

The Snowmass Energy Frontier

Snowmass Day

September 24, 2021

Laura Reina (FSU), Meenakshi Narain (Brown U.), [Alessandro Tricoli \(BNL\)](#)

Energy Frontier Restart

2020

- Energy Frontier **Kick-off Meeting**, May 21, 2020, [see agenda](#)
- [Energy Frontier Workshop “Open Questions and New Ideas”](#), July 20-22, 2020, with Panel discussion on “*The importance of the Energy Frontier in the US HEP future planning*” (Zoom recording of Panel Discussion)



2021

- **EF slowed down activities in 2021 until June**
 - Community continued to work collaboratively
 - Monte Carlo production activities continued to support the needs of EF
 - Occasional and informal Topical Group ‘conversations’ to assure scientific continuity and support of ongoing activities

- **EF Restart Workshop, Aug. 30-Sept. 3:** <https://indico.fnal.gov/event/49756/>
 - Many interesting talks in plenary and parallel sessions
 - Joint parallel sessions with CompF and CF
 - Unstructured discussion sessions with CEF and AF
 - **Regroup** after the few months of slowdown/pause of Snowmass activities
 - Assess **progress** made so far
 - Share **new studies** that may have been started in the meantime
 - Identify **gaps** in our strategies
 - Update the community with **schedule, goals and plans** towards the final reports in summer 2022

The Energy Frontier Group (I)

- **EF Convenors:** *Laura Reina* (FSU), *Meenakshi Narain* (Brown U.), *Alessandro Tricoli* (BNL)
- **Ten Topical Groups (TGs):**

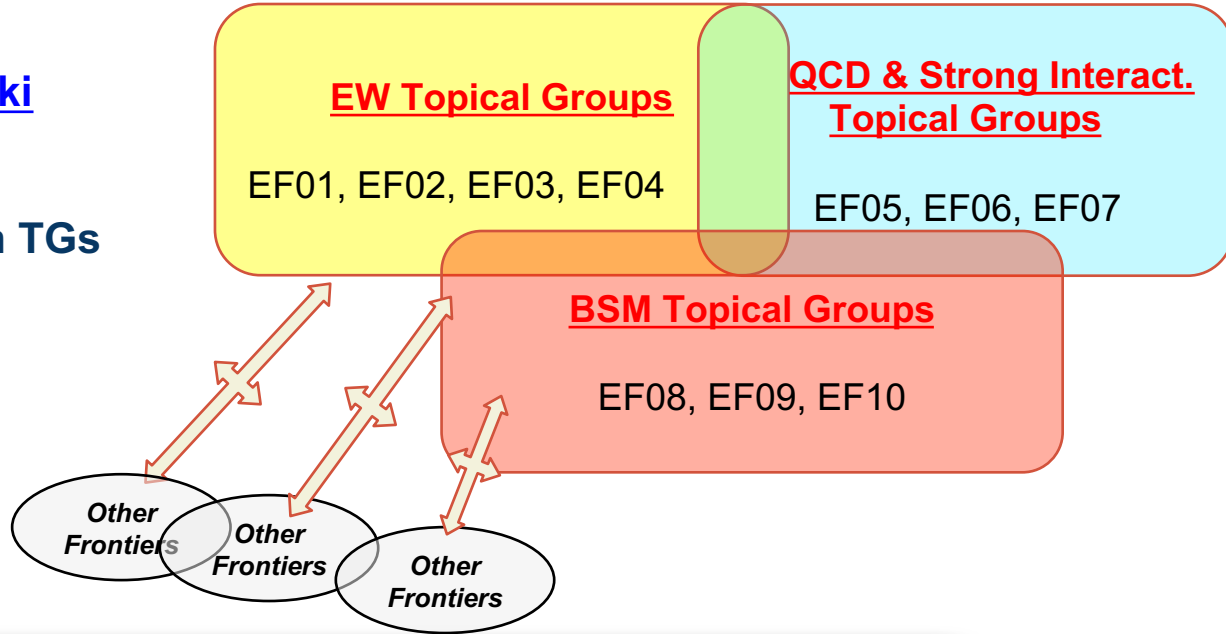
Topical Group	Co-Conveners
EF01: EW Physics: Higgs Boson properties and couplings	Sally Dawson (BNL), Andrey Korytov (U Florida), Caterina Vernieri (SLAC)
EF02: EW Physics: Higgs Boson as a portal to new physics	Patrick Meade (Stony Brook), Isobel Ojalvo (Princeton)
EF03: EW Physics: Heavy flavor and top quark physics	Reinhard Schwienhorst (MSU), Doreen Wackerroth (Buffalo)
EF04: EW Physics: EW Precision Physics and constraining new physics	Alberto Belloni (Maryland), Ayres Freitas (Pittsburgh), Junping Tian (Tokyo)
EF05: QCD and strong interactions: Precision QCD	Michael Begel (BNL), Stefan Hoeche (FNAL), Michael Schmitt (Northwestern)
EF06: QCD and strong interactions: Hadronic structure and forward QCD	Huey-Wen Lin (MSU), Pavel Nadolsky (SMU), Christophe Royon (Kansas)
EF07: QCD and strong interactions: Heavy Ions	Yen-Jie Lee (MIT), Swagato Mukherjee (BNL)
EF08: BSM: Model specific explorations	Jim Hirschauer (FNAL), Elliot Lipeles (UPenn), Nausheen Shah (Wayne State)
EF09: BSM: More general explorations	Tulika Bose (U Wisconsin), Zhen Liu (Maryland), Simone Pagan-Griso (LBL)
EF10: BSM: Dark Matter at colliders	Caterina Doglioni (Lund), LianTao Wang (Chicago), Antonio Boveia (Ohio State)

