TAsP: Theoretical Astroparticle Physics

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Main scientific activities and achievements of the IS TAsP during the year 2024.

Axion Physics:

Do finite density effects jeopardize axion nucleophobia in supernovae?
In [1], we studied nucleophobic axion models, wherein axion couplings to both protons and neutrons are simultaneously suppressed and can relax the stringent constraints from SN 1987A. In this study, we demonstrate that the nucleophobic solution remains viable also at finite density. Furthermore, we show that the SN axion bound relaxes significantly in nucleophobic models, even when accounting for the integration over the non-homogeneous environment of the SN core.

Axion-induced pair production: a new strategy for axion detection
In [2], we worked to study the detection of axions from astrophysical sources. In particular, we included a new process for detection: axion-induced electron pair production in the presence of nuclei (see Fig. 1, left). This is a process particularly relevant for highly-energetic axions, as expected from supernovae (SN) explosions. Indeed, we study the impact of including this process for axion detection both for solar and SN productions, and we find that this process greatly enhances the detection power for axions coming from SN, as depicted in Fig. 1 on the right.

Axion-like Particle Searches Combining Nuclear Reactors and Haloscopes
In ref. [3], we proposed a new experimental strategy to search for axion-like particles (ALPs) by employing the well-known techniques used for the search of solar and dark matter axions with magnetic field, repurposed for searches of ALPs emitted at nuclear reactors. We show here, as depicted by Fig. 1, that this new approach can probe parts of the parameter space currently unexplored by laboratory experiments, offering a much needed complementary probe to limits of astrophysical and cosmological origin.

Physics of dark sectors:

Production of Dark Sector Particles on Atomic Electrons
In ref. [4], we presented a formalism that allows for the inclusion of electron motion within the targets used in fixed-target experiments, something that had never been done rigorously before, in the context of resonant production of new particles. On top of providing this method, we also show that thanks to the effect of electron motion, experiments using high-Z targets, with PADME at LNF used as an example, cover a much bigger part of the parameter space than what the free-electron-at-rest (FEAR) approximation predicts (see Fig. 2). This initial work and results have sparked many other projects, in which we continue to work, and exchanges with several experimental collaborations.

Atoms as electron accelerators for measuring the $e^+e^- \to$ hadrons cross section

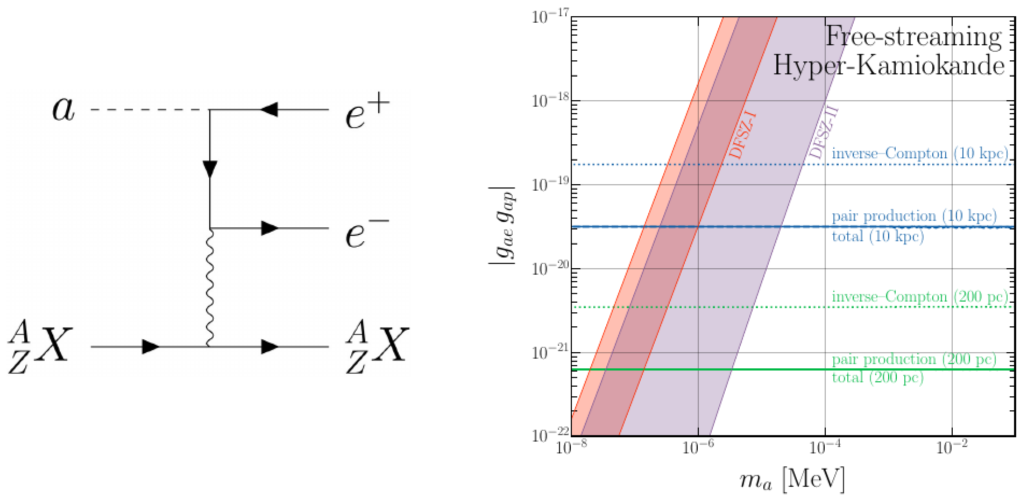

Figure 1: *Left: axion-induced electron pair production in the presence of nuclei. An axion coupling to electrons can produce an electron-positron pair if these exchange a photon with the nucleus of a certain target; this is simmilar to the well-known Bethe-Heitler process. Right: sensitivity of Hyper- Kamionkande for axions emitted in the free-streaming regime within a supernova at 10 (200) kpc in blue (green). The inclusion of this axion-induced pair production improves the reach in the axion couplings by nearly one order of magnitude.*

In Ref. [5], we have shown that electron motion in scattering processes, like $e^+e^- \to \mu^+\mu^-$, effectively provides a new method to scan in centre-of-mass energies with a beam fixed to one specific energy. We once again provided a robust procedure to include this effect in the computation of the scattering cross section, and we harness this power to provide a new way to measure the hadronic contribution to the muon anomalous magnetic moment, a quantity still under severe discussion given the different values found through different methods. As can be seen in Fig. 3, the statistics reachable at a high-intensity positron bean of 12 GeV (like the one that can be found at Jefferson Lab) are several orders of magnitude above the ones reached by the KLOE experiment.

