High Energy Response of TIGRESS detectors

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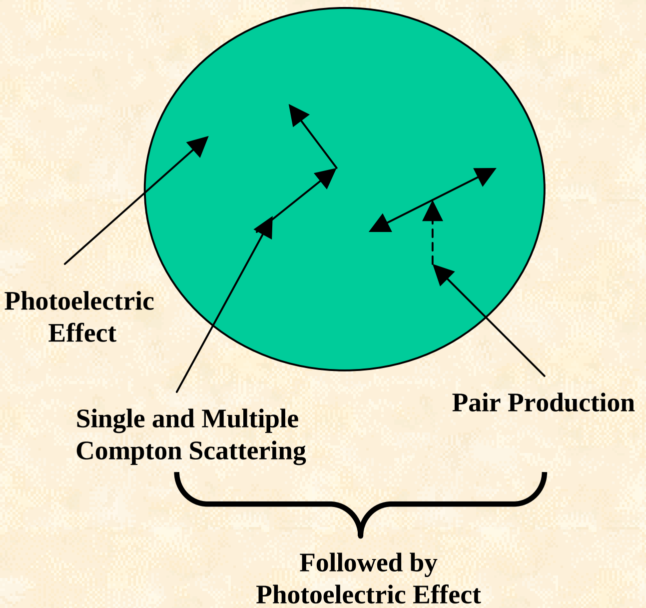
How does a composite detector work ?

Gamma-ray (Eγ = 100 keV – 10 MeV) interacts with matter primarily by
- **Photoelectric Effect**
- **Compton Scattering**
- **Pair Production**

Very large detector - Only Full Energy peak

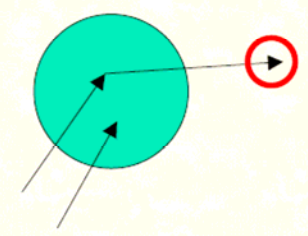


Detectors larger than 7 cm difficult to fabricate
Large Doppler broadening

Conventional detectors

Full ϒ-ray energy is deposited by

full absorption in the detector (single hit event)



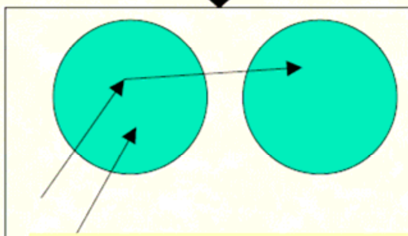
Full Energy peak + Background from Compton scattered γ-rays + Escape peaks

Solution

Full ϒ-ray energy is deposited by

full absorption in any one of the individual crystals (single hit event)

full absorption in two or more crystals (multiple hits event)



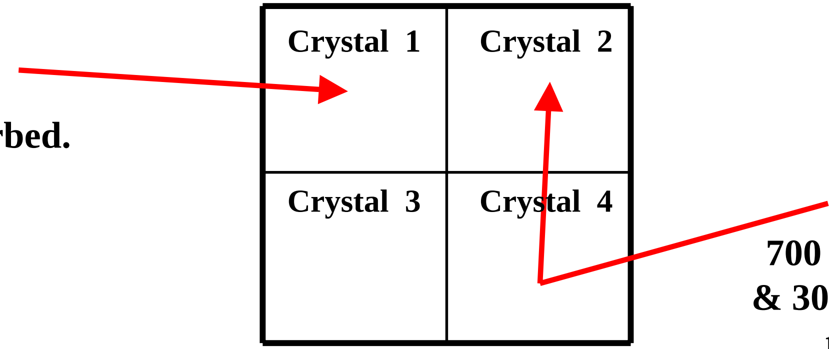
Escaped γ-rays can be got back !!

Composite detectors

Prog. Part. Nucl. Phys. 28 (1992) 495
Nucl. Instr. Meth. A 432 (1990) 90

Case 1

1 MeV absorbed.



Case 2

700 keV absorbed & 300 keV scattered to crystal 2.

Case	Time uncorrelated sum of data from four crystals (Single Crystal mode) only single hit events contribute to full energy peak (FEP)	Time correlated sum of data from four crystals (Addback mode) single & multiple hit events contribute to FEP
1	Fully absorbed	Fully absorbed
3	Both 300 & 700 keV γ-rays observed. Single event contributes to background.	300 + 700 = 1 MeV γ-ray **Event Reconstructed**

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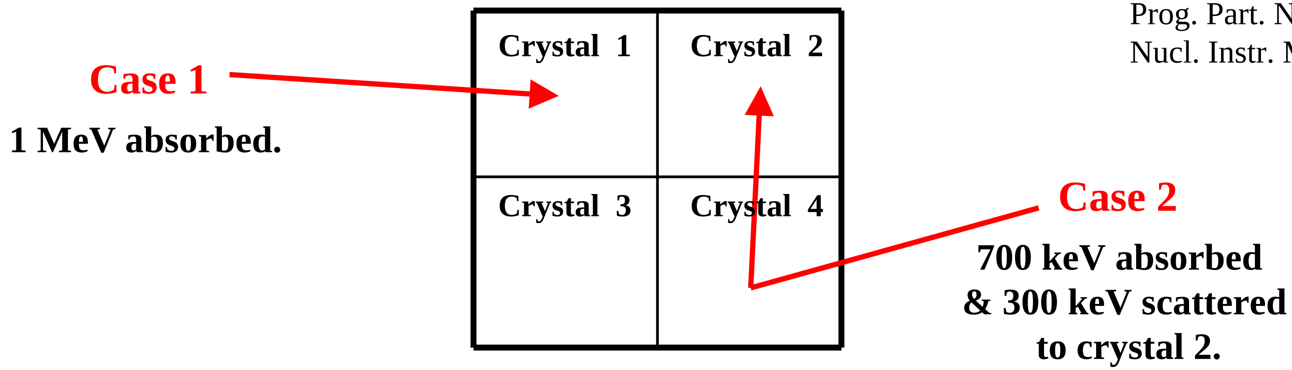


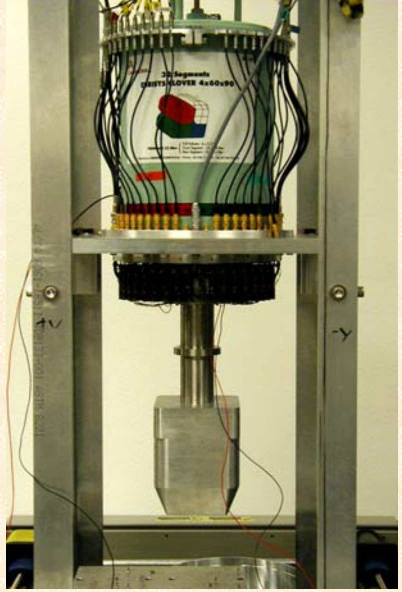
Case	Time uncorrelated sum of data from four crystals (Single Crystal mode) only single hit events contribute to full energy peak (FEP)	Time correlated sum of data from four crystals (Addback mode) single & multiple hit events contribute to FEP
1	Fully absorbed	Fully absorbed
2	Both 300 & 700 keV γ-rays observed. Single event contributes to background.	300 + 700 = 1 MeV γ-ray **Event Reconstructed**

