

# Snowmass 2021

Community Planning Meeting  
October 5-8, 2020

## Accelerator Frontier Summary

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# 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 on 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 facility?

# Joint Initial AF-EF Workshop on Future Colliders (16!) June 24 and July 1, 2020

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

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

9:00 AM	→ 9:10 AM	<b>Introduction: goals, format, etc</b>
9:10 AM	→ 9:25 AM	<b> FCCee</b> Speaker: Katsunobu Oide (KEK)
9:25 AM	→ 9:40 AM	<b>CepC</b> Speaker: Yu Chenghui
9:40 AM	→ 9:55 AM	<b>ILC</b> Speaker: Shinichiro MICHIZONO (KEK)
9:55 AM	→ 10:10 AM	<b>CLIC</b> Speaker: Steinar Stapnes (FNAL)
10:10 AM	→ 10:25 AM	<b>EIC</b> Speaker: Christoph Montag (BNL)
10:25 AM	→ 10:40 AM	<b>LHeC</b> Speaker: Oliver Brüning (CERN)
10:40 AM	→ 10:55 AM	<b>HE-LHC</b> Speaker: Frank Zimmermann (CERN)
10:55 AM	→ 11:10 AM	<b>SppC</b> Speaker: Jingyu Tang (Institute of High Energy Physics)
11:10 AM	→ 11:25 AM	<b>FCChh</b> Speaker: Michael Benedikt

9:00 AM	→ 9:10 AM	<b>Introduction: goals, format, etc</b>
9:10 AM	→ 9:30 AM	<b>Cold NC-Linear Collider</b> Speaker: Emilio Nanni (SLAC National Accelerator Laboratory)
9:30 AM	→ 9:50 AM	<b>ERL based FCCee</b> Speaker: Thomas Roser (BNL)
9:50 AM	→ 10:10 AM	<b>Gamma-Gamma Higgs factories</b> Speaker: Frank Zimmermann (CERN)
10:10 AM	→ 10:30 AM	<b>Plasma-Laser WFA 1 TeV +</b> Speaker: Carl Schroeder (Lawrence Berkeley National Laboratory)
10:30 AM	→ 10:50 AM	<b>Plasma-Beam WFA 1 TeV +</b> Speaker: Spencer Gessner
10:50 AM	→ 11:10 AM	<b>Structure-beam WFA 1 TeV +</b> Speaker: John Power (Argonne National Lab)
11:10 AM	→ 11:30 AM	<b>Muon Colliders: Higgs Factory and 3-14 TeV</b> Speaker: Daniel Schulte (CERN)
11:30 AM	→ 12:10 PM	<b>Discussion/ Q&amp;A</b>

# 329 AF Lols (incl.71 joint - EF, NF, RF...)

- AF1: Beam Physics and Accelerator Education **61 (14)**
- AF2: Accelerators for Neutrinos **18 (5)**
- AF3: Accelerators for EW/Higgs **32 (4)**
- AF4: Multi-TeV Colliders **56 (10)**
- AF5: Accelerators for PBC and Rare Proc. **37 (22)**
- AF6: Advanced Accelerator Concepts **71 (5)**
- AF7: Accelerator Technology R&D **137 (6)**

