Searching for X17 anomaly at nTOF experiment

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- C. Massimi (UNIBOLOGNA)
- N. Colonna (INFN BARI)
- S. Fiore (ENEA ROMA)
- A. Mazzone (CNR BARI)

n_TOF and LUNA

- L. E. Marcucci (UNIPISA)
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Theoretical group

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

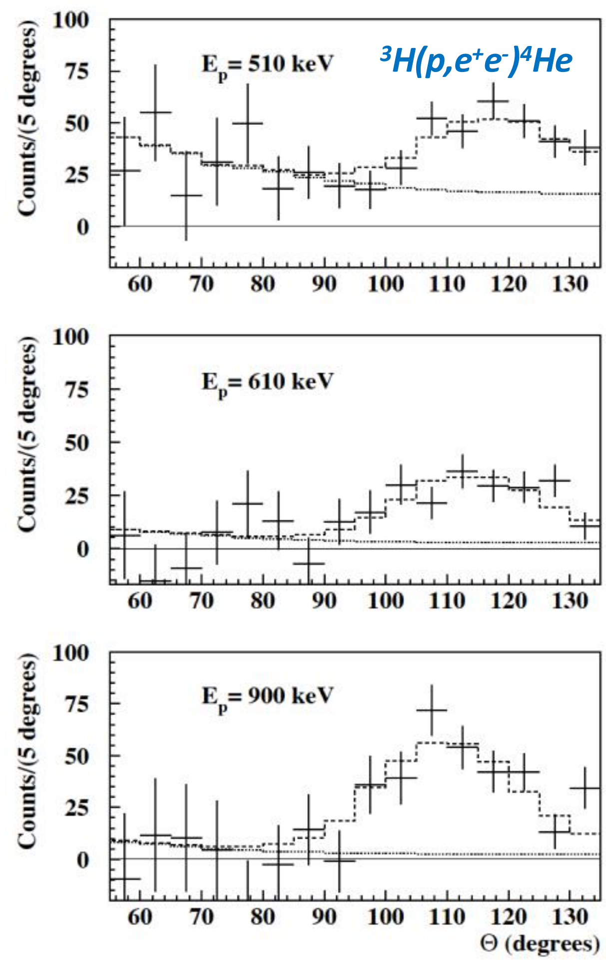
Detector R&D

Working group (in evolution)

X17 ATOMKI Results

A significant anomaly has been recently observed 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.

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 evidence supporting the existence of the hypothetic X17 particle".
arXiv:1910.10459v1 [nucl-ex] (23 October 2019).
Krasznahorkay, A.J.; et al.:
"A new anomaly observed in ^{4}He supports the existence of the hypothetical X17 particle".
arXiv:2104.10075v1 [nucl-ex] (20 April 2021).

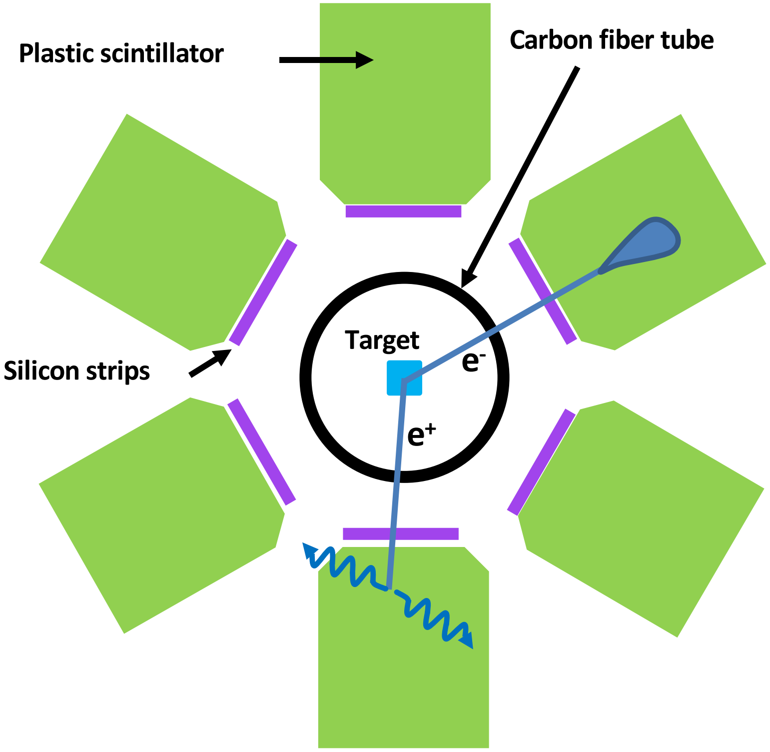


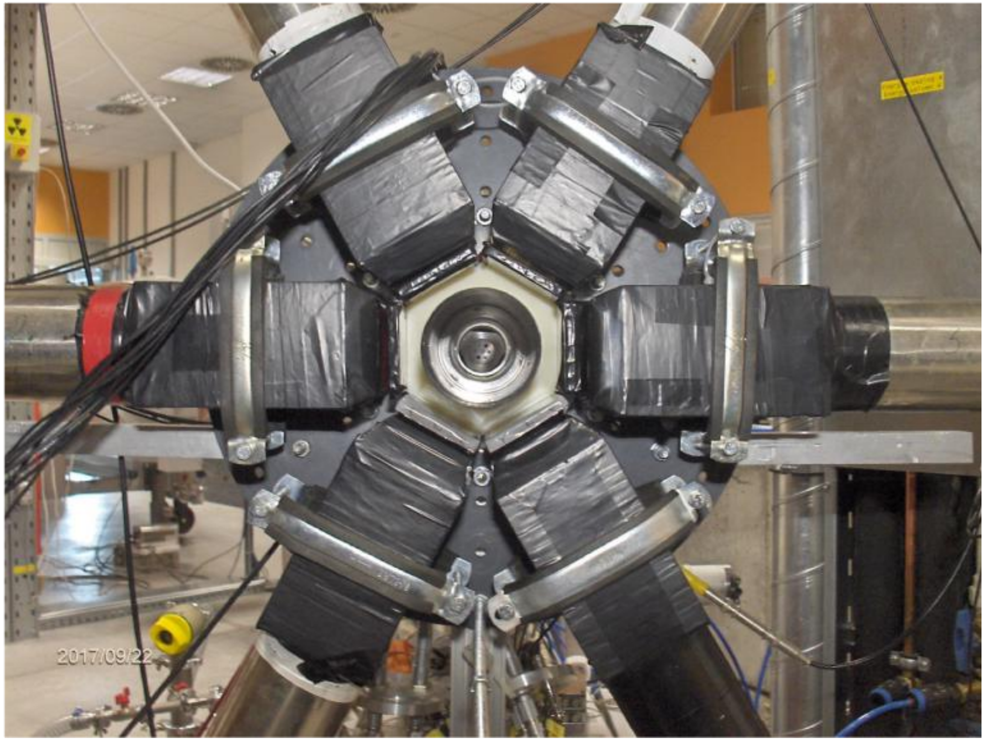
Reaction	$M_{X17} \pm \Delta M_{stat} \pm \Delta M_{syst}$ (MeV)	Statistical evidence
$^{7}Li(p,e^{+}e^{-})^{8}Be$	16.70±0.35±0,50	>5 sigma
$^{3}H(p,e^{+}e^{-})^{4}He$	16.94±0.12±0.21	>9 sigma

- ***This anomaly has been interpreted as the signature of a BOSON (hereafter X17) not foreseen in the standard model of particle physics.***
- ***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.***

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

- ^{3}H 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

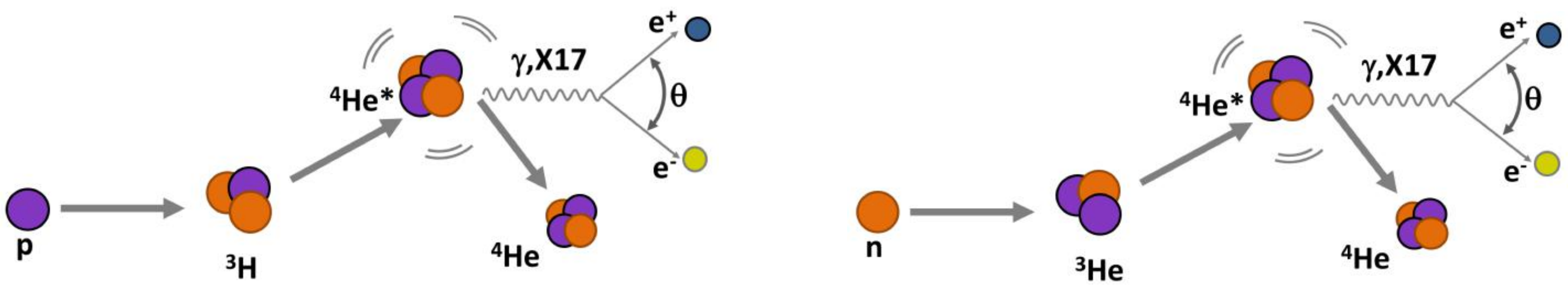




X17 @ nToF

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

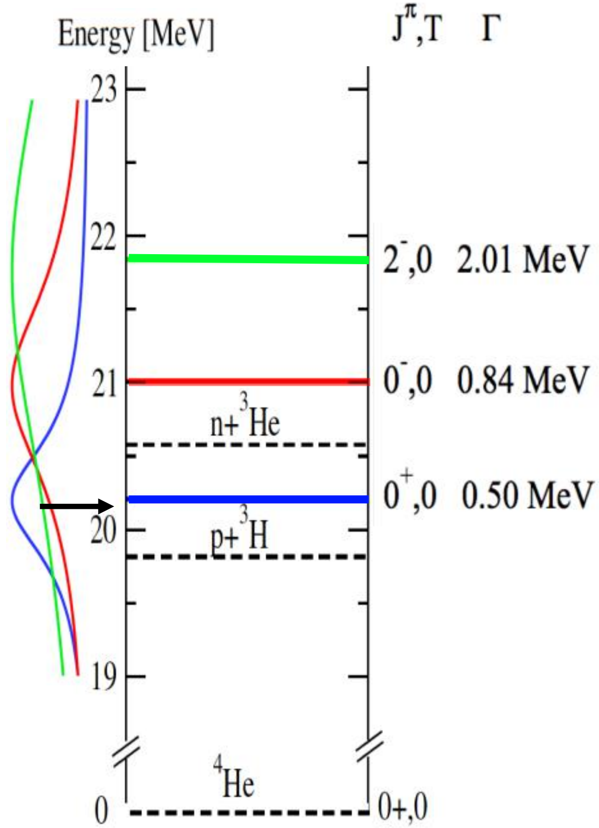
^{3}H(p,e$^+$e$^-$)^{4}He → ^{3}He(n,e$^+$e$^-$)^{4}He

