Study of exotic beta-decays of light nuclei with an implantation technique

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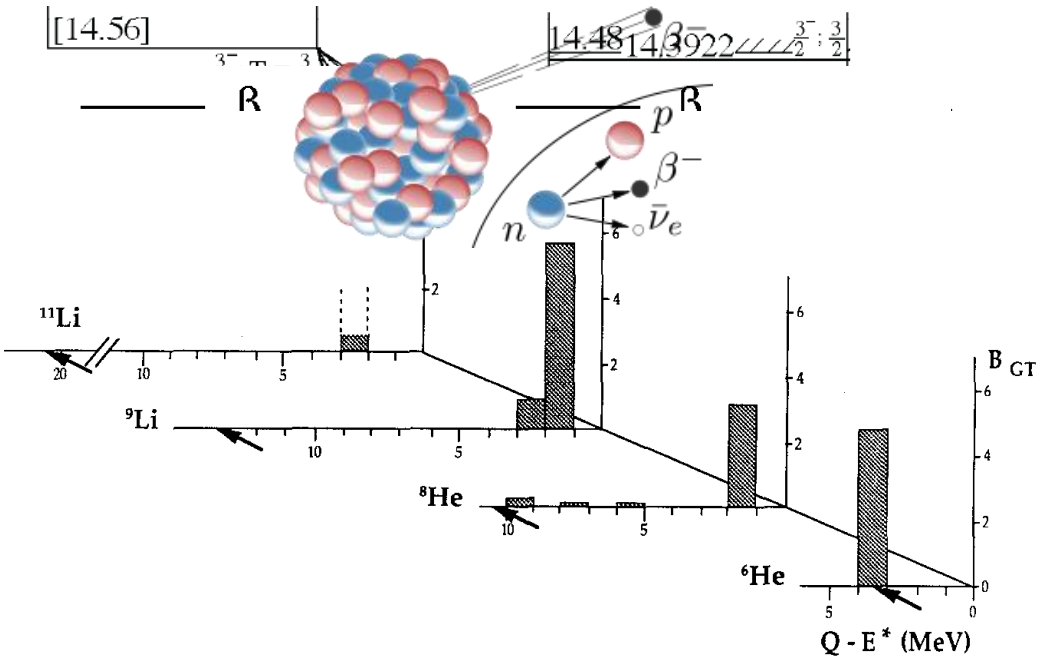
Exotic nuclei, exotic decays

- β-decay: interaction well-known
  ⇒ reliable information

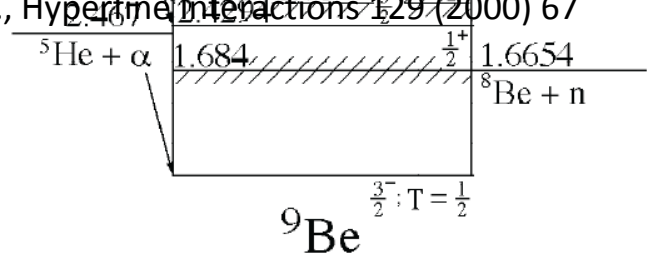
Light exotic nuclei

- Large *Q*-values,
  low binding energy
  ⇒ decay to unbound regions
- Separate decay of clusters
  ⇒ specific patterns:
  - strength concentrated close to the parent state;
  - halo states: poor overlap between initial and final states

  ⇒ decays to the continuum



M.J.G. Borge et al., Z. Phys. A 340 (1991) 255
T. Nilsson et al., Hyperfine Interactions 129 (2000) 67



Radioactive source from low-energy beams

- Accurate measurements,
  weak channels,
  $\Rightarrow$ need intense and pure sources
  $\Rightarrow$ ISOL beams
- Deposition on a tape or thin foil
- Detectors placed around

