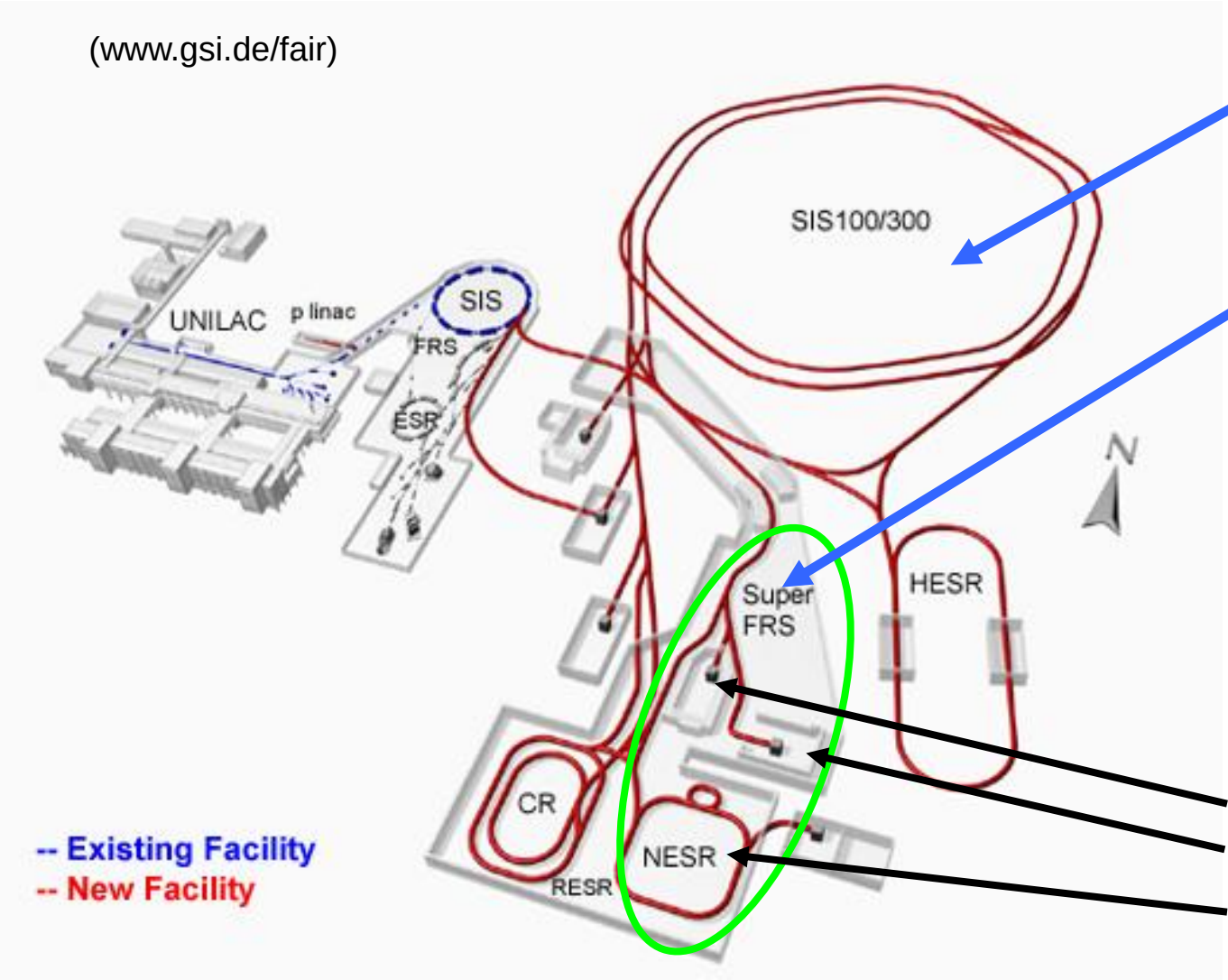
MONSTER: a Modular Neutron SpectromeTER for β-delayed neutron measurements

CIEMAT (Madrid, Spain)

IFIC – Valencia, University of Jyvaskyla, VECC – Kolkatta,

The FAIR facility

(www.gsi.de/fair)



Primary beams:
Z= -1 to 92
I = 100-1000 fold
Energies up to 30 GeV/u

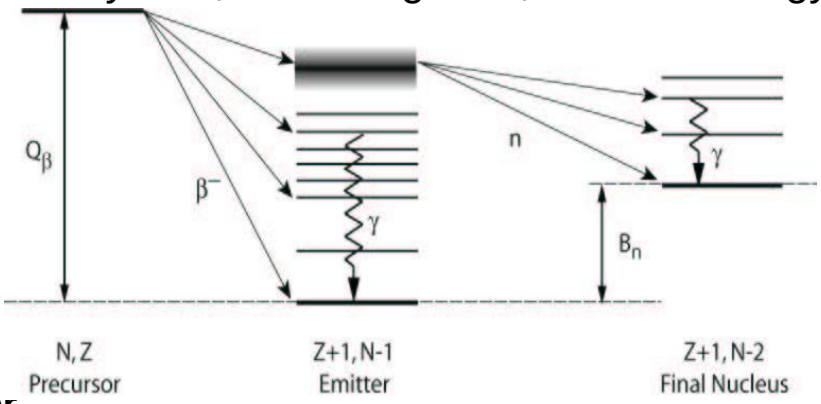
Radioactive secondary beams
Fission / Fragmentation
Energies up 2 GeV/u
I = 10000 fold

Nustar Collaboration
RIB, S-FRS

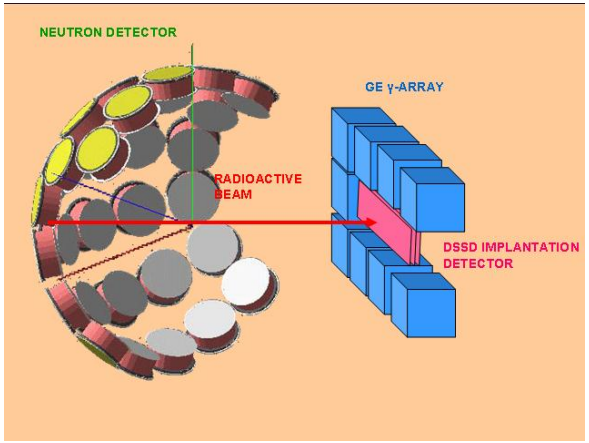
High Energy Branch
Low Energy Branch
Ring Branch

DESPEC Experiment (decay properties)

DN data: absolute neutron yields, branching ratio, neutron energy spectra



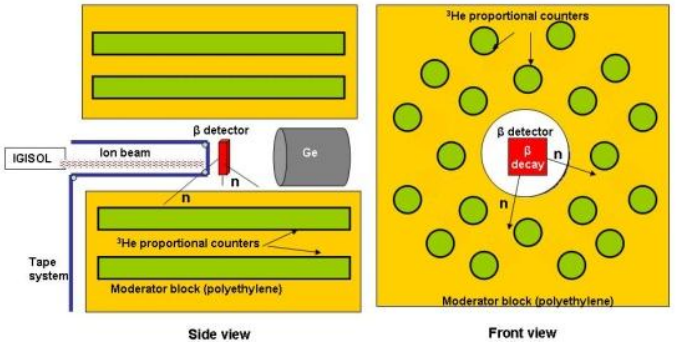
ToF spectrometer (neutron spectroscopy)



