FACET-II | Facility for Advanced Accelerator Experimental Tests

Plasma Wakefield Acceleration at FACET-II & GARD beam test facilities in the US

21-MAY–2021

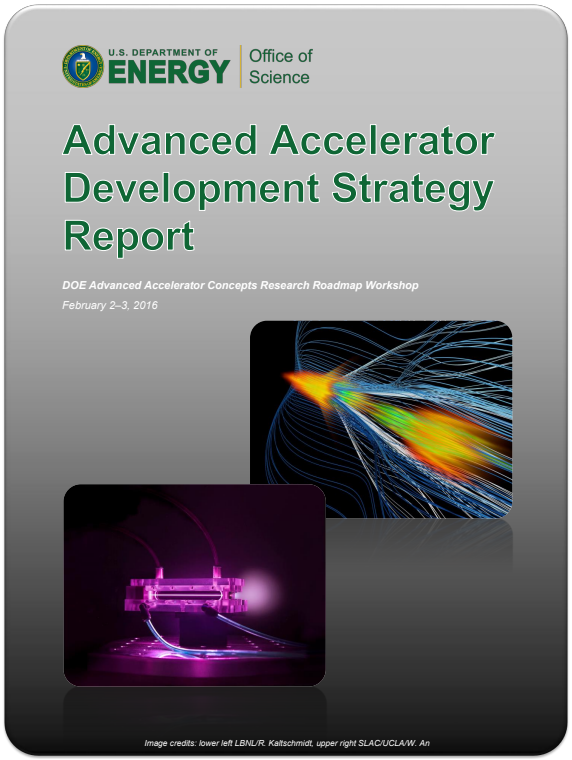
Mark J. Hogan
Senior Staff Scientist
FACET-II Division Director

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Advanced Acceleration Roadmaps Were Defined in 2016

- Following Snowmass 2013 and ensuing HEPAP sub panel community representatives from universities and laboratories organized a series of workshops
- Roadmaps and priorities summarized in the report
- Will be revisited as part of Snowmass ~~2021~~ 2022 (*see Pietro's presentation 1st Townhall*)

