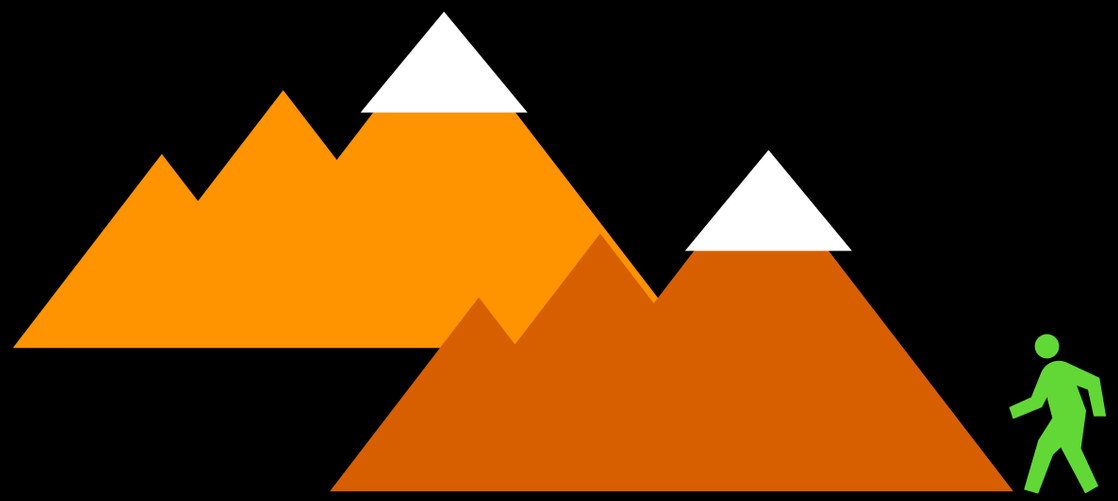
The Electroweak precision physics and constraining new physics (EF04) group from an early career perspective



EF04 Conveners:

Alberto Belloni
University of Maryland
Ayres Freitas
University of Pittsburgh
Junping Tian
University of Tokyo

Saptaparna Bhattacharya,
Northwestern University

Snowmass Day
September 24th, 2021

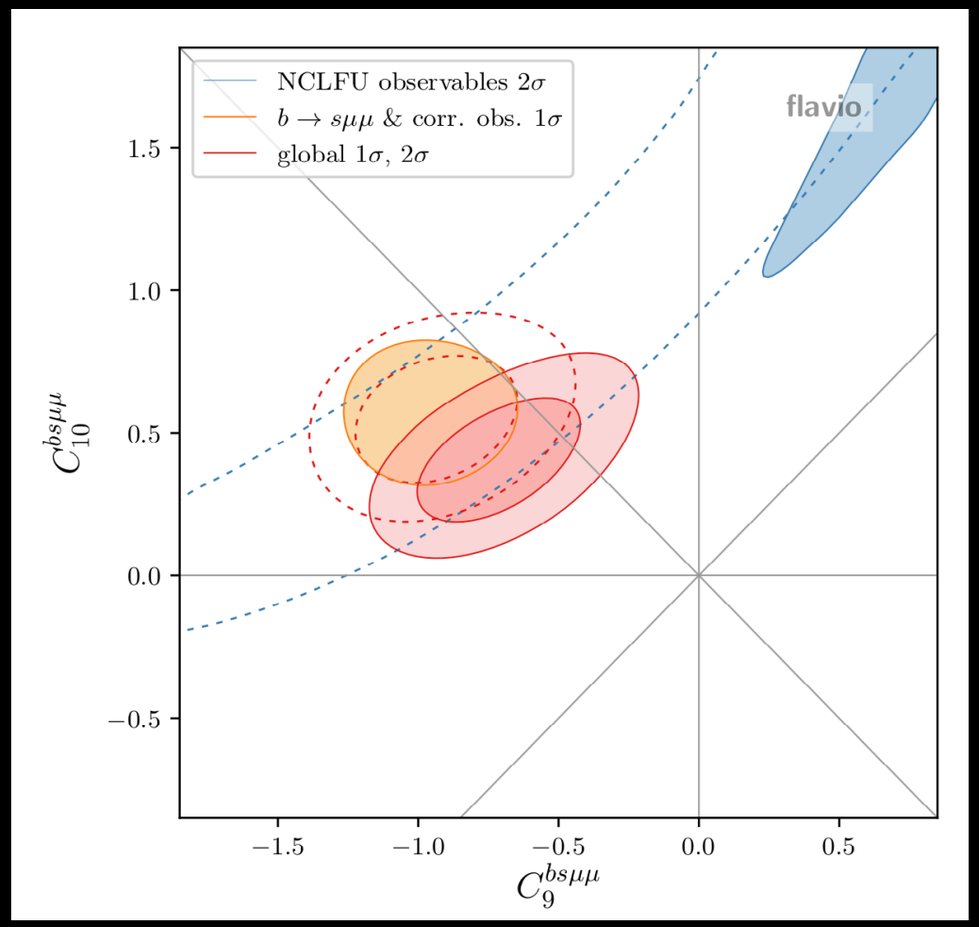
Addressing the **BIG** questions!

