HERD穿越辐射探测器TeV能区能量标定研究

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高能物理分会 2022.08.11

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- TRD粒子鉴别应用
- 空间TRD TeV能区能量标定方法
- 原理样机:侧窗式穿越辐射探测器
- 总结

HERD

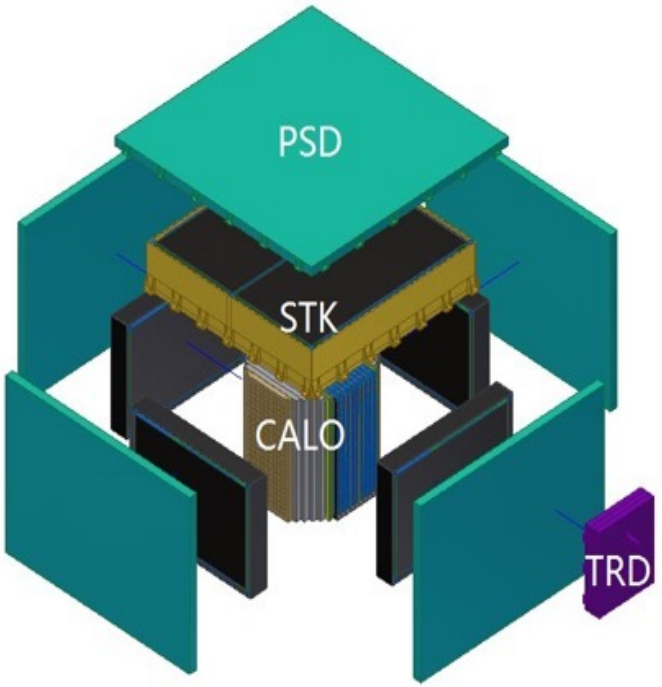
- 采用了三维位置分辨五面灵敏的创新设计
- 大能区、高精度宇宙辐射探测

- 探测能区：

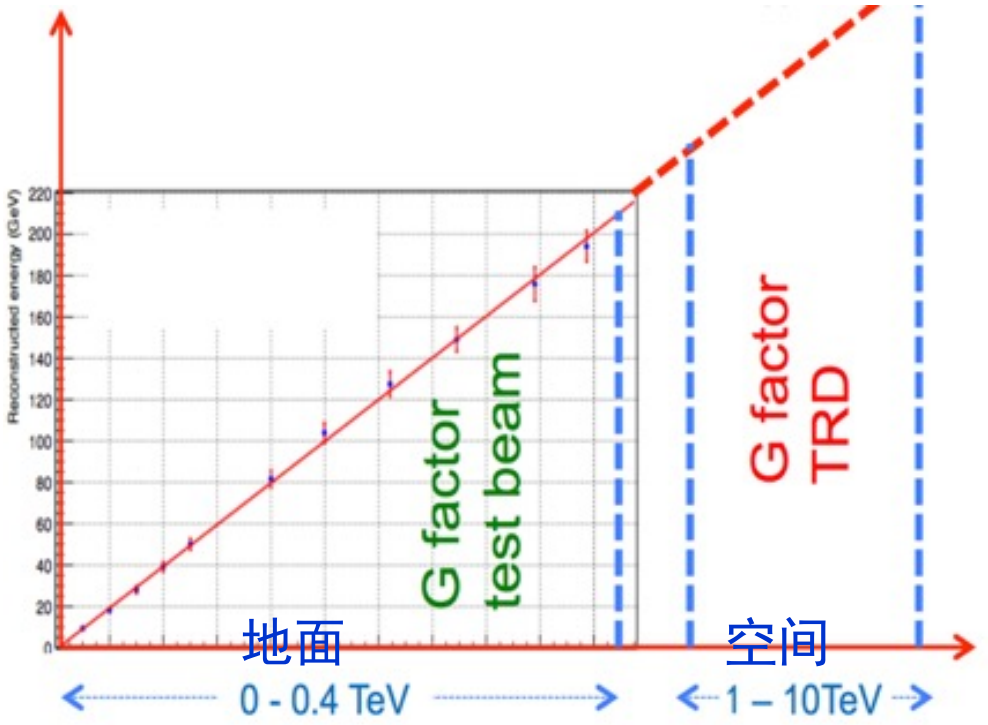
10 GeV－10 TeV (电子/光子)
0.5GeV – 10 GeV (光子)
30 GeV－3 PeV（核子）

- 能量分辨：

1%@200 GeV（电子）
20%@100 GeV-PeV（核子）



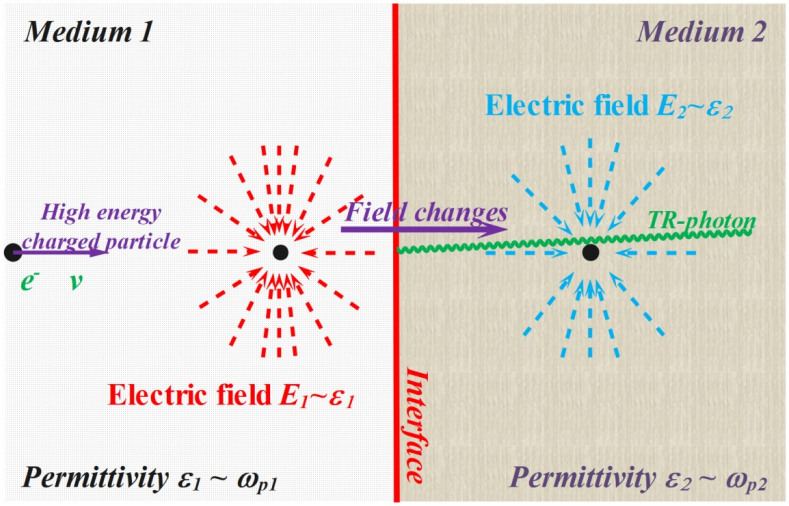
HERD量能器标定方法

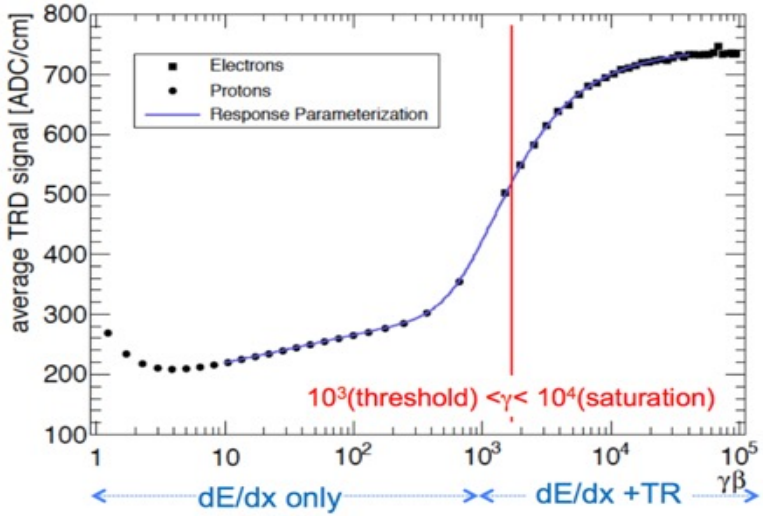


- 1. 地面束流 – CERN的400 GeV（质子）和250 GeV（电子）
- 2. 利用穿越辐射探测器（Transition Radiation Detector，**TRD**）

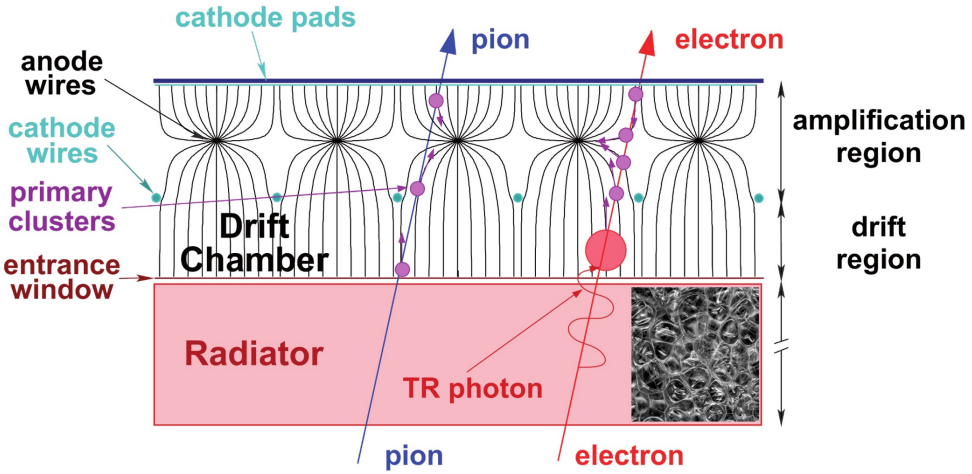
穿越辐射原理

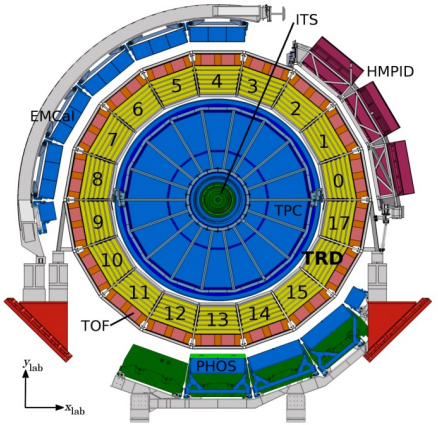
- 在相对论情况下，带电粒子在穿过不同介电常数的介质时，在介质表面产生的一种电磁辐射
- 辐射强度与入射粒子的速度成正比：$W \propto \gamma$
- 辐射角度与入射粒子的速度成反比：$\theta \propto 1/\gamma$
- 辐射产生和饱和：$\gamma_{\text{threshold}} \sim 10^3$，$\gamma_{\text{saturation}} \sim 10^4$



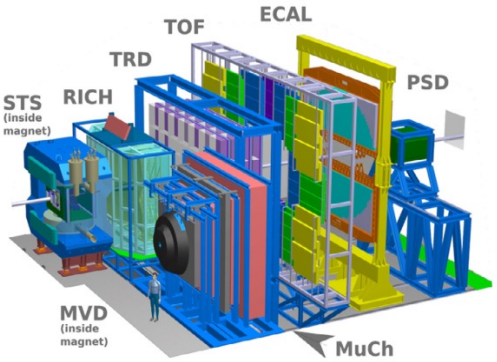


TRD用于粒子鉴别

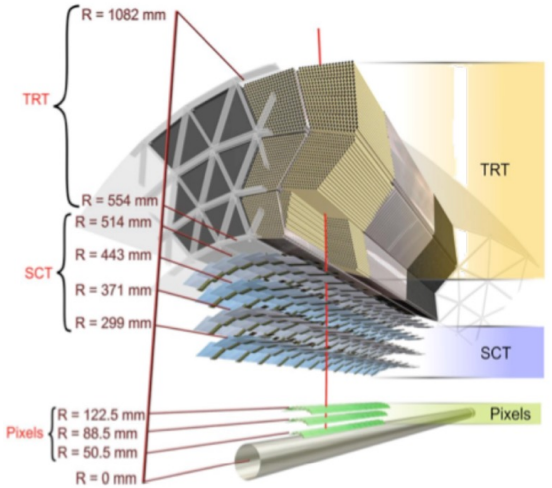




ALICE (MWPC-TRD)

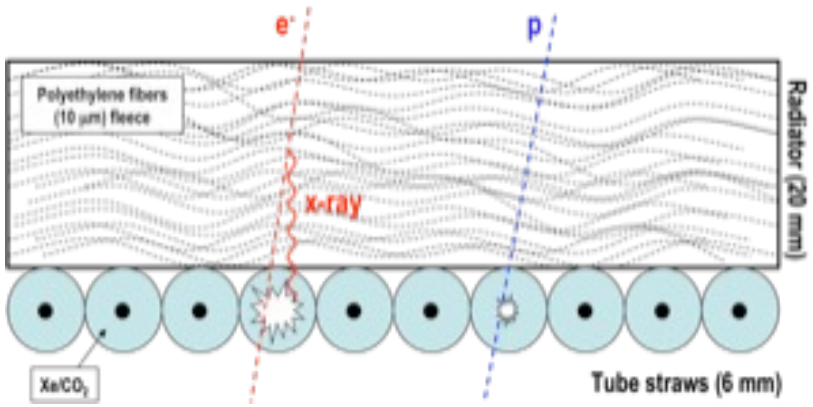


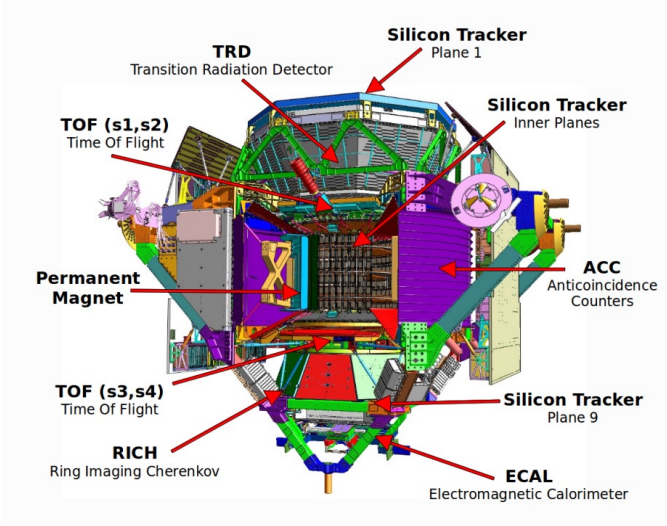
CBM (MWPC-TRD)



