应用于穿越辐射探测器的 mini-drift THGEM Chamber的宇宙线测试

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Outline

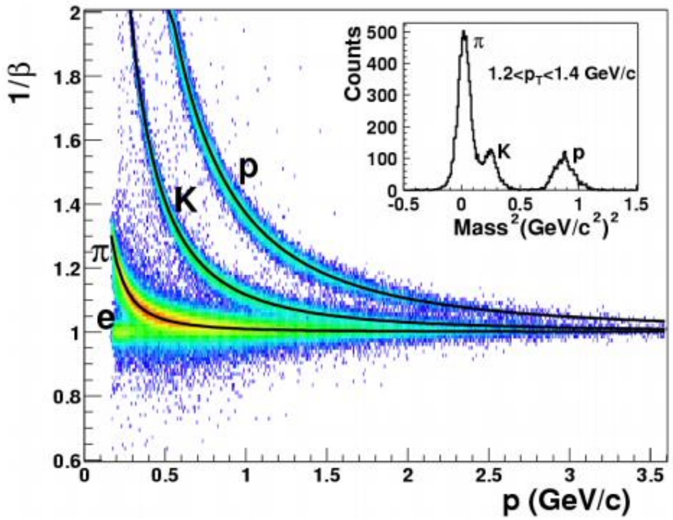
- 背景
- Mini-drift THGEM 读出的穿越辐射探测器(TRD)
- 宇宙线测试系统的建立
- 性能测试结果
- 总结

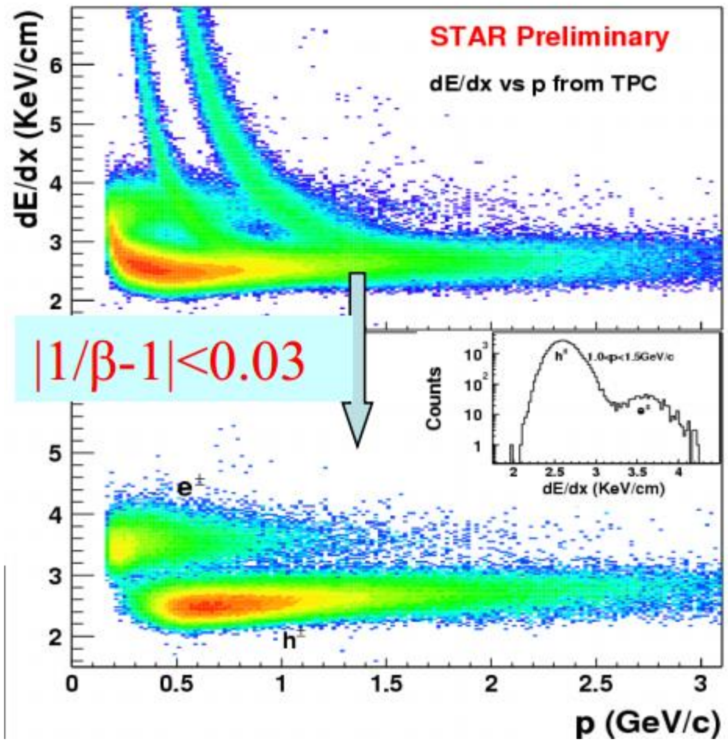
背景

- 电磁探针具有清洁性和易控性等优点，是提取原子核和核子内部信息的重要工具。电磁探针的一个新的发展方向是电子-离子对撞机(EIC)。
- EIC被认为是研究核子、原子核内部夸克胶子分布的最有效设备，是高能物理研究核子结构的下一代最重要的加速器装置。
- 实现EIC的提议之一是利用相对论重离子对撞机(RHIC) 实现电子-离子对撞(eRHIC)。
- 对于RHIC上运行的STAR探测器的挑战：
  - 精确测量小角散射粒子的运动学信息；
  - 散射电子与强子鉴别等。

背景

目前STAR-TOF Tray 的强子电子鉴别本领

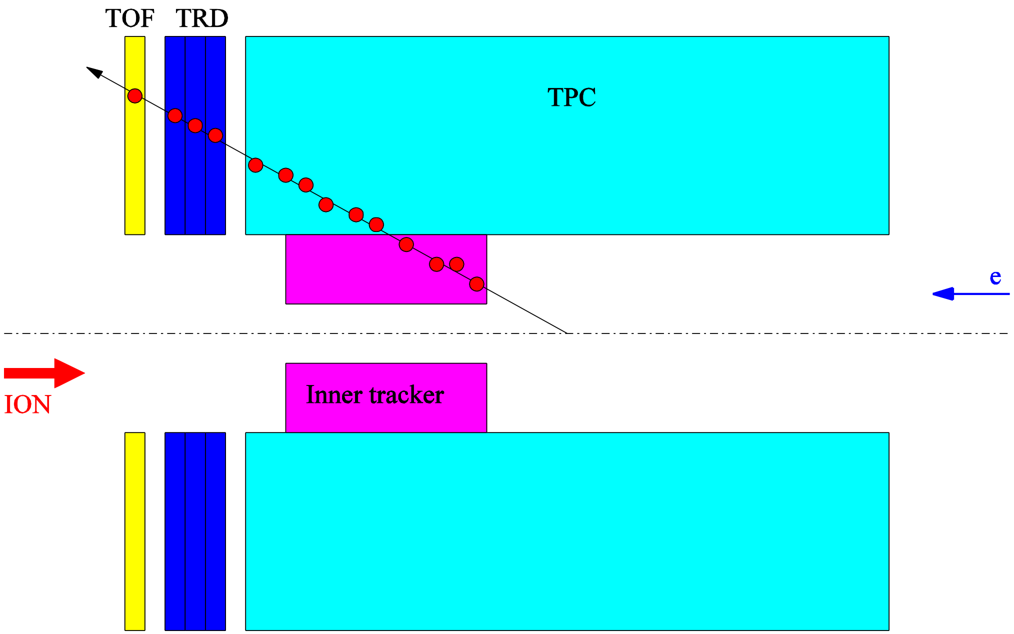


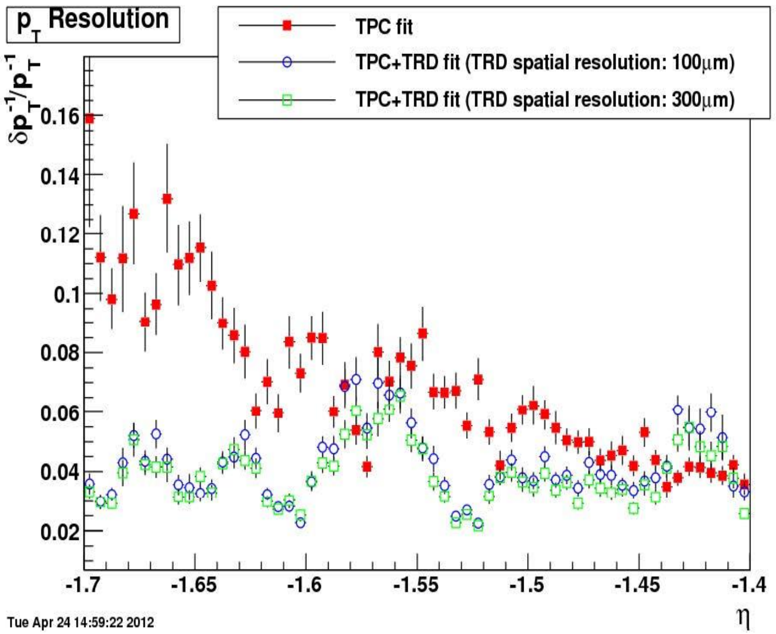


Hadron PID：
(π,K)~1.6GeV/c ; p~3GeV/c
STAR Collaboration,PLB 616(2005)8

Clean electron PID can be obtained up to p_T<3GeV/c
STAR Collaboration,PRL 94(2005)062301

eSTAR探测器概念图





- TRD提供的两个功能:
  - 利用穿越辐射信号进行电子鉴别；
  - 提供额外的dE/dx测量、增加径迹测量点，能够提高小角散射粒子的测试精度(1/√N rule)，如右图所示的模拟结果。

