

Accelerator Physics Opportunities at JLab and the Compact Positron Source at SLAC

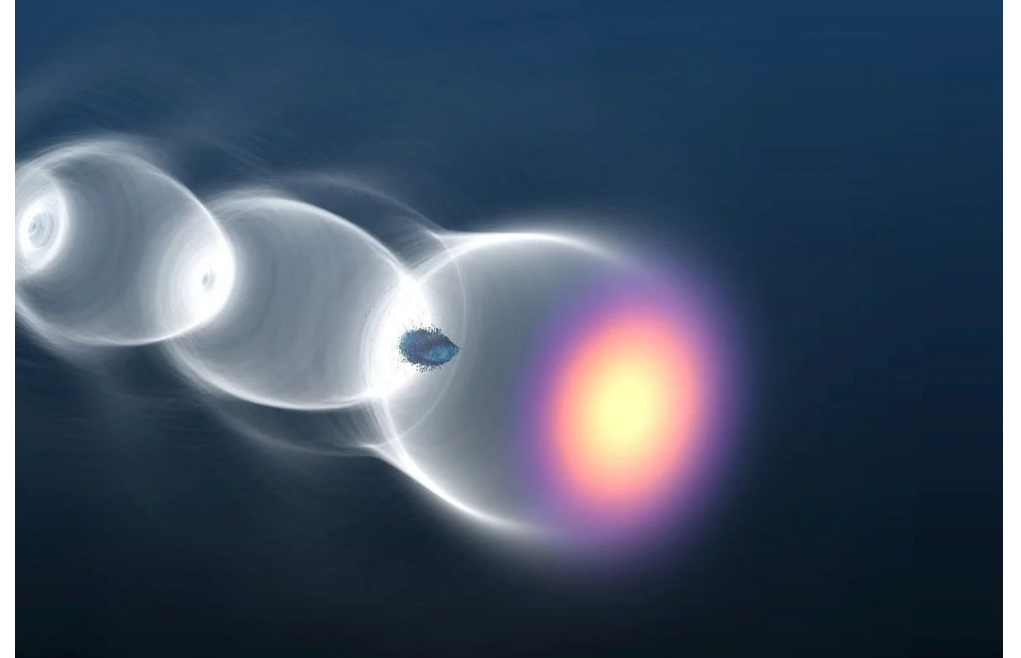
Spencer Gessner, Sophie Crisp SLAC

LEEPP Workshop, JLab
March 26, 2026

Plasma Acceleration

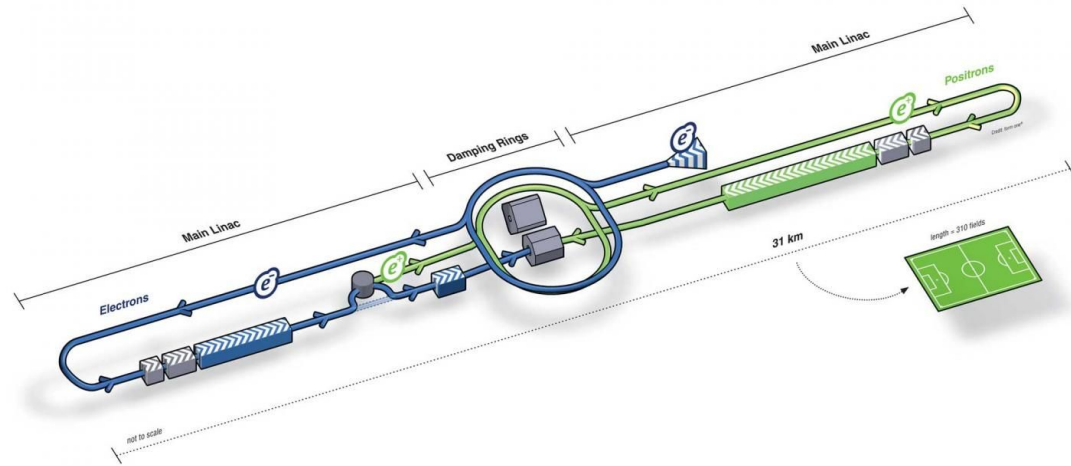


JLAB SRF Cavities 10-20 MV/m

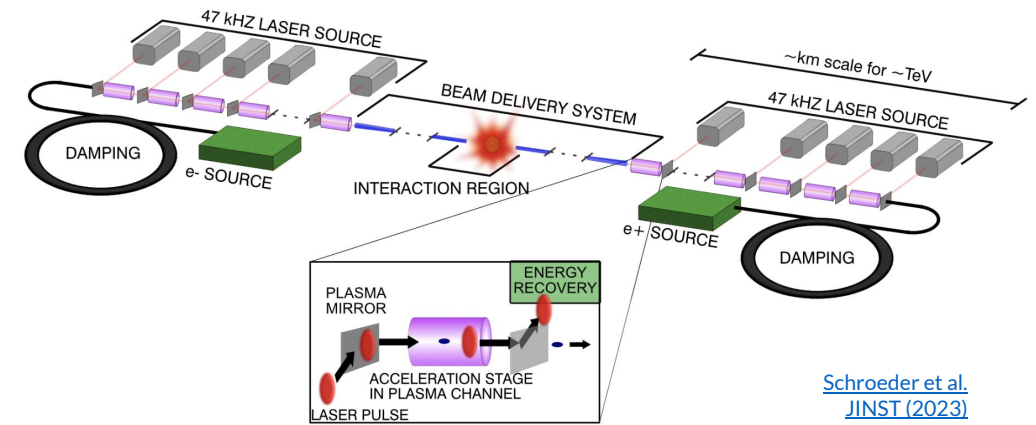


Plasma Accelerator 1-100 GV/m

Future Colliders



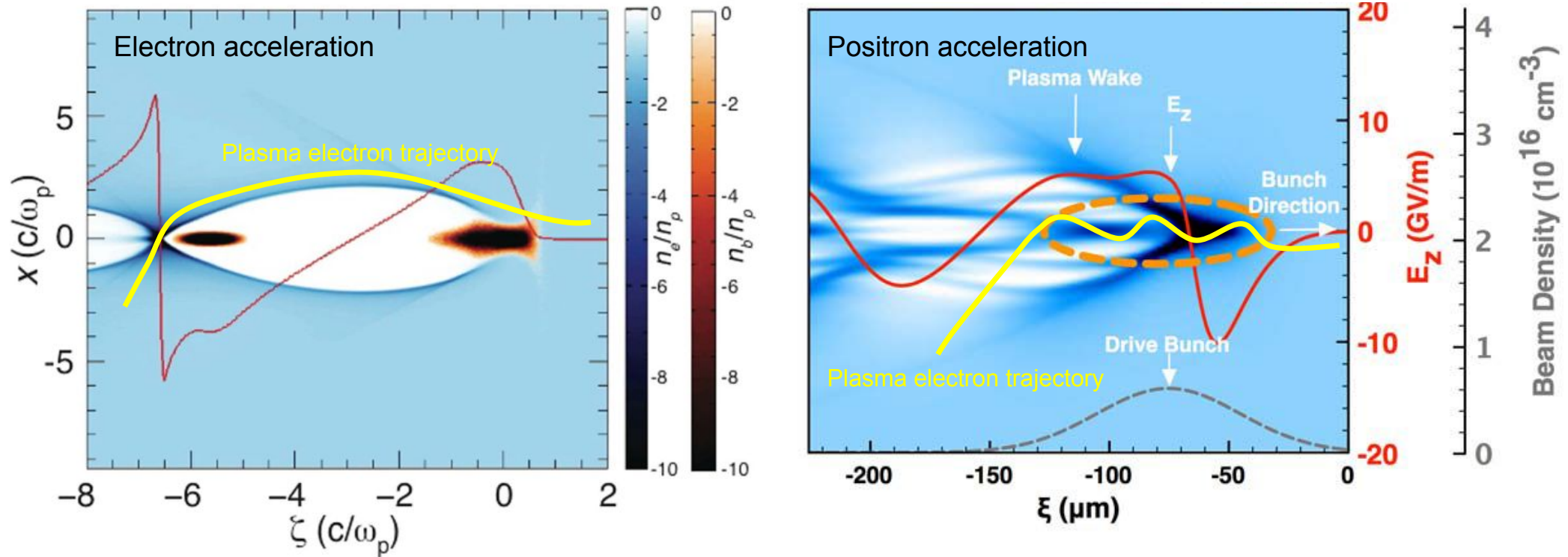
ILC Electron-Positron Collider
250 GeV - 1 TeV



