New accurate measurements of neutron emission probabilities for relevant fission products

- Motivation
- The experiment
- The analysis
- Preliminary Results
- Next steps
- Conclusions

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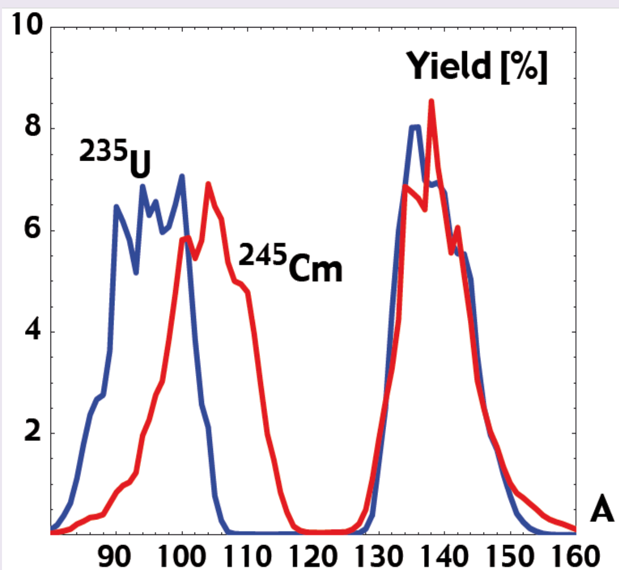
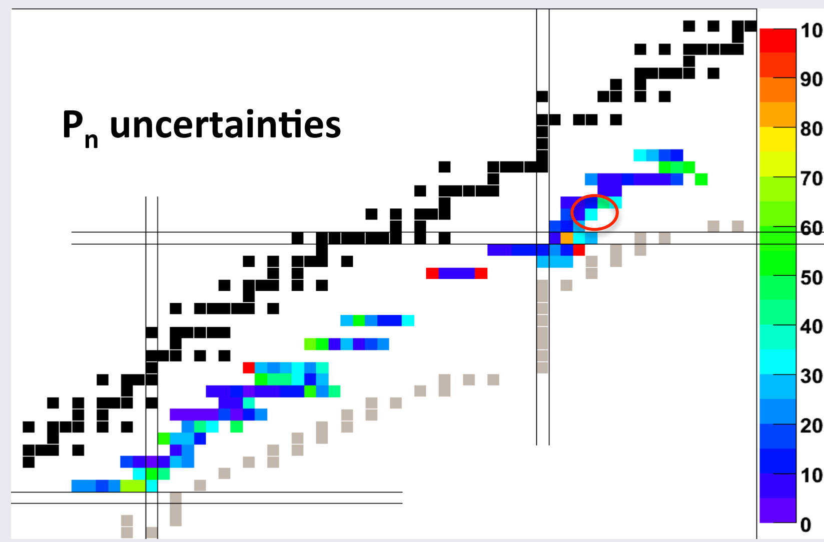
Motivation

- Nuclear reactor control: summation calculation of the delayed neutron fraction
- We try to improve data for fission products with :
  - Relatively large fission yields Y
  - Few P_n experimental values
  - Relatively large uncertainties on P_n

$$\bar{\nu}_d = \sum_i Y_i \cdot P_n^i$$

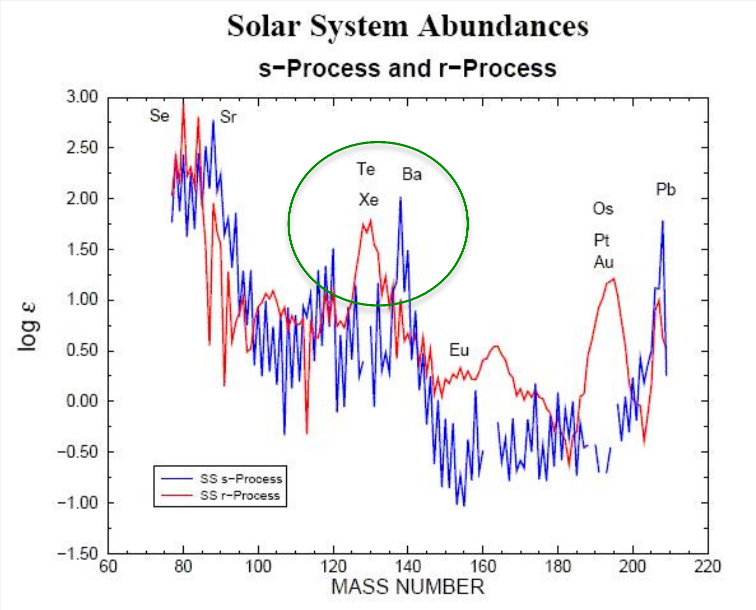


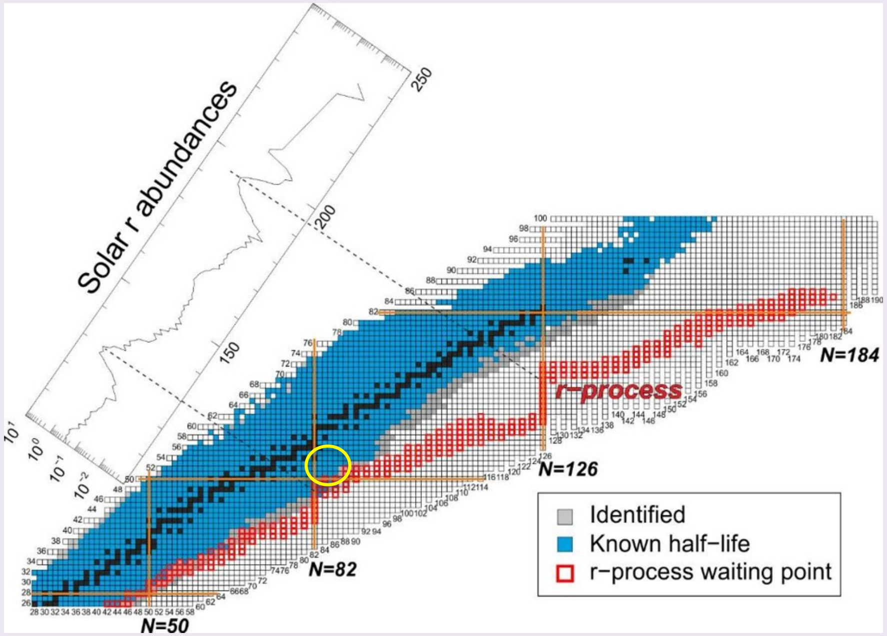


P_n: Pfeiffer et al., PNE41(2002)39

Motivation

- Pn Values are also important for the astrophysical r-process: They modify the final element abundance.
- We choose to measure fission products close to the r-process path around A=140





