A Novel Gamma-ray Detector for Gravitational Wave Electromagnetic Counterpart All-sky Monitor (GECAM)

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Outline

- **Research status of Gravitational Wave Electromagnetic Counterpart**
  - **Existing telescopes;**
  - **About GECAM.**
- **A novel Gamma-ray Detector: the crystal of $LaBr_3$ with SiPM**
- **Performance of the detector**
  - **Dynamic range;**
  - **Linear response;**
  - **Energy resolution;**
  - **Uniformity;**
  - **Detection efficiency.**
- **Summary**

Present research status

★ **Observation of Gravitational Waves from a Binary Black Hole Merger**

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

[1][2]

GW150914: The Advanced LIGO Detectors in the Era of First Discoveries

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 15 February 2016; published 31 March 2016)

- **A lot of high energy telescopes began to search the counterparts**
- **The counterpart is the electromagnetic radiation of gravitational wave source**
  - **Help confirm the gravitational wave events;**
  - **Help locate the gravitational wave sources;**
  - **Help research dark matter and dark energy.**
- **The key technology of searching high-energy counterparts**
  - **Wide field of view:** **gravitational wave bursts are random all day;**
  - **High sensitivity:** **range from radio wave to high-energy gamma-Rays;**
  - **Excellent localization:** **help confirm low-energy counterparts.**

Existing astronomy telescopes

Project	Field of view (All-sky)	Location (deg)	Energy (keV)	Status
Fermi/GBM	60%	5	10 - 40000	Running
Swift/BAT	10%	0.1	15-350	Running
Konus-Wind	80%	No	20-15000	Running
POLAR	30%	5	50-500	Running
HXMT	60%	10	200-3000	Running
SVOM/GRM	40%	5	15-5000	~2021
GECAM	**100%**	**1**	**6-5000**	**~2020**
EP	**10%**	**0.1**	**0.5-4**	**~2021**

Tab.1. The existing and planning astronomy telescope

Gravitational Wave high-energy Electromagnetic Counterpart All-sky Monitor (GECAM) is specially designed for the gravitational wave high-energy counterparts.

Einstein Probe (EP) is specially designed for the gravitational wave low-energy counterparts.

They will collaborate with each other for counterparts in the future.

About GECAM

➢ Objectives of GECAM

- Seek out the high-energy counterparts;
- Monitor Gravitational Wave and supply the key information;
- Research the physical mechanism of black-hole and gamma burst;

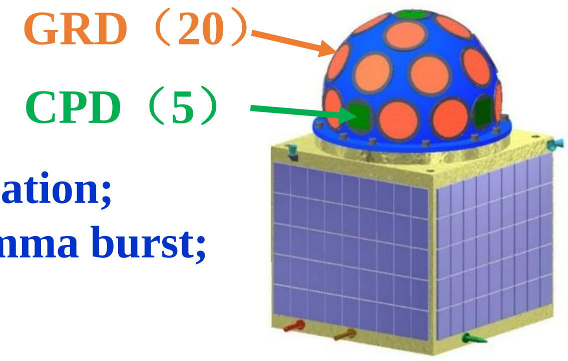


Fig.1. Micro-satellite for GECAM

➢ Performance requirements

- Large dynamic range: 6 keV – 5 MeV ;
- High sensitivity: ~2E-8 erg/cm^2/s ;
- Wide field of view: 4π All-sky ;
- Excellent localization: ~1 deg ;

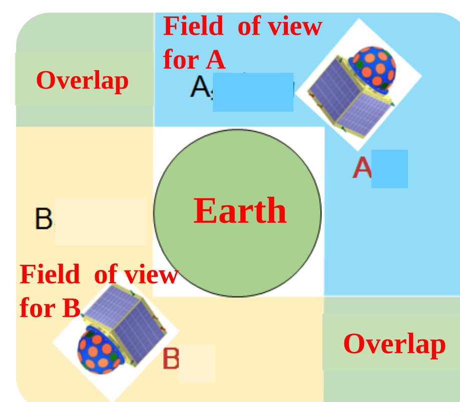


Fig.2. Micro-satellites in space

➢ Project requirements

- Two kinds of detectors: GRD and CPD;
- The space is limited, so the detector should be small;
- The detector should be compact and stable.

