Energy-differential measurement of the ^{12}C(n,p) reaction

Proposal to the INTC

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08. February 2017.

Motivation

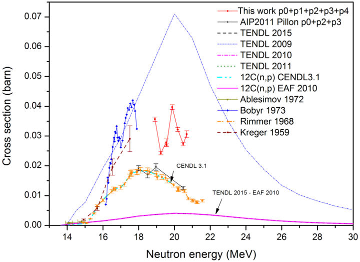
Importance of the $^{12}C(n,p)$ reaction:

- **dose estimation in radioprotection and hadrontherapy**
- **design of shields and collimators at accelerator facilities, spallation sources and irradiation facilities for fusion materials**
- **response of the diamond detectors to fast neutrons**
- **understanding of the nuclear structure of light nuclei**

Subject also under investigation by Pillon et al.

(shown with kind permission by M. Pillon)

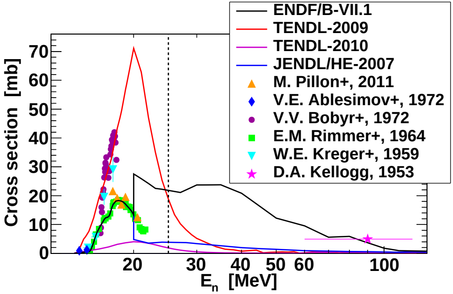
- continuation of work from **M. Pillon et al., NIMA 640 (2011) 185**
- the latest results presented at the ND2016 conference

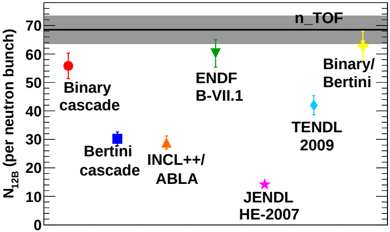


Status overview

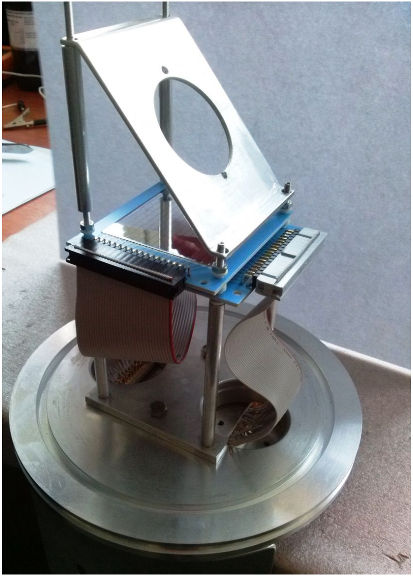
- **highly uncertain cross section throughout evaluated libraries, experimental data and between different models**
- **the latest integral measurement from n_TOF* indicates that existing data and evaluations may not be reliable**

*P. Žugec et al., EPJA 52 (2016) 101



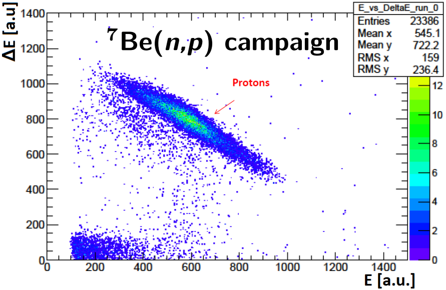


Proposed experimental apparatus

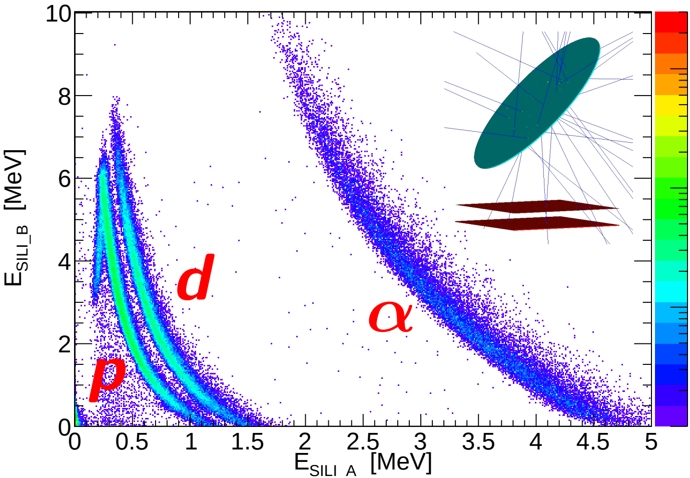


Detector features

- in vacuum
- out of beam
- telescope
- very thin Si-layers (20+300 μm)
- (limited) angular discrimination

