The $^3He(n,e^-e^+)^4He$ reaction at n_TOF: Probing X17 existence and properties

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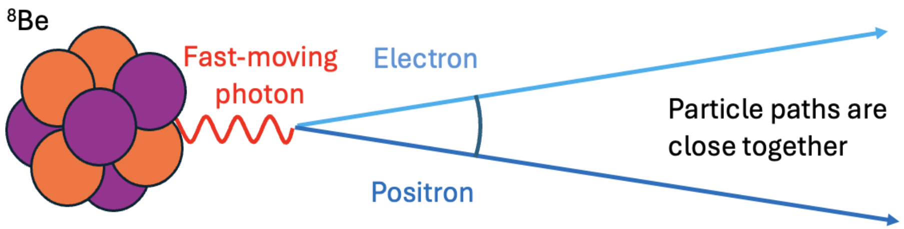
OUTLINE:

- ATOMKI results in a nutshell
- The $^3He(n,X17)^4He$ reaction
- The n_TOF experiment proposal

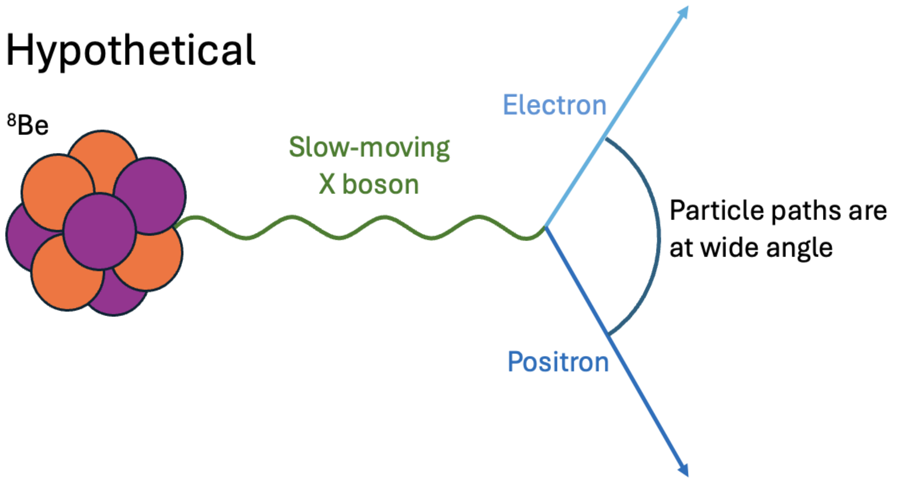
The X17 anomaly

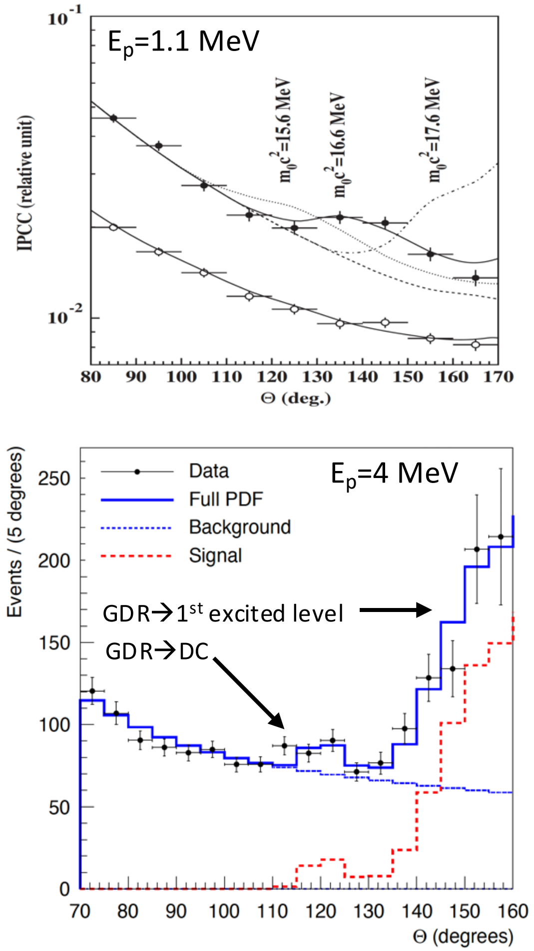
The ATOMKI group observed an excess of e^-e^+ pairs emitted at large relative angle in the **$^3H(p,e^-e^+)^4He$**, **$^7Li(p,e^-e^+)^8Be$**, **$^{11}B(p,e^-e^+)^{12}C$** nuclear reactions. This excess can be explained with the creation (and decay into e^-e^+ pairs) of a new particle with mass ~17 MeV, called **X17 boson**.

