Neutron induced reactions and Trojan Horse Method

Marisa Gulino
Università di Enna "Kore" &
Laboratori Nazionali del Sud - INFN
ITALY

Neutron induced reactions

NEUTRON INDUCED REACTIONS

fundamental nuclear physics

Get information about the mere nuclear interaction

Nuclear tecnologies

Nuclear Waste trasmutation

Energy production

Nuclear Astrophysics

- ***Nucleosynthesis of the elements heavier than Fe***
- ***abundance of some light nuclides modified by (n,γ), (n,p) and (n,α) reactions during the s- or r-processes or explosive nucleosynthesis***

Neutron induced reactions: problems of direct measurements

- non monocromatic beam
  - **TOF technique**
  - **neutron energy spectra which simulate a stellar (kT ≈ 25 keV) Maxwell-Boltzmann distribution (e.g. ^{7}Li(p,n)^{7}Be)**
  - **The on-line detection of the reaction products is often limited by high neutron fluxes.**
- Background subtraction
- Normalization of the cross section
- Security problems

USE OF an indirect technique

Several IM have been developped for nuclear astrophysics, like CD, ANC and THM

Neutron induced reactions: why using indirect methods

Trojan Horse Method

Main application: **measurements of cross sections of charged particles induced reaction at astrophysical energies**

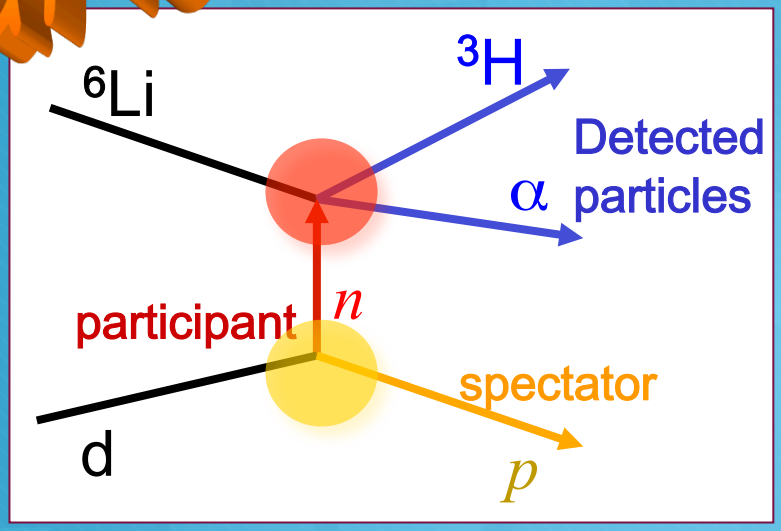
→ USE OF THE QUASI-FREE BREAK-UP OF DEUTERON TO PRODUCE A VIRTUAL NEUTRON BEAM

Advantages:

1. Get complementary information about the cross section of reactions induced by neutrons
2. Overcome the suppression due to the possible presence of centrifugal barrier
3. Allow to measure the neutron induced reaction on radioactive nuclei with low life time (minutes or less) by using the Radioactive ions beams

n-induced reaction using the deuteron break-up

what is new?



USE OF THE QUASI-FREE BREAK-UP OF DEUTERON TO PRODUCE A VIRTUAL NEUTRON SOURCE

To be used also with radioactive ion beams

$$\frac{d^3\sigma}{dE_b d\Omega_b d\Omega_B} \propto KF\left|\Phi(p_s)\right|^2\left(\frac{d\sigma}{d\Omega}\right)$$