Measure of enhancement by addback is given by:

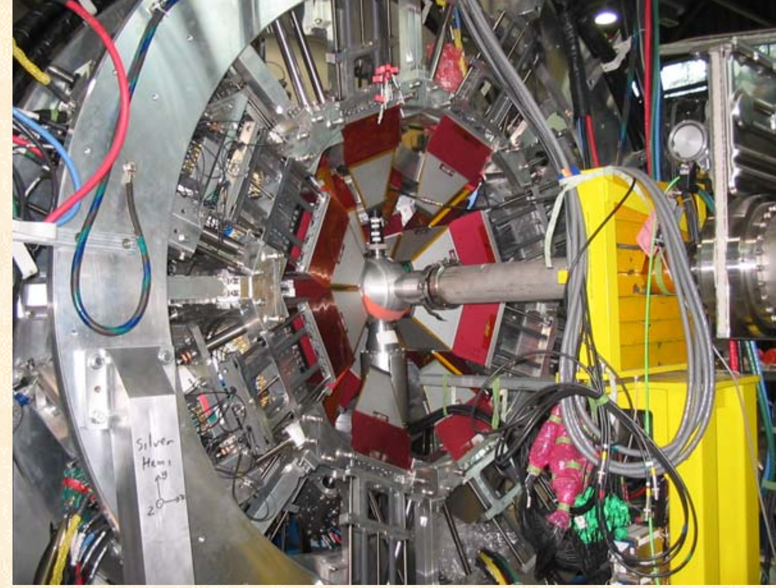
Addback Factor at $E_\gamma = E_0$, $F = \varepsilon_{addback} / \varepsilon_{sc}$

$$= \frac{\text{No. of single + multiple fold events that contribute to FEP at } E_\gamma = E_0}{\text{No. of single fold events that contribute to FEP at } E_\gamma = E_0}$$

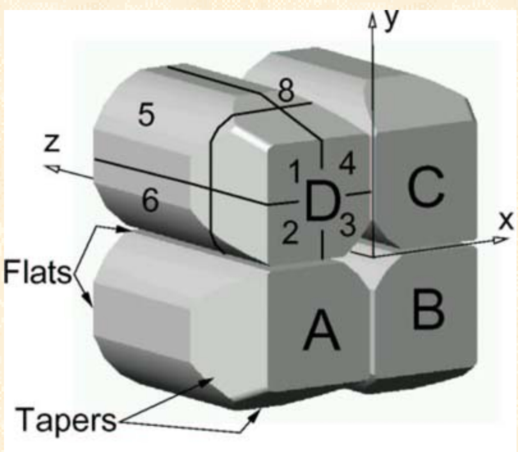
TRIUMF
ISAC
Gamma
Ray
Escape
Suppressed
Spectrometer



32-Fold Segmented HPGe Clover Detector



Current configuration – 12 detectors,
Full configuration – 16 detectors.



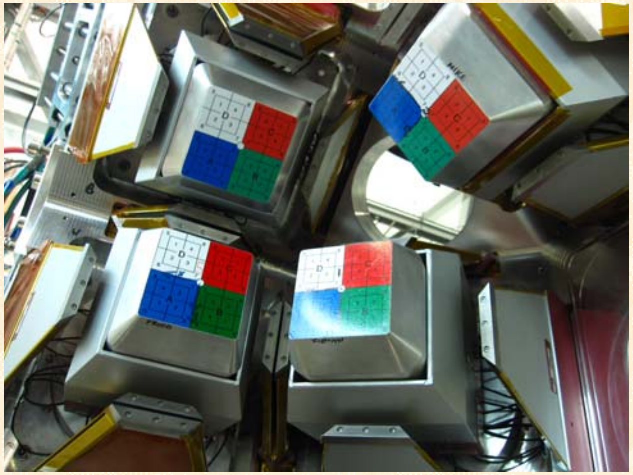
Four HPGe crystals close-packed in a four-leaf clover geometry. 32-fold segmentation of the outer contacts provide position resolution with waveform analysis by fast digitizers. The enhanced position sensitivity achieved through the segmentation of the crystals allows for accurate Doppler correction of gamma-ray spectra.

TRIUMF
ISAC
Gamma
Ray
Escape
Suppressed
Spectrometer

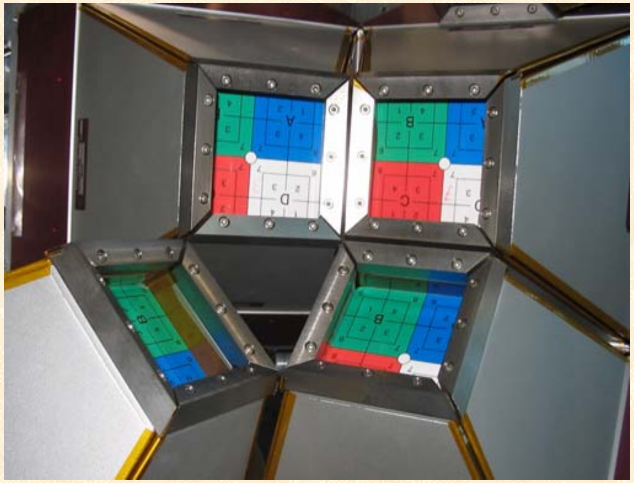
Each detector is shielded by a 20-fold segmented escape suppression shield – front shield (8) + side catcher (8) + back catcher (4).

In order to provide the best possible peak-to-total ratio and detection efficiency for a particular experiment, an element of flexibility has been incorporated into the array's design.

Forward or high efficiency configuration:
d = 11 cm, no front shield.



Backward or optimised peak-to-total configuration: d = 14.5 cm.



Why characterize - why need efficiency for higher energies ?

For performing discrete gamma-ray spectroscopy of light mass nuclei with TIGRESS, we need information about the full energy peak (FEP) efficiency for high energy gamma-rays. For example, the transition from the first 2^+ excited state to the ground state in ^{16}O has an energy of 6917 keV. However, suitable radioactive sources that emit gamma-rays of energies greater than ~ 3.5 MeV are not easily available. For such cases, the response of gamma spectrometers at higher energies are usually determined from simulation data.

Predictions from GEANT4 simulations (experimentally validated from 0.3 to 3 MeV) indicate that TIGRESS will be capable of detecting single 10 MeV gamma-rays with an absolute detection efficiency of 1.5% for the optimized peak-to-total configuration of the array [NIMA 570 (2007) 437].

