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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

A new approach to beta-delayed multi-neutron emission

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+ L. Fraile, U. Datta

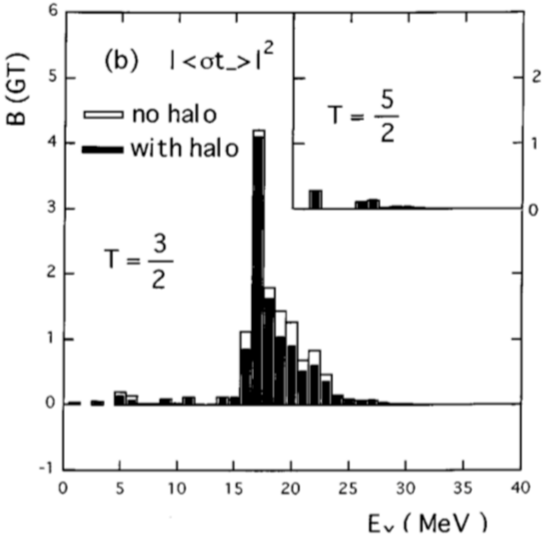
Summary of requested shifts: 15 shifts of ^{11}Li and 2 shifts of ^{9}Li from a Ta target.

Motivation: (1) beta strength (2) halo effect?

- Theoretical beta strength predictions – favours high energy

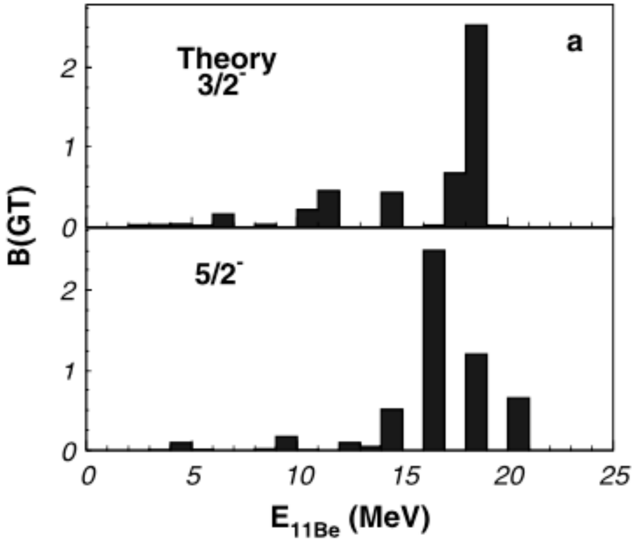
^{11}Li

Q = 20.55 MeV



T. Suzuki, T. Otsuka
PR C56, 847

M. Madurga et al.,
PL B677, 255



- Large beta strength = large wavefunction overlap
- No prediction of break-up patterns

Motivation: (1) beta strength (2) halo effect?

- Halo model - Nilsson et al., Hyperfine Interactions 129 (2000) 67

$$\mathcal{O}_\beta|\text{halo state}\rangle = \mathcal{O}_\beta\big(|\text{core}\rangle|\text{halo}\rangle\big) = \big(\mathcal{O}_\beta|\text{core}\rangle\big)|\text{halo}\rangle + |\text{core}\rangle\big(\mathcal{O}_\beta|\text{halo}\rangle\big)$$

- For ^{11}Li:
  - Core decay (^{9}Li to ^{9}Be) – threshold 7.3 MeV
  - Halo decay (2n to d) – threshold 17.9 MeV

- ^{9}Li decay: 51% to alpha-alpha-n (^{8}Be-n / alpha-^{5}He…)
  - M. Madurga et al., NP A810, 1 - alpha-^{5}He + 2n picture ok for ^{11}Li (?!)

