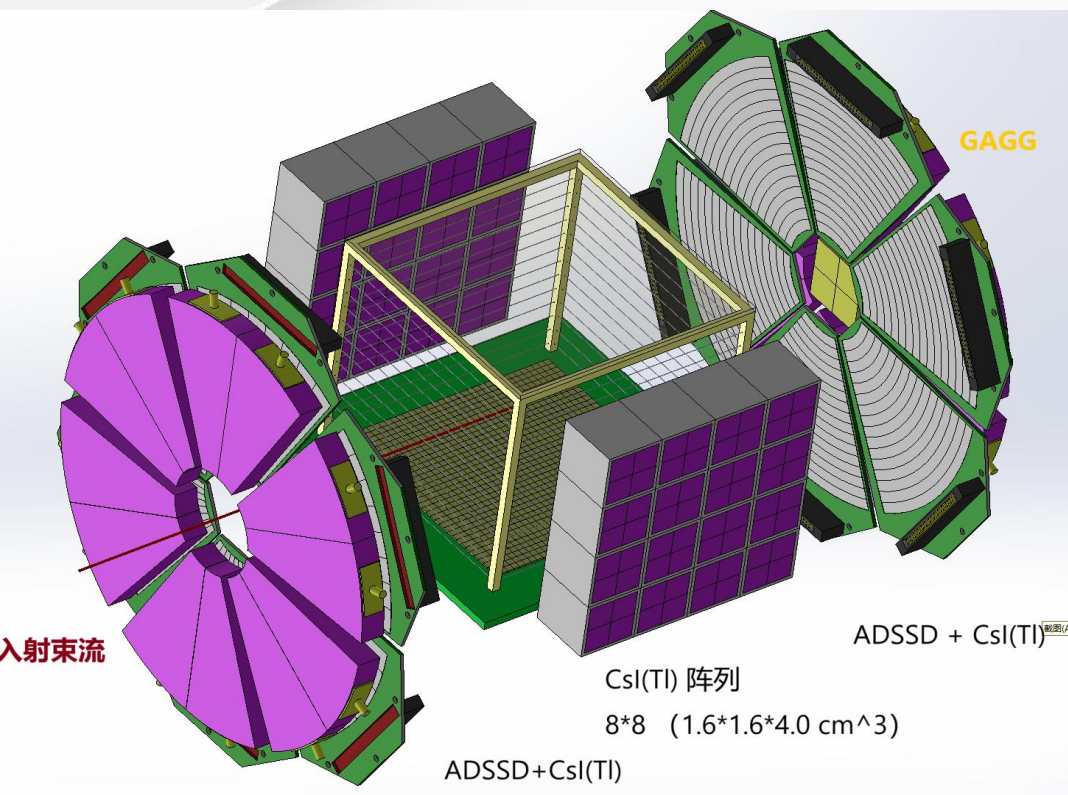


时间投影室实验技术暨第二届MTPC研讨会

北京大学活性靶时间投影室 研发进展和实验计划

李奇特 北大核物理实验组

2024.11.30
广东 深圳



目录

CONTENTS



01 物理动机



02 AT-TPC研发进展

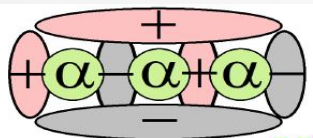


03 未来计划

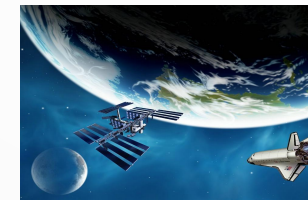
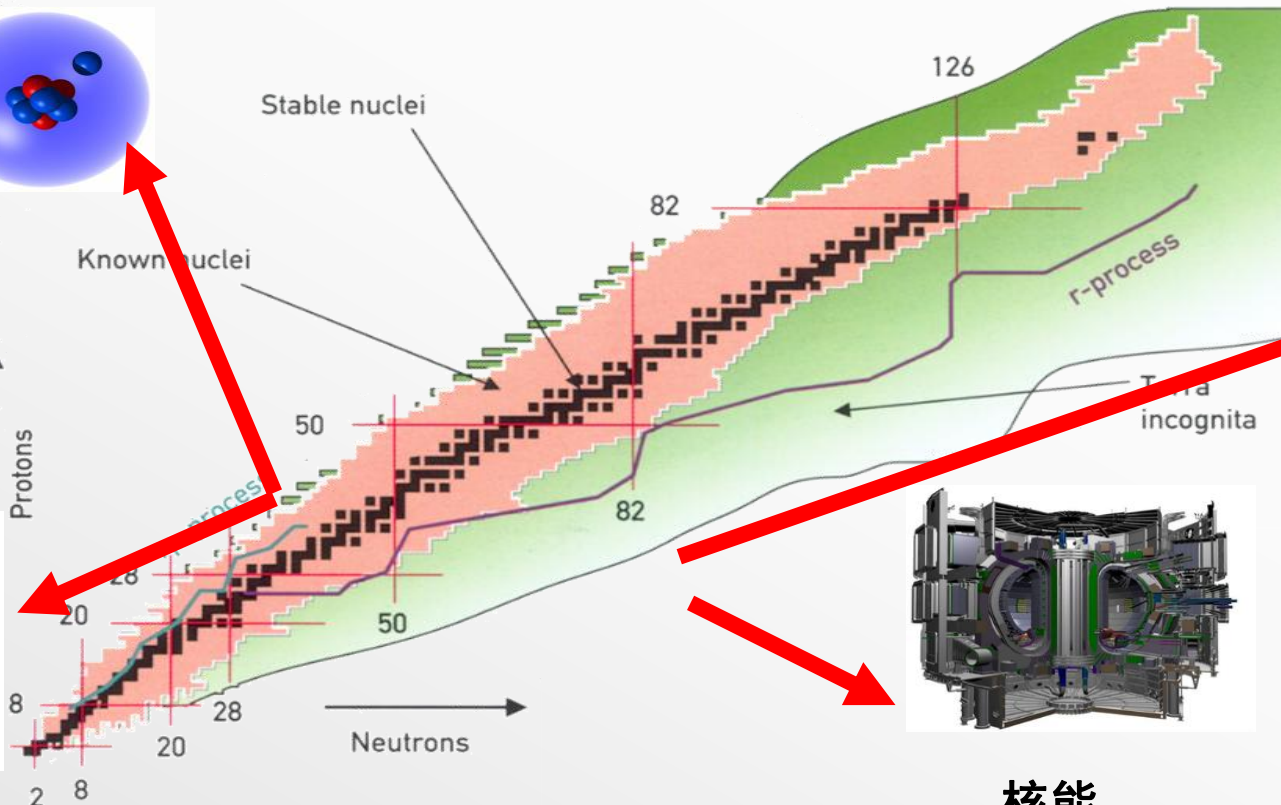
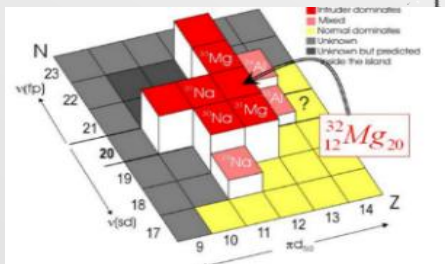
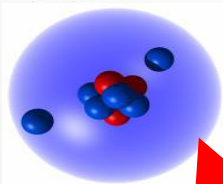
01

物理动机 | 放射性束物理：前沿领域

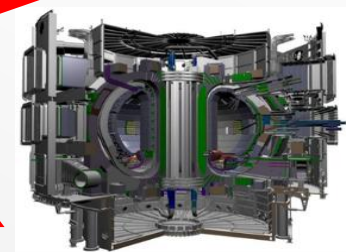
Motivation: Radioactive beam physics



放射性原子核的奇特结构



航天：核电池



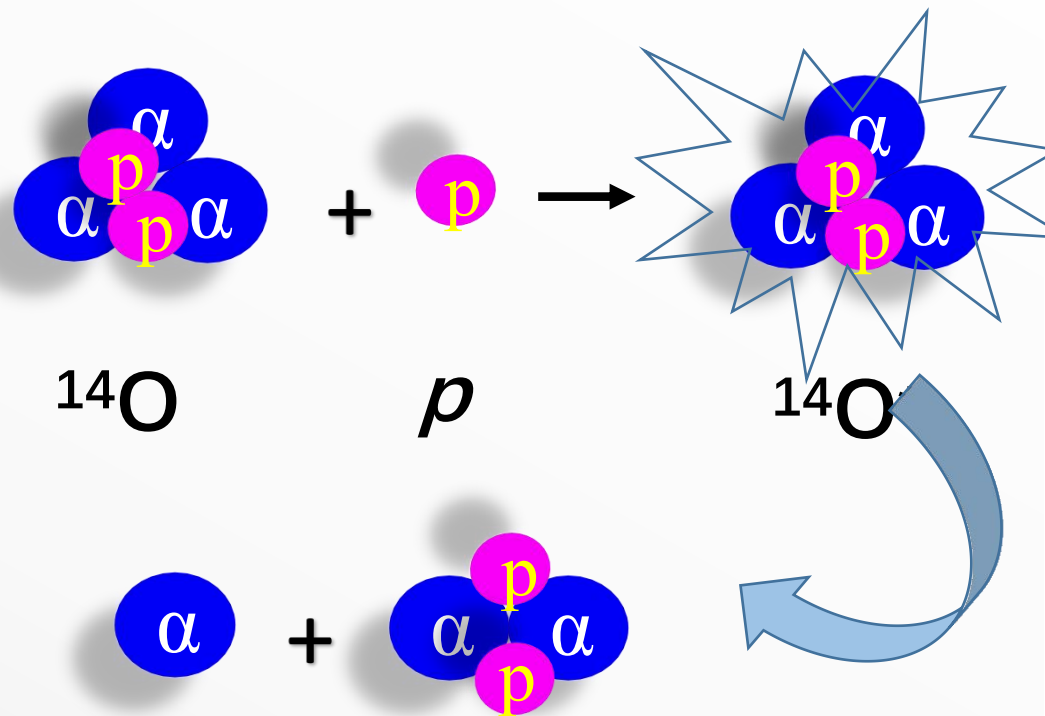
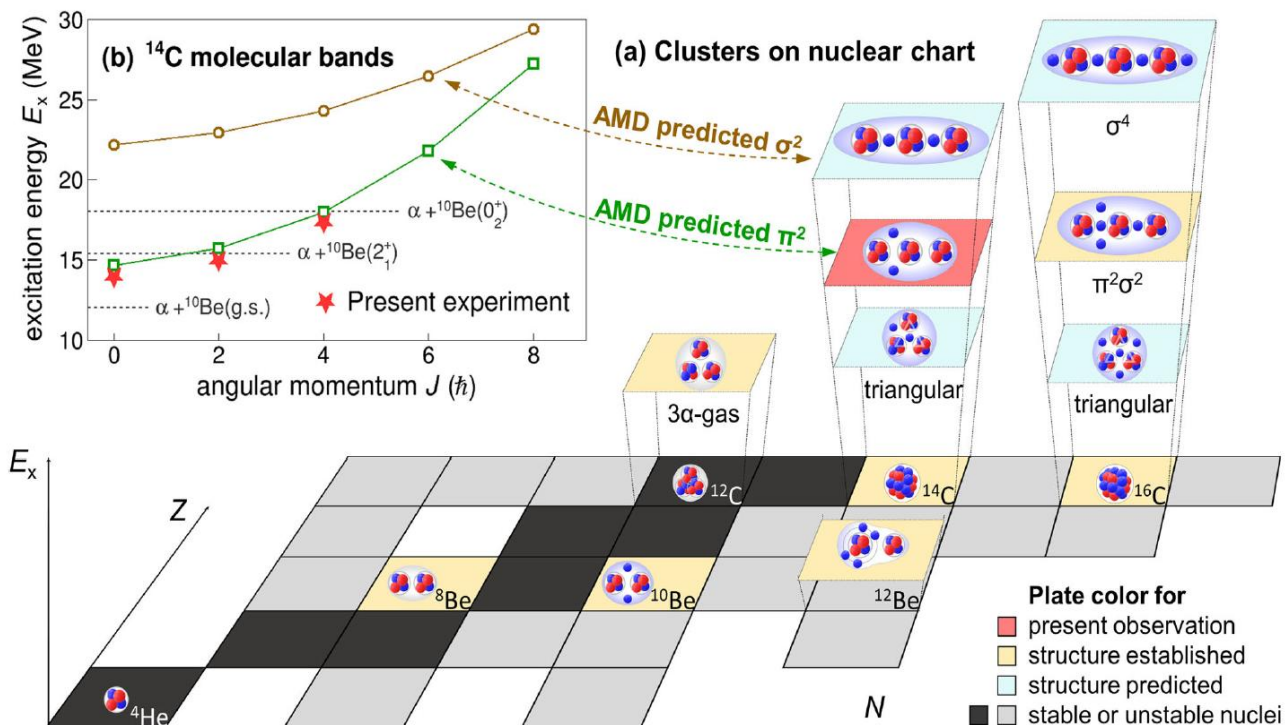
核能



福岛核电站

放射性核束物理已经成为国际上各科技强国均重点部署的前沿领域。

Motivation: direct nuclear reactions



p/d非弹激发 (逆运动学) + 衰变

◆ 中低能: MeV/nucleon

◆ 衰变产物 (不变质量, 角度, 集团)

◆ 反冲粒子 (缺失质量, 低能, 单粒子)

[1]Wei, K., Ye, YL. & Yang, ZH. Clustering in nuclei: progress and perspectives.

