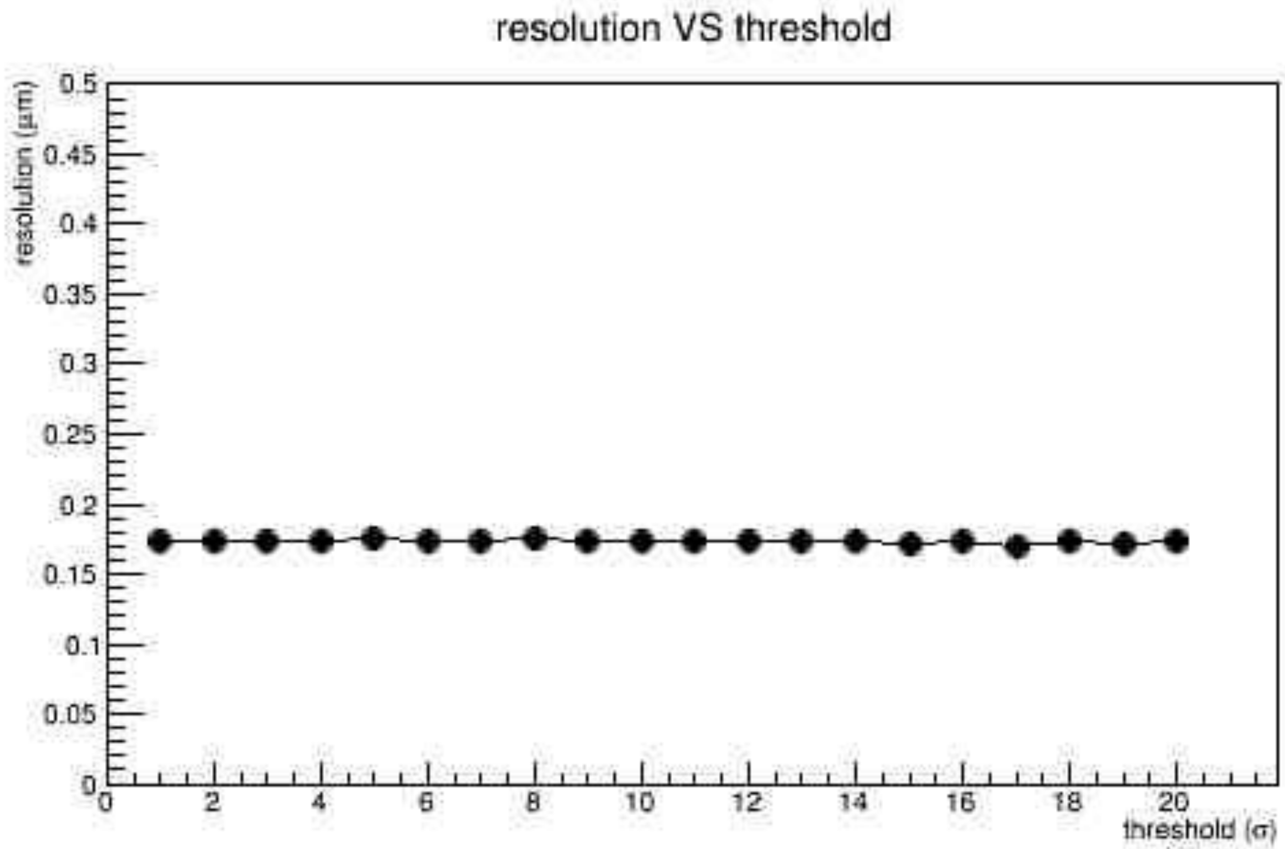
resolution VS pixel pitch
resolution (μm)
pixel pitch (μm)
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
5
10
15
20
25
30