2-bodies reaction

^{6}Li(n,α)^{3}H

d(^{6}Li,α ^{3}H)p

3-bodies reaction

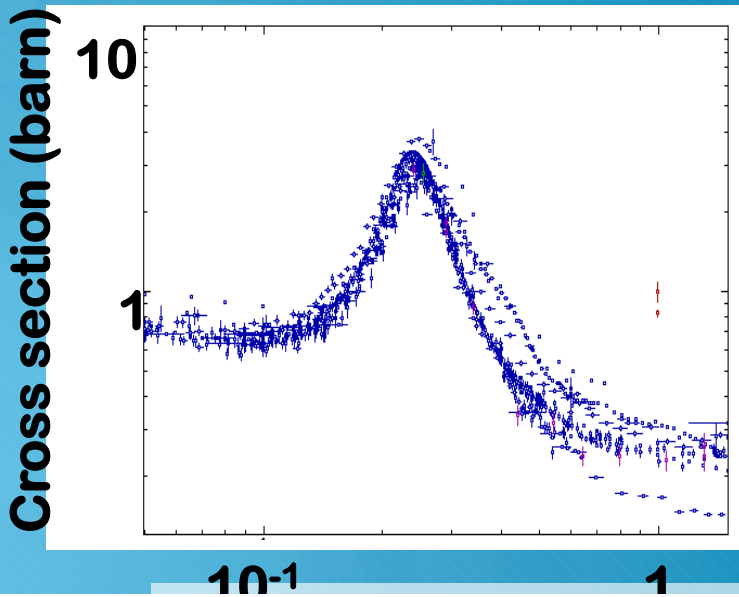
SUMMARY of performed experiments

$^{6}Li(n,\alpha)^{3}H$ ← $d(^{6}Li,\alpha\ ^{3}H)p$

- First run @LNS parassitic experiment

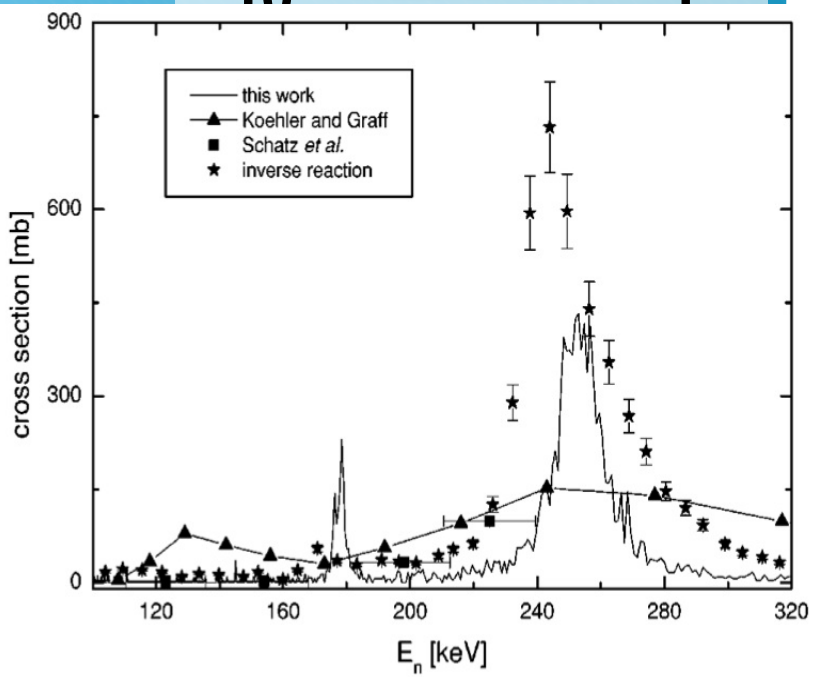
  → *good agreement but low energy resolution*

- Second run @LNS
  devoted experiment



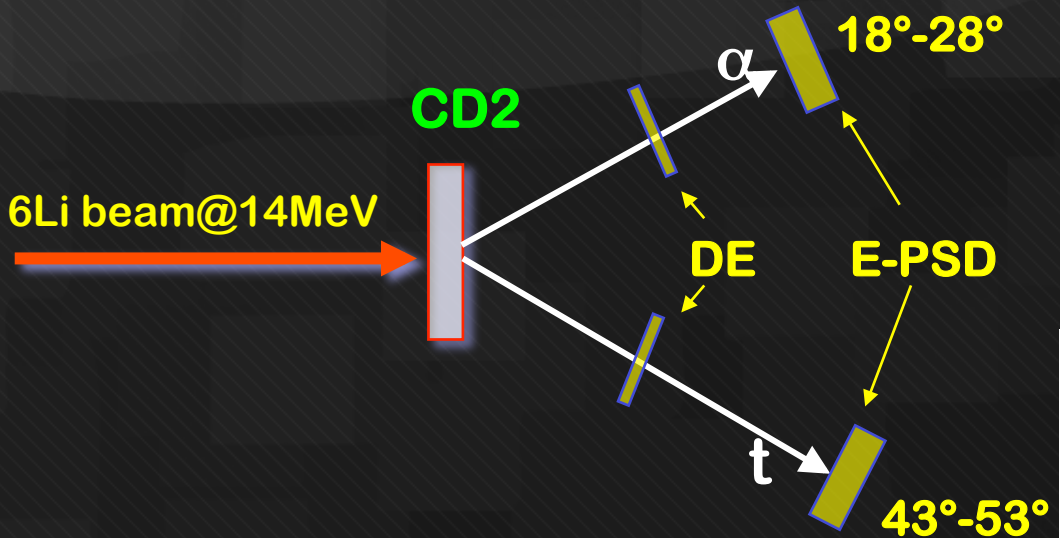
$^{17}O(n,\alpha)^{14}C$ ← $d(^{17}O,\alpha\ ^{14}C)p$

- First run @LNS
  parassitic experiment
- Second run @ND
  devoted experiment

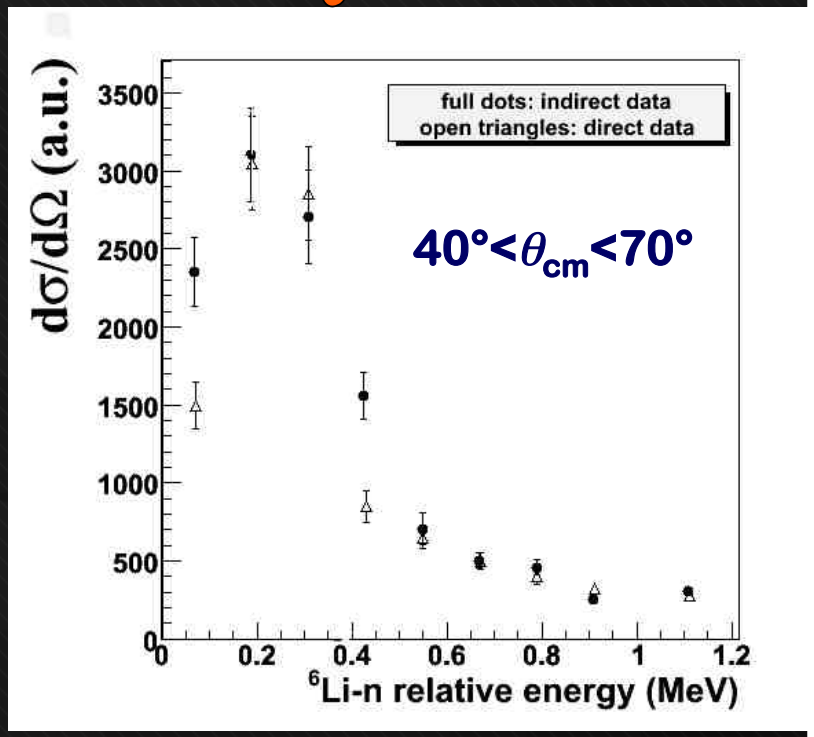


The experiment ^{6}Li+n: first test

Experiment performed @LNS,Catania



GOOD agreement but ...

