Analysis of ^{102}Tc, ^{104}Tc, ^{105}Tc, ^{106}Tc, ^{107}Tc, ^{105}Mo and ^{101}Nb measurements

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Outline

- High priority request list
- Experiment
  - Experimental technique
  - Experimental setup
- Analysis of the data
- Results
- Conclusions

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High priority request list

Radionuclide	Priority	Radionuclide	Priority	Radionuclide	Priority
35-Br-86	1	41-Nb-99	1	52-Te-135	2
35-Br-87	1	41-Nb-100	1	53-I-136	1
35-Br-88	1	41-Nb-101	1	53-I-136m	1
36-Kr-89	1	41-Nb-102	2	53-I-137	1
36-Kr-90	1	42-Mo-103	1	54-Xe-137	1
37-Rb-90m	2	42-Mo-105	1	54-Xe-139	1
37-Rb-92	2	43-Tc-102	1	54-Xe-140	1
38-Sr-89	2	43-Tc-103	1	55-Cs-142	3
38-Sr-97	2	43-Tc-104	1	56-Ba-145	2
39-Y-96	2	43-Tc-105	1	57-La-143	2
40-Zr-99	3	43-Tc-106	1	57-La-145	2
40-Zr-100	2	43-Tc-107	2		
41-Nb-98	1	51-Sb-132	1		

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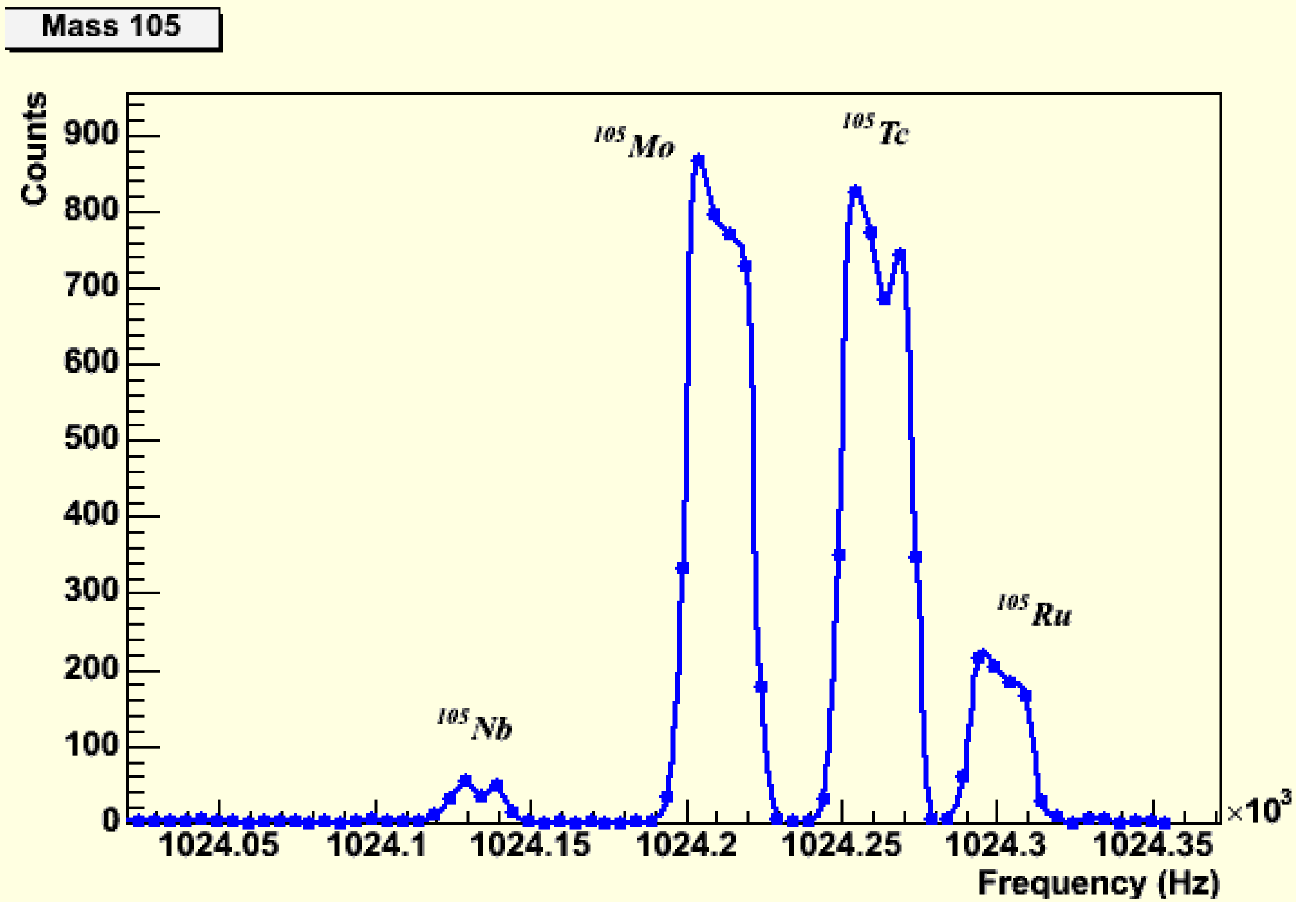
The experiment

- *Ion Guide Isotope Separator On-Line* (IGISOL) facility, University of Jyväskylä (Finland).
- Use of the *JFL TRAP* as a high resolution separator (first time that this kind of setup was used combined with a TAS)

