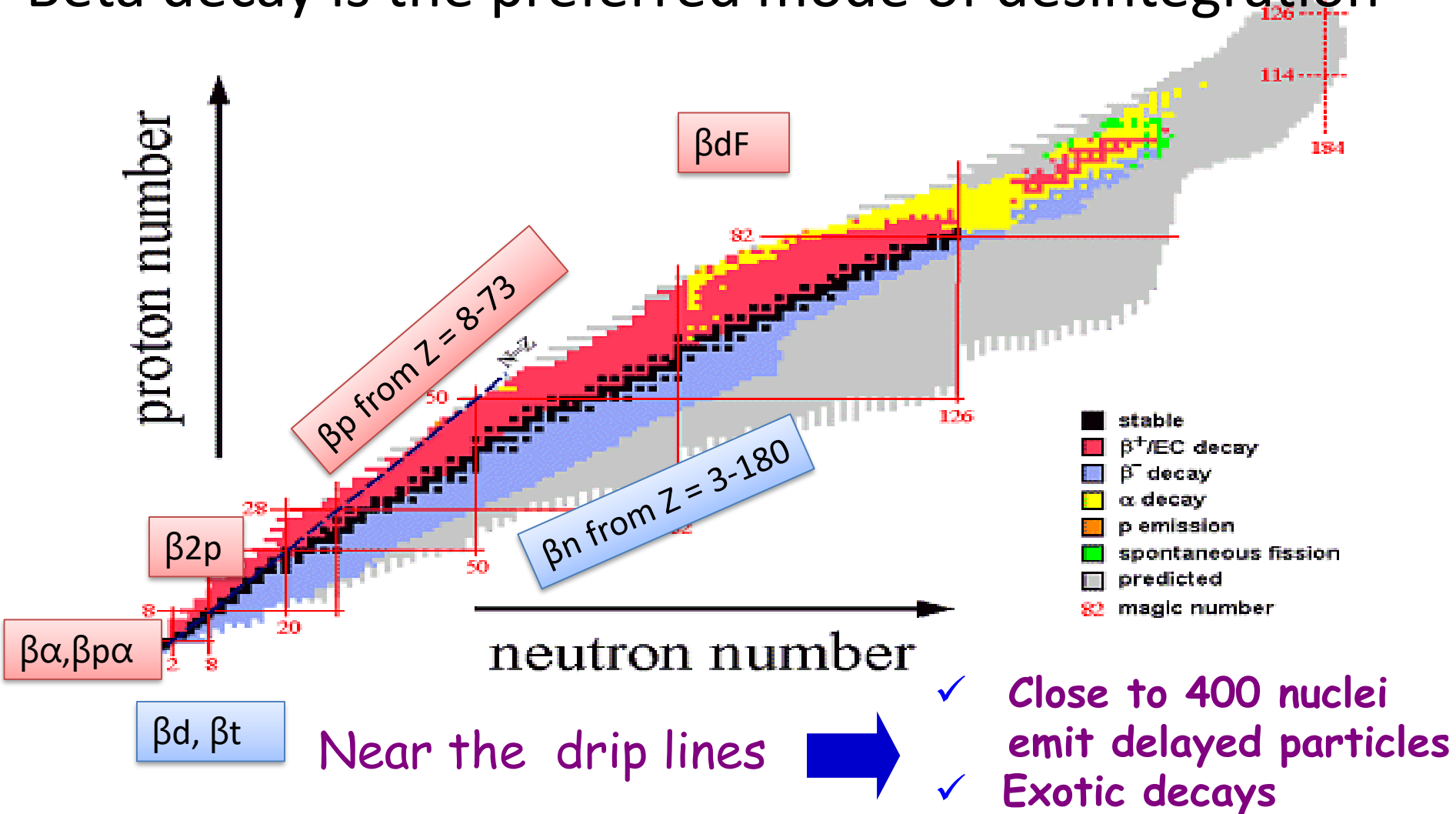


Beta Delayed Particle Emission

Beta decay is the preferred mode of desintegration



Planning and References

- ✚ Beta delayed Particle emission
 - ✚ Mechanisms of Breakup
 - ✚ Analysis technique

References:

- ✓ “Particle Emission from Nuclei” Ed. D.N. Poenaru & M.S. Ivaçcu
CRD 1989 Vol I, II, III
- ✓ B. Blank and M.J.G. Borge, Prog Part and Nuc. Phys 60 (2008) 403
- ✓ M. Pfützner, L.V. Grigorencu, M. Karny & K. Riisager,
Rev. Mod. Phys, ArXiv:1111.0482
- ✓ [Euroscool on Exotic Beams, Lectures Notes:](#)
“Decay Studies of N~Z Nuclei”, E. Roeckl,
[École Joliot-Curie de Physique Nucleaire, 2002](#)

Beta delayed particle emitters

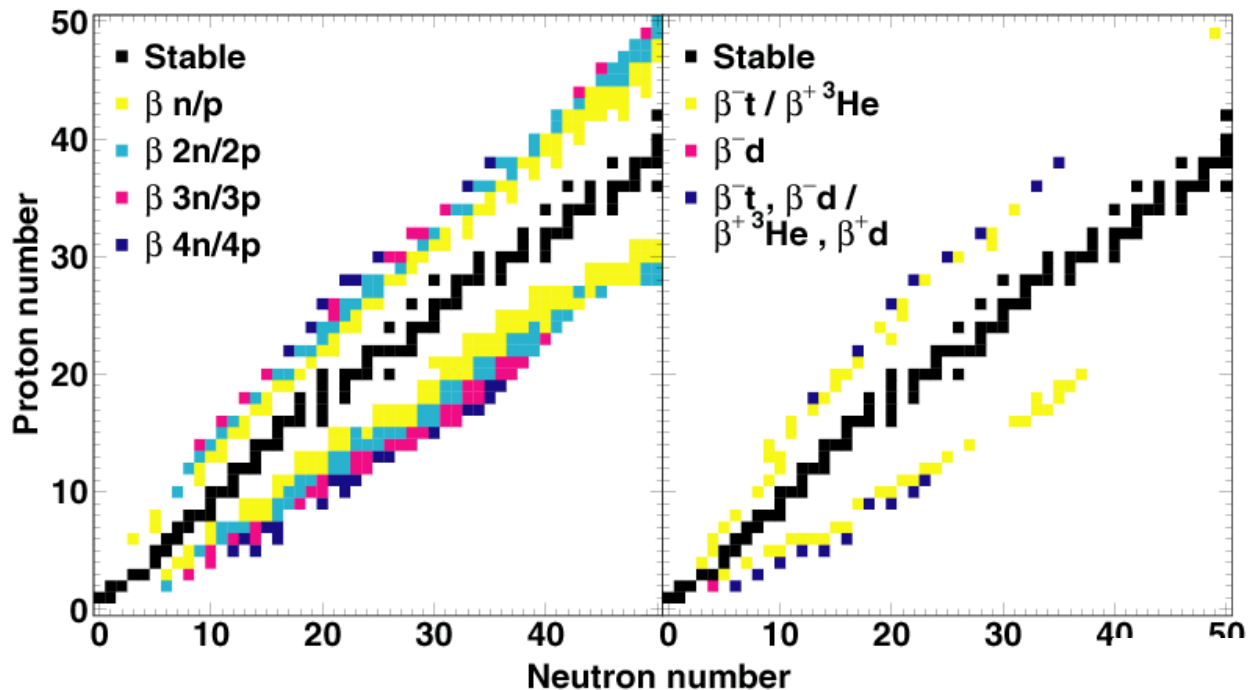
For β^- -delayed x-neutron emission of AZ

particles

$$Q_{\beta nx} = Q_{\beta} - S_{xn}({}^A(Z+1)) = Q_{\beta}({}^{A-x}Z) - S_{xn}$$

For β^+ -delayed x-proton emission of AZ $Q_{\beta^+} \rightarrow Q_{EC}$

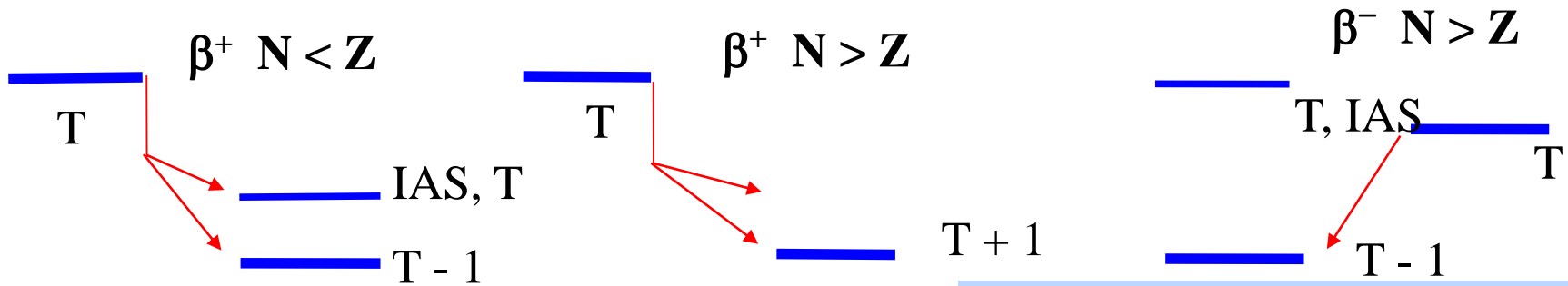
	N-5	N-4	N-3	N-2	N-1	N	
Z+1	$\beta 4n$	$\beta 3n$	$\beta 2n$	βn	β		
Z			βt	βd	βp	•	
Z-1			$\beta \alpha$				



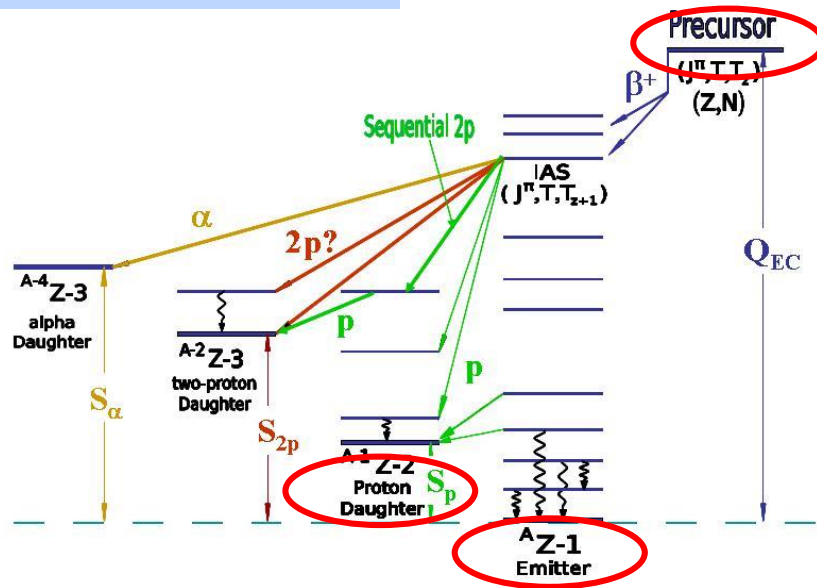
B.Jonson & K. Riisager, NPA693 (2001) 77

Frento
2001-03-01

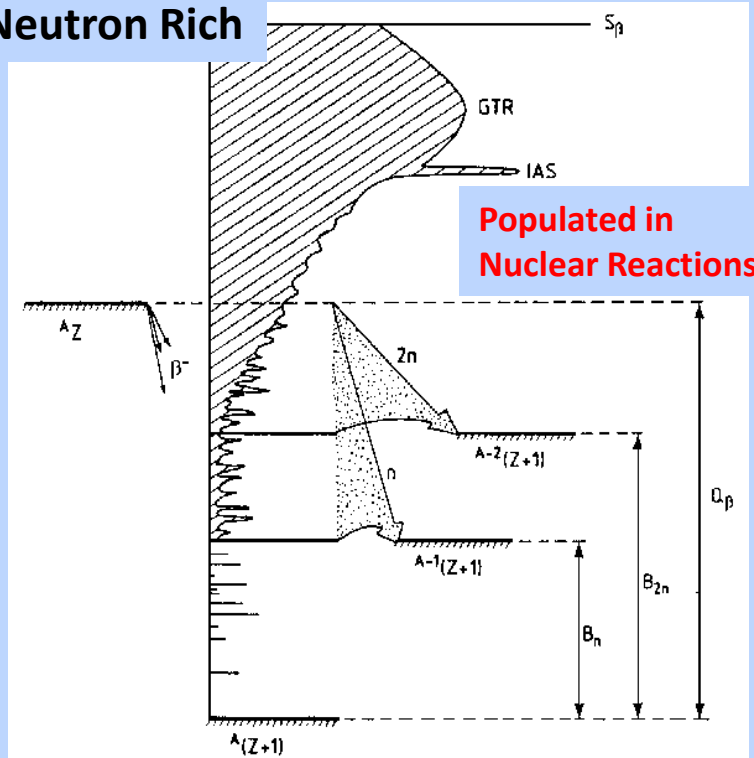
Beta Transitions



Neutron Deficient



Neutron Rich



Decay properties of exotic nuclei

➤ Global properties

- Short half-lives ($\sim ms$)

- High Q_β values

- Low $S_{p/n}$ values

β-delayed particle emission

- Reduced transition probability:

$$ft = f * \frac{T_{1/2}}{B.R.} = \frac{K}{G_V^2 |\tau|^2 + G_A^2 |\sigma\tau|^2} = \frac{C}{B(F) + B(GT)}$$

$$K/G_V^2 = 6144(1) \text{ s} = C \text{ and } (G_A/G_V)^2 = (-1,2695(29))^2$$

Fermi Strength independent of Nuclear Structure

$$B_F^+ - B_F^- = Z - N$$

Gamow-Teller strength obeys the Ikeda sum Rule

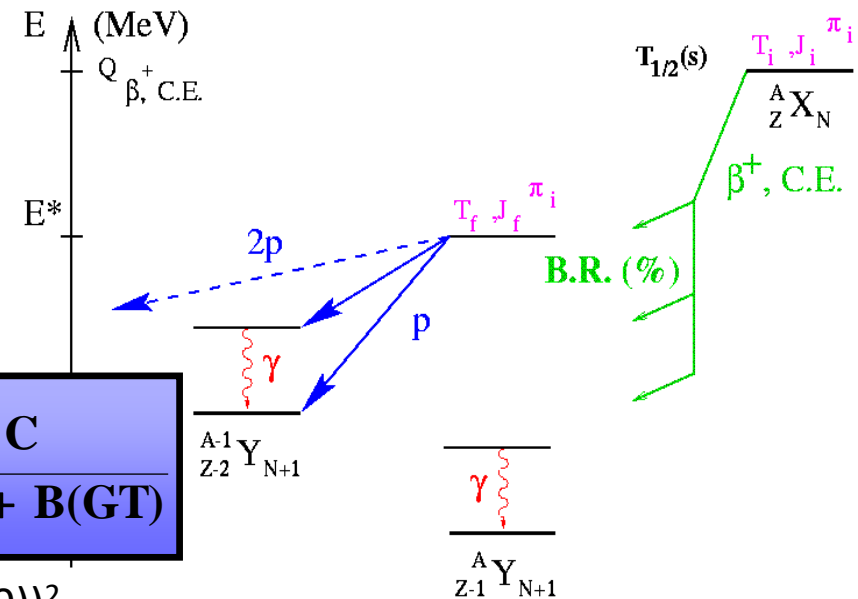
$$\Sigma B_{GT}^- - \Sigma B_{GT}^+ = 3 (N-Z)$$

±1916

Rutherford & Wood $\beta\alpha$ [*Philos. Mag.* **31** (1916) 379]

±1963

Barton & Bell identified ^{25}Si as βp

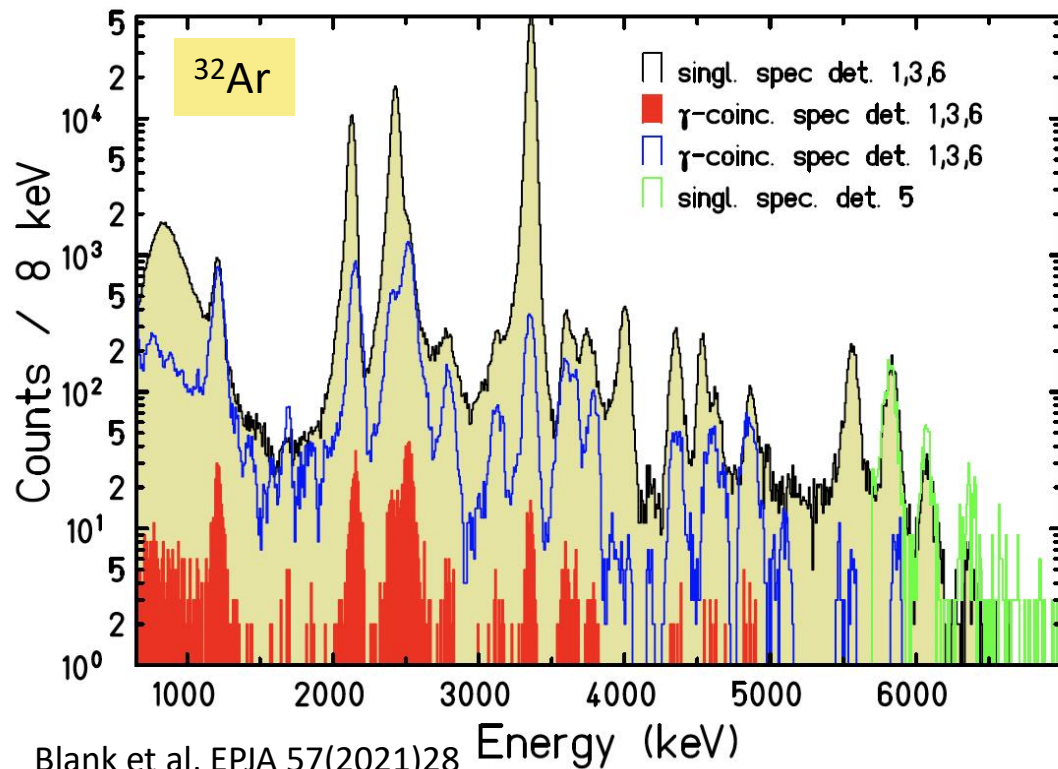


$$I_p^{if} = f(B_F^i + B_{GT}^i) \frac{\Gamma_p^{if}}{\Gamma_p^i + \Gamma_\gamma^i}$$

