Studies on neutron-induced reactions with MEDLEY at GANIL

Lucas de Arruda Serra Filho (GANIL and Uppsala University)*

Dr. Diego Tarrío (Uppsala University)
Dr. Stephan Pomp (Uppsala University)
Dr. Xavier Ledoux (GANIL)
Dr. Diego Ramos (GANIL)
and the **Medley team**

***email: dearruda@ganil.fr**

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We want to measure **double differential cross sections** (DDX) for light charged particles (LCP).

From DDXs we can obtain:

- **single-differential cross-sections** with respect to the angle of the emitted particle (for each neutron energy);
- integrated (n, LCP) **production cross sections** as a function of neutron energy.

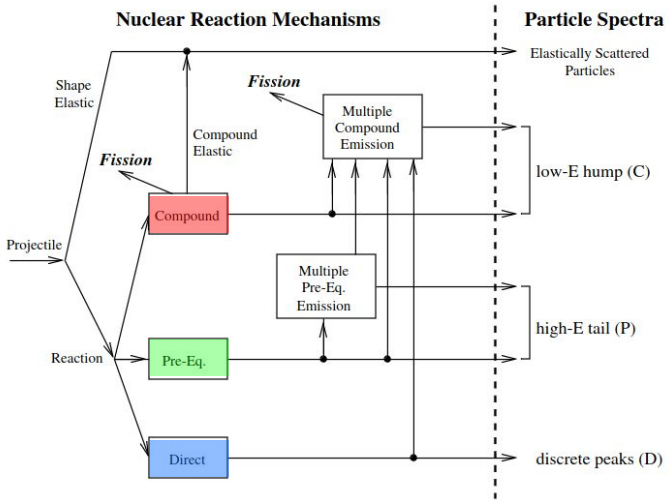


Figure from TALYS code manual.

62 MeV 56Fe(p,Xp)

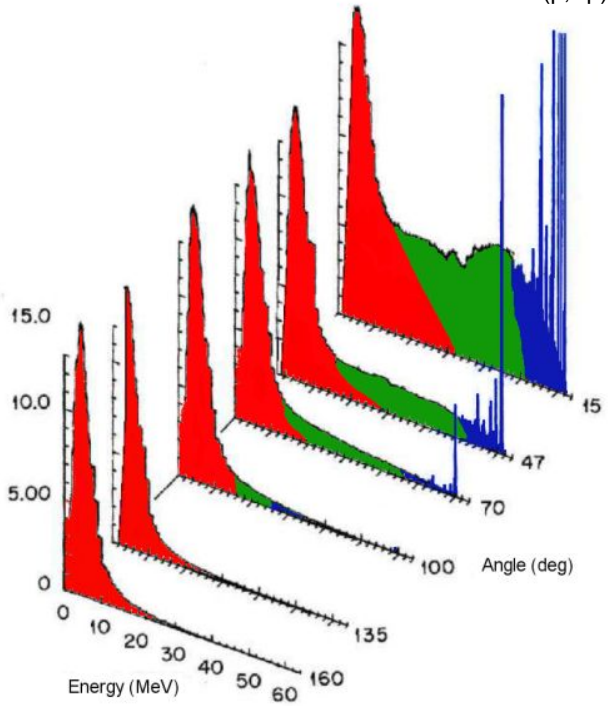
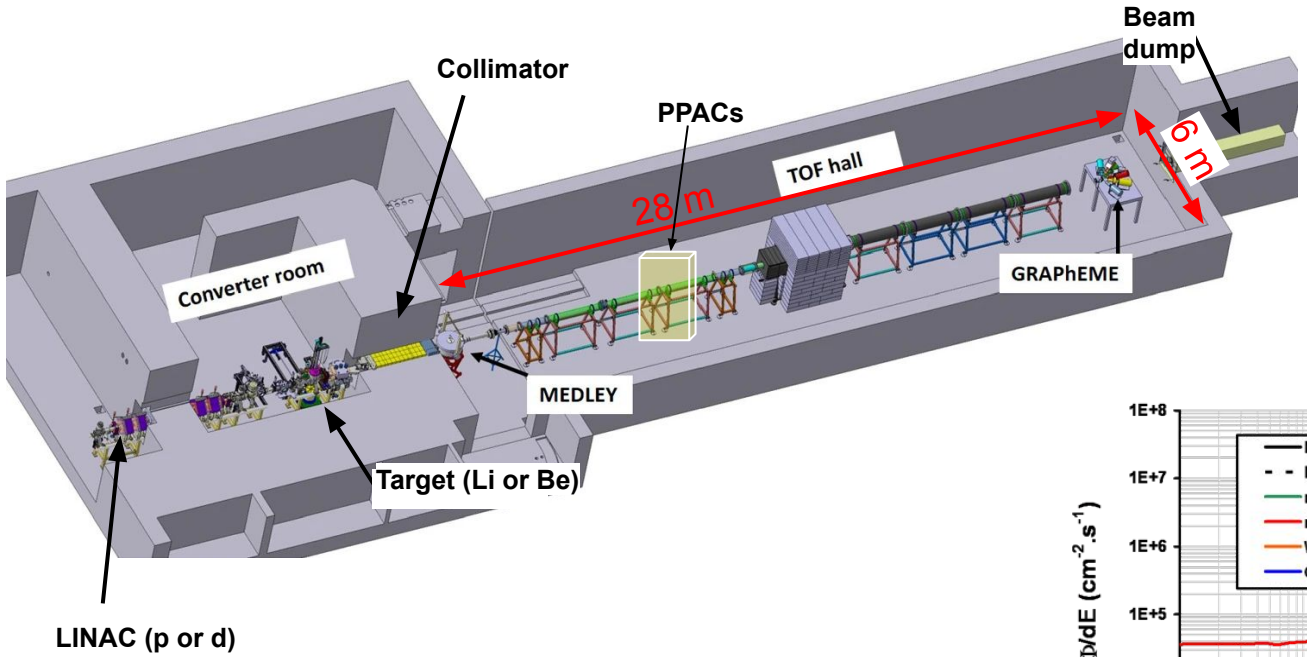
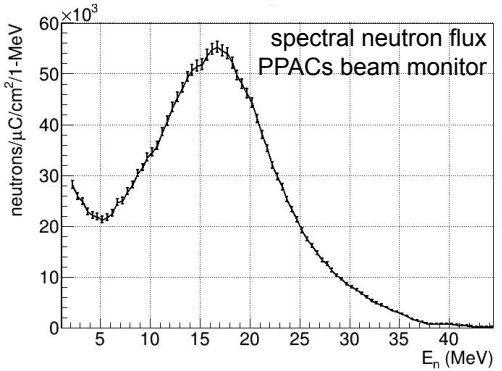
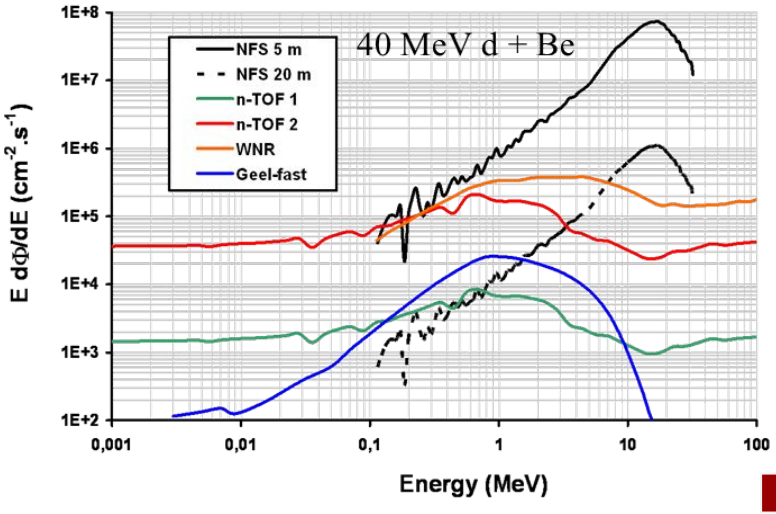


