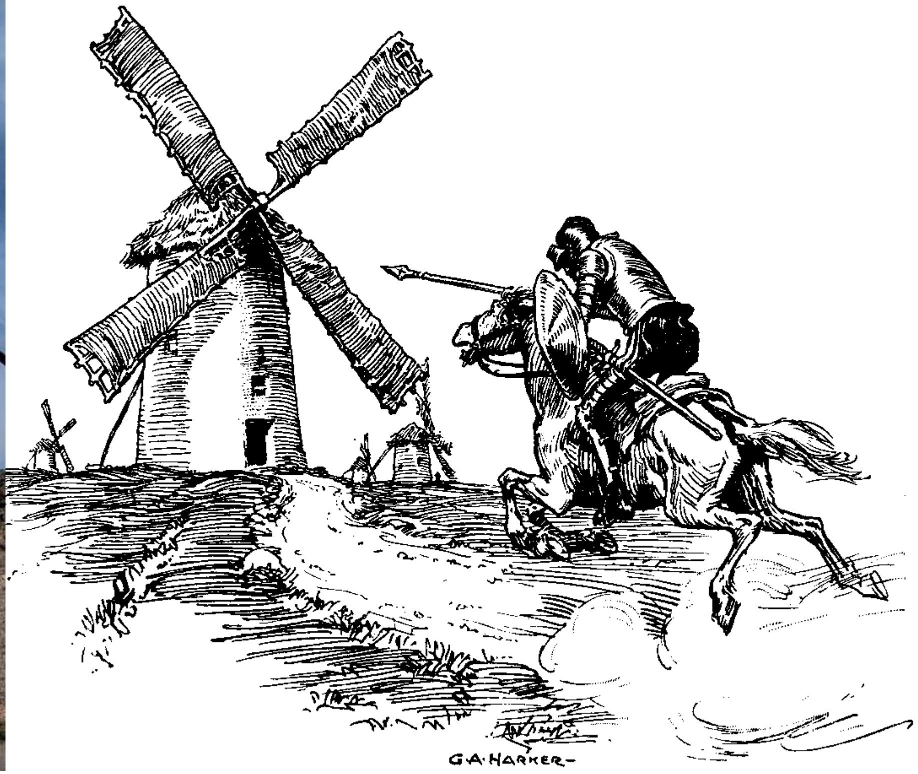


The Quest for ^{14}Be (4.35 ms half-life)

Aurelia Laxdal

Science Week 2025

Challenges:

- Extraction of ^{14}Be from the ISAC targets
- Increase the production of ^{12}Be and ^{11}Li

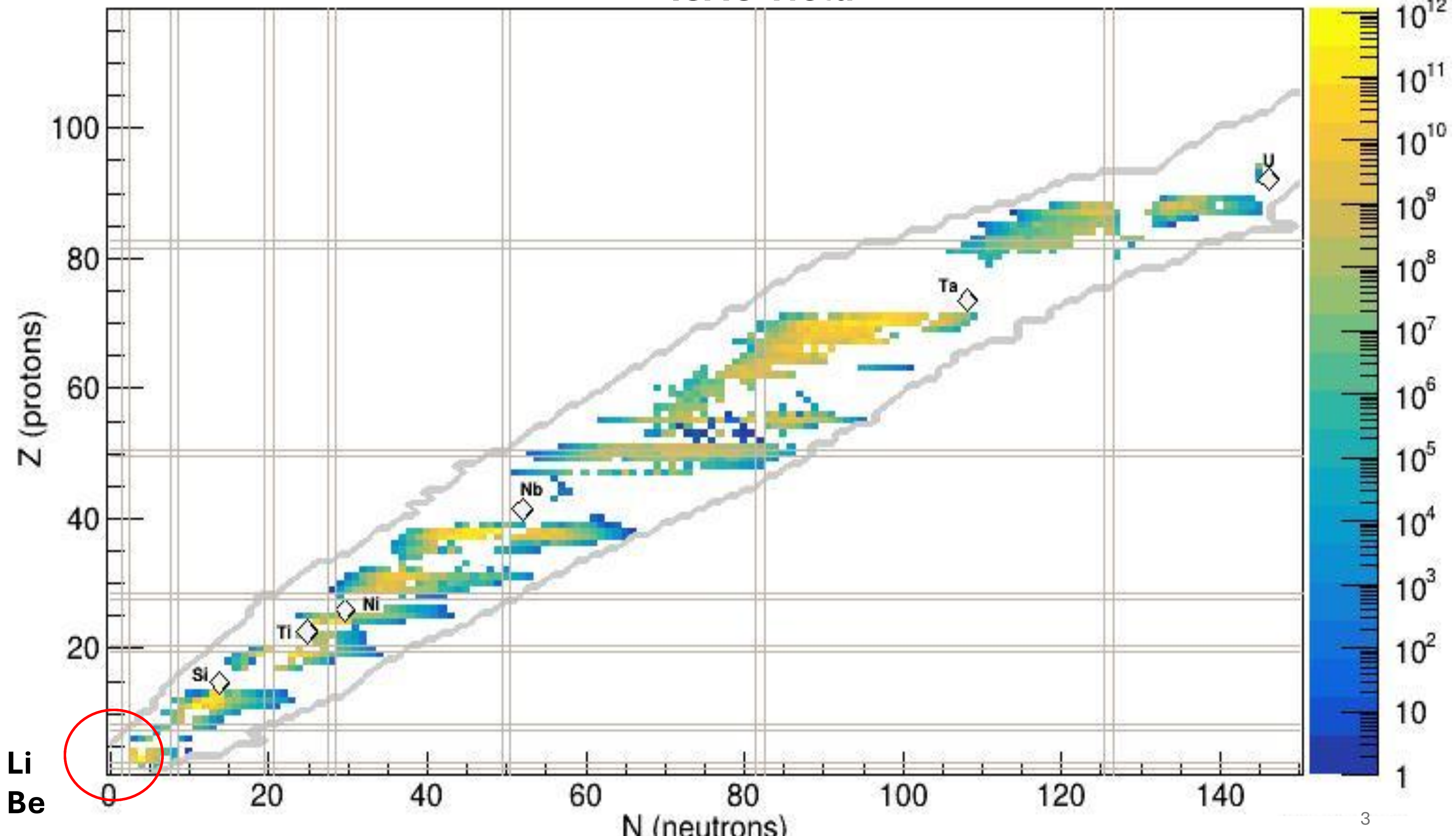
Reasons:

- LOIS1054 “Study of β-decay of Halo Nucleus ^{14}Be” – 8PI/GRIFFIN
- LOIS1621 “Detailed studies of nuclei close to the neutron drip-line” – TITAN including Penning-trap mass measurement of the light ^{14}Be
- PhD project

Isotopes	Half-life	ISAC Yields (average) [ions/sec]	In-target production [isotope/sec/(mmol/cm^2)/ μA p+]
^{11}Li	8.75 ms	1.86×10^4	8.74×10^2
^{10}Be	1.51×10^6 y	1.20×10^8	2.93×10^6
^{11}Be	13.76 s	1.27×10^6	1.49×10^5
^{12}Be	21.30 ms	2.86×10^3	2.58×10^4
^{14}Be	4.35 ms	-	3.74×10^2

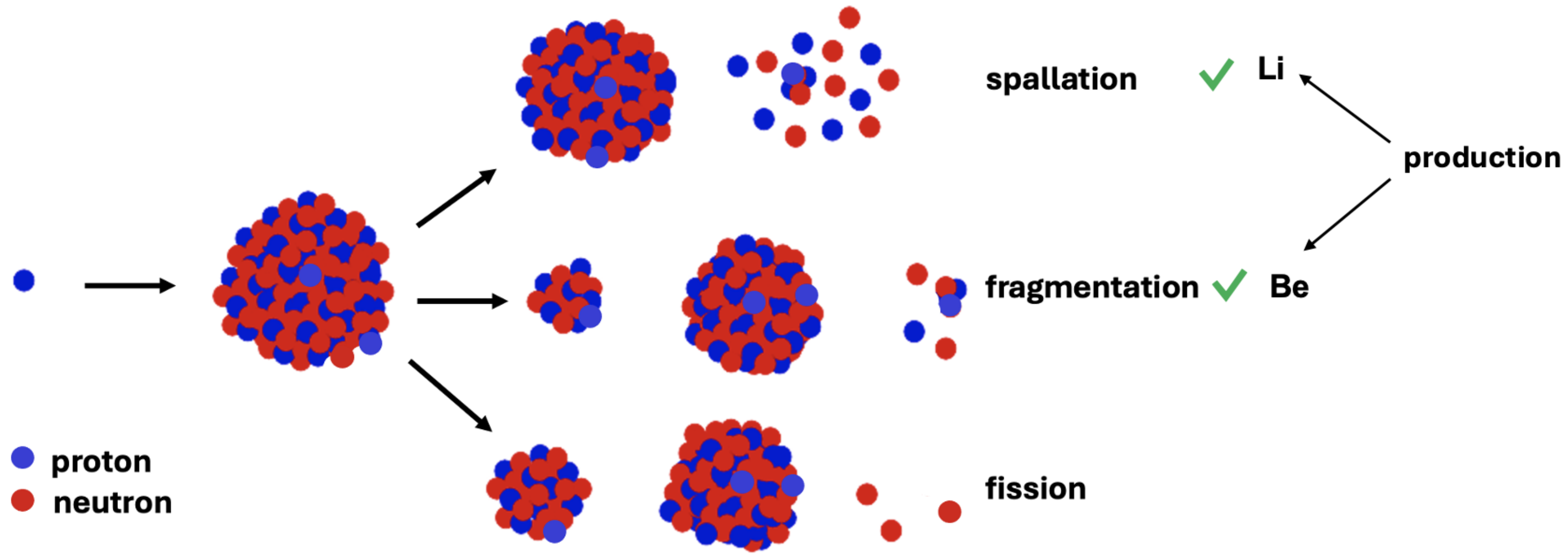
Processes are dominated by the half-life

