In-flight beta-decay of light exotic nuclei

Riccardo Raabe

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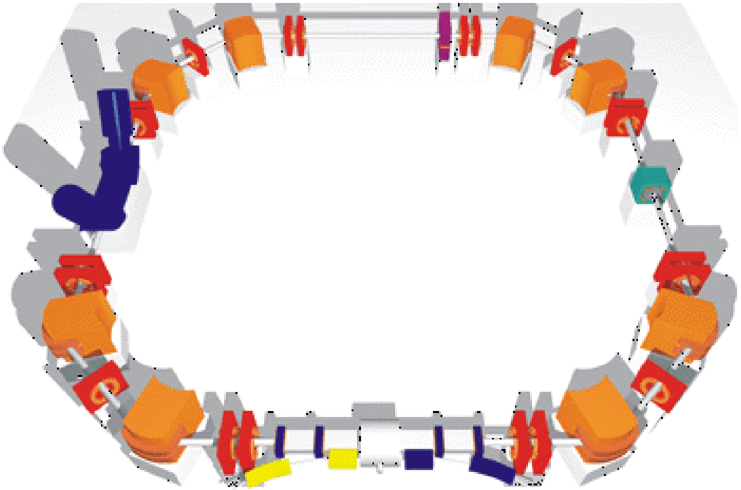


TSR@ISOLDE

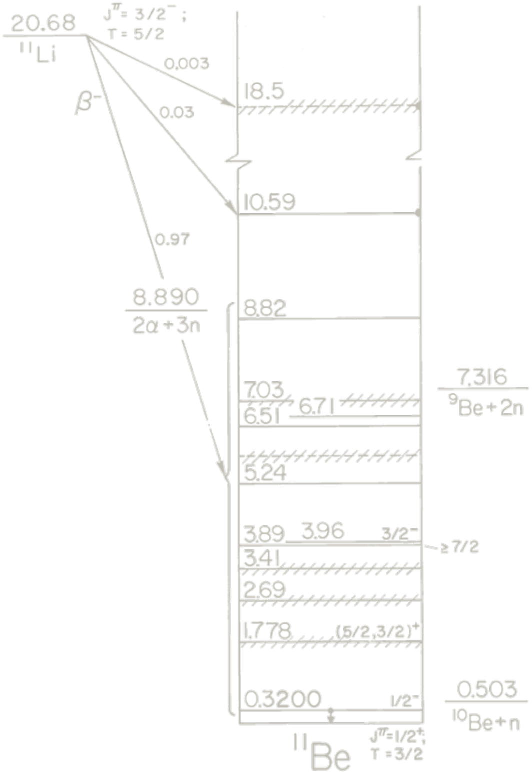
TSR@ISOLDE Workshop
29-30 October 2012 CERN

Decay as a probe

$$\lambda_{if} = \frac{2\pi}{\hbar} \left| \langle f | H' | i \rangle \right|^2 \rho_f$$

- β-decay: interaction well-known

  ⇒ reliable information



Light exotic nuclei

- Large *Q*-values, low binding energy

  ⇒ decay to unbound regions

  ⇒ emission of particles (light ions, neutrons)

- *Q*-value: position (and shape) of the populated state
- Decay probability: overlap of states

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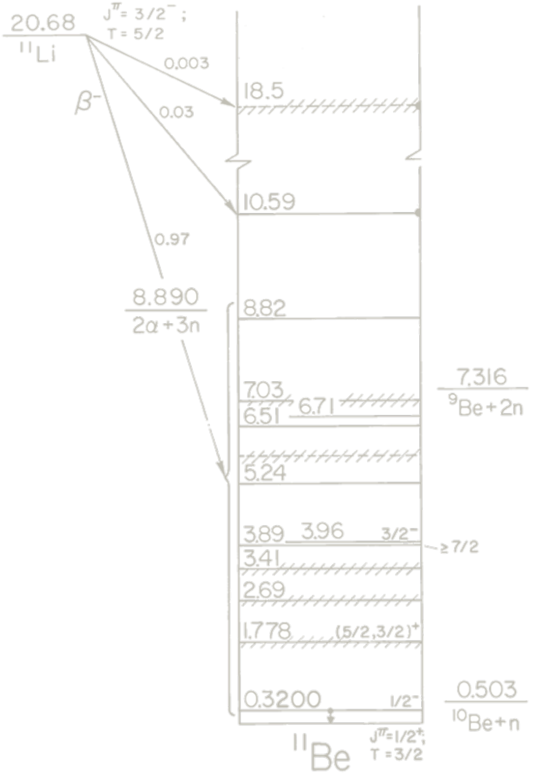

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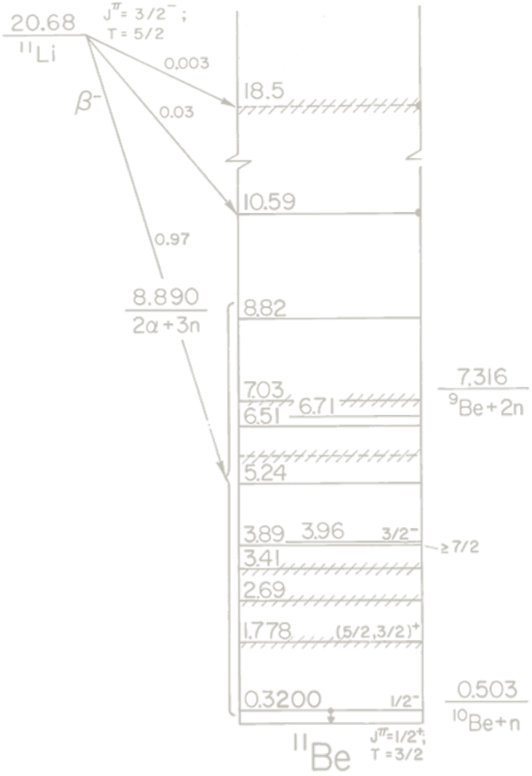

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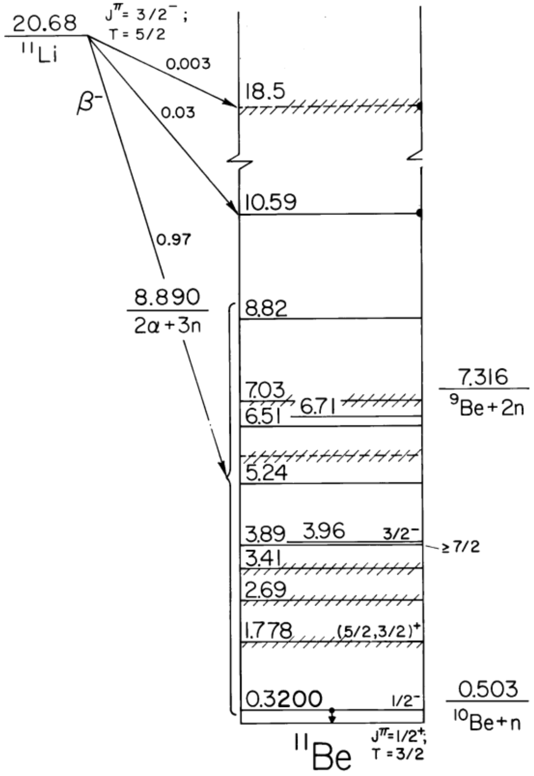

