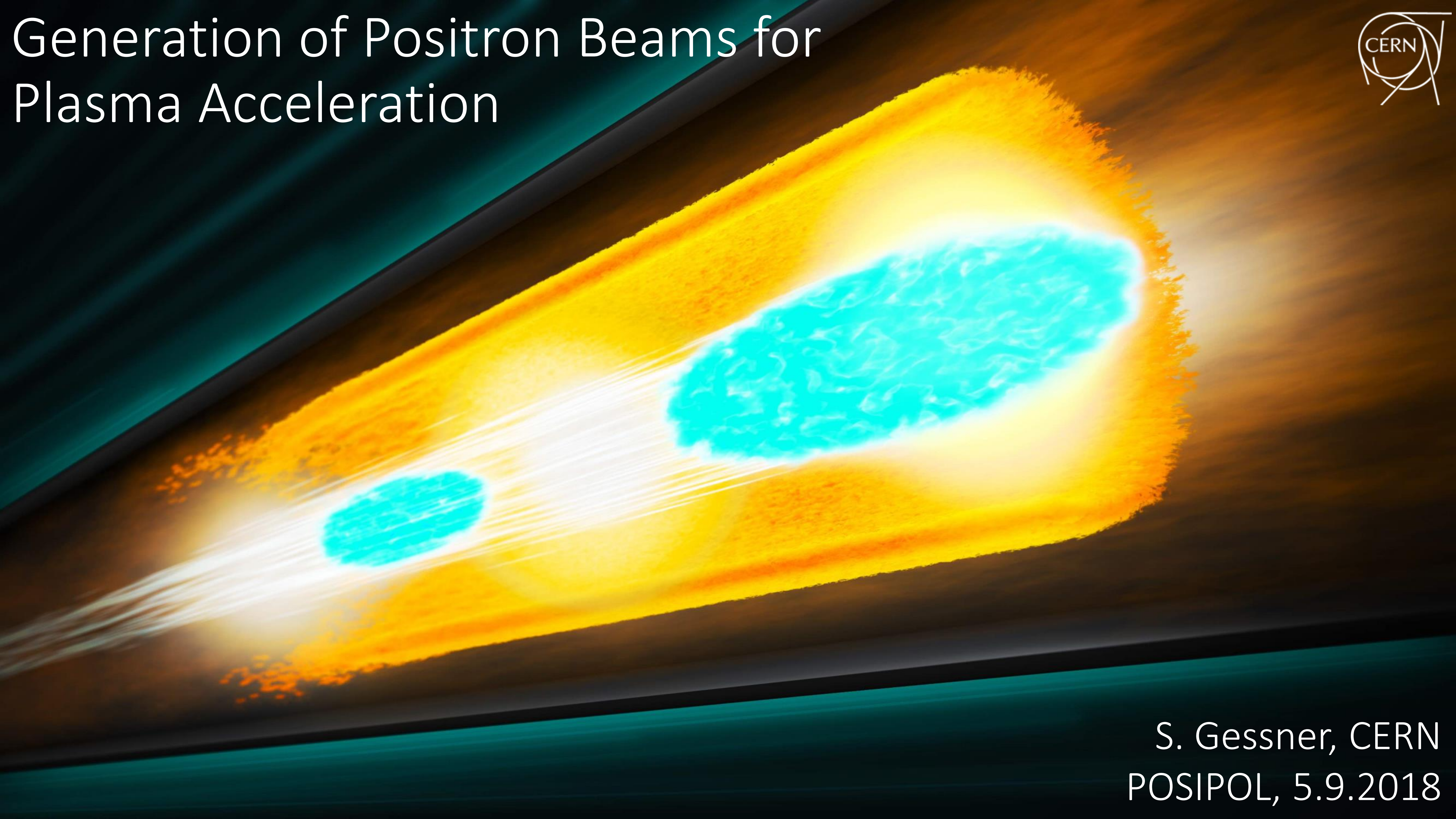
Generation of Positron Beams for Plasma Acceleration



S. Gessner, CERN

POSIPOL, 5.9.2018

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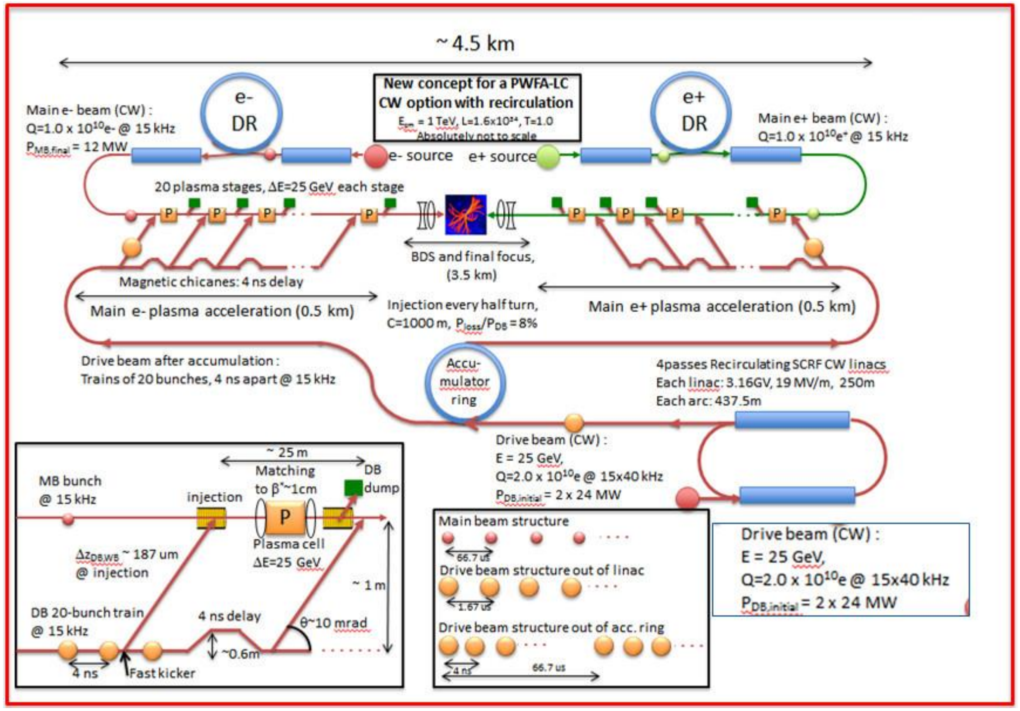
  - D. van der Werf, C. Carruth, CERN
  - C. Surko, UCSD
  - R. Greaves, FPS
  - D. Cassidy, UCL
- RF Source design:
  - M. Kelisani, S-Y Kim, S. Doebert, CERN

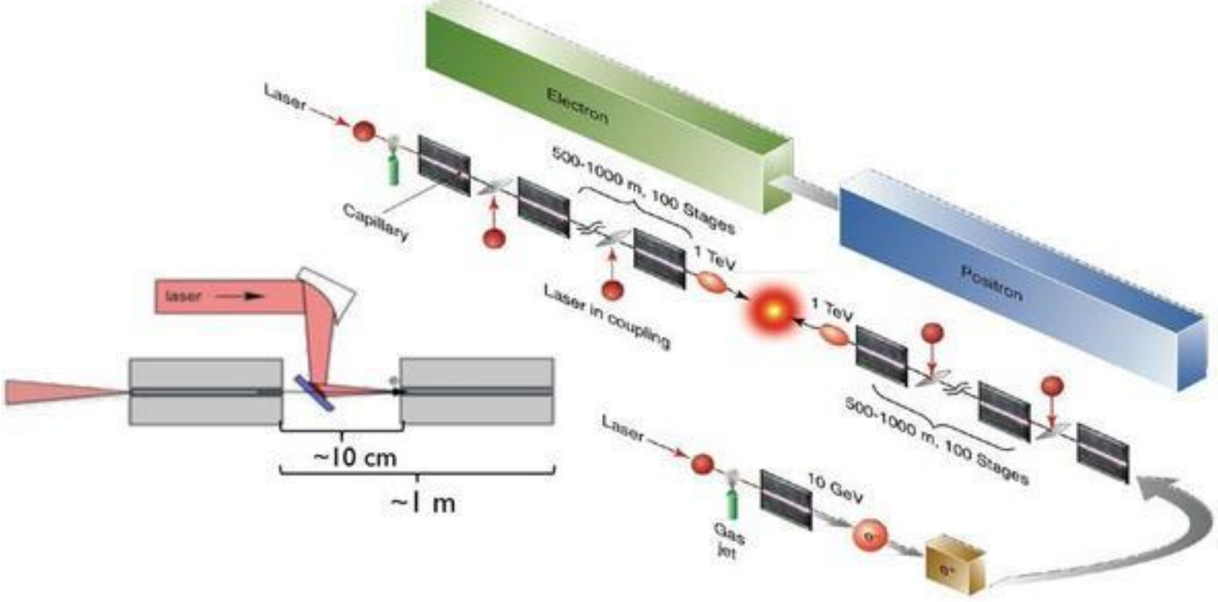
Outline

- Motivation
  - ➢ Why do we need to accelerate positrons in plasma?
- Challenge
  - ➢ What makes the acceleration of positrons in plasma difficult?
- Experimental Progress
  - ➢ What have we achieved and what facilities can we use?
- Novel Positron Sources
  - ➢ Low emittance, polarized positron beams from an electron static source.
- Conclusion and Outlook

