Characterization of neutron detectors for nuclear technology applications

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Outline:

- Context and Motivation
- Experimental Details
- Status of the Analysis
- Preliminary Results
- Conclusions

Motivation

Improvement of nuclear data for transmutation of radioactive waste (MA and LLFP)

Design, safety and operation of fast reactors and ADS rely on
Improved accuracy of nuclear data libraries.

- Neutron cross-section data (capture, fission, inelastic)
- Decay heat data, Delayed neutron data

Uncertainty reduction achieved development of facilities and improvement of detection techniques.

Facilities:

n_TOF@CERN (n cross-section data on Np, Pu, Bi, Pb …)
FAIR @ GSI radioactive beams available to study neutron rich nuclei (neutron emission probabilities)

Detection techniques:

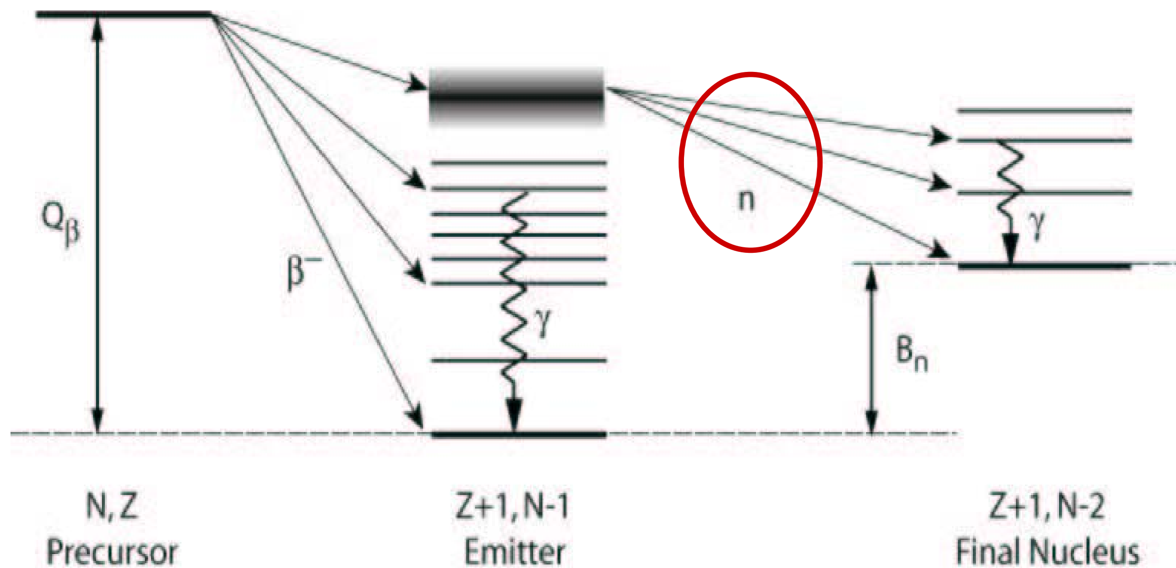
n_TOF spectrometer
Total Absorption Calorimeter (TAC)
New scintillation materials (LaCl3, LaBr3)
DAQ systems (flash ADC)

DESPEC experiment (Nustar collaboration) @ FAIR

Beta-delayed neutron emitters.

Radioactive beams will allow to populate nuclei produced in the fission reaction process in reactors.

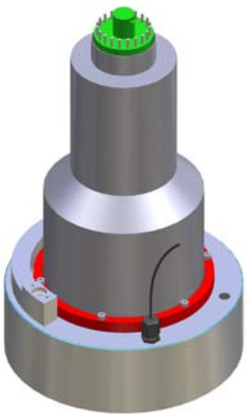
Beta decay properties and neutron emission probability should be studied with high accuracy.



-Delayed neutron data: absolute neutron yield, neutron energy spectra, time dependence with activity.

- High efficiency 4π moderated-based detector (V. Gorlychev talk's)
- n_ToF spectrometer

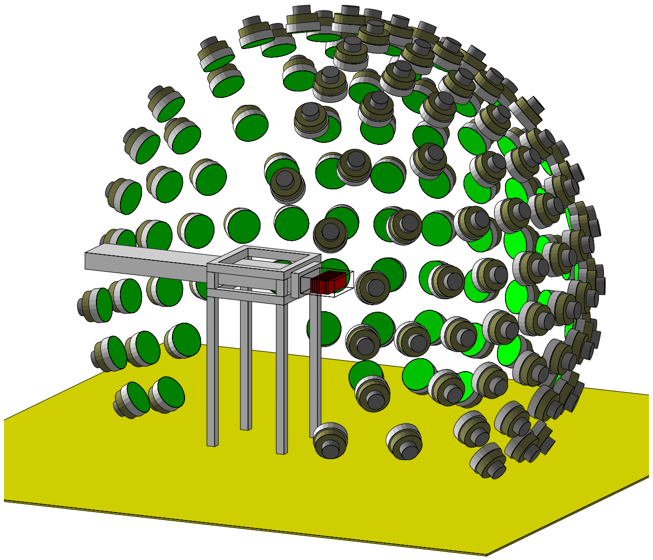
Neutron TOF spectrometer



Requirements:

High ε_n (large solid angle)
Improved $\Delta E/E$, (thin detectors)
Lowest threshold, (down to 30 keVee?)
n-γ discrimination, (reduced background)
cross-talk rejection (high granularity)

Liquid organic scintillator cells
Develop MonteCarlo simulations of prototype



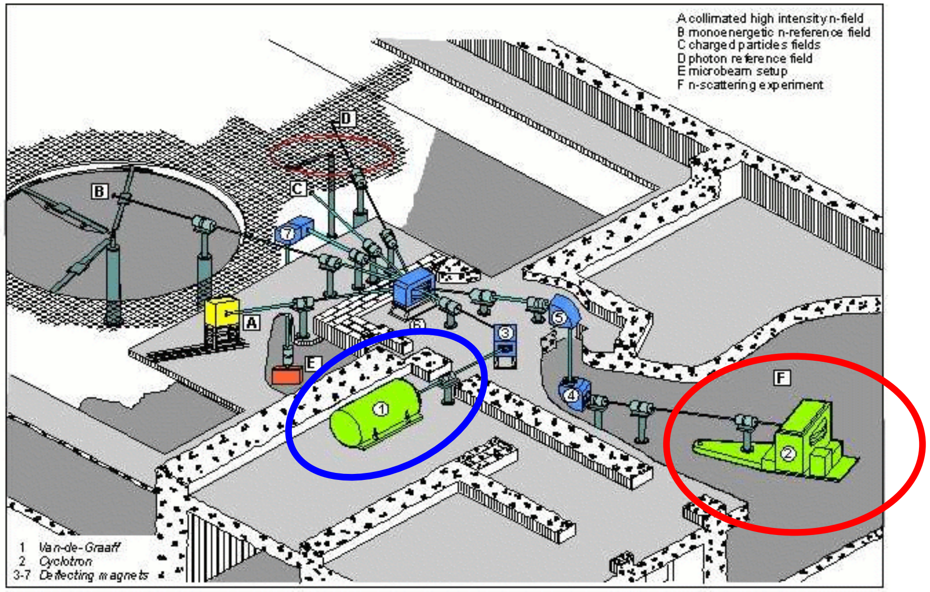
Measurements of characterization:

Light output calibration function for electrons and protons, L=f(E)
Energy resolution $\Delta L/L$(%) as a function of energy deposited
Absolute neutron sensitivity and detection efficiency
Comparison with MonteCarlo simulation

Performance of DAQ systems (flash ADC)

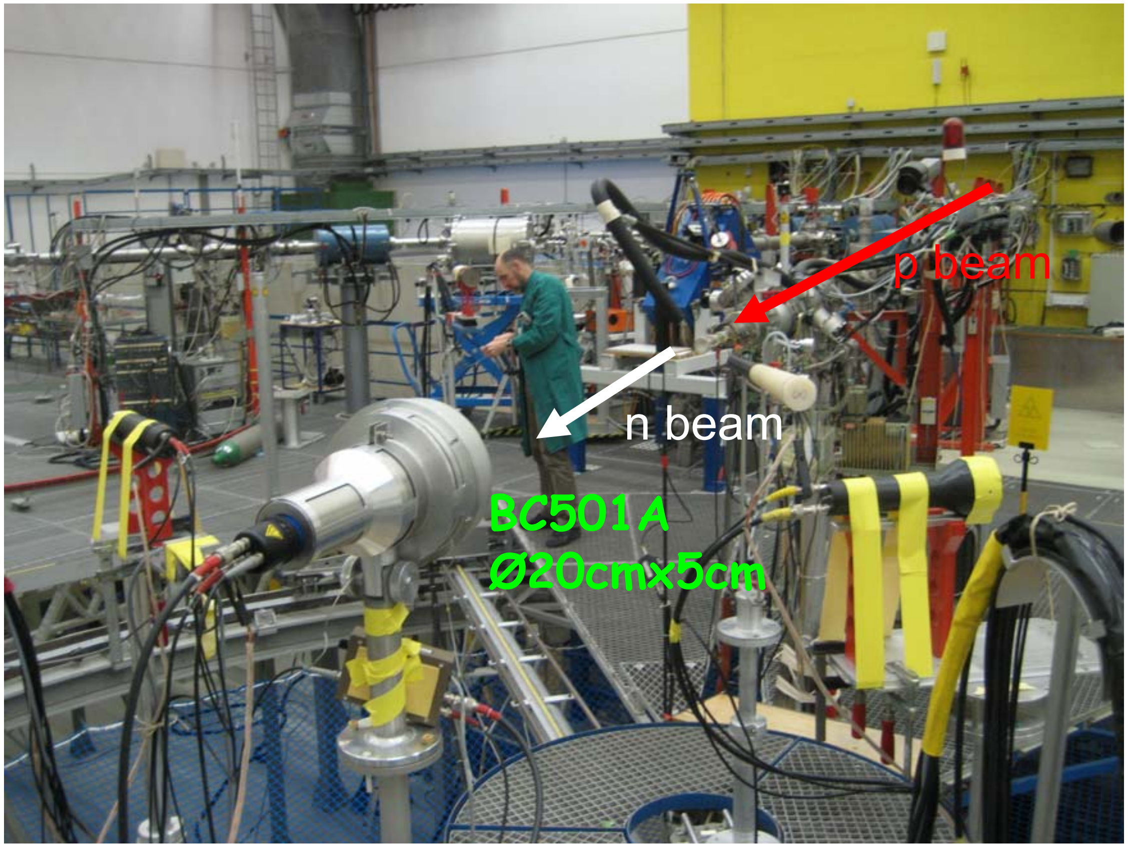
Transnational Access to the EFNUDAT facilities program

PTB: Production of mono-energetic neutron reference fields



Beam Time with Cyclotron and Van de Graaf accelerator at PTB
Test of liquid and inorganic scintillators
PAC 2 /1 approved 80h beam time
D(d,n), Li(p,n) and T(p,n) reactions provide mono-energetic neutrons
Variable fluences and distances
Experiment performed 9-13 March