JFLTRAP mass resolution



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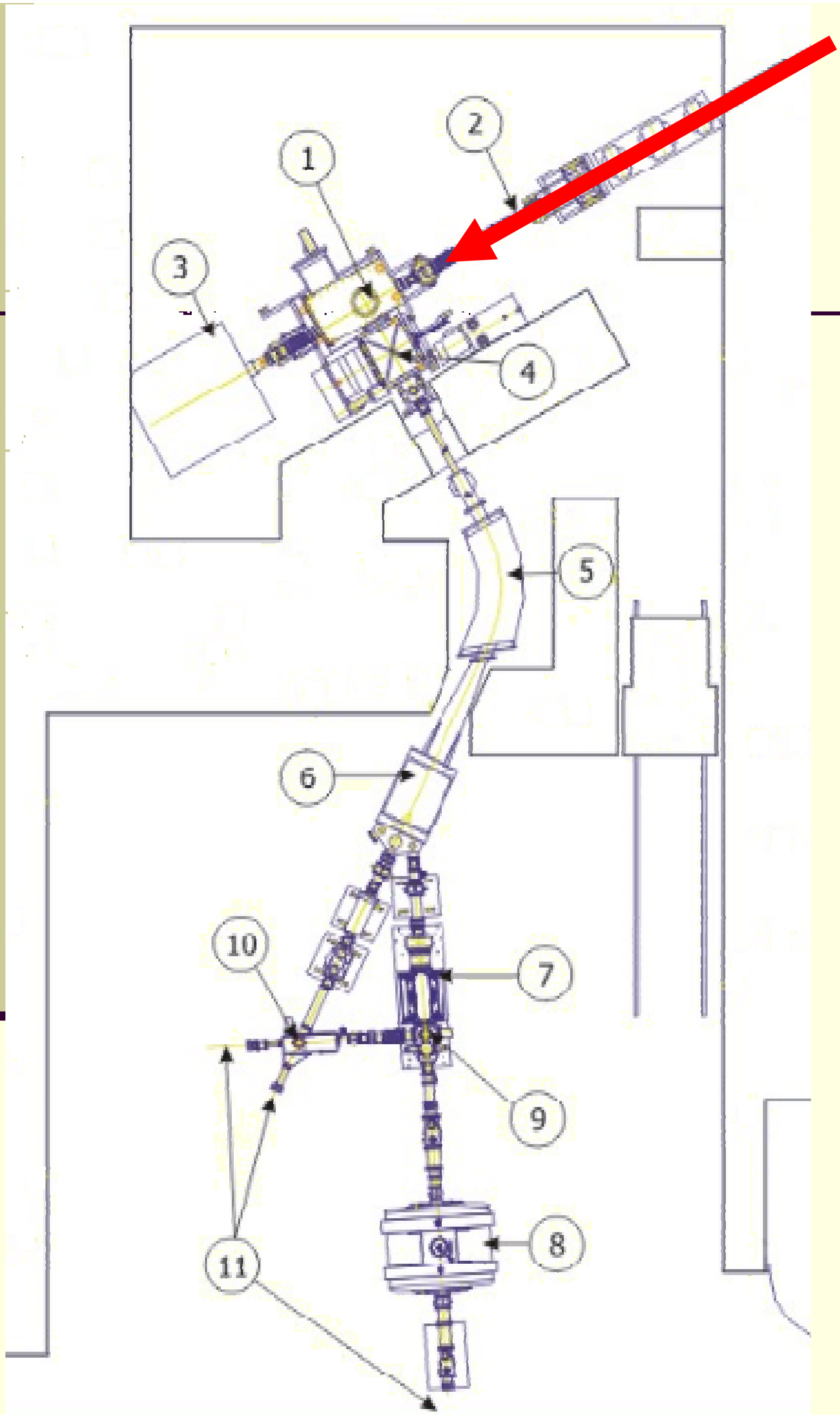
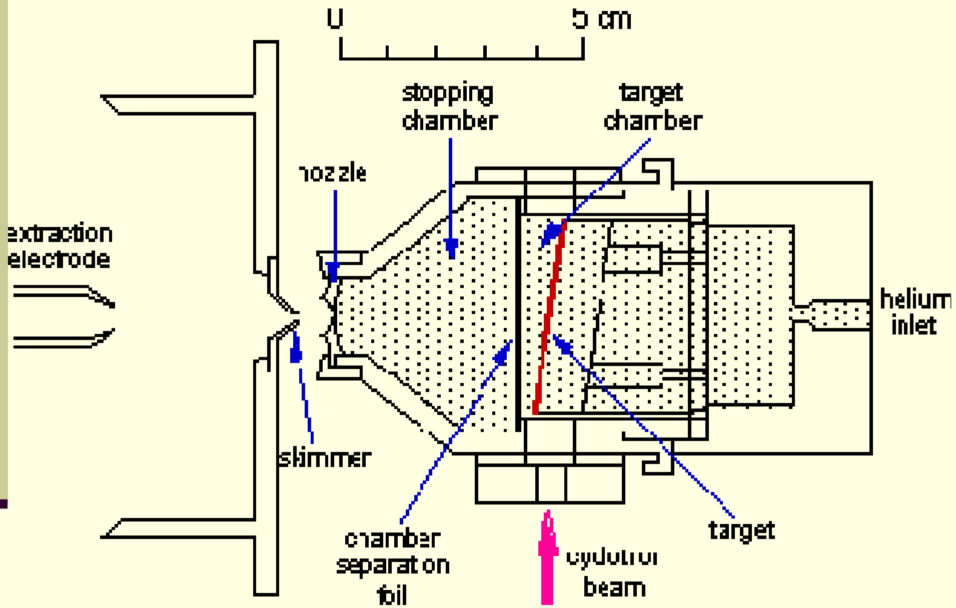


IGISOL layout

1) Ion guide
2) K130 cyclotron beamline
3) Beam dump
4) Acceleration chamber
5) Dipole magnet
6) Switchyard
7) RFQ cooler
8) Tandem penning trap
9) Miniquadrupole deflector
10) Electrostatic deflector and beamline to upstairs
11) Experimental setups

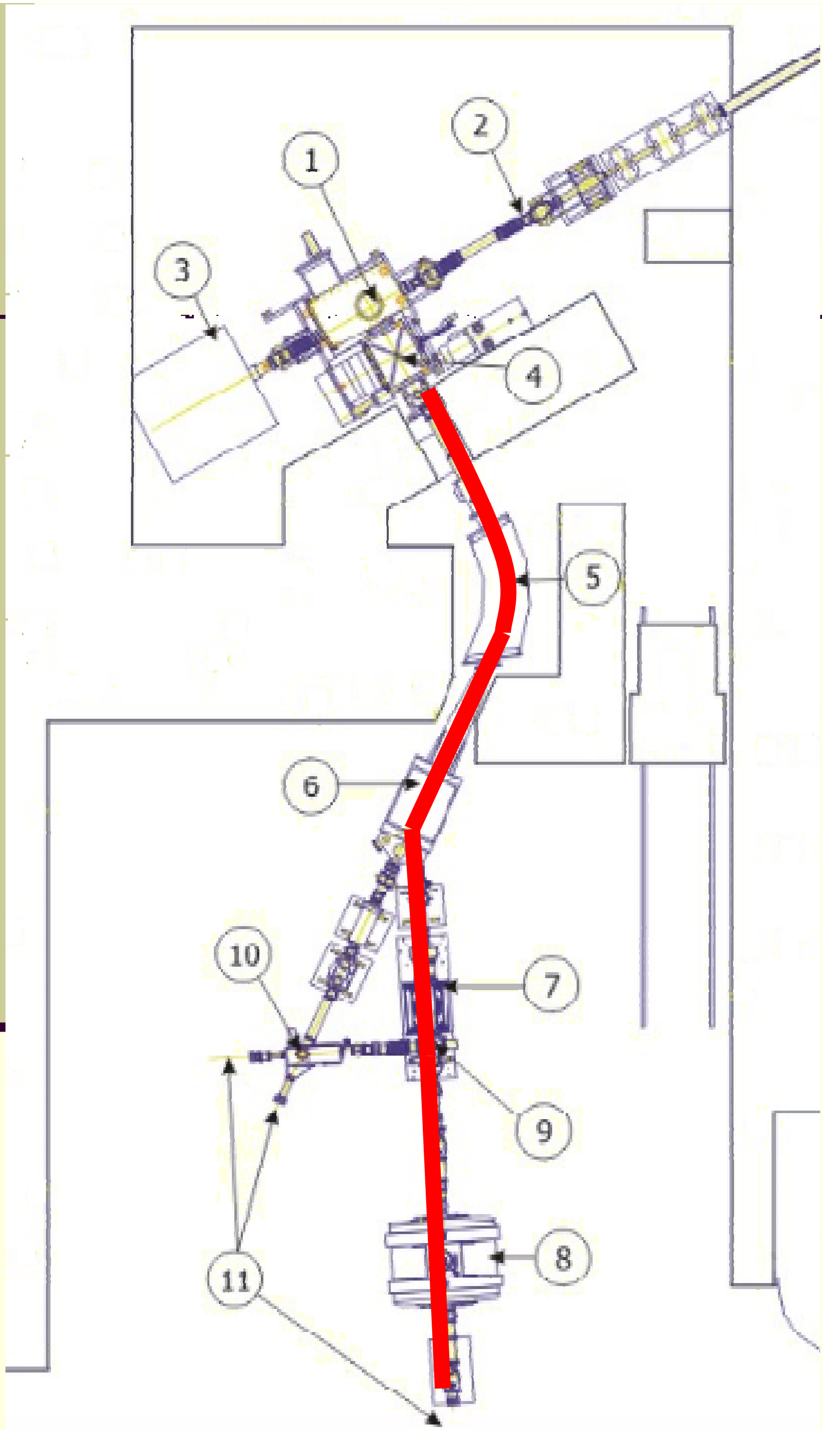
Some details…



- Fission Ion guide: 2700 ions/s per mb, eff. of 1.6×10^{-4} relative to the production in the target