E, Γ
Level density
Spin, Isospin
 β -decay properties

Beta-proton emitters

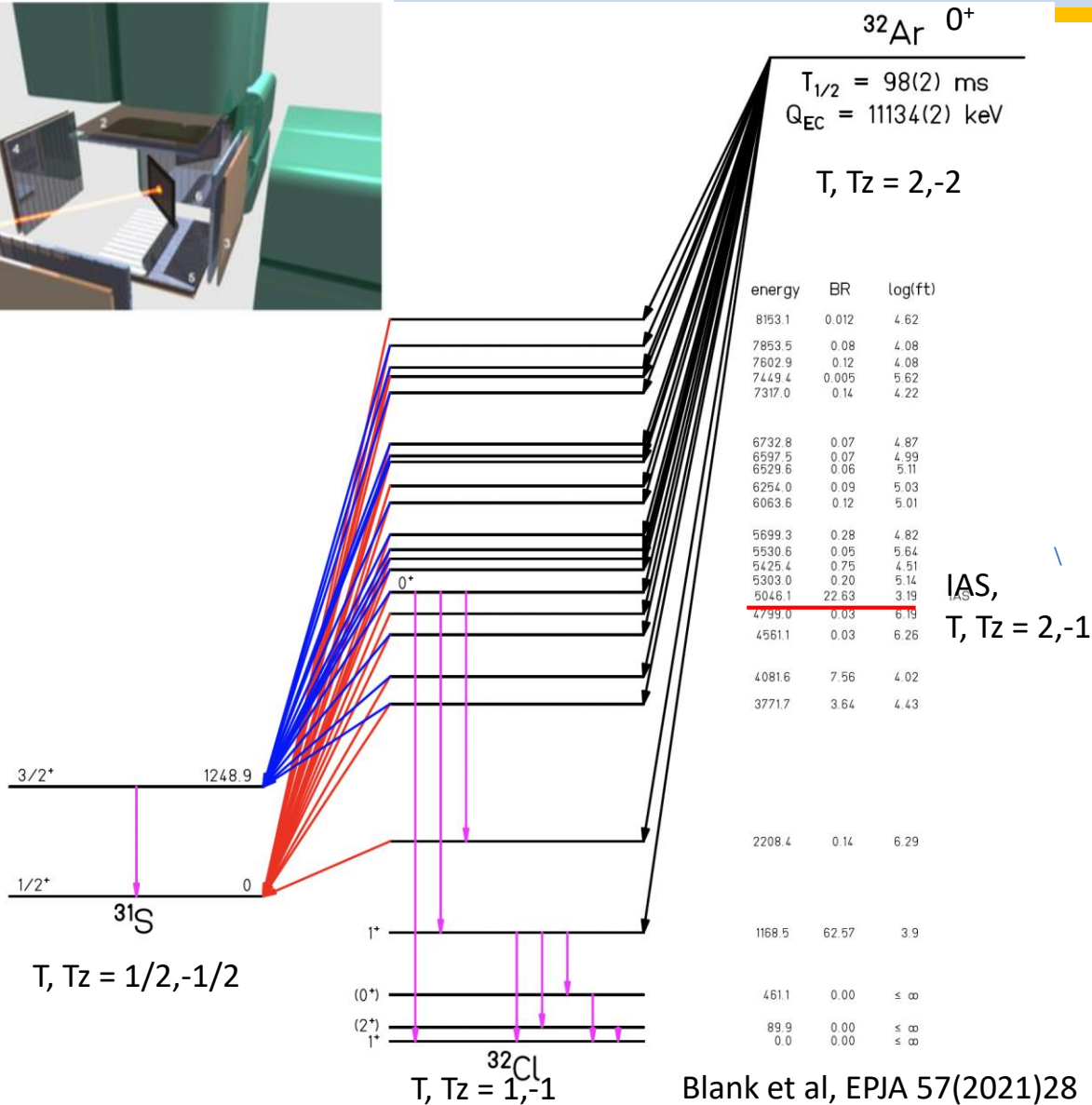
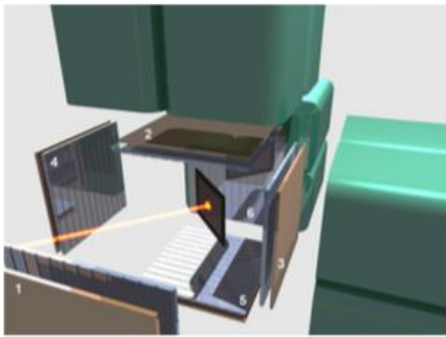
- ✓ More than 160 precursors identified
- ✓ For every element up to $Z = 73$ at least one proton precursor
- ✓ The βp spectrum depends on the Z and A of the precursor and differs in the different mass region due to differences in level density in the Q - Sp window
- ✓ Properties of βp well understood \rightarrow large variety of spectroscopic information



- ✓ For light nuclei with $Z \geq 8$, the IAS within the Q_{EC} window.
- ✓ From βp energy of IAS $\rightarrow Q_{EC}$ - Sp deduced.
- ✓ Test Isobaric Multiplet Mass eq.

$$M(A, T, T_z) = a + bT_z + cT_z^2 + \delta(dT_z^3 + eT_z^4)$$
- ✓ If strength to IAS $\neq B_F \Leftrightarrow$ Isospin Mixing
- ✓ If IAS in the middle of the Q_{EC} large part of the GTGR available \Rightarrow quenching factor deduced
- ✓ Test of Mirror Symmetry

$^{32}\text{Ar}(Z=18, N=14) \rightarrow ^{32}\text{Cl}(Z=17, N=15)$



- By $\beta p \rightarrow$ study up to 8153 keV \rightarrow 73% of energy window
- 22.6% feeding IAS \rightarrow $\log ft = 3.19$
 $\Gamma_p / \Gamma_\gamma(\text{IAS}) = 11.2(11)$
 $\Gamma = \Gamma_p + \Gamma_\gamma = 20(5) \text{ eV}$

The width of the IAS is very narrow as the proton emission is isospin forbidden, facilitating the emission of M1 transition of the 5.046 MeV IAS

$$B(F) = T(T+1) - T_{zi}T_{zf} = 2 \times 3 - (-2)(-1) = 6 - 2 = 4$$

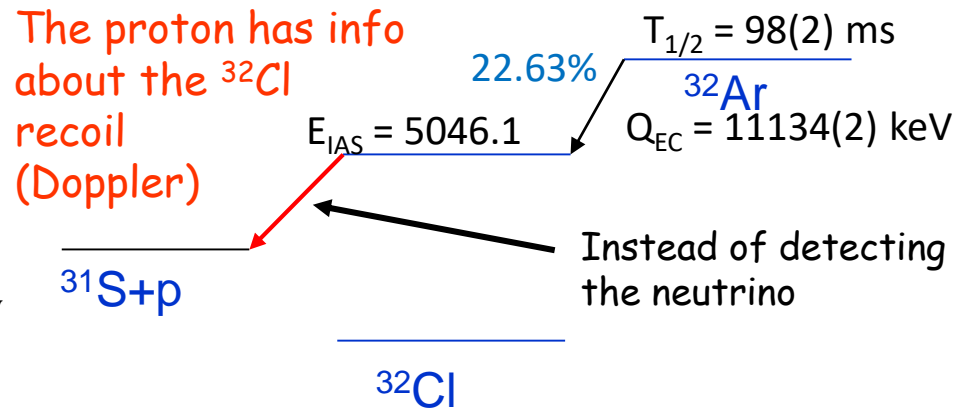
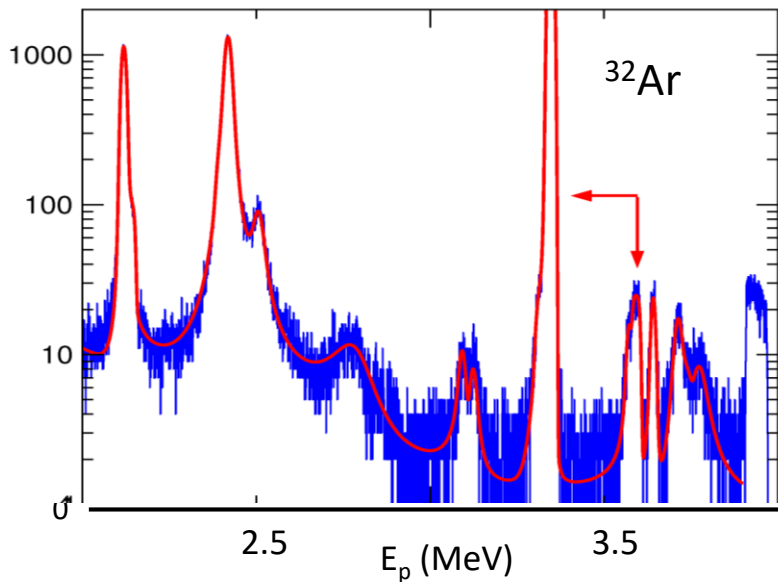
Predicted mixing with $0^+ T=1$ states \rightarrow No strong feeding observed to states nearby.
 Closest $E = 5425 \text{ keV}$ ($\Delta E = 379 \text{ keV}$)

Blank et al, EPJA 57(2021)28

Electron-Neutrino Correlations ($\beta\bar{\nu}$ emitters)

- ✓ $\beta\nu$ correlation depends of the type of the transition
- ✓ Important probe of the nature of weak interaction

The V-A character of β -decay was determined by measuring the recoil energy spectrum of ${}^6\text{He}$ [Johnson et al, PR132(63)1149]



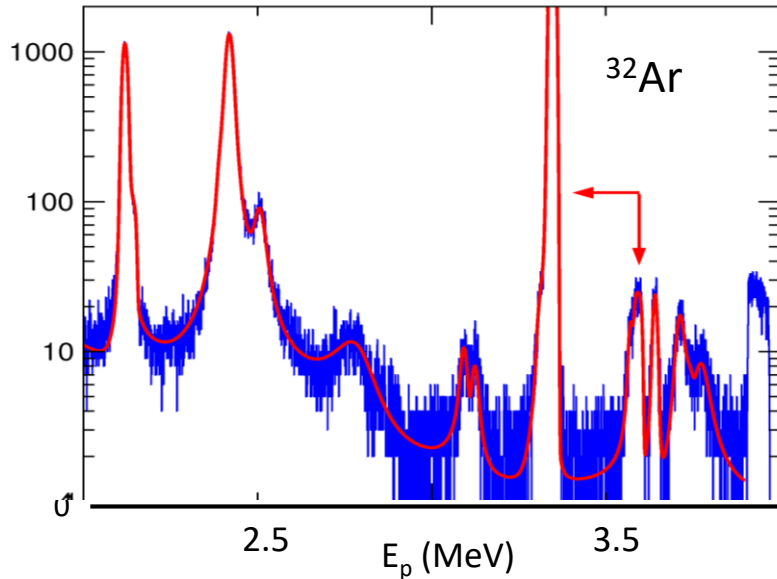
Study of the proton line shape

- Physics beyond the SM
 - Isospin mixing in ${}^{3,35}_{\text{MeV}}$ Fermi decays
 - Configuration mixing
 - Level interferences
 - Spin assignment
 - Excitation energies
-
- The diagram shows the energy levels of ${}^{32}\text{Cl}$ and ${}^{31}\text{S}$. The ground state of ${}^{32}\text{Cl}$ is at 0 MeV. The ground state of ${}^{31}\text{S}$ is at 0 MeV. A transition from the ground state of ${}^{32}\text{Cl}$ to the ground state of ${}^{31}\text{S}$ is labeled 370 eV. A transition from the ground state of ${}^{32}\text{Cl}$ to an excited state of ${}^{31}\text{S}$ is labeled 5.1 MeV. A transition from the ground state of ${}^{32}\text{Cl}$ to an excited state of ${}^{31}\text{S}$ is labeled 3.35 MeV. A transition from the ground state of ${}^{32}\text{Cl}$ to an excited state of ${}^{31}\text{S}$ is labeled 100 keV. A transition from the ground state of ${}^{32}\text{Cl}$ to an excited state of ${}^{31}\text{S}$ is labeled ${}^{\pm}$.

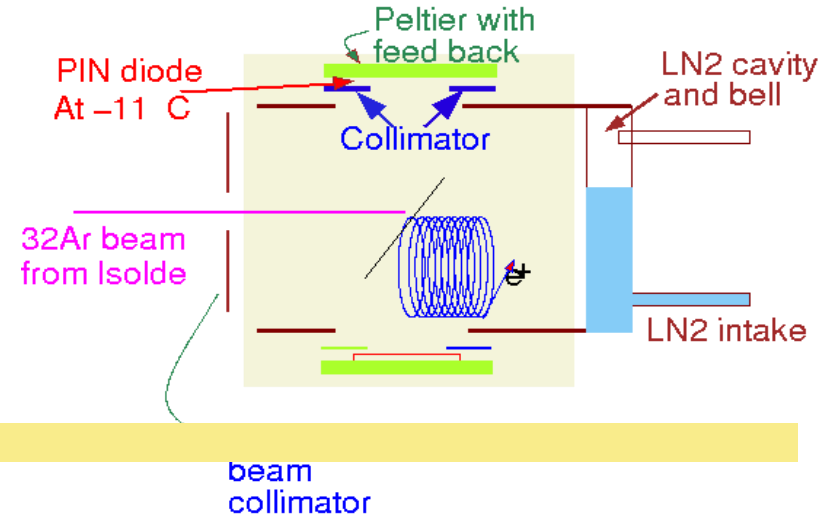
Schardt & Riisager, Z. Phys. A 345 (1993) 265

Adelberger & Garcia, Hyp. Int 129 (2000) 237

$\beta\nu$ correlation studies: Search for New Physics



- Set-up to avoid β -summing @ ISOLDE

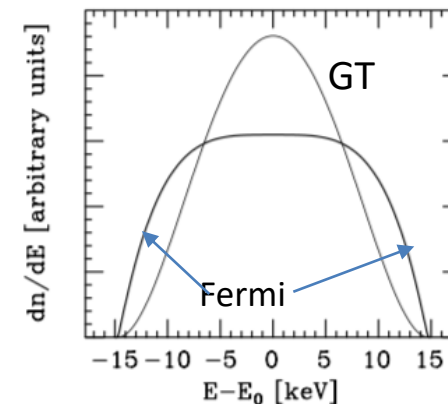


- If βp emitter \Rightarrow measurement of $e\nu$ correlation \Rightarrow F/GT nature of transition **from the broadening of proton peak.**

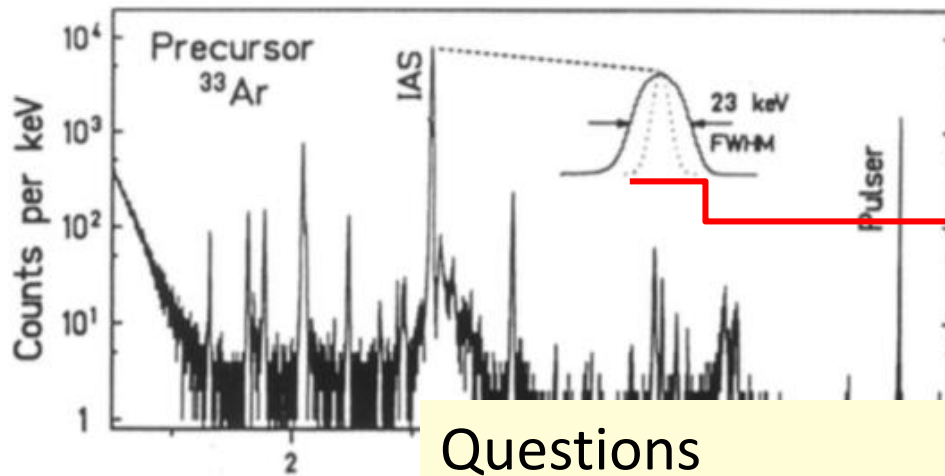
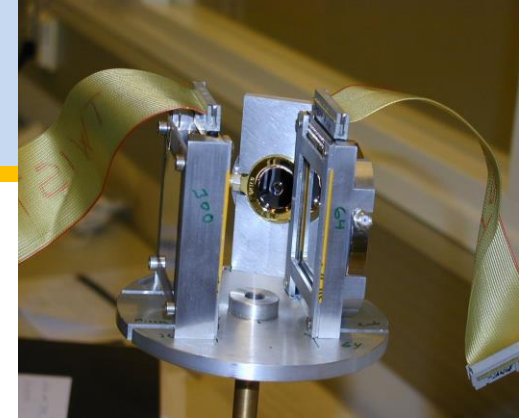
- Limit for scalar component in beta decays

$$M_S \geq 4.1 M_W$$

Adelberguer et al., PRL (1999)



$^{32,33}\text{Ar} - \beta$ decay



E-resolution = 8 keV

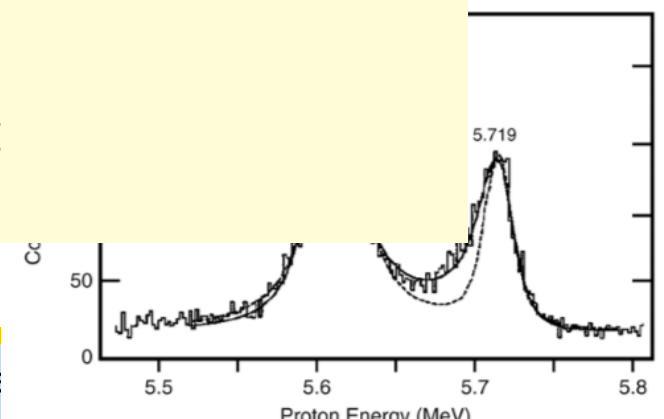
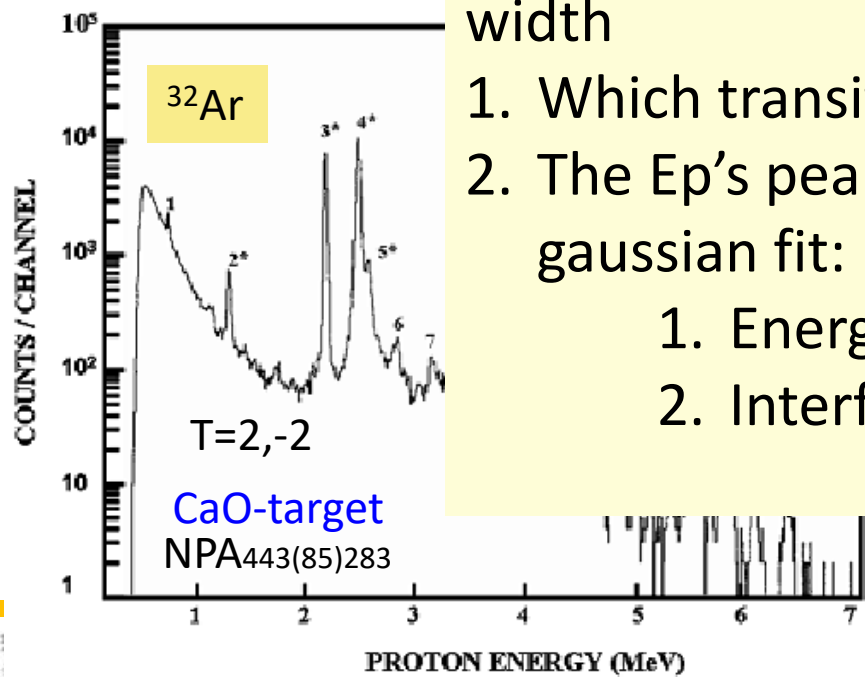
Angular correlations between e^+ and ν in the Fermi and GT transitions \rightarrow the adening an for recoil

Z. Phys. A 345, 265 (1993)

Questions

Assuming E resolution of Detector > transition width

1. Which transition is broader Fermi or GT ?
2. The E_p 's peaks are distorted versus gaussian fit: Reasons:
 1. Energy resolution
 2. Interference effect



Beta decay studie

$\beta\nu$ correlation studies: peering into Nuclear Structure

$$W(\theta) = 1 + a \frac{p\beta}{E_\beta} \cos(\theta_{\beta\nu}), \quad \text{with} \quad a = \frac{g_V^2 B_F - \frac{1}{3} g_A^2 B_{GT}}{g_V^2 B_F + g_A^2 B_{GT}}$$

If the decay is followed by particle emission, the recoil of the daughter shifts the energy of the delayed particle by about 10 keV that it is easy to measure.