Expected ^8Be Transition

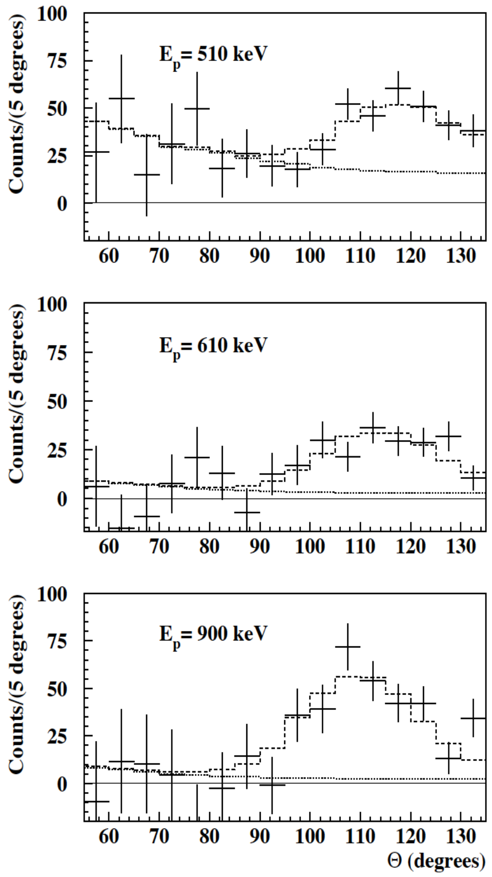


Hypothetical

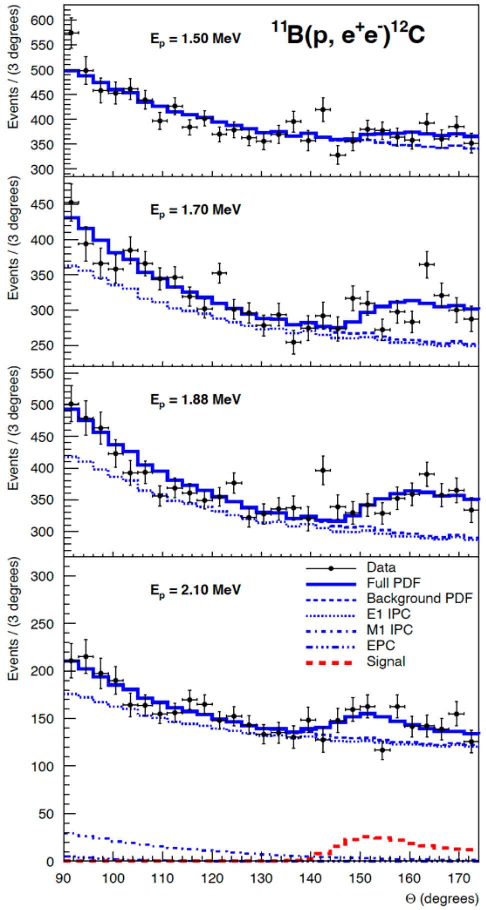




$^7Li(p,e^-e^+)^8Be$



$^3H(p,e^-e^+)^4He$



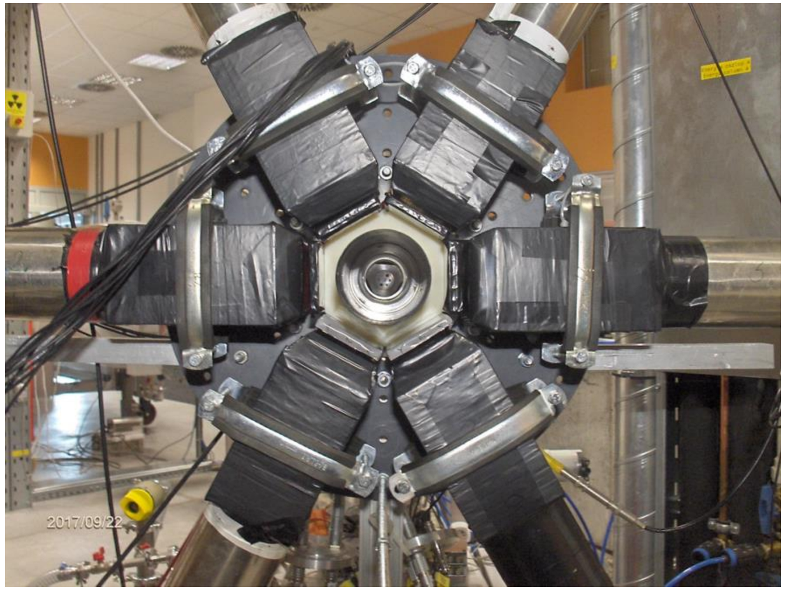
$^{11}B(p,e^-e^+)^{12}C$

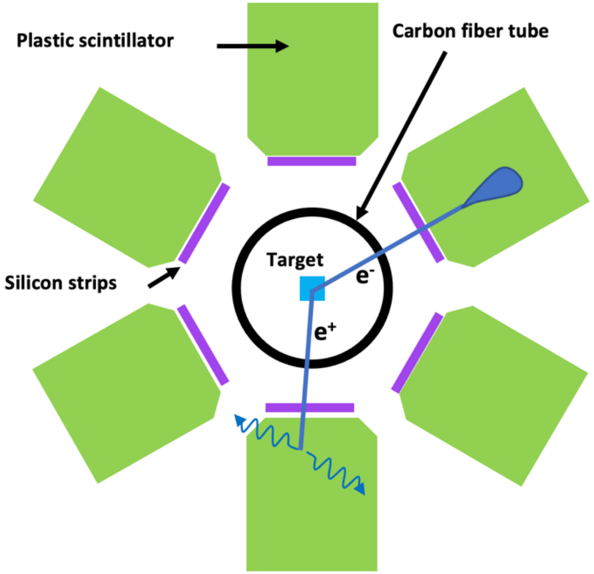
The ATOMKI setup

Let consider the setup used for the **$^3H(p,e^+e^-)^4He$** experiment.
(similar setup were used in the other experiments)

-Proton beam with Ep<1 MeV
-^{3}H thin target deposited on a Titanium backing
-Thin (1 mm thick) carbon fibre tube, to reduce the multiple scattering of ejectiles.
-6 double-sided silicon strip detector 3 mm wide strips, 0.5 mm thick, to measure the impact point of particles and to deduce the aperture angle of e^-e^+ pairs.
-6 plastic scintillator 82x86x80 mm^3, to measure the energy of e^-e^+ pairs.

Suited for electron and positron detection. However:
-Detector acceptance is only around 90° with respect to the beam axis
-No tracking.
-No charge and particle identification.

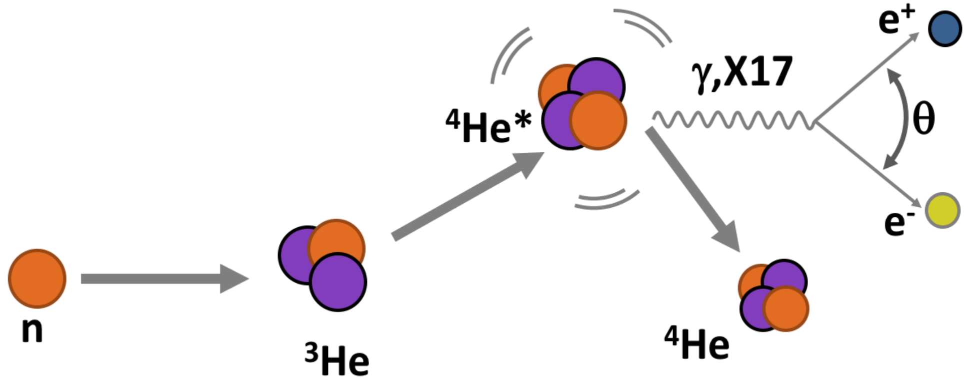




X17 @ n_TOF

First X17 search using a neutron beam.

$^{3}He(n,e^{+}e^{-})^{4}He$



n_TOF REACTION

Requirements:

- Pulsed Neutron beam with a wide energy range
- Detector with a low sensitivity to neutrons and gammas
- Large acceptance
- Particle identification

Physics:

- Probing X17 existence
- X17 Mass, quantic numbers, coupling, life time,..
- proto-phobic nature of the fifth force.
- Data Vs Theoretical nuclear physics

What about X17 quantum numbers?

