FACET-II | Facility for Advanced Accelerator Experimental Tests

Plans for Positron Acceleration

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U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

PWFA Experimental Program at FACET-II is Motivated by Roadmap for Future Colliders Based on Advanced Accelerators

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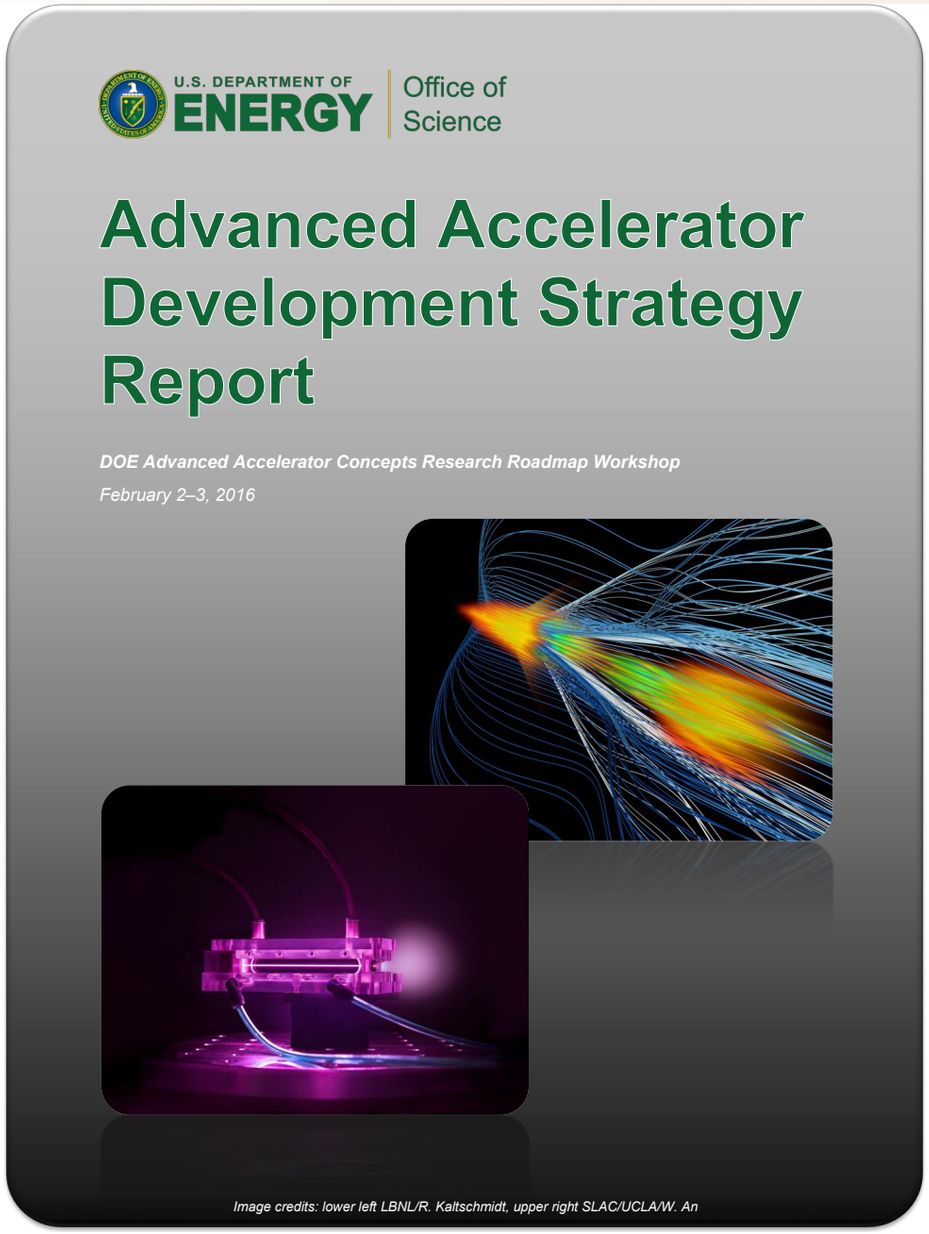
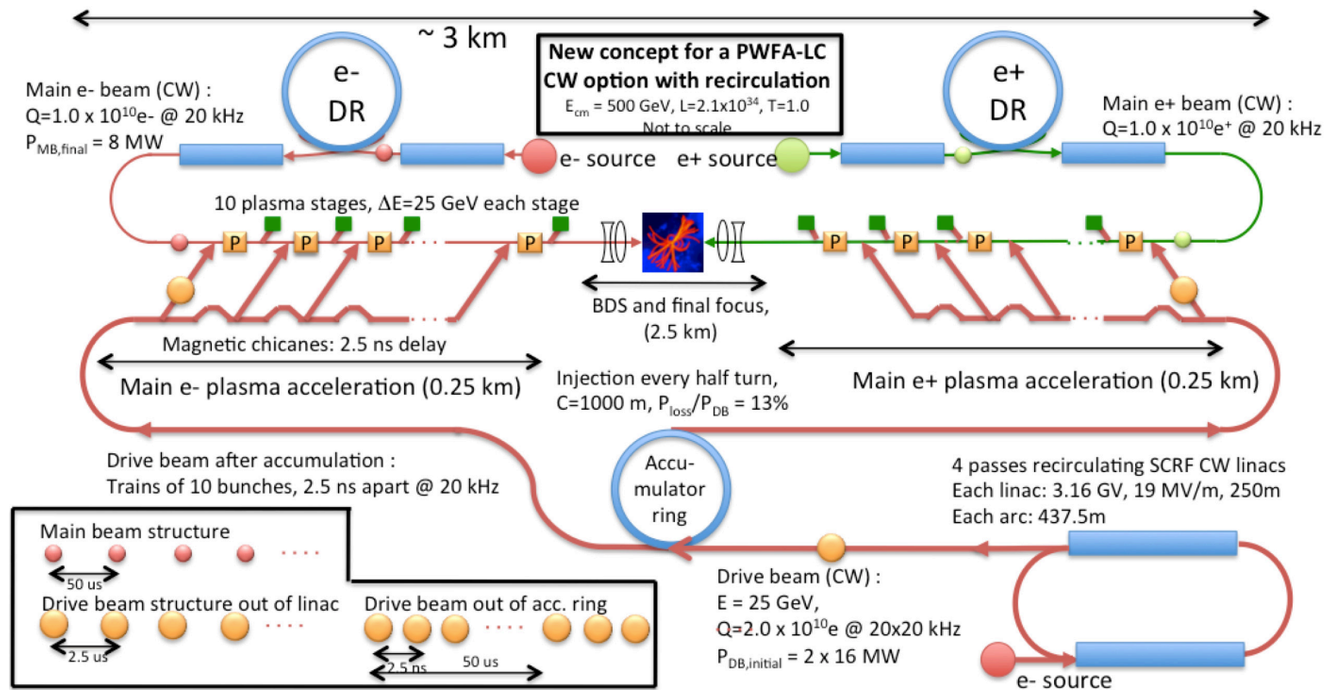


http://science.energy.gov/~/media/hep/pdf/accelerator-rd-stewardship/Advanced_Accelerator_Development_Strategy_Report.pdf

A Conceptual PWFA-LC



E. Adli et al., ArXiv 1308.1145
J. P. Delahaye et al., Proceedings of IPAC2014

- Collider concepts assume high degree of symmetry between electron and positrons
- This is not a good assumption
- Planning for FACET-II to offer ability to test concepts in collider relevant regimes

