EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

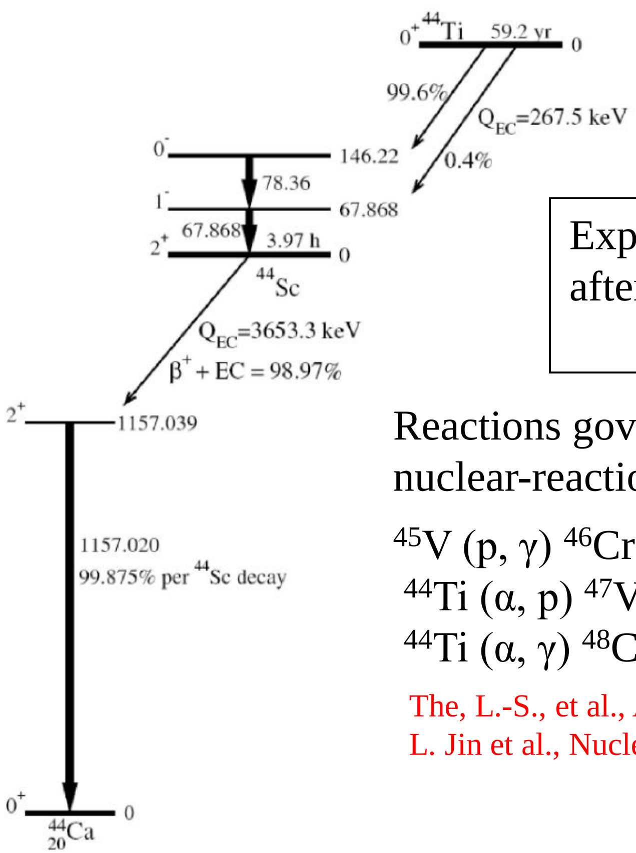
Study of the beta delayed particle emission from ^{48}Mn and its relevance for explosive nucleosynthesis (P-445)

Spokespersons: I. Martel, O. Tengblad

Local contact: Miguel Madurga

Motivations

One of the open problems in galactic chemical evolution is the source of ^{44}Ca; the dominant production channel is believed to be ^{44}Ti nucleosynthesis at core collapse supernovae.



The ^{44}Ti→^{44}Sc→^{44}Ca decay chain produces characteristic gamma lines that have been observed in young SNRs:
1157 keV from ^{44}Ca, and 78.4 keV, 67.9 keV from ^{44}Sc.

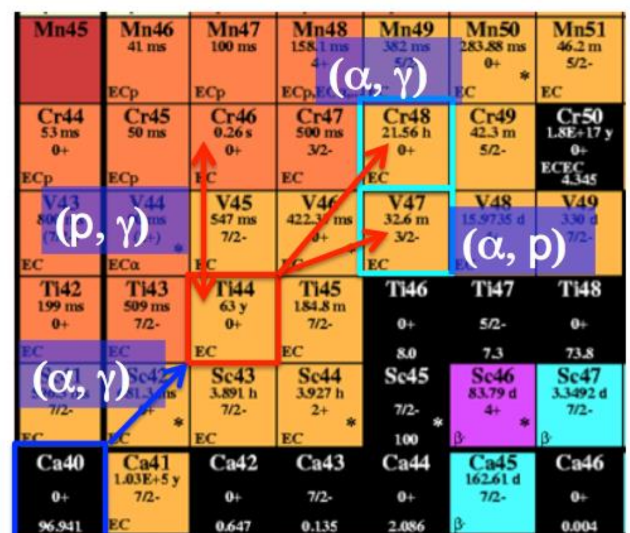
Expected synthesis of ^{44}Ti taking place at core collapse supernovae after alpha-rich freeze-out. Main production reaction:
^{40}Ca (α, γ) ^{44}Ti → Recent measurements @ (TRIUMF)

Reactions governing the abundance of ^{44}Ti have been investigated by using large nuclear-reaction network calculations.

^{45}V (p, γ) ^{46}Cr
^{44}Ti (α, p) ^{47}V
^{44}Ti (α, γ) ^{48}Cr

E ~3 – 7 MeV

The, L.-S., et al., A&A 450 (2006) 1037.
L. Jin et al., Nuclear Physics A 621 (1997) 319c.

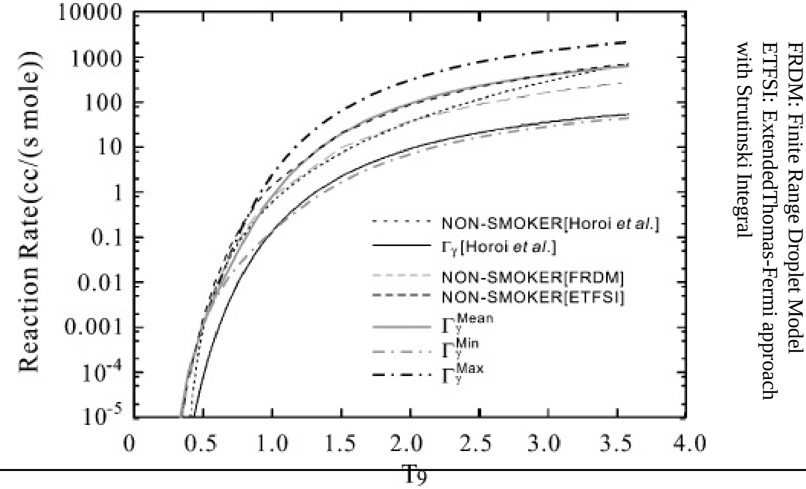


These reactions involve the use of low energy beam/targets of ^{45}V (T1/2 = 547(6) ms) and ^{44}Ti (T1/2 = 60.0(1) y) → radioactive beam facilities.

