Cross Frontier Session
TF-EF

Snowmass CSS Workshop

UW Seattle - July 19, 2022

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.

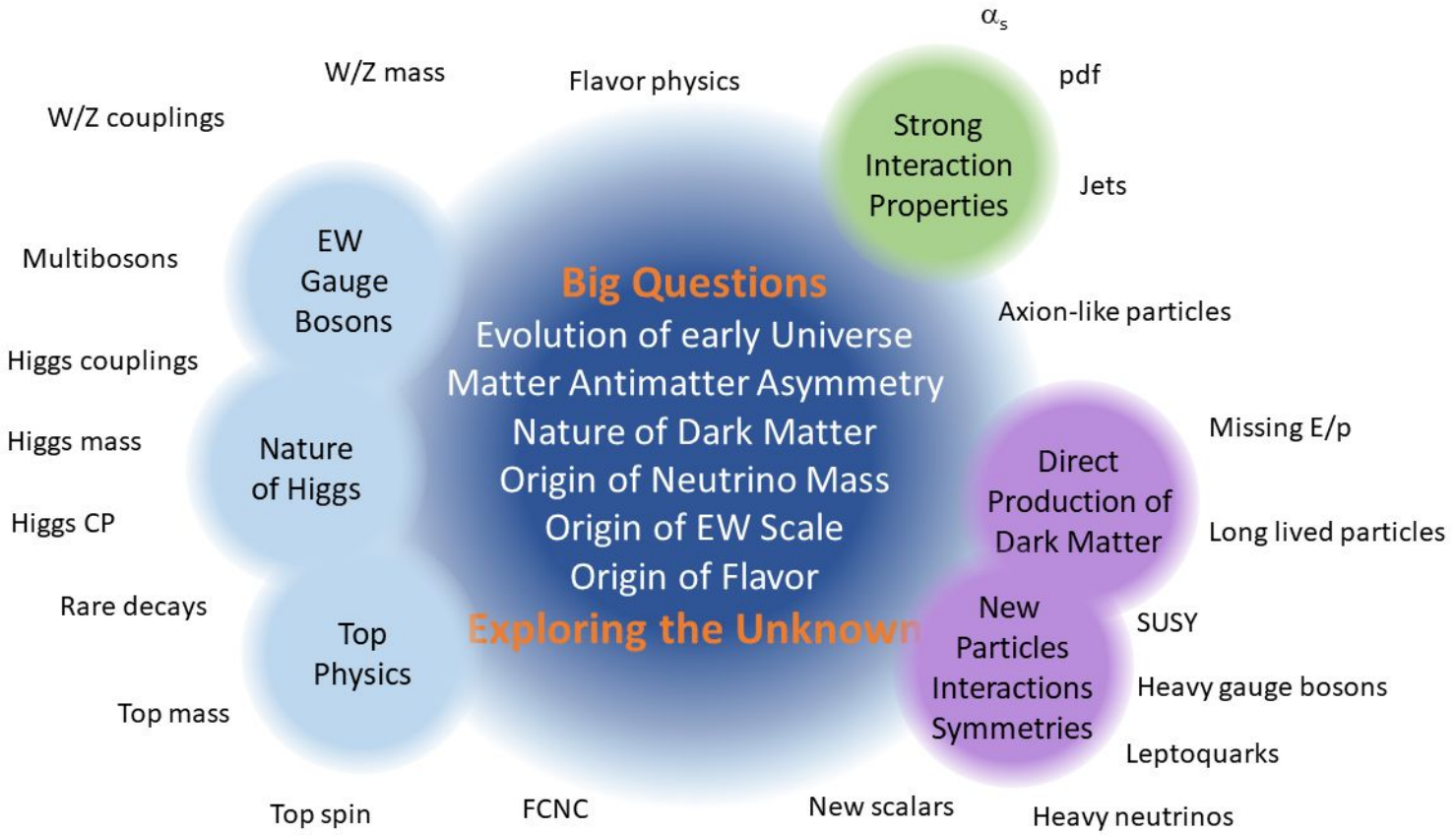
During Snowmass 2021-2022:

- 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



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**

Snowmass 2021:
EF Benchmark Scenarios

Higgs-boson factories
(up to 1 TeV c.o.m. energy)

Collider	Type	$\sqrt{s}$	$\mathcal{P}$[%] e^-/e^+	$\mathcal{L}_{\rm int}$ $\rm ab^{-1}$ /IP	Start Date Const.	Start Date Physics
HL-LHC	pp	14 TeV		3		2027
ILC & C^3	ee	250 GeV	$\pm 80/\pm 30$	2	2028	2038
		350 GeV	$\pm 80/\pm 30$	0.2		
		500 GeV	$\pm 80/\pm 30$	4		
		1 TeV	$\pm 80/\pm 20$	8		
CLIC	ee	380 GeV	$\pm 80/0$	1	2041	2048
CEPC	ee	M_Z		50	2026	2035
		$2M_W$		3		
		240 GeV		10		
		360 GeV		0.5		
FCC-ee	ee	M_Z		75	2033	2048
		$2M_W$		5		
		240 GeV		2.5		
		2 M_{top}		0.8		
μ-collider	$\mu\mu$	125 GeV		0.02		

Multi-TeV colliders
(> 1 TeV c.o.m. energy)

Collider	Type	$\sqrt{s}$	$\mathcal{P}$[%] . e^-/e^+	$\mathcal{L}_{\rm int}$ $\rm ab^{-1}$/IP	Start Date Const.	Start Date Physics
HE-LHC	pp	27 TeV		15		
FCC-hh	pp	100 TeV		30	2063	2074
SppC	pp	75-125 TeV		10-20		2055
LHeC	ep	1.3 TeV		1		
FCC-eh		3.5 TeV		2		
CLIC	ee	1.5 TeV	$\pm 80/0$	2.5	2052	2058
		3.0 TeV	$\pm 80/0$	5		
μ-collider	$\mu\mu$	3 TeV		1	2038	2045
		10 TeV		10		

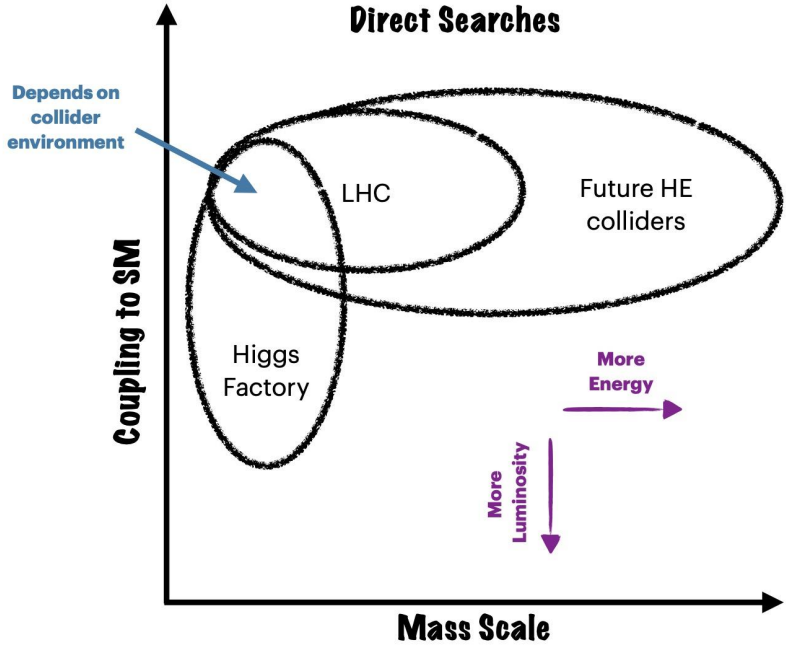
Timelines is taken from the ITF report from AF.

