Probing the X17 existence and properties using proton and neutron beams

Carlo Gustavino
INFN-Roma

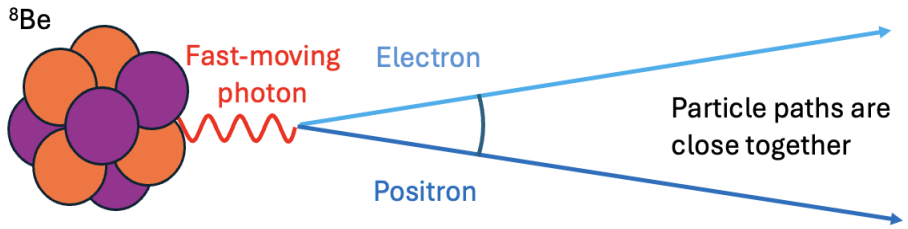
OUTLINE:

- ATOMKI experiments in a nutshell
- Experimental requirements
- n_TOF detector
- The $^{3}He(n,X17)^{4}He$ experiment at n_TOF
- Other measurements

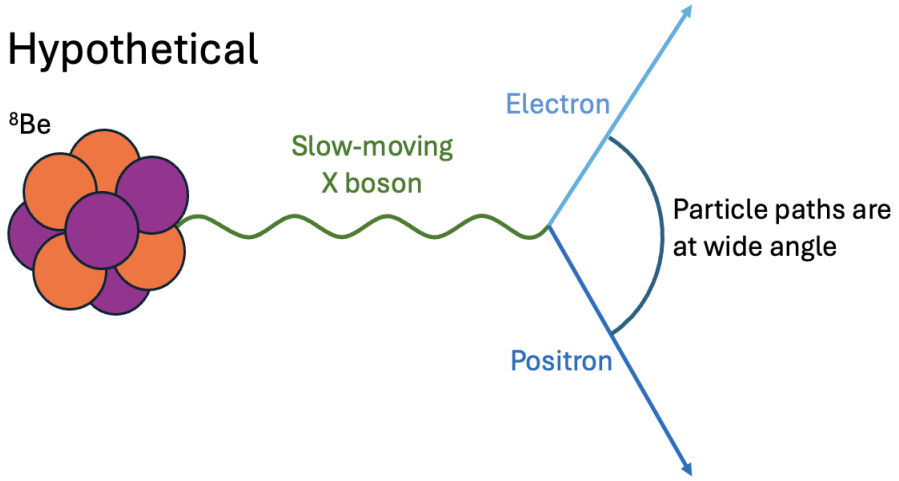
The X17 anomaly

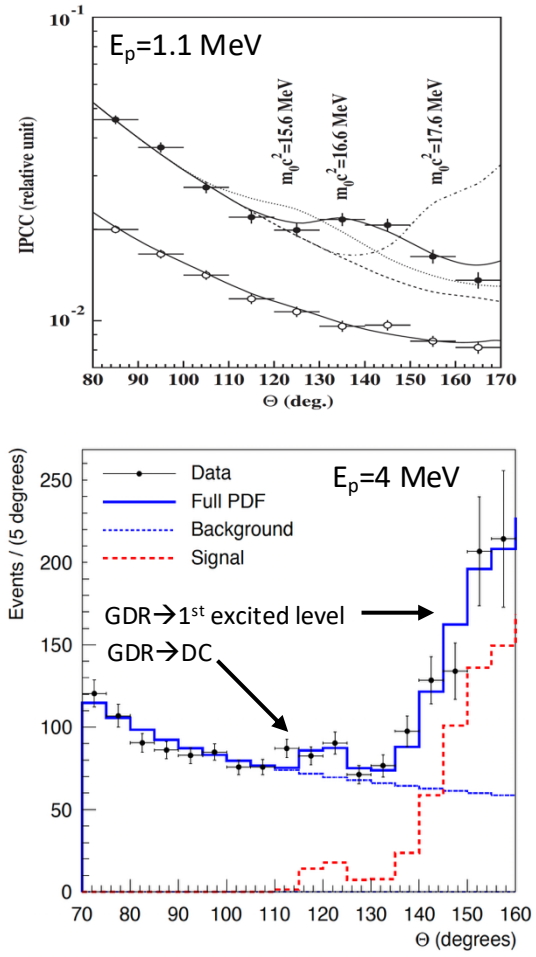
The ATOMKI group observed an excess of e^-e^+ pairs emitted at large relative angle in the **^{3}H(p,e$^-$e$^+$)^{4}He**, **^{7}Li(p,e$^-$e$^+$)^{8}Be**, **^{11}B(p,e$^-$e$^+$)^{12}C** nuclear reactions. This excess can be explained with the creation (and decay into e^-e^+ pairs) of a new particle with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

Expected ^{8}Be Transition

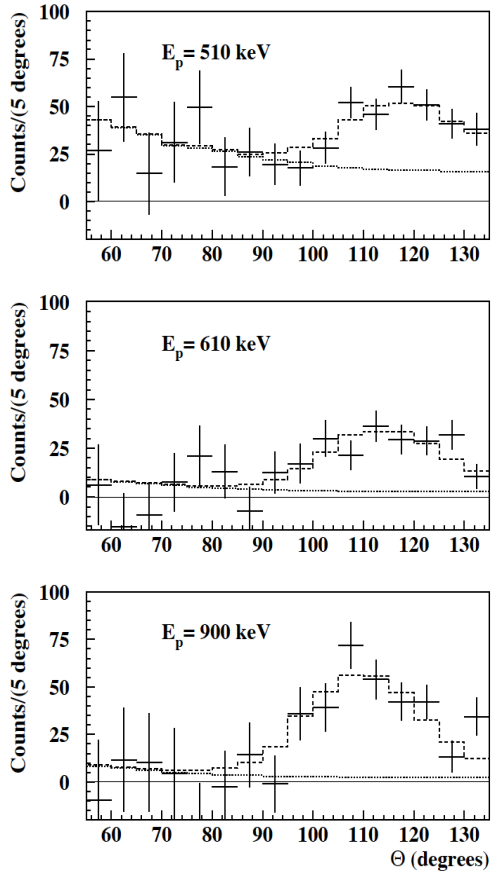


Hypothetical

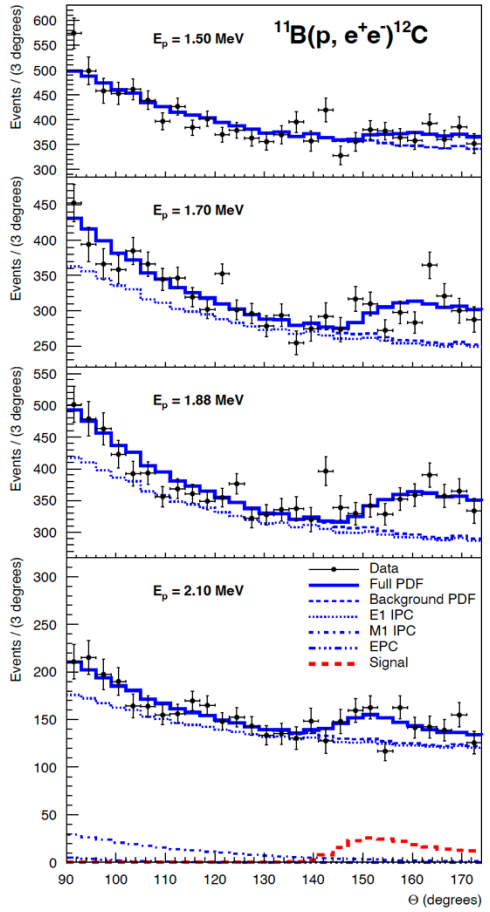




^{7}Li(p,e$^-$e$^+$)^{8}Be

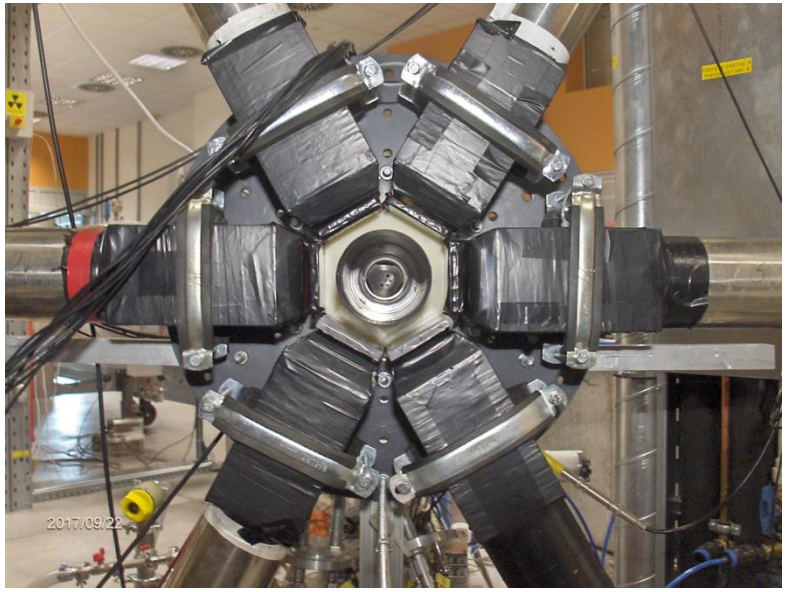


^{3}H(p,e$^-$e$^+$)^{4}He



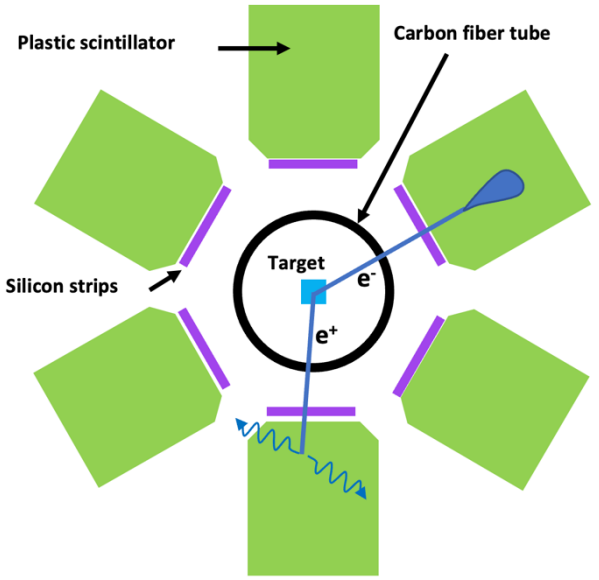
^{11}B(p,e$^-$e$^+$)^{12}C

The ATOMKI setup



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

-Proton beam with E_p<1 MeV
-^{3}H target deposited on a thin Titanium backing
-Thin (1 mm thick) carbon fiber tube to limit multiple scattering of ejectiles.
-6 double-sided silicon strip detector 3 mm wide, 0.5 mm thick, to measure the impact point of particles
-6 plastic scintillator 82x86x80 mm^3 to measure the energy of ejectiles



Well suited for electron and positron detection. However:
-No tracking.
-Detector acceptance is limited to pairs produced at around 90° with respect to the beam axis
-No charge and particle identification.

What about X17 quantic numbers?

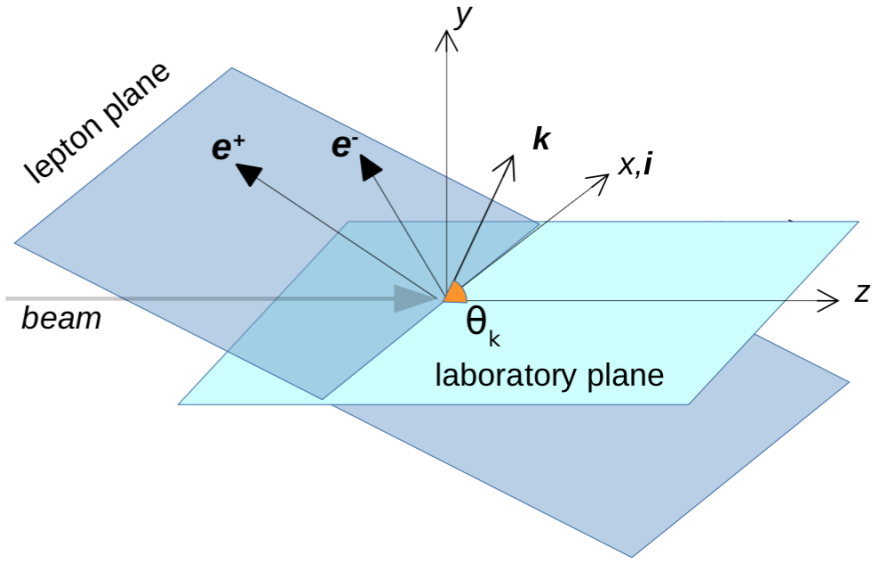
ATOMKI measurements indicate the existence of a particle with a mass of ~17 MeV. However, the properties of X17 (J^{π}, coupling with ordinary matter,..) are unknown, because of the limited experimental information.

