中国散裂中子源
Chinese Spallation Neutron Source

Application of LGAD as Zero-Degree Detector in Light Charged Ions Measurement

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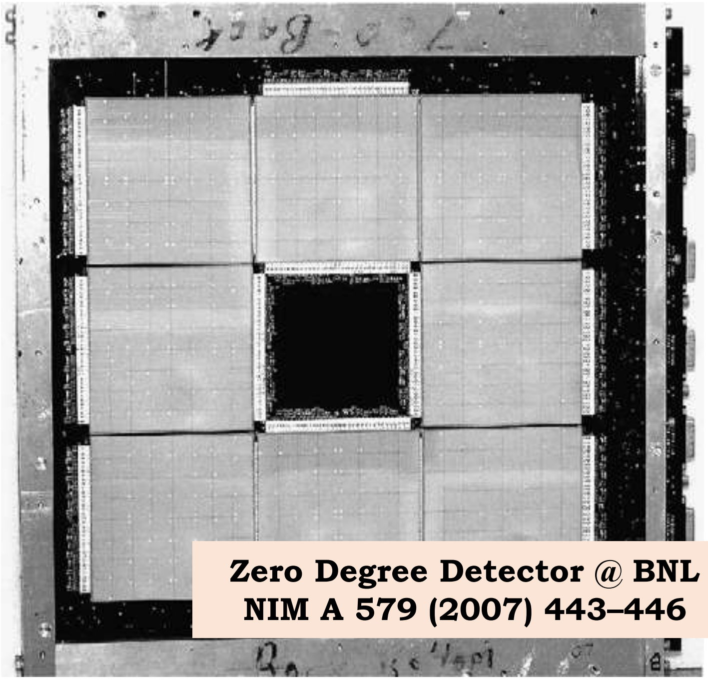
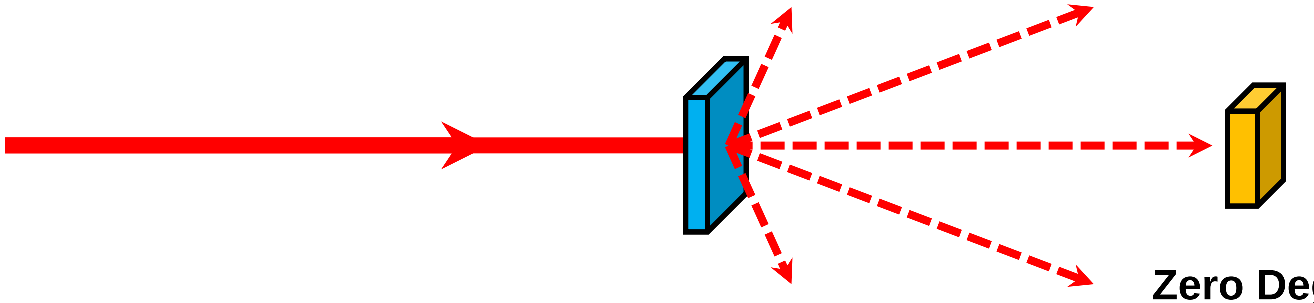
1.1 Light Charged Ions Measurement

- A comprehensive and reliable nuclear database of neutron-induced processes is required by the development of accelerator-driven system (ADS) technology.
- Measure of light charged ions (LCIs) in zero degree of the beam direction were not conducted with a high accuracy.


Zero Degree Detector @ BNL
NIM A 579 (2007) 443–446



- Limitations of detector：
  1. Heavy influence of irradiations. Unstable!
  2. Strong background from beam particles. Low SNR!

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1.2 Detectors

Detector Type		Problems
Gaseous		Low timing performance, Easy to Sparks.
Scintillator		Sensitive to γ, need n-γ identification.
Semi-conductor	Si	Poor irradiation hardness.
	SiC	Small sensitive area and depth. Bad MIP detection ability.
	Diamond	Expensive

- Have to find a zero-degree detector.
- Requirements：
  1. Good irradiation hardness.
  2. Not sensitive to gamma and neutron.
  3. Relatively good timing performance.

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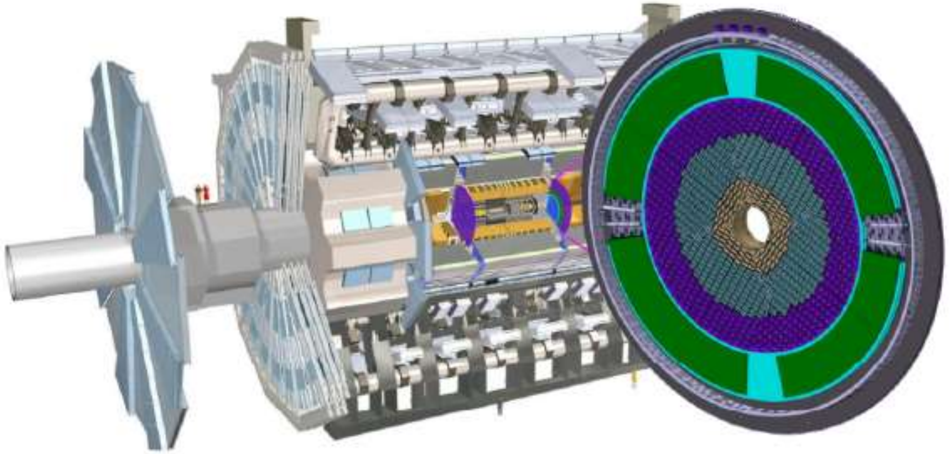
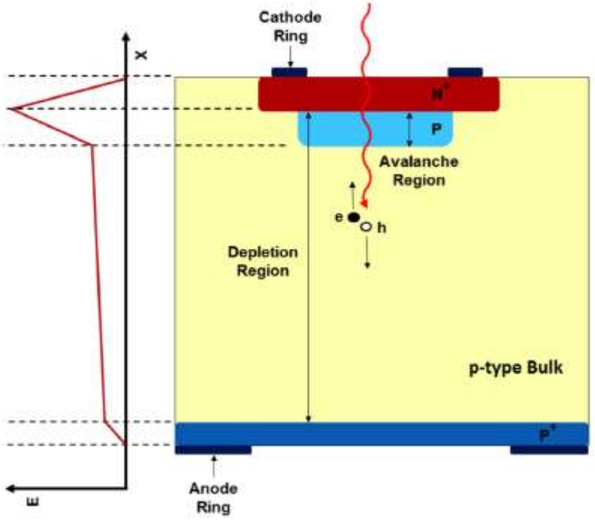
1.3 LGAD

