First measurements with a beta delayed neutron detector at the JYFL Penning trap

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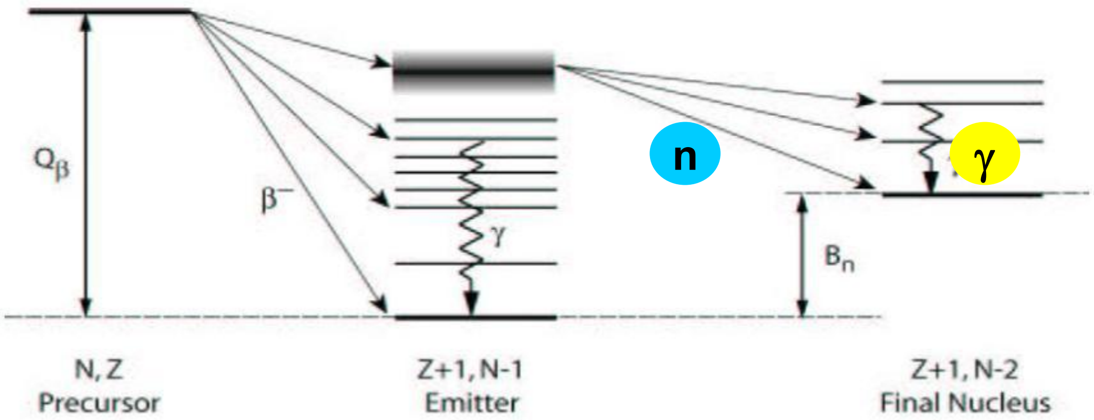
SUMMARY

- ✓ Motivation: Beta Delayed Neutron Emission
- ✓ Detector Layout
- ✓ Simulations
- ✓ Experiment at JYFL

Beta decay of neutron rich nuclei

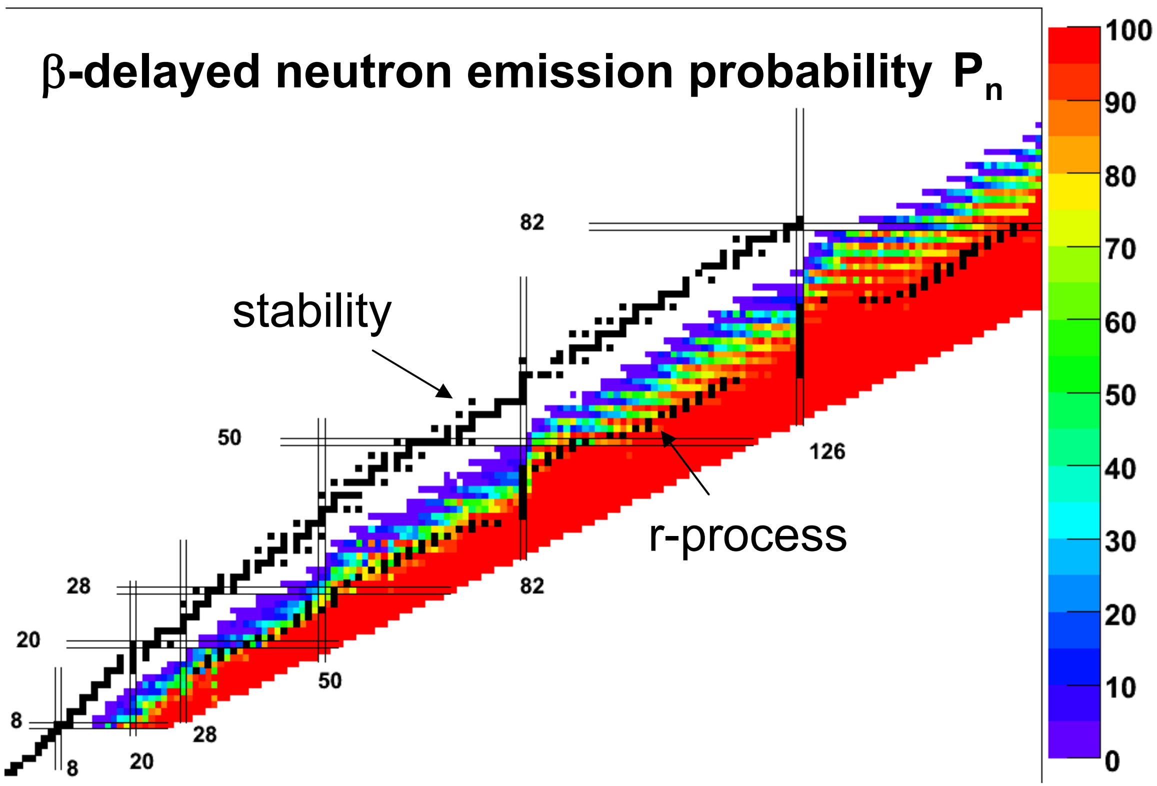


- For many neutron-rich nuclei S_n lies below Q_β
- If the decay proceeds to states above S_n, neutron emission dominates over γ-ray de-excitation

$$\beta^- : \quad n \rightarrow p + e^- + \tilde{\upsilon}$$

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^- + \tilde{\upsilon}$$

- Far enough from the stability, β-**delayed neutron emission** becomes the dominant decay process



IMPORTANCE OF BETA DELAYED NEUTRON EMITTERS

Nuclear power safety:

Some fission products undergo Beta Delayed Neutron Emission which is essential to control the reaction.

Nuclear Energy Agency (NEA) highlights the importance of experimental measurements and data evaluation of delayed neutron emission in its working group 6 “Delayed neutron data” [WPEC-SG6].

Rapid neutron-capture process of stellar nucleosynthesis:

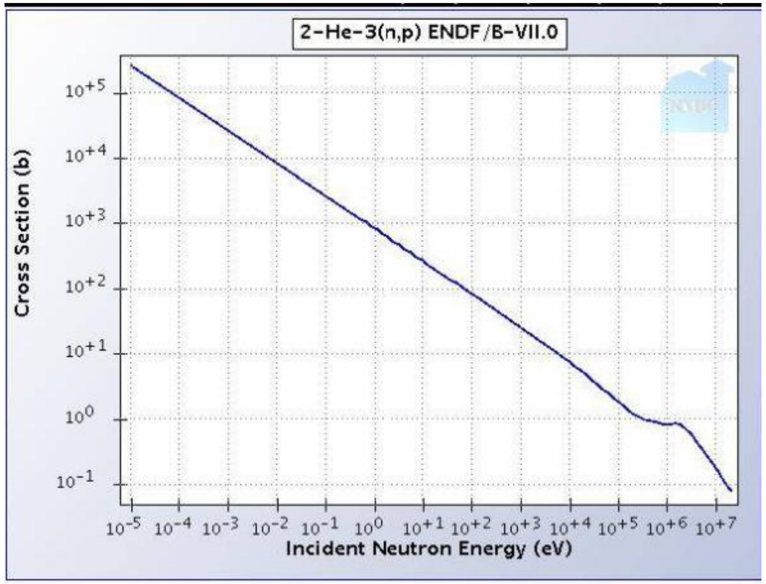
Stellar abundances: delayed neutron emission probability (P_n) of r-process isobaric nuclei define the decay path towards stability during freeze-out, and provide a source of late time neutrons.

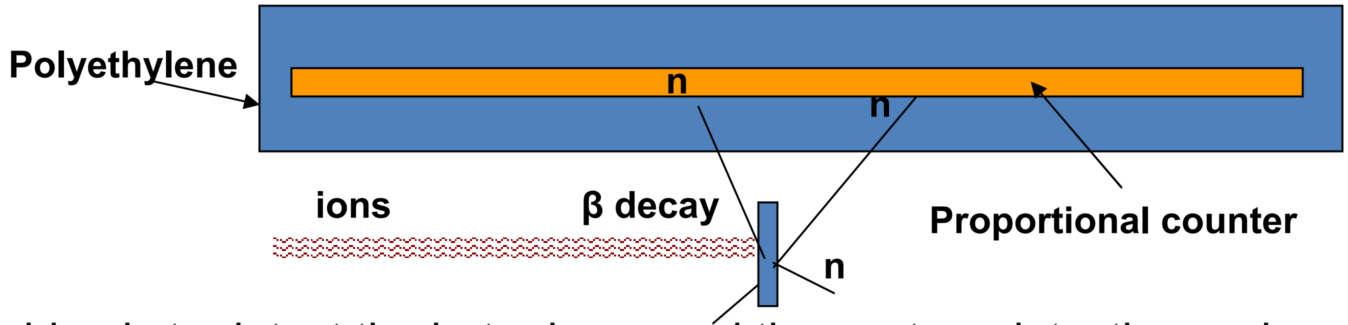
Nuclear Structure:

Additionally the measured half-lives ($T_{1/2}$) and β-delayed neutron-emission probabilities (P_n) can be used as first probes of the structure of the β-decay daughter nuclei in this mass region.