Details of our experiement:

- Beam: 30 MeV proton (4 μA)
- Target: natural U
- Target thickness: 15 mg/cm^2
- Target dimensions: 10x50 mm, tilted 7 degrees



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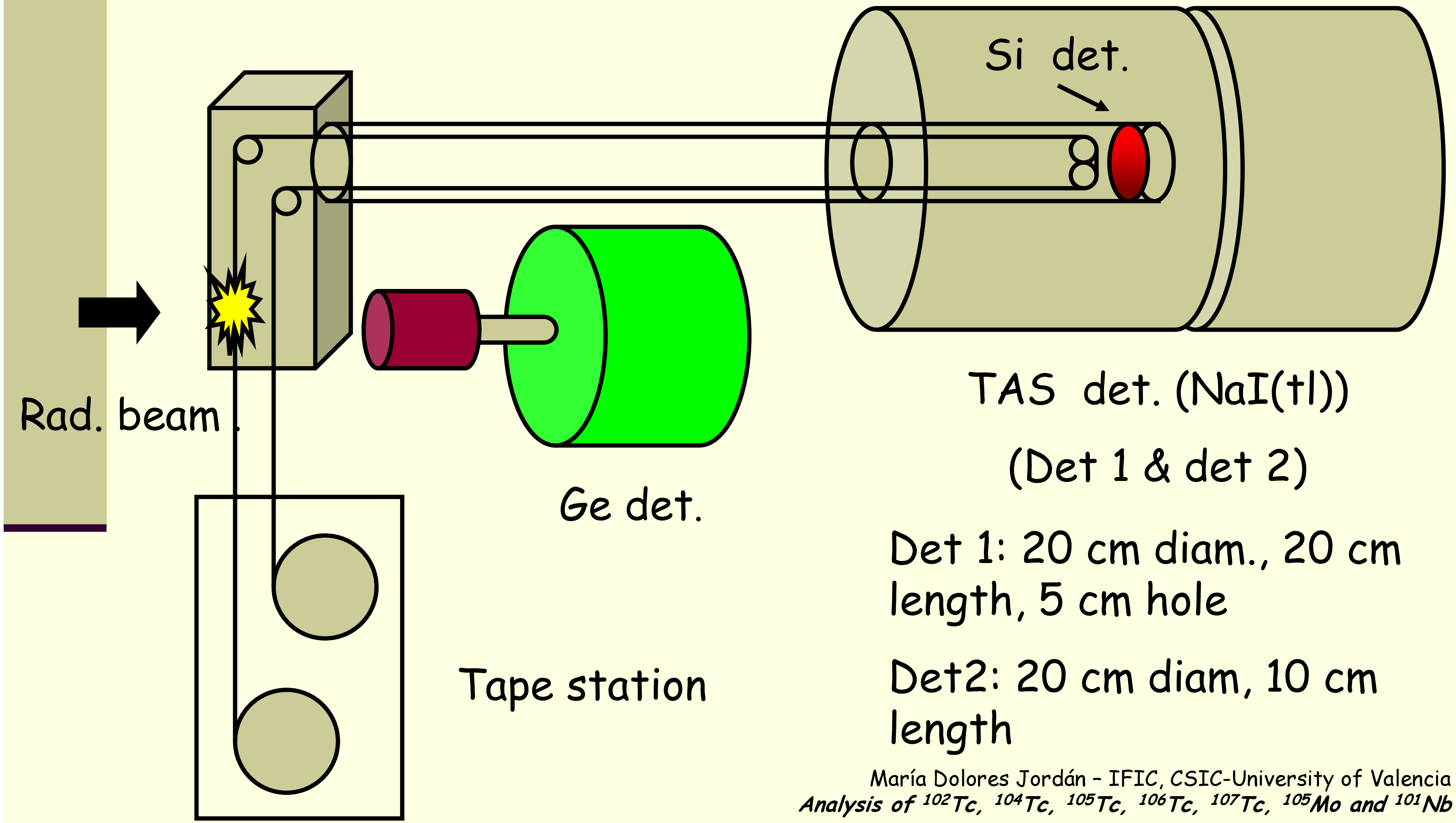
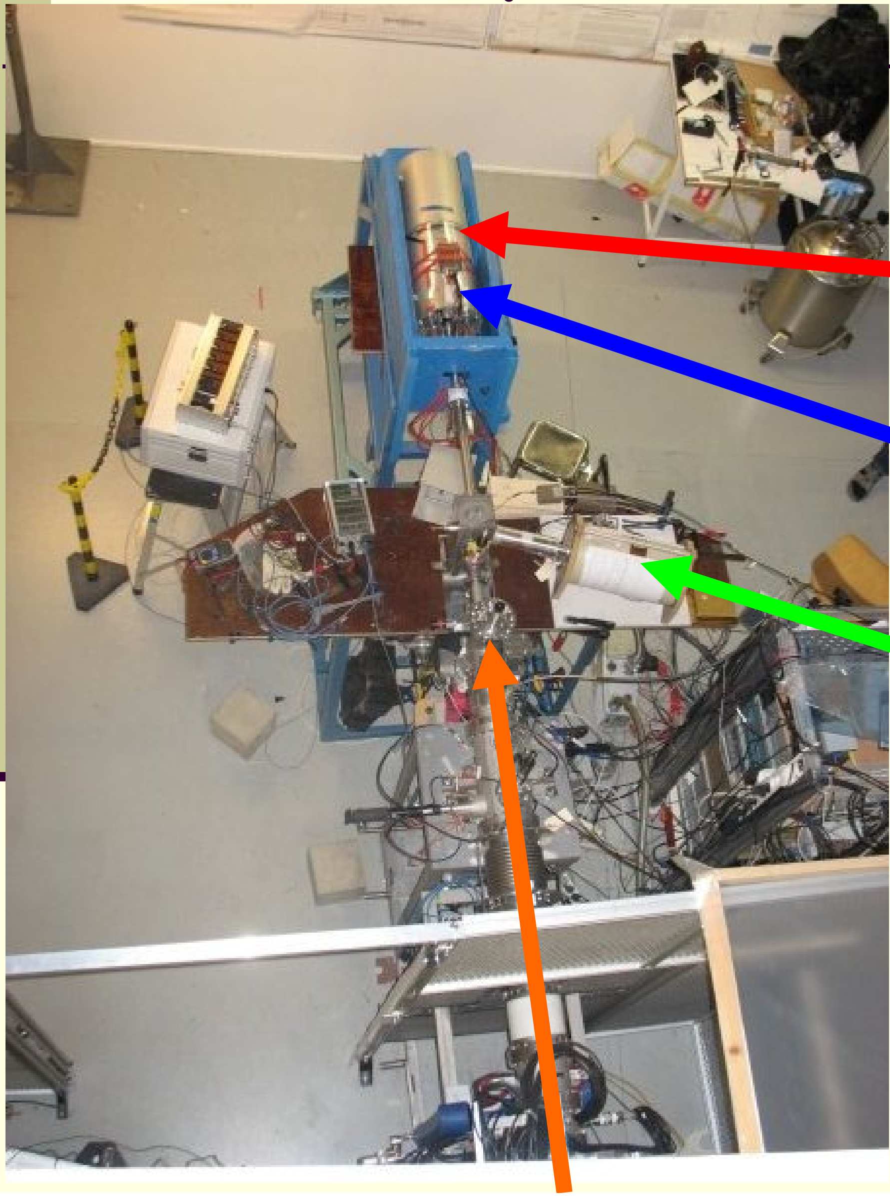
Our experimental setup



