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

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NuSPRASEN
Nuclear Structure Physics, Reactions, Astrophysics and Superheavy Elements Network

INTRODUCTION

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

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

Among Most Pressing Open questions …

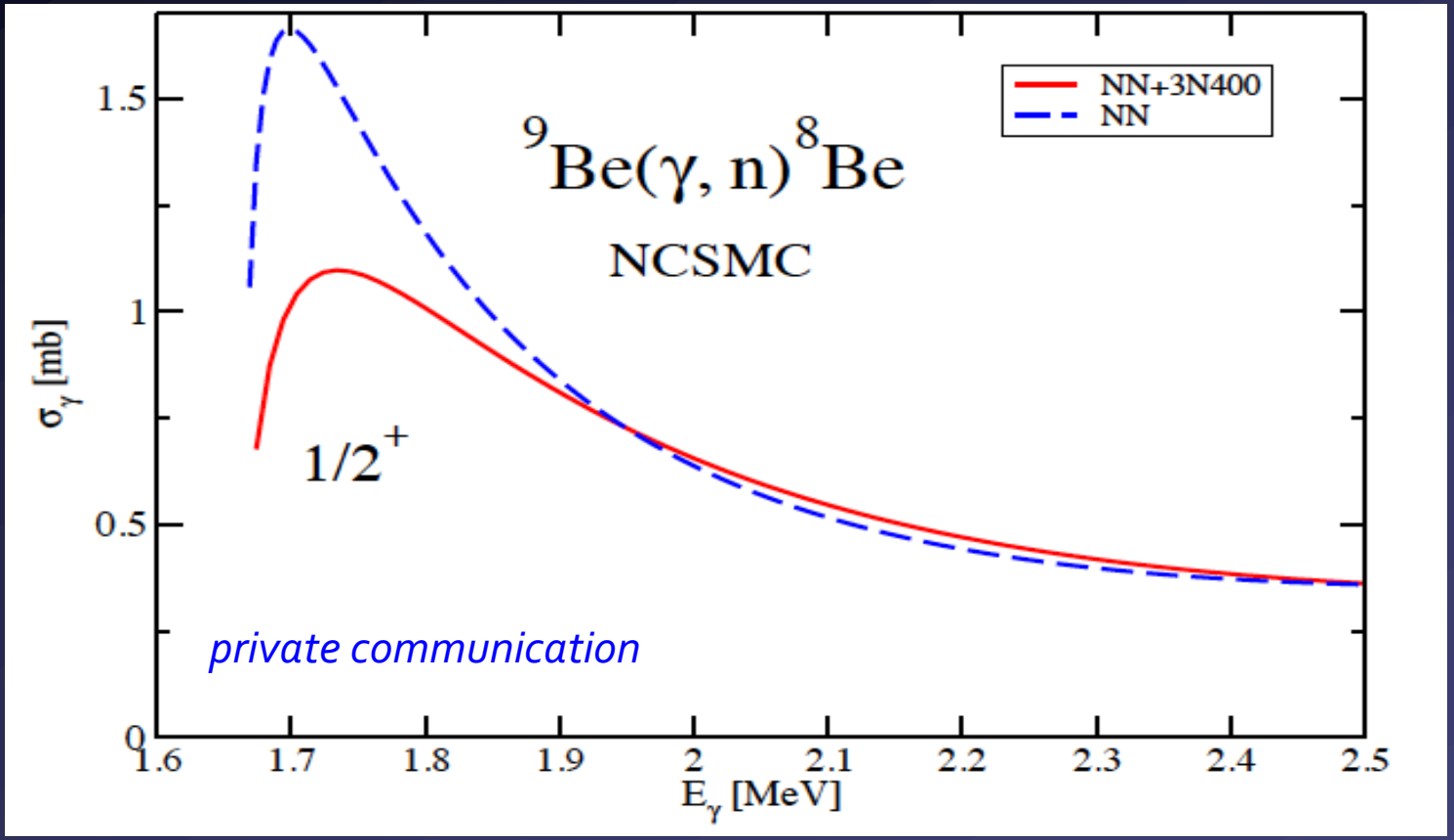
- Can we understand the NATURE of the CONTINUUM ?
  (continuum spectrum of scattering states and resonances above particle threshold …)
- Broad resonances and/or NON-resonant continuum ?

State-of-the-art *ab-initio* calculations for states in the continuum

(P. Navratil, S. Quaglioni)

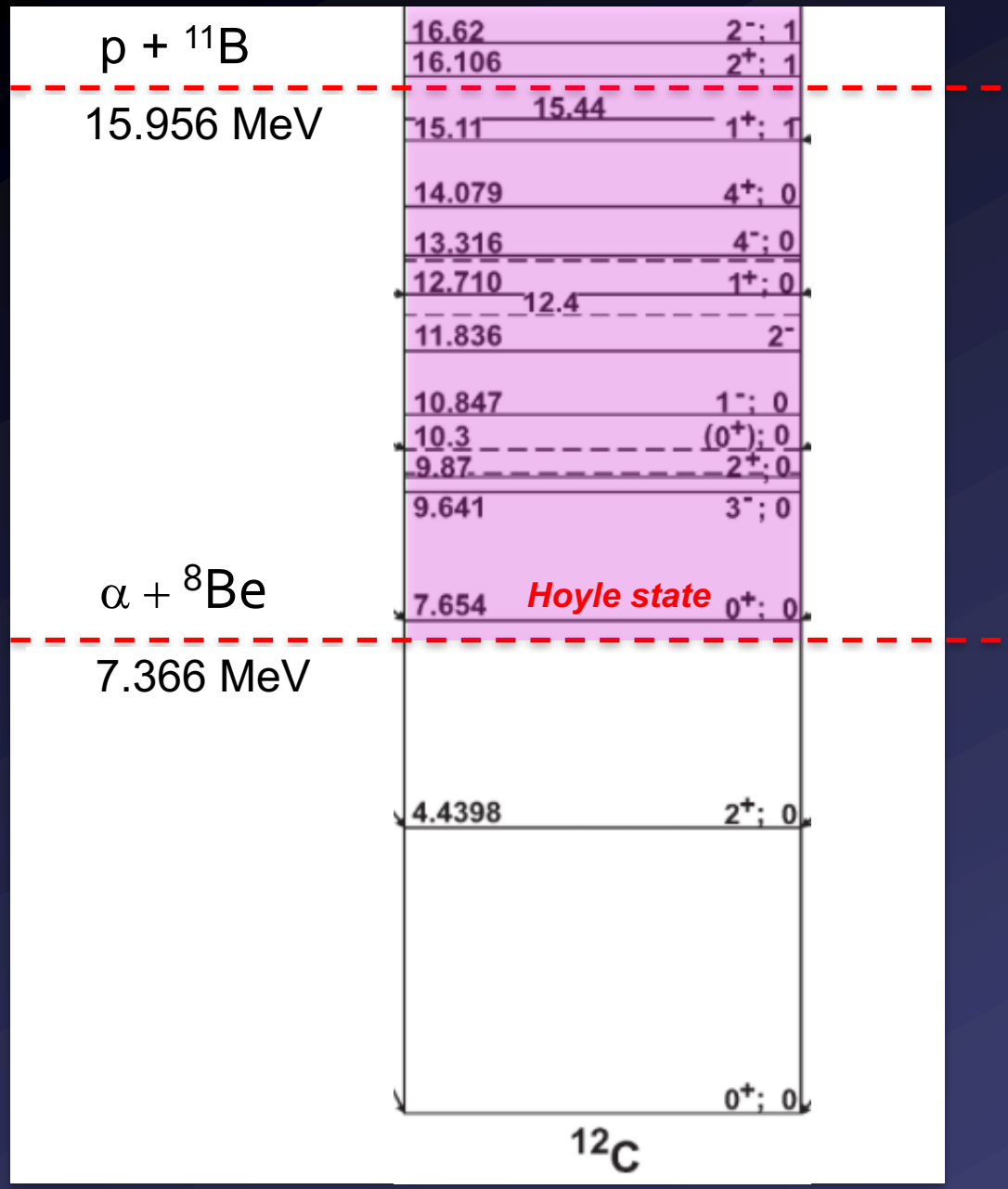
No Core SHELL model with Continuum (NCSMC)

UNIFIED ab-initio Theory: Nuclear Structure and Reactions



strong sensitivity
to the nuclear force !!!