Extending Plasma Acceleration to Positrons is Not Trivial

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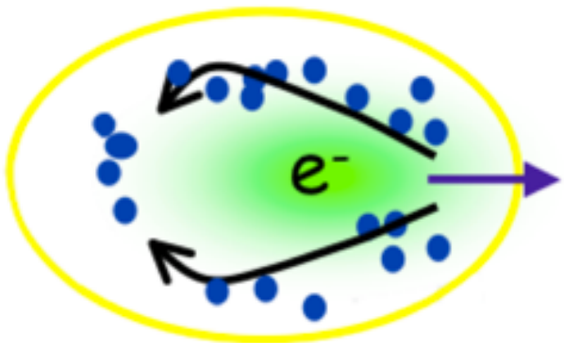
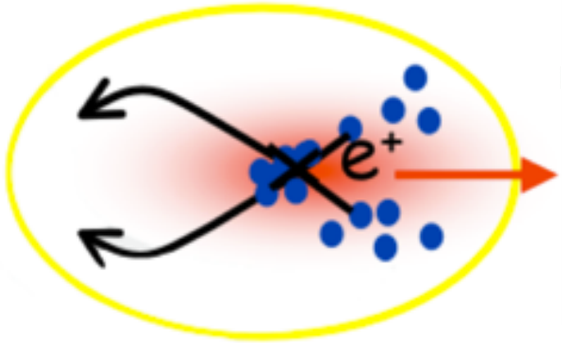
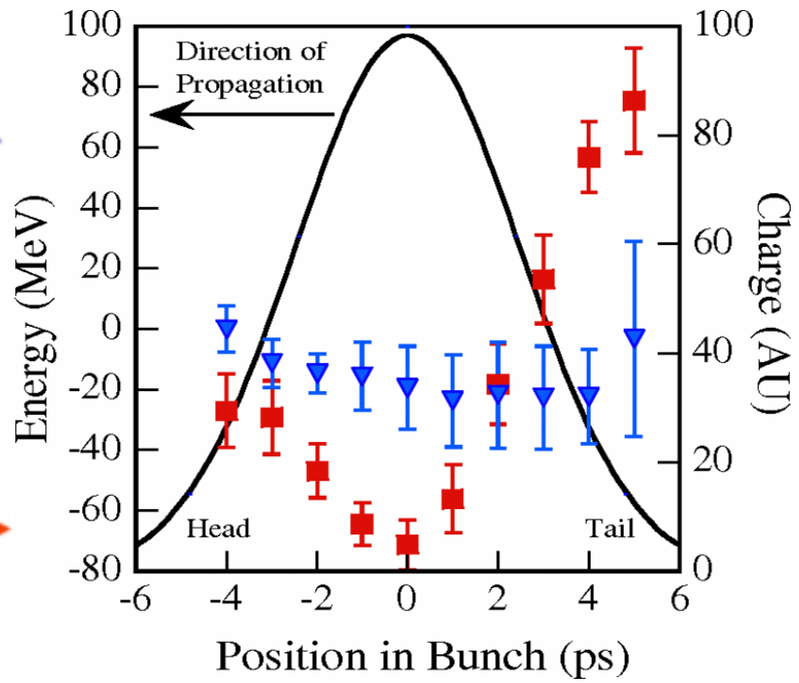
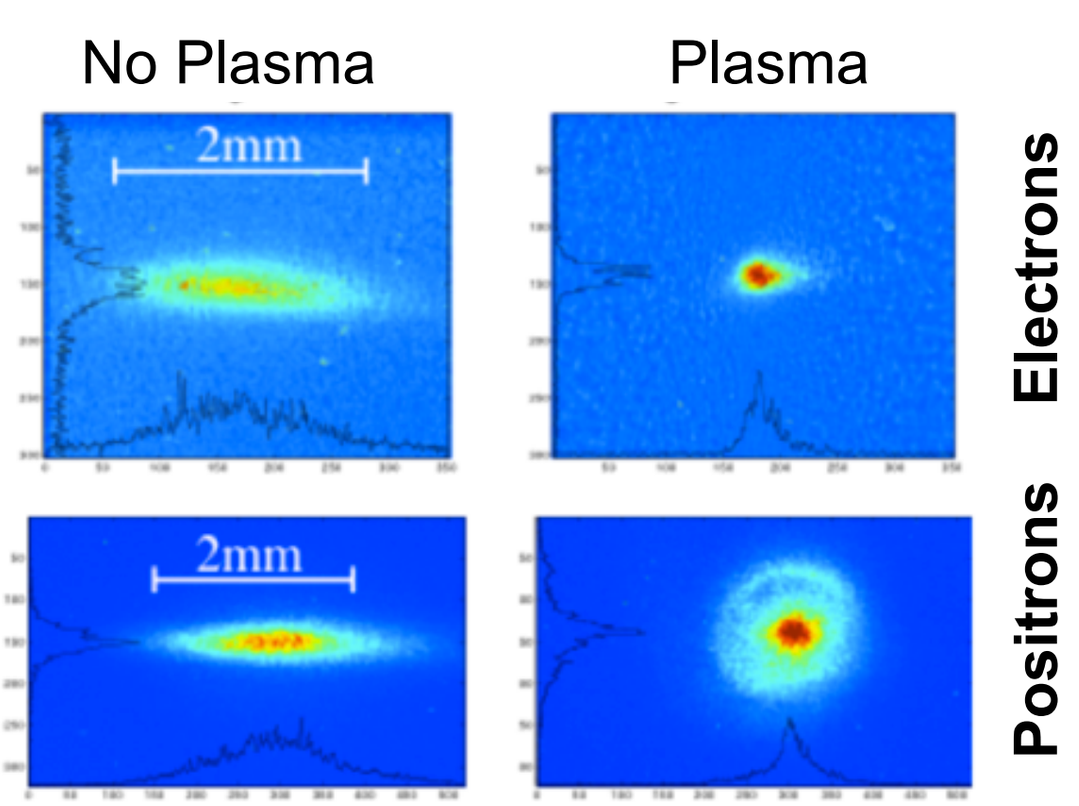
“Blow-out”





“Suck-in”





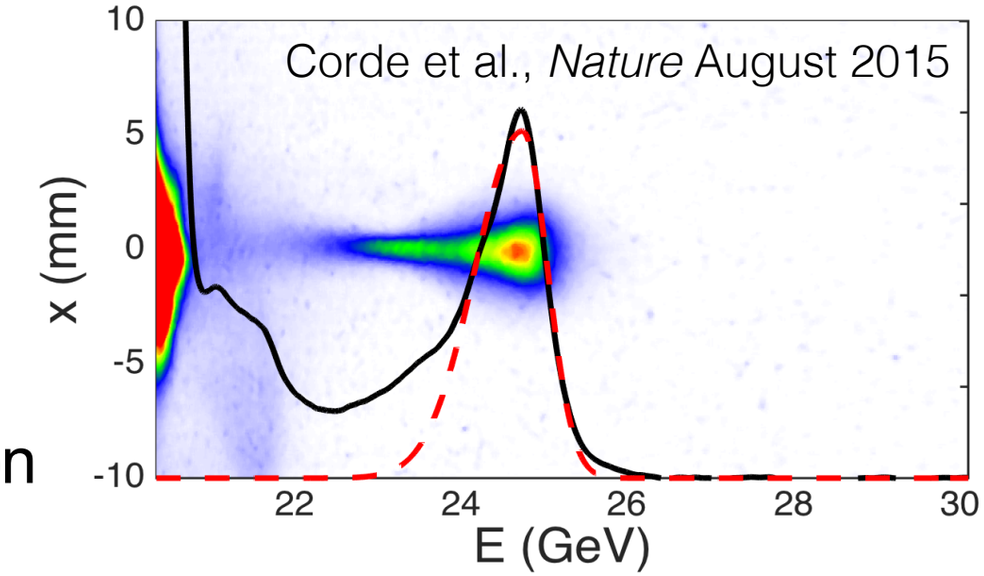
- First acceleration of positron beams in plasma
  - B. Blue et. al. *Phys. Rev. Lett.* 90 214801 (2003).
- Positron beam transport in plasma
  - M. J. Hogan et. al. *Phys. Rev. Lett*. 90 205002 (2003).
- Halo formation due to non-linear fields
  - P. Muggli et. al. *Phys. Rev. Lett*. 101 055001 (2008).