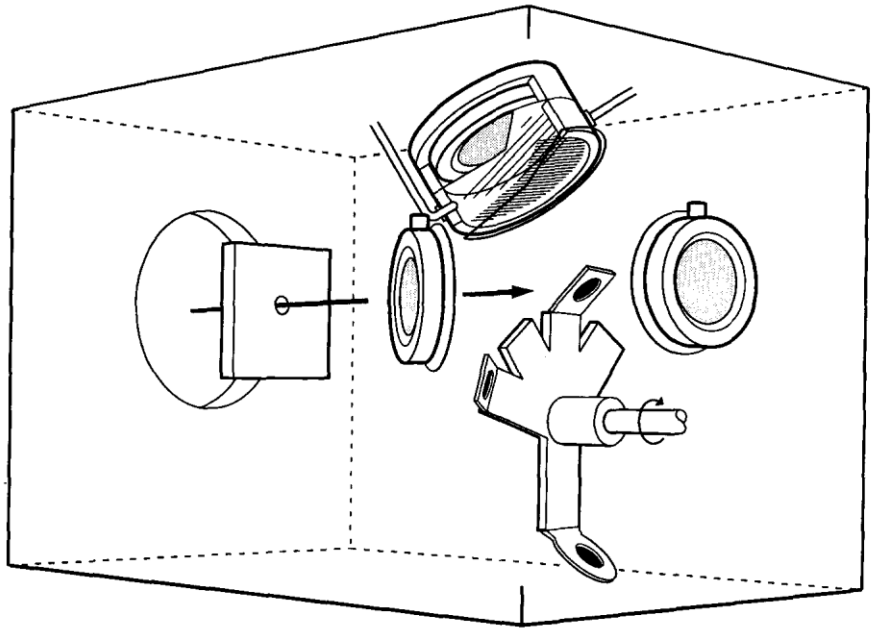
☺ Particle identification

☺ Spatial correlations

☹ Efficiency, normalisation

☹ High threshold

☹ β background



M.J.G. Borge et al., Nucl. Phys. A 560 (1993) 64

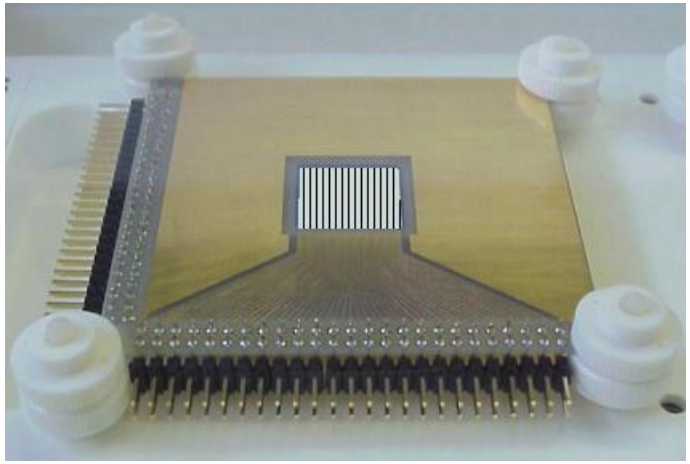
Implantation in a finely segmented detector

Post-accelerated ISOL beams
or fragmented beams

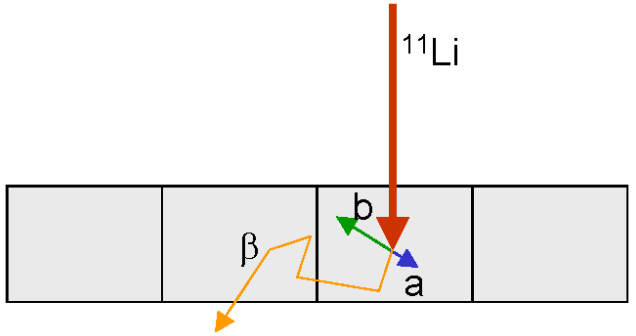
- High efficiency
- Very precise and accurate normalisation
- Full energy of ions is measured
- Suppression of signals
  from β particles
  ⇒ low detection threshold
- "History" of each decay

⇒ detailed spectroscopy is possible
(very weak channels are accessible)

D. Smirnov et al., NIM A 547 (2005) 480
J. Büscher et al., NIM B 266 (2008) 4652

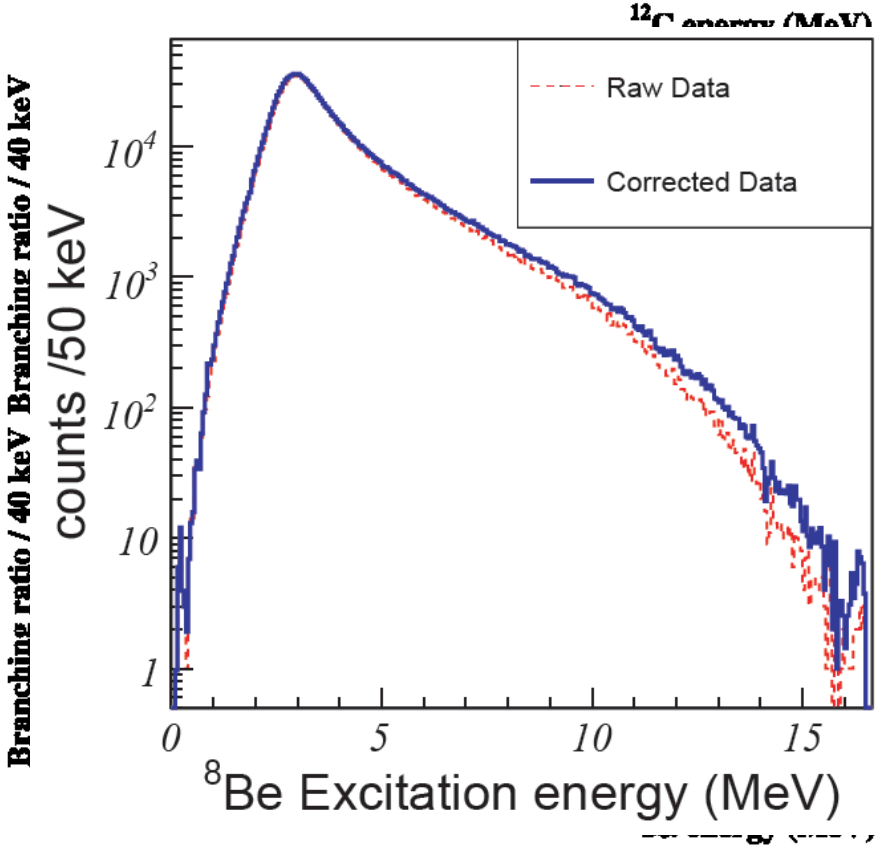


16×16 mm^2, 78 µm thick
48+48 strips, 300 µm wide, 2304 pixels



Measurements: ^{12}C, ^{8}B

- ^{12}N and ^{12}B decay to ^{12}C:
  Normalisation
  ⇒ accurate values for branching ratios
  S.G. Pedersen et al., PLB 678 (2009) 459
- ^{8}B decay to ^{8}Be:
  Low threshold, full energy detection
  ⇒ accurate determination of the decay spectrum (→ neutrino spectrum)