^{12}C – the most studied case …

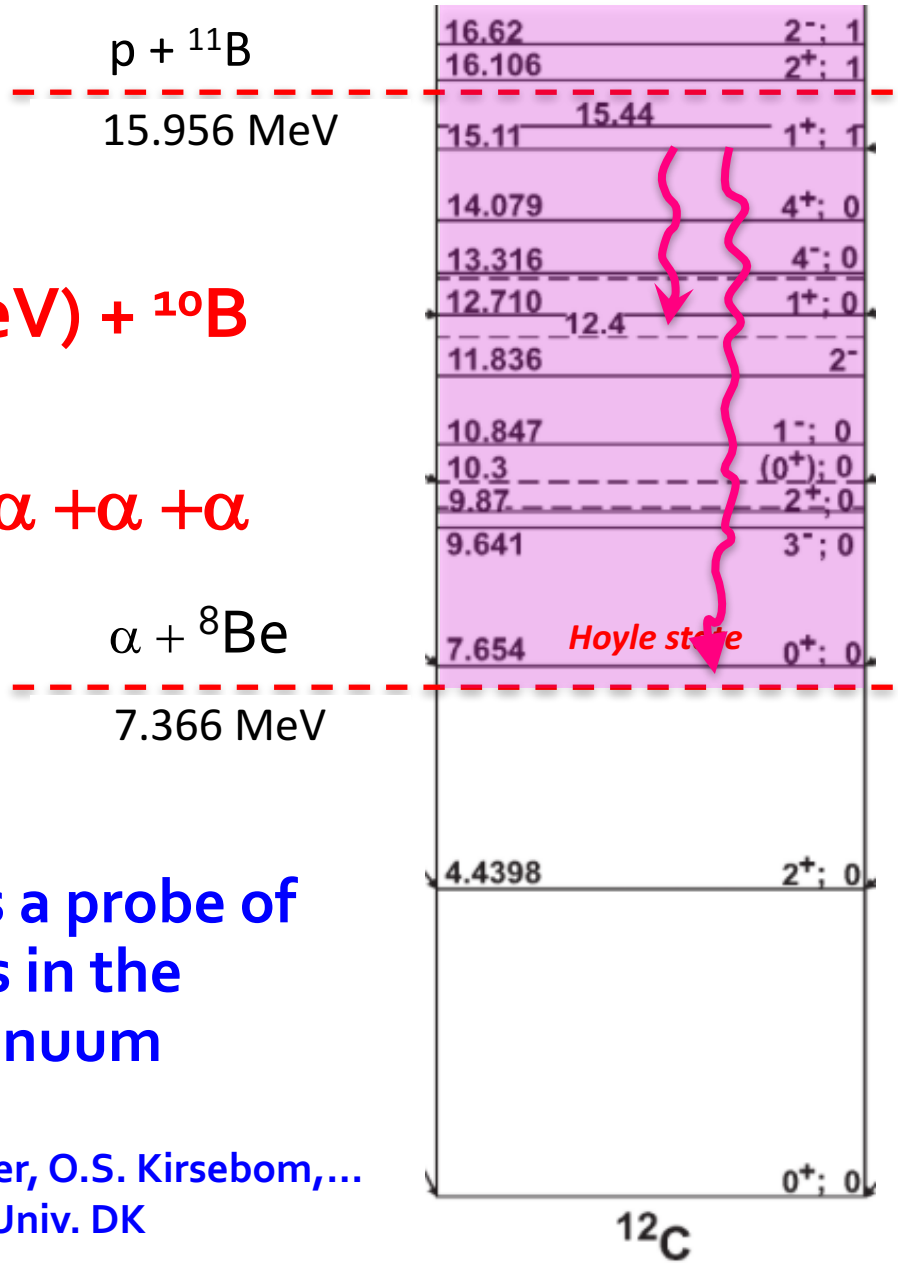


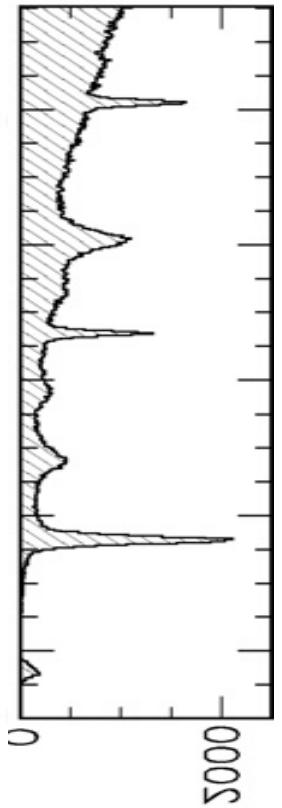
Experimental information

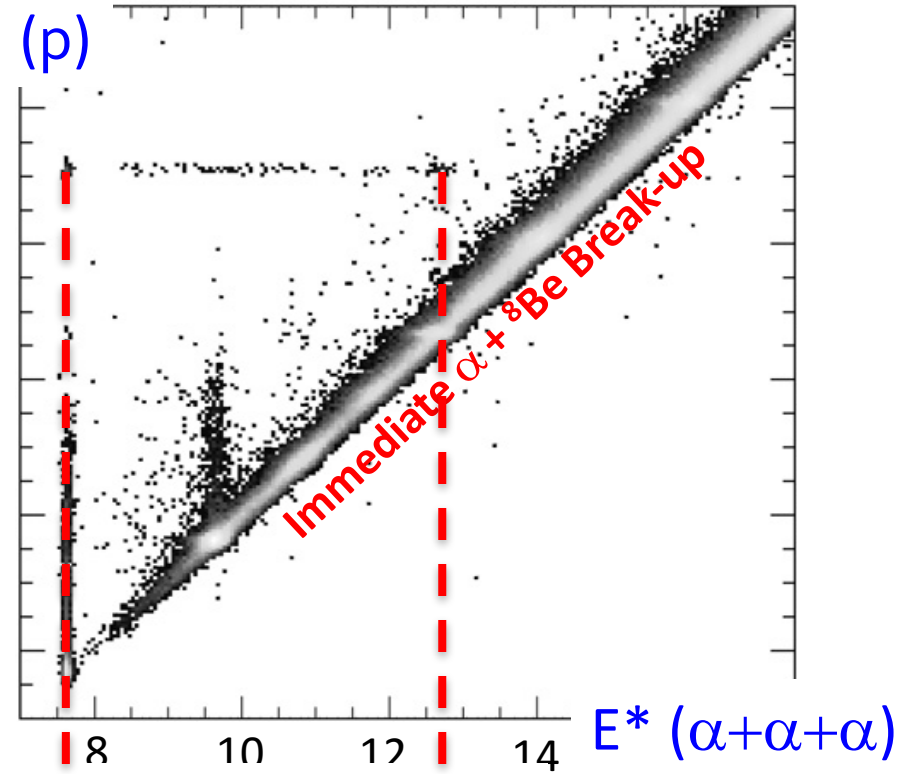
- very <u>complex spectrum</u> of resonances …
- almost entirely from <u>particle detection</u>
- <u>γ detection</u> is very challenging (10^{-5}-10^{-6} branches)
  → very important to have a *complete picture*
  → it is a *different probe* …

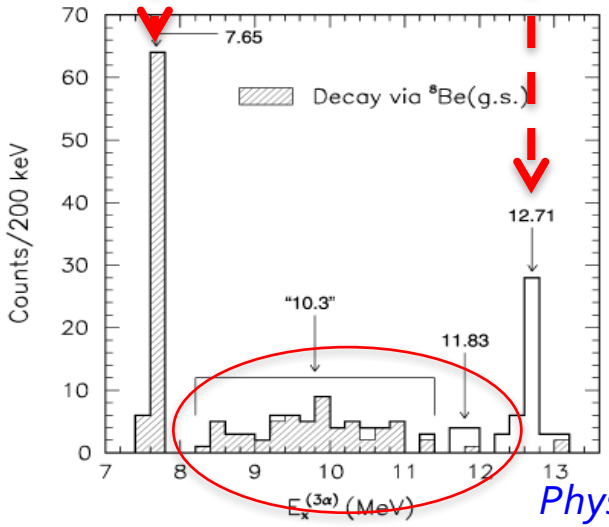
γ decay in the continuum reconstructed from particle detection

^{3}He (4.9 MeV) + ^{10}B
→ p + ^{12}C
↳ α +α +α









Broad distribution not clearly related to known resonace states

γ decay as a probe of states in the continuum

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

Phys. Lett. B680 (2009) 44

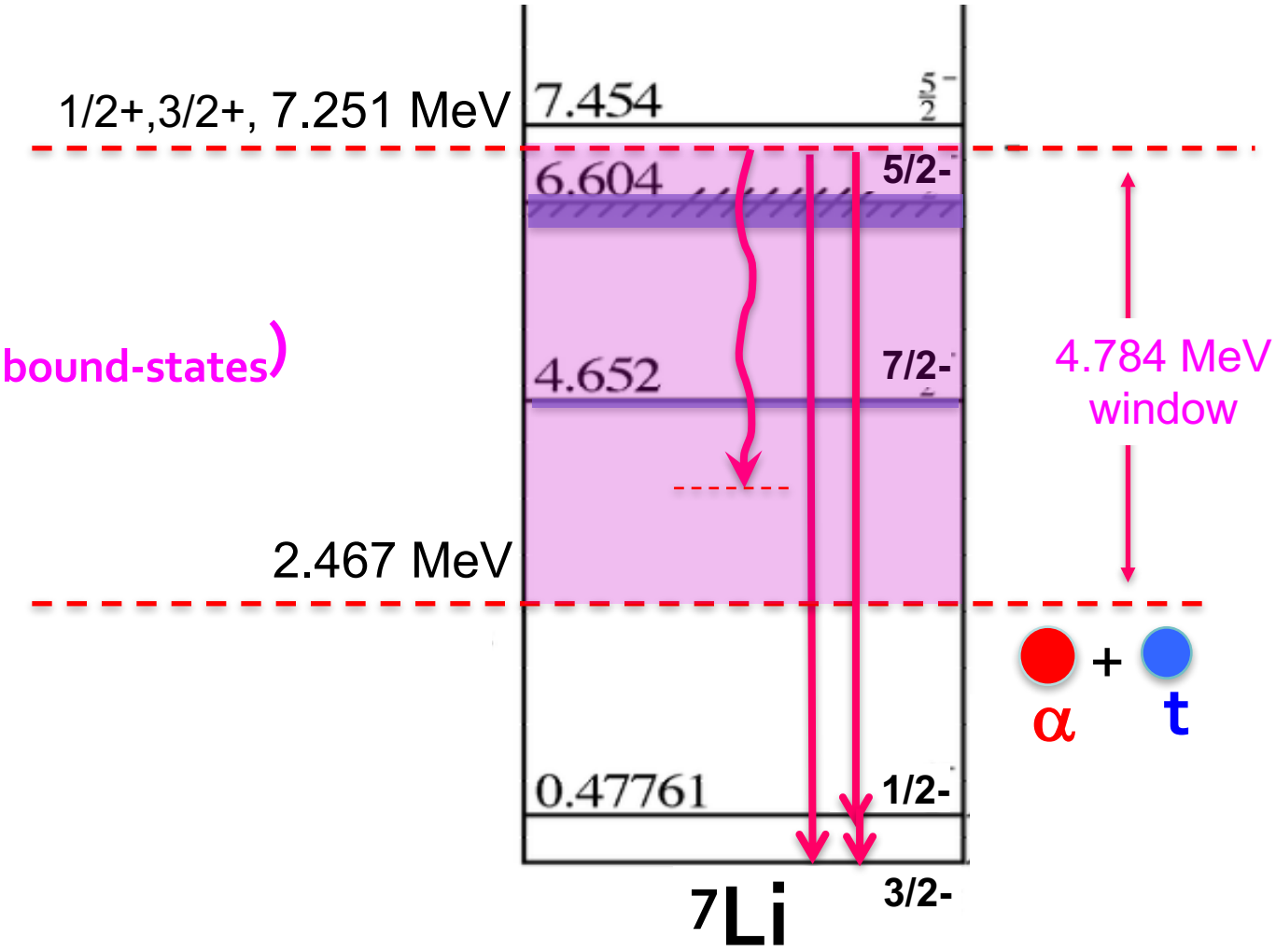
Looking for another/simpler case for γ decay in the continuum

