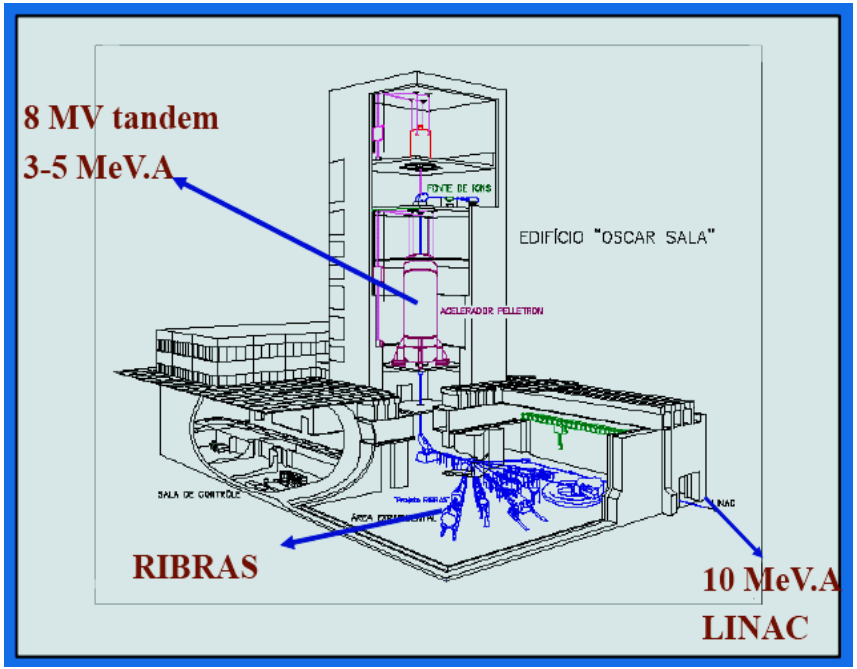
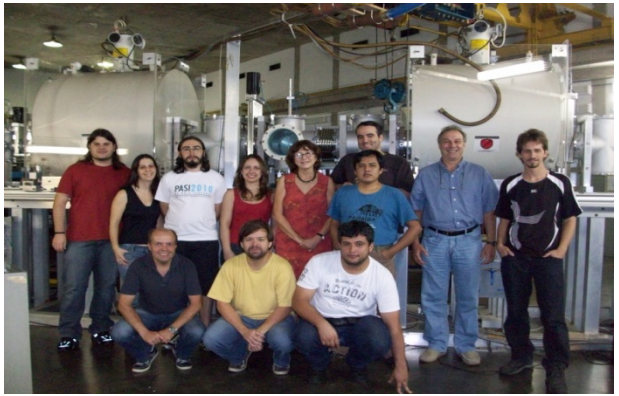
Study of high lying resonances in ^{9}Be by the measurement of (p,p), (p,d) and (p,α) reactions

Alinka Lépine-Szily,
and the
RIBRAS collaboration

International Nuclear Physics Conference
Adelaide Convention Centre, Australia
11-16 September 2016

Tandem Accelerator – Pelletron 8UD at the University of São Paulo - Brazil





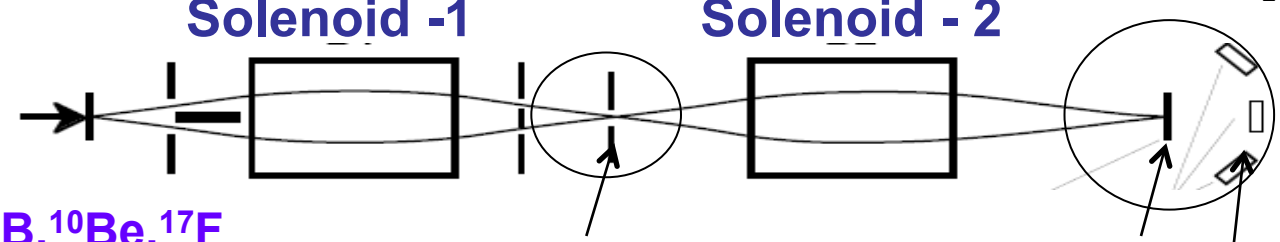
primary beams: ^{6,7}Li, ^{10,11}B, ^{9}Be, ^{12}C, ^{16,17,18}O ...

3.0 – 5.0 MeV/nucleon

RIBRAS - Radioactive Ion Beams in Brazil
First RIB facility in the Southern Hemisphere,installed in 2004

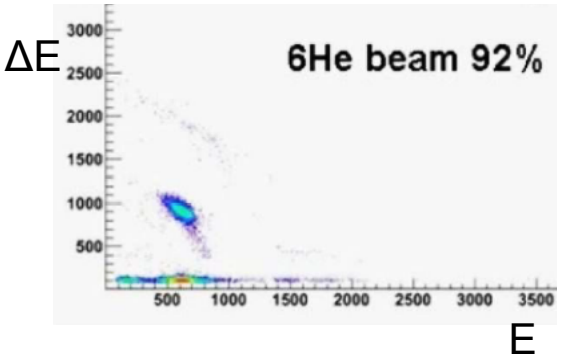
Two superconducting solenoids: in-flight radioactive ion beam production :

