Overview of ongoing/planned TAS measurements

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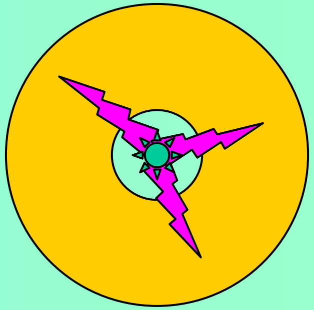
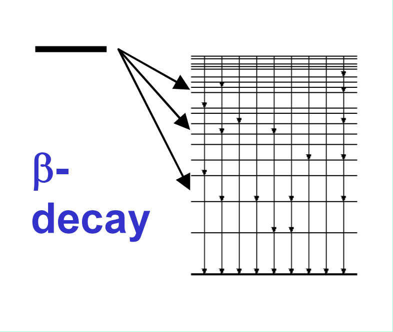
The TAS technique



• Total Absorption Spectroscopy is the best method to measure beta intensities/strengths for complex decay schemes

• Avoids the "Pandemonium effect" (displacement of β-intensity to low E_x) of the high resolution spectroscopy



Relation between β-strength S_β and β-intensity I_β:

$$S_i = \frac{I_i}{f(Q_\beta - E_i)T_{1/2}}$$

The importance of I_β / S_β

• It is a characteristic and basic property of the nuclei

• It is (very) sensitive to the nuclear wave function

→ we can learn about nuclear structure

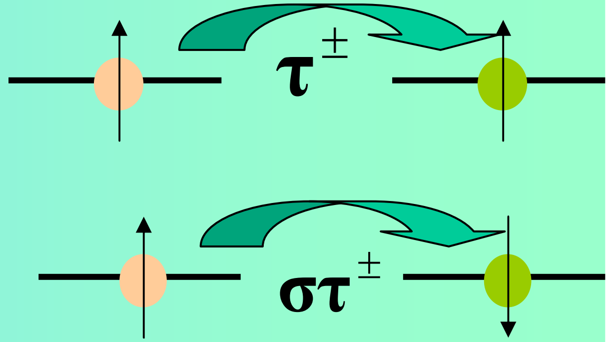
• Decay γ-ray, β-ray and ν distributions can be deduced

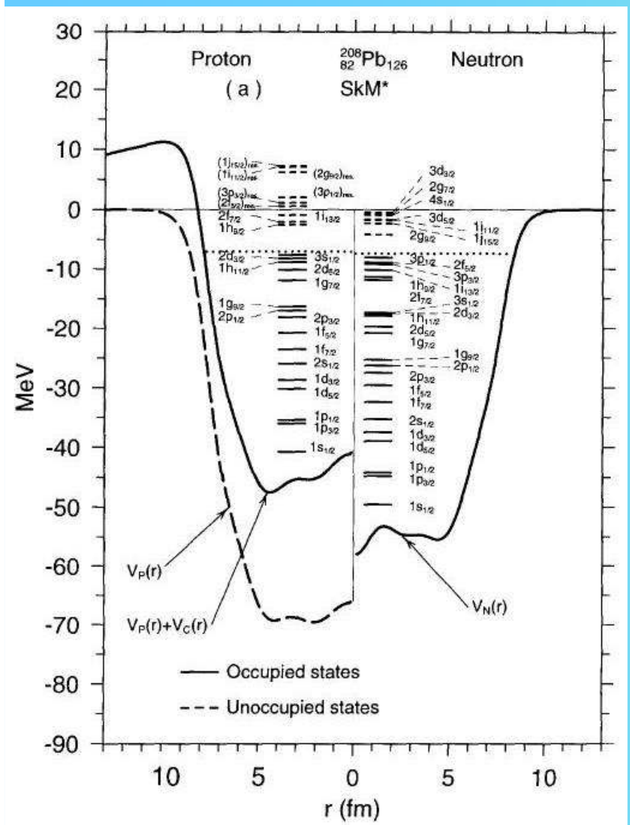
An accurate knowledge of the distribution of the β-decay probability over the daughter-nucleus levels provides information for the understanding of the structure of nuclei of importance on its own or for other fields as astrophysics

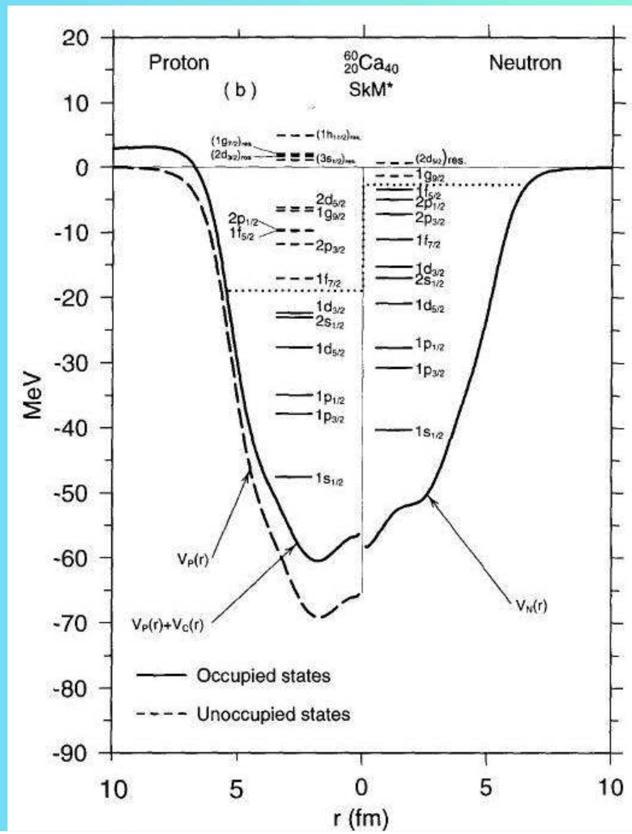
- **Basic process: simple and sensitive to the wave function**

Fermi / Gamow-Teller

$$\left|\left\langle \Psi_f \right| \tau^{\pm} \; or \; \sigma\tau^{\pm} \left| \Psi_i \right\rangle\right|^2$$







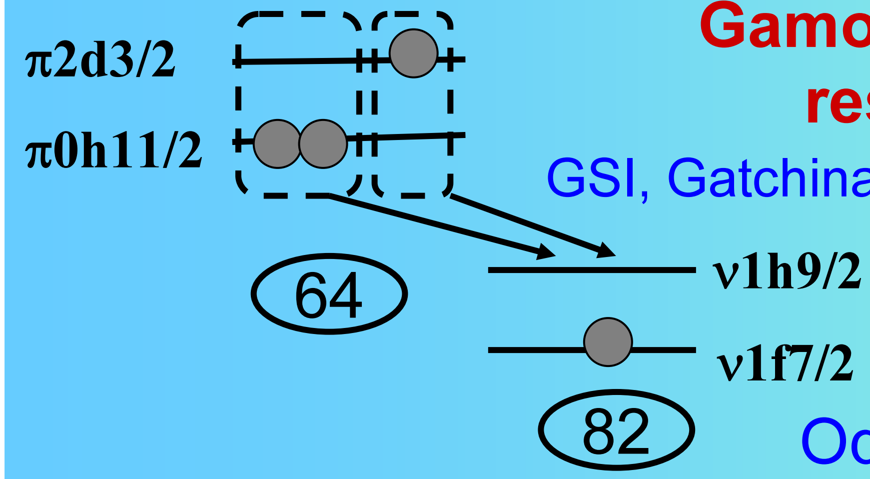
- **In general the bulk of the strength lies outside the Q_β window**

Exception:

