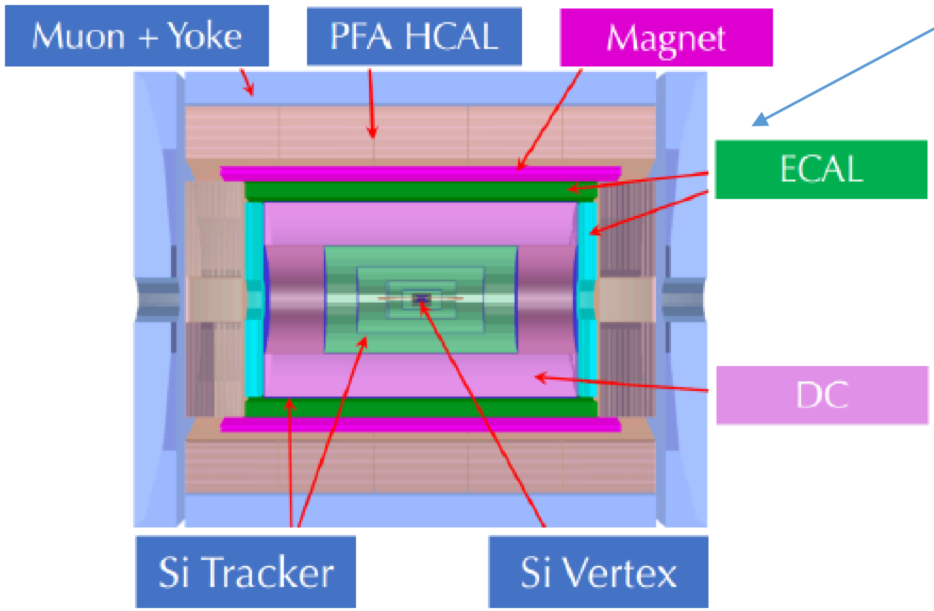
2022年 5-9月工作内容

CEPC tracker **漂移室体积的优化**
HVCMOS sensor **Trimming调试**
以及**宇宙线测试**

报告人：姜啸捷
导师：李一鸣
2022/9/2

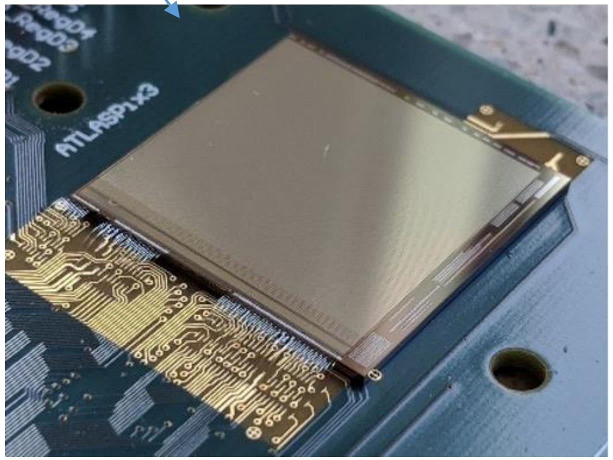
背景



The 4th CEPC Tracker 概念图

- The 4th CEPC Tracker的主要特征是使用**Drift Chamber**进行**粒子鉴别;**
- 不同的DC体积设计会带来不同的径迹参数误差;
- 需要使用大量高分辨、低物质量的**SiTracker**系统，比如SIT(silicon inner trcker)、SET(silicon external tracker)。

单块ATLASPix3 CMOS芯片

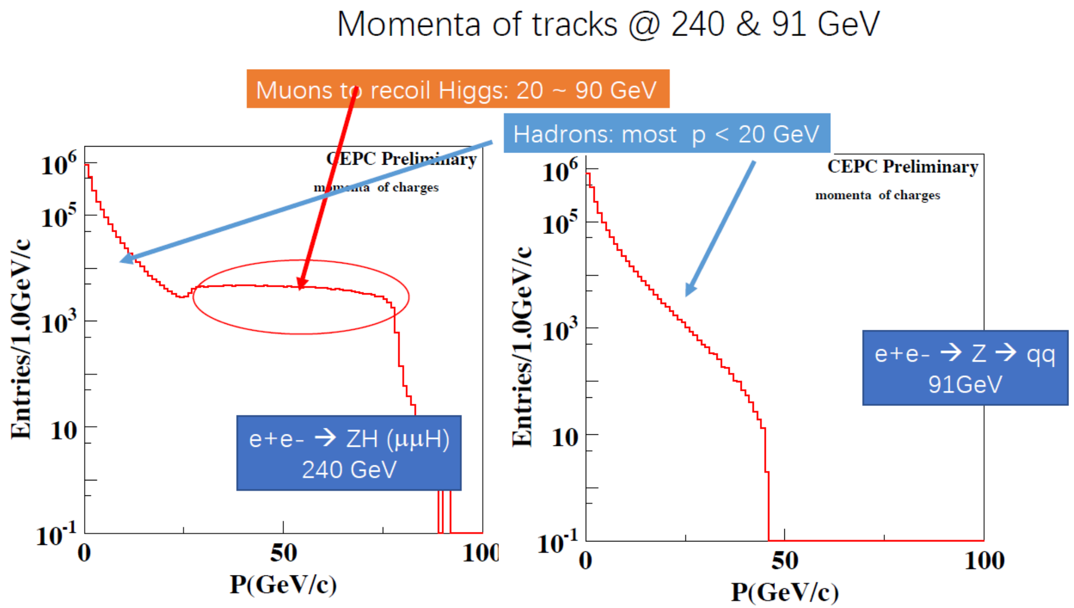


- CEPC tracker需要大面积的silicon:
  - DC/TPC + Silicon， ~ **70 m²**
  - full silicon tracker，~**140 m²**
- High Voltage Complementary Metal-Oxide-Semiconductor (HVCMOS)是经济且高效的候选

1.DC优化

CEPC物理要求（动量和碰撞顶点）

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$



- 优化目标：
  通过调整Drift Chamber的体积，以及随之移动的SIT位置来达到理想的P_t（横动量）(d_0, z_0, ϕ, θ, P_t)分辨。
  3种设计：DC=0.6-1.8m，DC=0.8-1.8m，DC=1-1.8m（rφ方向）

- 使用工具：
  - 基于Python的解析计算工具（李刚等开发）
  - LDT（MATLAB fast simulation， Wiener团队开发 ）

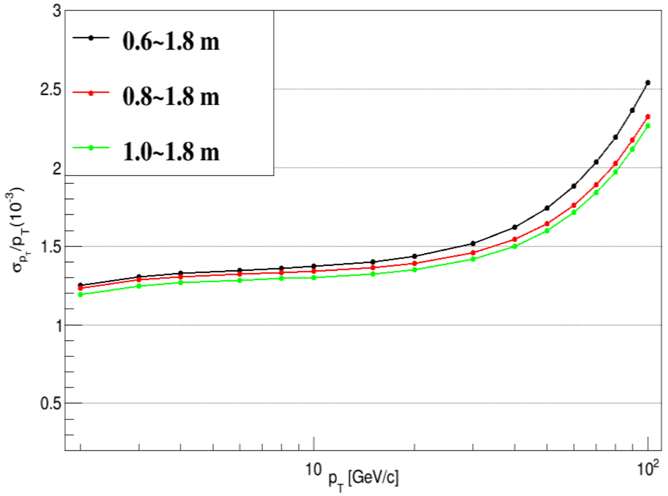
  } Fast tools
  - GenFit（张瑶等开发）
  - MarlinTrk（ ILCSoft tracking，傅成栋维护）

  } CEPCSW上的Full simulation

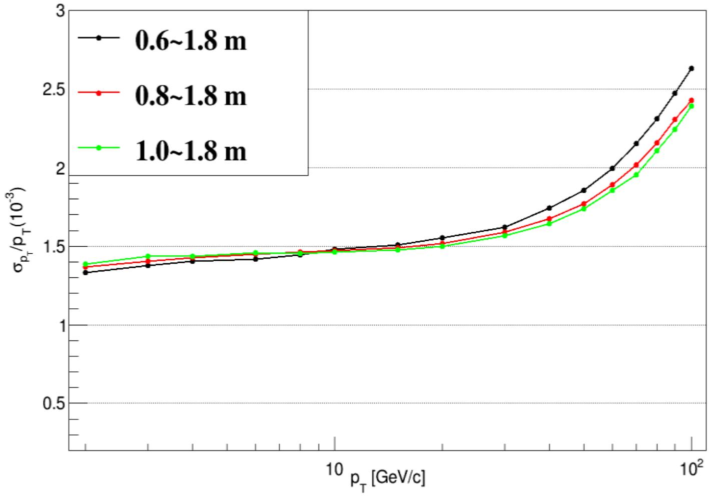
- 径迹探测器对<20 GeV/c的径迹需要有足够好的动量分辨率（重味物理驱动）

