Recent developments on SINBA detector

SILICON NTD BARREL

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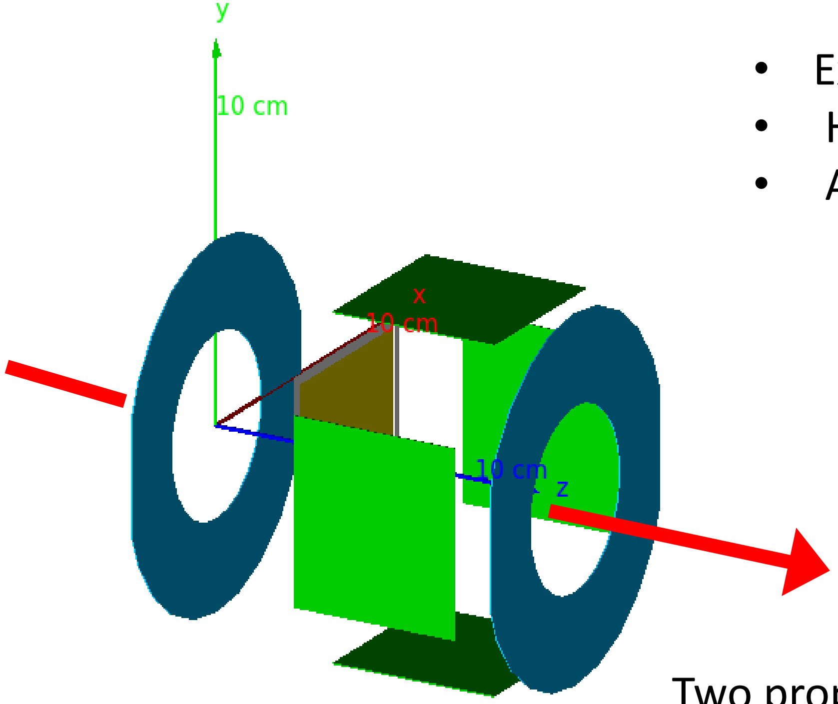
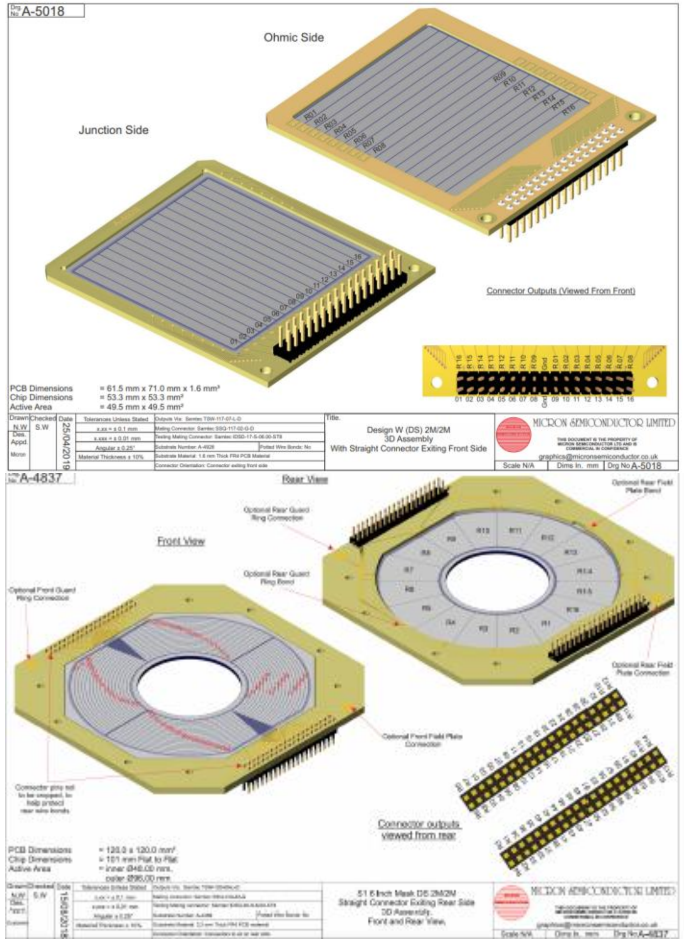
- The Proposal
- Latest Results from MC simulations

The SiNBA detector

The **SIlicon Ntd BArrell detector** will be composed by **two double sided annular detectors** and **four squares**, to be arranged in a cylindrical geometry to **maximize the acceptance**.

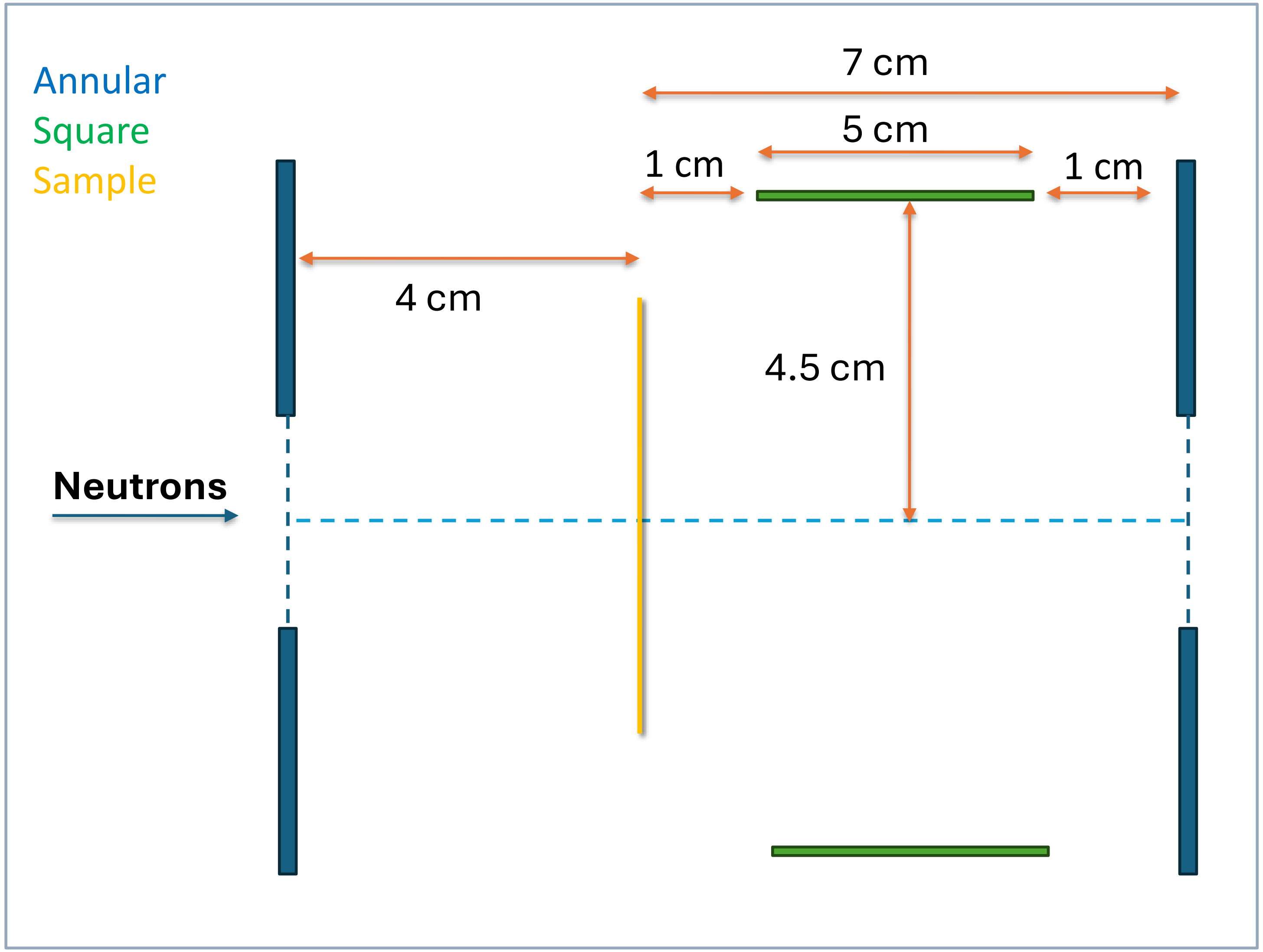


- Expected geometric efficiency ≈ 35/40 %
- Highly segmented:
- Angular acceptance:
  - 20° - 35° forward
  - 130°-150° backward
  - 37°-78° square



Two proposal related to Nuclear fusion motivations:
- Neutron Damage
- **Tritium Breeding** (submitted)

Geometry



Detector thickness:

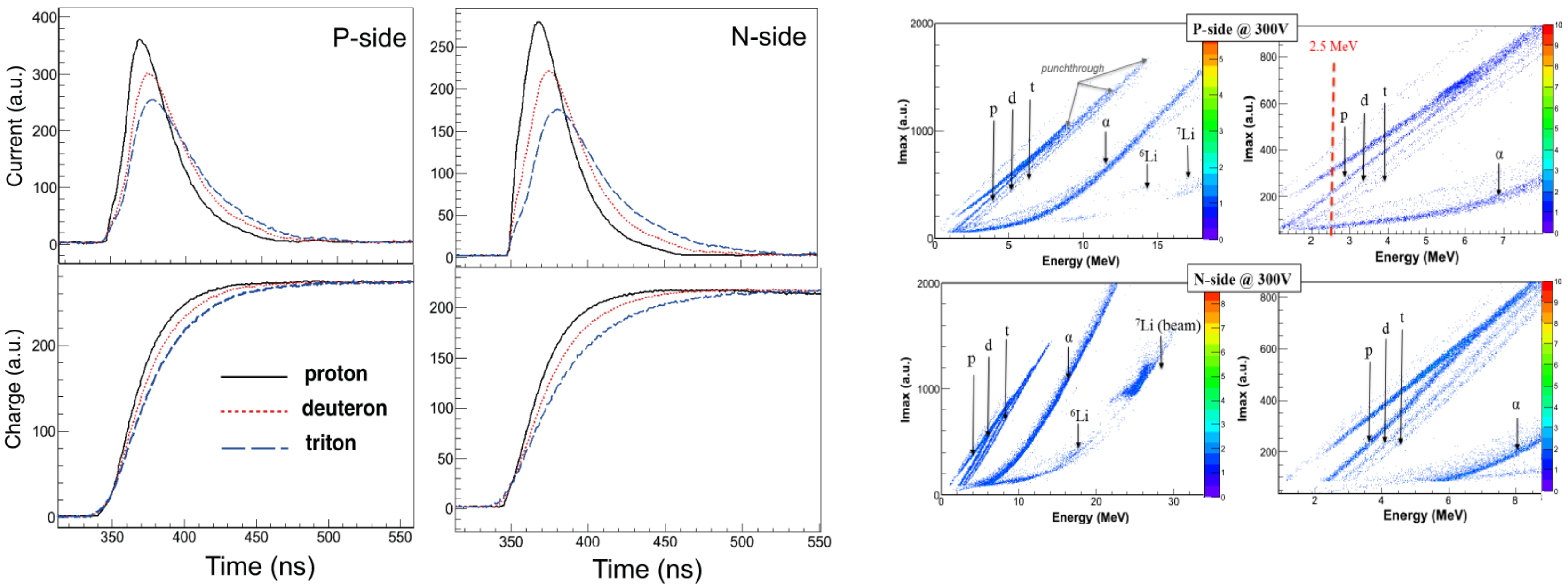
- 400 µm square
- 500 µm annular

Al Dead Layer thickness: 500 nm

Relative distances between detectors can be adjusted.