NUCL SCI TECH 35, 216 (2024). <https://doi.org/10.1007/s41365-024-01588-x>

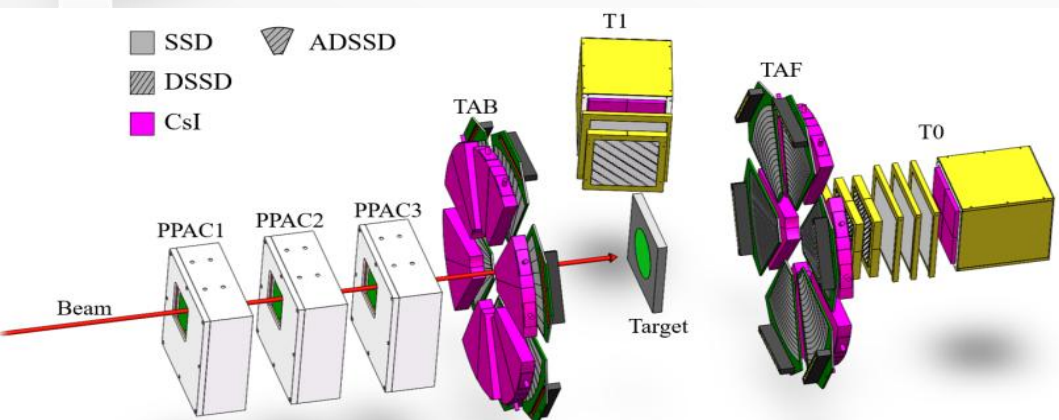
[2]楼建玲, 叶沿林, 杨再宏, 李奇特等, 科学通报 68(9), 2023, 1004-1015.

[3]J.X.Han, Ye, Y L*, J.L.Lou et al. Nat. Com. 2023, 6:220;

[4] Liu Y, Ye Y L*, Lou J L, et al. Phys Rev Lett, 2020, 124: 192501

01

物理动机 | 存在问题及解决方案



- ◆ 靶厚: 1 mg/cm^2
- ◆ Q值分辨: 0.5 MeV
- ◆ 流强: $> 10000 \text{ pps}$

◆ Si+ 固体靶。

厚: 带电粒子穿不出来

Q-值分辨差 $\sim \text{MeV}$

薄: 统计不足

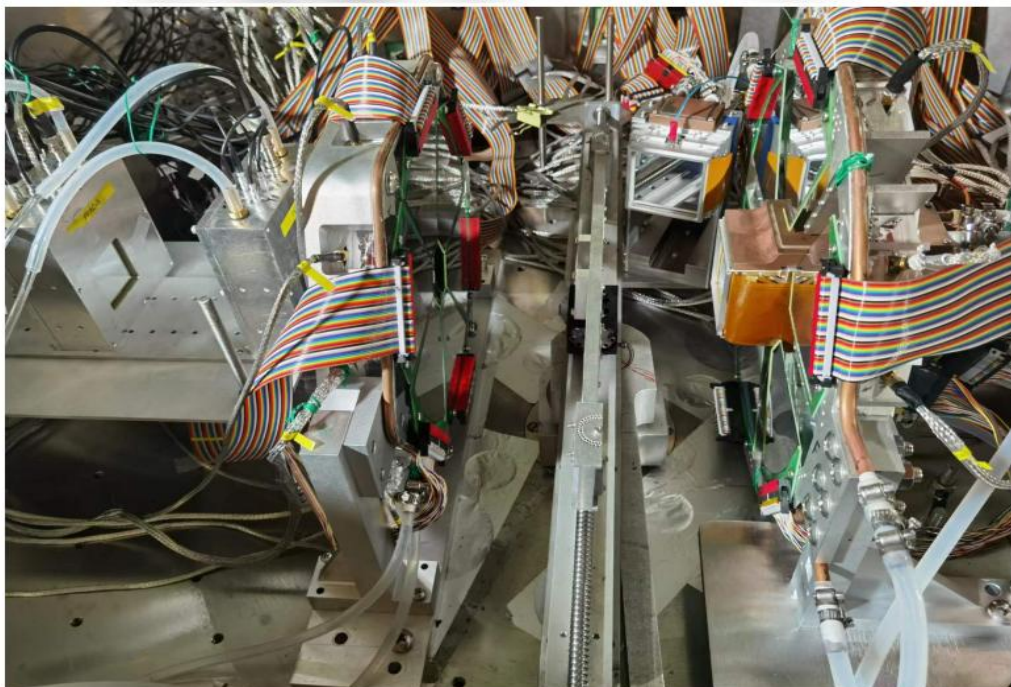
需要用流强高的束流

解决方案: 既可以做靶又可以做探测器的活性靶时间投影室探测器
(AT-TPC: Active target-time projection chamber)

◆ AT-TPC+辅助

- ◆ 靶厚: 100 mg/cm^2
- ◆ Q值分辨: 0.5 MeV
- ◆ 流强: $> 100 \text{ pps}$

- 粒子产生就可以直接测量, 粒子探测阈值低
- 靶很厚, 但不影响Q-值分辨, 统计较足
- 接受度大, 利于符合测量



目 录

CONTENTS



01 物理动机



02 **AT-TPC研发进展**



03 未来计划

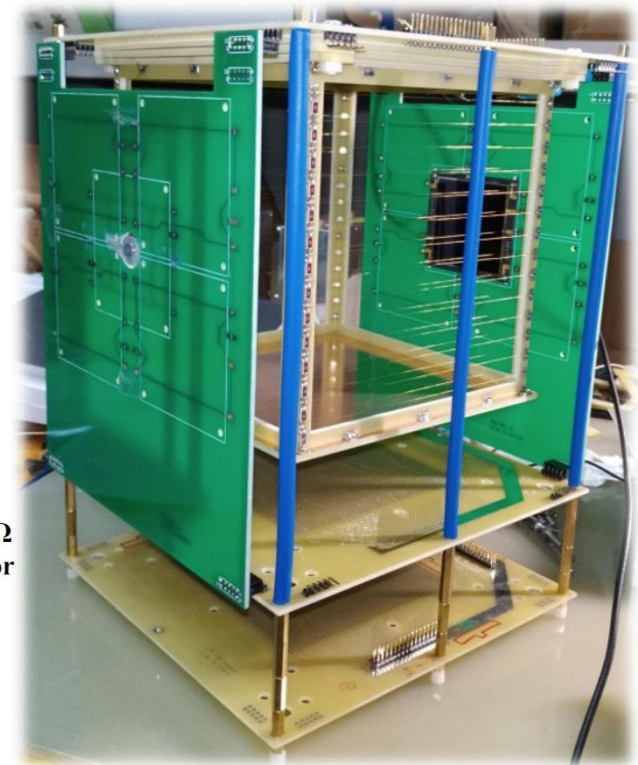
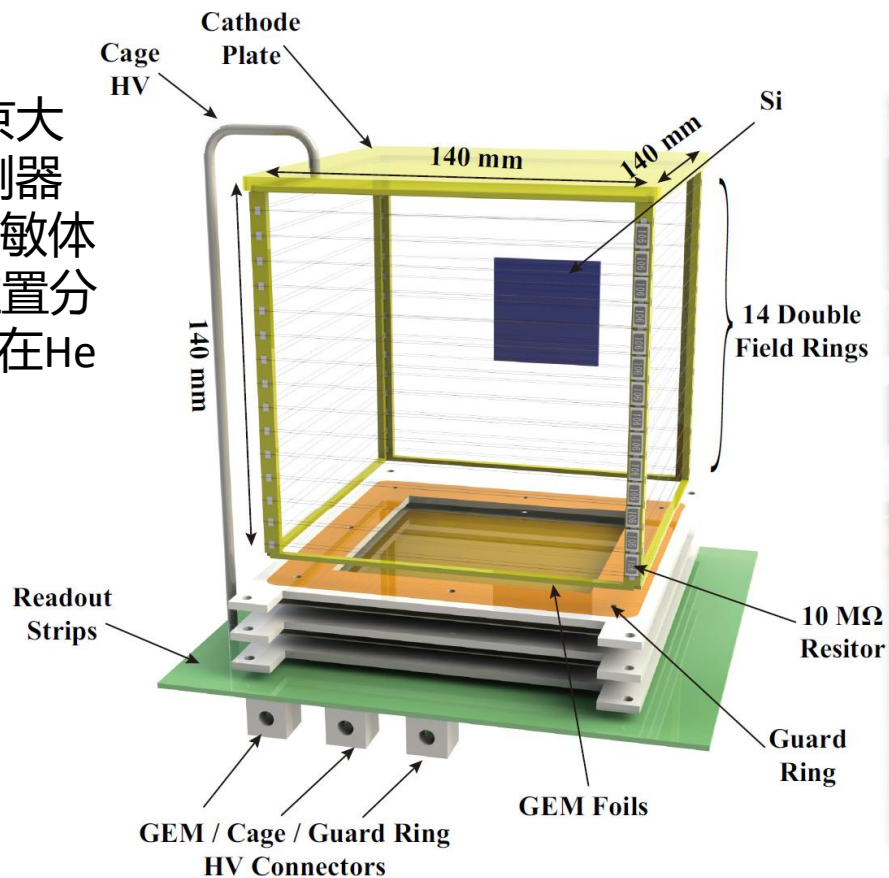
北京大学 PKU AT-TPC研发

为了研究不稳定核的集团结构相关物理，北京大学核物理实验团队研制了一个基于厚GEM探测器的活性靶时间投影室(AT-TPC)原型机，灵敏体积为14cm*10cm*10cm，测试了其时间分辨位置分辨等性能，进行了三维径迹重建，观察到了 α 在He上的弹散径迹。

组成部件:

- 漂移区
- 14×双层场笼+均压电阻
- 厚GEM*2
- 保护环改善电场均匀性
- 128路二维读出条读出
- 相关电子学获取系统
- 辅助探测器

- 工作混合气体: $^4\text{He}(96\%) + \text{CO}_2(4\%)$
- 气压400~500 mbar
- 场笼高压2150V, GEM膜高压820V, 场笼环高压890V

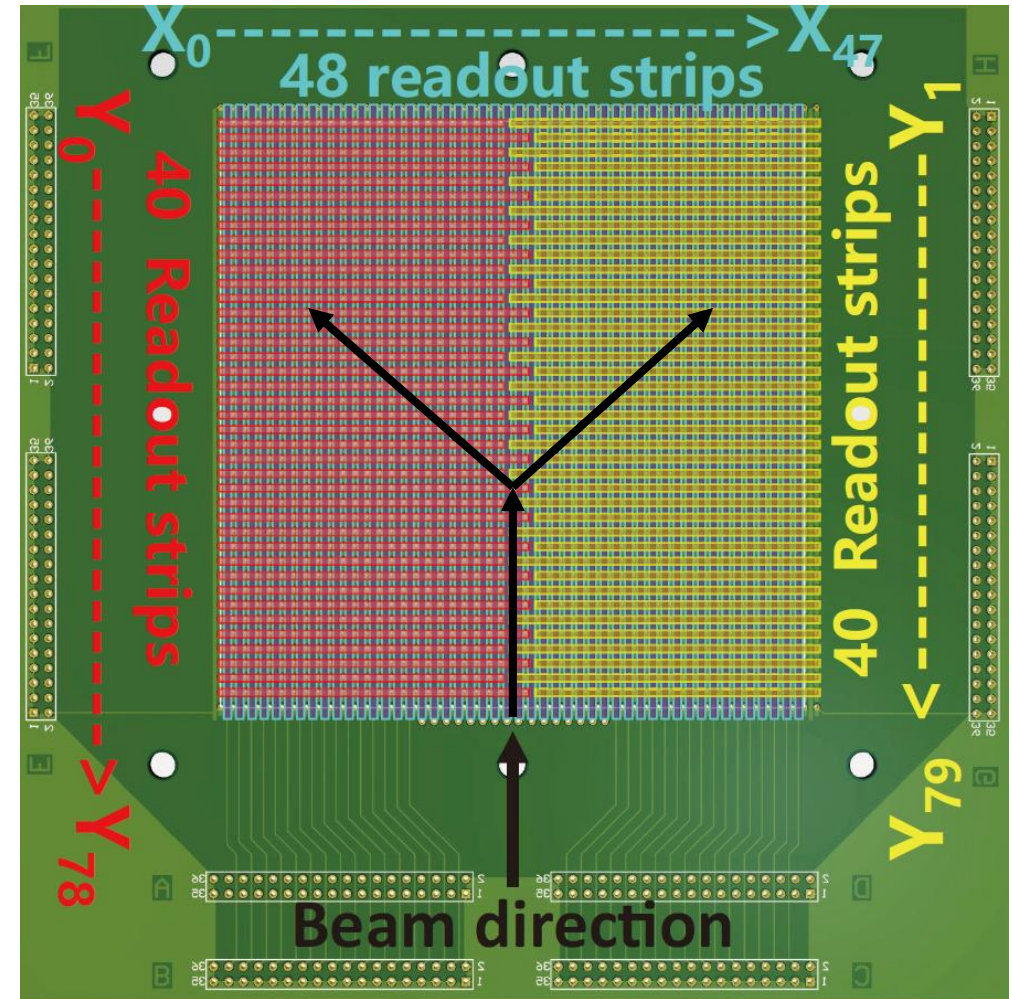
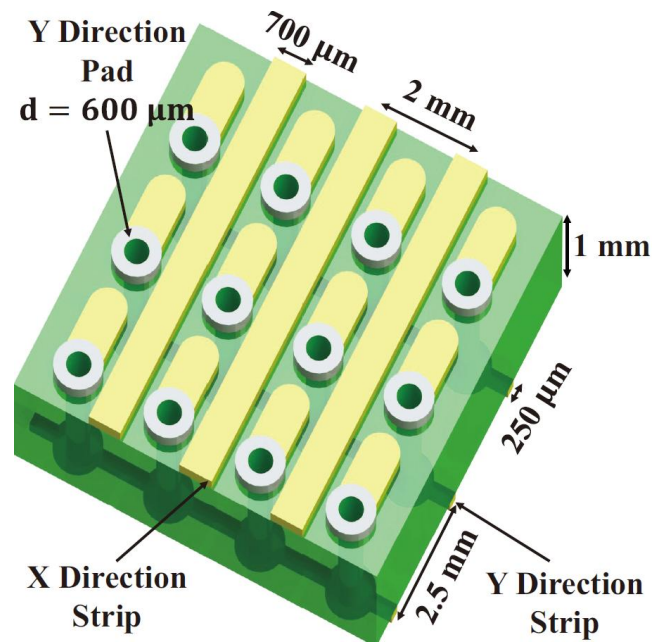


