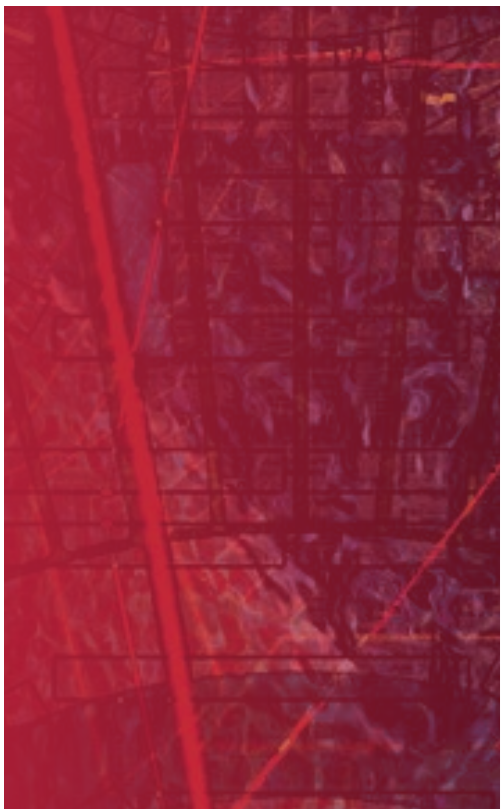
PILLAR 1.b –
HIGH INTENSITY/LOW ENERGY

Outline: Overview of the experiments, schedules and high-level recommendations that were presented in the 2020 Roadmap concerning PILLAR 1.b HIGH INTENSITY/LOW ENERGY



CHIPP Roadmap

for Research and Infrastructure 2025–2028 and beyond
by the Swiss Particle Physics Community

Swiss Institute of Particle Physics

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Overview of the experiments belonging to PILLAR 1.b. included in RM24

Beam EDM: The Beam EDM (Electric Dipole Moment) Experiment will measure the neutron EDM using a pulsed cold neutron beam. The experiment is intended to be conducted at the future European Spallation Source.
https://www.lhep.unibe.ch/research/neutron_and_precision

CREMA: (Charge Radius Experiments with Muonic Atoms) is an international collaboration aiming at high-accuracy measurements of the Lamb shift in muonic atoms, to be conducted using laser spectroscopy.
https://www.psi.ch/en/muonic-atoms

FASER: (ForwArd Search ExpeRiment at the LHC) is a small experiment 480 metres downstream of the ATLAS Detector at the CERN LHC. FASER is designed to capture decays of exotic particles produced in the very forward region, which are outside of the ATLAS Detector's acceptance. FASERnu, a FASER sub-detector, is designed to detect collider neutrinos for the first time and to study their properties. The experiment will take data during Run 3 of the LHC.
https://faser.web.cern.ch

GBAR: (Gravitational Behaviour of Antimatter at Rest) is an experiment that measures the gravitational free-fall acceleration of anti-matter. It operates in the Antiproton Decelerator Hall at CERN, using antiprotons slowed down by the ELENA facility. GBAR first combines the antiprotons with two antielectrons, to form antihydrogen ions with a positive charge. Using laser-cooling techniques, these ions are brought to micro-Kelvin temperatures before they are stripped of their additional antielectron, transforming them into antihydrogen atoms. These antihydrogen atoms are then allowed to fall from a height of 20 centimetres, and their annihilation at the end of the fall is recorded. GBAR was approved in May 2012 and received its first beam of antiprotons in 2018.
https://gbar.web.cern.ch/public

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Overview of the experiments belonging to PILLAR 1.b. included in RM24

MEG: (Mu to E Gamma) was an experiment located at PSI dedicated to measuring the rate at which a muon decays into an electron and a photon; this decay mode is heavily suppressed in the SM by lepton-flavour conservation, but is enhanced in many BSM models. MEG took data from 2008 until 2013, and in doing so established the world's best limit on the decay $\mu \rightarrow e\gamma$. In order to increase the sensitivity reach by an order of magnitude, a total upgrade involving substantial changes to the experiment has been performed; this new experiment is known as MEG II.
https://meg.web.psi.ch

Mu3e: the Mu3e Experiment at PSI is designed to search for the lepton-flavour-violating decay of a positive muon converting into two positrons and one electron, which violates lepton-flavour conservation. Since this decay is extremely suppressed in the SM, to the order of $\mathcal{O}(10^{50})$, any measurement of this decay would be a clear sign of new physics. In order to reach its ultimate sensitivity, the Mu3e Experiment will observe more than 10^{16} muon decays. This enormous number of muons will be reached by using the world's most intense muon beam, located at PSI, which delivers 10^9 muon-decays/s to the Mu3e detector.
https://www.psi.ch/en/mu3e

mu-Mass: (MUoniuM lASer Spectroscopy) is an experiment at PSI which is pushing the frontier of muonium spectroscopy, with the aim of measuring the 1S-2S transition frequency of muonium, an exotic atom consisting of a positive antimuon and an electron. The mu-Mass Experiment plans to measure this transition at an unprecedented precision of 10 kHz, a 1,000-fold improvement over previous measurements. This will allow for the best determination of the muon mass at the level of one part per billion.
https://www.psi.ch/en/ltp/mu-mass

muX: The muX Experiment measures the charge radii of highly radioactive elements, in addition to measuring atomic parity violation signals in the 2S-1S transition of muonic atoms.
(https://www.psi.ch/en/ltp/mux)

