Intro Pillar 1 High Energy*

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2024 Update to CHIPP Roadmap for Research and Infrastructure
for 2025-2032 and beyond

Focus on schedule & planning of projects for **2029-2032**

*ATLAS, CMS, LHCb + extensions

Start from **2020 Roadmap**
which focused on **2025-2028**

Brief reminder in the following

Who we are

The Swiss Institute of Particle Physics, CHIPP

The purpose of CHIPP is to coordinate the involvement of Swiss institutes in particle and astroparticle physics research and teaching. One of its important functions is to recommend priorities within the context of available resources. CHIPP consists of two bodies: the CHIPP Plenary and the CHIPP Board. The CHIPP Plenary consists of physicists with a postgraduate degree (PhD students, postdocs, senior scientists, and professors), who are active in the realm of particle and astroparticle physics, and who work for a Swiss institution; Swiss nationals with a PhD degree and who are employed by CERN are also included. The CHIPP Board is comprised of all professors with activities in experimental or theoretical particle and astroparticle physics, as well as the heads of the experimental and theoretical particle physics groups at the Paul Scherrer Institute (PSI). The CHIPP Board meets at least twice per year, and the CHIPP Plenary at least once. The CHIPP Board elects an Executive Board, consisting of a Chair and one to three Deputy Chairs, for periods of two years.

CH research activities

Institution	Main involvements
Uni Basel	Experiments at PSI: MUSE
Uni Bern	Experiments at CERN: ATLAS and FASER Experiments at PSI: n2EDM Detector R&D: Tracking detectors, data acquisition
Uni Genève	Experiments at CERN: ATLAS and FASER Experiments at PSI: Mu3e Detector R&D: Tracking detectors, trigger and data acquisition
Uni Zürich	Experiments at CERN: CMS and LHCb Experiments at PSI: Mu3e Detector R&D: Tracking detectors, trigger
EPFL	Experiments at CERN: LHCb Detector R&D: Tracking detectors, trigger
ETH Zürich	Experiments at CERN: CMS, NA64, GBAR, BASE Experiments at PSI: Mu3e, n2EDM, CREMA, mu-Mass, muX, piHe Detector R&D: Calorimetry, tracking detectors
PSI	Experiments at CERN: CMS Experiments at PSI: Mu3e, MEG II, n2EDM, CREMA, mu-Mass, muX, piHe Detector R&D: Tracking detectors

Major successes

With the discovery of the Higgs boson in 2012, the SM is now complete. Present activities are concentrated on measuring the parameters of the SM particles with high precision, as well as on searching for BSM physics to answer the many questions that the SM leaves unanswered. The ATLAS and CMS Experiments have recently observed Higgs decay channels that were not previously accessible due to their small production rates, and have provided measurements of other SM properties with unprecedented precision. They have searched for BSM theories and models, often significantly constraining them by setting limits on the masses of associated new particles; in this route, they have also revealed interesting and challenging directions for further searches. The LHCb Experiment has established itself as the front-runner in heavy flavour physics. Recently, it has discovered CP violation in charm decays, as well as in baryon decays. It has intensified studies into the so-called flavour anomalies and improved our knowledge of various rare decays, both of which have strong implications on BSM physics.

All three experiments have explored, with Swiss contributions, dark sector particles in regions complementary to the exquisite exclusions by the NA64 Experiment. The newly approved FASER Experiment will complement such searches in a unique way and its construction is successfully proceeding on a fast track. For a future SHiP Experiment, many detailed technical studies have shown an unprecedented DS sensitivity.

Swiss groups are responsible for various state-of-the-art tracking detectors used by the LHC experiments, which perform excellently and play a pivotal role in almost all analyses. They are equally engaged in the design and construction of upgraded detectors for the HL-LHC, as well as new detectors for other future experiments.

