Search for the γ-decay of ^{7}Li into the continuum by the cold neutron capture reaction ^{6}Li(n,γ)^{7}Li

S. Leoni, B. Fornal, U. Koester, S. Bottoni, S. Brambilla, G. Calvi, M. Jentschl, H. Fynbo, K. Riisager, F. Crespi, N. Cieplicka-Oryńczak, L. Iskra2, C. Michelagnoli, P. Mutti, O. Tengblad, R. Heinke

University of Milano and INFN sez. Milano (Italy) , Institute of Nuclear Physics, Kraków (Poland)
ILL, Grenoble (France), Aarhus University (Denmark), IEM–CSIC, Madrid (Spain), Mainz University (Germany)

XXth Colloque GANIL 2017

15-20 Oct 2017 Amboise (France)

INTRODUCTION

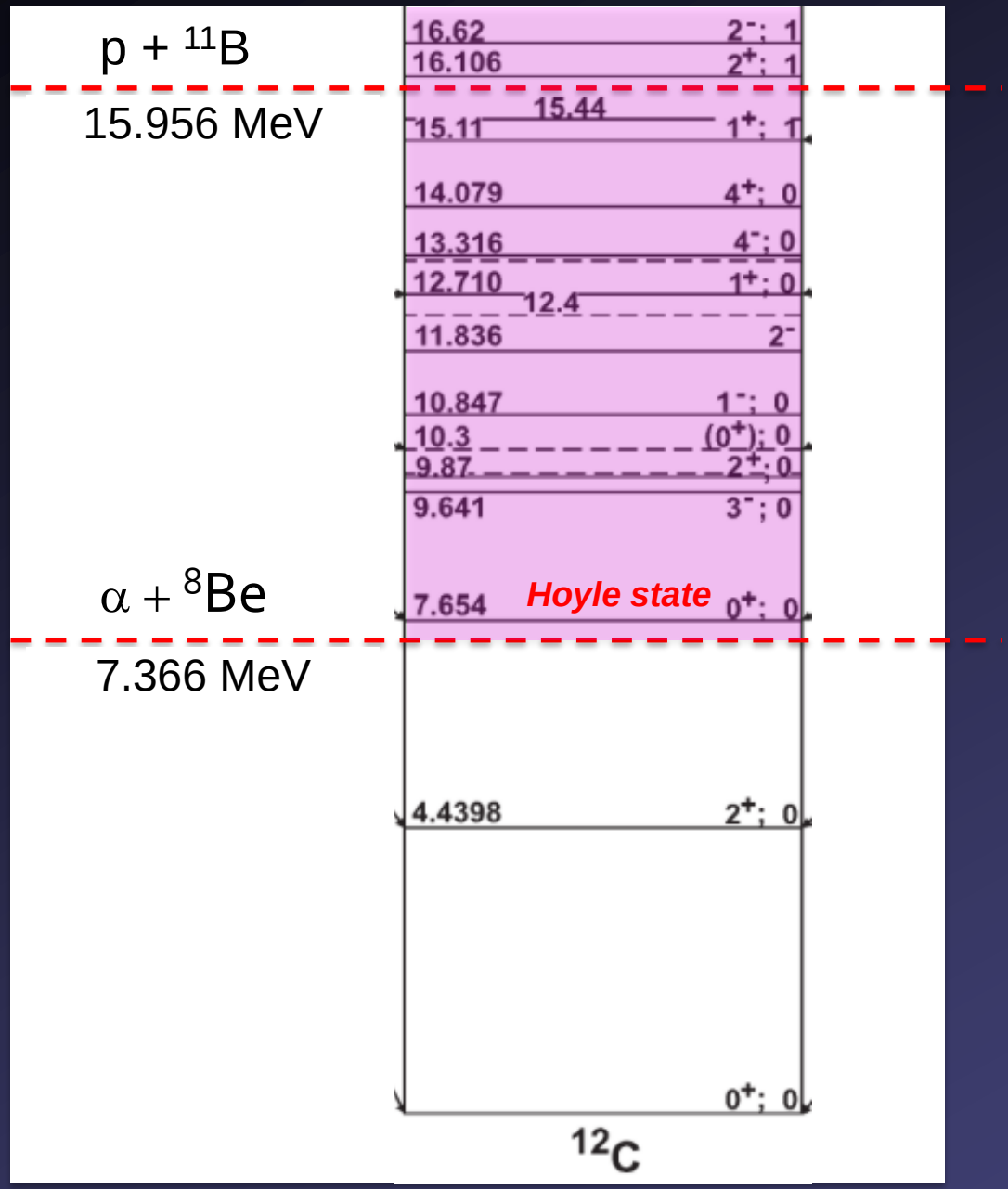
Light Nuclei: Li, Be, B, C, N, O, F, …

- Test Bench for different/VERY advanced Approaches:
  Cluster model / *ab-initio* / Shell Model in the Continuum
- Importance in ASTROPHYSICS (nucleosynthesis, …)

Among Most Pressing Open questions …

- Can we understand the NATURE of the CONTINUUM ?
  (continuum spectrum of scattering states and resonances above particle threshold …)
- Broad resonances and/or NON-resonant continuum ?

^{12}C – the most studied case …



Experimental information

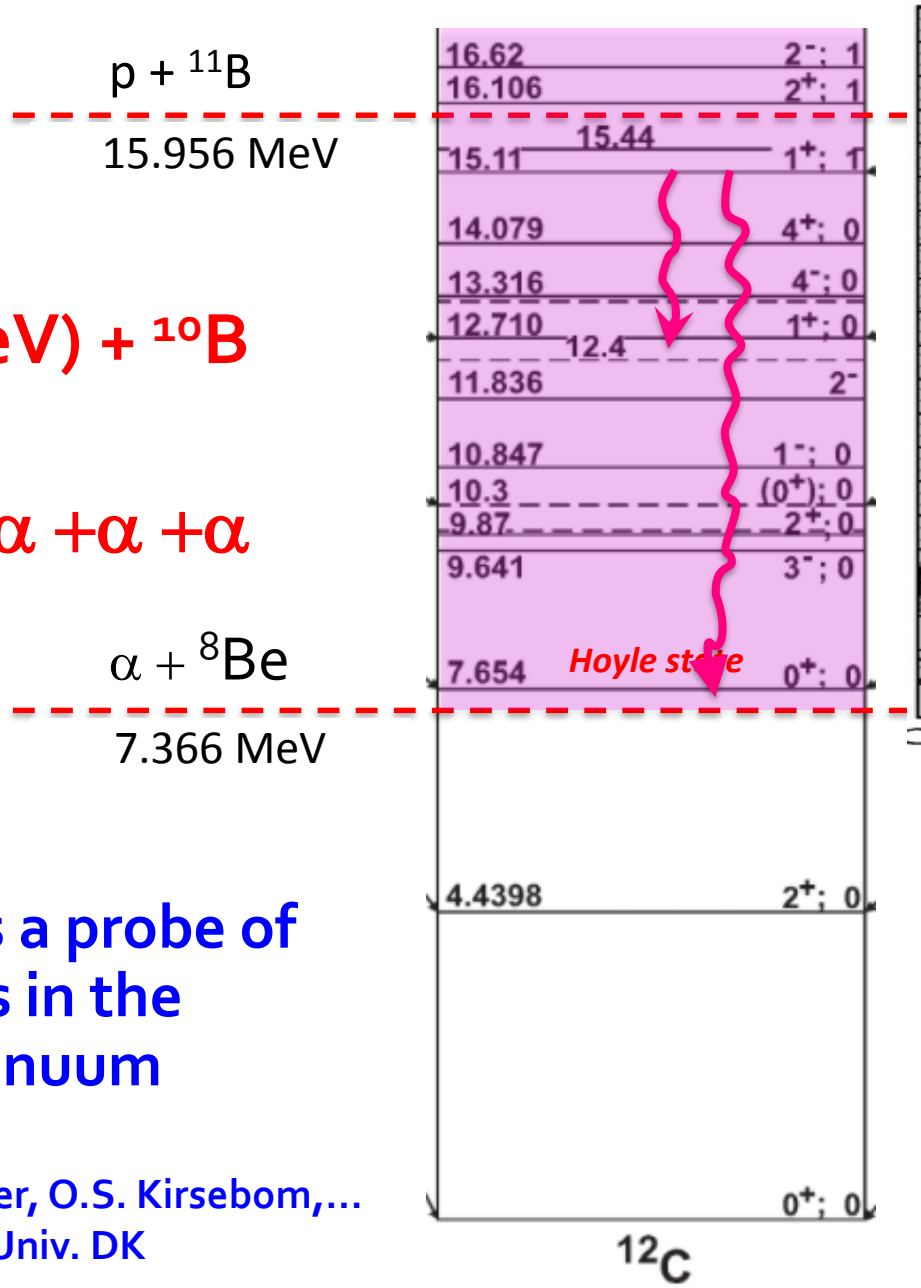
- very <u>complex spectrum</u> of resonances …
- almost entirely from <u>particle detection</u>
- <u>γ detection</u> is very challenging (10^{-5}-10^{-6} branches)
  → very important to have a *complete picture*
  → it is a *different probe* …

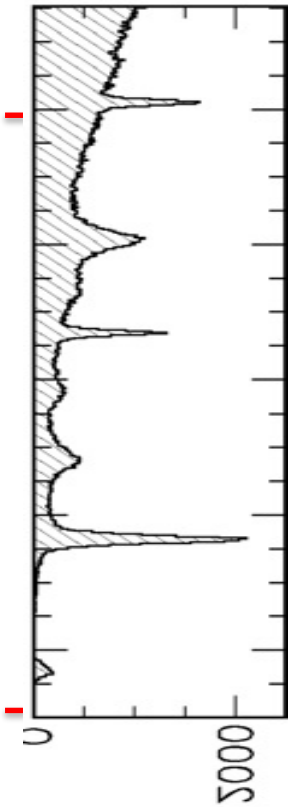
γ decay in the continuum reconstructed from particle detection