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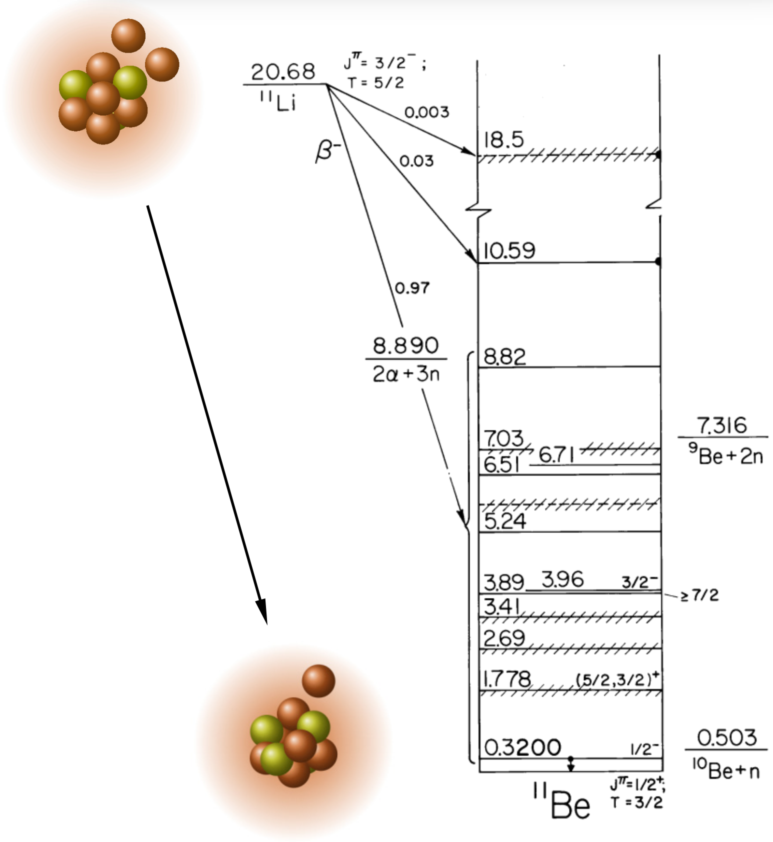

- β-decay: interaction well-known
  $\Rightarrow$ reliable information

Halo states

- Poor overlap
  $\Rightarrow$ decreased decay probability
- Patterns: decay of the halo (cluster)
- Contribution of different regions of the wave function: cancellation

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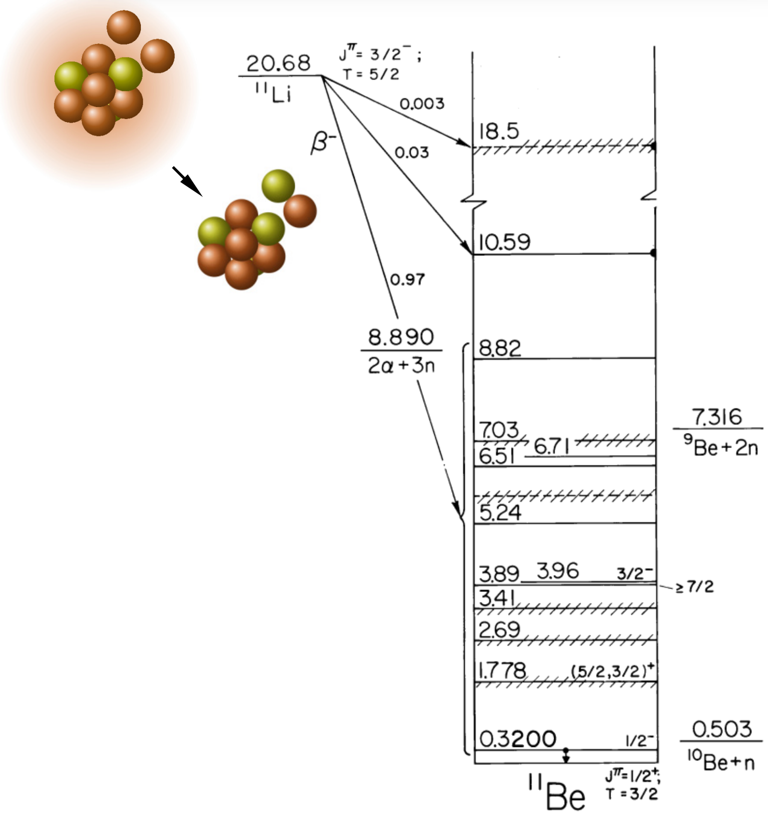

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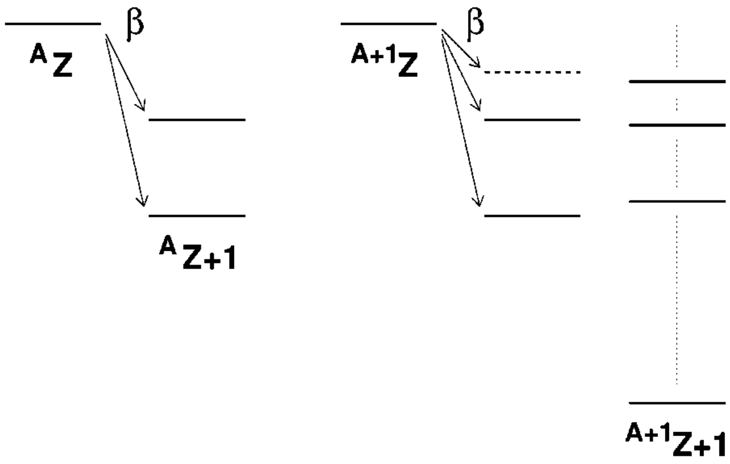

T. Nilsson et al., Hyperfine Interactions 129 (2000) 67

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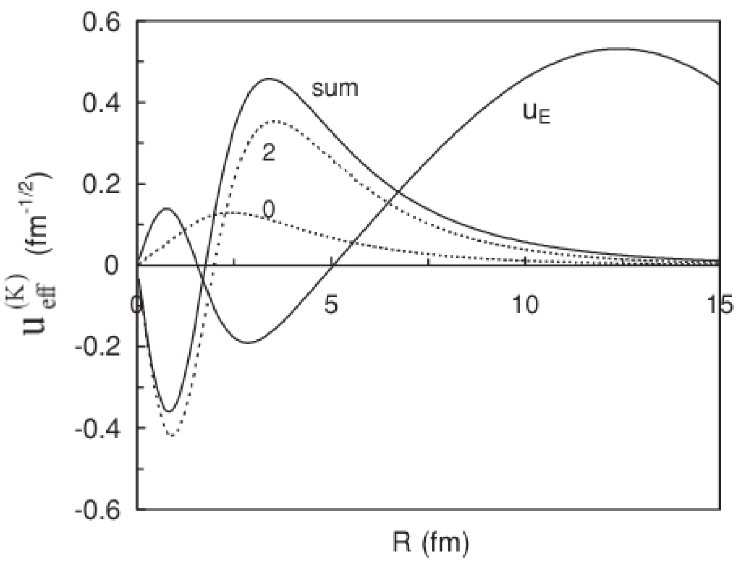

E.M. Tursunov et al., PRC 73 (2006) 014303

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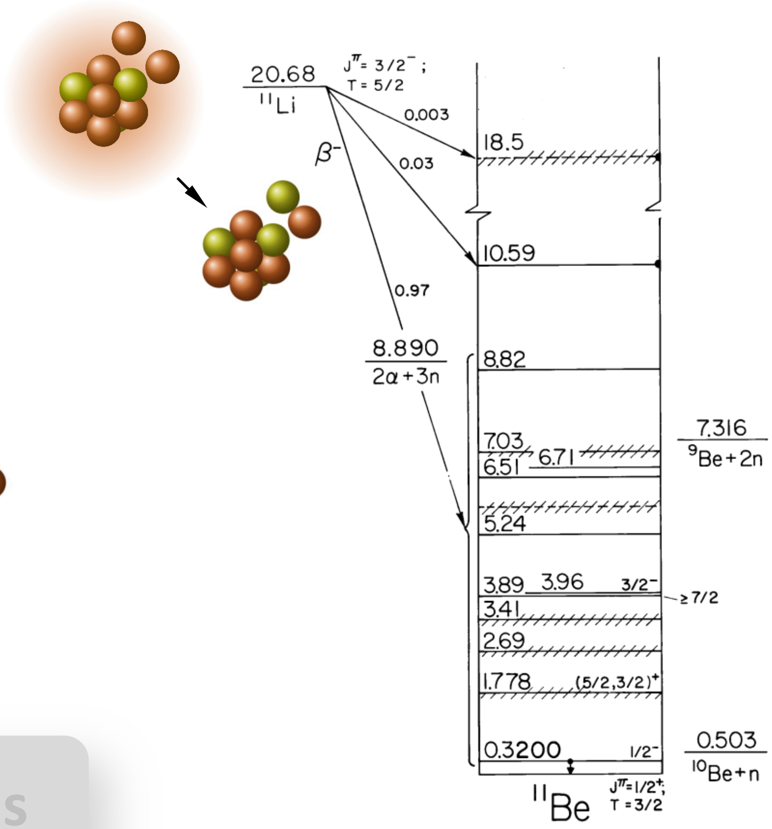
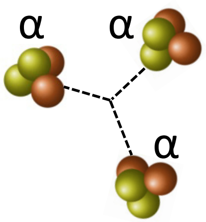
How to measure

