Superallowed $0^+ \rightarrow 0^+$ beta decay studies at GANIL

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Workshop on V_{ud} from pion, neutron and nuclear beta decay

05-06 November 2024

$ft^{0^+ \to 0^+} \xrightarrow{CVC} \langle \mathcal{F}t^{0^+ \to 0^+} \rangle \to V_{ud}$

Reminder ...

$$\frac{K}{V_{ud}^2\, 2\, G_F^2 (1+\Delta_R)} = \mathcal{F}t^{0^+ \to 0^+} = ft^{0^+ \to 0^+} (1+\delta_R')(1+\delta_{NS}-\delta_C)$$

constants

expt. observable

corrections

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \neq 1$$

$$|0.97373(31)|^2 + |0.22430(80)|^2 + |0.00382(20)|^2 < 1$$

<$\mathcal{F}t$> from superallowed $0^+ \to 0^+$ decays indicate **unitarity** is **violated** at **2σ level**

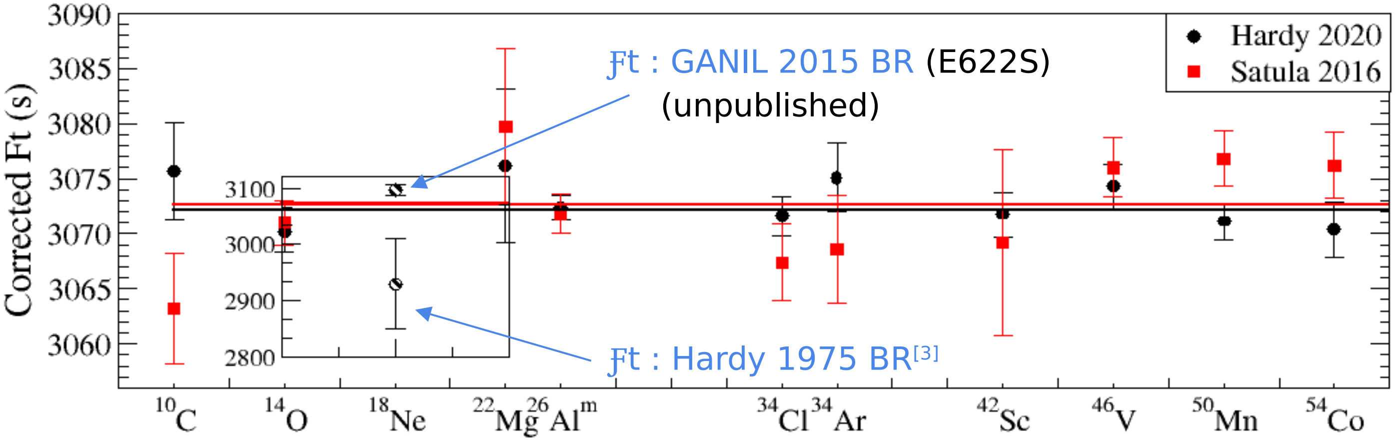
High precision on $ft^{0+ \to 0+}$

- Half-life of the decaying state, $\Delta t_{1/2} < 0.03\%$
- SA beta branching ratio, $\Delta BR < 0.3\%$
- Total transition energy $\Delta Q_{EC} < 0.02\%$

Experimental precision ✔

Theoretical corrections ?

δ_c corrections: role of experimental data



Hardy 2020[1]

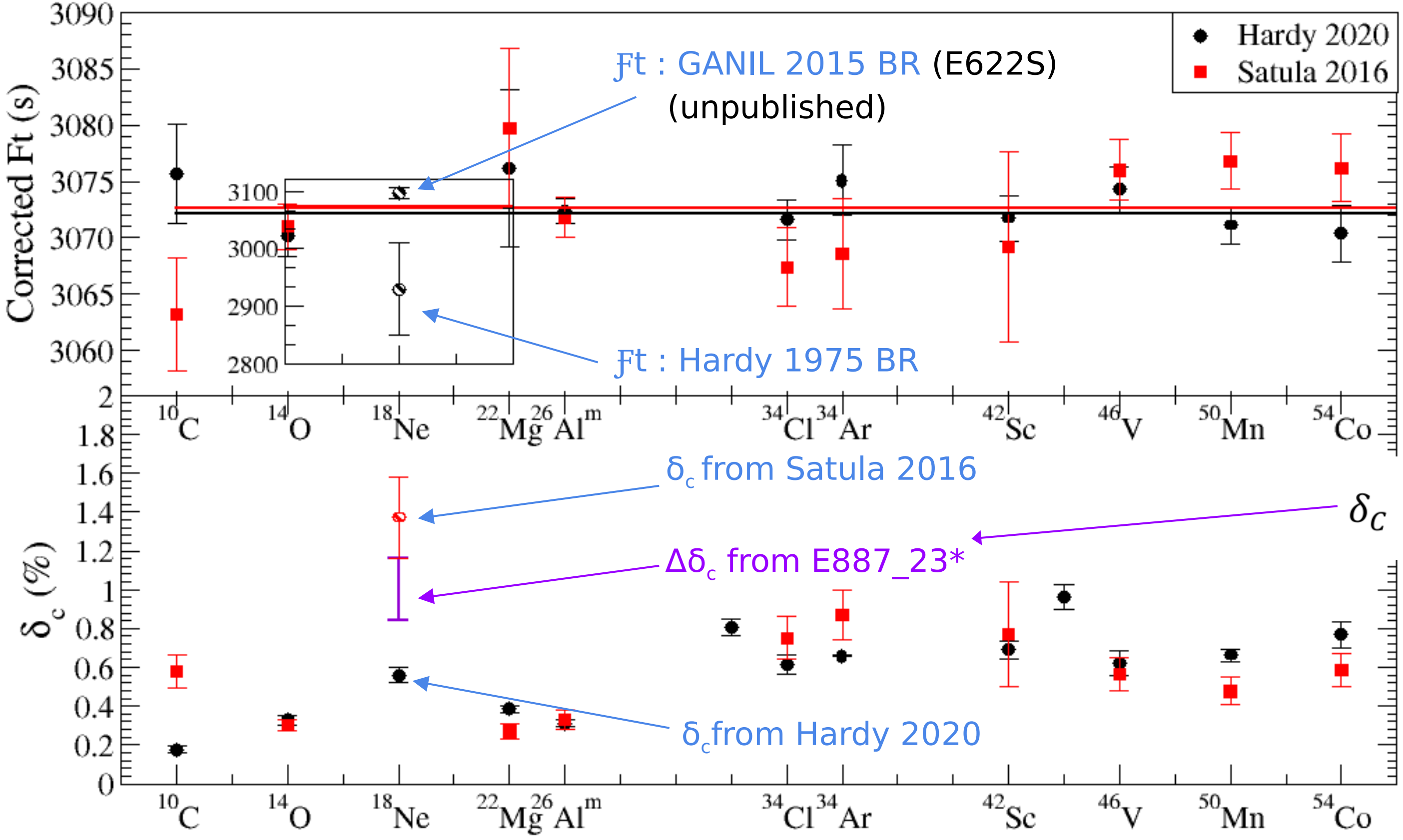
- Shell model
- <Ƒt> = 3072.08(65)
- Ƒt(^{18}Ne)= 2930(80)

Satula 2016[2]

- Density functional
- <Ƒt> = 3072.65(92)
- Ƒt(^{18}Ne)= 3097(22)

[1] Hardy & Towner, PRC **102**, 045501 (2020).
[2] Satula *et al.,* PRC 94, 024306 (2016).
[3] J.C. Hardy, *et al.,* Nucl. Phys. A246, **61** (1975).

δ_c corrections: role of experimental data



Hardy 2020 + E622S

- Shell model
- $\delta_c = 0.560(39)\%$

Satula 2016 + E622S

- Density functional
- $\delta_c = 1.37(21)\%$

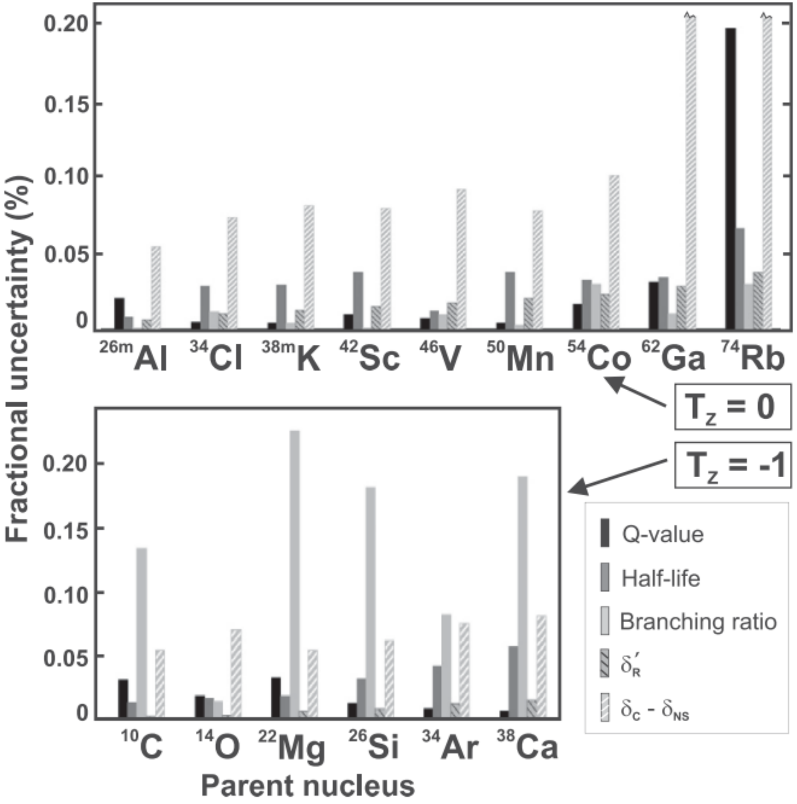
$$\delta_C = 1 + \delta_{NS} - \frac{\overline{\mathcal{F}t}^{0+\to 0+}}{ft^{0+\to 0+}\,(1+\delta_R')}$$

