Probing New Dark Boson with nTOF

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for the X17 Working group

X17 ATOMKI RESULTS

- ATOMKI group observed a significant anomaly in the emission of electron-positron pairs in the $^{7}Li(p,e^{+}e^{-})^{8}Be$ and $^{3}H(p,e^{+}e^{-})^{4}He$ reactions.

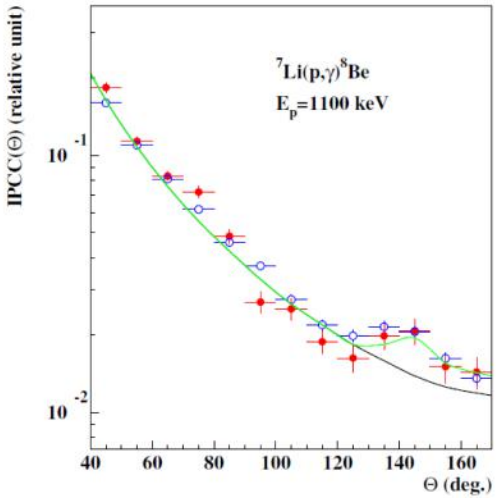
-This anomaly has been interpreted as the signature of a 17 MeV BOSON, not foreseen in the standard model of particle physics.

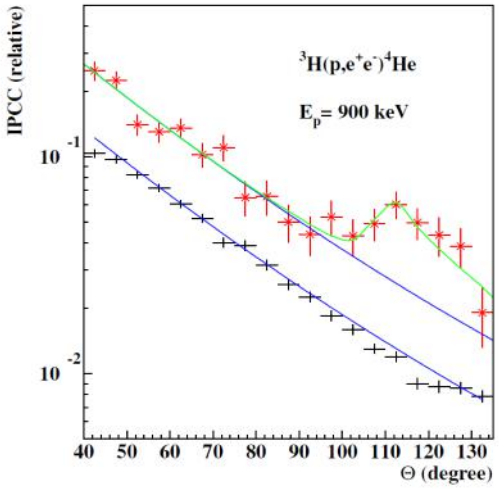
-The so called X17 boson could be a mediator of a fifth force, characterized by a strong coupling suppression of protons compared to neutrons.

-This evidence/scenario is presently not confirmed or excluded by other experiments or groups.

Reaction	$M_{X17}\pm\Delta M_{stat}\pm\Delta M_{syst}$
$^{7}Li(p,e^{+}e^{-})^{8}Be$	16.70±0.35±0,50 MeV
$^{3}H(p,e^{+}e^{-})^{4}He$	16.94±0.12±0.21 MeV

Krasznahorkay, A.J.; et al.: PRL**116** (42501): 042501 (2016).
Krasznahorkay, A.J.; et al.: PRC 104, 4, 044003 (2021).





PRESENT DATA:

-ATOMKI: $^{7}Li+p\rightarrow{}^{8}Be^{*}\rightarrow{}^{8}Be+X17$

-ATOMKI: $^{3}H+p\rightarrow{}^{4}He^{*}\rightarrow{}^{4}He+X17$

NEW PROJECTS:

MEGII@PSI: $^{7}Li+p\rightarrow{}^{8}Be^{*}\rightarrow{}^{8}Be+X17$

PADME@LNF: $e^{+}+e^{-}\rightarrow X17$

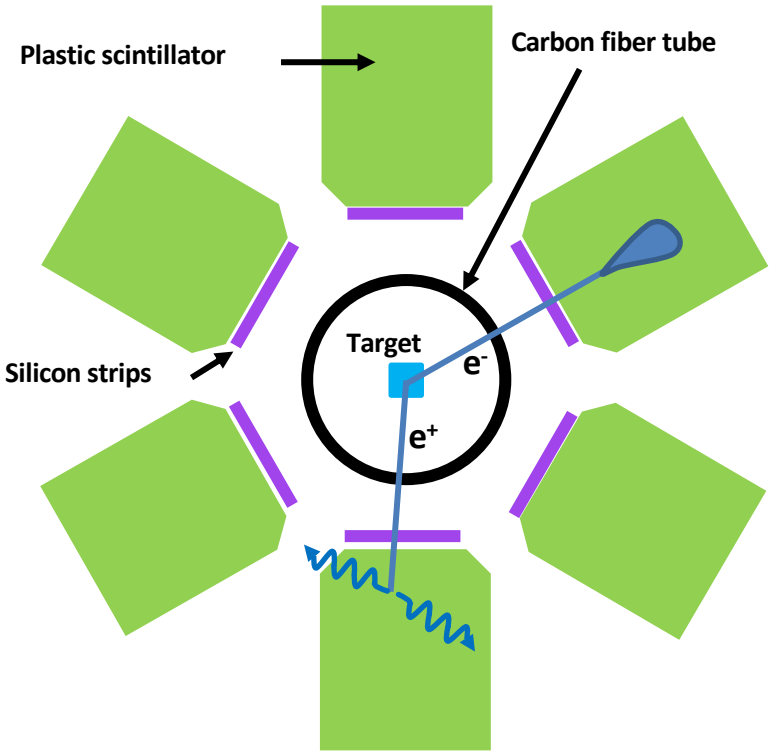
NewJedi@GANIL: $^{7}Li+p\rightarrow{}^{8}Be^{*}\rightarrow{}^{8}Be+X17$

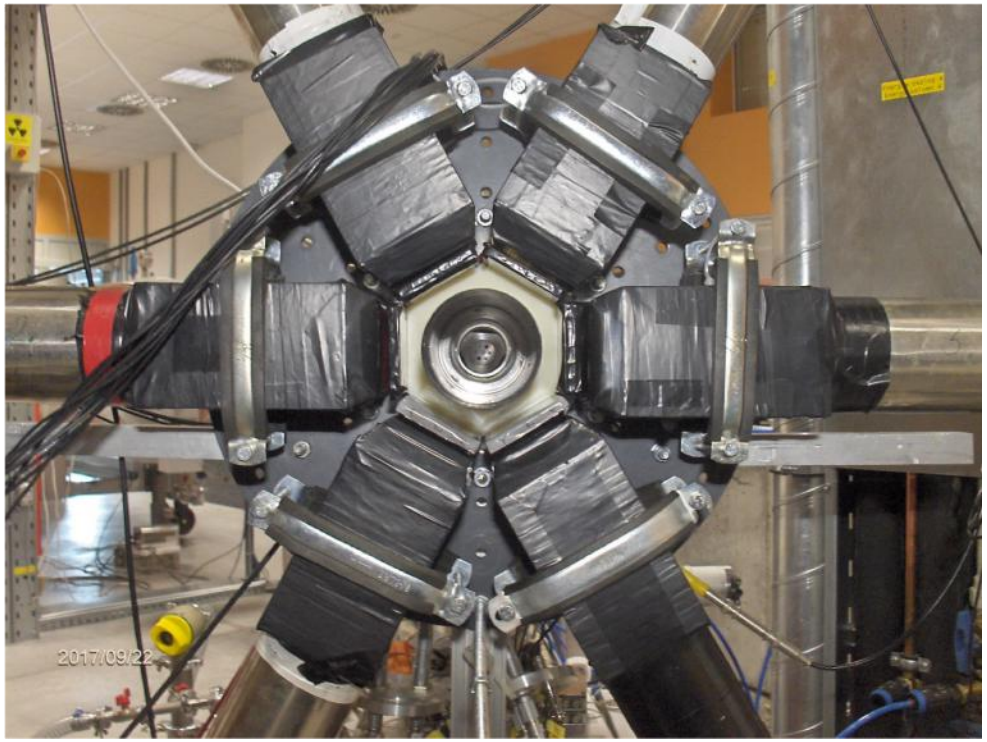
nTOF@CERN $\rightarrow{}^{3}He+n\rightarrow{}^{4}He^{*}\rightarrow{}^{4}He+X17$

Signature: e+e- pairs with E_{tot}>17 MeV at large relative angle.

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

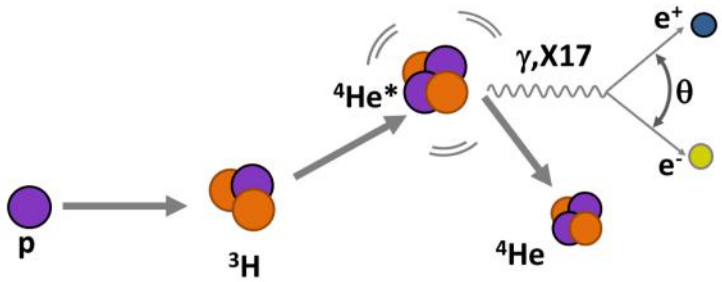
- ^3H target and proton beam with E_p=900 keV
- Detection of e^+e^- pairs using:
- 6 plastic scintillators 8.2x8.6x8.0 cm^3 (energy of e^+e^- pairs)
- 6 double-sided silicon strip detectors (angle between e^+e^- pairs)





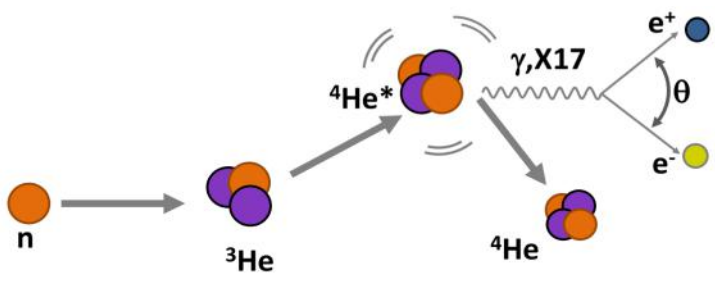
X17 @ nToF

Basic idea: new study of excited ^{4}He exploiting neutrons:



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

ATOMKI REACTION



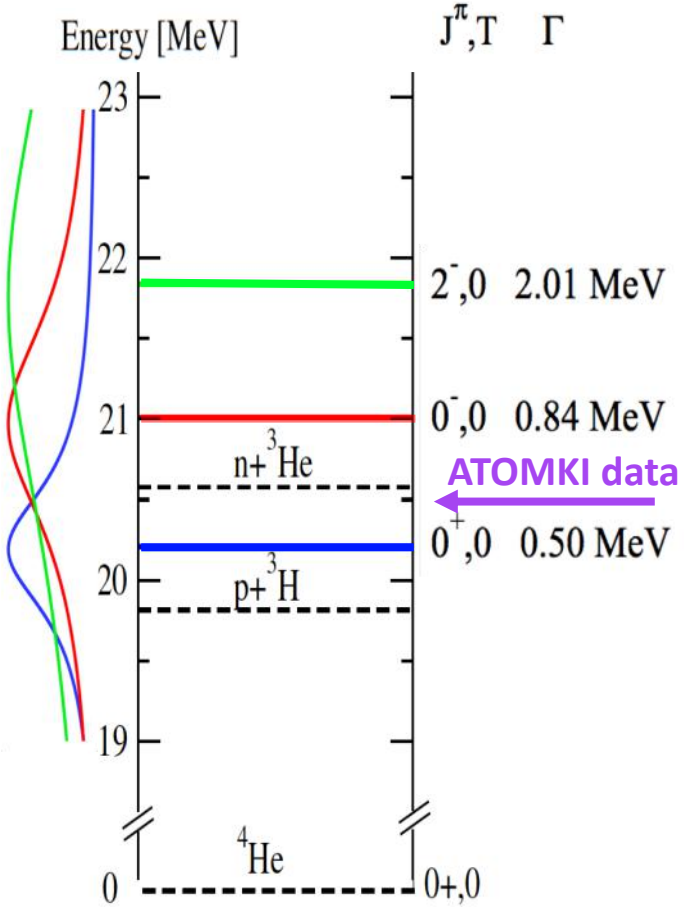
^{3}He(n,e$^+$e$^-$)^{4}He

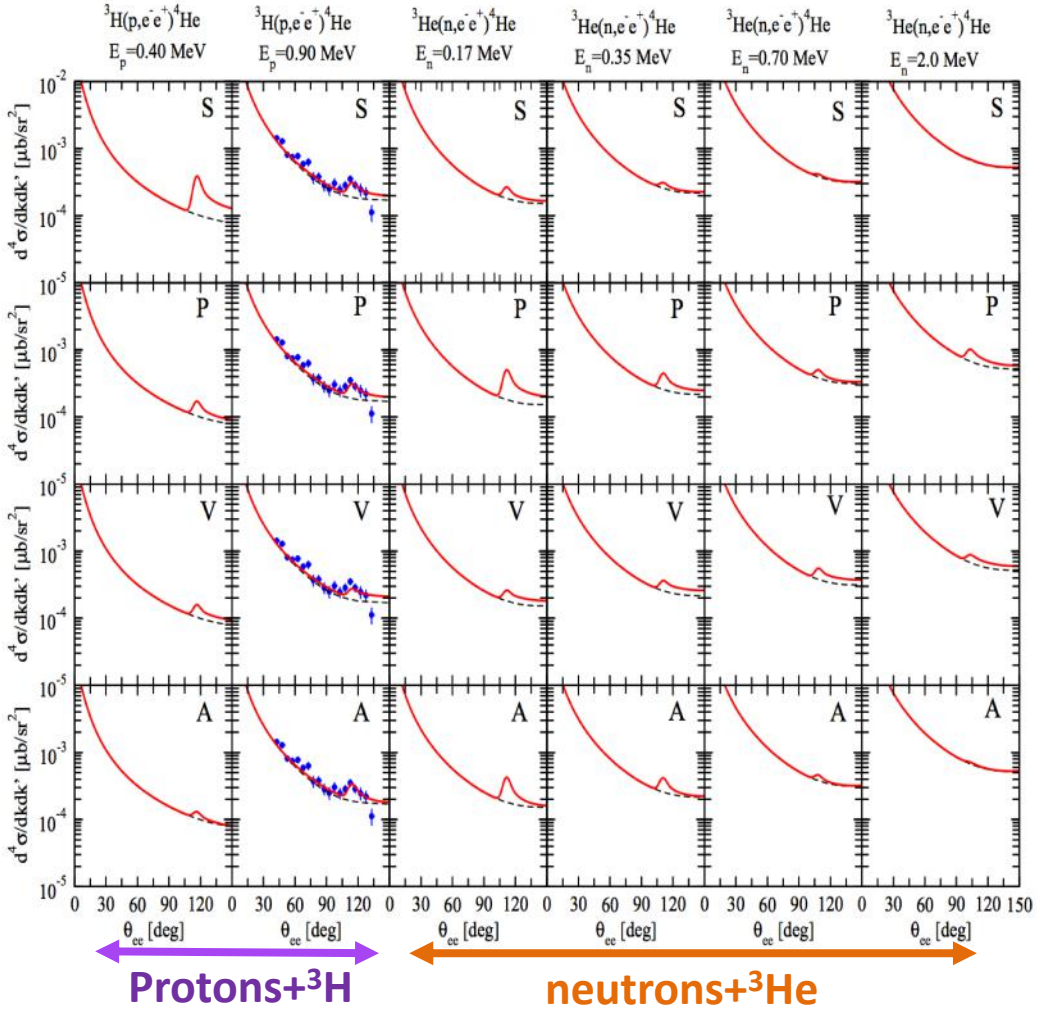
n_TOF REACTION

Physics:

- X17 existence
- X17 properties (mass, J^π, life time,..)
- X17 Coupling (e.g. proto-phobic nature of the fifth force).
- First measurement of the standard ^{3}He(n,e$^+$e$^-$)^{4}He cross section
- Comparison of experimental data with "ab Initio" calculation

X17 @ nToF

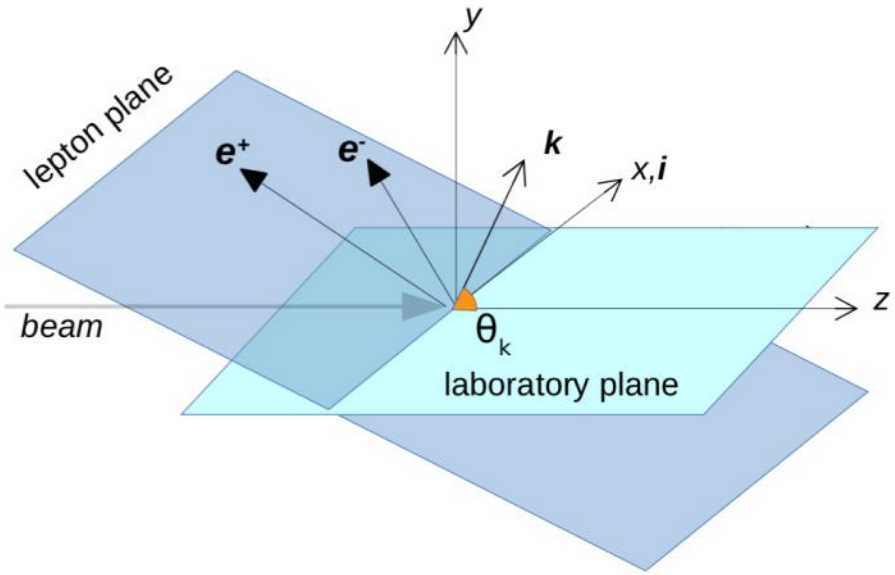


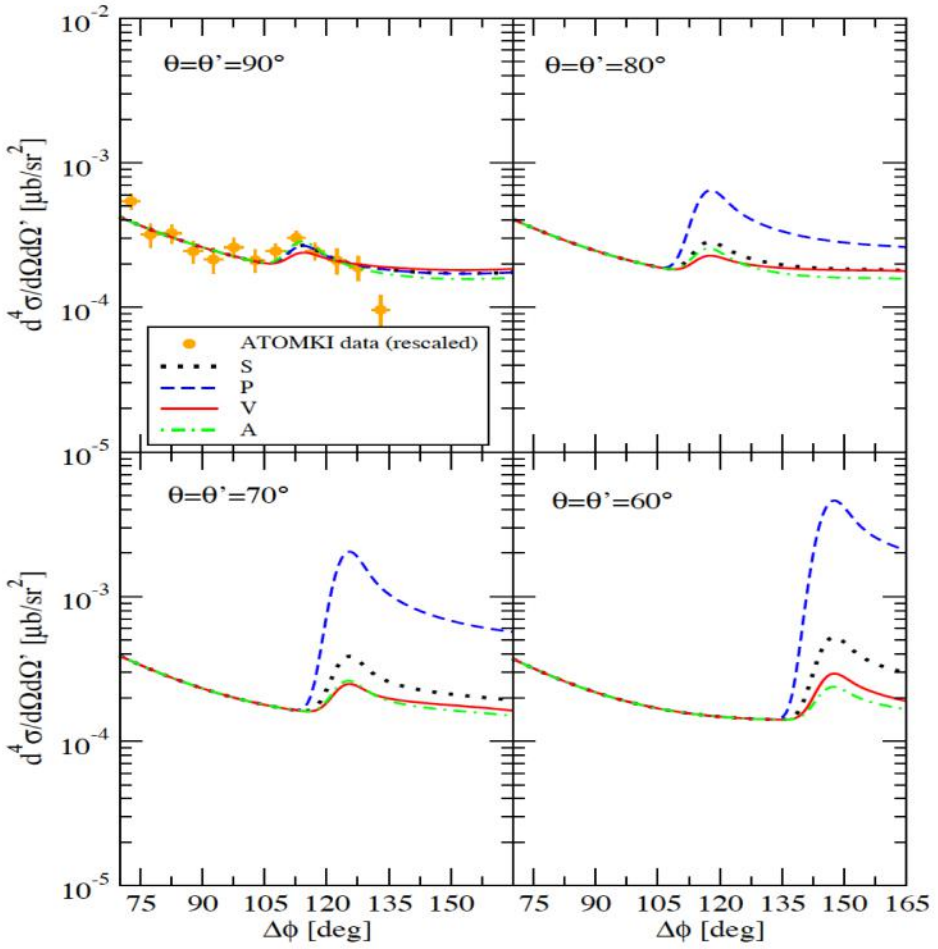


The wide energy range of neutrons at nTOF is well suited to study the X17 properties (e.g if it is a scalar, pseudo-scalar, vector or axial particle)