Features of the measurement

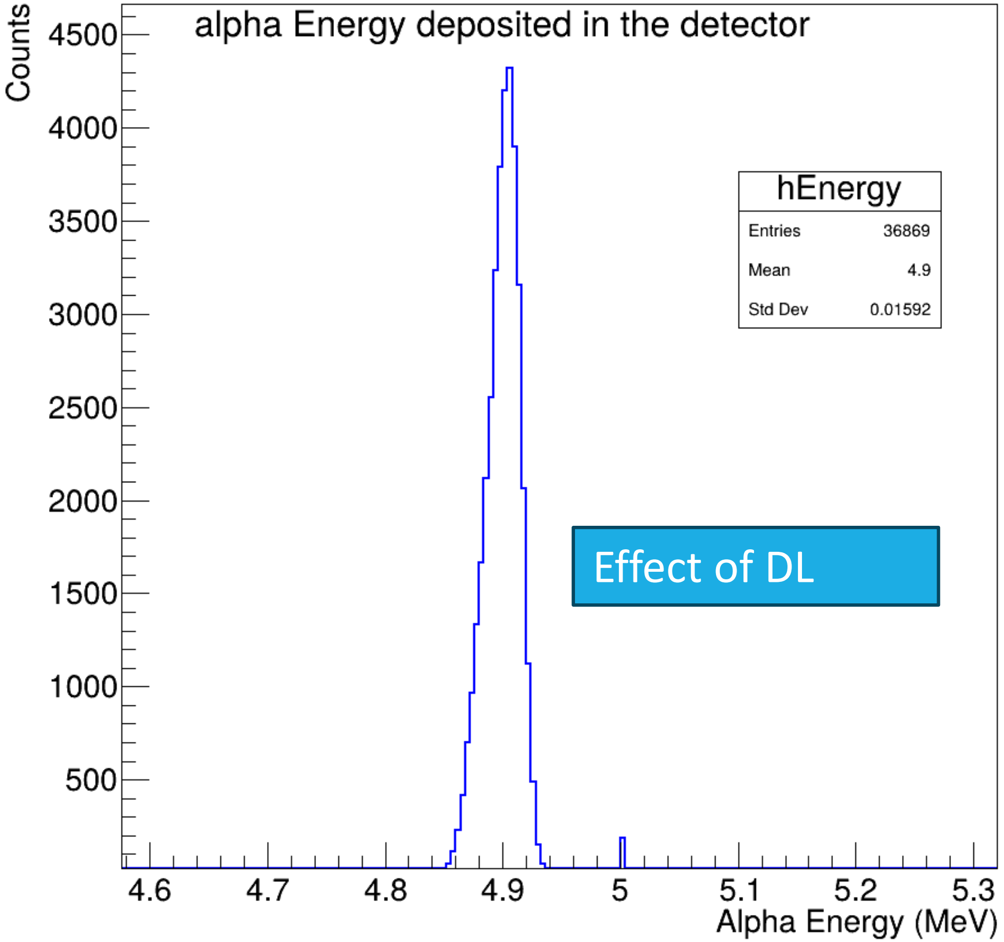
- The use of **Pulse Shape Discrimination**: different particles with the same kinetic energy produce different pulse shapes
- **Digital PSA** performed with an innovative Machine Learning based routine developed at LNS-INFN.
- **Neutron Transmutation Doped** detectors will be used to enhance the PSD capabilities.

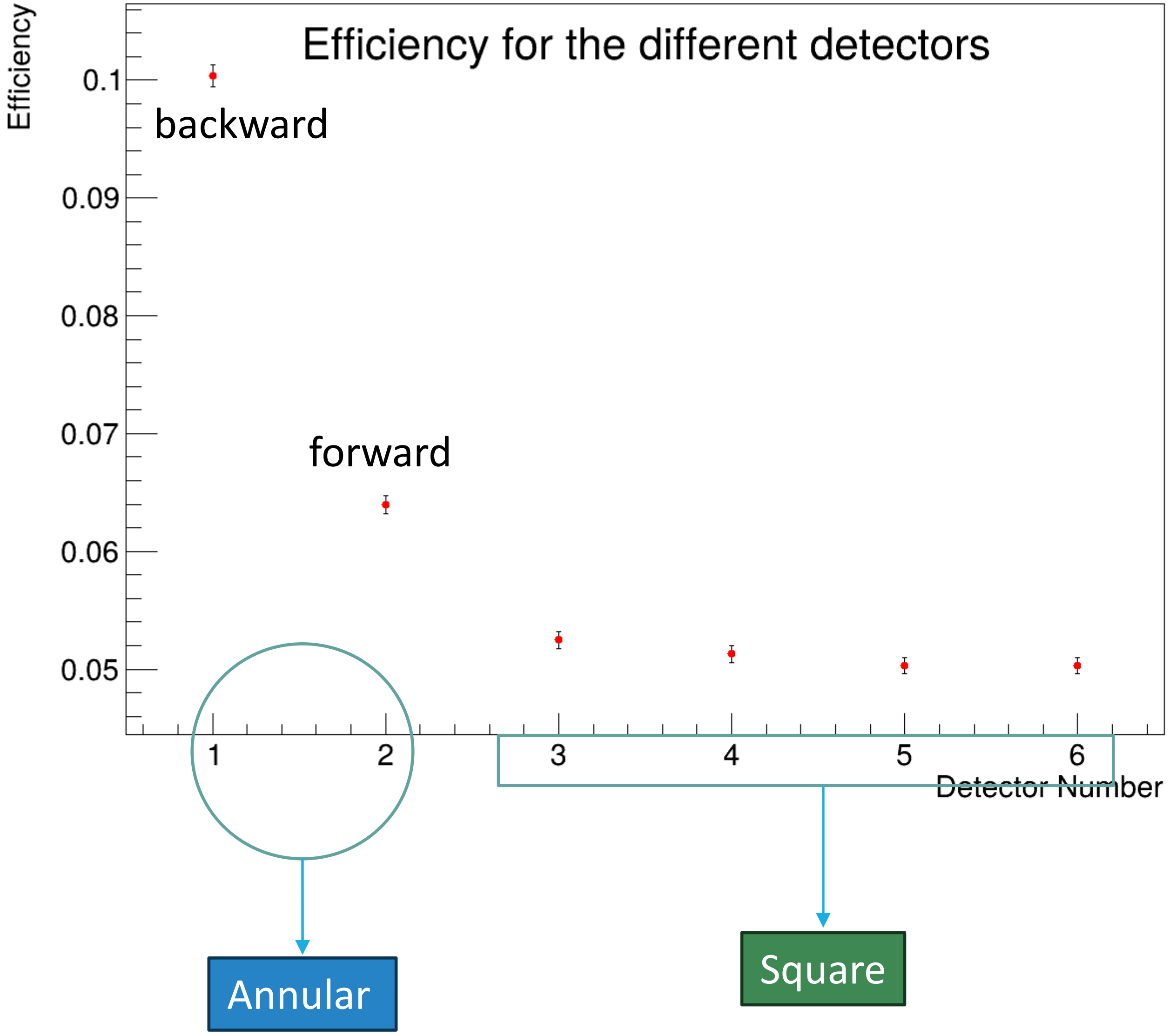


An example of different Pulse shapes and identification matrices. From Assié, M. et al, "Characterization of light particles ($Z \leq 2$) discrimination performances by pulse shape analysis techniques with high-granularity silicon detector."

The integration of **PSD** with **digital PSA** enables the measurement of (n,cp) reactions across **a wider neutron energy range** compared with traditional techniques.

Efficiency with Alpha

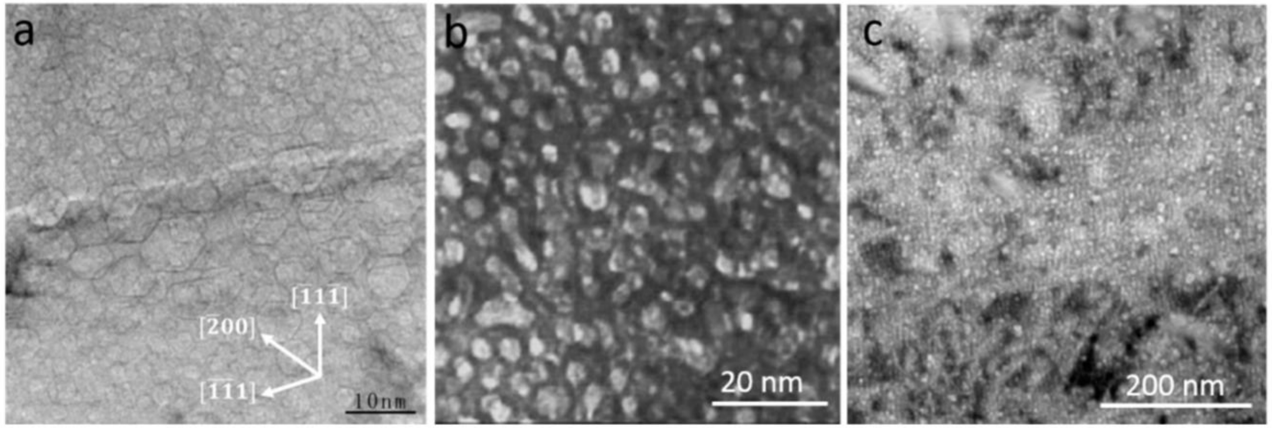




10^5 Alpha Point-Like isotropic source 5 MeV energy

Total ε = 36.8 ± 0.2 %

Neutron damage motivations



TEM image of He bubbles in various metals. From Li,S. et al "Radiation-Induced Helium Bubbles in Metals"

