Accelerator Frontier 6: Advanced Accelerator Concepts

AF6 "goal":

- Assess potential for new accelerator technologies to revolutionize cost and capability of future accelerators for frontier High Energy Physics
- Capacity for orders of magnitude higher acceleration gradient than conventional systems enabling new types of high energy colliders including energies at and beyond TeV.
- Consistent with collider luminosity and efficiency requirements
- Generation of beams with unprecedented parameters (ultrahigh brightness), enabling novel intermediate applications
- Identify challenges and capability gaps that new acceleration methods could address

AF6 Conveners

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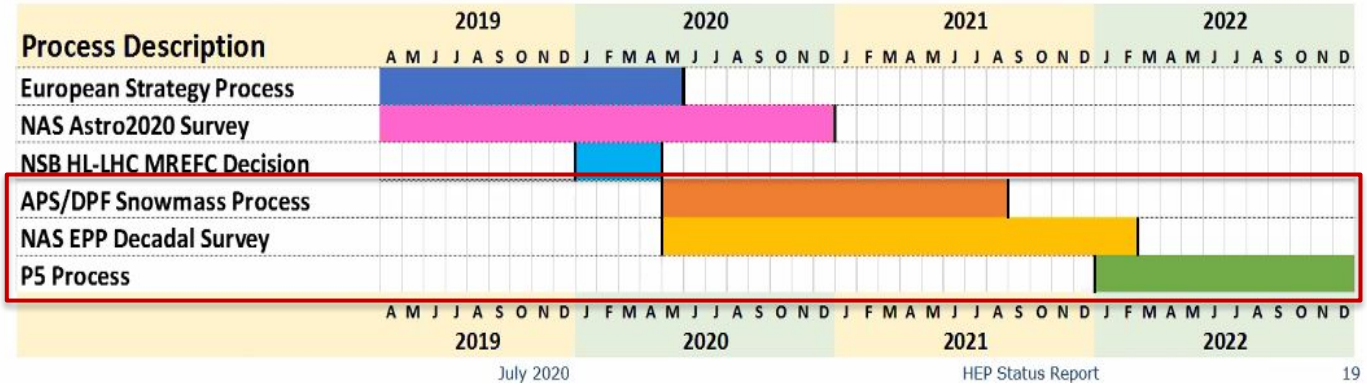
Snowmass Timeline

Jim Siegrist's presentation (2020-07-09)

Young-Kee Kim (U.Chicago), July 2020 HEPAP presentation

Strategic Planning Timeline

- To provide timely input to the FY25 budget formulation, the next P5 report will be required by March 2023
- U.S. Community Snowmass process is underway with major meeting occurring in summer 2021
- Potential timeline for the next NAS EPP Decadal Survey could be mid-2020 through early-2022
  - Overlap with Snowmass could enable synergy with Snowmass processes and delivery of report as P5 process begins



- Snowmass 2021
- NAS EPP 2022
- P5 2023

Today: brief presentation on process followed by discussion, Q&A, and coordination on upcoming submissions

Snowmass Timeline

AF6 Pre- CPM\ planning
Sept 23rd (1-2 days), 2020 (Zoom)

Virtual Kick-off
Town Hall
APS April Meeting

European
Strategy
Update

Community Planning Meeting (CPM)
Oct 5-8, 2020 (Zoom)

2021
APS April
Meeting

Community Summer Study (CSS)
July 11-20, 2021
(UW Seattle)
DPF 2021 (TBD) + CSS 2021

Snowmass
Report

Snowmass Structure & AAC linkages

Snowmass Frontiers

- ENERGY FRONTIER
- NEUTRINO PHYSICS FRONTIER
- RARE PROCESSES AND PRECISION
- COSMIC FRONTIER
- THEORY FRONTIER
- ACCELERATOR FRONTIER
- INSTRUMENTATION FRONTIER
- COMPUTATIONAL FRONTIER
- UNDERGROUND FACILITIES
- COMMUNITY ENGAGEMENT FRONTIER