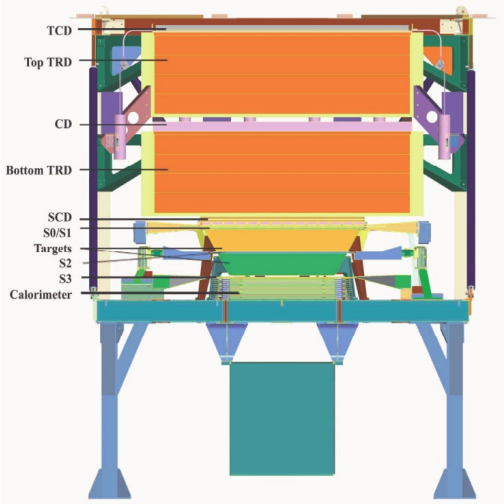
ATLAS (Straw-TRD)

TRD用于粒子鉴别

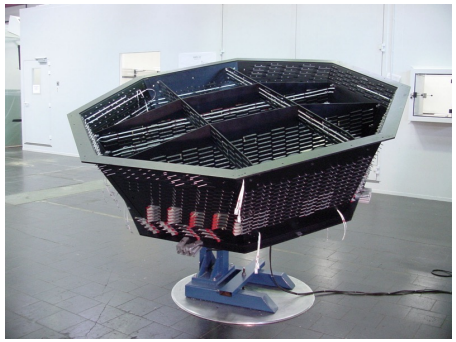


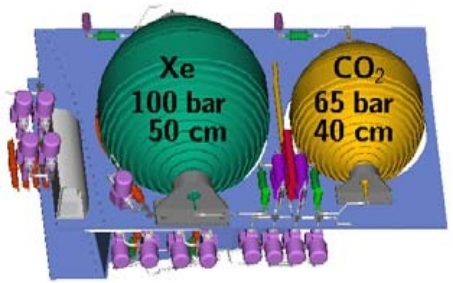


AMS-02



CREAM



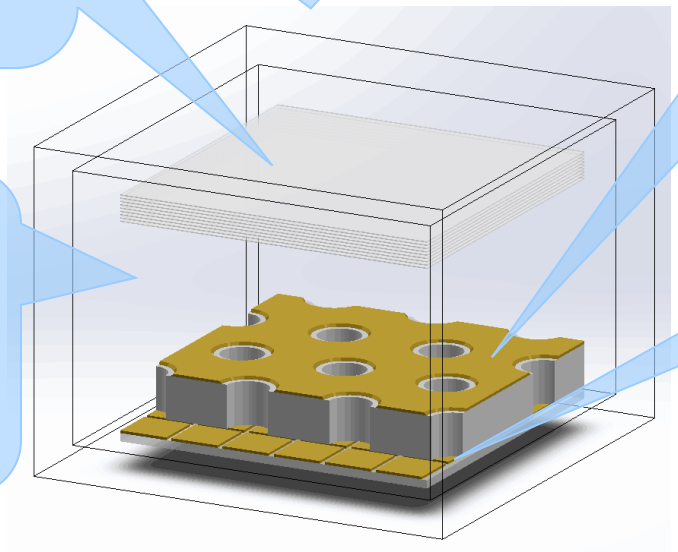


基于THGEM穿越辐射探测器

穿越辐射体研究：基于观测模拟，研究TR辐射体材料和结构设计

探测器封装技术研究：防探测器老化问题

厚型气体电子倍增器研究：优化孔径、孔距、厚度等参数

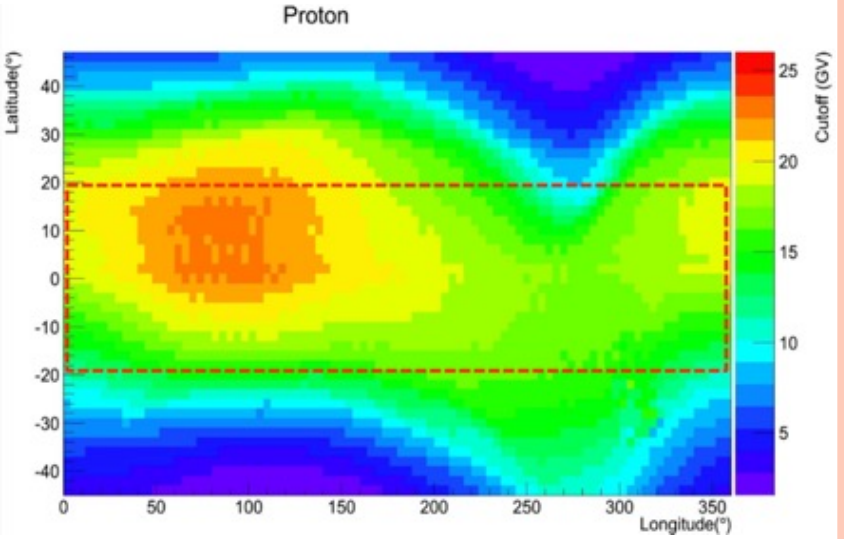


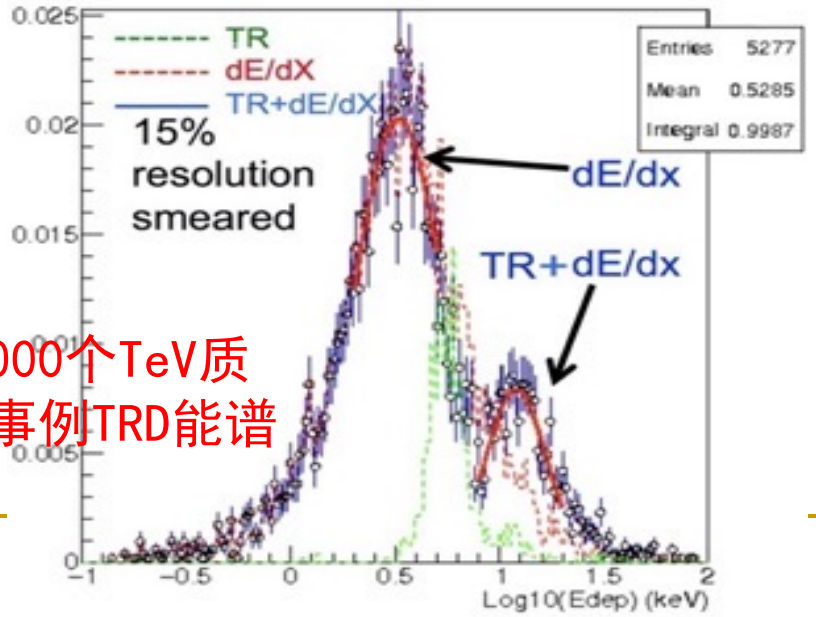
工作气体优化：探测器具有高X射线探测效率和TRD探测灵敏度

阳极及电子学读出设计

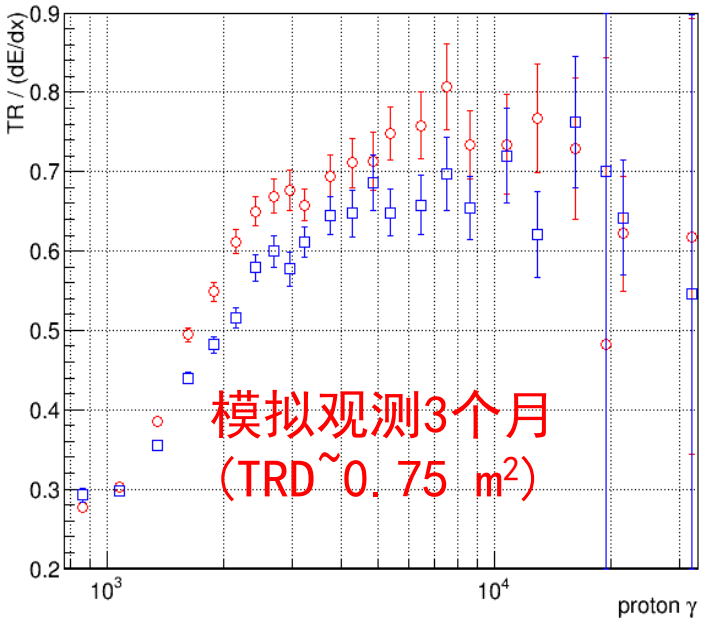
(1)模拟在轨观测

- 预计1-3个月完成一次TeV质子在轨能标
  - 确定TRD在轨能标方案
  - 确定TRD基本设计方案
  - 确定TRD反冲抑制方案



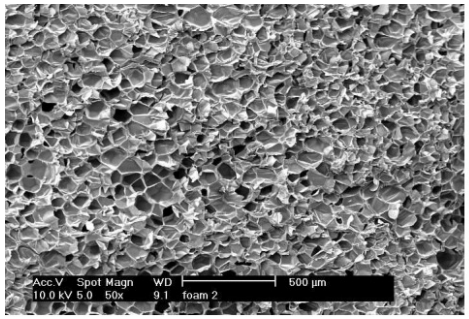


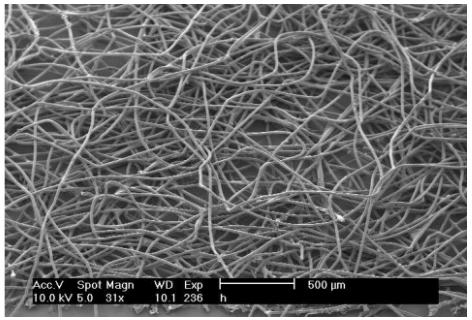
~5000个TeV质子事例TRD能谱

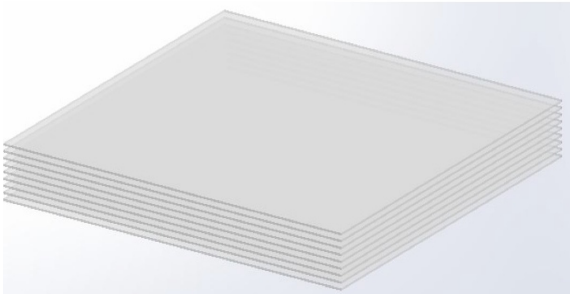


模拟观测3个月
(TRD~0.75 m^2)

(2) 穿越辐射体研究





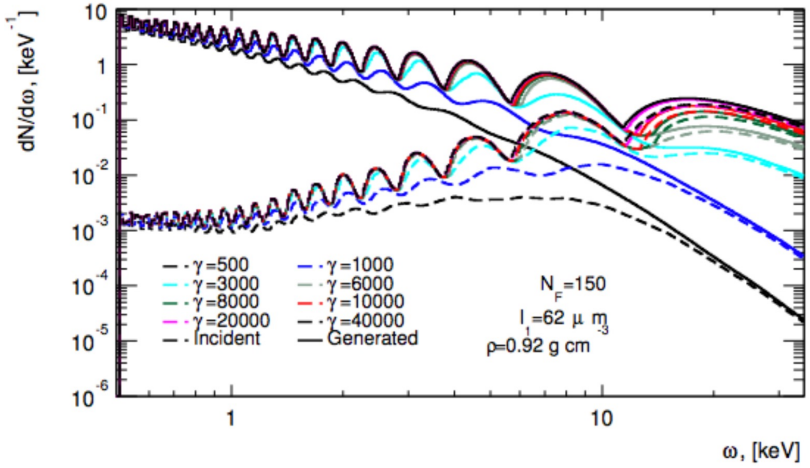


基于模拟观测，利用高能所E2实验束研究辐射体材料和结构设计

穿越辐射体模拟

RADIATOR: A program to calculate the Transition Radiation quanta yield （from P. Nevsky ）