ADC位数



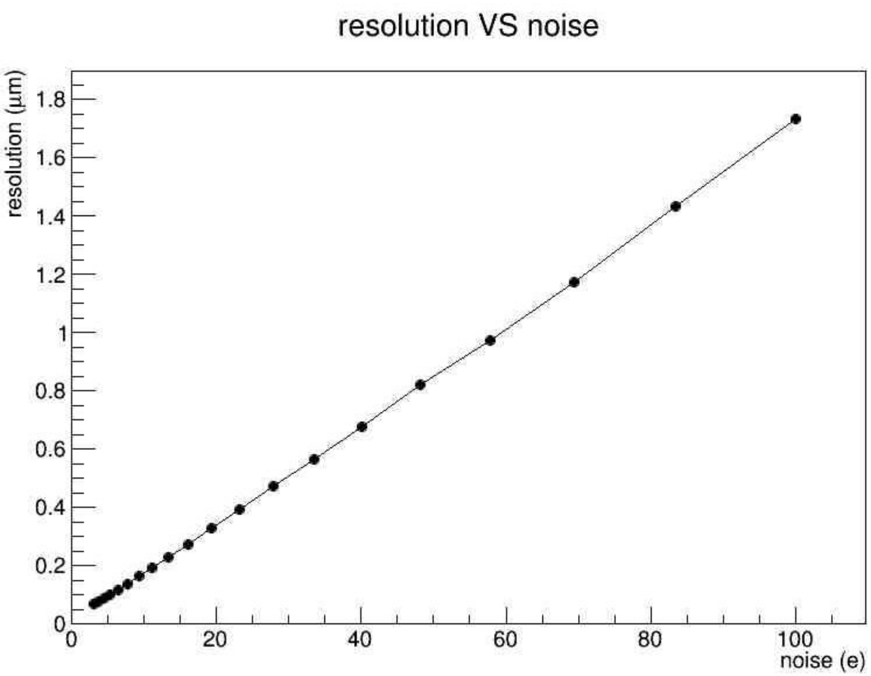
resolution VS ADC bins of dE
resolution (μm)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
500
1000
1500
2000
2500
3000
ADC bins

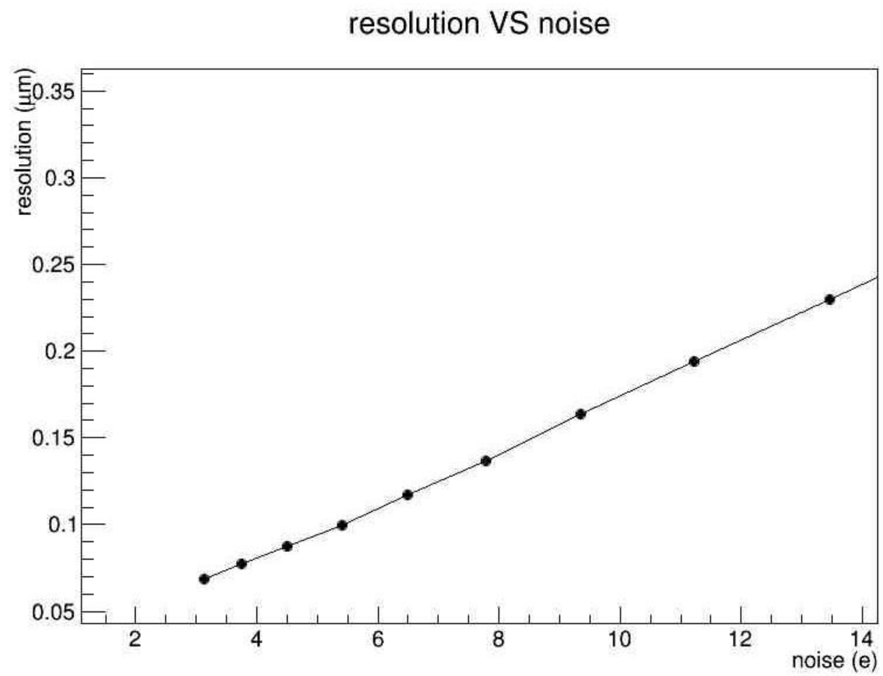
像素阈值



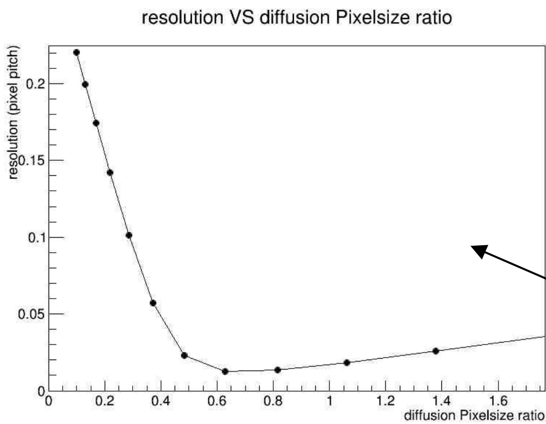
resolution VS threshold
resolution (μm)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
14
16
18
20
threshold (σ)

