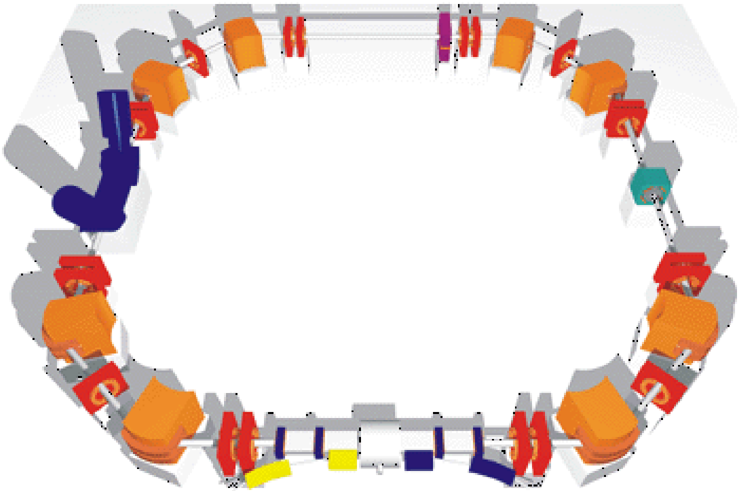
In-ring decay measurements

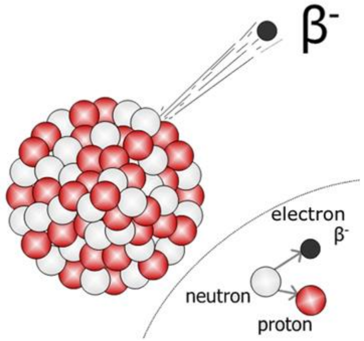
Riccardo Raabe

KU Leuven, Instituut voor Kern- en Stralingsfysica

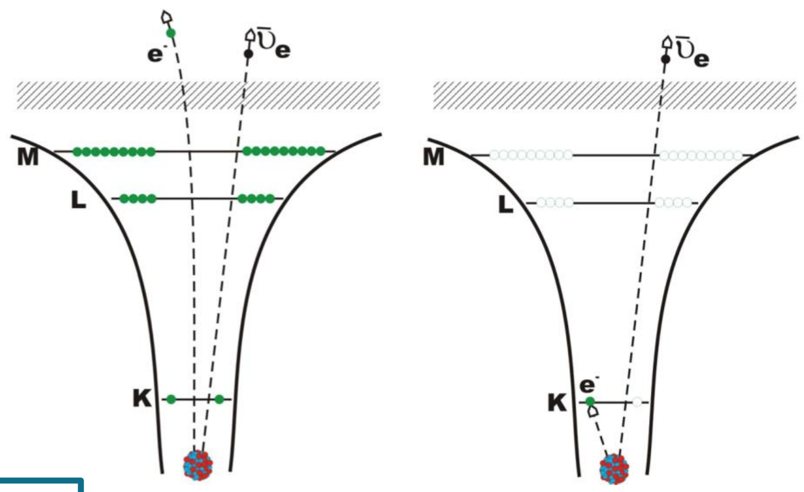


TSR@ISOLDE Workshop
CERN, 27-28 April 2015

Information in β-decay



- Well-established probe
- Structure of states from overlap (transition probability)
  - Light exotic nuclei: decay to continuum
- "Exotic" decay modes of few-electron ions
  - bound-state β-decay
  - He-like vs H-like nuclei
  - electron-screening effect