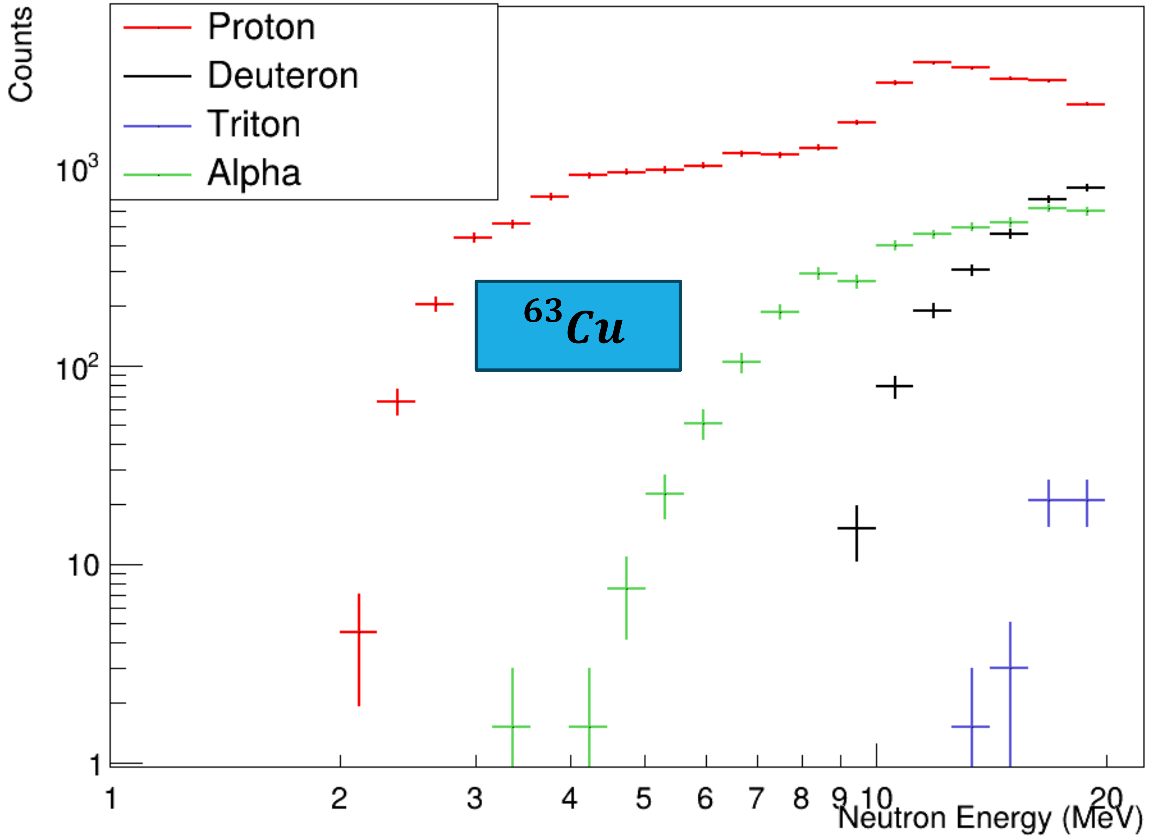
Neutron Damage is the most important limiting factor to the lifetime of a nuclear fusion reactor.

(n,cp) reactions: a **nucleus** capture a **neutron** and emits a **light charged particle**.

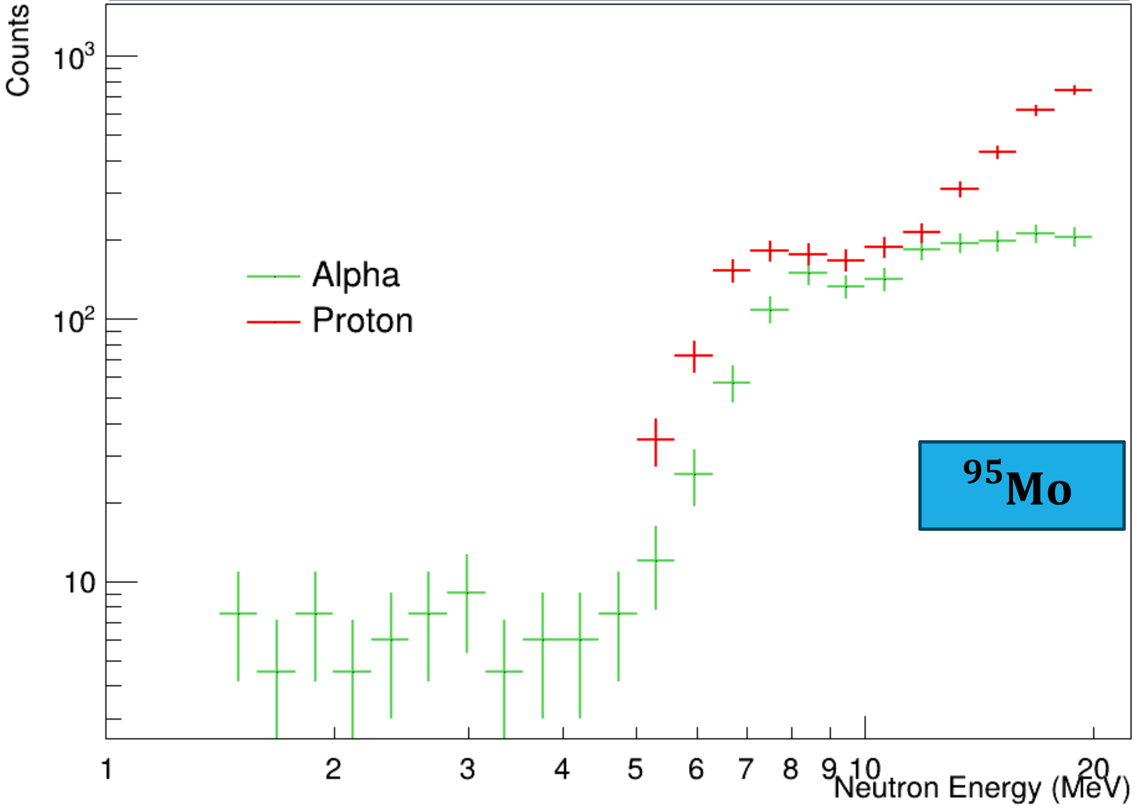
Very troublesome. They cause **formation of bubbles** in material that severely alter the **thermomechanical properties.**

Neutron Damage: Cu and Mo

CP detected E_{dep} > 1 MeV

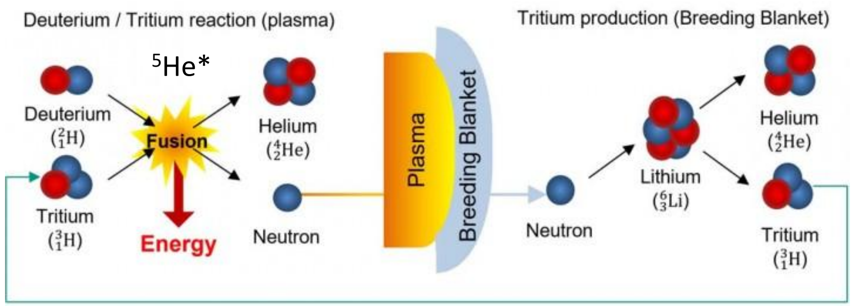


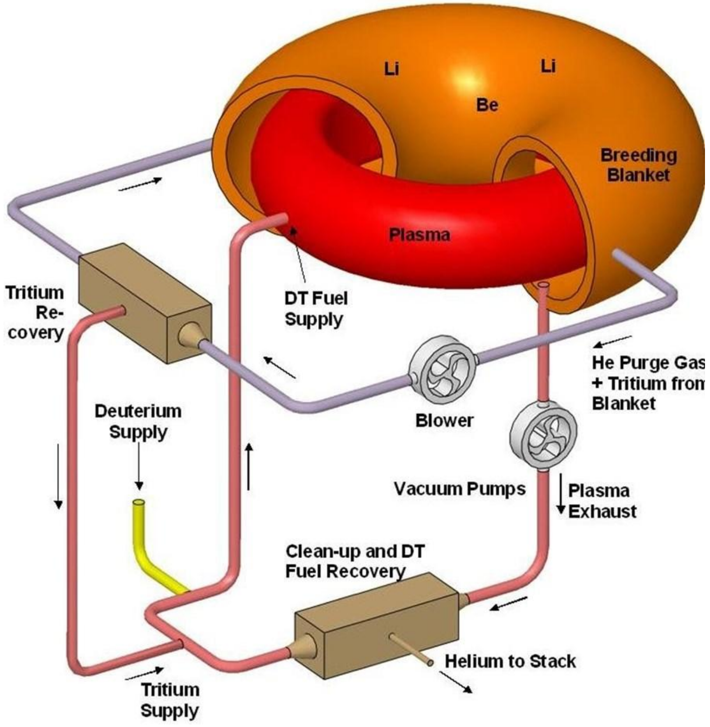
Alpha and protons detected E_{dep} > 1 MeV