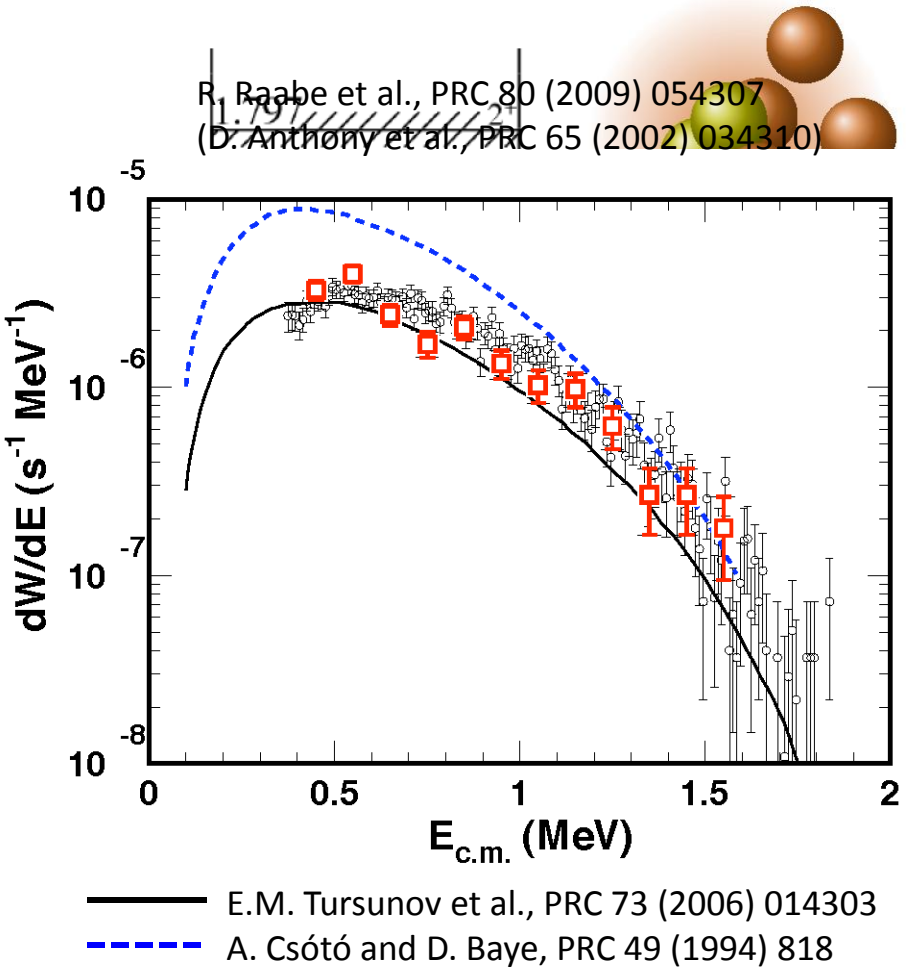


See poster n.9 Thomas Roger

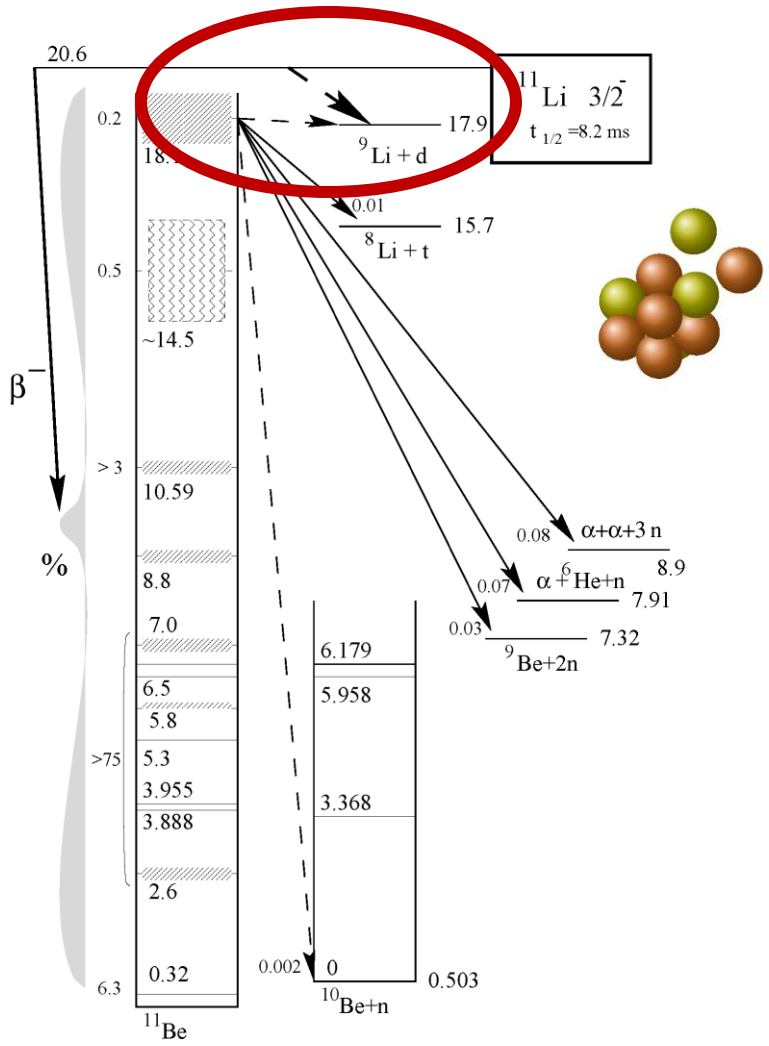
Deuteron emission of ^{6}He: decay into the continuum