1.DC优化- 只添加DC物质量，未使用DCHits

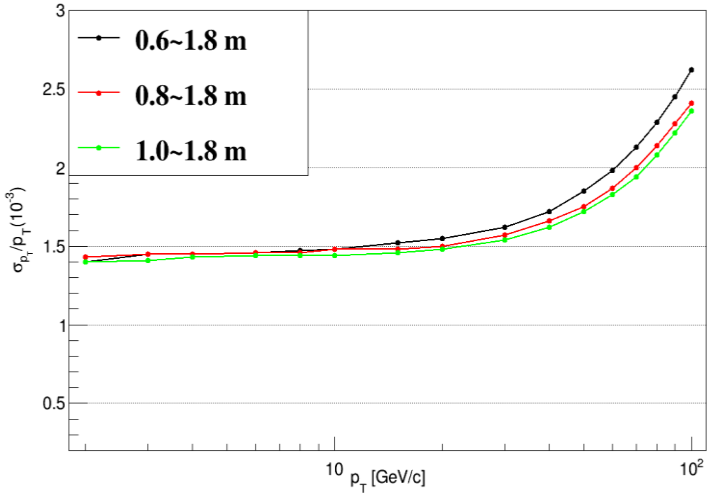
解析计算：



GenFit：



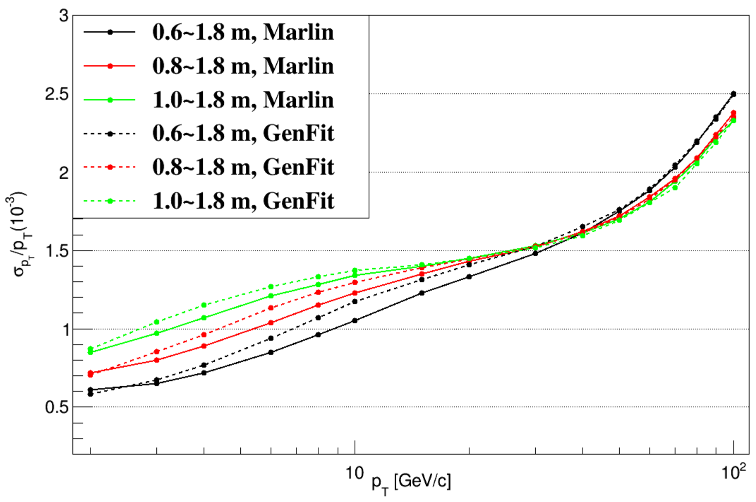
Marlin（模拟数据来自傅成栋）：



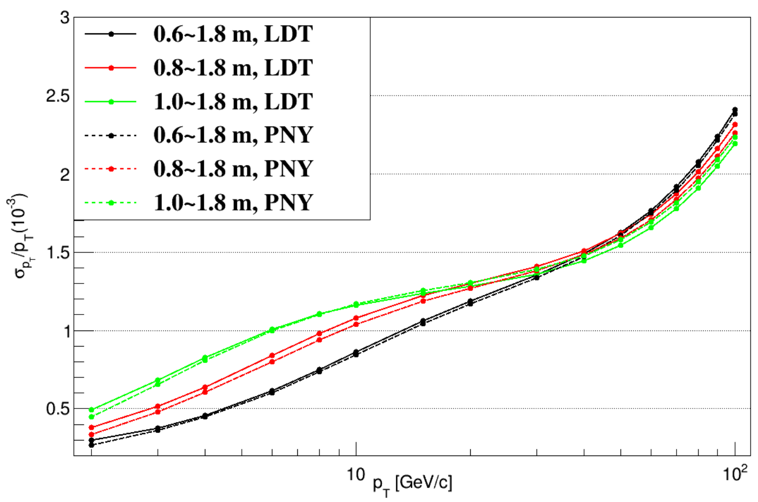
- SIT的位置对于动量测量的影响很小
- 三种工具结果在低动量区有细微的不同

1.DC优化-with DCHits

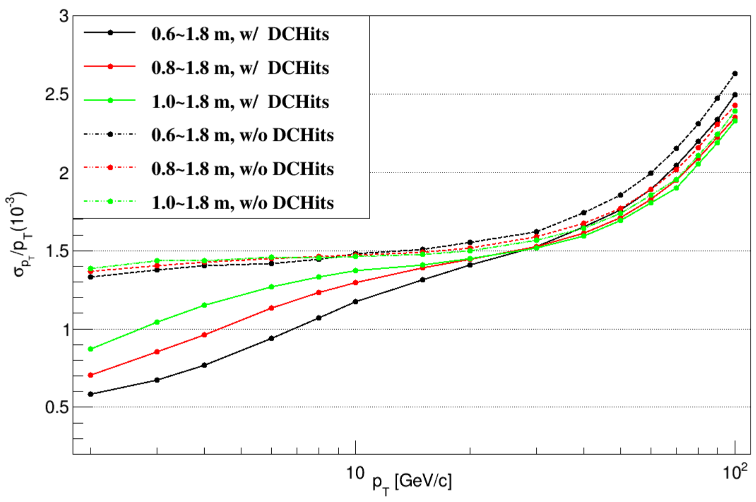
GenFit和MarlinTrk结果比较：



Python工具和LDT结果比较：



GenFit的有无DCHits结果比较：

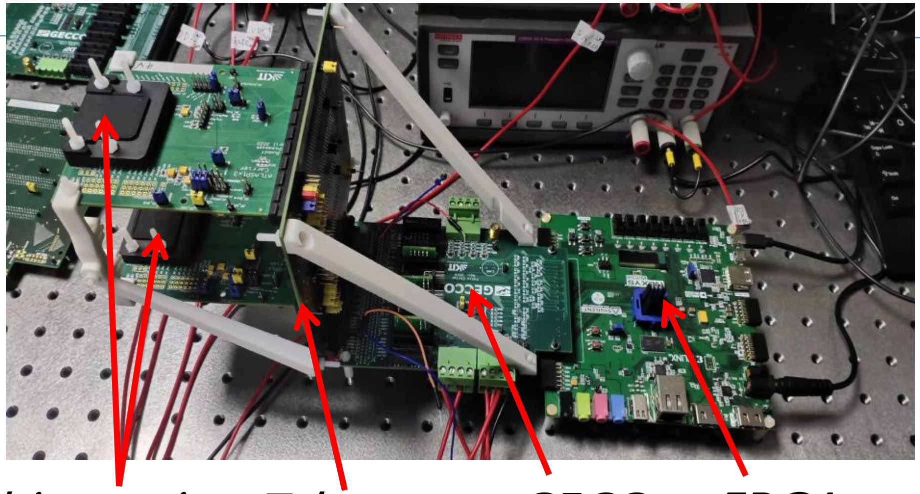


- Fast tools和Full simulation一致显示：
  - DC体积改变对低动量测量的影响显著
  - 更大体积的DC有利于低动量径迹（<20GeV）测量和粒子鉴别
  - DC对于动量测量有较大的贡献
- **CEPC tracker设计的重要参考，一篇paper正在准备中**

2.ATLASPix及其测试系统简介

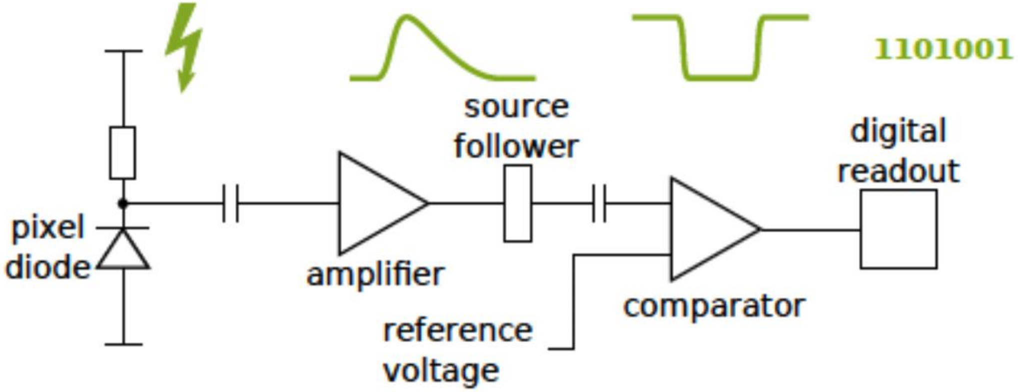
ATLASPix3, 一种High-Voltage CMOS pixel sensor

- 像素尺寸50 × 150 μm²(或更小)
- 132 columns × 372 rows (20.2 × 21 mm² 芯片尺寸
- 物质量: ~0.65% (TPC/DC+Si)/, ~1% (Full Si) X0 / 层
- 二进制ToT(Time over Threshold)信息读出(time bin size 25ns)
- Triggerless/triggered读出



Chip carrier board *Telescope card* *GECCO board* *FPGA board*

电路原理图:



Telescope测试系统，搭载四块芯片，可以看做小型的tracker，其组成:

- GEneric Configuration and COntrol System，GECCO通用配置和控制板（国产）
- LFP-FMC connection to Nexys FPGA
- Carrier board for ATLASPix3 single-chip（国产）
- Telescope cards

2.ATLASPix3.0-Trimming调试

Telescope系统通过阈值扫描（trimming）使sensor上所有的pixel的阈值都接近一致，通过优化设置显著提高了trimming速度

设置

SCurve Parameters	
Start(0.007V)	0
Step(0.007V)	4
End(0.007V)	255 or 250
Num Signals	50

结果

duration	8 h 19 min/ 14 h 37 min
target threshold(V)	0.6525/05475
Untuned pixs	4/10

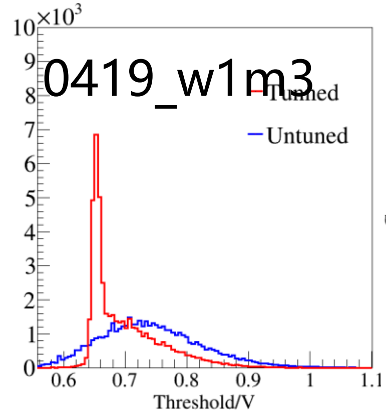
SCurve Parameters	
Start(0.007V)	0
Step(0.007V)	2
End(0.007V)	70
Num Signals	60

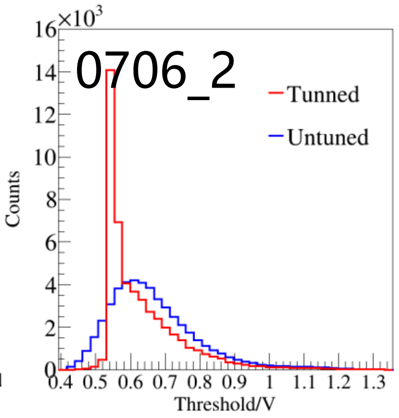
duration	5 h 33 min
target threshold(V)	0.3225
Untuned pixs	3284

SCurve Parameters	
Start(0.007V)	0
Step(0.007V)	2
End(0.007V)	80
Num Signals	60

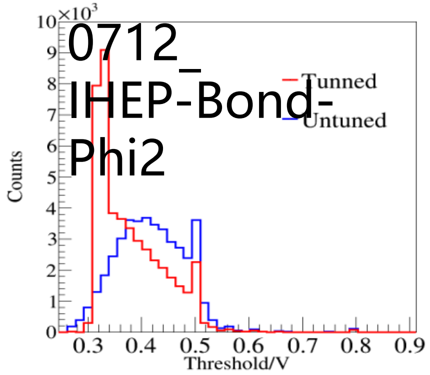
duration	5 h 45 min
target threshold(V)	0.3525
Untuned pixs	2

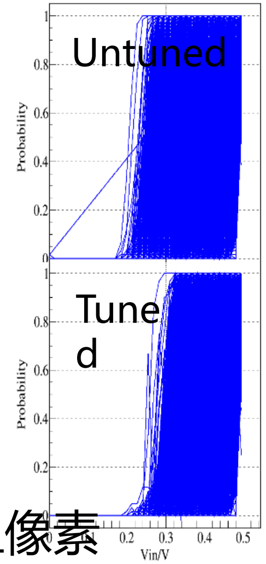
阈值分布



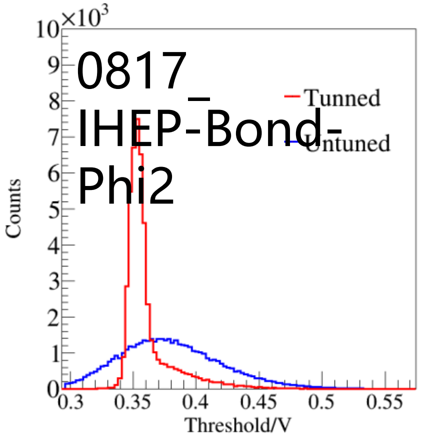


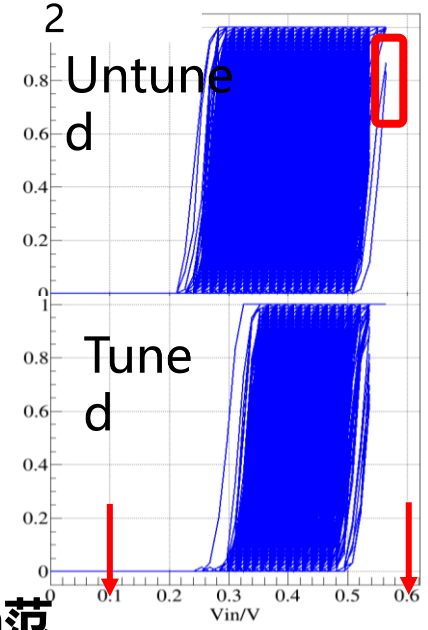
花费时间太长





花费时间大大减少，但像素点阈值信息缺失太多

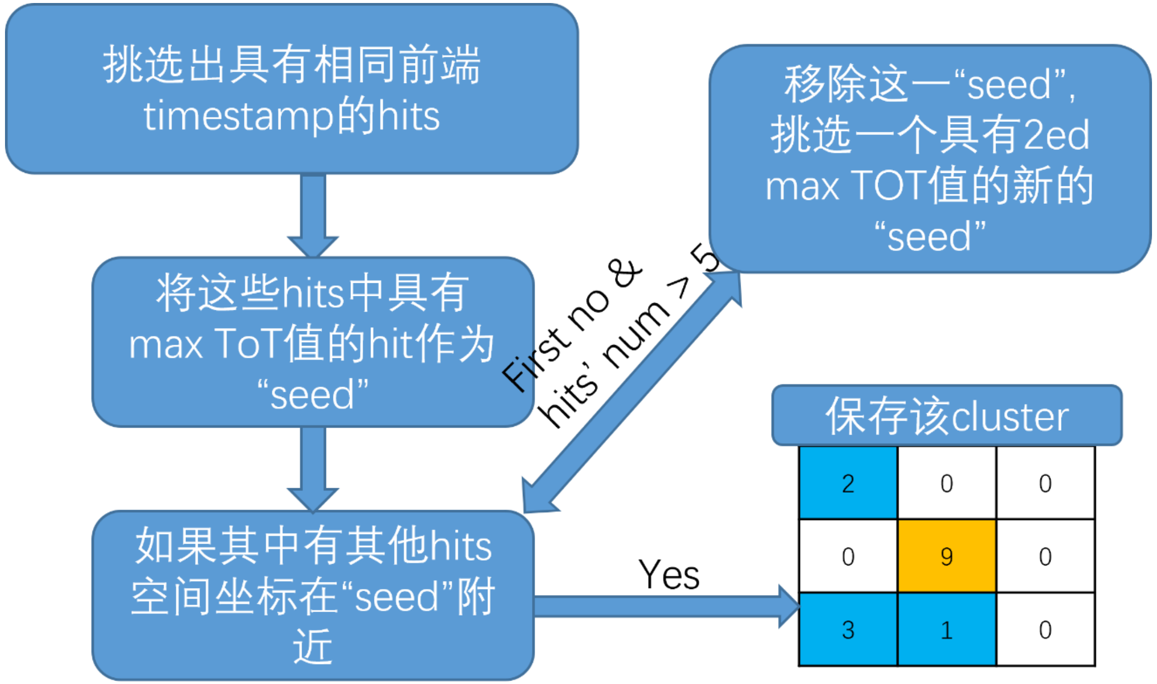




效果较好，建议Vin范围设置从0.1V-0.6V

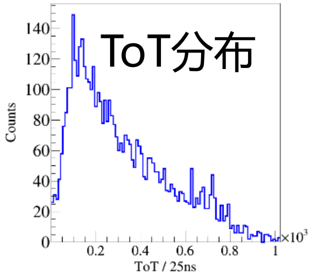
2.ATLASPix3.0-宇宙线测试

- 在宇宙线测试中，sensor表面可以接收到~4muons/min
- 仅使telescope的L4 工作(L3 or L1 也插入, 但是不打开读出通道)
- 设计了数据筛选程序，移除了wrong hits：
  - Column，或row是负值
  - 具有完全一致的时空坐标以及ToT数值，且重复数>10
  - 噪音（因为还没有做ToT刻度，所以噪音设置得很粗糙，且应该小于真实噪音）
- 初步设计了cluster的筛选程序