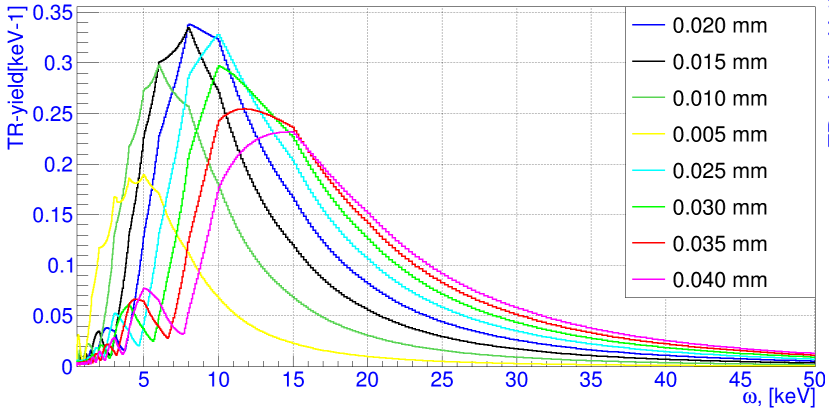
```
TR yield calculation - all data are in mkm (1e-3 mm)
+-----+-----+-----+-----+L rad+Nfoil+Dfoil+-----+-----+-----+-----+-----+
 SET  :BAREL:    1*1.   :    1*1.        0*0.        0*0.        0*0.
 BLOCK:NORMAL    1.    1.    1.          :
 ELEM :RADIA:PPROP+AIR  :158e3.  150*62   :
      :WALL :MYLAR      :    0.05         :
      :CHAMB:XE         :  3e4.           :
      :WALL :MYLAR      :    0.05         :
 ELEM :RADIA:PPROP+AIR  :158e3.  150*62   :
      :WALL :MYLAR      :    0.05         :
      :CHAMB:XE         :  3e4.           :
      :WALL :MYLAR      :    0.05         :
 THRES:     :  3.0   3.5   4.0   4.5   5.0   5.5   6.0   6.5
 ENERG:     :  0.5   500  .005
 GAMMA:     :   -1
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
 VAR  : G-1 :  5e2|  1e3|  3e3|  6e3| 8e3 |  1e4|  2e4|  4e4|     |     |
 END  : OF EXAMPLE
```



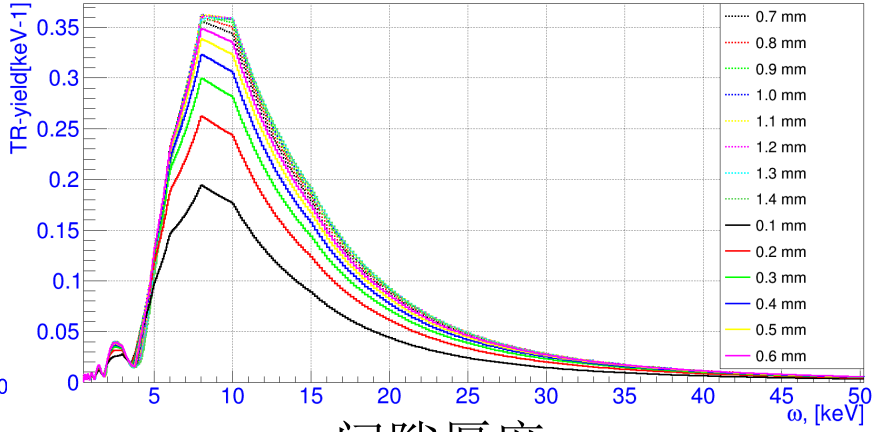
Material	Abbreviation
Hydrogen	H
Helium	HE
Carbon	C
Nitrogen	N
Nitrogen	N
Oxigen	0
Xenon	XE
Berilium	BE
Litium	LI
Boron	B
Bismuth	BIS
Germanium	GE
Polistirol	PST
Polypropylene	PPR
Mylar	MYL
Air	AIR
CH_2+20%B	20B
CH_2+30%B	30B
BGO	BGO
LIT	LIT

TR photon spectra, calculated for eight gamma-factor values with RADIATOR program for 150 foils of 62 μm thick mylar radiator

