Ground-based calibration and characterization of Insight HXMT/HE detectors

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On behalf of HXMT/HE Team

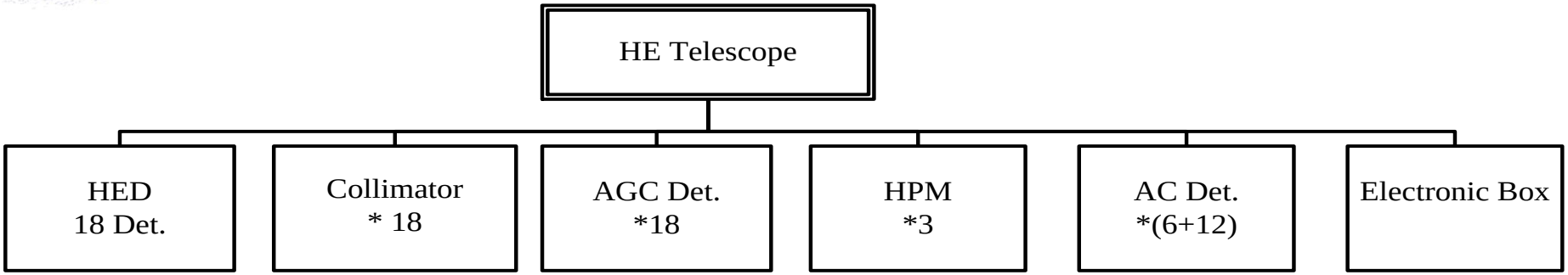
2018-4-9, 13th IACHEC Meeting 2018,Avigliano Umbro (Italy)

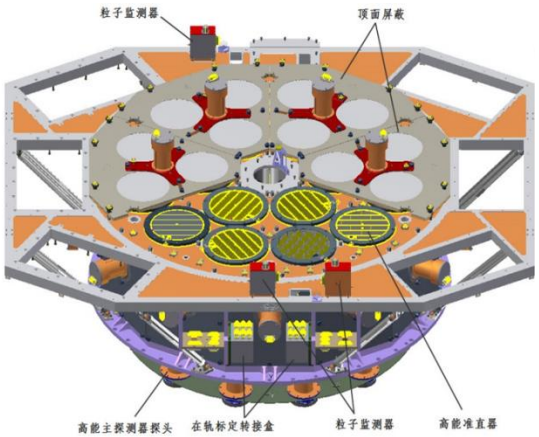
Outlines

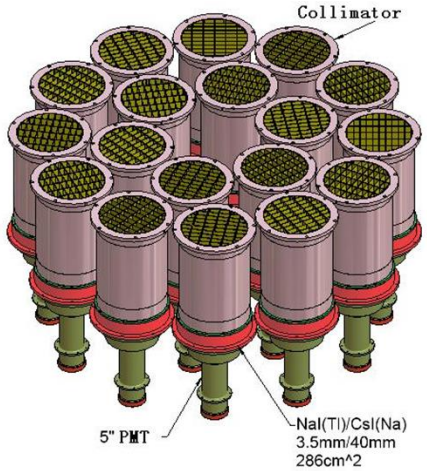
- HE telescope
- Calibration campaigns
  - Calibration at HXCF
  - Calibration with radioactive sources
- Data analysis and results
- Summary

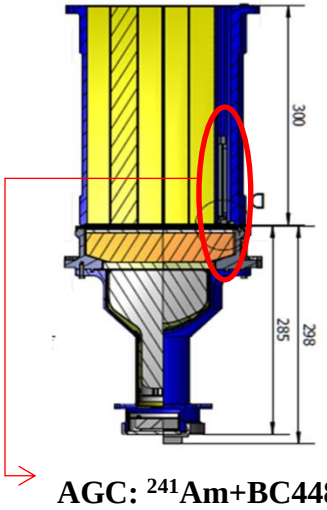
HXMT/HE telescope

Insight-HXMT

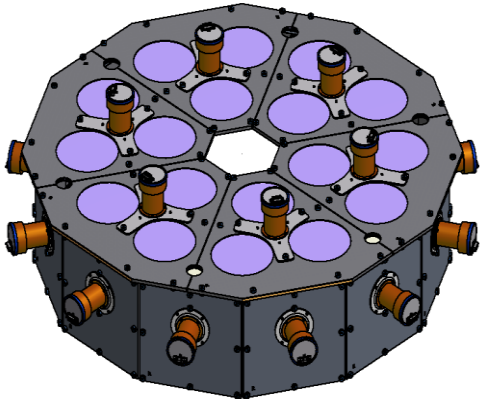








AGC: ^{241}Am+BC448M



HE: Normal Mode:

NaI, 20-250 keV, ~5000 cm^2

CsI, 50-800 keV, ~5000 cm^2

HE: GRB Mode

NaI, 100-800 keV, 5000 cm^2

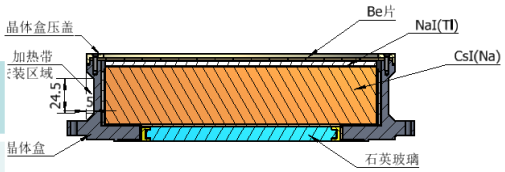
CsI, 250-3000 keV, 5000 cm^2

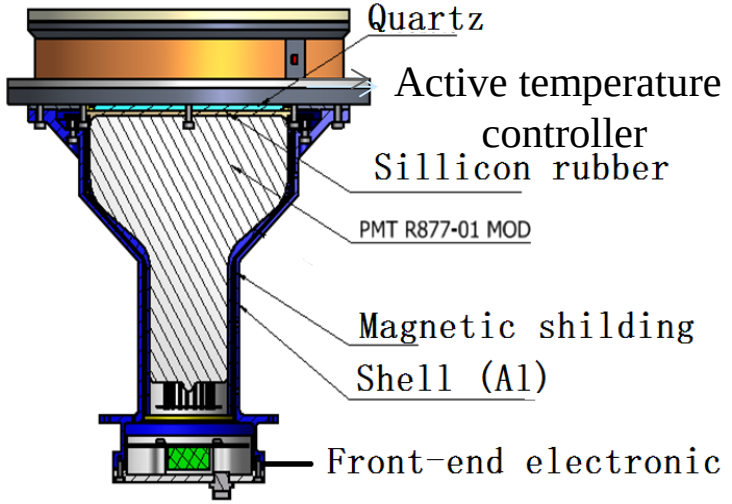
HE detector (HED)

Insight-HXMT

Main design features of HE

Parameter	Value
Detector	18 NaI(Tl)/CsI(NaI) (3.5/40mm) phoswich scintillation detectors
Total detector area	~5000cm^2
Energy range	20~250keV
Energy resolution	≤19%@60keV
Time resolution	≤25us
Field of View （FOV）	15 units 1.1°×5.7°，2 units 5.7°×5.7°，1 unit 1.1×5.7° shielded
Temperature operative range	18±2℃





NaI(Tl): primary detecor
CsI(Na): active sheild and GRB detector
PSD is used

Calibration campaigns

Insight-HXMT

Calibration campaign A:
at the X-ray Calibration Facility of China National institute of Metrology
Monochromator :
Si(220) crystal: X-ray 16.4~168keV

Calibration campaign B:
With radionuclides

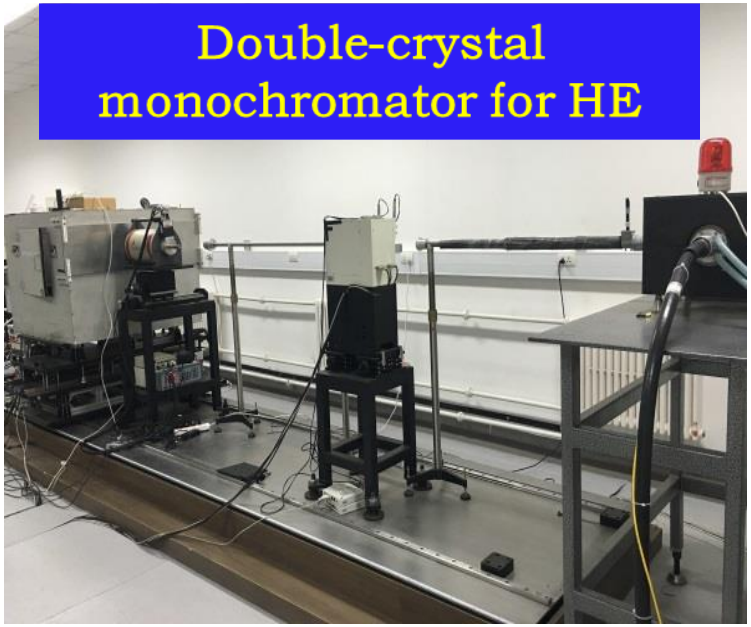
Instruments:
24 HEDs
EQM electronic unit
An EQM AGC
An Anticoincidence simulator

