Searching for X17 anomaly at nTOF experiment

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- C. Massimi (UNIBOLOGNA)
- N. Colonna (INFN BARI)
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- A. Mazzone (CNR BARI)
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nTOF

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Theoretical group

- E. Cisbani (ISS)
- F. Renga (INFN ROMA)

Detector R&D

Working group (in evolution)

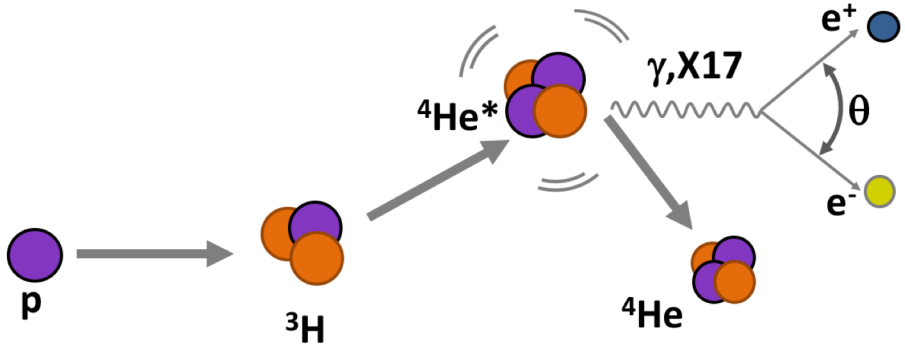
X17 ATOMKI RESULTS IN A NUTSHELL

-A significant excess of electron-positron pairs at large relative angle has been recently observed in the $^{7}Li(p,e^{+}e^{-})^{8}Be$ and $^{3}H(p,e^{+}e^{-})^{4}He$ reactions.

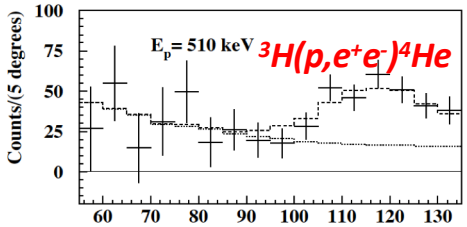
-This anomaly has been interpreted as the signature of a 17 MeV BOSON, not foreseen in the standard model of particle physics.

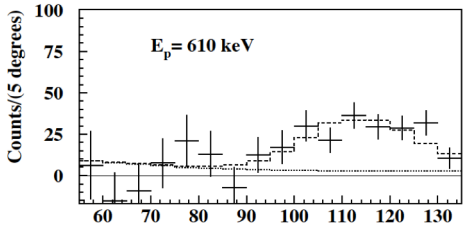
-The so called X17 boson could be a mediator of a fifth force, characterized by a strong coupling suppression of protons compared to neutrons.

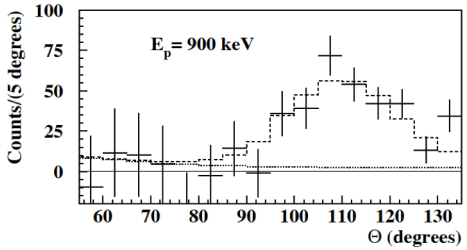
-This evidence/scenario is presently not confirmed or excluded by other experiments or groups.

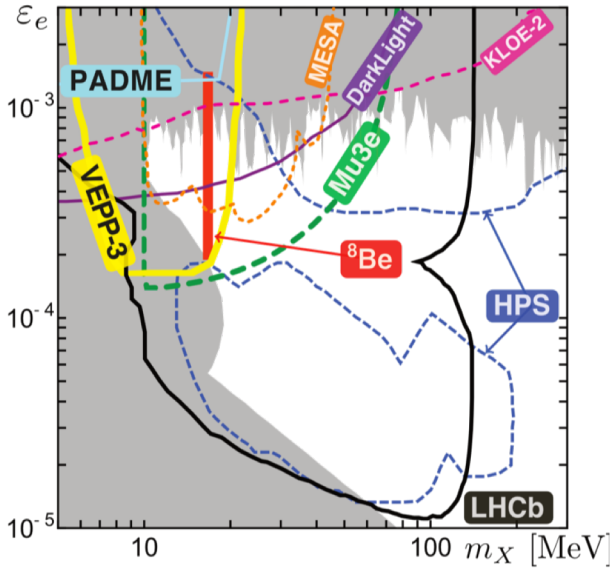


Reaction	$M_{X17}\pm\Delta M_{stat}\pm\Delta M_{syst}$ (MeV)	evidence
$^{7}Li(p,e^{+}e^{-})^{8}Be$	16.70±0.35±0,50	>5 sigma
$^{3}H(p,e^{+}e^{-})^{4}He$	16.94±0.12±0.21	>9 sigma









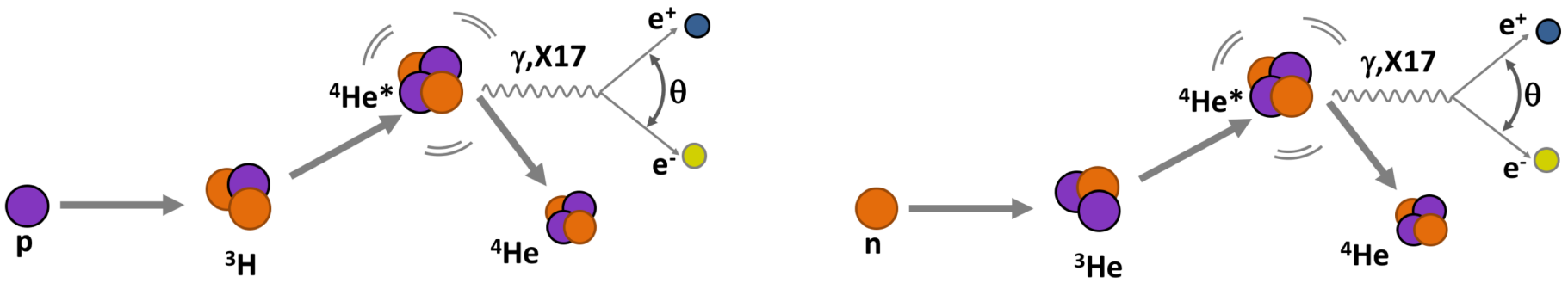
Krasznahorkay, A.J.; et al.:
"*Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson*".
Physical Review Letters. **116** (42501): 042501 (2016).

Krasznahorkay, A.J.; et al.:
"New anomaly observed in ^{4}He supports the existence of the hypothetical X17 particle".
Physical Review C. **104**, 044003 (2021)

X17 @ nToF

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

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

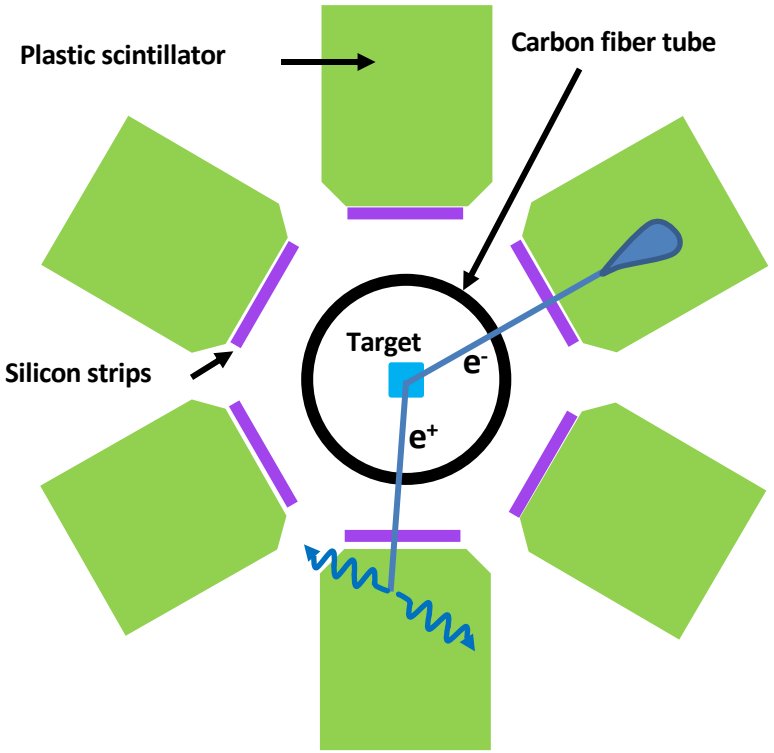


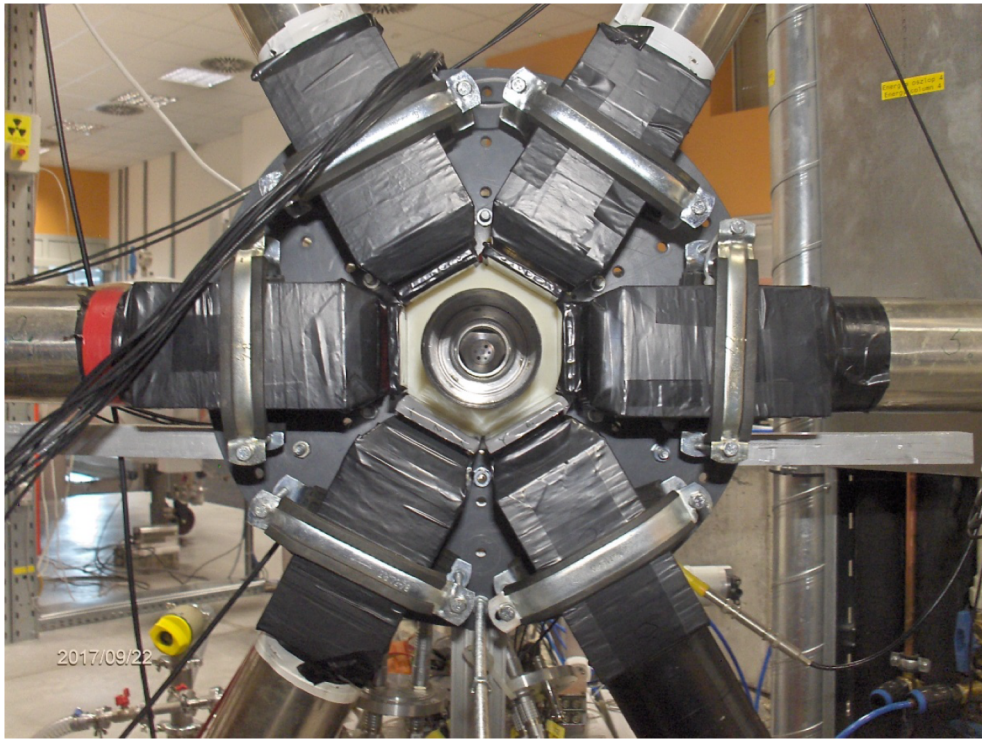
Physics:

- Probing X17 existence
- X17 Mass, quantic numbers, coupling, life time,..
- First measurement of σ(E) ^{3}He(n,e$^+$e$^-$)^{4}He
- Data Vs Theoretical nuclear physics

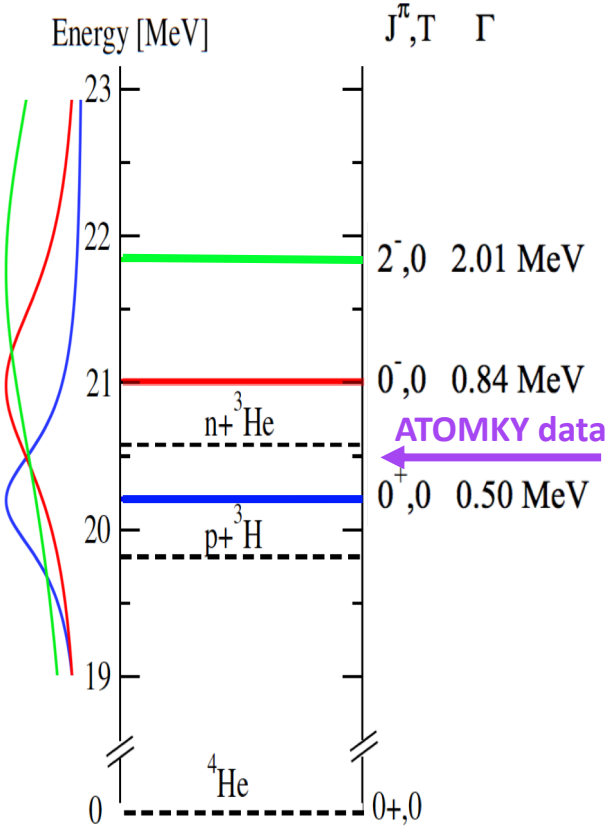
$^3H(p,e^+e^-)^4He$ setup @ ATOMKI

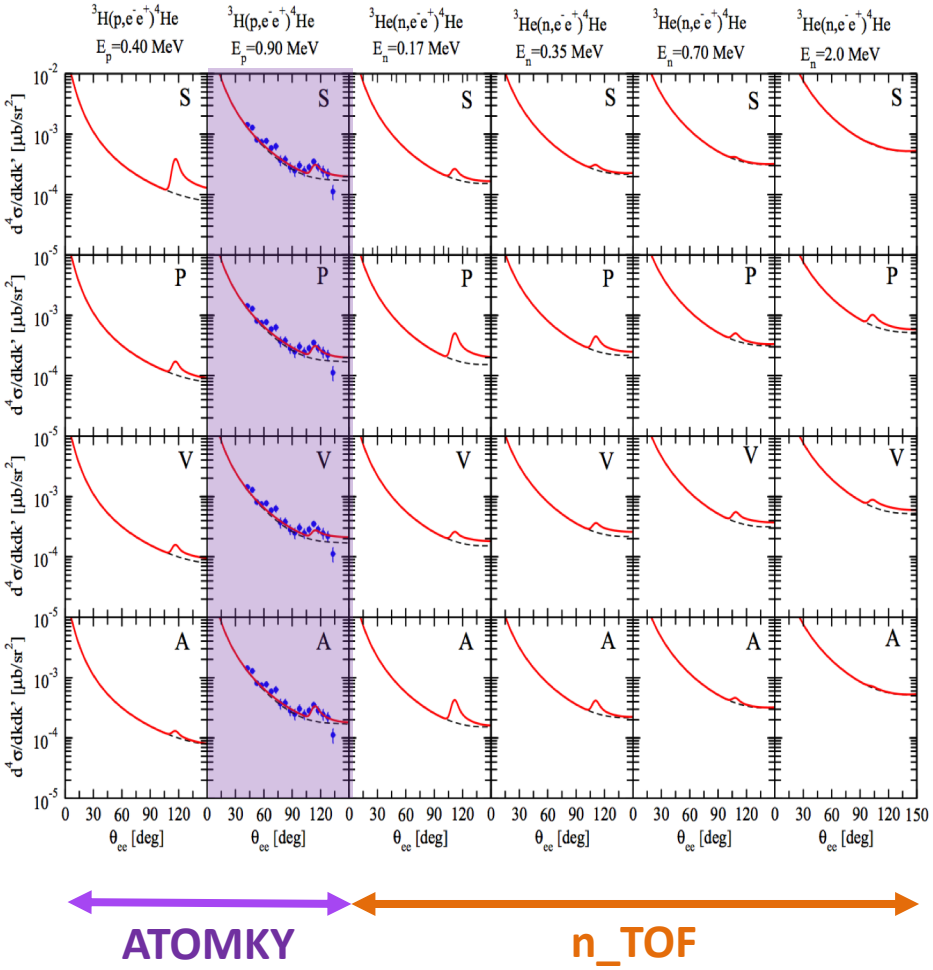
- ^3H adsorbed on Ti layer
- 6 plastic scintillator 82x86x80 mm^3
- 6 double-sided silicon strip detector (3 mm wide strips, 0.5 mm thick)
- 1 mm thick carbon fiber tube
- Detector acceptance only around 90° with respect to the beam axis
- no tracking