Accurate measurements of

- Branching ratios (often small!)
  ⇒ channel identification
  ⇒ efficiency
- Energy emitted particles
  ⇒ low thresholds
  ⇒ resolution
- Spatial correlations





⇒ Various experimental methods

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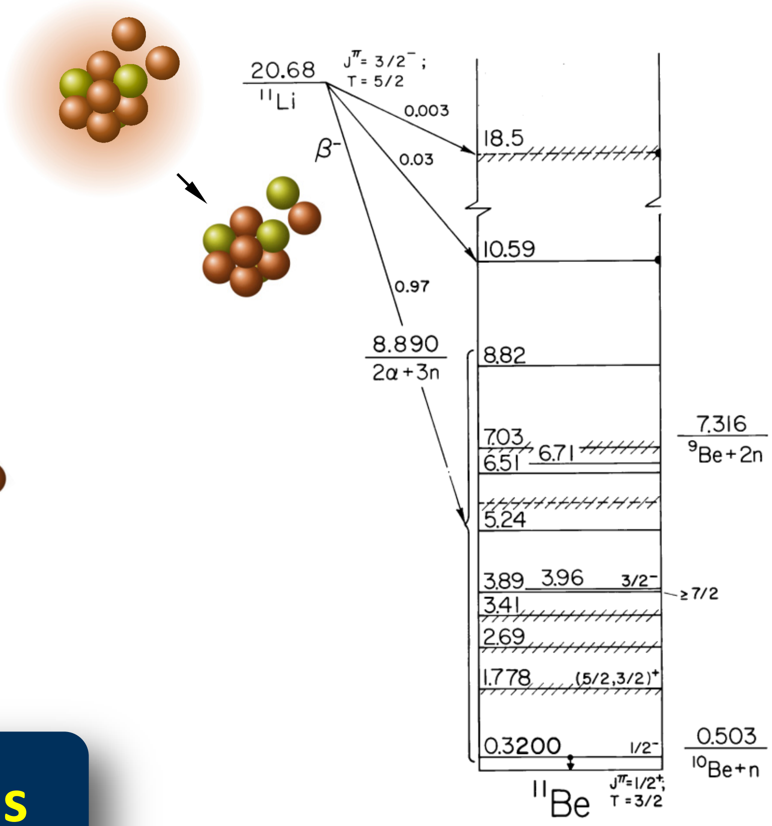
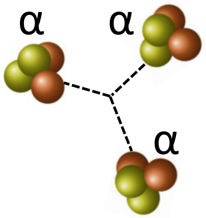


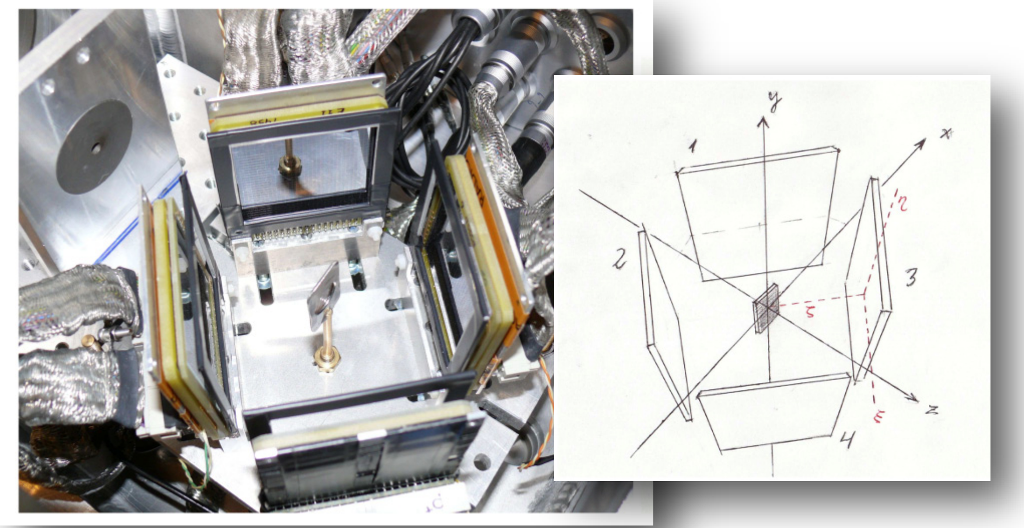


⇒ Various experimental methods

How to measure

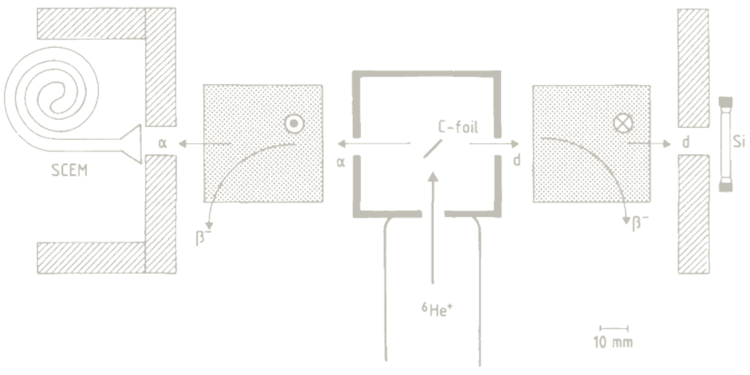
Deposition on a tape or thin foil

- Detectors placed around
  - ☺ Particle identification
  - ☺ Spatial correlations
  - ☹ Efficiency, normalisation
  - ☹ High threshold
  - ☹ β background



O. Kirsebom, PhD thesis (Aarhus University, 2010)

- Magnetic fields
  - ☺ β background



K. Riisager et al., PLB 235 (1990) 30

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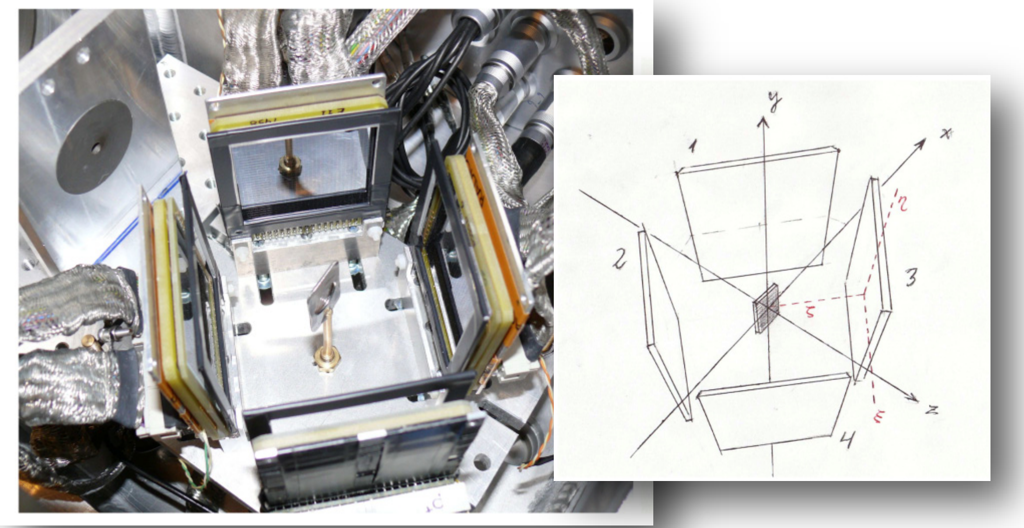