- ☑ At what scale does New Physics lie?
- ☑ What will we probe with new colliders?
- ☑ What kind of theoretical advancements are necessary to match experimental precision?
- ☑ What tools do we need for more precise and accurate Monte Carlo modeling?
- ☑ In the absence of telltale signs of New Physics, is our ultimate goal to perform a global fit of SM parameters?
- ☑ Best strategy for evaluation of SMEFT constraints in a coherent way?

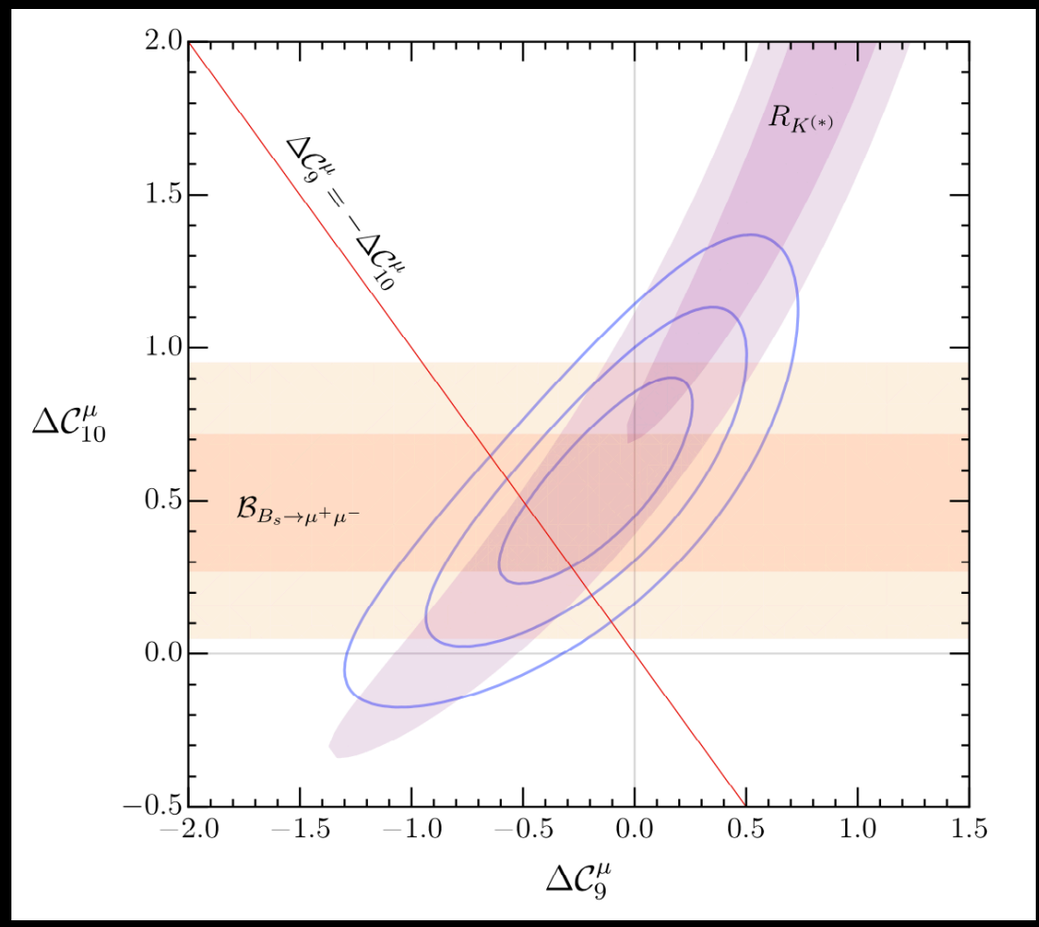
Broad mandate of the EF04 group

- ☑ Study of multi-boson and vector-boson fusion and scattering processes
- ☑ Constraints to the Standard Model (SM) with the Effective Field Theory (EFT) framework $\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i}{\lambda^2}\mathcal{O}_i + \sum_j \frac{f_j}{\lambda^4}\mathcal{O}_j$
  - ☑ specific models of SM-extension of particular relevance to electroweak precision physics
- ☑ Investigation of the impact of correlations between experimental and theoretical uncertainties with regard to combinations
- ☑ Discussions on state-of-the-art theoretical modeling of Electroweak (EWK) and QCD corrections/uncertainties

