LGAD用于BNCT中子束流测量

Study of LGAD sensor for BNCT Neutron Beam Measurement

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BNCT简介

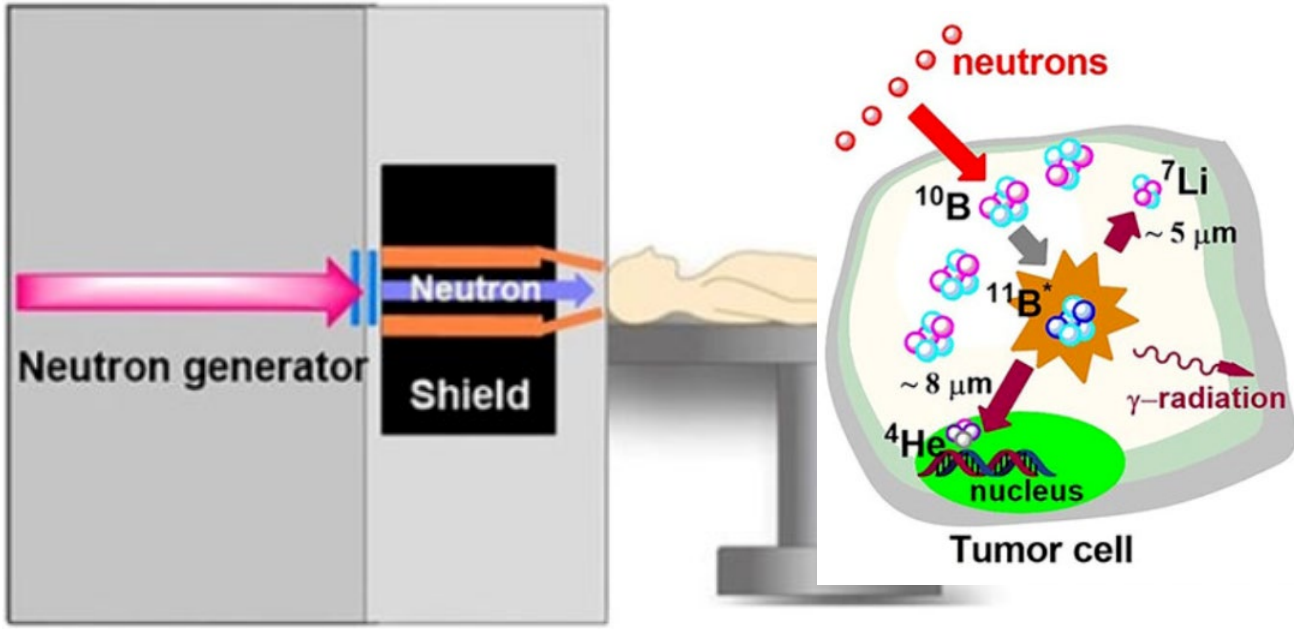
硼中子俘获治疗(BNCT): 一种治疗癌症的新利器

① 硼药(10B)在癌细胞富集

② 中子束流照射

③ 俘获反应产生α粒子和7Li

④ 选择性杀死癌细胞



$$^{10}_{5}B + ^{1}_{0}n \rightarrow [^{11}_{5}B]^{*} \rightarrow {}^{4}_{2}He + {}^{7}_{3}Li + \gamma\,(0.48MeV) + 2.31\ MeV \quad (93.9\%)$$

$$^{10}_{5}B + ^{1}_{0}n \rightarrow [^{11}_{5}B]^{*} \rightarrow {}^{4}_{2}He + {}^{7}_{3}Li + 2.79\ MeV \quad (6.1\%)$$

$(E_{^{4}_{2}He\,(\alpha)} = 1.47MeV,\ E_{^{7}_{3}Li} = 0.84MeV)$

加速器BNCT装置:

- 日本8家，至少2个已商业化并纳入医保
- 中国建成和在建有13家，规划中约15家

东莞人民医院：国产RFQ-BNCT一期临床完成

厦门弘爱医院：I期注册临床试验全部入组完成

青岛齐鲁医院：回旋加速器BNCT启动临床试验

湖州市中心医院：临床试验获批

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BNCT简介

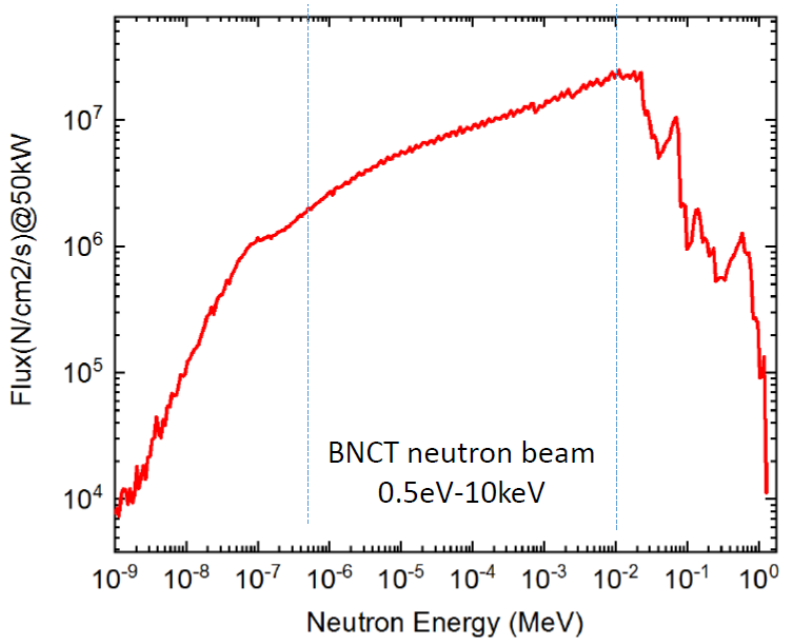
BNCT治疗束的精确测量对疗效和患者安全至关重要

BNCT中子束参数：

- 超热中子（0.5 eV–10 keV）
- 中子通量 > 1×10^{9} $cm^{-2}\cdot s^{-1}$
- γ本底注量率约 10^{7} $cm^{-2}\cdot s^{-1}$