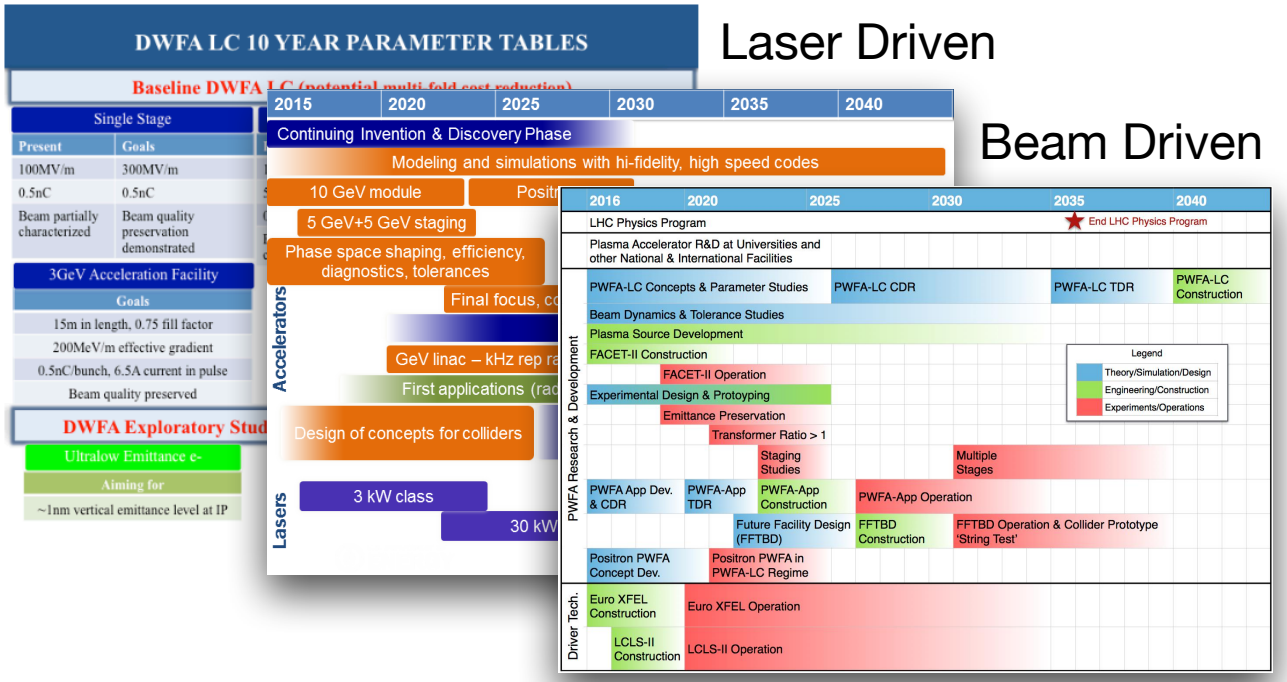


+ RF and Accelerator Beam Physics

Structure Wakefield

Laser Driven

Beam Driven



Roadmaps emphasize need for facilities to test concepts e.g.
AWA: SWFA, BELLA 2nd beamline: LWFA, and FACET-II: PWFA

Five U.S. beam test facilities with complementary and diverse capabilities: ATF@BNL, AWA@ANL, BELLA@LBNL, FACET-II@SLAC, FAST@FNAL

Capabilities:	ATF	AWA	BELLA	FACET-II	FAST
Operation model:					
National User Facility	✓			✓	
Accelerator Stewardship	✓				
Collaboration models		✓	✓		✓
Beams and accelerators:					
~100 MeV electrons	✓	✓			✓
10 GeV electron beams				✓	
10 GeV positron beams				planned	
High charge electron bunches		✓			
Proton beams					planned
NC S-band and X-band	✓			✓	
NC L-Band		✓			
SC L-Band linac					✓
Storage ring					✓
Lasers:					
TW class 0.8 μm laser (Ti:Sapphire)	✓		✓	✓	
PW class 0.8 μm laser (Ti:Sapphire)			✓		
TW class 10 μm laser (CO_2)	✓				
Plasmas:					
Plasma capillaries	✓ (2 cm)	✓ (2 cm)	✓ (10 cm)		
Gas Jets	✓		✓	✓	
Heat pipe oven				✓	
Hollow channel		✓		✓	

2021-2025 Plans

Research goals:	ATF	AWA	BELLA	FACET-II	FAST
Advanced Acceleration Concepts:					
Collider stage		DWFA	LWFA	P&D WFA	
Acceleration of positrons				✓	
Studies of staging		✓	✓		
High brightness beams	✓	✓	✓	✓	
Practical Application of AAC			✓	✓	
Feedback and stable operations with high rep. rate			✓		
Beams Physics:					
Intensity frontier (Integrable Nonlinear Optics)					✓
Cooling R&D		✓			✓
Physics of extreme compression		✓		✓	
SF QED, Single Electron and Cristal-like beams			✓	✓	✓
Technology:					
Stewardship facility (support for industry R&D)	✓				
CO2 laser	✓				
ML/AI to characterize intense bunches, improve efficiency		✓		✓	
High efficiency and rep. rate laser			✓		
Planned key upgrades					
CO2 laser power upgrade (20TW / 0.5ps)	✓				
Energy upgrade to 135 MeV		✓			
Second beam Line and High repetition rate laser (K-BELLA)			✓		
Positrons and Advanced bunch compressor				✓	
Proton beam capability + ILC CM testing?					✓

FACET-II: A National User Facility Based on High-energy Beams and Their Interaction with Plasmas and Lasers