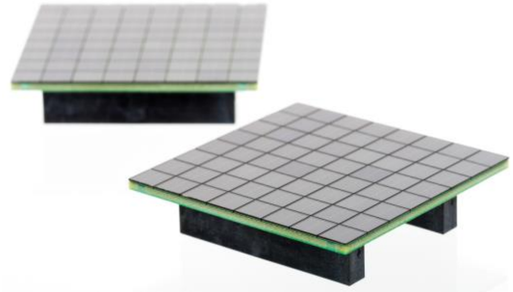
The $LaBr_3$ crystal with SiPM as read device may be the best candidate for GRD.

GRD : Gamme-Rays Detector CPD : Charged-Particle Detector

The Gamma-Rays detector

- **The $LaBr_3$ crystal (one of the best crystals which can be mass production)**
  - **Density: 5.3g/cm^3;**
  - **Fast decay time: <35ns;**
  - **High photo yield and good linear response: 60000 photons/MeV;**
  - **High energy resolution: 3%(FWHM)@662keV for small volume.[3-7]**

- **SiPM**
  - **Single-photon sensitively, low bias;**
  - **Small volume, excellent uniformity;**
  - **large dynamic range, high photon detection efficiency;**
  - **Large area SiPMs are available[8].**



- **The $LaBr_3$ crystal with SiPM as read device**
  - **Saint-Gobain_3 inch $LaBr_3$ + SensL_ArrayJ_60035_64P（50.44*50.44mm^2）；**
  - **Compare to PMT[9], SiPMs are more suitable.**

The Gamma-Rays Detector

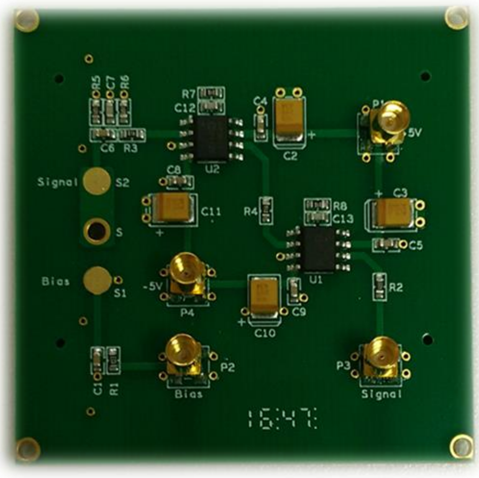
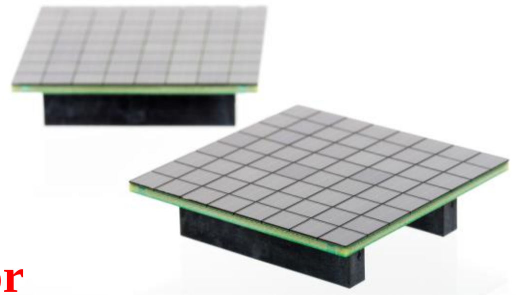


Fig.3. the preamp circuit

➢ **Preamp**

- **Low-noise: cascade two amplifiers（ADA-4895-1）**
- **high-gain: ~25 times**
- **Low-power: <0.1W/Channel**