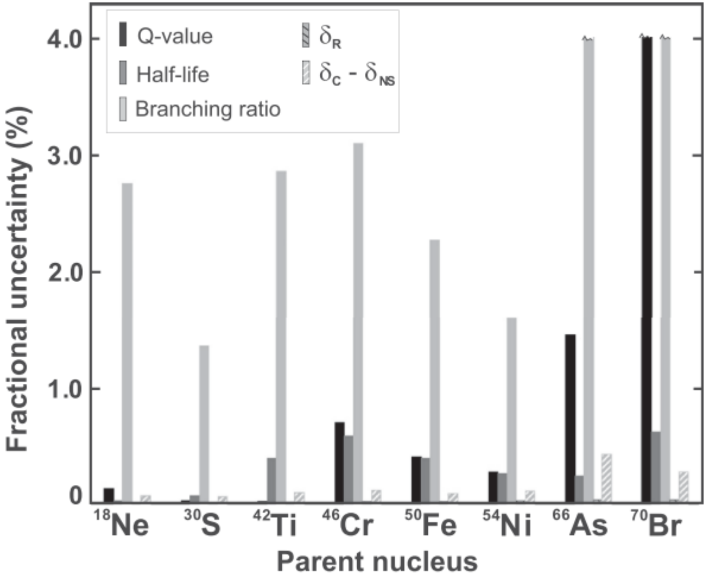
With ΔBR/BR= 0.3% we get $\Delta ft^{0+\to 0+}/ft^{0+\to 0+} = 0.3\%$

*Expt scheduled for 2025

Current scenario …

23 known cases, but precision ≅0.3% or better for **only** 15 transitions



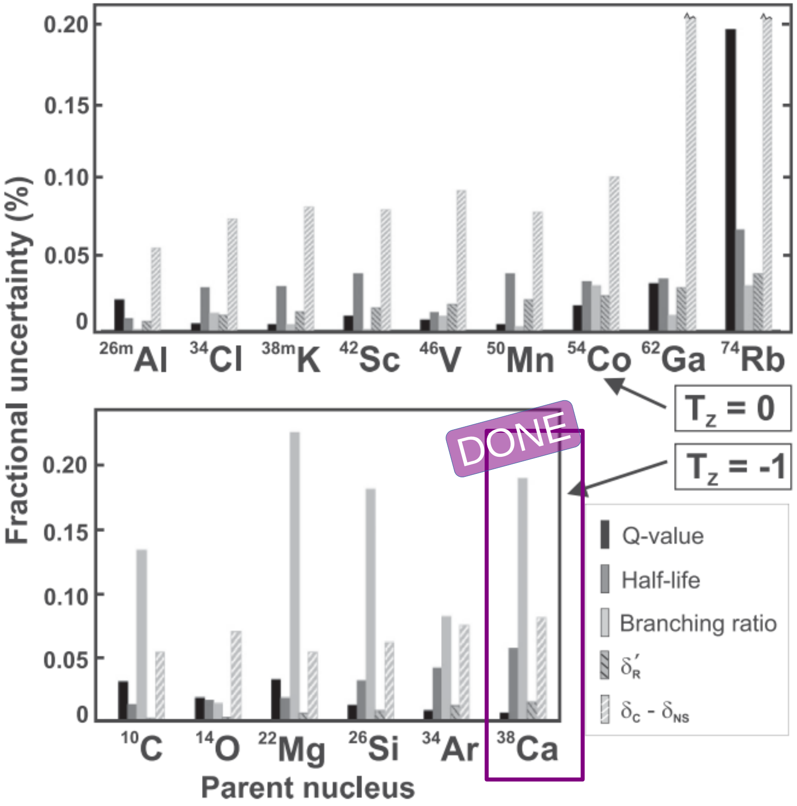


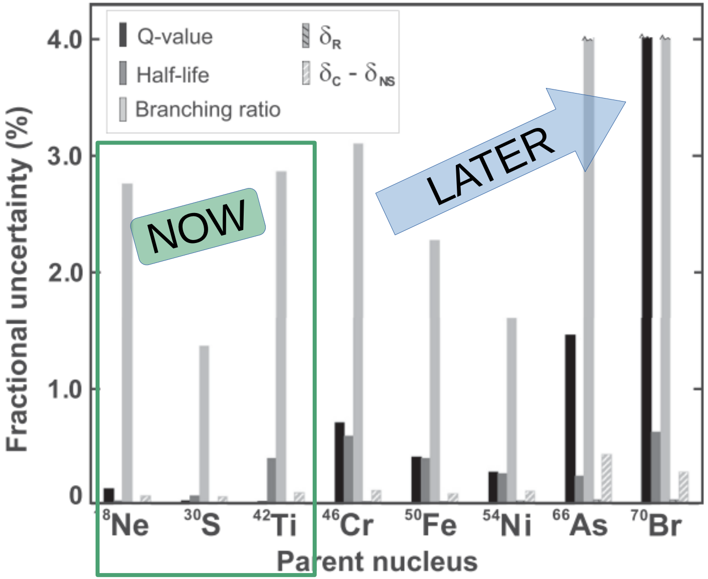
Remaining 8: NEED better precision esp. BR

Images from Hardy & Towner, PRC **102**, 045501 (2020)

Superallowed program @ GANIL

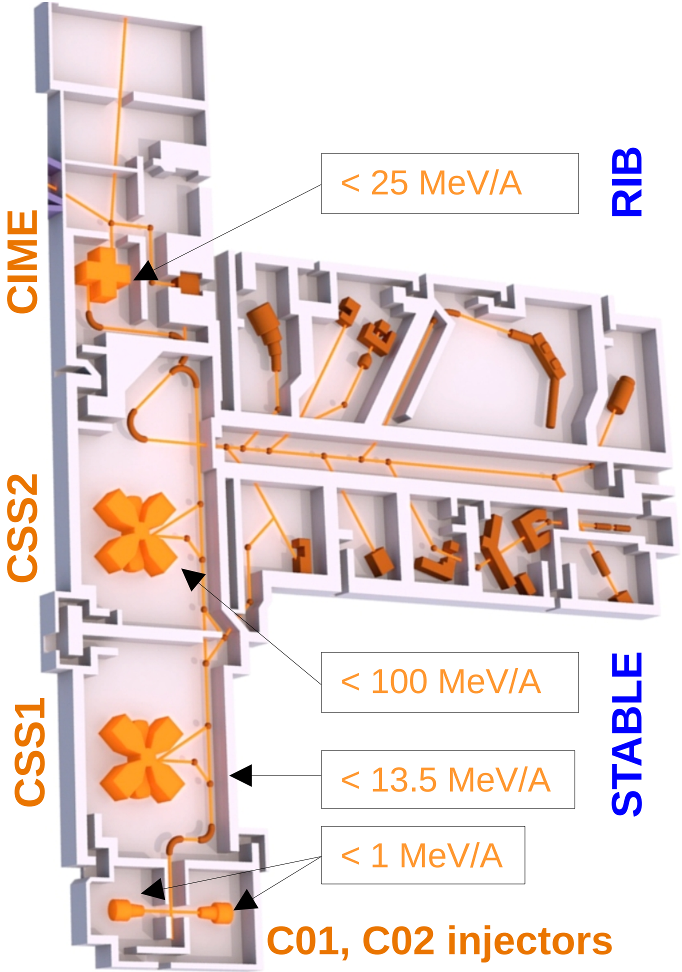
23 known cases, but precision ≅0.3% or better for **only** 15 transitions