ISAC Yield



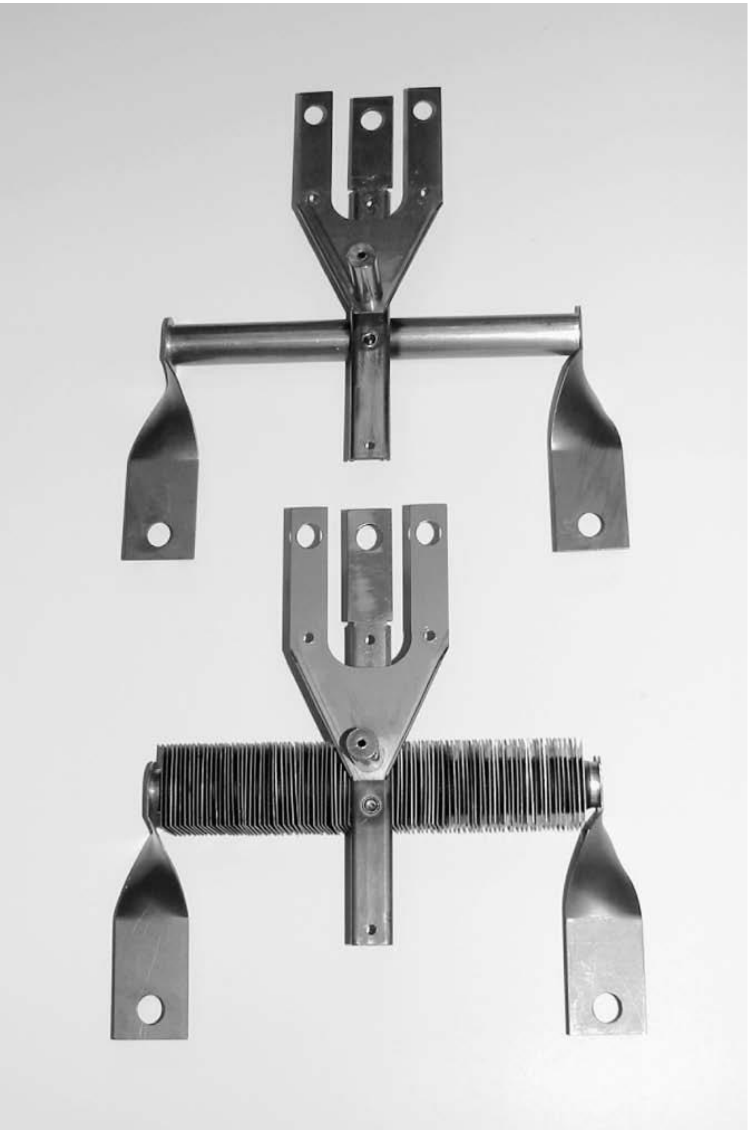
Courtesy of Peter Kunz

Li and Be production in ISOL facilities



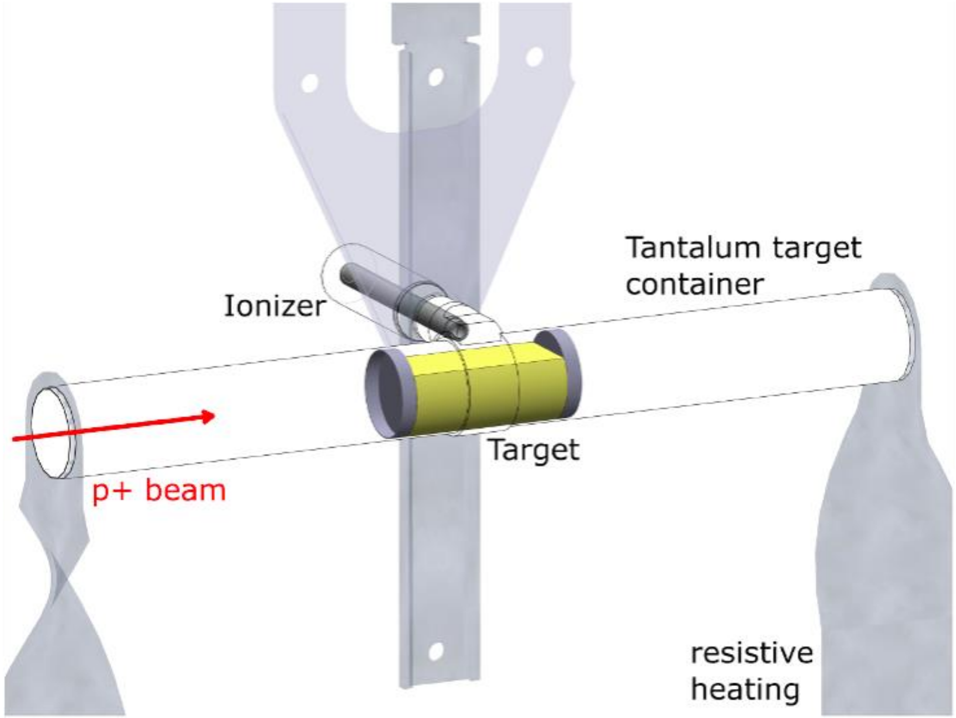
ISAC targets

Li and Be beams



Target materials: D-shaped
- **metal foils: Ta (25.4 μm)**, Nb
- graphite
- composite carbide on graphite backing foils: ZrC , TiC, SiC, UCx,
- composite oxide on metal backing foils: NiO

Target Containers: tantalum
- **Low Power target container**
  -> low intensity p^+
- High Power target container
  -> high intensity p^+



Ion sources:
SIS, FEBIAD, **LIS**, IG-LIS

Strategies

1. Target design

-> check current efficiency

➔ consider re-design: use thinner Ta target foils 10 μm

Ta#67

2. Ionization efficiency

- **Surface ionization -> Li**
- **Laser ionization -> Be**

3. Use rotating p^+ beam

-> increase p+ beam: 85 μA

4. Analyze Yield measurements of previous targets

5. Detection

- **previously at the Yield Station**
- **GRIFFIN**

RIB yields

$$I_{yield} = \varepsilon\, \sigma\, N_{target}\, \Phi_p$$

[ions/sec]