Det 1: 20 cm diam., 20 cm length, 5 cm hole

Det2: 20 cm diam, 10 cm length

Our experimental setup



Silicon detector
(inside TAS)

TAGS detector

Germanium detector

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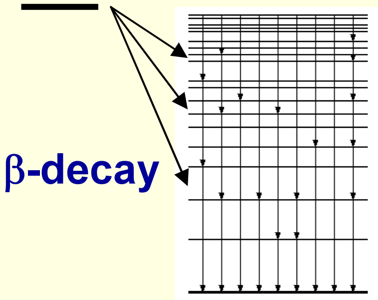
Analysis of the data



$$d_i = \sum_j R_{ij} f_j \quad or \quad \mathbf{d} = \mathbf{R} \cdot \mathbf{f}$$

R is the response function of the spectrometer,

$\boldsymbol{R_{ij}}$ means the probability that feeding at a level ***j***

gives counts in data channel ***i of the spectrum***

- Level scheme:
  - For low energies: high resolution measurements from databases
  - For unknown part: statistical model (level densities, strength function)
- Response for β and γ: Monte Carlo simulation

Analysis of the data

$$d_i = \sum_j R_{ij} f_j \quad or \quad \mathbf{d} = \mathbf{R} \cdot \mathbf{f}$$

- Analysis techniques:
  - J.L. Taín, D. Cano-Ott, Nucl. Instr. And Meth. A 571 (2007) 728
  - D. Cano-Ott, J.L. Taín, A. Gadea, B. Rubio, L. Batist, M. Karny, E. Roeckl, Nucl. Instr. And Meth. A 430 (1999) 333

Expectation Maximization (EM) method:
• modify knowledge on causes from effects

$$P(f_j | d_i) = \frac{P(d_i | f_j) P(f_j)}{\sum_j P(d_i | f_j) P(f_j)}$$

Algorithm: $$f_j^{(s+1)} = \frac{1}{\sum_i R_{ij}} \sum_i \frac{R_{ij} f_j^{(s)} d_i}{\sum_k R_{ik} f_k^{(s)}}$$

Some relevant data

Isotope	$T_{1/2}$ [s]	Q_β [keV]	Predicted number of levels	Beta intensity to g.s. [%] (HR)	g.s. J^π (Parent) (HR)	g.s. J^π (Daughter) (HR)
^{101}Nb	7.1(3)	4569(18)	4537	40 (13.5 keV)	$(5/2^+)$	$1/2^+$
^{102}Tc	5.28(15)	4532(9)	372	92.9	1^+	0^+
^{104}Tc	1098(18)	5516(6)	2030	----	(3^+)	0^+
^{105}Tc	456(6)	3746(6)	1769	<9	$(3/2^-)$	$3/2^+$
^{105}Mo	35.6(16)	4950(50)	82058	<4	$(5/2^-)$	$(3/2^-)$
^{106}Tc	35.6(6)	6547(11)	68358	----	(1,2)	0^+
^{107}Tc	21.2(2)	4820(90)	44572	22	$(3/2^-)$	$(5/2)^+$

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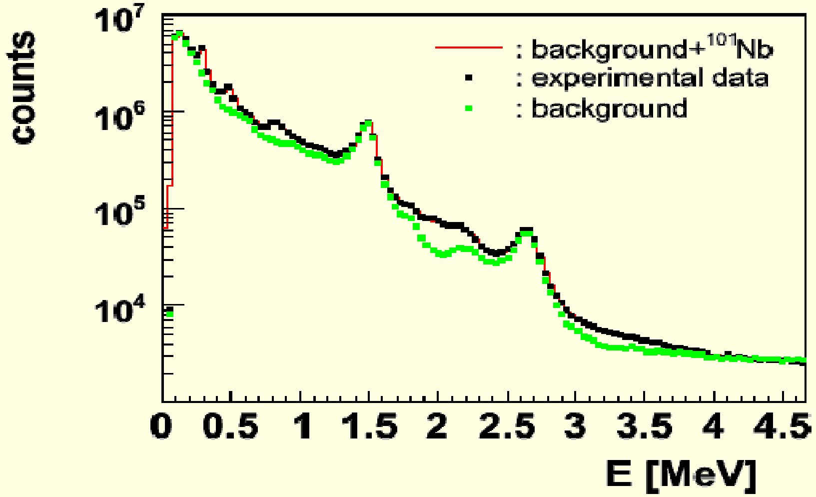
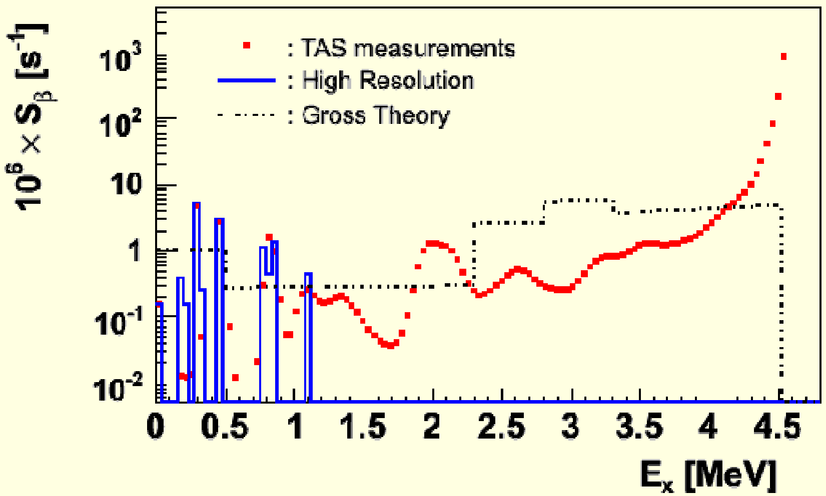
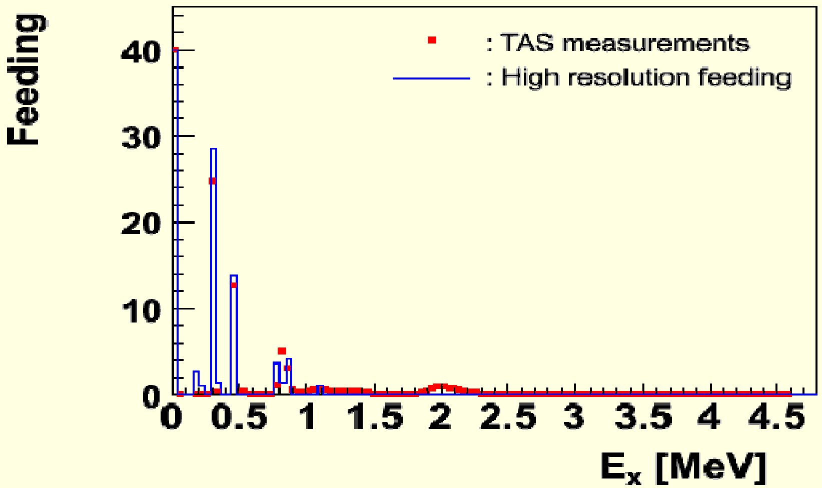
Results for ^{101}Nb







