Measurements of beta delayed neutron emission probabilities

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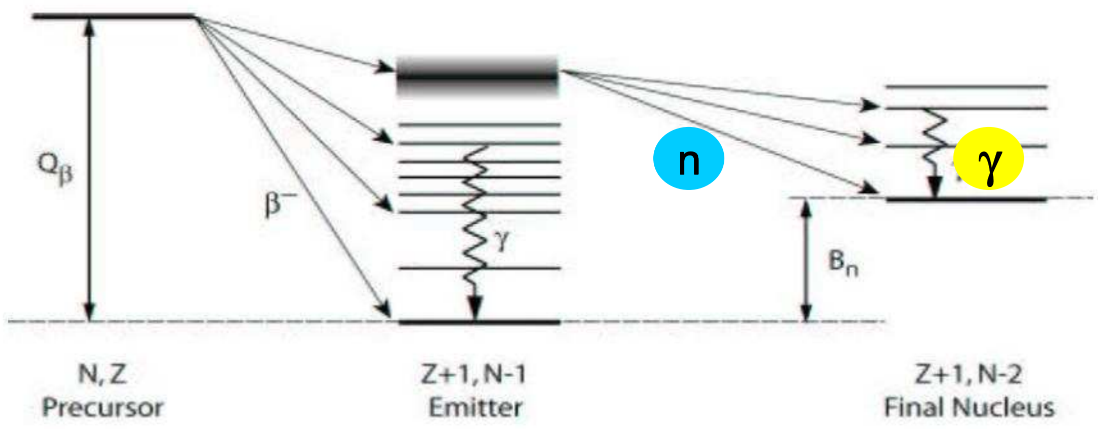
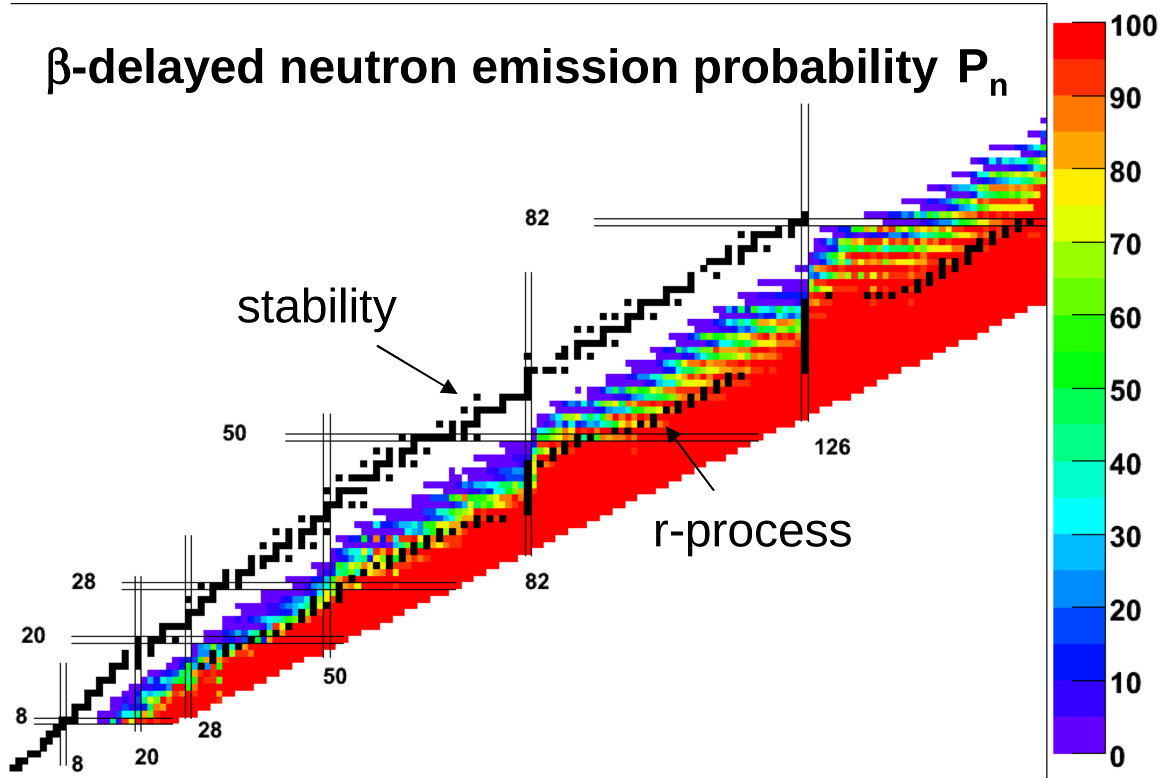
Beta decay of neutron rich nuclei



- For enough 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

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



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, shape the abundance curve and provide a source of late time neutrons.

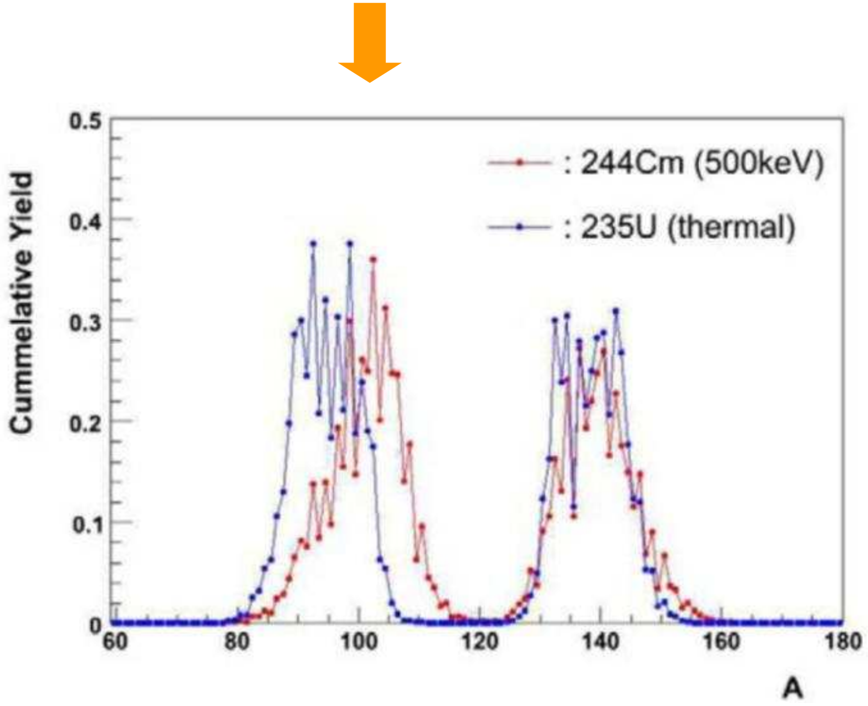
Nuclear Structure:

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.

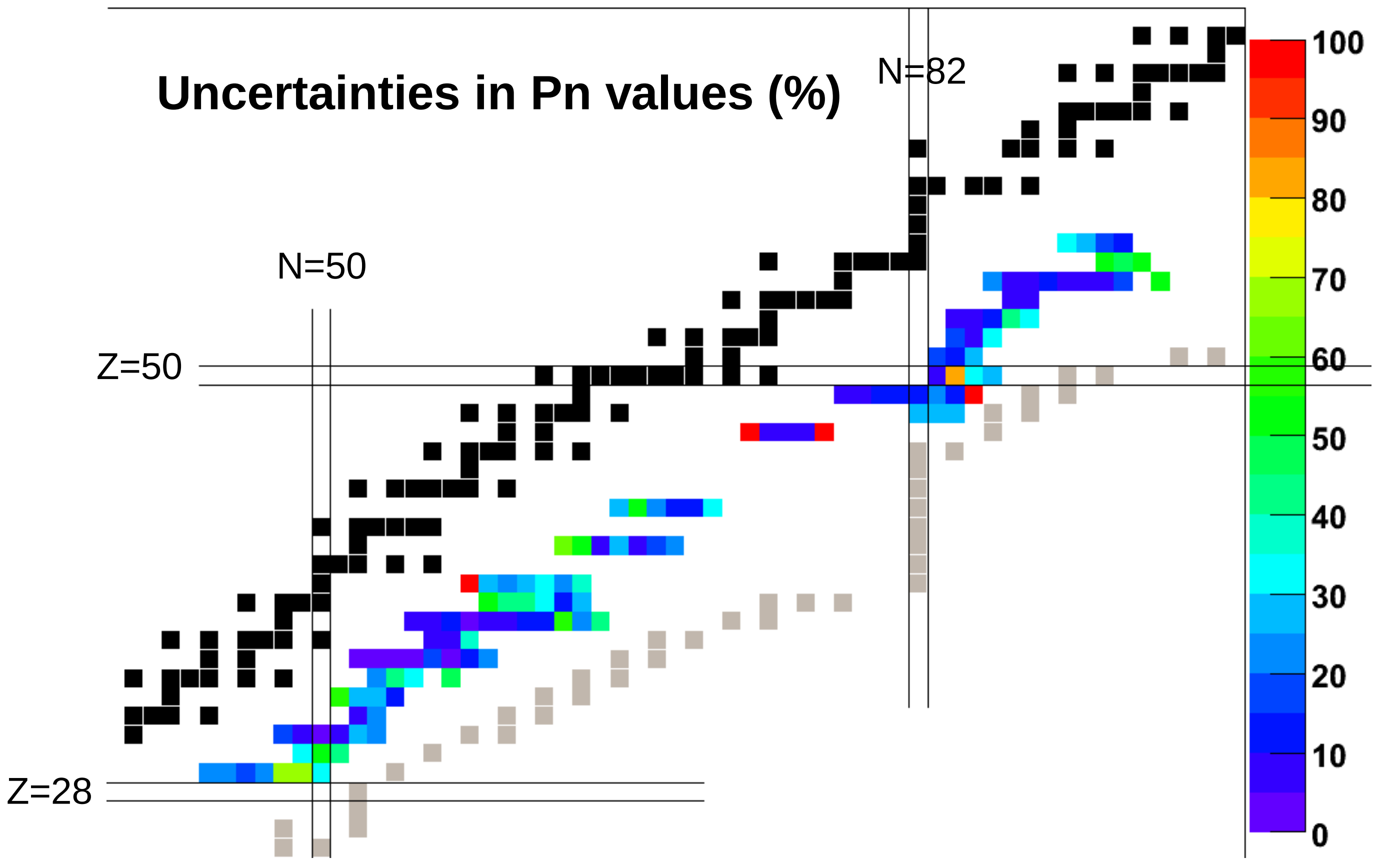
Nuclear technology

• **The neutron emission probability P_n determines the delayed neutron fraction β_{eff} : reactor kinetics. More accurate measurements will improve summation calculations for GenIV reactors with MA containing fuel**