束测要求：

- n/γ甄别
- 抗辐照能力
- 高计数率
- 空间分布扫描

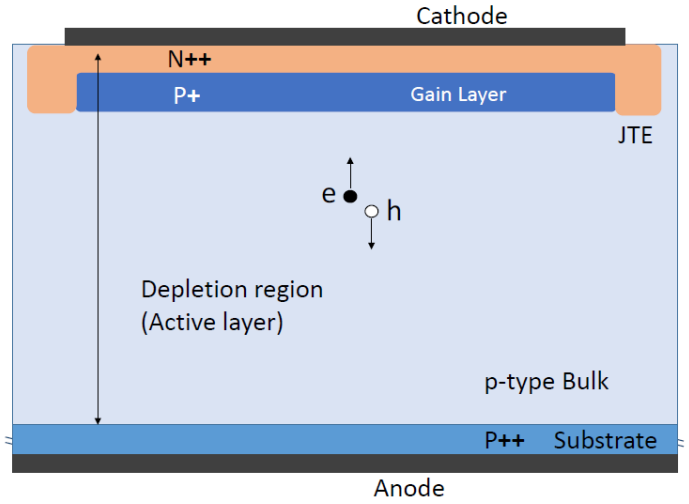


BNCT中子束流探测器

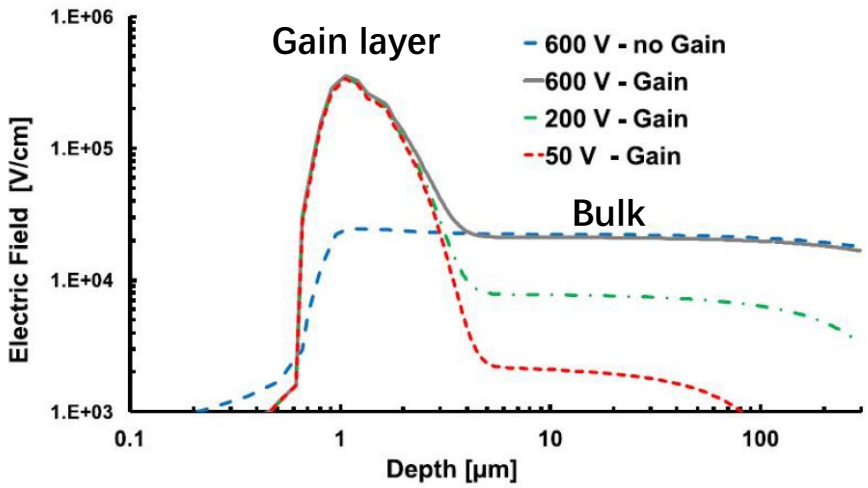
- ^{3}He管、金刚石
- 锂玻璃、LiCAF晶体

以进口探测器为主，需求量大、价格高、售后困难

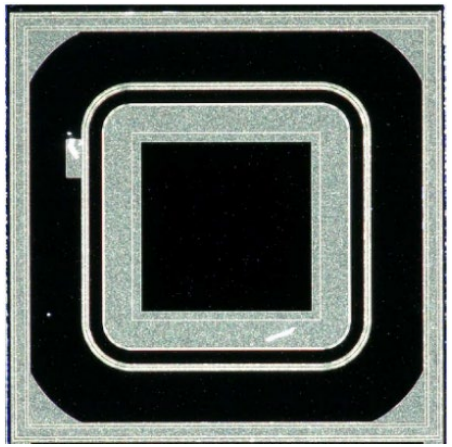
低增益雪崩探测器(LGAD)简介



LGAD (Low-Gain Avalanche Diode)



LGAD electric field distribution



Single pixel IHEP-LGAD sensor

IHEP (Institute of High Energy Physics) LGAD sensor design：

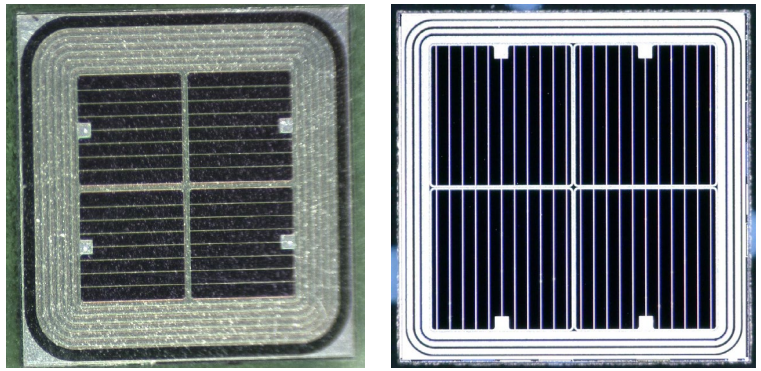
- Active thickness 30-50 μm → Short carrier drift time → Fast signal rise time → Ultra-fast pulse ~3 ns
- Gain layer under PN junction → Low gain 10-50 →Lower shot noise → Higher SNR → Time resolution ~30 ps
- Shallow carbon doping process →Protect the gain layer → Improve radiation hardness ~10^{16} n_{eq}/cm^2

LGAD is a promising domestic option for BNCT beam measurement.

