HERD穿越辐射探测器的研制

刘熙文

HERD-TRD合作组

10 August 2023

CONTENT

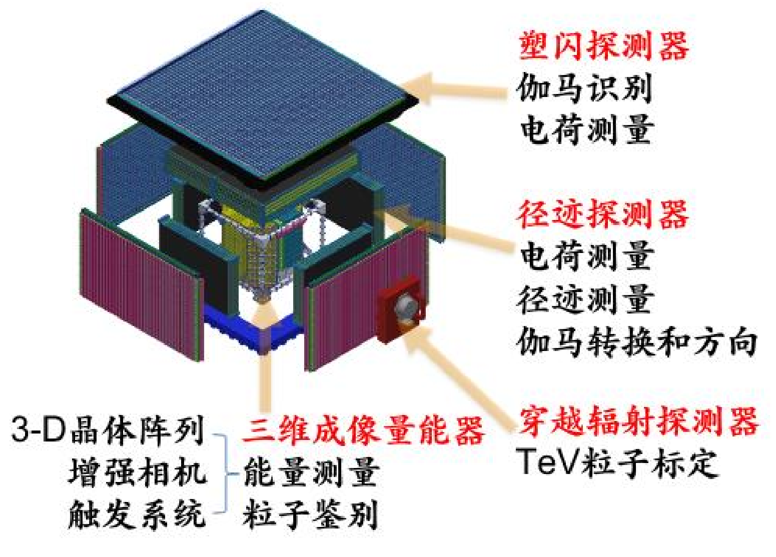
目 录

研究背景

- HERD：高能宇宙辐射探测设施（High Energy cosmic Radiation Detection facility）。
- 科学目标：暗物质探测、高能宇宙线起源和空间高能伽玛射线巡天等。

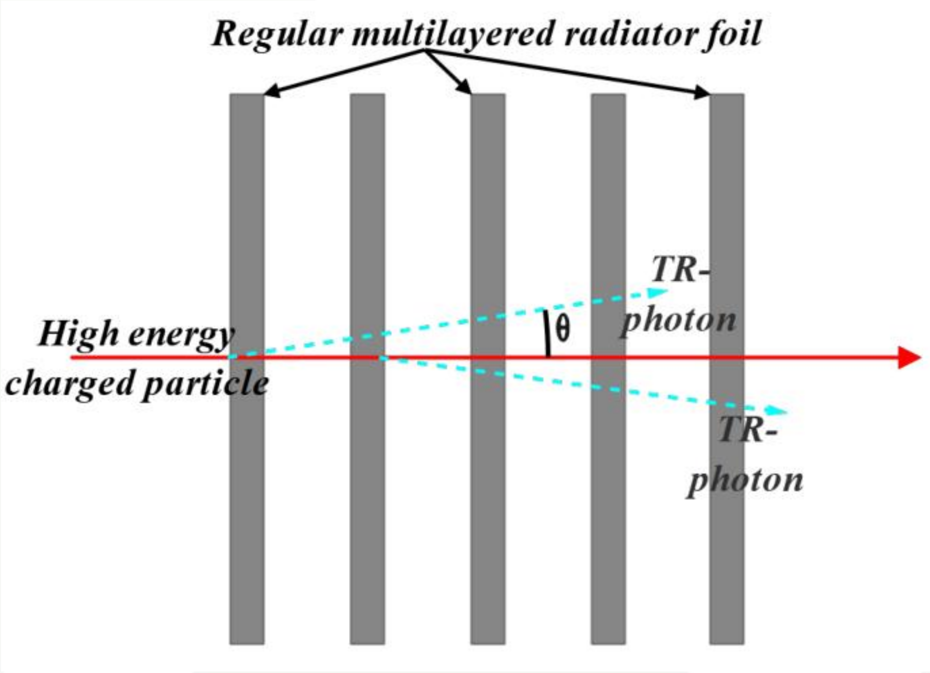
实验(运行时间)	探测能区(e/γ)	能量分辨(e/γ)	e/p鉴别	电子有效接收度 m²sr	质子有效接收度 m²sr
美国卫星FERMI (2008)	1GeV-300GeV	10%	10^{-3}	0.9	--
ISS-AMS-02 (2011)	1GeV-1TeV	2%	10^{-6}	0.12	0.12
ISS-CALET (2015)	1GeV-10TeV	2%	10^{-5}	0.12	--
中国卫星DAMPE(2015)	10GeV-10TeV	1%	10^{-5}	0.3	0.2
ISS-CREAM (2017)	100TeV(p)	--	--	--	0.2
中国空间站HERD (2025)	10GeV-10TeV (e/γ) 3PeV (p)	1%	10^{-6}	>3	>2

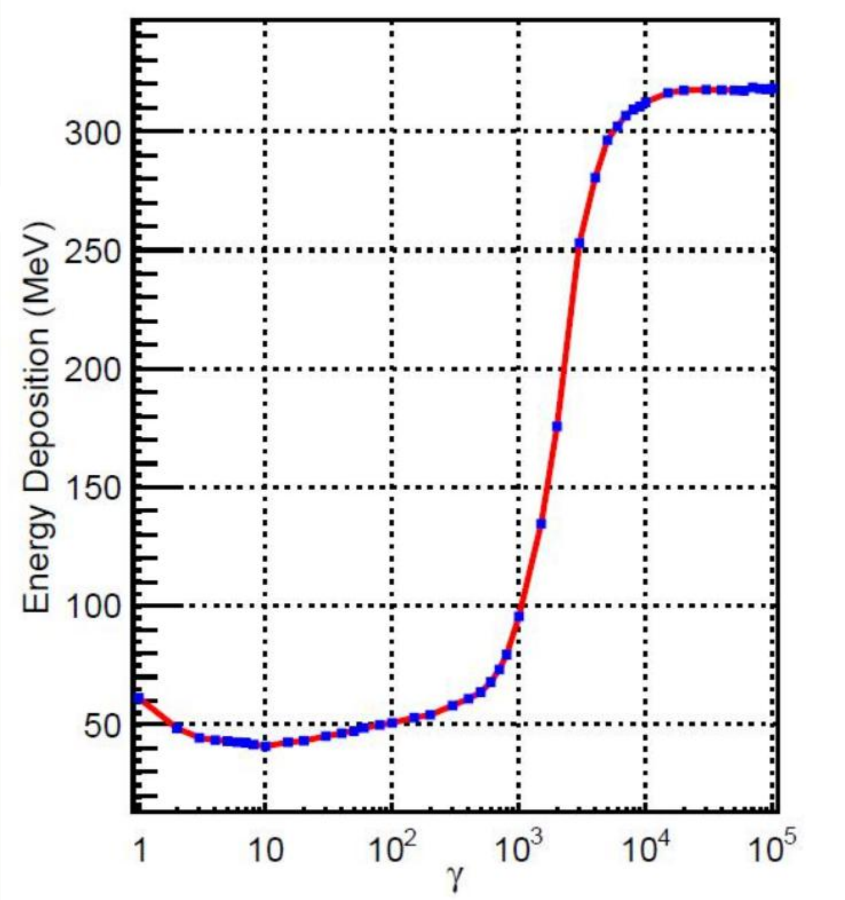
大探测能区、大有效几何因子、高能量分辨率、高粒子鉴别能力等突出优势。



穿越辐射探测器(Transition Radiation Detector, TRD)利用高能带电粒子的穿越辐射对洛伦兹因子的依赖关系，**对HERD量能器进行TeV能段质子的能量标定**。