Fission Fragment distribution



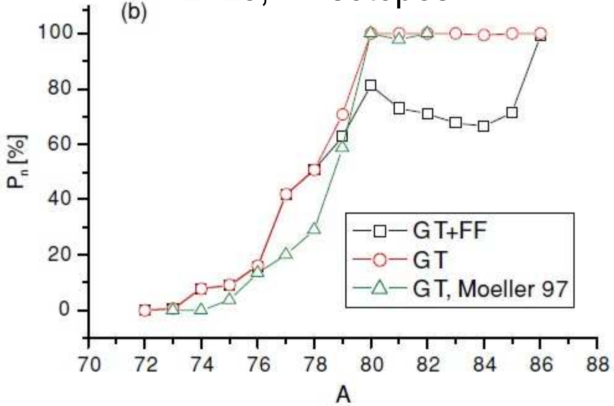
Studying the fission yields of both major actinides (^{235}U, ^{239}Pu) and minor actinides (^{237}Np, $^{241,243}Am$, $^{242,244}Cm$) and the neutron emission probabilities of the fission product a list of candidates for Pn measurements has been identified, which includes isotopes of Y, Ge, Br, As, I.



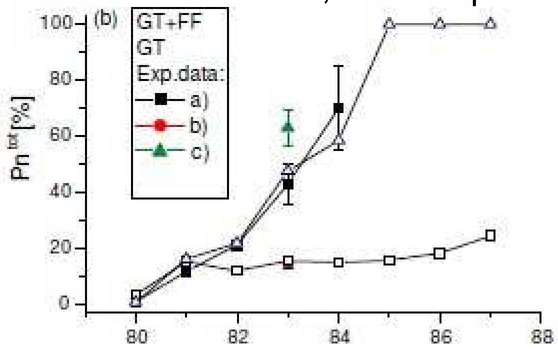
✓ Need of reducing uncertainty in Pn values for nuclear technology
✓ Need of measuring further away from stability to approach r-process path (experimentally or by theoretical extrapolation)

Theoretical Pn predictions

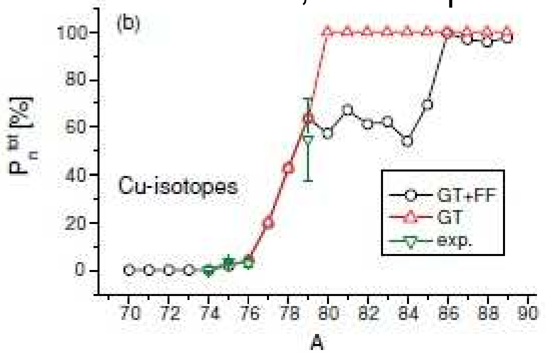
Z=28, Ni isotopes



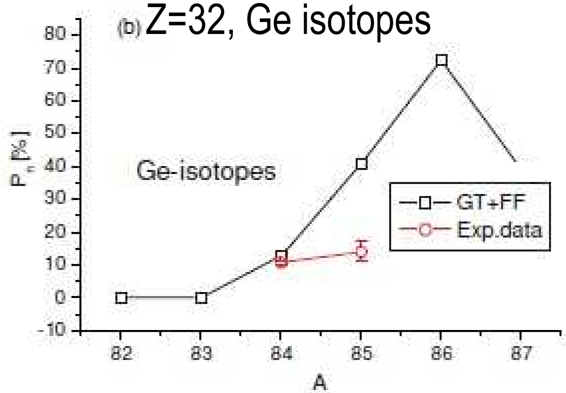
Z=31, Ga isotopes



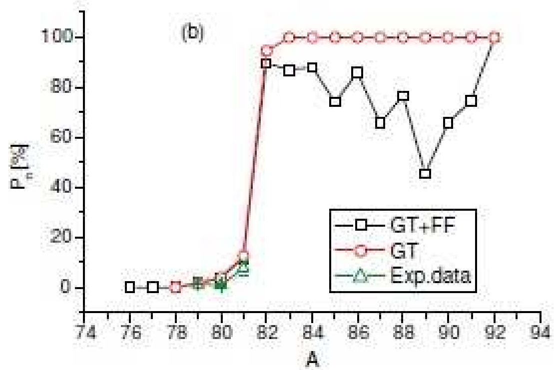
Z=29, Cu isotopes



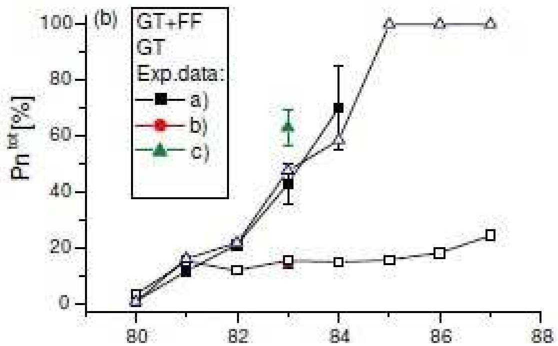
Z=32, Ge isotopes



Z=30, Zn isotopes



Z=33, As isotopes

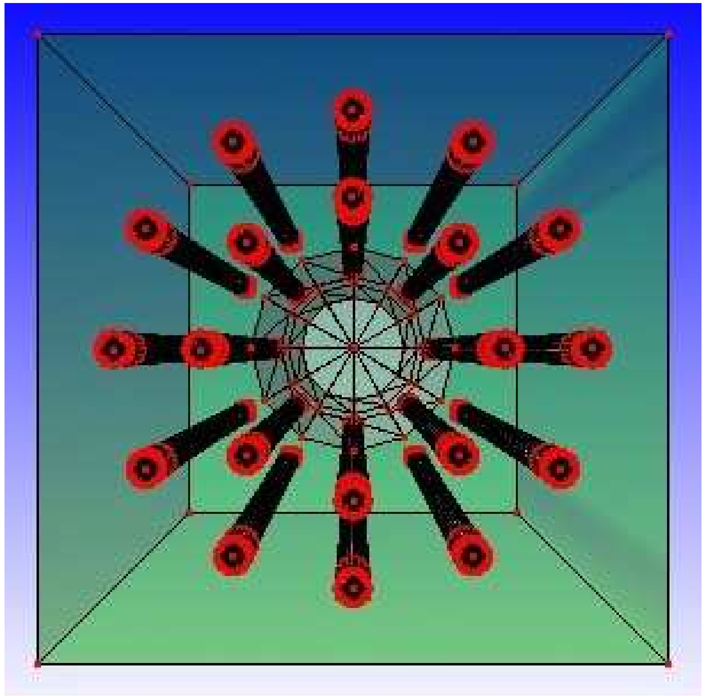


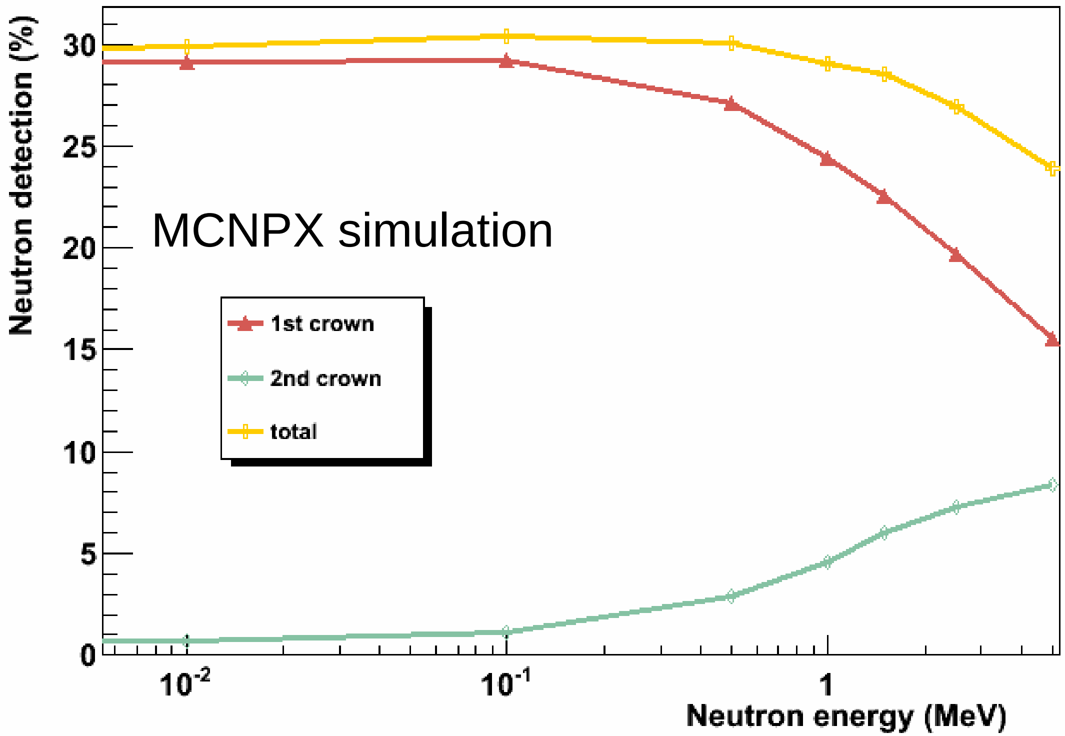
Need of experimental values to validate Gammow Teller + First Fobidden role in beta decay as shell closures are crossed in the r-process region.