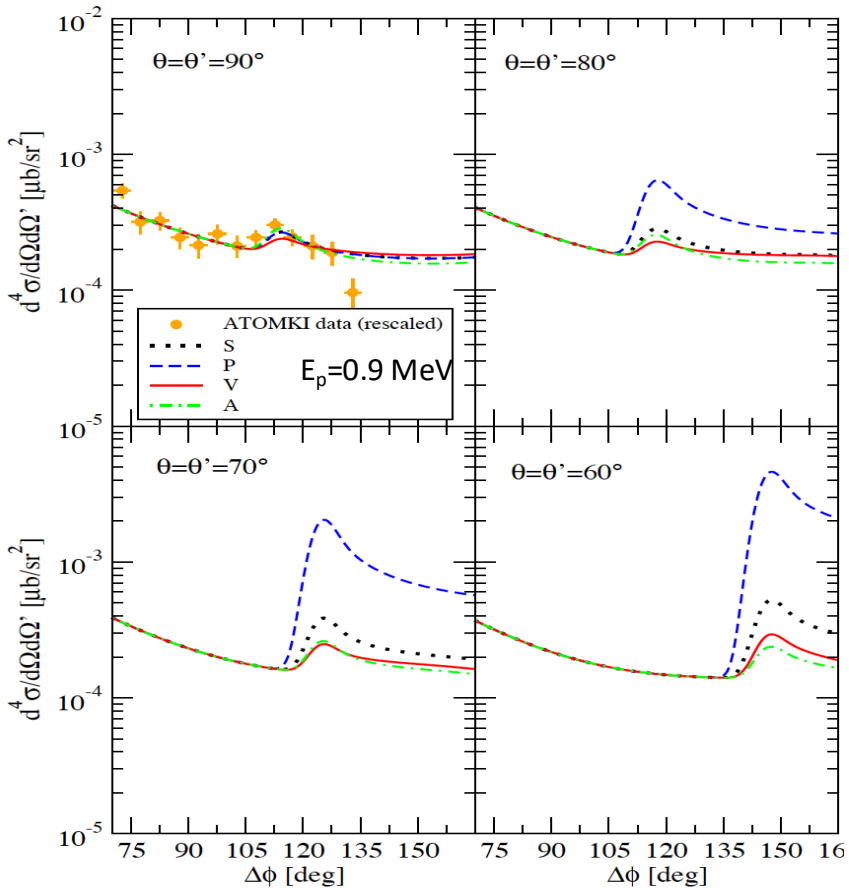
Concerning the $^4He^* \rightarrow {}^4He + X17$ process:

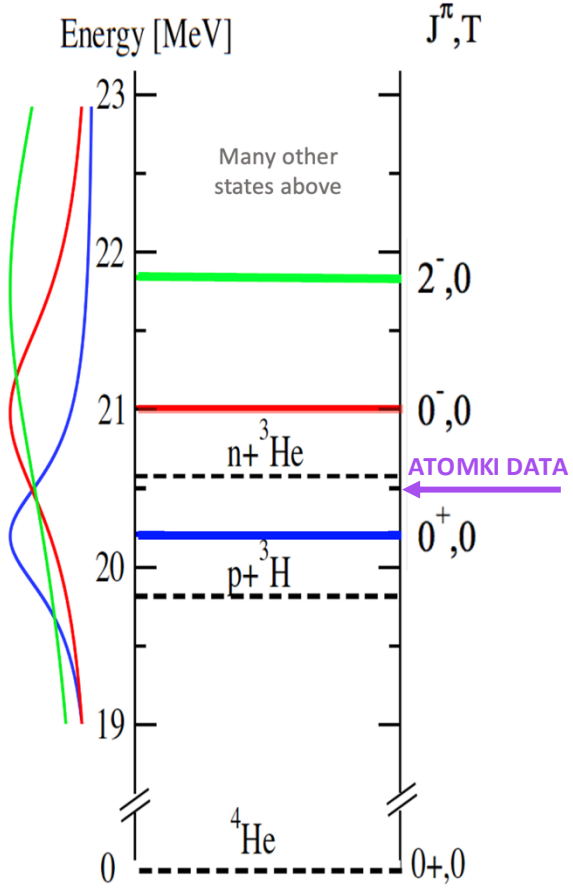
$\hookrightarrow e^+e^-$

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

→ A detector with a large acceptance is desirable







M. Viviani et al.: PRC 105, 014001 (2022)

See L.E. Marcucci talk

What about X17 quantic numbers?

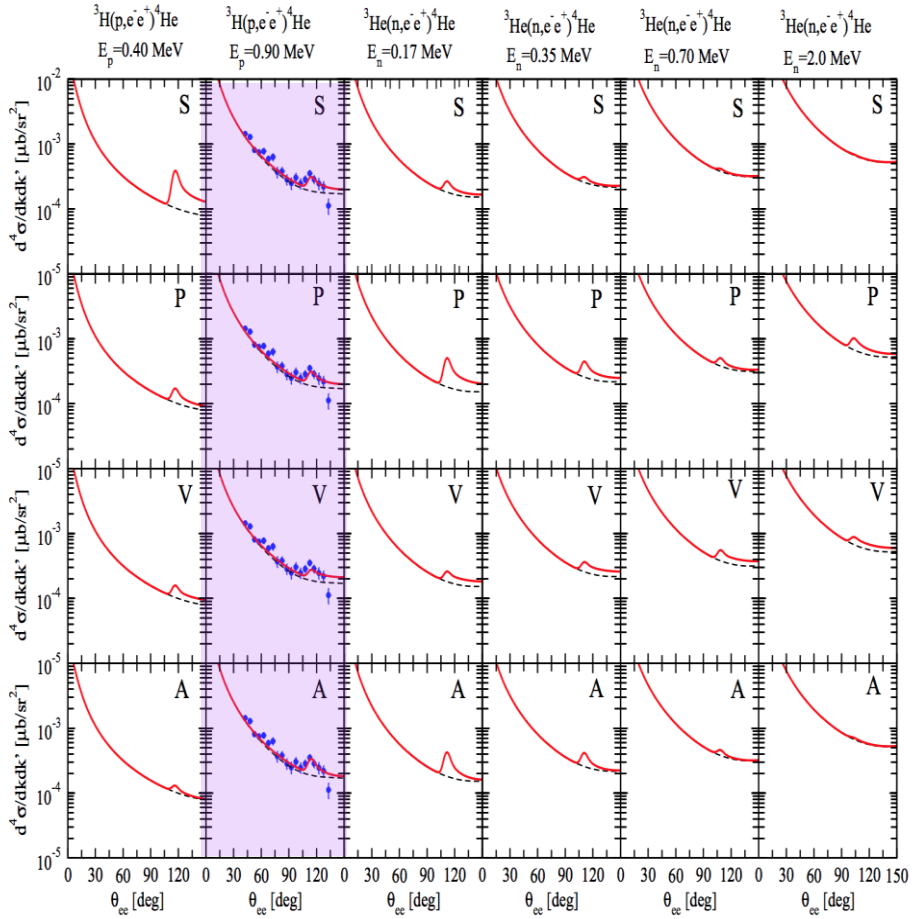
ATOMKI measurements indicate the existence of a particle with a mass of ~17 MeV. However, the properties of X17 (J^{π}, coupling with ordinary matter,..) are unknown, because of the limited experimental information.

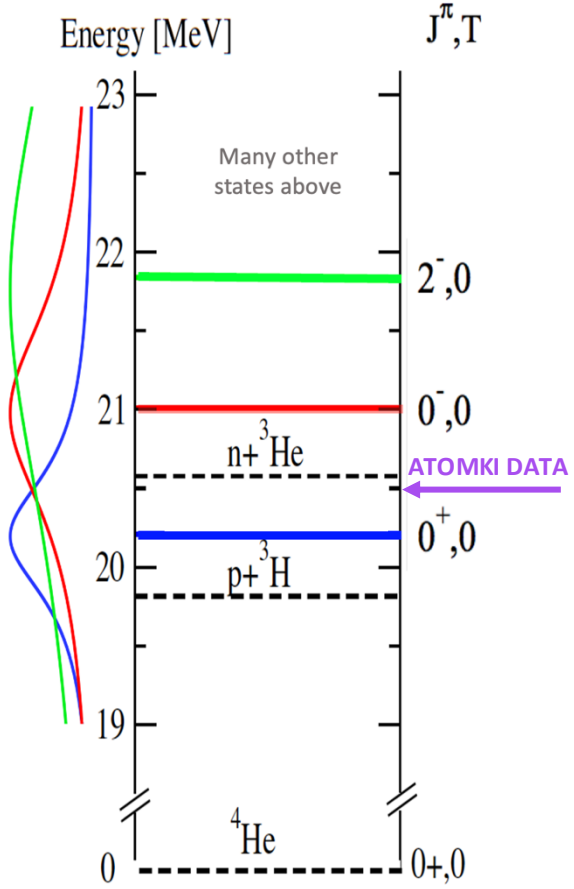
Concerning the $^4He^* \rightarrow {}^4He+X17$ process:

↳ e^+e^-

The strenght of the excess depends on X17 quantic numbers

→Data in a wide energy range is desirable.





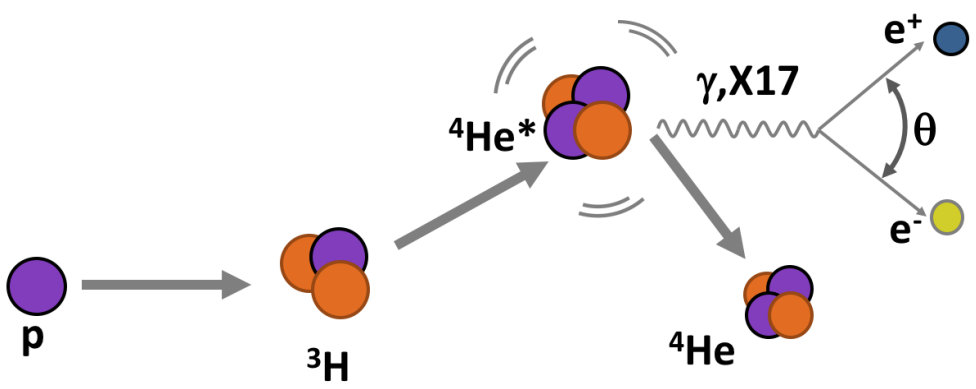
M. Viviani et al.: PRC 105, 014001 (2022)

See L.E. Marcucci talk

X17 @ n_TOF

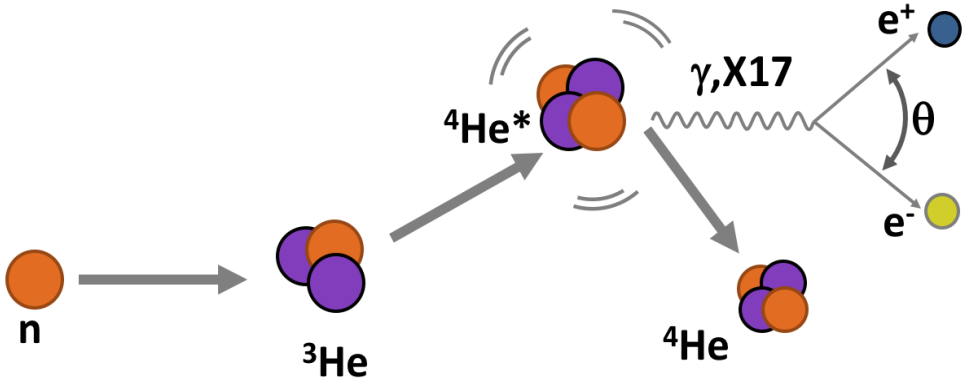
Basic idea: study of excited ^{4}He*
exploiting both the conjugated reactions:

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



ATOMKI REACTION

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

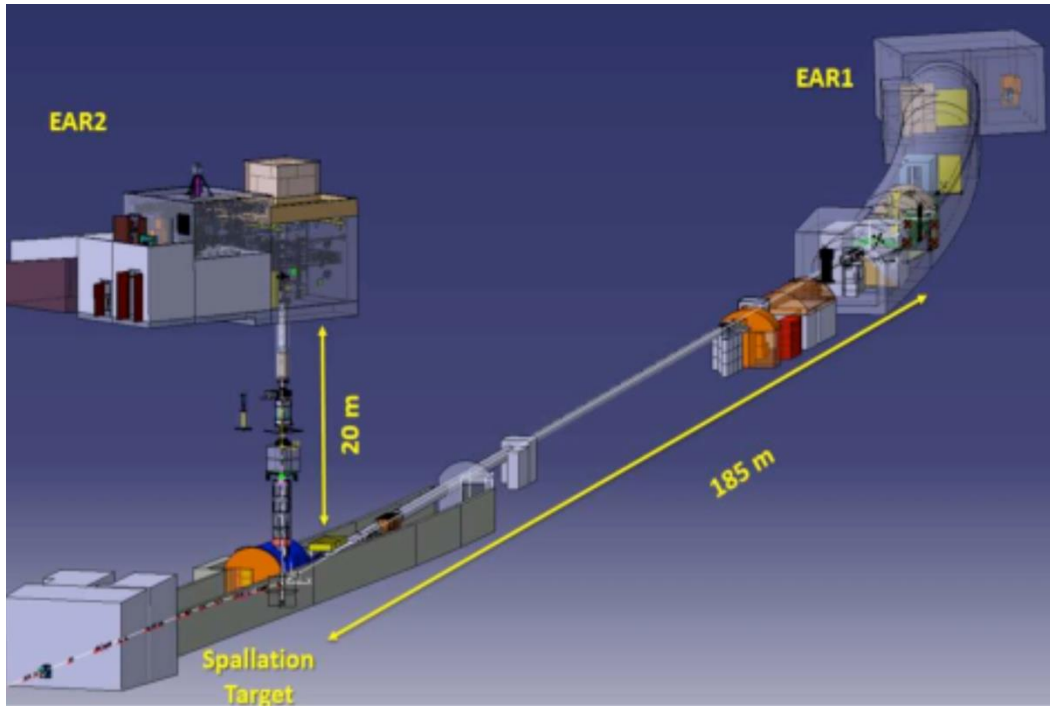


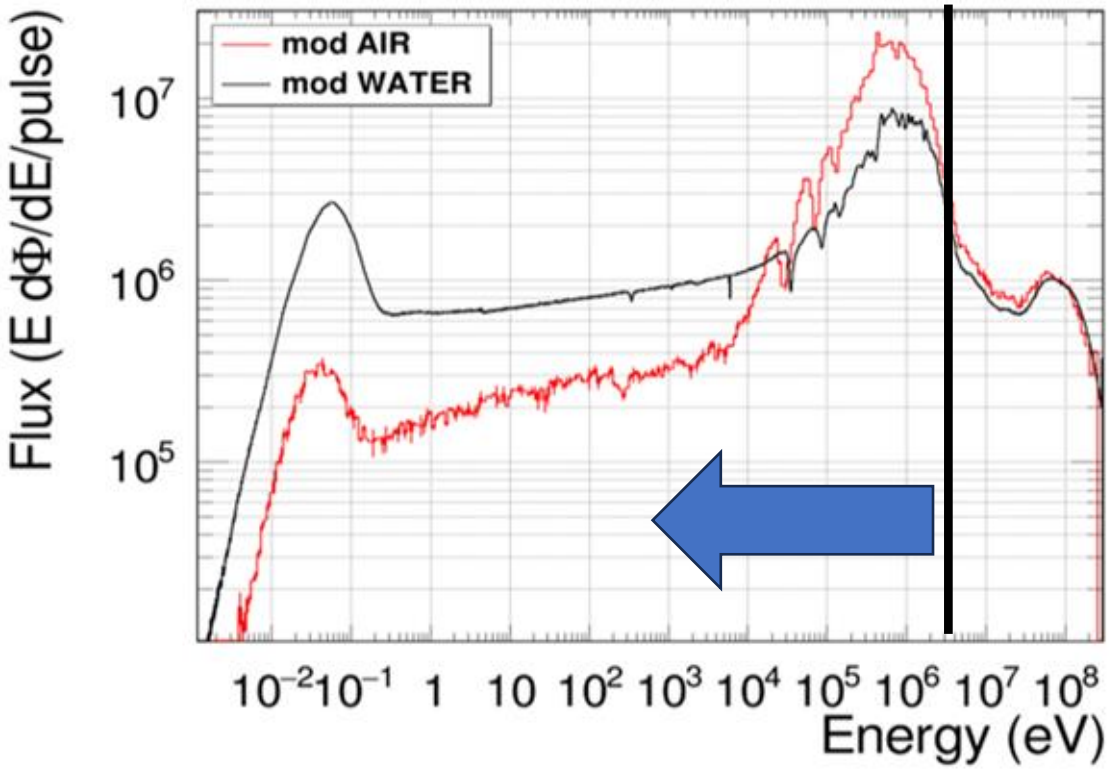
n_TOF REACTION

Physics:

- Probing X17 existence
- X17 Mass, hints on quantic numbers, coupling, life time,..
- Data Vs Theoretical nuclear physics

The n_TOF facility



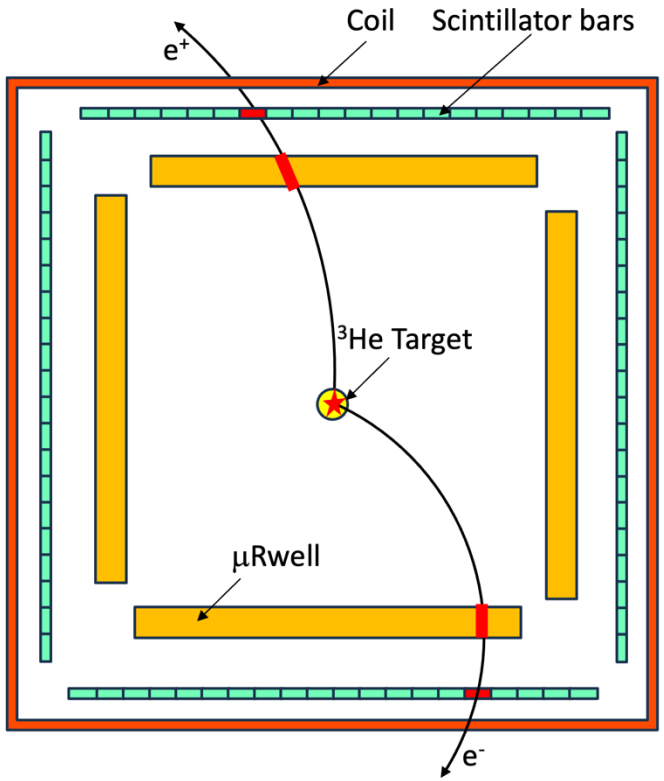


Pulsed neutron beam with a wide energy range $10^{-2}<E<10^{8}$
The Energy of the interacting neutron is derived with the Time-of-flight technique

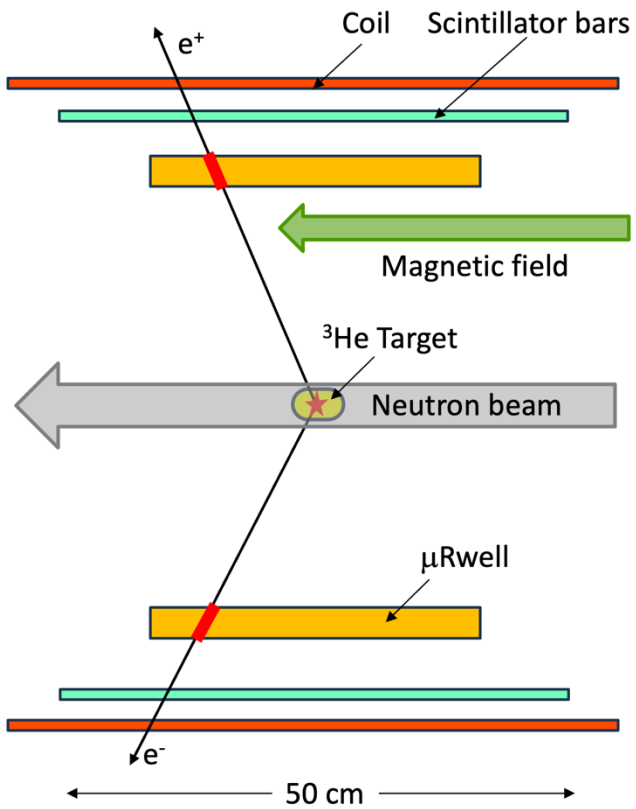
Detector

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

-4 large μRwells with a large (3 cm) ionization gap, 380x460x30mm^3 active volume → 3D tracking
-4 planes 50x50 cm^2, each one composed by 20 scintillator bars 3x25x500 mm^3 → Provide the trigger and neutron energy with the ToF technique
-Coil 60 cm long and with a square section 60x60 cm^2 (B = 500 Gauss) → charge and momentum reconstruction of ejectiles



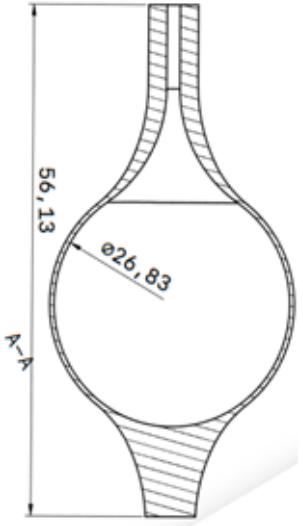
FRONT

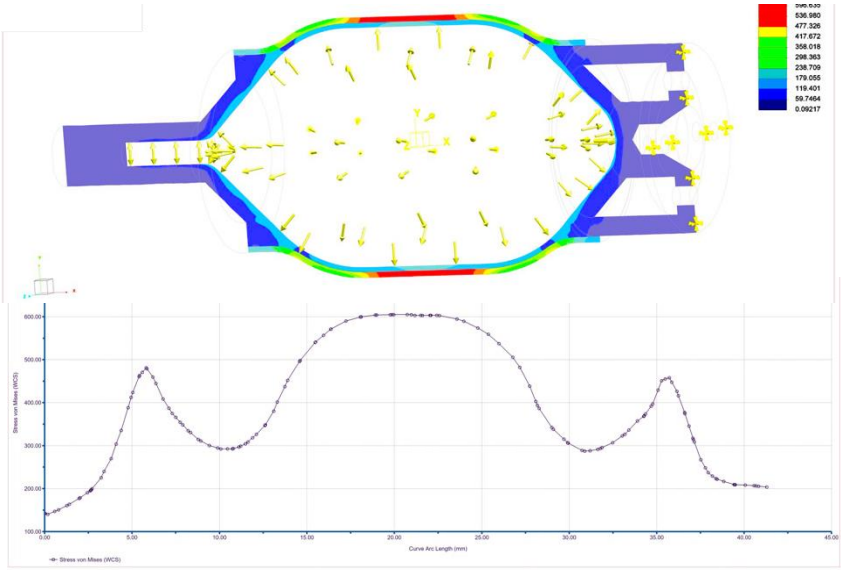


SIDE

The Target

- ^{3}He target (358 bar, 10 cm^3) in a quasi-cylindrical cell of 10 cm^3 inside a capsule of 0.5 mm SCALMALLOY 0.3 mm thick reinforced with 1 mm of carbon fibre, to limit Multiple Scattering and beam induced background.
- SCALMALLOY capsule realized with a 3D printer, to ensure a thight container
- Carbon fibre coat to increase the resistence to pressure.
- Leakage test: >3 months with capsules filled with Argon at 200 bar (MAREX experiment)
- Explosion test:: capsule breaking at 1000-1200 bar.
- R&D still in progress, to further optimize Pressure Vs thikness of capsule.