X17 @ nToF

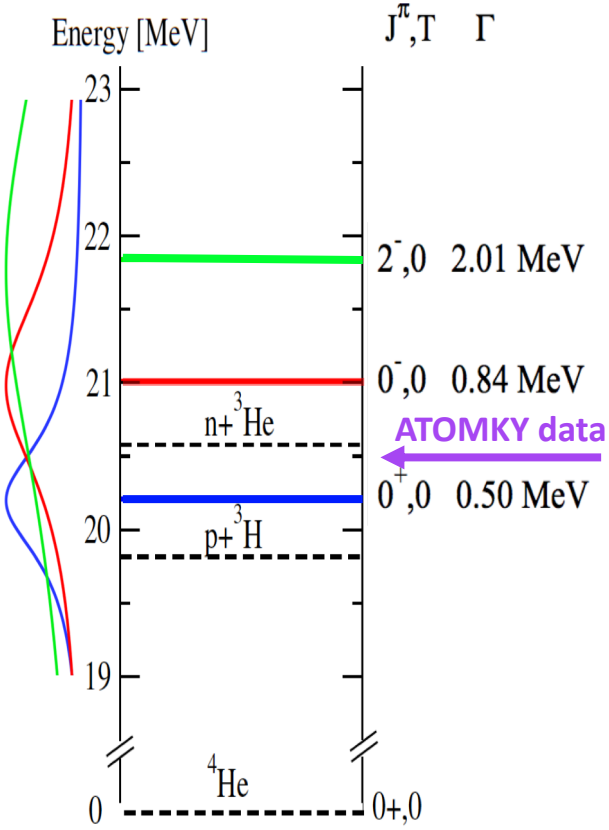


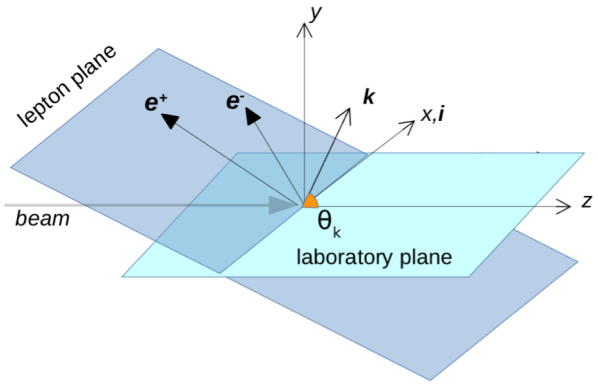


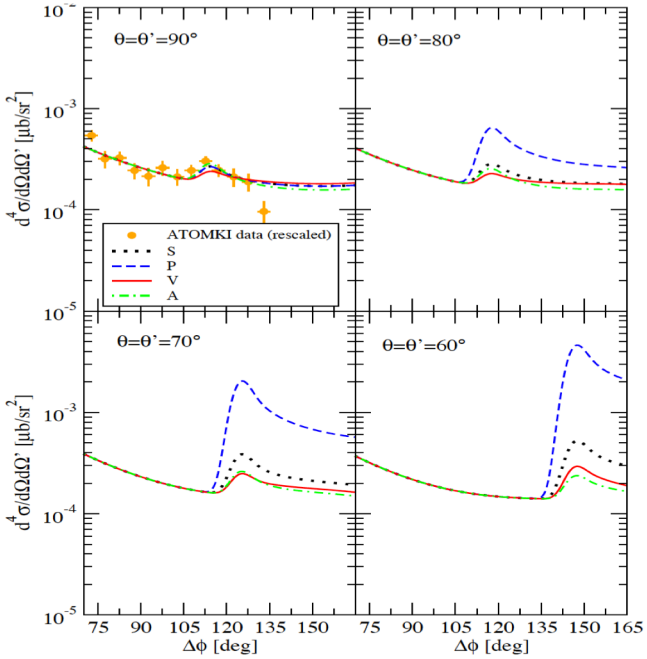
❖ **Wide energy range (proton and neutron beams) to explore all resonances with different J^{π}**

courtesy M. Viviani

X17 @ nToF







❖ **Wide energy range (proton and neutron beams) to explore all resonances with different J^{π}**

❖ **Large detector acceptance (statistics and kinematics)**

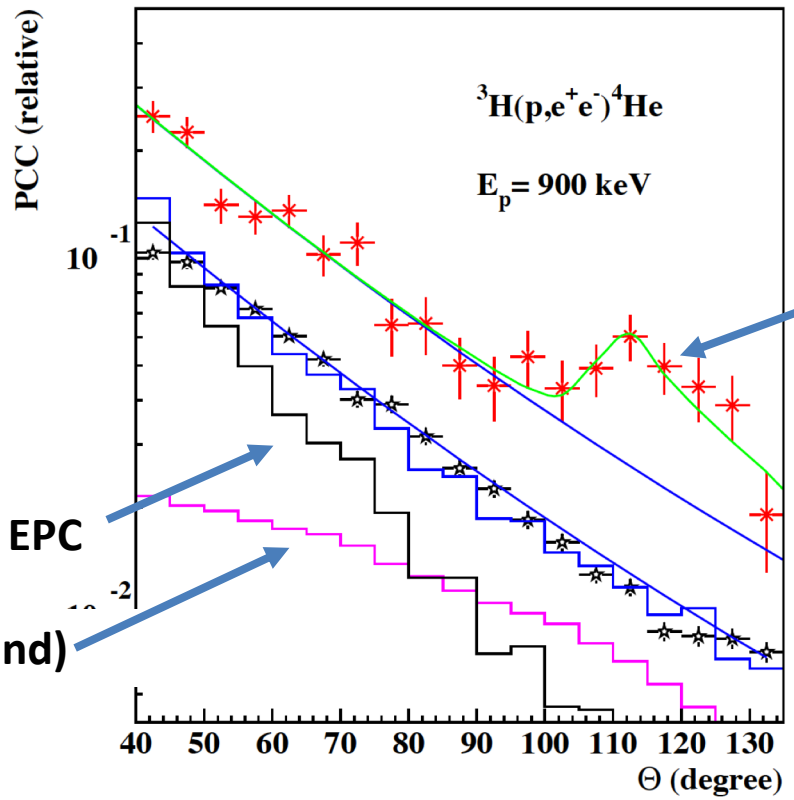
M. Viviani et al.:

"X17 boson and the 3H(p, e+e−) 4He and 3He(n, e+e−) 4He processes: A theoretical analysis"
PHYSICAL REVIEW C **105**, 014001 (2022)

courtesy M. Viviani

Backgrounds

- Internal Pair Convertion (IPC) through the ^{3}He(n,e+e-)^{4}He process (virtual gammas convert into e+e- pairs). Most of the pairs can be cut off because of their small relative angle.
- External Pair Convertion (EPC), i.e. ^{3}He (n,γ)^{4}He gammas converted into e+e- pairs in the material sorrounding the target. Also in this case, small relative angle between e+e- pairs.
- Gammas from ^{3}He (n,γ)^{4}He.
- protons from (n,p) reactions.
- neutrons interacting with setup.
-
-



Picture from *PRL* **116** (42501): 042501 (2016)

X17→e+e-

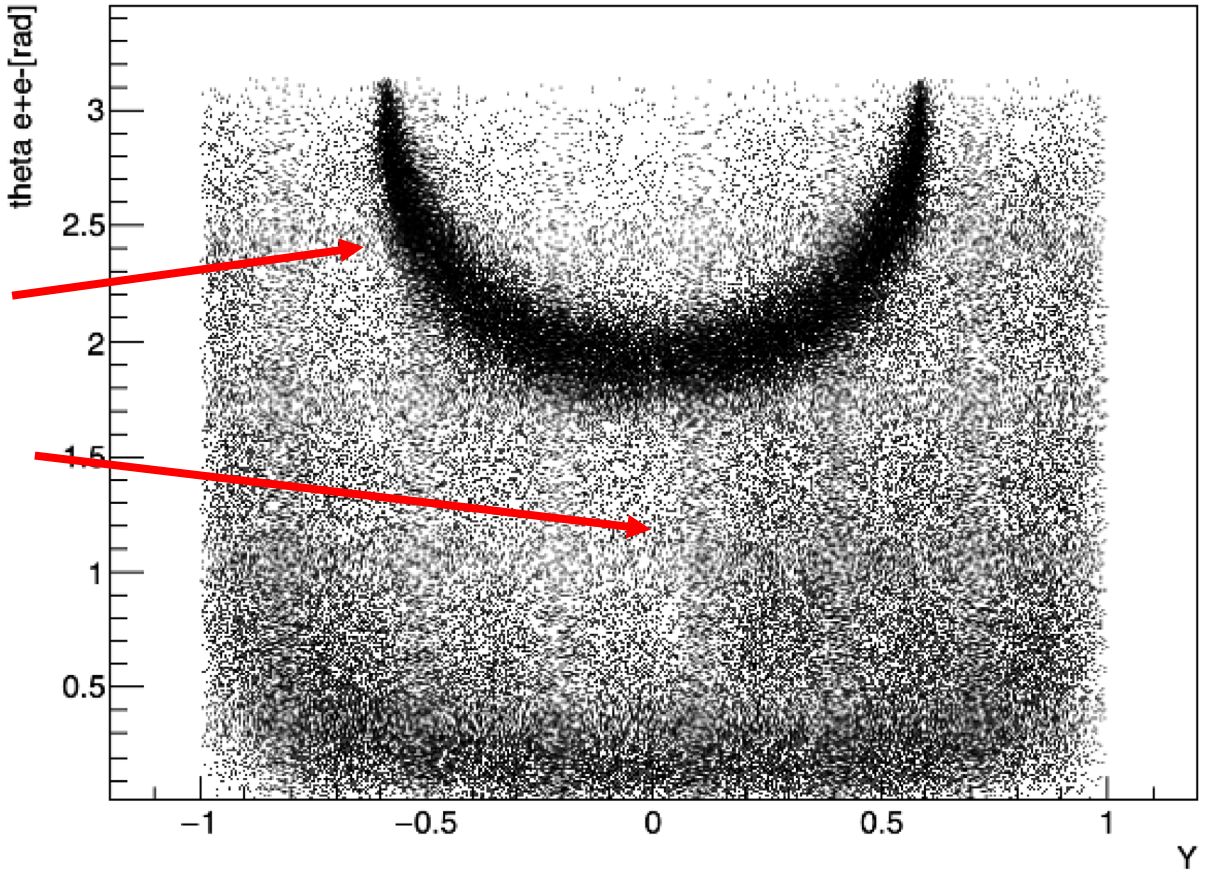
EPC

IPC (irreducible background)

X17 SIGNAL AND (irreducible) BACKGROUND

target: ^{3}He at P=30 bar, T= 300 k
thickness of Carbon fibre= 1 mm
Multiple scattering included
IPC background included
DATA From M. Viviani ab-initio calculations, normailzed to the ATOMKY results

