

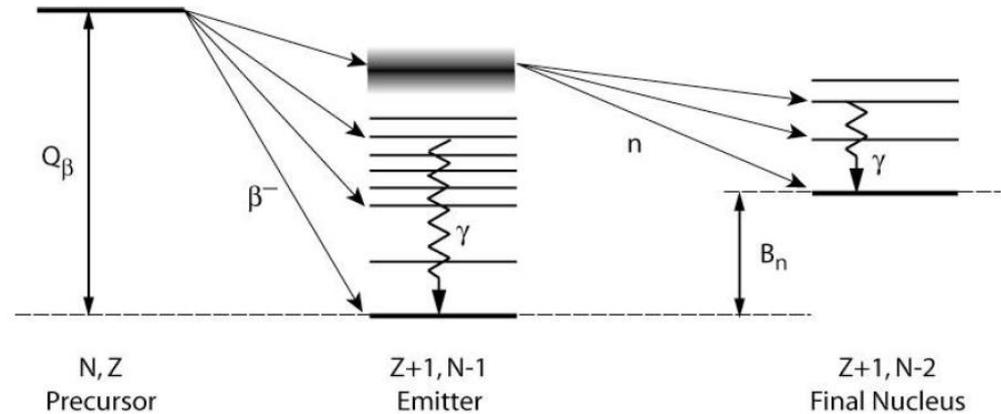
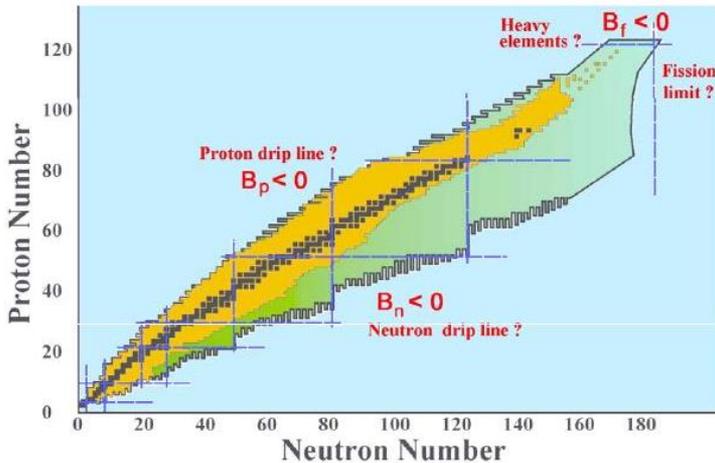
Overview of Neutron detector array MONSTER for DESPEC

Kaushik Banerjee

Variable Energy Cyclotron Centre

Motivation: Study the structure of neutron rich nuclei

For enough neutron rich nuclei S_n lies below Q_β ($Q_\beta > S_n$). If the decay proceeds to states above S_n neutron emission dominates over γ -ray de-excitation.



The accurate measurement of the half-lives, distribution of decay probabilities and particle emission probabilities provides essential data for the fields of **nuclear structure**, **astrophysics** and **nuclear technology**.

Nuclear structure:

To know the level scheme of neutron rich nuclei

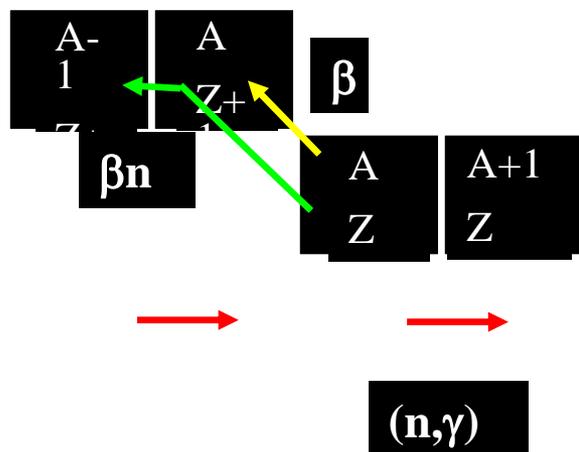
Modification of shell structure far off from stability (Look for the new magic number)

New effects near the driplines (halos, skins)

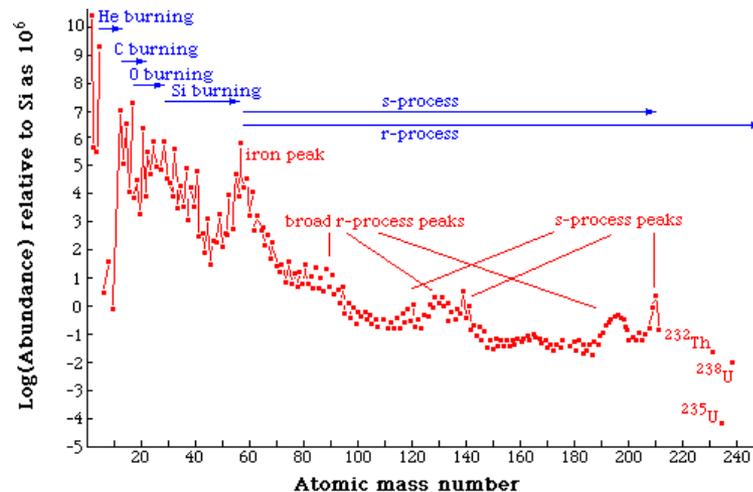
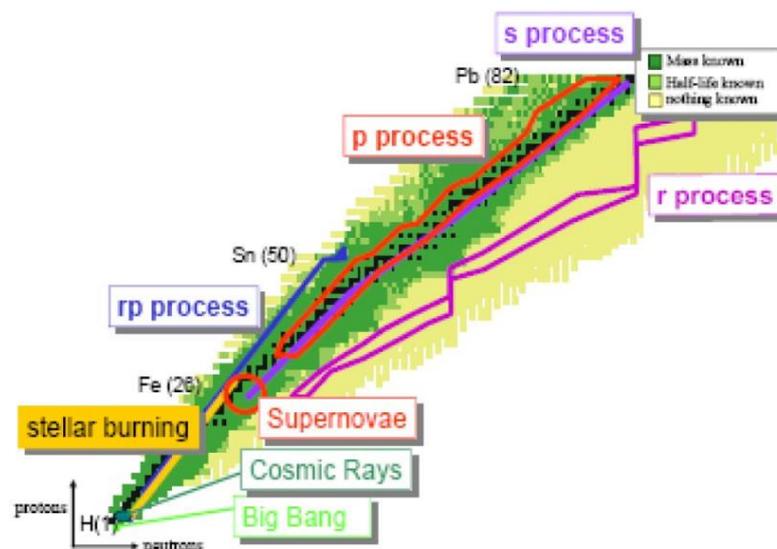
Study of nuclear level density as a function of iso-spin

Nuclear Astrophysics:

About half of the elements heavier than Fe are thought to be produced in a rapid neutron-capture process (*r*-process) nucleosynthesis, a sequence of neutron-capture and β -decay processes.