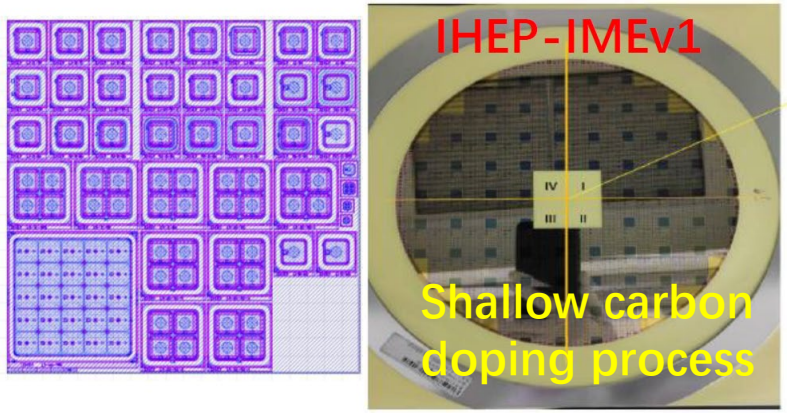
低增益雪崩探测器(LGAD)简介

Timeline of IHEP-LGAD R&D

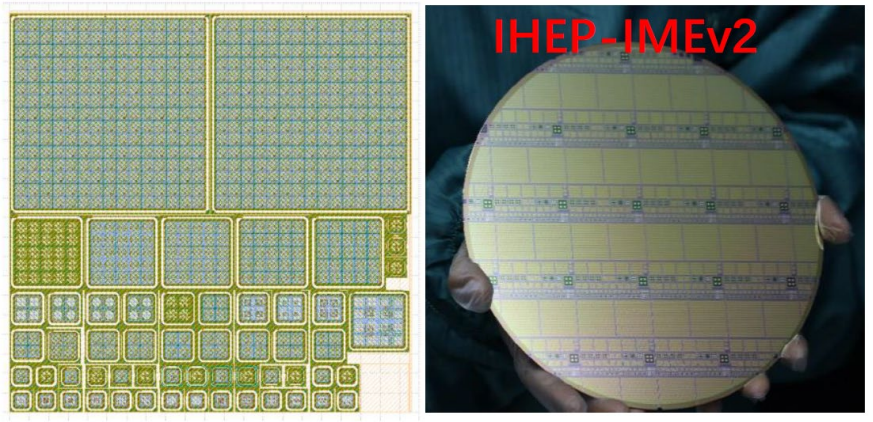
IHEP-NDL (2019)



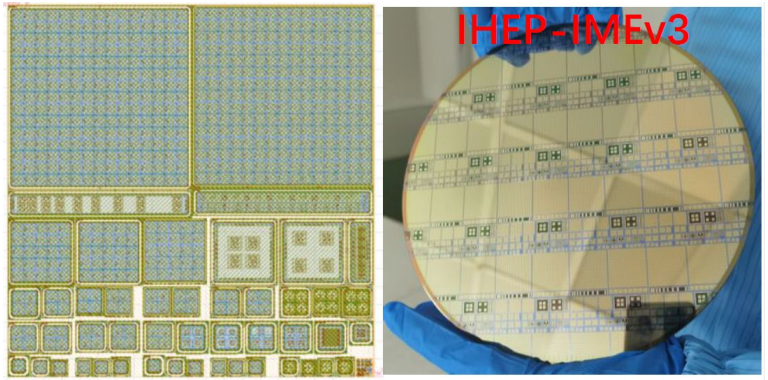
IHEP-IMEv1 (2020.9)



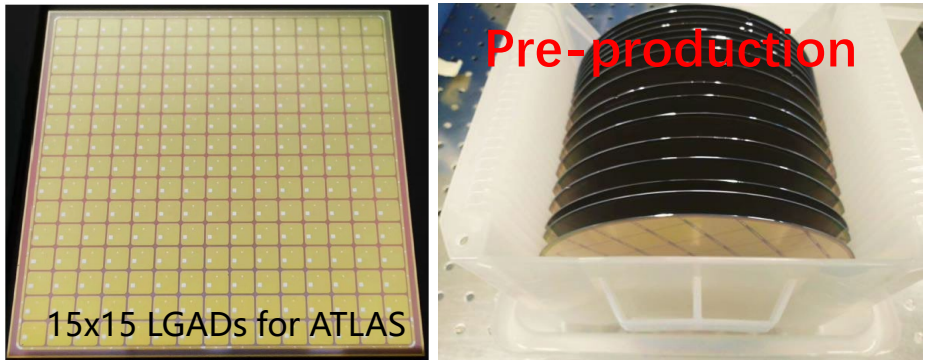
IHEP-IMEv2 (2021.6)



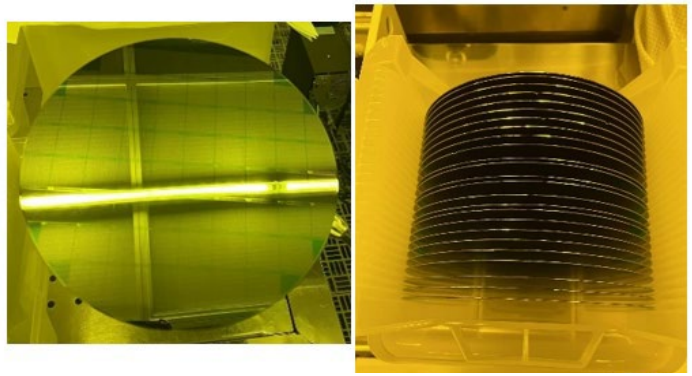
IHEP-IMEv3 (2022.5)



Pre-production for ATLAS (2023.7)



Mass production (2024.7) ongoing



IHEP-LGAD has been deployed in the CERN ATLAS HGTD, and is under active exploration for BNCT.