Plasma Collider
10 TeV

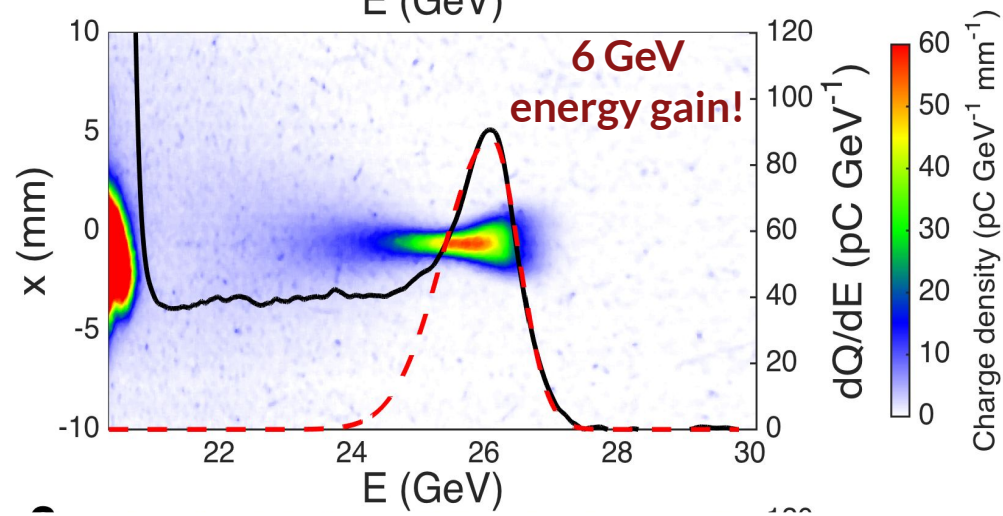
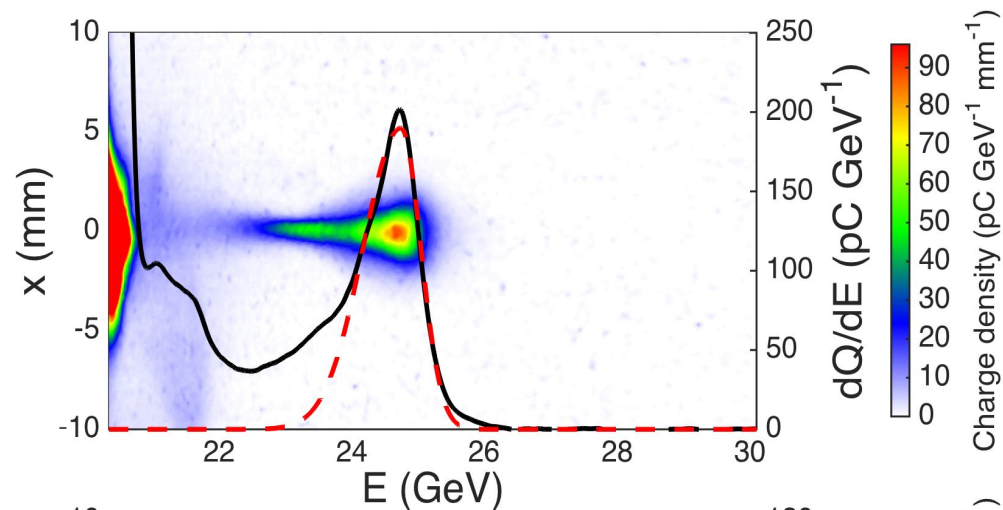
[Schroeder et al. JINST \(2023\)](#)

Positron Acceleration in Plasma

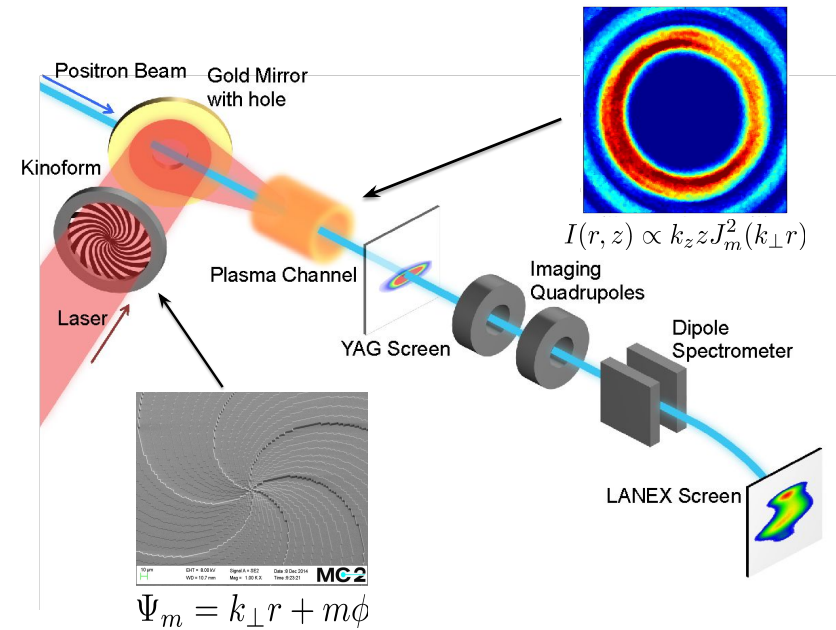


Plasmas are composed of mobile electrons and immobile ions. The plasma response to beams of opposite charge is *asymmetric*.