It is essential to experimentally check the simulation results for energies above 3.5 MeV.

How to characterise - preparing radioactive source through decay

Up to 1.4 MeV

^{152}Eu – 122 keV < E_γ < 1408 keV

Up to 3.5 MeV

^{56}Co – 847 keV < E_γ < 3548 keV

Up to 8 MeV

β– Decay of ^{11}Be ($\tau_{1/2}$ = 13.8 sec)

γ-ray energy	Relative Intensity
692.31 (10)	0.097 (3)
1185.98	< 0.011
1171.31 (30)	0.740 (40)
2124.473(27)	100.000
2346.64	< 0.007
2895.30 (40)	0.227 (8)
2957.10	< 0.01
3532.34	< 0.007
4443.90 (50)	0.153 (8)
4665.90 (40)	5.115 (140)
5018.98 (40)	1.316 (46)
5851.47 (42)	6.006 (240)
6789.81 (50)	12.618 (620)
7282.92	< 0.17
7974.73	5.342 (400)

Phys. Rev. C 26 (1982) 1176

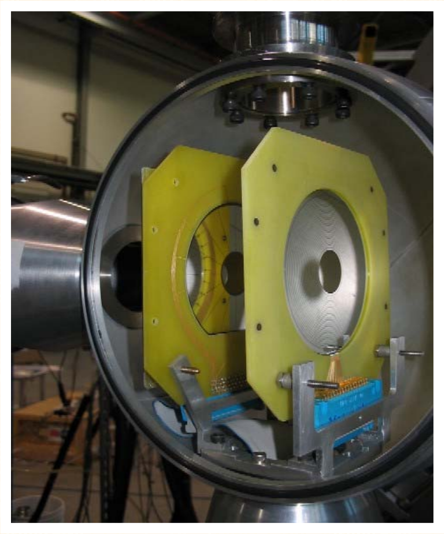
Experimental set up

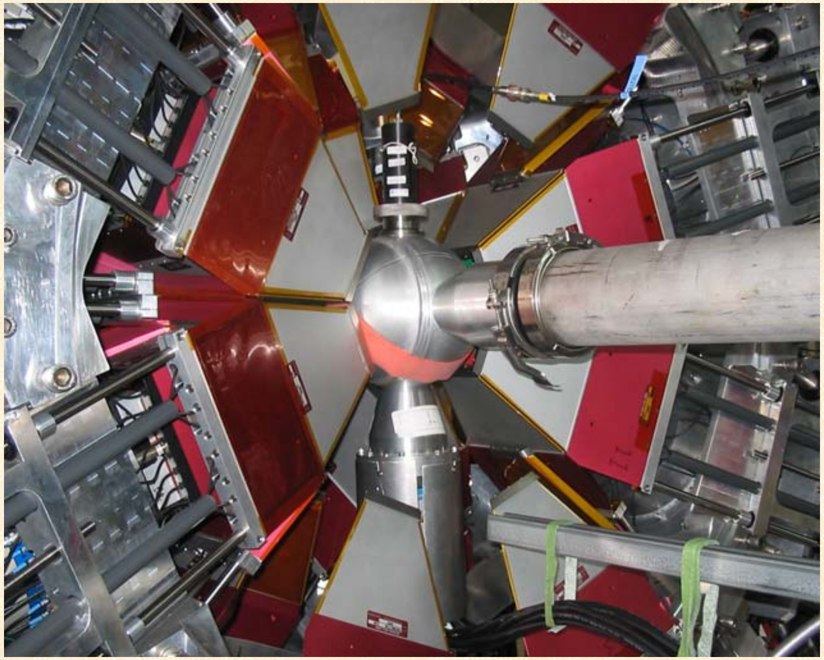
* 16.5 MeV ^{11}Be on thick Au target**

* Seven fully suppressed TIGRESS detectors at 14.5 cm (4 x 90^{o} + 3 x 135^{o})**
– 27 % solid angle coverage

* 1 mm thick annular DSSD of BAMBINO**
- downstream at 1.94 cm
- used for detection of electrons in coincidence with the gamma-rays from the TIGRESS detectors.

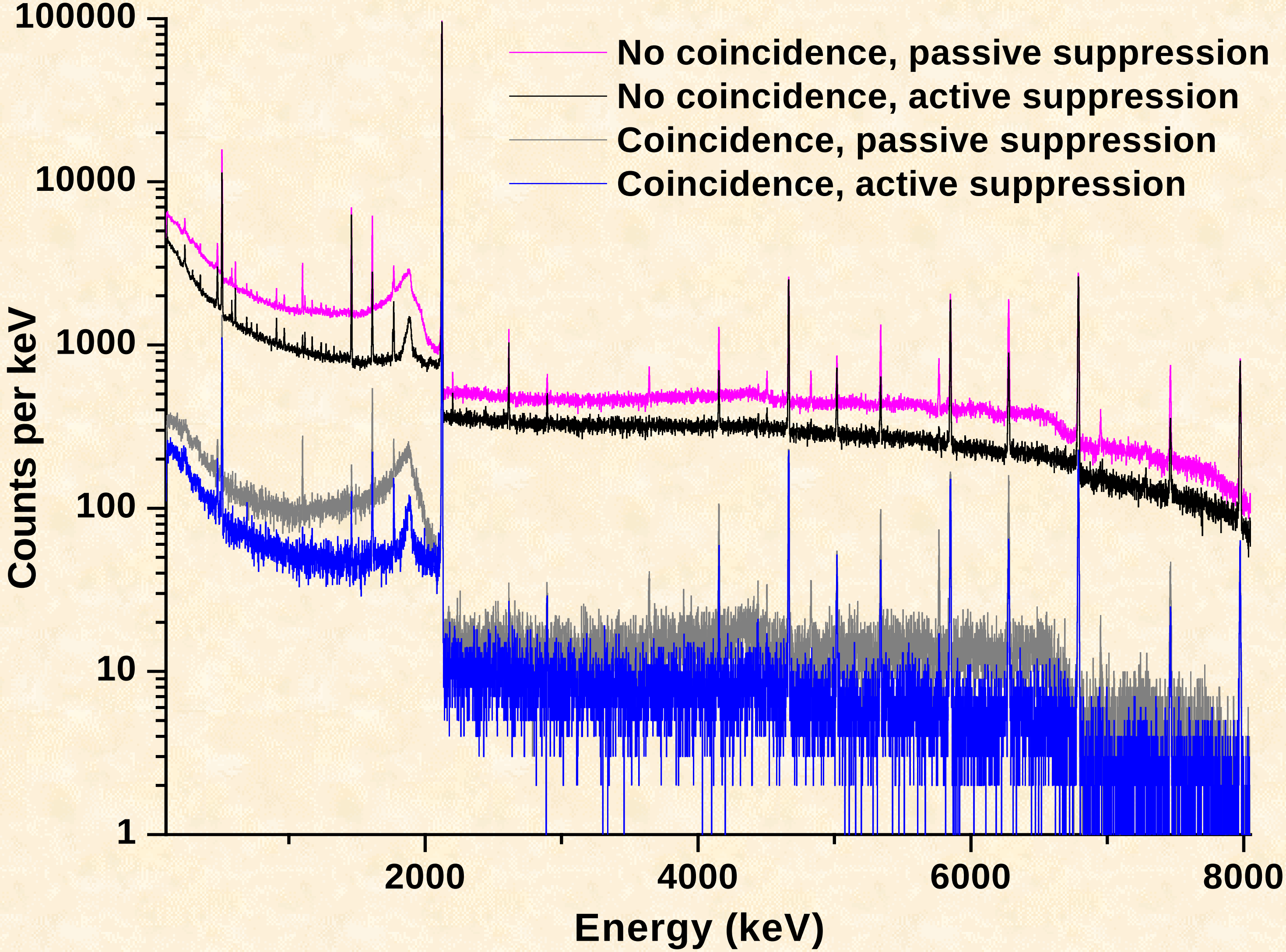
* Master Trigger – Ge singles OR Ge-Si coinc**