Figure from S. Hilaire - CEA,DAM,DIF.

The Neutrons for Science (NFS) facility at GANIL





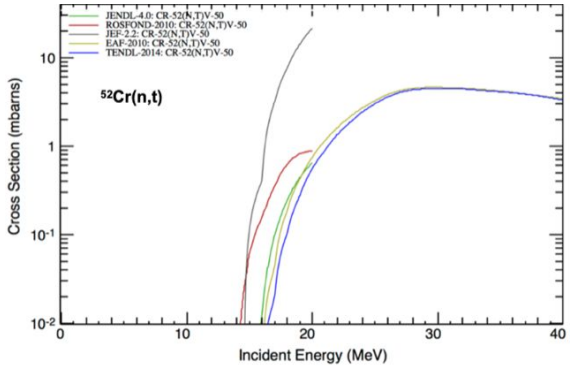


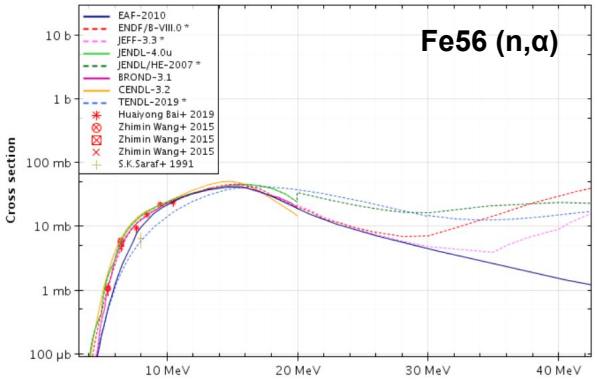
We use NFS (Neutrons for Science) new facility which provides white neutron spectra (2 MeV to 40 MeV) with reasonable flux.

