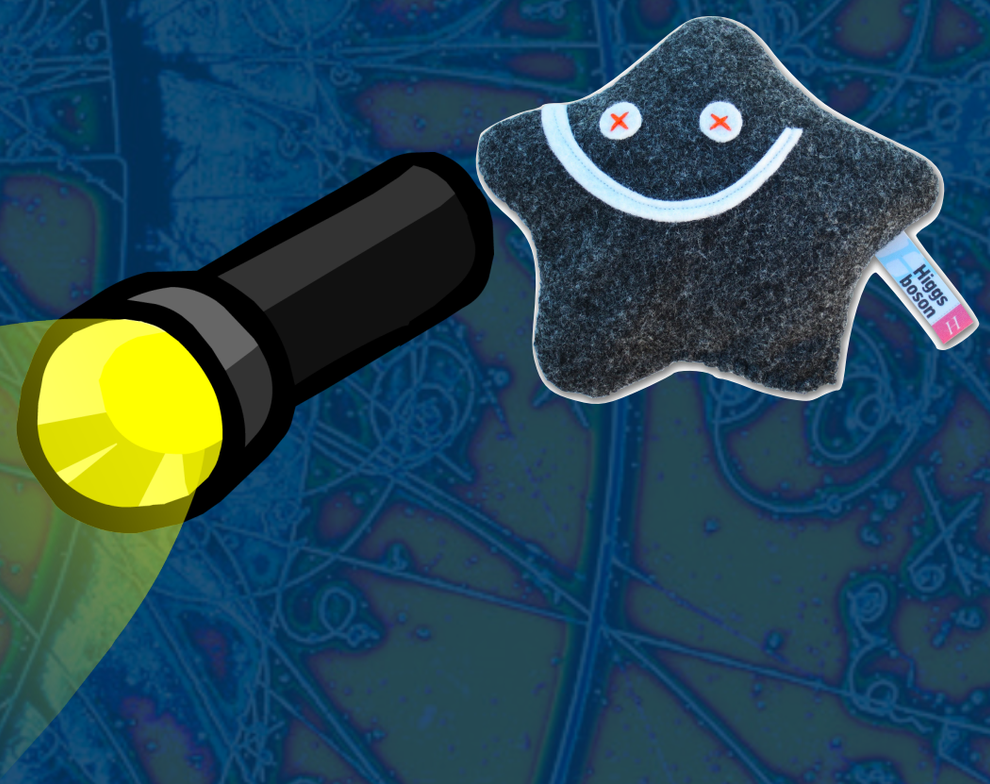
Higgs as a Portal to New Physics

Snowmass Energy Frontier Working Group - 2

Isobel Ojalvo
Princeton University
Patrick Meade
Stony Brook

ECFA Workshop - CERN
April 20 2022



Overview

- In EF02 we are particularly interested in searches for **BSM Higgses** and using the **125 GeV Higgs to search for BSM physics**

  As well as the implications of any possible discoveries

- Requires **precision measurements** and **global fits** to **search for deviations** and **BSM models** to **interpret discoveries/exclusions**

- **Writing a joint report with EF01**
  - Also connected with EF - 04, 08, 09, 10
  - And connecting with Accelerator Frontier, Theory Frontier, Instrumentation Frontier (and others!)

- Our job is to **summarize results** and **projections** (hopefully, in a ***compelling fashion***) and make calls for contributions

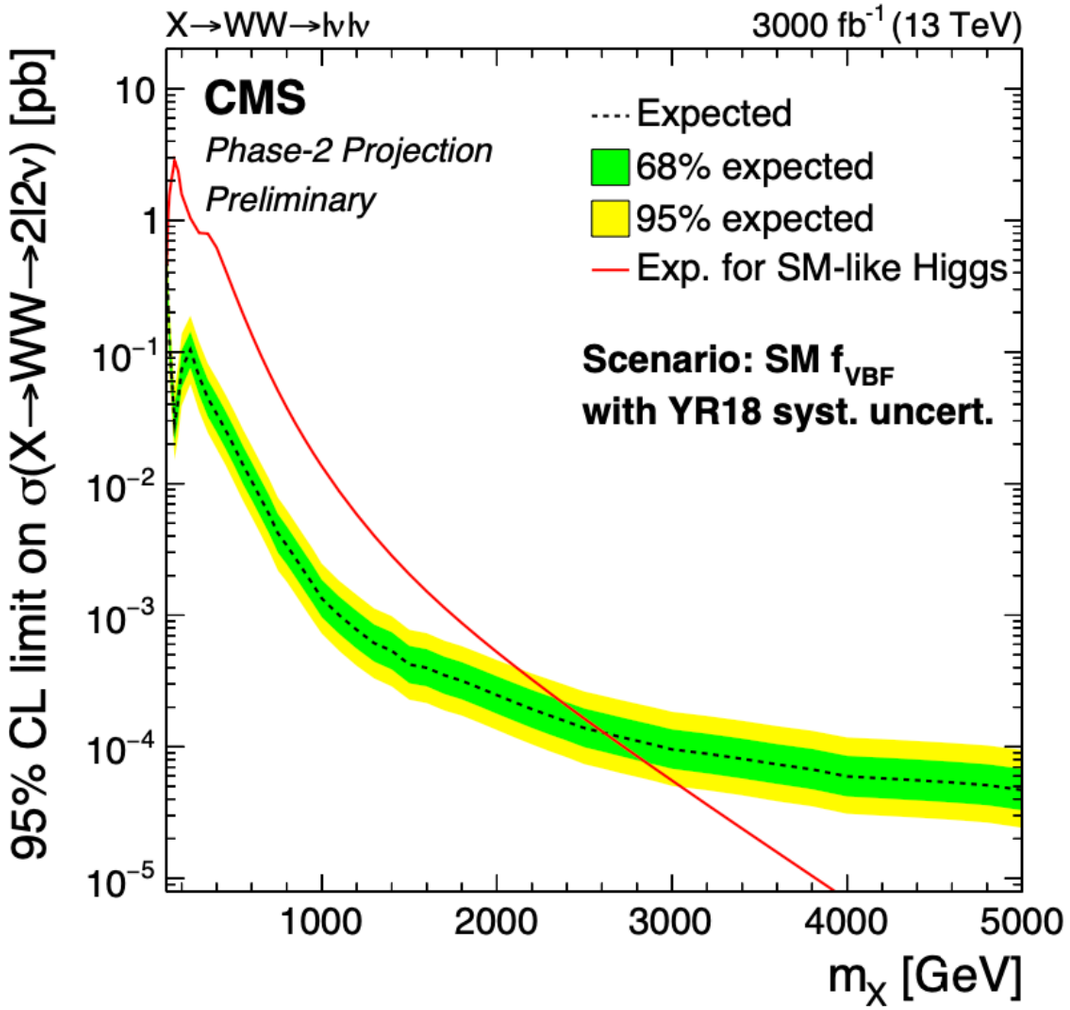
- Some recent plots and input to Final Report shown today

