Status of Neutron detection Activities for DESPEC at FAIR

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CIEMAT (Madrid)

EFNUDAT-Final Scientific Workshop, CERN (Geneva) 30/08/10-02/09/10

Outline:

- Context and Motivation
- DESPEC Experiment
- Neutron detection activities
  - ✓Montecarlo simulations
  - ✓Test prototypes
  - ✓Experimental Results
  - ✓Digital Electronics
- Conclusions

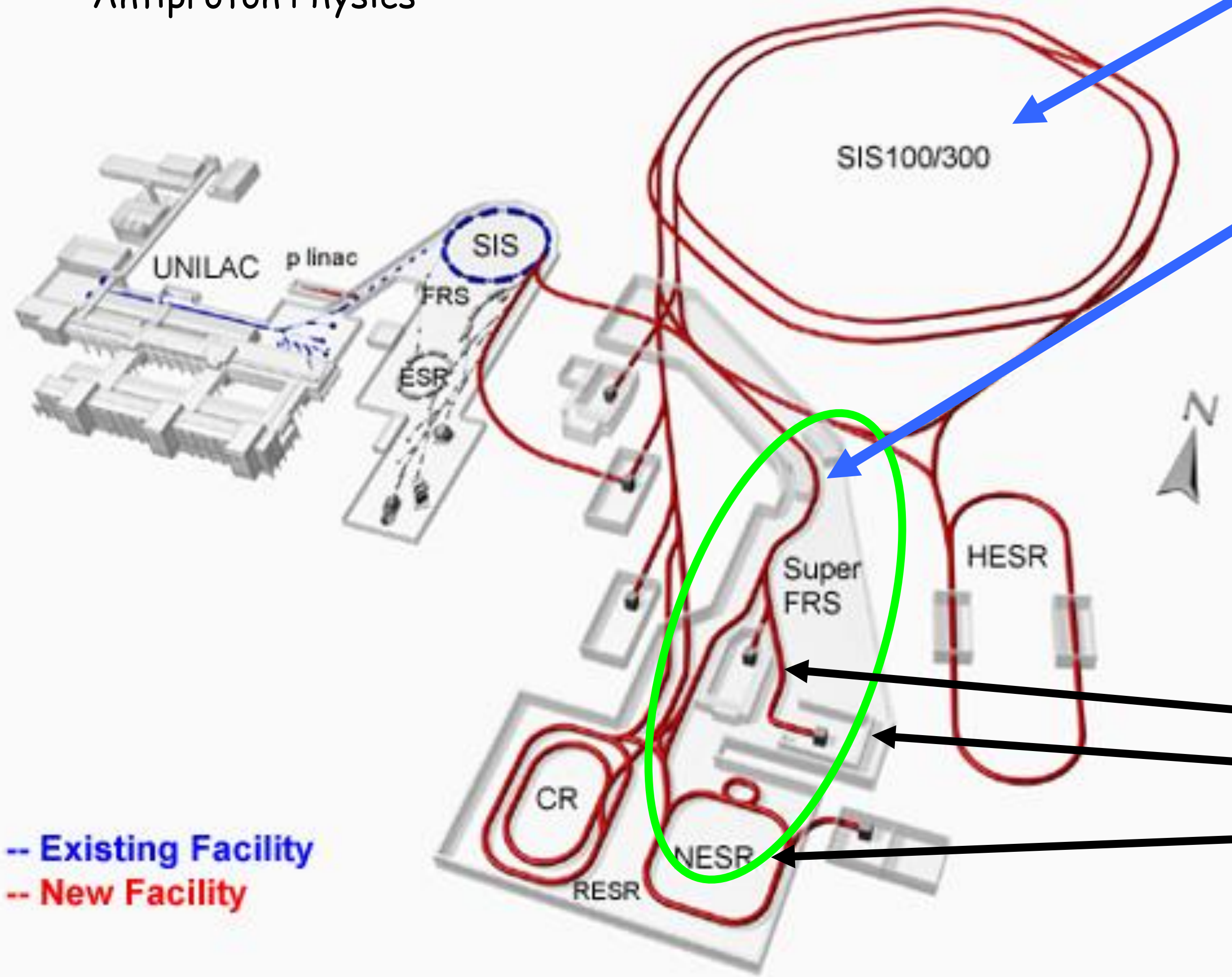
International FAIR facility at GSI

(Facility for Antiproton and Ion Research)

- Atomic & Plasma Physics
- Nuclear Structure and Astrophysics
- Compressed Baryonic matter
- Antiproton Physics

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



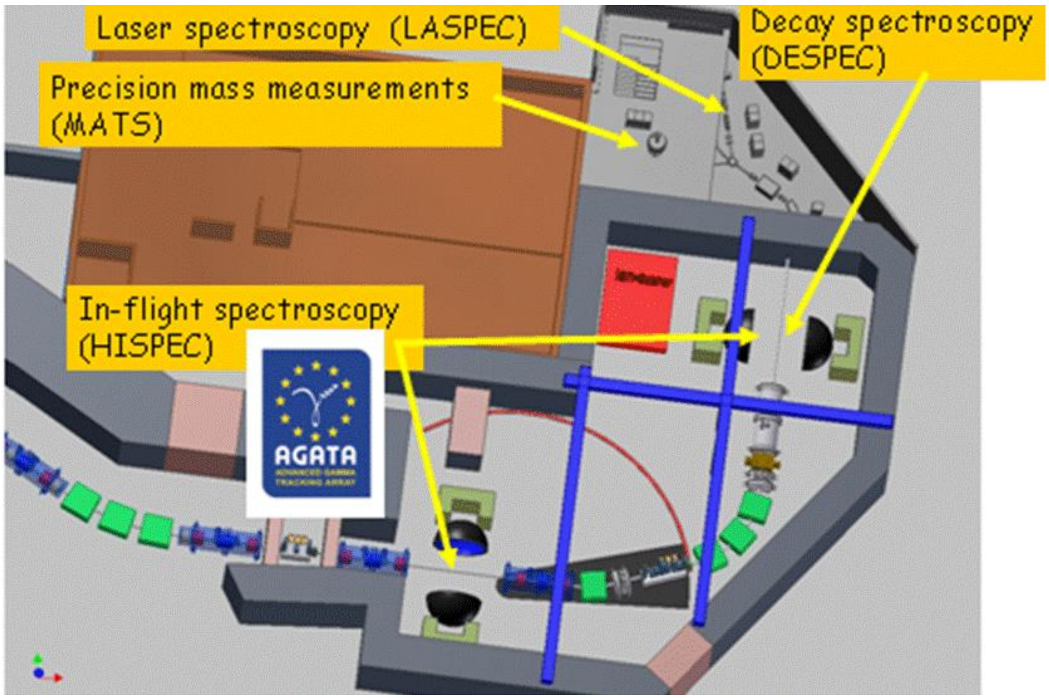
Nustar Collaboration
RIB, S-FRS

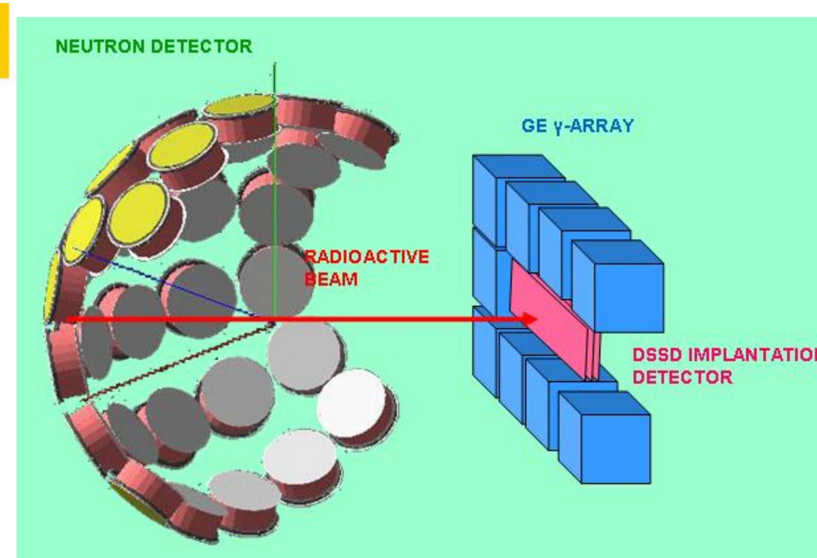
High Energy Branch
Low Energy Branch
Ring Branch

(www.gsi.de/fair)

Nustar Collaboration @ Low Energy Branch

NUSTAR Project is a collaboration of the international nuclear structure and astrophysics communities. The main goal is to develop, construct and operate the Super – FRS and its related experimental areas High Energy Branch, Low Energy Branch and Ring Branch.
Many experiments are being prepared to investigate nuclear and astrophysics questions related with exotic nuclei.



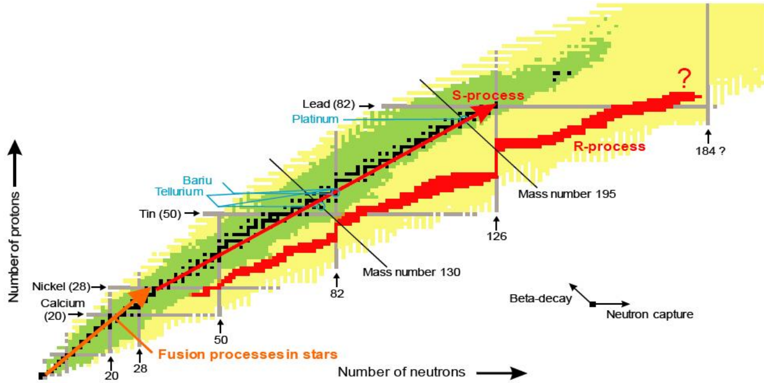


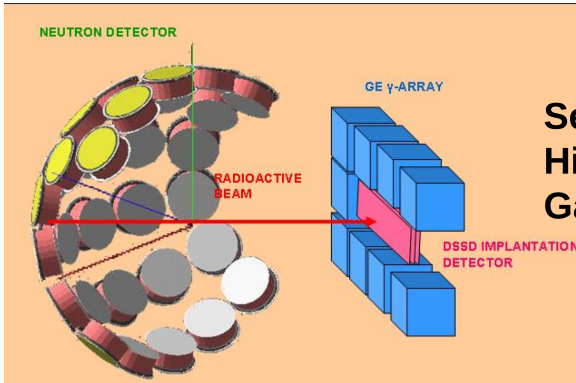
Low energy or stopped beams
0-150 MeV/u

DESPEC:
"Complete" decay spectroscopy of exotic nuclei
($T_{1/2}$, GT strength, Q-Moments, branching ratios, particle emission)

DESPEC Collaboration

Decay properties of exotic nuclei
($T_{1/2}$, branching ratio, GT strength, Q moments)