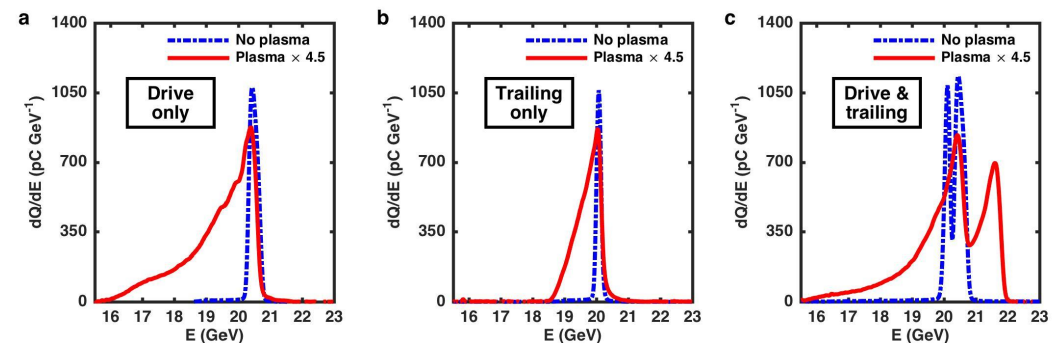
Experimental results on e^+ acceleration at FACET