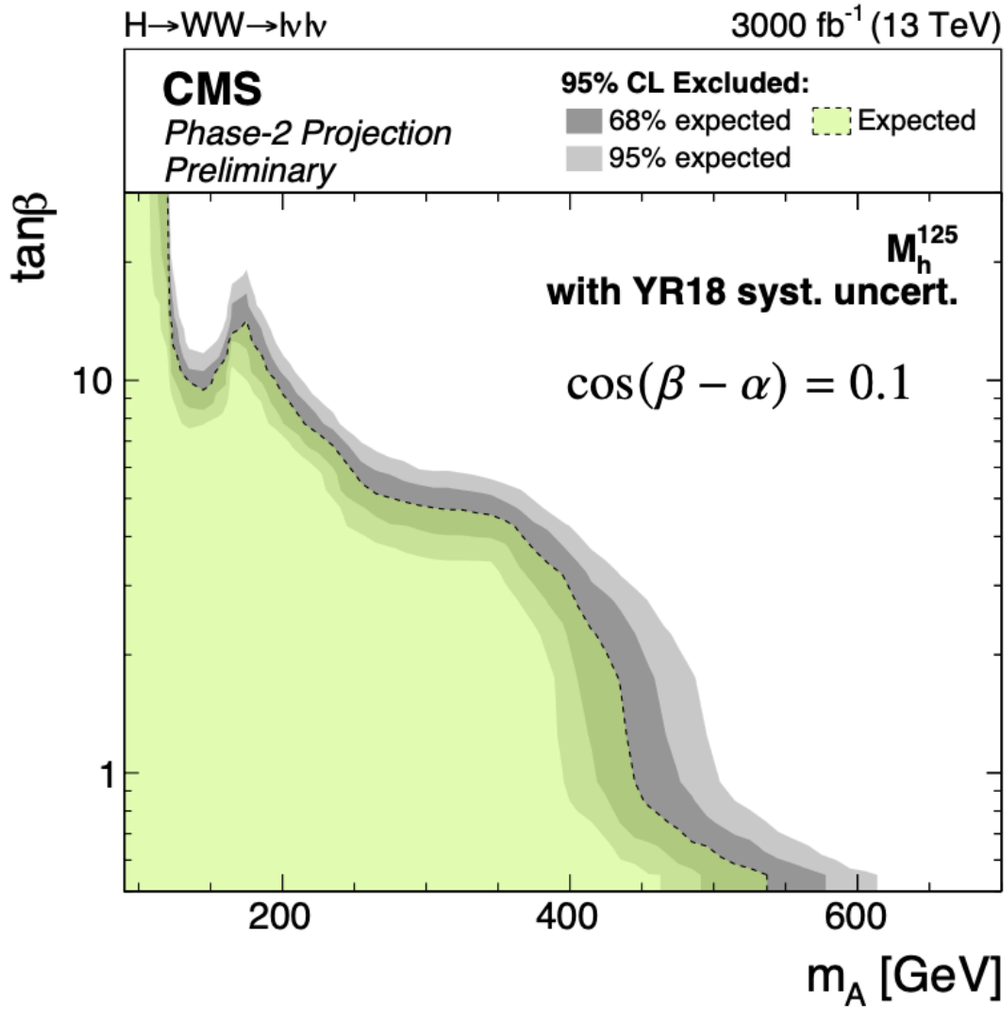
- EF01: EW Physics: Higgs Boson properties and couplings
- EF02: EW Physics: Higgs Boson as a portal to new physics
- EF03: EW Physics: Heavy flavor and top quark physics
- EF04: EW Precision Physics and constraining new physics
- EF05: QCD and strong interactions: Precision QCD
- EF06: QCD and strong interactions: Hadronic structure and forward QCD
- EF07: QCD and strong interactions: Heavy Ions
- EF08 - BSM: Model specific explorations
- EF09 - BSM: More general explorations
- EF10: BSM: Dark Matter at colliders

Energy Frontier Organization Cheat Sheet

New from the HL-LHC

(In addition to precision projections)



