中国科学院大学
University of Chinese Academy of Sciences

IMP

HIRFL上基于先进硅像素探测器的集成电路单粒子效应研究平台研制

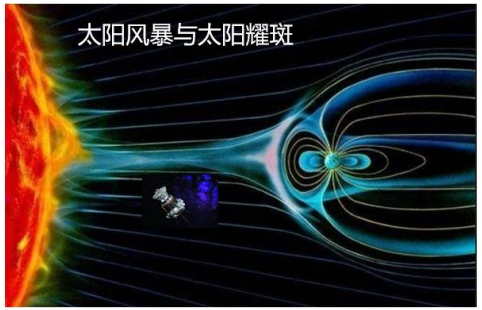
报告人：廖健巍

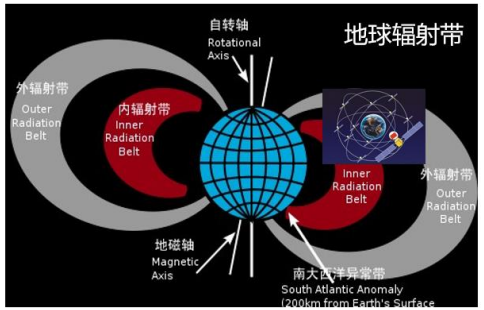
半导体辐射探测器研讨会

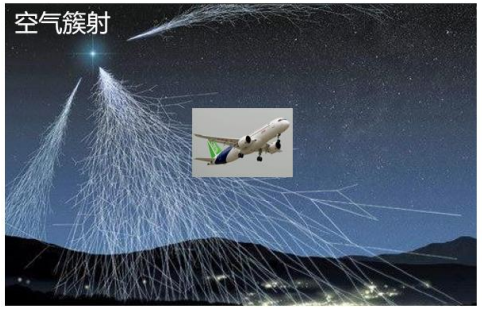
单粒子效应

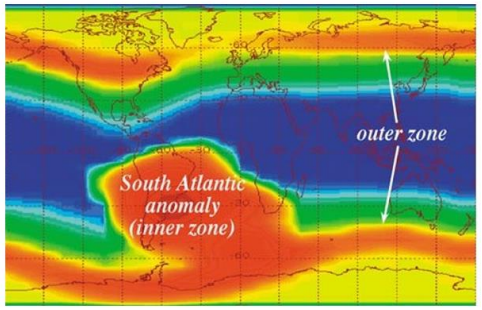
Silicon Lab at IMP
近物所像素探测器研究室

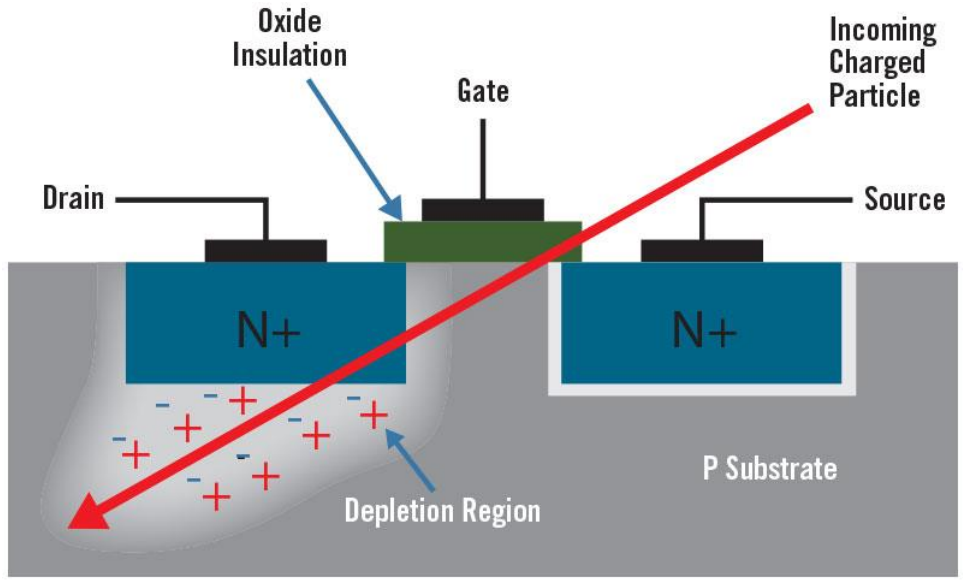
单个高能带电粒子击中集成电路器件引起的效应

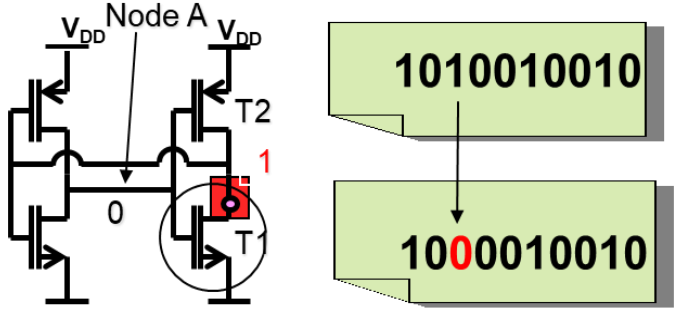


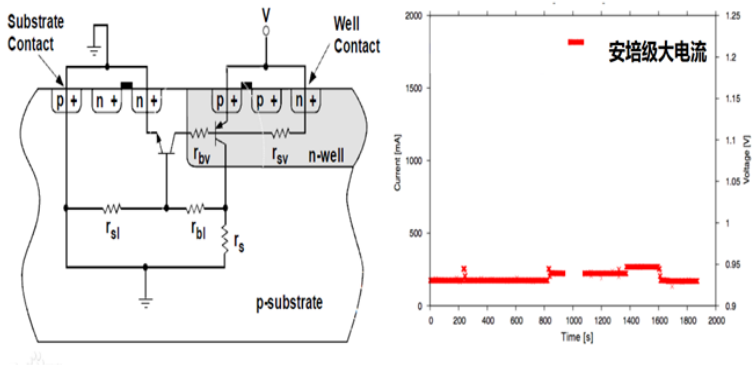