- Low Gain Avalanche Diode (LGAD), is an advanced detector in recent years。
- Utilized on the end-cap of ATLAS.
- Meet the requirements of ZDD.
- Produced by IHEP, China. Can be used as ZDD.





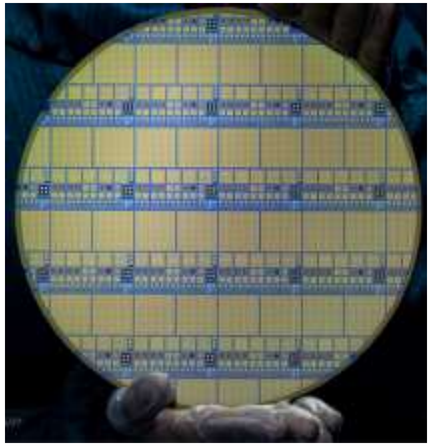
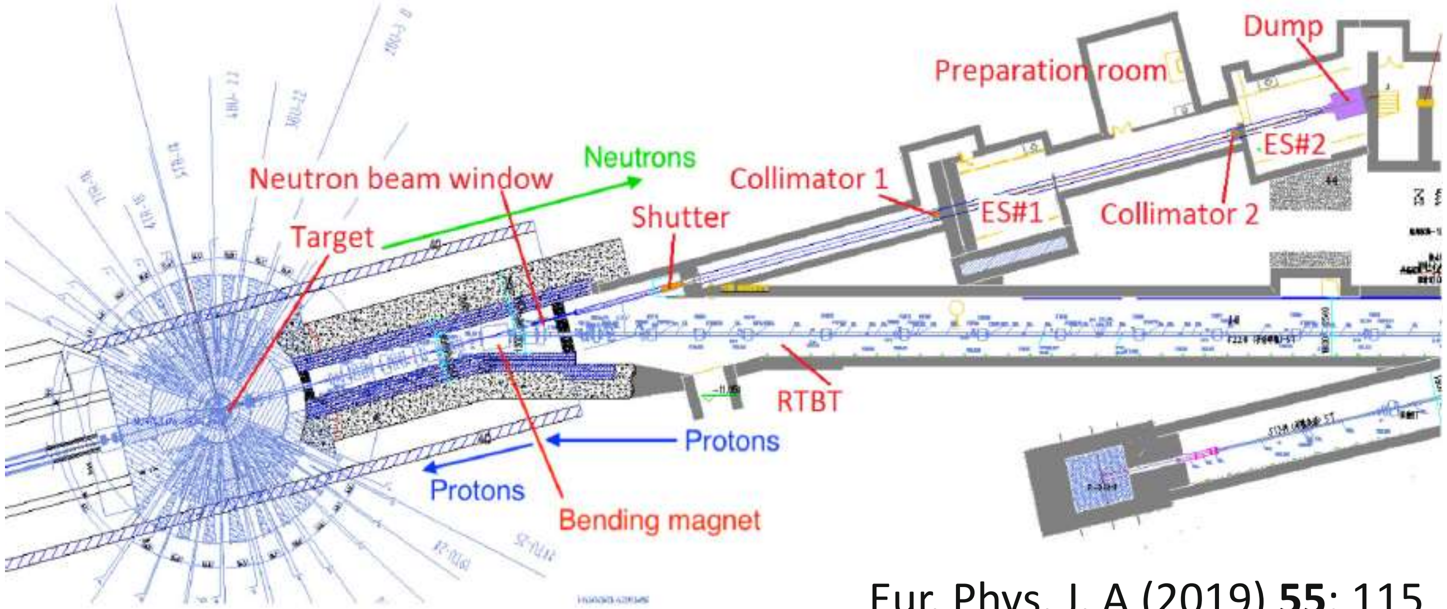


Table Performance of LGAD

Depletion Depth	Rising Time	Signal Width	Timing Resolution	Dimensions
50μm	~700ps	2~3ns	30 ps	$\sim 1\times 1\ mm^2$

1.4 Beam Test @ *CSNS-Back_n*

- To prove the idea, an test has been conducted on CSNS-Back_n.
- Instrumentations, result and conclusions will be introduced.