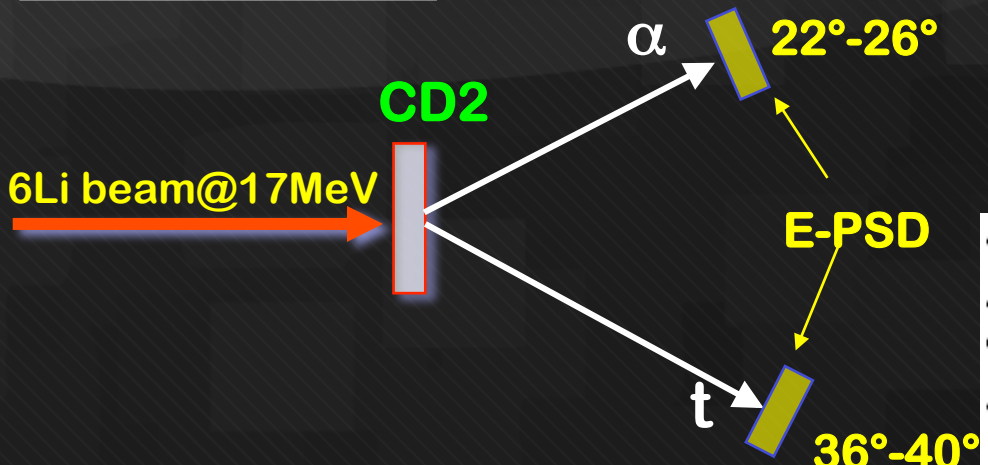


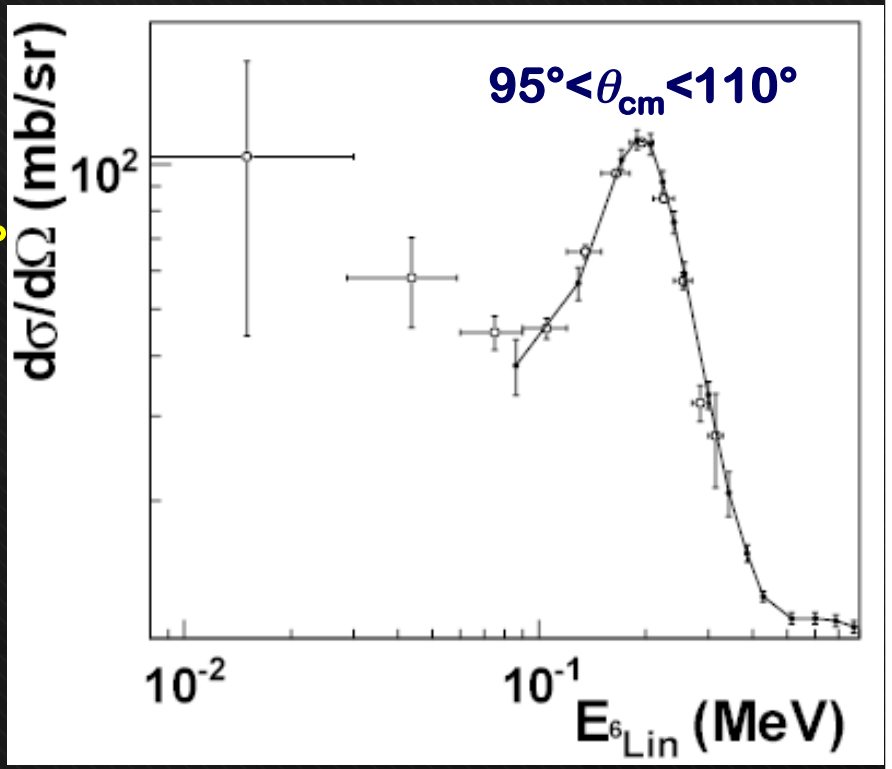
The directly measured cross section is integrated over the same θ_{cm} angular region and is averaged out at the same energy resolution of 120 keV

Eur. Phys. Jour. A, 25, 649 Volume: 25, 649-650 (2005)

The experiment ^{6}Li+n: second measurement

The new set-up → Resolution of 30 keV in 6Li-n relative energy





Data correction for the penetrability of the centrifugal barrier

$$\frac{d^3\sigma}{dE_b d\Omega_b d\Omega_B} \propto KF\left(\frac{d\sigma}{d\Omega}\right)^N \cdot |\Phi(p_s)|^2$$

$$\frac{d\sigma}{d\Omega} = C\left(\frac{d\sigma}{d\Omega}\right)^N \cdot P_l$$

J. of Phys. G, Nucl. Part.Phys. 37, 125105 (2010)

The $^{17}O+n \rightarrow {}^{14}C+\alpha$ reaction

NUCLEAR REACTORS

- the neutron induced reaction on ^{14}N and ^{17}O are the dominant sources of the radioactive isotope ^{14}C ($T_{1/2}$= 5730 yr).

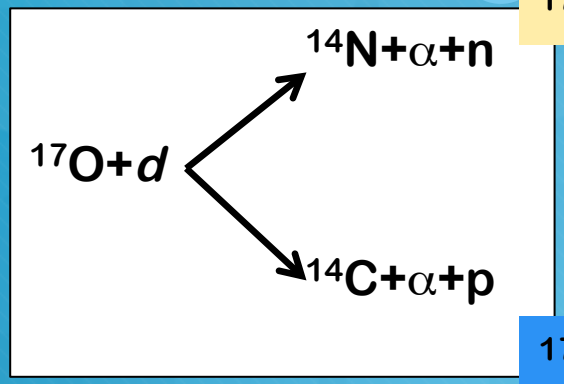
NUCLEAR ASTROPHYSICS

- In the inhomogeneous big-bang model the ^{14}C may act as a bottleneck in the production of elements heavier than A=17

- anomalies in $^{18}O/^{16}O$ and $^{17}O/^{16}O$ ratios found in asymptotic giant branch stars and in circumstellar Al_2O_3 meteorite grains