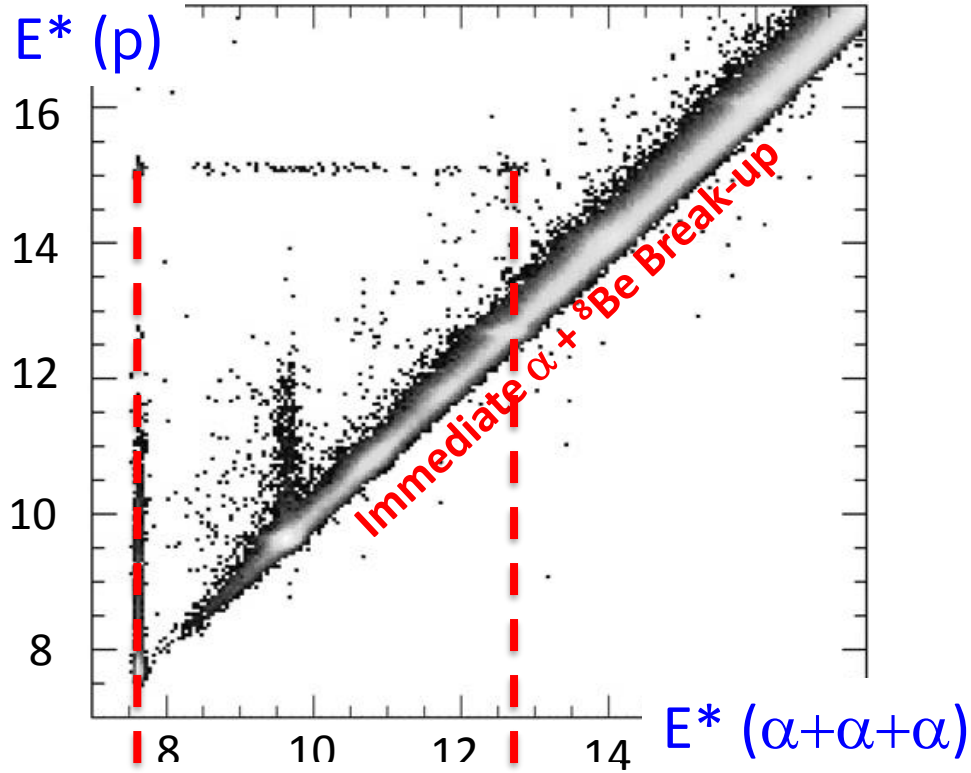
^{3}He (4.9 MeV) + ^{10}B

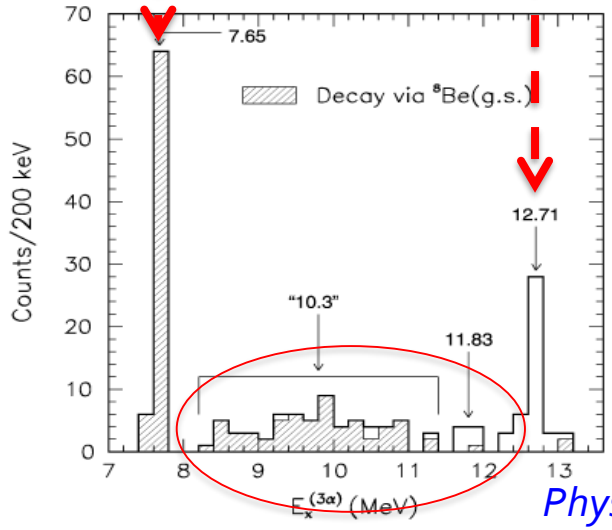
→ p + ^{12}C

↳ α +α +α









γ decay as a probe of states in the continuum

Broad distribution not clearly related to known resonace states

H. Fynbo, K. Riisager, O.S. Kirsebom,…
Arhus Univ. DK

Phys. Lett. B680 (2009) 44

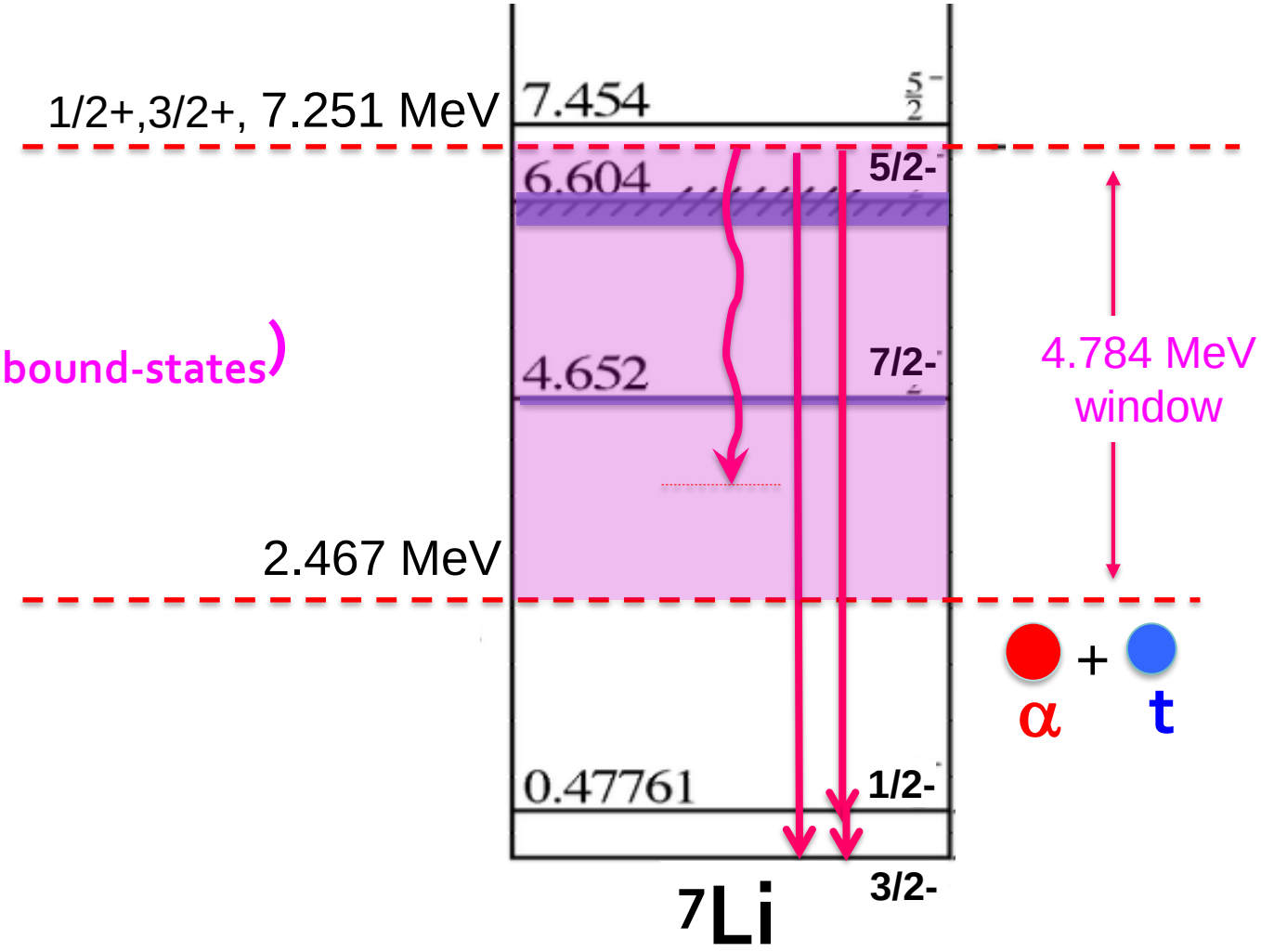
Looking for another/simpler case for γ decay in the continuum