Eur. Phys. J. A (2019) **55**: 115

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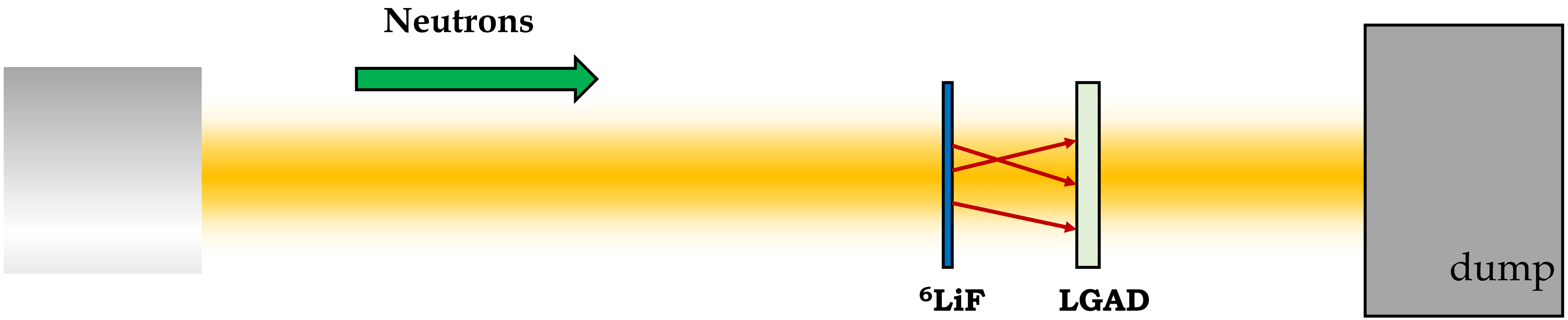
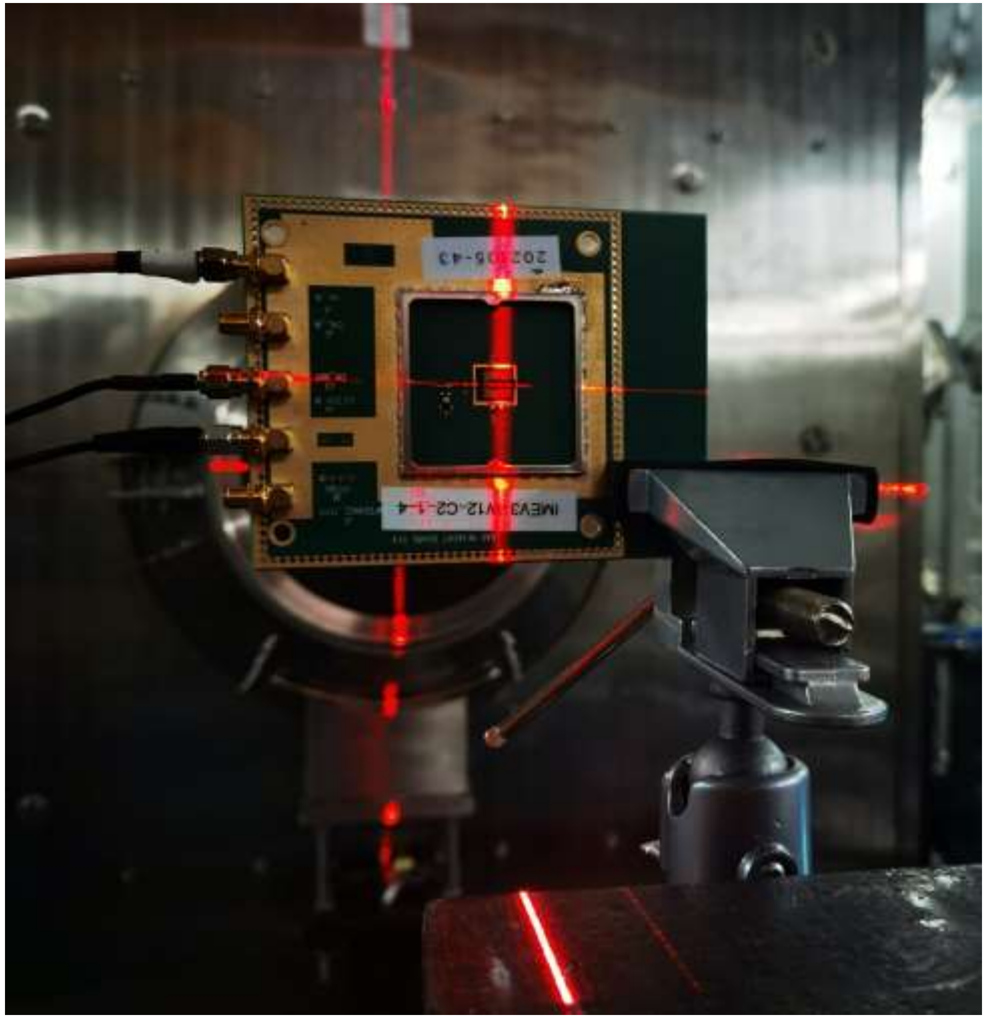
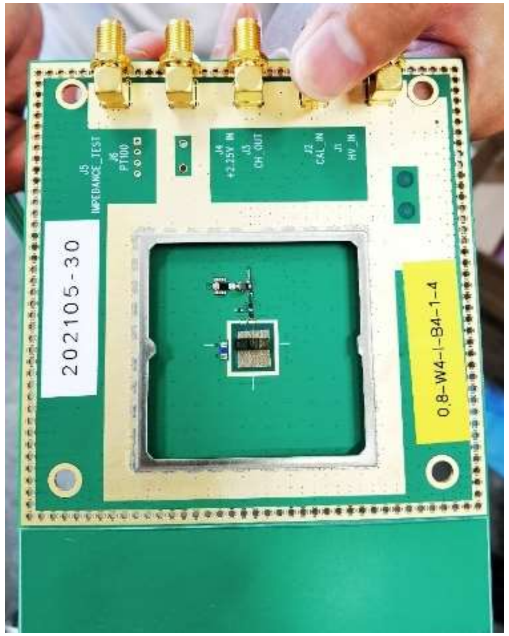
2.1 Experiment Method