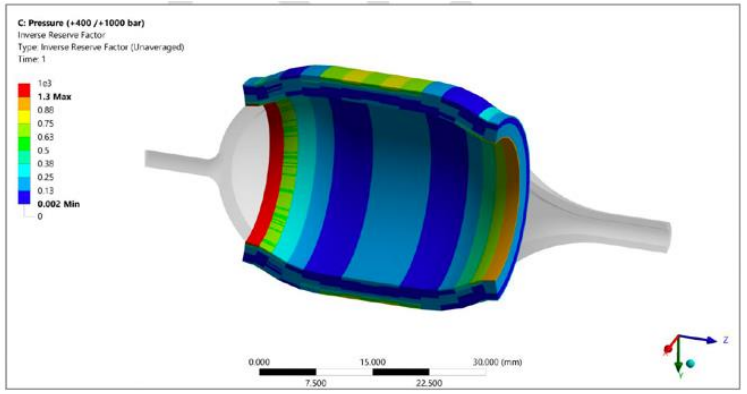
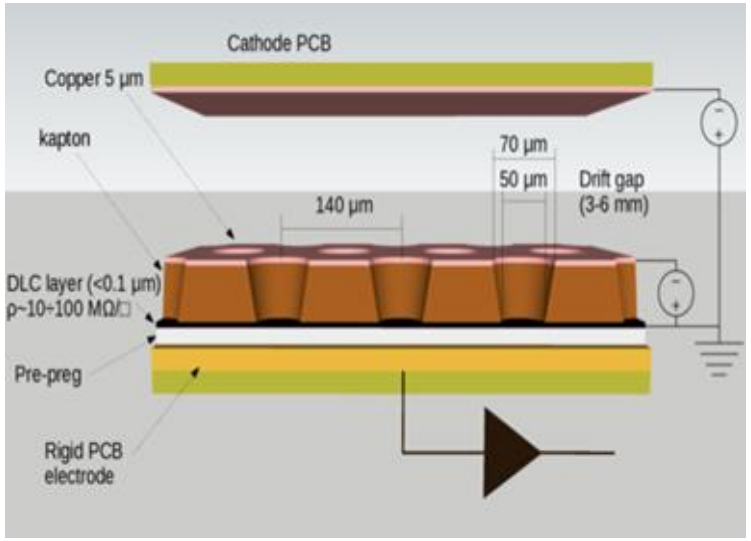


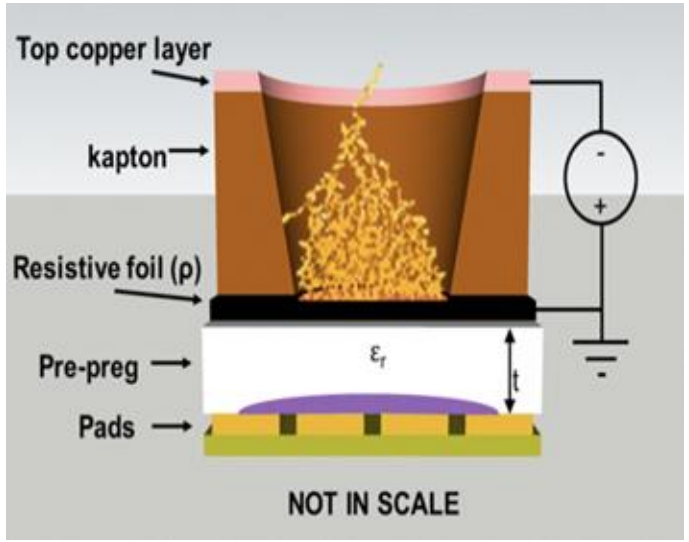
Figura 7 - Failure TEST (P = +1000 bar): Inverse Reverse Factor (rivestimento di di carbonio)
Failure criteria: Max Stress

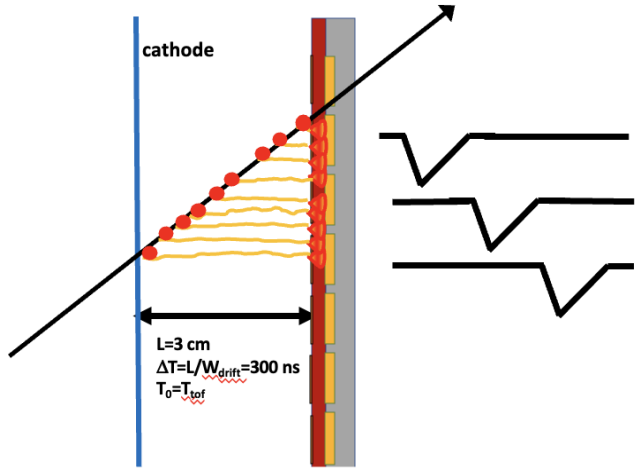
Images by P. Mastinu and E. Musacchio-Gonzales

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 ATOMKI (proton beam), to verify the tracking capability and at n_ToF to evaluate the background rate. The demontrator was composed by a single µRwell backed with a scintillator plane.

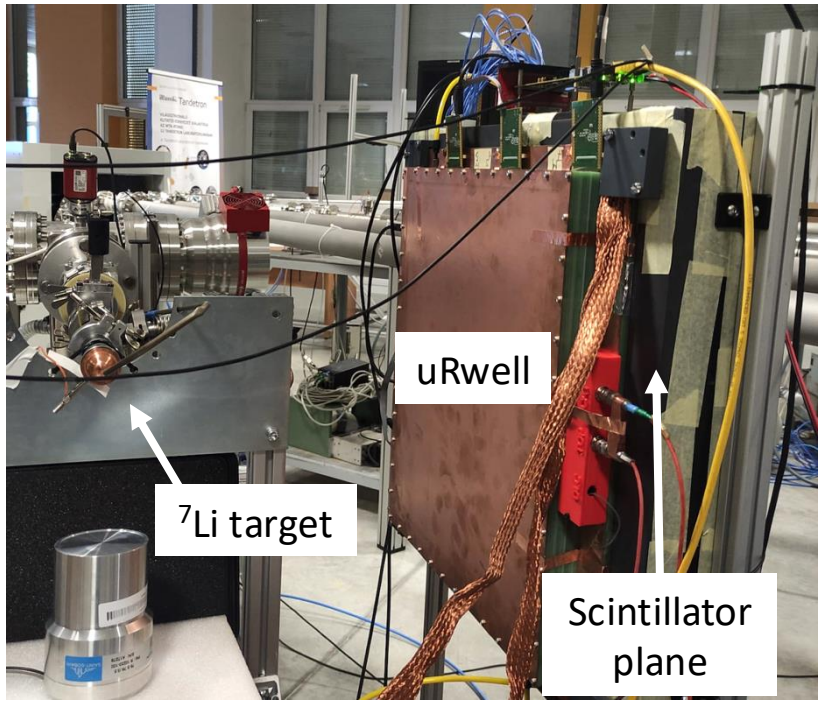


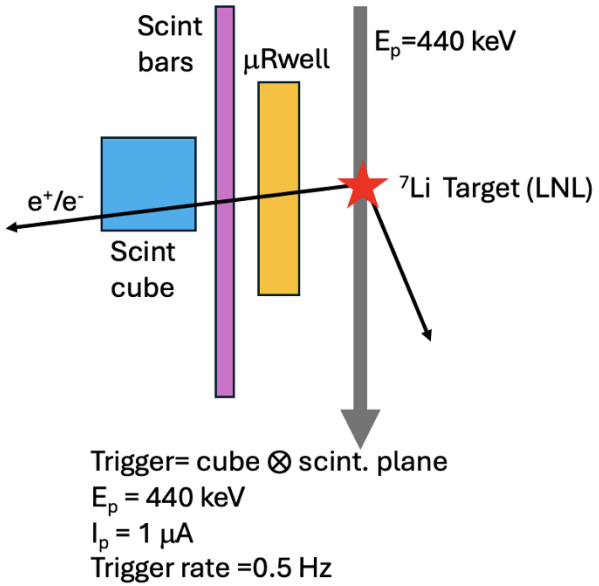


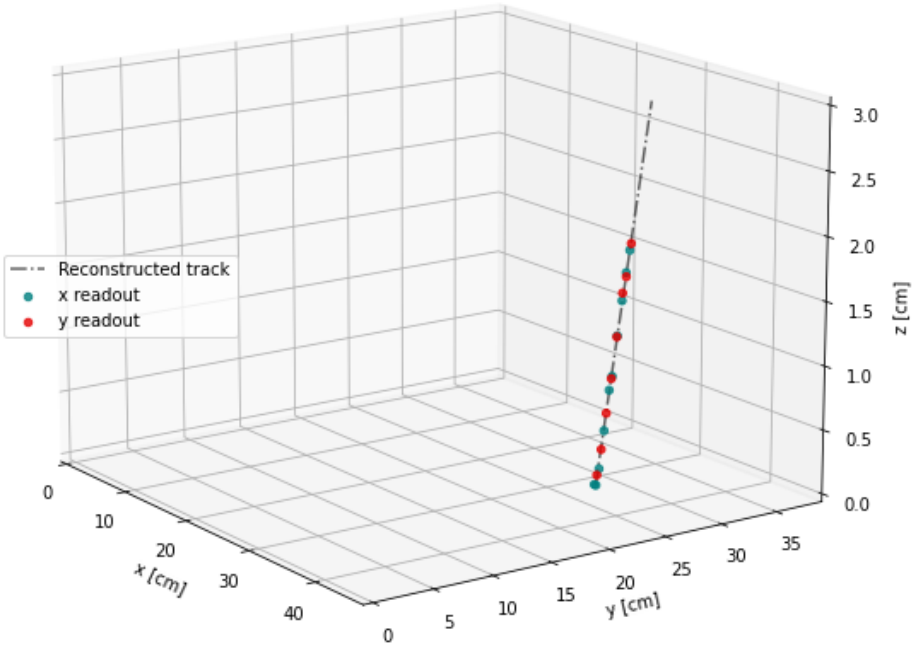


The μRwells

-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 ATOMKI (proton beam), to verify the tracking capability and at n_ToF to evaluate the background rate. The demontrator was composed by a single μRwell backed with a scintillator plane.