The EFT framework is useful — an example from the leptonic sector



https://arxiv.org/pdf/1903.10434.pdf



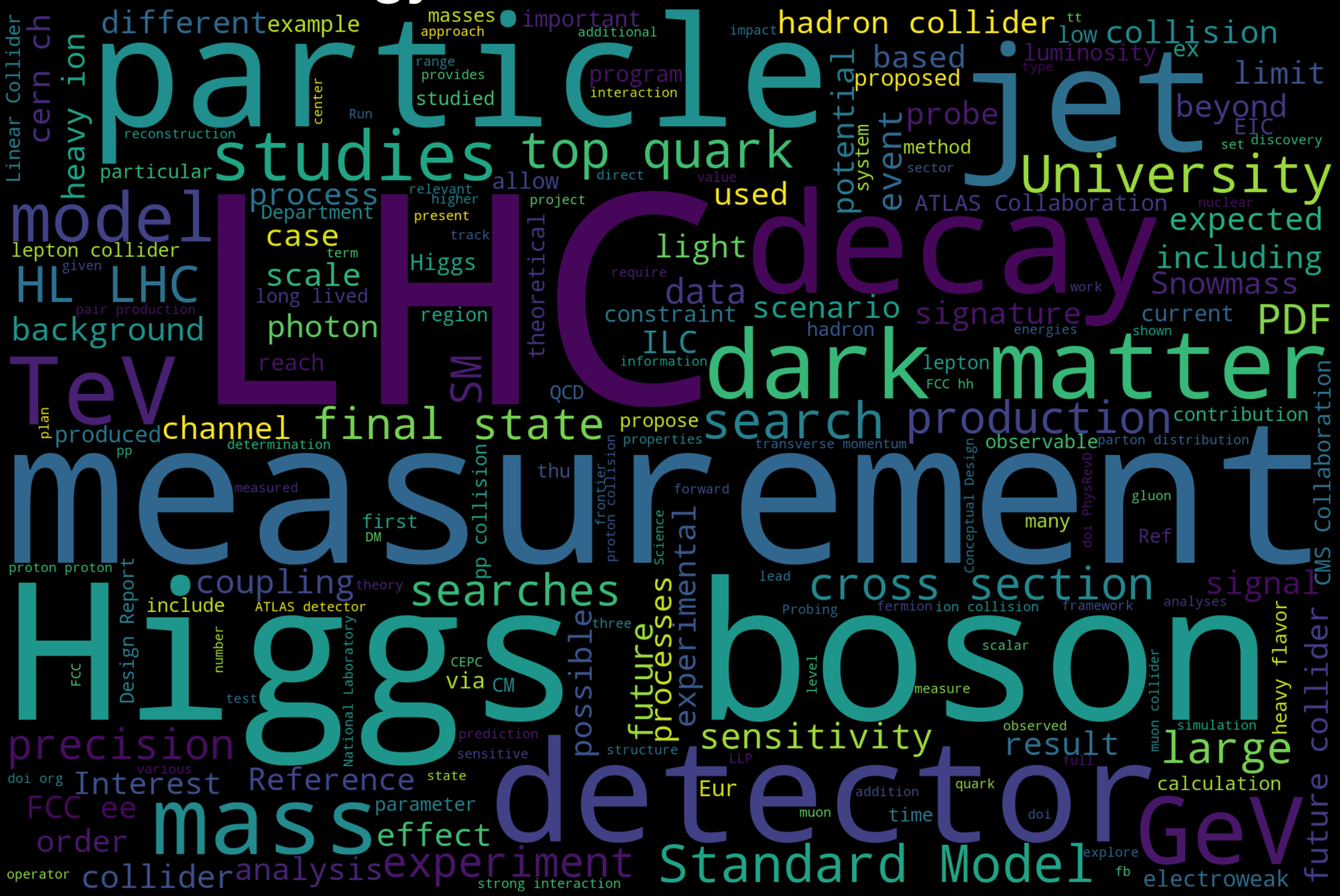
https://arxiv.org/pdf/2103.16558.pdf

- ☑ Tension in the leptonic sector with the SM at 3.6 σ observed in $b \to s l^+ l^-$
- ☑ EFT fits performed that factor 3.1 σ deviation from SM in measurement of R_k
- ☑ *Combination of these measurements leads to a **4.6 σ significance** of the hypothesis of a purely left-handed lepton flavor universality-violating contact interaction*