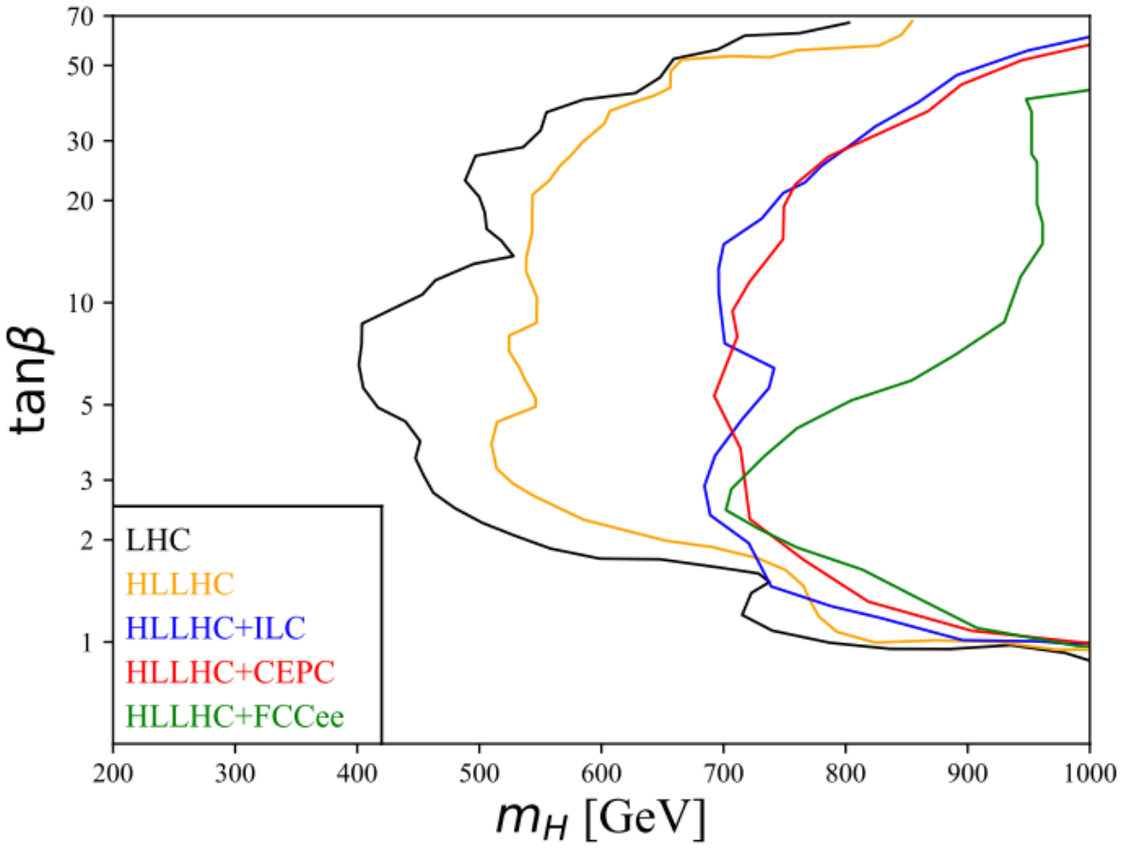


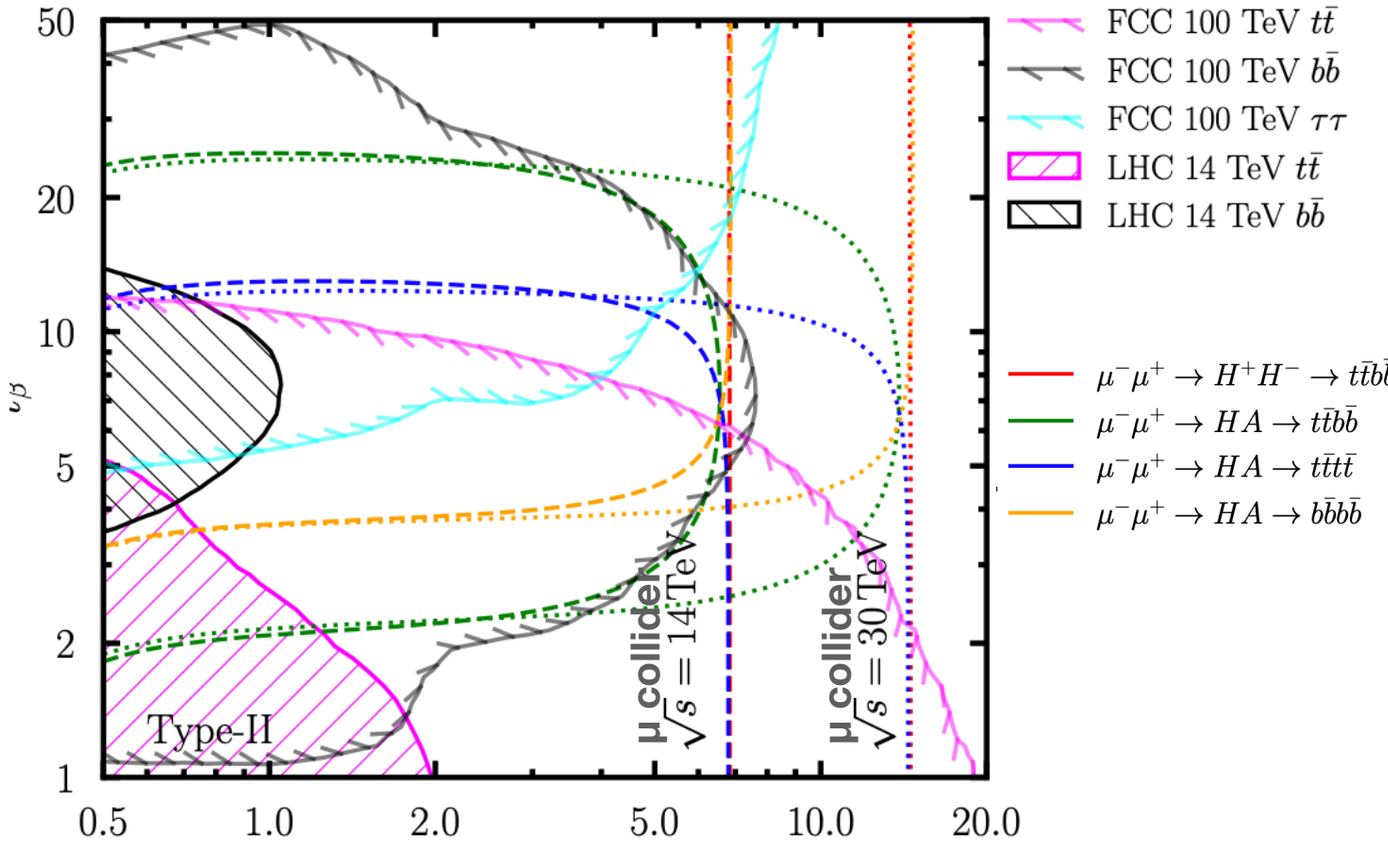
Search for high mass resonances decaying into W^+W^- in the di-leptonic final state with the CMS Phase-2 detector

