# High acceptance Silicon Detector for (n,cp) measurements

## GEANT4 SIMULATIONS ON THE PHYSICS CASE

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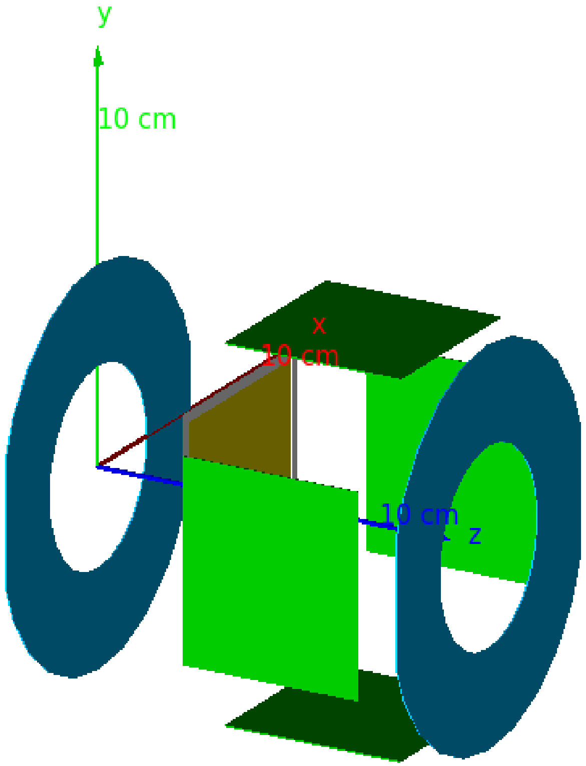
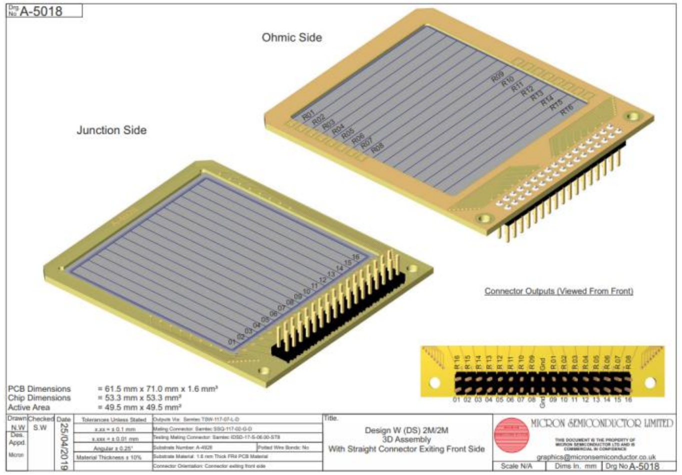
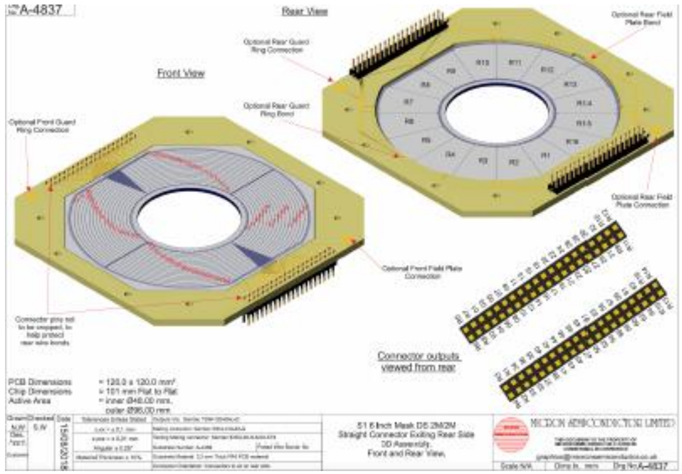
# The High Acceptance Detector

- This **Silicon based apparatus** is composed by **two double sided annular detectors** and **four squares**, arranged in a cylindrical geometry to **maximize the efficiency**.

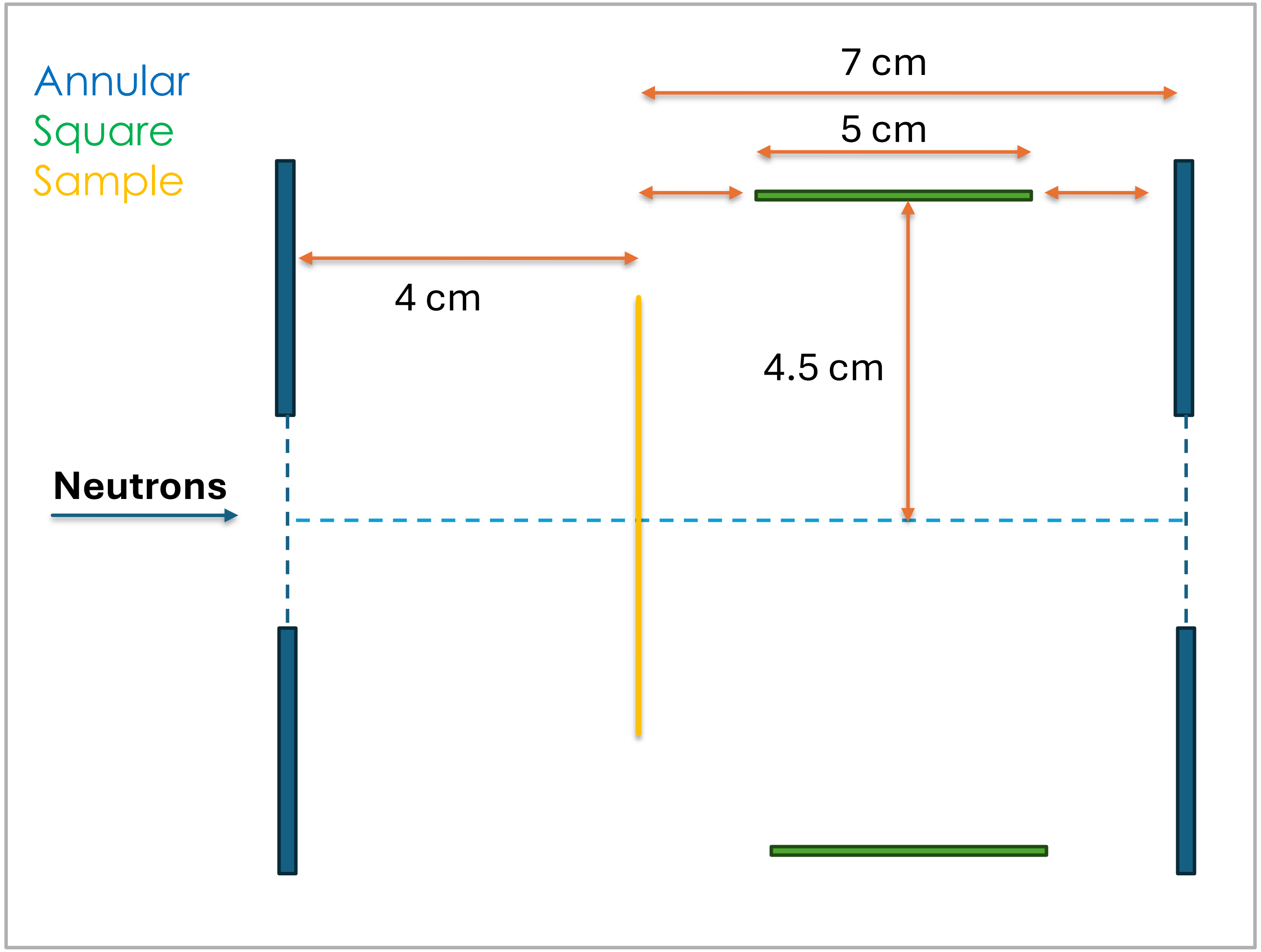


- **nTD** Silicon
- Based on SAD results: suitable for **PSD with digital PSA**
- Expected efficiency ≈ 35/40 %
- **Highly segmented**:
  - 32 channels on annular detectors (16 front and 16 back)
  - 16 channels on the square detectors (8 front and 8 back)





# Geometry



**Detector thickness:** 400 μm (7 MeV protons PT)

**Al Dead Layer thickness**: 500 nm

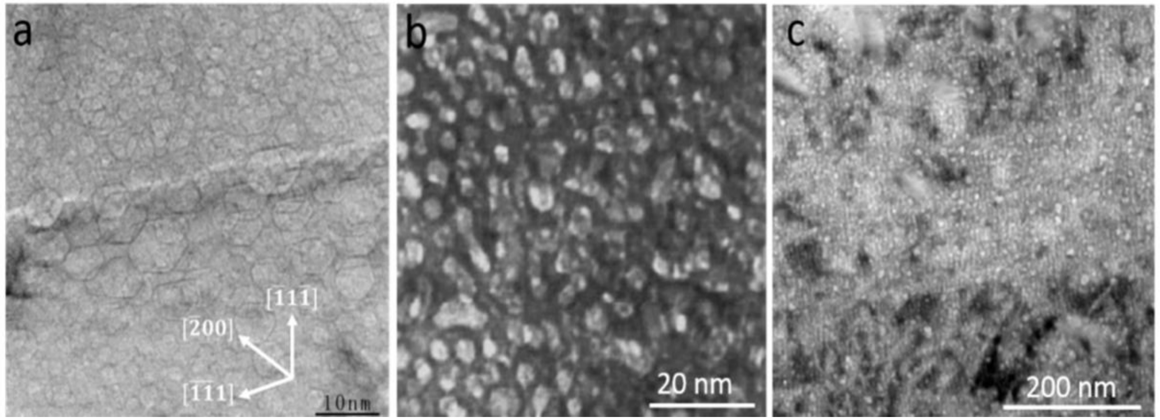
Relative distances between detectors can be adjusted.