穿越辐射原理及能量标定方法

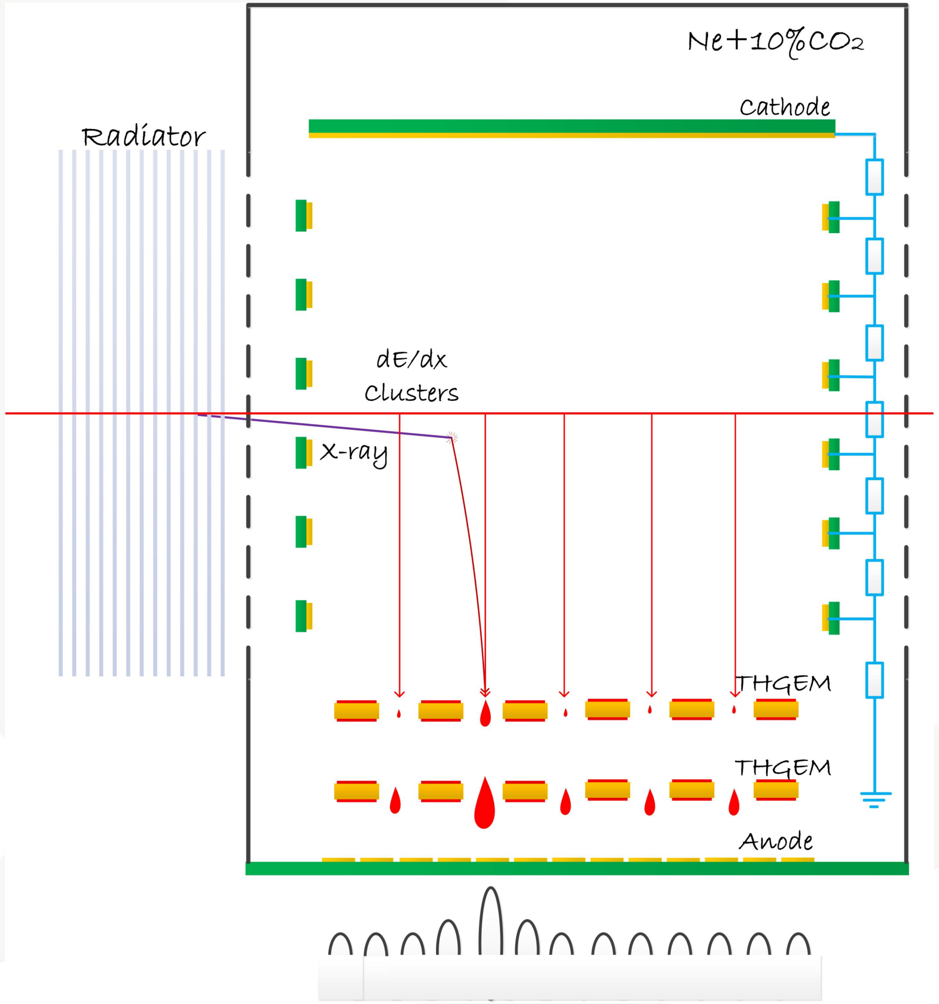


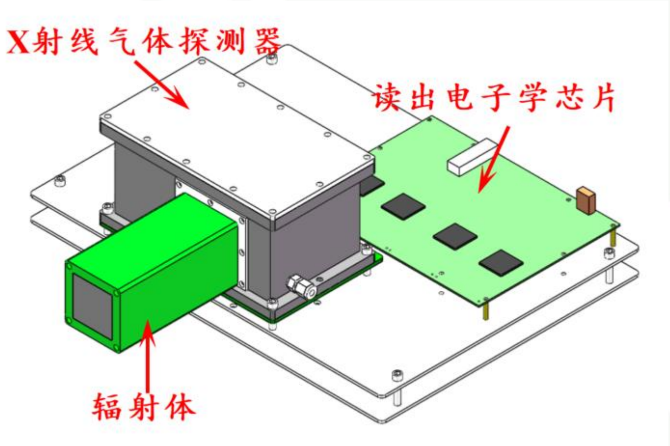


蒙卡模拟给出的电离沉积与洛伦兹因子γ的关系曲线

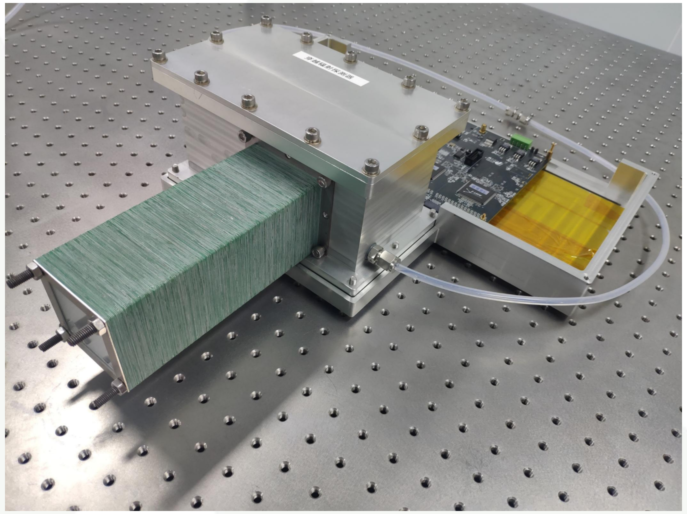
- 穿越辐射特性：
  1. 形成区效应
  2. 最可几发射角$\theta \sim 1/\gamma$
  3. TR光子集中于X射线能区@聚酯等
  4. N层箔片TR光子产额~Nα
  5. TR产生阈值$\gamma \sim 10^3$，饱和于$\sim 10^4$

原理样机:基于THGEM侧窗式TRD



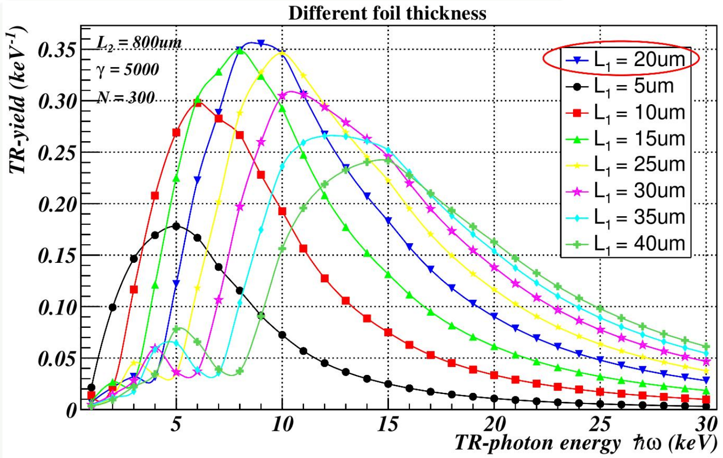


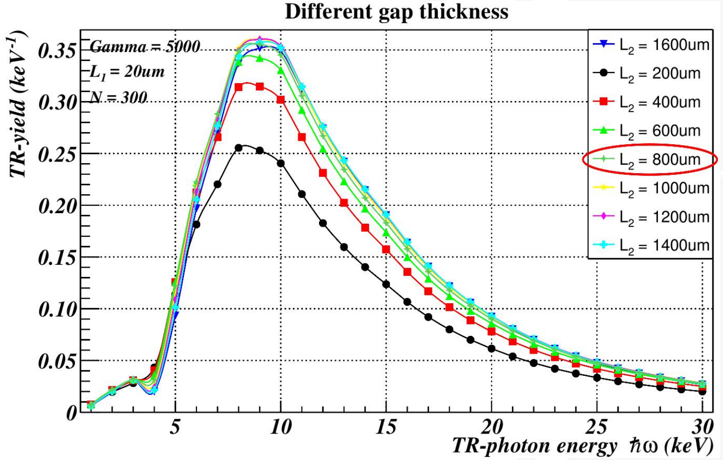
- 以提高探测TR光子数及降低电离本底为目的，实验组设计了侧窗式穿越辐射探测器原理样机

