

Advanced Accelerator Concepts: Plasma accelerators

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ACCELERATOR TECHNOLOGY &
APPLIED PHYSICS DIVISION



U.S. DEPARTMENT OF
ENERGY

Office of
Science

AF6: Advanced Accelerator Concepts (AAC) community is addressing the path to future plasma-based collider

September AF6 workshop: organized/discussed LOIs (<https://indico.fnal.gov/event/45651/>)

Test Facilities & Community
Convener: Mark Hogan (SLAC)

- 12:30 PM 96: GARD Beam Test Facility
Speaker: Vitaly Yakimenko (SLAC)
- 12:40 PM 141: EuPRAXIA – A Conceptual First user Applications
Speaker: Dr Massimo Ferrario (CERN)
- 12:50 PM 248: Plasma Accelerator Simulation
Speaker: Prof. Alec Thomas (University of Michigan)
- 12:55 PM 214: Laser-Plasma Acceleration
Speaker: Dr Eric Esarey (LBL)
- 1:00 PM 176: Development of LWIR-Generation of Colliders
Speaker: Prof. Navid Vafaei-Najafabadi (Stony Brook University)
- 1:05 PM 154: The ZEUS high intensity laser user facility for research into laser driven acceleration
Speaker: Prof. Karl Krushelnick (University of Michigan)
- 1:10 PM 43: Research and Educational Opportunities at the Argonne Wakefield Accelerator Facility
Speaker: John Power (Argonne National Lab)
- 1:15 PM 156: Exploiting Global Accelerator Network Synergies
Speaker: Dr Jia (SLAC)
- 1:20 PM Discussion

Near Term Applications
Convener: Pietro Musumeci (UCLA)

- 11:15 AM 200: Compact photon sources based on laser-plasma accelerators
Speaker: Jeroen van Tilborg (BNL)
- 11:25 AM 97: High-Intensity Laser-Driven Accelerators
Speaker: Dr Jia (SLAC)
- 11:30 AM 47: Transport and Storage of High-Intensity Beams
Speaker: Dr Jia (SLAC)
- 11:35 AM 28: Ion-Driven Accelerators
Speaker: Dr Jia (SLAC)

Laser Drivers
Convener: Mark Hogan (SLAC)

- 10:45 AM 221: High average power ultrafast laser technologies for driving future advanced accelerators
Speaker: Dr Jia (SLAC)

Beam Manipulation
Convener: Pietro Musumeci (UCLA)

- 10:55 AM 11: Underdense Thin Plasma Lens as a Tool for Future Colliders
Speaker: Dr Jia (SLAC)

Wakefield Acceleration
Convener: Mark Hogan (SLAC)

- 8:35 AM 251: Electron Beam Driven Plasma Wakefield Acceleration (PWFA)
Speaker: Prof. Chan Joshi (UCLA)
- 8:45 AM 68: Proton driven Wakefield Acceleration
Speaker: Dr Paul Scherf (Statholyde)
- 8:50 AM 197: Near-term applications of laser-plasma accelerators
Speaker: Dr Tom (SLAC)
- 8:55 AM 198: Plasma-based particle colliders
Speaker: Dr Tom (SLAC)
- 9:00 AM 42: SWFA driven accelerators
Speaker: Dr Jia (SLAC)
- 9:05 AM 44: Short-pulse large-scale multiparticle acceleration
Speaker: Dr Jia (SLAC)
- 9:10 AM 90: Structure of high-intensity laser-plasma accelerators
Speaker: Dr Ch (SLAC)

Interaction Point
Convener: Cameron Geddes (BNL)

- 2:30 PM Particle Colliders with Ultra-Short Bunches
Speaker: Vitaly Yakimenko (SLAC)
- 2:35 PM The impact of high-field physics on plasma-based particle colliders
Speaker: Stepan Bulanov (BNL)
- 2:40 PM Accelerator phase space-control using high-intensity lasers
Speaker: Prof. Alec Thomas (University of Michigan)
- 2:45 PM A Bright Beam-Filamentation Driven Gamma-ray Source
Speaker: Dr Frederico Filza (SLAC)
- 2:50 PM Monochromatization of e+e- colliders with a large crossing angle
Speaker: Prof. Valery Telnov (Budker INP)
- 2:55 PM Gamma-gamma collider with Wyy s12GeV based on the 17.5 GeV SC linac of the European XFEL
Speaker: Valery Telnov (Budker INP)