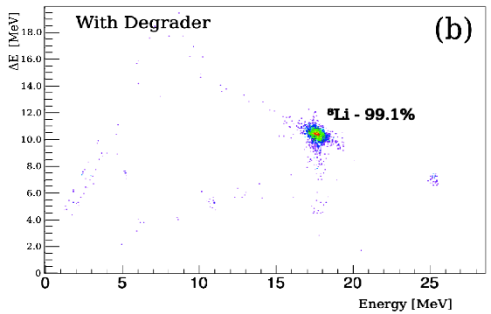
- Max field 6.5 Tesla
- versatile configuration
- persistent mode
- low LHe and LN_2 consumption



^{6}He,^{8}Li,^{7}Be,^{8}B,^{10}Be,^{17}F

Typical intensities: 10^4 - 10^6 pps

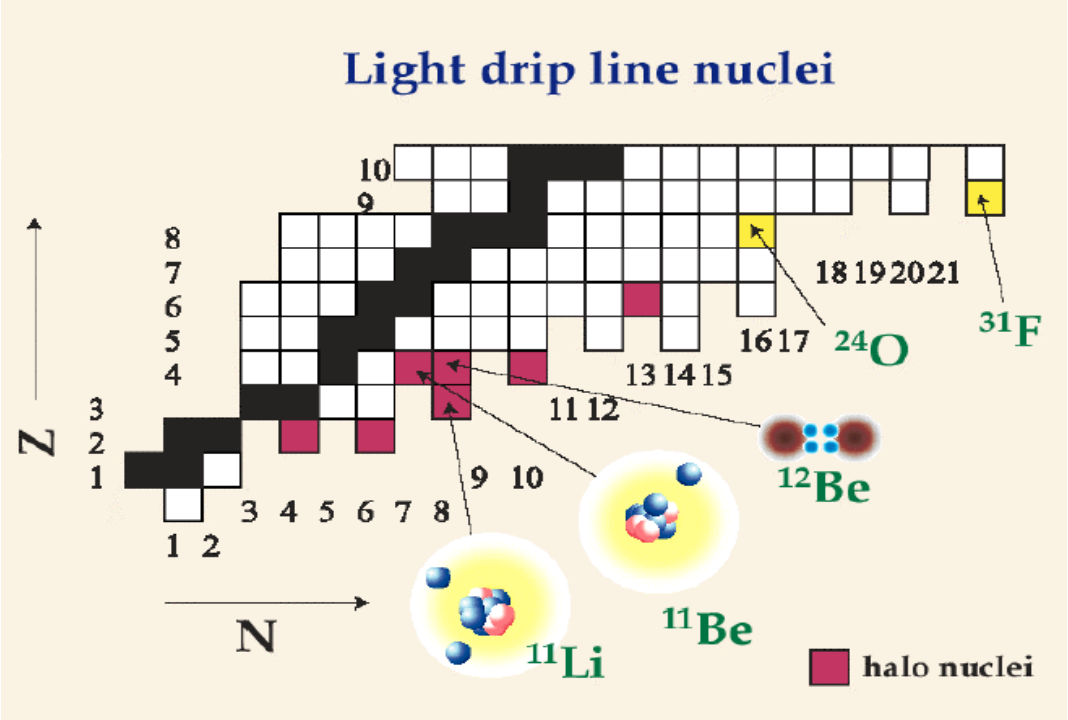


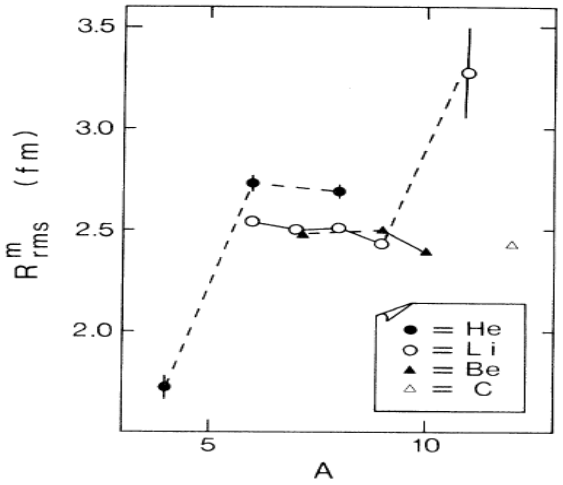


$$(B\rho)^2 = k\frac{AE}{q^2}$$

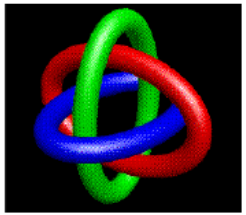
Evolution of the RIBRAS system

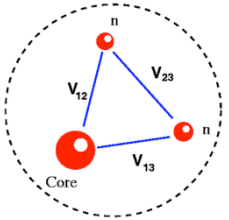
What is the interest of these light radioactive nuclei??