✓ First used to deduced the nature of the decay of $^8\text{Li} \beta 2\alpha$

$$W = 1 + \frac{1}{2}(3a - A) \frac{p\beta}{E_\beta} \cos\theta_{\beta\nu} + \frac{3}{2}(A - a) \frac{p\beta}{E_\beta} \cos\theta_{p\beta} \cos\theta_{p\nu}$$

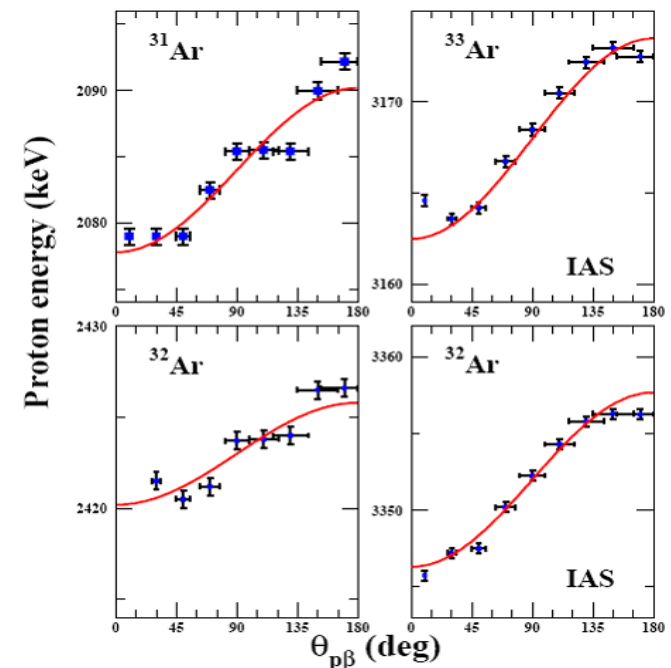
$$A = \frac{g_V^2 B_F - (\frac{1}{3} + \frac{2}{30}\tau\Theta)g_A^2 B_{GT}}{g_V^2 B_F + g_A^2 B_{GT}} \quad \Theta\tau \neq 0 \quad \begin{cases} \text{GT} \\ \text{lp} \neq 0 \end{cases}$$

$\beta - \nu$
correlations
allow to extract

Spins: ^{31}Ar
Fermi / GT character
Intrinsic widths of levels
Final state (gs/excited) of
delayed particle

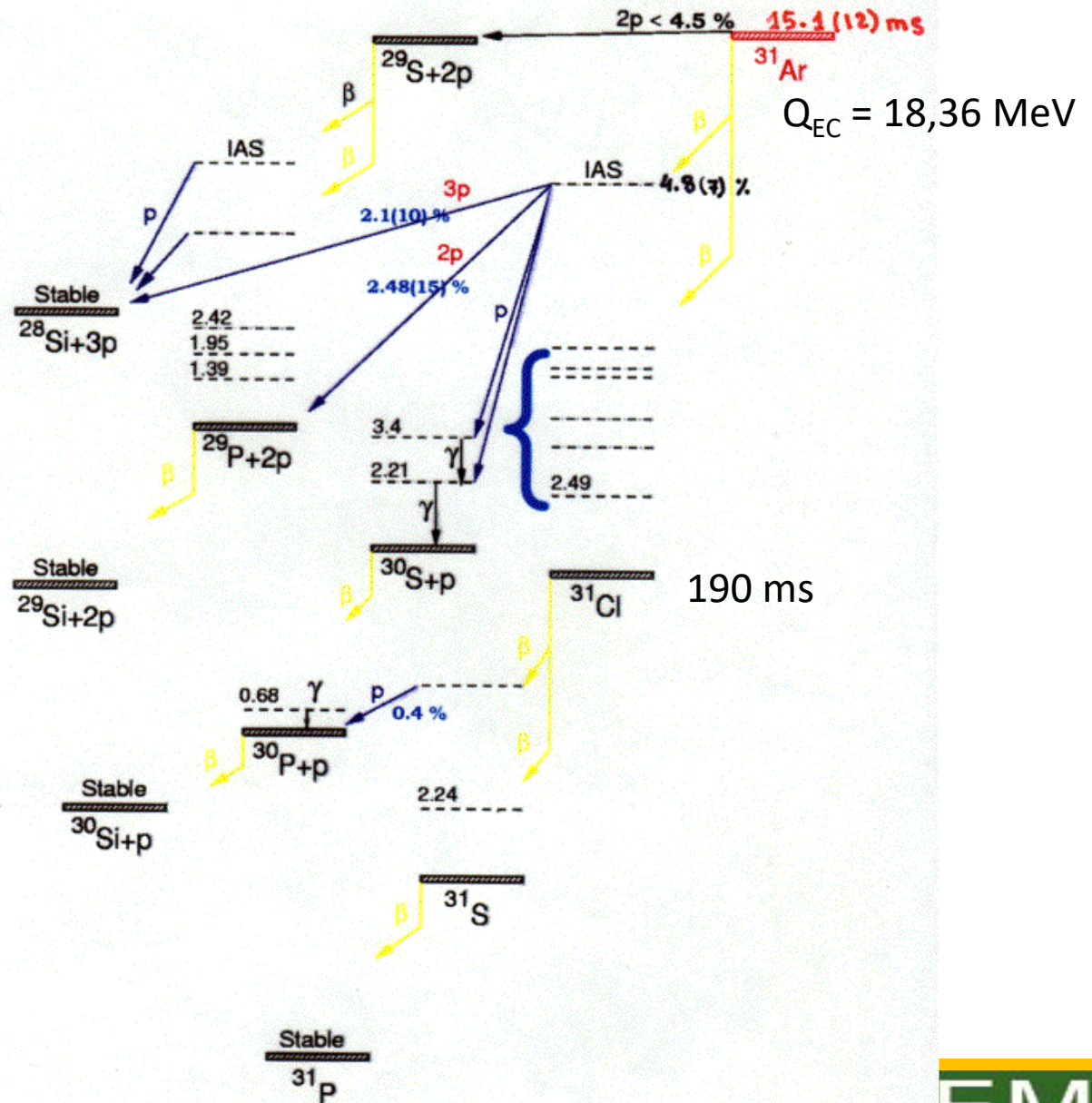
The energy shift in the delayed particle averaged over the neutrino angles

$$\langle t \rangle_\nu = -k \cos\theta_{p\beta} \left(1 + \frac{1}{3} A \frac{p\nu c}{E_\beta} \right) p\beta c$$

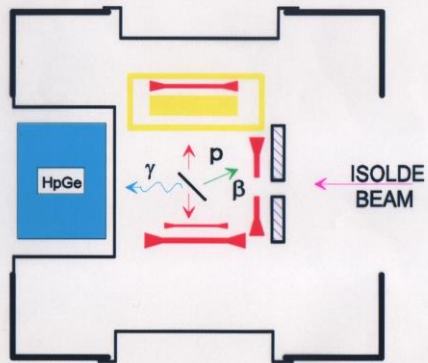


Thaysen et al, Phys. Lett B 467 (1999) 194

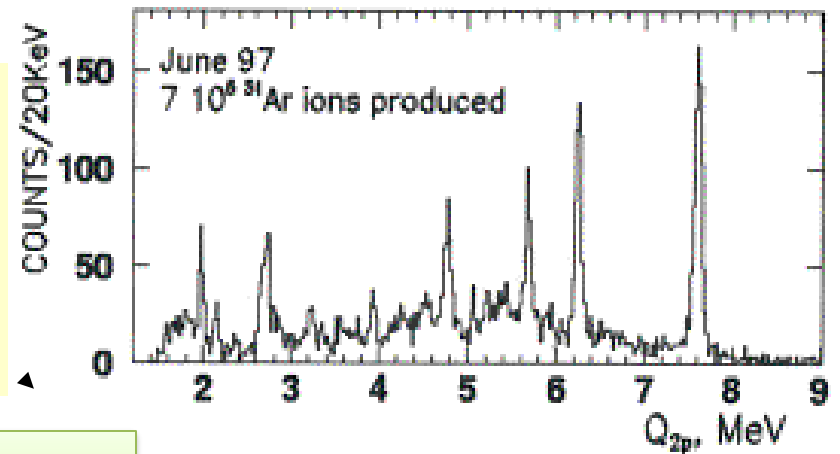
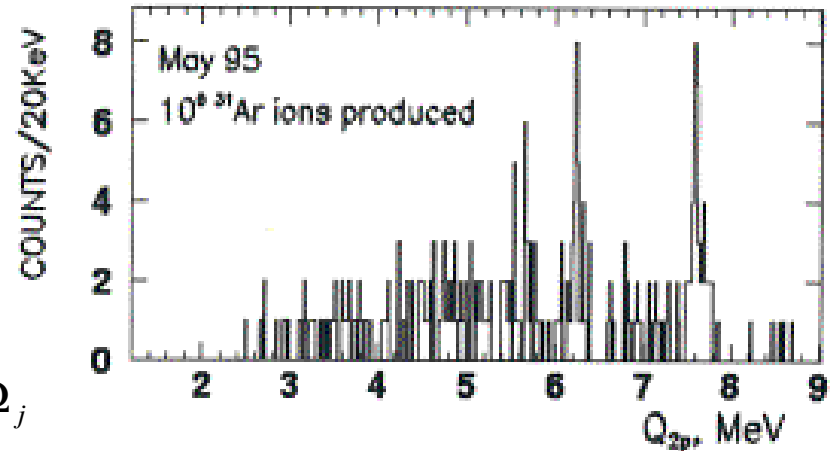
The decay of ^{31}Ar



β -delayed 2p emission from ^{31}Ar

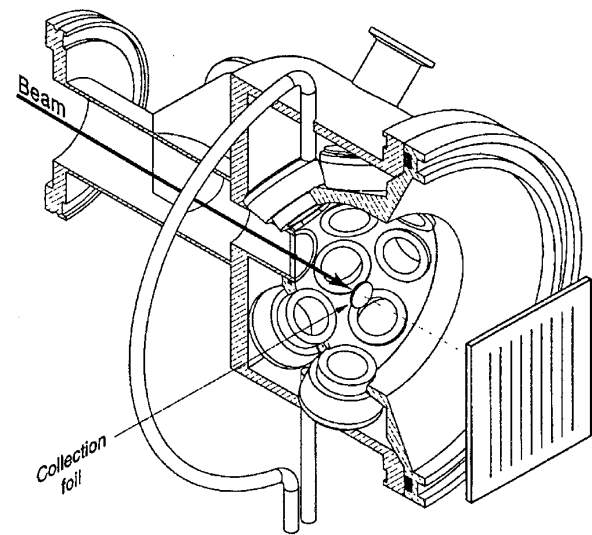


$$\varepsilon_{2p} = \left(\sum_{i=1}^N \Omega_i \right)^2 = \sum_{i=1}^N \Omega_i^2 + 2 \sum \Omega_i \Omega_j$$



Yield	2 atom/s
Solid angle	14 + 11 %
ε_{1p}	23.7 %
ε_{2p}	5.2 %
ε_{3p}	1.3 %

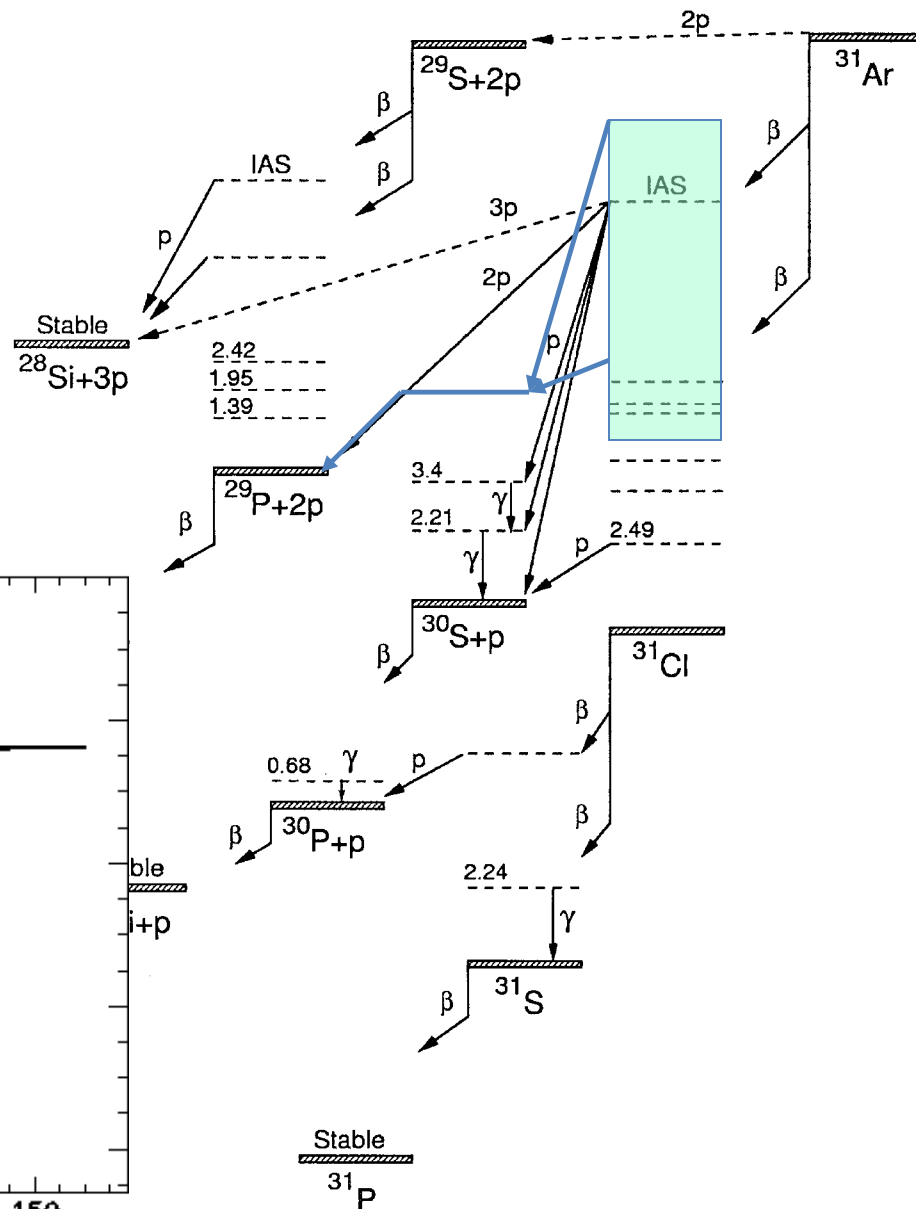
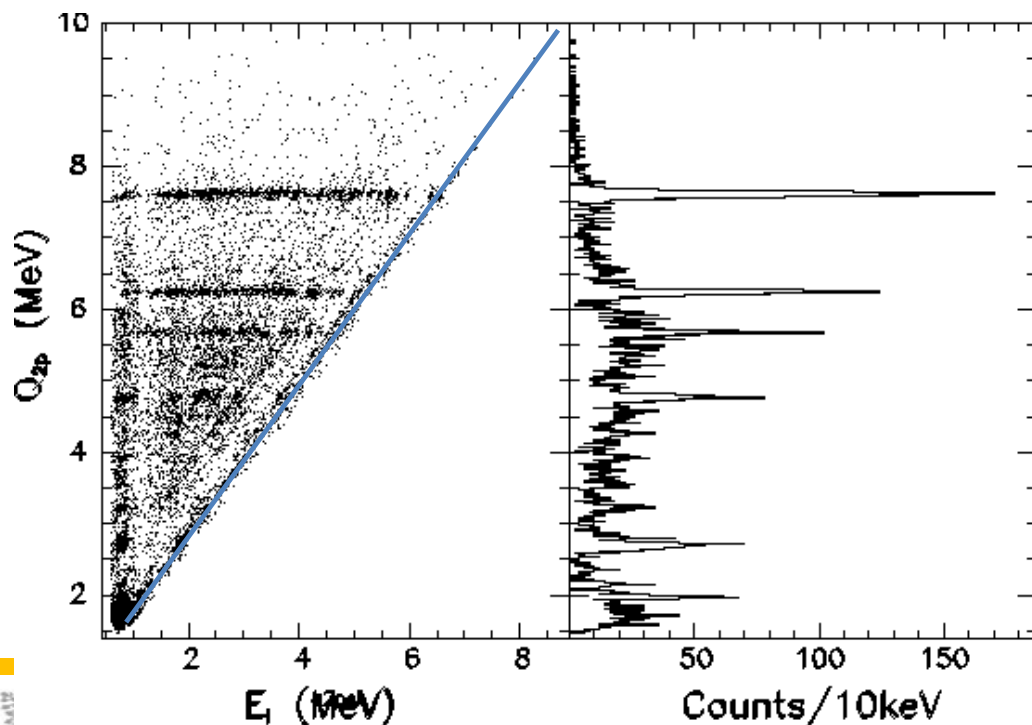
Granularity Increases
Multiparticle Efficiency



Diagonal from decays via single intermediate state from many initial states fed in beta-decay

$$E_1 = \frac{M_{D1}}{M_{D1} + m_p} Q_1$$

$$M_{D1} = M(^{30}\text{S})$$



Individual proton projections from $\beta 2p$ in ^{31}Ar

In sequential two-proton emission the energy of the first proton is

$$E_1 = \frac{M_{D1}}{M_{D1} + m_p} Q_1$$

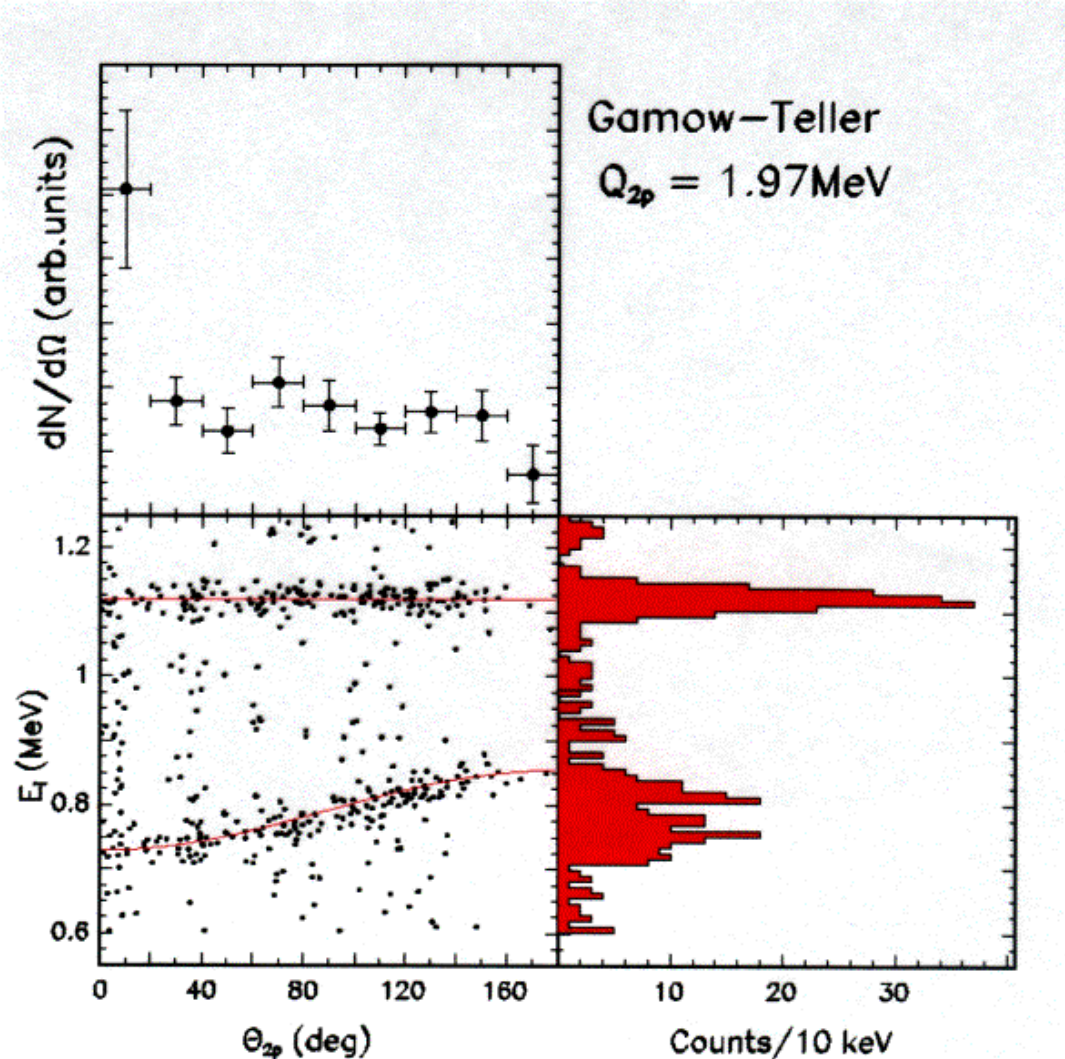
$$M_{D1} = M(^{30}\text{S})$$

$$Q_1 = E(^{31}\text{Cl}) - E(^{30}\text{S}) - S_{p1}$$

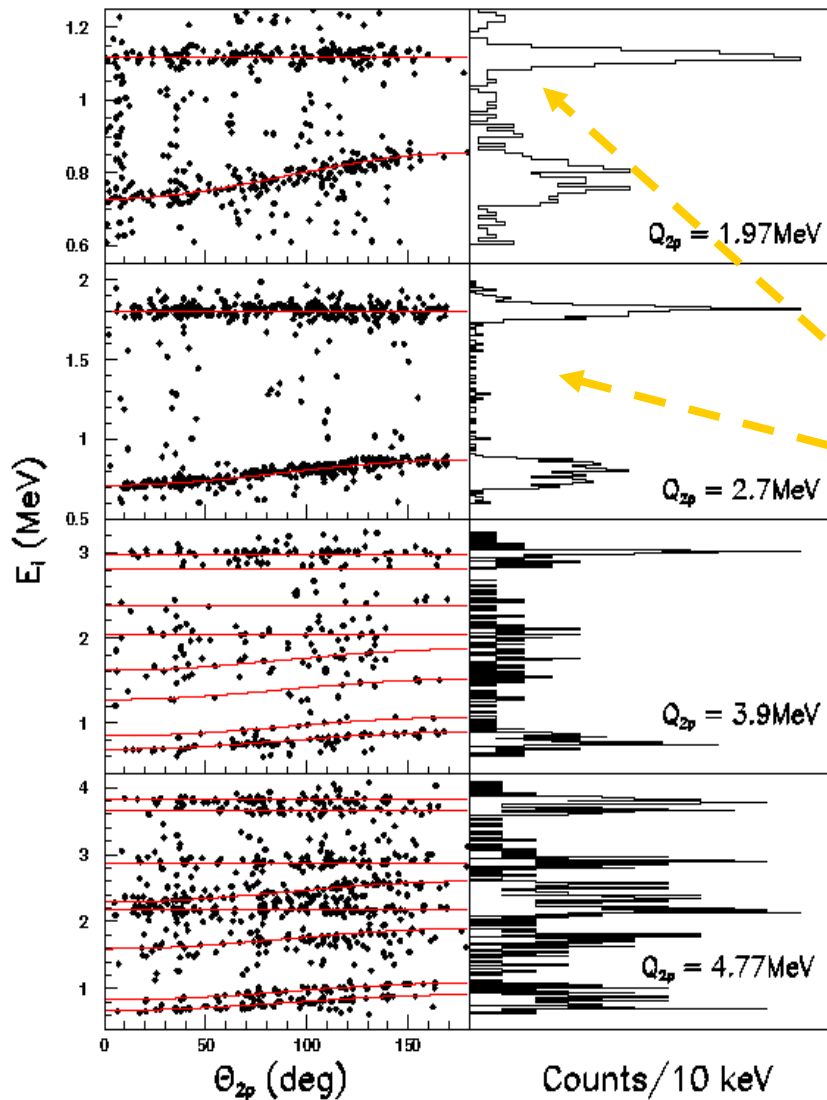
$$E_2' = \frac{M_{D2}}{M_{D2} + m_p} Q_2$$