    IS417

Decay scheme for ^{11}Li

Low E: 1n (+ γ) channel

C. M. MATTOON *et al.* PHYSICAL REVIEW C **80**, 034318 (2009)

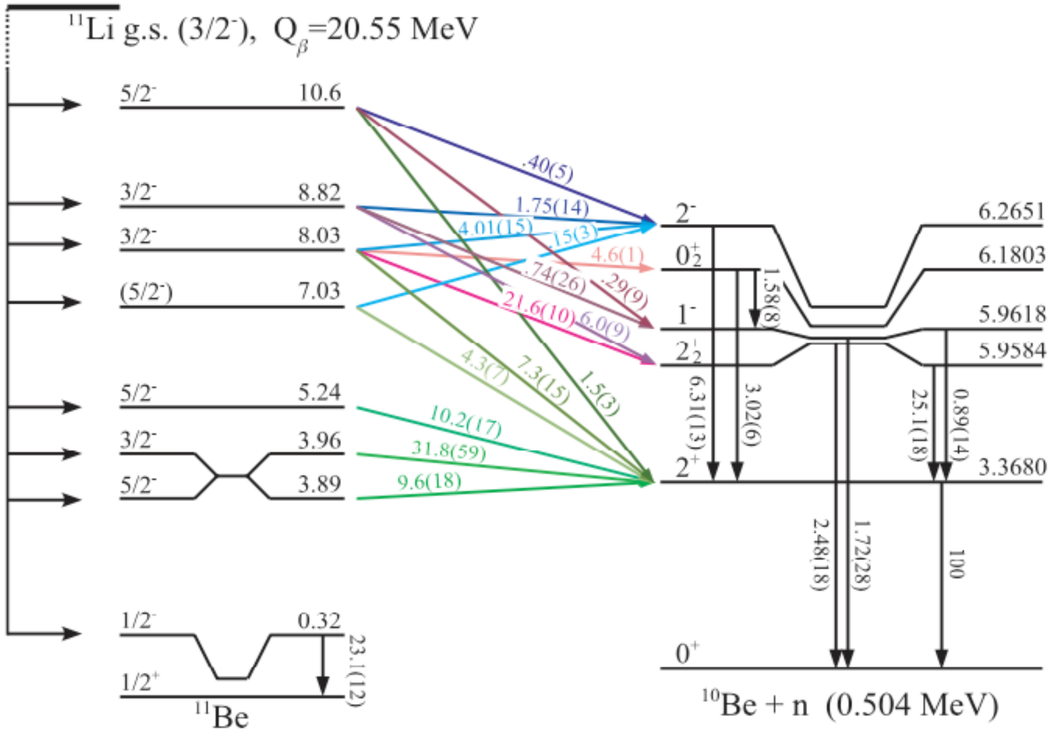
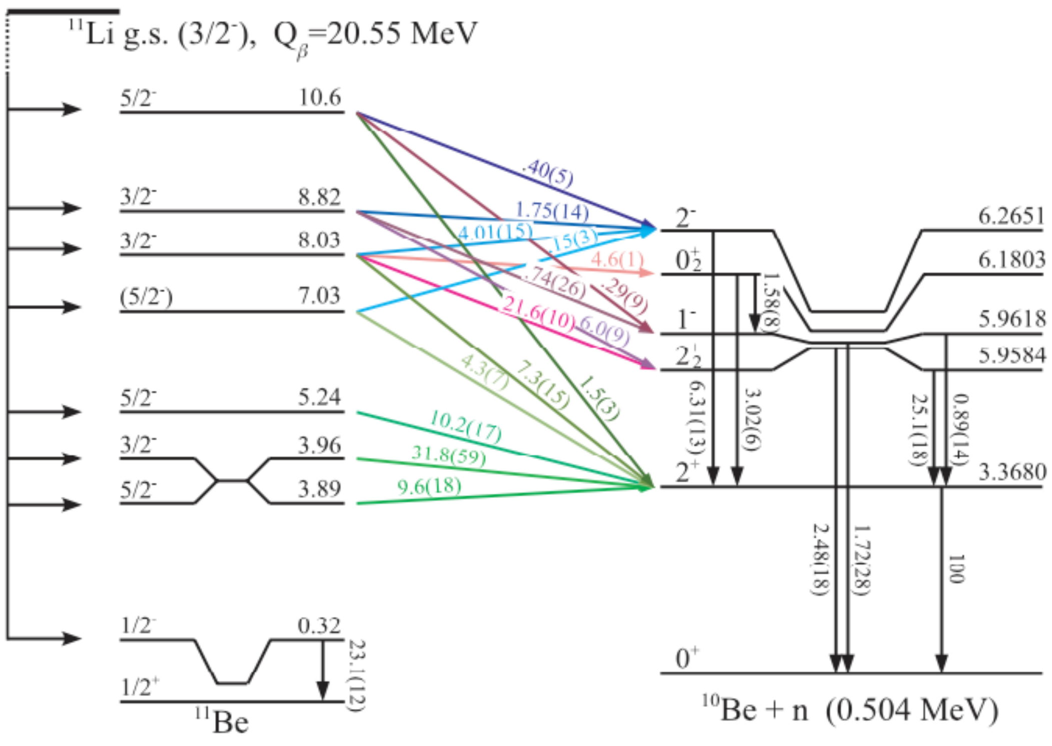


FIG. 15. (Color online) β-delayed one-neutron emission decay scheme of ^{11}Li extracted from this experiment. Intensities given are relative to the intensity of the $2_1^+ \rightarrow 0_1^+$ transition (100). The color scheme refers to the colors used to identify the neutron branches in the figures presenting the line-shape analyses.

