Characterisation of a 2X2 Array of Large Square Bars of $LaBr_3$:Ce Detectors With γ-Rays up to 22.5 MeV

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The Annual PARIS Collaboration Meeting 2018

Heavy Ion Laboratory, Warsaw

25th – 26th Jan. 2018

tifr

***raison d'etre* of the talk**

Dynamics of Hot & Rotating Nuclei at Low-Medium Excitation Energy

Primary motivations:

Nuclear structure and structural evolution with T, J

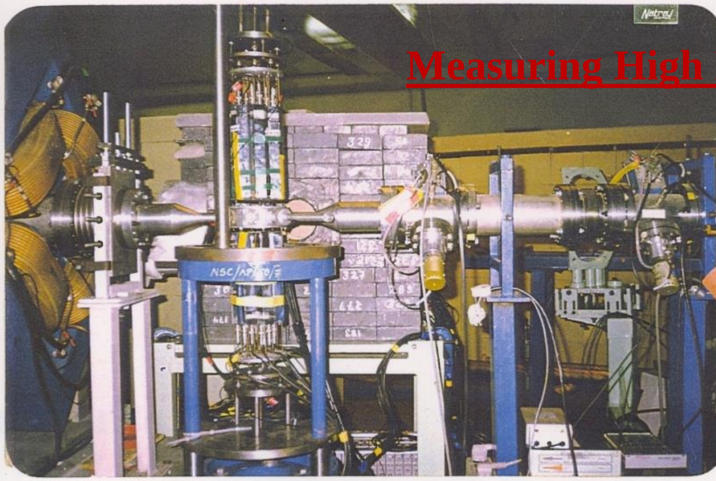
GDR decay studies, Search for IVGQR

Reaction dynamics below and above barrier

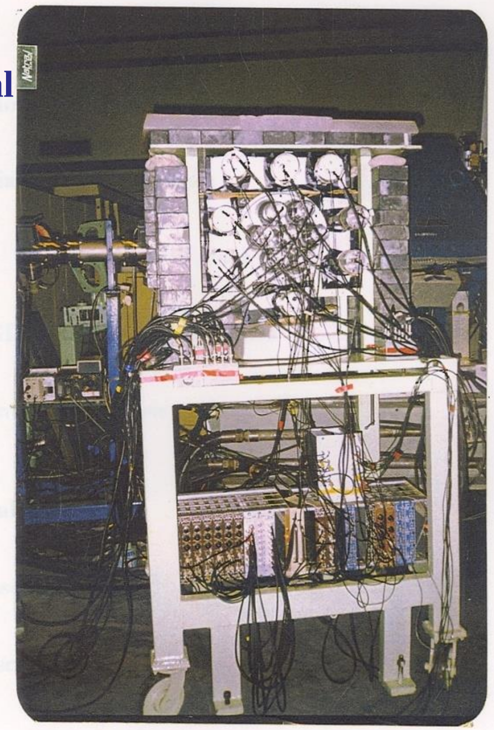
Fusion-evaporation reaction

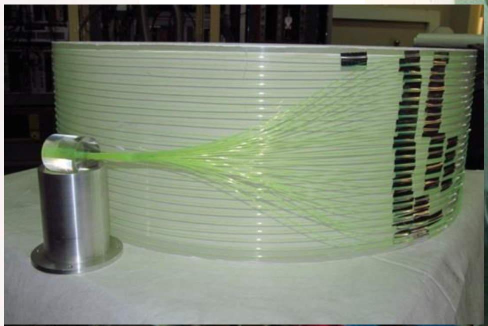
Fusion-fission reaction

Measuring High Energy γ-Rays (4 – 50 MeV)



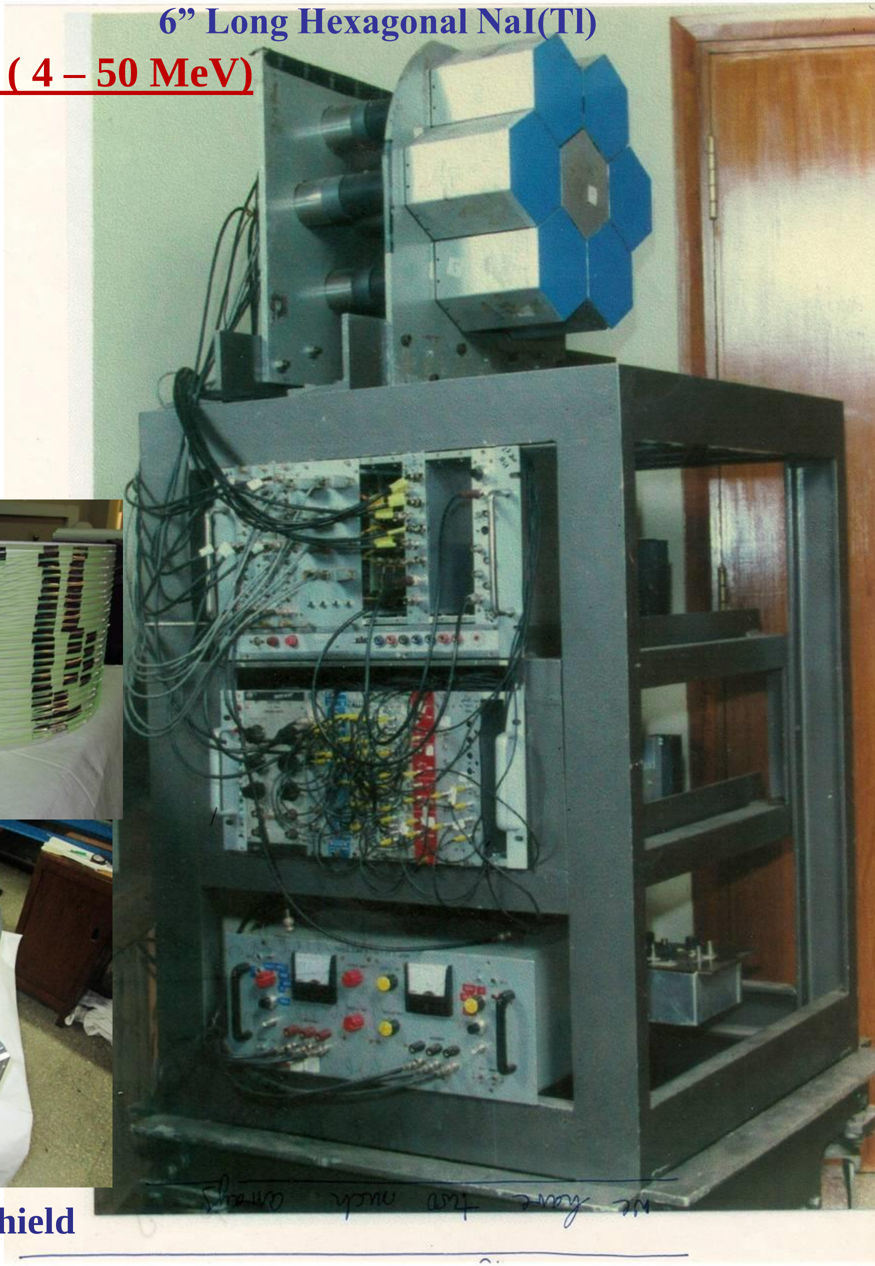
10”X12” Cylindrical NaI(Tl)





Annular anti-cosmic shield

6” Long Hexagonal NaI(Tl)

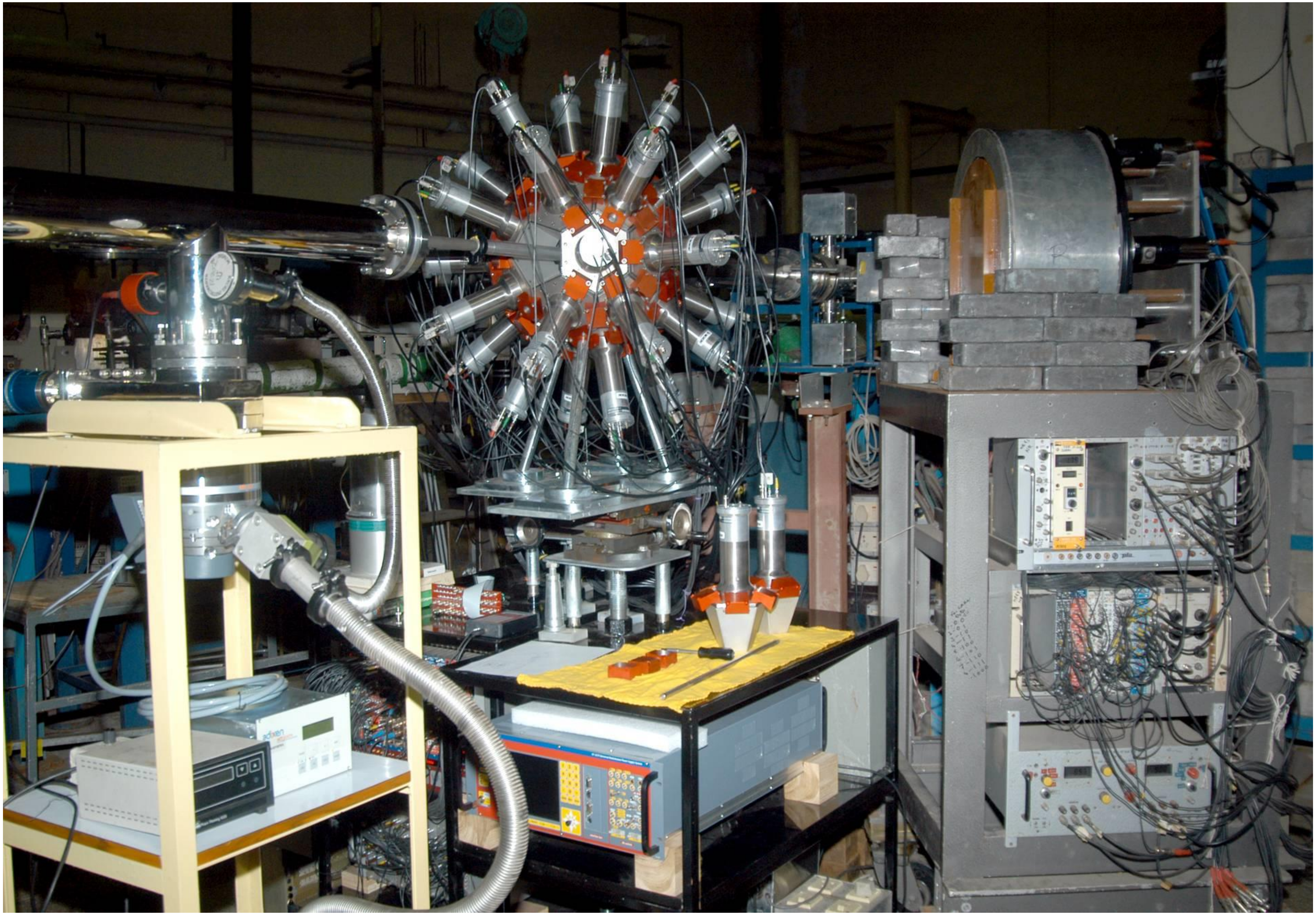


7 Elements NaI array,
TIFR, Mumbai

HIGRASP at IUAC, Delhi

I.Mazumdar et al.