$Y=(E_{e^-}—E_{e^+})/(E_{e^-}+E_{e^+})$
θ_{ee}= aperture angle of e+e- pairs

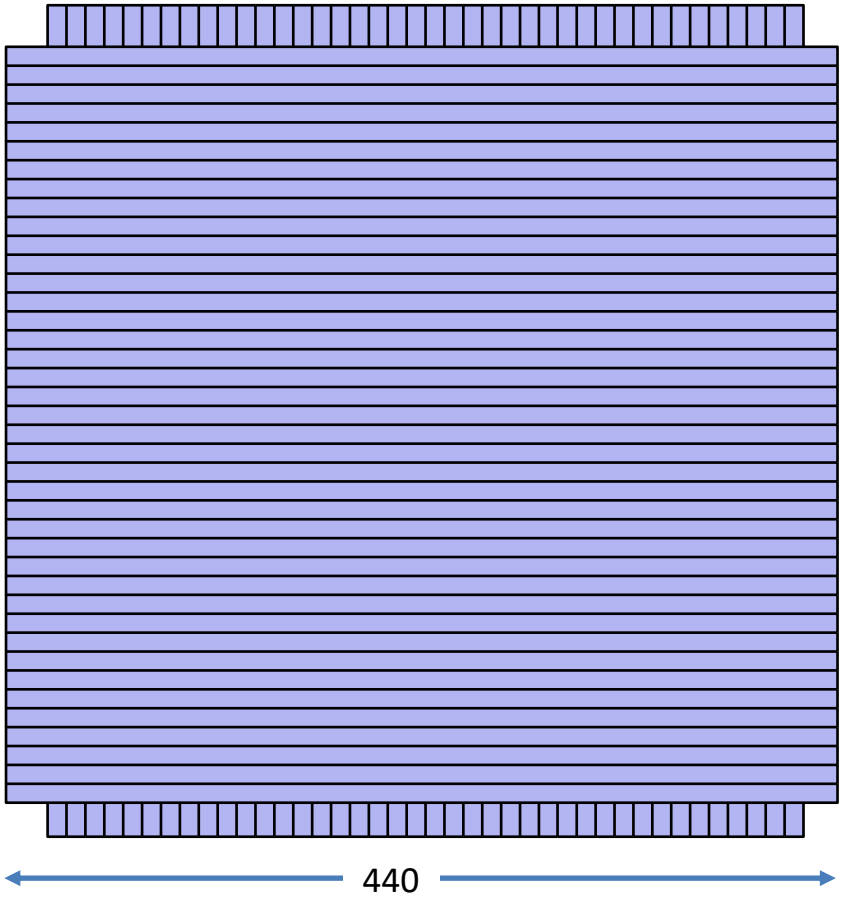


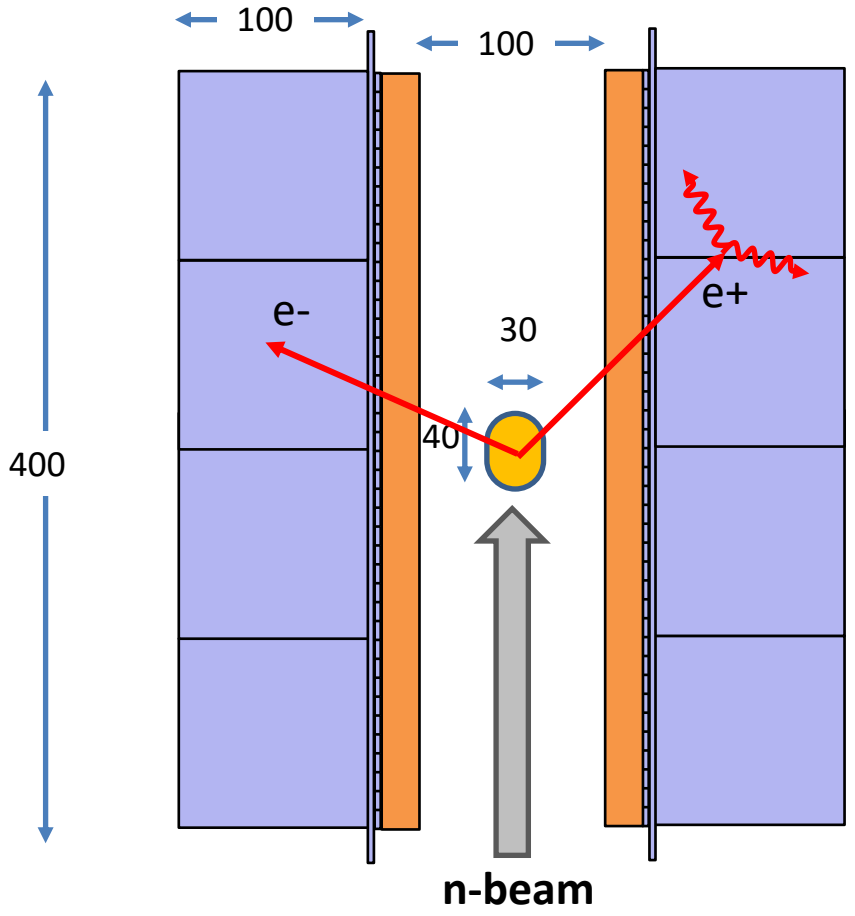
X17 Signal

IPC background

courtesy A. Mazzone

Detector Design

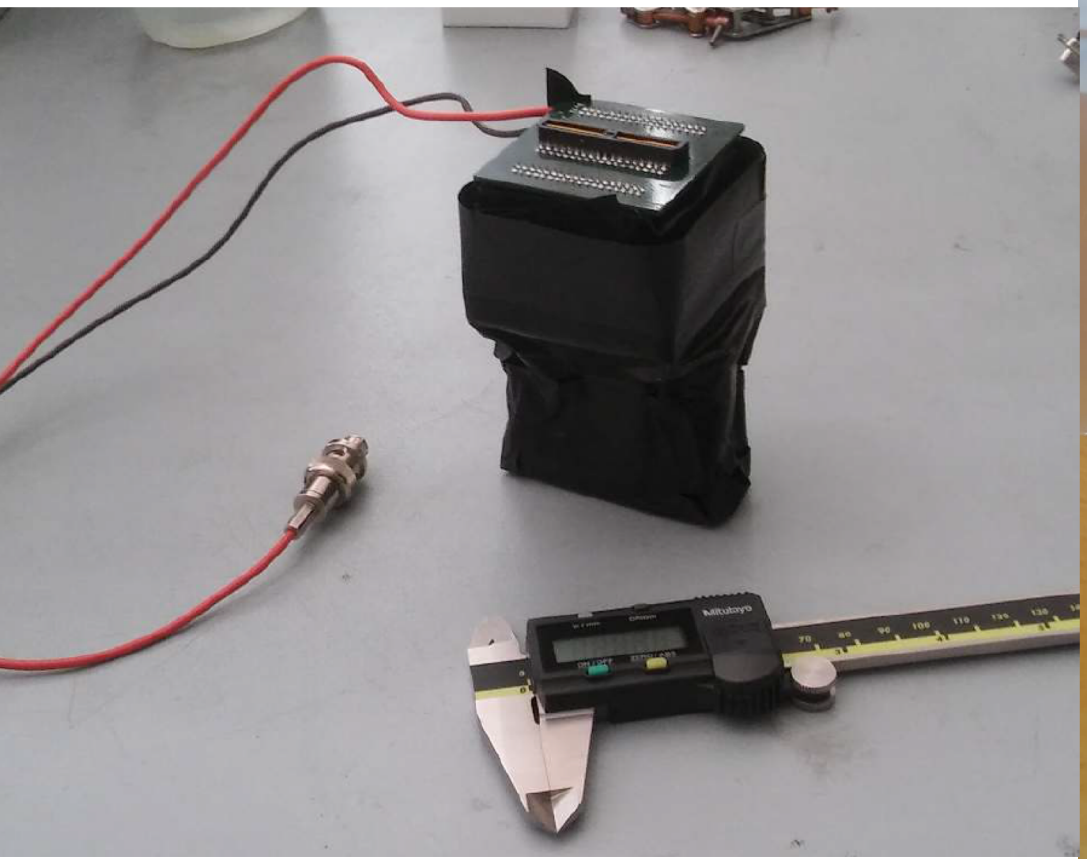




100 SiPM mod.S13363-3050-16=19k + IVA
32 PMT ALTA CORRENTE=32k + IVA
32 EJ200 "BULK" 10X10X10 CM3= 8k + IVA (LAVORAZIONE?)
160 STRIPS 0,3X1X40 cm^3= 0,125 k +IVA (10 k+IVA lavorazione)
320 ch (bacchette)+32 ch bulk =350 ch = 17,5 k +IVA
TOTALE: 86,5 k

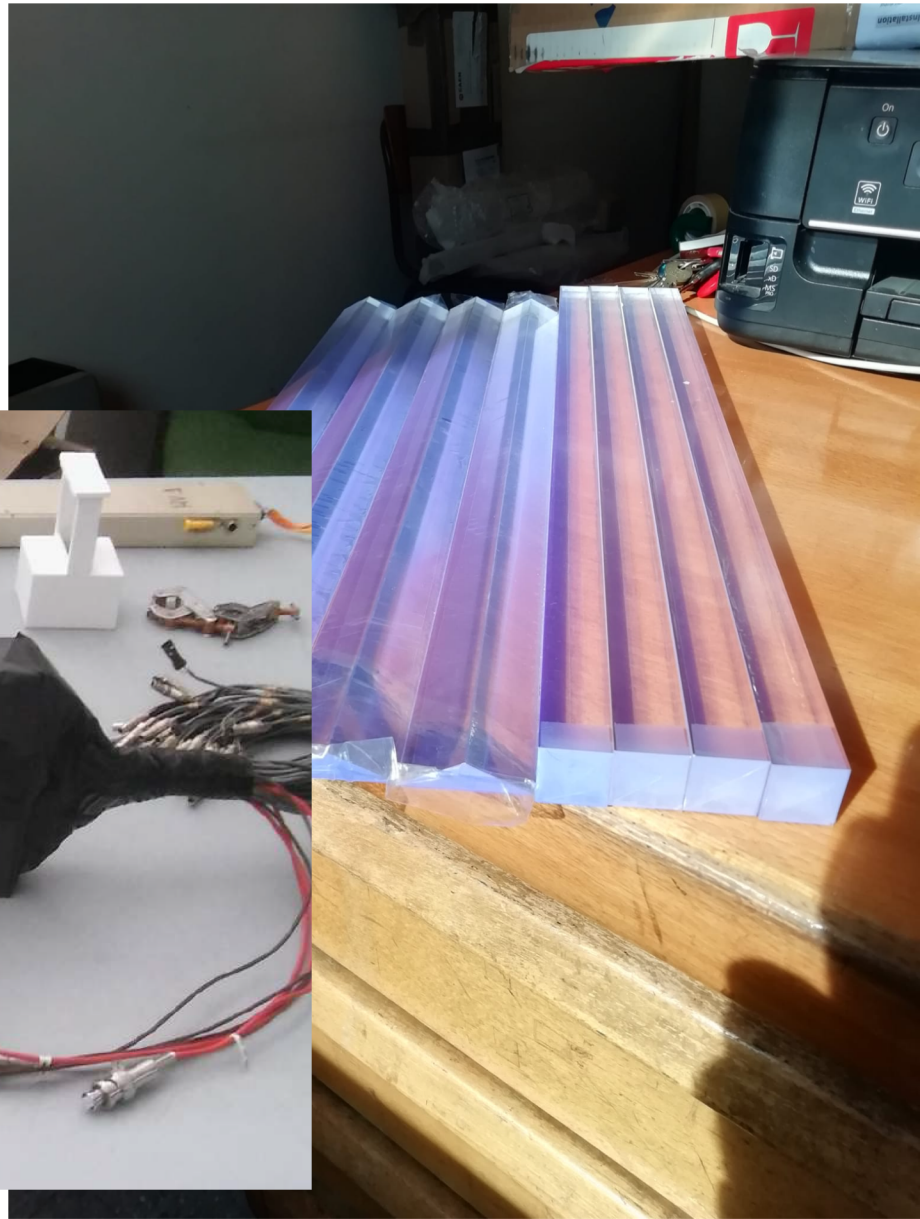
LYSO

3 planes 5x4,8x0,3 cm
3 channels



Ej-200

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

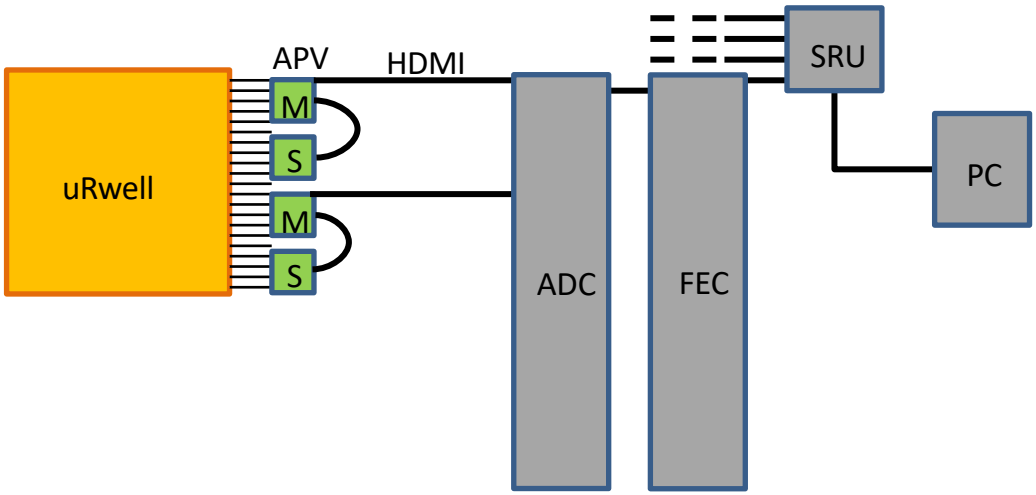


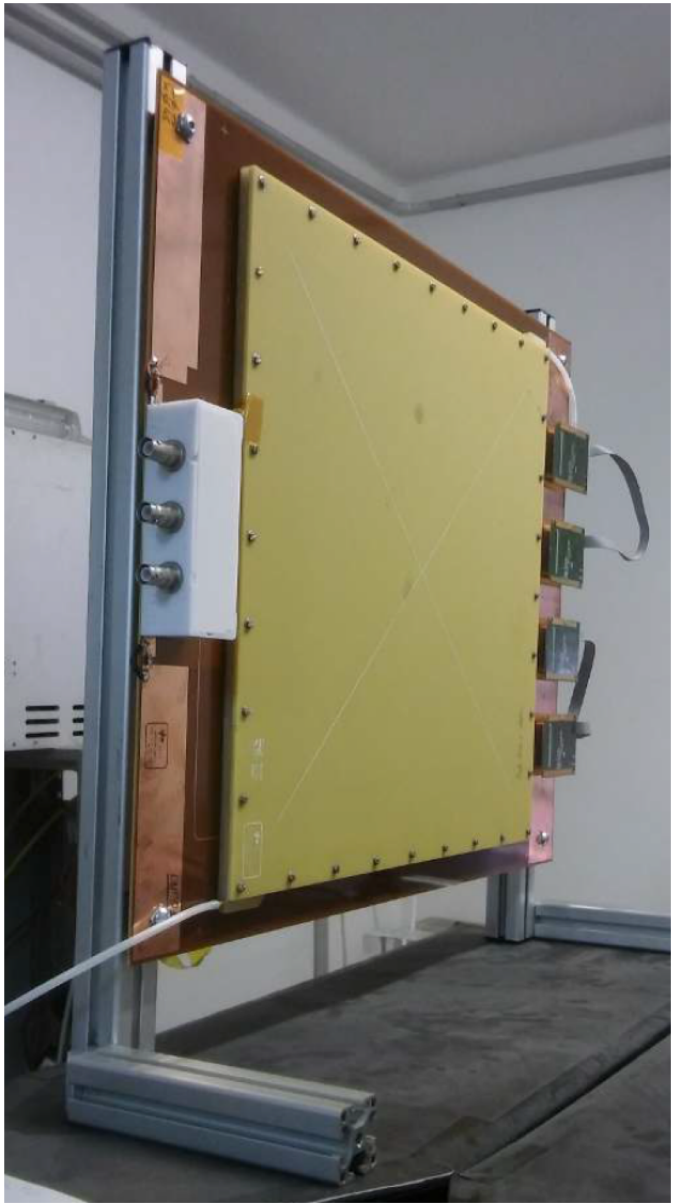
uRwell

- 2 uRwell with 30x30 cm2 active area

Each uRwell has:

- 512 horizonatl strips
- 4 Front-end cards (APV25)
- The APV25 stores the charges of128 strip every 25 ns (one time sample)



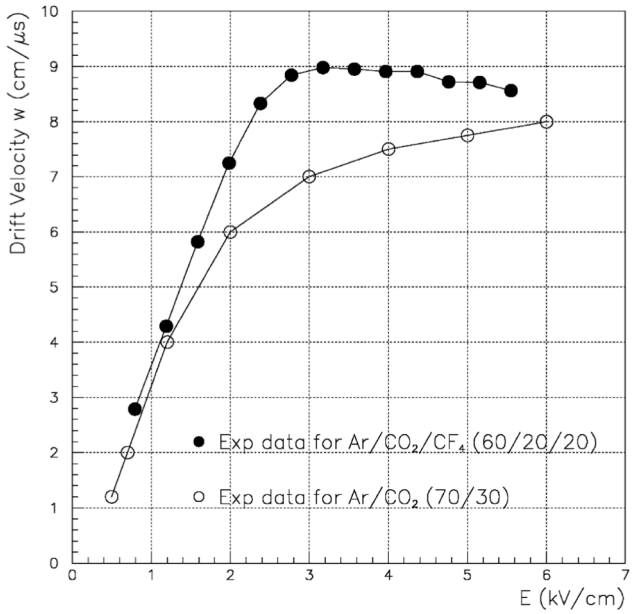


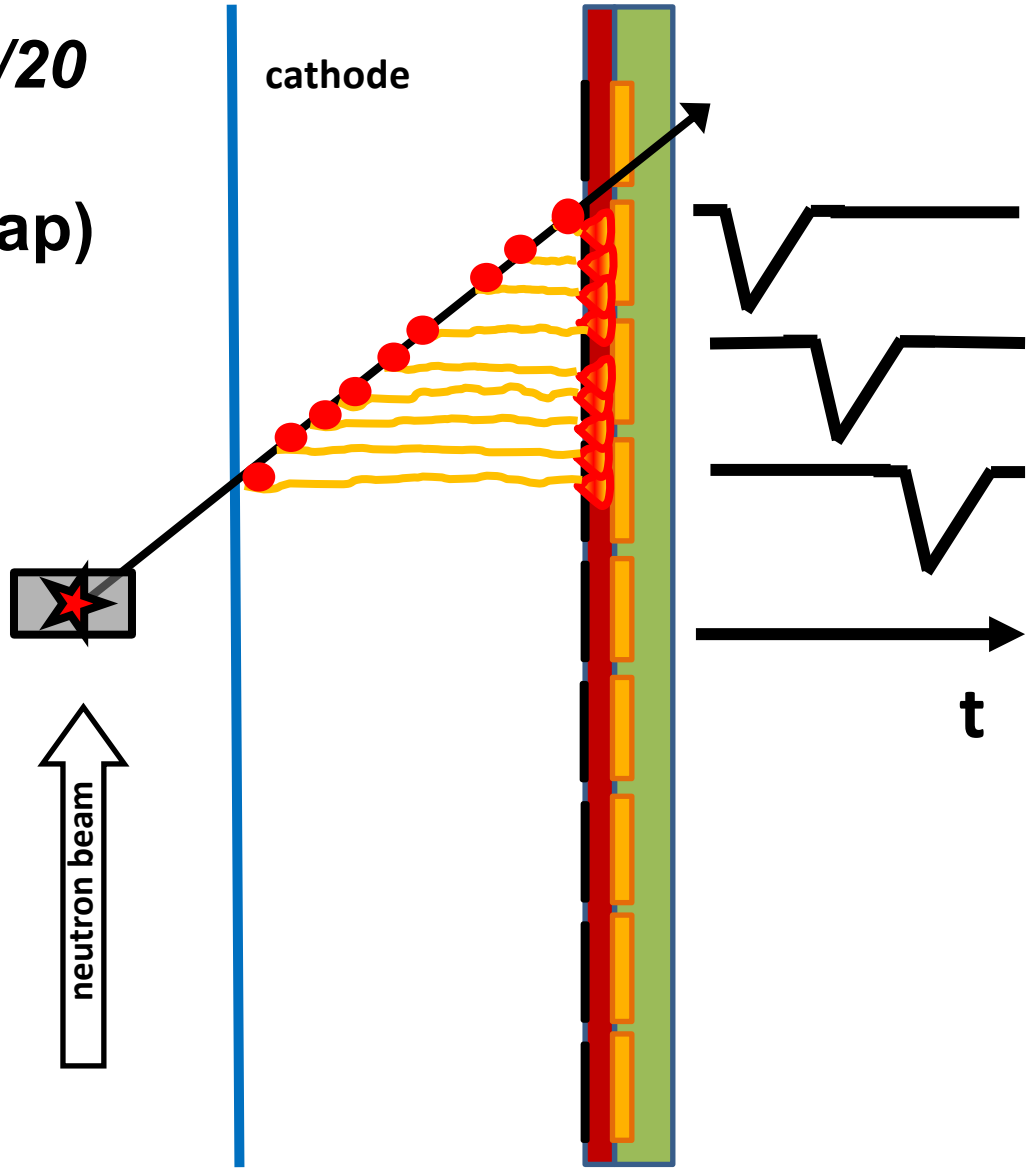
μTPC: Test at EAR2

with Ar/CO_2=/CF4=60/20/20

$1/W_{drift}$ ~ 10 ns/mm

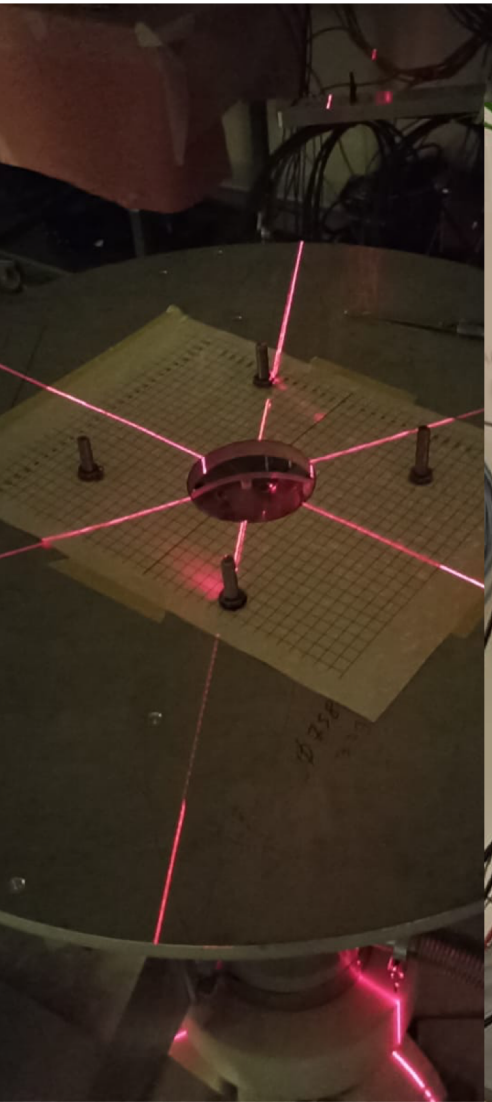
→60 ns signals (6 mm gap)