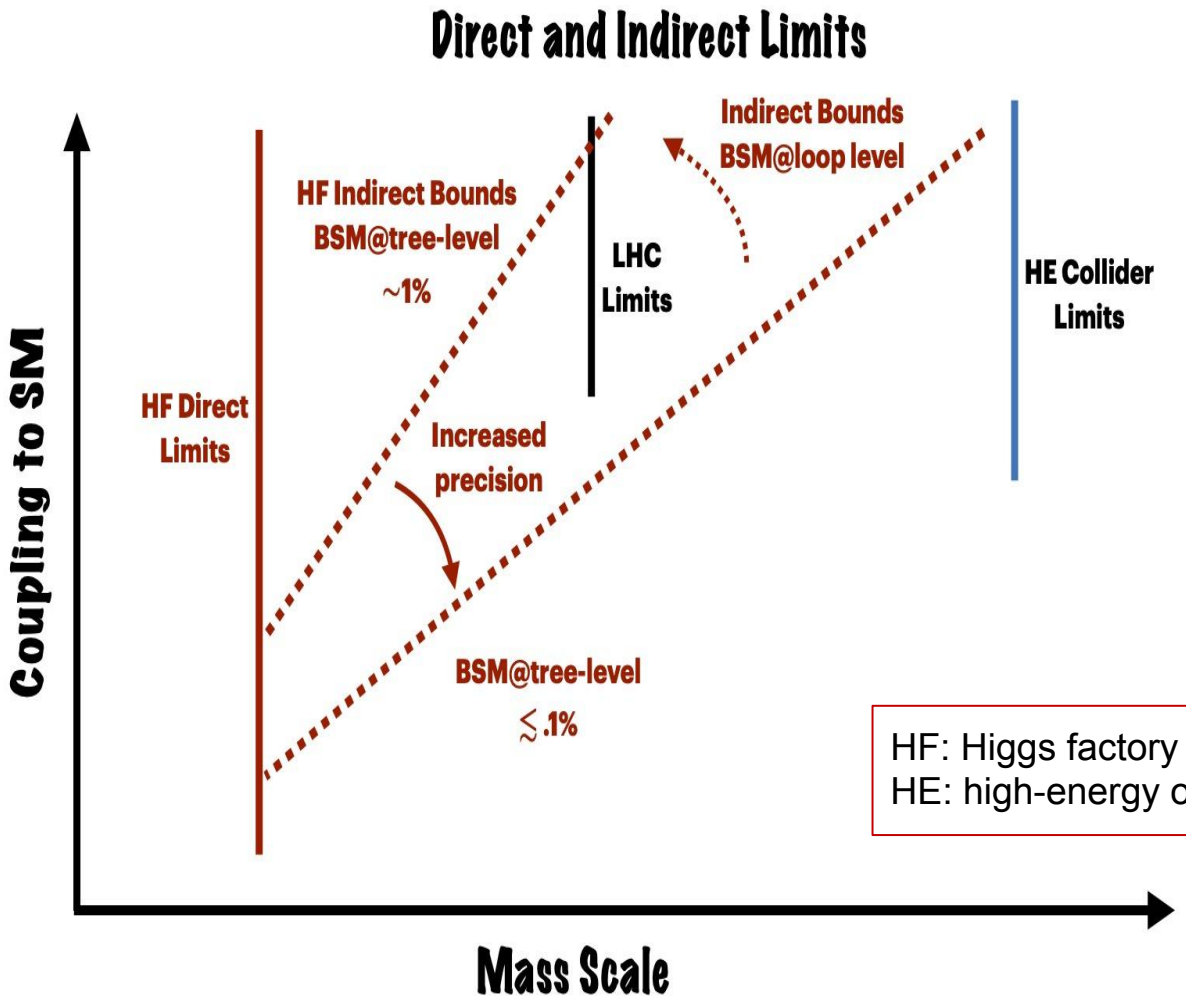
Energy Frontier Machines: energy and precision

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:
$\delta\eta_{SM} \sim g^2_{BSM} E^2/M^2$

New physics at loop level:
$\delta\eta_{SM} \sim 1/16\pi^2 \times g^2_{BSM} E^2/M^2$

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