Supported by the Croatian Science Foundation; Project No. 8570.

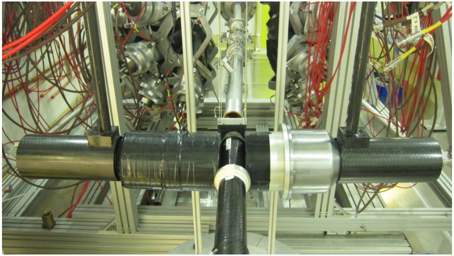
Recent developments in the analysis of $^{nat}C(n,p)$ and $^{nat}C(n,d)$ reactions

Petar Žugec

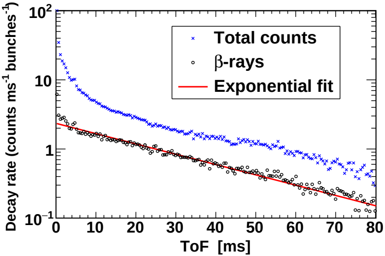
20. July 2022.

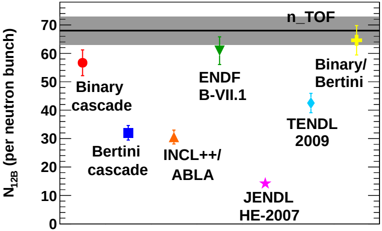
Quick reminder of the motivation

An integral $^{12}C(n,p)^{12}B$ measurement was first performed, using C_6D_6 liquid scintillation detectors and detecting β-rays from a decay of ^{12}B.



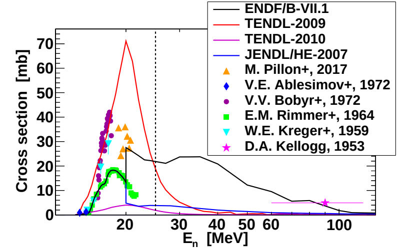
Integral result was found to be higher than predicted by all available cross section data (simulated or evaluated).

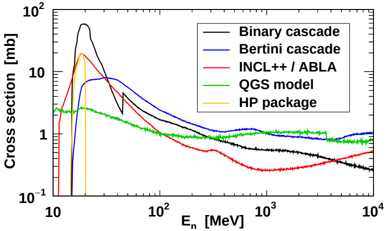




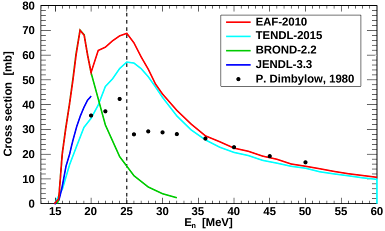
Status of the available cross section data

^{12}C(n,p)

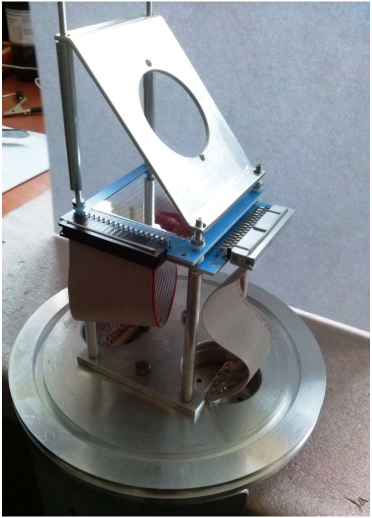




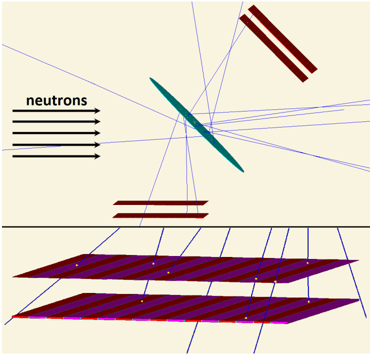
^{12}C(n,d)



Setup for the energy-differential measurement



Silicon-telescope principle:
coincidental detection between ΔE and E layers



Technical publications

Our data require a "heavy attack". To this end we have introduced some new procedures:

[1] P. Žugec et al., JINST **15** (2020) P02011

[2] P. Žugec et al., NIMA **983** (2020) 164606

[3] P. Žugec et al., NIMA **1033** (2022) 166686

They are to be implemented in this order: [2]→[3]→[1].