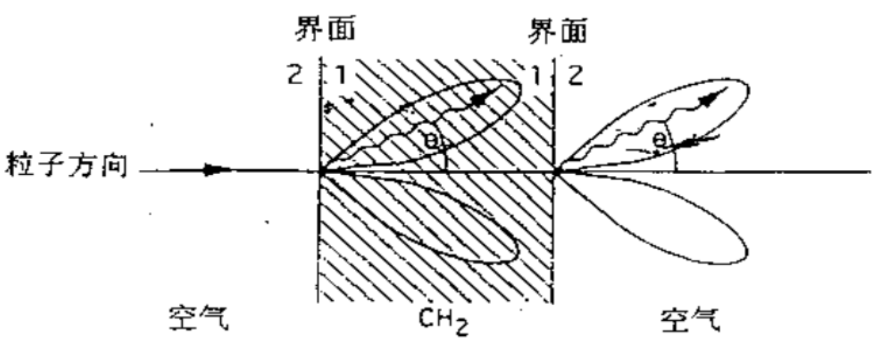
Mini-drift THGEM 读出的TRD

- 穿越辐射：带电粒子穿越两种介质的界面产生电磁辐射。穿越辐射强度对γ值有明显的线性关系。
  - $I = A \cdot Z^2 \cdot \gamma$

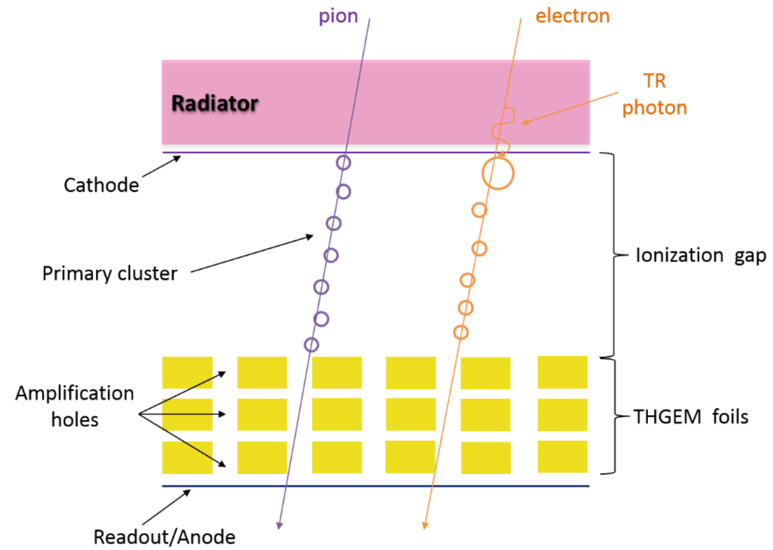
  I：辐射强度；Z：电荷；A：常数；$\gamma = \frac{1}{\sqrt{1-\beta^2}} = E/m_0c^2$

- 穿越辐射探测器
  - 构成：辐射体+探测器
  - 实际使用的TRD常被用于在动量范围为0.5~100GeV/c的e-π分辨

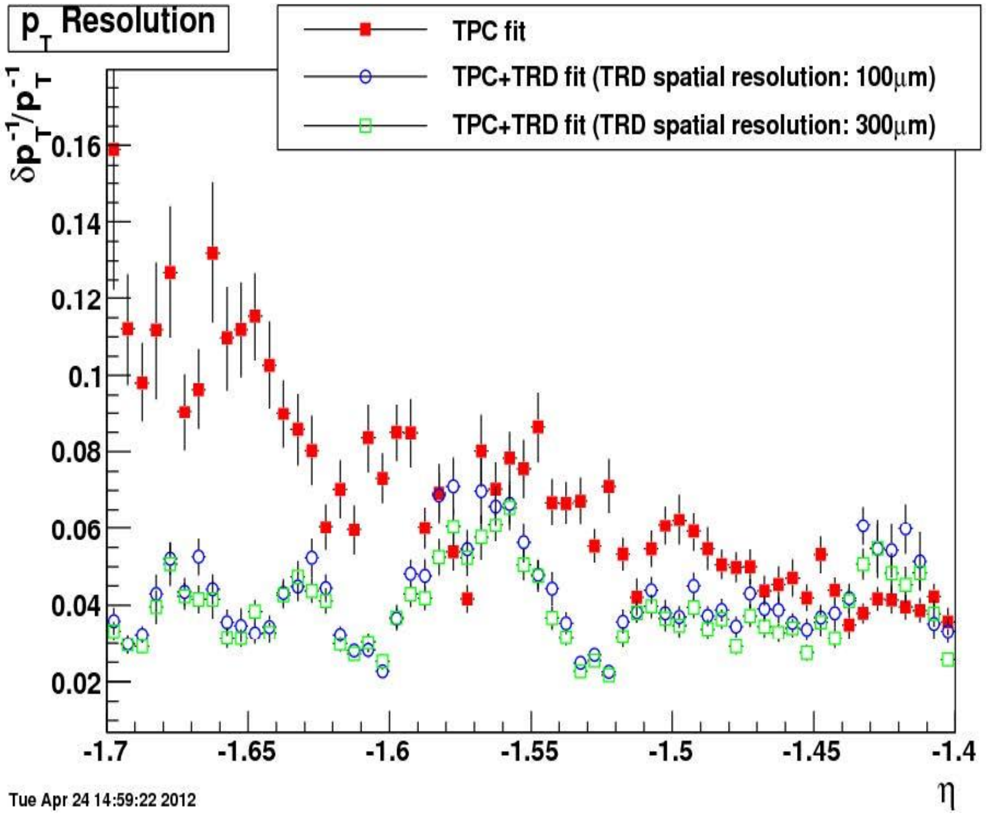
- eSTAR TRD
  - 探测器：Mini-drift THGEM Chamber
  - TR threshold is around γ > 1000~2000



穿越辐射示意图

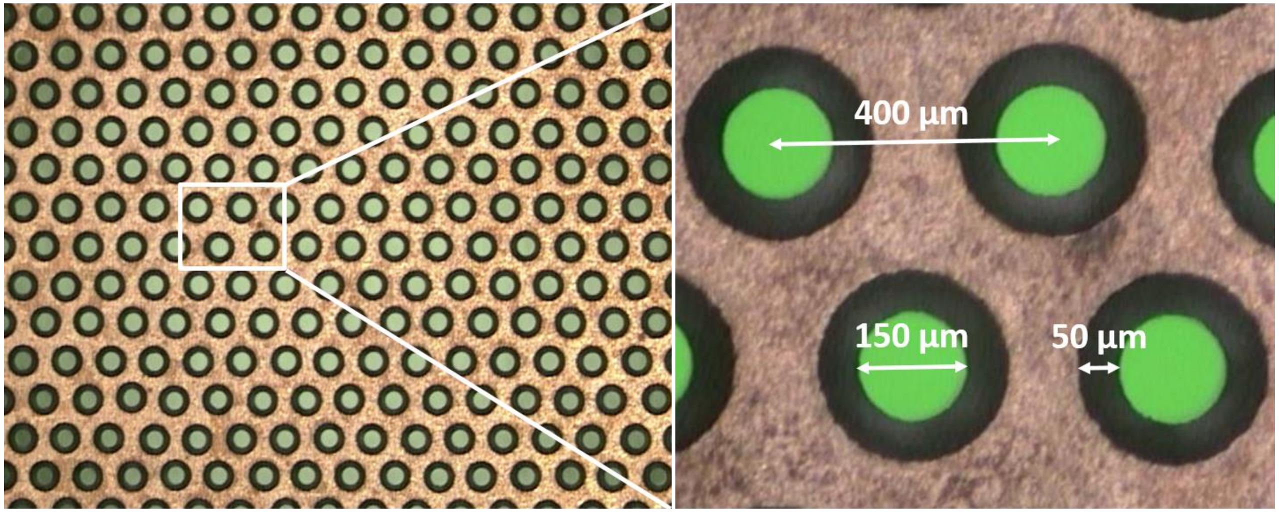


Why read out by THGEM chamber?

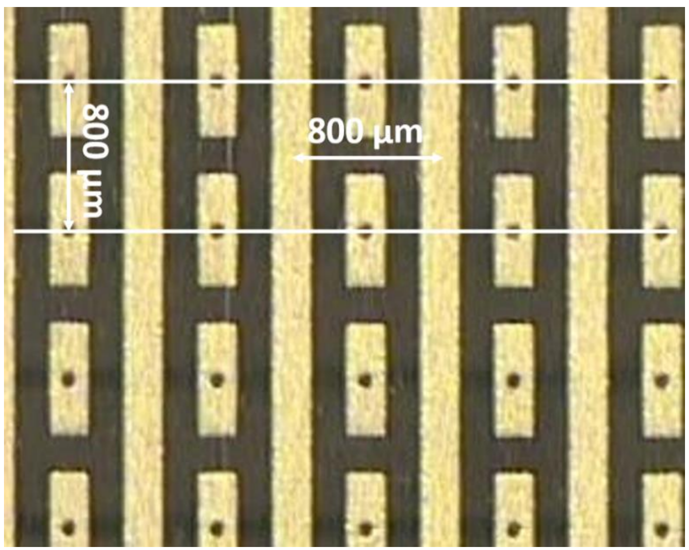


- 根据模拟结果，位置分辨为 300 μm 的TRD已经能够满足提高探测精度的需要。
- THGEM 优点：
  - 好的位置分辨能力
  - 高增益
  - 高探测效率
  - 结构紧凑、经济