- neutron poison in the nucleosynthesis of the s-process elements

The experiment $^{17}O+n$



$^{17}O+p \rightarrow {}^{14}N+\alpha$

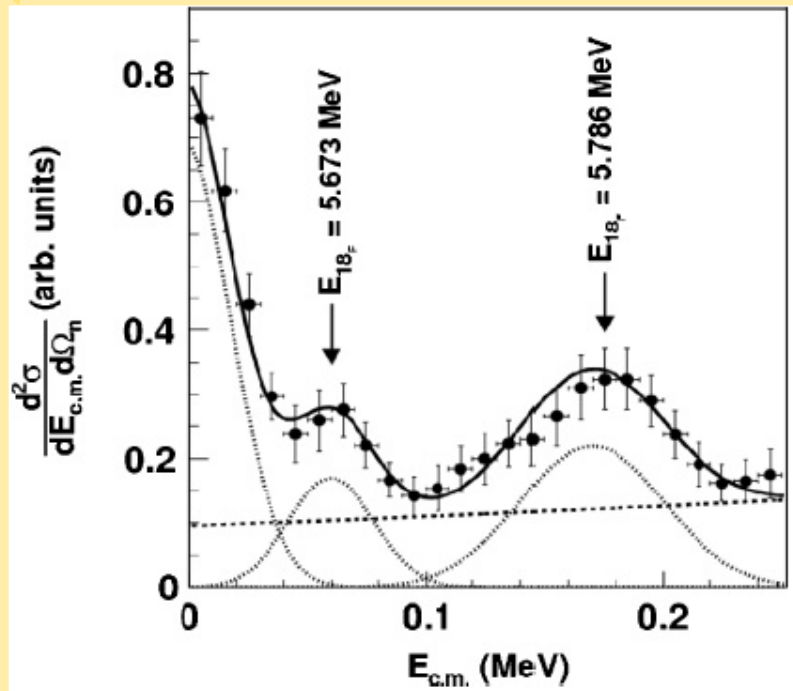
$^{17}O+n \rightarrow {}^{14}C+\alpha$

Two experiments were performed

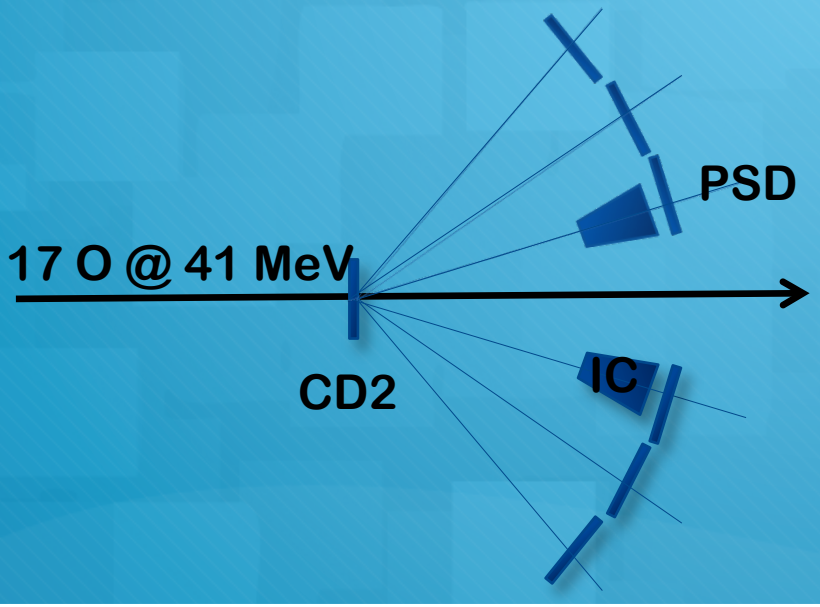
@LNS - Catania, Italy

@NSL – Notre Dame, IN, USA

PHYSICAL REVIEW C **82**, 032801(R) (2010)