- 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

- **AF1: Beam Physics and Accelerator Education**
- **AF2: Accelerators for Neutrinos**
- **AF3: Accelerators for EW/Higgs**
- **AF4: Multi-TeV Colliders**
- **AF5: Accelerators for PBC and Rare Processes**
- **AF6: Advanced Accelerator Concepts**
- **AF7: Accelerator Technology R&D**

- CommF1: Applications & Industry
- CommF2: Career Pipeline & Development
- CommF3: Diversity & Inclusion
- CommF4: Physics Education
- CommF5: Public Education & Outreach
- CommF6: Public Policy and Government Engagement

Snowmass Goals

- Define the most important questions for the field of particle physics
- Identify promising opportunities to address them
- Information is provided to P5 to develop a strategy for US HEP
- Accelerator Frontier : Each Working group will address the overall questions:

1. What is needed to advance the physics?
    - AF6: Enable new capabilities
2. What is currently available (state of the art) around the world?
    - AF6: progress in techniques, collider concepts and path
3. What new accelerator facilities could be available on the next decade (or next next decade)?
    - AF6: Will be test facilities, with coordinated plan to impact collider path
    - AF6: Intermediate applications and how they contribute to collider path
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?

AF6 to date

Liaisons with other Frontiers

Energy - D. Denisov and M. Narain
Computation - J. L. Vay
Community Outreach - TBA

Coordination with Energy Frontier

AF/EF meetings June 24th/July 1st. Especially 2nd day was relevant to AF6
slides can be found here Joint AF-EF Meeting on future colliders: Day 2

Invitations to mailing lists of conferences:

- EAAC, EuroNNAC, ICFA ANA lists
- Contacted major Advanced Accelerator groups/organizations. ALEGRO, ACHIP, LaserNetUS, AWAKE, EUPRAXIA, INFN
- **! To be replaced with AF6 mailing list. To sign up email to 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

Keep track of LOIs submitted or in the works

https://snowmass21.org/loi
https://snowmass21.org/accelerator/advanced/start

AF6 Specific Goals - Address HEP Impact

- Impact on High Energy Physics is the motivation
  - Drive from Luminosity at IP to collider IP parameters such as bunch length and focusing to accelerator charge/bunch, rate, efficiency...
- AAC are longer term technologies
- Path from current studies to realistic colliders needs to be clear
  - Includes intermediate applications
  - Coordinated AF6 community message is essential
- 2016 DOE Advanced Accelerator Development Strategy Report was a key step in defining a collider path for some AAC technologies
  1. Show the impressive AAC progress along the defined path
  2. Incorporate and assess new results and techniques, and their impact
  3. Articulate strategy of experimental tests, theory and modeling, facilities
  4. Plan towards integrated design studies of more mature technologies
- Roadmaps similarly needed for other new technologies, at varying levels

LoIs and White Papers

Letters of Interest (submission : April 1, 2020 – August 31, 2020)

- Informal documents intended to be useful in the first stages of the Snowmass study
- Help conveners to prepare the Snowmass Community Planning Meeting (Oct. 2020)
- Submission instructions: https://snowmass21.org/loi
- LoI authors are welcome to make a full writeup as a contributed paper (not required)

Contributed ("white") Papers (submission : April 1, 2020 – July 31, 2021)

- Scientific or technical articles on relevant physics / technical topics, and reasoned expressions of physics priorities, including those related to community engagement.
- Part of Snowmass proceedings (permanent record of Snowmass 2021)
- Submission instructions: https://snowmass21.org/submissions/
- LoIs are not required in order to submit contributed papers
- Note that the submission date is after the workshop to allow for final revisions, but AF6 requests complete drafts should be submitted before the workshop to support discussion.

AF6 plan:

- Discuss LOIs in September then incorporate feedback from the October Snowmass community workshop
- Work together to coordinate contributions (for example, merging similar submissions) and generate a compelling and coherent vision for our field and its impact on High Energy Physics.