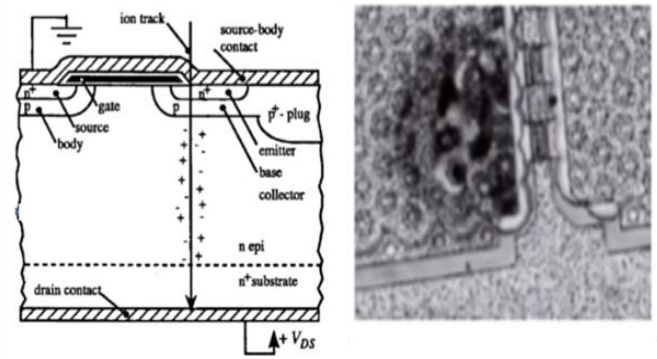












单粒子翻转：存储器逻辑状态改变（0变1，1变0），**导致电路错误**

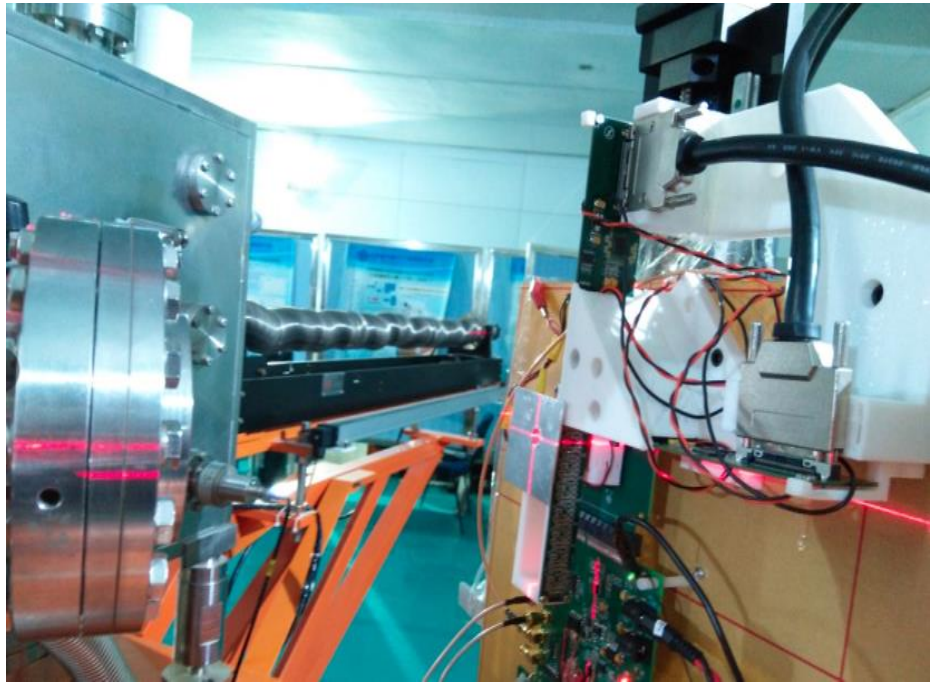
单粒子闩锁：器件寄生电容导通产生大电流，**导致器件损坏**

单粒子烧毁：PN结反向击穿烧毁**导致器件永久短路**

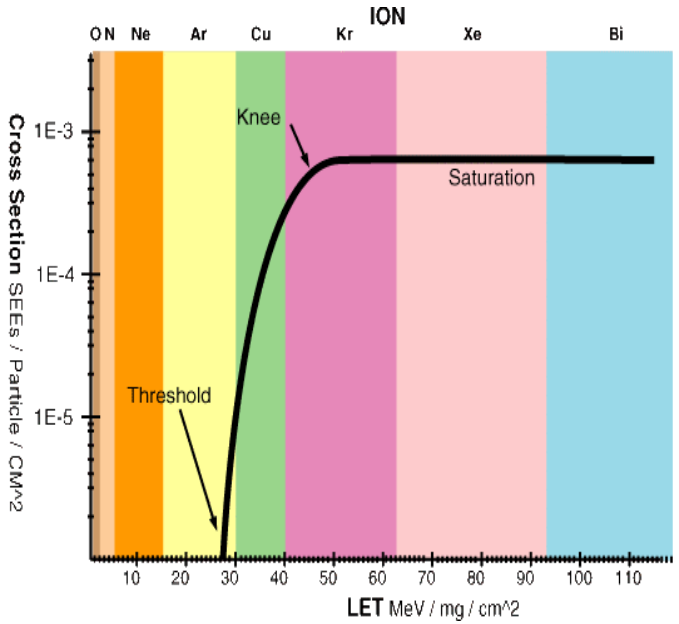
单粒子效应

HIRFL的单粒子效应实验终端是目前国内最重要的航天器件测试平台之一

- HIRFL单粒子测试采用**厘米级均匀束斑**照射集成电路
  - 验证器件是否存在单粒子效应
  - 反映器件的统计性平均参数



HIRFL单粒子终端



横截面积 vs 重离子LET值

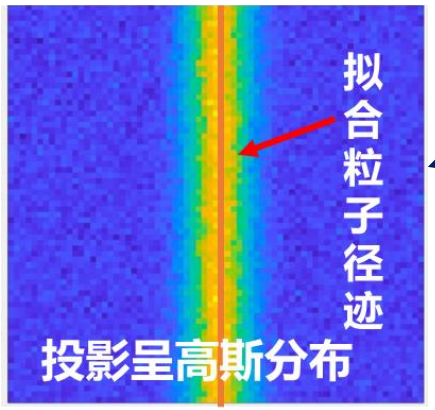
无法实现被测器件辐照敏感区域的精准定位!