Assumptions:

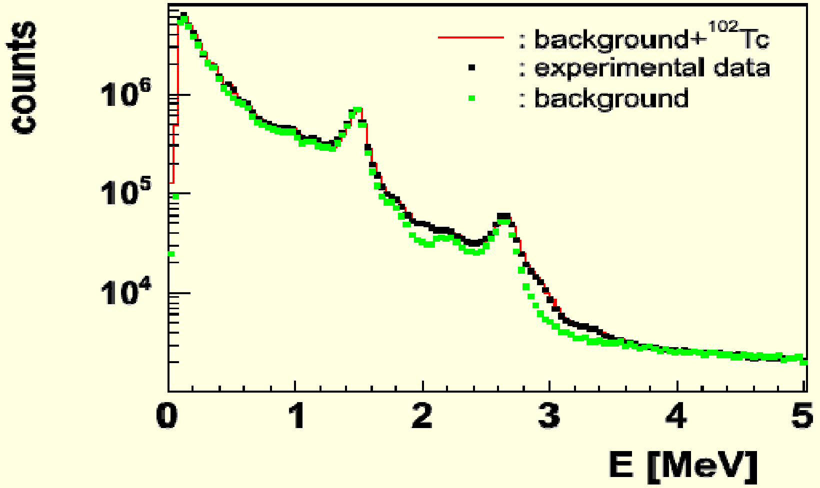
✓ Last known level, 479.78 keV (Q_β = 4569 keV)

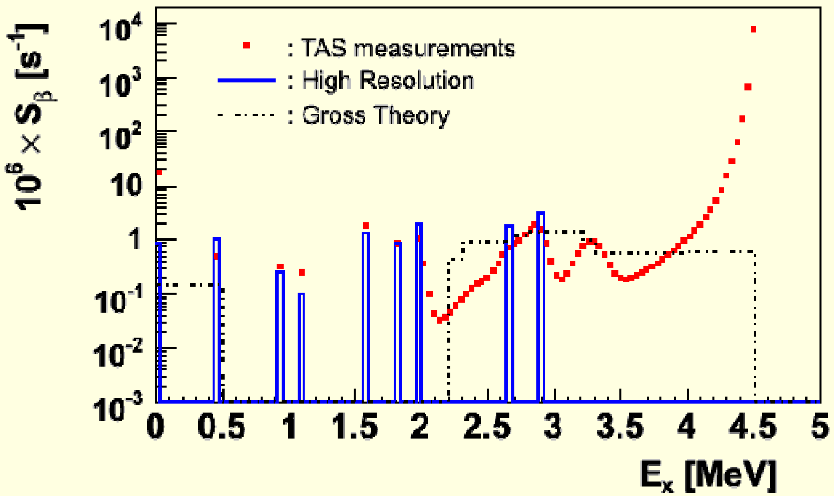
✓ Start unknown part, 520 keV

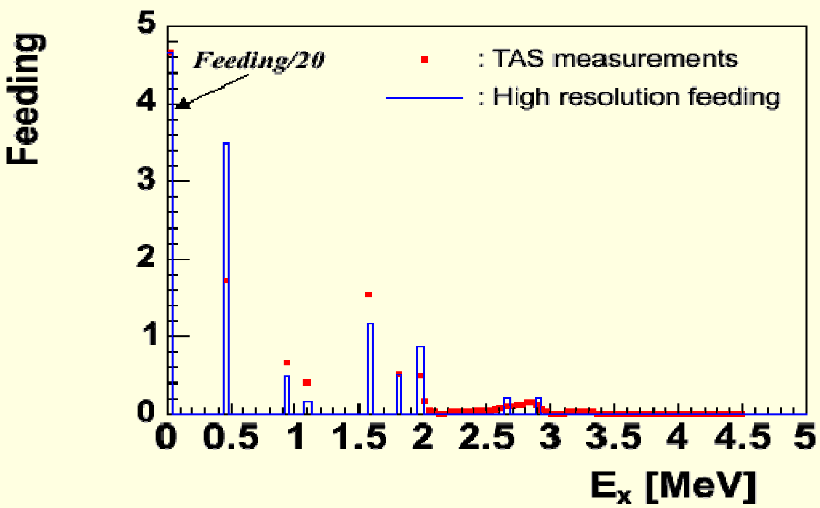
✓ g.s.(p) = $5/2^+$ & g.s(d) = $1/2^+$

✓ 13.5 keV level feeding fixed to 40%

Results for ^{102}Tc







Low production → ^{102}Tc obtained from ^{102}Mo

2 contamination sources: ^{102}Mo + background

Assumptions:

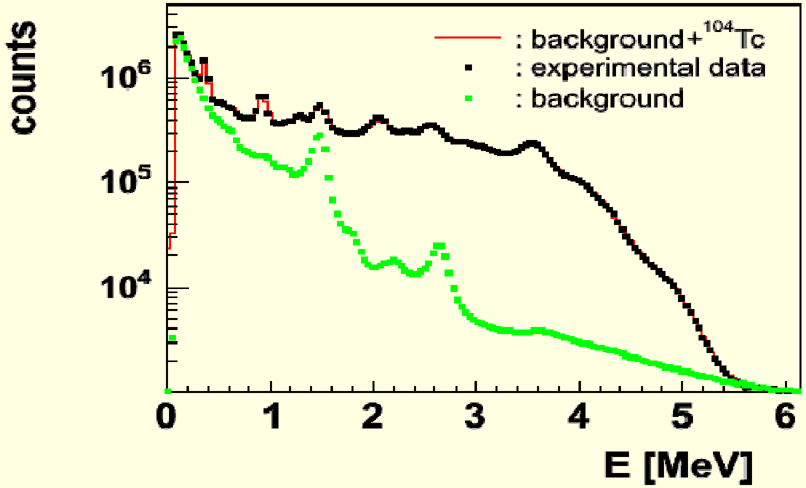
✓ Last known level, 1873.2 keV (Q_β = 4532 keV)