发表文章:

- Yang, LS, Xu, JY., Li, QT.* et al. *Nucl. Sci. Tech.*, 32 (2021) 85.
- 葛浩煜, 许金艳, 李奇特, 等. *物理实验*, 2024, 44(1):1-13.
- Jin-Yan Xu, Qi-Te Li* et al., *Nucl. Sci. Tech.*, 29 (2018) 97.
- 许金艳, 阳黎升, 李奇特*等. *原子能科学技术*, 054 (2020) 1068

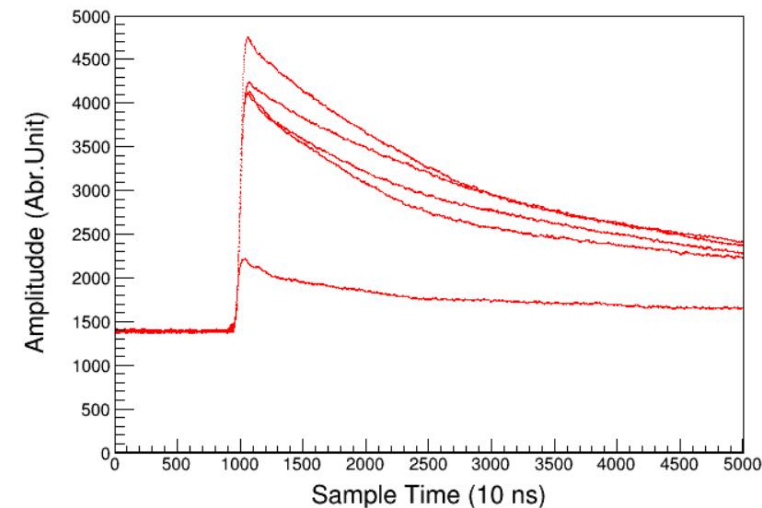
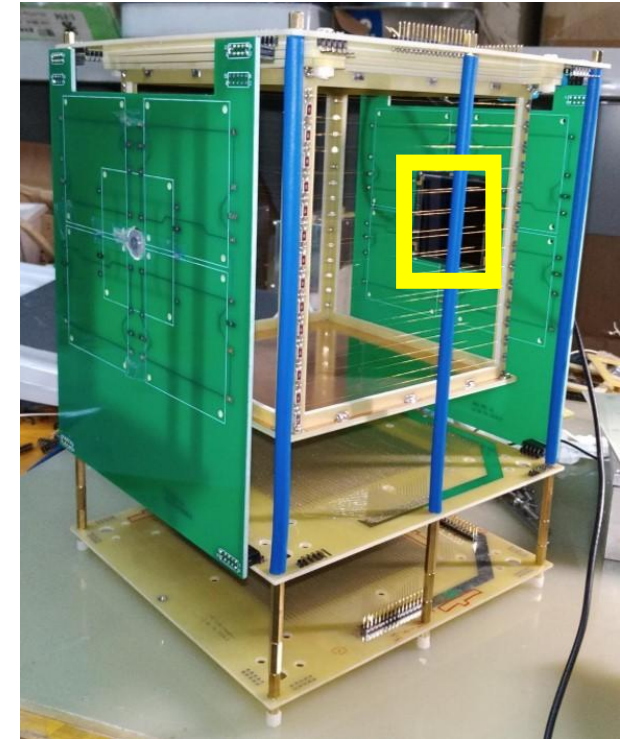
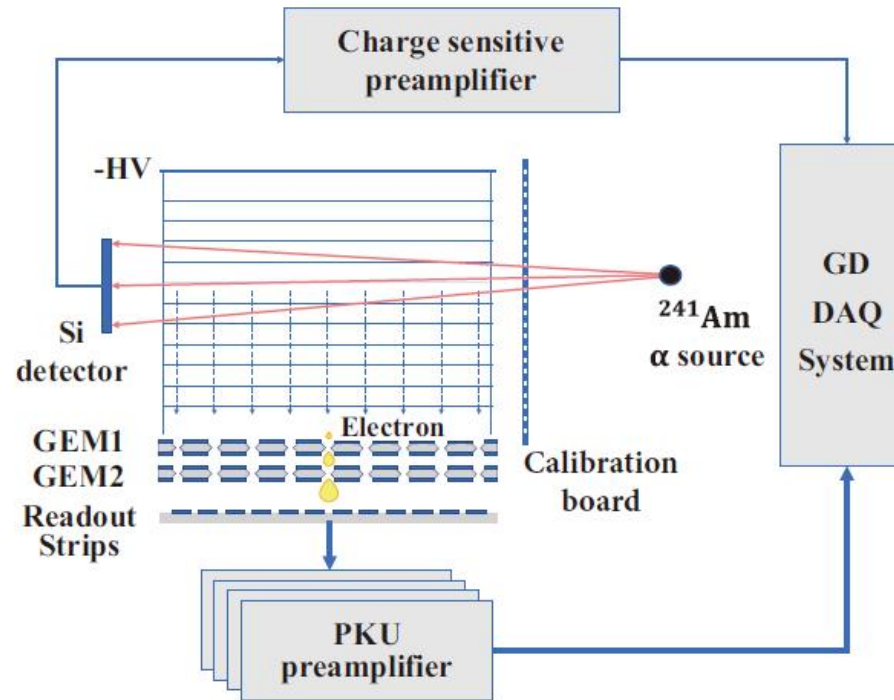
128 Readout Strips

- X direction: 48 parallel strips :
- Y direction: set of 40 strips were divided into 80 half-strips
- Active area 10cm*10cm



GDDAQ & Trigger detector

- Source : ^{241}Am
- A general-purpose digital DAQ system (GDDAQ)^[1]:
 - Based on XIA LLC
 - waveform
 - 109MByte/s
- Trigger by: Silicon
 - 48mm×48mm, 325 μm

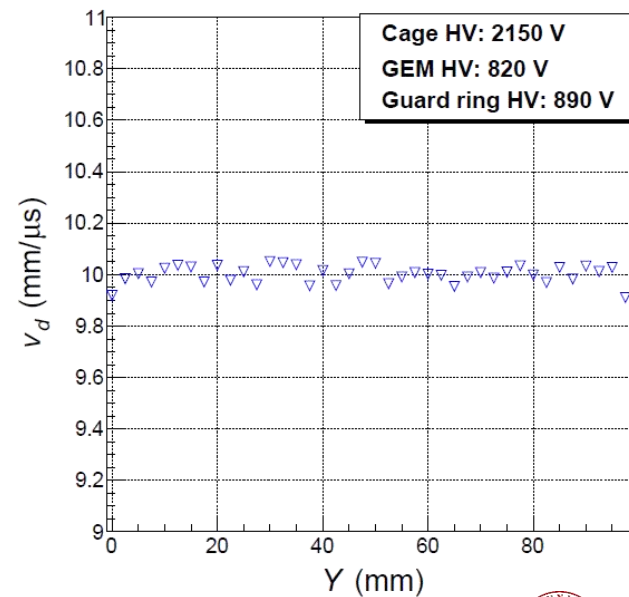
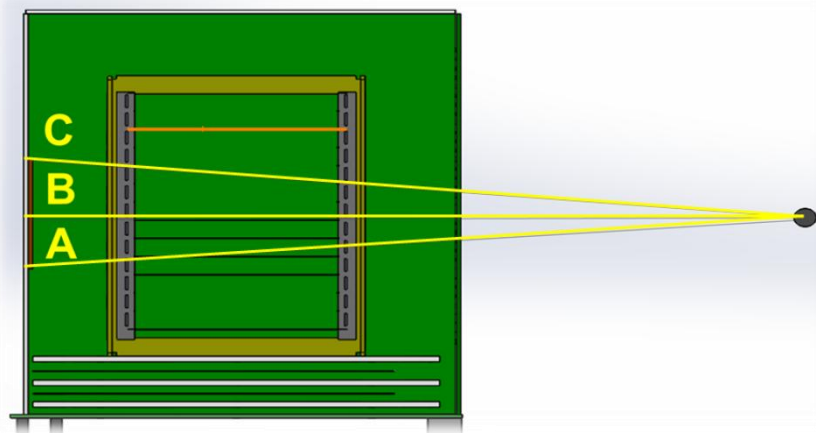
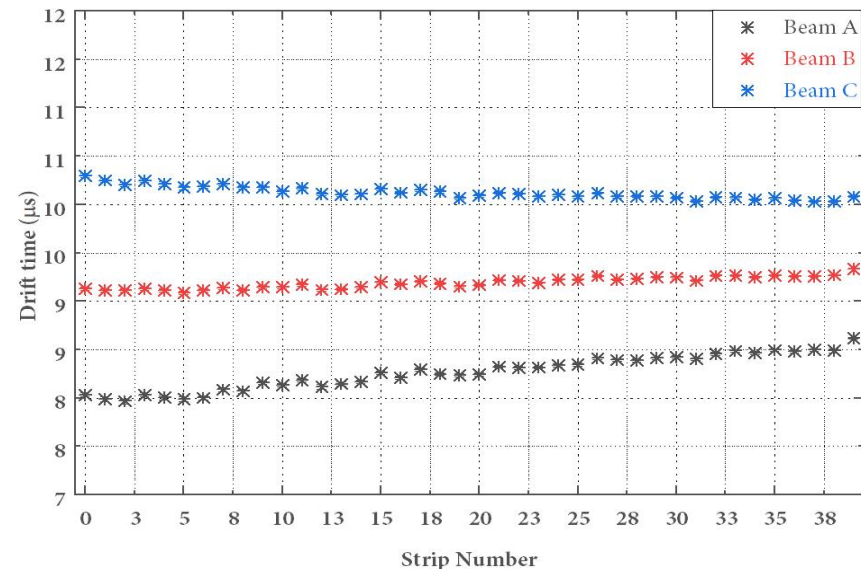
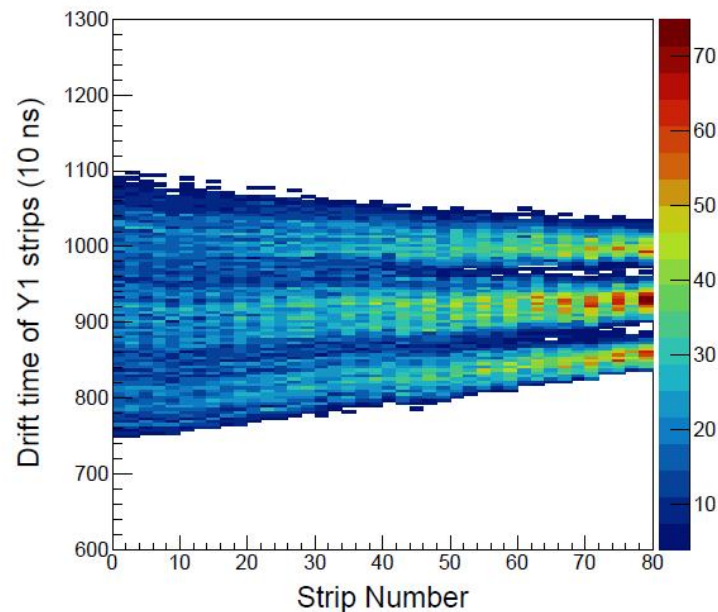


[1]H.Y. Wu, Z.H. Li, H. Tan et al., A general-purpose digital data acquisition system (GDDAQ) at Peking University. Nucl. Instrum. Methods A 975, 164200 (2020).
<https://wuhongyi.cn/PKUXIADAQ/>



Drift velocity

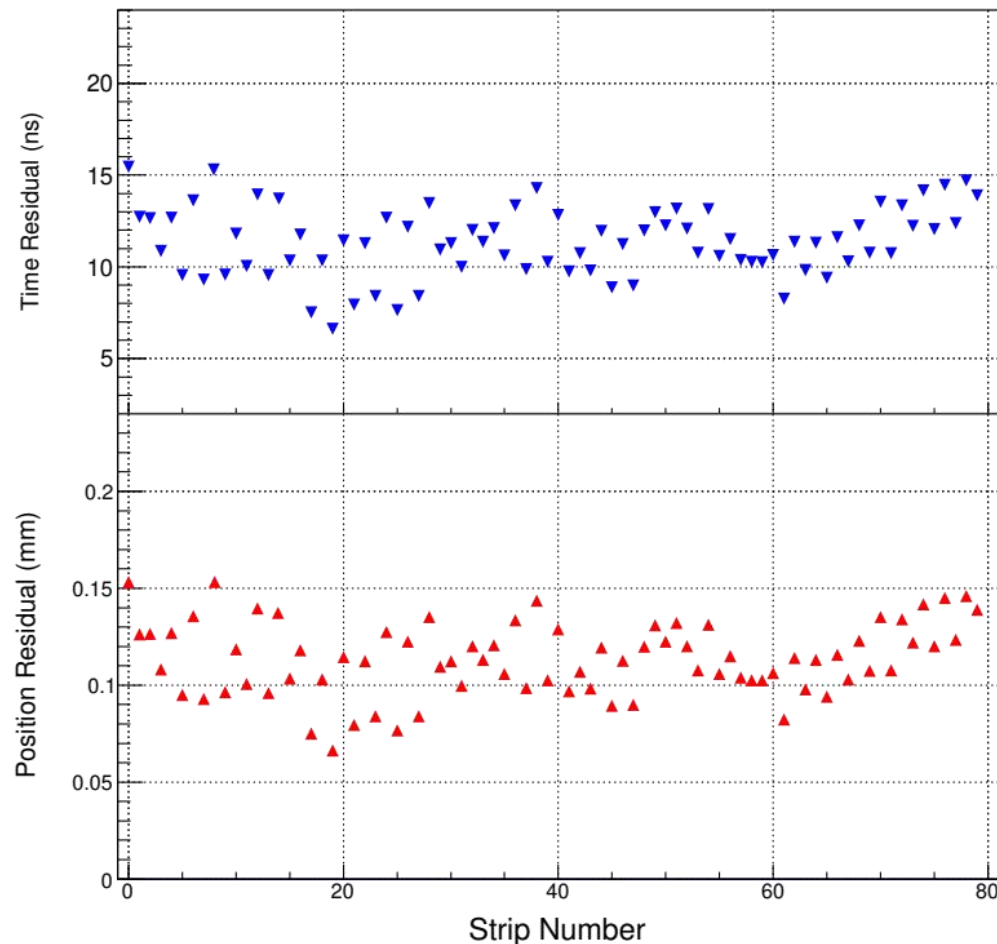
using drift-time centroids and the corresponding absolute positions, drift velocity along the Z-direction can be deduced.



