# Searching for X17 anomaly at nTOF experiment

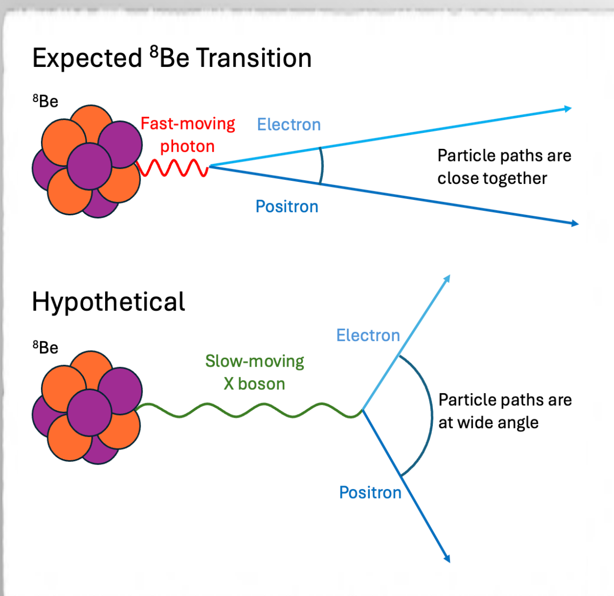
**Carlo Gustavino**
for the X17 working group
Catania, 29 May 2024

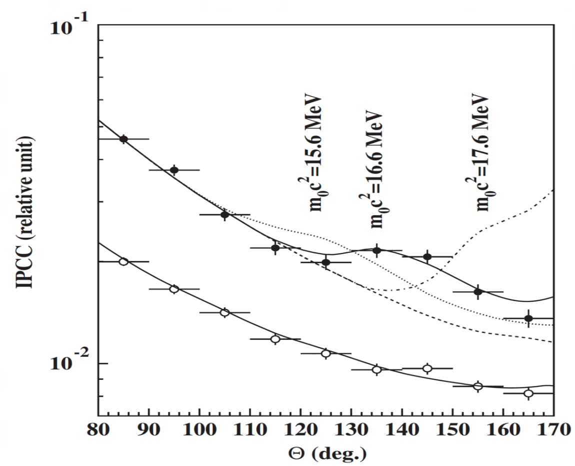
# A new detection set-up to search the X17 boson

Carlo Gustavino

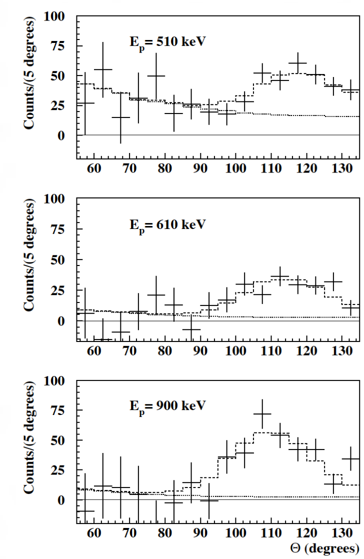
Three significant anomalies have been observed in the in the $^{3}H(p,e^{-}e^{+})^{4}He$, $^{7}Li(p,e^{-}e^{+})^{8}Be$, $^{11}B(p,e^{-}e^{+})^{12}C$ nuclear reactions. These anomalies consist in an excess of electron-positron pairs emitted at large relative angle. This excess have been interpreted as the signature of a new paricle with mass of about 17 MeV, called **X17 boson**.