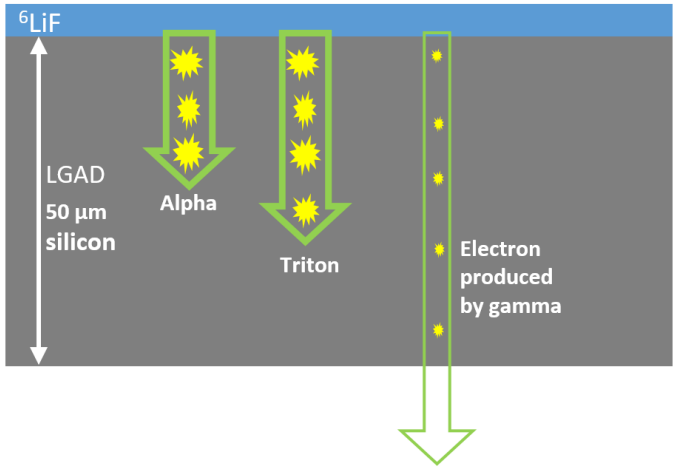
LGAD+转换层探测热中子

LGADs are designed for charged particles, how to detect thermal neutrons ?

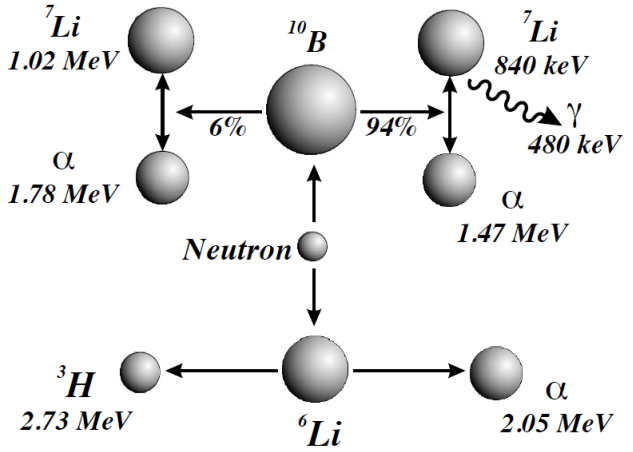
➢ Thermal neutron convertor materials

- ✓ Coating neutron convertor on LGAD surface, such as Lithium-6 (^{6}LiF), Boron-10 (^{10}B)
- ✓ The reaction between thermal neutrons and Li-6 produces Triton and α particles. Triton or α enter the LGAD sensitive region and generate neutron signals.
- ✓ Alpha and Triton will deposit all energy in 50 μm LGAD, and its signal is very large
- ✓ The electrons generated by gamma can only deposit a small amount of energy, and its signal is very small

LGAD coated with convertor ^{6}LiF



Neutrons react with Li-6 and B-10



基于LGAD的BNCT中子探测器模块

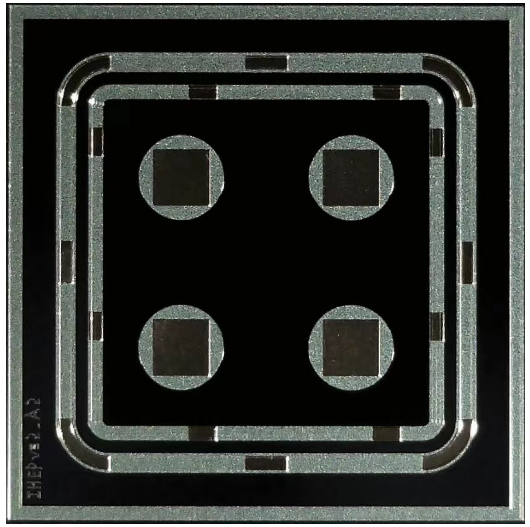
LGAD based BNCT beam detector

Sensor parameter： IHEP-LGAD

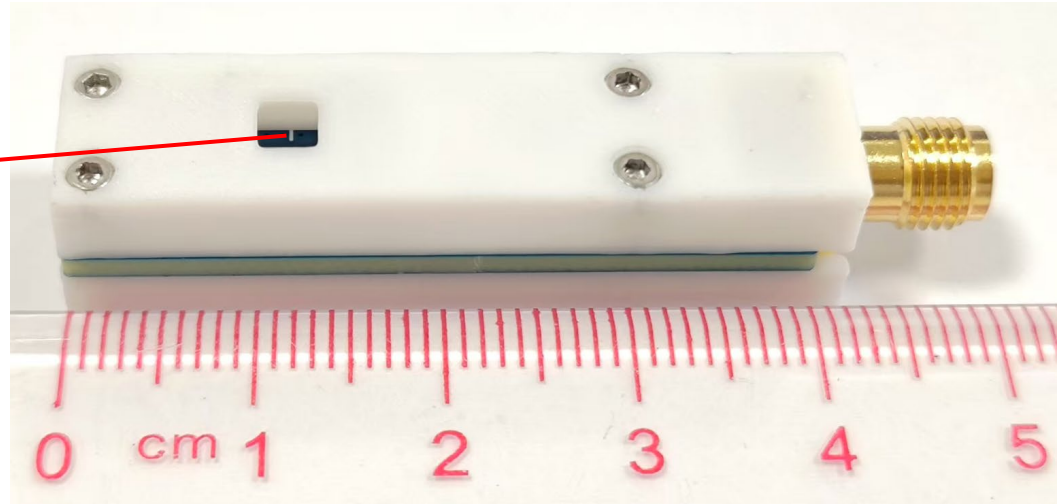
- Sensitive area: 2.6 mm × 2.6 mm
- Sensitive thickness: 50 μm
- ^{6}LiF thickness： 2 μm