ATOMKI measurements indicate the existence of a particle with a mass of ~17 MeV. However, the properties of X17 (J^π, coupling with ordinary matter,..) are unknown, because of the limited experimental information. Concerning the $^4He^* \rightarrow {}^4He + X17$ process:

$X17 \rightarrow e^+e^-$

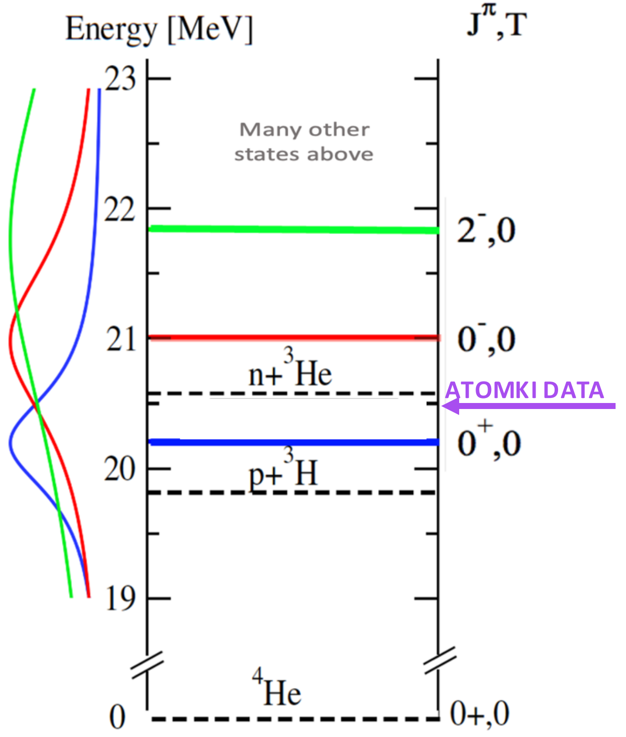
The strength of excess due to the X17, depends on the beam energy and on J^π,

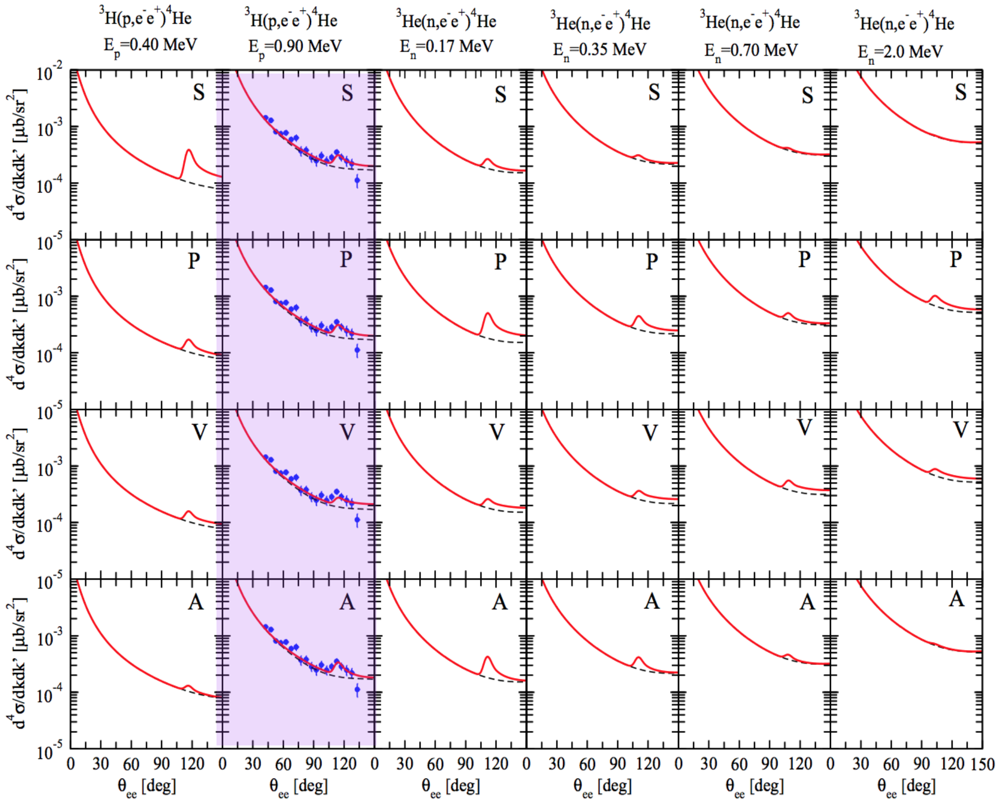
i.e. if X17 is a Scalar/Pseudoscalar/Vector/Axial Boson → neutron beam with a wide energy range

The angular distribution of e^+e^- pairs from the X17 decay strongly depends on its J^π

→ Detector with a Large acceptance

For more details, see M. Viviani et al.: PRC 105, 014001 (2022).