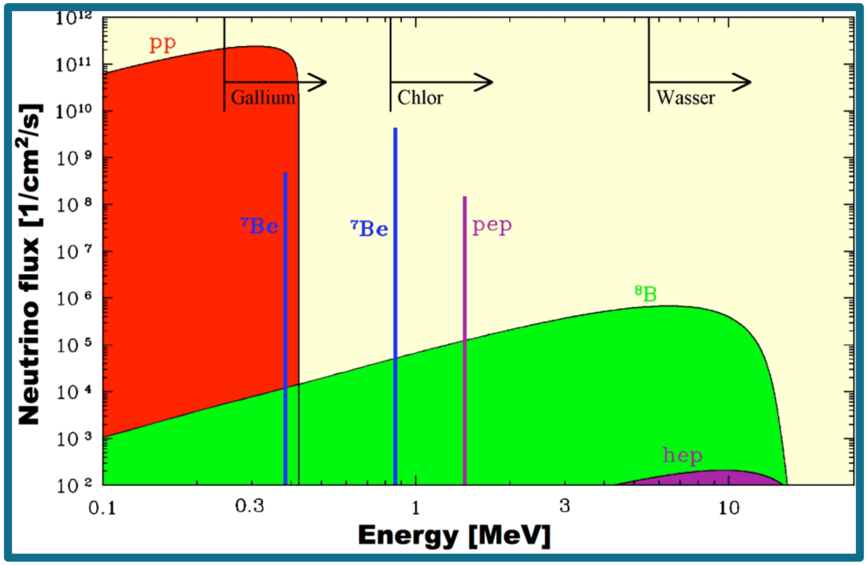


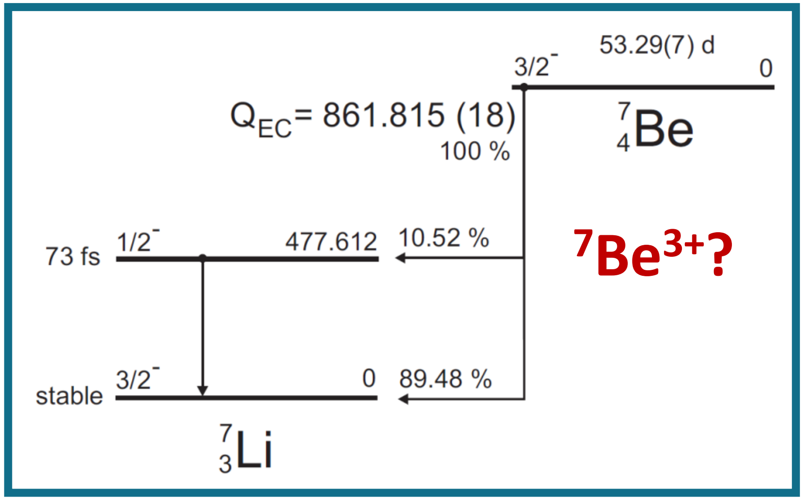
→ Y. Litvinov, TSR workshop 2014

Half life of H-like ^{7}Be

K. Blaum, F. Bosch, Yu. Litvinov, K. Zuber

- Half life of ^{7}Be in the Sun determines ^{7}Be and ^{8}B neutrino fluxes
- Mainly free EC, but 20% due to bound electrons
- Effects from hyperfine states and electron screening





^{7}Be^{3+}?