… to learn about
resonant and NON – resonant contribution

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

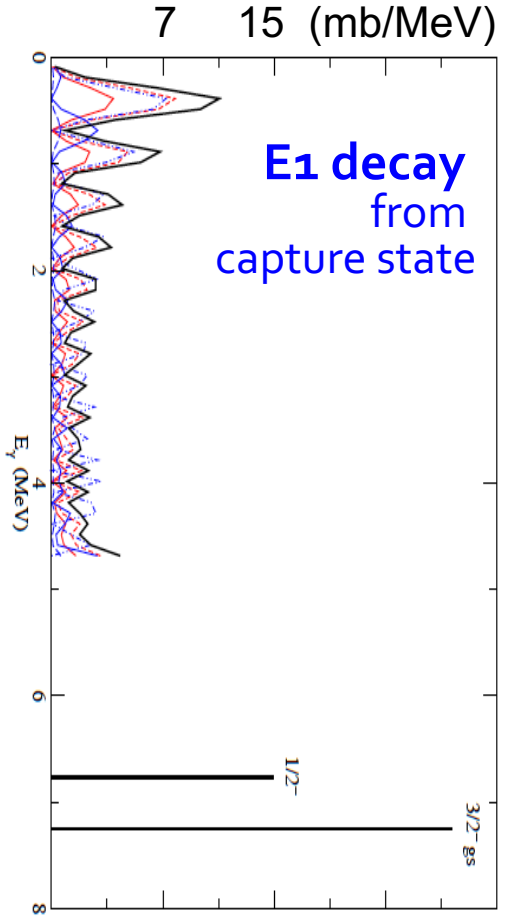
n+^{6}Li
σ = 940 b

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



Di-Cluster Model

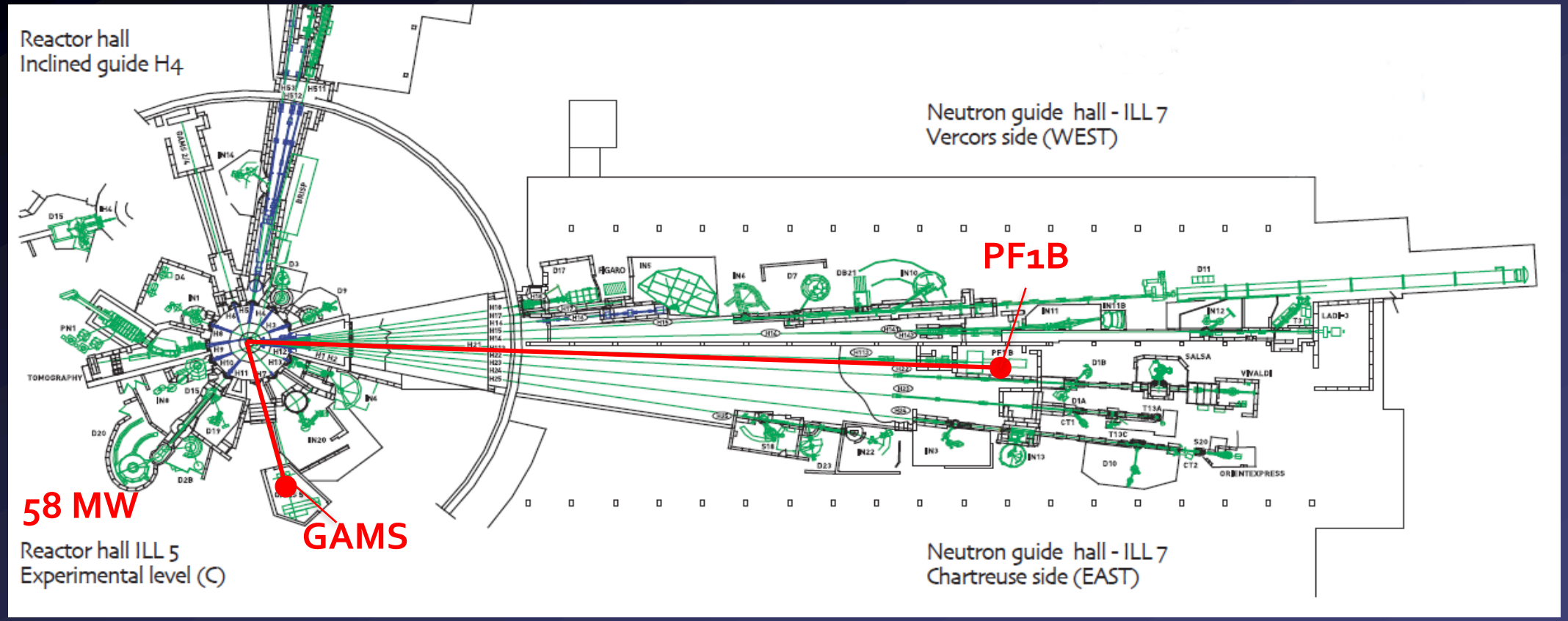
^{7}Li = α + t



L. Fortunato, A. Vitturi – Padova Univ.

→ *ab-initio* predictions in the future (P. Navratil and S. Quaglioni)

The experiments @ ILL-Reactor (GRENOBLE)



MOST INTENSE
Continuum neutron source

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

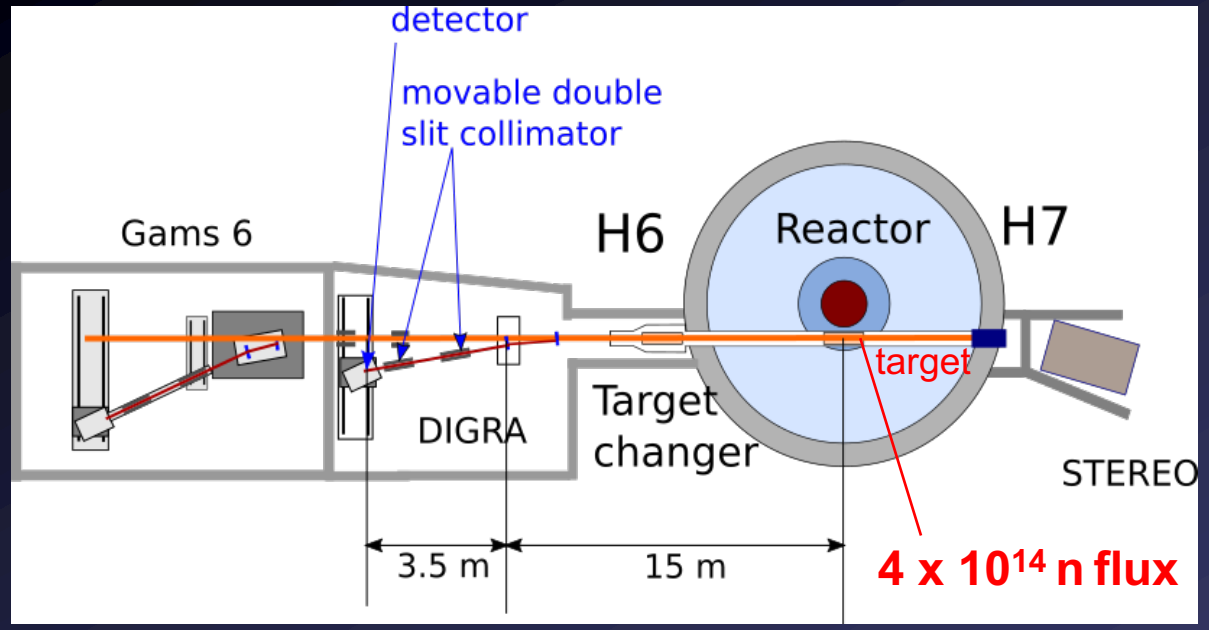
collimated $\Phi_n = 2 \times 10^{8}$ n cm^{-2} s^{-1}

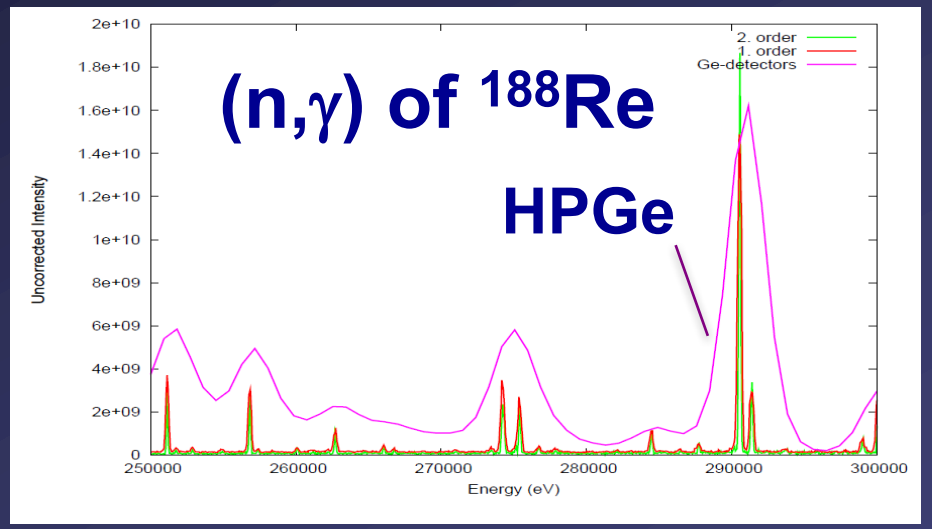
^{6}Li(n,γ)

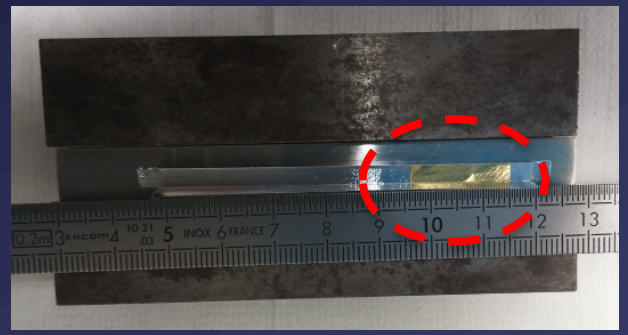
1. GAMS beam line (thermal n) – Dec. 2015
2. PF1B beam line (cold n) – Feb. 2017