Mechanisms of detecting neutrons are based on indirect methods

$^{3}He + n \rightarrow {}^{3}H + {}^{1}H + 765\ keV$



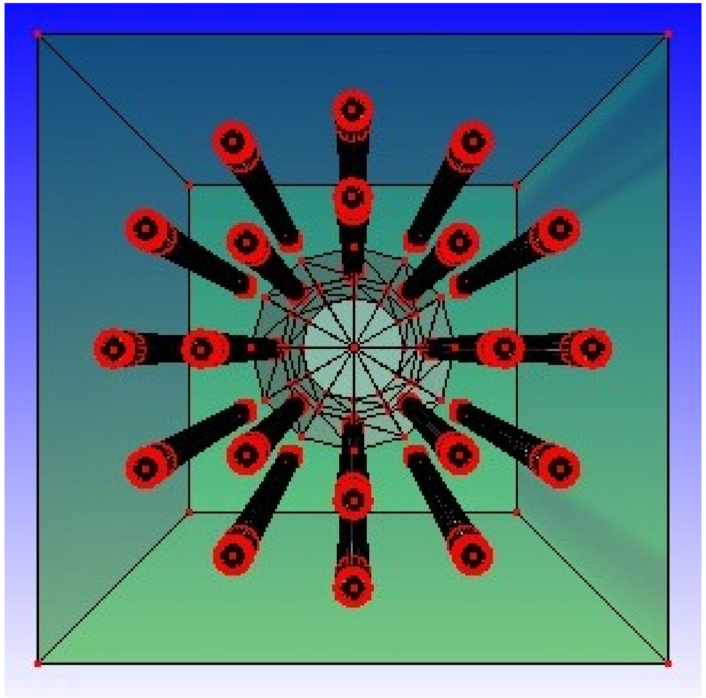


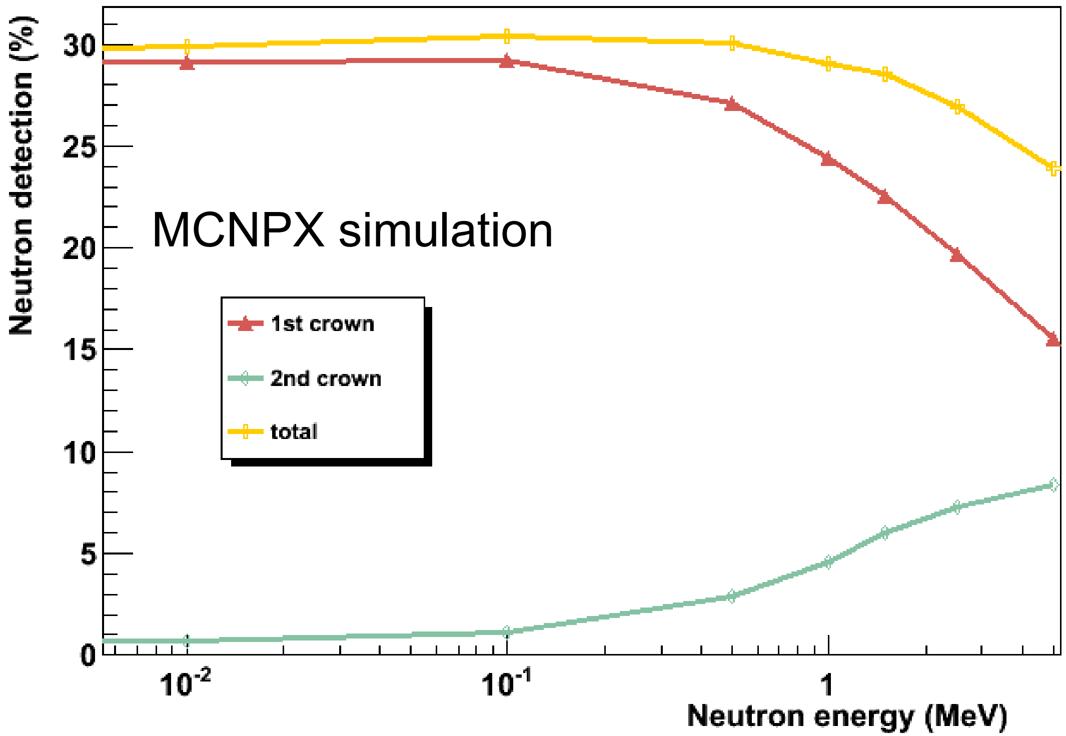
The idea is to detect the beta decay and the neutron detection and correlate both

Moderation time in the polyethylene is very long ~hundreds of μs. It needs to be taken into account in the simulation since it requires a long correlation time/trigger window between the beta decay and the neutron detection.

BEta deLayEd Neutron detector

Detector consists of two crowns of (8+12) ^{3}He detectors embedded in a polyethylene matrix with total dimensions 90x90x80 cm^3 and a r=5 cm beam hole

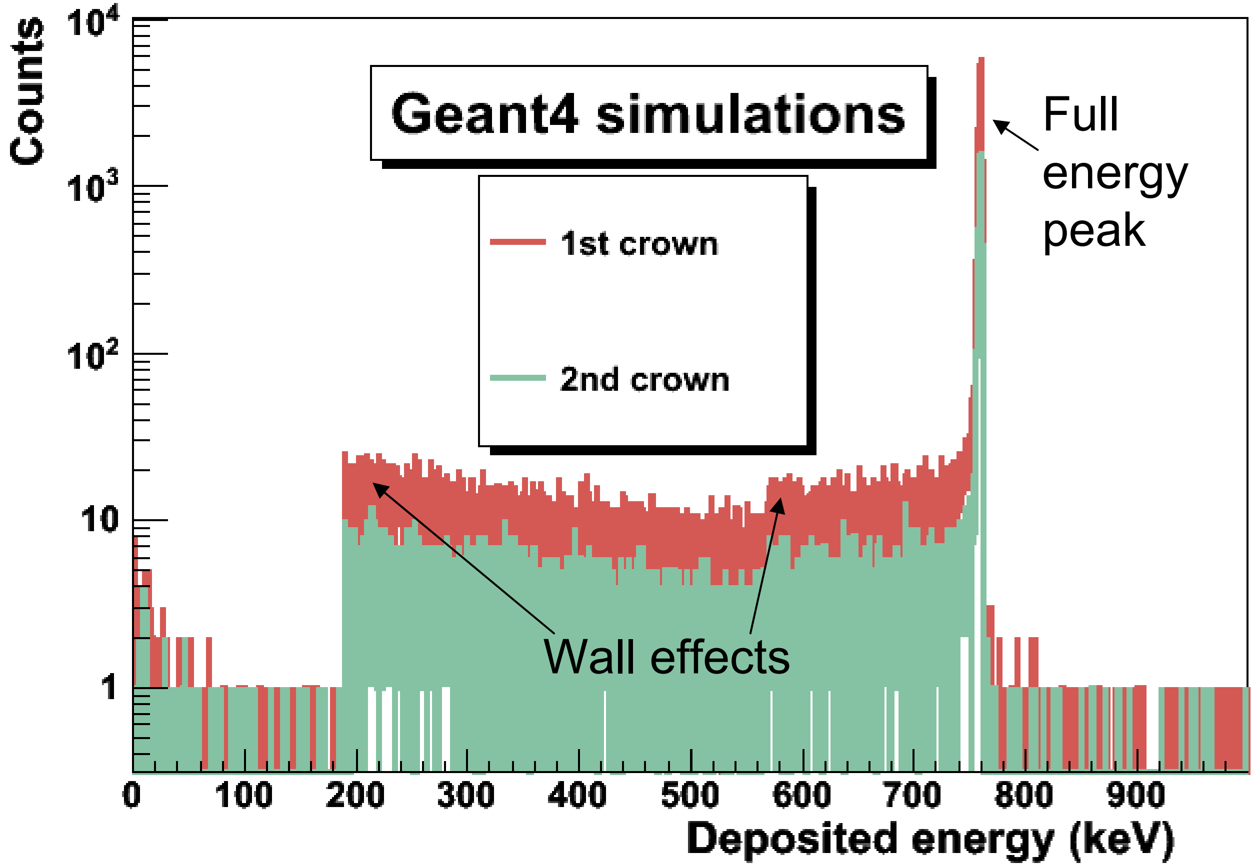




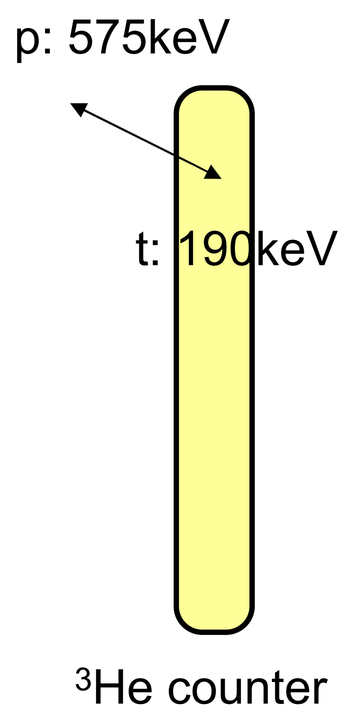
Counter	Gas	Maximum length (mm)	Effective length (mm)	Maximum diameter (mm)	Effective diameter (mm)	Gas pressure (torr)	Cathode material
2527 LND inc	^{3}He	686.84	604.8	25.4	24.38	15200	Stainless Steel