Segmented Ge Gamma detector

AIDA Implantation detector

4π neutron Detector (Pn branching ratio)



MONSTER will be used to determine the energy spectra and emission probabilities of β delayed neutrons with high resolution

Ideal Neutron TOF spectrometer design

Requirements for neutron spectroscopy:

(Conclusion of "workshop on neutron detectors for decay experiments", Madrid, 2006)

- n-γ discrimination, →reduce backgrounds,
- High ε_n → large solid angle, thick detectors (identification when low emission probabilities)
- Improved $\Delta E/E$, → thin detectors, large flight path
- Lowest threshold, → (down to 30 keVee?) allow increase efficiency
- cross-talk rejection,→ modular, high granularity >100 cell, identification of n,2n,3n
- Digital electronics → control of systematics

Liquid organic scintillator NE213/BC501A/EJ301 best discrimination performance, (crystal organic as well as new scintillation materials)

Constraint: Cost

CIEMAT coordinates the design and construction of a demonstrator for DESPEC

Status of the Project

Work done / in progress:

- Design of the spectrometer based on extensive Montecarlo simulations
- Purchase of cell prototype,
- Characterization of prototype with γ-sources & mono-energetic neutron beams (PTB, CEA)
- Purchase of detector cells and PMTs (demonstrator)
- Construction and test of a prototype at VECC (India)
- Design and building of mechanical structure
- Development of digital electronics (waveform digitizer)
- Design DAQ system, hardware and software

Next to be done:

- Tests with assembled detectors demonstrator configuration, 30 cells
- Test of digitizers with detectors and sources
- Testing demonstrator with delayed neutrons precursors

Monte Carlo simulation

Work already done:

- Simulation codes based on GEANT4 packages.
- Validation of neutron transport with other codes (MCNPX, NRESP)
- Nuclear cross section data from evaluated libraries (ENDF, JEFF, JENDL…)
- Implement light scintillation model based on Dekempeneer light functions (NIMA256(1987)489), with experimental resolution function.
- Implementation of geometry: Cylindrical cell and rectangular bar (NE213).
- Characterization of design parameters (efficiency, time and energy resolution) as a function of cell dimensions and detection energy threshold.
- Implement light collection processes.
- Optimization of prototype design.

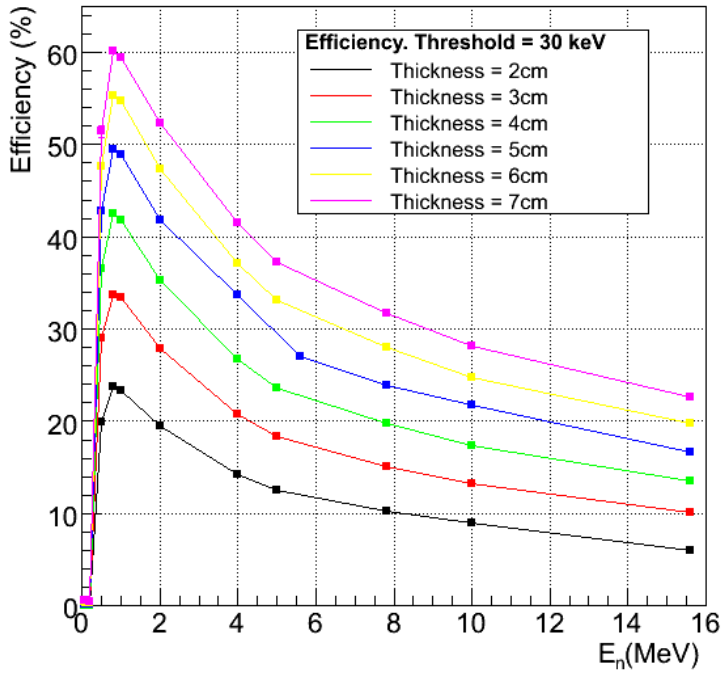
- Influence of implantation setup in terms of attenuation, Tof/Energy resolution …

Next :

- Definition of cross-talk (optimization)
- Influence of complementary set-ups (Ge detectors) and mechanical structure
- Simulation of a complete experiment

MC simulation: Intrinsic efficiency TOF resolution

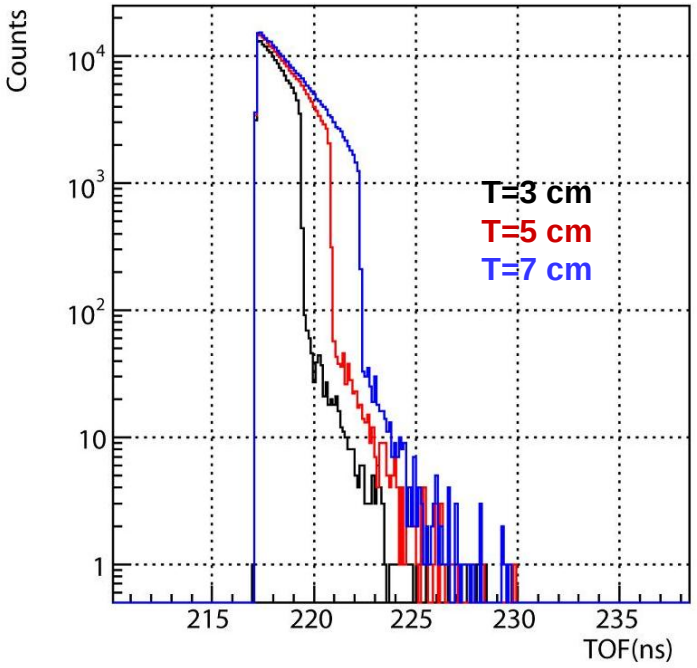
The intrinsic efficiency of the cell is strongly affected by the detector volume and by the detection threshold



Cell 10 cm radius

TOF depends:

- Intrinsic time resolution ~1ns (+4ns)
- Neutron transit time (thickness) ~7ns
- Multiple scattering (threshold) ~ms



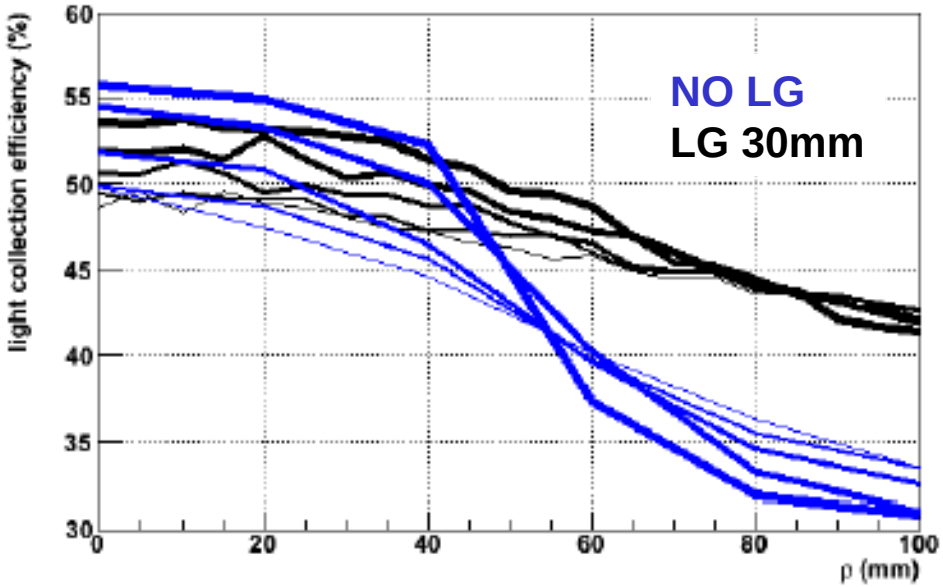
3m distance 10cmx5cm cell @1MeV

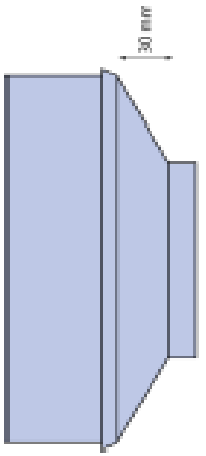
Optimisation of the cell in terms of its performance and cost → 20cm x 5cm