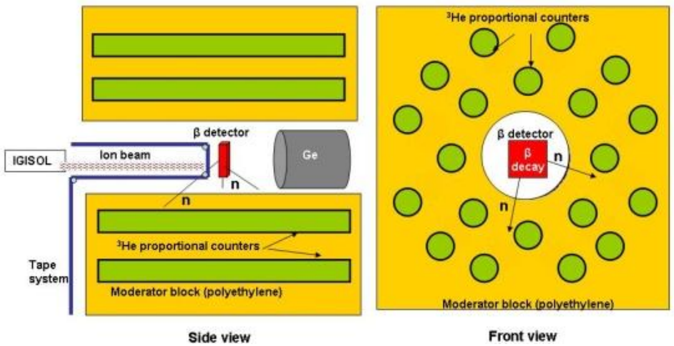




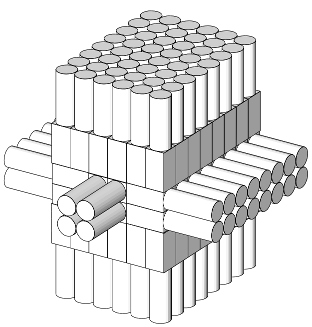
Segmented Ge Planar
High resolution
Gamma spectroscopy

Neutron ToF
(neutron spectroscopy)

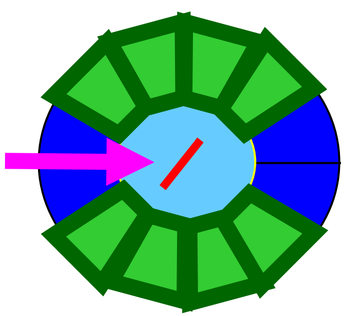
AIDA
Implantation detector
and particle detector



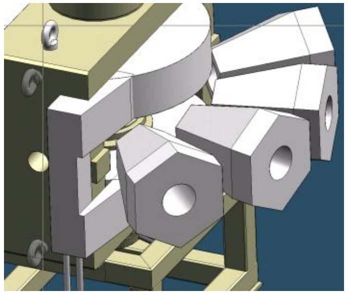
4π neutron Detector
(beta delayed n branching ratio)



Total Absorption Gamma
Spectrometer
Beta-strength functions



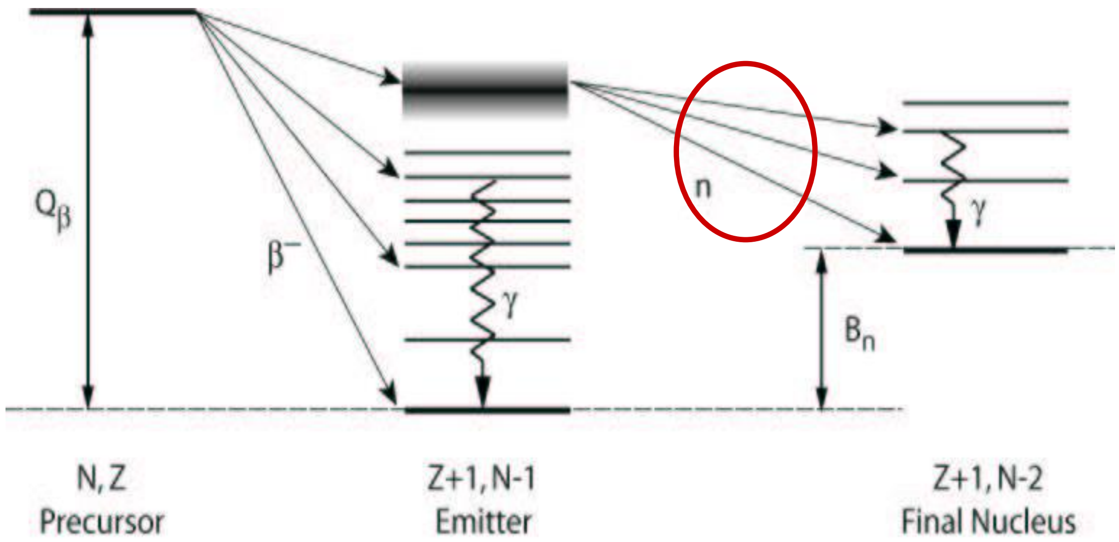
Fast timing Array,
$T_{1/2}$ of nuclear levels (ps)



g-factors and Q Moments
of isomeric states

Motivation for DESPEC experiment @ FAIR

Beta decay properties of exotic nuclei should be studied with high accuracy for nuclear structure and astrophysics.
Particular case of Neutron Rich Nuclei → beta delayed neutron emission (low Sn)
Delayed neutron data important from the nuclear technology point of view in the design, safety and operation of fast reactors and transmutation systems. (NEA List)



-Delayed neutron data: absolute neutron yield, branching ratio, neutron energy spectra

- High efficiency 4π moderated-based detector (low production)
- n_ToF spectrometer (high production)

Ideal Neutron TOF spectrometer design

Requirements for neutron spectroscopy:

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
n-γ discrimination, →reduce backgrounds, (Liquid scintillator, solid organic)
cross-talk rejection,→ modular, high granularity >100 cell, identification of n,2n,3n
Digital electronics → control of systematics

Liquid organic scintillator NE213 is the most used, (plastics and solids)
Develop MonteCarlo simulations for prototype design by optimization
Perform test with prototypes, materials, configurations

Ciemat is responsible of construction of prototype

Constraints: Interferences, cost.

Activities performed at Ciemat

Work done for TOF spectrometer design.

MonteCarlo Simulations:
Development of codes for
-Characterization of the parameters.
-Modeling of light production and collection processes

Validation of neutron transport codes (MCNPX,GEANT4)
Translator tool of cross section data format (ENDF, JEFF…) to GEANT4

Detector characterization: Test with several types (liquid, plastics) and characteristics. Test with PMTs. Test with commercial digital electronics.

Electronic developments A digitizer of 12bit and 1GS/s is being developed at Ciemat. Status.

Experiment at PTB, characterization of large liquid scintillator cell.

Experiment at Jyvaskyla (JYFL) next year. Decay of Br, Rb and I isotopes will be measured (Experiment with 4π and TAS prototypes already done)

Construction of TOF prototype (~30 cells already ordered) and for the design of the digitizer board of a 12 bit/1 GS (few channels).

1. MC Simulation

E. Reillo (Master Th) and A. Garcia (PhD)

Work already done:

- Simulation codes based on GEANT4 packages.
- Validation with other codes (MCNPX)
- Light scintillation response model based on Dekempeneer light functions (NIMA256(1987)489)), including a resolution function from data measurements.
- 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.
- Light collection processes have been studied.
- Optimization of parameters showed best results for cylindrical cells than rectangular bars.

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

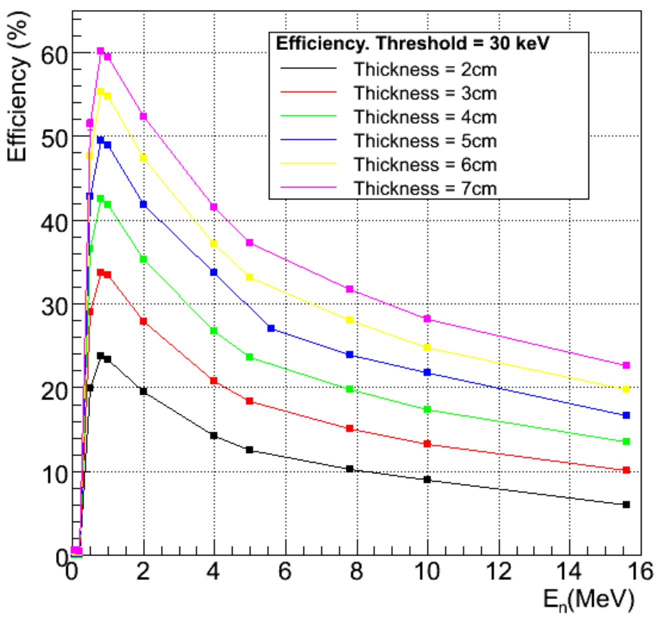
Next to be done:

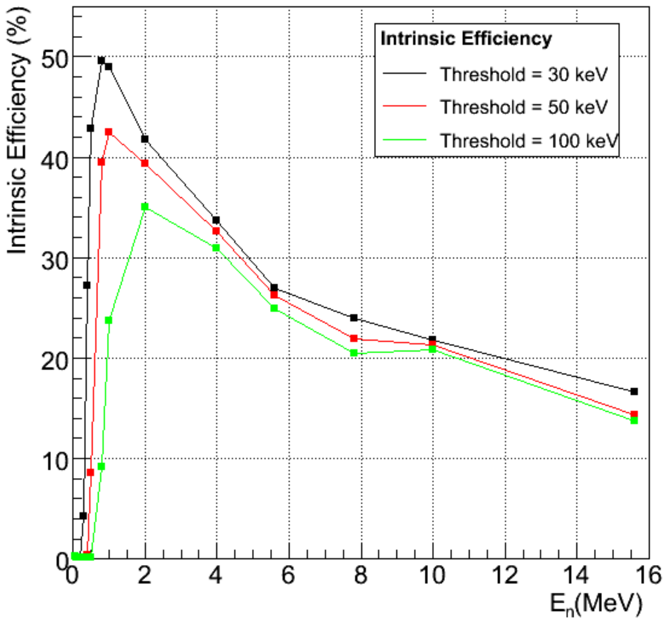
- Definition of cross-talk (optimization)
- Influence of complementary set-ups (Ge detectors) and mechanical structure
- Simulation of a complete experiment
- Final design

MC simulation: Intrinsic efficiency

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

For similar volume rectangular bar has lower efficiency





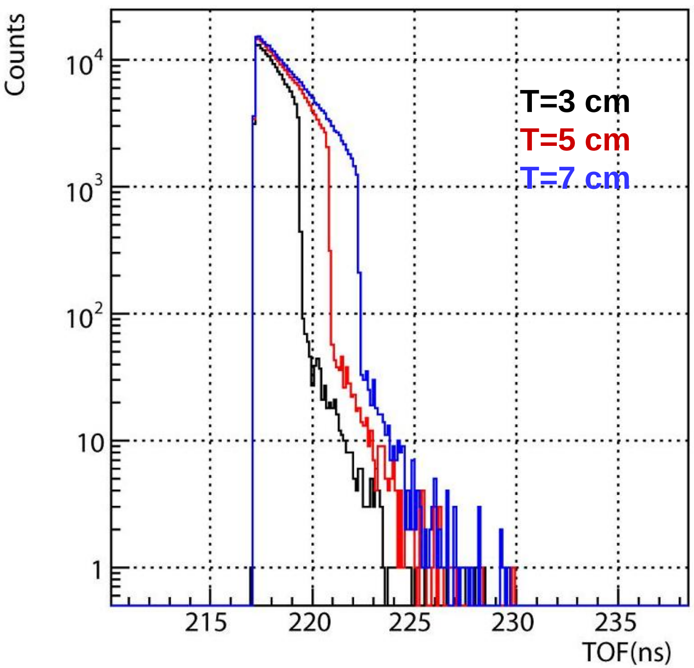
Efficiency vs thickness and threshold
Cell 10 cm radius 5cm thickness