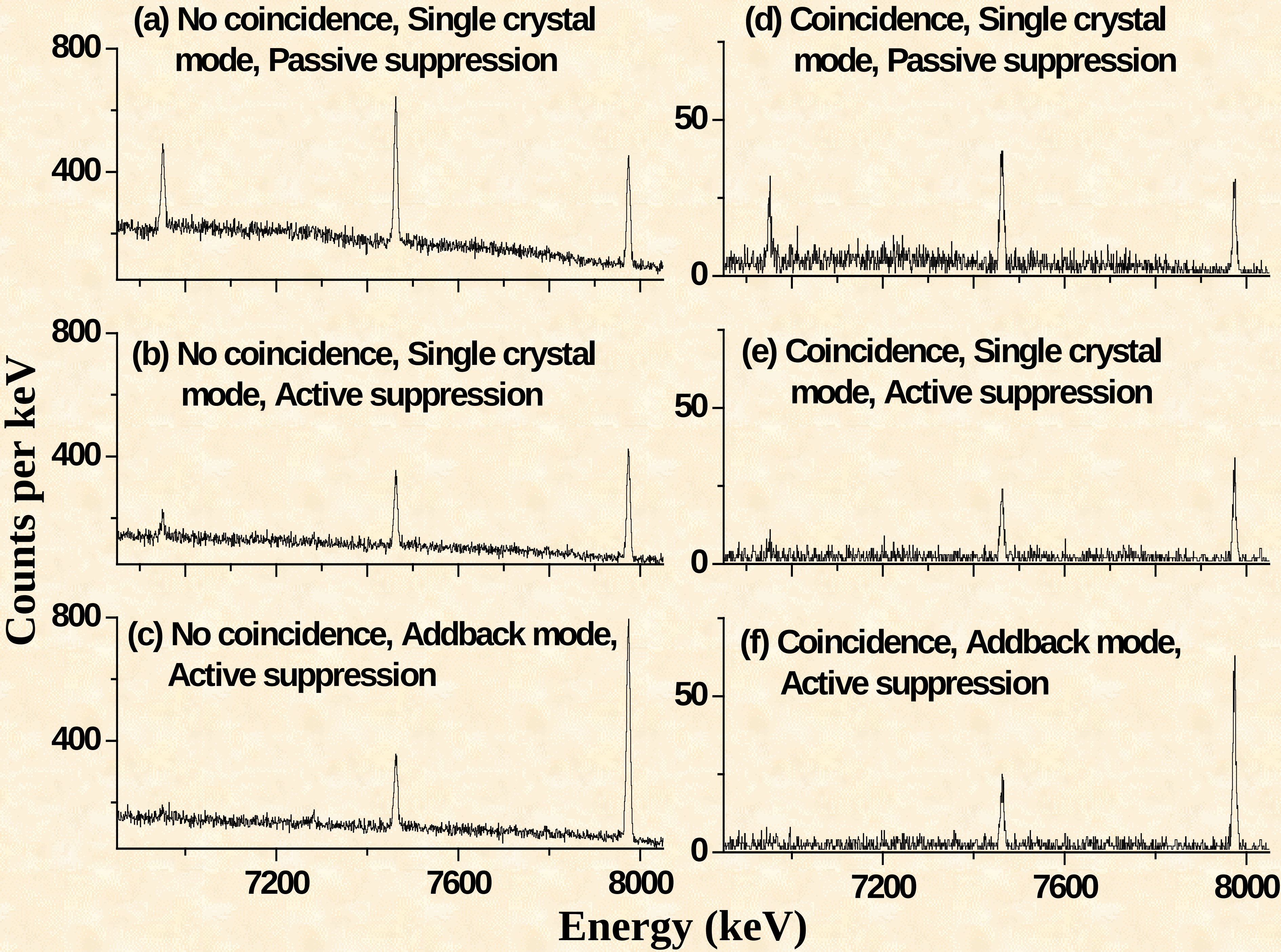


Addback spectra

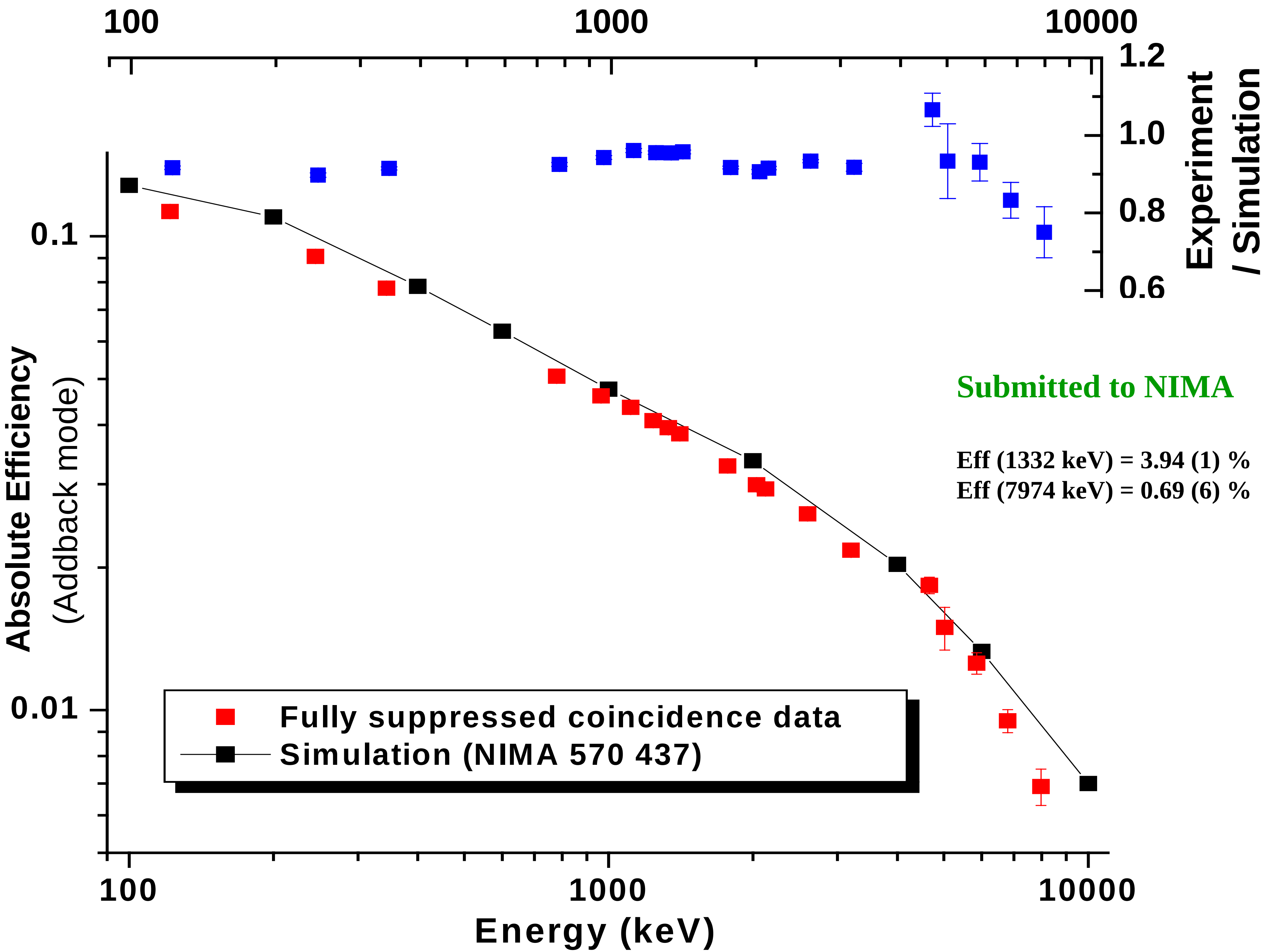
Effect of coincidence & suppression



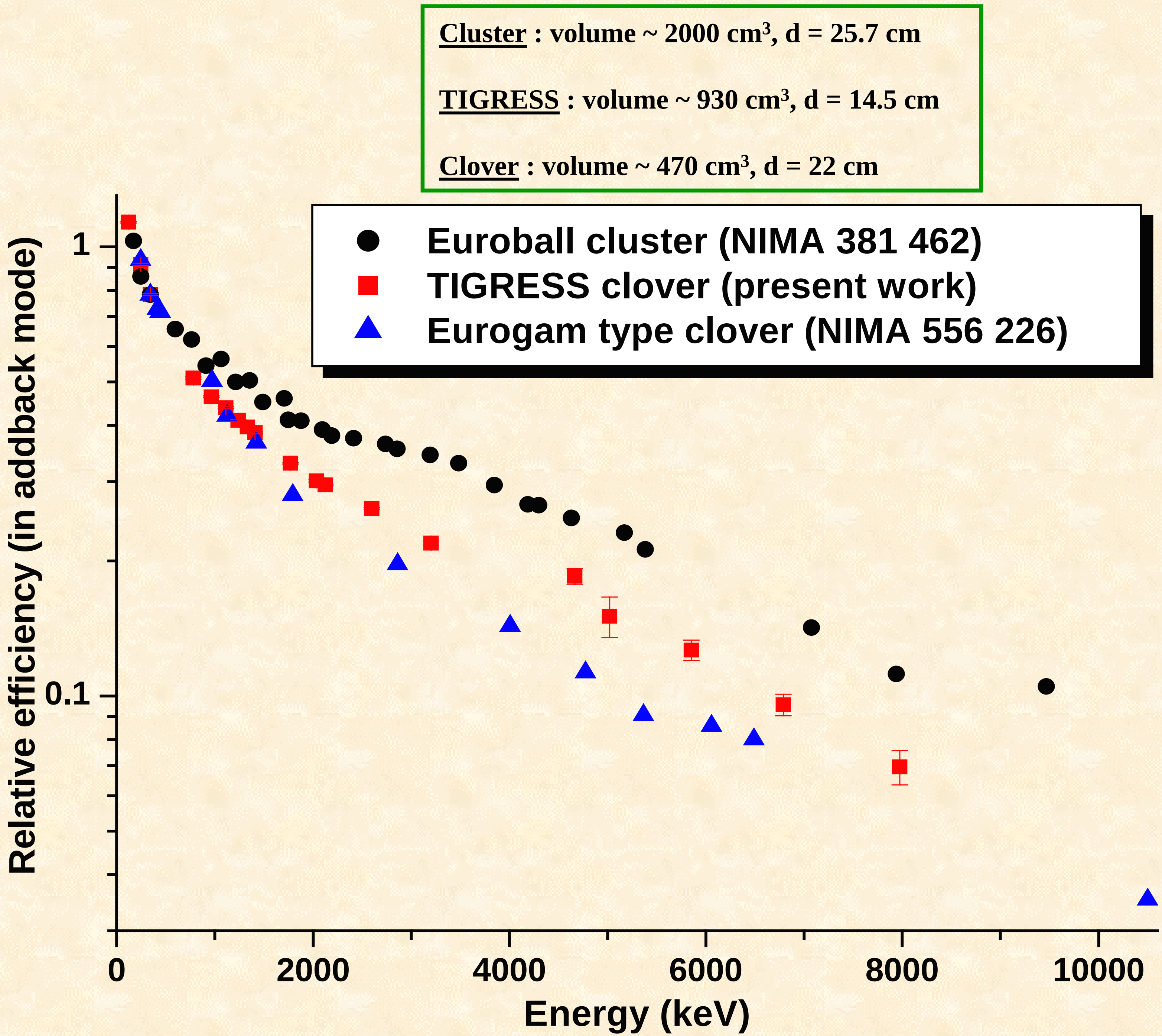
- use of BAMBINO detector helped in minimizing the contribution of the continuum arising from the interaction of high energy electrons (up to 11.5 MeV) with the germanium detectors.