E. Reillo (Master Th))

Monte Carlo simulation: light collection uniformity

Coupling large cell to largest PMT
200 mm diameter cell to 127mm diameter PMT





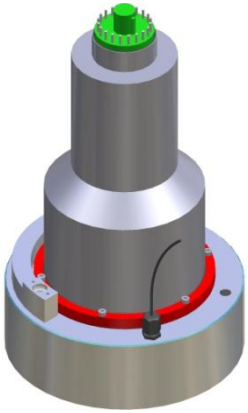
Light guide of 30 mm thick and painted surface

General characteristics of MONSTER

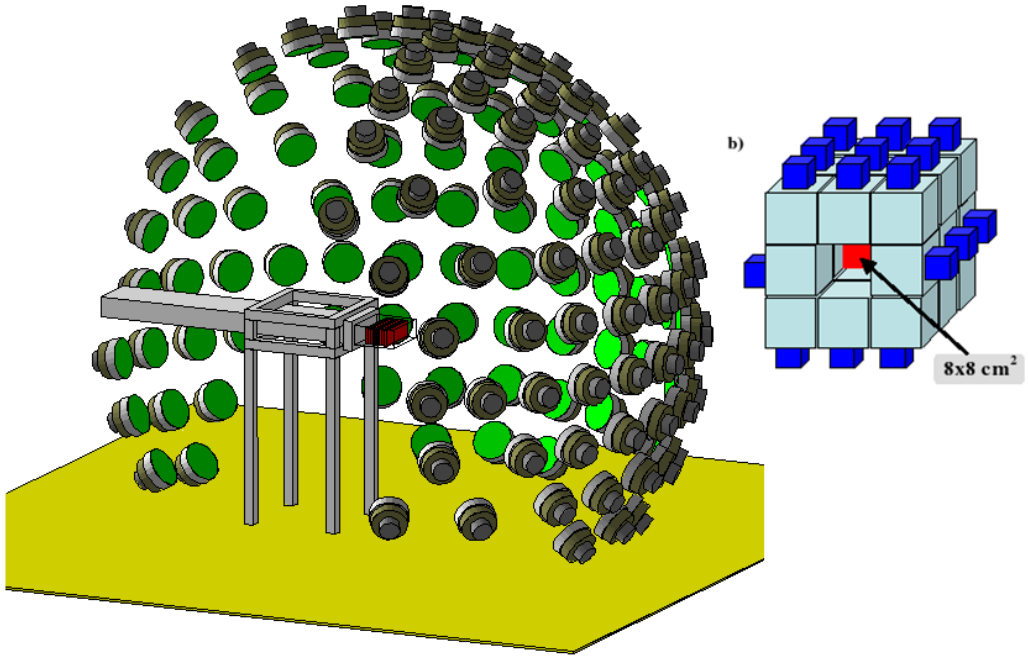
- Cylindrical cell of 20 x 5 cm filled with BC501A/EJ301
- Reasonable intrinsic efficiency (~50% @ 1MeV)
- Energy threshold ~ 30 keVee (E_n ~200 keV)
- Reasonable energy resolution < 10% up to 5 MeV:
- Good neutron timing ~1ns
- Good β timing: < 4ns (?)
- Reasonable flight path 2-3 m TOF
- Good total efficiency: 150 – 200 detectors

200 detectors, 10cm radius		ΔE/E @ 1 MeV	
TOF distance (m)	Geometric efficiency	1ns	4ns
2	**12.5%**	**3.5%**	**6.0%**
3	**5.6%**	**2.5%**	**4.2%**

Design similar to other projects (DESIR @ SPIRAL II)



Ø=20cm x L=5cm

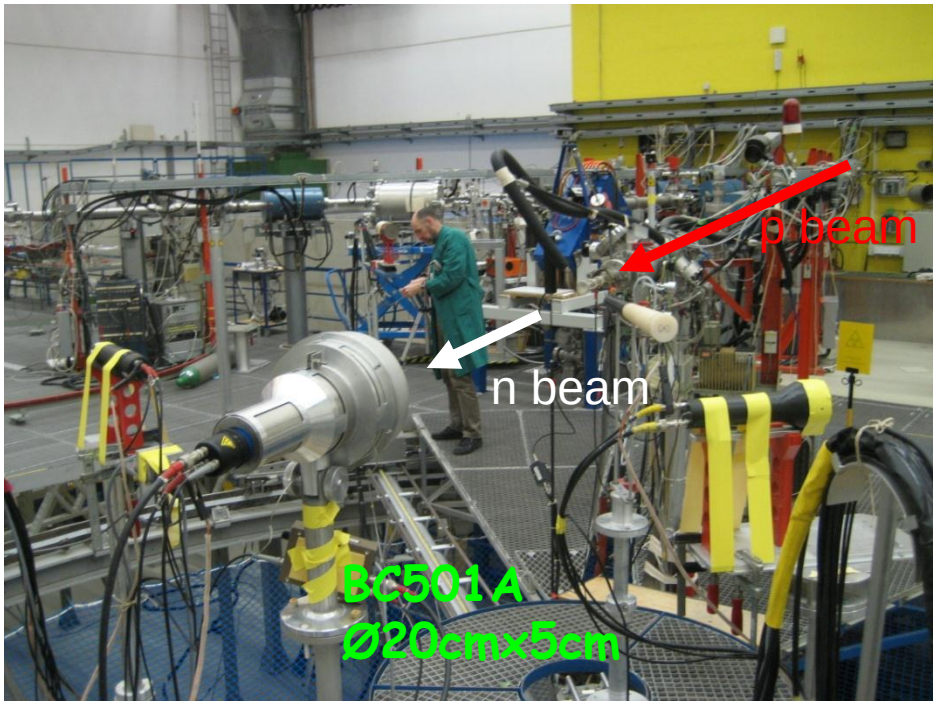


Characterization with reference neutron beams

@ PTB (EFNUDAT program)

Goals:

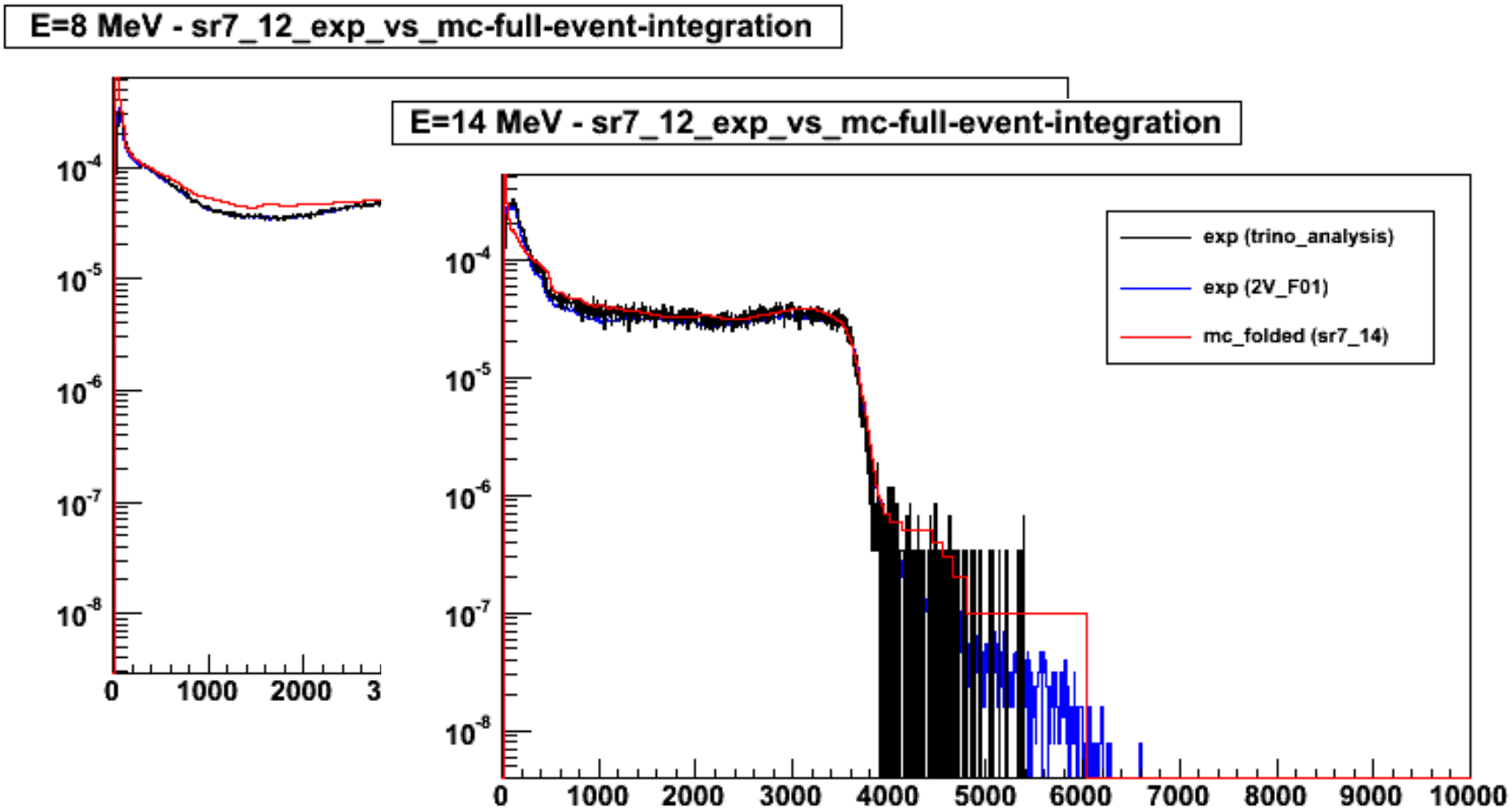
- Light output function for e and p, L=f(E)
- Light resolution ΔL/L(%)
- Absolute neutron detection efficiency
- Comparison with MonteCarlo simulation
- Performance of DAQ systems (flash ADC)



CIEMAT (Madrid), IFIC (Valencia), PTB and LNL (Legnaro)
Cyclotron and Van de Graaf accelerator at PTB

En= 0.144, 0.250, 0.565, 1.2 and 2.5 MeV
En= 8, 10, 12 and 14 MeV

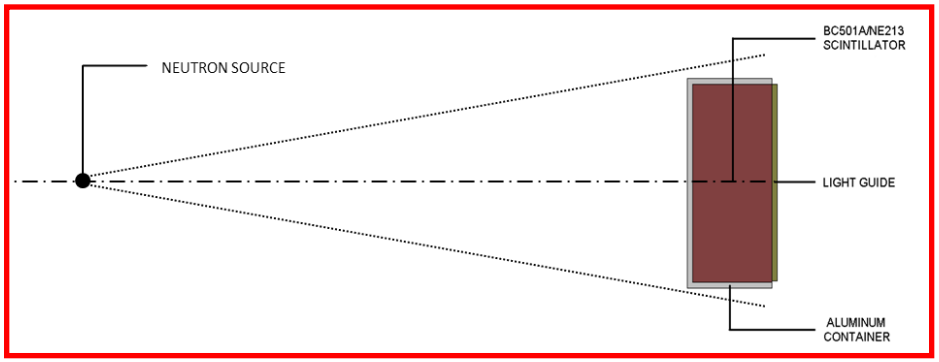
The data analysis



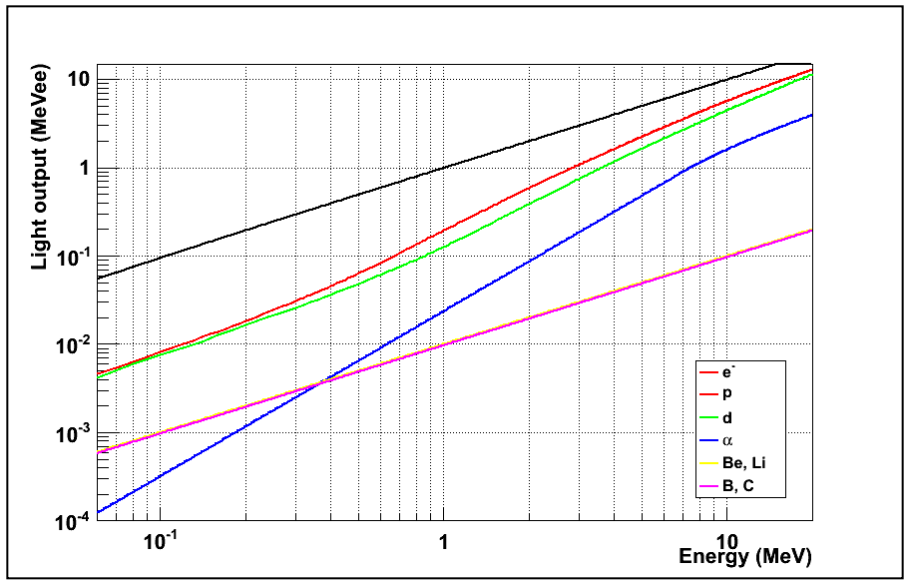
Validation of GEANT4 vs NRESP7 (coll. R. Nolte)

SIMPLE GEOMETRY

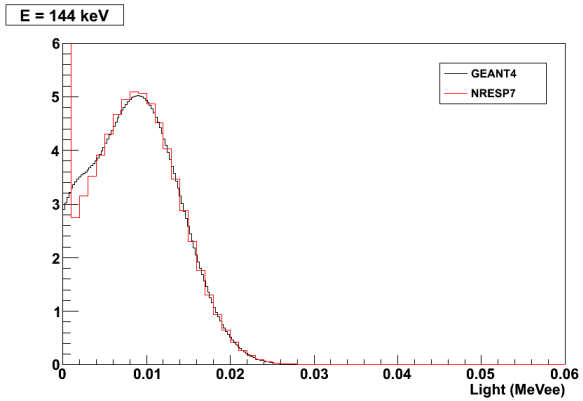
- Cylindrical BC501A (NE213) liquid scintillator DxL=20 cm x 5 cm
- 2 mm thick aluminum container: (ρ=2.7g/cm^3)
- 2 mm thick cylindrical light pipe defined as an organic compound of ^{1}H and ^{12}C:
  H/C=1.100 ρ=1.180g/cm^3