$$Q_2 = E(^{30}\text{S}) - E(^{29}\text{P}) - S_{p2}$$

$$E_2 = E_2' + \left(\frac{m_p}{M_{D1}}\right)^2 E_1 - \frac{m_p}{M_{D1}} \sqrt{E_1 E_2'} \cos \theta_{2p}$$



Gamow-Teller 2p-transition



Isospin allowed transitions
increasing # of intermediate
states possible

- Kinematics of sequential emission
- ${}^2\text{He}$ branch present at some level ?

1st emitted

2nd emitted

30S^*

29p

Decay of the IAS of ^{31}Ar ($Z=18, N=13$)

$E_{\text{IAS}} = 12322(2)(50)$ keV from Q2p

$Q_{\text{EC}} = E_{\text{IAS}} + \Delta E_c - \Delta n_p$

$\checkmark \Delta E_c = 1448.8 [ZA^{-1/3}] - 1026.3$ keV

\checkmark Antony & Pape [ADNDT 34 (86) 279]

$\checkmark \Delta E_c = 7045$ keV

Leaving the coef. free and using exp. Coulomb energy shifts

between $^{32,33,34}\text{Cl}$ and $^{32,33,34}\text{Ar}$

$\Delta E_c = 6950(90)$ keV \Rightarrow

$Q_{\text{EC}} = 18,49(11)$ MeV

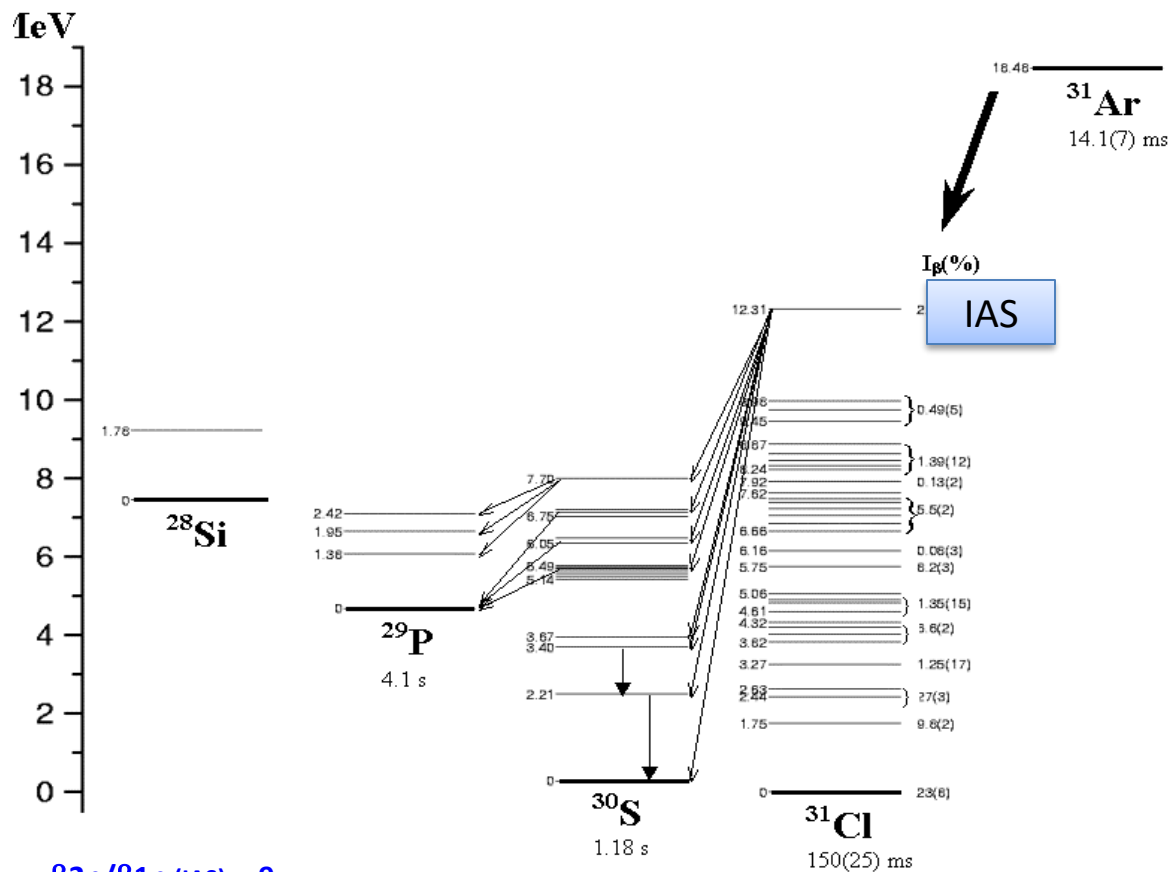
$f(E_{\beta\text{IAS}})t_{\text{IAS}} = 6145(4)$ s / [B(F) + B(GT)]

b.r.(IAS) = $T_{1/2} / t_{\text{IAS}}$

$B(F) = [T(T+1) - T_{zi}T_{zf}] \delta_{if} = 5$

Expected b.r. (IAS) = 4.35(31)%

Experimentally: b.r. (IAS) = 4.25(30) %



β_{2p}/β_{1p} (IAS) ~ 9

Fynbo et.al. NP A677(2000)38

Mapping of Neutron Deficient nuclei $22 < Z < 28$

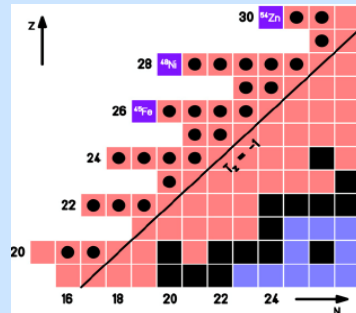
Spectroscopy studies with β -p- γ , β - γ

✓ 23 isotopes Studied

✓ Macroscopy Properties : $T_{1/2}$, P_p

✓ Spectroscopy:

- Partial Decay scheme
- IAS Identification
- IMME

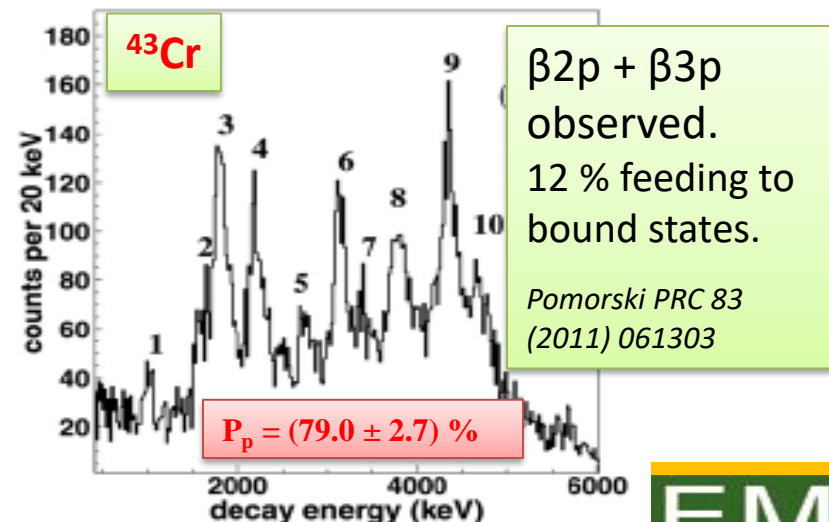
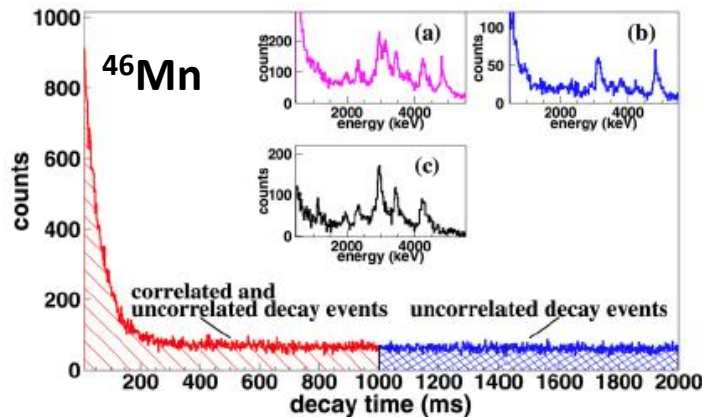
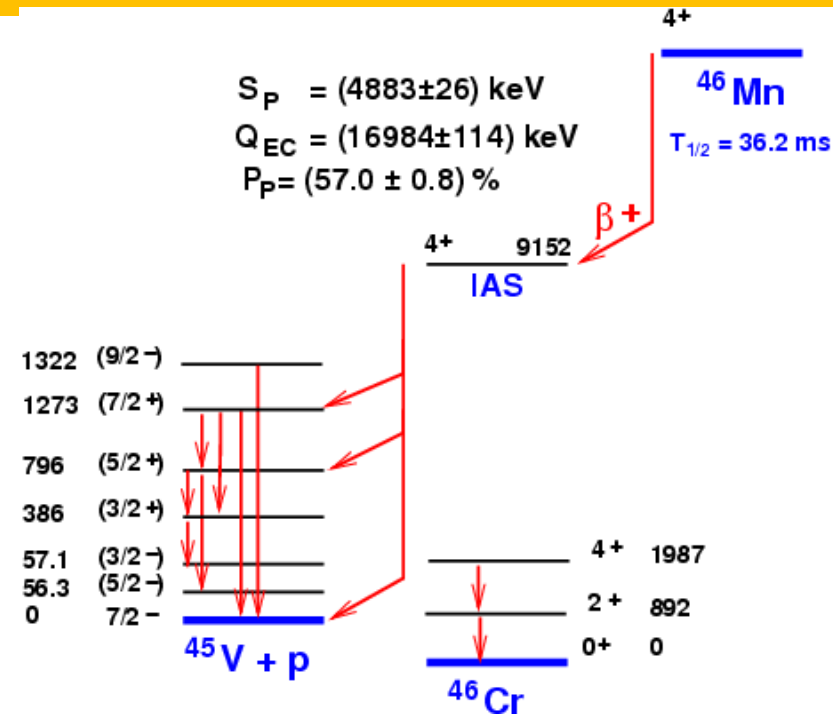


Dossat et al., NPA702 (2007) 18

$$S_p = (4883 \pm 26) \text{ keV}$$

$$Q_{EC} = (16984 \pm 114) \text{ keV}$$

$$P_p = (57.0 \pm 0.8) \%$$

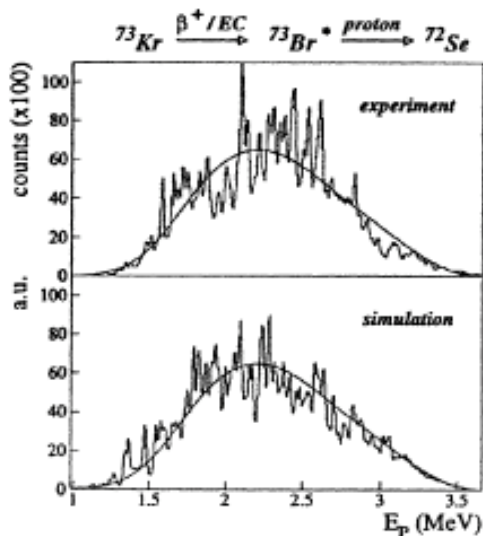
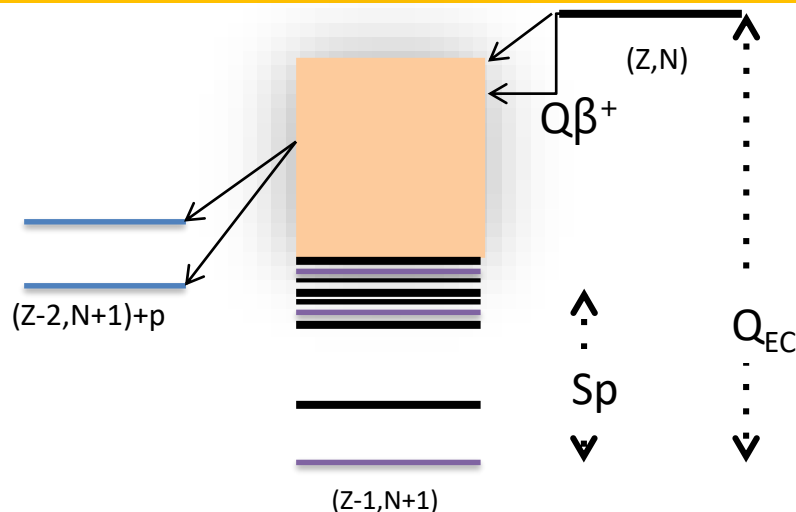


From peaks to continua (Hardy, Cargese, 1976)

βp explored high excitation energy in the daughter => individual transition are not longer resolved

$$I(E_p) = \sum_{i,f} f(Z, Q - E^i) S_\beta(E^i) \frac{\Gamma_p^{ij}}{\Gamma_p^i + \Gamma_\gamma^i}$$

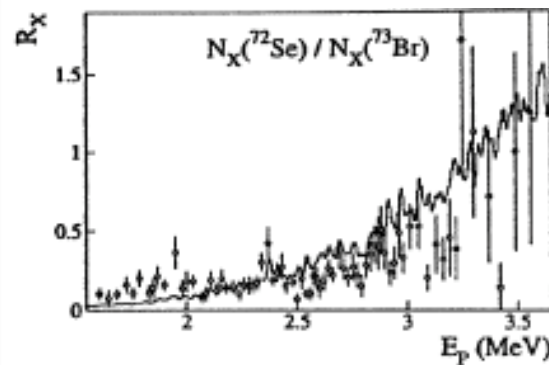
To fit the proton spectrum average of the above quantities are considered.



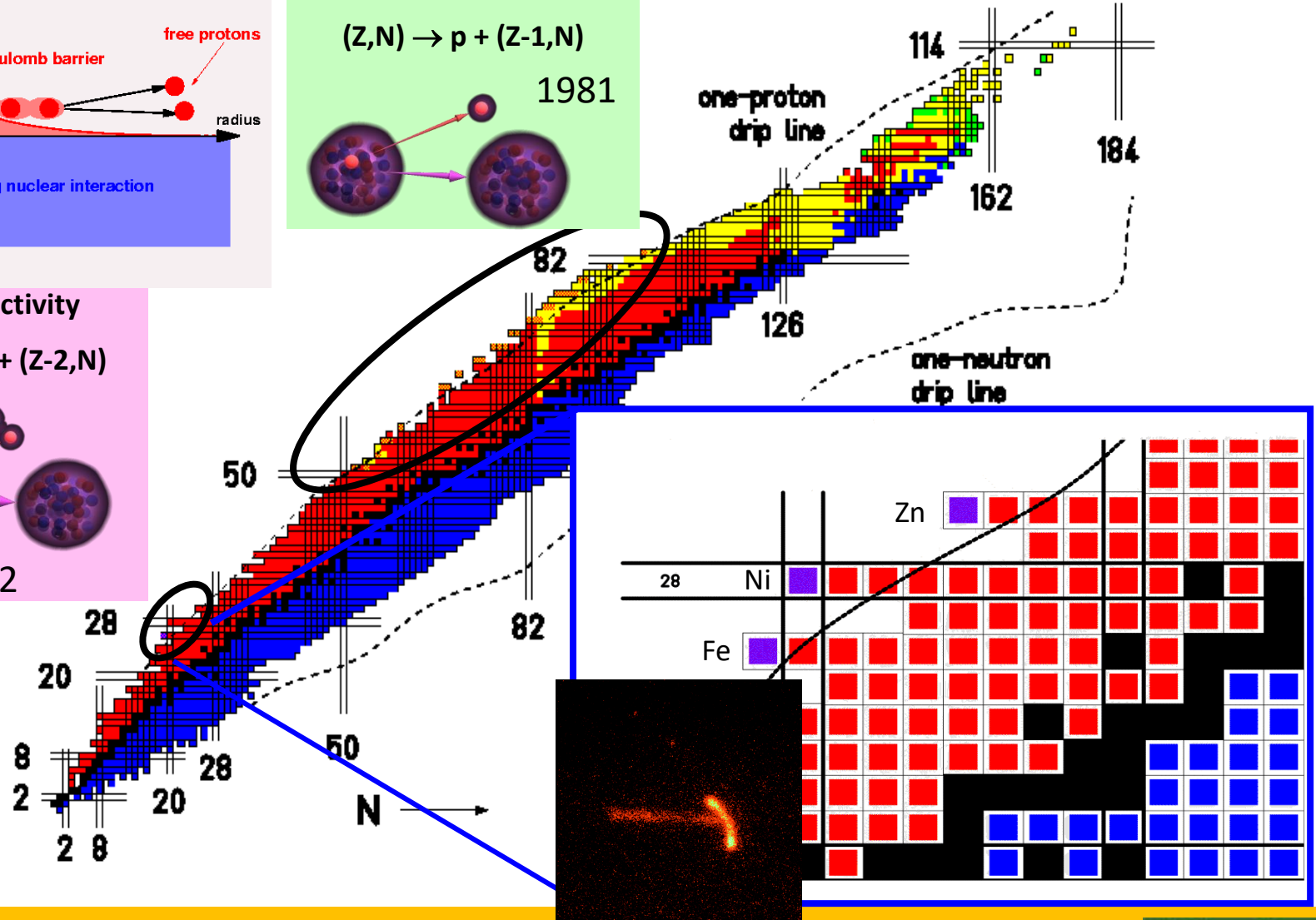
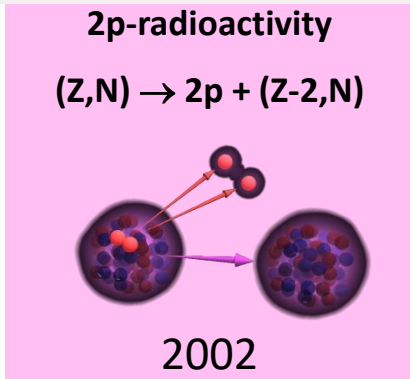
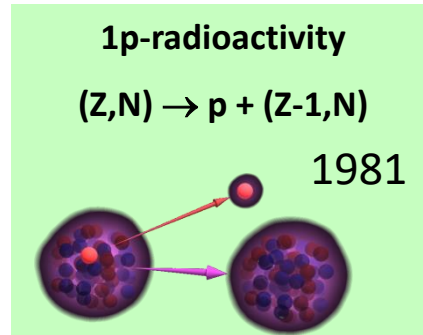
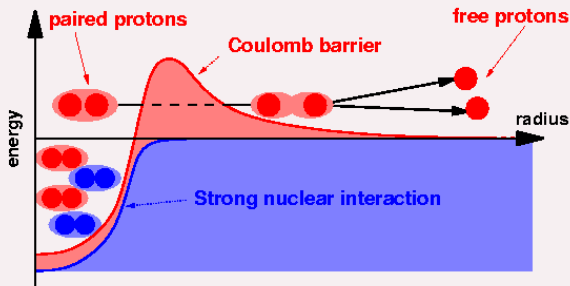
$\beta p + X$ -Ray ratio strongly constraint the level density distribution