The Mini-drift THGEM chamber

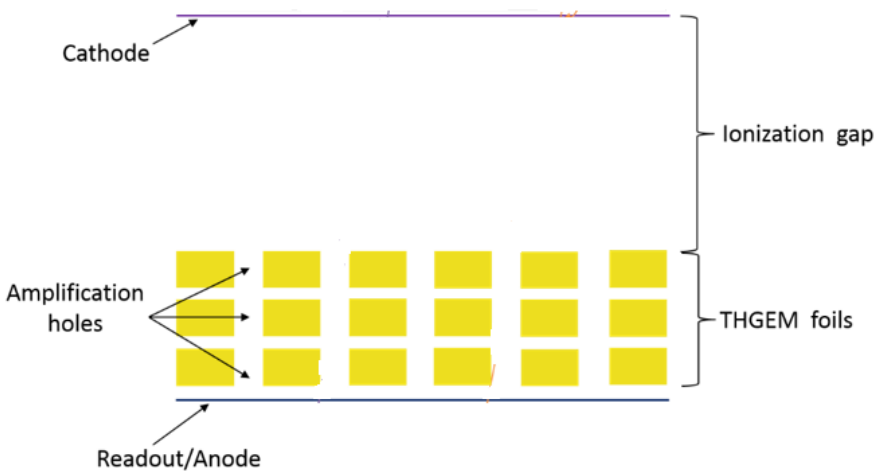


- Foil parameters
  - Thickness: 300 µm
  - Hole diameter: 150 µm
  - Hole pitch: 400 µm
  - Rim clearance: 50 µm
  - provided by the Institute of High Energy Physics (IHEP), China



- Effective readout area: 10×10 cm^2
- Readout style: strip(x) and pad(y)
  - Pitch width: 800 µm

The Mini-drift THGEM chamber

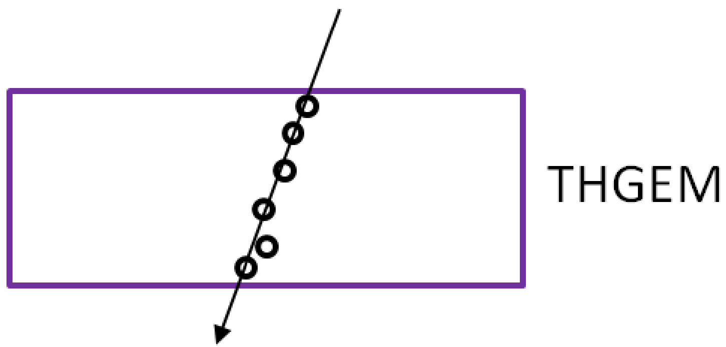


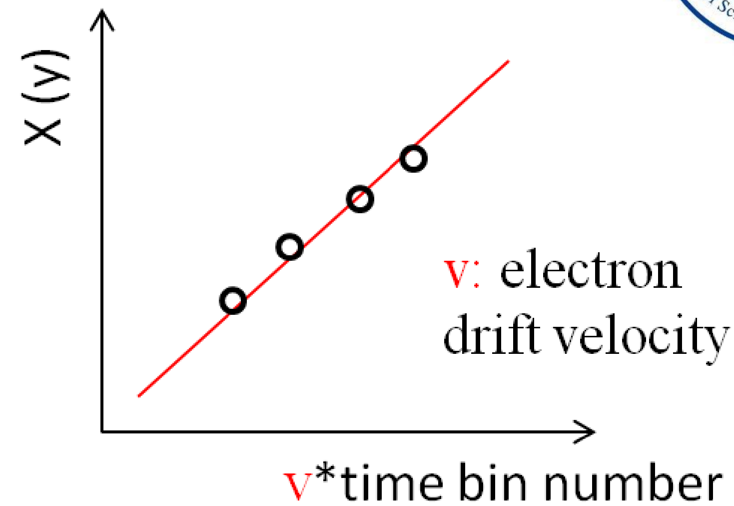
- Three THGEM foils in cascade
- Ionization gap thickness: 11.3 mm
- FEE: APV25-S1 chip
- Read out system: similar with FGT(the forward GEM tracker),STAR

(G.J. Visser, et al., Real Time Conference (RT), The 18th IEEE-NPSS, 2012, pp. 1–6)

实现三维读出，重建入射粒子径迹——mini drift

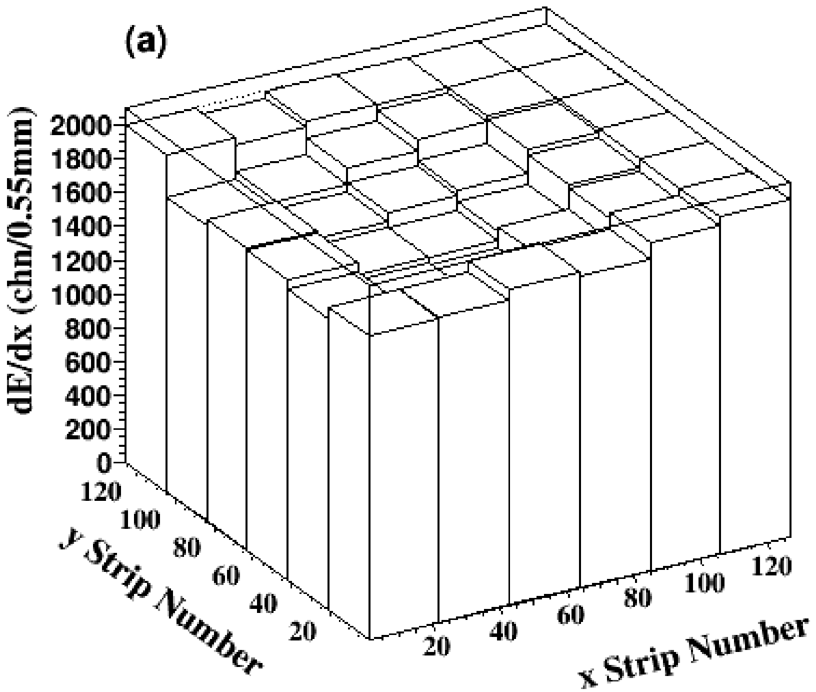
三维径迹重建原理

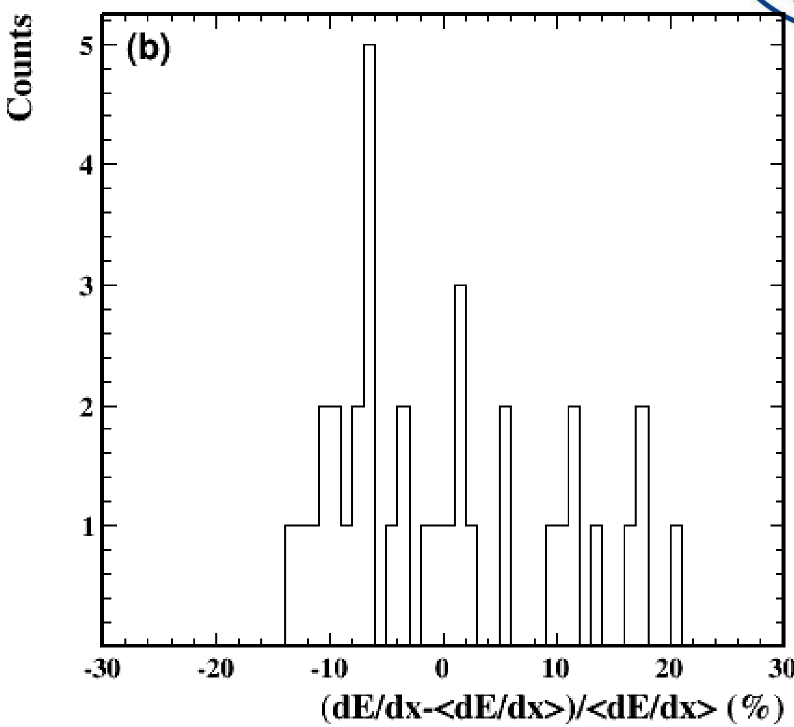




- Each readout unit is sampled in 27 time bins (26.7 ns bin width) along electron drift direction (*z* direction).
- z position： $v \cdot time\ bin\ number$ (v:electron drift velocity)
- the x, y positions： using the center of gravity method