Detector module parameter

- Size： 50 mm × 10 mm × 9 mm
- High voltage and signal share one SMA interface



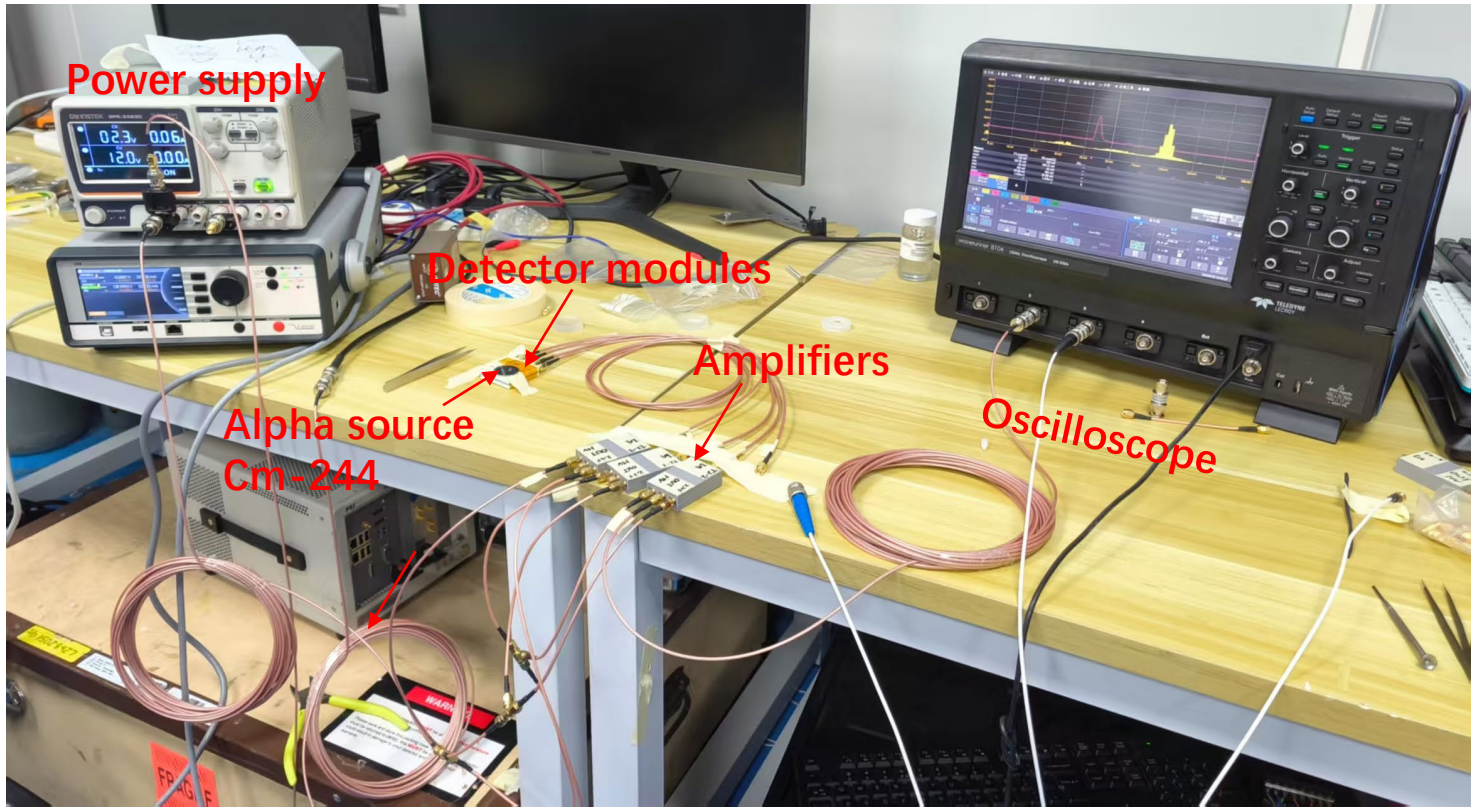
IHEP-LGAD sensor

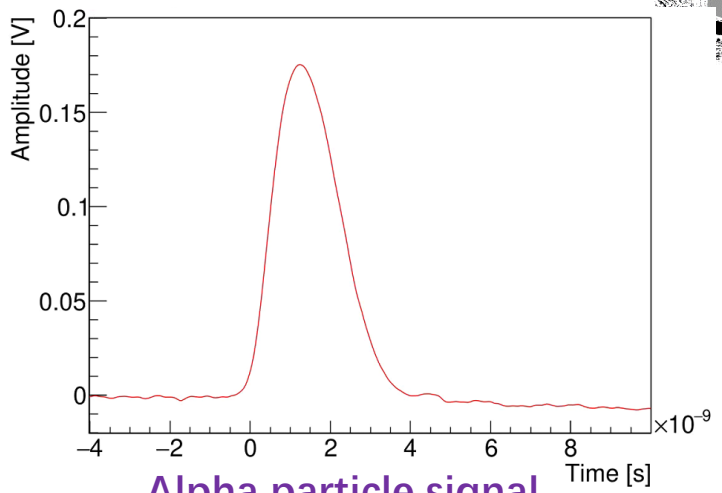


LGAD detector module

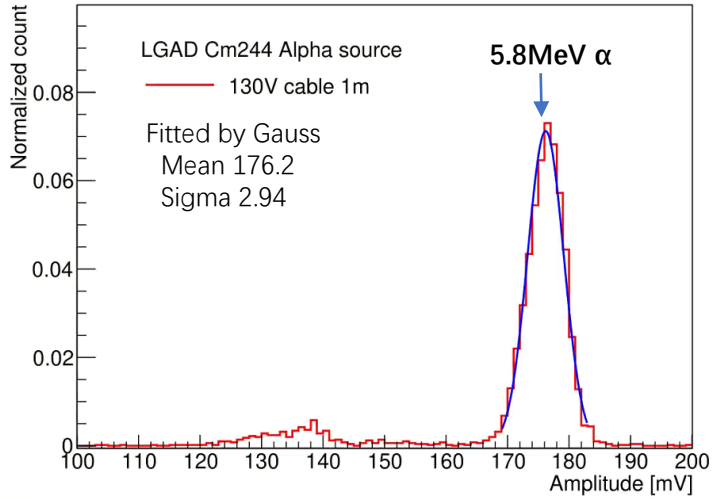
基于LGAD的BNCT中子探测器模块

Alpha source test in the Lab Curium (Cm244) source：5.8MeV α





Alpha particle signal



Pulse Height Spectrum (PHS)

- LGAD has a fast signal with a width of about 4 ns
- In the PHS of alpha, the pulse height of 5.8 MeV α is 176.2 mV, and the energy resolution is about 1.7% (sigma/mean)

LGAD模块在BNCT的测试

BNCT Equipment @ Dongguan

① Power source
② RFQ Accelerator
③ Power and control cabinet