Good estimate of proton and gamma widths for exotic nuclei of interest for nucleosynthesis

The Porter Thomas distribution accounts of the fluctuations observed in the spectrum



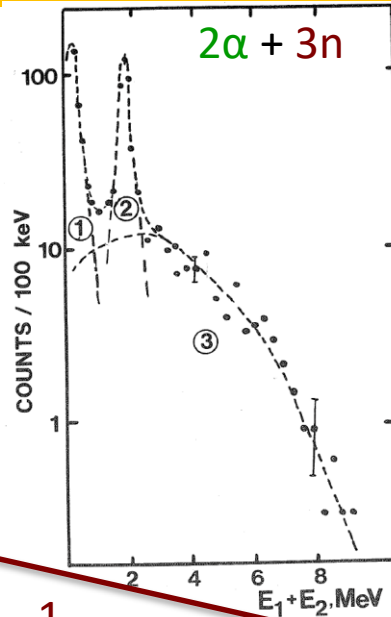
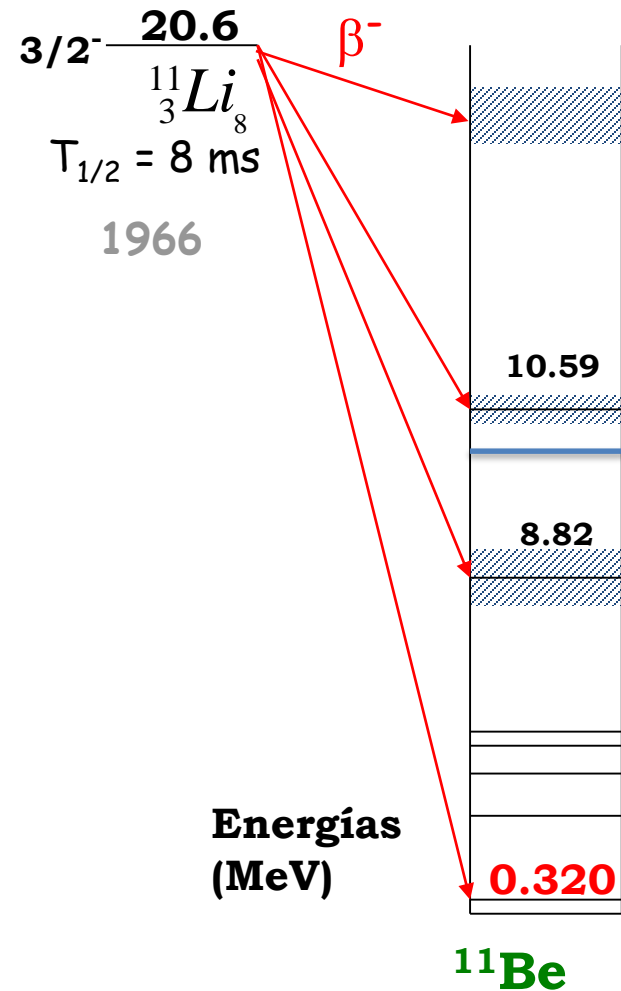
Exotic Radioactivities



Measurement of Neutrons & βn

- Long Counter: reduced energy to thermal values by scattering in parafine.
- Time-of-Flight, giving signals in plastic scintillator. Energy of neutron deduced.
- βn can be deduce by obsevation of γ -ray transition in the beta-delayed neutron daughter.

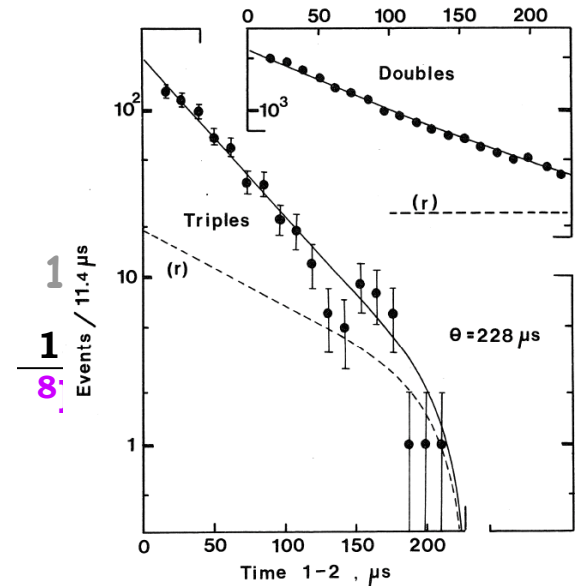
Beta decay of an exotic n-rich nuclei



1974 **0.504**
 $^{10}\text{Be} + n$
 $P_{1n} = 84.9 \pm 0.8 \%$

1979 **7.315**
 $^9\text{Be} + 2n$
 $P_{2n} = 4.1 \pm 0.4 \%$

1980 **8.982**
 $2\alpha + 3n$
 $P_{3n} = 1.9 \pm 0.2 \%$



Identification of
 2n & 3n by time
 correlations
Azuma et al., PLB 96
(1980) 31

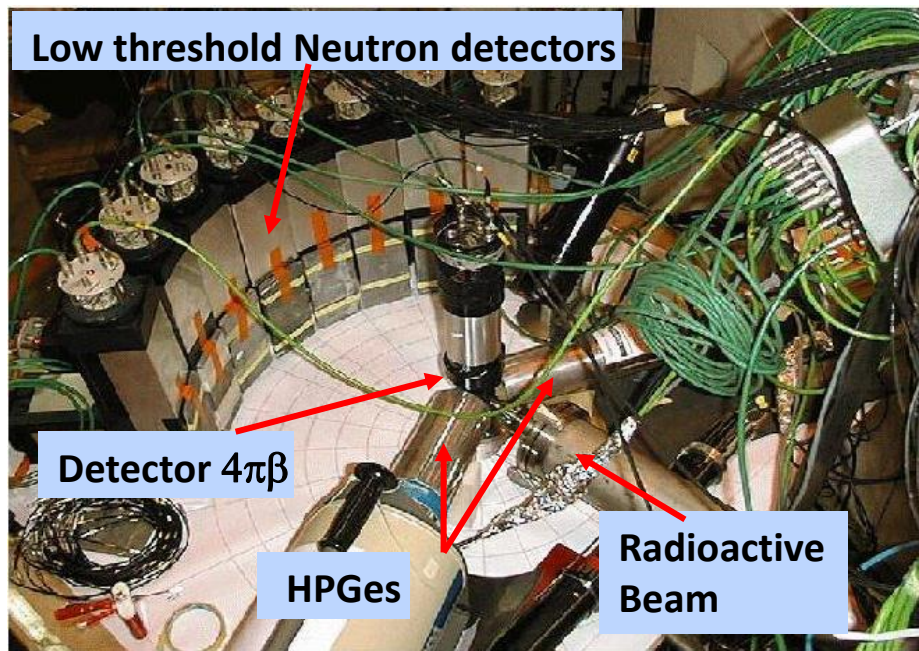
Decay Scheme → Structure Information (N= 20)

^{33}Na

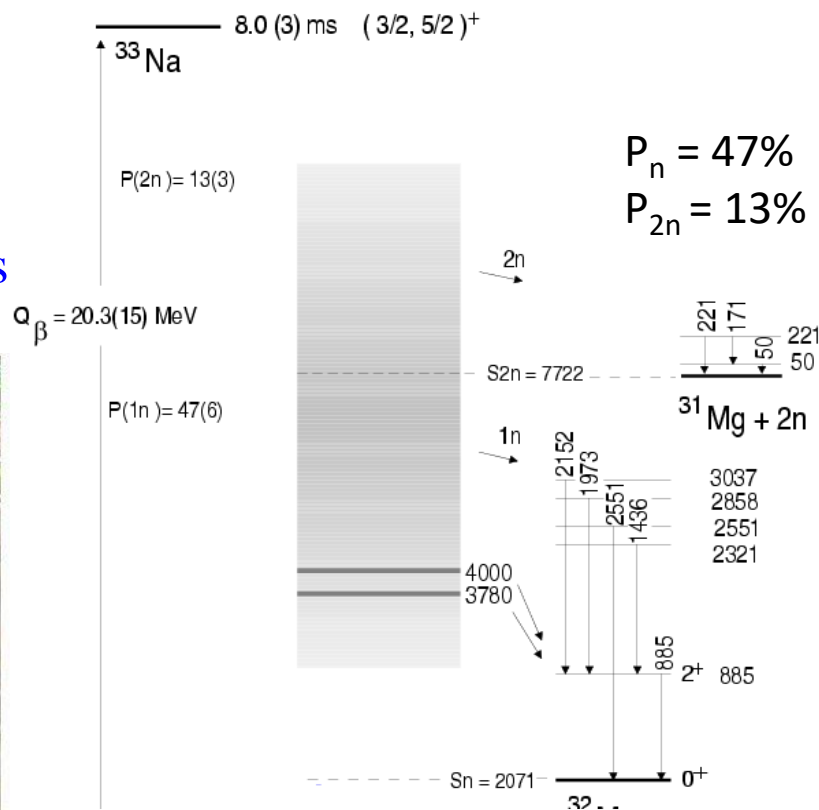
ISOLDE

fragmentation U (46g/cm²) 2000°

1,4 GeV protons $3 \cdot 10^{13}$ / pulse (1,2s) ^{33}Na 2 at / s



exp. : coinc. β neutrons β.γ.n

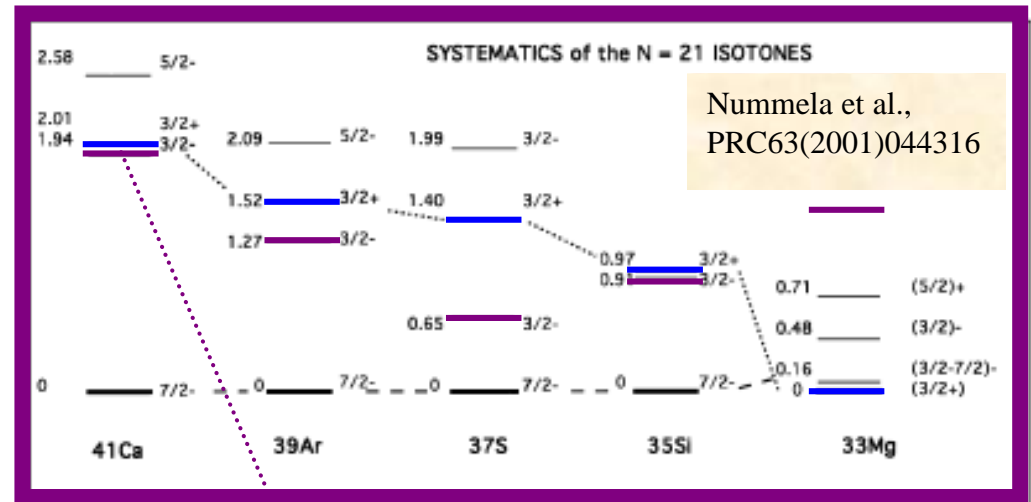
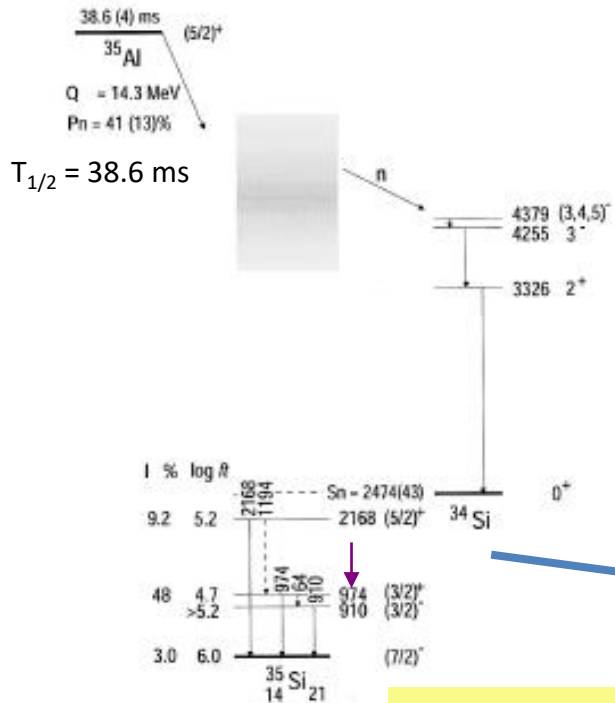


^{33}Na $T_{1/2} = 8.0 (3)$ ms

Detailed Level Scheme

inversion of 3/2⁺ 7/2⁻ orbits in ^{33}Mg

Intruder states & Effective interaction in sd-pf shell



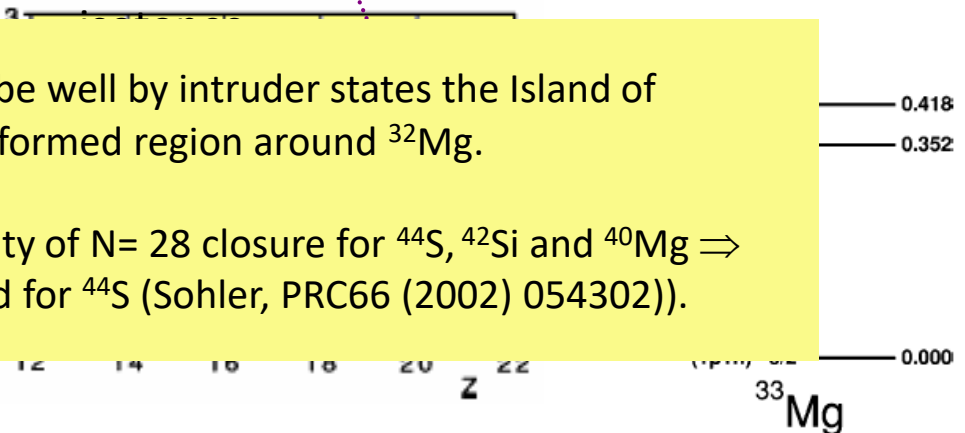
Position of $3/2^-$ state in N = 21

$(1p1h) \ 5/2^+ \ 0.811$
 $(2p2h) \ 5/2^- \ 0.793$

Nummela et al., PRC63(2001)

Fix the single particle energy, the effective interaction

- Shell Model describe well by intruder states the Island of Inversion and the deformed region around ^{32}Mg .
- Predicts vulnerability of N= 28 closure for ^{44}S , ^{42}Si and $^{40}\text{Mg} \Rightarrow$ confirmed for ^{44}S (Sohler, PRC66 (2002) 054302)).



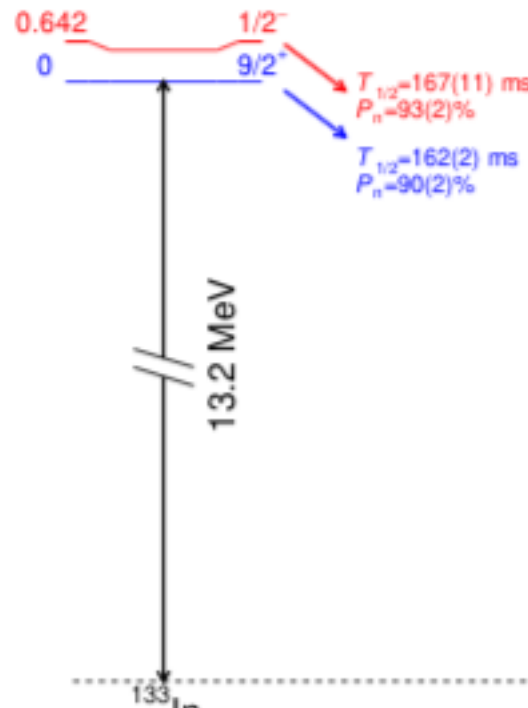
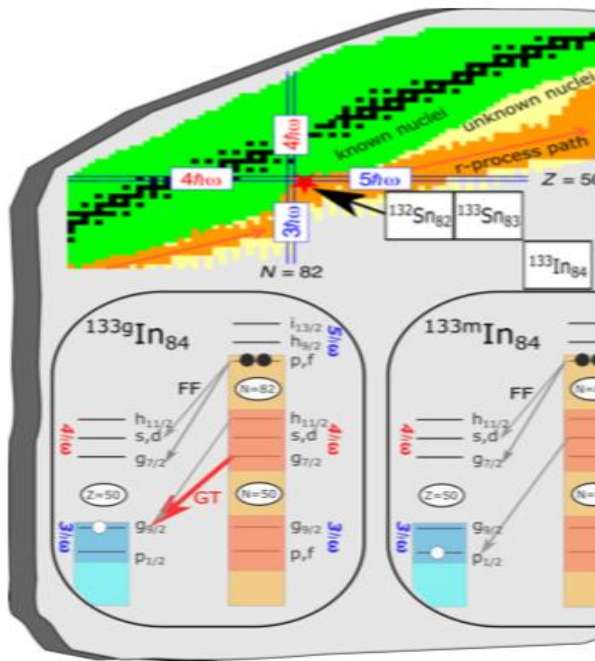
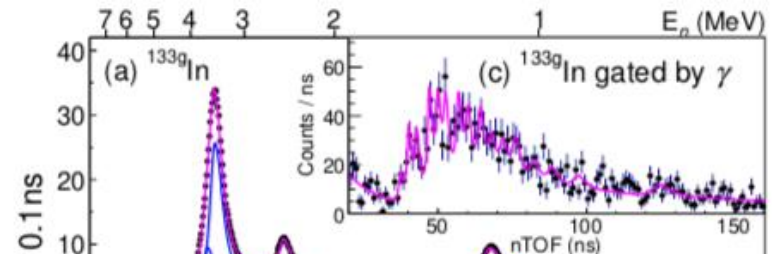
βn from $^{133g}\text{In}(9/2^+)$ and $^{133m}\text{In}(1/2^-) \rightarrow ^{133}\text{Sn}$ study

^{133}In is a key nucleus for

- Astrophysics due to its placement on the r-process bottleneck regions in most scenarios.
- its proximity to the doubly magic ^{132}Sn (50 protons and 82 neutrons) offers a uniquely simple β -decay system to validate nuclear theories.
- $\beta, \gamma, n, \beta n, \beta n \gamma$ measured