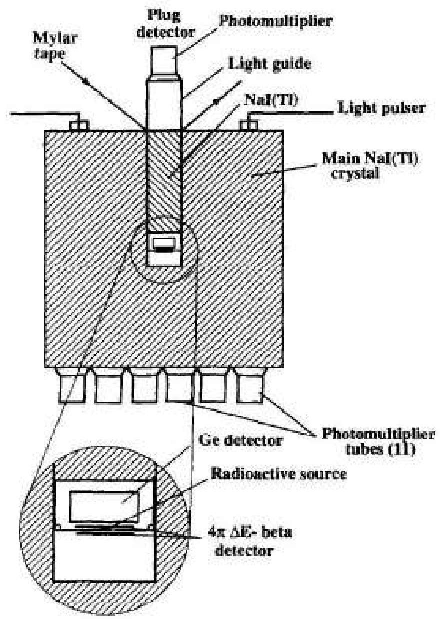
- **β+/EC for A~150, A~100, N~Z**

Gamow-Teller $\sigma\tau^+$ resonance

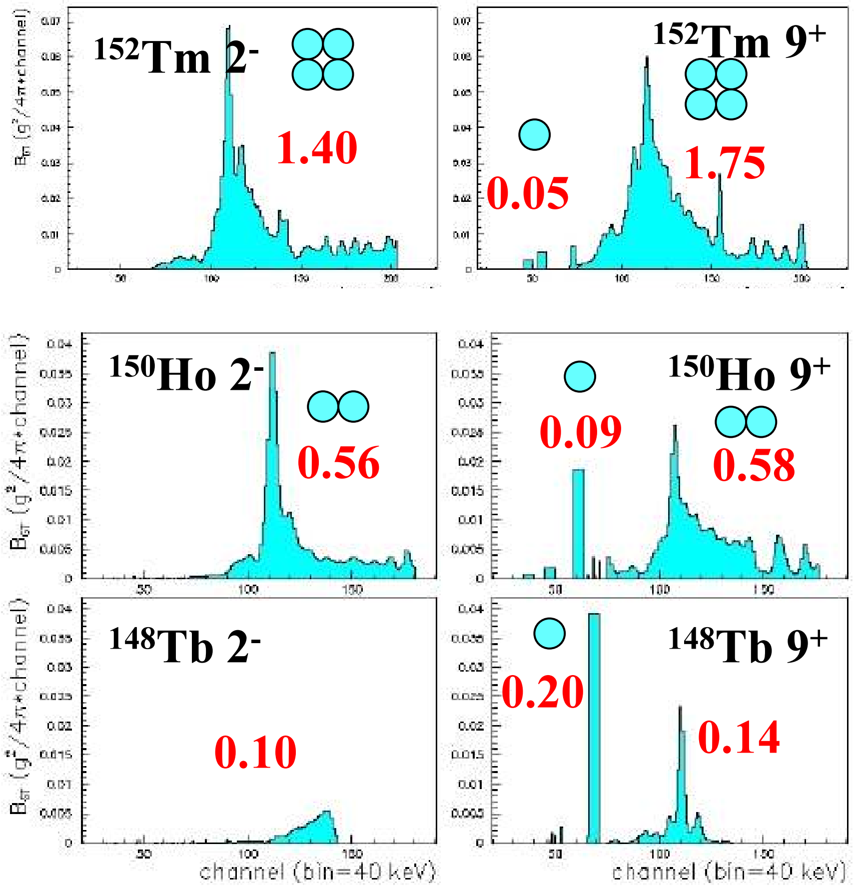
GSI, Gatchina, Valencia, Warsaw

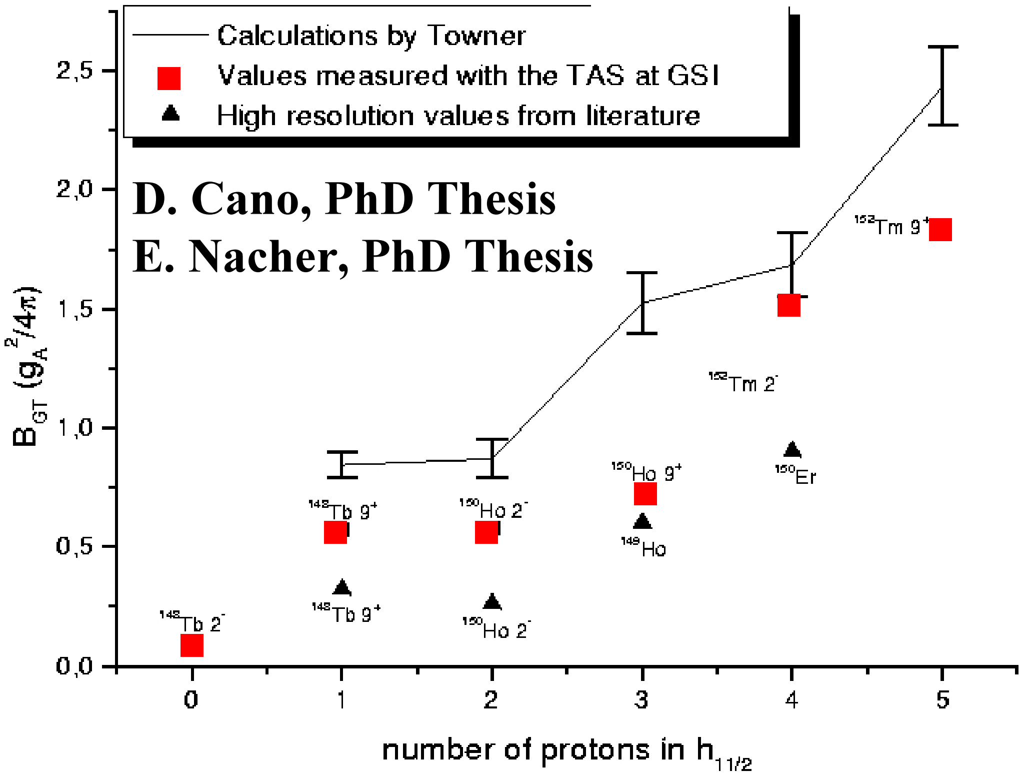


LBL TAS @ GSI



Odd-Odd N=83 nuclei above 146Gd

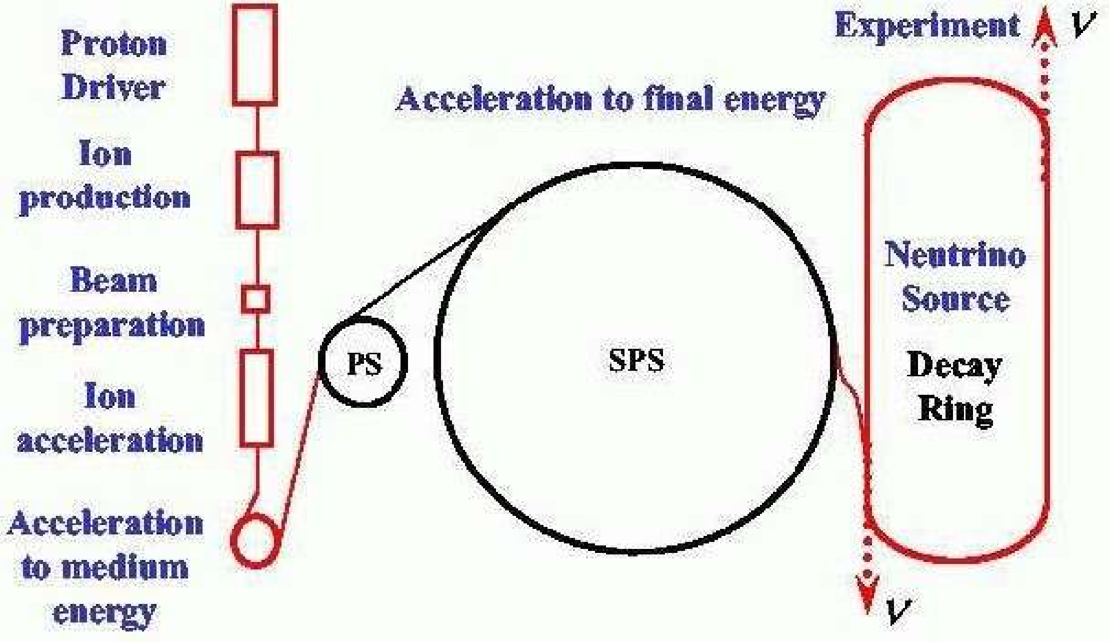




Mono-energetic neutrino beams ("beta beams")

Improved neutrino oscillation experiments exploiting the energy dependence:

$$P(\nu_e \to \nu_\mu) \simeq s_{23}^2 \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{13}^2 L}{4E}\right) + c_{23}^2 \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{12}^2 L}{4E}\right) + $$
$$+ \tilde{J} \cos\left(\delta - \frac{\Delta m_{13}^2 L}{4E}\right) \frac{\Delta m_{12}^2 L}{4E} \sin\left(\frac{\Delta m_{13}^2 L}{4E}\right),$$



- Accelerated (γ~100) and stored β^+/β^- emitters
- variable end-point ν_e and $\bar{\nu}_e$
- **monochromatic ν_e ?**

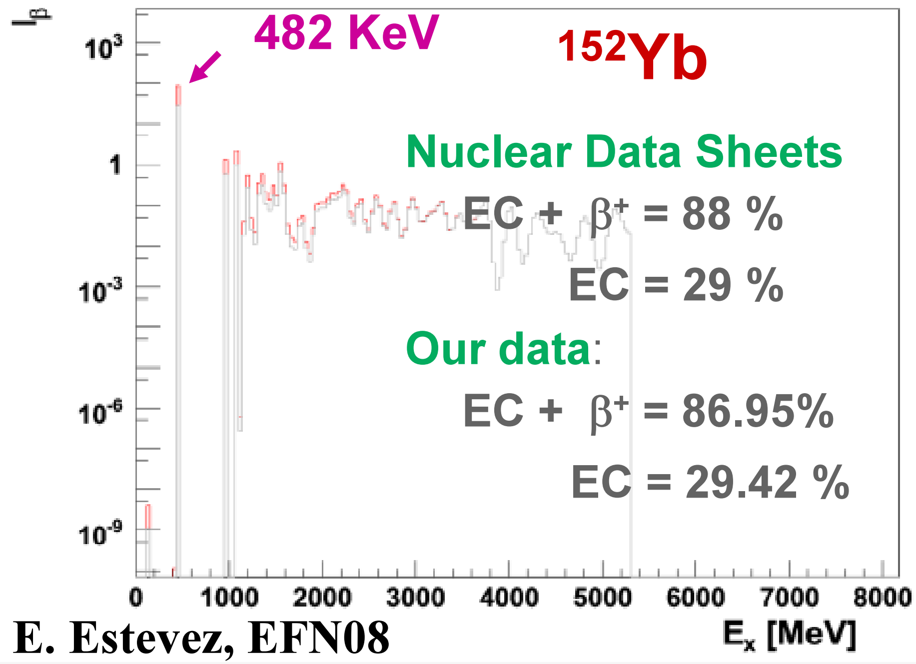
^{146}Gd region

ID	Parent Nucleus	Daugther Nucleus	Half-life	(EC+β^+) / α branch of the decay	EC int. [%] (to the level of interest)	Ex Daugther Level [keV]	I [%]	Q value [keV]	Yield (ISOLDE) [atoms/μC]
1	$^{146}_{66}Dy_{82}$	$^{146}_{65}Tb_{83}$	3.1 m	100*	92.5	620	96	2678	2.9x10^8
2	$^{146}_{68}Er_{80}$	$^{146}_{67}Ho_{81}$	4.6 s	100*	8.8	0.0 (+?)	70 (+?)	6800	-
3	$^{150}_{68}Er_{82}$	$^{150}_{67}Ho_{83}$	18.5 s	100*	59.4*	476+X	99.6	4108	7x10^6
4	~~$^{150}_{66}Dy_{84}$~~	~~$^{150}_{65}Tb_{85}$~~	~~7.17m~~	~~64/36~~	~~64.0*~~	~~397+Y~~	~~64~~	~~1794~~	~~2.4x10^9~~
5	$^{152}_{70}Yb_{82}$	$^{152}_{69}Tm_{83}$	3.1s	100*	29.0	482	88	5470	-
6	$^{152}_{69}Tm_{83}$	$^{152}_{68}Er_{84}$	8s	100*	50	4300	Res.	8700	-
7	$^{152}_{68}Er_{84}$	$^{152}_{67}Ho_{85}$	10.3s	(10/90)	8.0	179.4	10%	3105	7x10^7
8	$^{154}_{72}Hf_{82}$	$^{154}_{71}Lu_{83}$	2s	100*	-	-	-	6700	(Difficult)
9	$^{154}_{70}Yb_{84}$	$^{154}_{69}Tm_{85}$	0.404s	(7.2/92.8)	3.3	133.2	7.2	4490	2x10^3
10	~~$^{154}_{68}Er_{86}$~~	~~$^{154}_{67}Ho_{87}$~~	~~3.73m~~	~~99.53/0.47~~	~~96.8~~	~~26.9~~	~~99.53~~	~~2032~~	~~6x10^8~~
11	$^{156}_{72}Hf_{84}$	$^{156}_{71}Lu_{85}$	25ms	(alpha>81%)	-	-	-	5910	-
12	$^{156}_{70}Yb_{86}$	$^{156}_{69}Tm_{87}$	26.1s	90/10	61.0	115.2	90	3570	3.2x10^7
13	~~$^{156}_{68}Er_{88}$~~	~~$^{156}_{67}Ho_{89}$~~	~~19.5m~~	~~100*~~	~~58 (+38)~~	~~82.1 (+87.5)~~	~~58 (+38)~~	~~1370~~	~~6x10^8~~

EC beam candidates:

- "single" state populated
- large EC/β^+ ratio
- appropriate half life
- small other-radioactivities
- good production

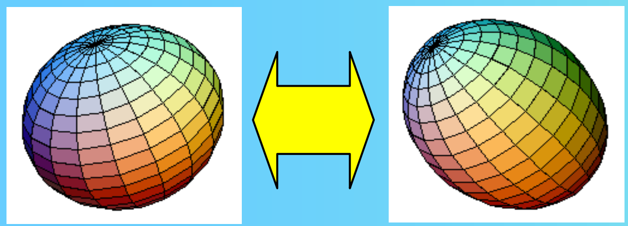
Old LBL TAS @ GSI
data reanalyzed!



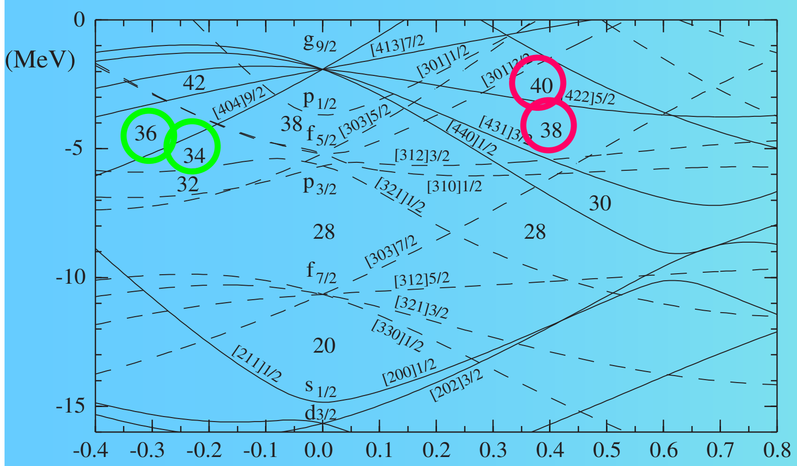
E. Estevez, EFN08

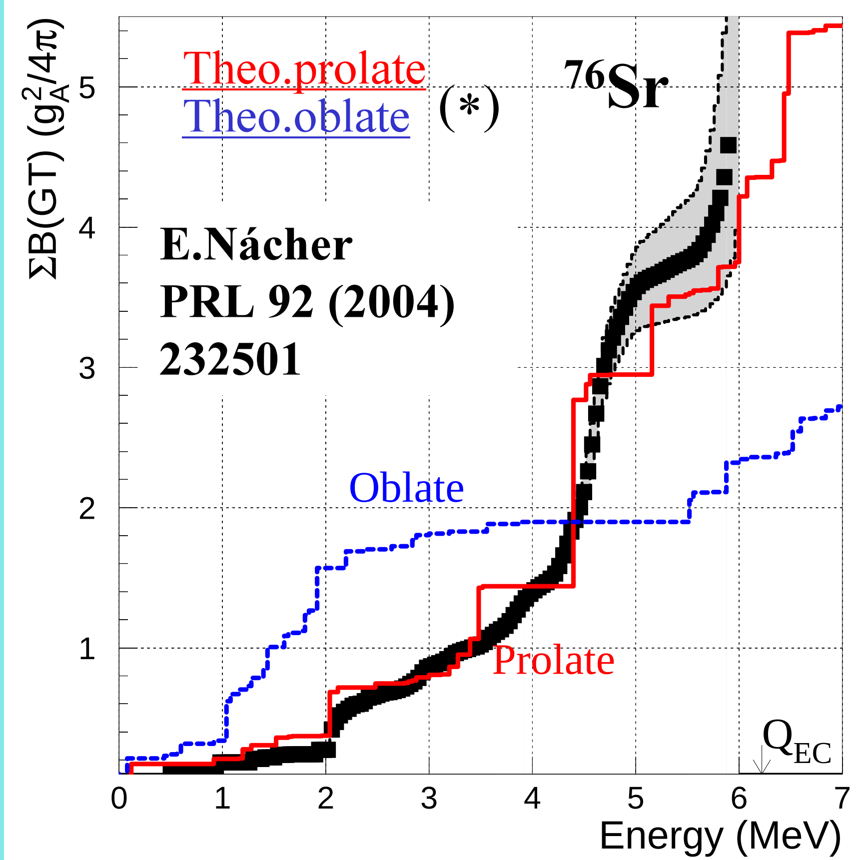
Other candidates to be investigated … ISOLDE?