- Small decay channel (**≈10^{-6}**) into α + d
- Measurement in Louvain-la-Neuve
  ≈5×10^{8} ^{6}He ions in 80h
  1s beam on / 2s beam off
  315 α+d decay events
  Efficiency, normalisation
- Branching ratio:

  $1.65(10)\times10^{-6}$ (E_d > 350 keV)
- Cancellation between the internal and halo components of the matrix element
  ⇒ Branching ratio sensitive to halo wave function at large distances

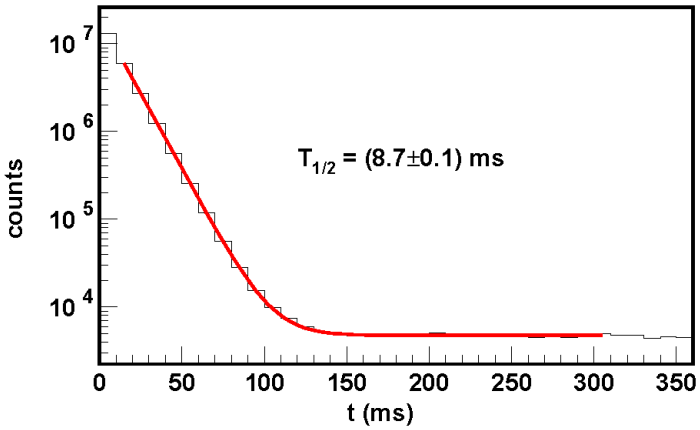


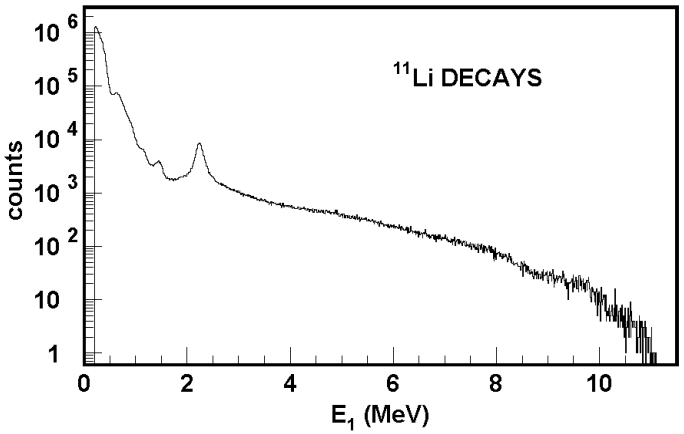
Deuteron emission of ^{11}Li: decay of the halo



K. Riisager, NPA 616 (1997) 169c

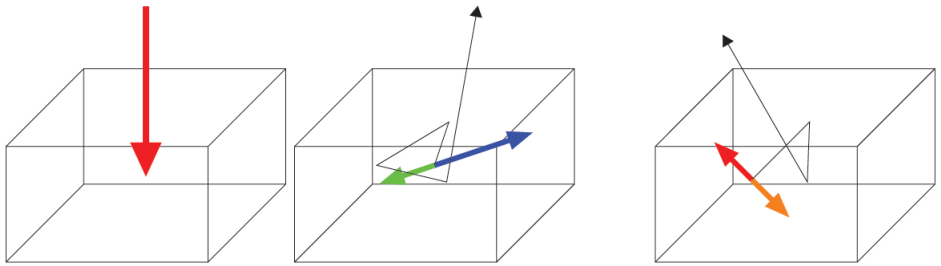
- Measurement in TRIUMF-ISAC
- 88×10^6 ^{11}Li ions in 133h