I. Borzov, PRC 71, 065801, (2005)

BEta deLayEd Neutron detector

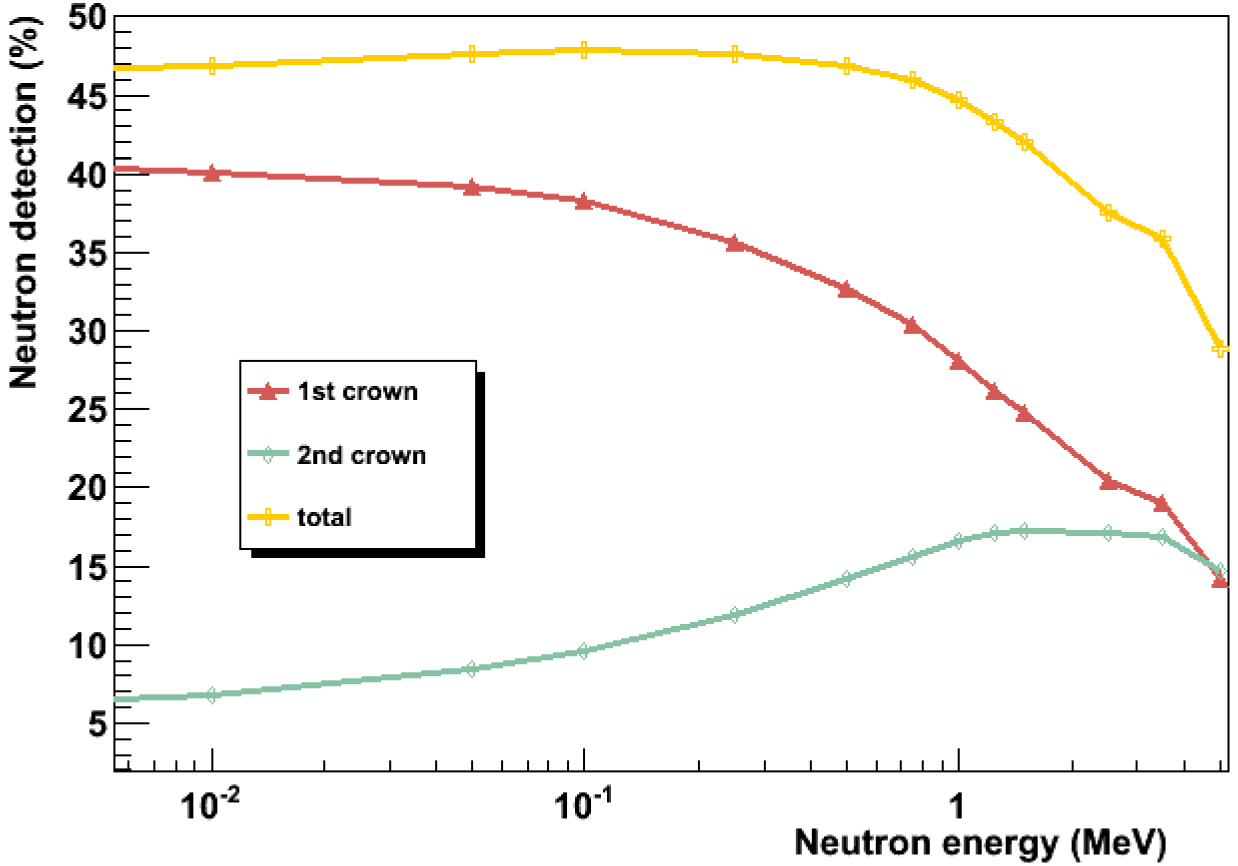
Detector consists of two crowns of (8+12) ^{3}He detectors embedded in a polyethylene matrix with total dimensions 90x90x80 cm^{3} and a r=5 cm beam hole



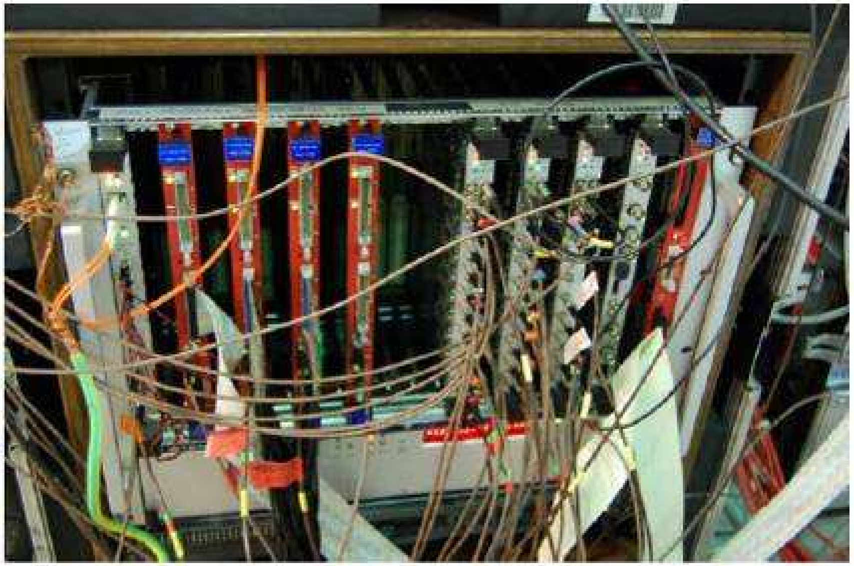


Counter	Gas	Maximum length (mm)	Effective length (mm)	Maximum diameter (mm)	Effective diameter (mm)	Gas pressure (torr)	Cathode material
2527 LND inc	^{3}He	686.84	604.8	25.4	24.38	15200	Stainless Steel

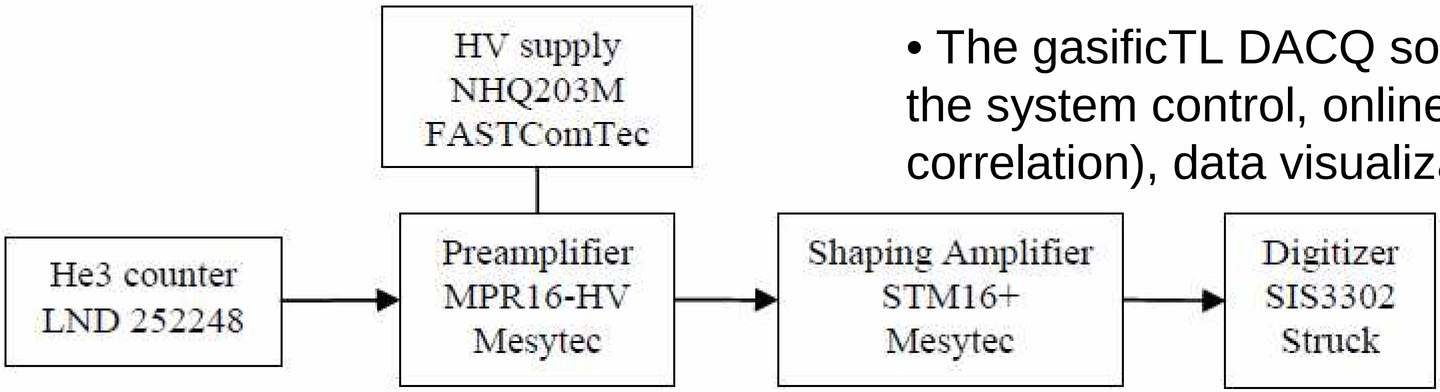
Alternative desing with 45% efficiency (although not so flat in the energy range up to 5MeV)



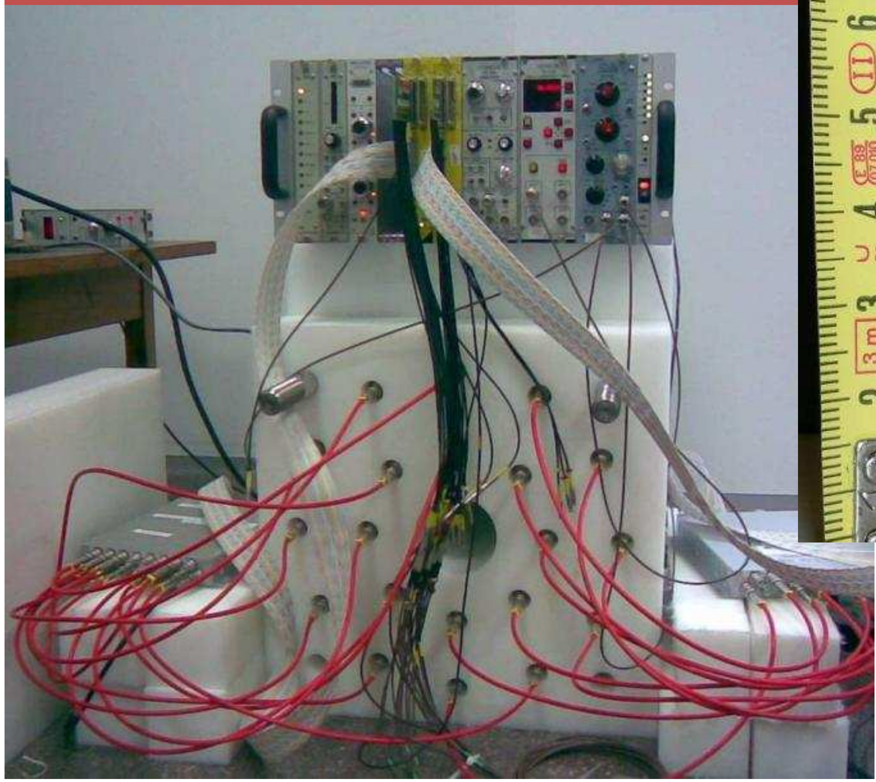
IFIC Triggerless DACQ for neutron detector



- 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.