PID threshold between P,D and T

Low Statistics, due to low cross sections



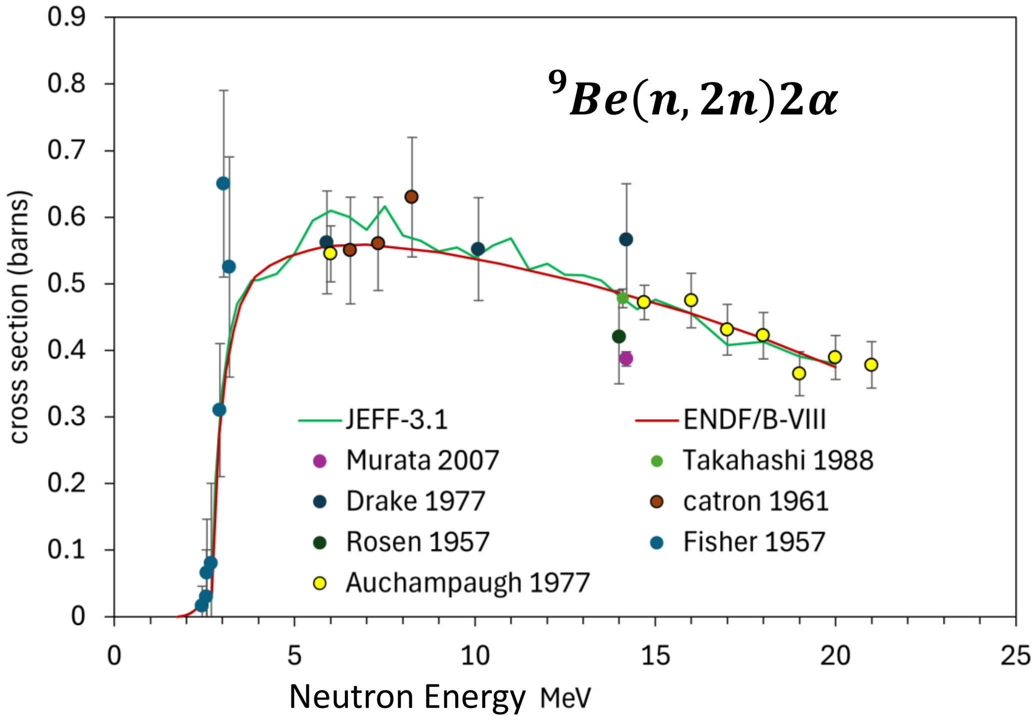


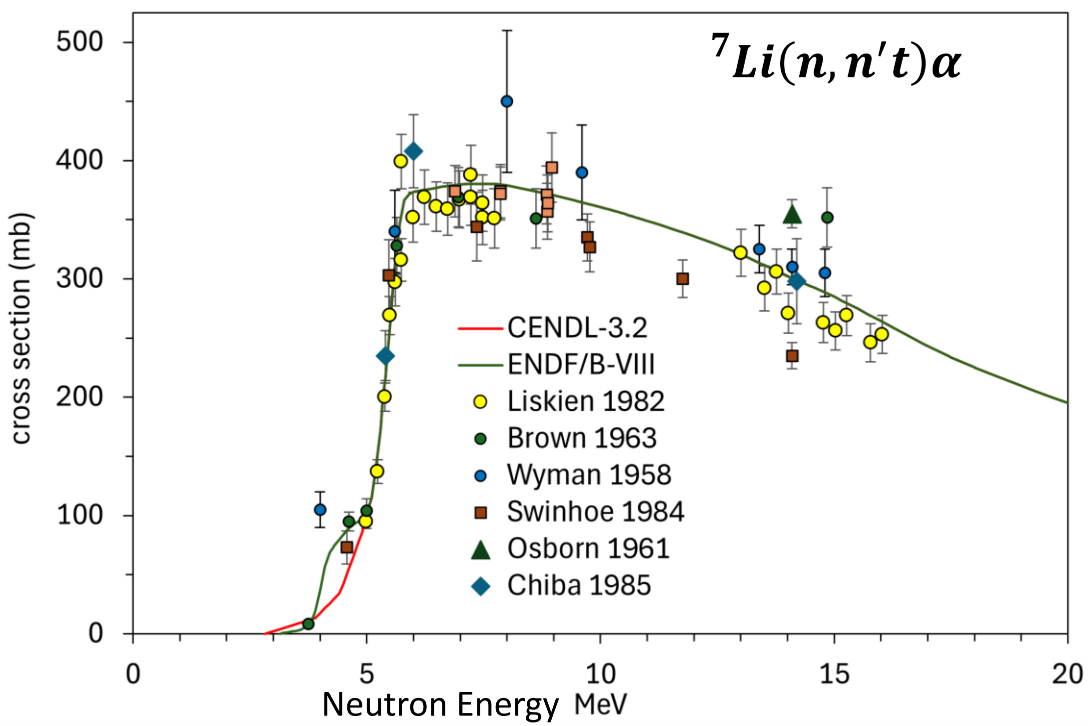
Tritium breeding Motivations

- Tritium (^{3}H) abundance is about 25 kg/year , while reactors would need 50/100 kg/year → ^{3}H must be produced *in situ*
- Main solutions rely on a combination of a tritium breeder(Li) and a neutron multiplier (Be or Pb)
- ^{6}Li(n,t)α cross sections is dominant up to 5 MeV and burns neutrons → $^{7}\boldsymbol{Li}$**(n,nt)α** reaction must be used too.
- Be is widely used e.g., ITER and DEMO (HCPB), ARC (FLiBe)…
- Tritium Breeding Ratio = $TBR = \frac{Tritons\ produced}{Tritons\ fused} > 1$

^{7}Li and ^{9}Be cross sections

We have submitted a proposal that will be discussed at the next INTC on 21 may.

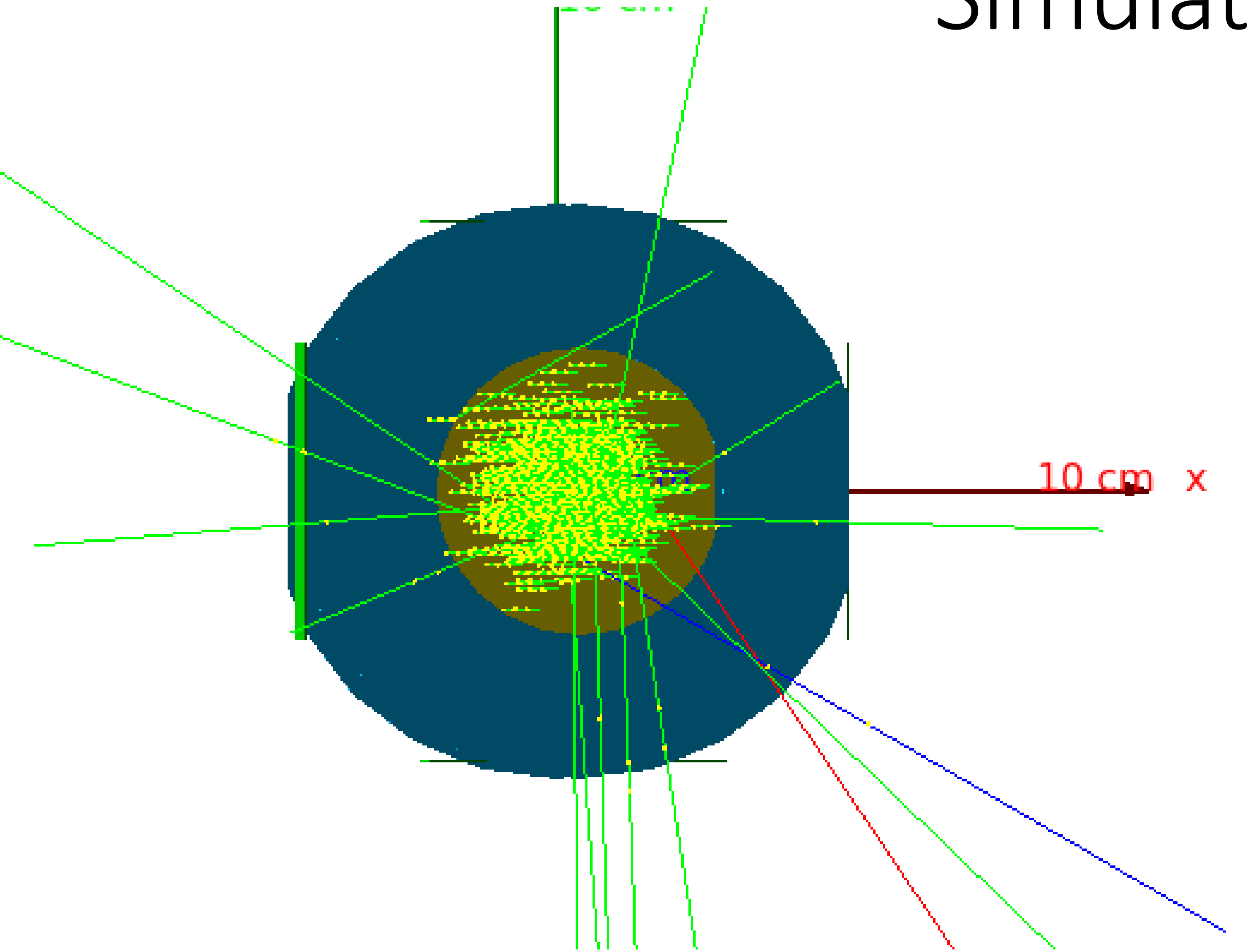




- Good agreement in energy trend
- ENDF/B-VIII.0 appears smoother than JEFF-3.1
- No data 3-5 and 10-14 MeV
- Murata 20 % lower than evaluated libraries

- Good agreement in energy trend
- Evaluation overestimates measurements
- No data 10-14 MeV
- Different behaviour around the threshold

Simulation Parameters:



- Input: **EAR1** energy distribution, with bigaussian profile
- Neutron Energy **1-20 MeV**
- **100 millions of primary neutrons**, cross section **bias of 100** for all neutron interactions.
- Results rescaled considering $\mathbf{2 \cdot 10^{18}}$ **protons**
- Counts: $E_{dep} > 250$ keV
- Physics List: FTFP_BERT_HP