NEW

- **Monte Carlo Task Force and Production Team:** coordinated by **John Stupak** (U. Oklahoma)
 - 1) Assess the MC needs ⇒ “Task force” (work completed)
 - 2) Produce MC samples ⇒ “Production Team” (ongoing)

Topical Group Activities

- General [Energy Frontier Wiki](#)
- Electroweak TGs
 - EF01, EF02, EF03, EF04
- QCD and Strong Interaction TGs
 - EF05, EF06, EF07
- BSM TGs
 - EF08, EF09, EF10



Multiple Ongoing Activities

- See Topical Group [Wiki pages](#) and [indico meeting agendas](#) for details of ongoing activities
- [EF calendar](#) and [communications](#) via mailing lists and Slack

The Energy Frontier Group (II)

- **Liaisons:** high-level and bi-directional communication b/w Frontiers

Other Frontier	Liaisons
Neutrino Physics Frontier	André de Gouvêa (Northwestern)
Rare Processes and Precision	Manuel Franco Sevilla (Maryland) NEW
Cosmic Frontier	Caterina Doglioni (Lund)
Theory Frontier	Laura Reina (FSU)
Accelerator Frontier	Dmitri Denisov (BNL), Meenakshi Narain (Brown)
Computational Frontier	Daniel Elvira (FNAL)
Instrumentation Frontier	Caterina Vernieri (SLAC), Maksym Titov (CEA Saclay)
Community Engagement Frontier	Daniel Whiteson (UCI), Sergei Gleyzer (Alabama)

- Renew interest in Snowmass community for Muon Collider:

Muon Collider Forum established with *Accelerator and Theory Frontiers* → [Wiki \(new\)](#)

Muon Collider Forum Coordinators

EF: **Kevin Black** (U. Wisconsin-Madison), **Sergo Jindariani** (Fermilab)

AF: **Derun Li** (LBNL), **Diktys Stratakis** (Fermilab)

TF: **Patrick Meade** (Stony Brook U.), **Fabio Maltoni** (Louvain U., Bologna)

The Energy Frontier Group (III)