NA62e+: dark sector searches with high intensity positron beams in ECN3

This proposal [6] seeks to significantly enhance NA62's discovery potential for dark sector candidates by using the positron-on-target technique. High intensity and high-energy positron beams, reaching up to 150 GeV energy, have already been produced at the SPS extracted beam lines. If a positron beam with an intensity in the range of 2×1014 positrons on target per year is delivered to the present K12 beam line, the NA62 detector would be ideal for searches of dark sector particles in both visible and invisible decay channels.

Scalar Rayleigh Dark Matter: current bounds and future prospects

In [7] we explores effective interactions between a real scalar Dark Matter particle, singlet under the SM gauge group, and electroweak gauge bosons. We present a comprehensive analysis of current constraints and projected sensitivities from both lepton and hadron colliders as well as direct and indirect detection experiments in testing Rayleigh Dark Matter interactions. We find that, thanks to the complementarity between collider experiments and cosmological probes, thermally produced Rayleigh Dark Matter at the hundreds of GeV scale can be thoroughly tested with the next generation of experiments. For lighter candidates, upcoming forecasts will explore uncharted parameter space, significantly surpassing the thermal Dark Matter benchmark.

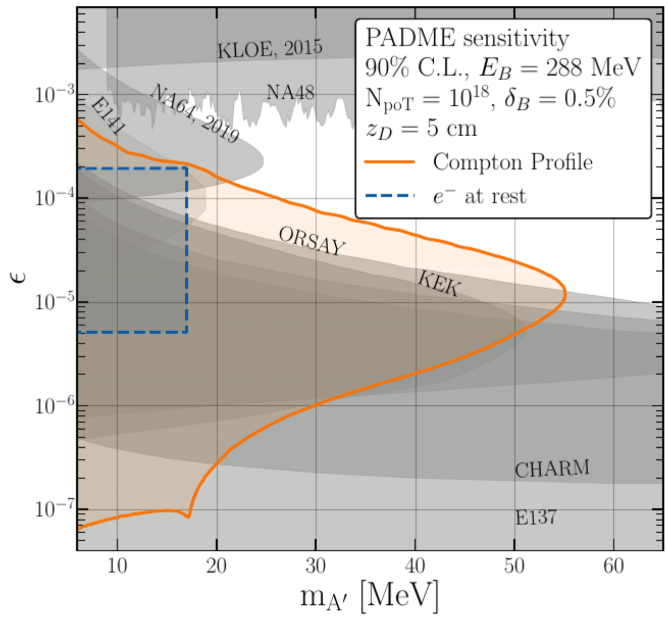

Figure 2: *Expected reach for PADME in the search of new vectors (dark photon). In blue, the obtained result within the FEAR approximation; in orange, our result accounting for electron motion within the target, extending greatly its reach in mass. In gray, previous limits are shown.*

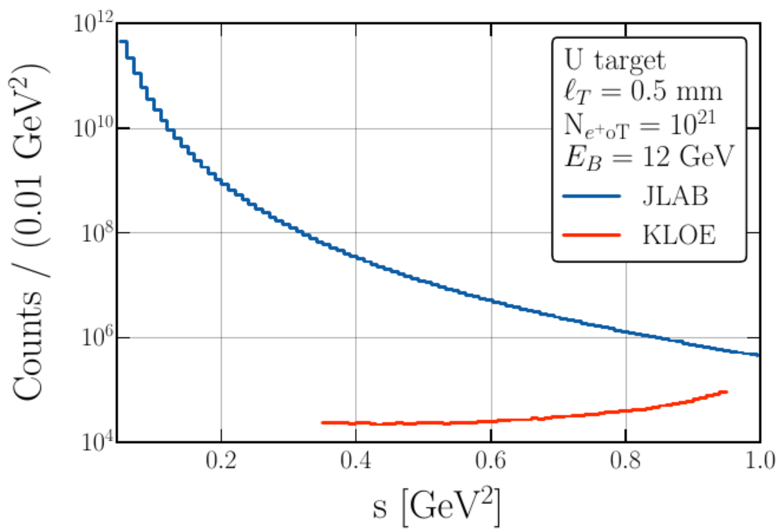

Figure 3: *Predicted number of muon pairs detected at JLAB (blue) when taking into account electron motion within a uranium target confronted to the measured number of di-muon events at KLOE (red).*

Multi-component dark matter from Minimal Flavor Violation

In ref. 8) we extend the Minimal Flavor Violation framework for dark matter and demonstrate that dark matter can naturally be multi-component across a broad parameter space. For illustration, we consider a gauge singlet, flavor triplet scalar field and identify parameter spaces for multi-component dark matter, where only the lightest flavor component is absolutely stable and heavy flavor components are decaying with lifetimes sufficiently longer than the age of the universe. Phenomenological, cosmological and astrophysical aspects of multi-component flavored dark matter are briefly discussed.

References

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