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

X17 @ nToF

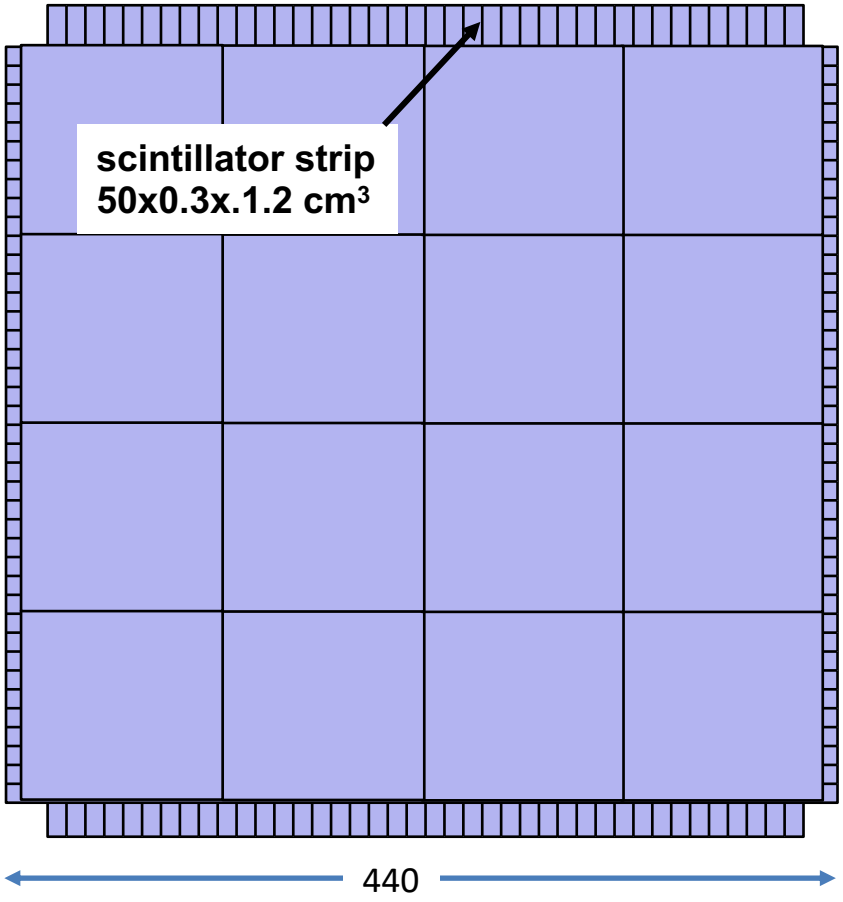


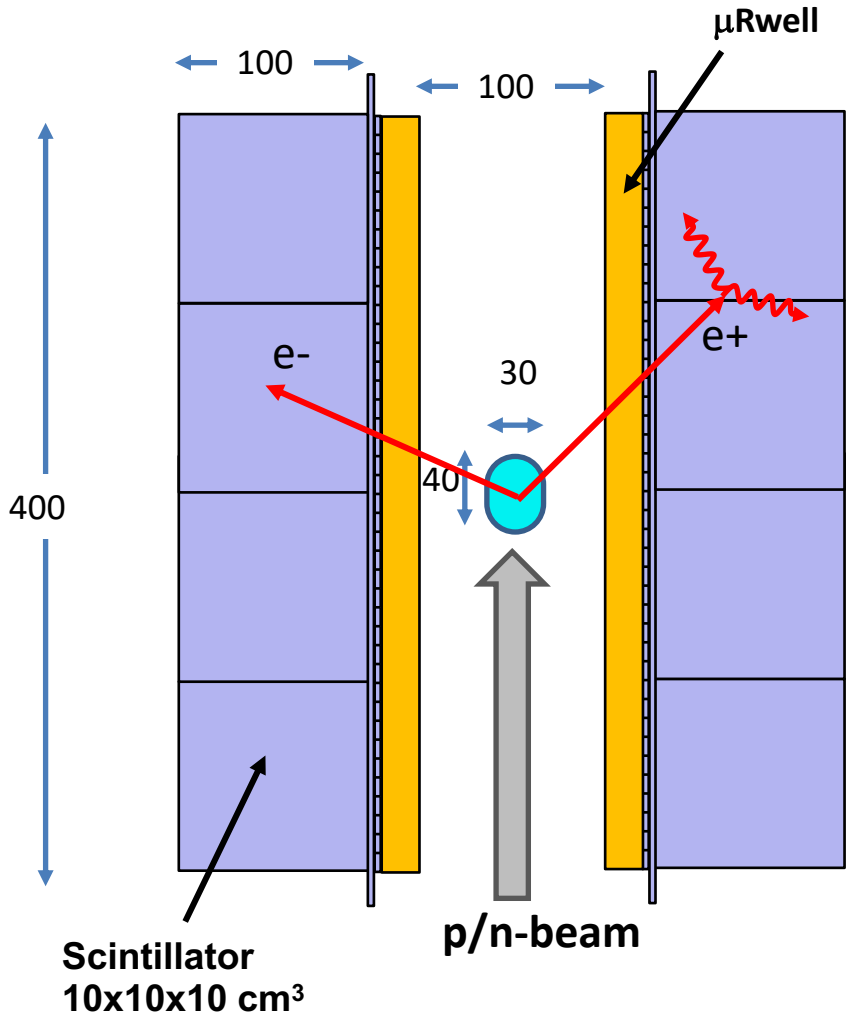


The study can be accomplished with a large acceptance detector to measure the spatial distribution of e+e- pairs, which is also sensitive to the x17 properties

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

X17 Detector





FINAL DESIGN.

Two large area module, each one composed by:

-1 μTPC faced to the target, realized with μRwell (e+e- tracking).

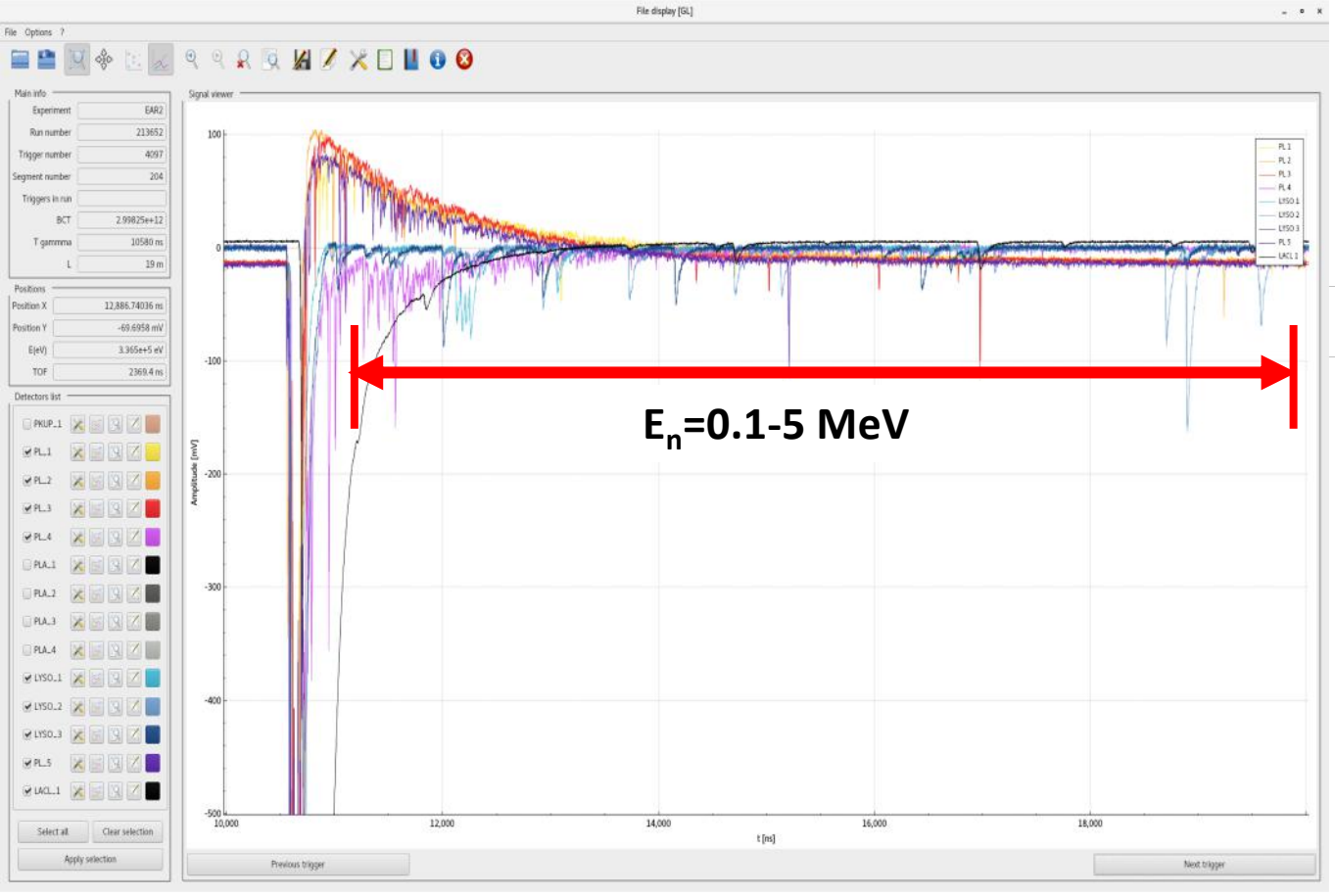
-2 planes 3 mm thick, composed by orthogonal scintillator strips (ΔE of e+e-).

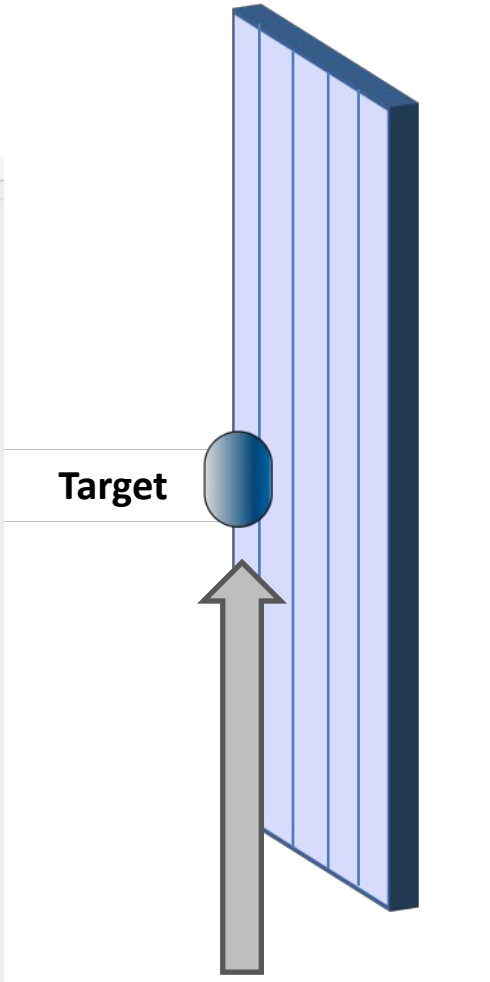
-1 plane 10 cm thick, composed by scintillator modules (Total energy of e+e-)

About 50% acceptance for e+e- pairs.