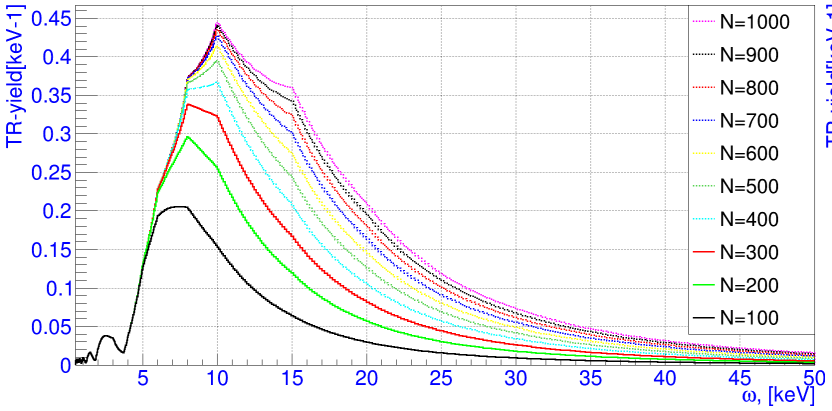
辐射体参数优化



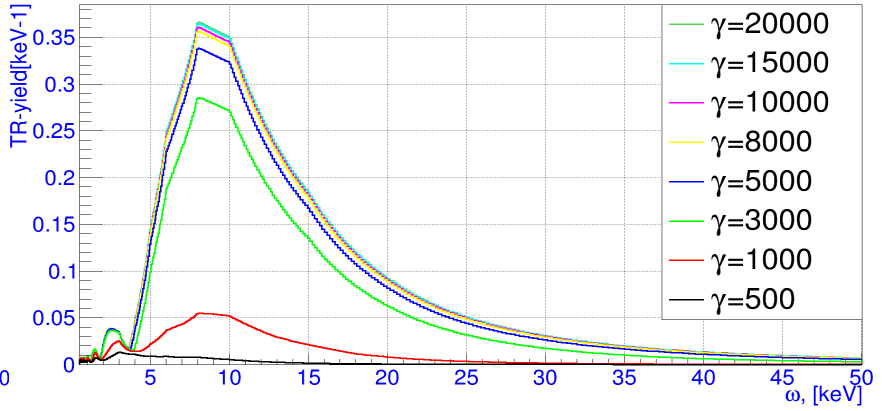
箔片厚度



间隙厚度

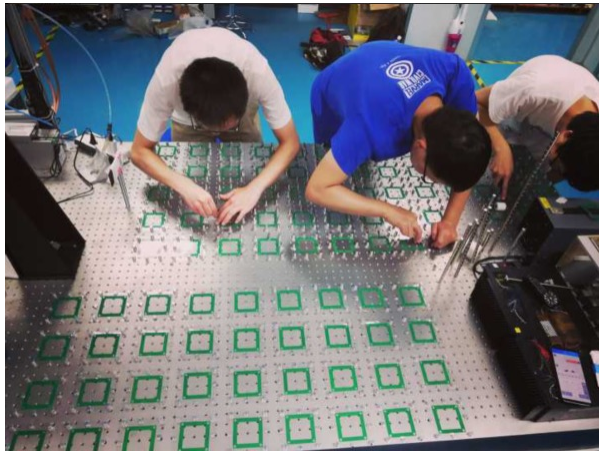


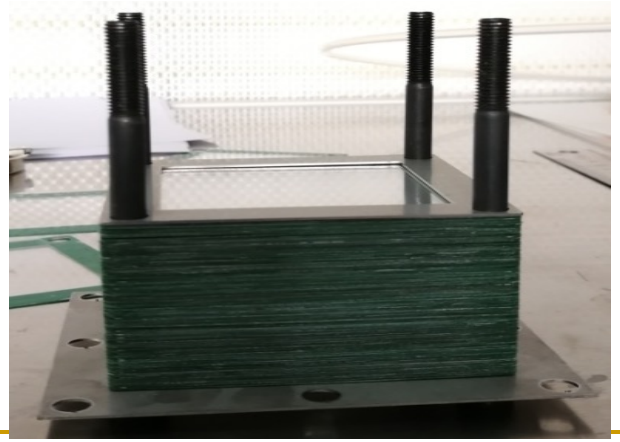
层数

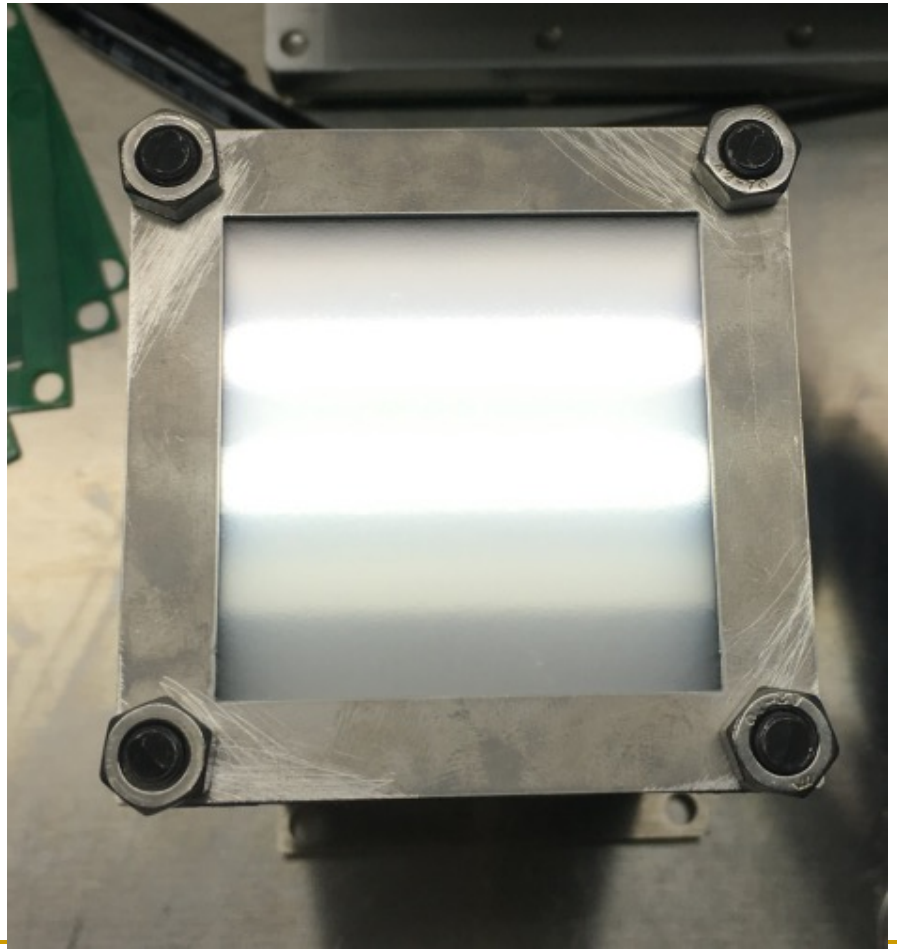


洛伦兹因子

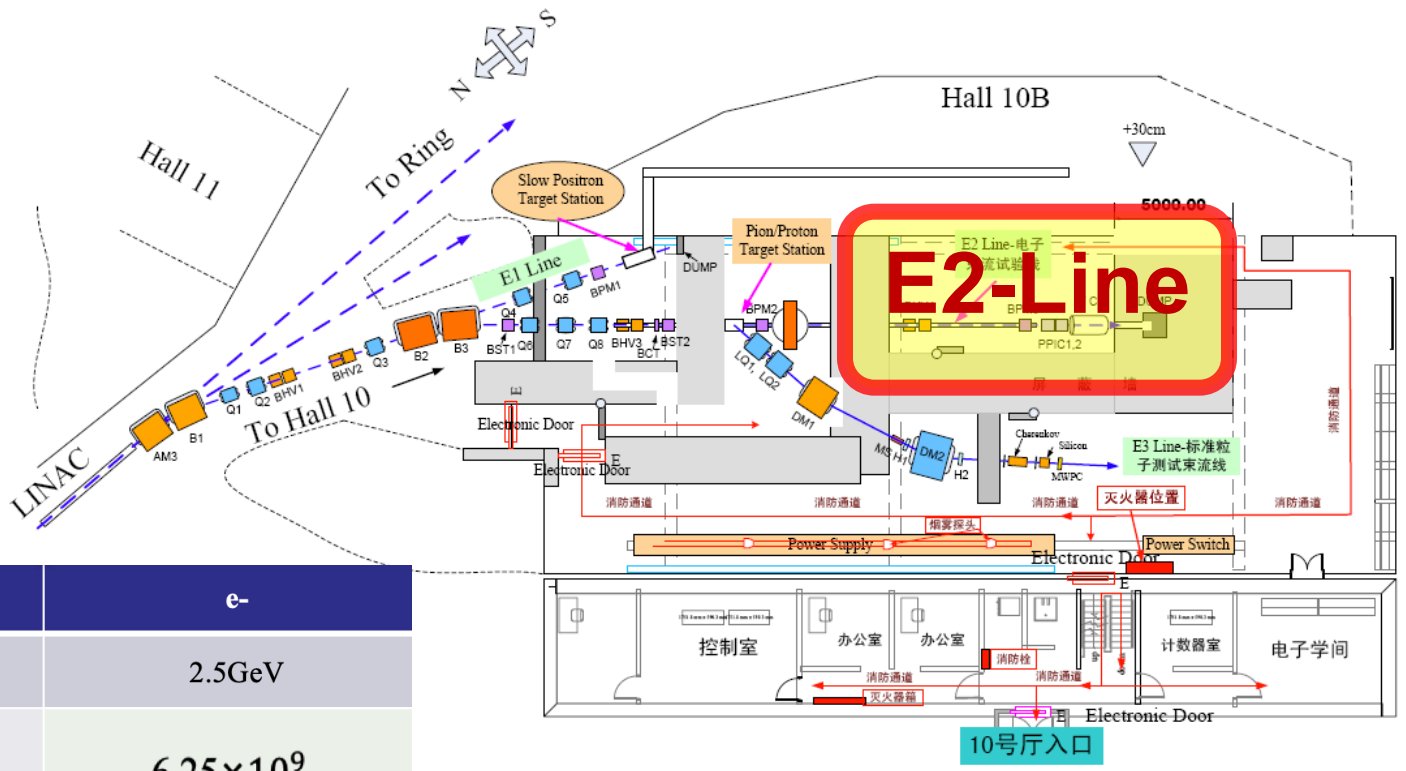
辐射体制作







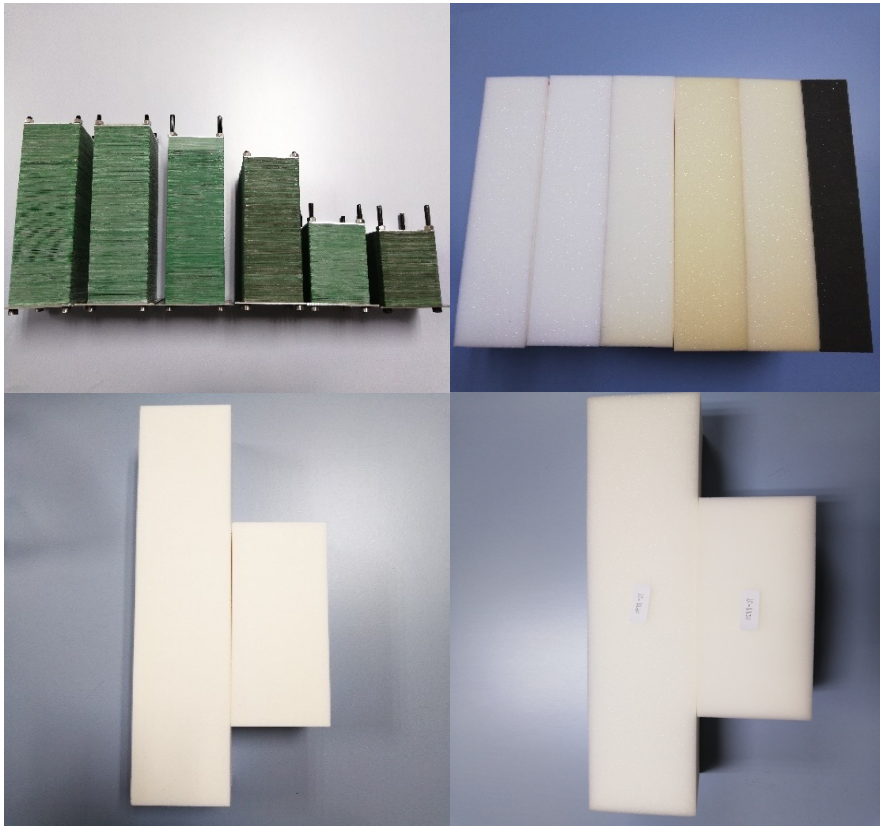
2019.12 Test Beam @ IHEP



Types of particles	e-
Energy	2.5GeV
Intensity（The accelerator operates at 12.5Hz）	6.25×10^{9}-1.25×10^{10}/pulse
Bunch time	10Ps
Charge	1-2nC
The height of beam	1.2m

Good place for radiator study

Radiators

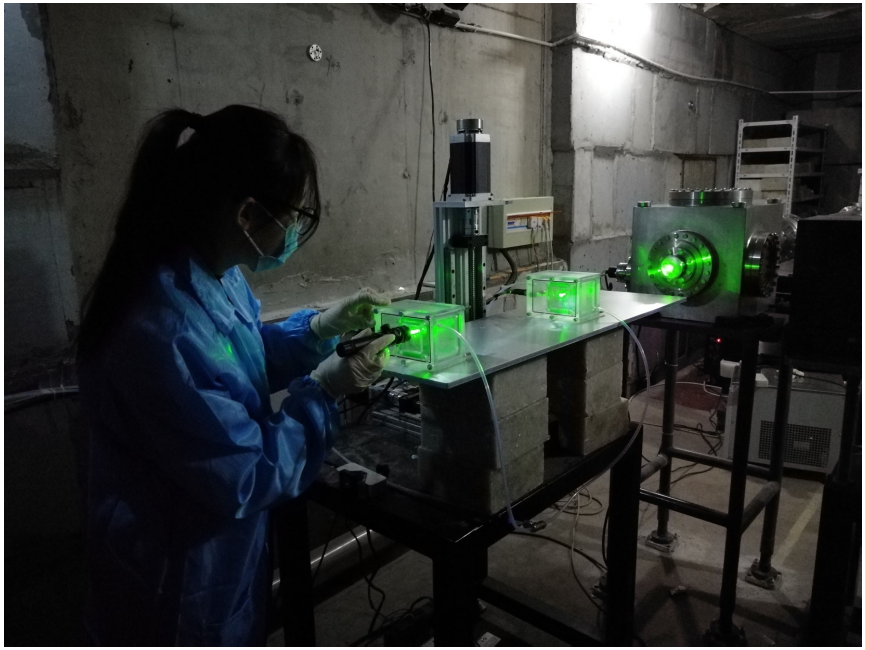


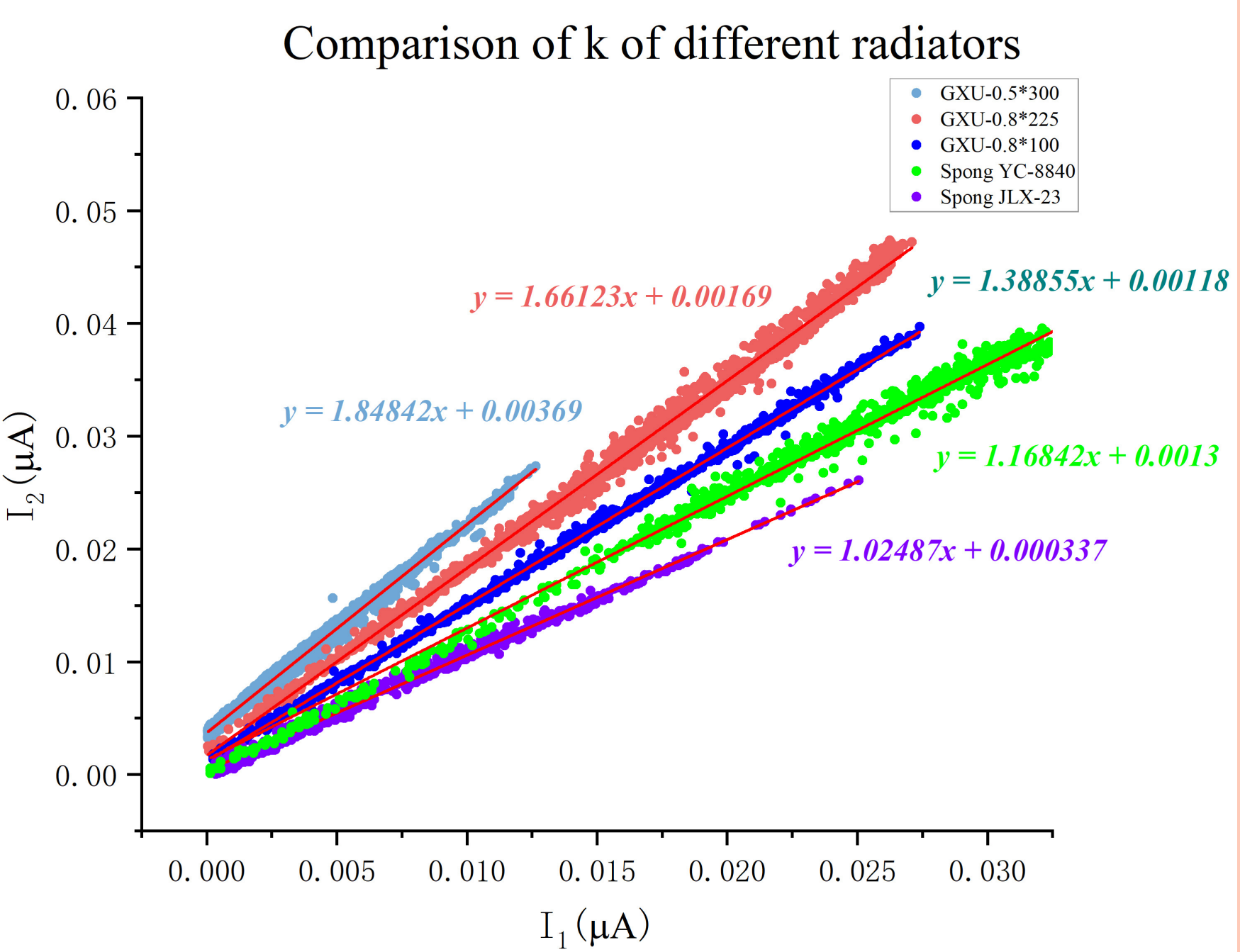
The radiator we have

Regular TR
GXU-0.5*300
GXU-0.5*150
GXU-0.8*225
GXU-0.8*100
Irregular TR
ROHA-69*69*200
ROHA-69*69*400
YC-8840
JLF-23K

The radiator we tested

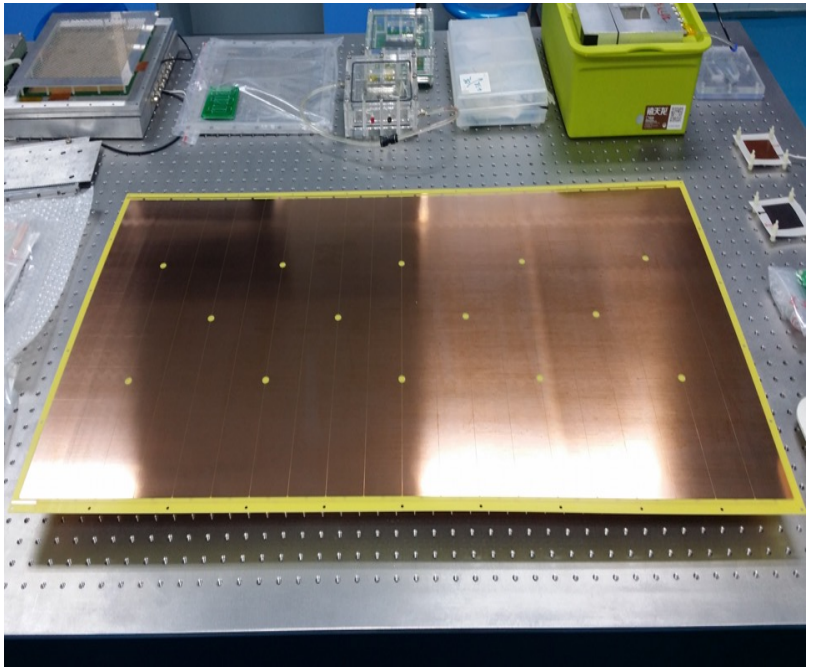
Layout of the detector




Comparison of k of different radiators
GXU-0.5*300
GXU-0.8*225
GXU-0.8*100
Spong YC-8840
Spong JLX-23
y = 1.66123x + 0.00169
y = 1.38855x + 0.00118
y = 1.84842x + 0.00369
y = 1.16842x + 0.0013
y = 1.02487x + 0.000337
0. 06
0. 05
0. 04
0. 03
0. 02
0. 01
0. 00
I2 (μA)
0. 000
0. 005
0. 010
0. 015
0. 020
0. 025
0. 030
I1 (μA)

