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MOSCOW STATE UNIVERSITY

Landscape of Modern and Future Accelerators and the Snowmass'21 Planning Process

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***SLAC National Accelerator Laboratory

Strategic Planning Process for US HEP

- Brief look at current US landscape of Projects and Programs
- Snowmass – the beginning of the process
  - Organization:
    - Committees, Frontiers and Topical Groups
  - Timeline
  - Accelerator Frontier
  - Topical Groups and Initiatives:
    - Implementation Task Force
    - Muon Collider Forum
    - Physics Limits of Ultimate Beams

Large US Accelerator Construction Projects

- Many large accelerator projects across the United States:
  - High Energy Physics:
    - High Luminosity LHC upgrade (~0.5B, ~2026)
    - Long-Baseline Neutrino Facility / PIP-II (~4B, 2030)
  - Nuclear Physics:
    - Facility for Rare Ion Beams (~0.6B, 2022)
    - Electron-Ion Collider (~2B, 2031)
  - Basic Energy Sciences:
    - Argonne Photon Source Upgrade (~1B, 2026)
    - Advanced Light Source Upgrade (~0.5B, 2026)
    - LCLS-II / LCLS-II High Energy (~2B, 2030)
    - SNS Power Upgrade and Second Target Station (~0.3B, 2027 / ~1B, 2030+)

US High Energy Physics Accelerator R&D Subpanel

- Guided by 2015 Accelerator R&D Subpanel Report:

- Near-term goals:
  - PIP-II → LBNF / DUNE
  - HL-LHC
  - ILC e+/e- collider

- Mid-term goals:
  - Multi MW proton accelerator
  - Very high energy proton-proton collider
  - TeV-scale upgrade of ILC

- Long-term goals:
  - Multi-TeV e+/e- collider
  - Neutrino factory

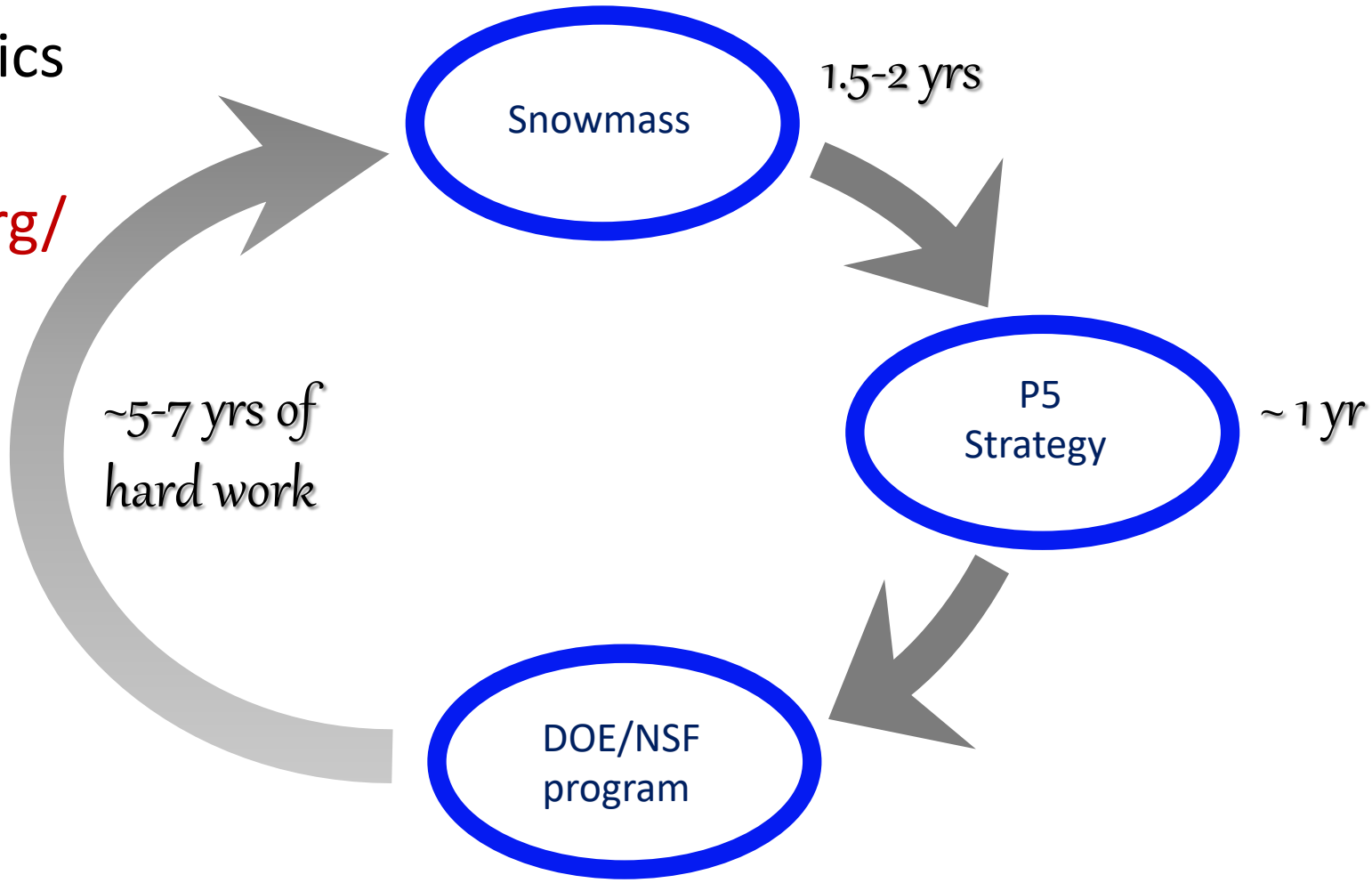
US HEP Accelerator Mid- and Long-term R&D Focus