^{6}He borromean , two-neutron halo nucleus



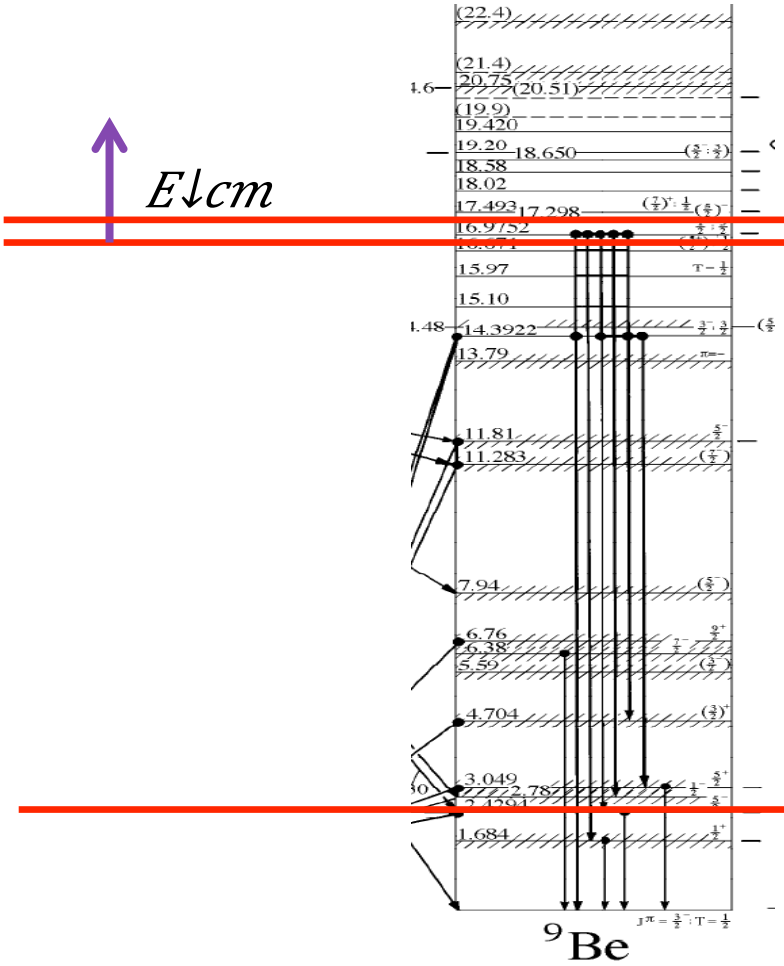


Measurements with purified radioactive beams:

Elastic scattering and transfer reactions of ^{8}Li on hydrogen target

Nuclear states with excited cores and with cluster structures: 2,3..

Study of ^{9}Be structure through ^{8}Li+p reactions



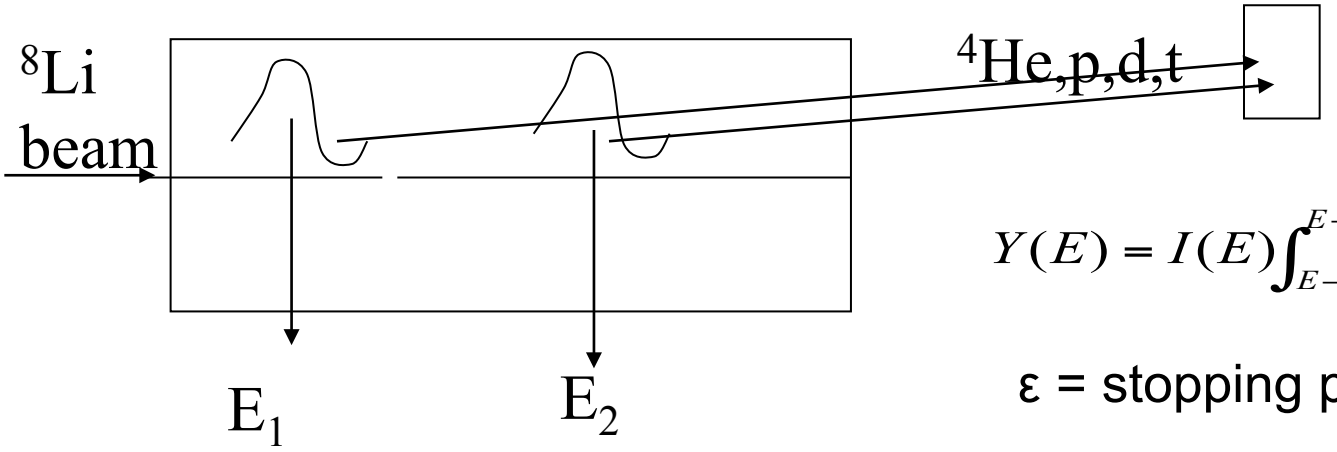
^{7}Li+d

^{8}Li+p

α+α+n

- Probes ^{9}Be around $E_x \approx 18-20$ MeV
- High excitation energies in ^{9}Be
  → unknown states
  → level density important
  → several open channels

Method: Inverse kinematics: ^{8}Li beam hitting a thick (7.7 mg/cm^2) $[CH_2]_n$ target
^{8}Li beam looses energy, stops in the target



$$Y(E) = I(E)\int_{E-\Delta E/2}^{E+\Delta E/2}\frac{\sigma(E_i)}{\varepsilon(E_i)}dE_i$$

ε = stopping power

Simultaneous measurement of all incident energies: excitation function
Resonances populated in the target →peaks in energy spectrum of light ejectiles
Energy spectrum of ^{4}He, p, d → excitation function of reactions
Energy resolution: independent of beam dispersion, depends on energy loss of light ejectiles in target
Normalization; Rutherford scattering of ^{8}Li on Au target

