XAPR

# The Design of Multi-Facets Fast Neutron Spectrum Detector and Research of Key Techniques

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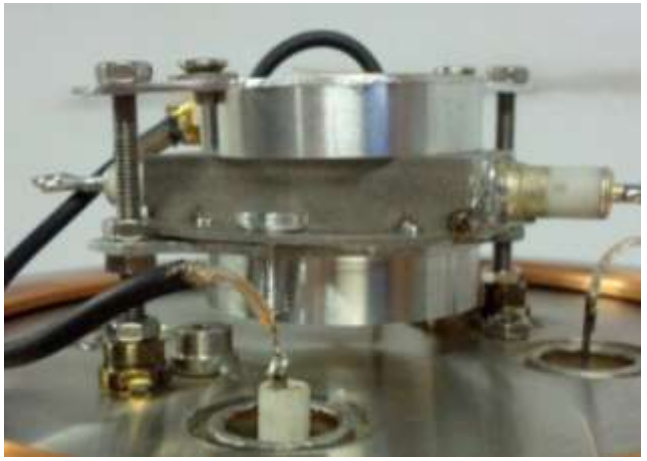
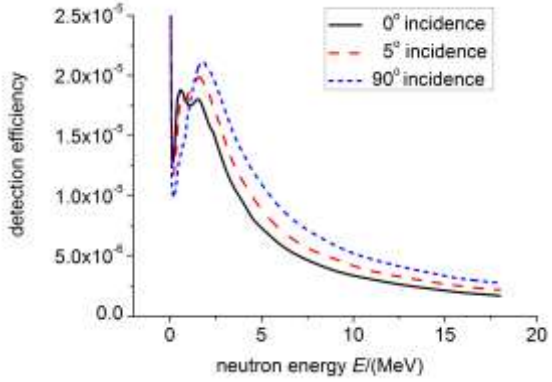
# 1 Introduction

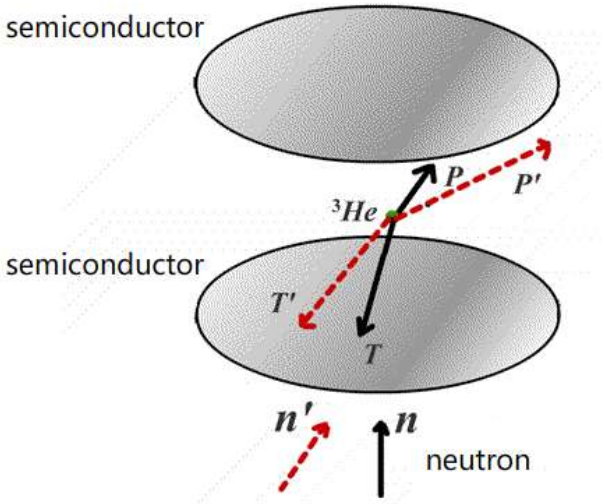
- $^3$He sandwich neutron spectrometer consists of two semiconductors and one $^3$He gas proportional detector. A pair of nucleus, proton and a tritium produced by neutron reaction with $^3$He, if they are detected by difference semiconductor respectively, can be recorded as a coincidence event.
- Owing to high accuracy of energy determination and simple relationship between neutron energy and measurement data, $^3$He sandwich neutron spectrometer performs excellent.

$$E_n = E_c - 765\text{keV}$$

- But the asymmetry of the structure of this device is the key problem which limits the detector be used to uncollimated neutron field energy measurement.
- So the multi-facets detector concept is proposed and the key problems of the neutron spectrum measurement in uncollimated neutron are solved.