… to learn about
resonant and NON – resonant contribution

^{7}Li – an ideal case for γ decay in the continuum

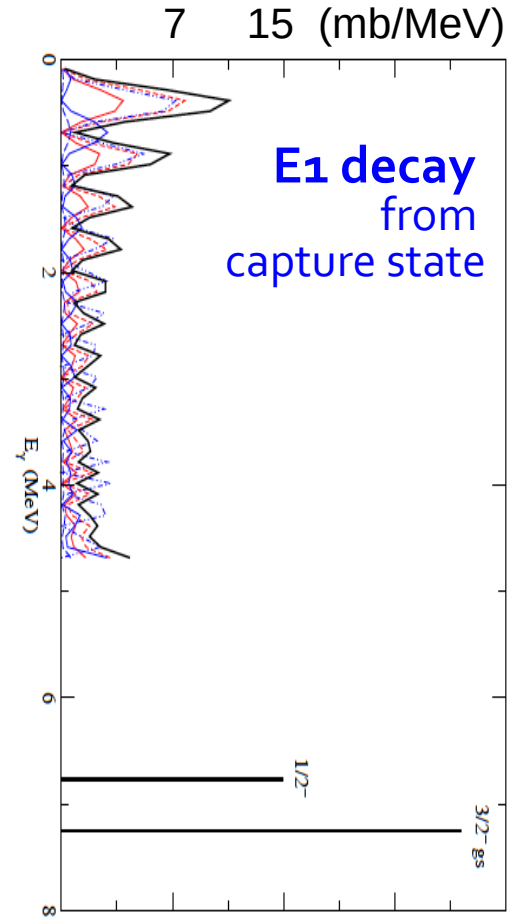
n+^{6}Li
σ = 940 b

^{6}Li(n,©$_{\text{to-bound-states}}$)
σ = 0.045 b



Di-Cluster Model

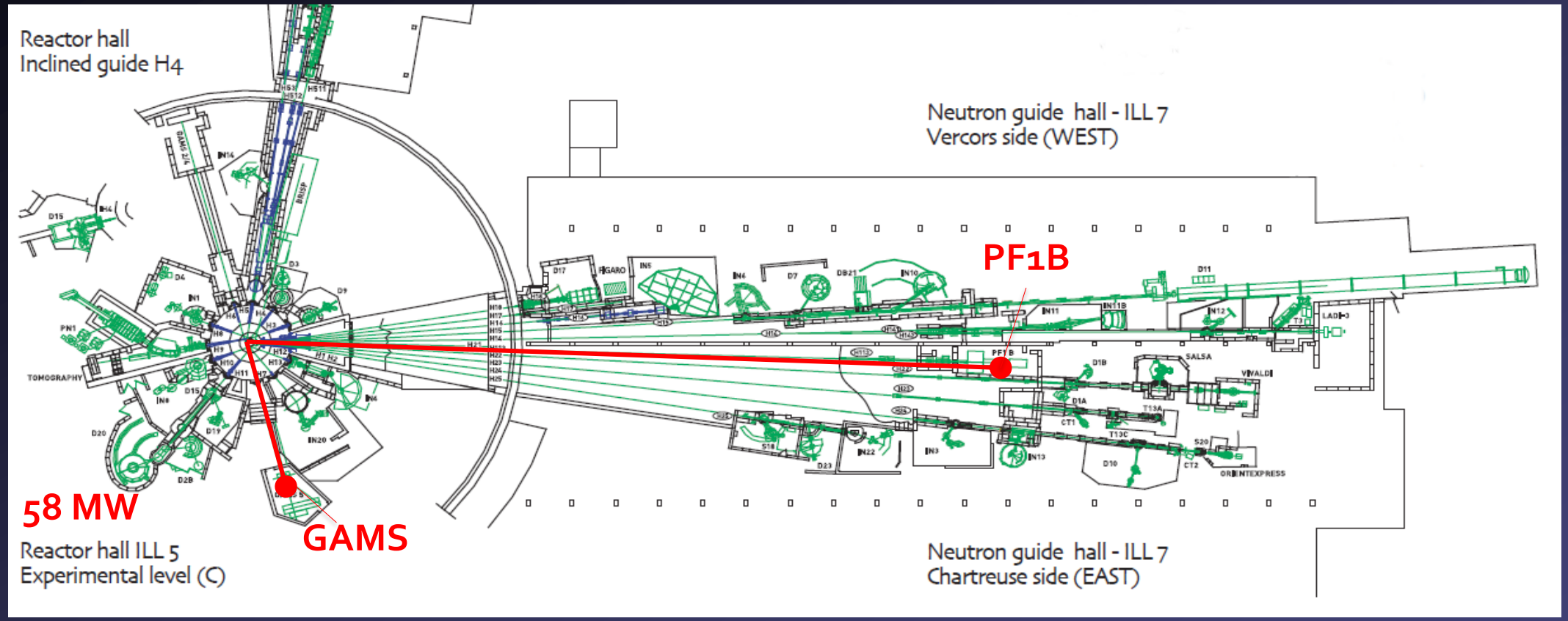
^{7}Li = α + t



Very Preliminary

L. Fortunato, A. Vitturi – Padova Univ.

The experiments @ ILL-Reactor (GRENOBLE)



MOST INTENSE
Continuum neutron source

In pile $\Phi_n = 5 \times 10^{14}$ n cm^{-2} s^{-1}

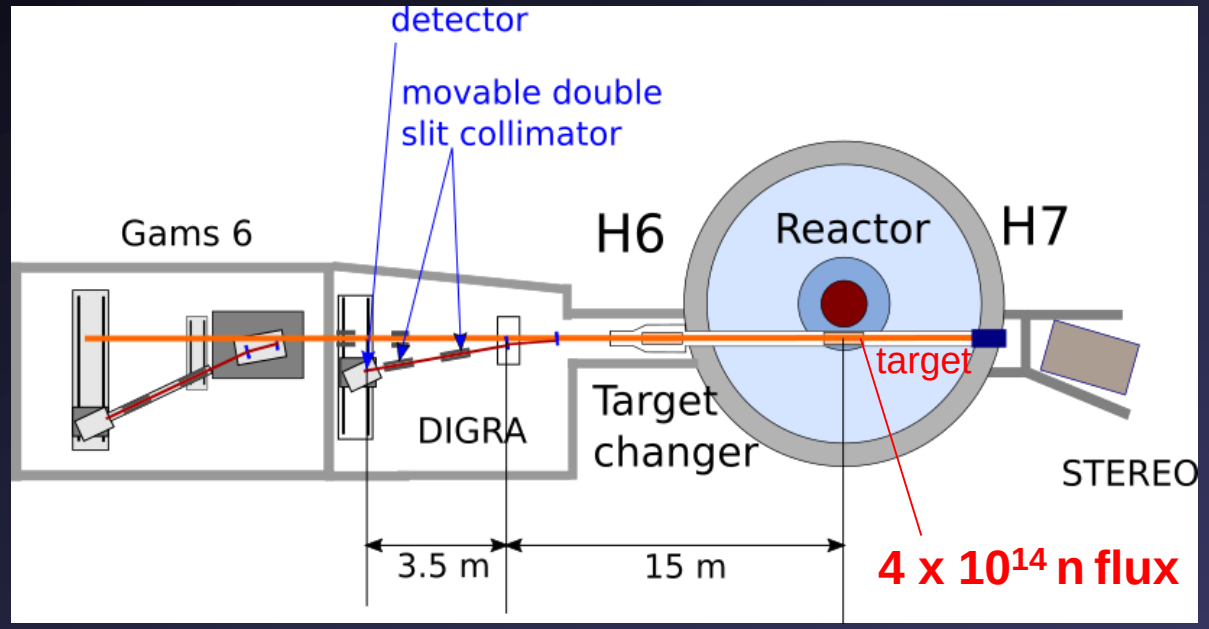
collimated $\Phi_n = 2 \times 10^{8}$ n cm^{-2} s^{-1}

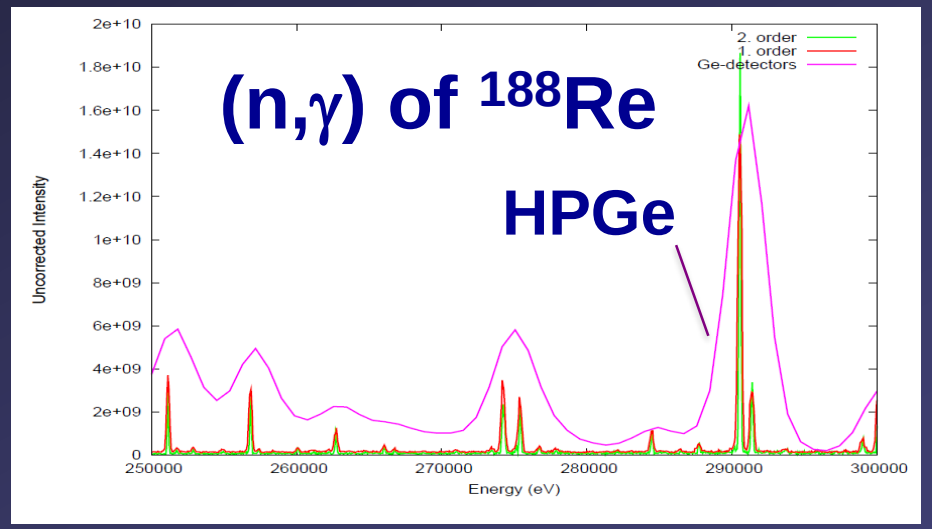
^{6}Li(n,©)

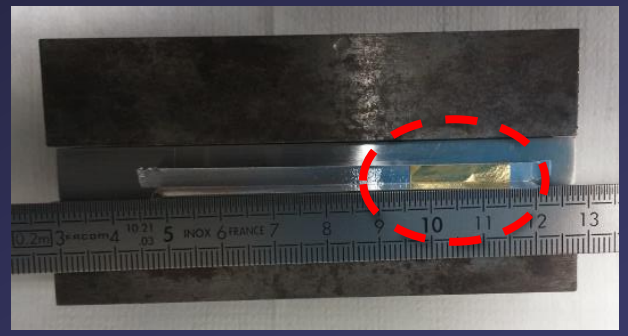
1. GAMS beam line (thermal n) – Dec. 2015
2. PF1B beam line (cold n) – Feb. 2017

^{6}Li(n,©) @ GAMS (Diffraction Interferometer)