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Overview of the experiments belonging to PILLAR 1.b. included in RM24

NA64: (North Area 64) is a fixed-target experiment using the 100 GeV electron beam of the CERN SPS fired at a fixed target, where the target is located in the CERN experimental North Area. The primary goal of NA64 is to search for light, dark bosons that are coupled to photons. The experiment started to take data in 2016, and will resume operation with an upgraded detector after the end of LS2 in 2021. https://na64.web.cern.ch

nEDM/n2EDM: (search for the Neutron Electric Dipole Moment) was designed to measure the electric dipole moment of the neutron with unprecedented precision. It used the ultracold neutron source at PSI, which supplies neutrons at a comparatively slow speed. The collaboration recently published the most sensitive measurement of the neutron EDM to date based on data collected during 2015 and 2016. https://www.psi.ch/en/nedm

piHe: (PIonic HElium) was an experiment at PSI that used laser spectroscopy and exotic atoms: starting from Helium atoms, one electron was replaced by a pion. This combination enabled high-precision measurements of the mass and other properties of the pion. https://www.psi.ch/en/ltp/experiments

SHiP: (Search for Hidden Particles) is a proposed general-purpose experiment to be installed in a beam dump facility at the CERN SPS. The primary objective of SHiP is to search for hidden particles, as predicted by models of hidden sectors, which are capable of accommodating dark matter, neutrino oscillations, and the origin of the full baryon asymmetry in the Universe. The present detector design incorporates two complementary apparatuses which are capable of searching for hidden particles through both visible decays and scattering signatures involving recoiling electrons or nuclei. Moreover, the facility is ideally suited to study the interactions of tau neutrinos. https://ship.web.cern.ch

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Timeline of representative ongoing projects in PILLAR 1.b. included in RM24

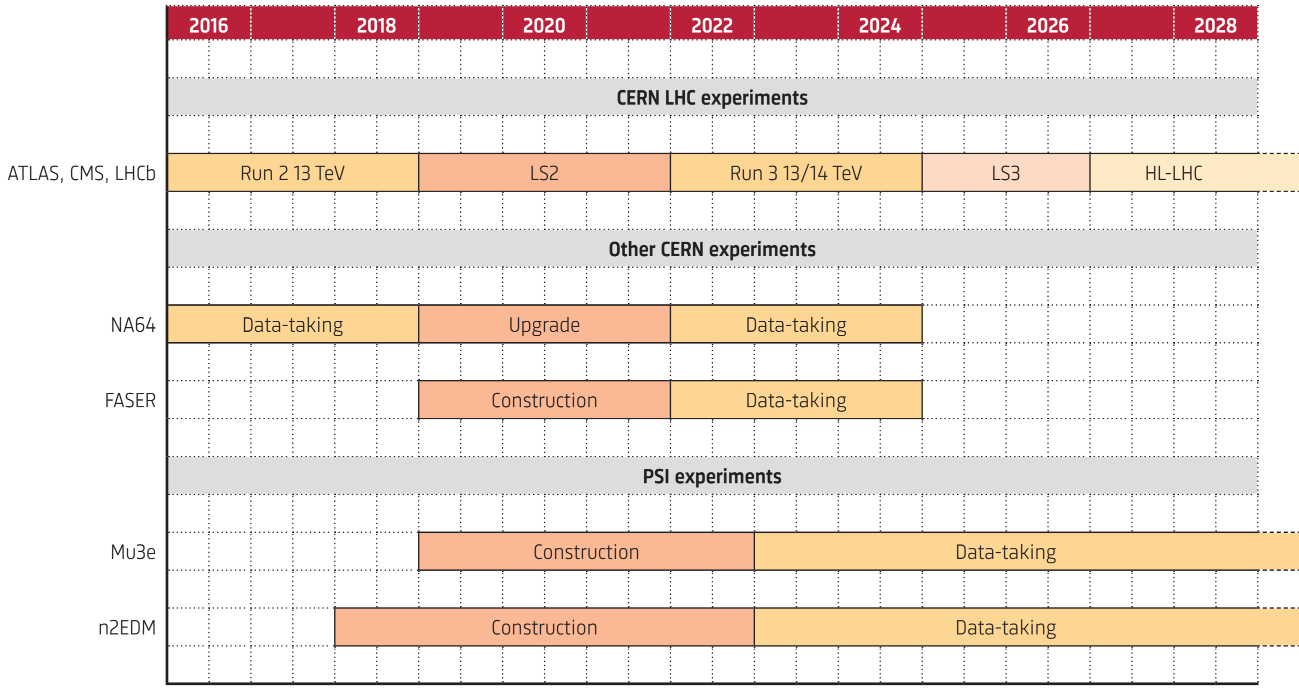

Figure 5: The timeline of the various representative ongoing approved projects where Swiss researchers are involved, at CERN and PSI. This timeline demonstrates activities in recent years, starting in 2016, and extending to 2028, one year after the HL-LHC project will have started.