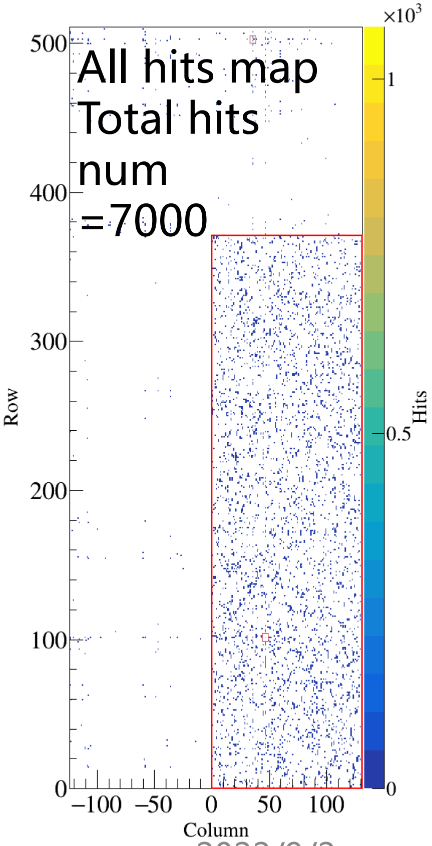


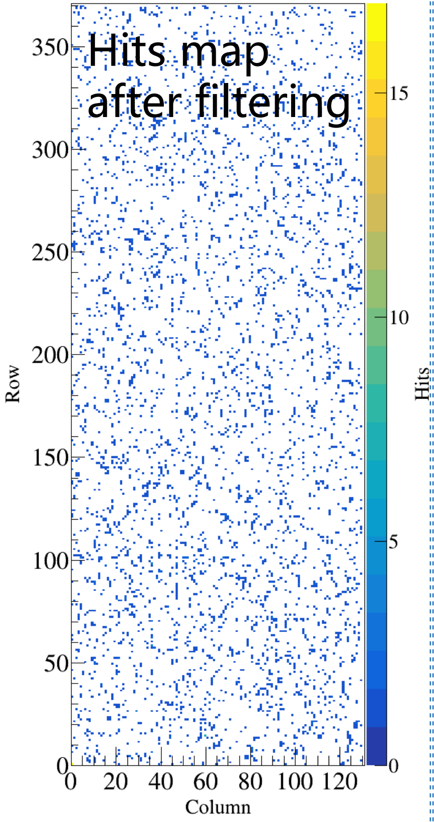
2.ATLASPix3.0-宇宙线测试结果

HV0_W3M7_16h：

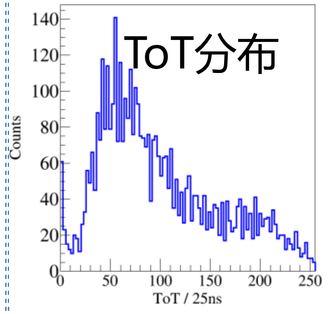


- 56 clusters
- single hit 4520
- effective hit: 4576
- >expectation ~4000, 但比较接近

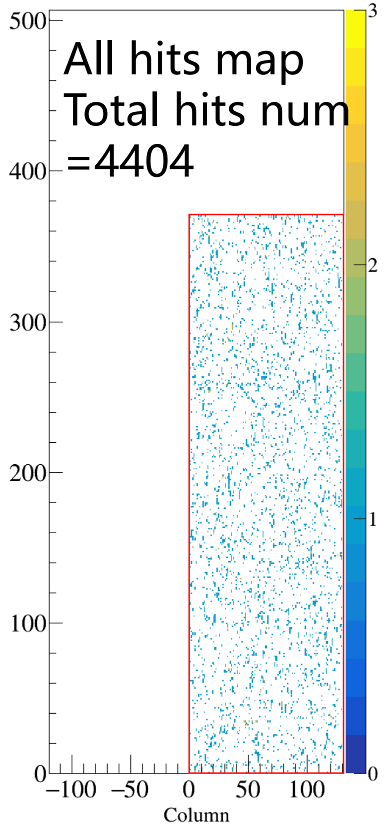


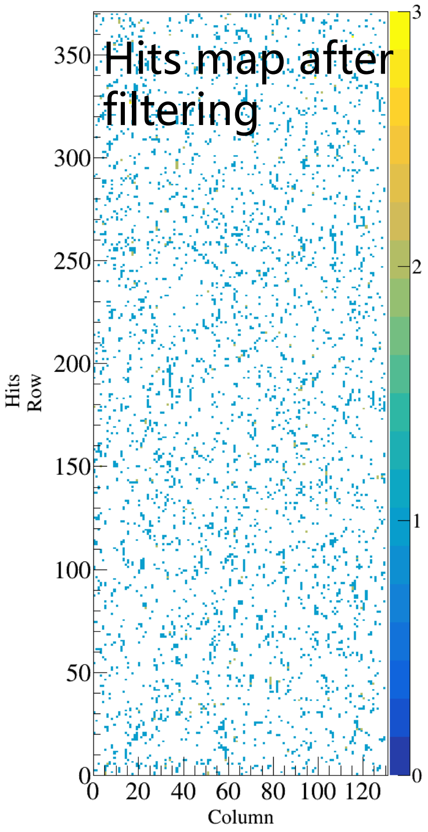


HV21_IHEP-Bond-phi2_6h_0817

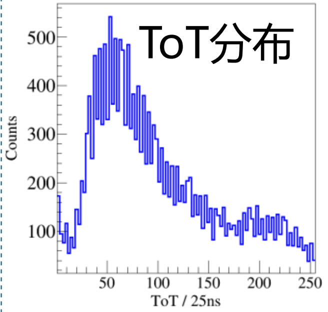


- 176 clusters
- single hit 4179
- effective hit: 4355
- >>expectation ~ 1440

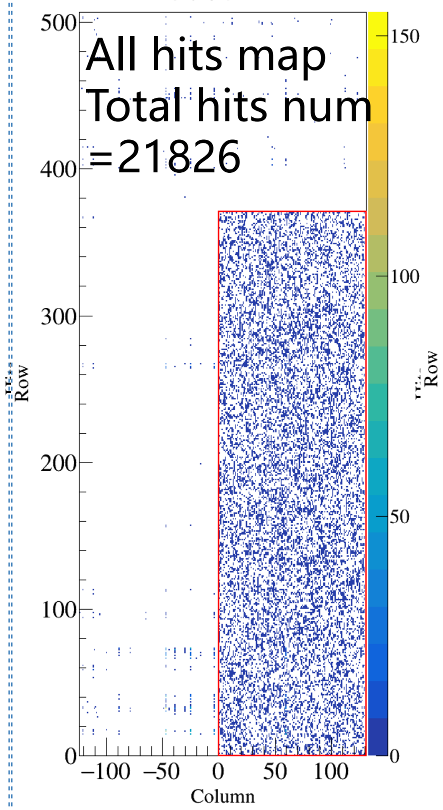


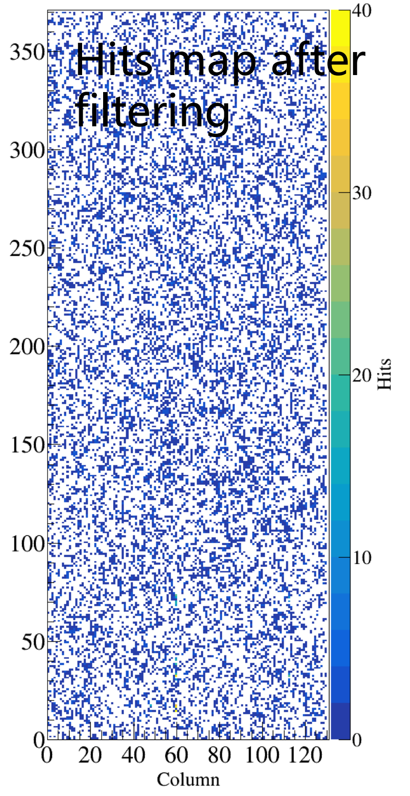


HV21_IHEP_Bond_phi2_23h_0822



- 240 clusters
- single hit 19031
- effective hit: 19271
- >>expectation ~ 5520

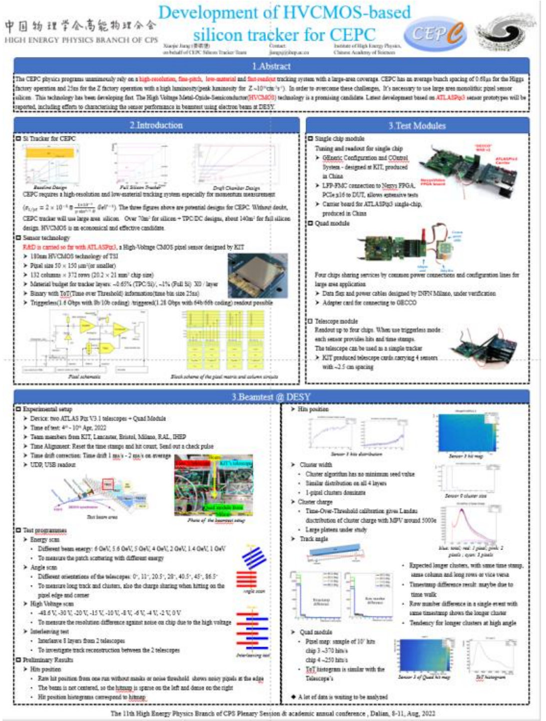




Summary

- 主要工作
  - ➢ 完善Python快速计算工具；首次将GenFit等全模拟工具应用于整个CEPC tracker优化
  - ➢ 用telescope系统进行芯片trimming调试，优化参数加快速度；编写Setup guide，培训师弟师妹
  - ➢ 用ATLASPix3进行宇宙线收集和数据分析

- 学术成果和学术活动
  - ➢ 代表CEPC Silicon Tracker组在中国物理学会高能物理分会做海报展示
    https://indico.ihep.ac.cn/event/16065/contributions/43592/
  - ➢ 参加第十届南山清北粒子物理暑期学校
  - ➢ 以共同作者名义发表了文章
    [1] Zou, Q. . (2021). The salt—readout asic for silicon strip sensors of upstream tracker in the upgraded lhcb experiment. Sensors, 22.