LoIs and White Papers

Letters of intent are encouraged to address the following accelerator areas, which will also serve as organizing themes:

1. PWFA - particle beam driven Plasma WakeField Acceleration
2. LWFA - Laser driven plasma WakeField Acceleration
3. Proton-driven plasma accelerators
4. Crystal / nanostructure accelerators
5. High frequency metal and dielectric structures
6. Dielectric laser-driven accelerators
7. High efficiency lasers and drivers
8. Injection, beam cooling, manipulation and focusing elements relevant to other accelerators
9. Creation and use of novel beam regimes to enhance luminosity
10. Hybrids of methods

Within each accelerator area, we will address topics including

A. System concepts, luminosity, and beam dynamics for colliders
B. Polarized positron production and transport
C. Intermediate applications such as compact photon sources: FELs, Gamma-ray sources
D. Controlled particle injection to produce beams that are: stable and reproducible, lower in energy spread and emittance, and higher in charge meeting collider requirements.
E. Efficient transfer of the driver energy to the particle beam, including drive pulse manipulation/guiding.
F. Staging, or combining multiple elements to reach high beam energy for HEP applications, and also has applications to beam disposal (deceleration) for radiation sources.
G. Diagnostic techniques suited to resolve unprecedented beam parameters
H. Compact beam manipulation techniques needed alongside accelerator structures. These include compact radiation cooling, focusing, and beam phase space exchanges.

Collaboration across the community is strongly encouraged
Focus on high level application impact, integrating techniques, will be helpful

Community Planning Meeting: Oct 5-8, 2020

- Focused on cross-frontier coordination
- AF6 will pre-develop its plan to lead into this workshop
- Workshop: opportunity to lay out goals and plans for the next 8 months leading to Snowmass
- Make needs of other Frontiers clear, e.g.
  - Expect that AF4 will want magnet dev. plan from AF7
  - Expect that AF4 & AF6 will want energy limits from AF1
  - Expect that AF3, AF4, & AF6 will want luminosity/energy requirements from Energy Frontier
  - Expect that AF5 will want suggestions for experiments from Rare Processes Frontier
  - Expect that AF2 will want goals from the Neutrino Frontier

Community Planning Meeting: Oct 5-8, 2020

CPM 2020				
Day 1	Plenary (1.5 hrs)	Introduction	30'	About Snowmass, About CPM
		Community Engagement	60'	
	Breakout Sessions (~2.5 hrs)	Focus on inter-frontier discussios and establish cross working group connections.		
		Establish new areas to focus		
		Identify further input needed to achieve Snowmass goals		
Day 2	Breakout Sessions (~4 hrs)	Focus on inter-frontier discussios and establish cross working group connections.		
		Establish new areas to focus		
		Identify gaps and further input needed to achieve Snowmass goals		
Day 3	Plenary (~4 hrs)	Input from Funding Agencies (30')	15'	Questions for the community from DOE
			15'	Questions for the community from NSF
		Particle Physics in Other Regions (80')	25'	Europe
			25'	Asia/Pacific
			10'	Canada
			10'	Latin America
			10'	Africa/Middle East
		Plans in Related Fields (30')	15'	Astro2020 Decadal Survey
			15'	Long Range Plan for Nuclear Science
		Laboratory Corner (45')	45'	Panel Discusssion with lab leaders
		Community Voices (60')	60'	Town Hall
Day 4	Plenary (~4 hrs)	Frontiers: Ongoing Activitites, Summaries of Breakout Sessions, and Next Steps (250')	25'	Energy
			25'	Neutrino
			25'	Rare Processes & Precision Measurements
			25'	Cosmic Frontier
			25'	Theory
			25'	Accelerator
			25'	Instrumentation
			25'	Computing
			25'	Underground Facilities and Infrastructure
			25'	Community Egagement
		Closing Remarks (5')	5'	

AF6 Preparation meeting Sept 23rd, based on LoIs

- Organized around the LOIs and the Advanced Accelerator Development Strategy Report and other planning documents

- Depending on the number of submissions, 1 or 2 days

- Starting September 23, 2020 at 0800 Pacific
  - https://lbnl.zoom.us/j/98660223097.