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

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





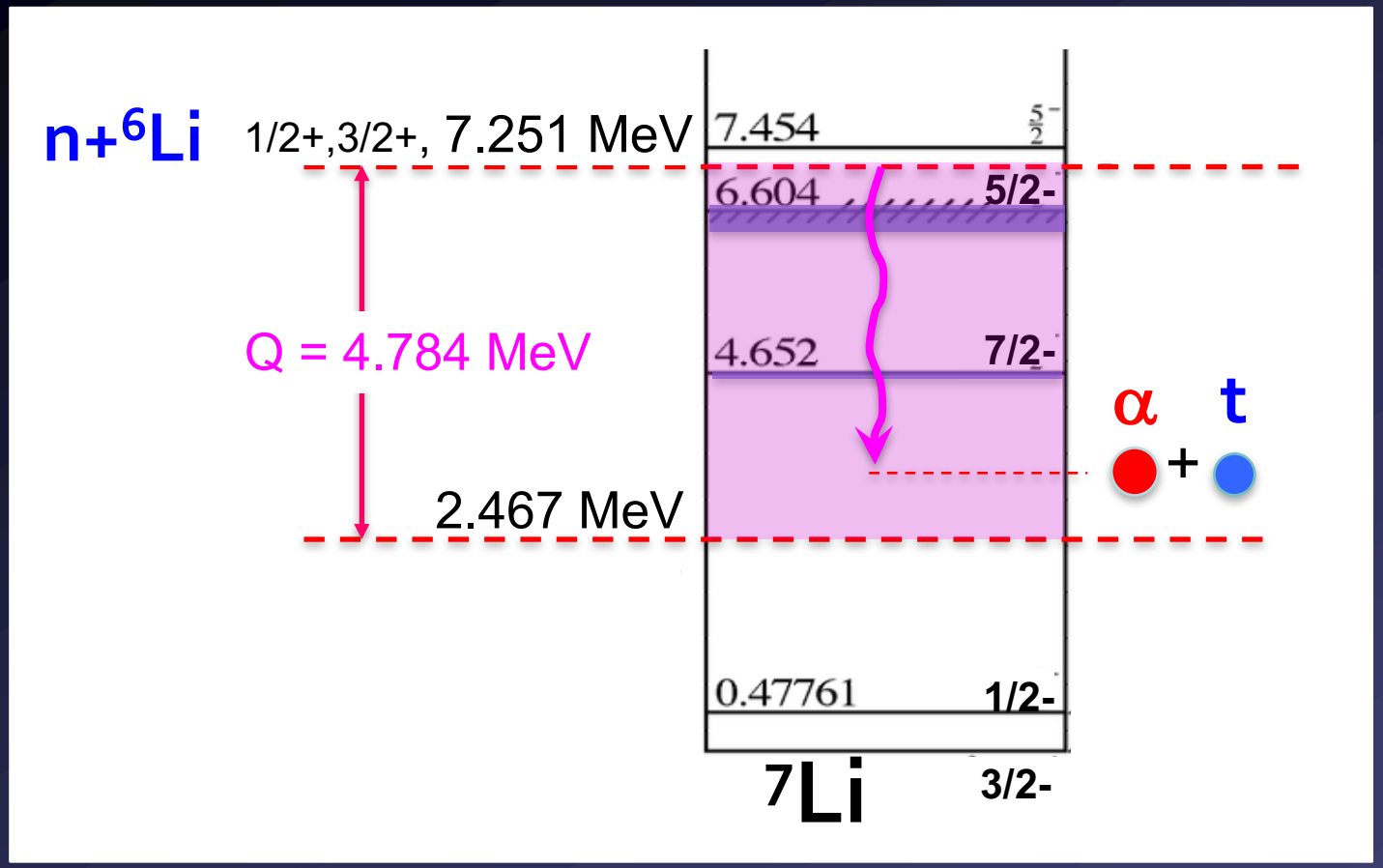


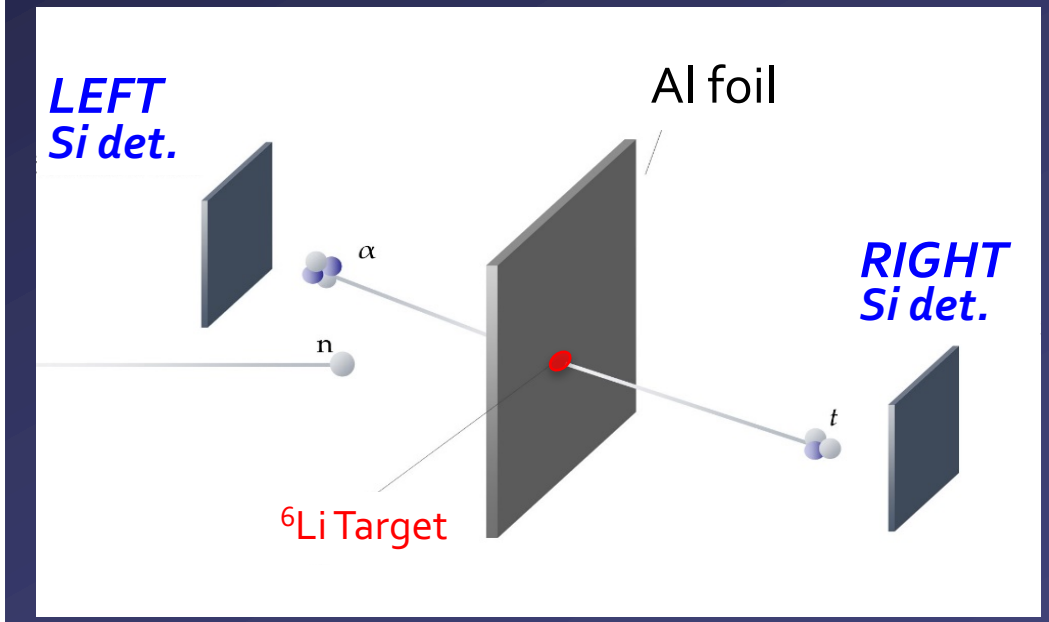
Test of background in the region above 2.5 MeV
with a Au target (weak high energy lines as a benchmark)

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

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

γ spectrum from full kinematic reconstruction





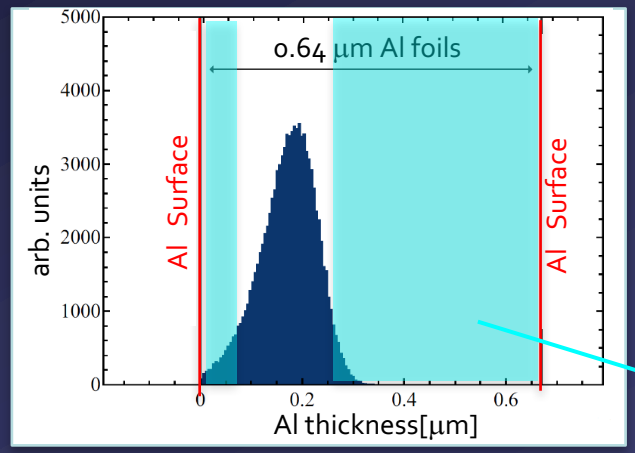
$$E_\gamma = Q - (E_\alpha + E_t)$$

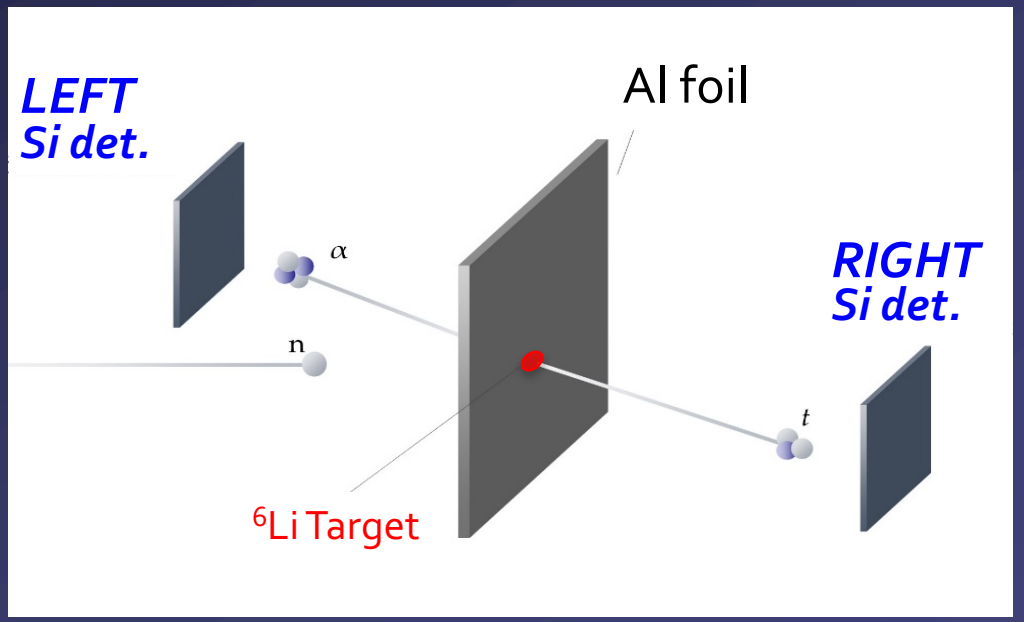
^{6}Li(n,γ) @ PF1B (cold neutrons, 2 x 10^{8} flux)

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, …

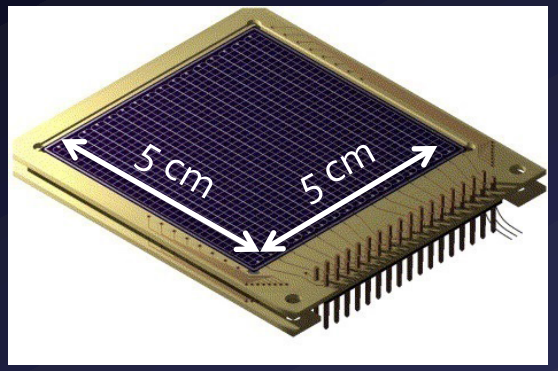
R. Heinke - Univ. Mainz : ^{6}Li (30 keV) + Al

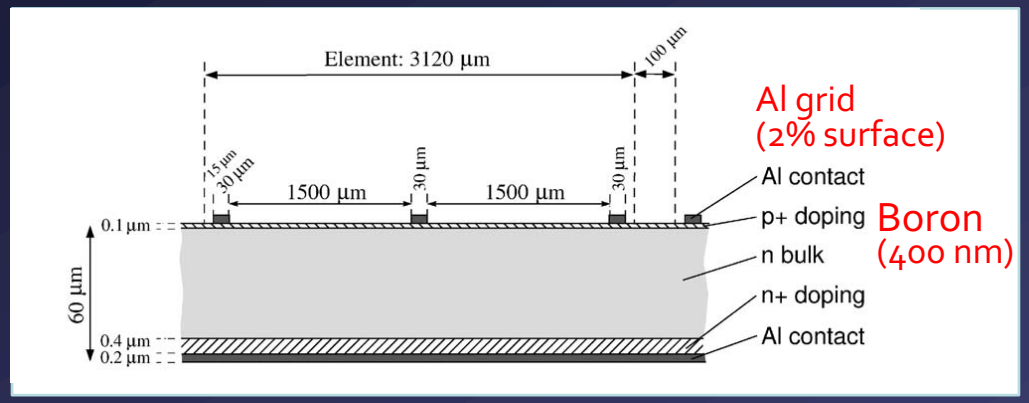
^{6}Li(n,γ) @ PF1B (cold neutrons, 2 x 10^8 flux)

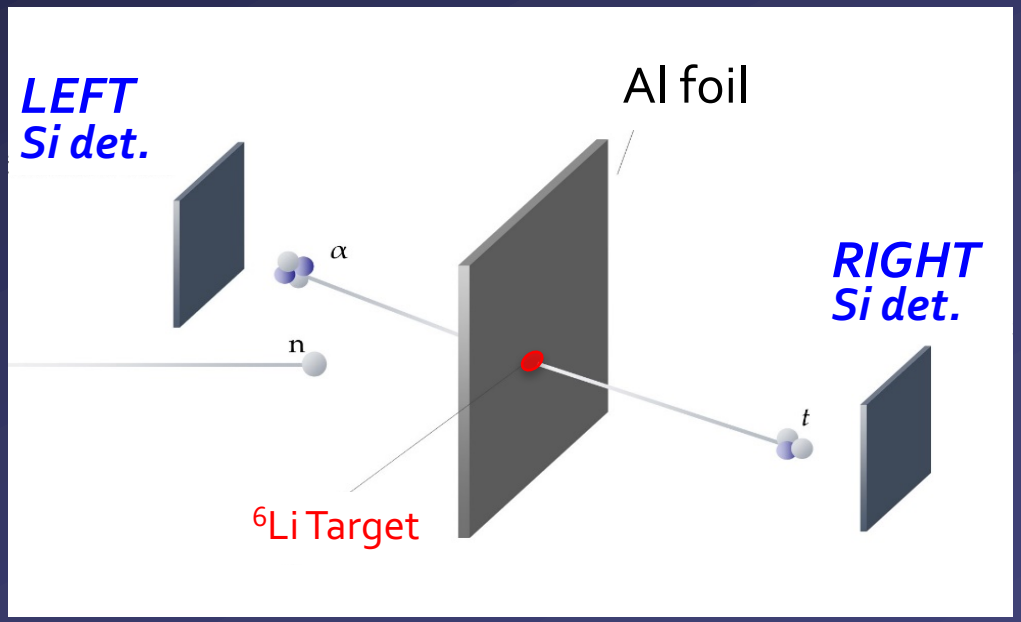
γ spectrum from full kinematic reconstruction

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

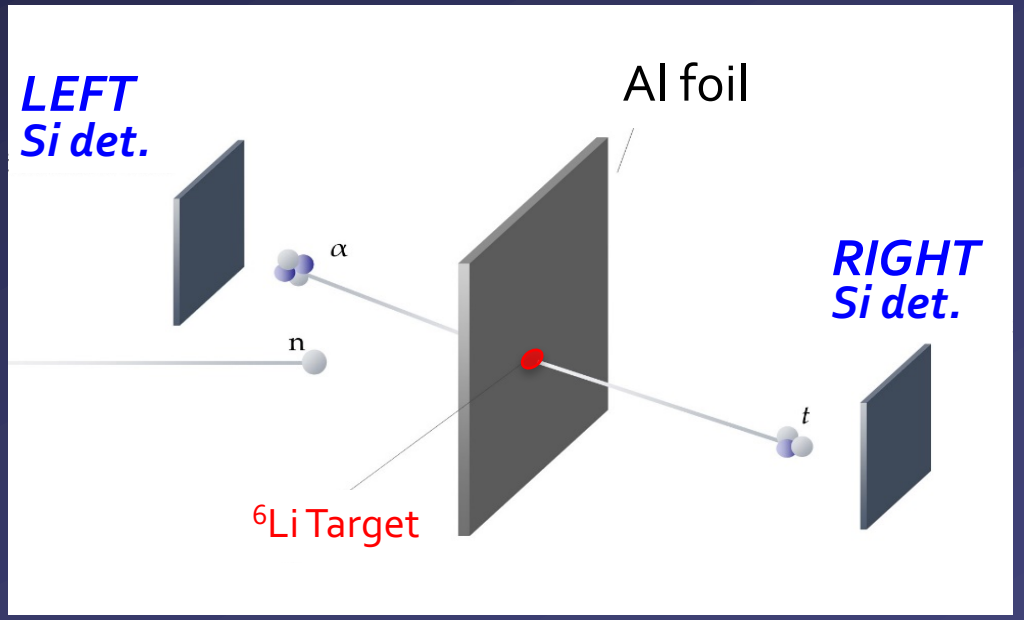
O. Tenblad, H. Fynbo, …, NIMA525 (2004) 458