# Choice of the sample

The High acceptance Si Detector was designed to measure (n,cp) reactions.

Different possible samples are now being studied for nuclear fusion applications. Main candidates for **plasma facing parts**:

- **W** it is the main component of the ITER **divertor** and **First Wall**, thanks to the high melting point → **Hard to fabricate**.
- **Mo** is an attractive alternative to Tungsten → **Easier to fabricate**, but significant radioactivity after neutron exposure.
- **Cu** is a component of the **divertor** with W-Cu **monoblocks**

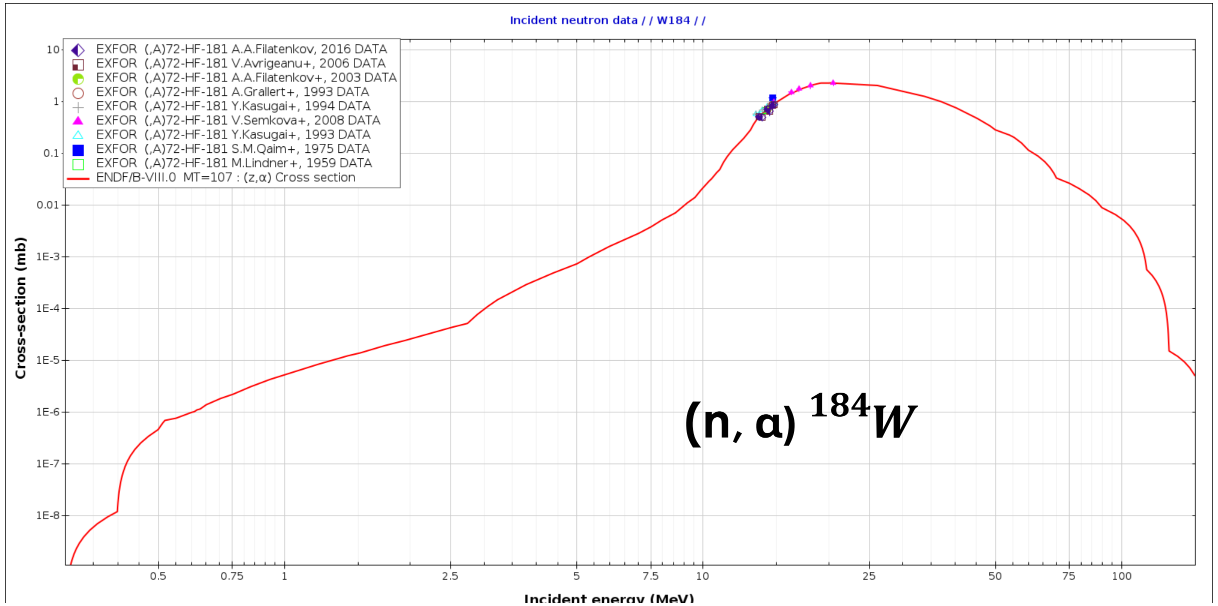


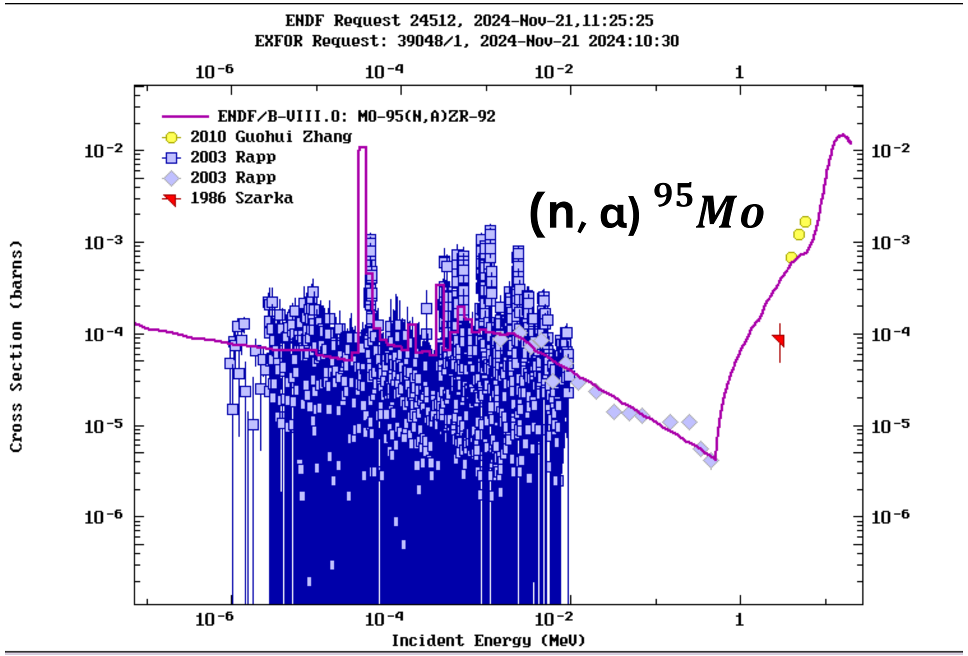
*TEM image of He bubbles in various metals. From Li,S. et al "Radiation-Induced Helium Bubbles in Metals"*

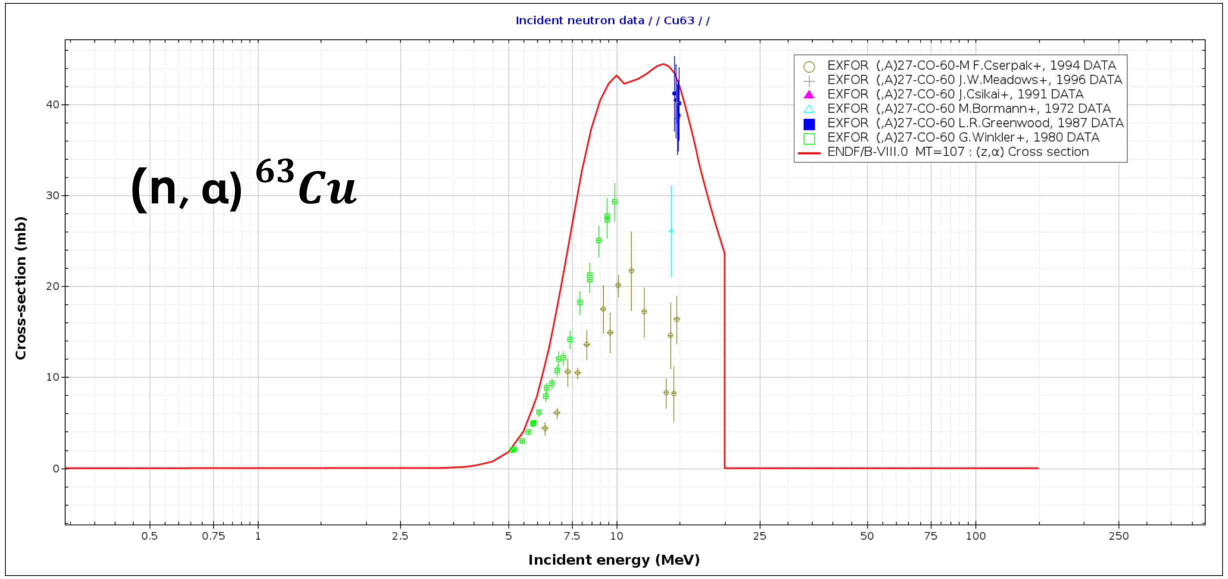
In these materials (n,cp) reactions cause the formation of bubbles, that severely alter the thermo-mechanical properties of hypothetical nuclear fusion reactors.