2009-2011 $^{8}Li(p,\alpha)\,^{5}He$. one solenoid. Q=+14.42 MeV,

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The $^{8}Li(p,\alpha)^{5}He$ reaction at low energies, and ^{9}Be spectroscopy around the proton threshold

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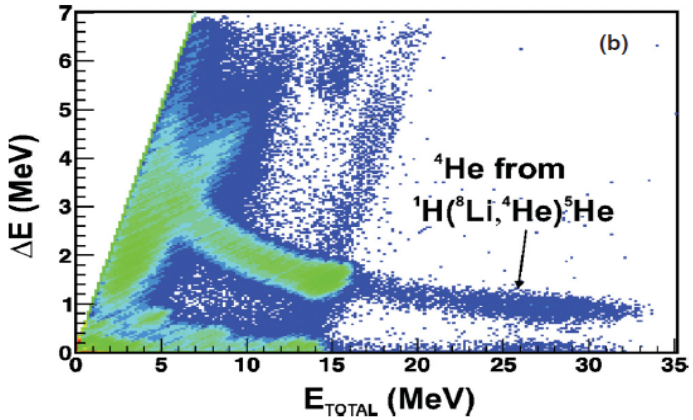
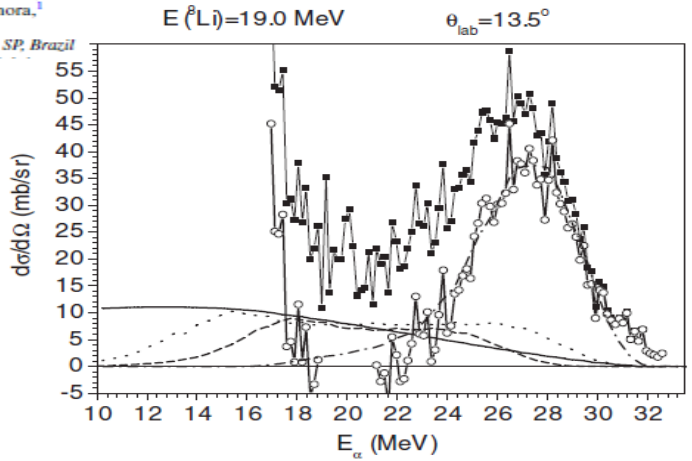
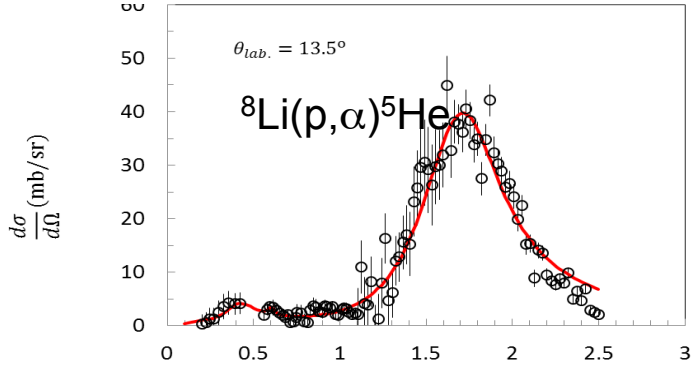