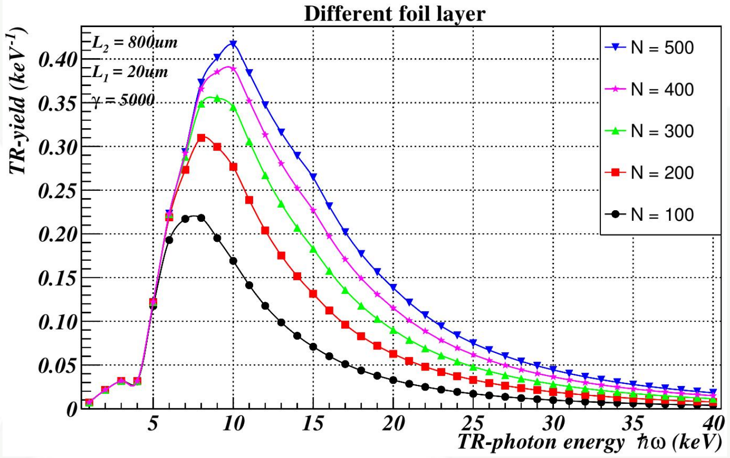


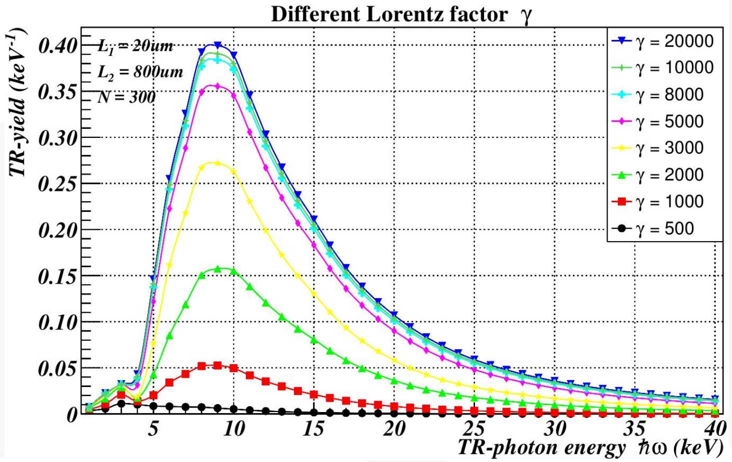
- TRD原理样机
  - 规则辐射体
  - 64路条读出

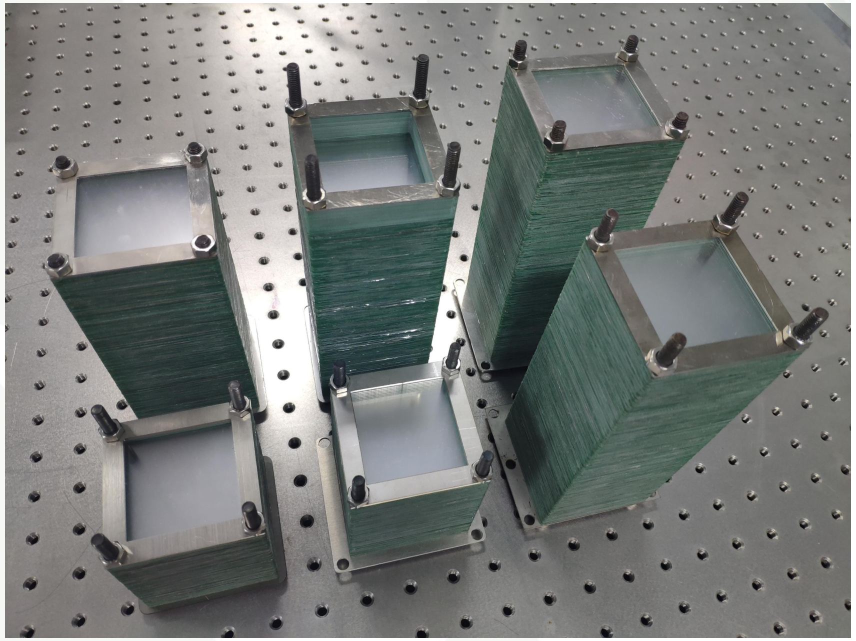
TRD原理样机：规则辐射体





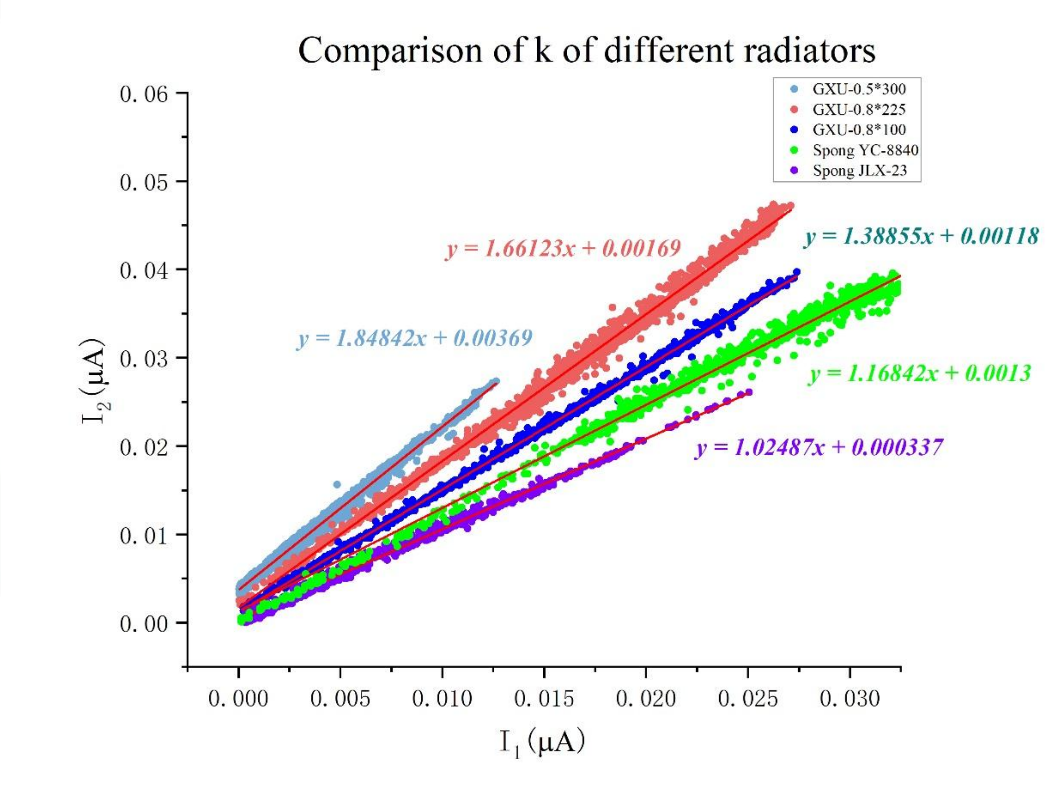






TRD原理样机辐射体最优参数	
箔片材料	聚丙烯(PP)
间隙材料	空气
箔片厚度	20um
间隙厚度	800um
箔片层数	300

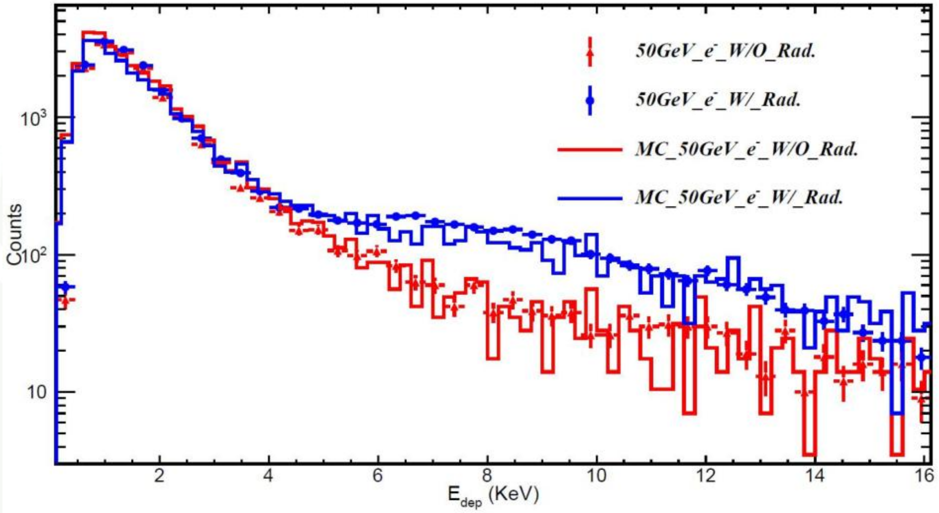
