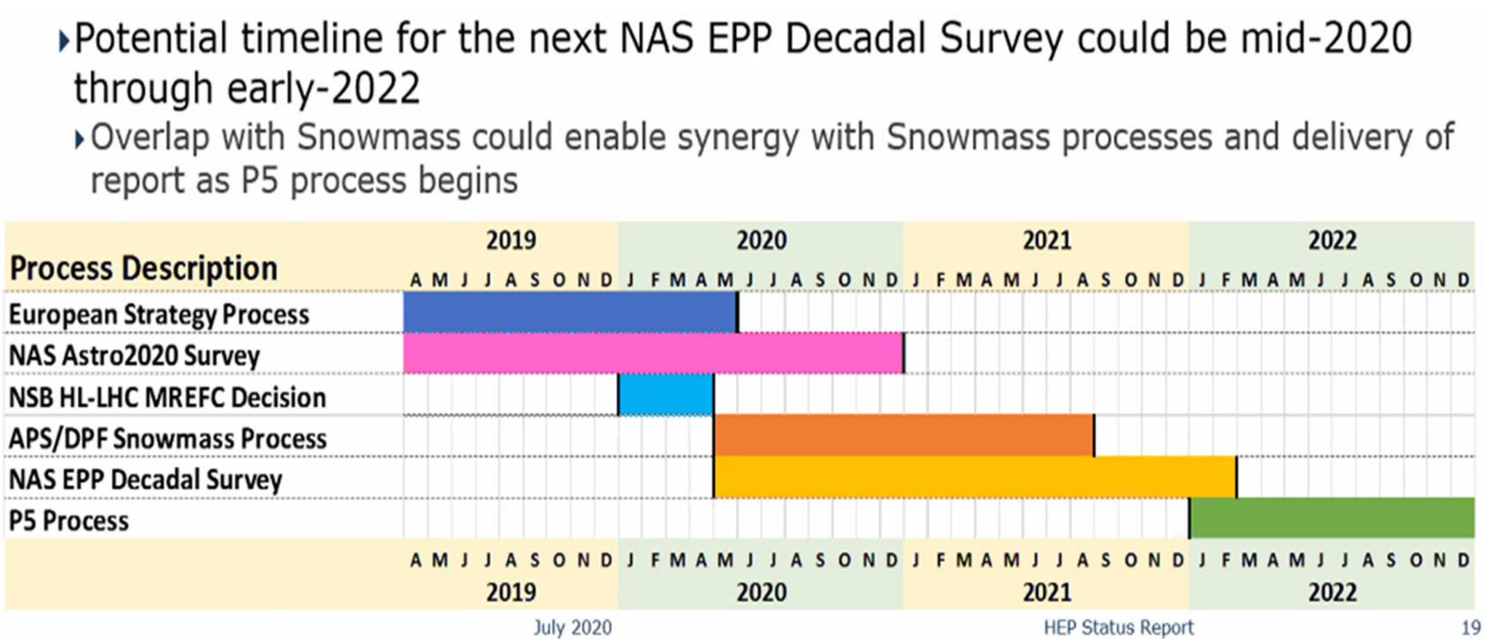
Snowmass Accelerator Frontier
Topical group on Advanced Accelerators

Pietro Musumeci (UCLA)

on behalf of AF6 conveners
Cameron Geddes
Mark Hogan
Ralph Assman

Snowmass community plan for high energy physics

- Particle Physics Community Planning Exercise ("Snowmass") for the entire community
- Identify and document a scientific vision for the future of particle physics in the U.S. and its international partners, with key questions and promising approaches
- P5, Particle Physics Project Prioritization Panel, will take the scientific input from Snowmass and develop a strategic plan which will guide future work
- <u>Timeline to make an impact:</u> to provide input to the FY25 budget formulation, next P5 report will be required by March 2023

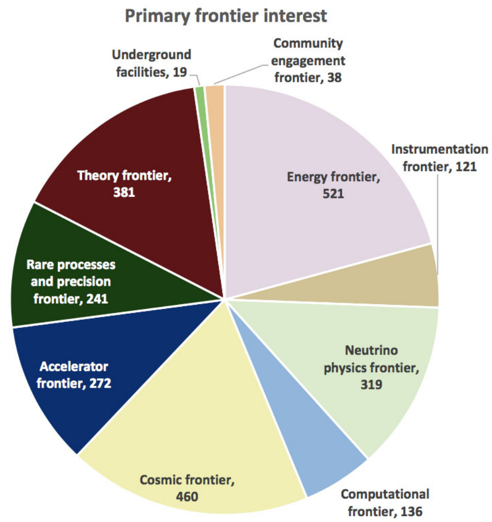


- Snowmass 2021 -> 2022
- NAS EPP 2022
- P5 2023

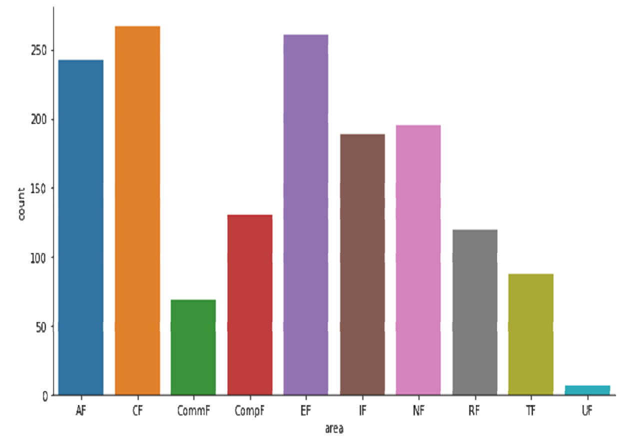
Snowmass Structure & AAC linkages

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



Participants at Snowmass Community planning meeting



Letter of Interest received

- **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**

+ Implementation Task Force

https://snowmass2021.org

Accelerator Frontier 6: Advanced Accelerator Concepts

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

Engage both across our field and with energy frontier and theory colleagues on future of field

AF6 Conveners

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Current Snowmass process: from LOIs to a coherent message

- ❑ Initial philosophy – let a thousand flowers bloom and get all the ideas on the table
- ❑ 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
- ❑ Last August 2020, open call for LOI to collect ideas for future direction of the field.
- ❑ Snowmass Community Planning workshop was held in October 2020 to facilitate inter-frontier and intra-frontier communications.