Experiments at SLAC FFTB in 2003 showed that the positron beam was distorted after passing through a low density plasma

FACET Provided Single & Double Positron Bunches With Higher Intensity to Probe Higher Density Plasmas

Multi-GeV Acceleration in **Non-linear wakes**

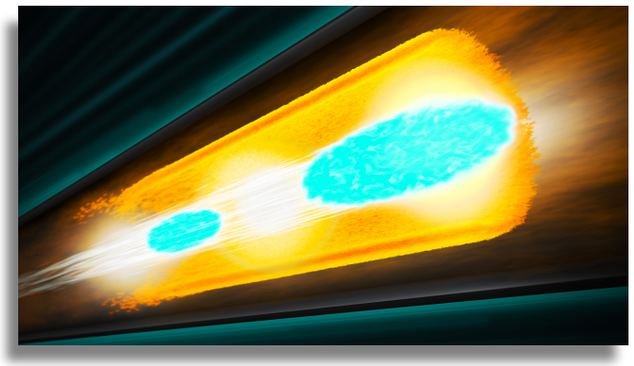
- New self-loaded regime of PWFA
- Energy gain 4 GeV in 1.3 meters
- Low divergence, no halo



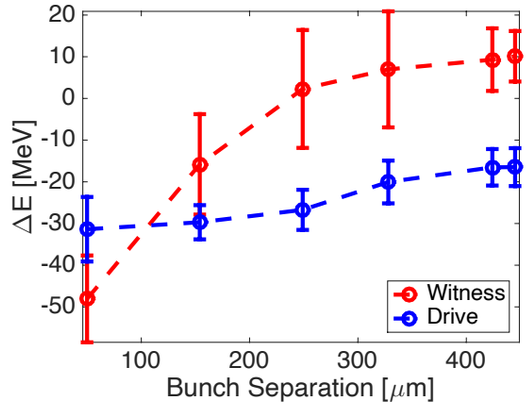
Gessner et al., *Nature* Communications 2016

Hollow Channel Plasma Wakefield Acceleration

- Engineer Plasma to Control the Fields
- No focusing on axis
- Measured transverse and longitudinal wakefields



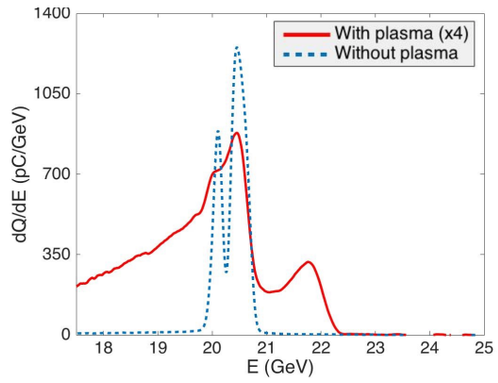
Lindstrom et al., *Phys. Rev. Lett.* 2018

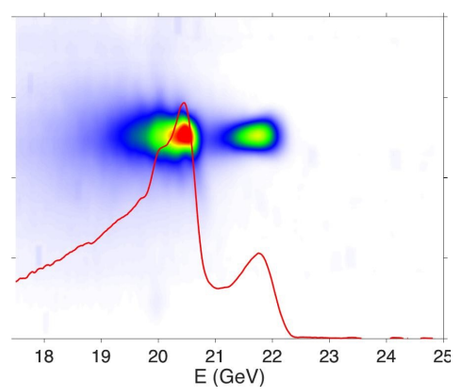


Quasi-linear Wakefield Acceleration

- > 1 GeV energy gain in 1.3 meters
- Of interest to both the PWFA and LWFA for linear collider applications
- This technique can be used to accelerate a positron witness beam in electron wake

Doche et al., *Scientific Reports* 2017





Additional Information

2017 FACET-II Science Workshop

- https://conf.slac.stanford.edu/facet-2-2017/agenda

2018 ALEGRO Positron Acceleration in Plasma Mini-Workshop

- https://indico.cern.ch/event/702515/

2019 FACET-II Science Workshop including Glen's overview of anticipated positron capabilities at FACET-II:

- https://conf.slac.stanford.edu/facet-2-2019/sites/facet-2-2019.conf.slac.stanford.edu/files/basic-page-docs/Glen-FACET2_positrons.pdf

2019 EAAC (just search for positron) good overview by Carl:

- https://agenda.infn.it/event/17304/contributions/97652/attachments/66657/81610/EAAC2019_Positrons_CAL.pdf

Positron Generation and Trapping without External Source

- Use a pair of electron beams to generate positrons in a tungsten foil at plasma entrance
- Some positrons will get trapped and accelerated in the electron-driven wake.
- E-303 experiment: P.I. K. Marsh, UCLA.

PHYSICAL REVIEW ACCELERATORS AND BEAMS **22,** 091301 (2019)

Positron beam extraction from an electron-beam-driven plasma wakefield accelerator

H. Fujii,[1] K. A. Marsh,[1] W. An,[1] S. Corde,[2] M. J. Hogan,[3] V. Yakimenko,[3] and C. Joshi[1]
[1]*University of California, Los Angeles, Los Angeles, California 90095, USA*
[2]*LOA, ENSTA Paris, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, 91762 Palaiseau, France*
[3]*SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*