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



S. Gessner et al. Nat. Comm. 7, 11785

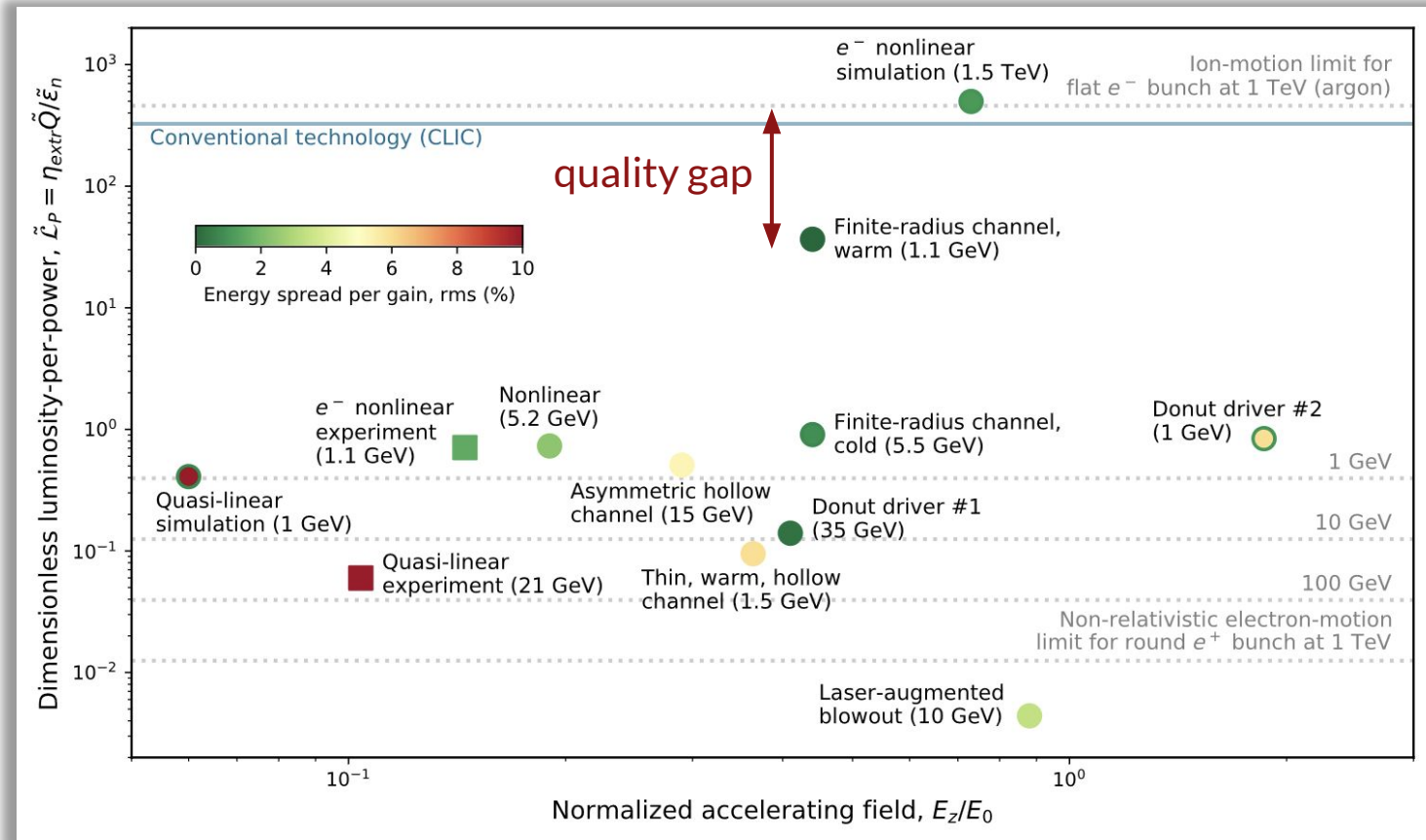


A. Doche et al., Nat. Sci. Rep. 7, 14180 (2017)

