Energy Frontier Plenary

Snowmass Community Summer Study (CSS)

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EF Reports: https://snowmass21.org/energy/start#final_reports

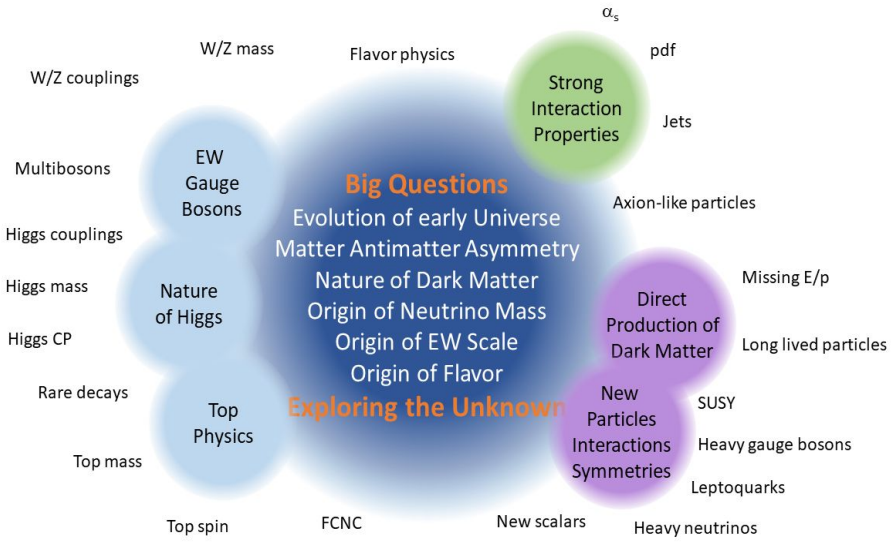
Goals and Context

- **Goals:**
  - Addressing the **"Big Questions"** and "**Exploring the unknown**" are the main scientific goals of the EF.
  - Two complementary directions are pursued:

    1) Study known phenomena

    2) Search for direct evidence of BSM physics
  - Discoveries at the EF are linked to *new accelerators*, *detector instrumentation*, advances in *theory,* and innovative *analysis technologies and frameworks*

    ⇒ Require substantial R&D in several scientific sectors



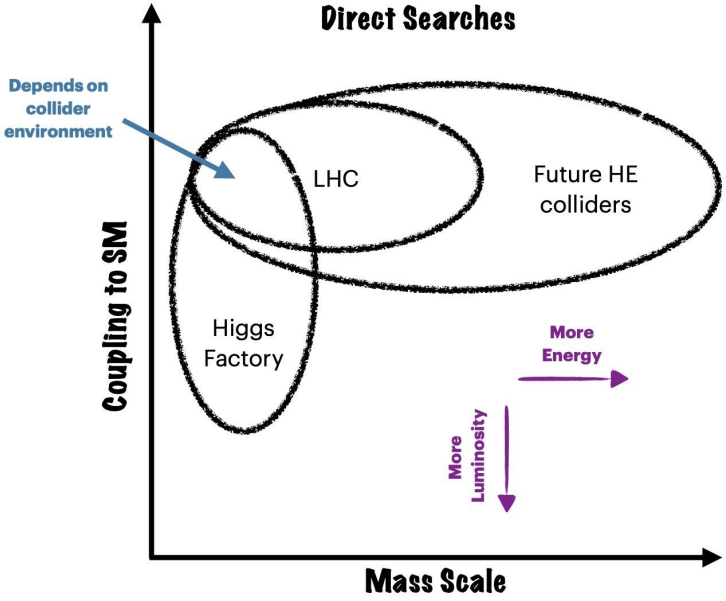
- **Context:**
  - The EF is at a turning point, in which *experimental guidance is needed to shed light on new physics* beyond the SM. Several projects have been proposed to provide such guidance:
    - The **HL-LHC** is the most awaited and the approved short-term project
    - Other projects identified as the next step in terms of precision measurements and direct searches, include **Higgs factories** and **multi-TeV colliders**
    - A clear path towards identifying the next collider project is needed.