arXiv: 2203.0788
arXiv: 2102.0838

2 Higgs Doublet Model Projections

Comparisons across proposed machines



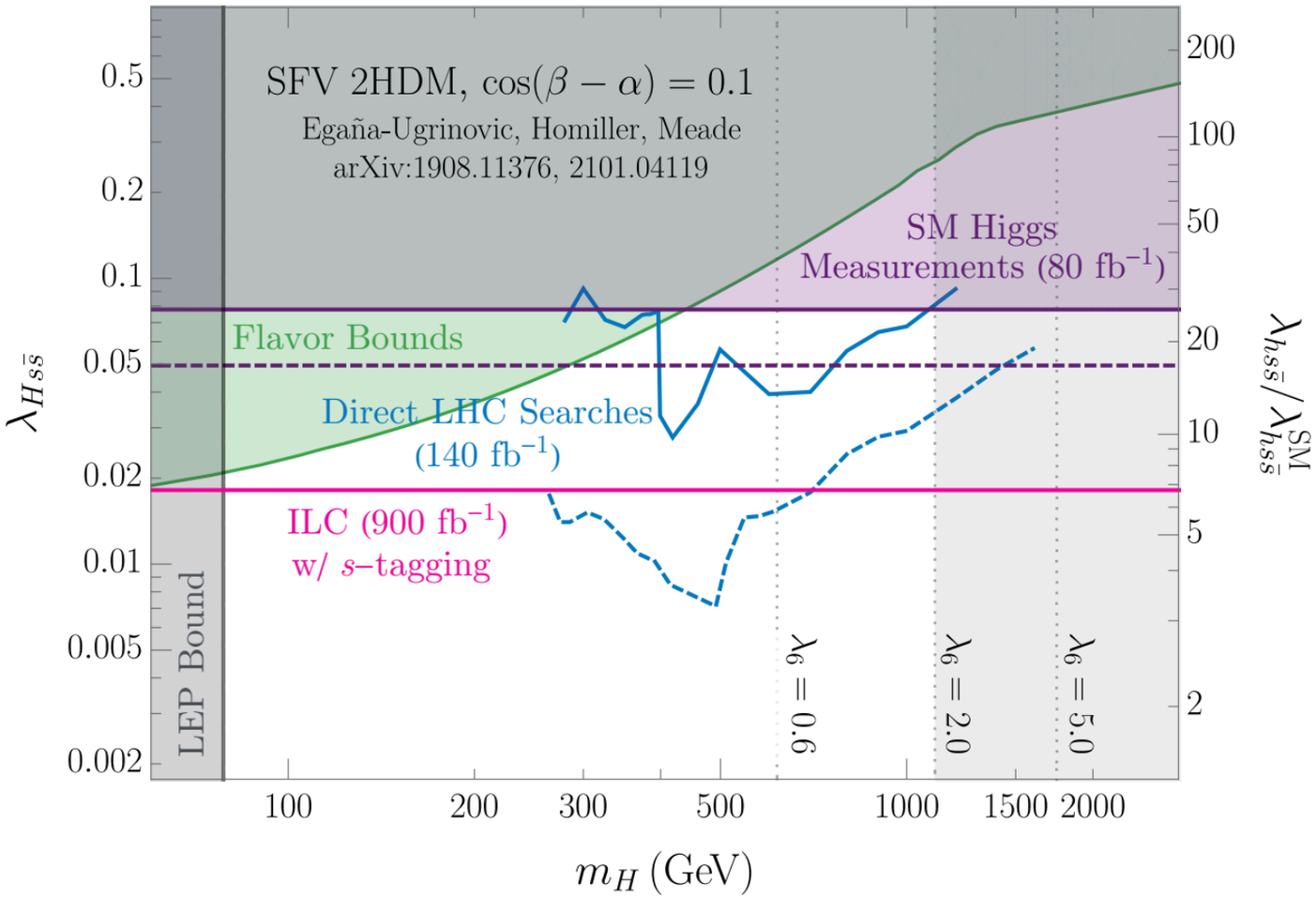


Showing recent projections for 2HDM Type-II

Will also use generic Higgs Single model for comparisons

The Higgs and Flavor

A probe for new physics



Strange Quark coupling as a probe for new physics

A spontaneous flavor violating (SFV) 2HDM allows for large couplings of additional Higgs to strange/light quarks while suppressing flavor changing neutral currents

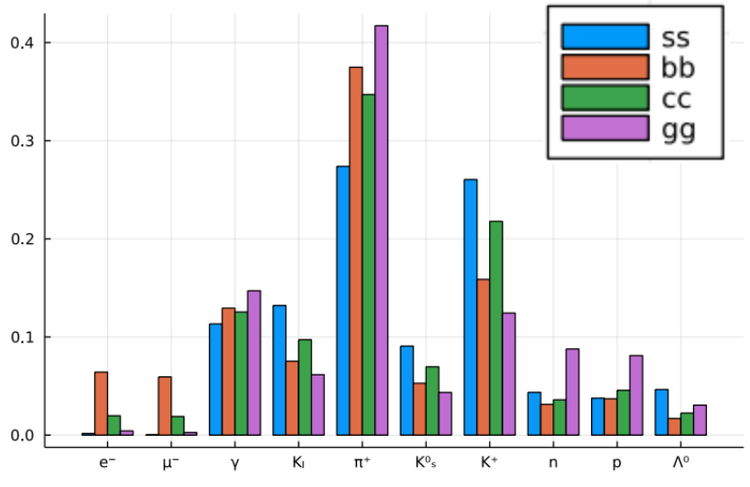
Huge room for deviations; searches at the LHC are difficult

Experimental techniques under development (next slide, later talks)