GEANT4 Libraries

Li Reaction

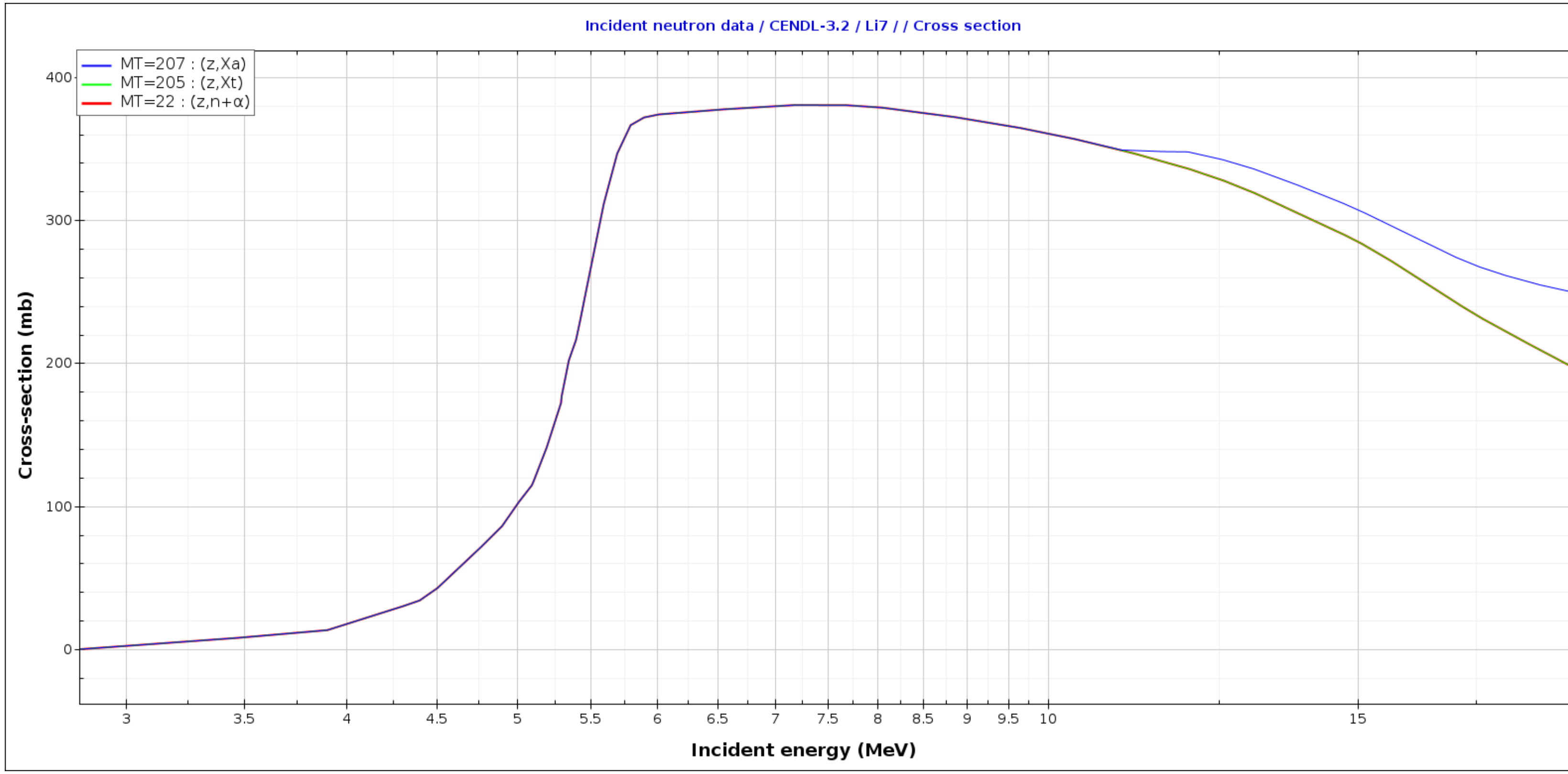
- Default G4 library (ENDF/B-VIII.0) does not include the **(n,nt)** reaction (MT = 33)
- Only provides inclusive **(n,xt)** cross sections → **Not suitable for G4** (introduces redundancies)
- **Solution:** Alternative library: **CENDL-3.2**
  - Includes (n,nα) reaction, which is equivalent in this case
  - Provides **energy-angle distributions** for some neutron energies

Be Reaction

- I Compared **(n,2n)** (MT = 16) and **(n,α)** (MT = 107) reactions
- **CENDL and ENDF provide identical cross sections**
- **CENDL 3-2 used**

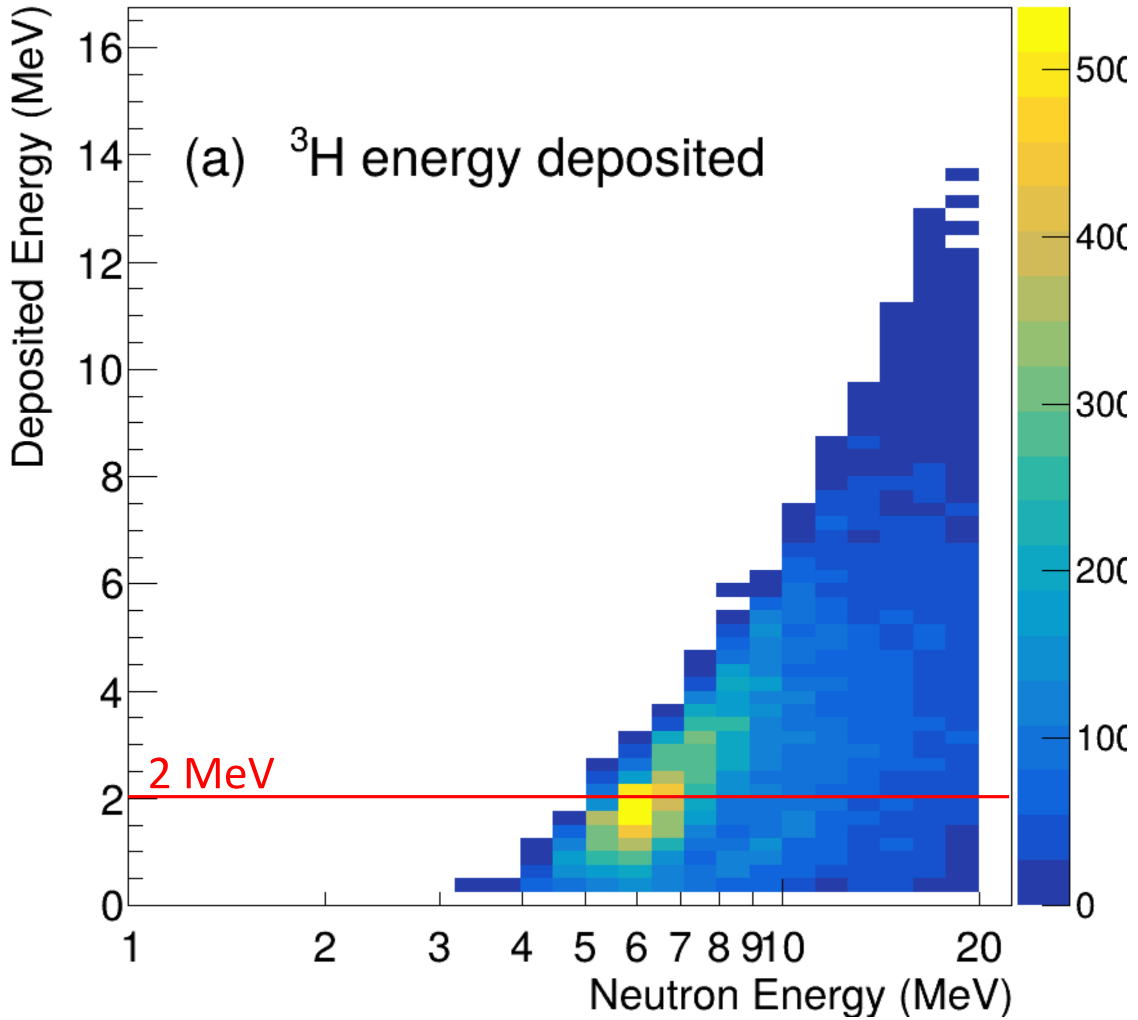
^{7}Li Cross Sections

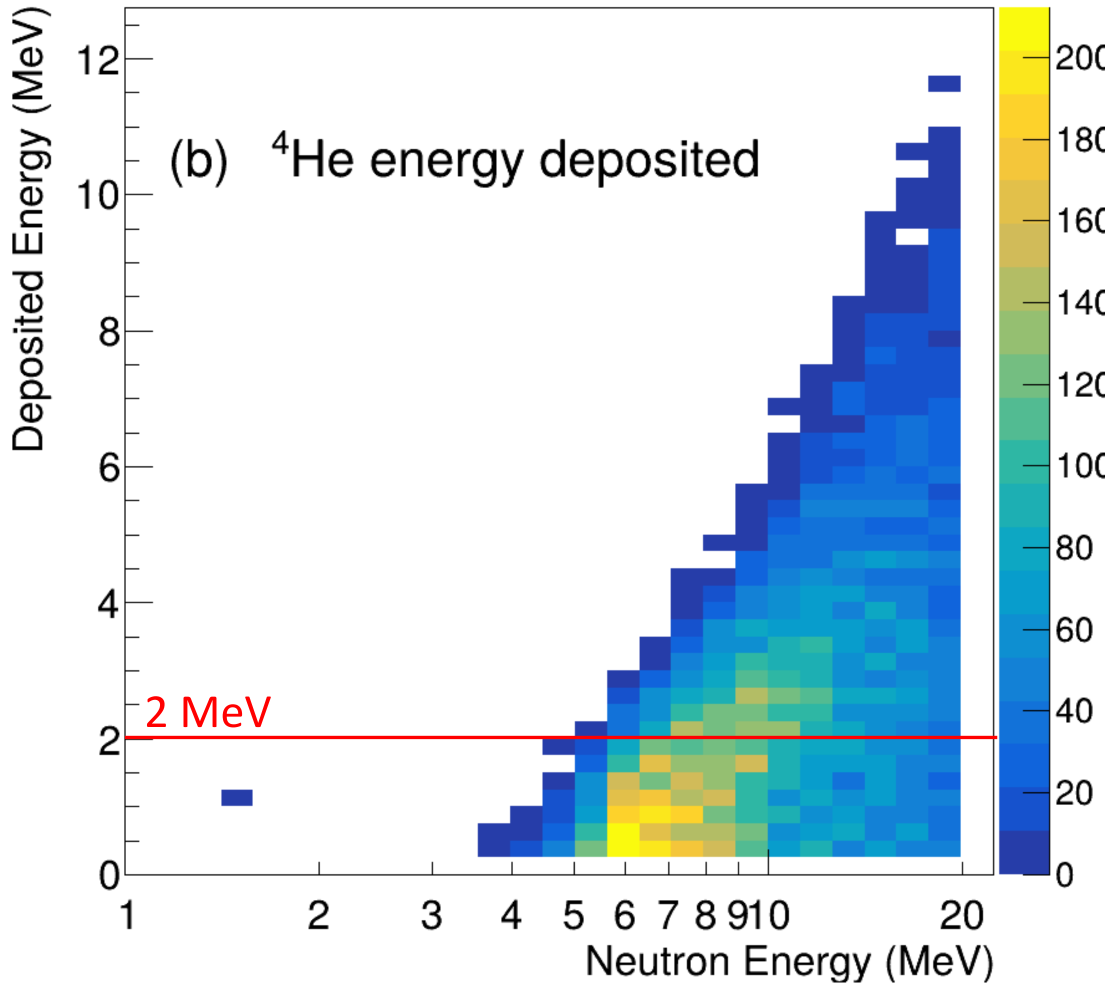
- ^{7}Li**(n,n’t)α: Tritium Production**
- Different reactions with a hydrogen isotope and α in the final state.
- Lower neutron energies, t is the only one.
- Above ~ 9MeV other channels open up, with smaller cross sections .