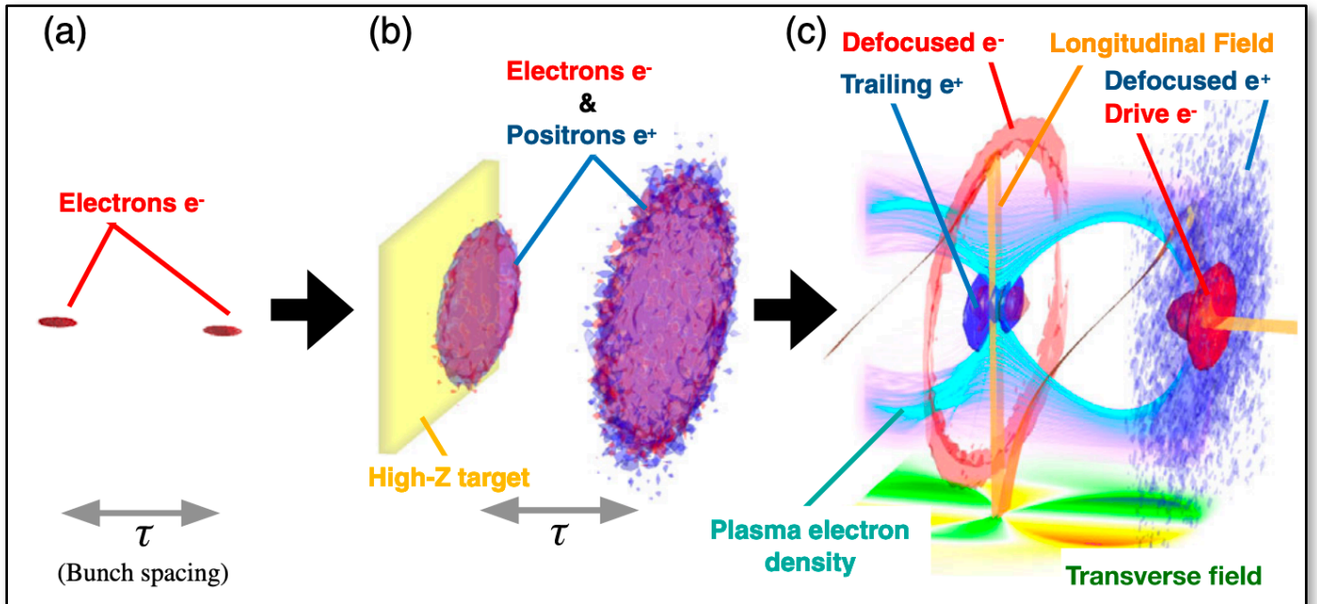
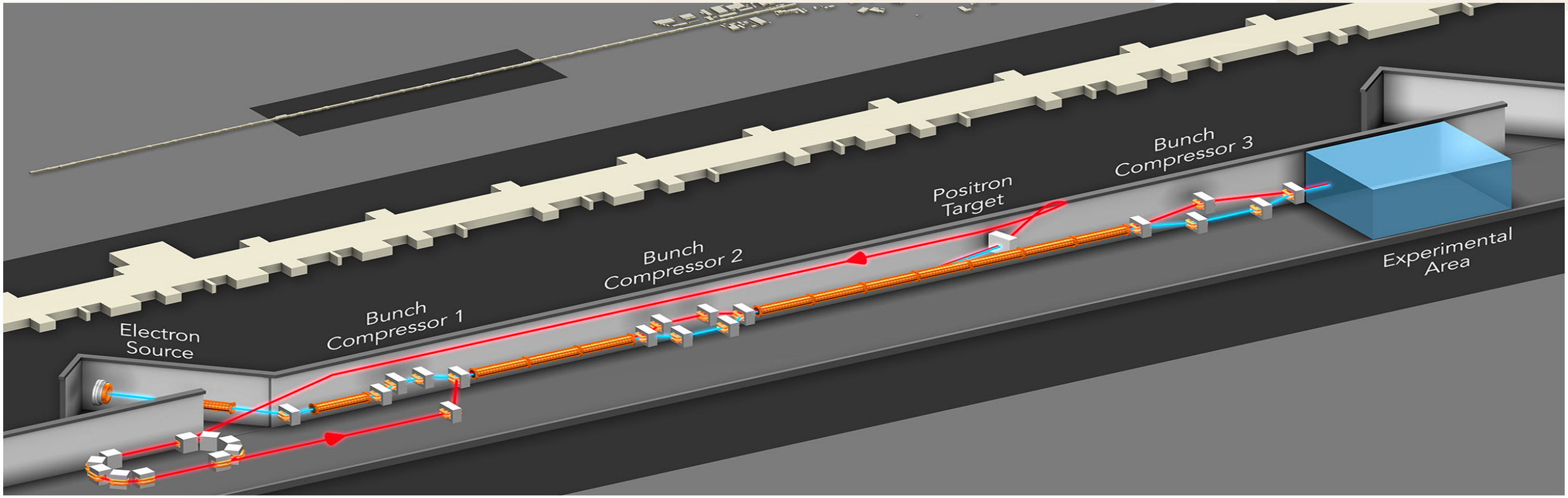


FIG. 1. Schematic diagram of the positron acceleration.

'Simple' way to probe volume of the region that is accelerating and focussing but cannot access collider level parameters

FACET-II Layout and Beams
A plan has been developed to restore positron capability

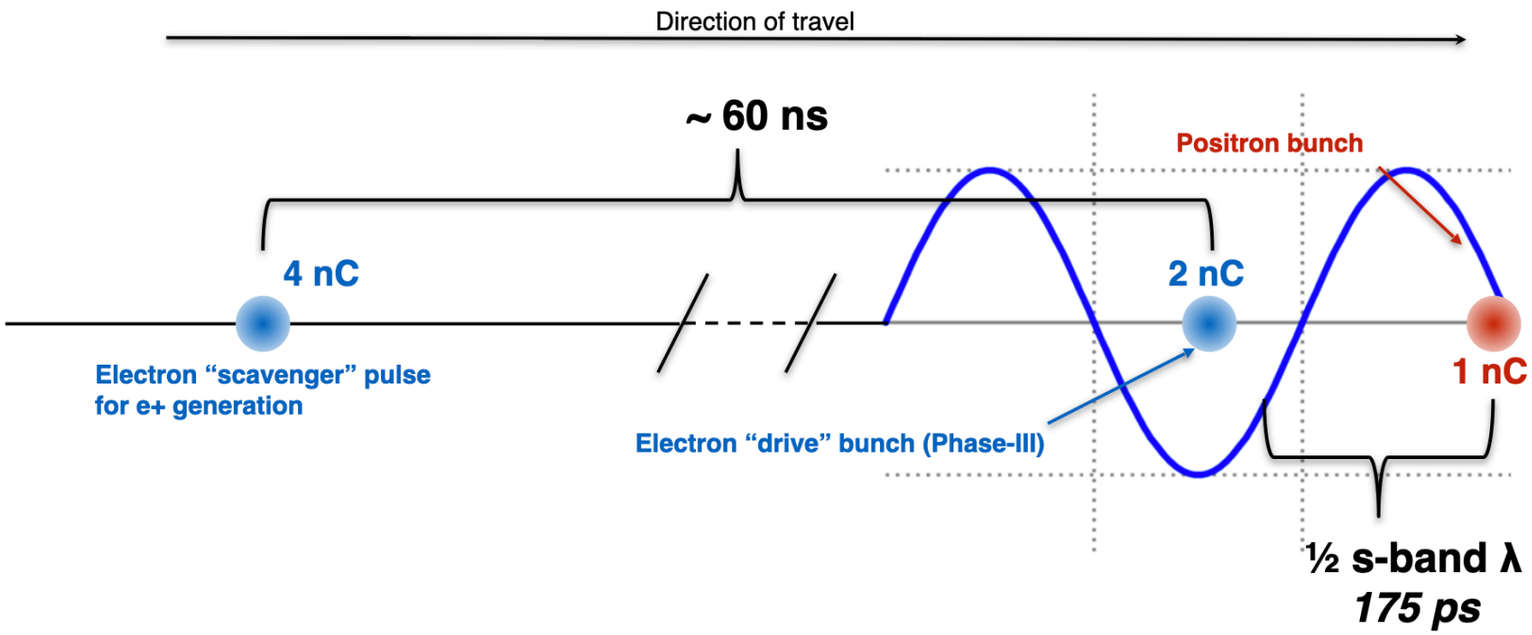


- Simultaneous delivery of up to 1nC e+ & 2nC e- to S20 IP region
- Expected performance modeled with particle tracking, including dynamic errors
- More details in TDR Ch. 8