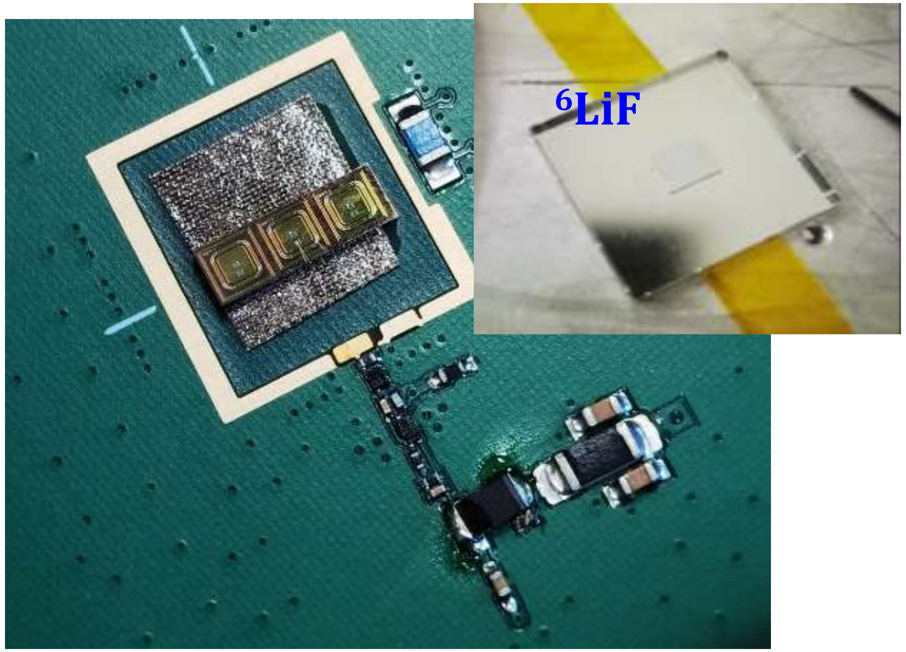


- Neutrons from back-n to hit ^{6}Li target and produce LCI (α and T).
- TOF of neutrons will be measured by LGAD via LCI.
- Calculate the $^{6}Li(n,T)\alpha$ cross-section based on the back-n energy spectrum.

2.2 Detectors



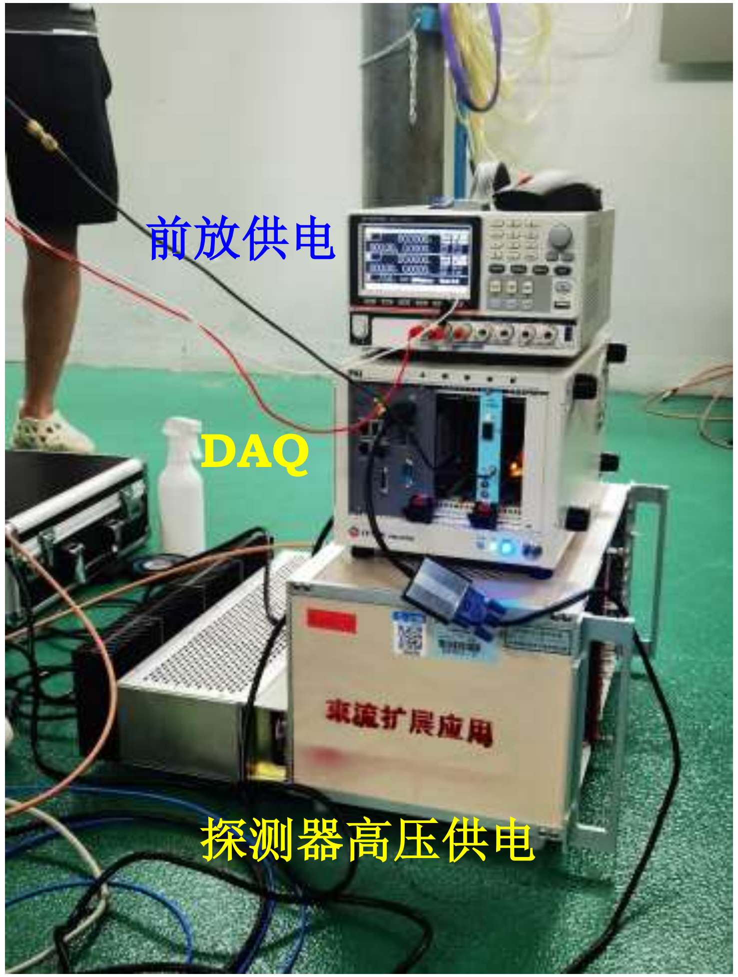




- **LGAD bonded on PCB.**
- **Only on channel was active.**
- **Size of detector 1.3mm×1.3mm.**