Remaining 8: NEED better precision esp. BR

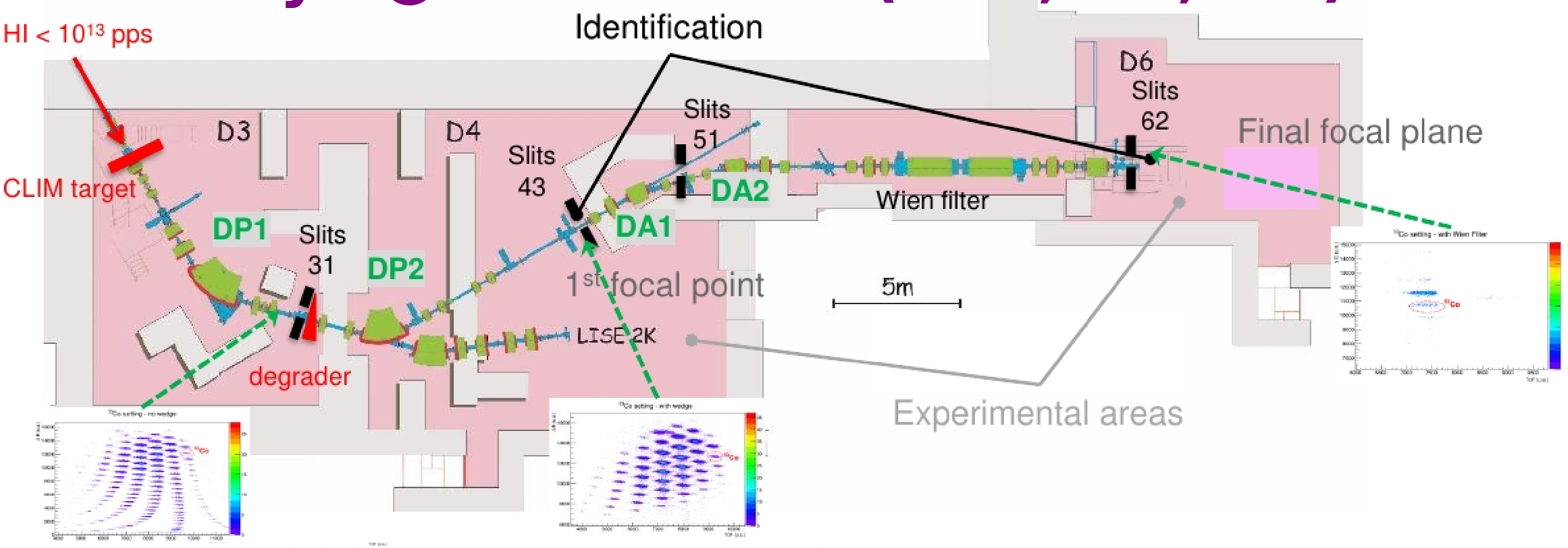
Images from Hardy & Towner, PRC **102**, 045501 (2020)



https://www.ganil-spiral2.eu/scientists/ganil-spiral-2-facilities/accelerators

Image credits: J.-C. Thomas & GANIL

SA decays @ GANIL:LISE (^{38}Ca, ^{30}S, ^{42}Ti)



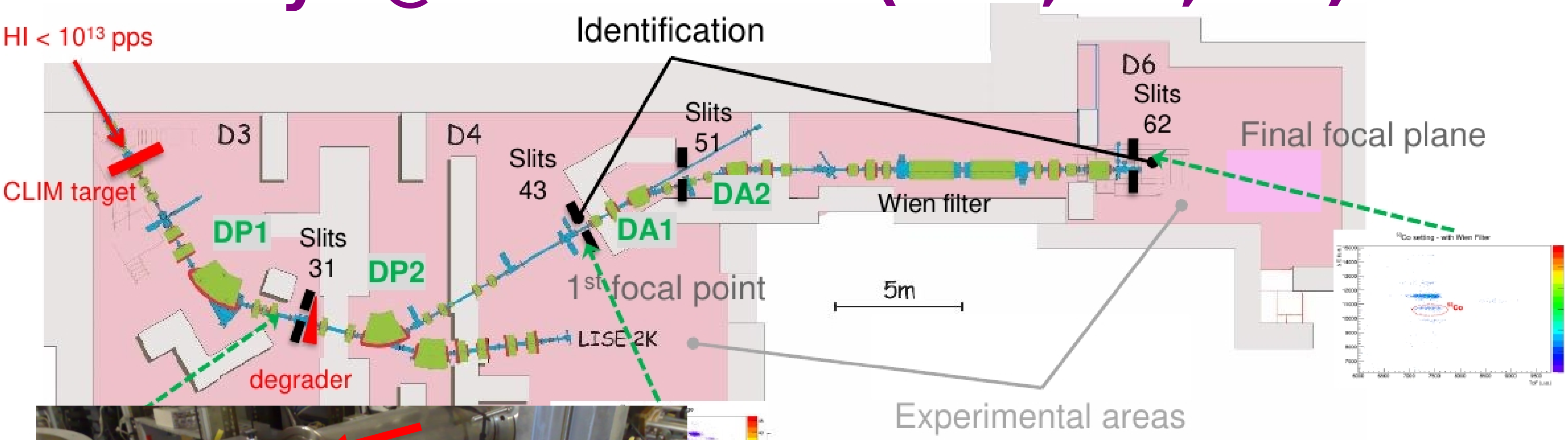
- 3 stages selection: $B_{\rho 1}$ ~p/Z (DP1); degrader + $B_{\rho 2}$ ~A^3/Z^2 (DP2); velocity filter (v) ++ a number of slits
- Identification: ΔE, ToF (+XY)
- Experimental areas: D4 (+ LISE2K), D6

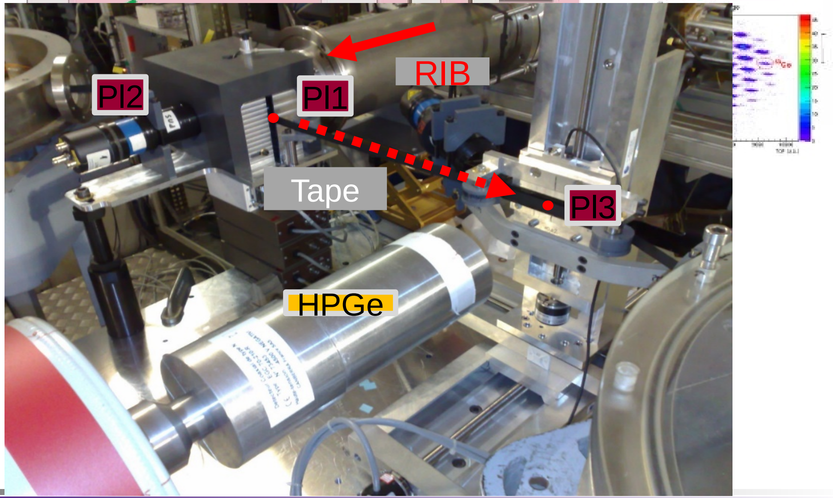
❑ $B_{\rho 2} \leq 3.2$ T.m (4.3 T.m on LISE 2K)
❑ $\Delta p/p \leq \pm 2.5$ %
❑ Angular acceptance: 1 msr (3.5 on LISE2K)

Slide credit: J.-C. Thomas

SA decays @ GANIL:LISE (^{38}Ca, ^{30}S, ^{42}Ti)

GANIL spiral2 laboratoire commun CEA/DRF CNRS/IN2P3

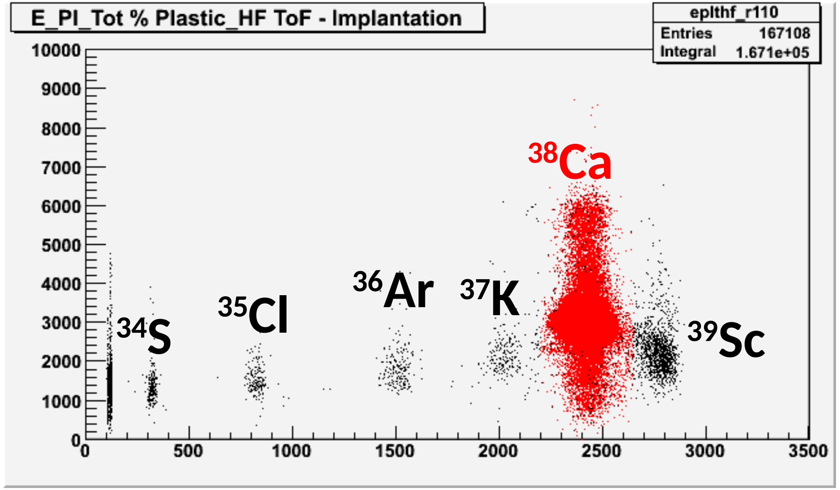


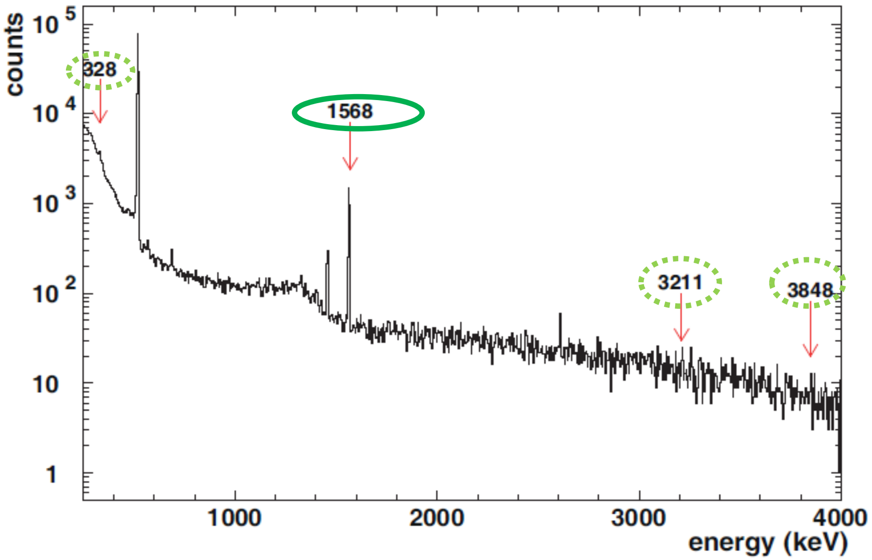


Experimental Setup for SA β decay studies

- PI1, PI2: implantation monitoring
- PI3: $t_{1/2}$ measurement
- HPGe: BR measurement
- Movable tape drive system

SA decays @ GANIL:LISE (^{38}Ca, ^{30}S, ^{42}Ti)