Previous studies

Horoi, M. et al. Phys.Rev. C66 (2002) 015801

J. J. He* and A. St. J. Murphy, Phys. Rev. C75 (2007) 068801



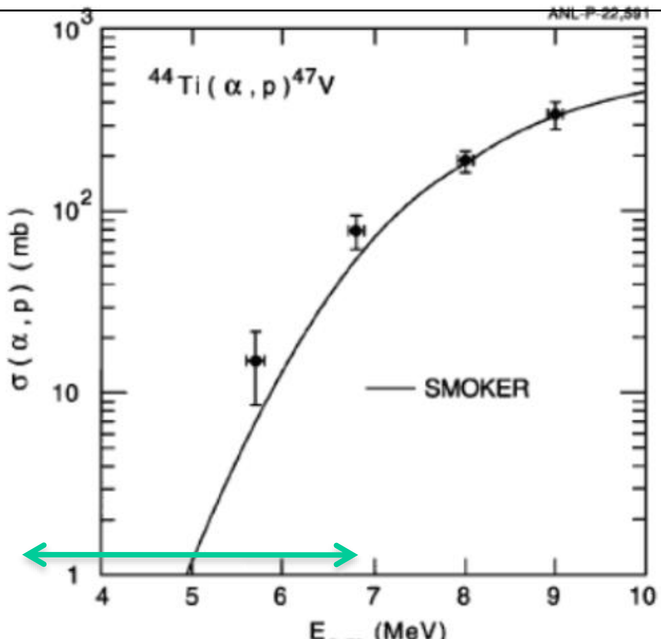
^{45}V (p, γ) ^{46}Cr

- dominates (p, γ) – (γ, p) equilibrium with ^{45}V
- ^{45}V very difficult to produce (refractory)
- Dominated by very narrow proton resonances (<< keV)
- Seems to be well described by statistical calculations

No experimental data so far

Difficult experiment:

- ^{45}V not available (at present) at ISOLDE
- Proposal for production of ^{45}V at TRIUMF



A.A. Sonzogni et al. PRL 84 (2000)

^{44}Ti (α, p) ^{47}V

- Dominant destruction of ^{44}Ti
- ^{44}Ti very difficult to produce (refractory)
- Previous measurements Argonne Nat. Lab. ~5 x 10^5 pps on target
- Typical cross sections ~ few 100's ub

Difficult experiment:

- ^{44}Ti not available (at present) at ISOLDE
- Measurements using ^{44}Ti at ISODE from PSI Targets (A. St. J. Murphy et al., (2012)
- Dedicated setup using gas target & silicon detectors

^{44}Ti (α, γ) ^{48}Cr → Destruction of ^{44}Ti

→No experimental data so far

Difficult experiments!! → possibly at ISOLDE in near future?

Different approach → Beta delayed proton emission from ^{48}Mn

Beta delayed particle emission → a very good spectroscopic tool at low production rates (~few pps)!!

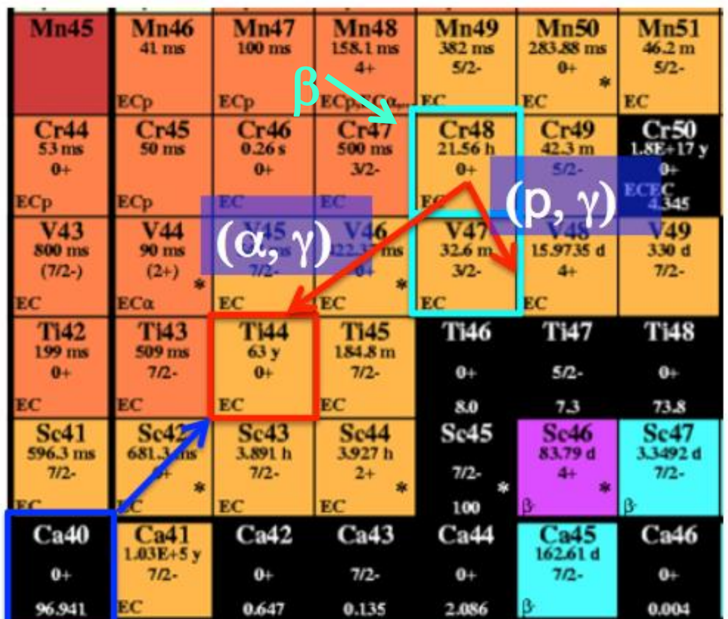
Experimental data:

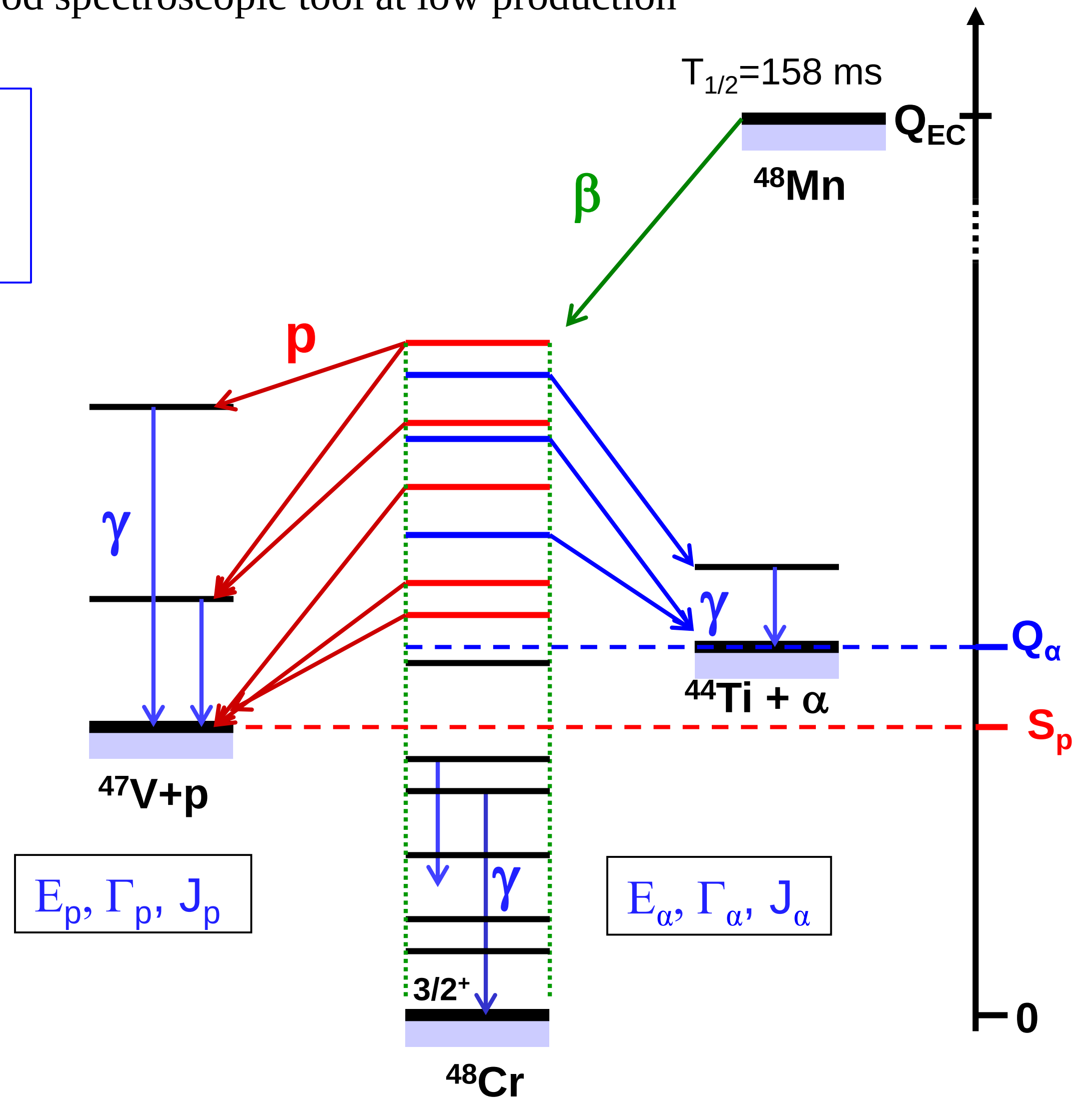
E, Γ, J,…

β-decay properties

^{48}Mn
$Q_{\beta+}$ =12480 keV

^{48}Cr
S_p = 8105 keV
Qα =7698 keV





(E_p, Γ_p, $J_{p)}$ & (E_α, Γ_α, J_α) are the critical parameters needed to evaluate the reactions rates of the reactions ^{44}Ti (α, γ) ^{48}Cr and ^{44}Ti (α, p) ^{47}V

The astrophysical S factors (example→ (α,p))

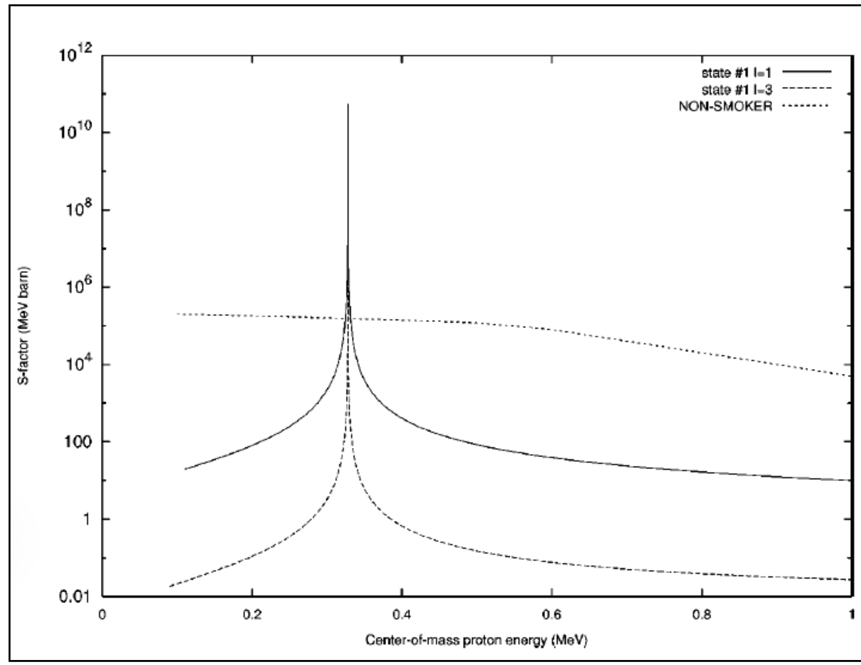
$$S(E)=\pi\frac{(2J+1)}{(2j_t+1)(2j_p+1)}\times\frac{\Gamma_\alpha\Gamma_p}{(E-E_r)^2+\Gamma^2/4}\exp(2\pi\eta)$$