DIRECT measurement of γ spectrum with **ULTRA-LOW** background





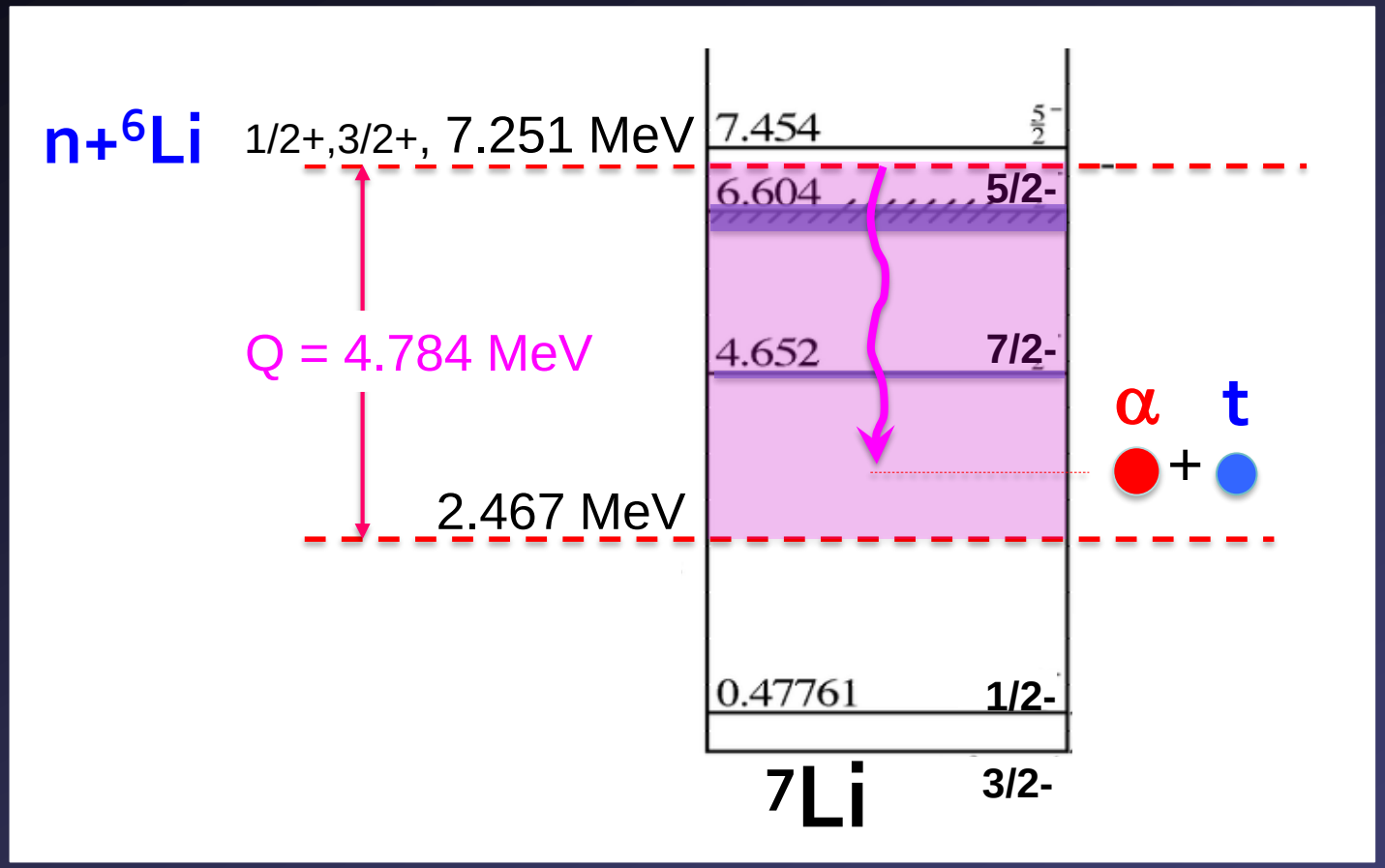


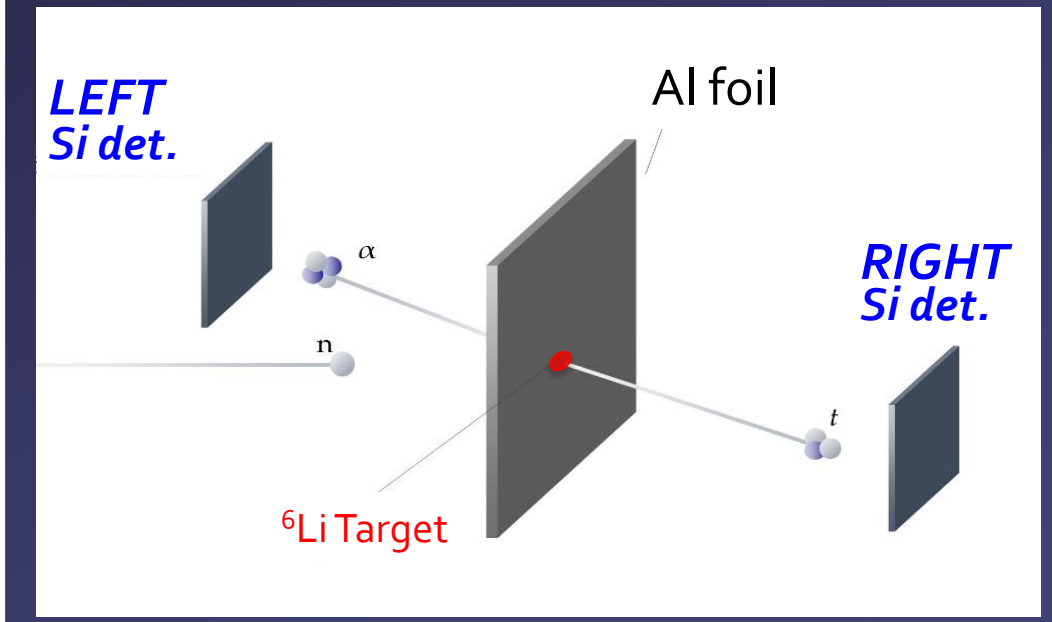
Test of background in the region above 2.5 MeV
with a Au target (weak high energy lines as a benchmark)

factor 100 too high background from the reactor…
we need to go further away (GAMS4) … in 2 years time !

^{6}Li(n,©) @ PF1B (cold neutrons, 2 x 10^8 flux)

γ spectrum from full kinematic reconstruction





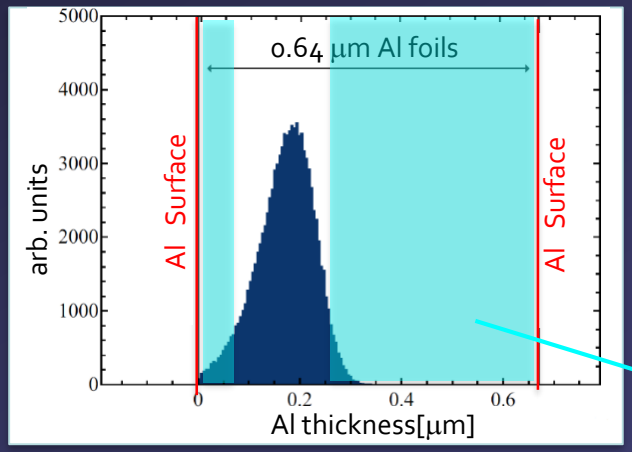
$$E_\gamma = Q - (E_\alpha + E_t)$$

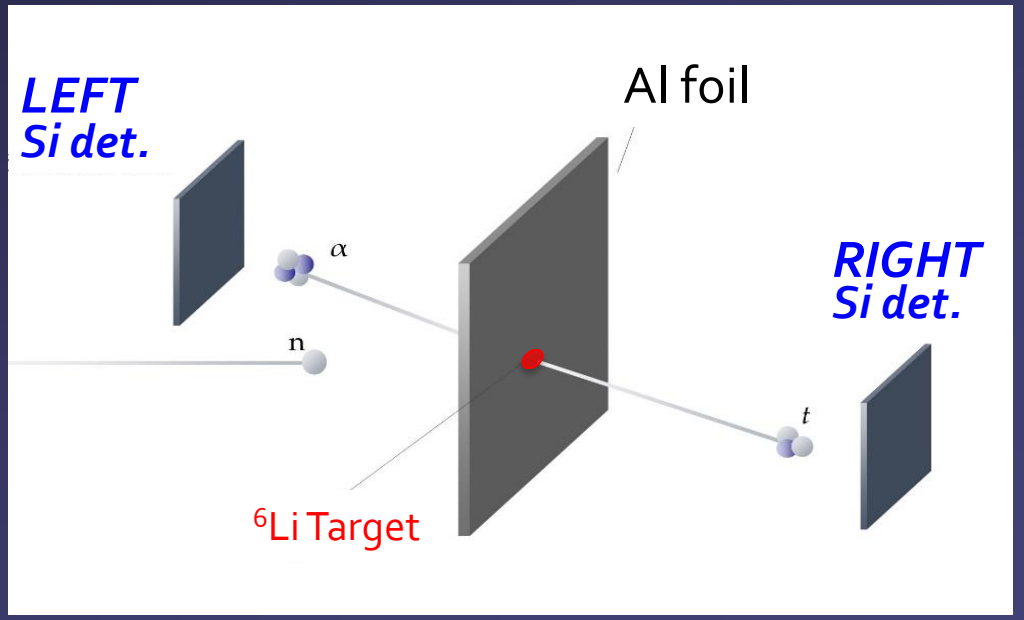
^{6}Li(n,©) @ PF1B (cold neutrons, 2 x 10^{8} flux)

γ spectrum from full kinematic reconstruction

2.8 10^{16} implanted ^{6}Li ions in 0.64 μm Al foil

implantation profile





α and t pass through Al material → Energy losses, …

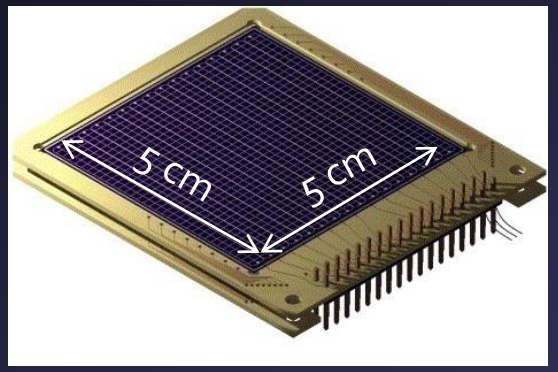
R. Heinke - Univ. Mainz : ^{6}Li (30 keV) + Al

