Spallation in a composite target

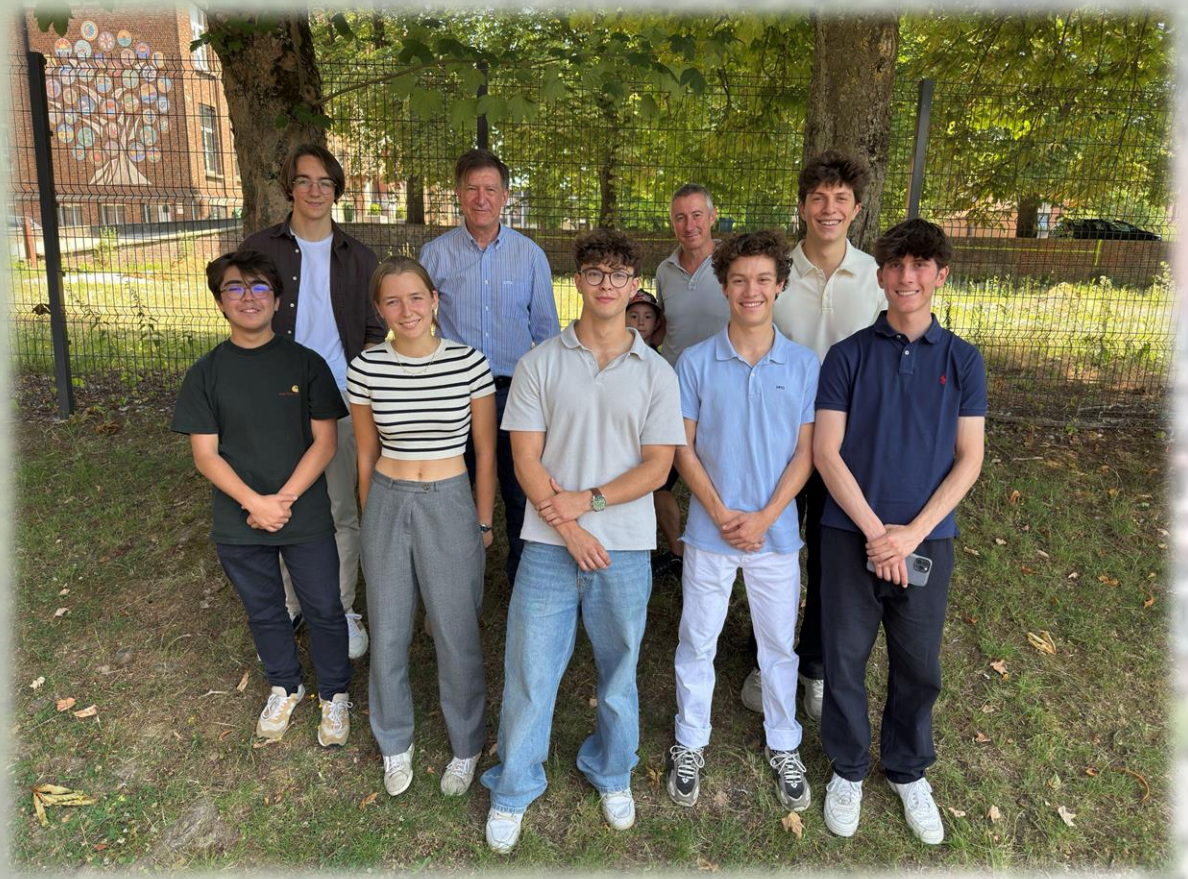
The Spallateam

Collège
Cardinal Mercier

23 September 2025

CERN

The spallateam



- ***Students :***

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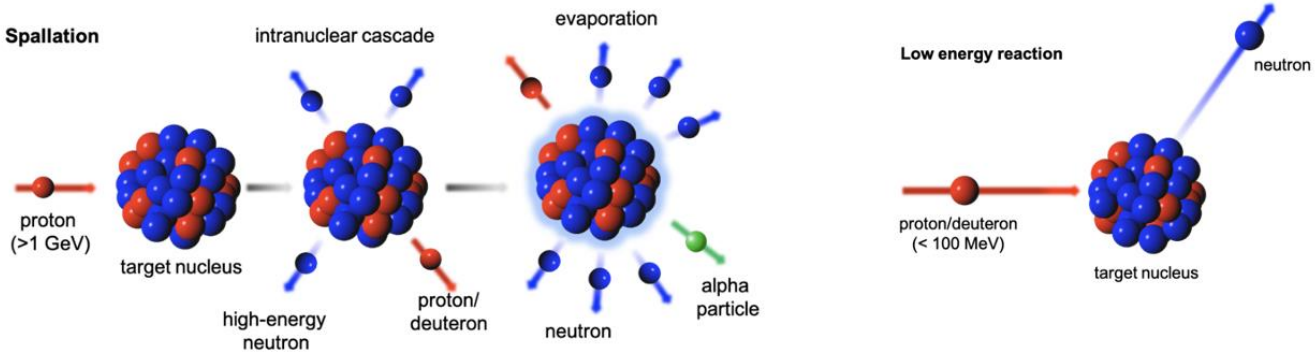
- ***Coaches :***