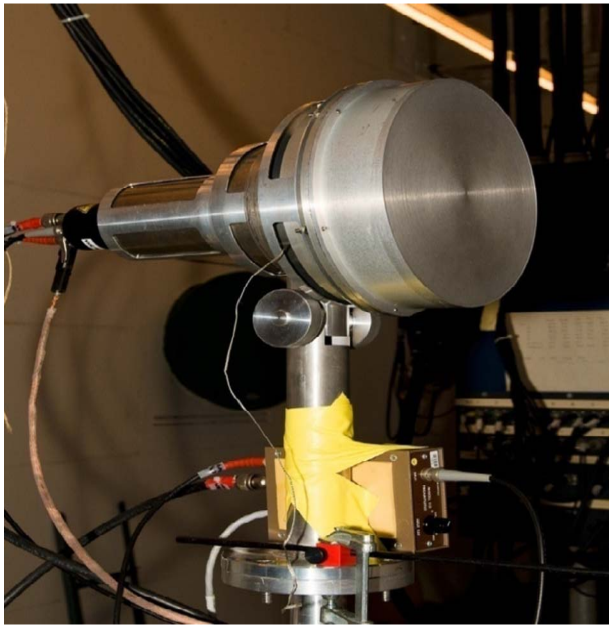
Measurement at VDG



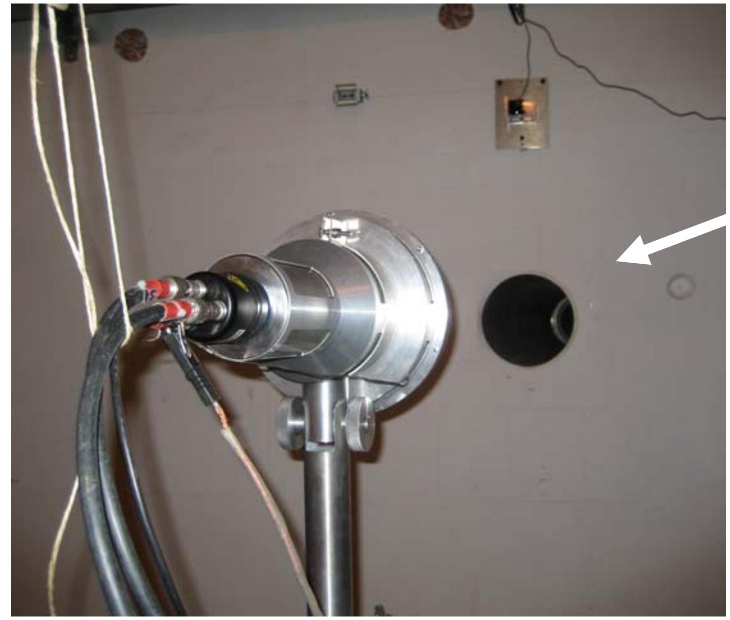
Van de Graaff:

- 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

Measurement at Cyclotron



BC501A
Ø20cmx5cm



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

The data acquisition system

Evaluate the performance of DAQ system

Digital System:
•Flash-ADC
•ACQIRIS DC271 8bits 1GS/s

Analogue System:
•VME based
•ADC, QDC, TDC modules

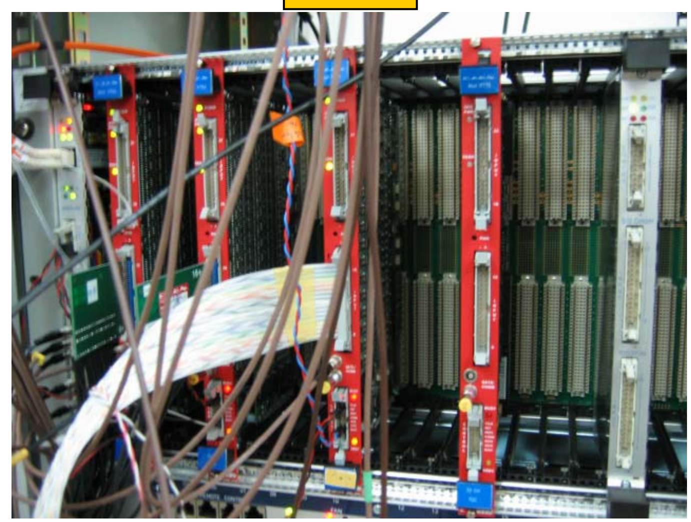
Trigger:
Detector (digital)
Detector+pulser (analogue)

Dead Time correction:
Digital scaler board NI (read / write mode)
Precision pulser 100Hz

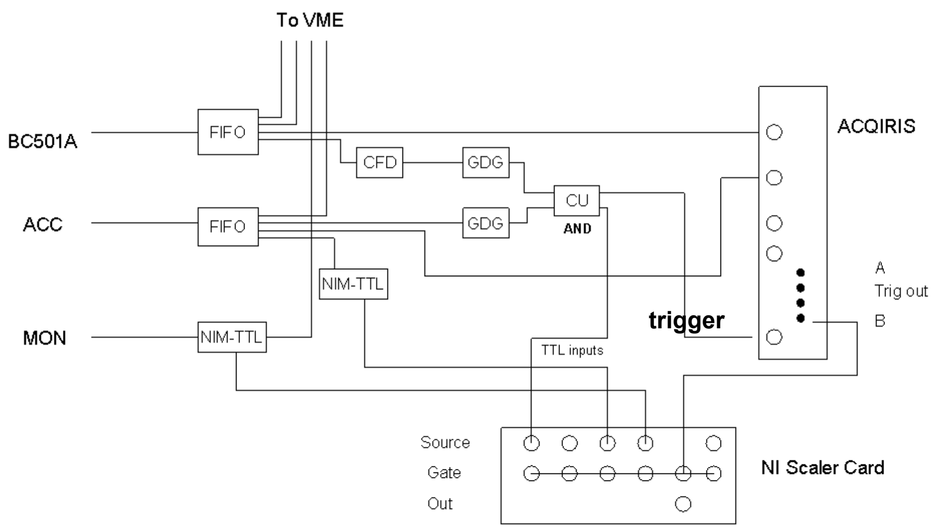
Total of 2TB of data

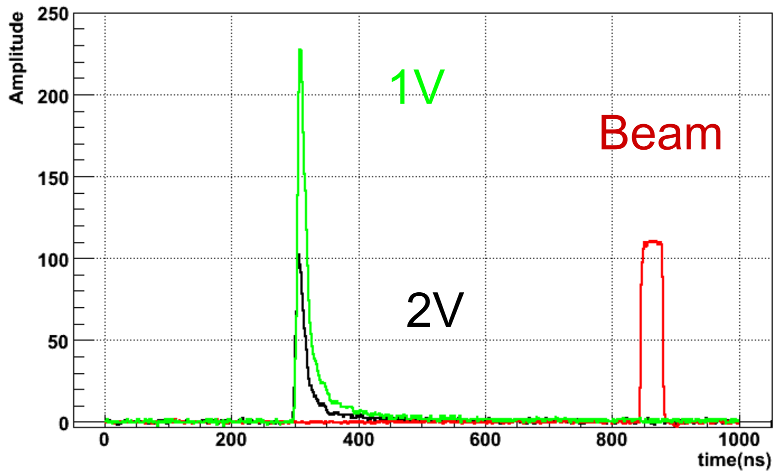
Acqiris DC271 8bits 1GS/s

VME



The digital system





Settings:

ACQIRIS:

Signals digitized over 1μs when trigger

5000 triggers each iteration

NI Board:

Monitoring of counting rates from Detector, Accelerator and Neutron monitor detectors during ACQ reading/writing mode

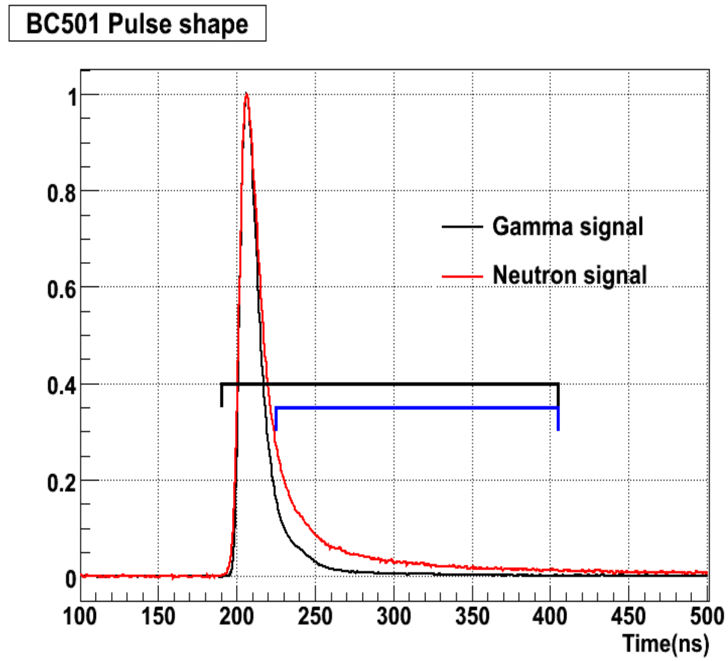
	FS c1	FS c3
VdG	1V	500mV
Cyc	2V	1V

Parameters

Digital System:

Pulse Shape Routine:

- Baseline
- Amplitude
- A_{TOT} (220 ns)
- A_{DEL} (180 ns)
- Time signal



Analog System:

List mode parameters:

- QDC gates:
  - A_{TOT} (370 ns)
  - A_{DEL} (250 ns)
- TDC:
  - Detector Time
  - Acc Signal Time

Analysis Procedure:

Light output Response Funtion

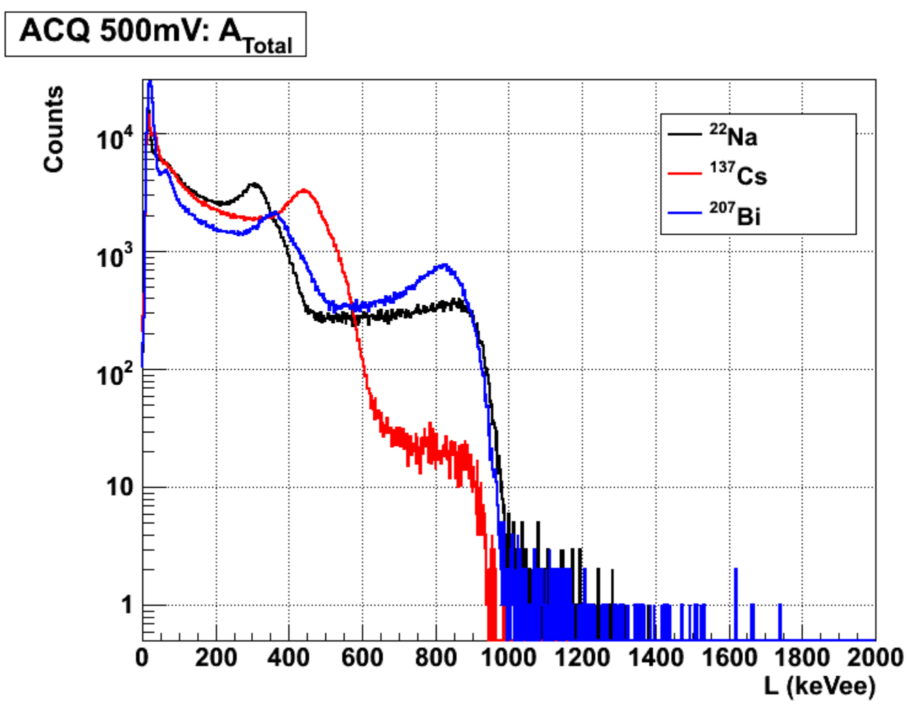
- Energy calibration, resolution function
- Dead-time corrections,
- TOF event selection, n-γ discrimination and background contribution, …
- Normalization to neutron fluence
- MC simulation comparison