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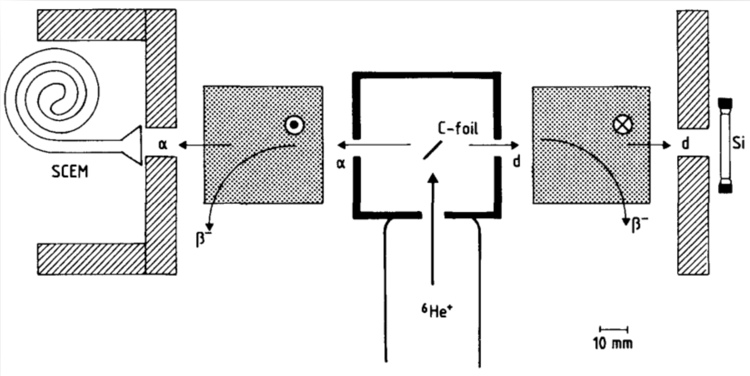


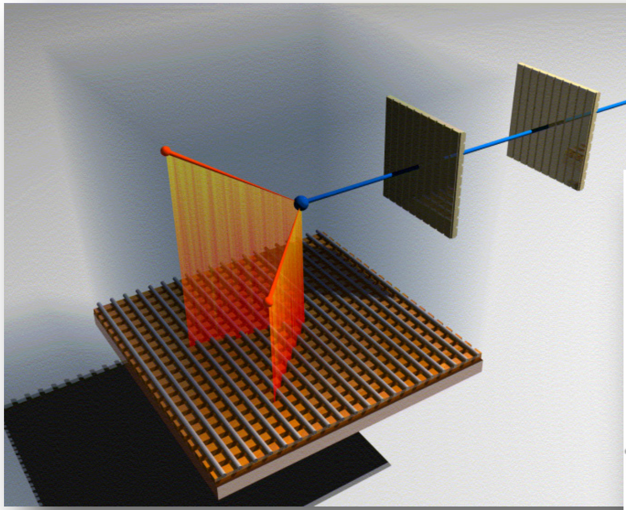
K. Riisager et al., PLB 235 (1990) 30

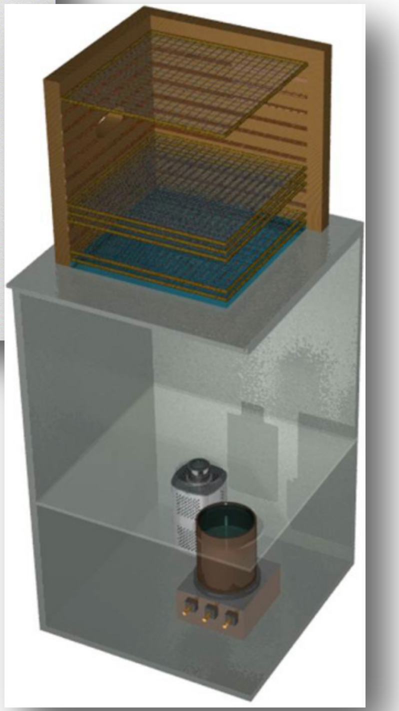
How to measure

Implantation in an active volume

- TPC’s:
  - ☺ Particle identification
  - ☺ Spatial correlations
  - ☺ β background
  - ☺ Low thresholds
  - ☹ Slow
- Strip detectors
  - ☺ Efficiency, normalisation
  - ☺ Correlation between mother- and daughter-decays
  - ☹ Particle id, β background

B. Blank et al., NIMB 266 (2008) 4606





K. Miernik et al.,
NIMA 581 (2007) 194

How to measure

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    - ☹ Slow

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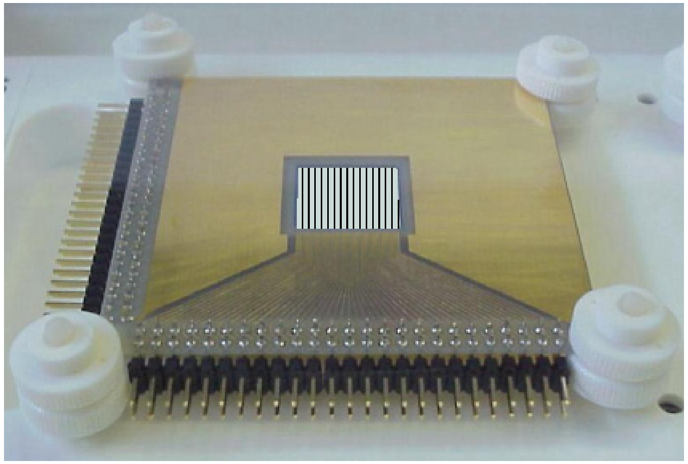
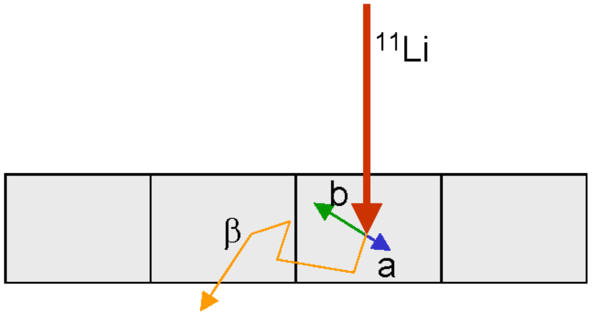
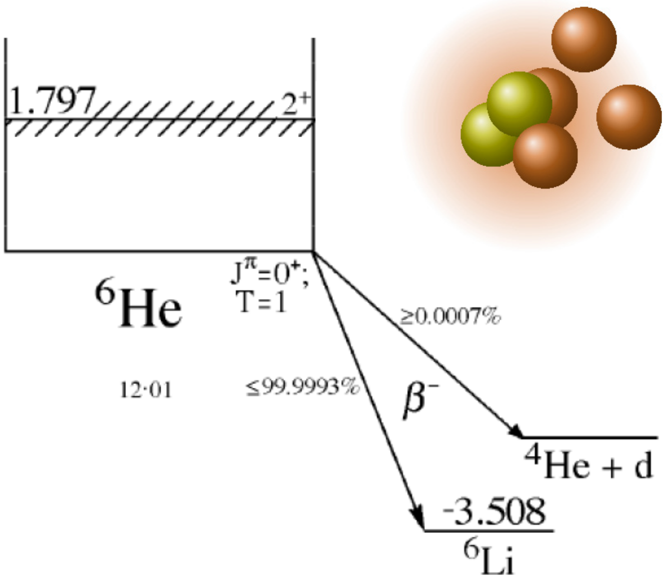
D. Smirnov et al., NIM A 547 (2005) 480
J. Büscher et al., NIM B 266 (2008) 4652