Jean-Pierre
Jean-Michel

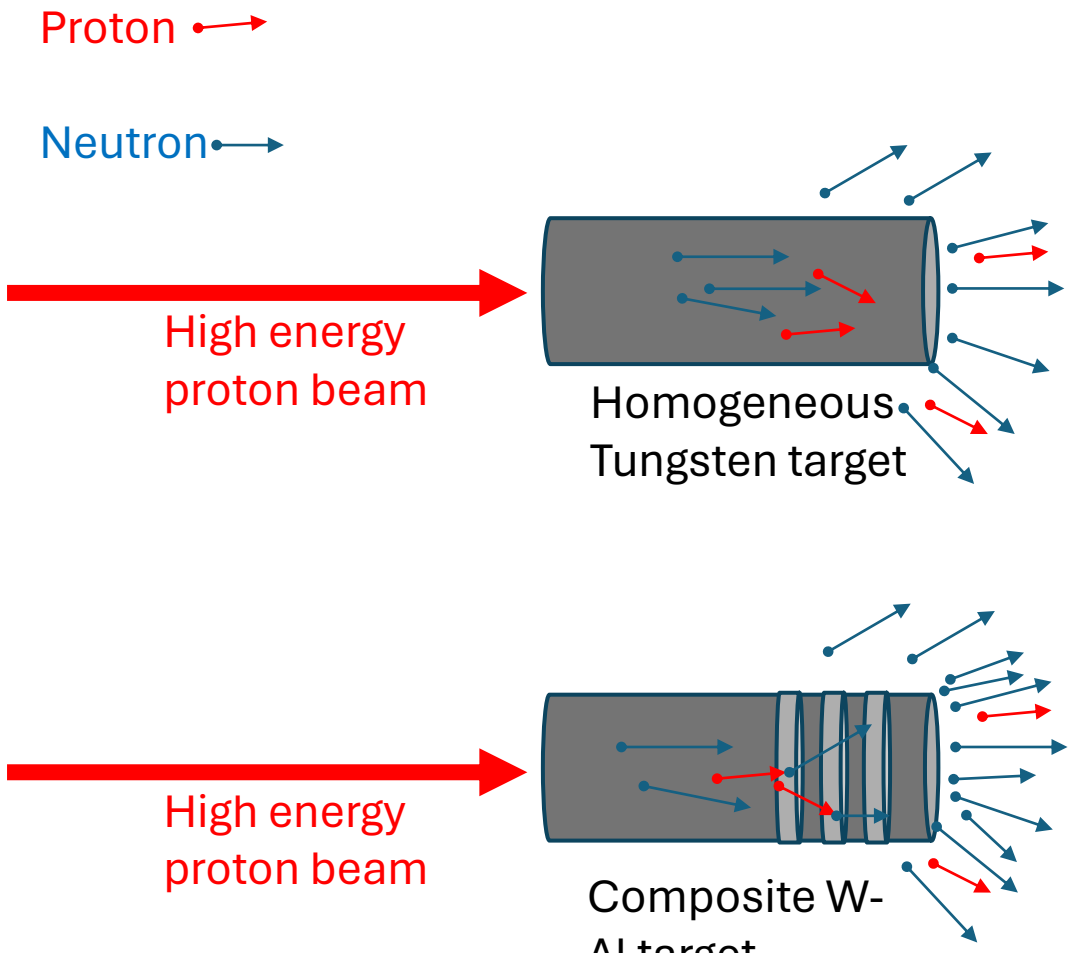
Our first goal



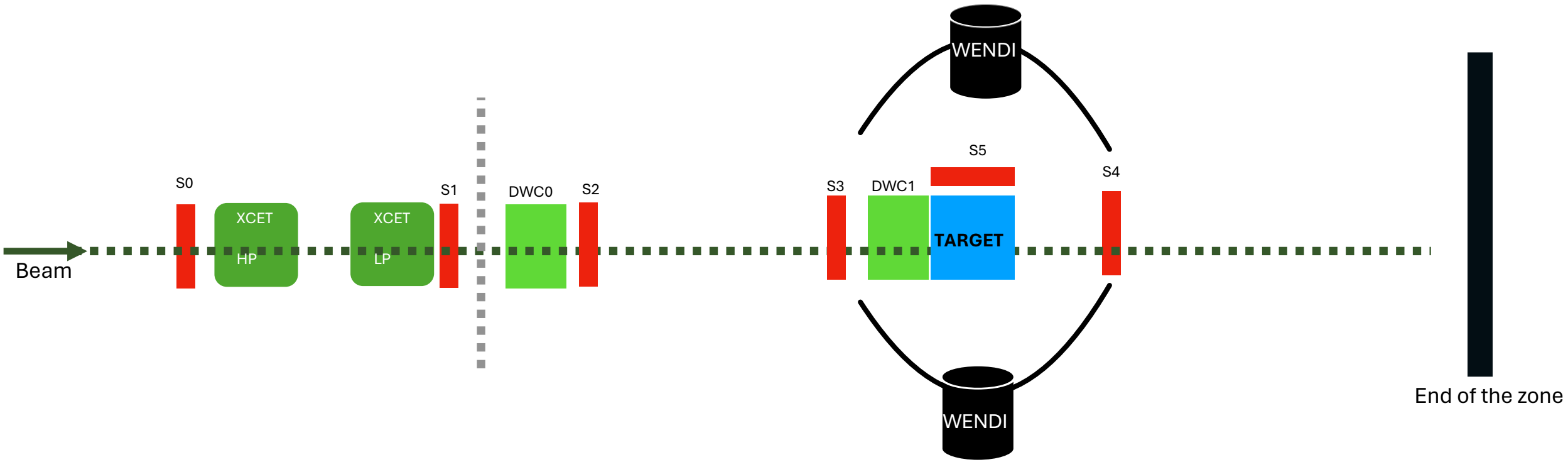
$$p + {}^{181}_{73}Ta \rightarrow kn + k'p + {}^{a}_{b}X$$

To use **secondary protons of low energy** produced by the first spallation with a heavy metal to make a **second spallation with a light metal** in the same target.