## The X17 anomaly



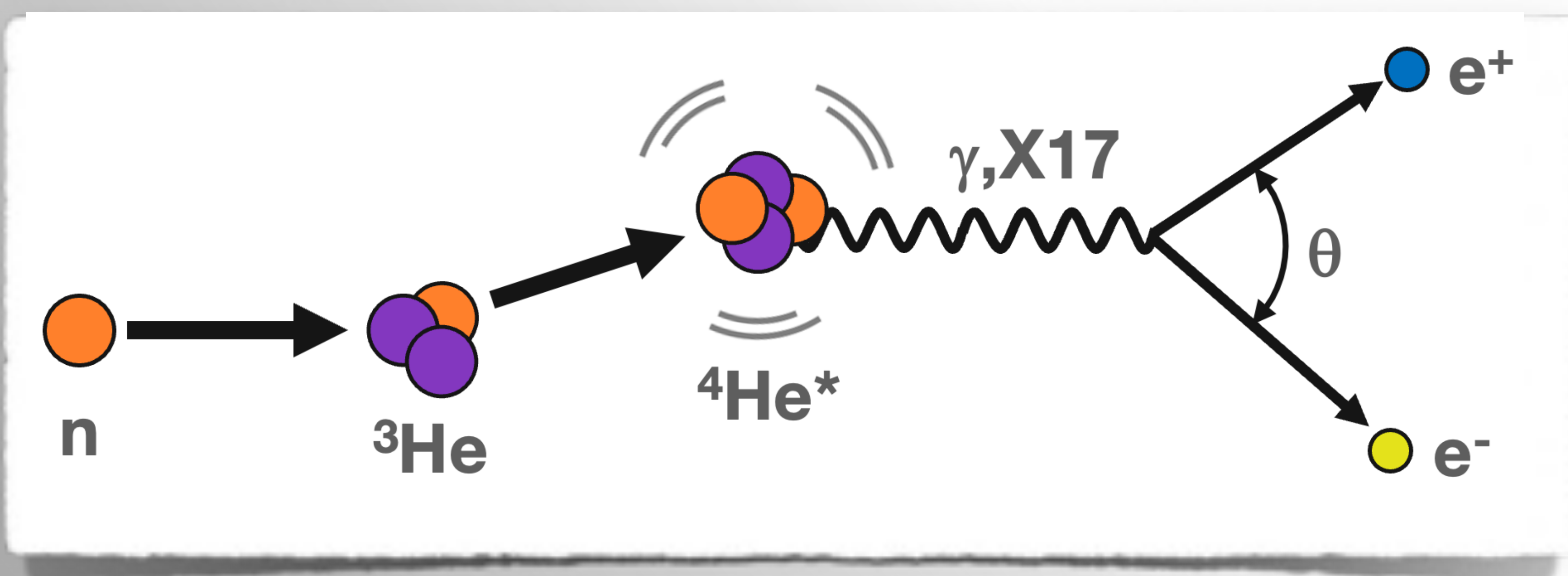




*Excess of $e^{-}e^{+}$ pairs at large relative angle observed in the $^{7}Li(p,e^{-}e^{+})^{8}Be$ reaction.*

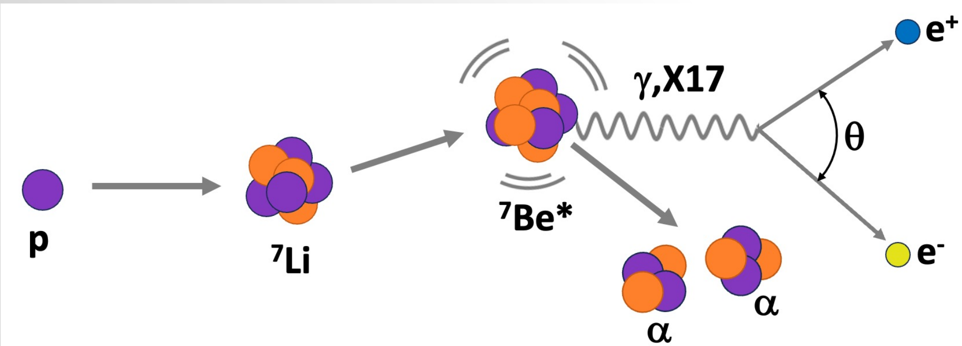


## Experimental Program

- Study of the $^{7}Li(p,e^{-}e^{+})^{8}Be$ reaction → X17 search.
- Study of the $^{3}He(n,e^{-}e^{+})^{4}He$ reaction in a wide energy at the **n_TOF** facility, using a custom target of $^{3}He$ at 380 bar → determination of X17 quantic numbers $J^{\pi}$.
- Study of the $^{2}H(p,e^{-}e^{+})^{3}He$ and $^{2}H(n,e^{-}e^{+})^{3}H$ "specular" reactions → probing the protophobic coupling.