# State of the data

- In the nuclear data libraries, there is a **scarcity** in (n,cp) cross sections for these elements, as well as several **inconsistencies**.
- The **evaluated** cross sections are relatively **small.**

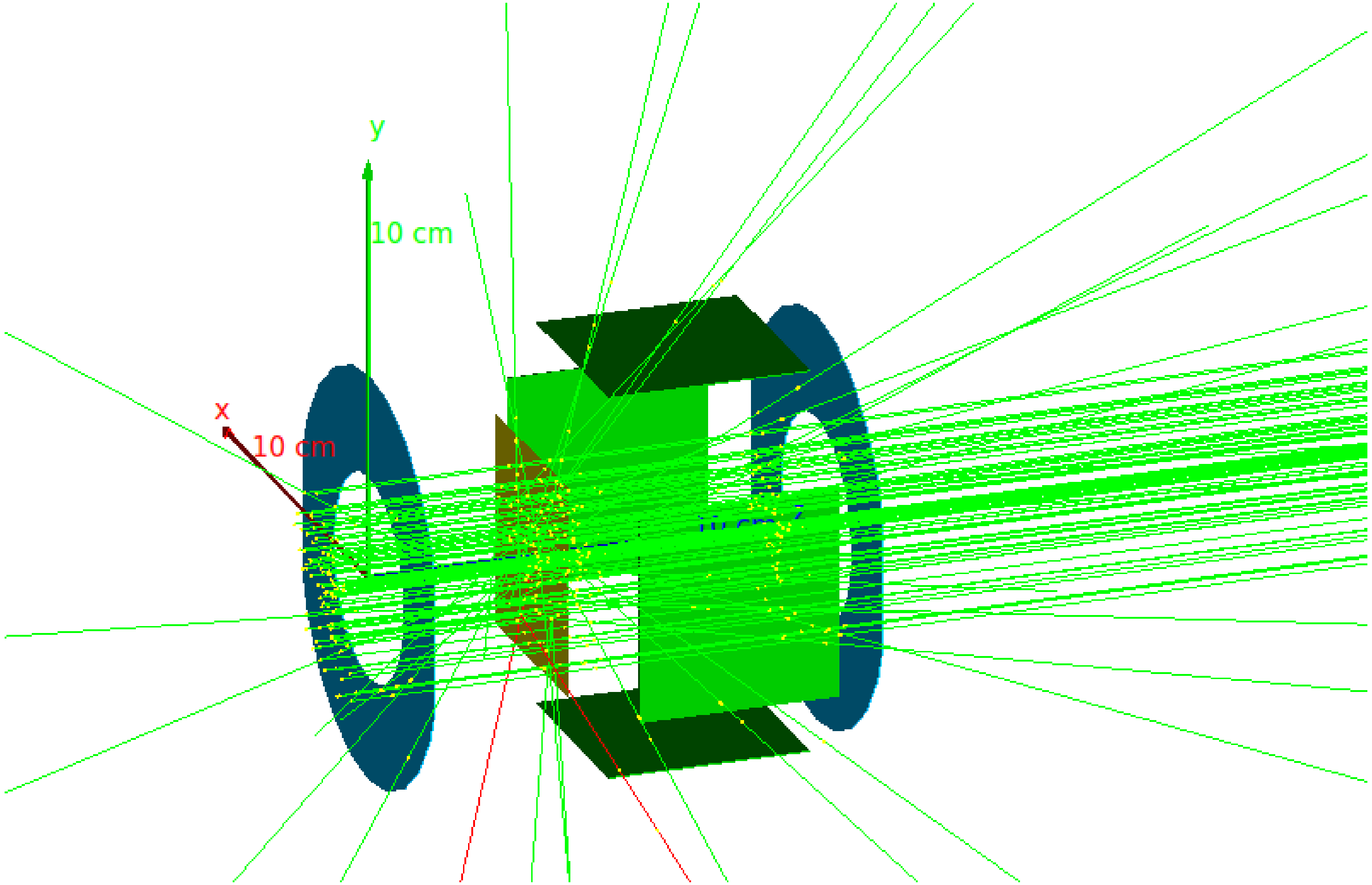






# GEANT4 Simulations

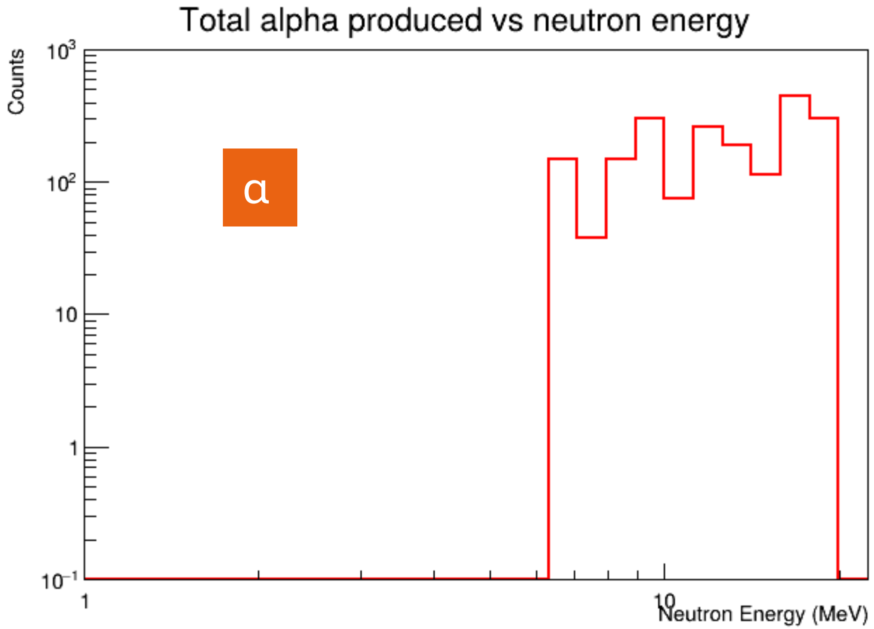
- $^{184}W$, $^{95}Mo$, $^{63}Cu$ samples tested
- $10^7$ **neutrons** with a cross-section **bias of** $10^3$ for all the interactions: equivalent to $10^{10}$ **neutrons**
- **EAR2 flux** with neutron energy **between 1 and 20 MeV**
- Results reported considering **a month of irradiation**

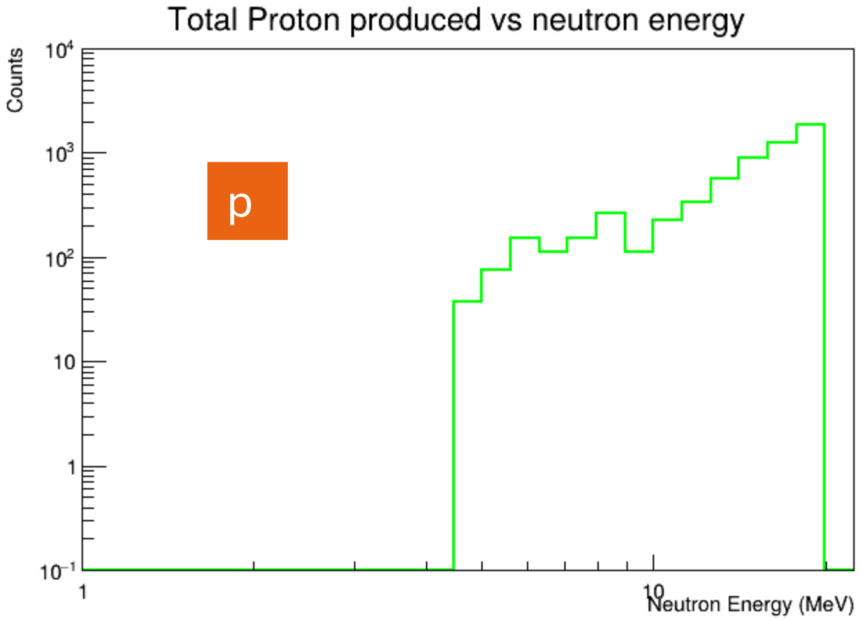


# W simulations

- **Produced Particles**
- Test on $^{184}W$
- Sample thickness = 7 µm
  - 6 MeV Alpha range in Tungsten: 10.4 µm
- Results for a month in EAR2
- 1MeV <$E_n$<20MeV

| Produced Particle | Counts |
|---|---|
| α | 1998 |
| p | 5920 |
| d | 851 |
| t | 37 |