- Discuss the submitted LOIs and identify additional material needed
- Opportunities for brief talks based on the submitted LOIs.

- Begin coordination of input

- Further information on this workshop will be announced to the mailing list below based on LOIs so please sign up to receive details.

LOI planning to date - invitation to collaborate

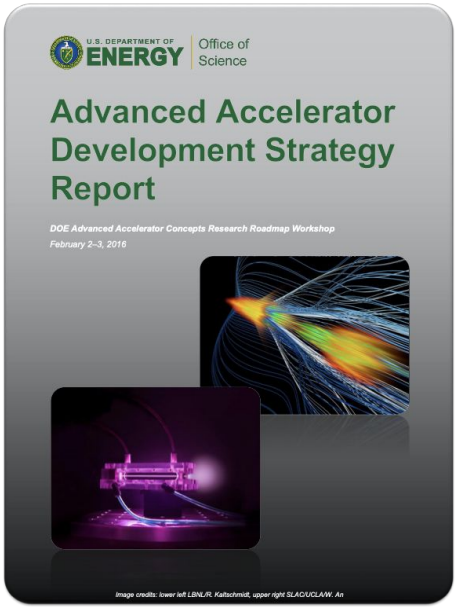
LOI # if sub.	Planned LOI Topic or submitted LOI title	Frontier	Contact for LOI
	Multiple technologies		
	Accelerator Test Facilities in the US	AF6	TBD
	Plasma acceleration theory and simulation needs	AF1, AF6, CompF2	Carl Schroeder
	ALIC studies through ALEGRO (ICFA)	AF6	TBD
AF6-011	Underdense Thin Plasma Lens as a Tool for Future Colliders	AF6	Christopher Doss
	Proposed EuPRAXIA facility in Europe	AF6	
	PWFA		
	The path towards a plasma collider	AF6	Spencer Gessner
	Short-bunch Colliders	AF1 & AF3 & AF4	Vitaly Yakimenko
	PWFA Program at FACET-II and Beyond	AF6	Chan Joshi
	High brightness injectors based on PWFA	AF6	Bernhard Hidding, Xinlu Xu
	Plasma lenses	AF6	Mike Litos
	Proton Driven Plasma Wakefield Acceleration and plans for AWAKE	AF6, AF4	Patric Muggli (tentative)
	Attosecond electron and photon beams	AF6	Ckaudio Emma
	Plasma Instability Driven Gamma-ray Source	AF6	Frederico Fiuza
	PWFA High-Energy Injector for rings like CEPC	AF6	TBD
	LWFA		
	Laser-plasma accelerator linear collider	AF6, EF	Carl Schroeder
	Interaction point effects, QED and short bunches	AF6	Stepan Bulanov
	LPA Program at BELLA	AF6	Eric Esarey
	High brightness injectors based on LWFA	AF6	
	High gradient focusing	AF6	Sam Barber
	Photon sources and near term applications of LWFA	AF6	Jeroen van Tilborg
	Precision high average power lasers & plasma accelerators	AF6, CF	Leily Kiani, Tong Zhou
	Spatiotemporal control of lasers	AF6	John Palastro
	Polarized beams from LWFA	AF6	M. Büscher
	SWFA		
	Continuous and Coordinated Efforts of Structure Wakefield Acceleration (SWFA) Development for an Energy Frontier Machine		John Power
	Beam Physics Challenges & Research Opportunities for Structure-based Wakefield Accelerators		
	SWFA demonstrators with integrated technologies for future large-scale machines		
	Research and Educational Opportunities at the Argonne Wakefield Accelerator (AWA) Facility		
	Short-pulse wakefield structure R&D for high gradient and high efficiency acceleration in future large-scale machines		
	Argonne Flexible Linear Collider (AFLC)–Beyond Concept: A 3-TeV Linear Collider Using Short rf Pulse (~20ns) Two--Beam A		
	Dielectric Wakefield Accelerators	AF6	
	Other		
	ACHIP	AF6	Joel England
AF6-005	Ultimate Acceleration in Crystals and Nanostructures	AF6	T. Tajima
AF6-006	Nanostructure Accelerators	AF6	A. Sahai