EXPERIMENTAL SET-UP

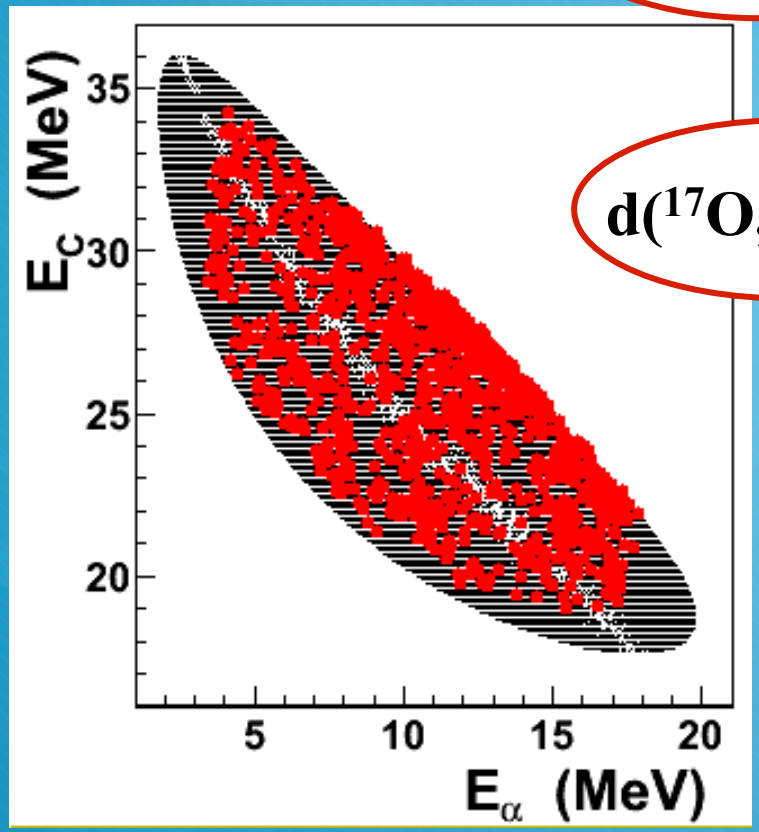


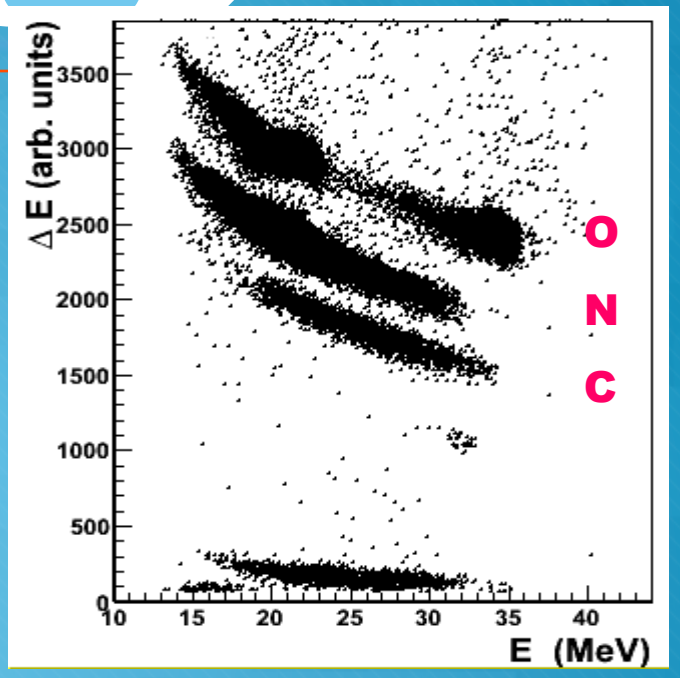
^{17}O+n -> first run

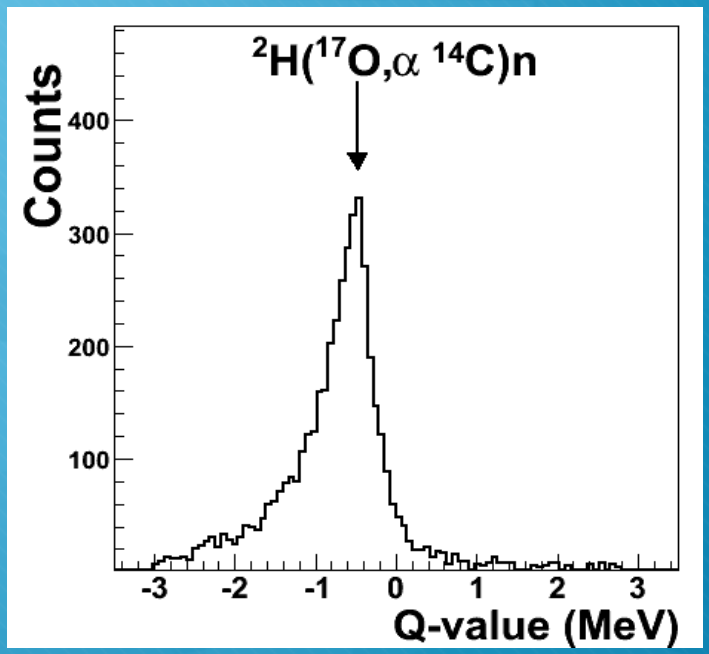
Indentification of the reaction channel

^{17}O(n,α)^{14}C

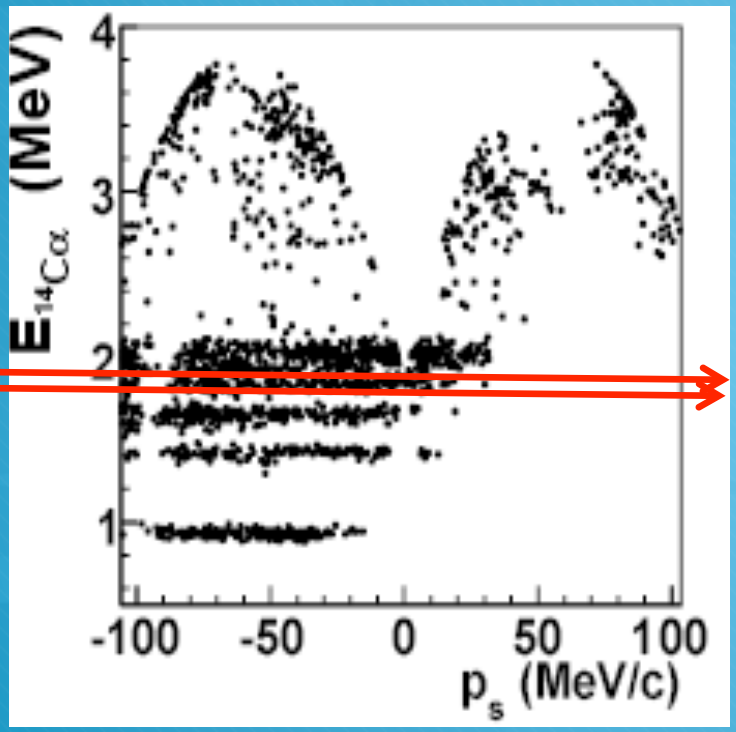
d(^{17}O,α ^{14}C)p

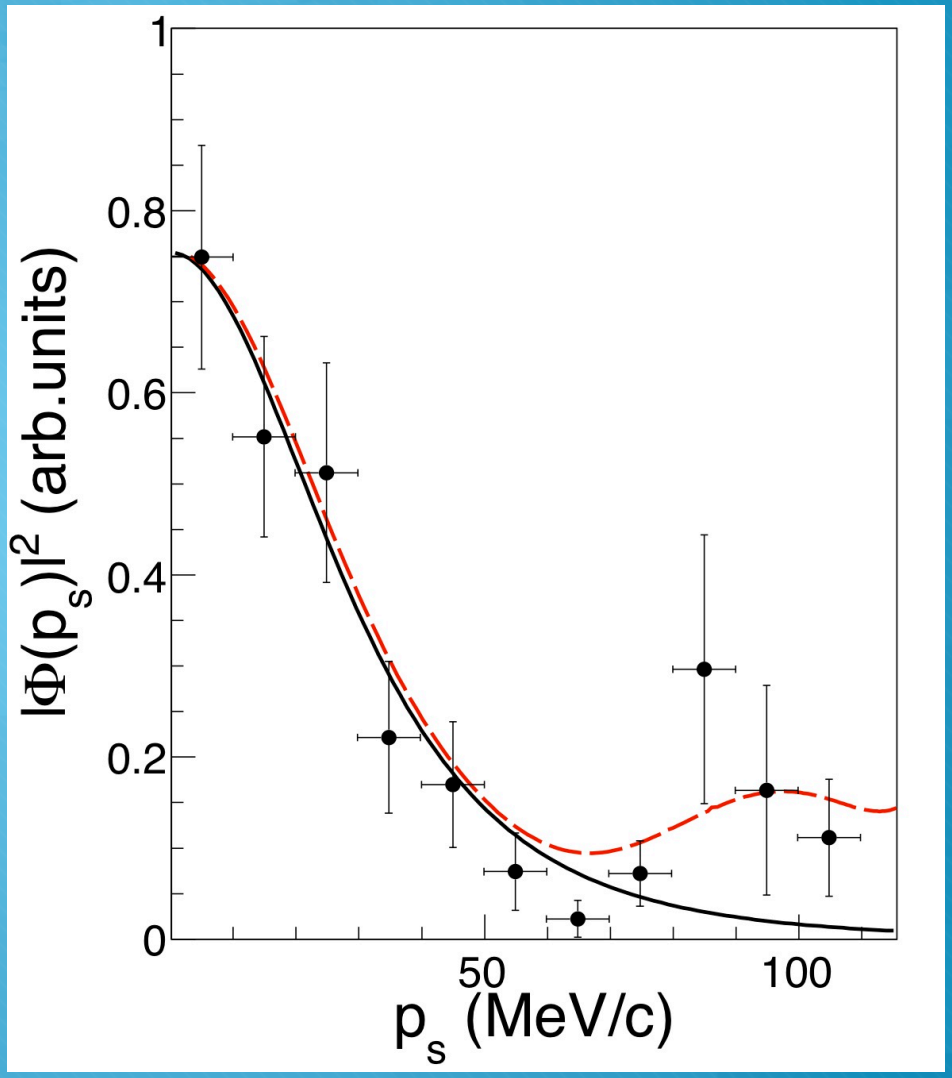






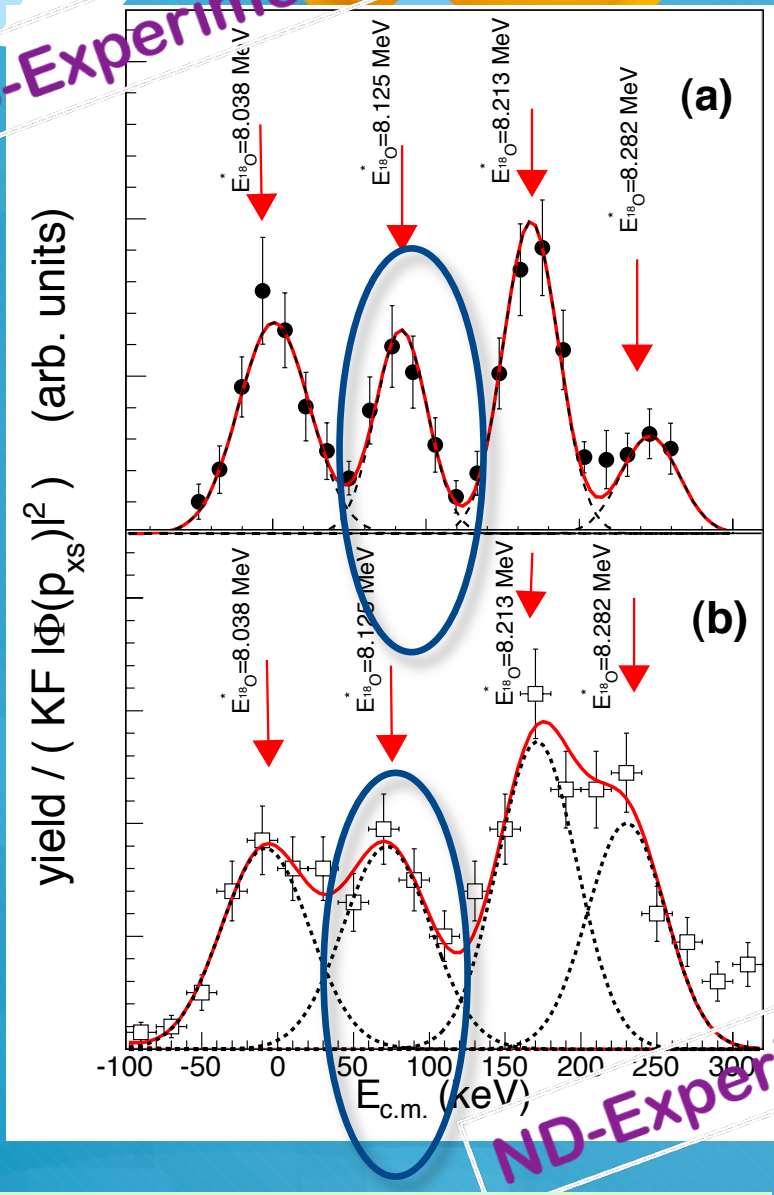
170+n > first run