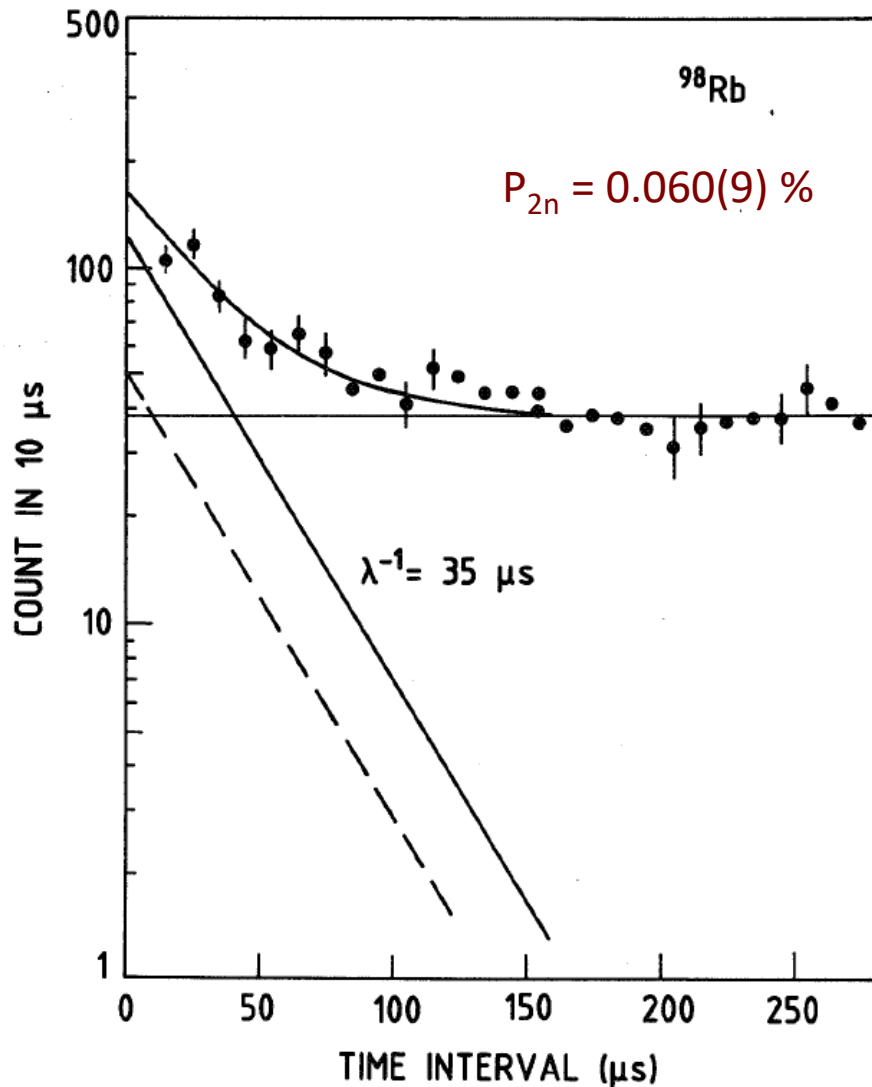
High resolution laser tuning allowed
Separate the contribution from gs and isomer ^{133}In

Neutron ToF Spectrum from VANDLE

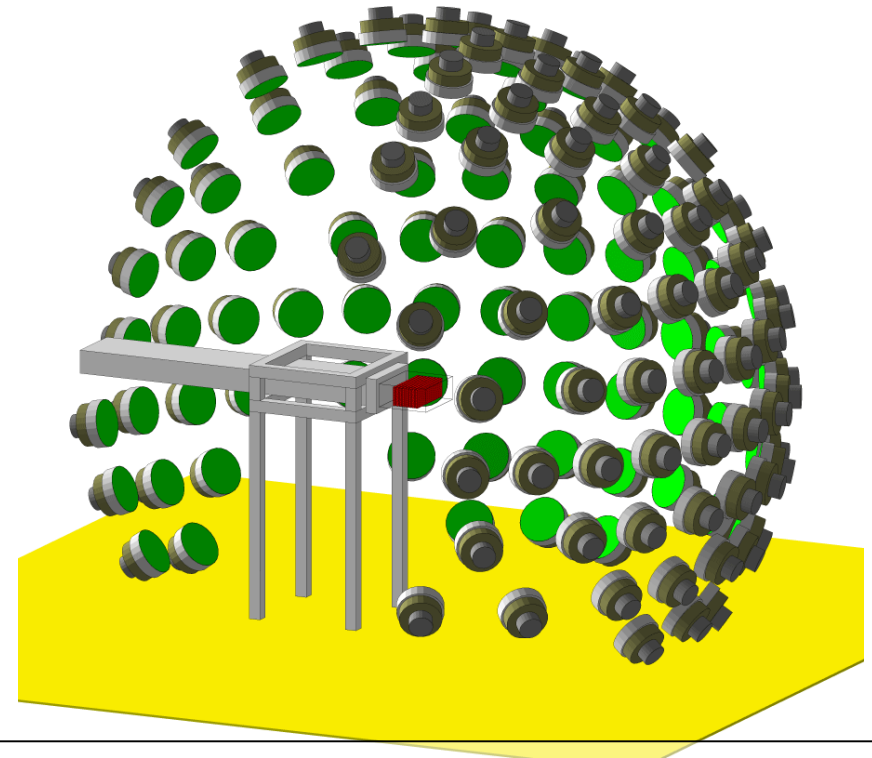


I_{β} (%)	$\log t$	$E_{\beta n}$ (MeV)	I^{π}
37.6	4.7	*5.92	$(7/2^+)$
11.7	5.5	5.60	$(1/2^-, 3/2^-)$
4.3	6.0	5.14	$(1/2^-, 3/2^-)$
9.5	5.6	4.91	$(7/2^-, 9/2^-, 11/2^-)$
0.9	6.8	4.64	$(1/2^-, 3/2^-)$
0.9	6.8	4.46	$(1/2^-, 3/2^-)$
1.1	6.6	4.33	$(7/2^-, 9/2^-, 11/2^-)$
0.8	6.8	4.24	$(7/2^-, 9/2^-, 11/2^-)$
0.6	6.9	4.12	$(7/2^-, 9/2^-, 11/2^-)$
13.6	5.8	4.10	$(1/2^-, 3/2^-)$
1.8	6.5	3.92	$(7/2^-, 9/2^-, 11/2^-)$
11.9	5.9	*3.79	$(1/2^-)$
32.5	5.5	*3.62	$(3/2^-)$
12.0	5.8	*3.56	$(11/2^-)$
		2.01	$5/2^-$
		1.56	$(9/2^-)$
		1.36	$1/2^-$
		0.85	$3/2^-$
		0.00	$7/2^-$

Neutron Detection systems

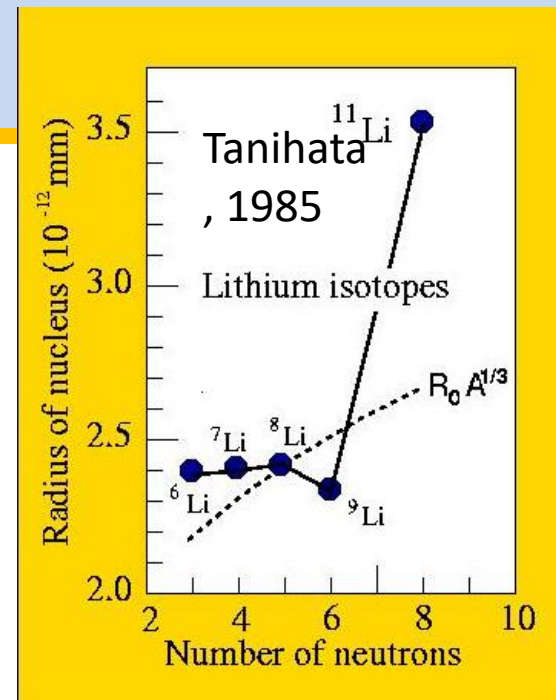
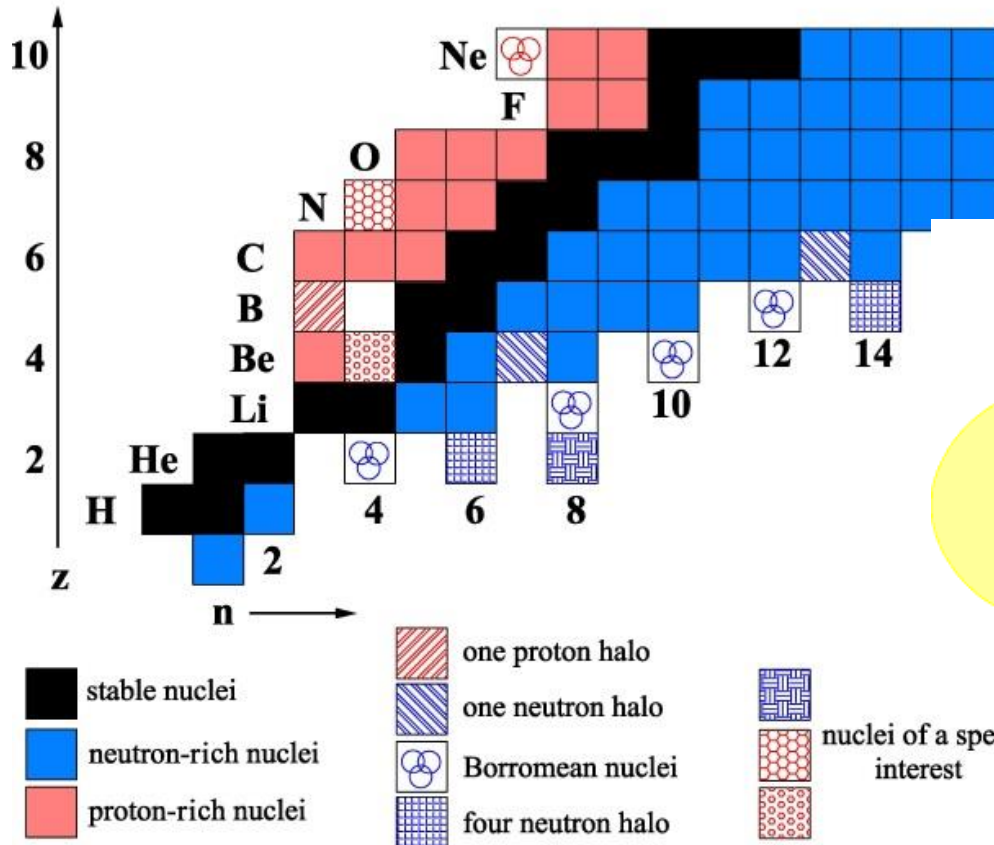


4 π Counter
Measured With 40 ^3He tubes embedded in parafine with 59 % efficiency.



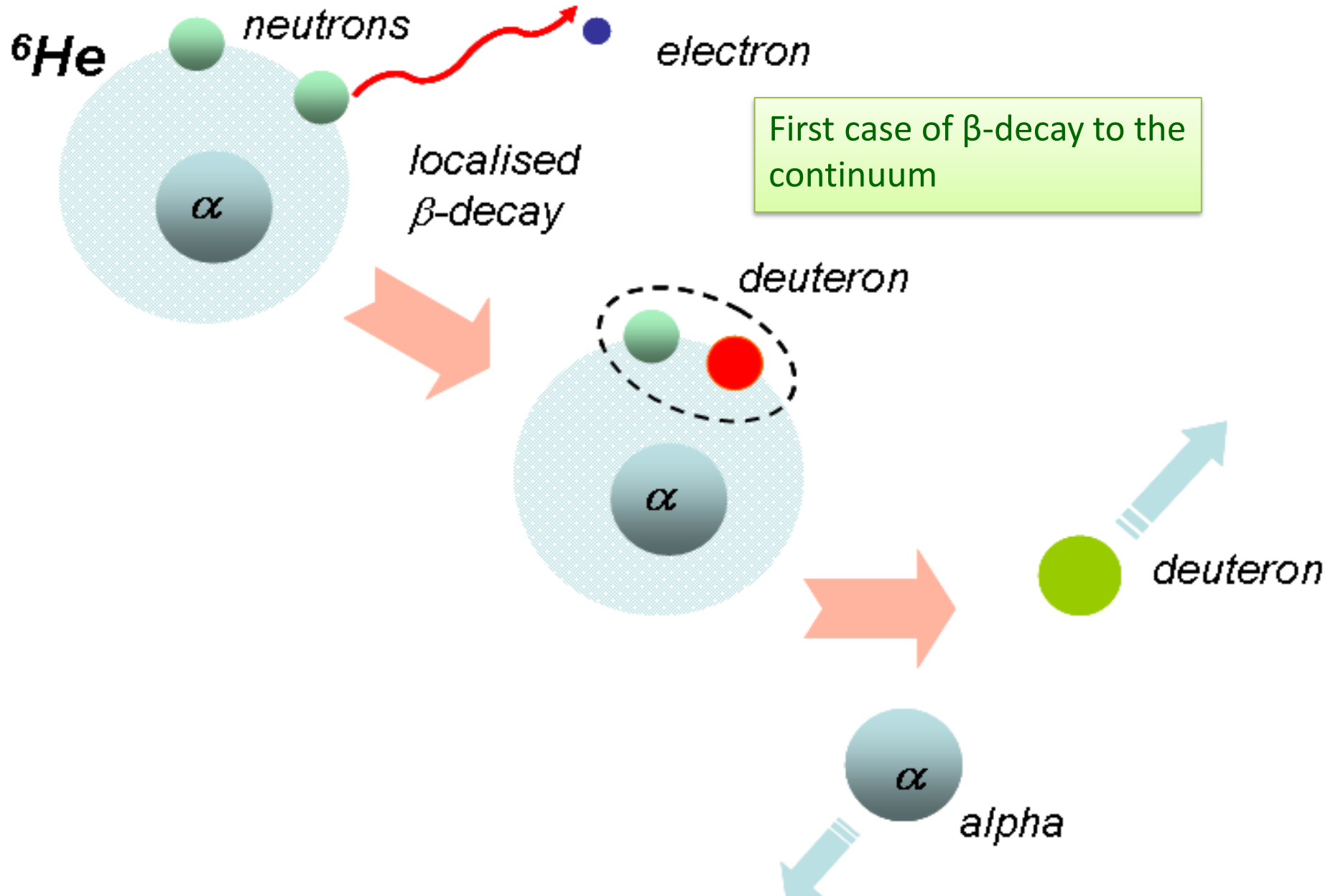
TOF spectrometer: array of liquid scintillators (BC501A)

Halo nuclei

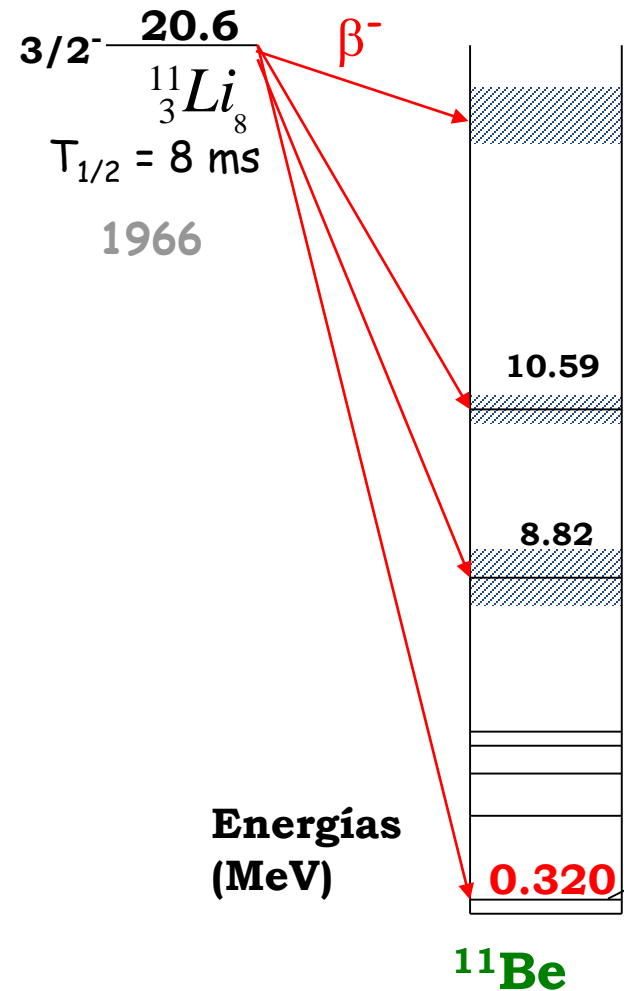


- ✓ Energy threshold effect
- ✓ Highlight by nuclear reactions
- ✓ Effects in beta decay

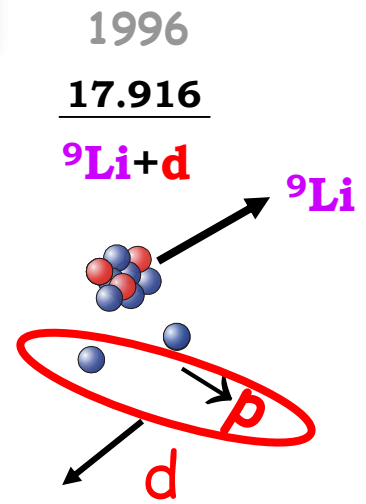
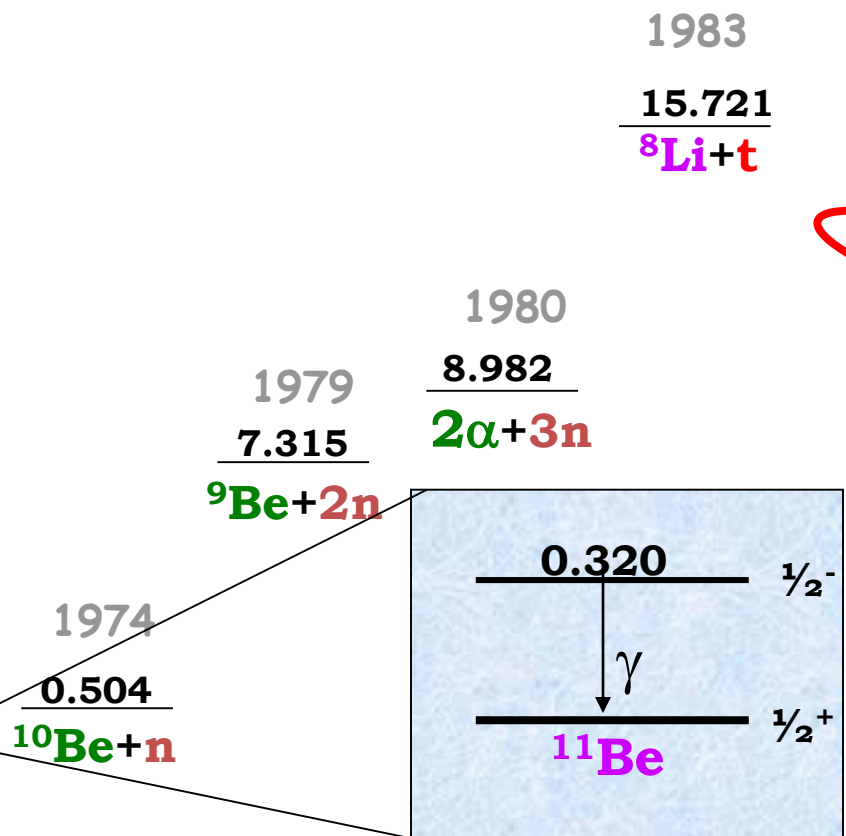
Beta-delayed deuterons