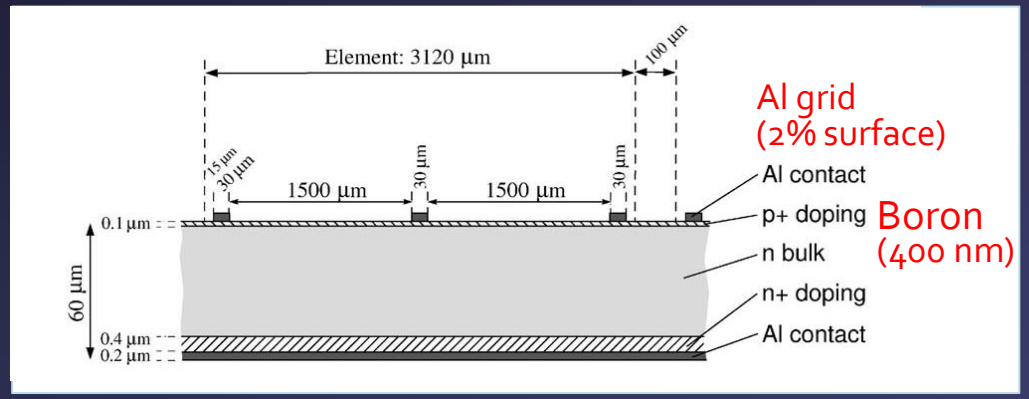
^{6}Li(n,©) @ PF1B (cold neutrons, 2 x 10^8 flux)

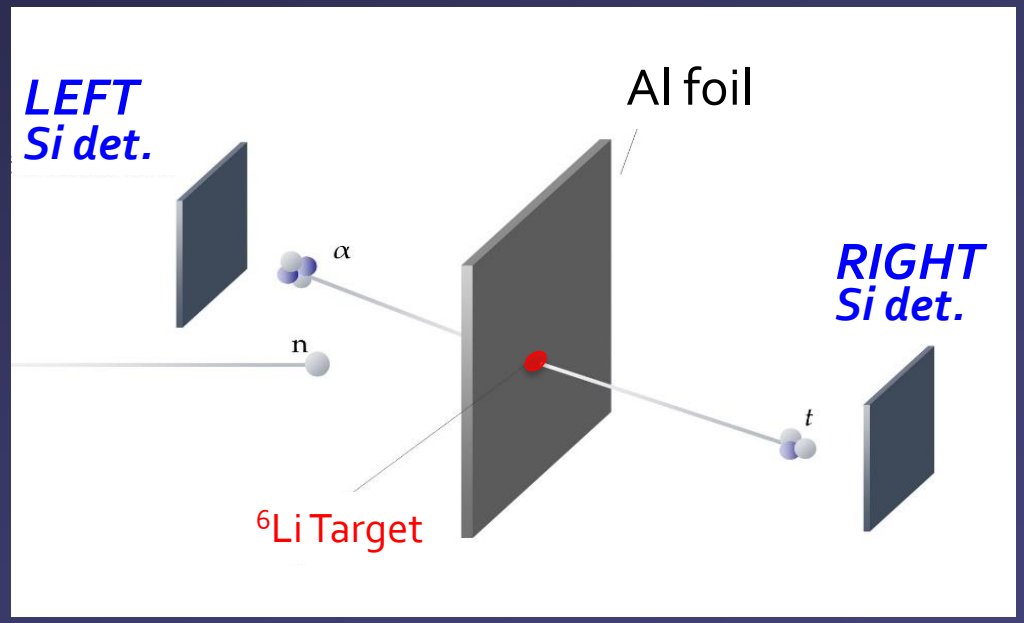
γ spectrum from full kinematic reconstruction

Double-Sided
Si Strip Detector
MICRON

16 strips X
16 strips Y







Special detector design:

the **Al contact** is a **grid** to reduce dead-layers

35 keV energy resolution

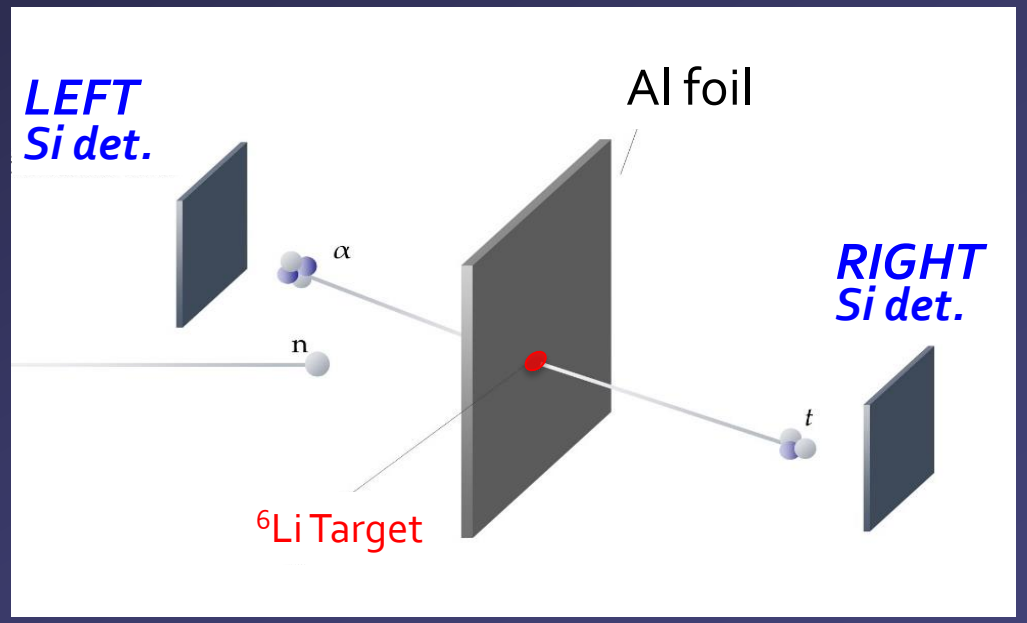
O. Tenblad, H. Fynbo, …, NIMA525 (2004) 458

^{6}Li(n,©) @ PF1B (cold neutrons, 2 x 10^{8} flux)

γ spectrum from full kinematic reconstruction

20 days of data taking

- **CALIBRATION:** Left and Right detector (16 X,16 Y strips)
  ^{6}Li(n,γ) and ^{10}B(n,γ) reactions
- **DRIFT Corrections** over 20 days
- **Multiplicity = 4** (X,Y in each detector)
- **$E_X - E_Y = 0$** (+/- ΔE)
- **Momentum conservation** (α and t emitted at θ = 180°)
- **Reconstruction of α and t energy at break-up point**
  energy losses in Al foil, dead-layer
  $E_{min}(\alpha)$ =240 keV, E_{min}(t) = 320 keV



^{6}Li(n,©) @ PF1B (cold neutrons, 2 x 10^{8} flux)