Our experiment



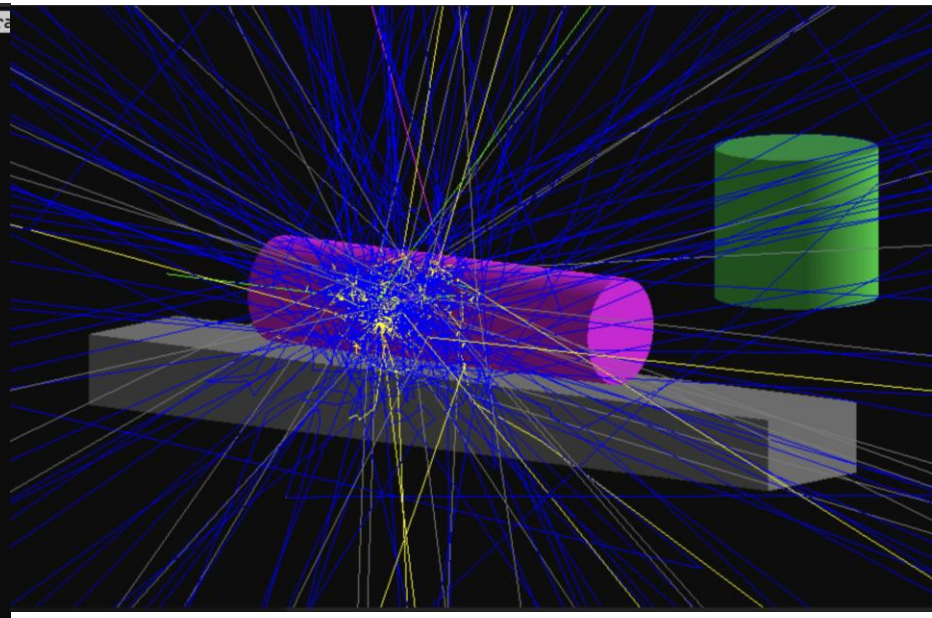
A quick reminder about the set up



Our journey

Geant4 and many many many simulations

```
 GNU nano 5.6.1                                          tungsten_gra
# Tungsten-Graphite Composite Target Macro
# Configuration:
# - Material 1: Tungsten (6.0 cm thick layers)
# - Material 2: Graphite (0.1 cm thick interlayers)
# - Number of tungsten layers: 10 (default)
# - Total particles: 1000

# Set up composite target parameters BEFORE initialization
/neutron/source/target/material Composite
/neutron/source/target/composite/material1 W
/neutron/source/target/composite/material2 Al
/neutron/source/target/composite/thickness1 6.0 cm
/neutron/source/target/composite/thickness2 0.5 cm
/neutron/source/target/composite/nlayers 3

# Set target dimensions
/neutron/source/target/diameter 15.0 cm
/neutron/source/target/positionZ 0.0 cm

# Set WENDI detector position
/neutron/source/wendi/positionX 88.95 cm
/neutron/source/wendi/positionY 0.0 cm
/neutron/source/wendi/positionZ -8.0 cm

# Disable debug output to reduce verbose messages
/neutron/debug false

# Initialize the geometry (this builds the composite target)
/run/initialize

^G Help        ^O Write Out   ^W Where Is   ^K Cut
^X Exit        ^R Read File   ^\ Replace    ^U Paste
```



Last update yesterday at 23:00

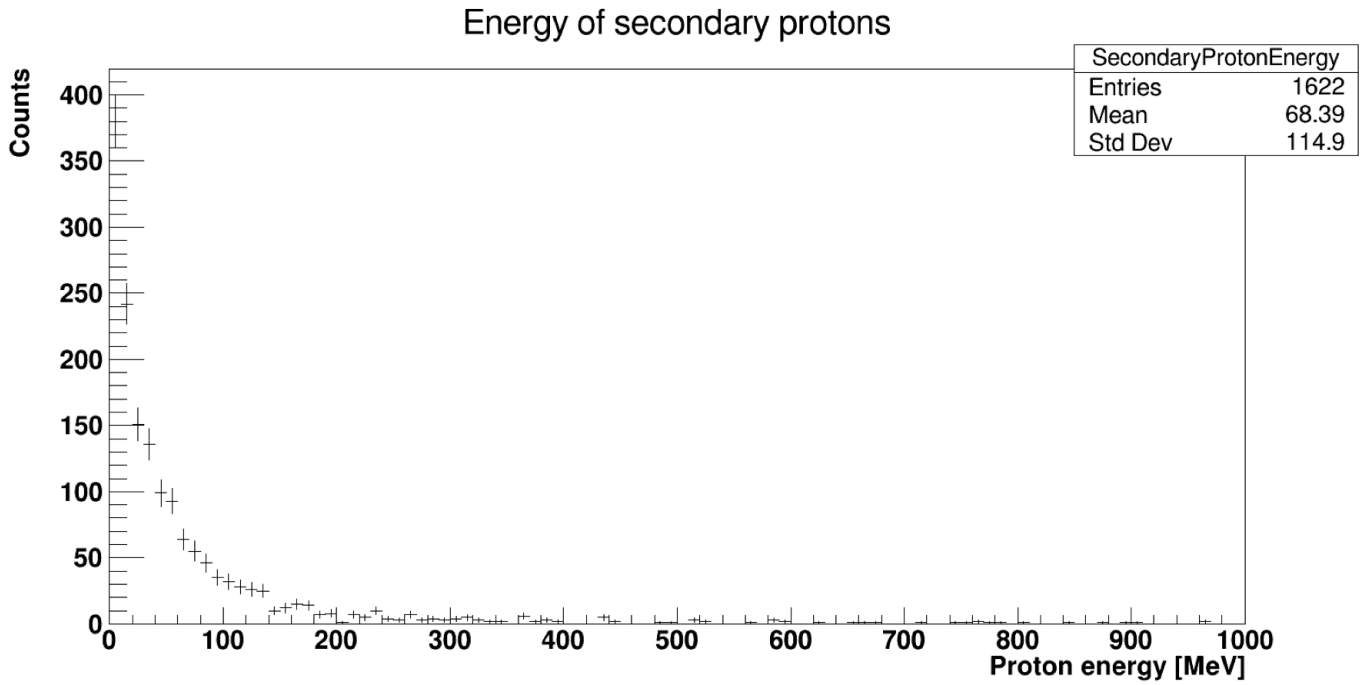
Many updates every day on our simulation’ s programme to adapt to our needs and to bring us closer to the reality of our experience.