(3) 厚型气体倍增器研究

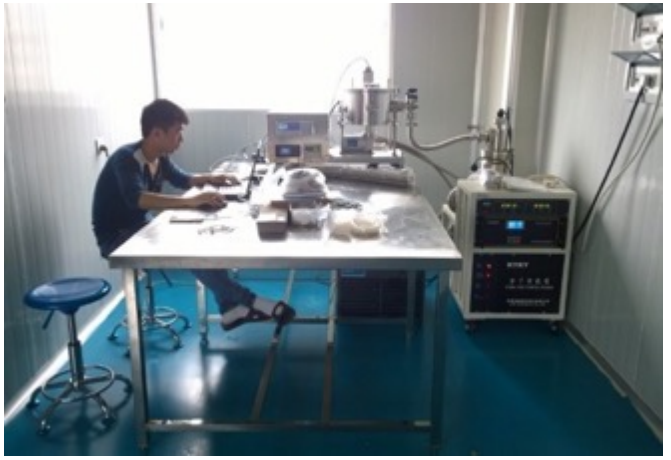
- 根据空间探测需要，研究不同气体探测器基材的出气率
- 研制低出气率、抗打火、抗老化的大面积THGEM
- 优化THGEM的孔径，孔间距，厚度等几何结构参数

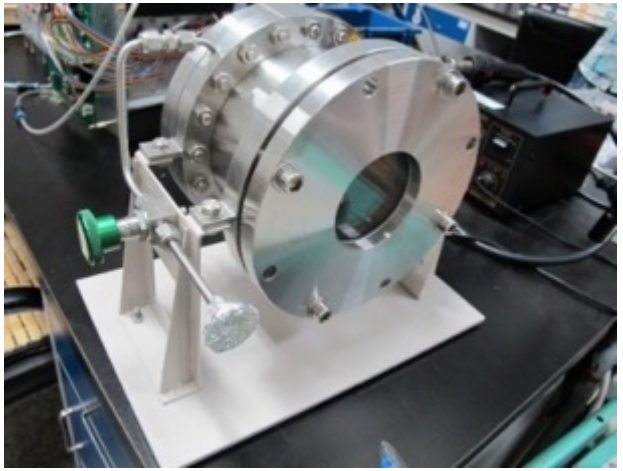


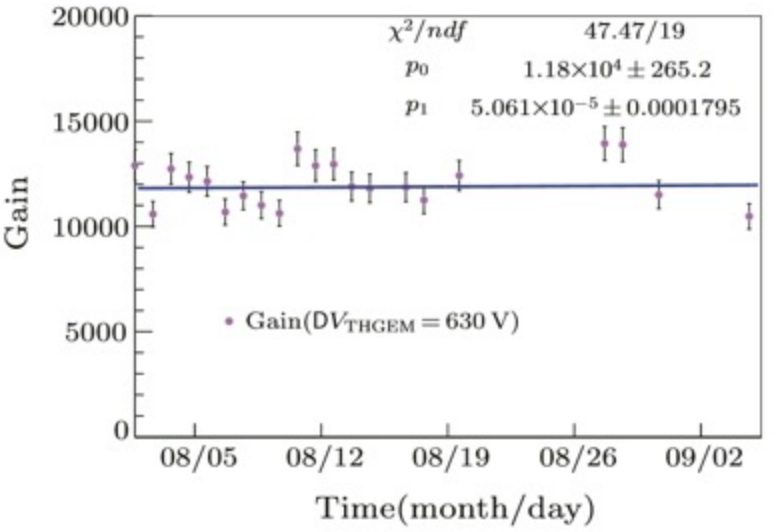
成功研制大面积THGEM探测器 1m*0.5m

(4) 探测器封装技术

- 研究空间探测器材料及封装技术，并对探测器进行简单的真空热循环试验

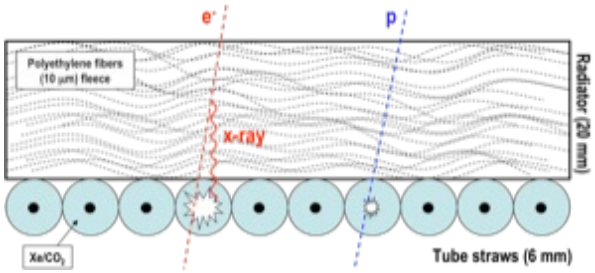


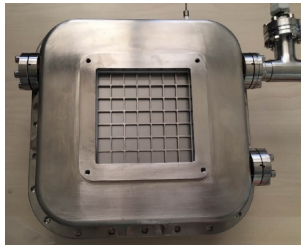


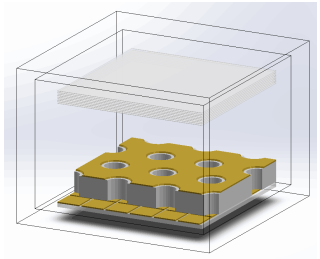


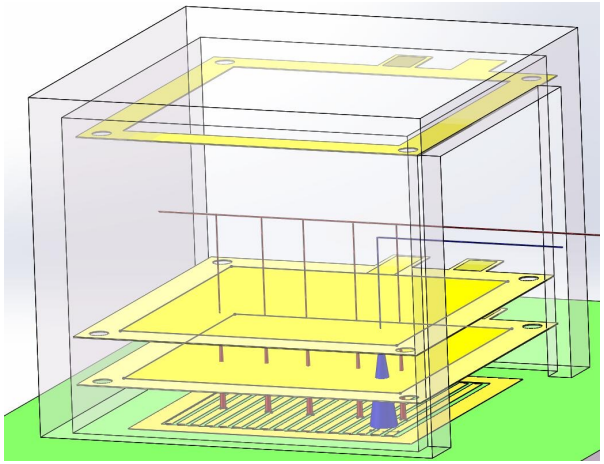
1个月的增益稳定性测试

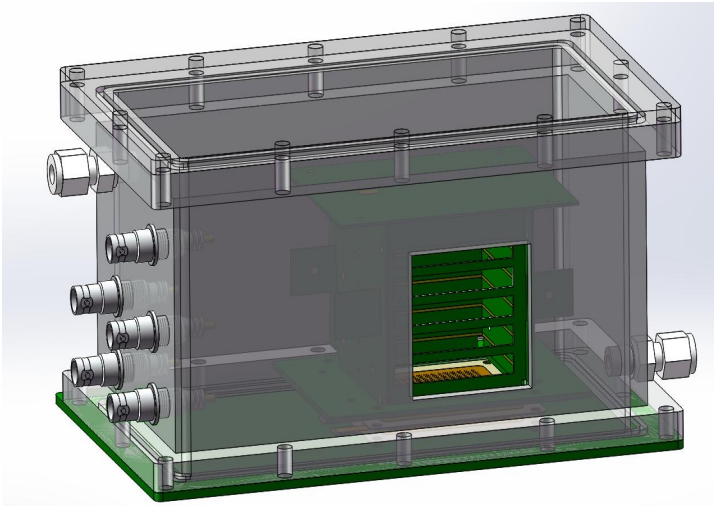
TRD探测器方案





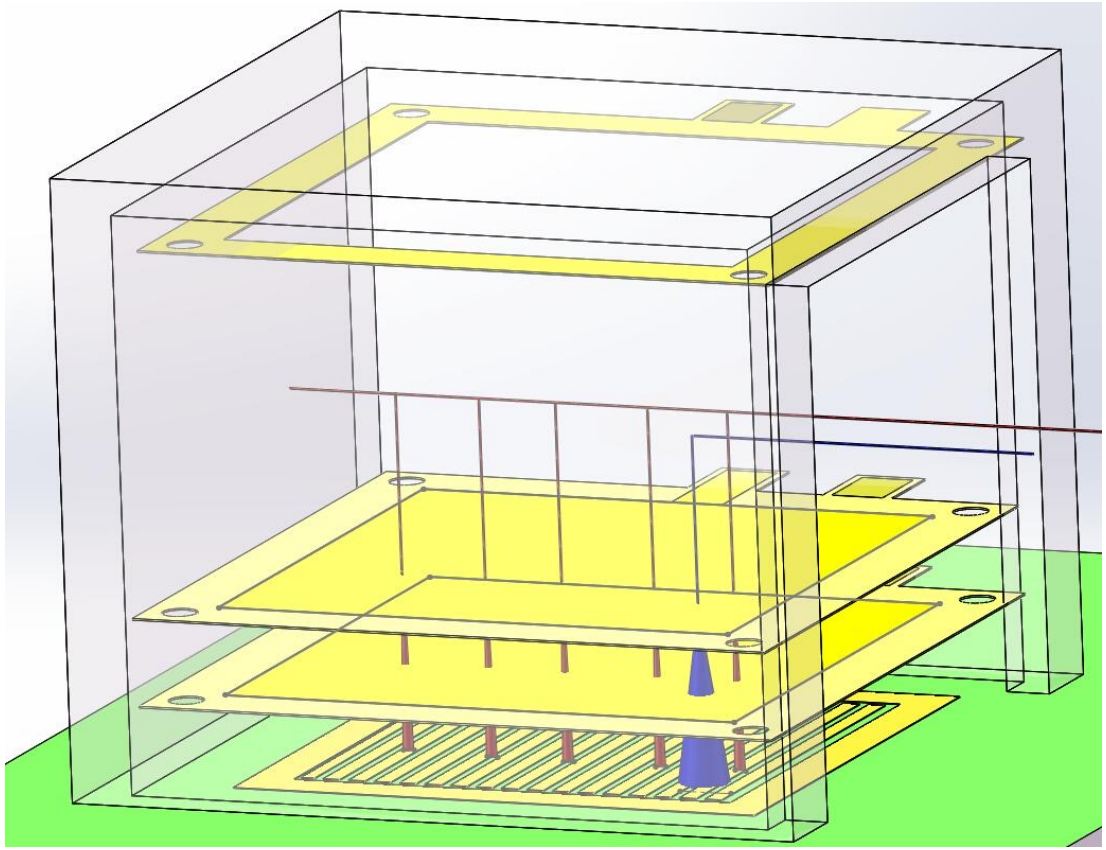






经过多次方案迭代，提出了全新结构的侧窗式TRD

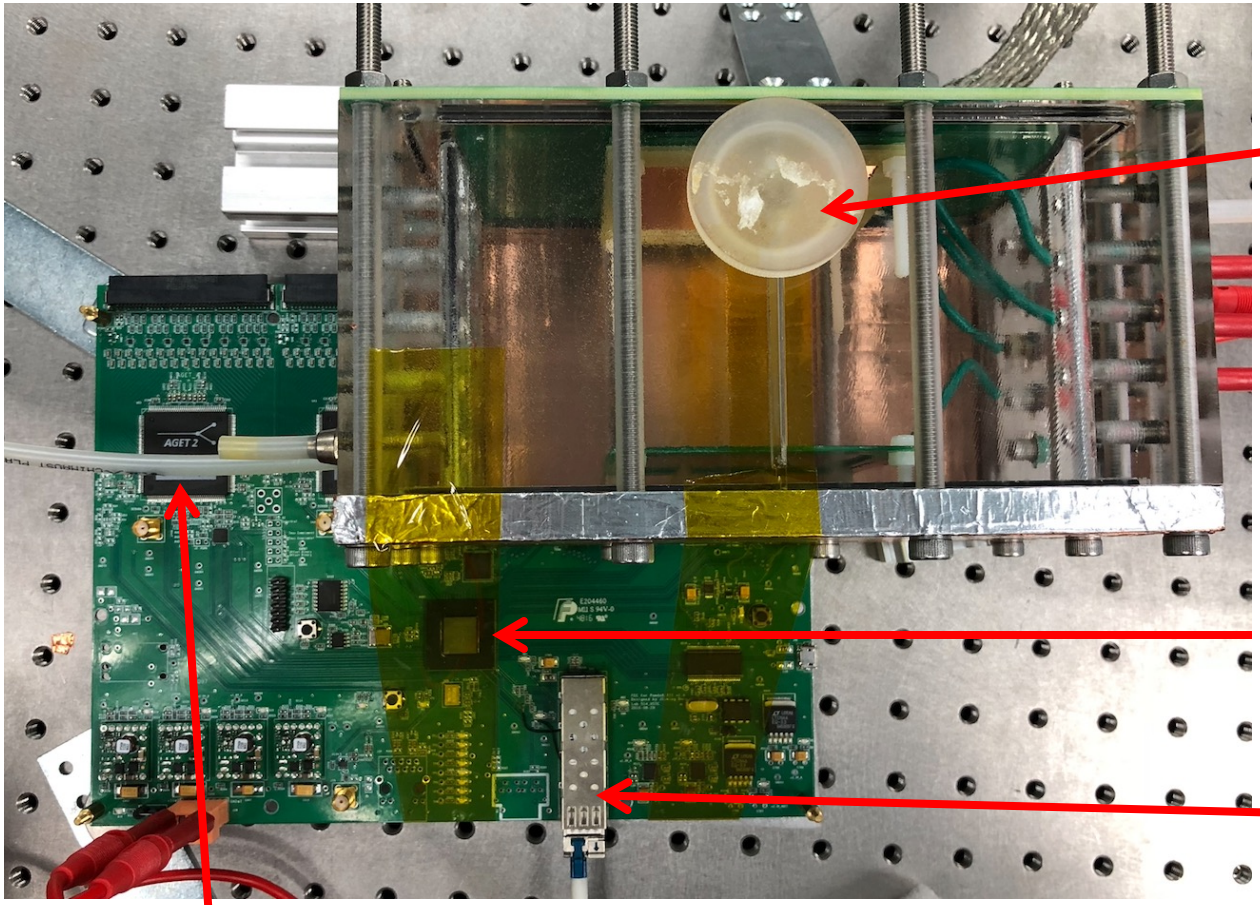
Side-on TRD



- The signals of TR are coupled with dE/dx in detector
- Side-on TRD have the ability to separate the TR signal form dE/dx EVENT by EVENT