$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ e^+ e^-)}$$

Where the interests of the community lie…

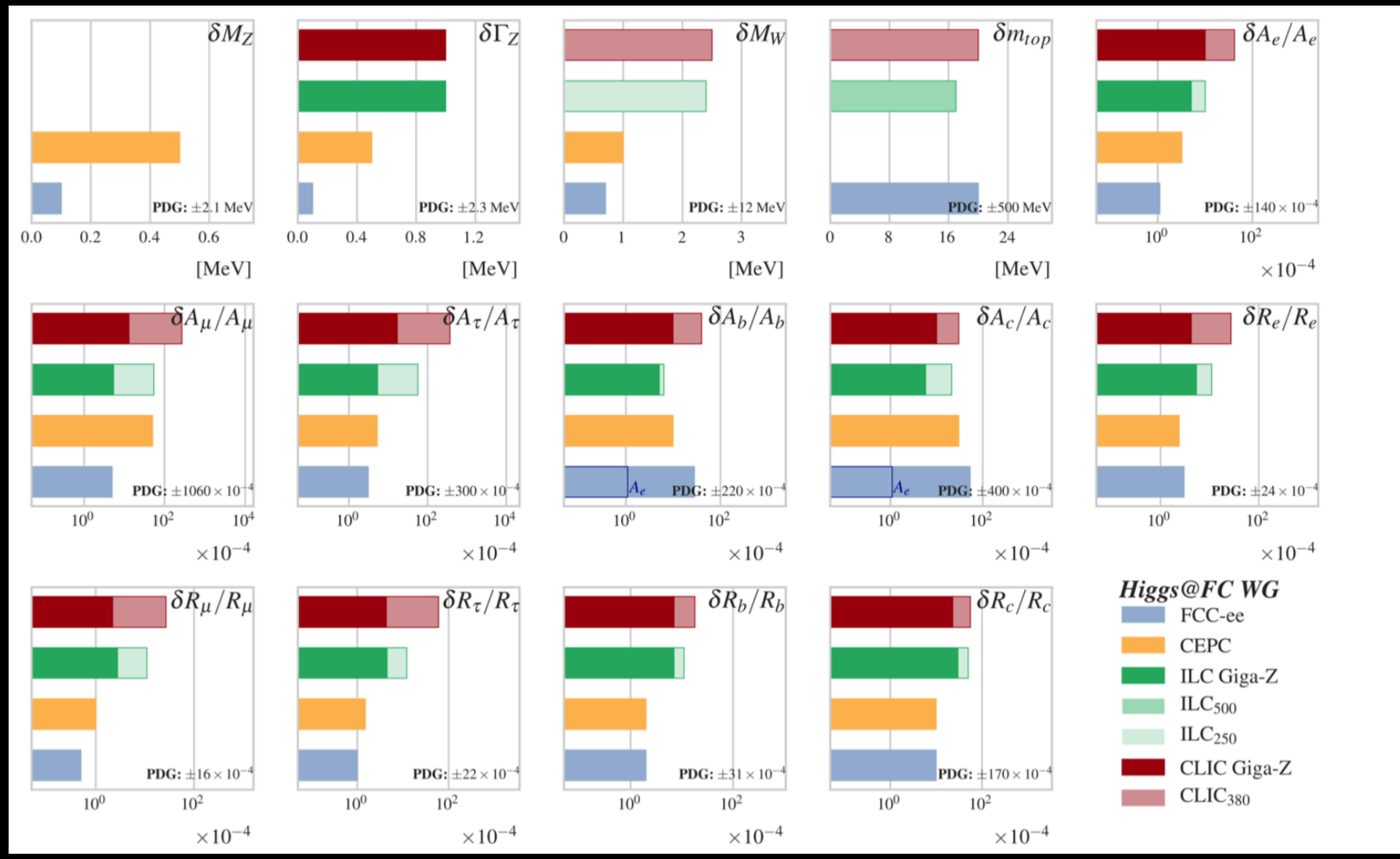
Energy frontier LOI word-cloud



☑ Notice the emphasis on M.E.A.S.U.R.E.M.E.N.T (vs. search)!

Snapshot of analysis topics in EF04

- ☑ Global fit of electroweak parameters
- ☑ Global fits using SMEFT
- ☑ Multiboson final states (VV, VVV)
- ☑ Vector-boson fusion and scattering topologies
- ☑ Measurement of W-mass and forward-backward asymmetry at hadron colliders
- ☑ Implementation of QCD and EWK corrections in MC computation



Global fits with the masses of the *Z* and *W* boson and the top quark, the *Z* boson width, and for fermion *f* the polarization asymmetries (A_f) and ratios of decay rates relative to the total hadronic decay rate (R_f)

ESG Physics Briefing Book, 2019

What's missing?

- Comprehensive discussion of systematic uncertainties
- Inclusion of multiboson processes (vector boson fusion and scattering)
- Role of differential observables
- EFT fits

Intersection with other groups

EF01: Higgs Boson properties and couplings

Contribution to EW and EFT fits from the Higgs sector

EF03: Heavy flavor and top quark physics

Contribution to EW and EFT fits from the top sector

EF04

EF05: Precision QCD

Correlations between EWK and QCD corrections

EF08/09: Interesting BSM models

Models with strong signals in VV(V) processes

Significant overlap with the theory, precision, computational and instrumentation frontier

How to Snowmass*?