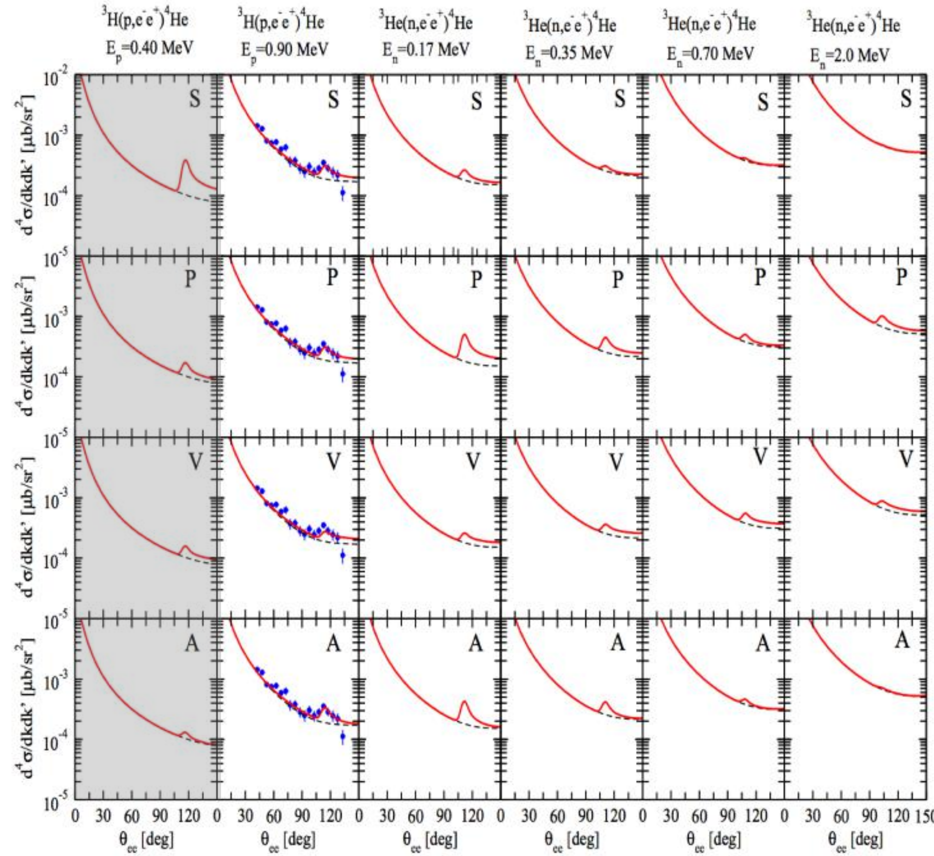


Physics:

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

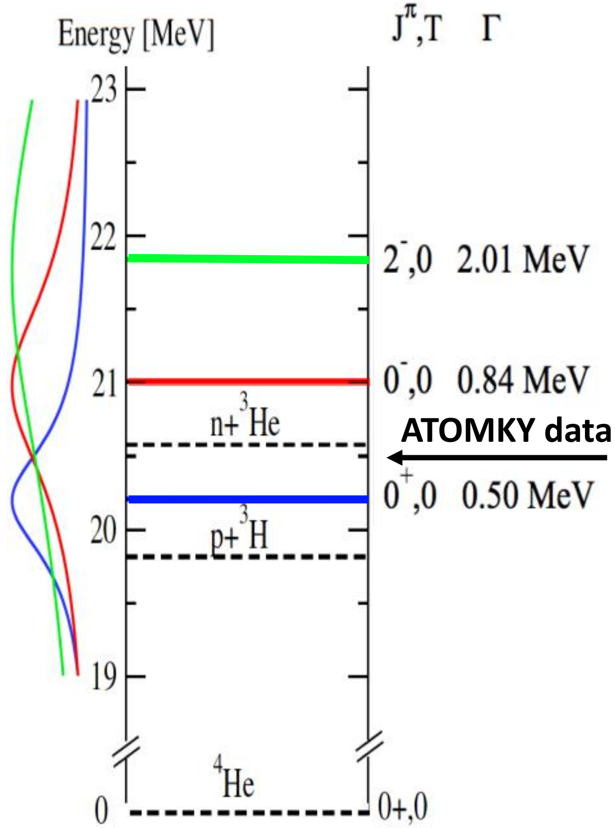
X17 @ nToF

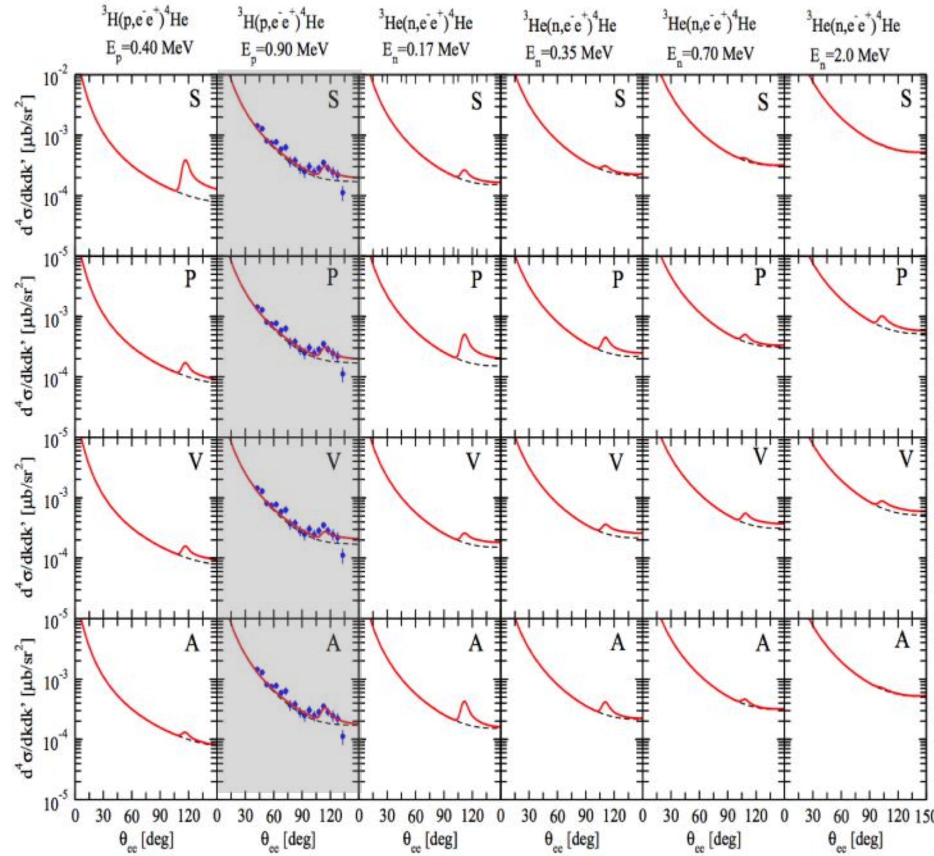




M. Viviani et al.: "X17 boson and the $^3H(p,e^+e^-)^4He$ and $^3He(n,e^+e^-)^4He$ processes: A theoretical analysis"
arXiv:2104.07808 [nucl-th] , submitted to PRC

X17 @ nToF





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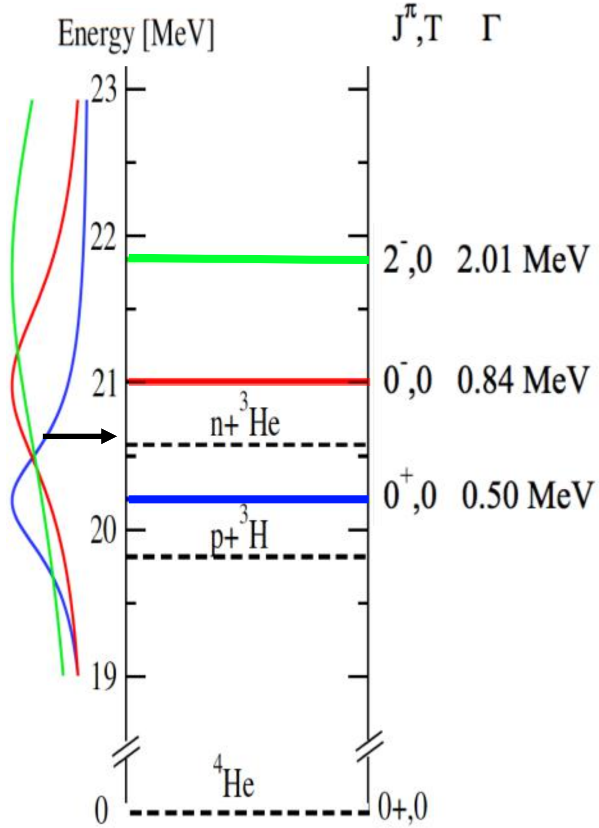

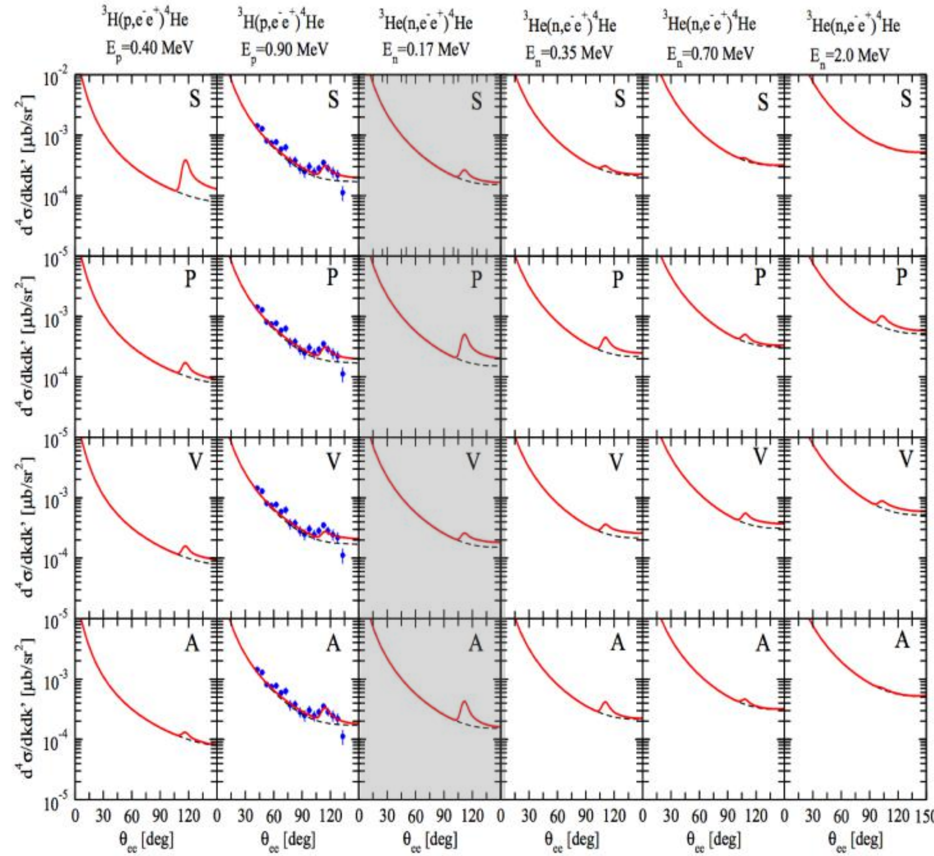

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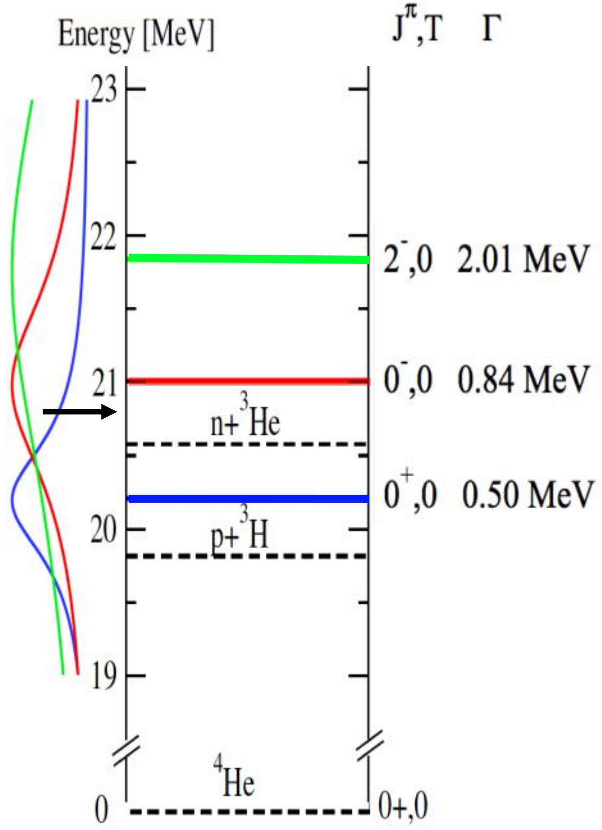