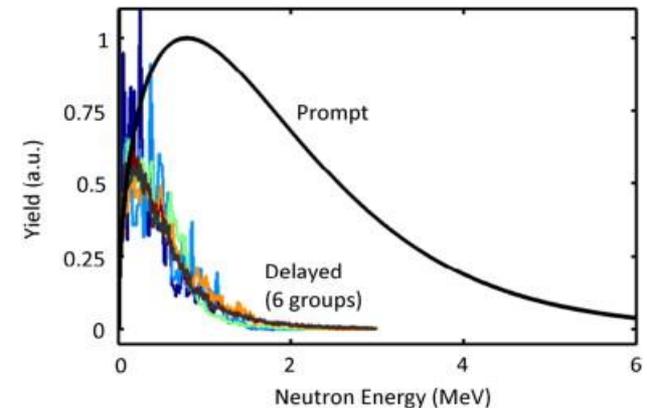
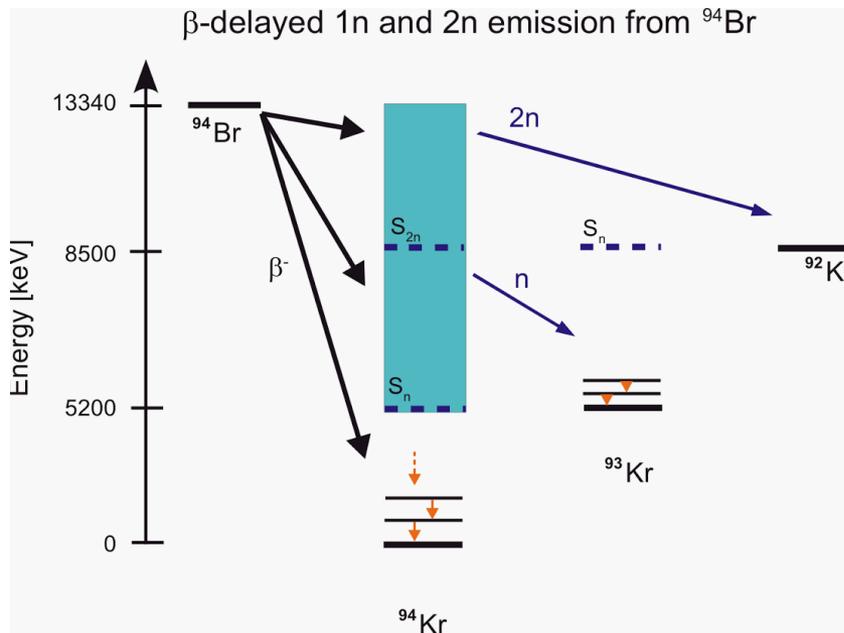
Elemental abundance



The *r*-process nucleosynthesis involves many neutron-rich unstable isotopes, whose masses, β -decay half-lives ($T_{1/2}$) and β -delayed neutron-emission probabilities (P_n), are crucial quantities to understand the possible *r*-process paths, the isotopic abundances, and the time scales of the process.

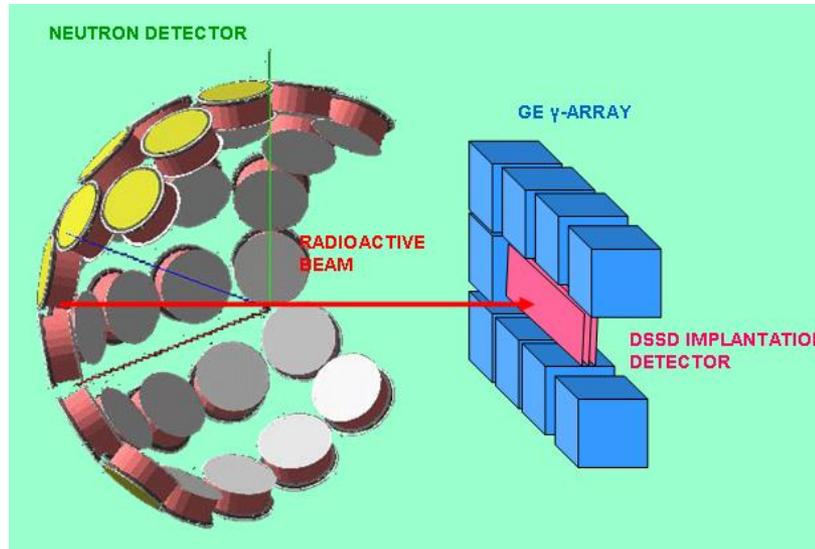
Nuclear Technology: Delayed neutron spectra from fission fragments.

- Some of the fission product undergo beta delayed neutron emission, which is essential to control the reactor (decay heat calculation), so value of P_n and neutron energy spectra are required.
- Fragment ^{94}Br , which beta decays to levels in ^{94}Kr , some of which are above the neutron separation energy. These levels decay by emitting a neutron.



Experimental Plan:

The selected nuclei from Super-FRS will be implanted in a sensitive detector at the focal plane, where the β -decays will take place.



Properties of neutron rich nuclei will be investigated through complementary detection systems consisting of an implantation detector for the detection of the implanted ions and their β -decays, and neutron and γ -ray detectors for the delayed neutrons and the γ -rays emitted along the entire de-excitation chain.

Half-life $T_{1/2}$ and the delayed neutron-emission probability P_n

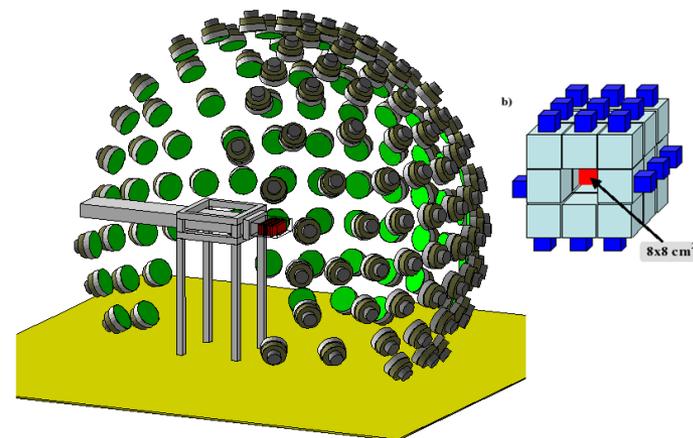
$$P_n = \frac{N_{n\beta}}{N_\beta}$$

$N_{n\beta}$ number of β decay going through neutron emission, N_β number of beta decay

Neutron neutron correlation => Direct/sequential decay

Proposal to develop a spectrometer MONSTER => **Modular Neutron Spectrometer** => Determine the energy spectra and emission probabilities of β delayed neutrons with high resolution.