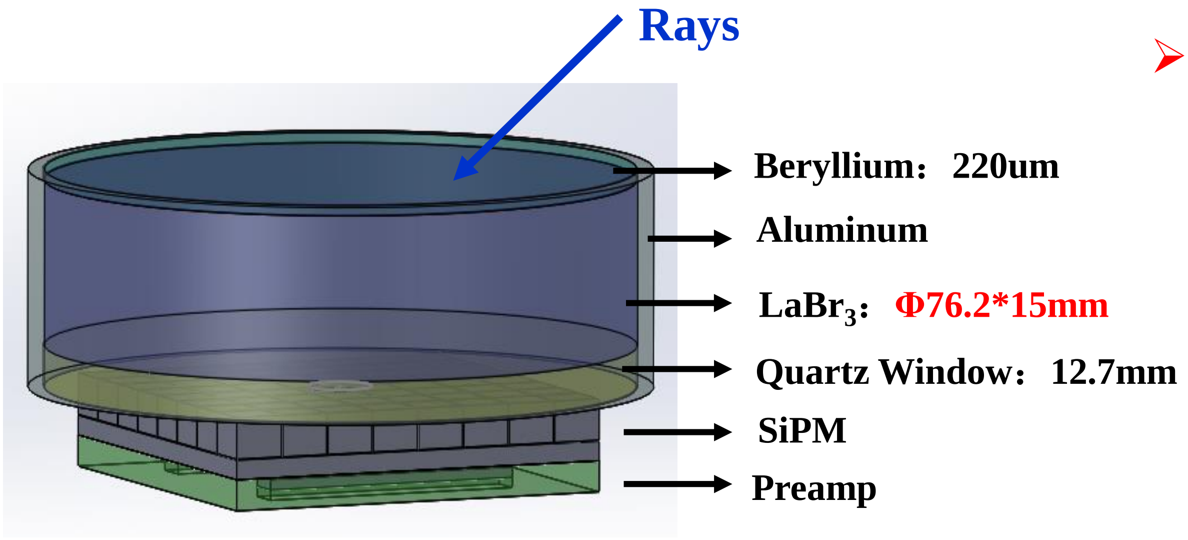


Fig.4. the gamma-rays detector

➢ **Detector**

- **64 pads of SiPM in parallel;**
- **SiPM and circuit are attached to both sides of the same PCB;**
- **Use Compton membrane and silicone oil to improve the light collection;**

Performance of GRD — Dynamic range

Internal radioactive of $LaBr_3$: **^{138}La@5.6keV and 37.4keV（X-Rays）**
Radioactive source : **^{55}Fe@5.9keV（X-Ray）**