Review of Positron Acceleration in Plasma

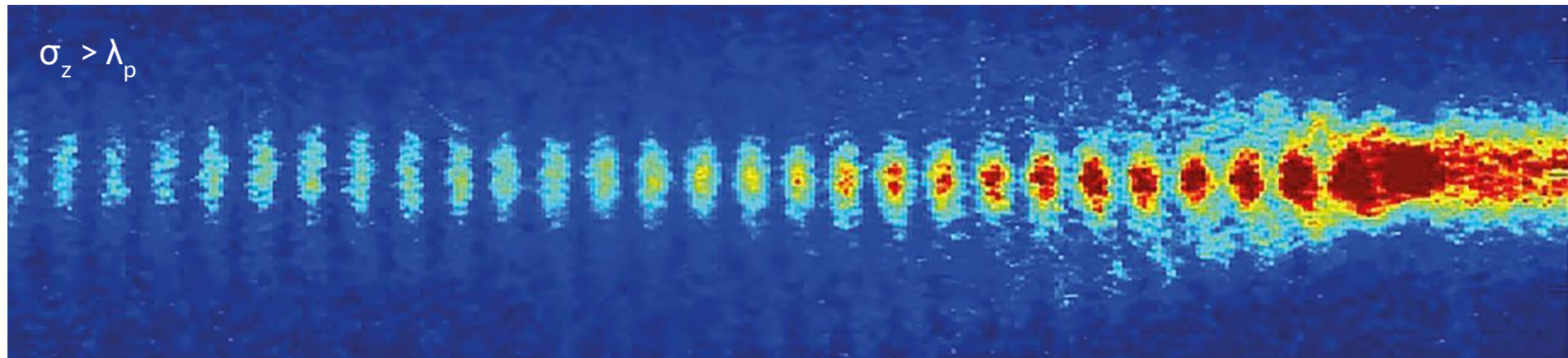
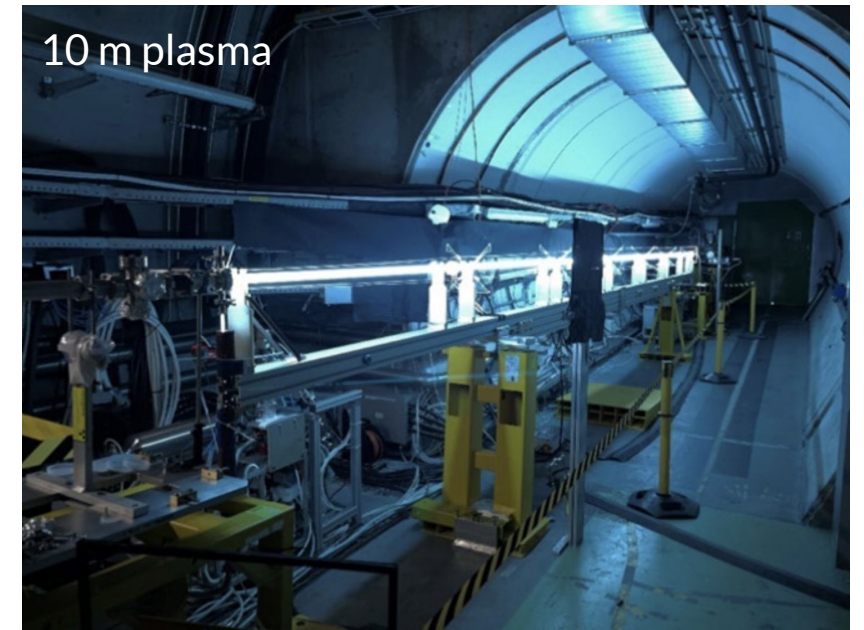
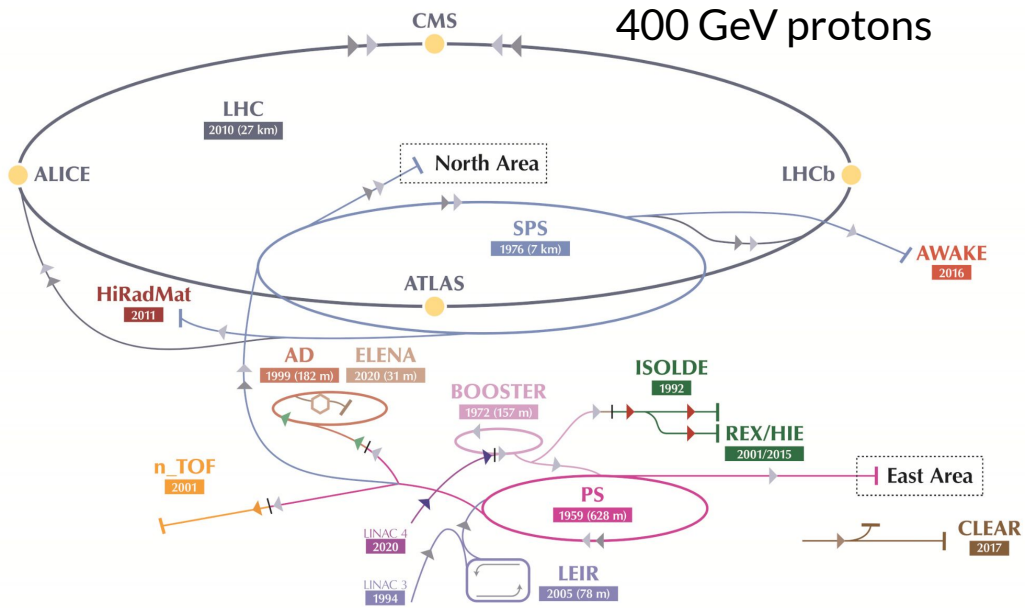
Review: Positron Acceleration in Plasma Wakefields