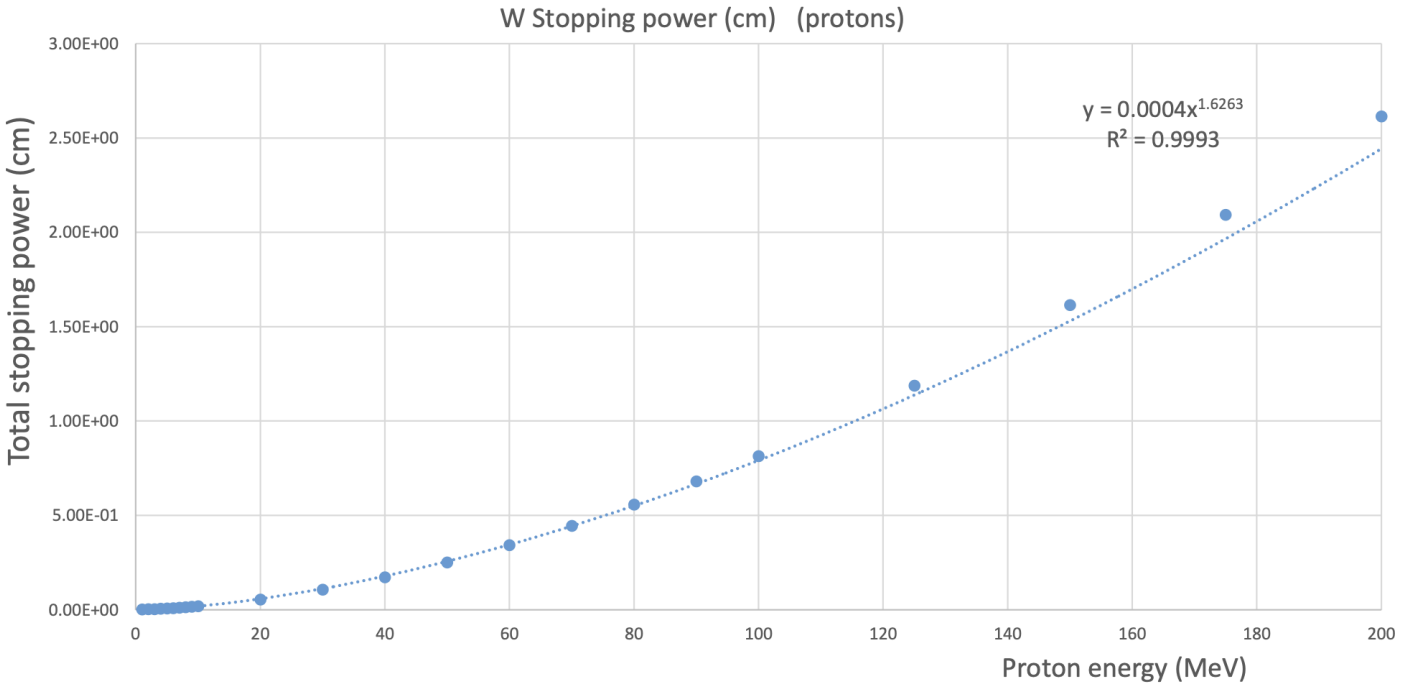
Maybe poor time management, which also had an impact on the experience.

Our journey

Secondary protons of low energy

The first graph allowed us to confirm the presence of secondary protons in the spallation as well as their energy.