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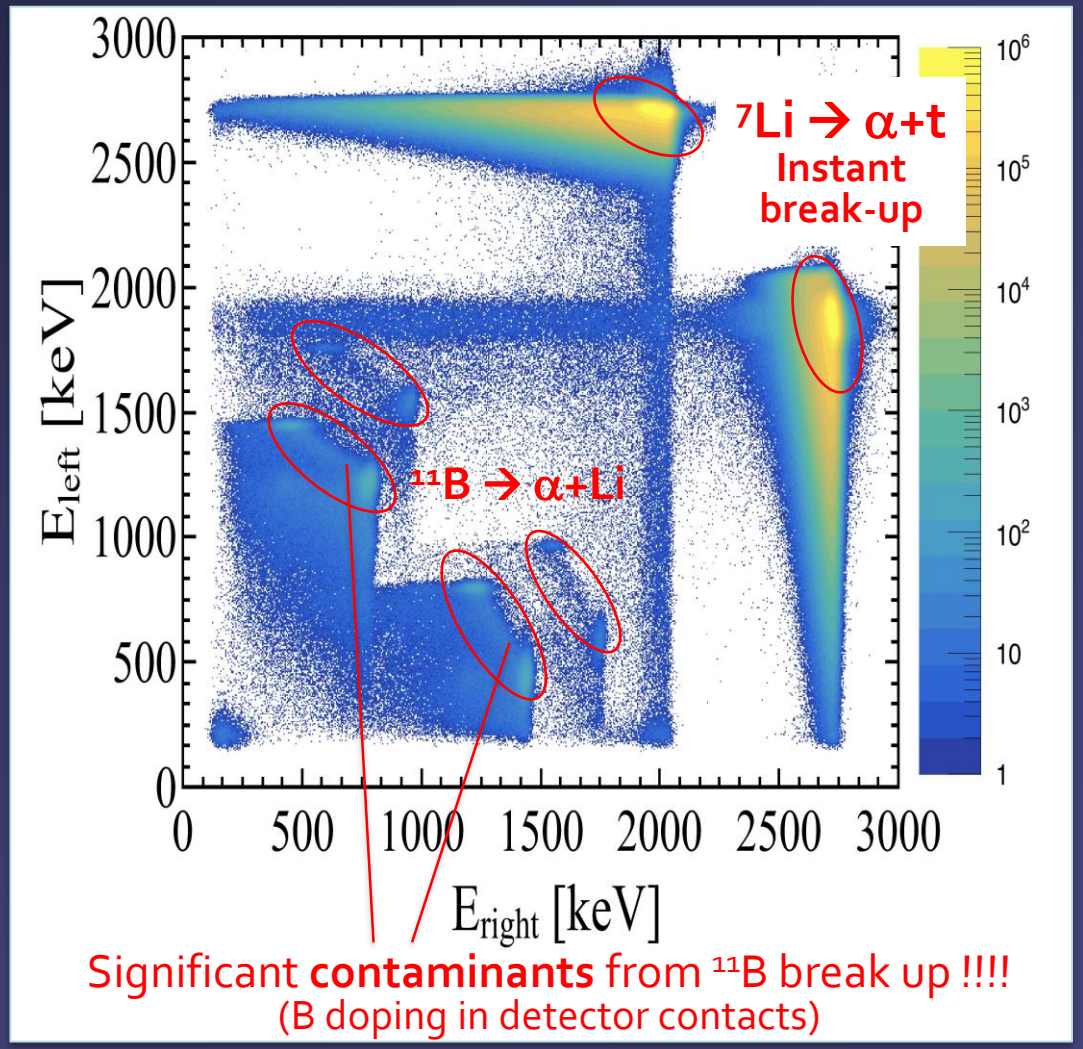
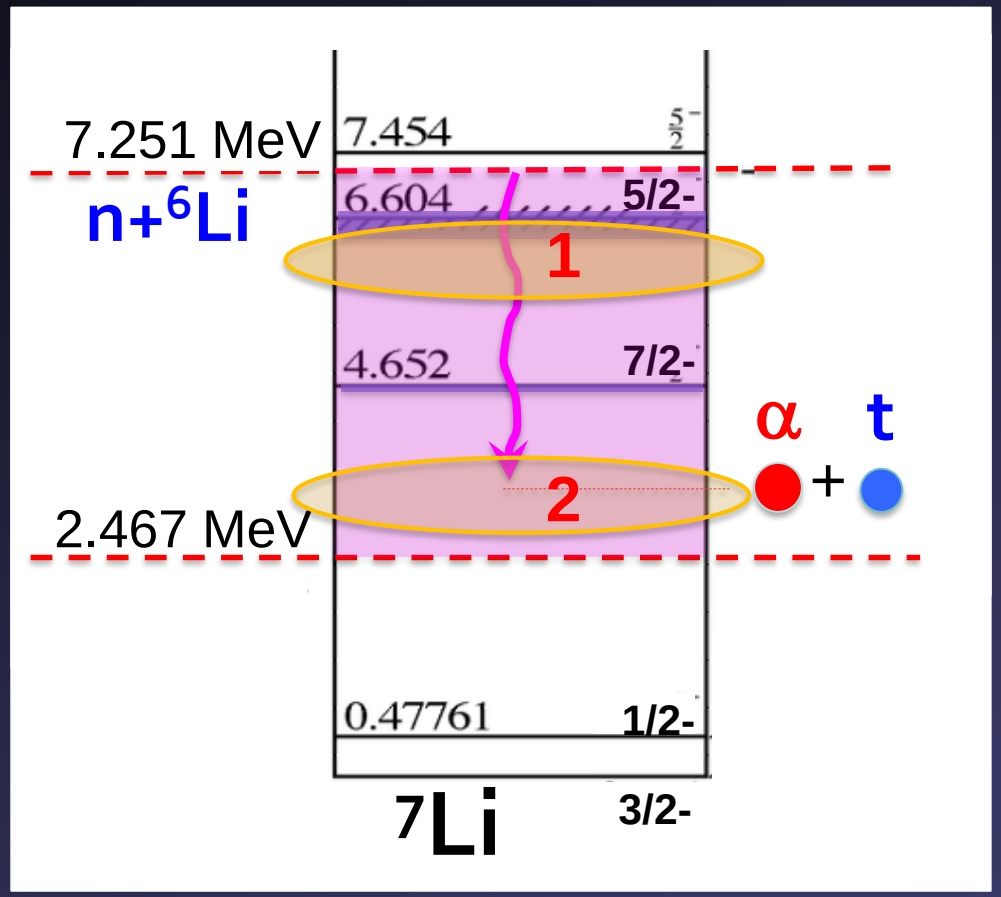
10^{9} α-t coincidence events



Significant **contaminants** from ^{11}B break up !!!!
(B doping in detector contacts)

^{6}Li(n,©) @ PF1B (cold neutrons, 2 x 10^8 flux)

γ spectrum from full kinematic reconstruction

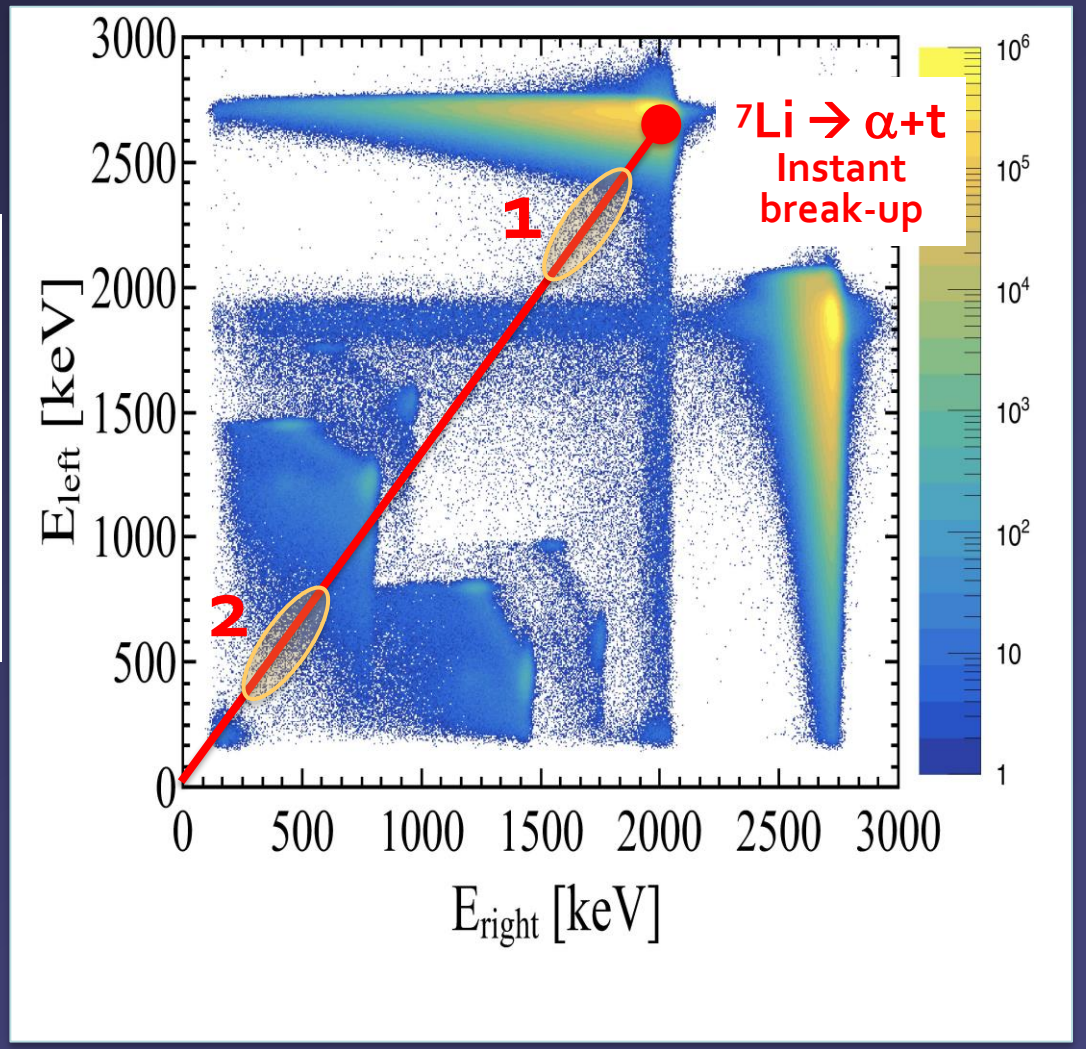


α – t

from

^{7}Li break-up

$E_t/E_\alpha = 4/3$



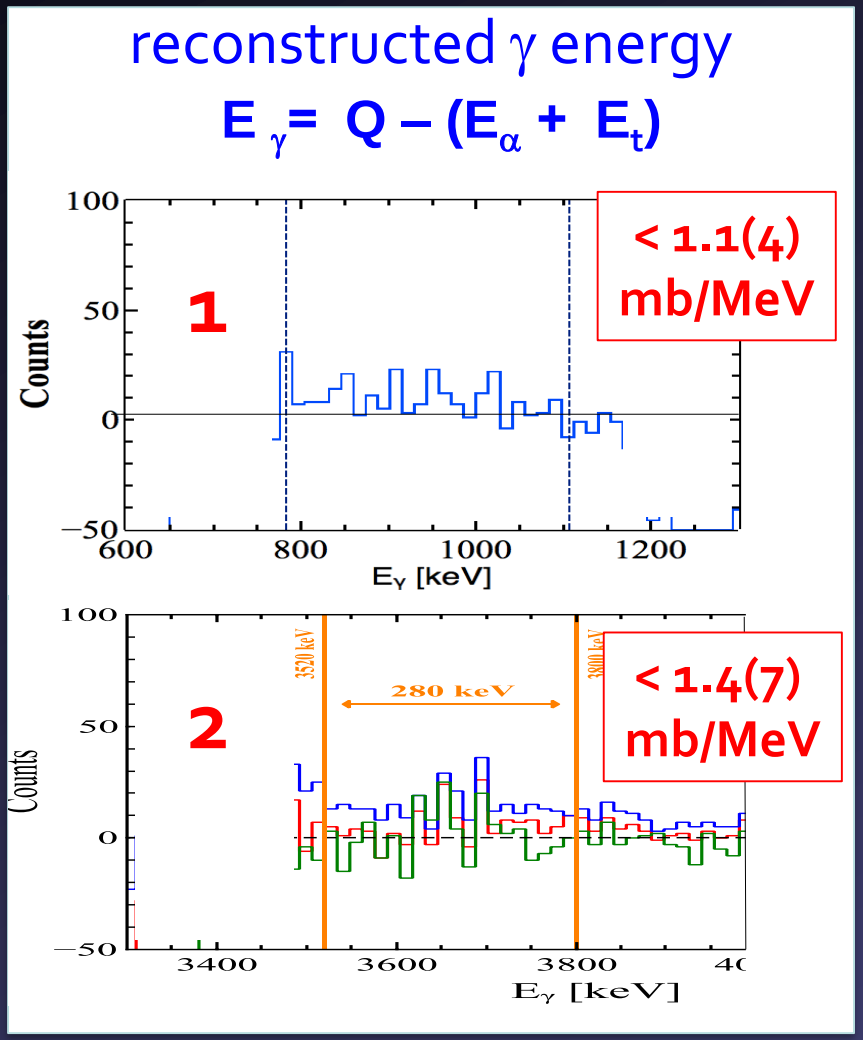
Two "clean" regions

^{6}Li(n,©) @ PF1B (cold neutrons, 2 x 10^{8} flux)