^{7}Li	Reaction	Q-value (keV)	Threshold (keV)
	(n,n’ t) α	-2467.622	2822.762
	(n,2n’d) α	-8724.85	9980.53
	(n,3n’p) α	-10384	11878

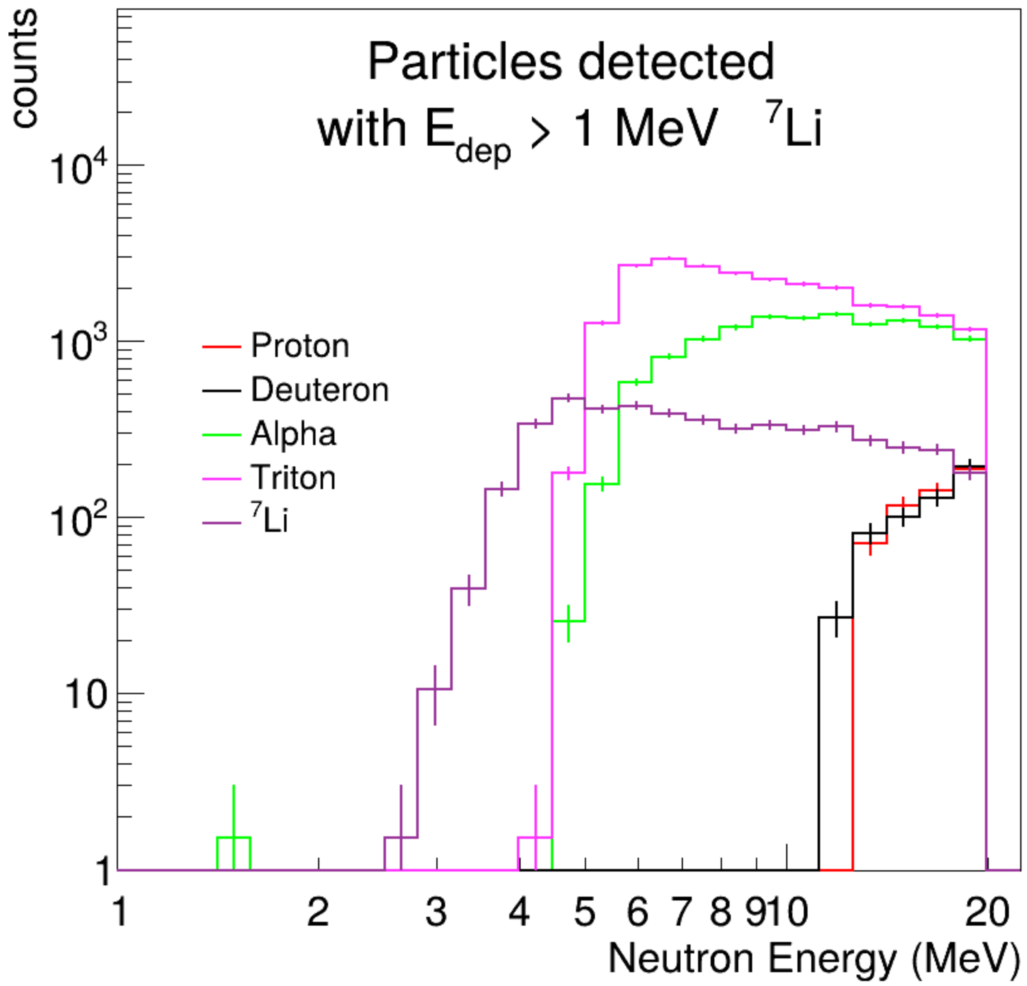
^{7}Li : results



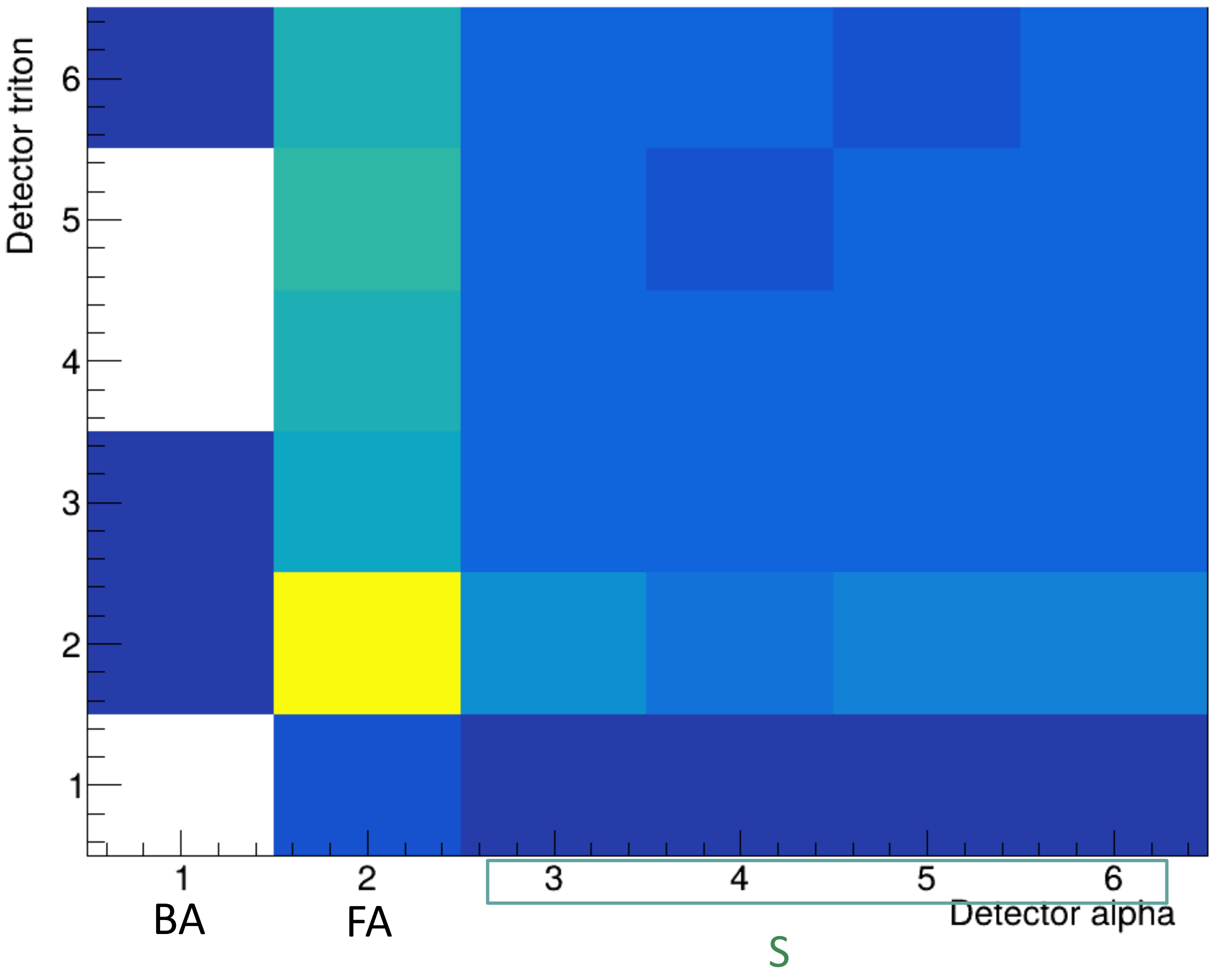


- With PID, identification threshold is around 2 MeV
- We aim to identify mostly tritons, less sensitive to PID threshold.

^{7}Li : results

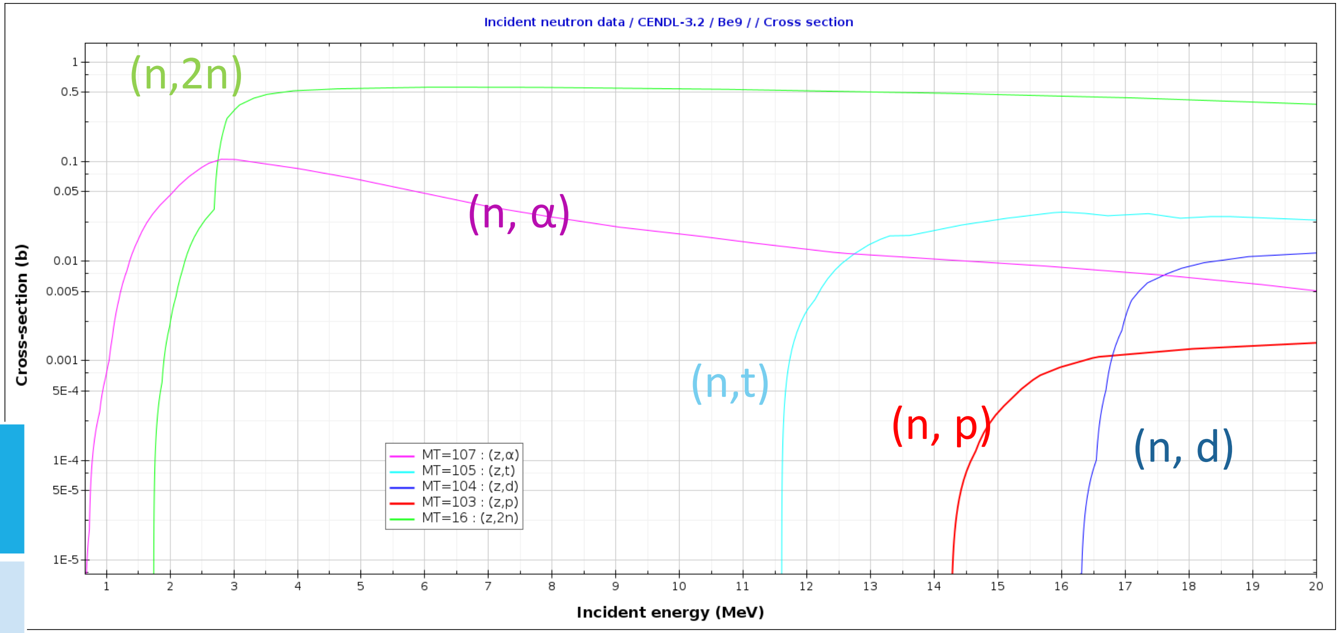


Alpha and Triton Coincidences E_{dep} > 1 MeV



$^1H/^2H$ particles from secondary reactions are expected to be negligible < 14 MeV