$^{6}Li(n,\gamma)$ @ 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)
  $^{6}Li(n,\gamma)$ and $^{10}B(n,\gamma)$ 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



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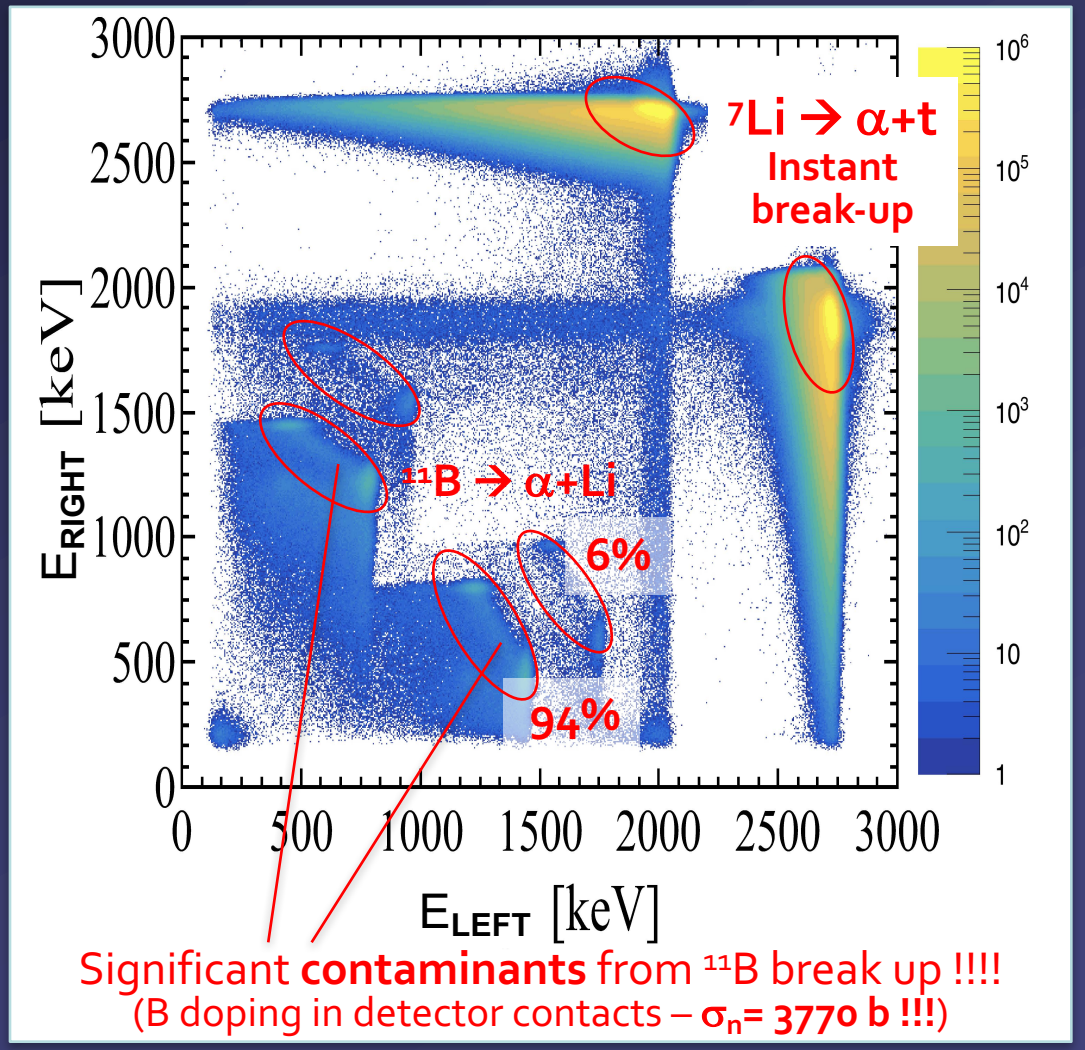
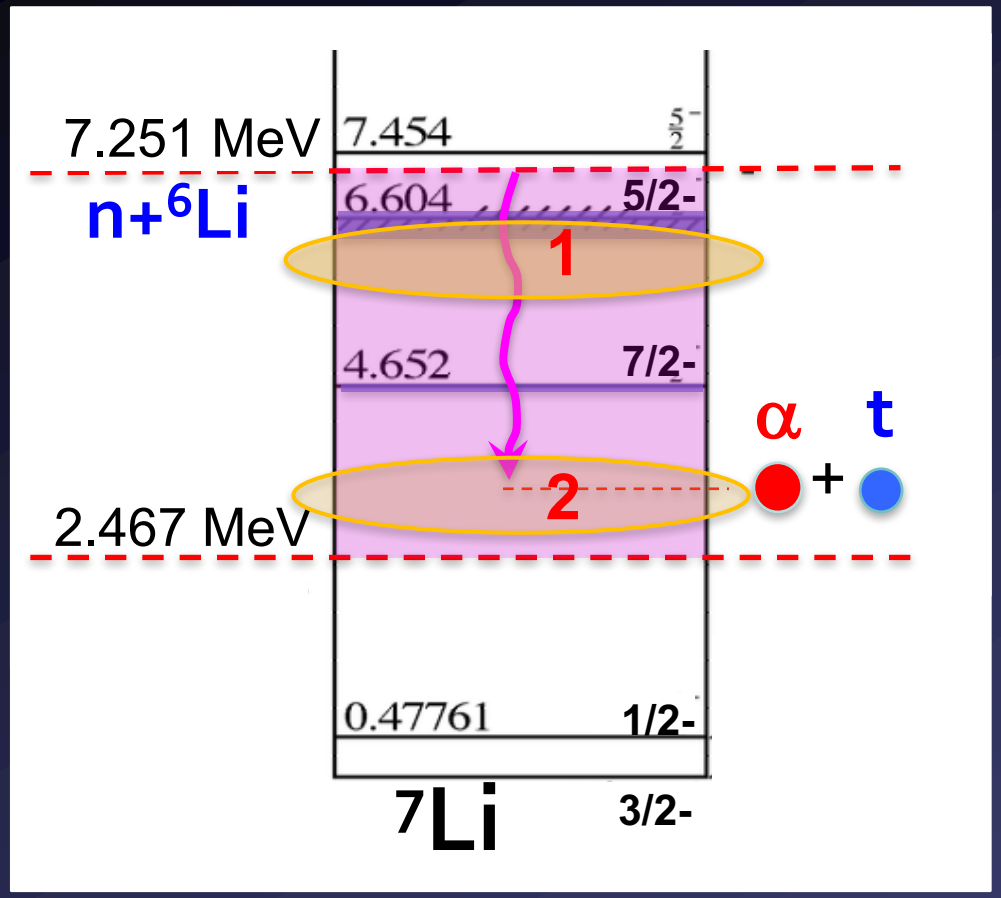
10^{9} α-t coincidence events



Significant **contaminants** from ^{11}B break up !!!!
(B doping in detector contacts – **σ_n= 3770 b !!!**)