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



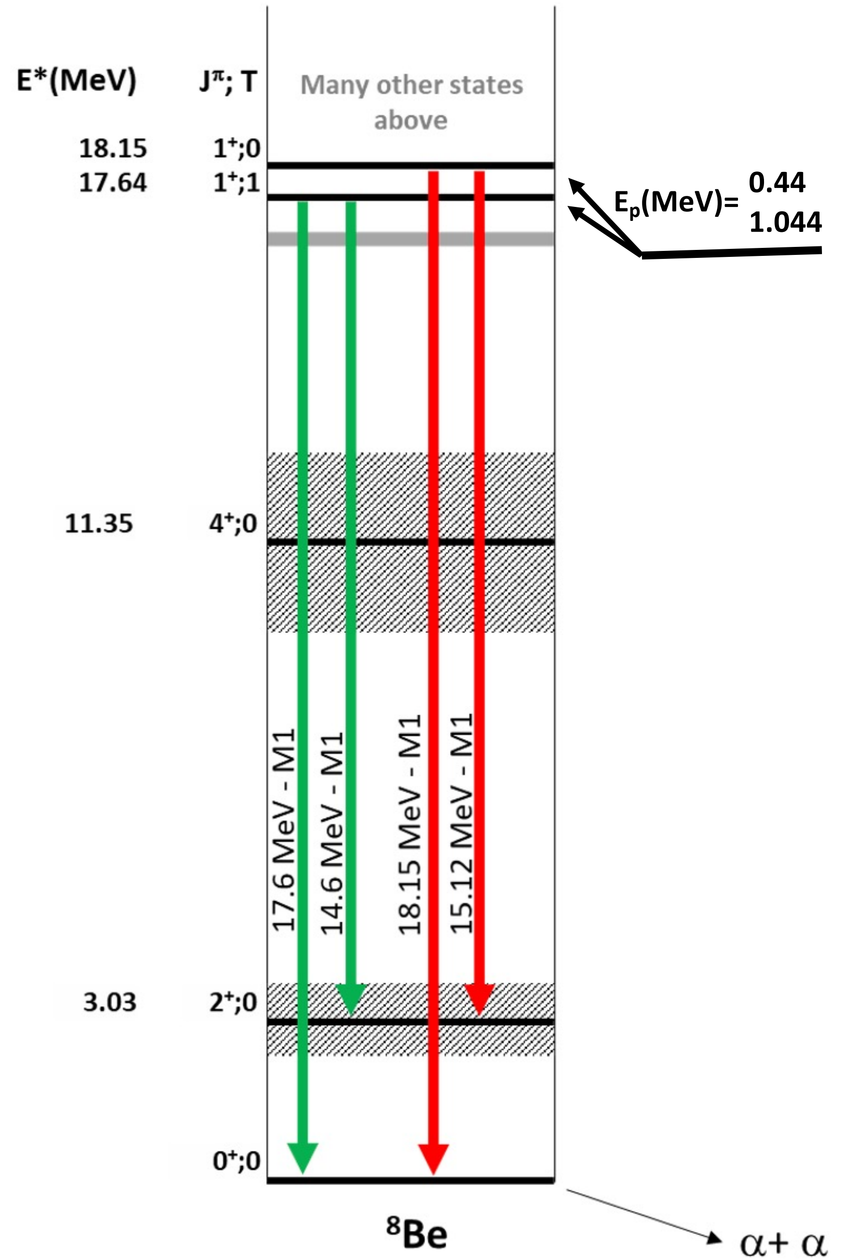

The reaction $^7Li(p,e^+e^-)^8Be$ allows to selectively populate the 17.64 MeV and 18.15 MeV resonances. The considered transitions are M1 type.

In SM, virtual photons can convert into $e^+e^-$ pairs (internal pair convertion, IPC). IPCs decreases smothly with the aperture angle.