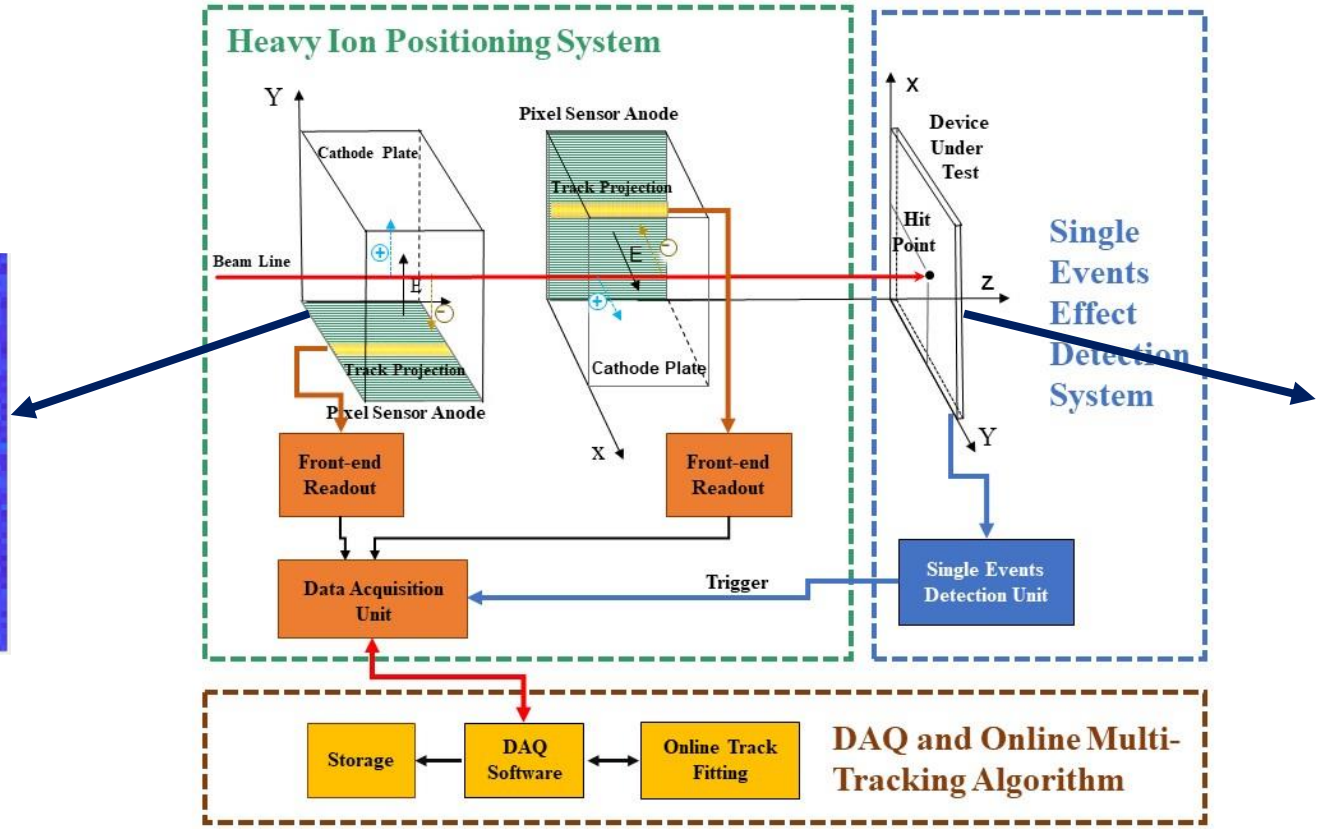
Hi’ Beam-SEE系统

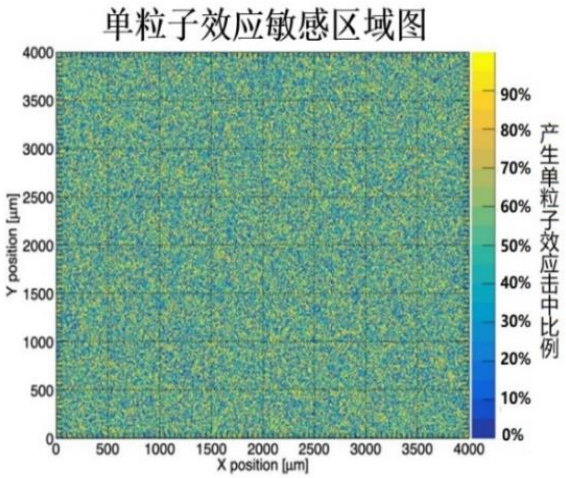
Silicon Lab at IMP
近物所像素探测器研究室

Hi‘Beam-SEE：一款用于HIRFL的单粒子终端高效率、微米级定位的装置

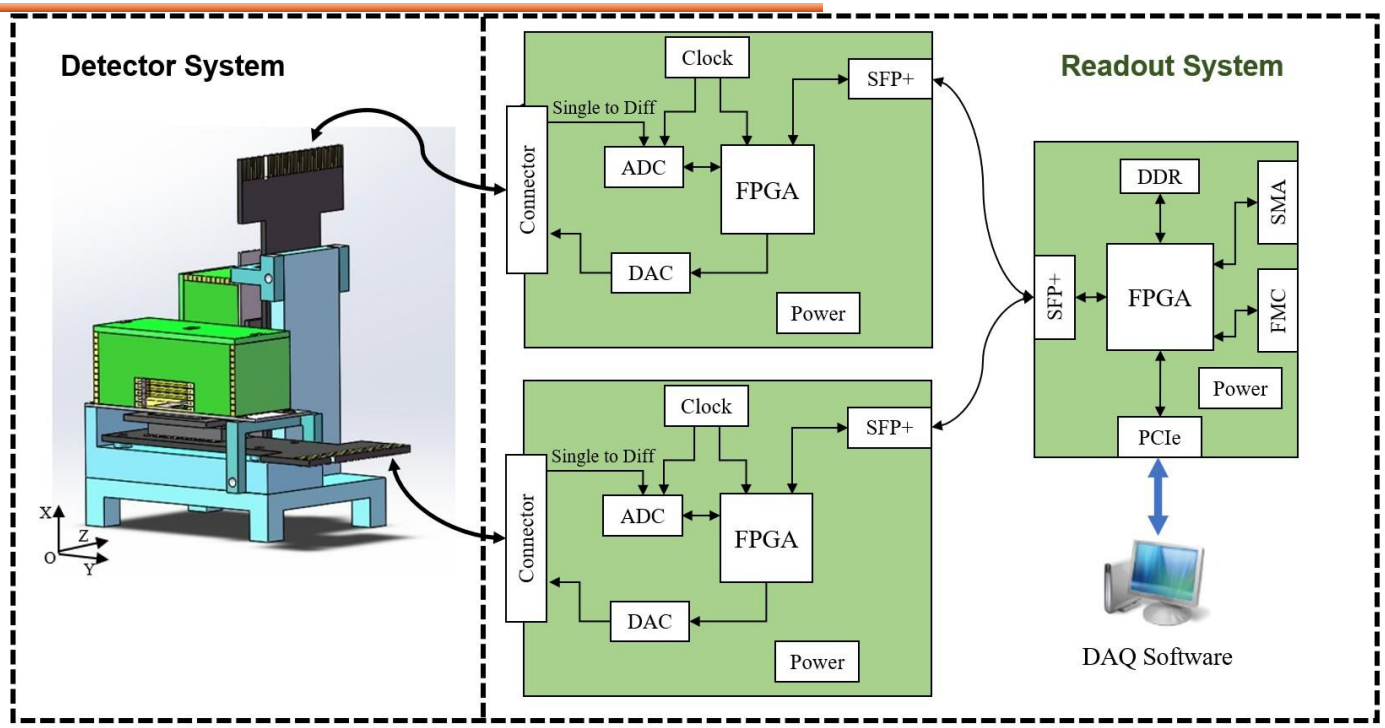
- **重离子定位：**定位重离子束中每个粒子的径迹，得到其在器件上击中位置
- **单粒子检测：**检测器件中发生的单粒子效应，为重离子定位提供触发信号
- **核心器件：**基于国产工艺自主研发的电荷搜集型像素芯片