Oblate-prolate competition



N~Z nuclei with A~70-80

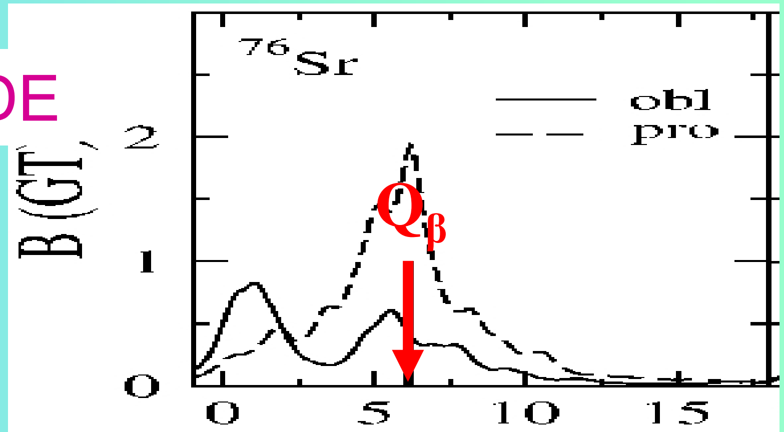




(*) P.Sarriguren et al.NPA 658 (1999)13

Lucrecia @ ISOLDE

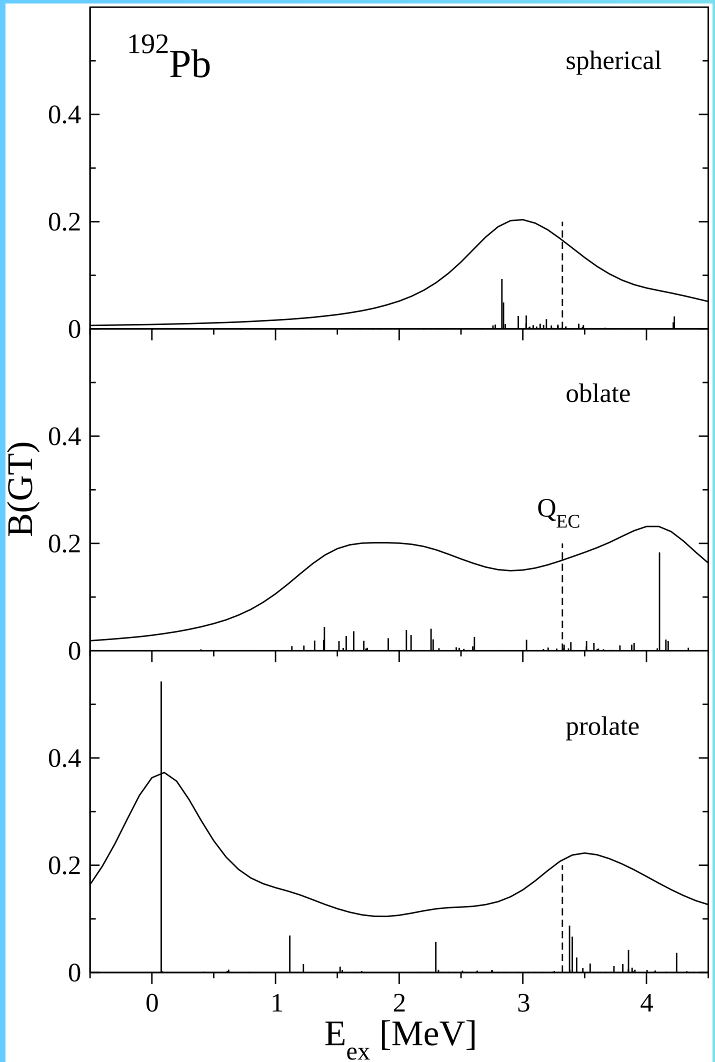
Madrid,
Strasbourg,
Surrey,
Valencia

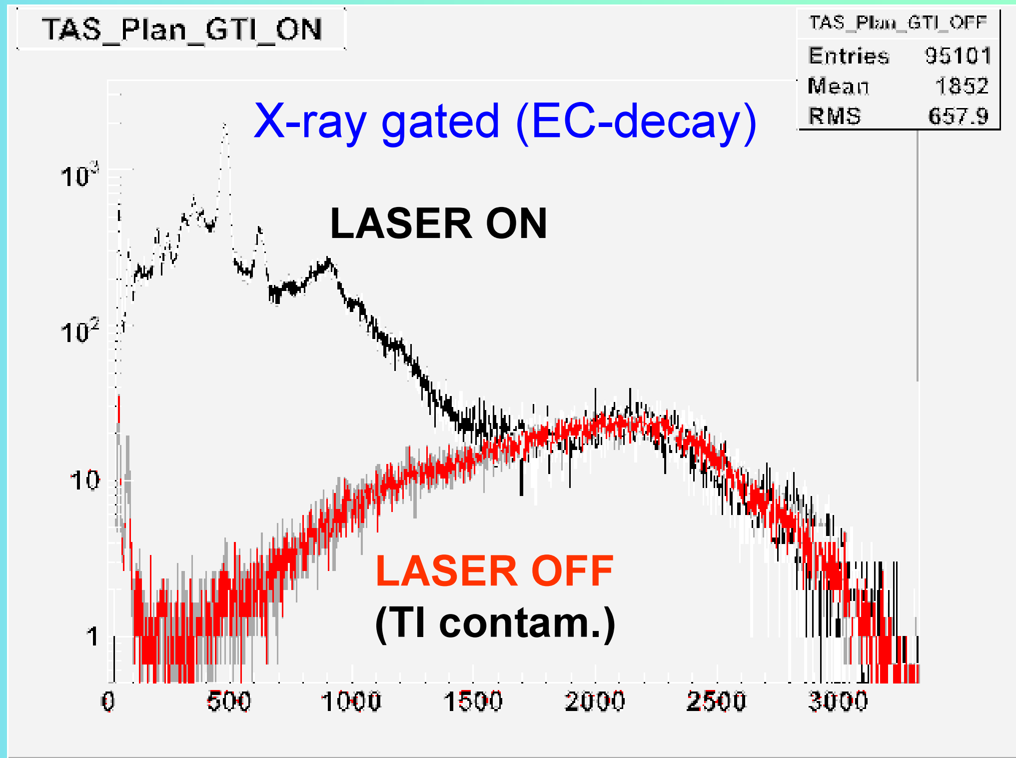


Region of shape coexistence:
neutron deficient Pb, Hg, Pt isotopes

Lucrecia @ ISOLDE

Recent measurement (Nov08)
using RILIS of $^{192,190,188}Pb$



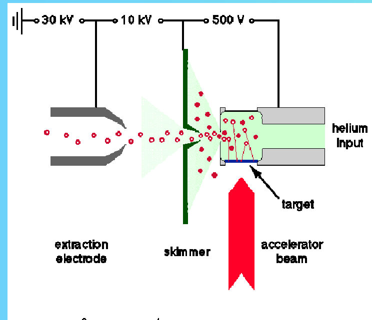


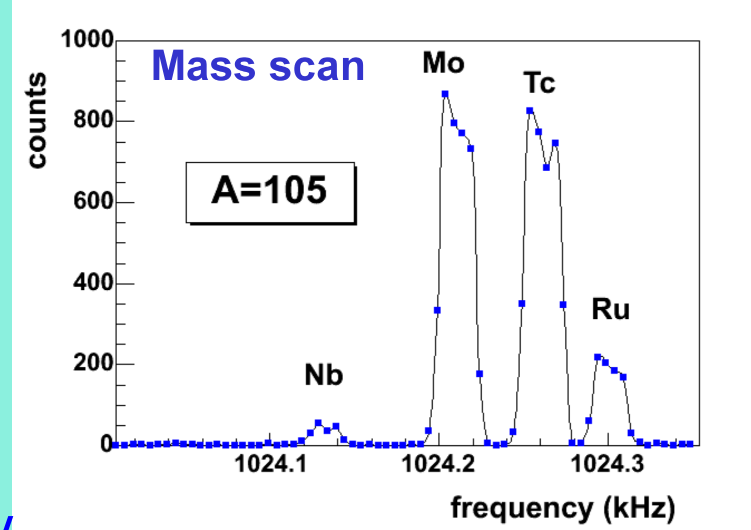
A. Algora et al.
Debrecen, Madrid, Surrey, Valencia

IGISOL separator + ion guide source: refractory elements

TAS measurements @ Univ. Jyvaskyla

JYFLTRAP Penning trap: isotopic purification

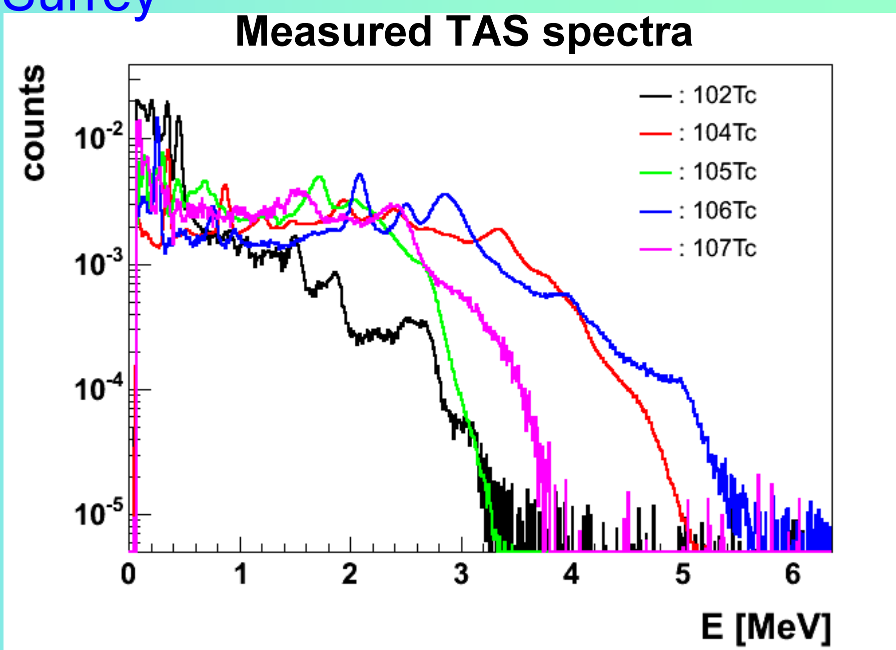


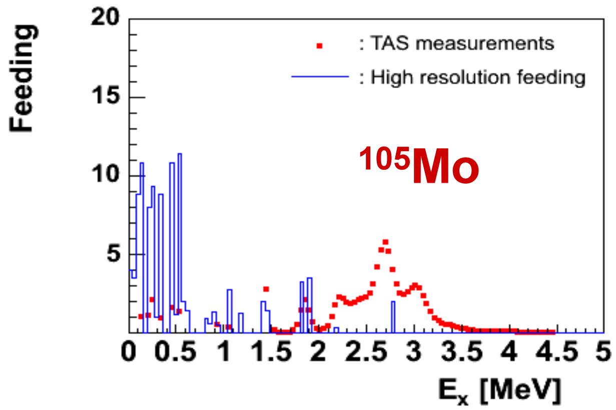


Measurement of Nb, Mo and Tc isotopes for Reactor Decay Heat

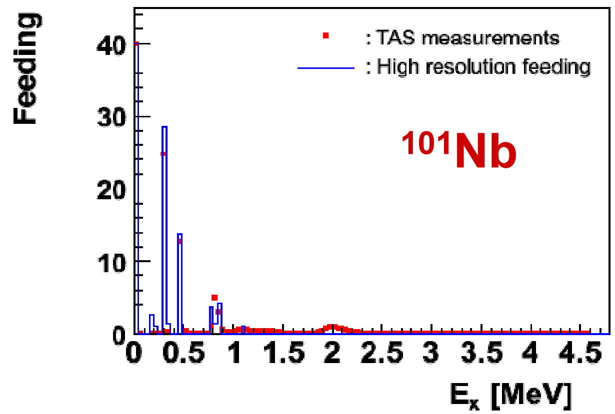
Valencia, Jyvaskyla, Debrecen, Gatchina, Surrey

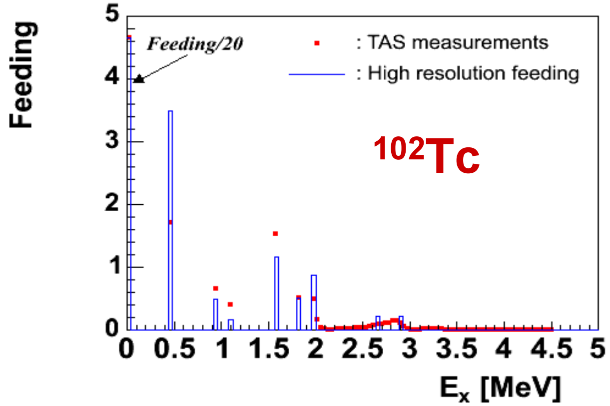
45	103Rh STABLE 100%	104Rh 42.3 S β-: 99.55% ε: 0.45%	105Rh 35.36 H β-: 100.00%	106Rh 29.80 S β-: 100.00%	107Rh 21.7 M β-: 100.00%	108Rh 16.8 S β-: 100.00%	109Rh 80 S β-: 100.00%	110Rh 28.5 S β-: 100.00%	111Rh 11 S β-: 100.00%
	102Ru STABLE 31.55%	103Ru 39.26 D β-: 100.00%	104Ru STABLE 18.62%	105Ru 4.44 H β-: 100.00%	106Ru 373.59 D β-: 100.00%	107Ru 3.75 M β-: 100.00%	108Ru 4.55 M β-: 100.00%	109Ru 34.5 S β-: 100.00%	110Ru 11.6 S β-: 100.00%
43	101Tc 14.22 M β-: 100.00%	102Tc 5.28 S β-: 100.00%	103Tc 54.2 S β-: 100.00%	104Tc 18.3 M β-: 100.00%	105Tc 7.6 M β-: 100.00%	106Tc 35.6 S β-: 100.00%	107Tc 21.2 S β-: 100.00%	108Tc 5.17 S β-: 100.00%	109Tc 0.86 S β-: 100.00% β-n: 0.08%
	100Mo 0.78E+19 Y 9.63% 2β-: 100.00%	101Mo 14.61 M β-: 100.00%	102Mo 11.3 M β-: 100.00%	103Mo 67.5 S β-: 100.00%	104Mo 60 S β-: 100.00%	105Mo 35.6 S β-: 100.00%	106Mo 8.4 S β-: 100.00%	107Mo 3.5 S β-: 100.00%	108Mo 1.09 S β-: 100.00%
41	99Nb 15.0 S β-: 100.00%	100Nb 1.5 S β-: 100.00%	101Nb 7.1 S β-: 100.00%	102Nb 4.3 S β-: 100.00%	103Nb 1.5 S β-: 100.00%	104Nb 4.9 S β-: 100.00% β-n: 0.06%	105Nb 2.95 S β-: 100.00% β-n: 1.70%	106Nb 1.02 S β-: 100.00% β-n: 4.50%	107Nb 330 MS β-: 100.00%
	58		60		62		64		66