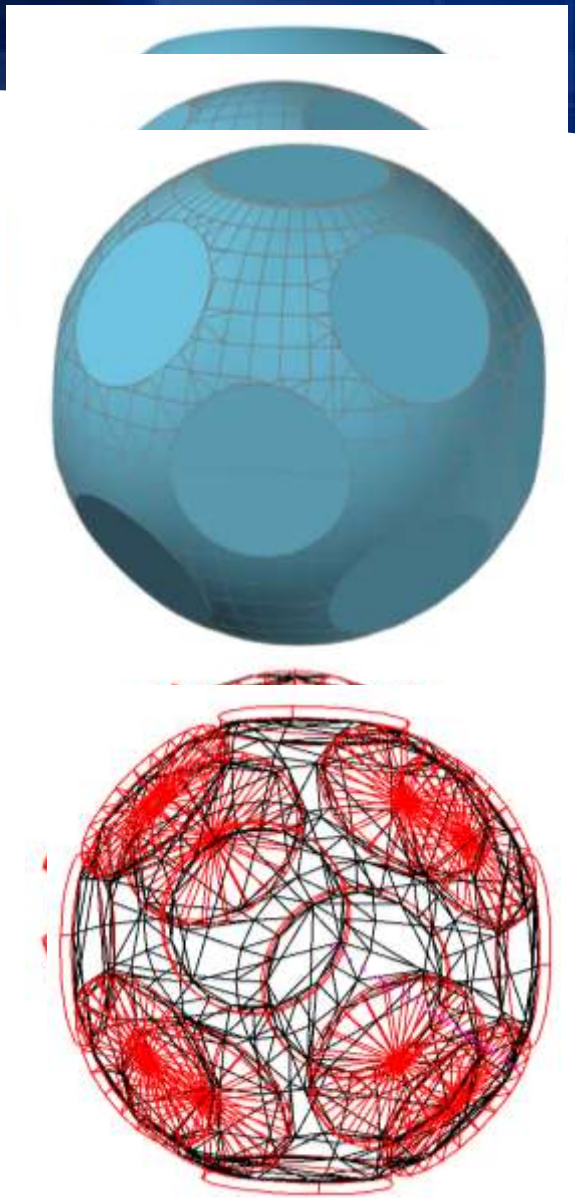



# 2 core analysis

## 2.1 core model

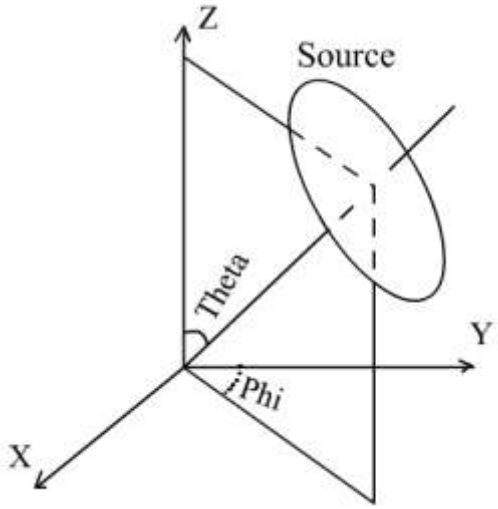
Five kinds of multi-facets detector core models which represent highly symmetry are constructed.

- Model I, spherical proportional detector and 6 circular semiconductor detector
- Model II, cubic proportional detector and 6 circular semiconductor detector
- Model III, cubic proportional detector and 6 square semiconductor detector
- Model IV, spherical proportional detector and 8 circular semiconductor detector
- Model V, spherical proportional detector and 14 circular semiconductor detector
- The size of proportional detector and semiconductor detector can be modified respectively, there are 30 kinds geometric parameter for each core model.
- The detection efficiency is calculated for each core model using 0.5MeV、1MeV、8.0MeV、14MeV neutron beam with difference incident angle.