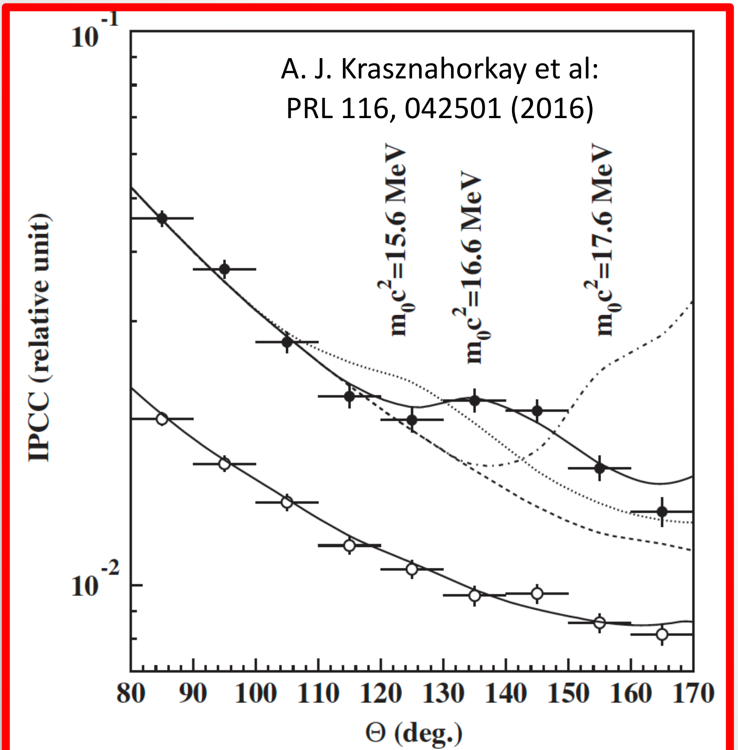
Typically,

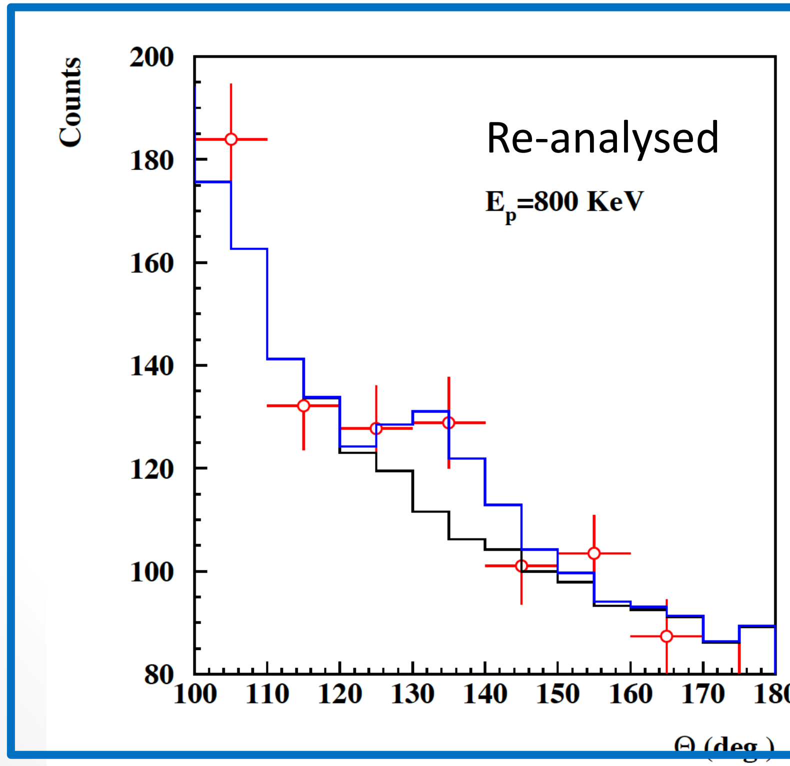
BR $e^+e^-/\gamma s=10^{-3}$

BR $X17/\gamma s=2{,}5^{-5}$



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




Clear counting excess for $\theta_{e+e-}$~140° for $E_p$ populating yje 18.2 resonance

No X17 signal at the 17.6 resonance

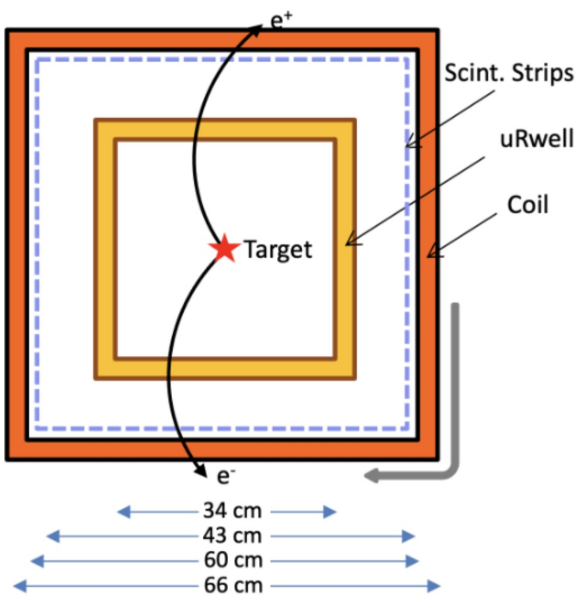
*Re-analysis of old data provide an excess also at 17.6 MeV (See arXiv:2205.07744v1)*

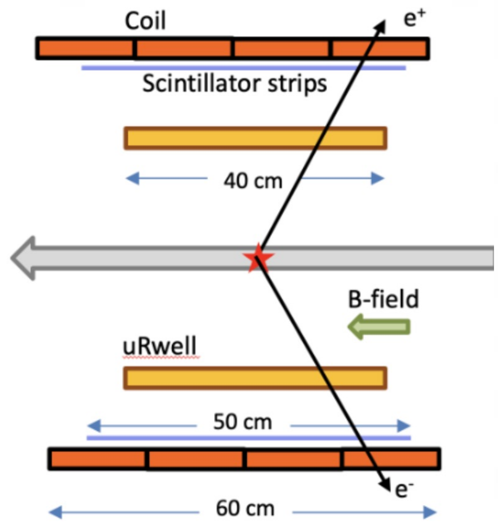
*Re-re-analysis cancelled out again the anomaly at 17.6 MeV*

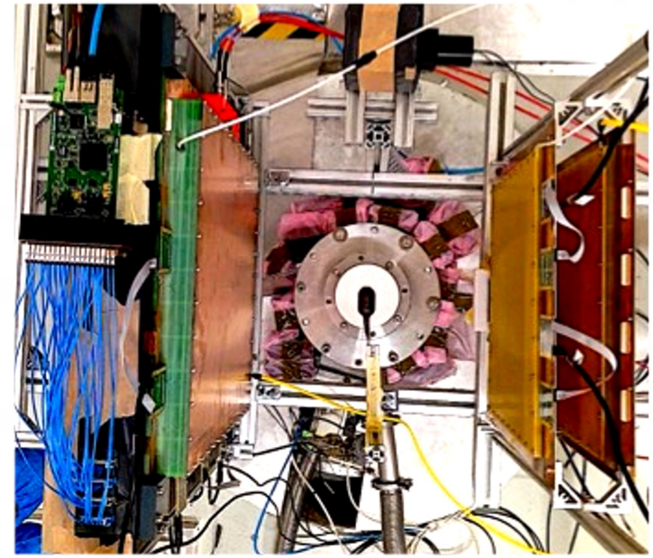
# Breaking news: X17 at MEG2

- Next week: MEGII meeting to decide if the analysis procedure is complete for the data “unblinding” for the **$^{7}Li(p,e^{-}e^{+})^{8}Be$** reaction.
- If yes, data will be unblinded--> summer conferences.
- If not, further work required.
- Data are of 2022 at $E_R$=17.6 MeV (no anomaly at Debrecen).
- Next step run at $E_R$=18.2 MeV (energy of the ATOMKI anomaly).
- Cockcroft-Walton accelerator presently broken.