$T_{1/2}$ ($^{7}Be^{4+}$) ~ infinity

$T_{1/2}$ ($^{7}Be^{3+}$) ~ 106 days

$T_{1/2}$ ($^{7}Be^{2+}$) ~ 53 days

$T_{1/2}$ ($^{7}Be^{1+}$) ~ 53 days

C. Rolfs et al., suggestion for an ESR proposal, ~2003
C. Rolfs, W. Rodney, Cauldrons in the Cosmos, 1988

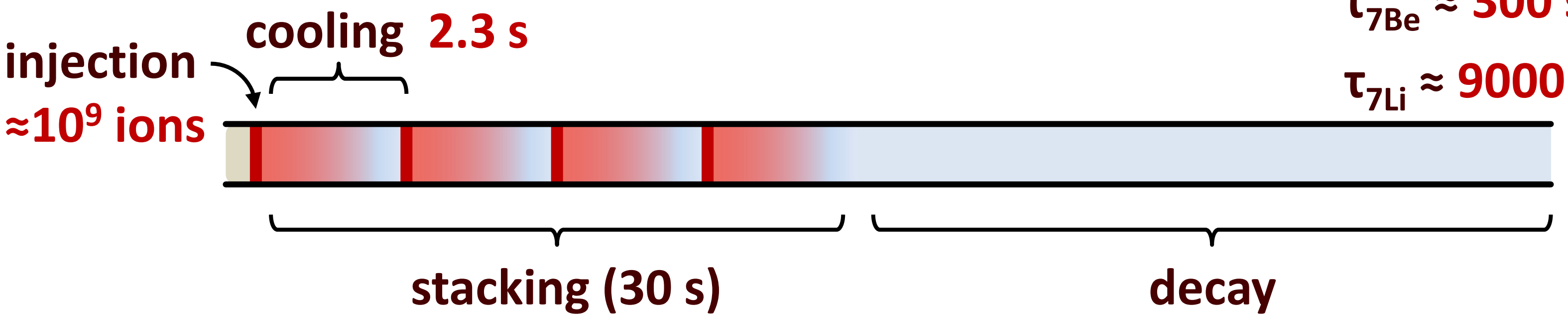
KU LEUVEN

Half life of H-like ^{7}Be

K. Blaum, F. Bosch, Yu. Litvinov, K. Zuber

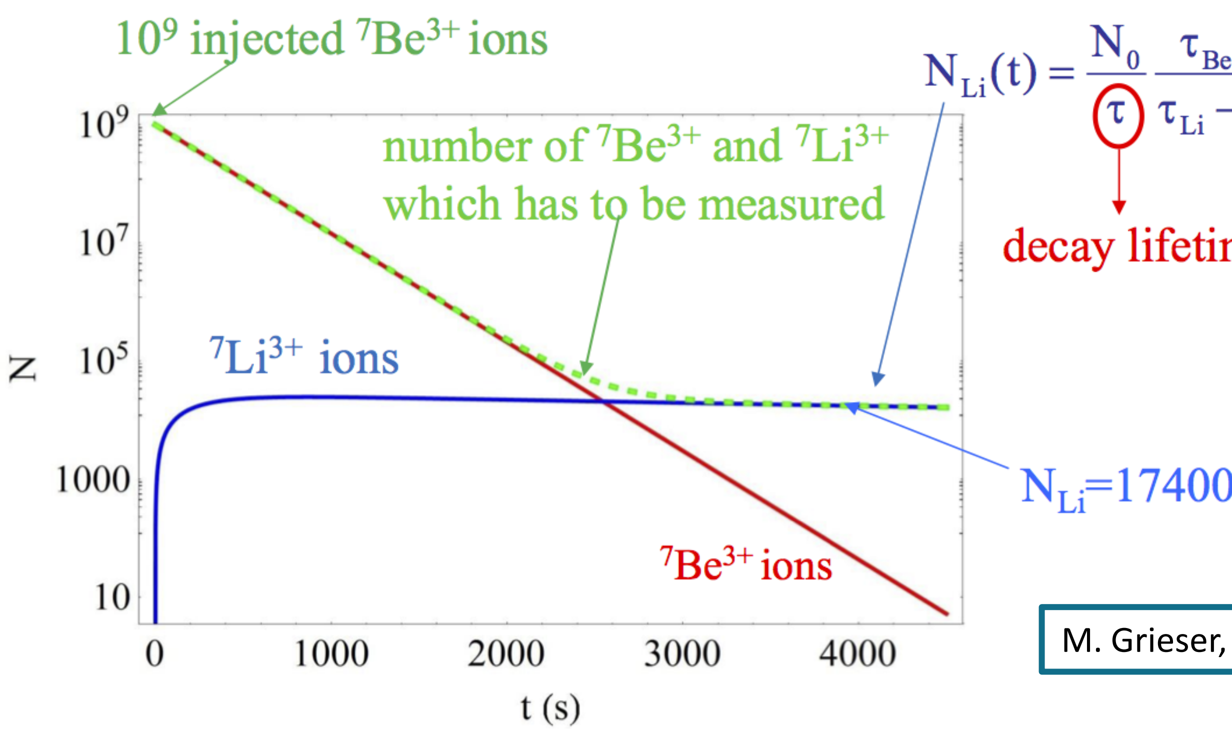
$\tau_{7Be} \approx 300$ s

$\tau_{7Li} \approx 9000$ s



$$N_{Li}(t) = \frac{N_0}{\tau} \frac{\tau_{Be}\tau_{Li}}{\tau_{Li} - \tau_{Be}} \left(e^{-\frac{t}{\tau_{Li}}} - e^{-\frac{t}{\tau_{Be}}} \right)$$

decay lifetime



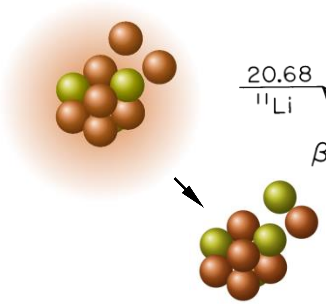
M. Grieser, TSR workshop 2014

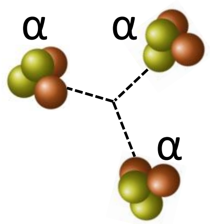
KU LEUVEN

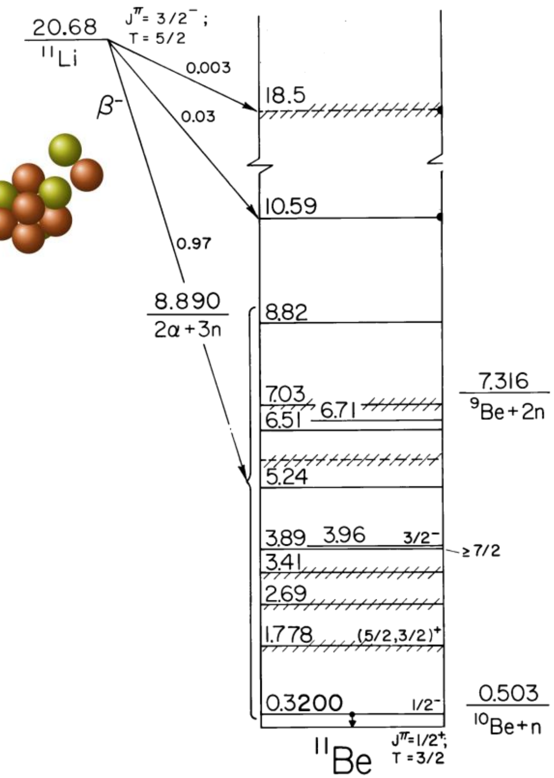
Light exotic nuclei: decay to the continuum