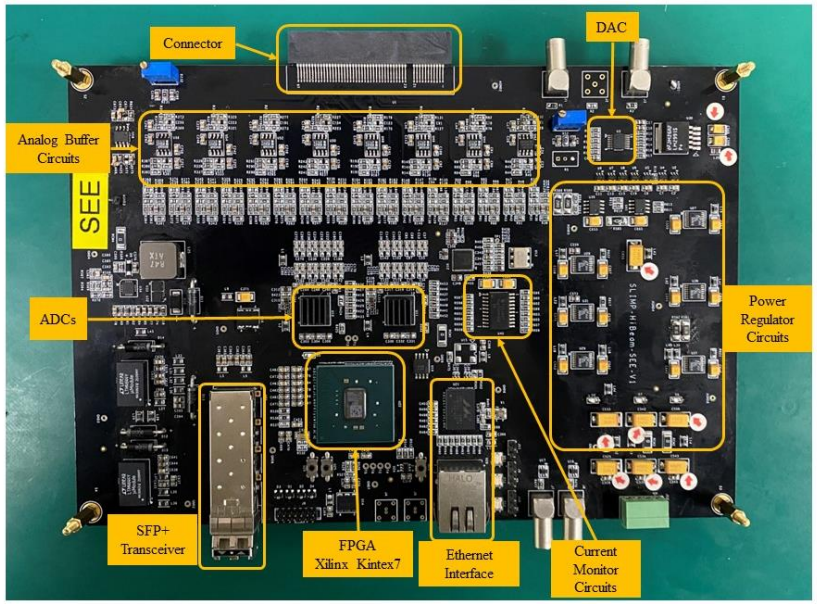




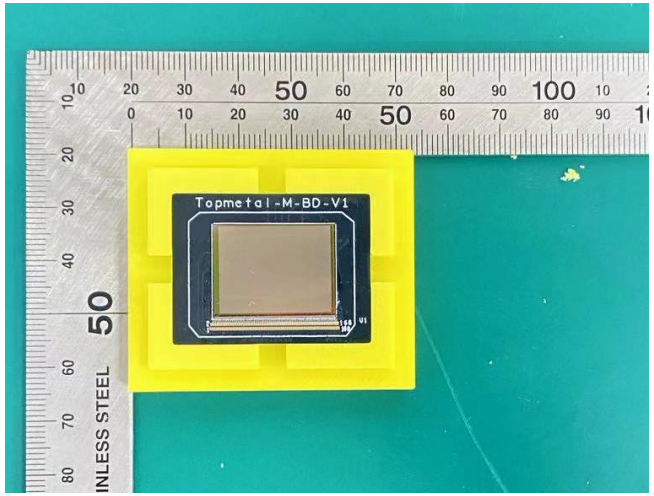


重离子定位系统



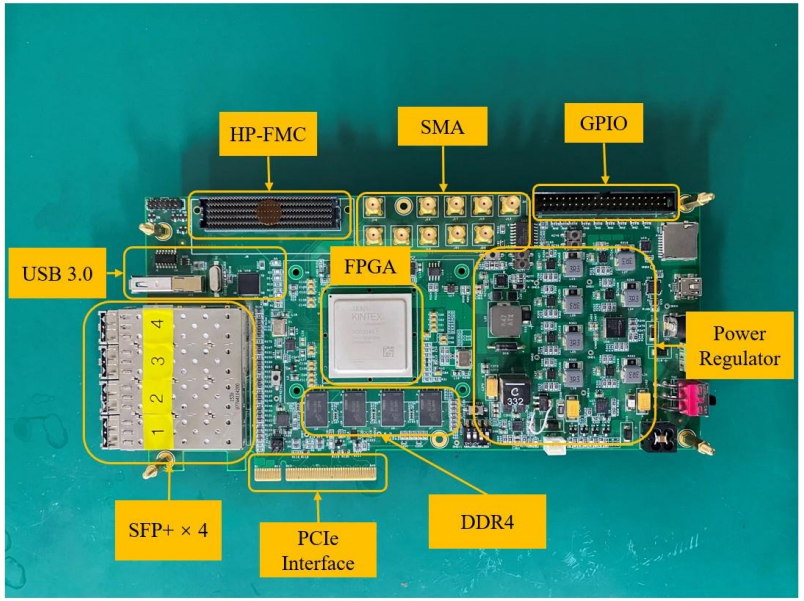


前端读出板



Topmetal-M

- 基于国内流片工艺
- 兼具时间、能量和位置测量功能
- 总尺寸：23mm × 17mm
- 20万个像素点，单像素40μm



数据汇总板

定位系统激光测试

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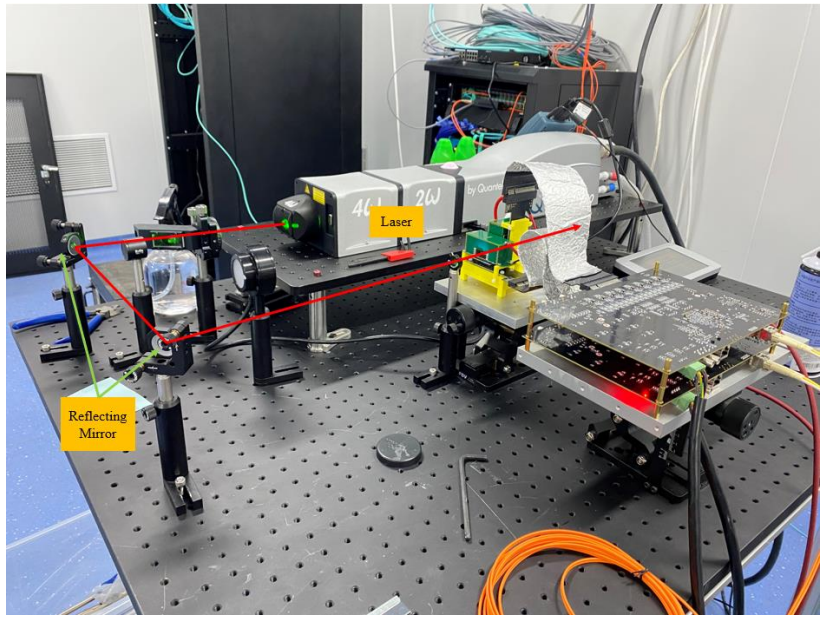
266nm紫外激光器