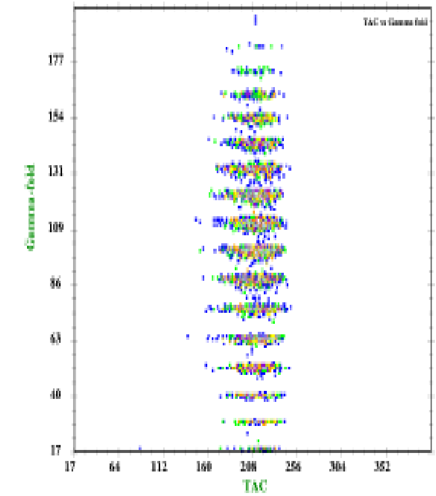
NIM A417

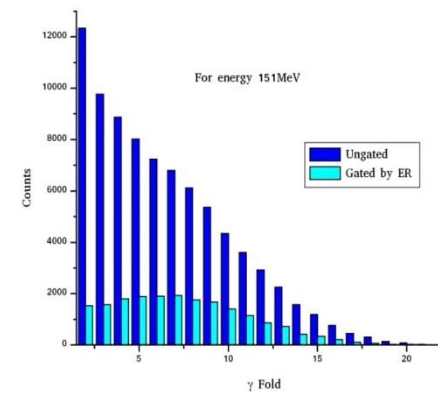


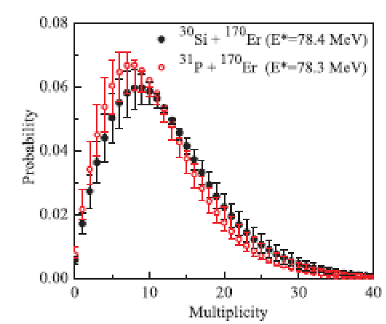
The 4π Sum-Spin Spectrometer at TIFR

Kumar, Mazumdar, Gothe, NIM-A 611 (76) (2009)

Hybrid Recoil Analyzer (HYRA) at Inter University Accelerator Centre, Delhi Coupled with the TIFR 4π Sum-Spin Spectrometer







- ***GDR decay from ^{192}Pt, ^{196}Hg, ^{144}Sm***
- ***ER cross section, spin distribution for***

(^{31}P+^{170}Er), (^{30}Si, ^{31}P+ ^{170}Er), (^{28}Si + ^{176} Yb) (^{48}Ti+^{150}Nd), (^{19}F,^{16}O + ^{197}Au)

- *Phys Rev. C 88 024312 (2013)*
- *Phys Rev C 88 034606 (2013)*
- *Nucl. Phys. A 890, 62 (2012)*
- *Jour. Phys. G 41 (2014)*
- *EPJ Web of Sc.(2011,2013)*
- *Phys. Rev. c 95, 024604 (2017)*
- *Phys. Rev. C 96, 34613 (2017)*

Studying $LaBr_3Ce$ detectors

- Small 1"X1" cylindrical detectors
- Small 2"X2" cylindrical detectors
- Large volume 3.5"X6" cylindrical detector
- Large volume square bars (2"X2"X8")
- Array of large volume square bars
- A combo arrangement of LaBr+NaI(Tl)
- $LaBr_3$:Ce-NaI Phoswich
- PARIS phoswich detectors

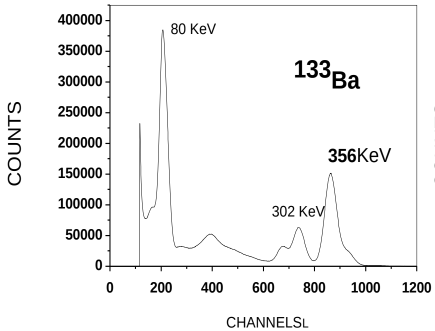
Complete characterisation

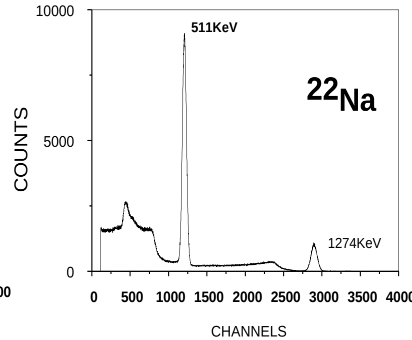
- *Energy & Timing resolution*
- *Linearity*
- *Uniformity & homogeneity*
- *Internal activity*
- *Absolute efficiencies (PP & TDE)*
- *Response (662 keV – 30 MeV)*
- *Efficiency corrections*
- *Performance with SiPM*

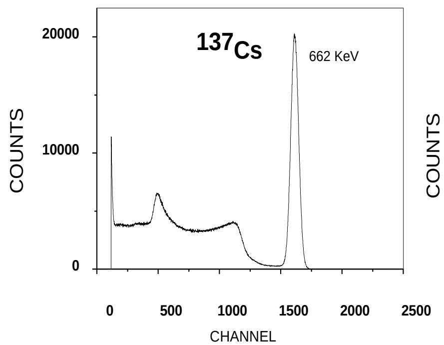
1. G. Anil Kumar, Mazumdar, Gothe, Nucl. Instr. Meth. A 609 (2009)
2. G. Anil Kumar, Mazumdar, Gothe, Nucl. Instr. Meth. A 610 (2009)
3. G. Anil Kumar, Mazumdar, Gothe, Nucl. Instr. Meth. A 611 (2009)
4. Mazumdar, G. Anil Kumar, Gothe, Manchanda, Nucl. Instr. Meth. (2010)
5. Mazumdar, Gothe, Chavan, Yadav, G. Anil Kumar, Nucl. Inst. Meth.A 705 (2013
6. M. Dhibar, D. Mankad, I. Mazumdar and G. Anil Kumar. Applied Radiation and Isotopes 118, 32 (2016).
7. M. Dhibar, I. Mazumdar, G. Anil Kumar, S. M. Patel, P. B. Chavan. Nuclear Inst. and Methods in Physics Research, A 883 (2018) 183

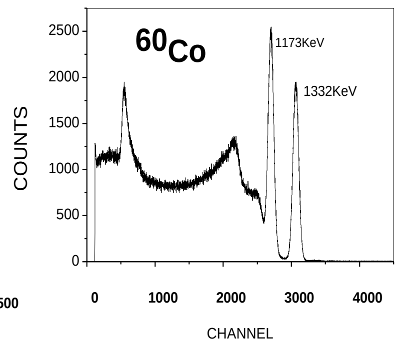
1" x 1" CYLINDRICAL DETECTOR

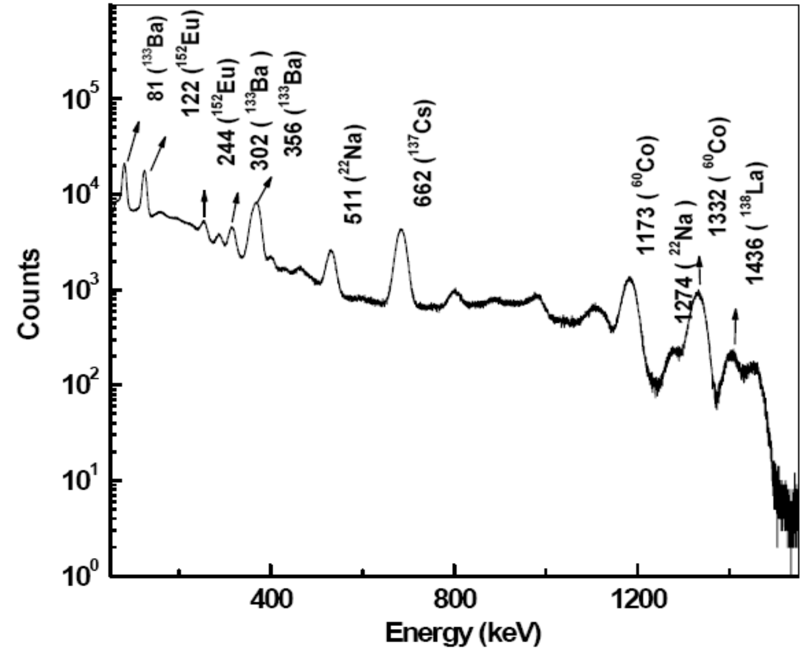
<u>^{137}Cs, ^{60} Co, ^{22}Na, ^{133} Ba, ^{57}Co, ^{147} Pm, ^{65}Zn, ^{152} Eu, ^{45}Ca.</u>

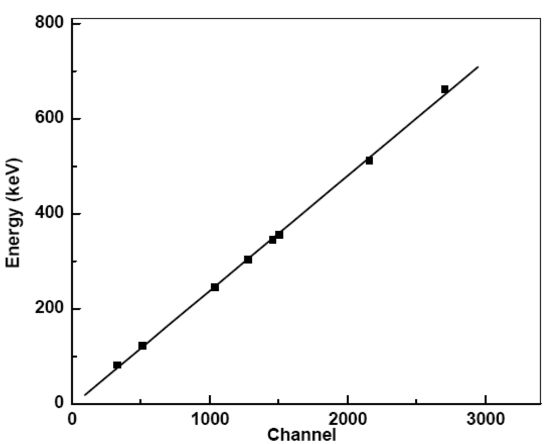


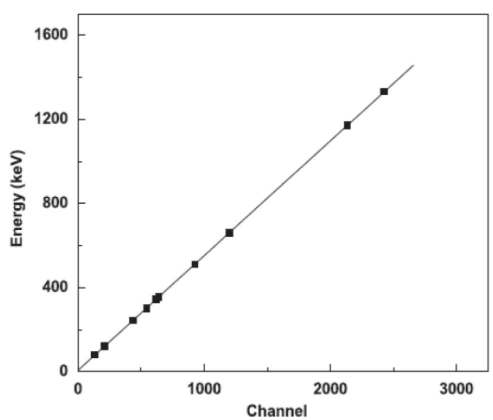


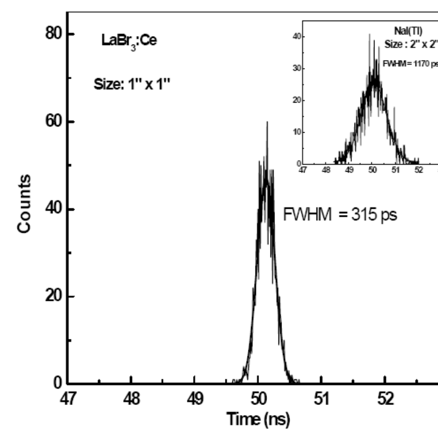








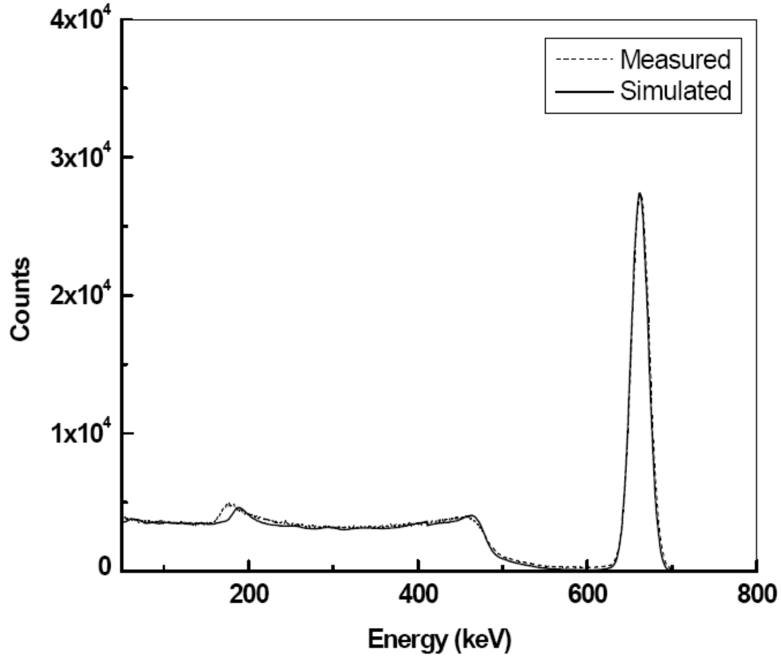


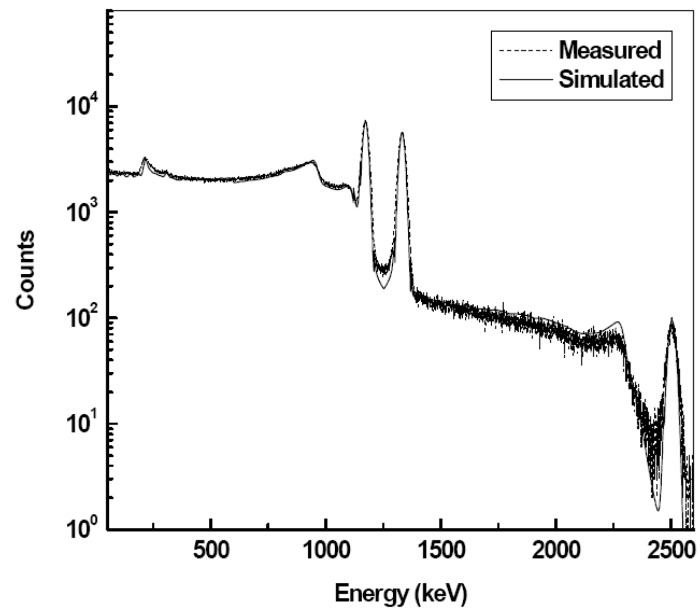


- **<u>2” ET9807B (Equiv. RCA8575)</u>**
- **<u>3” BURLE S83021E (Equiv. R1911-01)</u>**