Accurate measurements of

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

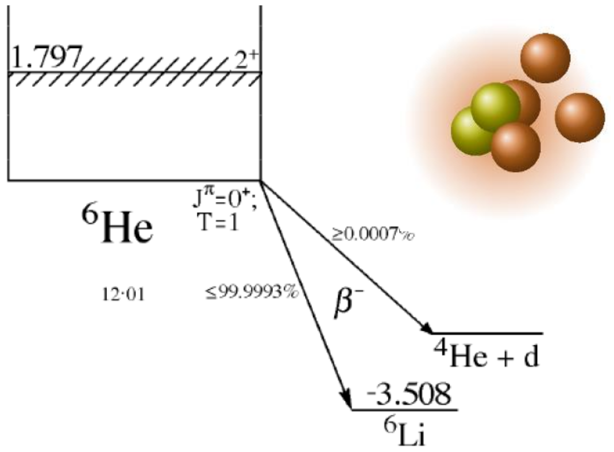






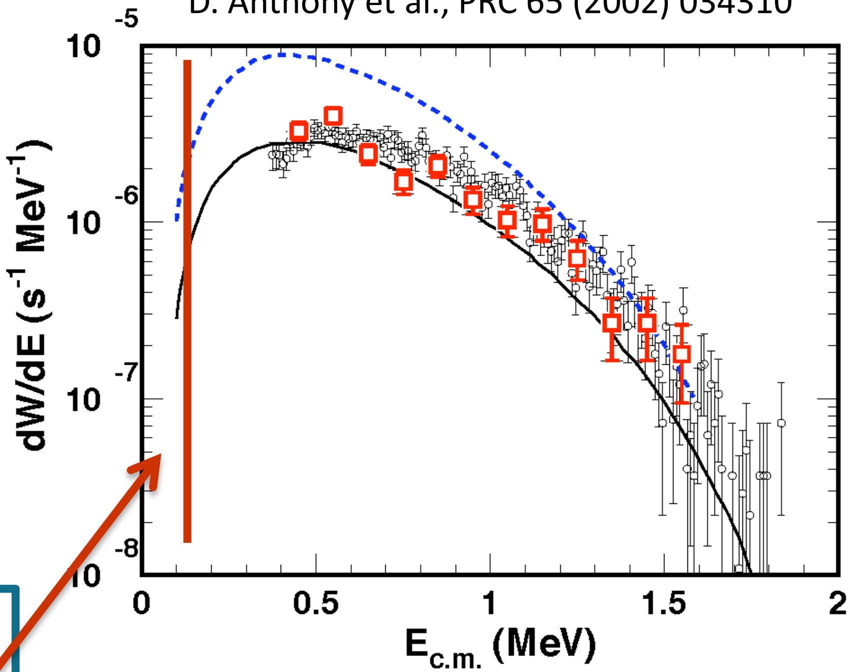
⇒ various experimental methods

β-delayed deuteron emission of ^{6}He

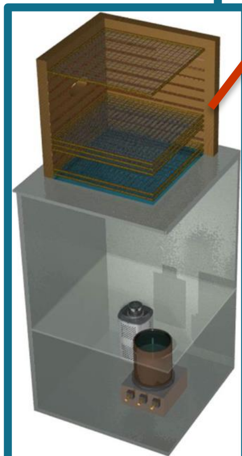


- Small decay channel (**≈10^{-6}**) into α + d
- Branching ratio:
  $1.65(10) \times 10^{-6}$ ($E_{c.m.}$ > 500 keV)
- New measurement REX-ISOLDE (2012) with Optical TPC
  [M. Pfutzner et al]
  new limit at 150 keV