- US largely focused on accelerator technology R&D
  - High Field magnet and High Gradient RF development as well as other technology development has been ongoing in part to support ILC and a high energy pp collider
- US was heavily engaged in Linear Collider R&D from 1980 → 2008
  - Refocused on SRF technology for cost reduction
- Strong advanced acceleration programs
  - No concept for a collider at this time but focused on fundamental demonstrations
- Muon Accelerator Program (MAP) from 2011 to 2015
  - Examined feasibility of MC subsystems but redirected before looking at integration

What is “Snowmass?”

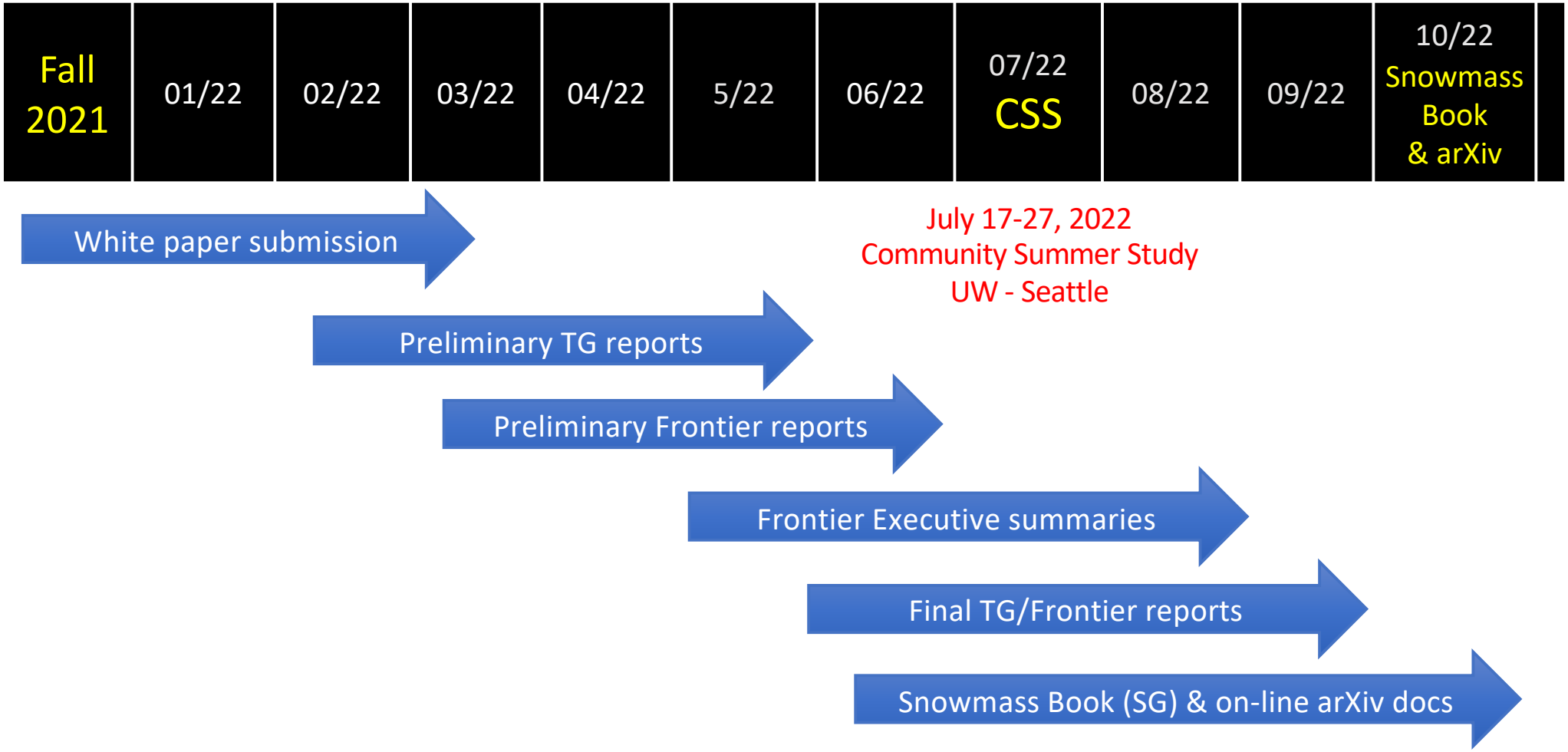
- “Snowmass is a particle physics community study”
- https://www.snowmass21.org/