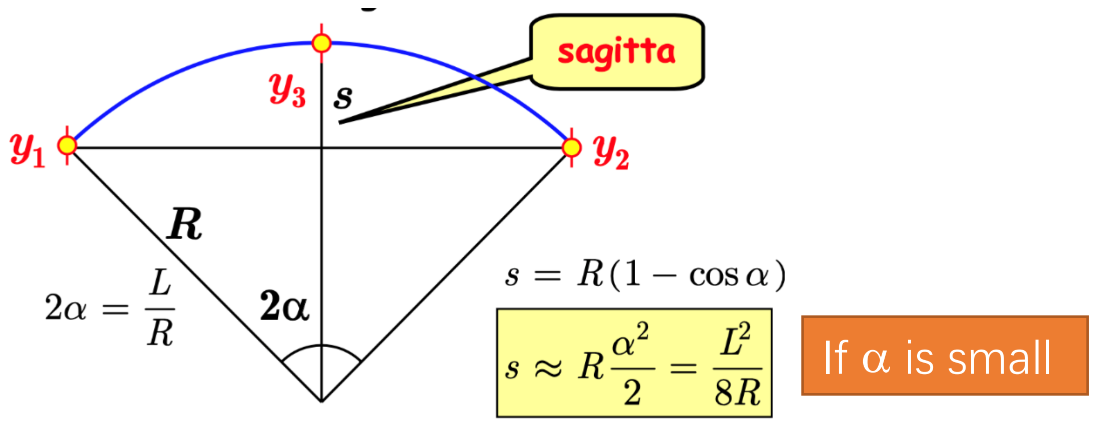
- 工作计划
  9月5日前往CERN进行LHCb UT探测器的安装，调试以及未来的升级工作

Thanks

BackUp

Momentum error-Sagitta measurement without multiple scattering

$$\frac{\delta p}{p} = \frac{8p\sigma_{r\phi}}{0.3BL^2}$$



$$s = y_3 - \frac{y_1 + y_2}{2}$$

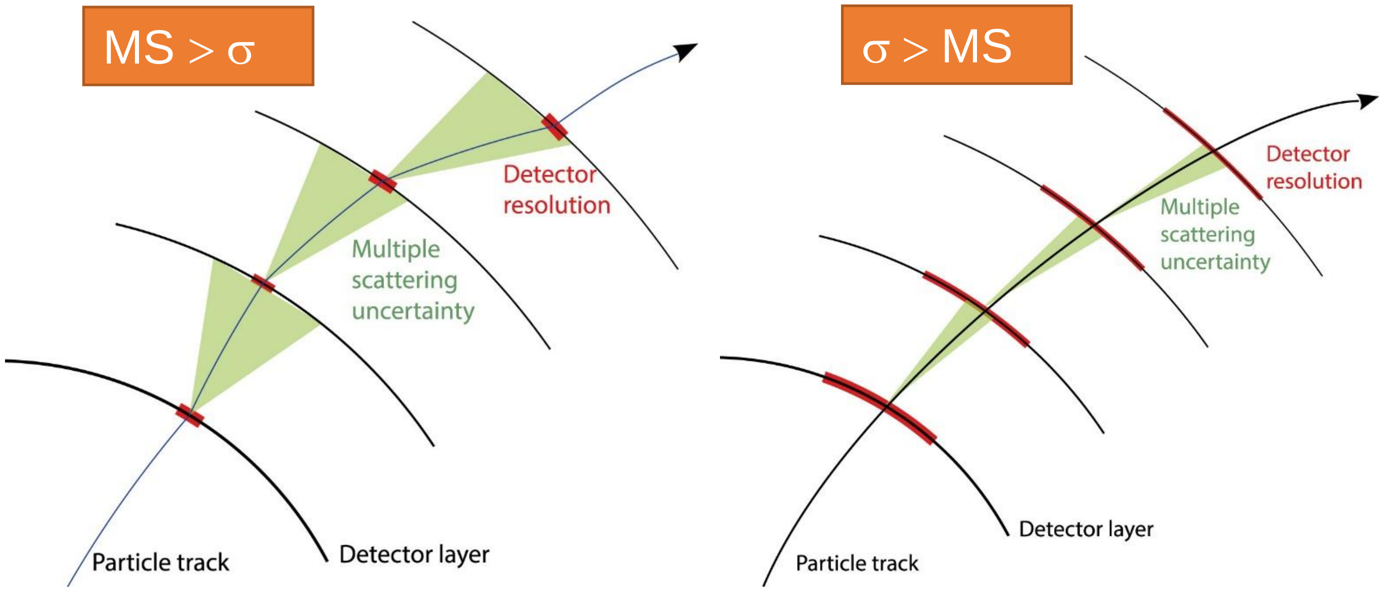
$$\delta s = \delta y_3 - \frac{1}{2}\delta y_1 - \frac{1}{2}\delta y_2$$

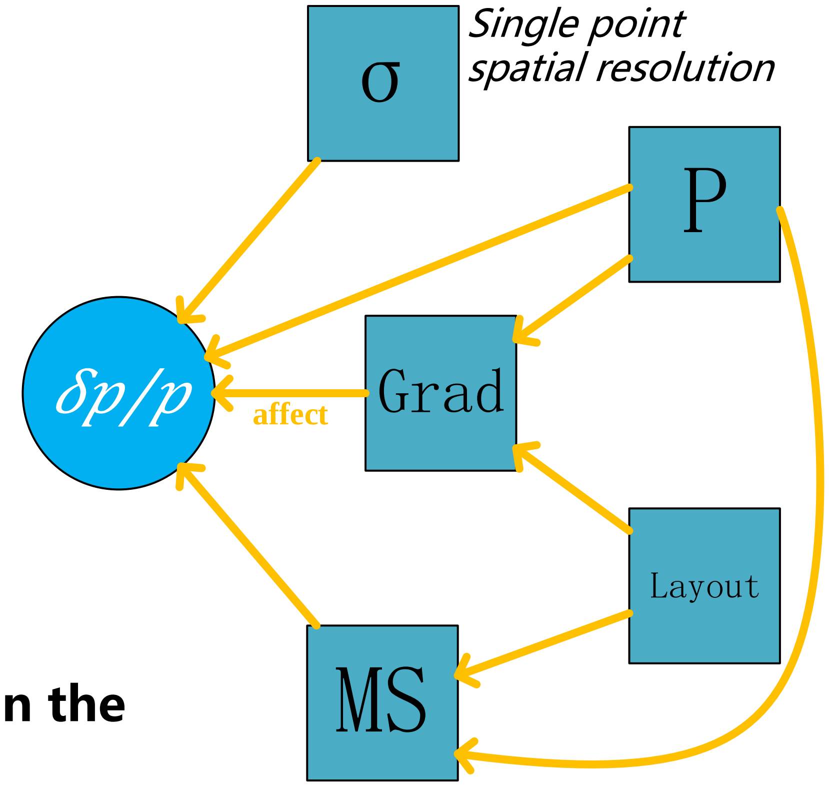
Important features

- ✓ **the percentage error is proportional to the p itself**
- ✓ **the error is inversely proportional to *B***
- ✓ **the error is inversely proportional to 1/L^2**
- ✓ **the error is proportional to spatial resolution**

- **Necessary to have more measurements at the middle for better resolution**
- **The optimal allocation of measurements is 1:2:1**

Momentum error with multiple scattering

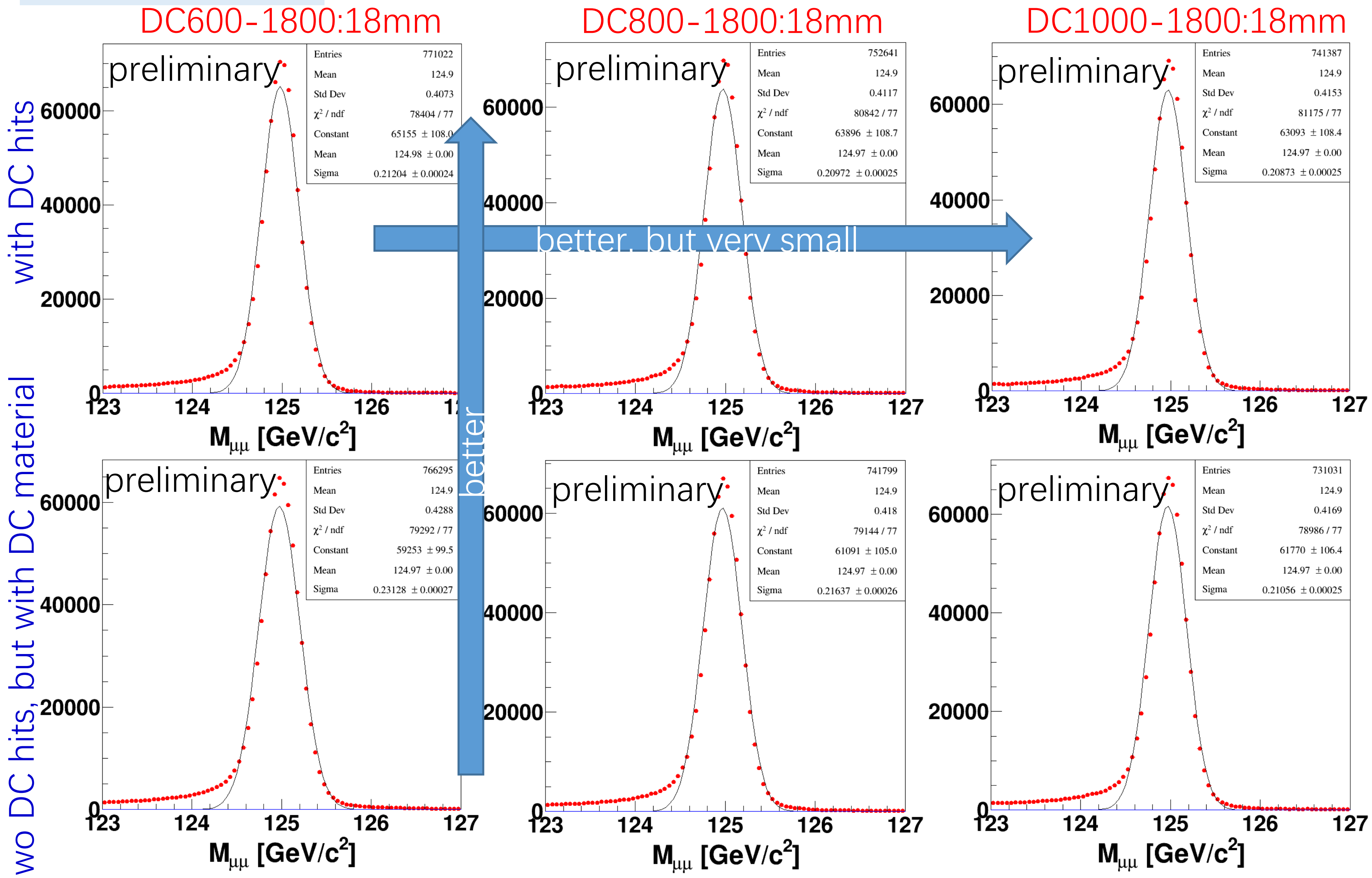




- It is found to be **complicated,** when considering more factors on the momentum measurement.
- **The left figures indicate that the MS affect the tracks, and the MS was influenced by the amount of materials, layout, momentum, and so on**
- **There are quite a few factors affect the momentum measurement, the relationships among them are shown in the right**

Resolution of Higgs Mass (H→μμ)

Rough gaussian fit



Resolution of Higgs Mass ($H \rightarrow \mu\mu$)

DC volume	0.6-1.8(m)	0.8-1.8(m)	1.0-1.8(m)
w/ DCHits(GeV)	0.212	0.210	0.209
w/o DCHits(GeV)	0.231	0.216	0.211

- For Higgs physics(at high momentum), the DC volume has little effect on momentum measurement
- Using DC will significantly improve higgs momentum measurement

Tracker parameters （-1800）

Components	Radius(mm)	$\sigma_{R\phi}$(μm)	σ_Z(μm)	Thickness(X_0 %)
Beam Pipe	10.35	-	-	0.172
VTX	12.3/14.4/35.5/37.5/58.3/60.3	2.8/6/4/4/4/4	2.8/6/4/4/4/4	0.156/0.156/0.154/0.154/0.153/0.153#
VTX-shell	65.245	-	-	0.139
SITs	81.5/332.2/582.7; 81.5/430.9/780.6; 81.5/520.8/920.5;	7.2/7.2/7.2	86.6/86.6/86.6	0.661/0.651/0.650#
DC inner wall	611.9;809.9;989.9	-	-	0.110
DC cell (66;55;45 x18x18mm)	612;810;990-1800	100	2828	0.00127×layernum##
DC outer wall	1801.93	-	-	1.349
SET	1811.3	7.2	86.6	**0.182***
TotalAir				0.262**