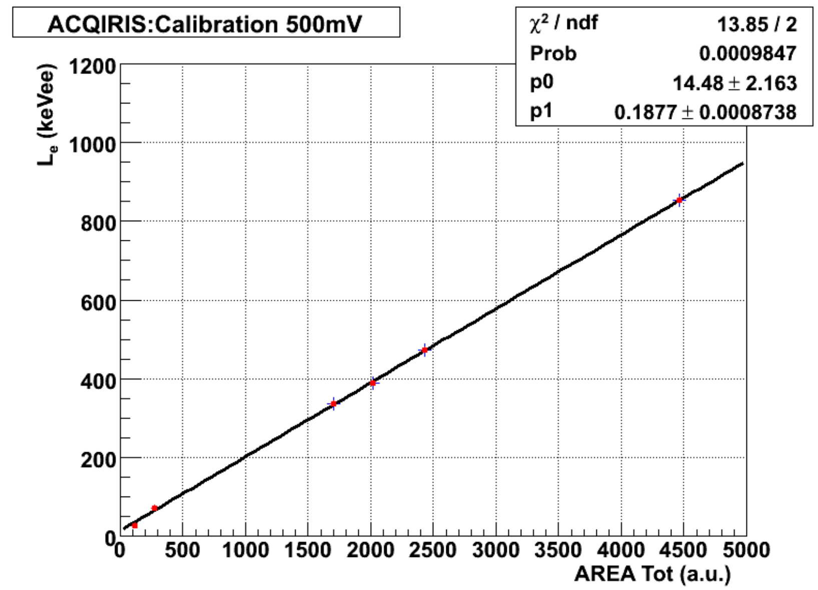
Eficiency by comparison with absolute calibrated detector (PTB)

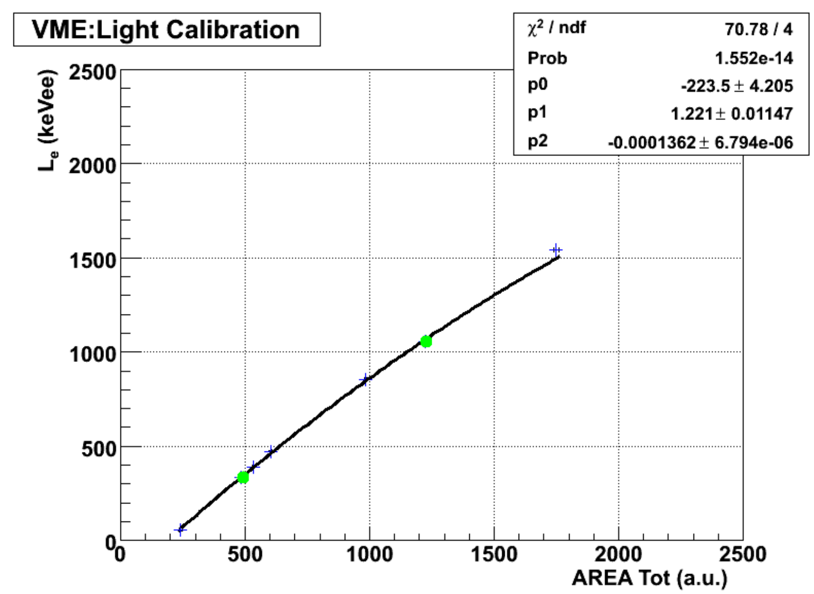
Energy Calibrations

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

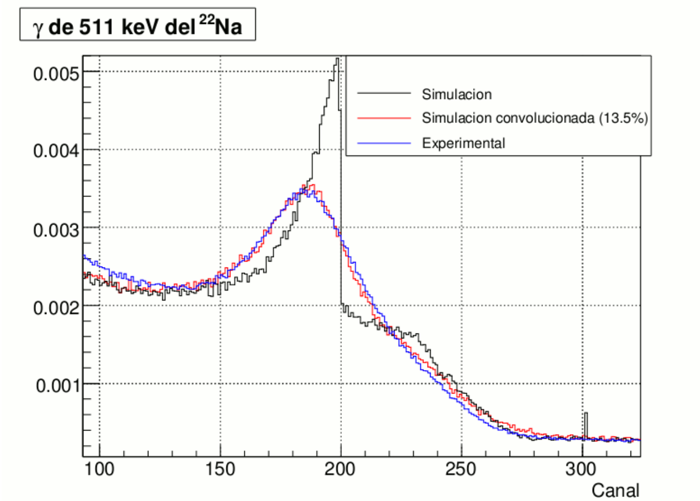
$L = k\,(E_e - 5.0) \quad E_e > 40\,keV\ \&\ k = 1$

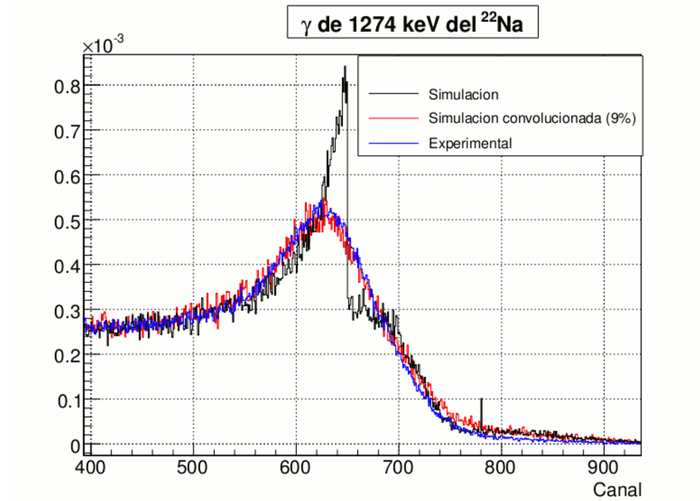


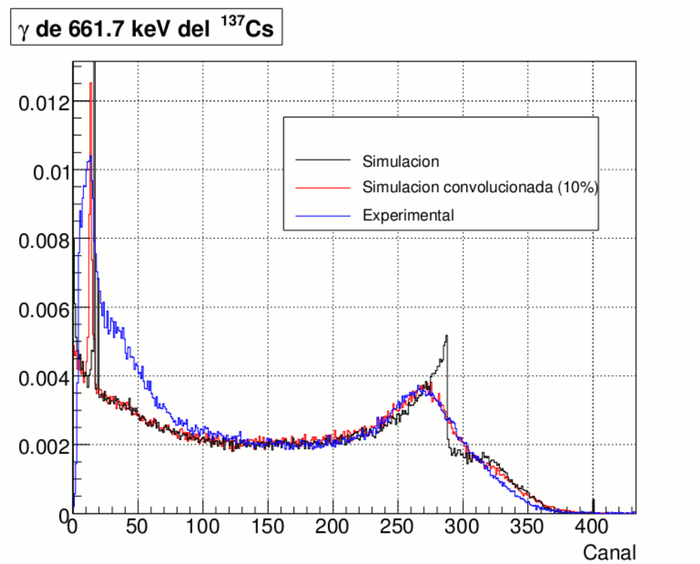


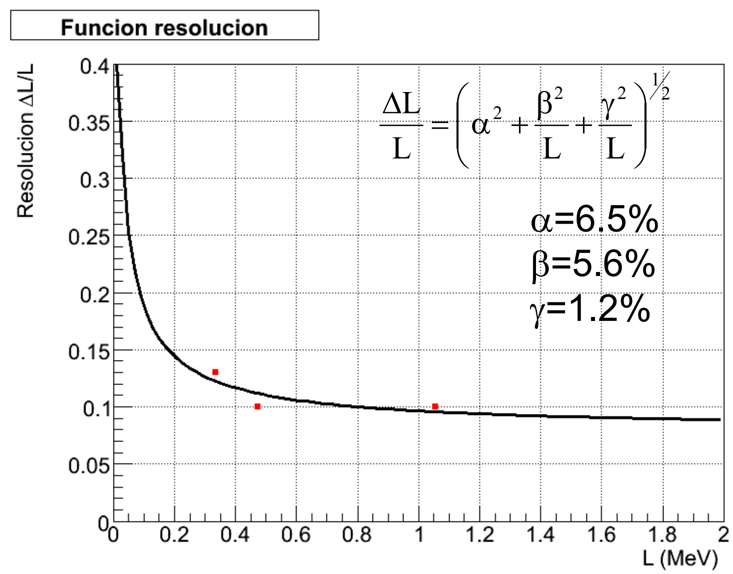


MC Calibrations



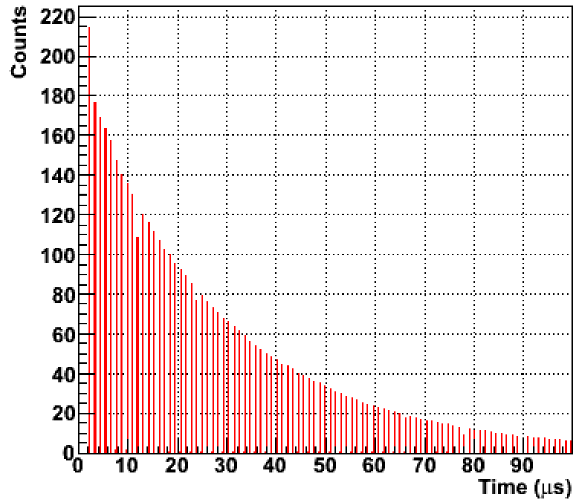


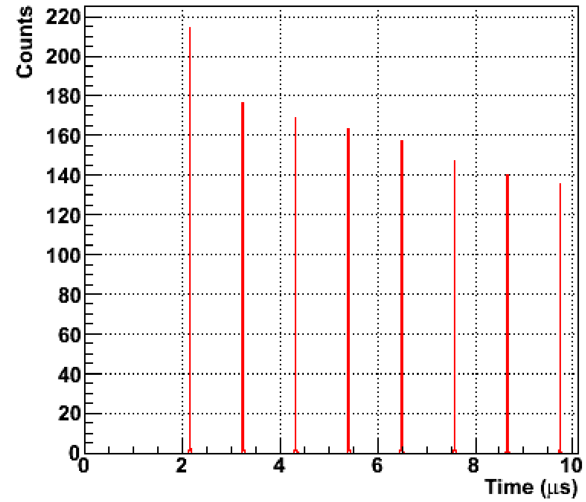




Dead Time

ΔT between consecutive triggers





Sources of count losses:

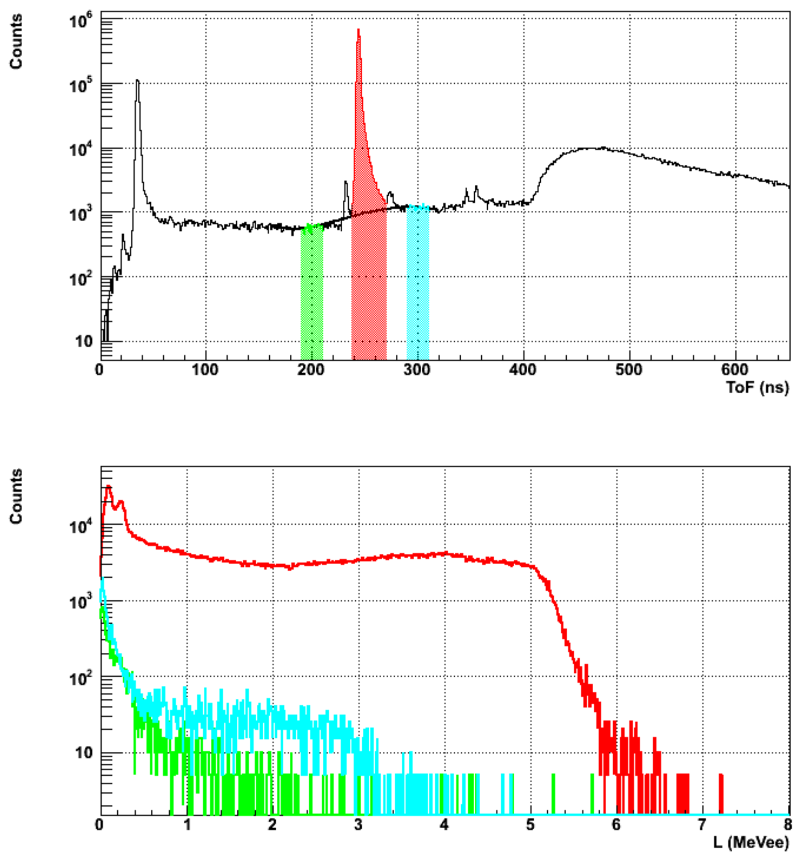
ACQIRIS not active → T digitization 1μs +Trigger Rearm of < 800ns
Pulsed beam (0.8 - 1.2 MHz)
➔Arriving pulse after detected is not registered

Routine Efficiency: 1 pulse for each segment, probability of loss other counts in the same segment

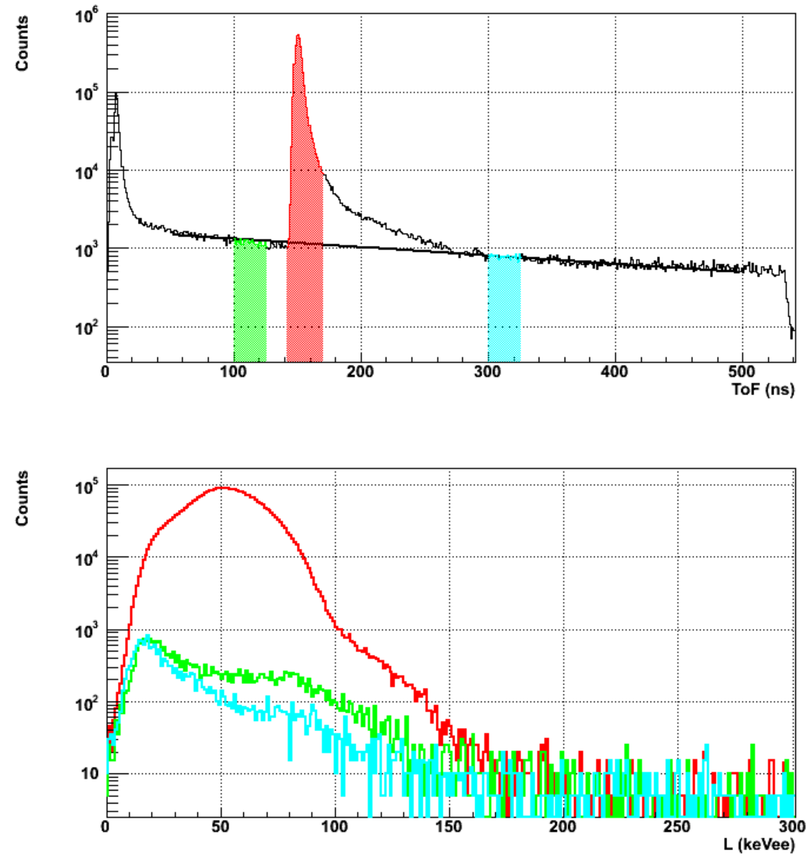
Pile-up, loss of events occurred within <50ns (Only in the case of 2500keV with a value of 4%)

TOF selection

Cyclotron Energies



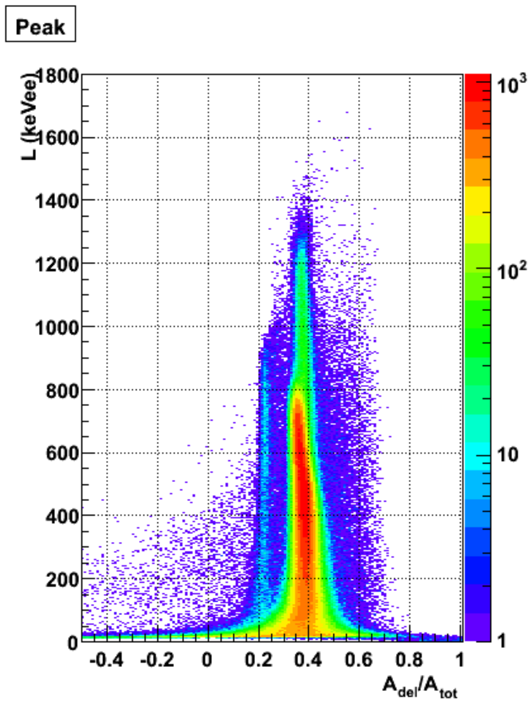
VdG Energies

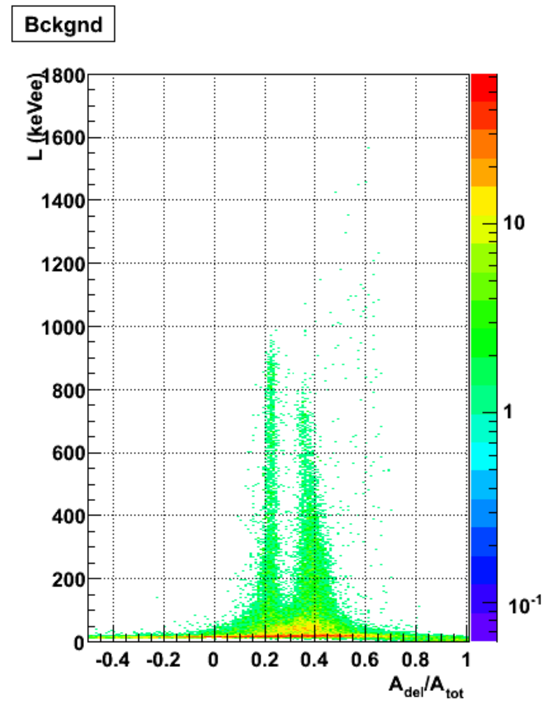


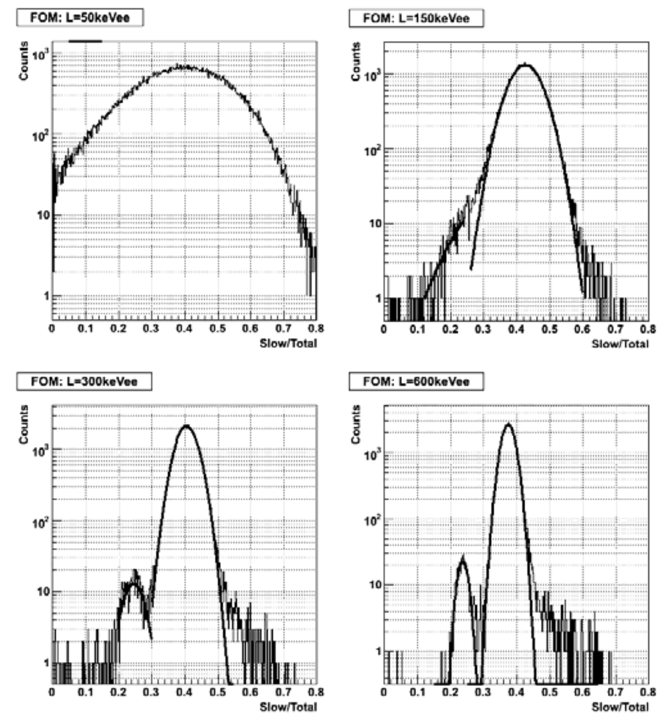
FWHM	0.144	0.250	0.565	1.2	2.5	8	10	12	14
EXP (ns)	6.0	5.5	2.4	2.8	1.6	4.3	2.9	2.8	2.7
MC (ns)	5.6	5.6	3.4	3.4	3.0	2.8	2.5	2.7	2.6