Energy deposition and time correlation in GEANT4

Neutron detection reaction: $^3He + n \rightarrow {^3H} + p + 764$ keV



Wall effect



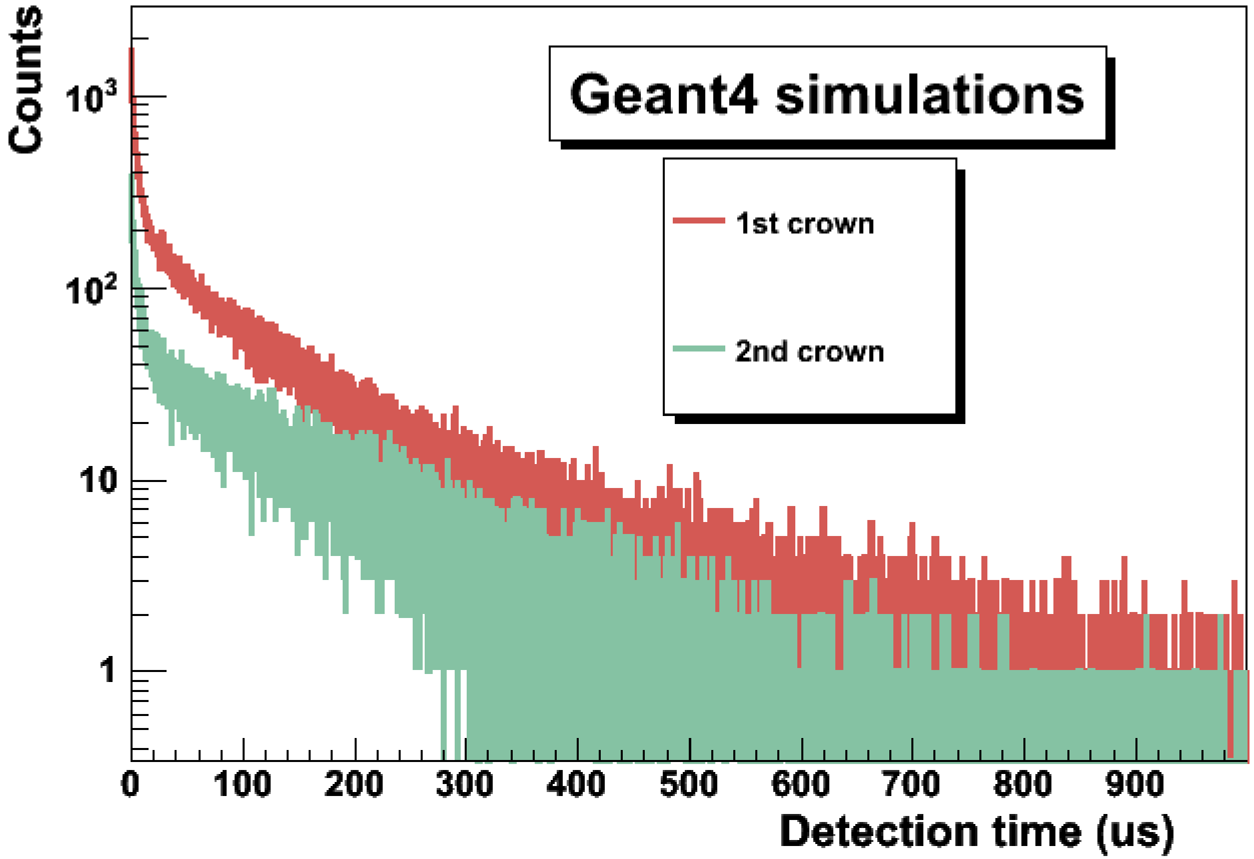
Energy deposited in the ^{3}He gas in the first and second crown.

Particles other than proton and tritons have a very small contribution compared to the neutron detection events.

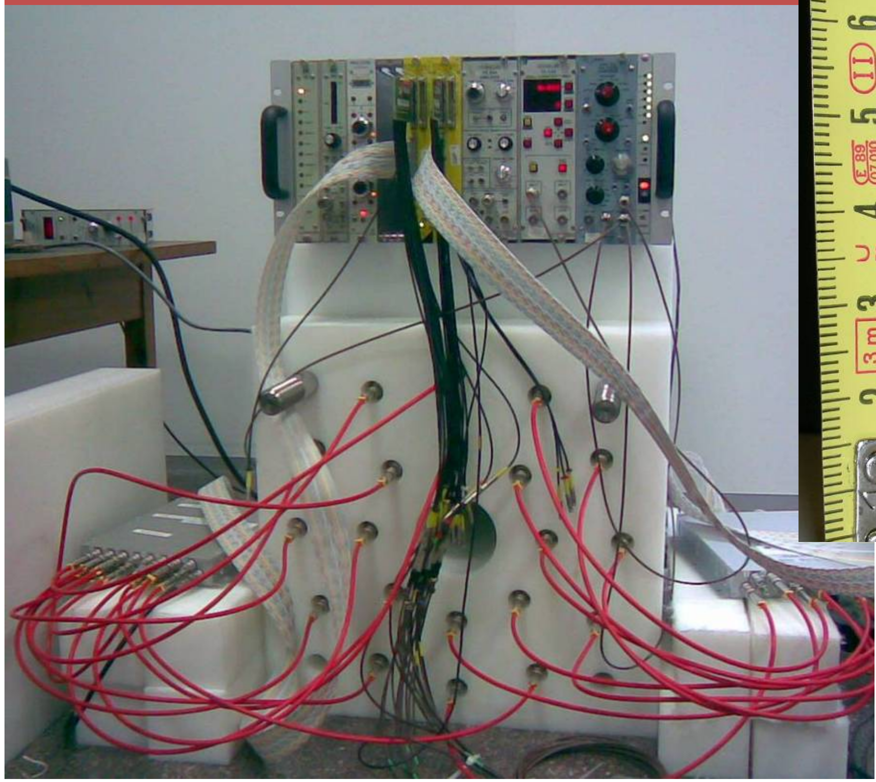
Energy deposition and time correlation in GEANT4

Correlation time from the emission of the neutron (β decay of precursor) and neutron detection in the ^{3}He gas. This time is of the order of 100s μs and it is due to the moderation process in the polyethylene.

A different slope can be appreciated for the two crowns.



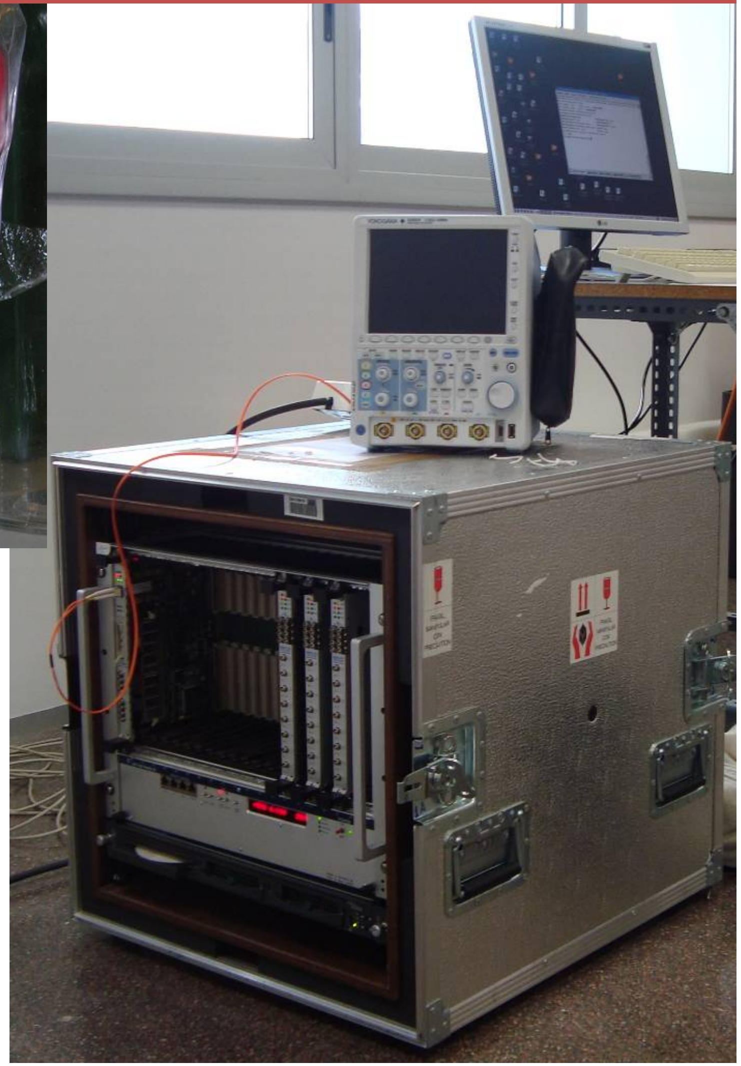
SIMULATION VALIDATION AT UPC WITH ^{252}CF