Energy Frontier Machines: energy and precision

New physics can be at low and at high mass scales: Naturalness would prefer mass scale close to the EW scale, but direct searches of specific models have placed stronger bounds around 1-2 TeV.

Depending on the mass scale of new physics and the type of collider, the primary method for discovery new physics can vary.

We need to use both energy and precision.



The Energy Frontier goals

- **The discovery of the Higgs boson at the LHC**, of which we are celebrating the 10th anniversary in 2022, has added one crucial piece of the puzzle to the SM.
- **The Higgs boson has completed the SM and** at the same time provided a **unique portal to explore physics beyond the Standard Model** thanks to its intimate connections to the still open big questions of particle physics.
  - see Sally Dawson's talk
- **Collider physics allows to explore a uniquely broad range of phenomena** and pursue both *indirect* and *direct* validations of BSM physics.
- **Discovery new physics will also involve the unknown and we need to explore it going beyond existing frameworks with multi-TeV colliders.**
  - see Simone Pagan Griso's talk

Backup

EF Vision

I. **The immediate future is the HL-LHC.**
   A. Complete the **highest priority recommendation of the last P5** and fully realize the scientific potential of the HL-LHC collecting at least 3 ab^{-1} of data.
   B. **Continued strong US participation is critical**: Phase-2 detector upgrades, the HL-LHC data taking operations and physics analyses based on HL-LHC data sets, including the construction of auxiliary experiments that extend the reach of HL-LHC in kinematic regions not covered by the detector upgrades

II. **The intermediate future is an e^+e^- Higgs factory, either based on a linear (ILC, C^3, CLIC) or circular collider (FCC-ee, CepC).**
   A. **It is important to realize at least one somewhere in the world.**
   B. **A timely implementation and strong US support** are important

III. **In the long term EF envision a collider that probes the multi-TeV scale, up or above 10 TeV parton center-of-mass energy (FCC-hh, SppC, Muon Coll.)**
   A. A 10-TeV **muon collider** and 100-TeV **pp collider** (FCC-hh, SppC) directly probe the ~10 TeV energy scale with different strengths that are unparalleled in terms of mass reach, precision, and sensitivity
   B. The main limitation is technology readiness. **A vigorous R&D program** into accelerator and detector technologies will be crucial.

EF Colliders: Opportunities for the US

- Our vision for EF can only be realized as a **worldwide program** and we need to envision that **future colliders will have to be sited all over the world** to support and empower an international vibrant, inclusive, and diverse scientific community.
- **The US EF community has expressed renewed interest and ambition to bring back energy-frontier collider physics to the US soil** while maintaining its international collaborative partnerships and obligations, for example with CERN.
  - **Attractive opportunities** to be considered are:
    - **A US-sited linear e^+e^- collider (ILC/C^3)**
    - **Hosting a 10-TeV range Muon Collider**
    - **Exploring other e^+e^- collider options to fully utilize the Fermilab site**

EF Resources and Timelines

- **Five year period starting in 2025**
  - Prioritize the *HL-LHC physics program,* including auxiliary experiments
  - Establish a targeted *e+e- Higgs Factory detector R&D* for US participation in a global collider
  - Develop an *initial design for a first stage TeV-scale Muon Collider* in the US (pre-CDR)
  - Support critical *detector R&D towards EF multi-TeV colliders*
- **Five year period starting in 2030**
  - Continue strong support for the *HL-LHC program*
  - Support *construction of an e+e- Higgs Factory*
  - Demonstrate principal risk mitigation and deliver *CDR for a first-stage TeV-scale Muon Coll.*
- **After 2035**
  - Support continuing the *HL-LHC physics program* to the conclusion of archival measurements
  - Begin and support the *physics program of the Higgs Factories*
  - Demonstrate readiness to construct and deliver *TDR for a first-stage TeV-scale Muon Collider*
  - Ramp up funding support for *detector R&D for EF multi-TeV collider*