Experiments since 2022:

- nat-C
- nat-Fe
- nat-Cr

Better nuclear data regarding light-ion (p, d, t, ^{3}He, and α) production induced by neutrons are of great interest for several applications; The data are really scarce for a number of reactions;



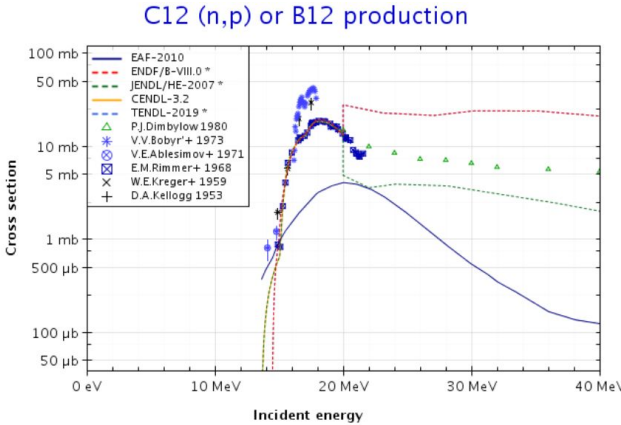


This data is important for fusion applications:

- Embrittlement of the material due to formation of gas inside it.
- Interpretation of IFMIF-DONES (International Fusion Materials Irradiation Facility – Demo Oriented NEutron Source) data.

And more diverse applications:

- Radiation protection
- Dosimetry for aviation and spaceflight, electronics (single-event effects)



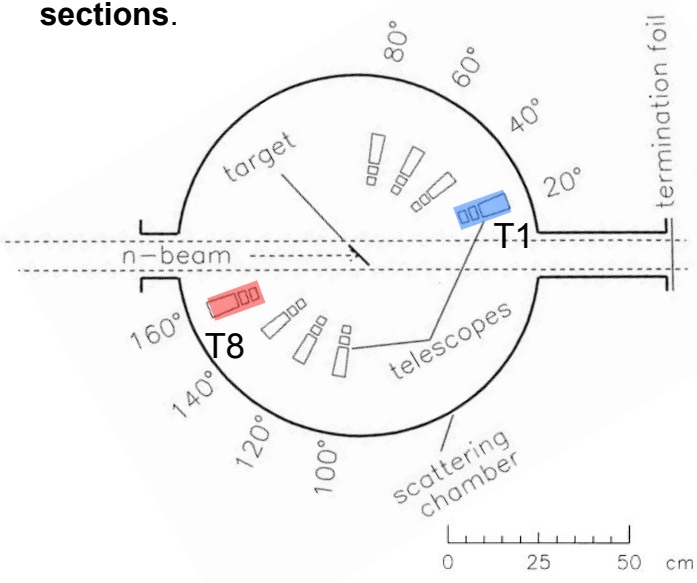
There are some other recent data not included in the figures:

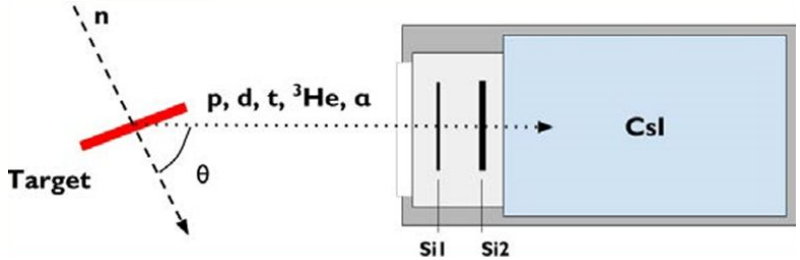
Fe-nat(n,α), Cr-nat(n,α): Kunieda (2012)

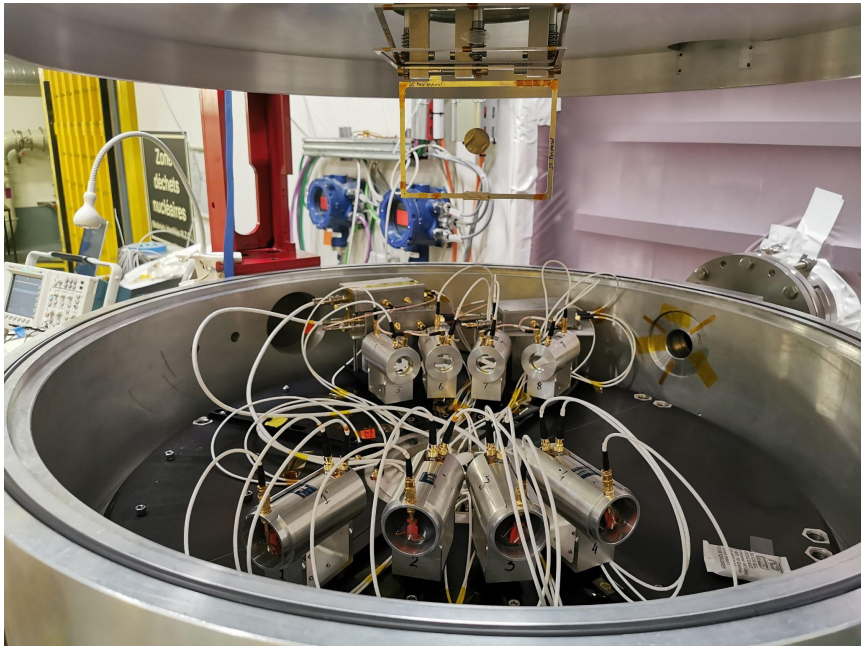
C(n,dX), only between 25 and 50 MeV. Zengqi Cui et al (2021).