Plasma-Based Linear Colliders



E. Adli *et. al.*,arXiv:1308.1145 [physics.acc-ph]

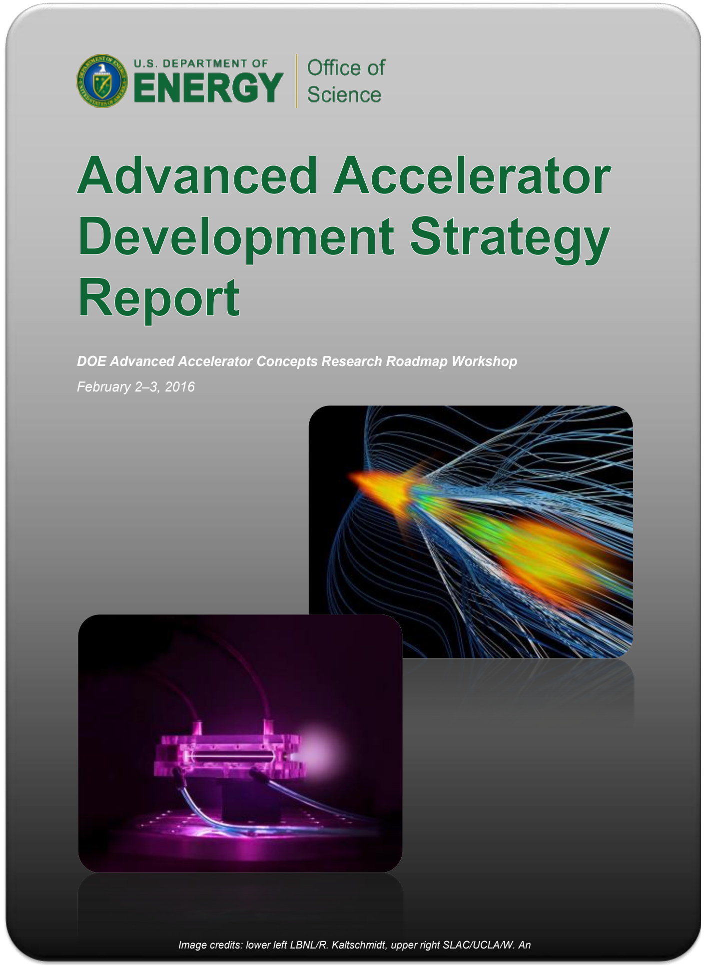


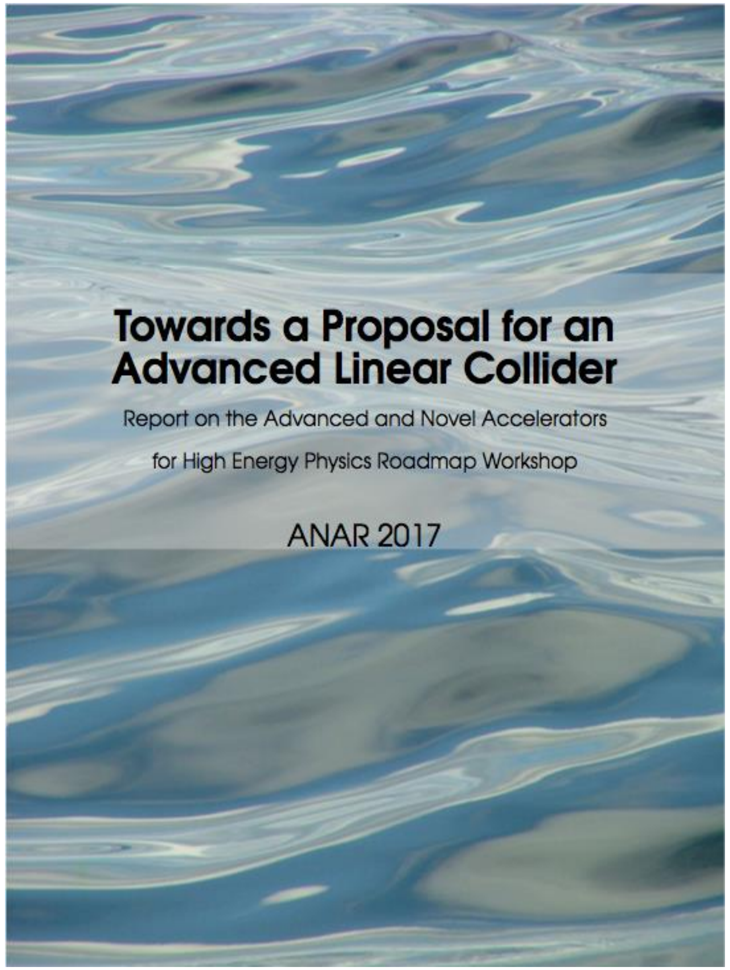
C. B. Schroeder *et. al*. Phys. Rev. ST Accel. Beams **13**, 101301

The preeminent application of research on plasma wakefield acceleration is to build a compact, efficient, Plasma-Based Linear Collider (PLC).

These machines need to accelerate both electrons and positrons.

Roadmaps for the Future



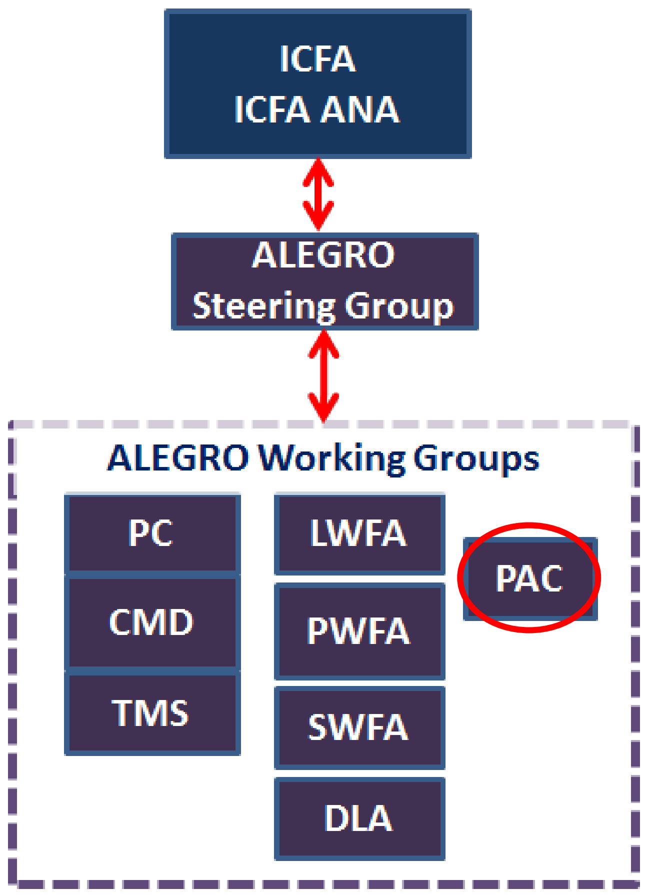


The DOE and ICFA commissioned reports on the path to an advanced linear collider. Both highlight the need for research on positron acceleration in plasma.

ALEGRO: Advanced Linear Collider Study Group

The ALEGRO study group seeks to not only highlight the *obstacles* on the path to an advanced linear collider, but also to identify the proposed *solutions*.

Positron acceleration in plasma is a unique challenge. Our working group seeks to answer 3 questions:



The steering group is chaired by B. Cros, P. Muggli and C. Schroeder

ALEGRO is opened to interested scientists worldwide

ALEGRO WG titles and leaders:

PC: Physics Case (M. Peskin, J. Tian)

CMD: Collider Machine Design (A. Seryi, D. Schulte, H. Yamamoto)

TMS:Theory, Modelling, Simulations (JL. Vay, J. Vieira)

LWFA: Laser wakefield Accelerators (C. Schroeder, S. Hooker, B. Cros)

PWFA: Plasma wakefield Accelerators (J. Osterhoff, E. Gschwendtner, P. Muggli)

PAC: Positron acceleration (S. Gessner, S. Corde)