MC simulation: ToF resolution and E resolution

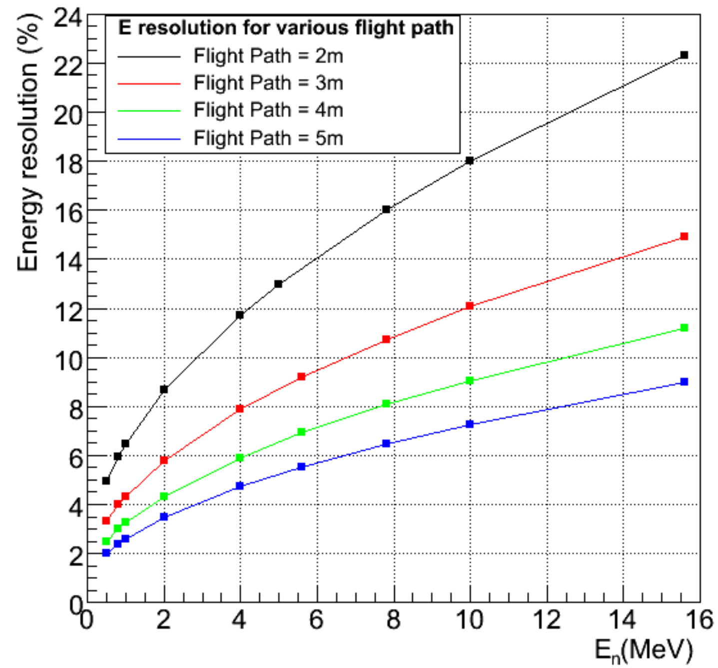
TOF depends:
•Intrinsic time resolution of detectors ~1ns for scintillator (4-5 ns implant detector)
•Neutron transit time (thickness) ~7ns
•Multiple scattering (threshold) ~ms

Energy depends:
ToF and flight path and uncertainties

$$\frac{\Delta E}{E} = 2 * \sqrt{\left(\frac{e}{L}\right)^2 + \left(\frac{\Delta t}{t}\right)^2}$$



3m distance
10cmx5cm cell
1MeV

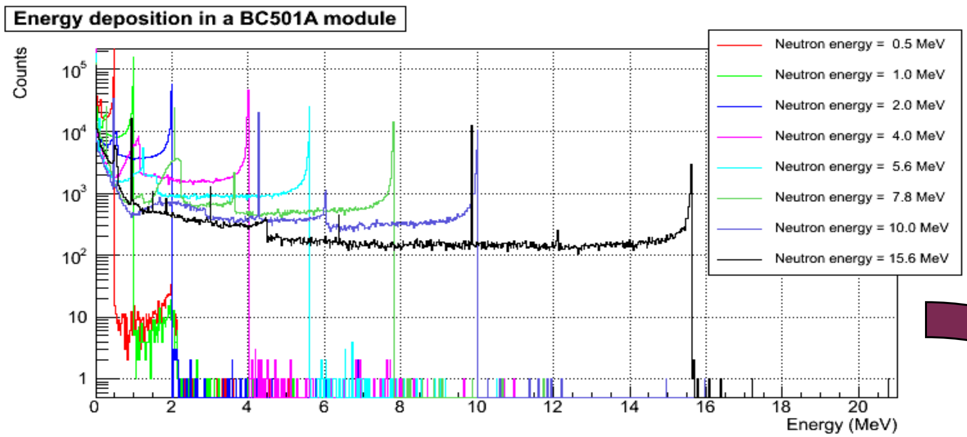


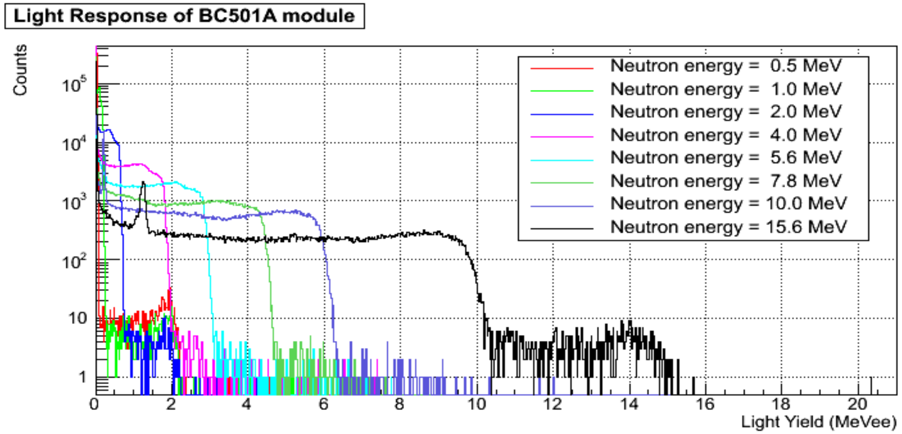
Better time resolution for thin detectors

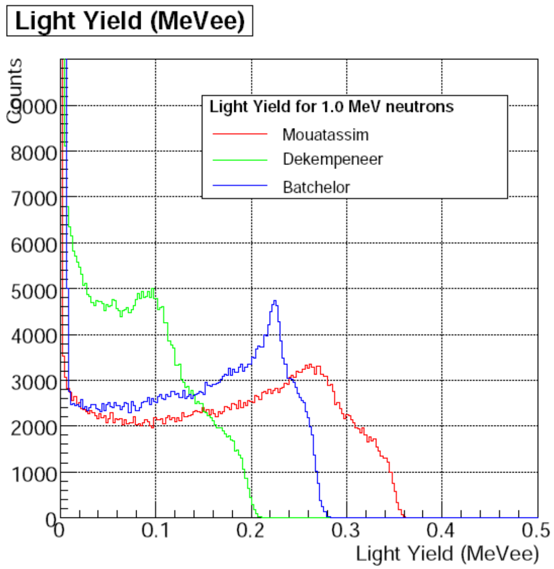
Better E resolution for longer path

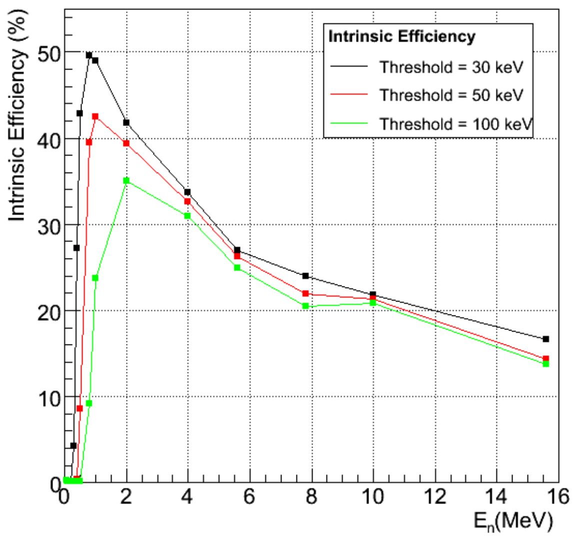
MC simulation: light yield model

Light yield model: Dekempeneer, Verbinski, Batchelor,…
A good light yield modeling is mandatory for precise efficiency determination







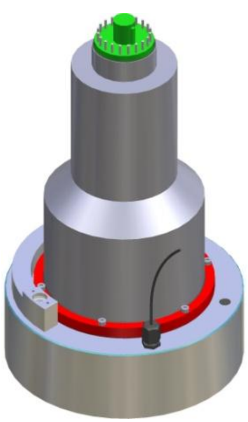


Proposal of conceptual design

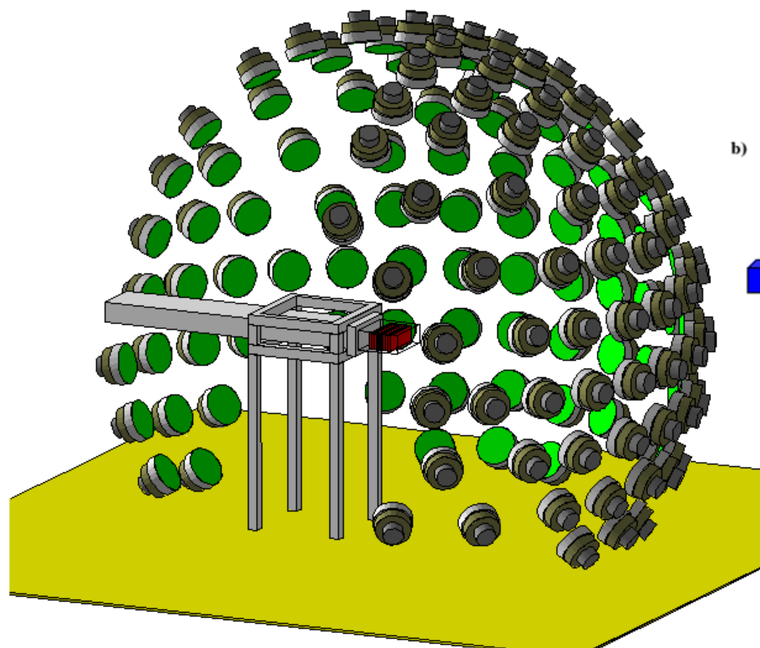
- Cylindrical cell of 20 x 5 cm filled with BC501A/EJ301
- Reasonable intrinsic efficiency (~50% @ 1MeV)
- Energy threshold ~ 30 keVee (E_n ~100 keV)
- Reasonable energy resolution < 10% up to 5 MeV:
- Good neutron timing ~1ns
- Good β timing: < 4ns
- Reasonable flight path 2-3 m TOF
- Good total efficiency: 150 – 200 detectors

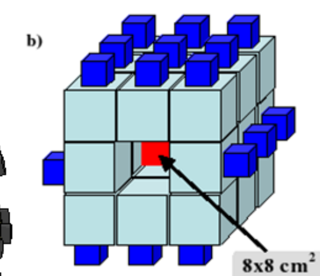
200 detectors, 10cm radius		ΔE/E @ 1 MeV	
TOF distance (m)	Geometric efficiency	1ns	4ns
2	**12.5%**	**3.5%**	**6.0%**
3	**5.6%**	**2.5%**	**4.2%**

Design similar to other projects (DESIR @ SPIRAL II)



Ø=20cm
L=5cm

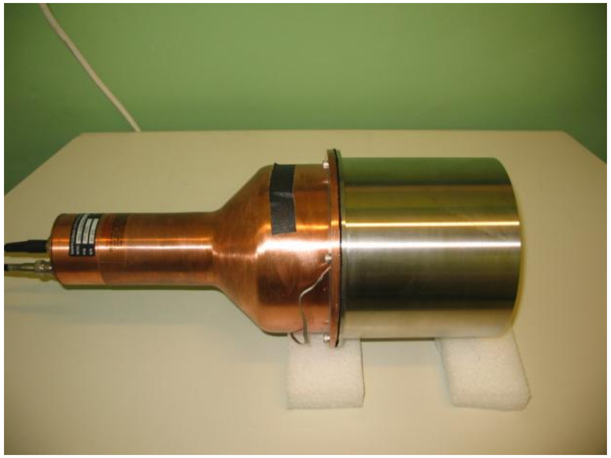




2. Test with detector prototypes

Cylindrical cells (BC501A, EJ301) dim. 12.7x12.7 cm and 20 x 5 cm

- Energy Resolution and E threshold
- Time resolution (TAC, Digital)
- n/γ discrimination and separation
- Uniformity of light collection
- Different models of PMTs (fast, slow)



BC-501A 5"x5"

Slow PMT Hamamatsu R877-01

EJ-301 5"x5"