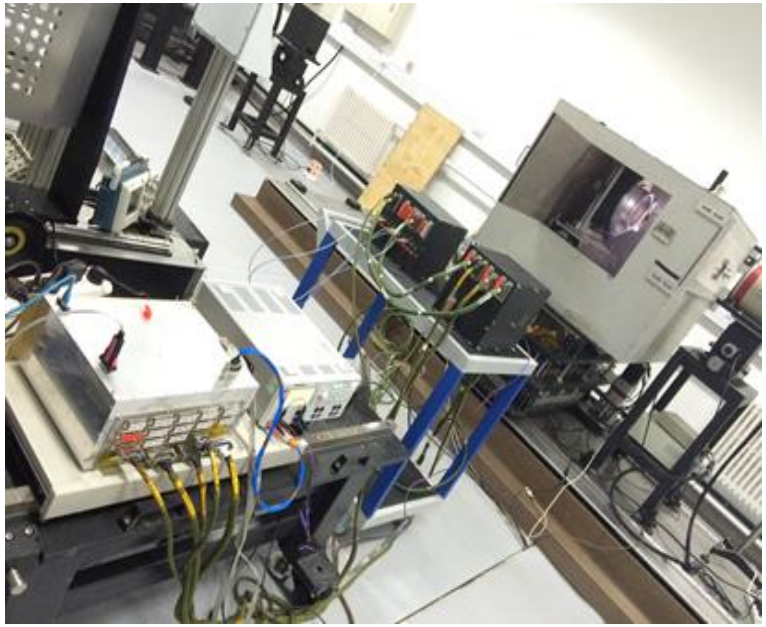
Environment temperature: 18℃

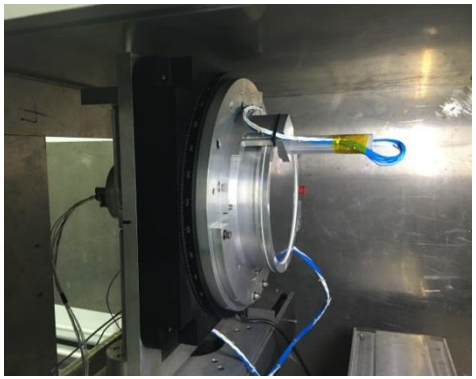
	HED serial Num.	On board No.	Normal operating state		Gamma-ray burst operating state
			Calibration A	Calibration B	Calibration B
Flight module	Z01-1	111a	√	√	√
	Z01-2	111b	√	√	√
	Z01-5	111e	√	√	√
	Z01-6	111f	√	√	√
	Z01-7	111g	√	√	√
	Z01-10	111j	√	√	√
	Z01-12	111m	√	√	√
	Z01-13	111n	√	√	√
	Z01-15	111q	√	√	√
	Z01-16	111r	√	√	√
	Z01-17	111s	√	√	√
	Z01-18	111t	√	√	√
	Z01-20	111d	√	√	√
	Z01-21	111k	√	√	√
	Z01-22	111p	√	√	√
	Z01-23	111h	√	√	√
	Z01-24	111i	√	√	√
	Z01-25	111c	√	√	√
Backup module	Z01-19	—	√	√	√
	Z01-9	—	√	×	√
Others	Z01-4	—	√	×	×
	Z01-8	—	√	√	×
	Z01-11	—	√	×	×
	Z01-14	—	√	√	×

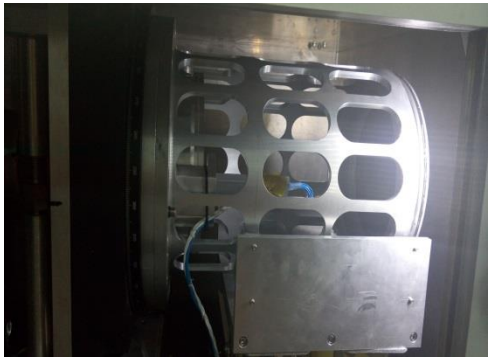
Calibration campaign A

Insight-HXMT





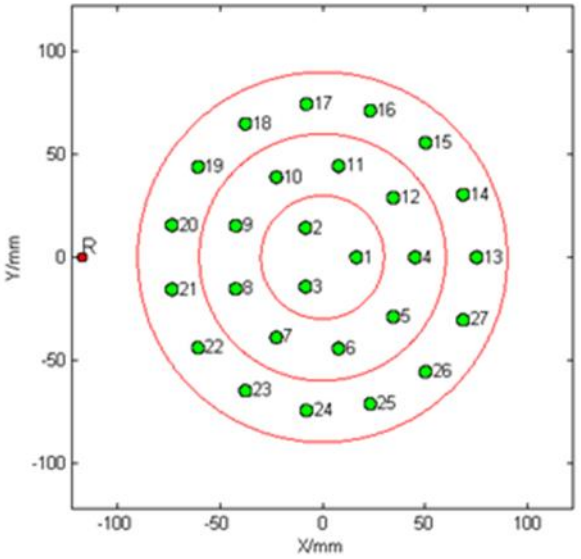




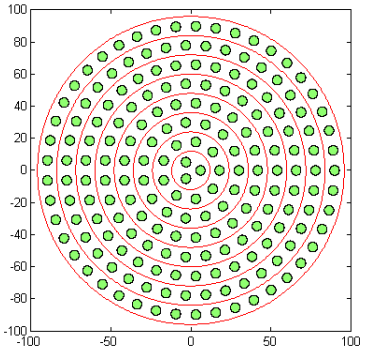
Energy scan

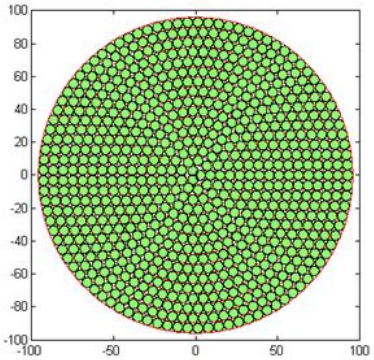
Insight-HXMT

	Energy （keV）	Tube voltage
monochromator in status 1	20、22（for Z01-1 /Z01-2）、24、26、28、	40KV
	30、31、32、32.8、33、34、35、36（except for Z01-5）、37、40、	60KV
	50、62	100KV
monochromator in status 2	50（except for Z01-2）、62、72、	100KV
	80、90、100	140KV
	110、130、150	180KV



Background spectrum in each tube voltage/current state was recorded





Positions scan @ all energies

$$P(E)=\sum_{i=1}^{j-1}P(E,i)+\sum_{i=j+1}^{N}P(E,i)$$

f the position j was sheilded by the AGC detctor

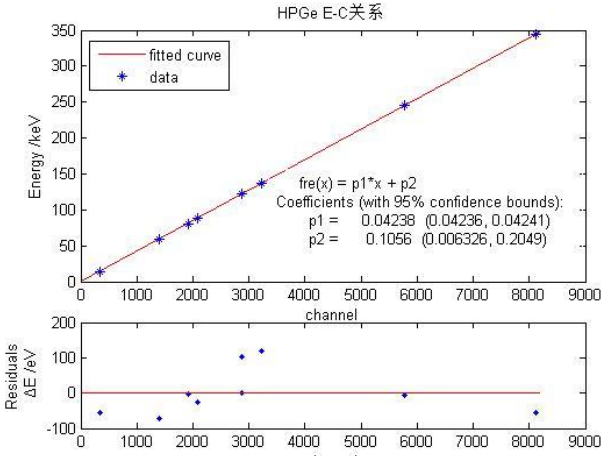
More detailed scan to study the non-uniformity @ 50keV(left: 192，right :768)