γ spectrum from full kinematic reconstruction

reconstructed γ energy

$E_\gamma = Q - (E_\alpha + E_t)$

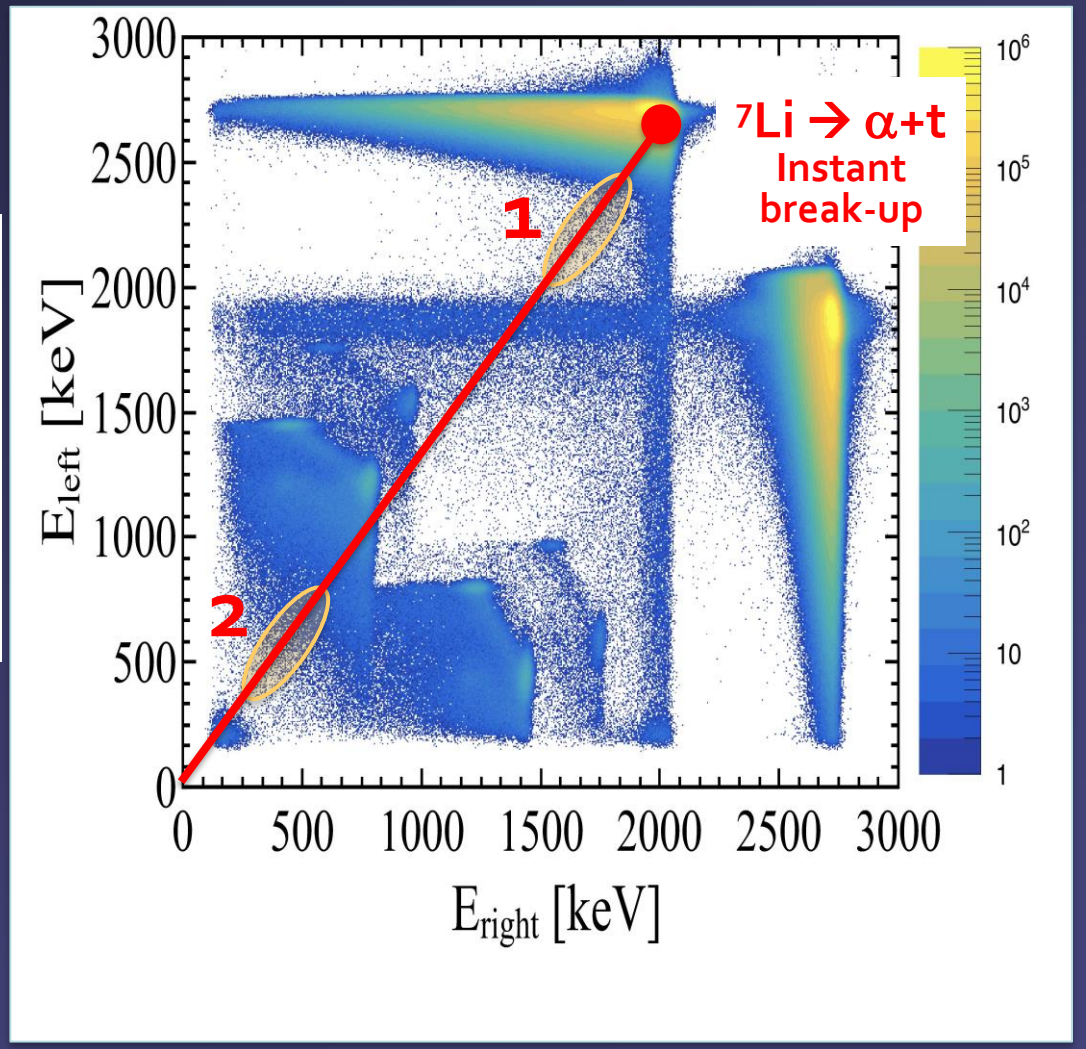


α – t

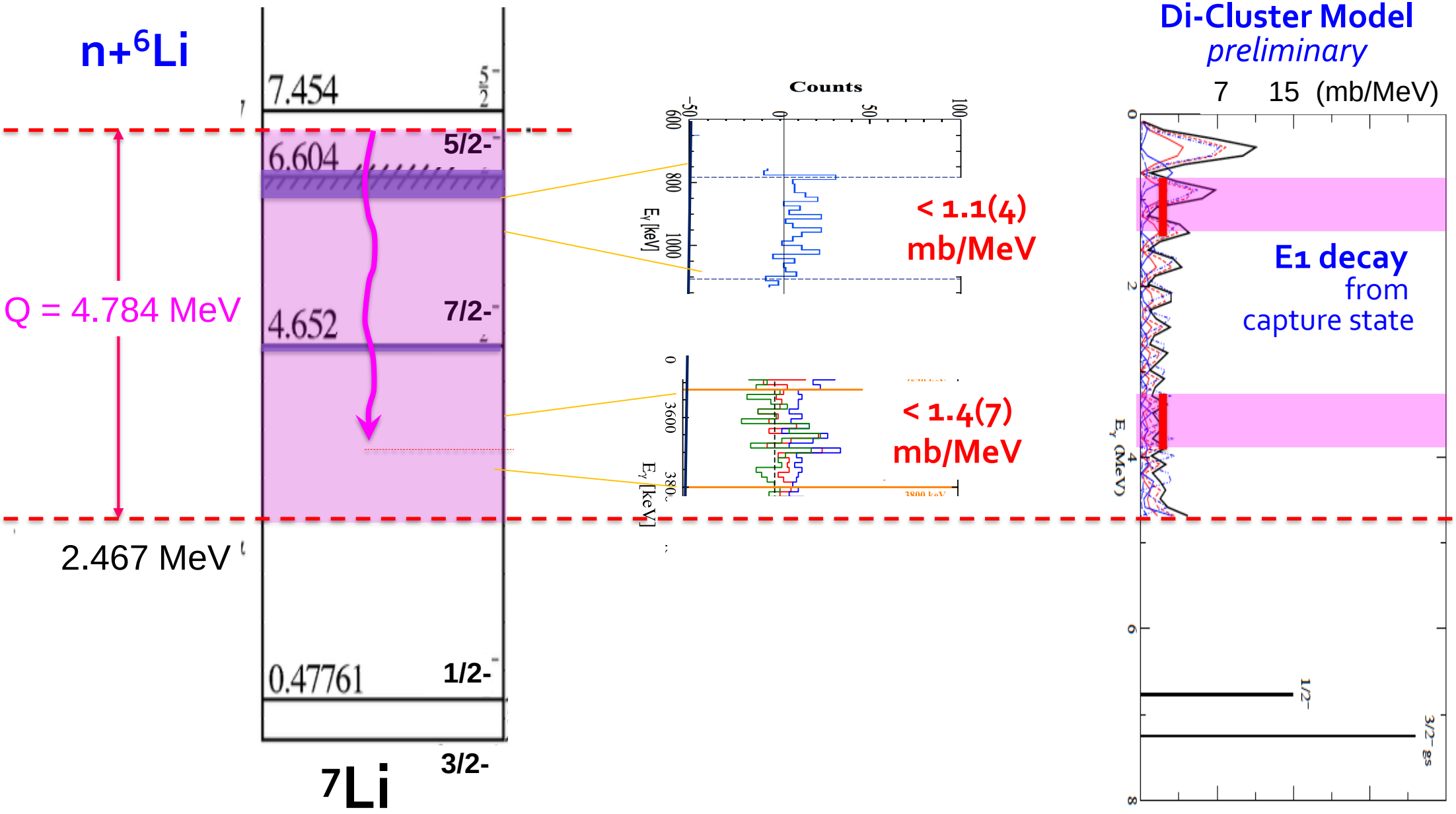
from

^{7}Li break-up

$E_t/E_\alpha = 4/3$



γ decay of ^{7}Li in the continuum - reconstructed



L. Fortunato, A. Vitturi – Padova Univ.

CONCLUSIONS

- We have studied the decay of the neutron capture state in ^{7}Li by measuring the break up products α and t