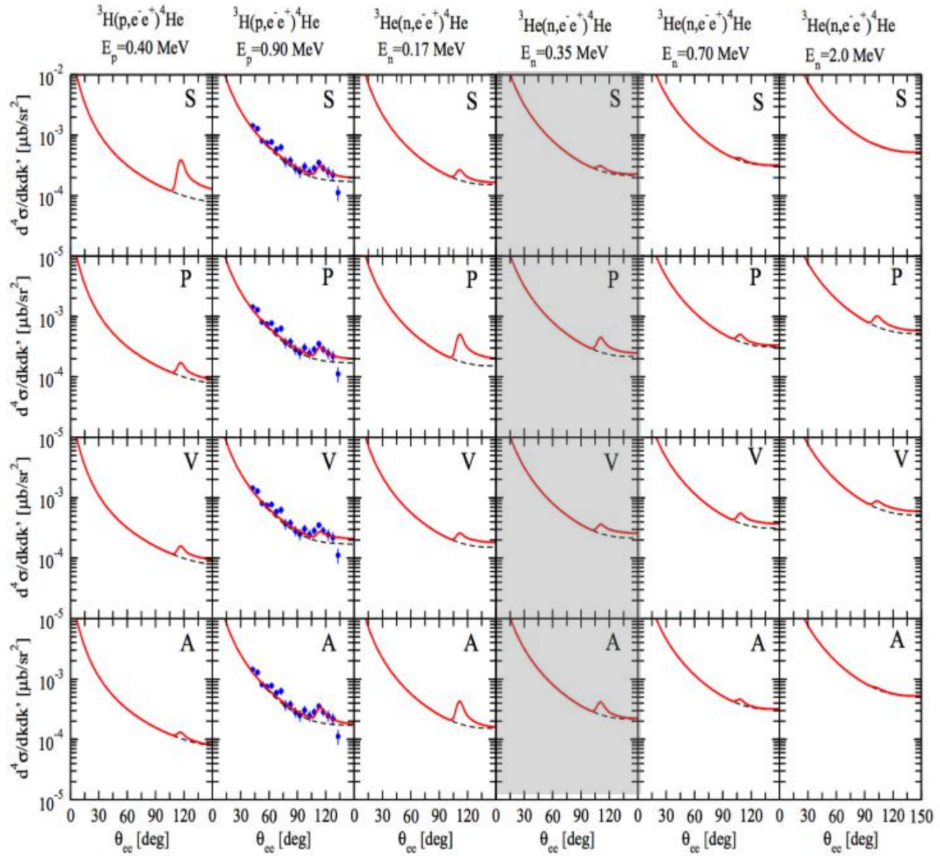

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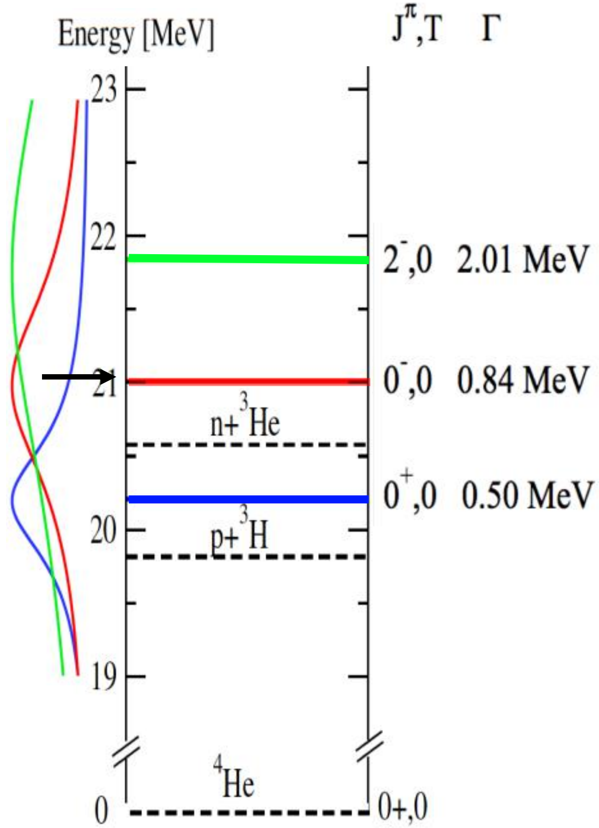

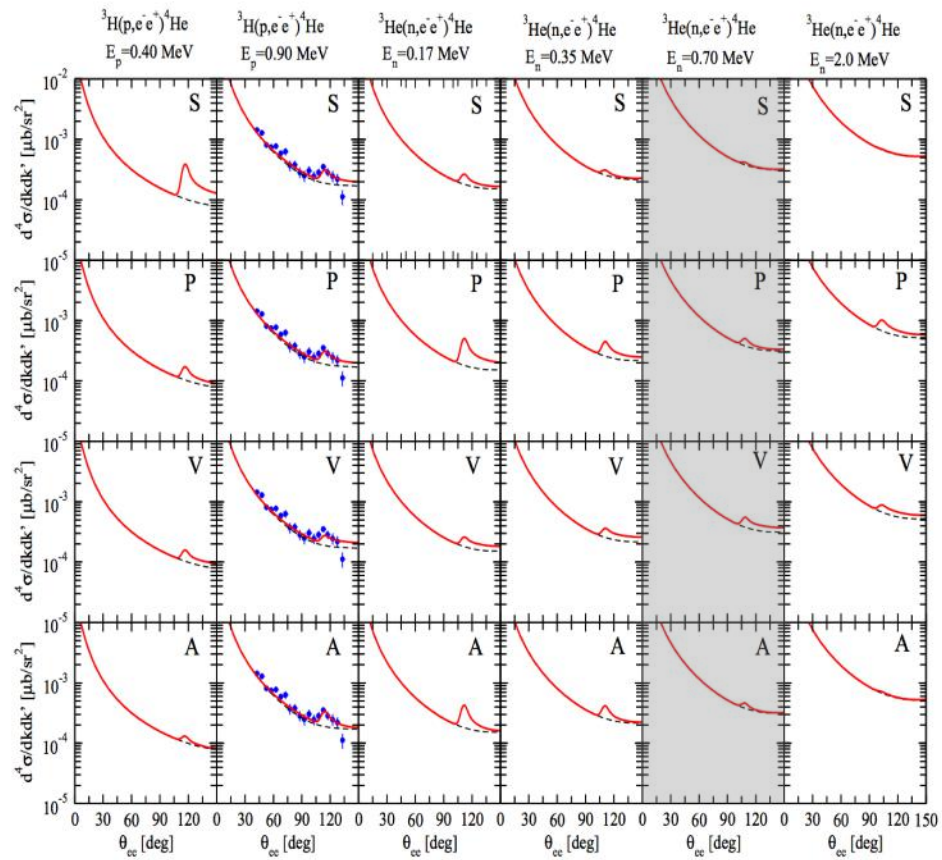

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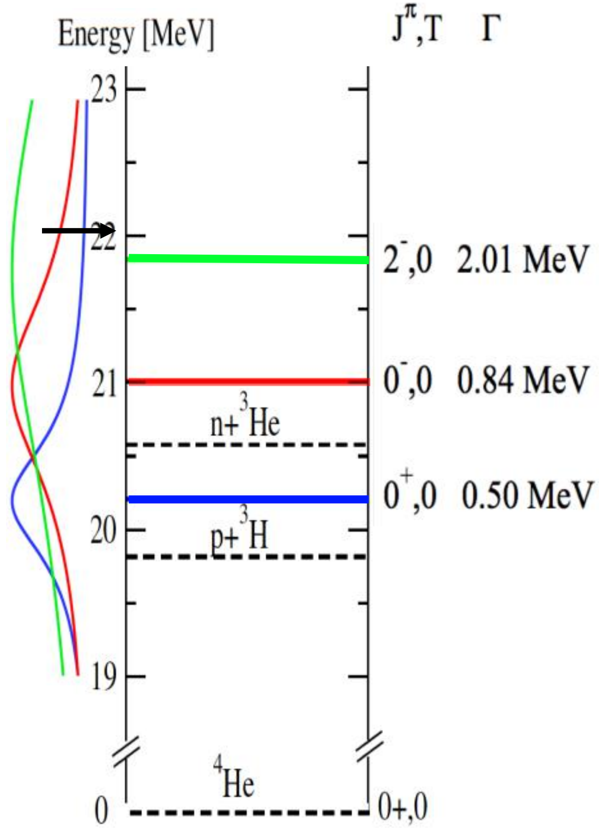
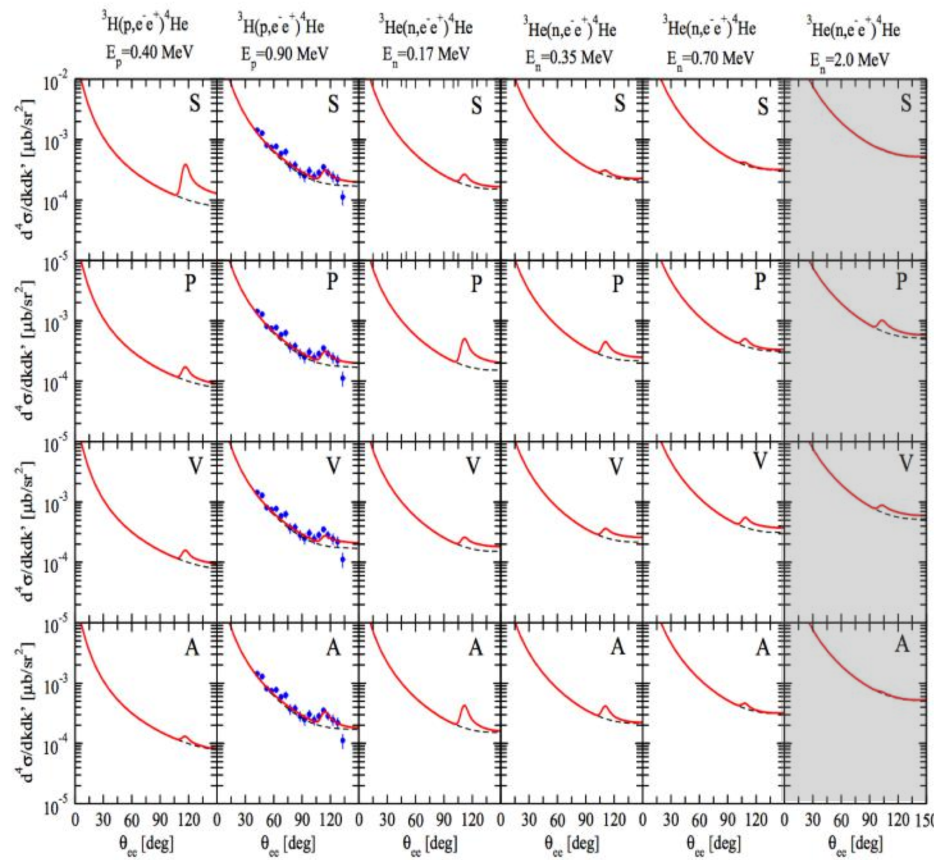
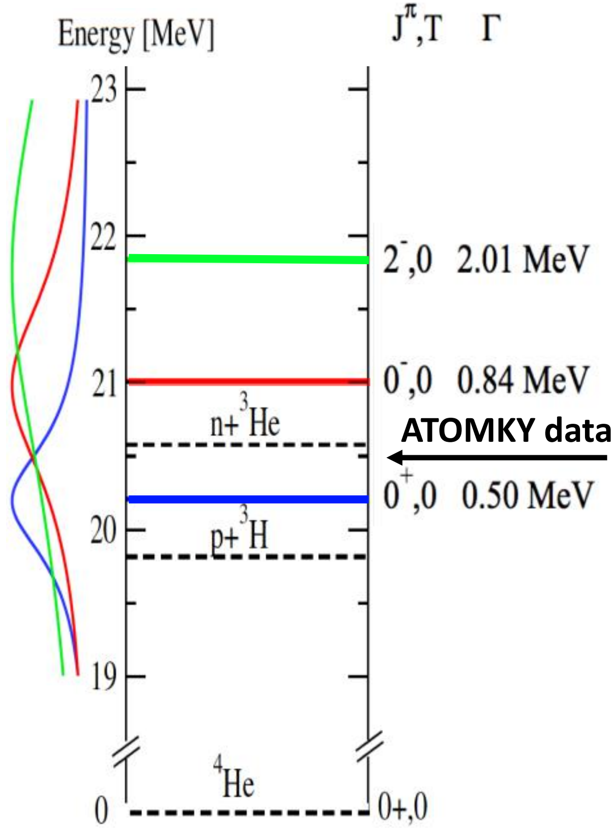