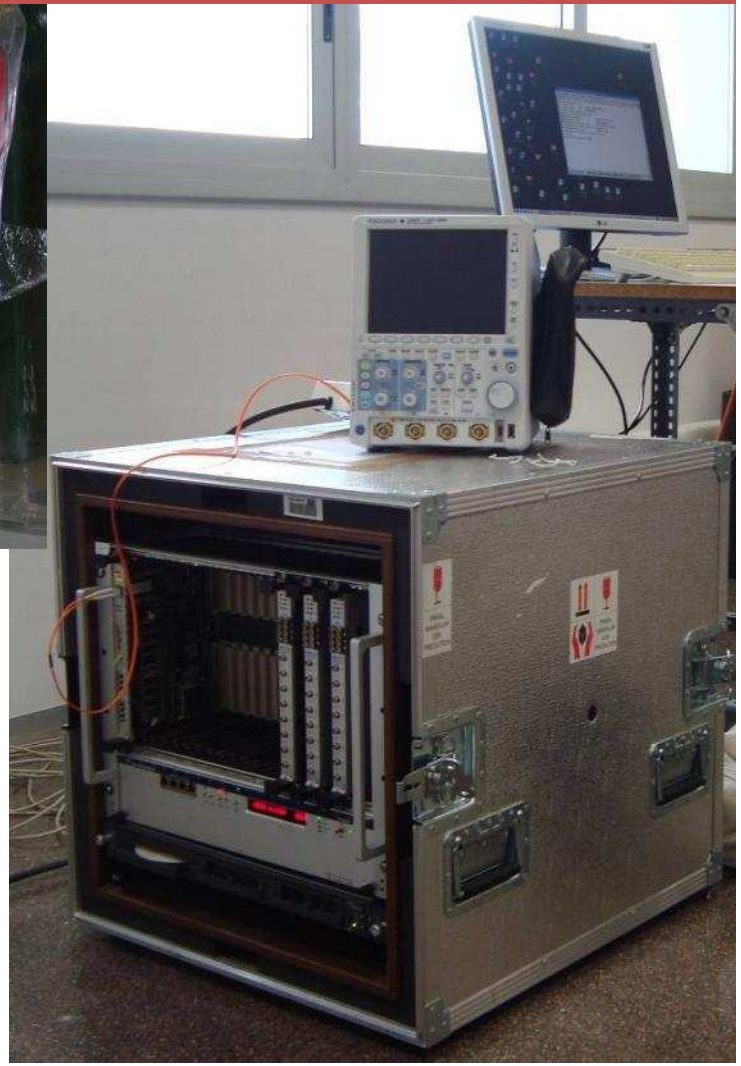
SIMULATION VALIDATION AT UPC WITH ^{252}CF



^{3}He counters + Mesytec electronics

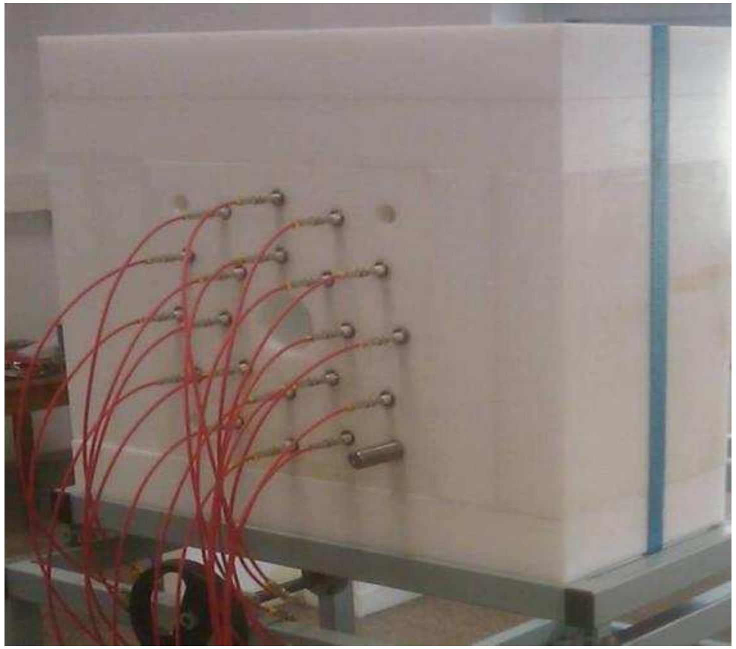
^{252}Cf source

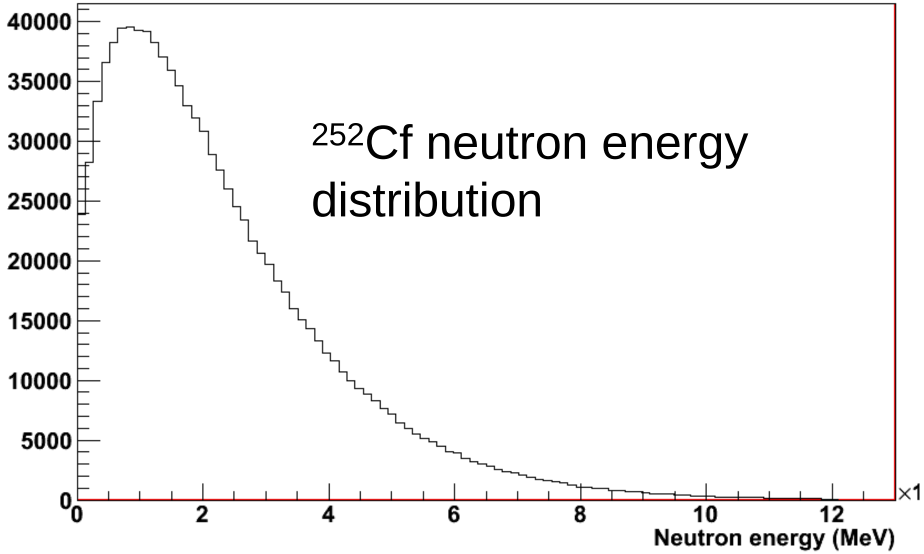
700n/s



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

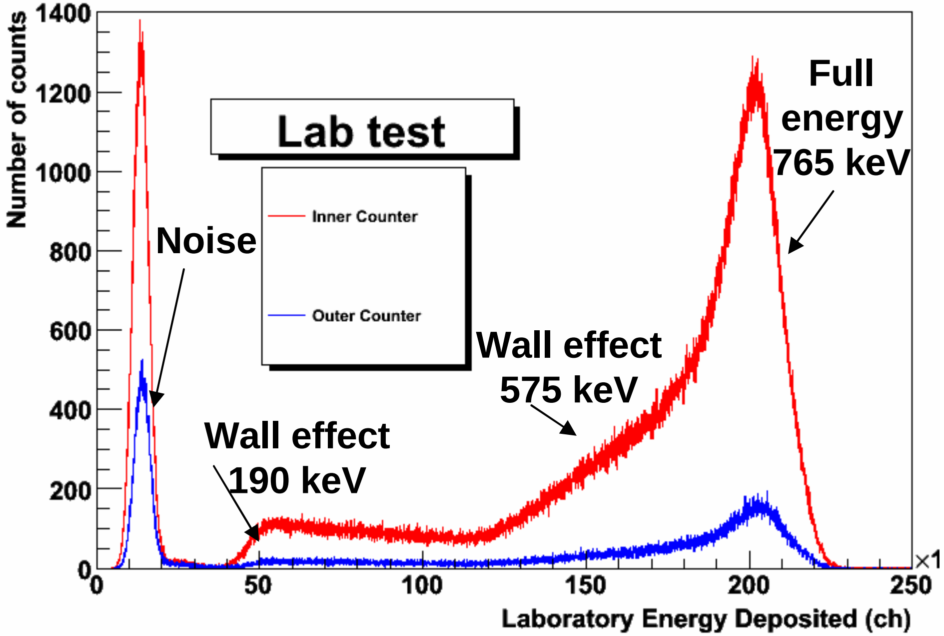
NaI detector for prompt fission γ. CIEMAT