Subtraction of α contribution

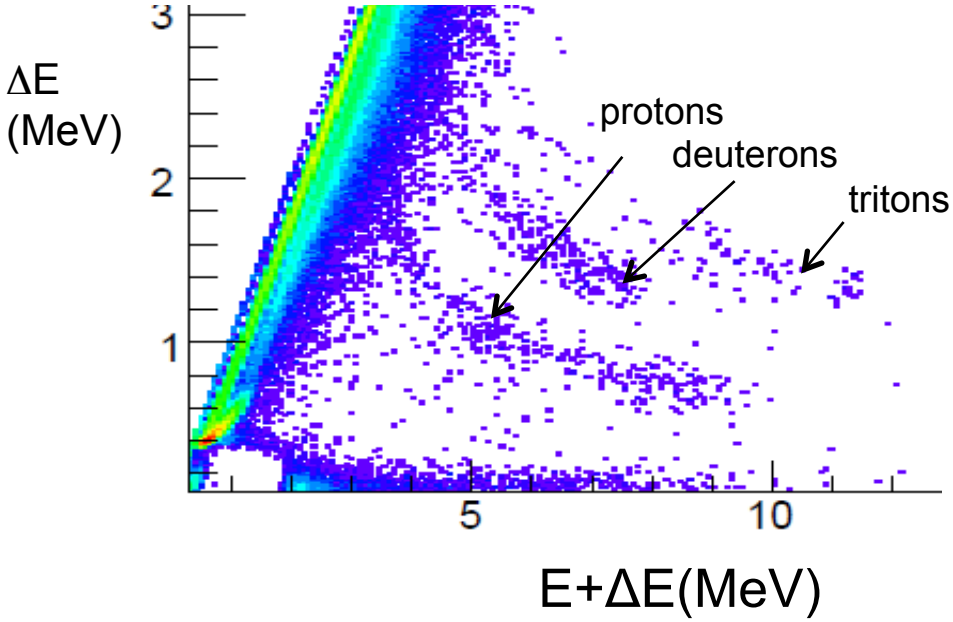
$^{5}He_{gs}$ → α +n

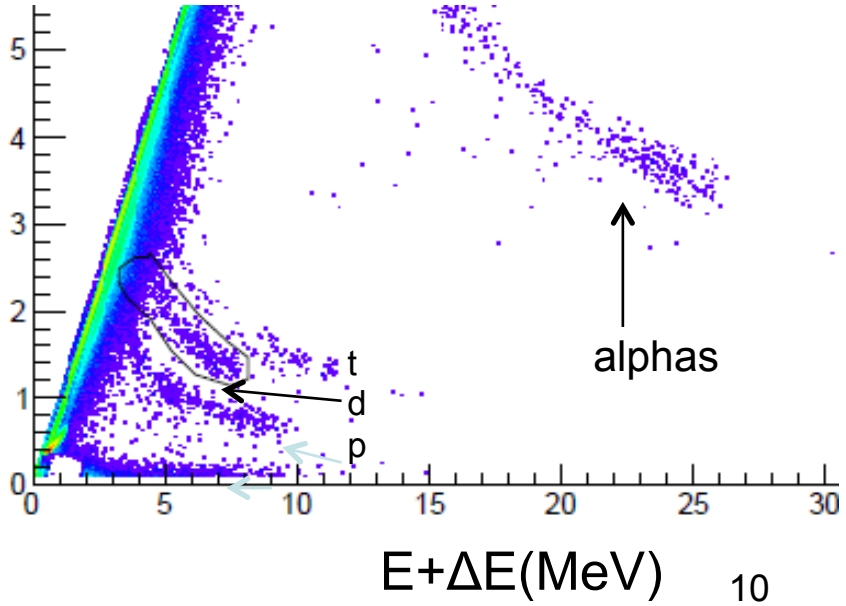
$^{5}He^{*}$→ α +n

Phase space ^{9}Be→ α+ α+n

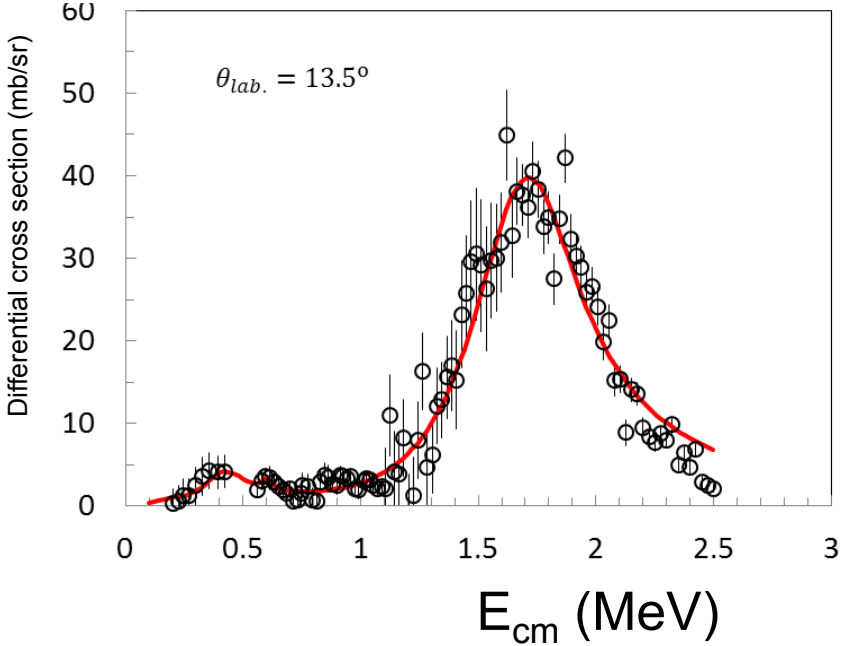
2013 – 2015 – 2 solenoids--purified ^{8}Li beam