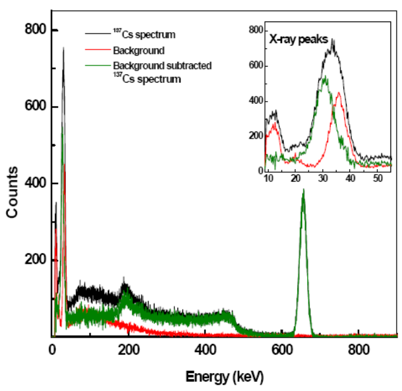
(Bialkali photocathodes with max.quantum efficiencies in 320 – 420 nm)

<u>Kumar, Mazumdar, Gothe</u>
<u>NIM-A 610 (2009)</u>





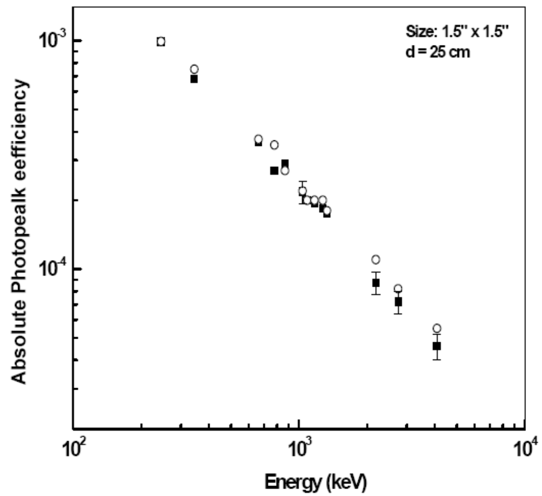
Kumar, Mazumdar, Gothe
NIM-A 610 (2009)



Measured and Geant simulated spectra
for ^{137}Cs (662 keV) and ^{60}Co (1173, 1332 keV).

Calibrated sources used.

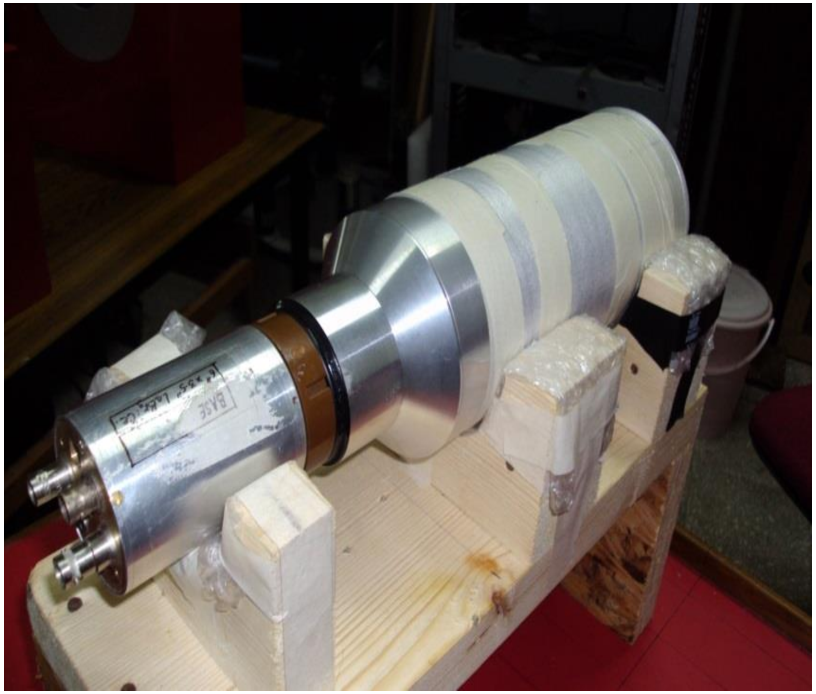
No normalization in the comparison



Distance (cm)	ε_{Total}		ε_{peak}	
	GEANT4	Exp	GEANT4	Exp
15	0.105 (0.012)	0.114 (0.005)	0.030 (0.004)	0.027 (0.001)
25	0.041 (0.003)	0.044 (0.002)	0.011 (0.001)	0.010 (0.001)

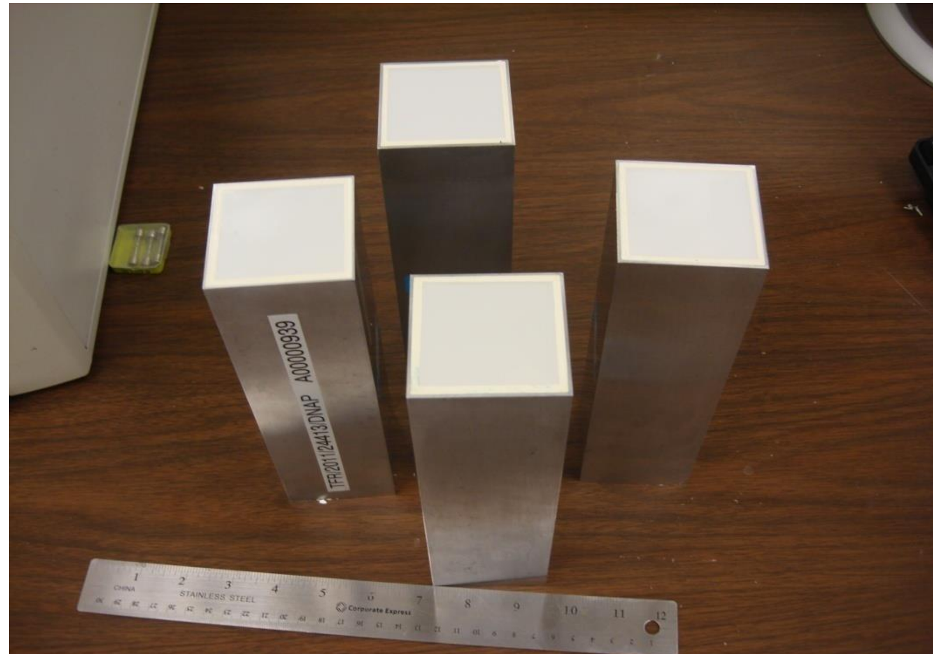
Data: Favalli et al (2008)

GEANT4 Simulation
Kumar, Mazumdar, Gothe
NIM 610 (2009)

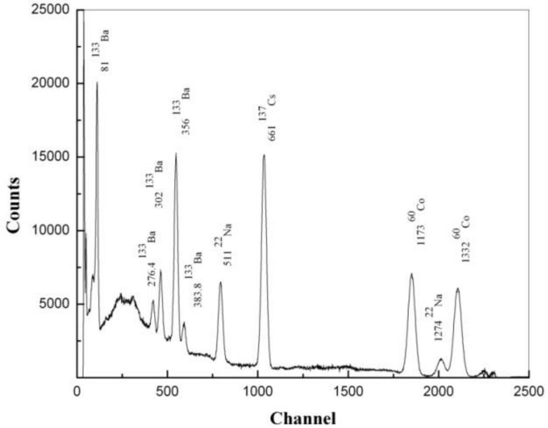


3.5"× 6" cylinder

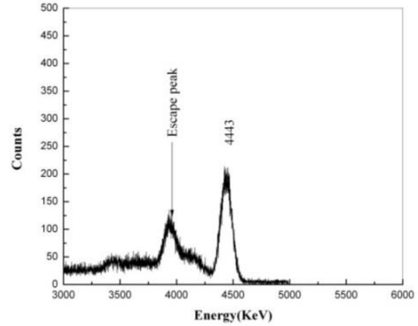
2x2 array of (2"×2"× 8") square bar

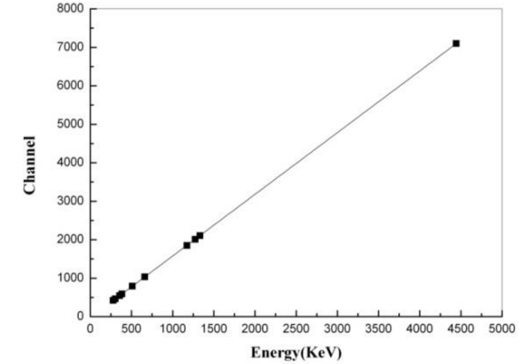


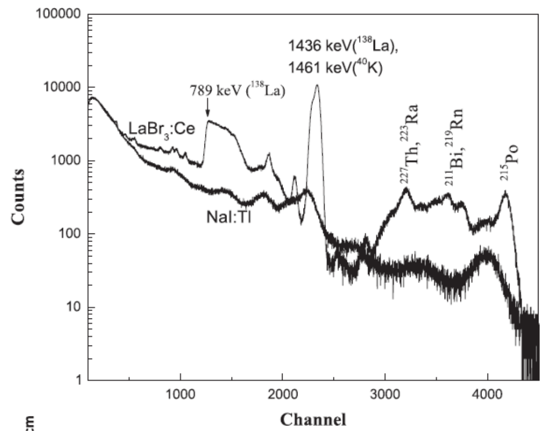
3.5" X 6" $LaBr_3$:Ce

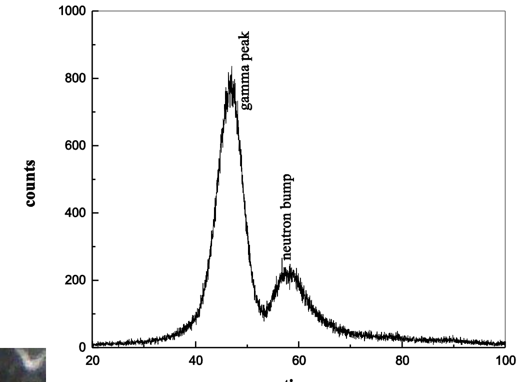


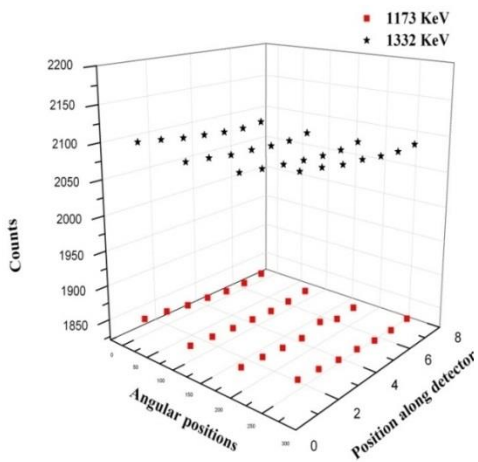
AmBe (4.433 MeV)