- ✓ White Paper submission to arXiv: no later than March 15, 2022.
- ✓ Preliminary reports by the Topical Groups due: no later than May 31, 2022.
- ✓ Preliminary reports by the Frontiers due: no later than June 30, 2022.
- ✓ Snowmass Community Summer Study (CSS): July, 2022 at UW-Seattle.
- ✓ All final reports by TGs and Frontiers due: no later than September 30, 2022.
- ✓ Snowmass Book and the on-line archive documents due: October 31, 2022.

LoIs (69)

	LOI title	Corresponding author	LOI Snowmass #	Classification /notes/CG added	Primary Topical Group	Secondary Topical Group
2	Strategy Towards Ultimate Limits	M. Bai (GSI)	155	Beam dynamics	AF1	
3	Ion Coulomb Crystals in Storage Rings for Quantum Information Science	K. Brown (BNL)	28	Beam dynamics	AF6	AF7-TF9-TF10-CompF6
4	High intensity attosecond electron and photon beams	C. Emma (SLAC)	97	Beam dynamics	AF6	
6	Machine Learning Meets the Challenges of HEP Research and Development	B. O'Shea (SLAC)	165	Beam Dynamics	AF6	AF4-CompF3-CompF2
7	Monochromatization of e+e with a large crossing angle					
8	High bandwidth adaptive contro for particle accelerators					
9	Accelerator phase space-contro high-intensity lasers					
10	Particle Colliders with Ultra-Sho Bunches					
11	Machine learning and surrogate for simulation-based optimizatio accelerator design					
12	High current field emission elec sources for linear colliders and source applications					
13	Pushing Brightness and Curren Normal- Conducting Radiofreq Electron Sources					
14	Bright Electron and Positron Be High-Charge Electron Bunches Beam-driven Structure-WakeFi Accelerators					
15	Gamma-gamma collider with W ≤12GeV based on the 17.5 Ge of the European XFEL					
16	Exploiting Global Accelerator N Synergies					
17	Plasma Accelerator Science Co Organization					
18	ALEGRO LOI for Snowmass202 Towards an Advanced Linear International Collider					
19	Computational modeling needs plasma-based accelerators tow future colliders					
20	Dual Axis SRF Structures – 'Th Both' Linear and Circular Accel					
21	Photonic Crystal (PhC)-based D Laser Accelerator (DLA)					
22	Laser-driven acceleration medi metallic nanostructures					
23	High-Gradient Accelerators at T Frequencies					
24	Dielectric Laser Acceleration					
25	High precision RF control for ne generation accelerators					
26	High-energy high-luminosity ER e+e- collider					
27	GARD Beam Test Facilities					
28	EuPRAXIA – A Concept for a R Infrastructure based on Plasma Accelerators and First user App					
29	The Path to Compact, High-Inte Beams					
30	High average power ultrafast las technologies for driving future advanced accelerators	L. Kiani (LBNL)	221	Laser sources	AF6	
32	High average power femtosecond laser driver for plasma accelerators by compression of spectrally broadened high energy Yb:YAG lasers	J. Rocca (Colorado State University)	124	Laser sources	AF7	AF6
33	kW average power frequency doubled Yb:YAG amplifiers to pump high energy femtosecond lasers at kHz repetition rates	J. Rocca (Colorado State University)	230	Laser sources	AF7	AF6
34	Optical Energy Recovery for a High Duty Cycle Gamma Ray Source	A. Murokh (RBT)	79	Laser sources / Driven structures	AF6	AF4
35	The ZEUS high intensity laser user facility for research into laser driven particle acceleration	K. Krishelnick (University of Michigan)	154	Laser sources / Facilities	AF6	

	LOI title	Corresponding author	LOI Snowmass #	Classification /notes/CG added	Primary Topical Group	Secondary Topical Group	Questions
36	Spatiotemporal Control of Laser Intensity for High Performance Plasmabased accelerators	J. Palastro (Rochester)	77	LWFA	AF6		
37	Near-term R&D at BELLA towards a laser-plasma-based collider	A. Gonsalves (LBNL)	197*	LWFA	AF6		
38	Compact photon sources based on laser-plasma accelerators	J. Van Tilborg (LBNL)	200	LWFA / applications	AF6		
39	Comprehensive Single-shot Diagnostics						
66	acceleration in future large-scale machines	J. Shao (ANL)	44	SWFA	AF6	AF7	
67	Argonne Flexible Linear Collider (AFLC) – Beyond Concept: A 3-TeV Linear Collider Using Short rf Pulse (~20 ns) Two--Beam Accelerator	C. Jing (ANL/Euclid)	88	SWFA	AF6	AF4	
68	Structure Wakefield Acceleration (SWFA) Development for an Energy Frontier Machine	C. Jing (ANL/Euclid)	90	SWFA	AF6	AF4	
69	Research and Educational Opportunities at the Argonne Wakefield Accelerator (AWA) Facility	J. Power (ANL)	43	SWFA/ Facilities	AF1	AF6	
70	Marine Engineering of the Collider in the Sea	P. McIntyre (Texas A&M)	240		AF6	EF0	Not AF6. Perhaps AF7?
71	Cosmic Explorer: The Next-Generation U.S. Gravitational-Wave Detector	S. Ballmer (Syracuse)	10		CF7	CF6-AF6-IF1	Not AF6
72	Transformative Technology for FLASH Radiation Therapy	R. Schulte (Loma Linda)	47**		CommF1	AF6-AF7-IF2-IF9-CompF3-CompF5	Propose to move to AF7/RF or Comm

AF6:

- 69 LOIs total
- 41 indicated AF6 as primary
- Many overlap with AF7 Accelerator technology and AF1 Beam Physics & Education.