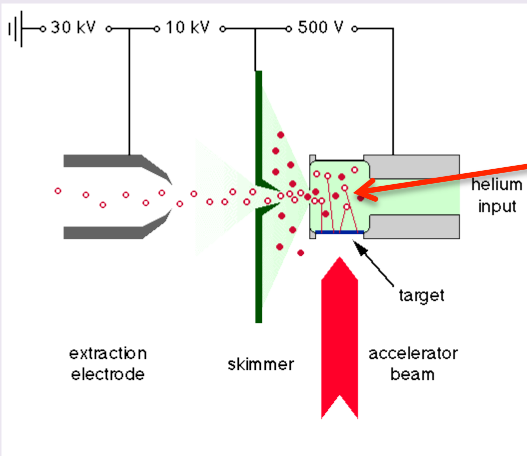
Experiment: The goal

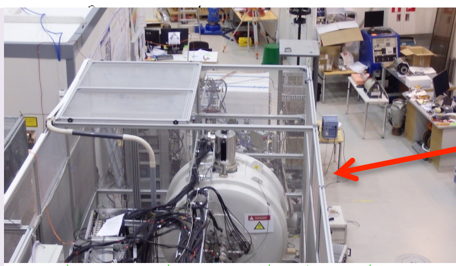
Nuclei with N>82 Z>50: $^{138\ 139\ 140}I$, ^{138}Te and $^{135\ 137}Sb$

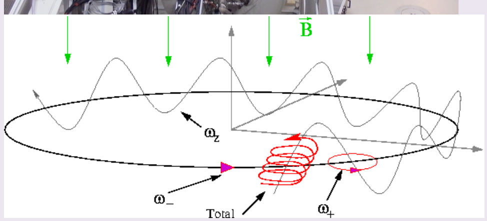
136Xe >2.4E+21 Y 8.8573% 2β-	137Xe 3.818 M β-: 100.00%	138Xe 14.08 M β-: 100.00%	139Xe 39.68 S β-: 100.00%	140Xe 13.60 S β-: 100.00%	141Xe 1.73 S β-: 100.00% β-n: 0.04%	142Xe 1.23 S β-: 100.00% β-n: 0.21%	143Xe 0.511 S β-: 100.00% β-n: 1.00%	144Xe 0.388 S β-: 100.00% β-n: 3.00%
135I 6.58 H β-: 100.00%	136I 83.4 S β-: 100.00%	137I 24.5 S β-: 100.00% β-n: 7.14%	138I 6.23 S β-: 100.00% β-n: 5.56%	139I 2.280 S β-: 100.00% β-n: 10.00%	140I 0.86 S β-: 100.00% β-n: 9.30%	141I 0.43 S β-: 100.00% β-n: 21.20%	142I 222 MS β-: 100.00% β-n	143I 130 MS β-
134Te 41.8 M β-: 100.00%	135Te 19.0 S β-: 100.00%	136Te 17.63 S β-: 100.00% β-n: 1.31%	137Te 2.49 S β-: 100.00% β-n: 2.99%	138Te 1.4 S β-: 100.00% β-n: 6.30%	139Te >150 NS β-n β-	140Te >300 NS β-n β-	141Te >150 NS β-n β-	142Te
133Sb 2.34 M β-: 100.00%	134Sb 0.78 S β-: 100.00%	135Sb 1.679 S β-: 100.00% β-n: 22.00%	136Sb 0.923 S β-: 100.00% β-n: 16.30%	137Sb 492 MS β-: 100.00% β-n: 49.00%	138Sb 350 MS β-: 100.00% β-n: 72.00%	139Sb 93 MS β-: 100.00% β-n: 90.00%	140Sb >407 NS β-2n β-n	
132Sn 39.7 S β-: 100.00%	133Sn 1.46 S β-: 100.00% β-n: 0.03%	134Sn 1.050 S β-: 100.00% β-n: 17.00%	135Sn 530 MS β-: 100.00% β-n: 21.00%	136Sn 0.25 S β-: 100.00% β-n: 30.00%	137Sn 190 MS β-: 100.00% β-n: 58.00%	138Sn >408 NS β-n β-		

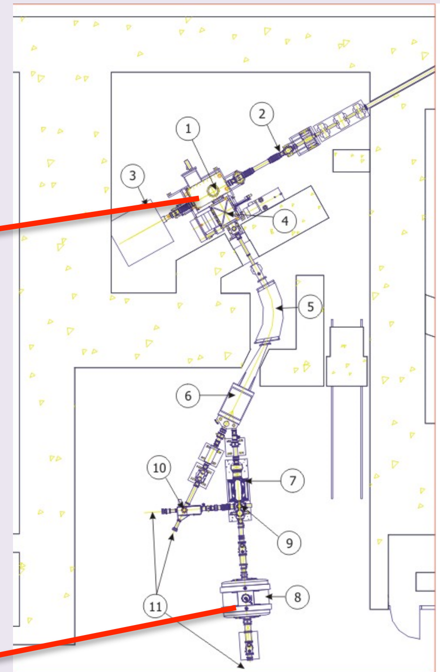
Experiment: The facility

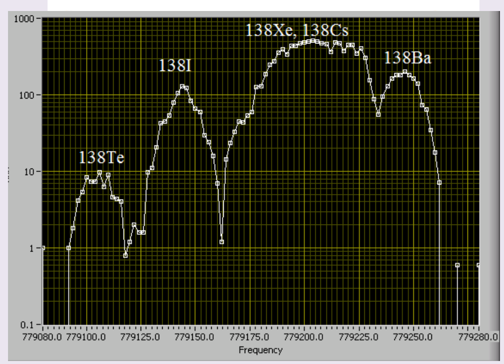
IGISOl + Penning trap





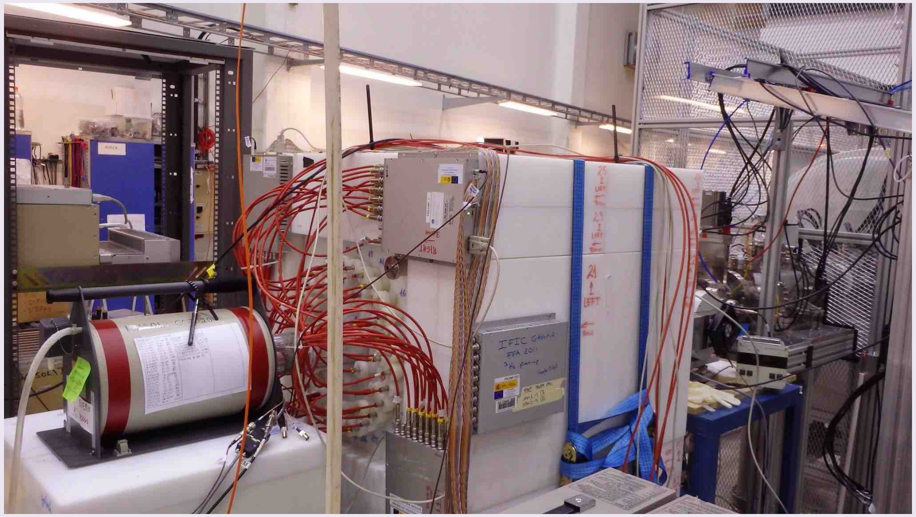


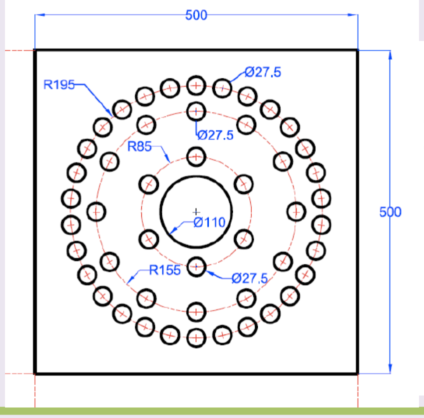


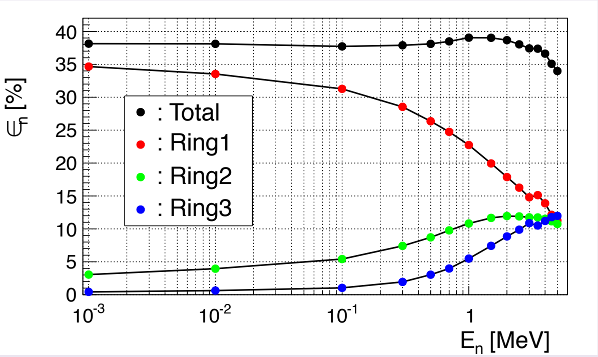


- Ion source with a Helium jet to extract ions
- Capable to extract refractory elements
- Fast extraction, so we can reach small half lives
- Mass separator connected to a Penning trap
- Isotopic purification