Thermonuclear reaction rates

$$N_A\langle\sigma v\rangle=\left(\frac{8}{\pi\mu}\right)^{1/2}\frac{N_A}{(kT)^{3/2}}\int_0^\infty S(E)\exp\left[-\frac{E}{kT}-\frac{b}{E^{1/2}}\right]dE$$

J - spin of the state in the compound nucleus
J_t - spin of the target nucleus
j_p- spin of the projectile
Γ- total decay width
Γ_α, Γ_p –partial decay widths
η- Sommerfeld parameter
Er- level energy

Astrophysical S factor calculated using the single resonance formula as a function of proton center-of-mass energy.

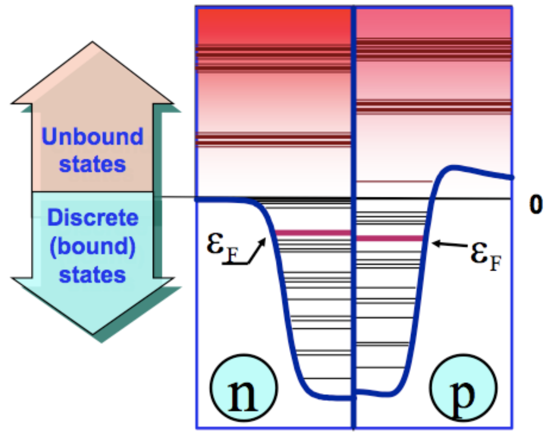


Data analysis of particle decay to extract E, Γ, J

"Ideal analysis": Shell model in the continuum (Gamow Shell Model - GSM)

→ Full shell model in the complex energy plane

N. Michel, W. Nazarewicz, M. Oloszajzak and T. Vertse, J. Phys. G.: Nucl. Part. Phys. 36 (2009) 013101// Humblet and Rosenfeld, Nucl. Phys. 26, 529 (1961); T. Berggren, Nucl. Phys. A 109 (1968) 265; R. de la Madrid, Nucl. Phys. A812, 13 (2008)



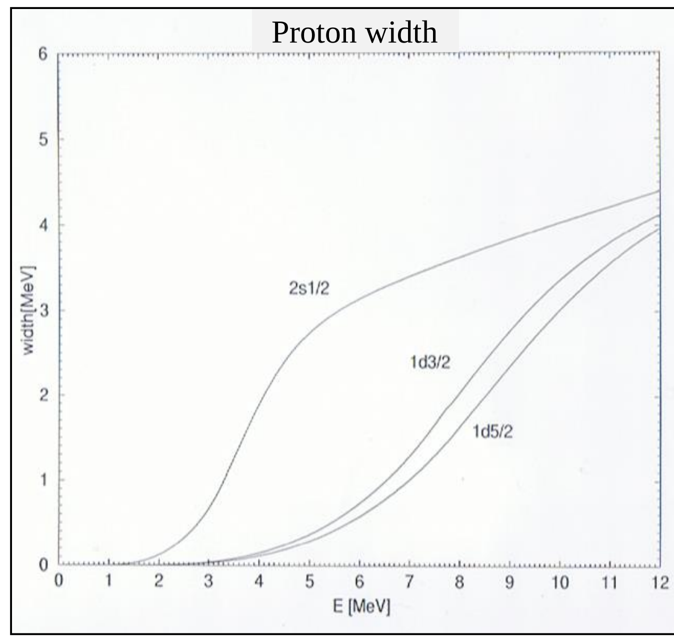
"Simple analysis": Shell model WITH Gamow wave functions SM-G.