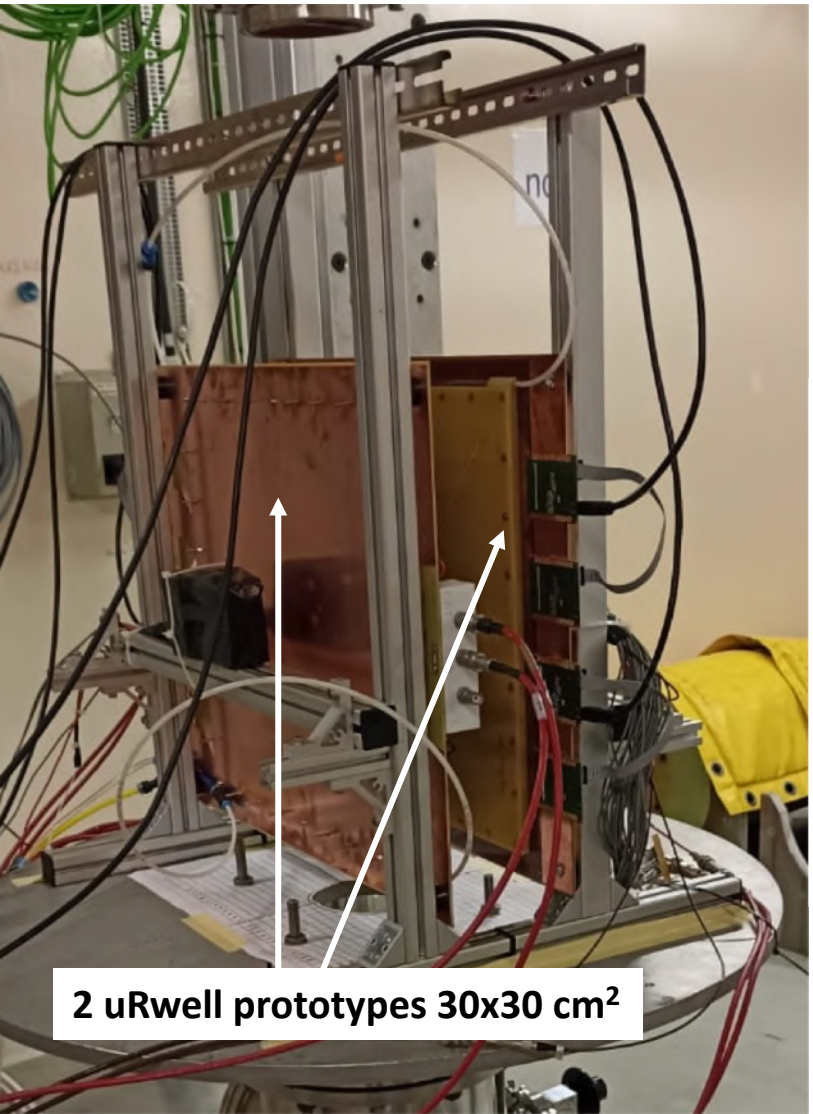
scintillators: Test at EAR2 (06/2022)

1 planes of 25x10x2 cm^3, composed by:
5 bars 25x2x2 cm^3
5 channels
Background OK
Data suggest active PMTs against gamma flash

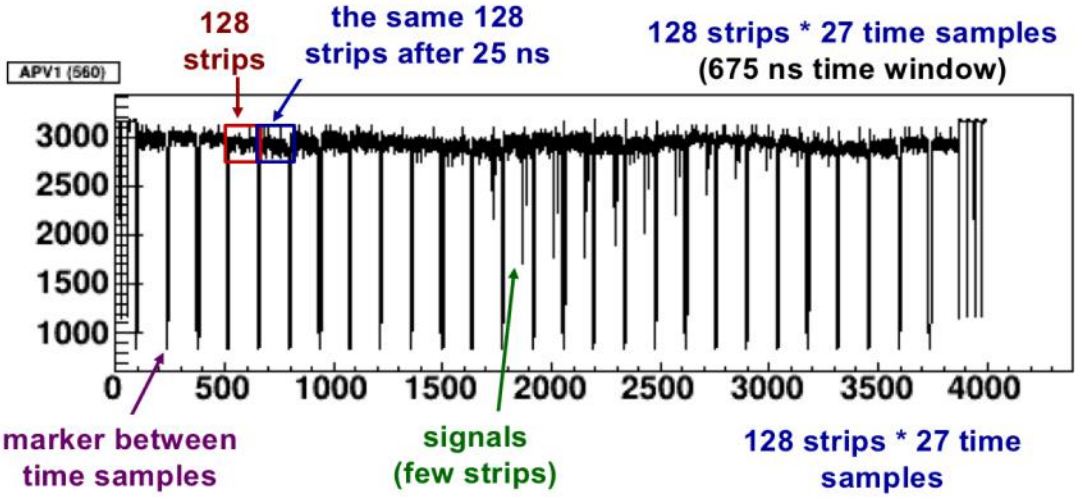




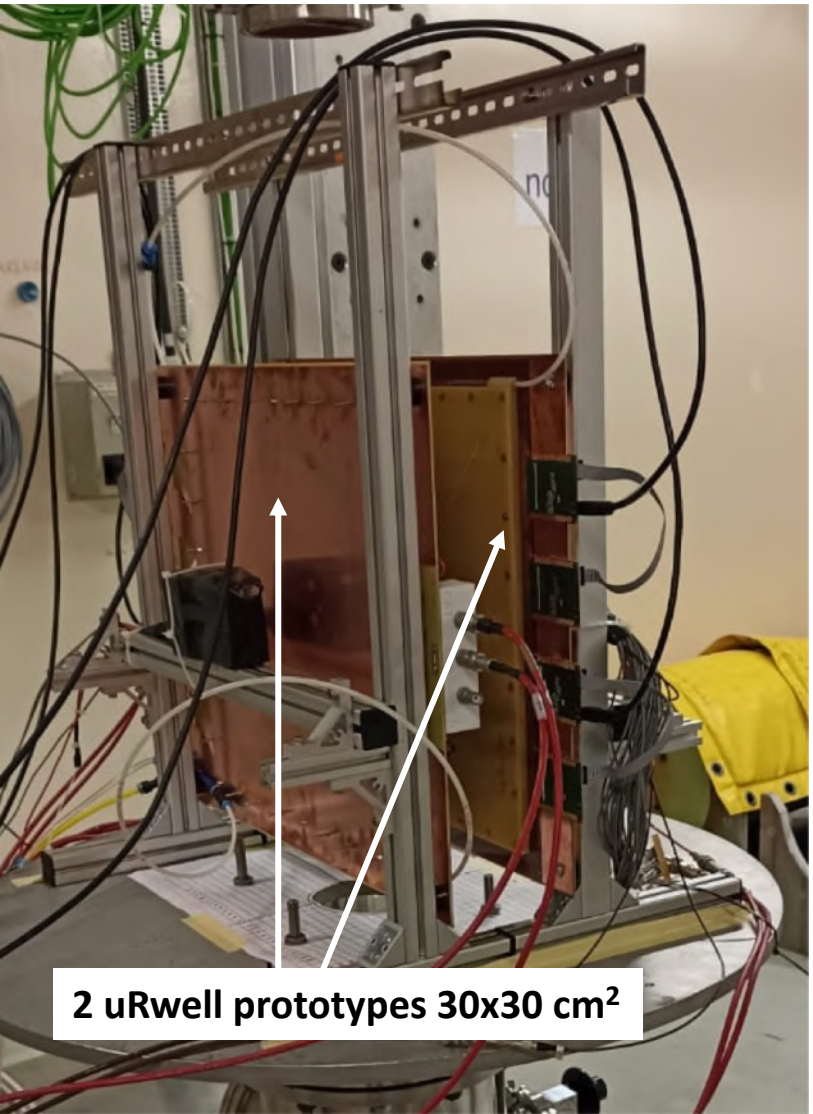
μRwell: Test at EAR2 (06/2022)



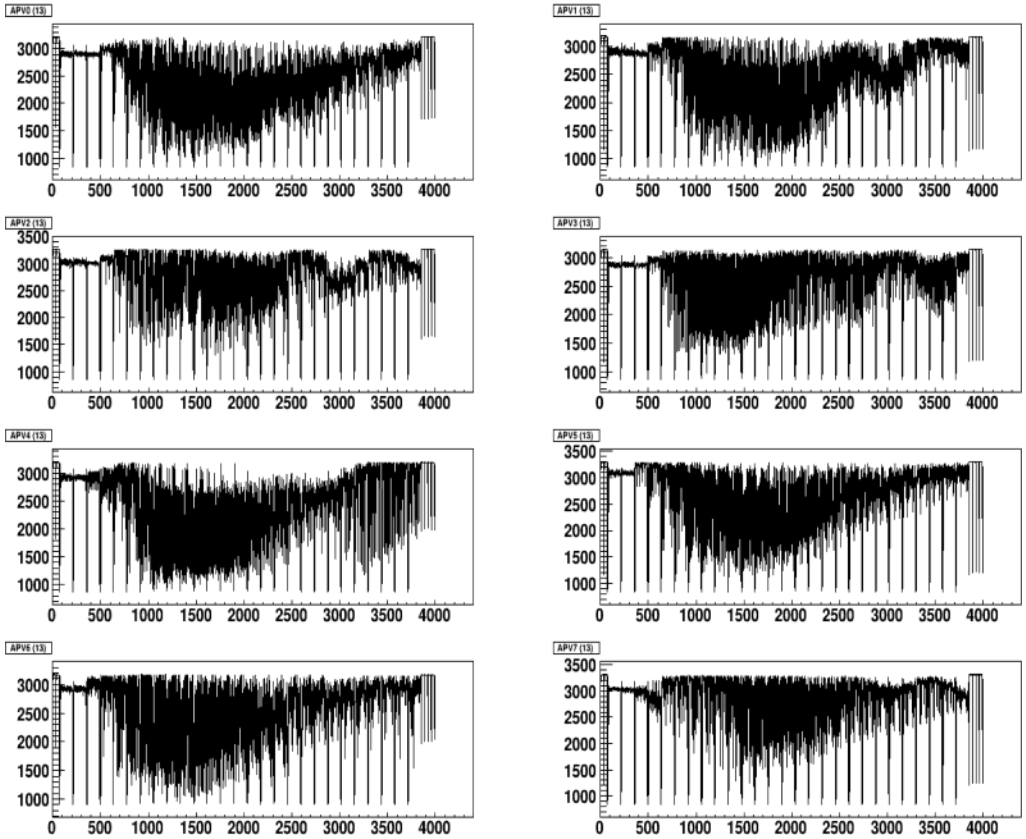
- Each uRwell has 512 strips (horizontal) readout by 4 Front-end cards (APV25)
- The APV25 stores the charges of 128 strip every 25 ns (one time sample)