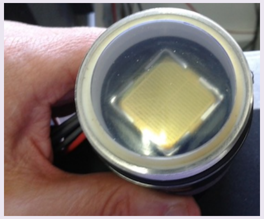
Experiment: The detectors

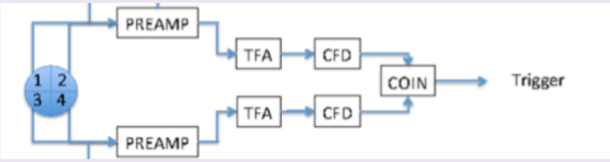




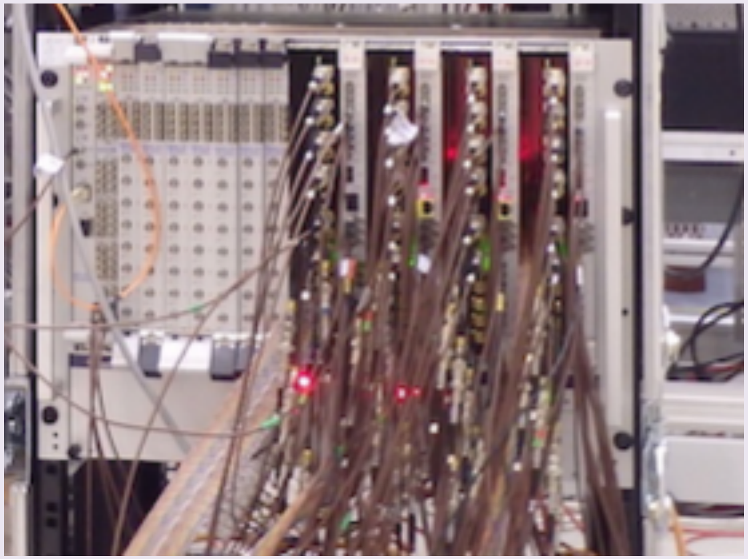


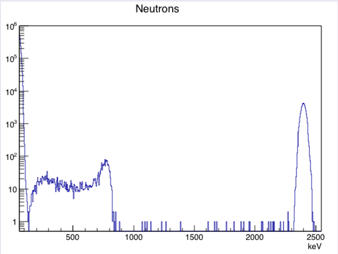
- 48 ^{3}He detector of 8 atm
- Distributed in 3 rings
- ~40% efficiency
- Flat efficiency until 2MeV
- Ions implanted in a transport tape in the center of the detector
- Thin plastic detector close to the implantation area
- HpGe Detector fit in the matrix(~10cm from center)
- Beta detector ~30% efficiency

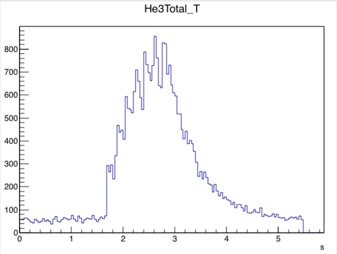


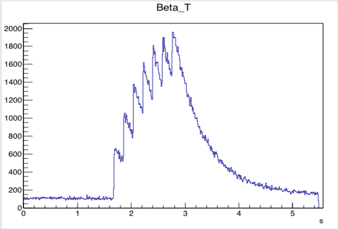


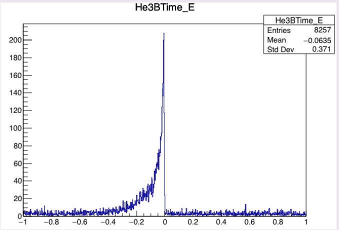
Experiment: The DAQ





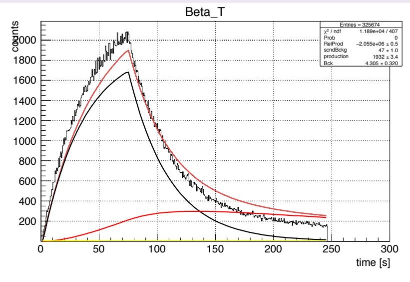






- Enhancement of our BELEN event-less DACQ
- Improved online analysis capabilities and display.
- Increased capabilities: More than one crate and up to 200 channels

Experiment: Analysis issues

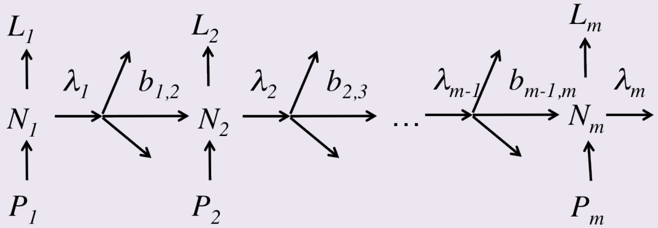


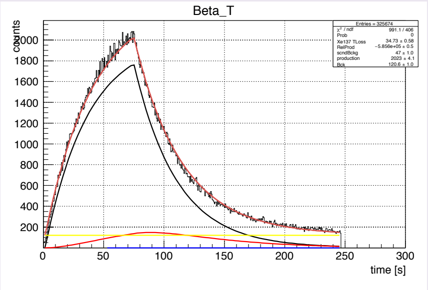
Problem:

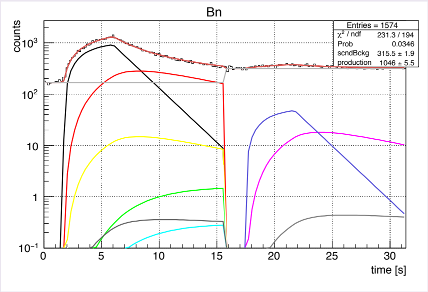
- The daughter Xe is a noble gas: escape from implantation tape

Solution:

- Add a loss term to Bateman equations

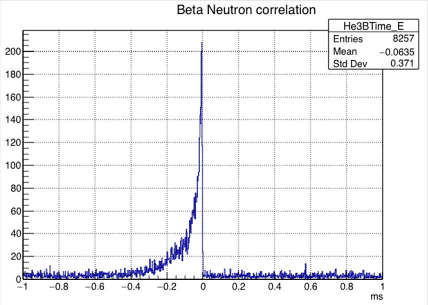






Two analysis ways:

- Betas and neutrons single counts.
- β-n correlation: This method is dependent on the β detection efficiencies in the $Q_{\beta n}$ window.