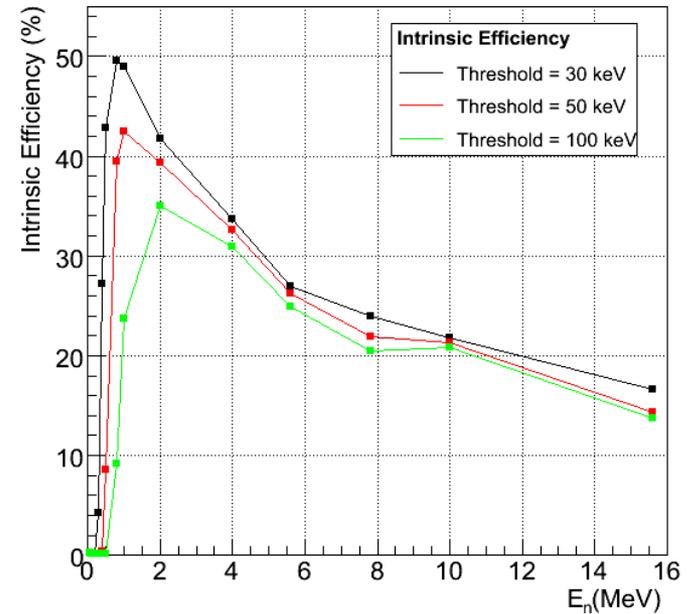
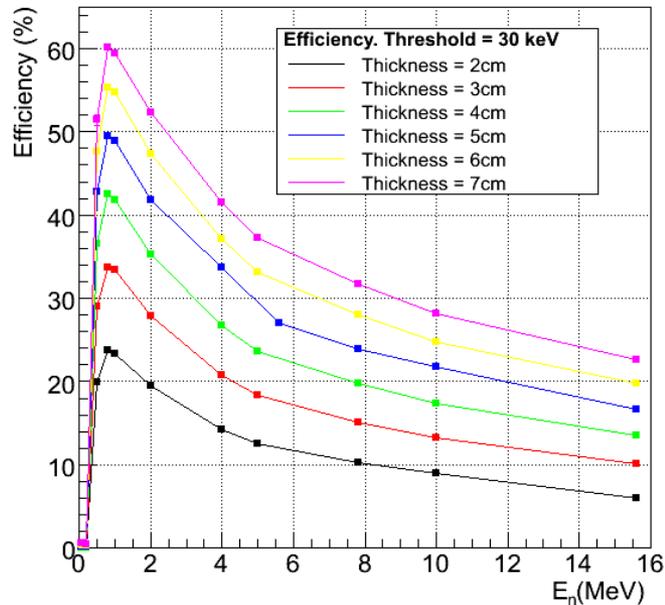
- Cylindrical cell of 20 x 5 cm filled with BC501A
 - Reasonable intrinsic efficiency (~50% @ 1MeV)
 - Energy threshold ~ 30 keVee ($E_n \sim 100$ keV)
 - Reasonable energy resolution < 10% up to 5 MeV:
 - Good neutron timing ~1ns
 - Reasonable flight path 2-3 m TOF
 - Good total efficiency: 100 detectors
- Typical Neutron Energy range : 50/100 keV – 20 MeV



200 detectors, 10cm radius		$\Delta E/E$ @ 1 MeV
TOF distance (m)	Geometric efficiency	1ns
2	12.5%	3.5%
3	5.6%	2.5%

Simulation Study:

The intrinsic efficiency of the cell is strongly affected by the detector volume and by the detection threshold, because of the light yield response.



Efficiency vs thickness and threshold

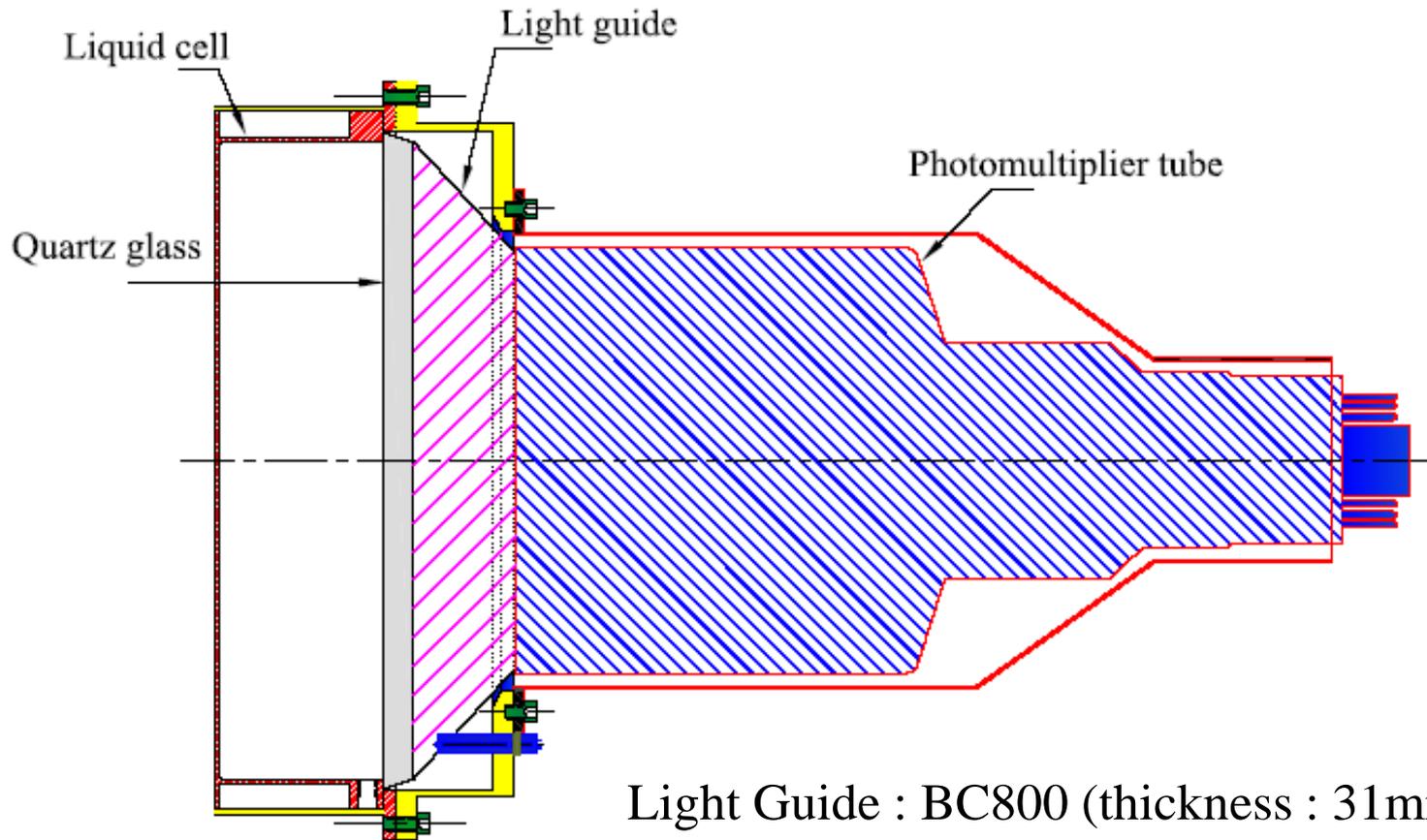
Cell 10 cm radius 5cm thickness

A R Garcia *et al*, IOP Journal of Instrumentation 7C, 05012 (2012)

T. Martnez et. al., Nuclear Data Sheets 120 (2014)

MONSTER cell assembly drawing

$\varnothing=20\text{cm}$, $L=5\text{cm}$



Light Guide : BC800 (thickness : 31mm)

Liquid sealing: quartz glass (9.3 mm)