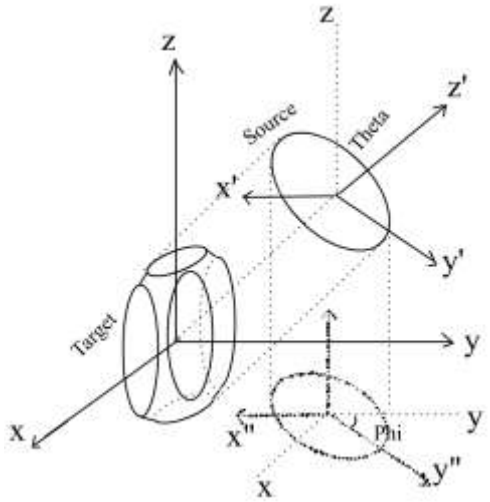


## 2.2 neutron source for calculation

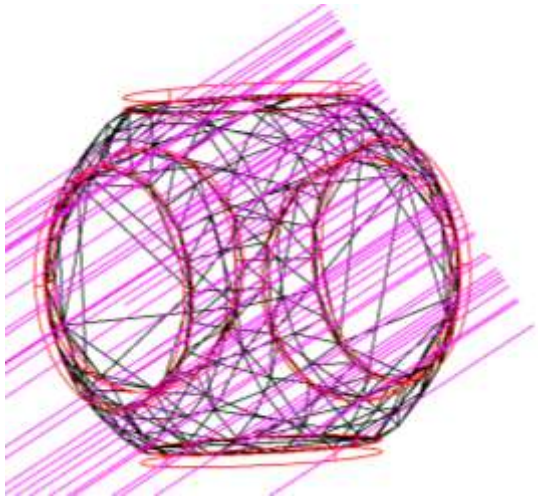
- For 6 facet core, theta and Phi are symmetrical 45 degree. the angle increase 5 degree for each calculation from 0 to 45 degree. For 8 facet or 14 facet core theta is symmetrical 90 degree. angle increase 10 degree for each calculation from 0 to 90 degree. So there need calculate 91 efficient data for each geometric parameter model.
- In order to improve the computation efficiency, the method which combine cross finite magnification and infinite magnification is adopted. The efficiency can be magnified about $10^5$ times.




incidence angle




Planar source diagram



Planar source instance

# 2.3 result of calculation

the neutron detection efficiency of five kinds of multi-facets detectors is calculated using the Geant4 software. The result indicates that because of the symmetrical structure, the detection efficiency is roughly equivalent for neutron beam with different incidence angel.

considering the factors such as the uniformity of the electric field, the difficulty of the producing process and background discrimination, model I is regarded as the optimal detector structure.

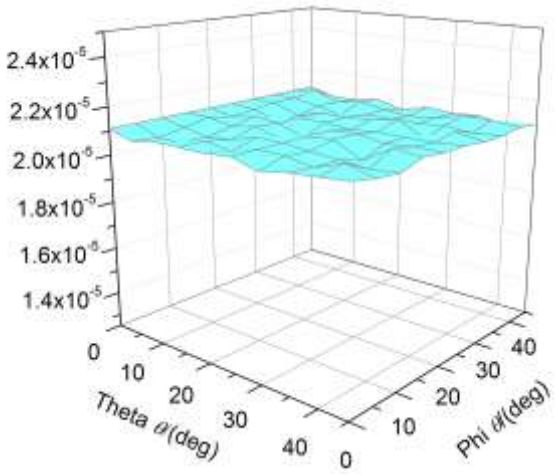
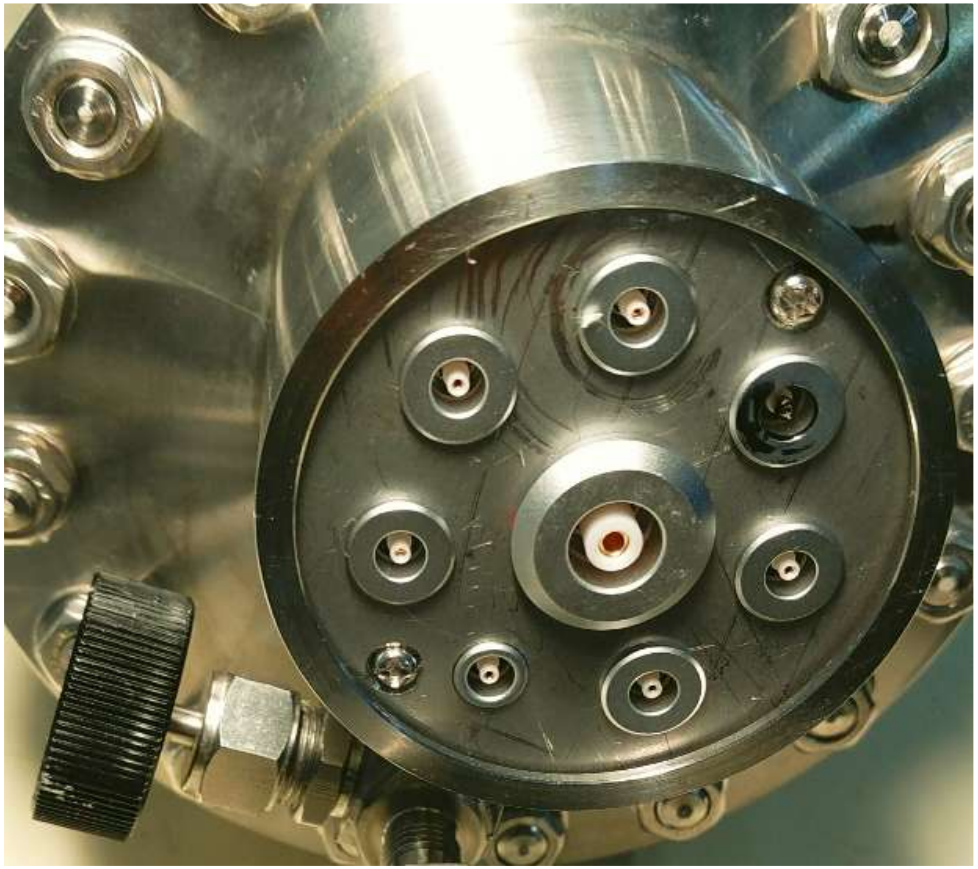



