Strong synergy between theory and experiments in the explorations at the energy frontier.

The LHC era has seen an unprecedented engagement of the theory community at all levels, from modelling and interpretation to planning the future of EF explorations.

During Snowmass 2021-2022:
- Large theory component in all EF topical groups
- Several TF topical groups have direct overlap with EF studies
  - TF05: Lattice Gauge Theory
  - TF06: Theory Techniques for Precision Physics
  - TF07: Collider Phenomenology
  - TF08: BSM Model Building

During this session: selected topics to illustrate this dialogue and its potential impact.
Energy Frontier: explore the TeV energy scale and beyond
Through the breadth and multitude of collider physics signatures

Big Questions
Evolution of early Universe
Matter Antimatter Asymmetry
Nature of Dark Matter
Origin of Neutrino Mass
Origin of EW Scale
Origin of Flavor

Exploring the Unknown

EW Gauge Bosons
Higgs couplings
Higgs mass
Higgs CP
Rare decays
Top mass
Top spin

Flavor physics
W/Z mass

Strong Interaction Properties

pdf
Jets
Axion-like particles
Missing E/\rho

Direct Production of Dark Matter
New Particles Interactions Symmetries

New scalars
Heavy gauge bosons
Leptoquarks
SUSY

Heavy neutrinos
Energy Frontier Machines

Discoveries at the Energy Frontier are enabled by the development of new accelerators and detector instrumentation.

EF explorations should proceed along two main complementary directions:

➢ **Study known phenomena at high energies looking for indirect evidence of BSM physics**
  - Need factories of Higgs bosons (and other SM particles)
  - Need high precision to probe the TeV scale and beyond
  - **Need both luminosity and energy**

➢ **Search for direct evidence of BSM physics at the energy frontier**
  - Need to explore the multi-TeV scale → **Need energy**
  - Need to explore what LHC/HL-LHC may have difficulty exploring → **Need luminosity**
### Higgs-boson factories
(> 1 TeV c.o.m. energy)

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<th>Collider</th>
<th>Type</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$\mathcal{P}[%]$ $e^-/e^+$</th>
<th>$\mathcal{L}_{\text{int}}$ ab$^{-1}$/IP</th>
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### Multi-TeV colliders
(> 1 TeV c.o.m. energy)

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Timelines is taken from the ITF report from AF.
Energy Frontier Machines: energy and precision

New physics can be at low as 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.
In a simplified picture:

New physics at tree level:
\[ \delta \eta_{SM} \sim g_{BSM}^2 \frac{E^2}{M^2} \]

New physics at loop level:
\[ \delta \eta_{SM} \sim \frac{1}{16\pi^2} \times g_{BSM}^2 \frac{E^2}{M^2} \]

HF: Higgs factory
HE: high-energy or multi-TeV collider