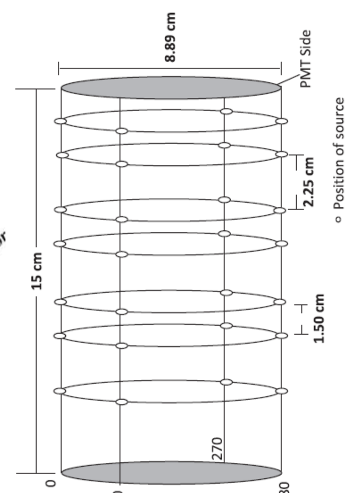


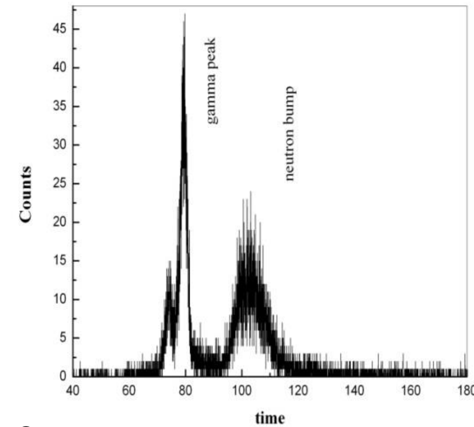












Mazumdar et al
NIM-A 705 (2013)

Internal radioactivity of the $LaBr_3$:Ce ~ 3 cts/s/cm^3

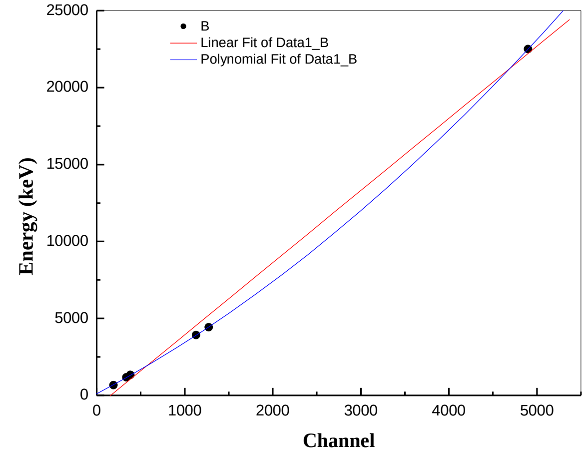
Reactions:

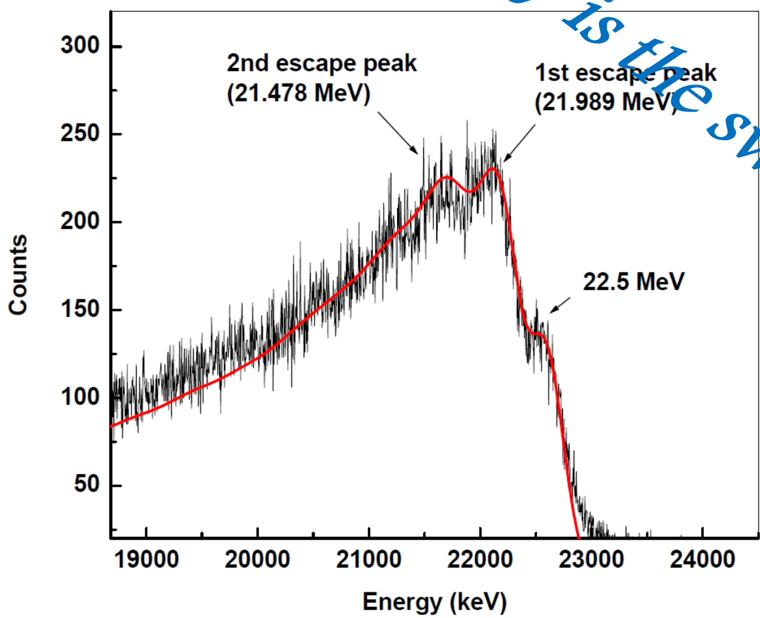
$^{11}B(p,\gamma)^{12}C$ (Capture Reaction)

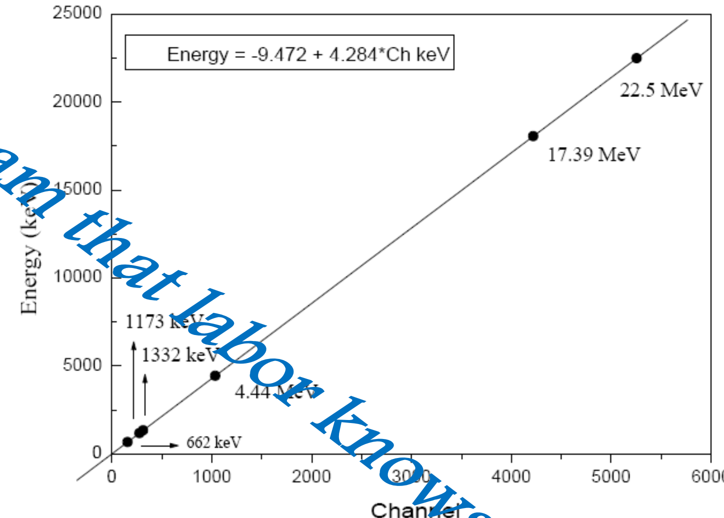
$^{12}C(p,p')^{12}C,\gamma$ (inelastic scattering reaction)

Mazumdar, Schmidt, Maj, PARIS Collaboration Web site

The linearity is the sweetest dream that labor knows







22.5 MeV γ-rays measured at TIFR with the large cylindrical $LaBr_3$:Ce.

E_p = 7.2 MeV proton beam from TIFR Pelletron

Taming the non-linearity up to 22.5 MeV

Mazumdar et al. Nucl. Instr. Meth. A (2013)

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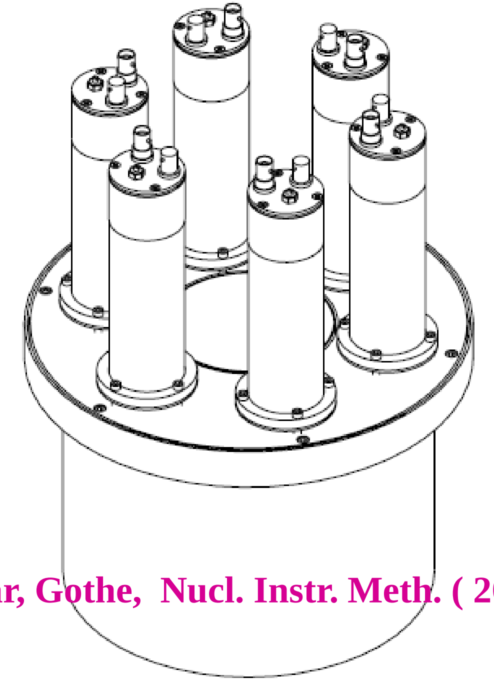
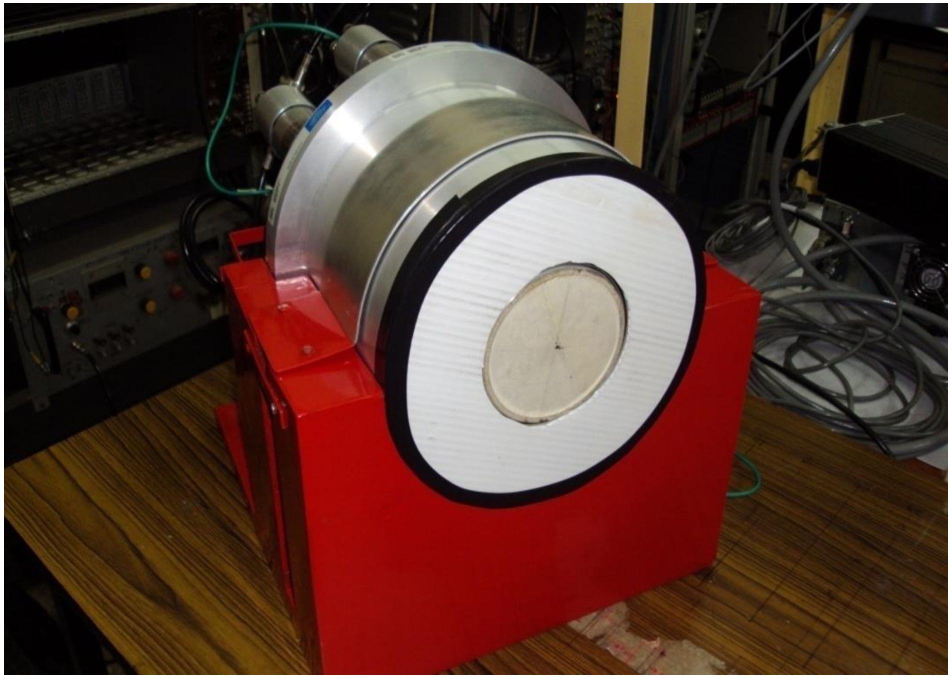
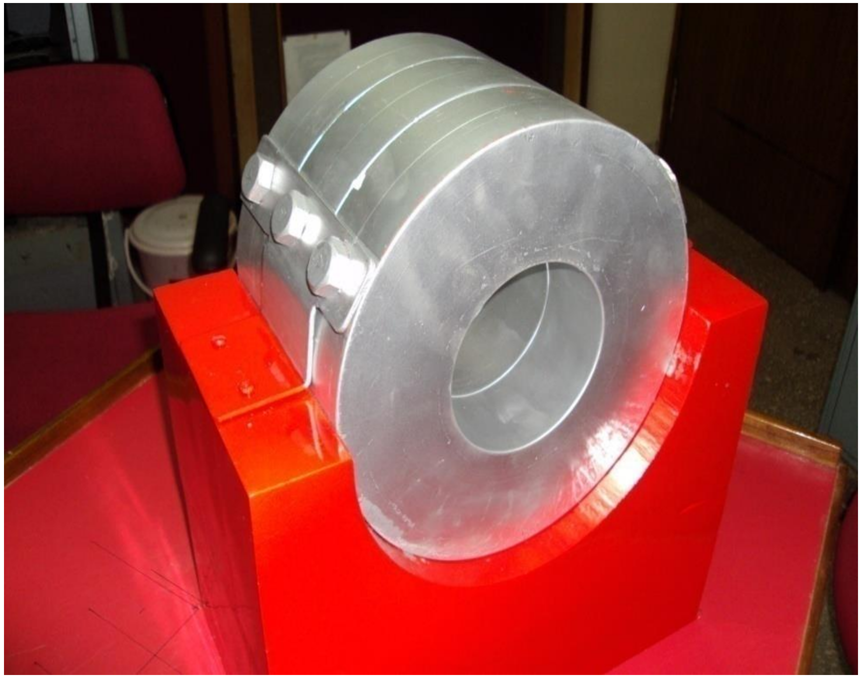
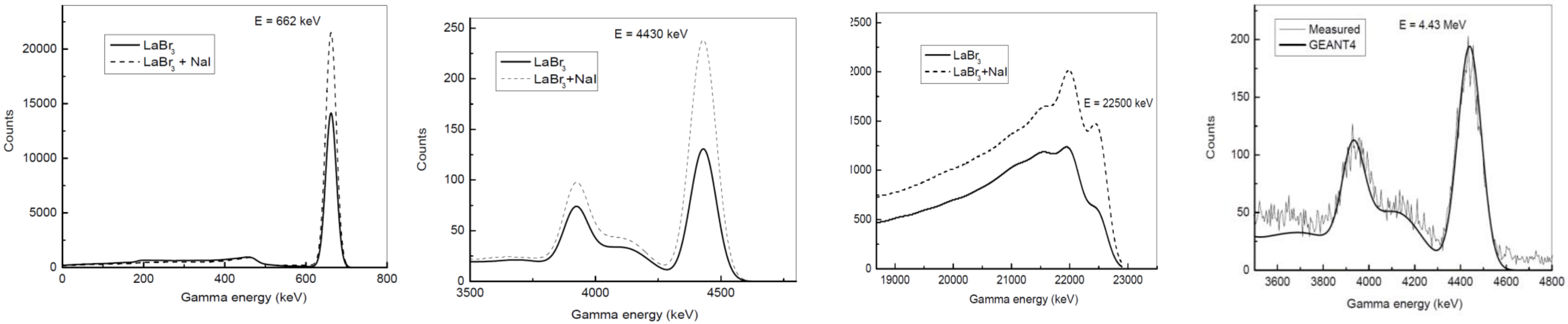