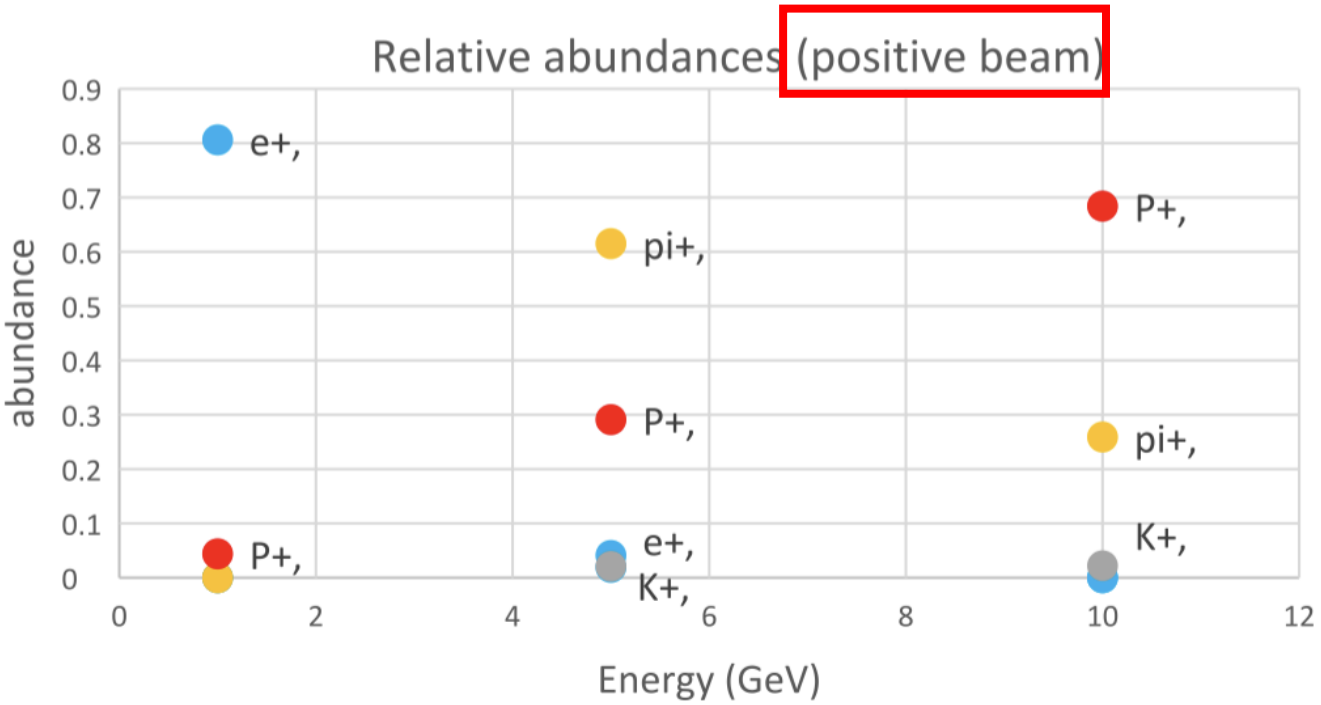


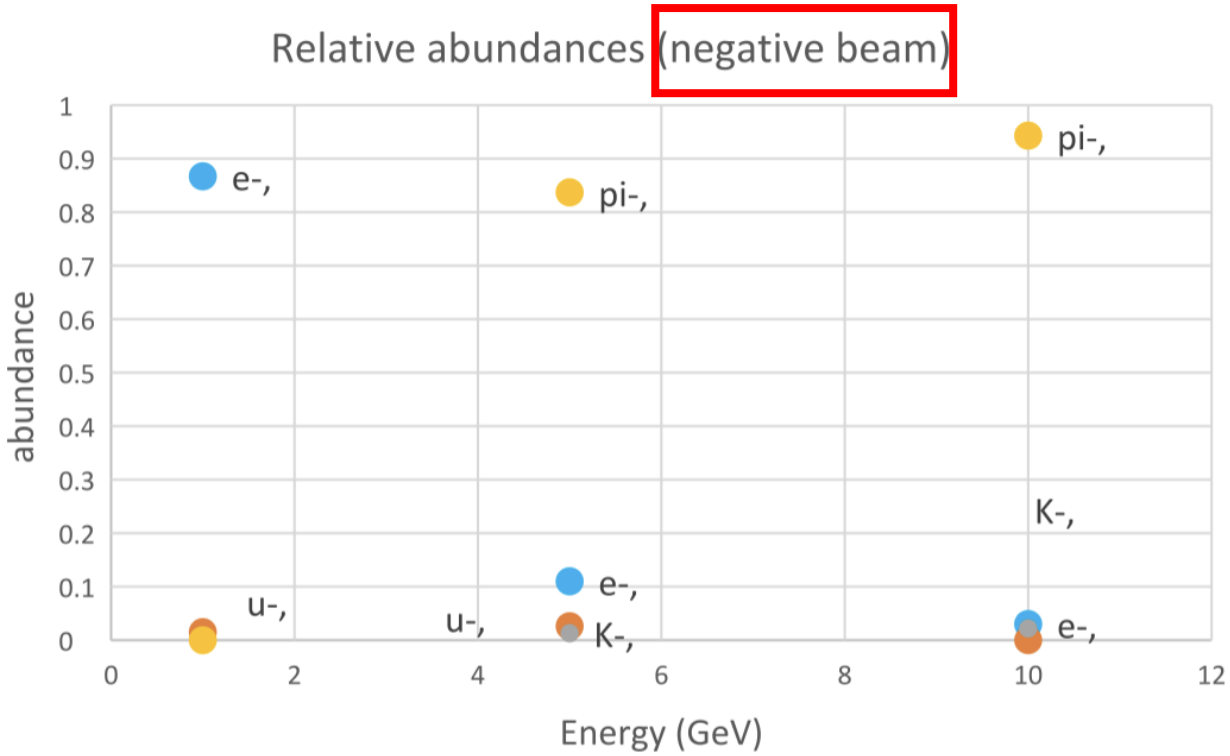


Their energy, combined with their stopping power, allowed us to further optimise our experiments.

Our journey

Relative abundances in beams

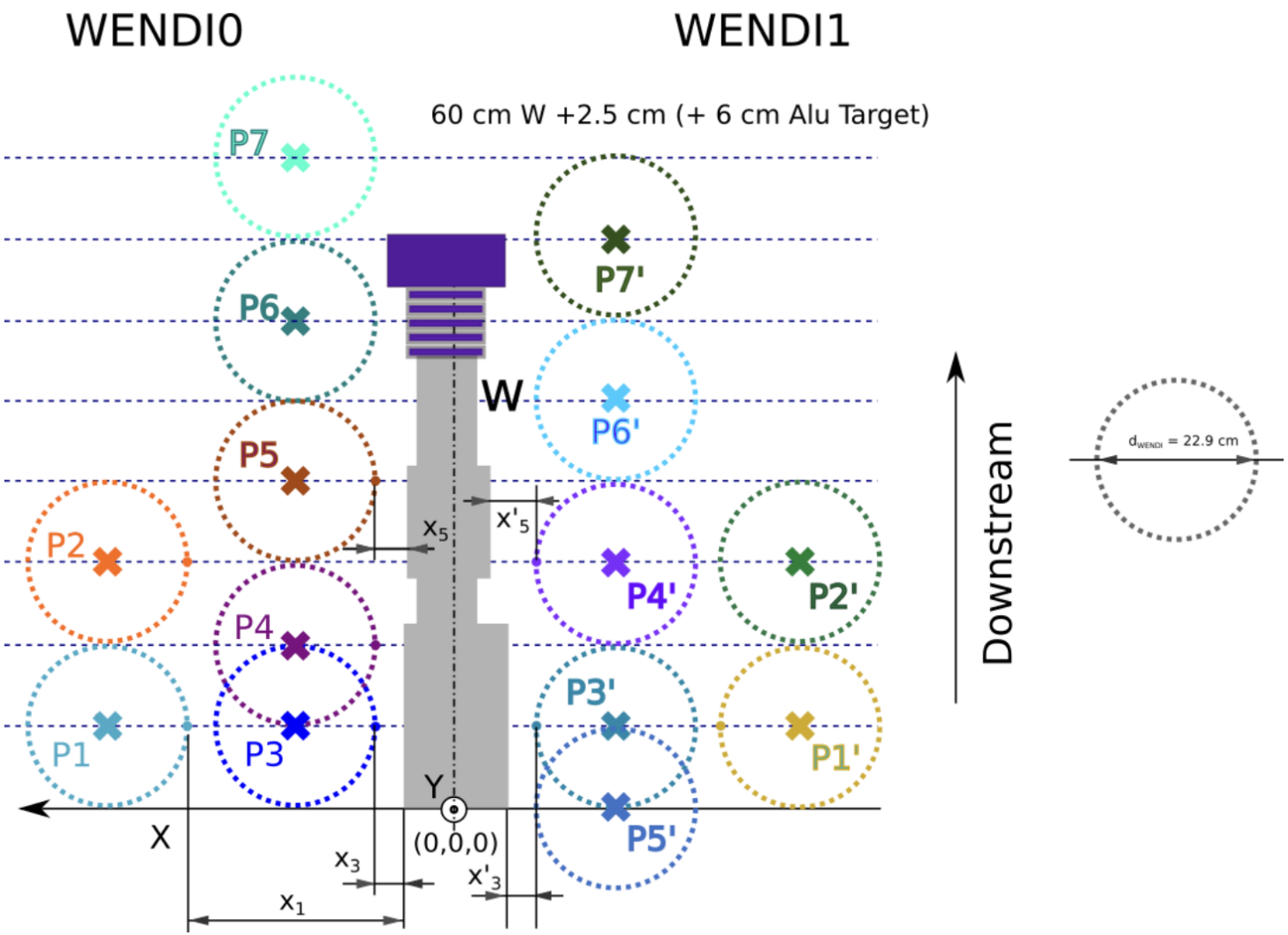




These data enabled us to perform simulations that were closer to the reality of the beam used in our experiment.