PTFE Teflon pipe capillary tube

Al structure = 6061-T6

Optical fibre connection for gain matching

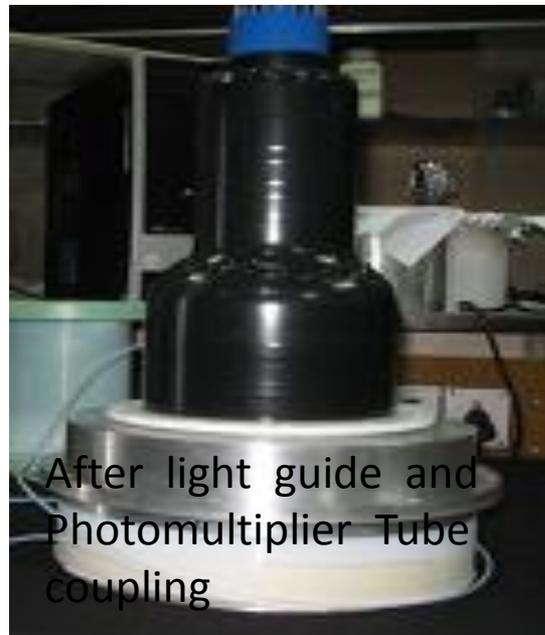
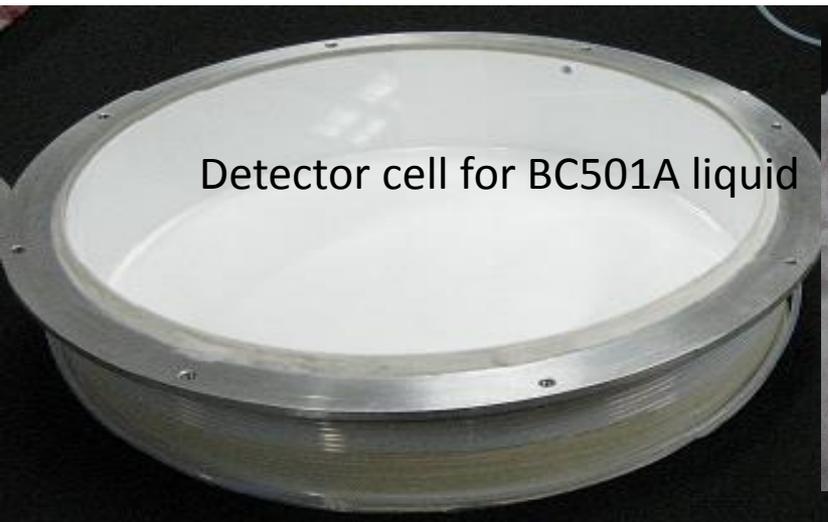
Liquid Scintillator : BC501A

Reflection coating = BC630

Optical Fibre : BCF 98MC

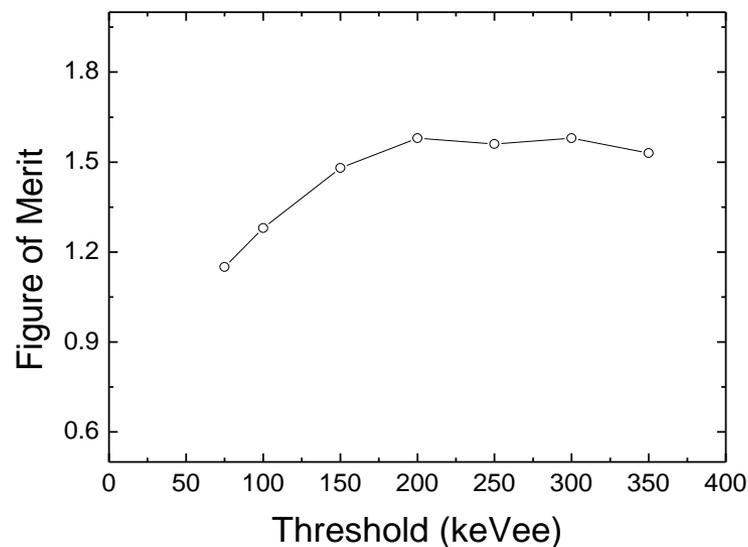
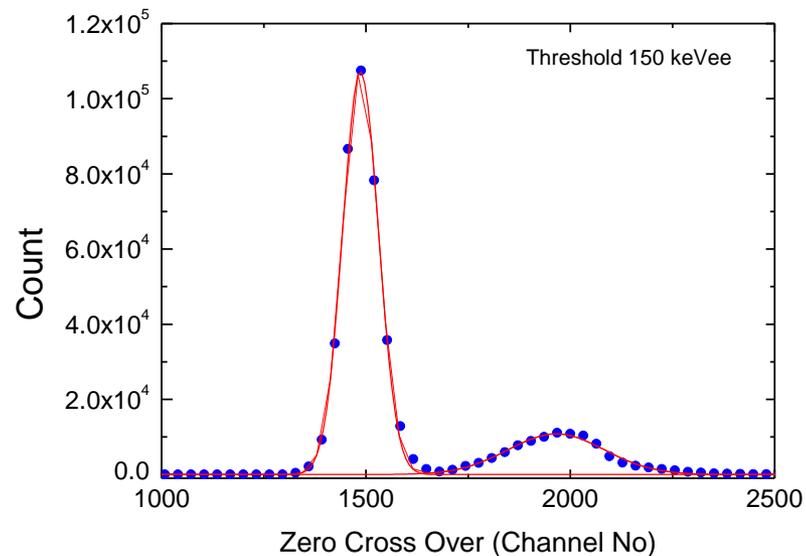
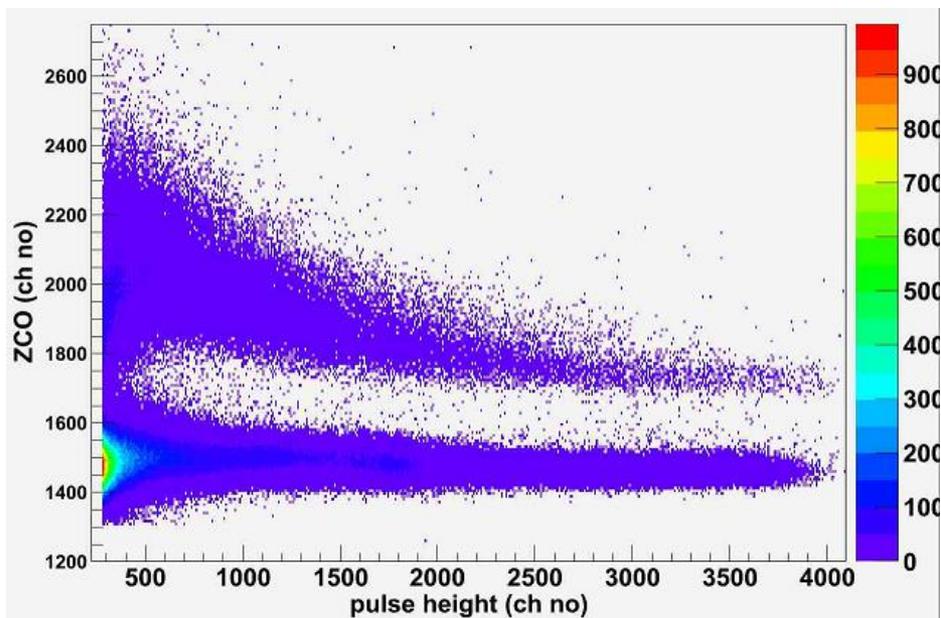
PMT: Hamamatsu R4144