Fig Maximum difference of efficiency between different incidence angle

| Neutron energy/MeV | Model I | Model II | Model III | Model IV | Model V |
|---|---|---|---|---|---|
| 0.5 | 0.049 | 0.056 | 0.050 | 0.067 | 0.047 |
| 1 | 0.045 | 0.053 | 0.044 | 0.054 | 0.039 |
| 8 | 0.037 | 0.035 | 0.033 | 0.052 | 0.028 |
| 14 | 0.043 | 0.045 | 0.037 | 0.048 | 0.041 |

# 2.4 Detector core assembly



# 3 Energy calibration using a thick alpha source

- **Two build-in $^{241}$Am alpha sources are used to calibrate the detector. Four semiconductor can be irradiated by one build-in $^{241}$Am source, so there need two $^{241}$Am to calibration;**
- **Semiconductor detector can be calibrated under vacuum;**
- **since the energy of alpha ray can only partially deposited in He-3 gas, the proportional detector can only be calibrated by coincidence method;**

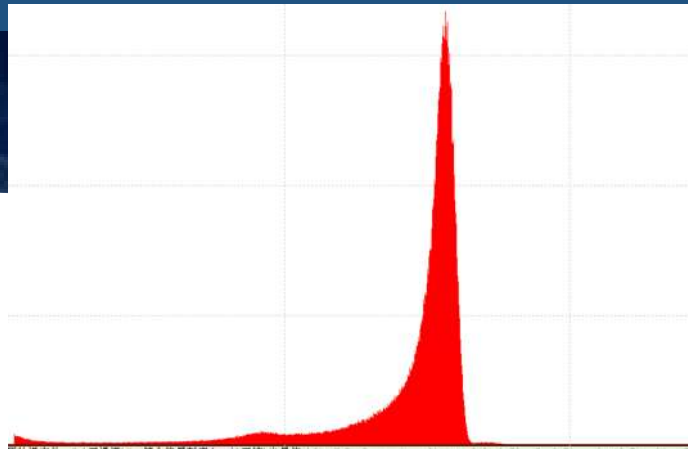
$$E_g = E_c - E_{St}$$

- **Owing to the small area, it is difficult to made the source enough thin to ignore self-absorption.**

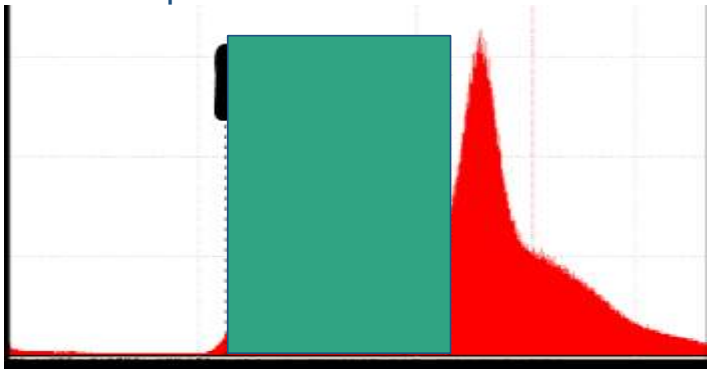
$$E_g = E_a - E_{St} - E_{self}$$

**To avoid the coincidence events which caused by the ray has been absorbed energy partially by the source, the coincidence events must be screened.**