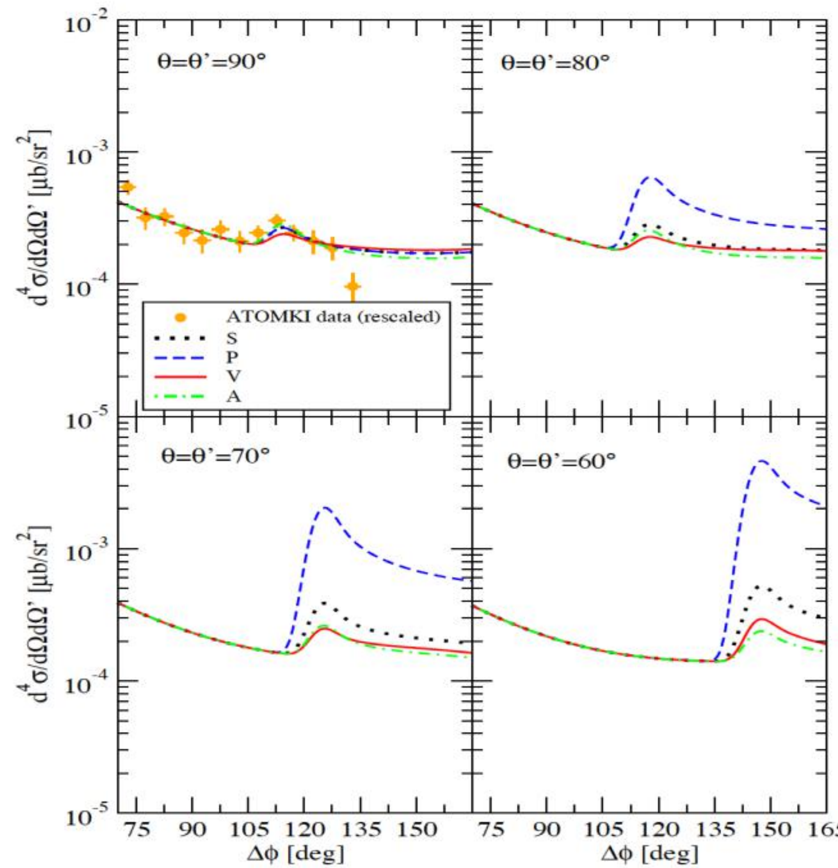


❖ **Wide energy range (proton and neutron beams) to explore all resonances with different J^{π}**

M. Viviani et al.: "X17 boson and the $^{3}H(p,e^{+}e^{-})^{4}He$ and $^{3}He(n,e^{+}e^{-})^{4}He$ processes: A theoretical analysis"
arXiv:2104.07808 [nucl-th] , submitted to PRC

X17 @ nToF

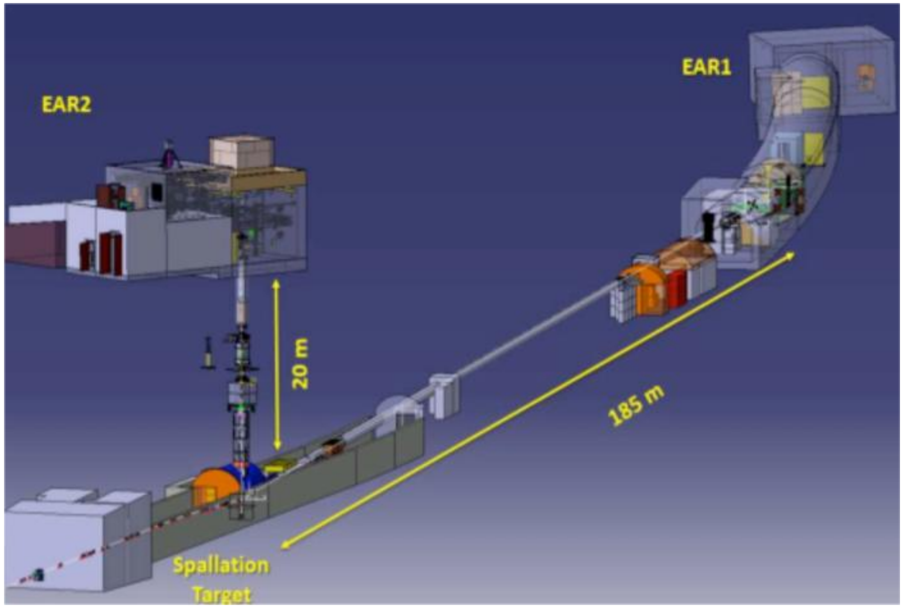




- ❖ Wide energy range (proton and neutron beams) to explore all resonances with different J^{π}
- ❖ Large detector acceptance (statistics and kinematics)

M. Viviani et al.: "X17 boson and the $^3H(p,e^+e^-)^4He$ and $^3He(n,e^+e^-)^4He$ processes: A theoretical analysis" arXiv:2104.07808 [nucl-th] , submitted to PRC

Facilities



- **n_ToF @ CERN: pulsed neutron beam in a wide energy range (thermal<E_n<100 MeV).**
- **Time of flight to establish the single neutron energy (10-10^8 eV)**
- **dedicated detector**

- **LUNA-MV @ LNGS: high intensity proton beam and low bacground**
- **Terminal Voltage ≈ 0.2 – 3.5 MV**
- **I_{max} ≈ 100 μA of protons**
- **Underground operation**
- **dedicated detector**

^{3}He(n,X17)^{4}He (new!)

↳ e^+e^-

Measurements:
2022-24 (CERN LoI approved)

^{3}H(p,X17)^{4}He

↳ e^+e^-

Measurements:
2023-5 (LoI in preparation)

EAR2 @ n_ToF

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

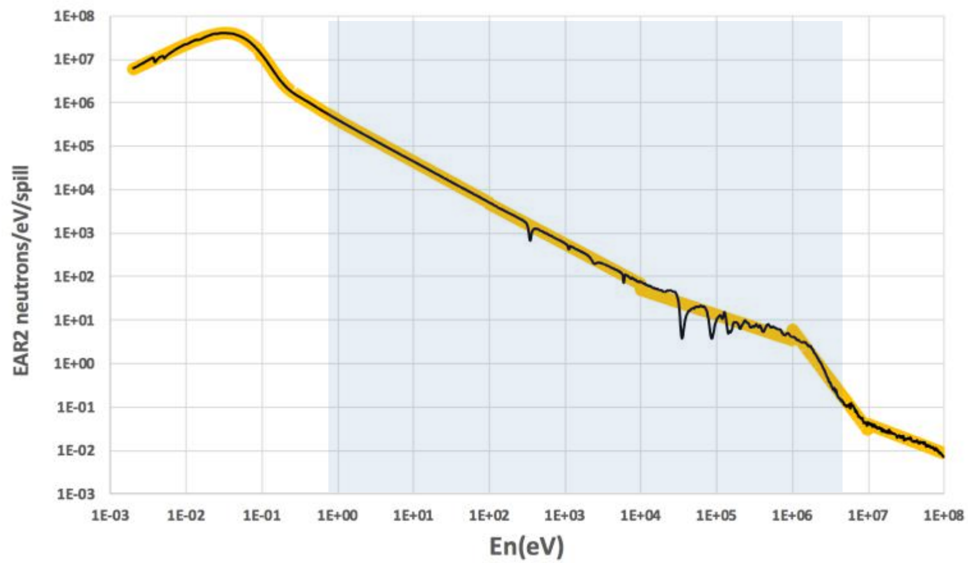


Table and Figure: neutrons per pulse (frequency=1.2 sec)

Assuming:
ρ=8.21*10^{21} atoms/cm^3
target lenght=10 cm
Duty Cycle=100%
efficiency=100%
acceptance=100%

En_min (eV)	En_max (eV)	3He(n,g)4He gamma/pulse	3He(n,e+e-)4He IPC/day	3He(n,X17)4He X17/Day (vector)	T_min (us)	T_max (us)
1	10	0,8	120	3	411	1300
10	100	0,9	133	3	130	411
100	1000	1,0	150	4	41	130
1000	1E+04	1,2	182	5	13	41
1E+04	1E+05	2,1	324	8	4	13
1E+05	1E+06	15,7	2518	63	1,30	4
1E+06	1E+07	11,3	1812	45	0,41	1,30
	TOTALI-->	33	5239	131	0,41	1300

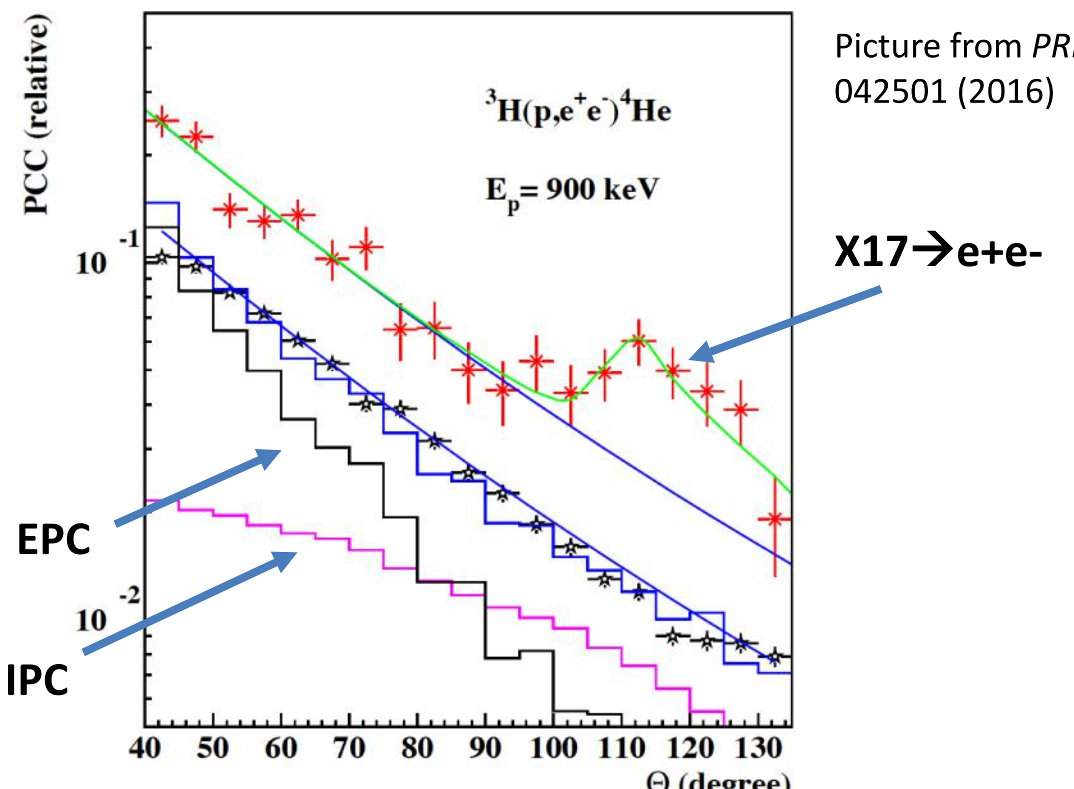
Wide energy range for n_ToF neutrons

Under study:

Moderator removal/change, to increase the abundance of neutrons in the MeV energy region

Backgrounds

- Gammas from ^{3}He (n,γ)^{4}He. Only one shower with E ≥18 MeV instead of the two e+e- tracks.
- External Pair Convertion (EPC), i.e. gammas convert into e+e- pairs in the material sorrounding the target. Most of the pairs can be cut off because of their small relative angle.
- Internal Pair Convertion (IPC) through the ^{3}He(n,e+e-)^{4}He process (virtual gammas convert into e+e- pairs). Also in this case, small relative angle between e=e- pairs.
- Cosmic rays. Not a problem, just needed background measurements (e.g. asyncrounous trigger with respect to the proton pulse)
- neutron interacting with setup→materials must be carefully chosen and tested.