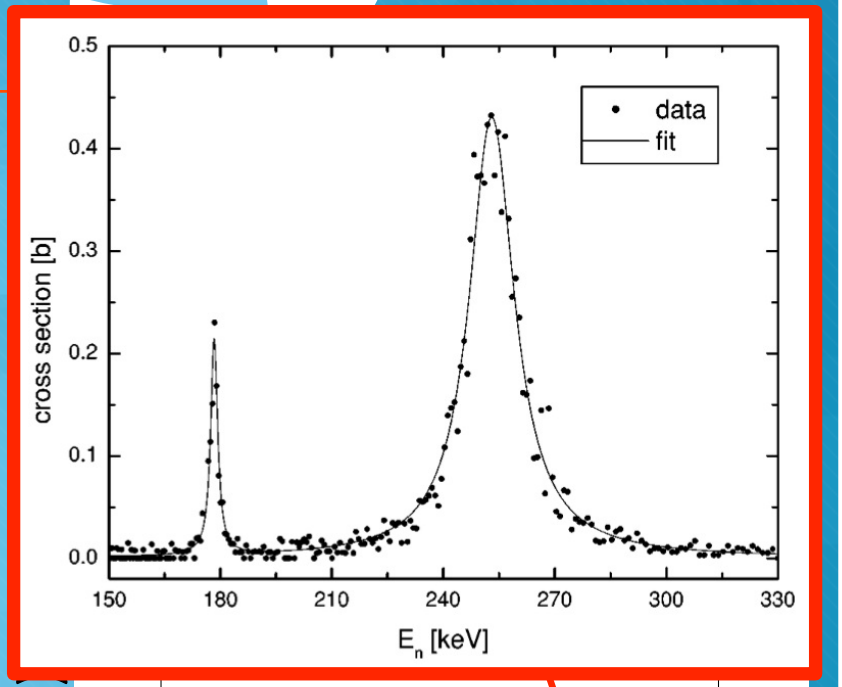




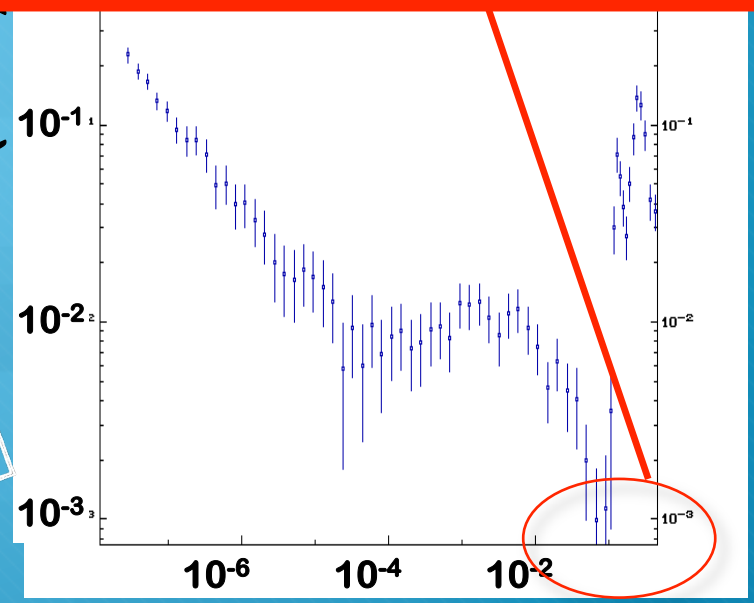
$^{17}O+n$

LNS-Experiment



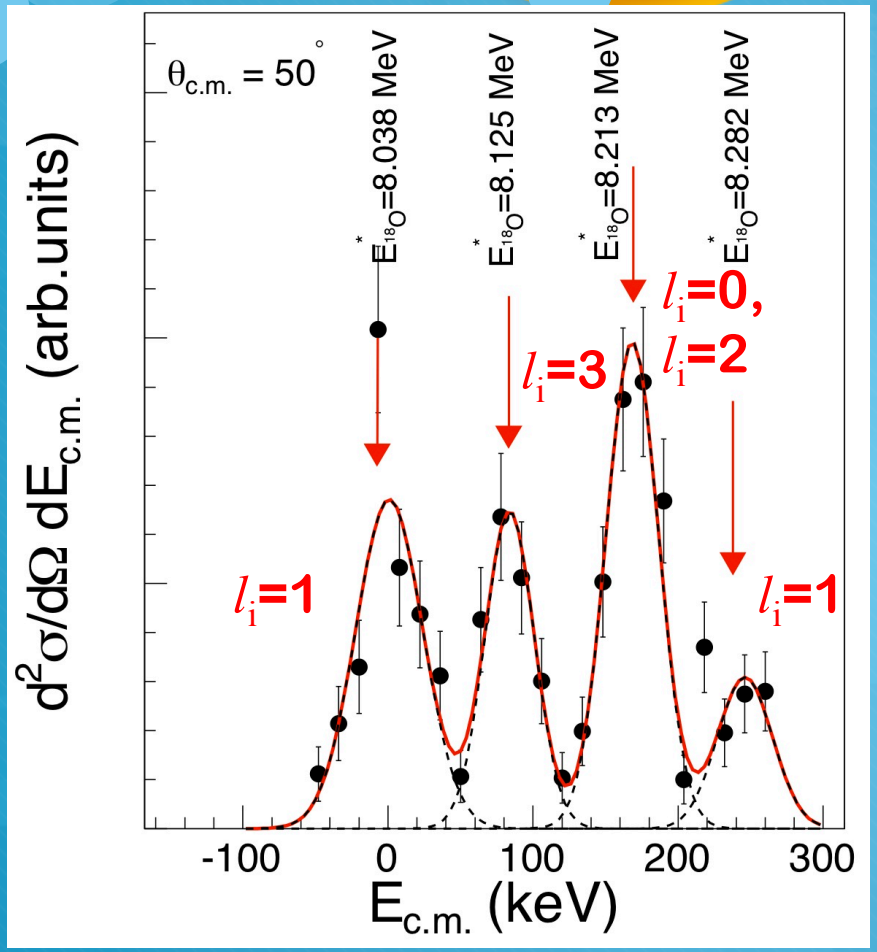


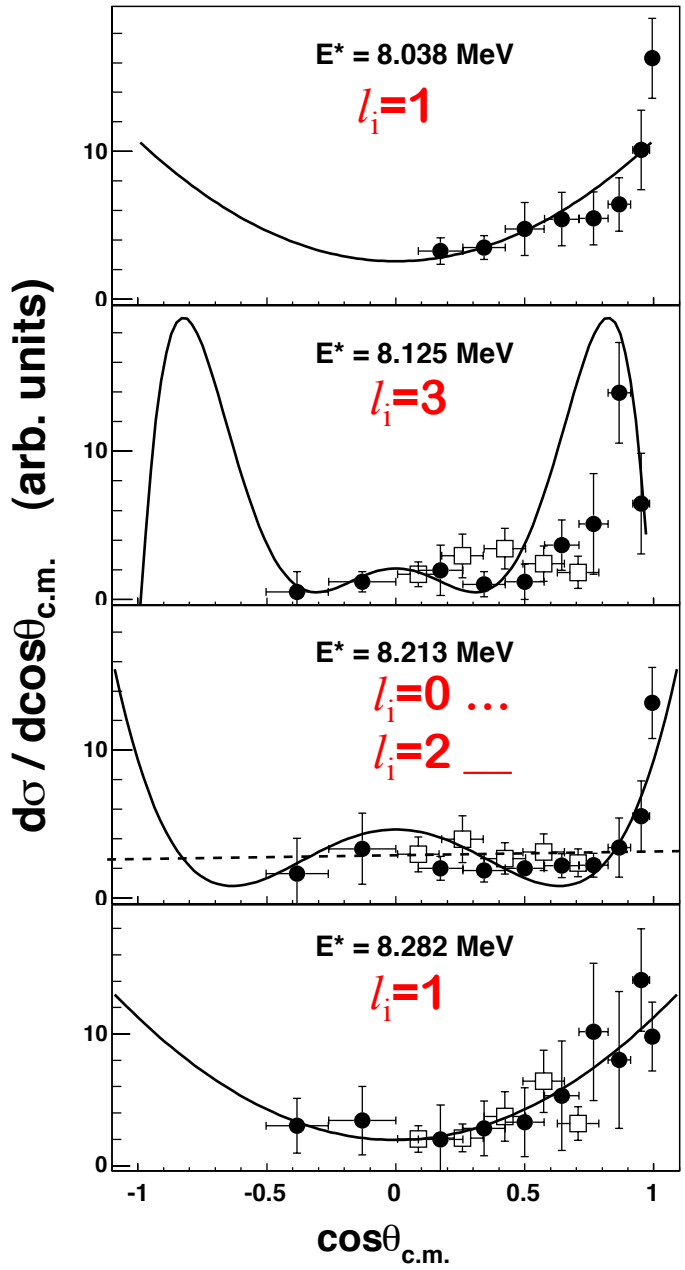
ND-Experiment



PHYSICAL REVIEW C 87, 012801(R) (2013)

^{17}O+n Angular Distributions





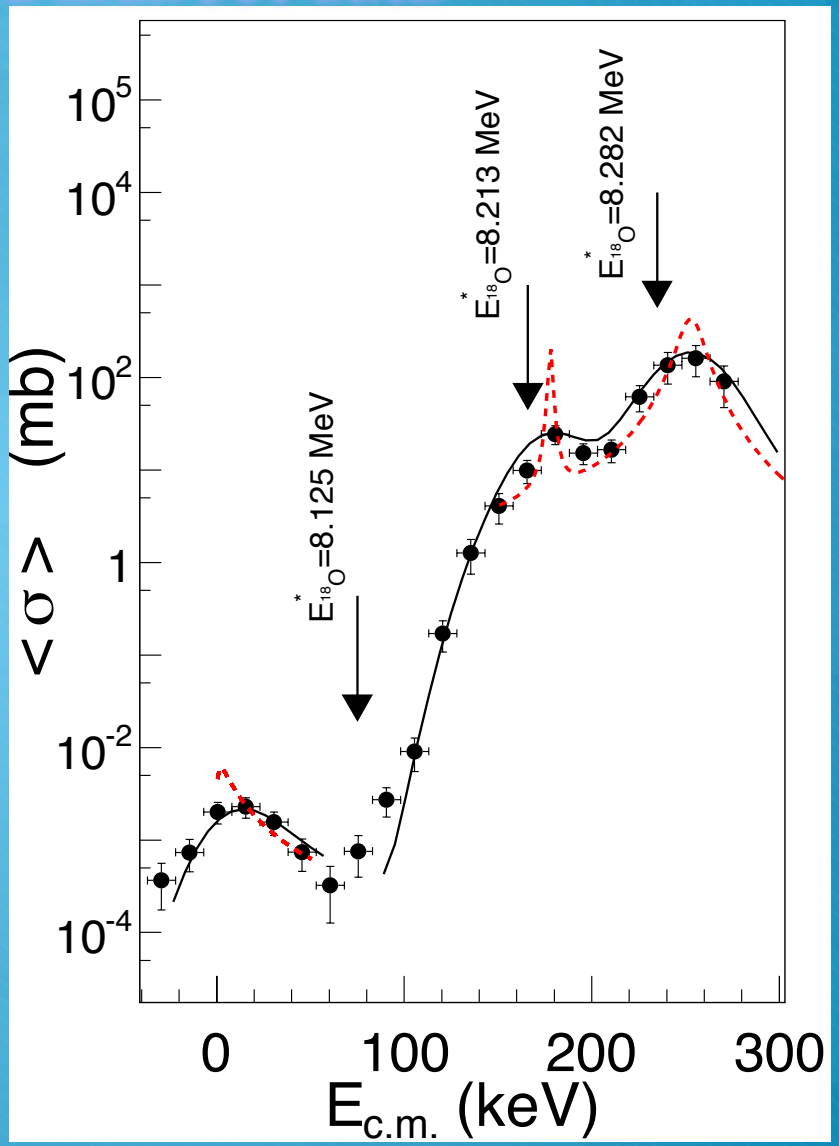
PHYSICAL REVIEW C 87, 012801(R) (2013)

^{17}O+n: cross section direct and indirect data

$$\frac{d^3\sigma}{dE_b d\Omega_b d\Omega_B} \propto KF\left(\frac{d\sigma}{d\Omega}\right)_N \cdot |\Phi(p_s)|^2$$

Data correction for the penetrability of the centrifugal barrier

$$\frac{d\sigma}{d\Omega} = C\left(\frac{d\sigma}{d\Omega}\right)_N \cdot P_l$$



PHYSICAL REVIEW C 87, 012801(R) (2013)

Conclusions

- The experiments demonstrated the possibility to measure a neutron induced reaction using the **DEUTERON AS SOURCE OF A VIRTUAL NEUTRON BEAM**

- The quasi-free mechanism can be used in the future to explore other neutron induced reactions of astrophysical interest, i.e. $^{14}N+n \rightarrow {}^{14}C+p$

- The Method offers the unique possibility to study neutron induced reactions on radioactive nuclei having short life times (minutes or less!)