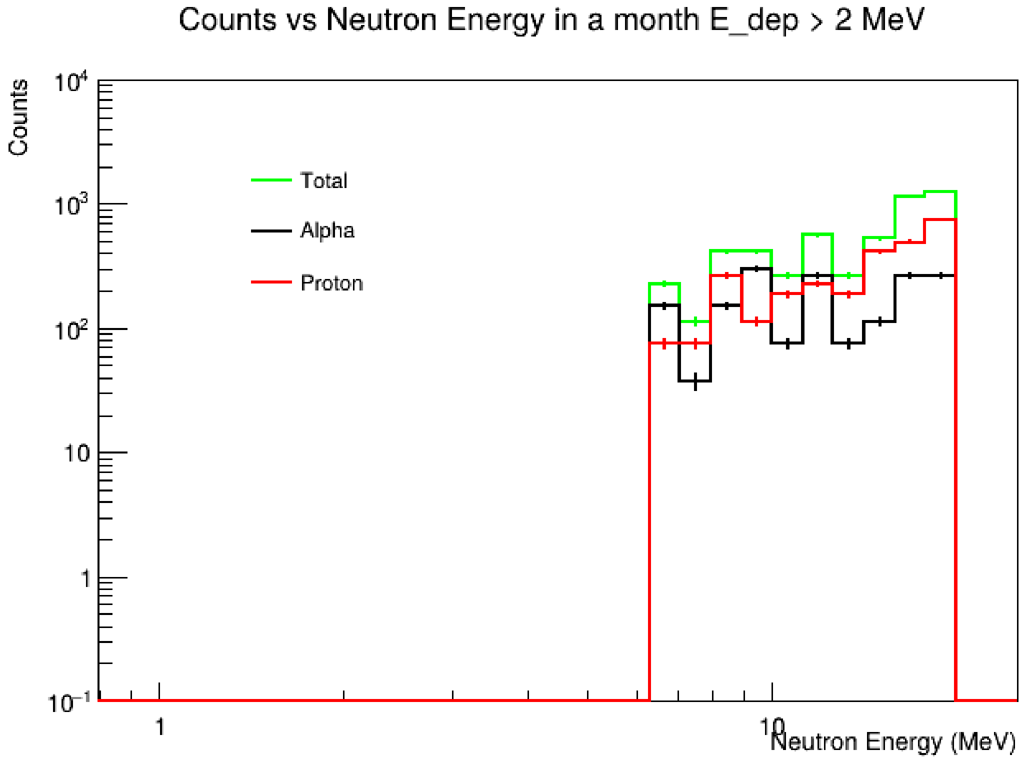


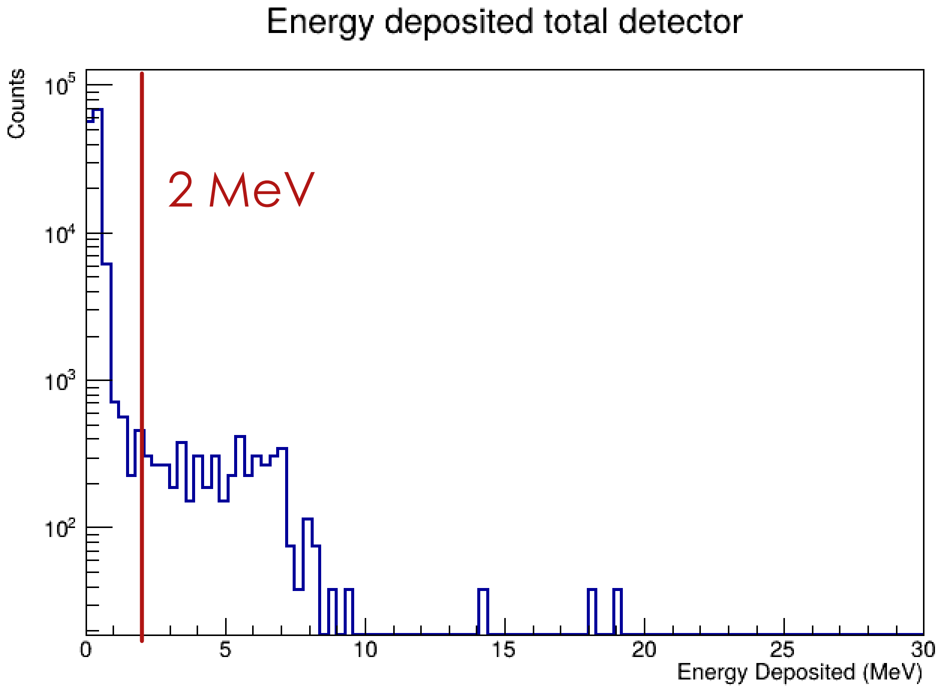
| Isotope | Reaction | Q-value (MeV) | Threshold (MeV) |
|---|---|---|---|
| $^{184}W$ | (n,p) | -2.08 | 2.10 |
| | (n,d) | -5.48 | 5.50 |
| | (n, α) | 7.34 | 0 |
| | (n,t) | -6.15 | 6.2 |

# W simulations

- **Detected Particles** in the whole detector

| Detected Particle | Counts |
|---|---|
| α | 1665 |
| *p* | 3552 |
| d | 481 |
| t | 0 |

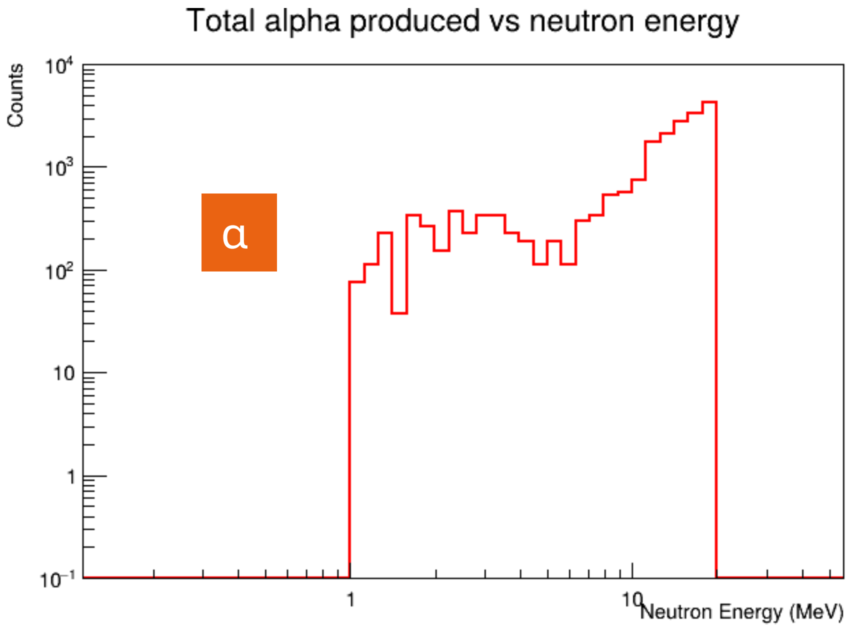


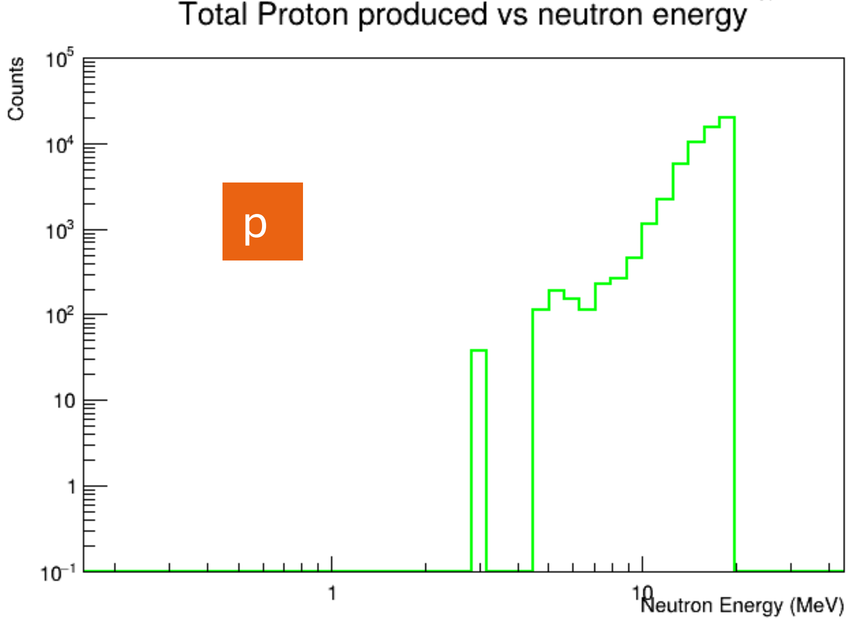


1036 α were detected in the forward annular

# Mo Simulation

- **Produced Particles**
- Test on $^{95}Mo$
- Sample thickness = 7 μm
  - 6 MeV Alpha range in Molybdenum: 12.4μm
- Results for a month in EAR2
- 1MeV < $E_n$ <20MeV





| Produced Particle | Counts |
|---|---|
| α | 19684 |
| p | 55611 |
| d | 0 |
| t | 0 |