Fast PMT

Photonis XP4508

BC-501A 20x5cm

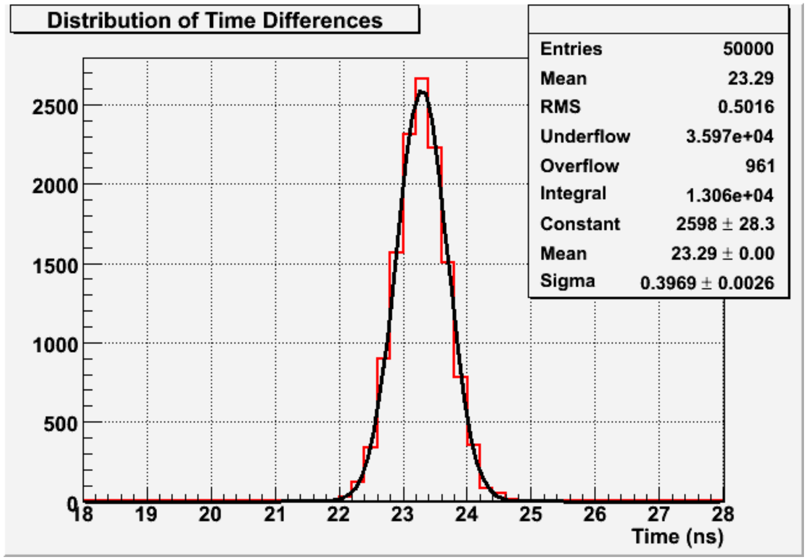
Fast PMT

Photonis XP4512

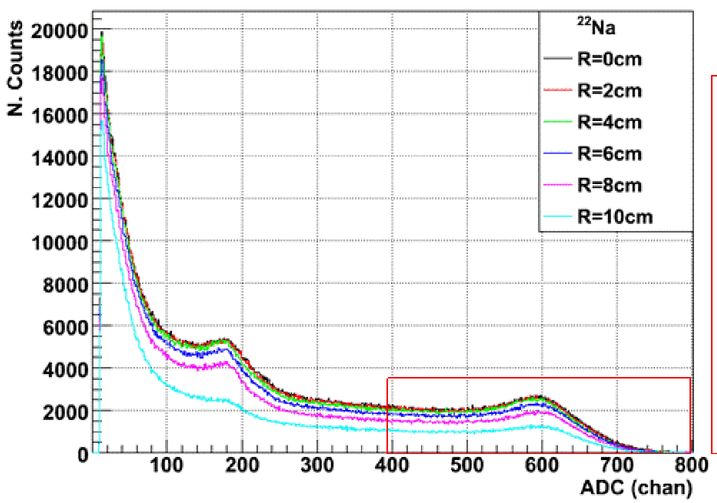
Test results

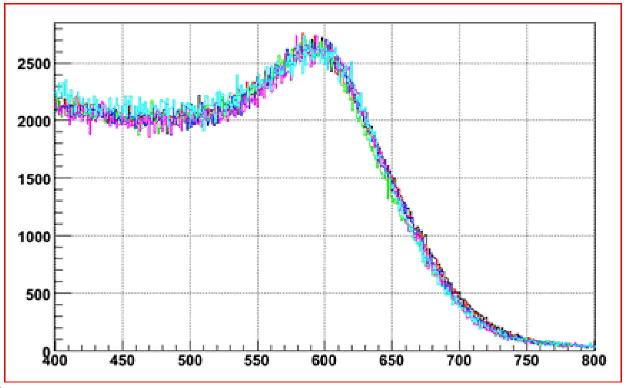
Intrinsic Time Resolution

	SLOW	FAST
Signal	**FWHM (ns)**	**FWHM (ns)**
TAC	**1.25 (7)**	**0.95 (7)**
DCFD	**1.20 (5)**	**0.93 (5)**



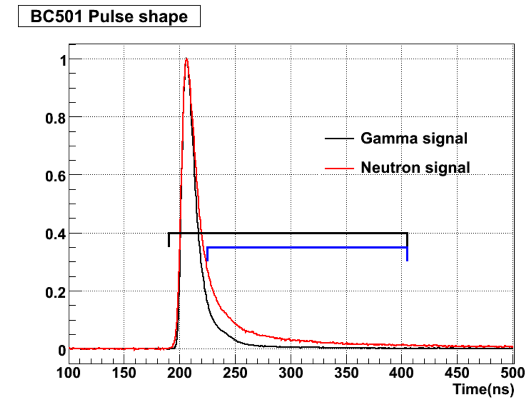
Uniformity of light collection (light guide)





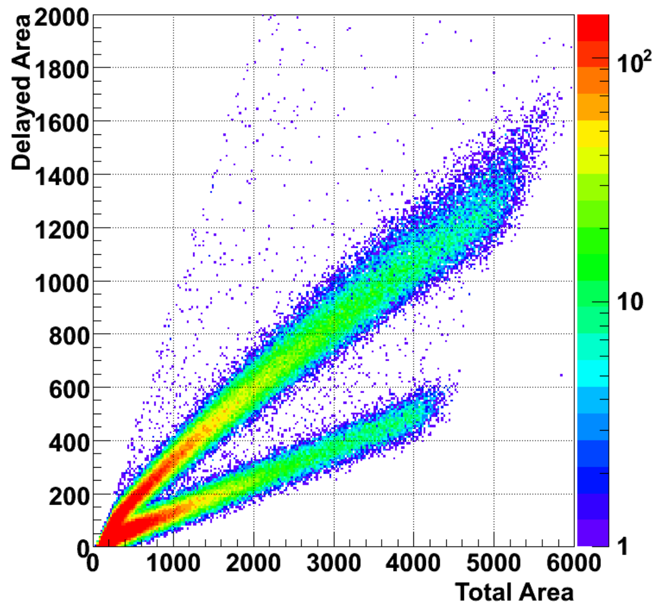
Distance (cm)	Relative Light (%)
0	100
2	98.5
4	95.6
6	88.8
8	77.4

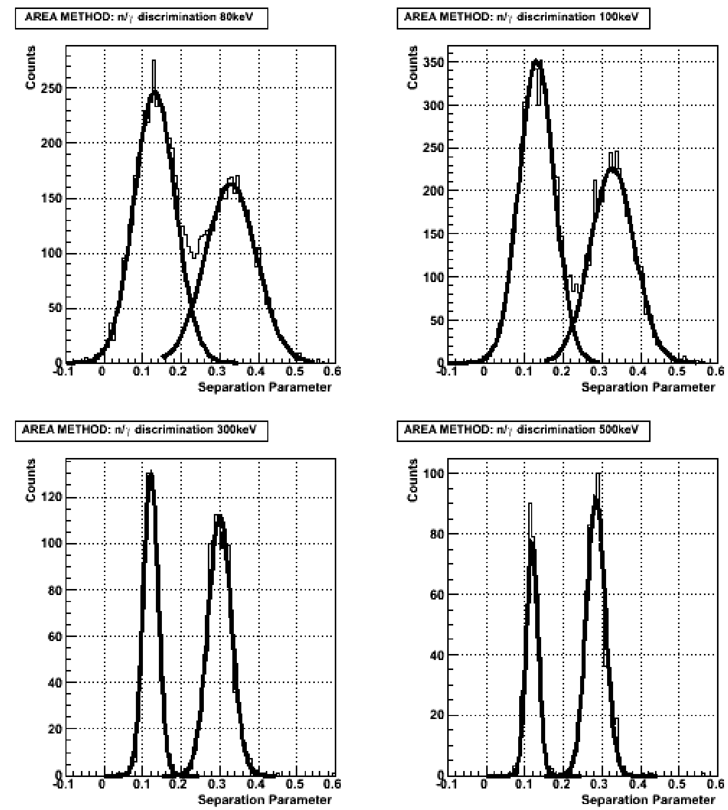
n/γ discrimination



Digital Charge Integration method

Reasonable n/γ separation for E_n>80 keVee with AmBe source comparable to N-Wall, EDEN, DEMON detectors





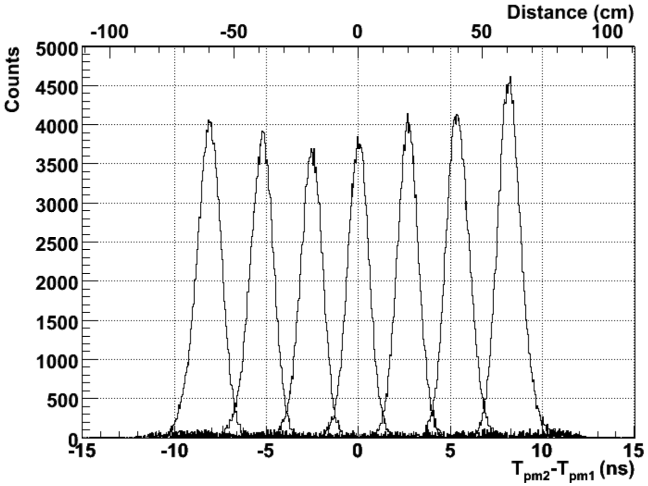
Test with detector prototypes

Plastic bar (EJ200)
Large 160x20x4 cm PMT E9214B fast
Small 50x10x1 cm PMT E9111B fast

Measurement of Time Resolution
Measurement of Position Resolution

Y-90/Sr-90 β-source
Co-60 source

Size	Time Res. FWHM	Pos. Res. FWHM
Large	1.4 ns	10.8 cm
Small	1.5 ns	10.6 cm



Similar results like TONNERRE

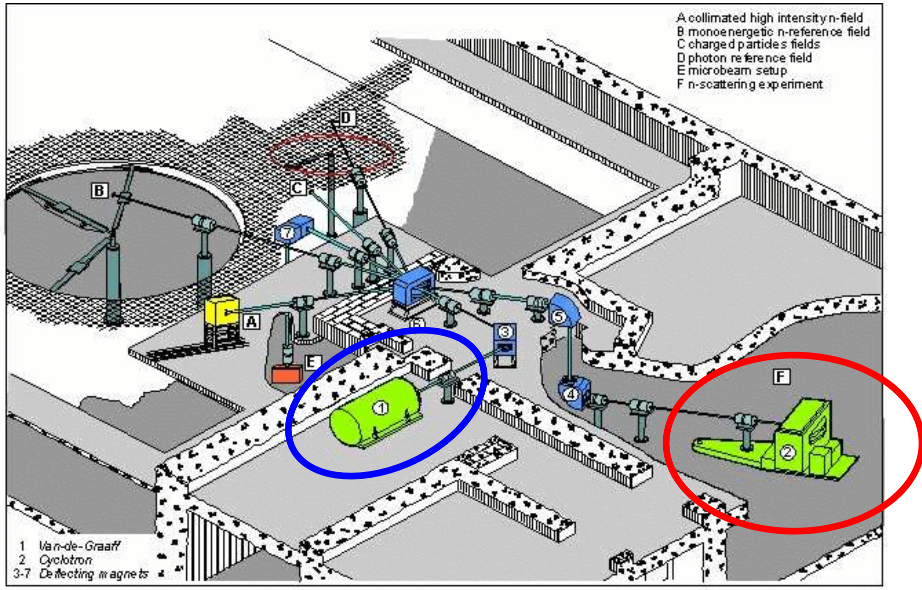
3. Characterization with neutron beams

Transnational Access to the EFNUDAT facilities program

Goals:
Light output function for electrons and protons,
L=f(E)
Energy (light) resolution $\Delta L/L(\%)$
Absolute neutron detection efficiency