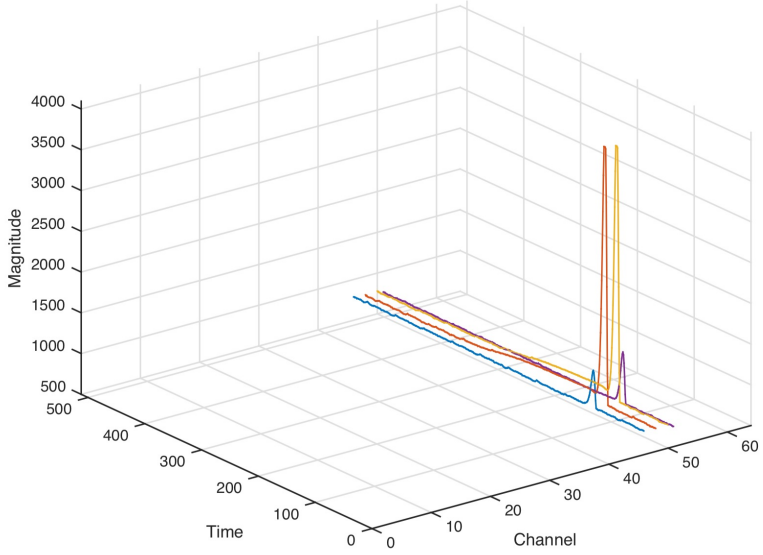
- TR：10 keV @ γ～10^3
- dE/dx：8.7keV/cm @1atm Xe

侧窗TRD原理样机

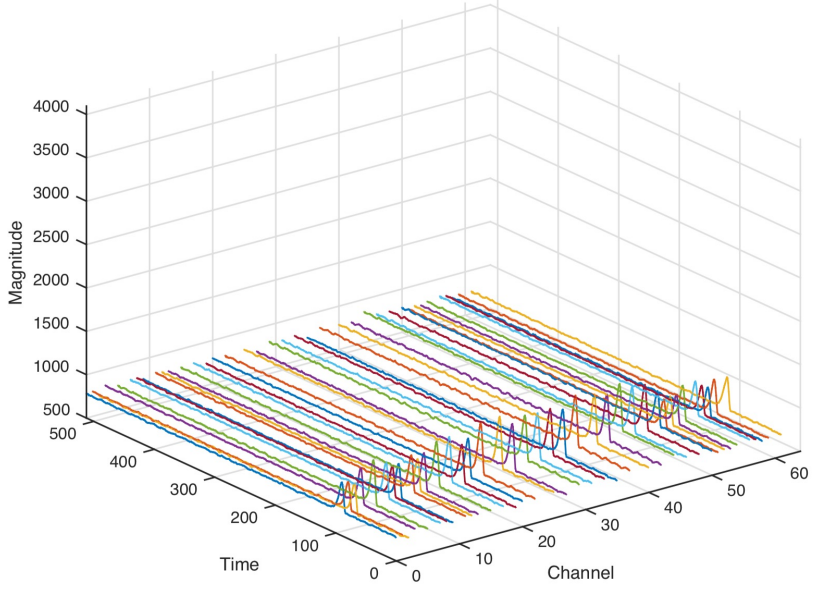


侧窗TRD初步实验结果

5.9 keV X射线

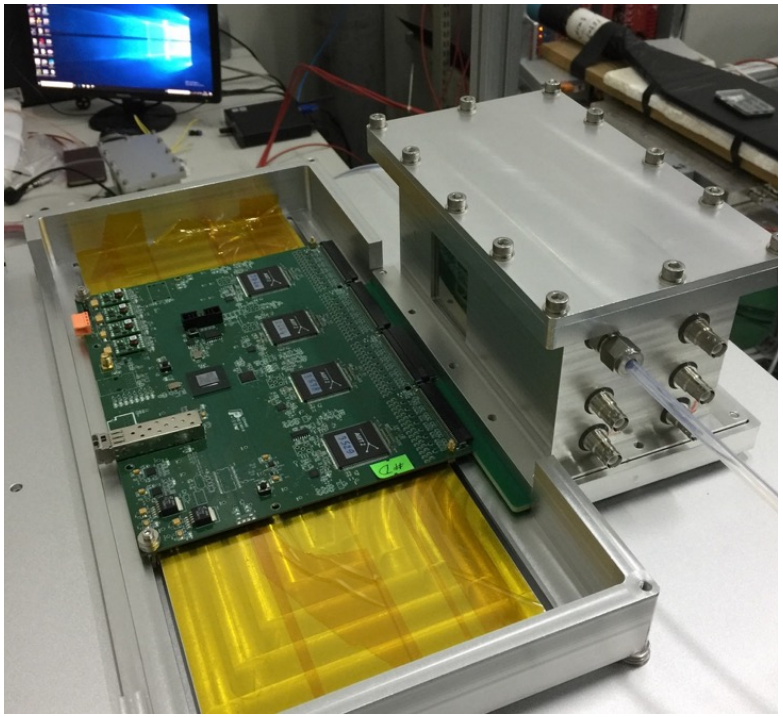


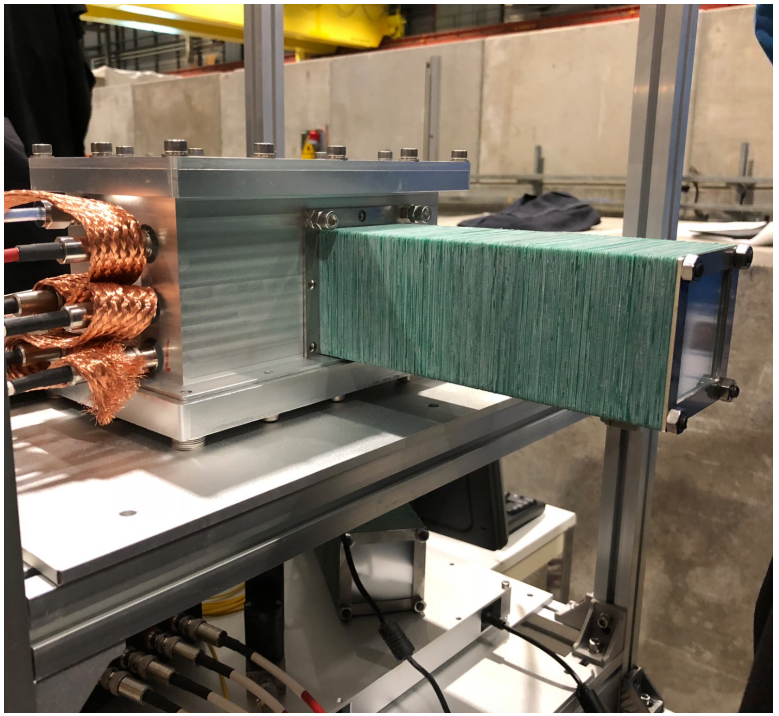
宇宙线



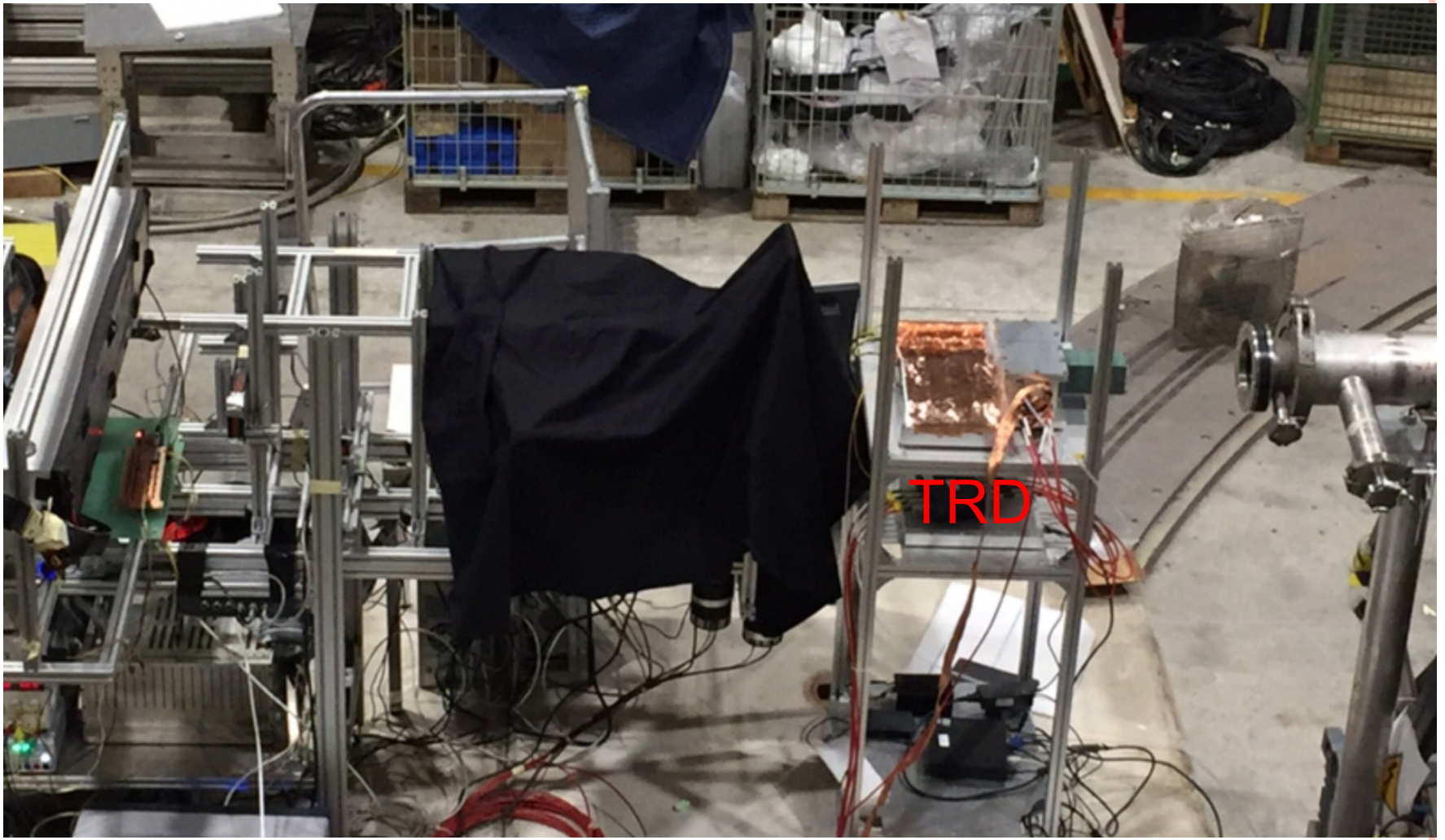
- 实现X射线信号与带电粒子信号逐事例分离
- 有效提高穿越辐射探测灵敏度
- TRD在轨能量标定时间从6个月缩短至1个月
- 欧洲核子中心CERN束流实验进行原理验证