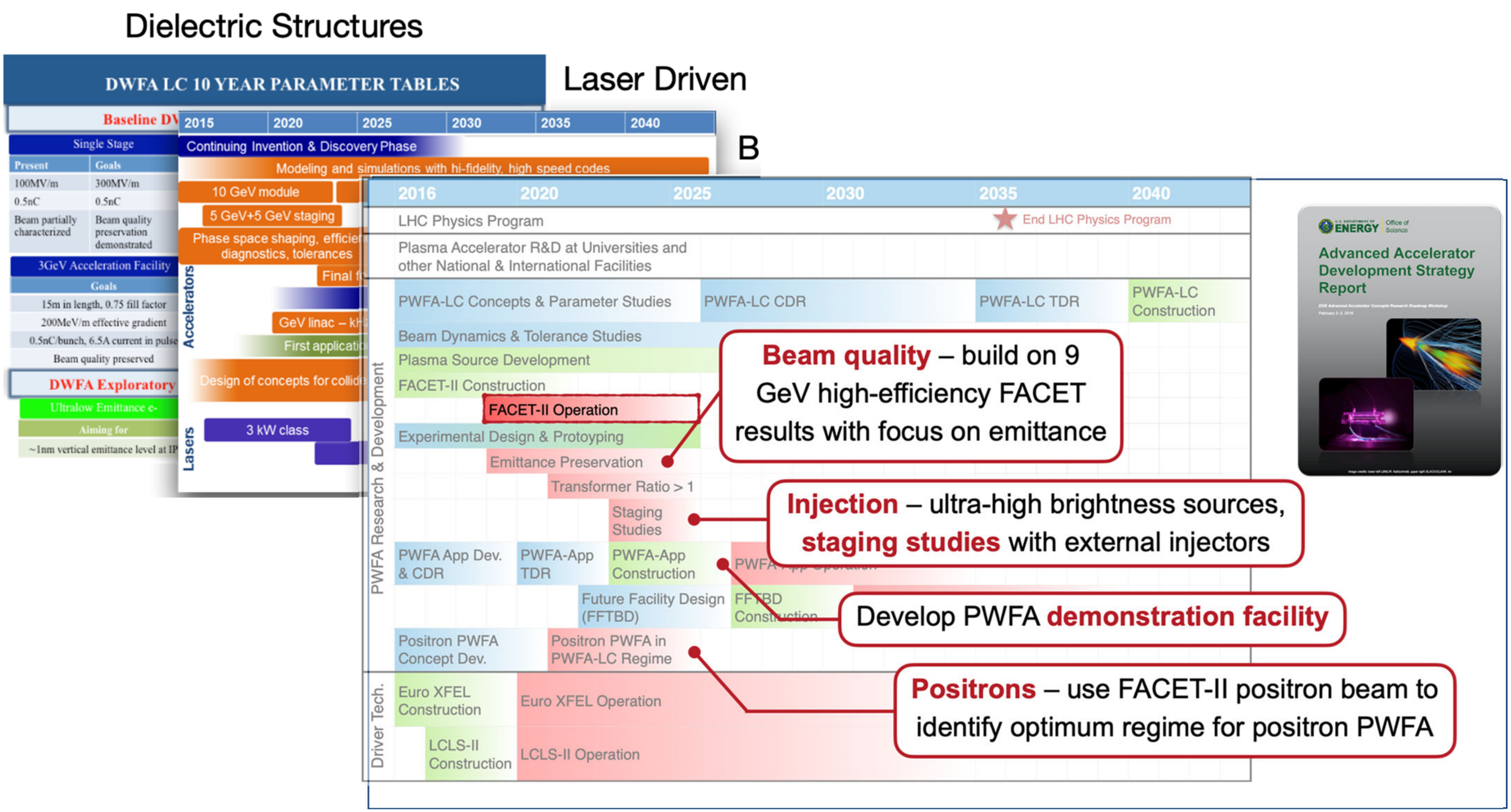
In terms of high-level topics:

LWFA (19), Beam Dynamics (16), PWFA (14), SWFA(11), Driven structure (7), Facilities (7).

All LOIs invited to present at the AF6 preliminary Workshop held on Sept 23-24 2020 - https://indico.fnal.gov/event/45651/

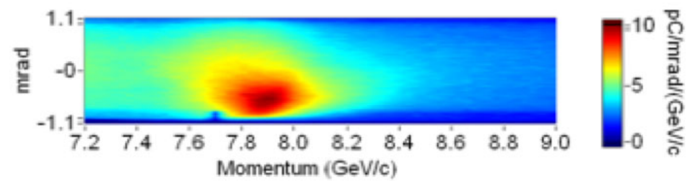
Looking at the previous Snowmass exercise
LOI Coordination and alignment with previous efforts

- 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)

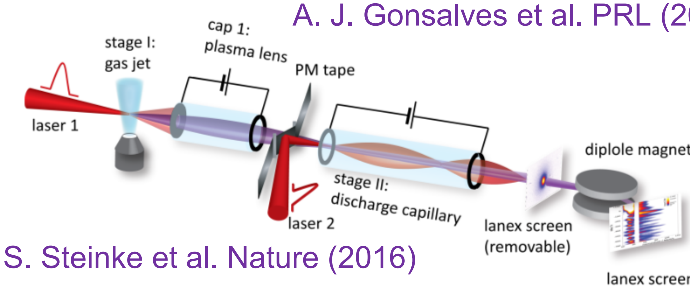


Rapid experimental progress since last Snowmass

- LWFA 8 GeV energy gain in single 20 cm stage using PW laser (also: multi– GeV PWFA).
- Proof–of–principle staging of LWFAs (~100 MeV energy gain) using plasma–based stage coupling
- Optimized beam loading in PWFA enables uniform, high–efficiency acceleration.
- Demonstration >1GeV/m gradients SWFA dielectric structures.

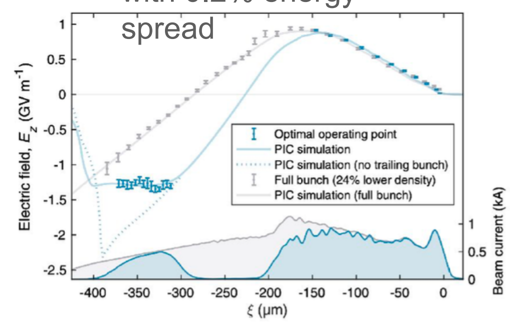


A. J. Gonsalves et al. PRL (2019



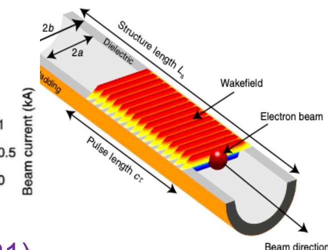
S. Steinke et al. Nature (2016)

42% transfer efficiency with 0.2% energy spread



C. A. Lindstrom et al. PRL (2021)

GeV/m structure



B. O'Shea et al. Nature Comm. (2016)

Also: positron PWFA, hollow channels for low emittance growth, 0.1 micron emittance with path to nm-class…