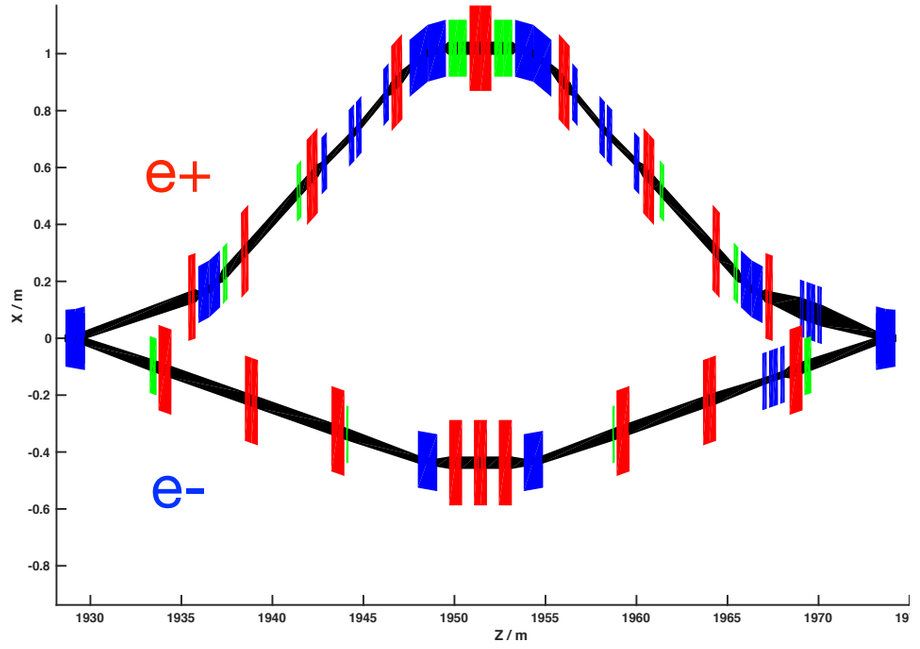
Positron Beam Parameter	Baseline Design	Operational Ranges
Final Energy [GeV]	10	4.0-13.5
Charge per pulse [nC]	1	0.7-2
Repetition Rate [Hz]	5	1-5
Norm. Emittance $\gamma\varepsilon_{x,y}$ at S19	10, 10	6-20
Spot Size at IP $\sigma_{x,y}$ [μm]	16, 16	5-20
Min. Bunch Length σ_z (rms)	16	8
Max. Peak current I_{pk} [kA]	6	12

Will be Possible to Study Positron PWFA in Electron Wakes

Positrons can be restored to Sector 20 by utilizing existing S19 positron source with a ~4 nC electron driver pulse



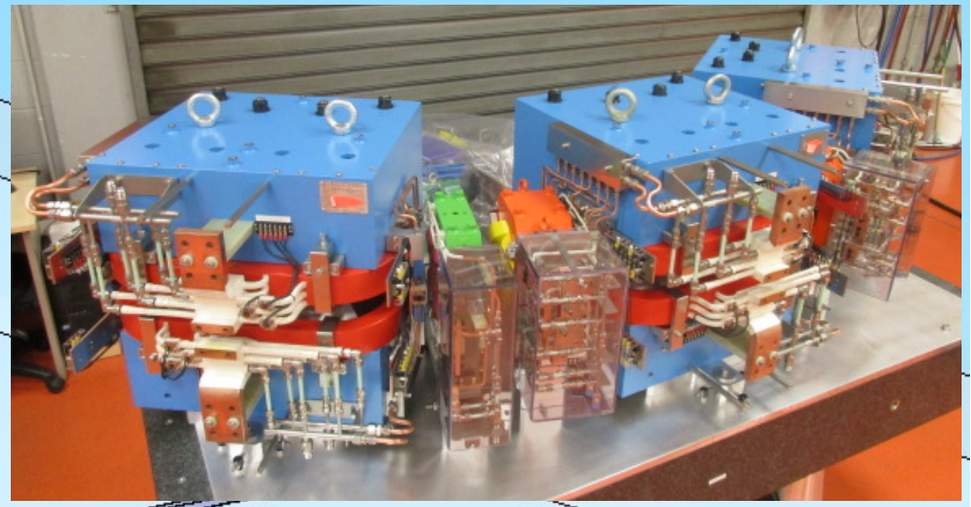
Simultaneous e- e+ delivery (dz +/- 600 μm) made possible by adding **BC20P beamline**



Hardware required to restore positrons:

- New BC14 chicane section
- 335 MeV booster Linac in return line
- **New compact DR in Sector 10**
- New beamlines to extract beam from return line into DR, extract beam from DR and extract, compress & inject into BC11

335 MeV Positron Damping Ring in Sector 10



- 2.9 m diameter ring
- Vertical injection & extraction
- SLC kickers & RF, new septa
- New combined-function arc magnet designs

Collider Designs Require New Ideas for Positron PWFA

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Beam Driven Plasma R&D 10 Year Roadmap

2016	2018	2020	2022	2024	2026

PWFA-LC Concept Development and Parameter Studies

Beam Dynamics and Tolerance Studies

Positron Acceleration

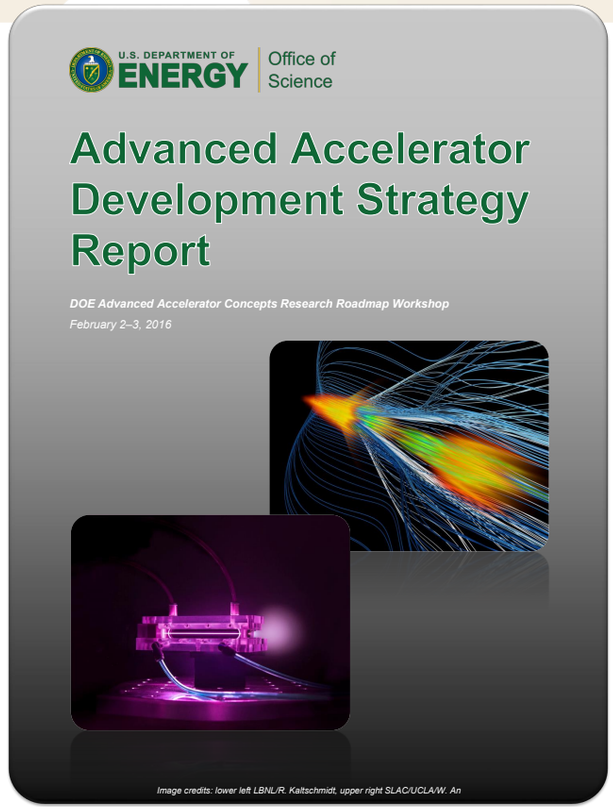
FACET | FACET-II Phase 2: Positrons

Simulate, Test and Identify the Optimal Configuration for Positron PWFA

Present ('New Regime' only)		Goals
4GeV		100pC, >1GeV @ >1GeV/m, dE/E < 5%, Emittance Preserved in at least one regime: 'New Regime' seeded with two bunches Hollow Channel Plamsas Quasi non-linear
Q ~ 100 pC		
3 GeV/m		
ΔE/E ~ 2%		
ε not measured		