束流实验 @IHEP

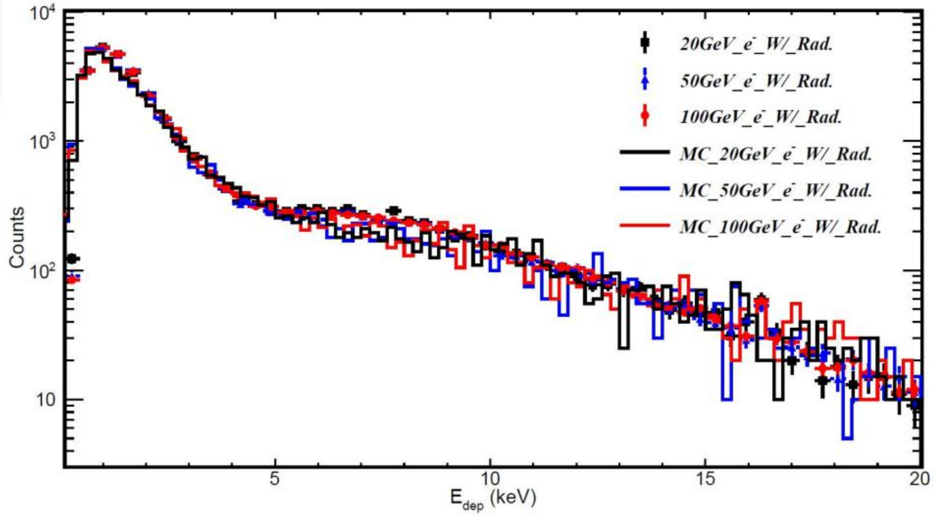


2019.12 @ IHEP, 2.5GeV electron

[1] Gu J , Liu H , Huang X ,et al.The photon yield efficiency study of transition radiators at E2 line of Beijing Test Beam Facility[J].Journal of Instrumentation, 2021, 16(08):P08041 (17pp).DOI:10.1088/1748-0221/16/08/P08041.