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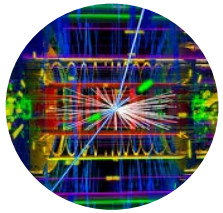
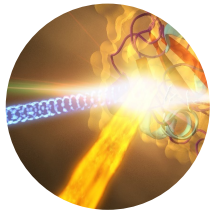
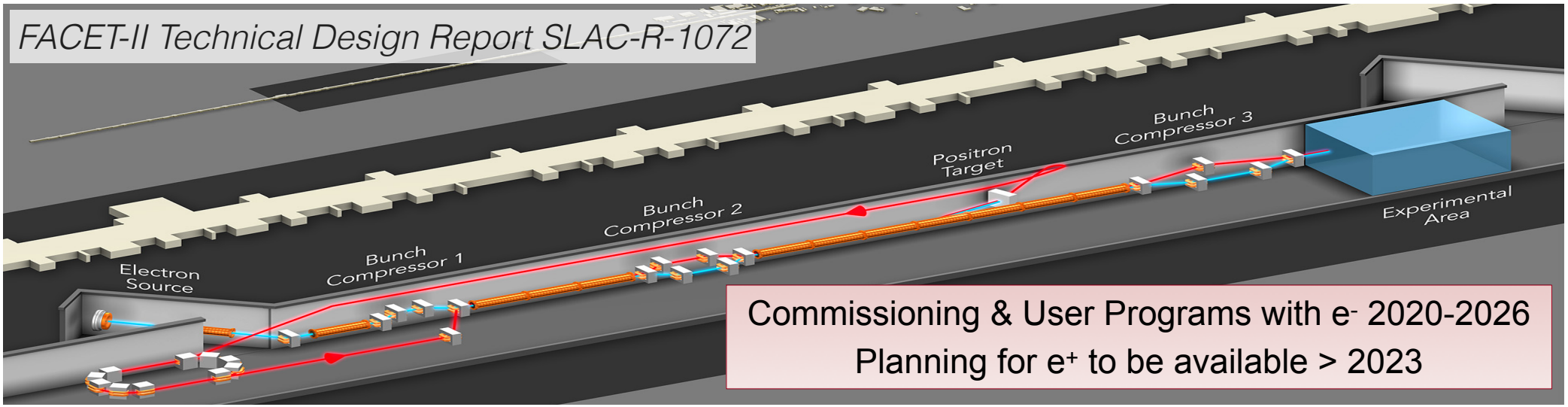


Advance the energy frontier for future colliders



Develop brighter X-rays for photon science



FACET-II: A National User Facility Based on High-energy Beams and Their Interaction with Plasmas and Lasers

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2nd Townhall Meeting High Gradient Accelerator Plasma/Laser

Friday 21 May 2021, 09:00 → 18:00 Europe/Zurich

09:55 **Optical probe of energy dissipation from e-beam driven plasma wakes**
Speaker: Zgadzaj Rafal

10:10 **Strong electron beam focusing with passive, underdense plasma lenses**
Speaker: Christopher Doss (University of Colorado Boulder)

14:30 **Ligh-source applications of advanced accelerators**
Speaker: Claudio Emma

14:45 **Exploring the fully no-perturbative regime of QED at a Future Linear Collider**
Speaker: Sebastien Meuren

15:00 **Towards an integrated design study for a Plasma Linear Collider / Positron plasma wakefield acceleration research at FACET-II** 10m
Speaker: Spencer gessner

→ Repetition Rate
#2: 6; #3: 7

→ Focussing
#2: 4,5,7,8

→ Intermediate Applications
#2: 9; #3: 5,6

→ Alternative Concepts
#2: 4,5,7; #3: 5,9

→ Collider Design & Positrons
#2: all; #3: 2,9

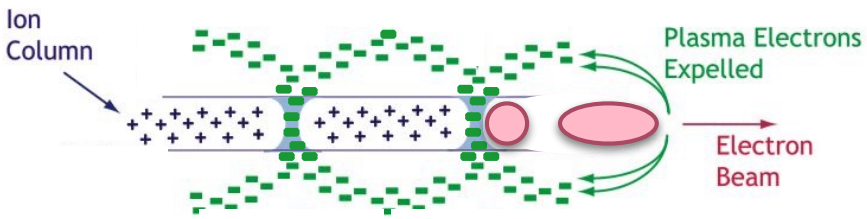
3rd Townhall Meeting (May 31st)

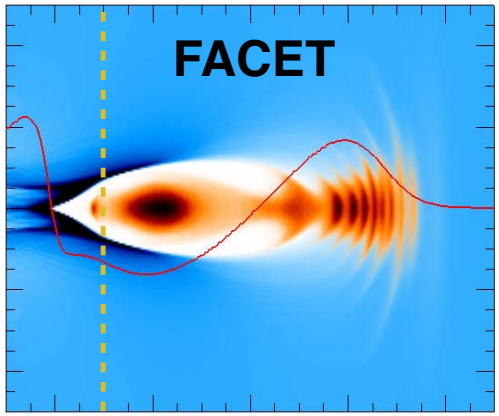
Plasma photocathode HEP R&D
Speaker: Fahim Habib