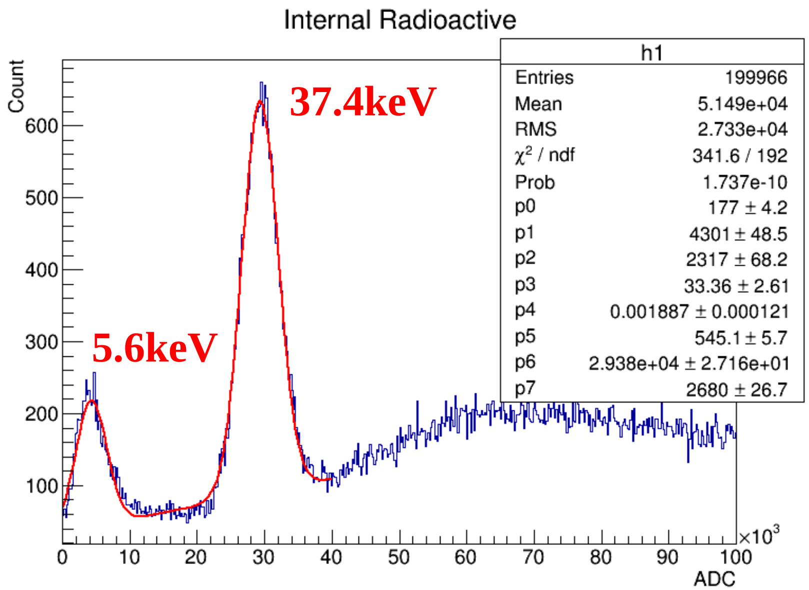


Fig.5. the energy spectrum of internal radioactive

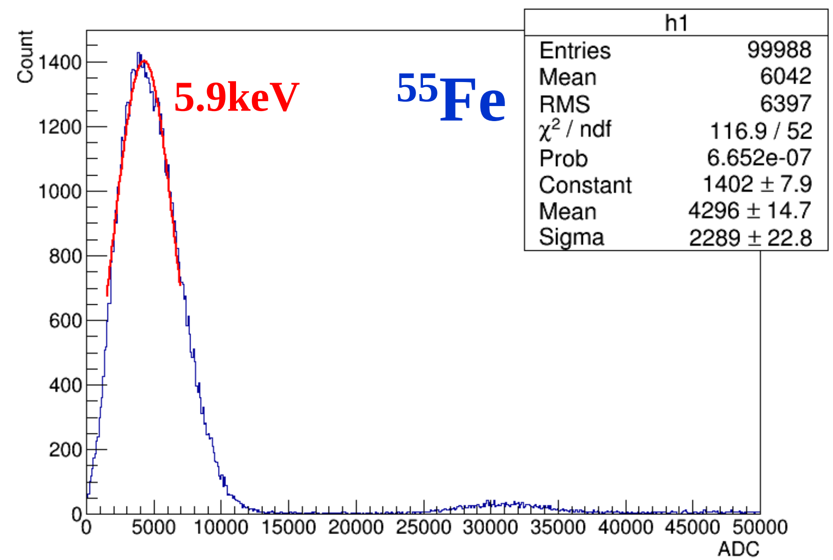


Fig.6. the energy spectrum of ^{55}Fe

The lower limit can reach 5.6keV, and this result satisfies the GECAM requirement.