The Medley setup

The objective is to measure **double differential cross sections**.





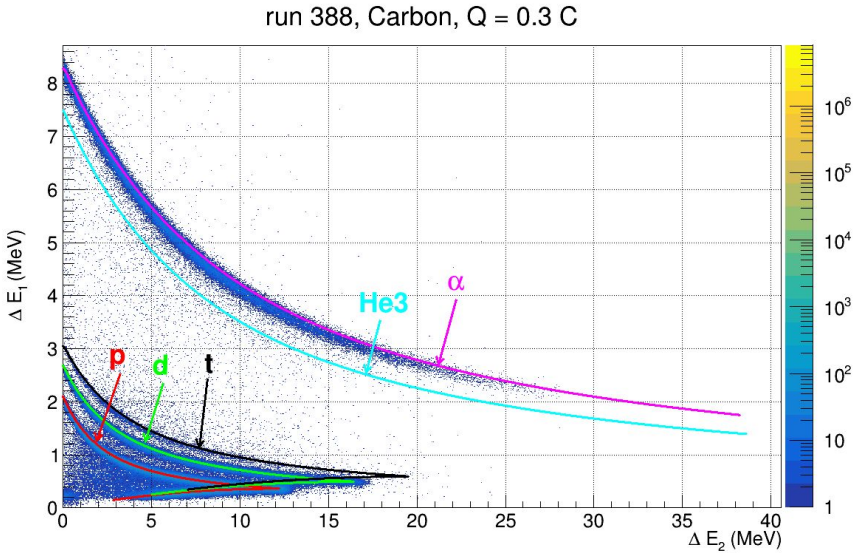


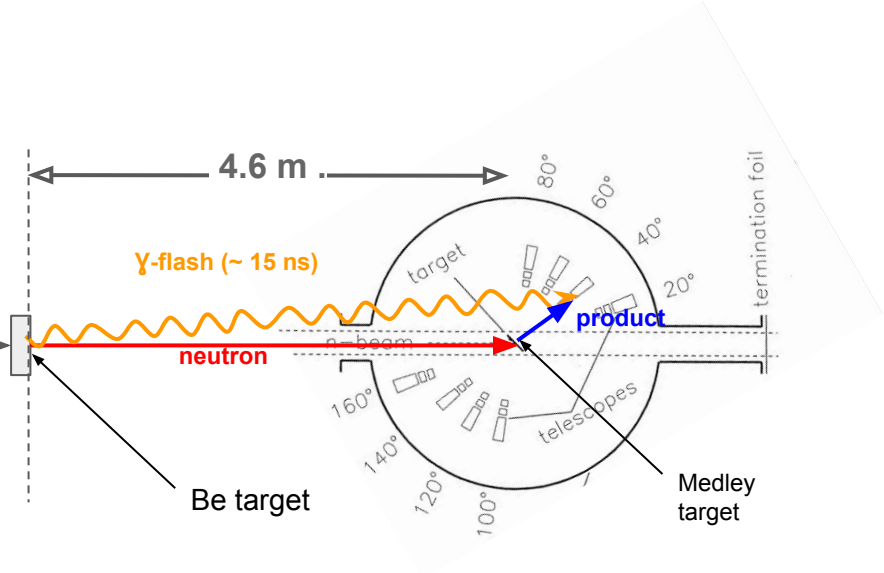
Medley (opened) chamber with Fe sample installed.

- 8 Si-Si-CsI(Tl) telescopes for light ion identification.
- coverage: 20º to 160º (20º steps); ~20 msr/telescope.

Adapting the Medley setup for NFS

Medley setup provides good resolution for PID:



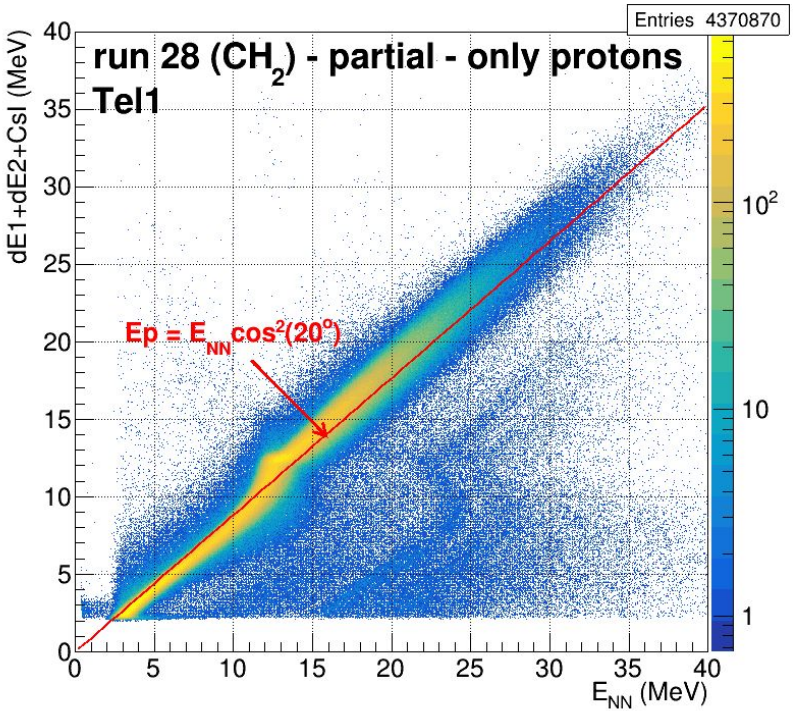


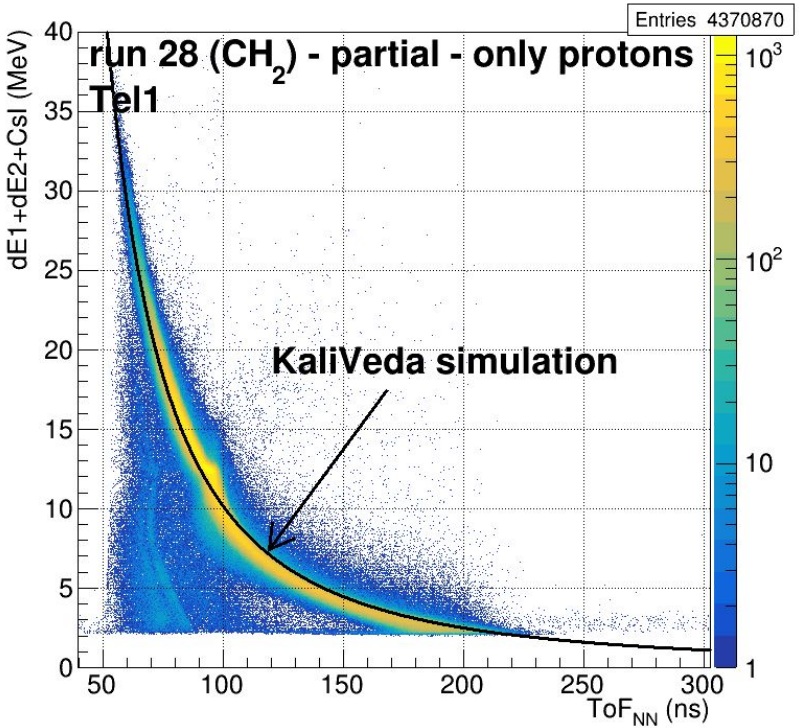
- The telescopes are self-triggered with exception to the CsI detectors
- A Good energy calibration will provide a good neutron energy measurement (ToF technique):

$$ToF_{MEASURED} = ToF_{NEUTRON} + ToF_{PRODUCT}(E_{particle})$$

Nonlinearity in ToF

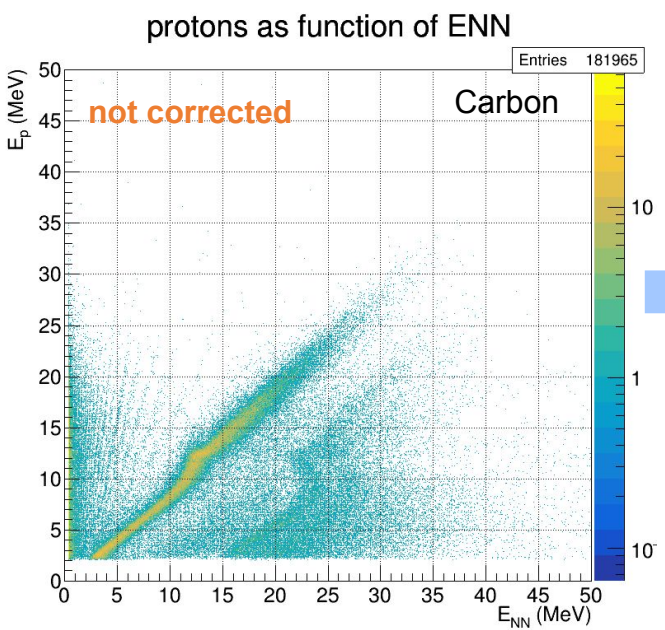
Since the beginning of the analysis we are dealing with non linearities in the the timing measurements. In the last campaign we were able to study the problem in more detail.