TRD 原理样机

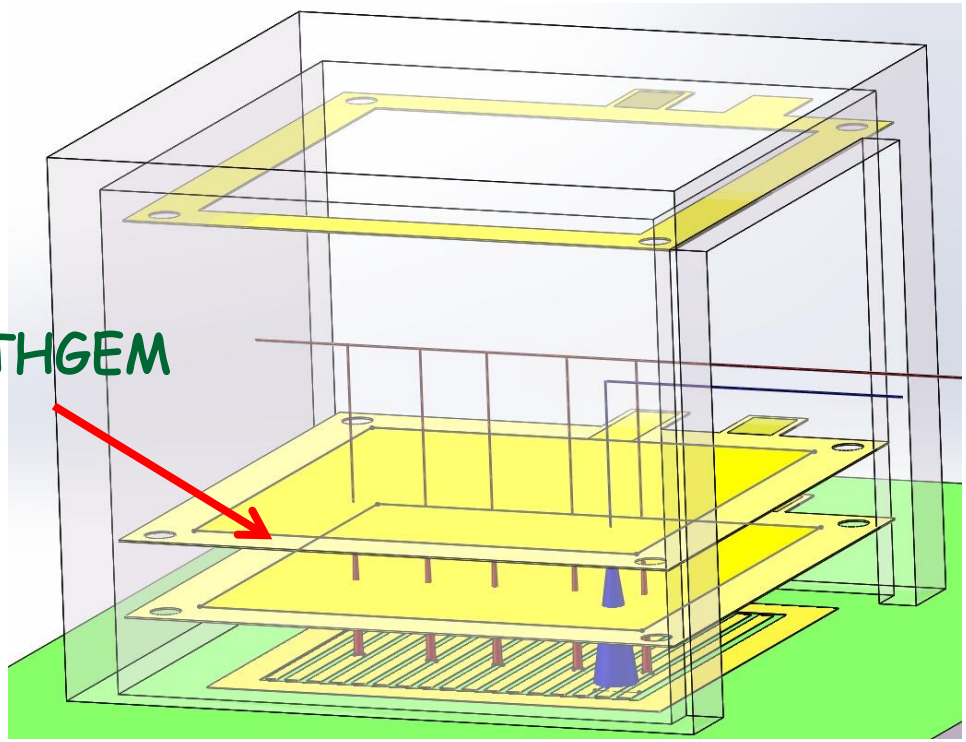


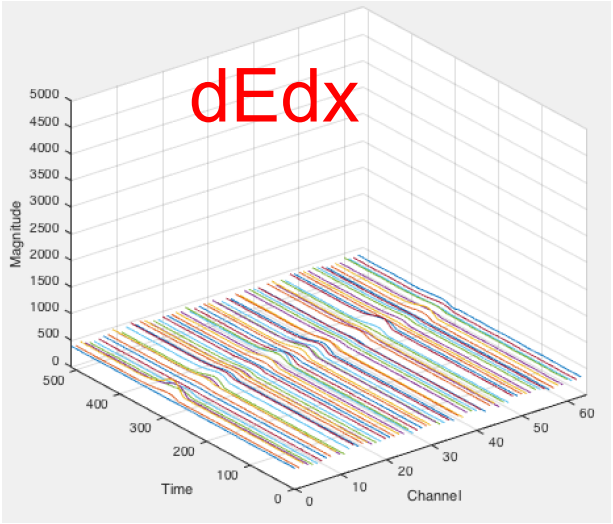


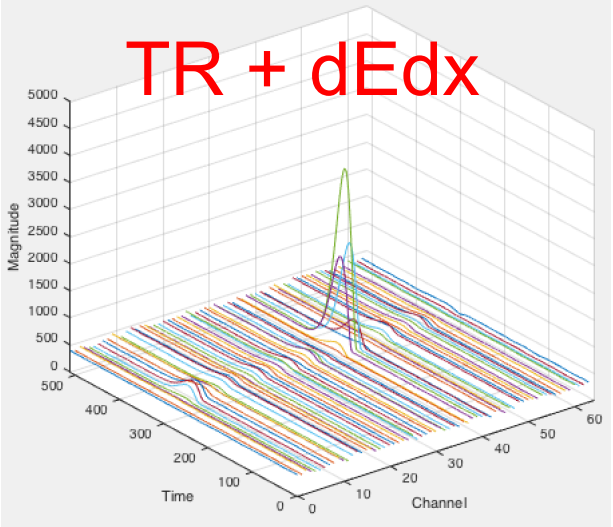
2018.10 Test beam @ CERN



Side-on TRD



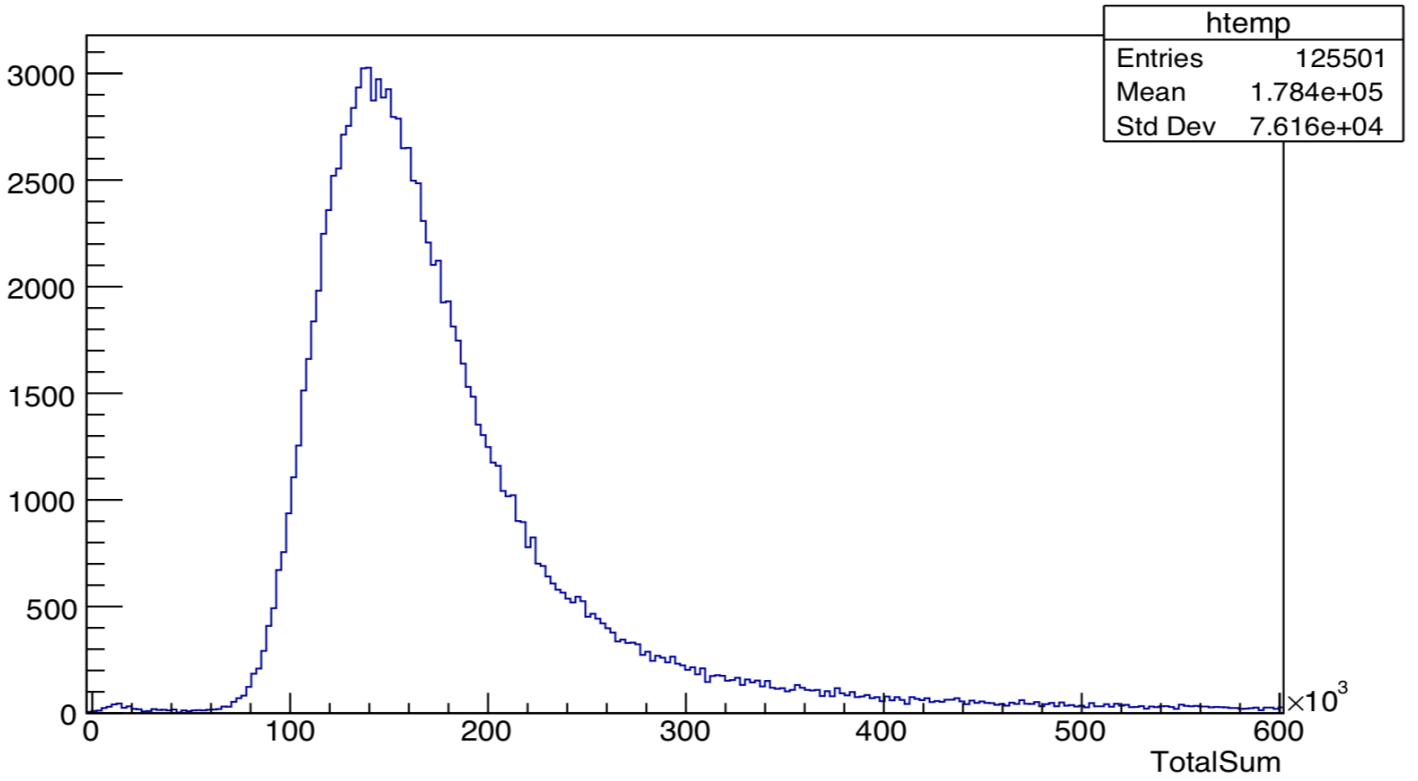




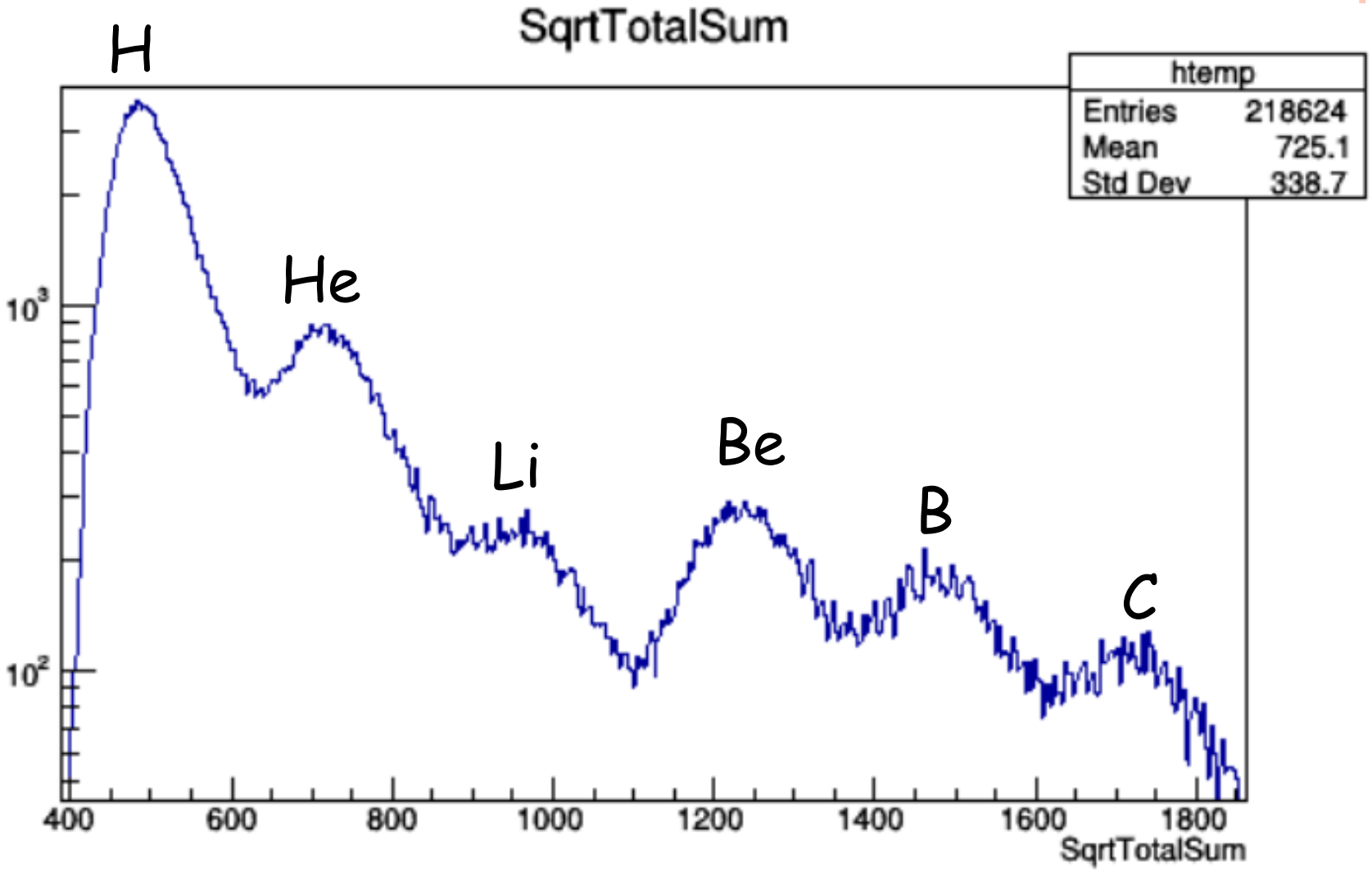
- TR：10 keV @ γ～10^3
- dE/dx：8.7keV/cm @1atm Xe