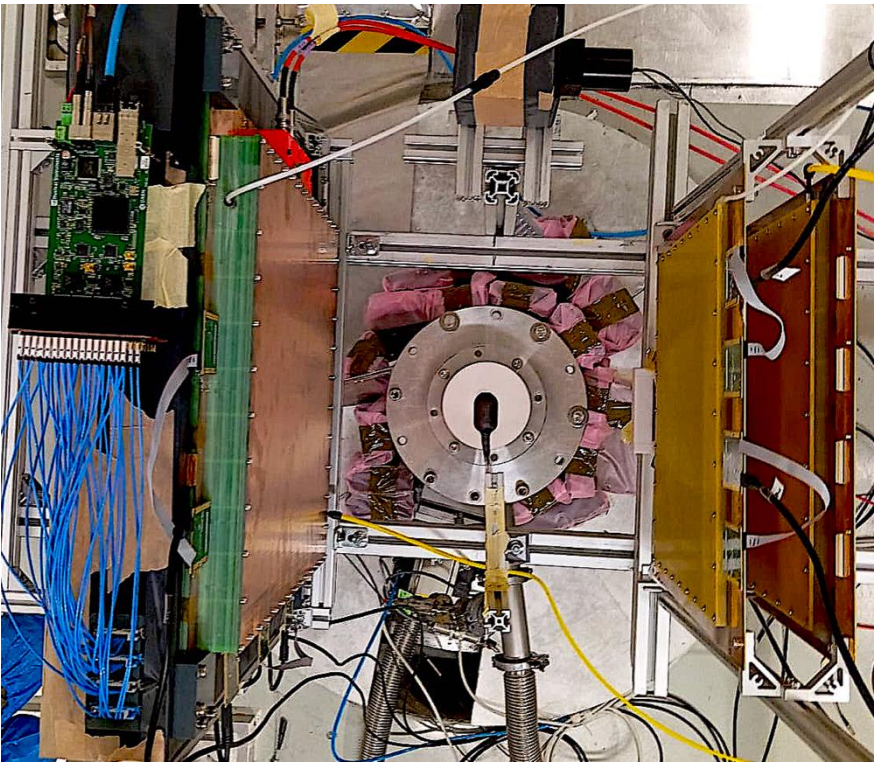


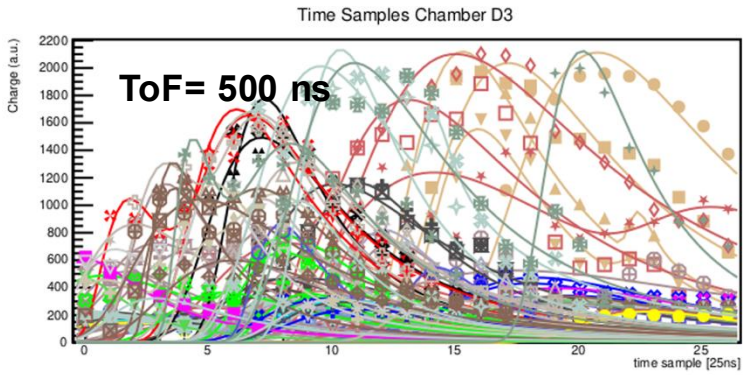


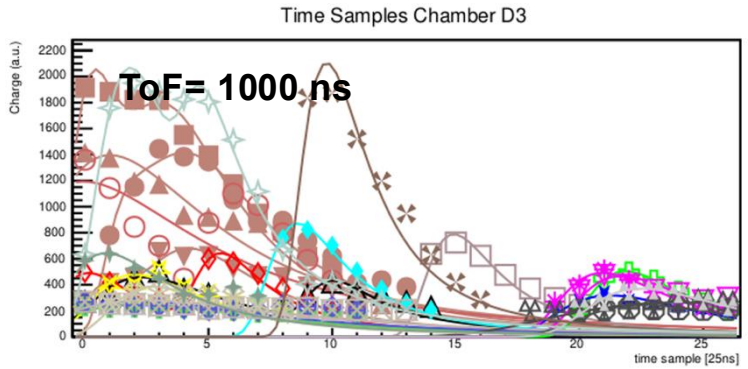
Plot by S. Scarpellini

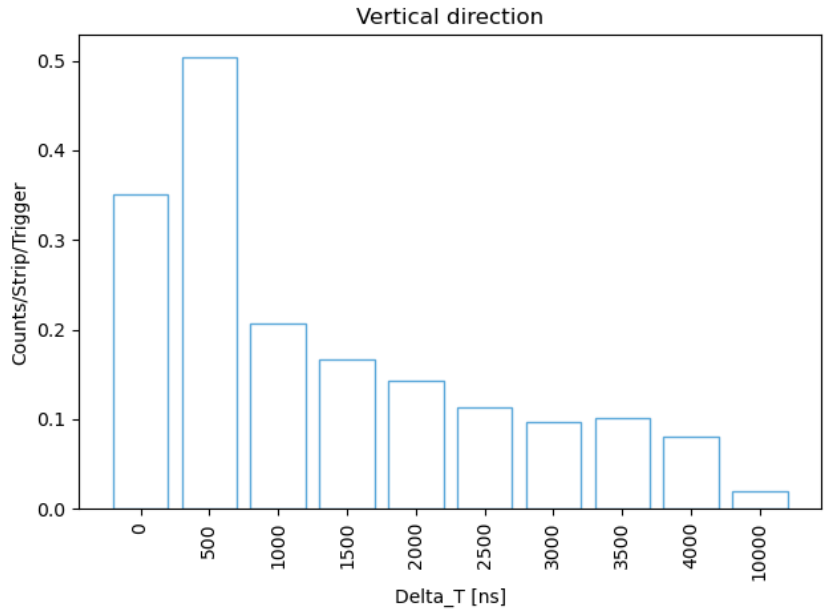
The μRwells

-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 ATOMKI (proton beam), to verify the tracking capability and at n_ToF to evaluate the background rate. The demontrator was composed by a single μRwell backed with a scintillator plane.



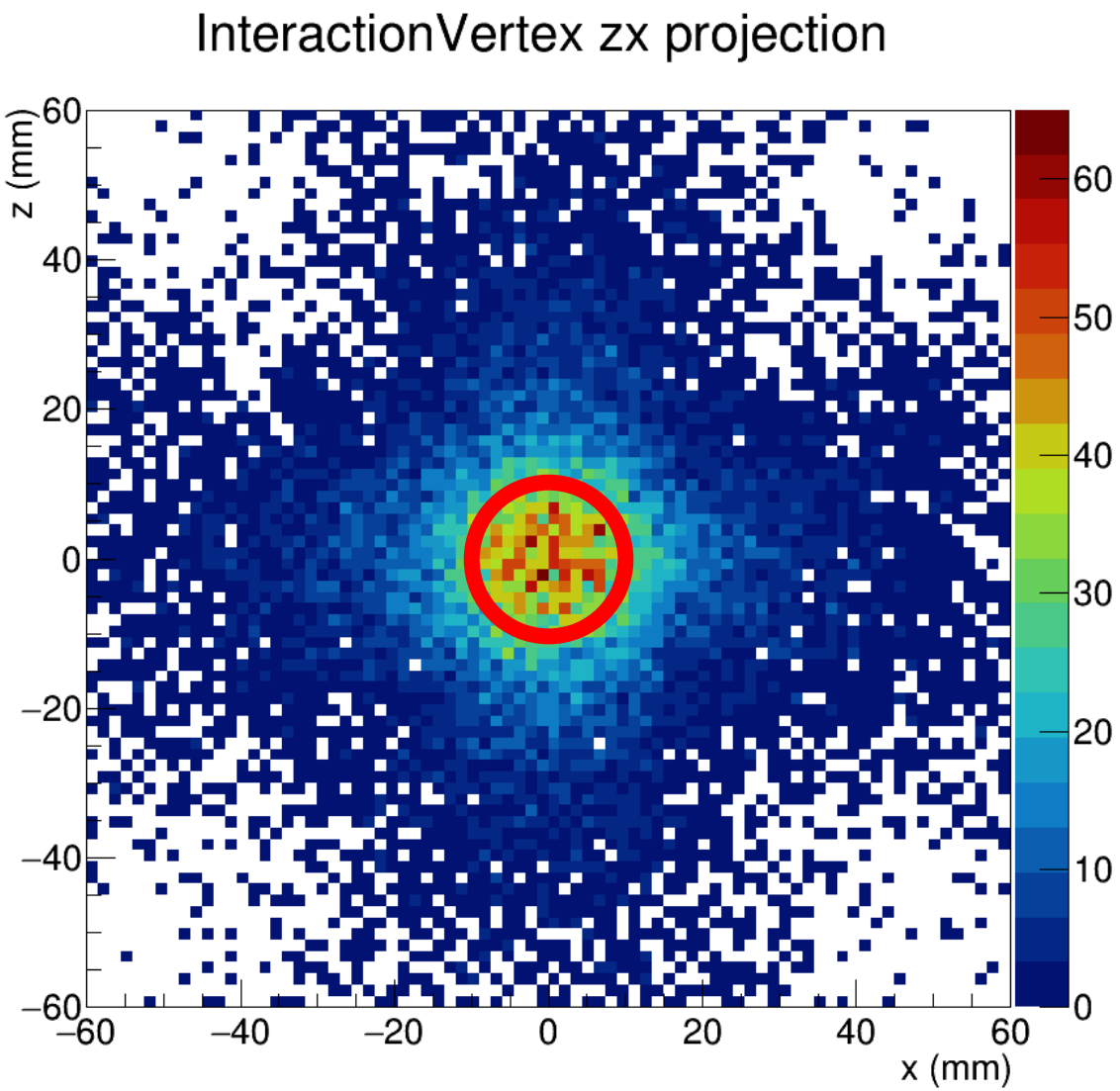


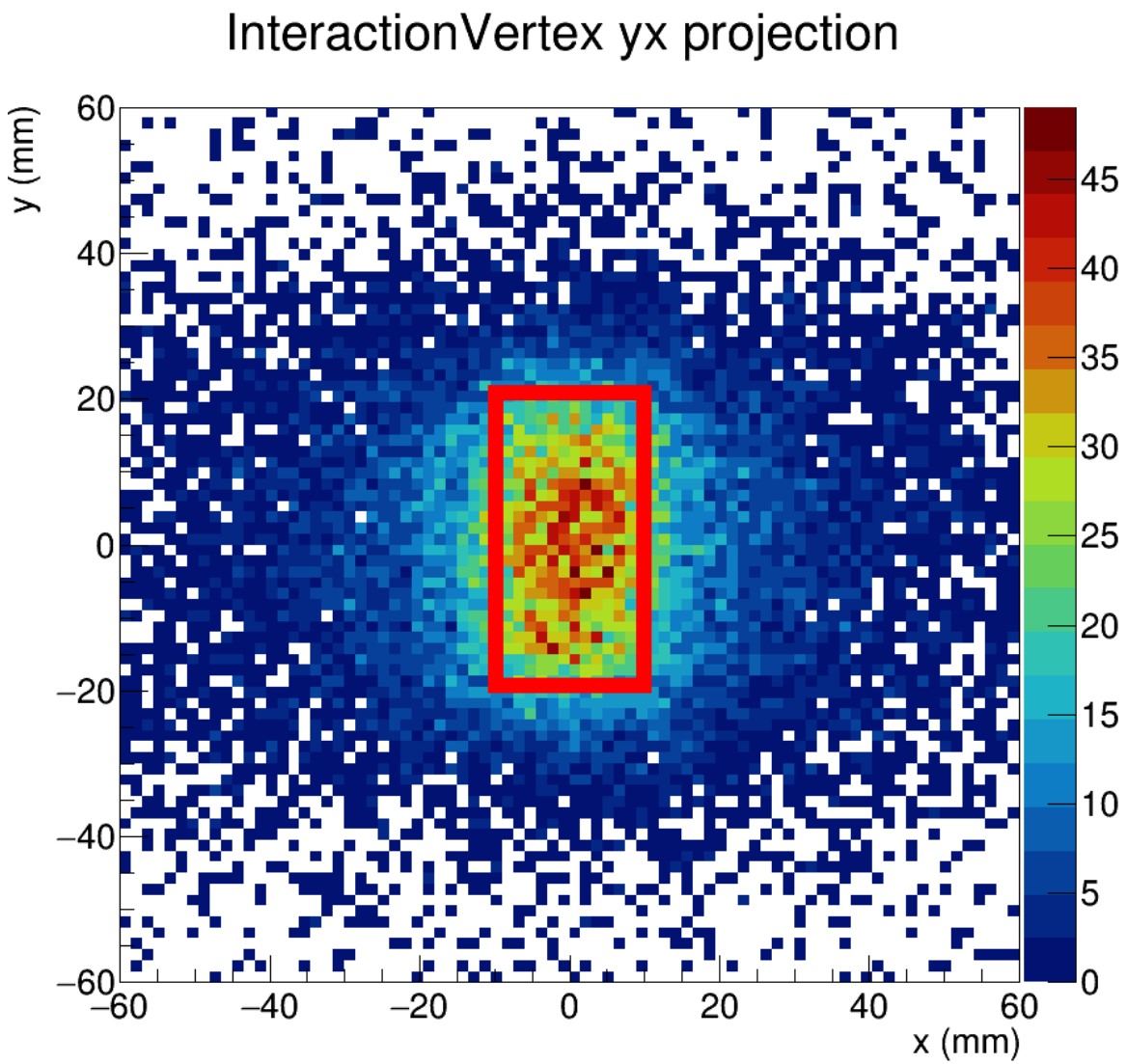




The μRwells

Vertex reconstruction (simulation w/o magnetic field).