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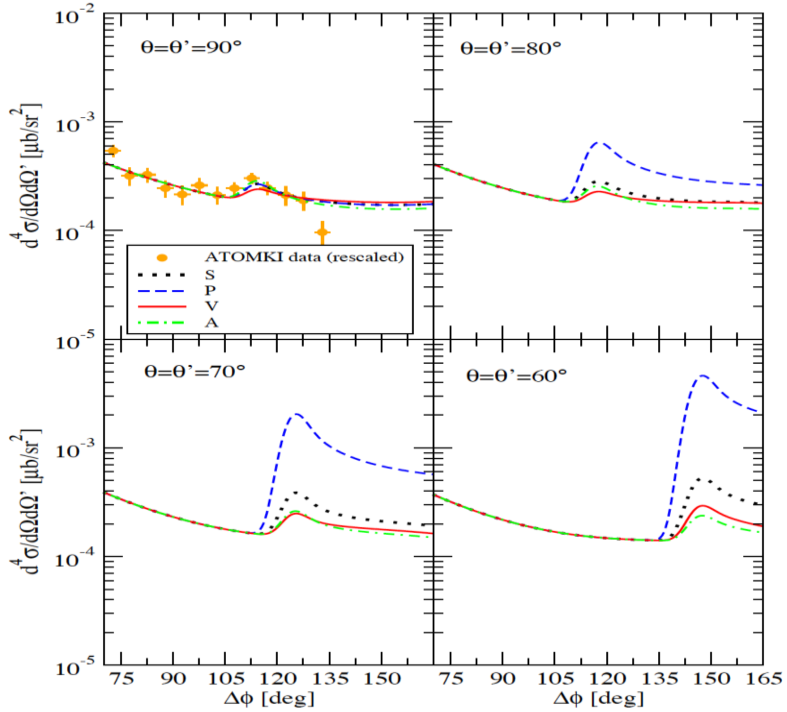
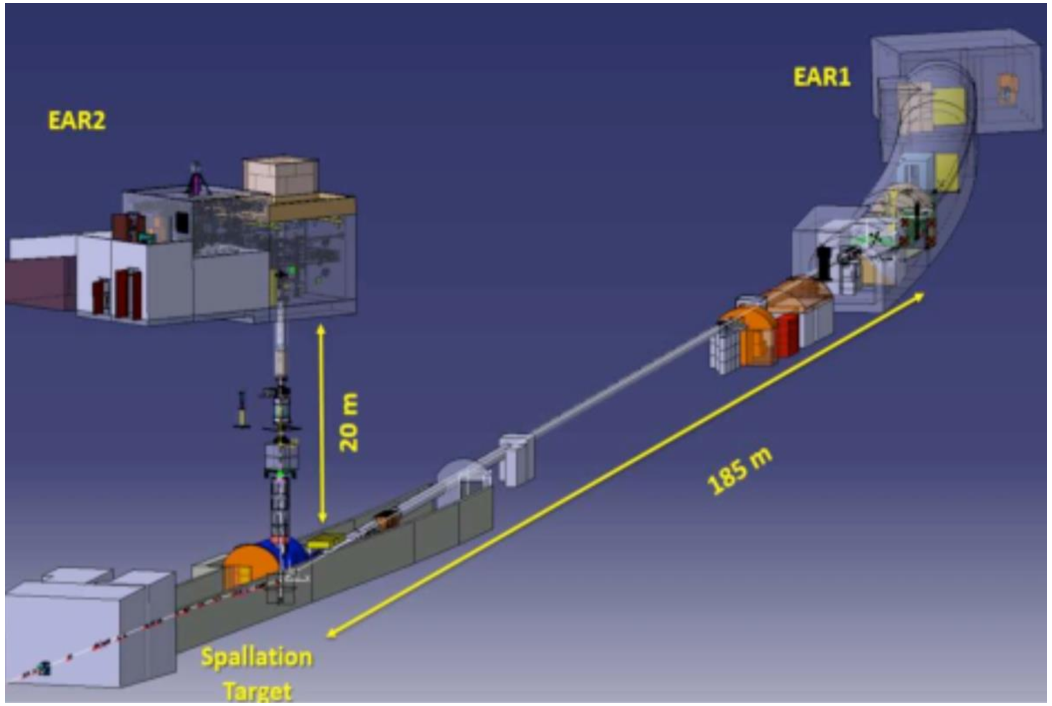
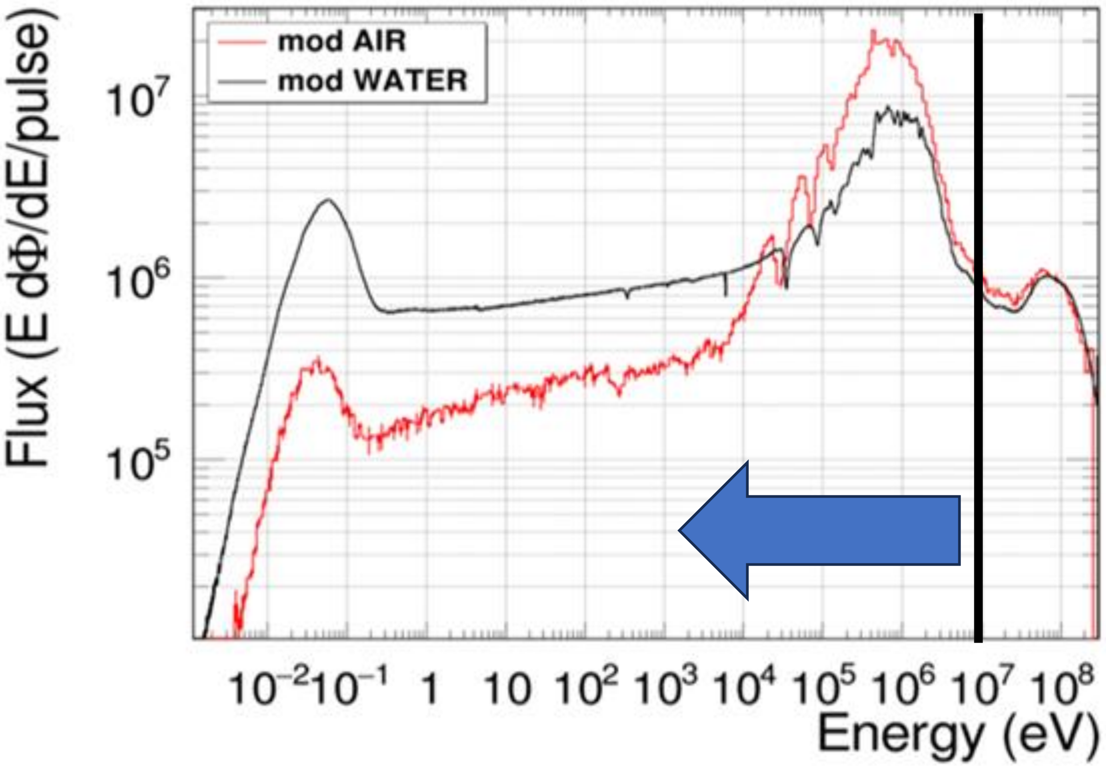