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

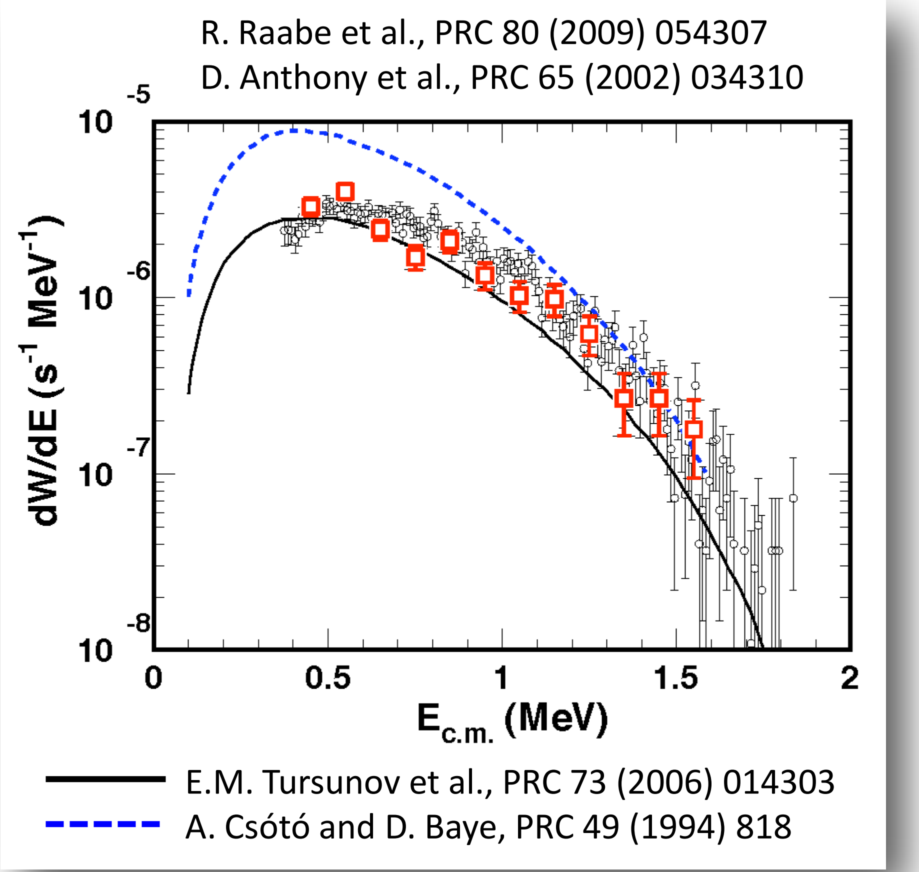


Where can we improve?



- Small decay channel (**≈10^{-6}**) into α + d
- Branching ratio:

  $1.65(10) \times 10^{-6}$ ($E_{c.m.} > 500$ keV)



R. Raabe et al., PRC 80 (2009) 054307
D. Anthony et al., PRC 65 (2002) 034310

E.M. Tursunov et al., PRC 73 (2006) 014303
A. Csótó and D. Baye, PRC 49 (1994) 818

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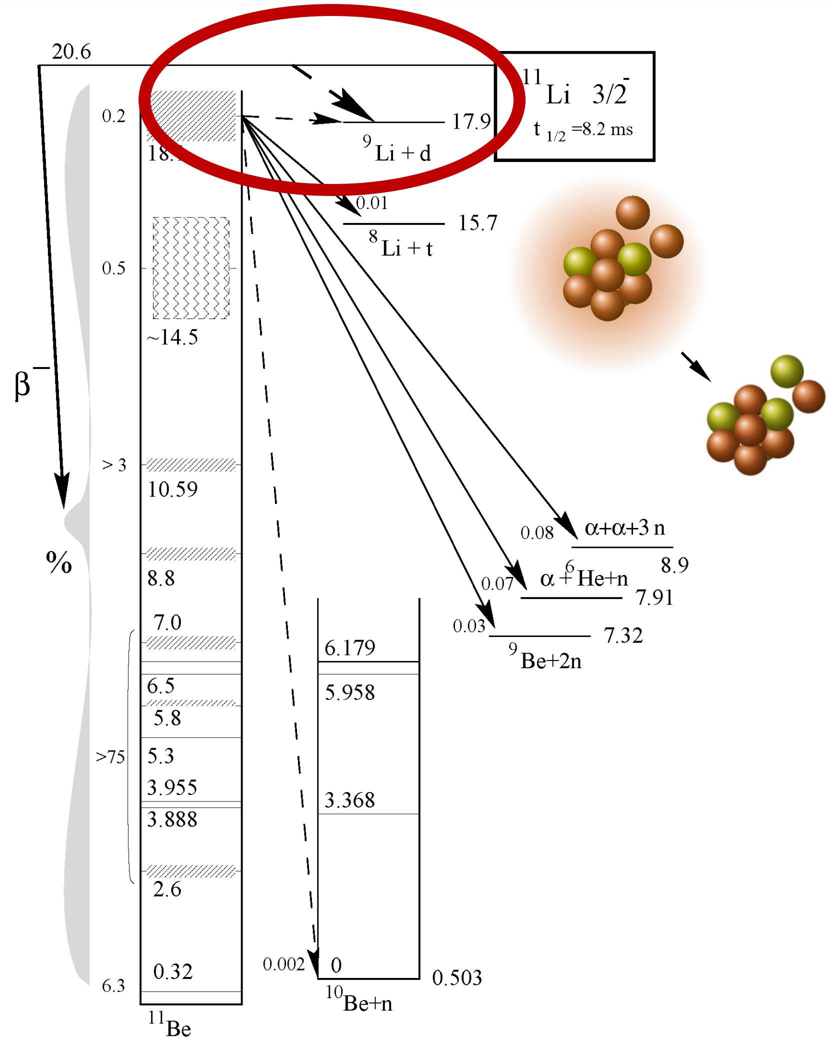
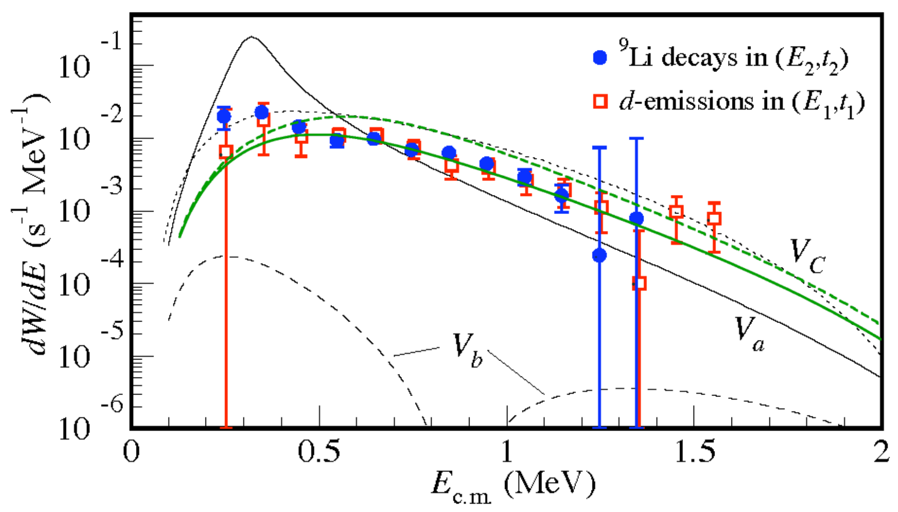


K. Riisager, NPA 616 (1997) 169c

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

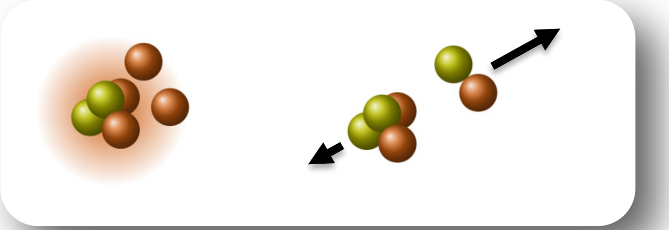
E.M. Tursunov, D. Baye, and P. Descouvemont, IJMPE 20 (2011) 803

- Branching ratio:

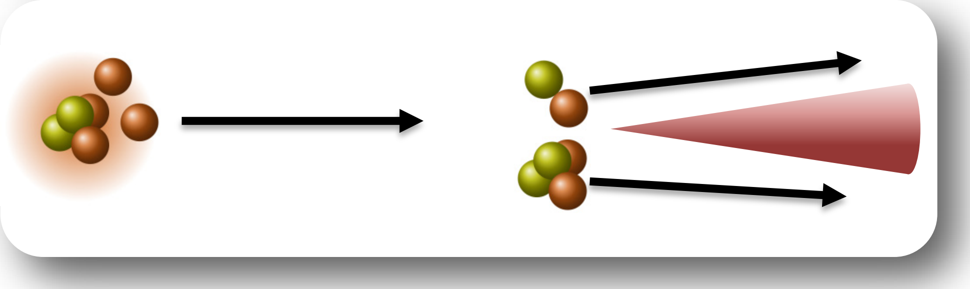
  1.30(13) × 10^{-4} ($E_{c.m.}$ > 200 keV)

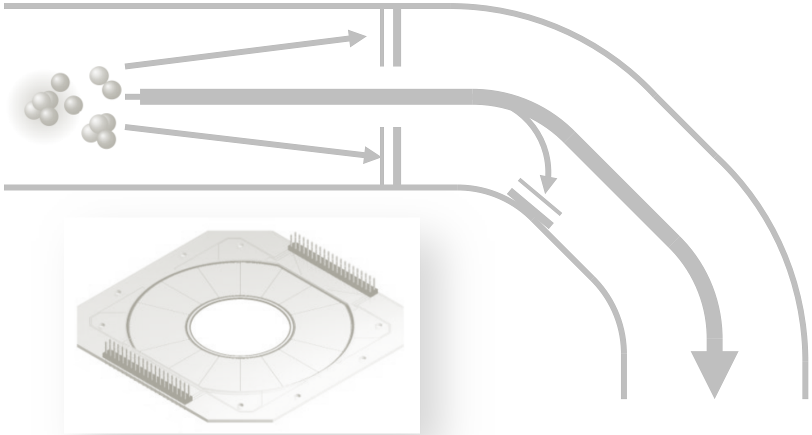
How to access lower energies?

- Decay at rest:
  Only energy of the decay is available



- Decay in flight:
  Use the momentum of the beam
  Emission in a narrow cone





- In the ring:
  Detection in annular arrays
  or after a bend
  Identification through Δ*E*-*E*

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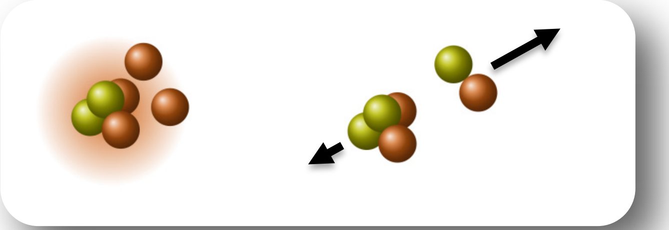

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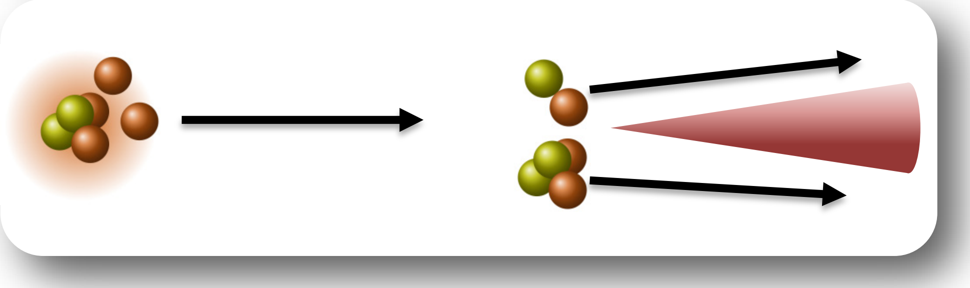

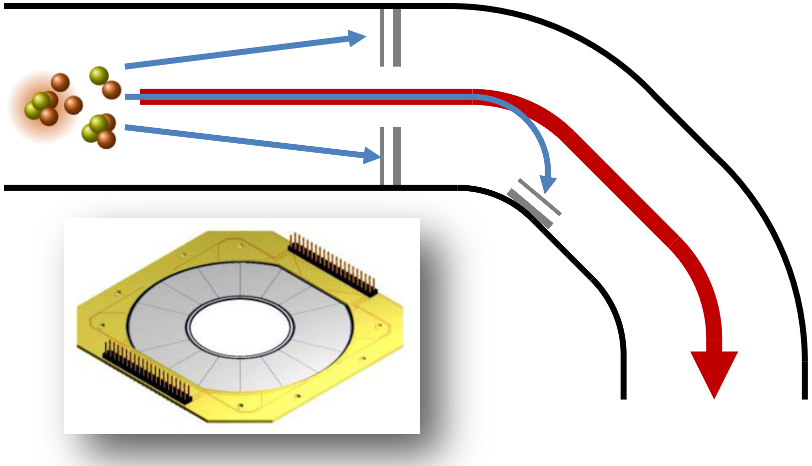

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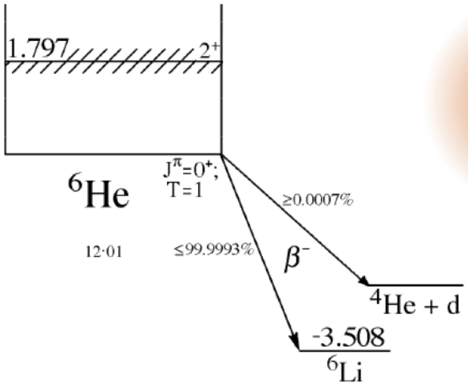
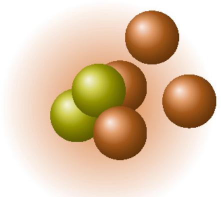
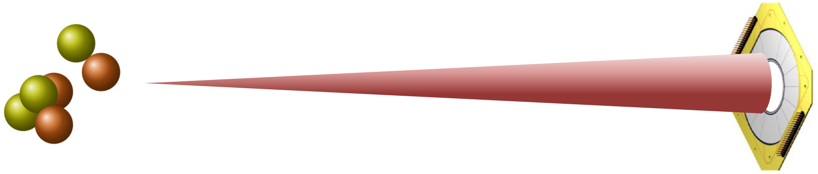
Example I – deuteron-emission decay of ^{6}He

- Branching ratio relates to details of wave function at large distances (⇒ halo)





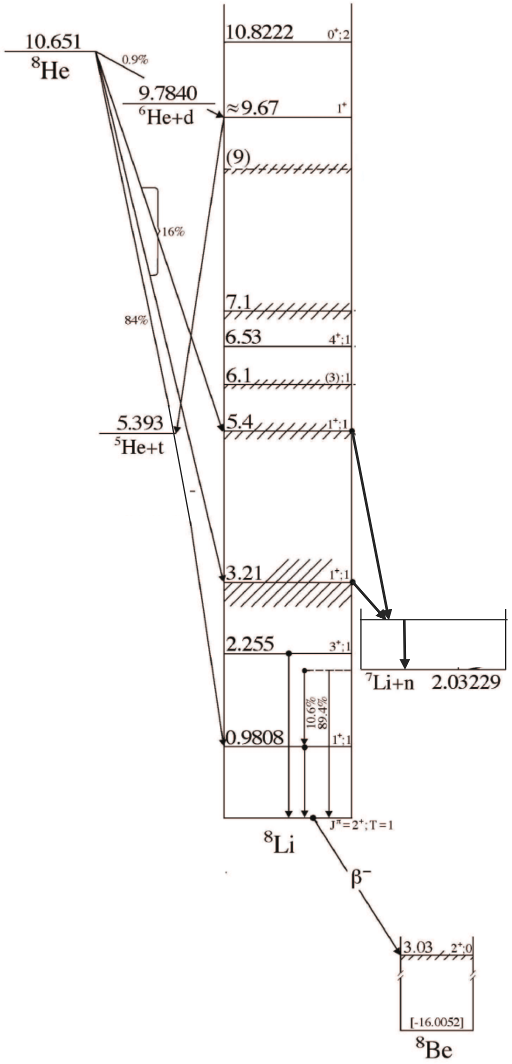
- Cone α-particles (E ≈ 40 MeV):
  $E_{c.m.}$ ≈ 500 keV ⇒ 3.7°
  $E_{c.m.}$ ≈ 100 keV ⇒ 1.6° (10 cm at 3.5 m)