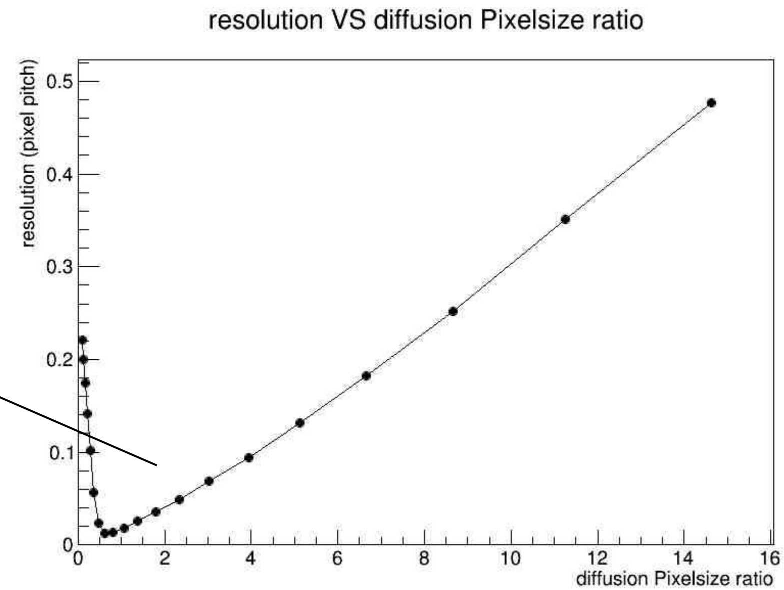
像素噪声

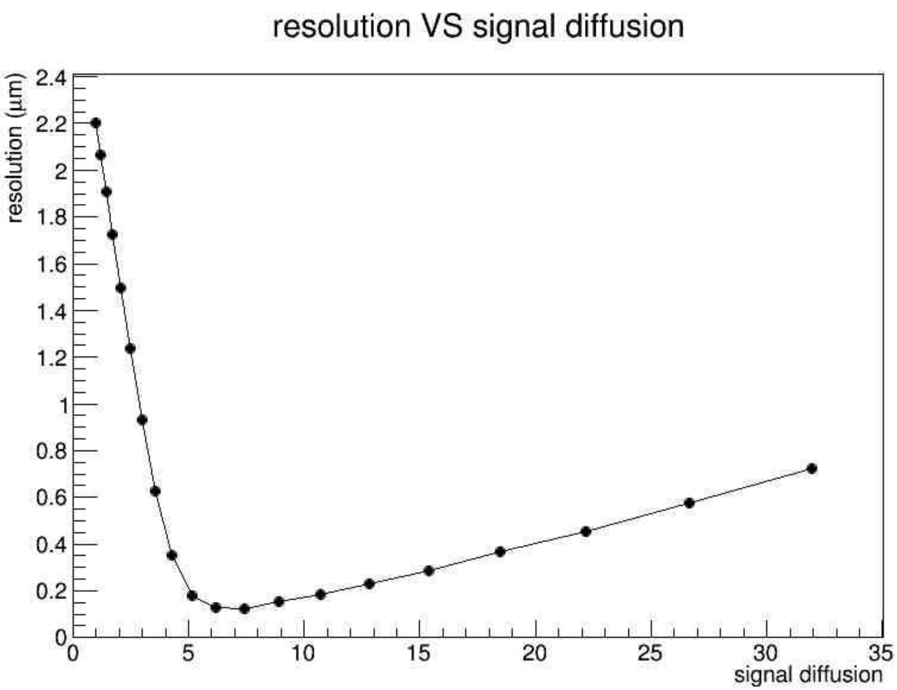

resolution VS noise
resolution (μm)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
noise (e)


resolution VS noise
resolution (μm)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
2
4
6
8
10
12
14
noise (e)