^{3}He counters + Mesytec electronics

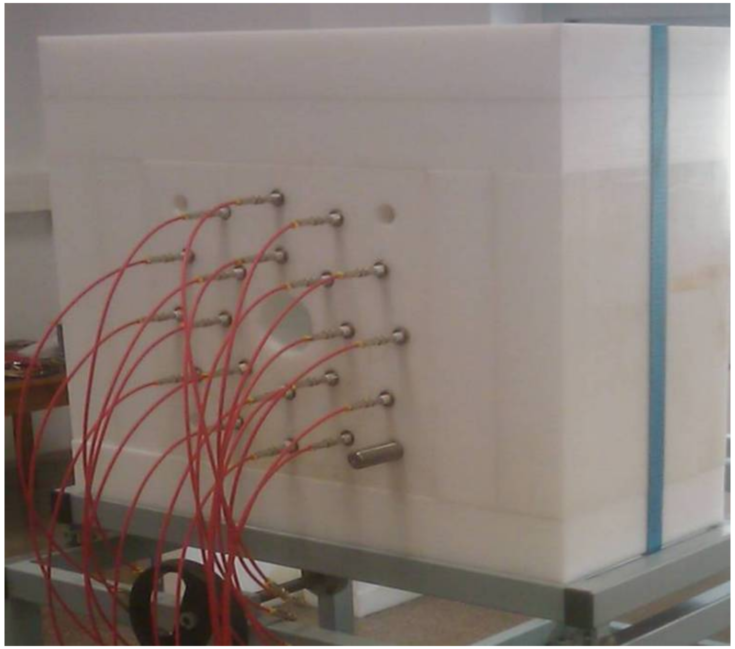
^{252}Cf source

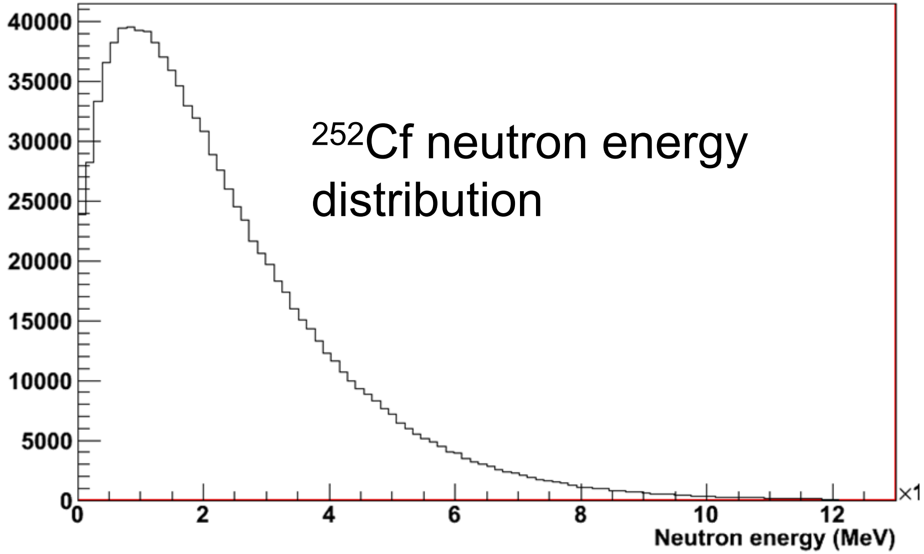
700n/s



IFIC. Triggerless DAQ to allow us to change the beta-neutron correlation time offline

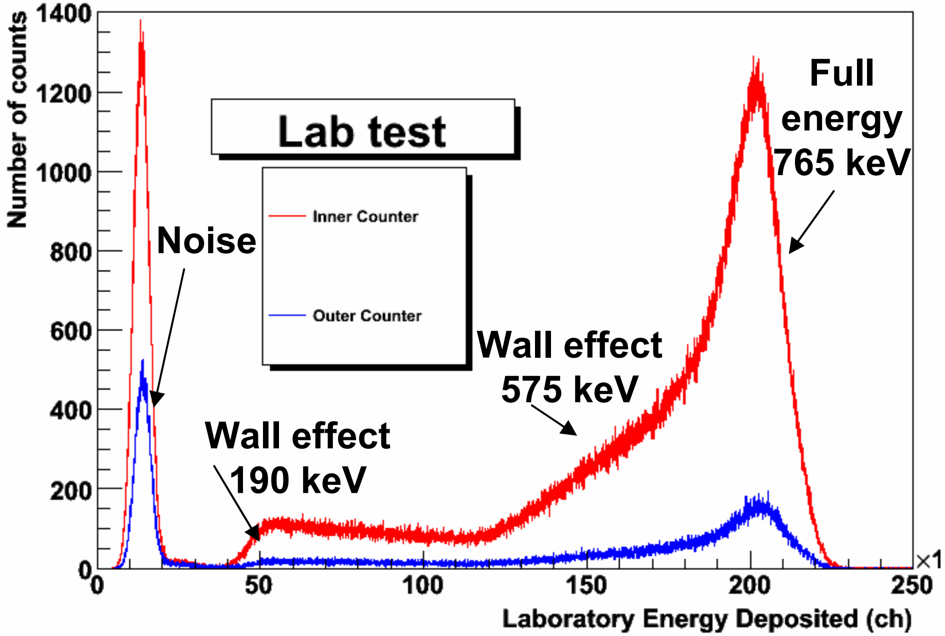
NaI detector for prompt fission γ. CIEMAT





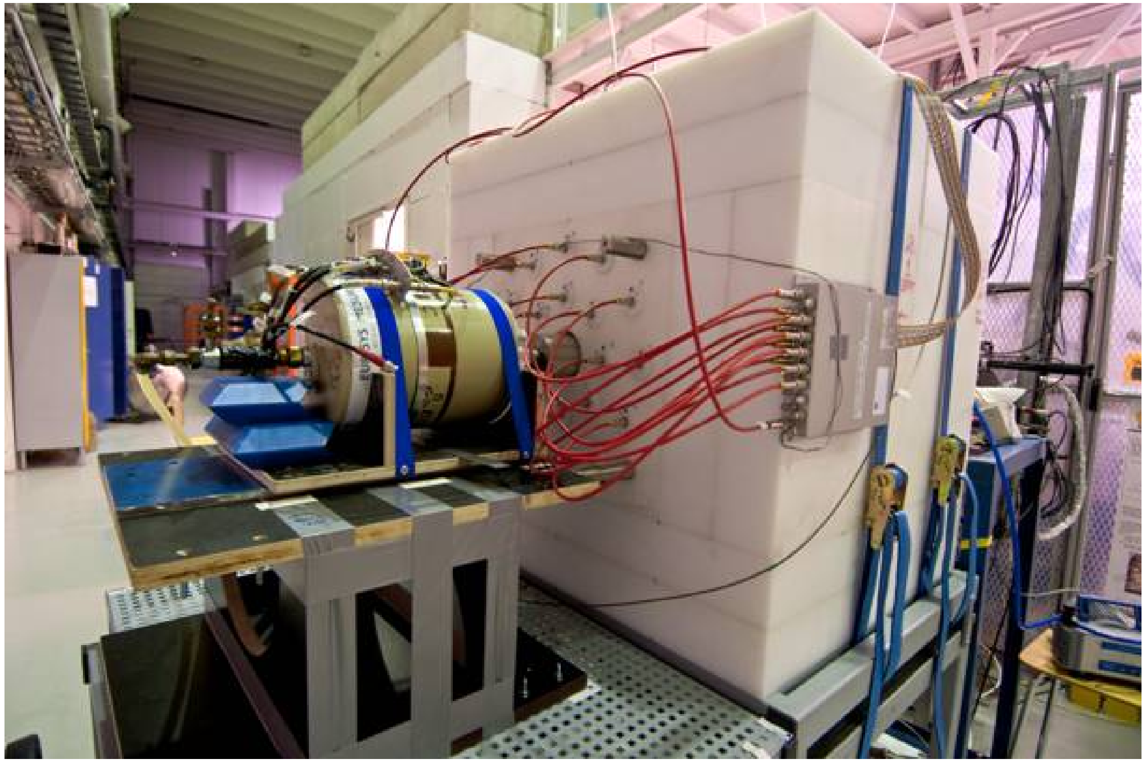
	Exp %	MCNPX %	GEANT4 %
Inner crown	21.3 ± 3.2	21.3 ± 1.5	25.0 ± 1.6
Outer crown	4.9 ± 0.7	6.0 ± 0.8	5.4 ± 0. 7
Tot	26.1 ± 3.9	27.3 ± 1.7	30.4 ± 1.7

Experimental uncertainty due to source activity uncertainty (15%)