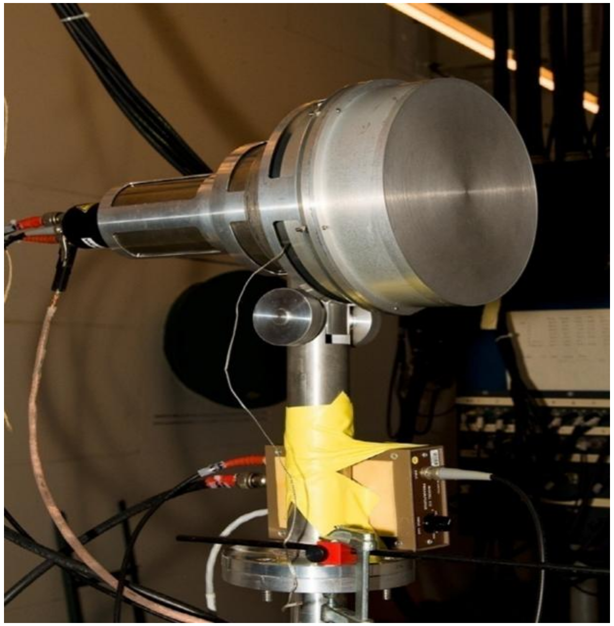
Comparison with MonteCarlo simulation

Performance of DAQ systems (flash ADC)

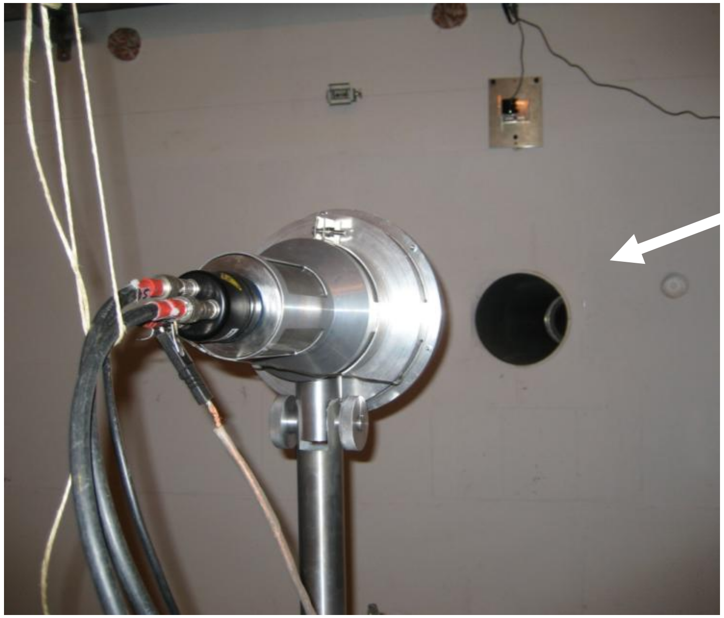


CIEMAT (Madrid), IFIC (Valencia), PTB and LNL (Legnaro)
Beam Time at Cyclotron and Van de Graaf accelerator at PTB
Test of liquid and inorganic scintillators
Standard mono-energetic neutrons beams
Experiment performed March 2009

Measurement at Cyclotron



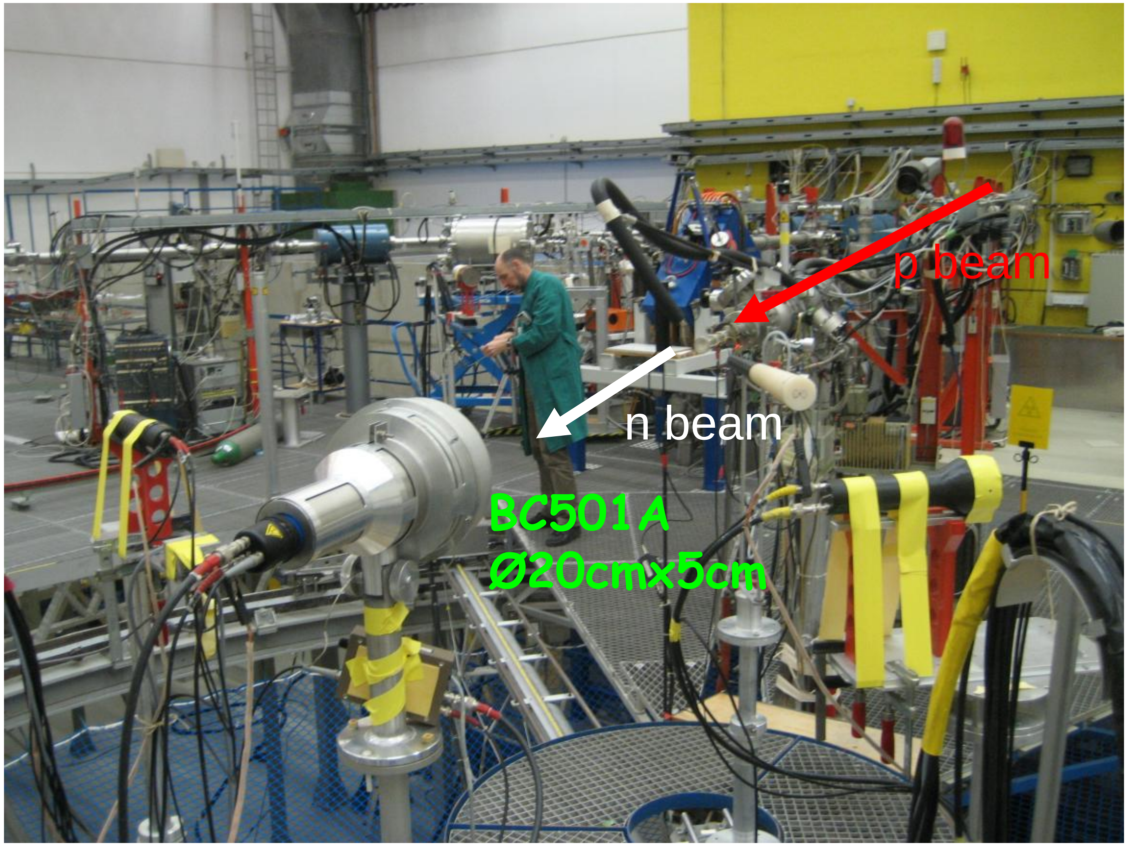
BC501A
Ø20cm×5cm



Cyclotron:

- D(d,n) reaction, gas target, E_n= 8, 10, 12, 14 MeV
- Pulsed beam mode, blocking system for 0.8-0.9 MHz (spurious pulses)
- Detector position, flight path of L=10.5 m

Measurement at VDG



Van de Graaff:

- Li(p,n) reaction, E_n= 0.144, 0.250, 0.565 MeV
- T(p,n) reaction, E_n= 1.2, 2.5 MeV
- Pulsed beam (1.25 MHz) for ToF background reduction
- Detector position, Flight path of L=1 - 2 m

Data analysis

DAQ system:
ACQIRIS: Flash ADC 8bits 1GS/s
Signals digitized over 1μs

NI Board: Monitoring of counting rates
from Detector, Accelerator and Monitors

Analysis Procedure:

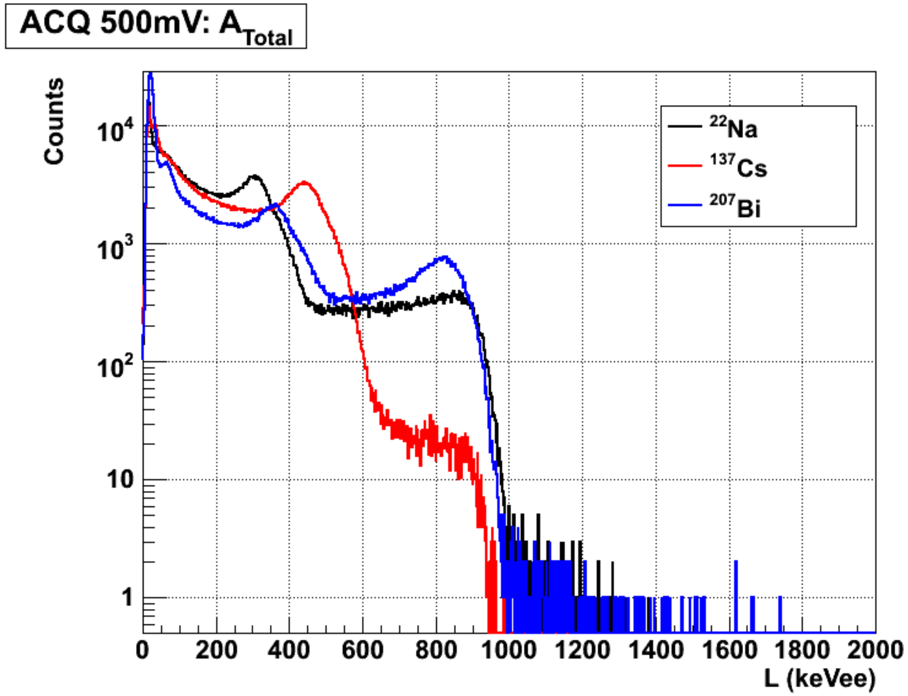
Neutron Response Functions
- Energy calibration, resolution function
- Dead-time corrections,
- TOF event selection, n-γ discrimination and background contribution, …
- Normalization to neutron fluence
- MC simulation comparison

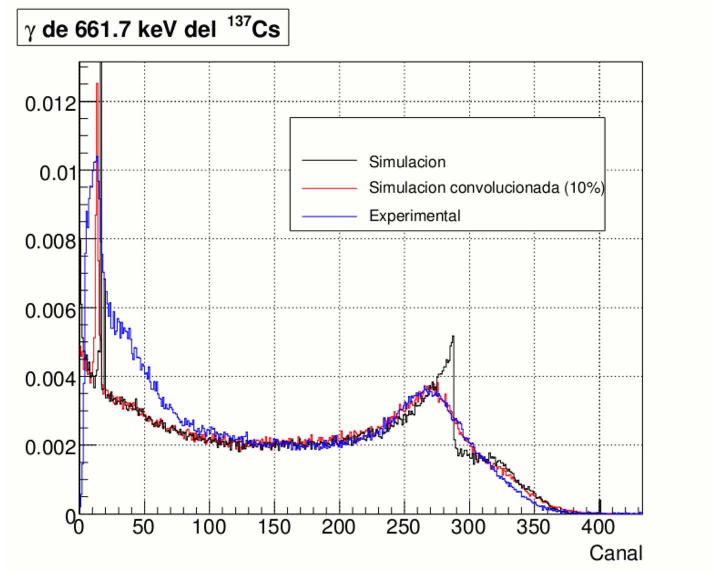
Efficiency by comparison with absolute calibrated detector (PTB)

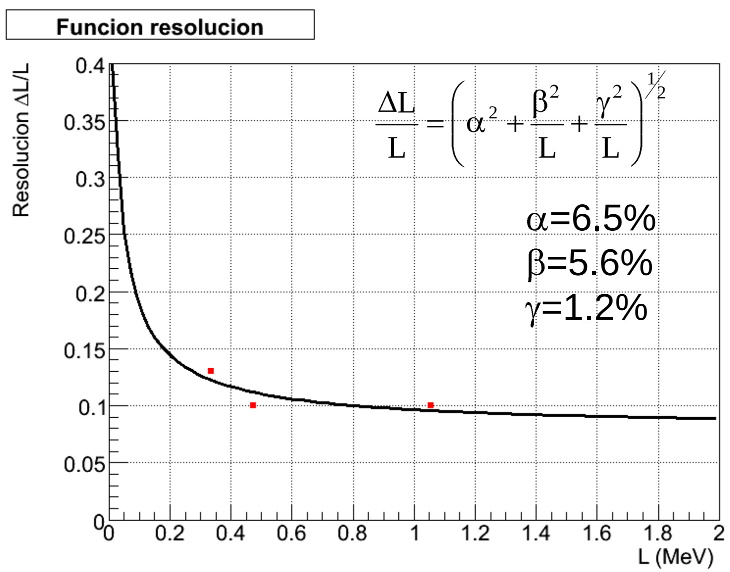
Energy Calibrations

Standard γ sources:
^{137}Cs, ^{22}Na, ^{207}Bi, Am/Be (^{241}Am)