束流实验 @CERN



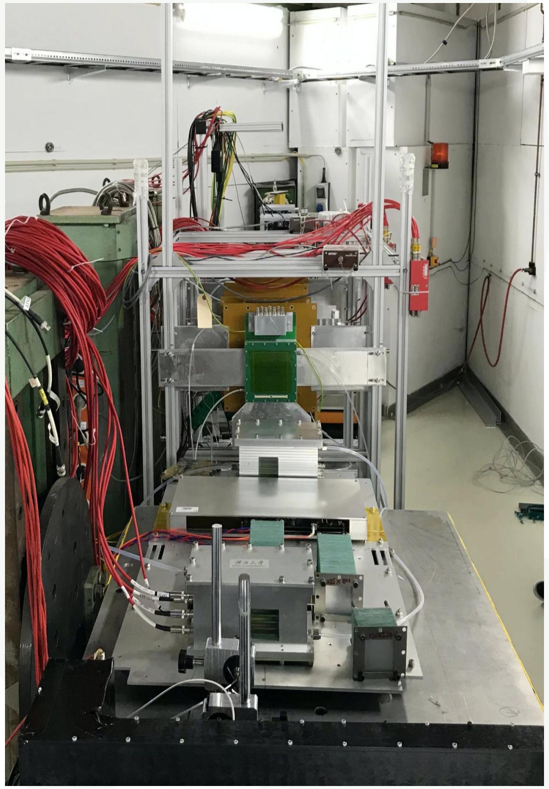


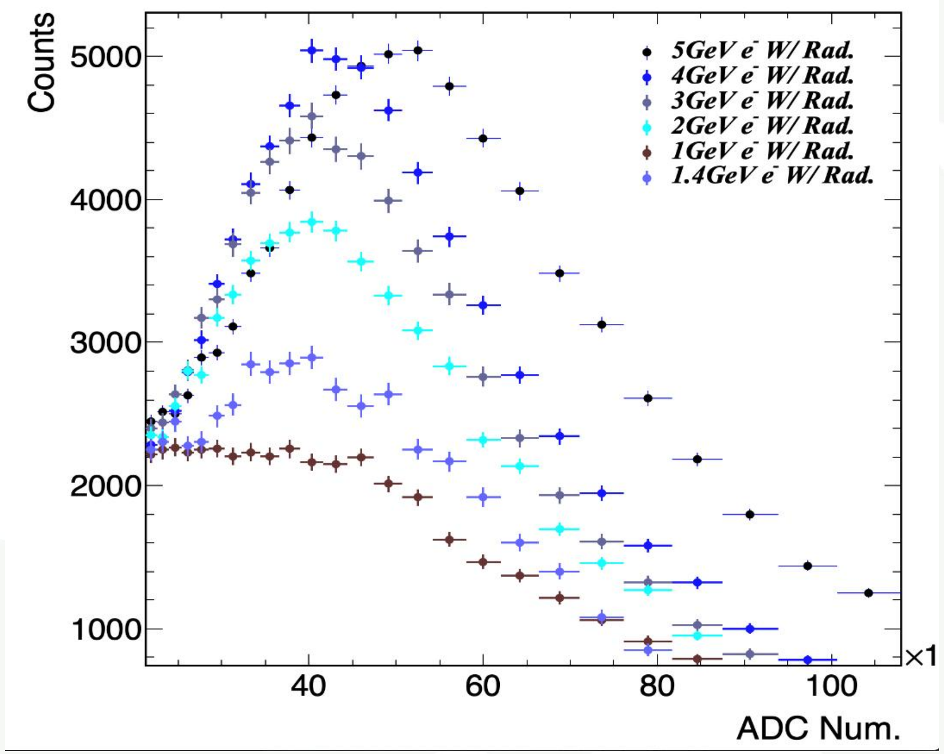
5cm 90%Ne+10%CO_2

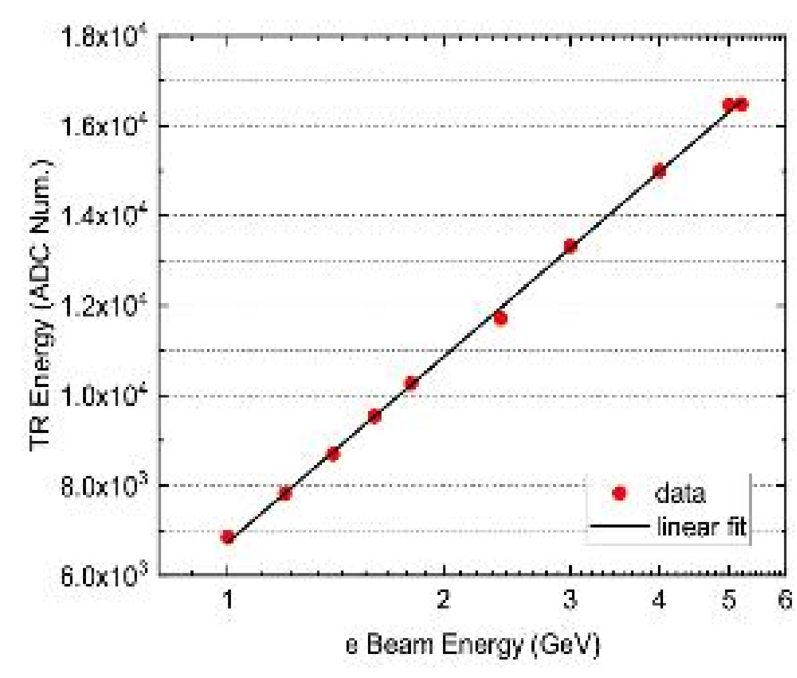
- ➢ 50GeV电子观测到明显的TR信号
- ➢ 20/50/100GeV电子的TR饱和效应

[1] Liu X , Huang B , Feng H ,et al.Side-On transition radiation detector (TRD) based on THGEM[J].辐射探测技术与方法(英文), 2020(3):6.DOI:10.1007/s41605-020-00178-w.
[2] Huang B , Liu H , Huang X ,et al.Side-On transition radiation detector: A detector prototype for TeV energy scale calibration of calorimeters in space[J].Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 962[2023-08-09].DOI:10.1016/j.nima.2020.163723.