Drift velocity: 9.91-10.08 $\text{mm}/\mu\text{s}$



time and spatial resolution



- track fitting and time residual

$$t_i = T_i^F - T_i^D$$

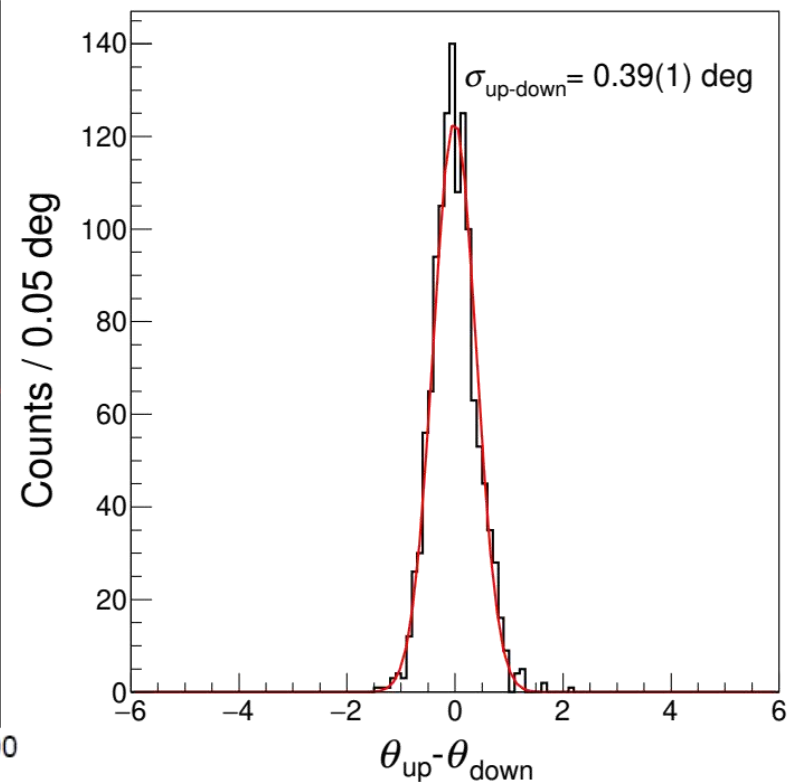
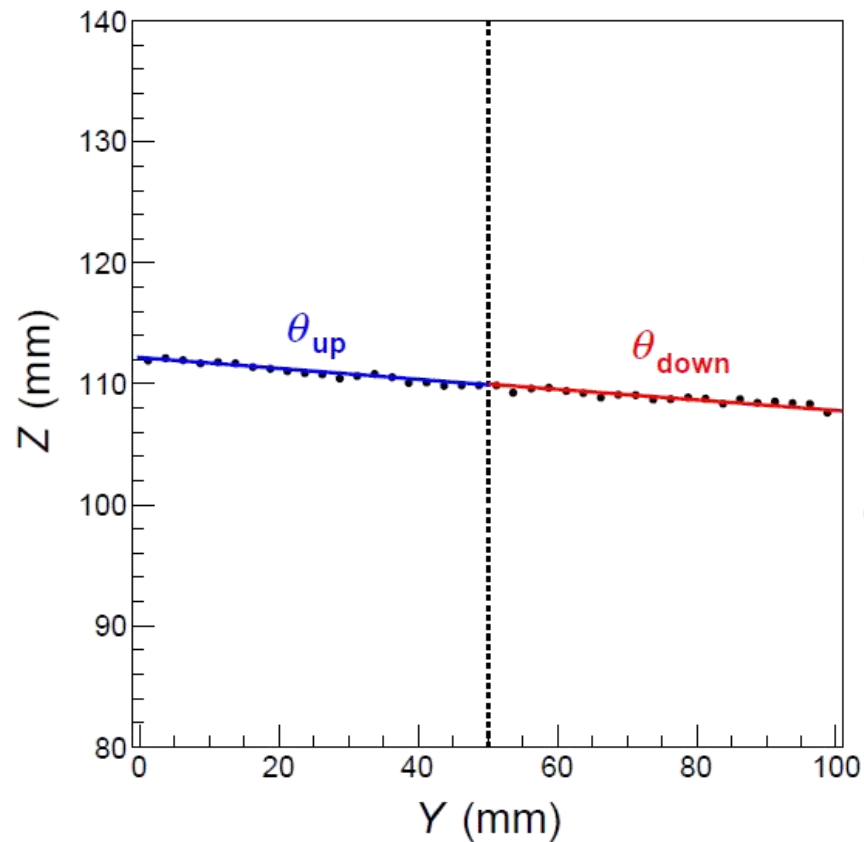
- time σ : 6.6-15.5 ns
- spatial σ : 0.1-0.15 mm
- strip σ :
 - X: $2(\text{mm})/\sqrt{12} = 0.58(\text{mm})$
 - Y: $2.5(\text{mm})/\sqrt{12} = 0.72(\text{mm})$



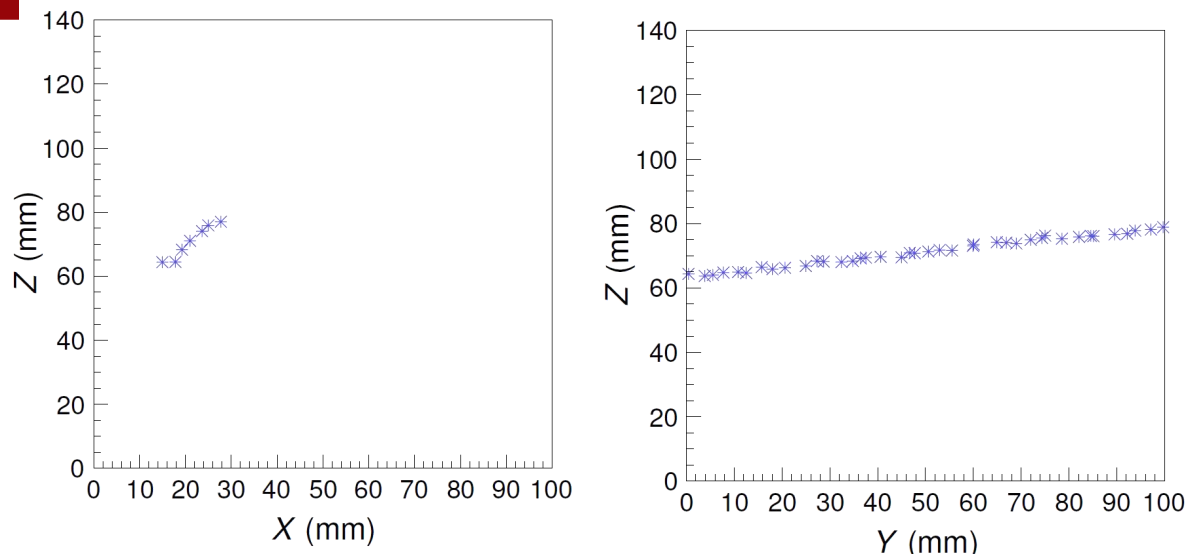
Angular Resolution

- The Difference of trajectory angles for the two sections

- $\sigma_{track} = \frac{\sigma_{up-down}}{\sqrt{2}} = 0.28^\circ$



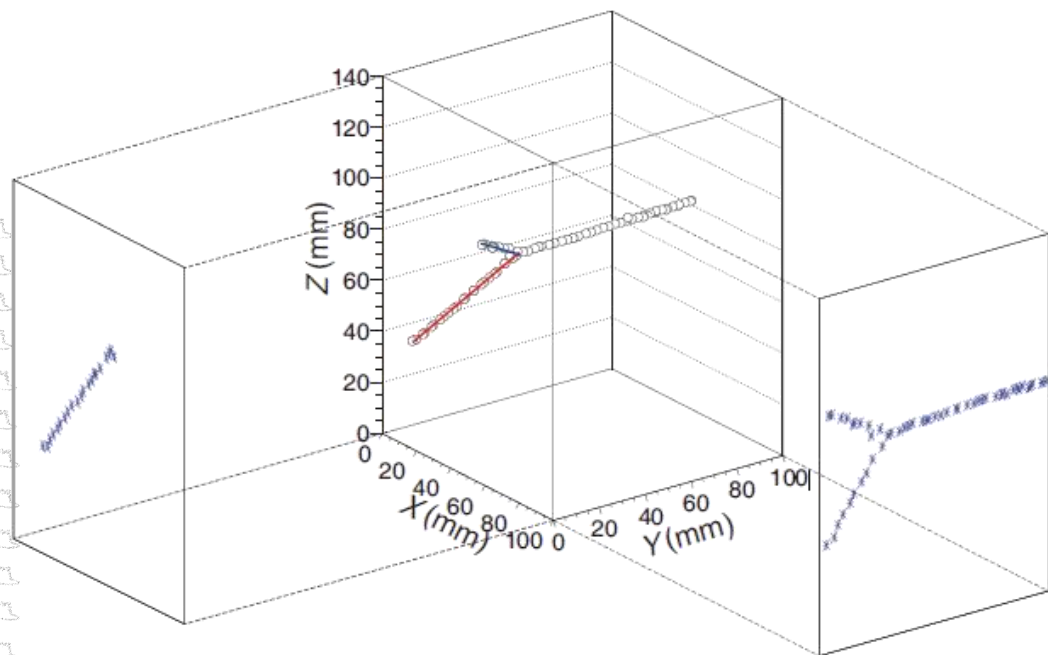
3D tracking



3.3 3-D tracking reconstruction

Using the recorded X - Z and Y - Z information for each track, we could reconstruct its 3-dimensional pattern. We adopted the following algorithm:

- (1) Fit all data points in X - Z plane by a two-dimensional straight-line to obtain the function $Z = f(X)$ and its inverse function $X = g(Z)$;
- (2) For each (Y_i, Z_i) point, find an associated $X_i = g(Z_i)$.
- (3) Collect all (X_i, Y_i, Z_i) to form a 3-dimensional track.

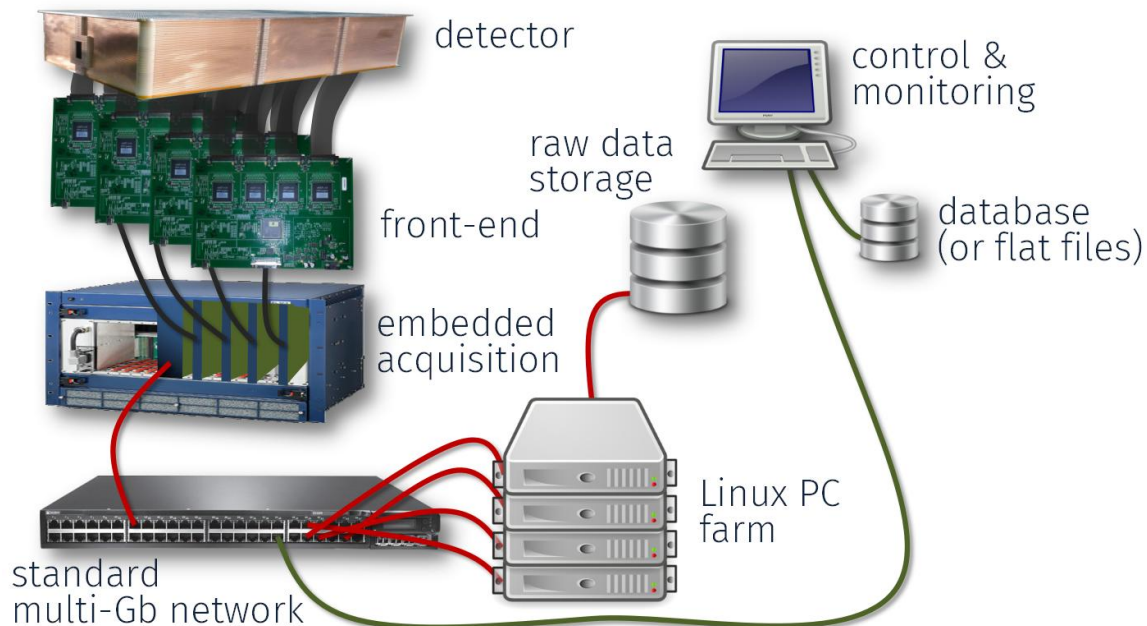
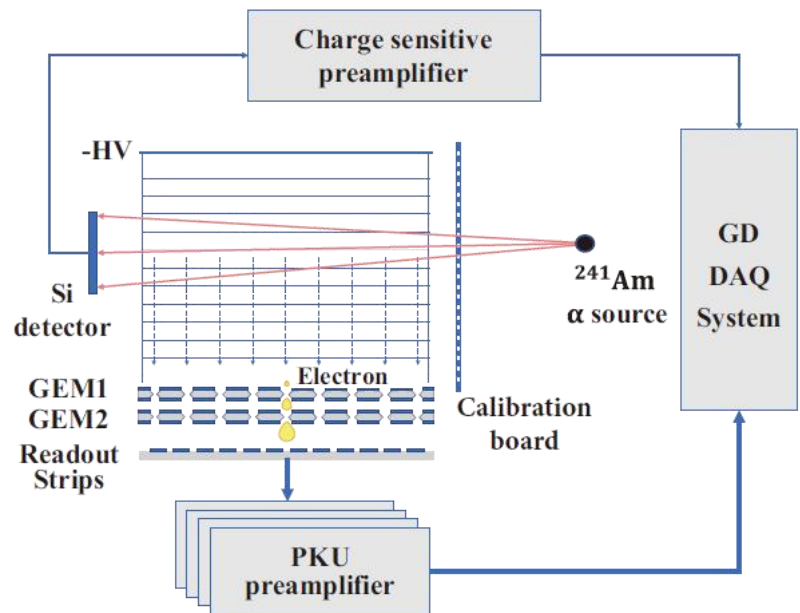