Our journey

Different WENDI positions



We tried a lot of different positions for WENDI0 and WENDI1 to find a position that gives us a good view of the neutrons release.

Our results

Experiments versus simulations

1) Experiments:

Target: 13 cm diameter, 60 cm thickness W, 0 cm Al, Beam +10 GeV

particles		WENDI 0 (P6)	WENDI 1 (P4’)
K+, pi+, P+			
	Total :	**0.0036 count/hadron**	**0.0186 count/hadron**

2) Simulations (GEANT4):

Target: 13 cm diameter, 60 cm thickness W, 0 cm Al, Beam +10 GeV

particles	abundance	events	WENDI 0 (P6)	WENDI 1 (P4')
K+	0.022	10000	16.5690 count/spill	120.4980 count/spill
pi+	0.259	10000	15.2799 count/spill	106.7960 count/spill
P+	0.684	10000	18.9602 count/spill	128.0710 count/spill
	TOTAL :	10000	0.0017291 count/hadron	0.0117912 count/hadron
	0.965		**0.0017918 count/hadron**	**0.0122188 count/hadron**

	WENDI 0 (P6)	WENDI 1 (P4')
Ratio exp/sim	**2.01**	**1.52**

Our results

Experiments versus simulations

3) Correction of the code:

The focus point of the beam is located before the target. Therefore, we must **increase the sigma of the beamwith** in the simulation and **add the concrete blocks under the tungsten**.

Target: 13 cm diameter, 60 cm thickness W, 0 cm Al, Beam +10 GeV

particles	abundance	events		WENDI 1 (P4')
K+	0.022	10000		155.002 count/spill
pi+	0.259	10000		117.322 count/spill
P+	0.684	10000		141.027 count/spill
	TOTAL :	10000		0.0134983 count/hadron
	0.965			**0.0139888 count/hadron**

		WENDI 1 (P4')
Ratio exp/sim		**1.33**

… a little better

Back on our experimental approach

- *Our goal : compare the effectiveness of a composite target vs homogeneous target.*

- *Use of the simulation tool to select the most promising configurations…bad idea*

- *Analysis of the experimental data and comparison with the numerical results >> Significant divergence*

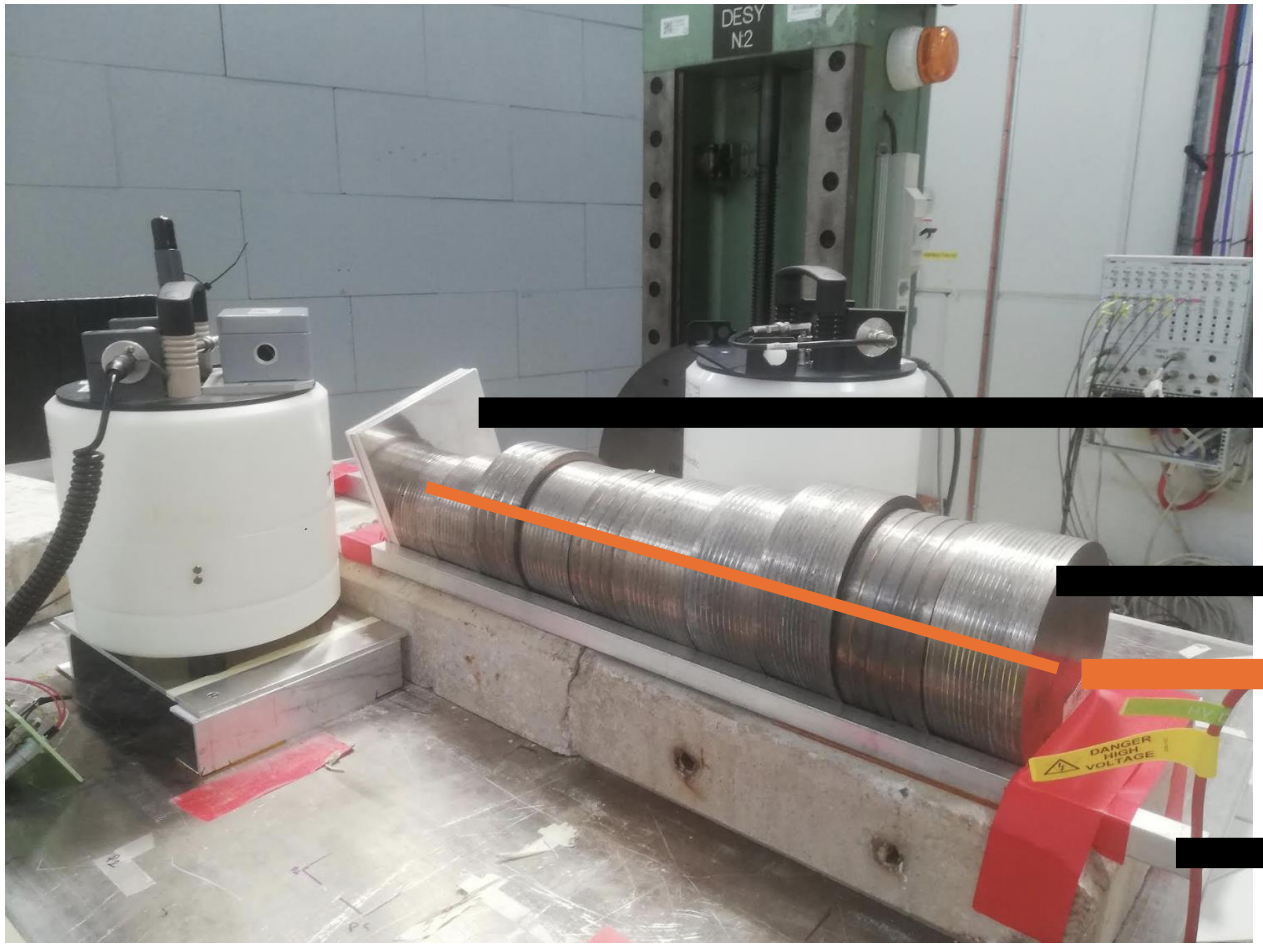
- *In fact, the simulation and the experiment do not exactly match…so far*

“Theory is when you know everything but nothing works. Practice is when everything works but nobody knows why. Here we have combined theory and practice : nothing works… and nobody knows why !”