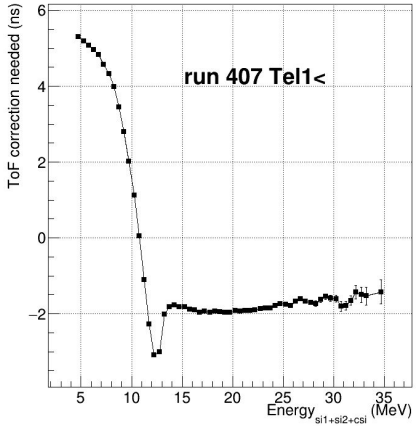


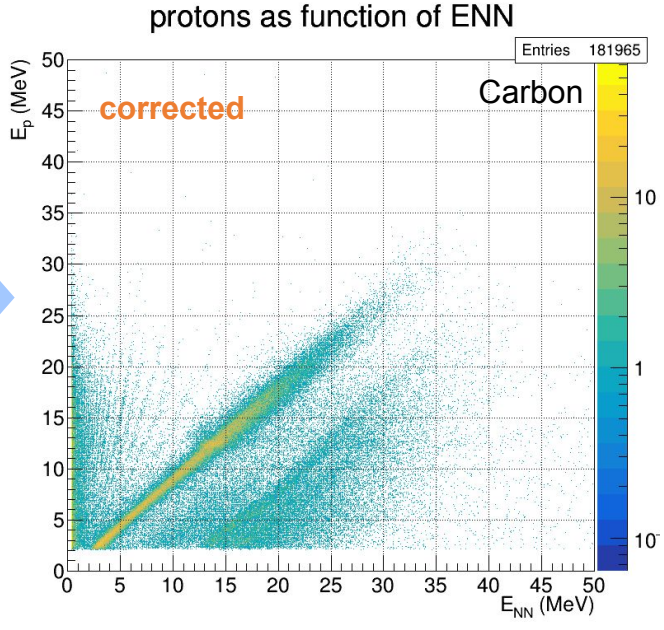


A correction can be obtained

For protons, the correction is calculated as the difference between the measure ToF_{NN} value and the expected one (since they are proportional to proton's energy).

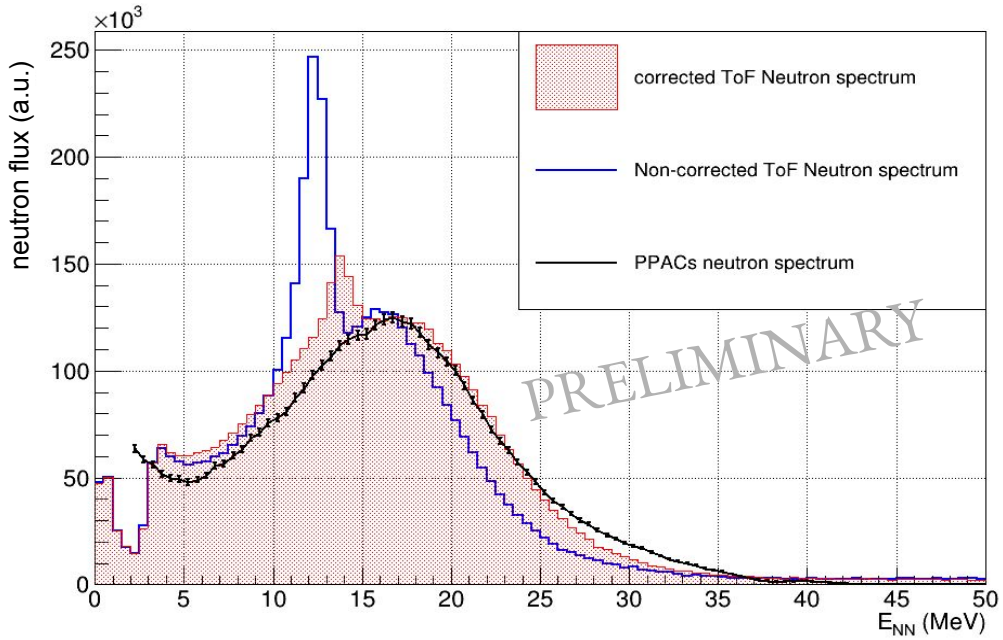






NFS's spectral neutron flux from elastic scattering

With ToF properly corrected, we could obtain the NFS' spectral neutron flux using the ToF method:

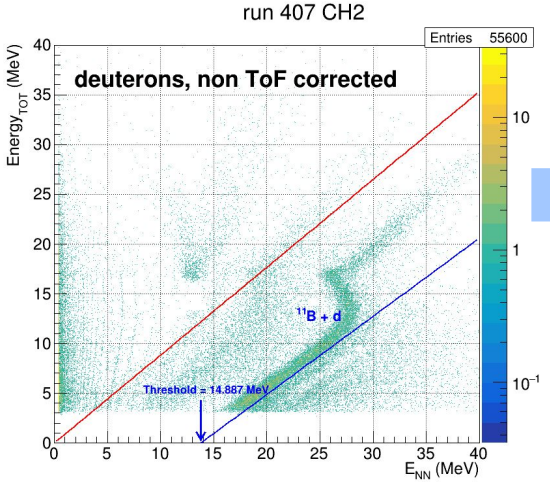


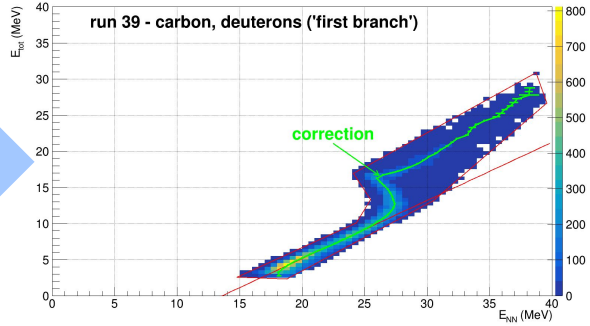
obtained from ToF

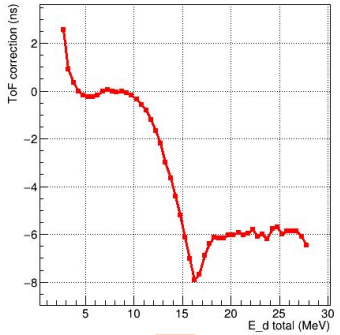
- The correction strongly enhances the agreement between Medley setup and the PPACs bema monitor.
- There is still room to improve, producing a second order correction to solve the residual peak.
- CATRIN experiment (RADNEXT 2022)