Cao, Lindstrom, Adli, Corde, Gessner, PRAB 2024

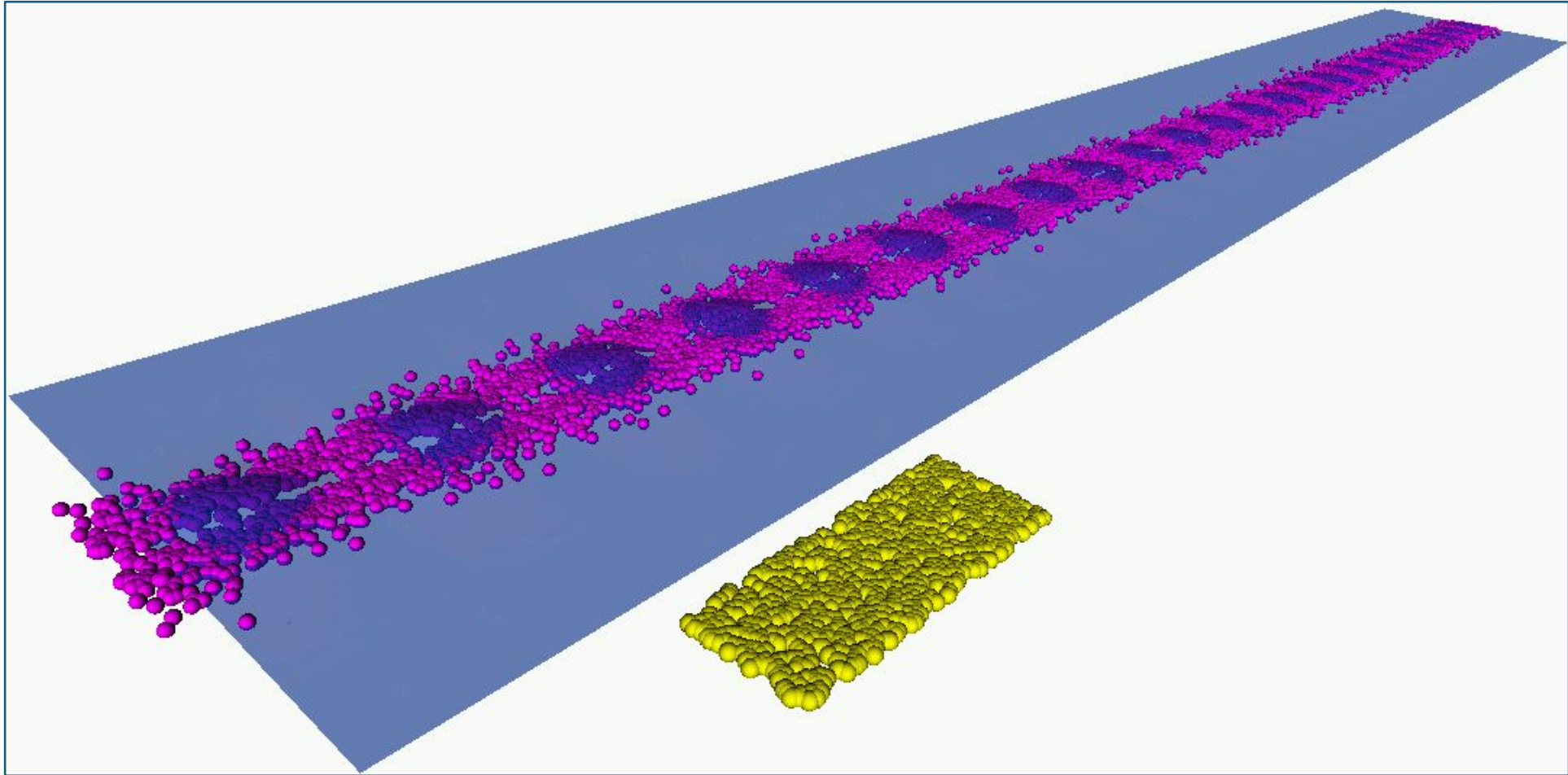


Positron acceleration in plasma experiments lags behind electron acceleration in plasma, in part due to a lack of experimental opportunities.