What Snowmass Can Do for You, and What You Can Do for Snowmass

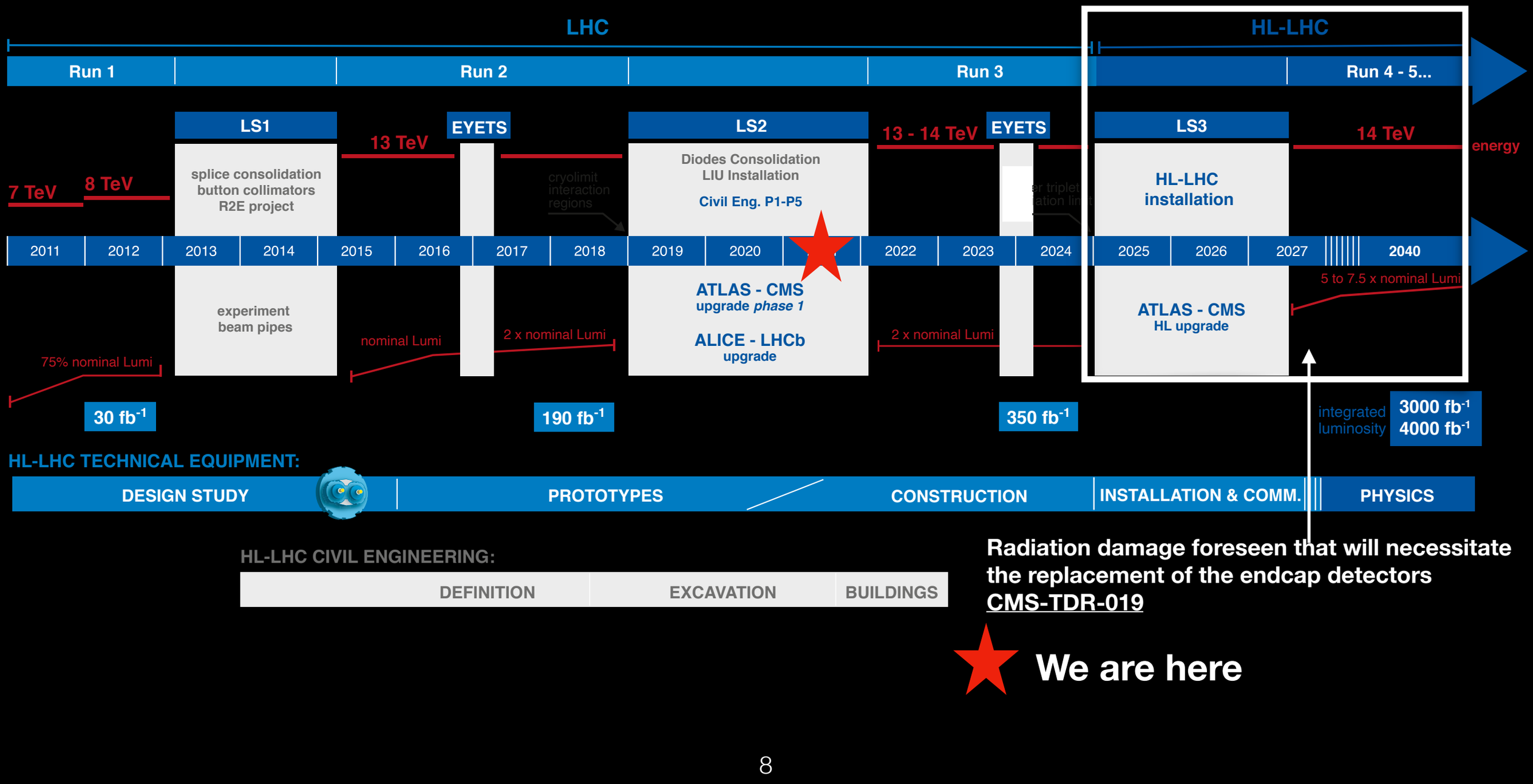
The goals of Snowmass—and the outcomes—are defined by individual participants, led by the organizers. This year's announcement speaks of an opportunity for the entire particle physics community to come together to identify and document a scientific vision for the future of particle physics in the U.S. with our international partners. How can we make that happen? Let me offer some advice to first-time participants (and maybe others).

As an early career member, I find it immensely useful to acquire a broad overview of the field…

*Chris Quigg's comments on Snowmass: https://indico.fnal.gov/event/45207/attachments/133652/164937/How_to_Snowmass-final-links.pdf

The LHC upgrade schedule

LHC / HL-LHC Plan



Radiation damage foreseen that will necessitate the replacement of the endcap detectors CMS-TDR-019

We are here

Timelines and complementarity

	T_0				+5					+10					+15					+20					...	+26
ILC	0.5/ab 250 GeV									1.5/ab 250 GeV						1.0/ab 500 GeV			0.2/ab $2m_{top}$		3/ab 500 GeV					
CEPC	5.6/ab 240 GeV									16/ab M_Z		2.6 /ab $2M_W$											SppC =>		
CLIC	1.0/ab 380 GeV														2.5/ab 1.5 TeV								5.0/ab => until +28 3.0 TeV		
FCC	150/ab ee, M_Z					10/ab ee, $2M_W$				5/ab ee, 240 GeV					1.7/ab ee, $2m_{top}$										hh,eh =>
LHeC	0.06/ab									0.2/ab					0.72/ab										
HE-LHC	10/ab per experiment in 20y																								
FCC eh/hh	20/ab per experiment in 25y																								

Timeline of collider projects starting at time T0 (~now)

(Higgs Boson Studies at Future Particle Colliders)

Precision measurements of W-mass at the LHC and FCC-ee discussed at EF04 meeting

Physics Goals*

(*defined with the current landscape in mind)

Today, the Standard Model seems to describe all data from particle physics. The major challenge of particle experimentation is to "stress-test" the SM or prove that it is insufficient.