2.3 Readout Electronics

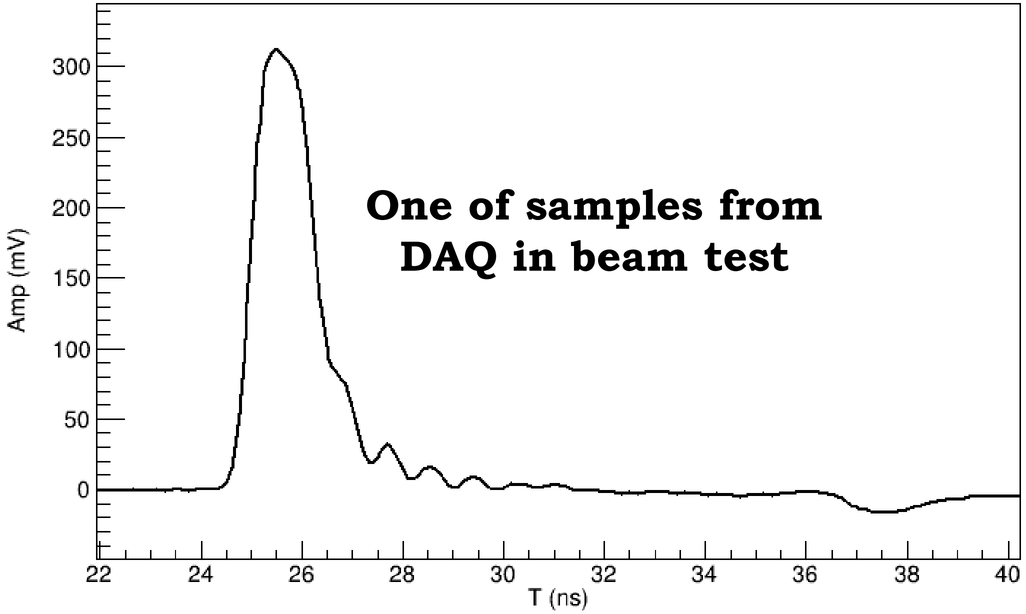
Thanks to the support provided by EVERACQ!



- The Fast Read Out System (FROS) read the signal of LGAD.
- Rising edge ~ 700 ps, signal width ~ 3 ns.

FROS

- PCIe-X1022 Board
- PXIe Protocol
- 6.4Gsps
- 2GHz
- Only data storage
- Zero dead time
- Max. 16 channels.



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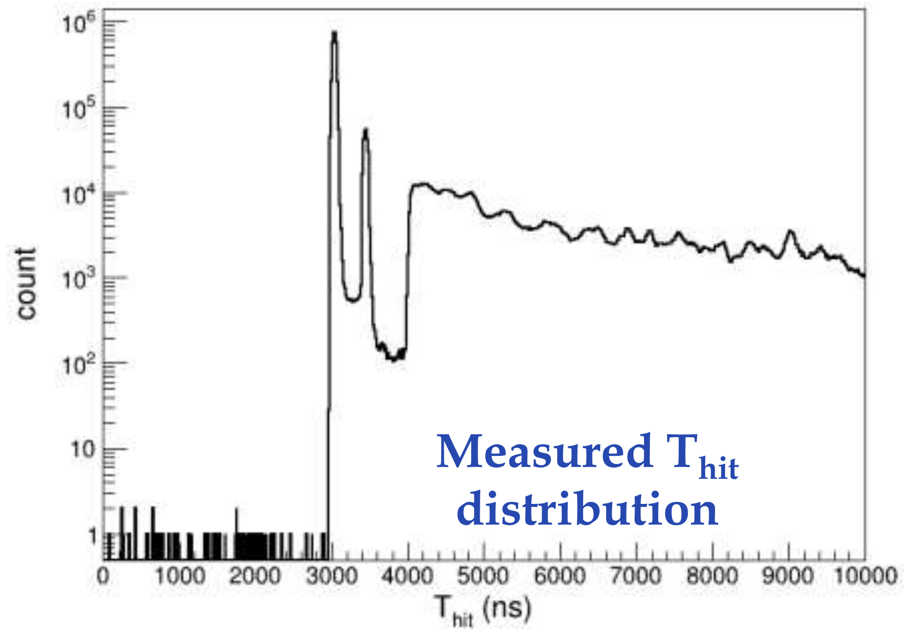
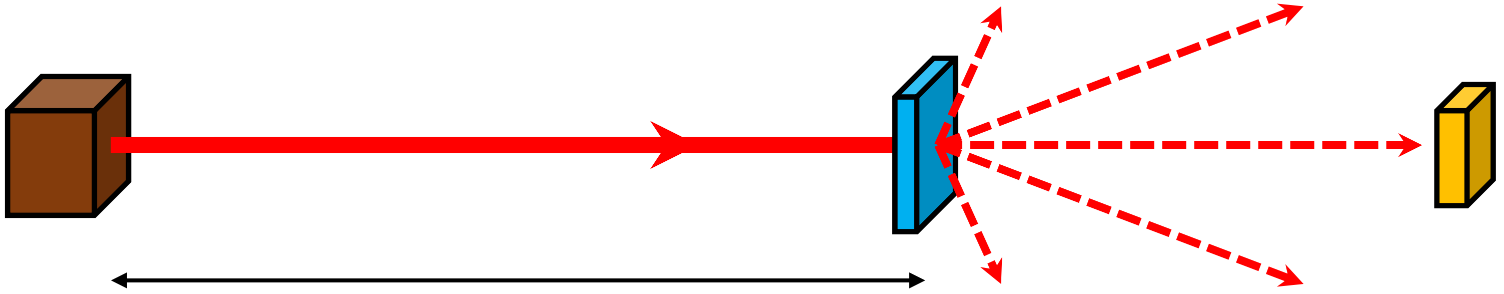
3.1 TOF calculations



- TOF_n is the time of neutron flight.
- T_{hit} is the time that LCI hit LGAD.
- $T_n \approx T_{hit}$ since ^{6}Li target is close to LGAD.
- T_{corr} can be deduced by γ-flash.
- Then TOF_n and E_n can be calculated.