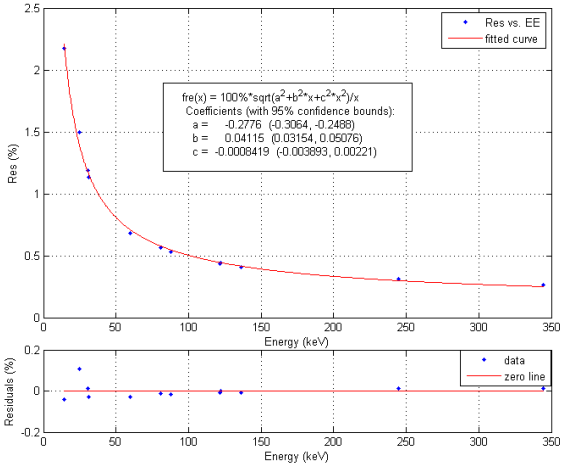
Standard detector-LEGe

Insight-HXMT

E-C and Resolution

nuclide	Energy（keV）
Am-241	26.3446
	59.54
Co-57	14.413
	122.061
	136.474
Eu-152	121.782
	244.697
	344.279
Cd-109	24.9
	88.0336
Ba-133	30.97
	30.67
	81





Intrinsic efficiency

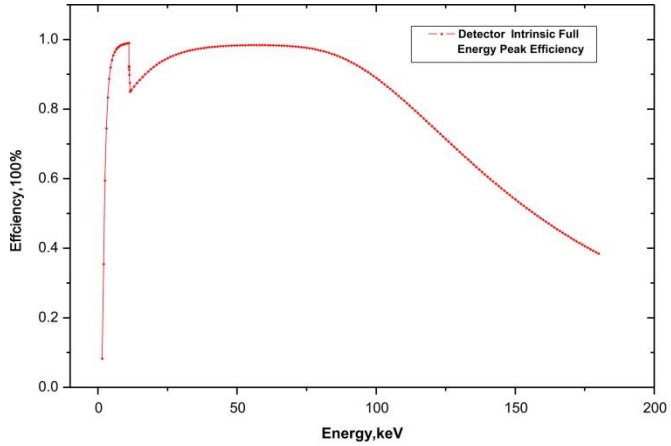


Table 4
Intrinsic FEPE and relative deviation RD(%) between experimental and simulation methods.

Energy (keV)	Experimental Intrinsic FEPE $\varepsilon_{ins}(E_i, d_2) \times 10^{-1}$	Simulation Intrinsic FEPE $\varepsilon_{ins}(E_i, \infty) \times 10^{-1}$	RD(%)
14.41	8.76 (15)	8.780 (9)	−0.28
22.08	9.29 (10)	9.329 (10)	−0.47
59.54	9.78 (9)	9.838 (10)	−0.52
88.03	9.46 (11)	9.481 (10)	0.04
122.06	7.26 (9)	7.388 (9)	−1.8
136.47	6.34 (10)	6.335 (8)	0.07

Liu Haoran，et al
Applied Radiation and Isotopes 109（2016）：551-554

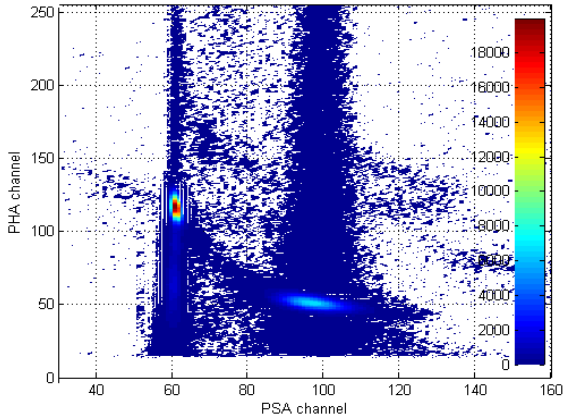
Calibration campaign B

	No.	nuclide	Half-life	Energy（keV）	Intensity (%)	activity （Bq）	uncertainty （k=2）	Data of test
Normal mode	1	Ce-139	137.641d 20	165.8575 11	80 % 8	3.004×10^{5}	3.00%	2015.10.16
	2	Ba-133	10.551y 11	80.9979 11	32.9 % 3	1.188×10^{6}	3.50%	2015.10.15
				356.0129 7	62.05%			
	3	Co-57	271.74d 6	122.06065 12	85.60 % 17	8.699×10^{5}	3.00%	2015.10.13
				136.47356 29	10.68 % 8			
	4	Am-241	432.6y 6	59.5409 1	35.9 % 4	8.089×10^{5}	3.70%	2015.10.26
	5	Cd-109	461.40d 12	88.0336 1	3.70 % 10	6.184×10^{5}	3.00%	2015.11.13
GRB mode	1	Cs137	30.08y 9	661.657 3	85.10 % 20	2.233×10^{6}	2.50%	2015.10.13
	2	Sn113	115.09d 3	391.698 3	64.97 % 17	1.519×10^{6}	3.00%	2015.11.17
	3	Co60	1925.28d 14	1173.228 3	99.85 % 3	4.729×10^{5}	3.00%	2015.11.17
				1332.492 4	99.9826 % 6			
	4	Y-88	106.627d 21	898.042 3	93.7 % 3	7.697×10^{4}	3.00%	2015.11.17
				1836.063 12	99.2 % 3			
	5	K-40 （from BKG）		1460.833 6	10.66 % 18			

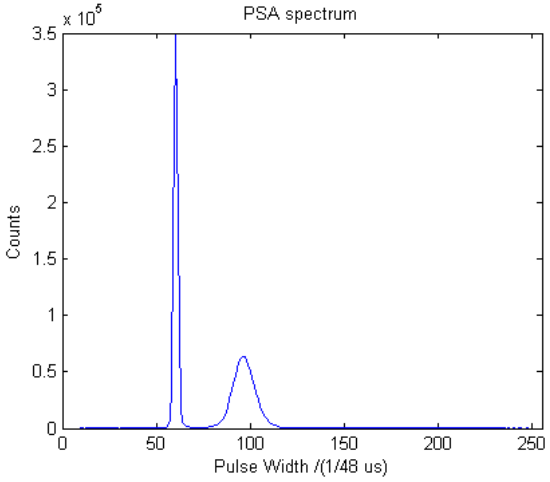
Data analysis and results

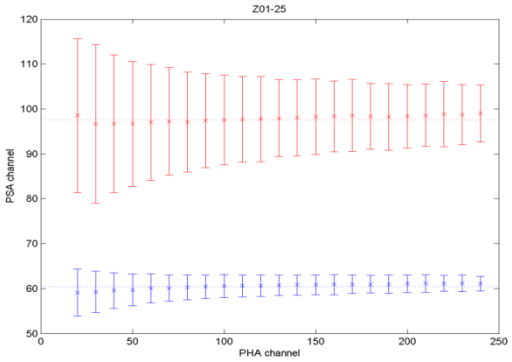
Insight-HXMT

Pulse shape discrimination



PHA versus PSA for monochromatic light at 150keV





Position of the pulse shape peaks of NaI and CsI crystals as a function of the pulse height channel as derived from background measurements during radioactive sources calibration campaign with HED Z01-25. One error bar is equal to one FWHM of each PSA peak.

The figure of merit: $A = \dfrac{PW_{CsI} - PW_{NaI}}{FWHM_{CsI} + FWHM_{NaI}}$

A of all FM HEDs： 2.6~3.0

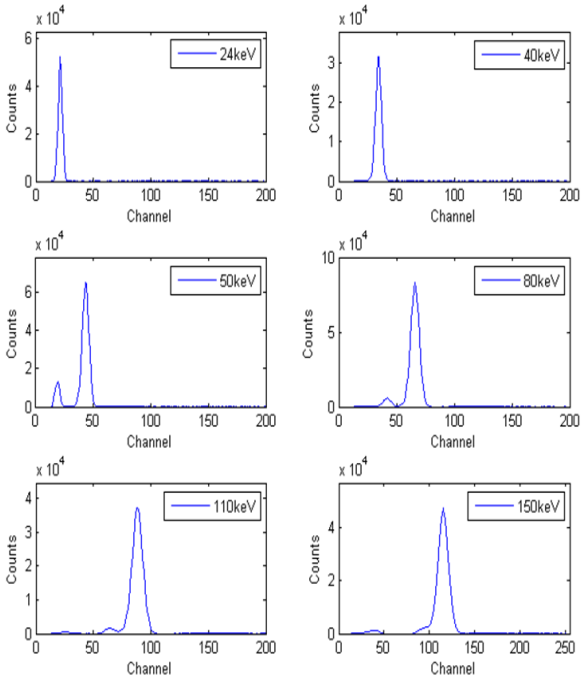
PSD :