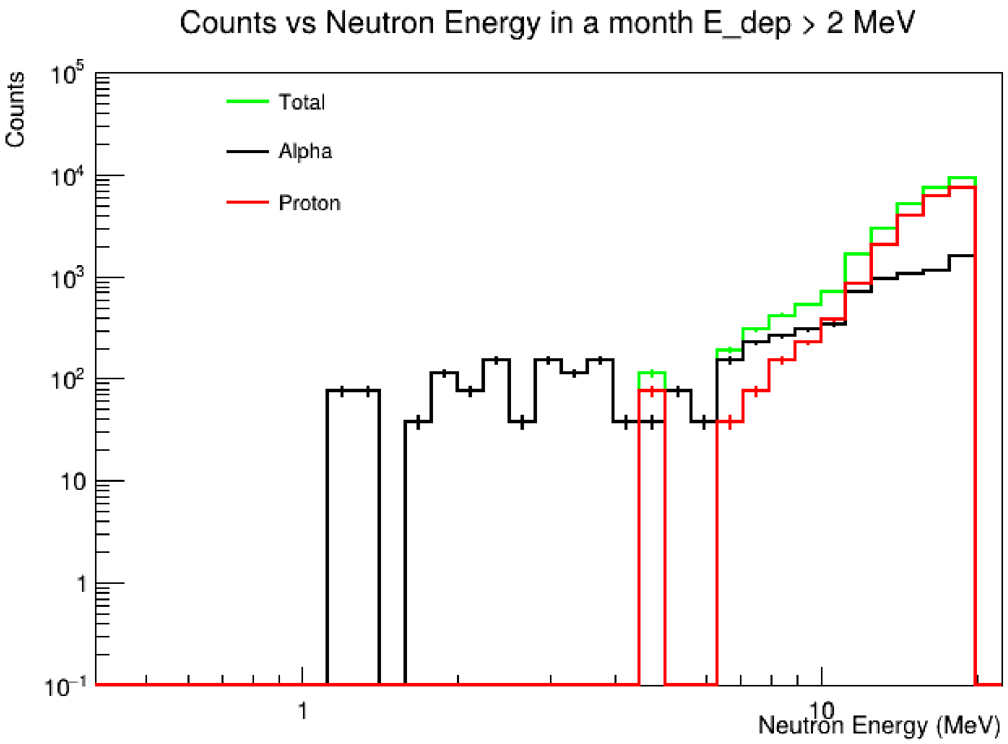
| Isotope | Reaction | Q-value (MeV) | Threshold (MeV) |
|---|---|---|---|
| $^{95}Mo$ | (n,p) | -0.14 | 0.14 |
| | (n,d) | -6.41 | 6.48 |
| | (n, α) | 6.39 | 0 |
| | (n,t) | -11.02 | 11.15 |

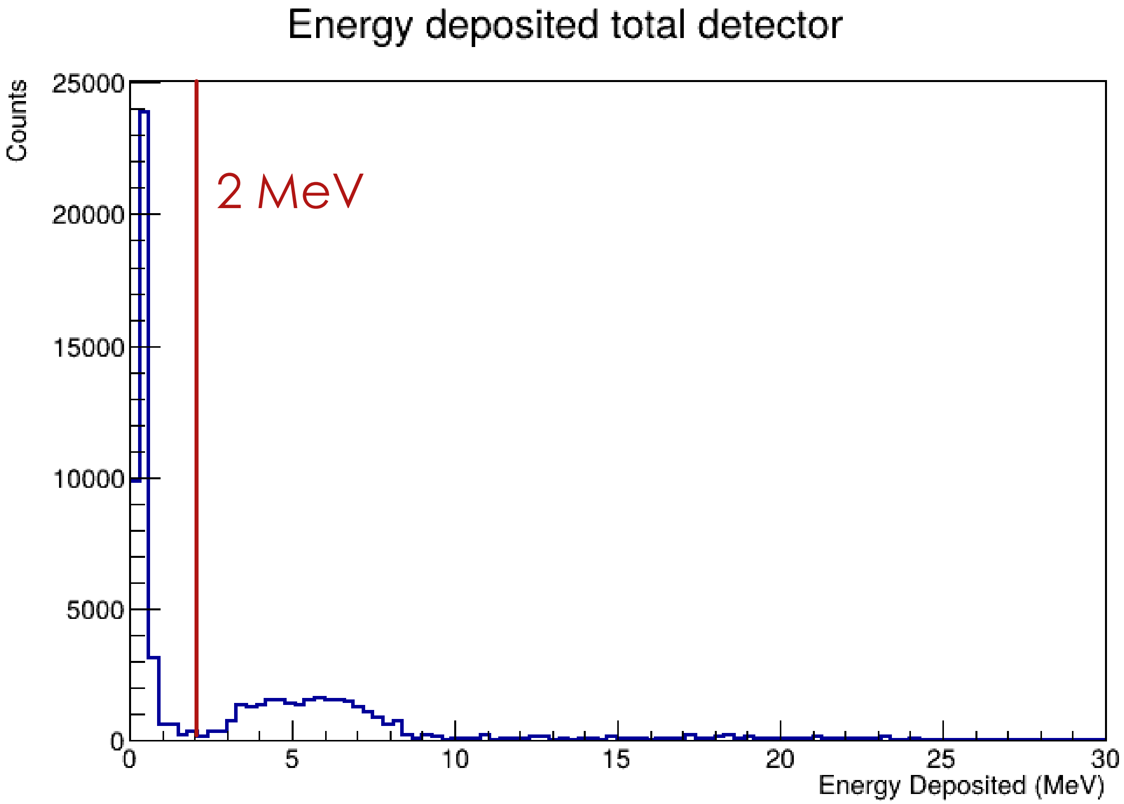
An order of magnitude higher than W

# Mo simulations

- **Detected Particles** in the whole detector

| Detected Particle | Counts | ε |
|---|---|---|
| α | 7844 | 0.40 |
| *p* | 21978 | 0.40 |

