



基于纯He正比计数器的研究

杨洲^{1, 2}、樊瑞睿¹、王艳凤¹、王小胡³

1. 散裂中子源科学中心
2. 西南科技大学
3. 深圳技术大学

中子的自旋

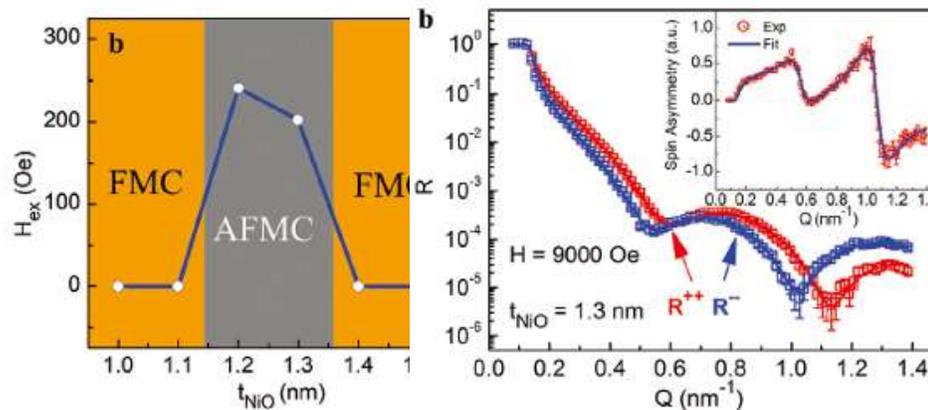
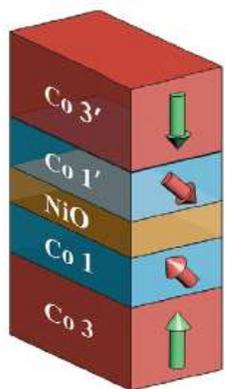
spin of neutron

自旋在中子散射中的应用

中子反射: 单原子层厚度氮化铬CrN薄膜透明电极

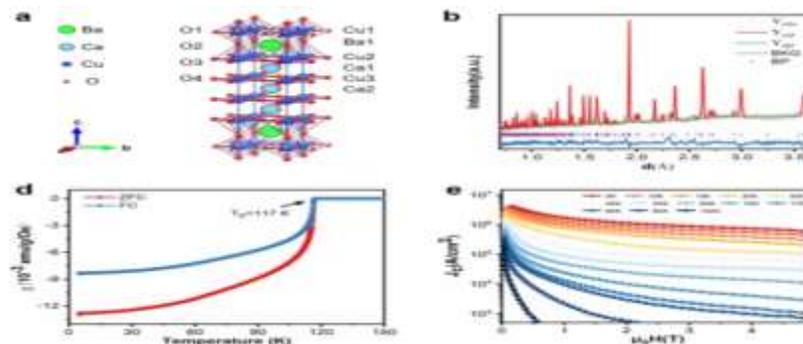
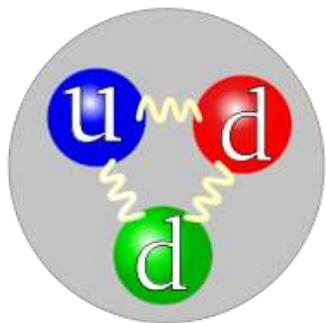
中科院物理所, 郭尔佳, Phys. Rev. Lett. 2022, 128, 017202

- 超导
- 磁性
- 自旋电子学



中子衍射: 临界温度最高的铜基高温超导体Cu-1234

中科院物理所, 靳常青, PG Asia Materials 2022, 14, 50

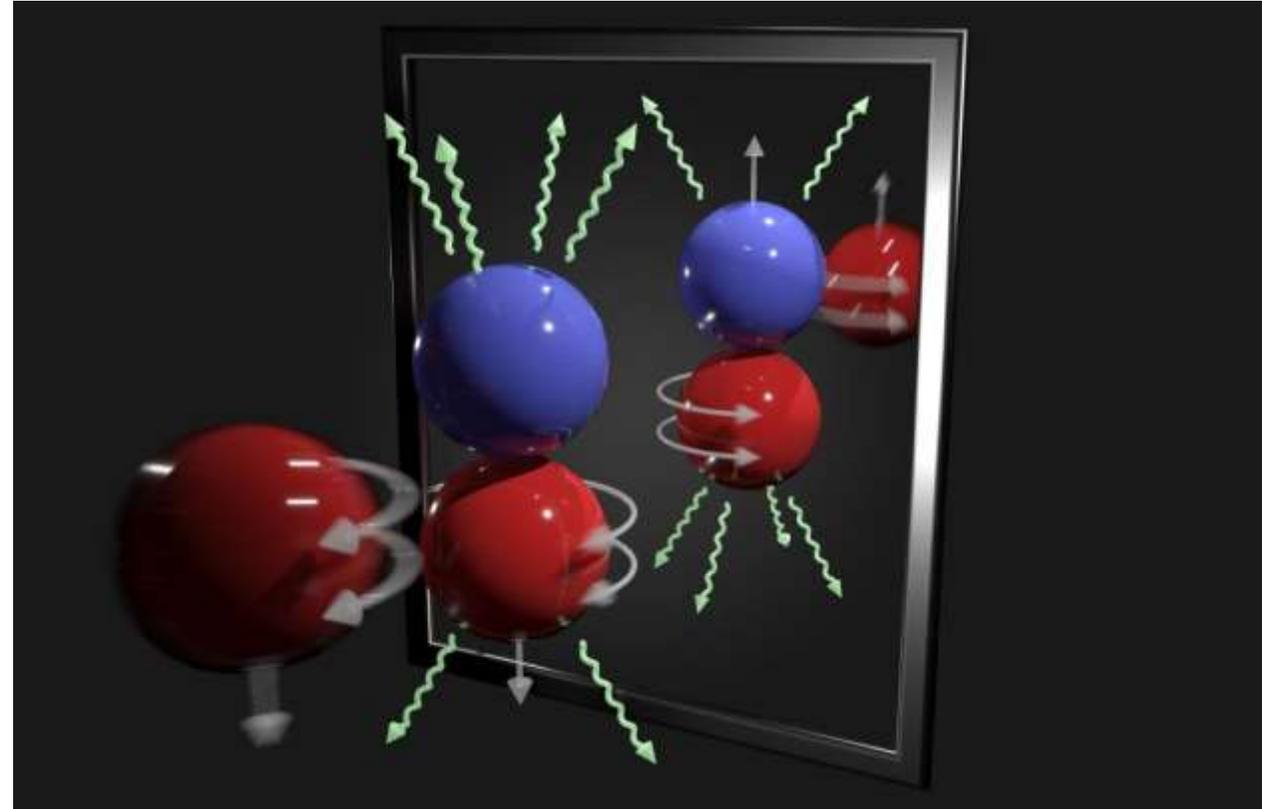


Borrowed from Junrong Zhang

Parity violation

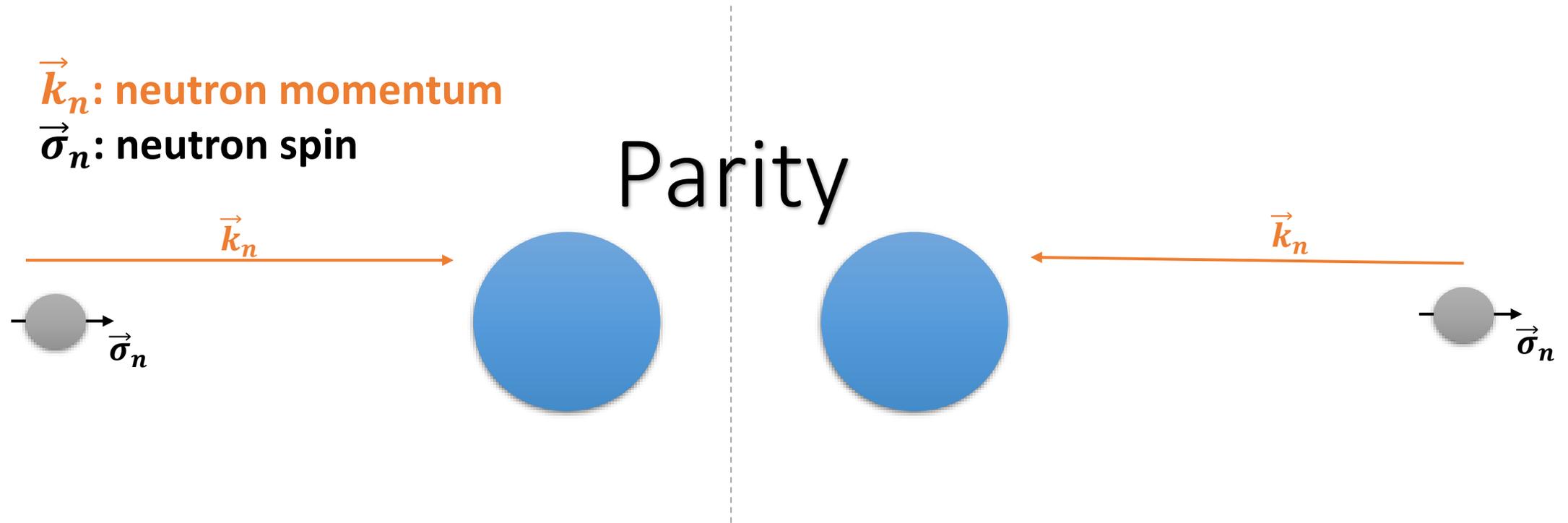


In 1957, Lee and Yang proposed that perhaps the weak interaction did not respect parity. This was confirmed by Wu et al using weak β -decay in ^{60}Co .