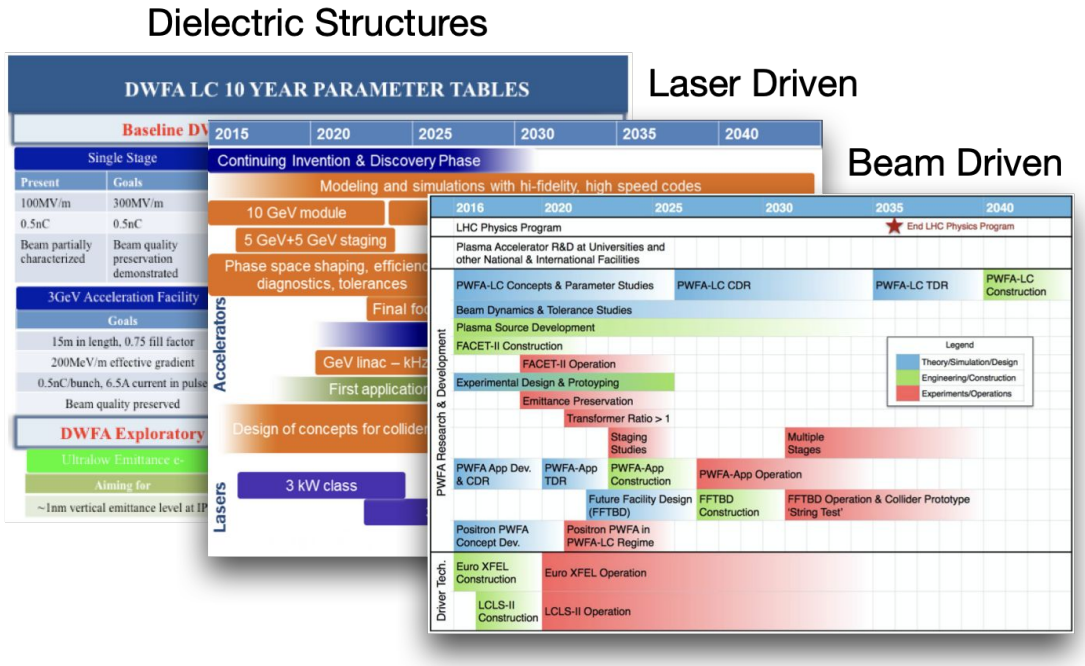
Example
Cross-links:
ATF's
Colliders
IP physics
Focusing
Injectors
Near term

Collaboration and linkages will be beneficial
Please contact us with additional ideas
Please reach out to contacts for collaboration