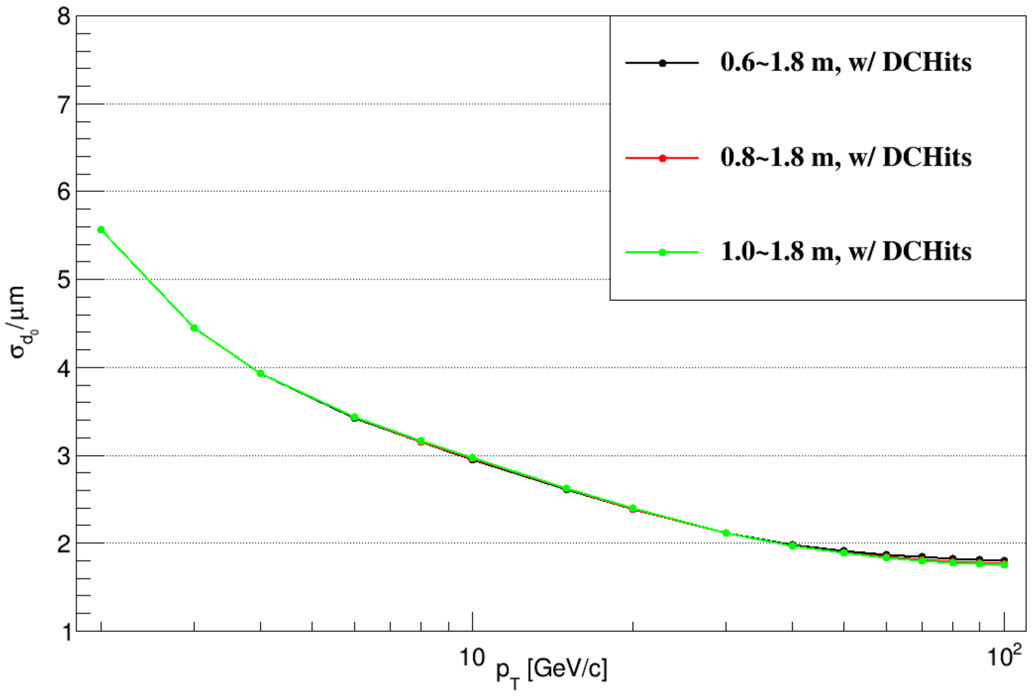
#average for ϕ(0,2π)

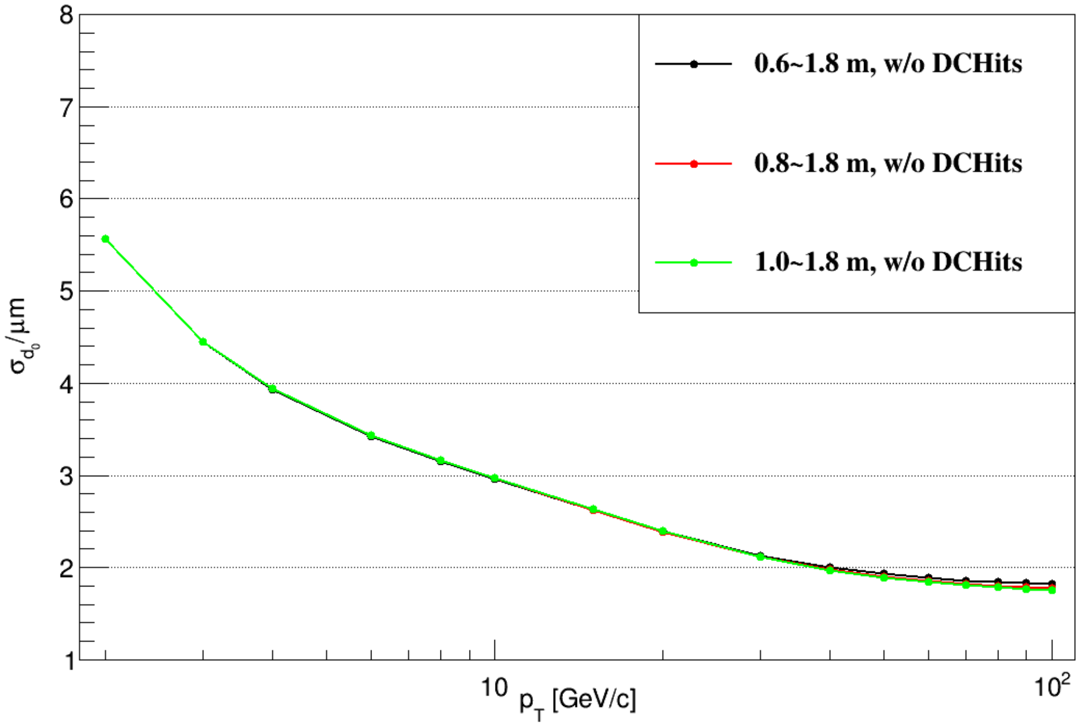
##GasHe_90Isob_10 without wire, if Air, 0.00592% per cell

* Sensor face to IP, 0.468% lie after sensor

** Dominant lie between SITs

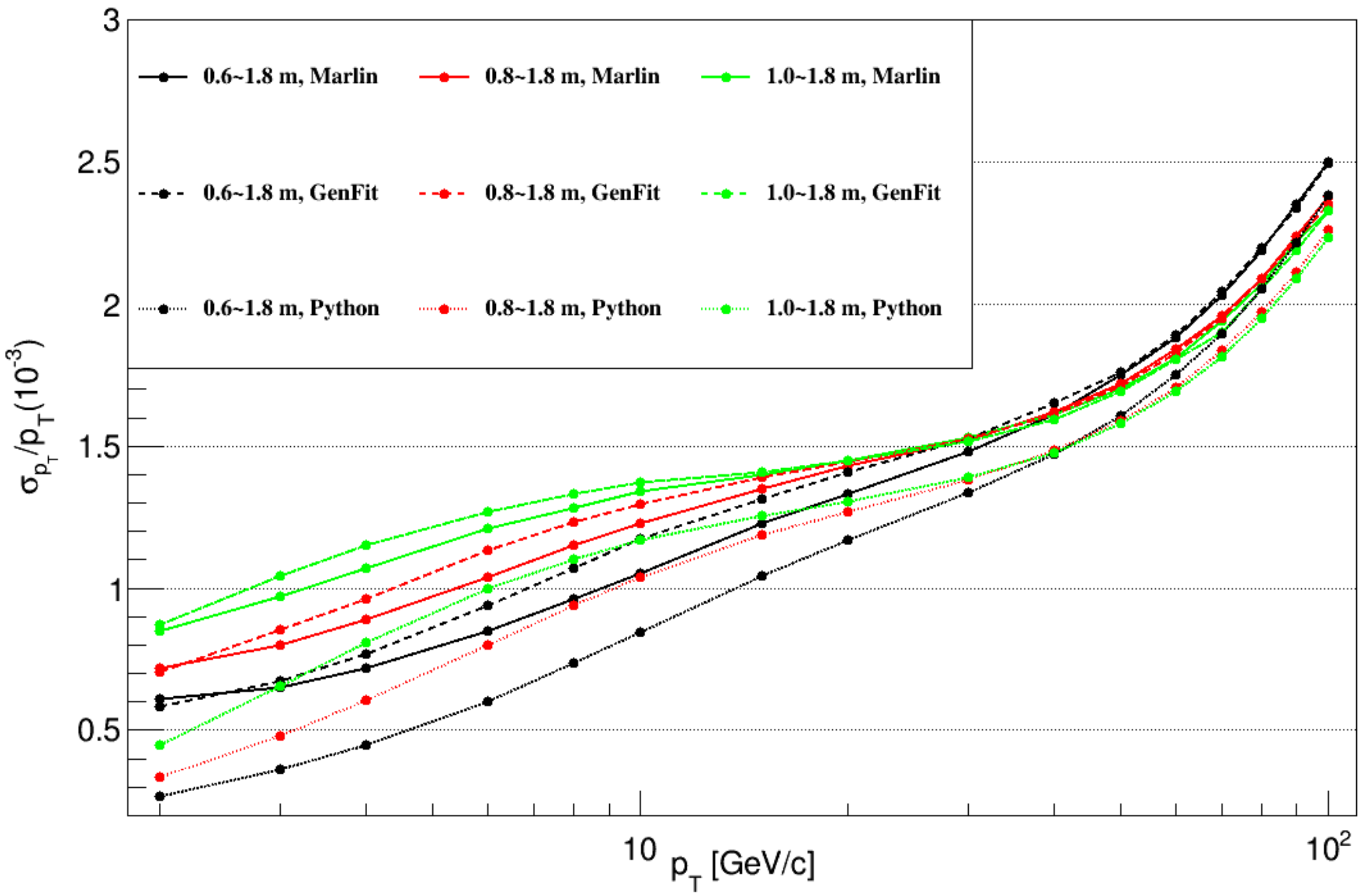
The effect on impact parameter(By analytic calculation)





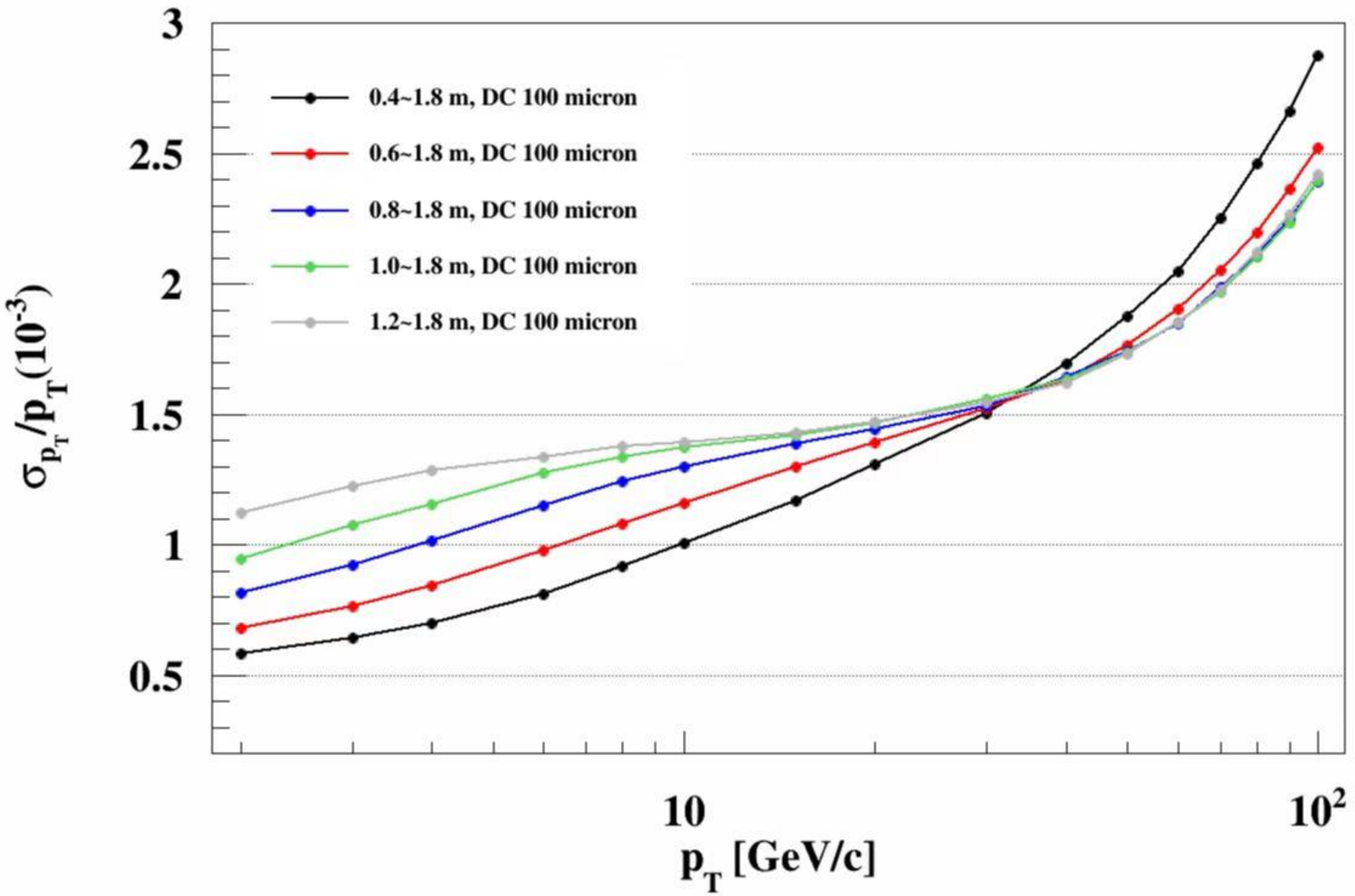
- There is nearly no effect on IP when we changed the volume of DC & the location of SIT outer.