3D tracking ang resolution: 0.45°
Scattering point spatial resolution: 0.49 mm



PKU AT-TPC与AGET获取系统

Typical Setup (here: GET electronics)



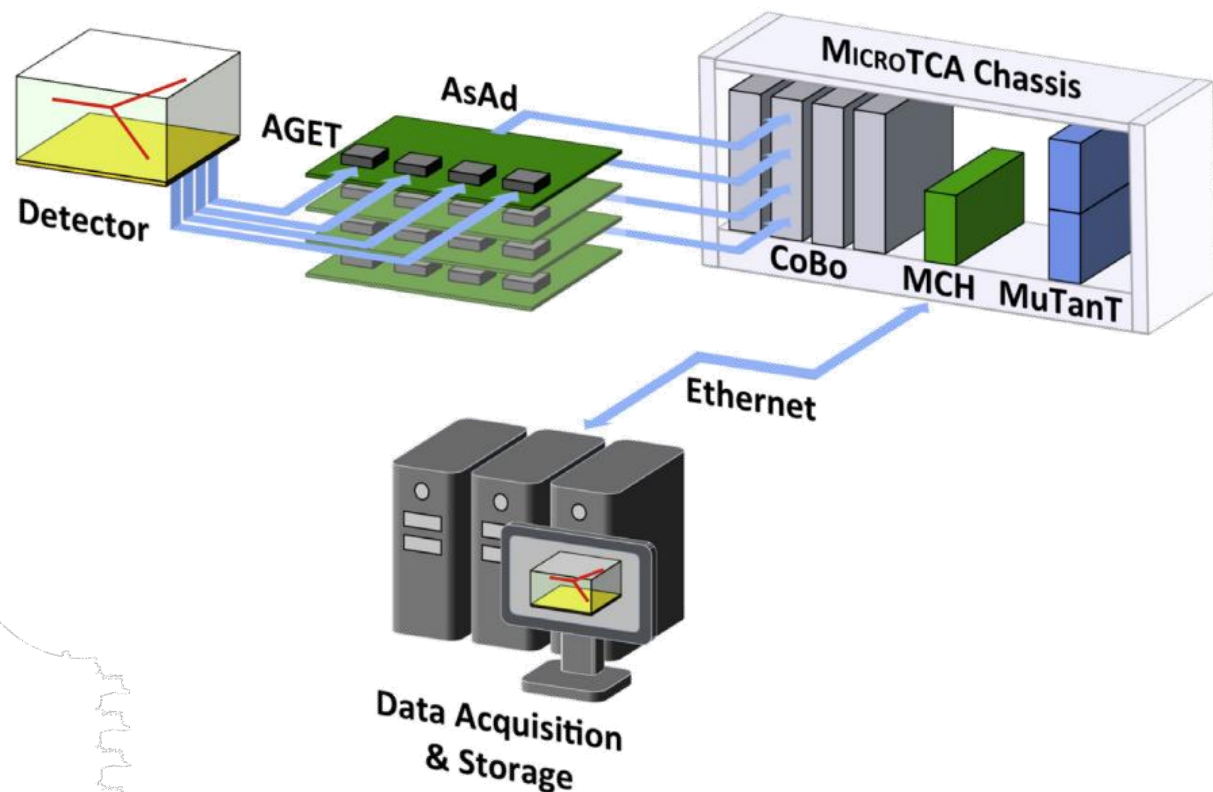
- 探测器→前放→XIA获取→电脑
 - 128路 最大<1000路

- 探测器→AGET芯片→电脑
 - 可获得1024~10240路电子学路数

- 张宁涛+李奇特, 核物理与核技术国家重点实验室开放课题, NPT2020KFY06
- 《AGET 数字获取系统在 TPC 和 SI 上应用的部分核心问题探索》

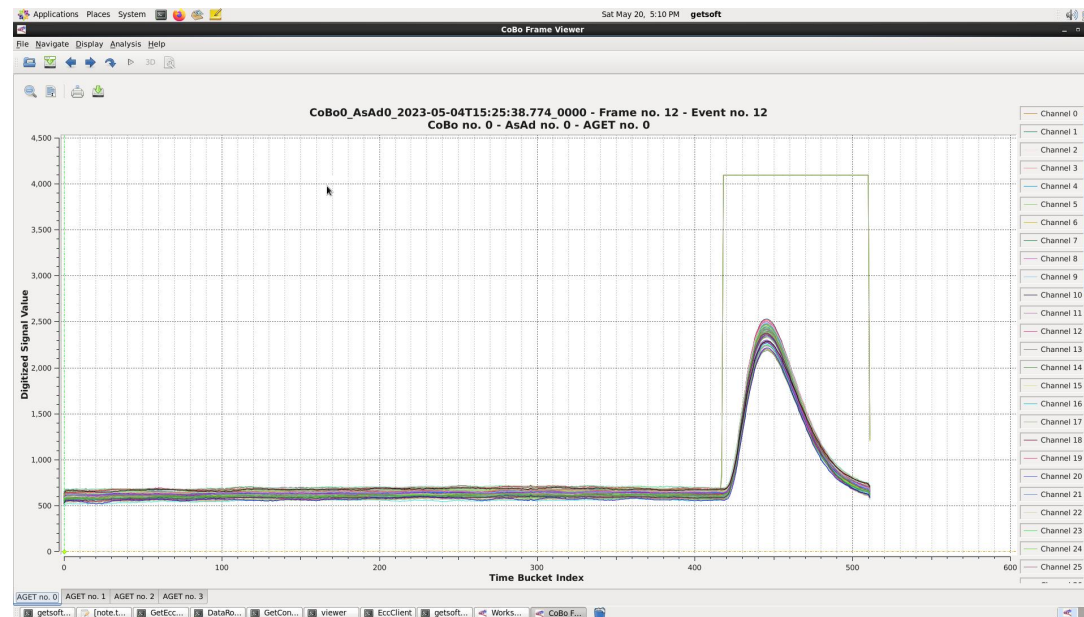


PKU AT-TPC + AGET:



参考文献:

E.C. Pollacco, et al. GET: A generic electronics system for TPCs and nuclear physics instrumentation[J]. Nucl. Instrum. Methods A 2018 (887) :81-93



时间投影室可编程通用电子学(GET)调试与原始数据处理方法

边佳伟¹, 李奇特^{1*}, 许金艳¹, 杨再宏¹

(1. 北京大学 物理学院, 北京 100871)

摘要: 介绍了时间投影室 (TPC) 通用的高密度电子学 GET 架构及调试过程, 对 GET 运行中出现的空事件及基线振荡问题提出可能的解决方法。测量了基线及内部脉冲信号, 简单介绍了基线数据的处理和输入信号重建的方法。采用 Cooley-Turkey FFT 算法对 GET 电子学响应函数进行估算, 分析电子学响应的时域和频域表现: GET 电子学响应非线性, 出于精度考虑需对输入信号进行重建; 高频噪声在重建中的影响较大, 实际重建中考虑引入低通滤波函数降低噪声影响。

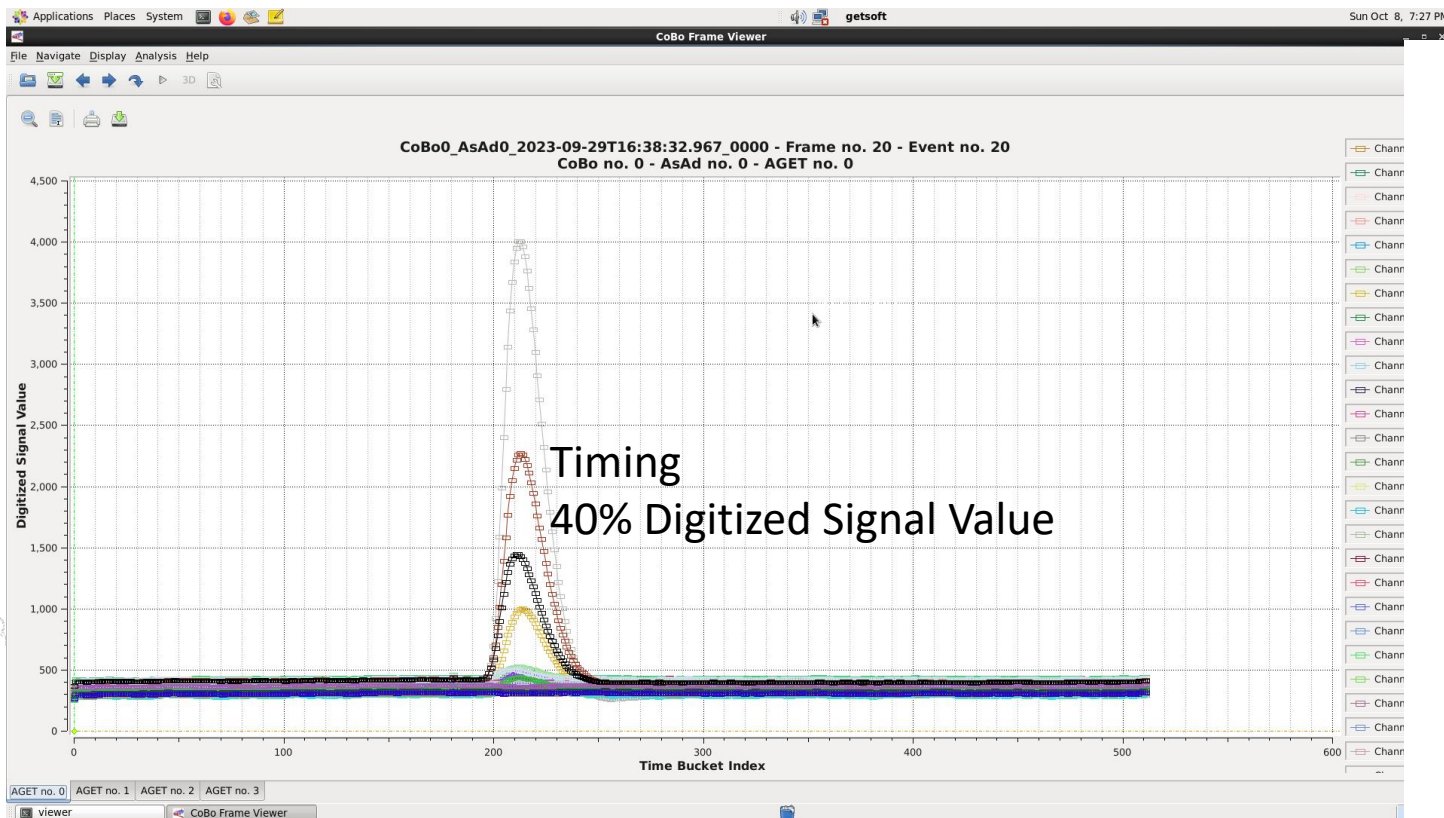
关键词: GET 调试; AGET; FPN; 响应函数

《核电子学与探测技术》DOI: 10.20173/j.cnki.ned.20241111.001

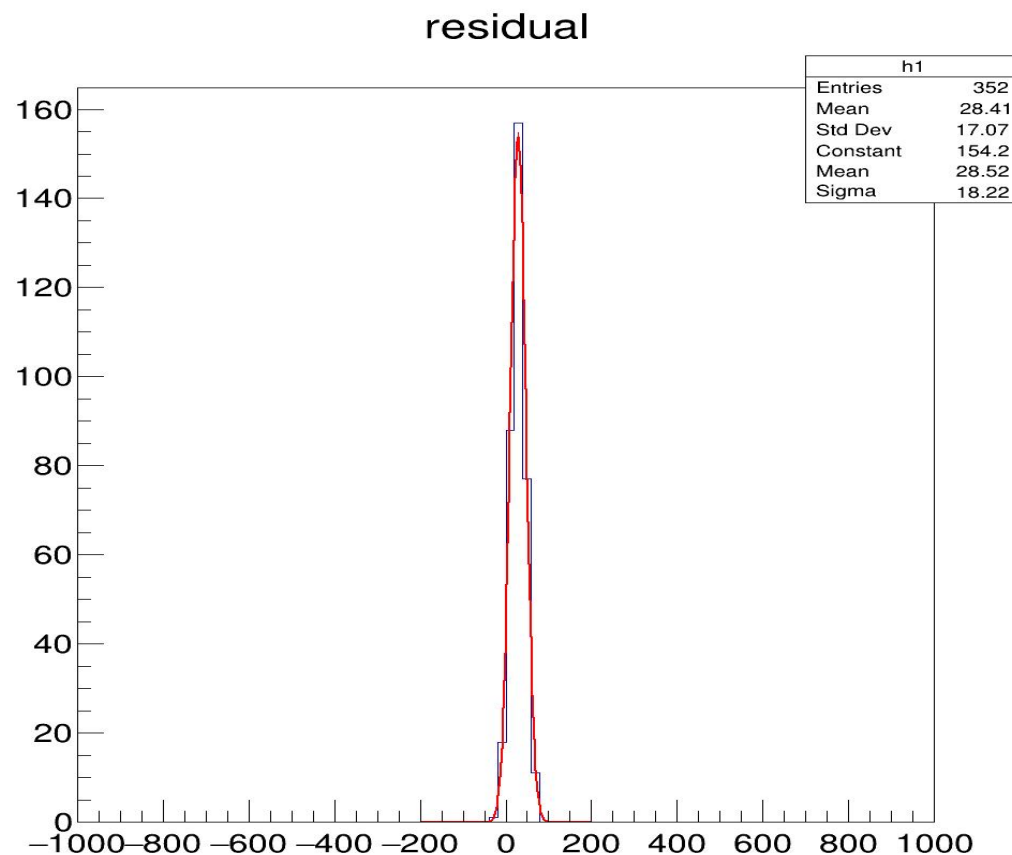


PKU AT-TPC +AGET Time Resolution (preliminary)