Decay scheme for ^{11}Li

Low E: 1n (+ γ) channel

C. M. MATTOON *et al.*



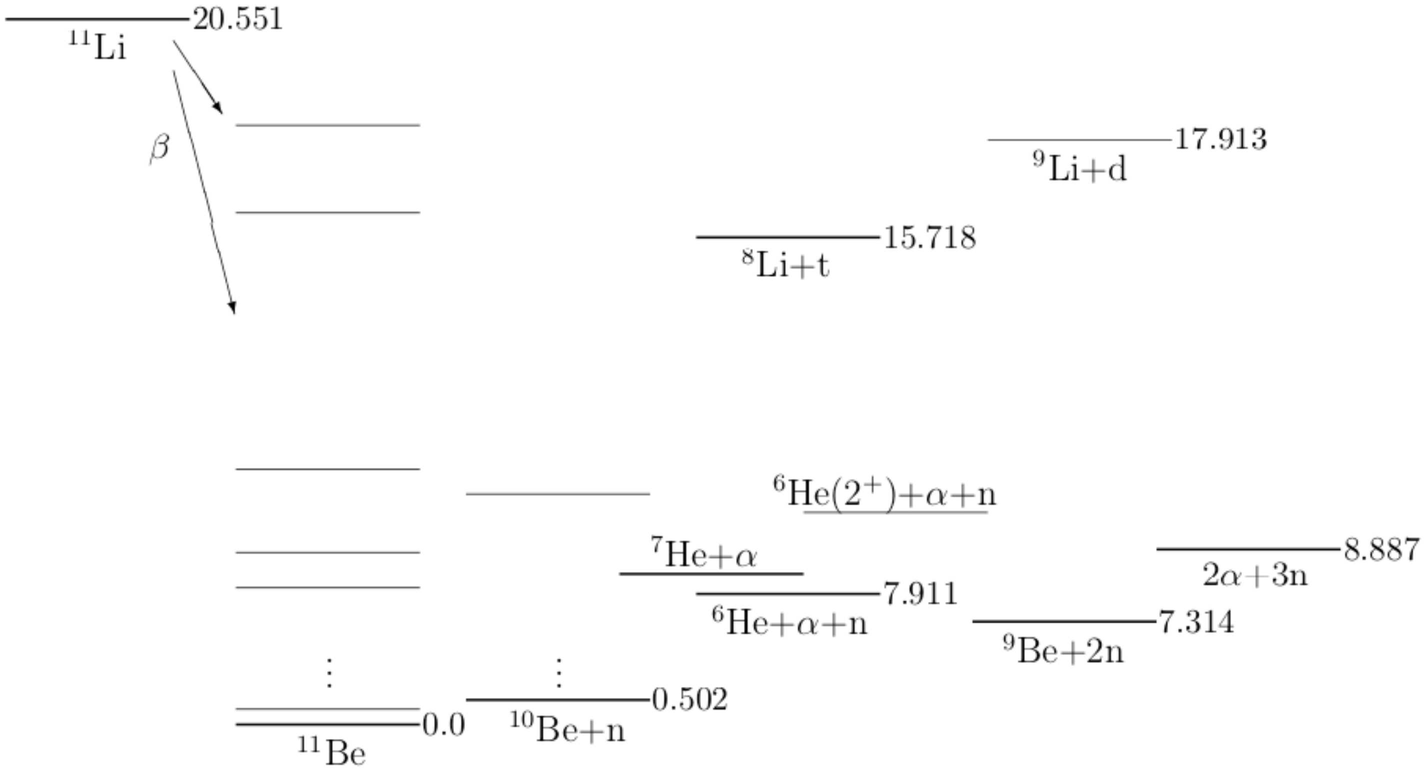


Figure 1: The ^{11}Li decay scheme above the two-neutron threshold. All energies in MeV.