束流实验 @DESY

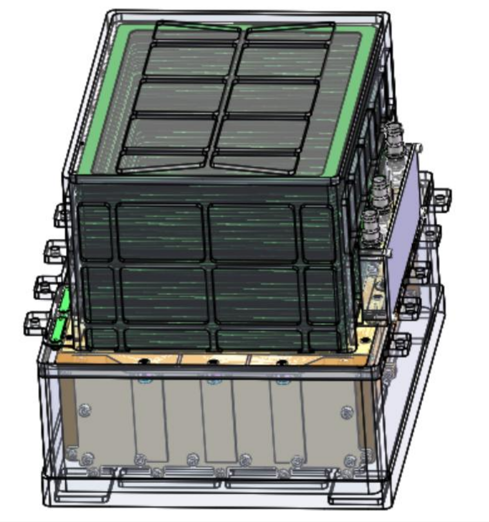


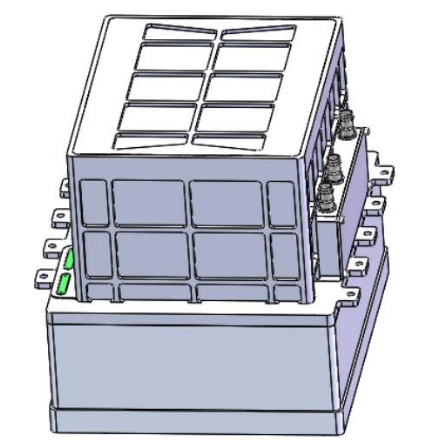


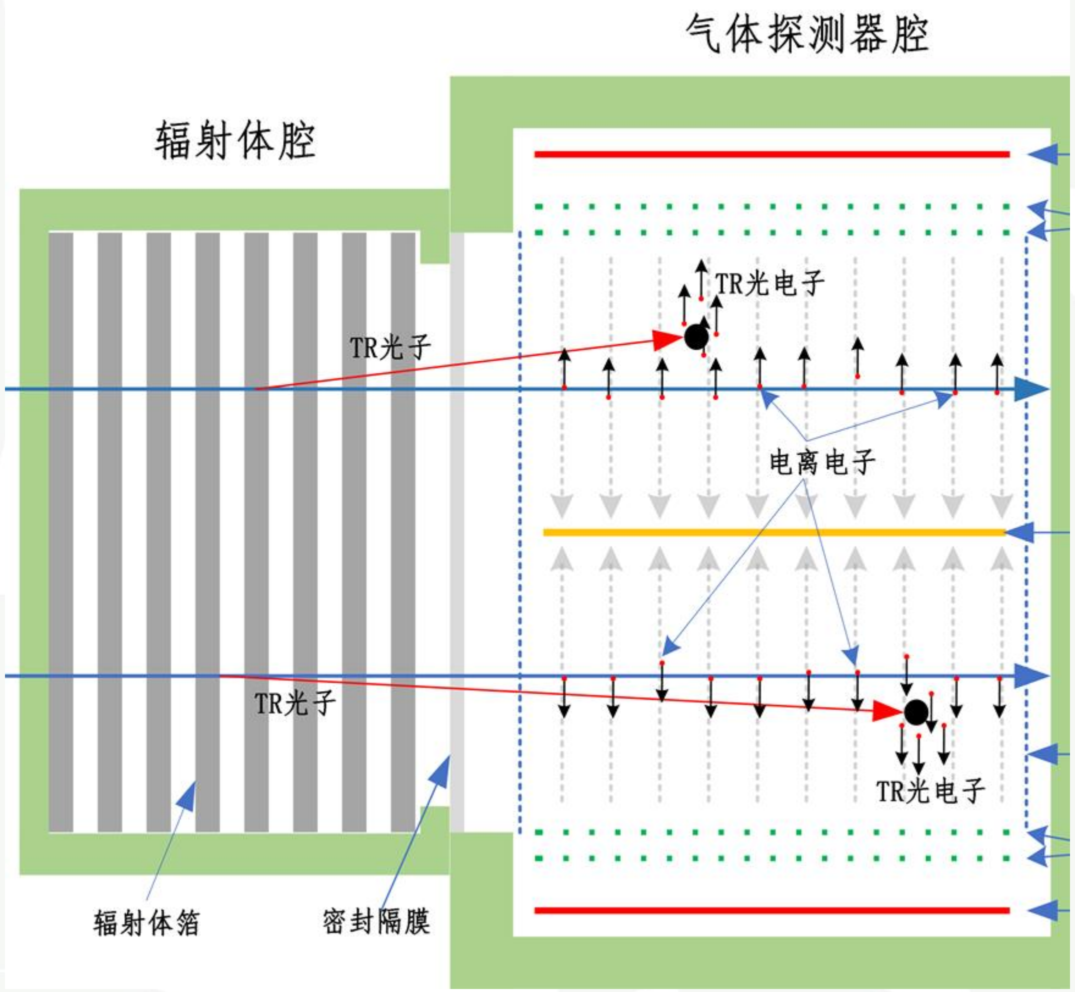


2019.09 @ DESY, 0.4-6GeV electron

工程样机:共腔式穿越辐射探测器

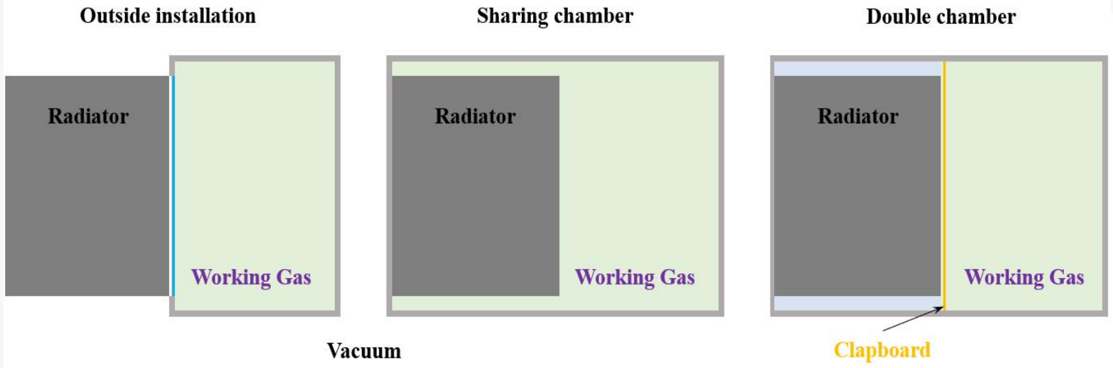


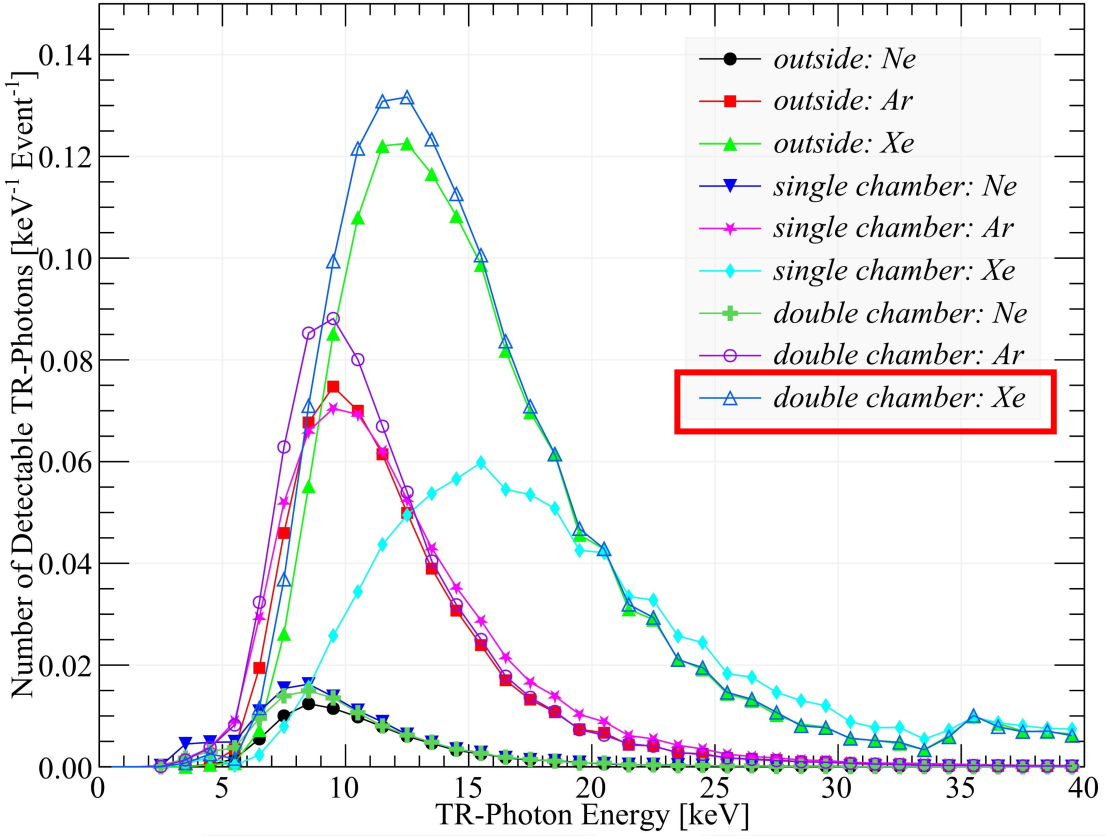




- ➤ **TRD工程样机**
  - ➤ **辐射体内放置**
    - ➤ 减小无效区吸收
    - ➤ 利于工程上的实现
  - ➤ **对称读出方式**
    - ➤ 增大有效面积
  - ➤ **丝结构场笼**
    - ➤ 减小电场不均匀区厚度