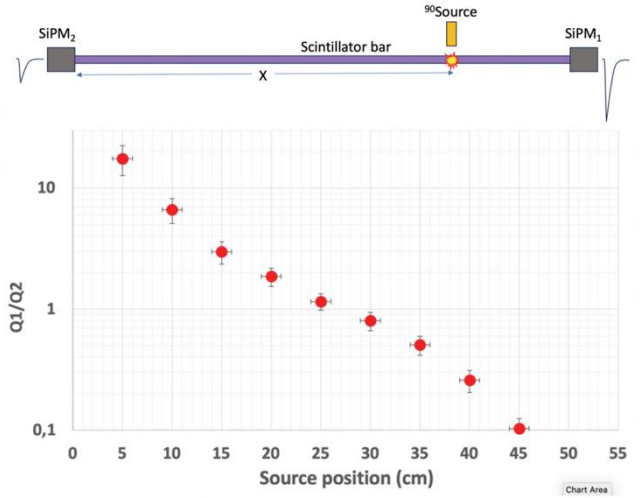


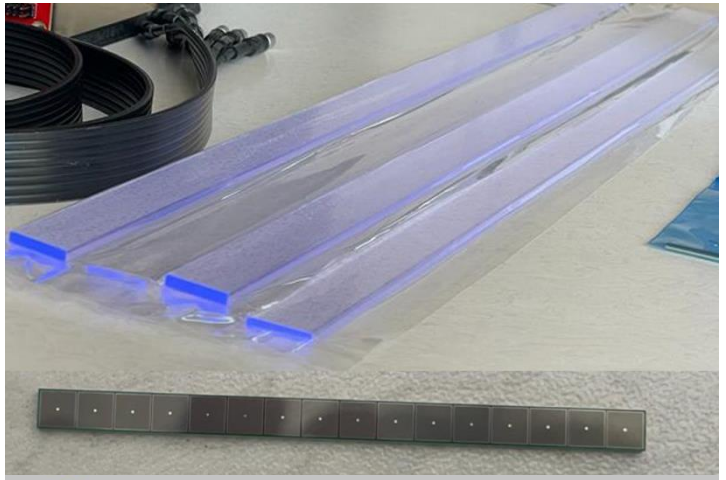
The scintillator system

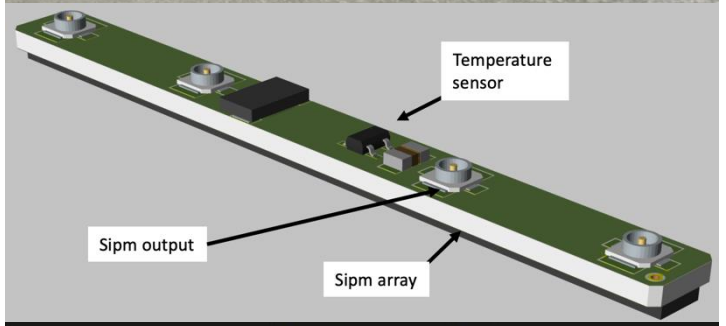
-Commercial scintillator bars by SCIONIX, 50x2.5x0.3 cm^3

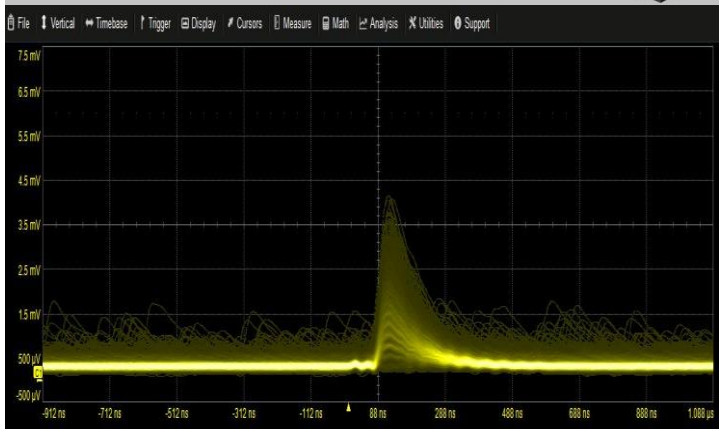
-readout performed with array of SiPM.

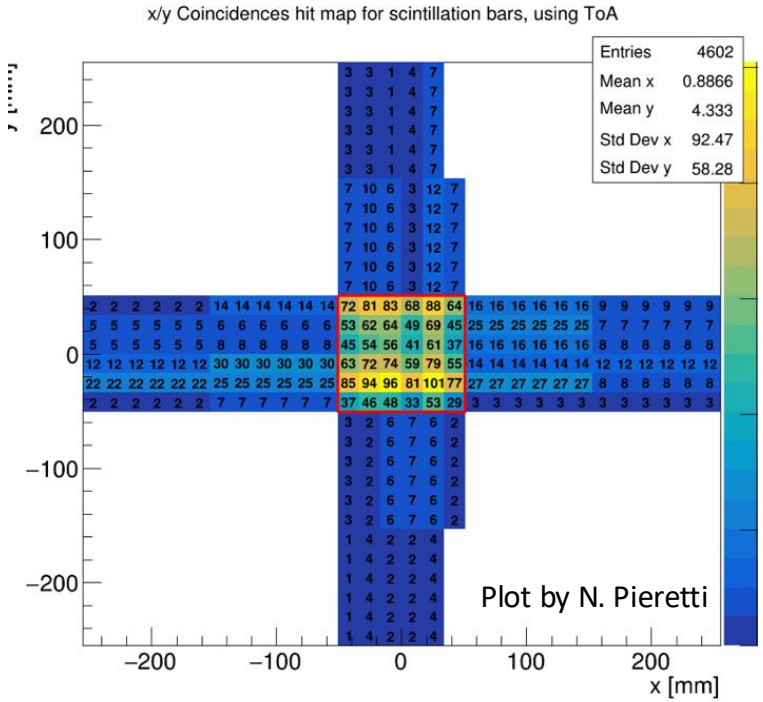
Tested at n_TOF and ATOMKI neutron and proton beams.

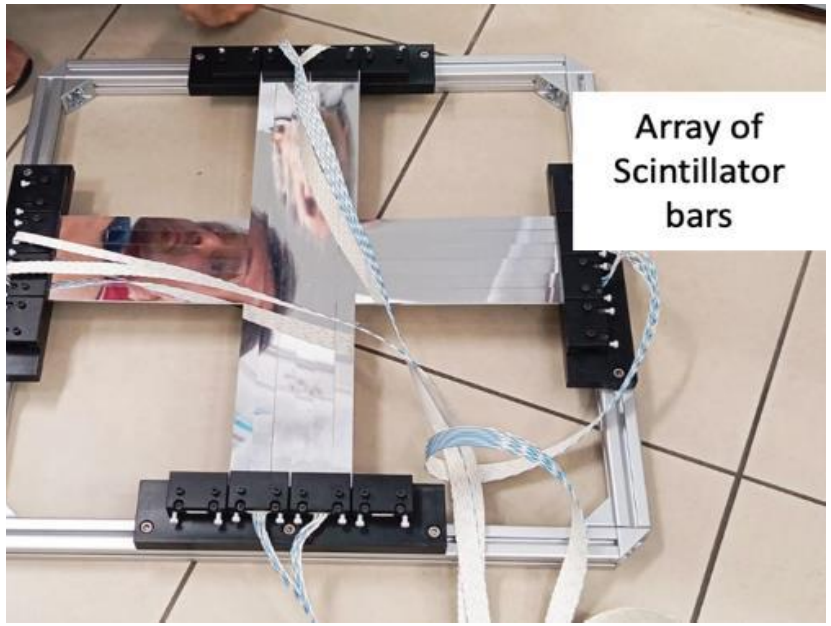






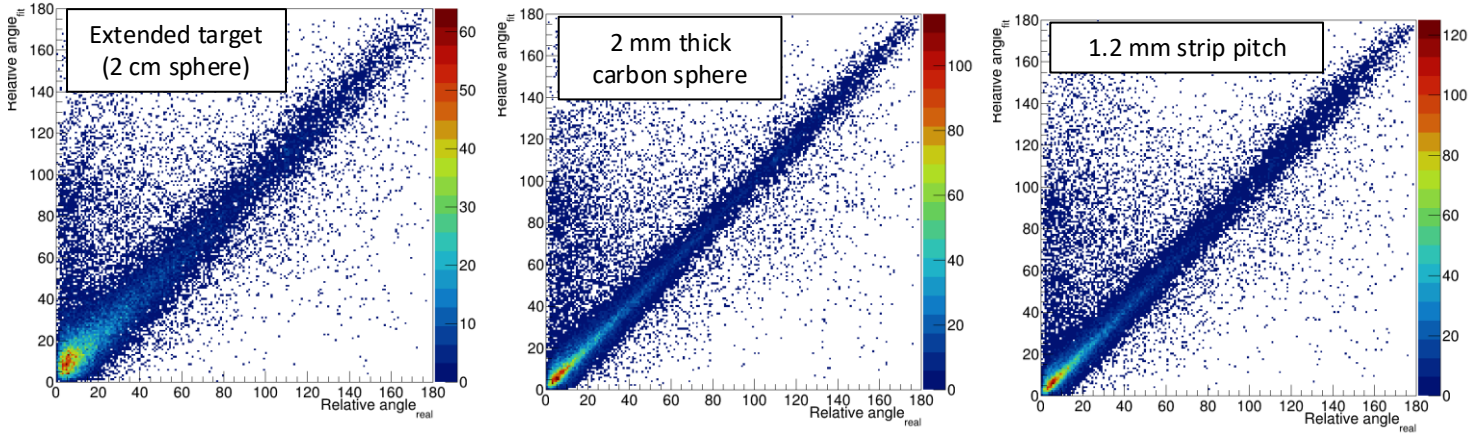


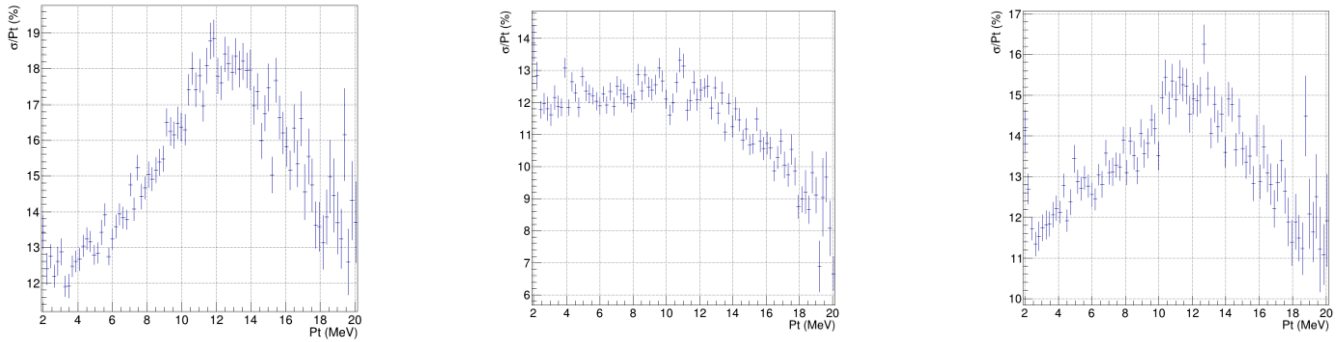




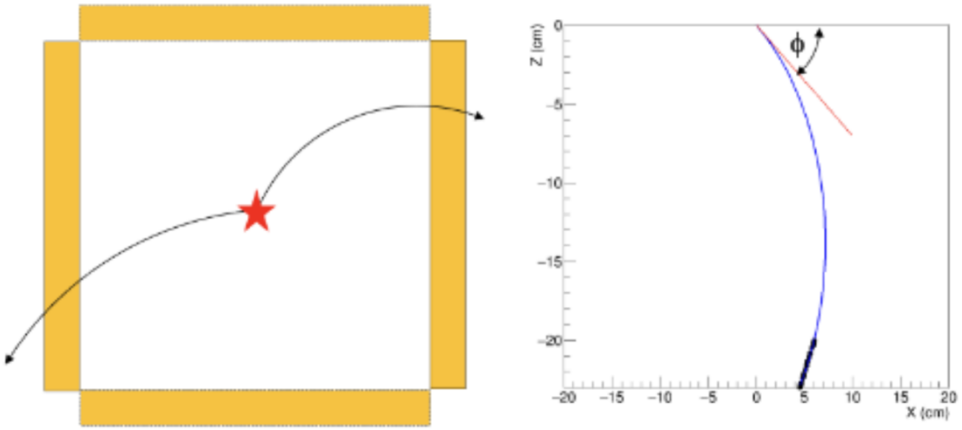
The magnet

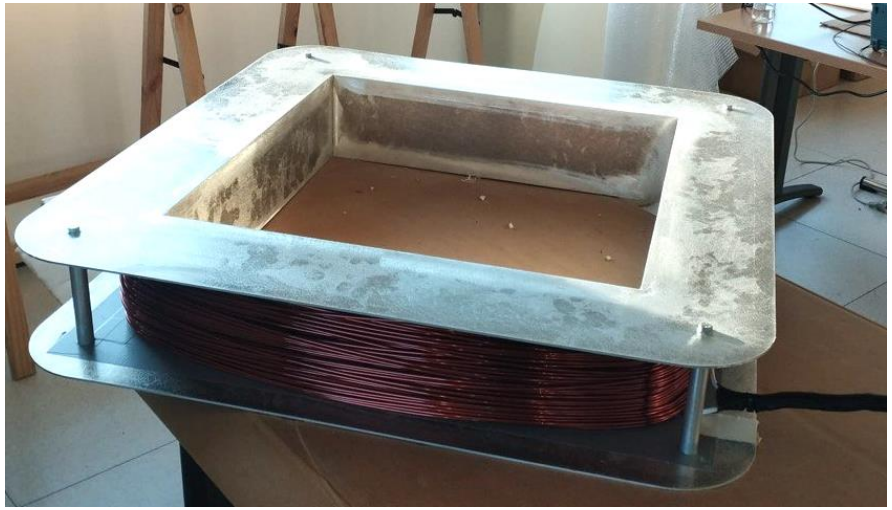
The magnet demonstrator has been realised and caracterised. Simulations provide an overall momentum reconstruction of ejectiles at the 20% Level.