The n_TOF facility



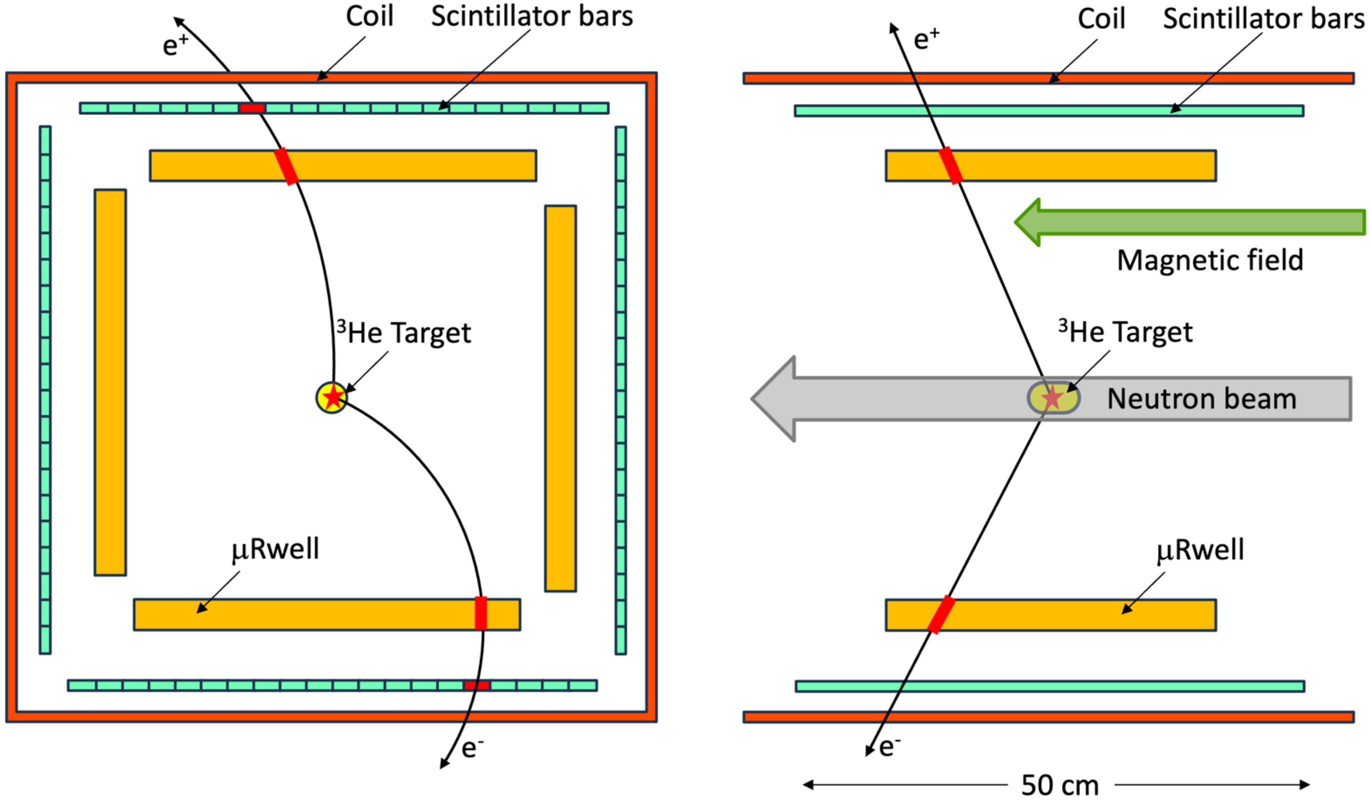


Pulsed neutron beam with a wide energy range, 10^{-2}-10^8 eV
The Energy of the interacting neutron is derived with the Time-of-flight technique

X17 Detector

-Large acceptance
-Reconstruction of ejectiles kinematics
-”Light” detector, with a low sensitivity to photons and neutrons

-4 large μRwells with a large (3 cm) gap, 380x460x30mm^3 active volume → 3D tracking
-4 planes 50x50 cm^2, each one composed by 20 scintillator bars 3x25x500 mm^3 → Trigger and neutron ToF
-Coil 60 cm long and with a square section 60x60 cm^2 (B = 50 mT)
→ charge and momentum of ejectiles