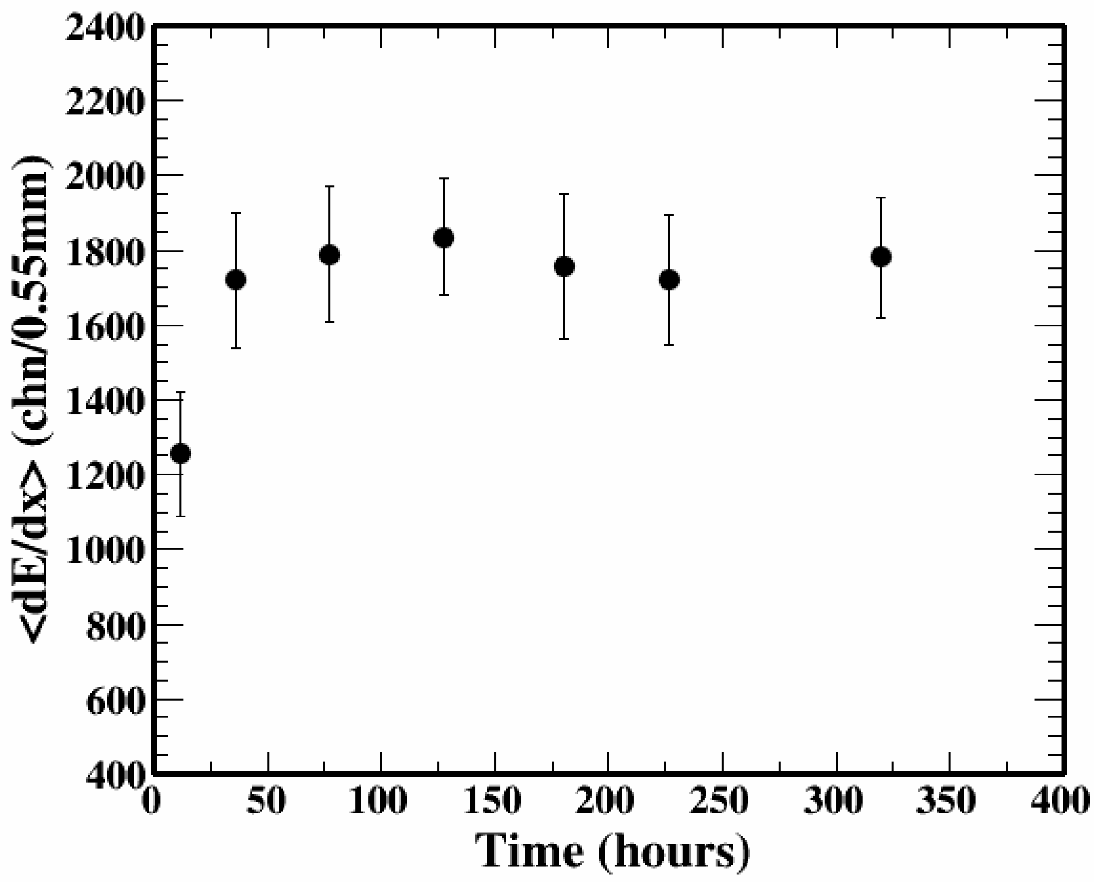
增益均匀性





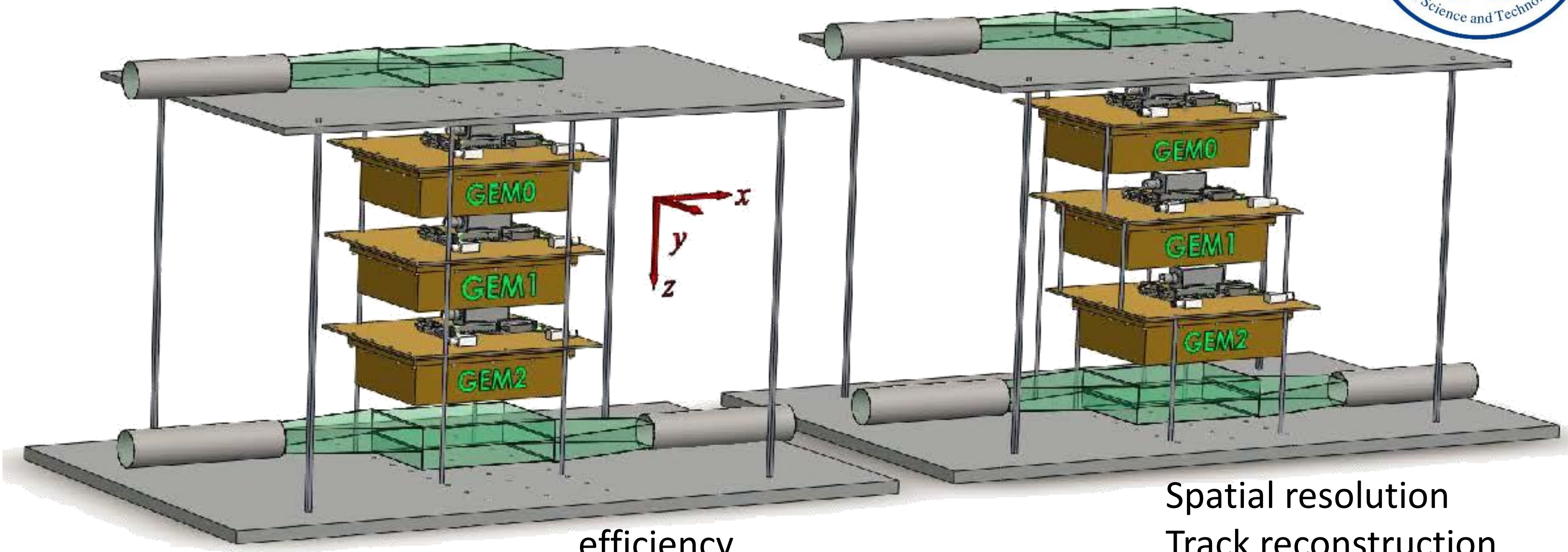
- The readout board is artificially divided into 6×6 identical sub-regions
- Non-uniformity for 32 out of 36 sub-regions is less than 15%

稳定性



- The THGEM shows an increase of gain in the first 24 hours and remains stable afterwards

宇宙线测试系统的建立



efficiency

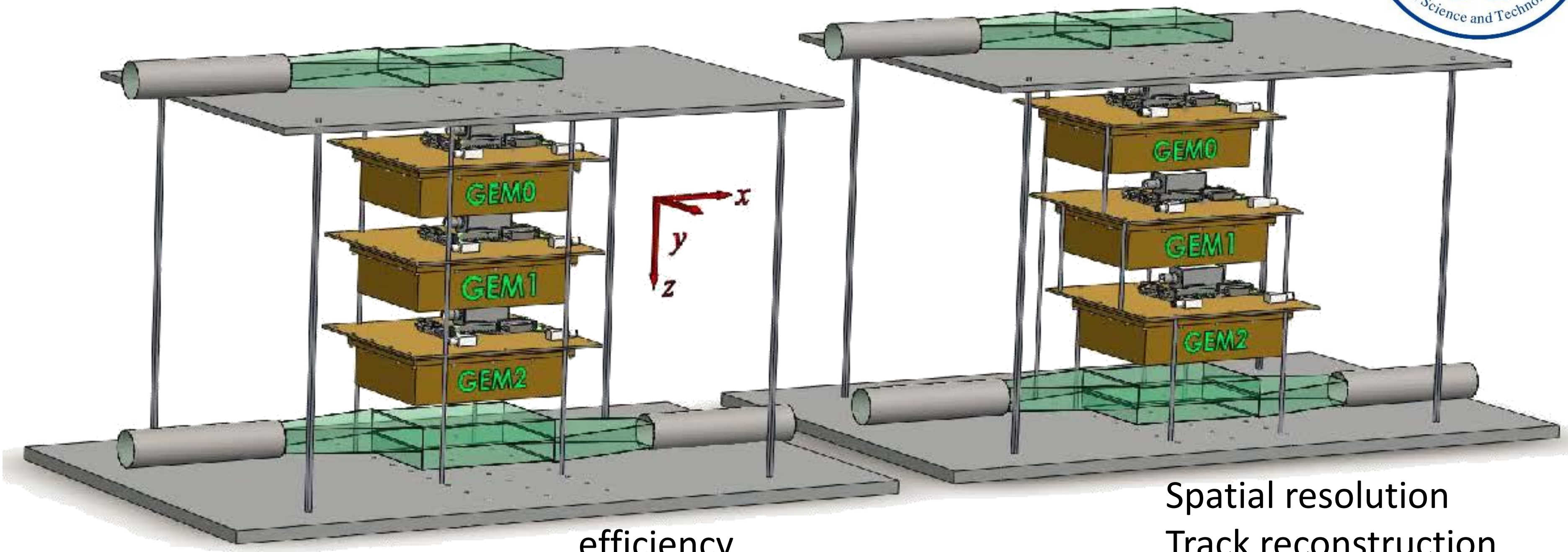
Spatial resolution
Track reconstruction

- Distance：

  4.1cm(horizontal offset ,y direction, right)

  10.5cm(z direction)