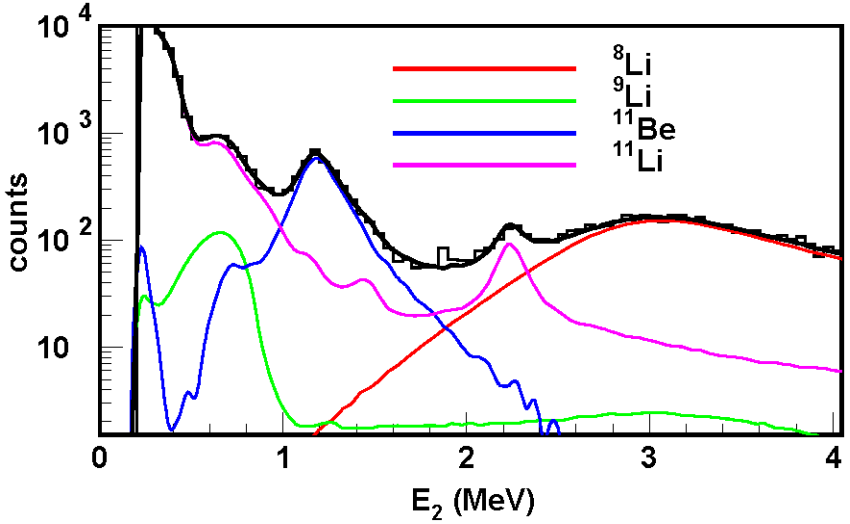


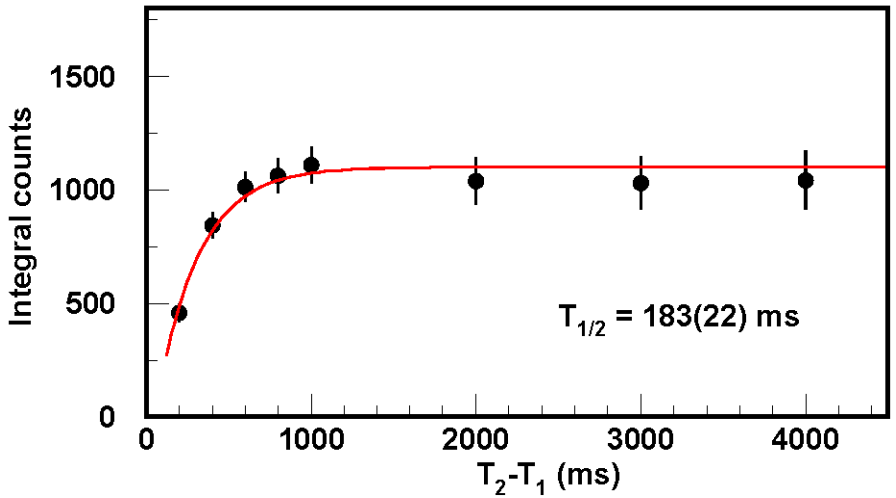
Deuteron emission of ^{11}Li: decay of the halo

- Event-by-event correlation identification of daughter decay



- Daughter decays:
  ^{8}Li, ^{9}Li, ^{11}Be, random ^{11}Li





Deuteron emission of ^{11}Li: decay of the halo

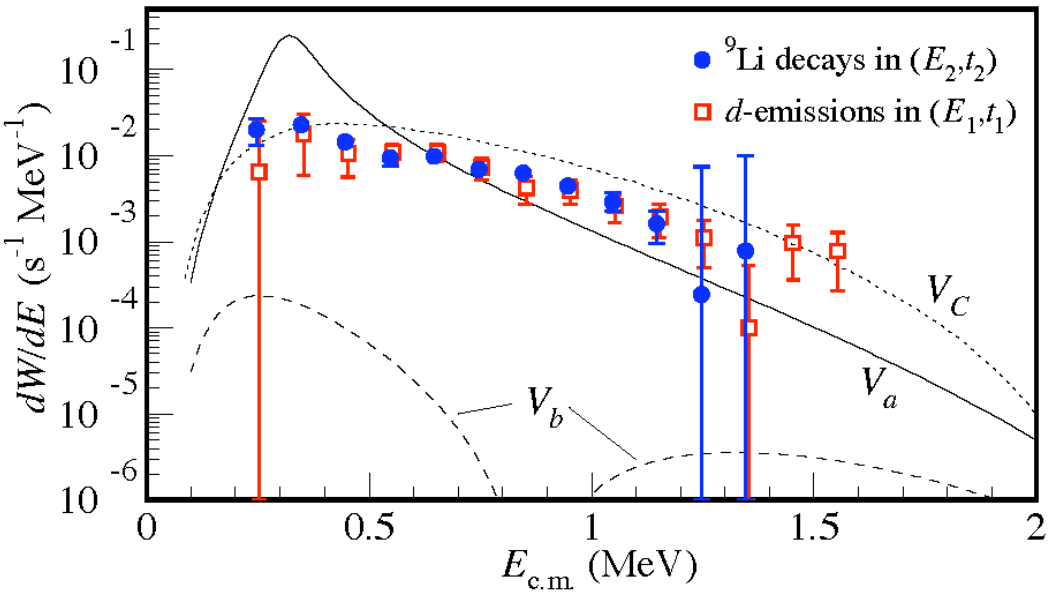
- Branching ratio:

  $1.30(13) \times 10^{-4}$

  (E_{cm} > 200 keV)

- Calculations:
  - V_a : ^{9}Li+d resonance at +0.33 MeV
  - V_b : ^{9}Li+d resonance at –0.18 MeV
  - V_c : ^{9}Li+d: Coulomb only (reference)

R. Raabe et al., PRL 101 (2008) 212501



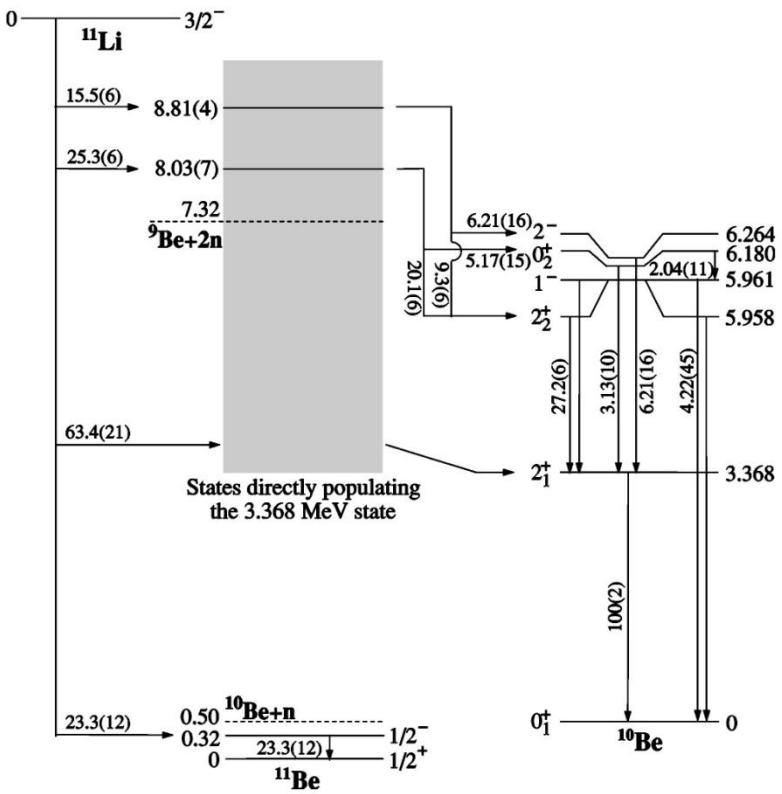
D. Baye, E. M. Tursunov, and P. Descouvemont, PRC 74 (2006) 064302