④ Treatment Room 1
⑤ Treatment Room 2
⑥ Vertical treatment room

BNCT Equipment @ Dongguan People's Hospital

- This BNCT equipment was built by CASBNCT company
- Technology transfer from IHEP and CSNS
- Proton beam provided by 2.8 MeV RFQ linear accelerator
- The proton beam hits the lithium target to produce high-flux neutron beam

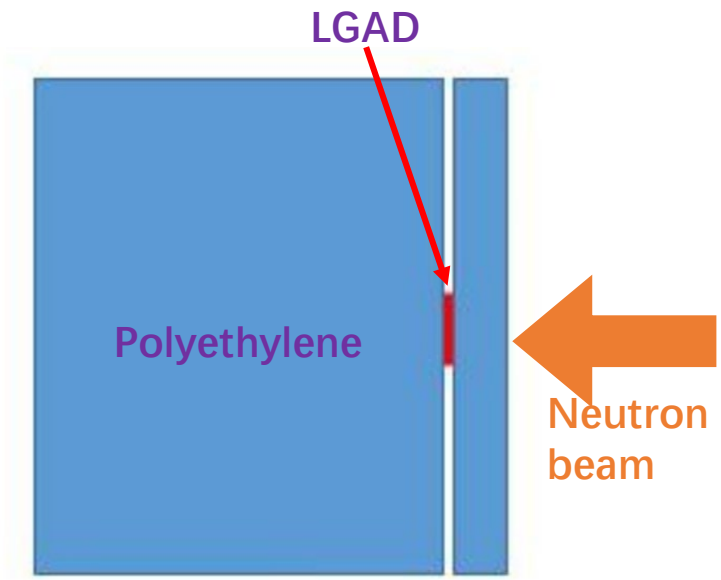
Neutron beam parameter

- Frequency: 200 Hz
- Duty ratio: 50 %

LGAD模块在BNCT的测试

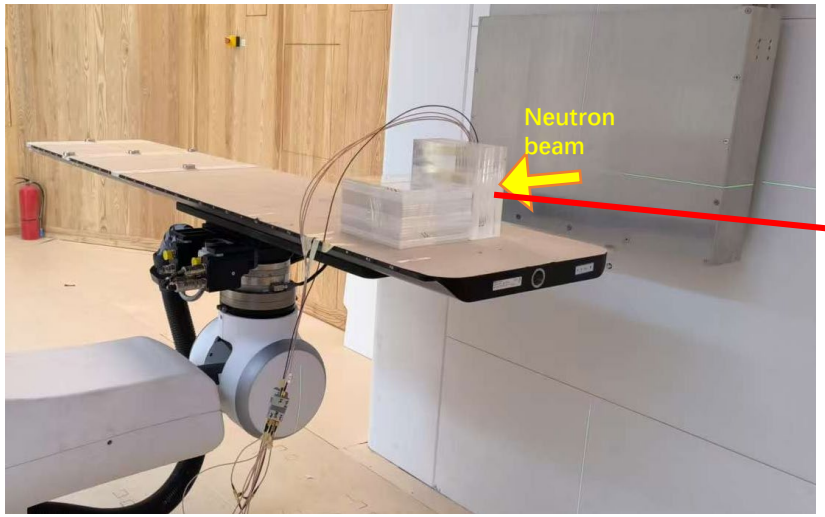
LGAD detector module：

- LGAD with ^{6}LiF 2 μm

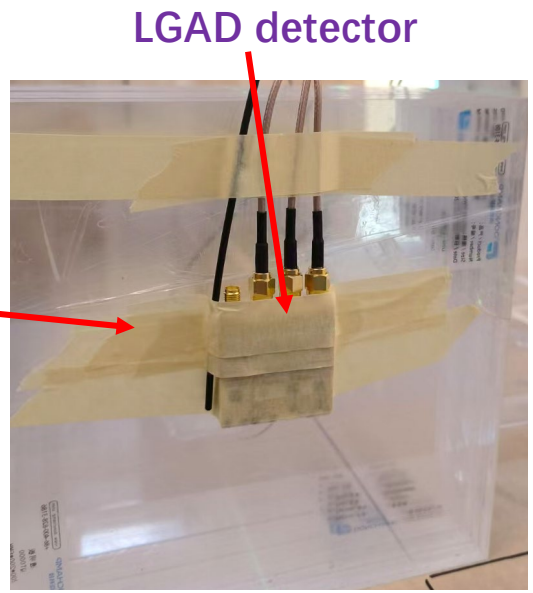


The neutron beam passes through the PMMA (polyethylene) moderator and hits the LGAD detector