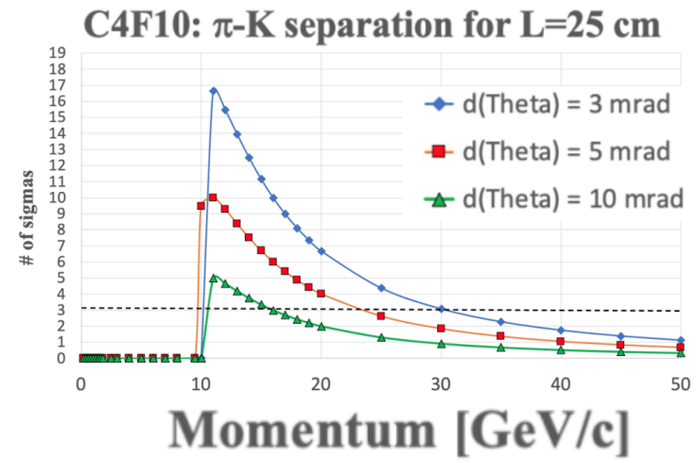
arXiv 2203.07535
arXiv 2203.04312

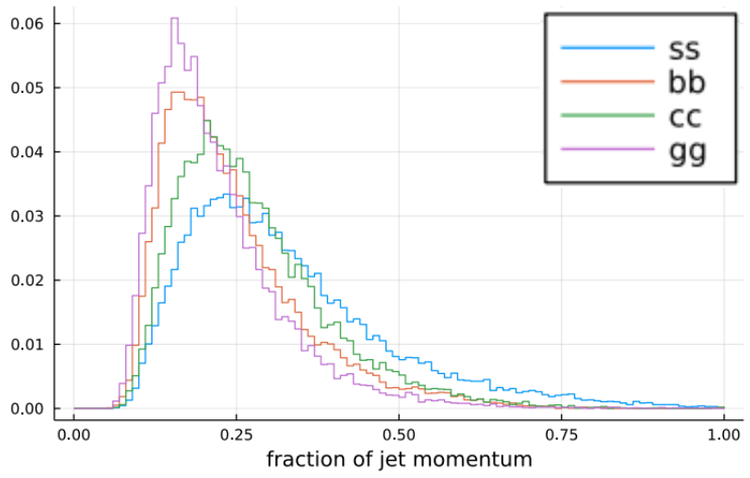
Flavor Measurements

An opportunity for Research and Development

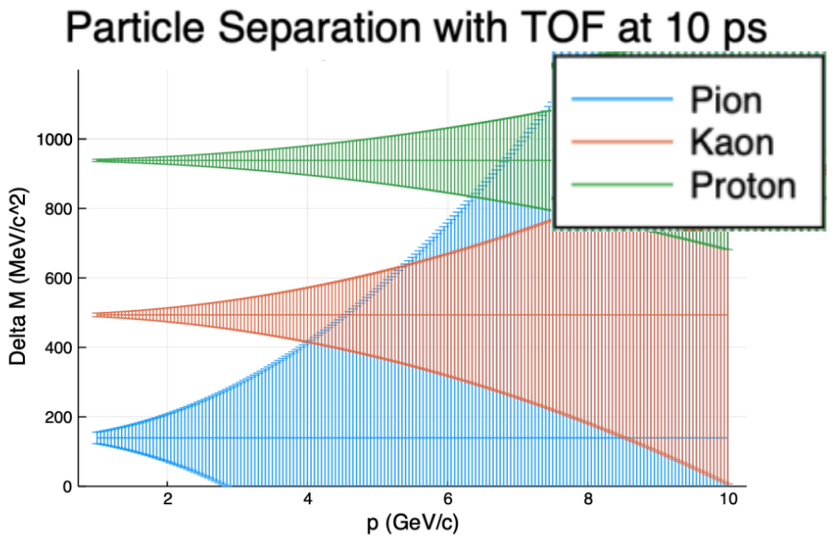


Leading Particle Fractions





Fraction of Jet Momentum
Carried by Leading Particle

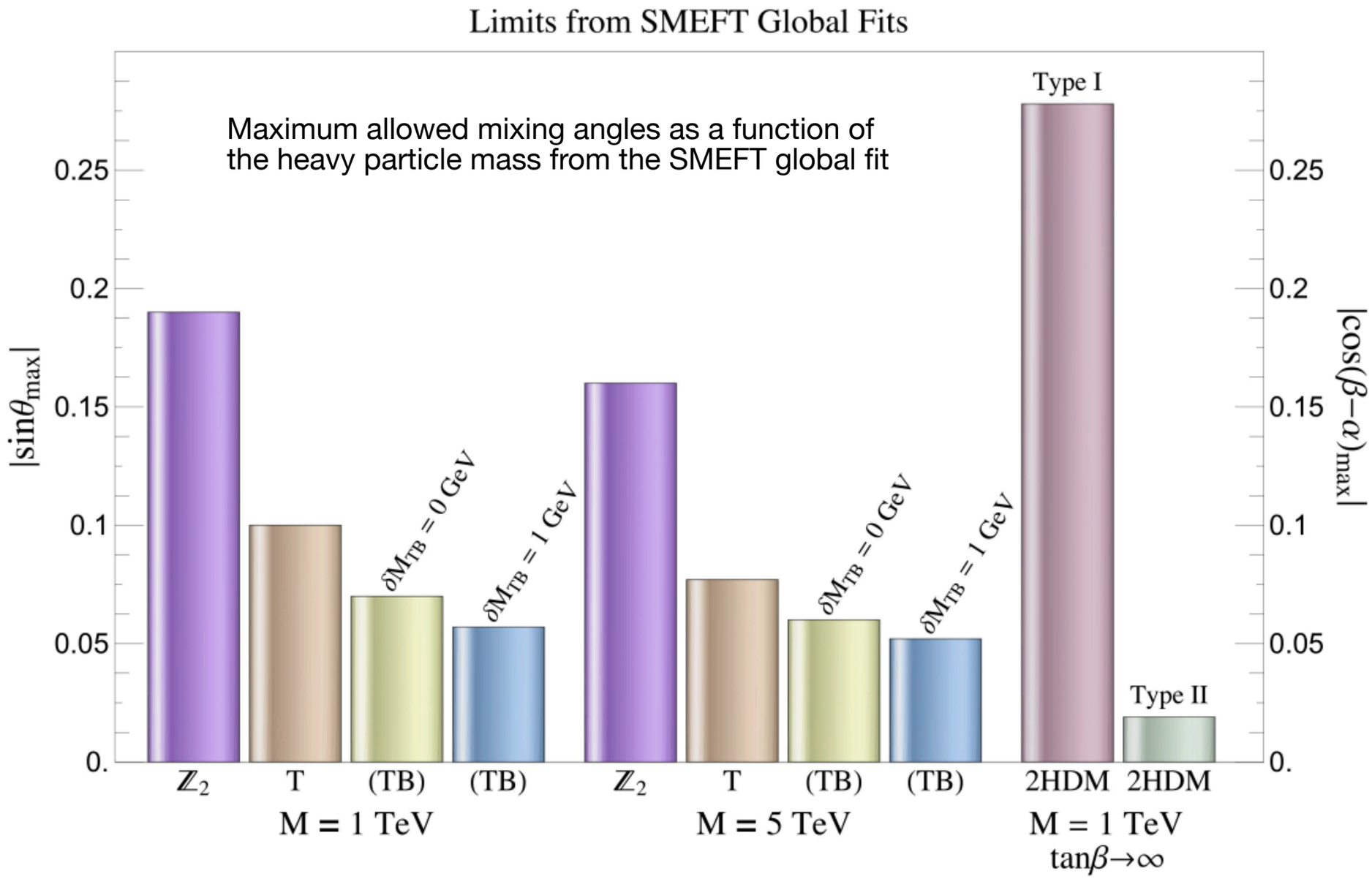


New Instrumentation, ML and Reconstruction techniques proposed

arXiv:2007.01296

Inverse Problem

How to map BSM models to SMEFT constraints
Include complete 1-loop matching for other models, more NLO effects in fits, and more distributions