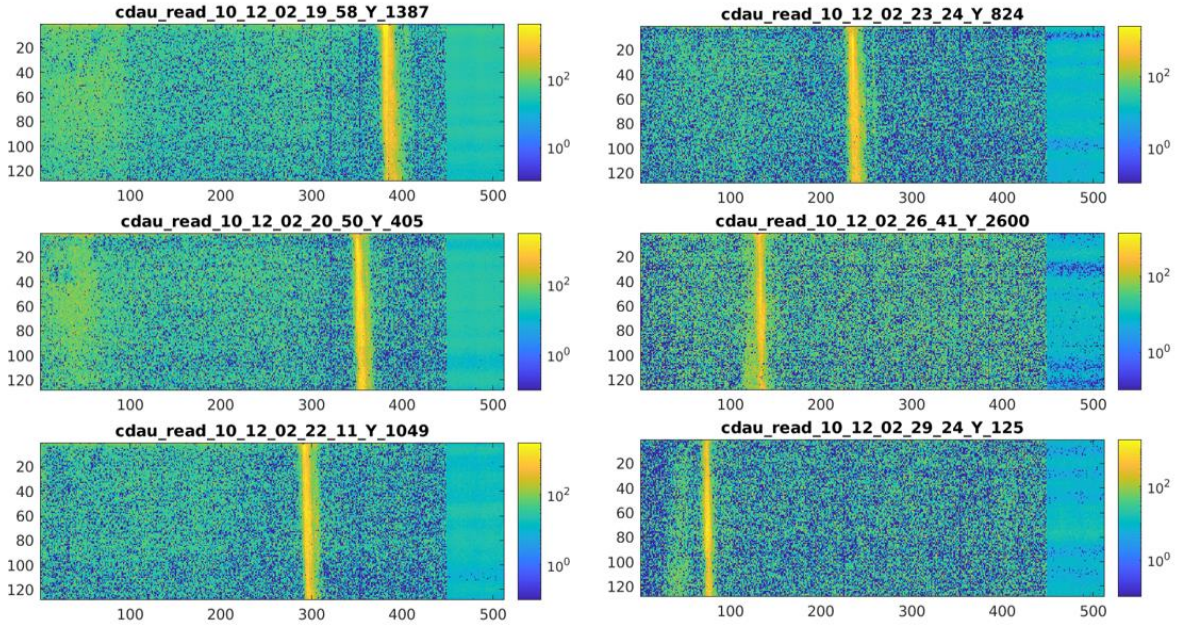
能量：5mJ

场强：1000V/cm

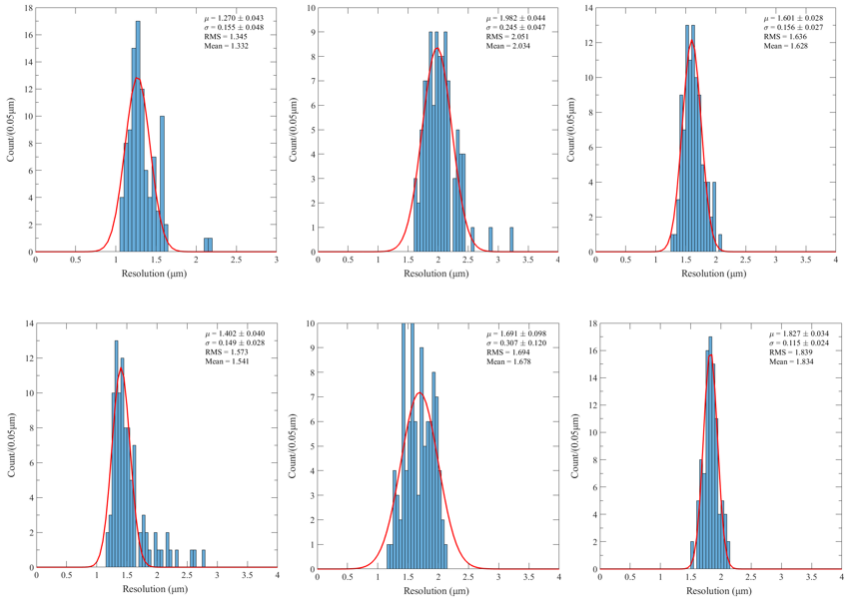
光栅：1mm



激光入射和场笼高度不变的情况下，水平移动场笼，看场笼不同入射位置的位置分辨。



位置分辨：~2 μm



定位系统重离子测试

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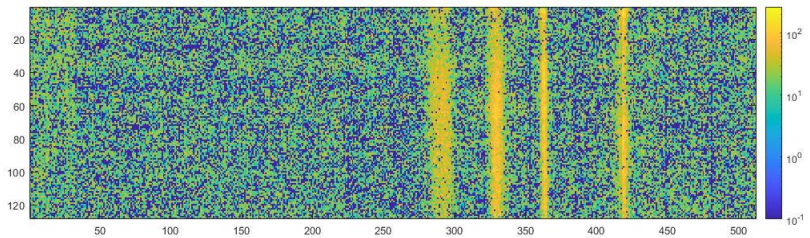
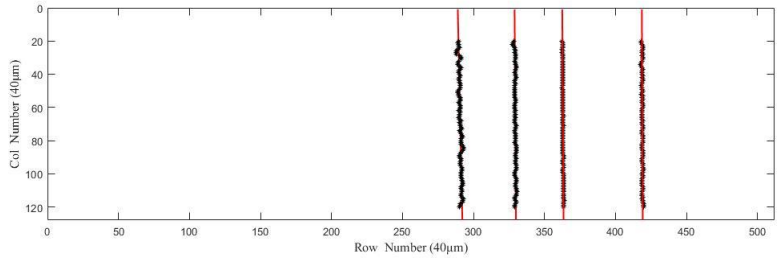
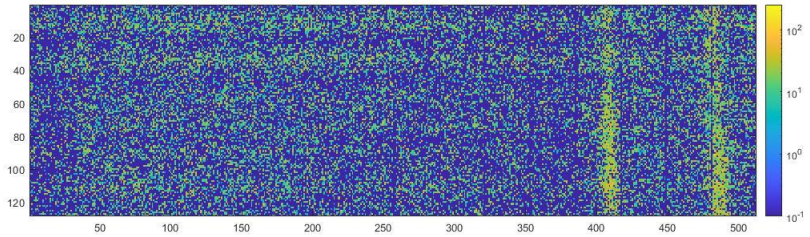
$^{181}Ta^{35+}$