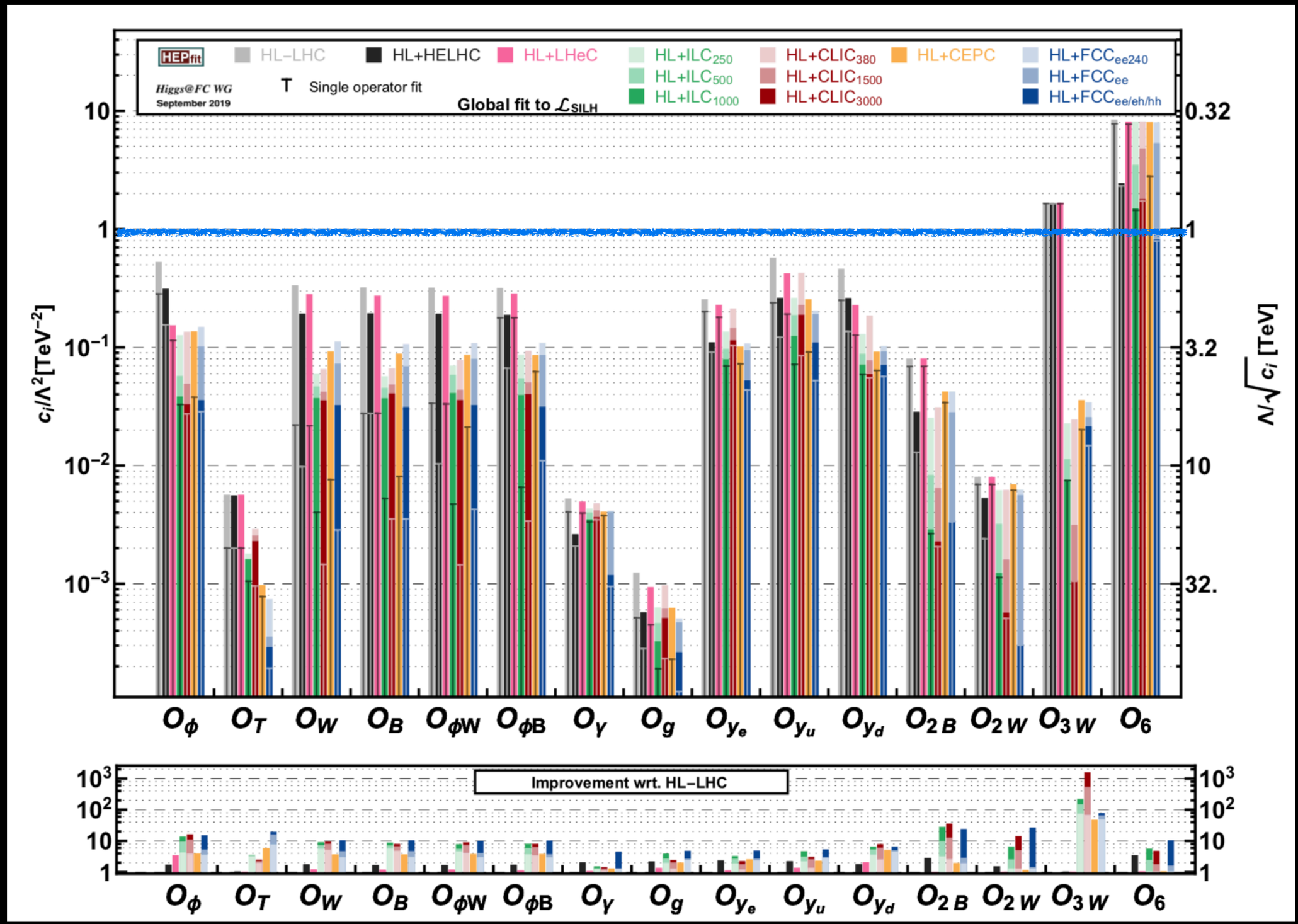
An important tool in this study is the combination of SM data into global fits. A particularly attractive formalism is that of the Standard Model Effective Field Theory (SMEFT). In this formalism, the SM is represented by the most general set of dimension 4 operators, and new physics appears as operators of higher dimension.

This formalism explains that BSM effects are small because new particles are heavy. Maybe we can show that dim-6 coefficients, e.g., are nonzero. Maybe we can show that they have a pattern that reveals the new theory underneath.