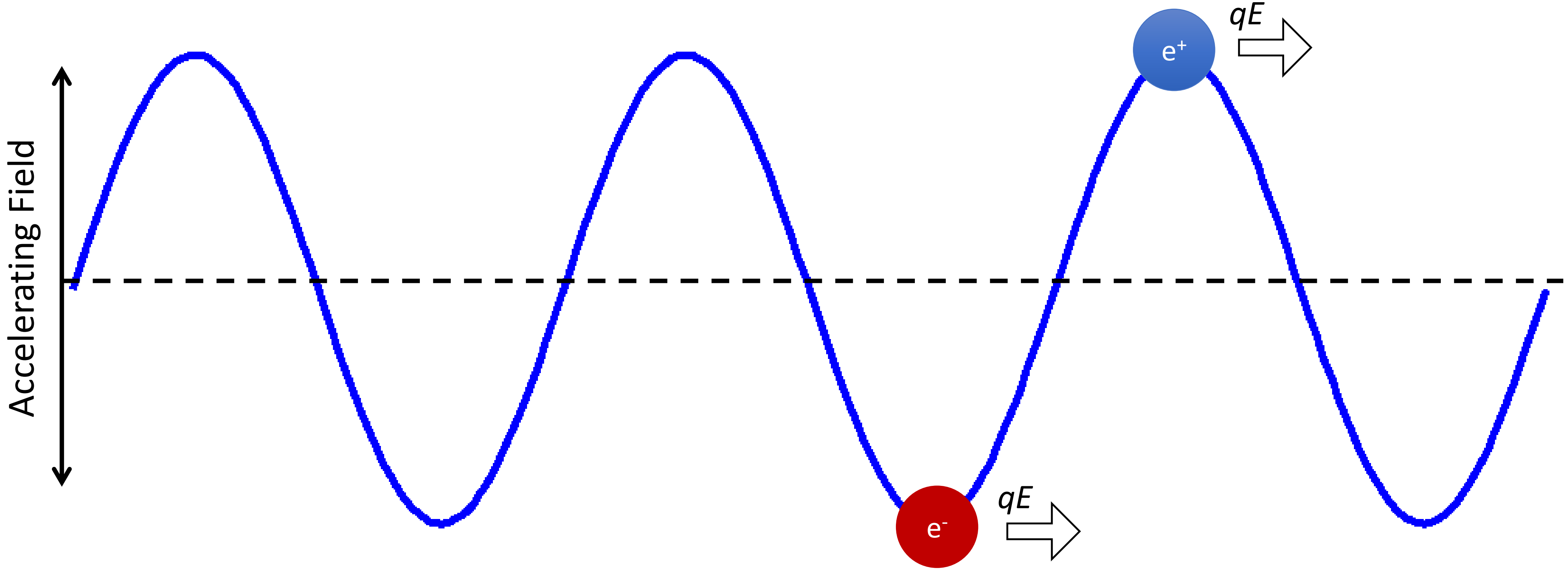
SWFA: Structure wakefield accelerator (P. Piot, J. Power)

DLA: Dielectric laser accelerator (J. England, B. Cowan)

1. What makes positron acceleration in plasma challenging?
2. What is the current state of positron PWFA/LWFA research?
3. What are the proposed solutions?

What makes positron PWFA challenging?

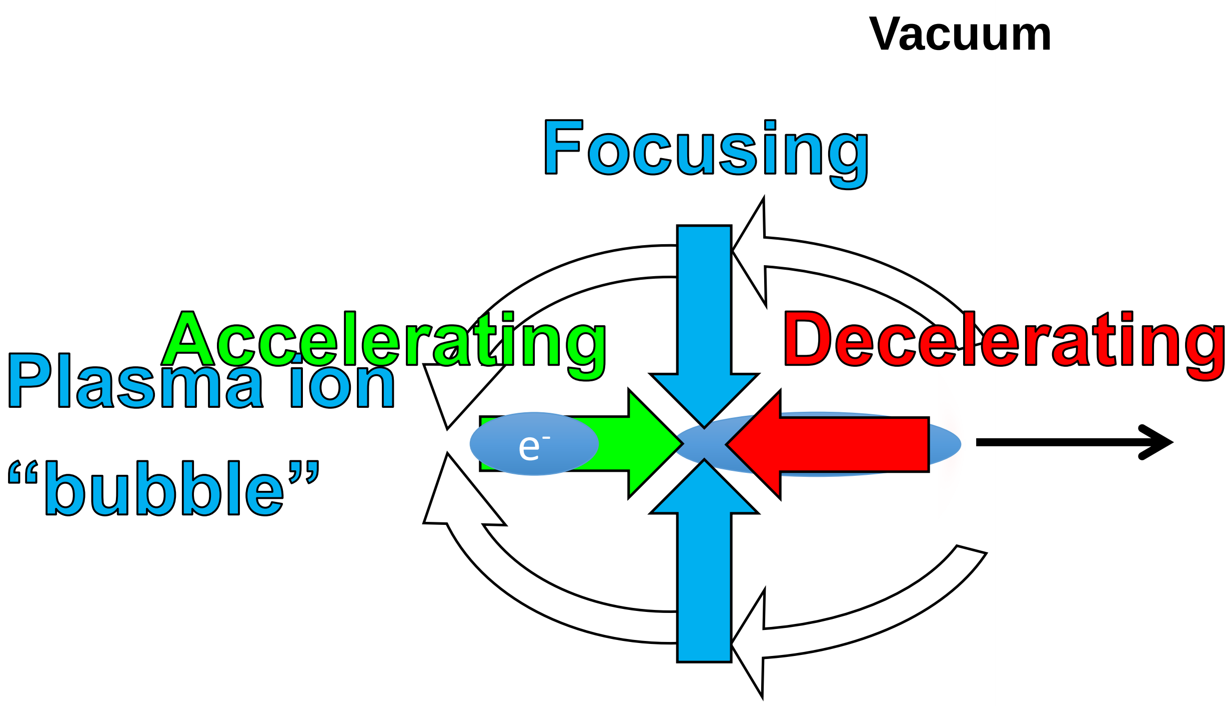
RF Accelerators



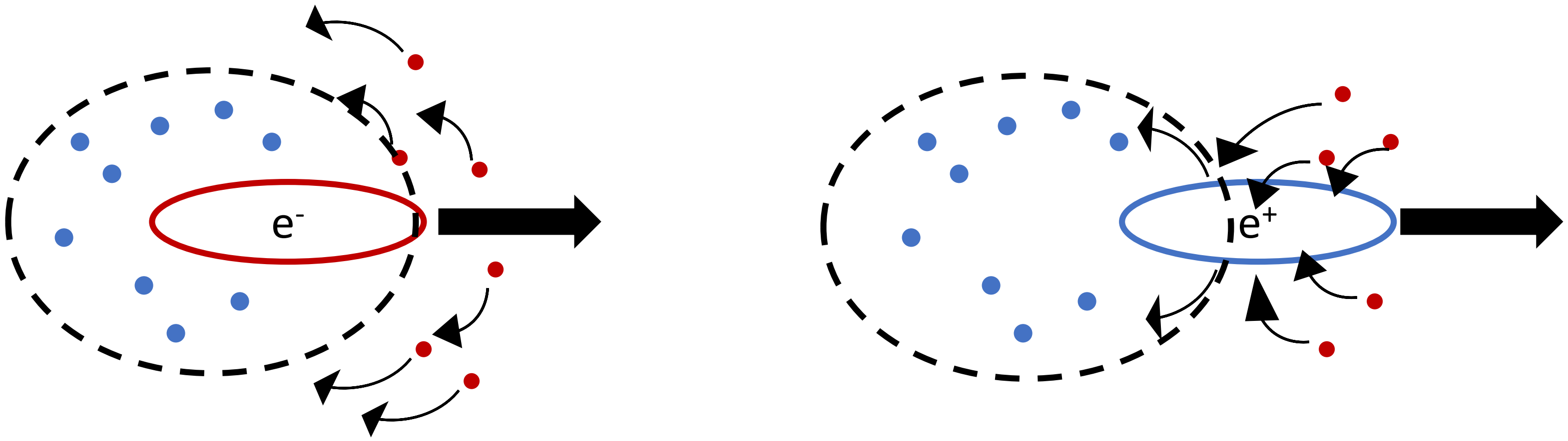
RF accelerators are equally good at accelerating electrons and positrons.

Just change the phase by 180°!