Particle Sources
Convener: Cameron Geddes (BNL)

- 1:30 PM Laser-driven injectors for future colliders
Speaker: Dr Matthias Fuchs (BNL)
- 1:35 PM High-Brightness Laser-Plasma-Based Injectors
Speaker: Dr Carlo Benedetti (BNL)
- 1:40 PM The Path to Compact, High-Intensity Beams
Speaker: Daniel Winklehner (Massachusetts Institute of Technology)
- 1:45 PM High brightness injectors based on PWFA
Speaker: Dr Paul Scherf (Statholyde)
- 1:50 PM Polarized target production
Speaker: Dr Ma (SLAC)
- 1:55 PM Compact laser-driven accelerators
Speaker: Stepan Bulanov (BNL)
- 2:00 PM Advanced ion sources
Speaker: Chris (SLAC)

Computation & Control
Convener: Pietro Musumeci (UCLA)

- 12:00 PM 218: Computational modeling needs of plasma-based accelerators towards future colliders; 82: Consortium for PIC Software in Accelerator Science
Speaker: Prof. Warren Mori (UCLA)
- 12:10 PM 99: Modeling of structured plasmas for next generation accelerators
Speaker: Nathan Cook (RadiSoft)
- 12:15 PM 165: Machine Learning Meets the Challenges of HEP Research and Development
Speaker: Brendan O'Shea (SLAC National Laboratory)
- 12:20 PM 197: Adaptive control systems, precision RF and machine learning for accelerators; 208: High precision RF control for next generation accelerator; 75 Machine learning and surrogate models for simulation-based optimization of accelerator design
Speaker: Filippo Lehe (SLAC)
- 12:25 PM 131: Comprehensive Single-shot Diagnostics for Quantifying LWFA Beam Quality
Speaker: Alex Lumpkin (Fermilab)

New Acceleration Concepts
Convener: Pietro Musumeci (UCLA)

- 11:00 AM 49: Dielectric Laser Acceleration
Speaker: Joel England (SLAC)
- 11:10 AM 5: Ultimate Acceleration in Crystals and Nanostructures
Speaker: Snowmass21_Cryst...
- 11:15 AM 6: Nanostructure Accelerators: Novel concept and path to its realization
Speaker: Akash Sahal (University of Colorado)
- 11:20 AM 78: Photonic Crystal (PhC)-based Dielectric Laser Accelerator
Speaker: LDI_talk_Torrisi.pptx
- 11:25 AM 196: Laser-driven acceleration mediated by metallic nanostructures
Speaker: Daniele Filippetto (Lawrence Berkeley National Lab)

Collider Concepts
Convener: Dr Cameron Geddes (BNL)

- 8:30 AM ALEGRO LOI for Snowmass2021 Towards an Advanced Linear International Collider
Speaker: Dr Brigitte Cros (CNRS)
- 8:40 AM Laser-Plasma Accelerator Linear Collider
Speaker: Carl Schroeder (Lawrence Berkeley National Laboratory)
- 8:50 AM Path towards a Beam-Driven Plasma Linear Collider
Speaker: Spencer Gessner (SLAC)
- 9:00 AM Argonne Flexible Linear Collider (AFLC) – Beyond Concept: A 3-TeV Linear Collider Using Short rf Pulse (~20 ns) Two-Beam Accelerator
Speaker: Dr Chunguang Jing (ANL)
- 9:10 AM Optical Energy Recovery for a High Duty Cycle Gamma Ray Source
Speaker: Alex Murokh (Radiation Technologies, LLC)
- 9:15 AM High energy physics applications of the AWAKE acceleration scheme
Speaker: Dr Matthew Wing (CERN)
- 9:20 AM Beamdump Experiments Driven by a Plasma Wakefield Accelerator
Speaker: Spencer Gessner (SLAC)
- 9:25 AM Strategy Towards Ultimate Limits
Speaker: Frank Zimmermann (CERN)