Validation： Compare full simulations & fast calculation together



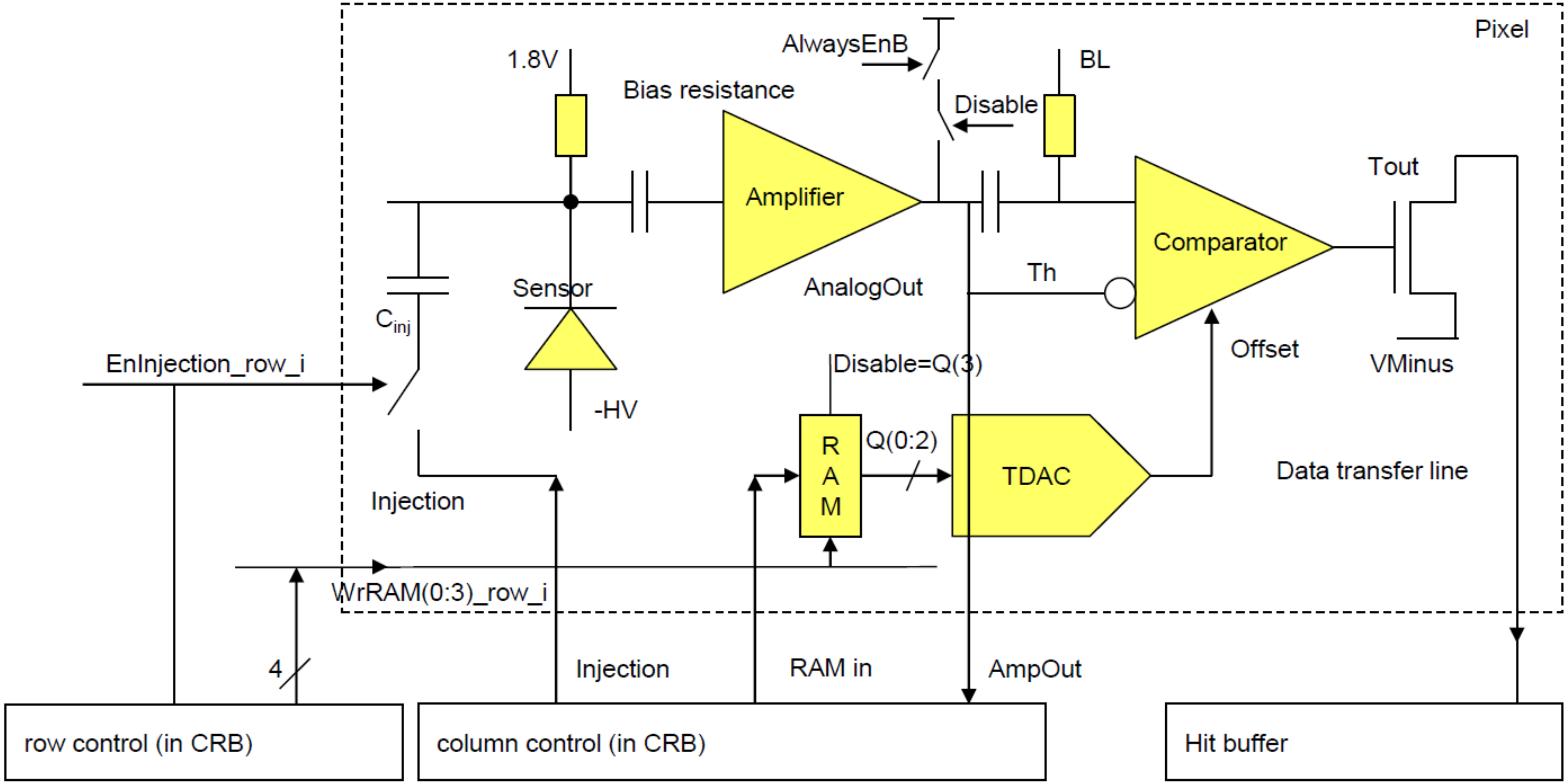
- Trends of the curves are similar
- DC = 0.6-1.8m is better

More options of DC volume



- When momentum below 30GeV, it looks like the volume of DC the bigger, the better, but at high momentum, the momentum error will grow a lot when we choose DC = 0.4-1.8m
- DC = 0.6-1.8m is better, which can consider both the measurement of high and low momentum well

芯片的电路设计

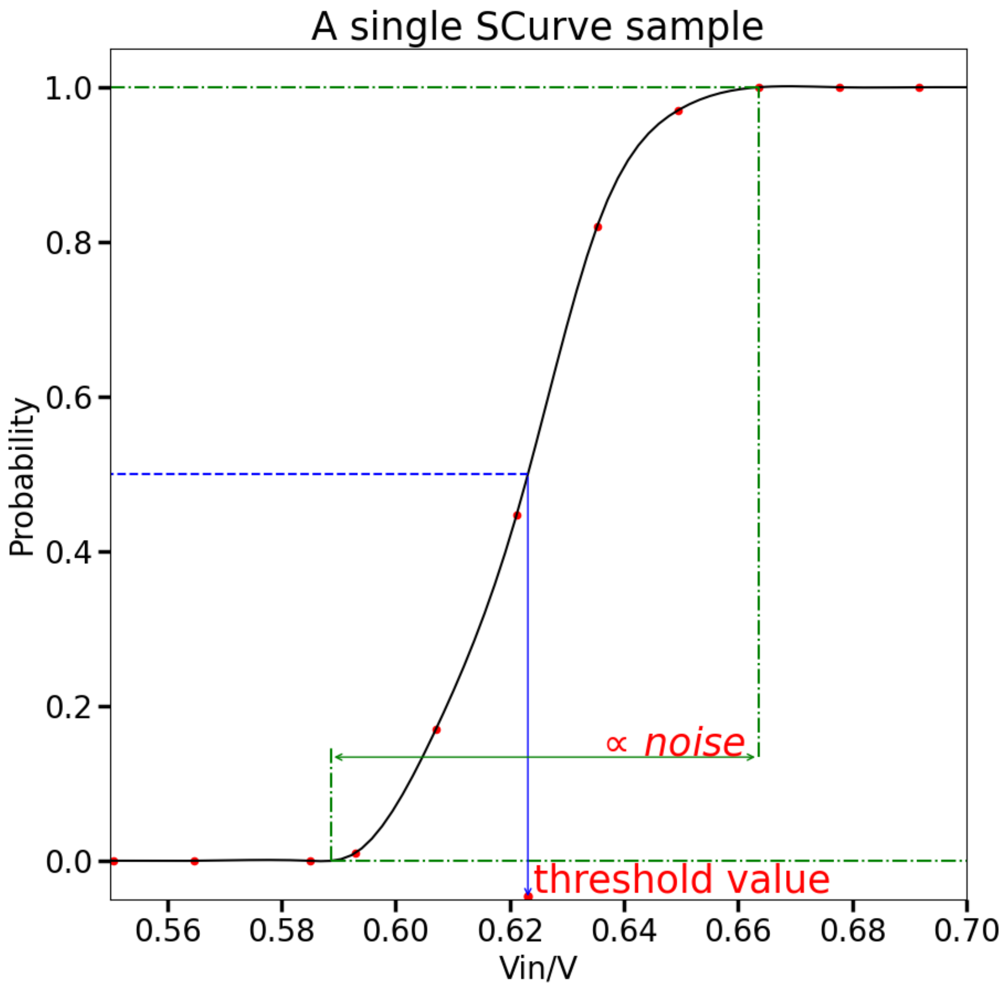


Pixel
1.8V
AlwaysEnB
Bias resistance
Disable
BL
Amplifier
Tout
Comparator
Th
Sensor
AnalogOut
Cinj
Offset
VMinus
EnInjection_row_i
Disable=Q(3)
-HV
R
A
M
Q(0:2)
TDAC
Data transfer line
Injection
WrRAM(0:3)_row_i
4
Injection
RAM in
AmpOut
row control (in CRB)
column control (in CRB)
Hit buffer

Threshold and Noise

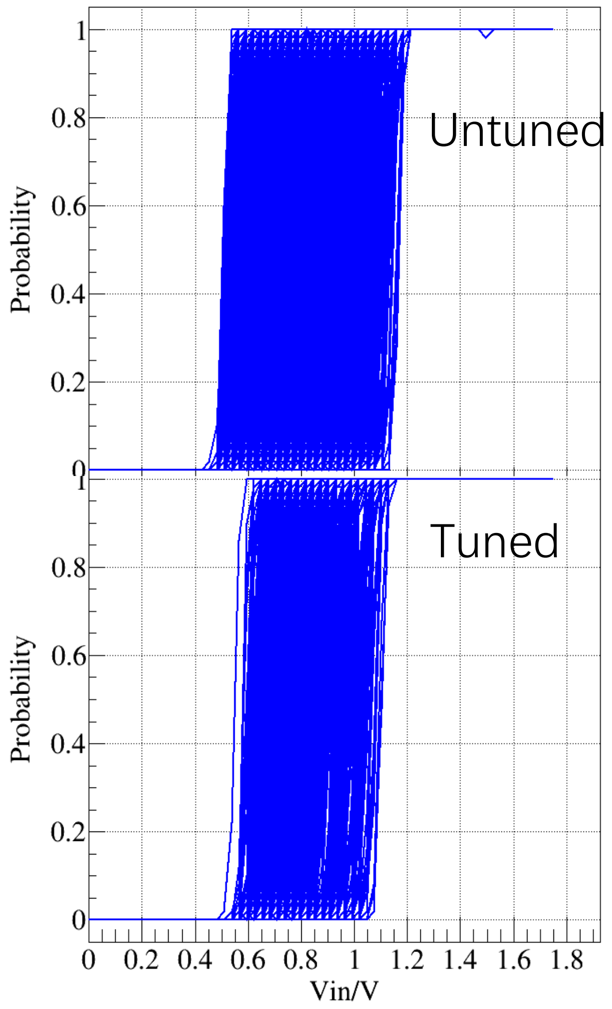
Threshold tunning(also be called trimming):

- Known Charge of increasing strength injected into the pixels. Fraction of detected signals measured.
- The combination of these measurements results produced a detection efficiency curve, also referred to as SCurve.
- The point at 50 % detection efficiency (and the symmetry point of the fit function) gives the detection threshold, the width of the transition is a measure for the noise in the pixel.