$$f = t_{63} - (t_{62} + t_{64})/2$$



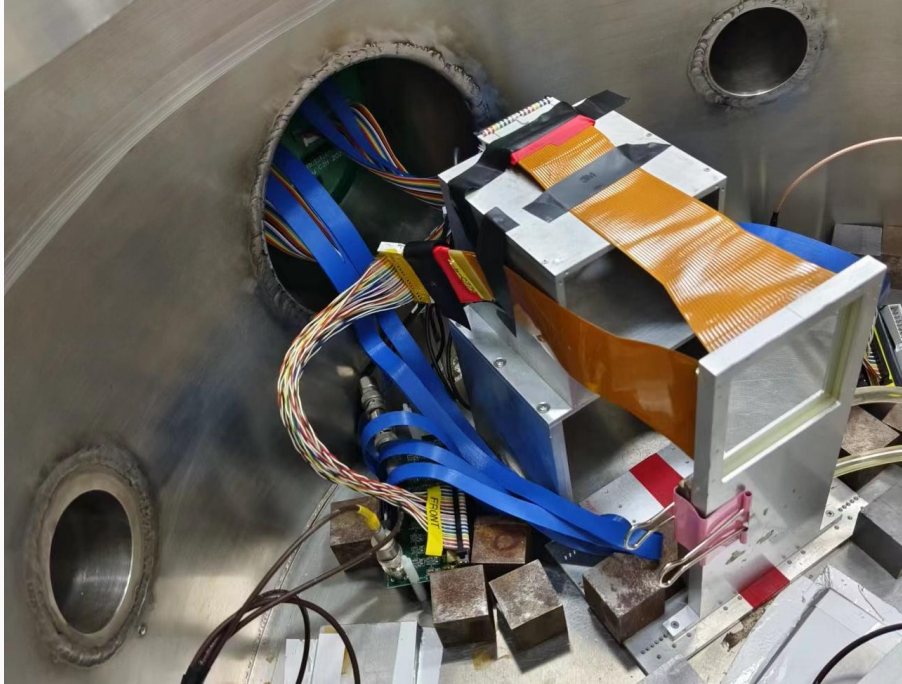
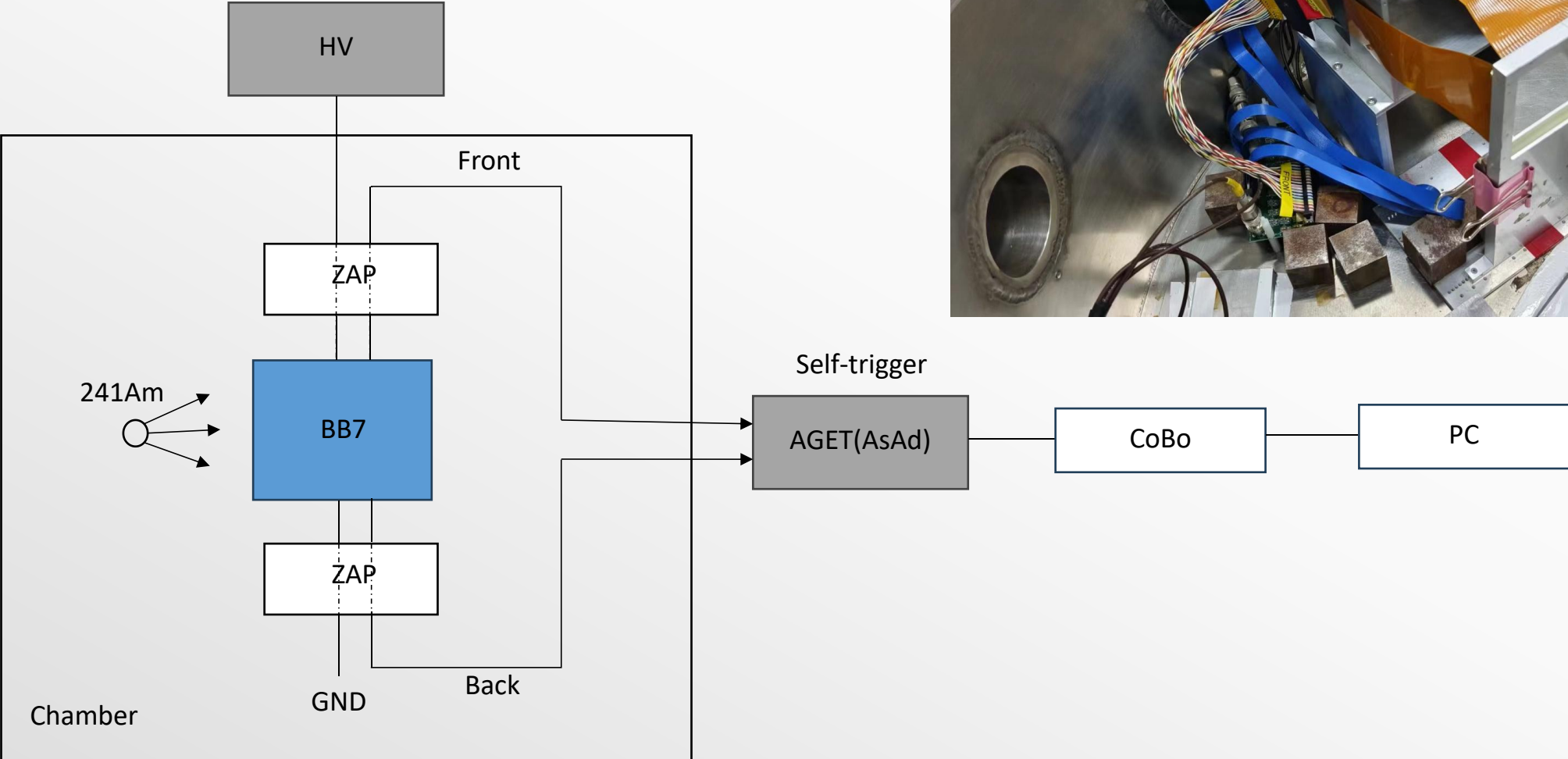
AGETO waveform



- time resolution~14.88ns, spatial resolution 0.15mm

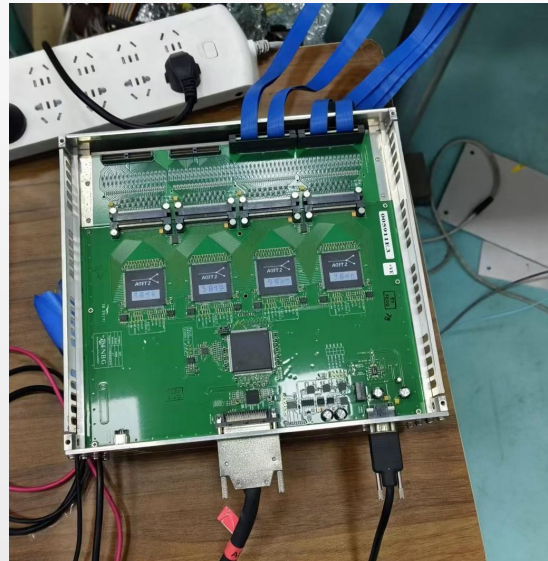


Si+AGET

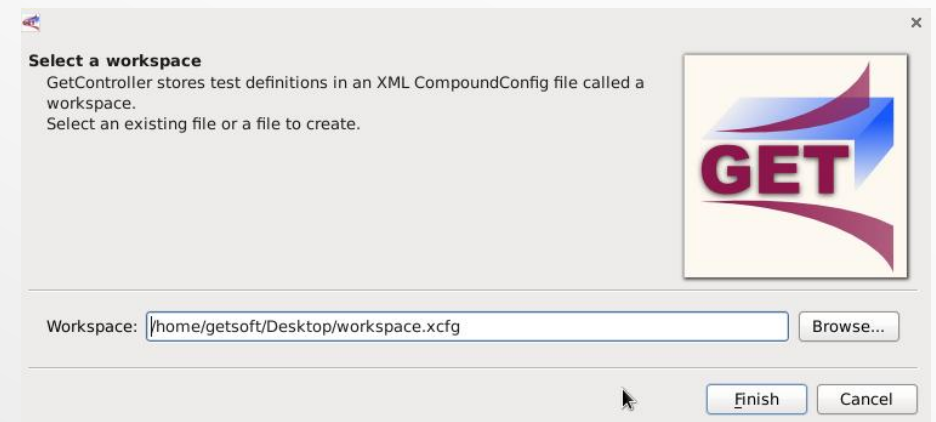
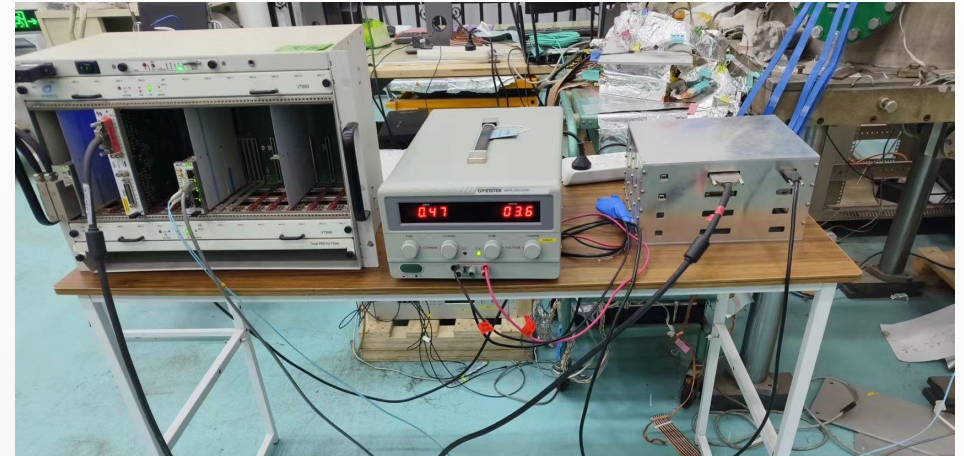


Si+AGET: Setup

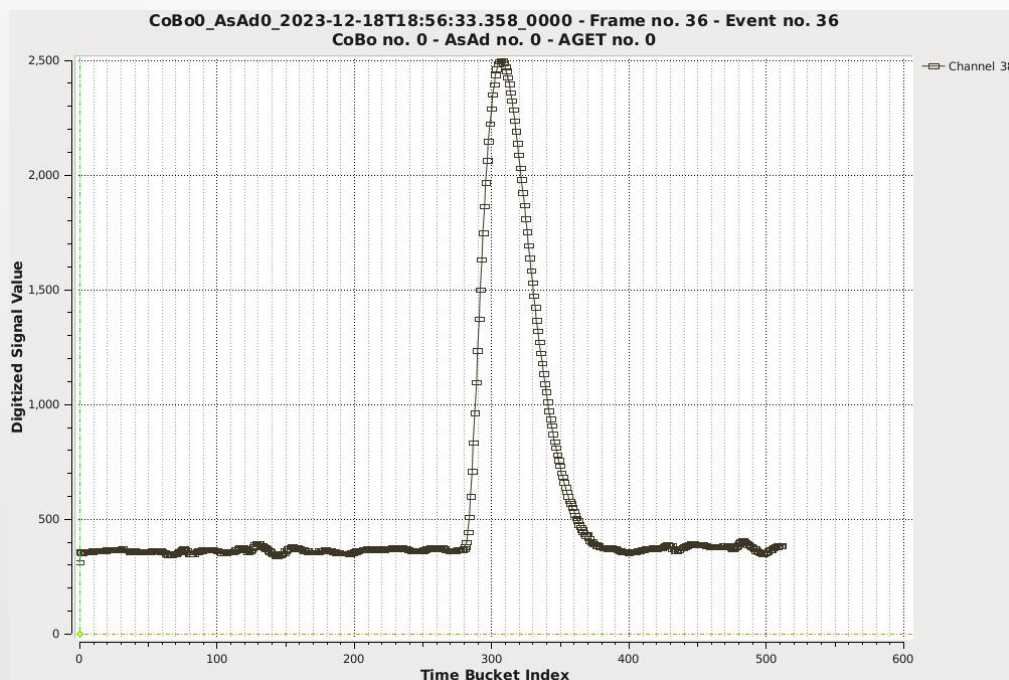
Out of chamber: flange->AGET



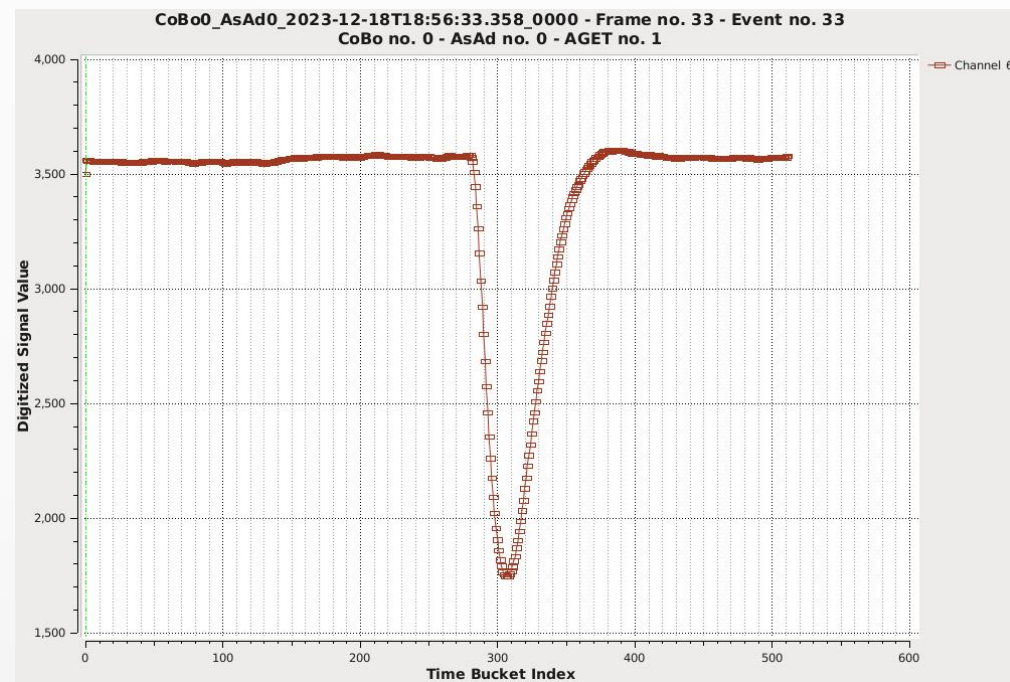
Out of chamber: CoBo(MicroTCA), AGET power supply, DAQ software(GetController)