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

Background of $^3He(n,p)^3H$ protons

Most energetic protons due to **$^3He(n,p)^3H$ reaction** can reach detectors and produce background/noise.

- RICH detector insensitive to protons
- ToF to discard early events→Fast detectors
- Proper Vetoing Electronics
- Proper thickness of ^3He container (range of protons<<range of electrons)
-

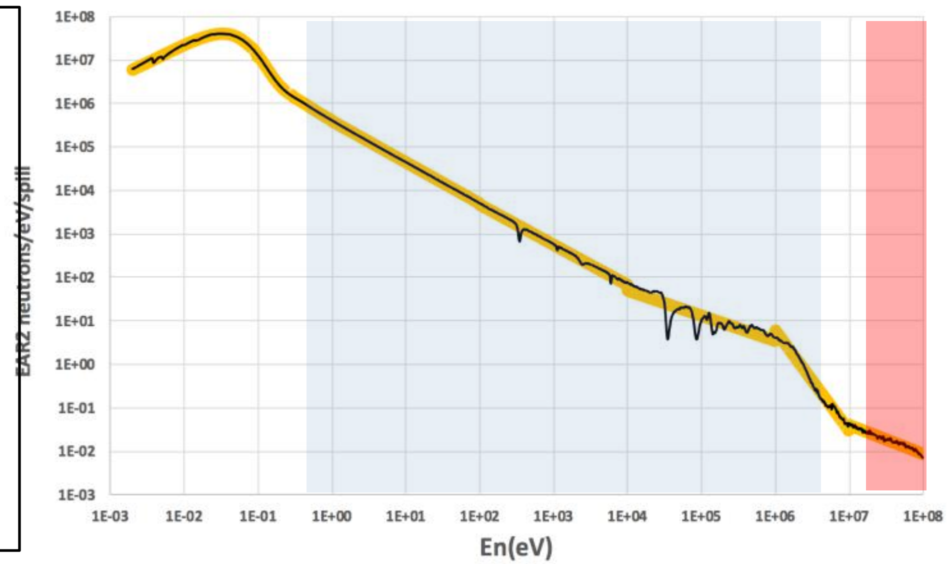
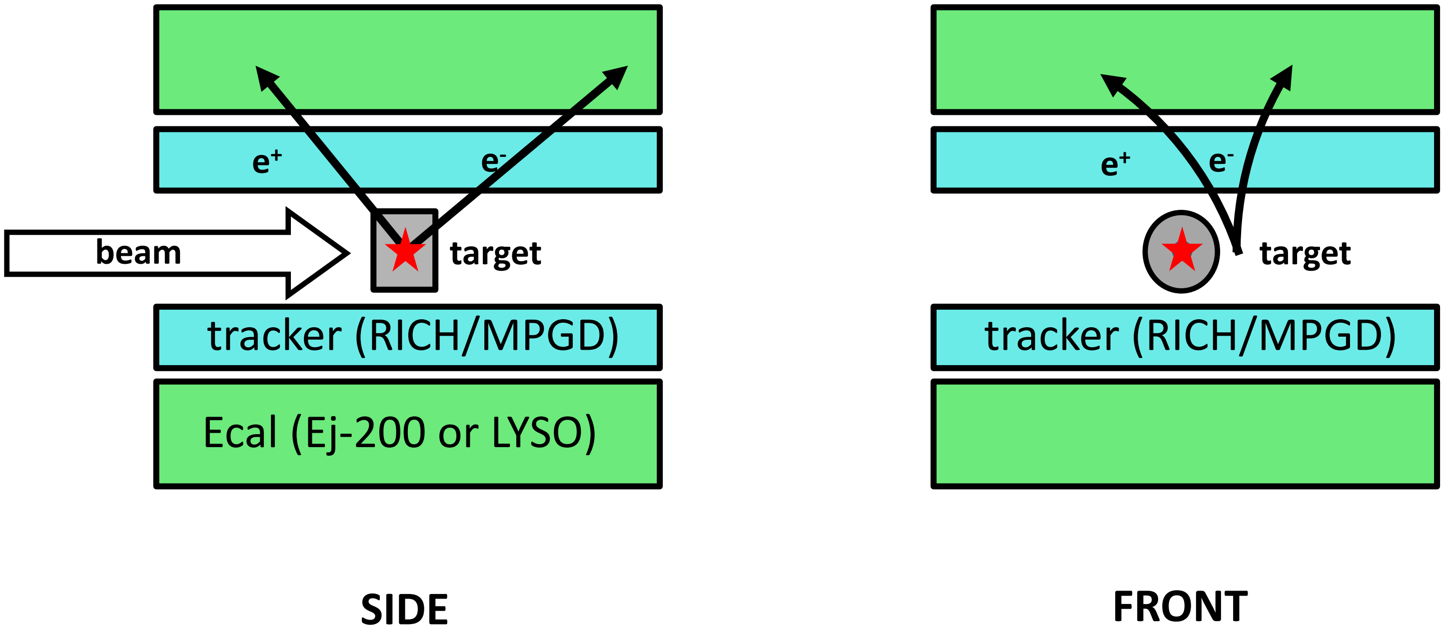


Table and Figure: neutrons/protons per pulse (frequency=1.2 sec)

Assuming:
$\rho=8.21*10^{21}$ atoms/cm^3
target lenght=10 cm
Duty Cycle=100%
efficiency=100%
acceptance=100%

Energy (MeV)	neutron/spill/10 MeV	proton/pulse	T_EAR2 (ns)
20	2,4E+05	3675	295
30	1,0E+05	869	243
40	5,6E+04	312	212
50	3,5E+04	141	191
60	2,4E+04	74	176
70	1,7E+04	43	164
80	1,3E+04	27	154
90	1,3E+04	147	147
10-100 MeV	1,5E+06	5288	147-295

DETETCOR Conceptual design



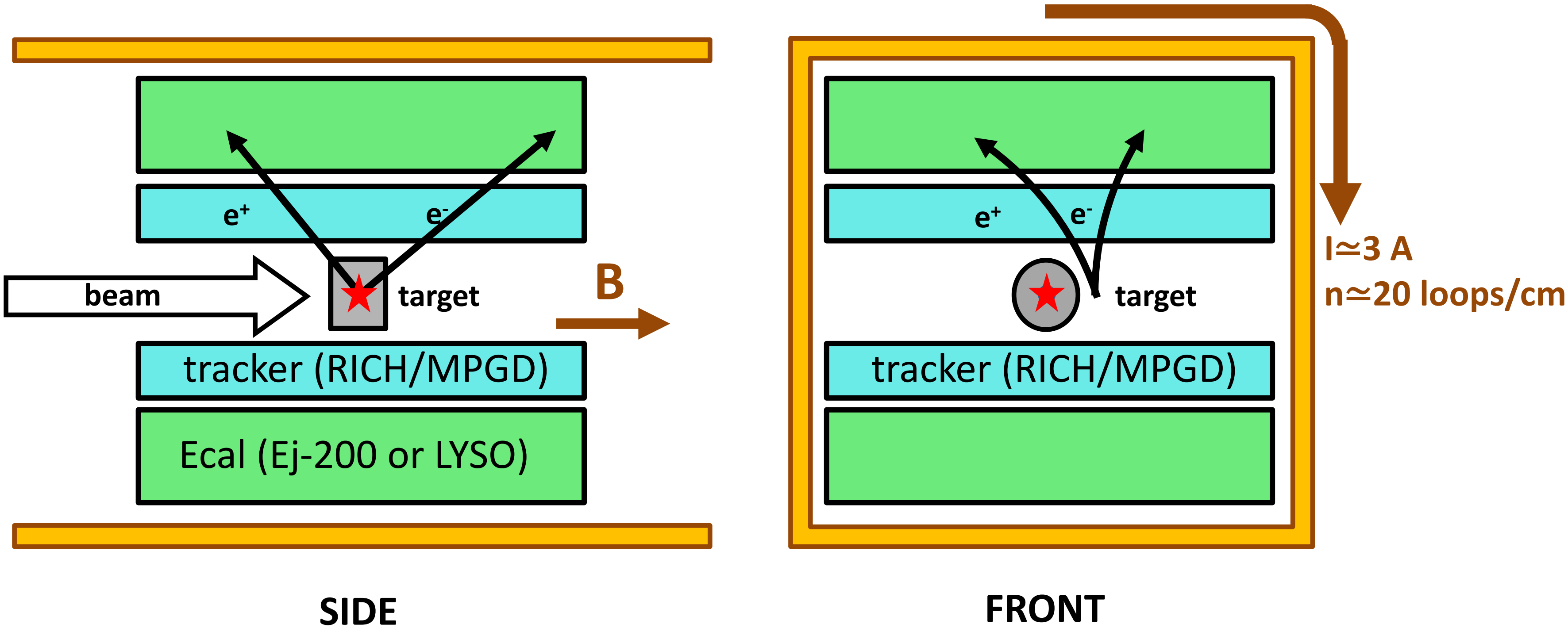
High intensity neutron beam $0<E_n[\mathrm{MeV}]<3$

High density target $\rho=10^{21}$ atoms/cm^3

Tracking (vertex and Pairs aperture angle energy)

4-momenta

DETETCOR Conceptual design



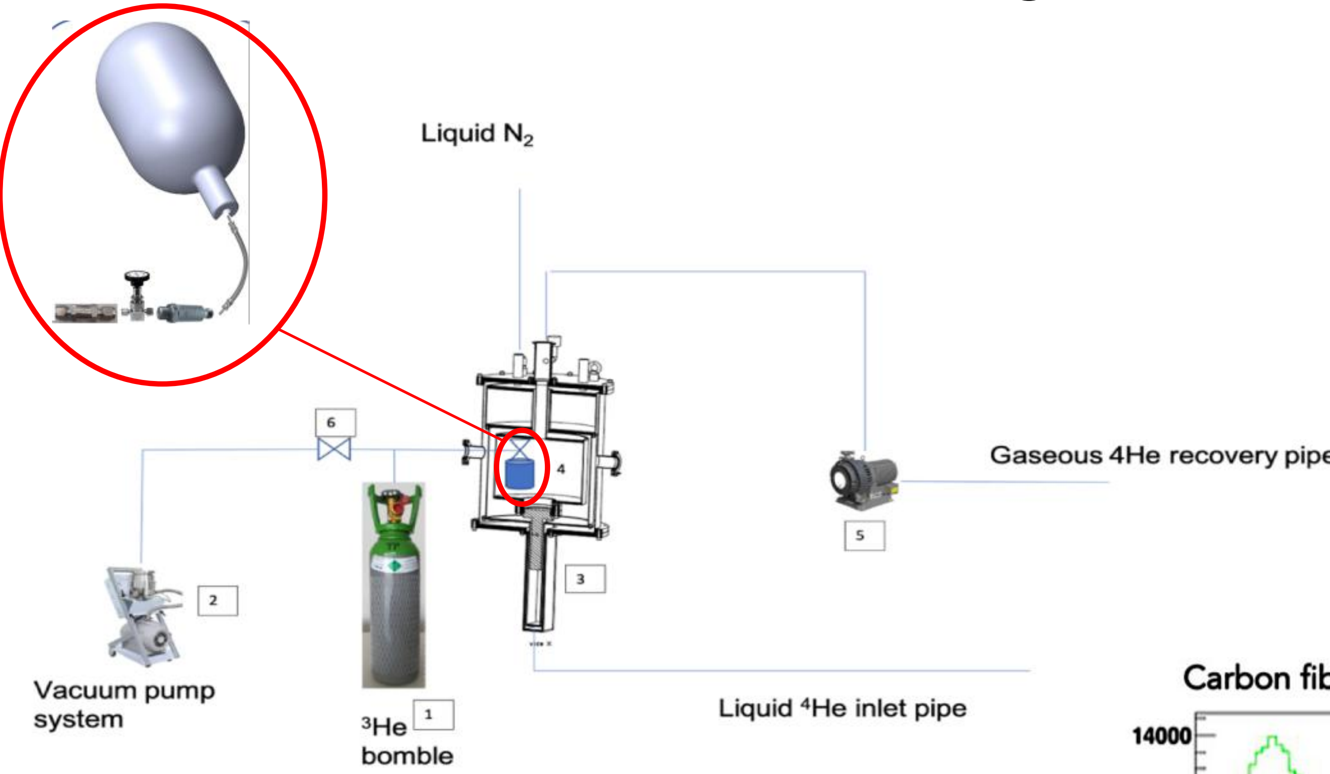
High intensity neutron beam $0<E_n[\mathrm{MeV}]<3$