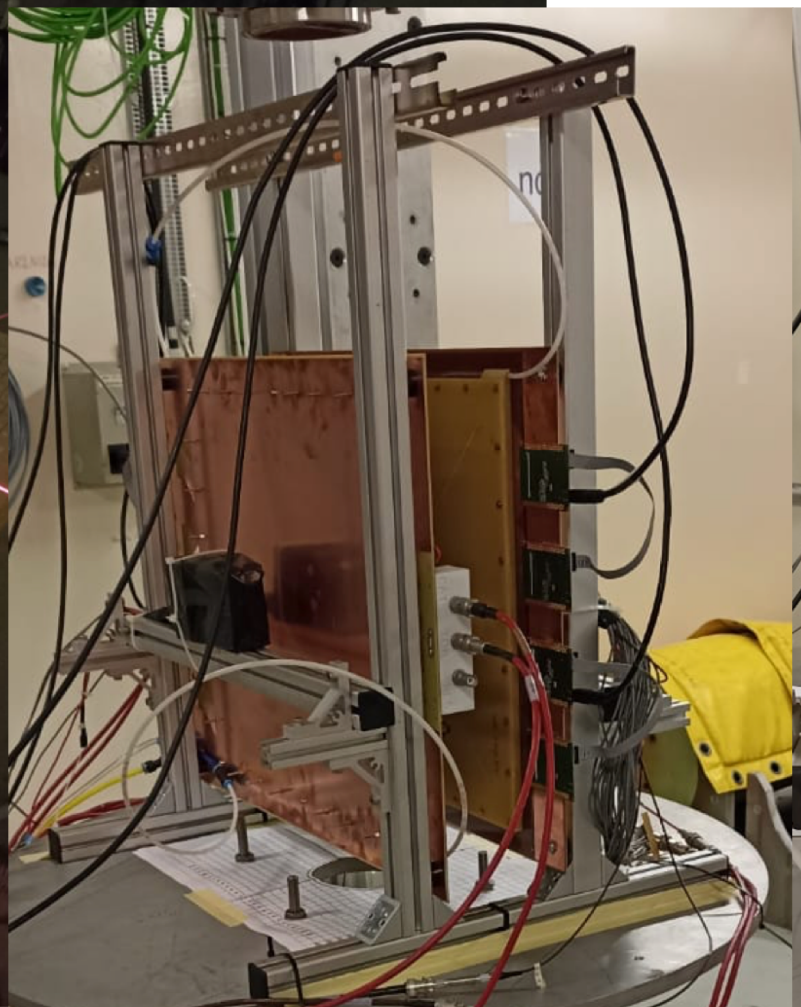


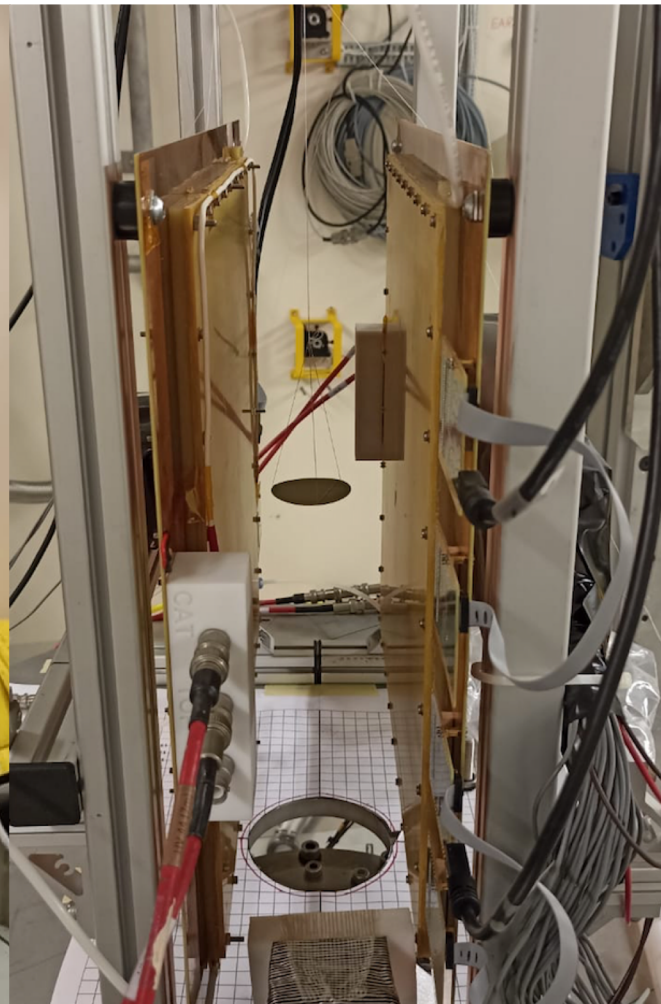


Goal of the test:
Background evaluation
Gamma Flash
interactions with materials

SETUP

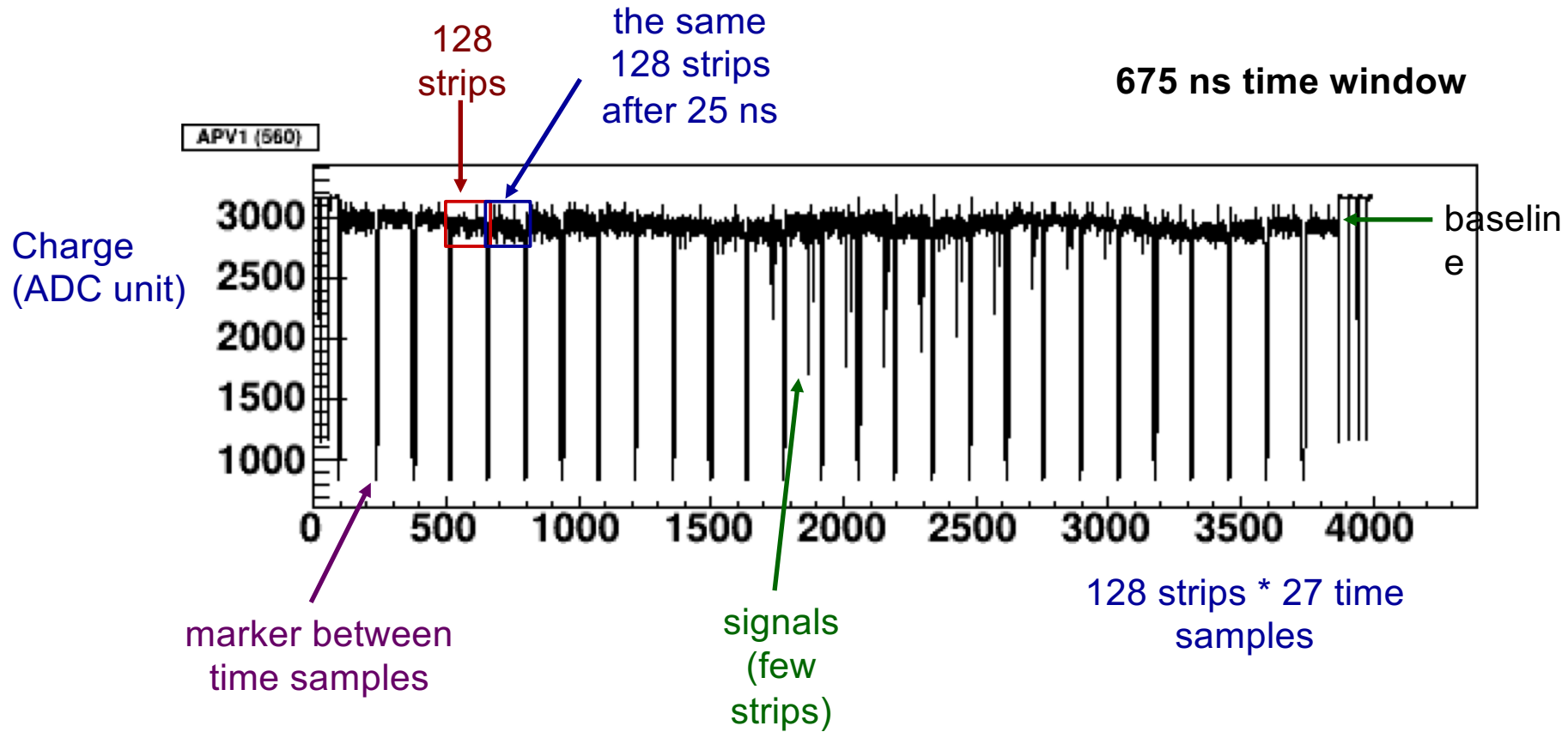




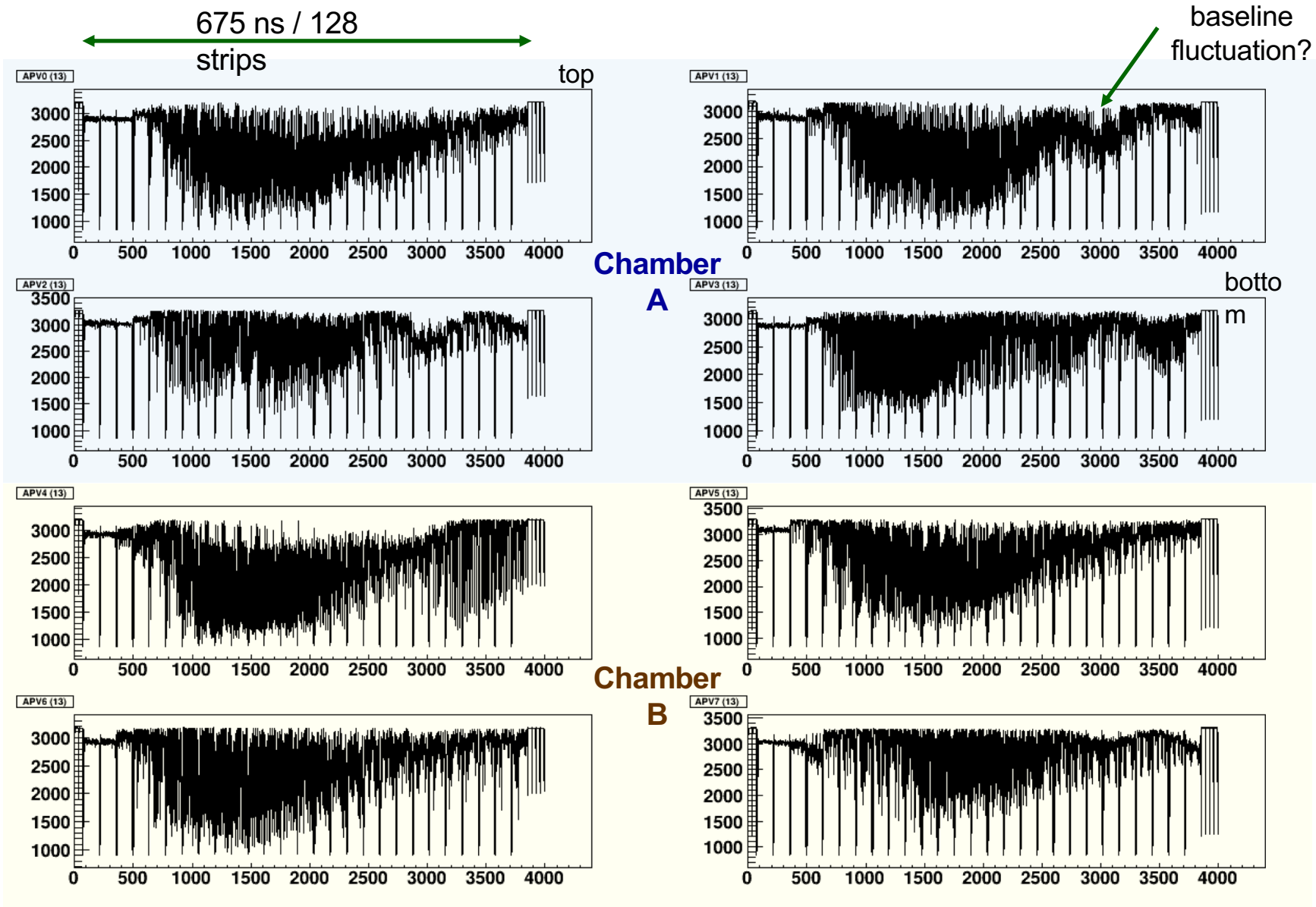


uRwell online signals

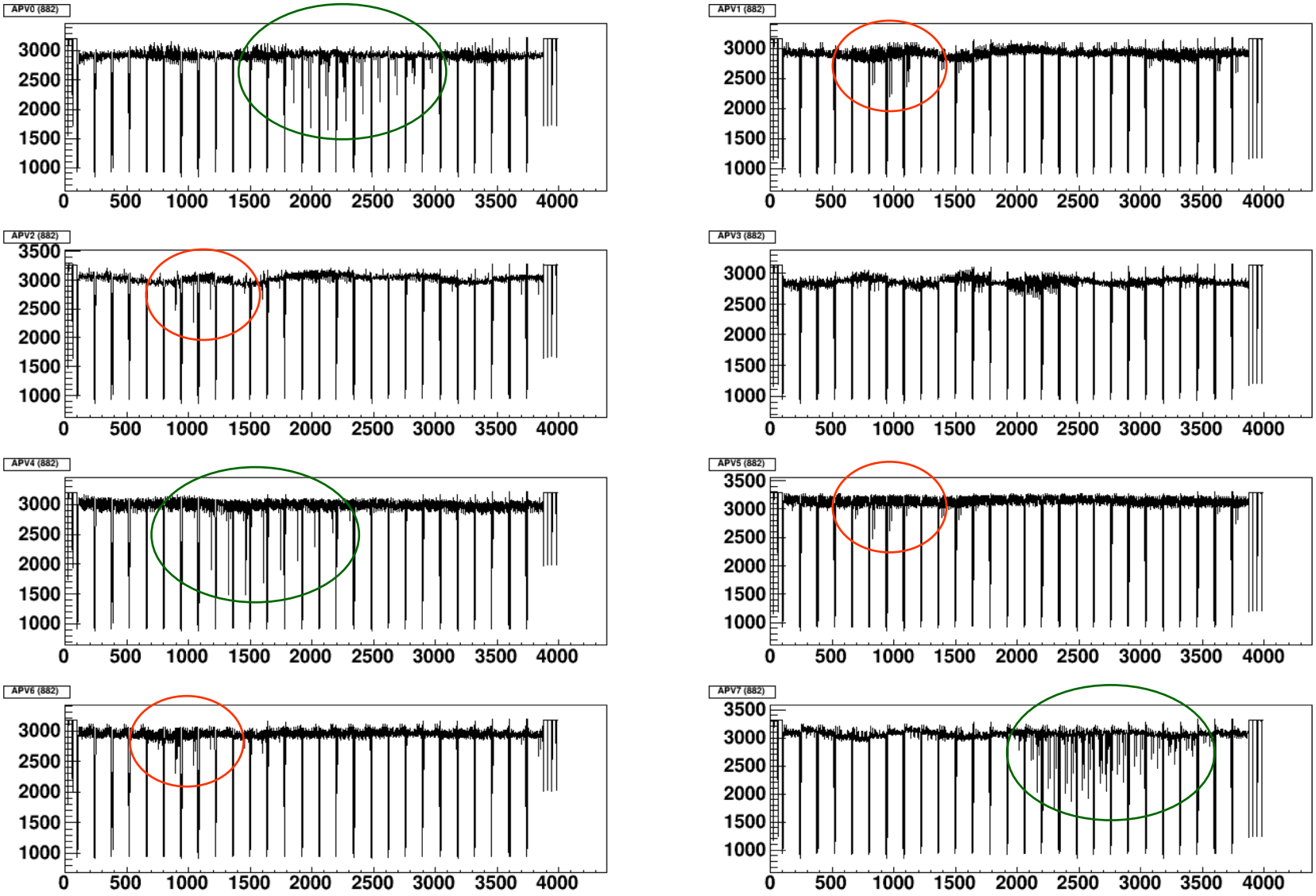
- Each uRwell has 512 strips (horizontal) readout by 4 Front-end cards (APV25)
- The APV25 stores the charges of 128 strip every 25 ns (one time sample)