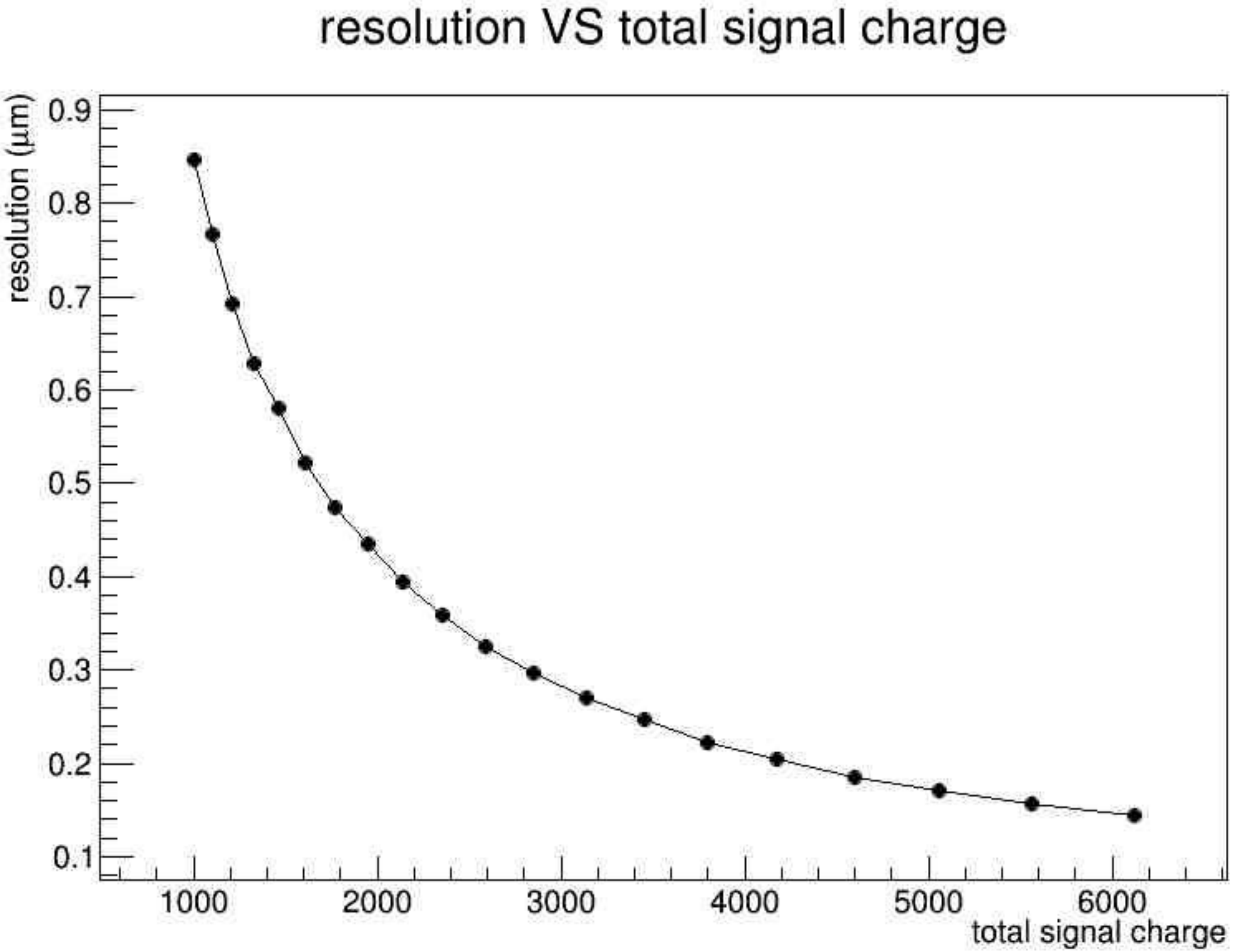
信号扩散


resolution VS diffusion Pixelsize ratio
resolution (pixel pitch)
diffusion Pixelsize ratio


resolution VS diffusion Pixelsize ratio
resolution (pixel pitch)
diffusion Pixelsize ratio


resolution VS signal diffusion
resolution (µm)
signal diffusion

信号电荷


resolution VS total signal charge
resolution (μm)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1000
2000
3000
4000
5000
6000
total signal charge

