EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

X17 boson through neutron-induced reactions: feasibility test at n_TOF EAR2

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E. Cisbani[1,2], N. Colonna[1], P. Finocchiaro[1], S. Fiore[1,3], G. Gervino[1,4], C. Gustavino[1], C. Massimi[1,5], P. Mastinu[1], A. Mazzone[1,6], F. Renga[1], M. Viviani[1],

[1] *Istituto Nazionale di Fisica Nucleare, INFN, Italy*
[2] *Istituto Superiore della Sanità, ISS, Italy*
[3] *Ag. naz. per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, ENEA, Italy*
[4] *University of Torino, Italy*
[5] *University of Bologna, Italy*
[6] *Consiglio Nazionale delle Ricerche, CNR, Italy*

Spokesperson: Carlo Gustavino (carlo.gustavino@cern.ch)
Technical coordinator: Oliver Aberle (oliver.aberle@cern.ch)

Abstract: Two striking anomalies have recently been observed in the electron-positron pairs emitted in the ^{7}Li(p,e^{-}e^{+})^{8}Be and ^{3}H(p,e^{-}e^{+})^{4}He reactions. These anomalies have been interpreted as the signature of a new particle, the so-called X17 boson. We aim to clarify the present scenario by studying at n_TOF the ^{3}He(n,e^{-}e^{+})^{4}He and ^{7}Be(n,e^{-}e^{+})^{8}Be reactions. These neutron-induced reactions are conjugated to the previous ones and will be investigated for the first time, thus providing a complementary experimental approach with respect to the experiments reported in literature. With this Letter of Intent we propose to test prototypes of a Ring Imaging Cherenkov and of a radial Time Projection Chamber, to evaluate their performance in the EAR2/n_TOF area, in view of an experiment to confirm or reject the X17 existence and eventually to establish its properties.

Requested protons: 6×10^{17} protons on target, (split into 2 runs).
Experimental Area: EAR2.

Two significant anomalies have been recently observed in the electron-positron pairs emitted in the ^{7}Li(p,e^{-}e^{+})^{8}Be and ^{3}H(p,e^{-}e^{+})^{4}He reactions [1, 2]. These anomalies have been interpreted as the signature of the existence of a boson (hereafter referred to as X17) of mass M_{X17} = 16.8 MeV that could be a mediator of a fifth force, characterised by a strong coupling suppression of protons compared to neutrons (protophobic force). Beyond the importance of such a discovery - if confirmed -, this scenario could explain, at least partially, the long-standing (recent) anomaly on the muon (electron) magnetic moment. More in general, the possible existence of a new particle is of paramount importance in particle physics and in cosmology (dark matter). Therefore, the ATOMKY claim [1, 2], clearly calls for new experimental studies.
The ATOMKI experimental setup used for the ^{3}H(p,e^{-}e^{+})^{4}He reaction (a very similar one was used for the other reaction) consisted of a tritium target adsorbed on Ti layer, bombarded with a proton beam with a current of about 1 μA. In correspondence of the target the beam line is surrounded by a 1 mm thick carbon tube. The detection of the ejectiles is performed with 6 telescopes mounted in a plane orthogonal to the beam line. Each telescope consists of a double-sided silicon strip detector coupled with a plastic scintillator. The silicon strips are used to measure the impact point of crossing particles, while the scintillators provide the measurement of their energy. As it can be seen in Fig. 1, data show a clear excess of e^{-}e^{+} pairs emitted at large relative angles, allowing to derive the invariant mass M_{X17}. The main limitations of this measurement are: (i) the limited energy range; (ii) no tracking and vertex recognition; (iii) only particles produced orthogonally to the beam line are detected; (iv) no charge and particle identification, i.e. the ejectiles are only deduced to be e^{-}e^{+} pairs.
We are currently investigating the possibility to carry out an experiment at n_TOF, in which are studied the ^{3}He(n,e^{-}e^{+})^{4}He and ^{7}Be(n,e^{-}e^{+})^{8}Be reactions. For the first time the X17 existence will be probed through neutron-induced reactions. The experimental program foresees a study of these reaction in a wide energy range and with a dedicated apparatus, tailored to confirm (or reject) its existence of the X17 boson and eventually to measure its properties.
This program can be accomplished with an apparatus of large acceptance, consisting of an inner tracker, a segmented calorimeter and a magnetic field for particle identification, operating at the EAR2 station of the n_TOF facility at CERN. The large acceptance of the apparatus and the wide energy range of the n_TOF facility would made possible to establish quantum numbers and mass of the X17 boson [4] and to shed light on the protophobic nature of a fifth force [3]. In fact, state-of-the-art "ab-initio" calculations provide quantitative predictions to establish the X17 nature, e.g. if it is a scalar, pseudoscalar, vector or axial boson and to get information on the interaction of the X17 boson with quarks and gluons [4]. The study of the ^{3}He(n,e^{-}e^{+})^{4}He (hereafter we consider this reaction only, although most considerations are valid also for the ^{7}Be(n,e^{-}e^{+})^{8}Be reaction) can be performed at the EAR2 station of the n_TOF facility at CERN. In fact, the facility provides a pulsed neutron beam in a wide energy range, which covers the region of interest for this experiment, i.e. $10^3 \lesssim E_n(eV) \lesssim 10^7$. Preliminary count-rate estimations have demonstrated that the neutron intensity at EAR2 is adequate to carry out a conclusive experiment within about one month of measurement.
The default ^{3}He target consists of a commercial ^{3}He neutron-detector, made of a steel tube 20 cm long, 2.54 cm in diameter and 0.5 mm thick, in which the gas is at 30