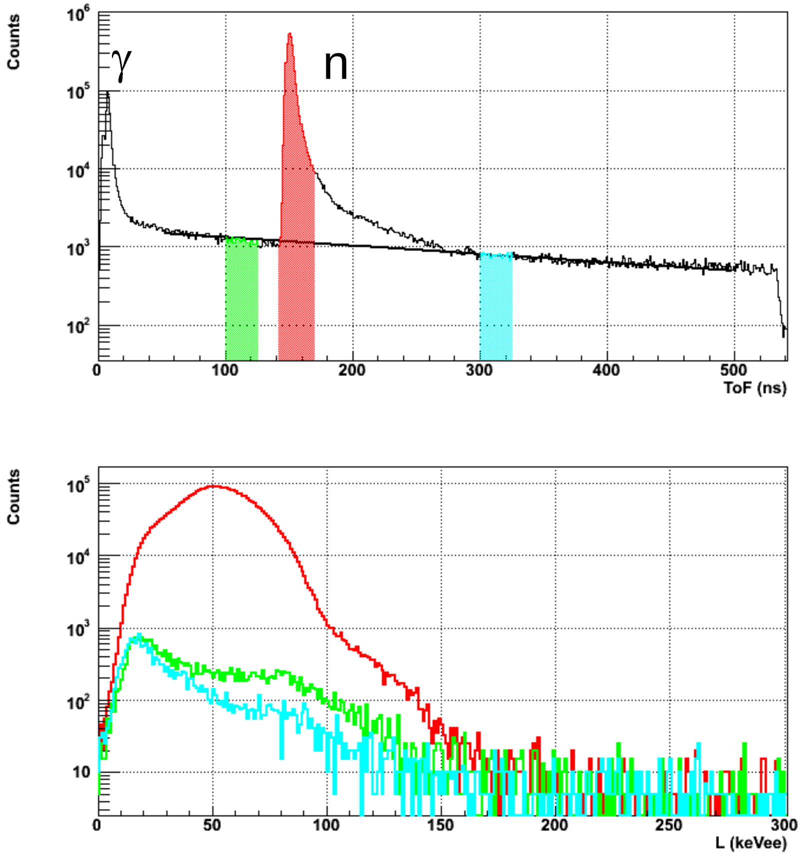
$L = k\,(E_e - 5.0)$ E_e>40keV & k=1

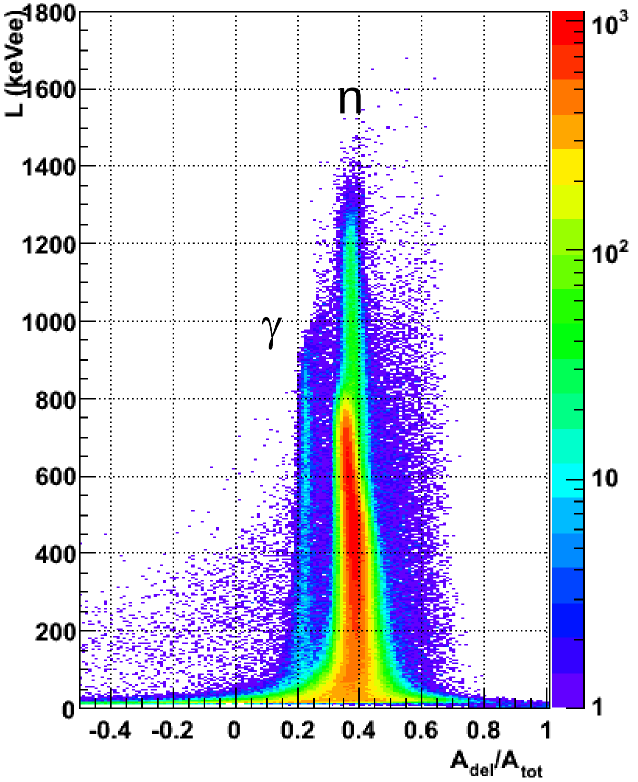






Event selection: TOF & n/γ discrimination



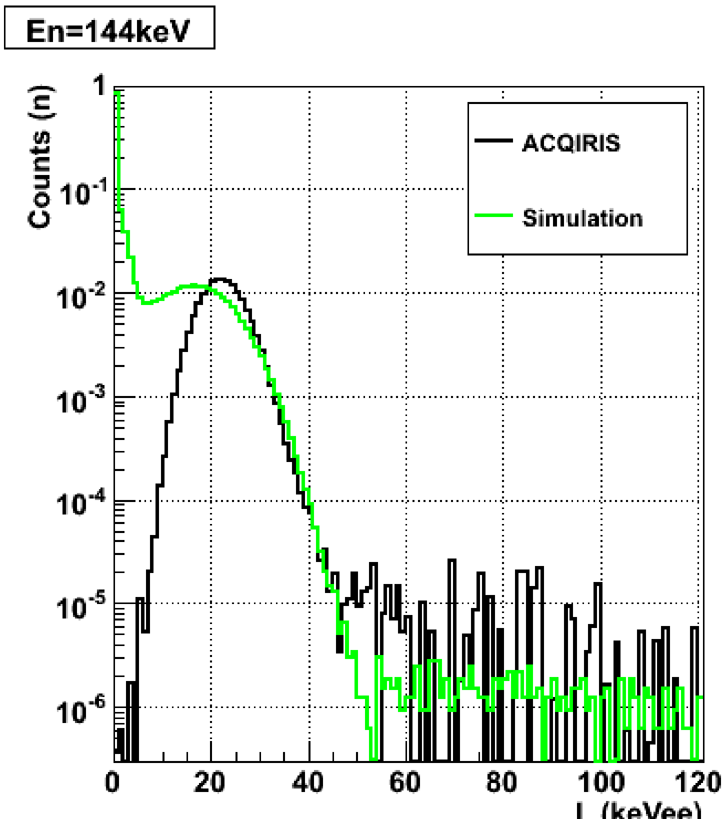


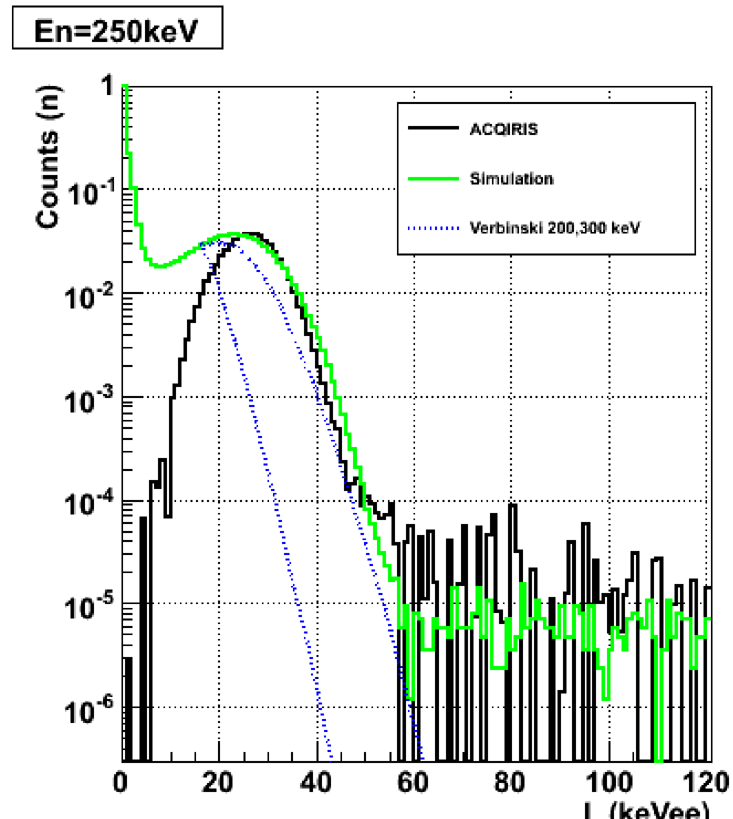
γ contribution is 10^2 lower than n

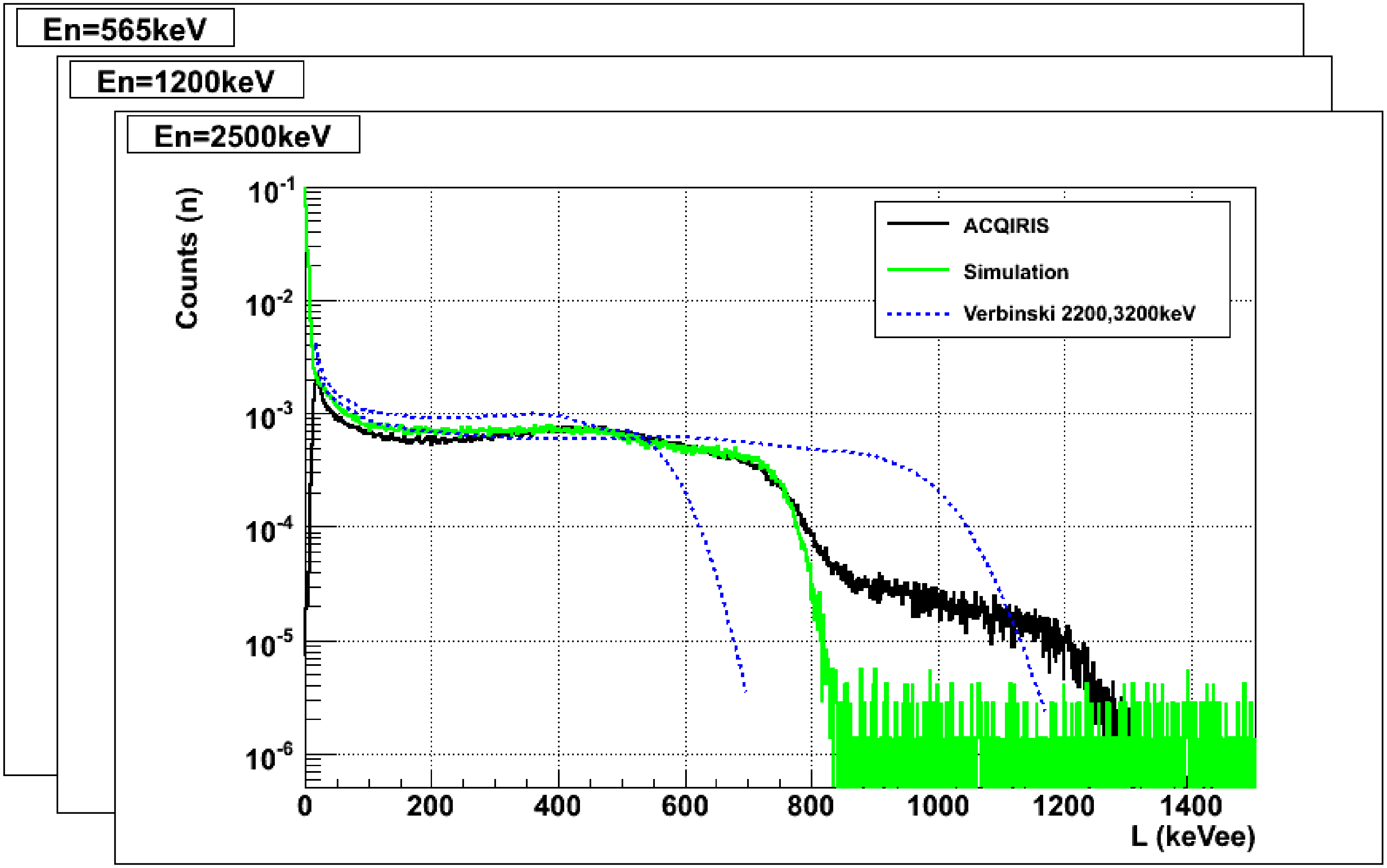
Preliminary Results

VdG data. Normalized to the neutron fluence (from PTB monitor)