D. Blyth *et al.* (NPDGamma Collaboration)
 Phys. Rev. Lett. **121**, 242002

Parity violation



Parity violation

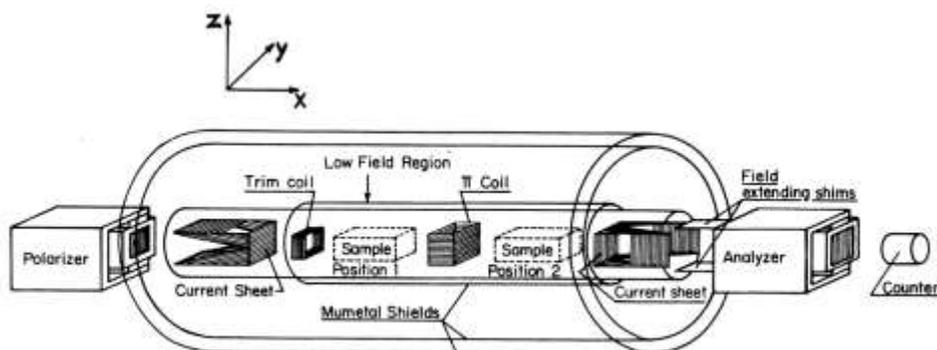


FIG. 1. Schematic view of experimental apparatus. The neutron beam polarization is along \hat{z} and momentum along \hat{x} .

in 1980 after the ILL measurements on tin with polarized cold neutrons. In ^{117}Sn PNC effects were observed: the spin rotation angle $\Phi = (3.7 \pm 0.3) \times 10^{-5} \text{ rad/cm}$ and the cross section longitudinal asymmetry $A = (9.8 \pm 4.0) \times 10^{-6}$.

Phys. Rev. Lett., 45 (1980), p. 2088

Nucl. Phys. A, 398 (1983), p. 93

Phys. Lett., 12 (1964), p. 334

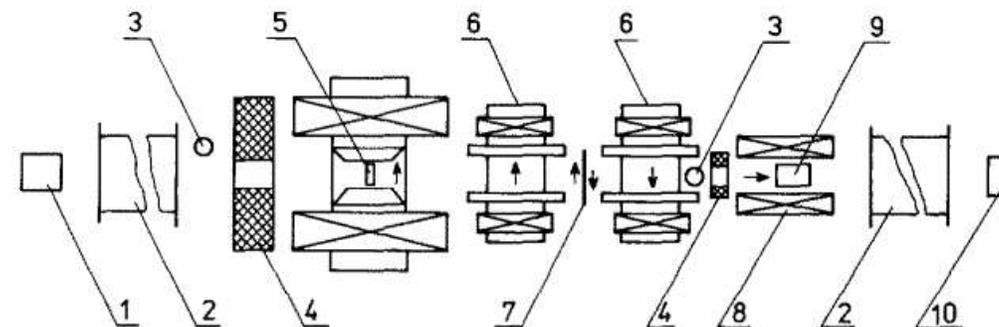


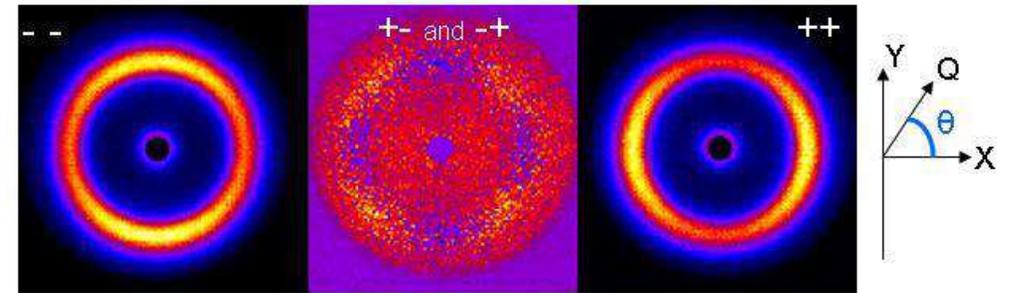
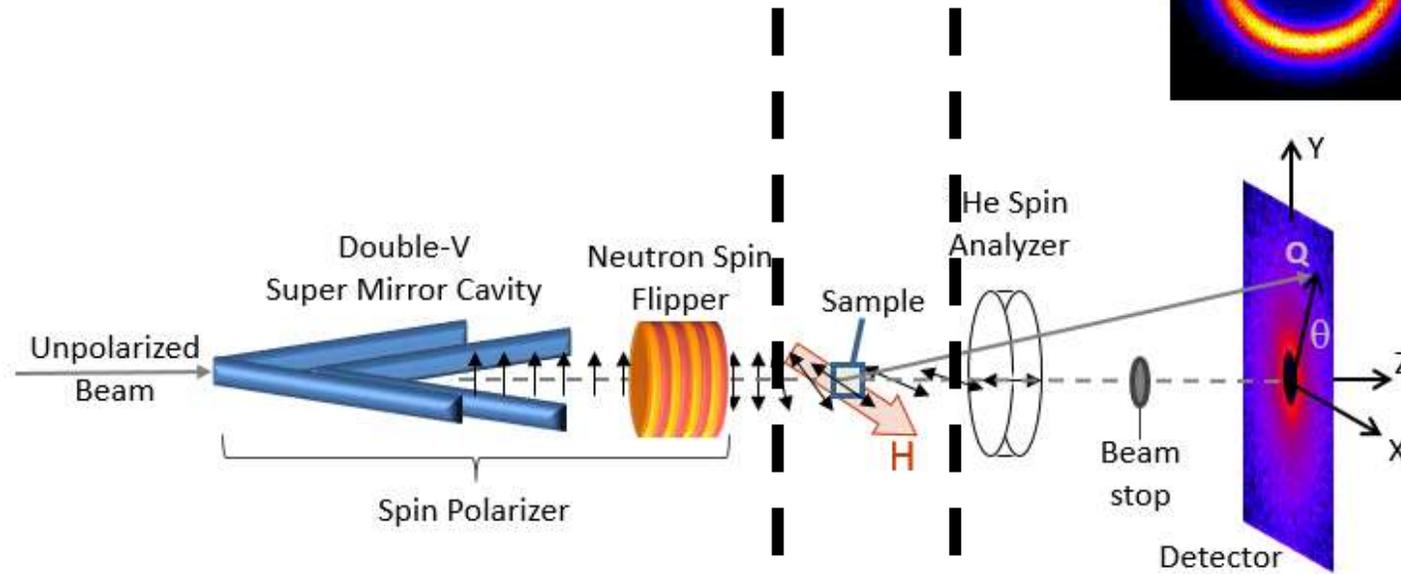
Fig. 1. Experimental arrangement: 1 – reactor, 2 – evacuated neutron guide tube, 3 – monitors, 4 – collimators, 5 – polarized proton target, 6 – electromagnets of the guide field, 7 – current sheet, 8 – solenoid, 9 – sample, 10 – neutron detector. Arrows along the neutron beam path show the direction of magnetic field.

Experiments at Dubna were performed using the IBR-30 pulsed reactor as a neutron source for time-of-flight measurements. The proton-filter transmission technique for polarizing resonance neutrons was first developed at the Joint Institute of Nuclear Research (JINR) by another team.

极化中子系统

System of neutron polarization

System of neutron polarization



Front-End:

Typically polarize, maintain polarization, and modify direction of neutrons for a non-divergent beam

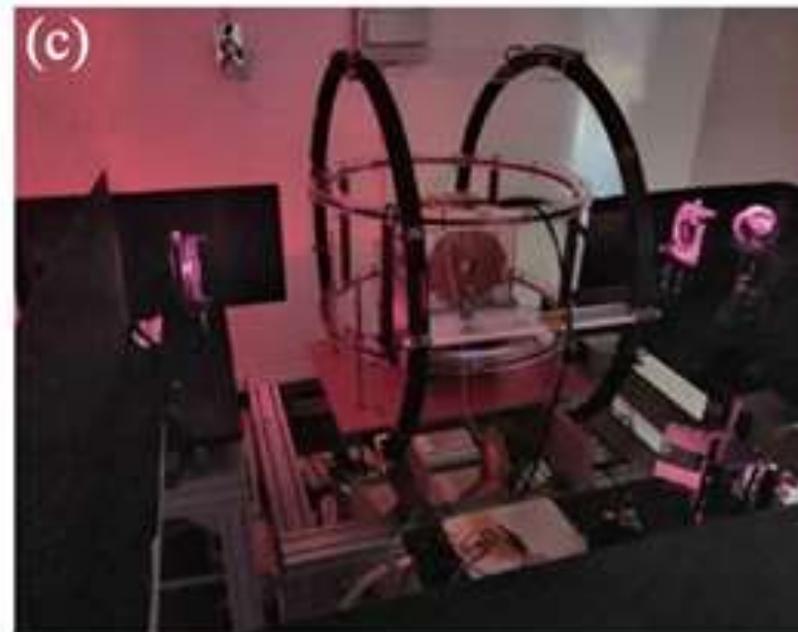
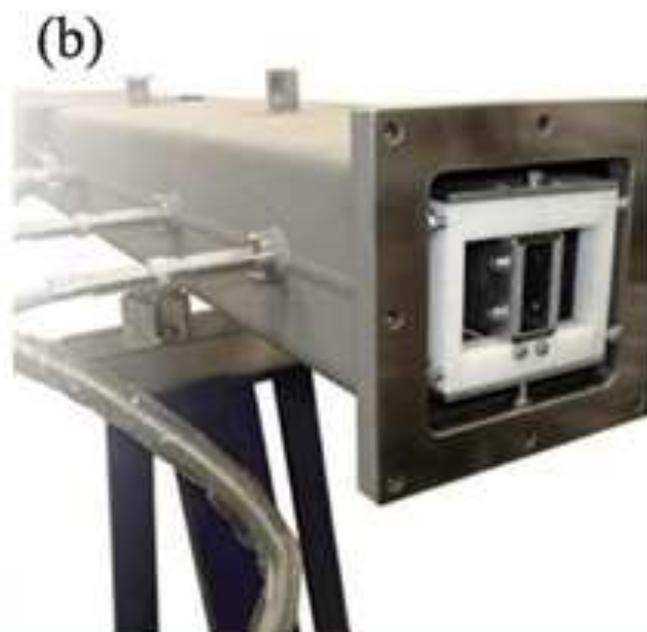
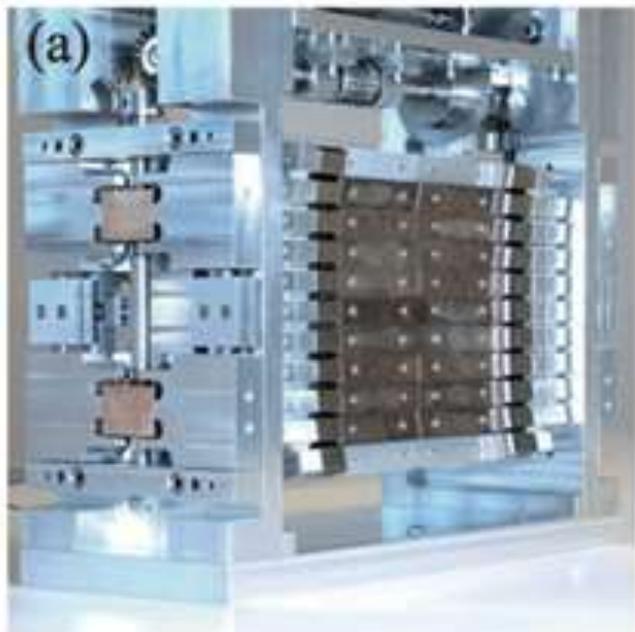
Sample Scattering:

Often 1D analysis w/ B-field, but 3D analysis w/o field possible (spherical polarimetry)

Back-End:

Maintain polarization, analyze neutron spin direction for non-divergent (reflectivity, diffraction) or divergent (SANS, off-specular) beam

中子极化方法



(a) Heusler合金极化单色器；(b) 极化中子超镜(MirrorTron®)；(c) ^3He 气体中子自旋过滤

几种中子极化方法的对比

	极化单晶	超镜	^3He 自旋过滤器 (NSF)
优势	<ul style="list-style-type: none"> 设备较简单 同时完成对中子的极化与在样品上聚焦 	<ul style="list-style-type: none"> 技术目前已经相当成熟效率高 可近似看成极化率为100% (没有中子损耗) 	<ul style="list-style-type: none"> 接收角度较好, 计数率及能量传输和散射角范围优于超镜。 中子波长范围广, 可极化反应堆和散裂源中的全部范围的热中子。 可根据中子波长改变气体压力和腔室长度调节不透明度至最佳值。 还可以同时作为一个极化中子生产装置, 过滤装置和分析装置
不足	<ul style="list-style-type: none"> 只能极化单色中子, 所以目前的应用仅局限于反应堆中子源的单色中子谱仪上 	<ul style="list-style-type: none"> 接受角度过小 可用波长范围窄 	<ul style="list-style-type: none"> ^3He价格昂贵 需要考虑磁场和磁性材料影响 极化^3He的产生有一定的温度要求

基于 ^3He 的中子极化方法



其原理依赖于自旋分量反平行 ^3He 核自旋的中子由于俘获截面特别高才会被吸收其吸收截面($\sigma_{\uparrow\downarrow} [\text{barn}] \approx 6000 \cdot \lambda [\text{\AA}]$), 忽略散射作用平行于 ^3He 的中子俘获截面特别低, 约为($\sigma_{\uparrow\uparrow} [\text{barn}] \approx 5$)。

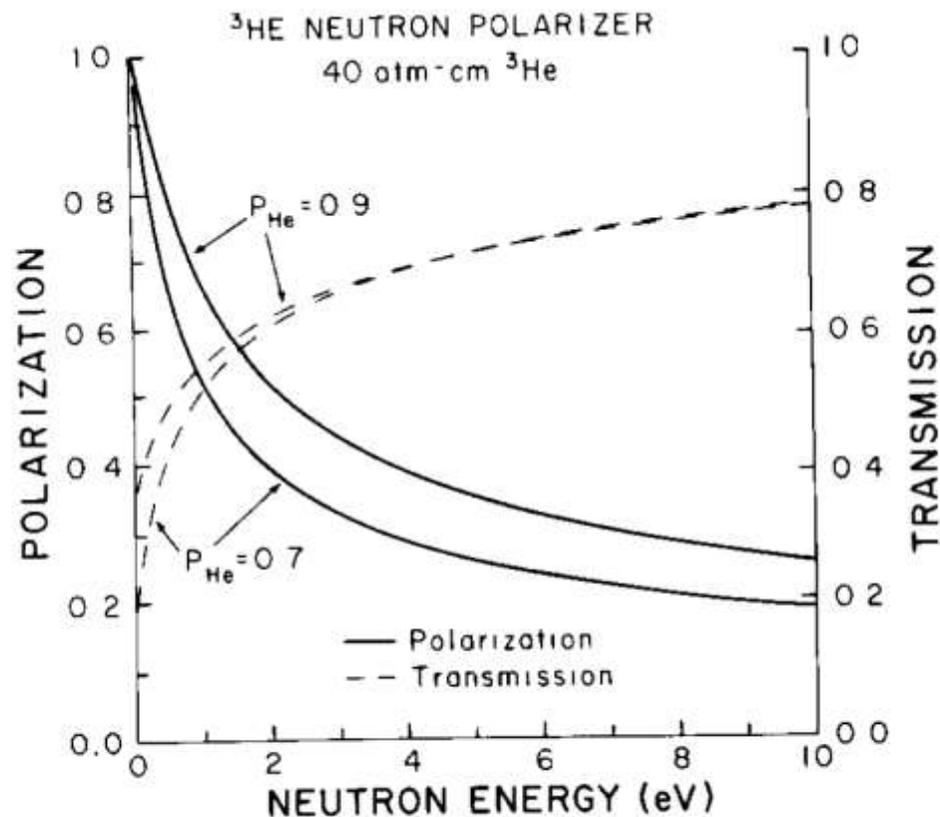
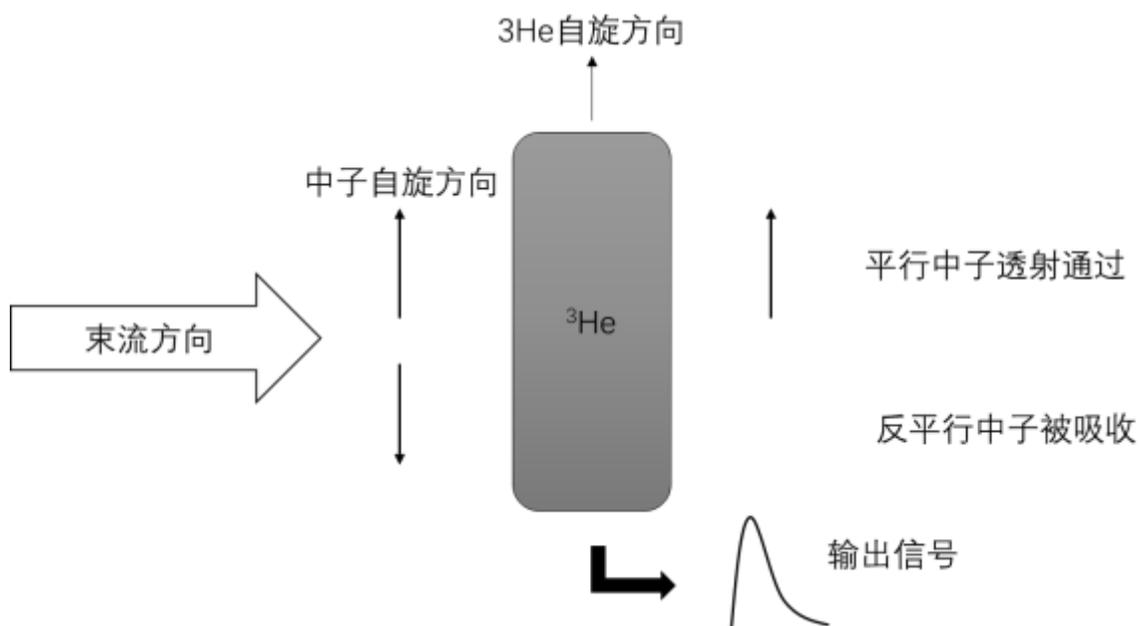


Fig. 2. Calculated values for the neutron polarization and transmission of a 40 atm cm polarized ^3He target with $P_{\text{He}} = 0.9$ and 0.7 .