- Provides input to P5 (Particle Physics Project Prioritization Panel) which develops a strategy for the US HEP program

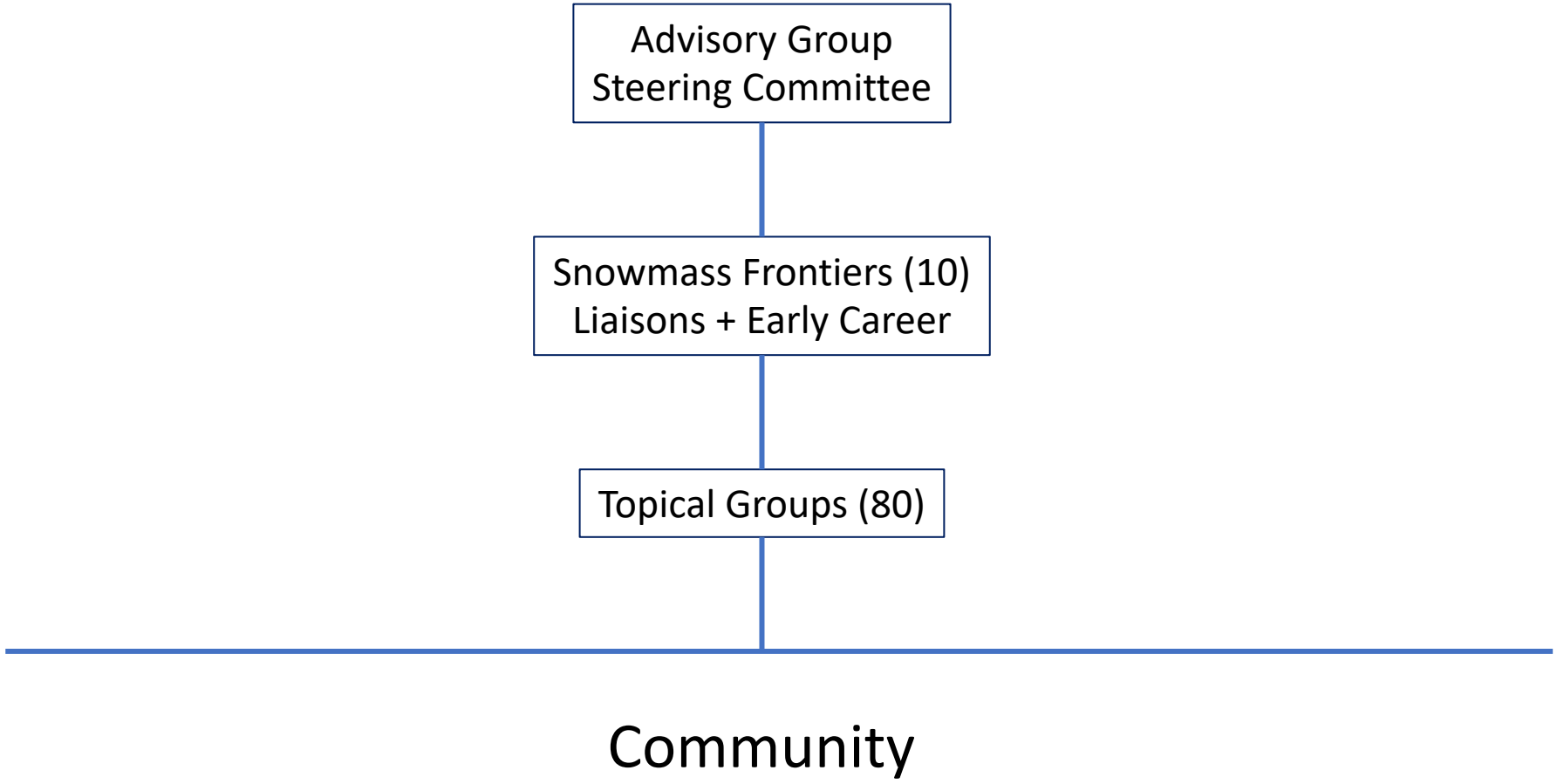


No prioritizations from Snowmass

Snowmass Timelines



Snowmass Organization



Snowmass'21 Frontier Conveners

Energy Frontier


Meenakshi Narain (Brown U)


Laura Reina (FSU)


Alessandro Tricoli (BNL)

Accelerator Frontier


Steve Gourlay (LBNL)


Tor Raubenheimer (SLAC)


Vladimir Shiltsev (FNAL)

Frontiers in Neutrinos


Patrick Huber (Virginia Tech)


Kate Scholberg (Duke U.)