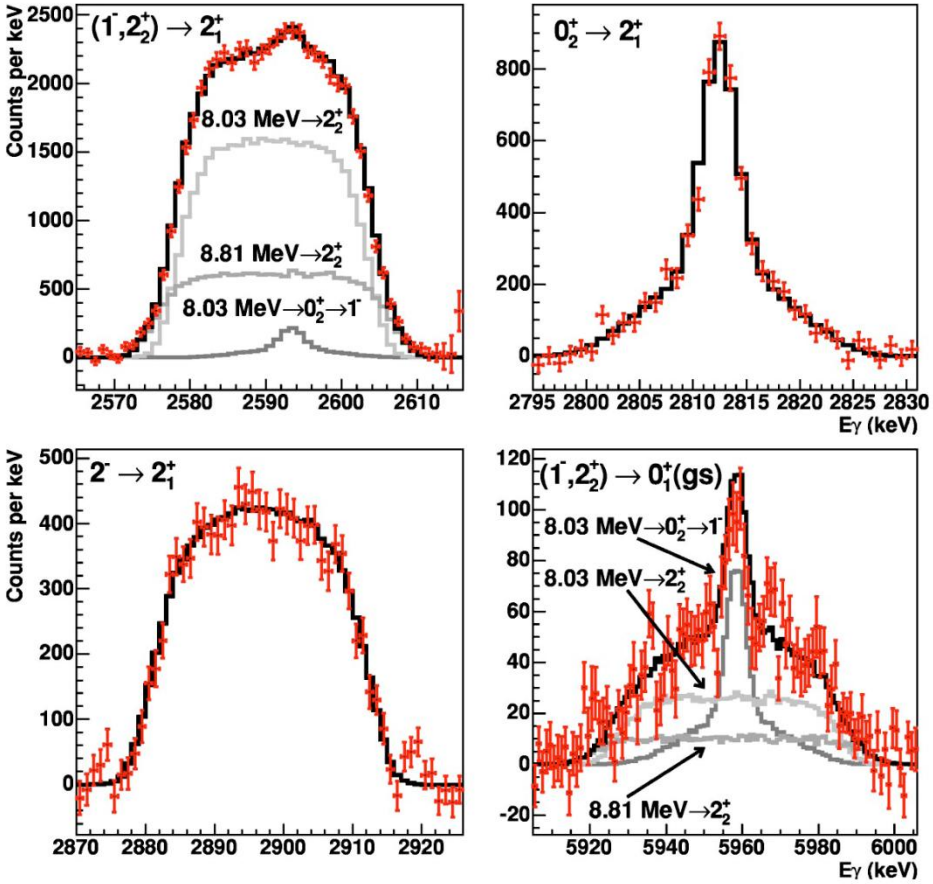
M.V. Zhukov et al., PRC 52 (1995) 2461

"Large" B.R. ⇒ halo decay to the continuum

^{11}Li: decay of the core