Test setup at BNCT treatment room



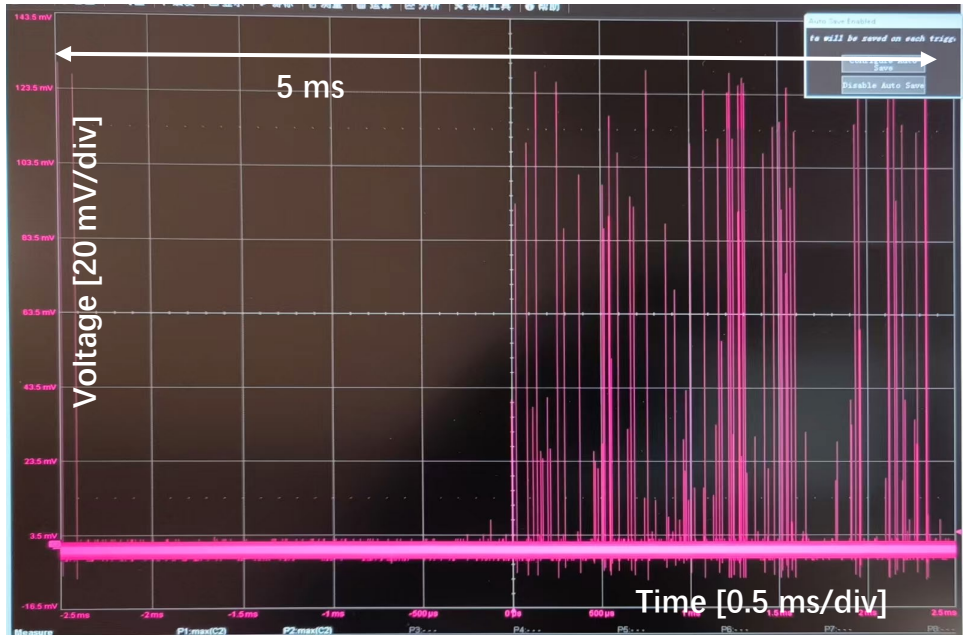
BNCT treatment room
@ Dongguan People's Hospital



LGAD detector modules

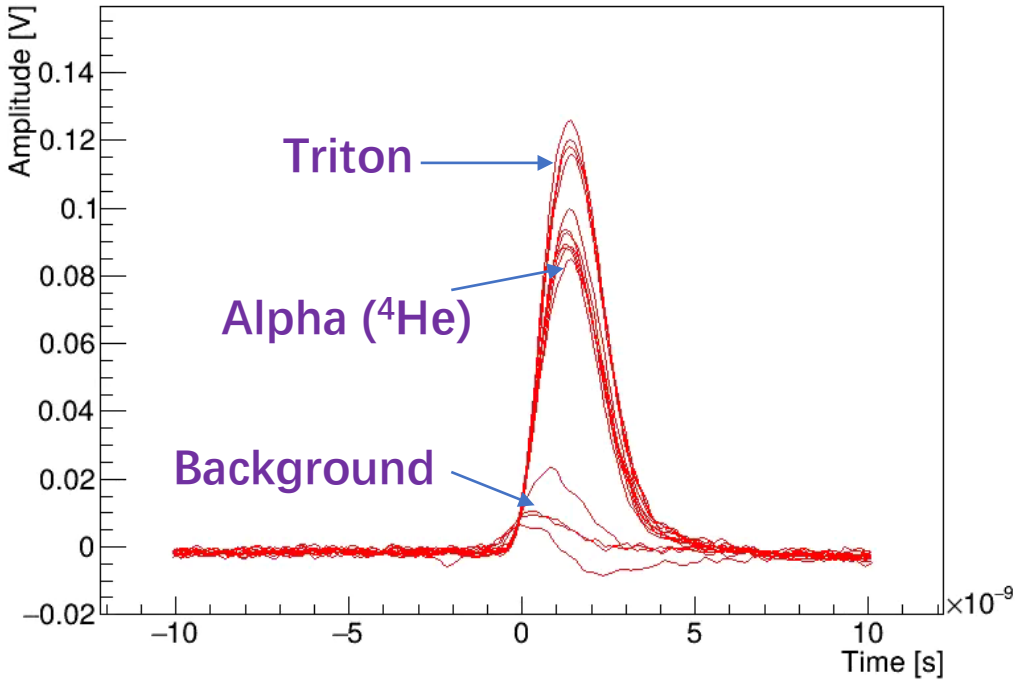
LGAD模块在BNCT的测试

The properties of LGAD signals



LGAD signals in one beam cycle

- One beam cycle: 5 ms
- Neutron pulse width: 2.5 ms （duty ratio 50%）
- These signals contain neutrons and background