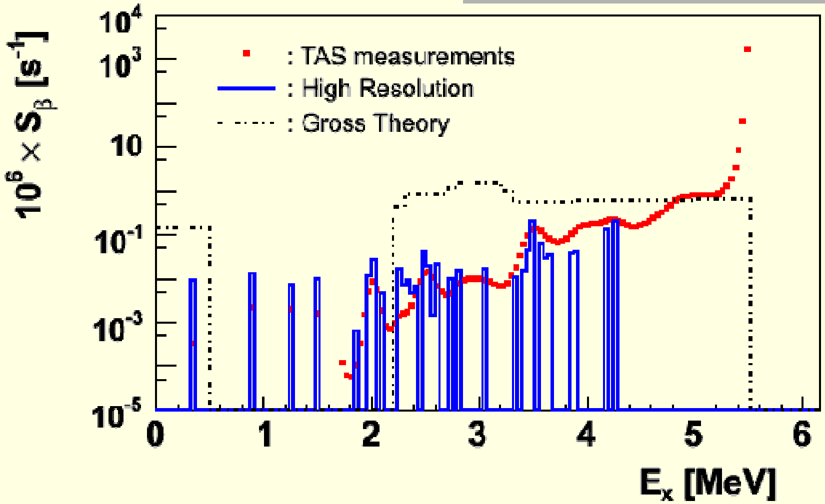
✓ Start unknown part, 1960 keV

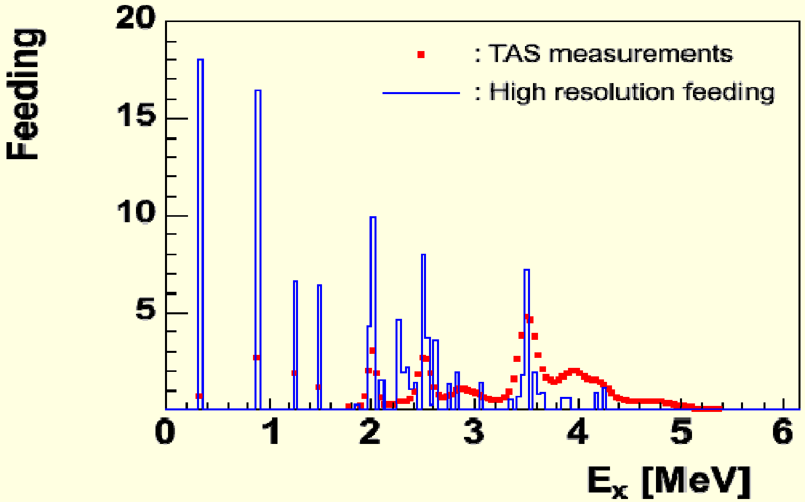
✓ g.s.(p) = 1^+ & g.s.(d) = 0^+

✓ g.s. feeding fixed to 92.9 %

Results for ^{104}Tc







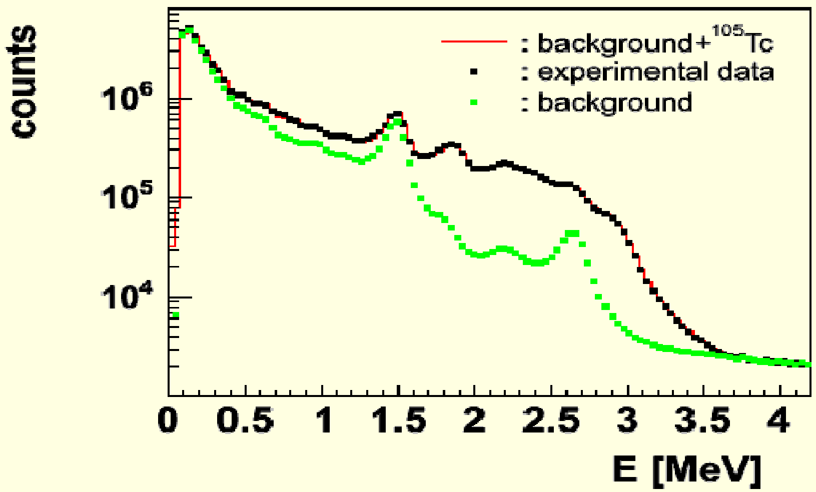
Assumptions:

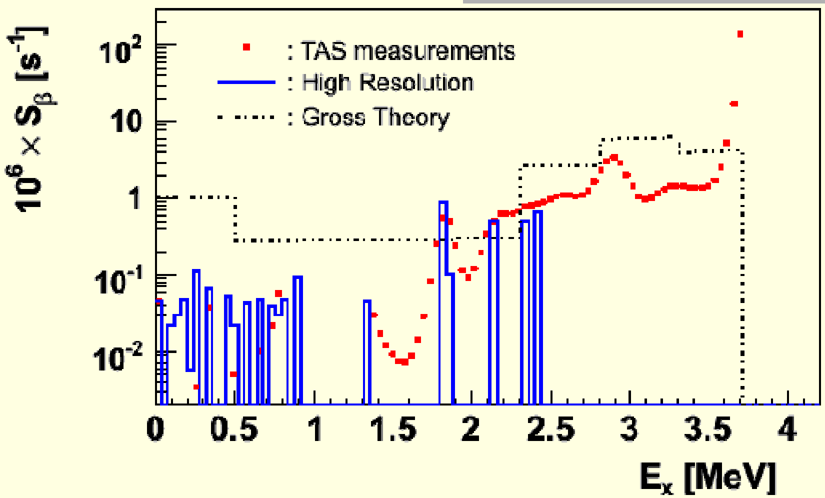
✓ Last known level, 1515.4 keV (Q_β = 5516 keV)