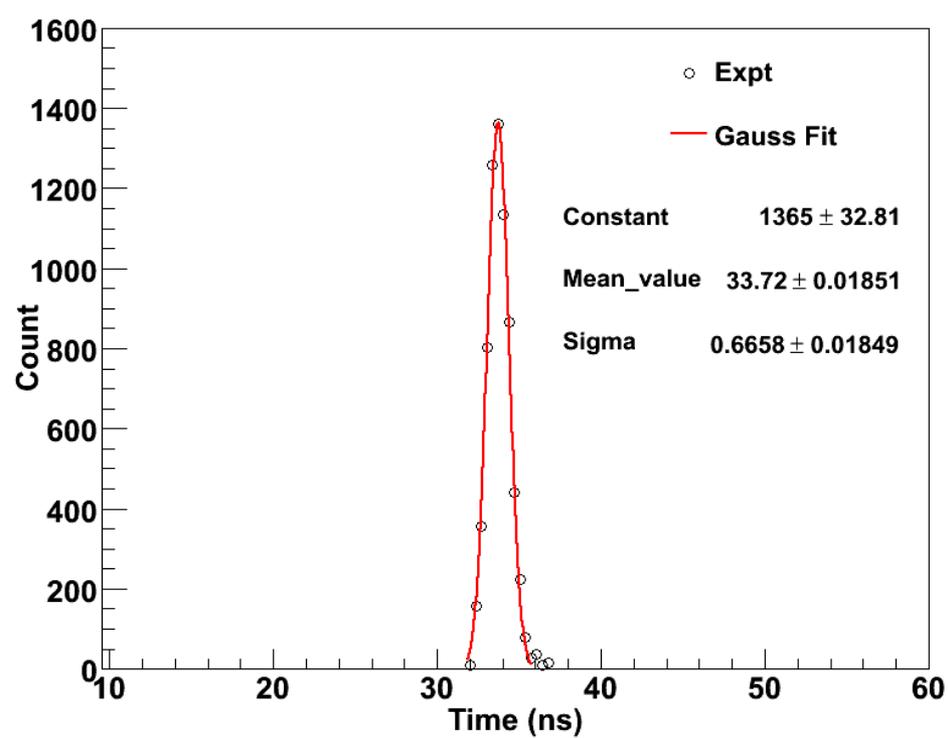
Proto-type detector fabricated at VECC



Pulse shape discrimination property

Pulse shape discrimination (PSD) property of the detector was studied by the zero cross over (ZCO) technique using Am-²⁴¹Be neutron source using Mesytec MPD4 module

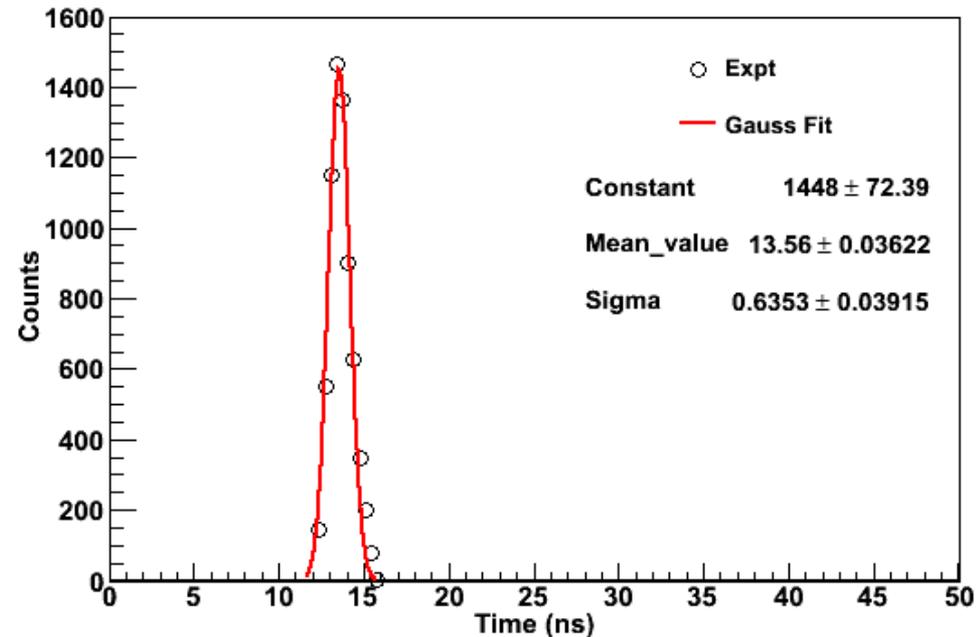




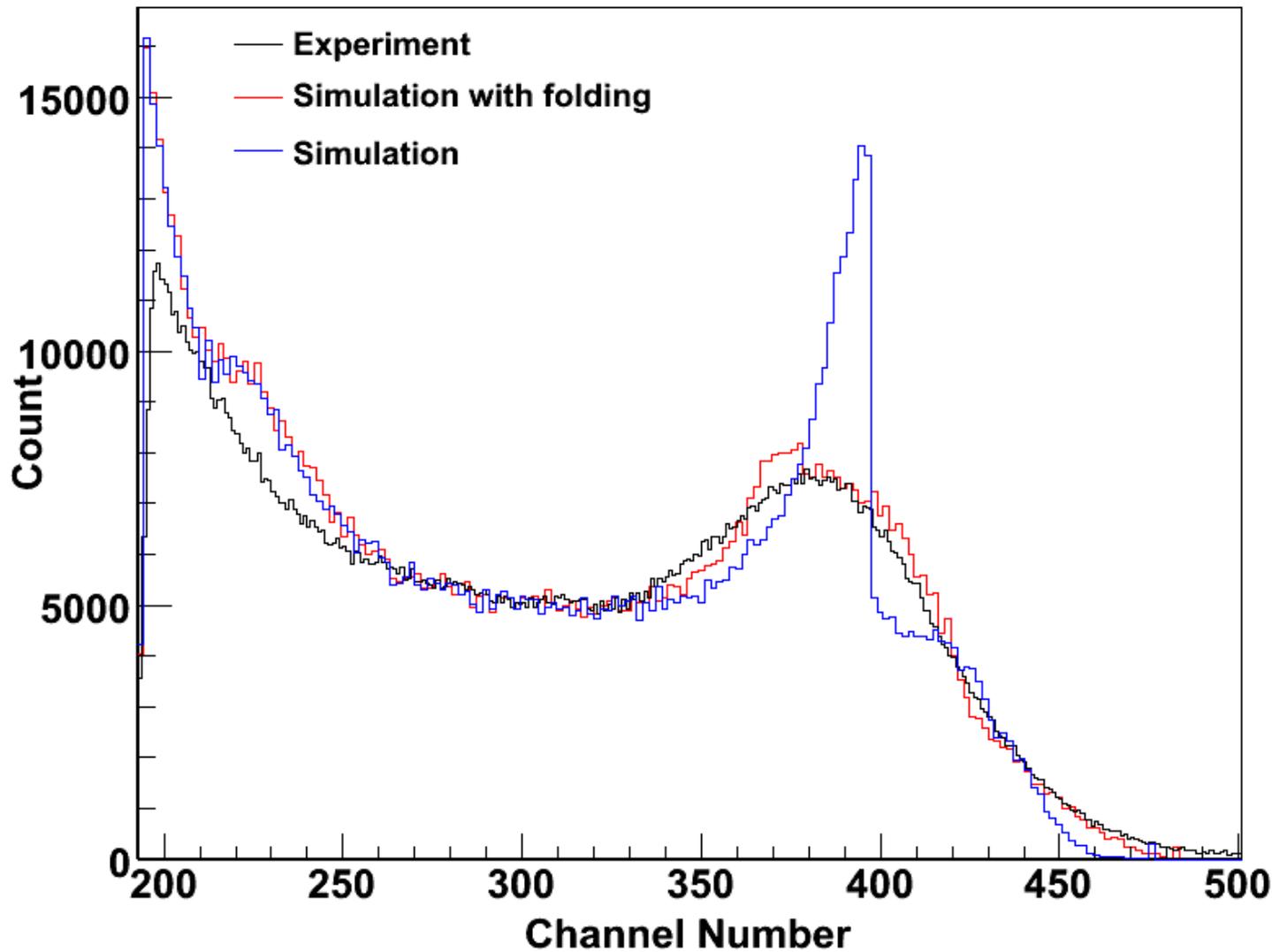
Timing spectra between two BaF₂ detectors (5cm x 3.5cm x 3.5cm)

Timing spectra between BaF₂ detector and MONSTER cell

The intrinsic time resolution of the neutron detector was found to be ~ 0.635 nsec at a threshold of 100 keVee.