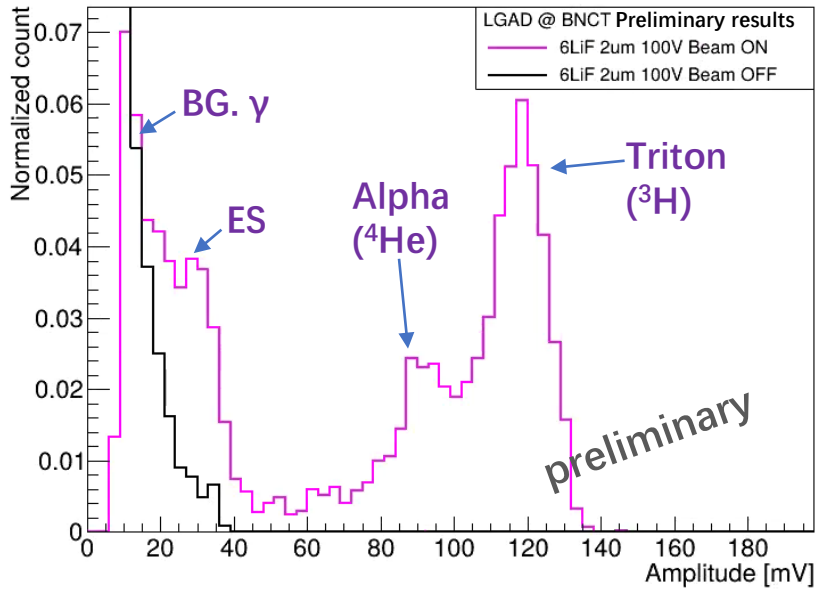


The LGAD signals

- Signal width ~4 ns
- Rise time ~1 ns
- Noise RMS < 2 mV
- SNR of neutron signal ~50

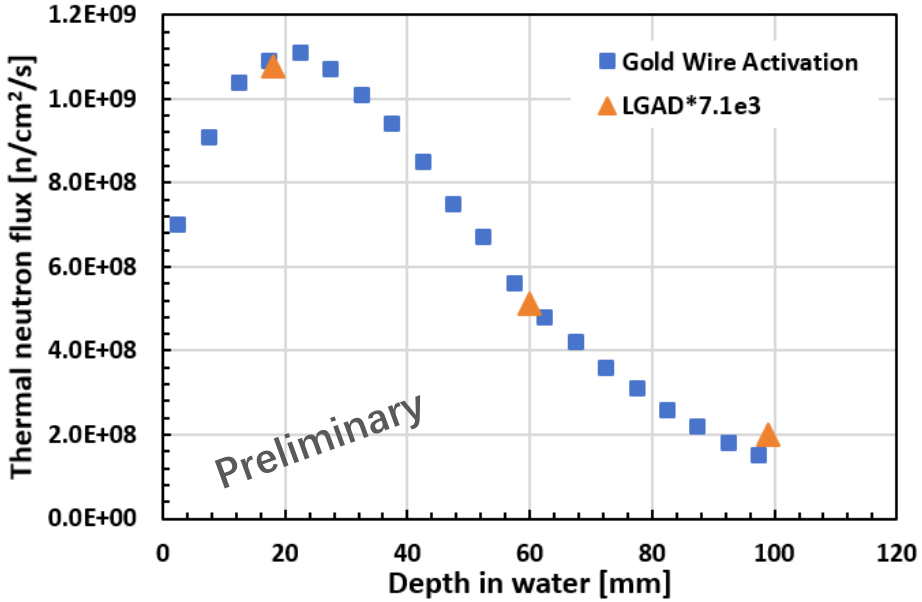
LGAD模块在BNCT的测试

PHSs of LGAD with ^{6}LiF



LGAD PHSs at beam ON & OFF

Neutron flux measurement



Neutron flux at different water depths

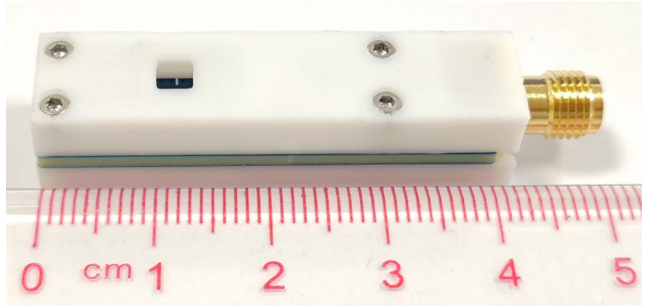
- Beam ON, the LGAD PHS consists of 4 parts:
  - The preliminary analysis should be triton, alpha particle, BG. γ, and elastic scattering (ES) of n and Li
- Beam OFF, the LGAD PHS has only background γ
- LGAD measurements align with gold wire activation, validating LGAD for BNCT flux monitoring.

总结

- LGAD is a new ultra fast silicon detector with strong radiation hardness
- The LGAD developed by IHEP has been used in the CERN ATLAS experiment
- We have developed a LGAD based neutron beam detector for BNCT
- Preliminary verification of the feasibility of LGAD for neutron measurement in BNCT

Next step

- Detection efficiency calibration
- Long time stability test (BNCT and CSNS beam)
- More BNCT beam test (fluence, profile, ect)



LGAD detector module

欢迎合作！共同拓展LGAD的应用研究。

THANK YOU!

高薪！

中国散裂中子源大气中子辐照谱仪公开招聘两名博士后：

岗位	岗位职责	岗位要求
岗位1： **高能中子能谱测量及方法研究**	聚焦**高能中子探测**，发展高能区中子测量新方法；开展新型中子探测器研发及多场景大气中子能谱测量；并参加谱仪日常工作	取得博士学位3年以内；核物理、粒子物理、辐射探测相关专业；具备辐射探测器研发、中子能谱解谱、蒙特卡罗输运仿真经验
岗位2： **先进半导体器件与辐照效应研究**	面向**先进工艺半导体器件及设备**，开展大气中子辐照效应实验及机理研究；并参加谱仪日常工作。	取得博士学位3年以内；微电子、半导体物理、辐射效应相关专业；熟练使用TCAD及蒙卡程序，具有单粒子效应实验经验

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