- ε → efficiency [%]
- σ → production cross-section [cm^2]
- N_{target} → **target thickness** [nuclei/cm^2]
- Φ_p → proton flux -> increase p^+ beam by 1.5 using **rotating p^+ beam** [particles/sec]

$$I_{yield} = \varepsilon\, I_{production}$$

[ions/sec]

- ε → efficiency [%]
- $I_{production}$ → in-target-production rate: Fluka, Geant4, etc. [ions/sec]

Transmission and Ionization efficiencies

82%
transmission

$$I_{yield} = I_{production} * \varepsilon_T * \varepsilon_I * \varepsilon_R$$

$I_{production}$ → in-target-production

ε_T → 82% transmission

ε_R → release efficiency of the target

ε_I →

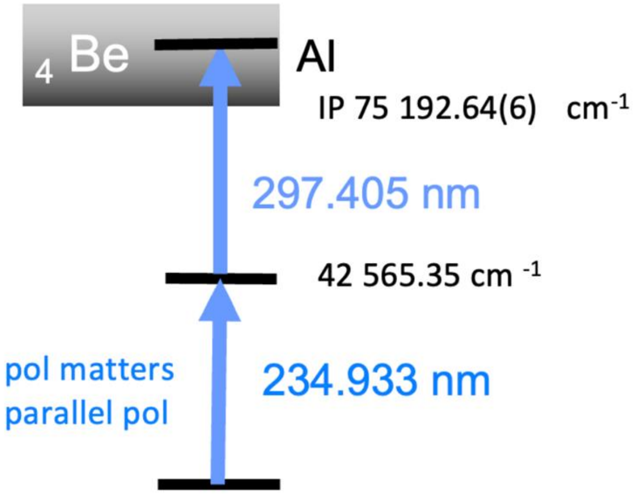
- Li surface ionized: 6.66%

from Saha-Langmuir equation
for a work function of rhenium at 2300 deg C

$$\frac{\Phi}{\Phi_0} = \epsilon_{is} e^{\frac{W - I_p}{kT}}$$

$\frac{\Phi}{\Phi_0}$: ion flux over neutral flux ratio per unit surface area
ϵ_{is} : ion source coefficient (super simplification ϵis = 1)
I_p : ionization potential
W : work function of surface (W_{Ta} = 4.12eV, W_{Re} = 5.10eV)
kT : Boltzmann constant (8.63 · 10−5 eV/K), surface temperature K

$_4$Be laser ionization scheme (Jens Lassen)



- Be laser ionized: 2-10%

-> optimize lasers for ^{12}Be
-> apply isotope shift and excitation scheme of ^{14}Be (V. Sebastian – PhD thesis)

$\varepsilon = \varepsilon_T \ \varepsilon_I \ \varepsilon_R$

$\varepsilon_R \rightarrow \varepsilon_D \ \varepsilon_E$

Solved via separation of variables assuming:
uniform temperature,
concentration,
and 1-dimensional

$$\begin{cases} J = -D \, \nabla C \\ \frac{\partial c}{\partial t} = D \, \nabla^2 C \end{cases}$$

Diffusion of atoms out of the target material (foil)

ε_D → Calculations: Fick's equations:
flux of particles coming out of the foil

- reduced the diffusion time:

-> **use thinner foils**

Arrhenius' equation: $D = D_0 \cdot e^{-\Delta H / RT}$

shows increase of diffusion with temperature

Estimation: characteristic diffusion time: 70% of atoms diffuse out

$$\tau_d = \frac{d^2}{\pi^2 D}$$

→ $\tau_{d\_10\mu m}$ -> 6.5 x faster diffusion time vs. $\tau_{d\_25.4\mu m}$

$\tau_{d\_10\mu m}$ -> 11 x faster diffusion time vs. $\tau_{d\_33\mu m}$

(B. Mustapha and J. A. Nolen – 2003 Elsevier)

Diffusion simulations: Monte Carlo simulations

Diffusion is the dominant slow process

Effusion of atoms out of the target container

ε_E → **Effusion simulations:** Monte Carlo simulations

Probability of escape from a surface:

$$\nu = \nu_0 \cdot e^{-\Delta H_{ads} / RT}$$

Sticking time:

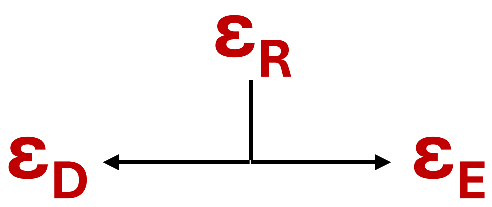
$t_s = 1 / \nu$

- reduce the effusion time:

reduced the number of collisions

-> foils arrangement

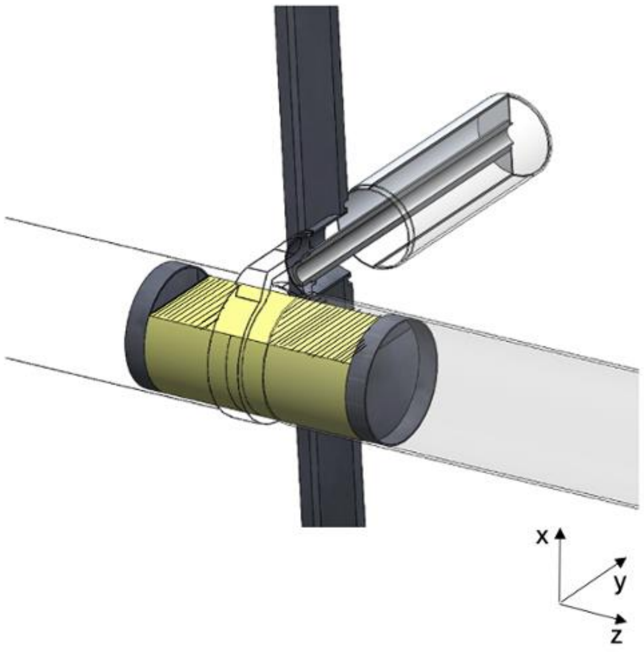
Diffusion of isotopes

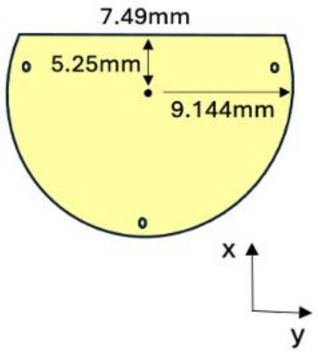


Diffusion of isotopes out of the foils

Ta foils used in ISAC: 25 μm thick dimpled D-shaped

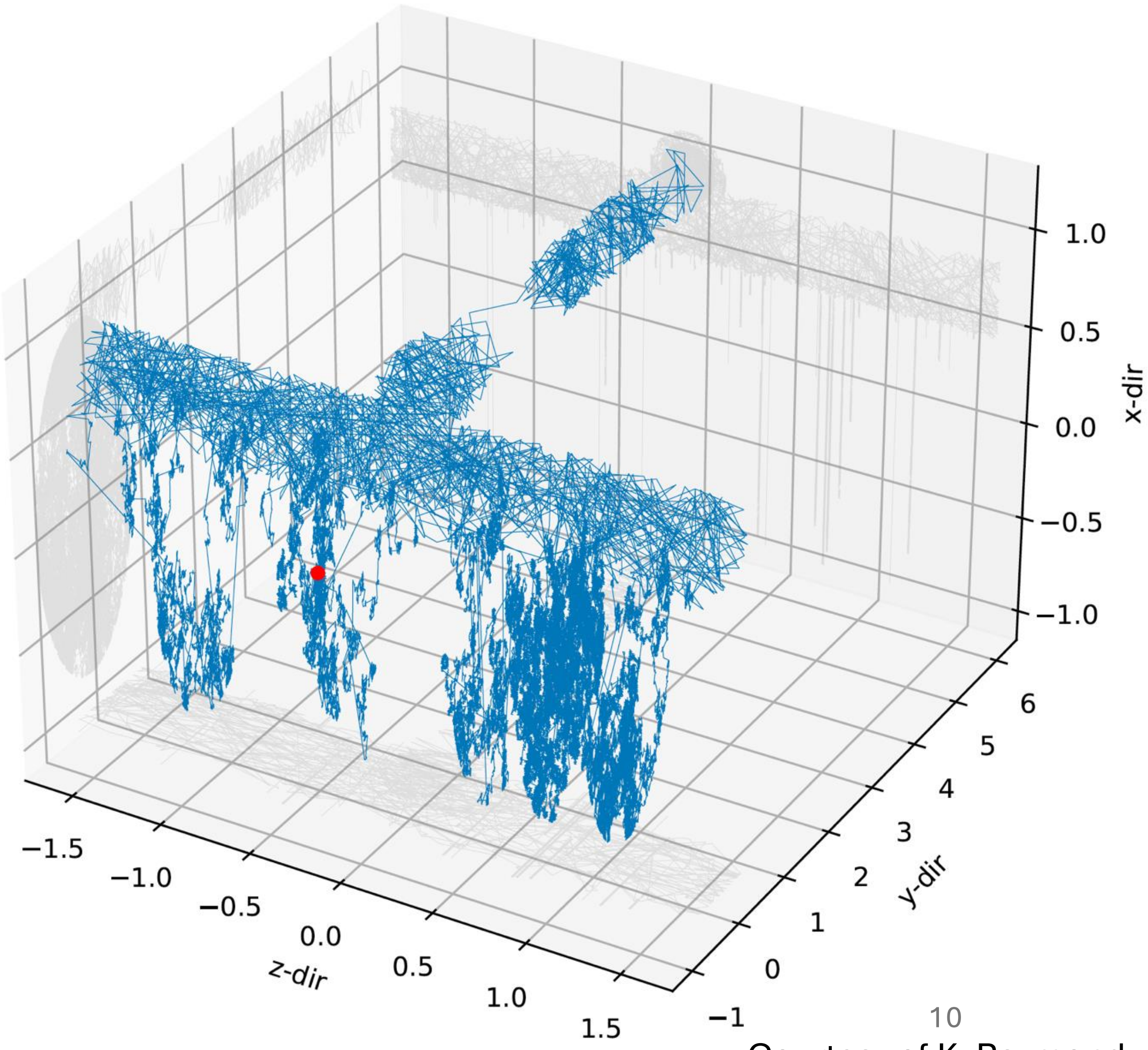
ISAC Ta target: 470 foils -> 3.4 cm long target





Effusion simulations (RIBO) of ^{8}Li through the foils, out of the target container

- on average 477,410 collisions with the surfaces of the foils, target container and ionizer