# Detector Requirements



## Detector requirements

- Large angular acceptance
- Reconstruction of $e^-e^+$ kinematics
- Low sensitivity to photons and neutrons

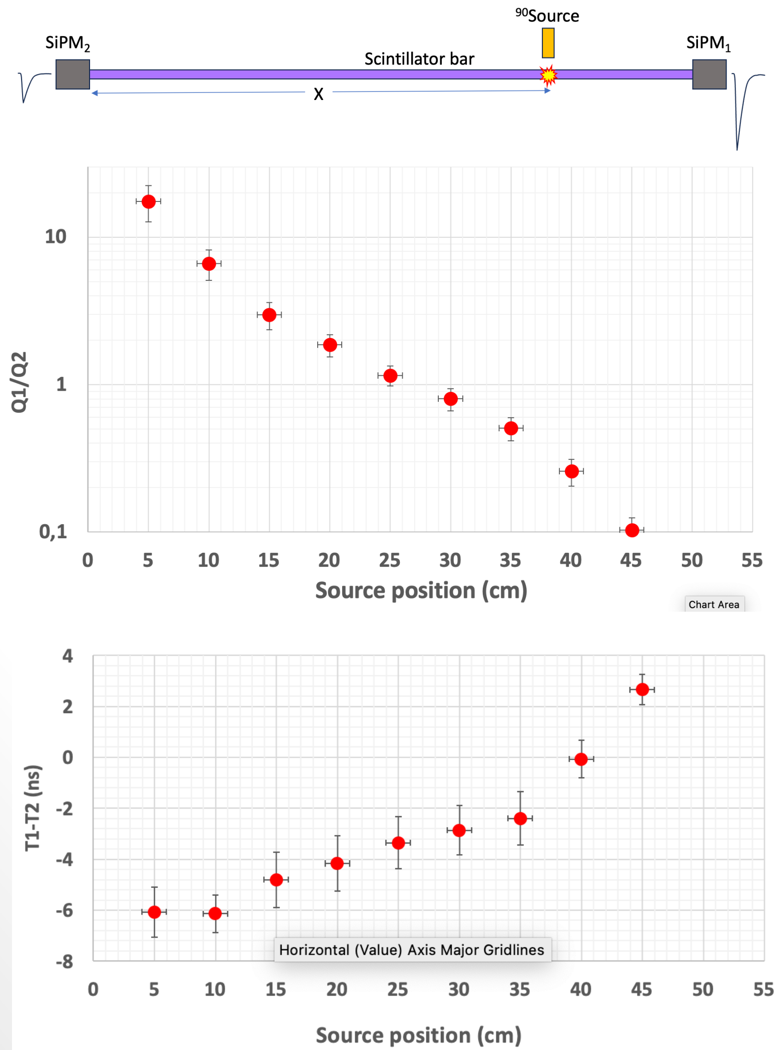
- 4 large μTPC with 380 x 460 x 30 mm$^3$ active volume → 3D tracking
- 4 planes composed by 32 scintillator bars 3 x 12 x 500 mm$^3$ → trigger
- 1 coil (B = 500 Gauss) → momentum reconstruction

# Scintillating bars

So far, modest (but sufficient) performance.
To Be done:

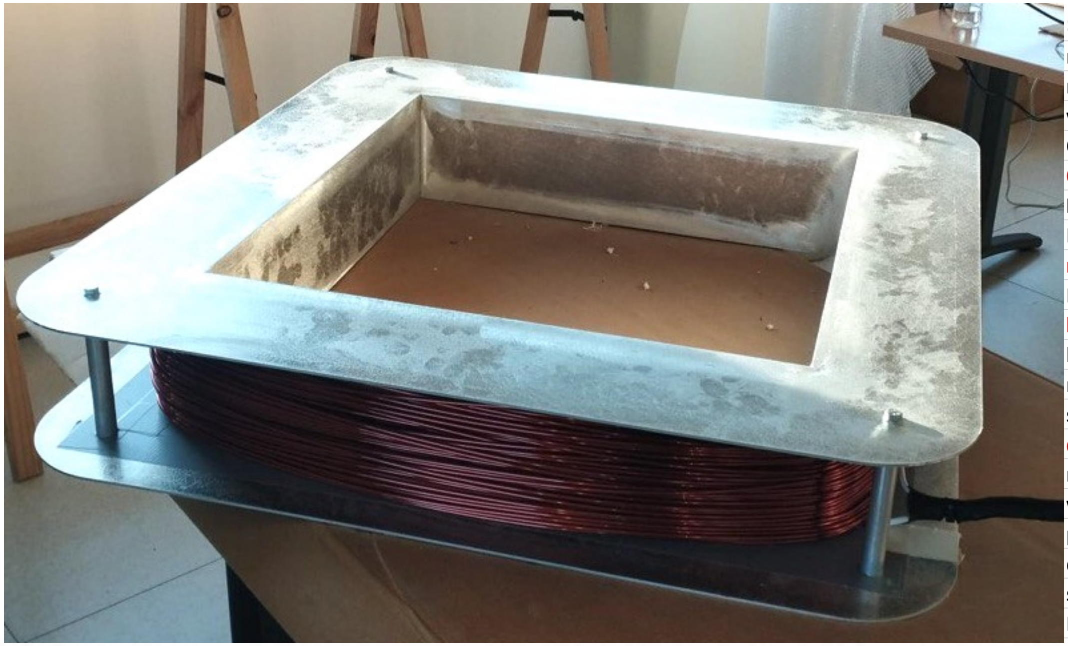
- New reflective procedure (Teflon tape).
- Measurement to simulate Gamma flash
- Circuit to prevent possible Gamma flash problem
- Follow solutions adopted by the Foot experiment (using ~same SiPM, bars of 500x20x3 mm$^3$ instead of 500x12x3 mm$^3$)
- Alternative to FERS (difficult to use and to integrate in the acquisition)