- **Snowmass thrives on the participation of Early Career (EC) physicists and offers an ideal environment for young people to get involved and promote their own initiatives**

Early Career Representatives

- **Grace Cummings** (U. Virginia) - gec8mf@virginia.edu
- **Matt LeBlanc** (U. Arizona) - matt.leblanc@cern.ch

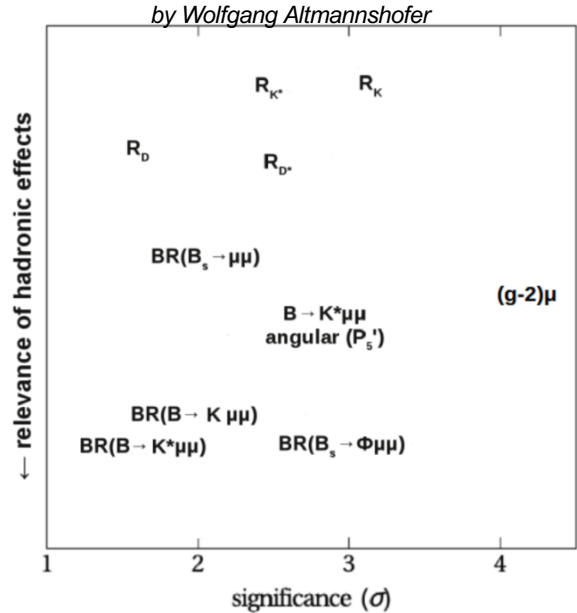
- EC leadership is for a 3-month term (staggered): Grace and Matt are current EF representatives
- Get in touch especially if you want to get involved in EF activities, but need guidance how to do it effectively: Grace and Matt will help build bridges between projects and new collaborators

Additional Snowmass resources for Early Careers:

- [#snowmass-young](#) and [#welcome-to-snowmass](#) as points of entry for newcomers
- The [Snowmass Early Career](#) twiki, which includes a description of our structure, current leadership, and the SEC calendar of all events.

Probing the energy scale for new physics

- Landscape changed since we started Snowmass → Evidence of the breaking of the SM in the lepton flavor sector?



Complementarity with other Frontiers

While slow at the start, the energy frontier is ultimately needed to “win the race”



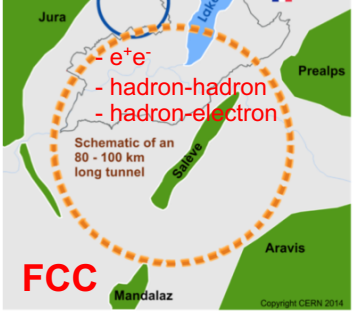
Patrick Meade

Nevertheless if we get indirect hints from existing or planned experiments its important to know how to test them!

Gravitational Waves, Astrophysics, Dark Matter, Rare Processes

- **Broad reach of Collider physics:** colliders are needed to test models across a broad range of observables
- **Unique complementarity** between electroweak precision fits and flavor observables etc.

Which machines?



Hadrons

- large mass reach \Rightarrow exploration?
- ▶ S/B $\sim 10^{-10}$ (w/o trigger)
- S/B ~ 0.1 (w/ trigger)
- requires multiple detectors (w/ optimized design)
- ▶ only pdf access to \sqrt{s}
- \Rightarrow couplings to quarks and gluons

Leptons

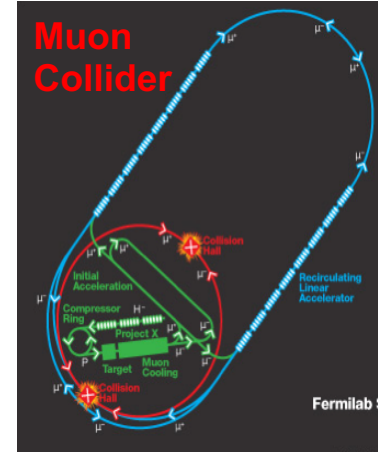
- S/B $\sim 1 \Rightarrow$ measurement?
- polarized beams (handle to chose the dominant process)
- limited (direct) mass reach
- identifiable final states
- \Rightarrow EW couplings