High E: 2n, 3n, t, d ... channels

The beta-2n and -3n branches

- $P_n = \Sigma\, iP_{in} = 100.3(1.4)$ %
  - $P_{1n} = 86.3(9)$ %
  - $P_{2n} = 4.1(4)$ %
  - $P_{3n} = 1.9(2)$ %
  - 14% of n's from 2n/3n
  - Multiplicity 2: more 3n than 2n

- IS525, Delauny et al
  arXiv:1906.04699

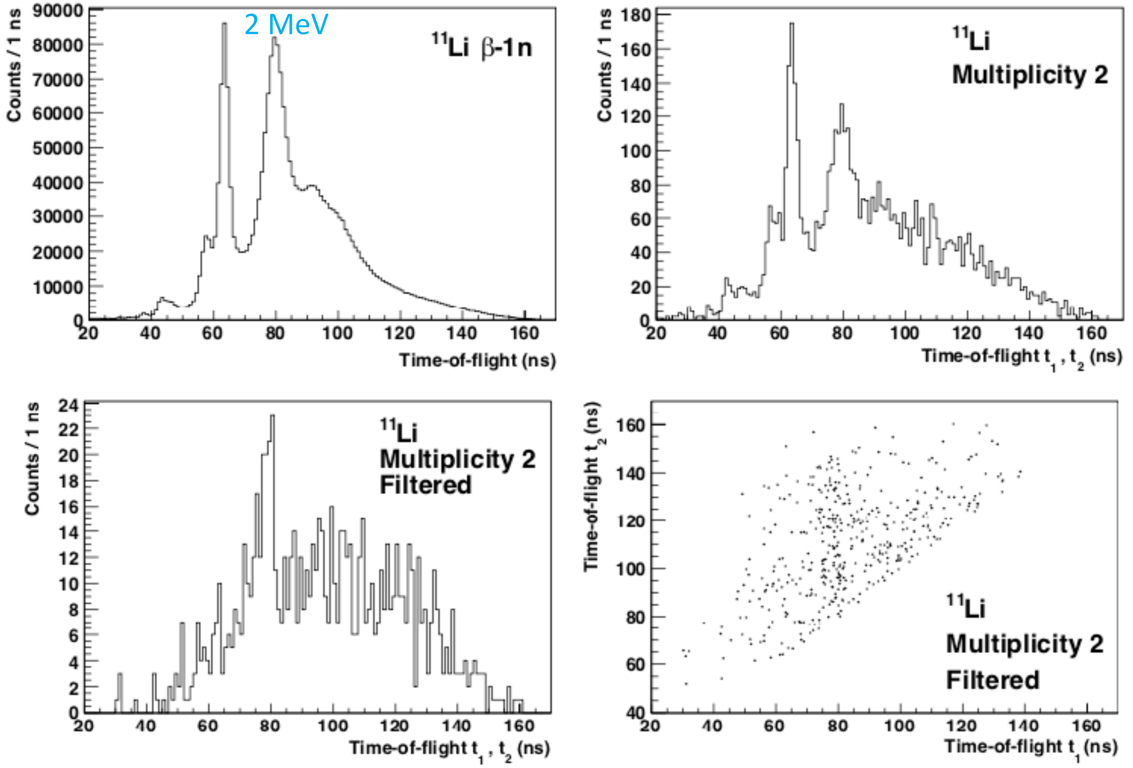
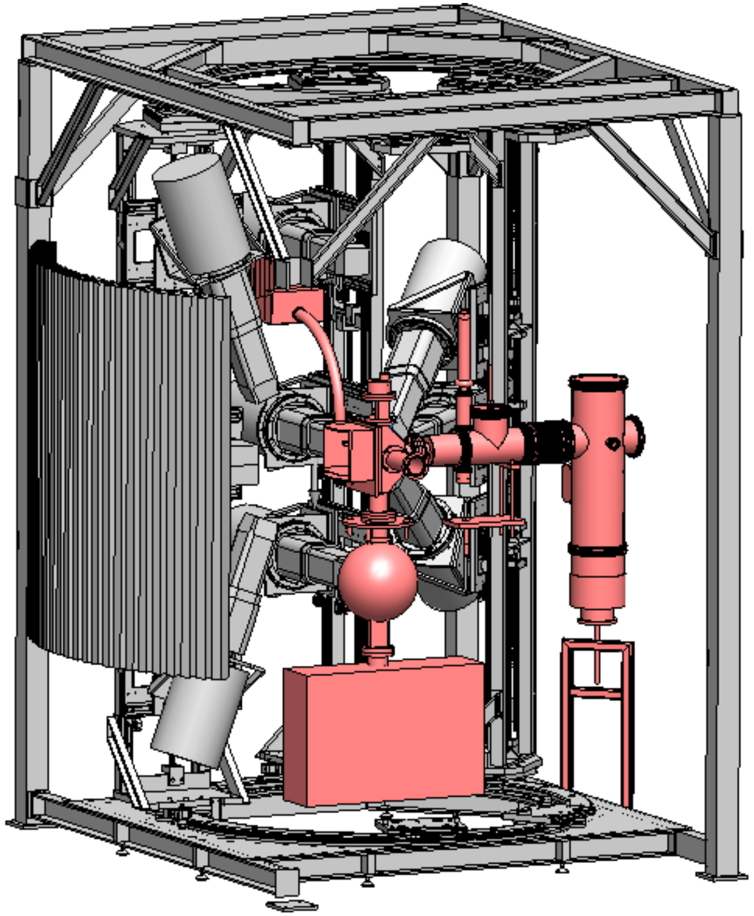