J. Res. Natl. Inst. Stand. Technol. 110, 293-298 (2005)

Nuclear Instruments and Methods in Physics Research A270 (1988) 90-94

基于极化 ^3He 的极化中子探测器设想



1. 这类探测器较传统氟化硼正比管等探测器更高效，可应用于大部分极化中子测试实验，测量误差小；
2. 与NSF装置一体设计，可以在不影响设备工作的状态下对极化中子进行实时监控测量；
3. 未来改进为多位置读出探测器系统，可以对极化腔不同位置的极化效果进行评估，从而给改善极化效果给出依据；
4. 区分中子极化方向，可用作中子极化分析探测系统；

该项工作受到自然科学基金支持12205326

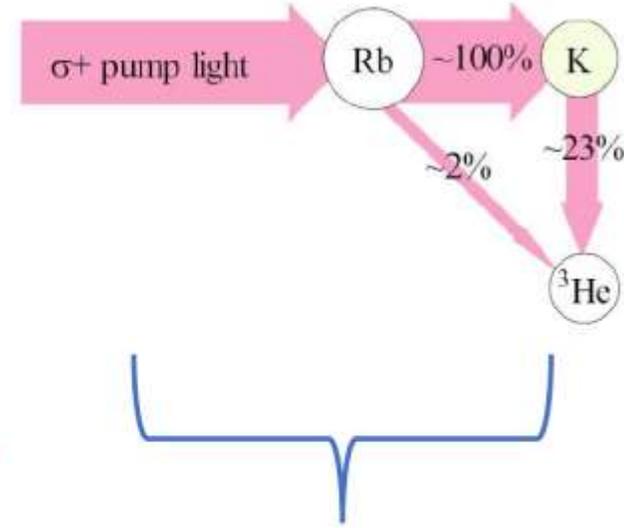
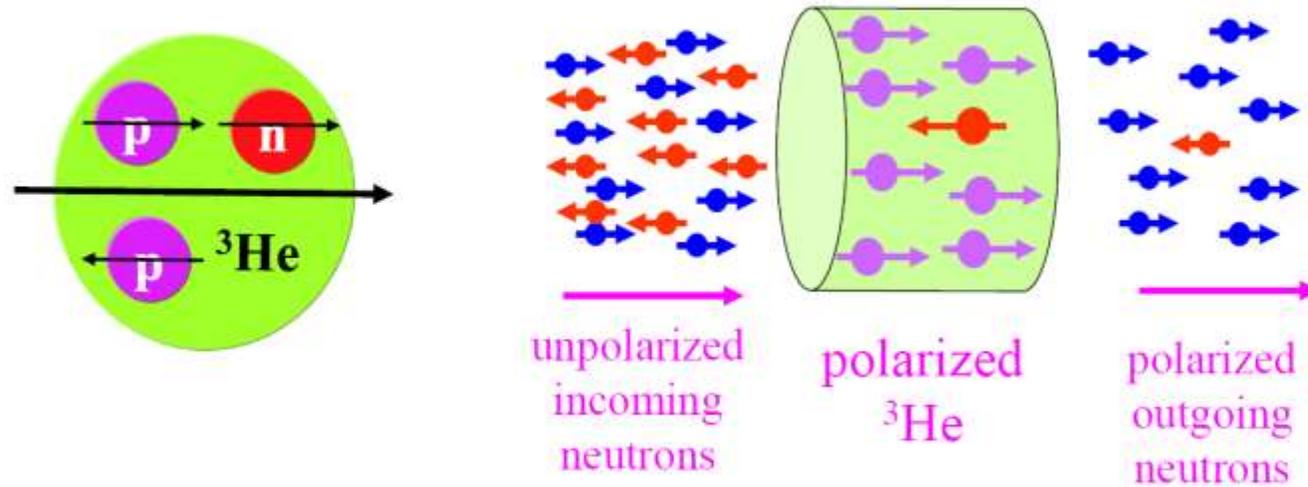
极化中子探测器原型

Prototype of polarized neutron detector

自旋交换光泵 (spin exchange optical pumping, SEOP)

^3He nuclear spin carried mainly by the neutron

K.P. Coulter et al, NIMA 288, 463 (1990)

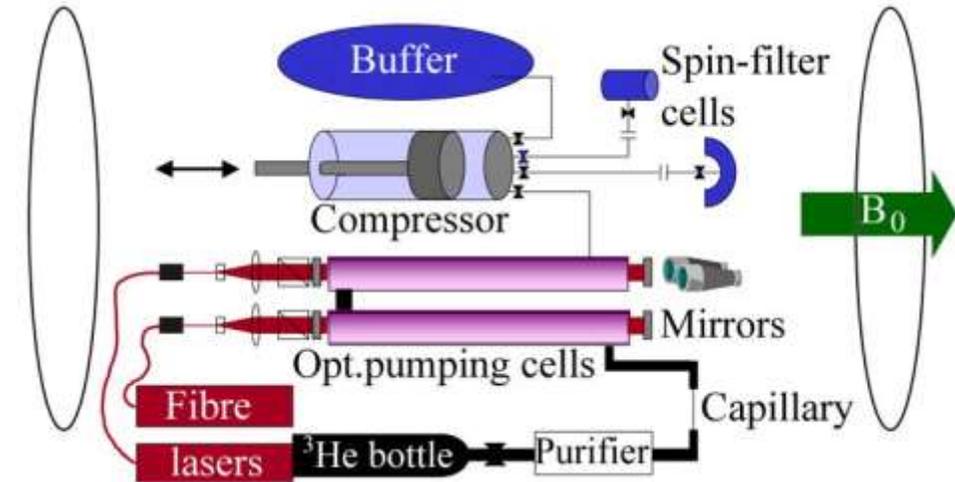
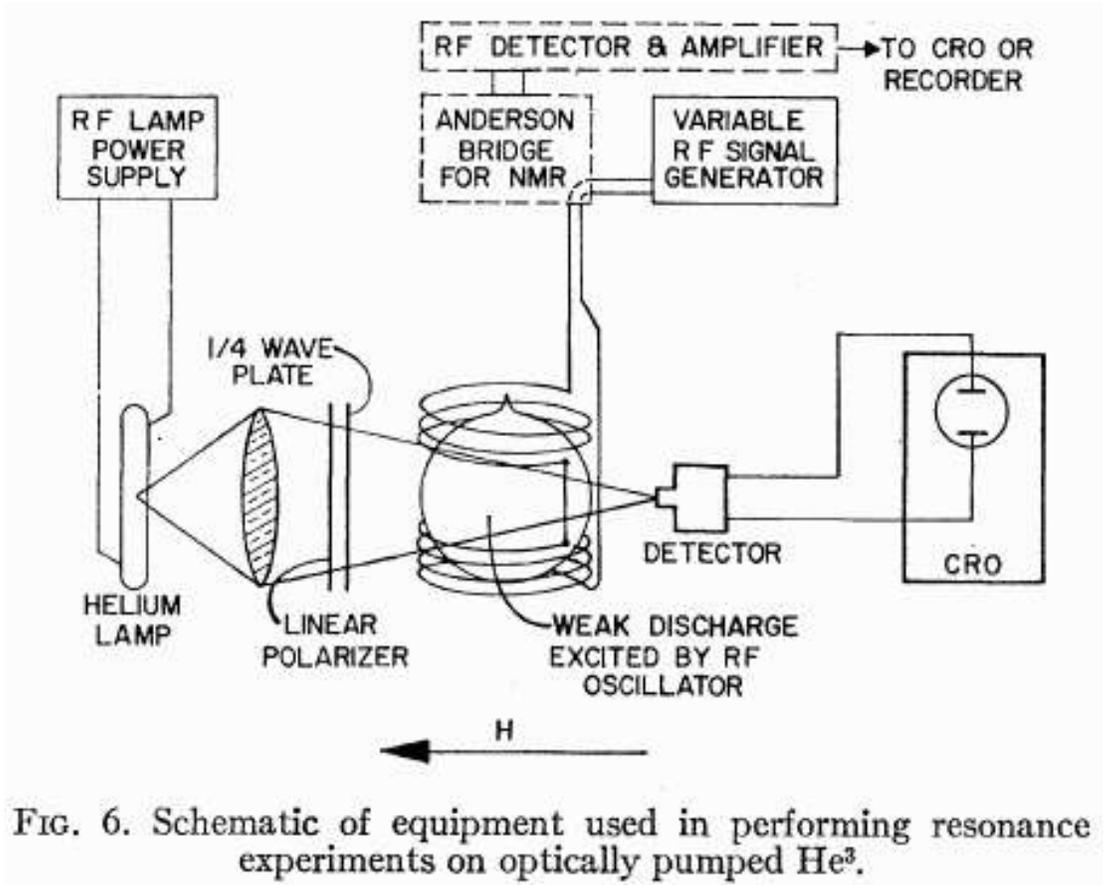


- **strongly spin-dependent** neutron absorption cross section.
- anti-aligned neutrons see a **thick** absorption target, aligned neutrons see a **thin** target.

优势：可以在较大气压范围内进行；不足：需要经历高温，需要充入碱金属蒸汽

Courtesy of WangchunChen. <https://www.nist.gov/ncnr/spin-filters/spin-filter-info/seop-method/optical-pumping>