Landscape of future collider interest has changed

- Strong interest in many TeV future parton energies to 10 TeV and above
  - Engage with energy frontier and theory colleagues
  - Determine and communicate potential energy reach
  - Facilitate consideration of physics signatures

- Need for definition of options ranging from TeV to beyond 10 TeV
  - Need common design points from AF6 that EF/TF can address

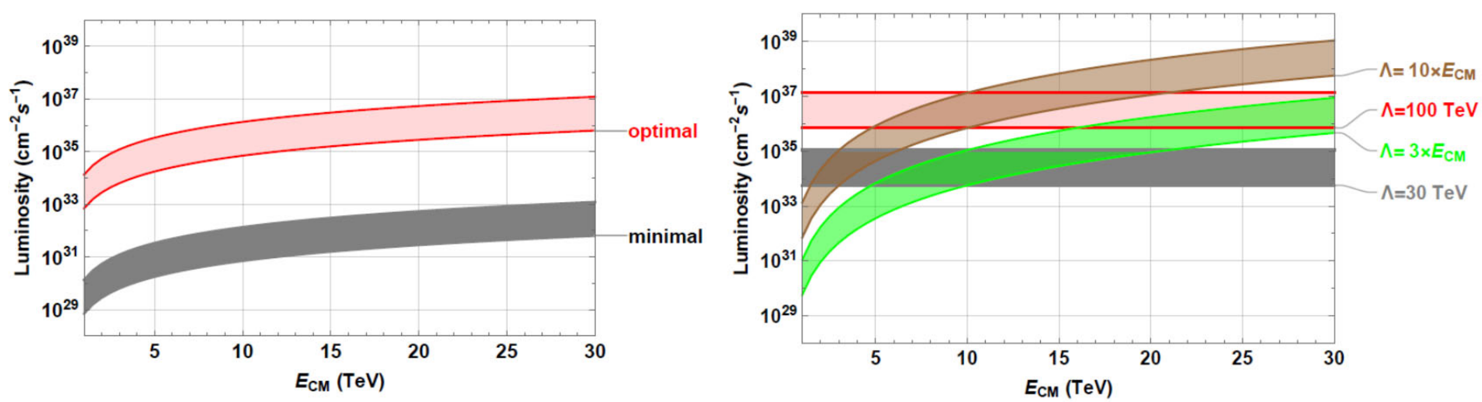
- Wall plug power becomes a key limit
  - Creativity is needed on efficiency, energy recovery, etc.

- Resurgent interest in muon collider options - articulated at 10 TeV and above
  - Most physics is common with e+e-
  - Significant overlap with gamma-gamma
  - Potential for AF6 contributions to muon systems

Energy Frontier contacts

- From L. Tao. “Physics requirements for future colliders”.
- EF restart workshop. AF+EF discussions.
- https://indico.fnal.gov/event/49756/timetable/

Lepton collider summary



Luminosity $cm^{-2}\ s^{-1}$	1.5 TeV	3 TeV	6 TeV	10 TeV	14 TeV	30 TeV	100 TeV
Direct search minimal	3×10^{29}	10^{30}	5×10^{30}	2×10^{31}	5×10^{31}	2×10^{32}	2×10^{33}
Direct search optimal	3×10^{33}	10^{34}	5×10^{34}	2×10^{35}	5×10^{35}	2×10^{36}	2×10^{37}
Precision minimal	3×10^{30}	8×10^{31}	2×10^{33}	10^{34}	5×10^{34}	10^{36}	2×10^{37}
Precision optimal	7×10^{32}	10^{34}	2×10^{35}	2×10^{36}	5×10^{36}	10^{38}	2×10^{39}

Towards 10-15 TeV-class e+e- colliders

- Collider concepts indicate 10 TeV and beyond possible with competitive efficiency
  - Polarized e+e-
  - gamma-gamma
- Organizing towards integrated design study

- Wall-plug power (operating costs) will limit energy reach of e+/e- linear colliders based on AAC
- Short beams – save power, reduced beamsstrahlung
- Laser and beam energy recovery may be used for improved efficiency

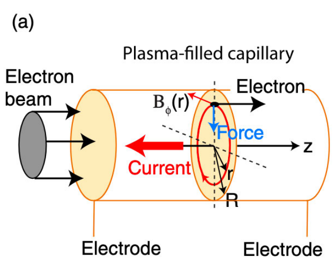
- Injectors. components for LEMMA muons, others

- The Final Focus uses the local chromatic correction in the final doublet.
  - Can we employ novel chromatic correction techniques with shaped plasma lenses?
  - Can we reduce the beam spot using strong focusing from plasma lenses?

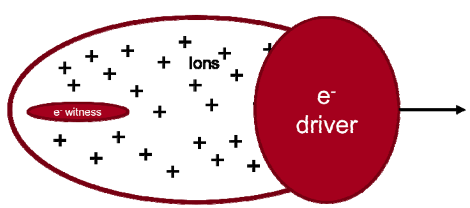
- Potential to re-use facilities of near term LC's like ILC to reach (much) higher energies in the future

- **High energy physics signature studies are important to guide accelerator R&D**

Active Plasma Lens



Passive Plasma Lens



AF6: Contributed Papers & Interest Groups

- Following Community Planning Meeting (Oct 2020), interest groups have formed (or are forming) to create and/or maintain momentum on topical areas in AF6
- Progenitor was the 'Snowmass21 Accelerator & Beam Modeling interest group'
- Descriptions and Points of Contact information can be found in AF6 Wiki.

Plasma and Advanced Structure Accelerators Interest Group (PASAIG)

Coordinators: Eric Esarey (LBNL), John Power (ANL), Vitaly Yakimenko (SLAC), Carl Schroeder (LBNL), Navid Vafaei-Najafabadi (Stony Brook), and Warren Mori (UCLA).