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

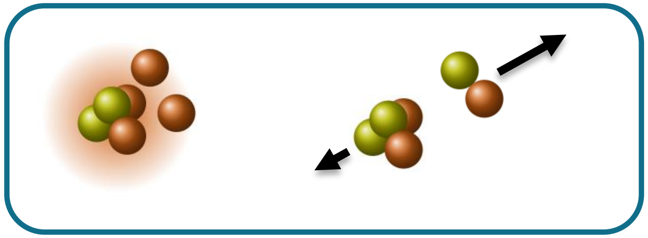


K. Miernik et al.,
NIMA 581 (2007) 194

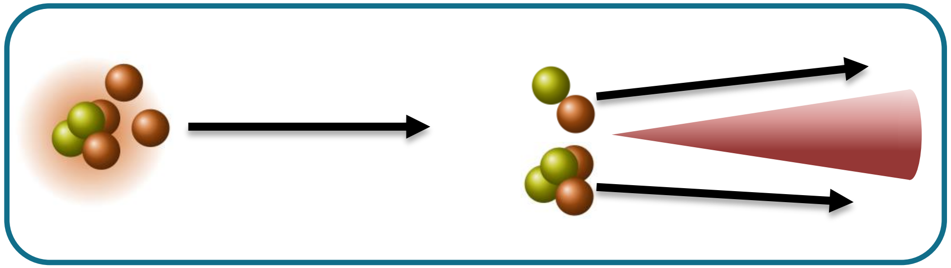
KU LEUVEN

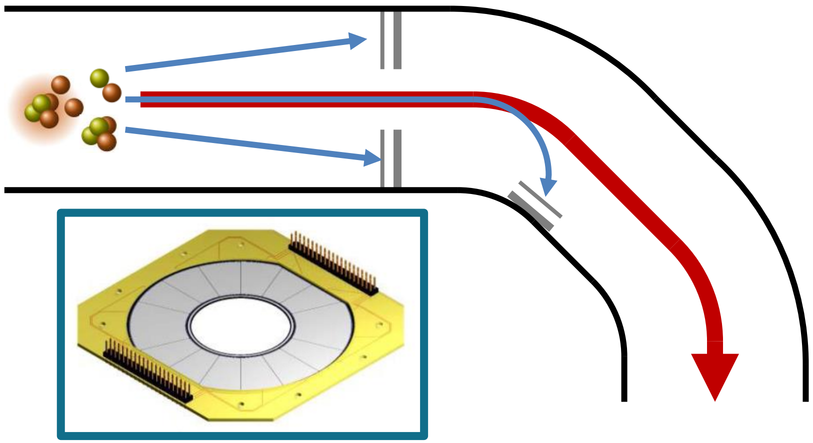
Low thresholds through momentum

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



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

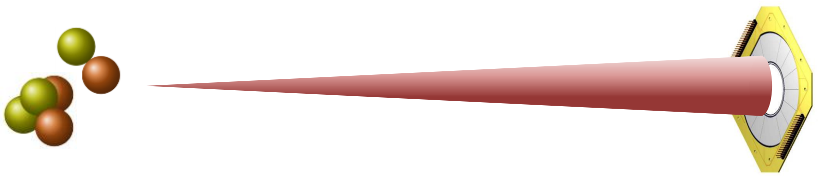


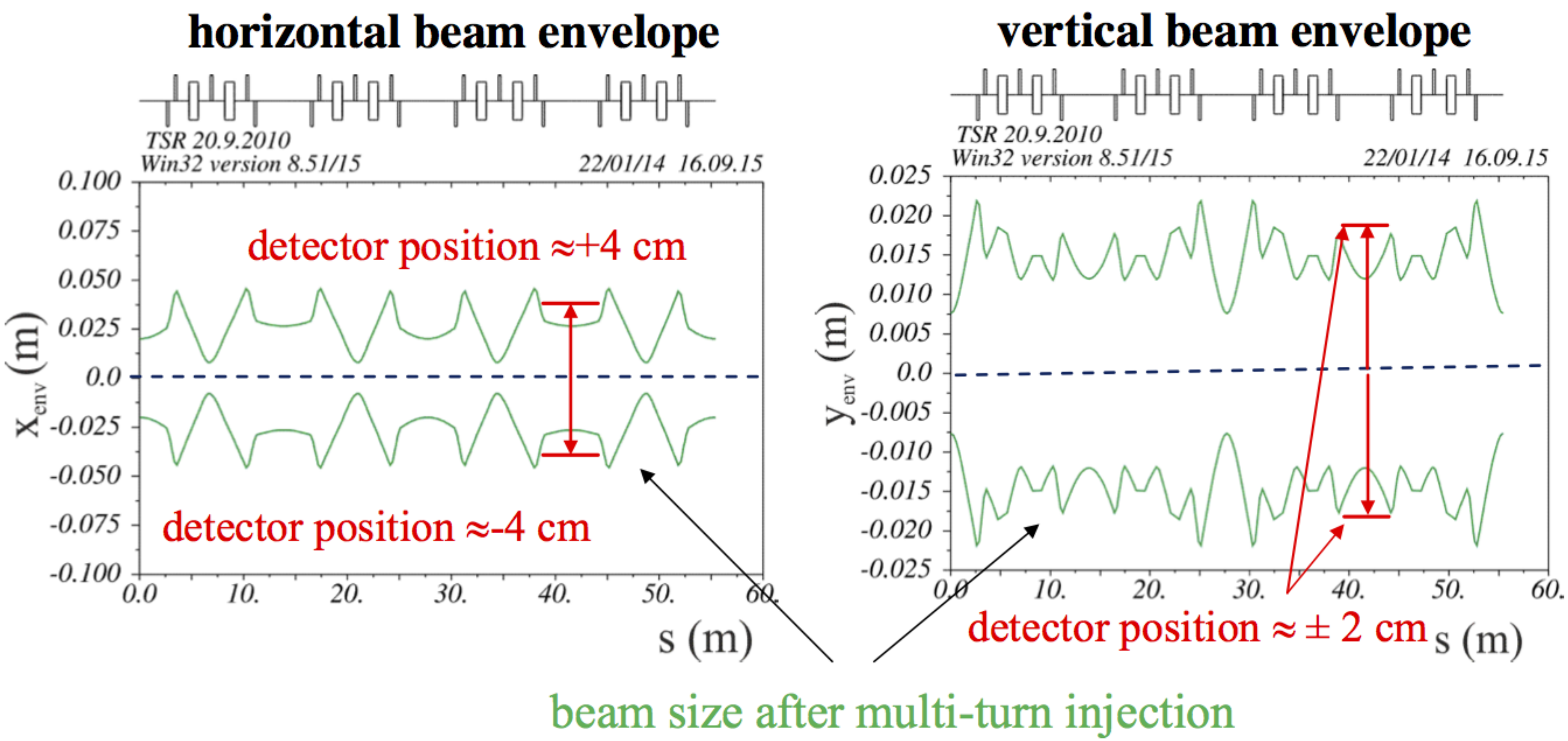


- In the ring:
  Detection in annular arrays
  or after a bend
  Identification through Δ*E*-*E*

Constraints in the TSR

- Detector position
- Nuclear lifetimes vs. cooling time





M. Grieser, TSR workshop 2014

Constraints in the TSR