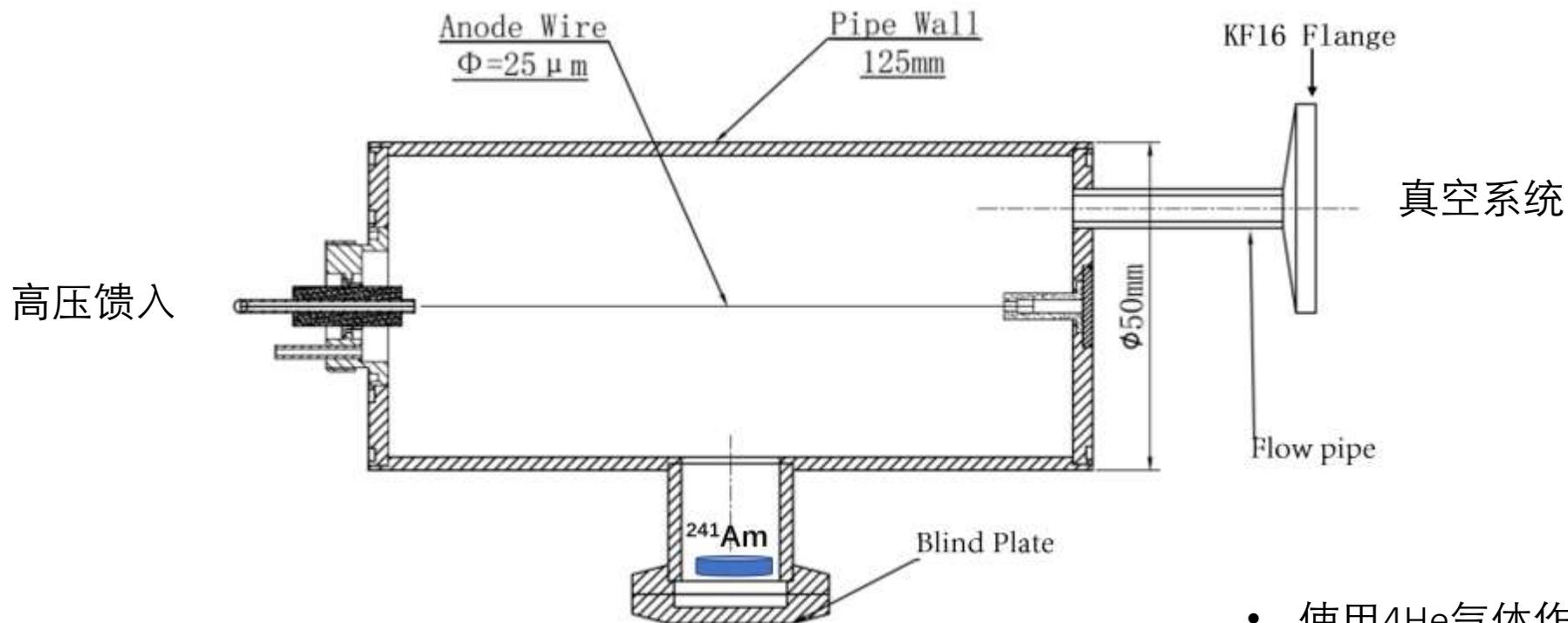
亚稳交换光泵(Metastability Exchange ,MEOP)



优势：极化速度快；
 不足：低气压极化（0.1Bar），需要压缩加压，纯 3He

Colegrove FD, Schearer LD, Walters GK. Polarization of 3He gas by optical pumping. *Phys Rev.* 1963;132(6):2561.
 Gentile TR, Nacher PJ, Saam B, Walker TG. Optically polarized 3He . *Rev Mod Phys.* 2017 Oct-Dec;89(4):045004.

样机设计

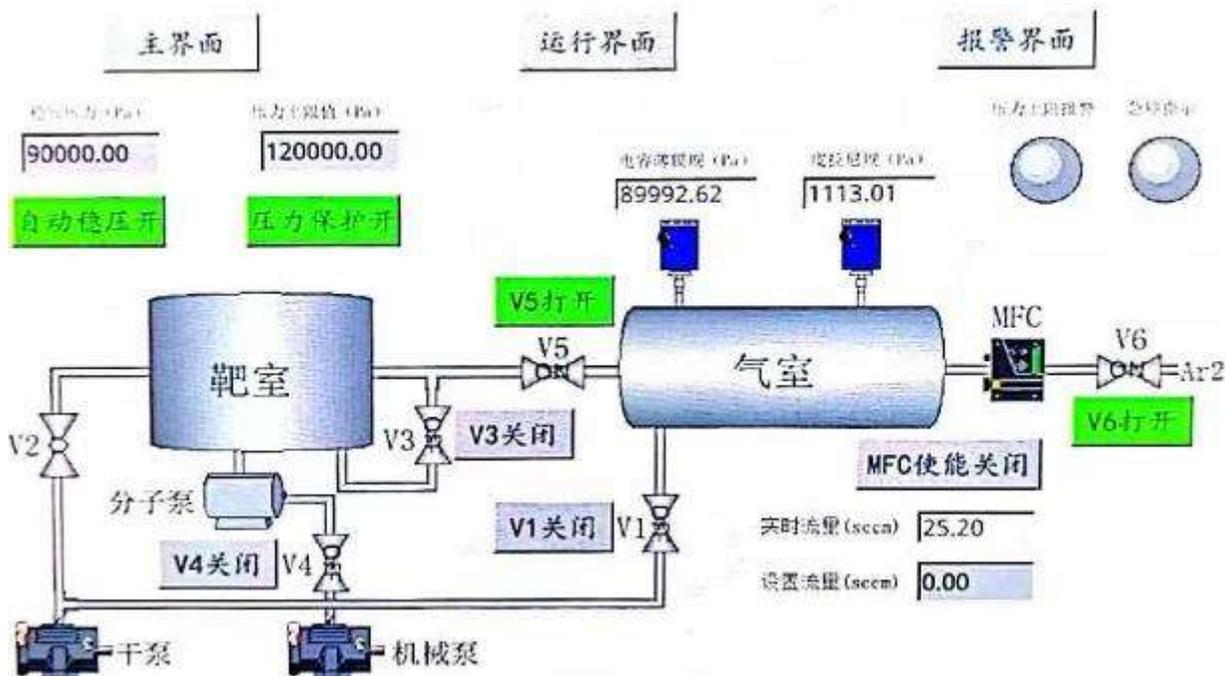


- 使用 4He 气体作为样机测试工作气体
- 制作气密型正比计数器
- 低气压系统控制探测器内 4He 气压
- 测试 4He 低气压正比室工作状态

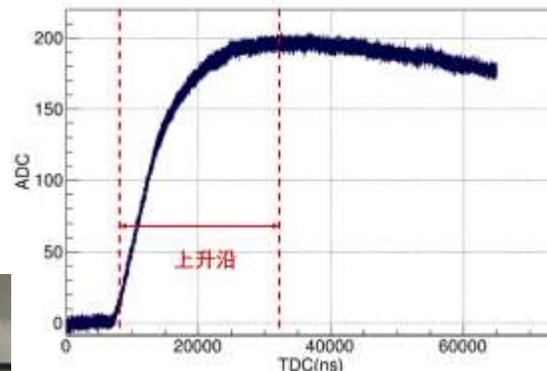
此工作文章已被《现代应用物理》接收

气路控制系统

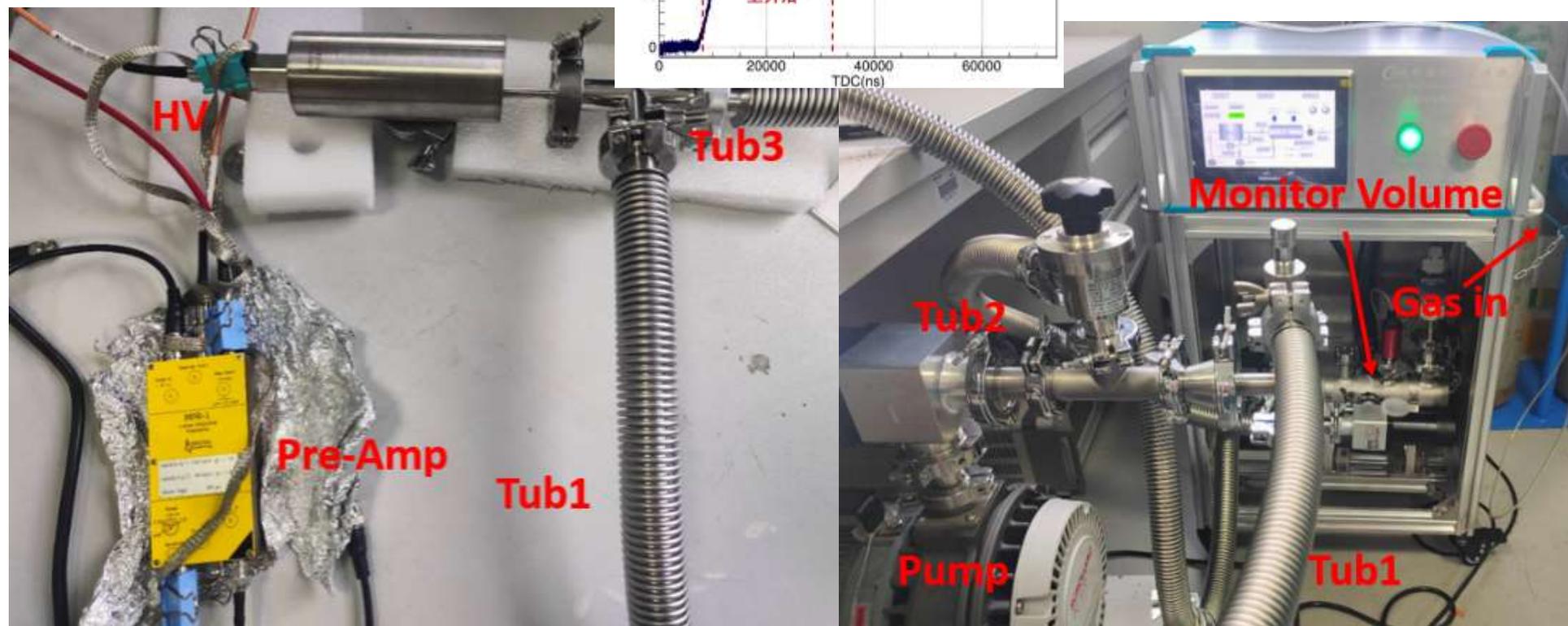
- 可设定气压值，通过针阀和流量计自动稳压
- 混气仪可根据流量控制配比不同组分的工作气体
- 探测器气体流量通过针阀进行调节
- 控制机柜接入白光束线控制系统，可远程进行压力调节