Contact: sign up at https://forms.gle/Th7fTiELbahaQkAM8

Description: The purpose of this interest group is to organize and coordinate community input for the Snowmass process via AF6 (Accelerator Frontier - Advanced Accelerator Concepts) on the topics of plasma-based and advanced structure-based accelerators. This includes accessing the status of current R&D, formulating an R&D strategy that addresses the near, mid and long term plans, reviewing and revisiting the advanced accelerator roadmap, and organizing and coordinating the writing and submission of white papers to Snowmass. This will involve coordination with the Snowmass Frontiers (e.g., Energy Frontier and Theory Frontier) on various topics, such as possible collider options (e.g., gamma-gamma and electron-positron) for very high energies (>10 TeV).

https://aacseminarseries.lbl.gov/pasaig

Theme	Point of contact
Plasma & advanced structures	E. Esarey, J. Power, V. Yakimenko, C. Schroeder, N. Vafei-Najafabadi, W. Mori
Laser driven structures	J. England
Nanostructure/plasma	A. Sahai
GARD beam test facilities	V. Yakimenko
Laser drivers	L. Kiani
BDS/IP issues	S. Gessner
Near term applications	J. van Tilborg & C. Emma
Novel particle sources	M. Fuchs

Note: Several LOI's from the international community have been received for AF6 and the presented plans will be included in the interest groups and contributed papers listed above.

AF Implementation Task Force

- 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* comprises of 12 world-renowned accelerator experts from Asia, Europe and US inc. 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

Thomas Roser (BNL, Chair)

Philippe Lebrun (CERN)

Steve Gourlay (LBNL)

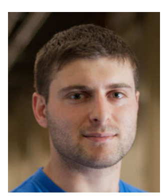
Tor Raubenheimer (SLAC)

Katsunobu Oide (KEK)

Jim Strait (FNAL)

Sarah Cousineau (ORNL)

Marlene Turner (LBNL)



Spencer Gessner (SLAC)

Vladimir Shiltsev (FNAL)

Reinhard Brinkmann (DESY)

John Seeman (SLAC)

Implementation Task Force: Charge and Status

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.

Raubenheimer, FCC Week, June 2021

- ITF continued to meet during the last year
- ITF is focusing on collider facilities. ITF developed a set of metrics to evaluate the proposals and concepts.
- Parameter spreadsheets (21) collected from proponents, and analysis and comparison has started on four topics:
  - Size, complexity, power consumption, environmental impact
  - Physics reach (impact), beam parameters
  - Technical risk, technical readiness, validation
  - Cost, schedule
- Proposal for four categories:
  1. Existing facilities for references (LHC, XFEL, …)**[Existing]**
  2. Proposals with TDR and/or CDR **[CDR/TDR]**
  3. Proposal without TDR or CDR but reasonably well thought through and mostly based on existing technologies. An estimate for component counts exists. **[Concept]**
  4. Future concepts and ideas **[Future concepts]**
- Tentative schedule: draft report by end of 2021 to be shared with proponents; final ITF report by May 2022; Snowmass discussions in Seattle in July 2022;

Collider studies establish accessible parameter sets

- Similar parameter ranges accessible to each technology: coordinated example assembled
  - TeV–class established as part of 2016 AARD report, extended to 15 TeV
  - Potential to re–use infrastructure of near–term LC (e.g. ILC)
  - Next step for AF: integrated design study, self consistent and including tradeoffs

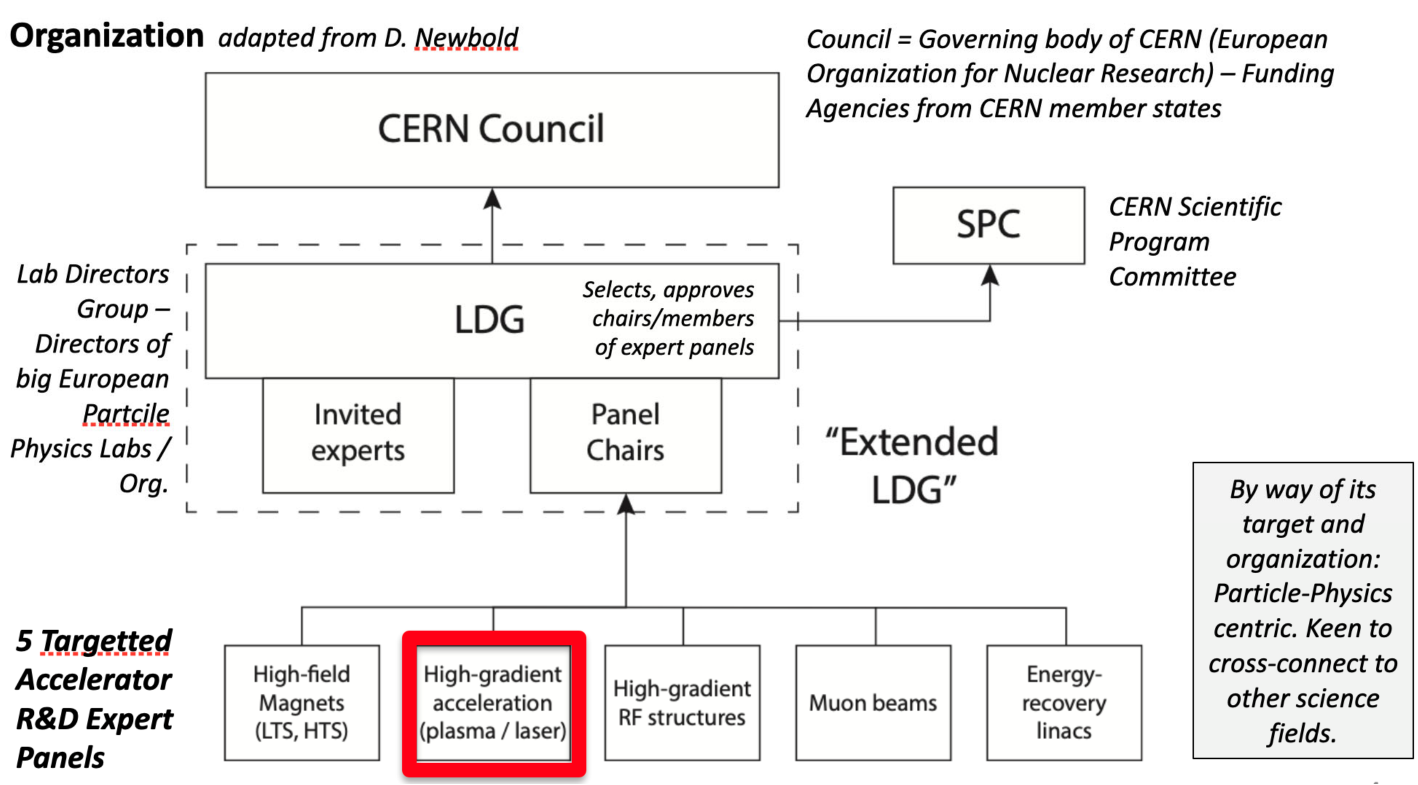
- Sequence of collider options available to the 15 TeV class: polarized e+e– or gamma–gamma
  - New concepts continue to emerge that extend this potential