Plasma Acceleration with Electron Beams



Plasma Response to Positron Beams

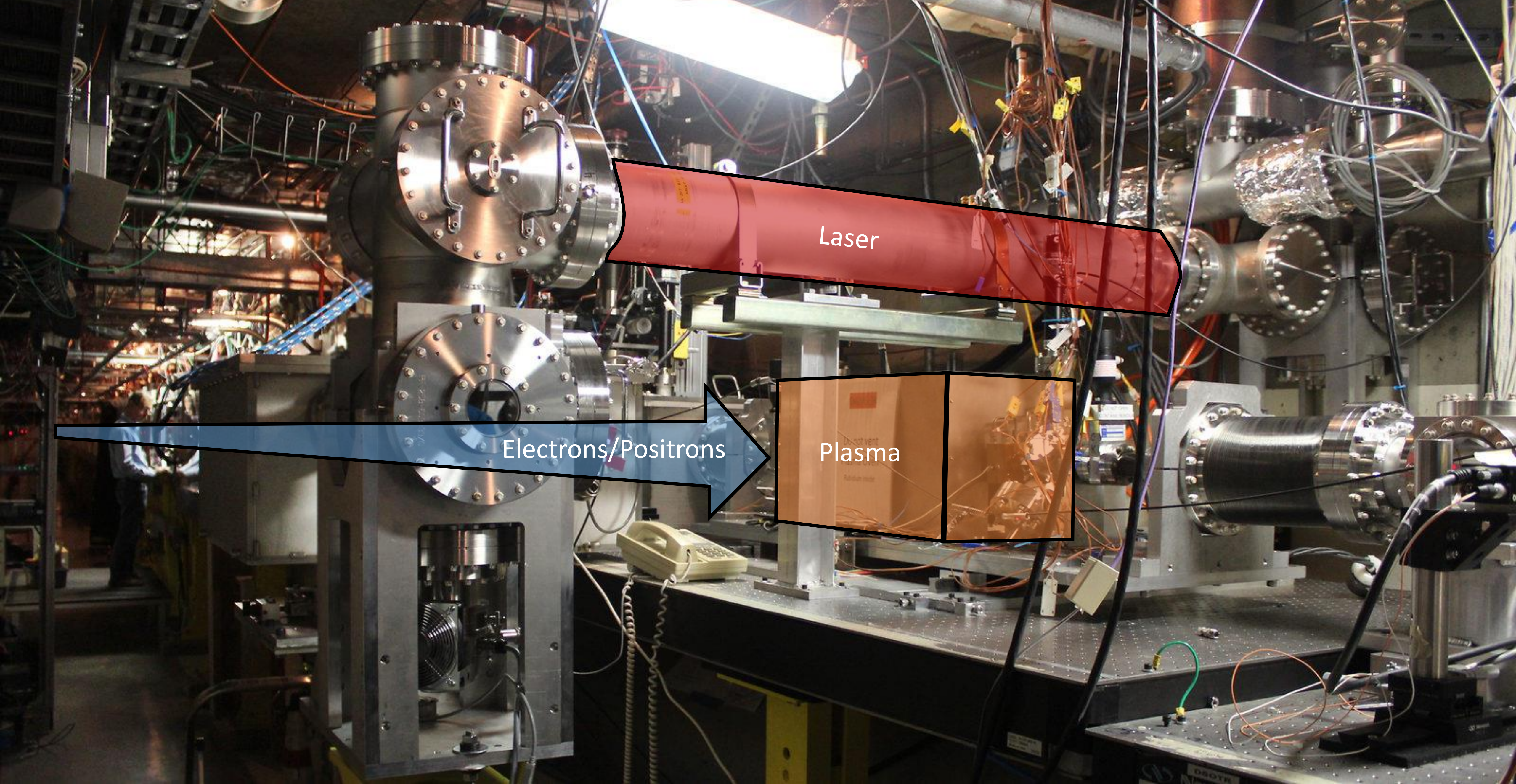


$$m_{ion} >> m_{elec}$$

The plasma electrons are mobile but the plasma ions are not. The plasma responds *asymmetrically* to beams of opposite charge. No other accelerating mechanism exhibits this behavior!

What is the current state of the experimental field?

Results from FACET



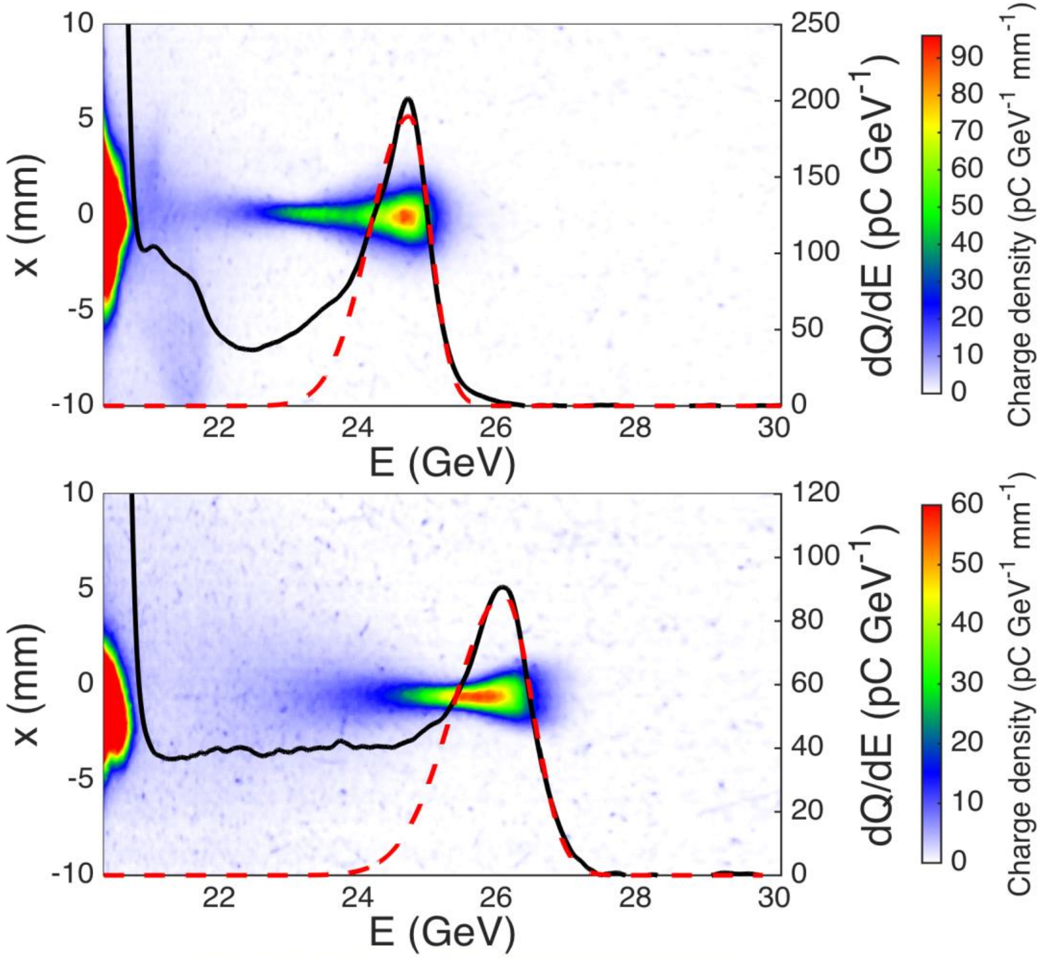
Positron Beam-Driven PWFA at FACET

FACET was able to provide high-density, compressed positron beams for non-linear PWFA experiments. This led to new observations:

- Accelerated positrons form a spectrally-distinct peak with an energy gain of 5 GeV.
- Energy spread can be as low as 1.8% (r.m.s.).

An exciting and unexpected result!

Experimental results in 1.3 m plasma



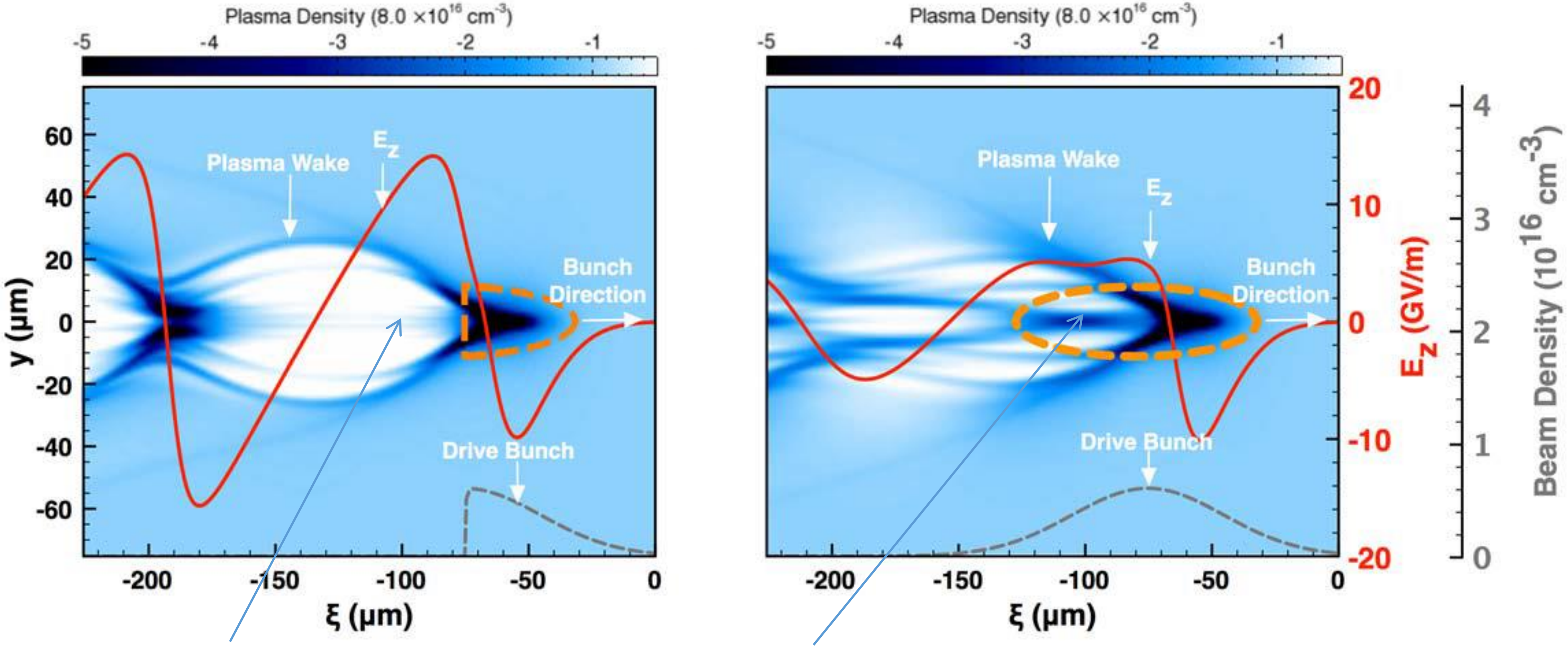
S. Corde *et al.*, Nature **524**, 442 (2015)

Positron Beam-Driven PWFA

QuickPIC simulations: loaded vs unloaded wake (truncated bunch)

Unloaded

Loaded



defocusing

focusing

Beam loading also affects transverse fields for positron driven wakes!