EXPERIMENT JYFL

First experiment with BELEN-20 at JYFL: IGISOL+JYFLTRAP



Measurement of
^{88}Br, ^{94,95}Rb, ^{138}I, ^{138}Te

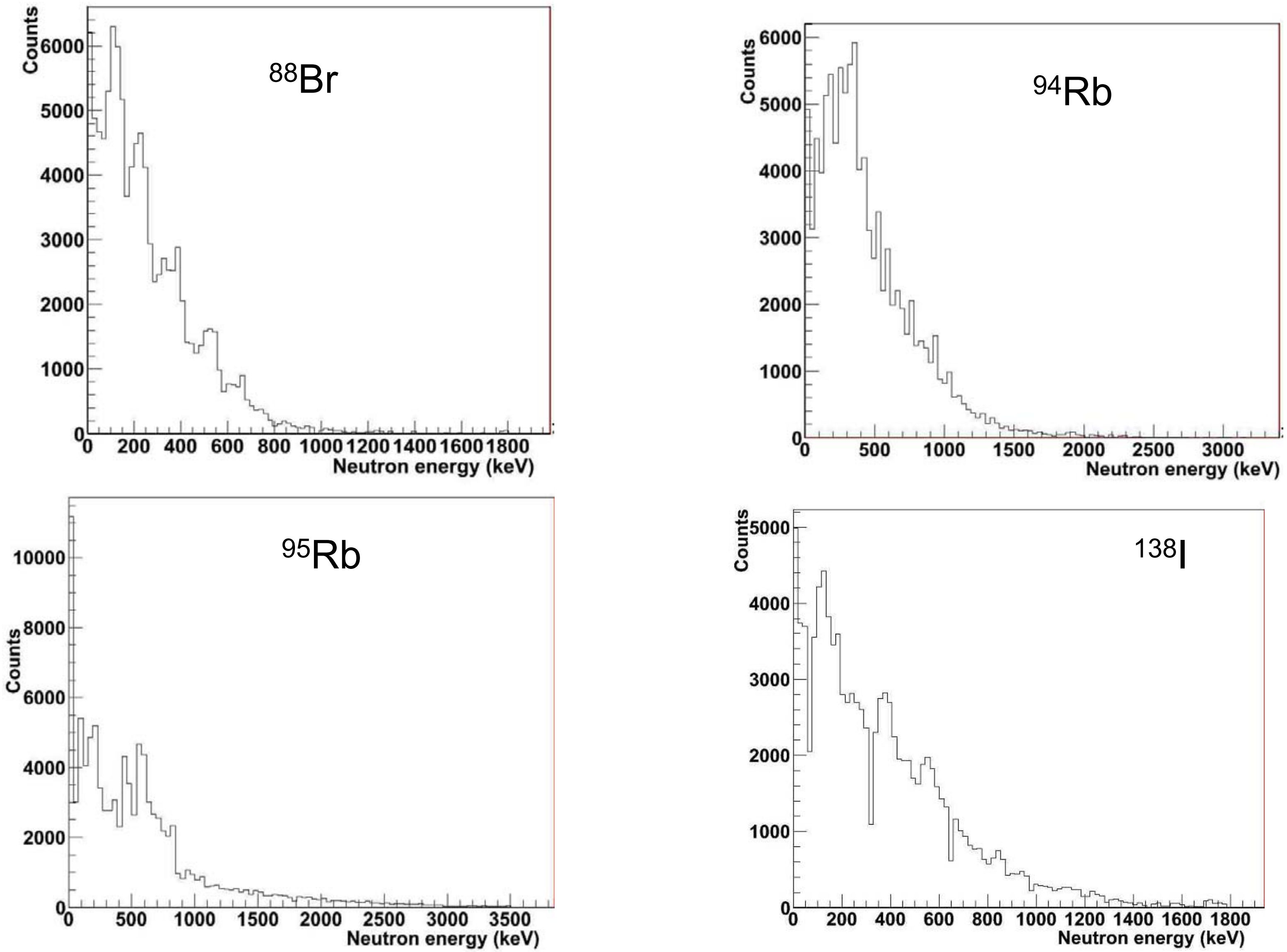
JYFLTRAP = Isotopically pure beams!

November 2009

Delayed Neutron Precussor	Half life	Q_β (MeV)	β-n branching %	Daughter Nucleus	Half life
$^{88}_{35}$Br	16.3 s	8.96	6.58	$^{88}_{36}$Kr	2.84 h
$^{94}_{37}$Rb	2.70 s	10.31	10.4	$^{94}_{38}$Sr	75.3 s
$^{95}_{37}$Rb	377.5 ms	9.29	8.73	$^{95}_{38}$Sr	23.9 s
$^{138}_{53}$I	6.23	7.82	5.56	$^{138}_{54}$Xe	14.1 m

Decay properties of β delayed neutron emitters ^{88}Br, ^{94}Rb, ^{95}Rb,^{138}I

Simulation of the expected neutron detection efficiency for each neutron energy distribution. ENDF/B VII (and Greenwood [NSE 91, 305 (1985)] for 95Rb)



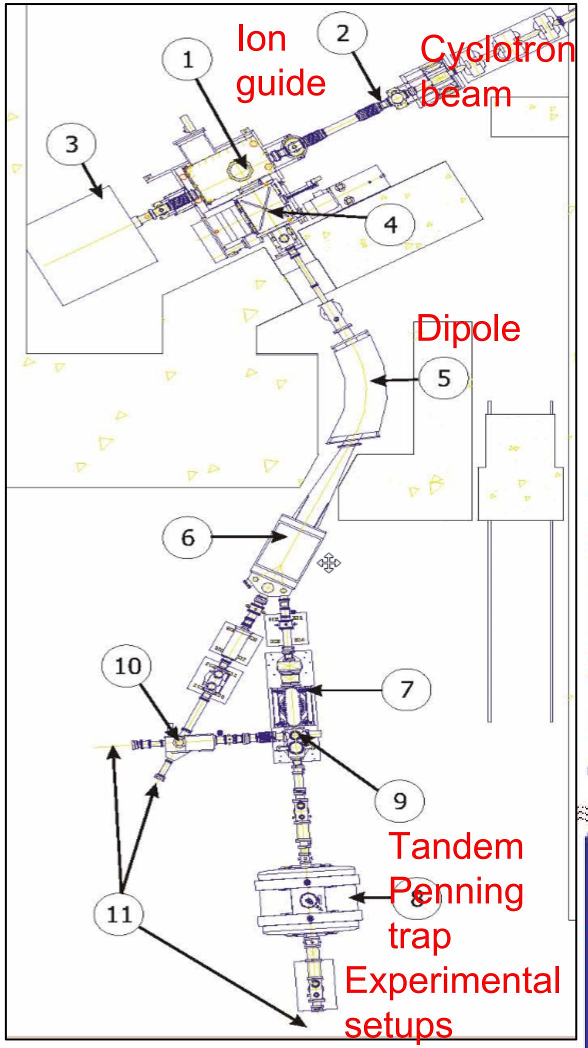
Decay properties of β delayed neutron emitters ^{88}Br, ^{94}Rb, ^{95}Rb, ^{138}I

The expected efficiency of the detector was calculated using the energy distributions from ENDF/B VI as neutron source in the simulations.

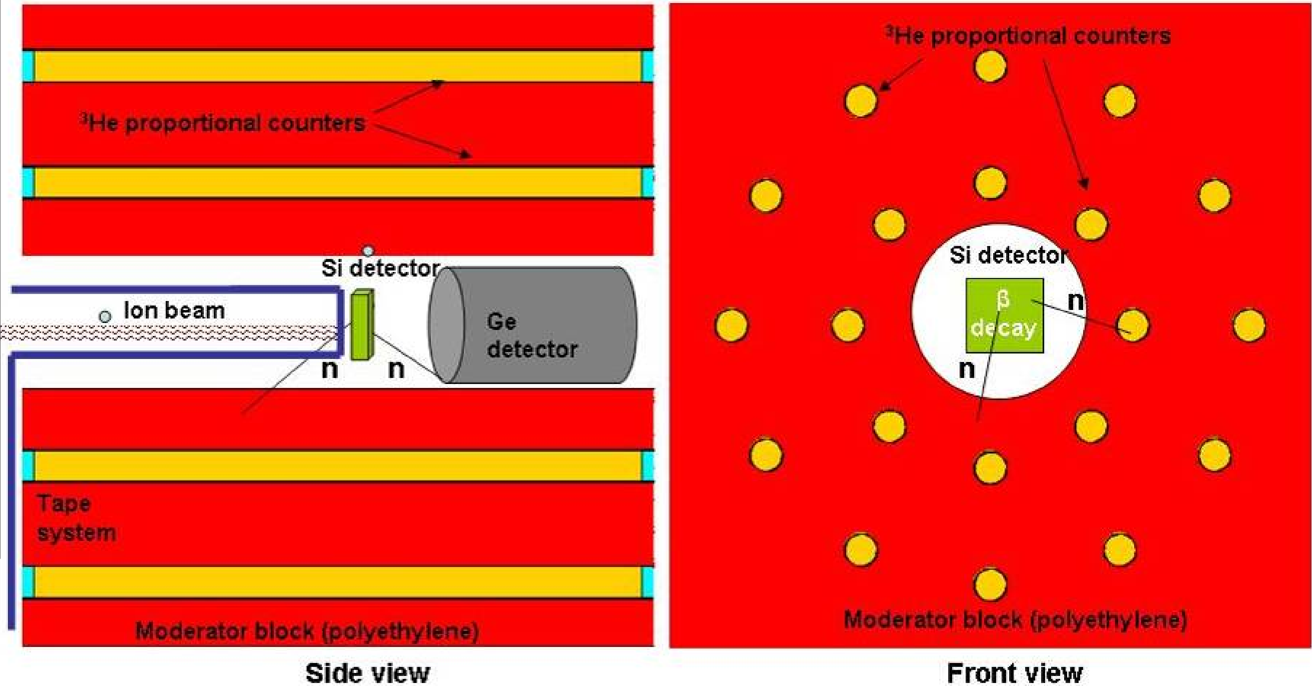
This simulation results will be compared to the experimental one, once the data analysis is finished.