	Components				Performance Parameters				
Concept	**Accelerator Technology**	**Beam source**	**Interstage Coupling**	**Beam Delivery**	**Effective Gradient**	**Energy**	**Luminosity**	**Efficiency**	**Power (no recovery)**
ILC	SC RF	Damp. Ring	N/A	ILC BDS	31.5 MV/m	0.5 TeV	2.7E34	5%	240 MW
AALC	Plasma or Str.	Damping	Trad. mag.	Trad. BDS	1 GeV/m	1 TeV	1E34	15%	70-100 MW
AALC	Plasma or Str.	Damping	Mag. or Plasma	Trad. BDS	1 or 10 GeV/m	3 TeV	3E34	15%	185-315 MW
AALC	Plasma or Str.	Plas. cath.@nm	Mag. or Plasma	Trad. BDS	1 or 10 GeV/m	3 TeV	1E35	15%	200-315 MW
AALC	Plasma or Str.	Plas. cath.@nm	Plas. lens	Trad. BDS	10 GeV/m	15 TeV	1E35	15%	900-1100 MW
AALC	Plasma or Str.	Plas. cath.@nm	Plas. lens	Plas. lens	10 GeV/m	15 TeV	5E35	15%	900-1100 MW

EF: Particle physics signature analysis needed to guide development, alternatives

International Coordination

- As Snowmass was pausing, the new European effort was ramping up beginning ~ March 2021
- Aggressive timeline with interim report September, final October 2021
- Representation from AF, AF6 to coordinate but there are some differences in time-scales and goals



DOE BESAC report

Executive Summary

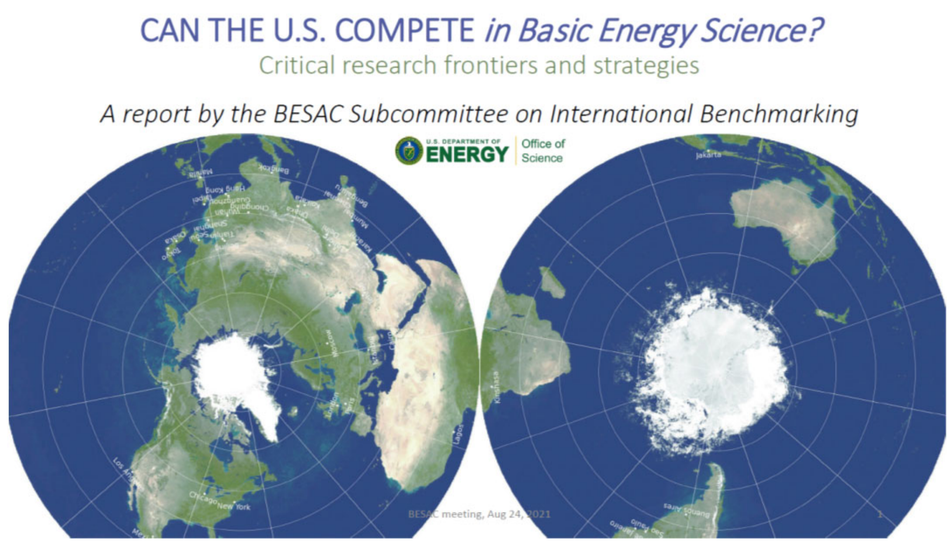
https://physicstoday.scitation.org/do/10.1063/PT.6.2.20210909a/full/

Scientific discovery is a cornerstone of American prosperity

The US has long been the leader in areas of research critical to BES Especially in development of large-scale facilities

Other nations are rapidly catching up and overtaking the US corresponding to rapid growth in research investment by China and EU, along with flattening US investment.

Without continued investment in basic science today, future discoveries and technological innovation will languish



Four Broad Strategies for Success

Increase investment in basic energy sciences research including the development of advanced research facilities and instrumentation.

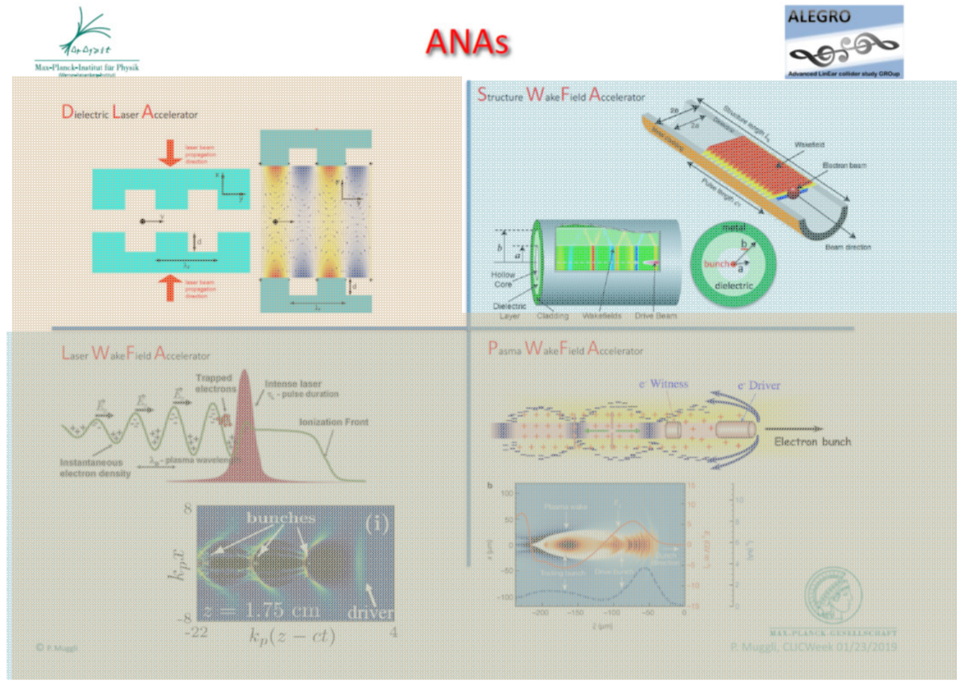
Boost support for early-career and mid-career scientists as to better attract and retain talent.