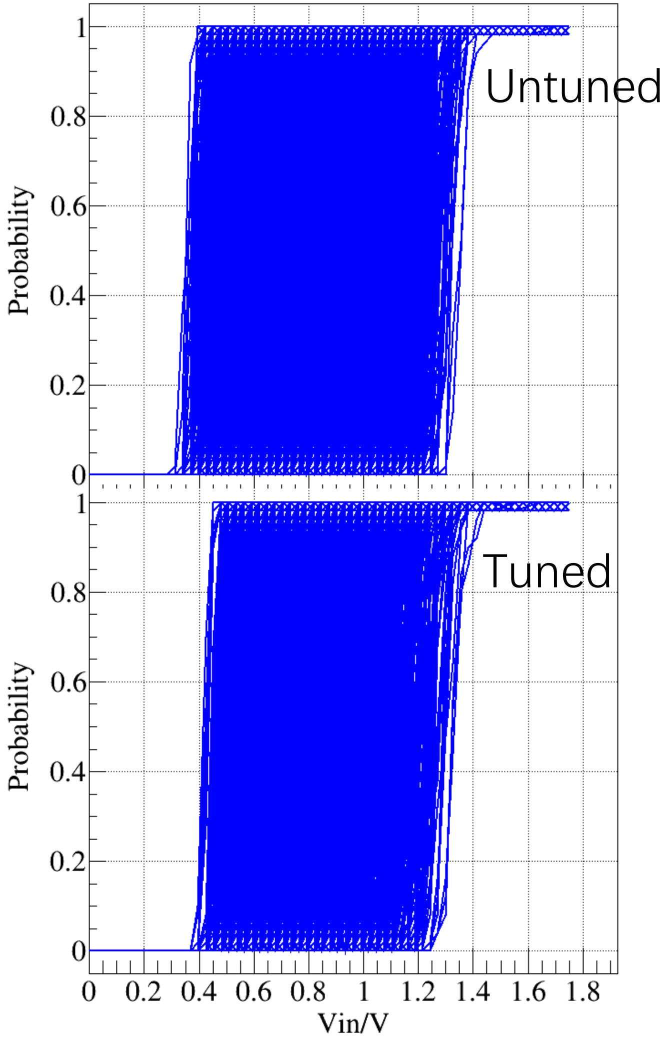


The SCurves distribution

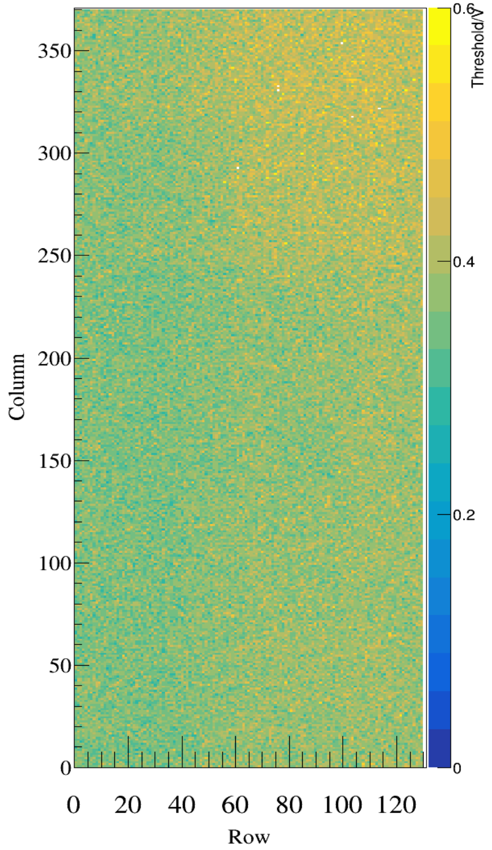
0419_w1m3



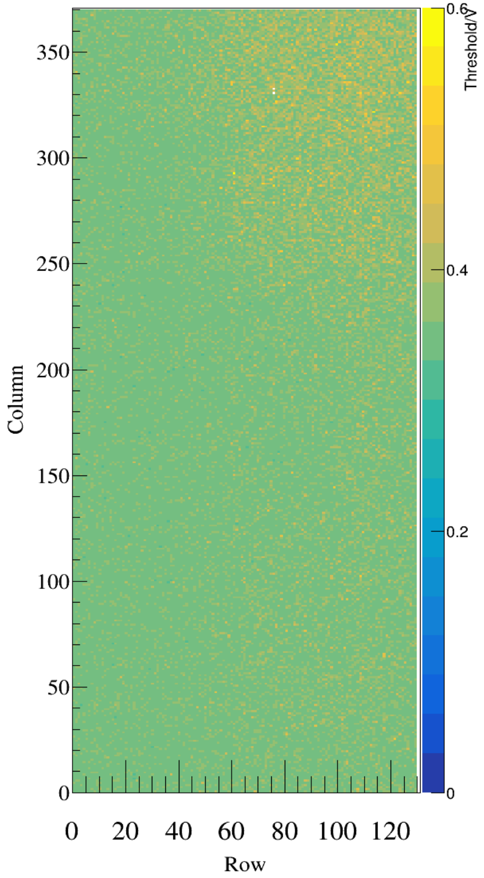
0706_2



Threshold map of “0817_ IHEP-Bond-Phi2”



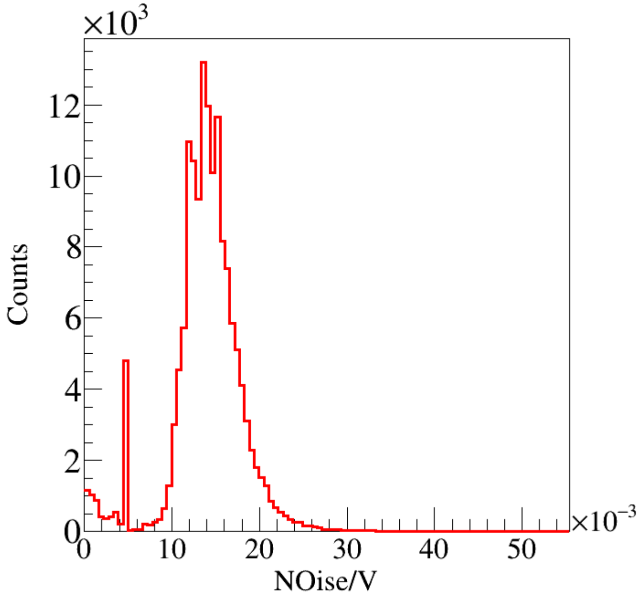
Untuned sensor, TDAC = 3,
49098 pixels worked



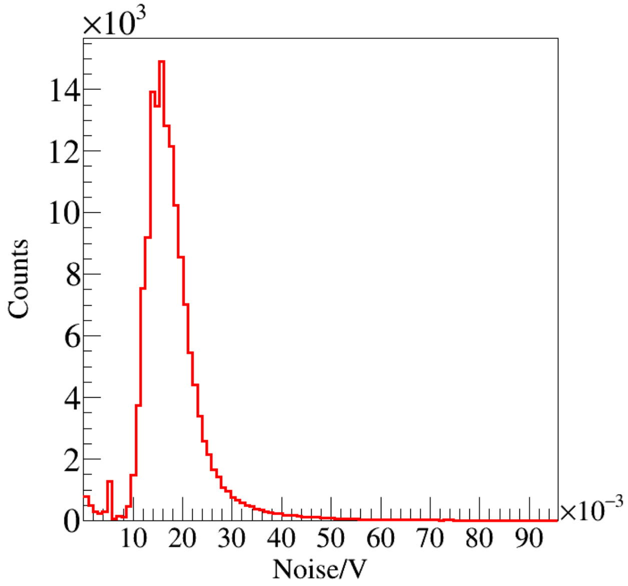
Tuned sensor,
49102 pixels worked

Noise

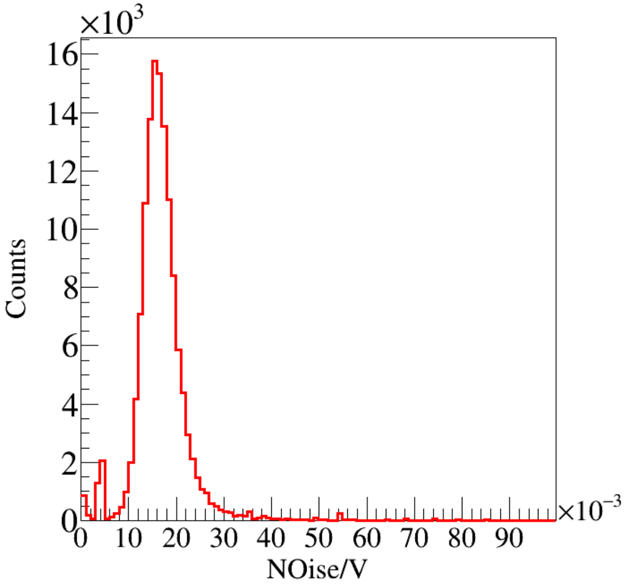
0419_w1m3



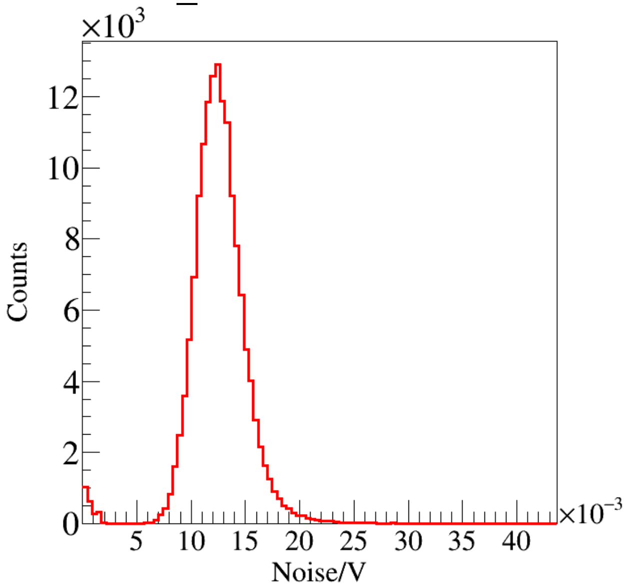
0706_2



0712_IHEP-Bond-Phi2

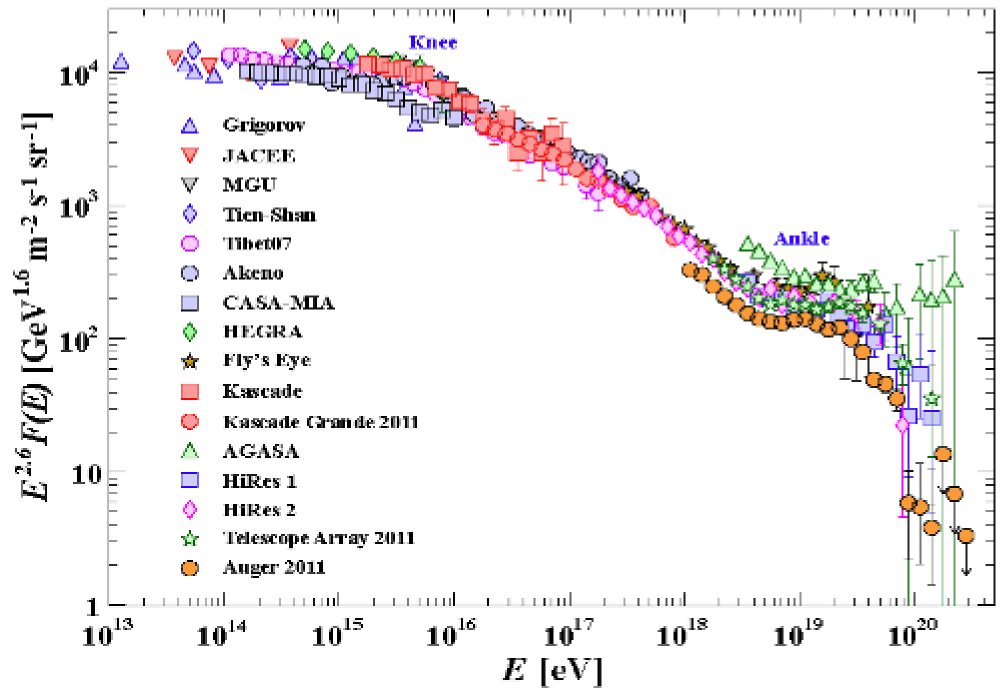


0717_IHEP-Bond-Phi2



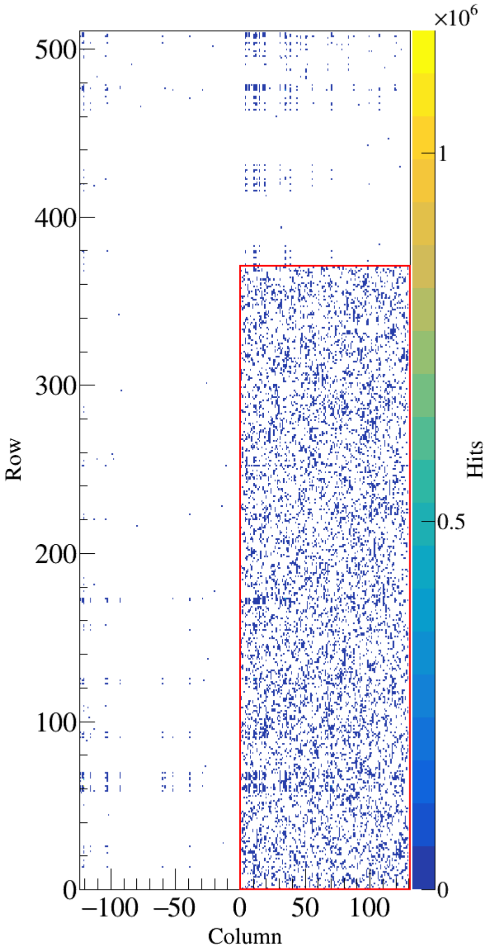
The distributions of noises are similar, and the means of noises are all between 0.01-0.02 V.