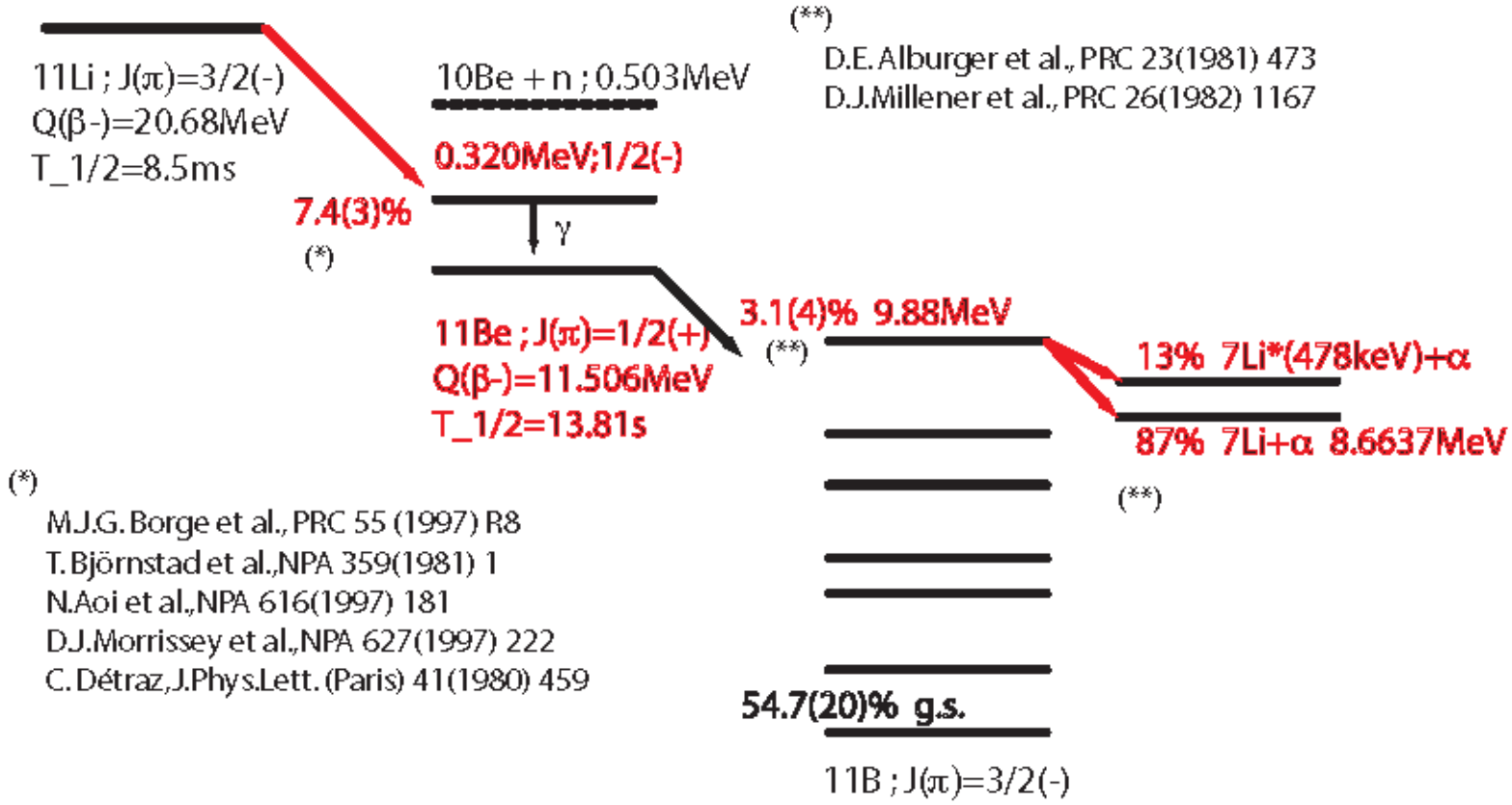
F. Sarazin et al., PRC 70 (2004) 031302(R)





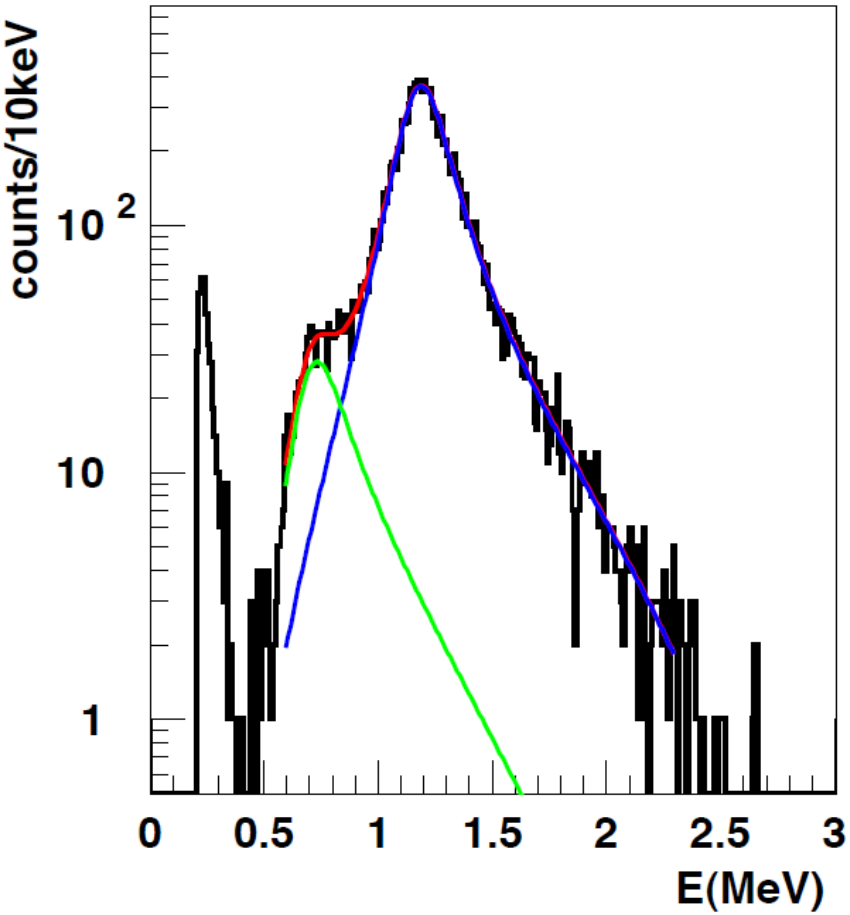
The α-emission channel in the β-decay of ^{11}Be