Presentations related to this one @ CPM:

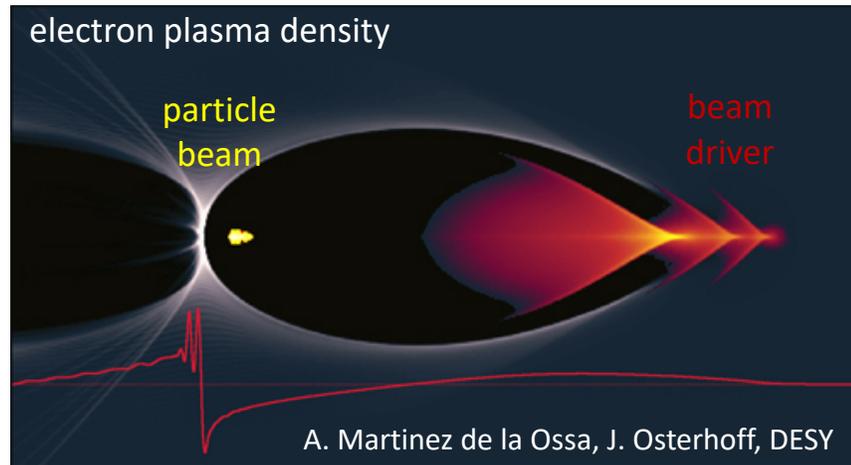
C. B. Schroeder, "Energy and power limits of plasma accelerators", Session 182

S. Gessner, "Machine Option", Session 183

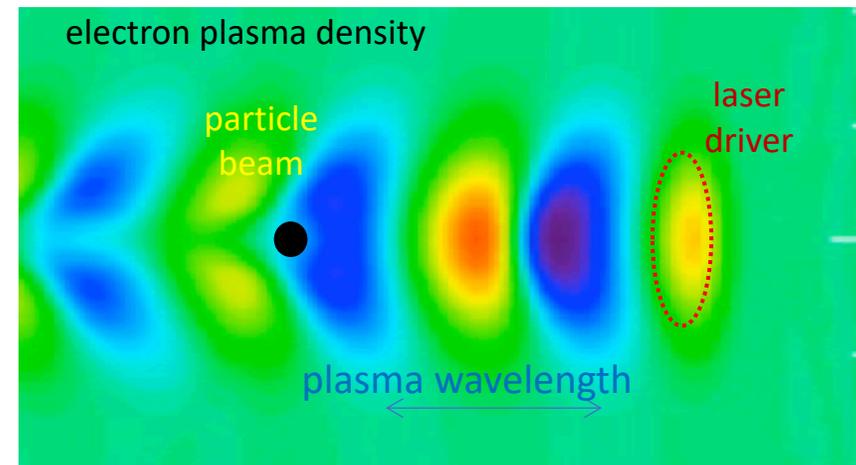
Plasma accelerators driven by intense particle beams or lasers achieve ultra-high accelerating gradients

- Plasma wave (wakefield) driven by space charge of particle beam or ponderomotive force of laser
- Focusing and acceleration provided by plasma wave
- Characteristic size of the electric field (depends on density): $10 - 100 \text{ GV/m}$ for $10^{16} - 10^{19} \text{ cm}^{-3}$
- Short witness beam (a fraction of the plasma wave): $\lesssim 100 - \lesssim 5 \text{ }\mu\text{m}$ for $10^{16} - 10^{19} \text{ cm}^{-3}$

Beam-driven plasma accelerator
(in nonlinear bubble/blow-out regime)



Laser-driven plasma accelerator
(in quasi-linear regime)