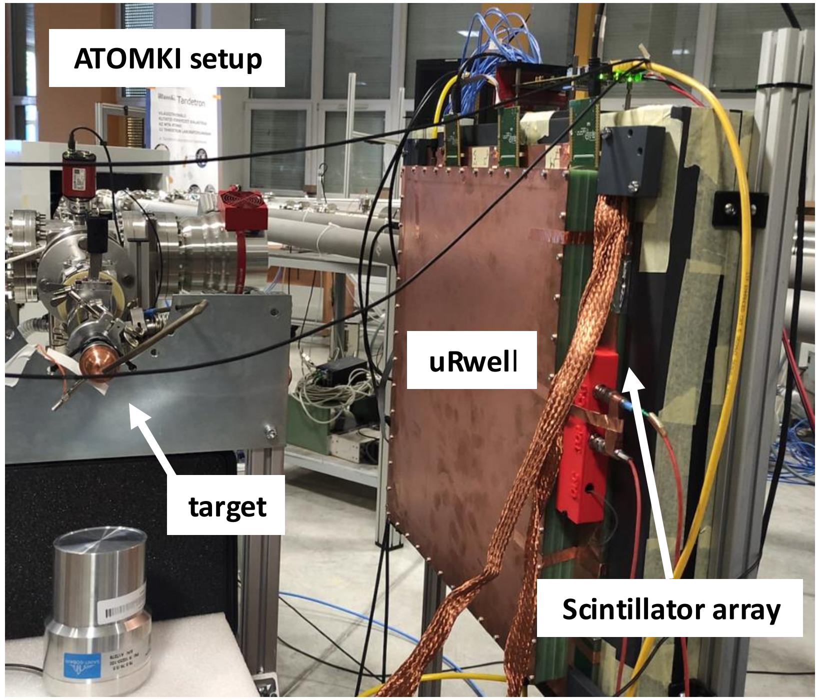


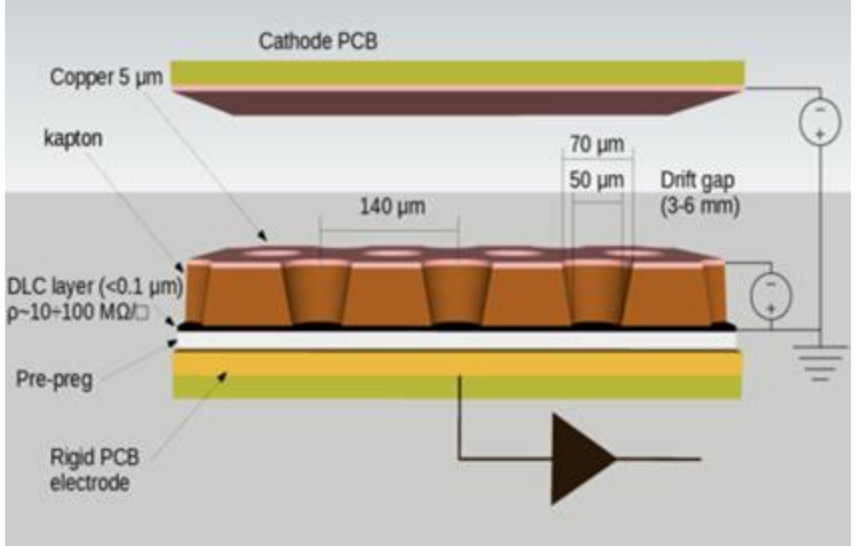
FRONT SIDE

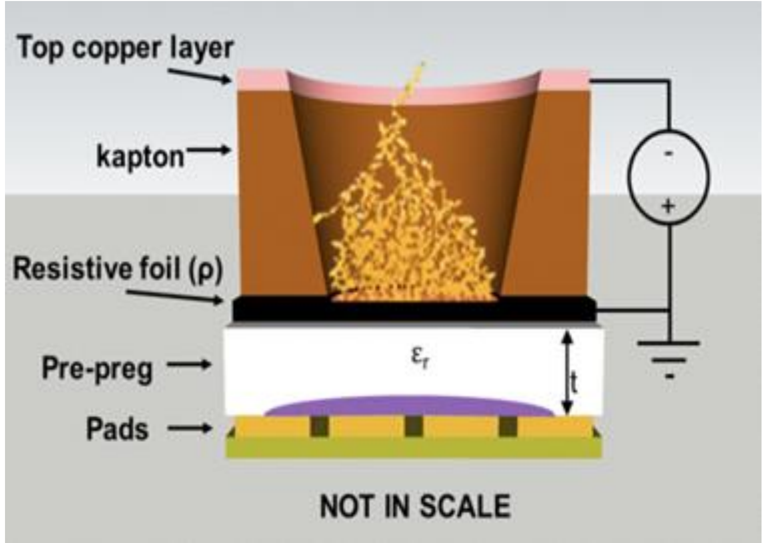
The μRwells

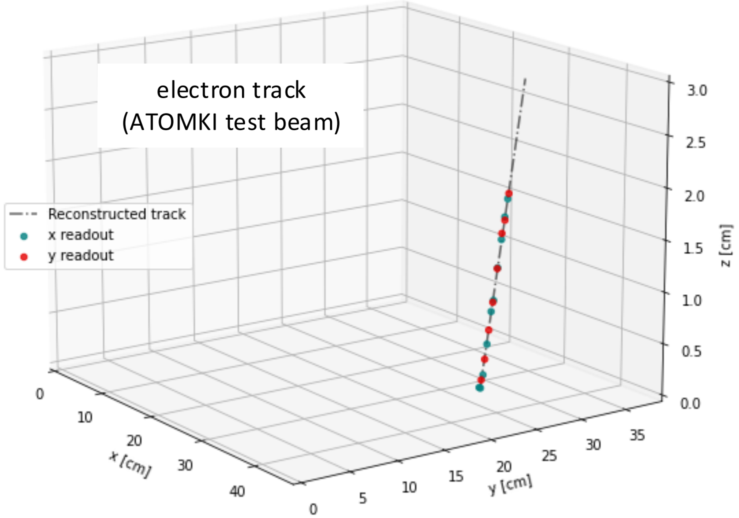
-The μRwells are MPGD like GEM and μMegas.
Our μRwells are equipped with X and Y readout strips, with a pitch 0f 1.7 and 0.7 mm, respectively.
-The 3D reconstruction of the tracks is obtained by operating the chambers In TPC mode (gas gap is 30 mm)

✓ Tested at n_TOF and ATOMKI neutron and proton beams, by using a demonstrator composed by a single μRwell backed with a set of scintillator bars.



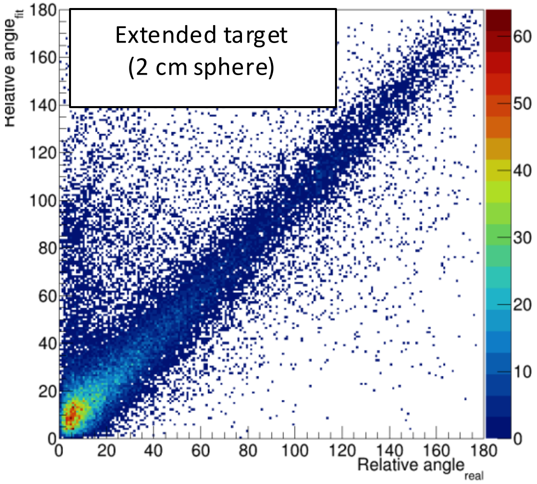


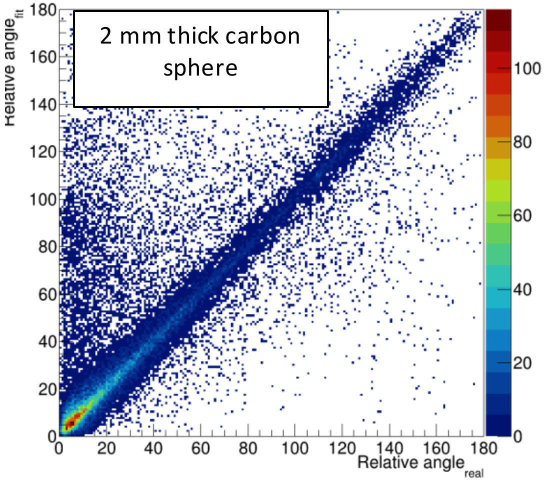


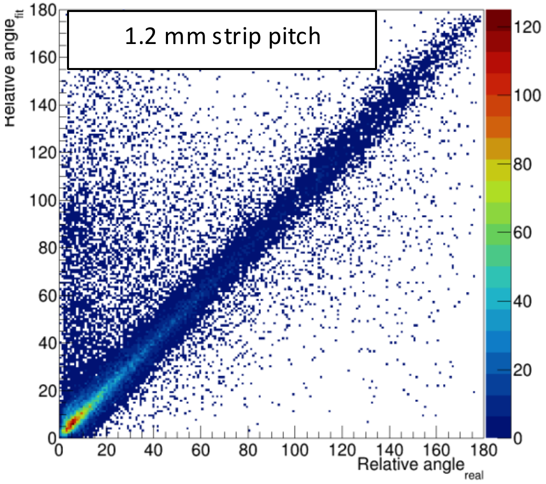


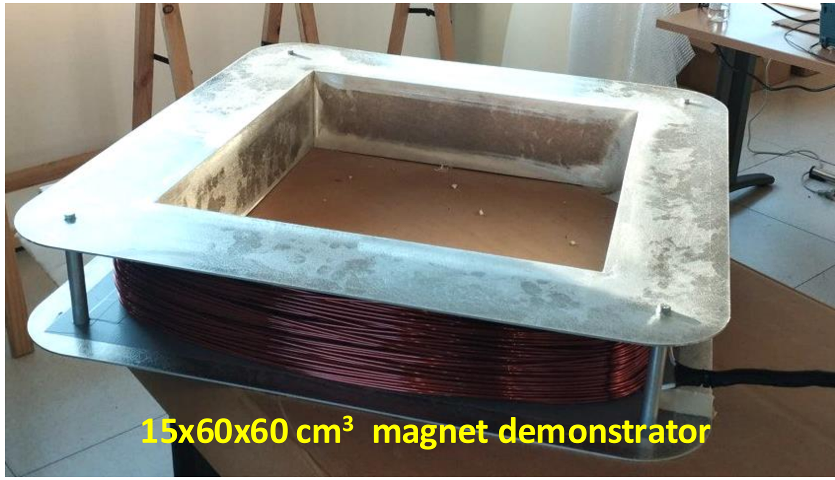
The magnet

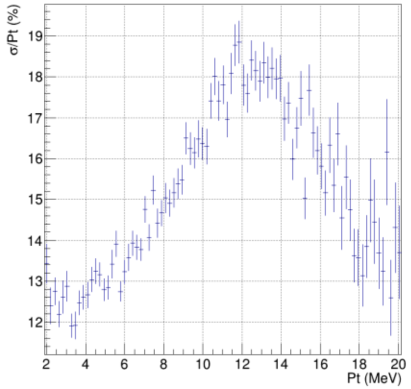
The coil demonstrator (15 cm long, i.e. 1/4 of the total lenght) has been realised and characterised.
By using the nominal magnetic field (B = 50 mT), the simulation provide the reconstruction of the ejectile momenta at 20% level.