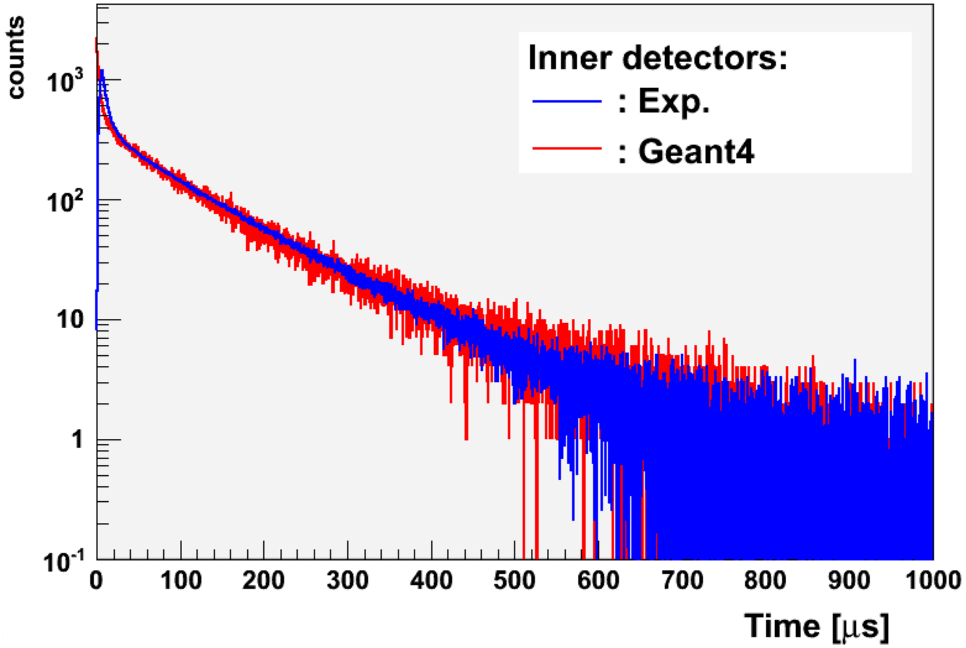


	Exp %	MCNPX %	GEANT4 %
Inner crown	21.3 ± 3.2	21.3 ± 1.5	25.0 ± 1.6
Outer crown	4.9 ± 0.7	6.0 ± 0.8	5.4 ± 0. 7
Tot	26.1 ± 3.9	27.3 ± 1.7	30.4 ± 1.7

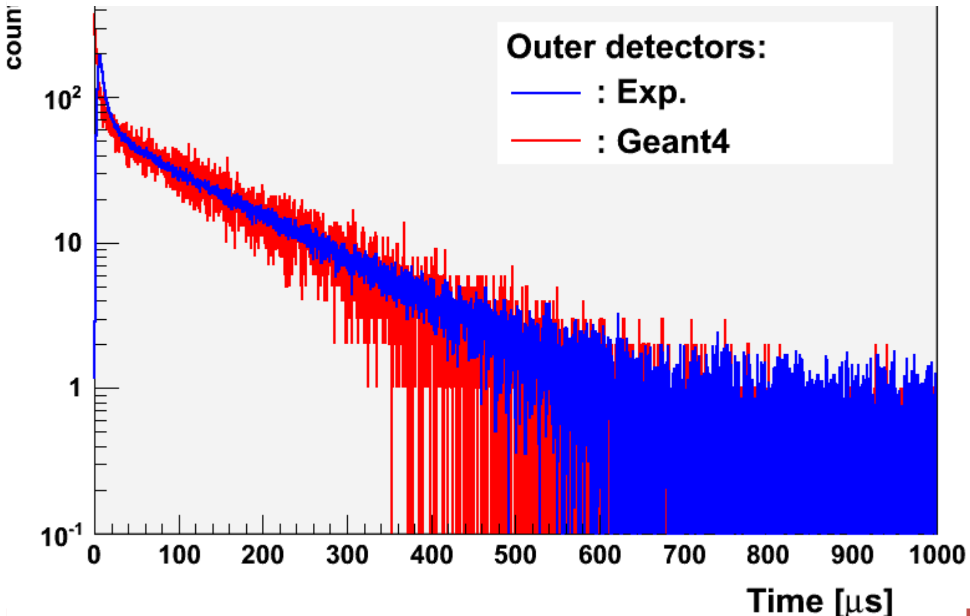
Experimental uncertainty due to source activity uncertainty (15%)



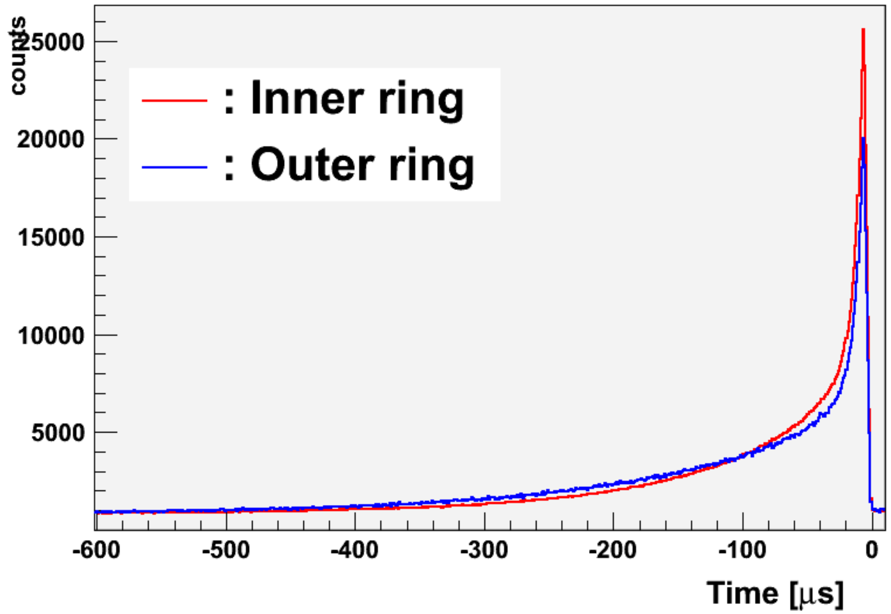
Monte Carlo simulations with GEANT4



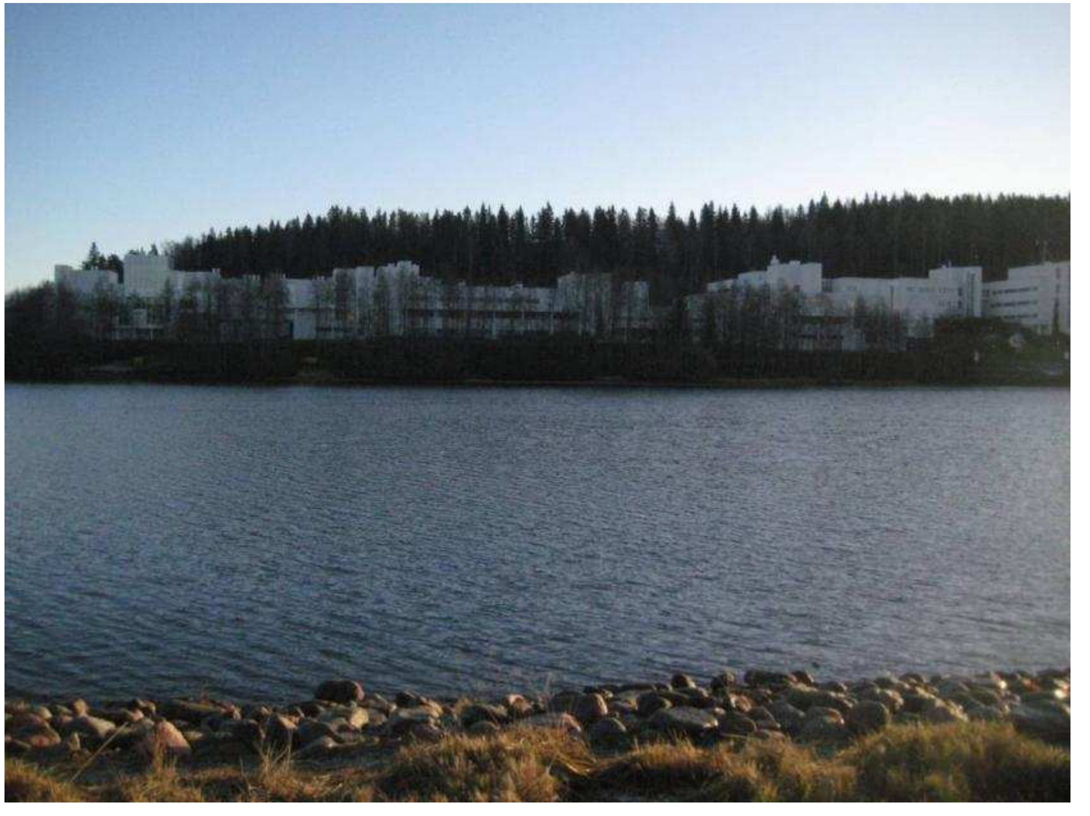
Comparison experimental vs
Geant4 detection time.



