Low energy proton induced reactions for application purposes

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The low – energy Compact Accelerator – driven Neutron Sources (CANS)

- ✓ Significant role in R&D in science, engineering and education
- ✓ Easy installation & operation
- ✓ Many peaceful applications with high economical interest

- ❑ Device development & irradiation effects in electronic devices
- ❑ Testing & evaluation of beam line instruments
- ❑ Materials characterization
- ❑ Applications in environmental protection
- ❑ Non-destructive cultural heritage applications
- ❑ Medical applications
- ❑ Nuclear data & nuclear astrophysics

I.S. Anderson et al., Phys. Rep. 654, 1 (2016)
F. Ott, Technical report cea-01873010 (2018)

Many low-energy CANS currently operating or under construction
SARAF-II (Israel), I. Mardor et al., Eur.Phys.J.A 54,91 (2018)
NUANS, KUANS, RIKEN RANS (Japan), www.jcans.net/nuans.html
LENS (U.S.A.), ceem.indiana.edu/lens/
FRANZ (Germany), exp-astro.de/index.php?id=expFRANZ

At higher energies: CYRIC (Japan), iThemba (S.Africa), ESS-Bilbao (Spain), NEPIR@SPES (Italy). At very low energies: FNG (Italy)

➢ Low – energy CANS using proton beam

- ❑ Proton beam @ 2 – 5 MeV
- ❑ Target choice to achieve high neutron rate production

$^{7}Li(p,n)^{7}Be$ reaction

$^{9}Be(p,n)^{9}B$ reaction

✓ Large cross section values

IPHI (SACLAY, France)

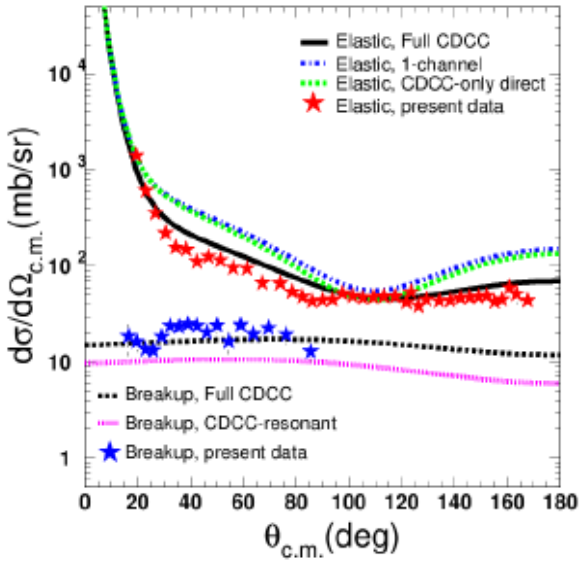
N. Alamanos talk (HINPw6)

Proton induced reactions with weakly bound nuclei:
a systematic study in inverse kinematics

^{6}Li + p

A global study including
- elastic scattering,
- breakup and
- ^{1}H(^{6}Li,^{3}He)^{4}He reaction,

in the Continuum Discretized Coupled – Channels (CDCC) framework.



V.Soukeras et al., Phys.Rev.C 91,057601 (2015)
V.Soukeras et al., Phys.Rev.C 95,054614 (2017)
Ch. Betsou et al., Eur.Phys.J.A 51,86 (2015)
A. Pakou et al., Eur.Phys.J.A 57,25 (2021)

^{7}Li + p

A global study including
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- breakup and
- all other reaction channels

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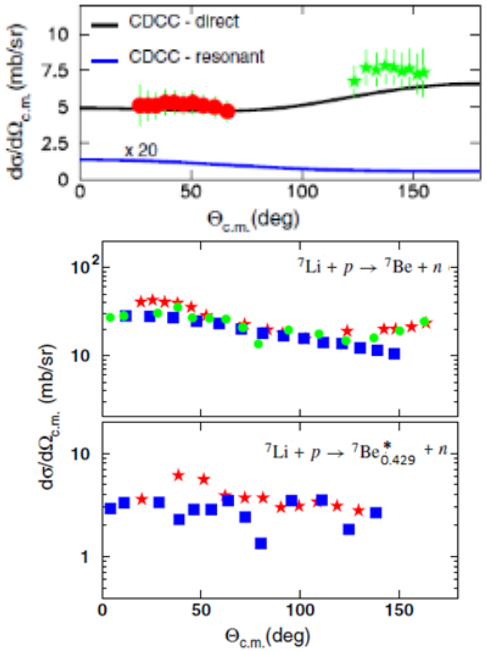

A. Pakou et al., Phys.Rev.C 94,014604 (2016)
A. Pakou et al., Phys.Rev.C 95,044615 (2017)
A. Pakou et al., Phys.Rev.C 96,034615 (2017)
A. Pakou et al., Eur.Phys.J.A 57,25 (2021)

^{9}Be + p

A global study including
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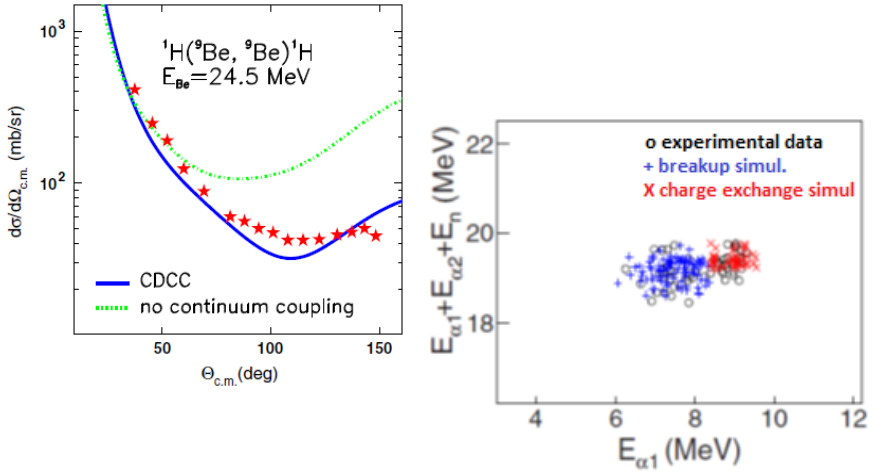
- all other reaction channels

in the CDCC framework.