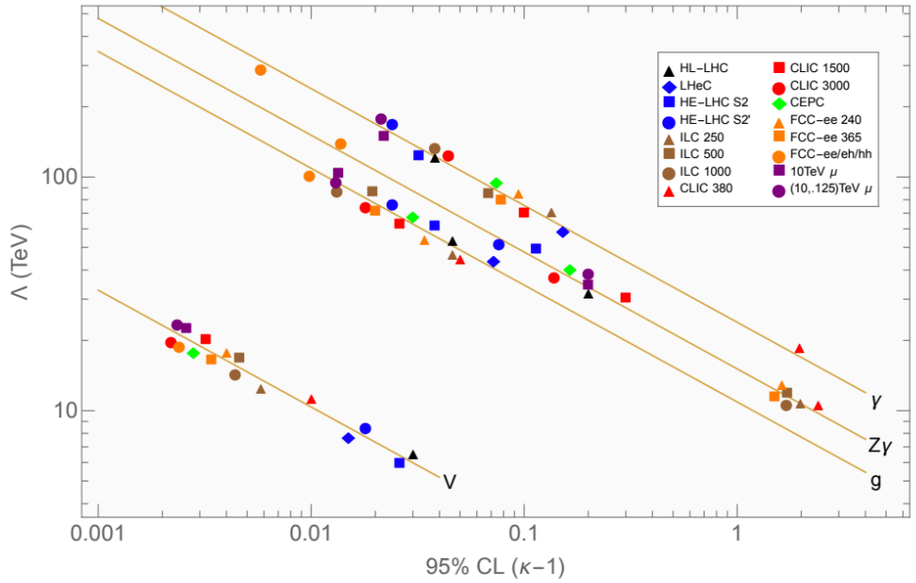


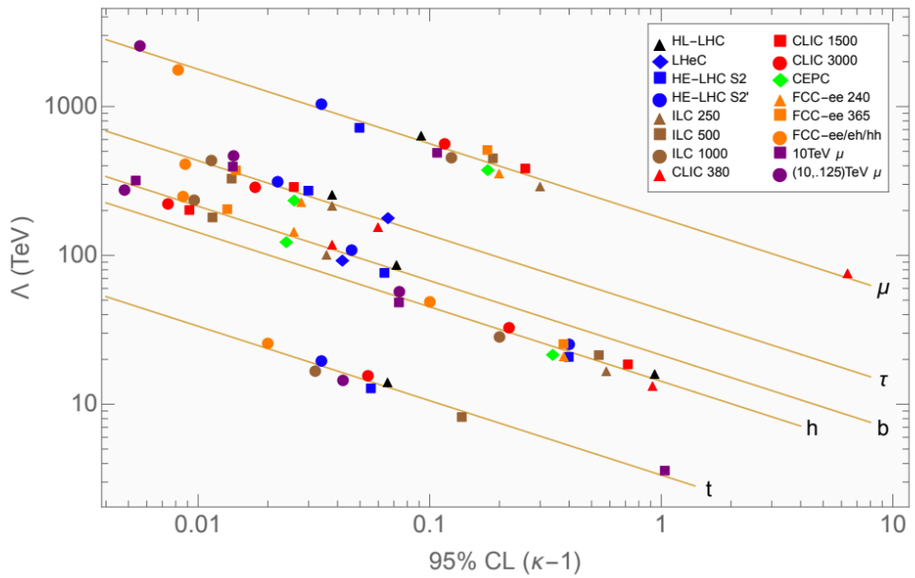
The observation of statistically significant non-zero SMEFT coefficients would correspond to BSM physics
What detailed information about the nature of the underlying high scale model can be obtained from these measurements?

arXiv 2203.09512

Model Independent Bounds on New Physics

Coupling (2σ)	HL-LHC	LHeC	HE-LHC		ILC			CLIC			CEPC	FCC-ee		FCC	Muon	
Unitarity Bound			S2	S2′	250	500	1000	380	1500	3000		240	365	ee/eh/hh	10 TeV	10 TeV+ 125 GeV
$2\delta\kappa_V$ [%]	3.0	1.5	2.6	1.8	0.58	0.46	0.44	1.0	0.32	0.22	0.28	0.40	0.34	0.24	0.26	0.24
Λ_V (TeV)	6.0	9	6.4	7.7	14	15	16	10	18	22	20	16	18	21	20	21
$2\delta\kappa_g$ [%]	4.6	7.2	3.8	2.4	4.6	1.94	1.32	5.0	2.6	1.8	3.0	3.4	2.0	0.98	1.34	1.31
Λ_g (TeV)	51	41	56	70	51	78	95	49	68	81	63	59	77	110	94	95
$2\delta\kappa_\gamma$ [%]	3.8	15.2	3.2	2.4	13.4	6.8	3.8	196	10	4.4	7.4	9.4	7.8	0.58	2.2	2.13
Λ_γ (TeV)	120	61	130	150	65	92	120	17	76	110	88	78	86	310	160	160
$2\delta\kappa_{Z\gamma}$ [%]	20	–	11.4	7.6	198	172	170	240	30	13.8	16.4	162	150	1.38	20	20
$\Lambda_{Z\gamma}$ (TeV)	34	–	45	55	11	12	12	10	28	41	37	12	12	130	34	34
$2\delta\kappa_t$ [%]	6.6	–	5.6	3.4	–	13.8	3.2	–	–	5.4	–	–	–	2.0	104	4.2
Λ_t (TeV)	13	–	14	18	–	9	19	–	–	14	–	–	–	24	3	16
$2\delta\kappa_b$ [%]	7.2	4.2	6.4	4.6	3.6	1.16	0.96	3.8	0.92	0.74	2.4	2.6	1.34	0.86	0.54	0.48
Λ_b (TeV)	80	100	85	100	110	200	220	110	220	250	140	130	180	230	290	310
$2\delta\kappa_\mu$ [%]	9.2	–	5.0	3.4	30	18.8	12.4	640	26	11.6	17.8	20	17.8	0.82	3.6	0.19
Λ_μ (TeV)	590	–	800	970	320	410	510	70	350	520	420	400	420	2000	540	2400
$2\delta\kappa_\tau$ [%]	3.8	6.6	3.0	2.2	3.8	1.40	1.14	6.0	2.6	1.76	2.6	2.8	1.46	0.88	0.47	0.47
Λ_τ (TeV)	220	170	250	290	220	370	410	180	270	330	270	260	360	460	360	360
$2\delta\kappa_h$ [%]	94	–	40	40	58	54	20	92	72	22	34	38	38	10	7.4	7.4
Λ_h (TeV)	15	–	23	23	19	19	32	15	17	30	25	23	23	45	52	52