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6 Major successes (2017–2020)

6.1.2 High energy: Other experiments at CERN

In the search for DS and possible DM candidates, NA64 has set the most stringent limit for light thermal DM below 0.1 GeV.[11, 12] It has also reported results that exclude part of the parameter space suggested by the so-called X17 anomaly. New experimental constraints have also been set on the mixing strength of photons with dark photons, as well as axion-like particles (ALPs), closing the gap in the ALP parameter space between previous fixed target and collider experiments.

In an effort to extend the pursuit of BSM phenomena beyond what can be done with the main LHC experiments, and in order to cover unexplored regions of parameter space which cannot be accessed by NA64, the FASER Experiment was proposed; a significant recent achievement was the approval of FASER by the CERN Research Board. The experiment has been primarily funded by the USA's Heising and Simons-Heising foundations and SNSF supports it with project funding. An ERC grant was recently awarded to a senior researcher associated with a Swiss institute. The construction of the experiment is progressing speedily (Fig. 15) and the experiment will collect data during Run 3 of the LHC.

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6.1.3 Experiments with low-energy beams

Low-energy experiments have achieved major results with high-sensitivity searches for BSM physics as well as in high-precision measurements of SM benchmarks and fundamental constants. Three ERC grants were recently (2016-2018) granted to scientists in Swiss institutes: one in neutron Electric Dipole Moment (EDM) searches using a neutron beam and two in exotic atom laser spectroscopy with muons. This reflects the considerable progress and impact that these approaches have made over several years.

The nEDM Collaboration at PSI released in 2020 the most stringent limit on the permanent electric dipole moment of the neutron, $d_n < 1.8 \times 10^{-26}$ ecm (90% C.L.),[13] which has a direct impact on theories explaining the matter-antimatter asymmetry of the Universe. The nEDM data were also analysed for an oscillating neutron electric dipole moment, which could be induced by coupling of ultralight ALPs to gluons. Assuming that these ALPs would constitute the DM in the Universe, first laboratory limits on ALP-gluon coupling for ultralight ALP masses were established.

The MEG Collaboration at PSI has established the world-leading limit on the lepton flavour violating decay $\mu^+ \to e^+\gamma$, which is the most stringent upper limit on any branching ratio in physics, $B(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}$.[14] From their dataset, MEG has recently provided the most stringent limits on hypothetical light, neutral particles X in the mass range between 20 and 40 MeV/c^2 for lifetimes of less than 40 ps and decaying to two photons $\mu^+ \to e^+X$, $X \to \gamma\gamma$.

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3 Executive summary, findings and recommendations

Finding 3: The quest for new physics, through either direct searches or indirect searches via precision measurements of SM particles including the Higgs boson, is complemented by and shared with a diverse set of experimental activities at the low-energy/high-intensity frontier. These activities are supported by the use of dedicated accelerators, either at the national laboratory (Paul Scherrer Institute, PSI) or elsewhere, or by running in parallel with existing high-energy accelerators. These experimental efforts are avenues towards exploring intriguing BSM scenarios, and are therefore extremely important for CHIPP's multi-prong approach towards searching for BSM physics and putting the Standard Model to the test.

Recommendation 3a: CHIPP strongly supports the present and future exploitation of the High-Intensity Accelerator (HIPA) accelerator complex at PSI. CHIPP recommends that a portfolio of dedicated experiments at the low-energy/high-intensity frontier should be pursued and strongly support the envisioned High-Intensity Muon Beam (HIMB) programme at PSI.

Recommendation 3b: CHIPP strongly supports the present and future exploitation of the CERN accelerator complex beyond the large LHC experiments, in experiments that search for new physics using novel approaches. It encourages the attempts to establish a high-power beam dump facility at CERN or elsewhere. CHIPP recommends that Switzerland engage in these diverse experiments.

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SUGGESTED LIST OF WORKSHOP PARTICIPANTS CONTRIBUTING TO PILLAR 1.b

Anna Sfyrla (FASER)
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Bernhard L. (n2EDM)
Florian (beamEDM)
Klaus (CREMA, HyperMu, *Quartet, muX, tauSPECT*)
Leysa (Ship/SND)
Malte (Mu3e)
Nico (Ship/SND)
Paolo (GBAR, MuMASS, NA64)
Philipp (muEDM)
Radoslav (*NA62/HIKE*)
Stefan (MEG II, Mu3e)