θ_{lab}= 10 and 18°

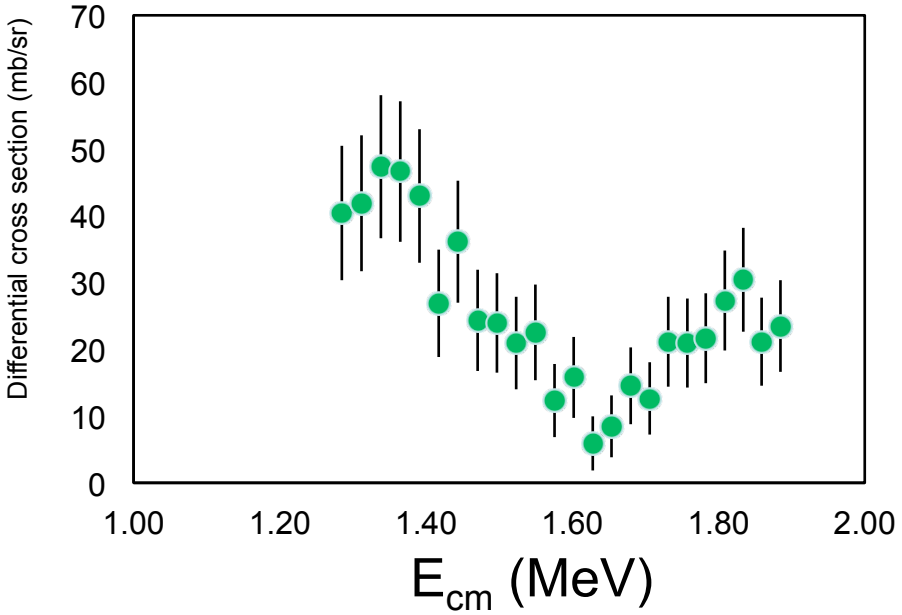




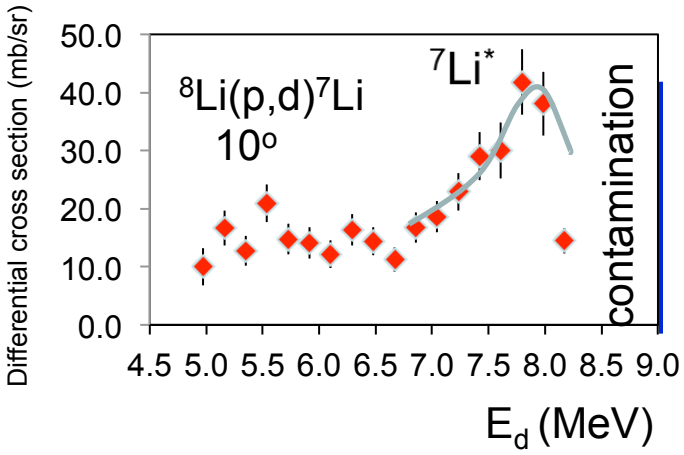
$^{8}Li(p,\alpha)^{5}He$ at 13,5º

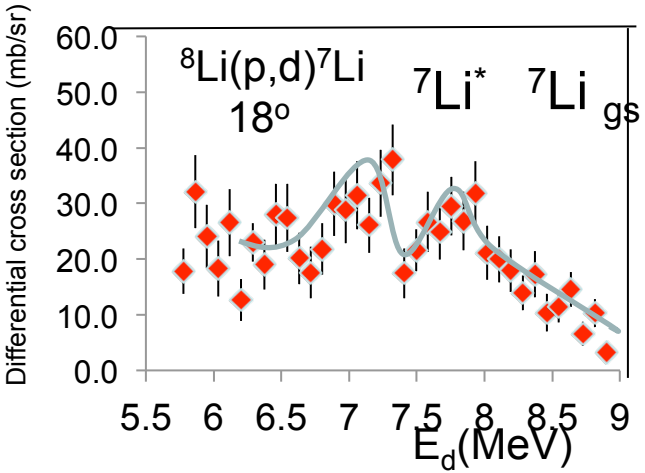


$^{8}Li(p,p)^{8}Li$ at 18º

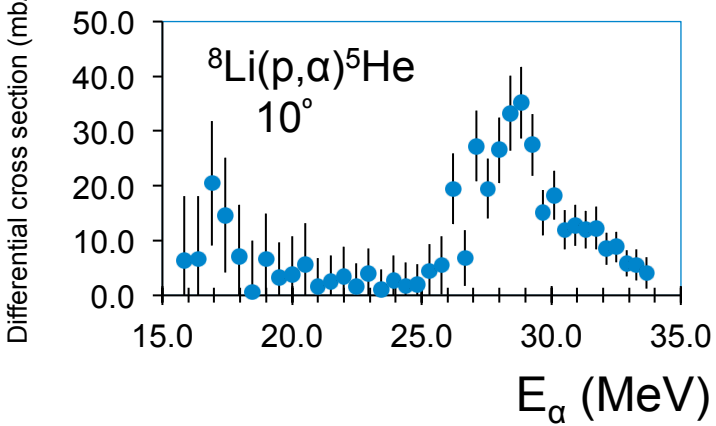


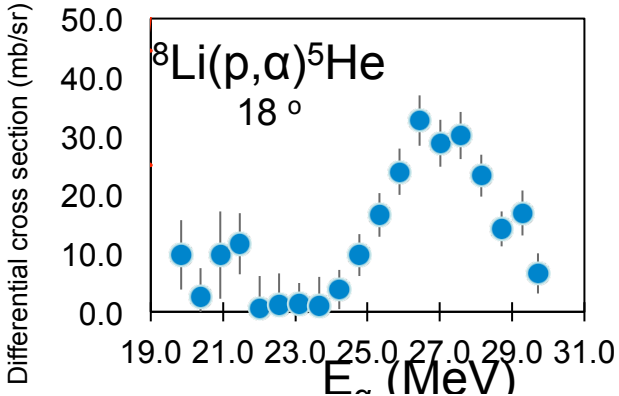
Broad resonance at E_{cm}~1.7MeV, observed in (p,α) and (p,p). In (p,d) it populates both $^{7}Li_{gs}$ and $^{7}Li^{*}$(0.477 MeV).