Performance of GRD — Linear response

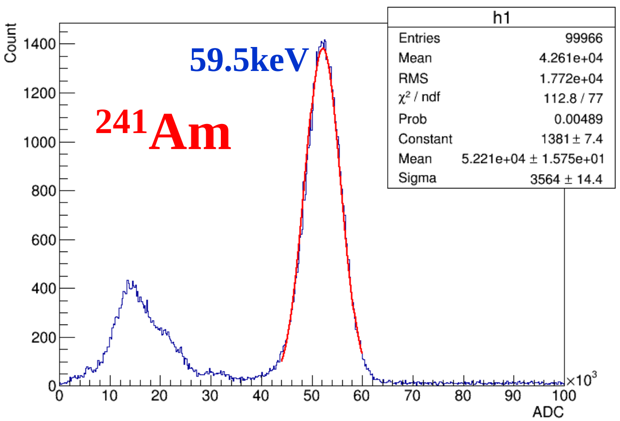


Fig.7. the energy spectrum of ^{241}Am

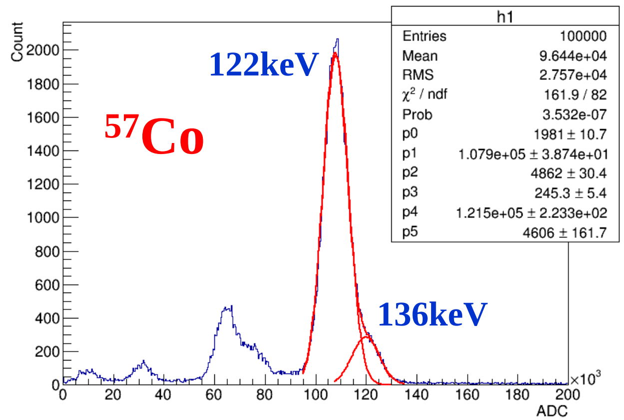


Fig.8. the energy spectrum of ^{57}Co

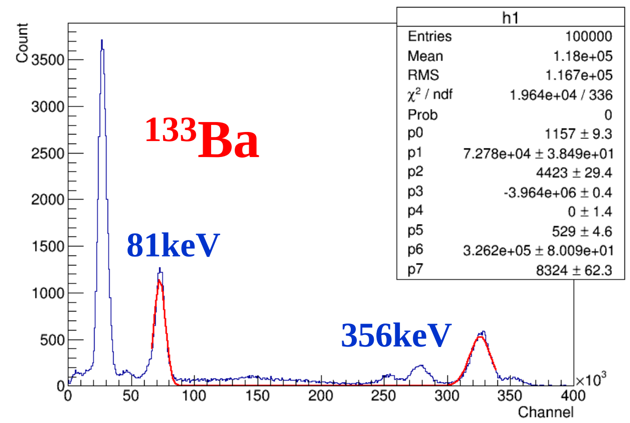


Fig.9. the energy spectrum of ^{133}Ba

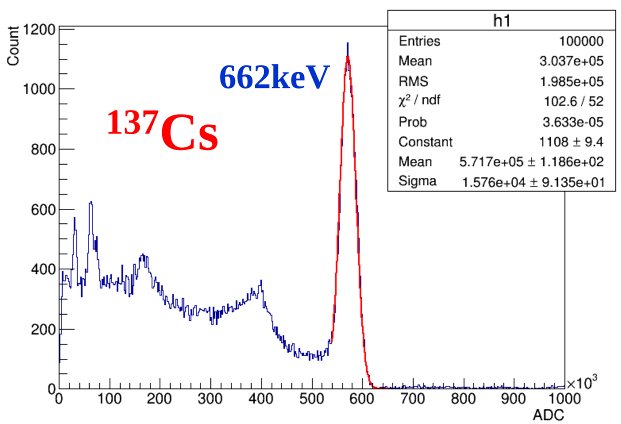


Fig.10. the energy spectrum of ^{137}Cs

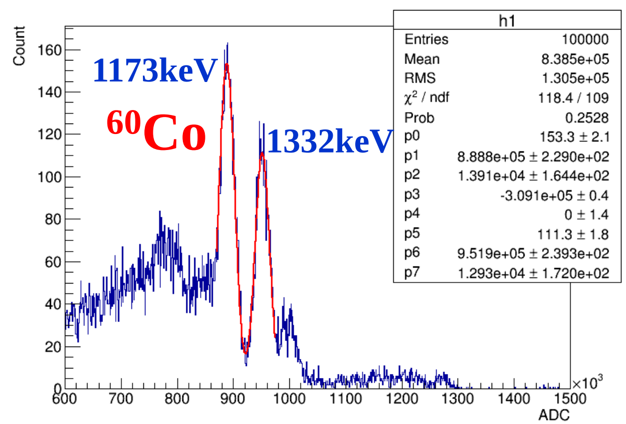


Fig.11. the energy spectrum of ^{60}Co

Performance of GRD — Linear response

Source	Energy	Rays
La decay	5.6keV, 37.4keV	X-Ray
^{55}Fe	5.9keV	X-Ray
^{241}Am	59.5keV	X-Ray
^{57}Co	122keV, 136keV	γ-Ray
^{133}Ba	81keV, 356keV	γ-Ray
^{137}Cs	662keV	γ-Ray
^{60}Co	1173keV, 1332keV	γ-Ray

Tab.2. the radioactive sources and rays

- **Linear response changes for high-energy;**
- **The amplitude is over-channel;**
- **Change Flash ADC and do correction.**