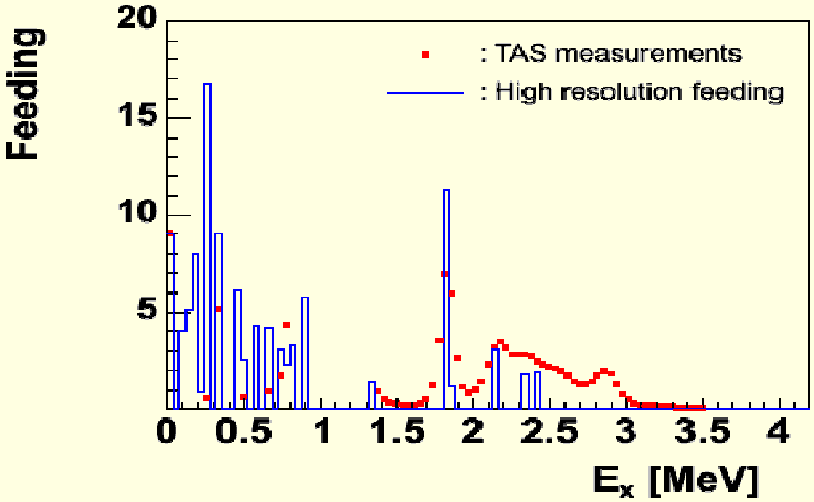
✓ Start unknown part, 1720 keV

✓ g.s.(p) = 3^+ & g.s.(d) = 0^+

Results for ^{105}Tc



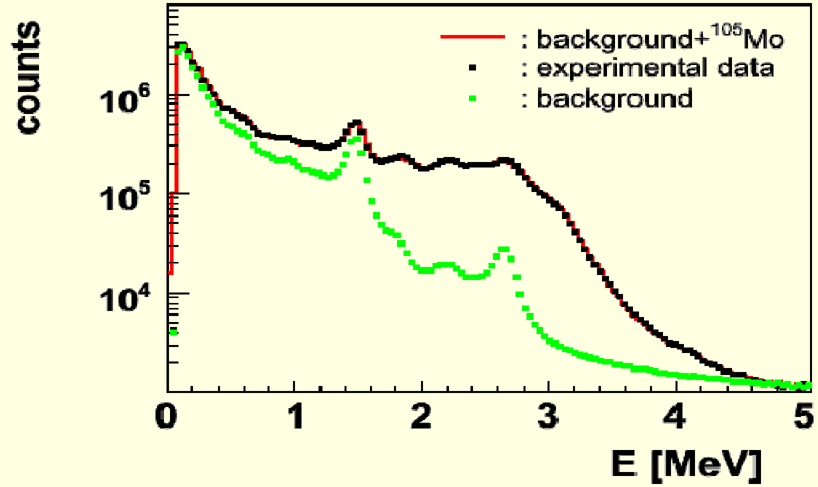


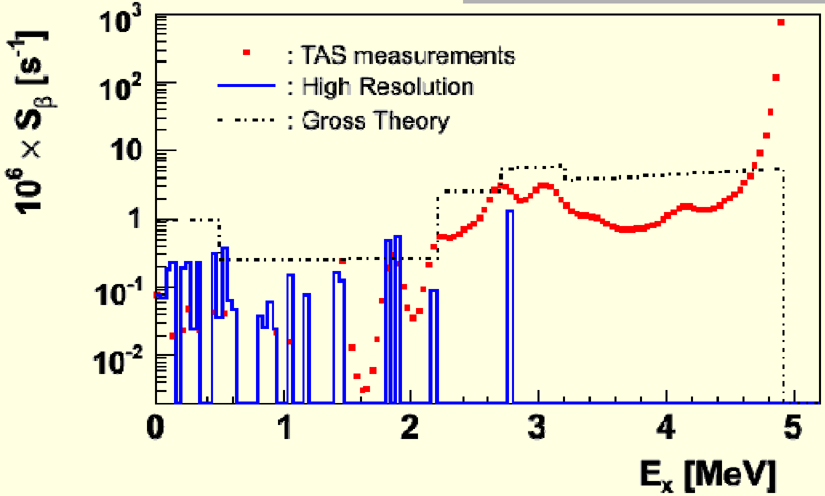


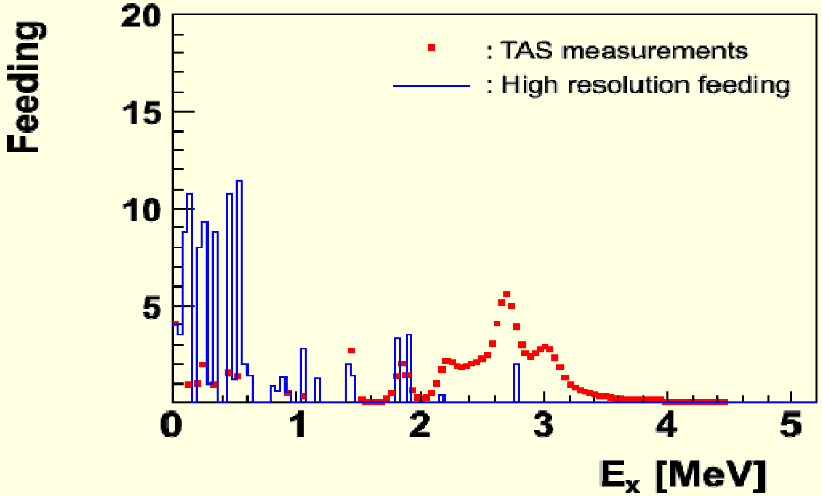
Assumptions:

- ✓ Last known level, 1325.5 keV (Q_β = 3746 keV)
- ✓ Start unknown part, 1360 keV
- ✓ g.s.(p) = $3/2^-$ & g.s.(d) = $3/2^+$
- ✓ g.s. feeding fixed to 9 %

Results for ^{105}Mo







Assumptions:

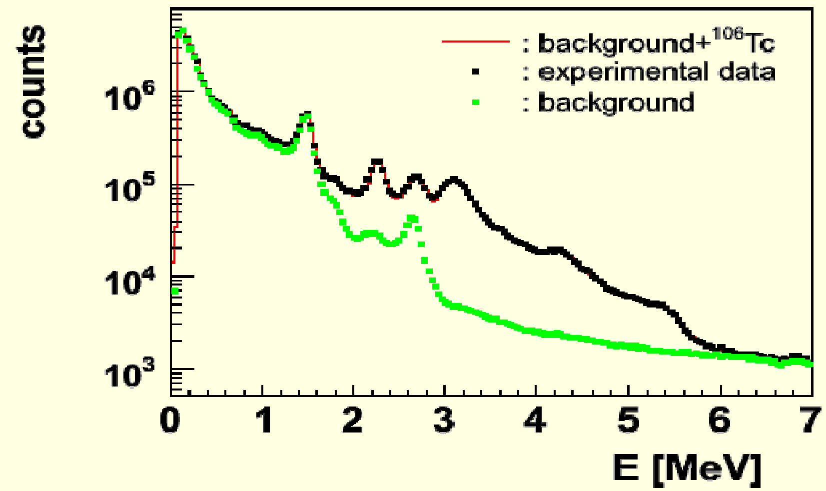
✓ Last known level, 1476.37 keV (Q_β = 4950 keV)