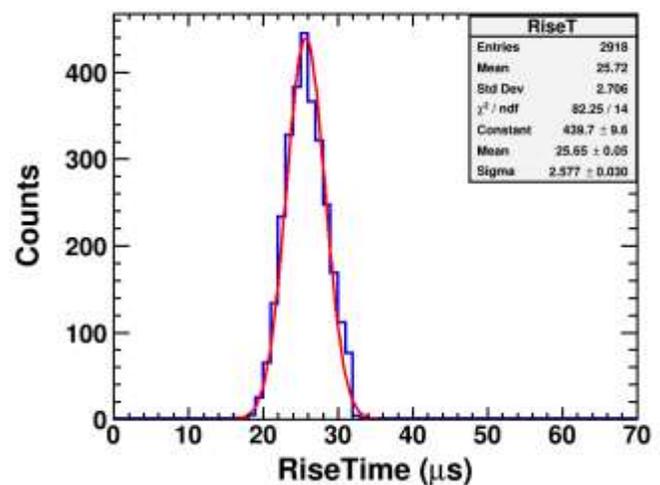
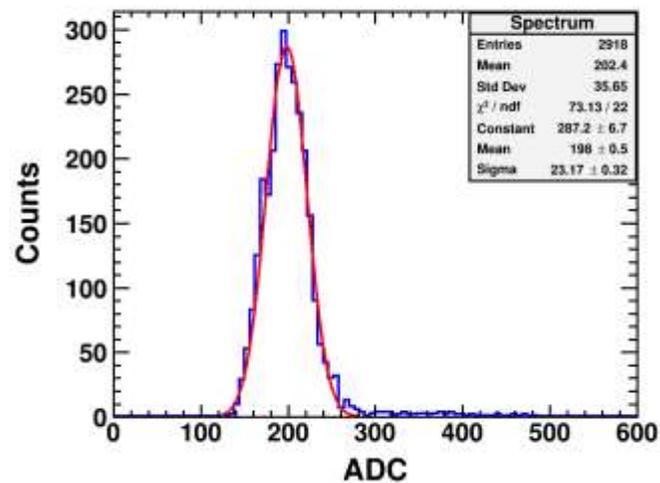
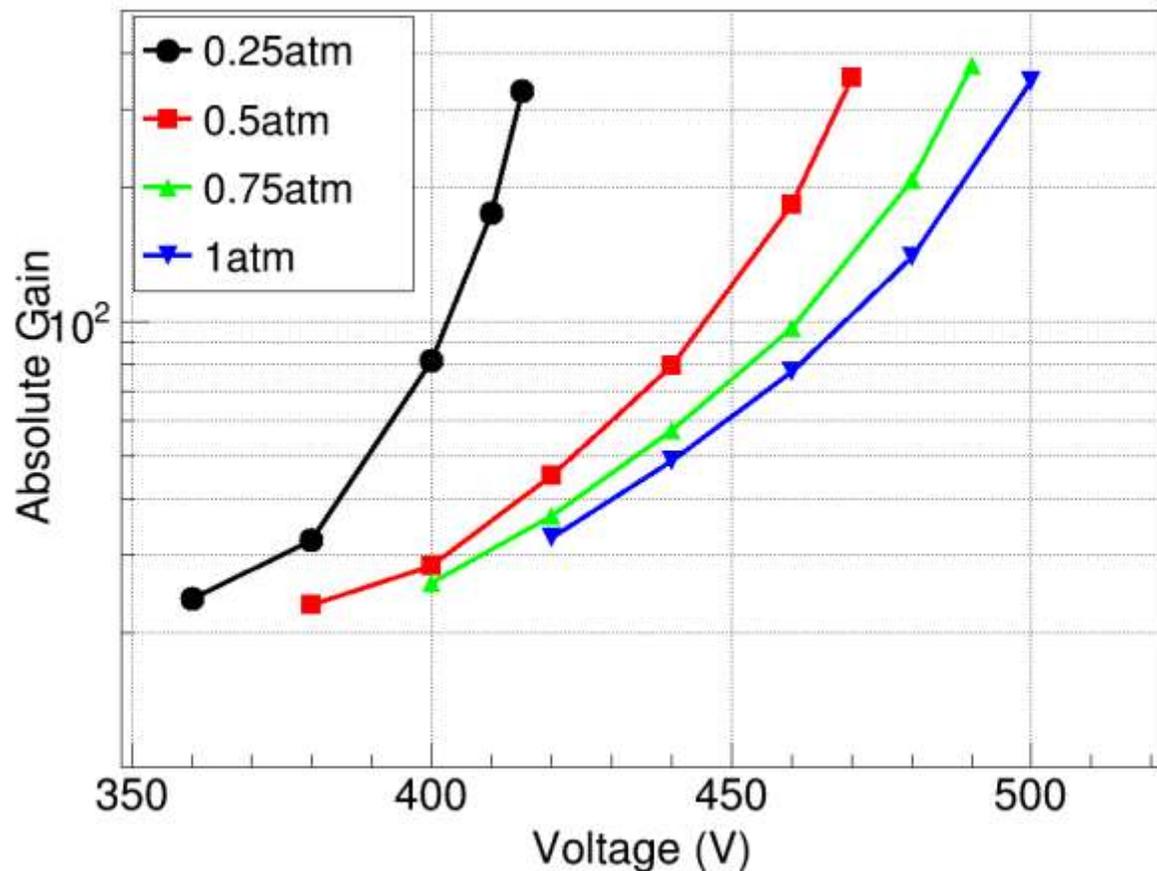
探测器测试系统搭建



采用1GHz采样率数字化仪记录实验波形



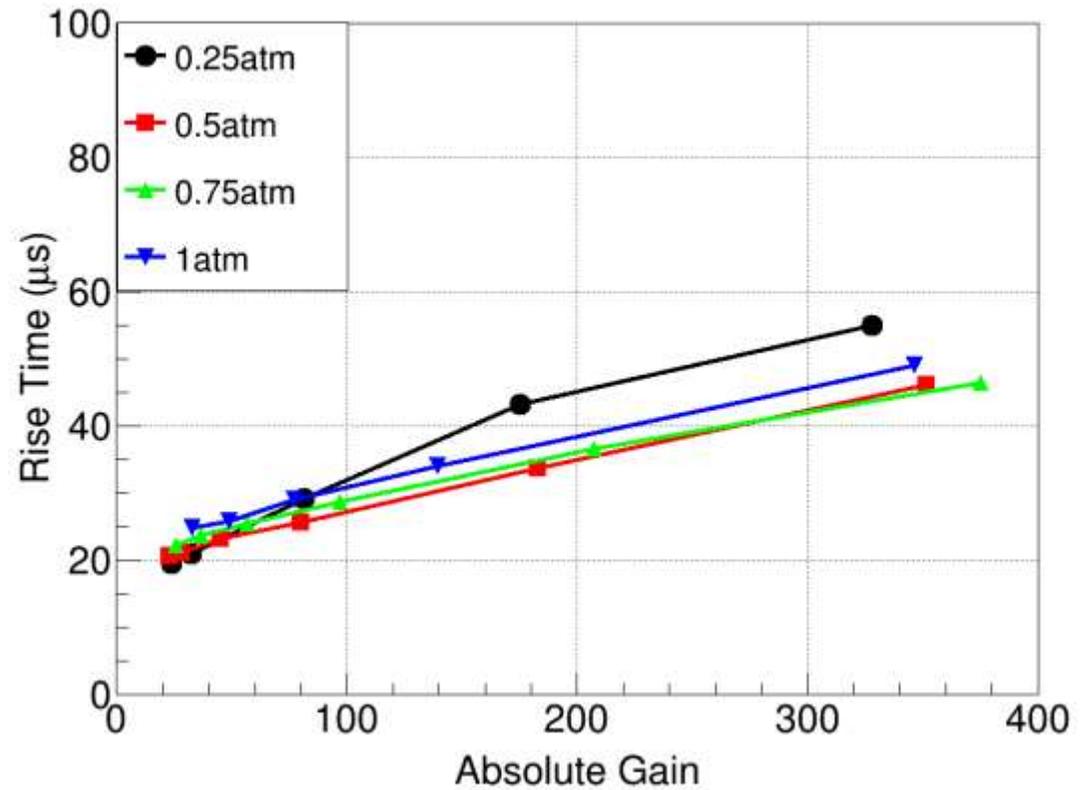
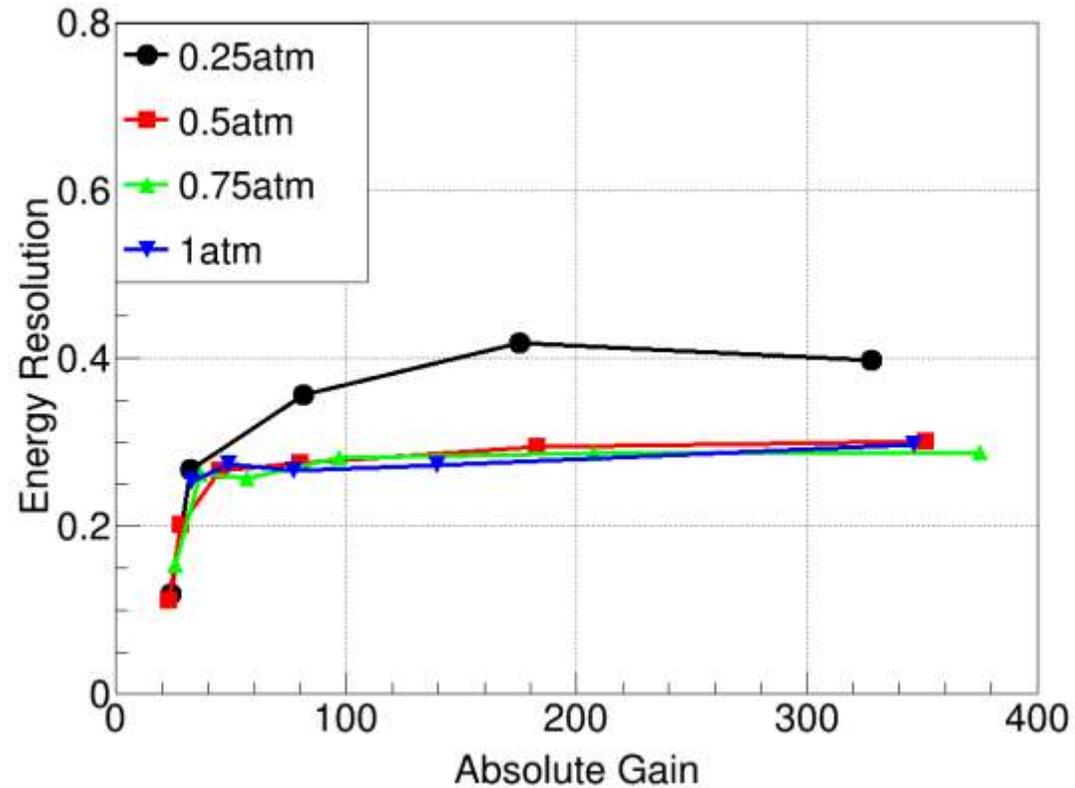
测试结果