Tof resolution

n/γ discrimination



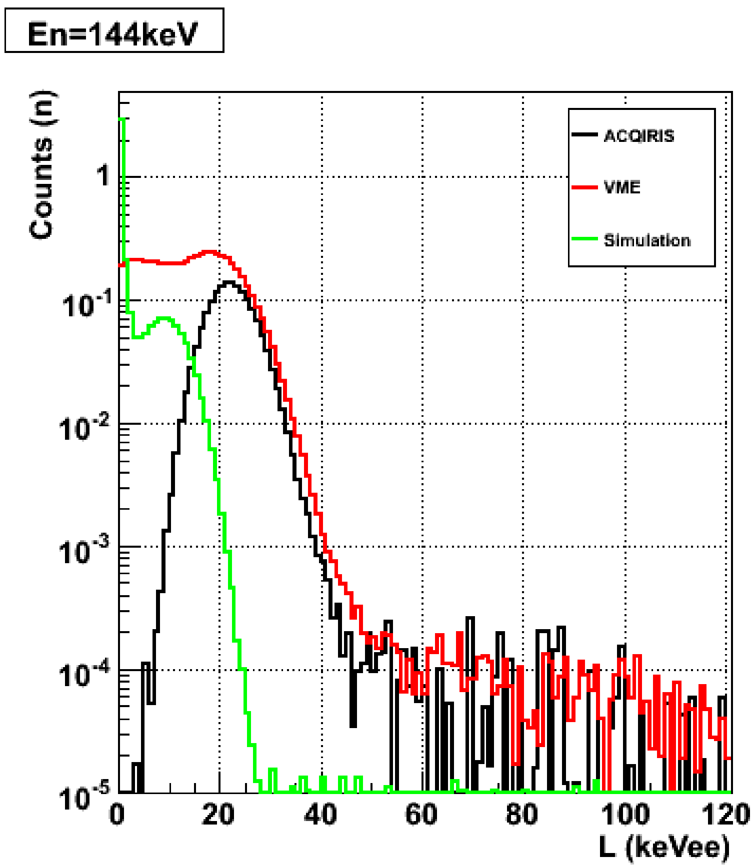


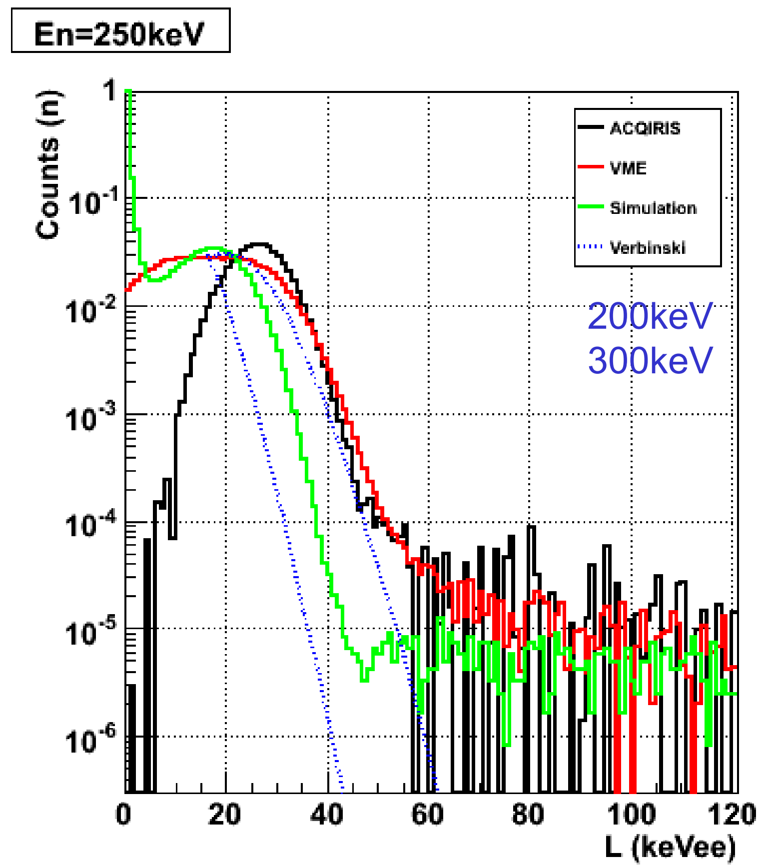


Gamma contribution is lower than 2 orders of magnitude.
A 2-dim cut has been aplied to select neutrons

Preliminary Results

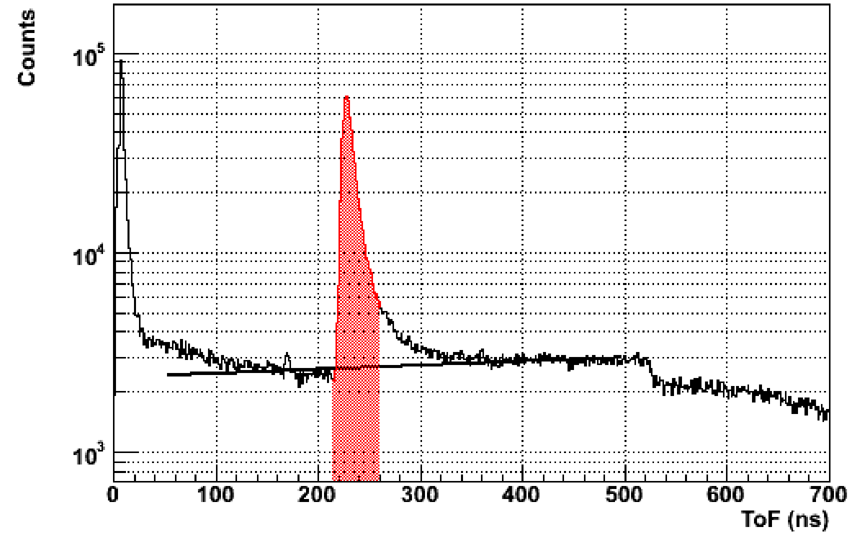
VdG data. Normalized to the neutron fluence (calibration factors)





HardwareThreshold CFD ~8 mV ➔ Th ~ 40keVee ???!!!