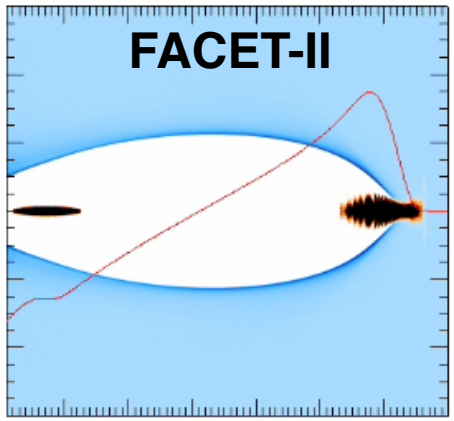
→ Low Emittance Sources
#2: 2; #3: 5,6

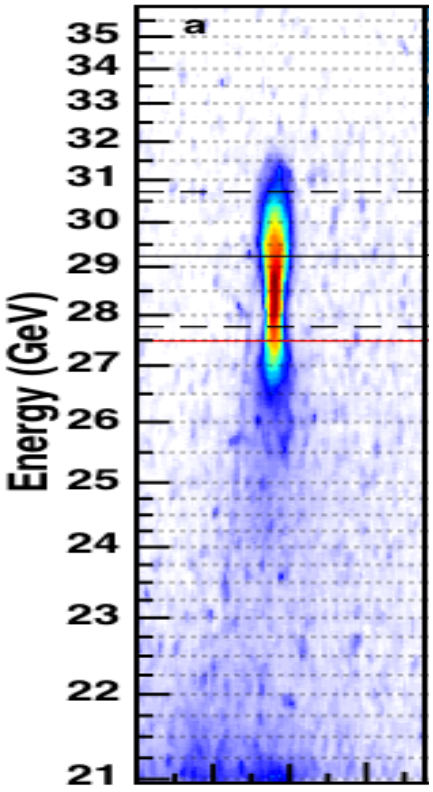
Planning for e^+ to be available > 2023

Beam Driven Plasma Wakefield Acceleration: Experiments @ FACET-II









Demonstrated @ FACET

Gradient:
- >100GeV/m (*Nature Communications 2016*)

Energy Gain & Energy Spread:
- 9GeV with 2% (*PPCF 2015*)

Efficiency:
- 30% instantaneous (*Nature 2014*)

Normalized Emittance:
- 100 mm-mrad

Proposed @ FACET-II

Gradient:
- >10GeV/m

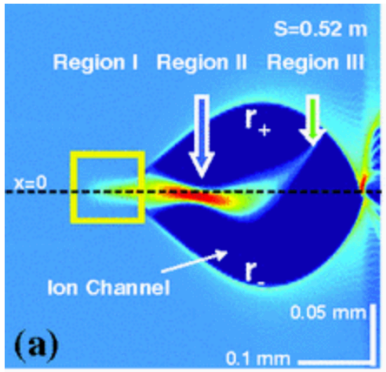
Energy Gain & Energy Spread:
- 10GeV with < 1%

Efficiency:
- 30% overall

Normalized Emittance:
- < 10 mm-mrad

Narrow energy spread acceleration with high-efficiency has been demonstrated
FACET-II experiments will focus on simultaneously preserving beam emittance

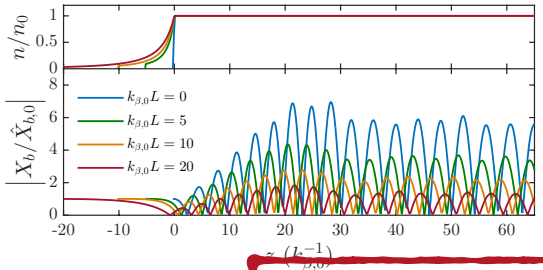
Need to answer the question: Is it possible to strongly load the longitudinal wake without strong transverse wakes and BBU?



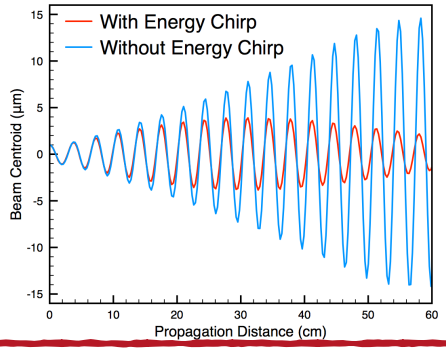
Various mechanisms of emittance growth and mitigation have been studied theoretically and numerically:

D. Whittum et al. PRL 67, 991 (1991) **LBNL/SLAC**
J. Rosenzweig et al., 95, 195002 (2005) **UCLA**
C. Huang et al., PRL 99, 255001 (2007) **UCLA**
V. Lebedev et al., PRAB 20, 121301 (2017) **FNAL**
T. Mehrling et. al., PRL 118, 174801 (2017) **DESY/IST**
W. An et al. PRL 118, 244801 (2017) **UCLA**
C. Benedetti et al., PRAB 20, 111301 (2017) **LBNL**
T. Mehrling et. al., PRL 121, 264802 (2018) **LBNL**
A. Burov et al., arXiv:1808.03860 **FNAL**

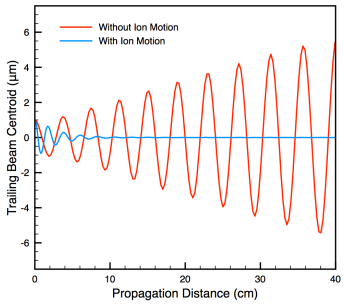
Plamsa ramps



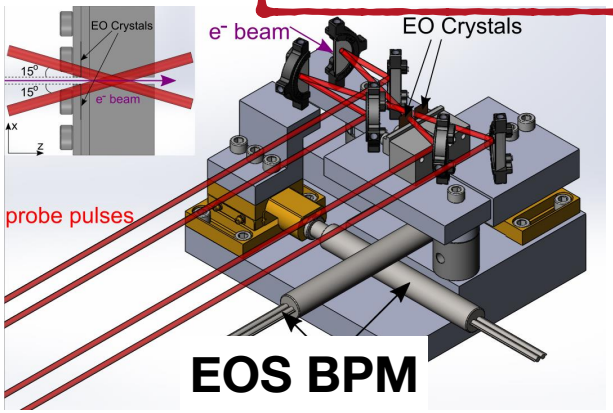
Energy Spread



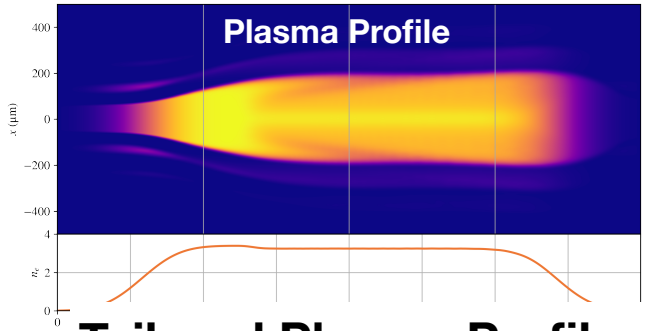
Ion Motion



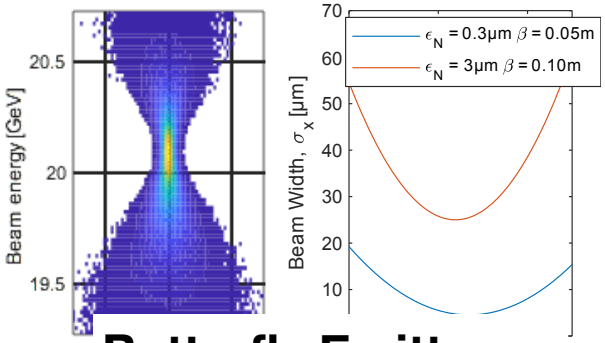
Benchmarking models and testing mitigations requires a new generation of beam diagnostics and plasma targets