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

γ spectrum from full kinematic reconstruction

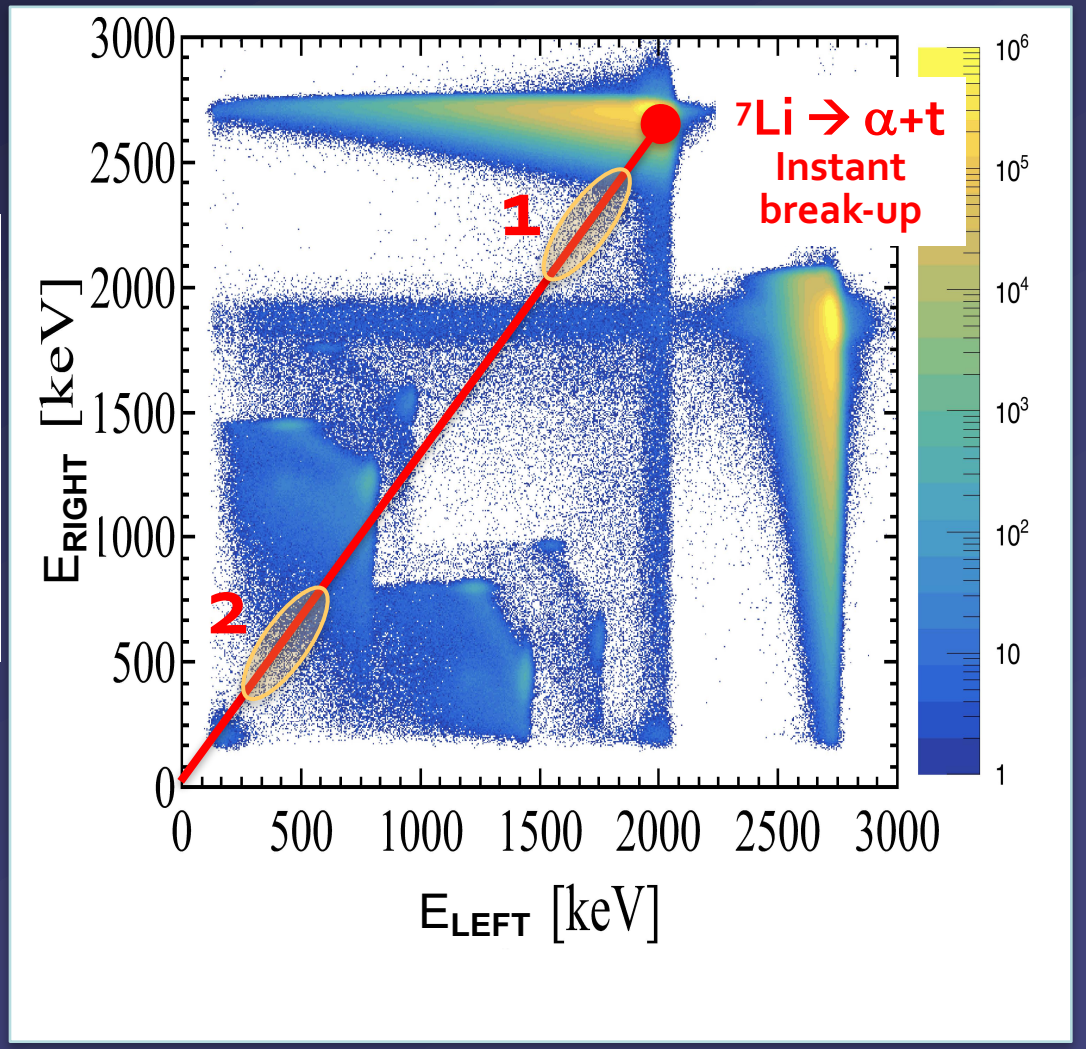


α – t

from

^{7}Li break-up

$E_t/E_\alpha = 4/3$



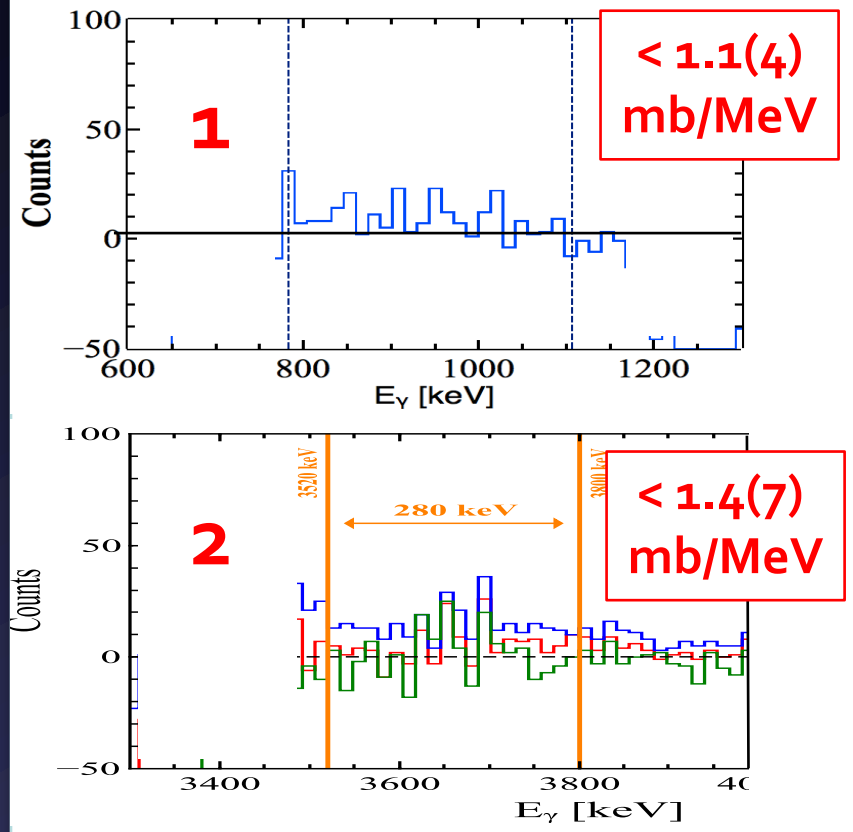
Two "clean" regions

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

γ spectrum from full kinematic reconstruction

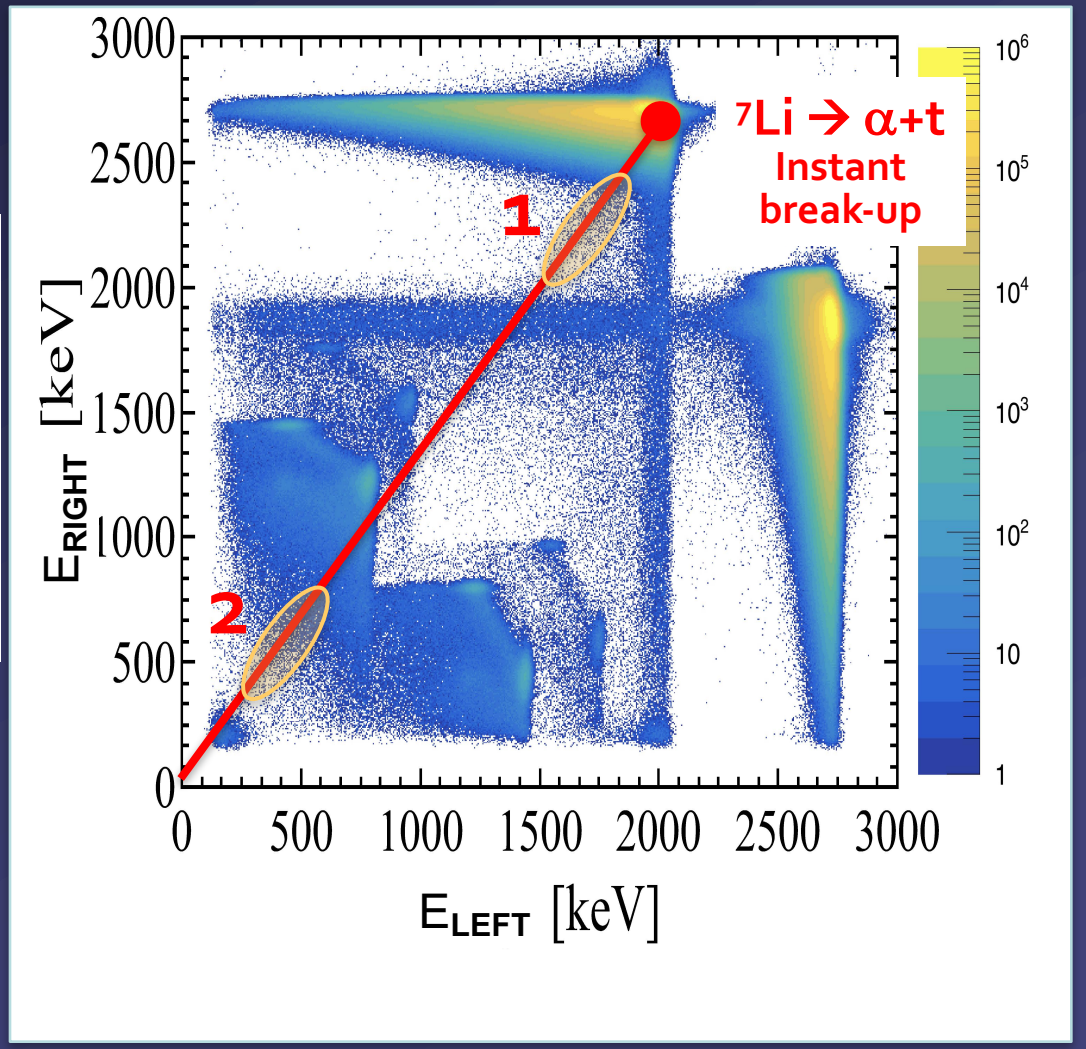
reconstructed γ energy

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

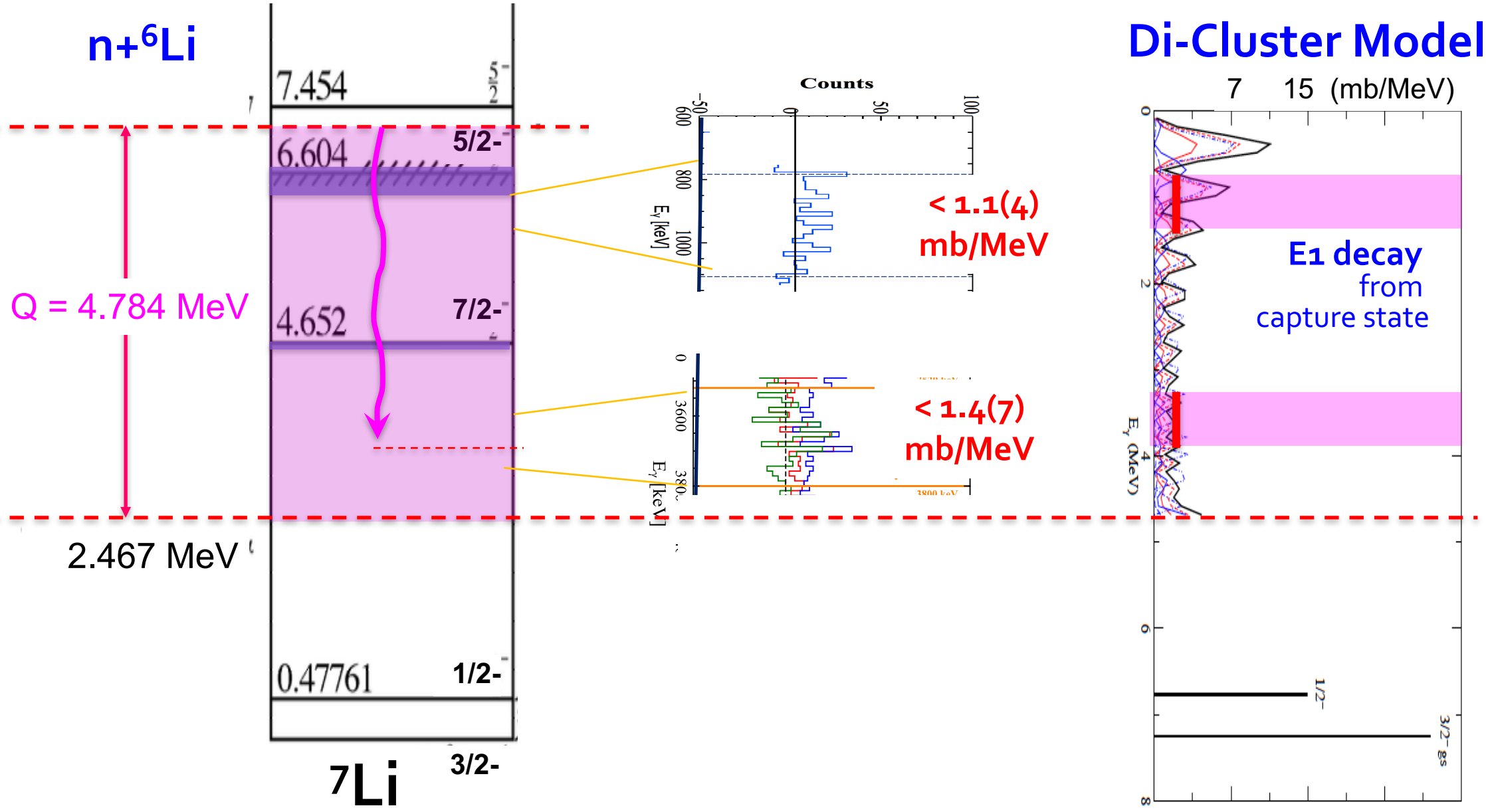


$\alpha - t$ from ^{7}Li break-up

$E_t/E_\alpha = 4/3$



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

PERSPECTIVES … short term …

NEW MEASUREMENT with increased precision is planned in 2018

- **Thinner Al foil for ^{6}Li implantation**
  [better particle energy resolution, lower energy thresholds]

- **Time coincidence between Si detectors**
  [strong reduction of B background]

TEST measurements aiming at particle-γ coincidence detection

- **Use of small scintillators (1"x1") based on new materials**
  $LaBr_3$ codoped, CLYC, CLLBC, CLLB … with different sensitivity to neutrons
  (F. Camera et al., MILANO)

PERSPECTIVES … longer term …

ADDITIONAL CASES of γ decay in the continuum

- ^{7}Be (mirror of ^{7}Li): $p + {}^{6}Li \rightarrow {}^{3}He + {}^{4}He$
- ^{8}Be (fully unbound): $p + {}^{7}Li \rightarrow {}^{4}He + {}^{4}He$

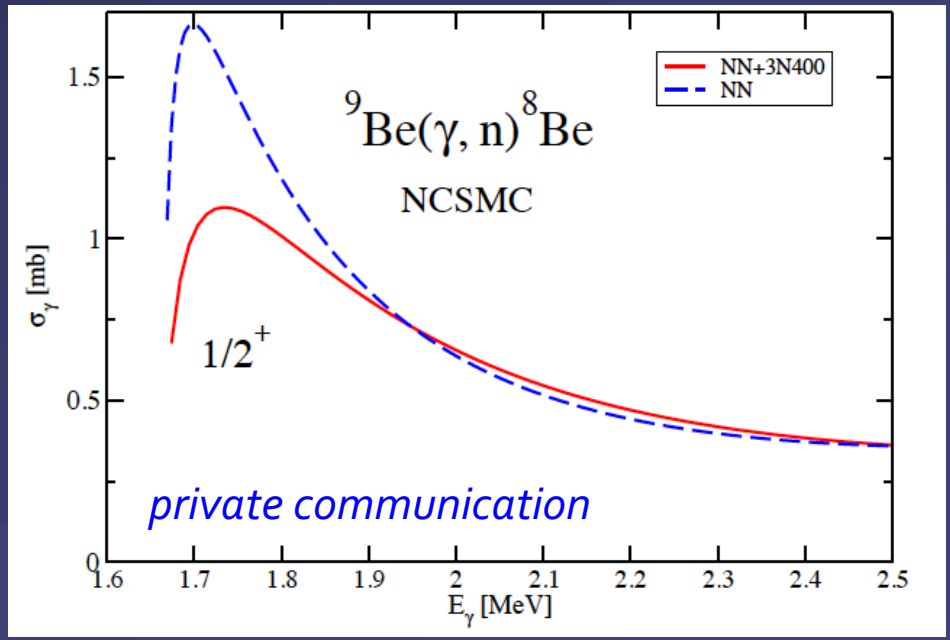
sensitivity to nuclear force !!!