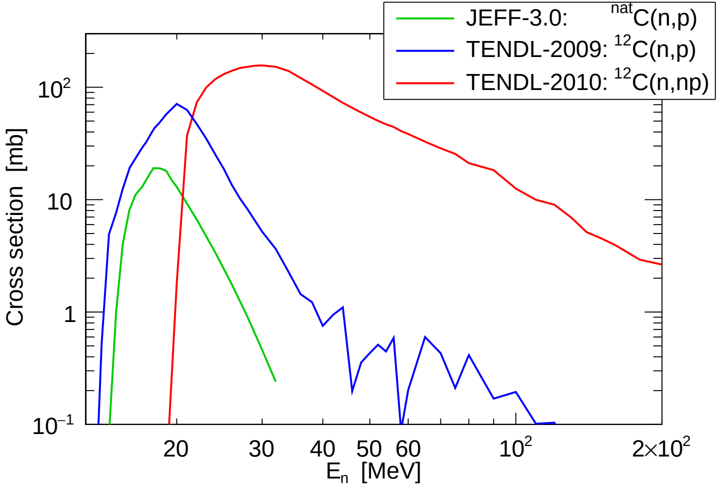


Expected particle discrimination (Geant4)



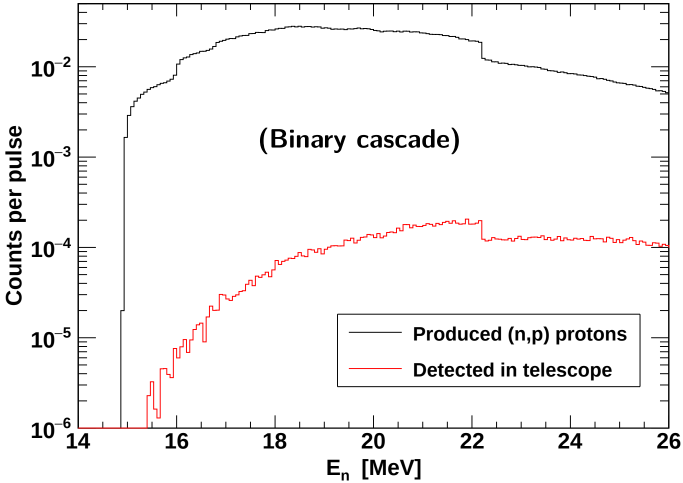
Intended use of neural networks for maximum efficiency in particle discrimination.

Expected (*n*,*p*) discrimination: up to 25 MeV



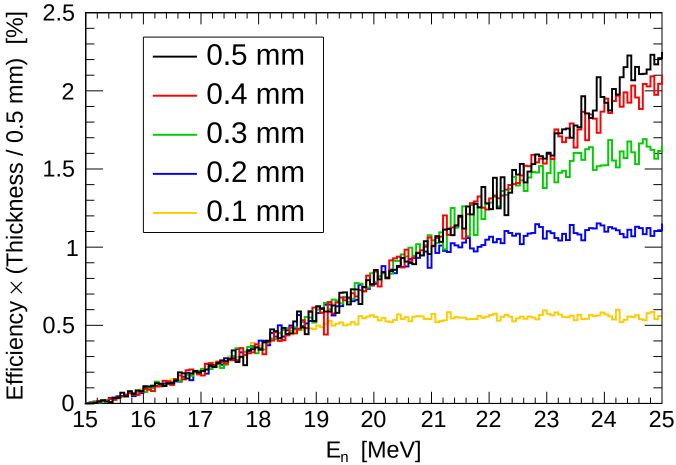
Above 25 MeV the proton yield from the ^{12}C(*n*,*np*) reaction is expected to start mixing with the ^{12}C(*n*,*p*) yield.

Distance to threshold: ~1 MeV



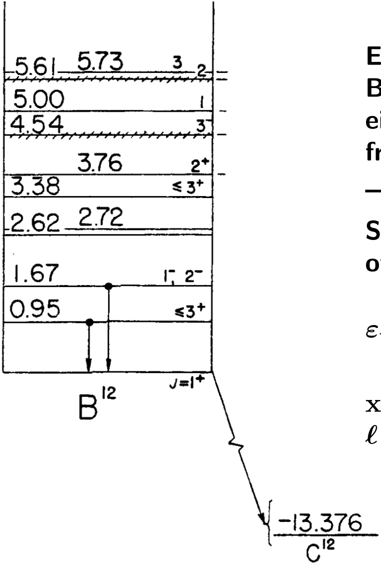
Detected counts reduced due to the limited solid angle, i.e. the geometrical efficiency. (discontinuities: an artifact of the Binary cascade, selected purely for the integral yield closest to the n_TOF value)

Sample thickness: 0.2–0.3 mm



0.2–0.3 mm: the optimum between the detected reaction yield up to 25 MeV and the background induced by the secondary reactions.