Nucleus	GEANT4(%)		MCNPX(%)	
	Value	Unc	Value	Unc
^{88}Br	31.7	1.8	30.1	1.7
^{94}Rb	32.3	1.8	29.9	1.7
^{95}Rb	32.2	1.8	29.8	1.7
^{138}I	31.5	1.8	30.0	1.7

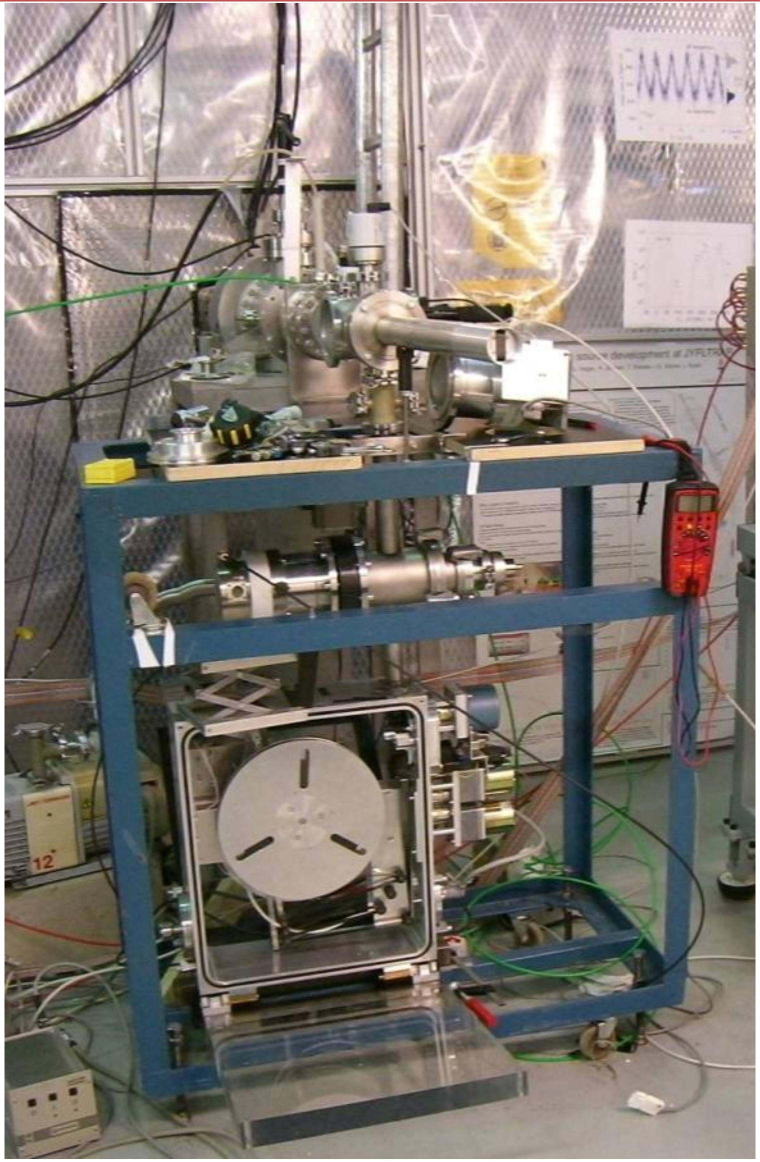
IGISOL

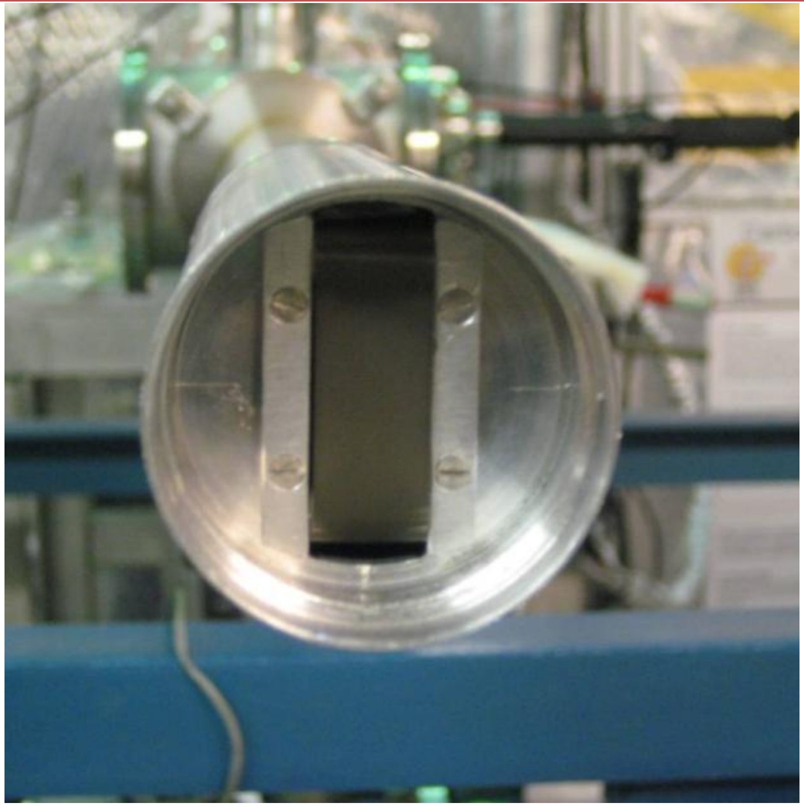


An isotopically pure beam was obtained using the JYFLTRAP Penning trap setup at the IGISOL facility and it was implanted on a movable tape placed in the centre of the neutron detector.



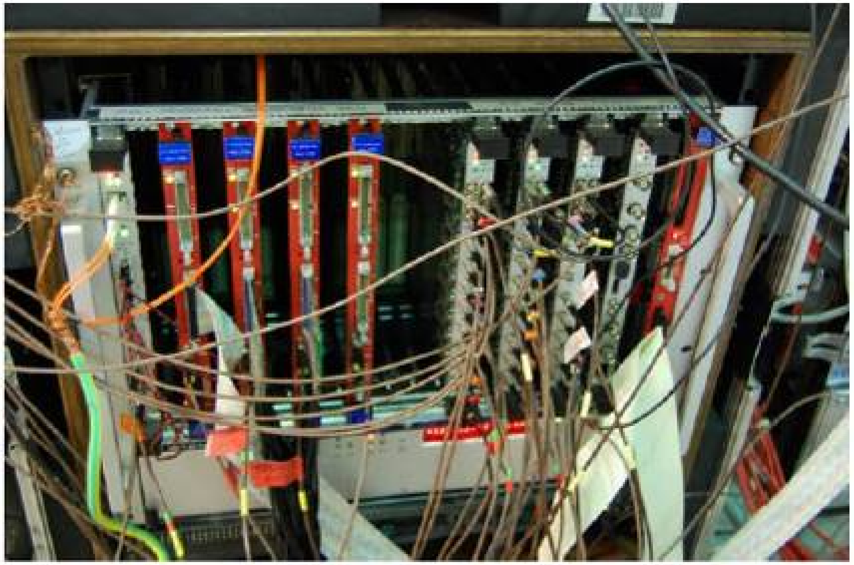
EXPERIMENT @ JYFL





Beta delayed neutron emissor precursors were implanted on a tape in the centre of the neutron detector.
A Si detector was placed next to the implantation point in the tape in order to detect the beta decay and be able to correlate this signal with the one from the neutron counters.

IFIC Triggerless DACQ for neutron detector



• Experiments will be run with triggerless DACQ. Full flexibility to modify correlation time neutron emission-detection => clean data.

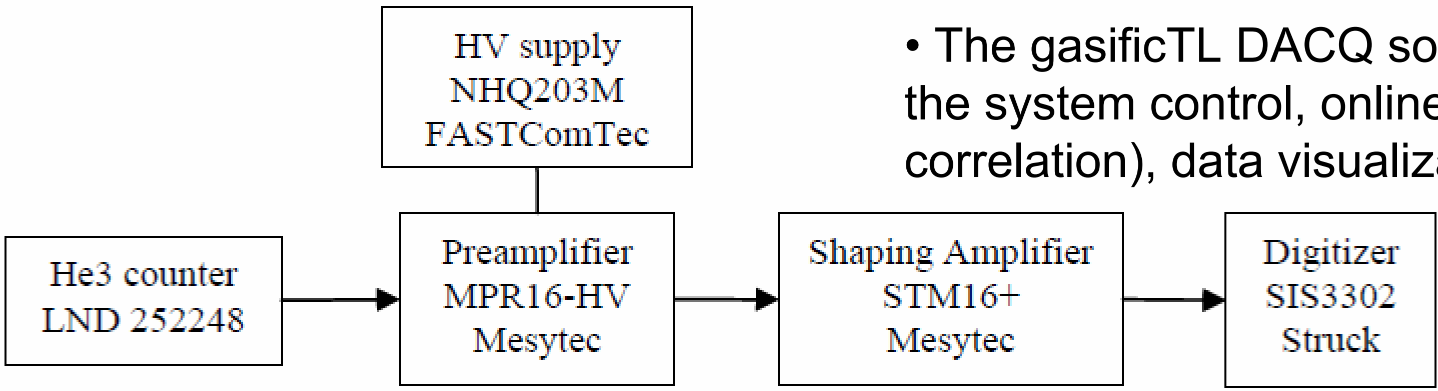
•New triggerless DACQ developped by IFIC Struck VME SIS3302 10MHz

• ADC signal above filter threshold (time mark) => energy filter (amplitude signal)

• Independent Time-Energy pairs for each channel.