Limits of the Pulse Shape Routine

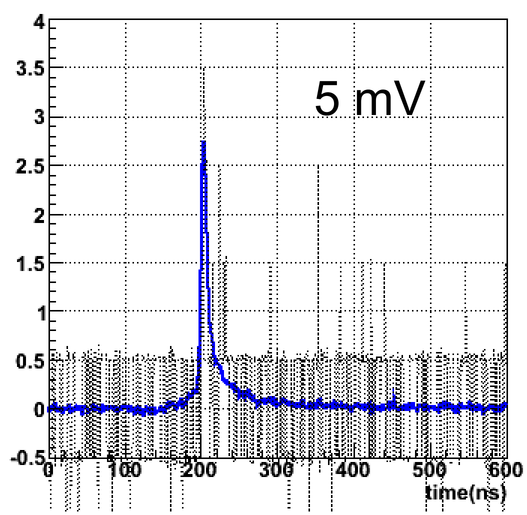


Small signals are detected, but
Area is not estimated properly

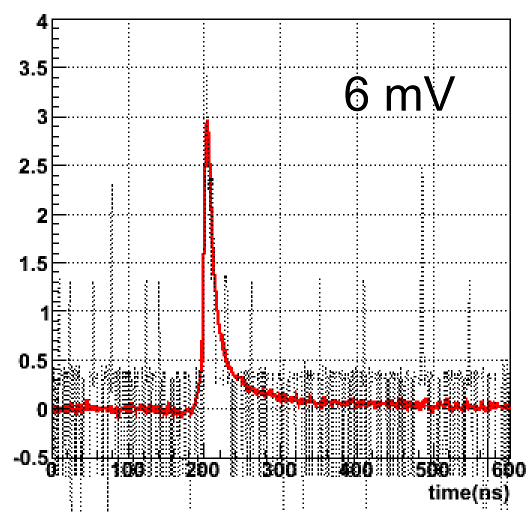
➔Routine with fit to averaged shape

Full Scale= 500mV

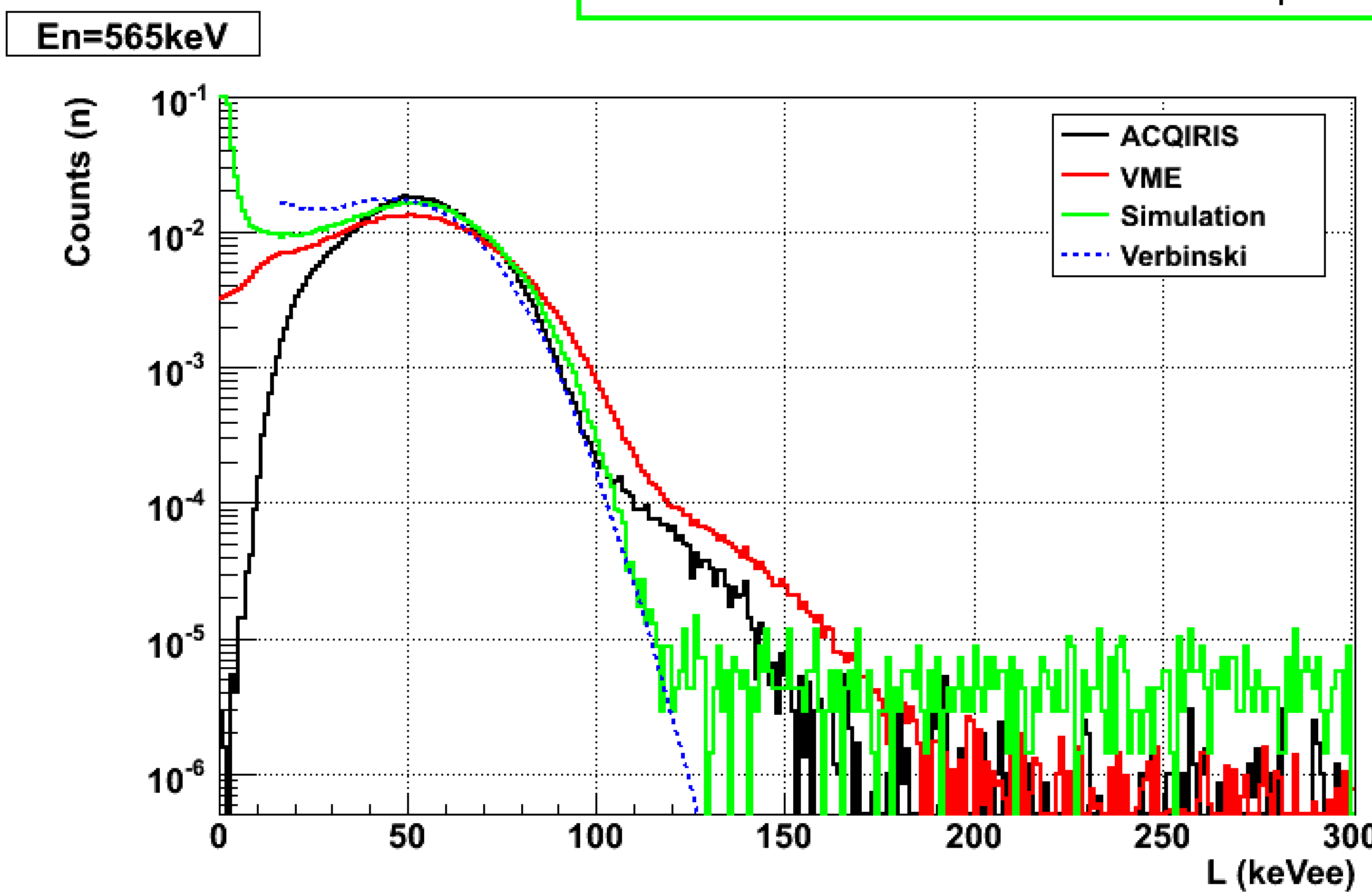
En=144 keV

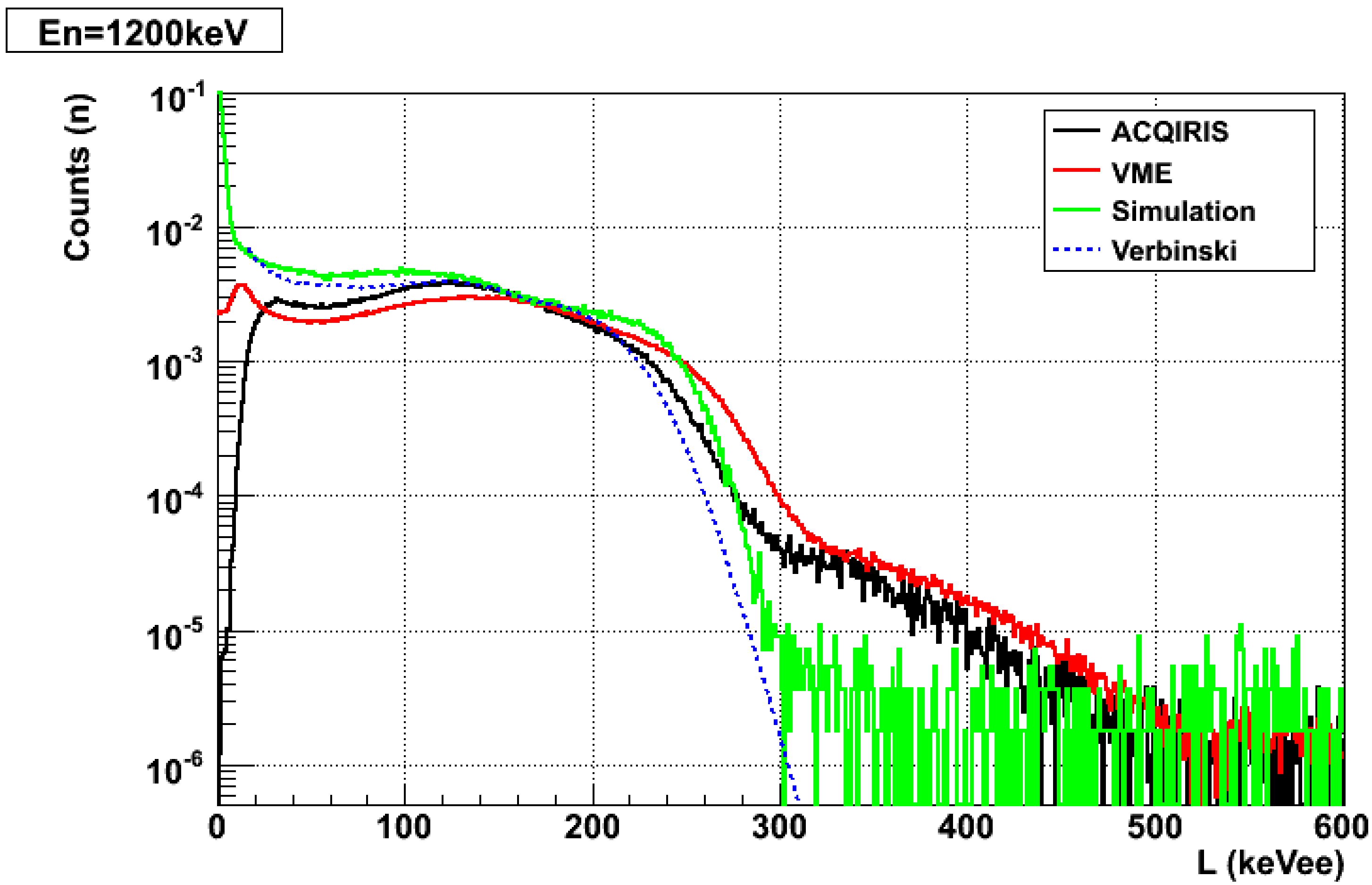


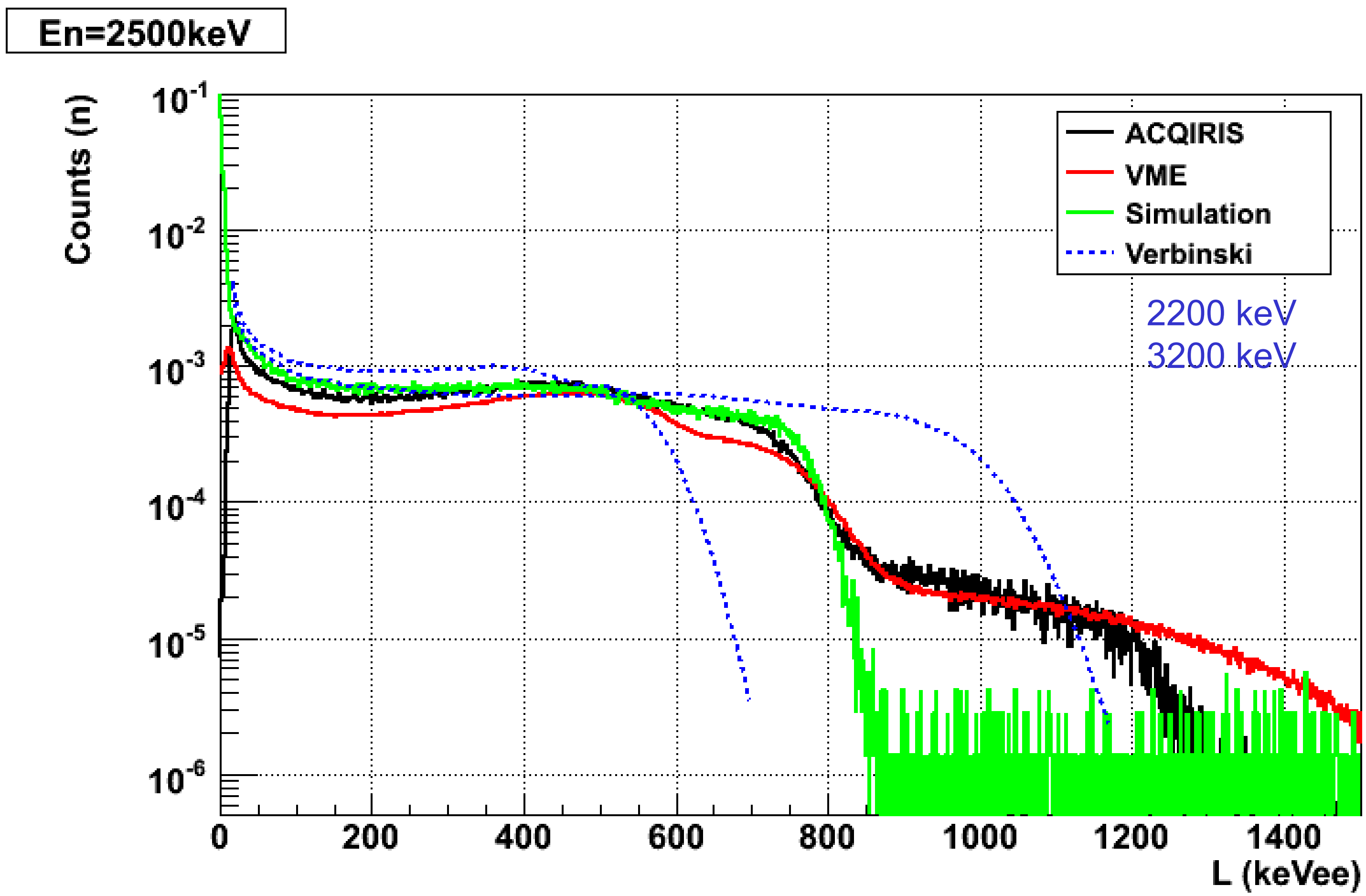
En=250 keV



Simulations are used to check the response function

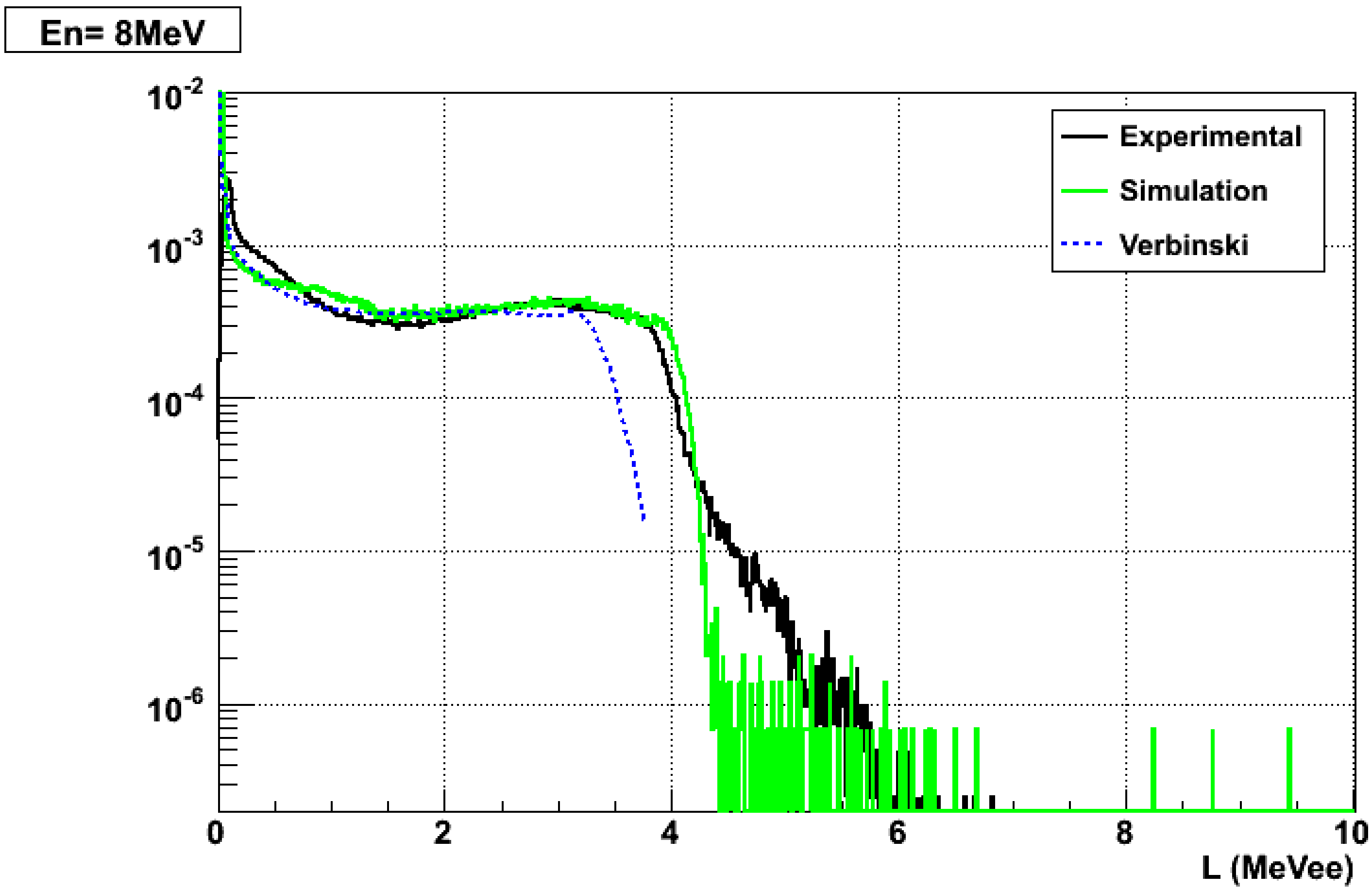



En=1200keV
Counts (n)
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
ACQIRIS
VME
Simulation
Verbinski
0
100
200
300
400
500
600
L (keVee)