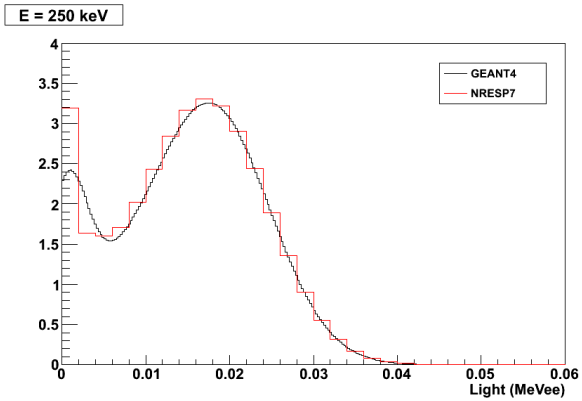


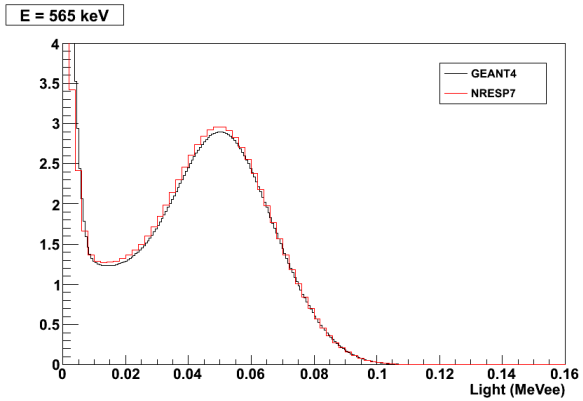
- Same light output functions (NRESP7).
- Same resolution function ΔL/L parameters (A=0.087, B=0.097, C=0.005)
- Same normalization factor