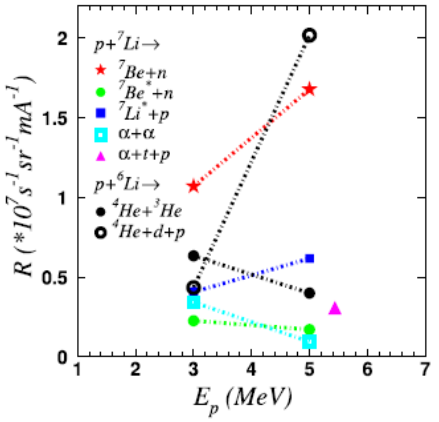
The different decay rates for ^{9}Be breakup were also investigated

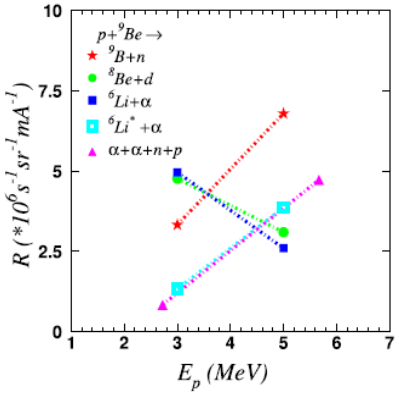


A. Pakou et al., Phys.Rev.C 99,014615 (2019)
A. Pakou et al., Phys.Rev.C 101,024602 (2020)
V. Soukeras et al., Phys.Rev.C 102,064622 (2020)
A. Pakou et al., Nucl.Phys.A 1008,122155 (2021)
A. Pakou et al., Eur.Phys.J.A 57,25 (2021)

How is our research related to the CANS development ?

- ✓ Rates for all reaction particles produced in the p + ^{6,7}Li and p + ^{9}Be reactions at low energies for an 1μg/cm^2 target
- ✓ Neutron production rate for p + ^{7}Li and p + ^{9}Be reactions at low energies for an 1μg/cm^2 target taking into account ENDF library data and our measurements
- ✓ Neutron production rate for p + ^{7}Li and p + ^{9}Be reactions at low energies for a **thick** target taking into account ENDF library data and our measurements
- ✓ ^{3}H production rate in the p + ^{7}Li reaction





E(MeV)	R(*10^6)
1.89	8.0
2	11.7
2.3	22.4
2.5	14.3
3	13.3
4	12.6
4.5	15.8
5	17.9

^{7}Li(p, n)^{7}Be

rate of neutrons (R) in s^{-1} mA^{-1} sr^{-1} for target 1 μg/cm^2 (ENDF/B-VIII.0 library)

E (MeV)	R(*10^6)	R_{tot}(*10^6)
2	0	
2.3	0.7	
2.5	1.5	
2.72	4.0	
3	3.2	3.7
4	5.0	7.1
4.5	6.6	9.4
5	6.8	10.5

^{9}Be(p, n)^{9}B rate of neutrons (R) in s^{-1} mA^{-1} sr^{-1} for target 1 μg/cm^2

^{9}Be(p, n)^{9}B and breakup R_{tot}

Neutron rates (R), for ^{7}Li and ^{9}Be **thick targets** in units s^{-1} mA^{-1} sr^{-1}

E (MeV)	^{7}Li R(*10^{11})	^{9}Be R(*10^{11})
3	1.4	0.2
5	5.0	2.0

Triton rate, R, due to breakup with a **thick ^{7}Li target** in units of s^{-1} mA^{-1} sr^{-1}

E (MeV)	R(*10^{10})
5	2.5
5.44	4.1

➢ O. Sgouros et al., Eur. Phys. J. A 57, 125 (2021)

How is our research related to the CANS development ?

Conclusions

- ✓ Our recent studies show that the ENDF/B-VIII.0 library, can be safely used for the conception of CANS at least in respect with (p,n) cross sections
- ✓ **For a ^{9}Be target, an additional source of neutrons is the breakup**, for $E_p \geq 4$ MeV. This process accounts for at least 30% of the total rate

No breakup cross sections are included in the libraries !

- ✓ Higher rates are obtained by using a thick lithium target than a beryllium one by a factor of 7 for E_p = 3MeV and a factor of 2.5 for E_p = 5 MeV
- ✓ By using a **^{7}Li target** special care should be taken, from the point of view of radioprotection, due to **^{3}H production**, which is a breakup product with quite high rate for a thick ^{7}Li target. The radioactive nucleus **^{7}Be** is also produced via the (p,n) channel.
- ✓ We point out the importance of the compatibility between experimental results and CDCC calculations for low – energy proton reaction channels, important on CANS targets. The results of comprehensive CDCC calculations can be implemented in simulations instead of experimental yields, for designing in the most accurate way CANS facilities.
- ✓ This work is an example of the strong impact that fundamental research may have on applications related with CANS.

➢ **O. Sgouros et al., Eur. Phys. J. A 57, 125 (2021)**

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Letter to the Editor

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Thank you very much for your attention !