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

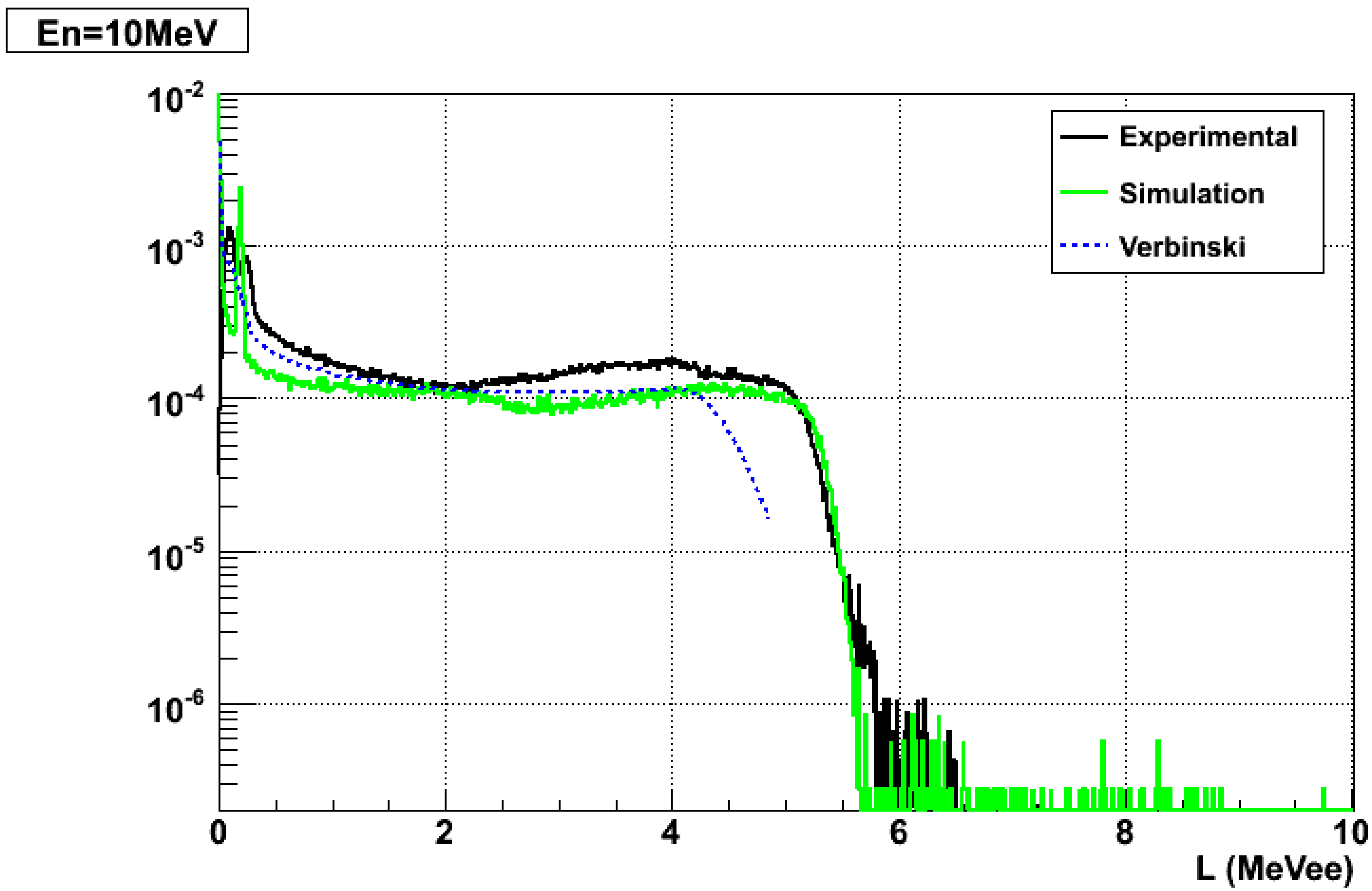
Cyclotron data.

Normalized to an estimated neutron fluence (not calibrated data yet)

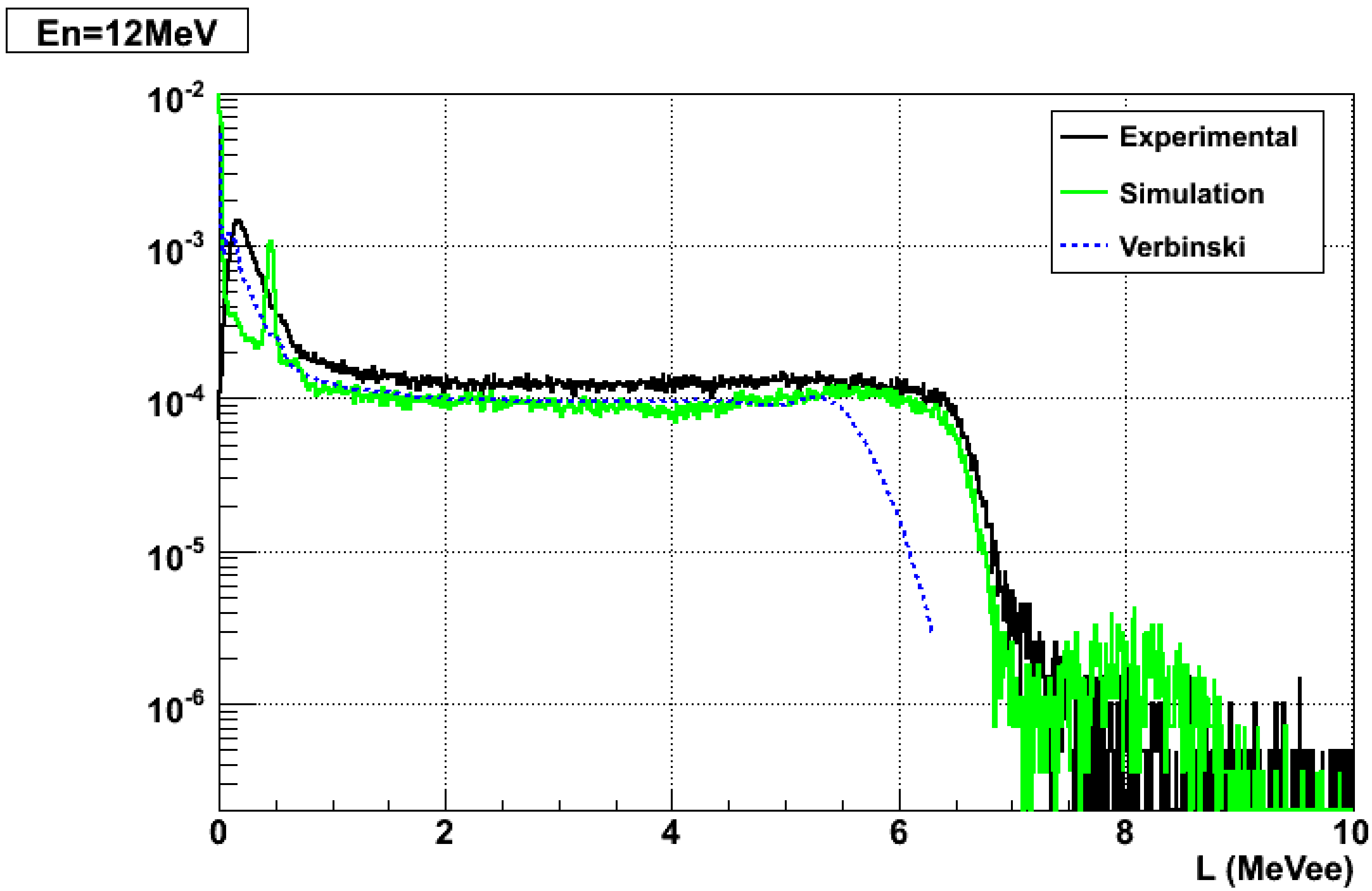


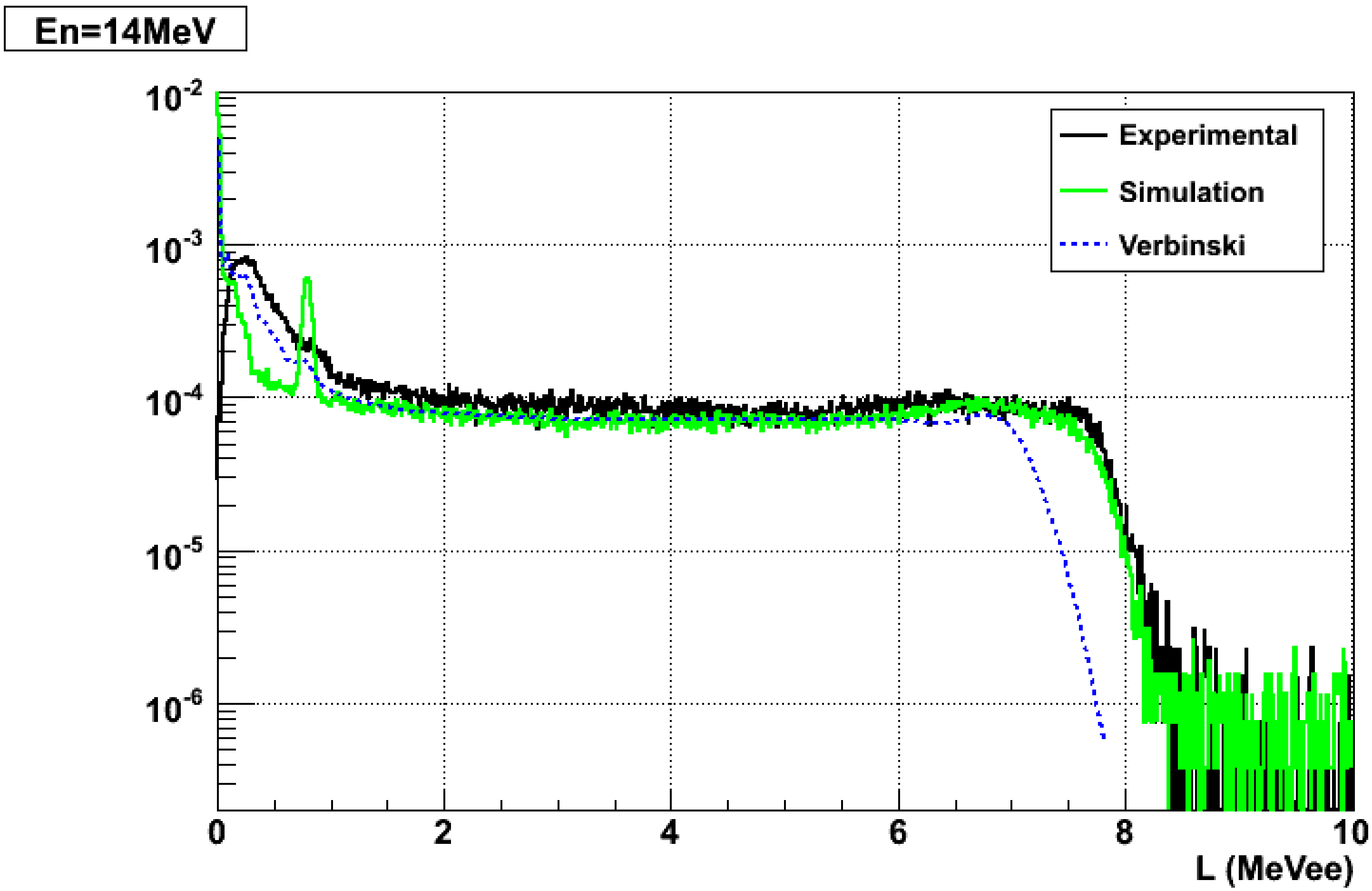
Problem with calibration ??!!!