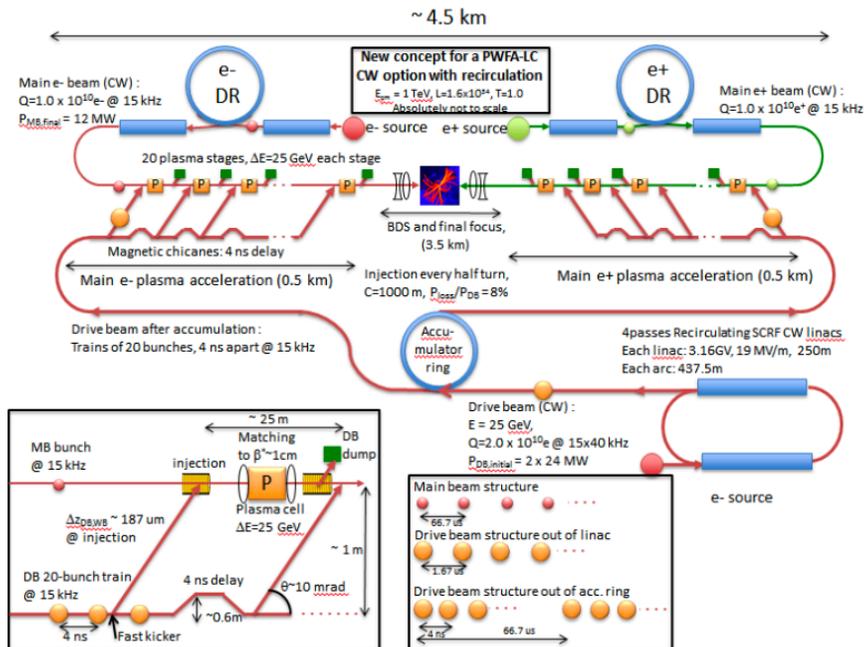


Plasma-based collider: staged plasma accelerators with >1 GV/m geometric gradients

- Preliminary designs (not integrated design studies) to outline a plasma collider and used to guide R&D

Beam-driven plasma accelerators (PWFA)

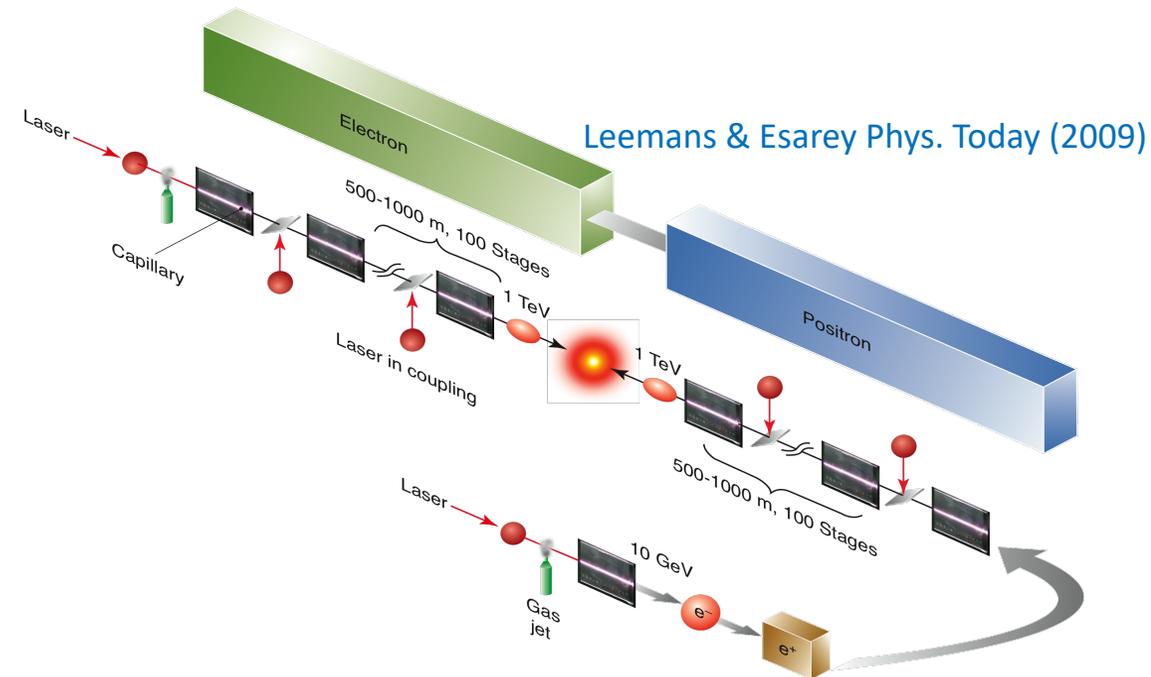
Figure 1: Layout of a 1 TeV PWFA Linear Collider