53<PS(NaI)<=70

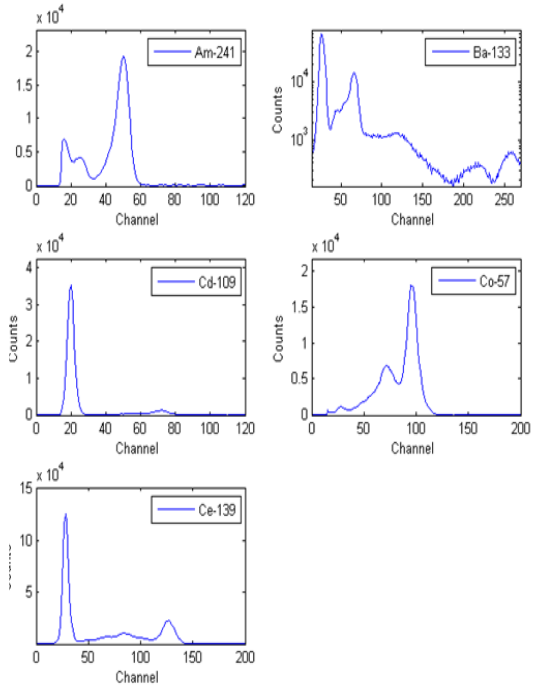
80=< PS(CsI)<120

Data analysis——spectra

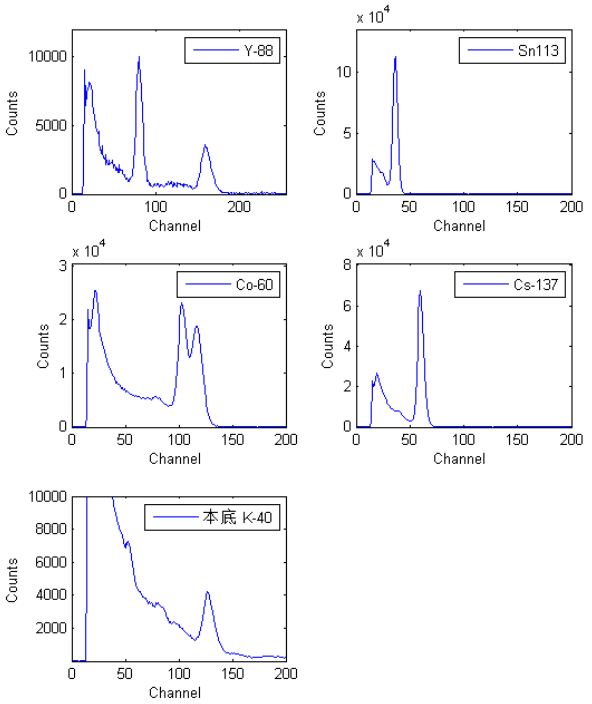
Insight-HXMT



(a) NaI- monochromatic light



(b) NaI- radioactive source



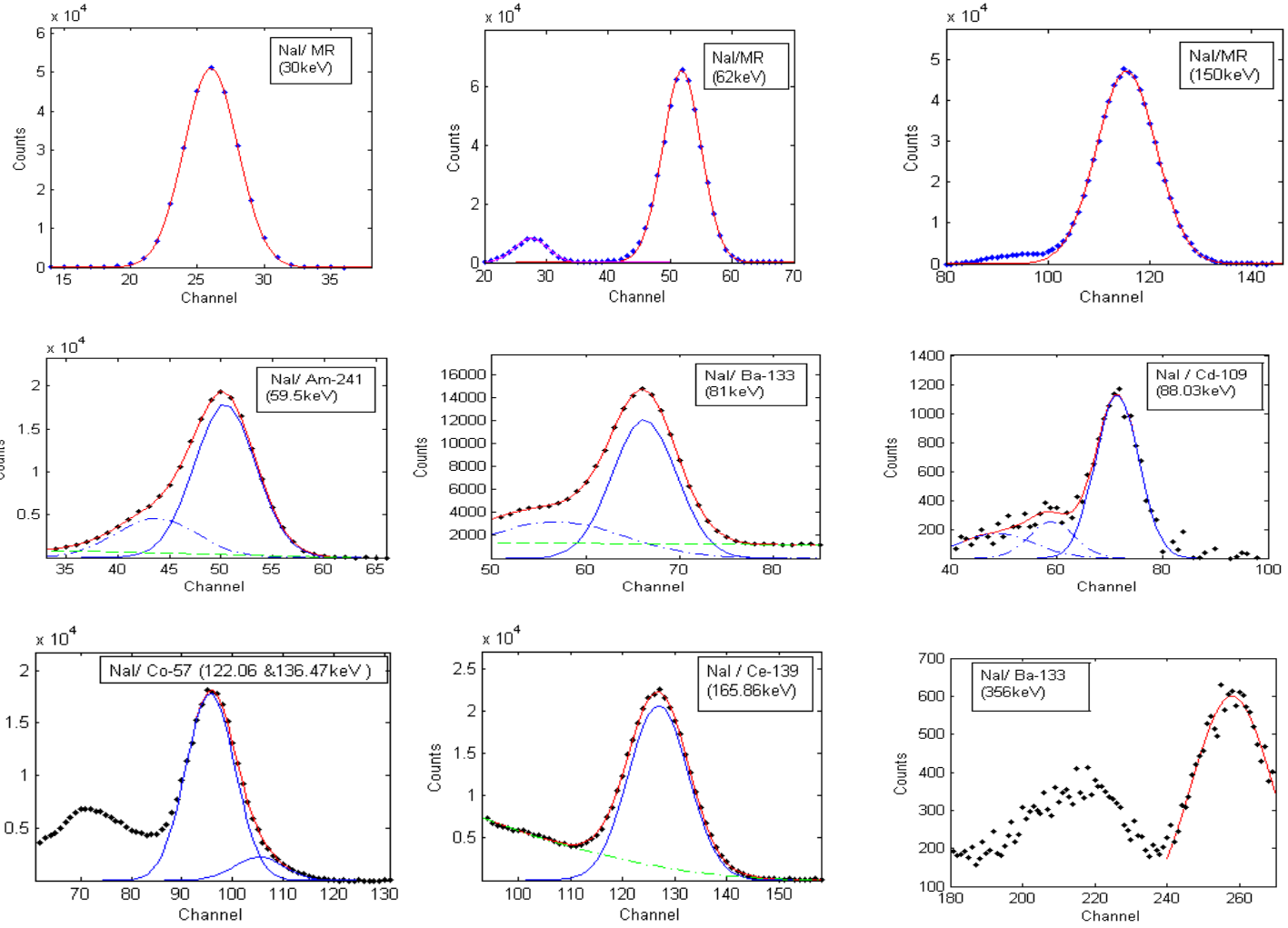
(c) CsI-radioactive source

Normalized background-subtracted spectra (Z01-25)