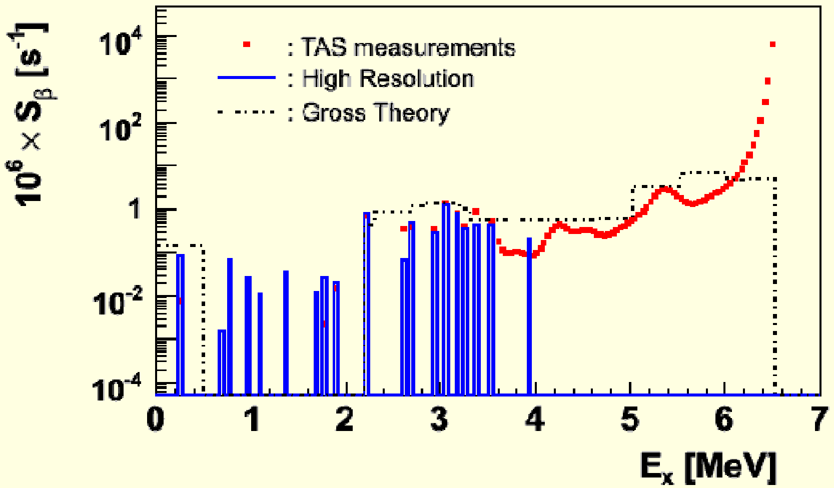
✓ Start unknown part, 1520 keV

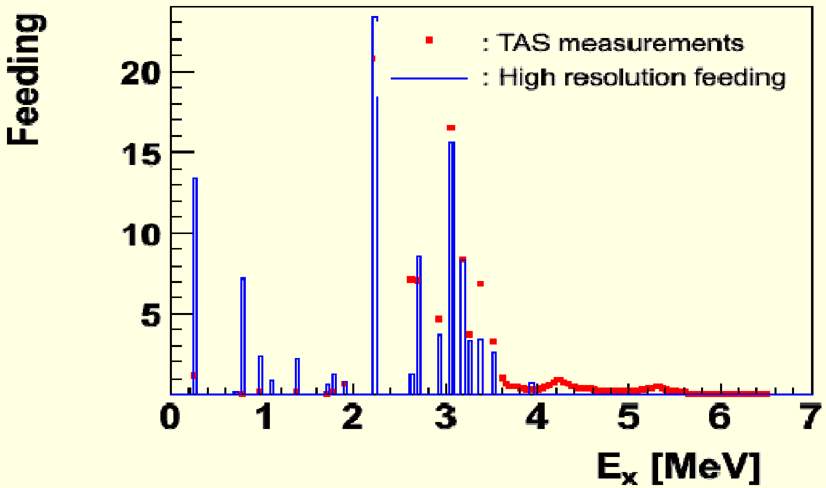
✓ g.s.(p) = $5/2^-$ & g.s.(d) = $3/2^-$

✓ g.s. feeding fixed to 4 %

Results for ^{106}Tc







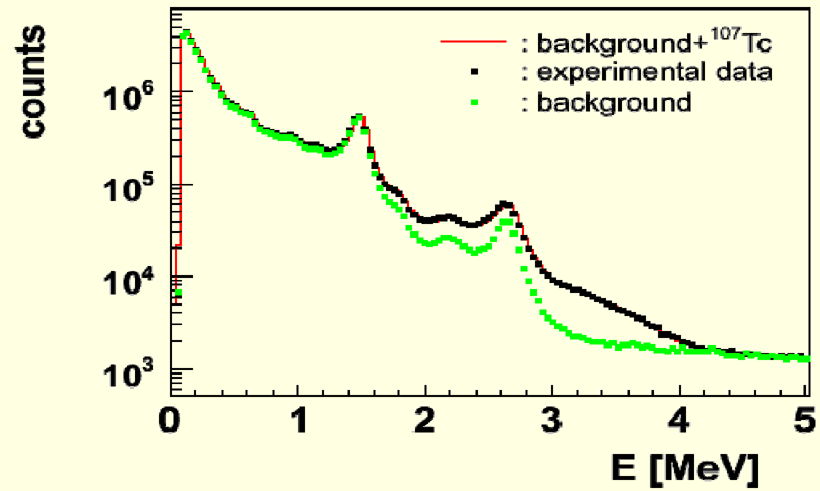
Assumptions:

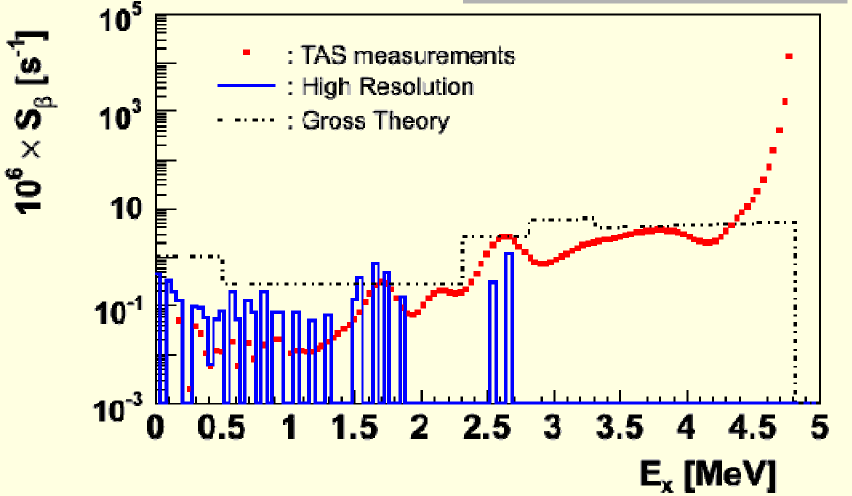
✓ Last known level, 3550.98 keV (Q_β = 6547 keV)

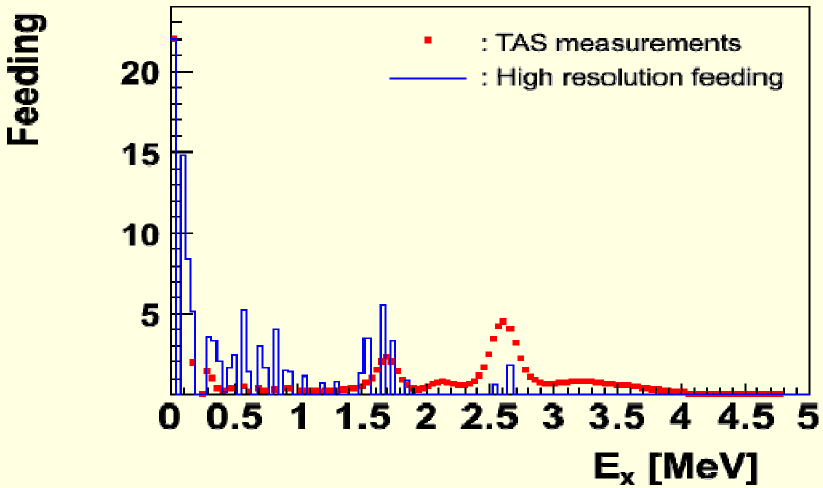
✓ Start unknown part, 3600 keV

✓ g.s.(p) = 1^+ & g.s.(d) = 0^+

Results for ^{107}Tc







Assumptions:

✓ Last known level, 957.09 keV (Q_{β} = 4820 keV)

✓ Start unknown part, 1020 keV

✓ g.s.(p) = 3/2⁻ & g.s.(d) = 5/2⁺

✓ g.s. feeding fixed to 22 %

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In numbers…

Nuclide	Energy Type	ENDF/B-VII (& Jeff 3.1) [keV]	TAS Experiment [keV]	Differences [keV]
^{101}Nb (7.1 s)	beta	1833 (307)	1797	-36
	gamma	244	445	201
^{102}Tc (5.28 s)	beta	1945 (15)	1933	-12
	gamma	81 (10)	110	29
^{104}Tc (1098 s)	beta	1590 (75)	930	-660
	gamma	1890 (30)	3229	1339
^{105}Tc (456 s)	beta	1310 (173)	764	-546
	gamma	668 (19)	1825	1157
^{105}Mo (35.6 s)	beta	1902 (122)	1076	-826
	gamma	548	2347	1799
^{106}Tc (35.6 s)	beta	1938 (69)	1463	-475
	gamma	2190	3119	929
^{107}Tc (21.2 s)	beta	2030 (254)	1276	-754
	gamma	511	1795	1284

Energies

$$E_\beta = \sum_i r(E_i)\frac{f_\beta(-E_i)}{f_0(-E_i)} \qquad E\gamma = \sum_i r(E_i)(Q_\beta + E_i)$$

$$f_\beta(-E) = \int_1^{-E/\ mc^2+1} mc^2 (E_0 - 1)\, pE_0 \left(\frac{-E}{mc^2} + 1 - E_0\right)^2 F(Z_d, E_0)\, dE_0$$

$$r(E_i) = \frac{I_\beta(E_i)}{\sum_i I_\beta(E_i)}$$

Results of the analysis for ^{102}Tc