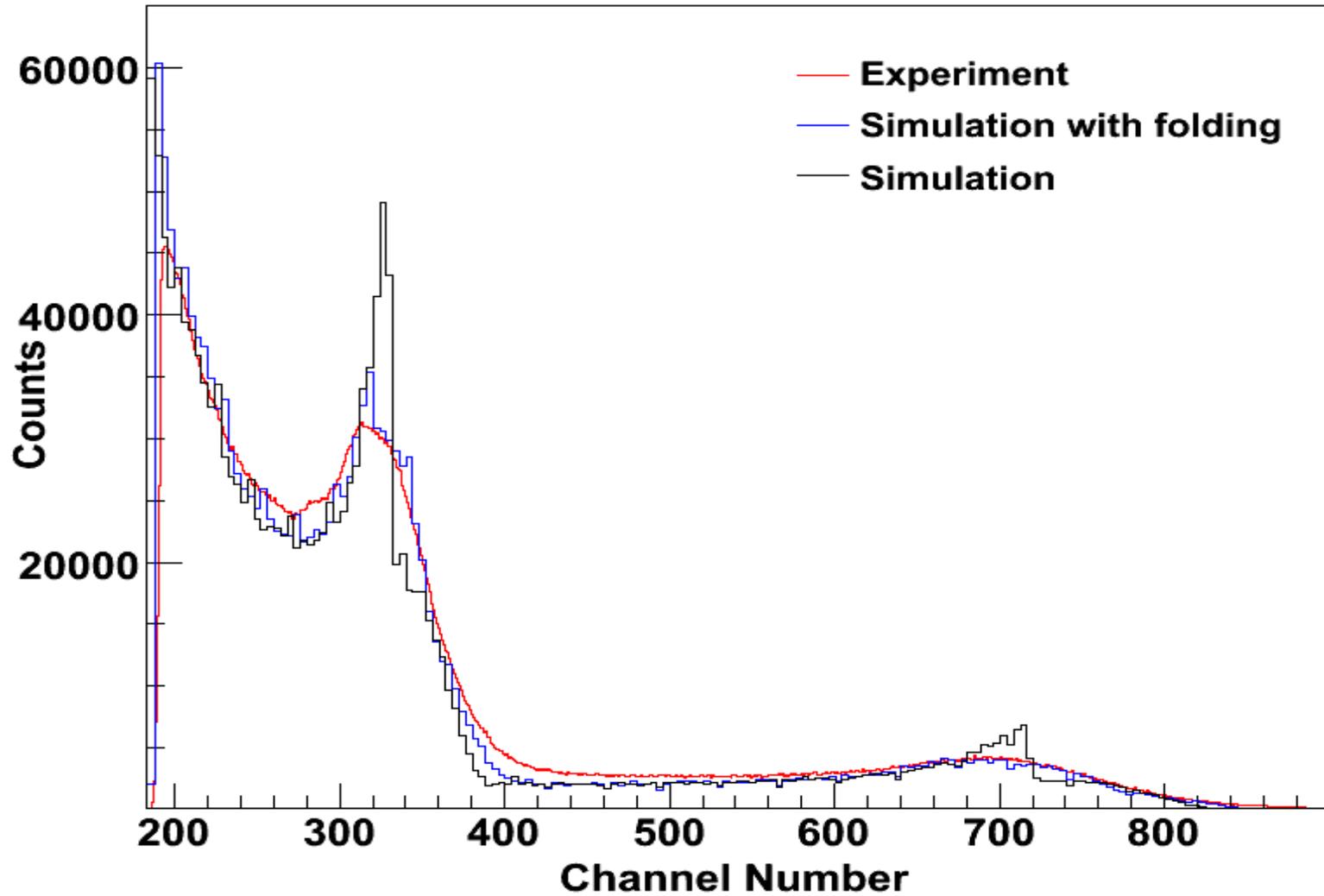


Pulse height spectra of ^{137}Cs γ source

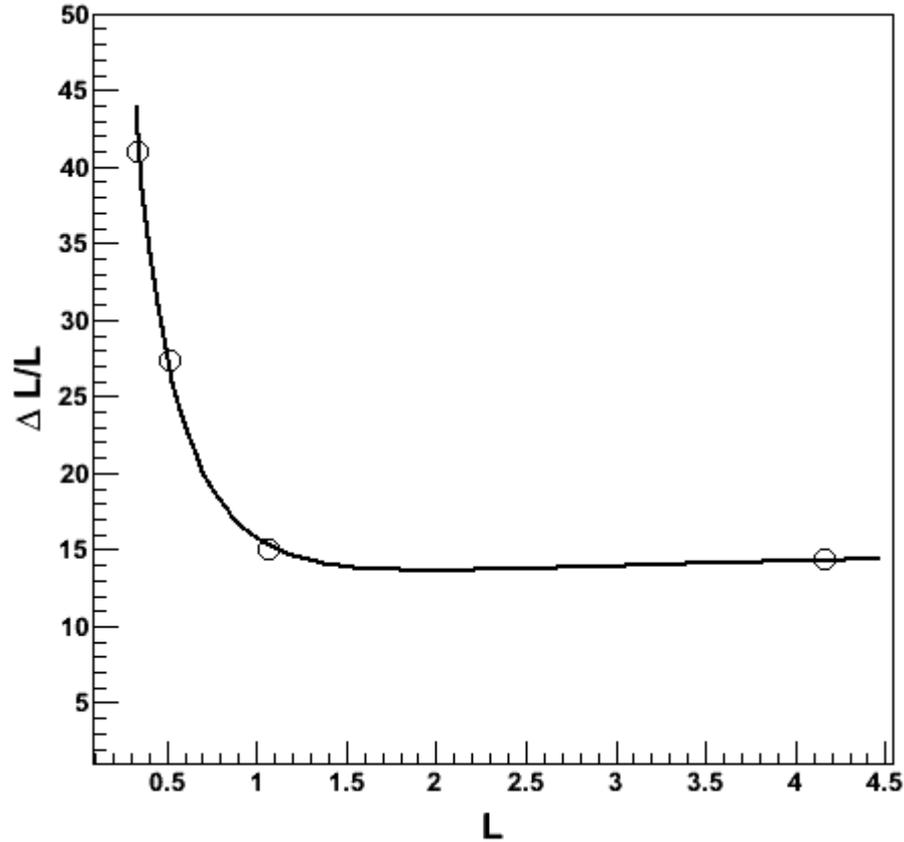


Simulation done using PHRESP code. The width of the Gaussian distribution which gives the pulse height resolution at the Compton edge, was found to be around 10% at 477 keV in the present case.