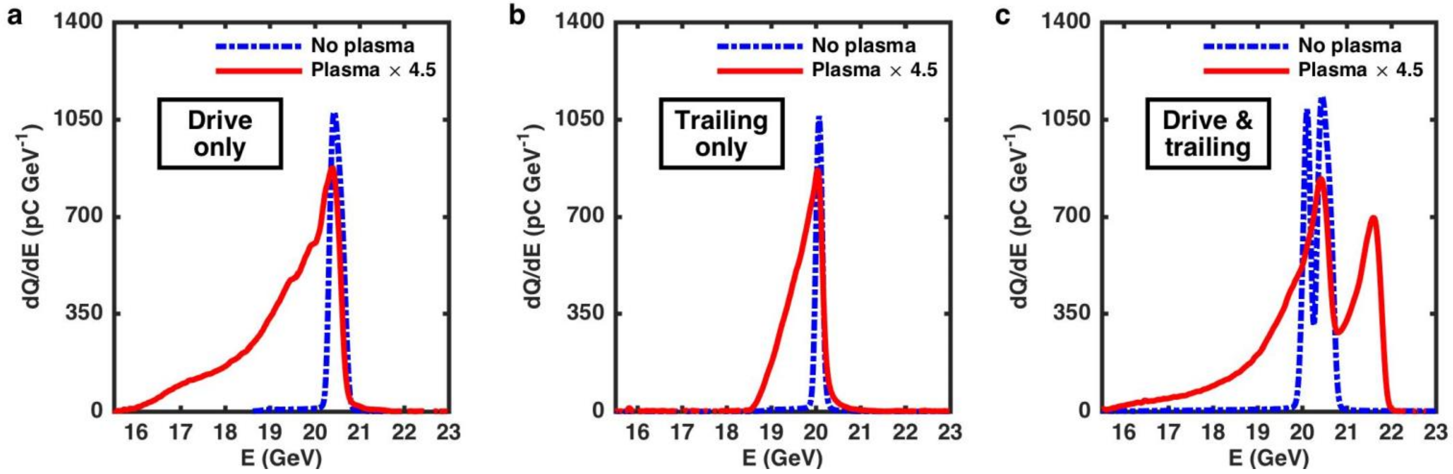
S. Corde *et al.*, Nature **524**, 442 (2015)

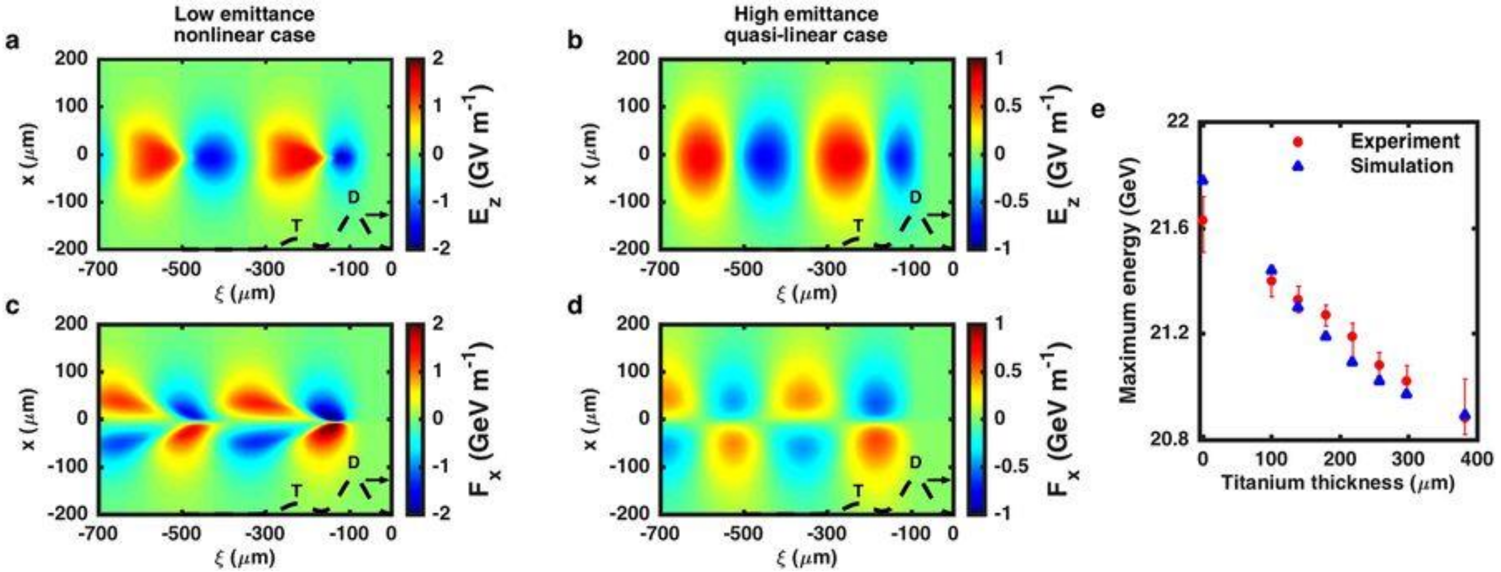
Two-Bunch Positron Beam-Driven PWFA

The results of the single positron bunch experiment naturally beg the question: Can we repeat these results in the drive-witness scenario?

This led to the first demonstration of *controlled* beam loading in the positron beam-driven wake.

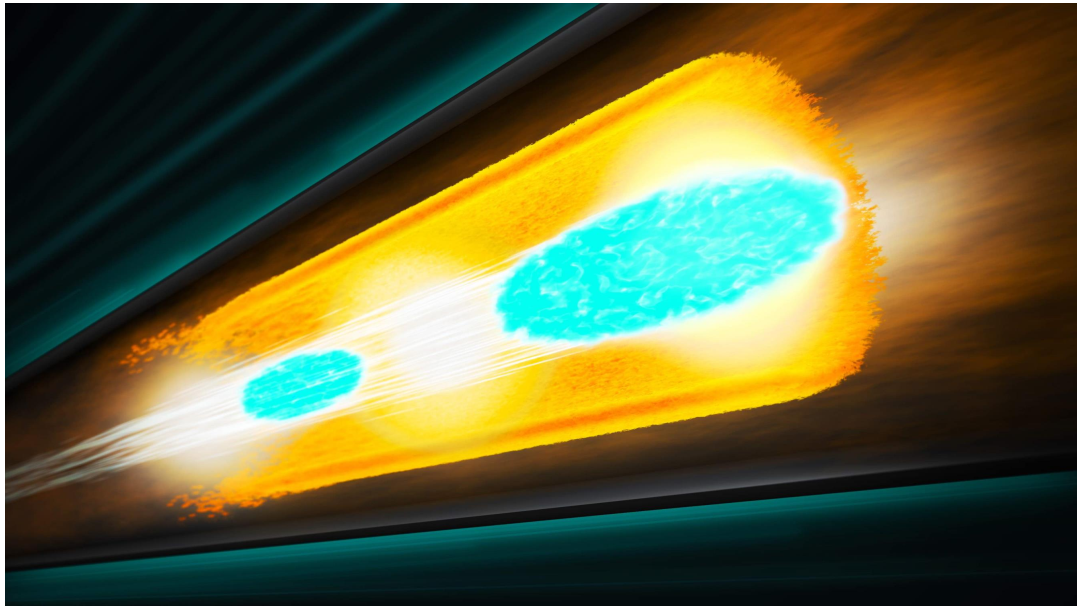
We tested this scenario in both the quasi-linear and non-linear regimes. The quasi-linear *requires* large emittance.