Si+AGET: Signal on GetController



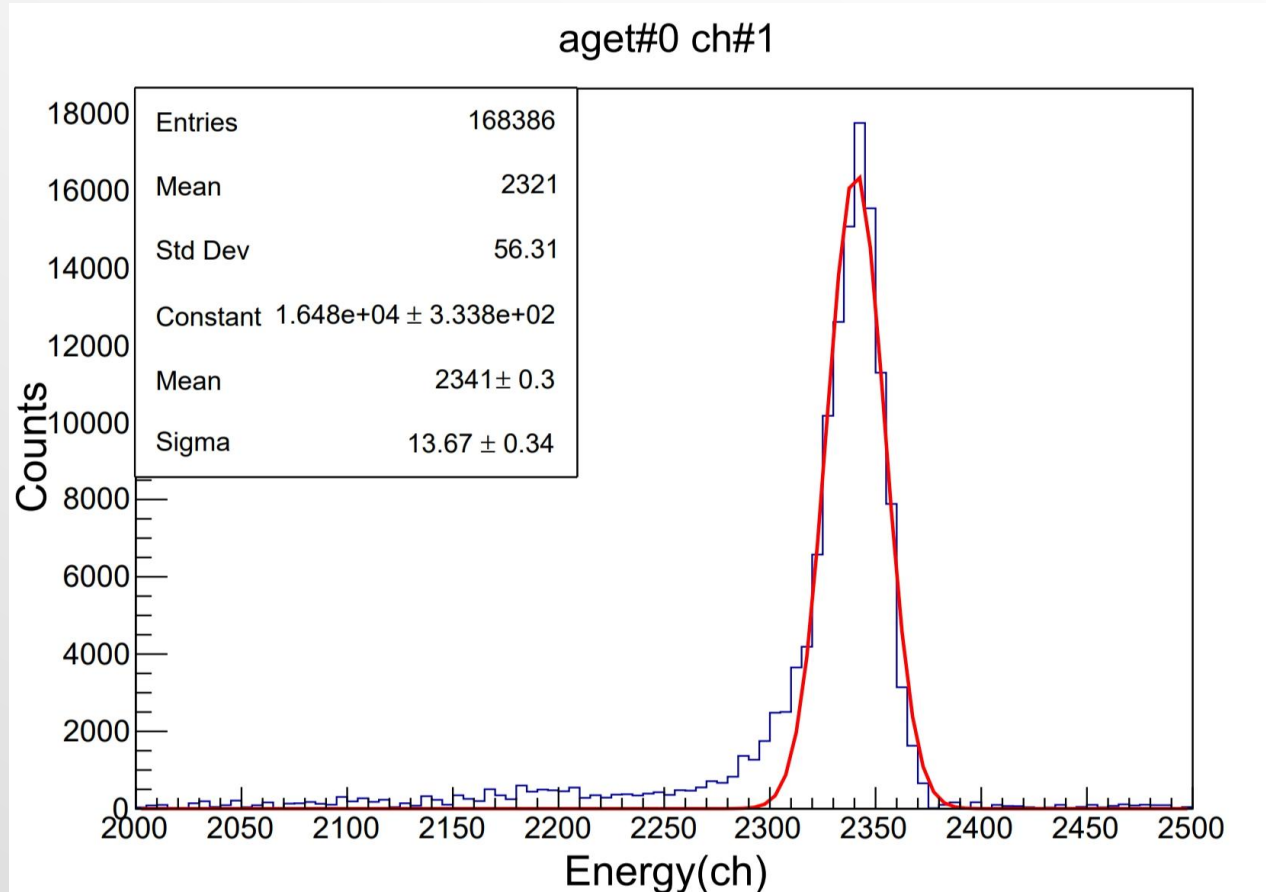
Front



Back

(2023.12.18 test, without noise reduction)

Si+AGET: Energy Resolution (preliminary)



Processing: extracting maximum of waves and cutoff the baseline.

Take ch42 as an example.

Energy resolution by unscaled spectrum is 1.37%.

(2024.01 test, with noise reduction on AsAd)

目录

CONTENTS



01 物理动机



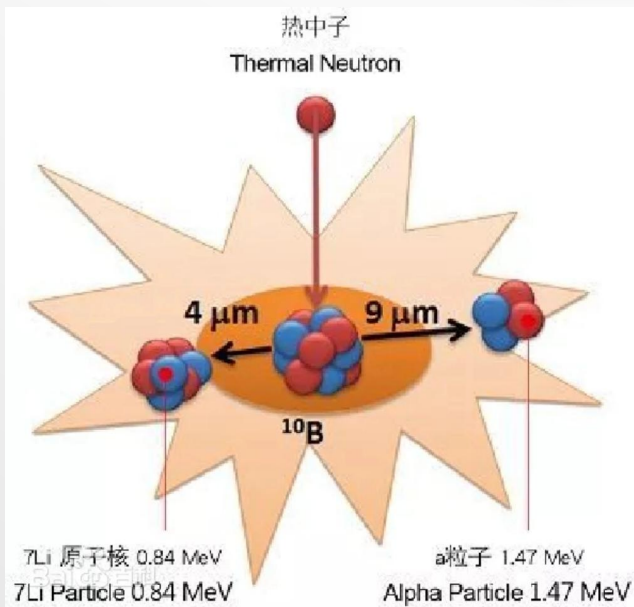
02 AT-TPC研发进展



03 未来计划

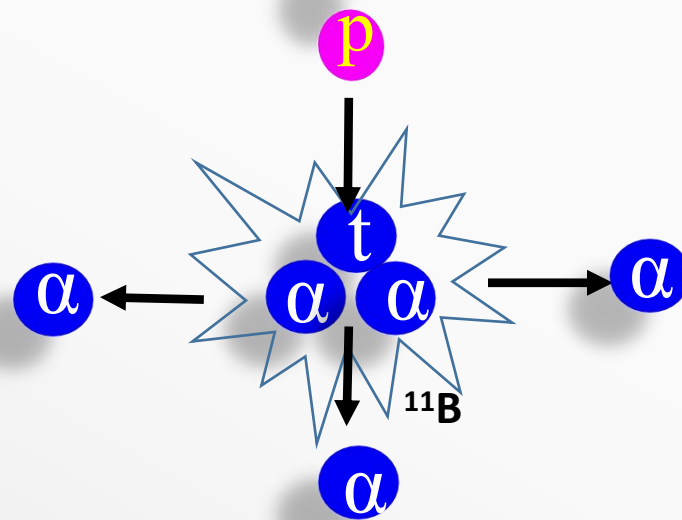
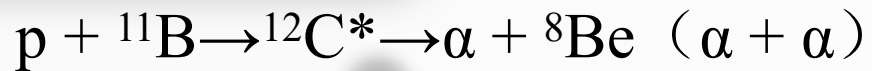


$^{14}\text{O}/^{11}\text{B}$ 束流



BNCT方法

^{11}B 激发态的集团结构很重要
已经成功用于肝肿瘤治疗

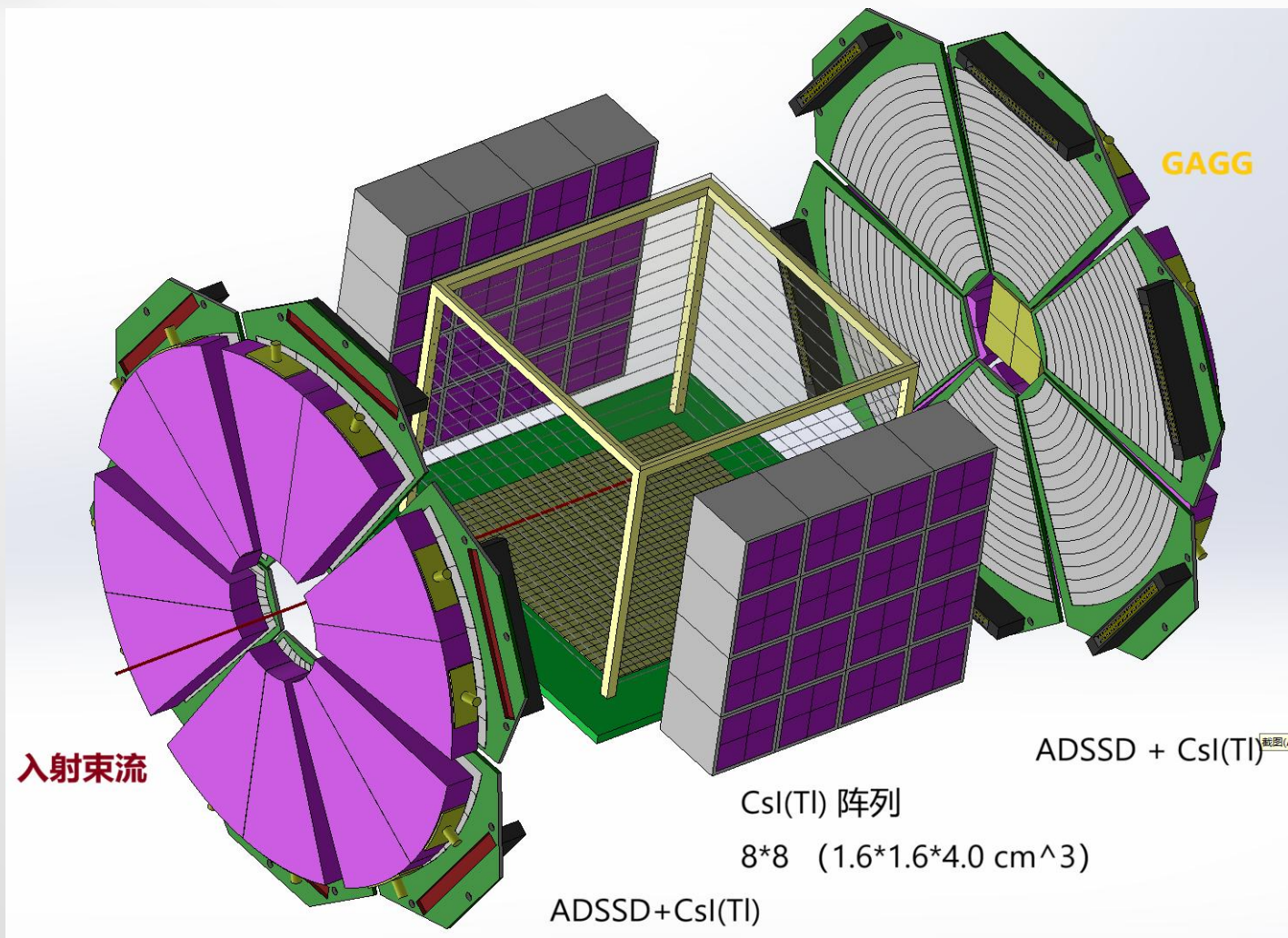


BPCT方法

理论阶段, ^{11}B 基态/ ^{12}C 激发态的集团结构很重要

03

未来计划 | 初步实验方案：AT-TPC+辅助探测器



升级方案

□ 更换工作气体

□ ⁴He 气体 → CH/CD 气体

□ 增加辅助探测器，实现PID

□ 设计专门的支架和靶室

□ 电子学逐渐国产化



物理目标

□ 研究原子核的奇特结构
单粒子结构
集团结构等

Jin-Yan Xu, Qi-Te Li, Yan-Lin Ye et al., Performance of a small AT-TPC prototype, Nucl. Sci. Tech (2018) 29: 97

Li-Shen Yang, Jin-Yan Xu, Qi-Te Li et al, Performance of the CAT-TPC based on two-dimensional readout strips, Nucl. Sci. Tech. 32, 85 (2021)

03

未来计划

物理需求及升级内容

Requirement & Developing content

物理需求

直接核反应：含氢/氦气体作为介质

(p, d), (p, t), (d, t), (d, p), (d, ^3He), (d, ^4He), (d, ^6Li), (d, d), (d, d')

粒子鉴别PID，区分各个反应道

- AT-TPC 射程 + 磁场
- AT-TPC + 辅助探测器

升级内容

实验含氢/氦气体的正常工作。

CH_4 , C_4H_{10} , C_3D_8 , C_4D_{10} , 纯 D_2 气体, 测试对比, 选择最佳 (国内首次)