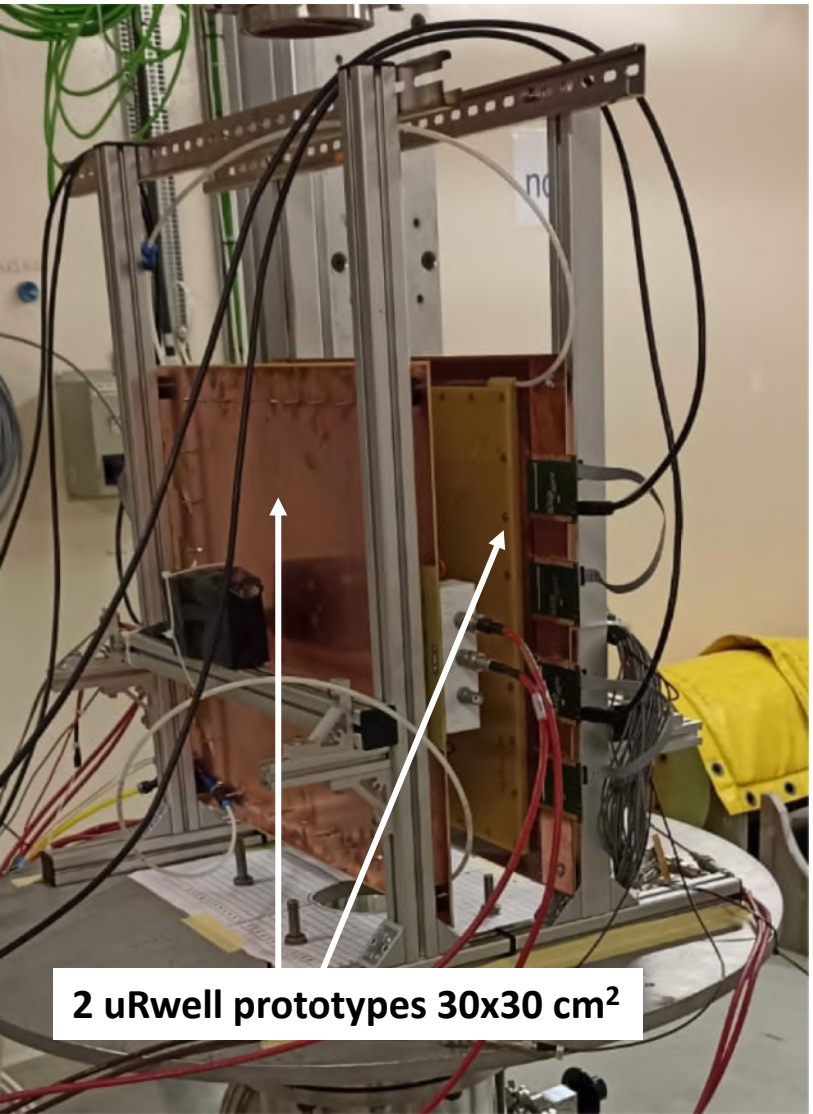
μRwell: Test at EAR2 (06/2022)



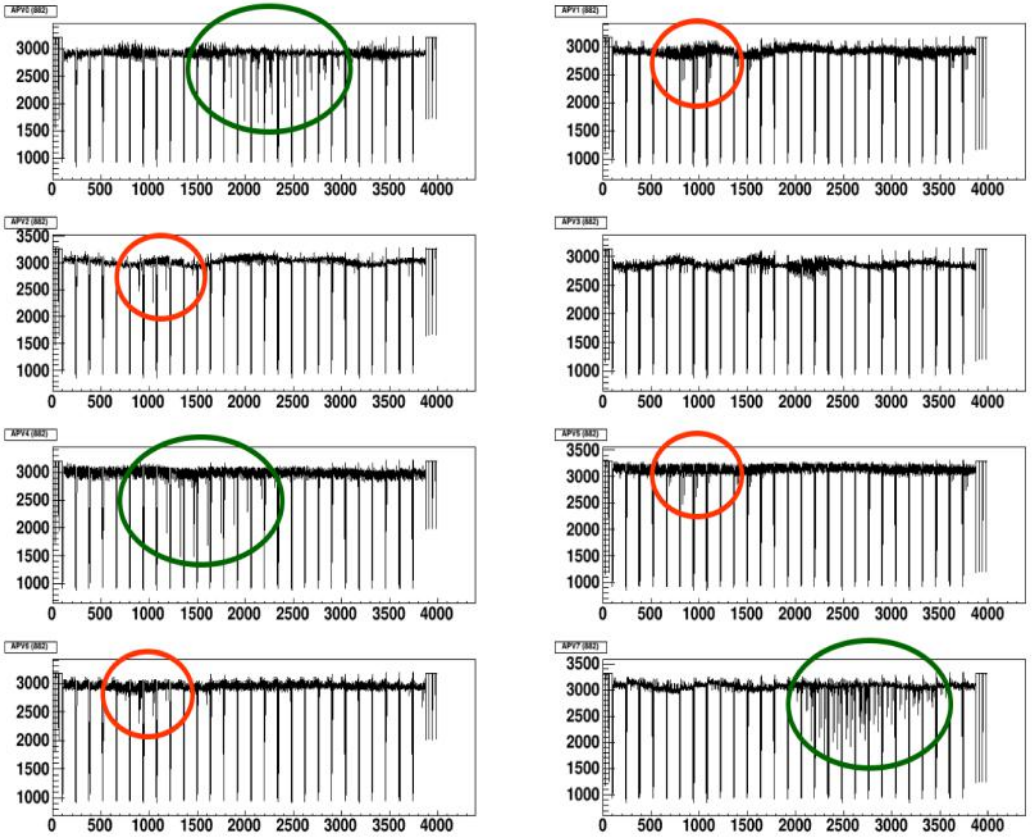
Signals in μRwell at gamma flash



μRwell: Test at EAR2 (06/2022)

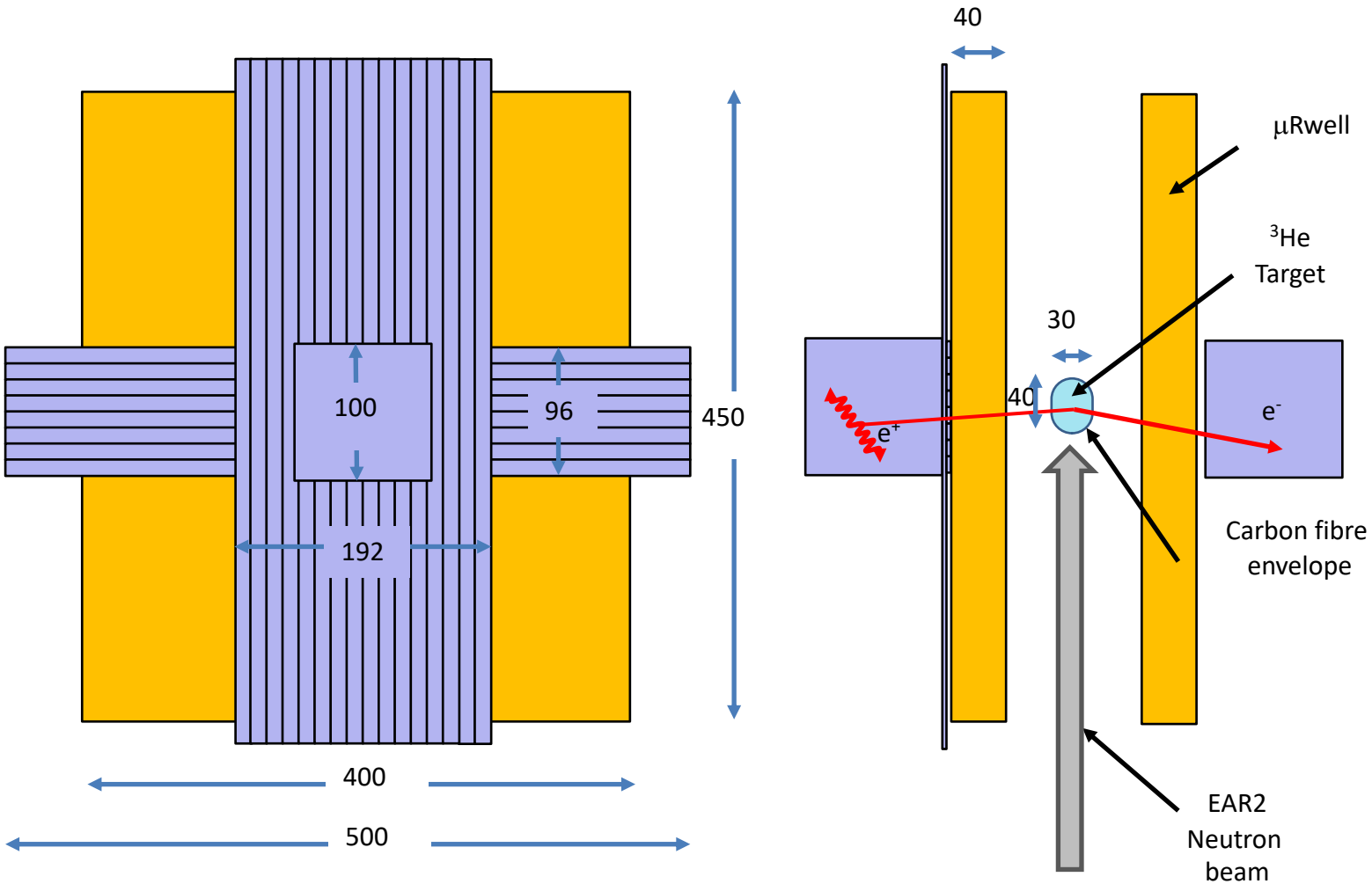


Signals in μRwell at gamma flash + 1.7 μs



Next: Demonstrator

Already funded by CSN3 (detectors+elecronics)
Test at LNL with the $^{19}F(p,\alpha\ e^+e^-)^{16}O$ reaction
Test at ISS with Cosmic rays (tracking, basic performance)
Test/final validation at EAR2 (using a ^3He target prototype)



Tentative 2023 activity schedule

-Fast test a EAR2 of scintillators coupled with active PMTs (<april 2023)

-Construction of the prototype funded by INFN (<may 2023)

-Detailed simulation using nTOF beam, setup geometry, ab-initio prediction (<june 2023)

-Tracking and energy resolution of the prototype with Cosmic rays (Throughtout 2023)

-Detection of e^+e^- pairs at LNL, exploiting the $p+^{19}F \rightarrow ^{16}O^*+\alpha + e^+e^-$ (proposal submitted to the LNL PAC)

-^{3}He target construction throughtout 2023 (MASTINU/CERN)

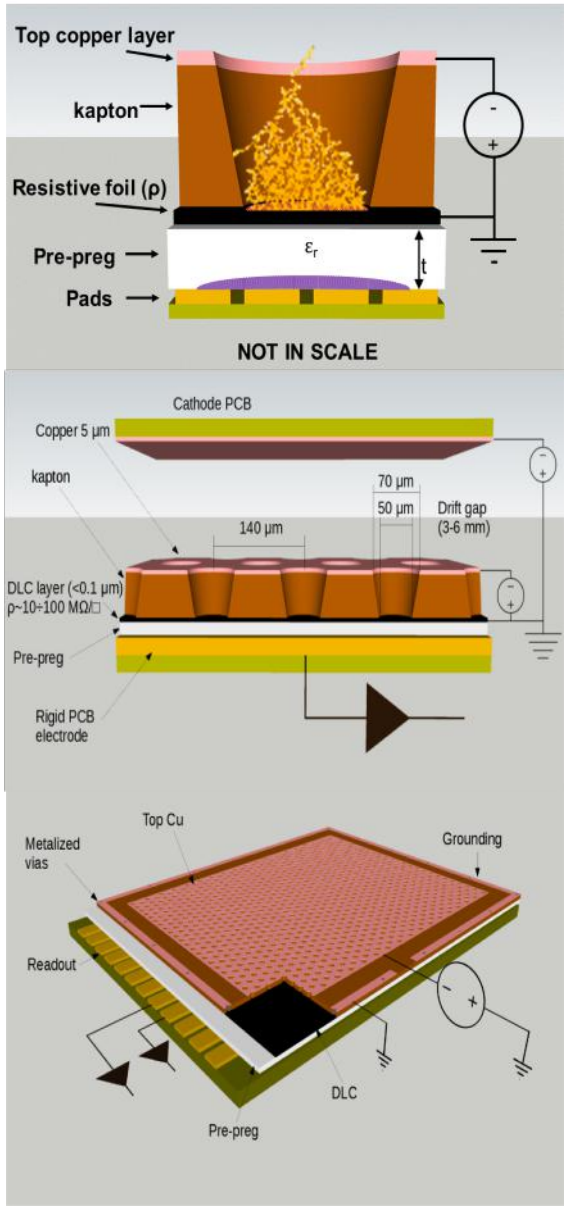
-Final test at EAR2 with ^{3}He target (<december 2023)