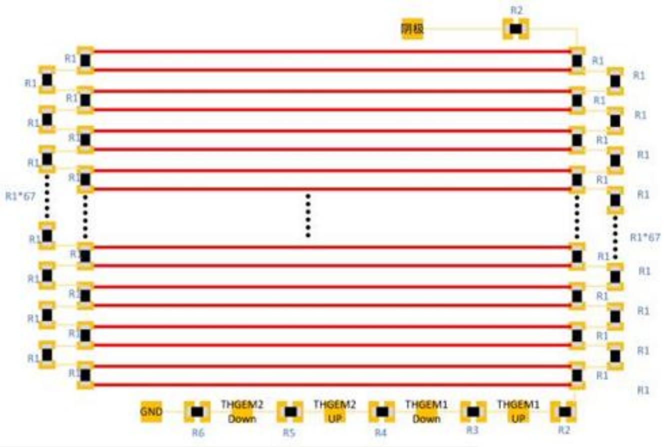
工程样机探测器结构研究



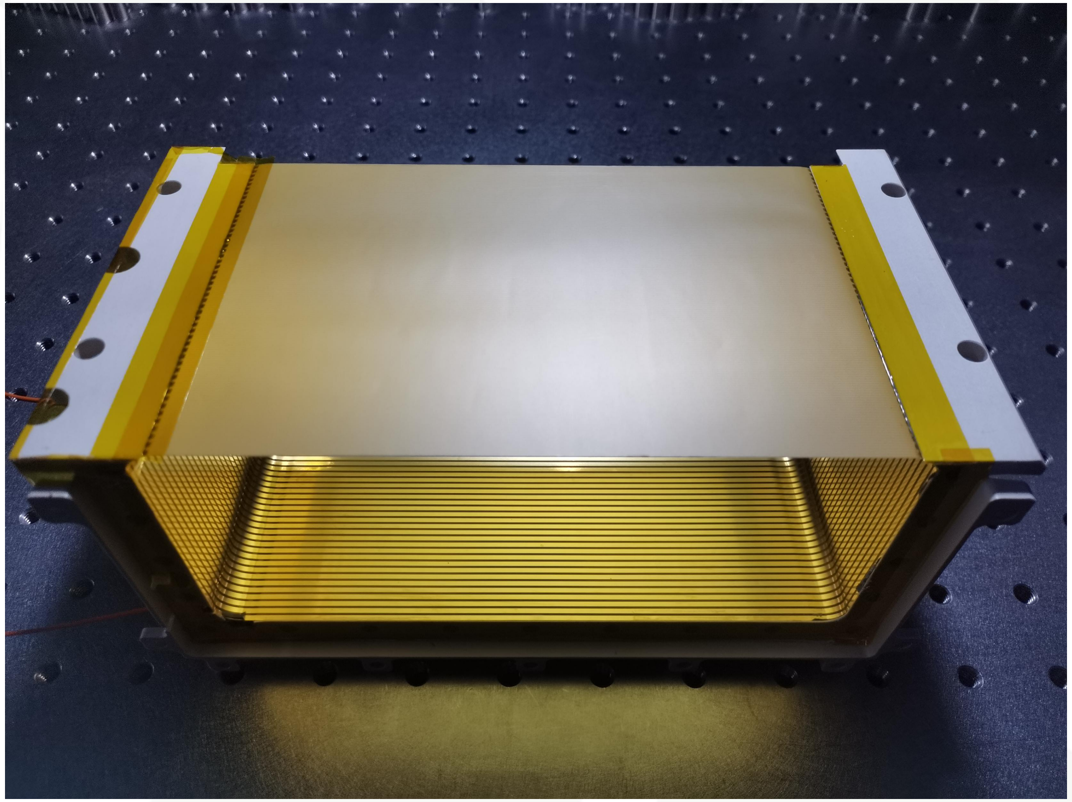


- 氙气为工作气体的穿越辐射信号显著性最高
- 双腔室与辐射体外放置有接近的可探测TR光子数，但双腔室的工程风险更低
- TRD结构：双腔室结构

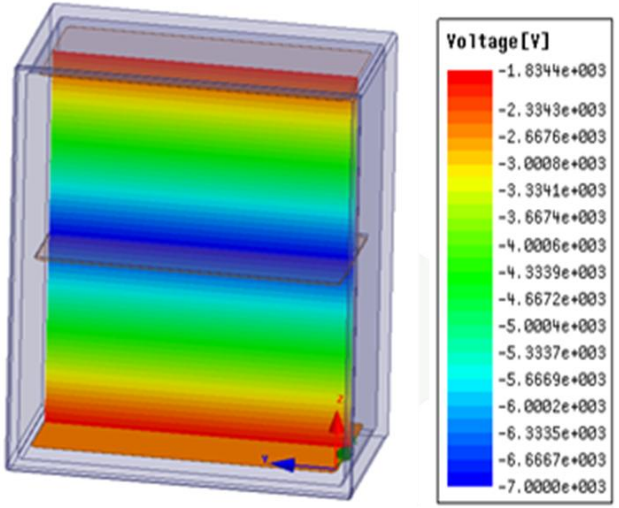
工程样机的场笼研制



- 场笼采用FPC技术
- 增加粒子透过率
- 增加电场的均匀性

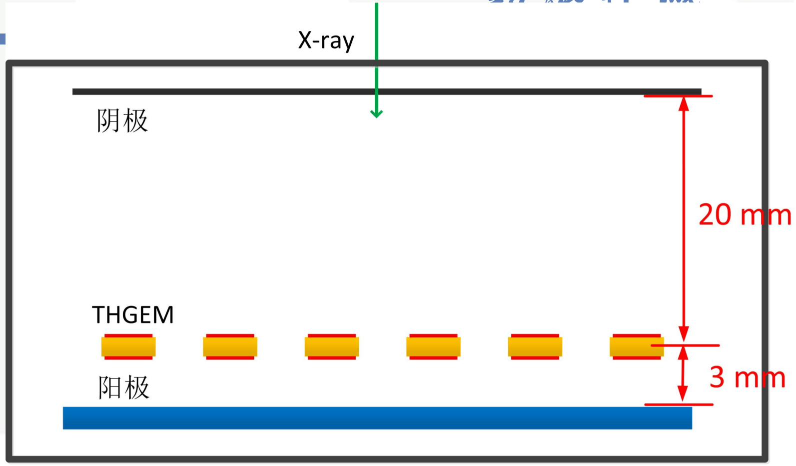


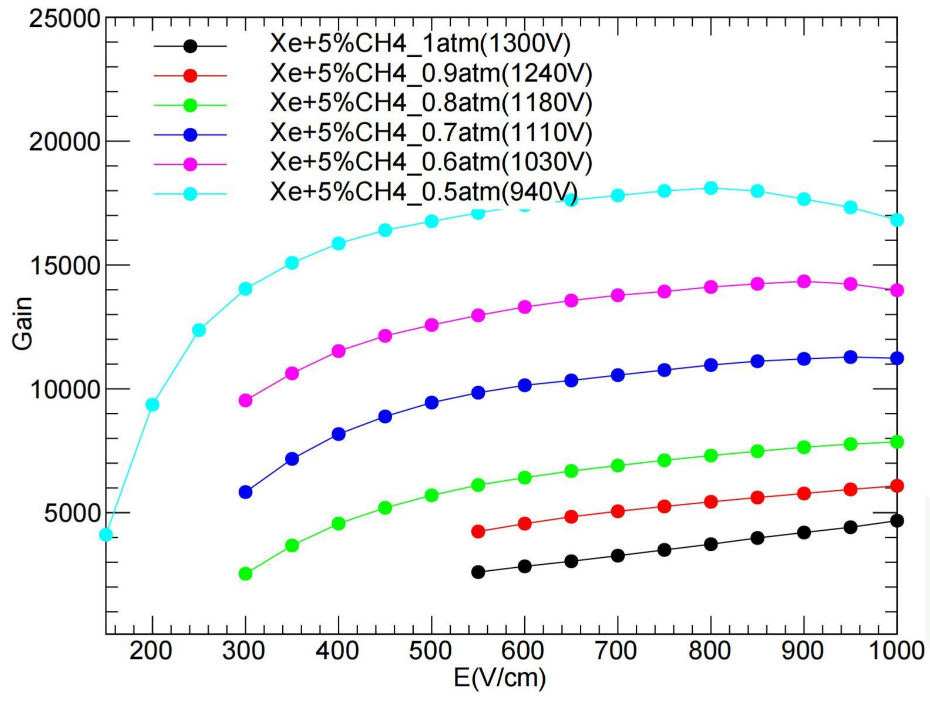
- 电场均匀性模拟



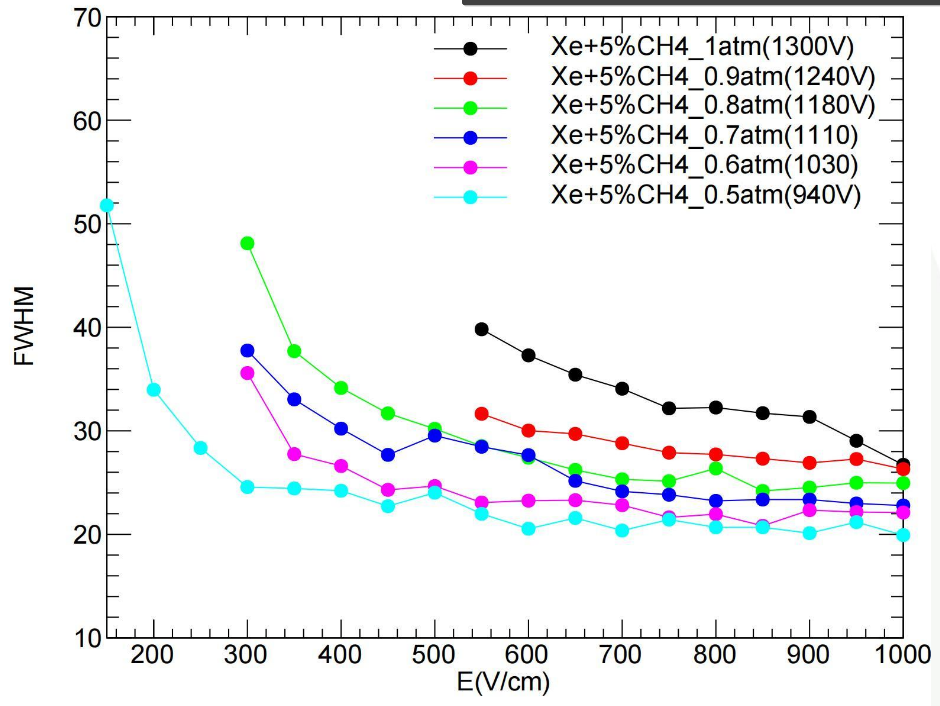
工程样机工作气体的研究

- 单层THGEM
- 密封腔室





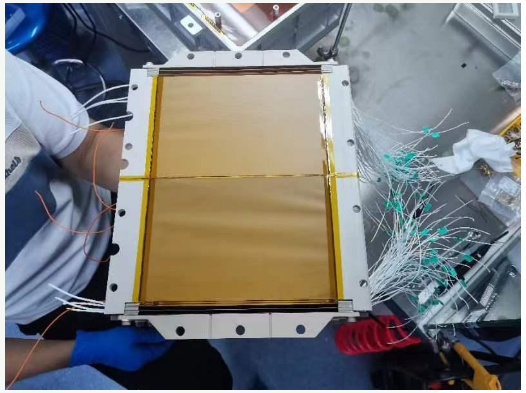
增益曲线

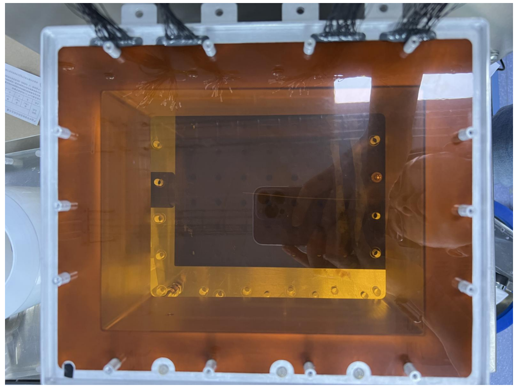