Gamma flash on uRwells

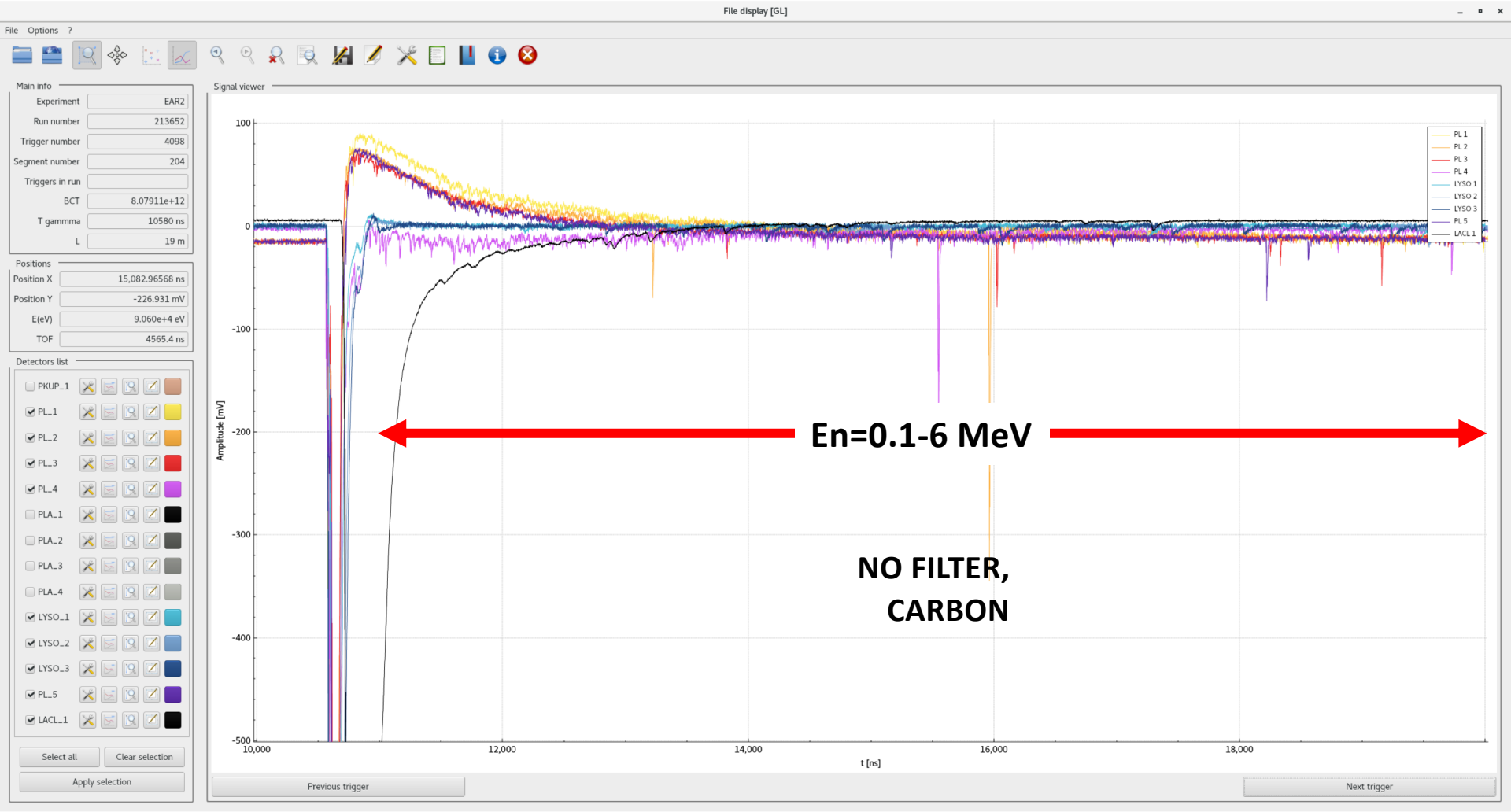


Signals in uRwell at gamma flash + 1.7 us



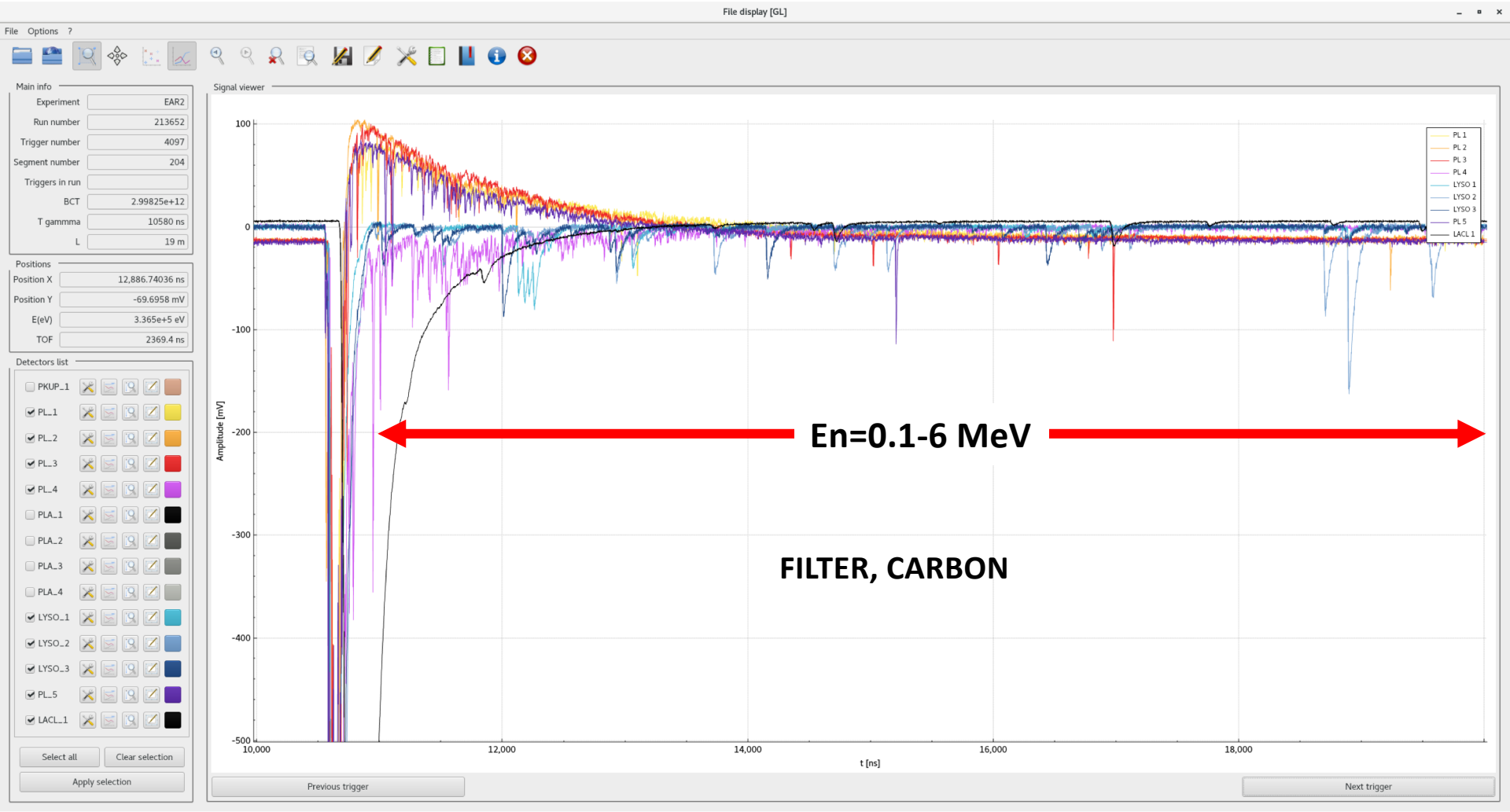
green are clear signals, red probably smaller signals

LYSO, EJ-200, $BrCL_3$

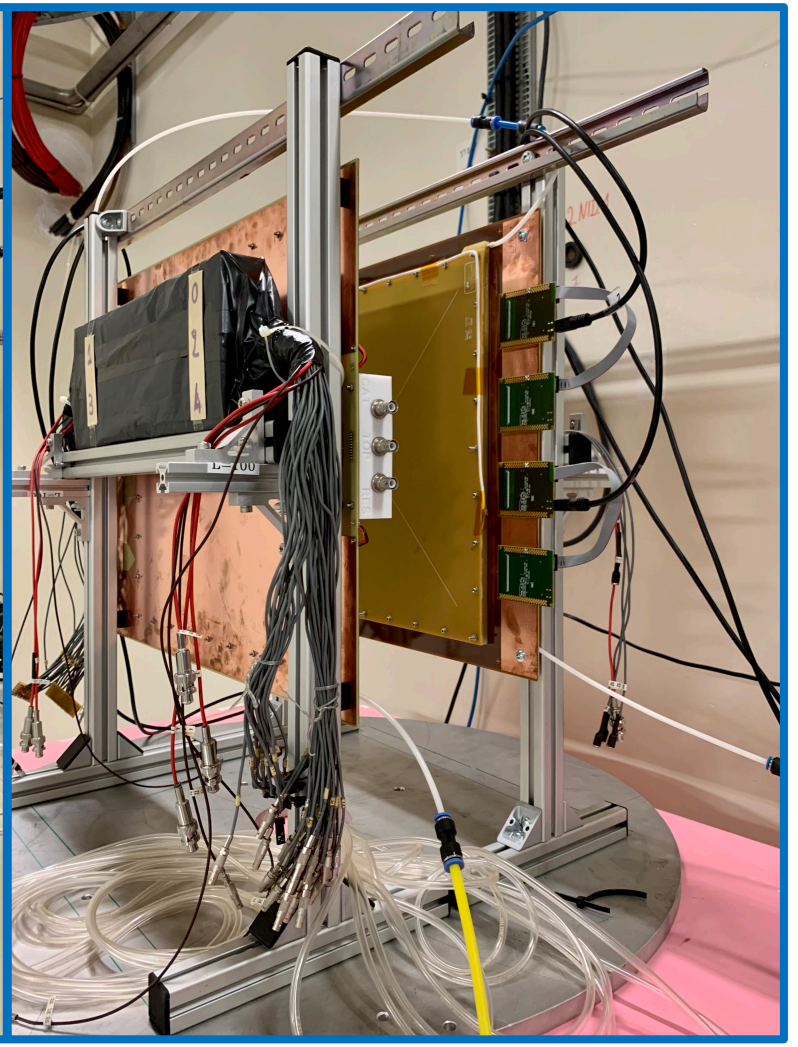


Faint signals due to huge Gamma Flash

LYSO, EJ-200, $BrCL_3$



TEST at EAR2



TO DO (By Evaristo)

- Finalize analysis code
  - common mode subtraction
  - clustering (time and space)
  - get consolidated code from uRwell/uMegas experts
- Integrate and synchronize scintillators and nTOF run data (e.g. single trigger beam intensity)
- Define relevant parameters and compare different conditions:
  - targets / no targets
  - flipped configuration
  - time windows
- Proper (high current) PMT (SiPM) and/or current drain to limit the gamma flash current
- Comparison with MC
- Analysis (energy linearity, energy resolution...)

It seems desirable a short test at EAR2, to validate electronics against gamma flash

TO DO

-Test a EAR2 per validare l'elettronica per eventi vicino (~0.5 ms) al gamma flash

-Test con raggi cosmici, per caratterizzare i rivelatori (energia, tracking)

-Test a LNL con protoni su bersaglio LiO_2 , per caratterizzare il rivelatore con e^+e^- $p+7Li \rightarrow 8B$ ma (soprattutto $p+{}^{16}O \rightarrow {}^{17}F^* \rightarrow {}^{17}F+e^+e^-$)

-costruzione dimostratore (impegni nel 2022)

-Lavoro teorico (reazioni 1+1, 1+2, 1+3)

-Proposta (misure con nuovo rivelatori)

-Contatti altre Facility (ENEA, Demokritos, iThemba)

-Simulazioni GEANT

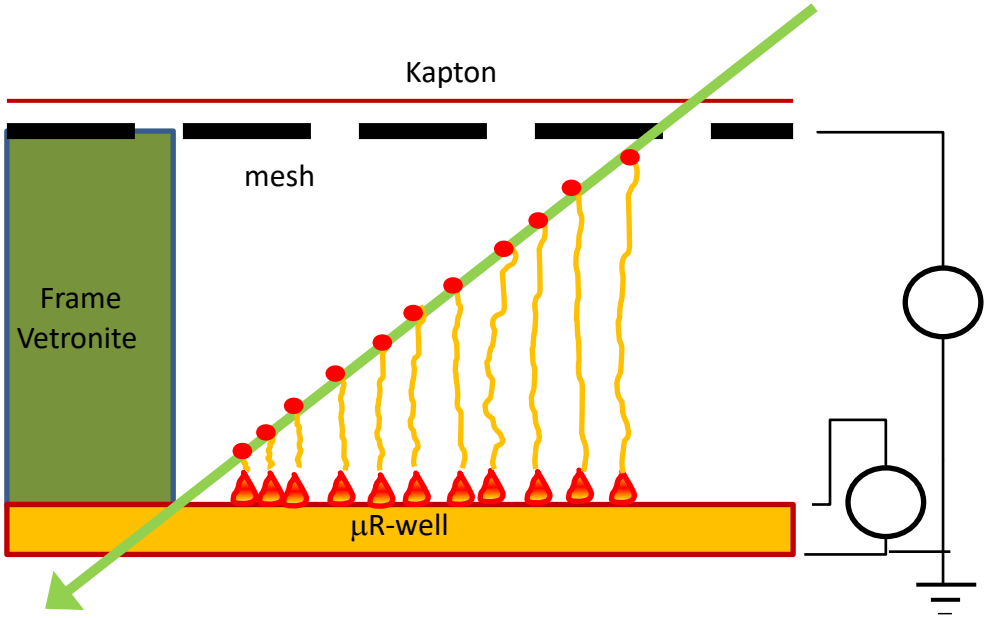
-POST DOC?

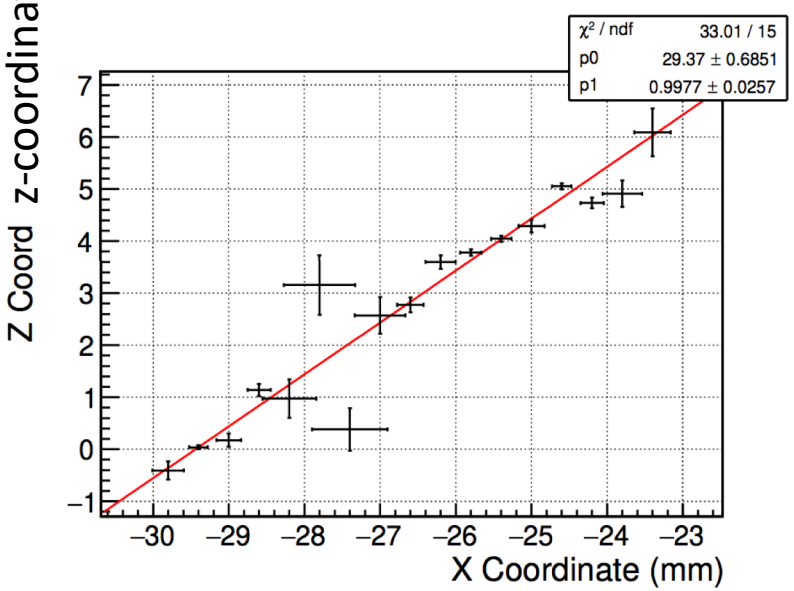
-Pubblicazioni/presentazioni

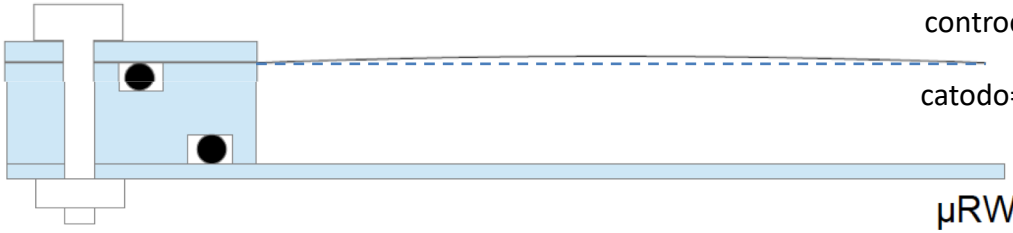
-Targhette 3He (in collaborazione con gruppo criogenia (CERN)