- Fragmentation of ^{40}Ca@50MeV/A
- ~99.5 % purity, ~10^4 pps @ 2 eμA

$t_{1/2}$ = 443.63(35) ms => 0.08 % precision
BR = 77.14(35)% => 0.4% precision

First SA beta decay studied at GANIL

B. Blank et al., Eur. Phys. J. A **51**, 8 (2015)

SA decays @ GANIL:LISE (^{38}Ca, ^{30}S, ^{42}Ti)

- Fragmentation of ^{32}S @ 50MeV/A => few 10^4 pps ^{30}S
- Wein filter issues
  - ~99% purity when operating
  - ~ 60% otherwise
- Analysis ongoing

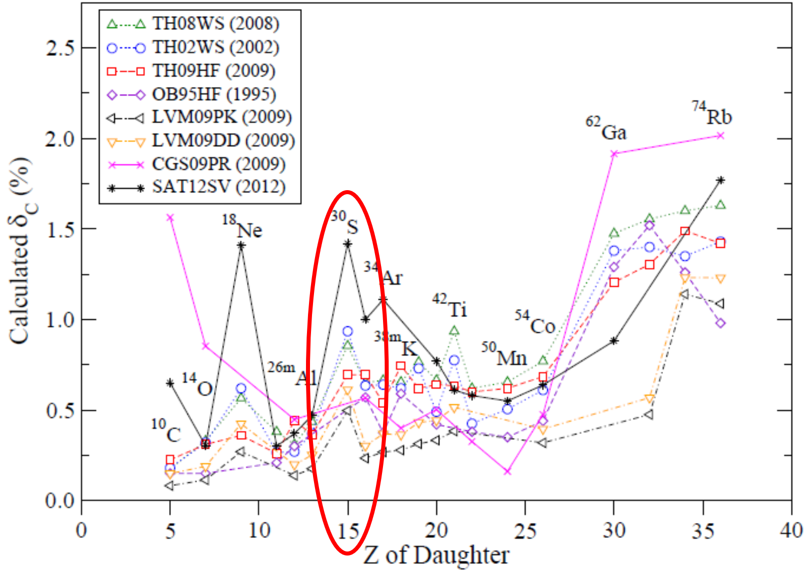
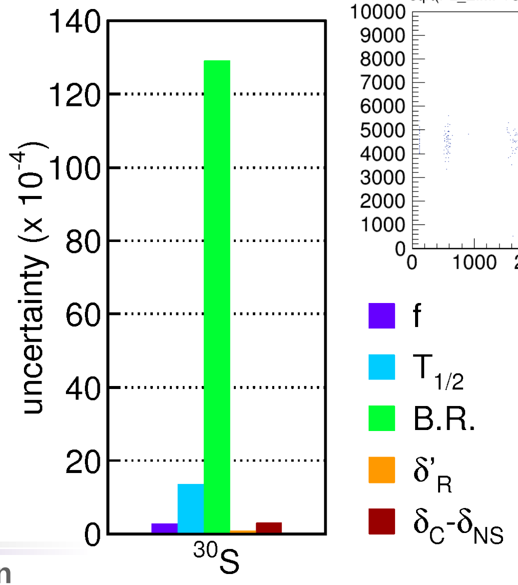
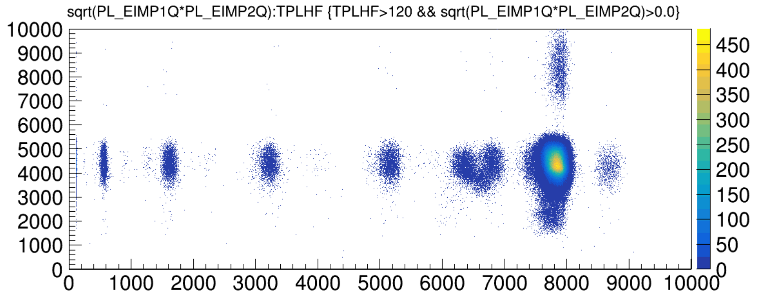
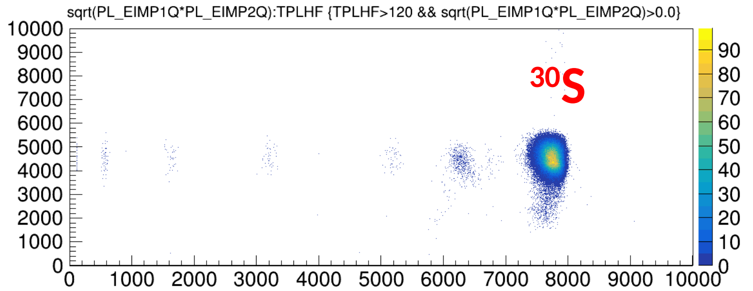


Image: J.-C. Thomas

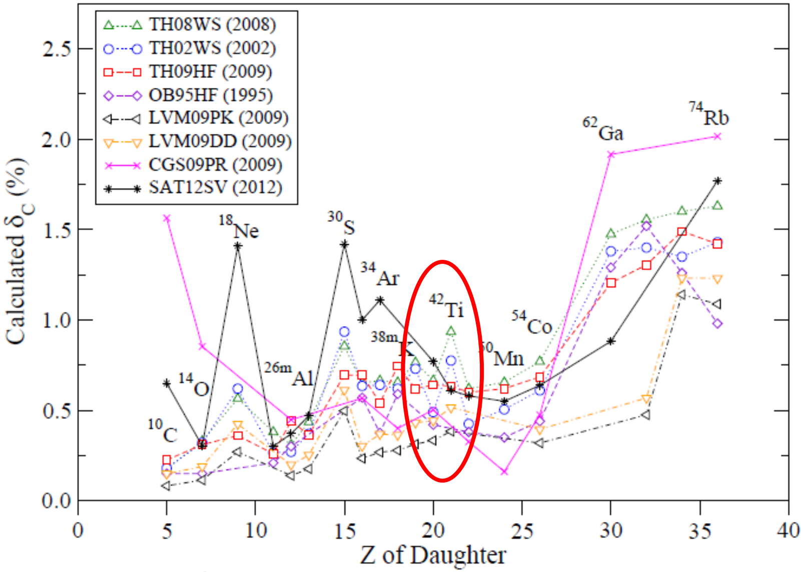


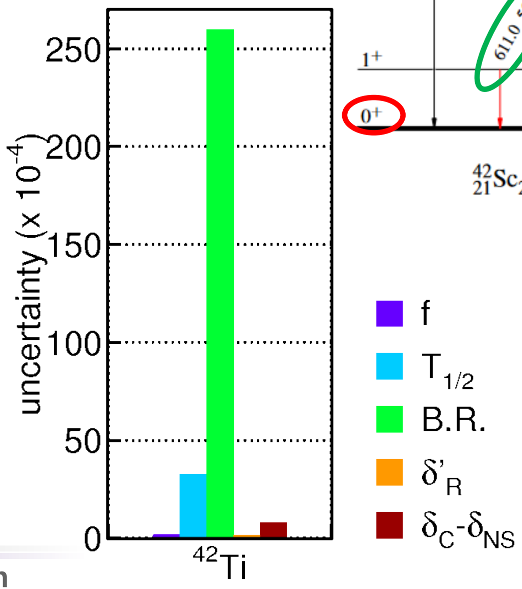


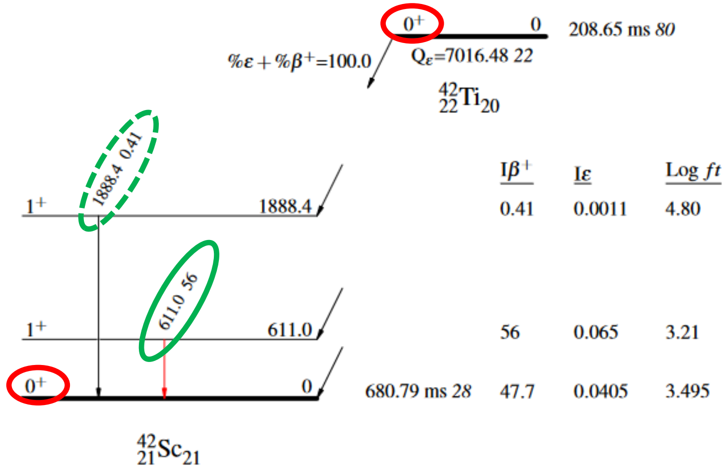


SA decays @ GANIL:LISE (^{38}Ca, ^{30}S, ^{42}Ti)

- Fragmentation ^{46}Ti@70 MeV/A -> ^{42}Ti@35 MeV/A
  - 4.10^4 pps ~99 % purity expected
- Concern about the LISE++ reliability
  - Scan of momentum distributions with CAVIAR
- Future proposal at LISE with Fast Tape System