High density target $\rho=10^{21}$ atoms/cm^3

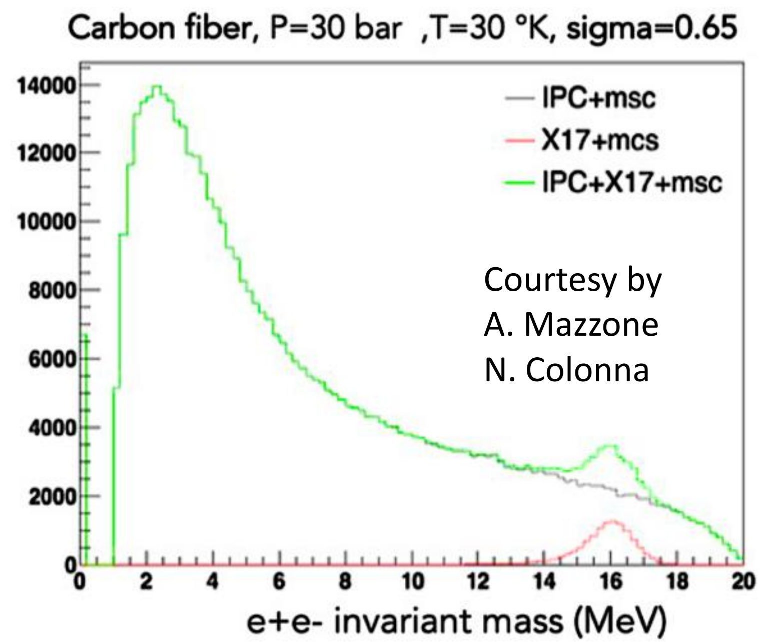
Tracking (vertex and Pairs aperture angle energy)

4-momenta

3He target

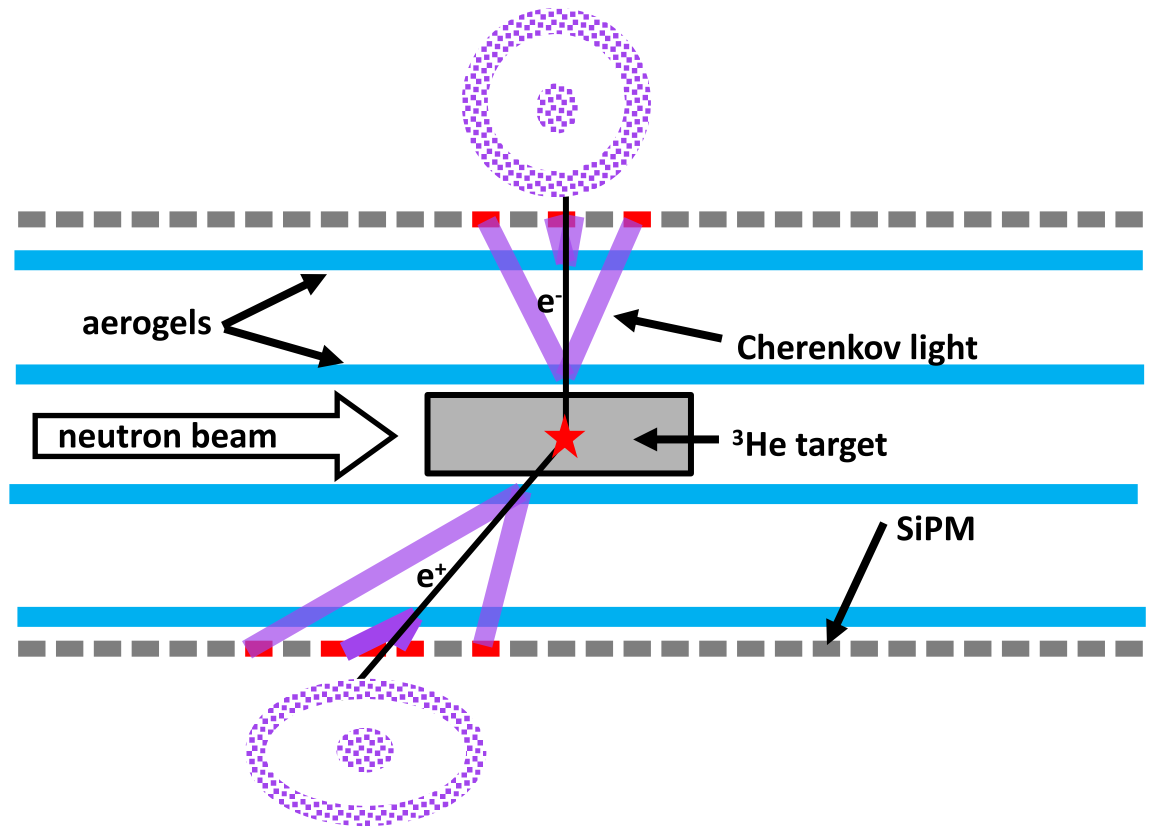


Courtesy by P. Mastinu



Courtesy by
A. Mazzone
N. Colonna

ROAD1: RICH (cfr. E. Cisbani)



β(e-,e+) @ 8 MeV = 0,993

β(p) @ 100 MeV = 0,42

→**No signals** due to the ^{3}He(n,p)^{3}H protons

Low ^{3}He(n,γ)^{4}He gamma background in the RICH

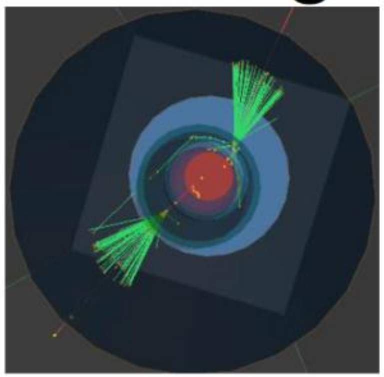
Standard Aerogels with n=1.05

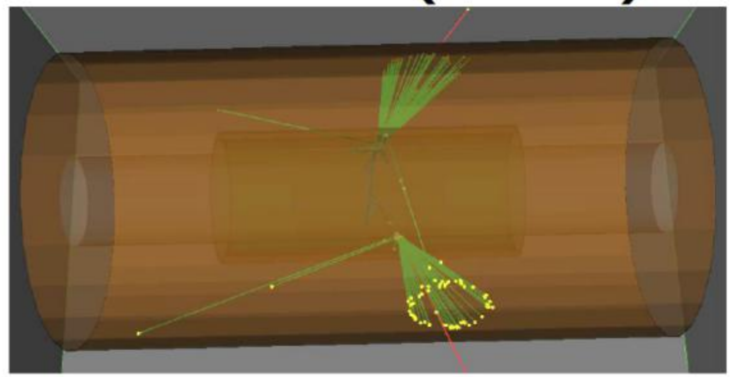
Ellipse centers: e+/e- impact points

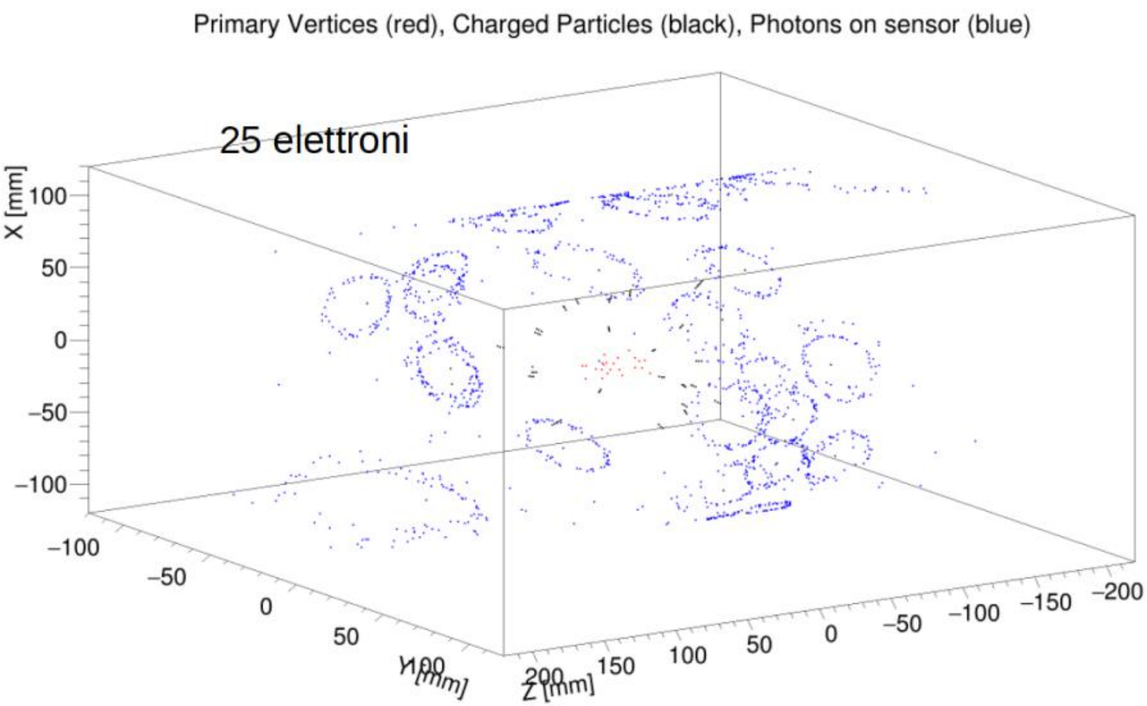
Ellipse shapes: e+/e- Directions

Single Aerogel Radiator (1.05) 5 mm

GEANT4 simulation



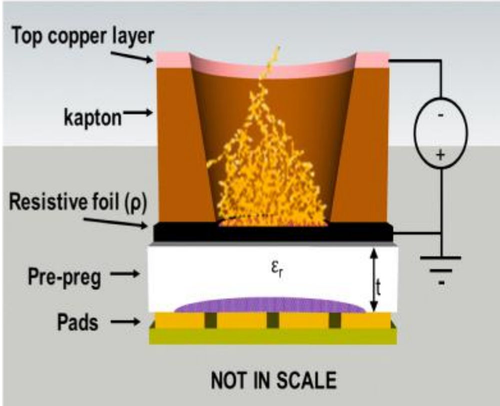


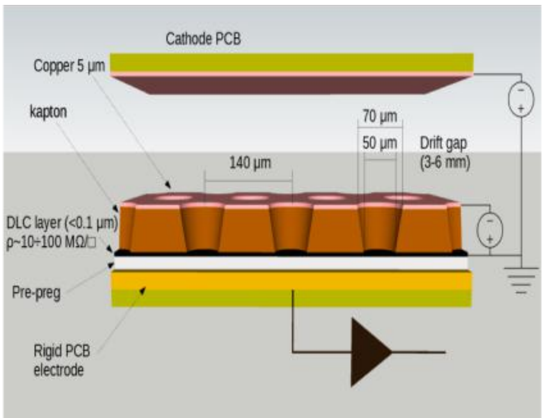


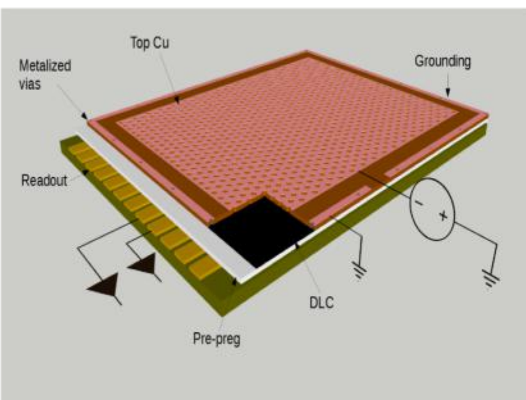
Realistic Aerogel model scaled from CLAS12-RICH data