Comparison with ab-initio calculations

(P. Navratil, S. Quaglioni)

No Core SHELL model with Continuum (NCSMC)

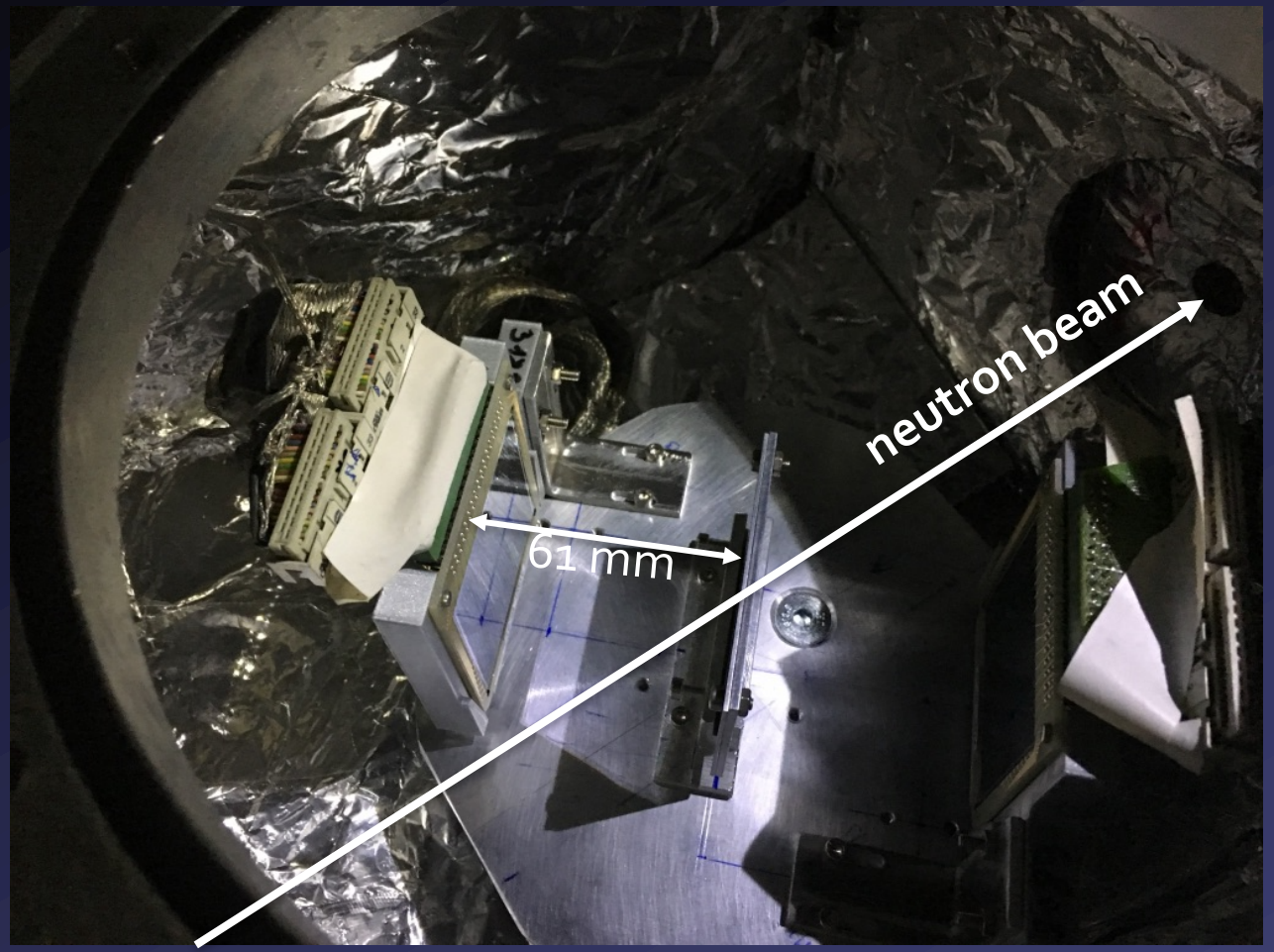
UNIFIED ab-initio Theory:
Nuclear Structure and Reactions

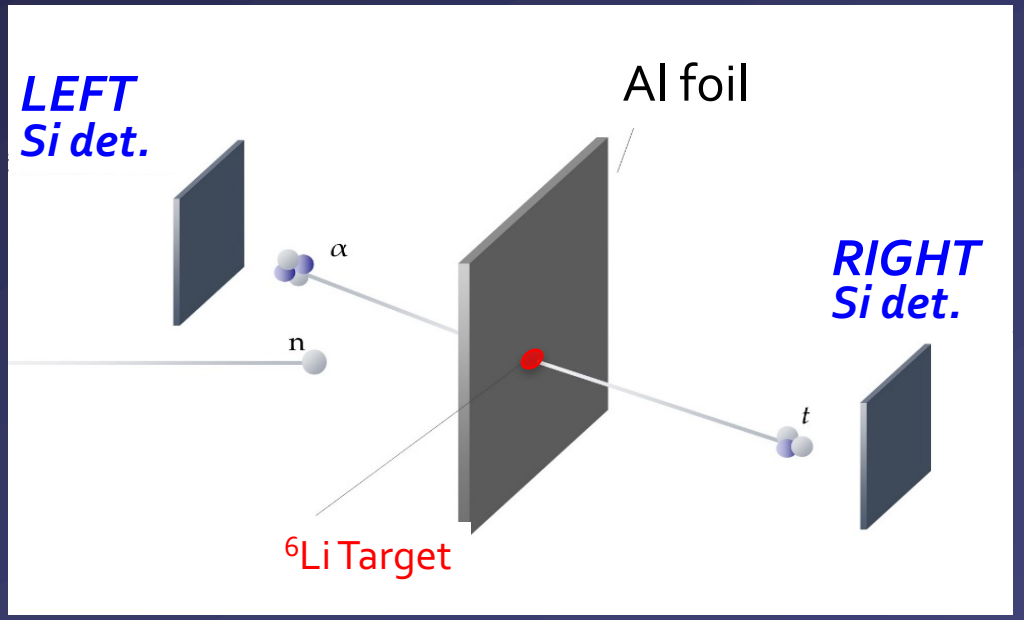


Thank you for the attention

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

γ spectrum from full kinematic reconstruction





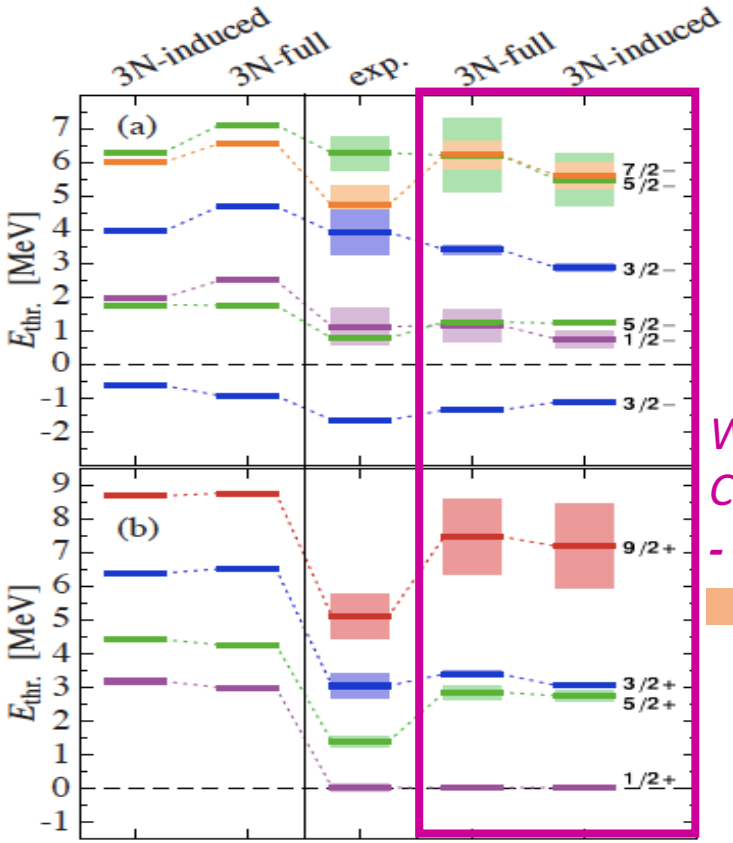
Physics Case: N-rich Be isotopes

No Core SHELL model with Continuum (NCSMC)

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

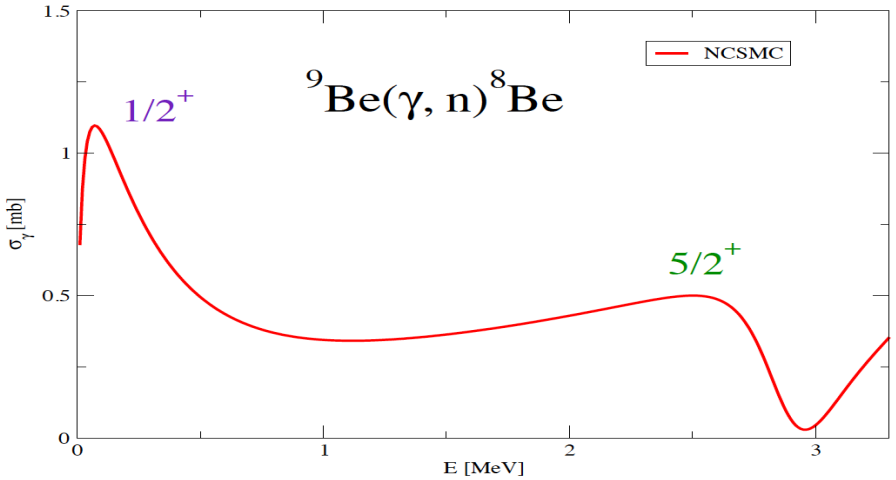
P. Navratil and S. Quaglioni, …

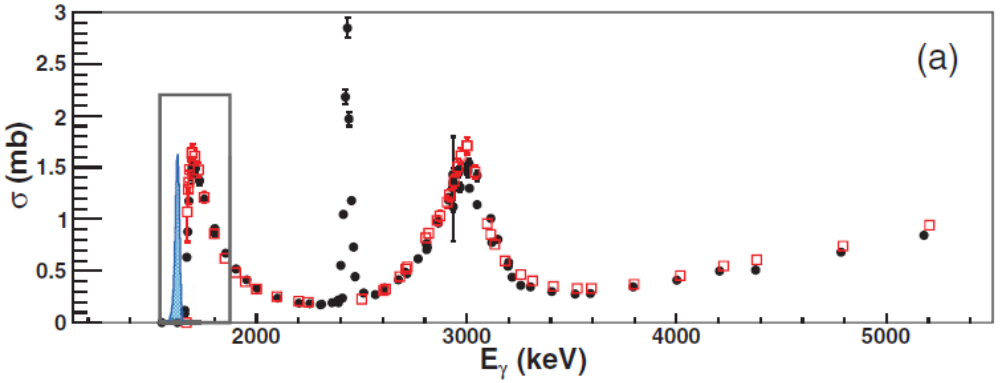
^{9}Be



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

Energy spectrum (with NNN force)