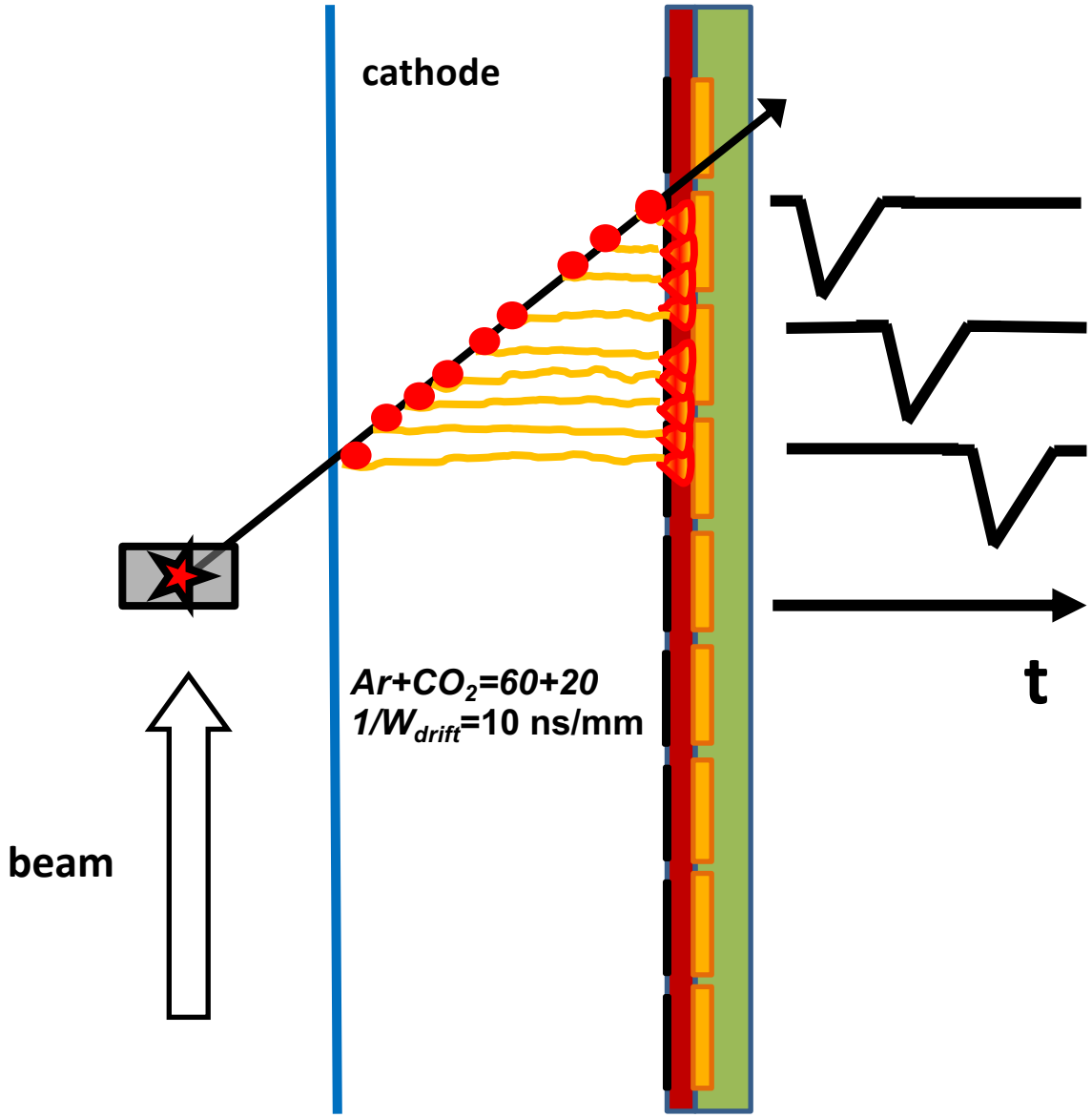
-Construction of the full detector (<june 2024)

-LONG RUN (2024)

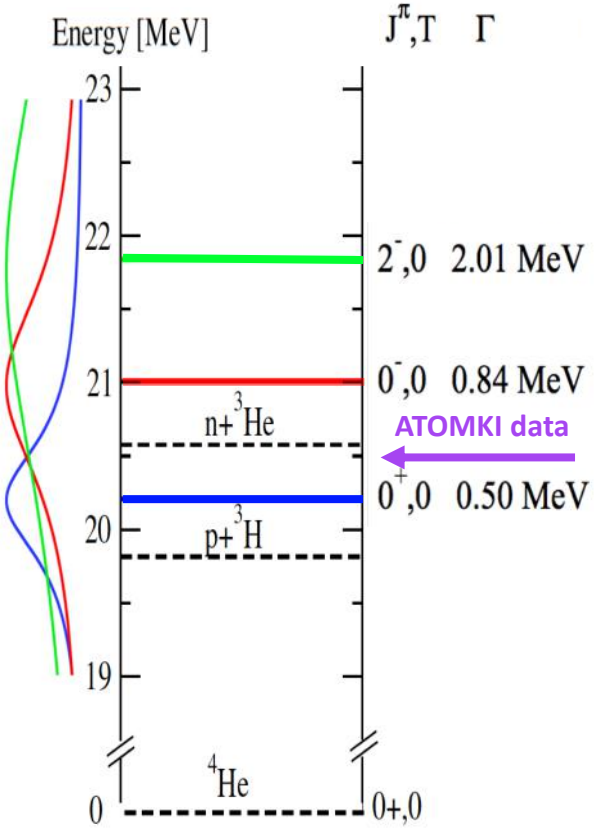
SPARES

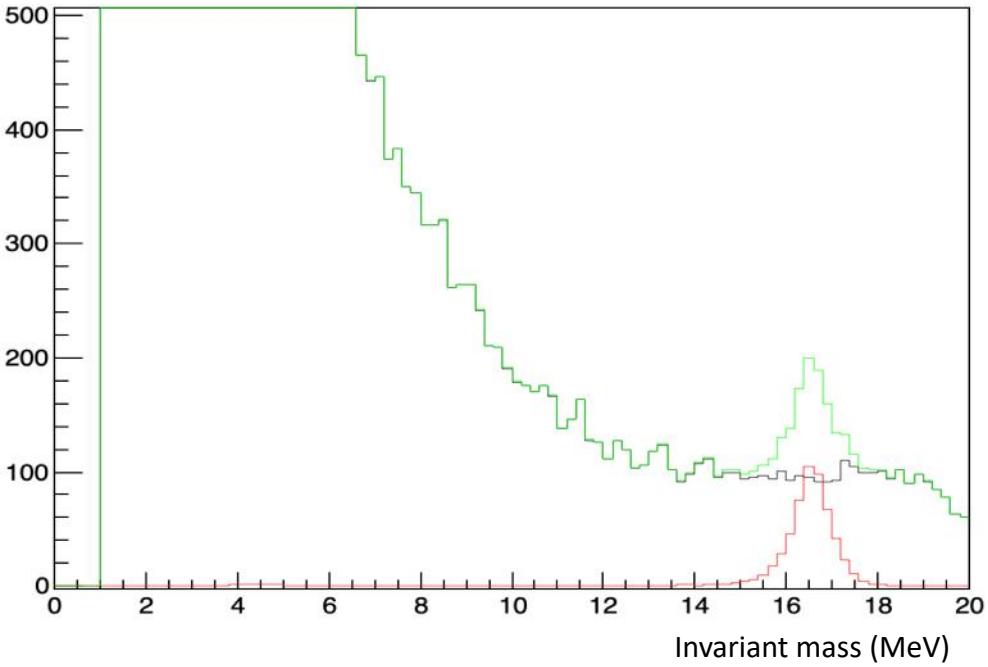
μTPC

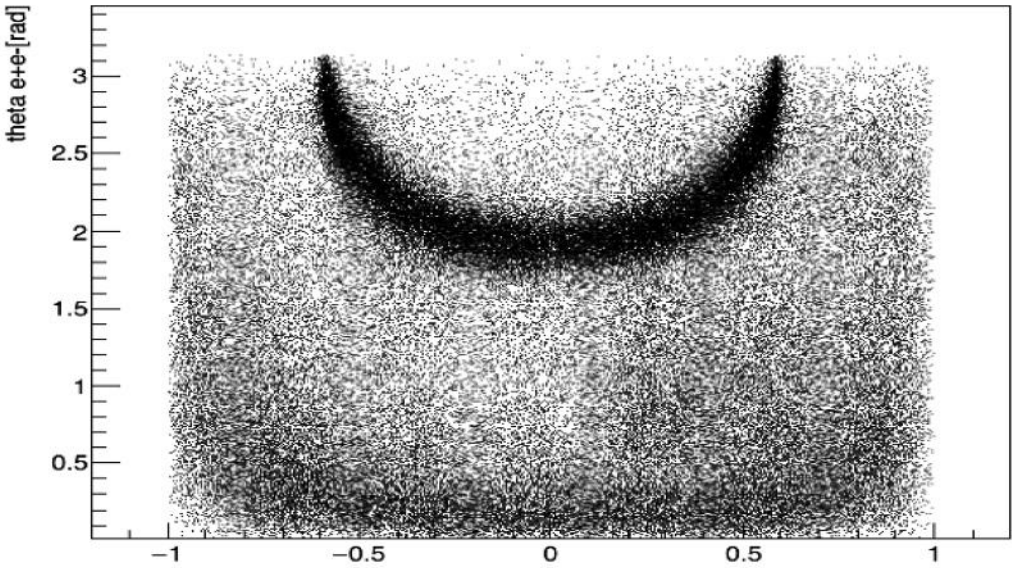

Top copper layer
kapton
Resistive foil (ρ)
Pre-preg
Pads
ε_r
t
NOT IN SCALE
Cathode PCB
Copper 5 μm
kapton
70 μm
50 μm
Drift gap
(3-6 mm)
140 μm
DLC layer (<0.1 μm)
ρ~10÷100 MΩ/□
Pre-preg
Rigid PCB
electrode
Top Cu
Metalized
vias
Grounding
Readout
DLC
Pre-preg