- $B\rho(^{6}\mathrm{He}) = 1.37$ Tm, $B\rho(^{4}\mathrm{He}) \approx 0.9$ Tm
- Efficiency: a few percent, possibly 10%-20%

- $T_{1/2}$ = 800 ms ⇒ injection in ring for 1s (each proton pulse)
- Intensity 10^4 pps ⇒ 1 event / 5 h

Example II – deuteron-emission decay of ^{8}He



- 84% β-γ followed by 2-α emission
  1% triton emission
- Deuteron emission *Q*-value: 870 keV
- Cone ^{6}He-particles ($E \approx 42$ MeV):
  $E_{c.m.} \approx 500$ keV ⇒ 3.1°
  $E_{c.m.} \approx 100$ keV ⇒ 1.4° (10 cm at 4 m)
- $B\rho(^8\text{He}) = 1.53$ Tm, $B\rho(^6\text{He}) \approx 1.1$ Tm
- $T_{1/2} = 120$ ms ⇒ injection each proton pulse
- Intensity 10^2 pps (?) but B.R. larger than ^{6}He

⇒ similar rates as on ^{6}He case

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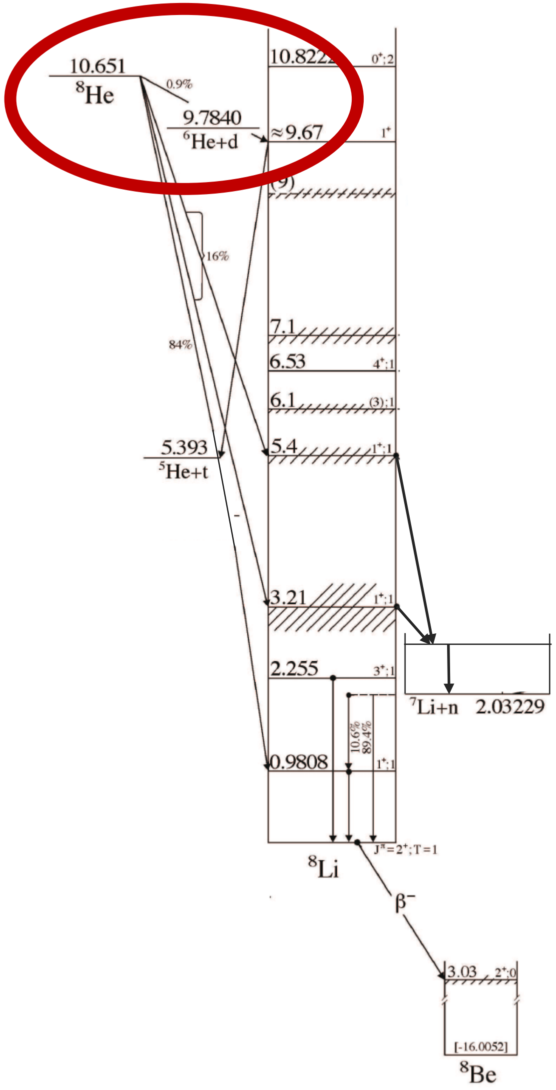

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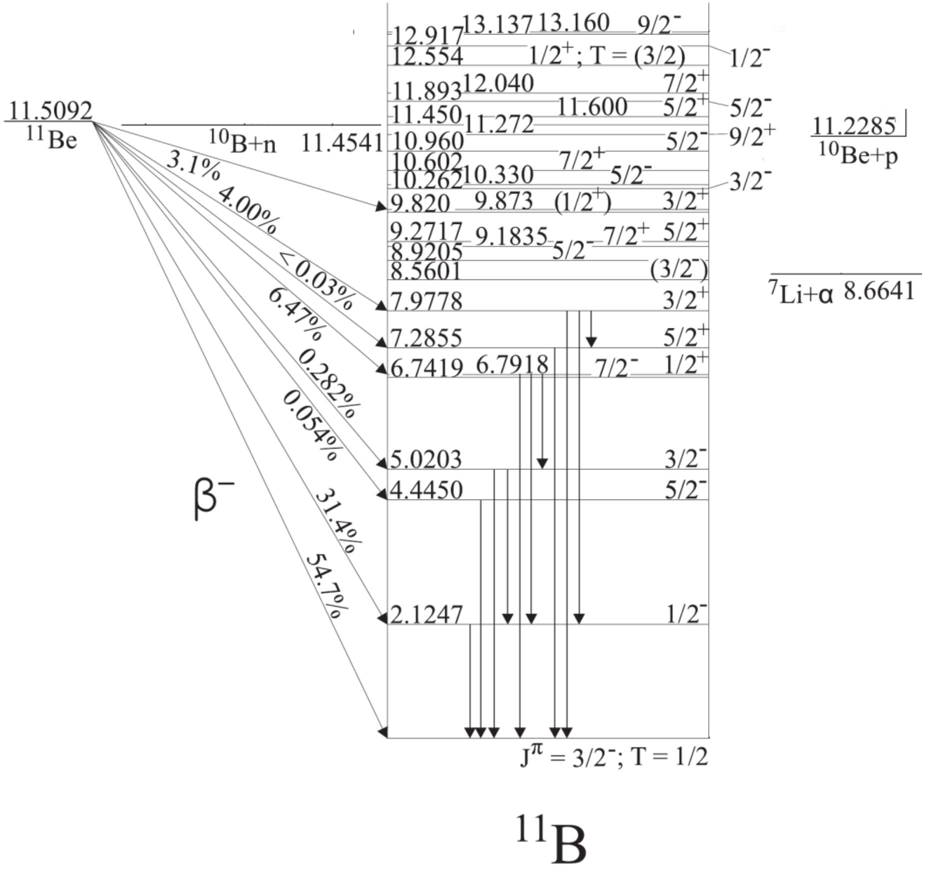
Example III – proton-emission decay of ^{11}Be



- Proton-emission decay of a neutron-rich nucleus!
- Q-value: 281 keV
- ^{10}Be-particles:
  $E \approx 100$ MeV
  0.5° (10 cm at 10 m) @ $E_{\mathrm{c.m.}} \approx 100$ keV
- $B\rho(^{11}\mathrm{Be}) = 1.26$ Tm, $B\rho(^{10}\mathrm{Be}) \approx 1.1$ Tm
- $T_{1/2} = 13.8$ s $\Rightarrow$ injection till saturation (a few 10^7 ions circulating)