Elizabeth Worcester (BNL)

Instrumentation Frontier


Phil Barbeau (Duke)


Petra Merkel (FNAL)


Jinlong Zhang (ANL)

Frontiers in Rare & Precision


Marina Artuso (Syracuse U.)


Alexey Petrov (Wayne State U.)


Bob Bernstein (FNAL)

Computational Frontier


Steven Gottlieb (Indiana U.)


Ben Nachman (LBNL)


Oliver Gutsche (FNAL)

Cosmic Frontier


Aaron Chou (Fermilab)


Marcelle Soares-Santos (U.Michigan)


Tim Tait (UC Irvine)

Underground Facilities and Infrastructure Frontier


Laura Baudis (U. Zurich)


Jeter Hall (SNOLAB)


Kevin Lesko (LBNL)


John Orrell (PNNL)

Theory Frontier


Nathaniel Craig (UCSB)


Csaba Csaki (Cornell)


Aida El-Khadra (UIUC)

Community Engagement Frontier


Kétévi Assamagan (BNL)


Breese Quinn (Mississippi)

Snowmass'21: Frontiers and Topical Groups

10 Frontiers	80 Topical Groups
Energy Frontier	Higgs Boson properties and couplings, Higgs Boson as a portal to new physics, Heavy flavor and top quark physics, EW Precision Phys. & constraining new phys., Precision QCD, Hadronic structure and forward QCD, Heavy Ions, Model specific explorations, More general explorations, Dark Matter at colliders
Frontiers in Neutrino Physics	Neutrino Oscillations, Sterile Neutrinos, Beyond the SM, Neutrinos from Natural Sources, Neutrino Properties, Neutrino Cross Sections, Nuclear Safeguards and Other Applications, Theory of Neutrino Physics, Artificial Neutrino Sources, Neutrino Detectors
Frontiers in Rare Processes & Precision Measurements	Weak Decays of b and c, Strange and Light Quarks, Fundamental Physics a… …aryon and Lepton Number Violation, Charged Lepton Flavor Violation, Dark Sector at L… …opy
Cosmic Frontier	Dark Matter: Particle-like, Dark Matter: Wave-like, Dark M… …Cosmic Acceleration: The Modern Universe, Dark Energy & Cosmic Accelerati… …gy & Cosmic Acceleration: Complementarity of Probes and New Faciliti…
Theory Frontier	String theory, quantum gravity, h… …iques, CFT and formal QFT, Scattering amplitudes, Lattice gauge theory, Theo… …ider phenomenology, BSM model building, Astro-particle physics and… …nce, Theory of Neutrino Physics
Accelerator Frontier	Beam Ph… …erators for Neutrinos, Accelerators for Electroweak and Higgs Physics, M… …ysics Beyond Colliders & Rare Processes, Advanced Accelerator Concepts, …Magnets, Targets/Sources
Instrumentation Front…	…ton Detectors, Solid State Detectors & Tracking, Trigger and DAQ, Micro Pattern Gas Detectors, …ctronics/ASICS, Noble Elements, Cross Cutting and System Integration, Radio Detection
Computational …	…perimental Algorithm Parallelization, Theoretical Calculations and Simulation, Machine Learning, Storage and processing resource access (Facility and Infrastructure R&D), End user analysis
Underground Faci… …and Infrastructure Frontier	Underground Facilities for Neutrinos, Underground Facilities for Cosmic Frontier, Underground Detectors
Community Engagement Frontier	Applications & Industry, Career Pipeline & Development, Diversity & Inclusion, Physics Education, Public Education & Outreach, Public Policy & Government Engagement

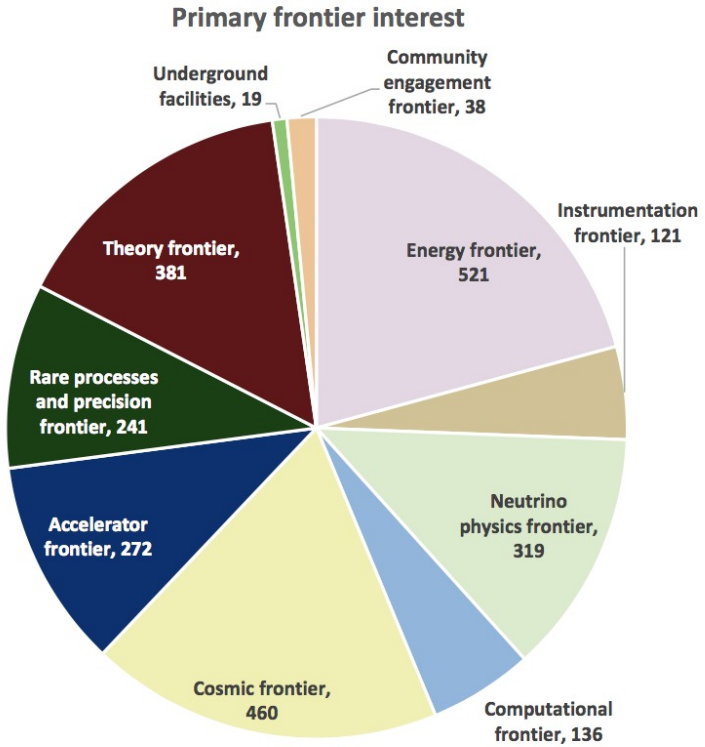
30 Frontier conveners, ~250 Topical Group conveners,
>40 Inter-Frontier Liaisons, ~25 Early Career Liaisons