Normal mode

NaI full-energy peak analysis

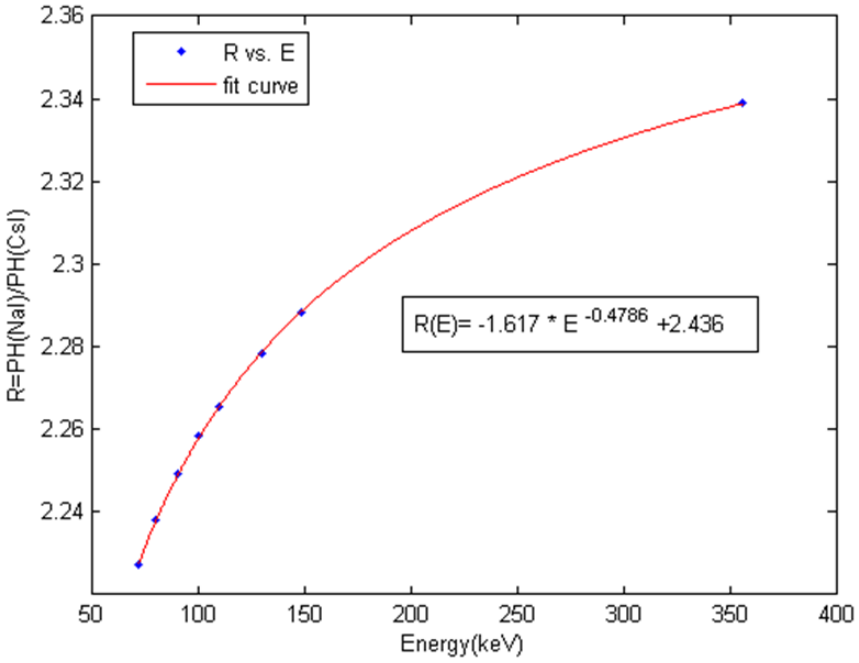
Insight-HXMT

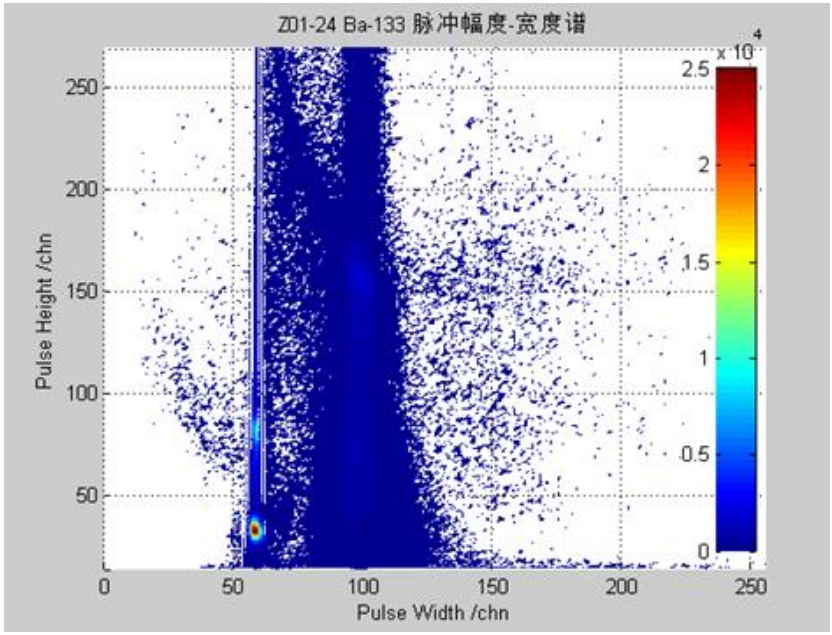


The 356keV (^{133}Ba) pch determination

Problem： for two HEDs the 356keV line just beyond the upper threshold

Solution: $R=\frac{PH(NaI)}{PH(CsI)}$





Calibration range： 20keV~356keV

Consistency for each HED

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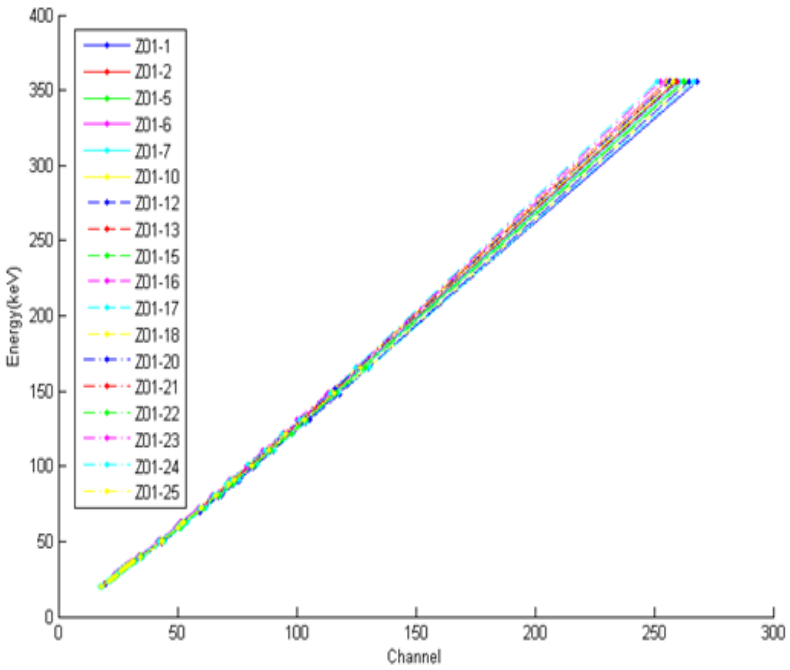
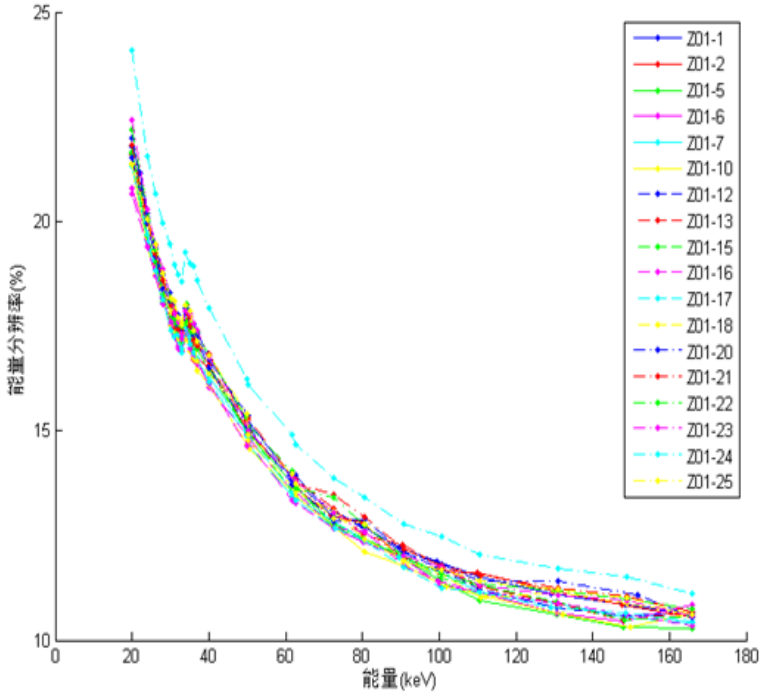
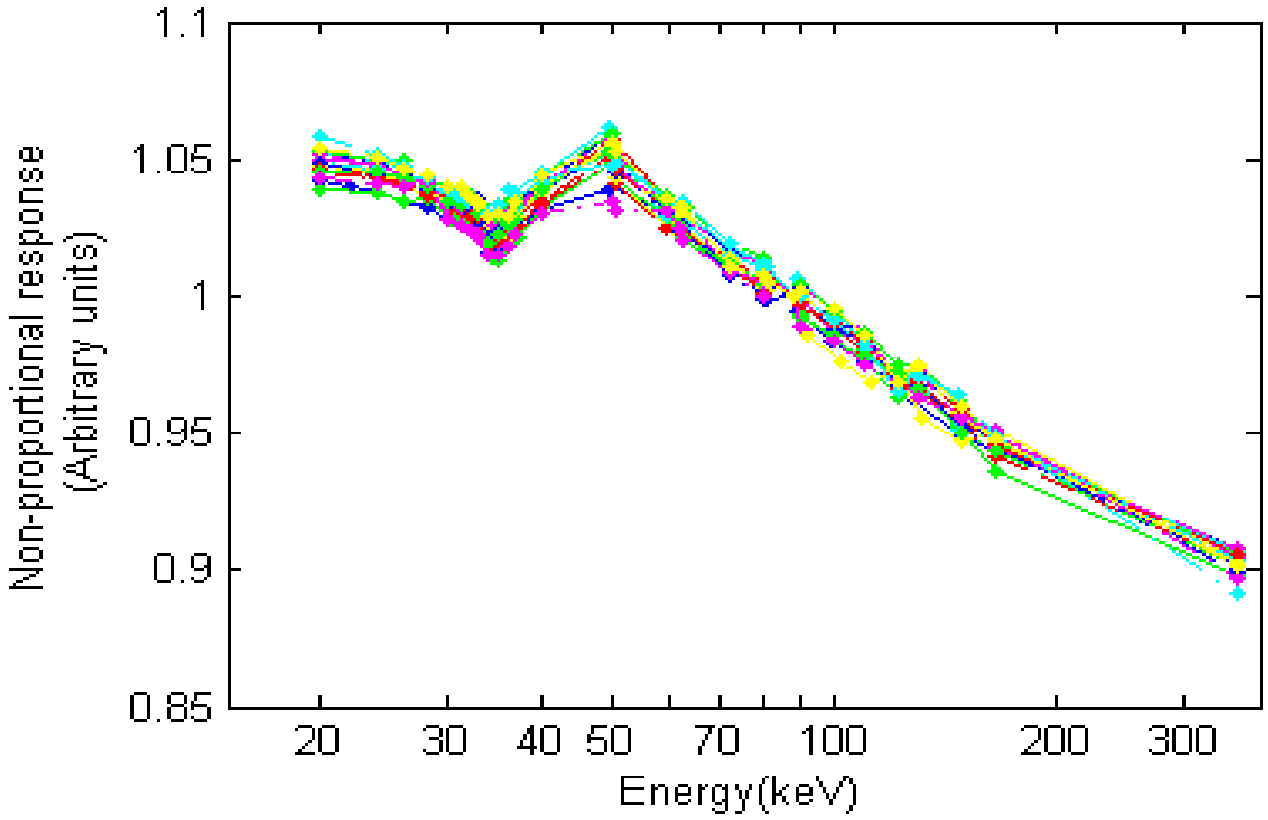