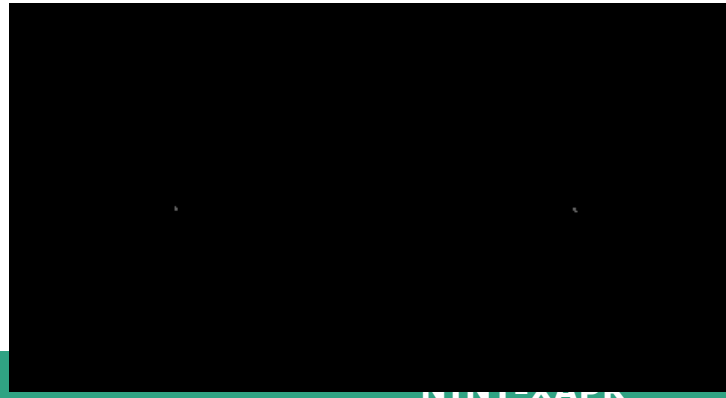
- **select those coincidence events which energy measured by semiconductor detector is in the peak or higher. When the energy in the semiconductor is fixed ,the energy in gas detector should be fixed too, at least distribute narrowly. but now the energy in the gas detector distribute widely, the gas detector can't be accurately calibrated.**
- **It means energy of ray absorbed by the source itself when the energy is significant lower. Less energy deposited in the gas that means the range in the gas is shorter and the trajectory is far away from the anode.**
- **So selecting the coincidence events that the delay time is in a smaller scope. Then the energy distribution in gas detector is narrower.**