Findings & Recommendations

Finding 1: The European particle physics community considers an electron-positron Higgs factory as the highest priority, together with the ambition to operate a proton-proton collider at the high-energy frontier of about or exceeding a centre-of-mass energy of 100 TeV. CHIPP points out that these ambitious goals will be best achieved through the Future Circular Collider (FCC) programme; an electron-positron Higgs factory (FCC-ee) as a first stage, followed by a hadron collider (FCC-hh) around 2045, would secure the future of high-energy particle physics with CERN as a world-leading laboratory well beyond the 2080s. One key ingredient in this ambitious programme is the development of suitable high-field magnets for FCC-hh that define the critical path.

Recommendation 1a: CHIPP recommends that Switzerland strongly support CERN as the world-leading laboratory in particle physics. CHIPP's research portfolio is well aligned with CERN's such that CHIPP will continue to benefit greatly from and lend strong support to CERN for the foreseeable future.

Recommendation 1b: CHIPP recommends the development of a national strategy towards the participation in CERN's programme for an FCC, starting with FCC-ee, which encompasses detector development, theoretical research, and data analysis and simulation. CHIPP supports CERN's goal to incorporate sustainability considerations into the design of future colliders.

Recommendation 1c: CHIPP recommends that Switzerland maintain involvement in accelerator physics development, especially towards the FCC projects. In particular, CHIPP recommends the continuation of the successful Swiss Accelerator Research and Technology (CHART) programme, it being an excellent example of close collaboration between CERN, a national laboratory, national institutes, and universities.

Recommendation 1d: CHIPP recommends that Switzerland maintain strong involvement in detector research and development, which is essential for the future of particle physics and which fosters synergies with other scientific fields.

Finding 2: In anticipation of the FCC, the Large Hadron Collider (LHC) continues to be the flagship project at the high-energy frontier until the end of its scheduled lifetime in the mid-to-late 2030s. The LHC, with its future high-luminosity running phase (HL-LHC), will provide a plethora of new data which will allow for measurements of the properties of the Higgs boson, provide increased precision measurements of Standard Model (SM) parameters, and enable both further exploration of the flavour sector as well as searches for physics beyond the Standard Model (BSM). The long-term support to operate the LHC detectors and eventually provide performance and longevity upgrades remains crucial during this period. Furthermore, the large volume of collected data will create challenges for computing in the Worldwide LHC Computing Grid (WLCG) paradigm.

Recommendation 2a: CHIPP strongly supports the experimental HL-LHC programme and recommends that Switzerland continue to secure the operation and upgrades of the ATLAS, CMS, and LHCb detectors, to ensure full exploitation of the investments so far.

Recommendation 2b: For the full HL-LHC exploitation to be feasible, further computing infrastructure is required, possibly in collaboration with other fields facing similar computing challenges with highly performant computing and data handling strategies. CHIPP recommends that Switzerland engage in providing the necessary resources.

Multi-prong DM search (across pillars)

Finding 5: Dark matter is one of the biggest open questions in particle physics and beyond. Astronomical observations reveal its large abundance in the Universe and underline its pivotal role in cosmic structure formation. The elucidation of the particle nature of dark matter continues to be one of the most important quests in contemporary particle and astroparticle physics. As experimental results begin to stress the paradigm for the Weakly Interacting Massive Particles (WIMPs) interpretation, alternative scenarios for dark matter (axions, an entire dark sector, etc.) come increasingly into focus. Direct dark matter detection experiments (such as DARWIN and DAMIC), searches for dark matter production at accelerators (in particular at the LHC), as well as indirect searches for dark matter via astrophysical observations continue to be the multi-prong approach that needs to be pursued in order to solve this puzzle.