Obtaining the correction for deuterons

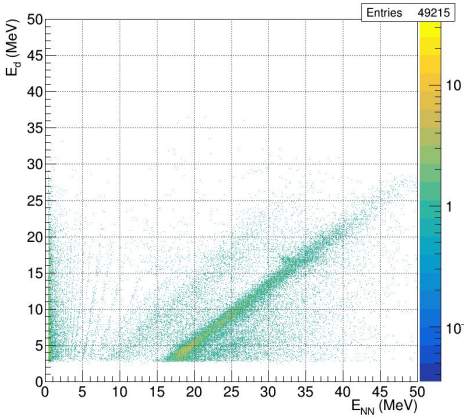
For deuterons, the correction is obtained from energy difference, and converted to TOF difference.







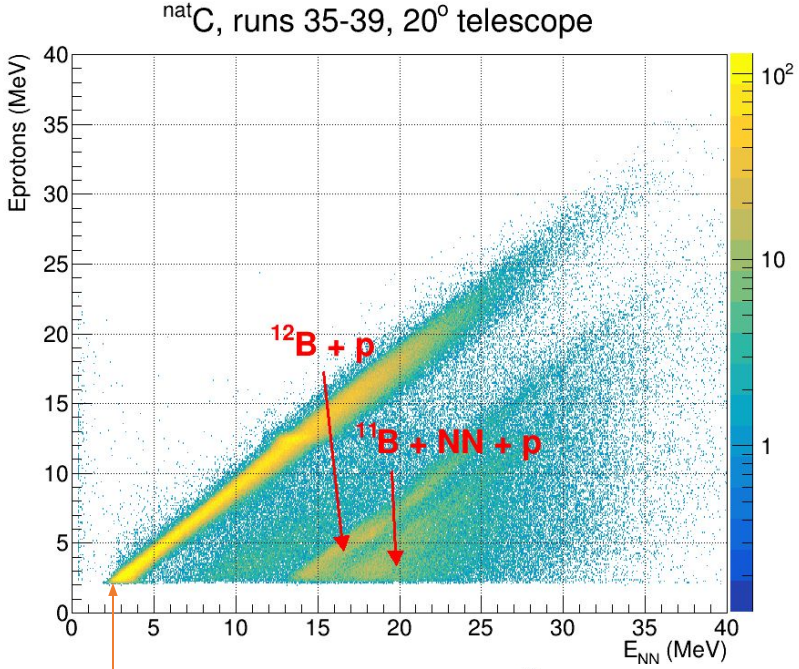
deuterons as function of ENN



- Similar procedure for correcting deuterons' ToF
- The resulting correction profile has essentially the same structure (with some different parameters)

Identifying reactions

The ToF corrections seems to work reasonably well, despite a second order correction can (and will) be introduced. Some reactions can also be identified:

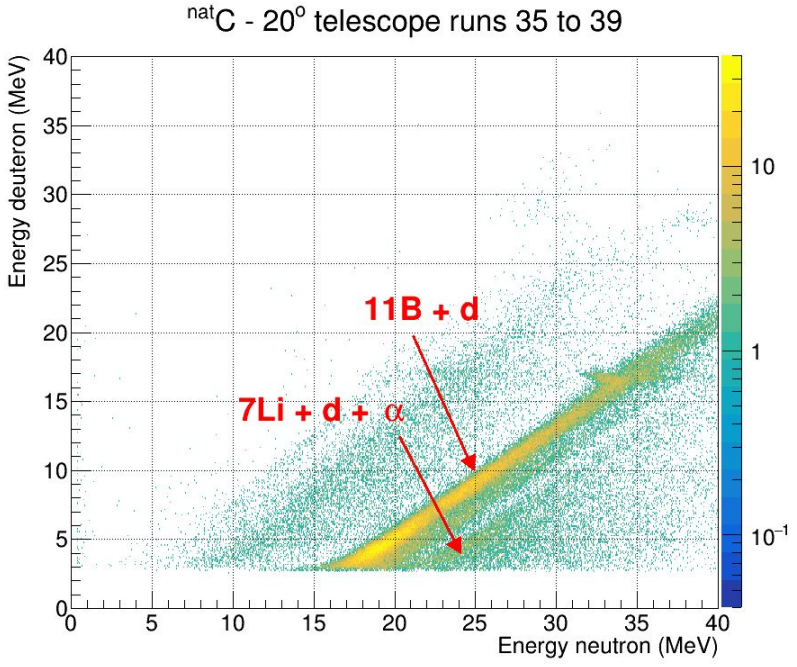


mass (C sample) = 40.8 mg,
equivalent mass of H_2O to produce same amount of scattering*: 1.8 mg

*given the material has some porosity, moisture could be a contaminant

^{12}C + NN
(E_{lab} = 40000 keV)

Reaction Products	Q-Value (keV)		Threshold (keV)	
^{12}B + p	-12587.1	13	13646.1	14
^{11}B + d	-13732.131	12	14887.553	13
^{11}B + NN + p	-15956.697	12	17299.293	13