Pulse height spectra of ^{22}Na γ source

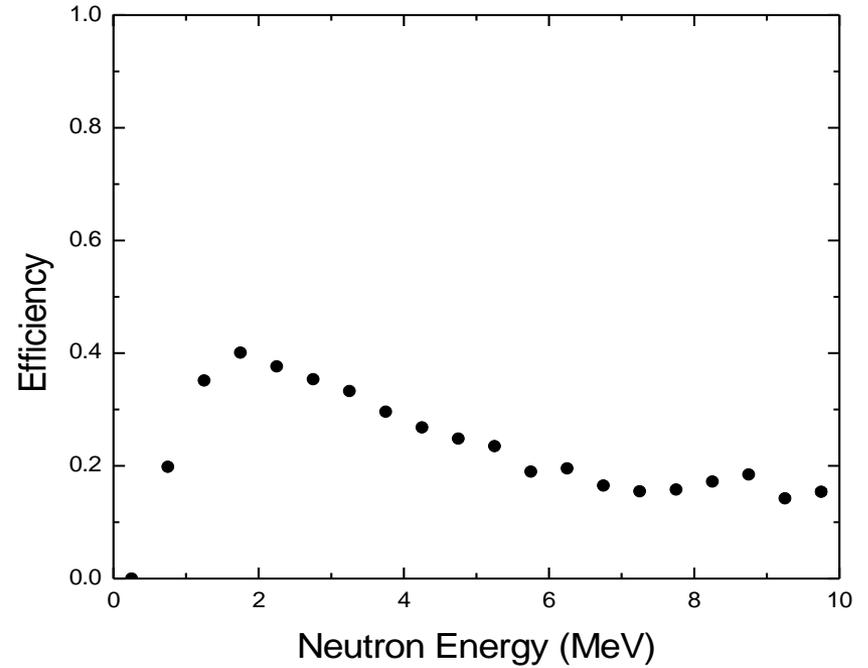


Pulse height resolution of the detector

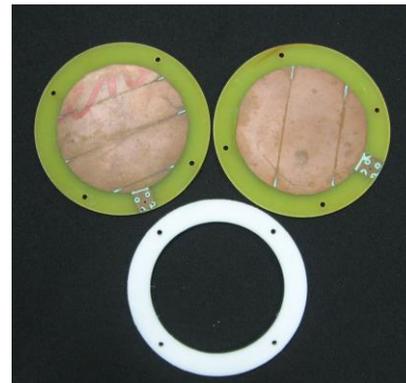


K Banerjee, Proceedings of the International Symposium on Nuclear Physics, BARC, Mumbai, India, Vol 58, Page 886 (2013).

Efficiency Measurement using ^{252}Cf source placed inside an ionization chamber



^{252}Cf source
mounted inside the
ionization chamber



Present status in VECC:
One prototype detector
build and characterisation
done.

Mechanical fabrication of
nine detectors housing
completed. PMT and mu
metal shield for 10 detectors
ready.

Project submitted to Indo-
FAIR council for the funding
of 50 detector.



Preliminary testing with digitizer card
(FASTER) is under process.

Readout electronics

Exploring digitizer

FASTER project => Faster Acquisition System on Ethernet network 1Gbits/s

LPC Caen, D. Etasse et al.

CFD + QDC: 12 bit, 500MHz, 2.4 V dynamic range

4 Channel

ROOT Histogram Builder for plotting data from FASTER

Running in a trigger less mode

Need to explore

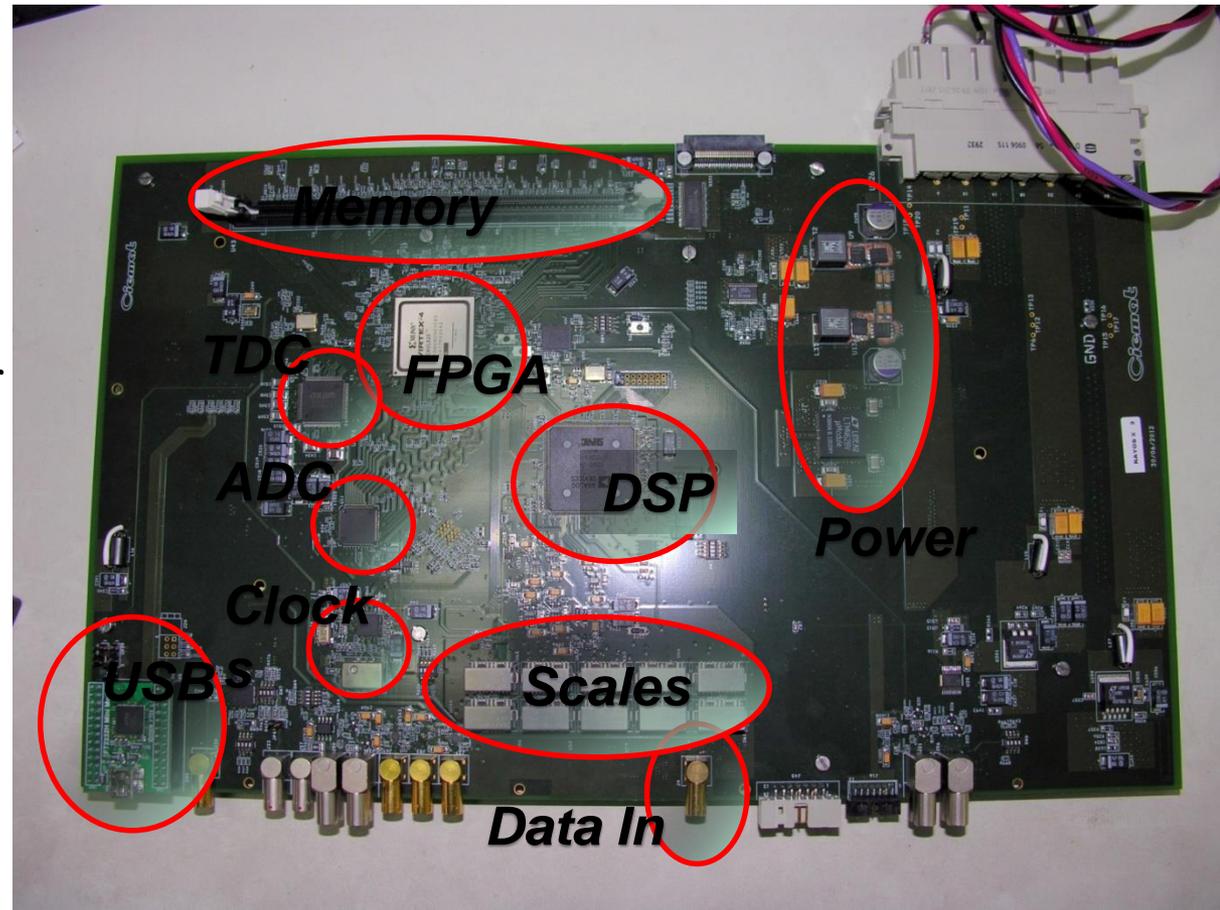
- synchronisation of the different channels and crates.
- triggered mode of operation.

Status of the MONSTER at CIEMAT Spain



Detectors: 45 detectors are ready.

Digitizer Board: A digitizer of 12bit resolution and 1Gsample/s sampling rate is being developed at CIEMAT.



First experimental demonstration of MONSTER in ISOLDE, CERN during October 2014 for complete Spectroscopy of ^{11}Li

30 MONSTER modules used,
total 40 neutron detectors

By simultaneous measurement of, **Beta, gamma, and neutrons**

Decay spectroscopy of ^{11}Li

$Q_{\beta} = 20 \text{ MeV}$

Weakly bound daughter

^{11}Be ($S_n = 0.5 \text{ MeV}$)

$P_{2n} = 4.2 \%$

$T_{1/2} = 8.7 \text{ ms}$

19 shifts

FASTER used for data taking.