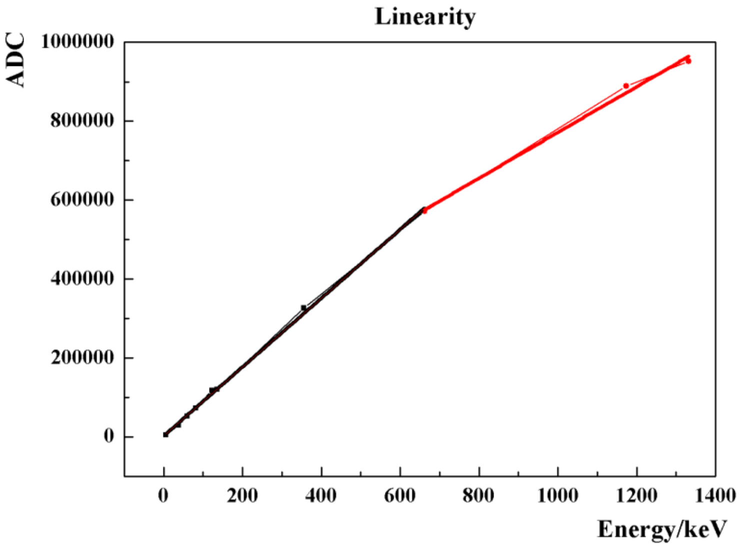


Fig.12. the relation of ADC and energy

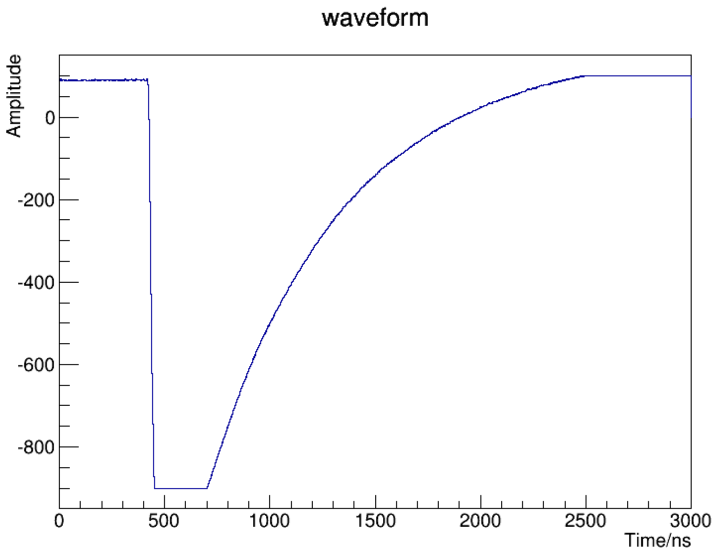


Fig.13. the waveform of high-energy γ-Ray

Performance of GRD — Energy resolution

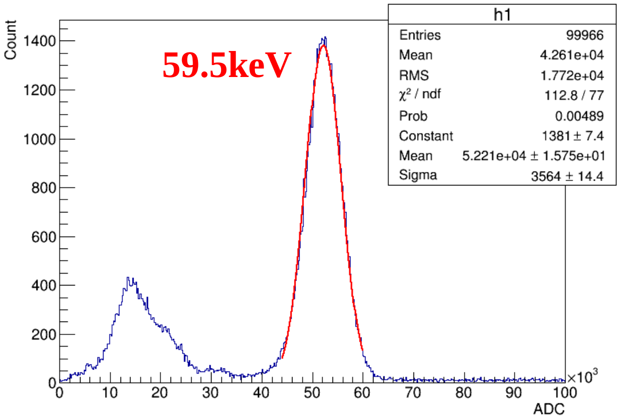


Fig.14. the energy spectrum of ^{241}Am

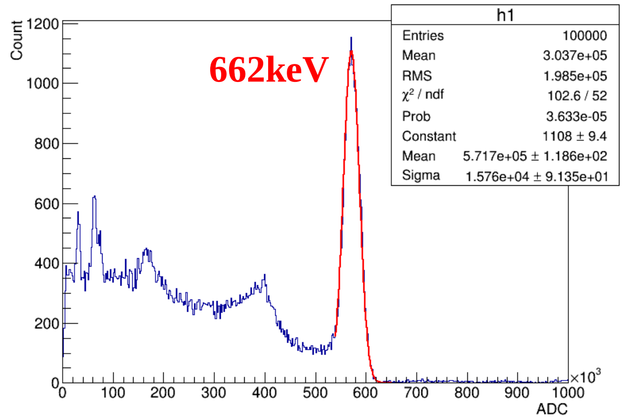


Fig.15. the energy spectrum of ^{137}Cs

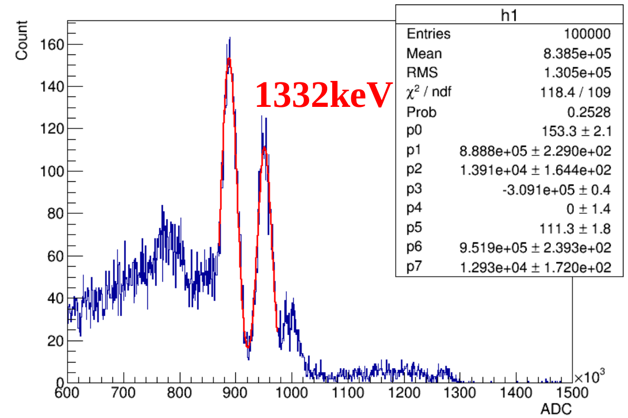