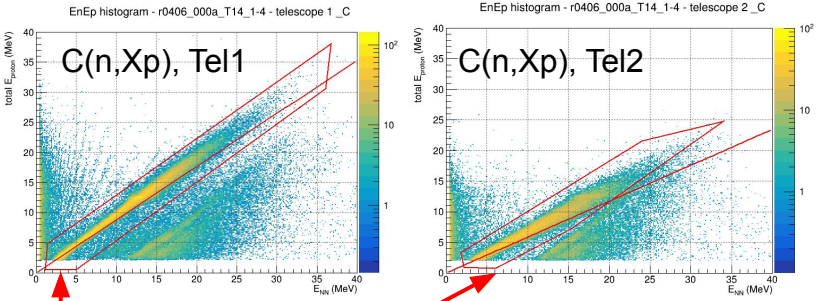
^{12}C + NN
(E_{lab} = 40000 keV)

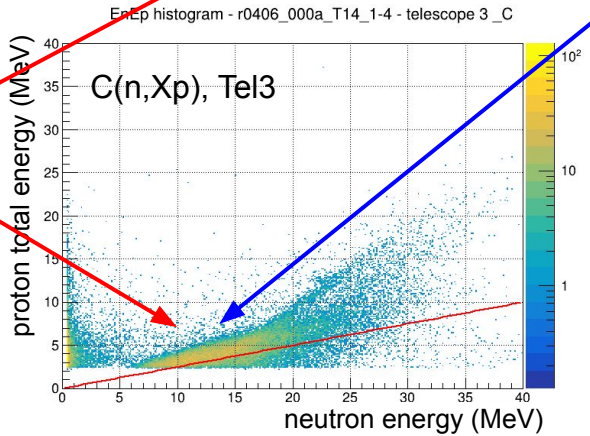
Reaction Products	Q-Value (keV)		Threshold (keV)	
^{10}Be + ^{3}He	-19467.41	8	21105.39	9
^{7}Li + d + α	-22396.443	4	24280.880	5
^{8}Li + p + α	-22588.39	5	24488.98	5

Very preliminary results

Very preliminary cross sections are already being produced. However, it is still needed to include more information to obtain the correct unit and uncertainties.

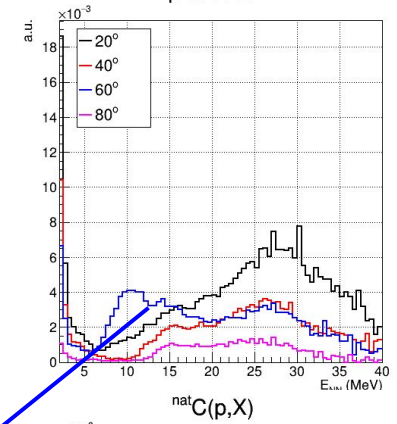
We also found some (probably) water contamination in C sample, since a strong EE band is present…



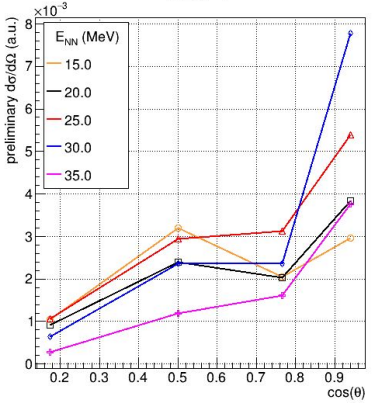


contamination band

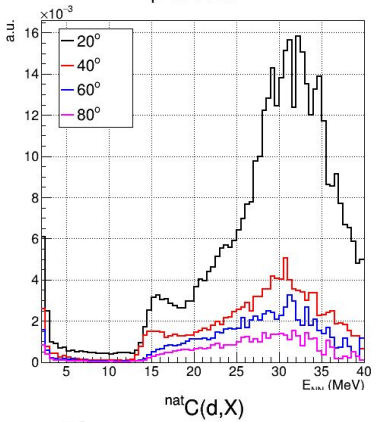
P production



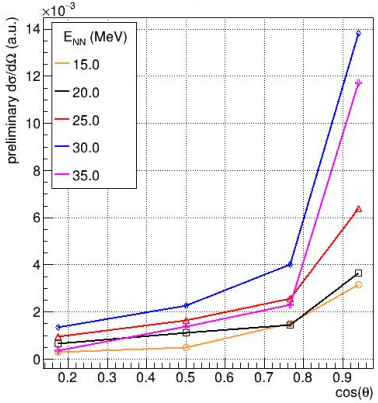
$^{nat}C(p,X)$



D production



$^{nat}C(d,X)$



Summary

- The experiments for C, Fe and Cr were successfully carried out at GANIL-NFS facility and the analysis is ongoing in parallel.
- We are able to identify H and He isotopes produced in neutron-induced reactions separately ⇒ provide DDXs for each isotope.
- Neutron energy resolution resolution well below than 1 MeV, allowing the determination of the double differential cross-sections as a function of the neutron energy.
- First version of correction factors working for p and d. The relations between the data observed with different telescopes correspond to the expected situation.
- Thick target corrections are being implemented.

Thank you for your attention