PROBLEM: Very long time (>4 months up to now) for the Hamamatsu delivering




*Top:Amplitude ratio between the pulses at the ends of a scintillator bar coupled SiPMs.*
*Botton: Time difference between the two ends of the scintillator bar*

# The Coil



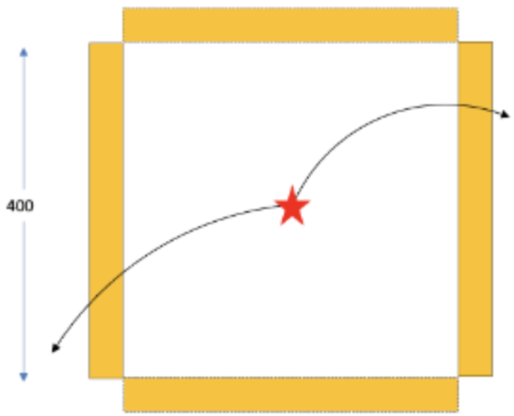
| solenoide sezione | QUADRATA | CIRCOLARE | | |
|---|---|---|---|---|
| massa protone (kg) | 1,82E-27 | 1,82E-27 | T_e- (MeV) | raggio curvatura (cm) |
| massa elettrone (kg) | 9,11E-31 | 9,11E-31 | 2 | 16 |
| velocità elettrone (m/s) | 3,00E+08 | 3,00E+08 | 3 | 23 |
| Carica elettrone (C) | 1,60E-19 | 1,60E-19 | 4 | 30 |
| Campo magnetico (T) | 0,05 | 0,05 | 5 | 37 |
| I (Ampere) | 19,9 | 39,8 | 6 | 43 |
| Lunghezza solenoide (m) | 0,5 | 0,5 | 7 | 50 |
| numero spire | 1000 | 500 | 8 | 57 |
| Mu_0 (permeab, T*m/A) | 1,26E-06 | 1,26E-06 | 9 | 63 |
| lato/diametro solenoide (m) | 0,6 | 0,6 | 10 | 70 |
| lunghezza rame (m) | 2400 | 942 | 11 | 77 |
| rho (Ohm*m) | 1,68E-08 | 1,68E-08 | 12 | 83 |
| sezione rame (m2) | 7,07E-06 | 7,07E-06 | 13 | 90 |
| diametro rame (mm) | 3 | 3 | 14 | 97 |
| resistenza | 5,71 | 2,24 | 15 | 103 |
| voltaggio (V) | 114 | 89 | 16 | 110 |
| potenza (Watt) | 2259 | 3548 | 17 | 117 |
| quantita rame (litri) | 17 | 7 | 18 | 123 |
| spessore solenoide (cm) | 1,4 | 0,6 | | |
| Peso solenoide (kg) | 152 | 60 | | |

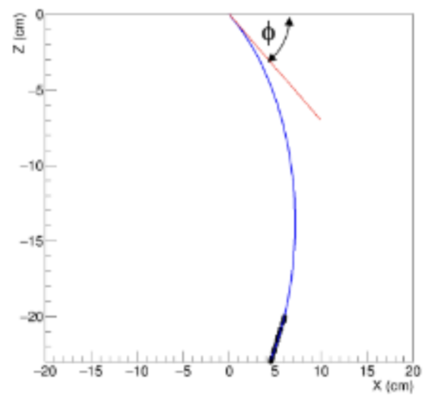
## Detector requirements

- 500 Gauss ($5x10^{-2}$ Tesla)
- Square 60x60 $cm^2$cross section, 60 cm length)
- 4 module with 15 cm length.
- Prototype wheight ~80 kg
- Towards a standard cylindrical monolithic magnet
- Test at LNL needed to evaluate momentum measurement with uRwells