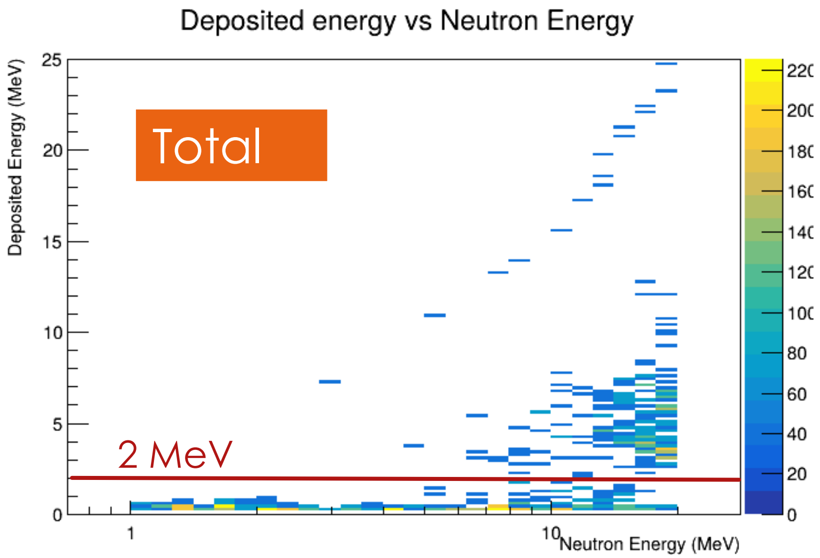


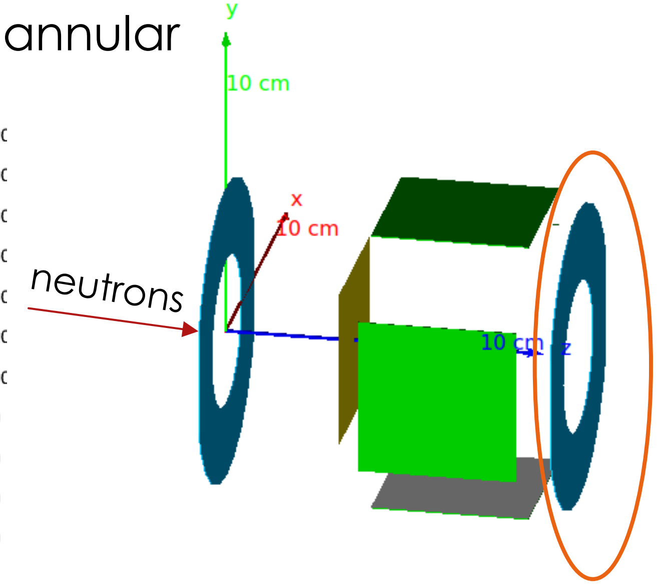


Alpha and Total are superimposed at lower energies

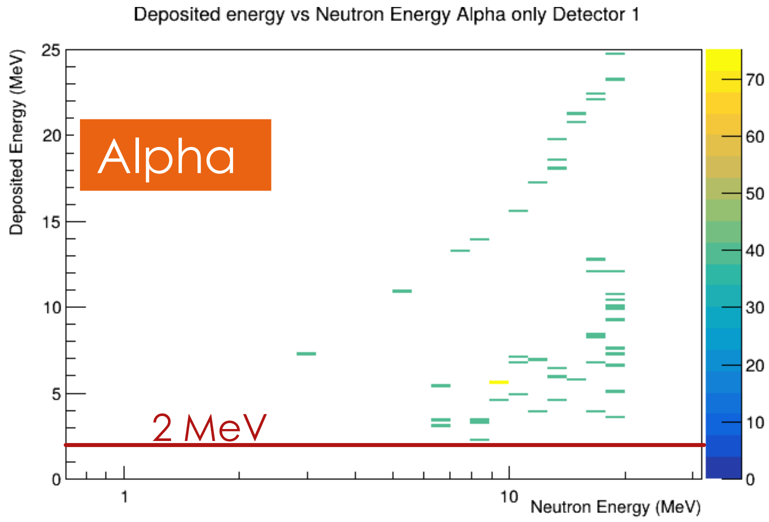
# Mo simulations

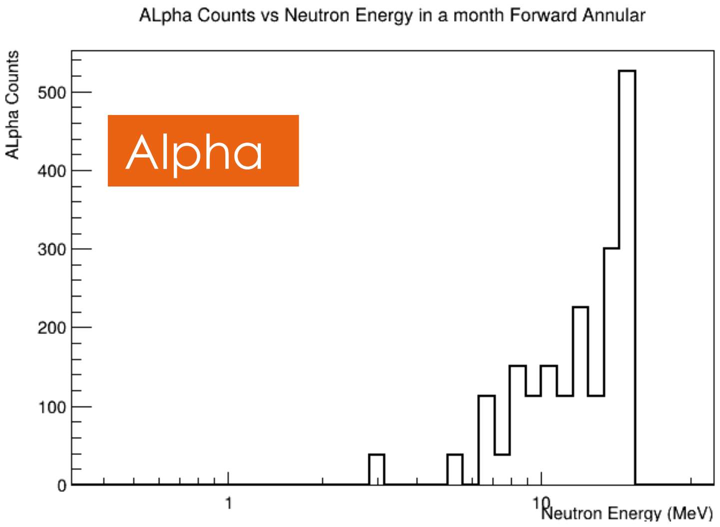
- **Detected Particles** in the Forward annular

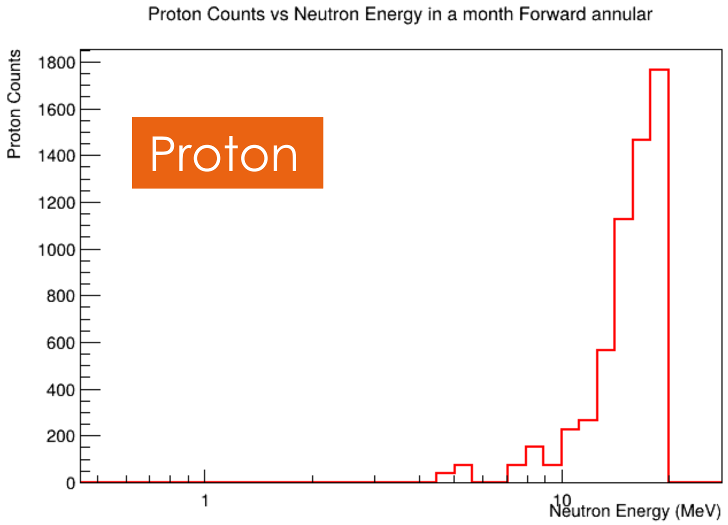

Deposited energy vs Neutron Energy



| Detected Particle | Counts | ε |
|---|---|---|
| α | 1887 | 0.10 |
| *p* | 5735 | 0.10 |


Deposited energy vs Neutron Energy Alpha only Detector 1

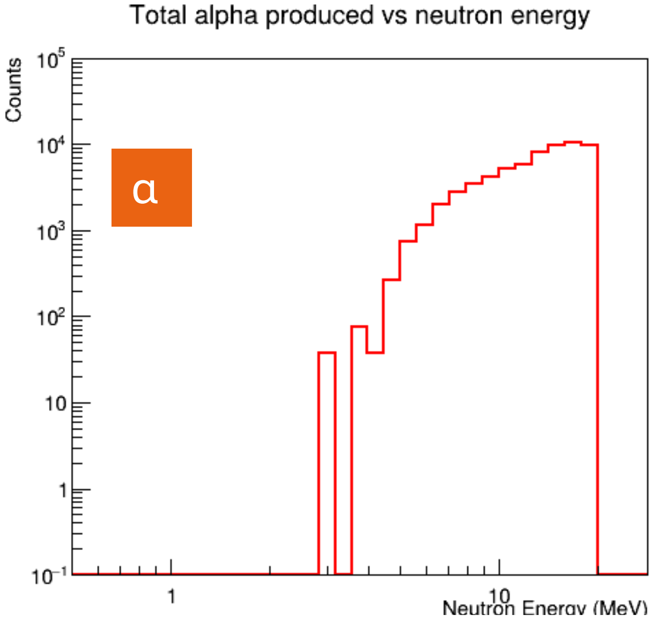

ALpha Counts vs Neutron Energy in a month Forward Annular


Proton Counts vs Neutron Energy in a month Forward annular

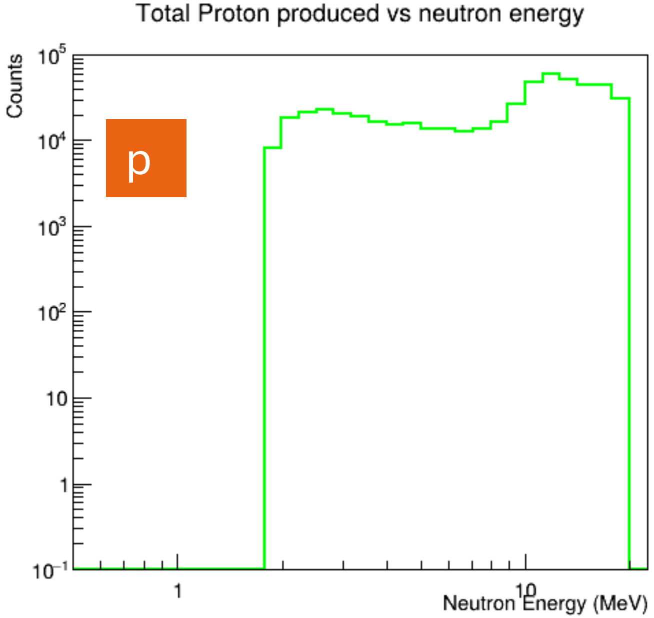
# Cu simulation

- Test on $^{63}\boldsymbol{Cu}$
- Sample thickness = 5 μm
  - 6 MeV Alpha range
  - in Copper: 12.7 μm
- Results for a month in EAR2
- 1MeV <$E_n$<20MeV

| Produced Particle | Counts |
|---|---|
| α | 62752 |
| p | 523143 |
| d | 31931 |
| t | 629 |



Total alpha produced vs neutron energy



Total Proton produced vs neutron energy

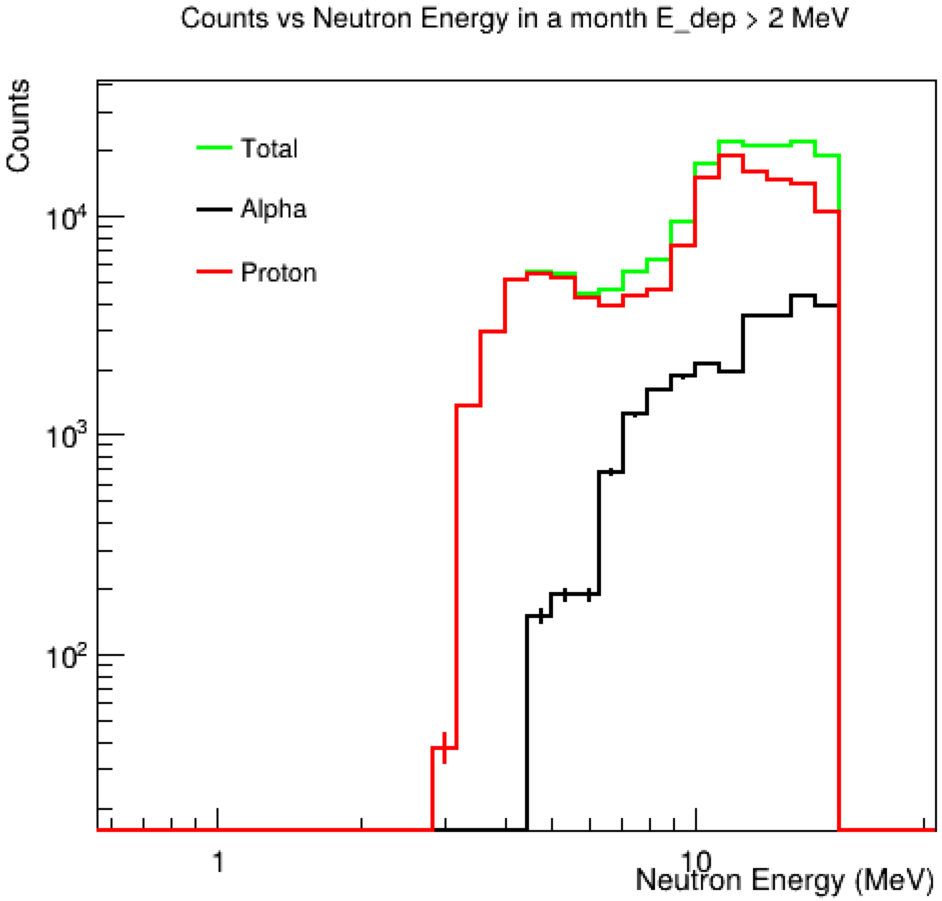
| Isotope | Reaction | Q-value (MeV) | Threshold |
|---|---|---|---|
| $^{63}\boldsymbol{Cu}$ | (n,p) | 0.71 | 0 |
| | (n,d) | -3.90 | 3.96 |
| | (n, α) | 1.71 | 0 |
| | (n,t) | -8.63 | 8.76 |