Simulations are used to compare the response function.
Dekempeneer light functions are used



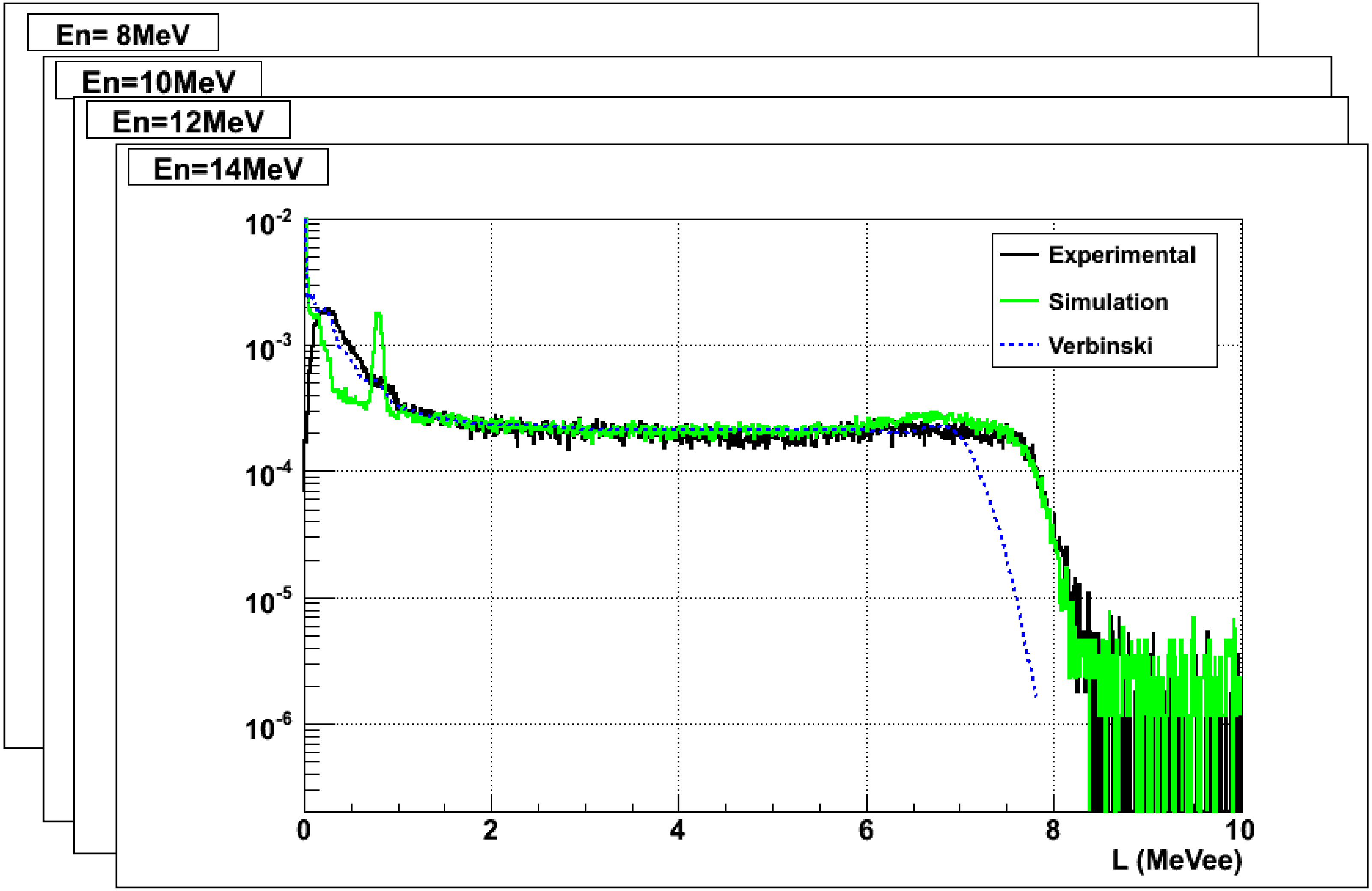




En=565keV
En=1200keV
En=2500keV
Counts (n)
L (keVee)
ACQIRIS
Simulation
Verbinski 2200,3200keV
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
200
400
600
800
1000
1200
1400

Cyclotron data.

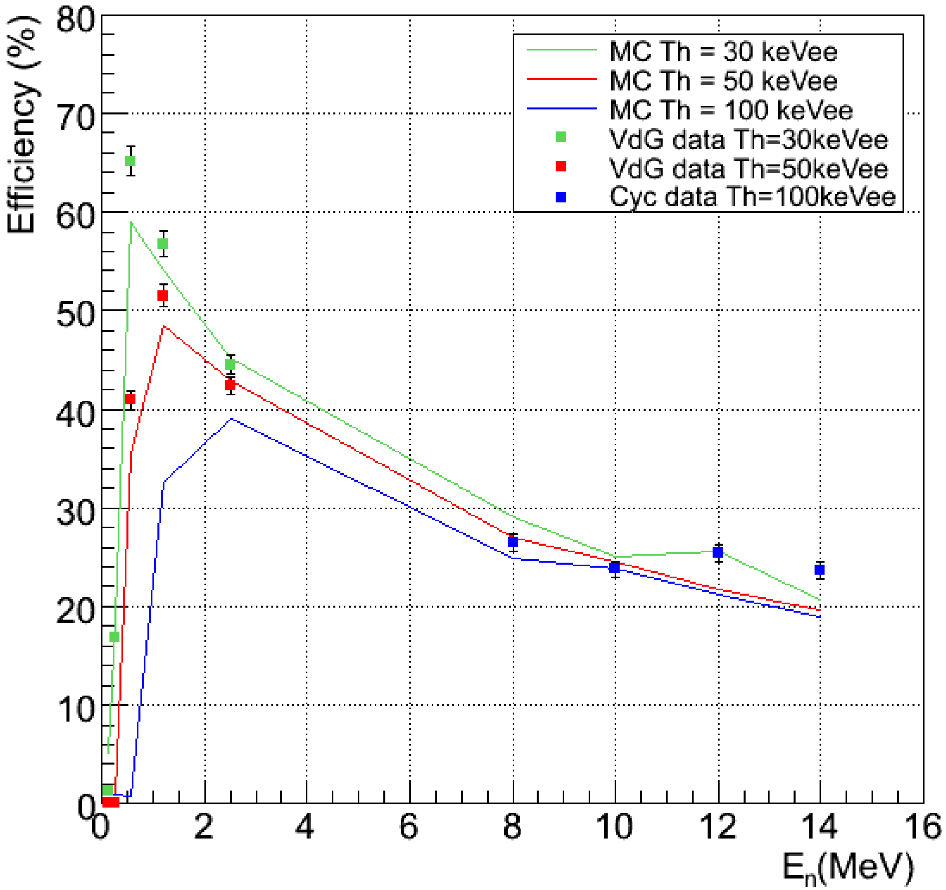
Normalized to neutron fluence (from monitor)



Differences on shape with simulated response ??!!!

Detection Efficiency

Preliminary Results:
VDG and Cyclotron estimated values follows roughly MC calculation.



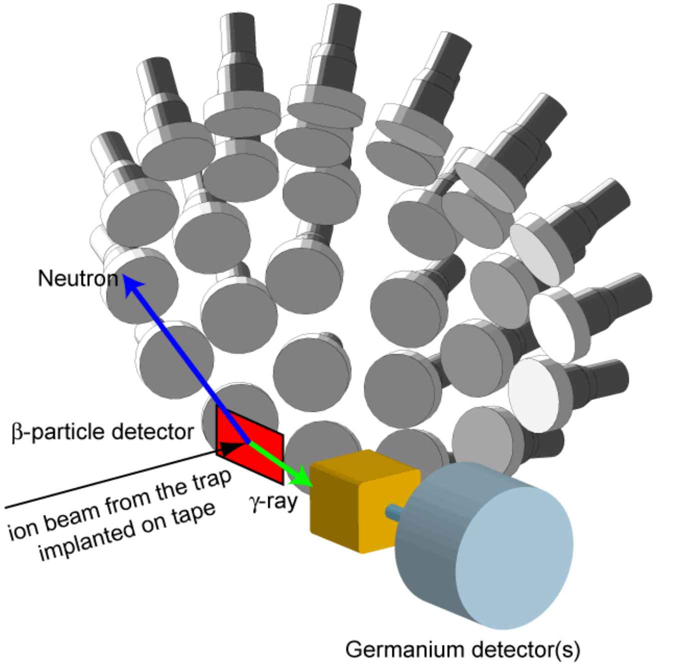
Working on:
Improved analysis routine for small signals and pileup
Better determination of proton light yield functions MC

4. Experiment with prototype @ Jyvaskyla Univ.

Test of DESPEC Prototypes at JYFL facility.
Validation of the techniques.
TOF spectrometer will be tested next year.
Goal: Measure neutron emission of known isotopes ^{87,88}Br, ^{94,95}Rb, ^{137}I

Prototype:
30 cells of BC501A liquid dim 20 x 5cm
(Ordered to St-Gobain)
Mechanical structure is being designed

Neutron Time Of Flight Spectrometer



Experimental details:
Flight path: ~100cm distance from the implantation position ΔΩ/Ω ~7.4%

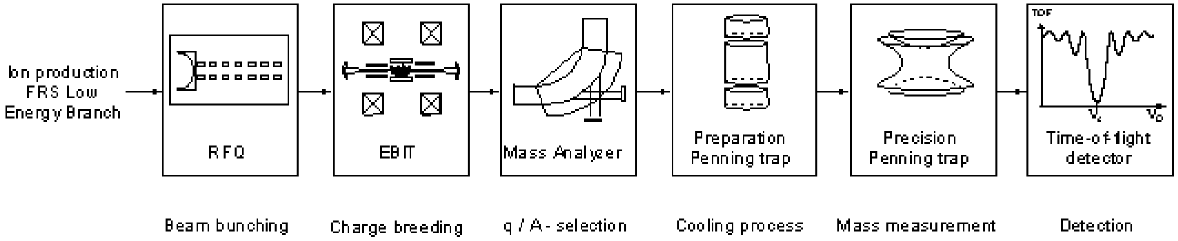
Start signal: Si (or plastic) β-detector in close geometry.
Stop signal: liquid scintillator.