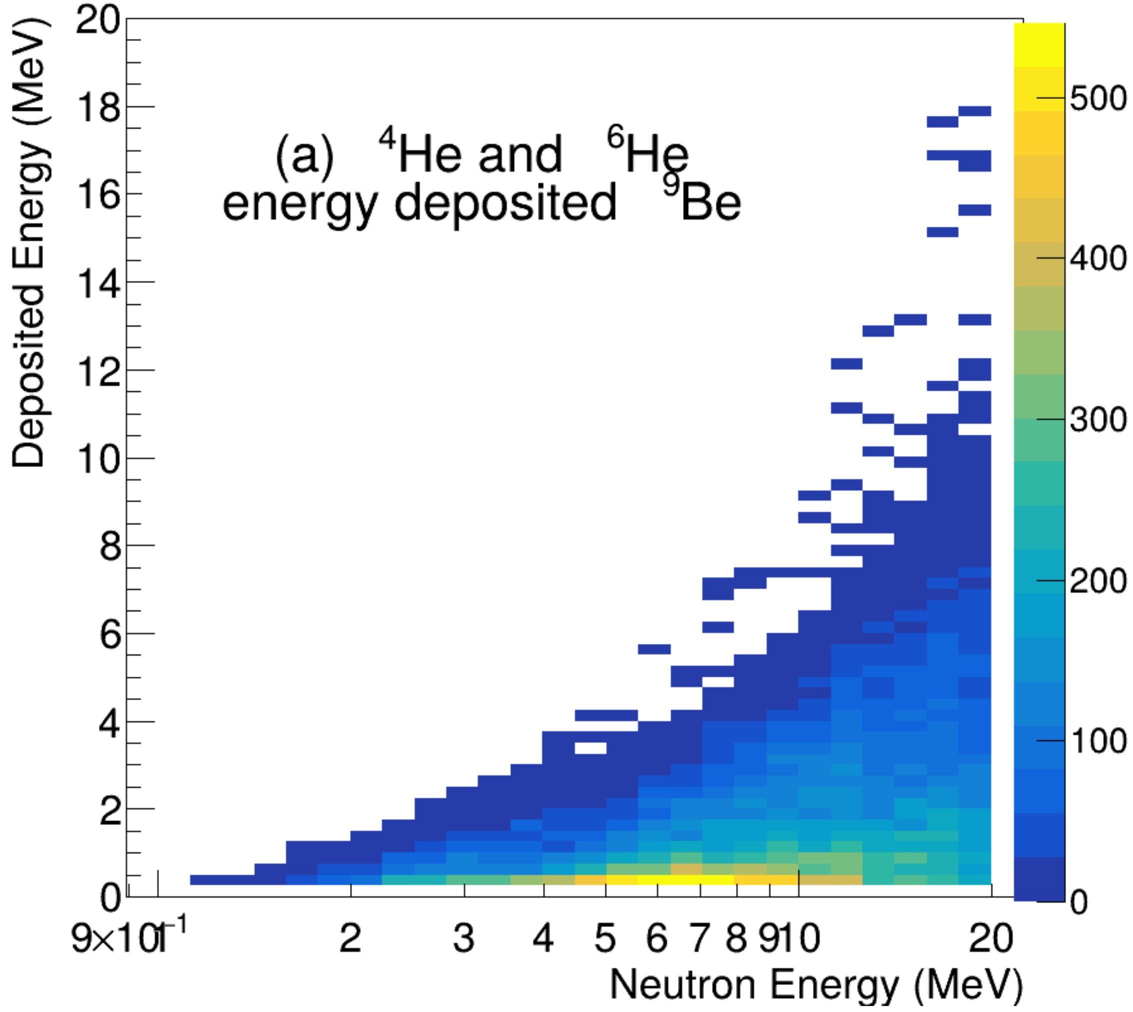
^{9}Be Cross Sections

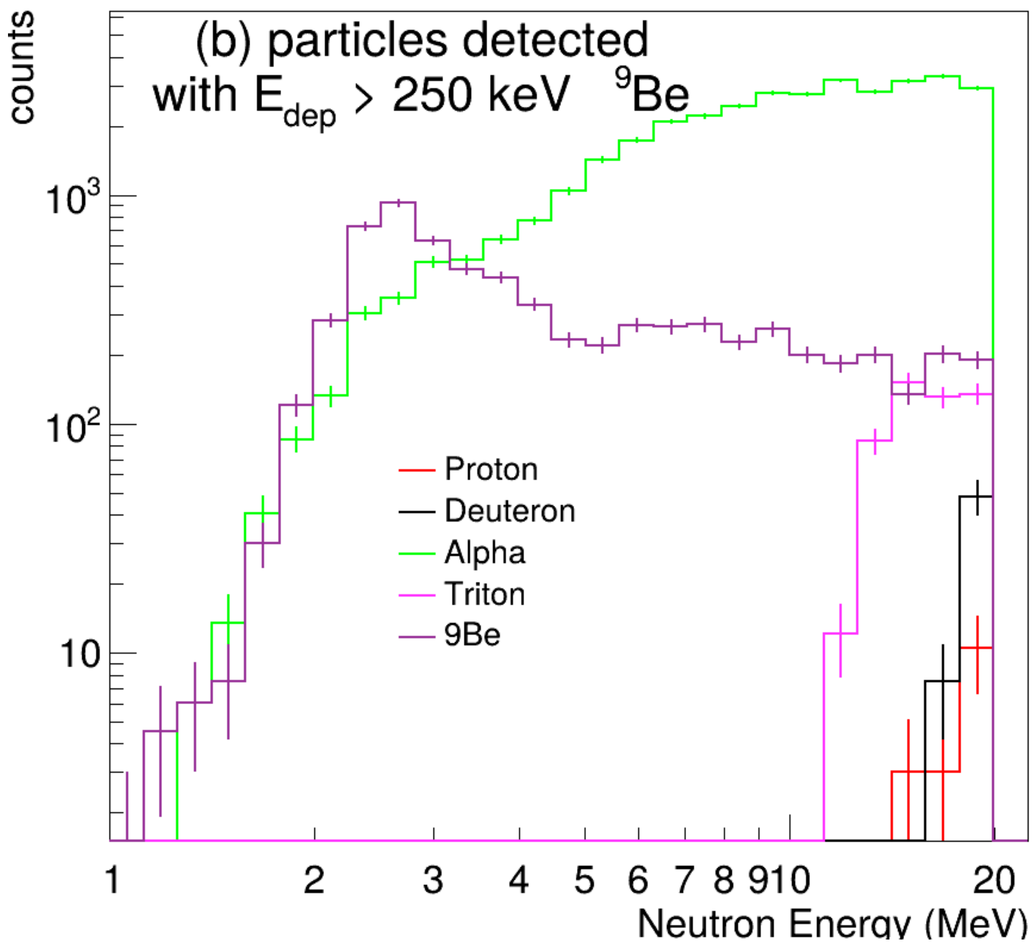


^{9}Be	Reaction	Q-value (keV)	Threshold (keV)
	(n,2n)2α	-1572.70	1748.90
	(n, α) ^{6}He	-597.24	664.16
	(n,p)	-12824.11	14260.92
	(n,d)	-14661.76	16304.46
	(n,t)	-10437.15	11606.52

- ^{9}Be**(n,2n)2α**: Neutron Multiplication
- Two processes with α in the final state: (n, α) and (n,2n)
- (n,2n) is dominant at higher energies
- Other (n,cp) have significantly lower cross sections