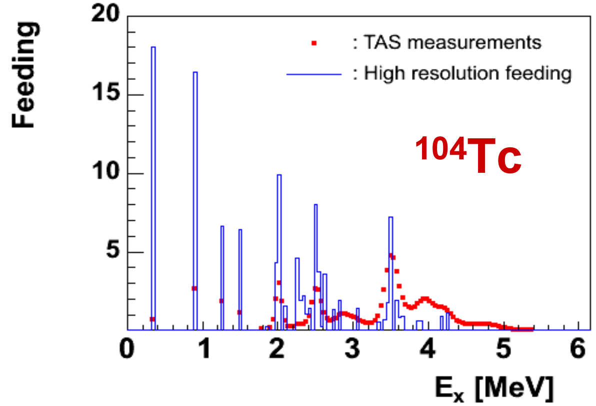


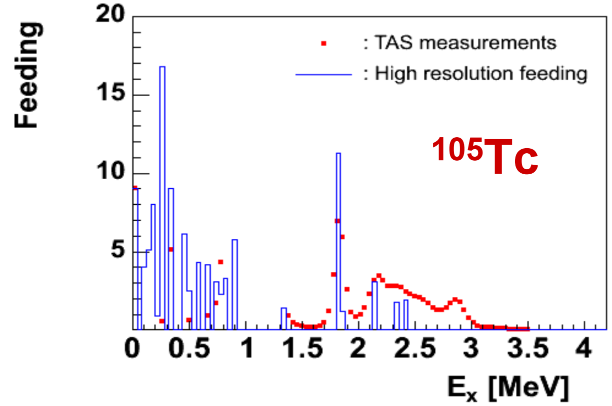


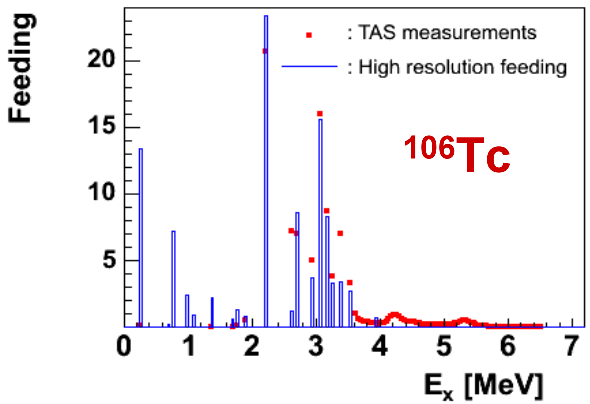
Systematic measurements: Opportunity to improve theoretical models in the region

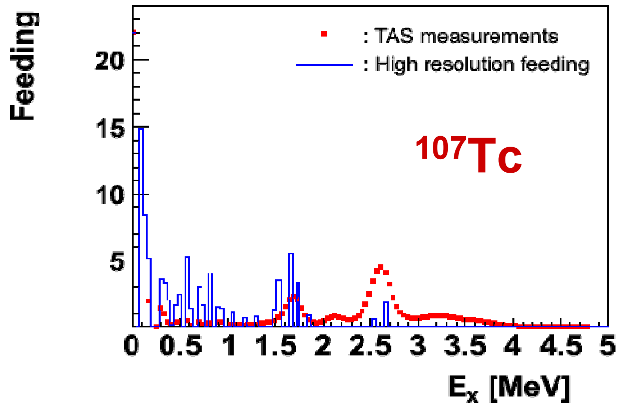












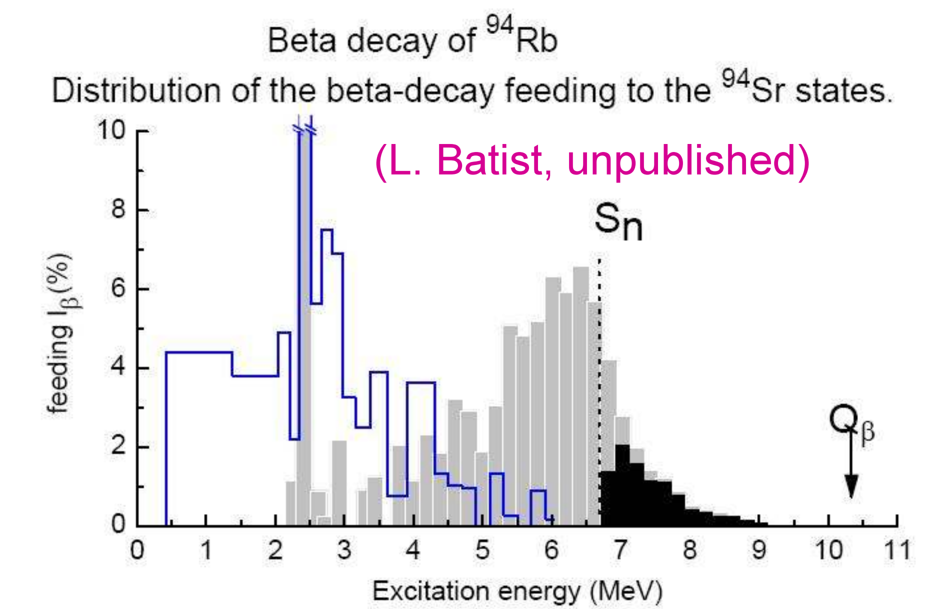
D. Jordan, PhD Thesis

Table 3: Requested TAGS Measurements.

Status 27-01-09	Radionuclide	Priority	Q_β (keV)	Half-life	Comments
	35-Br-86	1	7626(11)	55.1 s	
➨	35-Br-87	1	6852(18)	55.65 s	Complex known decay. Also (β^-, n) branch
➨	35-Br-88	1	8960(40)	16.36 s	(β^-, n) branch.
	36-Kr-89	1	4990(50)	3.15 min	Incomplete decay scheme.
	36-Kr-90	1	4392(17)	32.32 s	Incomplete decay scheme.
	37-Rb-90m	2	6690(15)	258 s	Repeat of INL TAGS measurement – data check.
	37-Rb-92	2	8096(6)	4.49 s	Small (β^-, n) branch.
	38-Sr-89	2	1493(3)	50.53 d	
	38-Sr-97	2	7470(16)	0.429 s	Short half-life (0.429 s), and possible (β^-, n) branch.
	39-Y-96	2	7096(23)	5.34 s	
	40-Zr-99	3	4558(15)	2.1 s	
	40-Zr-100	2	3335(25)	7.1 s	
	41-Nb-98	1	4583(5)	2.86 s	
	41-Nb-99	1	3639(13)	15.0 s	
	41-Nb-100	1	6245(25)	1.5 s	
➨	41-Nb-101	1	4569(18)	7.1 s	
	41-Nb-102	2	7210(40)	1.3 s	
	42-Mo-103	1	3750(60)	67.5 s	
➨	42-Mo-105	1	4950(50)	35.6 s	
➨	43-Tc-102	1	4532(9)	5.28 s	
	43-Tc-103	1	2662(10)	54.2 s	
➨	43-Tc-104	1	5600(50)	18.3 min	
➨	43-Tc-105	1	3640(60)	7.6 min	
➨	43-Tc-106	1	6547(11)	35.6 s	
➨	43-Tc-107	2	4820(90)	21.2 s	
	51-Sb-132	1	5509(14)	2.79 min	
	52-Te-135	2	5960(90)	19.0 s	
	53-I-136	1	6930(50)	83.4 s	Incomplete decay scheme.
	53-I-136m	1	7580(120)	46.9 s	
➨	53-I-137	1	5877(27)	24.13 s	(β^-, n) branch.
	54-Xe-137	1	4166(7)	3.82 min	Incomplete decay scheme.
	54-Xe-139	1	5057(21)	39.68 s	
	54-Xe-140	1	4060(60)	13.6 s	
	55-Cs-142	3	7308(11)	1.69 s	(β^-, n) branch.
	56-Ba-145	2	5570(110)	4.31 s	Repeat of INL TAGS measurement – data check.
	57-La-143	2	3425(15)	14.2 min	Repeat of INL TAGS measurement – data check.
	57-La-145	2	4110(80)	24.8 s	Repeat of INL TAGS measurement – data check.

Proposal approved at JYFL-Jyvaskyla

(Barcelona-Valencia-Madrid-Jyvaskyla-Debrecen-Gatchina-Surrey-Caen)

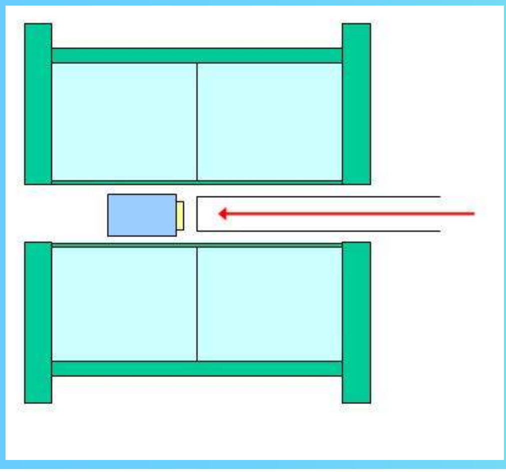


- Isotopes: ^{87,88}Br, ^{94,95}Rb, ^{137}I
- Production: U(p,f) or (d,f)
- Separation: IGISOL + Penning-Trap
- Detection: TAS + 4πn + nTOF

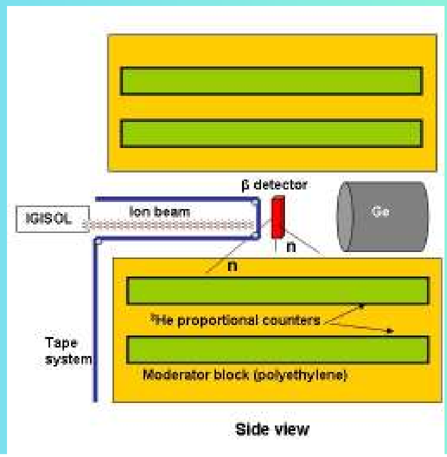
(+ β-det + Ge-det)

- Determine: I_β, P_n, E_n
- Interest for r-process
- Reactor decay-heat and reactivity
- Testing of principles

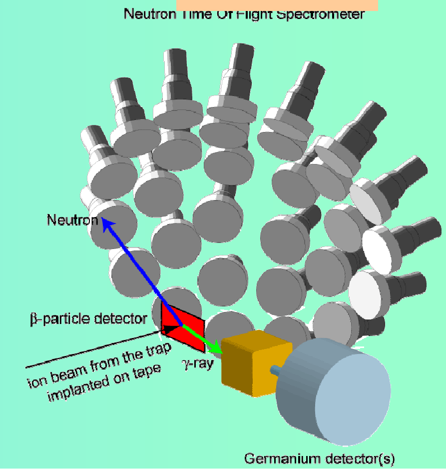
TAS



4πn

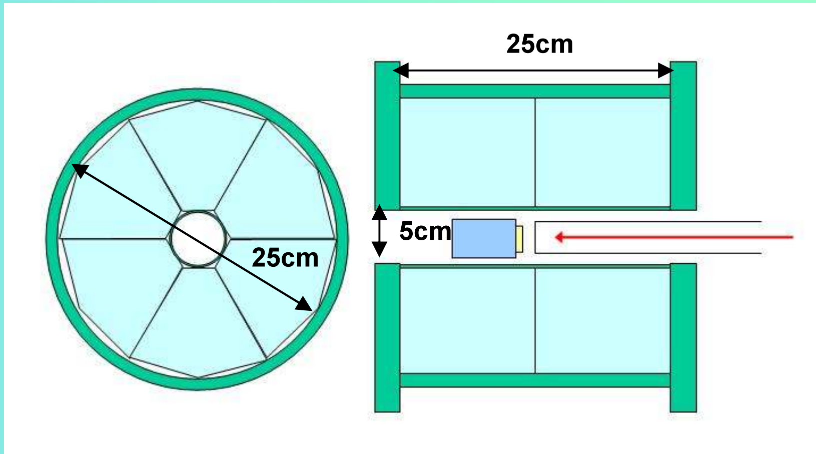


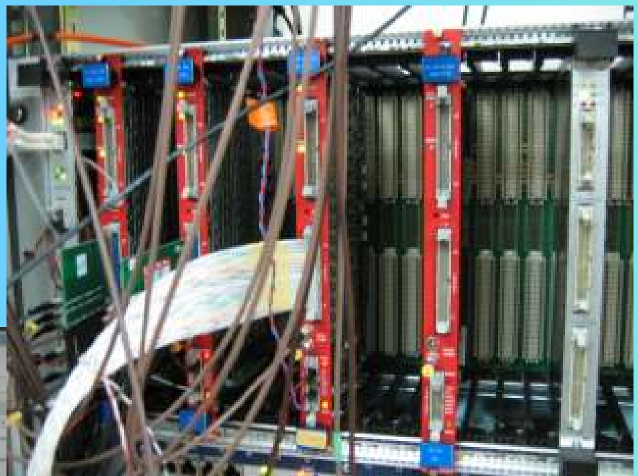
nTOF

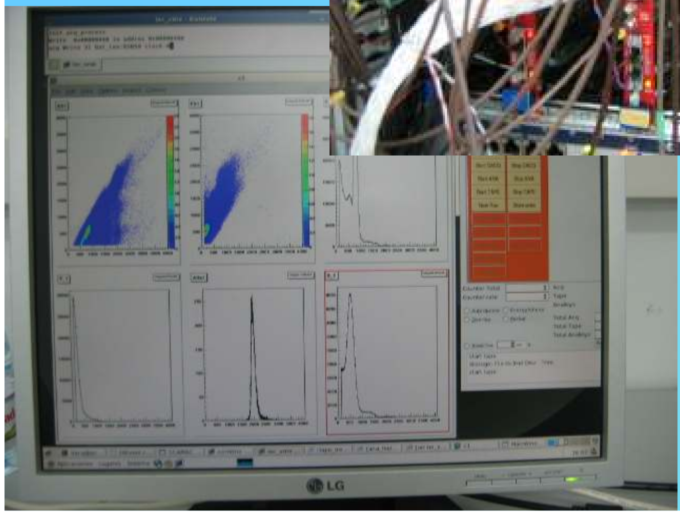


New Surrey-Valencia Total Absorption Spectrometer

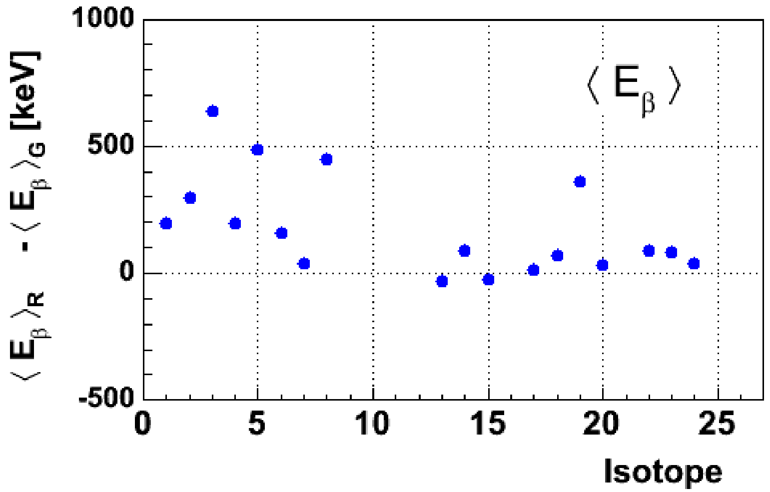
- efficient, compact
- cascade multiplicity
- good timing (neutron bckg. reduction)
- gain stabilized (α-peaks)