Collaboration Across LOIs for Coherent Message

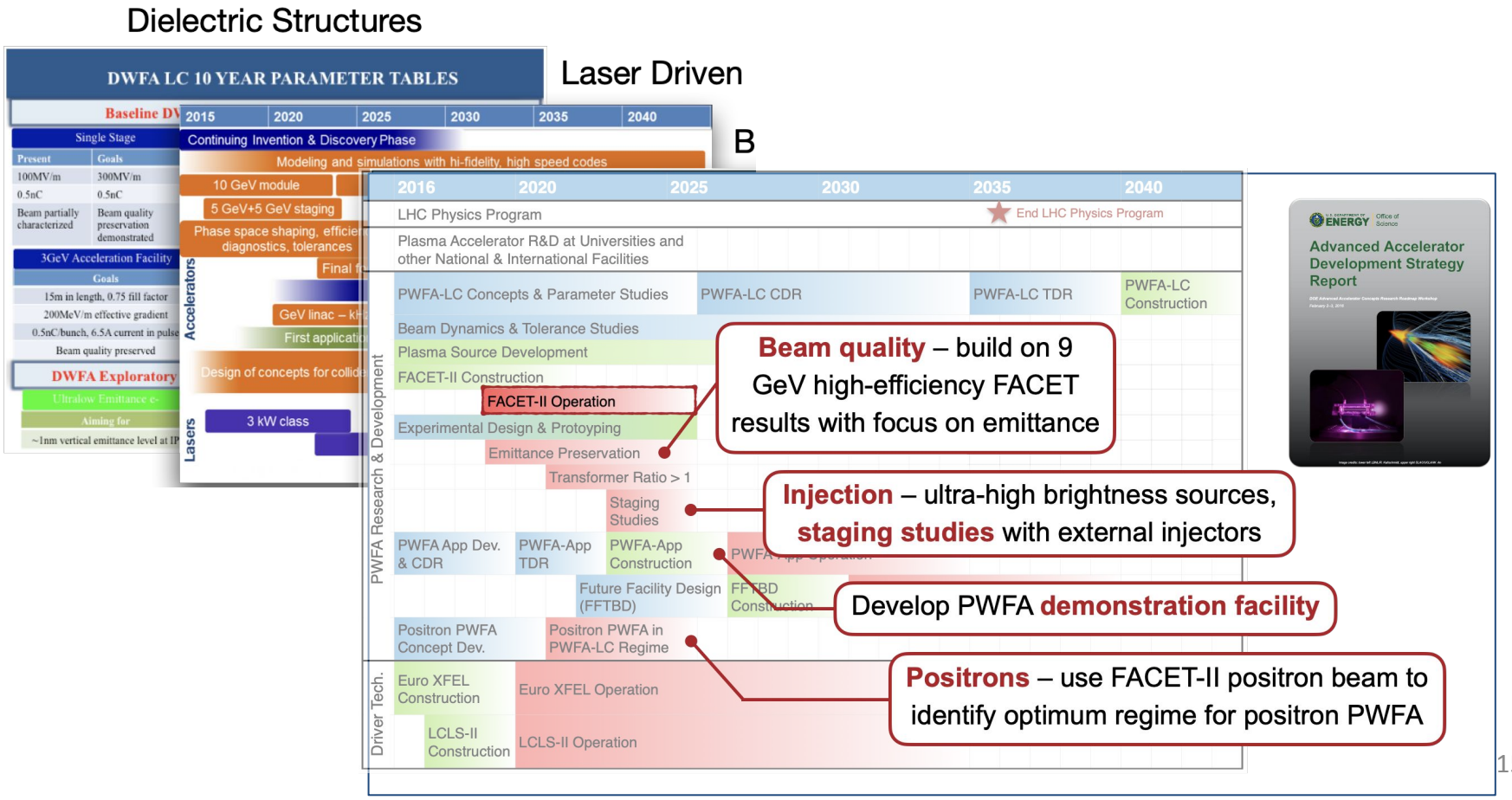
- Initial philosophy – let a thousand flowers bloom and get all the ideas on the table
- Following recent meetings and discussions we realized it's possible to get a more coherent message that (importantly) is also strongly aligned with HEP Roadmaps
- Roadmaps followed Snowmass 2013 and ensuing HEPAP sub-panel
- Community representatives organized workshops and worked with DOE HEP to define roadmaps for three AAC technologies: DWFA, LWFA, and PWFA
- Will be revisited as part of Snowmass 2021





Example of LOI Coordination

- Roadmaps outline expected progress in the next decade (in broad themes and more specific detail) - similar roadmaps for PWFA, LWFA, structures
- Beneficial if LOIs (and Contributed Papers) align to roadmaps and guidance from EF community about latest thinking (e.g. a few TeV vs. Higgs factory + 10TeV)