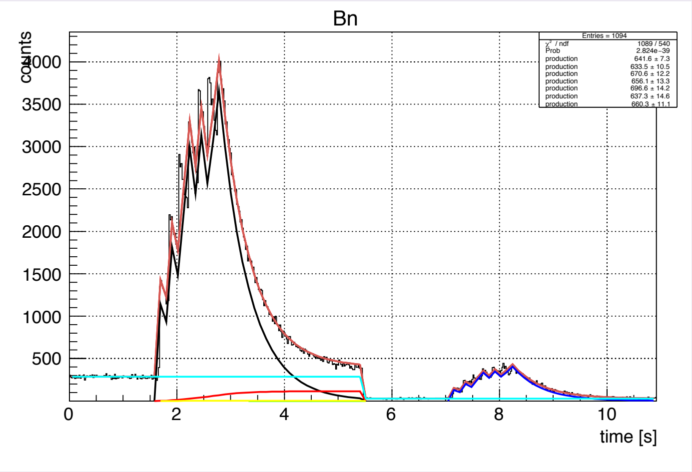


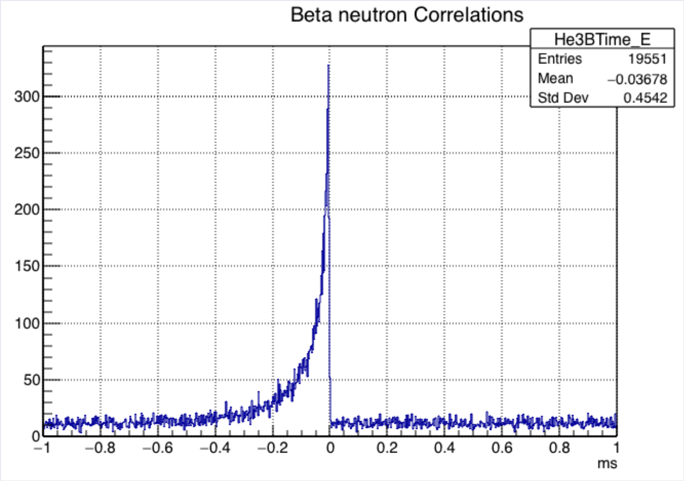
$$P_n = \frac{\varepsilon_\beta}{\varepsilon_n}\frac{N_n}{N_\beta}$$

$$P_n = \frac{\bar{\varepsilon}_\beta}{\bar{\varepsilon}_n \bar{\varepsilon}_\beta^{p_n}}\frac{N_{\beta n}}{N_\beta}$$

$$\bar{\varepsilon}_\beta^{p_n} \sim \bar{\varepsilon}_\beta \rightarrow P_n = \frac{1}{\bar{\varepsilon}_n}\frac{N_{\beta n}}{N_\beta}$$

Experiment: Calibration ^{95}Rb





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

$$\frac{\varepsilon_\beta}{\varepsilon_n} = 0.816(33)$$

$$\bar{\varepsilon}_n = \frac{1}{P_n}\frac{N_{\beta n}}{N_\beta}$$

$$\varepsilon_n = 38.48(16)$$

Agrees with MC simulation

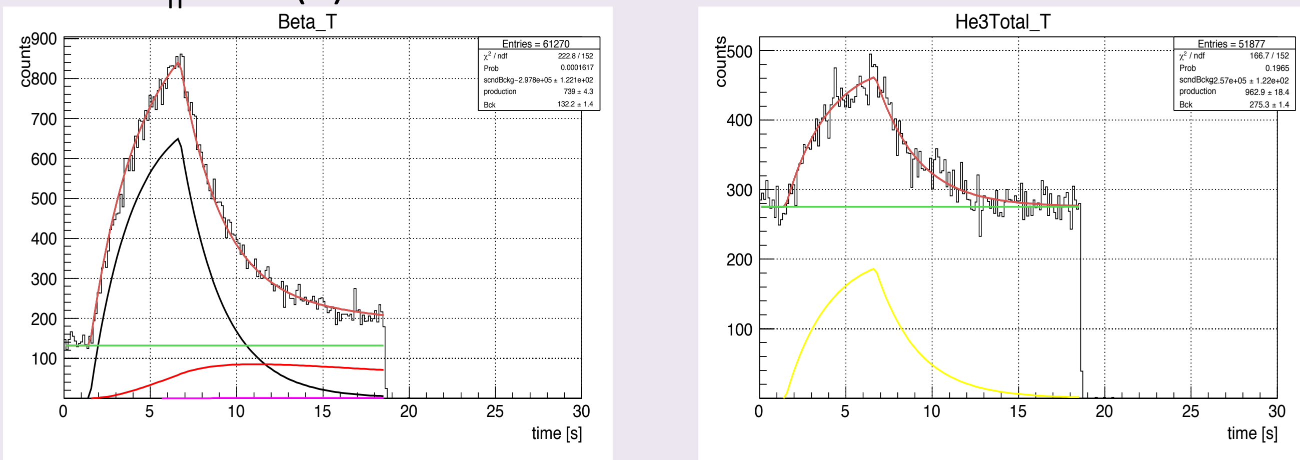
$$P_n = \frac{\varepsilon_\beta}{\varepsilon_n}\frac{N_n}{N_\beta}$$

$$P_n = \frac{\bar{\varepsilon}_\beta}{\bar{\varepsilon}_n \bar{\varepsilon}_\beta^{p_n}}\frac{N_{\beta n}}{N_\beta}$$

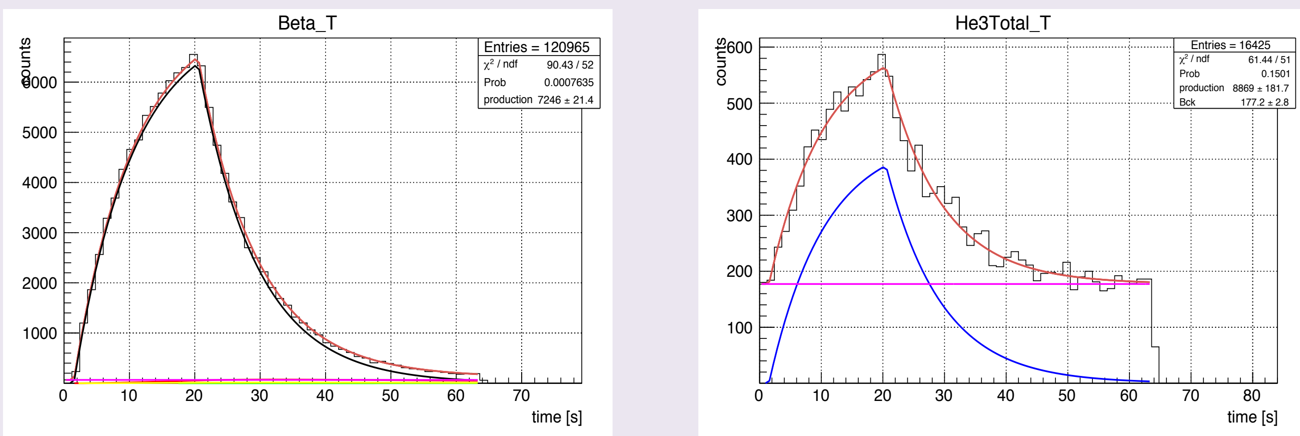
$$\bar{\varepsilon}_\beta^{p_n} \sim \bar{\varepsilon}_\beta \rightarrow P_n = \frac{1}{\bar{\varepsilon}_n}\frac{N_{\beta n}}{N_\beta}$$