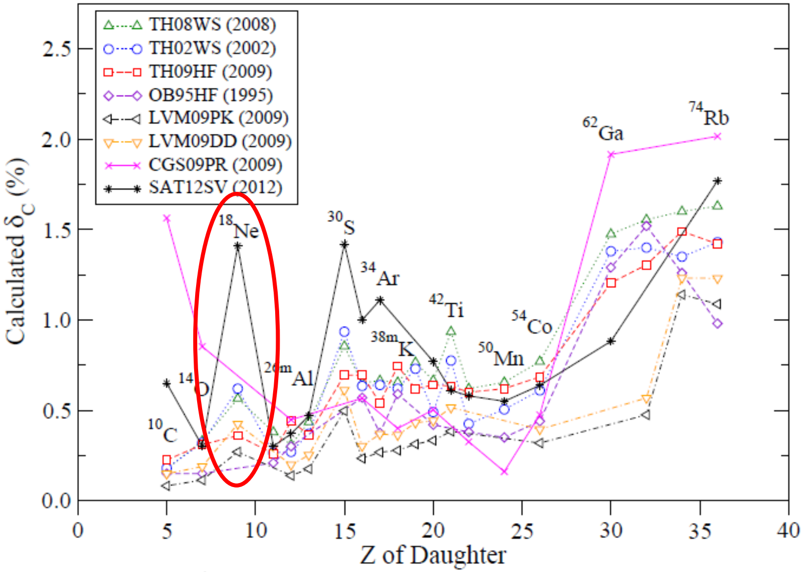


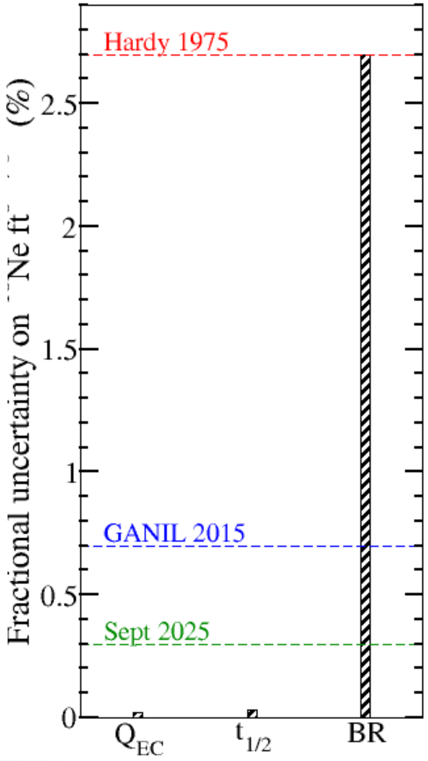


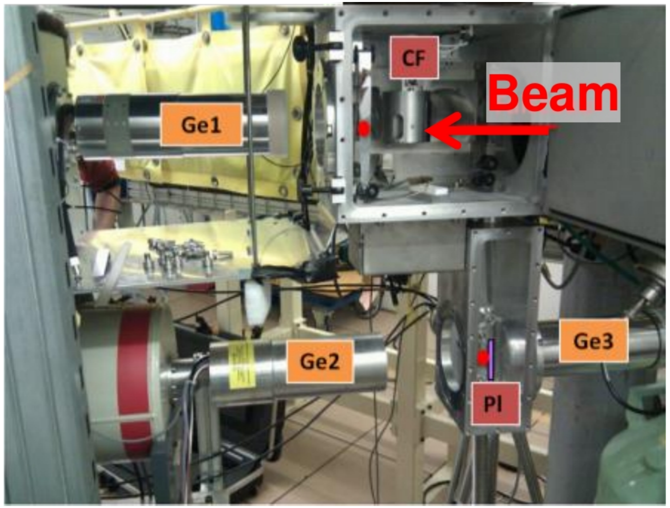
Images: J.-C. Thomas

SA decays @ GANIL:SPIRAL1 (^{18}Ne)

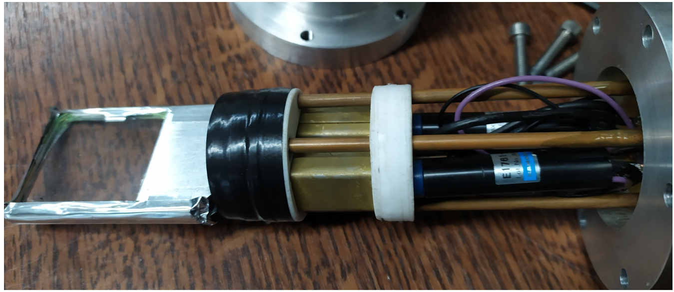
- 25 keV $^{18}Ne^{2+}$ beam
- Implanted on movable aluminized mylar tape
- Plastic scintillator + HPGe
- FASTER DAQ (2ns time resolution)
- Experiment scheduled for **2025**







G.F. Grinyer NIM A **741** (2014) 18-25



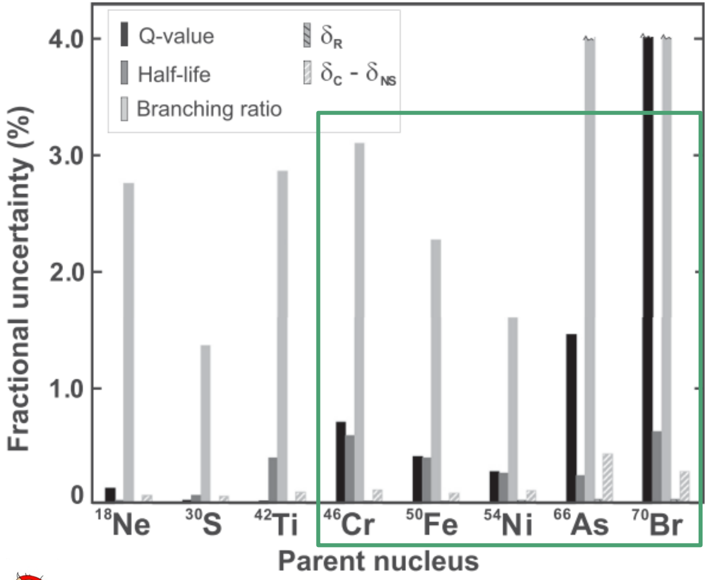
Images: J.-C. Thomas

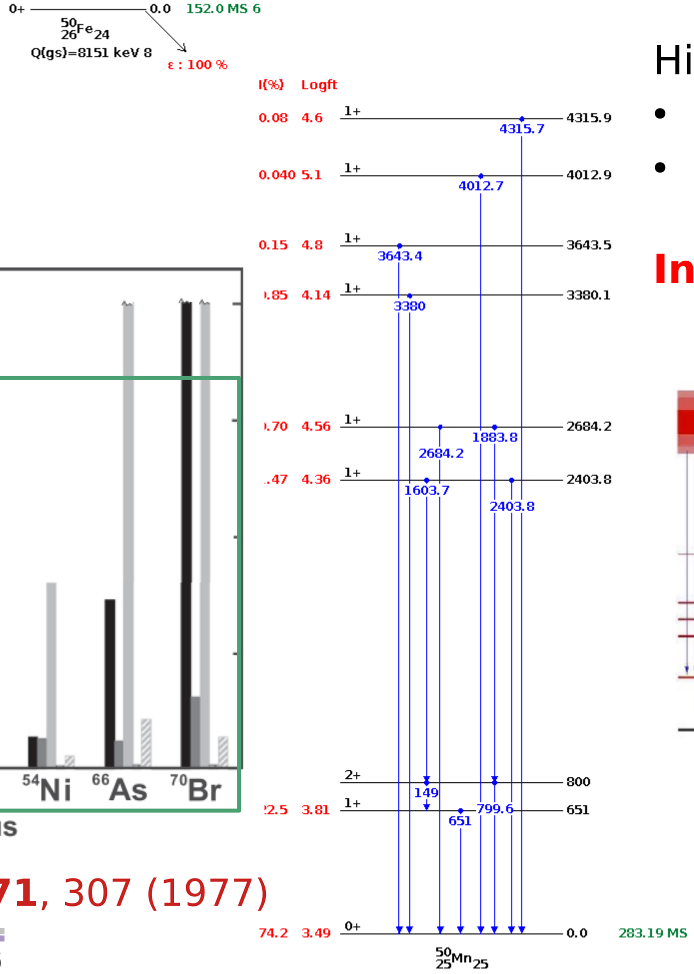
SA decays @ GANIL : What's next??

High resolution germanium detectors:

- low efficiency for large E_γ
- Could miss beta feeding to high energy levels

Incorrect branching ratio





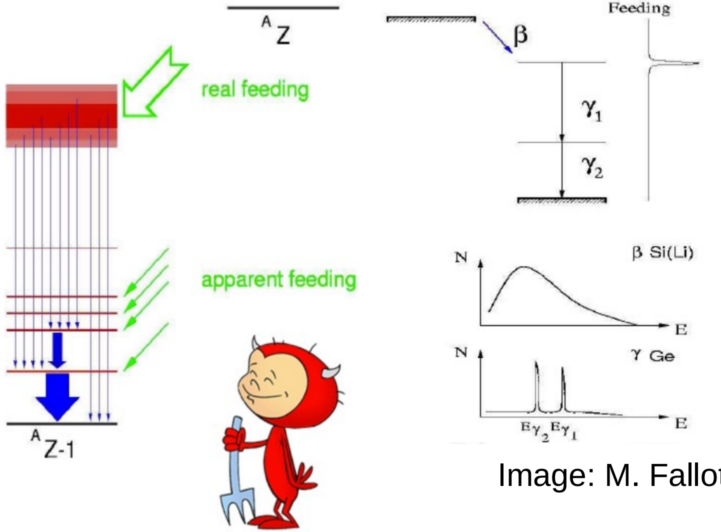
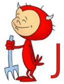


Image: M. Fallot



J.C.Hardy *et al.*, PLB, **71**, 307 (1977)

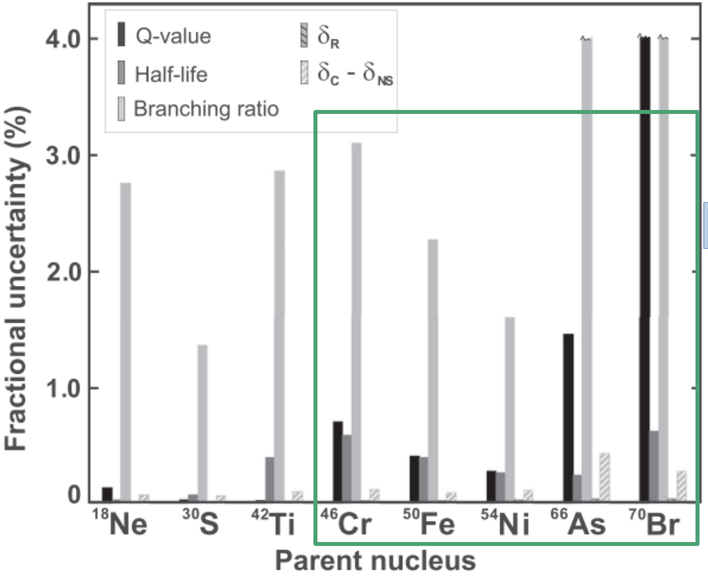
Total Absorption Spectroscopy (TAS)

SA decays @ GANIL : What's next??

