# European Strategy for Particle Physics

## Israeli Input

Steering committee

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### Interpretation of the charge and the rationale of the Israeli report

In our view, the goal of particle physics is to understand the basic laws of Nature. The Israeli input reflects the call for searching for new physics (NP) by a synergy of theoretical exploration and experimental innovation anchored by collider experiments, supplemented by a variety of smaller-scale experiments.

### Introduction

This document is based on a compilation of theoretical concepts and experimental methods solicited from the Israeli community by a steering committee with representatives from all the high-energy-physics (HEP) groups in Israel. An important component of this process was a national town-hall meeting, with presentations and status reports on the diverse experimental activity and future proposals that are pursued by various Israeli groups followed by an open discussion. A preliminary version of this report was discussed at the meeting and comments from the Israeli HEP community at large were received and impacted the document in an essential manner.

This report is divided into two parts: In the first, we list a set of outstanding basic scientific questions that we believe are important and relevant to the European Strategy with a 5-10 year horizon. In the second, we list experimental efforts addressing some of these questions, in which the Israeli community is active and can play a major role in the coming years.

### Overview

The Israeli HEP community emphasizes its commitment to continued involvement within the European community in particle-physics research, in terms of both theoretical and experimental efforts. We are committed to maintaining our activities within the ATLAS experiment, and in particular, to ensuring that the transition into the high-luminosity phase of the LHC (HL-LHC) is successful. We think that it is important for CERN to continue to play a central role in the exploration of basic science within Europe and beyond, and to serve as a focal point for the coordination of innovative scientific endeavors world-wide. In this regard, we believe that it is essential for CERN to maintain its role as the main laboratory for high energy experiments. Our perspective is that the combination of CERN being the main particle physics hub, surrounded by diverse experimental efforts across Europe, strengthens the particle physics program at large.

### Outstanding questions in fundamental particle physics

There are various open questions in fundamental particle physics. Some of these questions, ranging from the general behavior of strongly coupled field theories to the formulation of a quantum theory of gravity, are not yet connected to experiment. It is important to continue working on these more formal aspects of particle physics in the coming years. Other fundamental questions are connected to experiment. In the following, we discuss in detail several basic questions that we believe have realistic prospects of being addressed experimentally in the near future.

*Electroweak symmetry breaking and the Higgs Boson:*

What is the origin of electroweak symmetry breaking? Why is the Higgs boson light? What can we learn from measurements of the Higgs boson properties? Some of the answers to these questions may involve TeV-scale partners. These are featured in supersymmetric, composite-Higgs, and neutral naturalness extensions of the Standard Model (SM). Searching for these partners, measuring their properties, and understanding the underlying theory are important goals of future experiments.

Alternatively, the Higgs mass may be set by a cosmological selection or relaxation mechanism, as in several recent proposals. These alternative scenarios are important to study as they lead to new types of experimental signatures, and motivate new search strategies and experiments.

*Origin of the baryon asymmetry of the Universe:*

Is the electroweak phase transition first order? Are the Higgs couplings CP-conserving? Do the neutrino interactions conserve CP and lepton number? Can flavor diagonal measurements of CP violation (such as the electron EDM) constrain models of baryogenesis effectively?

*Nature of dark matter:*

Does dark matter (DM) have non-gravitational interactions? Does it interact with the SM, and if so, to which SM particles does it couple? Does it have self-couplings? Does it consist of particles, or is it a (light) coherent classical field, such as the QCD axion or an axion-like particle?

*New Ultra-light particles*

Are there new weakly-coupled ultra-light scalars or vectors? Do they mediate long-range forces? How can ultra-light particles or coherent oscillating fields be detected? Such particles may be related to DM, but can be considered more generally. If they account for the DM relic abundance, consisting of a coherent oscillating field: can we detect their impact on various time-dependent phenomena such as spin-precession or oscillation of the fundamental coupling constants? If DM forms macroscopic objects, can we detect them via a global effort of combining networks of “table-top” precision experiments on earth and in space?

*Flavor physics:*

Is the Higgs mechanism behind the masses of all matter fields? If there is NP at the TeV-scale, what mechanism suppresses its contributions to flavor- and CP-violating observables? Does the baryon asymmetry of the Universe originate from NP with CP violation in the quark and/or Higgs sectors?

*QCD:*

What are the contours of the QCD phase diagram? Is there a first order phase transition? A critical point? How do partons behave at high densities? Is hadron production the same in elementary collisions and in nuclear collisions?

## Experimental efforts

Below we discuss various experimental efforts that are relevant to the European Strategy, that Israeli researchers are actively involved with or are expecting to be involved with in the future.

*Energy frontier*

The upgrade of the LHC to the HL-LHC will provide a unique opportunity for detailed studies of electroweak symmetry breaking, and for searching for physics beyond the SM. Major upgrades of the LHC experiments are required to cope with the HL-LHC conditions and to fully exploit its physics potential. The Israeli experimental groups are members of the ATLAS collaboration and have contributed to its design and construction. The ATLAS-IL team is one of the major contributors to the Phase-I upgrade of the ATLAS muon spectrometer (the new Small Wheel). During this upgrade ATLAS-IL will contribute to the construction of the detectors and services (sTGC), electronics (Trigger Processor for the NSW, FELIX), and software (Simulation, Reconstruction and High-Level Trigger). ATLAS-IL is also committed to the ATLAS Phase-2 upgrade; during this upgrade ATLAS-IL intends to make major contributions to the Muon Spectrometer, Trigger electronics, Data Acquisition, High-Level trigger software and hardware, and muon reconstruction.