Preliminary Results

^{135}Sb :P_n=24.5(9)%

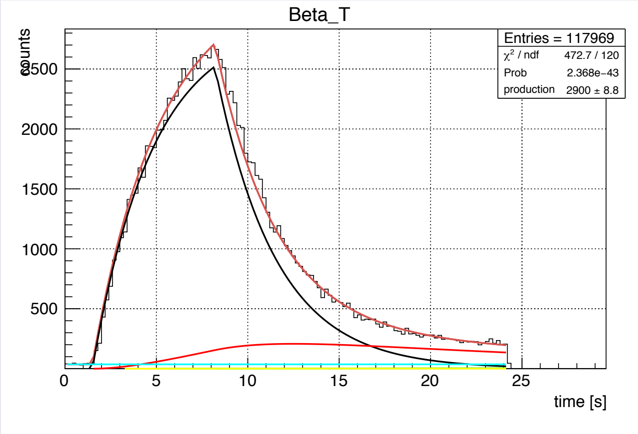


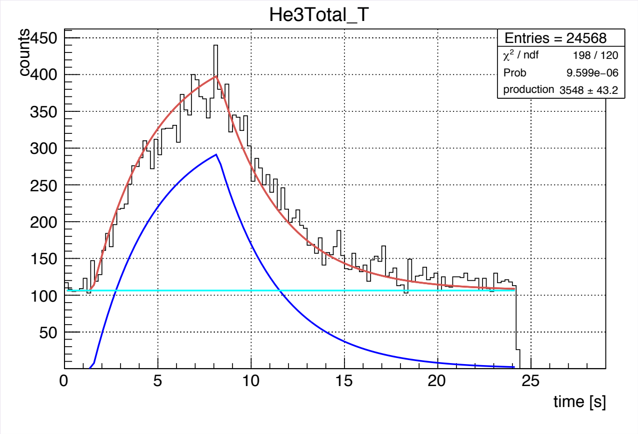
^{138}I:P_n=4.98(18)%



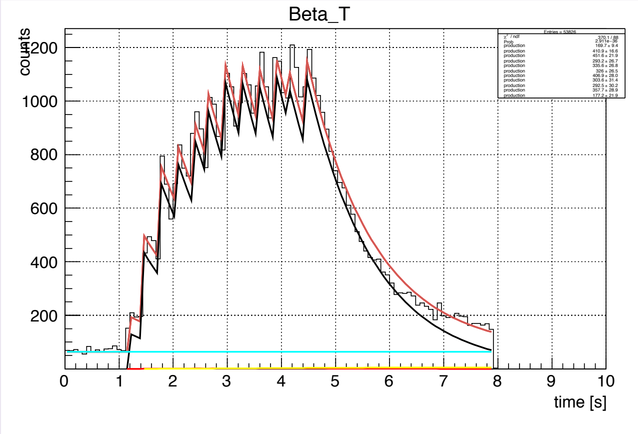
Preliminary Results

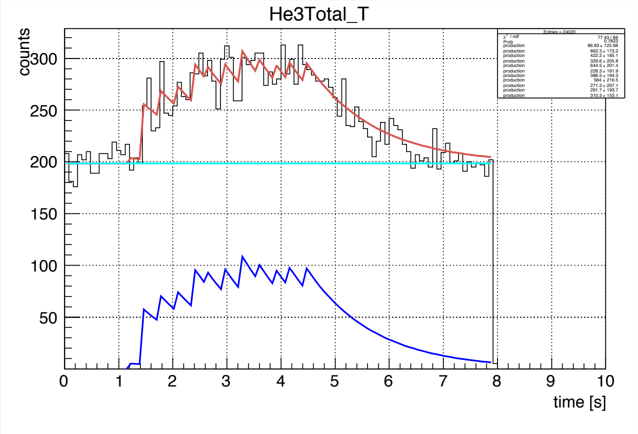
^{139}I: P_n=9.27(33)%





^{140}I P_n=7.60(28)%





Preliminary Results: ^{138}Te precedents

- Only one measurement from 1975
- Mass separated A=138, low amount of ^{138}Te.
- High uncertainty in P_n and $T_{1/2}$

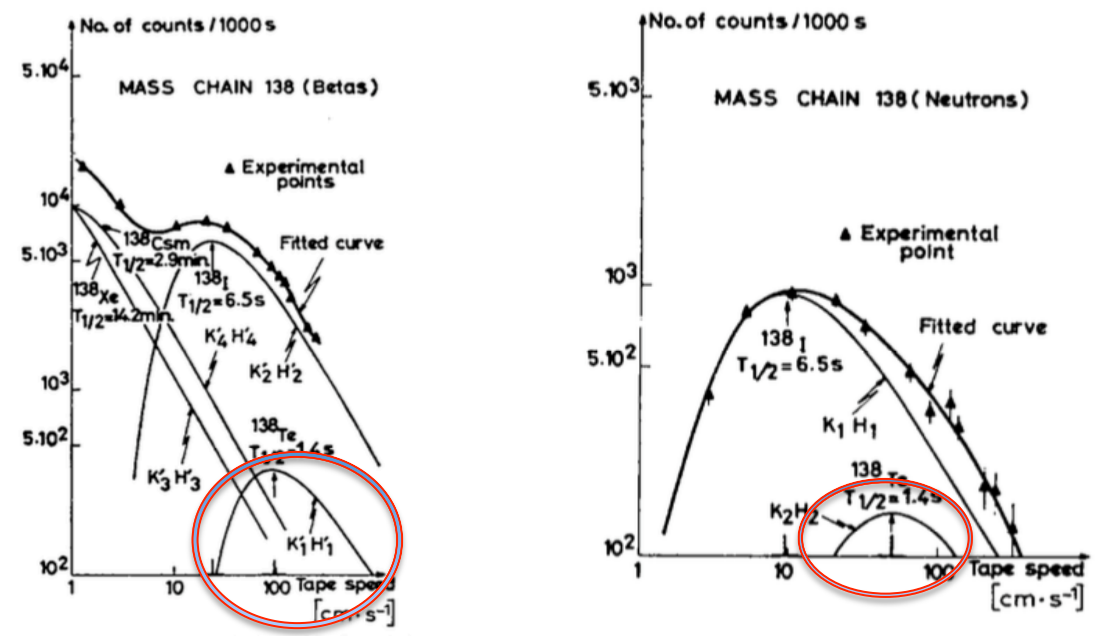
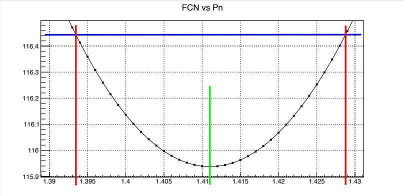


Fig. 17. The mass chain 138 β-activity as a function of tape speed and its decomposition in *KH'* components.