A. Einstein

We don’t know, but let’s try.

What could explain the difference between experiments and simulations ?



More neutrons detected than in the simulation due to reflexion on the concrete blocks

<u>Some elements not taken into account in Geant4 :</u>

- The size of Aluminium
- The different diameters of Tungsten
- Non-aligned centres
- The Aluminium structure

Our results

Evaluation of the efficiency of the composite target

1) Homogeneous target: 60 cm thickness tungsten (diameter 13 cm)

beam	P6 (count/hadron)	P4' (count/hadron)
1 GeV	0.003149154	0.003628447
5 GeV	0.001491552	0.008502714
10 GeV	0.0036	0.0186
-1 GeV	0.004131079	0.004668994
-5 GeV	0.001617207	0.009300613
-10 GeV	0.003226823	0.016959709

2) Composite target: 60 cm thickness tungsten (diameter 13 cm) **+ 2.5 cm thickness aluminium**

beam	P6 (count/hadron)	P4' (count/hadron)
1 GeV	0.003202981	0.003576313
5 GeV	0.001472664	0.008696787
10 GeV	0.003598892	0.018553187
-1 GeV	0.004071673	0.004842083
-5 GeV	0.00164286	0.009537102
-10 GeV	*Do not exist*	*Do not exist*

Our results

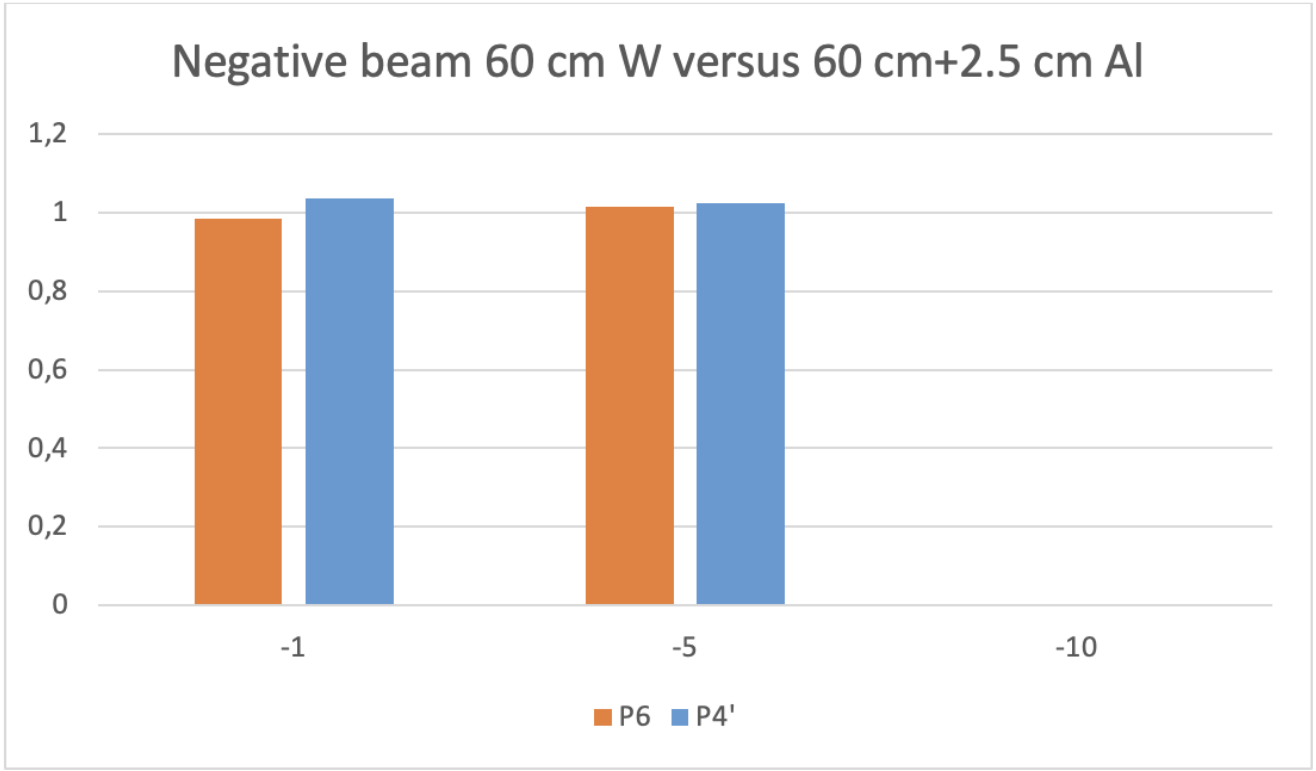
Evaluation of the efficiency of the composite target