**AF@CPM: >30 sessions → Outcome**

## **AF Topical Group Plans**

- a) main themes/topics for study
- b) plans of meetings/workshops

# AF1: Beam Physics and Accel. Education

- **Main themes/directions of study:**
  - Physics of Multi-TeV colliders and ultimate beams (intensity, energy, brightness)
  - Fundamental beam physics (space-charge, plasma, beam cooling, electron lenses, ERL, instabilities, etc)
  - Modeling, AI and Machine Learning
  - Education, Outreach, Diversity - centers/programs for general research/training
  - Sustainability and energy management of accelerators
- **Future events/meetings/workshops:**
  - **#1: On Education, Diversity and Outreach** - ~October 2020
  - **#2: Research Centers/Facilities** - TBD
    - Joint with AF4, AF6: discuss needs of test/R&D facilities to support accelerator R&D, training, and educational needs.
  - **#3: Computational Tools & Machine Learning** - TBD
    - joint with Computational Frontier to cover tools extending modeling capabilities, potential ML impacts, more efficient use of resources.
  - **#4: Physics Limits of Ultimate Beams** - Spring 2021 (TBC)
    - joint with AF4, AF6, and ARIES to discuss ultimate beam parameters such as energy, intensity, brilliance, beam power on-target allowed by the fundamental laws of physics. Discuss practical limits from engineering and technology.

# AF2: Accelerators for Neutrinos

- **Main Themes:**

- Existing Facilities
- Planned Upgrades
- Proposed New Facilities/Upgrades
- Test Facilities
- Enabling R&D / Technology

*Taking as input the anticipated needs of particle physics and the requirements for neutrino beams in terms of energy, flux, temporal and spatial characteristics, this group will discuss:*

- The **proton** (or other) **beam requirements** to meet the **neutrino physics** community needs
- The **capability** of existing or planned accelerator facilities to satisfy the above requirements, and If not: the necessary upgrades or new facilities.
- **Enabling R&D**, technologies, and test facilities necessary to develop upgrades and new facilities.

- **Meetings:**

1. AF2 Town Hall - Nov 12, 9am-noon
2. Solicited community workshops - TBD
3. **Joint workshops** under consideration - TBC
  - with AF5(rare processes) on joint use of facilities
  - with AF7t (targets for neutrino facilities)
  - with NF09 (artificial neutrino sources)
4. Plenary AF2 Workshop - April 27-28, 2021

AF2 Wiki page: <https://snowmass21.org/accelerator/neutrino/start>

List for AF2 announcements: [snowmass-af2-accel-for-nu@listserv.fnal.gov](mailto:snowmass-af2-accel-for-nu@listserv.fnal.gov)

# AF3: Colliders for Electro-Weak/Higgs

- Overview of 8 Higgs Factories schemes
- **Main themes:**
  - R&D needs for FCCee, CepC, ILC, and ERL-FCCee
  - upgrade sequencing to the high-energy frontier, inc.  $pp$  col.
  - upgrades to the ILC, e.g. by plasma acceleration
  - Technology push:
    - SRF and magnet tech for ring and linac Higgs factories
    - Potential technology improvements, esp. SRF
    - Progress toward superconducting undulator for pol.  $e^+$
- **Future events:**
  - Meetings on: *i) accelerator physics issues, ii) on key technologies, iii) on power consumption, and iv) on upgrade schemes.*
  - **Dates TBD... joint with other AF and EF groups**
  - Provide input for the AF ITF (Implementation Task Force)



# AF4: Multi-TeV Colliders

- **Key Topics:**

We are closely coupled with EF/TF (possibly IF). Key deliverable will be the summary of collider facility options. **Initially grouped by species  $ee$ ,  $pp$ ,  $ep/i$ ,  $\mu\mu$ ,  $\gamma\gamma$ ...** for each:

- Physics reach, Parameters, Technology challenges, Maturity

- **Actions/meetings between CPM and CSS:**

- Two Meetings, **Joint with EF/TF/IF:**
  1. **December 2020.** Main discussion – **physics reach / potential** for multi-TeV machines. Summarize for EF parameters /challenges /maturity. Make formal request to established collaborations for White Papers.
  2. **March 2021.** 2<sup>nd</sup> iteration based on new information. Added topics: **staging options**, revisit **R&D requirements**. Review draft White Papers.
- Meeting - **Joint with AF1:** Revisit fundamental challenges and thinking paradigms. Discuss ‘return on investment’ and novel approaches. - **TBD**
- Meetings on Technology challenges - **TBD**
  - On MDI ½-day in January across AF/IF.
  - Participate in AF7-Technology topical groups events.
- Provide **input to the ITF** once the process is well underway. Our work is closely related, need to agree how to proceed.