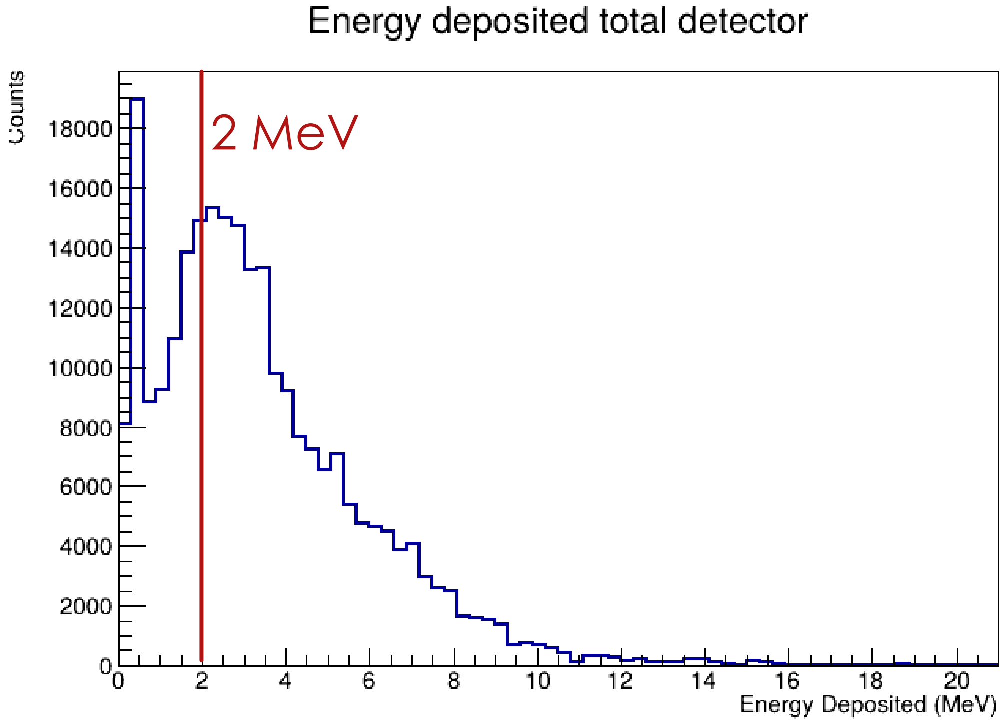
About:
3 times more than Mo case for α
9 times more than Mo case for p

# Cu simulations

- **Detected Particles** in the whole detector

| Detected Particle | Counts | ε |
|---|---|---|
| α | 24938 | 0.40 |
| *p* | 182928 | 0.35 |
| d | 13431 | 0.42 |
| t | 148 | 0.23 |

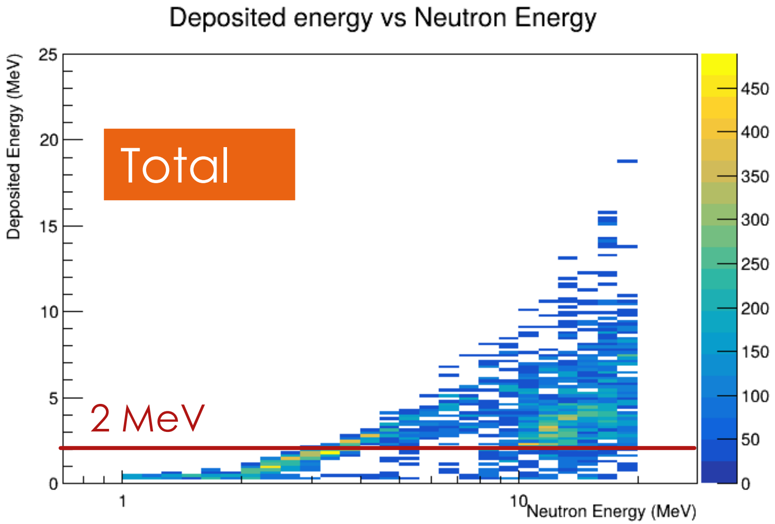


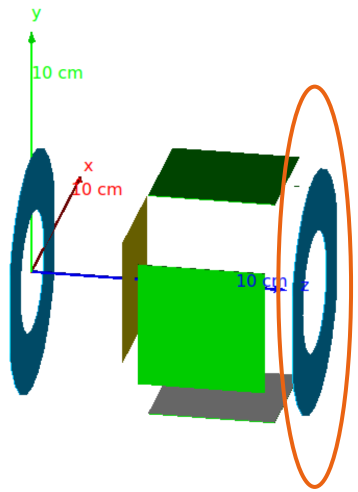


Proton and Total are superimposed at lower energies

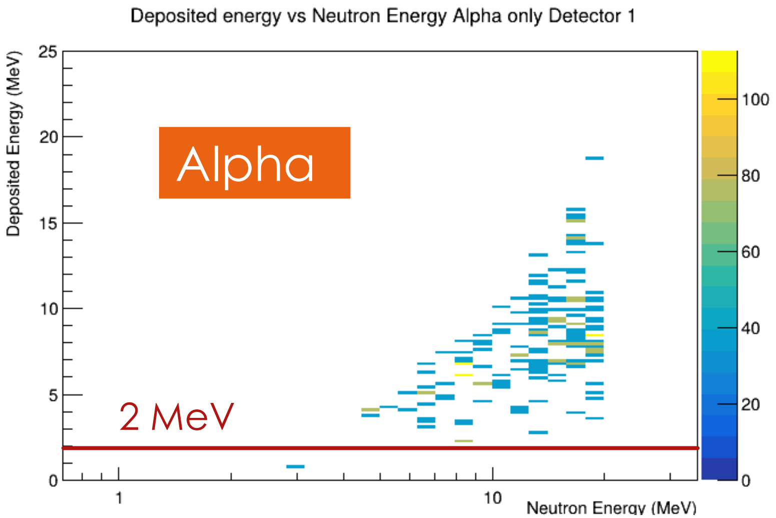
# Cu simulations

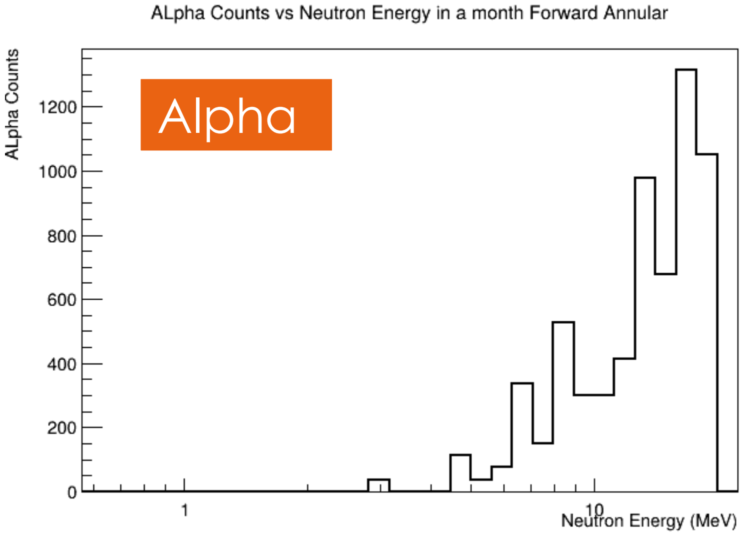
- **Detected Particles** in the Forward annular

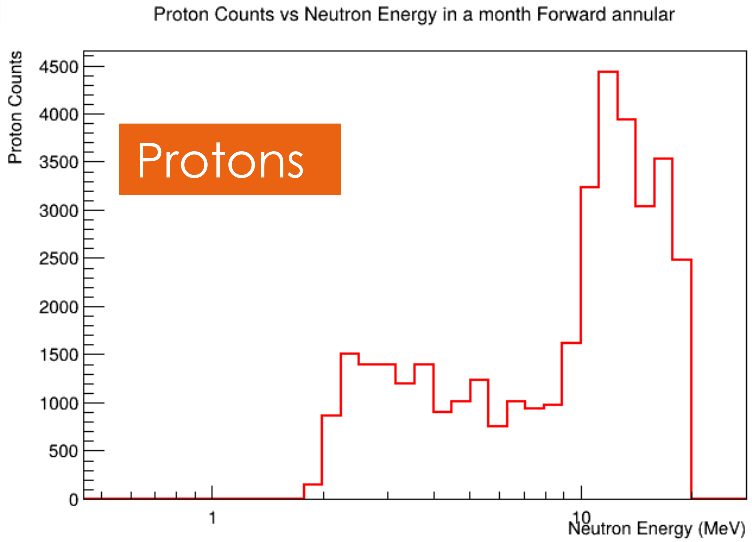

Deposited energy vs Neutron Energy



| Detected Particle | Counts | ε |
|---|---|---|
| α | 6216 | 0.10 |
| p | 36445 | 0.07 |
| d | 4144 | 0.13 |
| t | 37 | 0.06 |