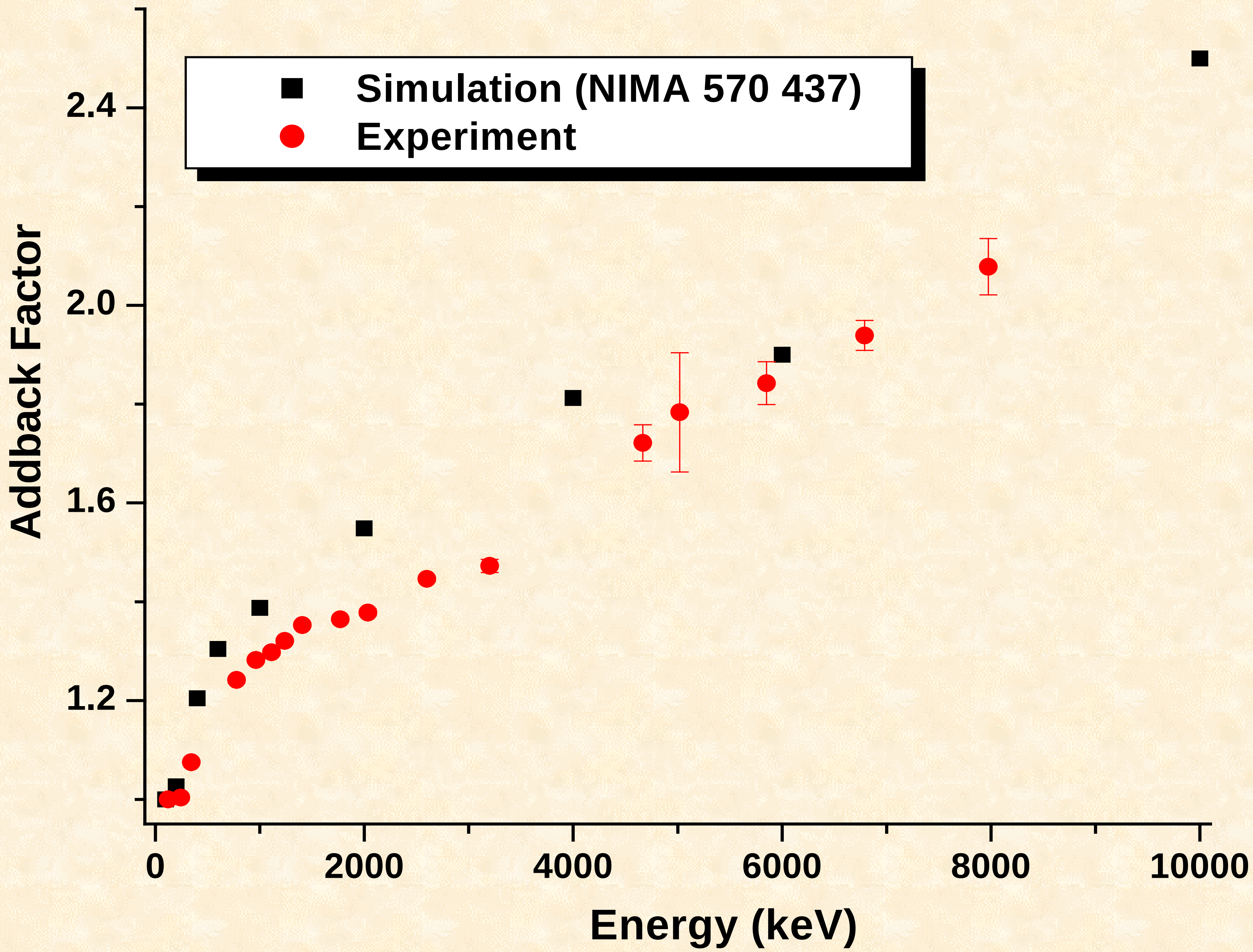


(a) No coincidence, Single crystal mode, Passive suppression
(b) No coincidence, Single crystal mode, Active suppression
(c) No coincidence, Addback mode, Active suppression
(d) Coincidence, Single crystal mode, Passive suppression
(e) Coincidence, Single crystal mode, Active suppression
(f) Coincidence, Addback mode, Active suppression
800
400
50
0
7200
7600
8000
Counts per keV
Energy (keV)



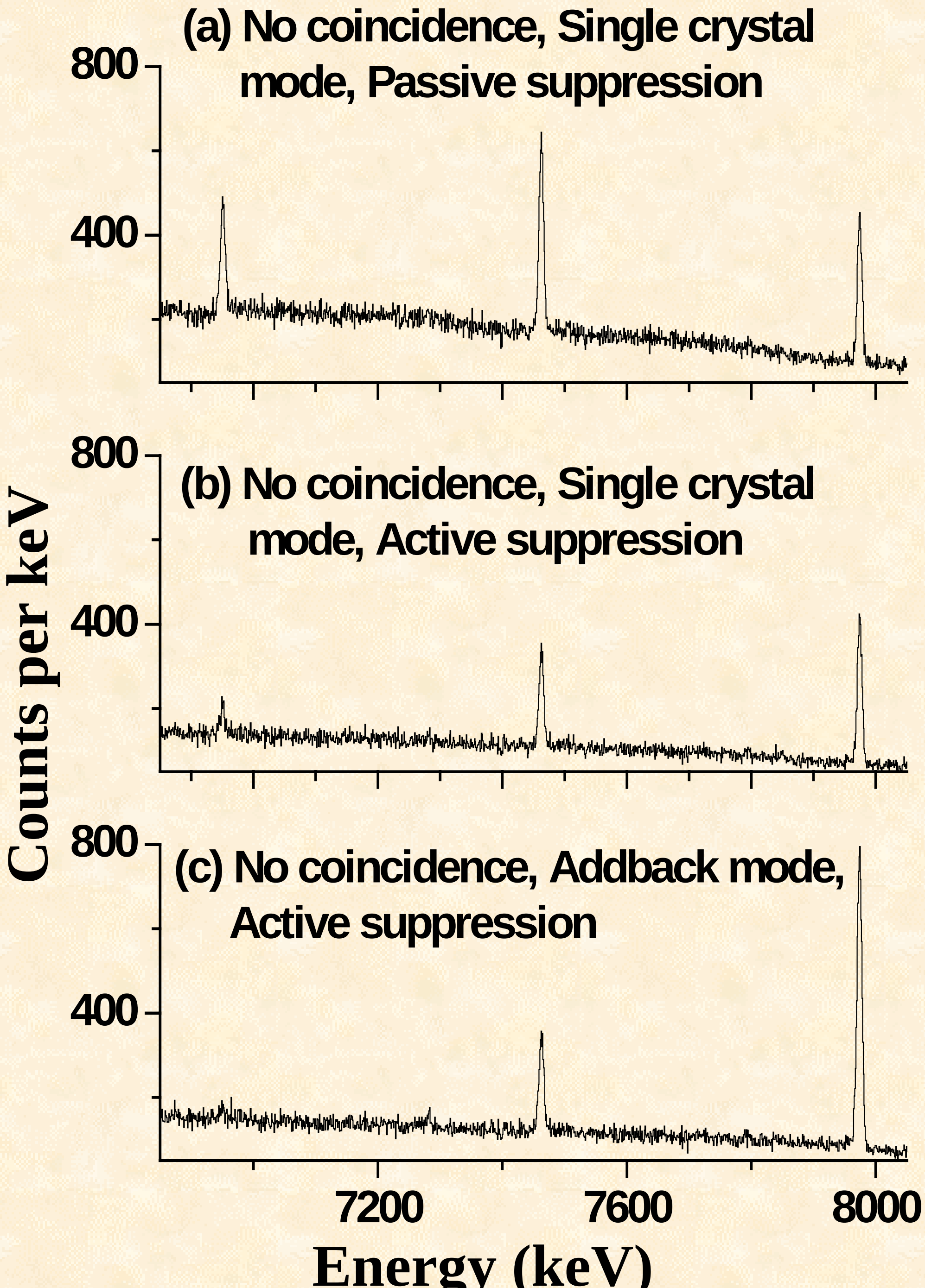
100
1000
10000
1.2
1.0
0.8
0.6
Experiment / Simulation
0.1
0.01
Absolute Efficiency (Addback mode)
Submitted to NIMA
Eff (1332 keV) = 3.94 (1) %
Eff (7974 keV) = 0.69 (6) %
Fully suppressed coincidence data
Simulation (NIMA 570 437)
100
1000
10000
Energy (keV)