Example of PWFA Collaboration LOIs Aligned with HEP Roadmap

- Goal to target a single LOI & contributed paper towards each roadmap theme (bold) that combines individual LOIs currently in progress –
- GoogleDoc already shows there is an opportunity for broader collaboration
- This should be revisited as we head to October planning workshop
- PWFA, DWFA & LWFA are conducting similar coordination including across techniqeues

Organized by Technology/Physics

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AF6-006	Nanostructure Accelerators	AF6	A. Sahai

Example Cross-links:
ATF's
Focusing
IP physics
Injectors
Near term

Organized by Roadmap Themes

PWFA Topics Grouped By Roadmap Theme
Beam Quality
PWFA Program at FACET-II and Beyond
Injection & Staging Studies
High brightness injectors based on PWFA
Plasma lenses
Demonstration Facility
The path towards a plasma collider
Short-bunch Colliders
PWFA Injector for High Energy Rings
Plasma Instability Driven Gamma-ray Source
Attosecond electron and photon beams
Positrons
Positron Acceleration in Plasma

International Input is Invited

- High energy physics today is a successful global endeavor with work share across countries and continents. This makes it a role model for a changing world… Accelerator research and development is embedded in this global research landscape. Many links exist, enabling sharing of ideas, concepts and infrastructures → faster progress.
- US has been the driving force for advanced accelerators since more than four decades and is still a leader in this field.
- International studies or projects with US links reinforce international approach and exchange (see ACHIP, AWAKE, ELI-beamlines, ALEGRO, EuPRAXIA).
- Europe and Asia are rapidly building up their own research capabilities and already set the theme in some aspects of of advanced accelerators. National projects in Europe (SPARClab, Apollon/CILEX, LUNEX, Lund facility, ATHENA, HZDR facilities, FLASHForward, LUX, KALDERA, JuSPARC, CALA, FELIX, Strathclyde facilities) and Asia (KEK, SPRING-8, Korea, Tsinghua, Shanghai) push progress on many fronts.
- The recognition of importance of advanced accelerators for our future is still growing. E.g. European strategy for Particle Physics explicitly mentions plasma accelerators for the first time and requests follow-up in coordination of R&D.
- Snowmass is a US driven effort. **International actors are explicitly invited so submit LOI's and join this process. It will help to strengthen our field and progress world-wide!**

Discussion Notes:AF-EF coordination & parameters

- Coordination with Energy Frontier and Collider Parameters will be key input to AF6 goals
  - Energy frontier targets for high energy systems have increased since last Snowmass - several key categories identified as of interest
  - Higgs factories at fraction of a TeV - conventional technology options exist, e.g. ILC
    - Easy to justify, high priority per EF discussions and European strategy
    - AF6 roles may include afterburners/upgrades tfrom 0.25-> 0.5TeV or in luminosity (accelerator structures and advanced focusing/cooling/etc. could be included)
    - AF6 designs can directly address but not the focus given conventional options
    - Options: polarization interesting but not core, e-p possible but not mainstream
  - Few TeV lepton or gamma-gamma colliders
    - Near LHC in parton energy - some EF discussions indicate less interest now. Alternatively some indications this range could still be of interest
    - Clearly not the main/only thrust as it was in past years
  - 10-30 TeV lepton or gamma-gamma colliders
    - Beyond LHC in parton energy by factor of a few desired -> 10 TeV or above
    - Conventional options feasible but expensive, luminosity requirement increases
    - Articulate AF6 path to build much cheaper - includes gradient, unique beam regimes, efficiency, focusing methods, and more. Show R&D strategy to realize.
    - Energy limits include: cost (AF6 has potential to address) luminosity per power (AF6 short/round beams and/or advanced focusing and cooling could help)
  - muon colliders - AF6 technologies can contribute to multiple components or full machine
    - Area of renewed interest