G. Anil Kumar, Mazumdar, Gothe, Nucl. Instr. Meth. (2009)



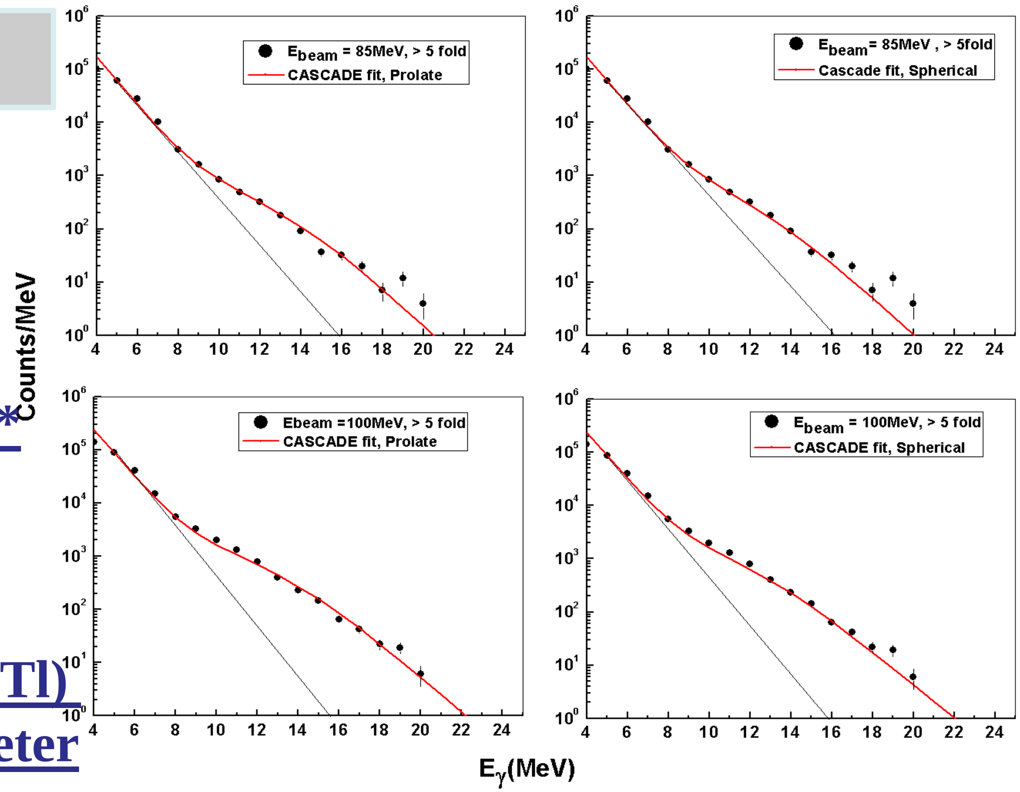




GDR Decay from hot-rotating 196Hg

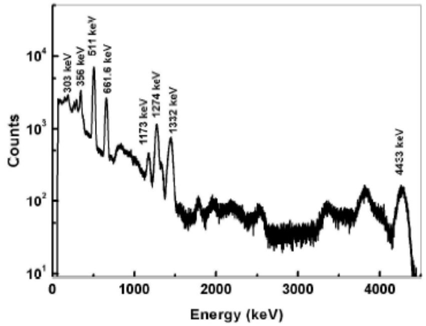
- Measurements carried out at IUAC,New Delhi
- Reaction: $^{16}O + ^{180}Hf \rightarrow ^{196}Hg^*$
- E_{beam} = 85 MeV & 100 MeV
- γ-rays measured in LaBr+NaI(Tl) assembly & 4π spin-spectrometer

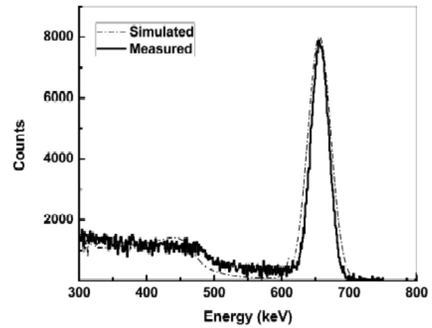
Mazumdar et al., (in preparation)

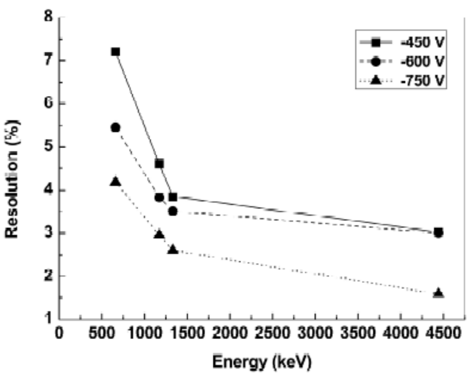


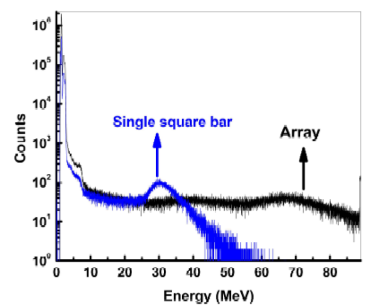
Characterisation of 2”X2”X8” bar & 2x2 array

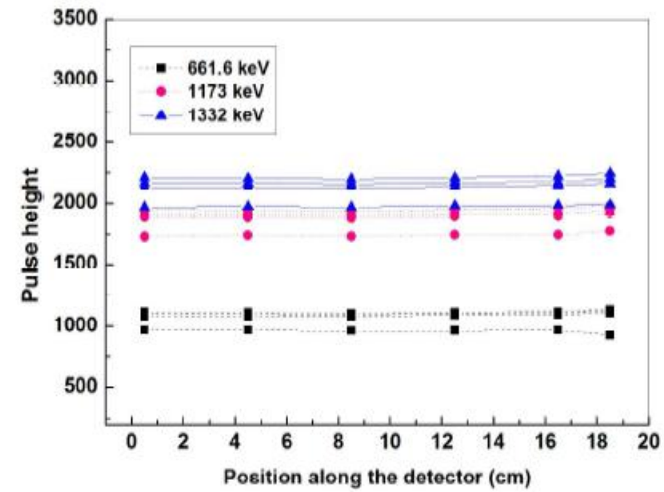
Dhibar, Mazumdar et al. NIM-A (2018)





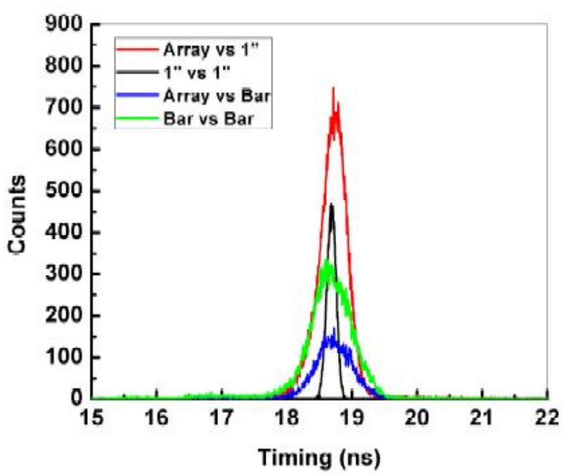


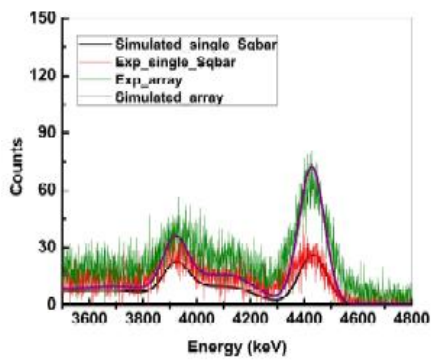




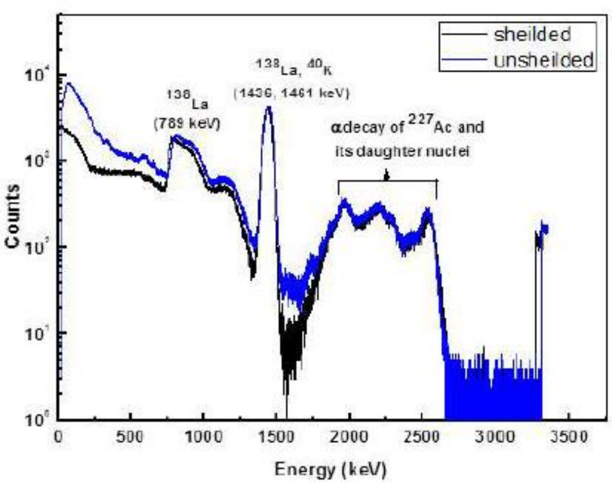
Energy Resolution

Uniformity



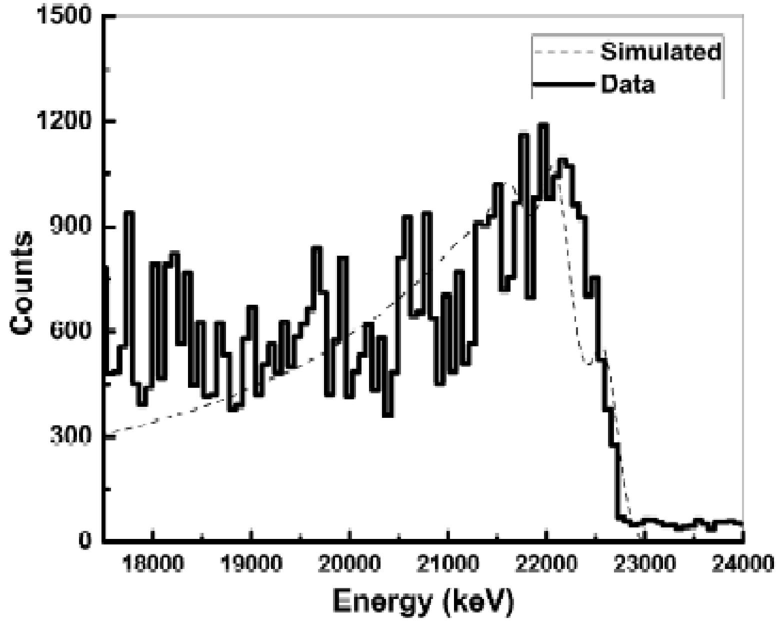


Detector geometry	Efficiency(%)	
	Experimental	Simulated
Single square bar	34.88 (0.03)	34.13 (0.05)
Array	40.50 (0.15)	41.00 (0.11)