Courtesy of K. Raymond

Before the experiment

ISAC Targets	Regular Ta LP	Ta 65	Ta 66	Ta 67
Foils thickness [μm]	25.4	33	33	**10**
Target length [cm]	3.4	3.4	5	3.75
Gap in between foils [μm]	4.7	3.9	7.3	**6.23**
Total target mass [g]	50	62.11	62.23	16.85
Target thickness [g/cm^2]	23.58	29.30	29.35	7.95
Target thickness [$mmol/cm^2$]	130.2	161.79	162.26	43.94
Maximum p+ [μA] stationary beam	40	30	**30**	**60**
Maximum p+ [μA] rotating beam	60	40	-	**95**

33.7% target thickness of the standard target

	From Yield database [isotopes/sec]	Measurement [isotopes/sec]	Measurement [isotopes/sec]	
Li8	**6E+8**	6.55E+8	5.8E+8	
			2.3E+8	
I_{FLUKA} 2011 Yield database (minimum) [isotopes/sec]	7.66E+09	7.13E+09	9.54E+09	5.66E+09
Li9	**4E+7**		3.9E+7	
		1.41E+7	2.4E+7	
I_{FLUKA} 2011 Yield database (minimum) [isotopes/sec]	1.12E+09	1.04E+09	1.05E+09	8.28E+08
Li11	**1.86E+4**	**8.6E+3**	**5.7E+3**	
		1.7E+3	**2.5E+3**	
I_{FLUKA} 2011 Yield database (minimum) [isotopes/sec]	4.55E+06	4.24E+06	4.25E+06	3.36E+06

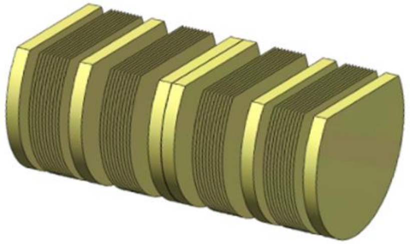
Li8 and Li9 yields are comparable regardless of the foils' thickness

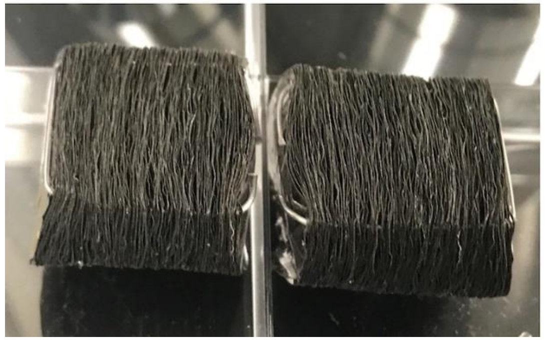
Li11 yields are lower for the 33-micron thick foils

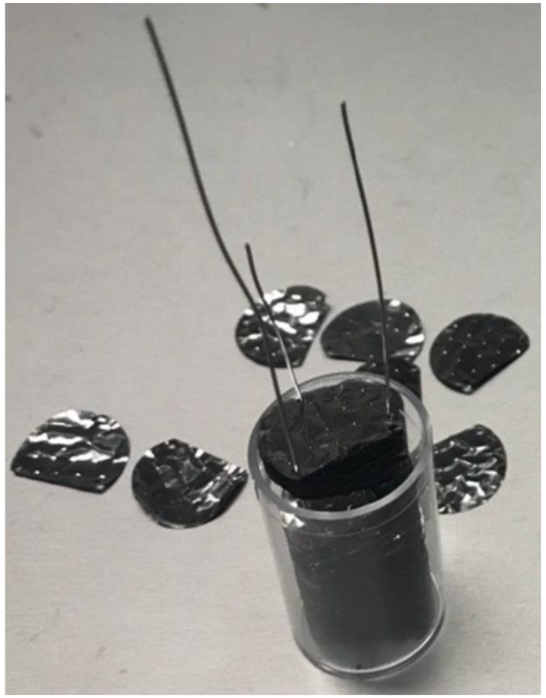
Ta Target Assembly

Standard Ta target:
3.4 cm long target
made with packs of 20 foils & loose foils: 470 foils in total
25.4 μm thick
gap in between foils: 4.7 μm

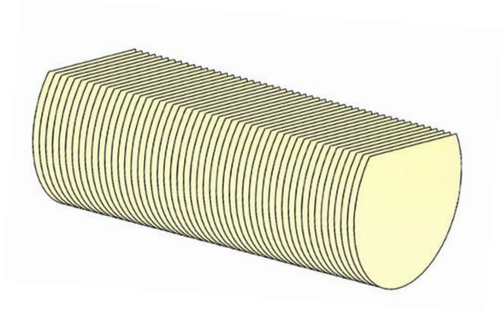
1 pack / 75 singles / 1 pack / 100 singles / 2 packs / 100 singles / 1 pack / 75 singles / 1 pack
← center →



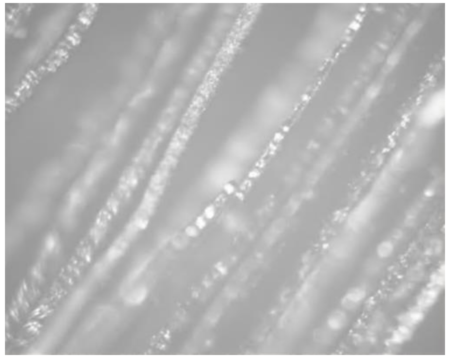




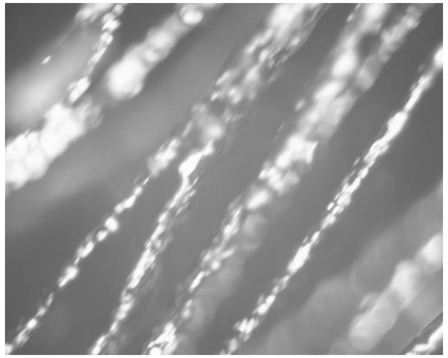
Thin Ta foil target: Ta#67
3.4 cm long target
made 2 packs of with 375 foils each
10 μm thick
gap in between foils: 6.23 μm