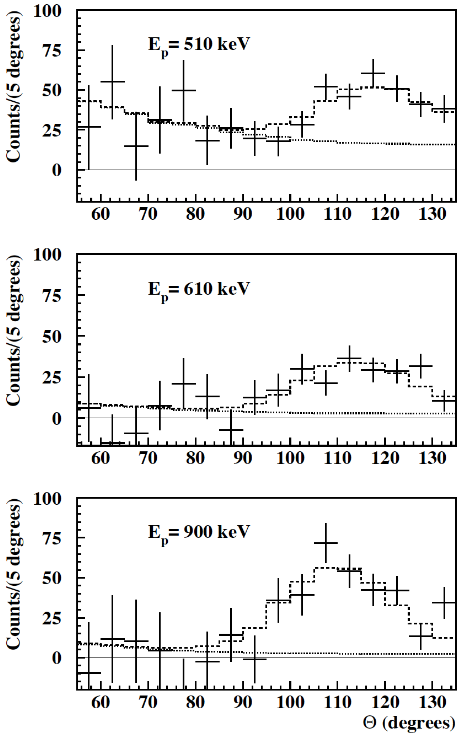

Figure 1: Angular correlations for the e$^-$e$^+$ pairs measured in the ^{3}H(p,e$^-$e$^+$)^{4}He reaction at E_p=510, 610, 900 keV. The the experimental data show a clear excess of e^-e^+ at large relative angle. Also shown are the expected angular distribution of e^-e^+ pairs based on standard physics (dotted lines) and the best data fit assuming M$_{X17}$ = 16.92 MeV (dashed lines) [2].

bar pressure. The dominant channel in the neutron-induced reaction is the ^{3}He(n,p)^{4}H reaction (Q-value = 764 keV). The sub-dominant process ^{3}He(n,γ)^{4}He produces single photons with E$_\gamma \geqslant$ 20 MeV. Finally, virtual photons can produce e^-e^+ pairs through the internal pair conversion (IPC) channel ^{3}He(n,e$^-$e$^+$)^{4}He. Clearly, the IPC pairs and the e$^-$e$^+$ pairs generated by the conversion of real photons with the material surrounding the ^{3}He target represent a background for the process of interest. However, the amount of e$^-$e$^+$ pairs produced by (virtual or real) photons rapidly decreases while increasing their relative angle. Instead, the ^{4}He* $\rightarrow^4$He+$X17$ process and successive X17$\rightarrow$e$^-$e$^+$ decay produces pairs with a large relative angle, determined by the X17 mass and energy. As a consequence, the excess of pairs at large relative angles (see Fig.1) represents a clear signature of new physics.
The proposed setup is based on the use of an inner tracker, to recognise e$^-$e$^+$ pairs and to reject background processes. The first option is a Ring Imaging Cherenkov (RICH) detector surrounding the target and equipped with two coaxial cylindrical aerogel radiators with refractive indices in the range $1.01 \leqslant n \leqslant 1.1$. The two aerogels produce two rings of Cherenkov light while crossed by a relativistic particle. The produced light is collected by a cylindrical array of Silicon Photomultiplier (SiPM) nominally 40 cm long and 20 cm diameter. In Fig.2 a preliminary Geant4 simulation of the RICH detector is presented. It is based on a single cylindrical radiator with n=1.05, inner radius=4 cm, thickness=0.5 cm and length=40 cm.
The second option is represented by a radial Time Projection Chamber equipped with