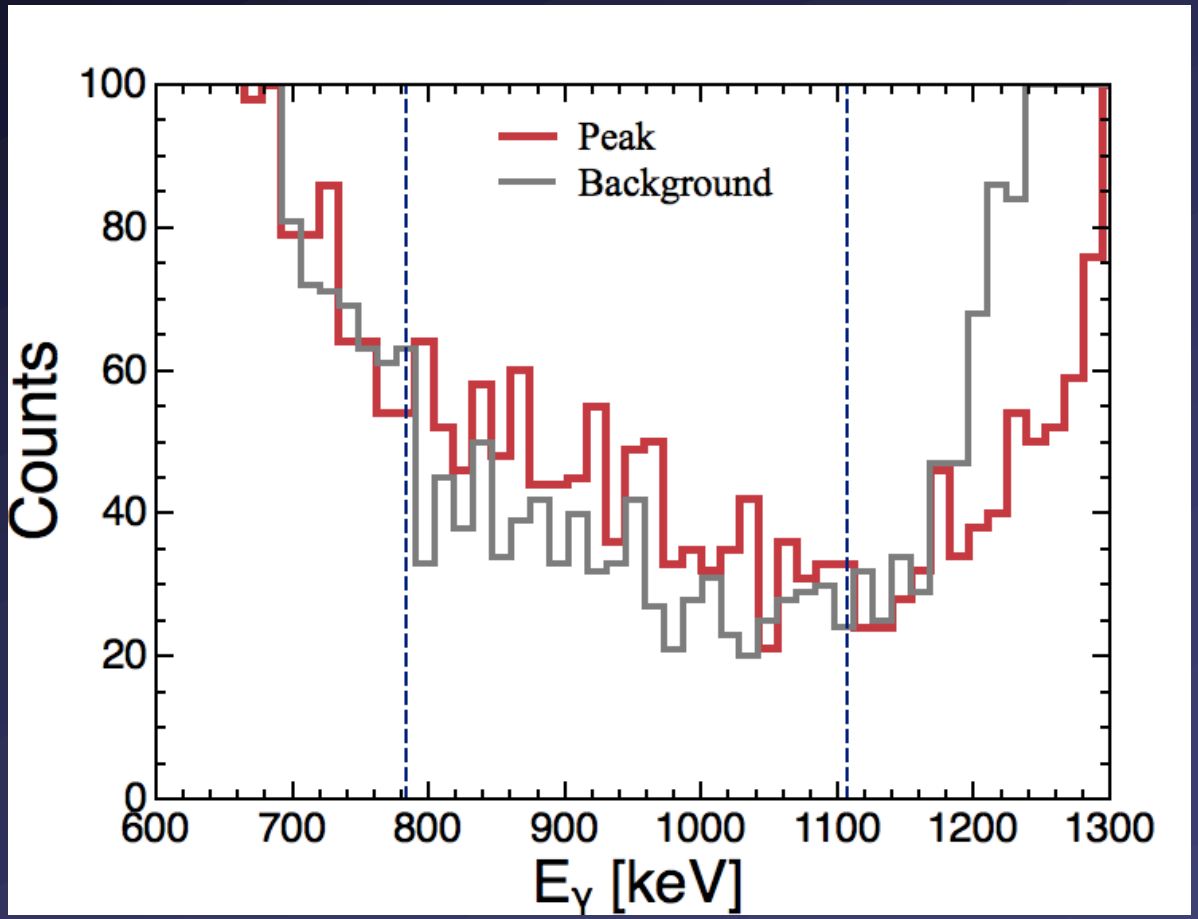
Cross section of E1 excitation:

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

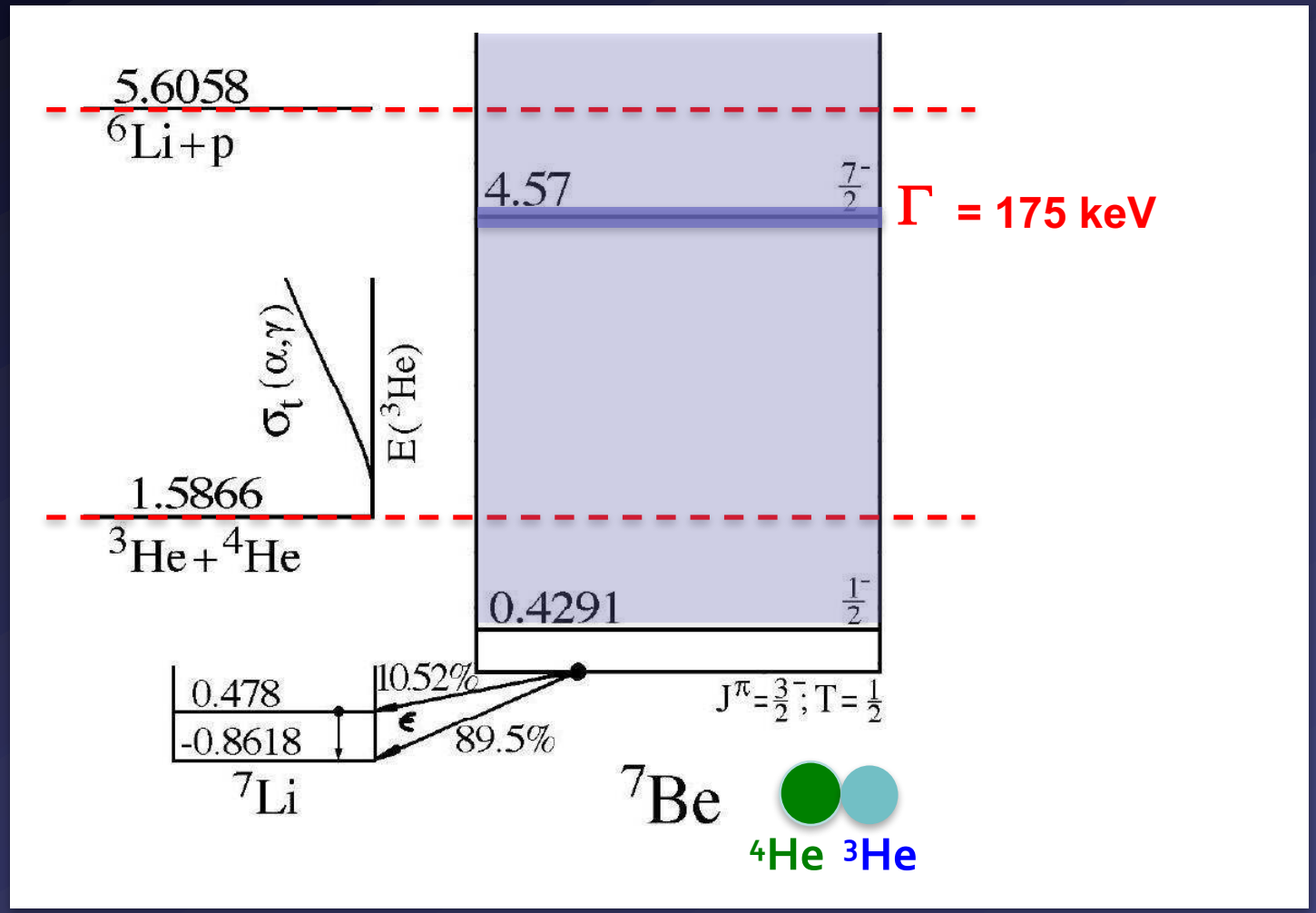
→ *In agreement with (γ,n) DATA from Hiγs*

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

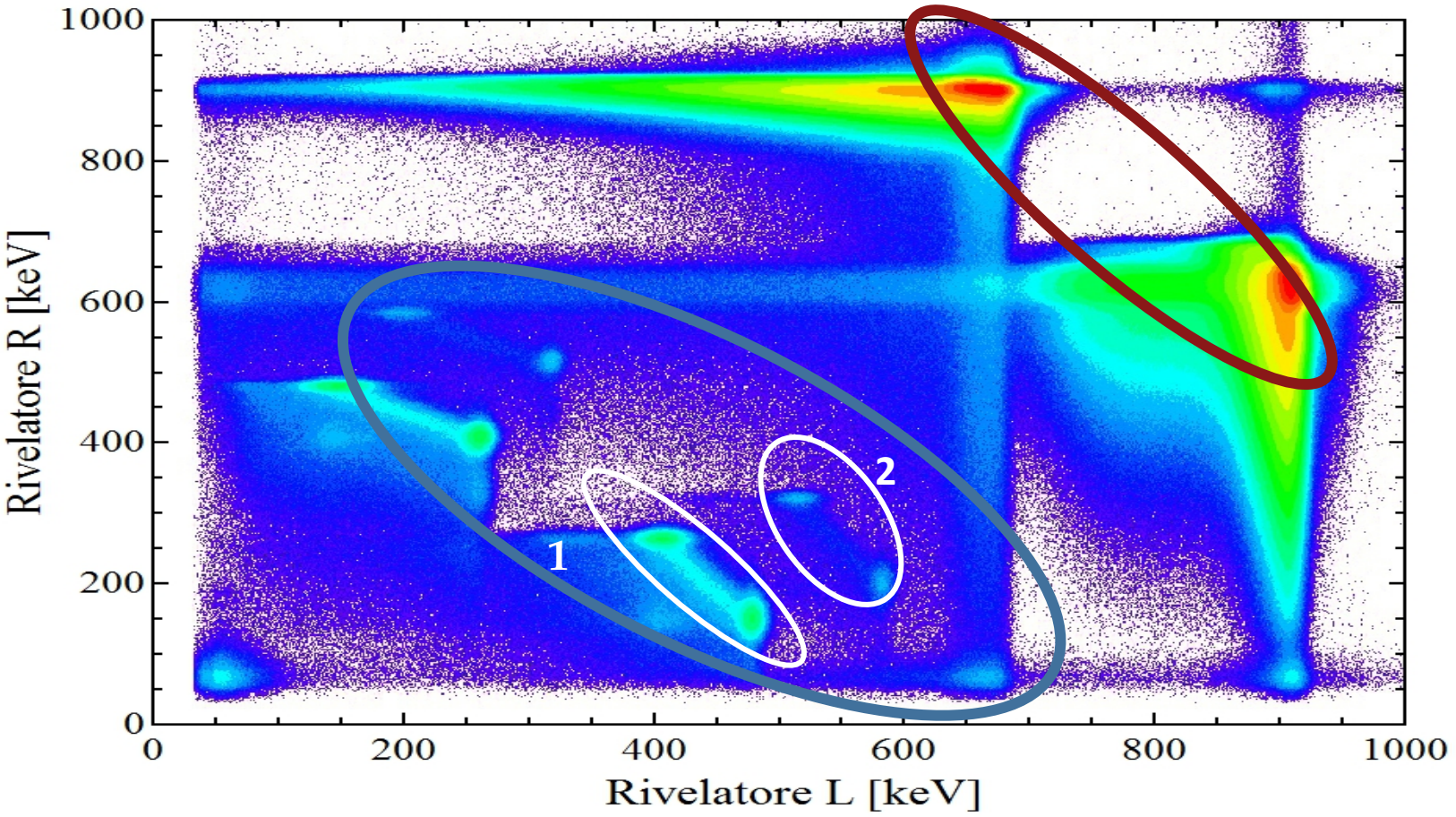
γ spectrum from full kinematic reconstruction



^{7}Be – a key nucleus for astrophysics



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