Fig.16. the energy spectrum of ^{60}Co

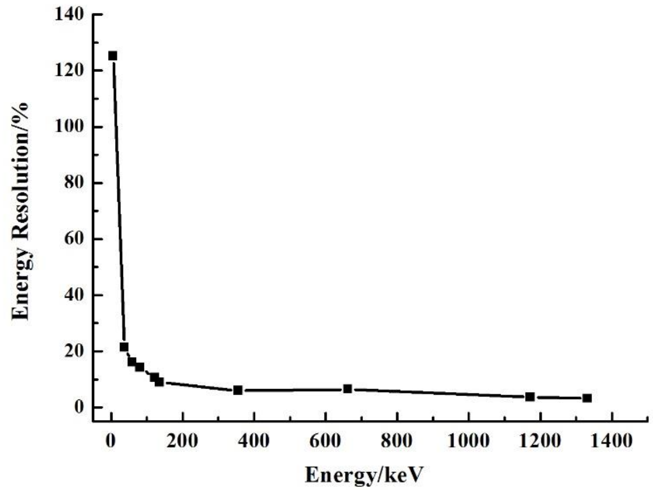


Fig.17. the energy resolution curve

16.1% (FWHM) @ 59.5keV(^{241}Am);
6.5% (FWHM) @ 662keV (^{137}Cs);
3.2% (FWHM) @ 1332keV (^{60}Co).

The energy resolution satisfies the GECAM requirement (<10% @ 662keV) .

Performance of GRD — Uniformity

The ^{241}Am source is placed on the crystal after being collimated.