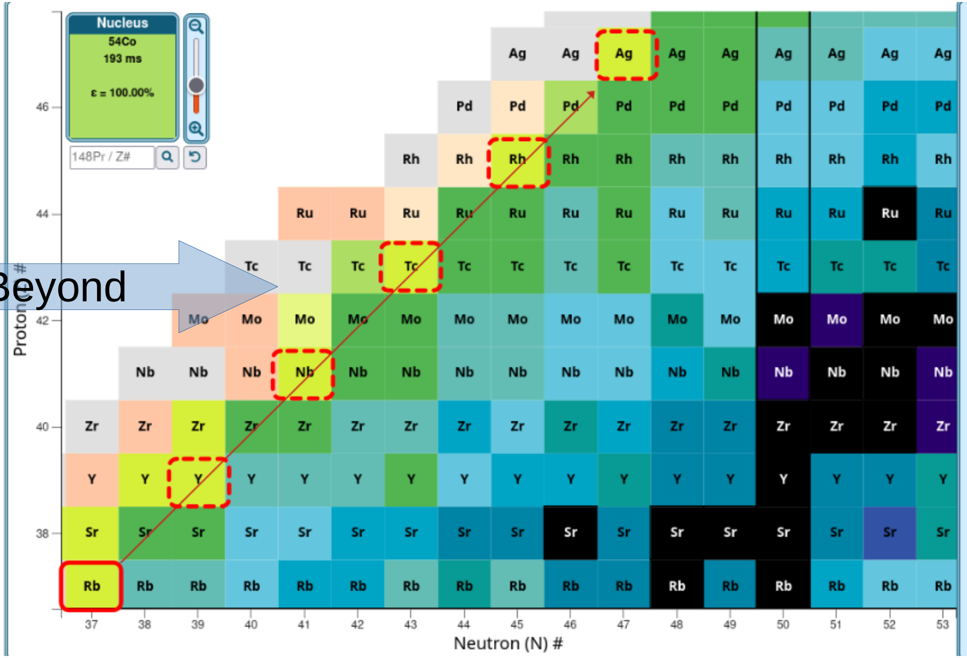
laboratoire commun CEA/DRF CNRS/IN2P3

Test CVC and ISB corrections on a larger scale : heavier super allowed β^+ emitters

- At LISE3: approaching limits on attainable purity required for SA studies
- At SPIRAL1: next SA elements refractory => release times $> t_{½}$

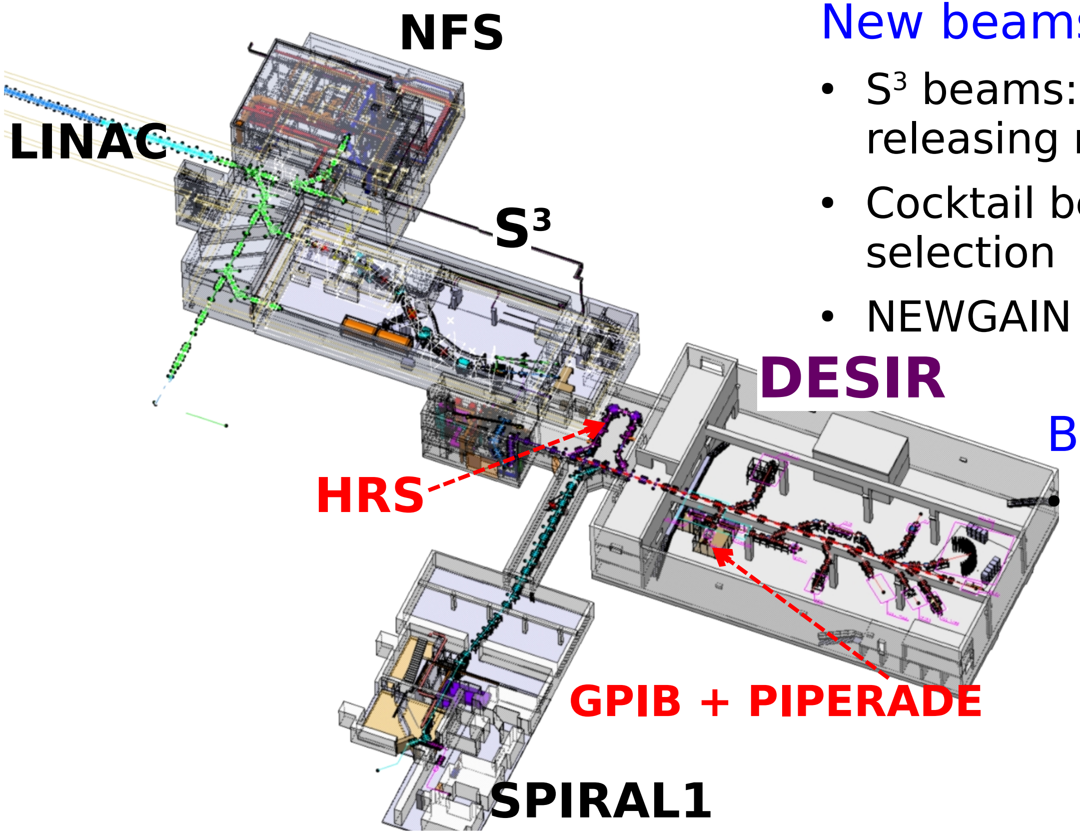


Beyond



Solution: Change RIB production method or improve purification

DESIR (Désintégration, excitation et stockage d'ions radioactifs)



Images from: J.-C. Thomas

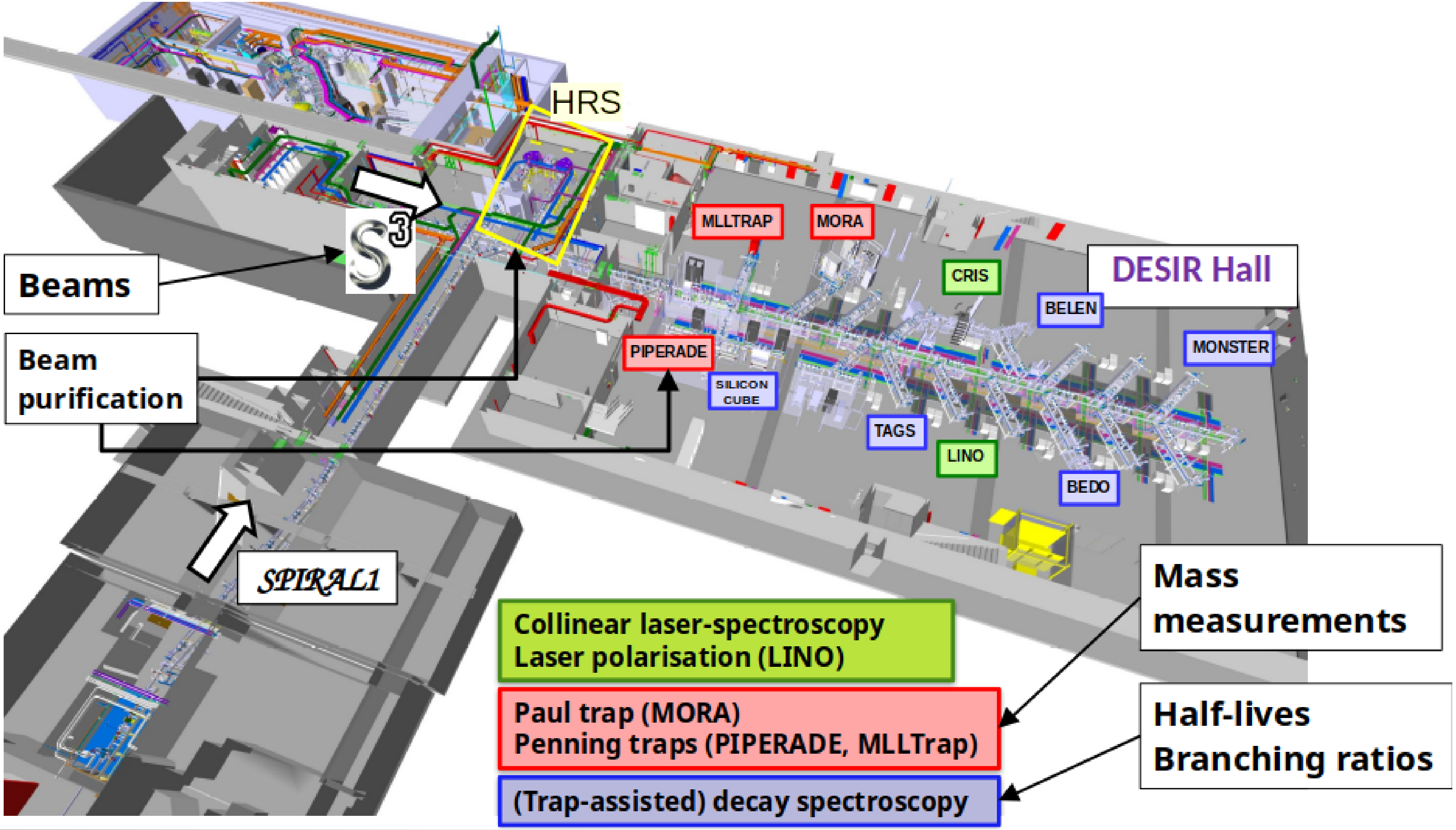
New beams

- S^3 beams: fusion evaporation => no problem releasing refractory elements
- Cocktail beam laser ionized => improved selection
- NEWGAIN : A/Q = 3-7 (existing A/Q=1,2)