As summarized by Michael Peskin at the EF04 session in the Energy Frontier Workshop

Constraints on higher order operators using the Effective Field Theory framework

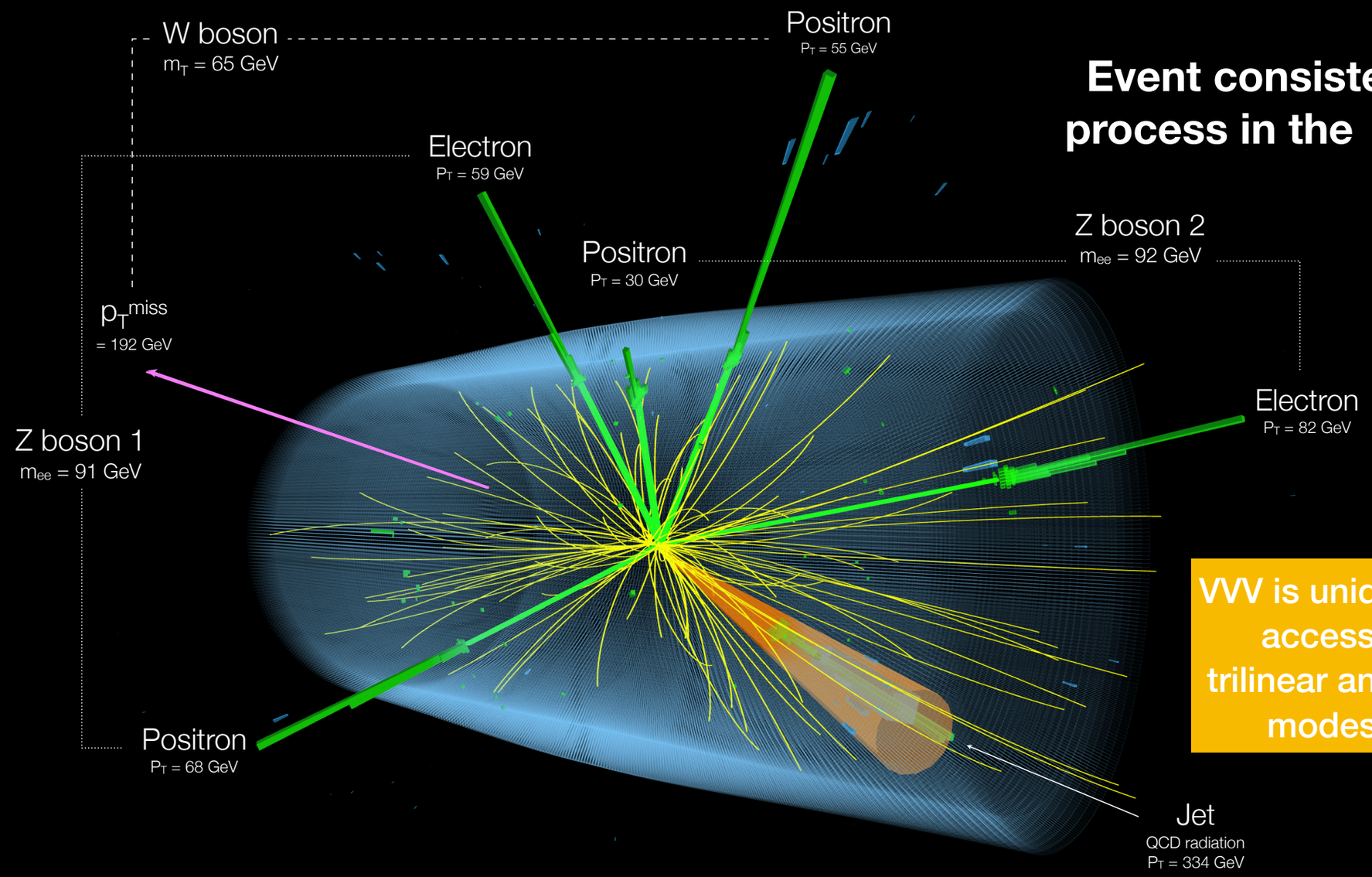
- ☑ Global fits of dim-6 operators in SILH basis (as opposed to Warsaw)
- ☑ LHC constraints derived from the Higgs sector
- ☑ A global fit combining constraints from Higgs, top, and multiboson final states imperative to gauge impact of the LHC



A discussion of dim-8 operators at lepton colliders can be found in Juergen Reuter's talk

We are *also* at the forefront of discovery at the LHC!