宇宙线测试系统的建立

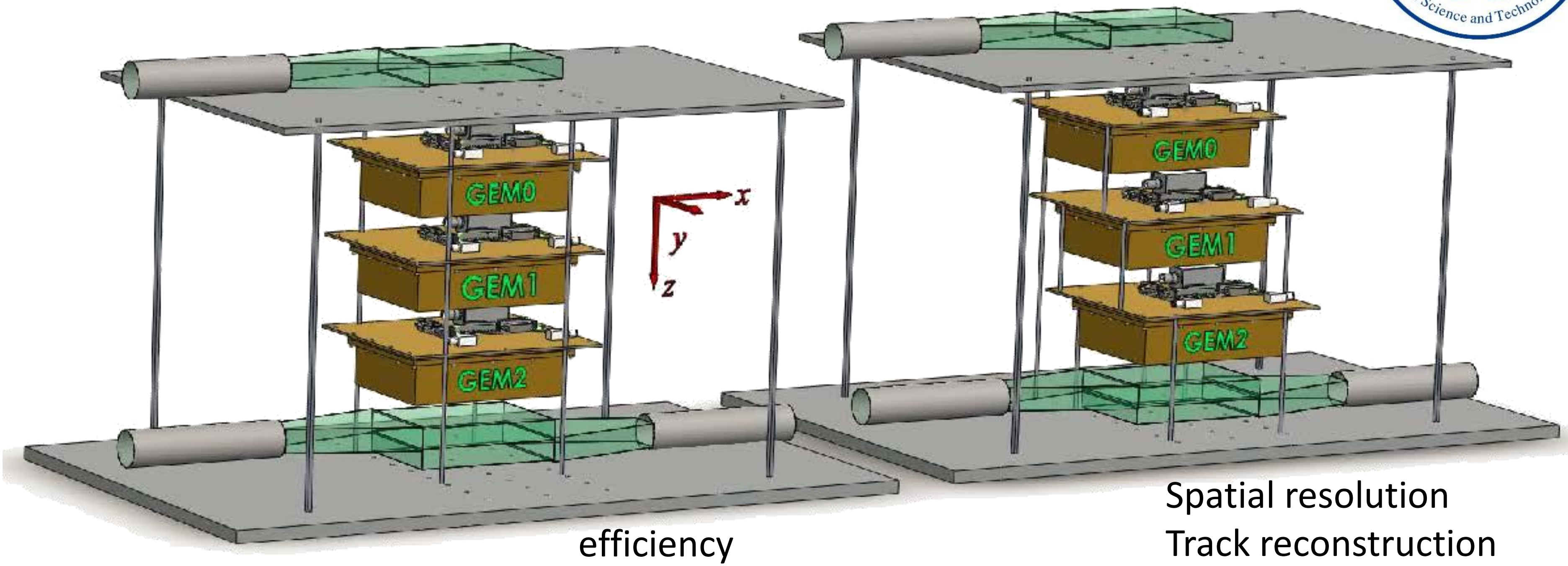


efficiency

Spatial resolution
Track reconstruction

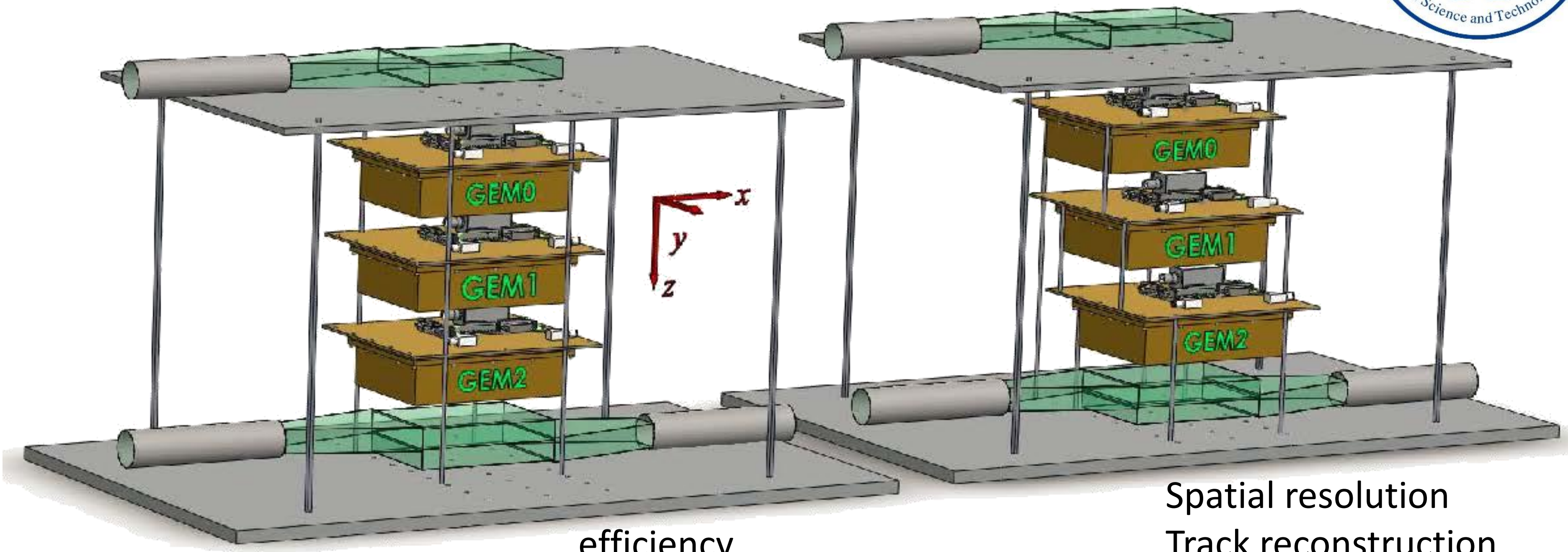
- Trigger: 3-fold scintillators, 12×12 cm^2

宇宙线测试系统的建立



- Calibration： GEM0&GEM2 (GEM Chanmber,3.8mm ionization gap width, spatial resolution <150μm)

宇宙线测试系统的建立



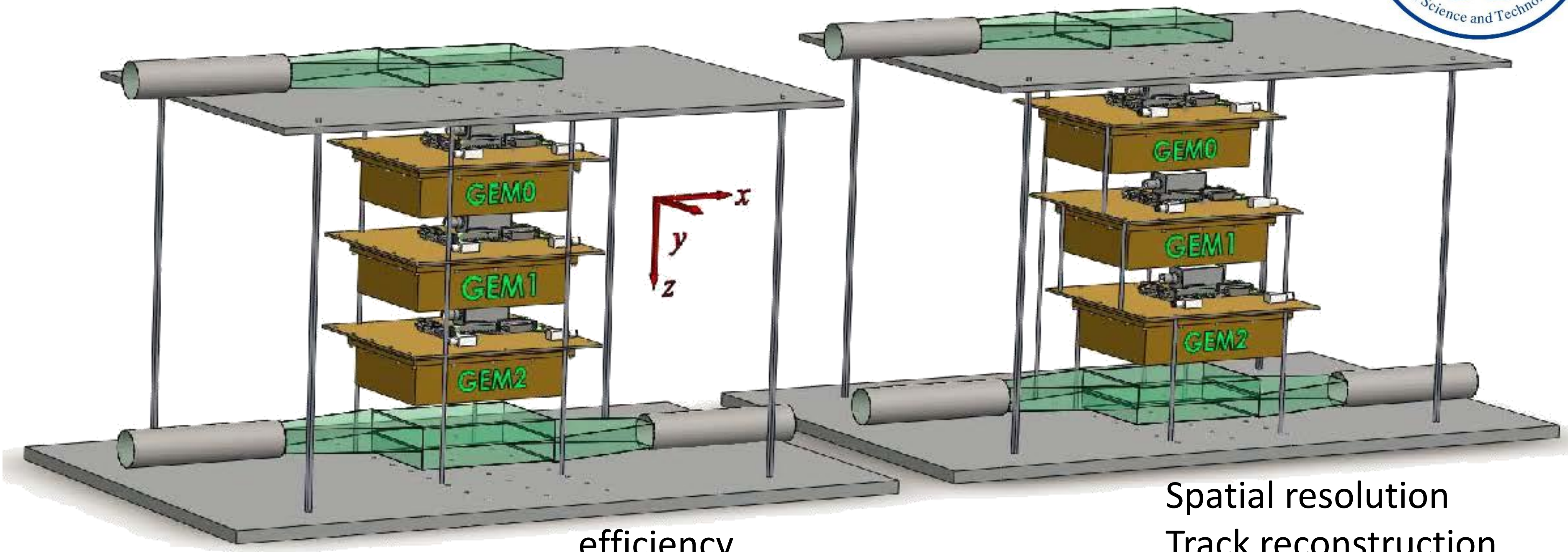
efficiency

Spatial resolution
Track reconstruction

- tracklet slope $$\tan\theta = \frac{\sqrt{(x_0 - x_2)^2 + (y_0 - y_2)^2}}{(z_0 - z_2)}$$

*x*0, *y*0 are the *x*, *y* positions measured by GEM0 using the center of gravity method while *x*2, *y*2 are provided by GEM2. *z*0, *z*2 are the positions of GEM0 and GEM2 along *z* direction.