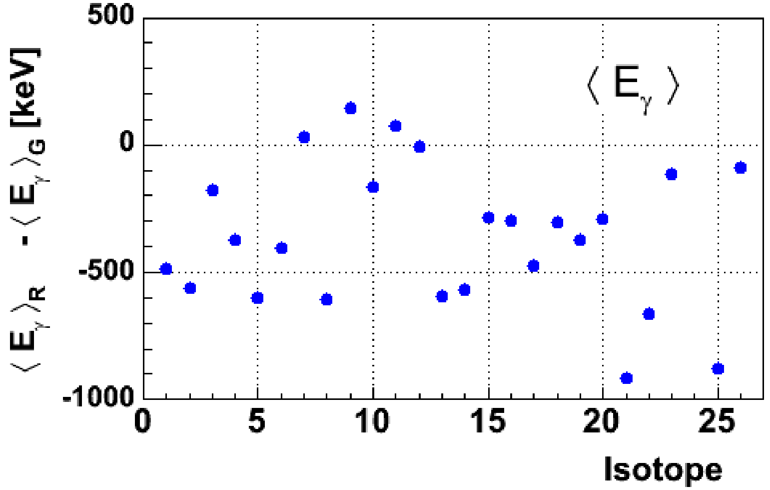






Also for experiments at ALTO, DESIR, …

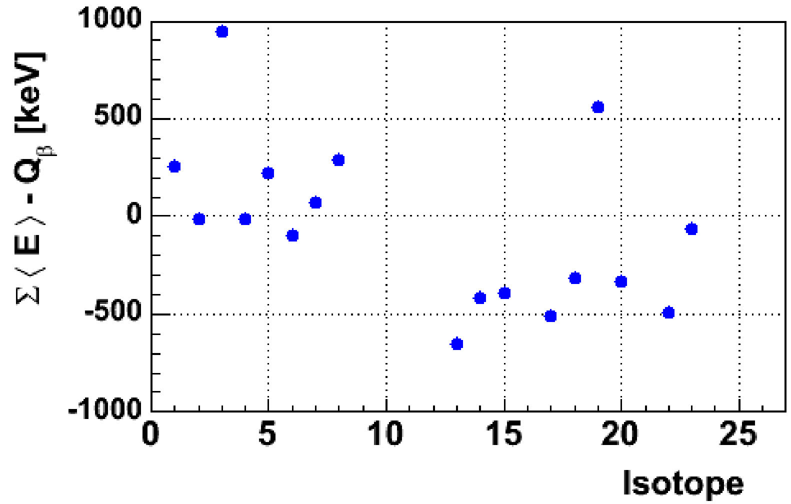




Comparison of average γ- and β-energies from **TAS** (Greenwood et al. NIMA 390, 95) with **direct measurements** (Rudstam et al. ADNDT 45, 239)

Consistency check for R:

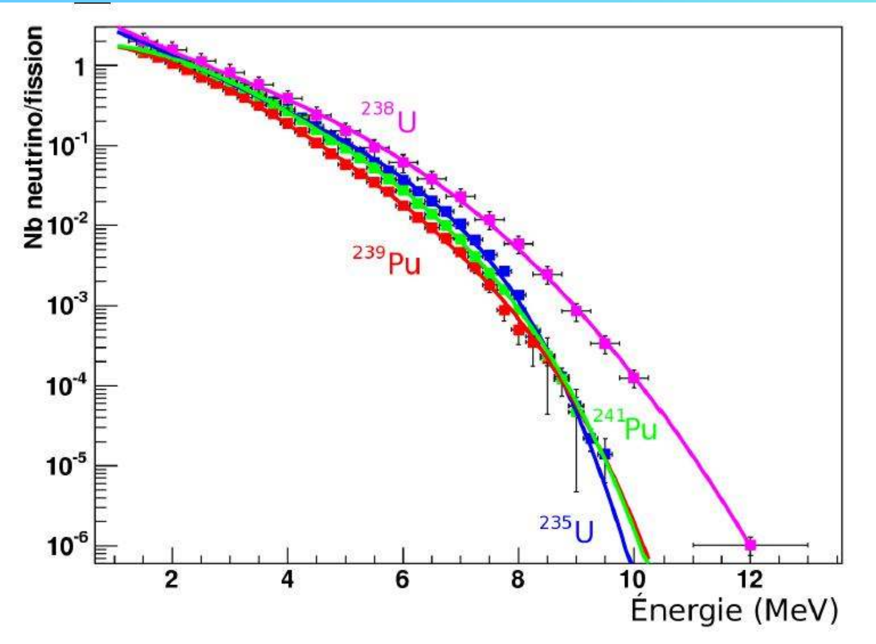
$$\langle E_\gamma \rangle + \langle E_\beta \rangle + \langle E_\nu \rangle = Q_\beta$$

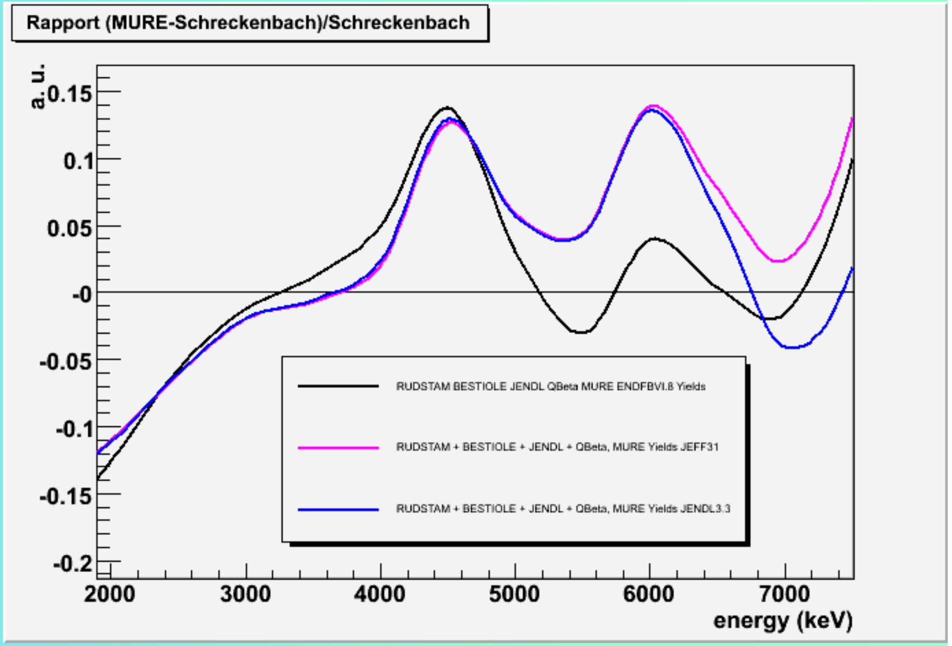


Both measurements are subject to several sources of systematic error: No reason to believe Rudstam et al. superior to Greenwood et al.

Reactor neutrino spectrum: neutrino oscillations and homeland security

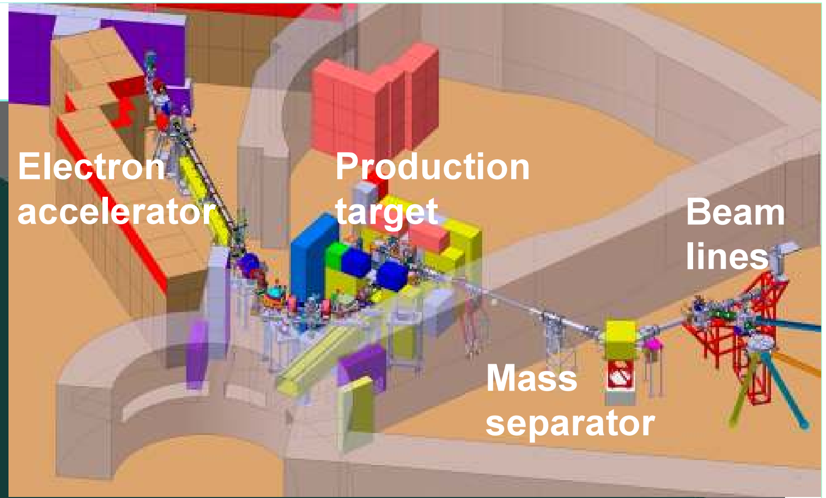
How well known is the reactor anti-neutrino spectrum?

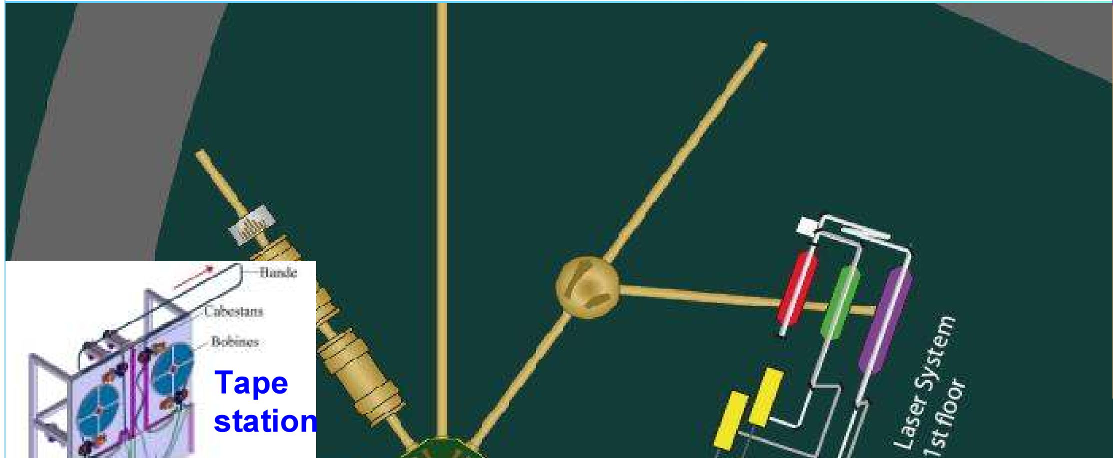


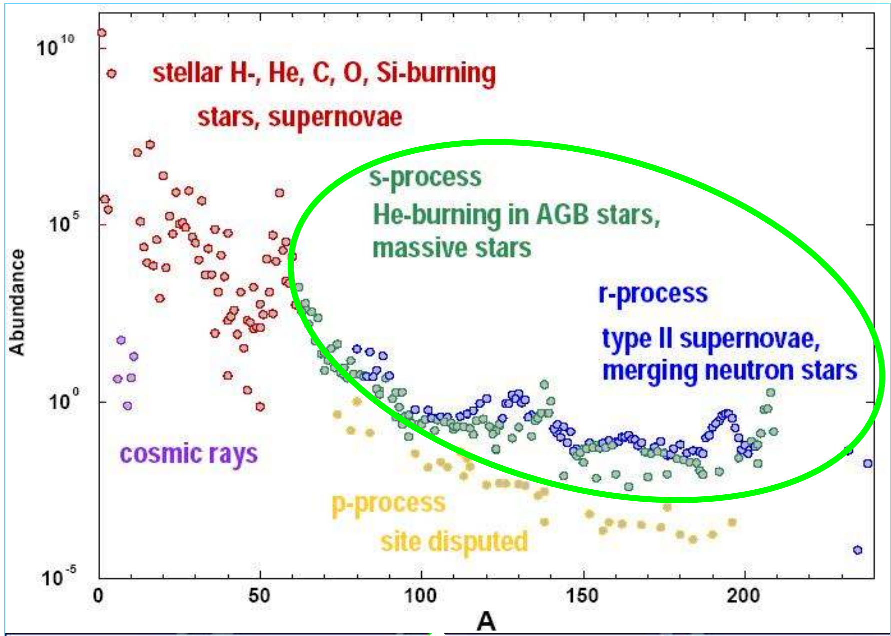


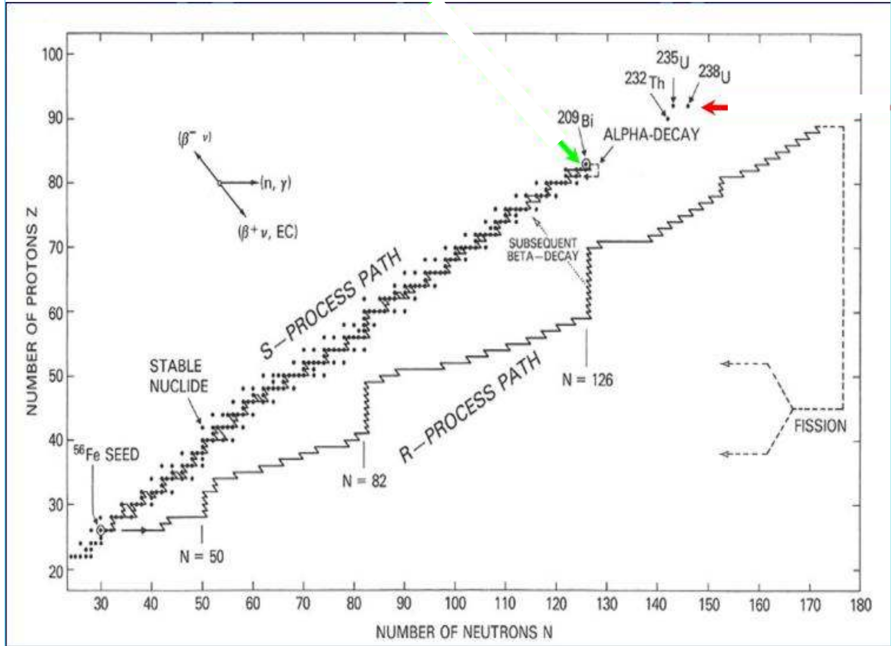
New collaboration: M. Fallot, L. Giot (Subatech-Nantes)
D. Lhuillier (CEA Saclay)