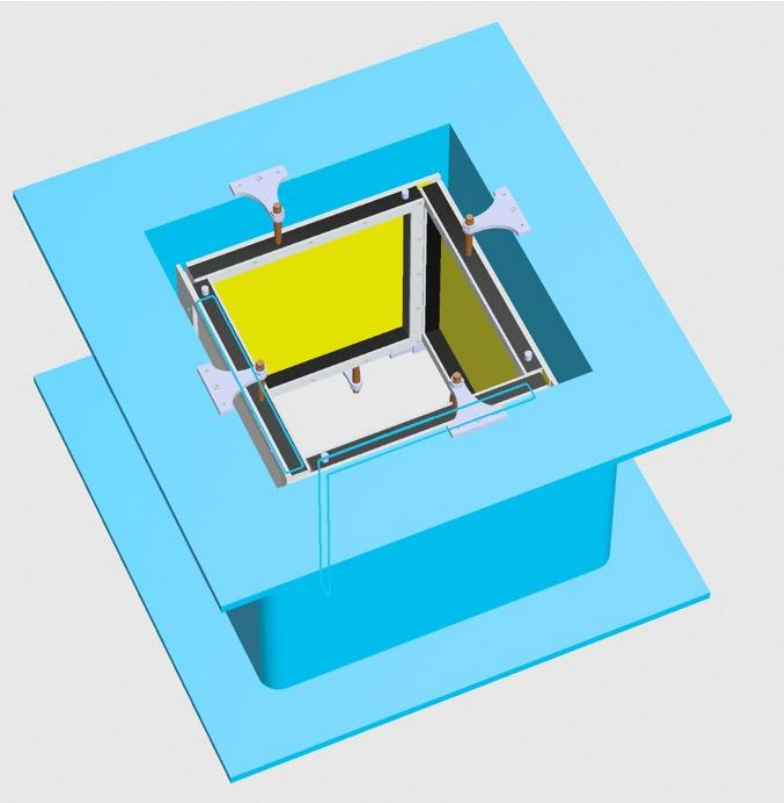
Plots by R. Mucciola

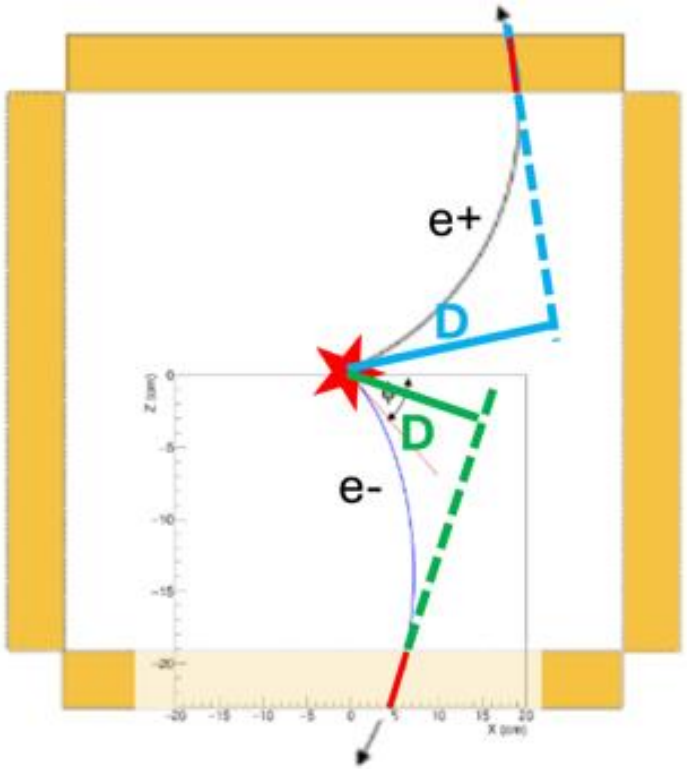


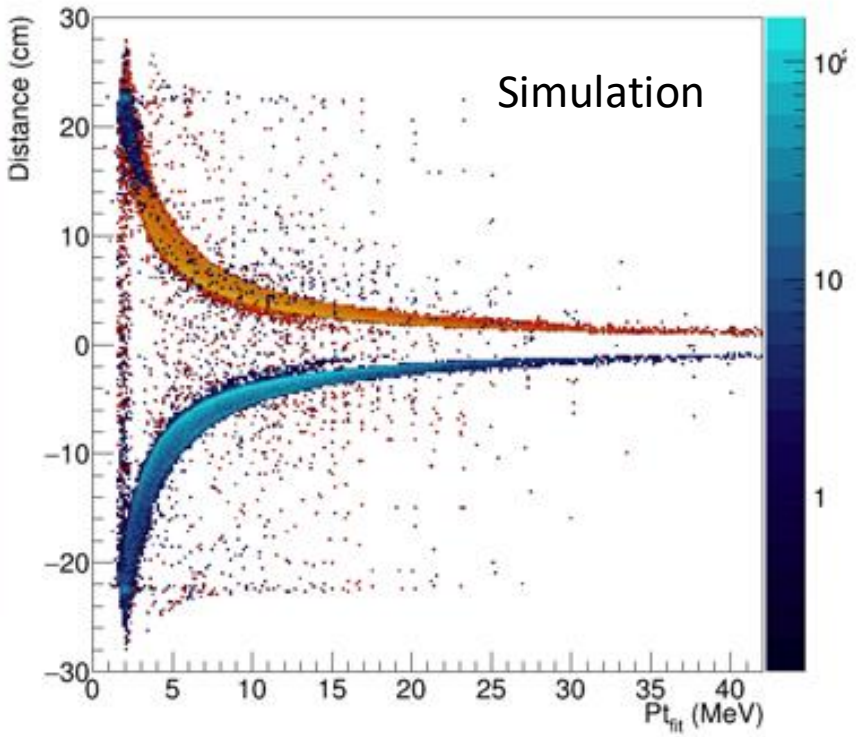


15x60x60 cm^3 magnet demonstrator

The magnet



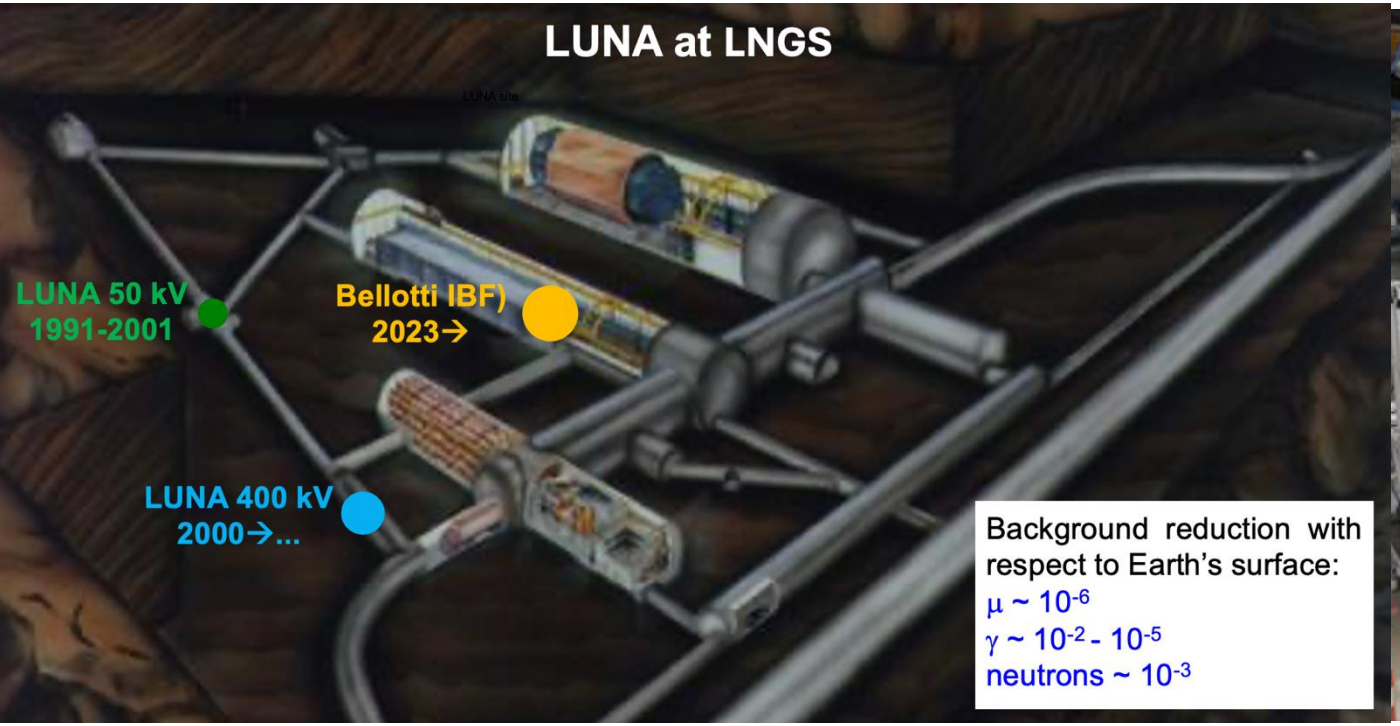




15x60x60 cm^3 magnet demonstrator

Other reactions

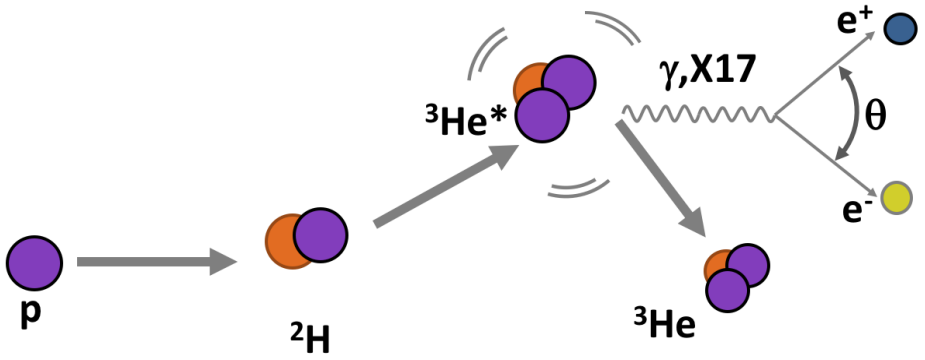
-The detectior is well suited also for proton-induced reactions. For instance, it can be used to repeat the ATOMKI experiments such as the $^{3}H(p,e^{-}e^{+})^{4}He$, $^{7}Li(p,e^{-}e^{+})^{8}Be$, $^{11}B(p,e^{-}e^{+})^{12}C$ nuclear reactions in a wide energy region, with a large acceptance and with improved kinematic reconstruction.
-An ideal location for such a program is the underground IBF facility at the LNGS Gran Sasso Laboratories.
-Unfortunately, IBF is ~100% used for the LUNA Nuclear Astrophyisics program. Moreover, The LNGS has very strict safety rules and rules to operate close to DM and $\beta\beta$ decay experiments.