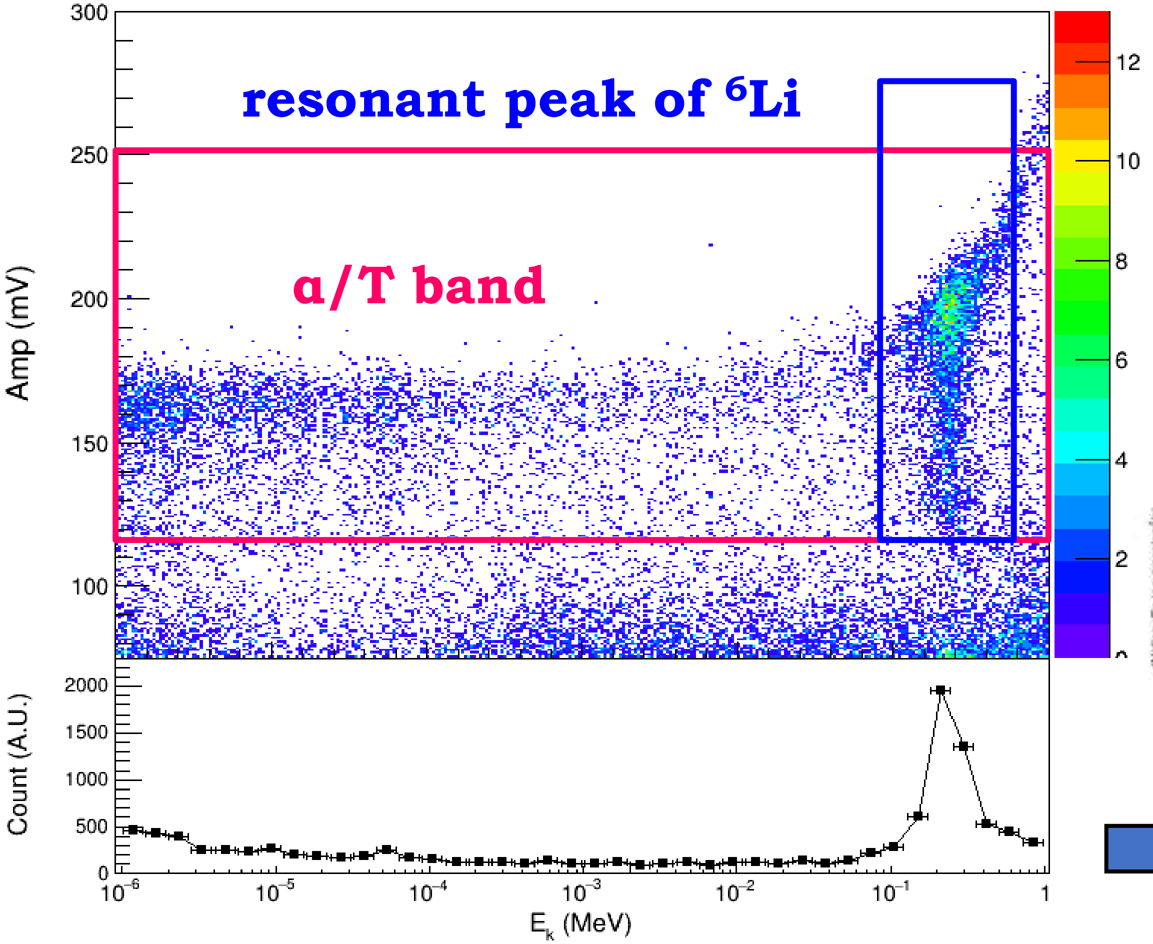
^{6}Li target to spallation neutron target L=77.0m

$$TOF_n = T_{hit} - T_0 - T_{corr}$$

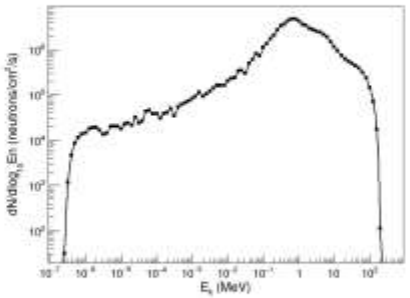
$$\beta = \frac{L}{TOF_n \cdot c}$$

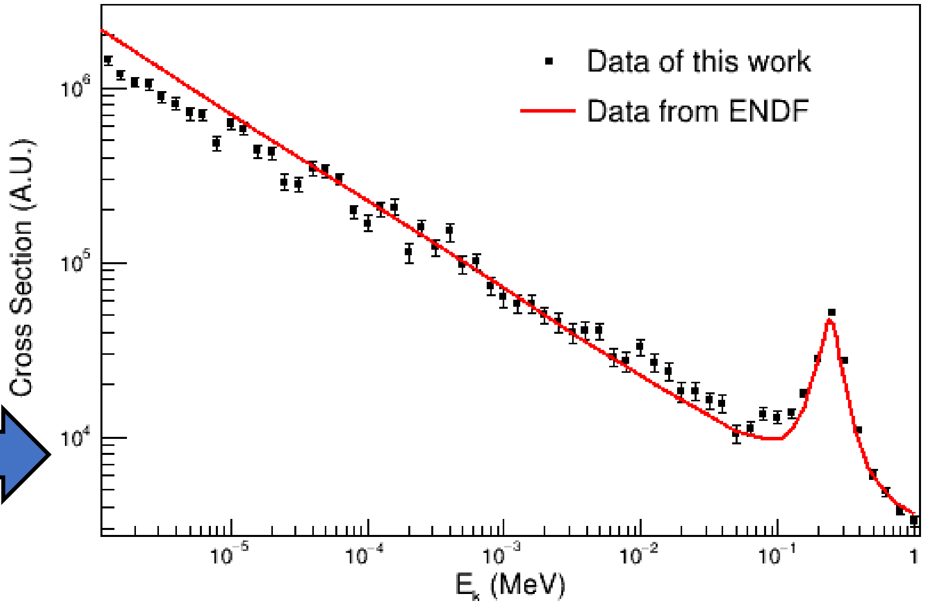
$$E_n = m_{n,0} \cdot \left(\frac{1}{\sqrt{1-\beta^2}} - 1 \right)$$