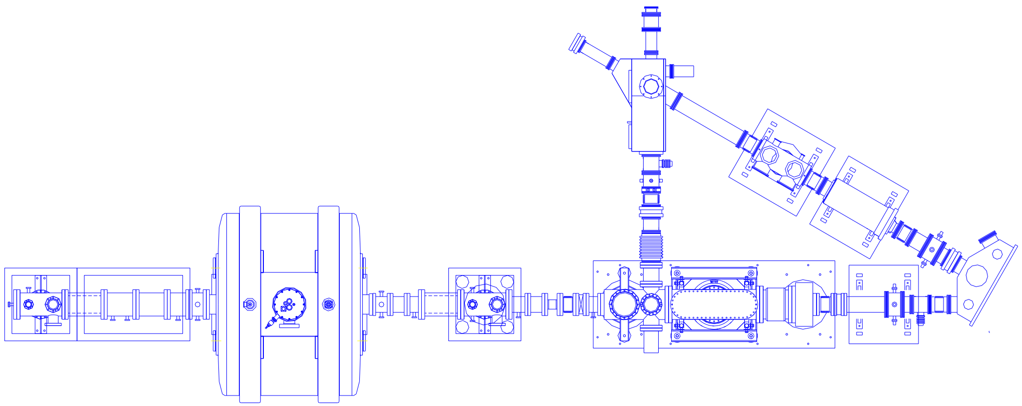
Coincidences: β-n and β-γ-n (total and partiall branching ratio)

The γ-ray background in the neutron detectors will be rejected by time of flight (for prompt coincident gammas) and by pulse shape discrimination.

JYFL experiment: IGISOL+JYFLTRAP

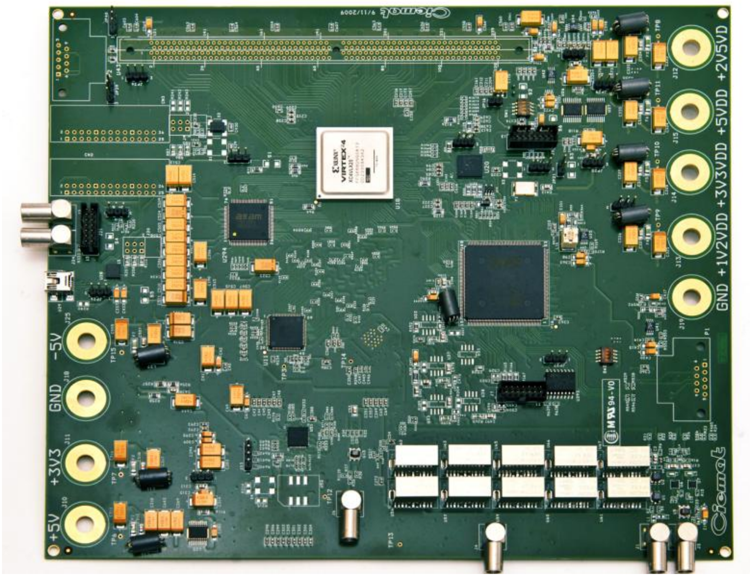
Production of ^{87,88}Br, ^{94,95}Rb, ^{137}I isotopes.
Fission fragments are first mass separated at IGISOL dipole magnet,
Then cooled and purified at the RFQ cooler-buncher and Penning Trap system giving rise to a very isotopically pure beam





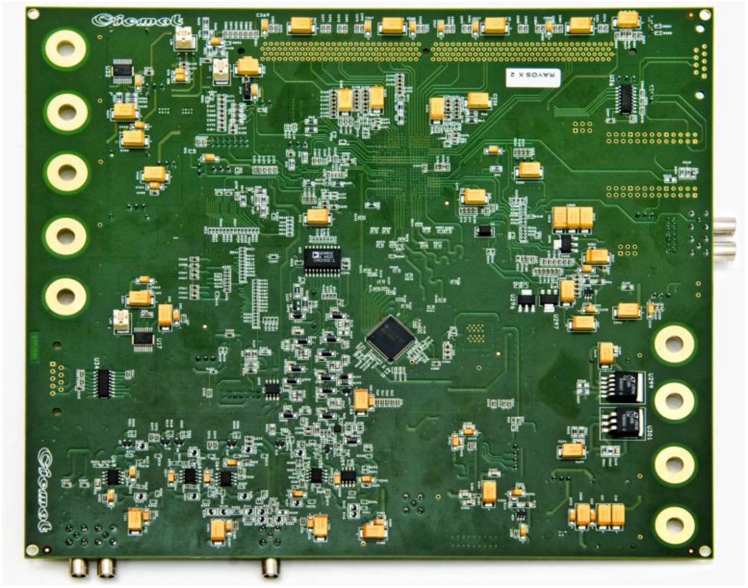
Double Penning Trap
Purification $\Delta M/M < 10^{-5}$
High Resolution $\Delta M/M < 10^{-6}$

5. Development of digital electronics



Digitiser design

- •Two interlaced ADCs of 500 MS/s and 12 bit resolution, 1GHz bandwidth, 2Vpp.
- •FPGA Virtex-4 (signal pre-processing)
- •Fast DSP (pulse shape analysis)
- •TDC (time signal determination)
- •2 Gb on board memory DDR
- •Input ranges: 100, 200, 500 mV & 1,2 V
- •External synchronization
- •fast data bus (not yet decided).
- •Operation Mode: on line psa or fast transmission
- •30 units cost estimate: < 2000 € / channel



Prototype Activities:

Test of board supply
Test of FPGA, ADC, TDC
Test on input channel and ranges
Test of noise performance
Test of firmware

Missing: Test on DSP, DDR, CLK
ADC and TDC calibration

Conclusions

• A neutron detector is being designed for DESPEC, TOF spectrometer based on BC501A. Sensitive to E_n > 100 keV.

• A large amount of work has been dedicated to develop and improve Monte Carlo simulation codes and tools: cross sections data, light output, light collection…

• Prototype cells have been tested to determine features as time resolution, n/γ discrimination, light collection uniformity,

• The liquid scintillator cell has been characterised with reference neutron beams. Analysis still ongoing. 30 new cells have been ordered to St-Gobain for spectrometer prototype.

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

• High performance digital electronics is being designed for the nTOF spectrometer. Prototypes are being tested.

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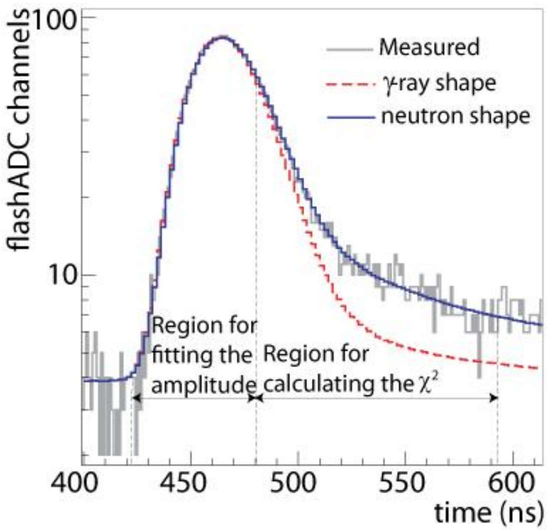
ENRESA

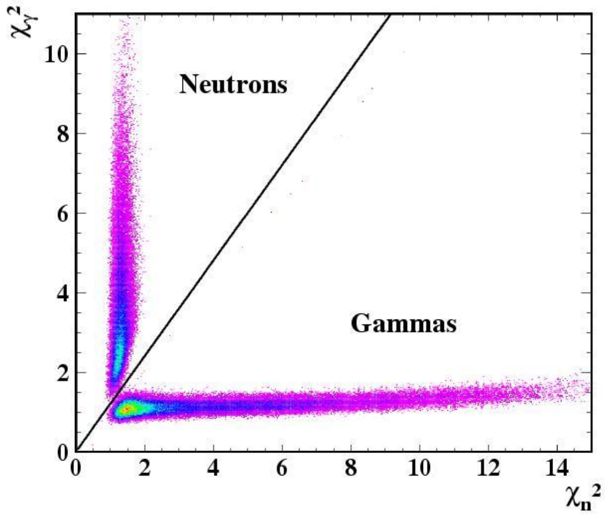
Thanks for your attention!

n/γ discrimination with digital electronics

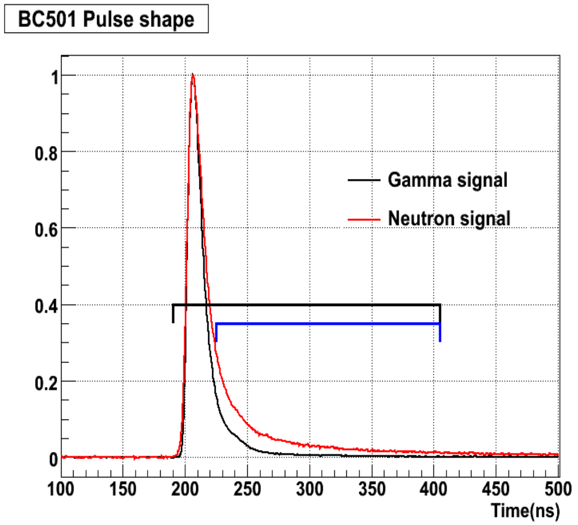
Fit to "true" pulse shape method



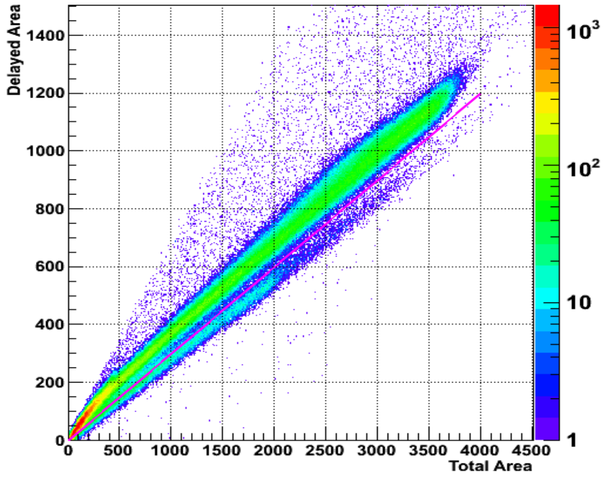
True pulse shape from averaged signals (neutron and gamma)
Fitting 1param (amplitude) to both signals, calculating the $\chi 2$
Guerrero et al. NIMA 597(2008)212



Charge Integration method



Integrate the signal in two ranges, total area and delayed area
Plot Atot vs Adel or Atot vs Afast



The aims of NUSTAR @ FAIR

- **Nuclear Structure Physics:**
  - Isospin dependence of effective nuclear interaction
  - Modification of shell structure far off stability (new magic numbers)
  - New effects near the driplines (halos, skins, soft modes, …)
  - Relevant symmetries, structural evolution, role of phase transitions
  - **Towards a unified description of nuclear structure and dynamics**
- **Nuclear Astrophysics Studies:**
  - reactions relevant for nuclear astrophysics (direct & indirect)
  - properties of nuclei participating in nucleosynthesis (M, $T_{1/2}$,…)
  - nuclear structure far off stability and its effect on stellar processes
  - **Towards the understanding of the origin of the heavy elements**
  - **Towards probing stellar objects and phenomena** based on the understanding of nuclear physics together with precise astrophysical observation
- **Nuclear Reaction studies**
  - Investigate reaction dynamics for RIB production, spallation, ADS
  - Dynamics in systems with weakly bound nucleons (halos, correlations)
  - **Towards a unified description of nuclear structure and dynamics**

- **The NUSTAR collaboration works towards an optimal facility and physics program (theory & experiment) to achieve these goals**