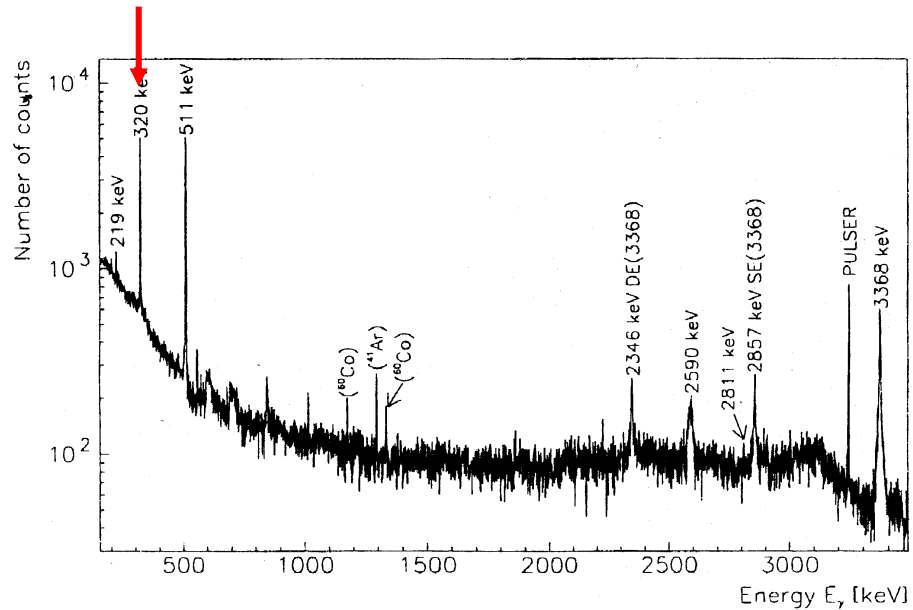
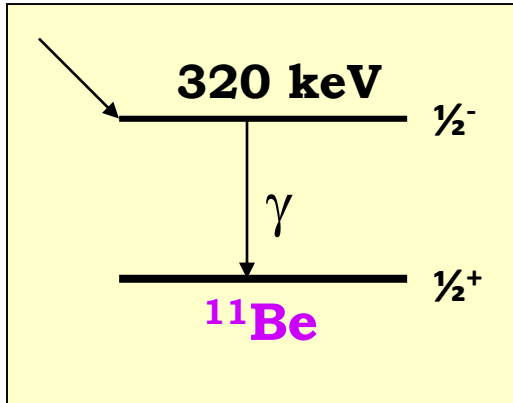
Beta decay of an exotic nuclei



Even a neutron rich - nuclei emit charged particles



^{11}Li , gamma rays

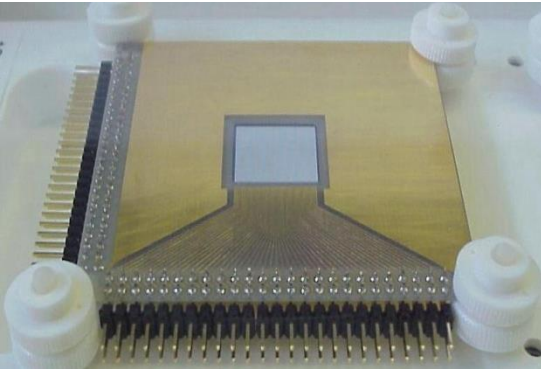


M.J.G. Borge et al., PRC55 (97) R8
 N. Aoi et al., NPA616 (97) 181c
 D. Morrissey et al., NPA627 (97) 222

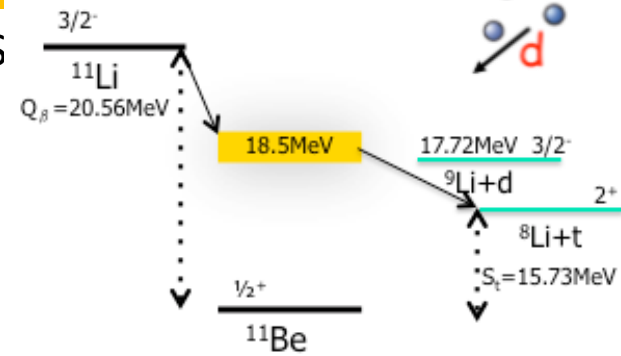
$Q = 20.62\text{ MeV}$, $T_{1/2} = 8.2\text{ ms}$
 $b(320) = 6.3(6)\%$
 $\log ft = 5.73$

$(1s_{1/2})^2 / (0p_{1/2})^2 \sim 1$

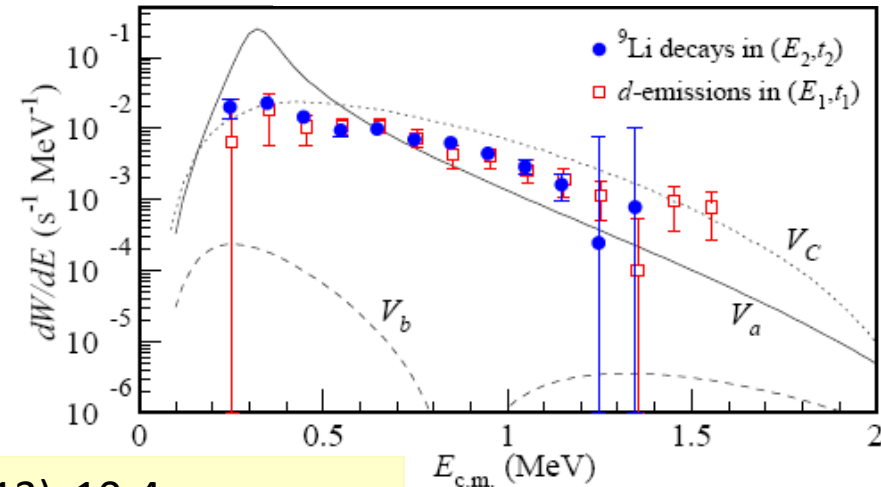
^{11}Li β d spectrum finally measured @ TRIUMF!!



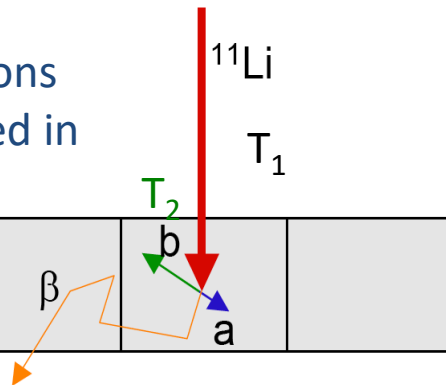
- Implantation of ^{11}Li beam on DSSS Detector
- Very precise B.R.
- Low detection threshold
- Low beta background
- History of each decay



DSSSD 16x16 mm², 70μm thick
48x48 strips, 300 μm, 2304 pixels
J. Büscher et al., NIM B 266 (2008) 19



8×10^7 ions
implanted in
133 h



B.R. = $1.30(13) \times 10^{-4}$
 $E_{\text{cm}} > 200$ keV
Deuteron Spectrum
Decay to the continuum
confirmed !

Raabe et al, PRL 101 (2008) 212501

Stringent test of Nuclear Models

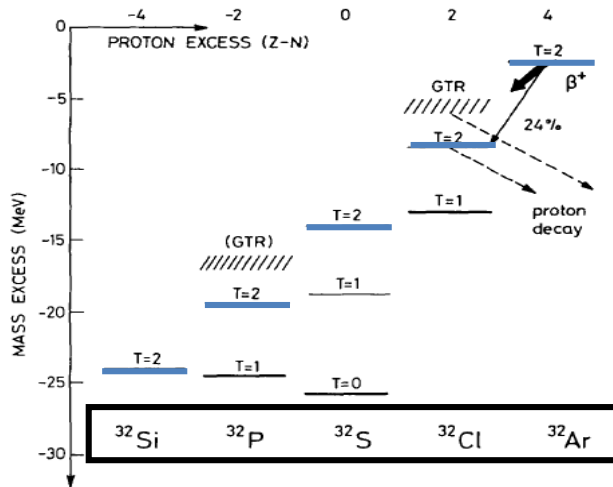
✓ Test Isobaric Multiplet Mass eq.

$$M(A, T, T_z) = a + bT_z + cT_z^2 + \delta(dT_z^3 + eT_z^4)$$

✓ If 2-body forces responsible of charge dependence in nuclei IMME to T_z^2

$$B_F = T(T+1) - T_{zi}T_{zf}$$

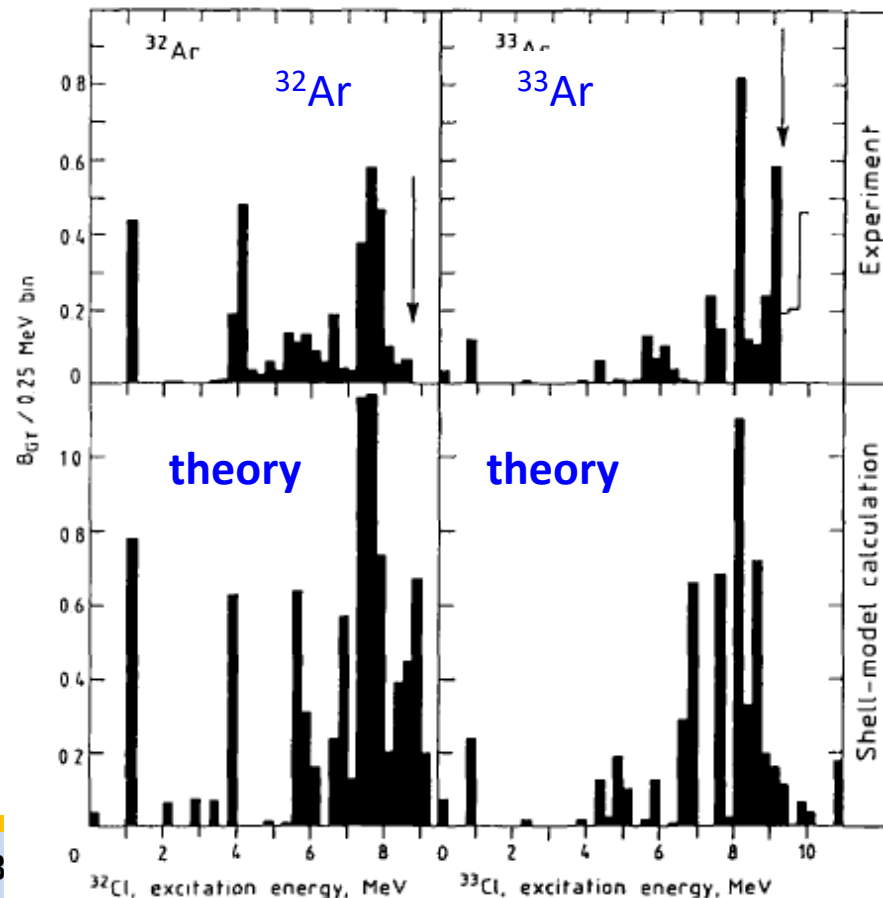
✓ If strength to IAS $\neq B_F \Leftrightarrow$ Mixing



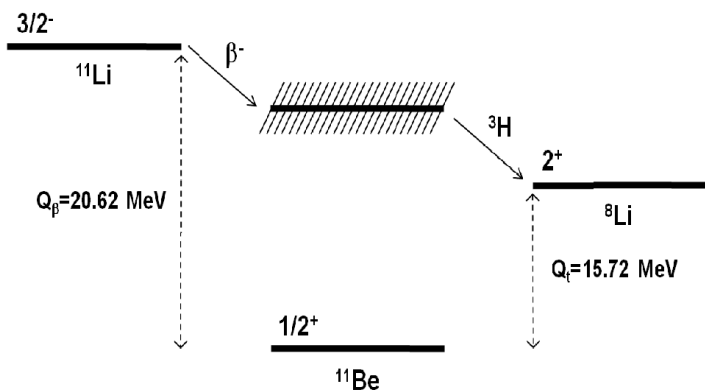
Quintet test $\rightarrow d = 0.89(11)$ keV

✓ Impressive reproduction of the B_{GT} distribution by Shell Model calculation

✓ Quenching factor close to one, sensitive to the placement of the GTGR

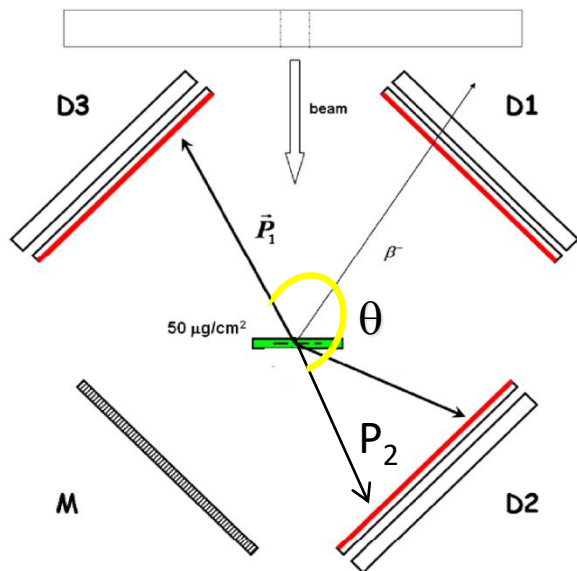


Kinematic identification of βt emission in ^{11}Li

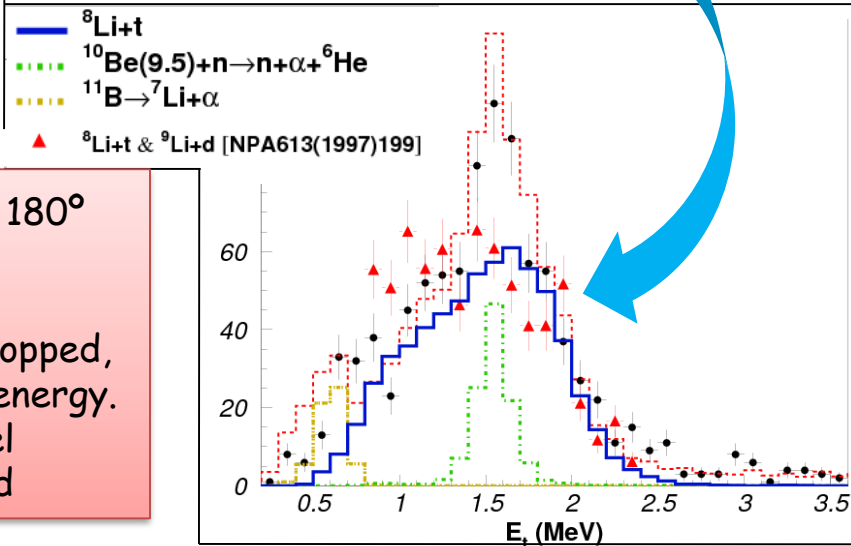
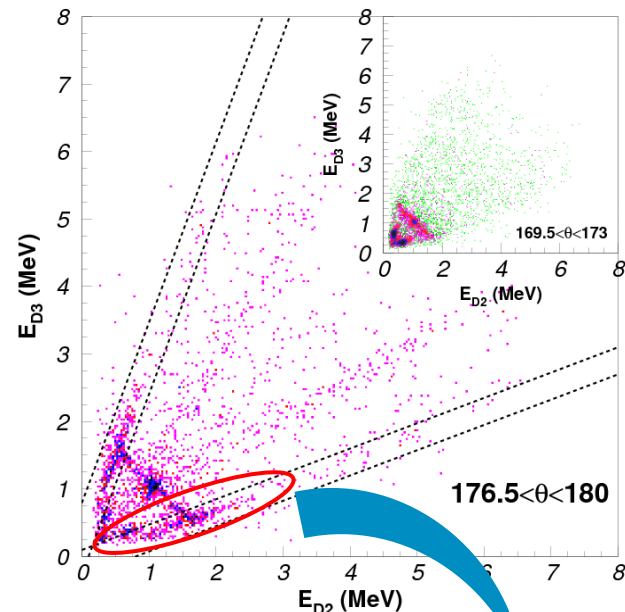


$$Q_{\beta t} = \Delta M(^{11}\text{Li}) - \Delta M(^8\text{Li}) - \Delta M(t) = 4822(5) \text{ keV}$$

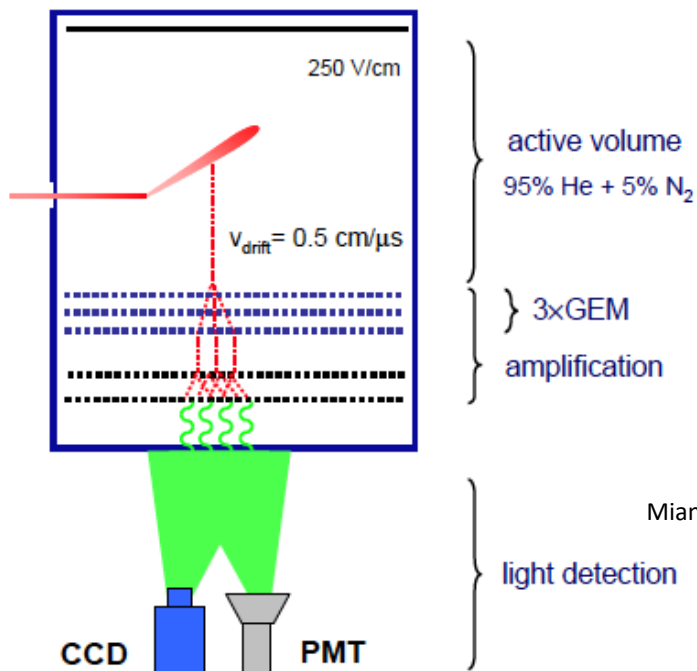
Madurga et al., Eur. Phys. J A42 (2009)415



- Kinematics near 180° between charged particles.
- $^9\text{Li}+d$ channel stopped, ^9Li too low recoil energy.
- The $^8\text{Li}+t$ channel uniquely separated

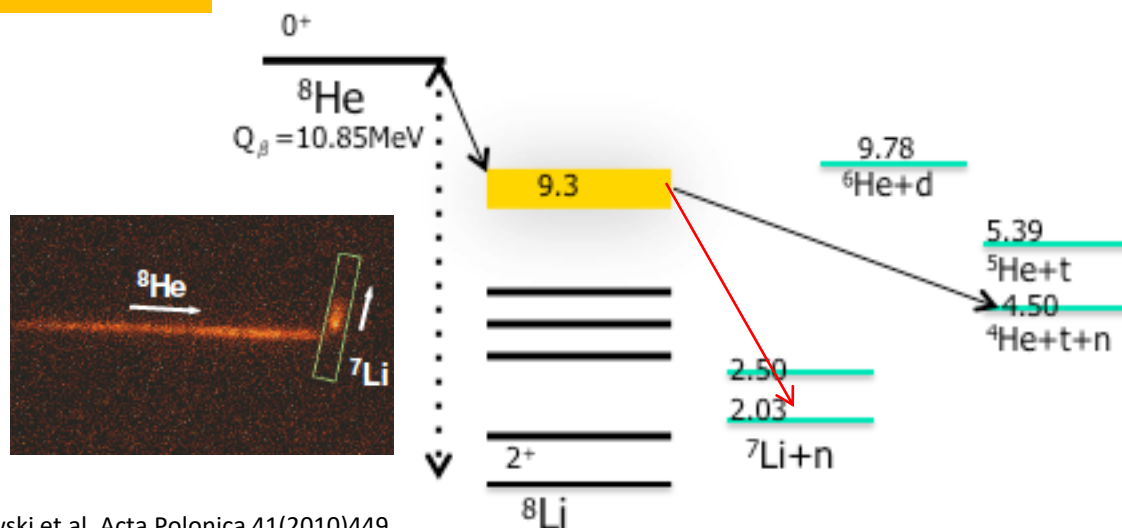


Viewing β -delayed triton emission

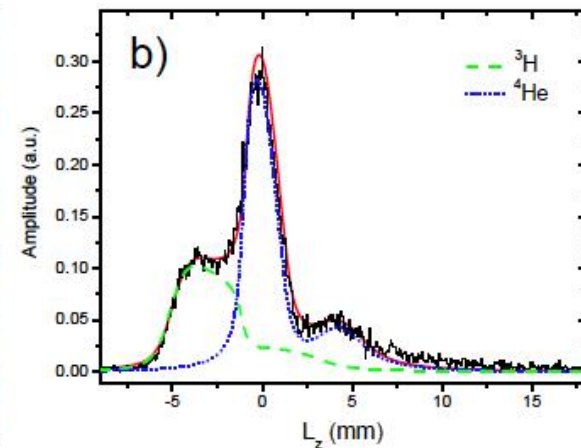
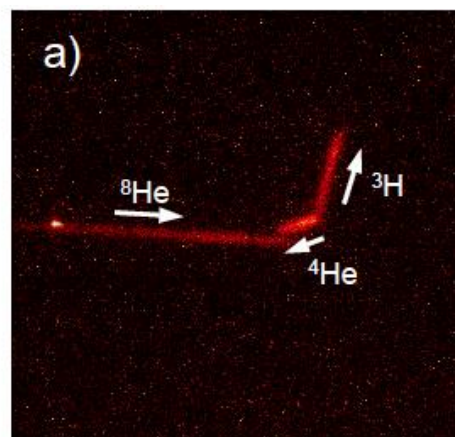