PhD thesis of J. Büscher



The α-emission channel in the β-decay of ^{11}Be

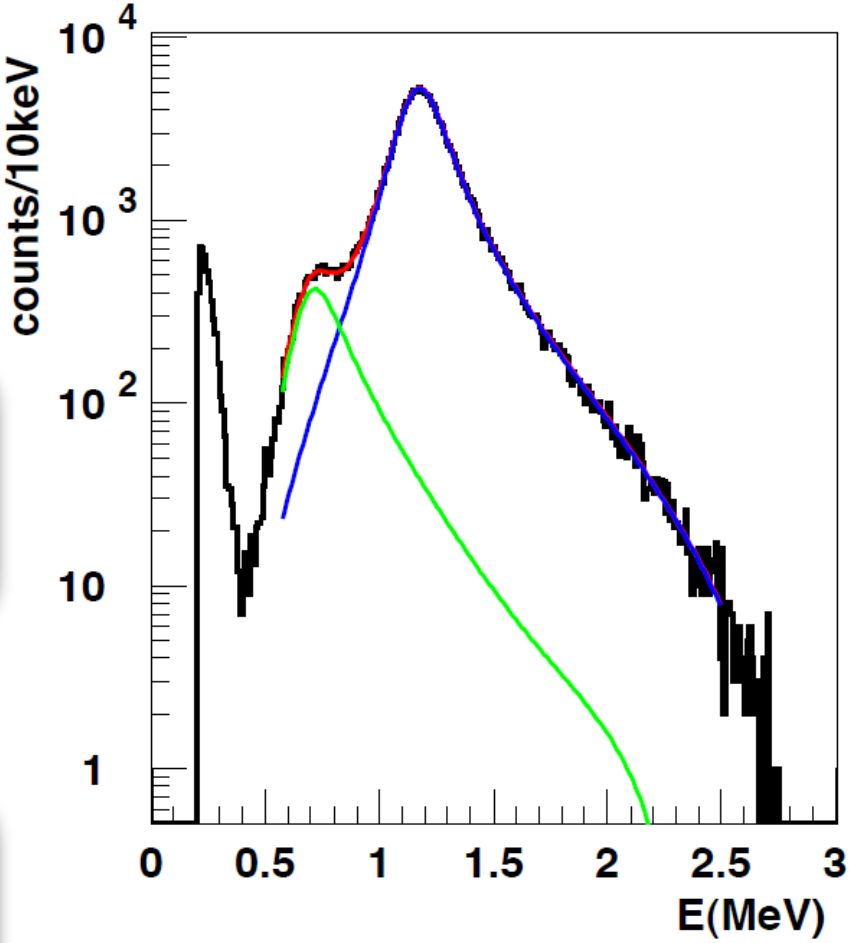
- Measurement at TRIUMF
  ^{11}Li ions implanted
  20 s beam on / 20 s beam off
- Combined probability
  $^{11}Li \rightarrow {}^{11}Be(gs) \rightarrow {}^{7}Li+\alpha$
- Ratio $^{7}Li(gs)/^{7}Li^{*}$
  $\Rightarrow$ independent value
  for $^{11}Li \rightarrow {}^{11}Be(gs)$: **(13.7 ± 1.8)%**
- *R*-matrix fit
  $\Rightarrow$ evidence for a $3/2^{+}$ state
  above the threshold



The α-emission channel in the β-decay of ^{11}Be

- Measurement at REX-ISOLDE
  ^{11}Be ions directly implanted
- ^{11}Be(gs)→^{7}Li+α : **(3.47 ± 0.12)%**
- ⇒ ^{11}Li→^{11}Be(gs): **(12.2 ± 0.4)%**

- **Disagreement not yet explained**
- **Revise ^{11}Li wave function to take into account this branching ratio?**



- 3/2^{+} state at ≈11.5 MeV

- **Missing strength corresponding to decay of the core ^{10}Be → ^{10}B(1^{+})**
- **3/2^{+} : ^{10}B(1^{+})+n or ^{7}Li+α**

Perspectives

Rich information from β-decay!

- Interaction well-known ⇒ structure models can be tested directly
  Nuclear halos, nuclear astrophysics
- Implantation technique: advantages and complementary information

Physics cases...

- Rate of $^{12}C(\alpha,\gamma)^{16}O$: β-decay of ^{16}N
  (present limit ≈400 keV above threshold)
- Particle-emission decay channels of ^{8}He
- $^{9}Li+p+n$ emission channel in ^{11}Li ($Q \approx 250$ keV...): ISOL@MYRRHA?

...and new methods

- Need for low threshold, particle identification, correlations, efficiency
  ⇒ Active targets (TPC): see experience with proton decay
  ⇒ Traps: see LPC trap (^{6}He at GANIL)

Collaborations

- **^{6}He**
  IKS Leuven, CRC Louvain-la-Neuve, Huelva
- **^{11}Li**
  IKS Leuven, TRIUMF, IEM-CSIC Madrid, Univ. Aarhus,
  Colorado School of Mines, Univ. Sevilla
- **^{12}B, ^{12}N**
  Univ. Aarhus, Chalmers Inst. Göteborg, IEM-CSIC Madrid,
  ANU Canberra, IKS Leuven, KVI Groningen, Univ. York,
  Univ. Jyväskylä, LBNL Berkeley, LLNL Livermore, Iowa State Univ.
- **^{8}B**
  IKS Leuven, Univ. Aarhus, GANIL, IEM-CSIC Madrid,
  Univ. Lisboa, FCT-UNL Lisboa
- **^{11}Be**
  IKS Leuven, TRIUMF, IEM-CSIC Madrid, Univ. Aarhus,
  Colorado School of Mines, ISOLDE