Enhance opportunities for staff scientists at advanced research facilities to provide for career development and talent retention to unleash their creativity for instrumentation development and facility improvements.

Better integrate energy sciences research across the full spectrum—from basic to applied to industrial research.

Differences between US and international advanced accelerator communities

- Technology approach
- Intermediate applications



June 2021 ESFRI announced that EuPRAXIA included in Research Infrastructure Roadmap 2021 (569 M€) http://www.eupraxia-project.eu

July 2021 LWFA based SASE FEL at 27nm published in ***Nature*** https://www.nature.com/articles/s41586-021-03678-x

PWFA based SASE FEL @INFN/SPARC this conference

Near term applications

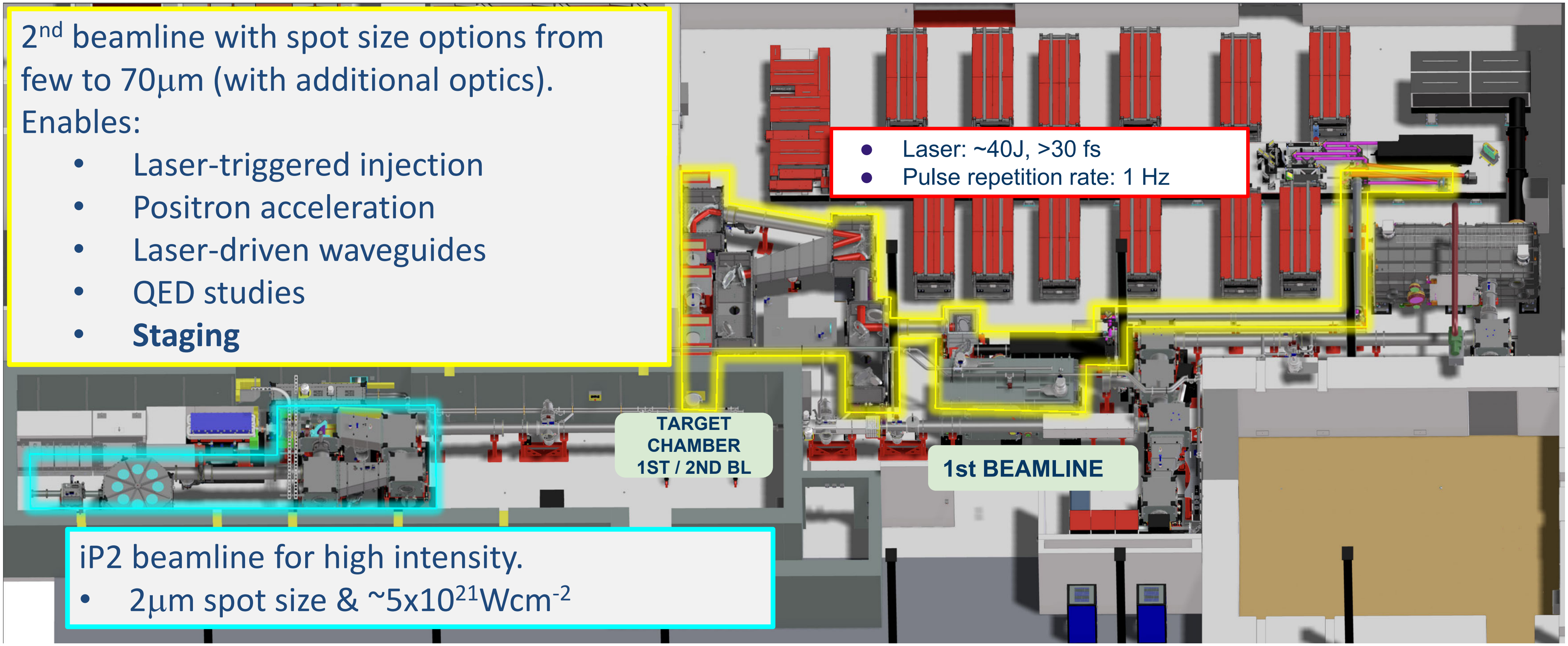
Coordinators: Jeroen van Tilborg (LBNL), Claudio Emma (SLAC)

Contact: Jeroen van Tilborg (LBNL) jvantilborg@lbl.gov, Claudio Emma (SLAC) cemma@slac.stanford.edu

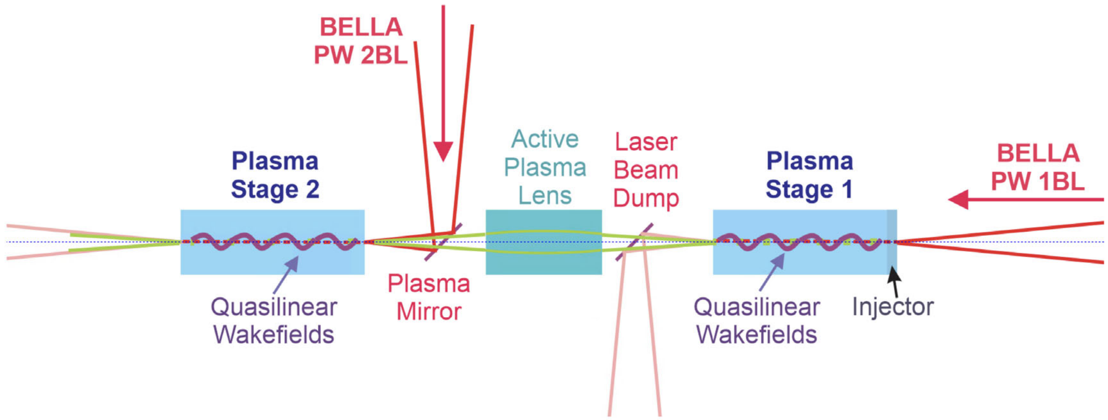
While the long-term vision of the advanced accelerator community is aimed at addressing the challenges of future collider technology, it is critical that the community takes advantage of the opportunity to make large societal impact, while also developing the technology towards future ollider requirements, through near-term applications. The white paper contributions that are solicited here will summarize the near-term applications ideas presented by the advanced accelerator community, assessing their potential impact, discussing scientific and technical readiness of concepts, and providing a timeline for implementation.