Optical Time Projection Chamber

The strong βt branch allowed to identified feeding to a highly excited state in ^8Li .
New branch βn from this state confirming the character of super-allowed transition

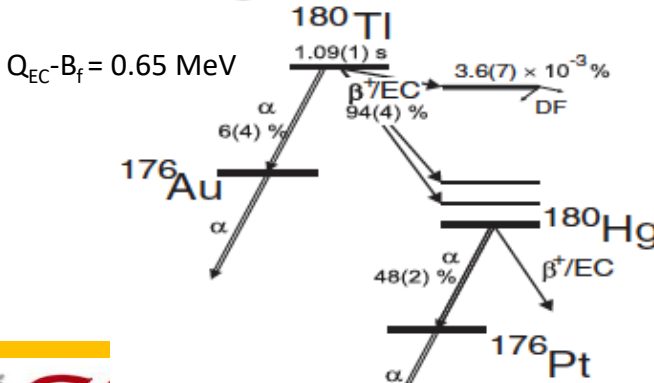
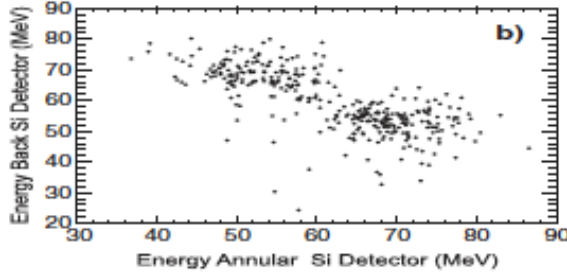
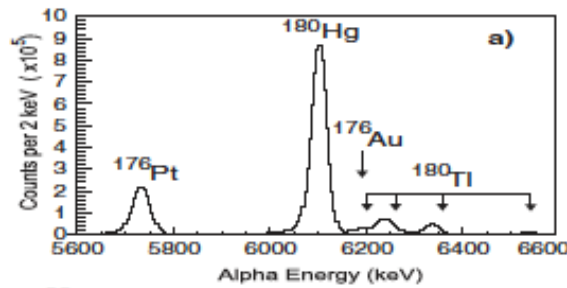
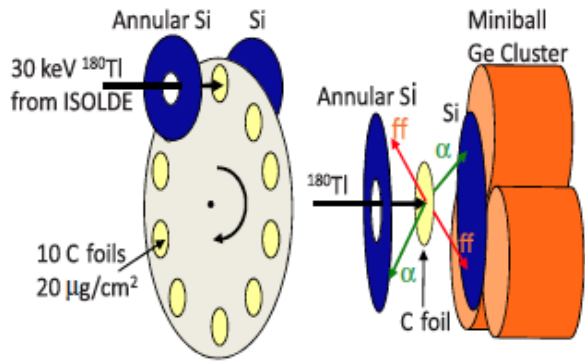
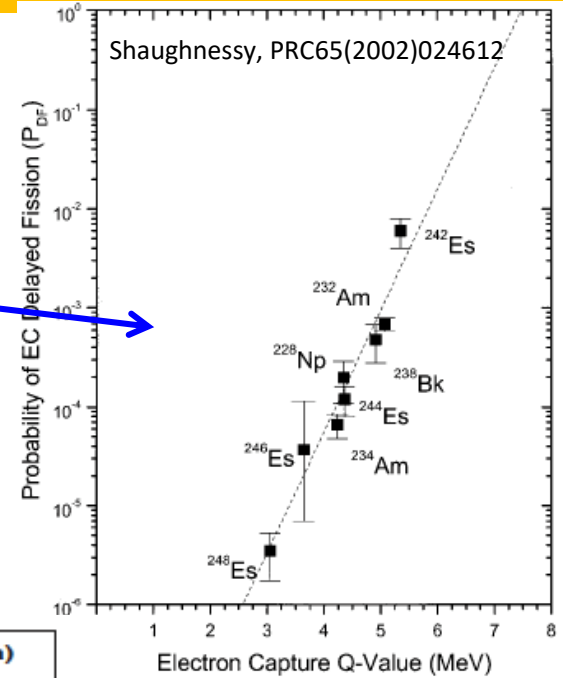


Mianowski et al, Acta Polonica 41(2010)449

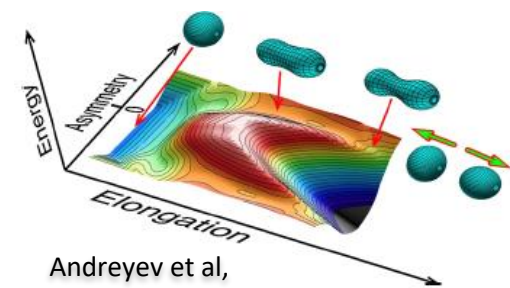


Beta-delayed Fission in the Pb-region

Discover in Dubna in $^{232,234}\text{Am}$ in 1966
 Allows to study low energy fission properties at unusual N/Z ratios
 Max energy of fissioning nucleus $< Q_{\text{EC}}$ of precursor
 Two region : 12 cases identified in the U-region
 neutron deficient Pb-region



Unexpected Asymmetric Fission Fragments !

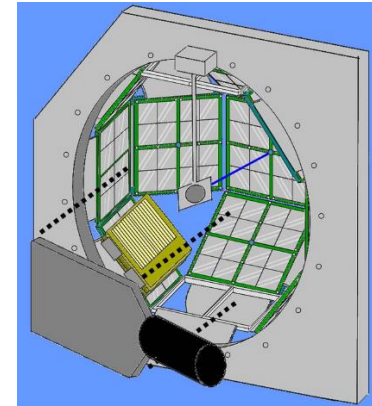
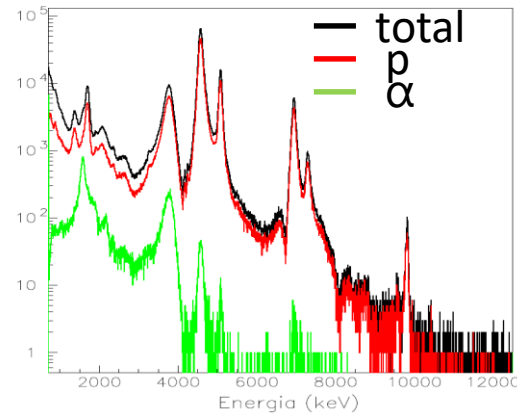
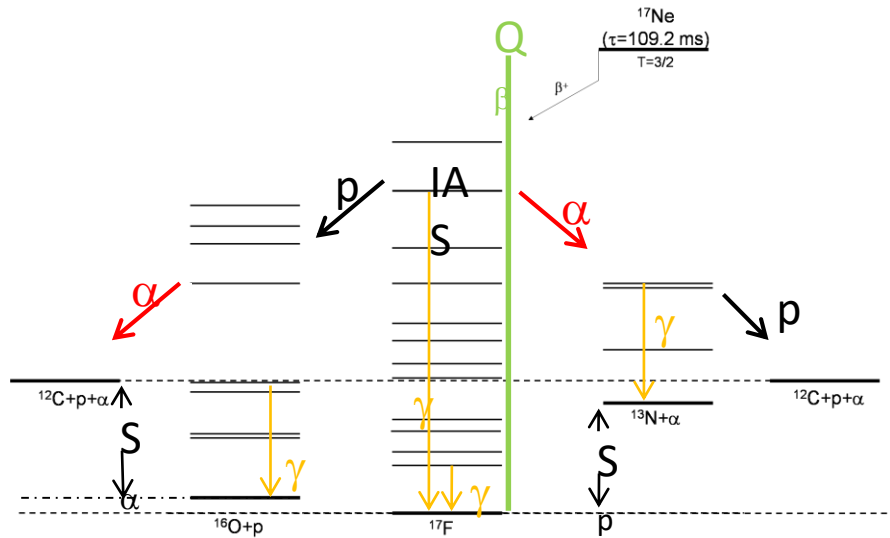


Andreyev et al, PRL105(2010)252502

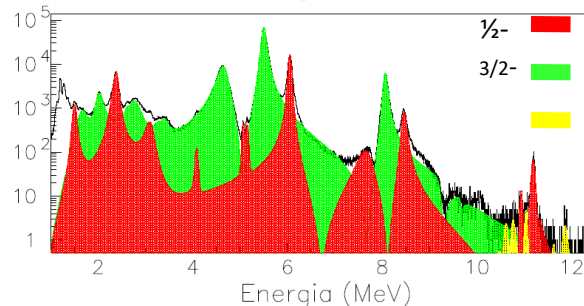
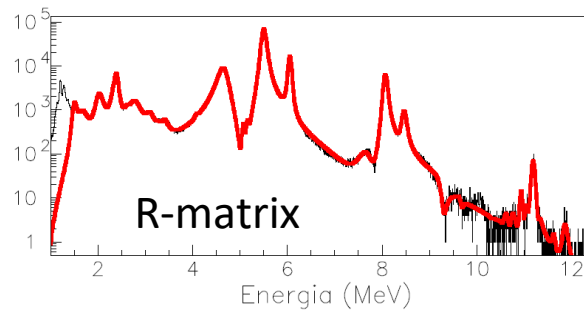
Beta-alpha emission

- $\beta\alpha$ -Identified first in Natural radioactivity
- $\beta\alpha$ favoured in light nuclei with $T_z = -1$: ${}^8\text{B}$, ${}^{12}\text{N}$, ${}^{20}\text{Na}$...
- In cases where both $\beta\alpha$ and βp are allowed $\Rightarrow \beta p$ dominates due to barrier penetrabilities
- Branches of $\beta\alpha > 1\%$ are only observed in nuclei $A < 20$ and ${}^{118}\text{I}$
- Some of these states are of astrophysical relevance
 - For instance the ${}^{16}\text{N}(\beta\alpha)$ helped to elucidate the ${}^{12}\text{C}(\alpha,\gamma){}^{16}\text{O}$
- $\beta p\alpha$ or $\beta\alpha p$ is a decay mode open for ${}^9\text{C}$, ${}^{13}\text{O}$, ${}^{17}\text{Ne}$, ${}^{21}\text{Mg}$ and ${}^{23}\text{Si}$
 - Only identified ${}^9\text{C}$ and ${}^{17}\text{Ne}$
 - ${}^9\text{C}$ special as the daughter is unbound to p-emission. Expectacular asymmetry in some of the mirror transitions with ${}^9\text{Li}$
 - ${}^{17}\text{Ne}$ astrophysical relevance to learn about the E2 capture rate in stellar ${}^{12}\text{C}(\alpha,\gamma){}^{16}\text{O}$ reaction

Beta-decay of ^{17}Ne

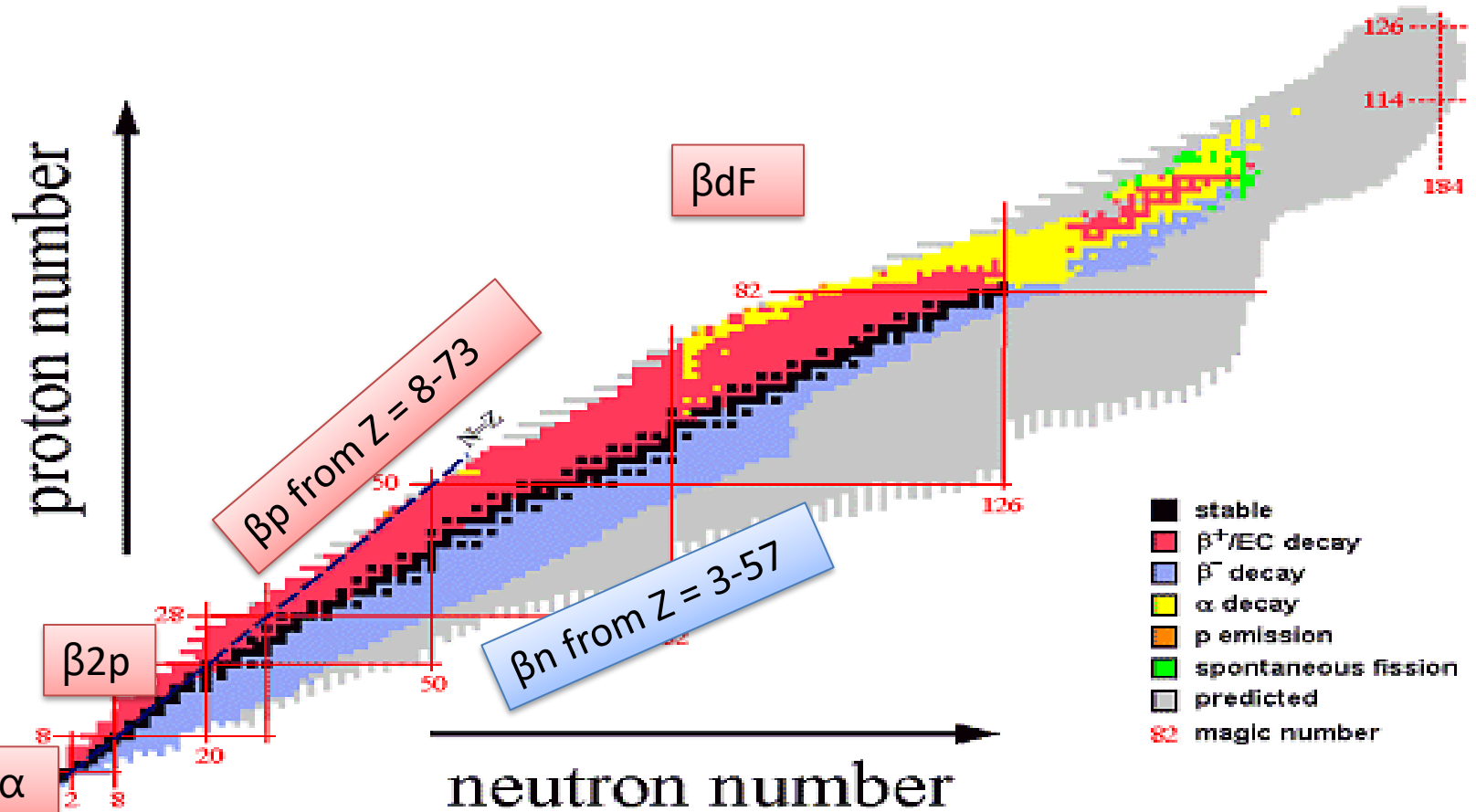


Characterization of the α -width of the subthreshold states of ^{16}O at 6.9 and 7.1 MeV of interest for the $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$ capture rate.



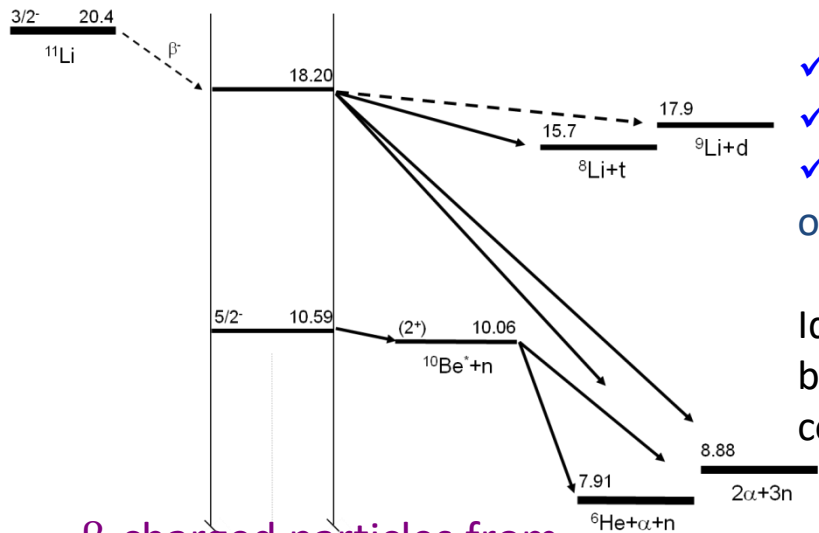
- Separation of βp , $\beta \alpha$ channels with ΔE -E and ToF techniques, allowing independent analysis of the two spectra.
- B_p and B_α branches confirmed previous values with higher precision.
- Treatment of the full proton spectrum using R-Matrix.
- Feeding to subthreshold ^{16}O states, study of their partial α -widths on progress.

Beta Delayed Particle Emission



A wonderful Tool to peer into Nuclear Structure!!

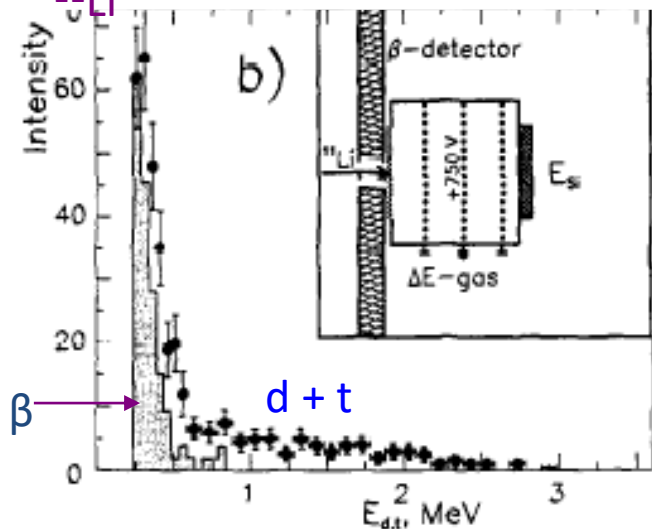
^{11}Li (βd) @ ISOLDE



- ✓ Complicated decay
- ✓ B.R. of $\beta d \sim \beta t \sim 10^{-4}$
- ✓ Used of pulsed structure of ISOLDE beam

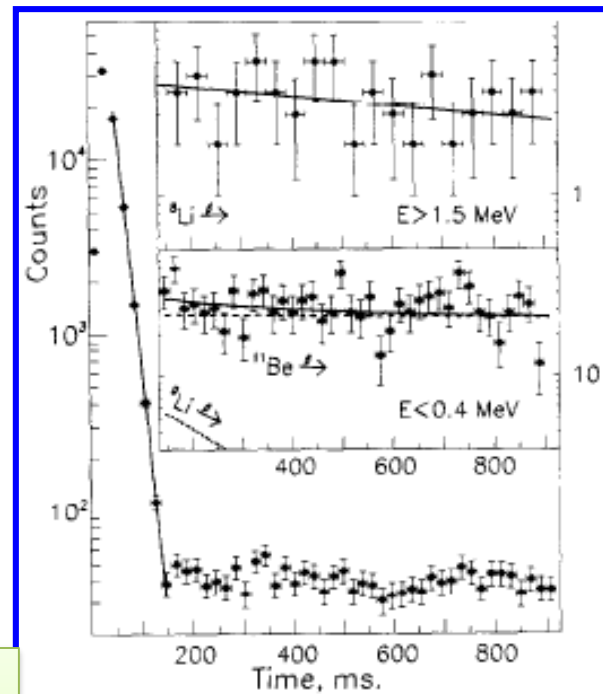
Identification of the βd branch by energy and time correlation

β -charged particles from ^{11}Li



Study of correlation between the $Z = 1$ particles ($T < 0.06$ ms) and delayed alphas between $0.15 < T < 0.9$ s

Time correlation



B.R. (βd) $\sim 1 \times 10^{-4}$
Mukha et al., PLB367 (96) 65

Facilities used by the Community for β -decay Studies