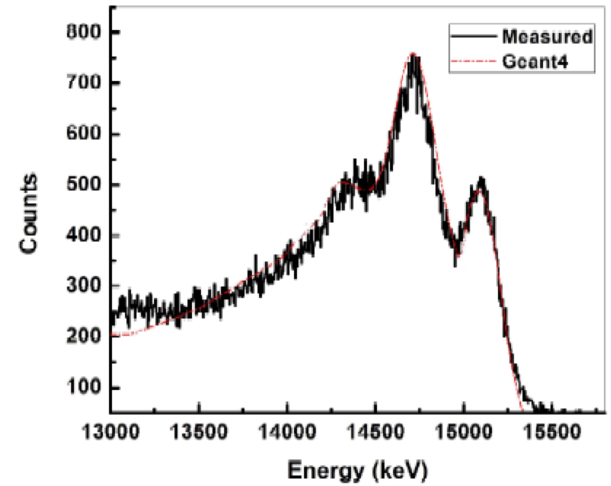


Timimg Resolution

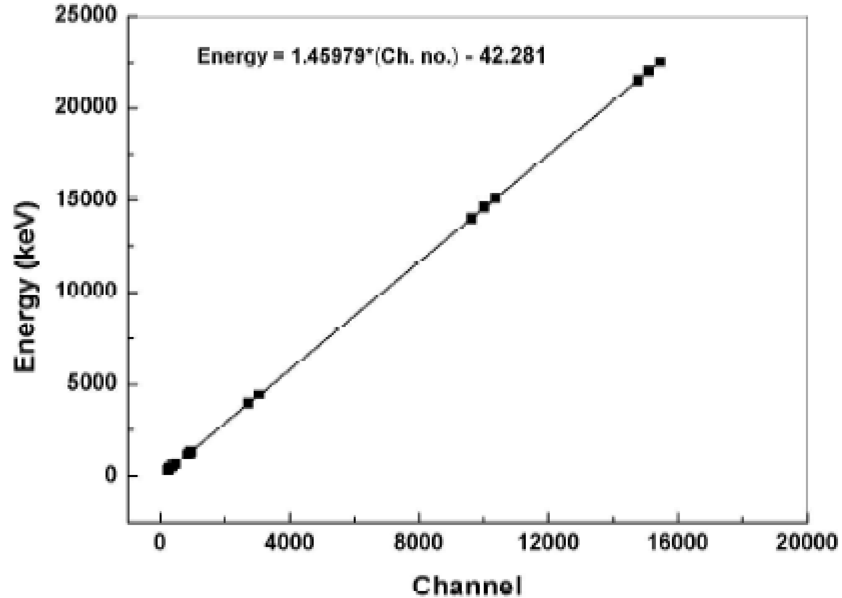
Internal activity



22.5 MeV from $p(^{11}B,\gamma)$ reaction

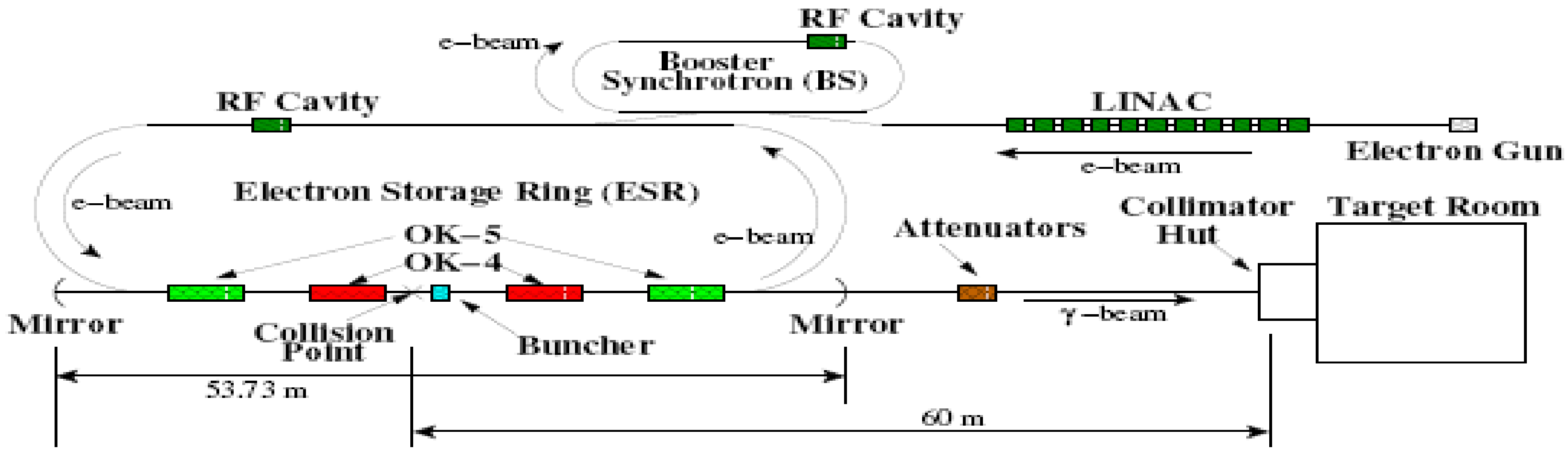


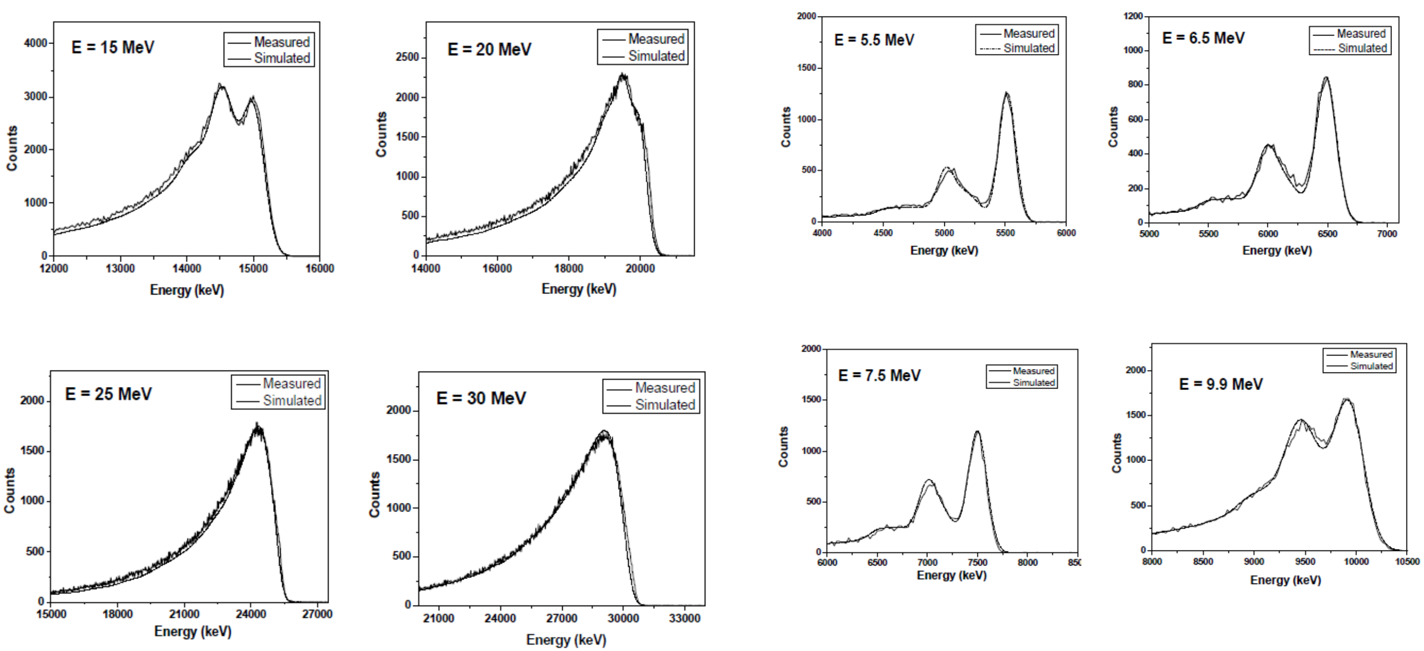
15.1 MeV from $^{12}C(p,p'),\gamma$ reaction



Linearity up to 22.5 MeV

Dhibar, Mazumdar et al., NIM-A (2018))





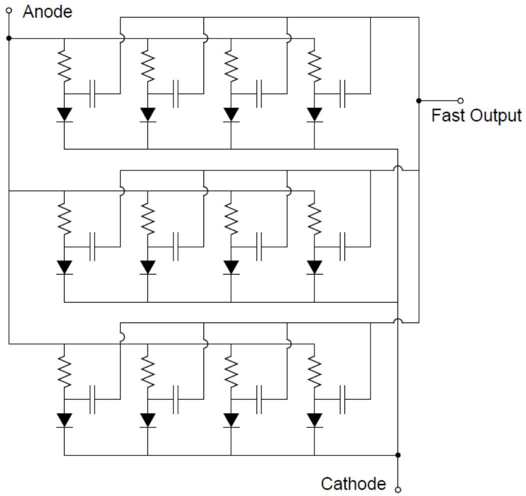
Mazumdar et al.

Studying the Performance of $LaBr_3$:Ce Crystals Coupled with SiPm

Studies with SiPm

Photo Multiplier Tube	SiPM
High Biasing Voltage	Low Biasing Voltage
Large Size causes difficulty when using arrays	Small Size covers small detector area
Sensitive to Magnetic field	Insensitive to Magnetic field
Reasonable cost	High Cost compared to PMT

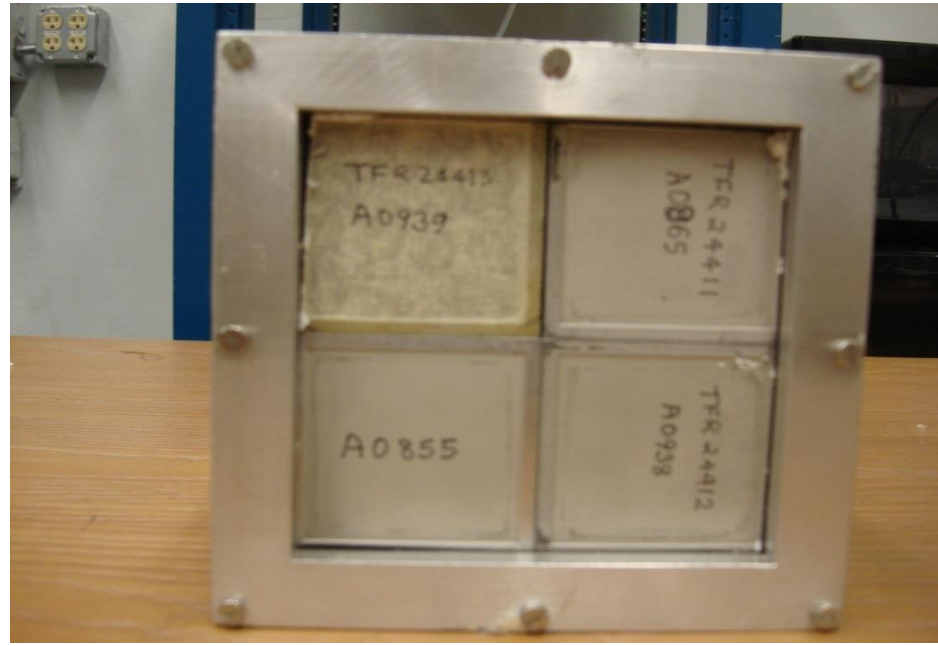
- **SiPM is a semiconductor device made up of avalanche photo diode pixel connected in parallel.**
- **Each APD is an individual photon counter and sum of all APD pixels is output of SiPM.**
- **APDs are operated in Geiger Mode**