Courtesy by E. Cisbani

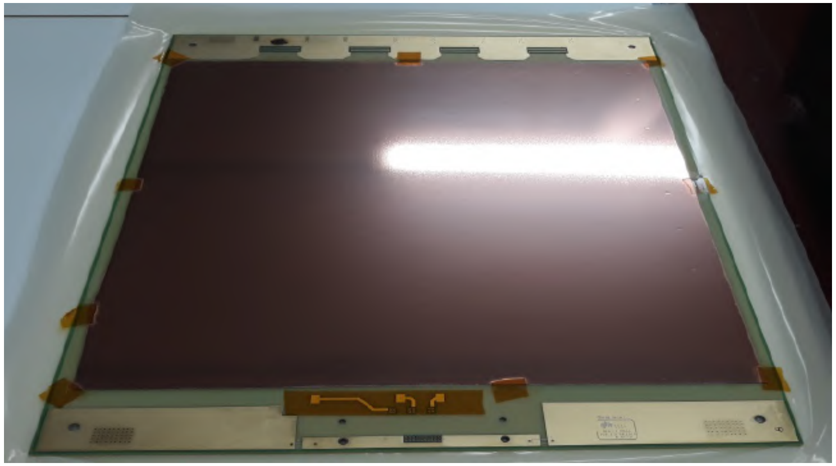
ROAD2: TPC with MPGD







307×307 mm^2 active area SRL - RWELL

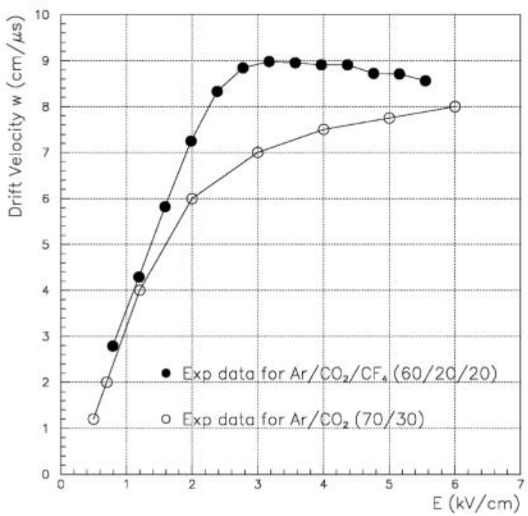


Prototype (Design: LNF-INFN)
PCB production: ELTOS SpA
Detector manufacturing: CERN – PH dept. DT group (Rui de Oliveira)
PCB characteristics:

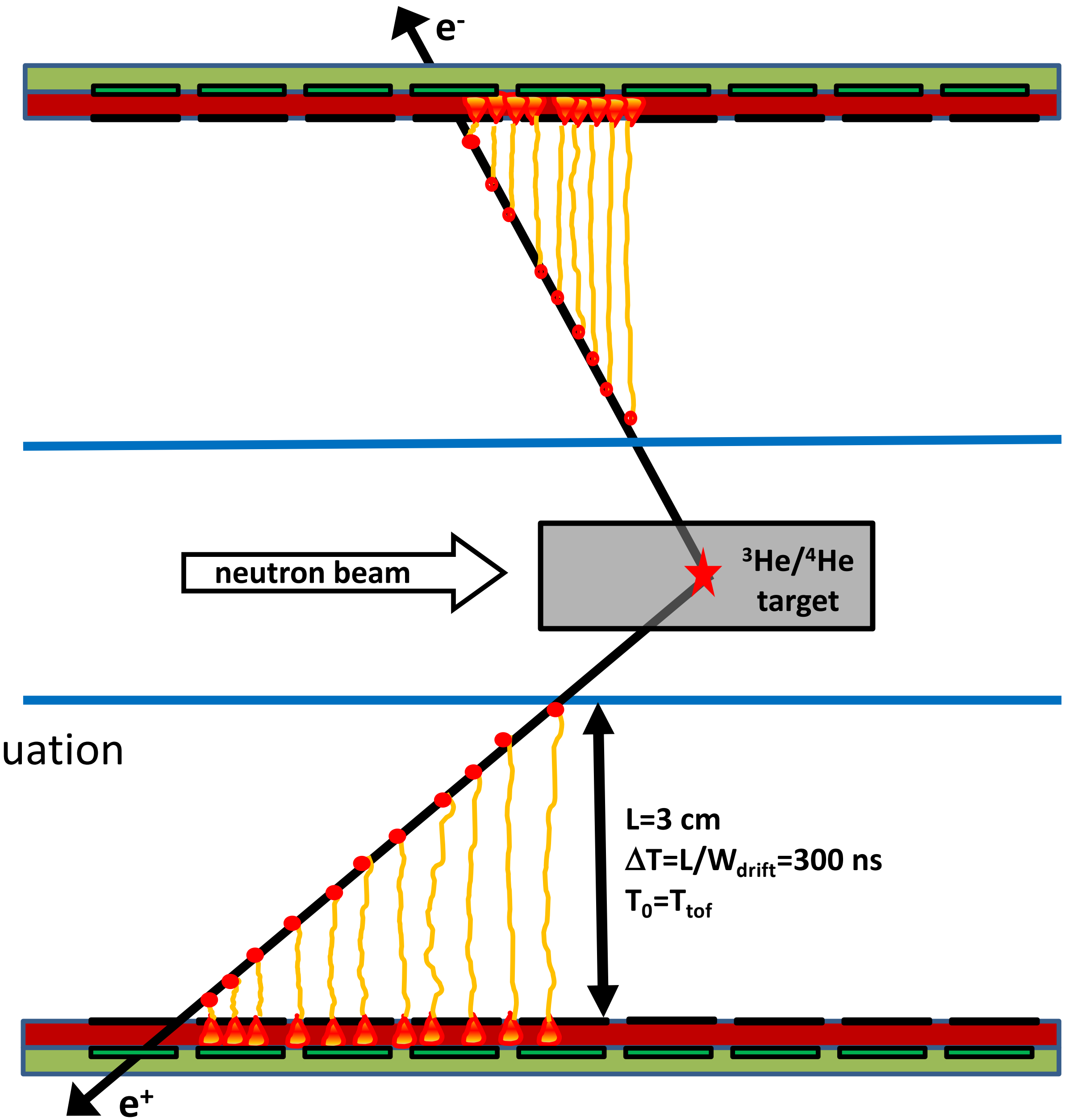
- n.512 1-D strip, with 600 um pitch
- 30 mm gas gap
- Gas mix → $Ar/CO_2/CF_4$ = 60/20/20
- Delivery: end of August

TPC: Test at EAR2

with Ar/CO_2=/CF4=60/20/20
***$1/W_{drift}$* ~ 10 ns/mm**
→300 ns signals (crossing e+e- pairs)

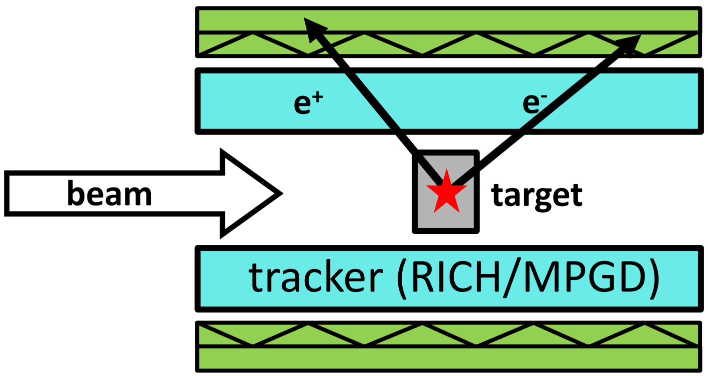


Goal of the test: Background evauation
^{3}He(n,p)^{4}He and E_n>10 MeV)
Gamma Flash
^{3}He(n,γ)^{4}He
^{3}He(n,e+e-)^{4}He
interactions with materials
Trigger/timing with pulsed beam

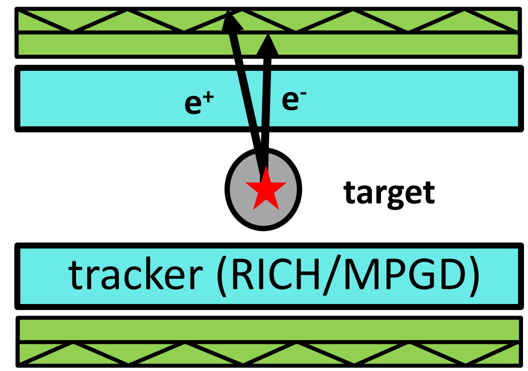


CALORIMETER: Test at EAR2

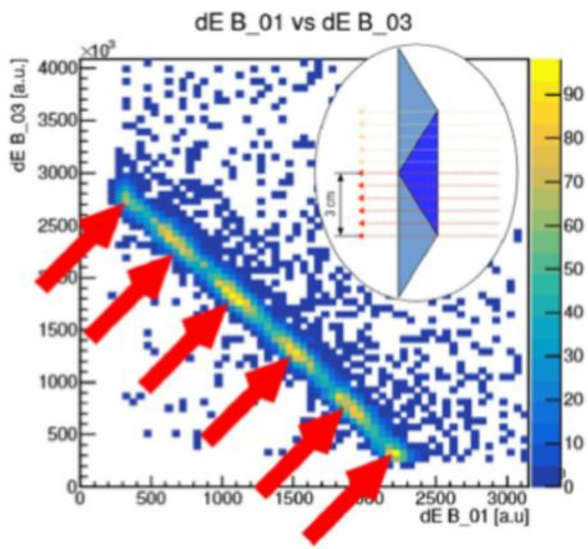
FINAL DESIGN Still in Progress. Presently 2 options: Ej-200 segmented SCINTILLATOR (~8 cm thick) or LYSO Crystal (~2 cm thick). TRIGGER and e+e- energies.