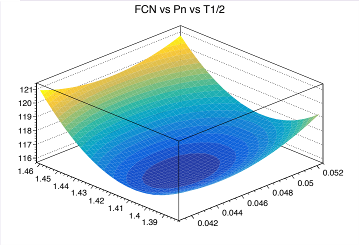
Fig. 10. The mass chain 138 neutron activity as a function of tape speed and its decomposition in *KH* components.

G.Bailleur Nuclear Physics A247

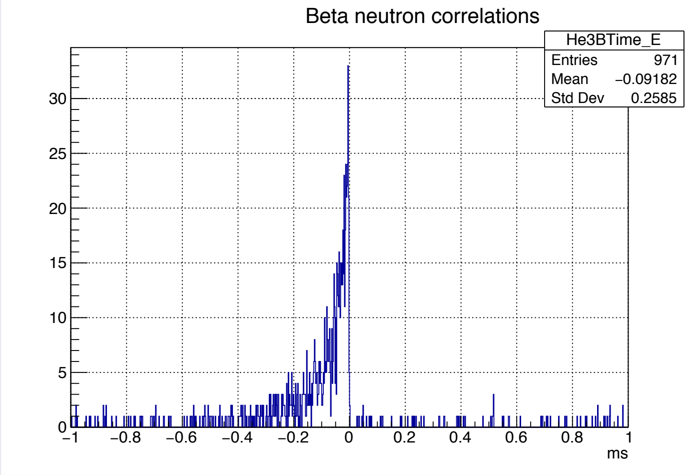
Preliminary Results

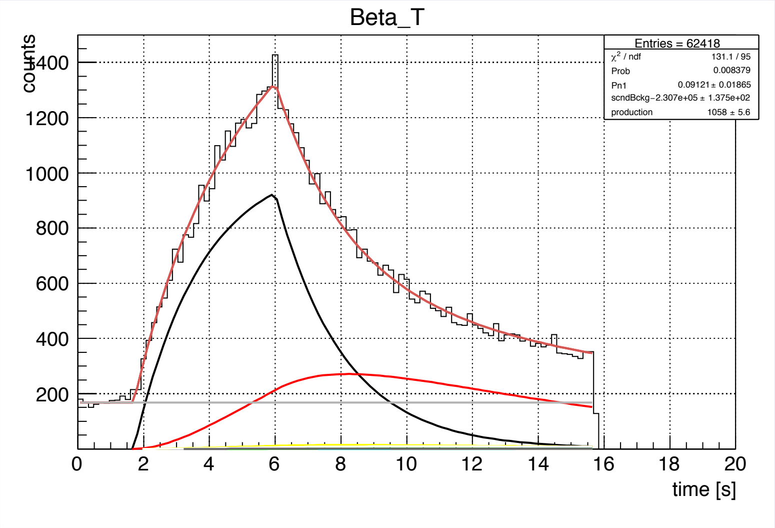


$T_{1/2}$=1.41(2)s

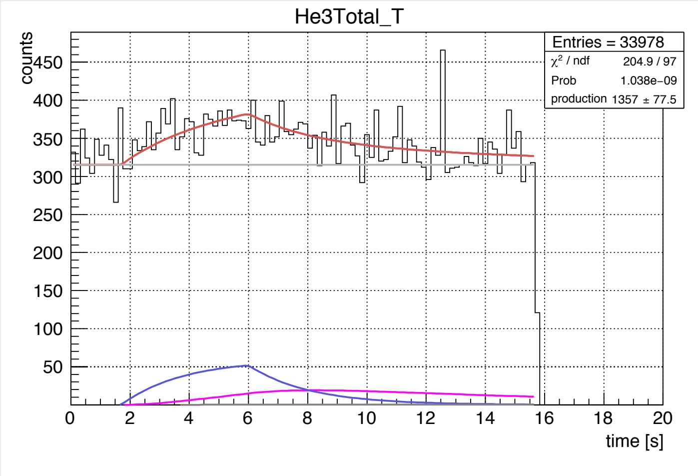


^{138}Te: Pn=4.3(3)%

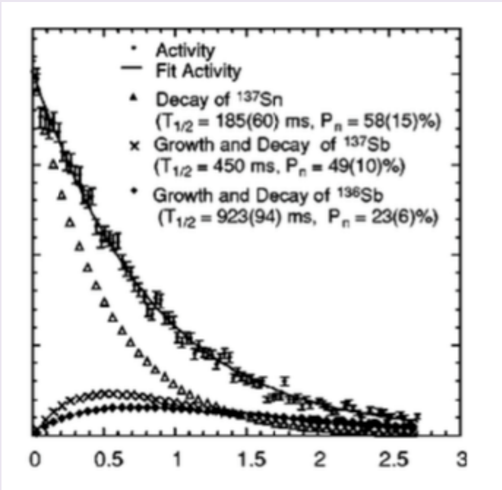




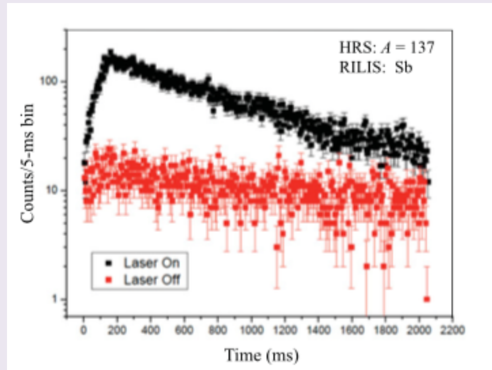
^{138}Te: Pn=4.3(2)%



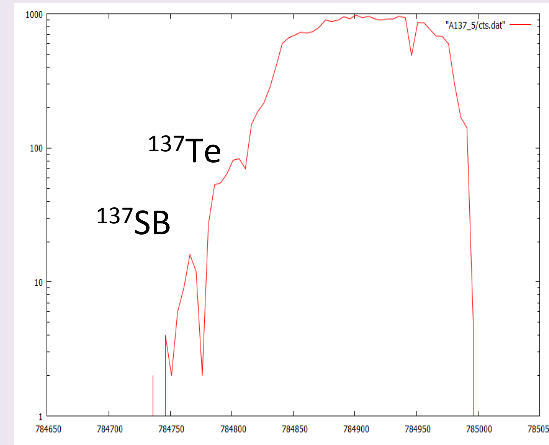
Preliminary Results: ^{137}Sb?