E. Adli et al., arXiv:1308.1145 (2013)

- Operating plasma density: 2×10^{16} cm⁻³
- 25 GeV/stage
- Geometric gradient: 1 GV/m

Laser-driven plasma accelerators (LWFA)

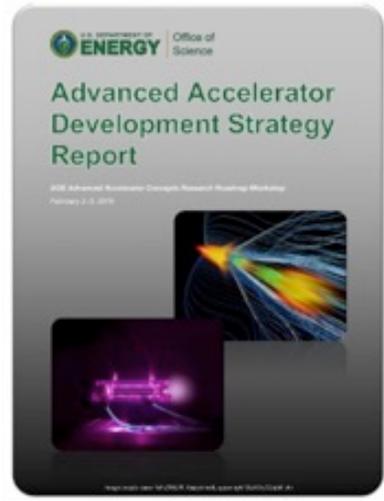


C. Schroeder et al., NIMA (2016)

- Operating plasma density: 1×10^{17} cm⁻³
- 5 GeV/stage
- Geometric gradient: 2.3 GV/m

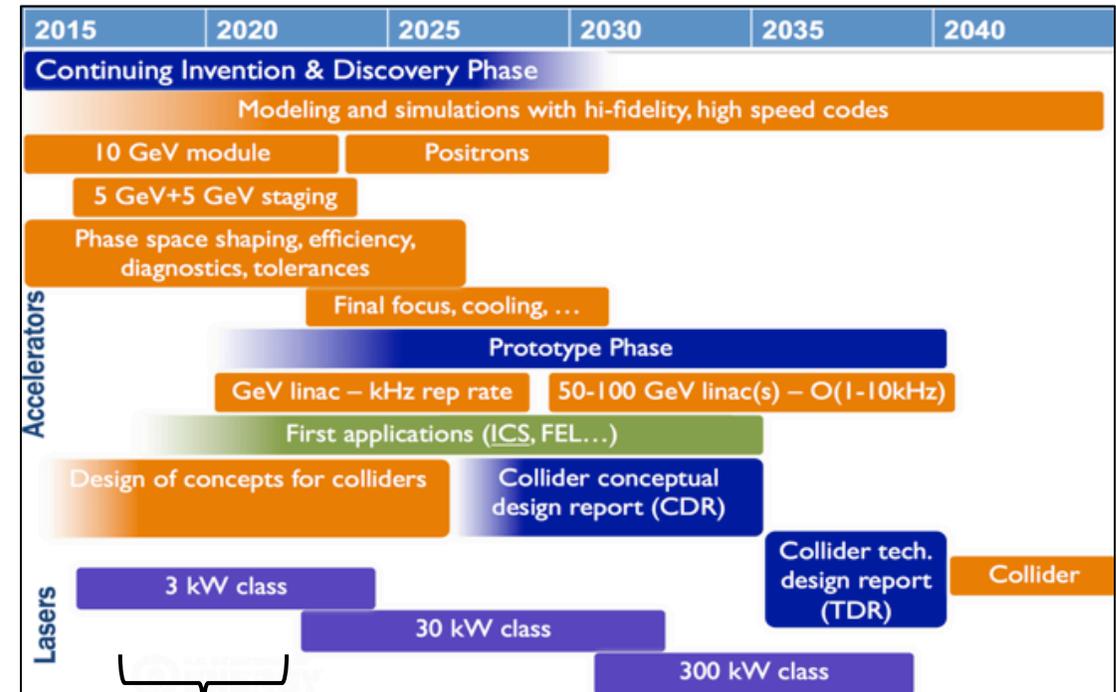
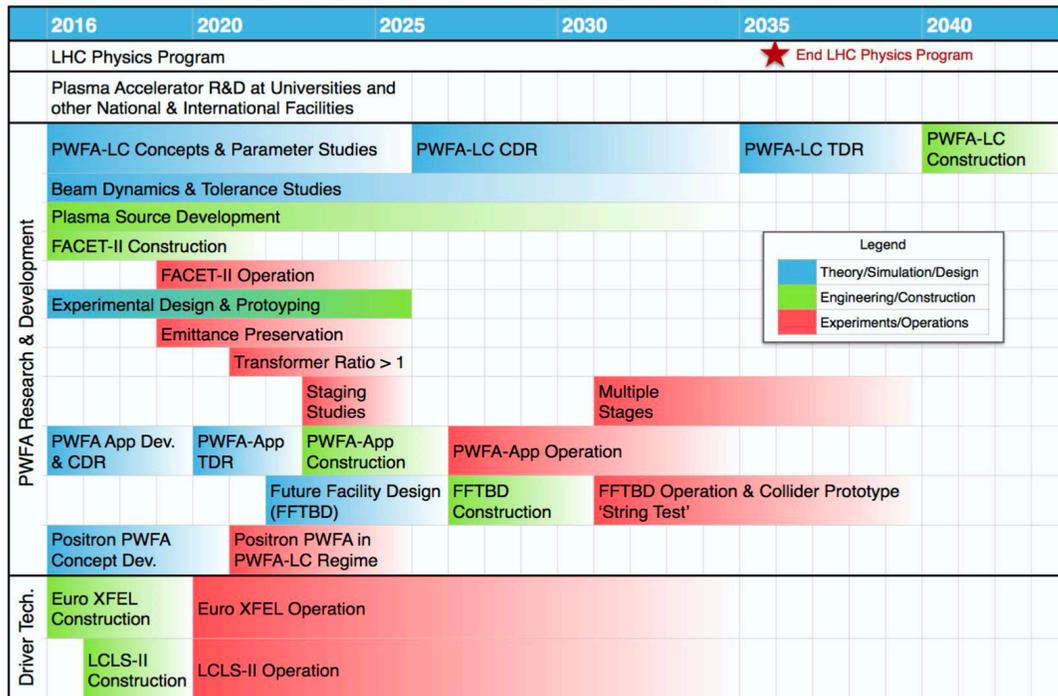
DOE AAC Roadmap: R&D timeline towards a collider

- US AAC community outlined AAC R&D goals in 2016
- Significant and steady progress on all R&D goals since 2016



DOE HEP AAC Roadmap (2016)

Beam Driven Plasma Accelerator Roadmap for HEP



Status and technical readiness

- Plasma accelerators
 - High geometric gradient accelerators: $>1\text{GV/m}$
 - e-/e+/gamma linear collider at multi-TeV, with much reduced footprint
 - Short beams in plasma accelerators yield reduced power costs: $L/P \sim 1/\sigma^{1/2}$
- High gradient accelerator technology has been demonstrated
 - key R&D challenges remain to be addressed for collider application: staging, beam quality-preservation, efficiency/stability, driver development, etc.
- Concepts require integrated collider design
 - Preliminary designs developed to guide accelerator R&D
 - Integrated design studies required
 - Integration of all collider sub-systems
 - Plasma-based upgrades to existing or future RF-based facilities (e.g., ILC)
- Advancing accelerator R&D in next decade toward collider requires sustained support and new/upgraded facilities:
 - kBELLA – high-rep rate (kHz) laser system; laser tech development for colliders
 - FACET-II upgrade -- positron capability
- Nearer-term applications (compact x-FEL, γ -ray sources, medical applications, etc.) are being pursued
 - Nearer-term applications are important demonstrations that will advance collider R&D