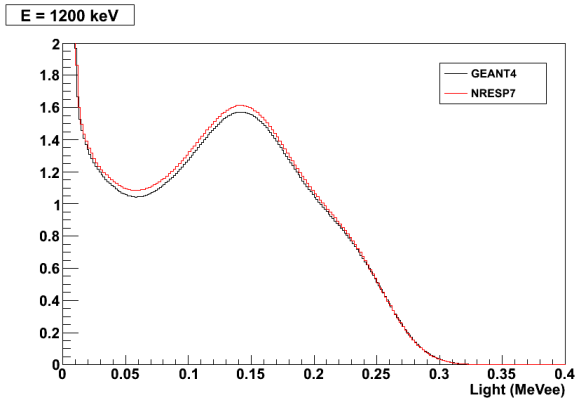


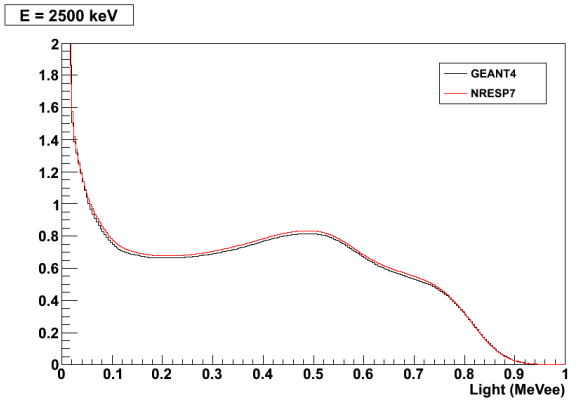
FOLDED LIGHT RESPONSE FUNCTIONS

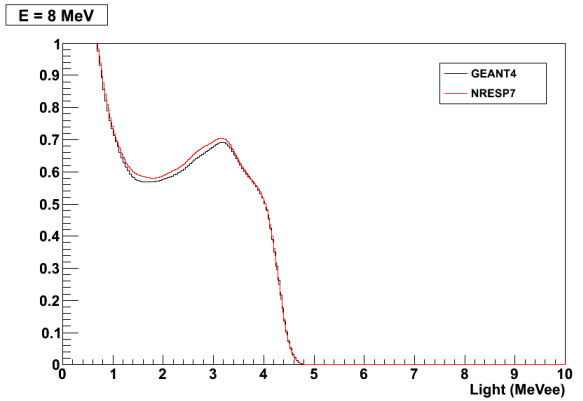


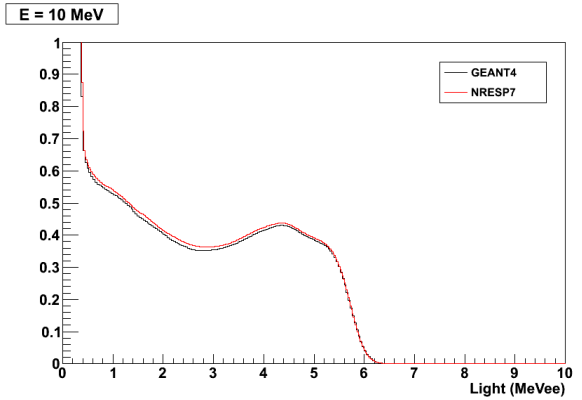


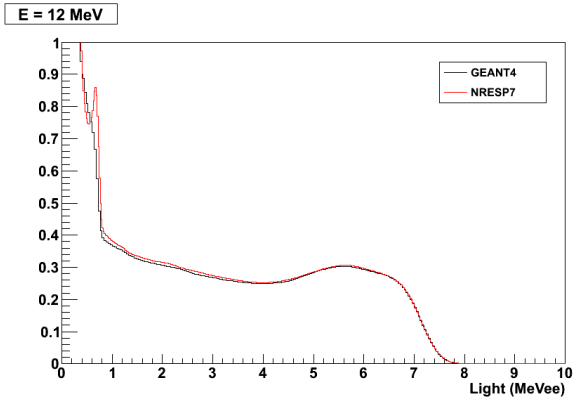


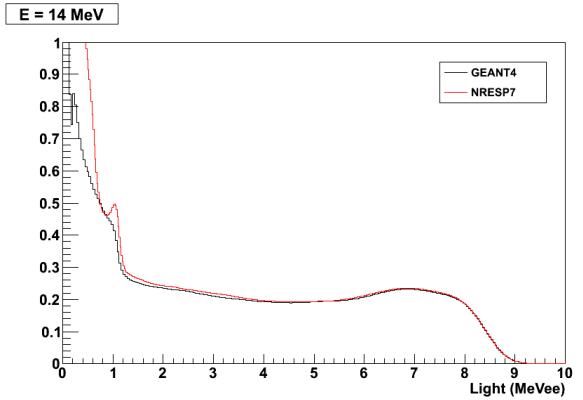








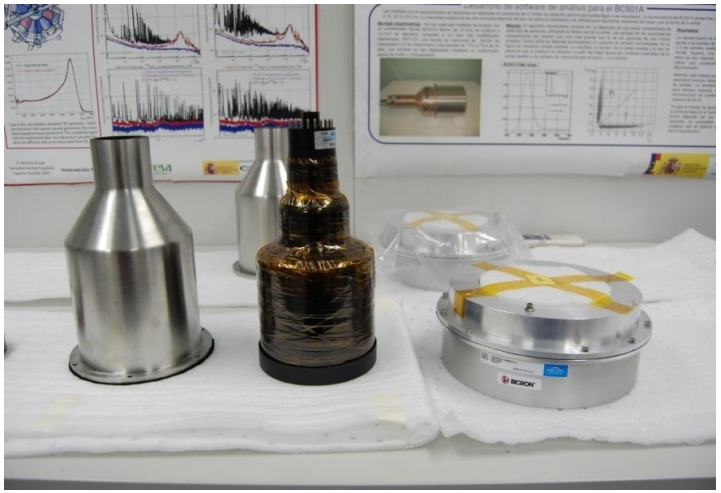


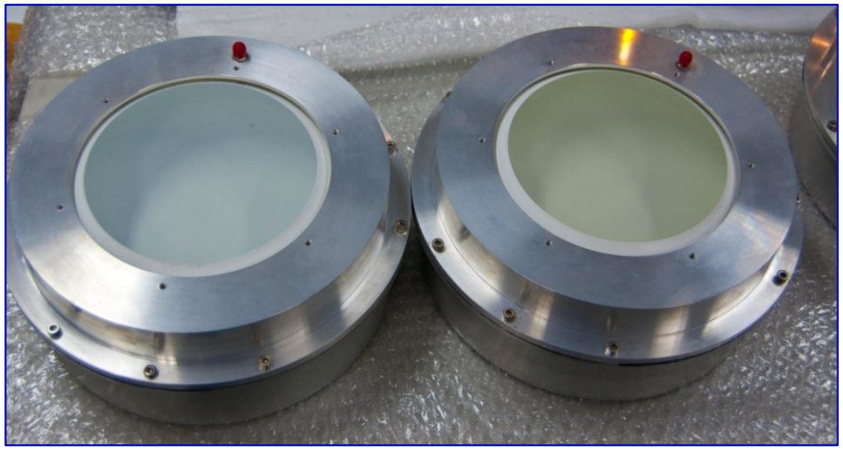


MONSTER demonstrator Status

Detectors:
St. Gobain supplied detectors separately
Cells 30 units, magnetic shielding
PMTs:
model R4144 Hamamatsu

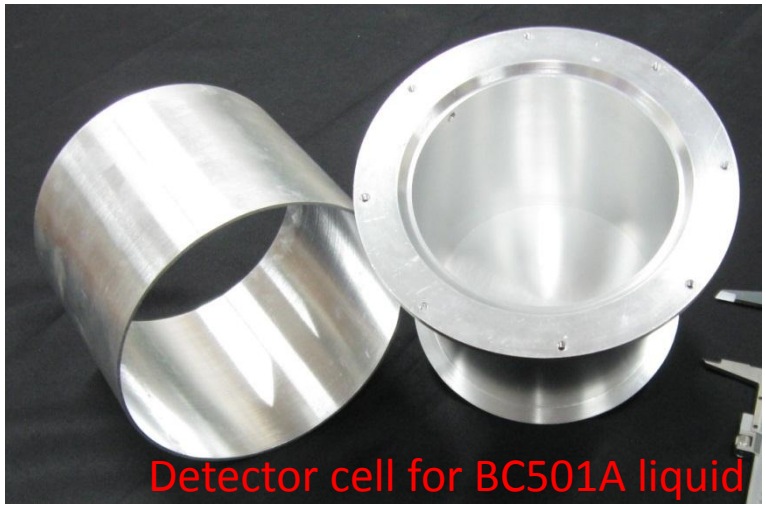
Troubles:
Initial problems with cell paint coating, has been solved.
However, some cells shows a yellowish liquid (but still good n/g separation)