3. Cosmic rays introduction

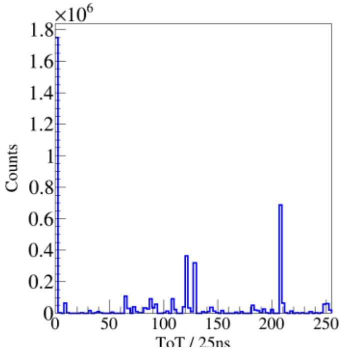


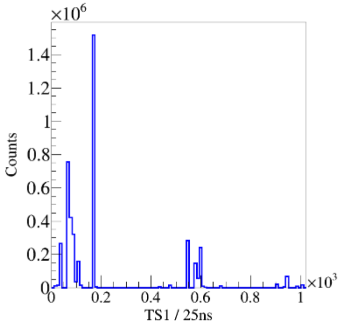
- 能够到达地球附近的初级宇宙线能量跨度从10^9eV至10^{20}eV（约为12个量级），强度跨越32个量级，随着能量的增加流强服从dN/dE ~ E^{γ} 的幂律谱形式
- 在10^{11}eV 附近，每秒每平方米大约能接收到一个粒子；在5×10^{15} eV（第一个"膝"）附近，每年每平方米大约能够接受到一个粒子；到了3×10^{18} eV（"踝"）附近，需要每年每平方公里才能接收到一个粒子

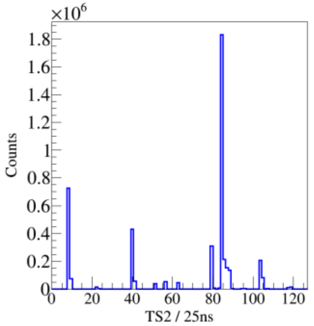
Cosmic rays analysis of “HV21_L4_IHEP_Bond_phi2_10h_0818”



Hits map
Total hits =4431395

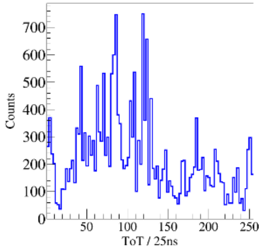


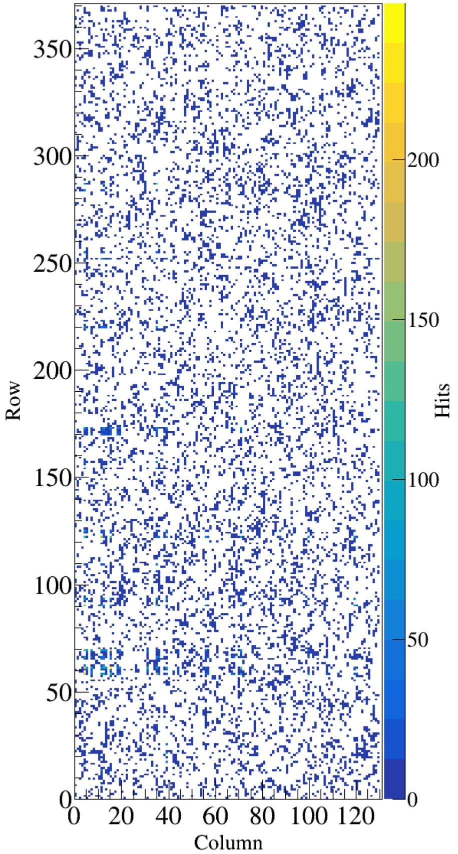




“duplicate num > 10” has 4397770 kinds, and the usual space-time coordinate is (36 503 618 89) but with different ToT value

Filter 4409016 wrong hits



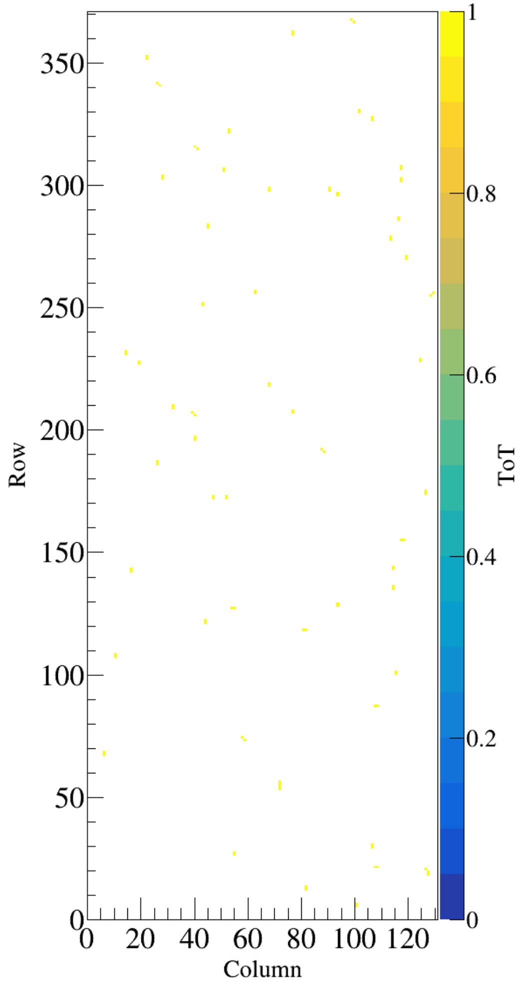


239 clusters+
21822 single hits
=22061 effective hits

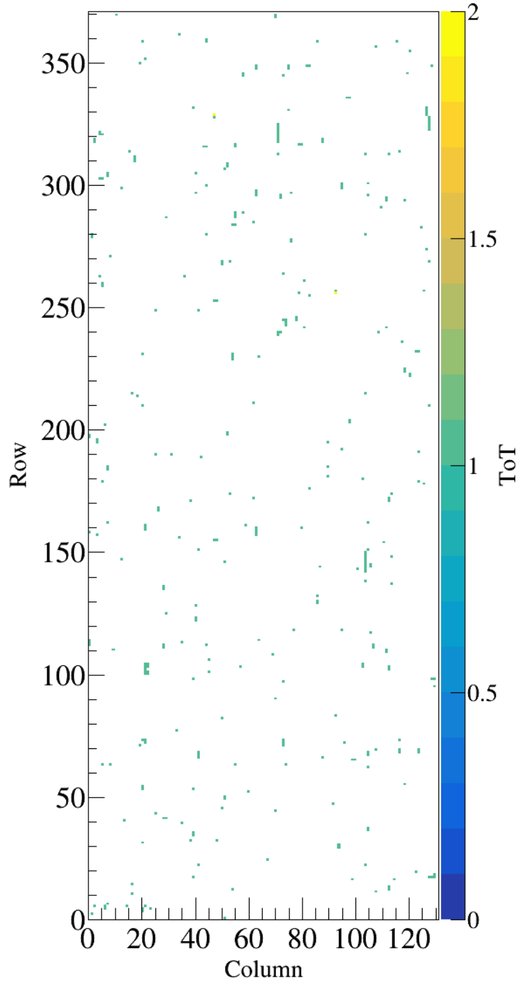
A failed test as well!

Cluster map

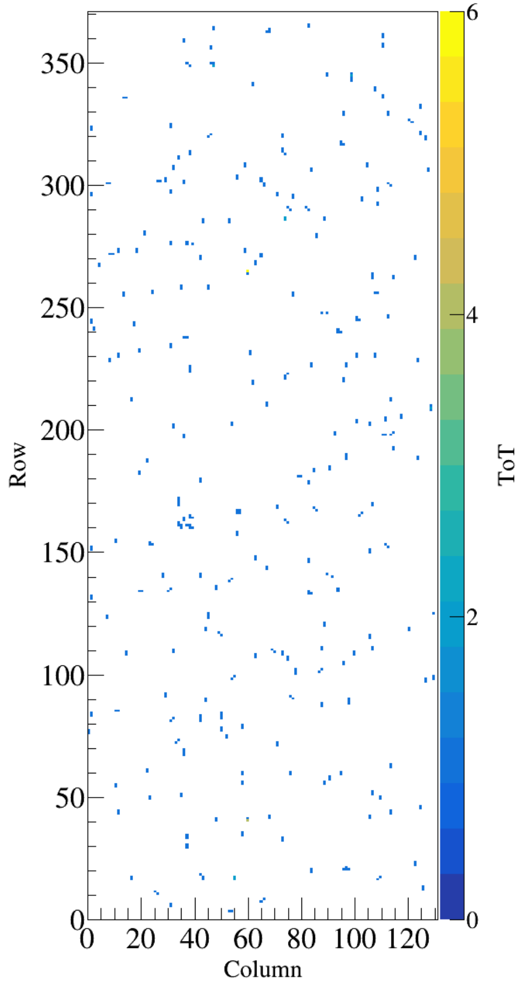
HV0_L4_W3M7_16h



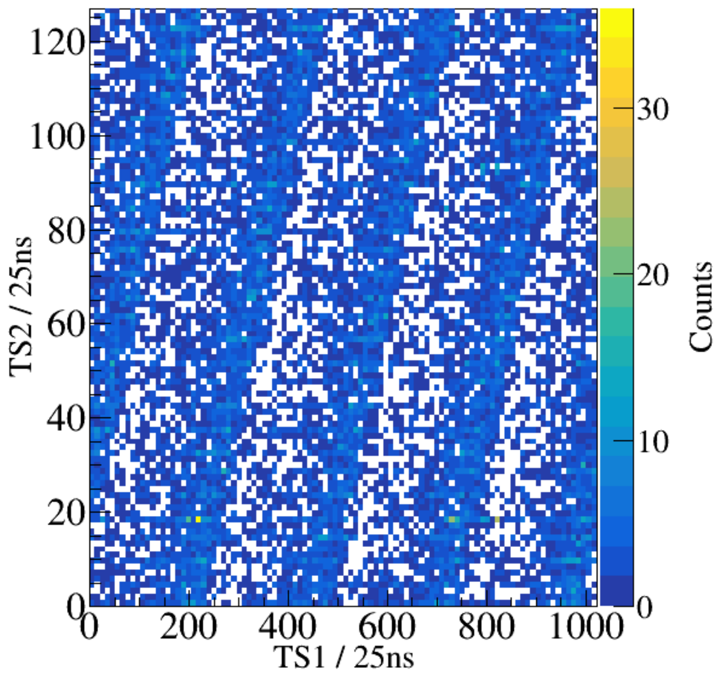
HV21_L4_IHEP_Bond_phi2_6h_0817

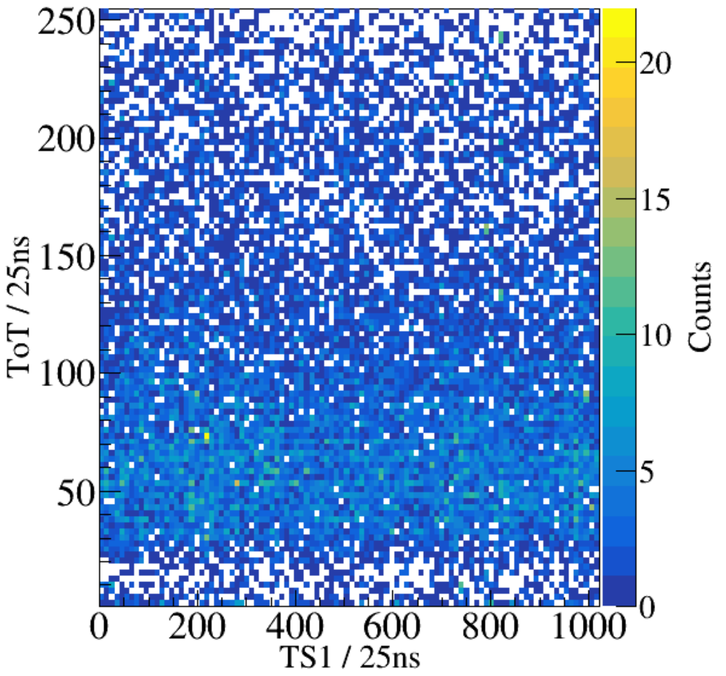


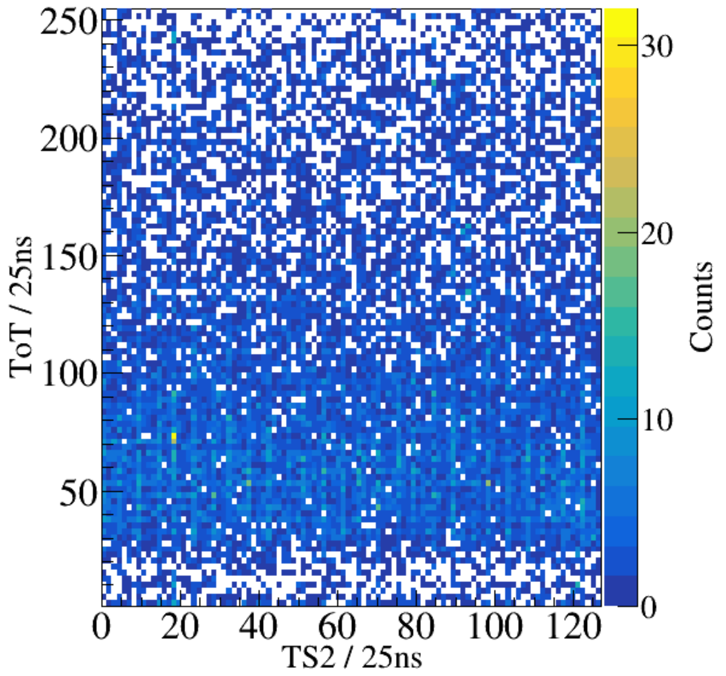
HV21_L4_IHEP_Bond_phi2_23h_0822



3. Cosmic rays analysis of “HV21_L4_IHEP_Bond_phi2_23h_0822”







Timestamps seems to be regular as well