EOS BPM



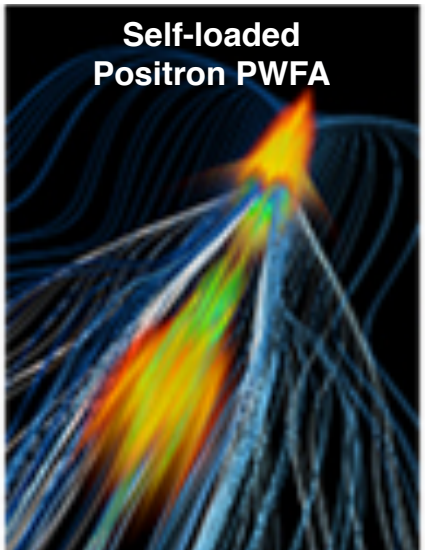
Tailored Plasma Profiles

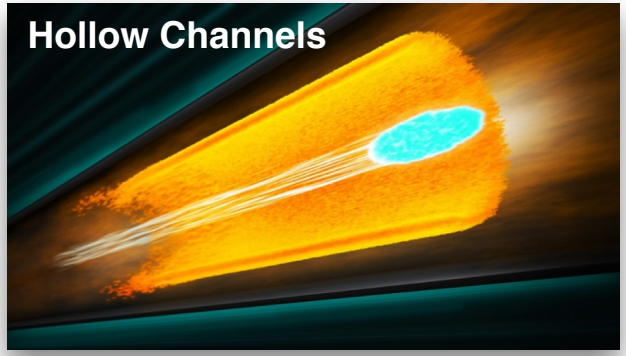


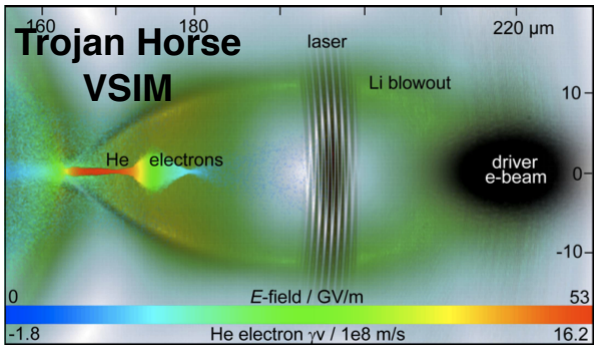
Butterfly Emittance

Computation is an Essential Component of PWFA Science

- Suite of codes (especially QuickPIC, OSIRIS) have been benchmarked against experiments at SLAC for the last 20 years
- Provide capabilities to model next generation experiments at FACET-II
- Strong connection between theory, computation and experiment – every major result benefited from strong collaborations

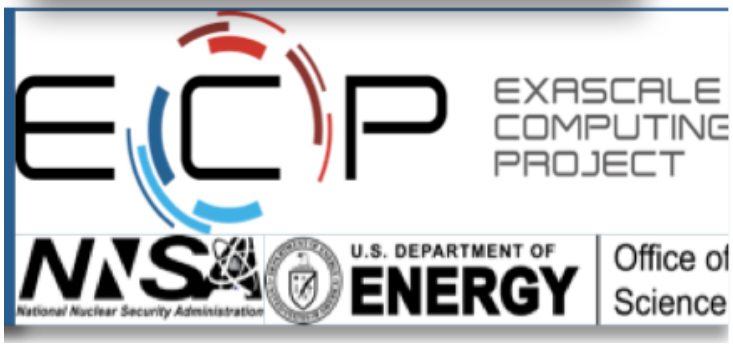


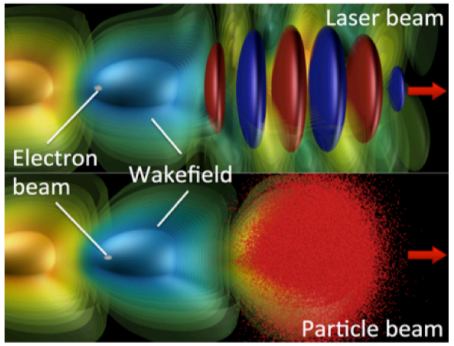




Exascale Computing to Support Detailed Collider Design

- LBNL-SLAC-LLNL collaboration
- Ultimate goal to model 100 stages for TeV collider design by 2025





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- Provide capabilities to model next generation experiments at FACET-II
- Strong connection between theory, computation

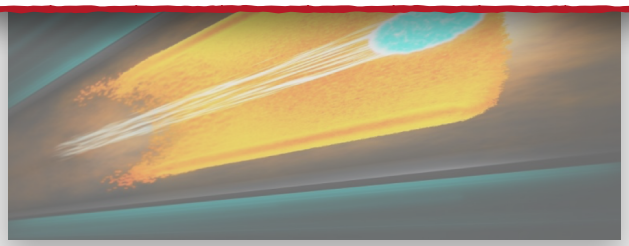
3rd Townhall Meeting (May 31st)

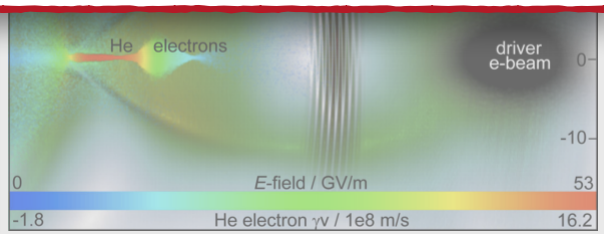
Open-source simulation ecosystem for laptop to Exascale modeling of high-gradient accelerators
Speaker: JL Vay