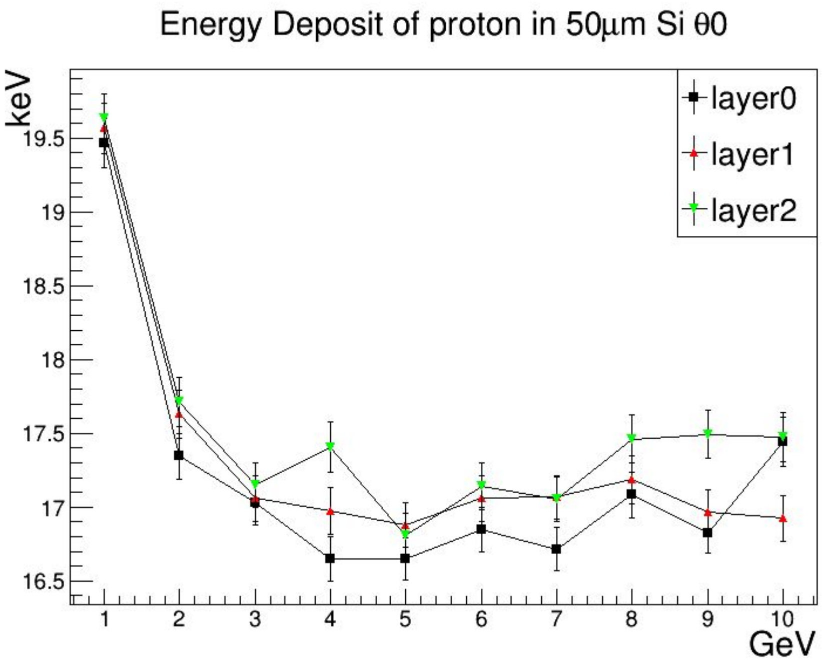
束流管层的空间分辨

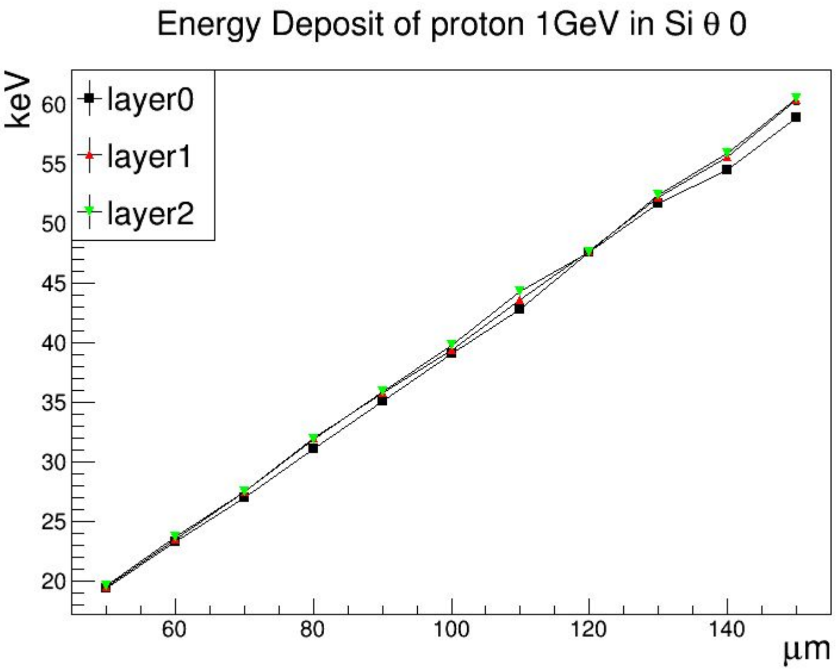
- 像素大小 10um
- ADC位数 9位
- 像素阈值 3 σ
- 像素噪声 10 e
- 信号扩散 10um
- 耗尽层厚度 60 um