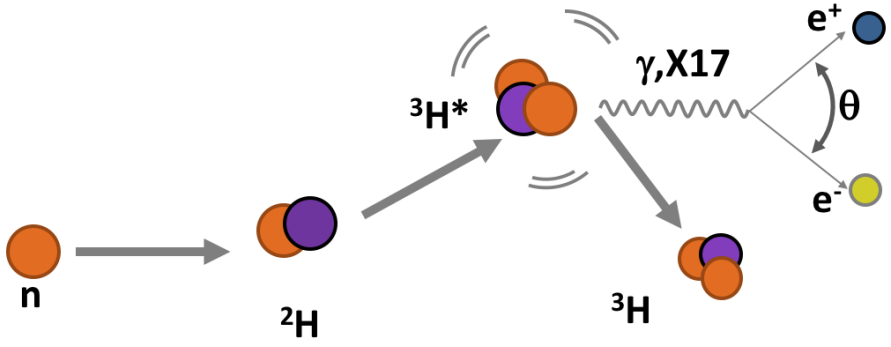
Other reactions

The low sensitivity to neutrons suggests the use of the detector to study the **^{2}H(n,e$^+$e$^-$)^{3}H** and **^{2}H(p,e$^+$e$^-$)^{3}He** reactions.

- Reliable ab-initio predictions
- Investigate on the isospin dependency of the X17-nucleon interaction, as the alleged “proto-phobicity”
- Kinematic threshold the X17 channel at about Ep/n=17 MeV



^{2}H(p,e$^+$e$^-$)^{3}He (Q=5.5 MeV)

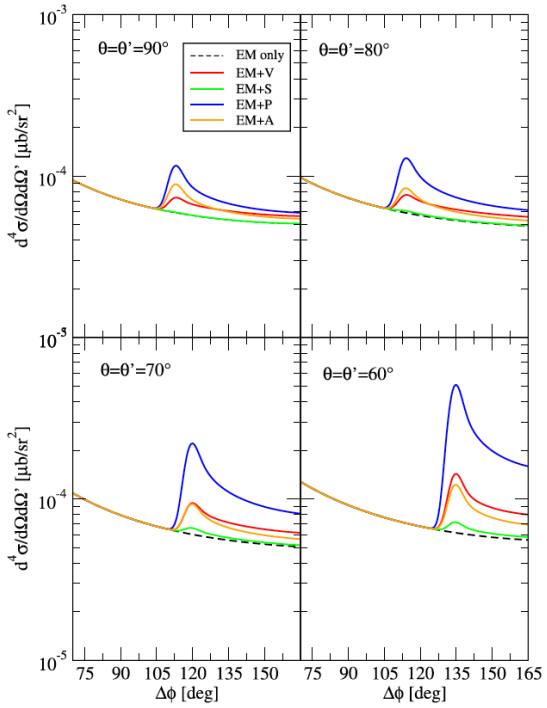


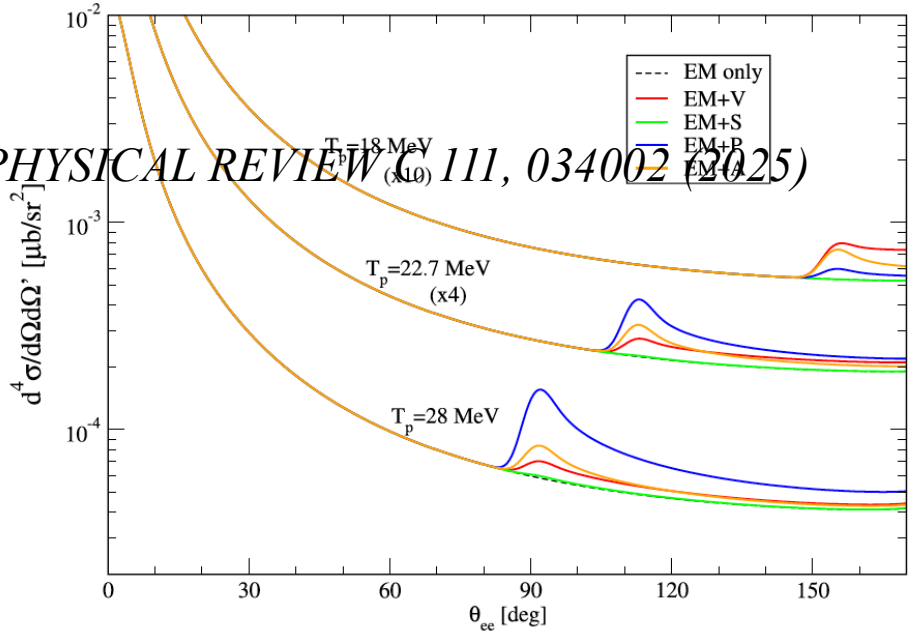
^{2}H(n,e$^+$e$^-$)^{3}H (Q=6.3 MeV)

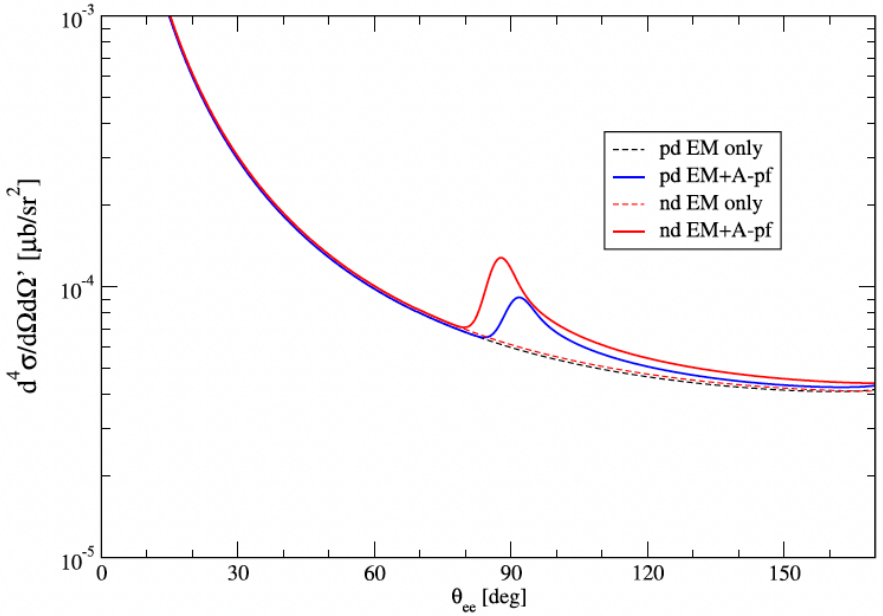
Other reactions

The low sensitivity to neutrons suggests the use of detector to study for the first time the **^{2}H(n,e$^+$e$^-$)^{3}H** and **^{2}H(p,e$^+$e$^-$)^{3}He** reactions.

- Reliable ab-initio predictions
- Investigate on the isospin dependency of the X17-nucleon interaction, as the alleged “proto-phobicity”
- Kinematic threshold for the X17 channel at about Ep/n=17 MeV







PHYSICAL REVIEW C 111, 034002 (2025)

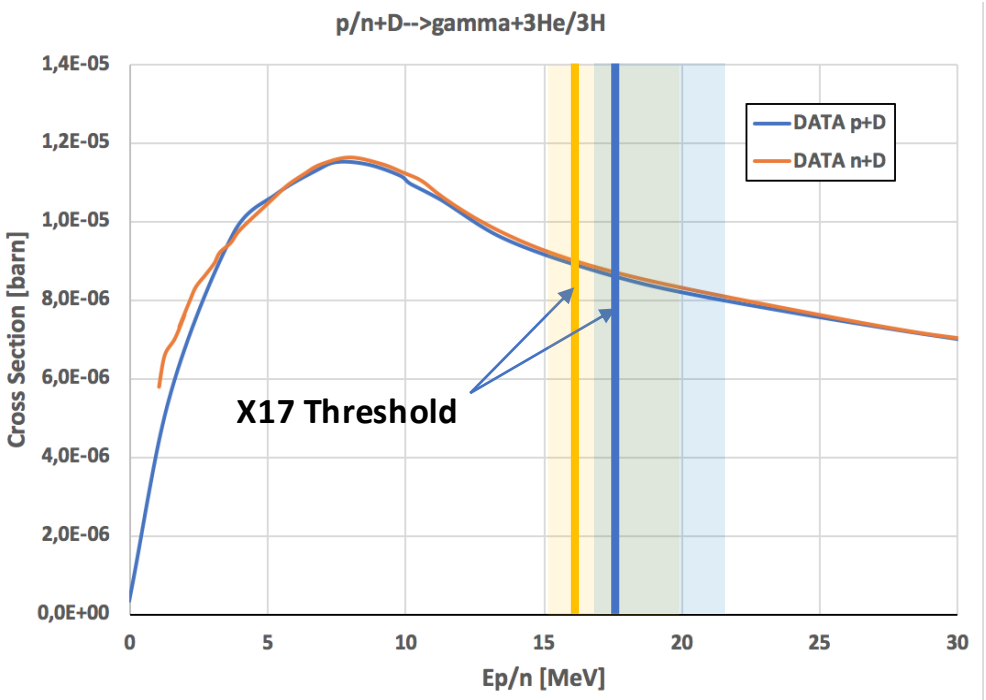
M. Viviani et al.: PRC 111, 034002 (2025)

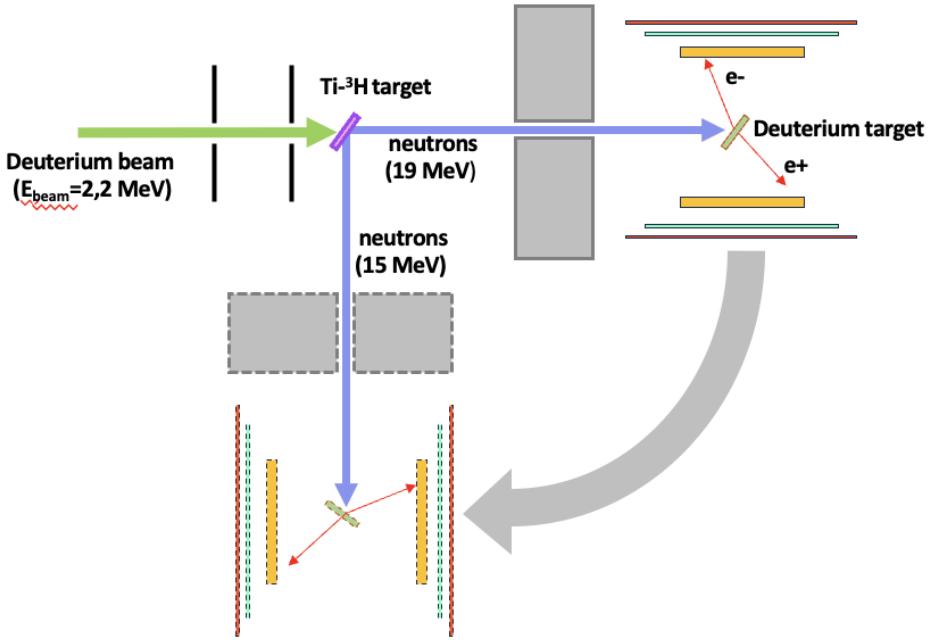
See L.E. Marcucci talk

Other reactions

The low sensitivity to neutrons suggests the use of detector to study for the first time the $^{2}H(n,e^{+}e^{-})^{3}H$ and $^{2}H(p,e^{+}e^{-})^{3}He$ reactions.

- Reliable ab-initio predictions
- Investigate on the isospin dependency of the X17-nucleon interaction, as the alleged “proto-phobicity”
- Kinematic threshold fot the X17 channel at about Ep/n=17 MeV





Conclusions

The experimental goal of n_TOF approach is to perform the first measurement of the **^{3}He(n,e^{+}e^{-})^{4}He** process **in the 2nd half of 2026.**

After that, there will be the "long shutdown"→ no neutron beam for years. However, it will be possible to exploit other facility for old and new proton induced reaction, such as as **^{7}Li(p,e^{-}e^{+})^{8}B, ^{3}H(p,e^{-}e^{+})^{4}He**, **^{11}B(p,e^{-}e^{+})^{12}C** in a wider energy region, with a large acceptance and with improved kinematic reconstruction, to verify the existence of X17 and to probe its properties (spin, parity, coupling, life time).

Finally, low sensitivity to neutrons suggests its use to study for the first time the **^{2}H(n,e^{+}e^{-})^{3}H** and **^{2}H(p,e^{+}e^{-})^{3}He** reactions, well suited for a reliable theoretical analysis.