HPGe detectors

Neutron detectors

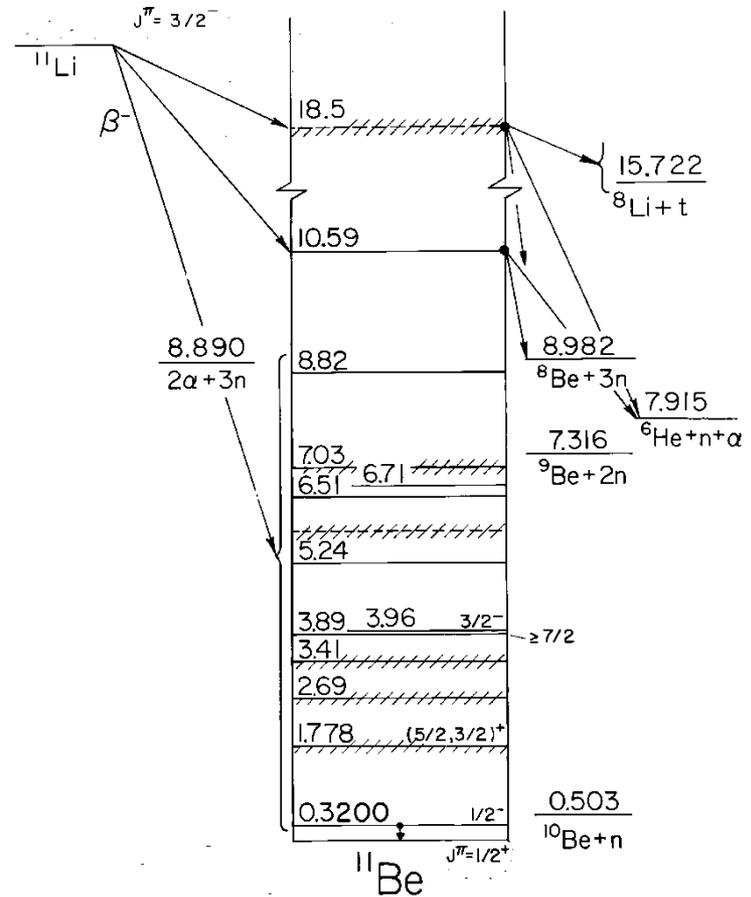
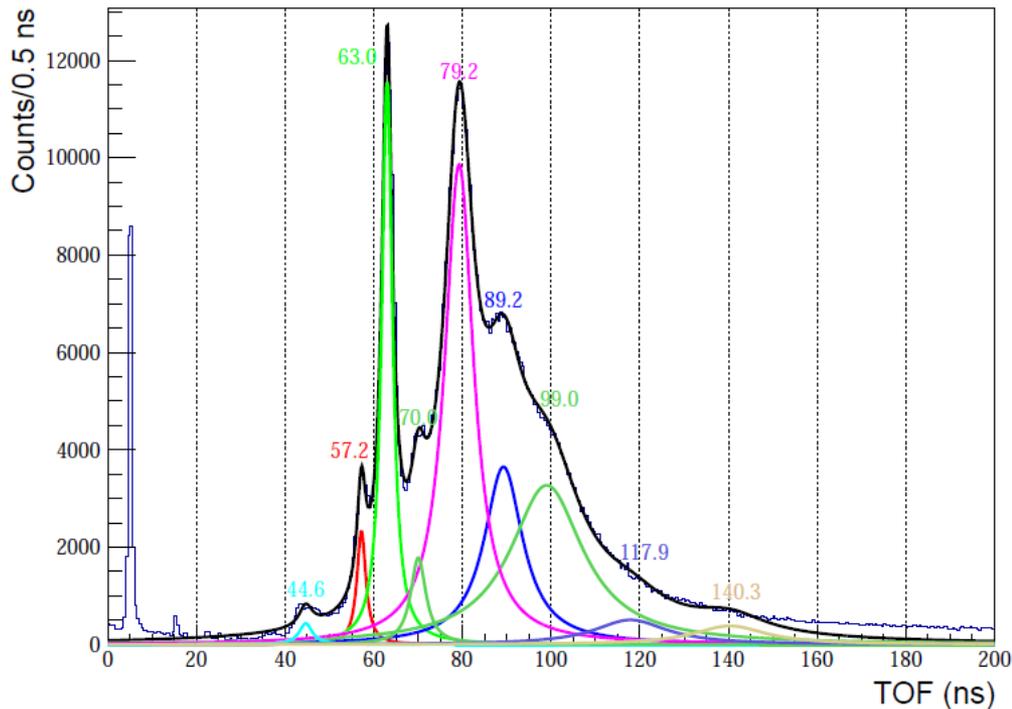


Plastic Scintillator detector inside the Chamber

1.4 GeV proton beam from PS incident on Tantalum Target
 Which generates ^{11}Li ,
 Separated at GPS and delivered at LA1 beam line, ^{11}Li beam
 intensity (1000 p/s)

$^{11}\text{Li} \beta\text{-1n}$ Neutron TOF spectra

$^{11}\text{Li} \beta\text{ n decay}$



Monster Modules used in in-beam experiment at K130 Cyclotron in VECC



Angular momentum dependent of nuclear level density
Shell effect in nuclear level density in ^{208}Pb region
Fade out of collectivity in nuclear level density

Project Status:

- TDR accepted in FAIR council on July 2014.
- Project submitted to BI-IFCC on March 2014.
- One proto-type detector has been successfully demonstrated at VECC. First batch of actual detector fabrication under process.
- 45 detectors are ready in CIEMAT, Spain. Working on digitizer for in-house development.
- Experimental demonstration of MONSTER has been done in October 2014 at ISOLDE, CERN, where decay spectroscopy of ^{11}Li has been performed.
- Presently working on digitizer board “FASTER”
- We are also working on IAEA research project on “beta delayed neutron emission”.

Collaborators

CIEMAT, Madrid, Spain

IFIC, Valencia, Spain

University of Jyvaskyla, Finland

Variable Energy Cyclotron Centre, Kolkata, India

Bhabha Atomic research Centre, Mumbai, India

Panjab University, Chandigarh, India

University of Uppsala, Sweden

LPC – Caen, France

Thank You

Budget for Indian participation is 6.14 Cr (0.8MEero).

Model	Form factor	Resolution	Bandwidth	Sampling Rate	Memory	Channels/price	Coupling	Prog. FPGA
NI PXIe-5170R	PXIe	14 bit	100 MHz	250 MS/s	1.5 GB	9470€/8ch= 1183.75€/ch	AC/DC	Yes
AlazarTech ATS9350-2G	PCIe	12 bit	250 MHz	500 MS/s	2 GS	8645€/2ch= 4322.5€/ch	AC/DC	No
Spectrum M4i.4451-x8	PCIe	14 bit	250 MHz	500 MS/s	2GS	9690€/4ch= 2422.5€/ch	AC/DC	No
SP Devices ADQ14DC-4A	PCIe/PXIe	14 bit	250 MHz	500 MS/s	2 GB	8500€/4ch= 2125€/ch	DC	Yes
Keysight U5309A	PCIe	8 bit	500 MHz	1 GS/s	128 MS (up to 2 GB)	19712€/8ch= 2464€/ch	DC	Yes (not included in price)
NI PXIe-5160	PXIe	10 bit	500 MHz	1.25 GS/s	2 GB	13200€/4ch= 3300€/ch	AC/DC	No
SP Devices ADQ14DC-4C	PCIe/PXIe	14 bit	500 MHz	1 GS/s	2 GB	9900€/4ch= 2475€/ch	DC	Yes (not included in price)
Keysight U1065A	cPCI	10 bit	Up to 2GHz	2GS/s (4 ch)	128 MS (up to 1 GS)	24388€/4ch= 6097€/ch	AC/DC	No
Keysight M9703A	AXIe	12 bit	650 MHz	1 GS/s	1 GB (64 MS/ch)	58636€/8ch= 7329.5€/ch	DC	Yes (not included in price)