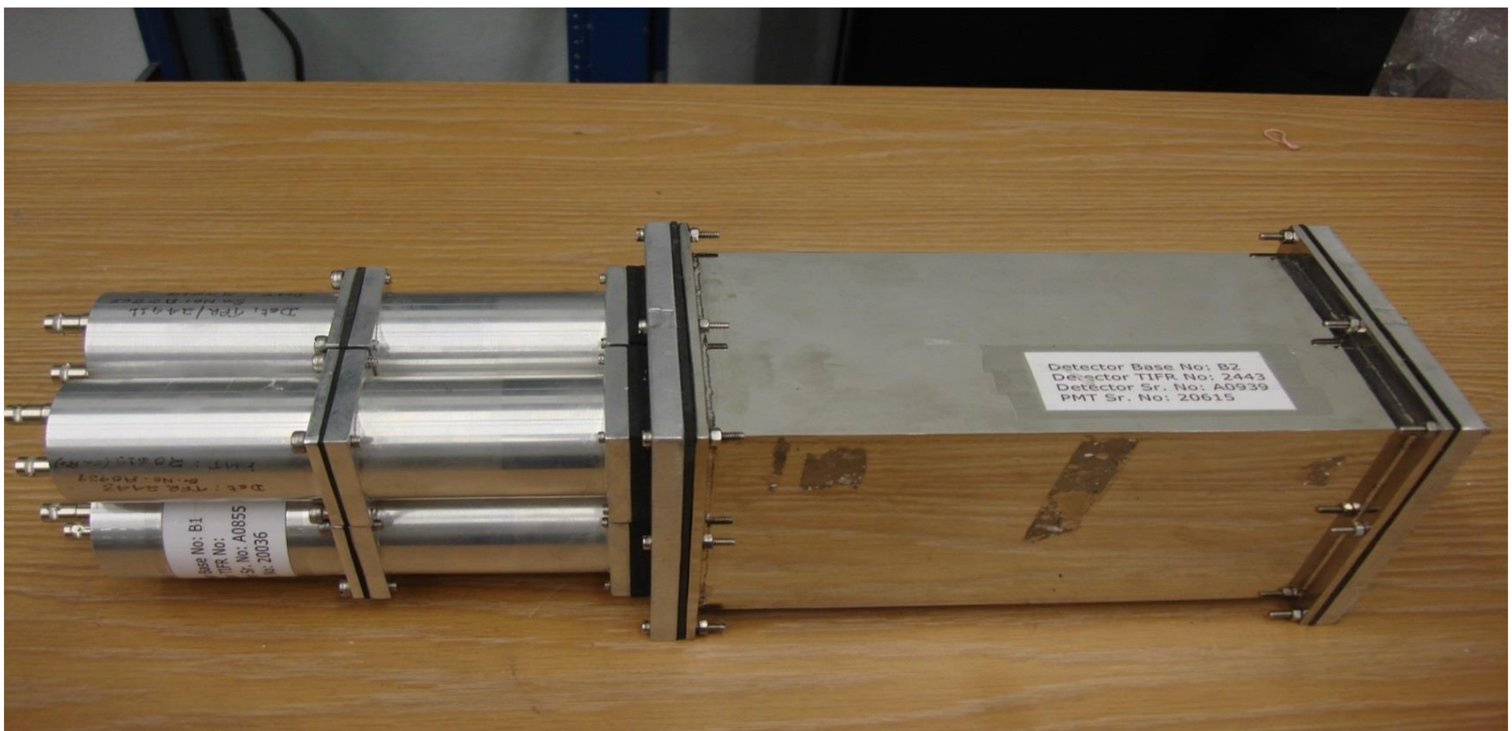


SiPM - MicroFB 60035

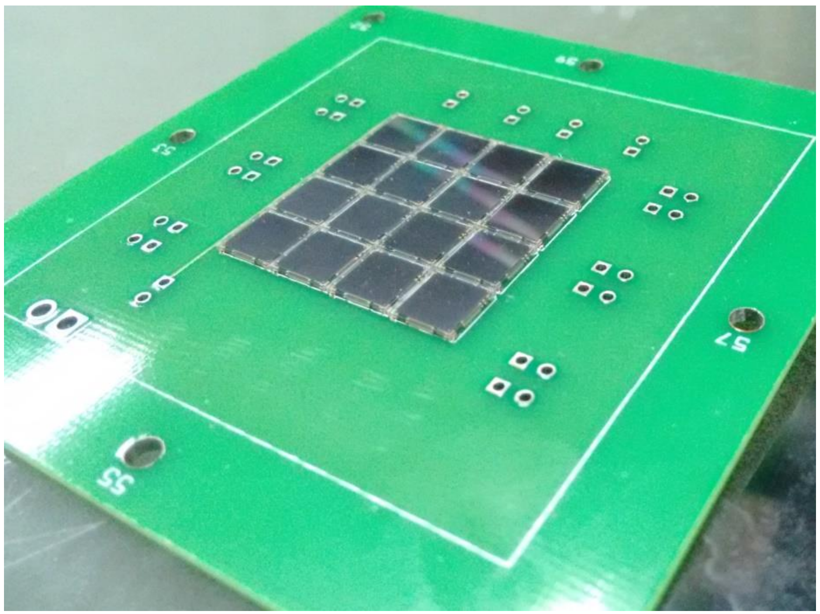
- Fast Rise Time, Blue Sensitive,
- Dimension: 7mm X 7mm
- Active Area: 6mm X 6mm
- Peak Wavelength: 420nm
- Spectral range: 300nm to 800nm
- No of Pixels: 18980
- Breakdown Voltage: +24V
- Overvoltage range: 0-5V

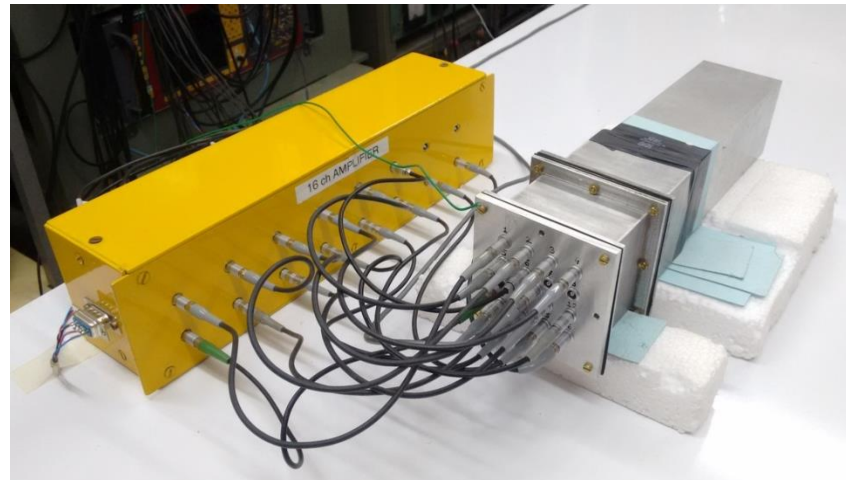
2" X 2" X 8"

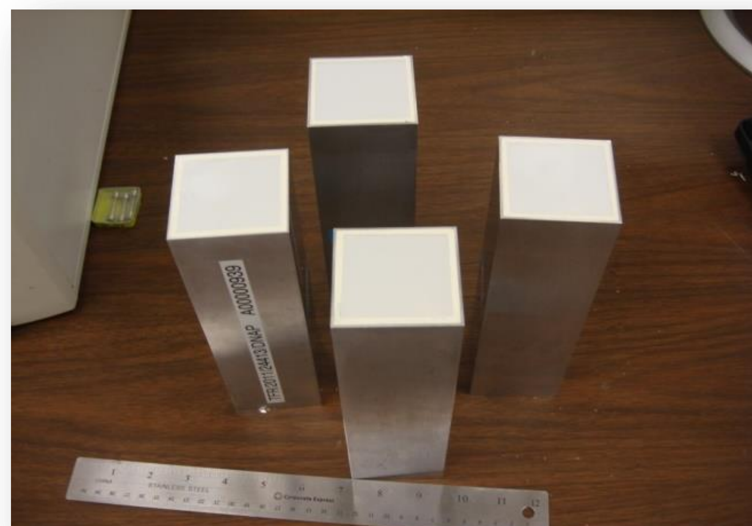




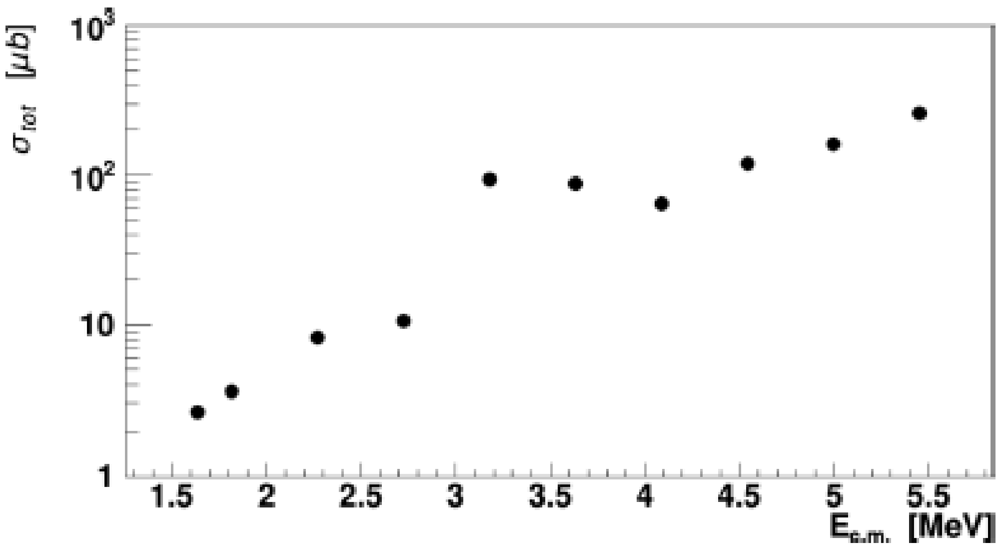
We plan to augment this array




16 ch AMPLIFIER



Some Physics Results



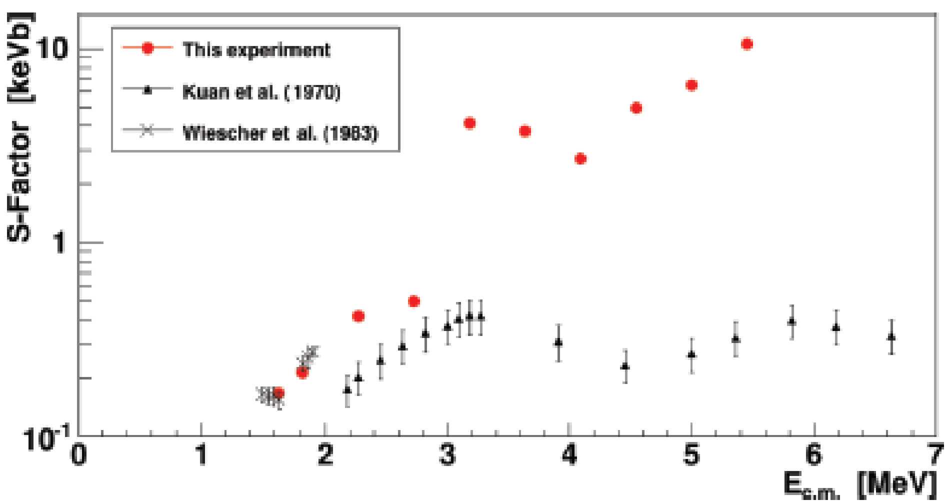
Excitation function of the total ^{11}C production cross section via The $^{10}B(p,\gamma)^{11}C$ reaction.