Deposited energy vs Neutron Energy Alpha only Detector 1


ALpha Counts vs Neutron Energy in a month Forward Annular

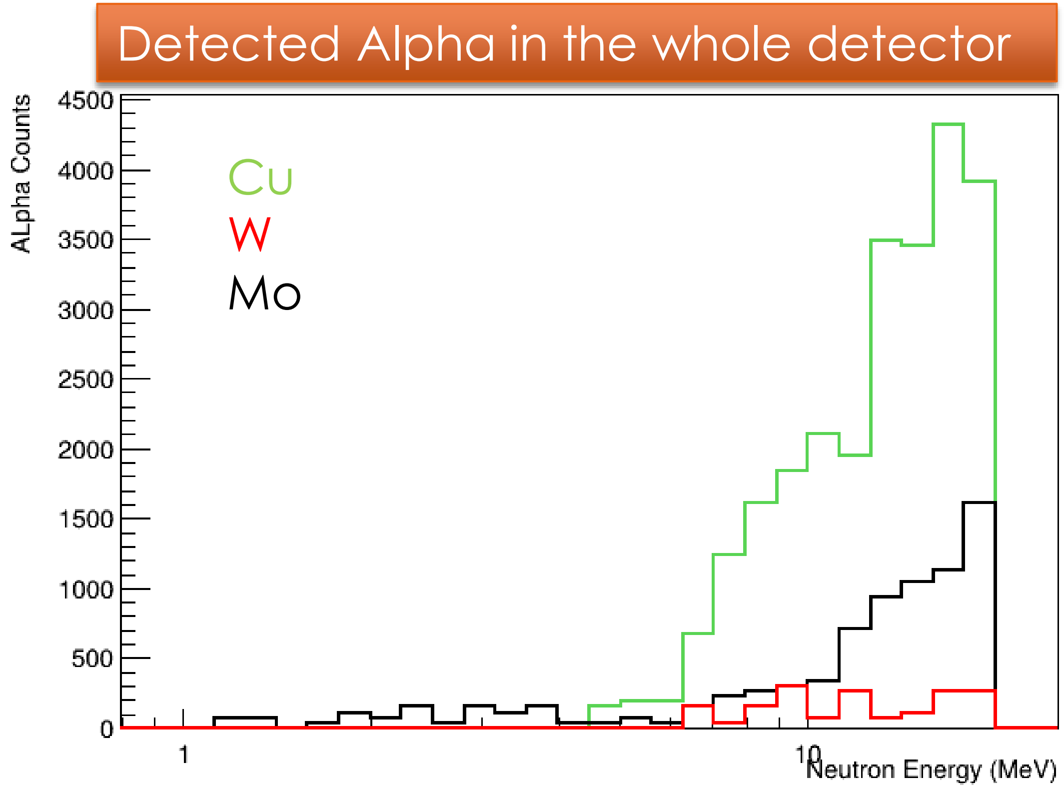

Proton Counts vs Neutron Energy in a month Forward annular

# Comparison between samples

We have considered reactions as candidate

- Relevant for nuclear fusion
- Should Have a High Yield
- (n,a) has a better PSD performance

| Isotope | Results |
|---|---|
| $^{184}W$ | • Very small Yield<br>• Higher Z |
| $^{95}Mo$ | • Higher Yield<br>• Very High Q-value |
| $^{63}Cu$ | • Highest Yield<br>• Smaller Q-value<br>• Smallest Z<br>• Available |



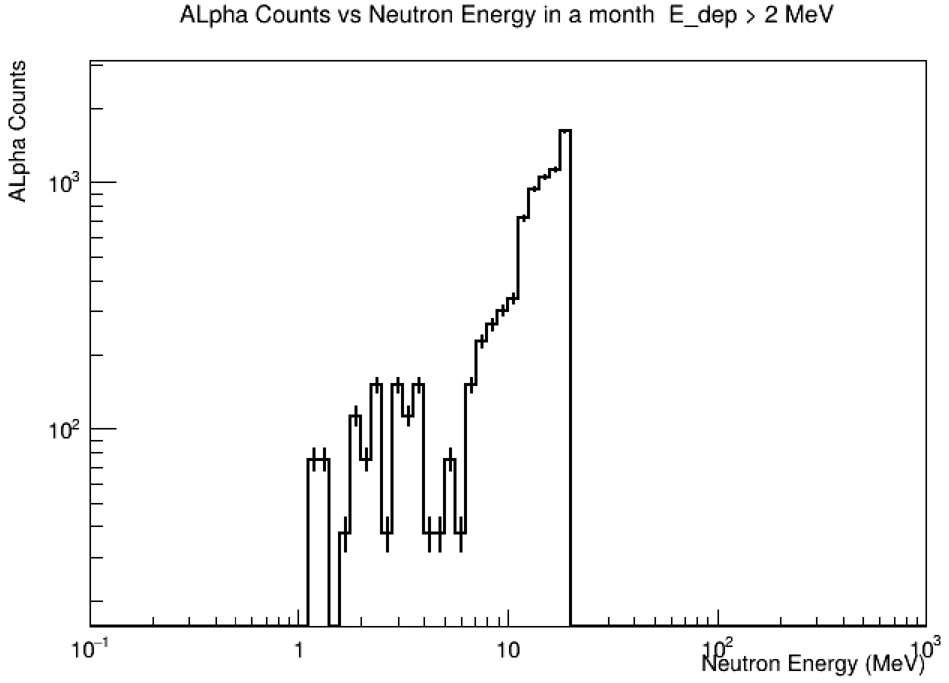
Detected Alpha in the whole detector

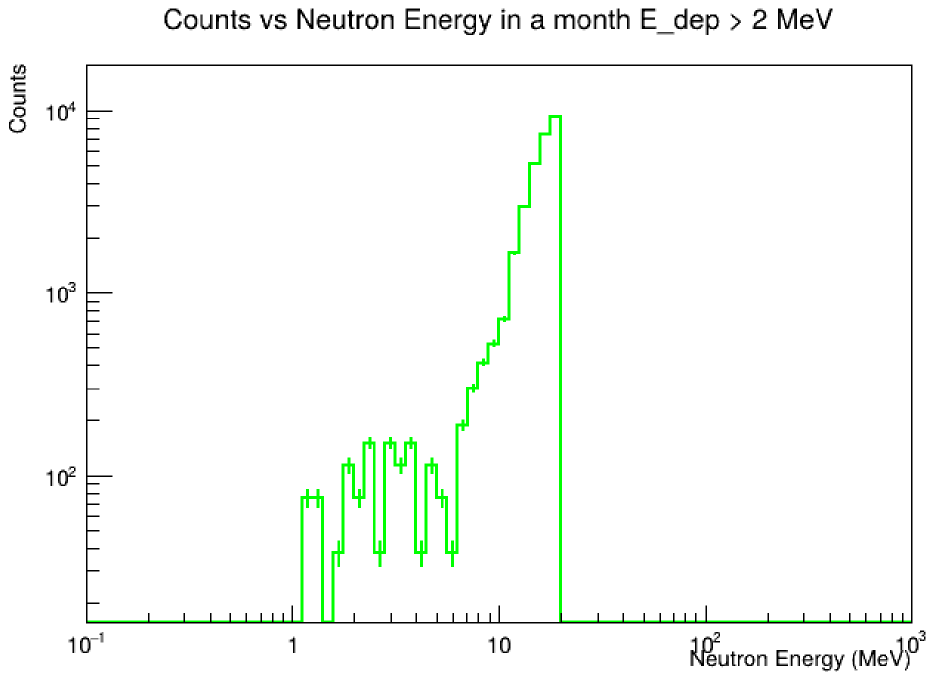
# Thanks for the attention!

# Reactions involved

| Isotope | Reaction | Q-value (MeV) | Threshold |
|---|---|---|---|
| $^{184}W$ | (n,p) | -2.08 | 2.10 |
| | (n,d) | -5.48 | 5.50 |
| | (n, a) | 7.34 | 0 |
| $^{95}Mo$ | (n,p) | -0.14 | 0.144.8 |
| | (n,d) | -6.41 | 6.48 |
| | (n, a) | 6.39 | 0 |
| $^{63}Cu$ | (n,p) | 0.71 | 0 |
| | (n,d) | -3.90 | 3.96 |
| | (n, a) | 1.71 | 0 |

# Total detected 95 Mo


ALpha Counts vs Neutron Energy in a month  E_dep > 2 MeV


Counts vs Neutron Energy in a month E_dep > 2 MeV