实现PID。

选择技术路线

研发辅助探测器

联合AT-TPC, 实现 $\Delta E-E$ 的PID

设计专门的支架和靶室。

支撑/冷却辅助探测器

密封探测介质

03

未来计划

Technology

PID技术路线

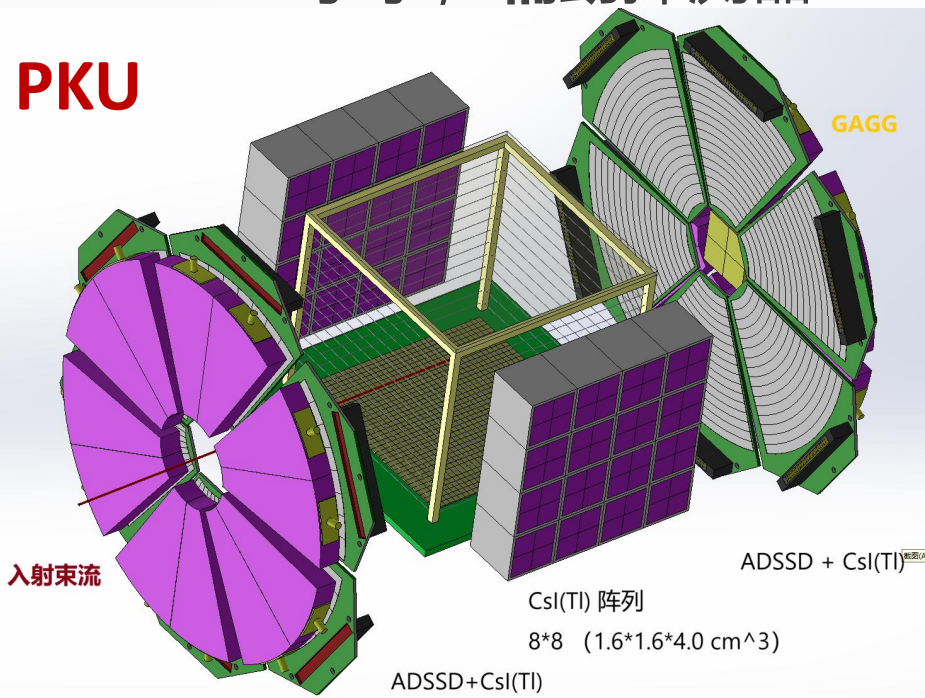
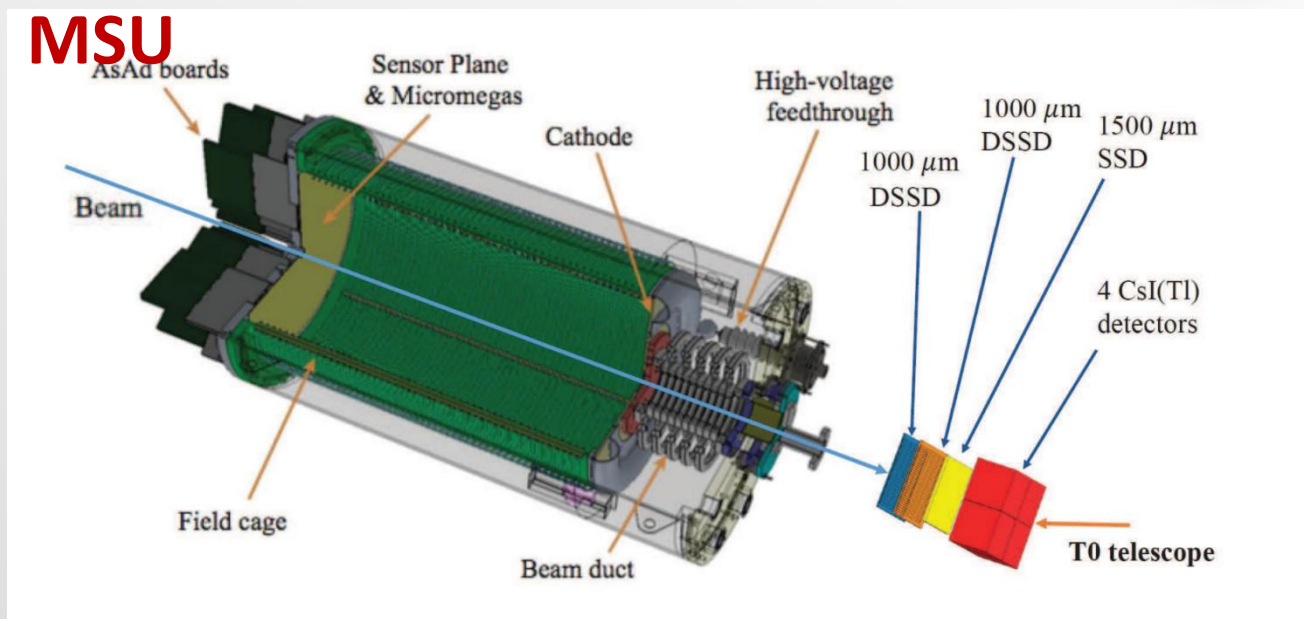
技术
路线

AT-TPC + 磁场

尺寸大, 上万路电子学, 2T强磁场

AT-TPC + 辅助探测器

尺寸小, 上千路电子学, 辅助探测器



G.Li, J.L.Lou, Y.L.Ye et al., Property investigation of the wedge-shaped CsI(Tl) crystals for a charged-particle telescope, Nucl. Inst & Meth.A (2021) 1013: 165637

H.Y.Zhu, J.L.Lou, Y.L.Ye et al., Two annular CsI(Tl) detector arrays for the charged particle telescopes, Nucl. Sci. Tech (2023) 34:159

W.W.Wan, J.L.Lou et al., Upgrade and test of CsI(Tl) detector array, Nucl. Phys.Rev, (2024), in press.

03

未来计划

Previous work foundation

国际合作

	发件人	主题	日期	大小	★
▼ 三周前 (2 封)					
	Santam...	[ml-attpc-cam...	06-06	15 KB	★
	Santama...	AT-TPC @ RCN...	06-06	9 KB	★
▼ 上个月 (2 封)					
	Santama...	[ml-attpc-camp...	05-08	17 KB	★
	Santama...	[ml-attpc-camp...	05-08	15 KB	★
▼ 更早 (209 封)					
	Santama...	[ml-attpc-camp...	04-12	21 KB	★
	Santama...	AT-TPC @ RCN...	04-12	11 KB	★
	Santama...	[ml-attpc-camp...	03-13	24 KB	★
	Santama...	[ml-attpc-camp...	02-17	24 KB	★
	Santama...	AT-TPC @ RCN...	02-17	11 KB	★
	FERNAN...	[ml-attpc-camp...	02-08	25 KB	★
	Santama...	[ml-attpc-camp...	02-08	15 KB	★
	Santam...	[ml-attpc-cam...	02-03	23 KB	★
	Santam...	AT-TPC @ RC...	02-03	11 KB	★
	Li Qite	Agenda and Z...	01-09	580 KB	★
	Soomi Cha	Re: mini TPC w...	01-08	42 KB	★
	Xiaodon...	Re: mini TPC w...	01-08	44 KB	★
	Soomi Cha	Re: mini TPC w...	01-08	34 KB	★
	Tony Ahn	Re: mini TPC w...	2023-12	32 KB	★

获批物理实验

E581

“Investigation of the shell inversion in ^{10}Li via the $d(^{11}\text{Be}, ^3\text{He})^{10}\text{Li}$ reaction with an Active Target Time Projection Chamber(AT-TPC)”

Spokespersons: Jianling Lou jllou@pku.edu.cn
 Yanlin Ye yeyl@pku.edu.cn

Beam Time: **Approved 5 days** (requested 5 days)

Budget: **(requested 0 kYen)**

国家重点实验室支持项目
 获批NSCF-JSPS交流项目
 获批北京大学仪器创制项目

03

未来计划

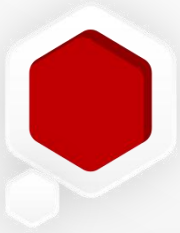
与国内外专家学者沟通

Previous work foundation



研讨会





总结

summary



PKU AT-TPC:

研制了一个基于厚GEM探测器放大的AT-TPC原型机，灵敏体积为 $14\text{cm} \times 10\text{cm} \times 10\text{cm}$ ，128路二维读出条读出，获取为XIA (GDDAQ)。

测试了其时间分辨位置分辨等性能，进行了三维径迹重建，观察到了 α 在He上的弹散径迹。

AGET+TPC

时间分辨率10~15ns

AGET+Si

成功调通， α 能量分辨率~1.3%



AT-TPC用于直接核反应实验研究原子核的奇特结构:

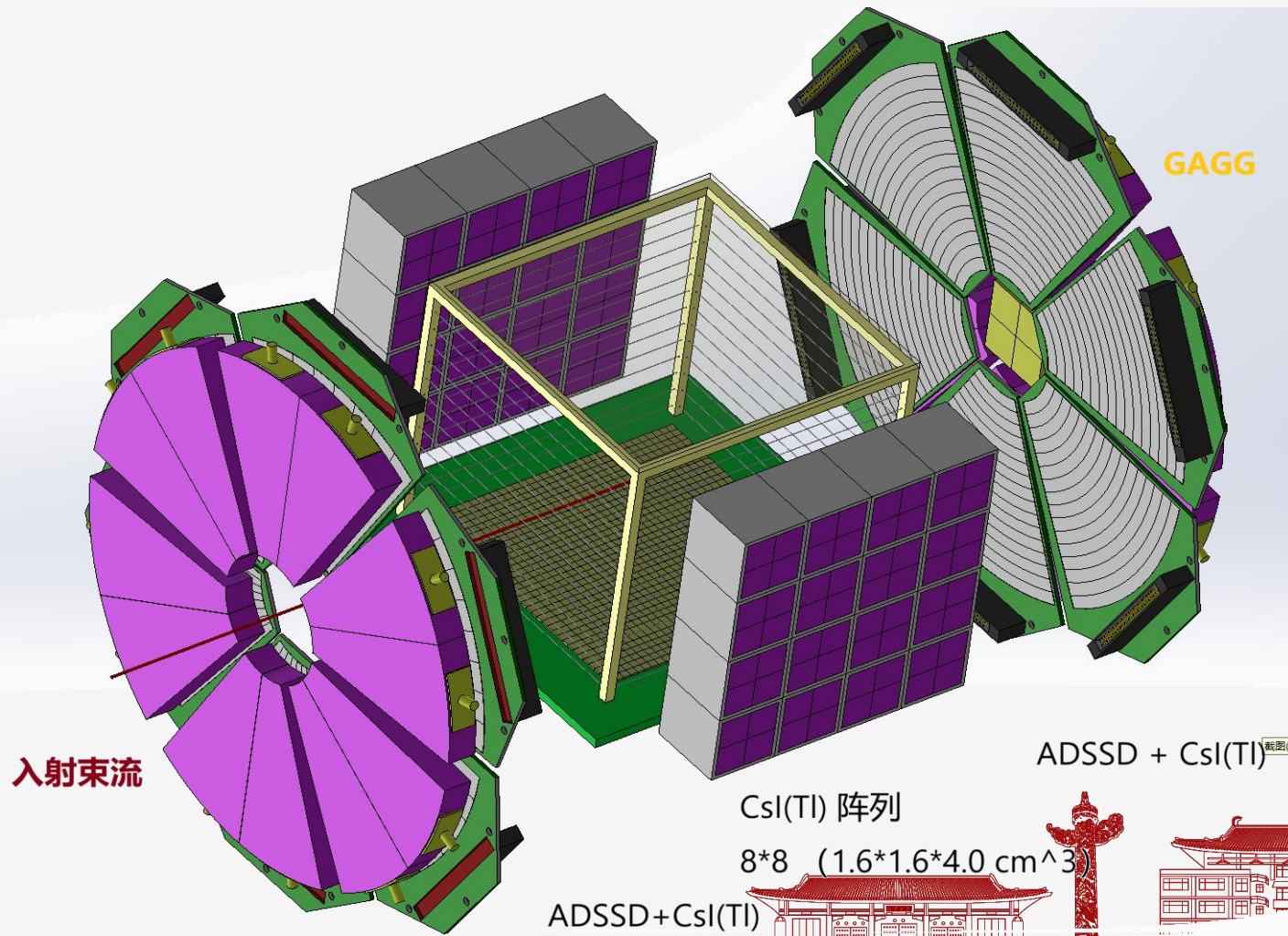
- 已经获批束流实验/陆续申请实验
- 基金：北大创新仪器项目
NSFC-JSPS交流项目
- 路线：AT-TPC + 辅助探测器



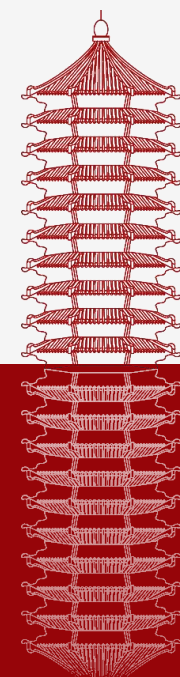
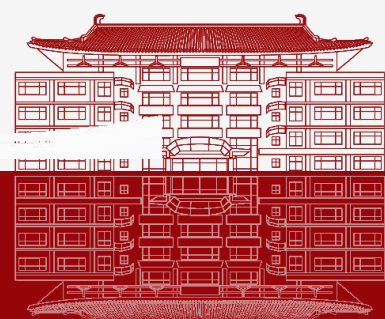
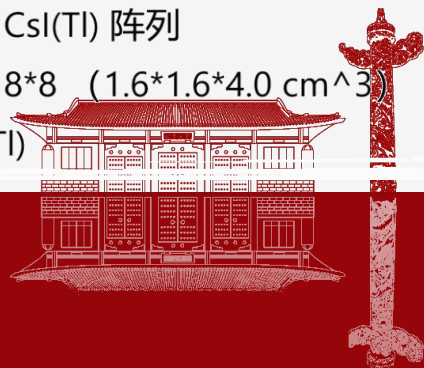
未来升级内容:

- 充含CH/CD气体的AT-TPC研发
- AT-TPC + 辅助探测器，实现PID
- 设计专门的支架和靶室
- 推动AT-TPC电子学国产化

THANKS



2024-11-30



求是園 圖書館