Given that we are a small community, our experimental strategy is to continue building strength in areas that will be applicable in any future effort in the energy frontier. This implies efforts both in R&D and dete(Hctor development, and in analysis that is expected to be relevant and of quality impact to whatever accelerator will be chosen by the European international community.

Beyond the HL-LHC, the Israeli community is supportive of a future high-energy collider. Colliders are crucial for the advancement of particle physics and will continue to be so for the foreseeable future. The realization of any of these facilities will be immensely beneficial to the field. The Israeli community plans to participate in the future collider experimental program that is chosen by the wider HEP community. The community is already involved in development of future detector projects, and has active R&D targeting the various future proposals.

In addition to our commitment to ATLAS and the firm interest in a future collider experiment, members of the community are involved in, and have a strong interest in, a variety of different and diverse experimental efforts, as follows.

*Intensity frontier including flavor physics*

High-intensity, low-energy experiments are sensitive to flavor-non-diagonal NP at energy scales far above those accessible by direct searches. These experiments also teach us about QCD via studies of exotic hadrons with 4 or more valence quarks. Members of the Israeli community are involved in studies of lepton-flavor non-universality, lepton-flavor violation, and exotic hadrons at the Belle-II experiment. In addition, the intensity frontier experiments are sensitive to NP with very small flavor-diagonal couplings to the SM states, such as dark photons, axion-like particles and long lived particles. Several PIs are involved in an effort to study the unique signatures of these models in experiments at the HL-LHC (including ATLAS and LHCb), and photon beam experiments at Jefferson Lab (such as GlueX). Furthermore, several PIs are involved in ongoing efforts to develop experiments complementing the larger LHC detectors, in order to extend the experimental sensitivity to NP. These efforts includes the FASER and MATHUSLA collaborations.

*Neutrino physics*

Israeli PIs are involved in the NEXT experiment, searching for neutrinoless double beta decay in Xe-136, and in MicroBooNE, which will perform cross section and oscillation measurements. These are crucial for the R&D of some of the major next generation experiments.

*Dark Matter*

Israel is involved in some of the major DM direct detection efforts, searching for weakly interacting massive particles (WIMPs), including the XenonNT detector, and the future DARWIN project, as well as novel noble-liquid DM-detector concepts. We believe the search for DM beyond the WIMP paradigm is of much importance. We thus highlight the burgeoning experimental efforts to search for sub-GeV DM in which Israel is already involved and where Europe can play a large role. The SENSEI (CCD-based) experiment, co-led by Israeli PIs, is fully funded and running, and is looking for electron recoil processes. Additional efforts include graphene targets being developed for the PTOLEMY experiment that will sit in LNGS; color center targets (under development in Israel); diamond targets (being developed as part of superCDMS); superconducting nanowires (under development at MIT); and superconducting bulk targets, among others.

### *Precision frontier*

The rapidly evolving field of precision measurements is making remarkable progress, with tabletop experiments expected to reach an astonishing sensitivity of roughly $1 : 10^{19}$. This will have profound implications for experimental probes of new long-range forces as well as for oscillating light DM. In addition to individual experiments, a network of experiments on earth and in space will have crucial impact in this field. Israeli PIs are running several table-top experiments to search for NP locally in Israel and are also part of the GNOME network. CERN could play a key role in this area by coordinating these global-network based searches, and by bridging the gap between the atomic-molecular-optics (AMO) experimental community and the particle physics community. In addition, the new accelerator facility under construction in Israel (SARAF), is expected to provide a low energy but high current (5 mA) beam, which can also be used to generate large amounts of neutrons. This facility can host several experiments looking for new forms of light NP.

### *High-density QCD and Relativistic Heavy-Ion Collisions*

Heavy-ion collisions create strongly interacting matter in a laboratory setting. In order to study the properties of QCD matter, as well as the fundamental nature of partons within a nucleus, Israeli PIs are active in the heavy-ion program at the HL-LHC. The HL-LHC will enable the study of QCD in the high-density regime and in particular attempt to reach the goal of a unified description of particle production from pp to pA to AA collisions and probe parton densities in a broad kinematical phase space.

### *Detector and Electronics R&D*

Future HEP and astroparticle-physics experiments often rely on novel detector and hardware development. Our community has the necessary expertise, experience and infrastructure for carrying out front-edge R&D in radiation detectors, electronics and data acquisition. Among present and near-future research topics that Israeli PIs are involved in are: gas-avalanche multipliers for tracking and digital hadron calorimetry, solid-state calorimetry and tracking, ion-blocking concepts for TPC detectors, noble-liquid detectors for DM and neutrino physics, secondary-emission ion-based TPCs, basic phenomena in liquid xenon and more.

### *Machine Learning*

Machine Learning (ML), in particular Deep Learning, is becoming a common tool in HEP. The ATLAS-IL group is involved in applying these tools in current and near future analyses (for instance in jet tagging, fast simulation, and more), and we foresee a much heavier involvement and usage of our community in ML tools. This requires preparation, both in terms of peripheral computing and software power but also in terms of education and supporting human resources.

### *Non-academic professionals for future HEP*

Future HEP experiments will require increasing sophistication of electronics and software — knowledge possessed less and less by physicists and more and more by professional engineers. For software and electronic engineers, even the flexibility of academia often cannot compensate for the higher salaries and attractive challenges of industry. Physicists who do become experts in these fields have trouble getting stable positions and therefore are forced to leave academia, taking with them crucial knowledge that new hires cannot provide. These two factors, already a problem, endangering the ability to build and maintain future experiments. Ways for academic institutions to provide stable employment and more competitive salaries for these crucial professionals must be found.