Non-proportional response of NaI

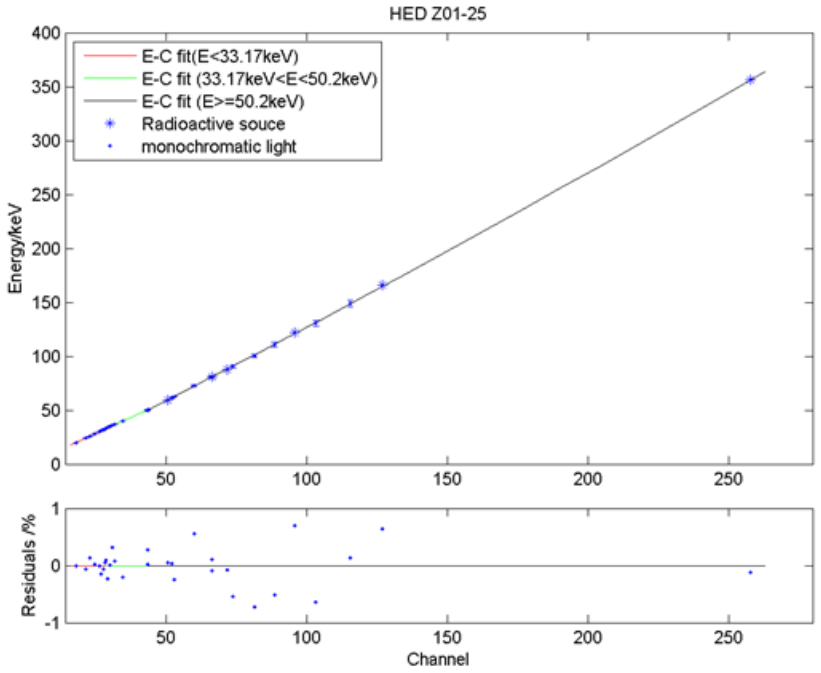


The Photopeak-nPR of each FM HED as a function of photon energy, normalized to unity at 88.03keV

NaI(Tl) Energy response

Insight-HXMT

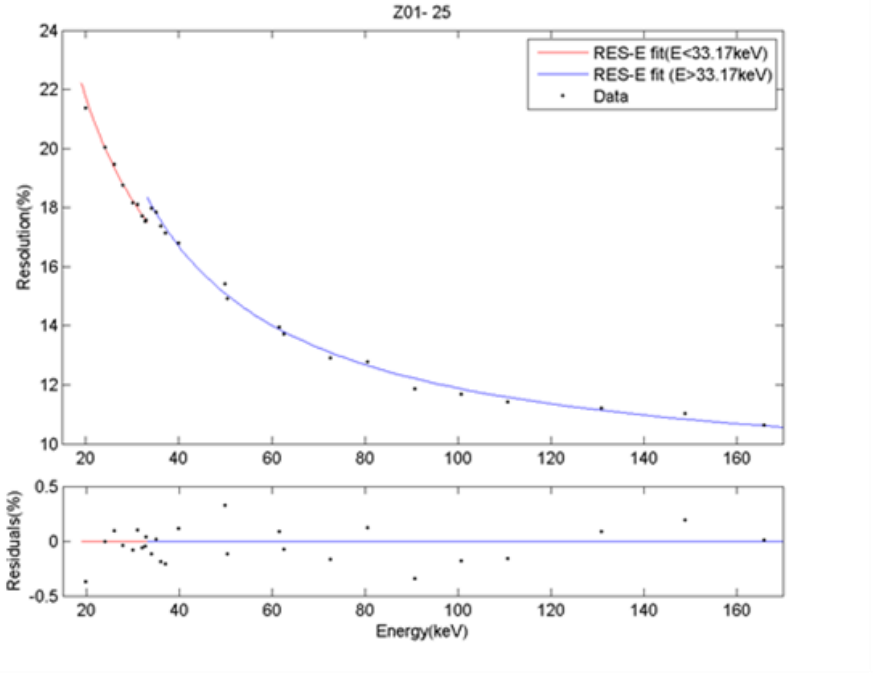
Energy-Channel relationship



$$E(ch)=p_1\,ch^2+p_2\,ch+p_3$$

$$E_{escape}=E(pch)-E(\Delta ch+step)$$

Resolution-Energy relationship



$$R_1=\frac{FWHM}{pch}\times 100\% \qquad R=\sqrt{R_1^2-\eta^2}$$

$$Res(E)=\frac{\sqrt{a^2+b^2E+c^2E^2}}{E}\times 100\%$$

Crystal geometric dimensioning

Insight-HXMT

Module of electronic unit	No.	Code No. of HED on board	HED Serial No.	Crystal No.	Diameter / mm		Thickness /mm		Geometric area /cm²	
					NaI(Tl)	CsI(Na)	NaI(Tl)	CsI(Na)	NaI(Tl)	CsI(Na)
A	1	111a	Z01-1	#31	190.13	190.23	3.58	38.95	283.8	284.1
	2	111b	Z01-2	#32	190.31	190.31	3.5	39.26	284.3	284.3
	3	111c	Z01-25	#38	189.89	190.05	3.6	39.28	283.1	283.5
	4	111d	Z01-20	#48	189.69	190.3	3.48	38.48	282.5	284.3
	5	111e	Z01-5	#33	189.44	190.3	3.51	38.88	281.7	284.3
	6	111f	Z01-6	#35	190.04	190.45	3.59	38.9	283.5	284.7
B	1	111g	Z01-7	#36	190.02	190.42	3.59	39.02	283.4	284.6
	2	111h	Z01-23	#53	190.13	190.3	3.65	39.06	283.8	284.3
	3	111i	Z01-24	#51	190.35	190.45	3.53	39.33	284.4	284.7
	4	111j	Z01-10	#41	189.89	190.04	3.57	39.36	283.1	283.5
	5	111k	Z01-21	#50	190.04	190.41	3.48	39.12	283.5	284.6
	6	111m	Z01-12	#43	189.35	190.31	3.6	39.21	281.4	284.3
C	1	111n	Z01-13	#44	189.95	190.07	3.51	39.12	283.2	283.6
	2	111p	Z01-22	#52	189.88	190.34	3.65	39.45	283.0	284.4
	3	111q	Z01-15	#46	189.9	190.41	3.51	38.94	283.1	284.6
	4	111r	Z01-16	#47	189.84	190.31	3.58	38.14	282.9	284.3
	5	111s	Z01-17	#54	189.83	190.37	3.6	38.94	282.9	284.5
	6	111t	Z01-18	#55	189.96	190.36	3.56	38.98	283.3	284.5
Total area/cm²									5096.9	5117.1