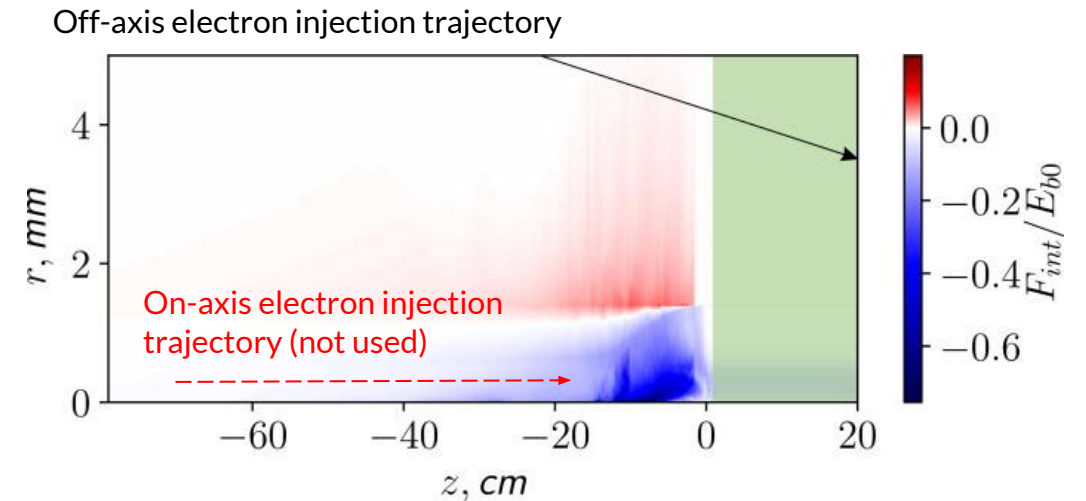
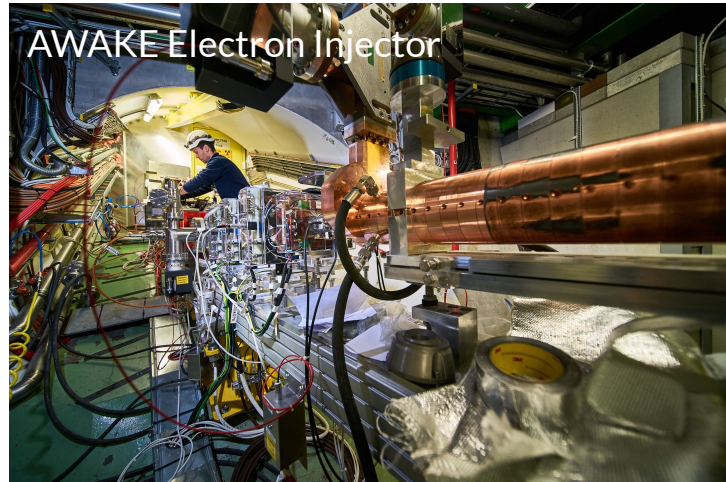
AWAKE at CERN