Can provide preliminary summary after December **Joint meeting with EF.**

# AF5: Accelerators for Rare and BCP

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- **Main themes:**

- Beam dump opportunities ( $p$  and  $e$ )
- Non-collider axion/dark sector synergy with HEP magnet, RF, and quantum sensor R&D
- Dedicated rings for EDM measurement
- Beam delivery from PIP-II (incl. compressor ring)
- Potential for laser wakefield driven experiments

- **Future events:**

- Facilities workshop: AF5 and **guests**
  - Accelerator and other support (RF, Magnets, etc) available or potentially available at labs.
- At least one more joint meeting with **RPF subgroups**
- The idea of a small joint beam dump/ $\nu$ -target workshop to discuss targetry needs came up – **joint with AF2**
- Coordinate with “Beyond PIP-II” group.
- **Dates: TBD**

# AF6: Advanced Accelerator Concepts

Recent AF6 Workshop September 23-24, 2020 to prepare for CPM:

- Chance for all LOI's 'to be heard' - two-full days with over 50 LOIs!

<https://indico.fnal.gov/event/45651/>

AF5 is organized around **common themes** that are suggesting possibilities for a much smaller number of collaborative, focused *Contributed Papers* (to be confirmed):

- i) Collider concepts, ii) wakefield acceleration, iii) particle sources, iv) test facilities, v) interaction point, vi) near term applications, vii) alternate schemes

## **Looking ahead:**

- Once a month: Interest groups are being formed to maintain momentum heading to June 2021 and afterwards – so far **Joint AF6-Computation** (Jean-Luc Vay), **Advanced Accelerator Concepts** (Eric Esarey), **Test Facilities** (Vitaly Yakimenko)
- Once a week: Re-branded AAC Seminar Series this winter will be a forum for continued community engagement with **weekly meetings beginning Nov. 16th** (<http://aac2020.lbl.gov>)
- **Additional AF6 workshops** will be organized after cross frontier CPM input is digested

To stay up to date on AF6 planning/workshops please subscribe to the mailing list:

- To sign up, send an email to [listserv@fnal.gov](mailto:listserv@fnal.gov) with a blank subject and with the body of the message consisting of the text: SUBSCRIBE SNOWMASS-AF-06-AAC firstname lastname