宇宙线测试系统的建立



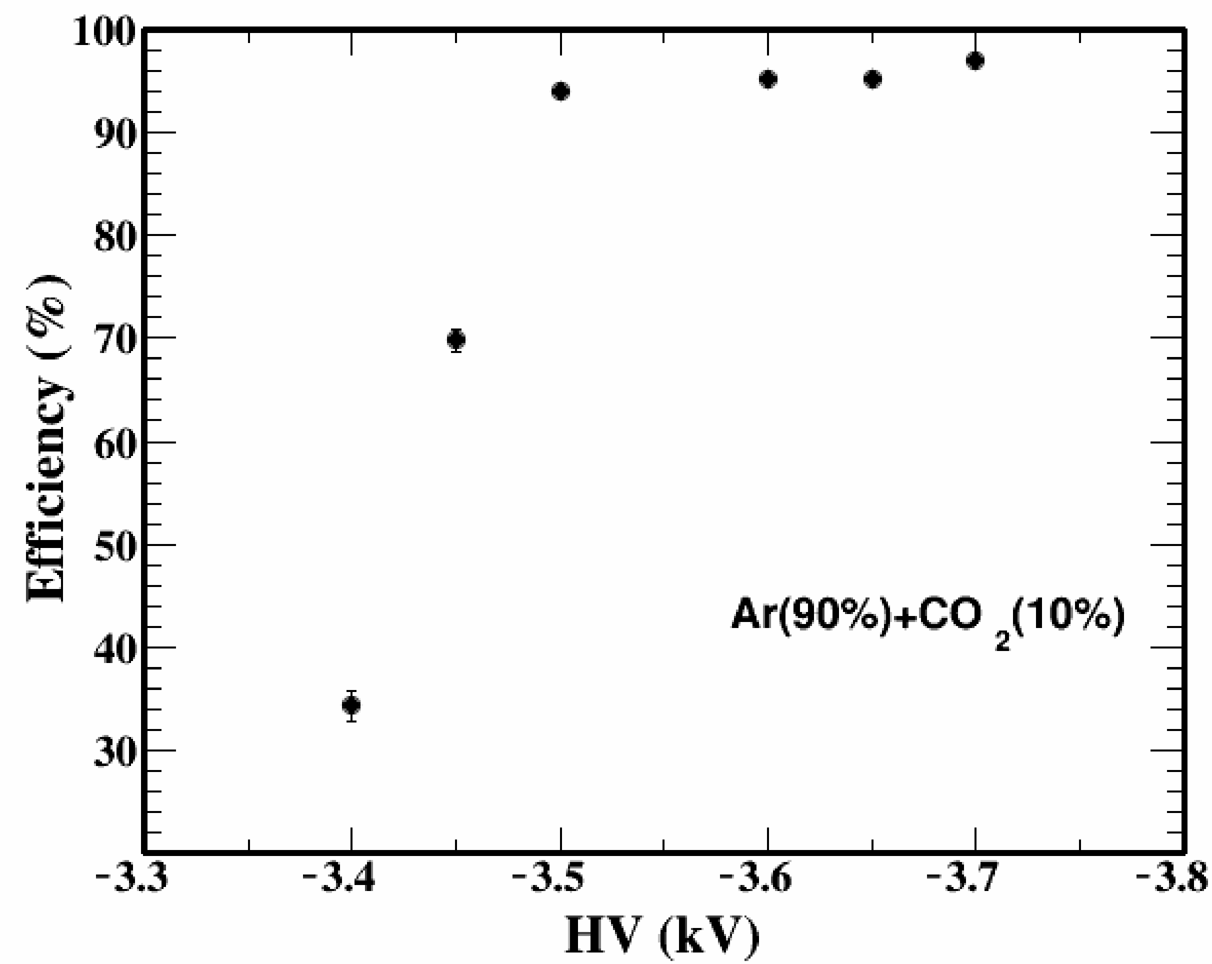
efficiency

Spatial resolution
Track reconstruction

- reference position $\frac{\sqrt{(x_0 - x_2)^2 + (y_0 - y_2)^2}}{(z_0 - z_2)} = \frac{\sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2}}{(z_0 - z_1)}$

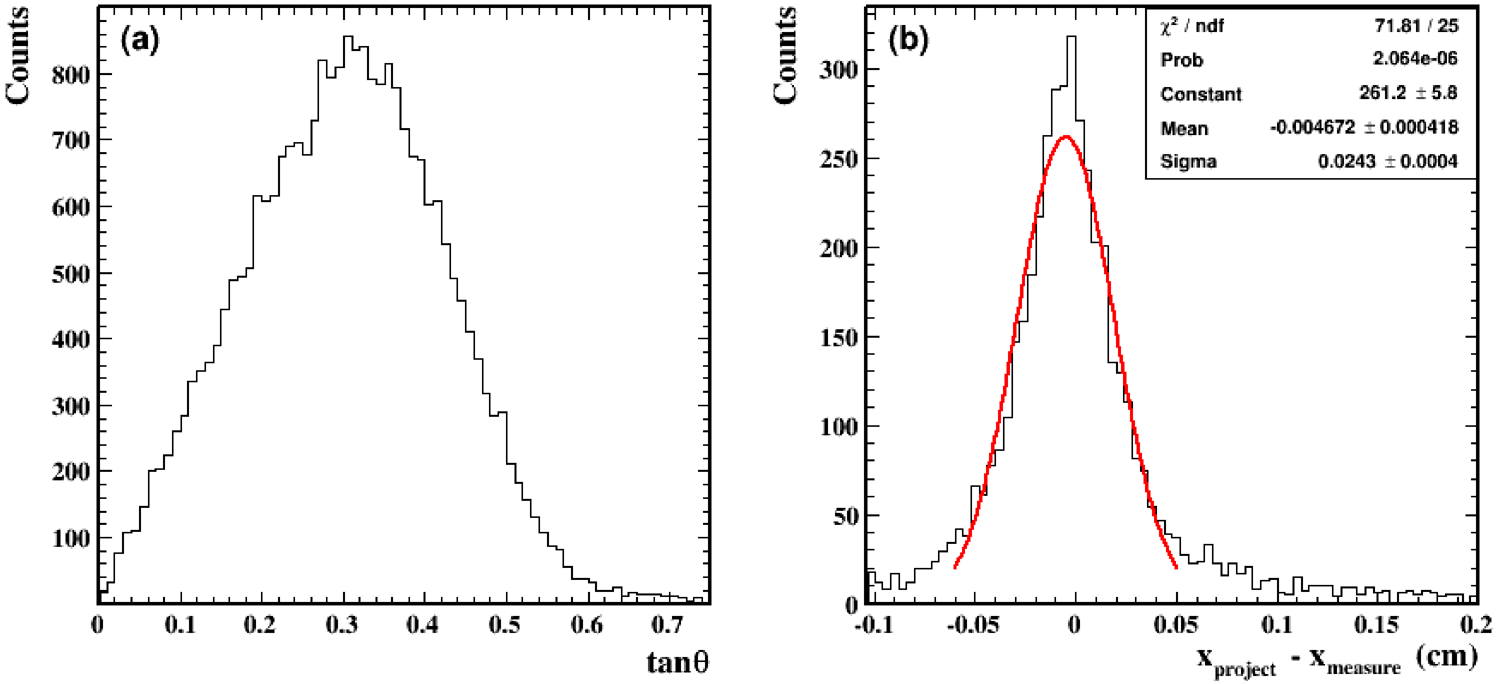
The *x*, *y* positions (*x*1, *y*1) of this point are calculated by the center of gravity method by THGEM.

效率坪曲线



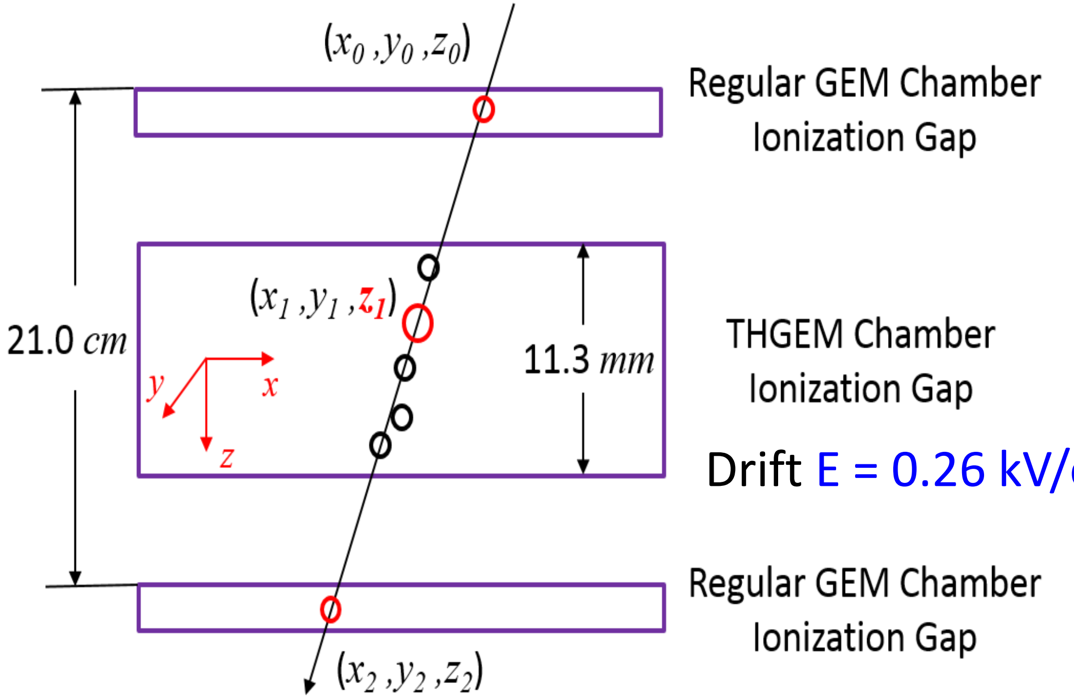
- When HV > -3.5 kV, efficiency > 90%
- -3.65 kV is selected as the working HV
- Efficiency > 94%

x,y direction 位置分辨



- Event select： $tan\theta < 0.1$, to select vertically incident cosmic ray track
- Regular GEM spatial resolution: <150 μm
- THGEM intrinsic x (y) spatial resolution: ~220 μm