- We have reconstructed the γ–ray energy spectrum in the continuum

- We have obtained the upper limit for γ-decay cross sections of

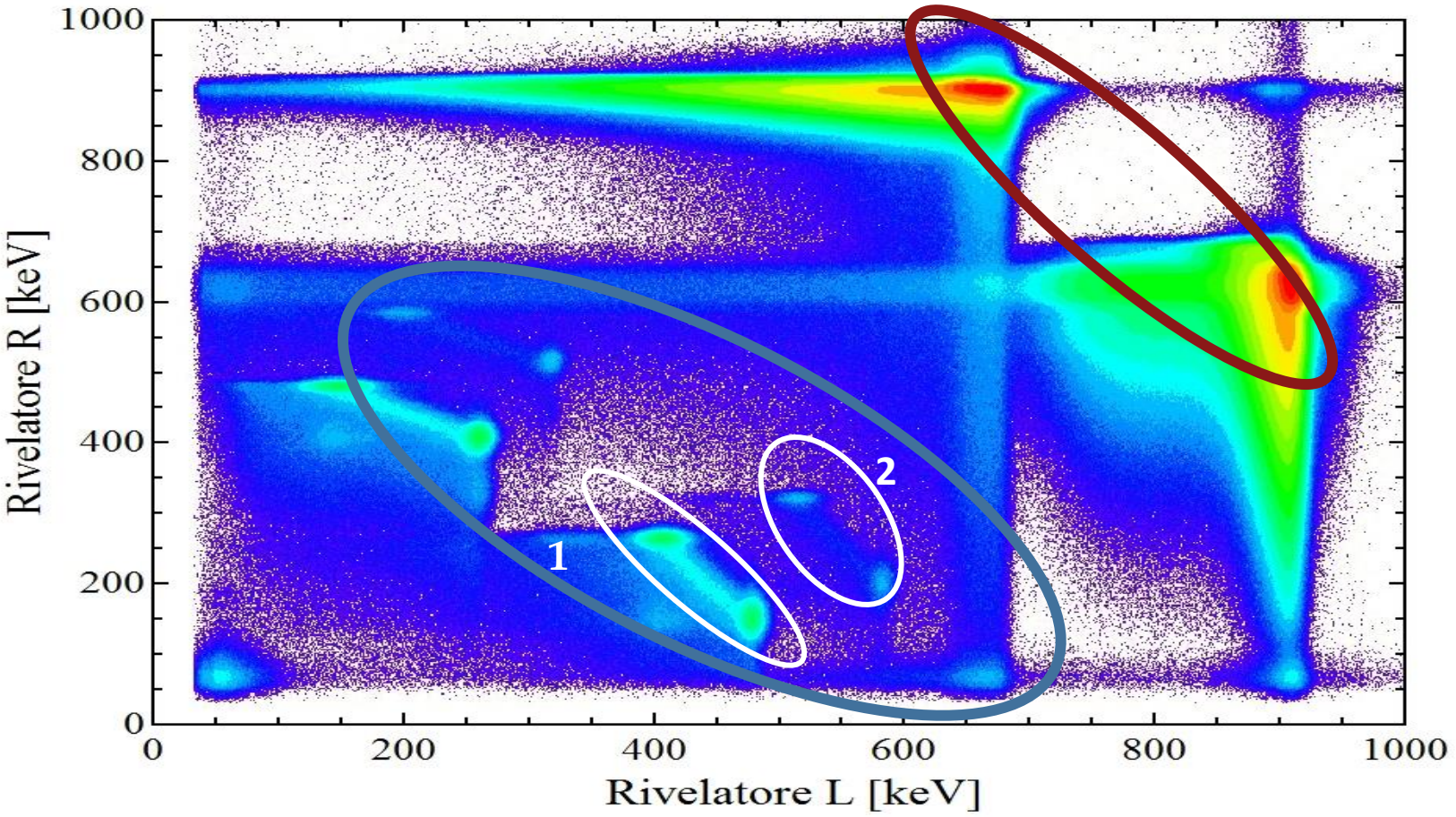
  $< 1.1(4)$ mb/MeV for $0.8 < E_\gamma < 1.1$ MeV
  $< 1.4(7)$ mb/MeV for $3.5 < E_\gamma < 3.8$ MeV

- Preliminary comparison with Di-Cluster model

→ *New measurement with increased precision is planned in 2018*

Thank you for the attention

Matrice di correlazione delle energie rivelate



$^{7}Li \rightarrow \alpha$, t

$^{11}B \rightarrow 7Li$, α

1 Branching 94%

2 Branching 6%

Nucleo	Probabilità	Prodotto di decadimento	Energia (keV)
11B	6%	7Li	1014
		α	1775
	94%	7Li	840
		α	1471
7Li		α	2050
		t	2733

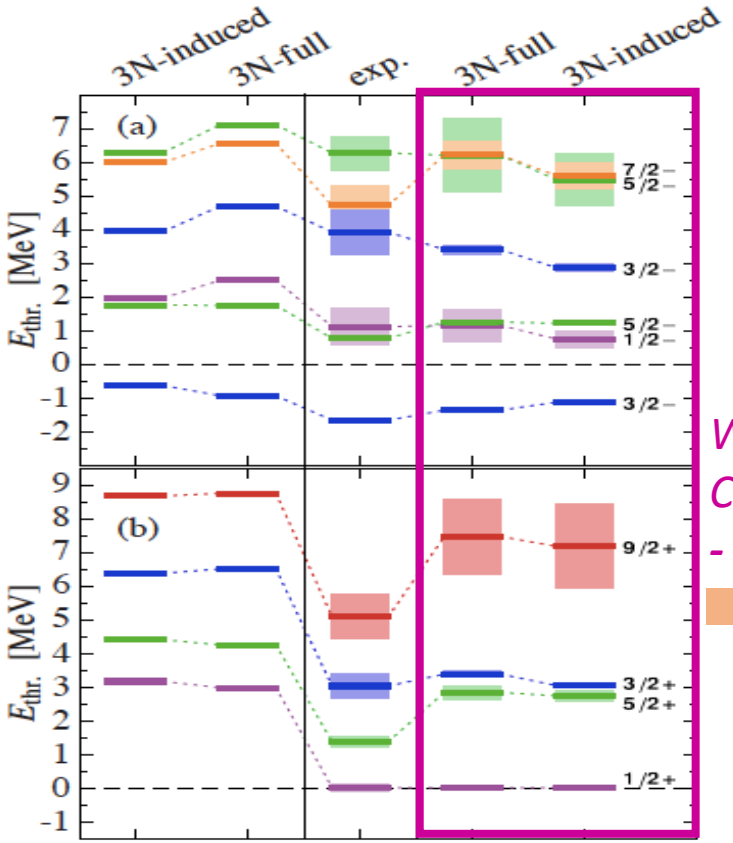
Physics Case: N-rich Be isotopes

No Core SHELL model with Continuum (NCSMC)

***UNIFIED ab-initio Theory**: Nuclear Structure and Reactions*

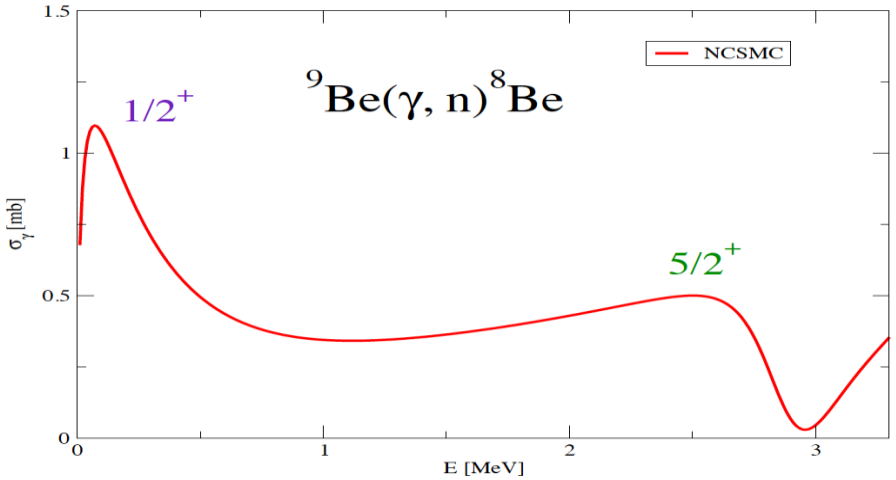
P. Navratil and S. Quaglioni, …

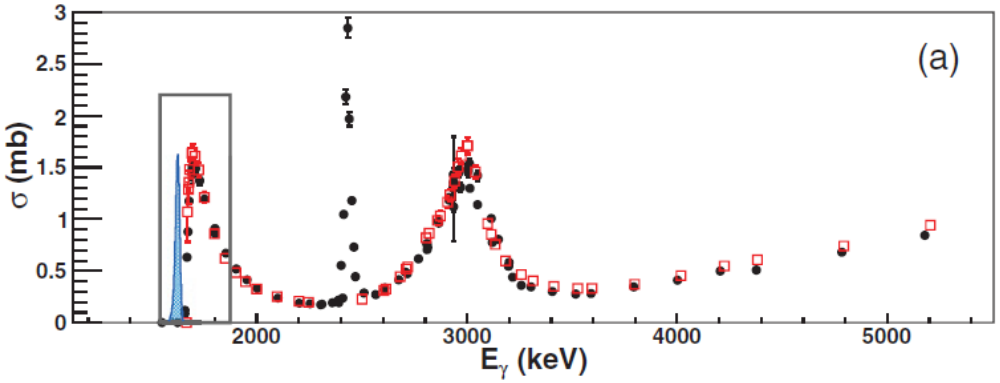
^{9}Be



With Continuum:
- ***Energy***
- ***Width***

Energy spectrum (with NNN force)





Cross section of E1 excitation:

Partial gamma width $\Gamma_\gamma \approx 1$ eV

→ *In agreement with (γ,n) DATA from Hiγs*