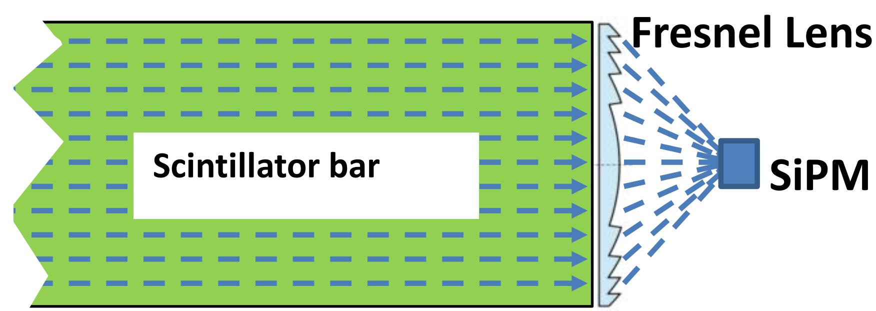


SIDE



FRONT

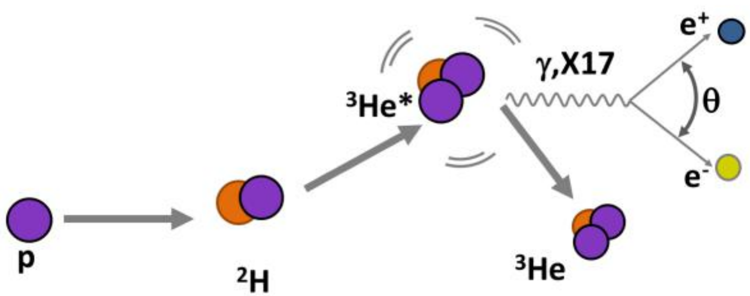




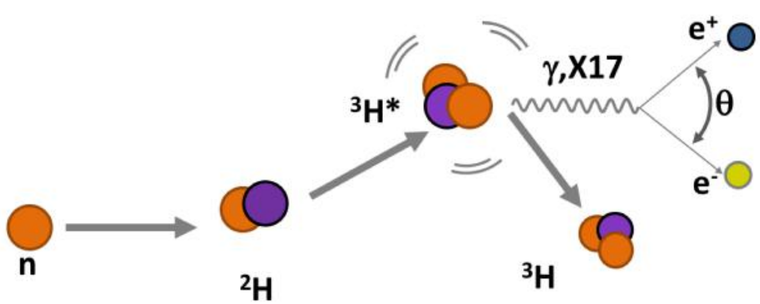
See also Tommaso Marchi talk

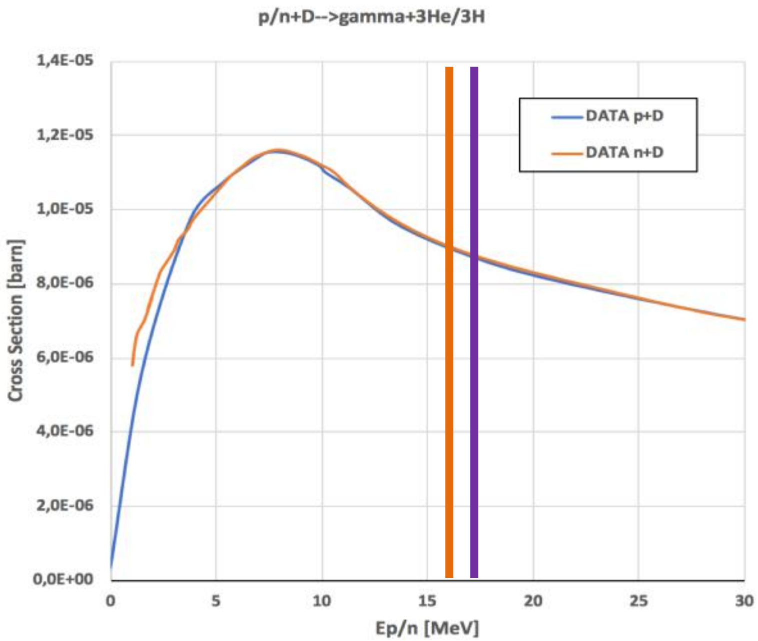
Comparison of A=3 nuclei "decay"

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



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





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

High energy neutrons

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

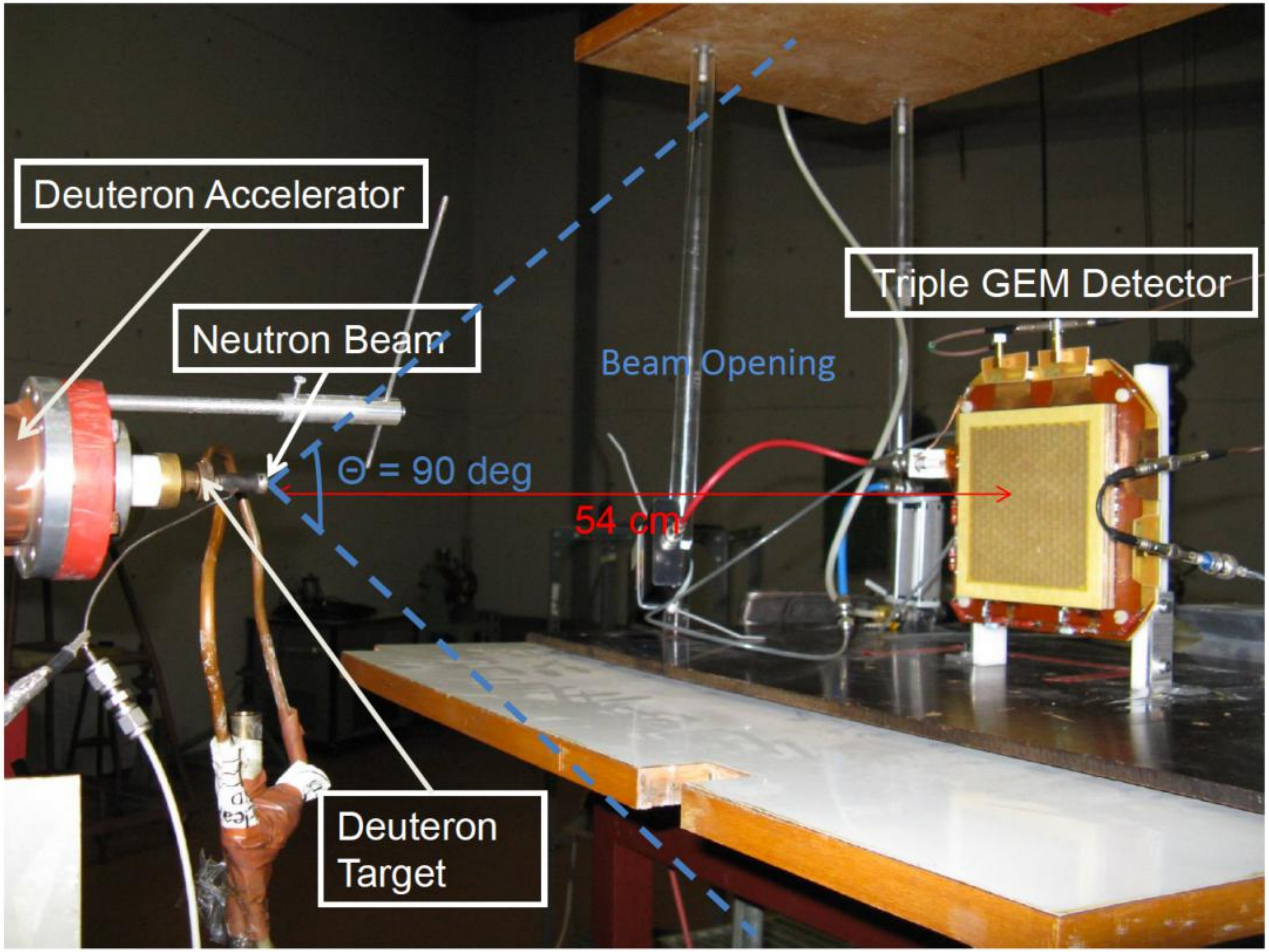
Nuclear Reaction	Proton/Deuteron Energy Range (MeV)	Neutron Energy Range (MeV)
$^7Li(p,n)^7Be$	1.9 to 8.4	0.1 to 6.7*
$^2H(d,n)^3He$	0.8 to 8.4	3.9 to 11.5**
$^3H(d,n)^4He$	0.8 to 8.4	16.4 to 25.7***

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

ERC tentative program

GEM neutron Beam Test at Demokritos



Conclusion

The existence of X17 can be confirmed/rejected with a dedicated program in several neutrons/protons reactions such as:

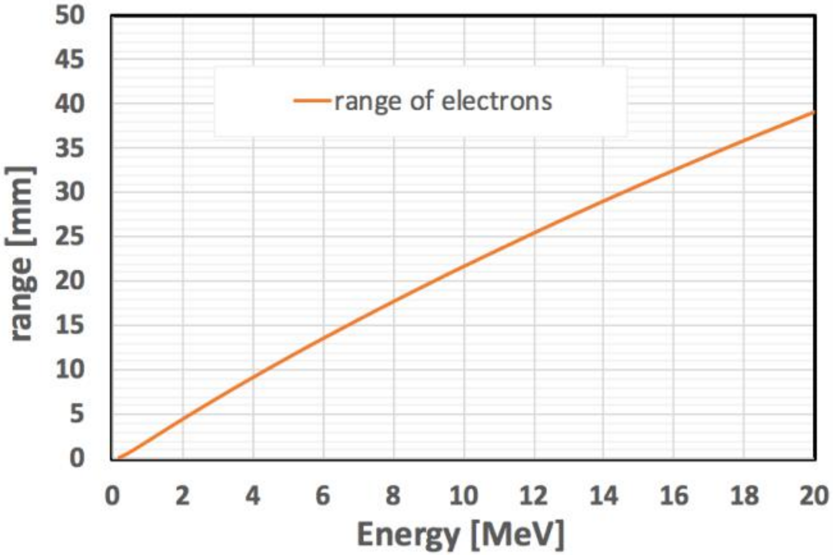
$^{3}He(n,X17)^{4}He$, $^{7}Be(n,X17)^{8}Be$, $^{2}H(n,X17)^{3}H$ @ n_ToF, Demokritos...

$^{3}H(p,e+e-)^{4}He$, $^{7}Li(p,X17)^{8}Be$, $^{2}H(p,X17)^{3}He$ @ LUNA, ENEA/Frascati...

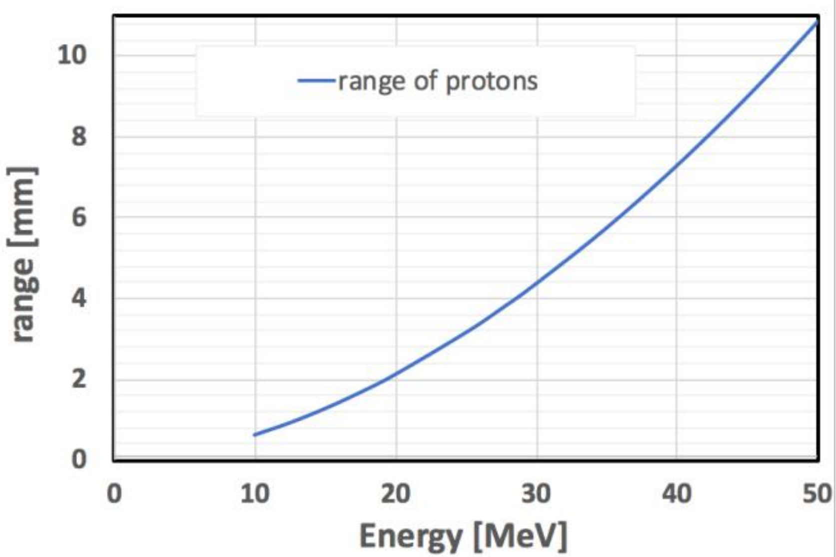
Setup is in preparation. Most of the concerns will be clarified at the end of this year with beam tests at n_ToF (backgrounds) and ENEA/Frascati (detector performance)

Thanks for the attention!

SPARES



$\Delta E/dx$ (electrons)~0.5 MeV/mm [2-20 MeV]



$\Delta E/dx$ (protons)~4 MeV/mm [10-50 MeV]

DETECTOR Conceptual design