0.25atm条件下的幅度谱和上升时间谱。

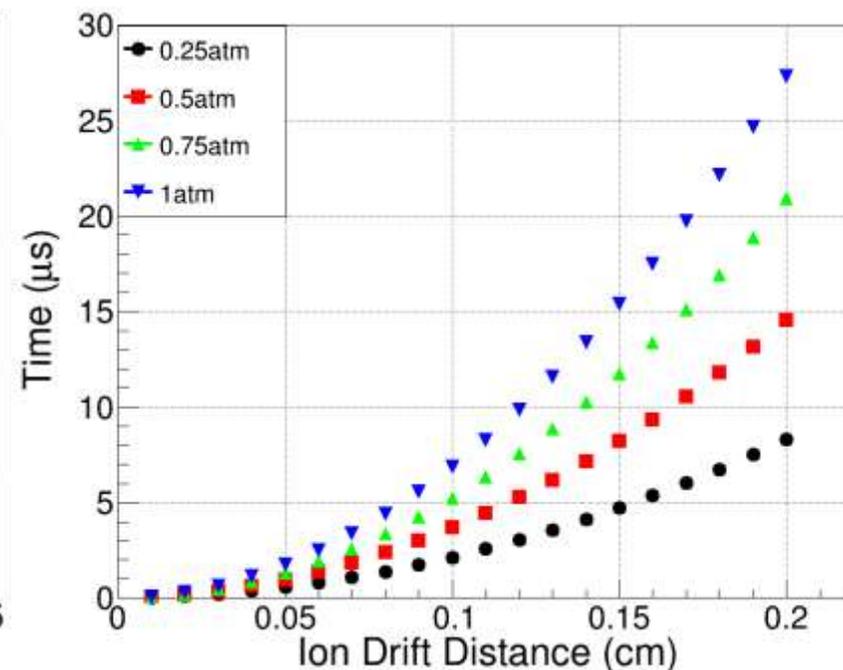
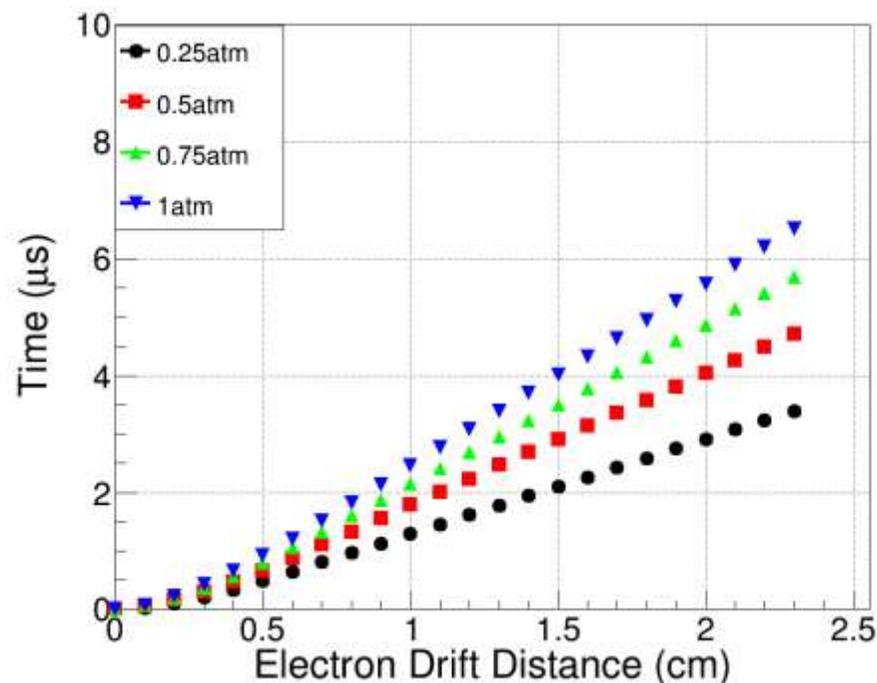
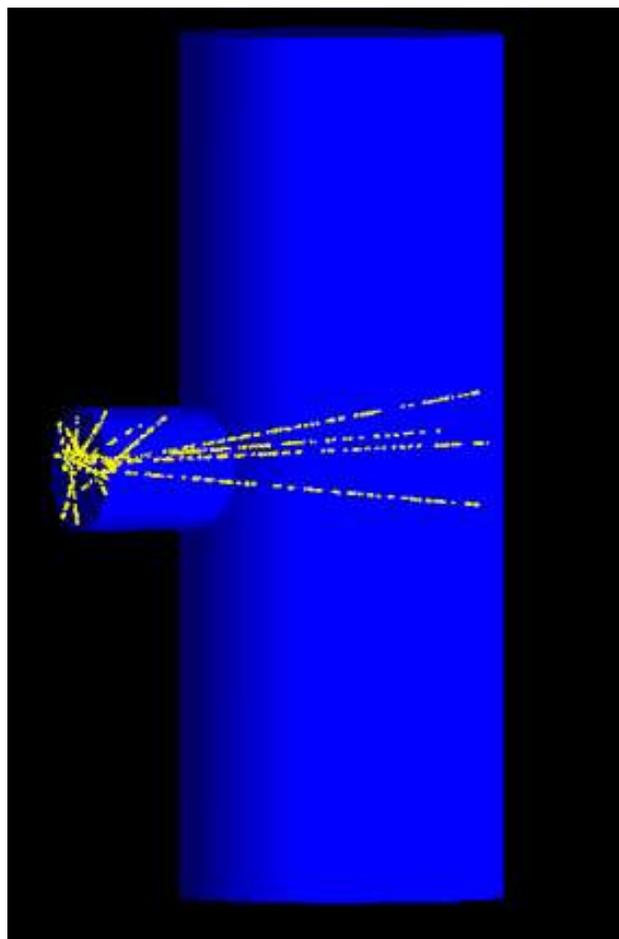
基于纯⁴He 气体中的正比计数管能在0.1~1atm气压下稳定工作；在0.25atm的低气压情况下，探测器的增益能够达到约400左右。

能量分辨与时间分辨



能量分辨与时间分辨都随着气压降低而变差。时间分辨变差与传统低气压多丝室研究结果不符。

Geant4与Garfield++模拟



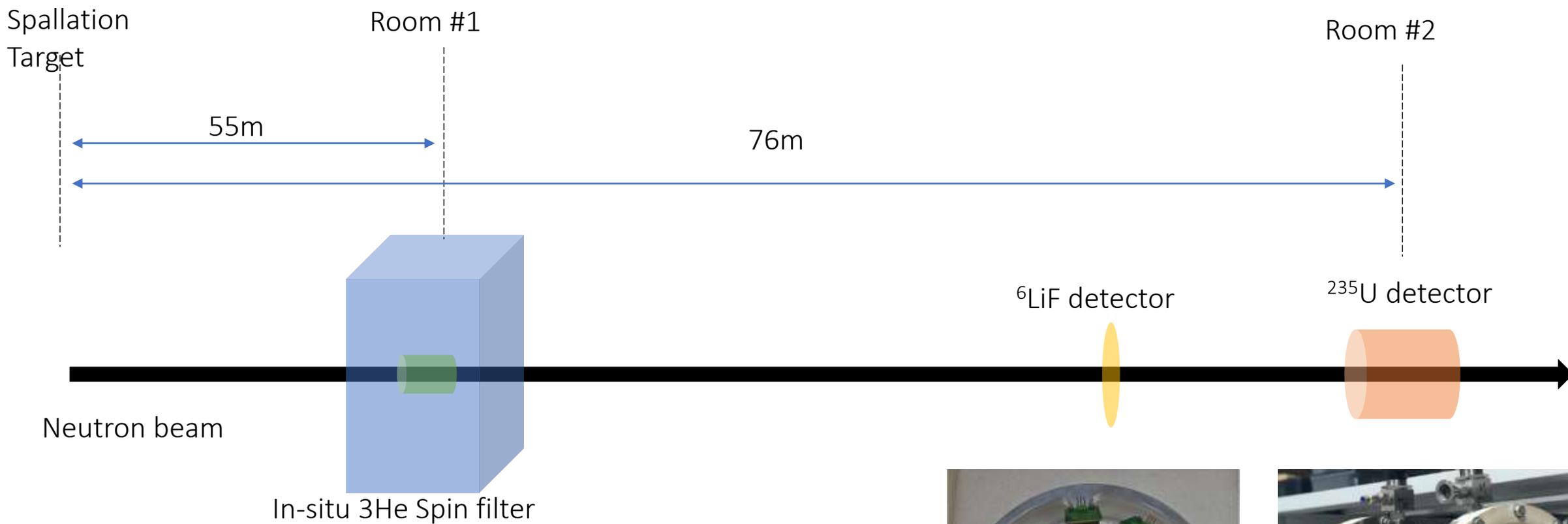
低气压探测器增益较大时，光子反馈现象变得明显，产生的光电子变多，这部分光电子漂移到丝网附近产生感应信号，对探测器信号的上升沿产生额外的贡献。对于低气压，光子反馈现象更加严重，因此0.25atm气压下，探测器具有最长的上升沿时间。