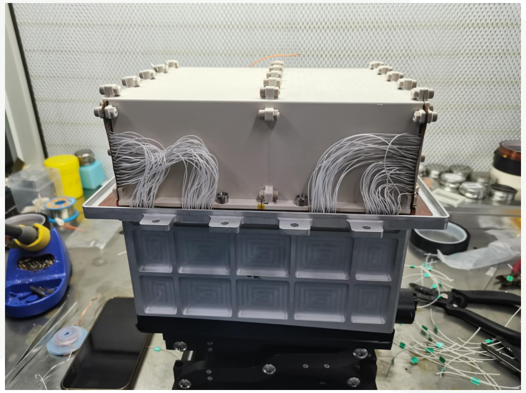
能量分辨率曲线

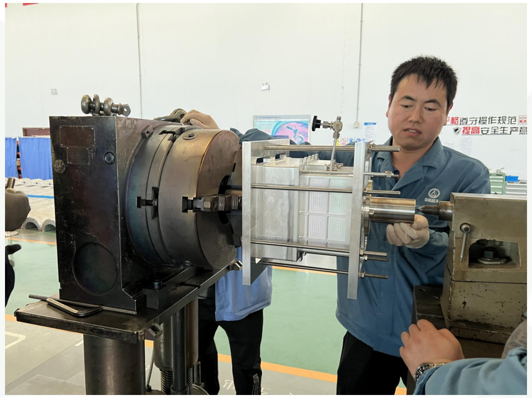
工程样机的工程化

探测器工程化组装

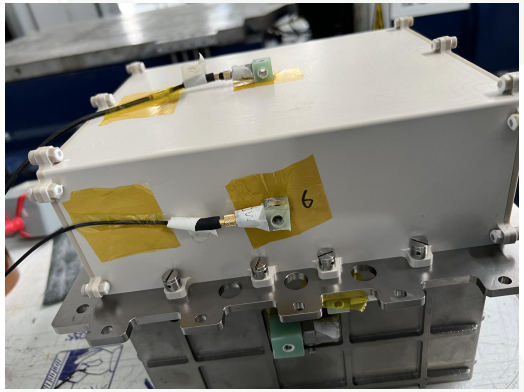


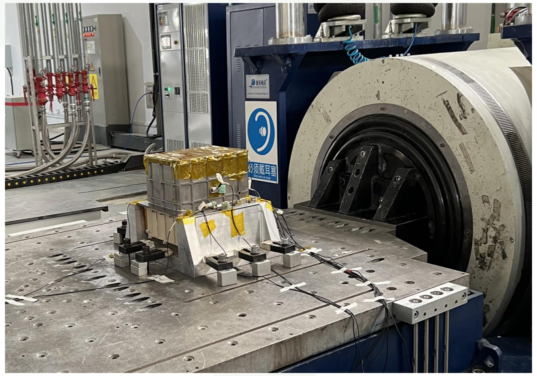


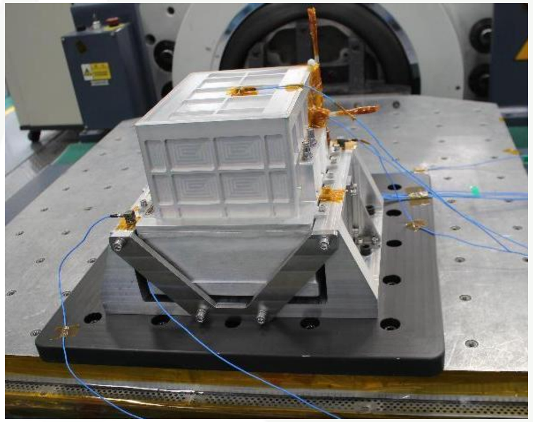


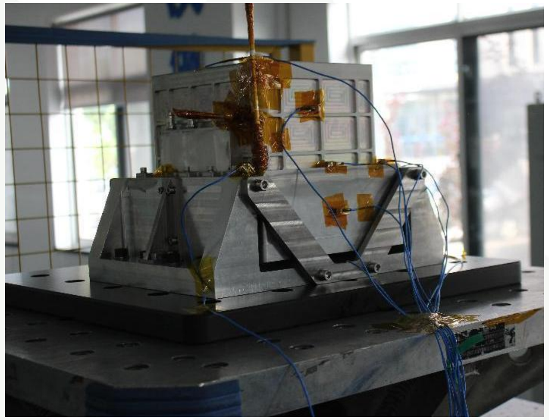


探测器环境试验--力学









总结与展望

- **总结**
  - 目前实验组已使用TRD原理样机进行多次束流测试，实验结果都与理论预期吻合
  - 在原理样机基础上，为提高能量标定精度，增加TR光子统计量，进一步优化了各项参数
  - 结合工程上的实现以及航天要求，研制了侧窗共腔式对称读出结构穿越辐射探测器

- **未来计划**
  - 参与合作组计划于2023年的CERN束流测试，根据实验结果对TRD提出要求以及进一步优化TRD性能
  - 完成HERD-TRD载荷的研制

谢谢！