TAsP: Theoretical Astroparticle Physics

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Main scientific activities and achievements of the IS TAsP during the year 2023.

Axion Physics:

Running effects on QCD axion phenomenology.
In Ref. [1] we have study the impact of renormalization group effects on QCD axion phenomenology. Focusing on the DFSZ model, we have argued that the relevance of running effects for the axion couplings crucially depends on the scale where the heavier Higgs scalars are integrated out. We have studied the impact of these effects on astrophysical and cosmological bounds as well as on the sensitivity of helioscopes experiments such as IAXO and XENONnT.

The axion flavour connection.
A local flavour symmetry acting on the quarks of the Standard Model can automatically give rise to an accidental global $U(1)$ which remains preserved from sources of explicit breaking up to a large operator dimension, while it gets spontaneously broken together with the flavour symmetry. Such non-fundamental symmetries are often endowed with a mixed QCD anomaly, so that the strong CP problem is automatically solved via the axion mechanism. In Ref. [2] we have illustrated the general features required to realise this scenario, and we have discussed a simple construction based on the flavour group $SU(3)SU(2)U(1)_F$ to illustrate how mass hierarchies can arise while ensuring at the same time a high quality Peccei-Quinn symmetry.

Contribution to the proposal for the FLASH resonant cavity experiment at LNF.
We have contributed to the proposal for a new experiment at the LNF: the FINUDA magnet for Light Axion SearcH (FLASH), see Ref. [3]. FLASH is a large resonant-cavity haloscope in a high static magnetic field, that will be able to probe new physics in the form of dark matter axions, scalar fields, chameleons, hidden photons, as well as high frequency gravitational waves. We have highlighted its physics case, and the sensitivity reach to these different types of new physics.

New Directions for ALP Searches with reactorscopes.
A novel experimental setup for axion-like particle (ALP) searches, denoted *reactorscopes*, was proposed in Ref. [4]. Nuclear reactors produce a copious number of photons, a fraction of which could convert into ALPs via Primakoff process in the reactor core. After leaving the core, the flux of ALPs could passage through a regions with strong magnetic fields, like the ones of conventional axion haloscopes, converting back into photons which can be detected. While the derived sensitivities are not competitive with the astrophysical limits, they are free from uncertainties related to stellar evolution and star energy emission.

Physics of dark sectors:

A GeV-scale new physics explanation of the $(\mathbf{g-2})_\mu$ window discrepancy.
Recent lattice determinations of the hadronic vacuum polarization contribution to the muon anomalous magnetic moment have confirmed the discrepancy with the data-driven dispersive method. In the meanwhile the CMD-3 collaboration has reported a result for the $e^+e^- \to \pi^+\pi^-$ cross section considerably larger than previous experimental results (and close to the lattice determinations) exacerbating the discordance between different e^+e^- datasets. In Ref. [5] we have explored to what extent these disagreements can be accounted for by the same type of new physics effects proposed in Ref. [6], that alter selectively the individual experimental determinations of

$\sigma(e^+e^- \to \text{hadrons})$. We have shown how specific effects of GeV-scale new particles are able to shift upwards the KLOE and BaBar results in the low and intermediate energy windows, while leaving unaffected the CMD-3 energy scan. Remarkably, the additional loop corrections involving the new particles concur to solve the residual discrepancy with the experimental value of $(g-2)_\mu$.

Status of and strategies to search for the X_{17} boson.
The workshop "Shedding light on X17" was held at "Centro Ricerche Enrico Fermi" in September 2021. We have contributed to the workshop report [7] with discussions on the implications of the X_{17} anomaly, its possible theoretical interpretations, and experimental proposal aiming at confirming/disproving the X_{17} hypothesis.

Enhancing $B_s \to e^+e^-$ to an observable level in the two-Higgs-doublet model.
As a result of the helicity suppression effect, within the Standard Model the rare decay channel $B_s \to e^+e^-$ has a decay probability which is five orders of magnitude below current experimental limits. Thus, any observation of this channel will give unambiguous evidence of Physics Beyond the Standard Model. In Ref. [8] we have presented for the first time a New Physics scenario in which the branching fraction for $B_s \to e^+e^-$ is enhanced up to values which saturate the current experimental bounds. Furthermore, we have demonstrated how this scenario can arise from a UV-complete theory of quark-lepton unification that can live at a low scale.

Publications

1 Running effects on QCD axion phenomenology,
L. Di Luzio, M. Giannotti, F. Mescia, E. Nardi and S. Okawa,
Published in: Phys. Rev. D **108**, no.11, 115004 (2023).

2 The axion flavour connection,
L. Darmé, E. Nardi and C. Smarra,
Published in: JHEP 02 (2023) 201.

3 The future search for low-frequency axions and new physics with the FLASH resonant cavity experiment at Frascati National Laboratories,
D. Alesini et al.,
Published in: Phys.Dark Univ. 42 (2023) 101370.

4 New Directions for ALP Searches Combining Nuclear Reactors and Haloscopes,
F. Arias-Aragón, V. Brdar, J. Quevillon,
arXiv:2310.03631[hep-ph].

5 The $(g-2)_\mu$ window discrepancy: a GeV-scale new physics explanation,
L. Darmé, G. Grilli di Cortona, E. Nardi,
Published in: Phys.Rev.D 108 (2023) 9, 095056

6 The muon $g-2$ anomaly confronts new physics in $e^\pm$ and $\mu^\pm$ final states scattering,
L. Darmé, G. Grilli di Cortona, E. Nardi,
Published in: JHEP 06 (2022) 122.

7 Shedding light on X17: community report,
D.S.M. Alves at al.
Published in: Eur.Phys.J.C 83 (2023) 3, 230

8 Enhancing $B_s \to e^+e^-$ to an observable level in the two-Higgs-doublet model,
M. Black, A.D. Plascencia, G. Tetlalmatzi-Xolocotzi,
Published in: Phys. Rev. D **107** (2023) 3, 035013.