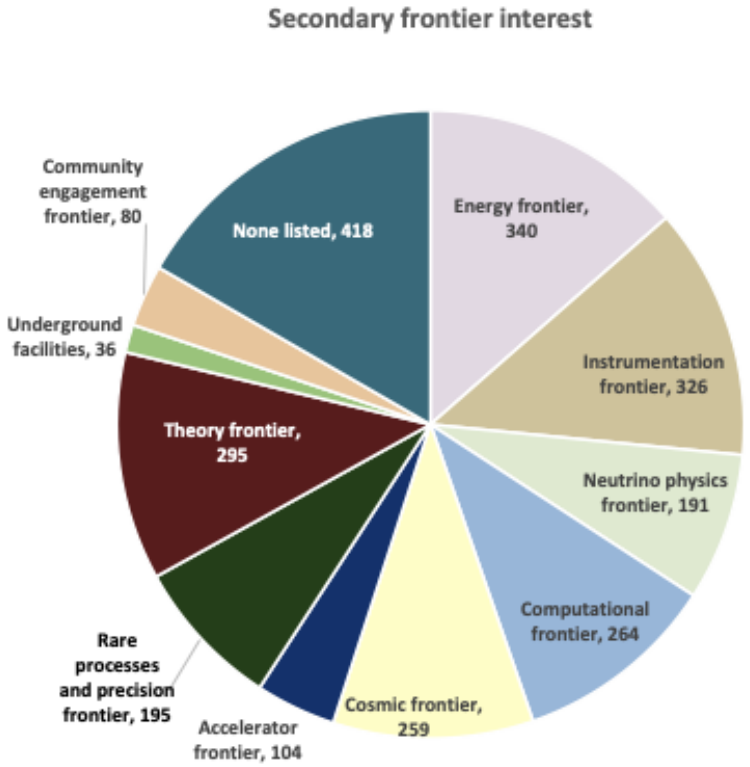
Snowmass Community Planning Meeting: Oct 5-8, 2020

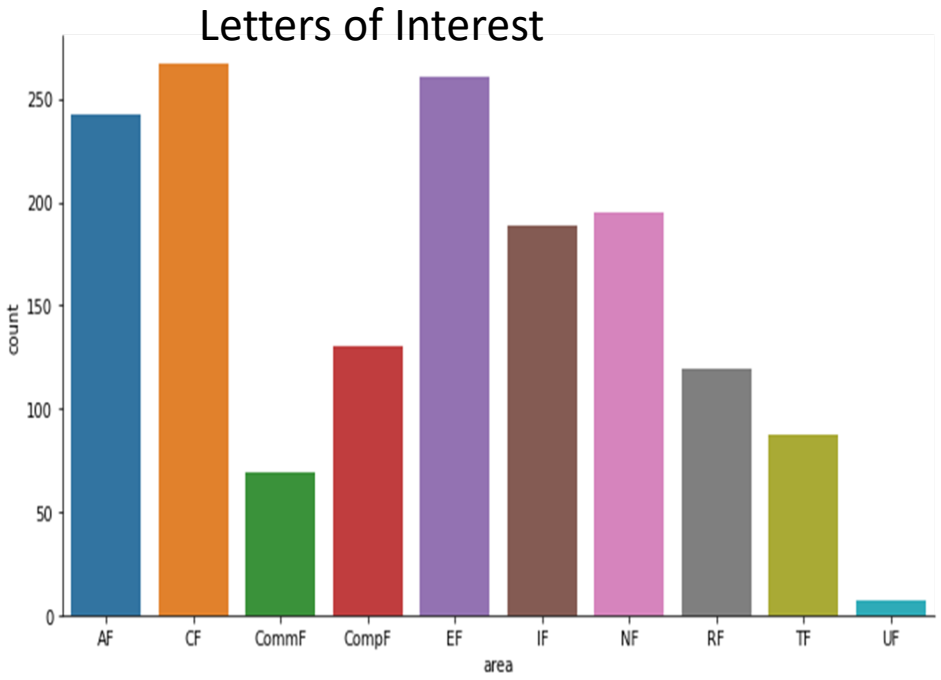
~3,000 participants

~650 outside the North America Time Zone

(Note that 11am-4pm U.S. Central time was inconvenient – very inconvenient for many countries)







Accelerator Frontier

- **Co-Conveners**

- Steve Gourlay (LBNL, Retired)
- Tor Raubenheimer (SLAC)
- Vladimir Shiltsev (FNAL)