3.2 Cross Section



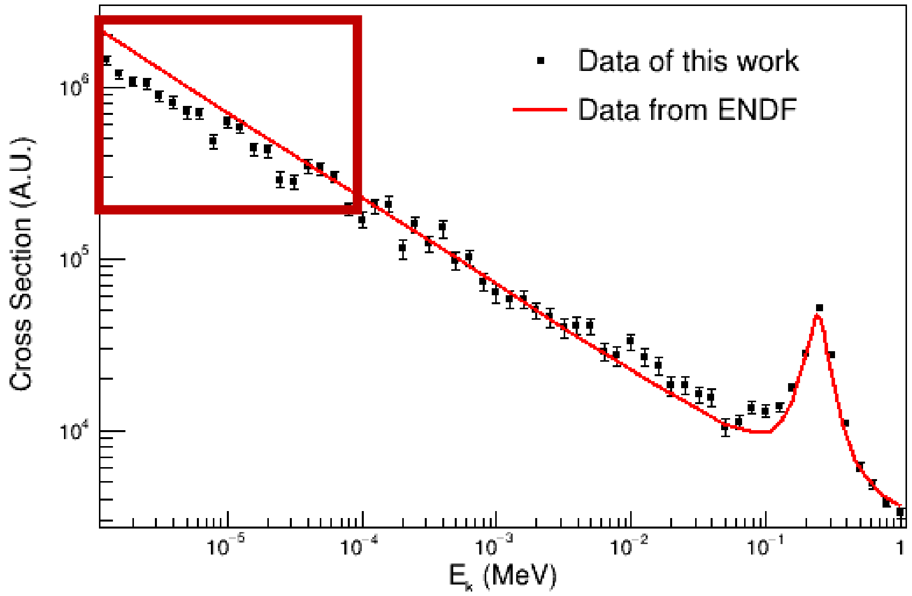
- Event band of $^{6}\boldsymbol{Li(n,T)\alpha}$ can be found.
- Corrected by back-n energy spectrum, cross section of $^{6}\boldsymbol{Li(n,T)\alpha}$ can be acquired.
- Data is generally coincident to ENDF database.

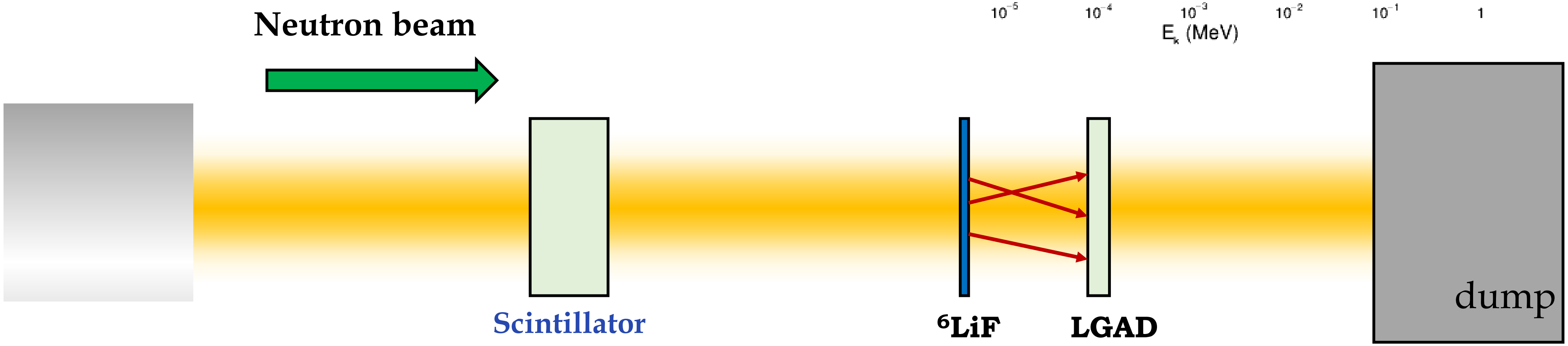




3.3.1 Deviation in low energy range

- Deviation occurs when E_k < 100 eV.
- This experiment is in parallel with a scintillator test.
- Low energy neutrons were absorbed by device in forward.