Strong theory connection

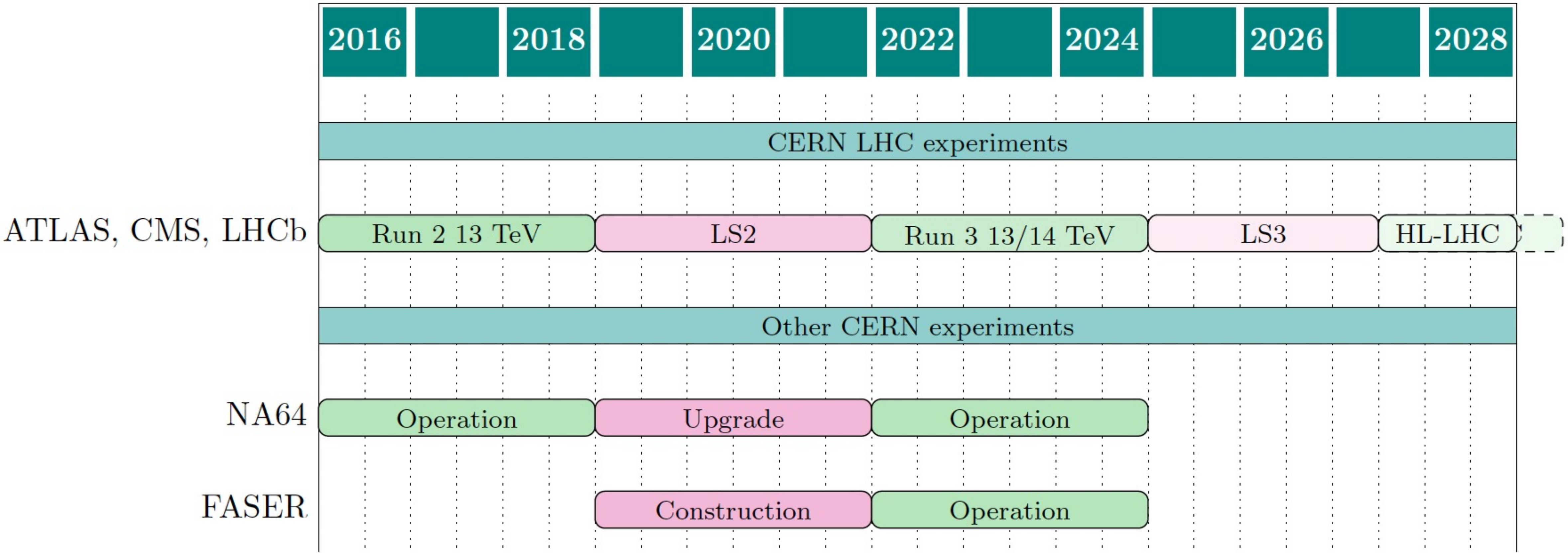
Finding 7: Theoretical physics is of pivotal importance to the development of fundamental physics and is a research area in which Switzerland has an outstanding track record. It is a salient feature of particle physics that its theory provides us with an extremely powerful paradigm, namely the Standard Model. Unravelling the puzzles that the SM cannot answer will require renewed theoretical efforts on phenomenology, precision calculations, and model building. Now that the field seems to be leaving the realm of "guaranteed" discoveries, i.e. theoretically predicted, but very rare phenomena such as the Higgs boson discovery or the detection of gravitational waves, theoretical guidance, even if "only" of heuristic nature, is more important than ever. At the same time, efforts towards improved theoretical predictions within the Standard Model are of key relevance for the interpretation of current and planned experiments at particle accelerators. Similarly, theoretical physics plays a key role in the interpretation of astrophysical phenomena, the area from where we presently observe the strongest indications for BSM physics.

Recommendation 7: CHIPP recommends that Switzerland continue to strengthen its vigorous programme in theoretical particle and astroparticle physics, and cosmology. Besides its intrinsic goal to understand and adequately formulate the laws of nature, this effort is a necessary ingredient for the interpretation of current and planned experiments at accelerators, as well as astrophysical phenomena. Theoretical research is also of pivotal importance as a guide in planning long-term experimental efforts in particle and astroparticle physics.