Description

The Accelerator Frontier activities include discussions on high-energy hadron and lepton colliders, high-intensity beams for neutrino research and for the “Physics Beyond Colliders”, accelerator technologies, science, education and outreach as well as the progress of core accelerator technology, including RF, magnets, targets and sources. Participants will submit Letters of Intent, contributed papers, take part in corresponding workshops and events, contribute to writing summaries and take part in the general Snowmass'21 events

Accelerator Frontier – Key Questions

1. What is needed to advance the physics?
2. What is currently available (state of the art) around the world?
3. What new accelerator facilities could be available in the next decade (or next next decade)?
4. What R&D would enable these future opportunities?
5. What are the time and cost scales of the R&D and associated test facilities as well as the time and cost scale of the facilities?

Accelerator Frontier Topical Groups and Conveners

Topical Group		Topical Group co-Conveners			
AF1	Beam Phys & Accel. Education	Z. Huang (Stanford)	M. Bei (GSI)	S. Lund (MSU)	
AF2	Accelerators for Neutrinos	J. Galambos (ORNL)	B. Zwaska (FNAL)	G. Arduini (CERN)	
AF3	Accelerators for EW/Higgs	M. Ross (SLAC)	Q. Qin (IHEP, Beijing)	G.Hoffstaetter (Cornell)	
AF4	Multi-TeV Colliders	M. Palmer (BNL)	A. Valishev (FNAL)	N Pastrone (INFN, Torino)	J.Tang (IHEP, Beijing)
AF5	Accelerators for PBC and Rare Processes	E. Prebys (UC Davis)	M. Lamont (CERN)	R.Milner (MIT)	
AF6	Advanced Accelerator Concepts	C. Geddes (LBNL)	M. Hogan (SLAC)	P. Musumeci (UCLA)	R. Assmann (DESY)
AF7	Accelerator Technology R&D				
	Sub-group RF	E. Nanni (SLAC)	S. Belomestnykh (FNAL)	H. Weise (DESY)	
	Sub-Group Magnets	G. Sabbi (LBNL)	S. Zlobin (FNAL)	S. Izquierdo Bermudez (CERN)	
	Sub-Group Targets & Sources	C. Barbier (ORNL)	Y. Sun (ANL)	F. Pellemoine (FNAL)	

Plus, the **Accelerator Implementation Task Force** (ITF) to evaluate and compare various options

9 out of 29 are representatives of Asia and Europe; 5 women

Agenda – Joint AF/EF Workshop on Future ColliderS

Day 1: https://indico.fnal.gov/event/43871/

Day 2: https://indico.fnal.gov/event/43872/

Some Working Group Activities

- AF1 – has been running a series on physics of Ultimate Beams and examining the fundamental limits of accelerator technology
- AF3 – looking broadly at Higgs factories from e^+/e^-, γ/γ, μ^+/μ^-
- AF4 – considering multiple paths to high energy including e^+/e^-, γ/γ, μ^+/μ^- and p/p; lots of enthusiasm for μ^+/μ^- in part because of potential to fill in the gap from 3-14 TeV with US MC Forum and Int. MC Collab.
- AF5 – working on many small or moderate scale proposals
- AF6 – working to understand options to upgrade a more conventional linear collider as well as limits of plasma acceleration (Multi-TeV)
- AF7 – 3 subgroups exploring limits of accelerator technology (many efforts supported in part by US-Japan)

AF Implementation Task Force (ITF)

- Key question for Snowmass'21 Accelerator Frontier to address: *"…What are the time and cost scales of the R&D and associated test facilities as well as the time and cost scale of the facility?"*
- A large number of possible accelerator projects: ILC, Muon Collider, gamma-gamma and ERL options, a large circumference electron ring, and a large circumference hadron ring amongst others.
- Comparison of the expected costs (using different accounting rules), schedule, and R&D status for the projects.
- The *Accelerator Implementation Task Force is* comprised of 9 world-renowned accelerator experts from Asia, Europe and US and two representatives of the *Snowmass Young*; it is chaired by Thomas Roser (BNL) and charged with developing metrics and processes to facilitate a comparison between projects
- Focused on HEP Colliders


Thomas Roser (BNL, Chair)


Philippe Lebrun (CERN)


Steve Gourlay (LBNL)

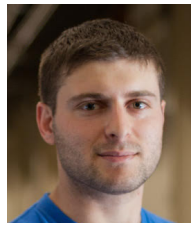

Tor Raubenheimer (SLAC)


Katsunobu Oide (KEK)


Sarah Cousineau (ORNL)


Jim Strait (FNAL)


Marlene Turner (LBNL)


Spencer Gessner (SLAC)


Vladimir Shiltsev (FNAL)


Reinhard Brinkmann (DESY)


John Seeman (SLAC)