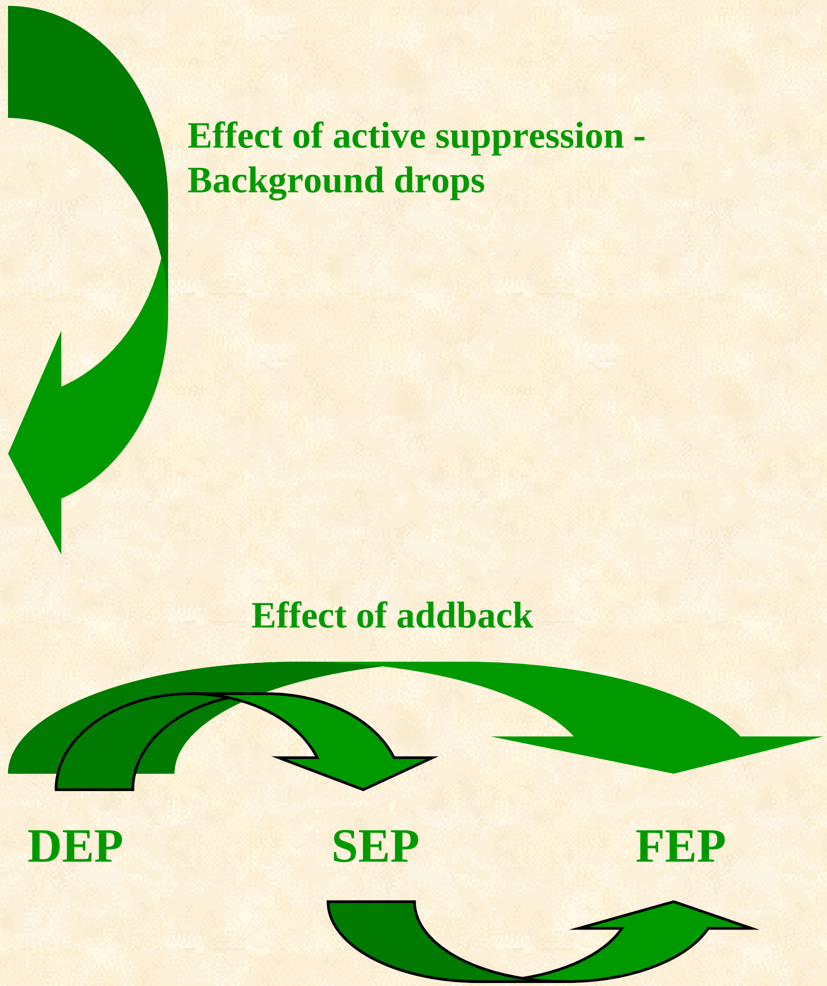

Cluster : volume ~ 2000 cm³, d = 25.7 cm
TIGRESS : volume ~ 930 cm³, d = 14.5 cm
Clover : volume ~ 470 cm³, d = 22 cm
Euroball cluster (NIMA 381 462)
TIGRESS clover (present work)
Eurogam type clover (NIMA 556 226)
Relative efficiency (in addback mode)
1
0.1
0
2000
4000
6000
8000
10000
Energy (keV)



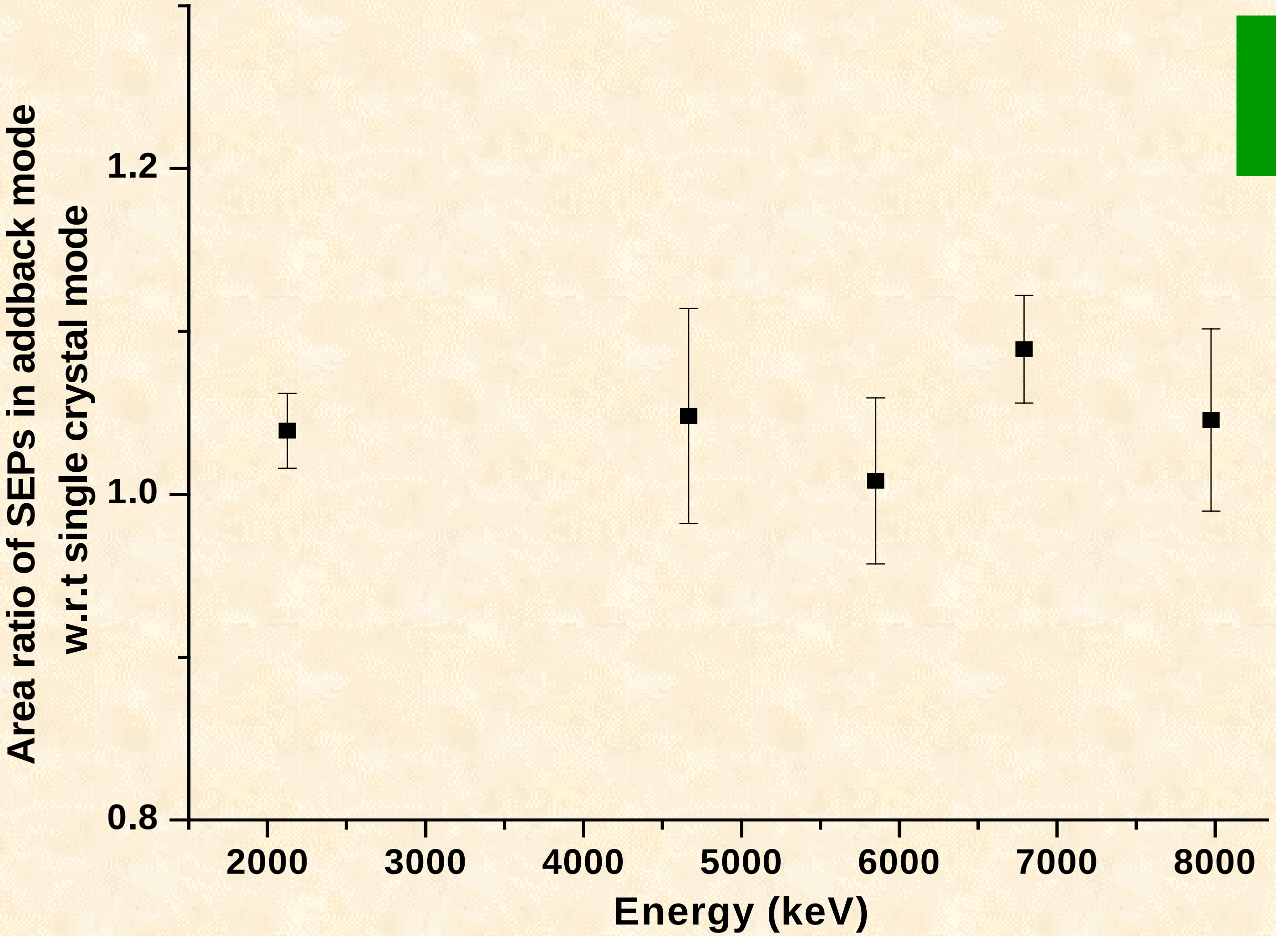
Simulation (NIMA 570 437)
Experiment
Addback Factor
2.4
2.0
1.6
1.2
0
2000
4000
6000
8000
10000
Energy (keV)