Spectrum of semiconductor

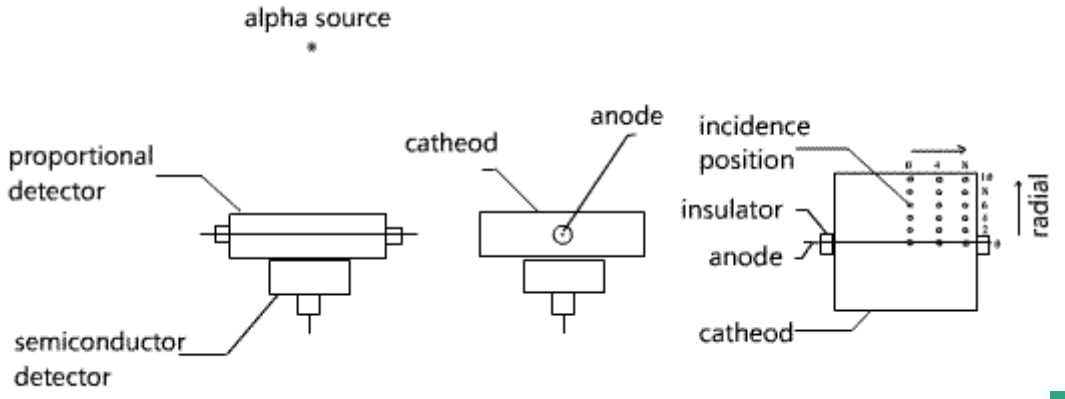


Spectrum of gas detector



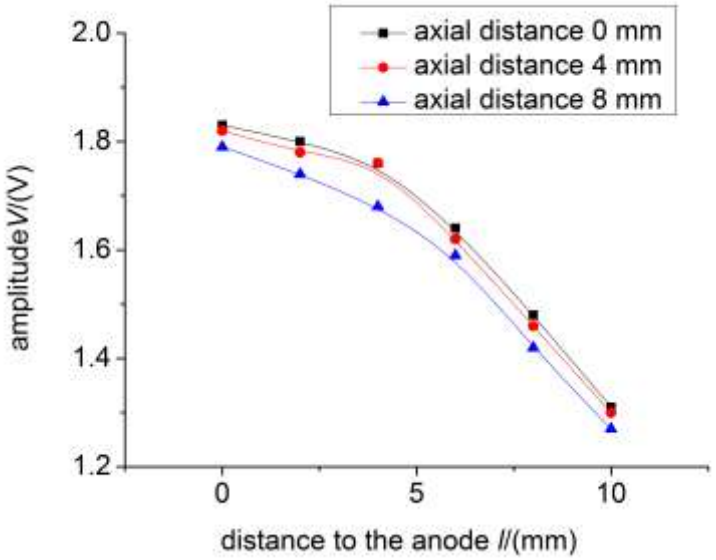
# 4 Proportional detector output amplitude compensation

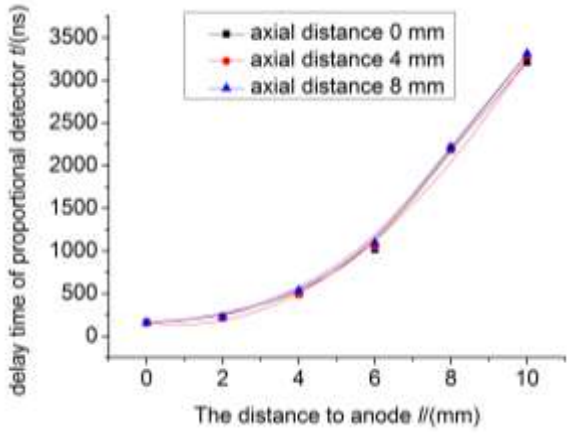
- **The output amplitude of proportional detector is related to the position of original ionization**
- **To get the relationship between the amplitude and delay time relate to semiconductor, the measure device are established. The device include an alpha source, a rectangular proportional detector and a semiconductor detector.**

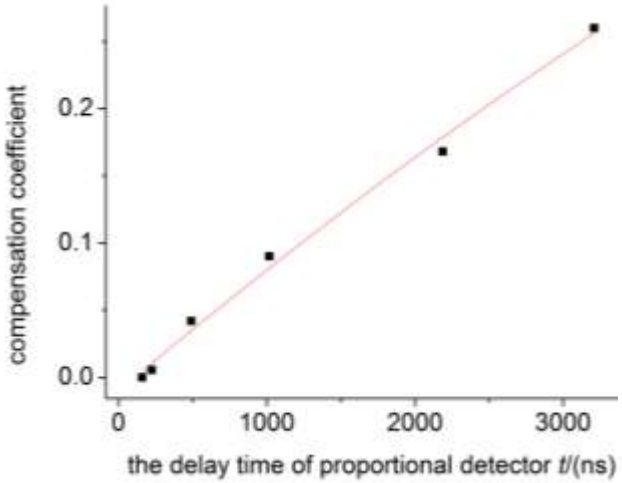


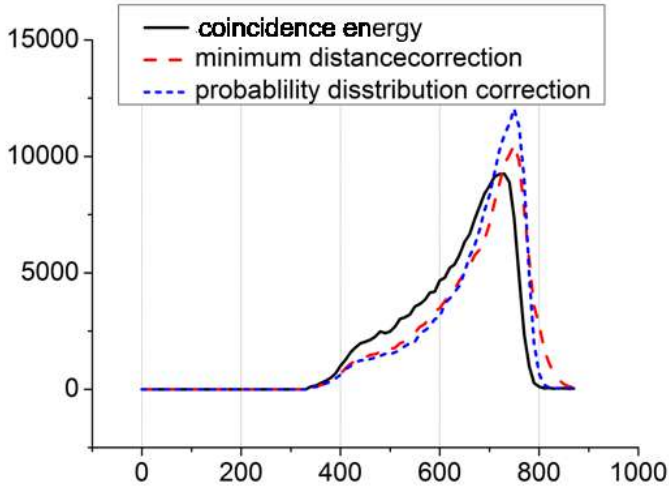
- The relation between output amplitude and delay time can be obtained by using this device.
- In actual measurement, the output amplitude can be corrected by obtaining the delay time of proportional detector.