Charge to the ITF

1. **Develop the metrics** to compare projects' cost, schedule/timeline, technical risks (readiness), operating cost and environmental impact, and R&D status and plans;
2. **Select the accelerator projects** to be evaluated (provided by the AF topical groups);
3. **Work with the proponents** of the selected accelerator projects to evaluate them against the metrics from item 1;
4. Consider the **ultimate limits** of various types of colliders: e^+/e^-, p/p, mu^+/mu^-;
5. Consider **limits and timescales** due to accelerator technology for various types of colliders: e^+/e^-, p/p, mu^+/mu^-;
6. Lead the **evaluation of the different HEP accelerator proposals** and inform and communicate with the Snowmass'21 AF, EF, NF and TF;
7. **Document the metrics, processes, and conclusions** for the *Snowmass'21* meeting in the Summer 2022; write and submit a corresponding White Paper.

ITF: Higgs Factory Concepts/Proposals (8)

Name	Details	POC	AF Group
CepC	e+e-, $\sqrt{s}$ = 0.24 TeV, L= 3.0 $\times 10^{34}$	Jie Gao (gaoj@ihep.ac.cn)	AF3
CLIC (Higgs factory)	e+e-, $\sqrt{s}$ = 0.38 TeV, L= 1.5 $\times 10^{34}$	Steinar Stapnes (Steinar.Stapnes@cern.ch)	AF3
ERL ee collider	e+e-, $\sqrt{s}$ = 0.24 TeV, L= 73 $\times 10^{34}$	Thomas Roser (roser@bnl.gov)	AF3
FCC-ee	e+e-, $\sqrt{s}$ = 0.24 TeV, L= 17 $\times 10^{34}$	Katsunobu Oide (katsunobu.oide@ern.ch)	AF3
gamma gamma	X-ray FEL-based $\gamma\gamma$ collider	Tim Barklow (timb@slac.stanford.edu)	AF3
ILC (Higgs factory)	e+e-, $\sqrt{s}$ = 0.25 TeV, L= 1.4 $\times 10^{34}$	Shin-ichi Michizono (shinichiro.michizono@kek.jp	AF3
LHeC	ep, $\sqrt{s}$ = 1.3 TeV, L= 0.1 $\times 10^{34}$	Oliver Bruening (oliver.bruening@cern.ch)	AF3
MC (Higgs factory)	$\mu\mu$, $\sqrt{s}$ = 0.13 TeV, L= 0.01 $\times 10^{34}$	Mark Palmer (mpalmer@bnl.gov)	AF3

ITF :18 (!) high energy collider concepts/proposals

Name	Details	POC	AF Group
Cryo-Cooled Copper linac	e+e-, $\sqrt{s} = 2$ TeV, L= 4.5 $\times 10^{34}$	Emilio Nanni (nanni@slac.Stanford.edu)	AF3
High Energy CLIC	e+e-, $\sqrt{s} = 1.5 - 3$ TeV, L= 5.9 $\times 10^{34}$	S.Stapnes (steinar.stapnes@cern.ch)	AF4
High Energy ILC	e+e-, $\sqrt{s} = 1 - 3$ TeV	Hassan Padamsee (hsp3@cornell.edu)	AF4
FCC-hh	pp, $\sqrt{s} = 100$ TeV, L= 30 $\times 10^{34}$	M.Benedikt (Michael.Benedikt@cern.ch)	AF4
SPPC	pp, $\sqrt{s} = 75/150$ TeV, L= 10 $\times 10^{34}$	J.Tang (tangjy@ihep.ac.cn)	AF4
Collider-in-Sea	pp, $\sqrt{s} = 500$ TeV, L= 50 $\times 10^{34}$	P.McIntyre mcintyre@physics.tamu.edu	AF4
LHeC	ep, $\sqrt{s} = 1.3$ TeV, L= 1 $\times 10^{34}$	Y.Zhang (yzhang@jlab.org)	AF4
FCC-eh	ep, $\sqrt{s} = 3.5$ TeV, L= 1 $\times 10^{34}$	Y.Zhang (yzhang@jlab.org)	AF4
CEPC-SPPpC-eh	ep, $\sqrt{s} = 6$ TeV, L= 4.5 $\times 10^{33}$	Y.Zhang (yzhang@jlab.org)	AF4
VHE-ep	ep, $\sqrt{s} = 9$ TeV	Y.Zhang (yzhang@jlab.org)	AF4
MC – Proton Driver 1	$\mu\mu$, $\sqrt{s} = 1.5$ TeV, L= 1 $\times 10^{34}$	D.Schulte (daniel.schulte@cern.ch)	AF4
MC – Proton Driver 2	$\mu\mu$, $\sqrt{s} = 3$ TeV, L= 2 $\times 10^{34}$	D.Schulte (daniel.schulte@cern.ch)	AF4
MC – Proton Driver 3	$\mu\mu$, $\sqrt{s} = 10 - 14$ TeV, L= 20 $\times 10^{34}$	D.Schulte (daniel.schulte@cern.ch)	AF4
MC – Positron Driver	$\mu\mu$, $\sqrt{s} = 10 - 14$ TeV, L= 20 $\times 10^{34}$	D.Schulte (daniel.schulte@cern.ch)	AF4
LWFA-LC (e+e- and $\gamma\gamma$)	Laser driven; e+e-, $\sqrt{s} = 1 - 30$ TeV	Carl Schroeder (CBSchroeder@lbl.gov)	AF6
PWFA-LC (e+e- and $\gamma\gamma$)	Beam driven; e+e-, $\sqrt{s} = 1 - 30$ TeV	Gessner, Spencer J. (sgess@slac.edu)	AF6
SWFA-LC	Structure wakefields; e+e-, $\sqrt{s} = 1 - 30$ TeV	Chunguang Jing (jingchg@anl.gov)	AF6