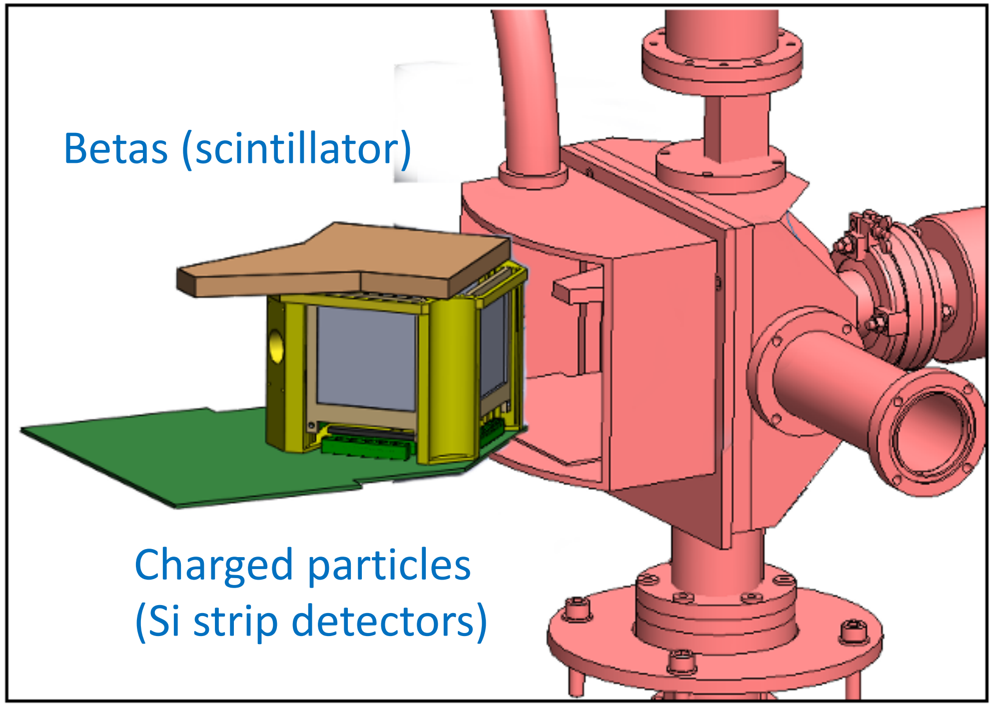
Fig. 1. – Time-of-flight spectra of ^{11}Li β-delayed neutrons detected in the near array. Top left: single neutron events. Top right: Multiplicity-2 events before cross-talk rejection. Bottom left: Multiplicity-2 events after cross-talk rejection. Bottom right: Time-of-flight of the second hit t_2 *vs.* time-of-flight of the first hit t_1, after cross-talk rejection.

The set-up - our approach: n + ”recoils”

Gamma rays (IDS)

Neutrons (INDIe)





Analysis outline for observed neutron "lines"

- Coincident gamma-ray: 1n channel ($^{10}Be^*$)

Test of n-scattering

- Energy above 2.5 MeV:
  - 1 collinear charged particle (cp) 1n channel (^{10}Be ground state) !!
  - 1 non-collinear cp n-n-^{9}Be channel
  - 2 cp n-alpha-^{6}He (if momenta sum to 0) or n-n-n-alpha-alpha
- Energy below 2.5 MeV:
  - If cp proceed as above
  - If no cp 2n or 3n channel or n-alpha-^{6}He

- Expect to identify all strength above 11 MeV up to sensitivity limit…

Motivation: (3) understand beta-xn emission

- More knowledge on beta-xp emission
  - E.g. ^{31}Ar from ISOLDE – G.T. Koldste et al., PL B737, 383

- Effect of Coulomb in low-energy multi-particle continuum ??