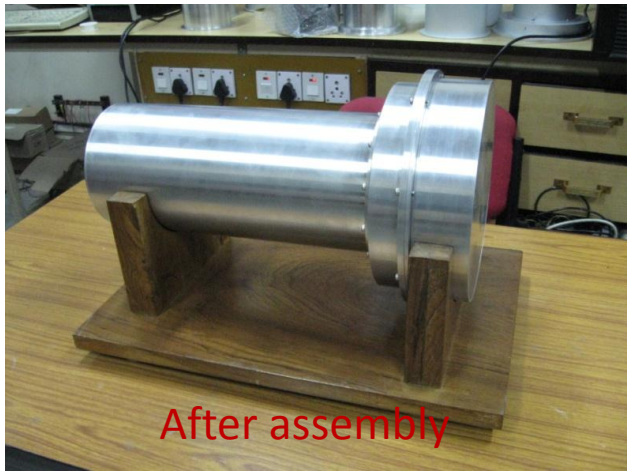


MONSTER prototype at VECC

VECC will contribute with 50 detector modules for MONSTER



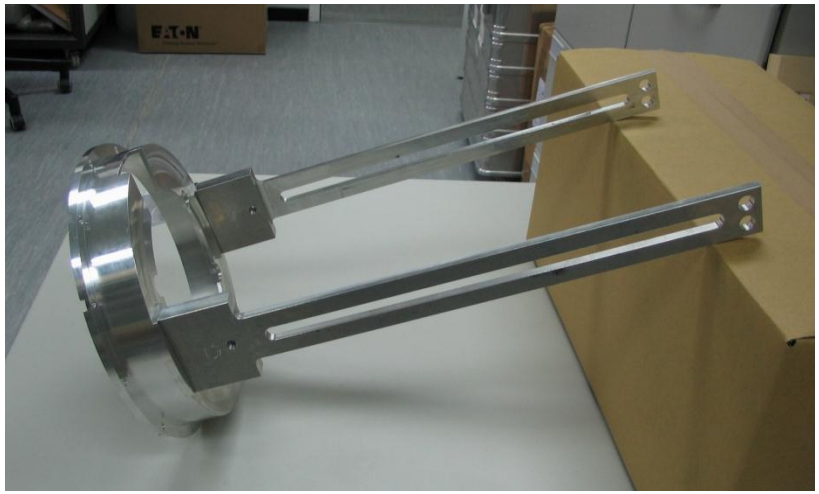
Light Guide

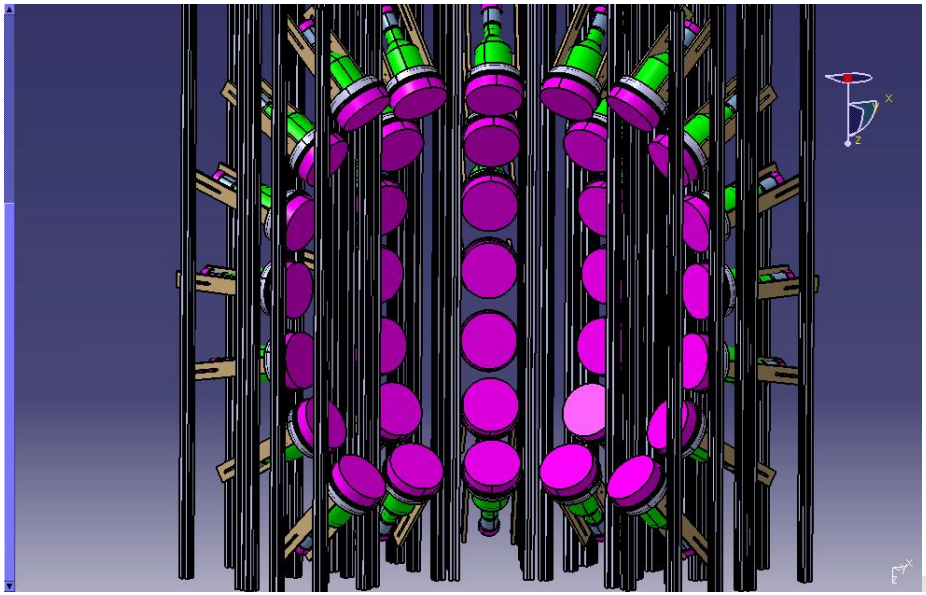


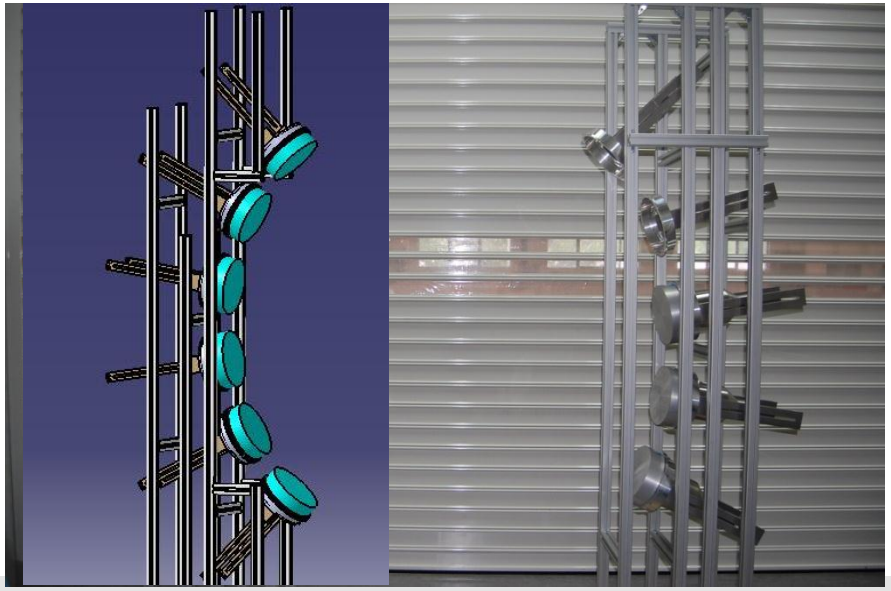
Detector support and Mechanical structure

CAD designed and machined at Ciemat workshops
Aluminum based
Types: racks and sphere-like

Applied a reduction of material to both supports and structure, keeping stability.



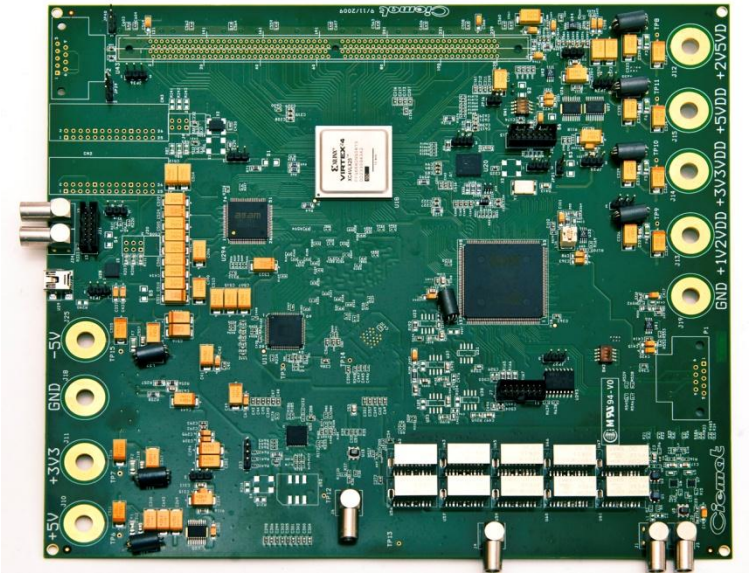




CIEMAT Digitizers

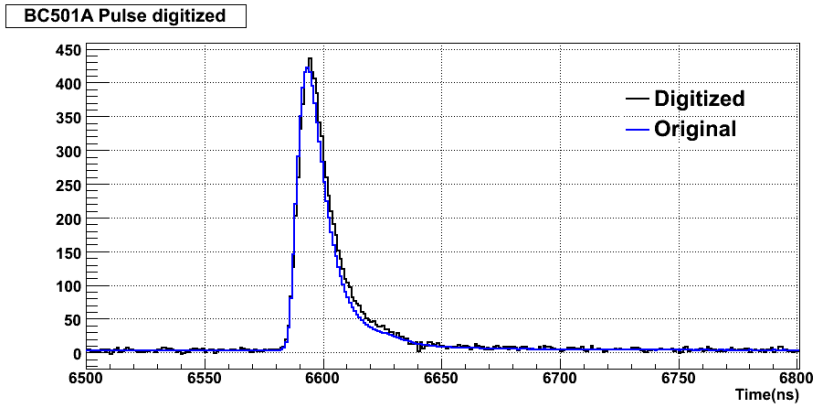
Digitizer design

•ADC with 1Gsample/s and 12 bit resolution, 1GHz bandwidth, 2Vpp.
•FPGA Virtex-4 for trigger, signal pre-processing
•Fast DSP for pulse shape analysis
•TDC for precise timing
•2 GB DDRII memory
•Input ranges: 0.2, 0.5, 1, 2 & 5 V (FS)



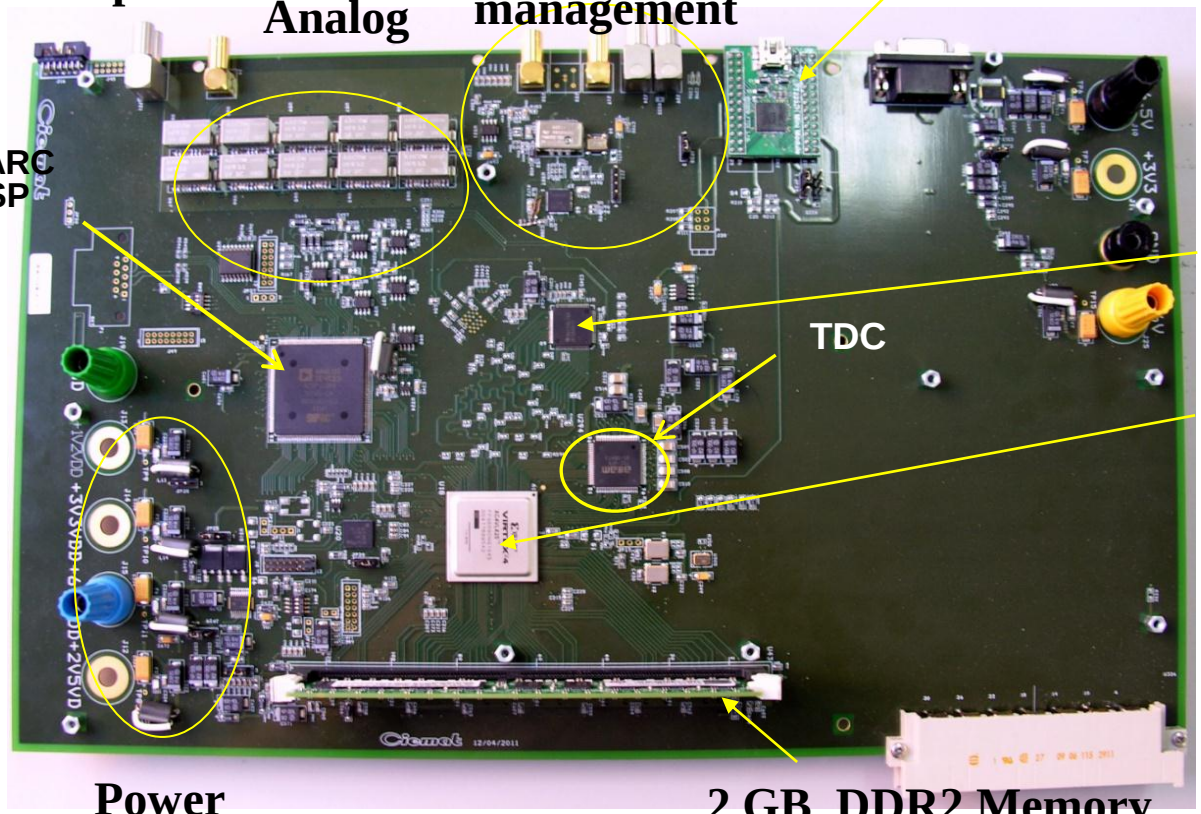
Prototype Activities:

➢Firmware and test of performances
➢USB 2.0 tested and operational R/W @ 42MB/s
➢Constant noise ~1.2 mV (@ full power load)
➢Controller for Micron DDR2 module
2 GB/s. bandwidth (1.5 needed @ 12 bits, 1 GHz))
➢Clock management
(Input 10 MHz clock to synchronize)
➢DAC offset control between 0 - 2.5 Volts for pulse conditioning and analog triggering
➢SHARC DSP alive
➢TDC set up



Digitizer development: 2nd evolution of board

PCB updated to reduce the noise, modify the input ranges for analog signals improve the synchronization between boards, reduce the power consumption, add a 100 Mbytes/s transfer bus (besides the USB 2.0)



Front View

Measurement test @ JYFL

Delayed neutron data:
Pn, neutron energy spectra of known emitters
^{87,88} Br, ^{94,95} Rb, ^{137} I

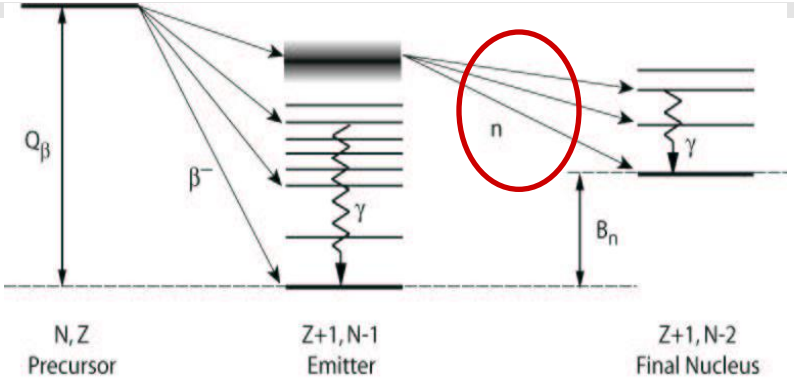
Nuclei production: IGISOL + Penning Trap

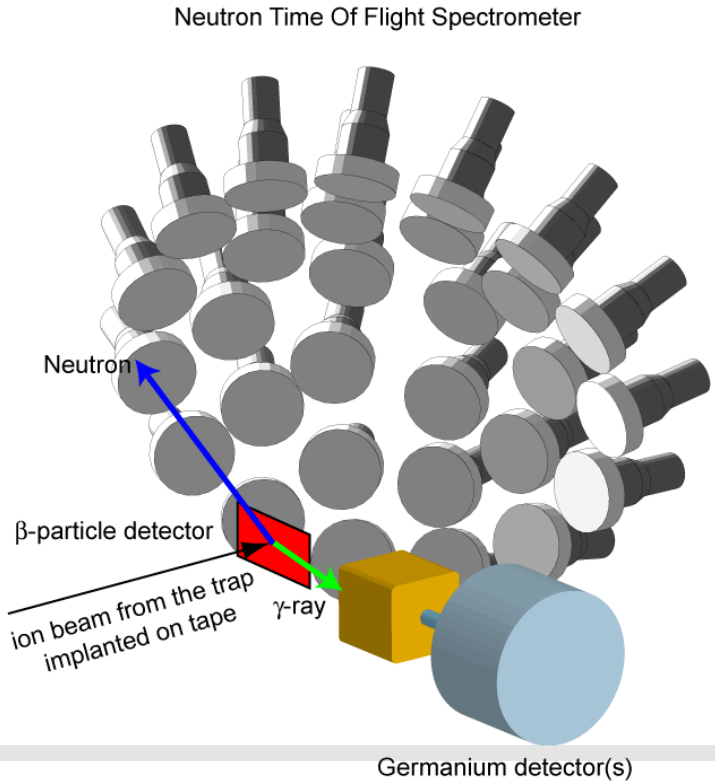
SET-UP:
MONSTER: 30 cells of BC501A (dim 20x5 cm)
Flight path: L ~100cm distance from the implantation position ΔΩ/Ω ~7.4%

Si detector for β particles with 25-30% efficiency
HpGe (Clover desirable)

Coincidences: β-n and β-γ-n (total and partial branching ratio)

Neutron event selection by time of flight and by pulse shape discrimination.





Summary and conclusions

• Accurate DN data are needed for design of new reactor systems (Gen-IV). New RIB facilities offer opportunity to perform required measurements

• A neutron TOF spectrometer has been designed for DESPEC, based on BC501A. Sensitive to E_n > 200 keV.
• A large amount of work has been dedicated to develop and improve Monte Carlo simulation codes GEANT4 and tools: cross sections data, light output, light collection…
• Prototype cell has been designed and tested (time resolution, n/γ discrimination, light collection uniformity).
• The prototype cell has been characterized with reference neutron beams. Analysis not yet concluded.

• Construction of MONSTER demonstrator is progressing. 30 new cells have been purchased to St-Gobain for spectrometer demonstrator. Problem with cells will be solved.
• Mechanical supports and structure have been design and is being constructed.
• High performance digital electronics is being designed for the TOF spectrometer. Prototypes are being tested

•Experiment have been accepted at the Cyclotron Laboratory of the University of Jyvaskyla (Finland) for commissioning.

Involved Institutions:

FAIR

- CIEMAT (Madrid, Spain)
- Instituto de Física Corpuscular (Valencia, Spain)
- Universidad Politécnica de Cataluña (Barcelona, Spain)
- VECC (India)

SPIRAL-II

- LPC (Caen, France)
- Laboratori Nazionali di Legnaro (Italy) – NEDA project
- University of Uppsala (Sweden) – NEDA project

Acknowledgement:

Ministry of Science and Innovation, Spanish Government
EFNUDAT program, PTB staff
ENRESA

Thanks for your attention!

n/γ discrimination

Digital Charge Integration method

Reasonable n/γ separation for E_n>80 keVee (AmBe)

FOM