TAS @ ALTO-Orsay status





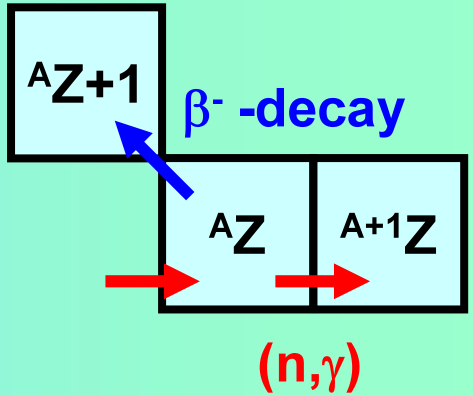




$$T_{1/2}^{-1} = \int_0^{Q_\beta} f(Q_\beta - E_x) S_\beta(E_x) dE_x$$

Neutron capture is the source of elements heavier than iron

The **interplay** between **β-decay** and **(n,γ)** determine the isotopic abundances

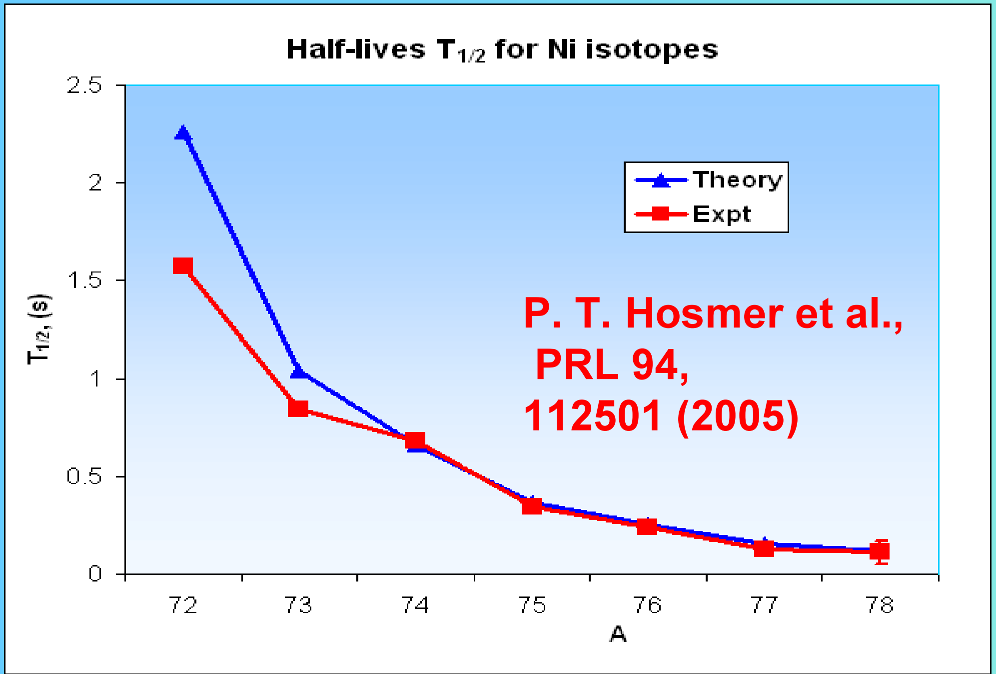


- For the s-process (close to stability) the relevant quantity (except at branching points) is $\sigma_{(n,\gamma)}$ (experimental)

- For the **r-process** (very far from stability) the relevant quantity is $T_{1/2}$ (theoretical)
  ✦ trimming of the codes to reproduce S_β may help to improve their predictive power

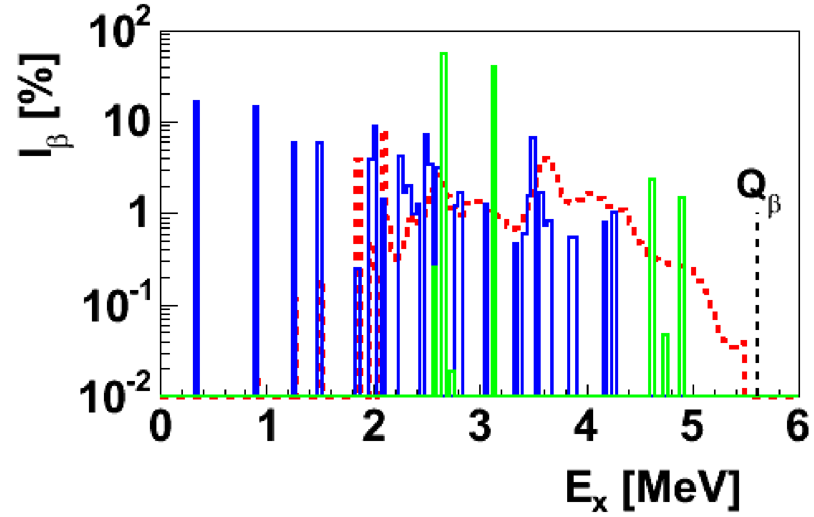
Example: Ni isotopes (taken from A. Lisetskiy)

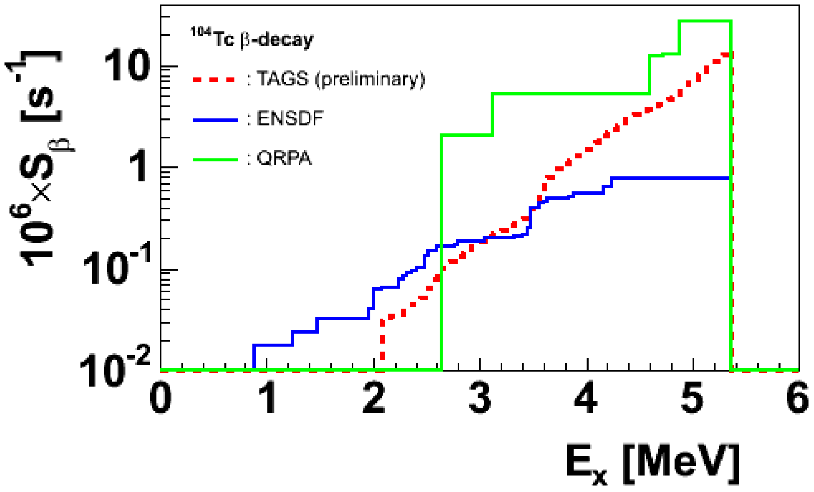
Quenching for GT operator: up to q=0.37! (Standard value is 0.70-0.75)



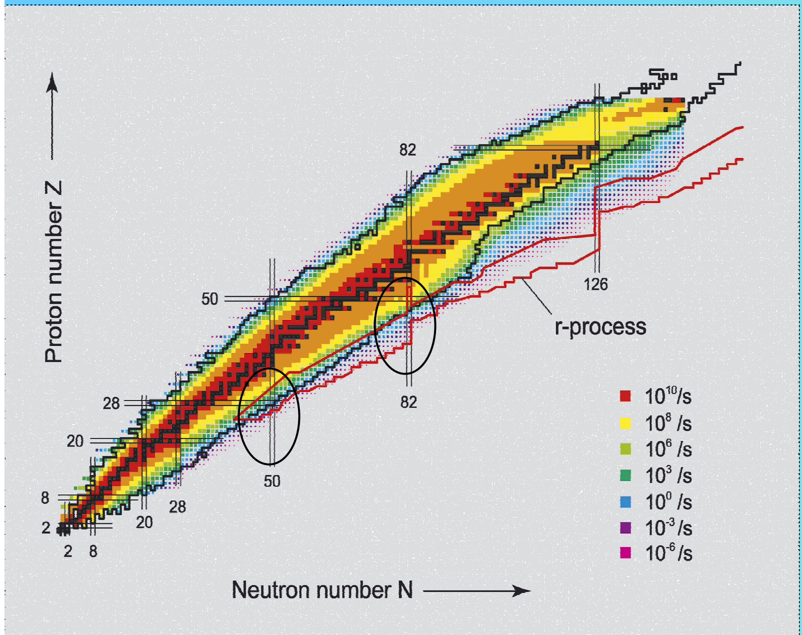
Anomalous quenching or wrong S_β distribution?

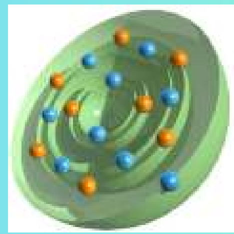
Example: ^{104}Tc
QRPA: P. Möller & K.L. Kratz
T1/2=2.7 min (Exp: 18.3 min)



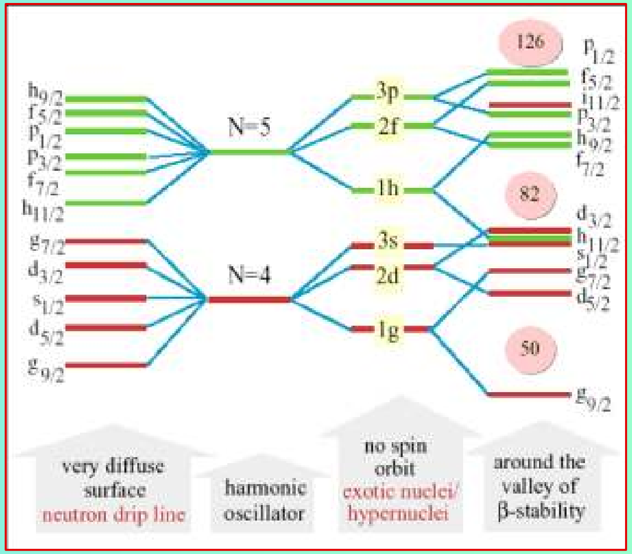


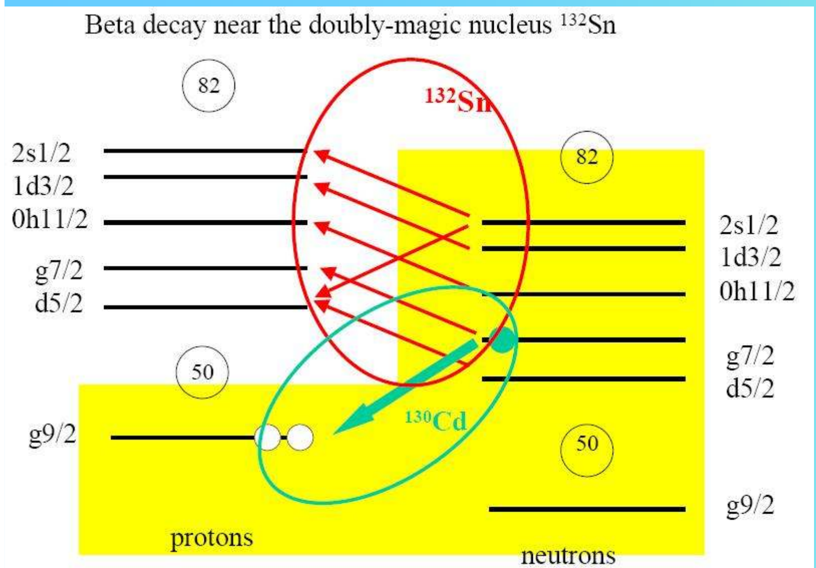
A related but more general nuclear structure question:
Is the shell structure altered at extreme isospin values?