Circular

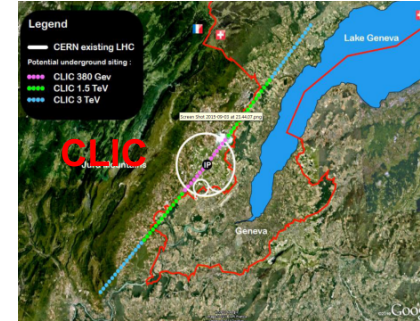
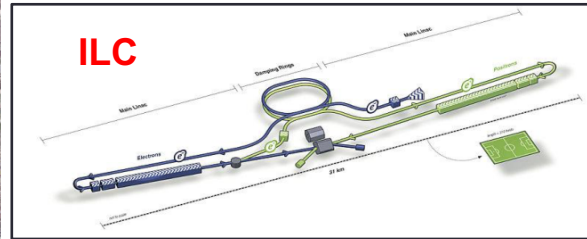
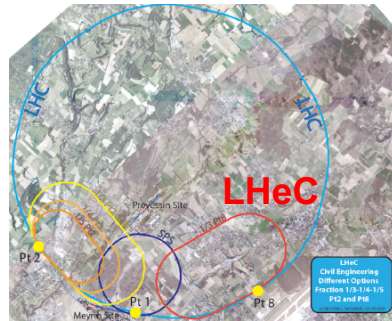
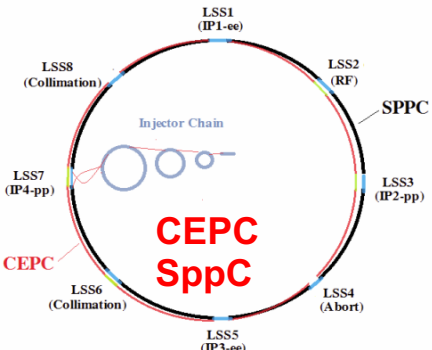
- higher luminosity
- several interaction points
- precise E-beam measurement ($\propto (0.1 \text{ MeV})$ via resonant depolarization)
- ▶ \sqrt{s} limited by synchrotron radiation

Linear

- easier to upgrade in energy
- easier to polarize beams
- "greener": less power consumption*
- ▶ large beamstrahlung
- ▶ one IP only



*energy consumption per integrated luminosity is lower at circular colliders but the energy consumption per GeV is lower at linear colliders
Christophe Grojean Future Measurements 9 Inst. Pascal, Dec. 4, 2019



○ gamma-gamma colliders?

Activities and Timeline

- **Broad effort of LOI solicitation through dedicated Topical Group meetings**
 - 376 received - see list [here](#)
 - 268 have EF as primary
 - Cross-frontier LOIs: TF (21), AF (20), IF(17), RF (16), CF (14), NF (11), CompF (9)
- **LOIs have contributed to shaping Topical Group activities**
 - see breakout sessions of the [Community Planning Meeting \(CPM\), Oct 5-8,](#)

1/21-6/21	6/30/21	2020 7/12/21	8/30/21	9/24/21	3/15/22	5/31/22	6/30/22	7/22	9/30/22	10/31/22
Activity Slowdown	Restart of Activities	DPF Meeting + Snowmass Townhall	EF restart Workshop	Snowmass day	Deadline Contributed Paper Submission	Prelim. TG Reports	Prelim. Frontier Reports	Community Summer Study (UW-Seattle)	Final Reports	Snowmass Book & ArXiv docs

- **Winter 2021-2022: few one-day virtual EF workshops by topic (SM, Higgs, BSM, Colliders,...)**
 - Check progress towards March deadline for contributed papers
 - Discuss overlap with other frontiers
- **Spring 2022: EF workshop to review contributed papers**
 - Focus on main themes and messages by contributed papers, towards May deadline for TG reports.
 - Converge on summary plots and other contributions involving multiple TGs or multiple frontiers
- **March-July 2022: circulations of preliminary TG and EF reports, then public readings**