γ-Rays measured using large square bars of $LaBr_3$:Ce

Measurements done at TUNL, Duke Univ.

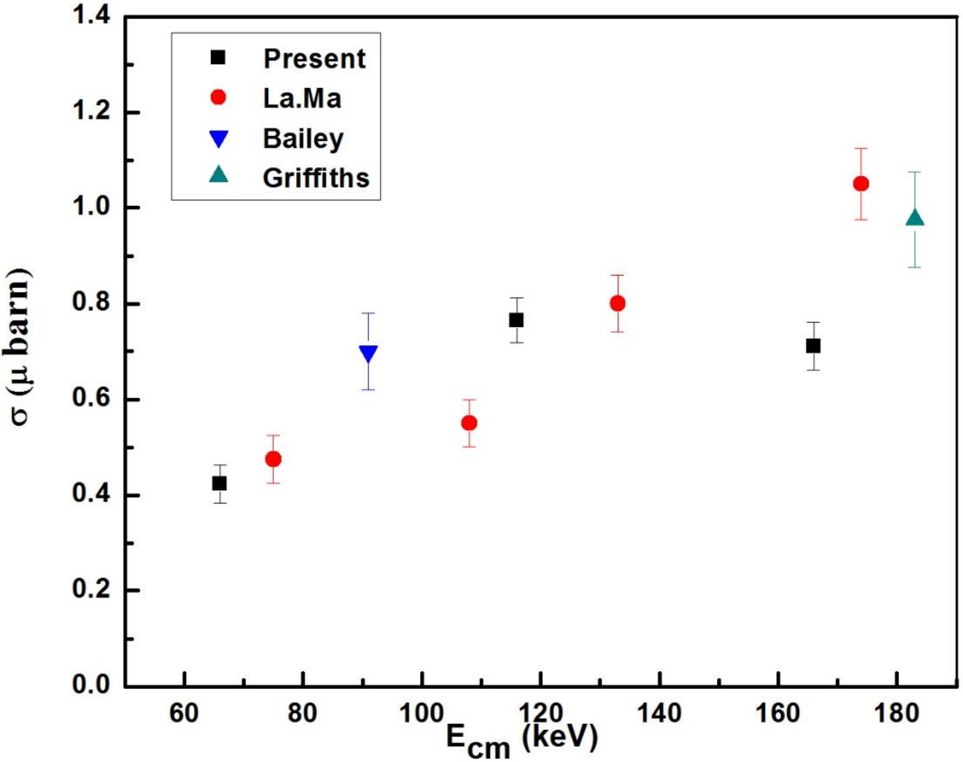
Astrophysical S factors for the $^{10}B(p,\gamma)^{11}C$ reaction.

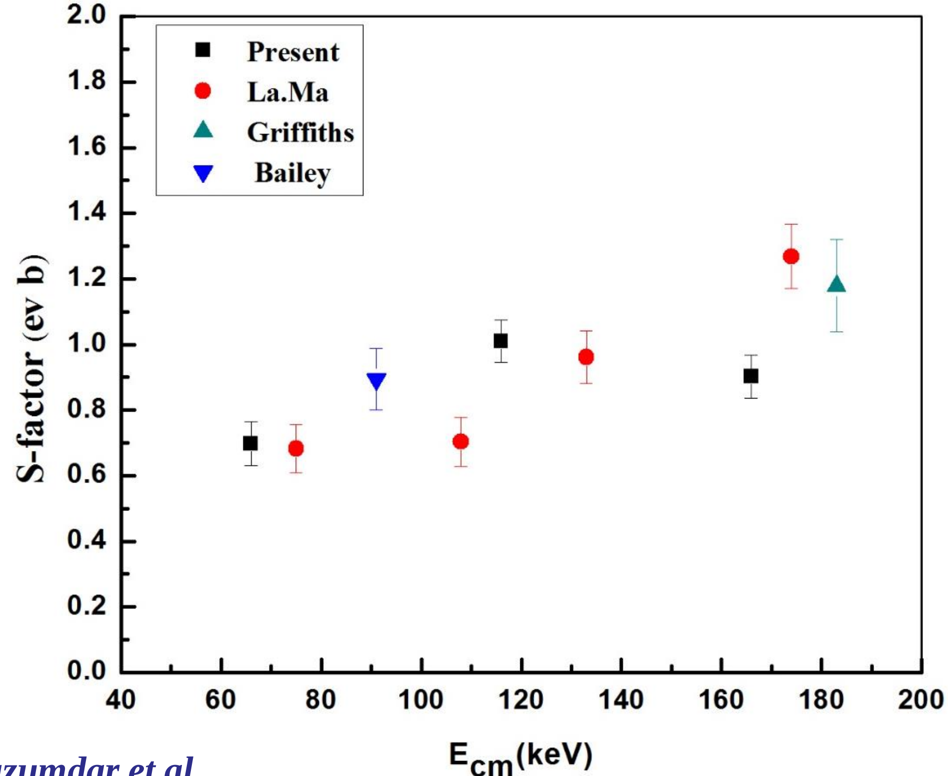
Kafkarkou et al.,
Phys. Rev. C 89 (2014)



Cross section and S-factor

$$d + p \rightarrow {}^{3}He + \gamma$$





Dhibar, Mazumdar et al, under review

E_{cm} (keV)	σ (μb)	S-factor (eV-b)
166.66	0.71±0.05	0.902±0.066
116.66	0.73±0.04	0.967±0.064
66.66	0.42±0.04	0.698±0.067

Grifffths *et al.,* Can. J. Phys. 41 ,724 (1963).

Balliey *et al.*, Can. J. Phys. 48 , 3059 (1963).

Ma *et al.,* Phys. Rev. C 55, 2 (1997).

Motivation

The measurement of $^{12}C(p,p'\gamma)$ cross section is important for both fundamental and applied nuclear physics
No optical model is successful in reproducing the data at low energy (5-30 MeV)
Structure of excited states and their decay to lower states.

Nuclear Structure:

- **Very little data available for 12.7 and 15.1 MeV states**
- **No *(p, p'γ)* data for 9.64 MeV state!**

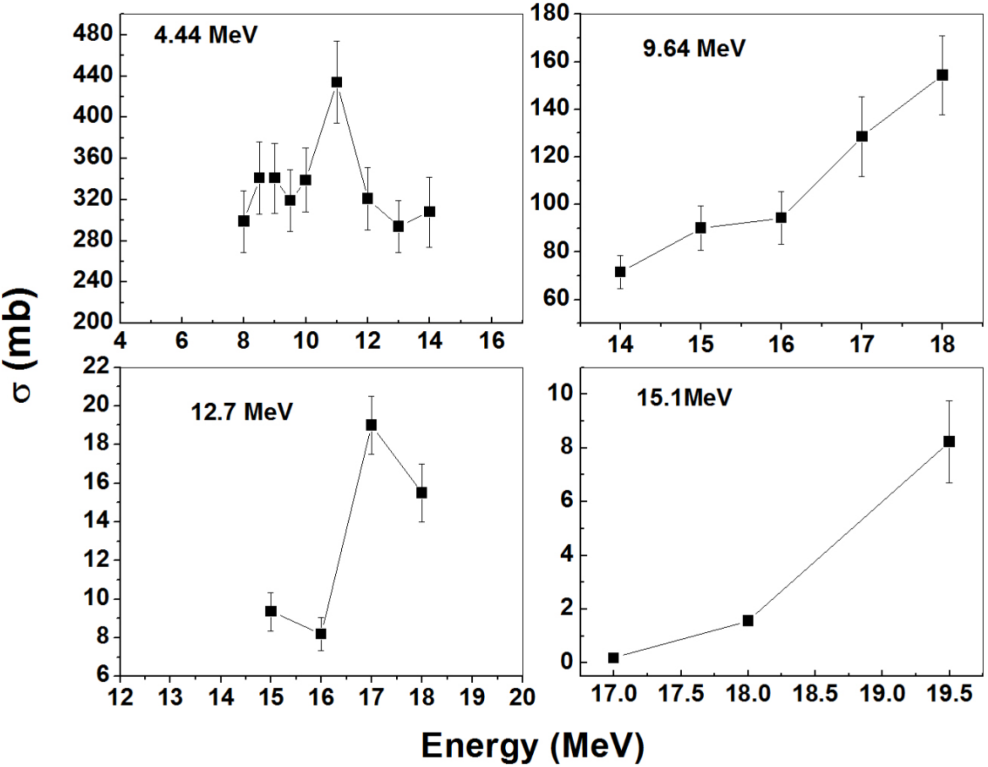
Astrophysical Importance:

γ-ray lines observed during solar flares have strong contribution for 15.1 MeV & 4.43 MeV line.

Ramaty *et al.*, APJ, 229, 1979; Murphy *et al.*, APJ Supplement Series, 215, 2014

State (MeV)	Beam Energy (MeV)	Angle(θ)
4.44	8	60°, 75°, 90°, 105°, 120°, 135°
	8.5	60°, 75°, 90°, 105°, 120°, 135°
	9	60°, 75°, 90°, 105°, 120°, 135°
	9.5	60°, 75°, 90°, 105°, 120°, 135°
	10	60°, 75°, 90°, 105°, 120°, 135°
	11	60°, 75°, 90°, 105°, 120°, 135°
	12	60°, 75°, 90°, 105°, 120°, 135°
	13	60°, 75°, 90°, 105°, 120°, 135°
	14	60°, 75°, 90°, 105°, 120°, 135°
9.64	14	60°, 75°, 90°, 105°, 120°, 135°
	15	60°, 75°, 90°, 105°, 120°, 135°
	16	60°, 75°, 90°, 105°, 120°, 135°
	17	60°, 75°, 90°, 105°, 120°, 135°
	18	60°, 75°, 90°, 105°, 120°, 135°
12.7	15	60°, 75°, 90°, 105°, 120°, 135°
	16	60°, 75°, 90°, 105°, 120°, 135°
	17	60°, 75°, 90°, 105°, 120°, 135°
	18	60°, 75°, 90°, 105°, 120°, 135°
15.1	17	60°, 75°, 90°, 105°, 120°, 135°
	18	60°, 75°, 90°, 105°, 120°, 135°
	19.5	60°, 75°, 90°, 105°, 120°, 135°
	20	90°,
	21	90°,
	21.5	90°,
	22	90°,

Total γ-Cross sections and Branching ratios



Energy Level (MeV)	14 MeV	18 MeV	19.5 MeV
9.64	.0035±.0003		
12.7		0.021±.0025	
15.1			0.79±0.19

Branching Ratios =$\sigma_\gamma / \sigma_{pp}'$

9.64 MeV σ_{pp}'	**70 mb ± 0.2**	**HARADA *et al.*, Journal of Nuclear Science and Technology, 36(4), 313, 1999.**
12.7 MeV σ_{pp}'	**15 mb ± 1.1**	**Daehnick *et al.*, Phys. Rev., 133, B934, Feb 1964.**
15.1 MeV σ_{pp}'	**8.3 mb ± 1.2**	**Warburton *et al.*, Phys.Rev.128, 4, 1962.**

Collaborators

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Thank You