Plasma Source Development

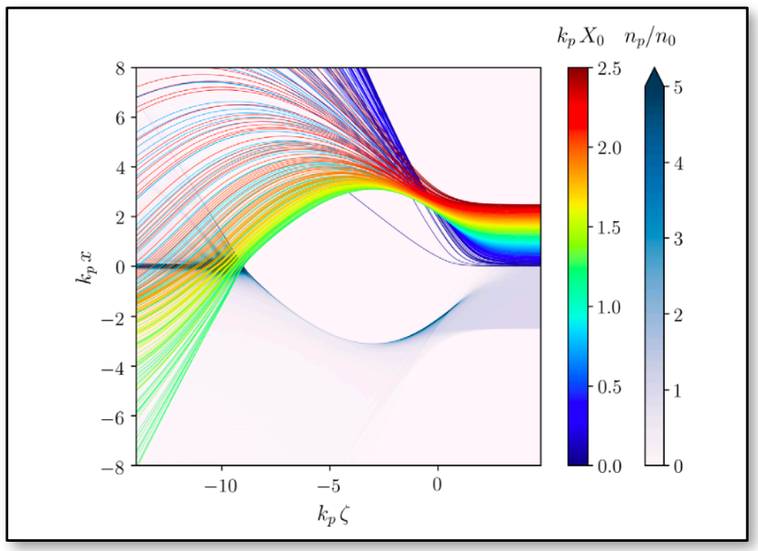
Goals
Tailored density ramps for beam matching and emittance preservation
Uniform, hollow and near-hollow transverse density profiles
Accelerating region density adjustable from 10^{15} - 10^{17} e^-/cm^3
Accelerating length > 1m
Scalable to high repetition rate and high power dissipation

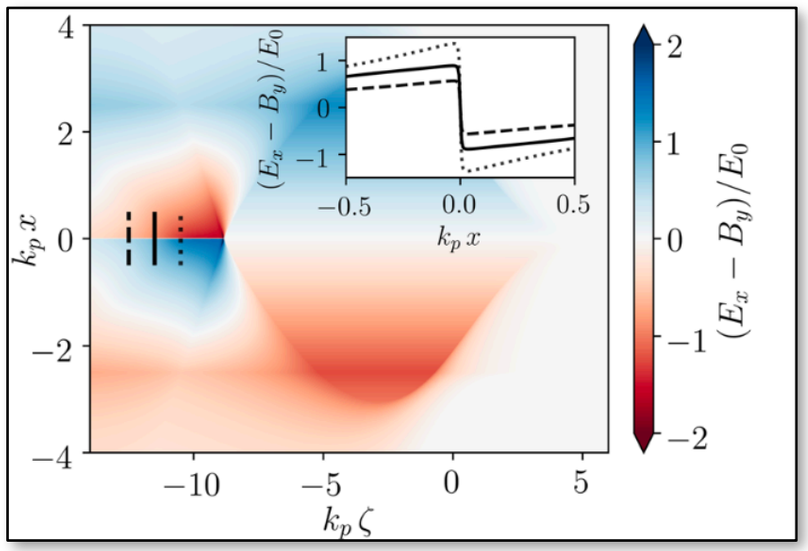


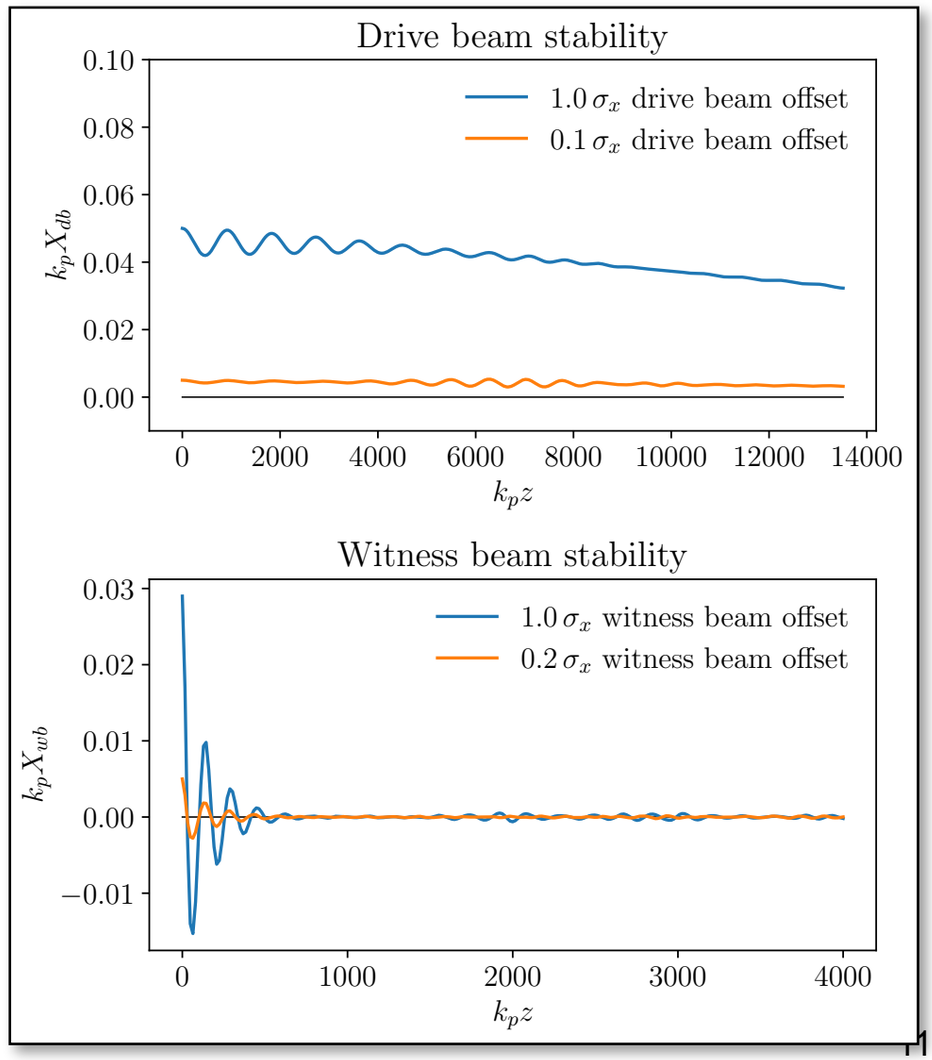
- Transversely tailored plasmas
- Transversely tailored drivers
- Long term evolution of beams/plasmas into exotic equilibrium

Transversely Tailored Plasmas

- Changing the shape of the ionized plasma region modifies the trajectories of plasma electrons in the wake.
- This leads to an elongated region in the back of the wake where positron bunches are focused and accelerated.
- E-333 experiment: DESY/LBNL/SLAC collaboration