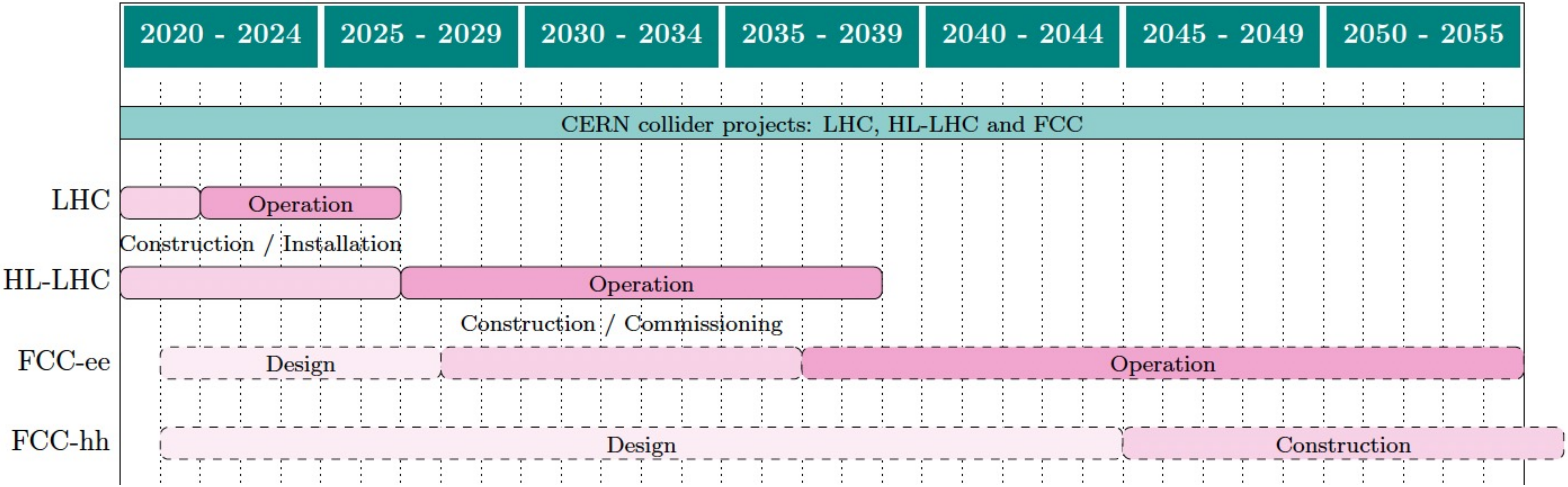
LE connection

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.

Timeline


2016
2018
2020
2022
2024
2026
2028
CERN LHC experiments
ATLAS, CMS, LHCb
Run 2 13 TeV
LS2
Run 3 13/14 TeV
LS3
HL-LHC
Other CERN experiments
NA64
Operation
Upgrade
Operation
FASER
Construction
Operation

Extended timeline



International context

Research in the domains of particle and astroparticle physics is carried out by international collaborations, which can be composed of thousands of members from all over the world. Switzerland, being one of the two host states of CERN and featuring an important number of very strong academic research groups, is a key player in this international environment and has strongly contributed to establishing the main strategic lines for the future evolution of the field, in particular in the context of the recent update of the European Strategy for Particle Physics.

Synergies with other fields

Developments in particle and astroparticle physics naturally provide a solid foundation for synergies with other fields. From instrumentation to large-scale equipment such as accelerators, and from (big) data analysis and computing techniques to theoretical and mathematical tools, particle and astroparticle physics developments find important uses elsewhere. Examples include synergies within the physical sciences, such as in the rapidly emerging field of gravitational waves, as well as in other fields of research, particularly including the medical and bio-medical sectors.

Relationship to industry

The fields of experimental particle and astroparticle physics have a long-standing tradition of (i) very close collaboration with (high-tech) industry and (ii) pushing technological frontiers, ultimately resulting in innovations that are successfully transferred to the private sector and industry. These frontiers are typically related to leading-edge nuclear and particle physics instrumentation, developed for and installed in small- and large-scale detectors, as well as particle accelerator technology. In all of these areas, Switzerland is particularly well placed, thanks to (a) its hosting of a considerable number of national and international high-tech companies, (b) the fertile grounds and resources available for founding spin-off companies, and (c) the substantial support given by the Swiss academic institutions and its national lab (PSI) to those researchers who are interested in the technology transfer of their ideas, developments, and inventions.