WZZ → 5 lepton event



Event consistent with WZZ process in the CMS analysis

VVV is unique in that it allows access to the quartic, trilinear and Higgs-mediated modes of production

☑ CMS Collaboration reports first observation of the VVV process in 2020
☑ ATLAS Collaboration reports first observation of the WWW process in 2021

Resources for early career physicists

EF04 specific:

- ☑ A complete spate of EF04 activities: https://indico.fnal.gov/category/1138/
  - ☑ Extensive discussions on electroweak precision observables at future colliders/low energy neutrino experiments
  - ☑ Physics reach of muon colliders

Snowmass early career group activities:

- ☑ Indico category: https://indico.fnal.gov/category/1202/
  - ☑ Excellent town hall on September 21st with focus on supporting early career members in academia

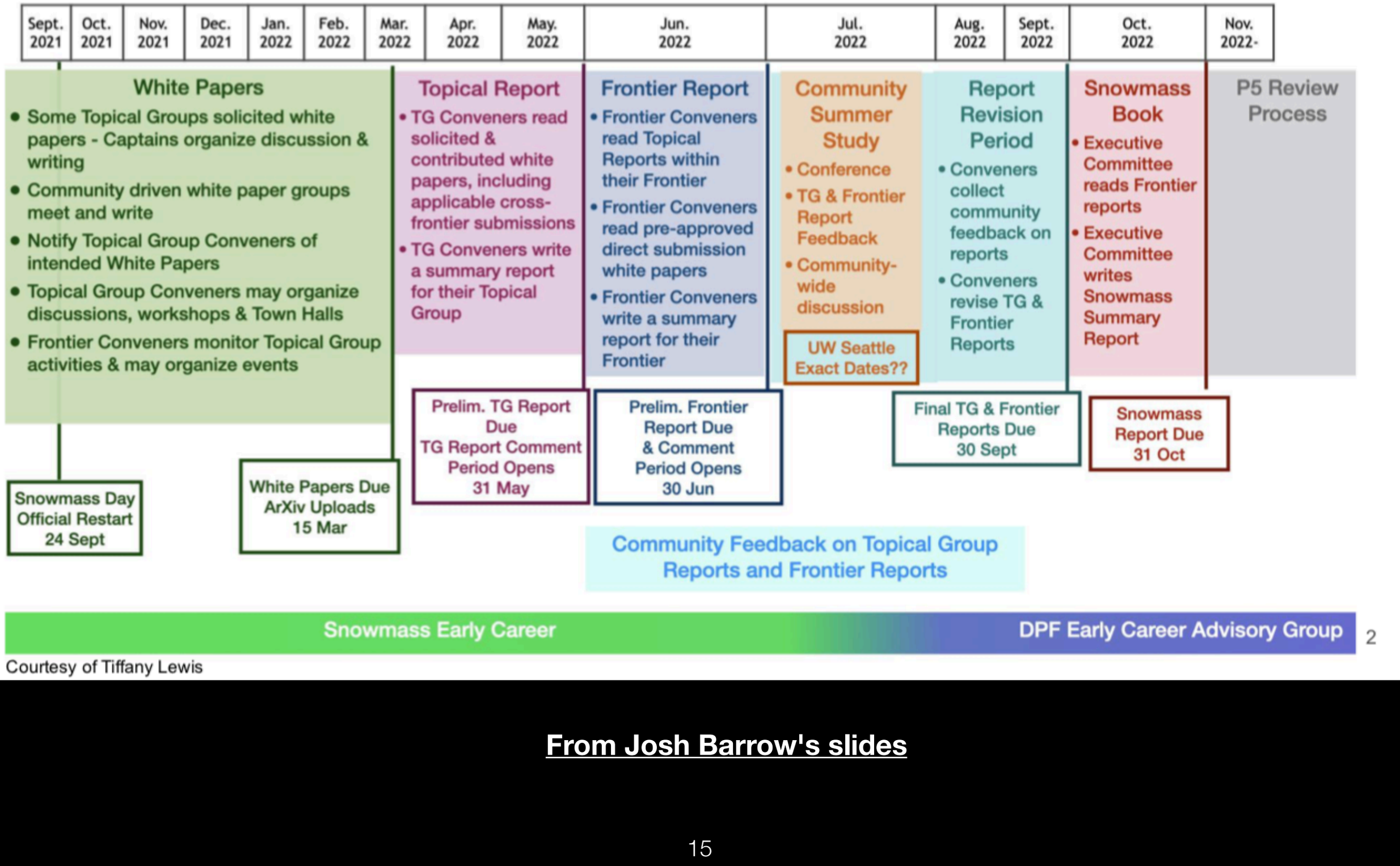
30 Sep	SEC Core Initiatives (LTO, DEI, Inreach)	
23 Sep	SEC Core Initiatives (LTO, DEI, Inreach)	
21 Sep	SEC Survey Team Meeting	NEW
21 Sep	SECDEI/CEF03 Town Hall: Supporting Early Career People in Academia	
17 Sep	"Big Questions in ... Muon g-2!" Colloquium	

Slack channels:

- early-career-diversity
- early-career-org
- early-career-rep
- early-career-snowmass

Additional Material

Post-Break Snowmass Timeline



Courtesy of Tiffany Lewis

From Josh Barrow's slides