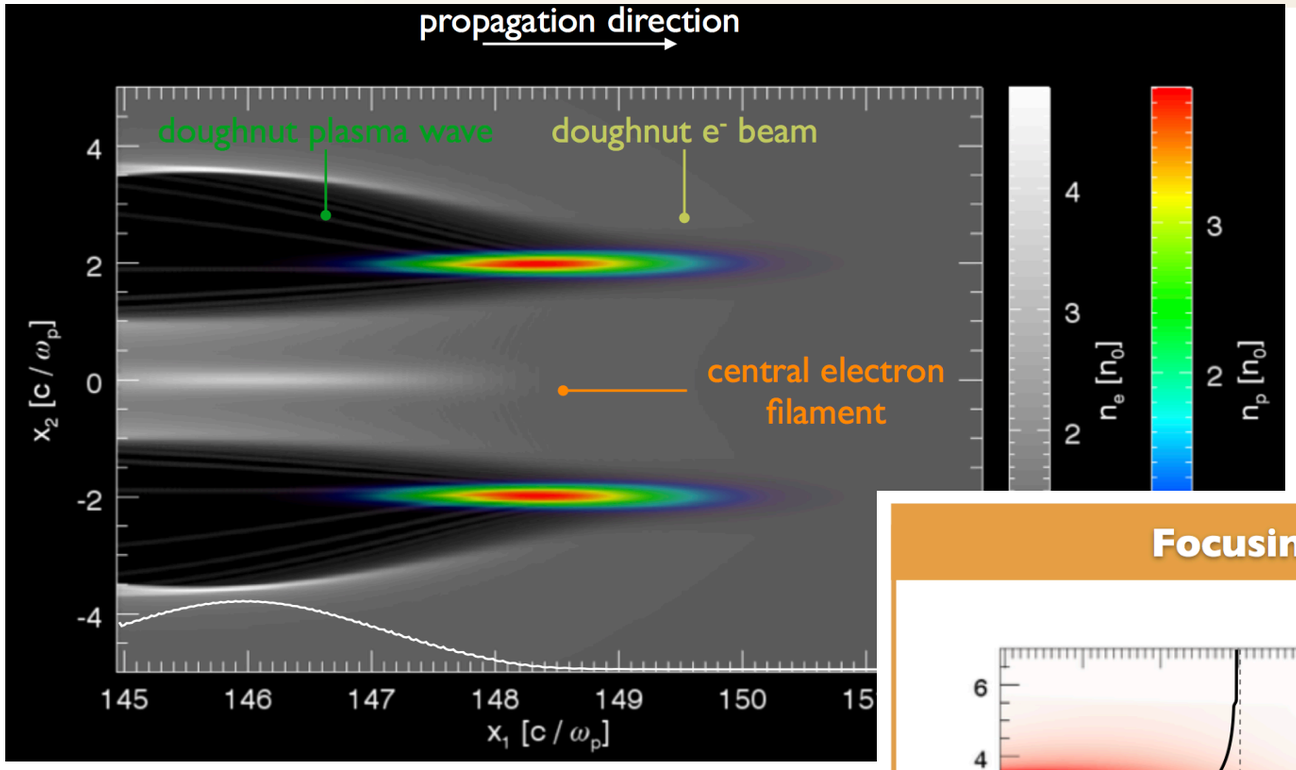




S. Diederichs et. al. *Phys. Rev. Accel. Beams* **22** 081301 (2019)

S. Diederichs et. al. *Phys. Rev. Accel. Beams* **23** 121301 (2020)

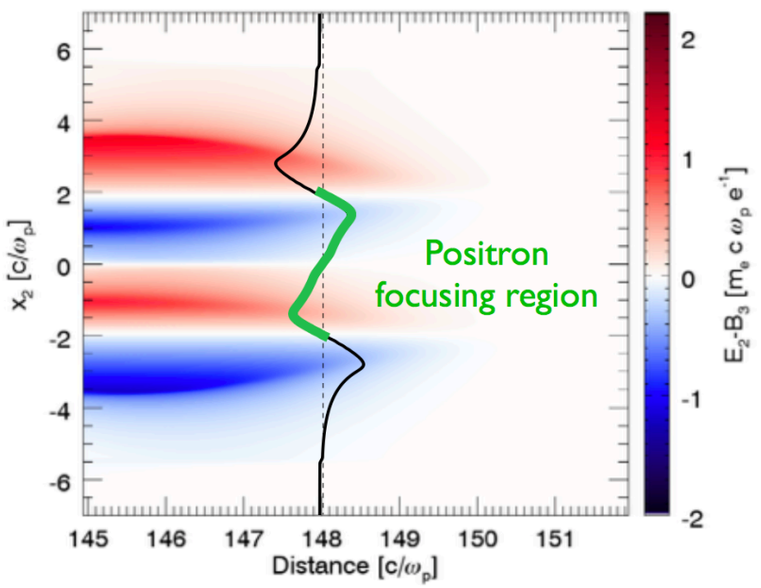
Transversely Tailored Drivers a.k.a. Wake Inversion



J. Vieira, et al. PRL 112 215001 (2014)
N. Jain et al. PRL 115 195001(2015)

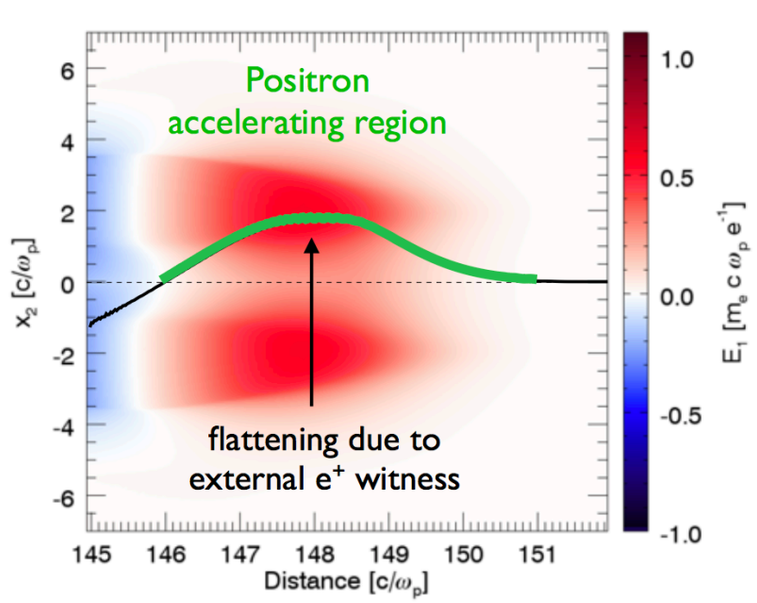
- Certainly a challenge for the accelerator physicists
- Optimizations are possible trading efficiency, energy spread and emittance

Focusing force



- **Linear focusing** force for e^+
- Width of linear focusing region on the order of the skin depth
- Focusing varies but **may not compromise divergence/emittance growth**