z direction位置分辨

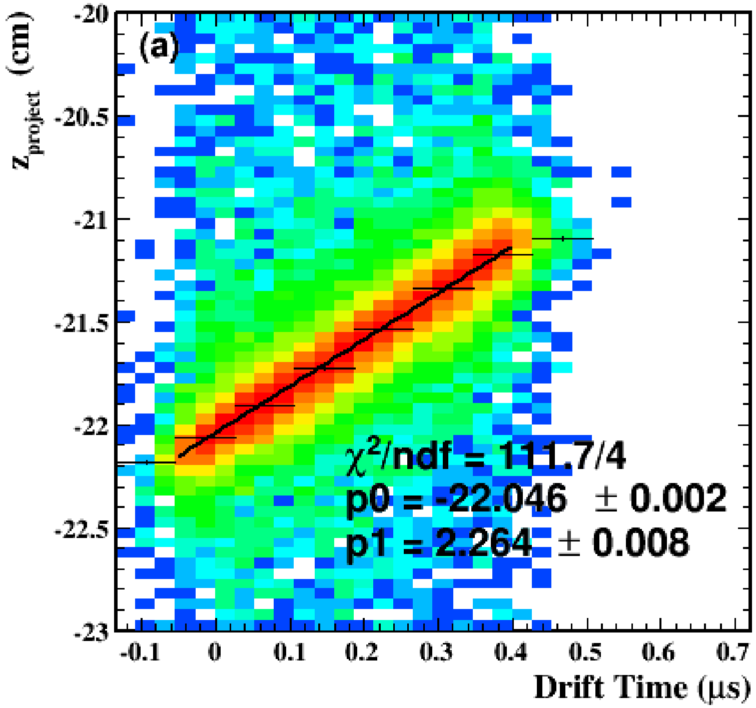


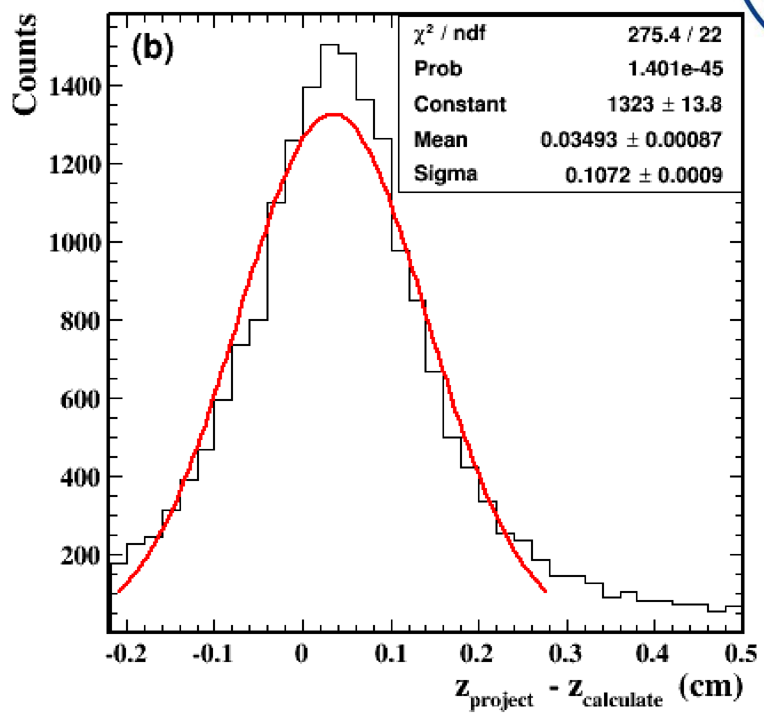
Drift E = 0.26 kV/cm

➢ The electron drift velocity

- Pick up the hit point with maximum energy deposit of a large zenith angle track
- Calculate the z position of the hit point
- correlating the hit point's z position with its corresponding drift time

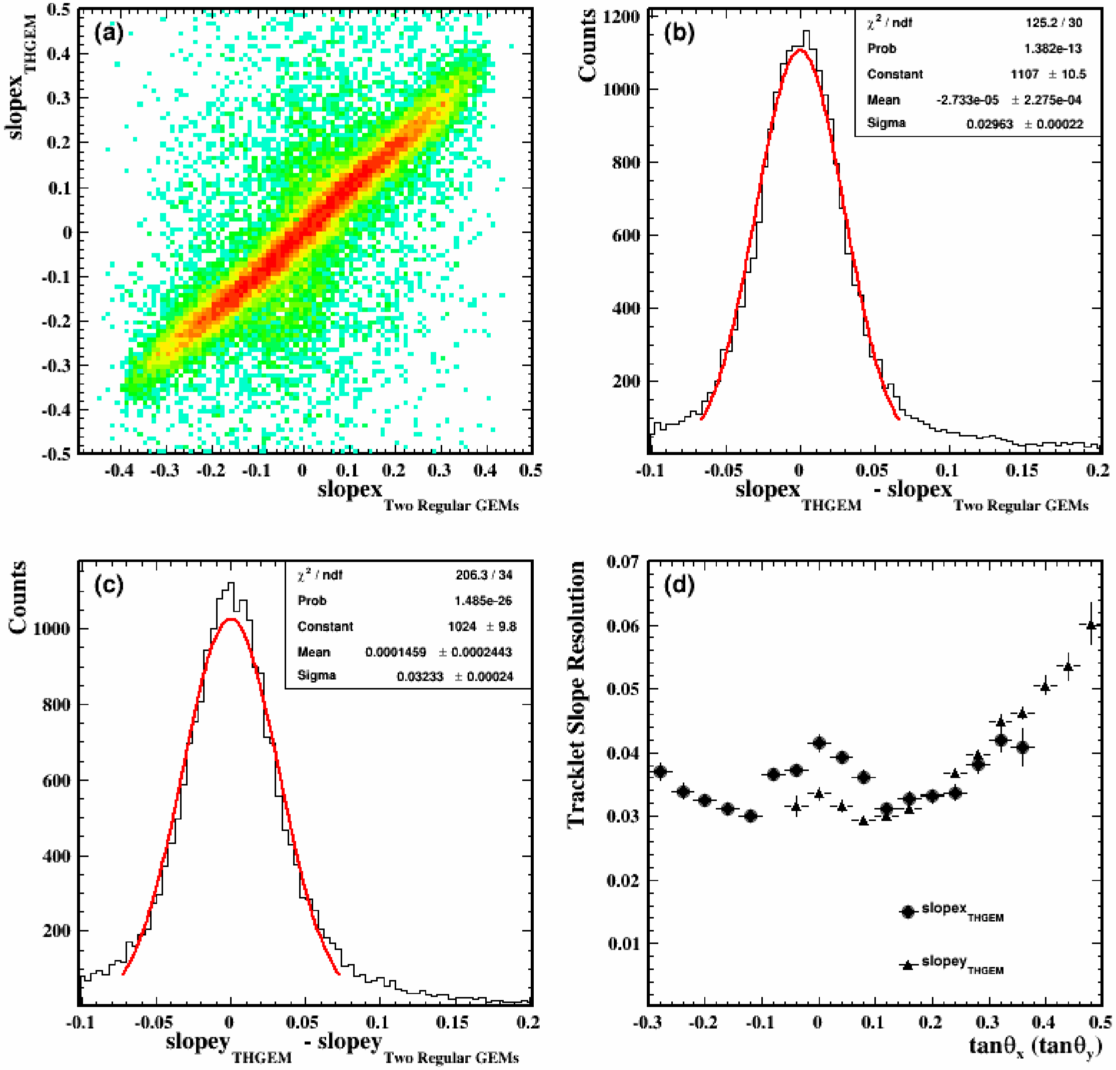
z direction位置分辨





- Electron drift velocity: 2.26 cm/μs
- THGEM overall spatial resolution along electron drift direction is ~1.1 mm , the intrinsic part is ~0.7 mm
  - Uncertainty from the trigger clock distribution: ~0.2 mm
  - Uncertainty from two regular GEM chamber: ~0.8 mm

径迹重建能力



- Tracklet slope resolution in x (y) direction is ~0.03
- Tracklet slope resolution deteriorates with increasing incident angle

总结

系统的完成了mini-drift THGEM的宇宙线测试，测试结果展示了THGEM Chamber的优良性能：

- 正常工作电压下的测试效率大于94%；
- x-y平面一维位置分辨约为220μm，沿电子漂移方向的位置分辨约为0.7mm；
- 好的径迹重建能力：径迹斜率分辨率约为0.03；
- THGEM chamber具有好的增益均匀性，长期运行下工作性能稳定。