25.4 μm thick foils
half pack = 1.7 cm long



10 μm thick foil
half pack = 1.7 cm long



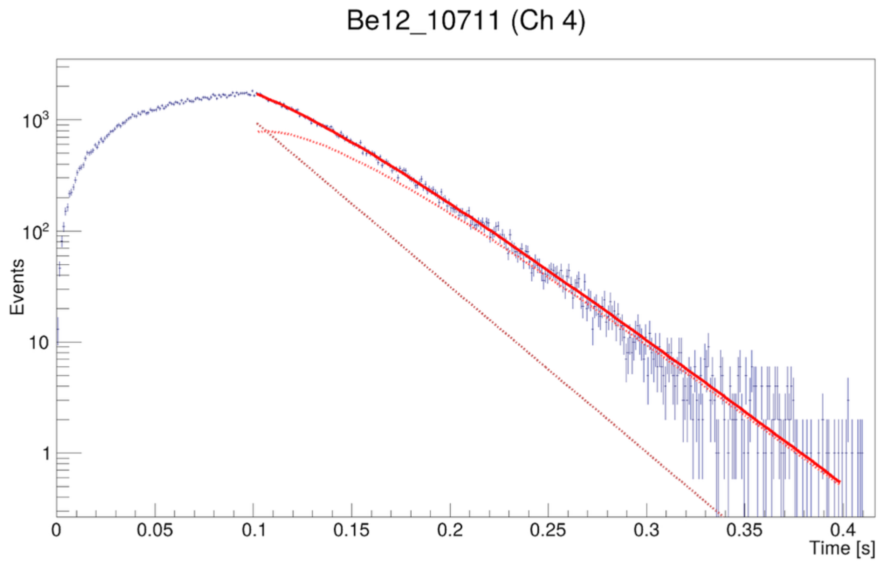
Highlights of the experiment

Isotope	Half-life	Ta67 yields [ions/sec]	Rotating p^+ [μA]
^{11}Be	13.76s	3.70E+06	65
^{12}Be	21.30ms	**1.82E+04**	80
^{11}Li	8.75ms	4.80E+04	80
^{9}Li	178.3ms	1.50E+08	60
^{8}Li	839.9ms	1.60E+09	60

Historical yields [ions/sec]	Rotating p^+ [μA]
2.59E+06	60
5.56E+03	60
5.33E+04	60
6.85E+07	55
1.37E+09	60