# AF7m: Accelerator Technology - Magnets

## Two main categories

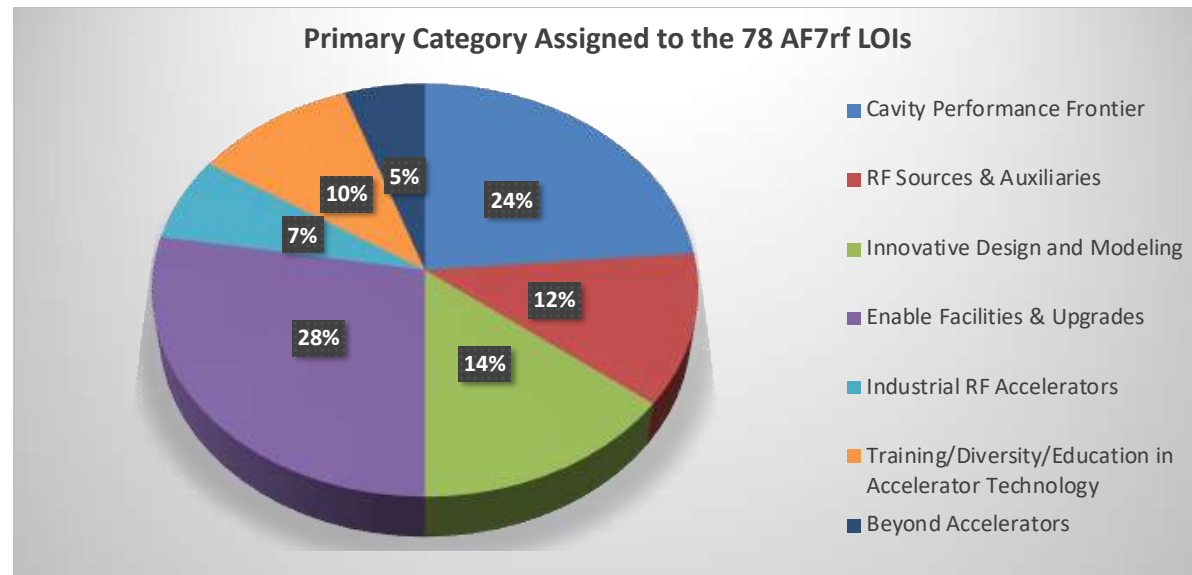
- Magnets for various machines:
    - high field and low field accelerator magnets for hadron colliders
    - fast cycling magnets and solenoids for muon colliders
    - solenoids for detectors
    - undulators for  $\gamma\gamma$  and linear colliders
    - beam lines
  - General accelerator magnet R&D:
    - SC wires and cable
    - magnet design (HTS, LTS, Hybrid, Fast Cycling HTS magnets)
    - diagnostics, test facilities and cryogenics
    - magnet R&D programs in the U.S., EU, Japan and China
- Excellent representation of various magnets from the 3 regions (US, EU, Asia)!*
- Two working groups will be formed (leads TBD)
    - Magnets for various machines (AFs)
    - General accelerator magnet designs, technologies, performance, cost optimization
  - **Work organization:**
    - AF7-Magnets joint group meeting(s) to develop key questions and opportunities – by January 2021
    - AF7-Magnets virtual workshop and **joint meetings/workshops with AF1-6** to produce preliminary report and WP drafts – by April 2021
    - AF7-Magnets virtual group meeting to coordinate various contributions to the report and WP status – by June 2021

# AF7rf: RF

- **Categorized into 7 different categories**  
(see pie chart on the right)

- **Plans include :**

- Workshop on “Cavity Performance Frontier” - **TBD**
- Workshop on “RF Sources & Auxiliaries” – **TBD**
- Workshop on “Innovative Design and Modelling” – **TBD**
- **Joint workshops** with other groups for other four categories, or have smaller mini-workshops
- **Online survey** conducted during & after AF7rf session on Tuesday shows good agreement on proposed path forward
- Also plan to continue **seminar series** – see previous seminars at [indico.fnal.gov/category/1117/](https://indico.fnal.gov/category/1117/)



# AF7ts: Accelerator Technology - Targets/Sources

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- **Main topics – Targets:**

- Material Studies to Extend Radiological Material Science
  - Radiation damage in material
  - Post Irradiation Examination (PIE)
  - Irradiation station
- Improved Modelling
  - Capturing more physics, Better prediction of target lifespan, Code integration, Leverage AI to optimize target design
- Novel Materials and Novel Concepts
- Rad-Hard Instrumentation
  - Device monitoring
- Remote Handling and Operations (leverage AI)
- Specialized “Physics” targets
  - For individual experiments

- **Events – Targets:**

- Town Hall Meeting with AF liaisons (Nov-Dec?)
- Satellite workshops:
  - High Power Targetry Workshop (RIKEN, May 21)
  - RaDIATE annual collaboration meeting (BNL, Spring 21)
- Workshop on Modeling and instrumentation (Date TBD)

# AF7ts: Accelerator Technology – Targets/Sources

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## • Main topics – Sources:

- High Brightness / High Average Current Electron Sources:
  - Cathodes
  - Guns
  - Injectors
- High Intensity Ion Sources
  - Intensity
  - Charge state
- High Intensity Positron/Proton/Muon Sources
  - Polarization;
  - High intensity (orders of magnitude higher than existing positron sources)

## • Events – Sources:

Three workshops with invited talks; dates TBD.