- ^{11}Li would be the first well studied beta-xn case

- Several more (close to neutron dripline) beta-xn emitters known

Beam time request

TAC comment

- Ta foil target (as in latest ^{11}Li runs)

- Expect of order 1000 ^{11}Li/s
  - 10 n-beta events/s
  - 1-6 n-(2 cp) events/min

- Ask for 15 shifts of ^{11}Li
  - Around 500 counts for weakest branches seen so far (0.035% branching)

- Ask for 2 shifts of ^{9}Li for calibration (may join with P549)

Extra slides

M. Madurga et al., Nucl. Phys. A810 (2008) 1

Table 3
Branching ratios for channels determined in this work following ^{11}Li β-decay. The total branching ratio to charged particle emitting channels obtained in [2] is 3.1(9)%, compared to the value of 1.73(2)% in this work. The ^{11}Li activity was deduced from the branching of the β-(^{7}Li + α) decay channel of the daughter

Channel	β-feeding (%)[a]	β-feeding (%)[b]	β-feeding (%)[c]
^{11}Be(10.59) $\rightarrow$ n + ^{10}Be(9.5) $\rightarrow$ 2α + 3n	1.08(2)	1.1(2)	1.4(2)
^{11}Be(10.59) $\rightarrow$ n + ^{10}Be(9.5) $\rightarrow$ n + α + ^{6}He	0.227(5)	0.23(4)	0.29(4)
^{11}Be(10.59) $\rightarrow$ α + ^{7}He $\rightarrow$ n + α + ^{6}He	0.0348(5)	0.035(6)	0.044(7)
^{11}Be(18.15) $\rightarrow$ ^{6}He(2^{+}) + ^{5}He $\rightarrow$ 2α + 3n	0.337(7)	0.34(5)	0.43(7)
^{11}Be(18.15) $\rightarrow$ α + ^{7}He $\rightarrow$ n + α + ^{6}He	0.057(1)	0.057(9)	0.072(10)

[a] Only the statistical error is consider in this column.
[b] Including the normalization uncertainty.
[c] Assuming a 2% feeding to the ground state in ^{11}Be, stated as upper limit in previous works [25].

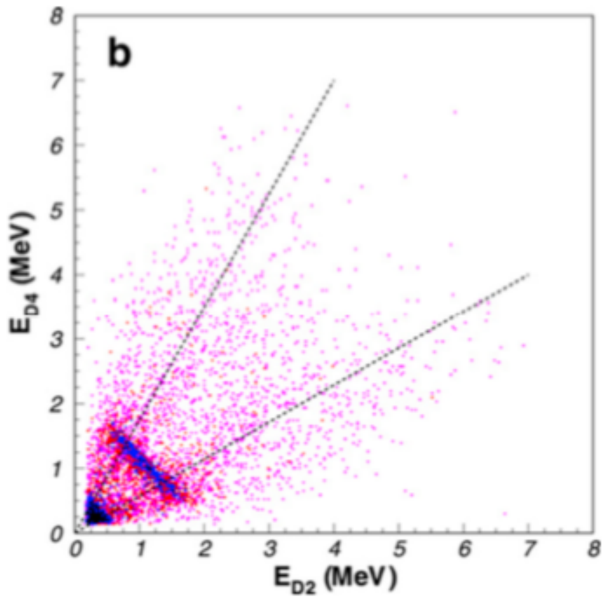


Fig. 3. Left: The energy sum of ^{11}Li β-delayed coincidence spectrum collected during the first 40 ms after the proton impact. The dashed histogram is the result of a Monte Carlo simulation of the charged particle decay channels as described in the literature [2,8]. The inset shows the same sum energy spectrum for a longer time window ($t < 200$ ms). The peak appearing at 1.2 MeV, indicated by an arrow, corresponds to the break-up into ^{7}Li + α of the 9.88 MeV state in the granddaughter ^{11}B. Right: (b) shows the energy-vs-energy scatter plot for charged particle coincidences between the D2 and D4 opposite detectors for $t < 40$ ms. The major features of the plot are the intensity at low energy and the transverse line (corresponding to peaks at 0.7 and 2.2 MeV in figure (a)). The scatter events at high energy form two lobes (at around 30 and 60 degrees).

Y. Hirayama et al., Phys. Lett. B611 (2005) 239