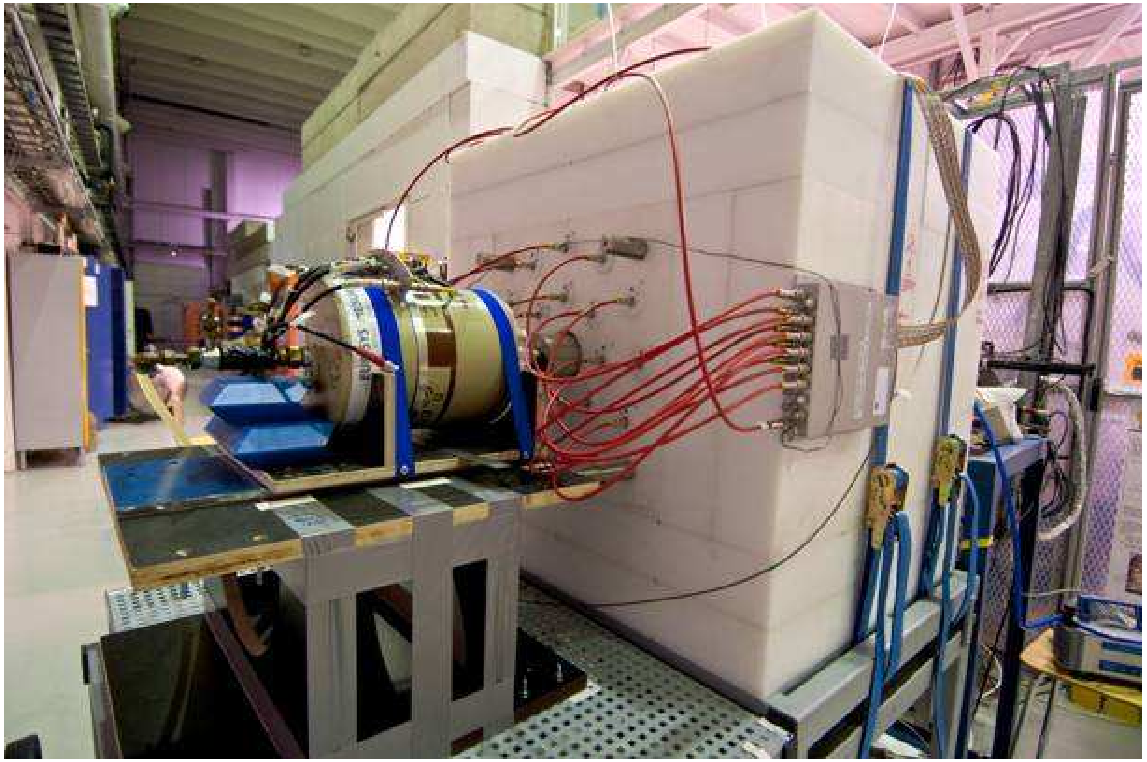
Experimental detection time
in inner and outer ring



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



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



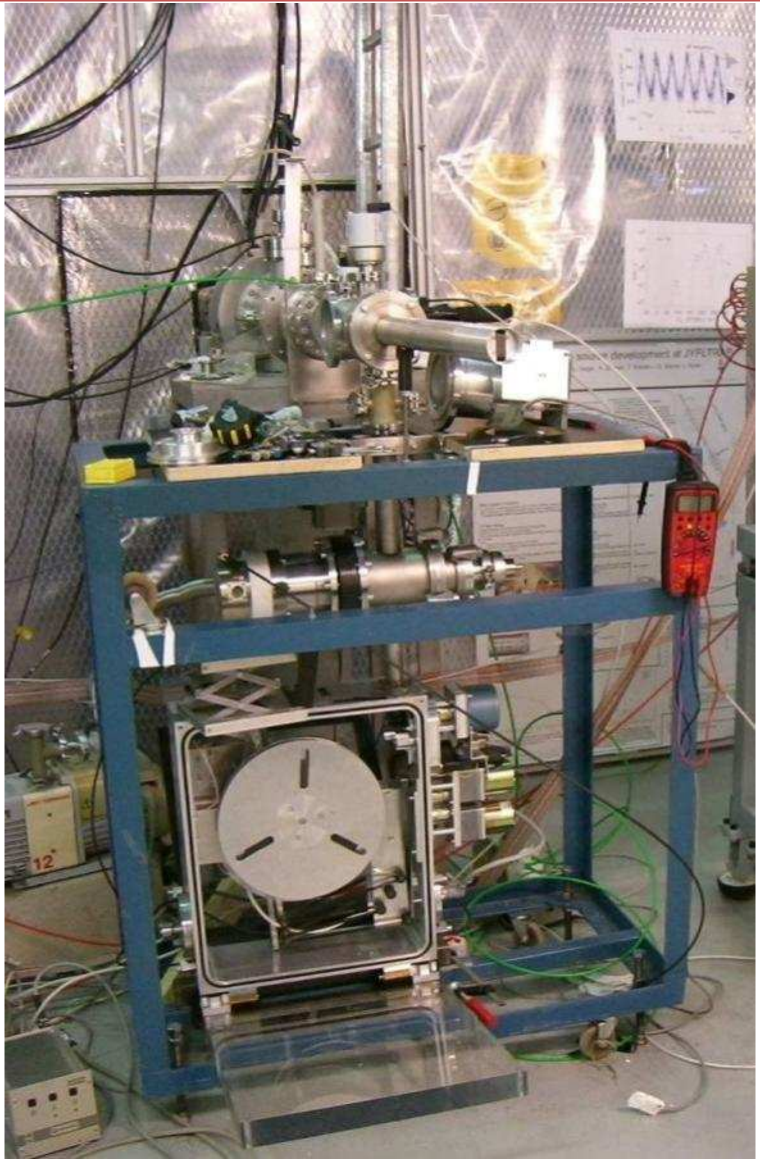
Measurement of
^{88}Br, ^{94,95}Rb, ^{138}I, ^{138}Te

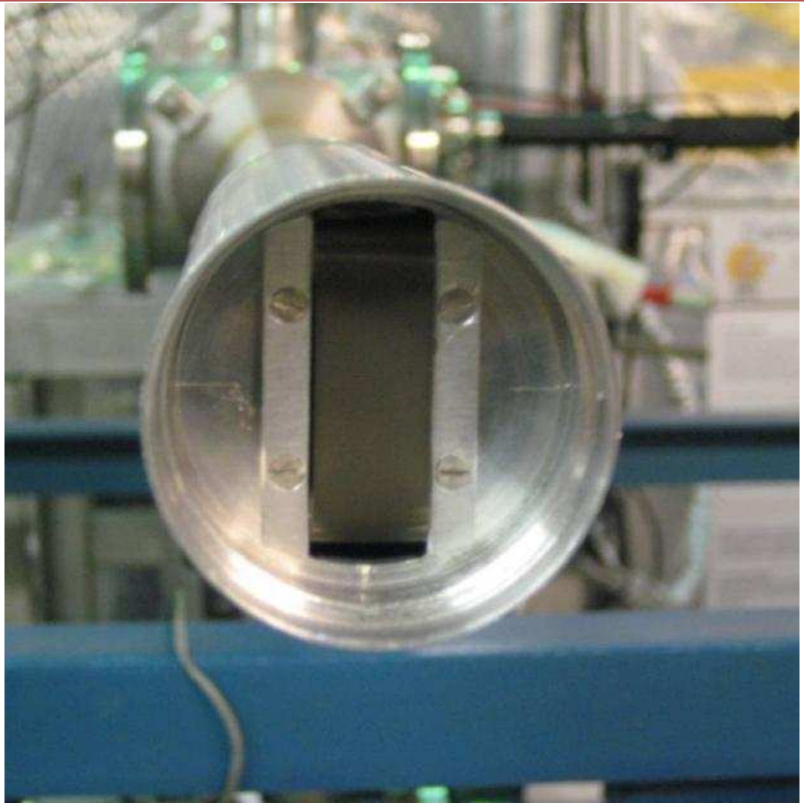
JYFLTRAP = Isotopically pure beams!

November 2009

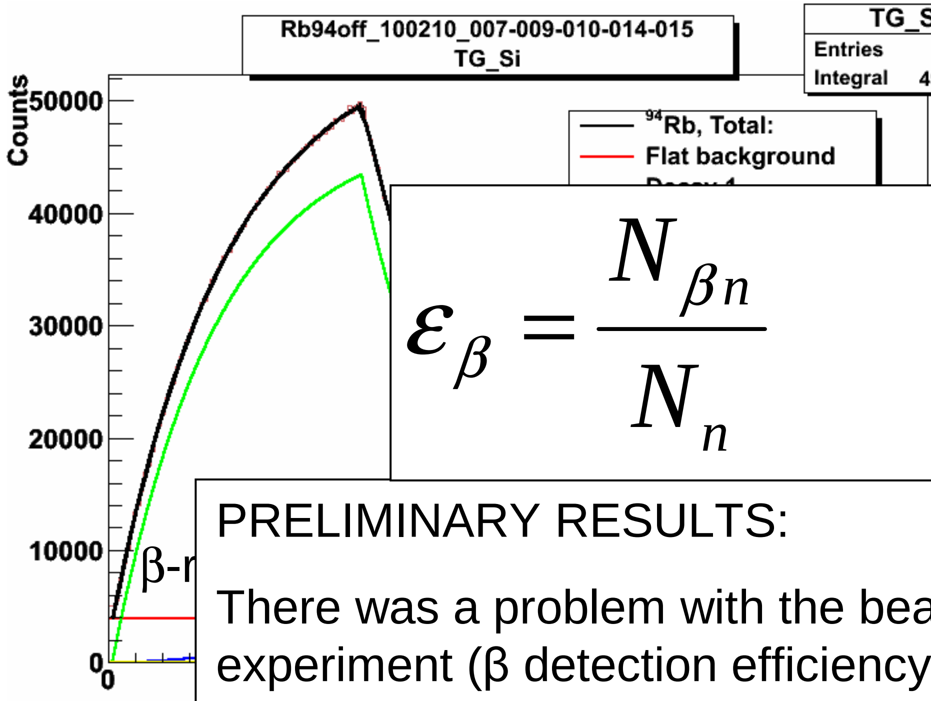
Delayed Neutron Precussor	Half life	Q_β (MeV)	β-n branching %	Daughter Nucleus	Half life
$^{88}_{35}$Br	16.3 s	8.96	6.58	$^{88}_{36}$Kr	2.84 h
$^{94}_{37}$Rb	2.70 s	10.31	10.4	$^{94}_{38}$Sr	75.3 s
$^{95}_{37}$Rb	377.5 ms	9.29	8.73	$^{95}_{38}$Sr	23.9 s
$^{138}_{53}$I	6.23	7.82	5.56	$^{138}_{54}$Xe	14.1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