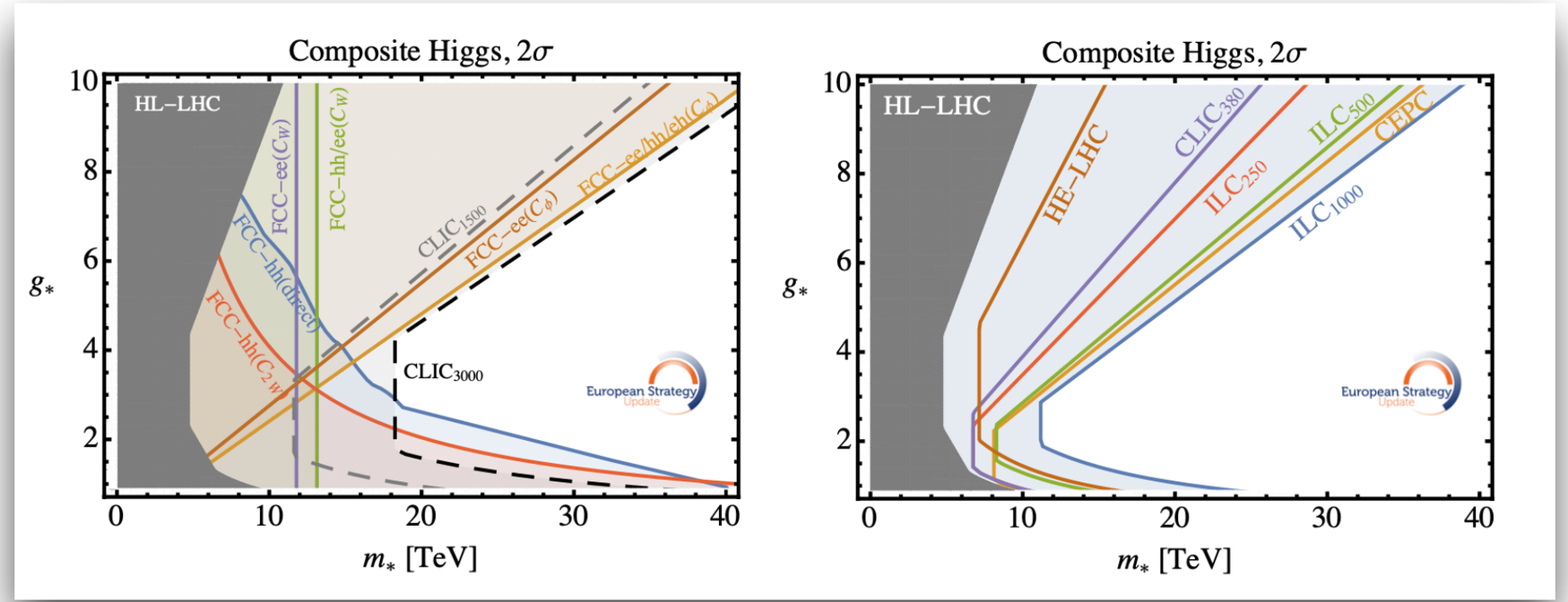




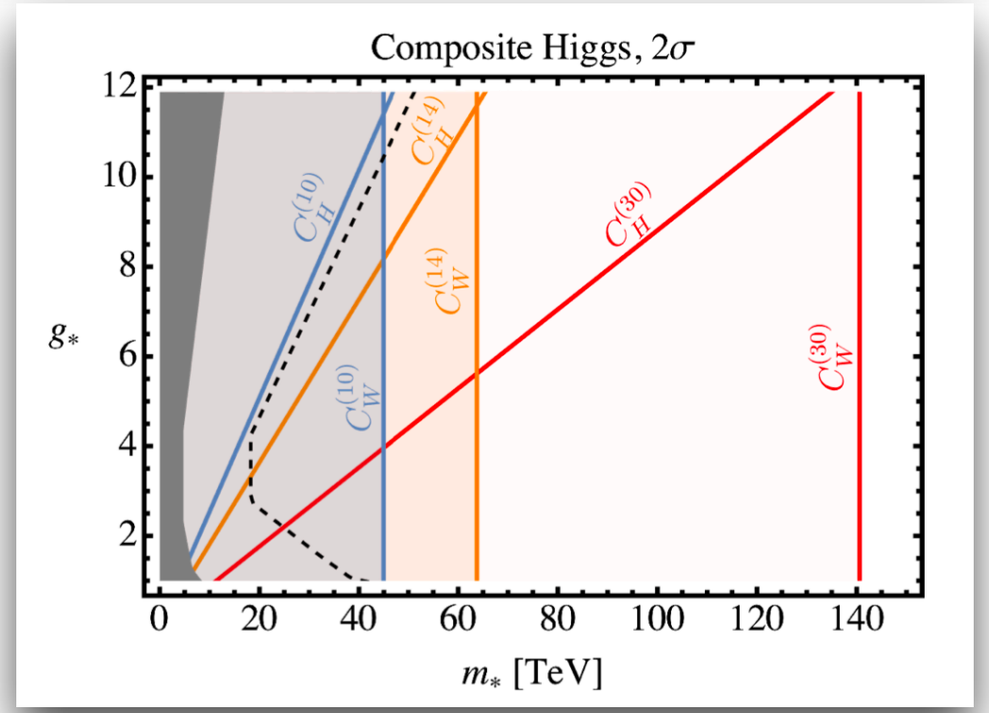
Unitarity bounds can convert sensitivities for Higgs couplings at future colliders into sensitivities to the scale of new physics

- Model-independent consequence of improving these sensitivities
- Illustrate the impact they would have on constraining new physics

Composite Higgs at Future Colliders



arXiv: 1910.11775
Showing HL-LHC
CLIC380, ILC, CEPC



arXiv: 2014.05770
Showing 10 TeV, 14 TeV and
30 TeV Muon Collider

The Big Questions

Challenges and Opportunities for Higgs Physics

- **Which physics beyond the Standard Model can be probed by precision measurements of Higgs couplings?**
  - How **precise** do these measurements need to be in order to probe BSM physics scenarios?
  - How are direct searches for new Higgs-like particles **complementary** to precision Higgs coupling measurements?
    - This should be studied by exploring the **complementarity between HL-LHC and future colliders** (***accounting for their different timelines***).

- **How can measurements in the Higgs sector be combined with measurements in other sectors to improve our understanding of new physics scale?**
  - **What theory calculations are needed** to enable the theory precision to match the projected experimental precision of future measurements?
  - **What R&D** (theory, instrumentation, computing, etc) is needed to make full use of opportunities at future colliders?