The resonance at Ecm ~ 1.7 MeV decays to d + ^{7}Li$_{gs}$ and ^{7}Li* (0,477MeV). At 10° the peak of d + ^{7}Li$_{gs}$ was covered by a contamination





R-matrix calculation

Procedure:

1. Inputs for each resonance: $J,I,\ell,E_0,\gamma_p,\gamma_\alpha,\gamma_d$
2. Calculation of the R-matrix for each J values
3. From R-matrices: calculation of the scattering matrices U_J for each J
4. From the scattering matrices U_J : elastic and transfer cross sections

Several reactions with the same entrance channel → constrains

Energy E_0 , proton width γ_p are common → constrains

^{8}Li(p,p)^{8}Li: $R_{pp}(E)=\gamma_p^2/(E_0-E)$

^{8}Li(p,α)^{5}He: $R_{p\alpha}(E)=\gamma_p\gamma_\alpha/(E_0-E)$

^{8}Li(p,d)^{7}Li: $R_{pd}(E)=\gamma_p\gamma_d/$

5-channels:

^{8}Li + p

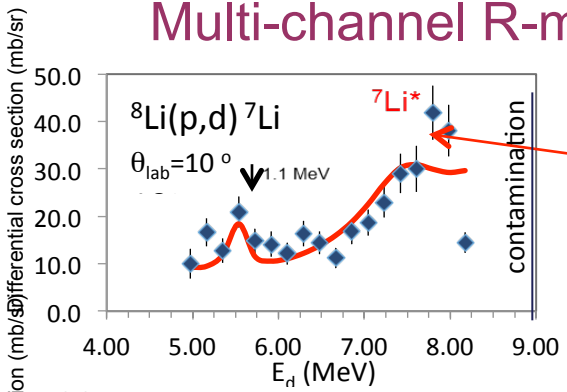
^{5}He + α

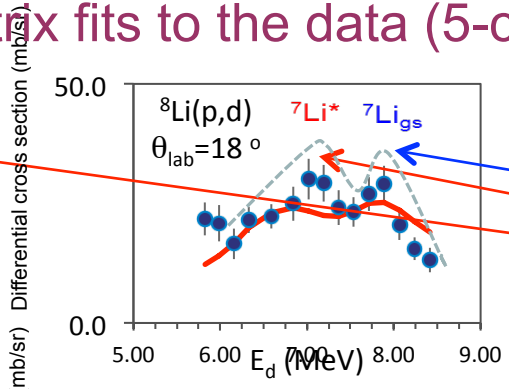
^{5}He*(1/2$^-$)+ α

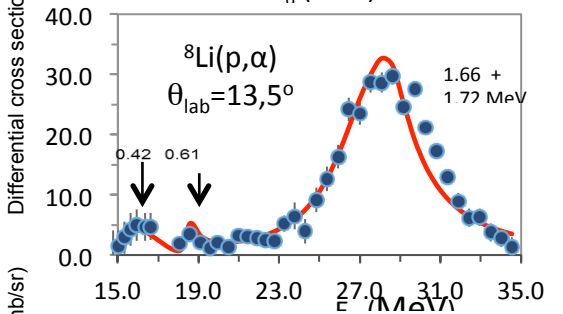
^{7}Li$_{gs}$ + d

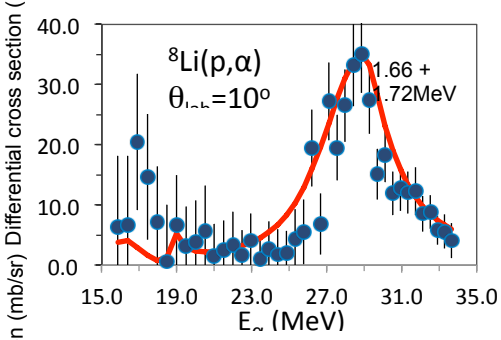
^{7}Li* (1/2$^-$) + d

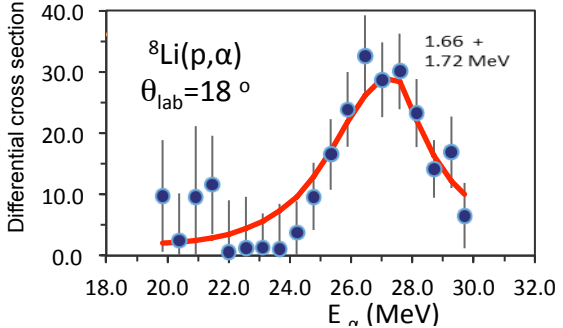
Multi-channel R-matrix fits to the data (5-channels)

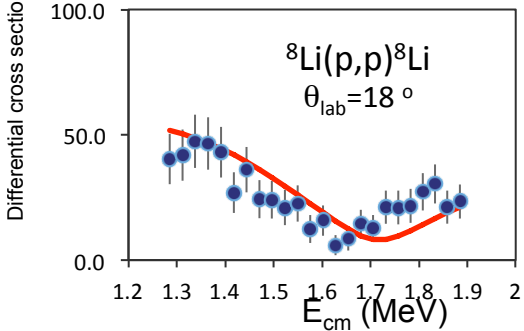


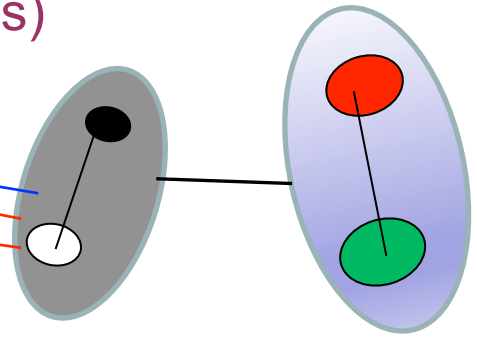












d=p+n

^{7}Li=α + t

deuteron channel: large reduced width

→ Strong ^{7}Li+d structure

→ State with excited core

→ α+t+p+n four-body state

R-matrix fits:

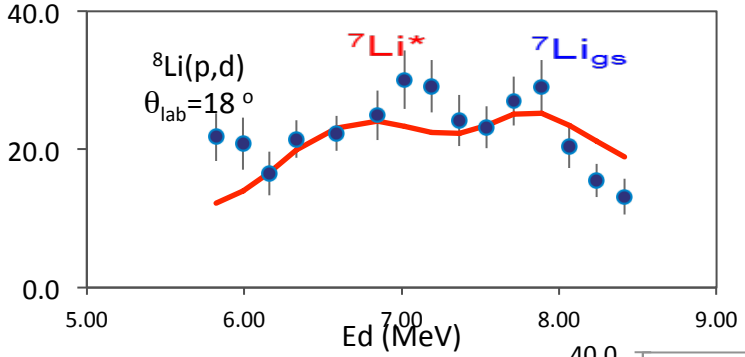
5 resonances at 0.42, 0.61, 1.10, 1.66 and 1.72 MeV.

At 1.66 broad state

(Γp, Γα ~200 keV, , Γ_d ~100 keV)

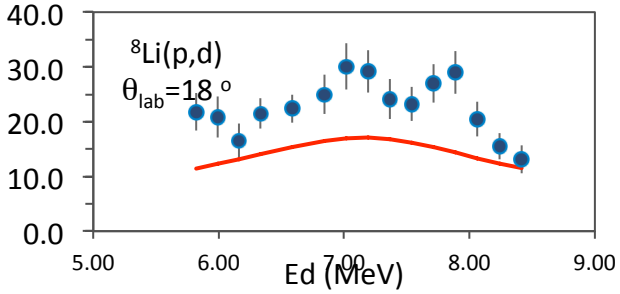
At 1.72 MeV narrower state

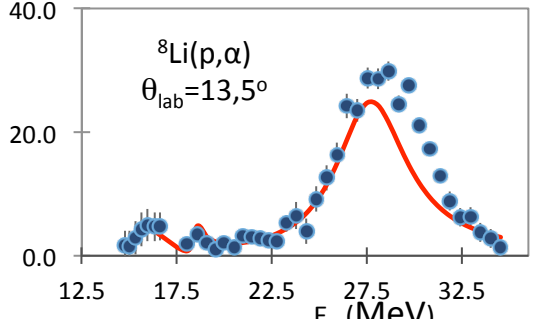
(Γp, Γα ~ 50 keV, , $\Gamma_{d'}$ ~ 100 keV)



2 resonances close:
at 1.66 and 1.72 MeV

E_R	Jπ	Γp	Γα	Γd	Γd'
1.66	7/2-	0,26	0,18	0,10	0,04
1.72	5/2-	0,06	0,03	0,04	0,1



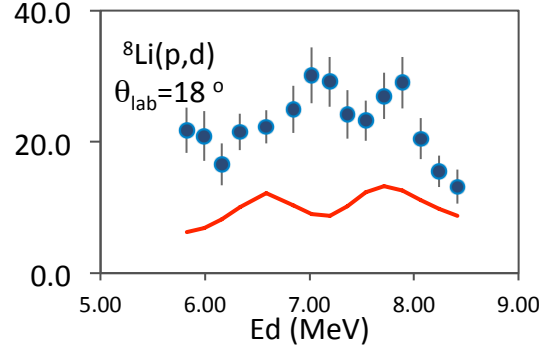


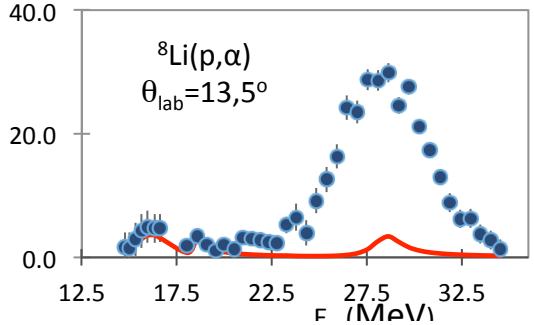
1 resonance only

E_R	J^π	Γ_p	Γ_α	Γ_d	$\Gamma_{d'}$
1,66	7/2-	0,26	0,18	0,10	0,04

or

E_R	J^π	Γ_p	Γ_α	Γ_d	$\Gamma_{d'}$
1,72	5/2-	0,06	0,03	0,04	0,1





Conclusion: need for 2 resonances to reproduce the separation of peaks in (p,d)

Conclusions

- The simultaneous measurement of resonant elastic scattering ^{8}Li(p,p)^{8}Li, and transfer reactions ^{8}Li(p,α)^{5}He and ^{8}Li(p,d)^{7}Li, allows to determine the resonance parameters of highly excited states in ^{9}Be.

- 5 resonances, at E_{cm}= at 0.42, 0.61, 1.10,1.66 and 1.72 MeV have E_R, J^{π} and partial widths Γ_p, Γ_α, Γ_d, $\Gamma_{d'}$ determined
- Future measurements: extend the energy range and measure angular distributions
- Study other systems ^{6}He+p, ^{8}B+p, ^{7}Be+p

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In memoriam of our dear colleague and friend Paulo Gomes. Rest in peace

~1980

2015