- 1. Workshop on High Brightness / High Average Current Electron Sources (C. Hernandez-Garcia, S. Karkare)**
  - Cathodes
  - Guns
  - Injectors
- 2. Workshop on High Intensity Ion Sources (D. Xie)**
  - Electron Cyclotron Resonance Ion Sources(ECRISs)
  - Electron Beam Ion Source (EBIS)
- 3. Workshop on High Intensity Positron/Proton/Muon Sources/H<sup>-</sup> (M. Biagini)**
  - Positron sources for e<sup>+</sup>e<sup>-</sup>/ μ<sup>+</sup>μ<sup>-</sup> collider projects (ILC, CLIC, SuperKEKB, FCC-ee, LEMMA, etc.)
  - Photons→Protons
  - Positron→ Muons (e.g. LEMMA)
  - Protons→Muon (MAP Muon source for MCC)
  - H<sup>-</sup>



# Accelerator Frontier Implementation Task Force

- One of the key goals of the Snowmass'21 Accelerator Frontier is to address the question *"...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 accelerator projects are being considered and/or developed as part of the Snowmass'21 effort. Examples include: ILC, a Muon Collider, gamma-gamma and ERL options, a large circumference electron ring, and a large circumference hadron ring amongst others.
- One of the challenges for the Accelerator Topical groups will be to *compare the expected cost scales, schedule, and R&D status for the projects as they will be at varied stages of development* and possibly proposed using different accounting rules.
- The AF Implementation Task Force is charged with *developing metrics and processes to facilitate such a comparison between projects.*



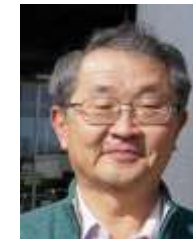
Thomas Roser  
(BNL, Chair)



Philippe Lebrun  
(CERN)



Steve Gourlay  
(LBNL)\*



Katsunobu  
Oide (KEK)



Jim Strait  
(FNAL)



or Raubenheimer  
(SLAC)\*



Reinhard  
Brinkmann  
(DESY)



John Seeman  
(SLAC)



Vladimir Shiltsev  
(FNAL)\*

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# Implementation Task Force: Next Steps

To begin with, the ITF will focus on **collider facilities**.

- **AF topical groups (AF3,4,6)** provide initial lists of proposals and concepts for evaluation to the ITF. Additional proposals and concepts can be added later.  
**Four categories:**
  1. Existing facilities for references (Tevatron, RHIC, LEP, LHC, Super KEKB, XFEL, LCLS II ...)
  2. Proposals with TDR and/or CDR
  3. Proposal without TDR or CDR but **reasonably well thought through** and mostly based on existing technologies
  4. Future concepts and ideas
- The ITF will develop a **set of metrics** that will be used to evaluate the proposals and concepts. Input is welcome.
  - Possible list of metrics: Performance, construction cost, schedule/timeline, physics reach (with input from EF), technical risks and R&D status and plans, operating cost and environmental impact, life cycle cost.
  - Proponents of proposals and concepts are asked to provide the information of their proposal and concept for each metric item **by the end of 2020**
- ITF will assemble and evaluate all this information and prepare an overall comparison of all the proposals and concepts. This will be presented to the AF topical groups at a **workshop, probably during spring 2021**, for comments and feedback.
- ITF will prepare a **White Paper** with the metrics, processes and conclusions for Snowmass'21 in **summer 2021**.

# Thanks to the *Accelerator Frontier Conveners*

for leading >30 CPM AF sessions (including with other Frontiers)

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. Posen (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)	

...and liaisons: M. Narain (Brown), D. Denisov (BNL) – EF; L.T. Wang (U Chicago) – TF; A. White (UT Austin) – IF; R. Bernsten (FNAL) – RF; J.L. Vay (LBNL) – CF; J. van Tilborg (LBNL) – CEF; M. Turner (LBNL) – *Snowmass Young*  
 ...and thanks to the Zoom Room Hosts who were hosting four or more parallel AF sessions and the LOC for pulling this whole thing together!