Summary

- **Ambitious Energy Frontier plans to pave the way towards addressing big questions**
- **Cross-fertilization across fields** (Theory, Cosmics, Accelerators, Instrumentation etc.)
 - Anomalies in related fields require dedicated and long-term effort in the EF to confirm new physics and unveil their origins
- **Energy Frontier activities have taken off in 2020, and have already restarted at full steam**
 - Great interest and response from national and international community (numerous LOIs, and ongoing contributions)
- ***EF organization carries on from 2020 with few additions, Strategic plans have been laid out, Connection with other frontiers is established, Early Career representation is active, Monte Carlo sample production has started, Studies are on-going***
- **Plenty of time to join activities, propose new studies and address the many open questions**

- **Join the **EF Parallel session!** today 2:30 pm - 5:00 pm (EDT)**
 - TG Highlights given by Early Career speakers
 - An Early Career perspective to EF activity and highlight of EC studies

Backup

Big Picture Questions

- Why is physics at the energy frontier important?
- *How should the US be involved in near future and far future energy-frontier machines after HL-LHC?*
- What could be the energy-frontier machines that follow the HL-LHC?
- *How can the US continue to play a leadership role in energy-frontier experiments?*
- *How can the Snowmass process help develop a plan for the energy-frontier research and convince the community about our priorities?*
- *Should we start entertaining the idea of a future collider in the US again? If so, what are our goals, the benefits for the US and the international community, and how can we get there?*
- etc...

- Energy Frontier Kick-off Meeting on May 21, 2020, [see agenda](#)
- These questions were discussed in the Panel: **“The importance of the Energy Frontier in the US HEP future planning”** at the [“Energy Frontier Workshop - Open Questions and New Ideas”, July 20-22, 2020](#)
 - By Jorgen D'Hondt, Nima Arkani-Hamed, Sarah Eno, Vladimir Shiltsev, Xinchou Lou, Young-Kee Kim
 - See [Zoom recording of Panel Discussion](#)

Accelerator Benchmark Parameters

Snowmass 2021 Energy Frontier Collider Study Scenarios

Collider	Type	\sqrt{s}	P [%] e^-/e^+	L_{int} ab^{-1}
HL-LHC	pp	14 TeV		6
ILC	ee	250 GeV	$\pm 80 / \pm 30$	2
		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
		1.5 TeV	$\pm 80 / 0$	2.5
		3.0 TeV	$\pm 80 / 0$	5
CEPC	ee	M_Z		16
		$2M_W$		2.6
		240 GeV		5.6
FCC-ee	ee	M_Z		150
		$2M_W$		10
		240 GeV		5
		$2 M_{\text{top}}$		1.5

Snowmass 2021 Energy Frontier Collider Study Scenarios

Collider	Type	\sqrt{s}	P [%] e^-/e^+	L_{int} ab^{-1}
FCC-hh	pp	100 TeV		30
LHeC	ep	1.3 TeV		1
FCC-eh	ep	3.5 TeV		2
muon-collider (higgs)	$\mu\mu$	125 GeV		0.02
High energy muon-collider	$\mu\mu$	3 TeV		1
		10 TeV		10
		14 TeV		20
		30 TeV		90

Note for muon-collider: It is important to note that the plan is not to run subsequently at the various c.o.m etc. These are reference points to explore and assess the physics potential and technology. The luminosity can be varied to determine how best to exploit the physics potential.

Other options to explore:

- Muon collider at a very high energy (>30 TeV?)
- FCC pp >150 TeV? and ~75 TeV documenting sensitivity loss
- Very high energy e+e- collider
- Other emerging ideas:, e.g. $\gamma\text{-}\gamma$ collider, and the C^3 e^+e^- collider [C³=Cool Copper Collider]