I. Martel et al., NPA(2001)424-436

-Shell model to calculate energy levels, spectroscopic factors, and beta decay strenght
- Gamow-wave functions to evaluate particle decay widths
- Already tested in the analysis of 31Ar beta delayed particle emission
- Collaboration with A. Poves (Madrid)

Total width (r)

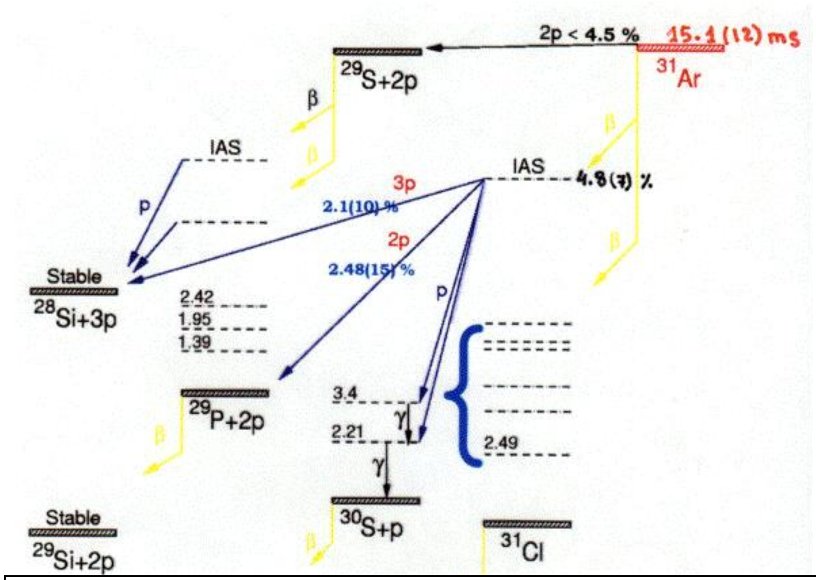
$$\Gamma\,(i;\,r\,;\,Ek\,) = \Sigma_{lj}\,|SPA(i\,;\,r,\,nlj\,)|^2\,\gamma\,(nlj\,;\,Ek\,)$$

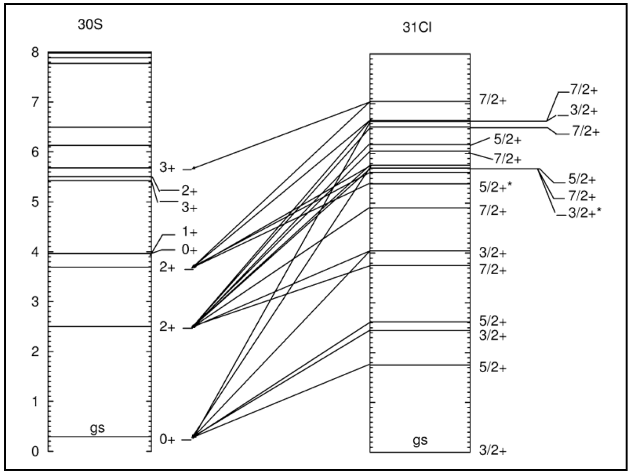


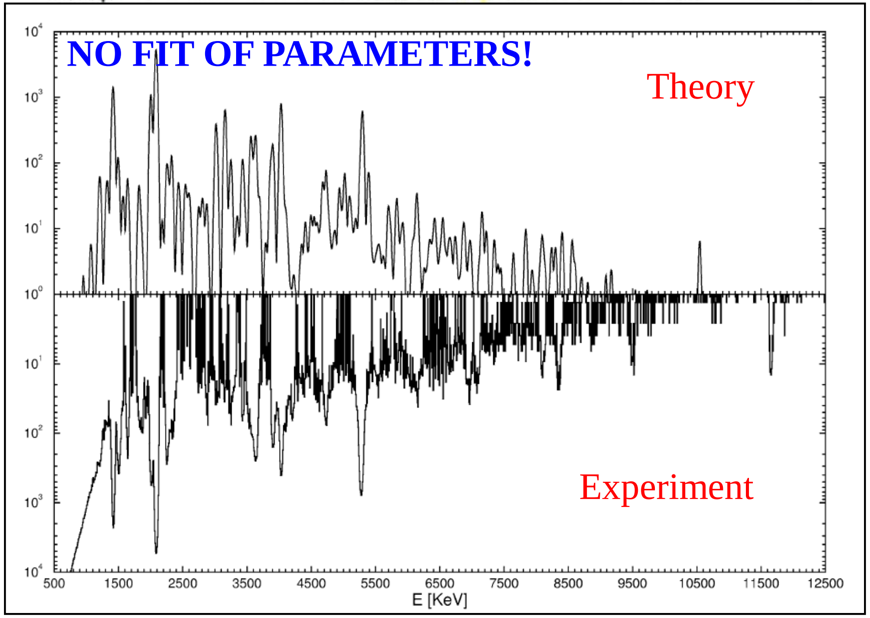
Gamow state calculation~ Woods-Saxon (a=0.65fm, r=1.27fm), select depth V0 to reproduce Ek, ^{31}Ar β-delayed proton emission