Published by IOP Publishing for Sissa Medialab
Received: *January 13, 2020*
Accepted: *January 19, 2020*
Published: *February 12, 2020*

Study of a data analysis method for the angle resolving silicon telescope

P. Žugec,[a,1] M. Barbagallo,[b,c] J. Andrzejewski,[d] J. Perkowski,[d] N. Colonna,[b] D. Bosnar,[a] A. Gawlik,[d] M. Sabaté-Gilarte,[c,e] M. Bacak,[c,f] F. Mingrone,[c] E. Chiaveri[c] and M. Šako[a] on behalf of n_TOF collaboration

Nuclear Inst. and Methods in Physics Research, A 983 (2020) 164606
Contents lists available at ScienceDirect
Nuclear Inst. and Methods in Physics Research, A
journal homepage: www.elsevier.com/locate/nima

A synchronization method for the multi-channel silicon telescope

P. Žugec [a,*], M. Barbagallo [b,c], J. Andrzejewski [d], J. Perkowski [d], N. Colonna [b], D. Bosnar [a], A. Gawlik [d], M. Sabaté-Gilarte [c,e], M. Bacak [c,f], F. Mingrone [c], E. Chiaveri [c], The n_TOF Collaboration [1]

Nuclear Inst. and Methods in Physics Research, A 1033 (2022) 166686
Contents lists available at ScienceDirect
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Machine learning based event classification for the energy-differential measurement of the $^{nat}C(n,p)$ and $^{nat}C(n,d)$ reactions

P. Žugec [a,*], M. Barbagallo [b,c], J. Andrzejewski [d], J. Perkowski [d], N. Colonna [b], D. Bosnar [a], A. Gawlik [d], M. Sabaté-Gilarte [c,e], M. Bacak [c,f], F. Mingrone [c], E. Chiaveri [c], The n_TOF Collaboration [1]

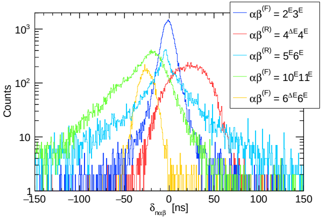
[2] A synchronization method

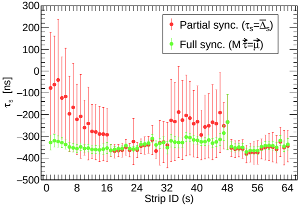
Completely unplanned; we were "lucky" enough to have a problem that led to a publication.

"Source of all evil": we want to synchronize our SITE-pulses to a γ-flash pulse from PKUP (γ-flash in SITE is unreliable).

Gist of the method: consider not only SITE-PKUP correlations, but also the correlations between all triggered pairs of SITE strips.

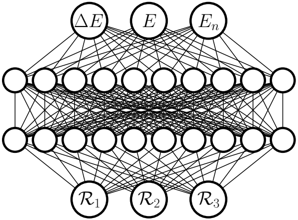
Epilogue: in a later discussion with M. Bacak we have identified the meaning of $\tau \approx 300$ ns offests between SITE and PKUP. They correspond to **extra** 100 m of cables (relative to the neutron flight path) going from PKUP to DAQ: $\tau \approx (L_{\text{PKUP-DAQ}} - L_{\text{beamline}})/c$.

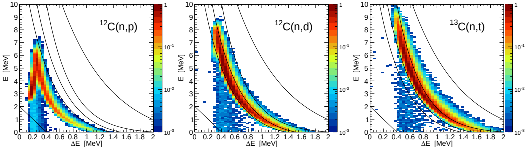




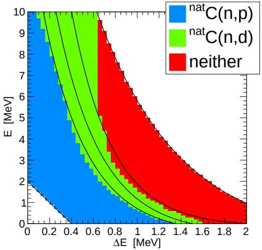
[3] Machine learning (neural networks)

Simulate reaction products (protons, deuterons, tritons) of well defined kinematics and let the computer sort them out. Why? Because it has to be done for 60–70 pairs of strips. Separately! And because the separation "bends" in a 3D parameter space $(E_n, \Delta E, E)$.