Detection

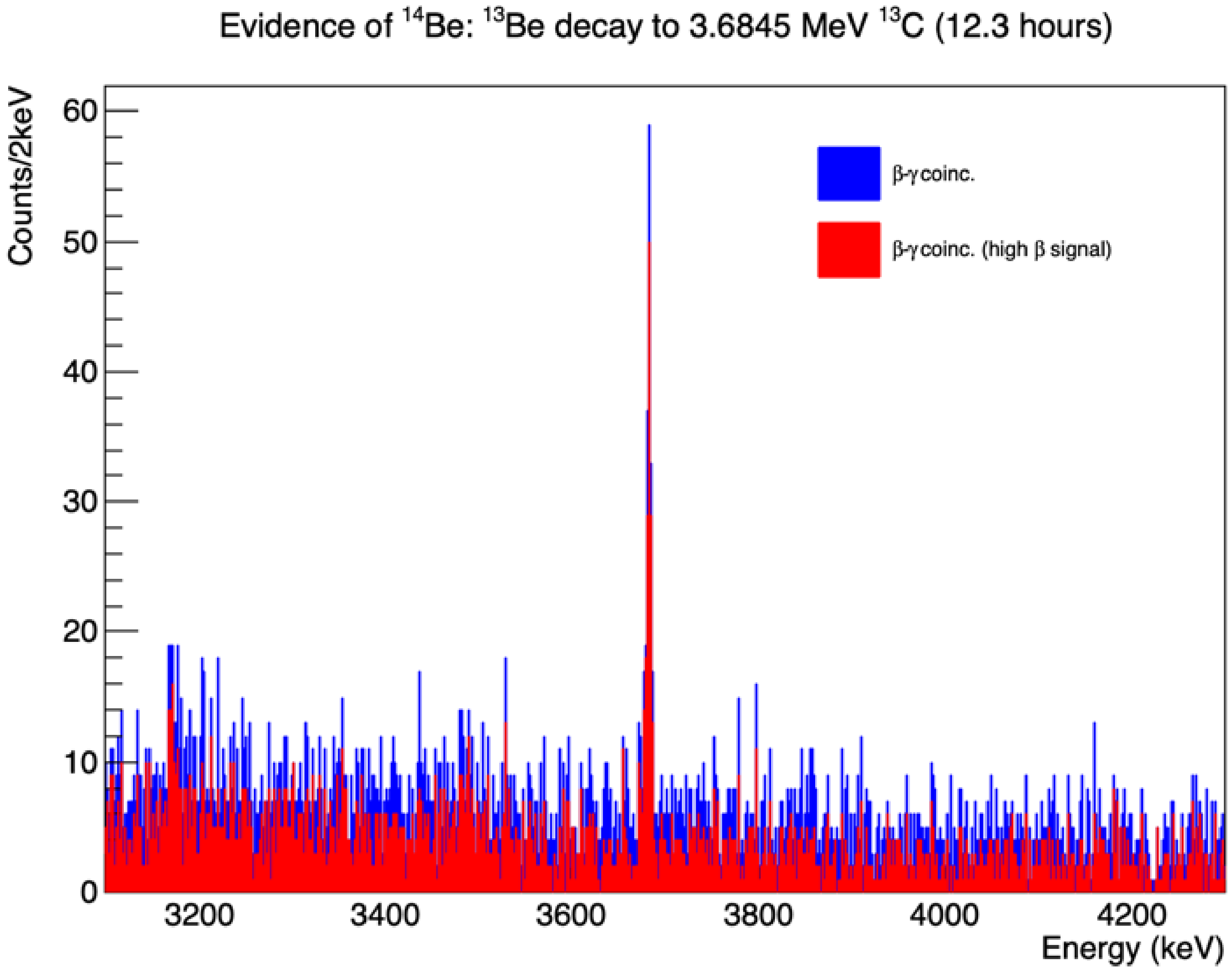
Beta decay

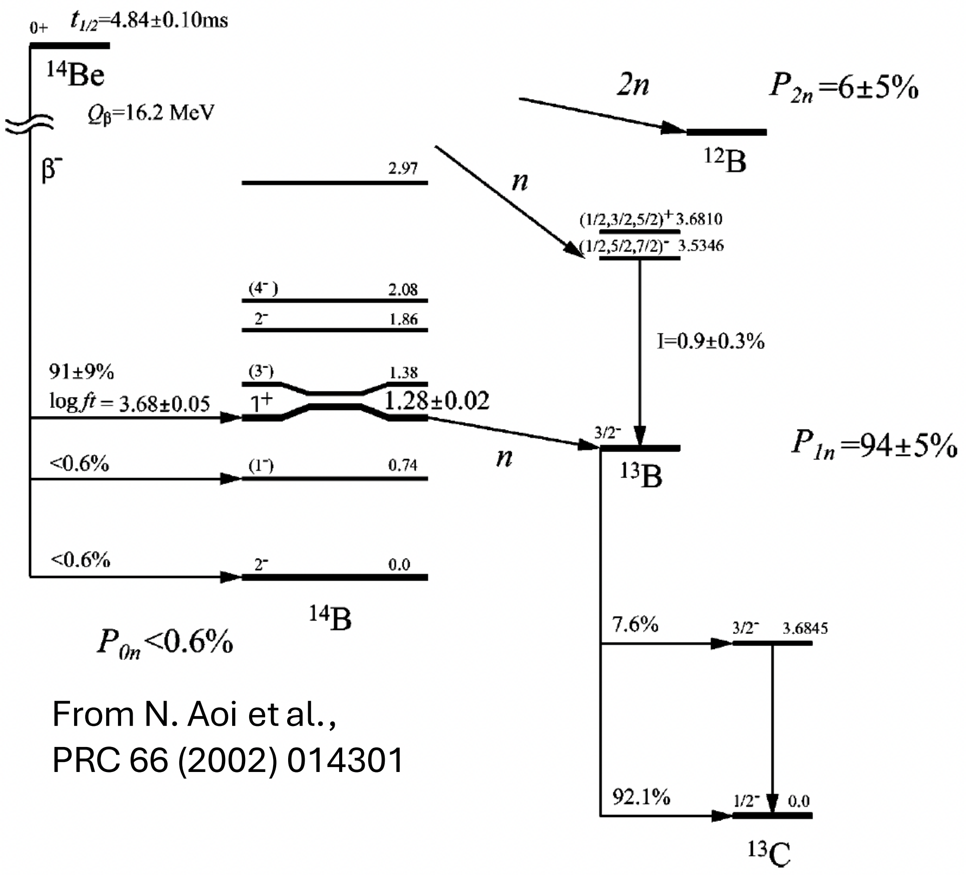


Beta decay

Beta – Gamma coincidence

Evidence of ^{14}Be at the GRIFFIN spectrometer





From N. Aoi et al.,
PRC 66 (2002) 014301

Counts in the peak:	165 (blue)
Total time*:	12.3 hours
Est. gamma eff.:	6% @ 3.6 MeV
Est. beta eff:	80%
Beta-n:	90% (see Aoi et al.)
^{13}B to ^{13}C (3.68MeV)	7.6% (see Aoi et al.)
Est. ^{14}Be rate (/s):	1.13 for this calculation

* Includes different p+ intensity and various magnet settings (hence the ^{14}Be rate for a “good” setting is likely greater than 1 pps).

Courtesy of Fred Sarazin & GRIFFIN group

Future work

Ionization efficiency	• improve the **stability and accuracy of the laser** • use new crystal	} for ^{12}Be
Target foils	• optimize foil thickness: thinner foils	
Rotating p+ beam	• find optimal p^+ beam rotation settings for the ^{12}Be releases	
Mass separation	• Optimize/control the mass separation (separator magnets)	

Future goals

-> Measure the isotope shift of ^{14}Be

-> LOIS1621 "Detailed studies of nuclei close to the neutron drip-line" – TITAN including Penning-trap mass measurement of the light ^{14}Be

Thank you

to all the department, groups and people that help with this experiment

GRIFFIN Group

Targets R&D Group

Beam Physics and Delivery

TPO group

Driver Ops & RIB Ops