Peak efficiency

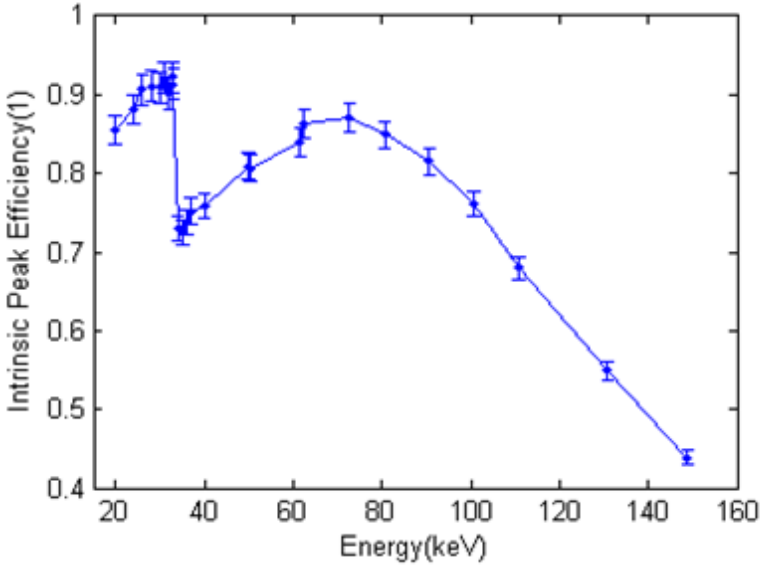
Insight-HXMT

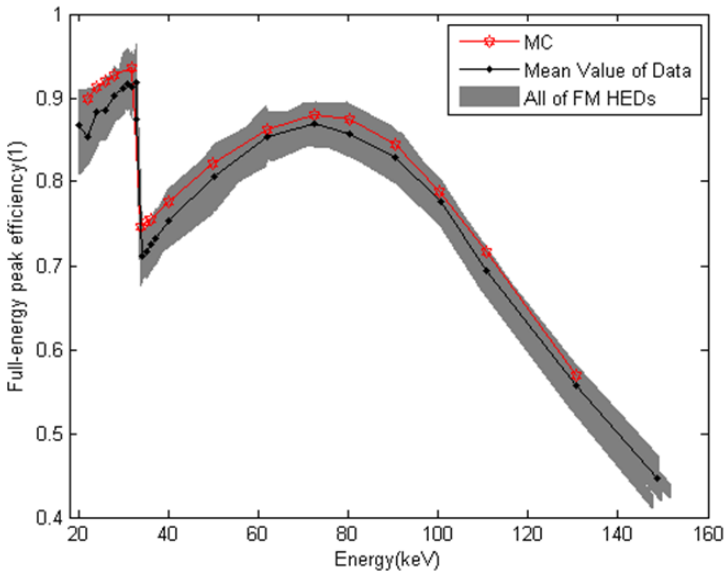
$$\varepsilon_{inp}(E_X)=\frac{n(E_X)}{I(E_X)\cdot\kappa_I}=\frac{n(E_X)\cdot\varepsilon_{HPGe}(E_X)}{n_{HPGe}(E_X)\cdot\kappa_I}$$

$$\sigma_{eff(E_n)}=eff(E_n)\times\sqrt{\left(\frac{\sigma_{n_1(E_n)}}{n_1(E_n)}\right)^2+\left(\frac{\sigma_{I(En)}}{I(E_n)}\right)^2+\left(\frac{\sigma_{\kappa_I}}{\kappa_I}\right)^2}$$

$$\sigma_{I(E_n)}=I(E_n)\times\sqrt{\left(\frac{\sigma_{n(E_n)}}{n(E_n)}\right)^2+\left(\frac{\sigma_{eff_0(En)}}{eff_0(E_n)}\right)^2}$$

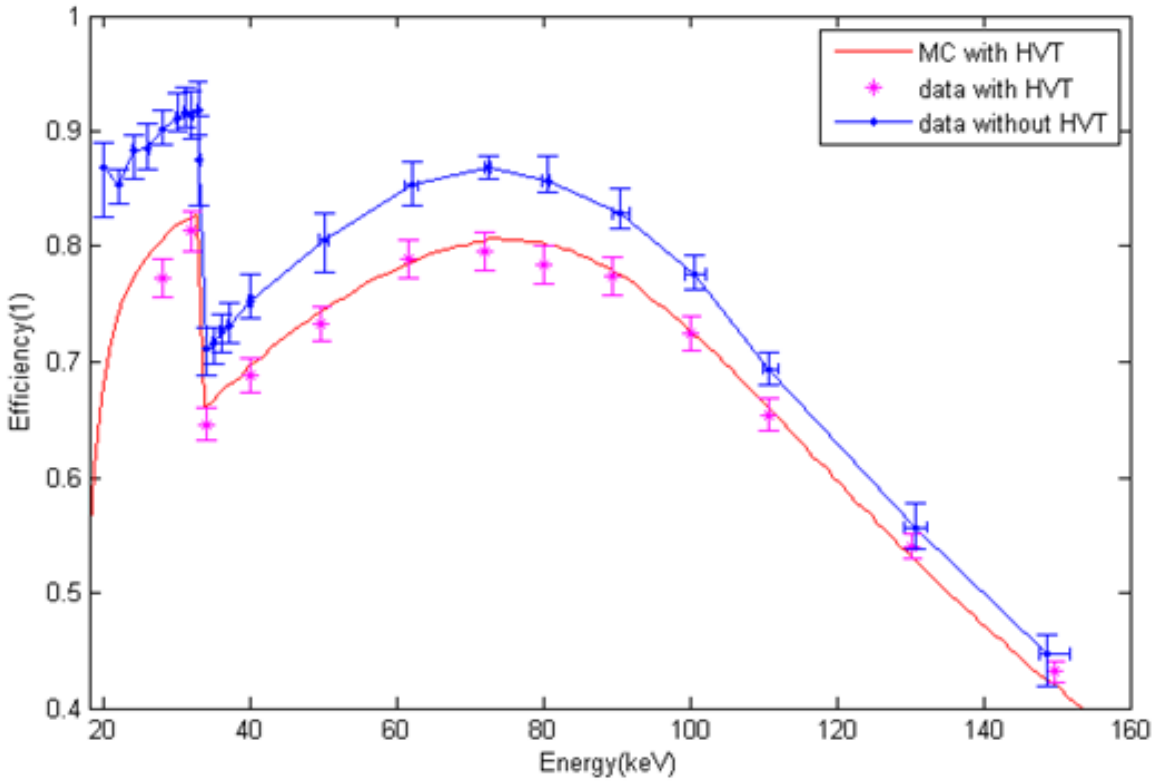
$$\left(\frac{\sigma_{eff_0(En)}}{eff_0(E_n)}\right)=1.8\%\qquad\frac{\sigma_{\kappa_I}}{\kappa_I}=1\%$$





NaI(Tl) full-peak efficiency

The effect of ACD detector on efficiency



Spatial uniformity of HED

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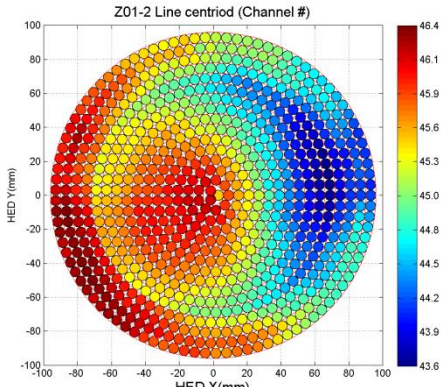