- Detector position
- Nuclear lifetimes vs. cooling time

$$T_{cool} \approx \frac{A}{q^2} \cdot 3\,s$$

fraction of particle left after electron cooling

ion	T_{cool} (s)	nuclear T_n (s)	fraction of particles left
$^{6}He^{2+}$	4.5	0.806	0.4 %
$^{11}Be^{4+}$	2.1	13.8	86 %
$^{16}N^{7+}$	1.0	7.13	87 %

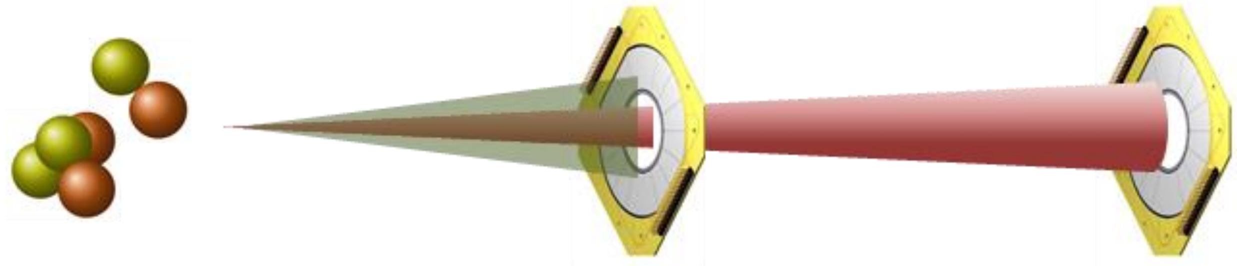
ECOOL stacking can be applied to increase ion intensity

M. Grieser, TSR workshop 2014

KU LEUVEN

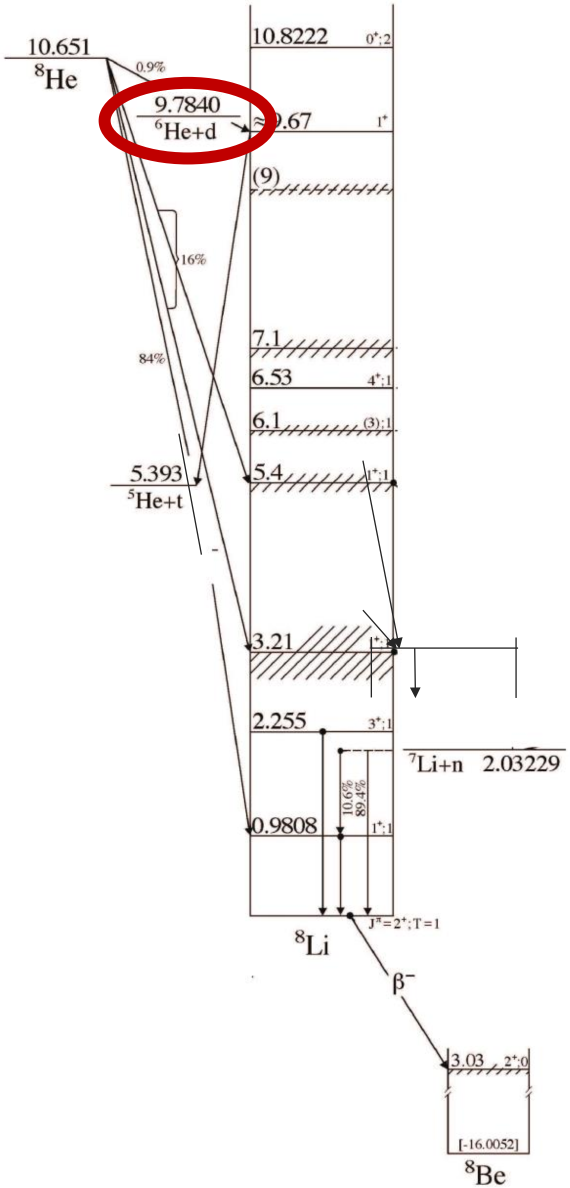
Constraints in the TSR

- To reconstruct E_{cm}:
  need to measure both particles
- "Typical" resolutions needed: E ≈ 50 keV, θ ≈ 0.5° within reach



- Placement of 2-3 detector rings
- Cooling can be relaxed?