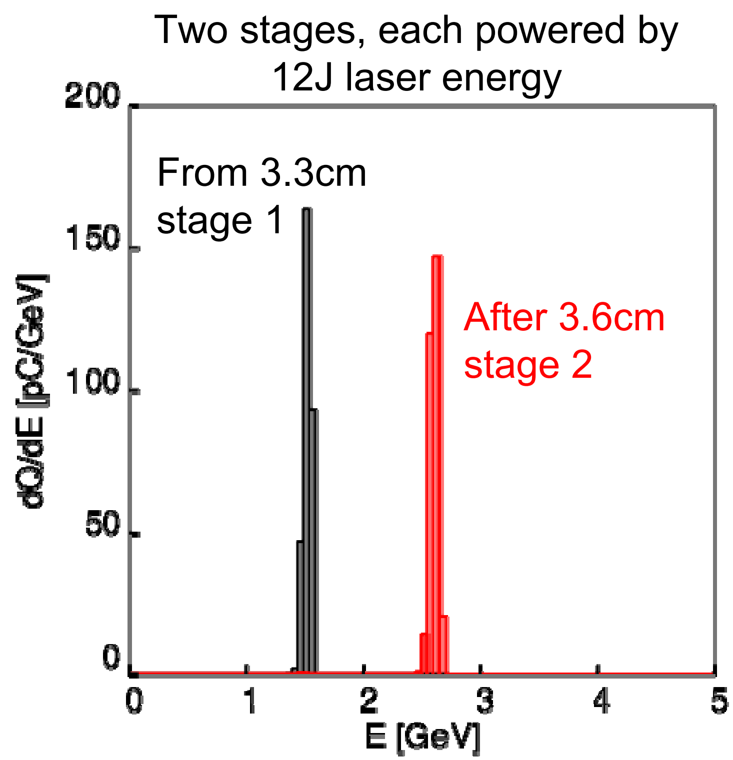
white paper 'Free electron lasers driven by plasma accelerators: status and near-term prospects' published in HPLSE DOI: https://doi.org/10.1017/hpl.2021.39

Two new beamlines to extend science reach of BELLA PW laser are nearing completion



BELLA 2nd beamline expected to allow for staging with high capture efficiency





- First experiments
  - using 24J of the available BELLA PW 40J
  - Simulations show 99% particle capture and GeV energy gain
- Subsequent research
  - ~5GeV stages: increase laser energy and guide over longer lengths for higher energy gain
  - Demonstrate emittance preservation

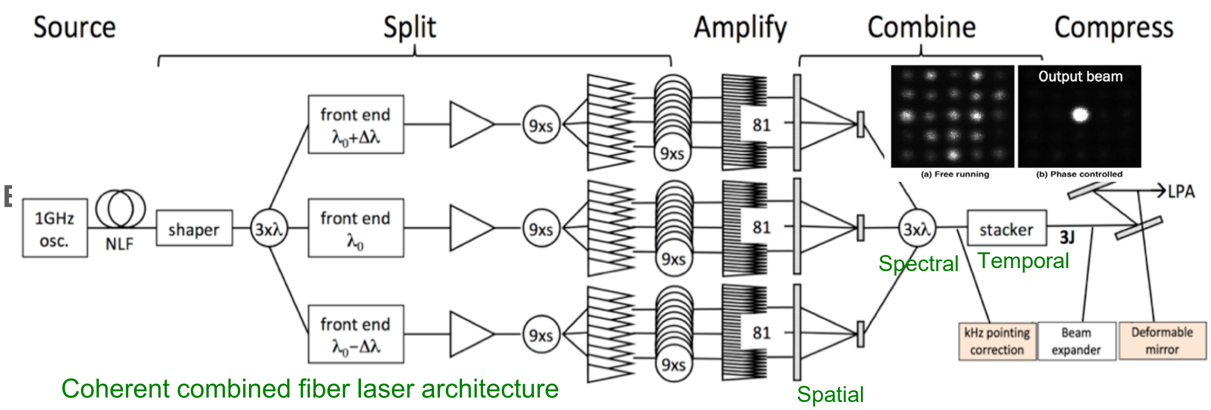
BERKELEY LAB ACCELERATOR TECHNOLOGY & APPLIED PHYSICS DIVISION ATAP BELLA U.S. DEPARTMENT OF ENERGY Office of Science

BELLA center working towards Application Luminosity Needs: Developing High Repetition Rate Lasers

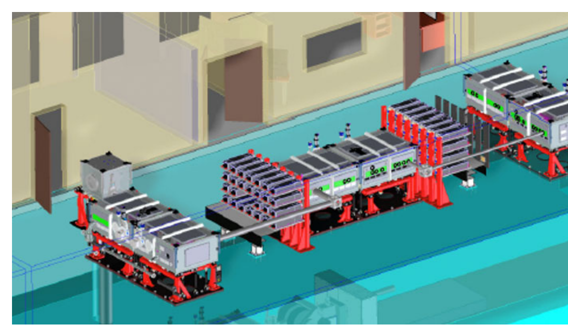
- Explore options towards multi-kHz (sub)PW laser technology
  - Coherent fiber combining (Yb glass fibers)
  - Ti:sapphire architecture
  - Other emerging options (Tm:YLF)
- Near-term from 100s of mJ to multi-Joule driver (GeV-class e-)
- Key step on collider roadmap, and enables photon sources and precision laser-plasma science

- Enables Near-term applications
  - Compact FEL
  - Light sources (betatron X-rays, Thomson-scattering gammas, CTR-based THz generation)
  - Particle sources (protons, ions, positrons)
  - High-field QED

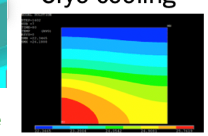
LBNL - LLE - LLNL
MIT-LL and Colorado State discussions



Coherent combined fiber laser architecture



Heat extraction
Cryo cooling



Titanium sapphire high-average power architecture

Conclusions

- Snowmass is restarting !
- All invited to participate to contributed papers and ongoing discussions/workshops etc.
- Looking forward to the Expert Panel report
- AAC Community is well-connected, but muon collider example stands out
- Suggestions on how to make concrete steps towards international case for AAC are welcome !
- Clear opportunities in staging, laser development, positrons, etc.