Excited states and angular distribution



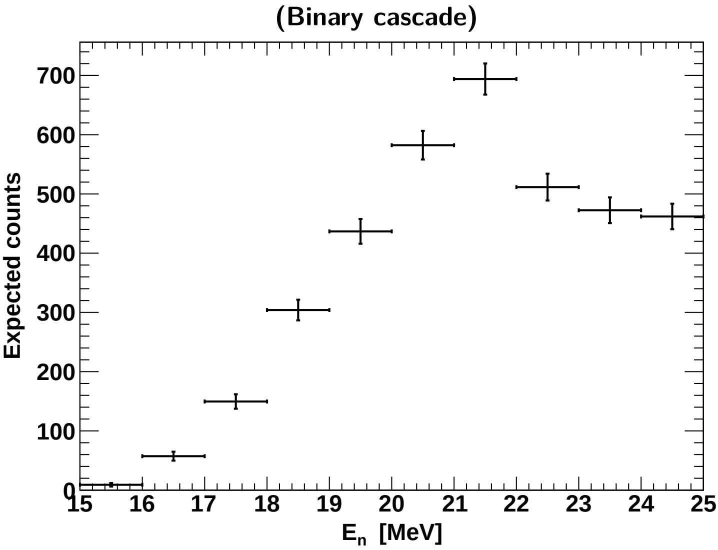
Excited states of ^{12}B are known! Branching ratios may be taken either from other experiments or from the calculations.

Strategy: expansion of efficiency over partial contributions:

$$\varepsilon_{\mathrm{tot}}(E_n) = \sum_{\mathrm{x},\ell} c_{\mathrm{x},\ell} \cdot \varepsilon_{\mathrm{x},\ell}(E_n)$$

x = excited state
ℓ = partial wave

Proposed number of protons: 2×10^{18}



Conclusions

- **the data on the ^{12}C(*n,p*) reaction are, at present, largely discrepant, between experiments, models and evaluations**
- **the latest integral measurement from n_TOF suggests that none of them are quite reliable**
- **we propose an energy-differential measurement up to 25 MeV, to be performed by detecting the protons from the ^{12}C(*n,p*) reaction**
- **the challenges will be met by using a high-end stripped Si-telescope, in combination with the advanced data analysis**
- **we ask for the total of 2×10^{18} protons on target**

Thank you for your attention!

Backup slide

NUCLEAR SCIENCE AND ENGINEERING: **123**, 17–37 (1996)

Calculation and Evaluation of Cross Sections and Kerma Factors for Neutrons up to 100 MeV on Carbon

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Received May 5, 1995
Accepted August 10, 1995

Abstract – *We present an evaluation of the interaction of neutrons with energies between 20 and 100 MeV with carbon nuclei. Our aim is to accurately represent integrated cross sections, inclusive emission spectra, and kerma factors, in a data library for use in radiation transport simulations of fast neutron radiotherapy. We apply the Feshbach-Kerman-Koonin-GNASH nuclear model code, which includes Hauser-Feshbach, pre-equilibrium, and direct reaction mechanisms, and use experimental measurements to optimize the calculations. We determine total, elastic, and nonelastic cross sections; angle-energy-correlated emission spectra for light ejectiles with $A \leq 4$ and gamma rays; and average energy depositions. Coupled-channel optical model calculations describe the total, elastic, and nonelastic cross sections well. Our results for charged-particle emission spectra agree fairly well with University of California–Davis as well as new Los Alamos National Laboratory and Louvain-la-Neuve measurements. We compare our results with the recent ENDF/B-VI evaluation and argue that some of the exclusive channels between 20 and 32 MeV should be modified. We also compare kerma factors derived from our evaluated cross sections with the measurements, providing an integral benchmark for our work. The evaluated data libraries are available as electronic files.*

I. INTRODUCTION

A number of new applications, such as radiation transport simulations of cancer radiotherapy and the accelerator-driven transmutation of waste, require evaluated nuclear data libraries when modeling the interaction of neutrons above 20 MeV (Ref. 1). The major efforts in nuclear data evaluation work over the last few decades have concentrated on reactions below 20 MeV for fission and fusion applications. Above this energy, transport calculations have been generally performed with codes that calculate nuclear cross sections on an event-by-event basis using intranuclear cascade (INC) methods. However, the underlying physical assumptions of the INC theory are not well satisfied below 100 MeV, and there is a need to extend evaluated nuclear data libraries up to higher energies. Furthermore, evaluated libraries can represent the physical interactions more accurately because they can be based on experimental measurements in addition to model calculations. Our

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17

Most modern fast neutron therapy facilities use a ^{9}Be(p,n) source reaction, which produces a broad spectrum of neutrons with energies up to 70 MeV. (...) With the exception of hydrogen, sufficiently accurate nuclear data do not yet exist in this energy range to allow neutron therapy to reach its full potential. Because "standard man" consists (by mass) of hydrogen (10%), carbon (18%), nitrogen (3%), oxygen (65%), and various trace elements (4%), an accurate understanding of neutron nuclear reactions on carbon is essential.

M. B. Chadwick et al.
Nucl. Sci. Eng. 123, 17 (1996)