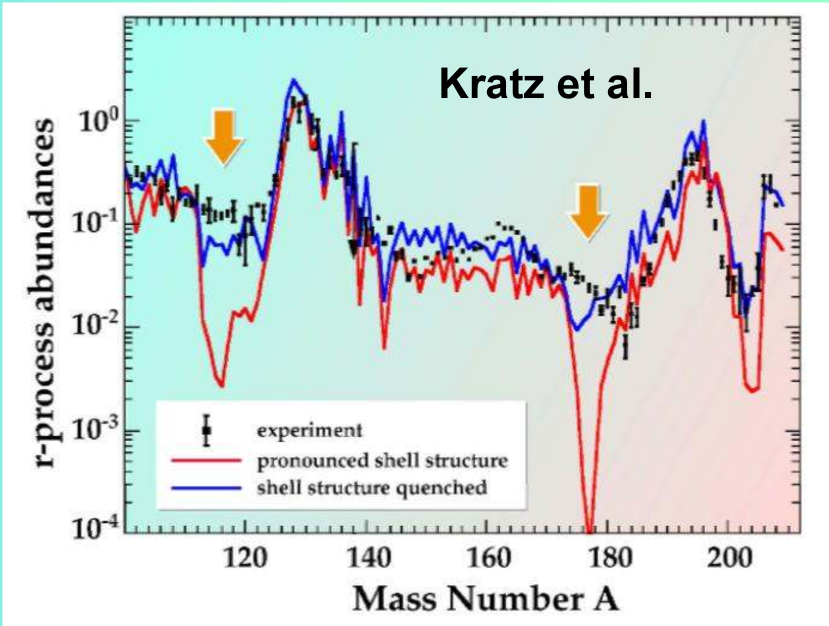




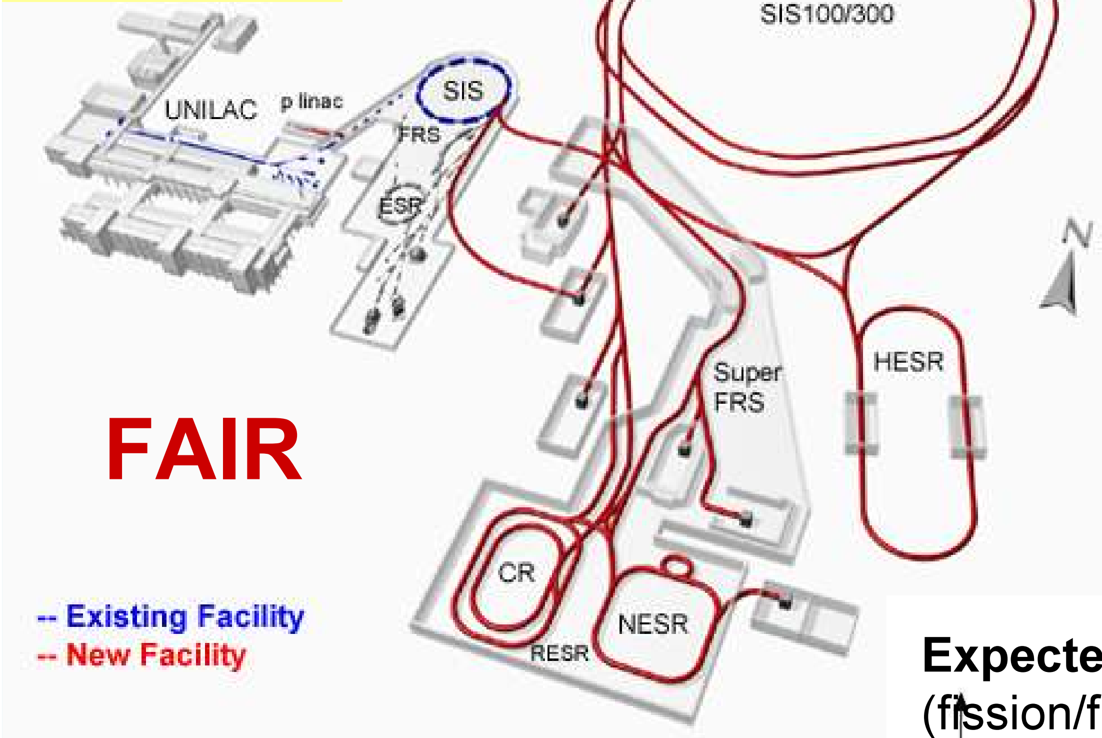
Modifications of mean field and residual interactions







Facility for Antiproton and Ion Research



Primary beams:

- 10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- 2(4)x10^{13}/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ up to 35 (- 45) GeV/u

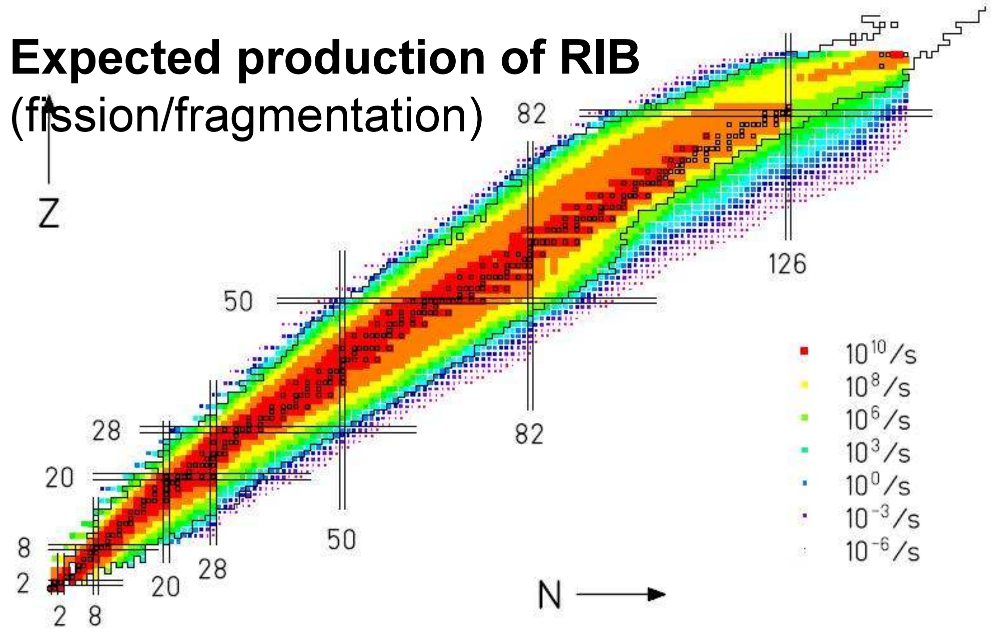
Storage/cooler rings:

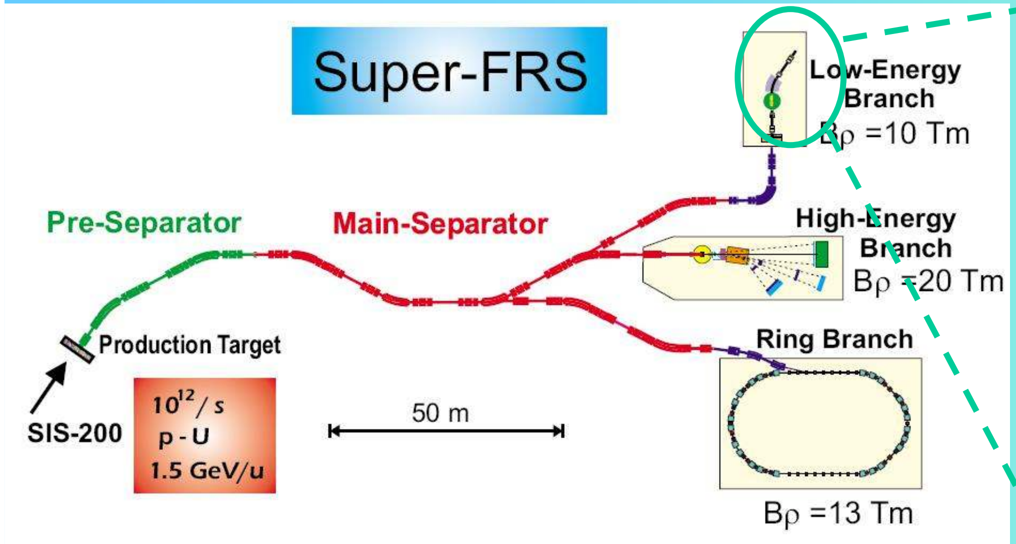
- Radioactive beams
- e – A collider
- 10^{11} antiprotons stored and cooled at 0.8 - 14.5 GeV

Secondary beams:

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV

Expected production of RIB (fission/fragmentation)



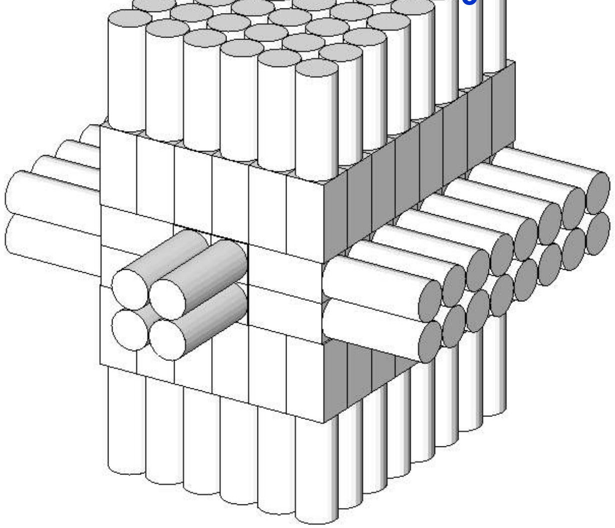


DESPEC experiment of the NUSTAR collaboration

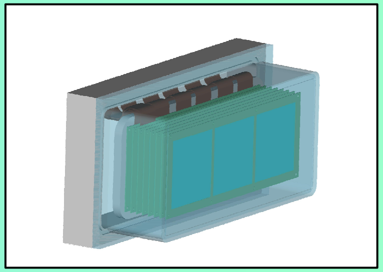
New TAS under development

Valencia, Madrid, Gatchina, Darmstadt, Debrecen, St. Petersburg, Surrey

128 + 32 modules:
5.5×5.5×11 cm³ **$LaBr_3$:Ce**



Fast ions active stopper: Stack of DSSSD

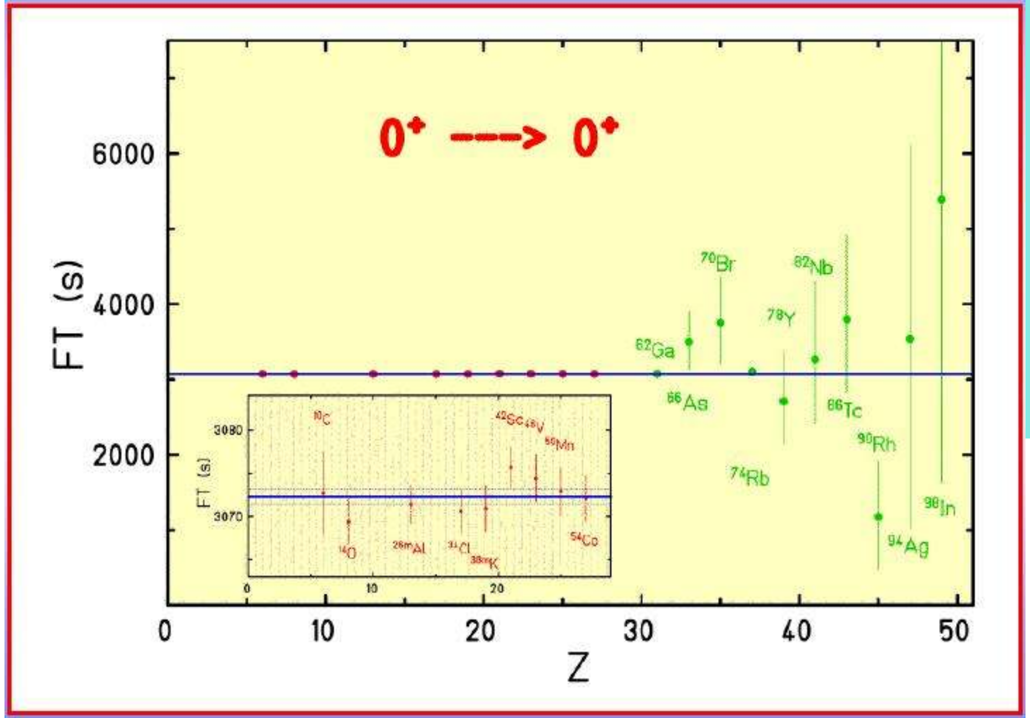


Test of the CVC hypothesis and unitarity of CKM matrix

Super-allowed $0^+ \rightarrow 0^+$ β-decay

$$ft = \frac{T_{1/2} \cdot f(Q_{EC})}{I_\beta}$$

$$Ft = ft(1+\delta_R')(1-\delta_C+\delta_{NS}) = \frac{K}{g_V^2(1+\Delta_R)\langle M_F\rangle^2}$$

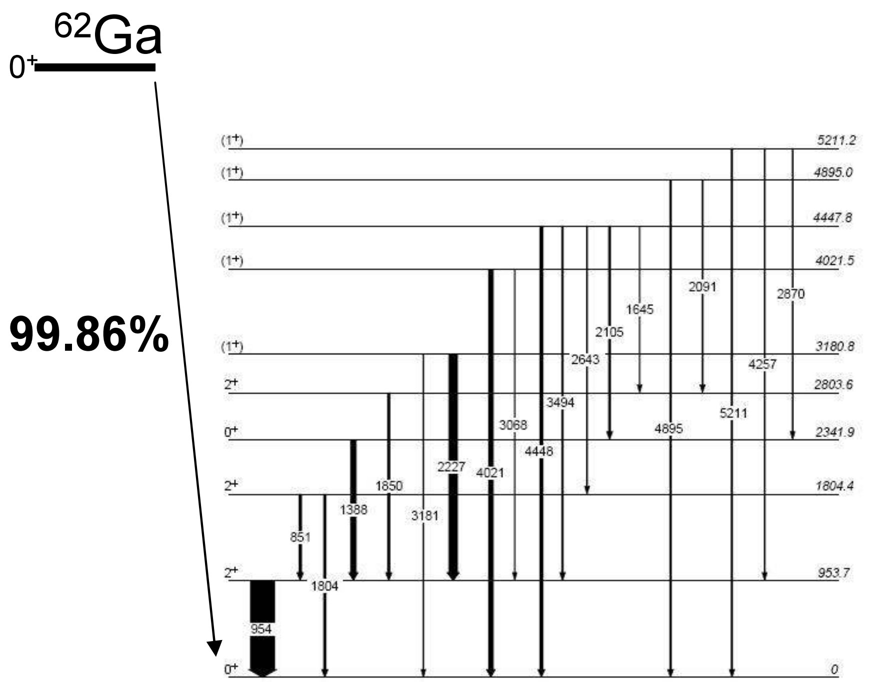


N=Z odd-odd nuclei:

^{62}Ga, ^{66}As, ^{70}Br, …, ^{94}Ag

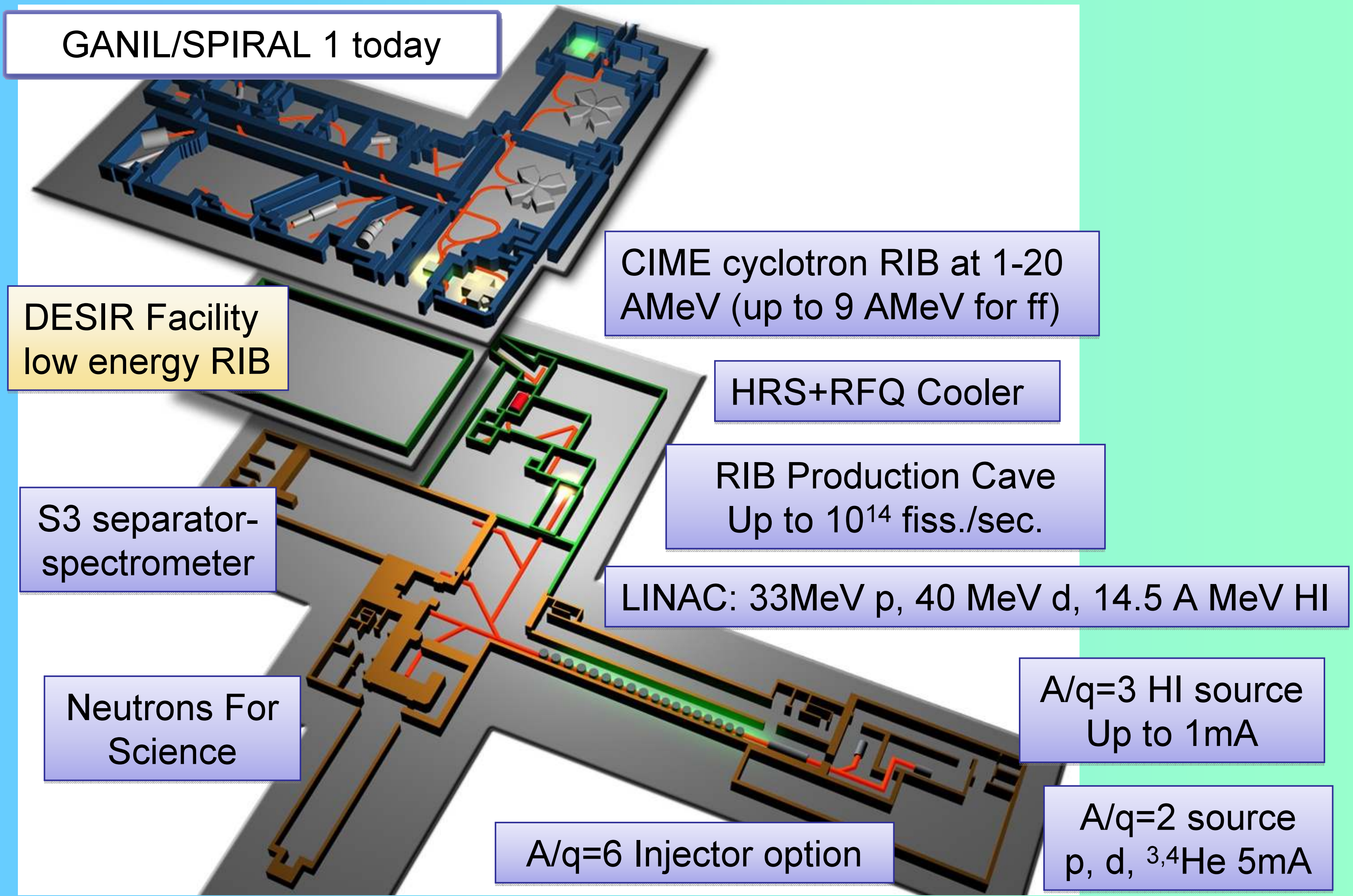
Use of TAS to detect high lying weak GT branches

Precision of 10^{-3} !

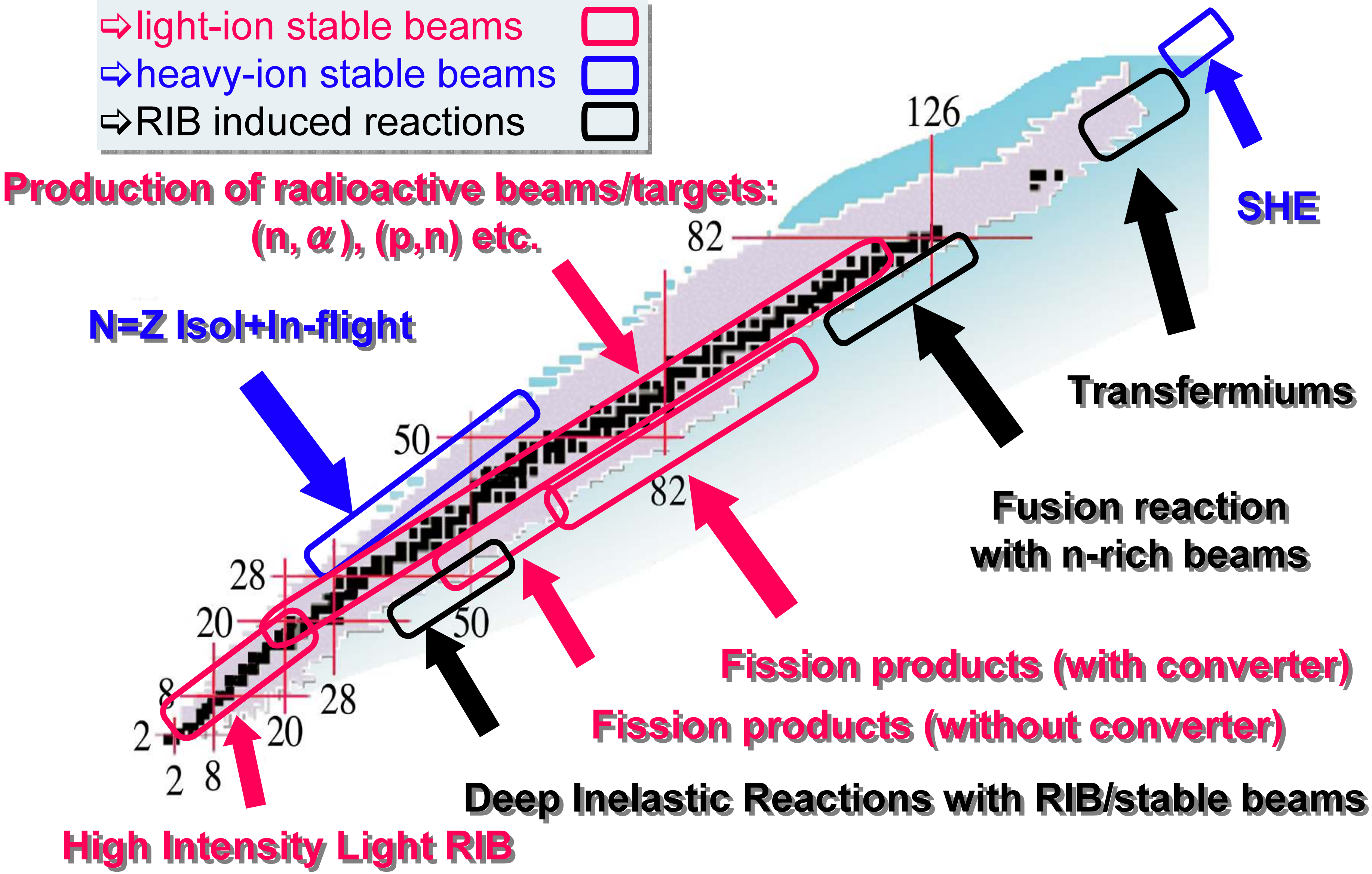


Hyland, PRL97, 102501 ^{62}Zn

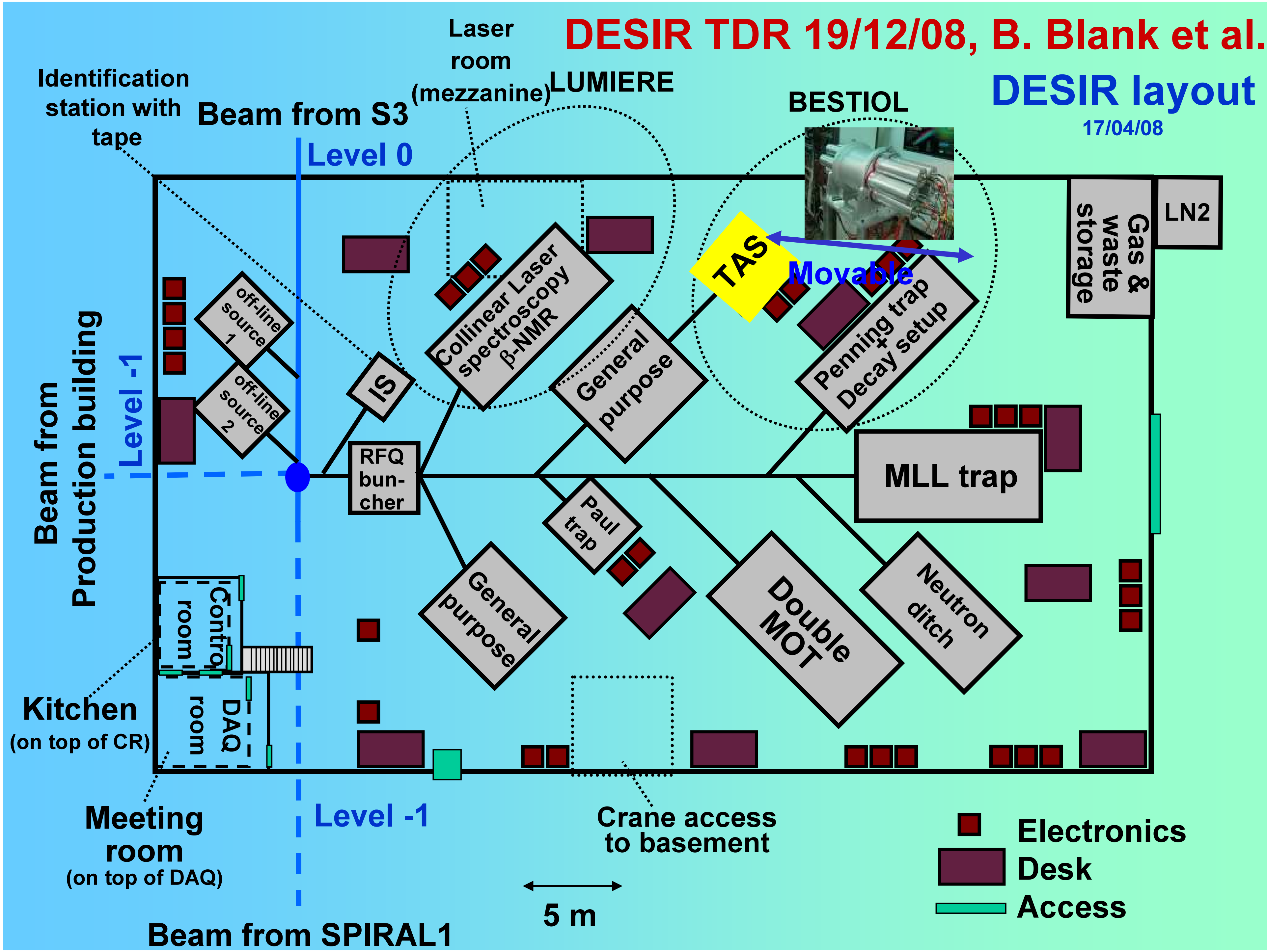
GANIL/SPIRAL1/SPIRAL2 facility layout



Regions of the Chart of Nuclei Accessible with SPIRAL 2 Beams : LINAG & RIB



Energy range of SPIRAL2 RIB : ≤ 60keV and 1-20 MeV/nucl.


DESIR TDR 19/12/08, B. Blank et al.
DESIR layout
17/04/08
Identification station with tape
Beam from S3
Level 0
Laser room (mezzanine)
LUMIERE
BESTIOL
TAS
Movable
Gas & waste storage
LN2
Beam from Production building
Level -1
off-line source 1
off-line source 2
IS
Collinear Laser spectroscopy β-NMR
General purpose
Penning trap + Decay setup
RFQ bun-cher
MLL trap
Paul trap
General purpose
Double MOT
Neutron ditch
Control room
DAQ room
Kitchen (on top of CR)
Meeting room (on top of DAQ)
Level -1
Crane access to basement
5 m
Electronics
Desk
Access
Beam from SPIRAL1

Conclusions:

- **The TAS technique is the most powerful technique to investigate the β-strength distribution far from stability, (supplemented when necessary by delayed particle spectroscopy)**

- **β-strength/distributions are key ingredients of our understanding of the nuclear structure and are relevant for fundamental physics, astrophysics and technology**

- **New developments in existing installations or the construction of new facilities opens new perspectives for this type of measurements**