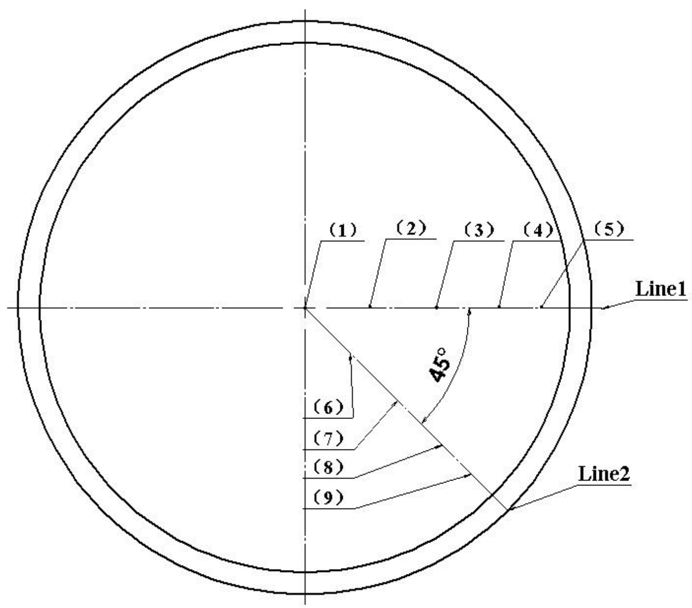


Fig.18. the position that ^{241}Am is put

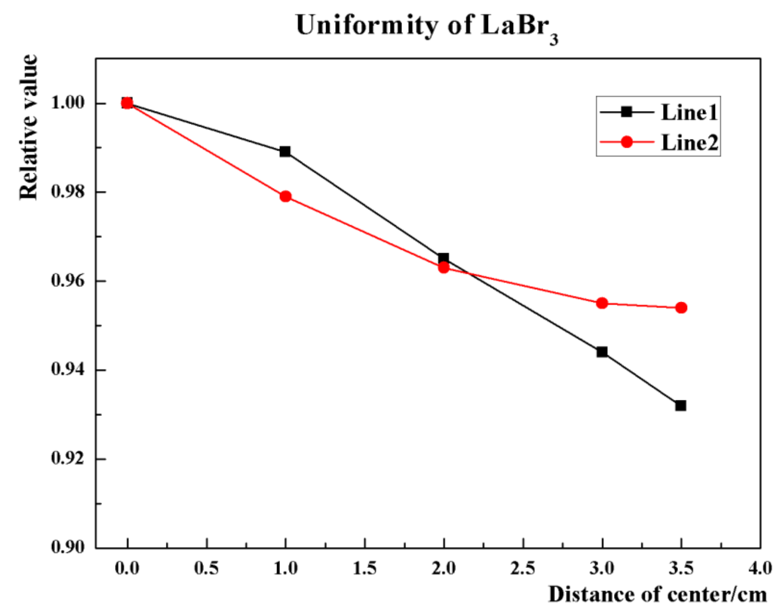


Fig.19. the uniformity of line1 and line2

- **Regard the result of point(1) as reference value;**
- **The uniformity get worse with the position moves to edge;**
- **The reflection of edge may cause the loss of light;**
- **The difference between center and edge is less than 10%;**
- **This value is acceptable, and we can do correction afterwards.**

Performance of GRD —Detection efficiency

For ^{55}Fe source:

Source	Energy	$T_{1/2}$(year)	Date in A_0 is measured (year)	Activity
^{55}Fe	5.9keV	2.7	1986	2.59E+07

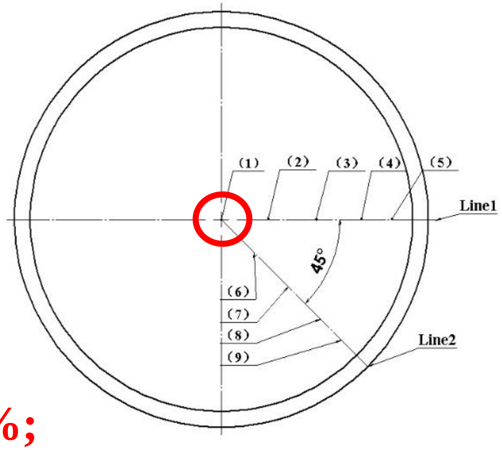
Tab.3. the information of ^{55}Fe source

The present activity **A** can be calculated by

$$A = A_0 e^{-\lambda t}$$

T: time, λ: decay constant;

A_0: the activity when t=0.



- For 2π spatial angle, Detection efficiency: 42%--65%;
- This value will be influenced by beryllium window…

Fig.20. the place that the source put

Summary

- **GECAM as high energy astronomy telescope which is specially designed for searching gravitational wave high–energy counterparts is a necessary and important work.**

- **The performances of GRD（the LaBr3 crystal with SiPM）are good.**

  - **The dynamic range can be as low as 5.6keV;**
  - **The energy resolution can reach 6.5%(FWHM)@662keV, 3.2%@1332keV;**
  - **The uniformity and linear of the crystal are acceptable;**
  - **The detection efficiency of the detector can reach 42%--65%;**
  - **The power of the detector can be lower than 0.1W/channel.**

- **The GECAM plans to be sent and to get data in 2020.**

Thanks for your attention!

References

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