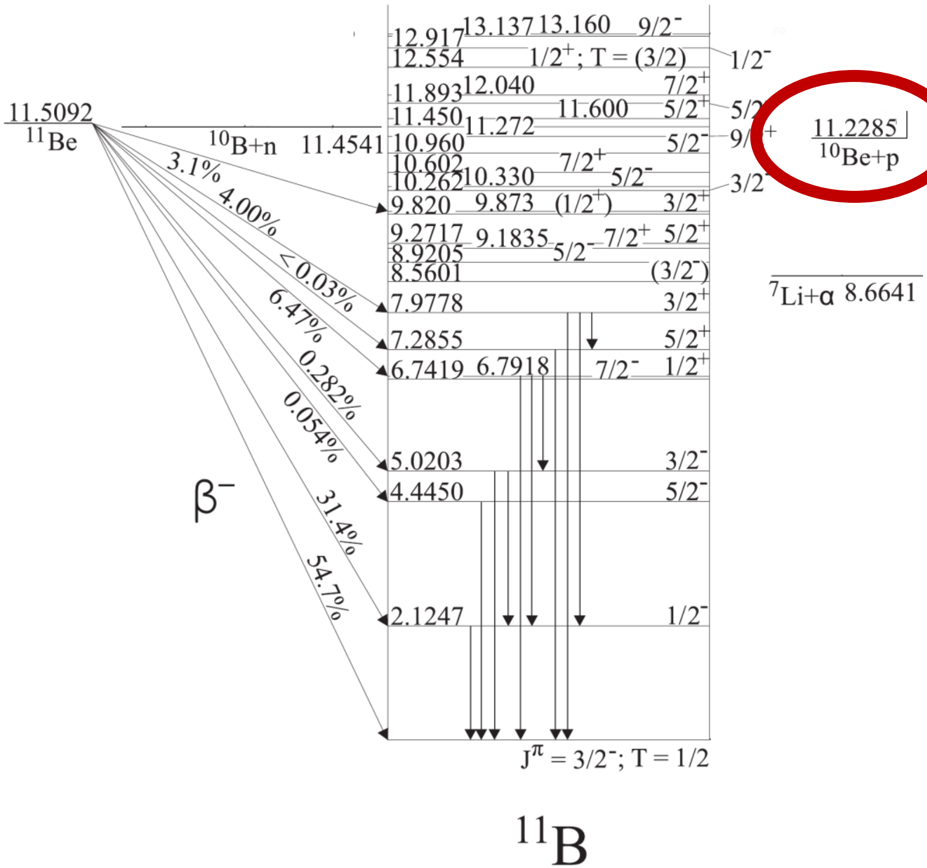
β-delayed deuteron emission of ^{8}He



- 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 $\Rightarrow$ 3.1°
  $E_{c.m.} \approx 100$ keV $\Rightarrow$ 1.4° (10 cm at 4 m)
- $T_{1/2} = 120$ ms, $T_{cool} = 6$ s $\Rightarrow$ no survival … ☹

$\Rightarrow$ No cooling, to be checked

β-delayed proton emission of ^{11}Be

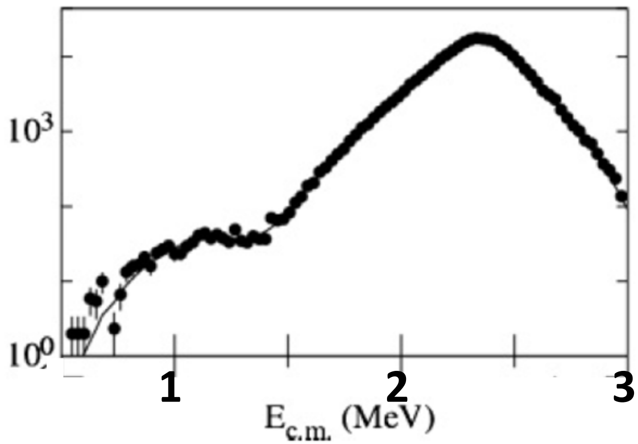


- Proton-emission decay of a neutron-rich nucleus!
- *Q*-value: 281 keV
- BR = (8.3±0.9) 10^{-6}
  [K. Riisager et al, PLB 732(2014) 305]
- ^{10}Be-particles:
  E ≈ 100 MeV
  0.5° (10 cm at 10 m) @ $E_{c.m.}$ ≈ 100 keV
- 86% survival after cooling
  a few 10^{7} ions circulating
  10^{9} in one hour