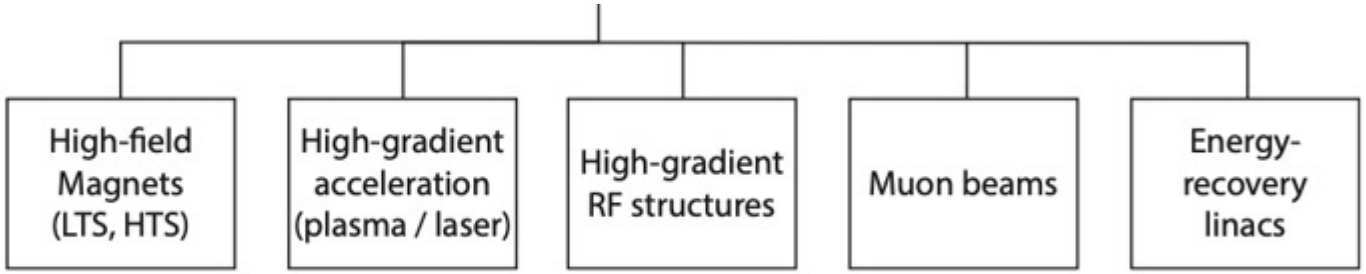
Muon Collider Forum

- Joint EF-AF-TF-IF Initiative
- Aspirations for energy frontier facility in the US
- Based on results of successful US-Muon Accelerator Program (MAP) that ended in 2016 and bold CERN-led initiative in Europe

European Planning Influences Snowmass Topics

- European Strategy for Particle Physics (ESPP) describes strategy for particle physics in Europe and their contributions world-wide (June 19, 2020)
- European National Laboratories Directors Group (LDG) – July 2 (Chaired by Lenny Rivkin)
  - Immediate outcome → Accelerator R&D Task Forces reporting to Lab Directors Group (LDG) and CERN Council
- Address the question of what are the most promising Accelerator R&D activities for HEP

5 Targetted Accelerator R&D Expert Panels



Snowmass AF participants are active on all the LDG panels

Steps Toward a Muon Collider in Europe

- EU Strategy –International Design Study
- High-priority future initiatives . . . In addition to the high field magnets the accelerator R&D Roadmap could contain:
- . . . An international design study for a muon collider, as it represents a unique opportunity to achieve a *multi-TeV energy domain beyond the reach of e^+e^- colliders*, and potentially within a *more compact circular tunnel* than for a hadron collider. The biggest challenge remains to produce an intense beam of cooled muons, but *novel ideas are being explored*;

  - LDG agrees to start building the collaboration for an international muon collider design study
  - Daniel Schulte as interim project leader – with N. Pastrone and L. Rivkin
  - Kick-off meeting held – July 3
  - > 250 participants – https://indico.cern.ch/event/930508/

Physics Limits of Ultimate Beams

As part of the Snowmass2021 community discussion, AF1 (Accelerator Science, Education, Outreach), AF4 (Multi-TeV Colliders) and AF6 (Advanced Accelerator Concepts) launched a joint workshop on the topic of Physics Limits of Ultimate Beams. The main scope of this workshop was to engage the community to explore:

- Fundamental ultimate beams for various physics goals. In particular, for colliders, we would like to understand the required luminosity scaling with energy
- Potential and feasibility of advanced concepts towards the ultimate physics limits, such as PeV beams yet low luminosity, etc.

Snowmass'21 Accelerator Frontier: Summary

- Times have been difficult
  - Impact of COVID-19 on particle physics and accelerator research – delays in projects and programs
  - All of the Snowmass meetings and workshops so far have been virtual.
  - We have challenges to deal with uncertainty in 2021-22.
- In spite of this, there has been tremendous effort and major progress by the community:
  - *Huge thanks to the AF community, Topical Groups' and ITF leaders!!*
- Snowmass is a community-driven process:
  - We appreciate the community's continued strong participation in the process
  - We very much welcome the international accelerator community - **please, join us!!**
  - Visit the Snowmass AF wiki page (https://www.snowmass21.org/accelerator/) to find out the best way to contribute
- We very much look forward to a productive Snowmass study