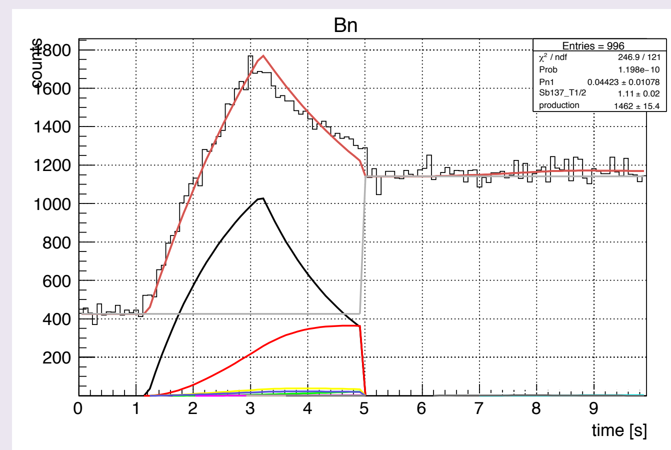
Shergur:PHYSICAL REVIEW C, VOLUME 65, 034313



ARNDT:PHYSICAL REVIEW C **84**, 061307(R) (2011)

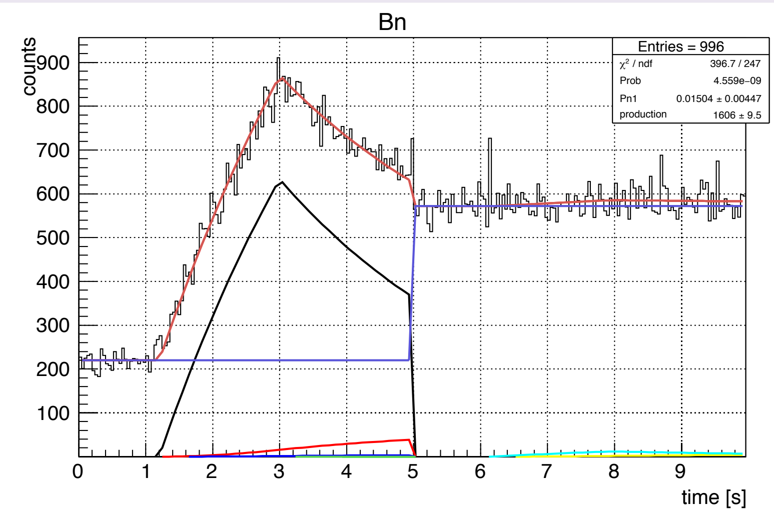


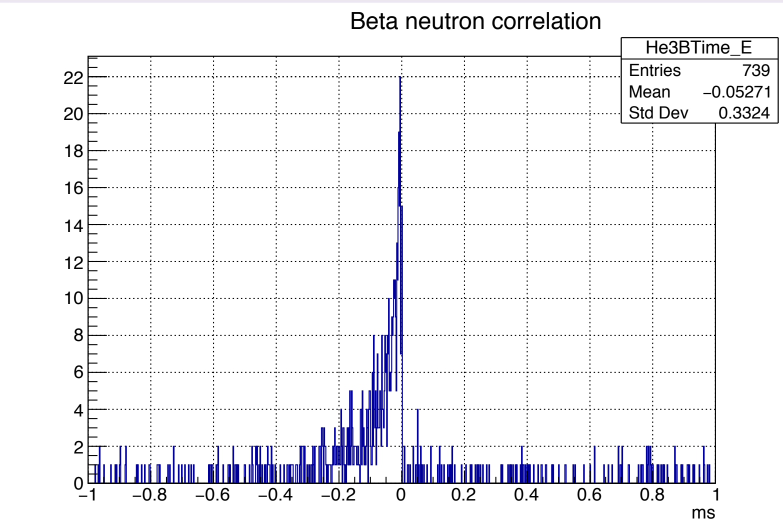
- In first measurement, systematics for ^{133}Sb and ^{135}Sb was used to obtain $T_{1/2}$=0.45(5)s, P_n=49(10)%
- In the second experiment $T_{1/2}$=0.492(25)s and no P_n.
- Our data:
  - Small production
  - Half life to fit plot: 1.1s, too long for previous values.



Preliminary Results: But what about ^{137}Te?

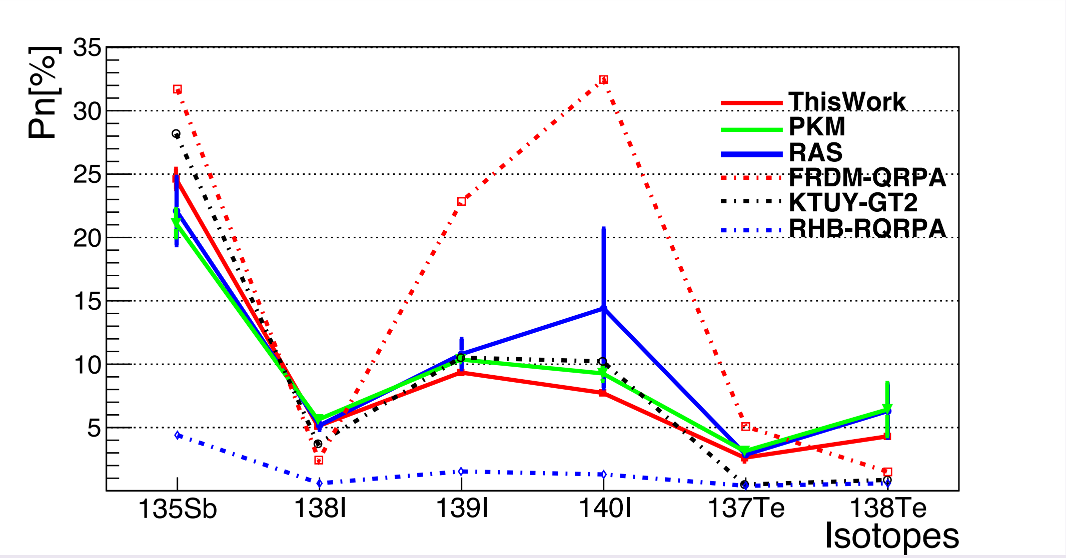
^{137}Te: P_n=2.6%(3)





We thought that we measure 137Sb, but we were measuring the tail of the 137Te

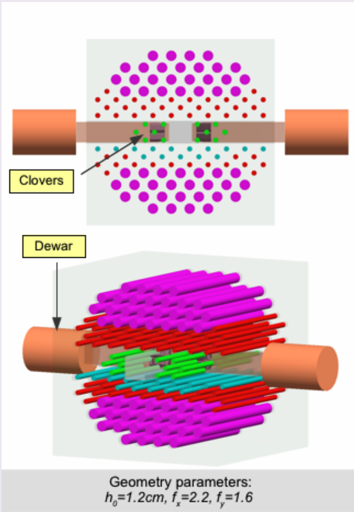
Preliminary Results: Comparison with previous data