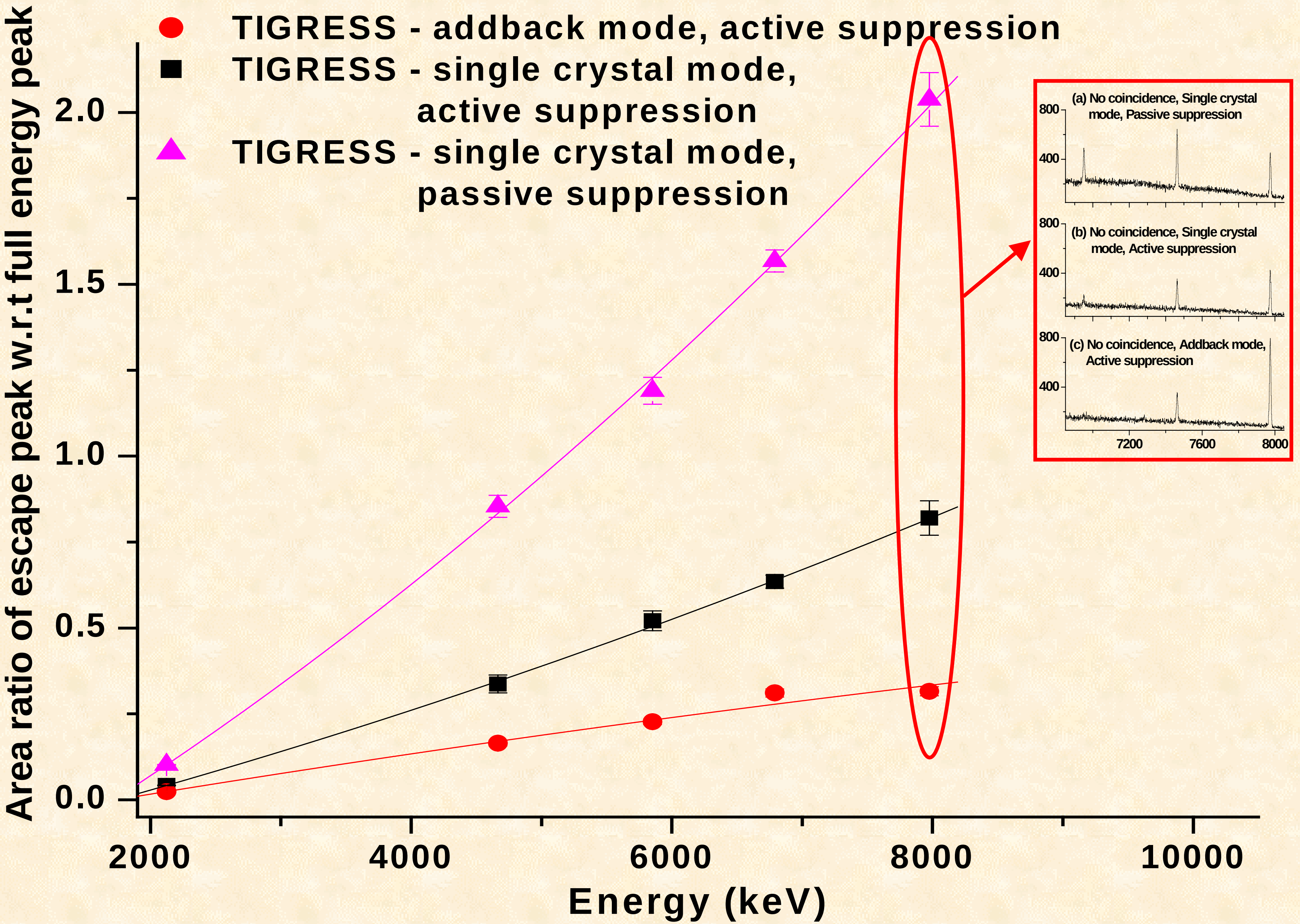
Effects of pair production





Effect of addback to SEP




TIGRESS - addback mode, active suppression
TIGRESS - single crystal mode, active suppression
TIGRESS - single crystal mode, passive suppression
Area ratio of escape peak w.r.t full energy peak
Energy (keV)
0.0
0.5
1.0
1.5
2.0
2000
4000
6000
8000
10000
(a) No coincidence, Single crystal mode, Passive suppression
(b) No coincidence, Single crystal mode, Active suppression
(c) No coincidence, Addback mode, Active suppression
800
400
7200
7600
8000

Summary and Conclusion

The gamma-ray response of an array of seven TIGRESS detectors has been studied for photon energies up to 8 MeV using a radioactive ^{11}Be beam and standard radioactive sources.

Measurements of absolute full energy peak detection efficiency and addback factor have been performed as a function of gamma-ray energy. The absolute efficiency at 1332 keV and 7974 keV are found to be 3.94(1)% and 0.69(6)%, respectively. These measured efficiencies will be useful for performing data analysis and planning gamma-ray spectroscopy experiments for energies above 3.5 MeV.

Ratio of escape peak area to full energy peak area have been extracted. The addback process along with the active suppression reduce the escape peak areas, but they cannot eliminate these peaks.

Comparisons have been made between TIGRESS and similar composite detectors.

Collaborators

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