^{9}Be : results

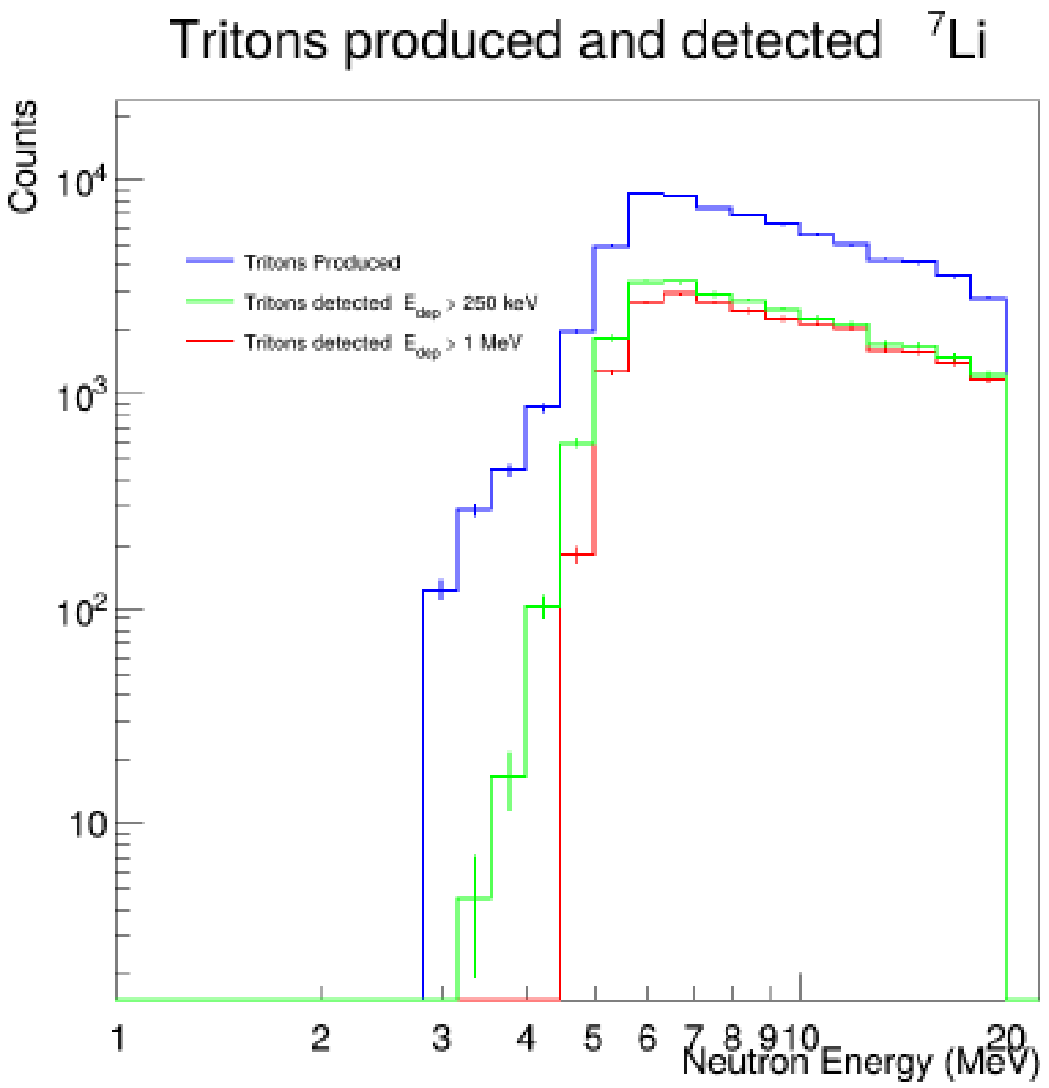


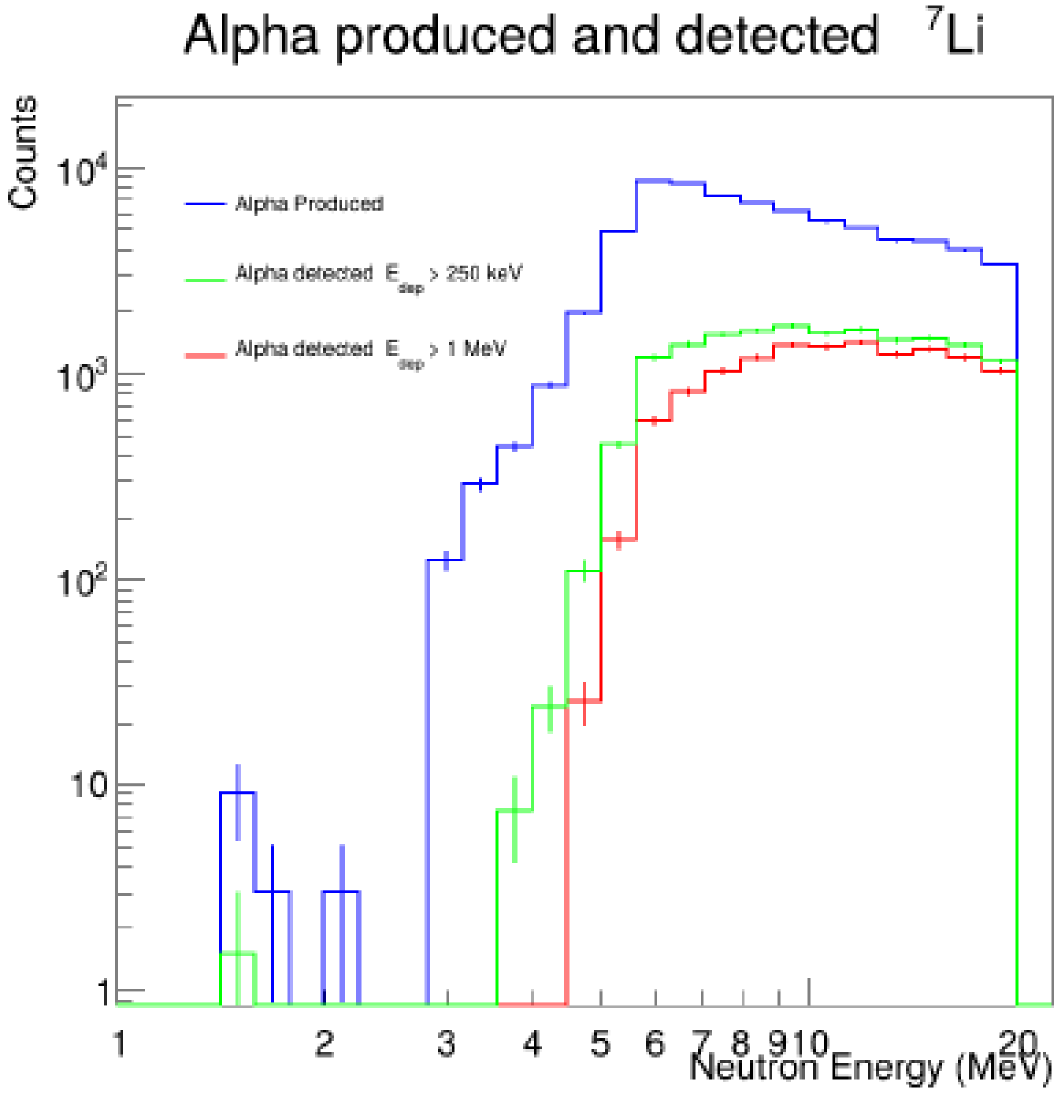


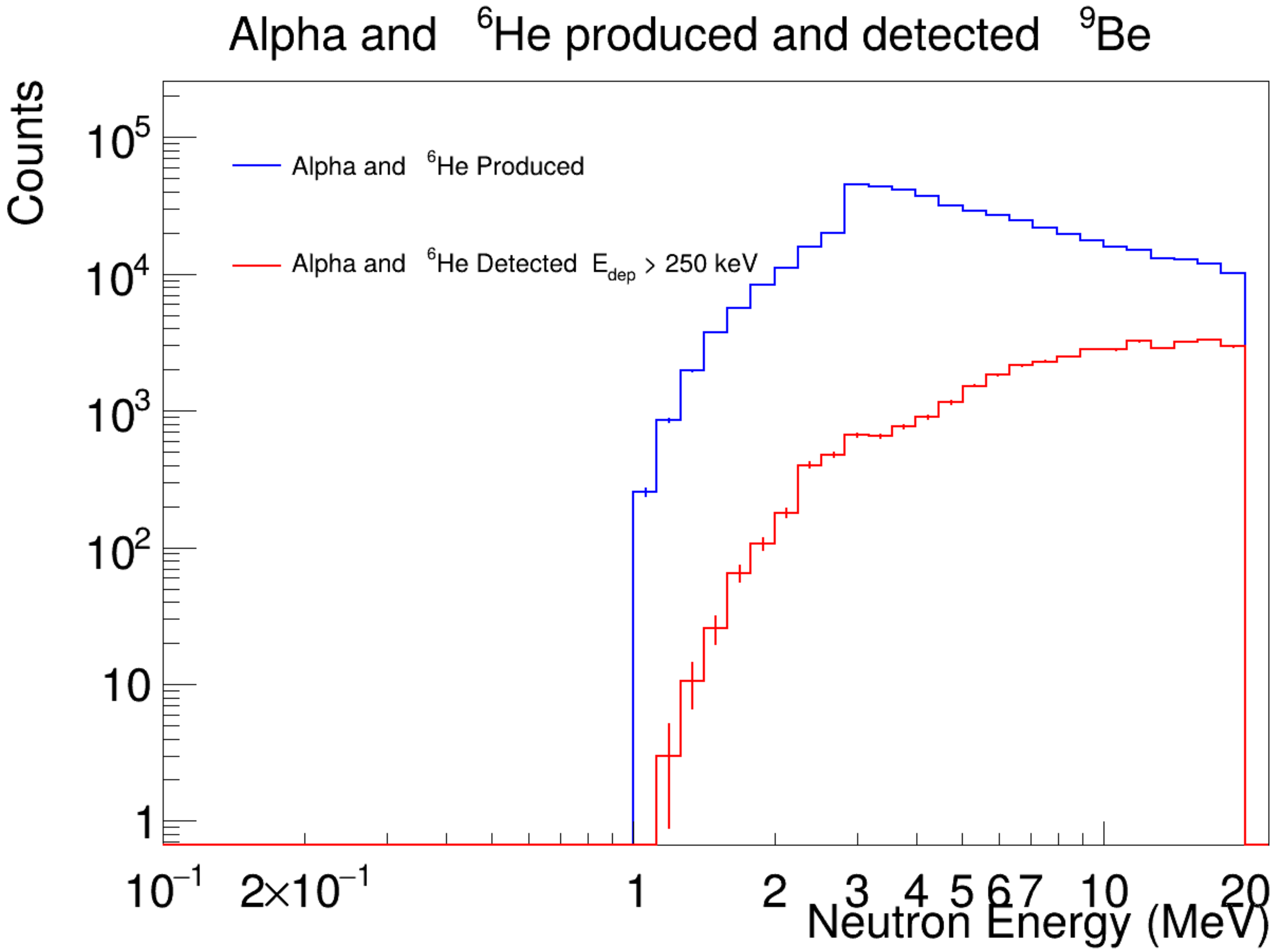
- Some Be ions are expected from elastic scattering.
- After 4 MeV the distinction should be feasible. Contribution from (n, α) and Be estimated.
- T,P,D negligible at lower neutron energy

Study of coincidences ongoing

THANKS !


Tritons produced and detected ^{7}Li
Counts
Tritons Produced
Tritons detected E_{dep} > 250 keV
Tritons detected E_{dep} > 1 MeV
Neutron Energy (MeV)


Alpha produced and detected ^{7}Li
Counts
Alpha Produced
Alpha detected E_{dep} > 250 keV
Alpha detected E_{dep} > 1 MeV
Neutron Energy (MeV)


Alpha and ⁶He produced and detected ⁹Be
Counts
Alpha and ⁶He Produced
Alpha and ⁶He Detected E_dep > 250 keV
Neutron Energy (MeV)
10⁵
10⁴
10³
10²
10
1
10⁻¹
2×10⁻¹
1
2
3
4
5
6
7
10
20