SPARES

TPC Detector cost







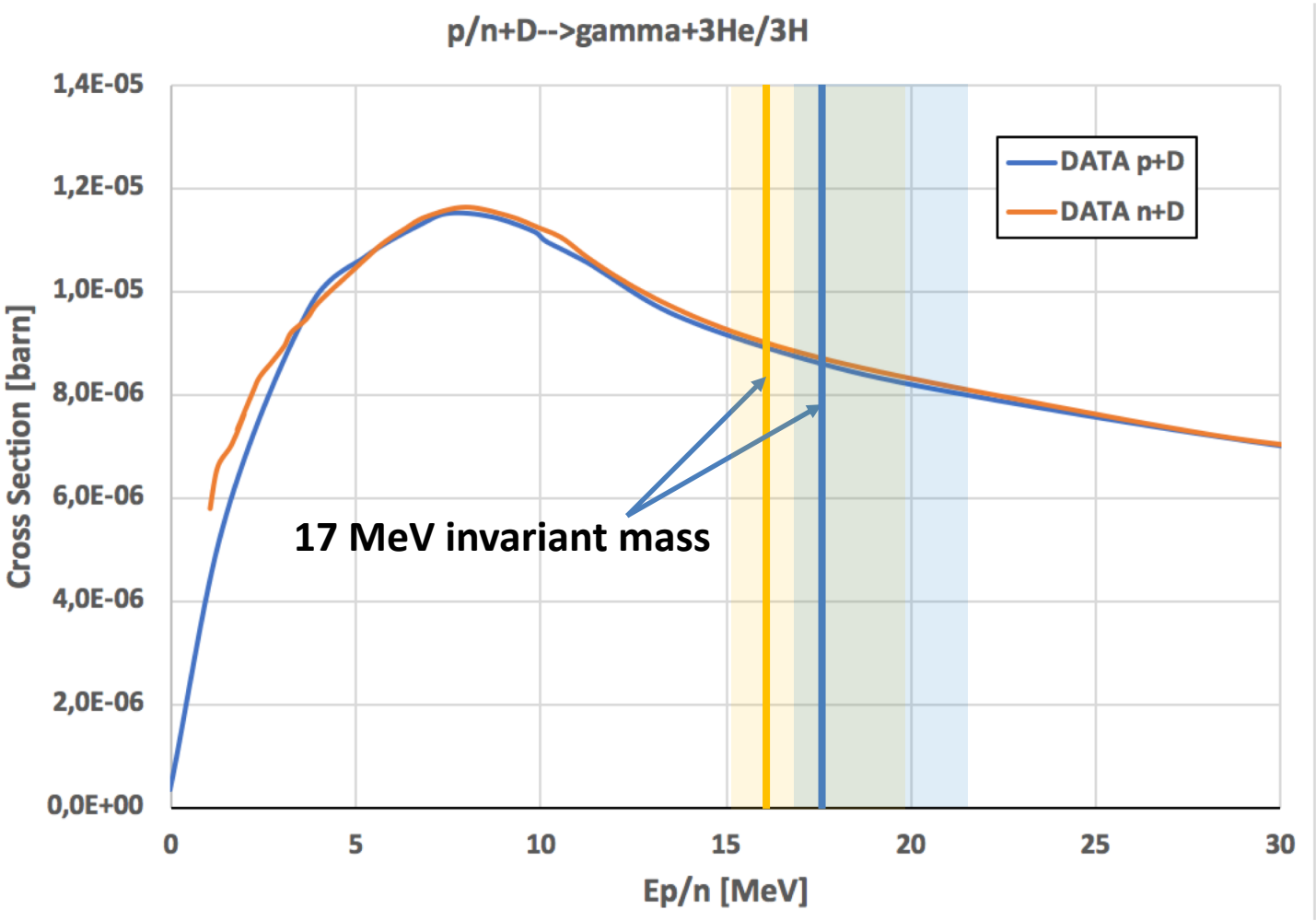
controcatodo=contenimento gas

catodo=kapton alluminato o mesh

µRWell

D(n,X17)^{3}He and D(p,X17)^{3}H reactions

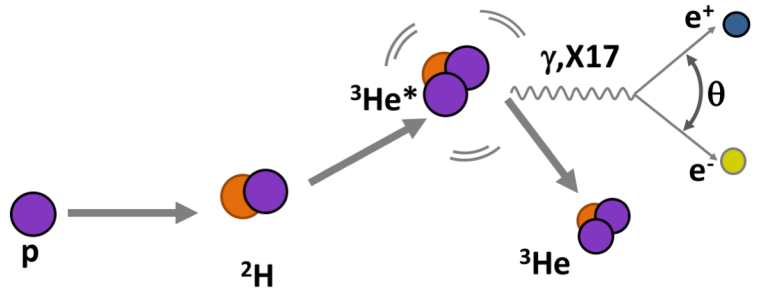
The **D(p,X17)^{3}He and D(n,X17)^{3}H reactions can be exploited**



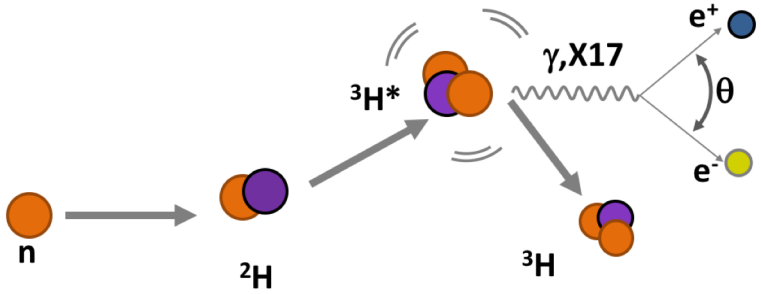
Thresholds for the production of a 17 MeV boson are shown

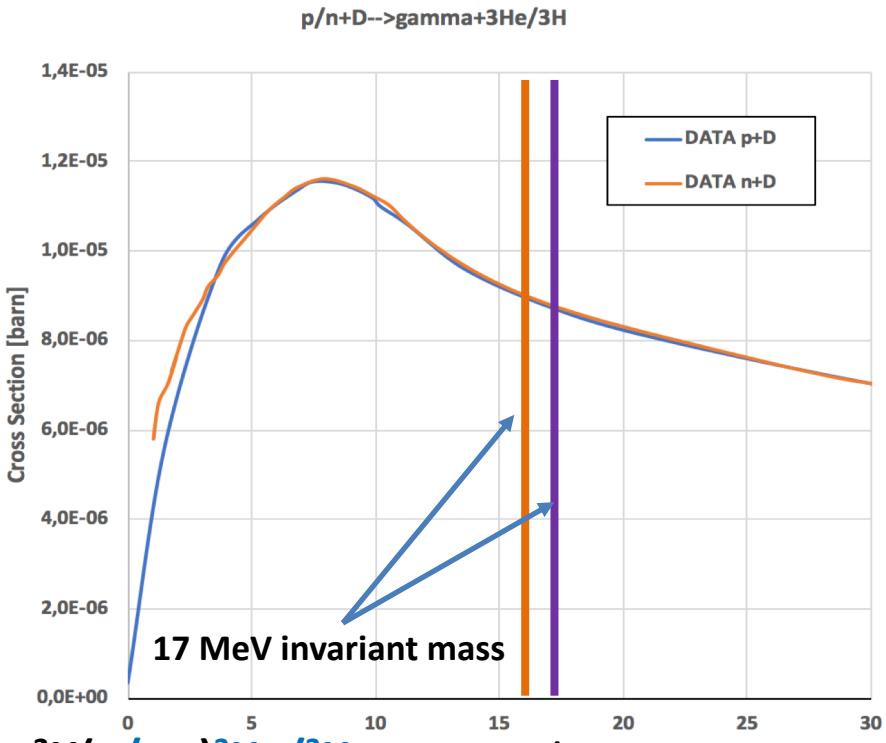
Comparison of A=3 nuclei "decay"

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



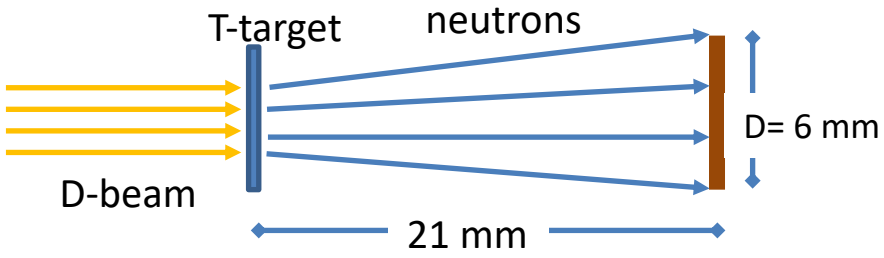
$^2H(n,e^+e^-)^3H$ (Q=6.3 MeV)

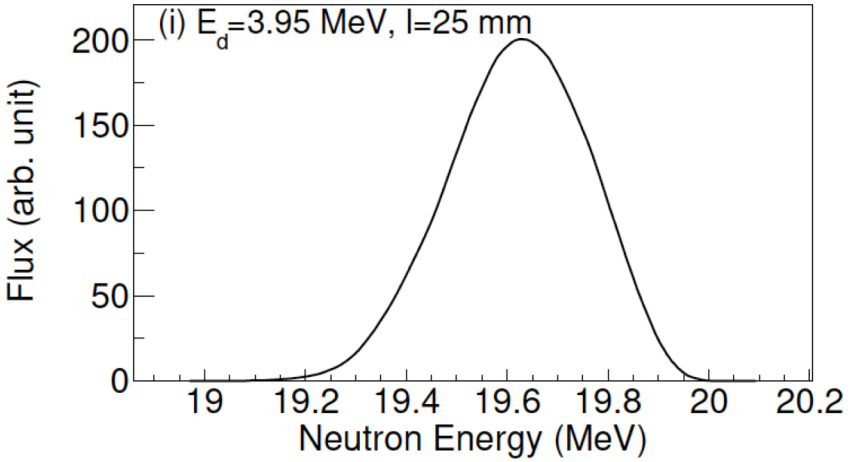




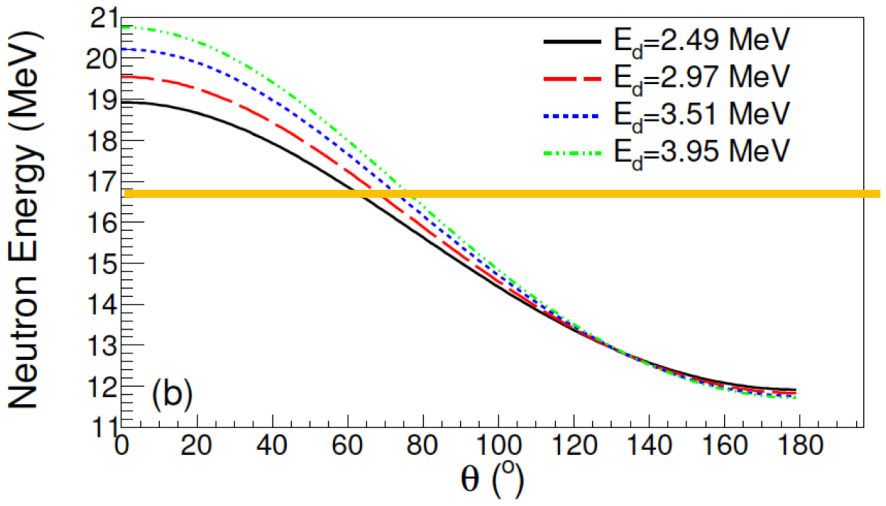
$^2H(p/n,\gamma)^3He/^3H$ cross sections are very similar. The A=3 nuclei are well suited for ab-initio calculations, giving well defined prediction for IPC/X17 $^2H(p/n,e+e-)^3He/^3H$ processes. in particular the production of X17→e+e- is favoured for Tritium with respect to ^3He, in case of the protophobic 5^{th} force. Proton and neutron beams with E_{beam}>16 MeV are needed for such a program .