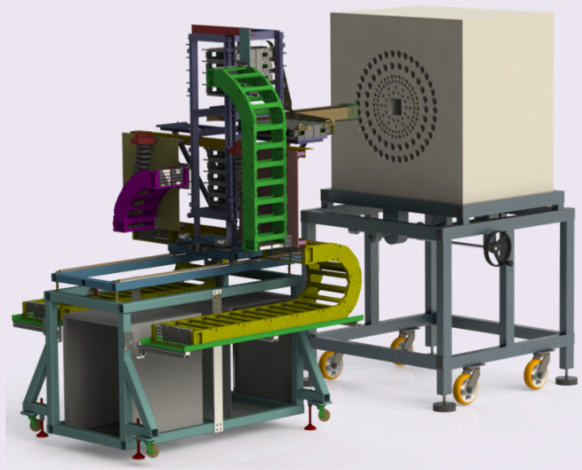


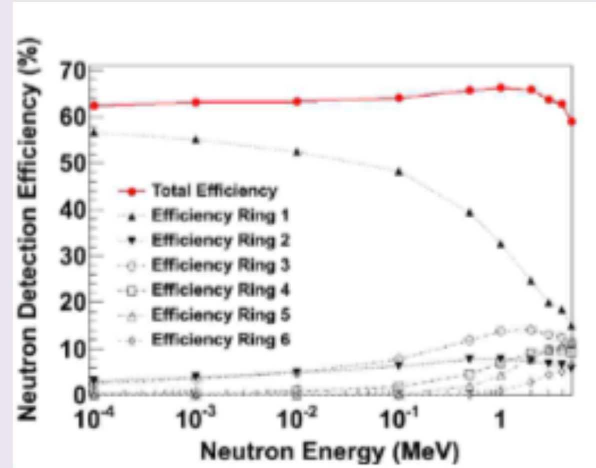
- RAS: Rudstam et al., ADNDT 53 (1993) 1
- PKN:Pfeiffer et al., Prog.Nuc.Ene. 41 (2002) 39
- KTUY-GT2:H. Koura, T. Tachibana, M. Uno, and M. Yamada, Prog. Theor. Phys. 113, 305 (2005).
- RHB-RQRPA: Marketin PHYSICAL REVIEW C 93, 025805 (2016)
- FRDM-QRPA: Moeller et al., PRC67(03)55802

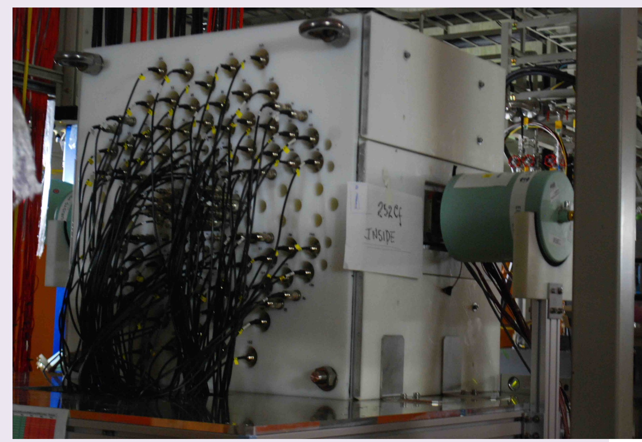
P_n%	This Work	PKM	RAS	FRDM-QRPA	KTUY+GT2	RHB-RQRPA
^{135}Sb	24.5(9)	22.0(27)	21.0(11)	31.71	28.03	4.4
^{138}I	4.98(18)	5.17(36)	5.56(22)	2.39	3.62	0.6
^{139}I	9.27(33)	10.8(12)	10.3(4)	22.84	10.48	1.5
^{140}I	7.60(28)	**14.4(63)**	9.2(6)	32.46	10.17	1.3
^{137}Te	2.6(3)	2.86(24)	3.04(16)	5.08	0.41	0.4
^{138}Te	4.8(23)	6.3(21)	6.3(21)	1.5	0.79	0.6

Next step: BRIKEN









- **The largest moderated neutron detector for beta-delayed neutrons**
- **The AIDA implantation detector**
- **BigRIPS spectrometer @ RIKEN**
- **Nov 2016 First commissioning in beam**

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Conclusions

- More accurate measurements for ^{135}Sb and $^{138\ 139\ 140}I$.
- Improve for the badly known $T_{1/2}$ and P_n of ^{138}Te
- We failed to measure 137Sb we planed to do in the future.
- Good test and training for the upcoming biggest ^{3}He array -> BRIKEN

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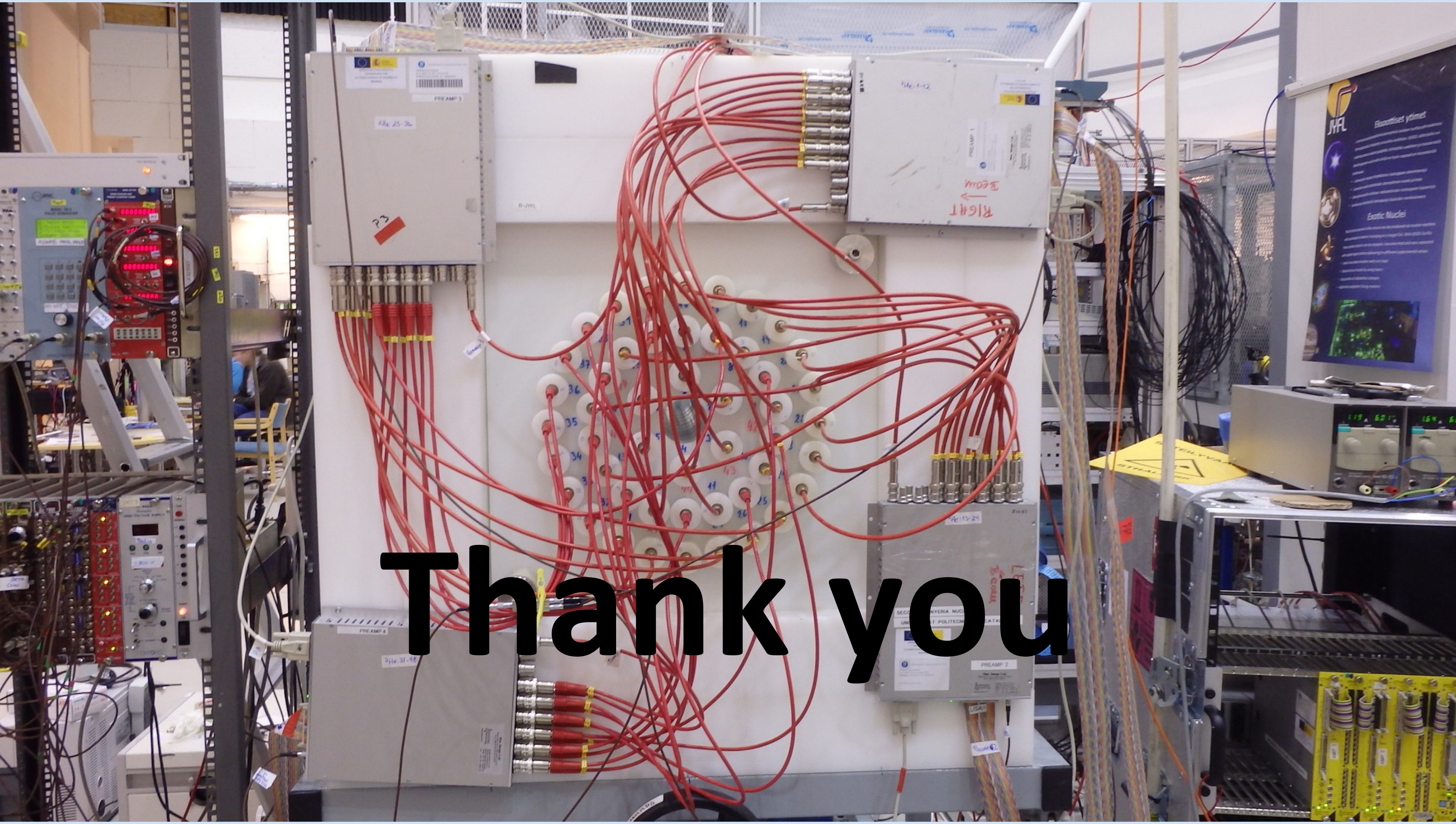

Thank you