nTOF

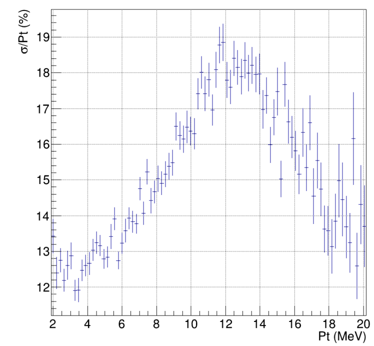
# Simulation

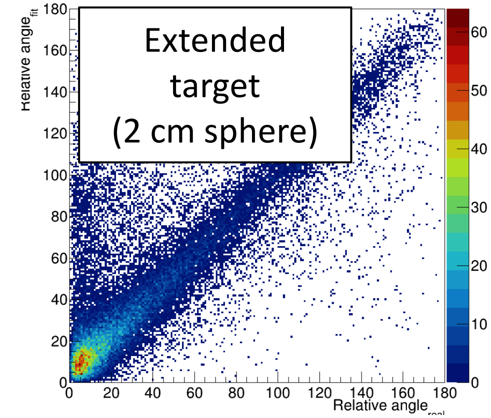


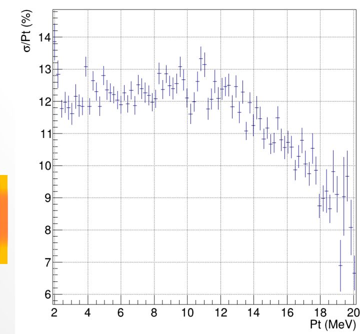



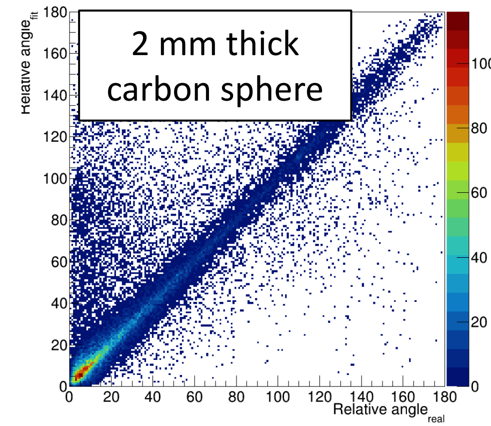

## Detector performance Vs mechanical parameters

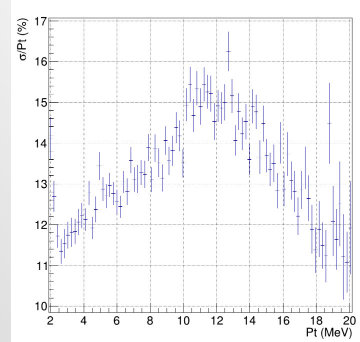
Simulation of reconstructed Vs true aperture angle of $e^- e^+$ pairs and $P_T$ of electrons (positrons). Main worsening due to the target extension (2 cm). Negligible worsening due to the carbon sphere and the $\mu$Rwell strip pitch. Transverse momentum reconstruction at the level of 10-20%.