cathode
beam
$Ar+CO_2=60+20$
$1/W_{drift}$=10 ns/mm
t

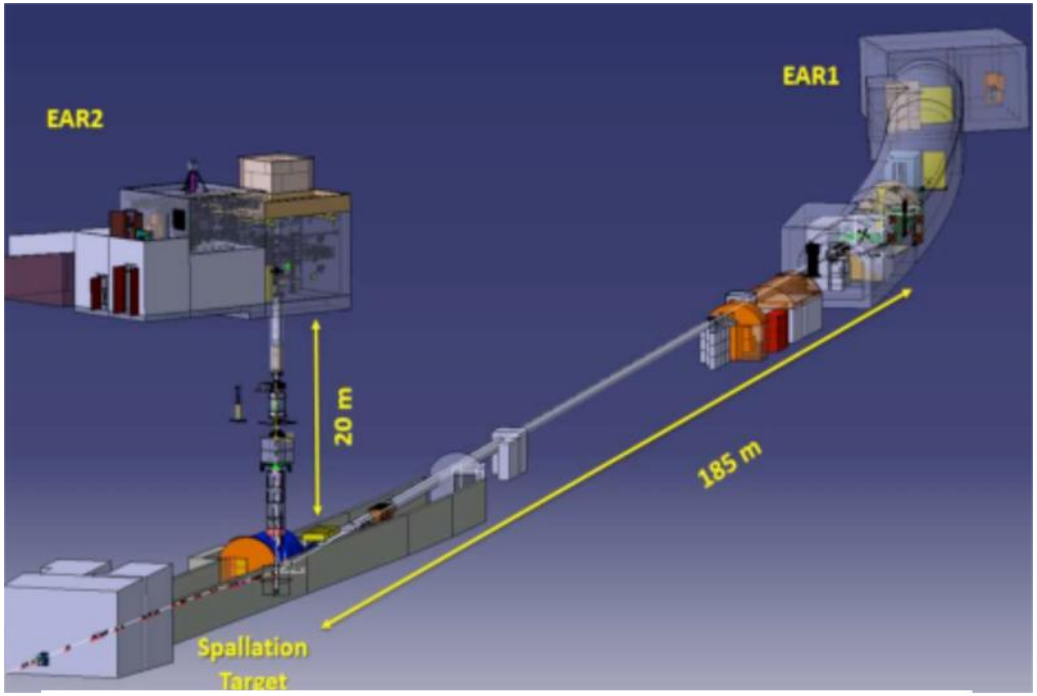
X17 @ nToF


Energy [MeV]
J^{π},T Γ
23
22
21
20
19
0
^{4}He
0+,0
n+^{3}He
p+^{3}H
2$^-$,0 2.01 MeV
0$^-$,0 0.84 MeV
0$^+$,0 0.50 MeV
ATOMKI data

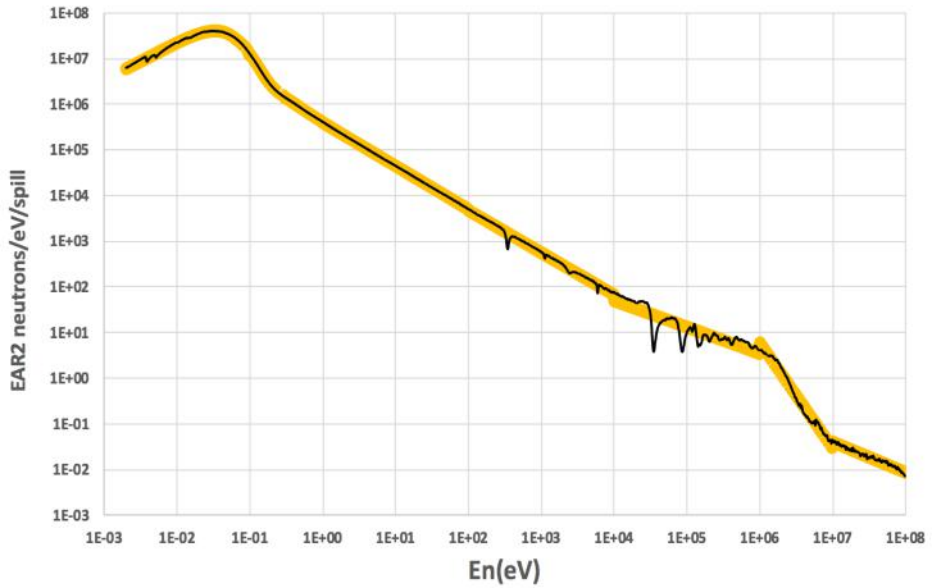

500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20
Invariant mass (MeV)


theta e+e-[rad]
3
2.5
2
1.5
1
0.5
−1
−0.5
0
0.5
1
$(E_{e^-} - E_{e^+})/(E_{e^-} + E_{e^+})$

n_TOF @ CERN



Pulsed neutron beam in a wide energy range. Time of flight to establish the energy of each interacting neutron energy
→ ^{3}He(n,e^{+}e^{-})^{4}He; ^{2}H(n,e^{+}e^{-})^{3}H; H(n,e^{+}e^{-})^{2}H; ^{7}Be(n, e^{+}e^{-})^{8}B...

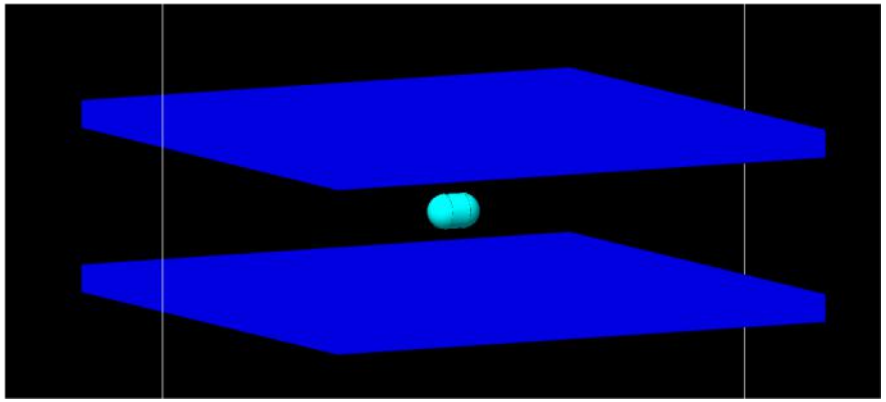


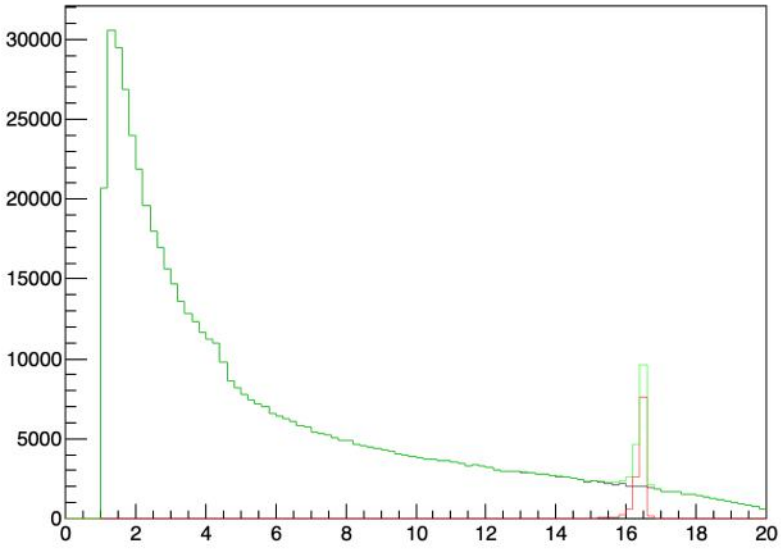
Neutron energy	Neutrons
$1 - 10$ eV	0.9×10^6
$10 - 100$ eV	1.1×10^6
$0.1 - 1$ keV	1.2×10^6
$1 - 10$ keV	1.4×10^6
$10 - 100$ keV	1.9×10^6
$0.1 - 1$ MeV	5.8×10^6
$1 - 10$ MeV	4.5×10^6
$10 - 100$ MeV	1.4×10^6

Neutrons per pulse

ACCEPTANCE:
|Theta_x,y|<76 degrees
(2 planes 40x40 cm2, each at a distance of 5 cm from the beam axis)

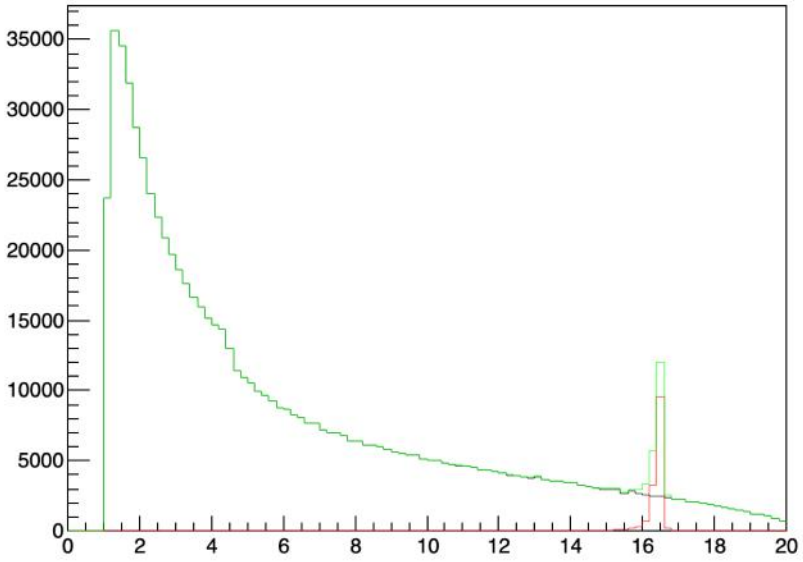
- #coppie rivelate
- IPC: 59%
- X17: 47%

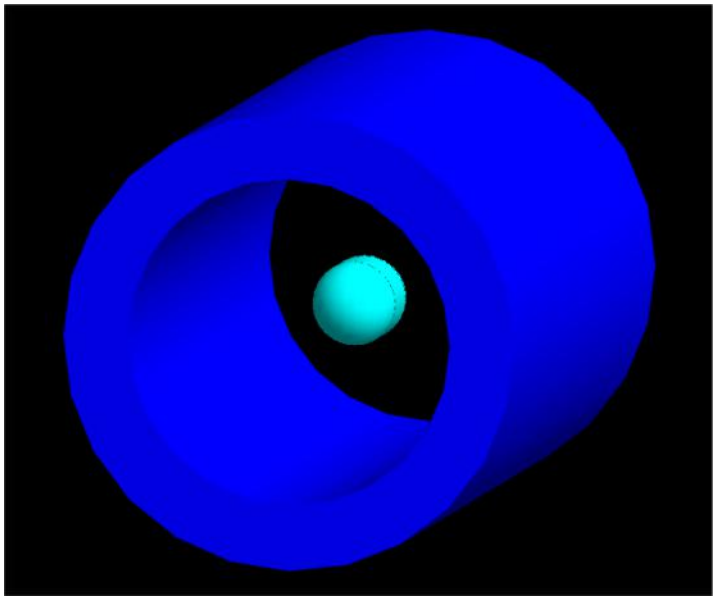




|Theta_x|<63.4 degrees -> (cylinder 20 cm long with a radius of 5 cm)