Beam purity

- Additional beam purification at entrance of DESIR hall
  - General Purpose Ion Buncher (GPIB)
  - High Resolution Seperator (HRS)
  - Double penning trap (PIPERADE)
  - (MR-TOF-MS)

DESIR – multi experiment setup

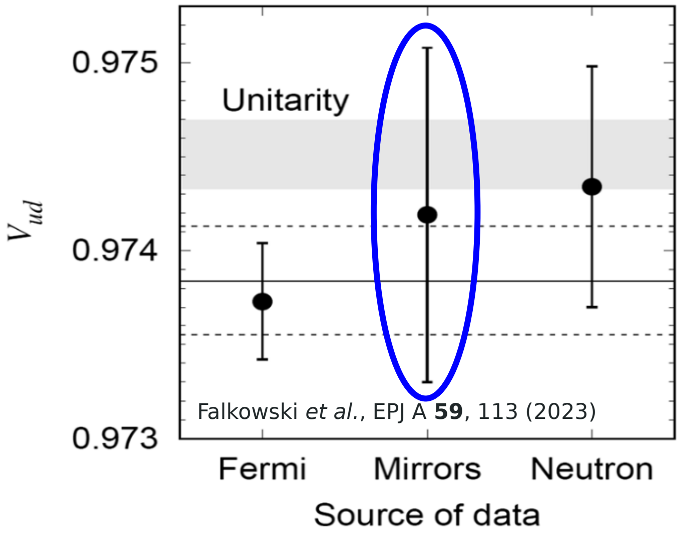


DESIR (MORA): Towards SA mirror decays

Mirror decays

- $J_i = J_f \neq 0$
- T = ½ isospin multiplet

$$2\mathcal{F}t^{0^+\to 0^+} = \mathcal{F}t^{mirror}(1 + \frac{f_A}{f_V}\rho^2) = \frac{K}{2V_{ud}^2 G_F^2 (1 + \Delta_V^R)}$$



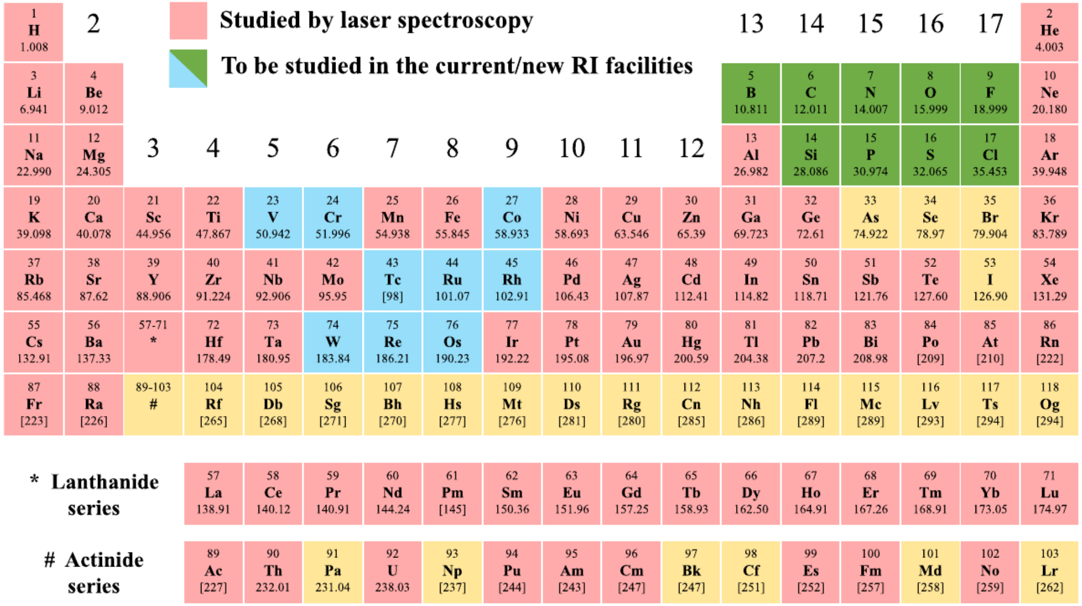
- In addition to BR, $t_{½}$ and masses require
  ρ = Gamow-Teller/Fermi mixing ratio
- Requires correlation measurements
- Beta asymmetry (A_β) : sensitive to right-handed currents

Some challenges

DESIR beams via S³-LEB

1. $t_{½}$ for know (heavier) SA emitters ^{54}Ni - ^{70}Br : **115 ms and less**
    - Current gas cell extraction time 300-600 ms (projected to 50 ms)
    - Could be a major bottleneck

2. LASER ionization schemes currently not available for all SA emitters
    - Need support from LASER community to develop efficient laser ionization schemes



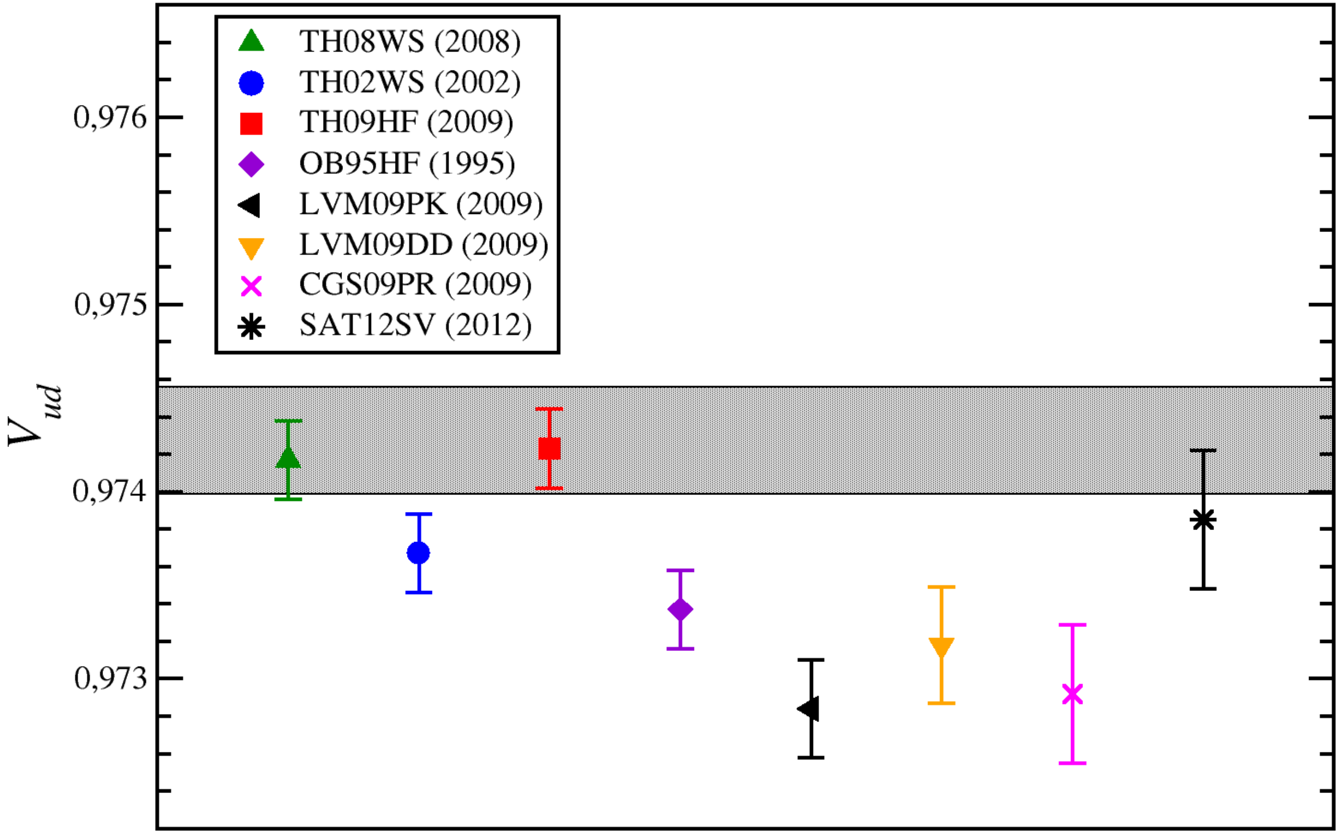
X.F. Yang, *et al.* Prog. Part. Nucl. Phys. **129** (2023) 104005.