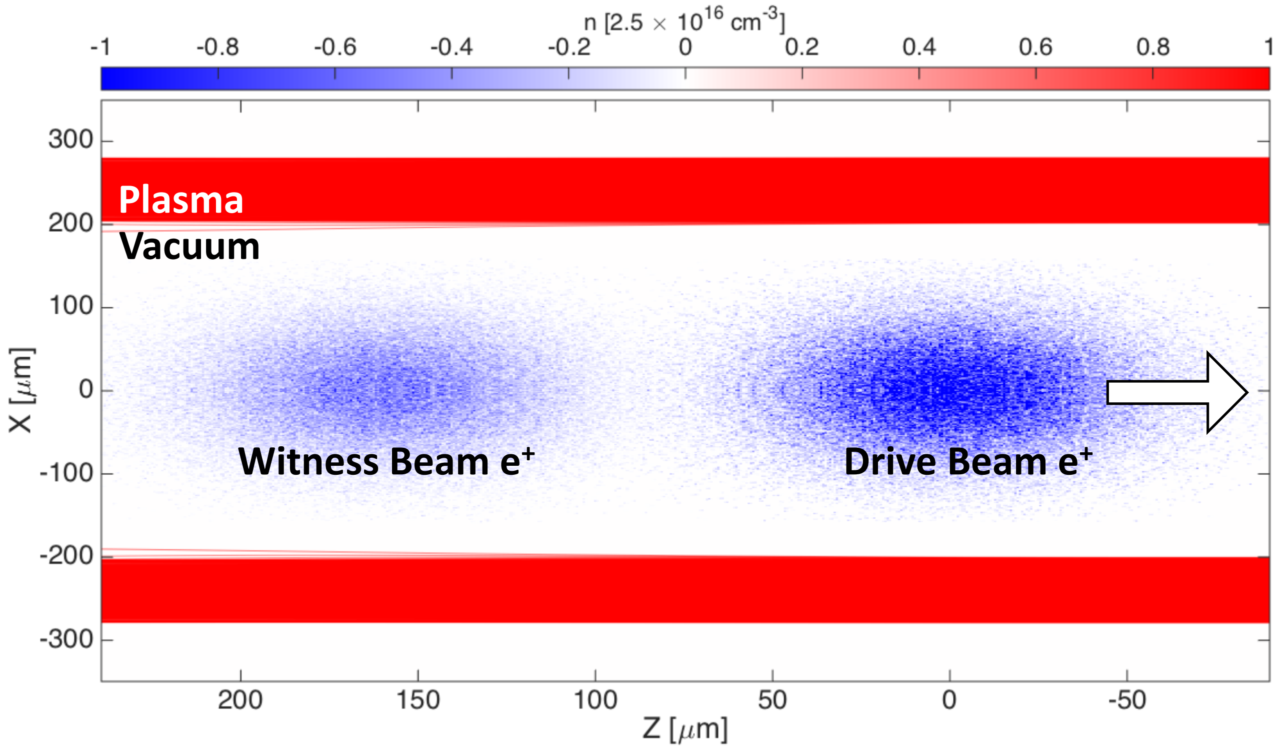




S. Doche *et al.*, Nat. Sci. Rep. 7, 14180 (2017)

The Hollow Channel Plasma Accelerator

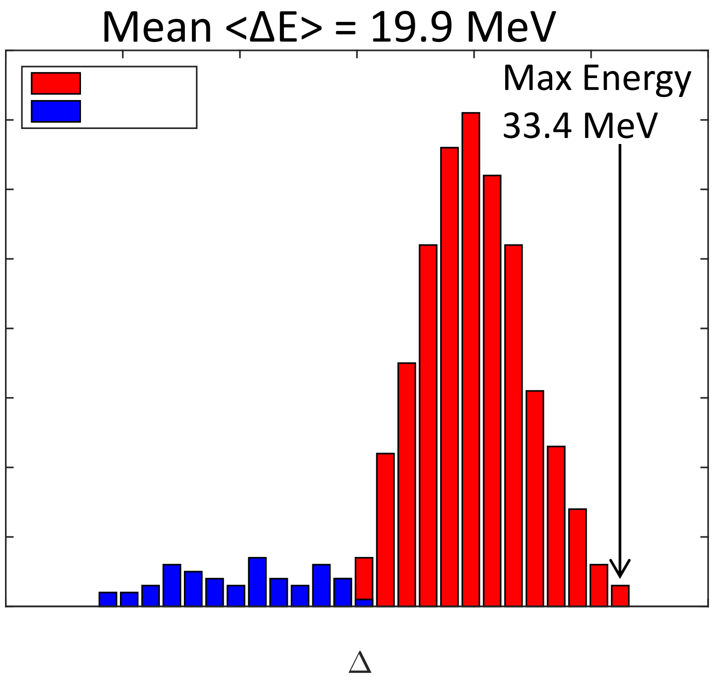


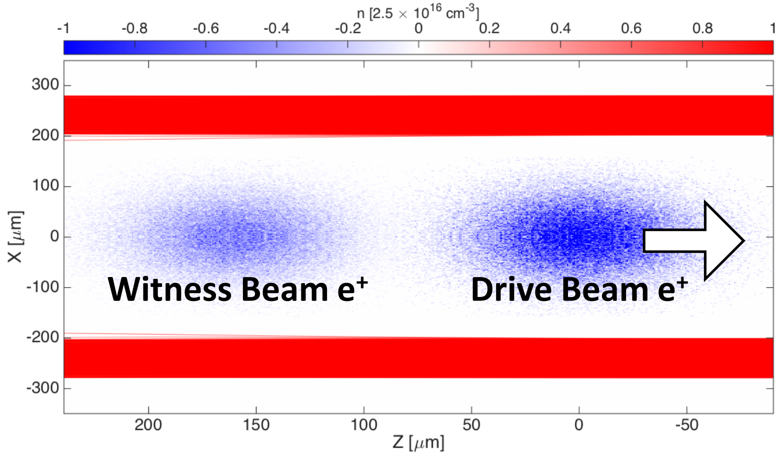


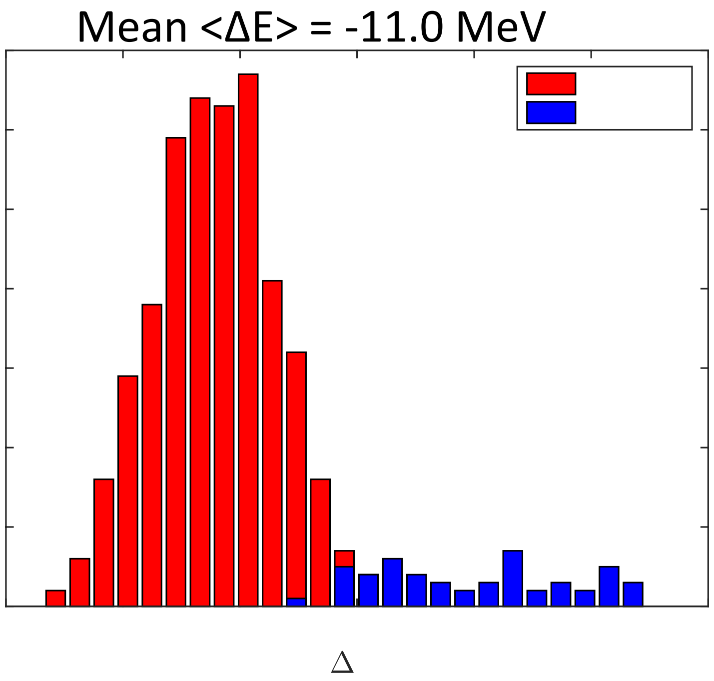
The Hollow Channel Plasma is a *structure* that symmetrizes the response of the plasma to electron and positron beams.

There is no plasma on-axis, and therefore no focusing/defocusing force from plasma ions.