低气压纯氦气模拟程序尚不完善，其中物理过程尚需进一步研究。

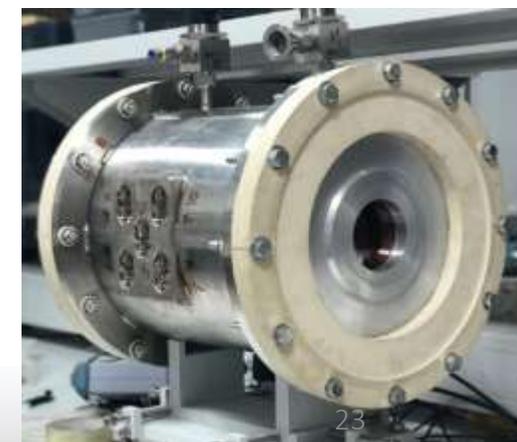
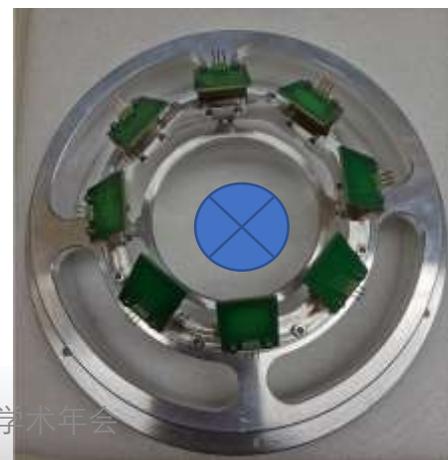
展望

prospect

First Polarized neutron test at Back-n

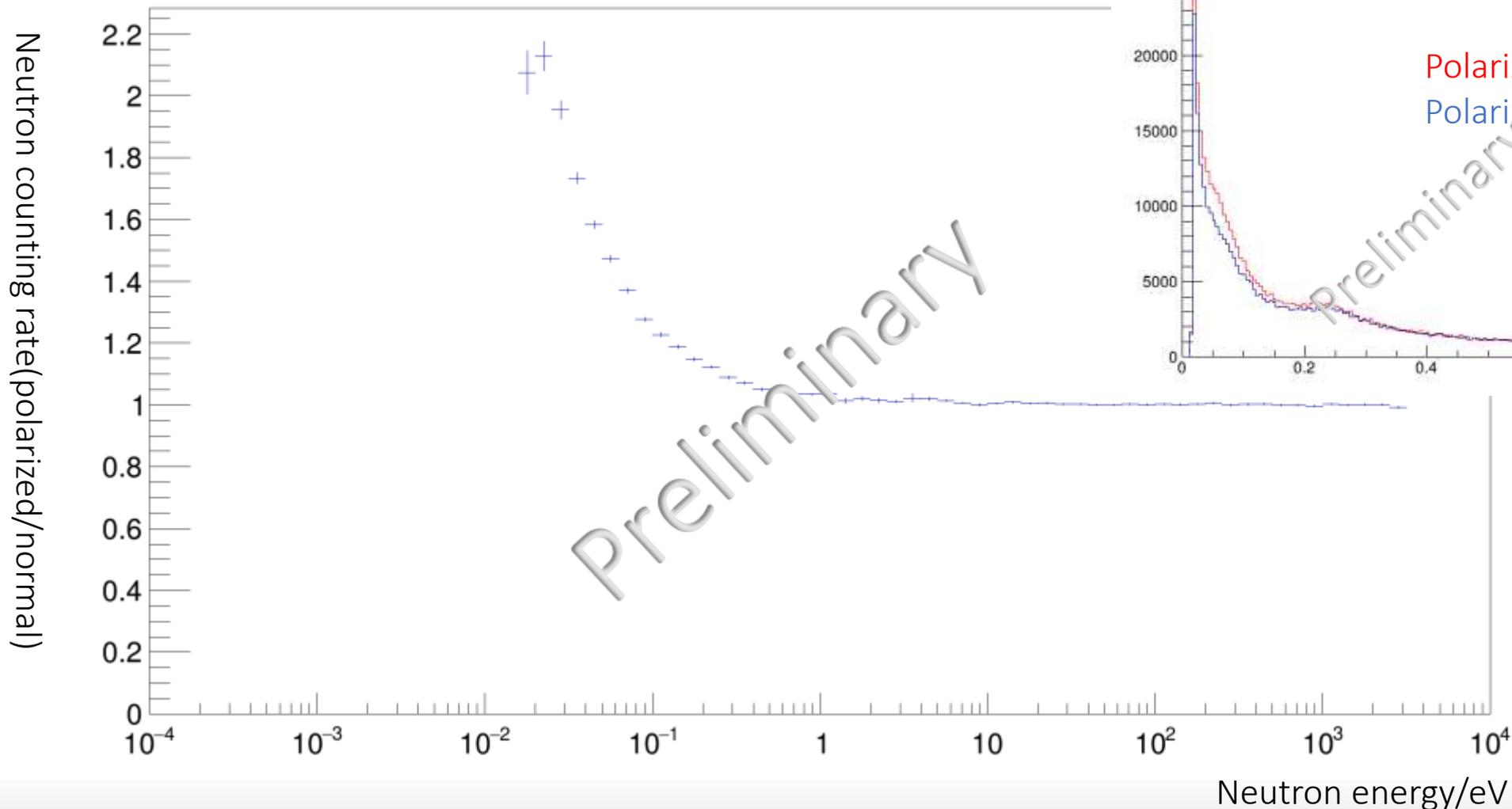


April 2023

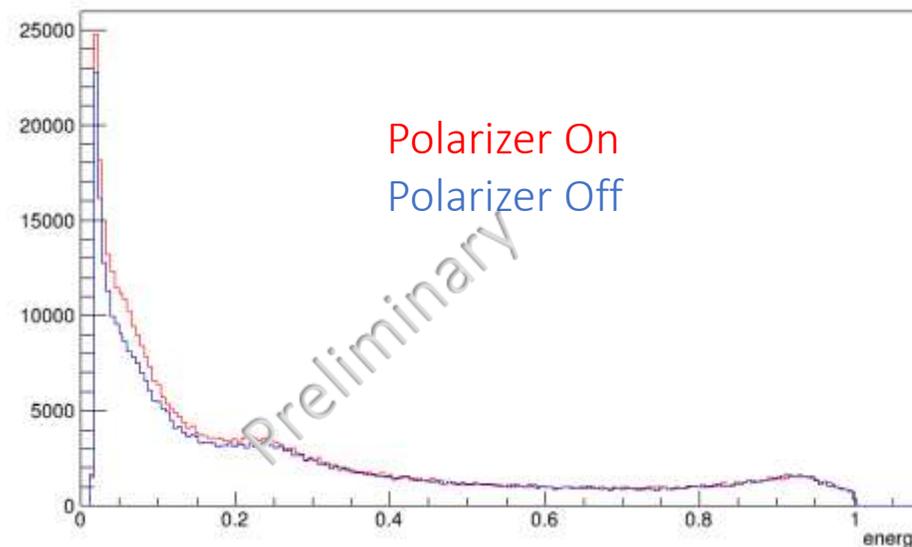


极化器工作状态随中子能量关系

data of neutron Energy



energy {energy<1&&channel<3}



探测器研发计划



- 2023年底完成系统对接
- 2024年进行 ^3He 探测器初步研究
- 2025年完成极化中子探测器实验

本工作基于散裂中子源科学中心极化中子组童欣、王天昊、张俊佩老师和黄楚怡同学的支持和帮助!

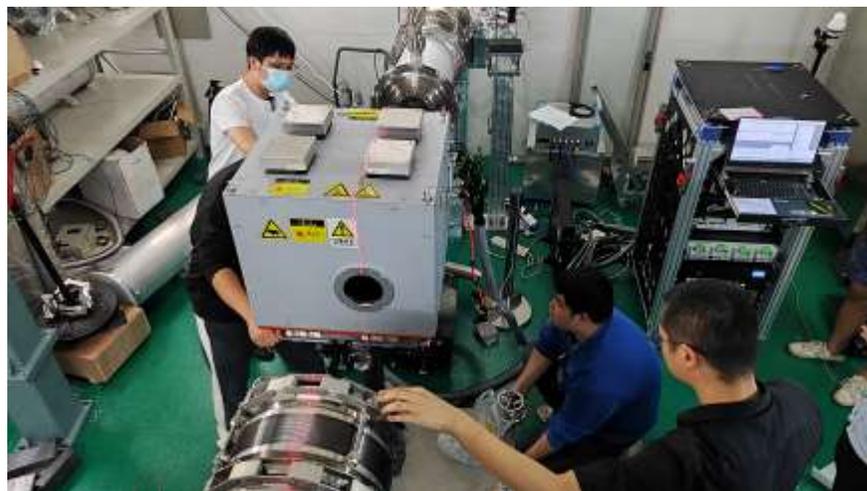


Photo of polarizer's installing

礼
Thanks

[Mailto: fanrr@ihep.ac.cn](mailto:fanrr@ihep.ac.cn)