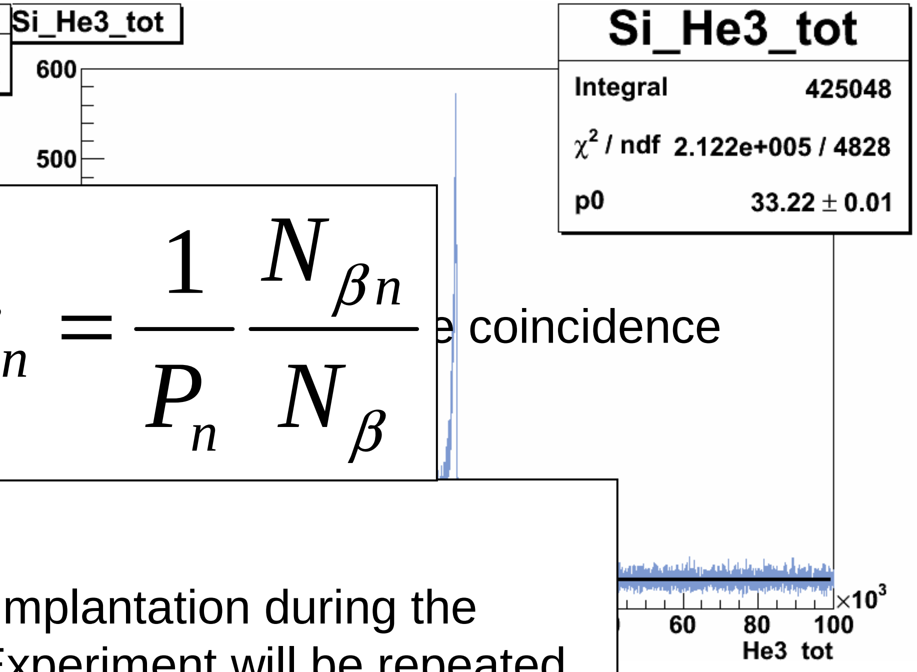
EXPERIMENT @ JYFL





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.





$$\varepsilon_\beta = \frac{N_{\beta n}}{N_n} \qquad \varepsilon_n = \frac{1}{P_n}\frac{N_{\beta n}}{N_\beta}$$

e coincidence

β-r

PRELIMINARY RESULTS:

There was a problem with the beam implantation during the experiment (β detection efficiency). Experiment will be repeated in June.

Decay fits

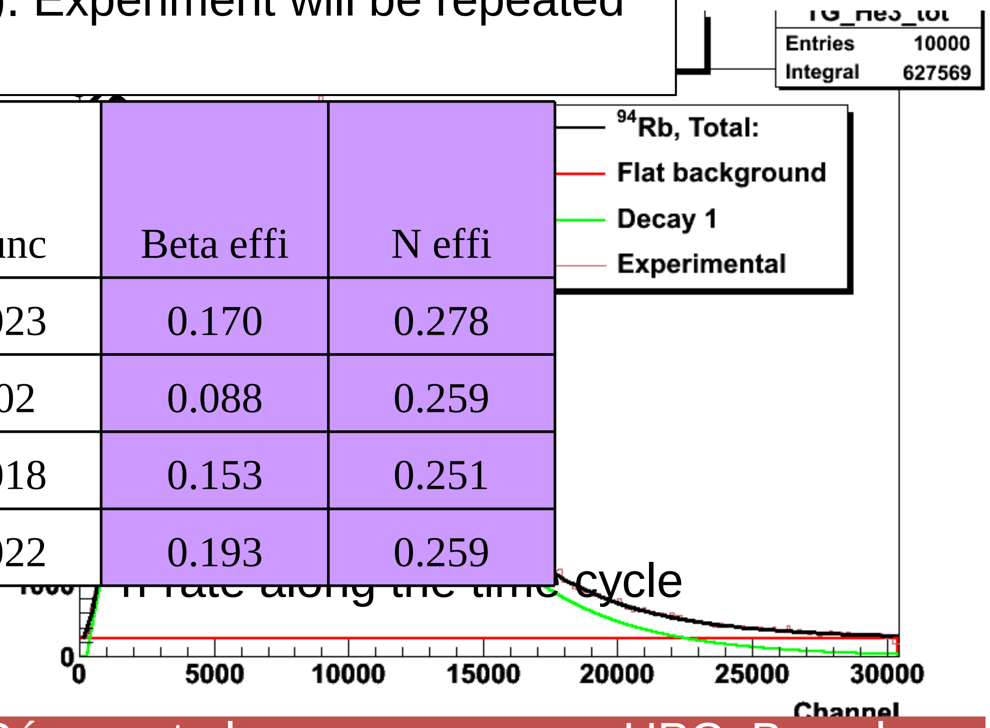
Ions were im

$3T_{1/2}$ and left

moving it aw

DATA IS U

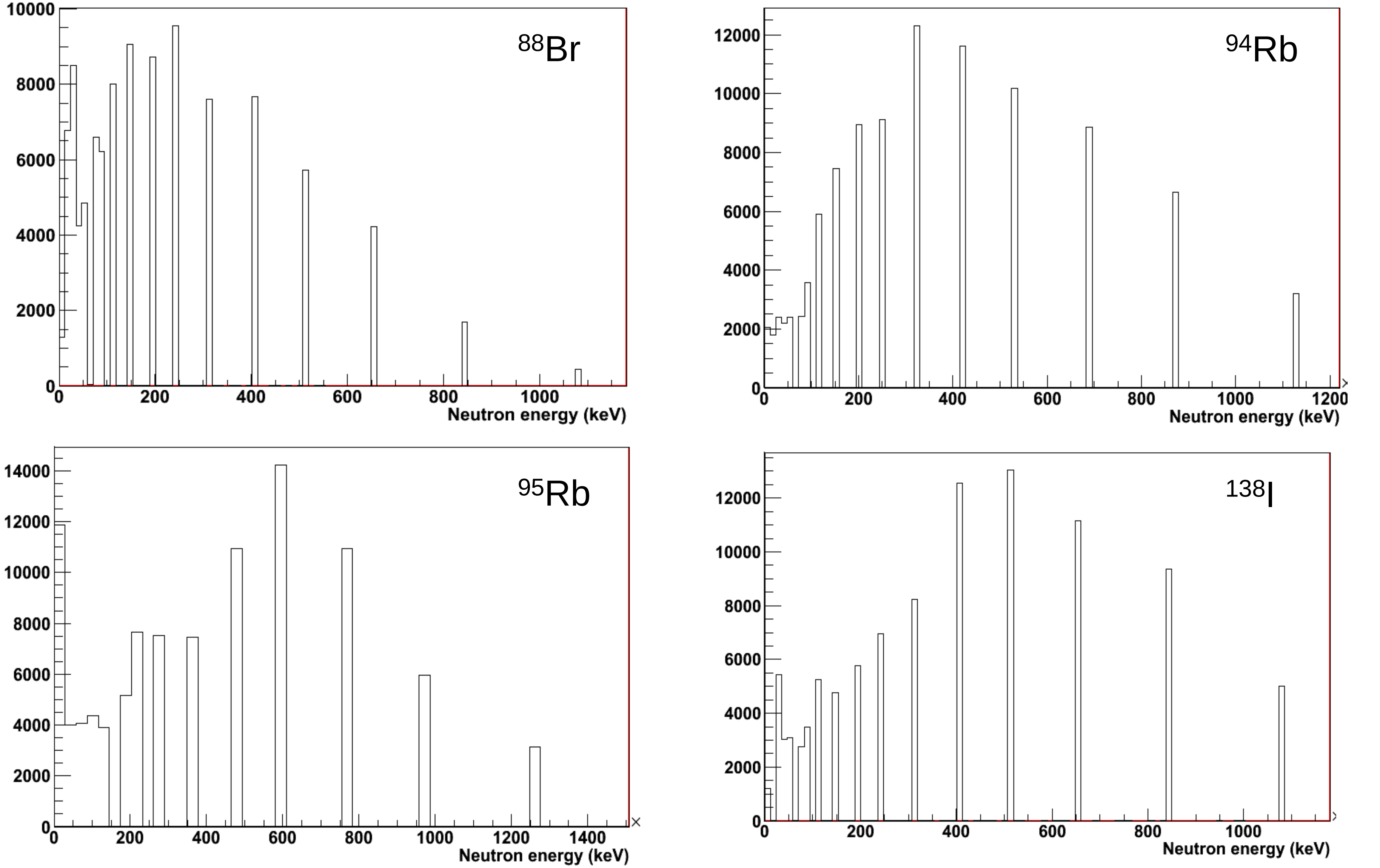
Isotope	Pn [Rudstam]	Pn unc	Beta effi	N effi
94Rb	0.1001	0.0023	0.170	0.278
95Rb	0.0873	0.002	0.088	0.259
88Br	0.0658	0.0018	0.153	0.251
138I	0.0556	0.0022	0.193	0.259



n rate along the time cycle

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)



The expected efficiency of the detector was calculated using the energy distributions from ENDF/B VII (and Greenwood [NSE 91, 305 (1985)] for ^{95}Rb) as neutron source in the simulations.