National infrastructures

The computing needs for the High-Luminosity LHC (HL-LHC) era (operating until the mid-to-late 2030s) are expected to grow by a factor of about 50 with respect to the present. Technology advance alone is expected to accommodate a factor of about five, leaving roughly an order of magnitude increase to be adsorbed in other ways. The particle physics community has started a global effort to expand its computing horizons beyond the classic customised cluster model, and has begun investing in software development to support heterogeneous architectures (mixtures of CPUs, GPUs, FGPAs, and possibly more), which are expected to help in bridging the gap to the HL-LHC computing needs.

CHART, the Swiss Centre for Accelerator Research and Technology, was founded to support the future-oriented accelerator project of the FCC at CERN, as well as the development of advanced accelerator concepts in Switzerland that go beyond existing technologies. Particle accelerators enable a broad range of research activities and applications. The CHART programme is of strategic importance not only for CERN, but also for Switzerland. Research and development efforts in CHART are addressing a number of technological topics, including high-field superconducting magnets, but also conceptual and beam-dynamics aspects for future accelerator facilities.

Vision

The future strategy of CHIPP

I. *Long-term prospect at the high-energy frontier*. The FCC programme at CERN represents a unique multi-purpose facility, which can maximise the potential for the discovery of new physics in its possible two stages (ee and hh): it is the facility that would allow for a more in-depth exploration of the high-energy frontier (in the FCC-hh phase) and it is the Higgs-factory with the maximal possible luminosity (in the FCC-ee phase); it would also offer unique opportunities for more specific high-precision searches (again in the FCC-ee phase). Swiss particle physicists are playing a seminal role in the FCC accelerator concept, contributing greatly to the development of high-field magnets and working on key aspects of the FCC-ee accelerator design. At the end of 2018, when providing input to the ESPP update, the Swiss community has clearly indicated the FCC programme as their main long-term priority. This input has been largely endorsed by the official ESPP update released in 2020.

What changed 2020 → 2024?

Discuss in parallel sessions

Today: High-level discussion
Tomorrow: editorial groups, do actual work

Guidance for parallel sessions

- Same document outline?
  - Present landscape, Major successes, International context, Synergies, Vision
  - Need to shorten by factor ~5
  - Text → tables (e.g. major success)
- Update schedules of facilities / experiments
- Evolution of scientific priorities?
- Emerging technologies? Invest in innovation to maximize science return: Quantum information science, microelectronics, AI/ML,…

Special topics !

- Flavor discussion with Tatsuya
  - Flavor to uncover BSM
  - Origin of flavor

- *Feebly* discussion with Gaia
  - Across pillars
  - Inform future experiments

- ML discussion with Thea
  - Online, offline, hardware, infrastructure, interdisciplinary

Expected deliverables

- Collect:
  - new information (e.g. HL-LHC schedule, FCC interim report, CHEF)
  - new physics opportunities
  - new experiments (phase-3 upgrade)
- Update project timelines
- Update high-level recommendations
- Vetted out synergies between experiments, theory and pillars
  - E.g. feebly, flavor, ML
- Determine:
  - writing assignments
  - timeline

Concrete for parallel discussion

- $H \to \mu\tau$, HH, H/SM/top precision (EFT)
- Direct NP: resonances, SUSY/RP-viol., HNLs, unconv. signatures
- More model-agnostic (AI/ML)
- Flavor…
- New tools: trigger (real time, software), sim, reco, data analysis
- New experiments: HL-LHC, FCC,…
- Upgrade: phase-2/3, tracker, calo,…
- ML: design, processing, trigger, fast sim, reco, precision, anomaly, productivity
- Computing: speed, storage,…
- Tracking, calo, trigger, DAQ
- Feebly…
- DM ↔ other pillars
- Theory: guidance, precision & model building, → ML, ↔ other pillars