micro pattern gas detectors and orthogonal readout strips. The advantage of the RICH

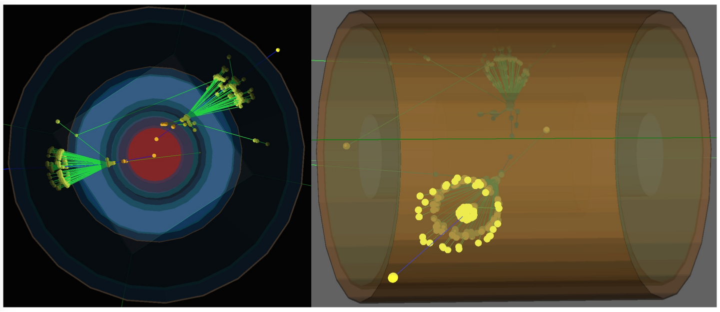

Figure 2: Example of a realistic Geant4 simulated event with two lepton tracks (blue lines), emitting Cherenkov photons (green lines) on the inner and outer aerogel radiators; the yellow points represent the photons and leptons starting and ending points on the different materials, including emission and impact points on radiators and sensor.

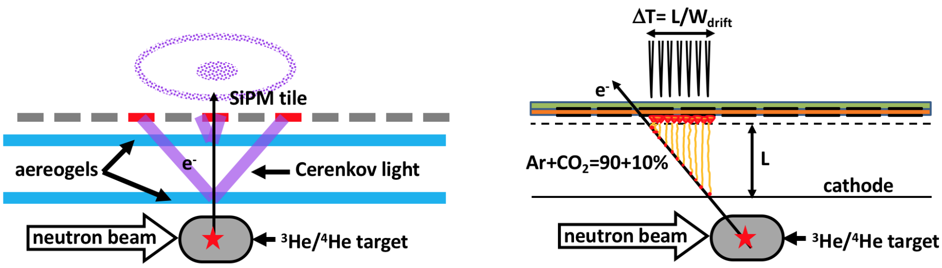

Figure 3: Sketch of the proposed experimental setup based on RICH and aerogels radiators (left); TPC based on Micro pattern gas detectors (right). See text for details.

detector is its insensitivity to the ^{3}He(n,p)^{3}H protons, since their velocity is largely below the threshold to produce the Cherenkov light. The TPC would provide a better tracking, although the earliest, most energetic protons ($E_p \gtrsim 15$ MeV, assuming 0.5 mm a ^{3}He container 0.5 mm thick) represent a background that must be carefully evaluated. Work is in progress to fully define the RICH and TPC parameters. The results of the mentioned simulations will be benchmarked with a RICH and TPC prototypes to be tested at the FSN-TECFIS-APAM ENEA/Frascati Linac (Italy). In particular the ENEA linear accelerator provides electrons in the few MeV energy range [5].
The test at EAR2 proposed in this LoI is mainly devoted to understand Signal e background behaviour for both the detector considered, by using different configurations of target/materials/tool that can potentially be used during the X17 measurement. Figure 3 shows the setup of the test proposed in this LoI. Not shown in the figure are the triggering plastic scintillator placed outside the RICH and the TPC respectively. As stated above, the detection setup of the full experiment include a coil generating a longitudinal magnetic field to obtain curved tracks for the ejectiles. By using two cylindrical aerogels each ejectile generates two eccentric rings attributable to the Cherenkov effect and providing an adequate signature for pulse and particle identification. In addition, a dedicated calorimeter composed by an array of scintillating tiles with a segmentation of $\Delta\theta = \Delta\phi = 5$ deg, is under study. As mentioned above, the ^{3}H(p,e$^-$e$^+$)^{4}He reaction is conjugated to the ^{3}He(n,e$^-$e$^+$)^{4}He one and represents a natural counterpart for