3.3.2 Irradiation hardness

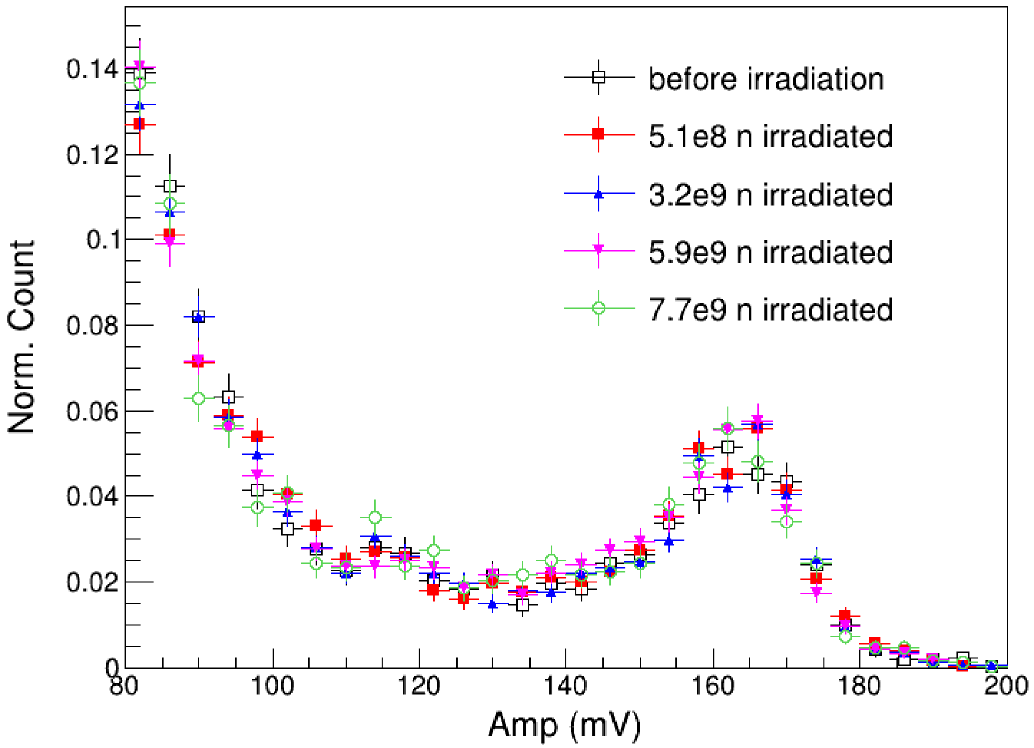


Fig a. Amp of LGAD signal distribution under different amount of irradiations

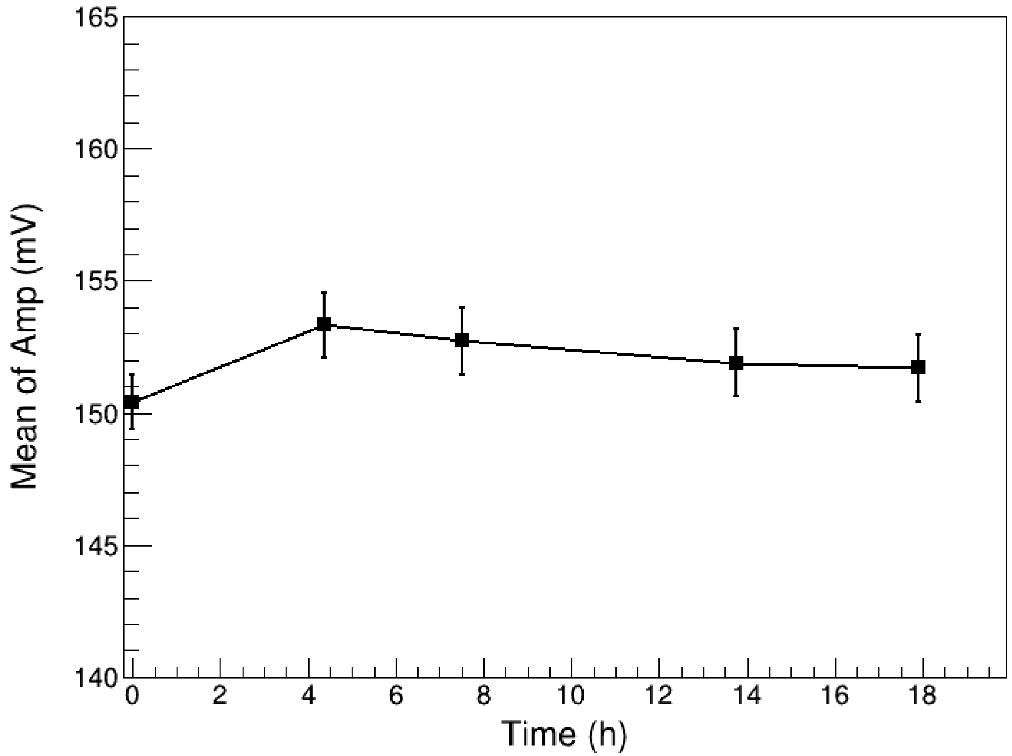


Fig b. Average Amp of LGAD signals under different amount of irradiations

- Effective 1 MeV neutron flux 1.1×10^{10}, no obvious influence on detector performance.
- Irradiation hardness of LGAD meet the requirement of ZDD.

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4. Conclusion

- It is verified that LGAD is a viable option for the application of a ZDD in the measurement of LCI produced by neutron-induced processes:
  - Irradiation hardness: performs well under irradiation of 1.1×10^{10} effective neutrons.
  - Neutron TOF measurement to MeV LCI.
  - Zero-degree data of $^{6}\boldsymbol{Li}(\boldsymbol{n},\boldsymbol{T})\boldsymbol{\alpha}$ measured with LGAD, capable of ZDD.

- Paper has been published. DOI: 10.1109/TNS.2024.3432762

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致谢

承蒙厚爱
感谢倾听
Thanks!