Simulation depends on light parametrization



En=10MeV
10^-2
10^-3
10^-4
10^-5
10^-6
0
2
4
6
8
10
L (MeVee)
Experimental
Simulation
Verbinski

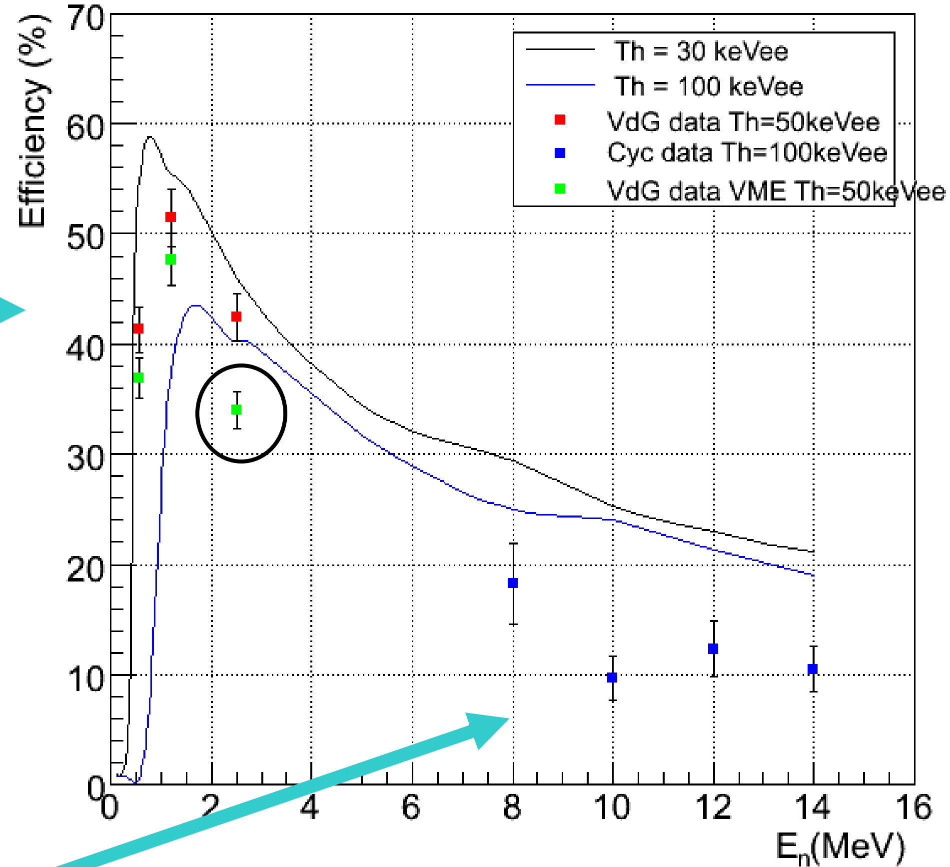

En=12MeV
Experimental
Simulation
Verbinski
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
2
4
6
8
10
L (MeVee)



En=14MeV
Experimental
Simulation
Verbinski
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
2
4
6
8
10
L (MeVee)

Detection Efficiency

VDG estimated (Th=50 keVee) values follows values with MC, ACQIRIS and VME systems.



Cyclotron values are deduced with A rough fluence value used for beam Estimates. Need of fluence values from calibrated monitor detectors.

Conclusions:

We have characterized a liquid organic scintillator BC501A
for DESPEC experiment at PTB.
We have explore the region between 144 keV and 14MeV
Lower energies data are on the limits → test for pulse shape routines
Light Response shape needs to be modeled with more accuracy

Digital DAQ data and VME data show discrepancies
Data analysis is still on going

Next work:

Data analysis from PTB calibration detectors VdG and Cyclotron
Modified pulse shape routine (pile-up)
Improved MC simulation

PARTICIPANTS:

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M. Mosconi and R. Nolte PTB (Braunschweig)

A. Gottardo and J.J. Valiente LNL-INFN (Legnaro)

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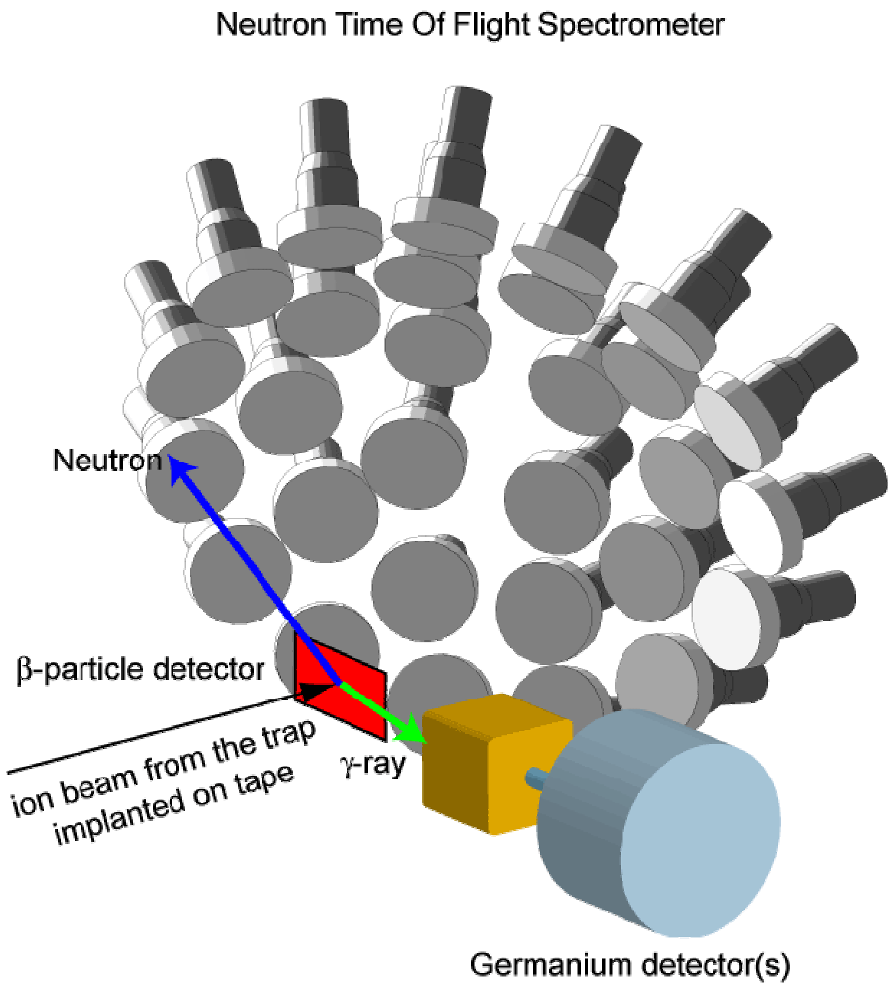
ENRESA

Thanks for your attention!

The ToF spectrometer



Flight path: ~75cm distance from the implantation position
ΔΩ/Ω ~13%

The calibration of the complete spectrometer will be made in-place with on-line and off-line neutron sources.

Coincident β-n and β-γ-n events (for the most intense transitions).

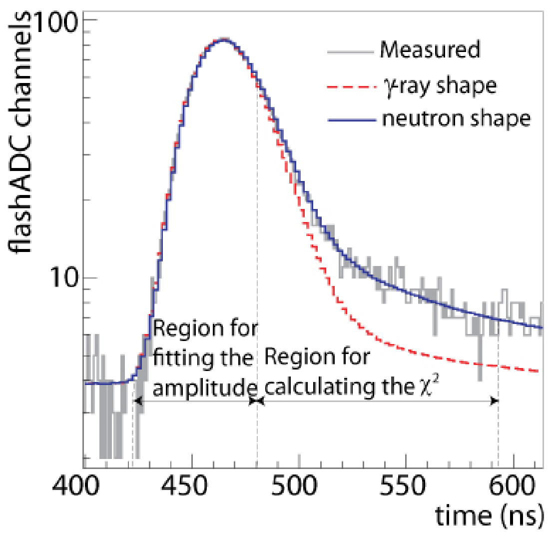
Start signal: plastic β-detector in close geometry.
Stop signal: liquid scintillator.

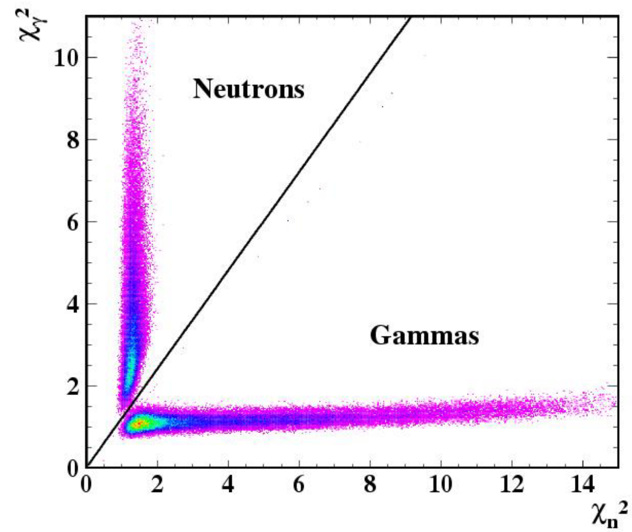
The γ-ray background in the neutron detectors will be rejected by time of flight (for prompt coincident gammas) and by pulse shape discrimination.

n -γ discrimination

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