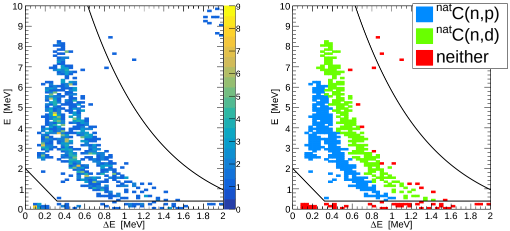
NEURAL NETWORK (TMultiLayerPerceptron from ROOT)



Application to the experimental data

Nice separation, could even be done manually.

(If I weren't so lazy.)



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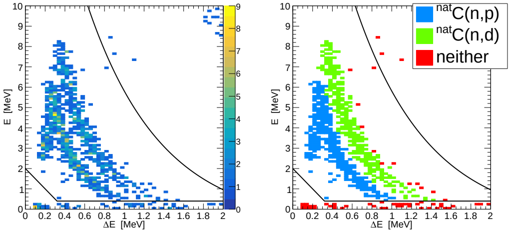
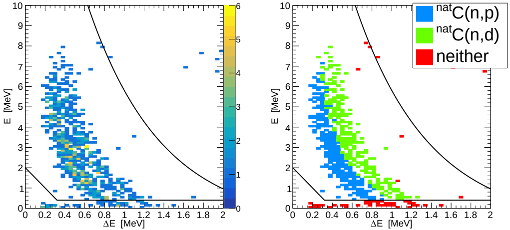
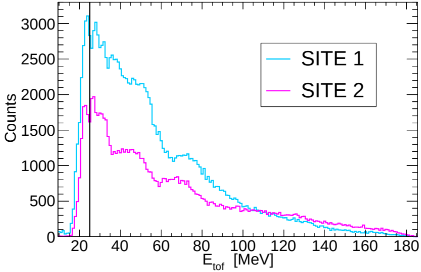


But where to manually separate it now?

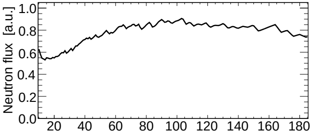
(Lesson: laziness is the mother of invention.)



Experimental counts



Above 25 MeV: indistinguishable mixture of protons, deuterons, tritons and even protons from (n,np) reaction. Structures above 25 MeV are **not** due to the shape of neutron flux.



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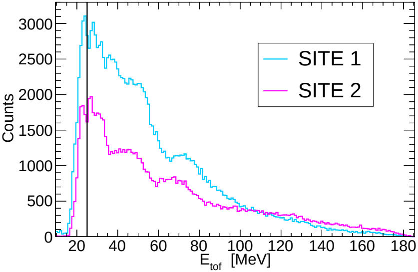

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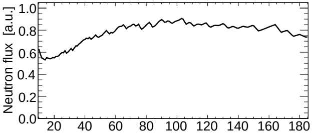
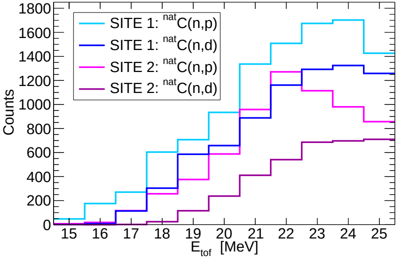
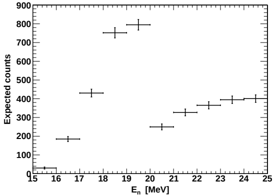


Classified (n,p) and (n,d) data.

(Not secret, just categorized :)



Compare (n,p) statistics to INTC proposal.



SITE1+SITE2 = **3.5**× more than expected!