**The results show that the method of proportional detector energy calibration and amplitude compensation is feasible.**



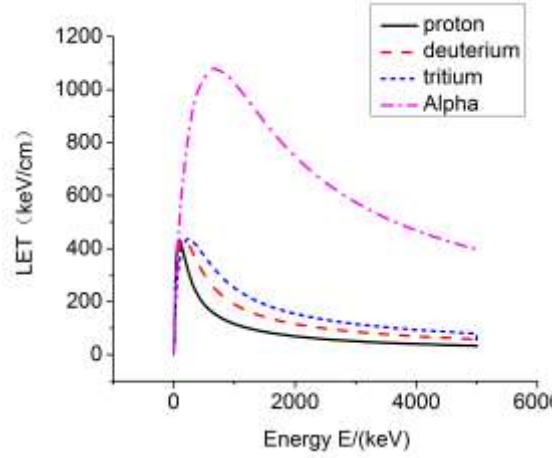



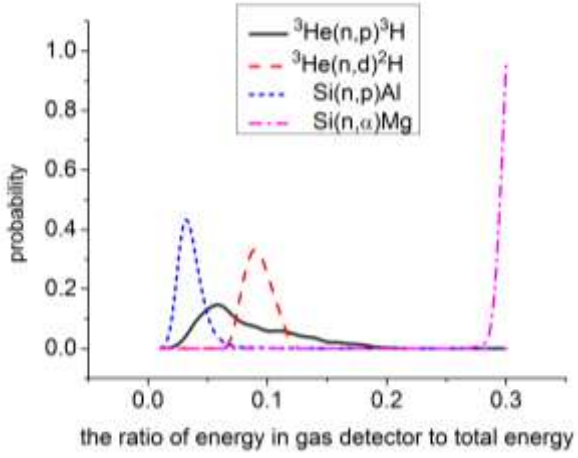



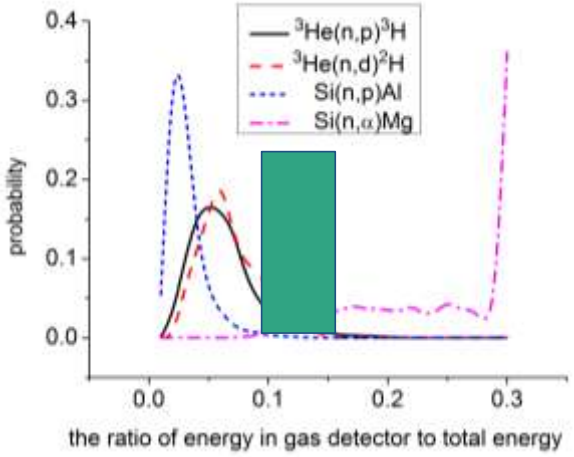

Thermal neutron spectrum

# 5 discrimination of background coincident events caused by the fast neutron react with silicon

- **Fast neutron react with silicon to release protons or Alphas, which can cause the true coincidence interference events.**
- **The method which discriminating the background coincident events synchronously during neutron spectrum measurement is put forward.**
- **First, Due to the higher LET value of Alpha, the coincidence event that caused by Si(n,α)Mg reaction can be discriminated according to the energy deposited in gas detector.**