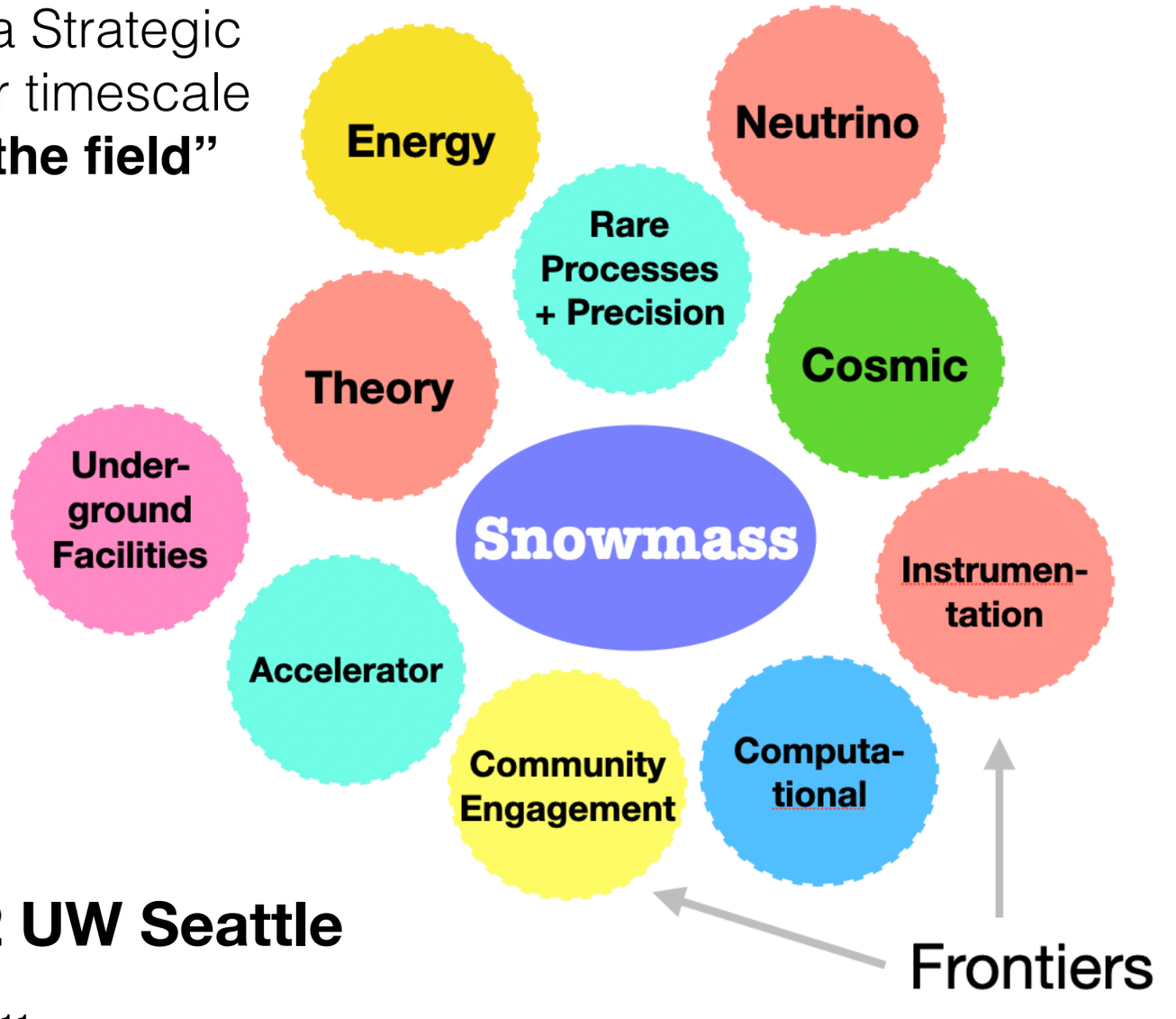
Snowmass 2021 Endgame

Snowmass Process: *

APS Division of Particles and Fields
Particle Physics Community Planning Exercise
Snowmass 2013
P5 (Particle Physics Project Prioritization Panel)
Takes the scientific input and develop a Strategic plan for the US - executed over 10 year timescale in the context of a "**20-year vision for the field"**

Final Products:

Snowmass report
Higgs/Higgs BSM working groups
- Outline the Big Questions
- Write Narrative
- Create Summary plots



Snowmass Summer Study - July 2022 UW Seattle

Summary

Much work to be done for the EF01/EF02 write up

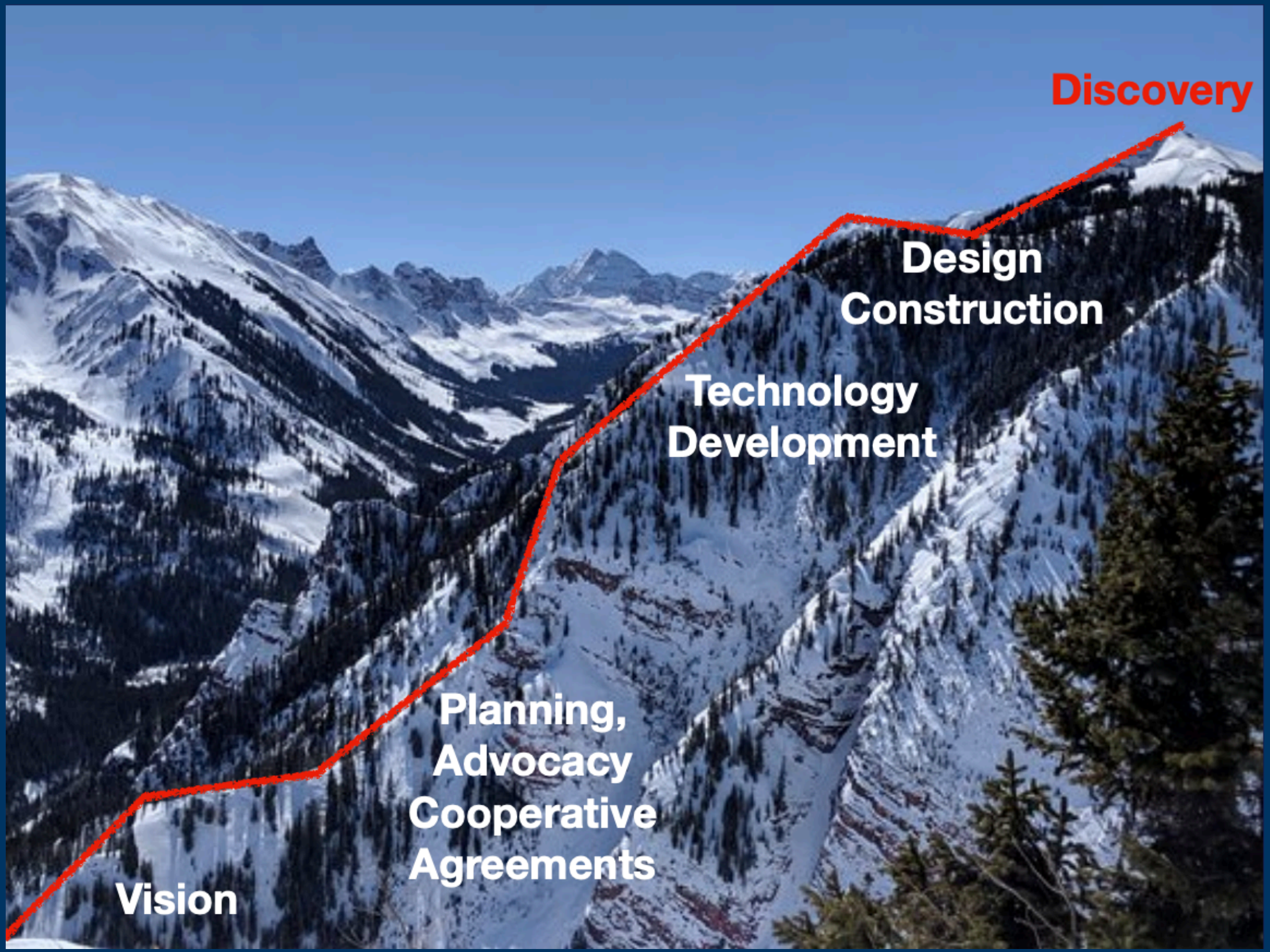
- Internal Draft “due” in a few weeks time
- Submission deadlines already past but it is up to conveners’ discretion to consider late contributions

This Snowmass Process will be used to motivate HEP funding for the next 10+ years

- ***Exciting Opportunities at Future Colliders***
- It is important to continue to **make the case for** US participation in **the HL-LHC** (especially as budgets remain flat)

Opportunities to collaborate across Frontiers and advocate for our field

Going Forward



Thank You!