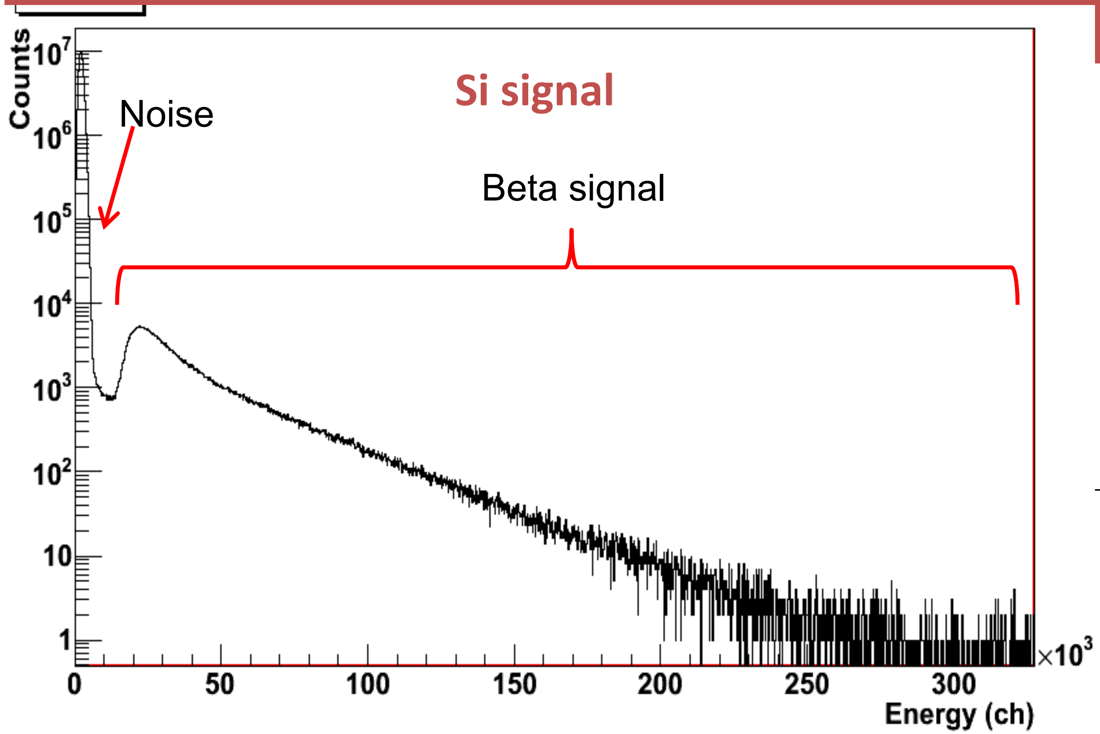
• Data transfer to PC via the Struck SIS1100/3100 PCI/VME interface.

• The gasificTL DACQ software performs the system control, online analysis (event correlation), data visualization.