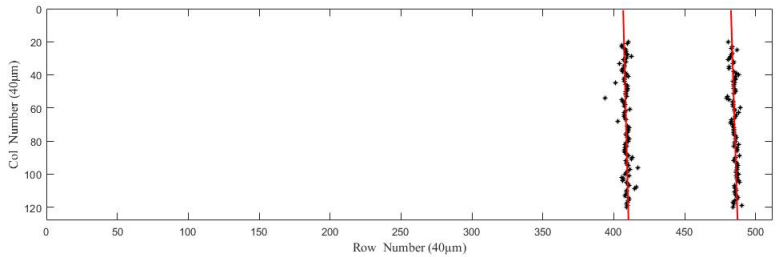
能量：16 MeV/u

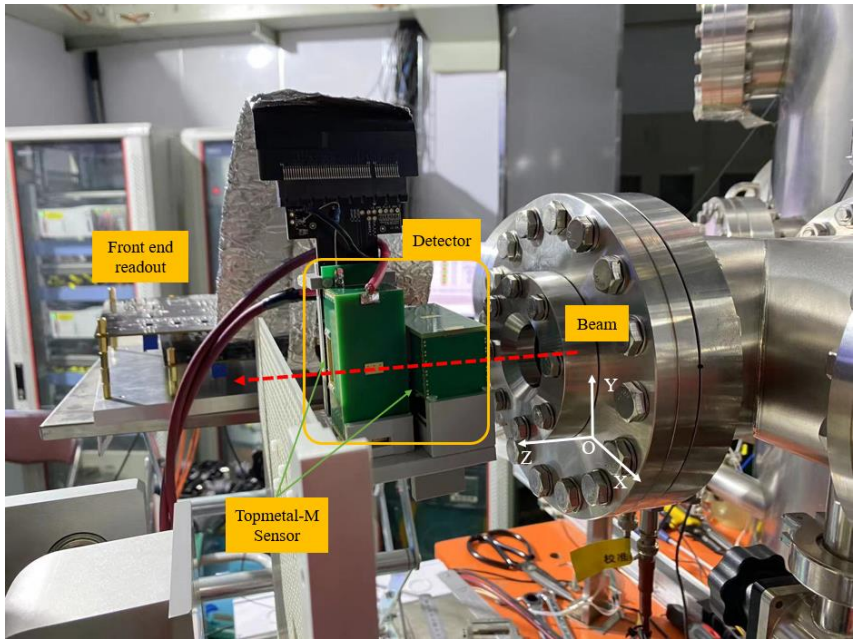
场强：1000V/cm

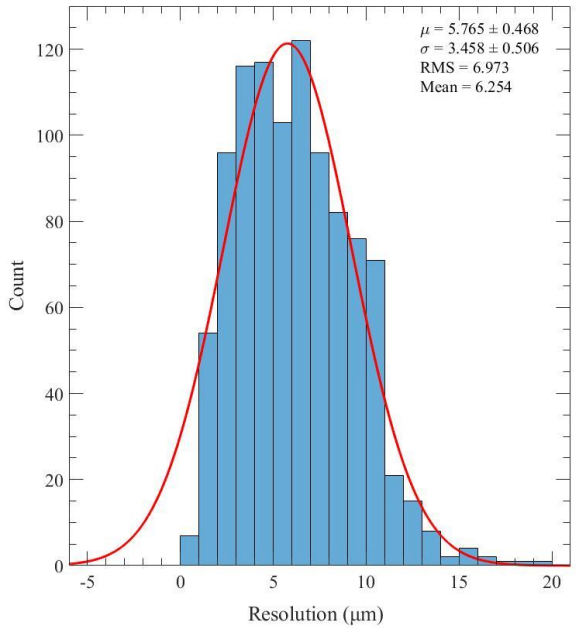


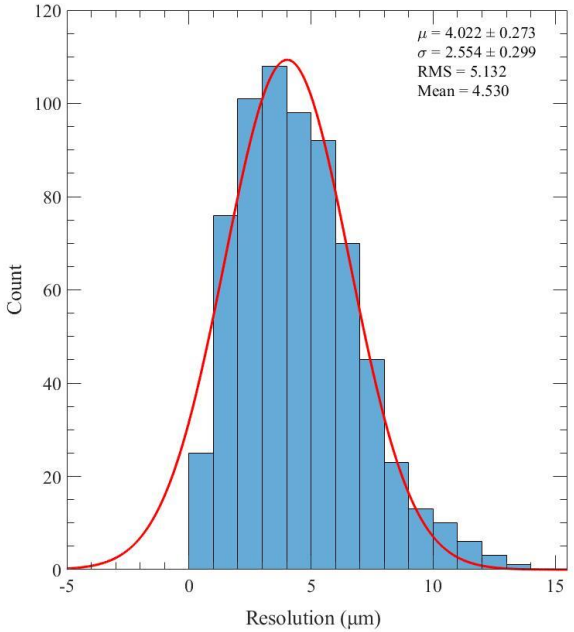












位置分辨

XOZ平面：

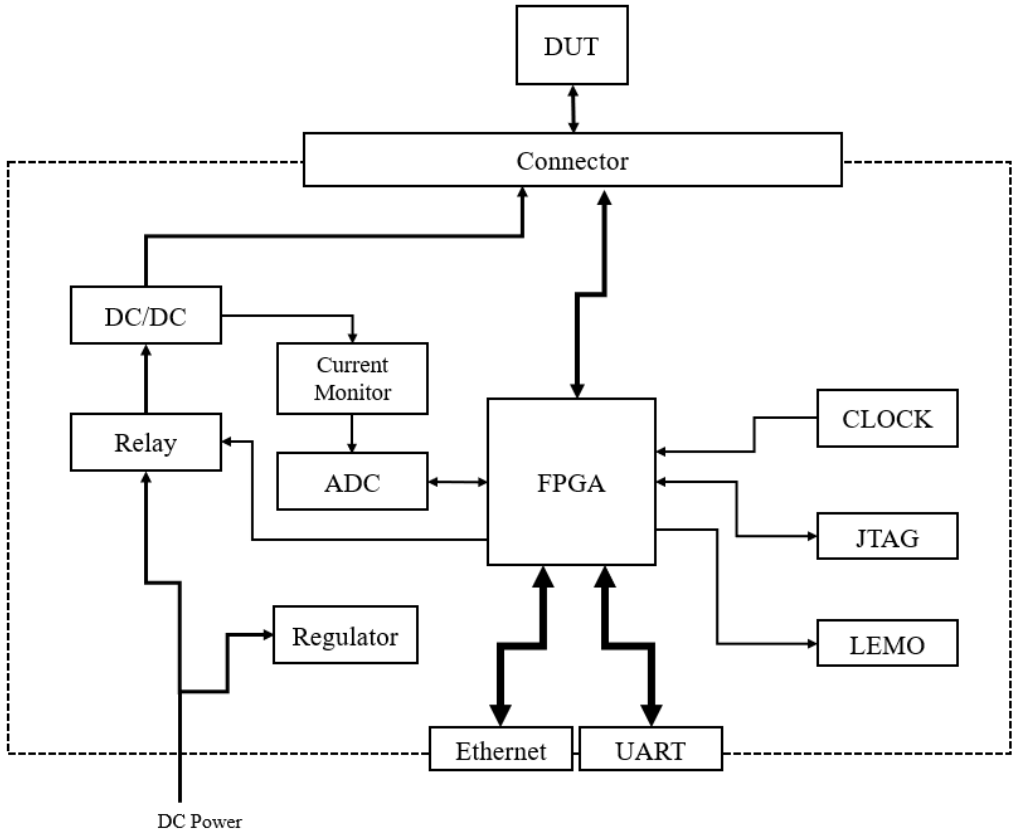
5.765 ± 0.468 μm