an exhaustive program. The proton reaction induced on tritium could be studied by a proton beam striking upon a thin tritium target. For instance, the proposed setup is well suited for a measurement at the LUNA-MV accelerator at LNGS, which has very suitable characteristics for these measurements with respect to the ATOMKI one.
In summary, the combined n_TOF and LUNA-MV measurements would provide a unique opportunity to study the reaction in a very wide energy range and using both proton and neutron beams, thus revealing possible effects due to protophobic nature of the X17 coupling. Fig.4 shows the level scheme of excited ^{4}He together with the energies accessible with n_TOF and LUNA-MV. As an example, the expected signal using an ATOMKY-like setup is shown in the case of a vector boson [4]. In this particular case the energy dependence of the X17 excess is expected to be rather weak, because the direct capture transition is dominated by the broad $J^\pi = 2^-$ resonance.

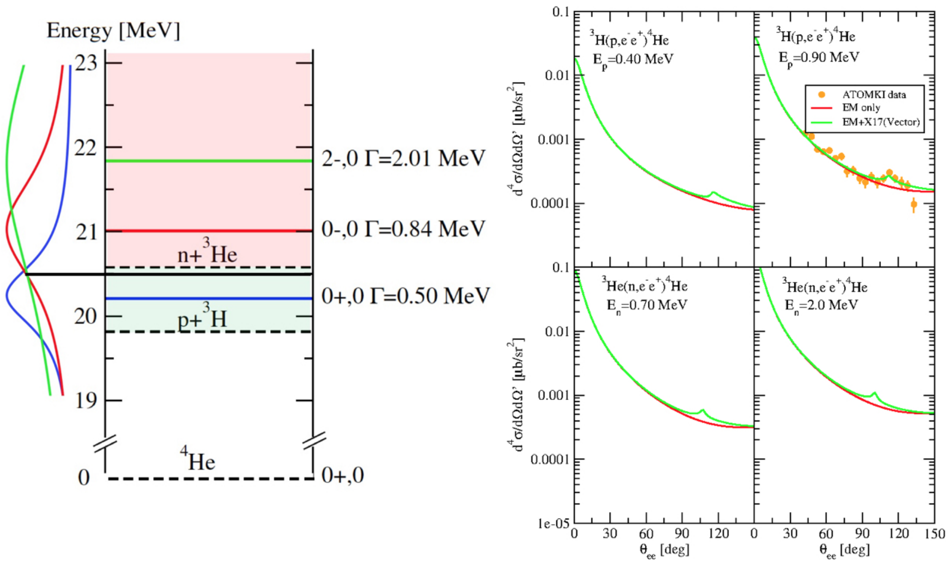

Figure 4: LEFT: Level scheme of ^{4}He nucleus, with also indicated the rest mass of the ^{3}He+n and ^{3}H+p systems. The Breit-Wigner resonance curves of the first excited states above the ^{4}He ground level are also shown. The horizontal black line corresponds to the proton beam energy used in ref. [2] (E_p = 0.9 MeV). The green area shows the energy range that can be explored with the LUNA-MV accelerator. The red area shows the energy range that it is possible to study with the n_TOF facility. RIGHT: The differential cross section for either the process ^{3}H(p,e$^-$e$^+$)^{4}He or ^{3}He(n,e^-e$^+$)^{4}He for four different energies and the setup used in ref. [2]. Here is considered the case of a vector X17 with M_{X17} = 17 MeV [4].

In this Letter of Intent we propose to test the RICH and TPC prototypes at n_TOF (the same prototypes which, in the meanwhile, will have been tested under electron beam at ENEA Frascati). In particular, we propose to study their response when irradiated with the EAR2 neutron beam, to validate the setup in the real experimental conditions.
The performances of the prototype will be investigated with and without a ^{3}He tube on the beam. The results of the proposed test will provide:

- information on the response to the γ-flash and related determination of the highest neutron energy that can be reached;

- determination of the background rate induced by the neutron beam in the target.

We propose to split the test into 2 runs. The second run is mainly devoted to optimise the performance of the full target+detection setup.
Summary of requested protons: 6×10^{17}

References

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