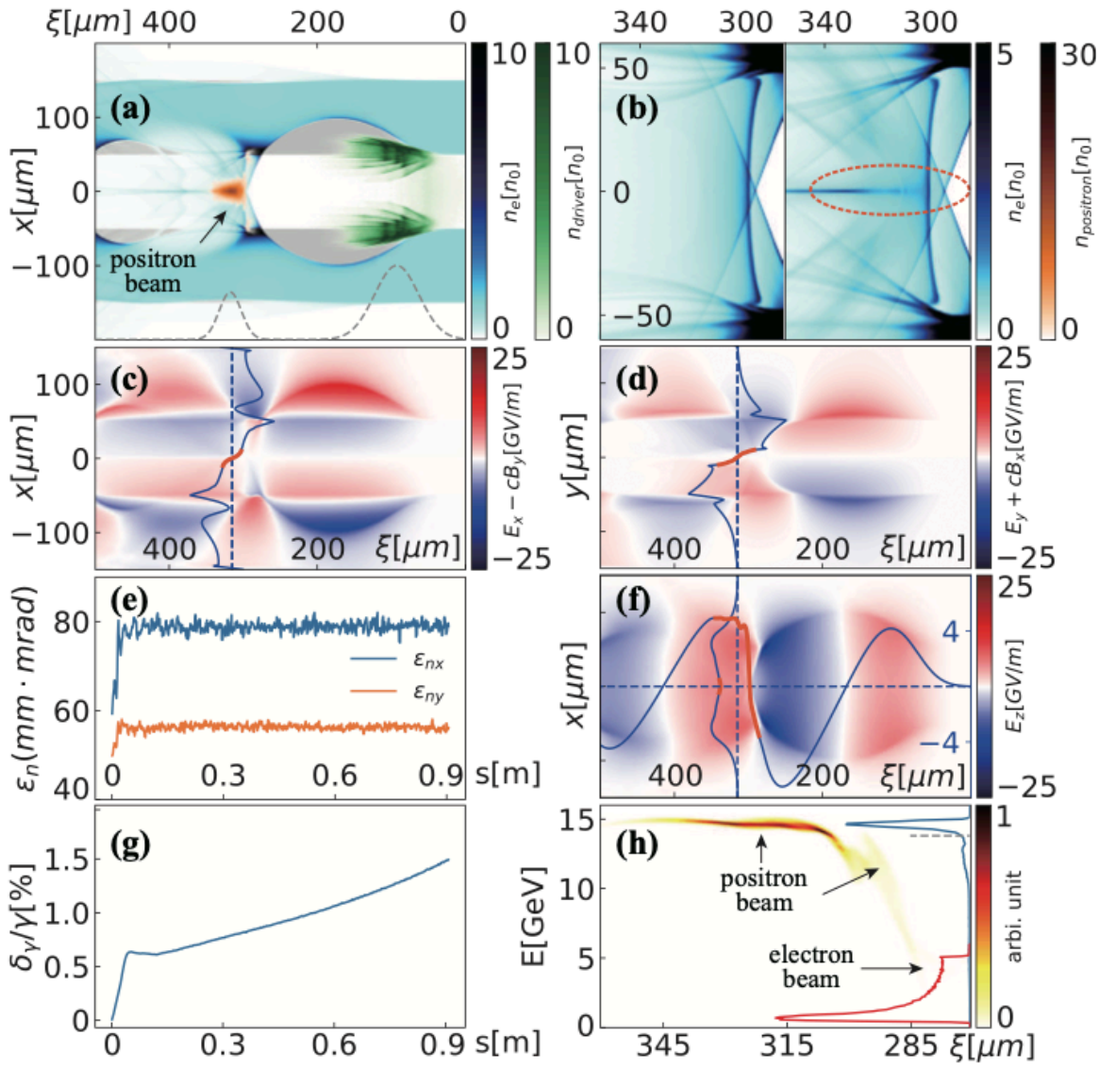
Accelerating force



- e+ can **accelerate at the front**
- **Beam loading** is possible
- **Energy spread** growth can be **controlled**

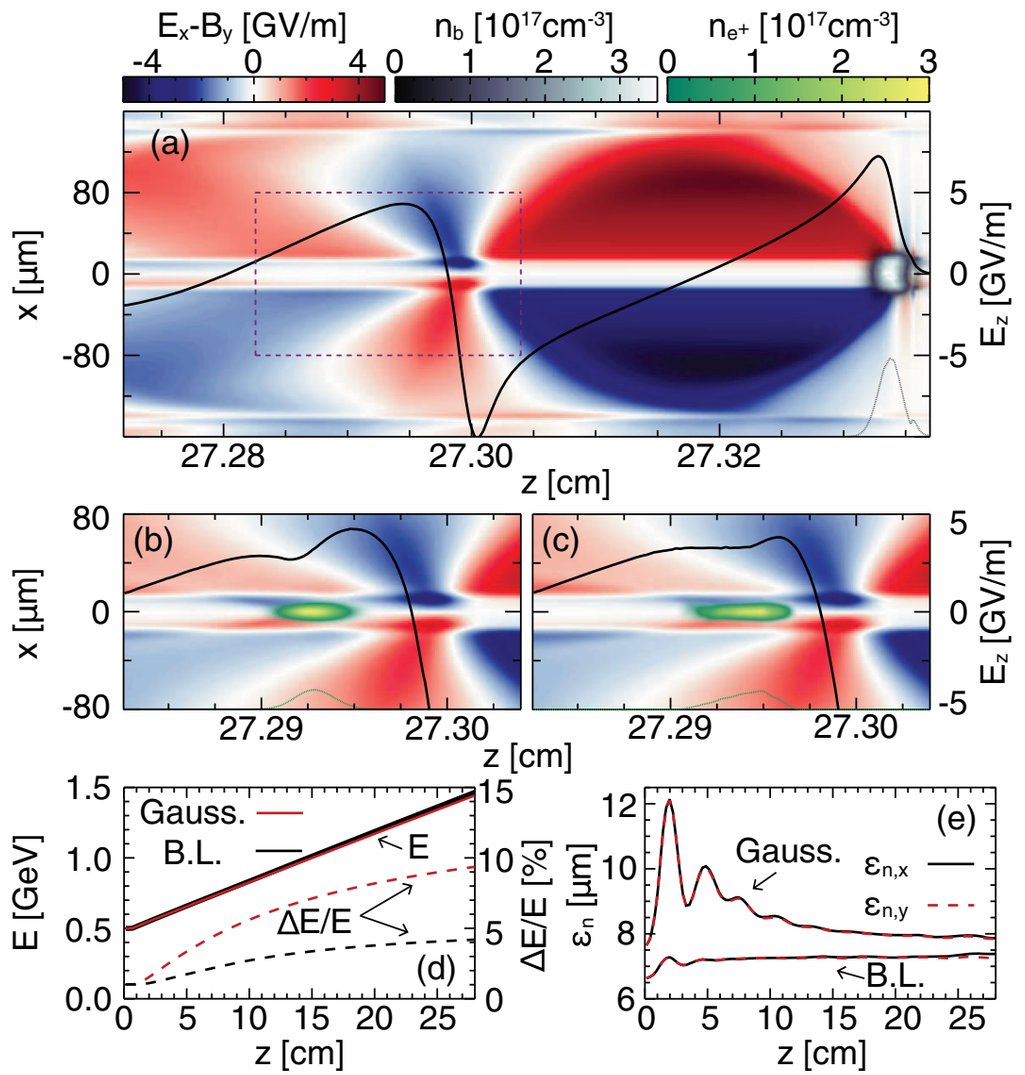
Recent Proposals with New Equilibrium Conditions

"Stable Positron Acceleration Mode in Hollow Plasma Channel Driven by an Asymmetric Beam"



S. Zhou *et al.* (Tsinghua)
https://arxiv.org/abs/2012.06095

"Electron and positron acceleration in self-generated, thin, warm hollow plasma channels." E-337



T. Silva *et al.* (IST)
Phys. Rev. Lett. 127, 104801 (2021)

Conclusions & Outlook

- A plan has been developed to restore (and improve) our capabilities to test concepts for positron PWFA at FACET-II
- With positron upgrade FACET-II will be first facility capable of studying electron-driven, positron witness PWFA
- FACET-II can explore issues on beam loading and beam quality that were only touched upon at FACET (C. S. Hue, G. Cao, S. Corde et. al. https://arxiv.org/pdf/2107.01145.pdf)
- With a decision in 2022 may be ready in 2025
- Requires coordination with ongoing FACET-II electron programs, LCLS, LCLS-II, LCLS-II HE and our sponsors (DOE HEP)

Help maintain the momentum and submit new ideas at:
https://facet.slac.stanford.edu/proposals