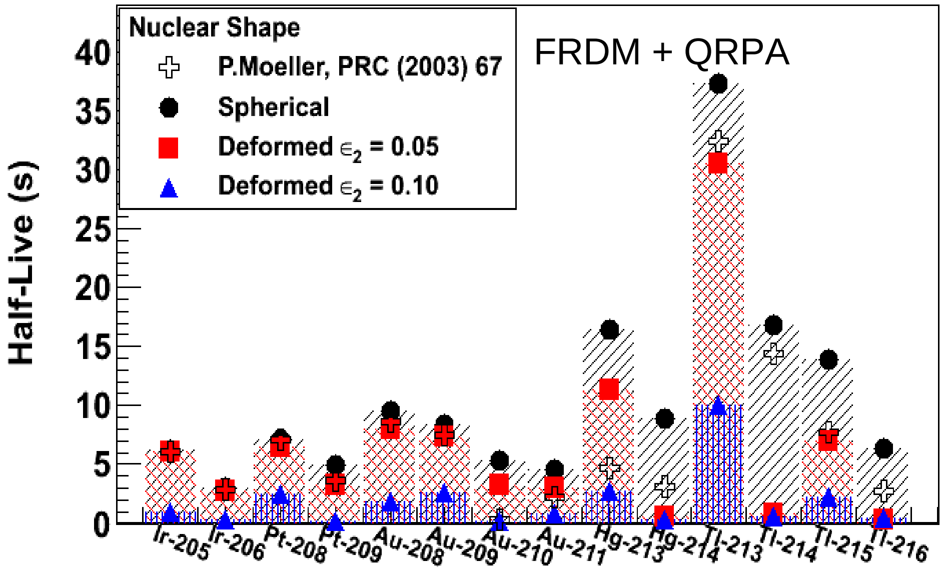
This simulation results will be compared to the experimental one, once the data analysis is finished.

Nucleus	GEANT4(%)		MCNPX(%)	
	Value	Unc	Value	Unc
^{88}Br	32.4	1.8	30.2	1.7
^{94}Rb	32.3	1.8	30.0	1.7
^{95}Rb	32.0	1.8	30.1	1.7
^{138}I	32.0	1.8	30.1	1.7

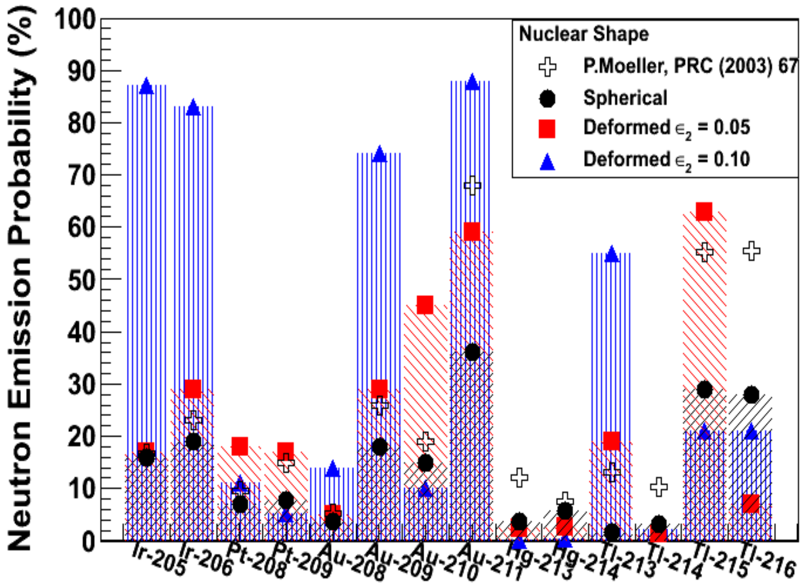
Future Pn measurements at GSI Fragment Separator (FRS) around the 3rd r-process peak

NEED OF EXPERIMENTAL DATA FOR THE R-PROCESS

• Difficult to calculate/predict half-live and Pn-values of the nuclei around the 3rd r-process peak:

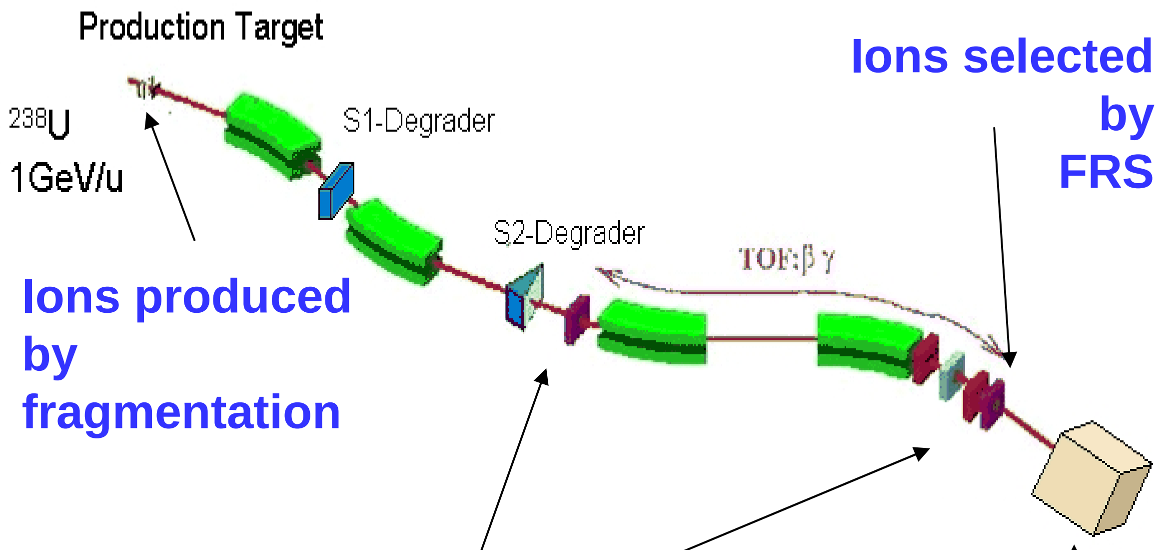


K.-L. Kratz, (private communication)



K.-L. Kratz, (private communication)

Pn measurements at GSI Fragment Separator (FRS)

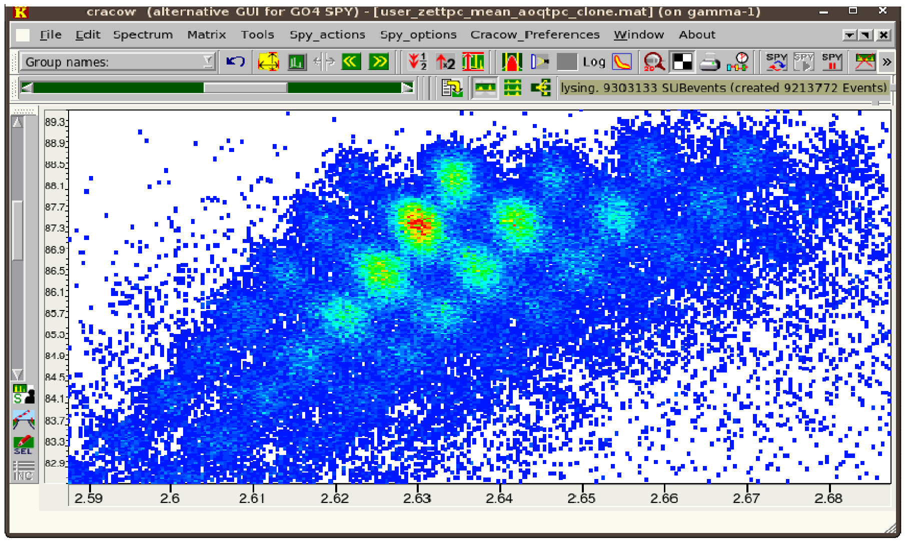


Ions produced by fragmentation

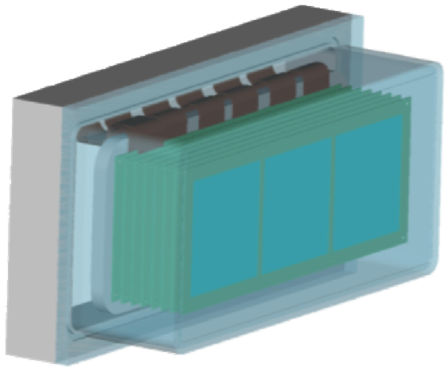
Ions selected by FRS

Selected ions identified using ToF and energy loss information

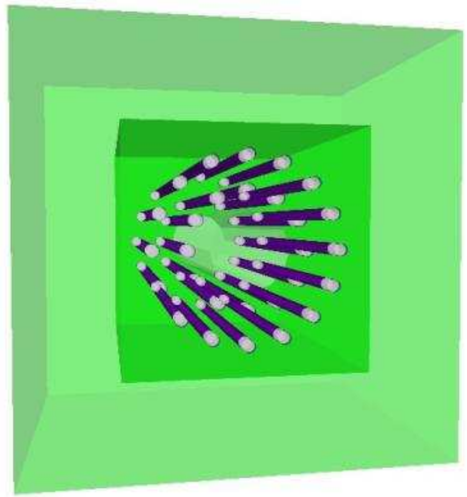
Detection setup



Ions implanted and their β-decay measured in a stack of DSSDs (AIDA)



Neutrons detected with the BELEN detector



SUMMARY

✓ Importance of beta delayed neutron emission in technological application and r – process calculations.

✓ GenIV reactors need accurate data for fission products of MA fuel regarding delayed neutron emission.

✓ Ample field for research at DESIR and future facilities.

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

✓ Simulation validation tests show good agreement.

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

✓ First experiment has been successfully perfomred at JYFLTRAP to measure beta delayed neutron emission of fission products.

✓ Experiment has been proposed regarding neutron emission in the r-process at GSI.