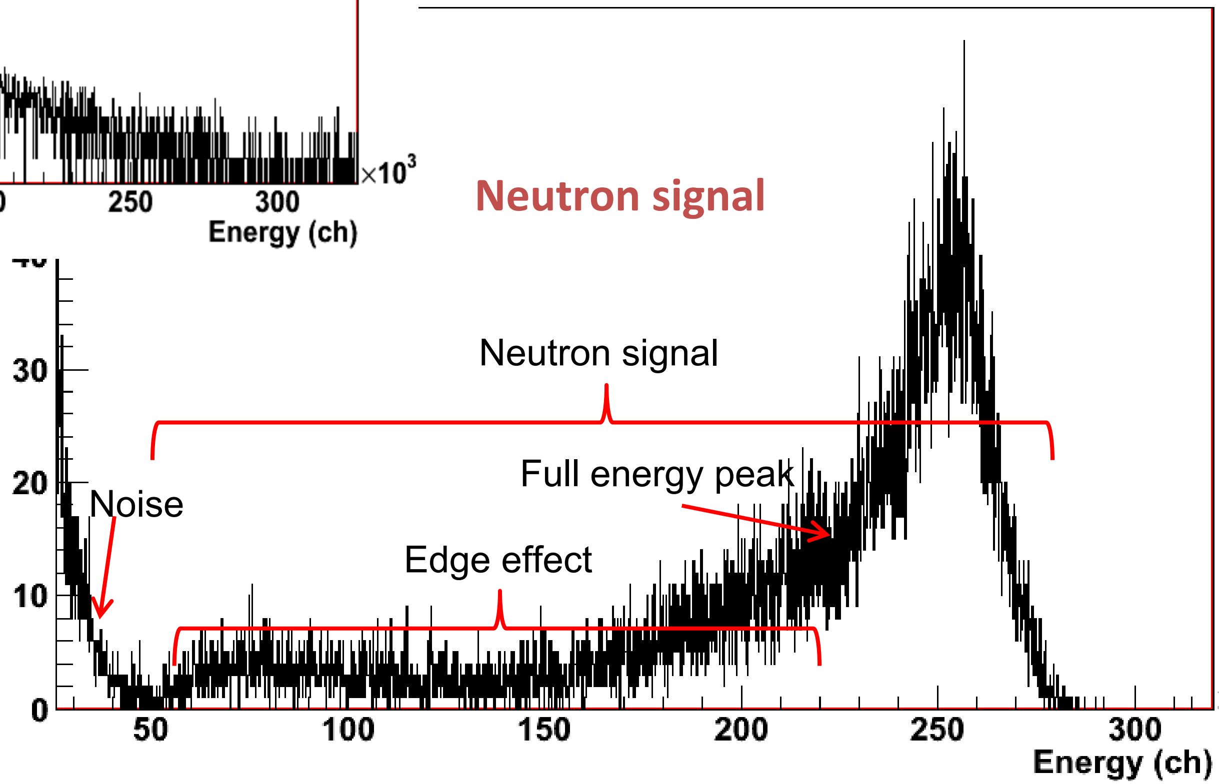


Online spectra

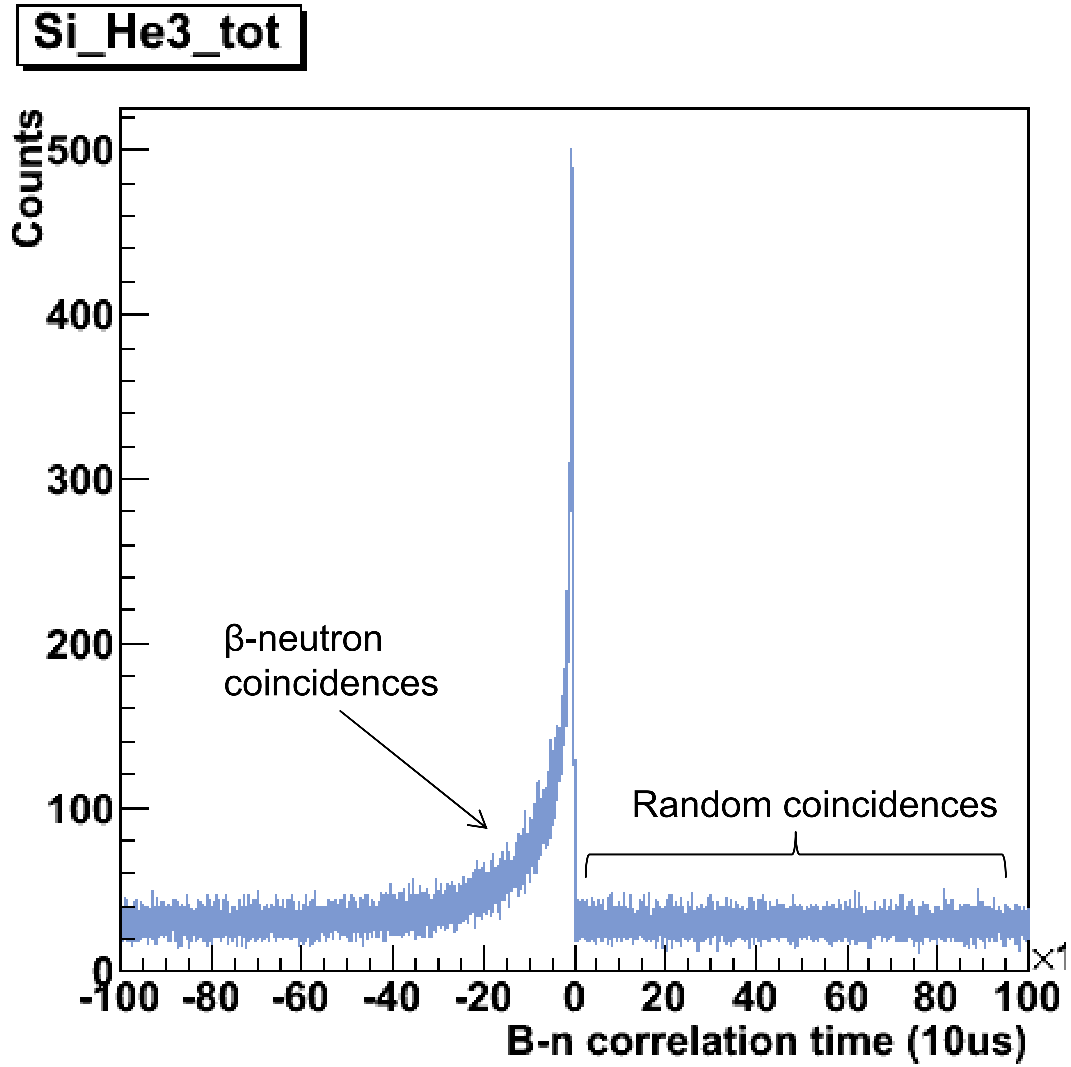
Si signal

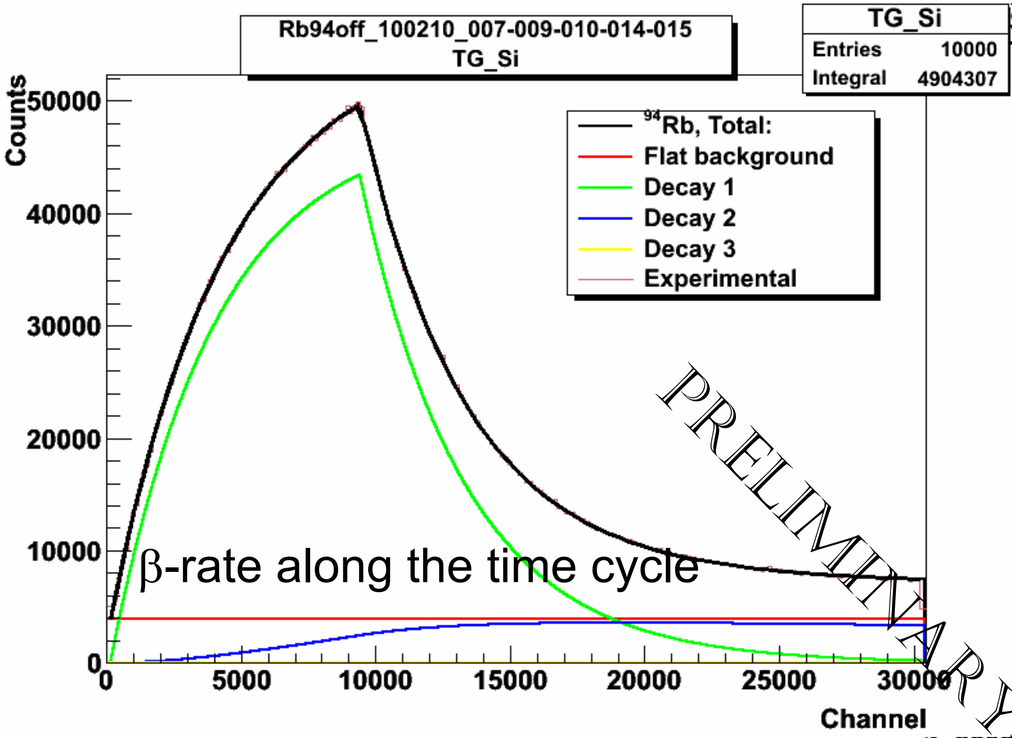


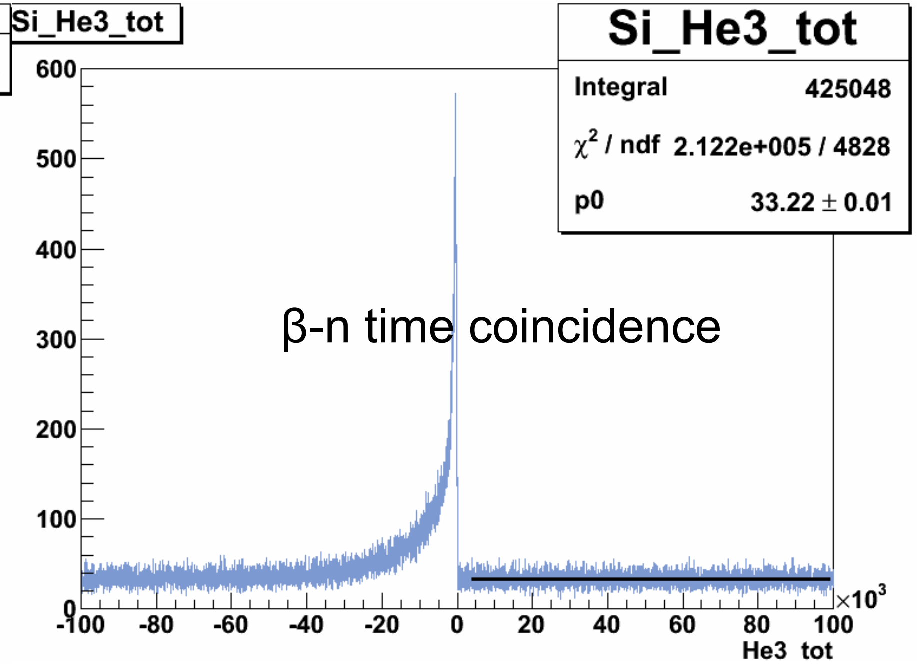
Neutron signal



Online spectra





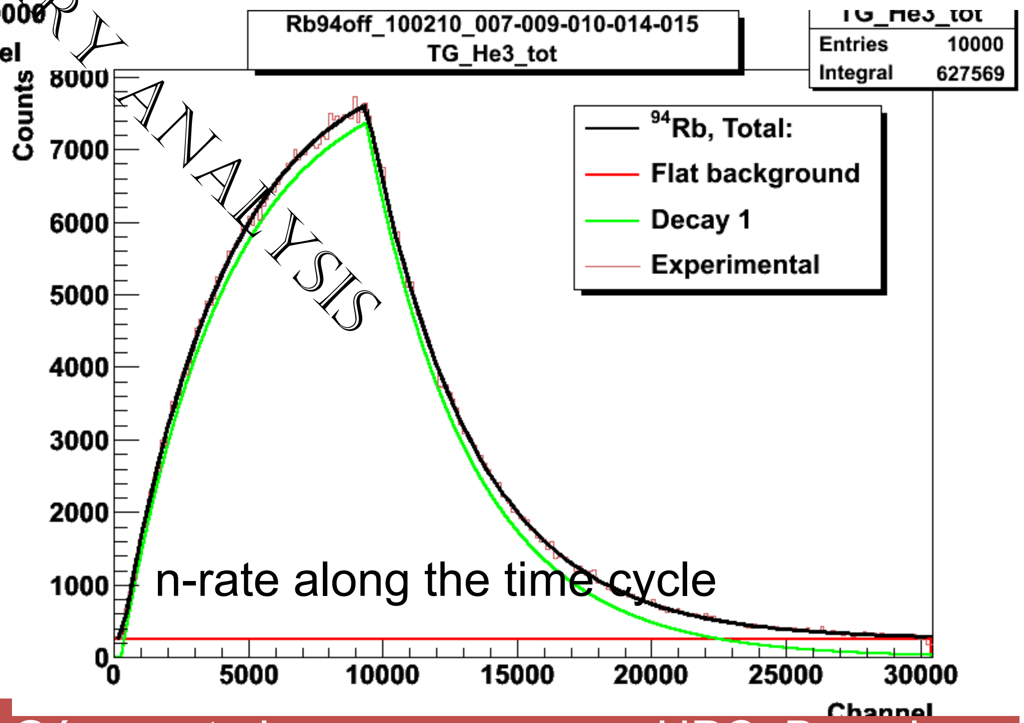


PRELIMINARY ANALYSIS

Decay fits to Bateman equations.

Ions were implanted on a tape for $3T_{1/2}$ and left decay for $7T_{1/2}$ before moving it away from the Si detector.

$$\boxed{\varepsilon_n = \frac{1}{P_n}\frac{N_{\beta n}}{N_\beta}}$$



The P_n values of ^{88}Br and ^{95}Rb were used as references to calculate the efficiency of BELEN-20 since there is good agreement in their values.
The average efficiency for BELEN-20 is (27.1±0.8) %.

Isotope	ε_n	unc
^{88}Br	0.276	0.007
^{95}Rb	0.266	0.008

Using the above average efficiency, the P_n for ^{94}Rb and ^{138}I were calculated and they are in good agreement with values from other authors.

Isotope	P_n (%)	unc	Author
^{94}Rb	10.28	0.31	This work
	10.01	0.23	Rudstam
	9.1	0.11	Pfeiffer
^{138}I	5.32	0.20	This work
	5.46	0.18	Rudstam
	5.17	0.36	Pfeiffer

SUMMARY

✓ Beta Delayed Neutron detector has been designed through Monte Carlo simulations with MCNPX and GEANT4.

✓ GEANT4 has been used to study the spectrum of the energy deposited in the ^{3}He gas and the time correlation between neutron emission and detection.

✓ This detector will be used with a Triggerless DACQ designed by IFIC group. Flexibility to modify correlation time.

✓ First experiment at JYFL to measure beta delayed neutron emission.

✓ Expected detector efficiencies according to neutron energy distributions. have been calculated with MCNPX and GEANT4

✓ The results of the preliminary analysis are in good agreement with previous measurements from other authors.