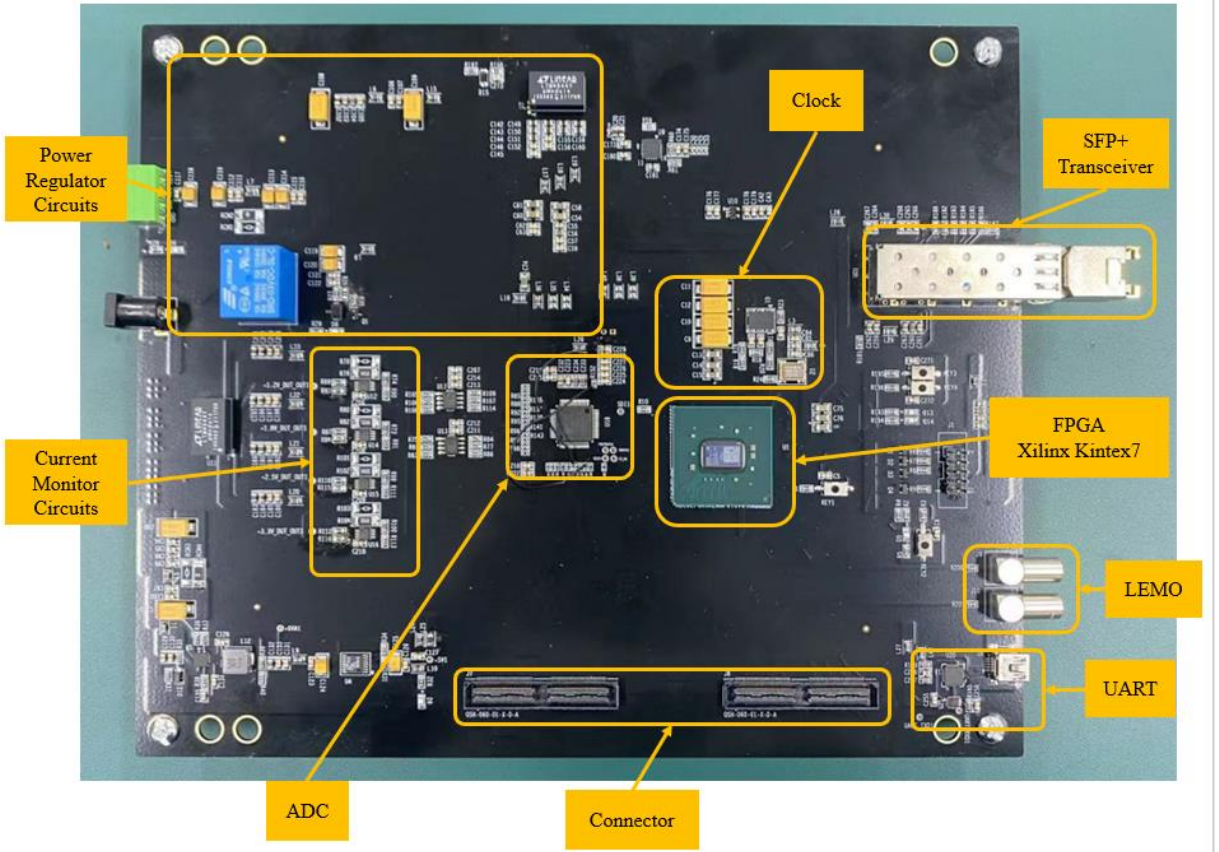
YOZ平面：

4.022 ± 0.273 μm

单粒子检测系统

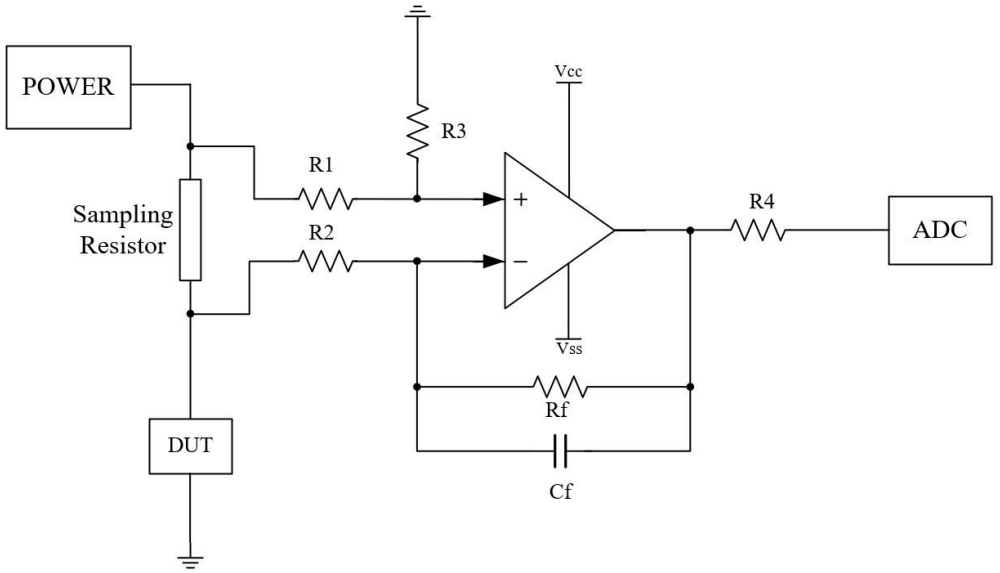
单粒子检测系统：检测被测器件中发生的单粒子效应



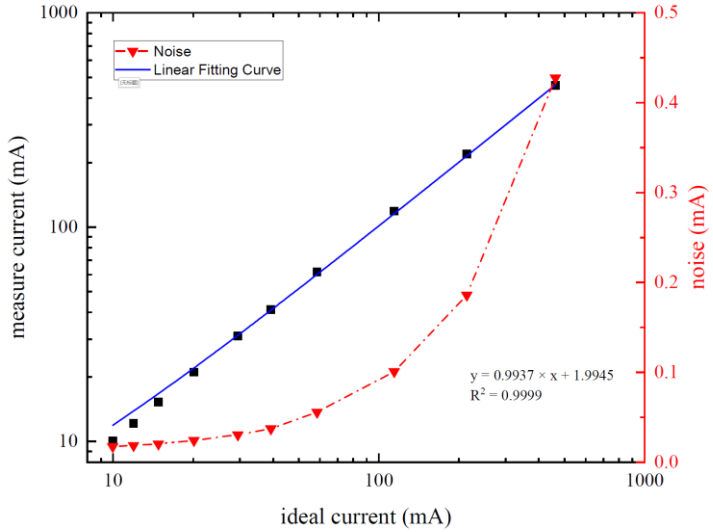


电源：外部电源通过继电器后再通过电源芯片为子板供电
ADC：8通道，16bit，1MHz采样率，动态范围可配置
通信：串口用于低速数据传输，以太网用于高速数据传输