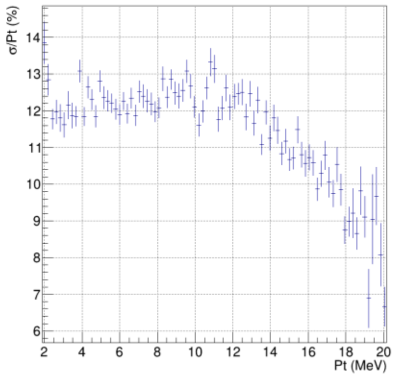


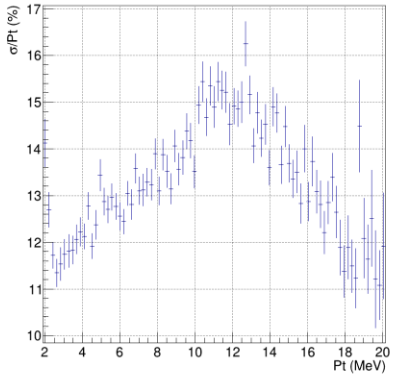


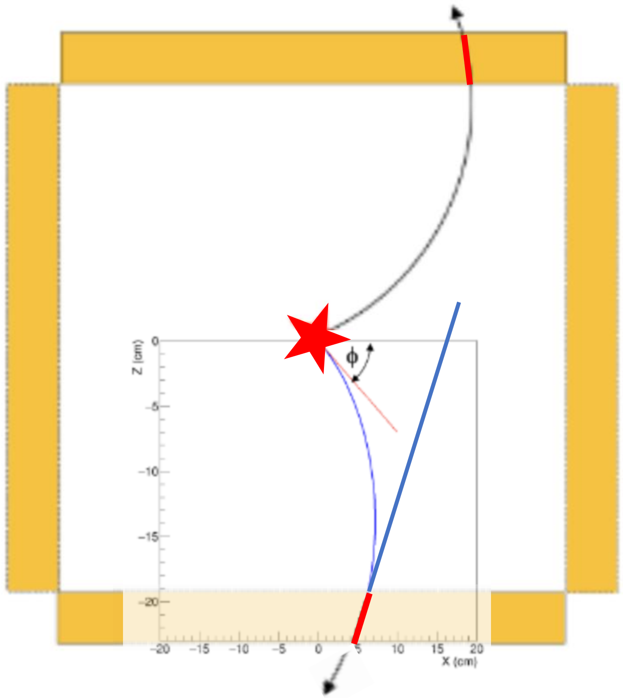










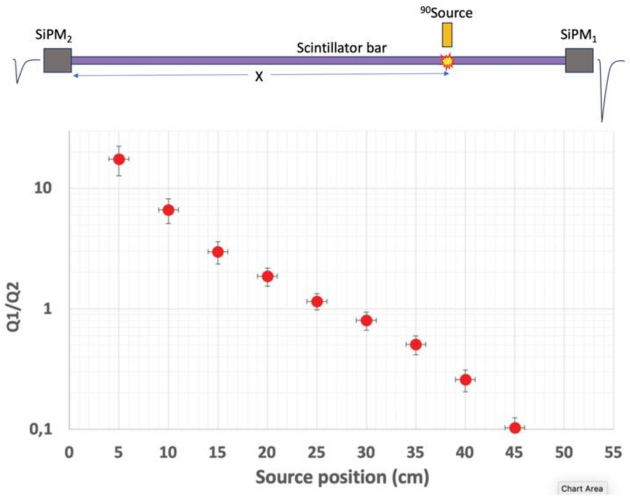


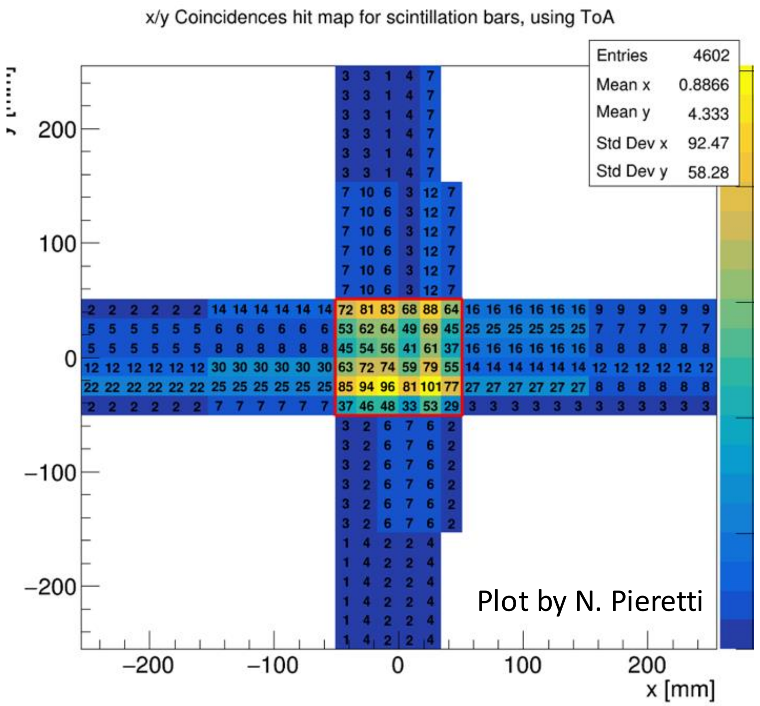
The scintillator system

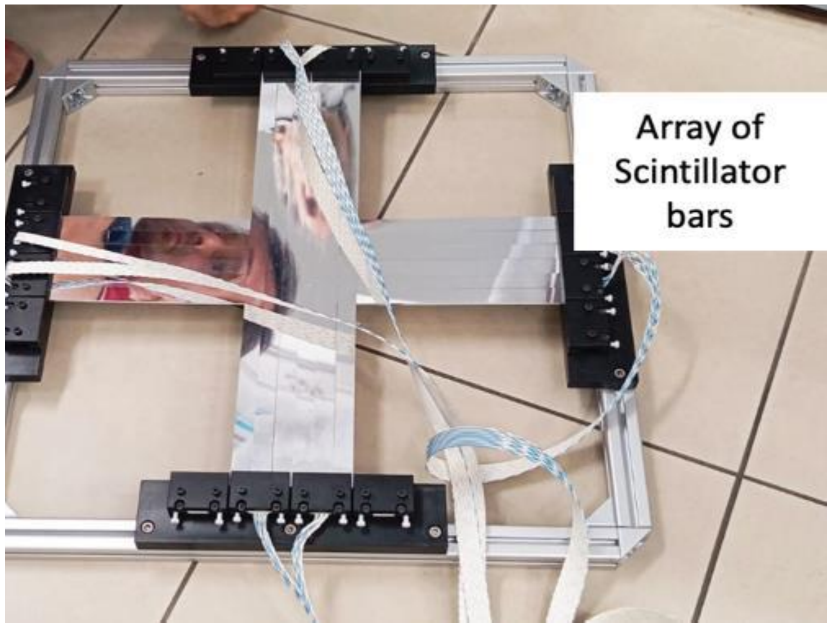
-Commercial scintillator bars by SCIONIX, 500x25x3 mm^3