Discussion Notes:AF-EF coordination & parameters

- Coordination with Energy Frontier and Collider Parameters will be key input to AF6 goals (cont.)
  - Physics studies - physics not strongly affected. No specific studies identified to date
    - Detector considerations? Beamstrahlung? Time structure may differ. Events are rare, wait seconds for triggers, sonot a big deal
  - Need a strong strategy for AF6 mid term 10-20 year impact and plan
    - EF issue: AAC is long term and physics may be a moving target. So far away that by then physics goals may be different, colliders might be less critical.
    - Need to create medium term reality at 15 year scale and range of options to address range of physics possibilities to best justify a strong program
  - Coordinated Advanced Accelerator Development Strategy Report of 2016 documents strong advancement by AF6 technologies since last P5 and AF6 impact/plan
    - Resource limited, approved program for 15-20 years of R&D, potential for CDRs in 2035 compatible with goals above. Re-visiting and updating this plan and incorporating new goals is a priority
    - Plan going forward currently as detailed on Slide 7, including coordinated plan of test facilities and advancement towards integrated design studies.
    - Target Integrated Design Studies in next 5-10 years: believable concept and can do calculations with focusing and staging, costing (not TDR). Will be cheaper because X. Much of this is in the Accelerator Development Strategy Report and needs to be pushed forward
    - First applications could be light sources, then possibly a Higgs factory or upgrade setting up technology towards multi-TeV
    - Further input welcome

Discussion/Comment/Question Notes

- Like the theme and coordination. Message is to the particle physicists - here is what we think we can deliver and how. End will be a short summary of accelerator physics, 15 pgs level.
  - Like the coordination idea, collider idea surfaces at P5 and in Europe. There is need to sustain focus over time. ALEGRO tried but find response not as strong as desired. Support ongoing Snowmass AF6.
- Interest group on plasmas and advanced structures, motivated by ABP, is in progress. Plan to update and further develop roadmaps from Advanced Accelerator Development Strategy Intent to also continue beyond Snowmass ala ALEGRO?
  - Computational interface, need for advanced computing are important and need development - Jean-Luc Vay is the liason and there is an interest group for this.
  - IDS best targeted by focus/interest group,
  - European parallel discussions, focus group is the right path - build internationally. Suggest more formalized, binding between groups working on it. Not only a interest group but formalize commitment. Meetings are not enough. Need for deliverables/deadlines/resources.
  - Not only interest but institutes and resources behind us are needed. Can be MOU or less formal but needs directors not just a few people.
  - One way to make it happen is funding, hard to do. Even a webpage with place to keep each other up to date, establish collaborations will be a step. Start through Snowmass and show plan to justify a funded program.

Discussion/Comment/Question Notes

- Snowmass young is addressing the concerns and input of younger scientists. Designation of liasons is in progress and will attend meetings.
- Community engagement frontier described. Alex Murok addressing industrial connections. Both industrial participation and applications of AF6 accelerators in industry are of interest
  - Post-townhall: Jeroen van Tilborg will be a liason for AF-CF
- Diagnostics for measuring beam quality essential, potential for joint program across test facilities. Across all injection processes & staging
- University perspective: need to join efforts better. Europe through EuPRAXIA has set an example. Very pertinent to novel concepts and new capabilities opening.
  - Also link to Snowmass Young, try to exhibit whole panel of fields that can be open to AAC to help students: Website joint vision? AF1 also focused on this training aspect.
- High average power lasers will be important - LOI in progress from US community and others are invited.
- Look for cross links between DPP-CPP and this process (DOE-FES planning), and also other recent planning activities . See common themes, but Snowmass focus is to HEP. See some gaps: Muons needed. Ion acceleration? not a current GARD thrust but could be a near term application. Make sure all are present.
- As AF6 techniques mature and required funding for facilities grows it is essential to have more coordination. Compare where we are now with where we were: 10 years ago many small efforts with little coordination. Next generation facilities are at $100M level, need community input. Europe is implementing some of this. US lagging. ATFC just formed this year among national labs - needs to strengthen and grow with interest group and university programs and industry.