Positron Acceleration





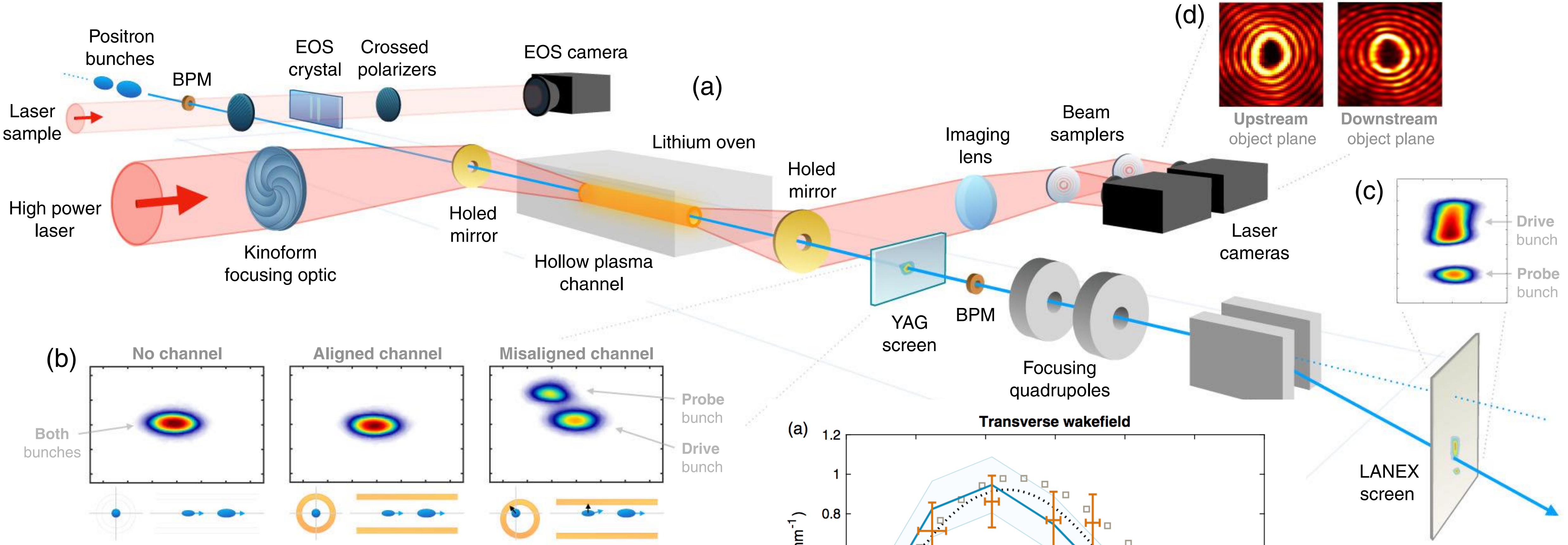


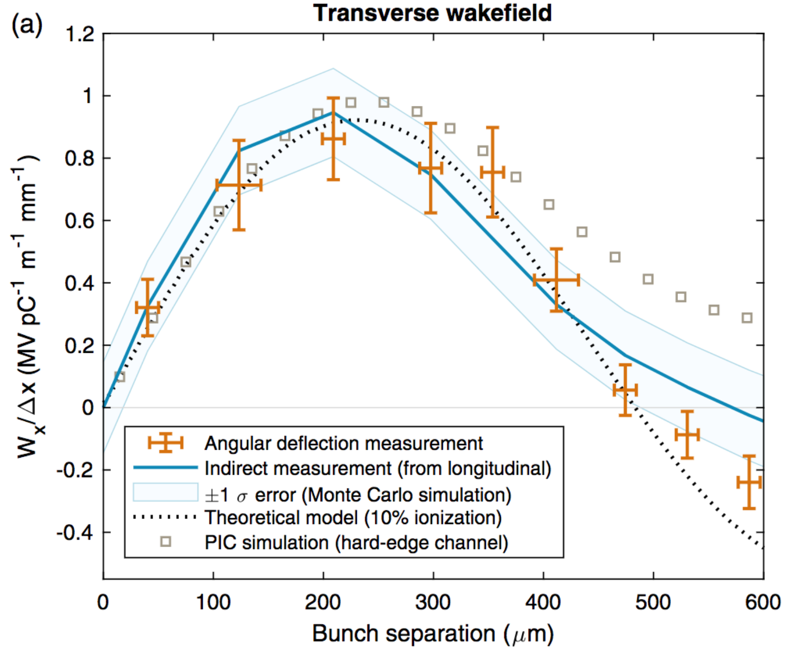
Witness beam gains energy from the wake.

Drive beam transfers energy to witness beam.

S. Gessner et. al. *In Preperation*

Transverse Fields in the Hollow Channel



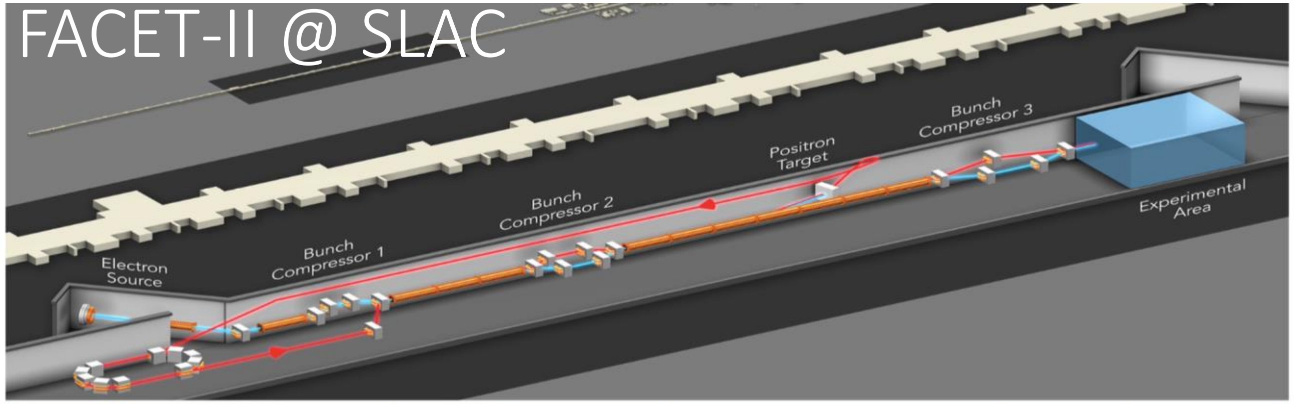


C. A. Lindstrøm et. al. *Phys. Rev. Lett.* 120 124802 (2018).

Positron Sources

Positron PWFA Facilities

FACET-II @ SLAC



Electron Beam Parameter	Baseline Design	Operational Ranges	Positron Beam Parameter	Baseline Design	Operational Ranges
Final Energy [GeV]	10	4.0-13.5	Final Energy [GeV]	10	4.0-13.5
Charge per pulse [nC]	2	0.7-5	Charge per pulse [nC]	1	0.7-2
Repetition Rate [Hz]	30	1-30	Repetition Rate [Hz]	5	1-5
Norm. Emittance $\gamma\varepsilon_{x,y}$ at S19 [μm]	4.4, 3.2	3-6	Norm. Emittance $\gamma\varepsilon_{x,y}$ at S19	10, 10	6-20
Spot Size at IP $\sigma_{x,y}$ [μm]	18, 12	5-20	Spot Size at IP $\sigma_{x,y}$ [μm]	16, 16	5-20
Min. Bunch Length σ_z (rms) [μm]	1.8	0.7-20	Min. Bunch Length σ_z (rms)	16	8
Max. Peak current I_{pk} [kA]	72	10-200	Max. Peak current I_{pk} [kA]	6	12

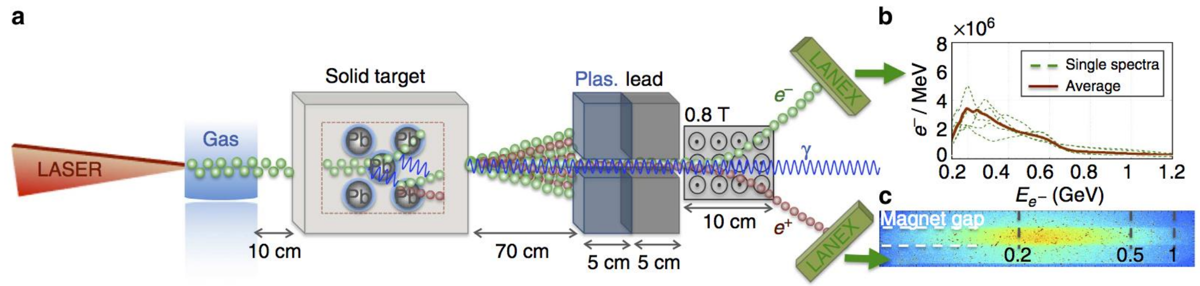
SLAC is the only laboratory that provides positron beams for plasma wakefield experiments.

World-wide research on this topic is impeded by a lack of access to PWFA-quality positron beams.

Novel Positron Sources

Laser Generated Positron Beams

G. Sarri, Nat. Comm., 6747, 2015



The "all plasma" concept uses an LWFA accelerated electron beam to create positrons in a high-Z target.

Advantages:

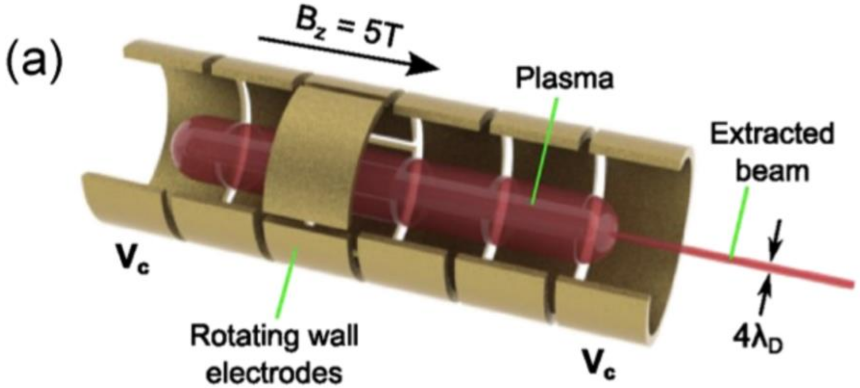
- The positron beam will be very short in time
- Compact source
- This solution takes advantage of existing tools in LWFA labs

Disadvantages:

- Large energy spread
- Large divergence

Positron Beams from Electro-static Traps

J. Danielson, Rev. Mod. Phys., Vol. 87, 2015



The electrostatic trap accumulates positrons from a radioactive source, cools them, and then ejects them.