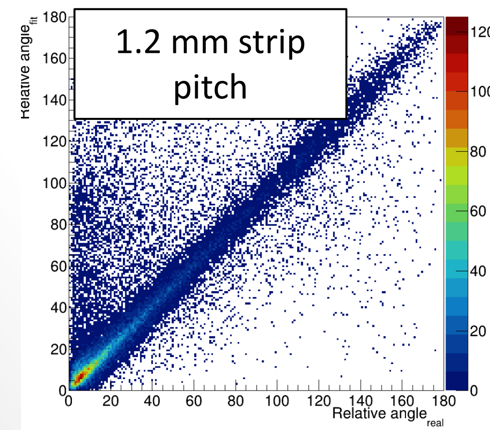


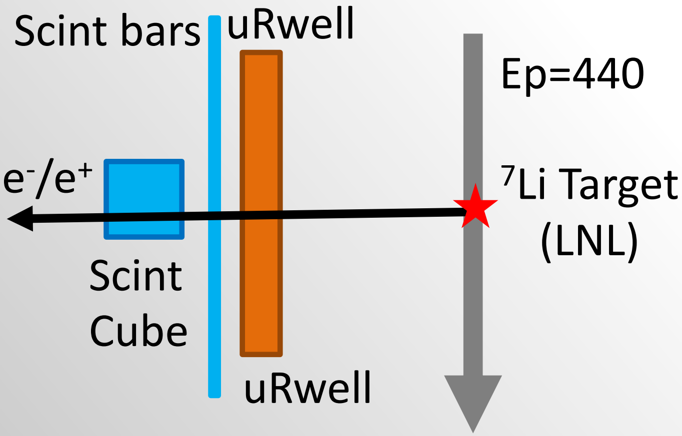



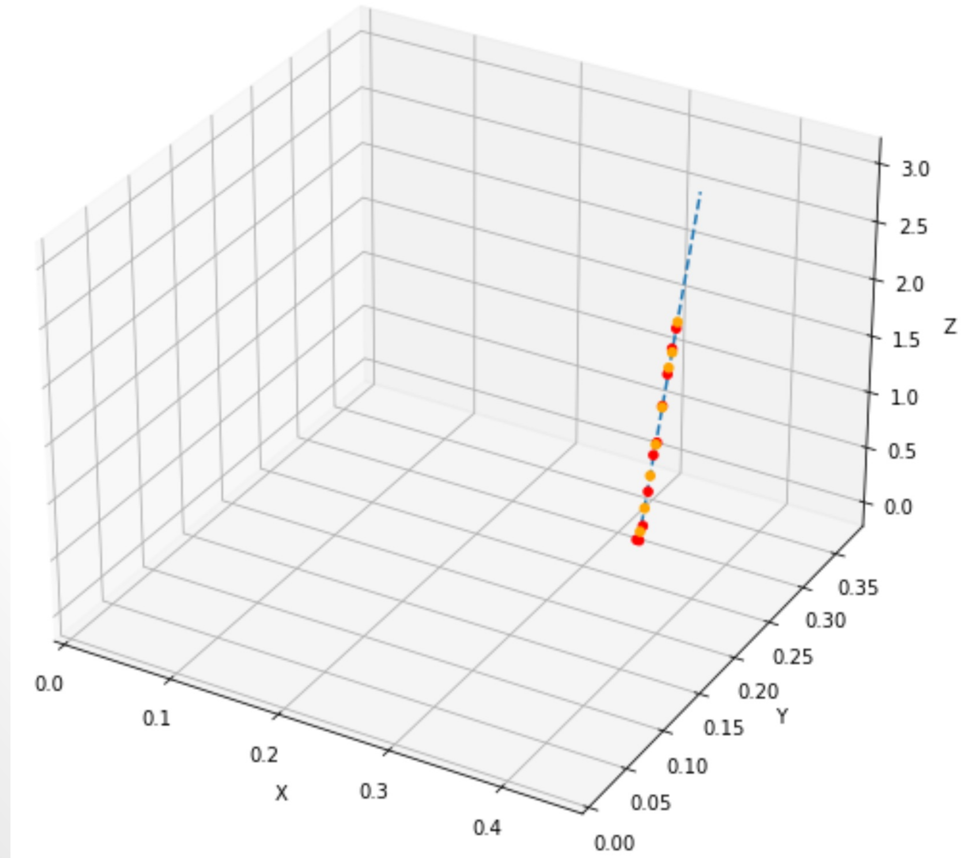
# Test beam at Debrecen




- Trigger= cube ⊗ scint bar plane
- $E_p$= 450 keV
- $I_p$= μA
- Trigger rate =0,5 Hz

↓

- 3D track reconstruction
- direction of tracks (target "shadow")
- Track slope
- Instrumental parameters (cathode electric field etc.




*Example of a real electron track reconstructed with the large μRwell operated in μTPC mode. The electron is produced by the $^{7}Li(p,e^{-}e^{+})^{8}Be$ reaction at $E_p$=0.450 MeV.*

# uRwell results

Encountered problems:

1) Read out with capacitative sharing (big clusters but small signals)
→ No capacitative sharing for X17.
2) Bad trasmission of signal (high noise level of even strips)
→ New design for readout system
3) Too low resistivity of DLC layer (small operating voltage, small amplification)
→ $\sigma_{DLC}$>100 MΩ/square
4) …Minor problems

In conclusion, we understand everything. Altough we foresees to increase S/N of a factor 4, the main concern is the intrinsic small signals of uRwell. Switch to μMEGAS can be a solution (big signal, saturating APV25 electronics) but..

BIG PROBLEM: ONLY 1 producer for all the MPGD (Rui De Oliveira, CERN). **Delivery time and costs out of control**

# The $^{3}He(n,e^{-}e^{+})^{4}He$ at n_TOF

Assuming:

X17 vector boson

10 cm$^3$ of 3He at 380 bar (cylinder 2,21 cm long , 2,4 cm diameter:

No moderator

0,2 Pulse/second

Pot/pulse= 7x10$^{12}$ (Check!)

Neutron/pulse=1,7x10$^{7}$

**570 IPC /day (standard physics, data for ab-initio calculations)**

**14,38 X17/day**

**Very long run is needed in dedicated conditions.**

# Forthcoming activities and conclusion

We must do:

Technical design report

Test at LNGS for gamma-flash Vs SiPM

Circuit to prevent gamma flash saturation (if any)

Test at LNL ($P_t$ resolution with magnet prototype)

Test at CERN (SPS): tracking Vs angle with m.i.p.s DRD1 period: 15 september 2 October

Test at CERN (EAR2, end of October). (in)sensitivity to gammas and neutrons.

Simulation of detector setup at n_ToF.

From the collaboration we need:

Main power for laboratory tests and beam tests.

Simulation of the n_Tof measurement $^3He(p,e^-e^+)^4He$ with pressurized target

Technology development of dense, thin and "nake" targets of $^3He$, $^2H$, $^7Li$

Simulation of the $^2H(p, e^-e^+)^3He$ measurement (based on the M.Viviani results)

Advanced ERC

LNGS beam request

From INFN (and n_ToF) we need money NOW (Last Train!)

Sipm Hamamatsu (extremely urgent)

Scint bars Scionix (urgent)

Chambers (microMEGAS or uRwell in any case only one producers, extremely urgent, see above))

$^3He$ (???)

FERS2 (test with CAEN needed, to convince me) (Not urgent)

APV25 (at the moment, only to be borrowed from other groups).

Final Magnet (probably cylindrical, see above)

~20 liters of $^3He$