TRD detection efficiency

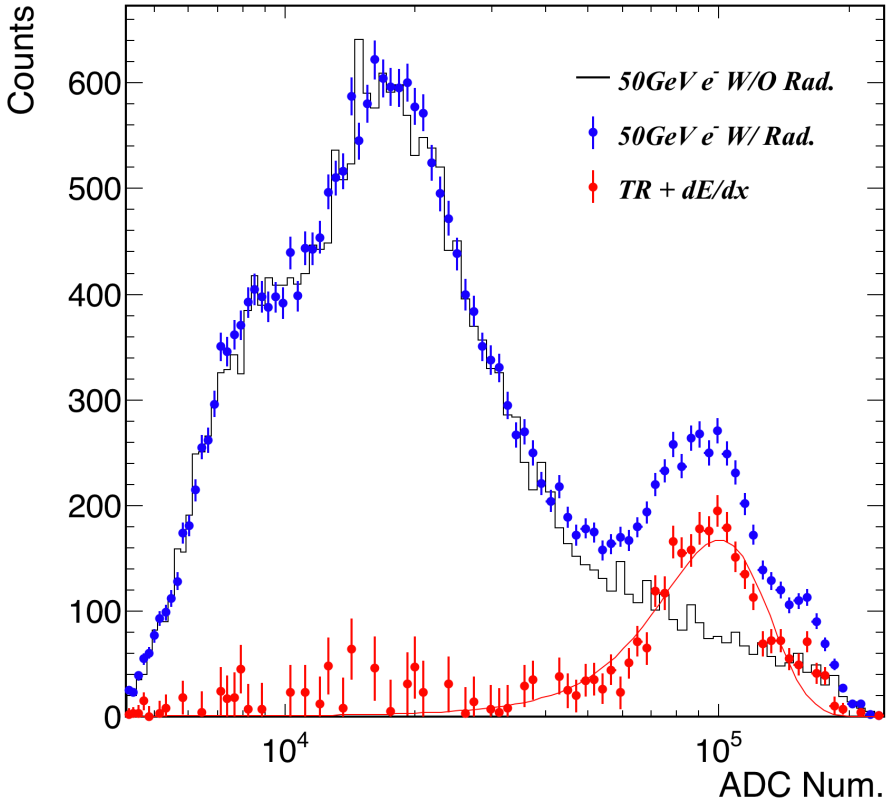
- 400GeV Proton beam
- 99.8% MIP detection efficiency

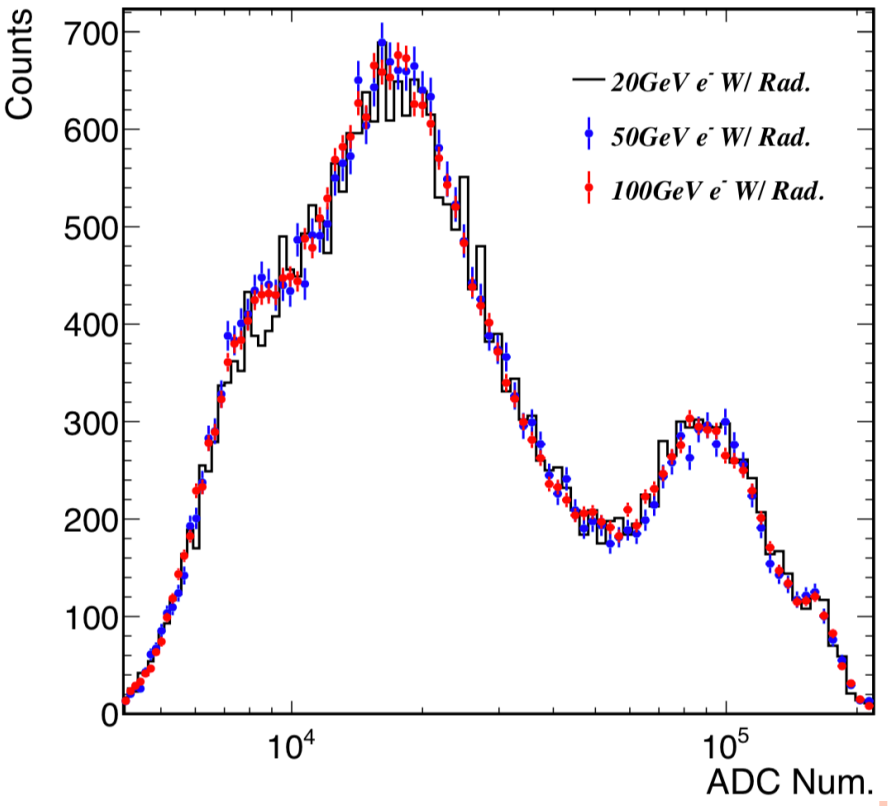


H4 Testbeam


SqrtTotalSum
H
He
Li
Be
B
C
htemp
Entries 218624
Mean 725.1
Std Dev 338.7
10^3
10^2
400
600
800
1000
1200
1400
1600
1800
SqrtTotalSum

TR detection





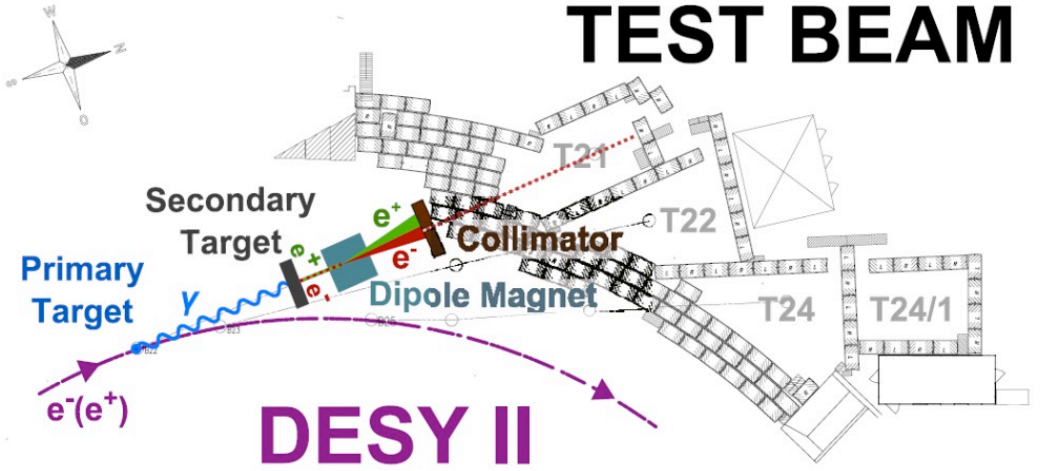
20GeV, 50GeV,100GeV electron beam

Significant TR signal

2019.9 Test Beam @ DESY

e− beam @ TB24

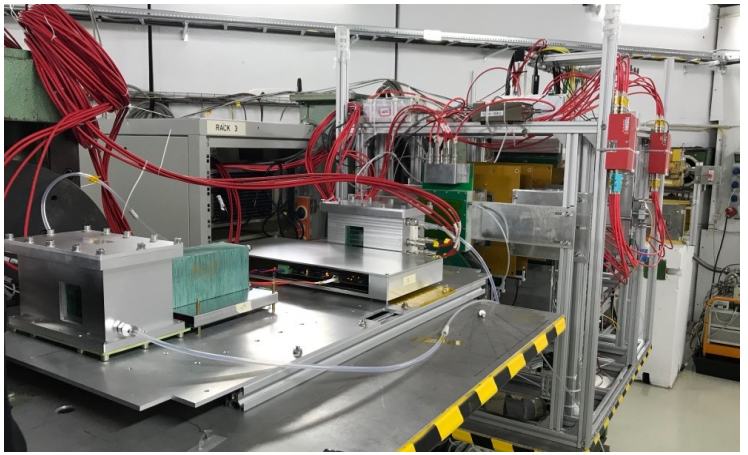
- Beam momentum: 0.4-6GeV/c
- Rate: ~10Hz-4kHz, depending on beam energy etc.

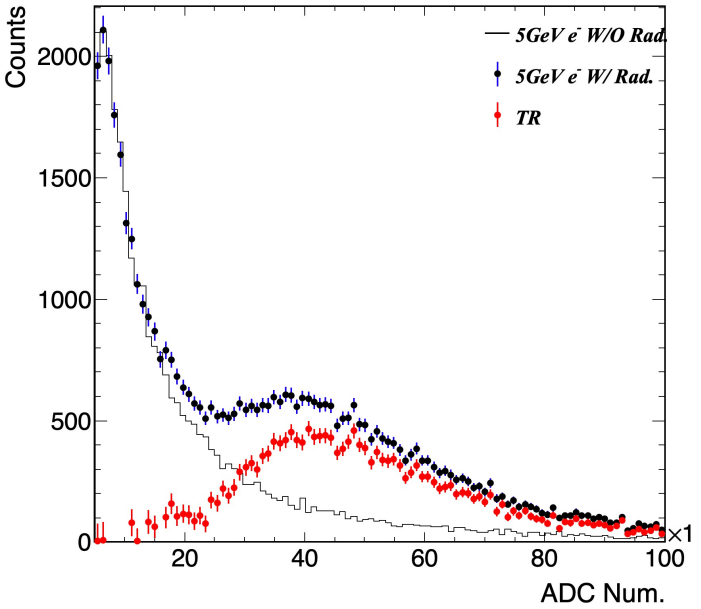


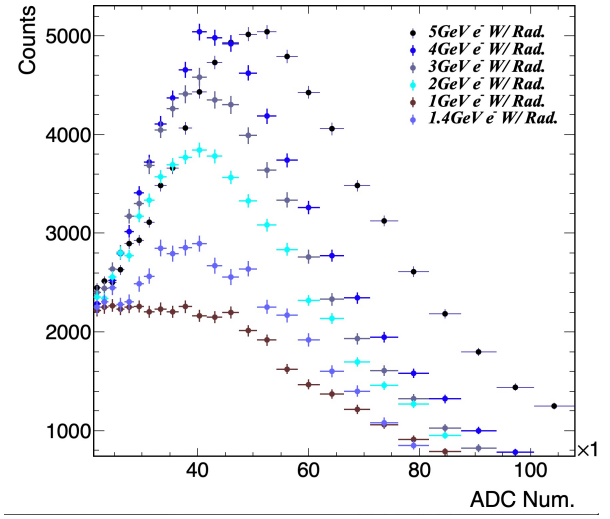
穿越辐射探测器通过束流实验验证

2019年9月DESY束流实验结果：

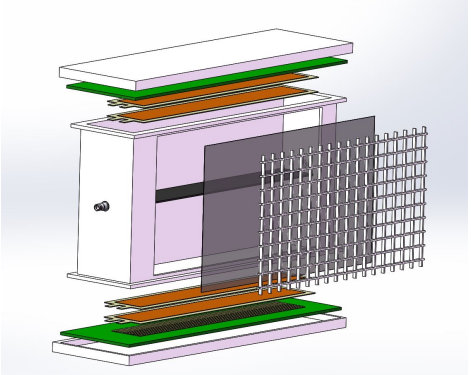
- 完成1-5GeV电子的穿越辐射能量标定
- 完成TRD能量标定原理验证

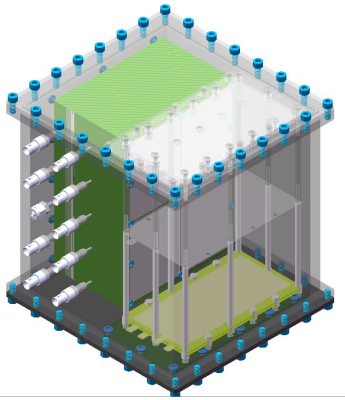


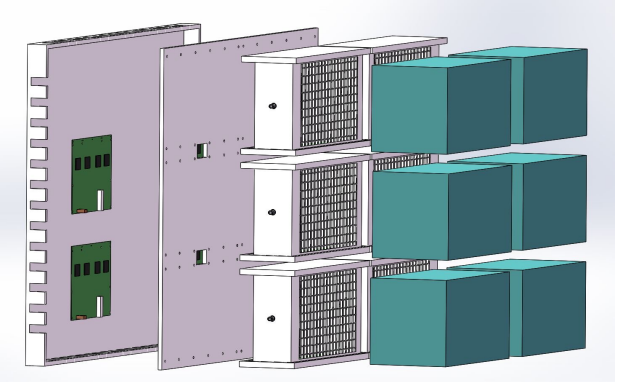


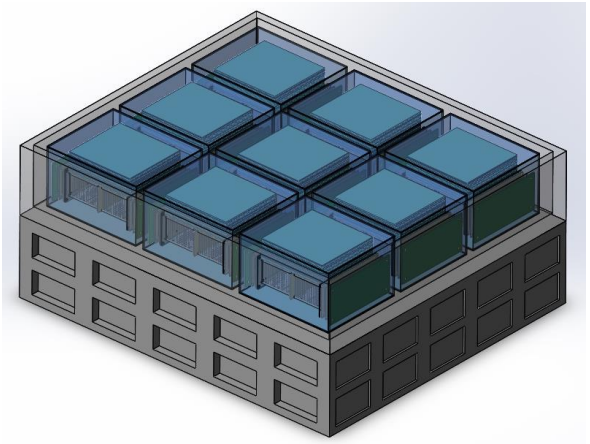


工程样机方案初步









谢谢！