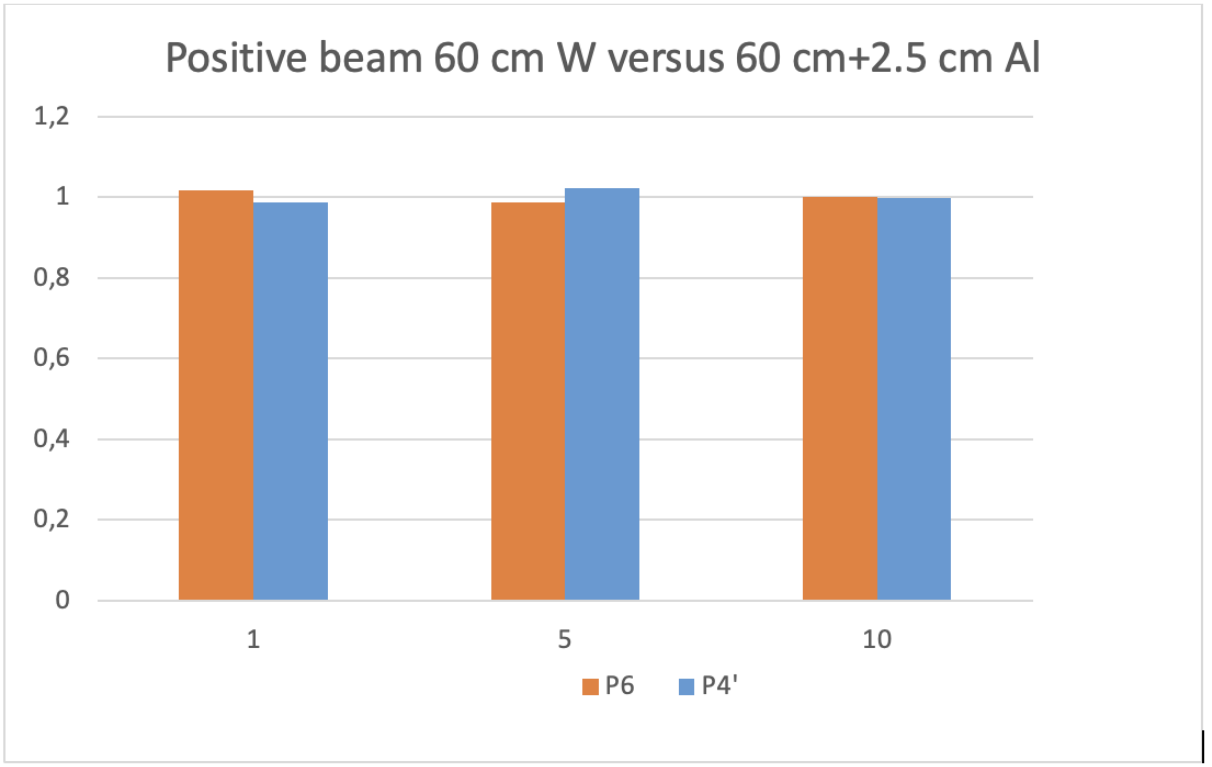
3) Efficiency?

beam	P6 (composite/homogeneous)	P4' (composite/homogeneous)
1 GeV	1.017092394	0.985631943
5 GeV	0.987336191	1.022824923
10 GeV	0.999692213	0.997483184
-1 GeV	0.985619651	1.037072141
-5 GeV	1.015862976	1.025427227
-10 GeV	///	///

Our results

Evaluation of the efficiency of the composite target





Our results

Comparison between proton (p+) and pion (pi+)

1) At high energy, positive and negative pions have almost the same spallation efficiency. Positive pions are **1.5%** less efficient.

2) The negative beam does not contain antiprotons. Consequently, at -10 GeV, spallations are exclusively produced by pions.

3) Cherenkov detectors 2 bar and 14 bar:

P (GeV/c)	electron (bar)	muon (bar)	pion (bar)	kaon (bar)	proton (bar)
1	0.0002901	12.37	21.55	259.9	824.6
2	0.00007253	3.099	5.407	67.75	232.3
3	0.00003224	1.378	2.405	30.36	106.1
4	0.00001813	0.7751	1.353	17.13	60.28
5	0.00001161	0.4961	0.8660	10.98	38.77
6	0.000008059	0.3445	0.6014	7.629	26.99
7	0.000005921	0.2531	0.4419	5.608	19.86
8	0.000004533	0.1938	0.3383	4.295	15.22
9	0.000003582	0.1531	0.2673	3.394	12.04
10	0.000002901	0.1240	0.2165	2.750	9.755
11	0.000002398	0.1025	0.1789	2.273	8.065
11.2	0.000002313	0.09889	0.1726	2.192	7.780
11.4	0.000002232	0.09545	0.1666	2.116	7.510
11.5	0.000002194	0.09379	0.1637	2.079	7.380

Our results

Comparison between proton (p+) and pion (pi+)

S0S1 counts $N(e^+) + N(\mu^+) + N(\pi^+) + N(K^+) + N(P^+)$

S0S1C1 counts $N(e^+) + N(\mu^+) + N(\pi^+)$

Since:

$$N(e^+) + N(\mu^+) \cong 0$$

$$N(e^+) + N(\mu^+) + N(\pi^+) \cong N(\pi^+)$$

Assuming that $N(K^+) \cong 0.022\,.N$

$$N(P^+) \cong 0.978\,.N - N(\pi^+)$$

Therefore, we can compare the efficiency of pions and protons in producing neutrons by spallation.

Negative beam (-10 GeV, 94.3 % negative pions):

S0S1:

$$N \cong 348314$$

Therefore:

$$N(\pi^-) \cong 0.943\,.N \cong 328460$$

WENDI 1 (P4') counts 7060 neutrons, i.e. **0.0215** neutron per pion.

Our results

Comparison between proton (p+) and pion (pi+)

Positive beam:

At +10 GeV, with the same homogeneous target of tungsten we find:

S0S1:

$$N \cong 8.806 \,.\, 10^6$$

S0S1C1:

$$N(\pi^+) \cong 2.917 \,.\, 10^6$$

Therefore:

$$N - N(\pi^+) = N(P^+) \cong 5.889 \,.\, 10^6$$

The number of neutrons produced by de pions and detected by WENDI 1 (P4') are given by:

$$0.0215 \frac{neutron}{pion} \,.\, 0.985 \,.\, 2.917 \,.\, 10^6 \; pions \; \cong 61775 \; neutrons$$

WENDI P4' counts 193397 neutrons. Therefore, the protons have produced 131622 neutrons, i.e. **0.0224** neutron per proton.

Protons are therefore slightly more effective than pions (**+4 %**).

The simulations (10000 particles) shows that de protons are more efficient (**+18.7 %**).

What we couldn’t do but could be interesting

- Test with graphite and/or beryllium, as they have different properties and may be more effective.

- Test placing empty spaces between tungsten’s blocks to allow the neutrons to escape and not remain “trapped”

- Test placing a light metal cylinder around the tungsten layer

More analysis when we get back

- Finish analysing the rest of the data

- Improving the simulation code → In order to model aluminium rails, for example

- Rerun the simulations with new coding.

- Compare the experiments with the simulations again.

- Share our results with the Turkish team.

Research, science and physics

So many memories

Thanks to all the staff !

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Marcus Jankowski
IPPOG Volunteers
ELSA Volunteers
The University of Bonn Volunteers
Eva Lechenard

Thank You...

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