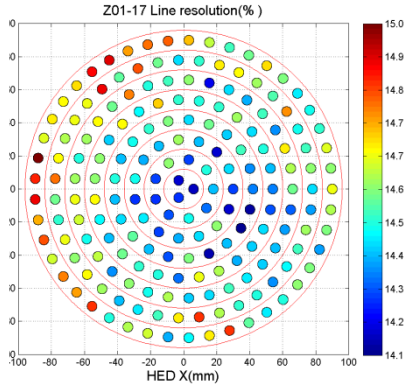

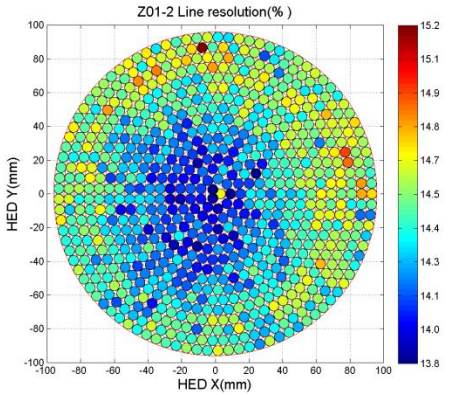

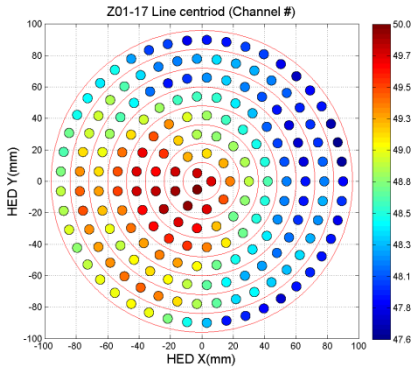

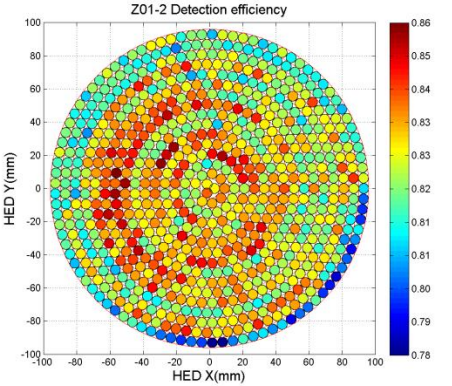

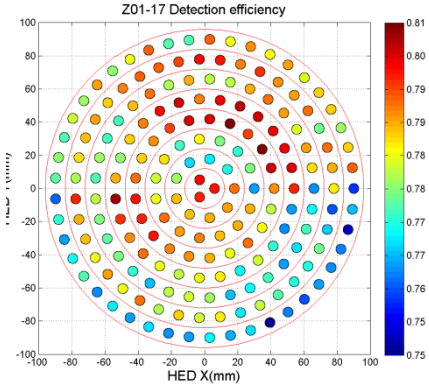

Serial Num.	Line centriod		Resolution		Peak efficiency	
	$\frac{max-min}{max+min}$	RSD	$\frac{max-min}{max+min}$	RSD	$\frac{max-min}{max+min}$	RSD
Z01-1	0.031	1.41%	0.042	1.60%	0.059	1.91%
Z01-2	0.031	1.50%	0.047	1.40%	0.046	1.44%
Z01-5	0.024	1.04%	0.037	1.32%	0.029	1.31%
Z01-6	0.039	1.69%	0.036	1.36%	0.036	1.37%
Z01-7	0.029	1.55%	0.038	1.66%	0.031	1.41%
Z01-10	0.028	1.46%	0.042	1.88%	0.035	1.53%
Z01-12	0.027	1.39%	0.052	1.97%	0.045	1.77%
Z01-13	0.027	1.55%	0.033	1.48%	0.036	1.58%
Z01-15	0.031	1.42%	0.037	1.42%	0.036	1.35%
Z01-16	0.030	1.35%	0.039	1.52%	0.042	1.58%
Z01-17	0.025	1.26%	0.031	1.17%	0.038	1.53%
Z01-18	0.037	1.73%	0.040	1.61%	0.040	1.52%
Z01-19	0.053	1.87%	0.099	3.73%	0.043	1.67%
Z01-20	0.029	1.48%	0.030	1.28%	0.038	1.53%
Z01-21	0.029	1.70%	0.041	1.73%	0.053	2.20%
Z01-22	0.035	1.67%	0.028	1.04%	0.055	2.19%
Z01-23	0.034	1.65%	0.044	1.65%	0.028	1.15%
Z01-24	0.027	1.02%	0.029	1.08%	0.035	1.36%
Z01-25	0.044	1.75%	0.104	2.38%	0.030	1.13%

CsI calibration

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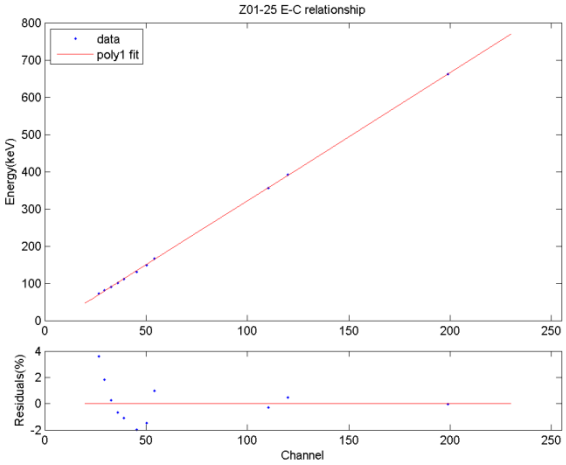
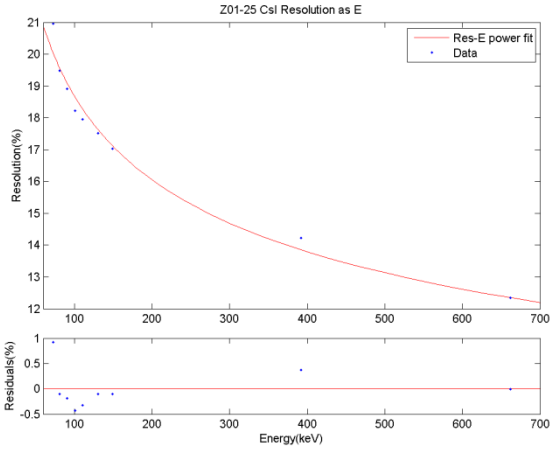
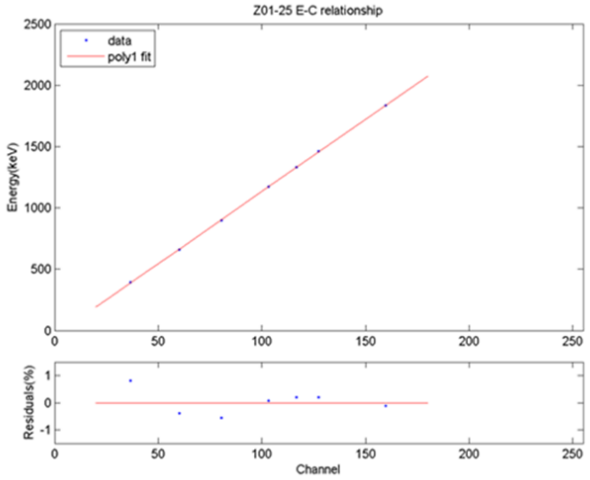
Norm Mode

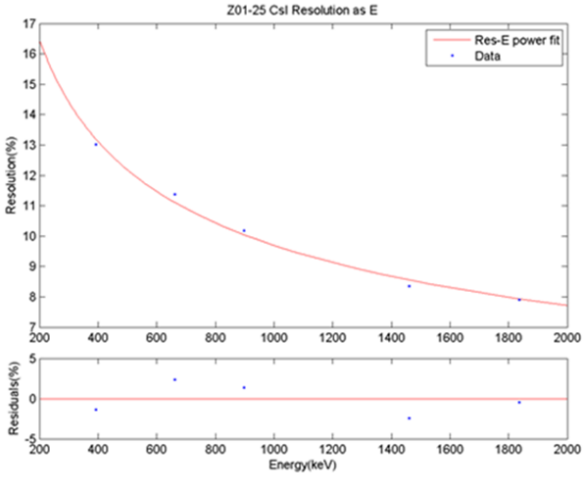




$E\ (ch) = p_1 ch + p2$

GRB mode





$Res(E) = a\ E^{b}\ 100\%$

Energy range

Insight-HXMT

Normal mode Energy range

HEDnum	NaI(Tl) （keV）		CsI(NaI) (keV)	
	E@15 ch	E@ 255	E@15 ch	E@ 255
Z01-1	16.3	338.2	25.8	880.1
Z01-2	16.6	350.1	30.0	849.5
Z01-5	16.7	346.3	28.6	860.6
Z01-6	16.9	356.6	27.5	814.6
Z01-7	16.6	348.1	26.2	806.2
Z01-10	16.3	342.6	27.3	797.0
Z01-12	16.2	342.1	28.5	826.4
Z01-13	16.8	353.9	26.2	812.1
Z01-15	16.7	351.0	27.1	844.9
Z01-16	16.6	349.2	28.0	829.0
Z01-17	16.2	340.0	26.4	805.3
Z01-18	16.9	356.0	29.8	862.7
Z01-19	16.3	341.5		
Z01-20	16.8	354.0	27.9	823.4
Z01-21	16.7	350.2	32.8	874.2
Z01-22	16.5	345.4	29.0	820.4
Z01-23	17.2	359.9	29.4	846.6
Z01-24	16.7	361.9	26.8	807.0
Z01-25	16.6	351.9	29.3	854.7

GRB mode Energy range

HEDnum	CsI(Na) energy range（keV）	
	E @ 15 channel	E @ 255 channel
Z01-1	135	2965
Z01-2	136	2976
Z01-5	137	2947
Z01-6	136	2954
Z01-7	136	2955
Z01-10	134	2960
Z01-12	137	2943
Z01-13	134	2959
Z01-15	135	2956
Z01-16	134	2960
Z01-17	133	2958
Z01-18	135	2954
Z01-19	134	2961
Z01-20	134	2963
Z01-21	134	2975
Z01-22	133	2967
Z01-23	134	2973
Z01-24	134	2957
Z01-25	134	2958

Summary

Insight-HXMT

- All of FM HEDs were calibrated with X-ray beam and radioactive sources.
- The E-C relations, energy resolutions and detection efficiencies of the single HEDs were determined, and their performances meet the design requirements.
- When the nPR of electronic was employed, the simulated spectrum can be well fitted with the one of the experiment.
- The results of on-ground calibration have directly or indirectly contributed to the in-flight RMF and ARF determination.

Thank you for your attention