$\Rightarrow$ **1 event / hour**

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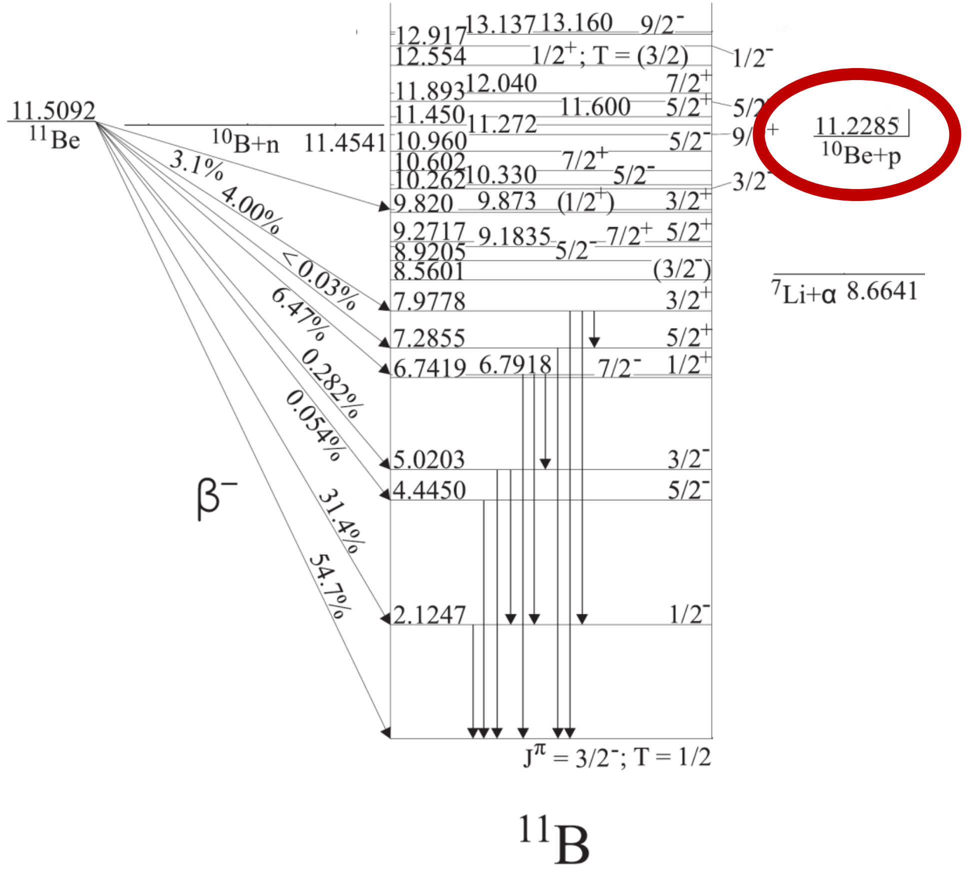

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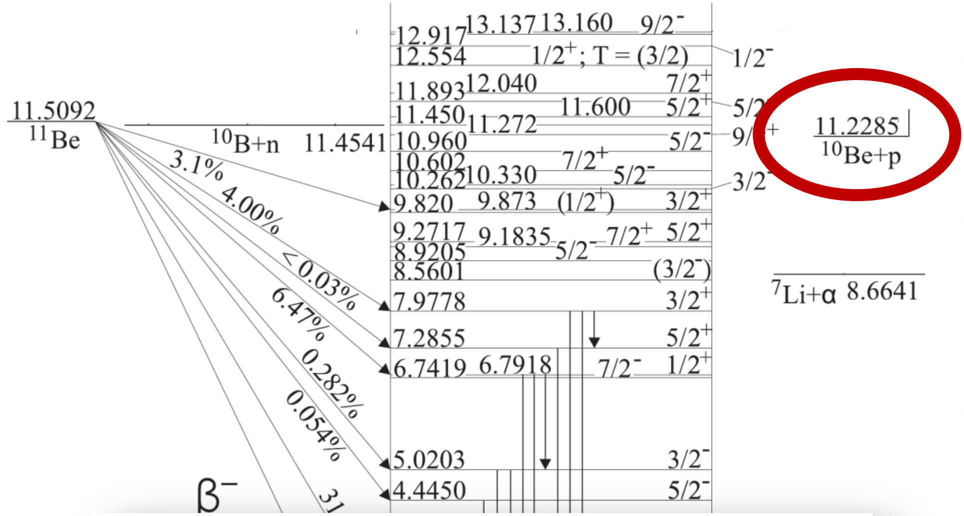

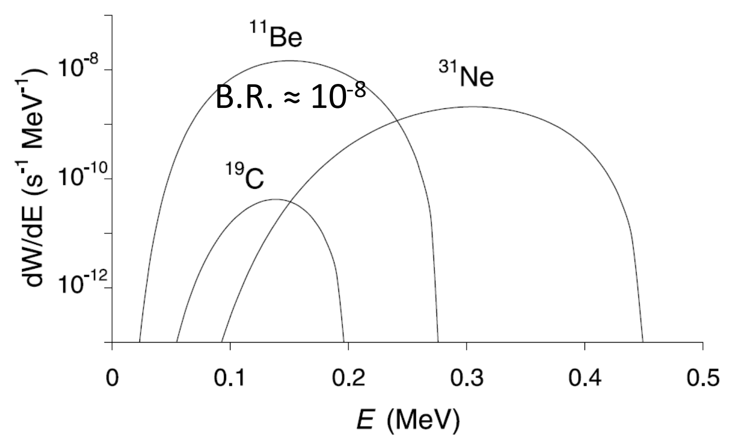

D. Baye, E.M. Tursunov, PLB 696 (2011) 464

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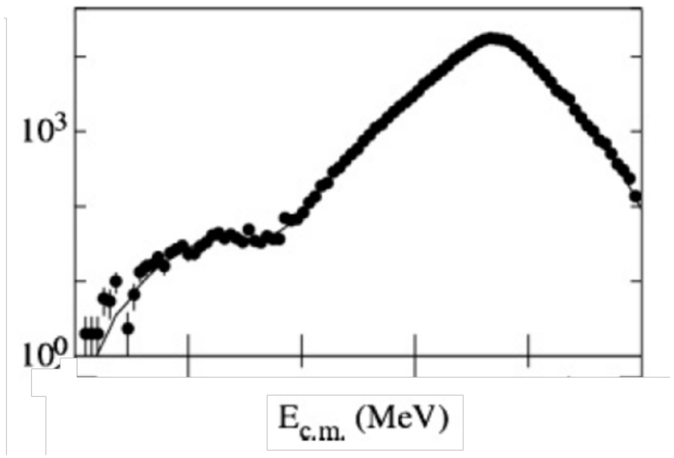
Example IV – α-emission decay of ^{16}N



X.D. Tang et al., PRC 81 (2010) 045809

- $^{16}N \rightarrow {}^{16}O \rightarrow {}^{12}C + \alpha$
  E1 contribution to $^{12}C(\alpha,\gamma)^{16}O$
  B.R. known to 10%
- ^{12}C-particles:
  $E \approx 120$ MeV
  0.8° (10 cm at 7 m) @ $E_{c.m.} \approx 100$ keV
- $B\rho(^{16}N) = 1.04$ Tm, $B\rho(^{12}C) \approx 0.9$ Tm
- $T_{1/2} = 7.1$ s $\Rightarrow$ injection till saturation
  (a few 10^4 ions circulating)
- 10^{11} ions needed
  → needs higher ^{16}N intensity

Summary

Rich information from β-decay!

- Interaction well-known ⇒ structure models can be tested directly
  Nuclear halos, clusters, new decay modes
- Storage and in-flight decay: access to the lowest c.m. energies

Possibilities for the TSR

- Deuteron-emission decay of ^{6,8}He
- Proton-emission decay of ^{11}Be
- Alpha-emission decay of 16N
  (present limit ≈400 keV above threshold)

- Focus on events at low $E_{\text{c.m.}}$
- Complementary to other methods measuring absolute B.R.

Summary

Rich information from β-decay!

- Interaction well-known ⇒ structure models can be tested directly
  Nuclear halos, clusters, new decay modes
- Storage and in-flight decay: access to the lowest c.m. energies

Possibilities for the TSR

- Deuteron-emission decay of ^{6,8}He
- Proton-emission decay of ^{11}Be
- Alpha-emission decay of 16N
  (present limit ≈400 keV above threshold)

- **Focus on events at low $E_{\text{c.m.}}$**
- **Complementary to other methods measuring absolute B.R.**