Backup

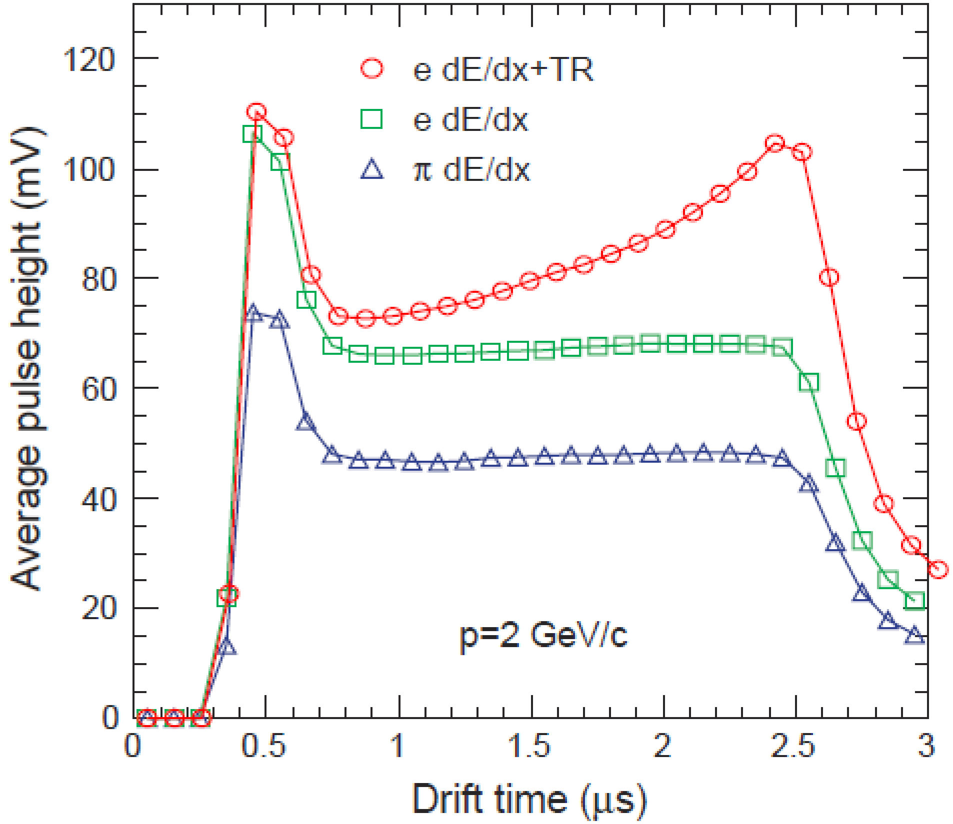
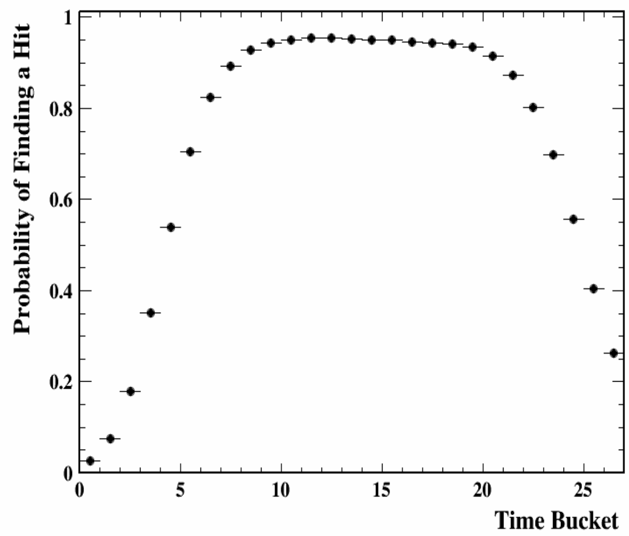
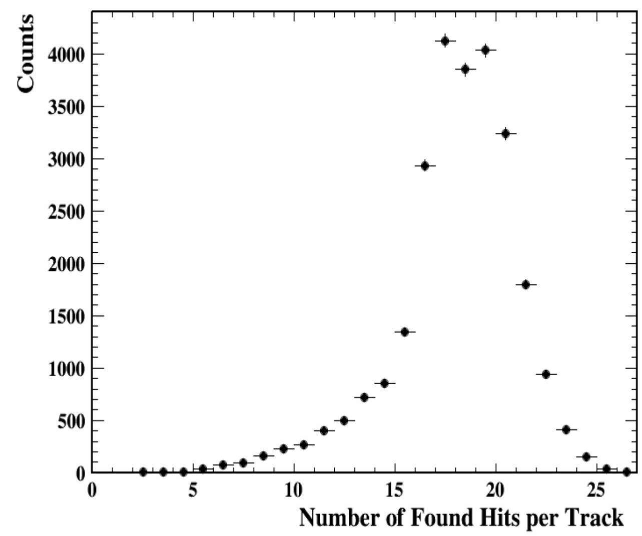
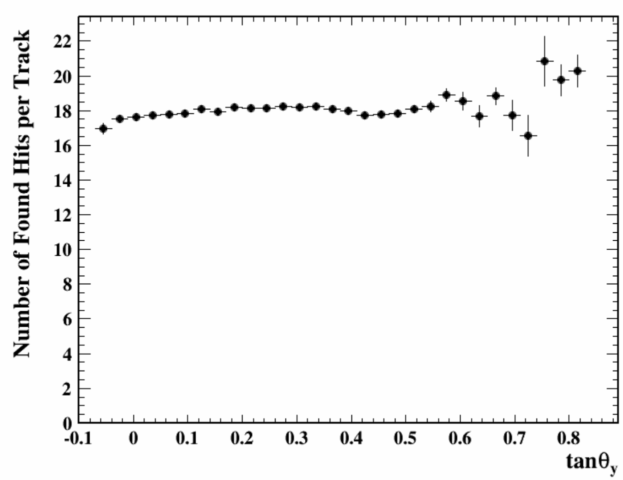
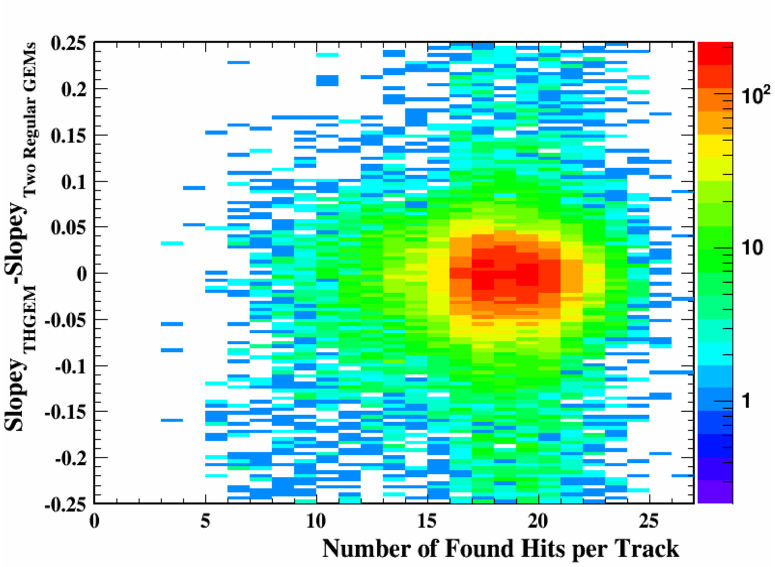


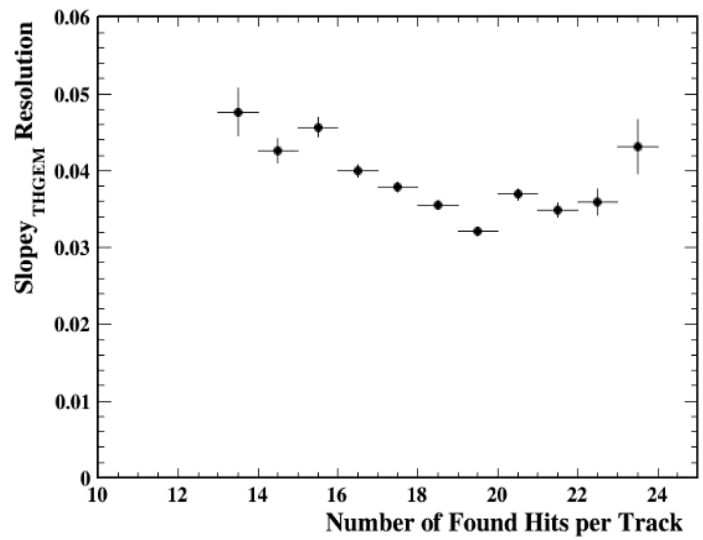
Fig. 1. Average pulse height as a function of drift time for pions and electrons (with and without radiator).


Probability of Finding a Hit
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
Time Bucket


Counts
4000
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
Number of Found Hits per Track


Number of Found Hits per Track
22
20
18
16
14
12
10
8
6
4
2
0
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
$\tan\theta_y$





- Because the total number of found hit points are very concentrated. It’s hard to say the tracklet slope resolution has number of found hit points dependence or not. We would say the tracklet slope resolution has no obvious number of found hits dependence at the region [16,20] (this region has large statistics).

Absolute gain estimation

- The total ionization for MIP in 90%Ar/10%CO_2 is 94 electrons/cm, and APV readout sensitivity is 500 electrons at the input per ADC count. The ionization gap width is 1.13cm and the total charge record by the readout is 14404. So the absolute gain = 14404*500/94/1.13 = $6.78*10^4$.