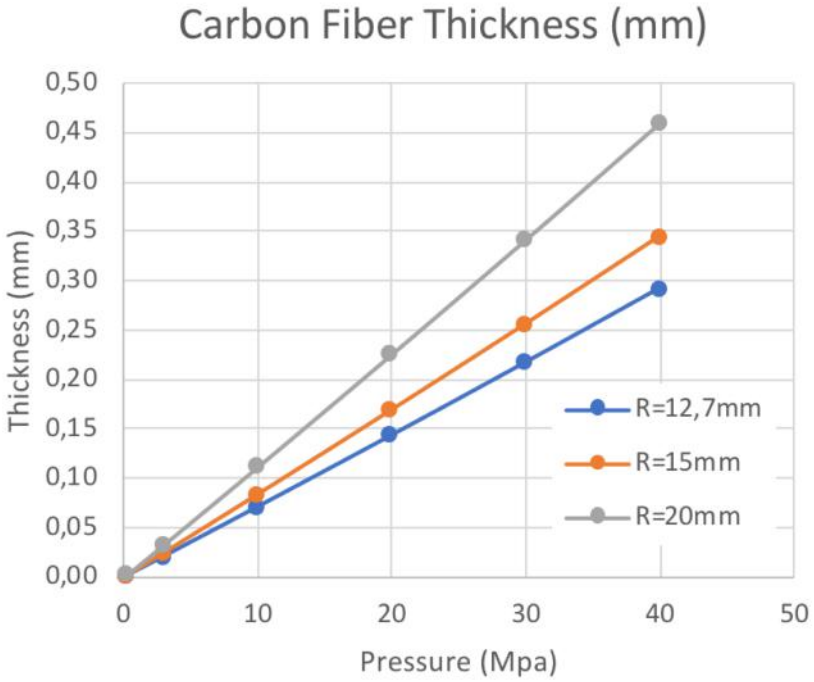
- #coppie rivelate
- IPC: 75%
- X17: 58%





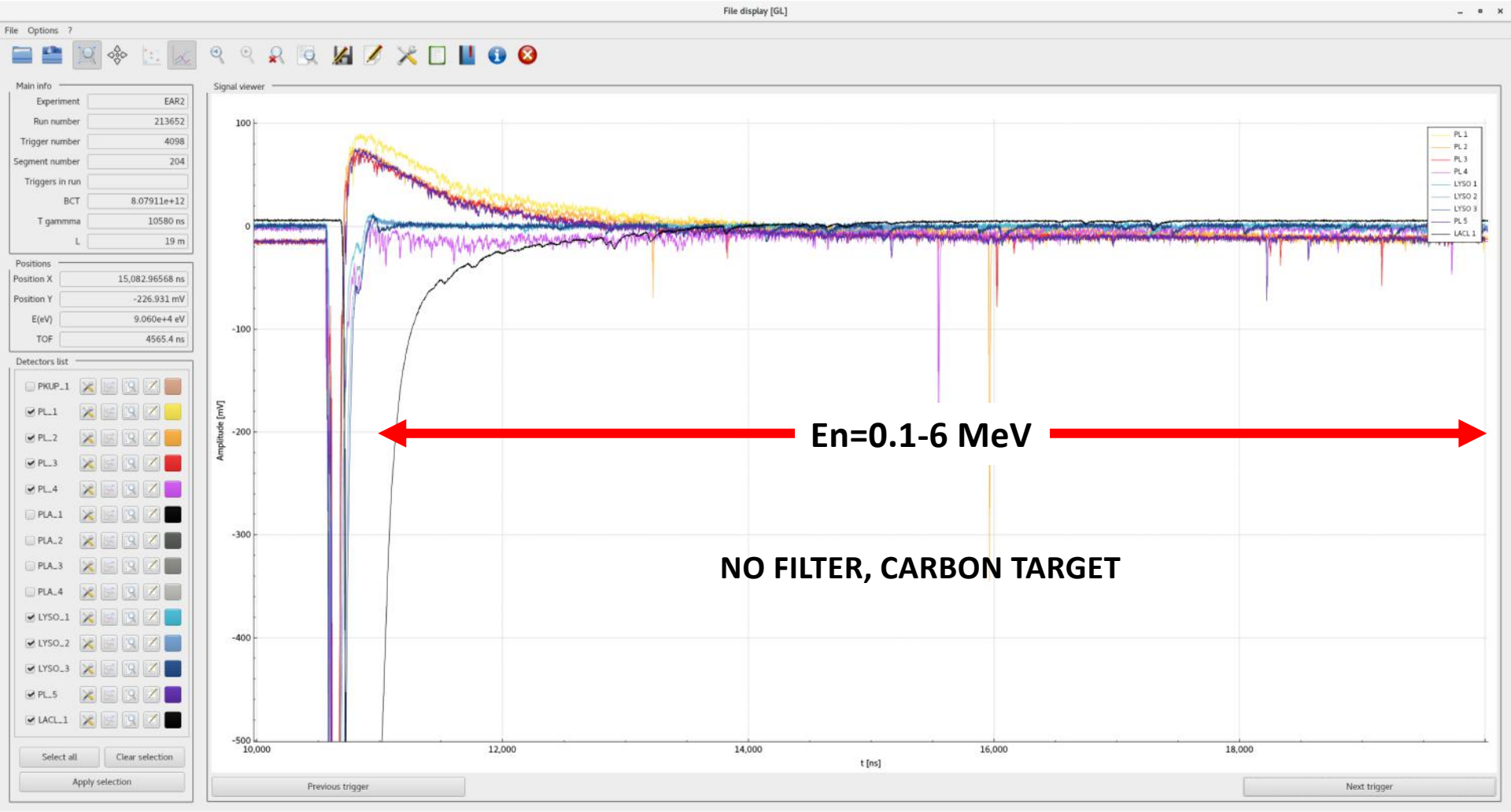
Target

0.6 mm thick envelope of Carbon Fibre will be tested to operate with ^{3}He at 380 bar, 300 K. This pressure corresponds to 59 g/L (density of liquid ^{3}He)



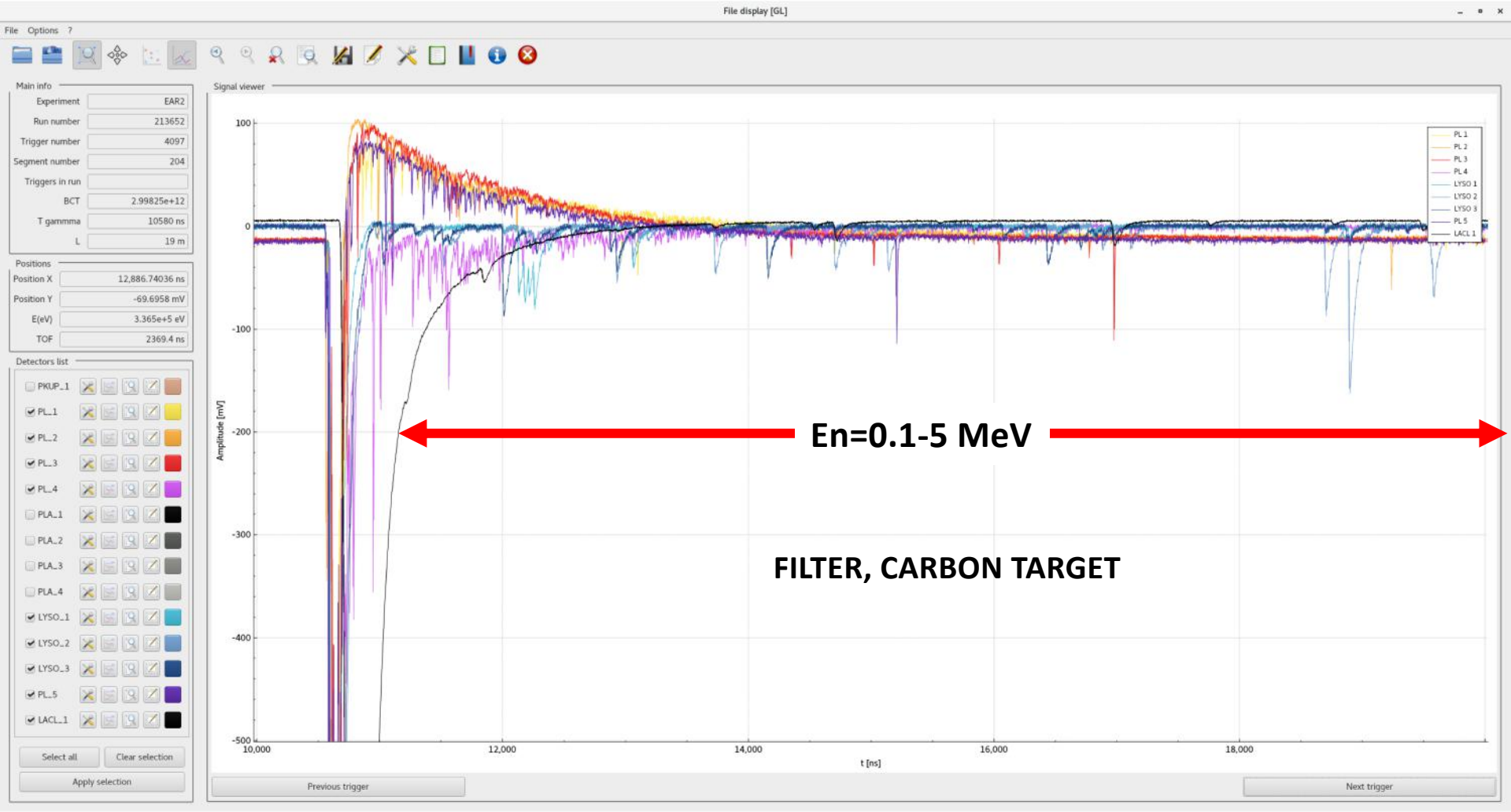
courtesy P. Mastinu

LYSO, EJ-200, $BrCL_3$



Faint signals due to huge Gamma Flash

LYSO, EJ-200, $BrCL_3$



Ej-200

1 planes of 25x10x2 cm3, composed by
5 bars 25x2x2 cm3x4,8x0,3 cm
5 channels