[1] Cross section extraction

$$\frac{\mathrm{d}N_{ij}(E_\mathrm{tof})}{\mathrm{d}E_\mathrm{tof}} = \sum_{\mathcal{C}\in\{^{12}\mathrm{C},^{13}\mathrm{C}\}} \eta_\mathcal{C} \int_0^\infty \mathrm{d}E_n \times R(E_\mathrm{tof}, E_n)\phi(E_n) F_{ij;\mathcal{C}}(E_n) \boldsymbol{\sigma_\mathcal{C}(E_n)}$$

- i,j: lables for $\Delta E - E$ strips
- N_{ij}: counts detected by ij-pair
- E_tof: eng. reconstructed from ToF
- E_n: true neutron energy
- $R(E_\mathrm{tof}, E_n)$: resolution function of the neutron beam
- $\phi(E_n)$: neutron flux
- $\mathcal{C}$: carbon isotopes from natural abundance (^{12}C and ^{13}C)
- $\eta_\mathcal{C}$: number of atoms per unit area for particular isotope
- $\boldsymbol{\sigma_\mathcal{C}(E_n)}$: sought cross section(s)
- $F_{ij;\mathcal{C}}(E_n)$: all other physical technicalities (next page)

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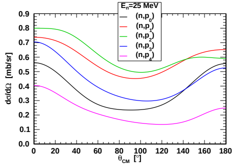
The method will produce cross sections σ_{12} and σ_{13} for two isotopes separately. The separation for ^{13}C is expected to be highly uncertain due to its low natural abundance, so the main result will be the cross section for natural carbon:

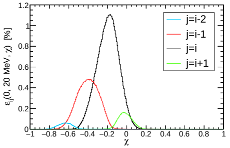
$$\sigma_\mathrm{nat} = \frac{\eta_{12}\sigma_{12} + \eta_{13}\sigma_{13}}{\eta_{12} + \eta_{13}} = 0.989\sigma_{12} + 0.011\sigma_{13}$$

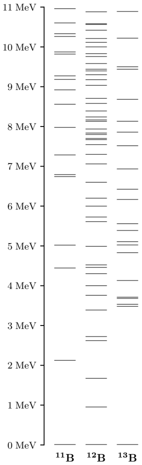
Computational input

$$F_{ij;\mathcal{C}}(E_n) = \sum_{\mathrm{x}} \rho_{\mathcal{C}}(\mathrm{x}, E_n) \int_{-1}^{1} \mathrm{d}(\cos\theta) \times \varepsilon_{ij;\mathcal{C}}(\mathrm{x}, E_n, \cos\theta) A_{\mathcal{C}}(\mathrm{x}, E_n, \cos\theta)$$

- x: excited states in daughter nuclei (for considered reactions on C-isotopes: ^{11}B, ^{12}B, ^{13}B)
- θ: emission angle of reaction products (p/d), either in LAB or CM
- $\rho_{\mathcal{C}}$: branching ratios for excited states
- $A_{\mathcal{C}}$: angular distribution of products
- $\varepsilon_{ij;\mathcal{C}}$: detection efficiency







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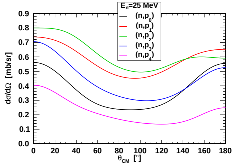

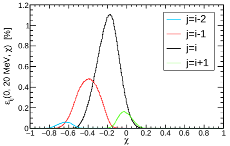

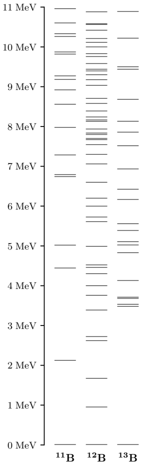

All these data **are obtainable**, from databases (excited states x), simulations ($\varepsilon_{ij;\mathcal{C}}$) or theoretical calculations ($A_{\mathcal{C}}$, $\rho_{\mathcal{C}}$). The main source of $A_{\mathcal{C}}$ and $\rho_{\mathcal{C}}$ will be TALYS calculations. Analysis will also be performed with "dummy" distributions (isotropic $A_{\mathcal{C}}$ and artificial $\rho_{\mathcal{C}}$) in order to estimate the systematic uncertainty due to TALYS.

Thank you for your attention!