Shell model WITH Gamow wave functions SM-G

I. Martel et al., NPA(2001)424-436







Results of the analysis of the beta-delayed proton energy spectrum

J^π_{Cl}	E_{Cl}	B(GT) (th)	J^π_S	E_p (exp)	I_p (th)	I_p (exp)	Γ (th)
$5/2^+_1$	1753	0.053	0^+_1	1416(2)	27.1	34.0(3)	0.02
$3/2^+_2$	2443	0.243	0^+_1	2084(2)	100	100.0(6)	0.4
$5/2^+_2$	2618	0.004	0^+_1	2253(2)	1.6	4.0(3)	0.8
$7/2^+_1$	3752	0.004	2^+_1	1211(4)	1.1	1.7(5)	0.11
$3/2^+_3$	4045	0.028	0^+	3634(3)	4.4	6.1(8)	9.8
			2^+_1	1504(2)	2.3	6.2(2)	5.1
$7/2^+_2$	4905	0.014	2^+_1	2327(4)	2.4	5.1(4)	1.7
$5/2^+_3$	5390	0.011	2^+_2	1643(2)	1.1	2.88(14)	3.4
$7/2^+_3$	5621	0.057	2^+_1	3020(3)	7.4	1.08(14)	3.1
$3/2^+_4$	5658	0.010	1^+_1	1643(2)	0.8	2.88(14)	3.8
$5/2^+_4$	5767	0.360	0^+_1	5276(5)	11.5	17.6(3)	7.4
			2^+_1	3153(4)	12.2	0.44(10)	7.8
			2^+_2	2008(2)	20.9	10.0(2)	13.4
$7/2^+_4$	6047	0.022	2^+_1	3432(3)	2.1	0.89(11)	9.8
$5/2^+_5$	6180	0.047	2^+_1	3561(11)	4.5	3.6(8)	30.8
$7/2^+_5$	6533	0.044	2^+_1	3902(3)	3.4	2.22(14)	11.3
$3/2^+_5$	6640	0.023	0^+_1	6145(7)	0.5	0.51(12)	5.4
$7/2^+_6$	6665	0.186	2^+_1	4030(3)	14.7	7.0(2)	4.6
			2^+_2	2881(3)	0.4	0.99(13)	0.13
$7/2^+_7$	7050	0.050	2^+_2	3249(4)	1.9	1.17(15)	2.6
			3^+_2	1300(13)	0.9	0.7(11)	1.3

Previous measurements on beta delayed proton emission from ^{48}Mn

GSI (Darmstadt, Germany)

T. Sekine et al., Nucl. Phys. A467 (1987) 93
J. Szerypo et al., Nucl. Phys. A528 (1991) 203

UNILAC + GSI on-line mass separator
$^{12}C(^{40}Ca, p3n)$ reaction

Beam time:

50 hours,, I=200-600 pps

Contaminants:
48Cr, 48V, 48Sc and 12F (Al-F)

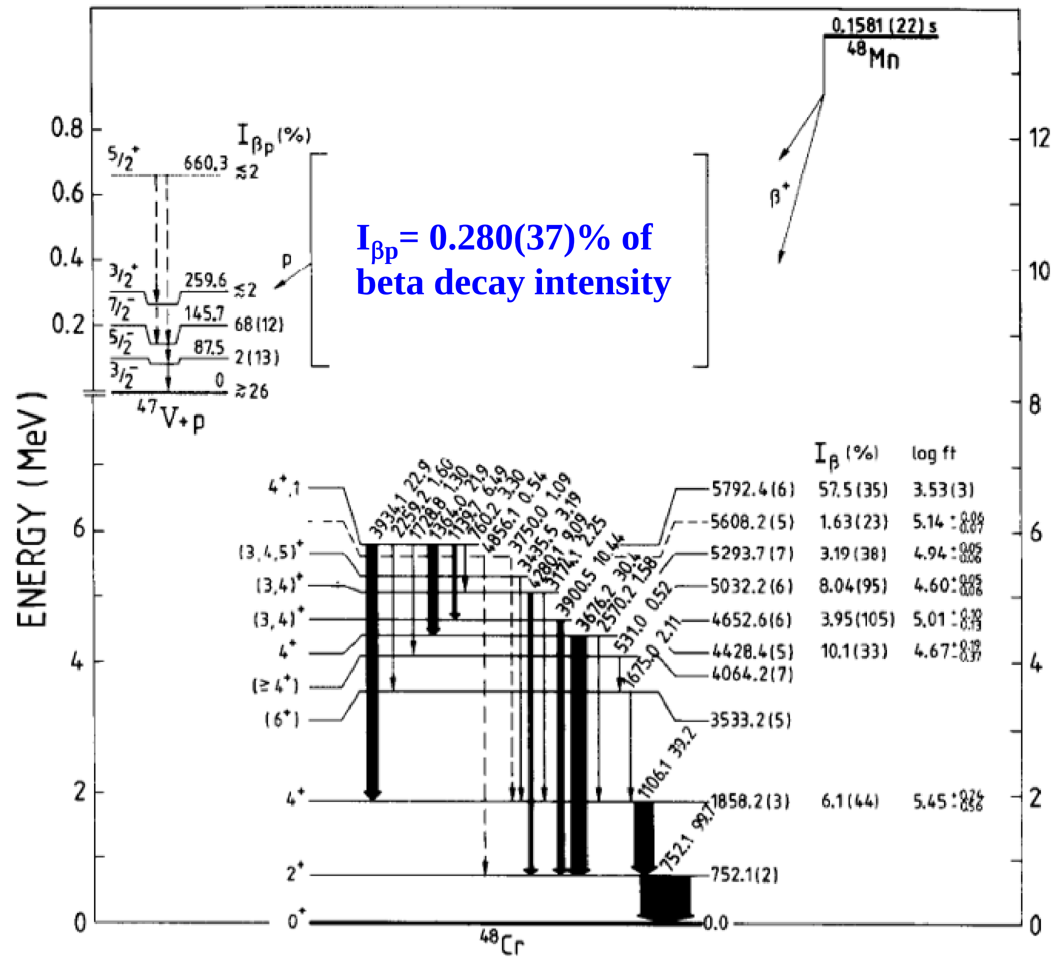
Set-up:

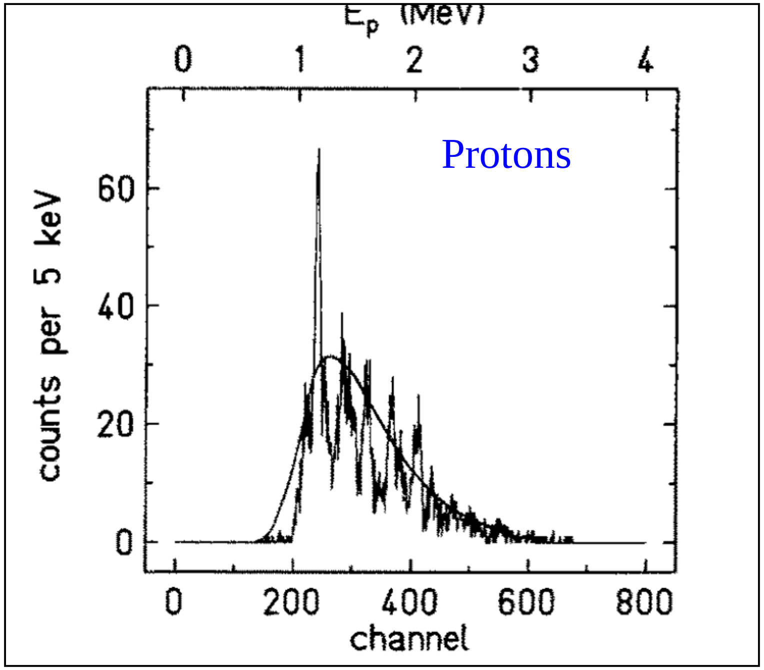
2 x particle telescopes

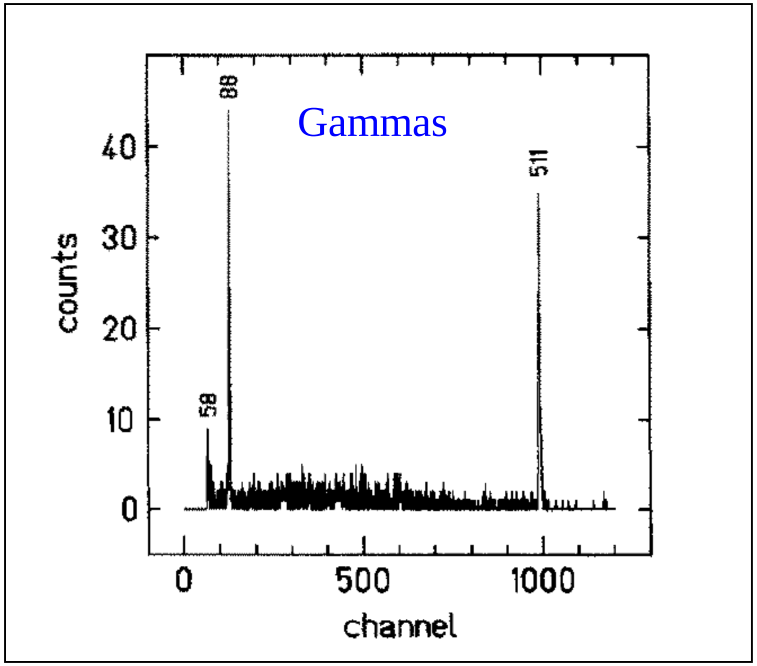
- Efficiency of 4%
- E_{res}= 50 keV

2 x gamma detectors:

- Efficiency of 4% (1.3 MeV)







Protons: expected bell-shaped overall structure

Ep ~1-3 MeV range → Structures @ 1.2, 1.4, 1.6, 1.8, 2.0, 2.2 MeV

Coincidence with gamma rays:	~2%	→	^{47}V(660.3 keV)
	~2%	→	^{47}V(259.6 keV)
	68(12)%	→	^{47}V(145.7 keV)
	2(13)%	→	^{47}V(87.5 keV)
	~26%	→	^{47}V (gs)

$I_{\beta\alpha} < 6.0 \times 10^{-4}$ %

Sekine et al. → singles:1 event!

However, due to statistics, it was not possible to identify the initial and final levels in ^{48}Cr involved in the process. → Main objective of the present proposal.