单粒子系统电子学测试

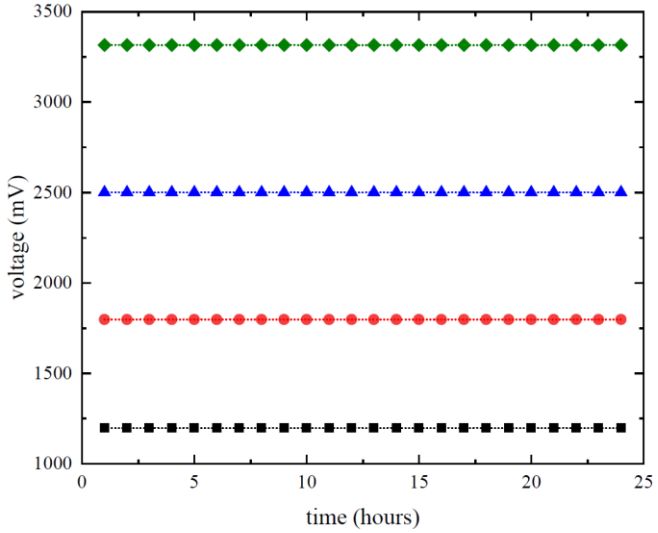


电流监测电路

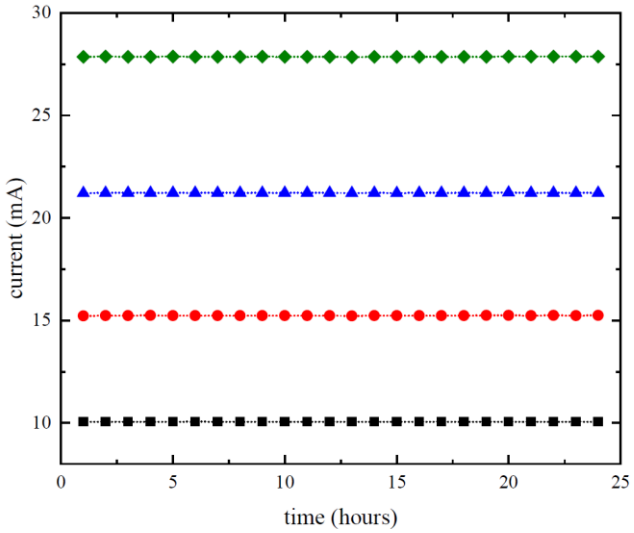


电流线性测试

长时间稳定性测试



电压通路测试



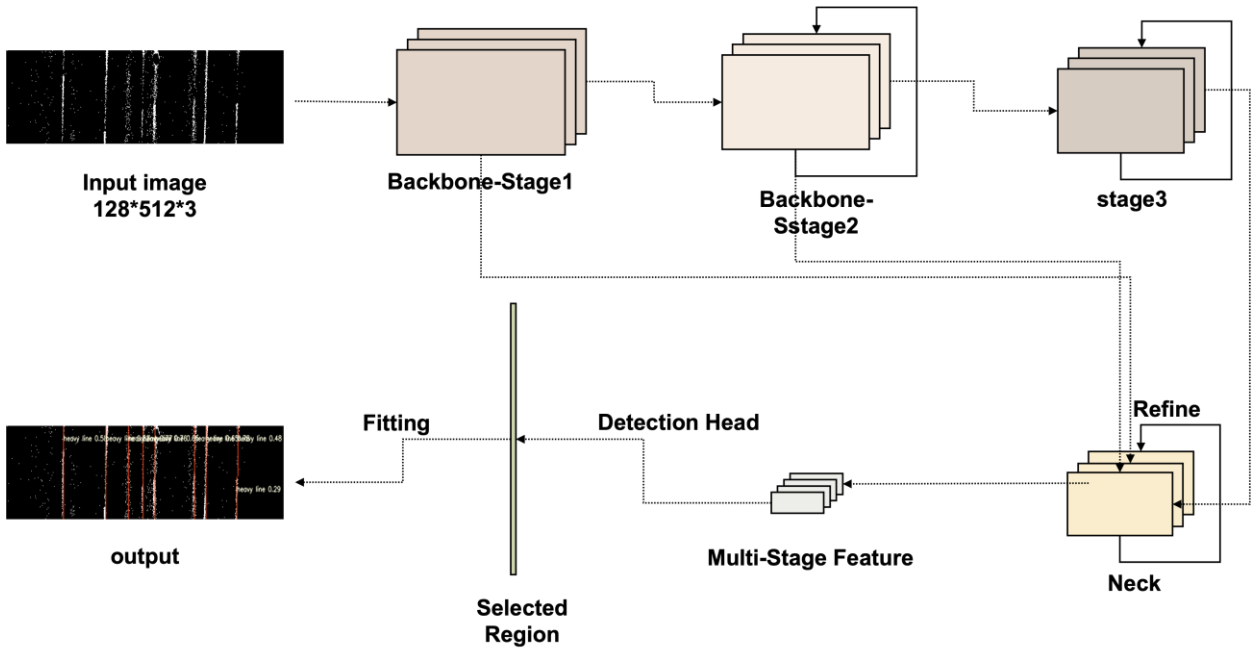
电流通路测试

最大非线性4.85mA

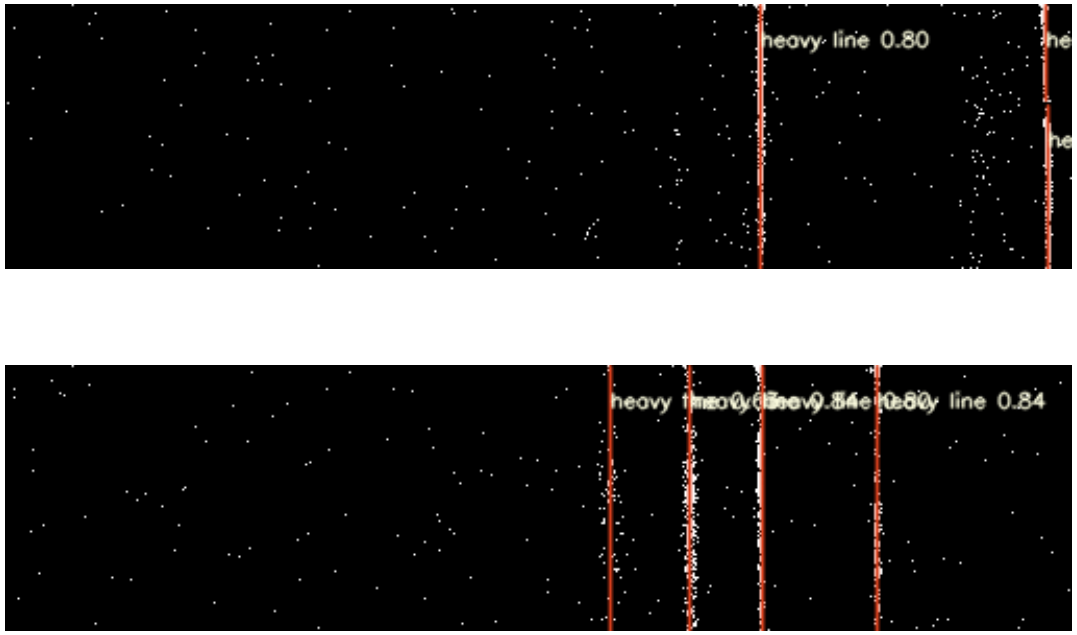
电压波动小于0.5 mV

电流波动小于0.02mA

径迹检测算法



算法结构



检测结果

径迹检测算法横向比较结果

#	Method	Miss detection rate [%]	False detection rate [%]	Speed [fps]	Position accuracy [μm]
1	CLRNet	43.2	4.9	270	7.92 ± 3.918
2	Yolov7-base	15.6	8.9	93	8.95 ± 4.476
3	Gaussian method	0	0	offline	4.55 ± 2.885
4	OML	0.52	0	172	4.64 ± 0.070

算法具体实现可见5.25报告：
基于人工智能的在线径迹检测算法研究

总结

基于国产像素芯片设计了一款可用于HIRFL单粒子实验终端高效率、微米级定位装置

- **重离子定位系统：**定位束流中每个粒子的位置。束流实验表明对于定位系统能实现 5μm的位置分辨
- **单粒子检测系统：**为被测器件提供控制信号，检测是否发生单粒子效应。电子学测试表明对于SEL检测具有较高的分辨
- **径迹检测算法：**像素芯片图像重建，识别并拟合粒子径迹。真实数据集测试表明算法能实现 4.64μm的位置分辨，速度可达172 fps

THANKS!

恳请各位专家批评指导！

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PRESENTED BY Liao Jianwei