⇒ **1% efficiency → 10 event / hour**

KU LEUVEN

β-delayed α emission of ^{16}N



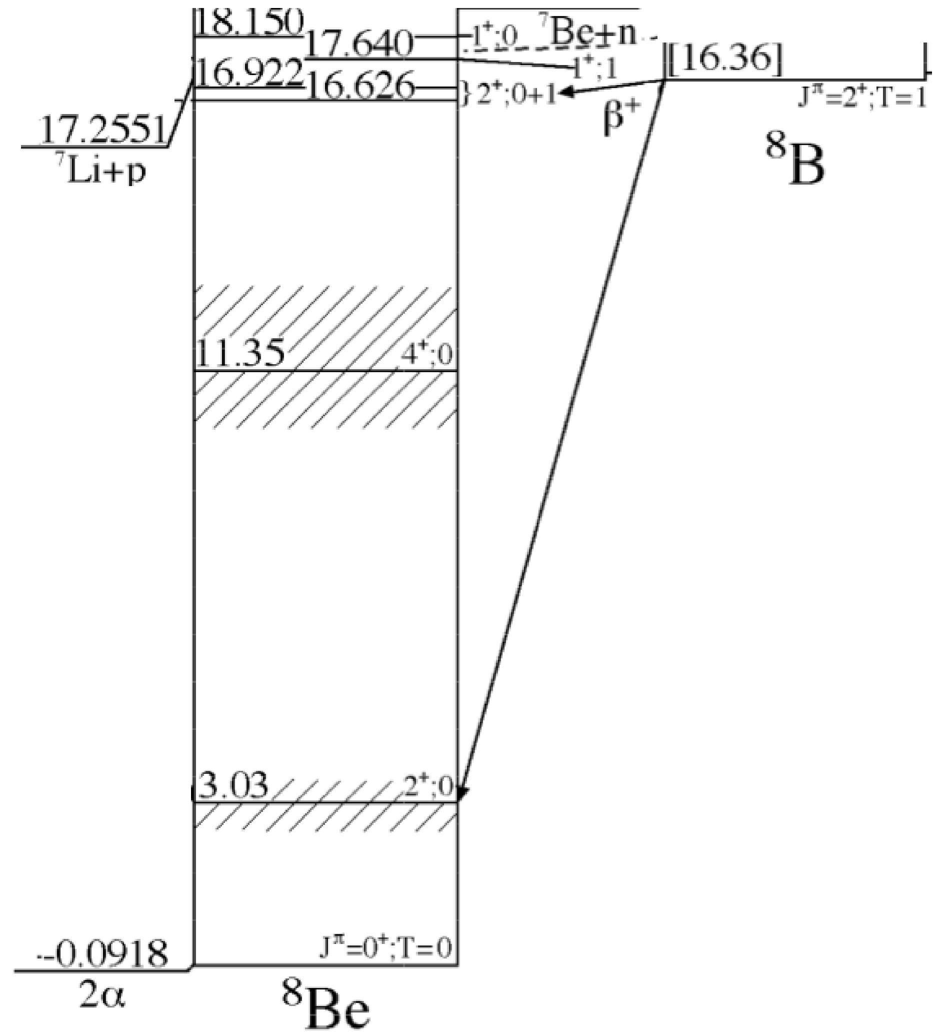
X.D. Tang et al., PRC 81 (2010) 045809

- ^{16}N → ^{16}O* → ^{12}C + α
  E1 contribution to ^{12}C(α,γ)^{16}O
  B.R. known to 10%
- ^{12}C-particles:
  E ≈ 120 MeV
  0.8° (10 cm at 7 m) @ $E_{c.m.}$ ≈ 100 keV
- 87% survival after cooling
  a few 10^4 ions circulating
- 10^{11} ions needed
  → needs higher ^{16}N intensity

^{8}B: decay of the core

- $^{8}B \rightarrow {}^{8}Be^{*} \rightarrow {}^{7}Li + p$
  $Q(\beta^{+}p) = 724$ keV

- $T_{1/2} = 770$ ms, $T_{cool} = 1.5$ s
  $\Rightarrow$ 14% survival
- A few 10^{6} ions circulating re-filled each few seconds
- 1% efficiency, BR $\approx 10^{-8}$
  $\Rightarrow$ 100 events in 10 days



Summary

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

At TSR:

- Proton-emission decay of ^{11}Be
- ^{8}B decay of the core
- Alpha-emission decay of ^{16}N
  (present limit ≈400 keV above threshold)

Focus on events at low $E_{c.m.}$

Complementary to other methods measuring absolute B.R.

KU LEUVEN