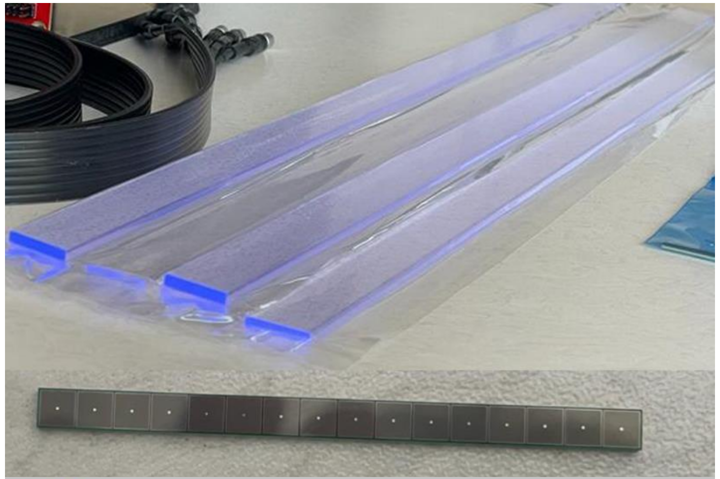
-readout performed with array of SiPM by Hamamatsu.

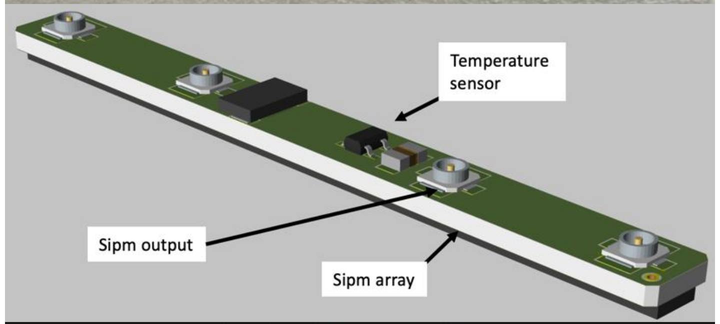
✓ Tested at n_TOF and ATOMKI beams.

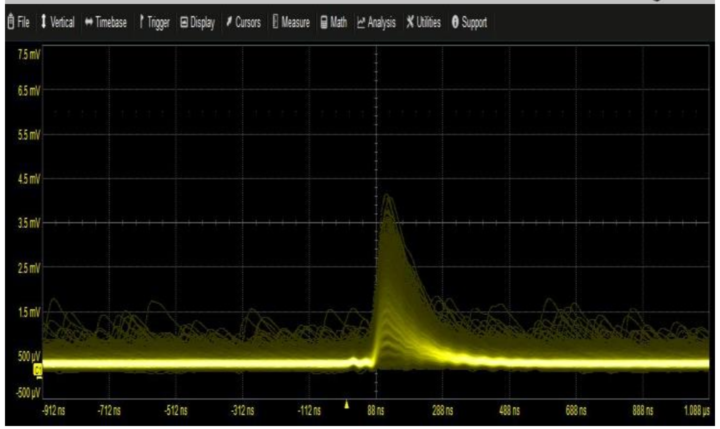










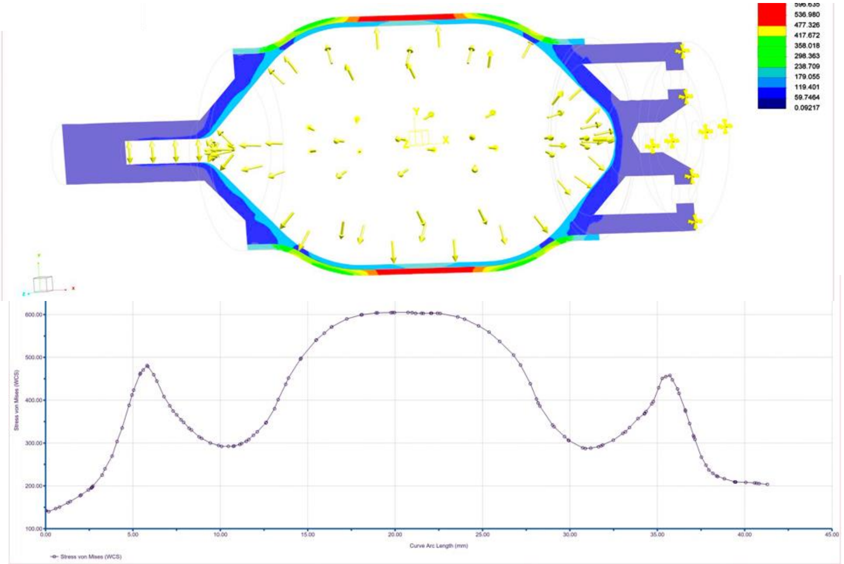


The Target

- ^{3}He target (358 bar, 10 cm^3) in a quasi-cylindrical cell of 10 cm^3 inside a capsule of SCALMALLOY 0.5 mm thick reinforced with 0.9 mm thick carbon fibre, to limit Multiple Scattering and beam induced background.
- SCALMALLOY capsule realized with a 3D printer, to ensure a thight container
- Carbon fibre layer to increase the resistence to pressure.

✓ Leakage Test: capsules filled with Argon at 200 bar. No pressure decrease after >2 months. Succesfully used at the MArEX experiment at n_TOF.

✓ Fracture Test: 3 capsule tested (explosion pressure above 800 bars). Approved by CERN safety to work up to 400 Bars.



Close collaboration with T.Koettig (cryogenic group of CERN)

Beam time request

Beam request: $5x10^{18}$ pot.

-First run ($2.5x10^{18}$ pot) is used to fine-tune the parameters and for a first, low statistics acquisition.
-Few weeks of stop (no beam), to carry out the preliminar data analysis.
-Second run ($2.5x10^{18}$ pot) dedicated to the long acquisition.
Expected statistics : ~ $2x10^3$ X17 detected events.
Expected IPC background: $7x10^4$

Neutron energy	ToF (μs)	neutrons/pulse	γ's/pulse	IPC/10^{18}pot	X17/10^{18}pot
1 -10 eV	411 - 1300	3.0×10^5	2	128	3
10 – 100 eV	130 -411	3.3×10^5	2	141	4
0.1 – 1 keV	41 - 130	3.7×10^5	2	159	4
1 – 10 keV	13 – 41	5.8×10^5	3	257	6
10 – 100 keV	4 - 13	2.8×10^6	4	1601	40
0.1 – 1 MeV	1.3 - 4	1.5×10^7	33	23117	578
1 – 10 MeV	0.41 – 1.3	7.8×10^6	24	10876	272
Total		2.7×10^7	70	36278	907