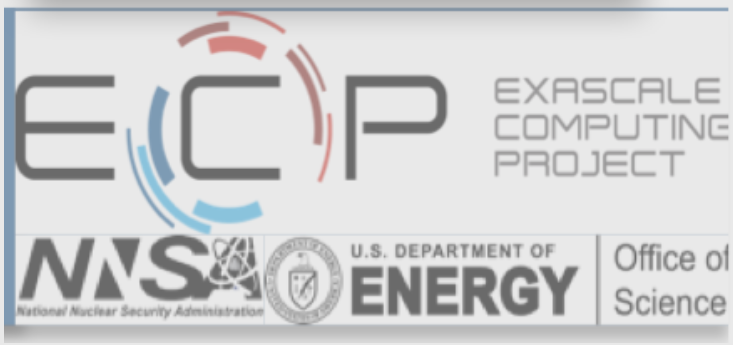
→ Simulation Development #3: 4,9

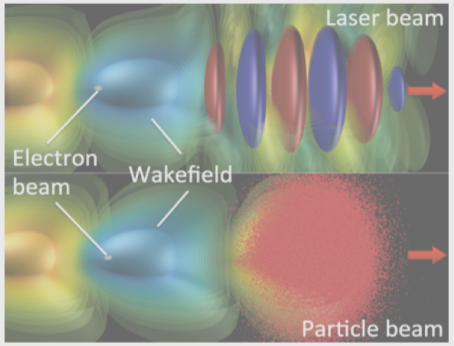
Detailed Collider Design

- LBNL-SLAC-LLNL collaboration
- Ultimate goal to model 100 stages for TeV collider design by 2025









Questions for the Community – Part 1

SLAC

1) Where do you see HEP applications of advanced accelerators in 30 years?

- If ILC or Higgs Factory, offer a path towards an energy upgrade. If no ILC, propose green-field collider concepts
- If CEPC, FCC, pursue concepts for injectors

2) What intermediate physics applications/steps do you see until a HEP linear collider?

- Light sources with new capabilities, e.g. shorter attosecond pulses, higher peak power, harder photons…

3) What is the synergy with related fields?

- Beam physics, tolerances etc common to many colliders (traditional & advanced)
- Plasma sources, diagnostics, simulations, positrons – LWFA/PWFA, Beam shaping for optimal loading – SWFA/PWFA

4) What is the role of your work here?

- Develop new concepts, provide facilities/capabilities to the community to test new ideas and perform critical path R&D towards a collider and other applications

Questions for the Community – Part 2

SLAC

1) What are the important milestones for the next 10 years to get there from today?

- Beam quality (with gradient, efficiency etc), understand tolerances and mitigations needed for stability, design for staging that scales well to > TeV, integrated design study, credible concept for e+ acceleration on par with e- developed and tested

2) What additional support is needed to achieve these?

- $$$: Upgrades and/or new facilities
- Mandate, funding $$, and the community will to pursue integrated design(s)

3) What should be proposed as deliverables until 2026? Please list in order of priority.

- See (1) and comment below

4) Is the R&D work for each of those deliverables already funded and, if not, what additional resources / support would be needed?

- Concepts need to be tested and demonstrated. It takes 5 years to realize a new facility so need to develop concepts for what comes next while we execute on goals for next five years

Questions for the Community – Part 3

SLAC

1) What key R&D needs can be achieved in existing R&D facilities?

- Most of what is described in 'Part 2' except staging, positrons

2) What is the role of the already planned future facilities in Europe and world-wide?

- Depends on what is realized for EuPRAXIA. FLASHForward, AWAKE, FACET-II are going with planned upgrades but not aware of large new facilities – yet.

3) What can be done with the existing and planned funding base?

- A lot but like HEP we are victims of our own success. Answering some questions, especially demonstrations closer to operational collider or light source parameters requires more complex and expensive facilities

4) Is a completely new facility needed?

- Yes, but optimized design (scope, cost, schedule) is still needed

5) Are additional structures needed beyond existing networks and projects, e.g. a design study for a collider or an advanced accelerator stage?

- Yes – see comments earlier and talk by Spencer Gessner (today 15:00)

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Questions?

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