Demokritos facility





	Deuteron beam energy (MeV)	Neutron beam energy (MeV)	Neutron beam energy uncertainty (MeV)
DD reaction	7.23	10.1	0.1
	7.54	10.4	0.1
	7.84	10.7	0.1
	8.17	11.0	0.1
	8.47	11.3	0.1
DT reaction	2.49	17.1	0.3
	2.97	18.1	0.2
	3.51	19.0	0.2
	3.95	19.6	0.2



Example: 1 measurement at 0 and one at 90 degree with E_d=2,49 MeV

Demokritos facility

Neutron Beam Test at Demokritos

- Neutron energies up to 25 MeV depending on the initial reaction
- Neutrons of 5.5 MeV with fluxes up to 1.5 x 10^6 n/cm^2 s

Nuclear Reaction	Proton/Deuteron Energy Range (MeV)	Neutron Energy Range (MeV)
$^7Li(p,n)^7Be$	1.9 to 8.4	0.1 to 6.7*
$^2H(d,n)^3He$	0.8 to 8.4	3.9 to 11.5**
$^3H(d,n)^4He$	0.8 to 8.4	16.4 to 25.7***

Neutron fluences can reach ~5x10^6 neutrons/cm^2 s but for d-^{3}H is lower an order of magnitude compared to the d-^{2}H reaction due to cross sectio energy dependence

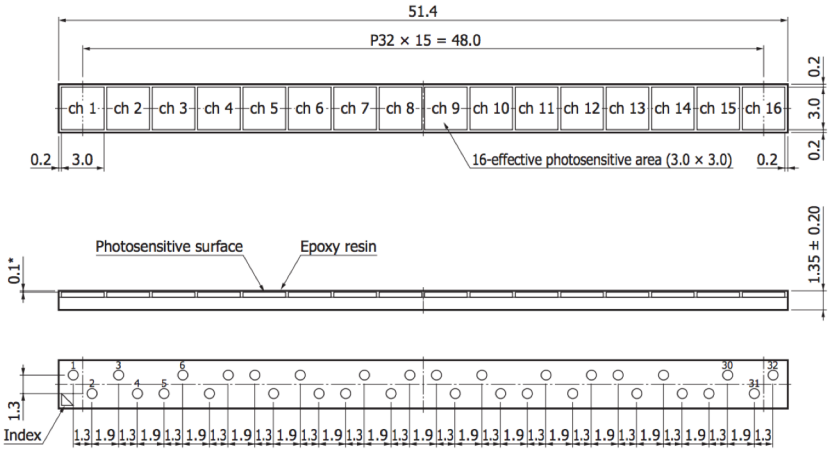
- used to test ATLAS MDT's
- for the upgrade of the ATLAS NSW TGC's & Micromegas were (and will be) tested
- GEM detectors were tested

at 2 cm from the 3H target: 10^5 n/cm^2s

HAMAMATSU

MPPC (Multi-Pixel Photon Counter) arrays | **S13363-3050NE-16**

Dimensional outline (unit: mm)



Buongiorno Carlo,
ho ricevuto oggi la quotazione ed i tempi di consegna per l'array S13363-3050NE-16.
Ti riporto di seguito i costi per scaglione (legame cambio 1€=135JPY):

	1pce	5pcs	10pcs	50pcs	100pcs
S13363-3050NE-16	290,40 €	254,40 €	220,80 €	188,40 €	159,60 €

I tempi di consegna sia per i campioni che per 100pcs sono di circa 4mesi.

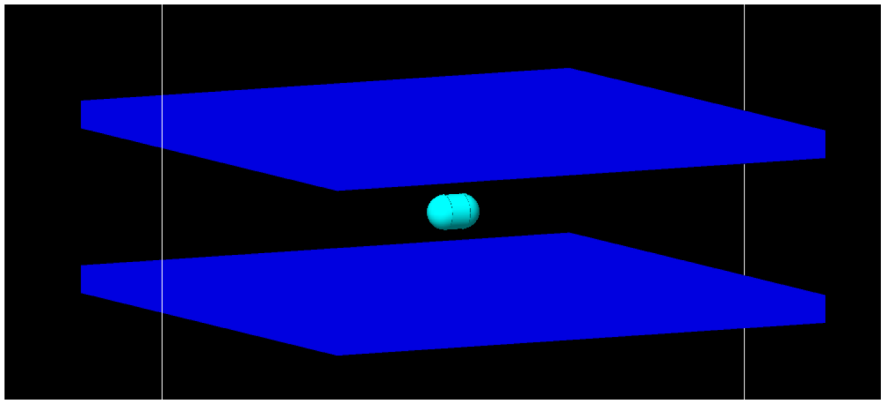
Non esitare a contattarci per ulteriori informazioni.

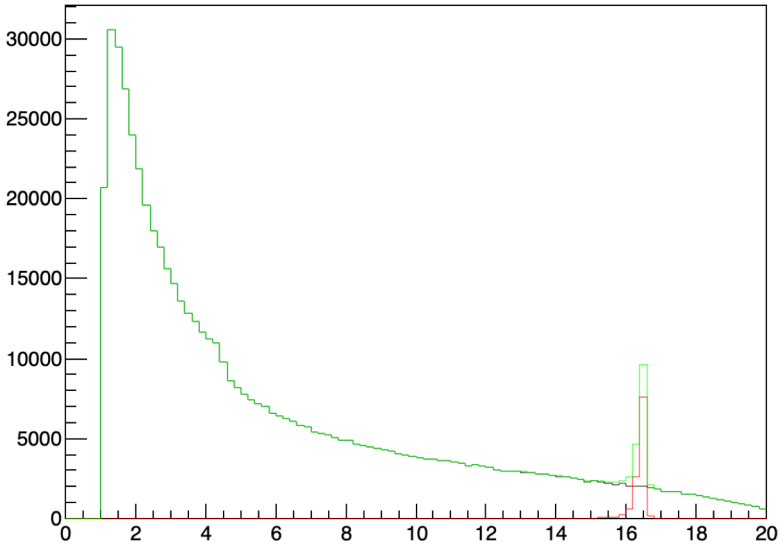
Cordiali Saluti

Massimo

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

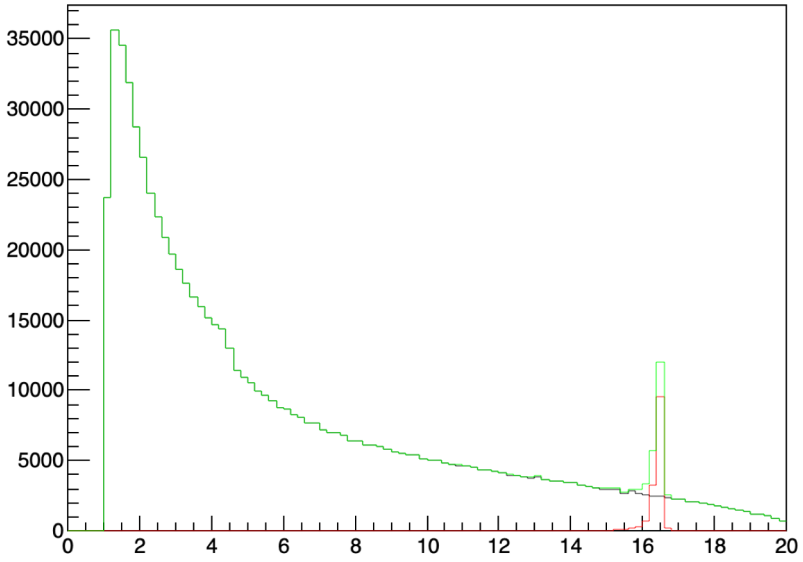
- #coppie rivelate
- IPC: 59%
- X17: 47%

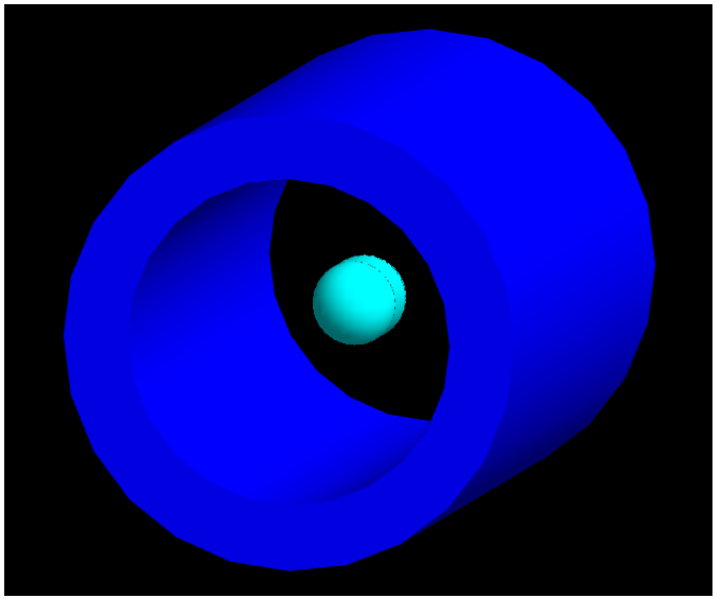




|Theta_x|<63.4 degrees -> (cylinder 20 cm long with a radius of 5 cm)

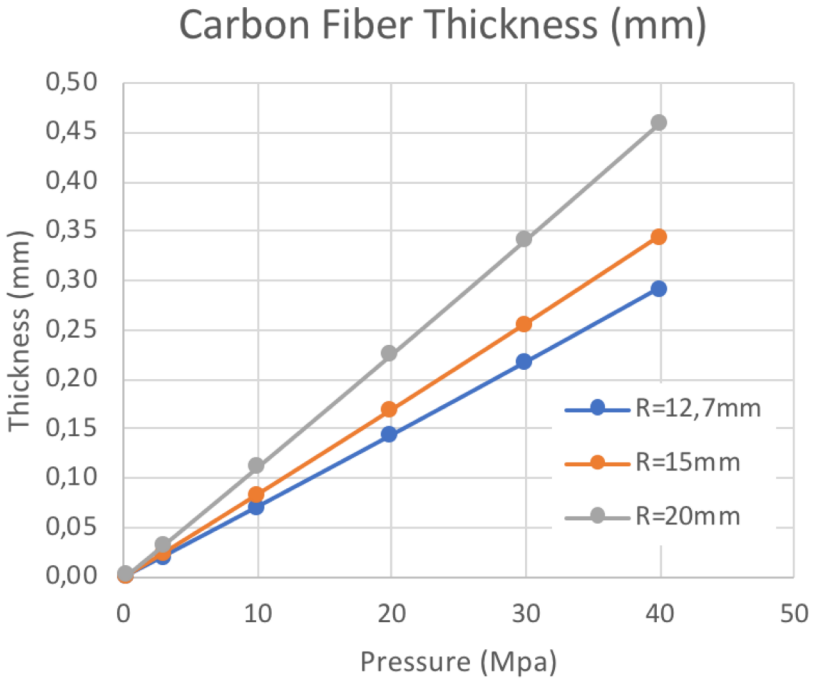
- #coppie rivelate
- IPC: 75%
- X17: 58%





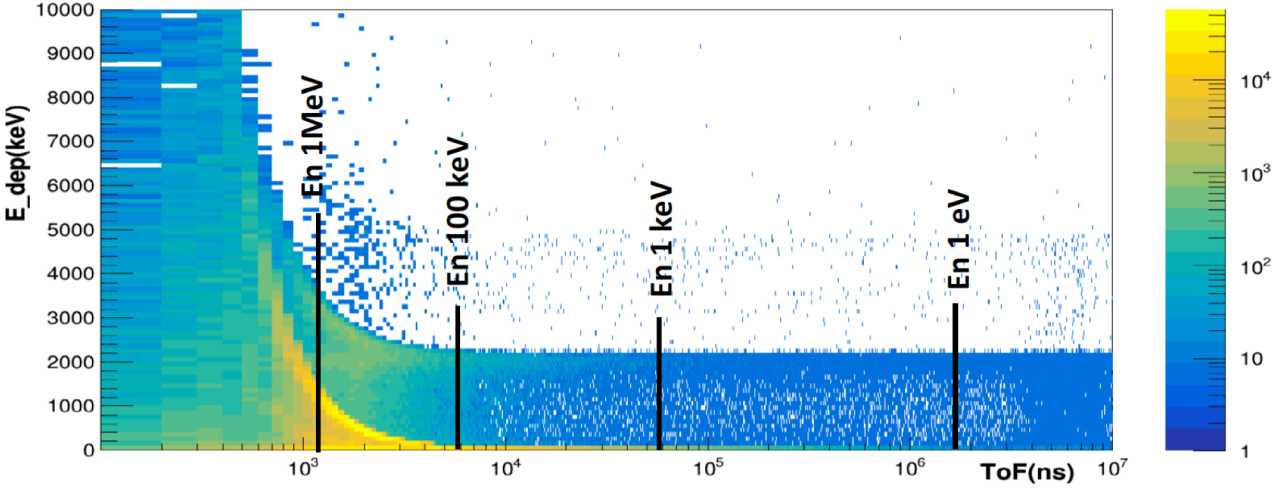
Target

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)

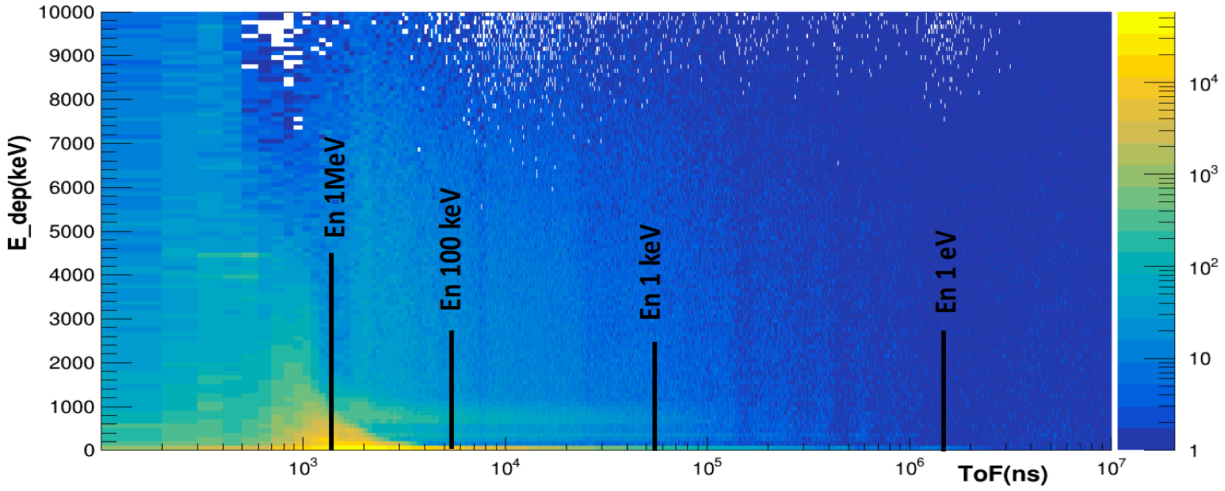


courtesy P. Mastinu

Energy deposition as a function of time of flight (by Cristina Petrone)



EJ-200
Neutron induced events



LYSO
Neutron induced events
•Gamma radiation from (n,n') or(n,el) on different elements from the detector (Lu1.8YSiO5:Ce)