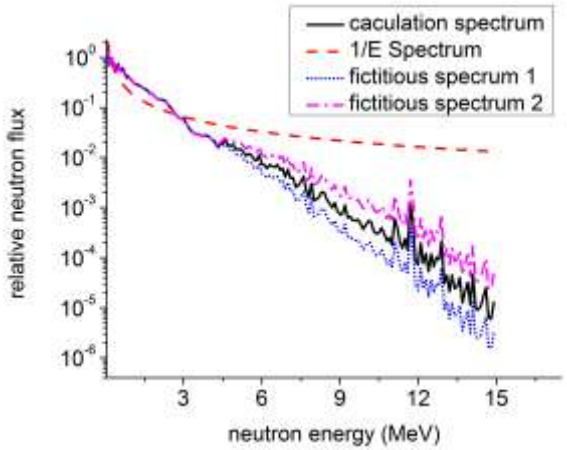





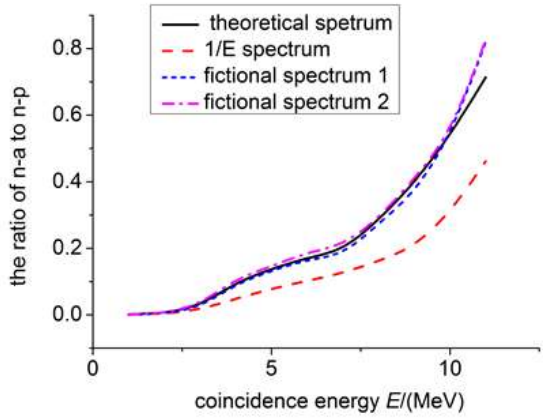

opposite

adjacent

- **Second, The calculation shows that the ratio of the coincidence event Si(n,p)Al to Si(n,α)Mg is not obviously response to the variation of neutron spectrum. So the coincidence event that caused by Si(n,p)Al reaction can be discriminated by the counts of Si(n,α)Mg events and the calculated value of the ratio Si(n,p)Al to Si(n,α)Mg.**




Neutron spectrum

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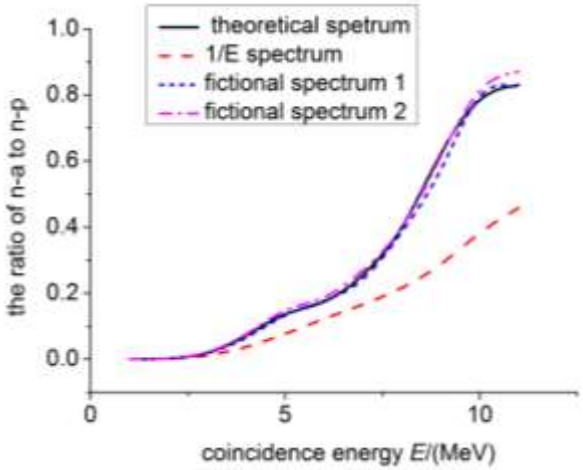


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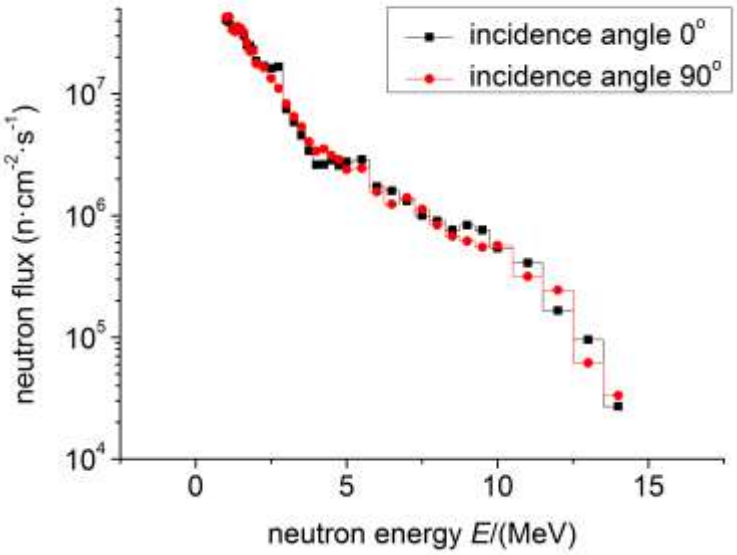
# 6 theoretical model verified

- **Due to the malfunction of the 9 channels digital coincidence device, the multi-facets detector has not been used to complete the measurement of the fast neutron spectrum. But the theoretical model is verified with $^{3}$He sandwich neutron spectrometer .**
- **First, the efficiency of the $^{3}$He sandwich neutron spectrometer under different incident angles be calculated using above theoretics.**
- **Second, neutron spectrum of XAPR 1$^{\#}$ radial pipeline has been measured by $^{3}$He sandwich neutron spectrometer with 0$^{o}$ and 90$^{o}$ angle respectively.**

- **The final result indicates that the two spectrums agree with each other roughly and the relative error is within the uncertainty. It can be concluded that the design of the neutron spectrometer in this thesis and the techniques associated with it are reasonable and feasible.**



# Thanks for your attention !