Advantages:

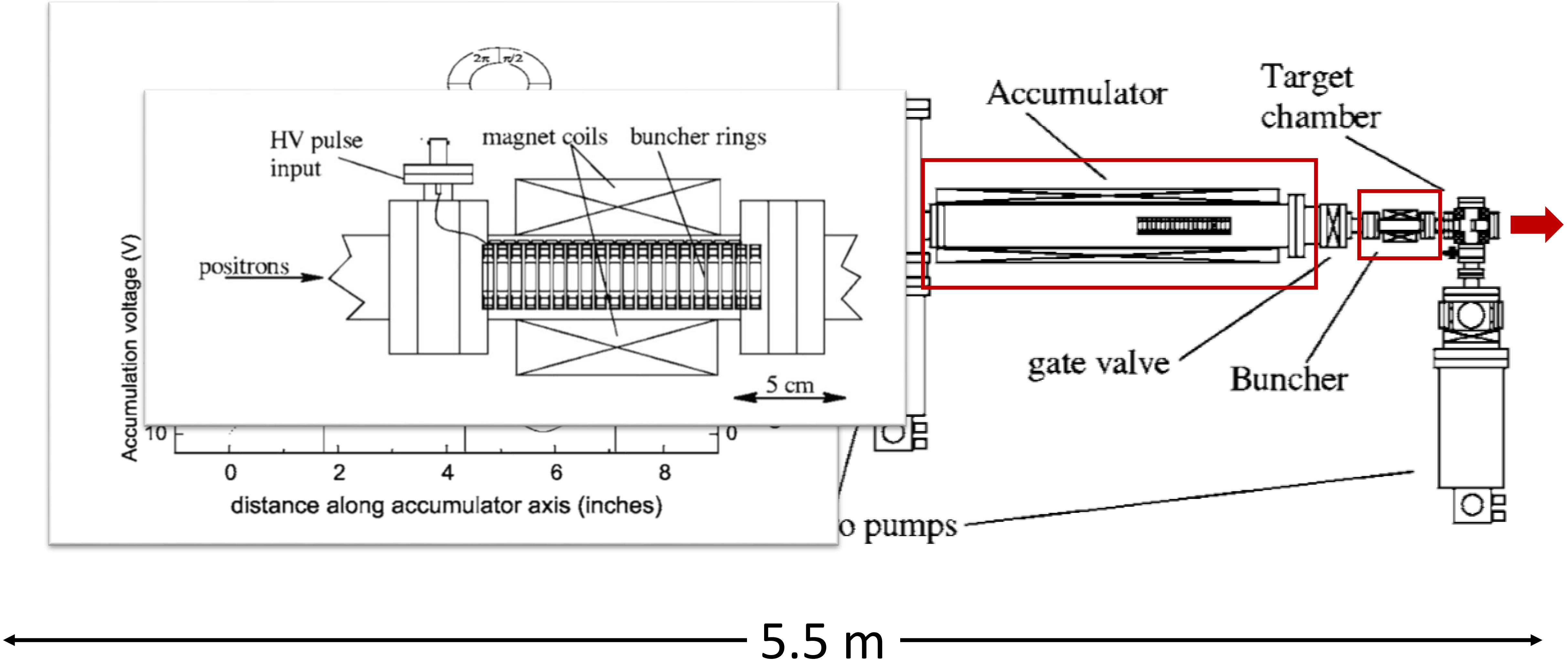
- Extremely cold beams (small transverse emittance)
- Compact source

Disadvantages:

- Low initial energy
- Long bunch length
- Low rep-rate

Positron Beams from Electrostatic Traps

D. B. Cassidy et al, Rev. Sci. Inst. 77, 073106, (2006)



Positrons are compressed longitudinally with a buncher.

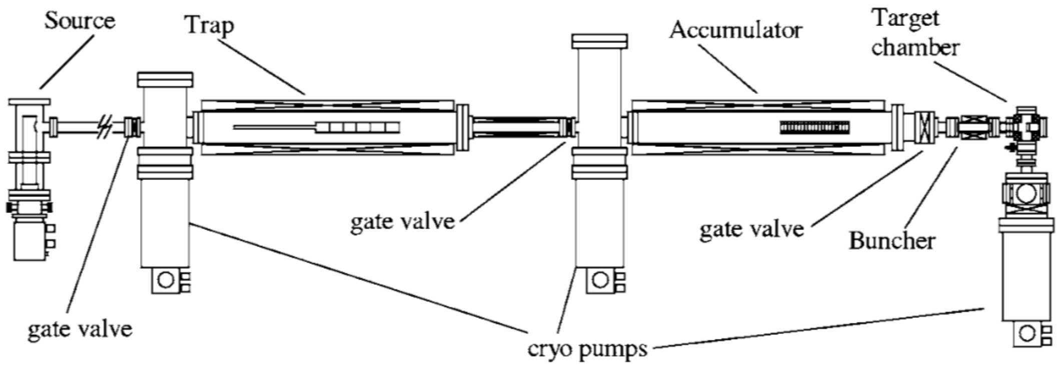
Positron Beams Parameters

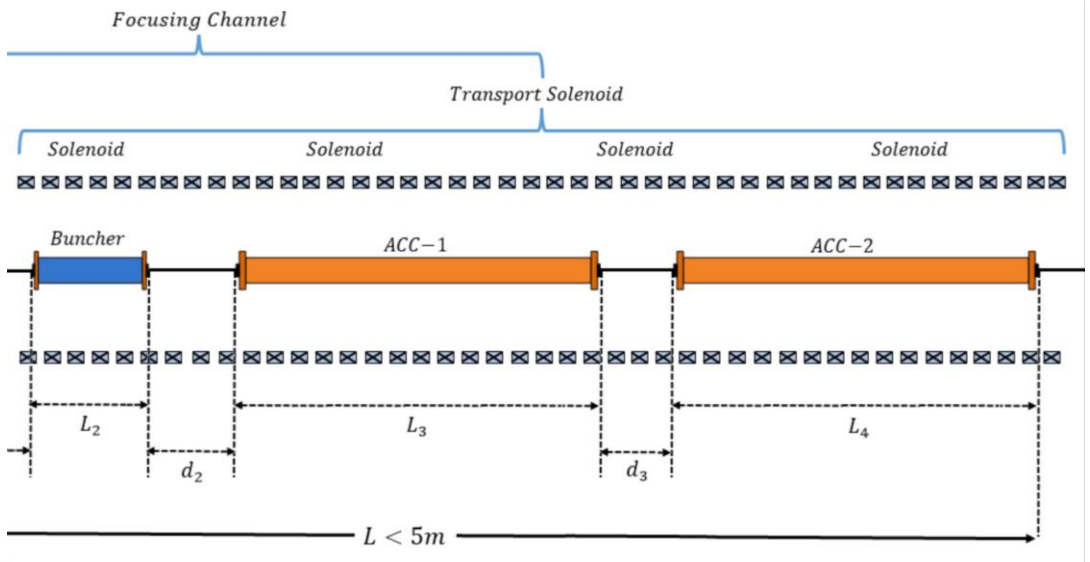
Cassidy et. al. have achieved the following beam parameters with this approach:

- Charge: 10^7 positrons per bunch
- Bunch length: < 1 ns after compression
- Energy spread: 5-10 kV
- Transverse beam energy: < 1 eV
- Transverse spot size: < 1 mm

Positron Capture and Acceleration

M. Kelisani





Idea: Couple positron accumulator into conventional RF accelerator structure.

By placing an RF capture section at the location of the “time focus”, we can start to accelerate and bunch the positron beam.

Challenges

M. Kelisani

- Can we compress the positron beam from ns-scale to ps-scale using just bunching cavities?
  - Do we need a chirp-and-chicane scheme?
- Can we maintain the high quality of the positron beam through the compression process?
- How does this scale with beam charge?

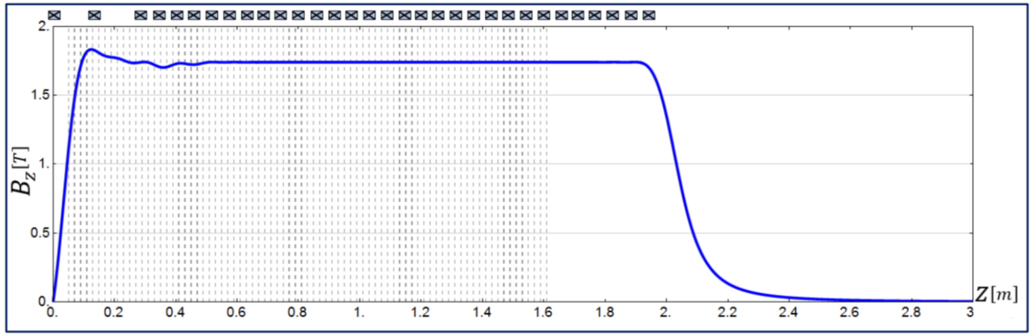


Fig.1: On axis magnetic field profile for the designed focusing channel along the injector.

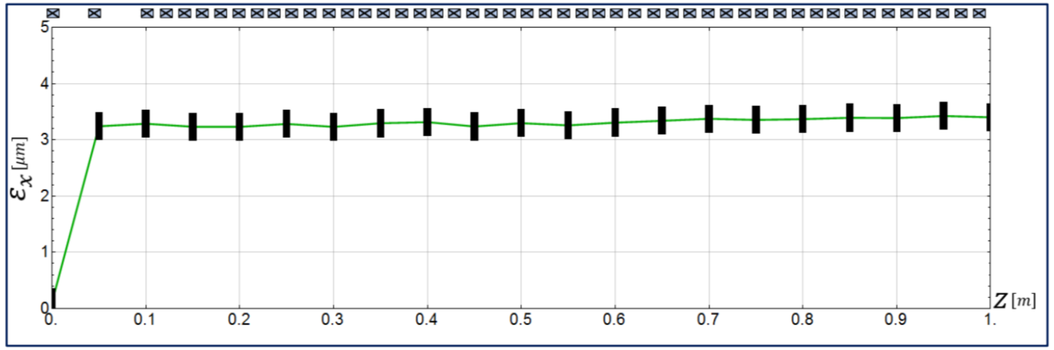


Fig.4: Normalized emittance variations along the injector

Conclusions

- The acceleration of positrons in plasma is a critical challenge to be solved on the path to a PLC.
- Positron PWFA is conceptually more challenging than electron PWFA, and it is also severely understudied.
- No progress without experimental facilities!
- We are investigating alternative sources.

Thank You!