Main objectives of present proposal

Detailed study of ^{48}Mn beta delayed proton emission:

- Identify proton emitter levels in ^{48}Cr
- Identify alpha emitter levels (branching ratio limits)
- Extract proton widths, angular momentum (alpha width limits)

→ **Cross section evaluation**

Dedicated experimental setup at the IDS

"Silicon-cube" device

5 **DSSSD** telescopes for protons/alphas → high granularity

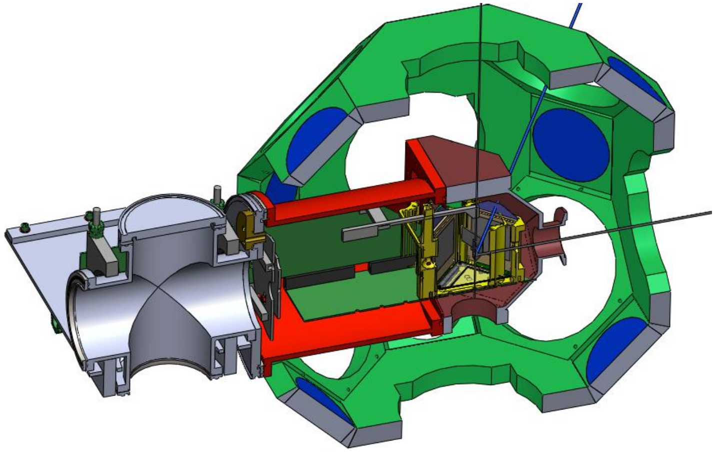
→ default detection efficiency ~46%

→ energy FWHM ~ 25 keV (low noise P.A.)

→ 40um and 1mm thickness

→ back-detectors for beta suppression

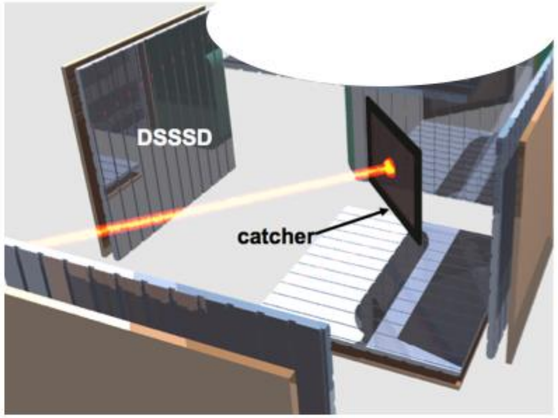
→ ions deposited on a thin **carbon catcher**



Germanium detectors

4 Clover detectors

- high resolution
- efficiency ~4% (1 MeV)



- closer geometry possible: particle/gamma (60% / 10%)

Beam-time request

ISOLDE ^{48}Mn production (Nb target, 1.4 GeV) ~10 pps on target (Isolde Yields Data Base)

Beam request: 21 shifts

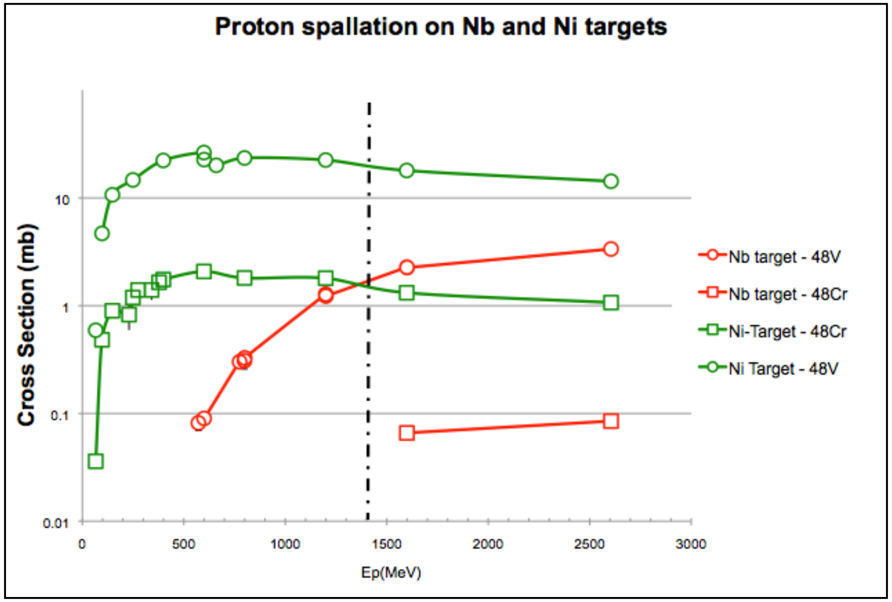
Assuming 46% efficiency (particles) & 4% efficiency (gammas)

Expected beta delayed proton yield: 8300
Expected proton-gamma coincidences: 330

Remark: For doing the proposed measurements, it would be very interesting to investigate a target test with a mixed Ni-Al composition.

Estimated gain in Yield by ~ 10 - 20

EXFOR: Experimental Nuclear Reaction Data.
https://www-nds.iaea.org/exfor/



^{48}Mn collaboration

CERN – Huelva (Spain) – Madrid (Spain) – Warsaw (Poland) – Belfast (UK) – Leuven (Belgium) – Gradignan (France) – Lund (Sweden) – Mexico (Mexico) – Warsaw (Poland) – Aarhus (Denmark)

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Thanks for your attention!!

^{35}Ca decay
beta-delayed 1- and 2-proton

spokespersons: J. Giovinazzo (CENBG), O. Tengblab (CSIC)

Germanium detectors

- **efficiency ~10-15%** (at 1 MeV)
  close geometry (~8 cm)

"Silicon-cube" device

6 **DSSSD** for protons

→ detection efficiency ~60% for 1 proton

→ energy FWHM ~ 25 keV (low noise P.A.)