DESIR is getting ready …

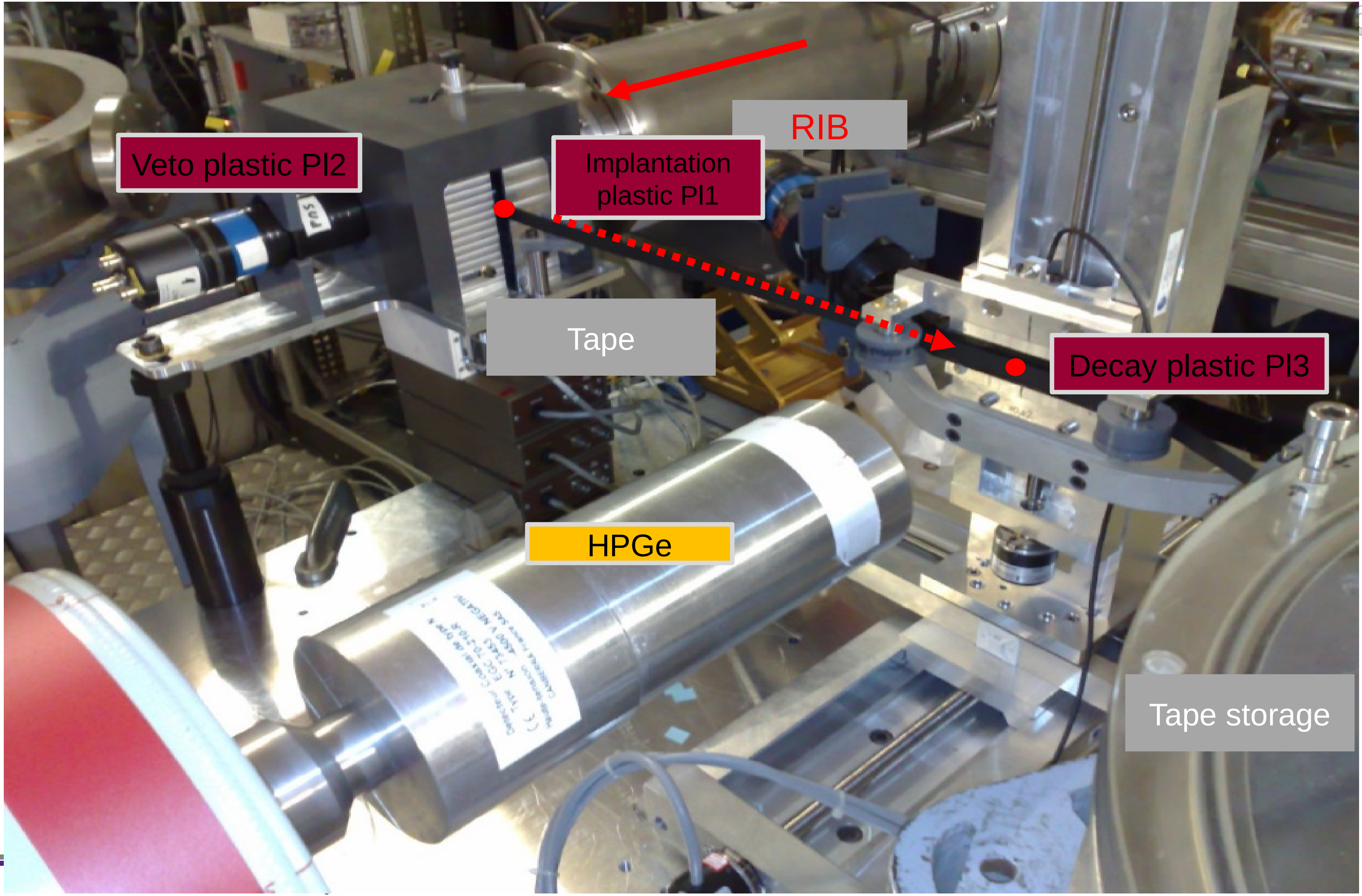
- Next month… installation of building utilities, ventilation, electricity, water supply, etc.
- Bare bones beam operation: May 2025
- First experiment with decay station : December 2027
- Others May 2028++

Thank you for your attention!

Same experimental data corrected by different dC calculations



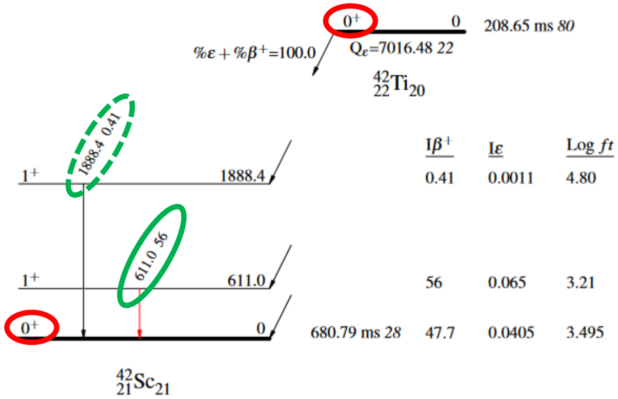
Slide courtesy: J. Grinyer, J.-C. Thomas


RIB
Veto plastic Pl2
Implantation plastic Pl1
Tape
Decay plastic Pl3
HPGe
Tape storage

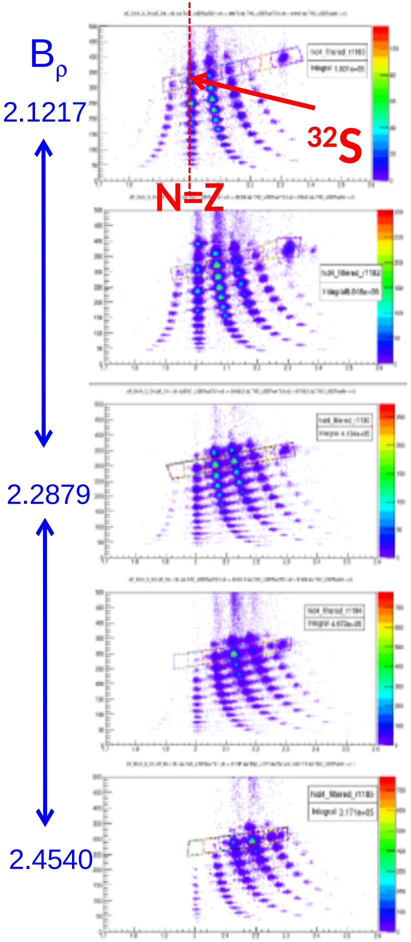
Perspective: ^{42}Ti -> ^{42}Sc

Production: ^{46}Ti@70 MeV/A -> ^{42}Ti@35 MeV/A
-> 4e3 pps/eµA, ~99 % purity expected

However: concern about the LISE++ reliability
-> Scan of momentum distributions with CAVIAR (ongoing analysis)

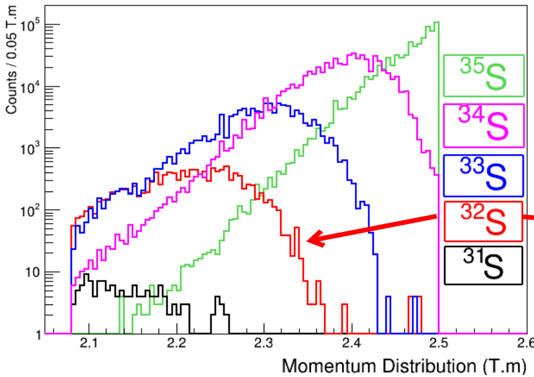


^{36}S -> $^{32-34}S$ momentum scans

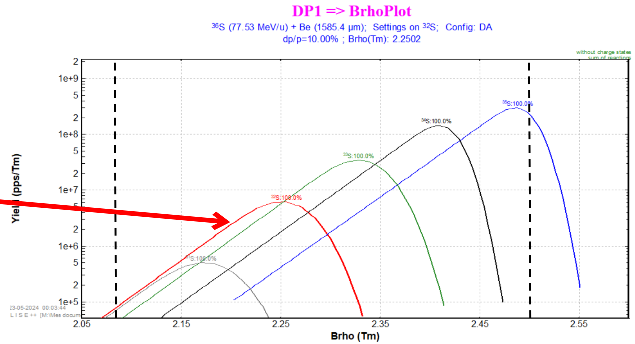


- 5 $B_{\rho1}$=$B_{\rho2}$ settings with F31 = ±30 mm

Experiment



LISE++ (Tarasov Opt. 1)



[2.08,2.5] T.m scan, i.e. 14.6%

Isotope	Max dist. Exp. (T.m)	Max dist. LISE++ (T.m)*
^{32}S	2.25	2.25
^{33}S	2.31	2.33
^{34}S	2.41	2.41

*** Assuming the target was at 10°**

-> target deconvolution to deduce the actual momentum distribution to be used in LISE++

-> absolute production cross sections: primary beam intensity measurement required

What are Superallowed beta decays??

β^+ decays between isobaric analog states (IAS) in mirror nuclei => $J_i = J_f$

Two class of SA decays

Fermi decays

- $J_i = J_f = 0^+$
- T = 1 isospin multiplet

Mirror decays

- $J_i = J_f \neq 0$
- T = ½ isospin multiplet

Located on the neutron deficit side of the nuclear chart