在以上参数时，仿真得到空间分辨可到200nm

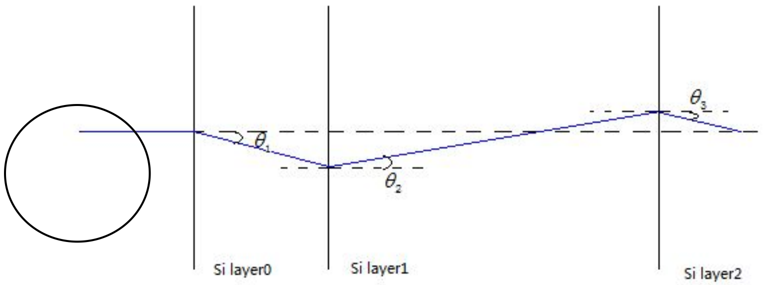
但是……

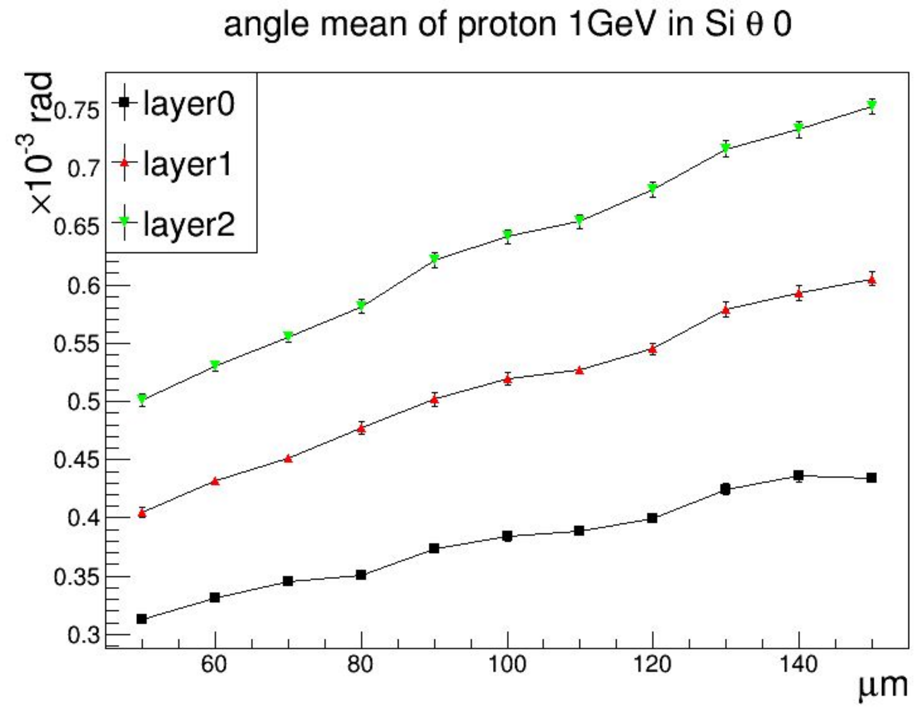
能量损失

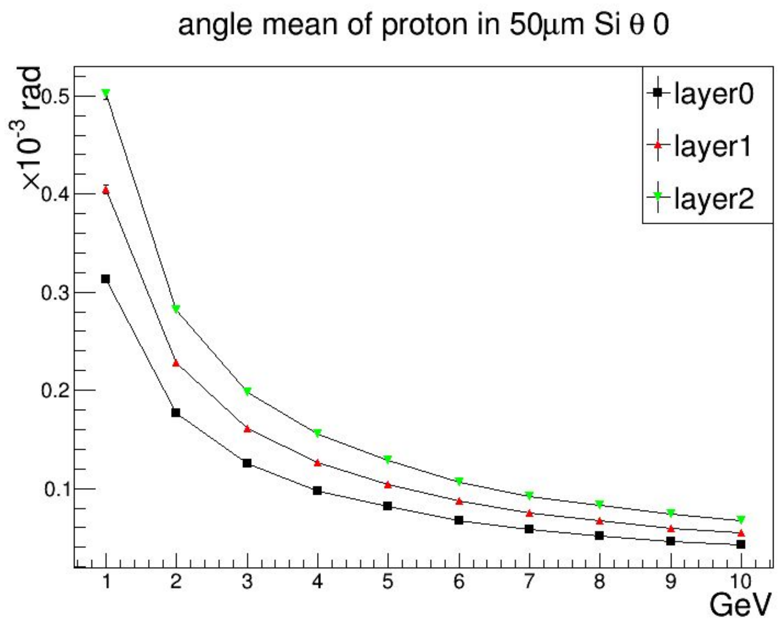

Energy Deposit of proton in 50μm Si θ0
keV
GeV
layer0
layer1
layer2
19.5
19
18.5
18
17.5
17
16.5
1
2
3
4
5
6
7
8
9
10


Energy Deposit of proton 1GeV in Si θ 0
keV
μm
layer0
layer1
layer2
60
55
50
45
40
35
30
25
20
60
80
100
120
140

散射角度







依靠自支撑技术，
可将散射角度减小约
30%

第一层的散射角在1cm距
离上产生2-3um的偏移

谢谢