Electron Injection



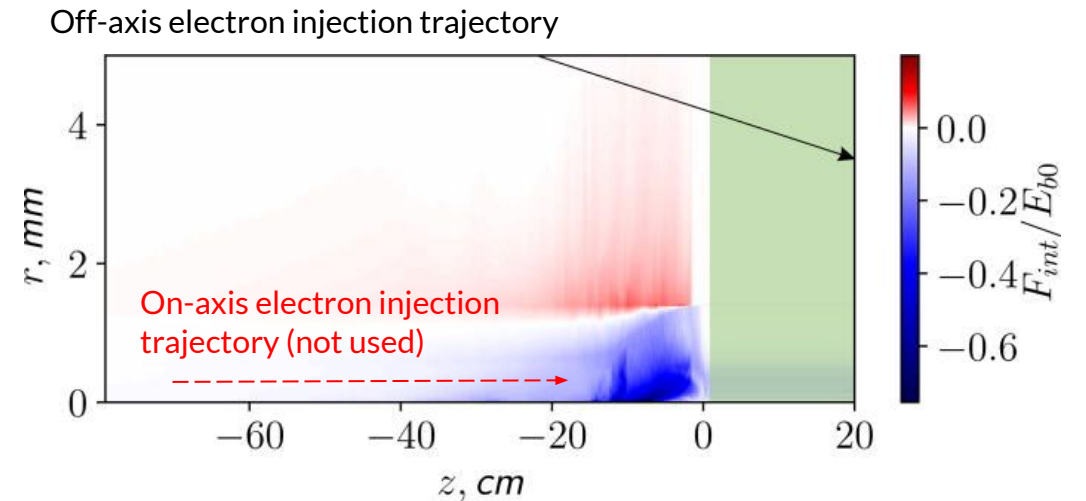
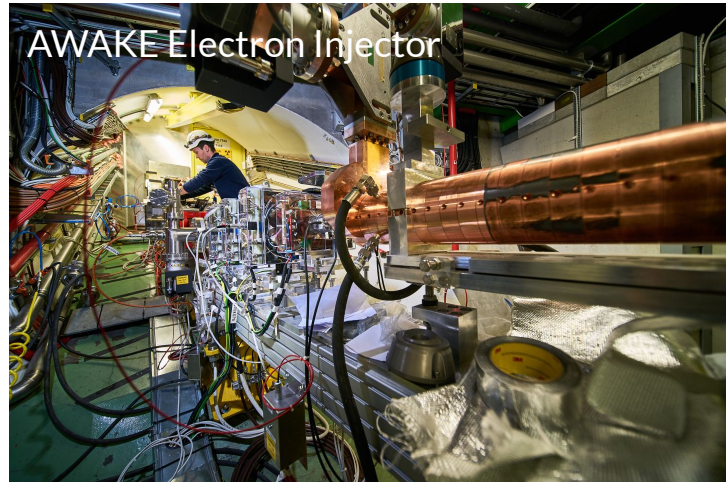
Seed of an Idea



A. Gorn et. al. *Phys. Plasmas* 25, 063108 (2018)

“This would be a lot easier with positrons.”

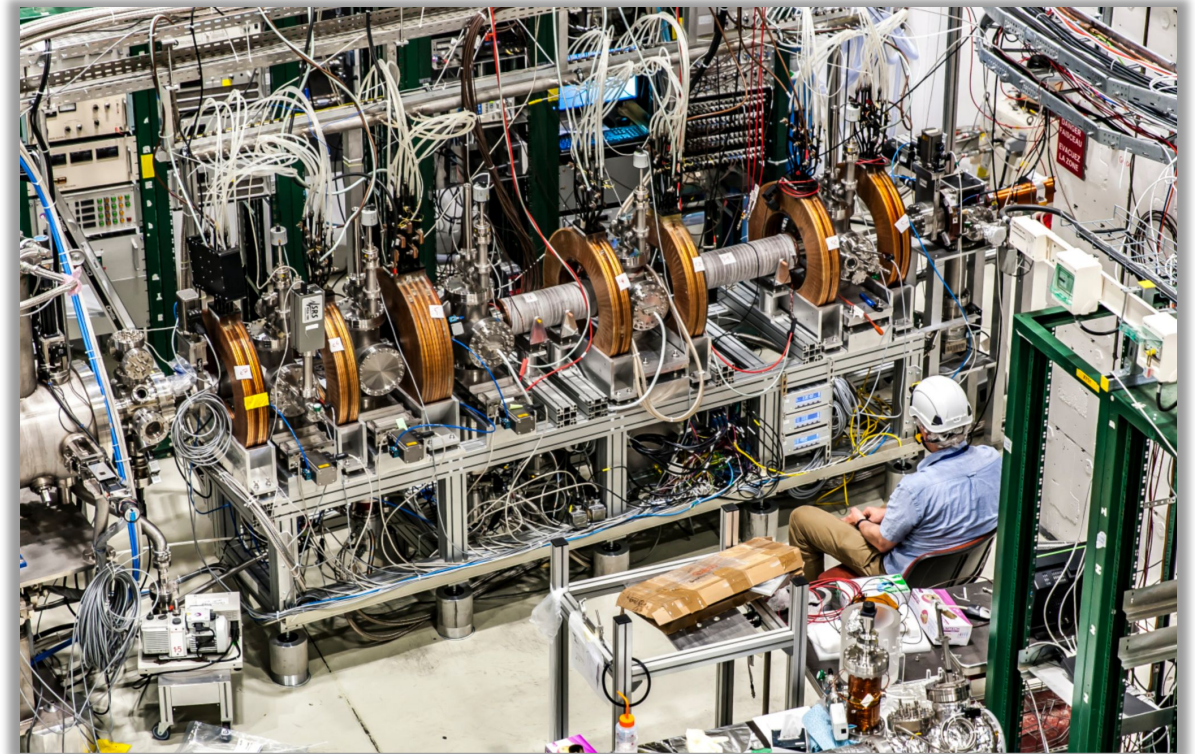
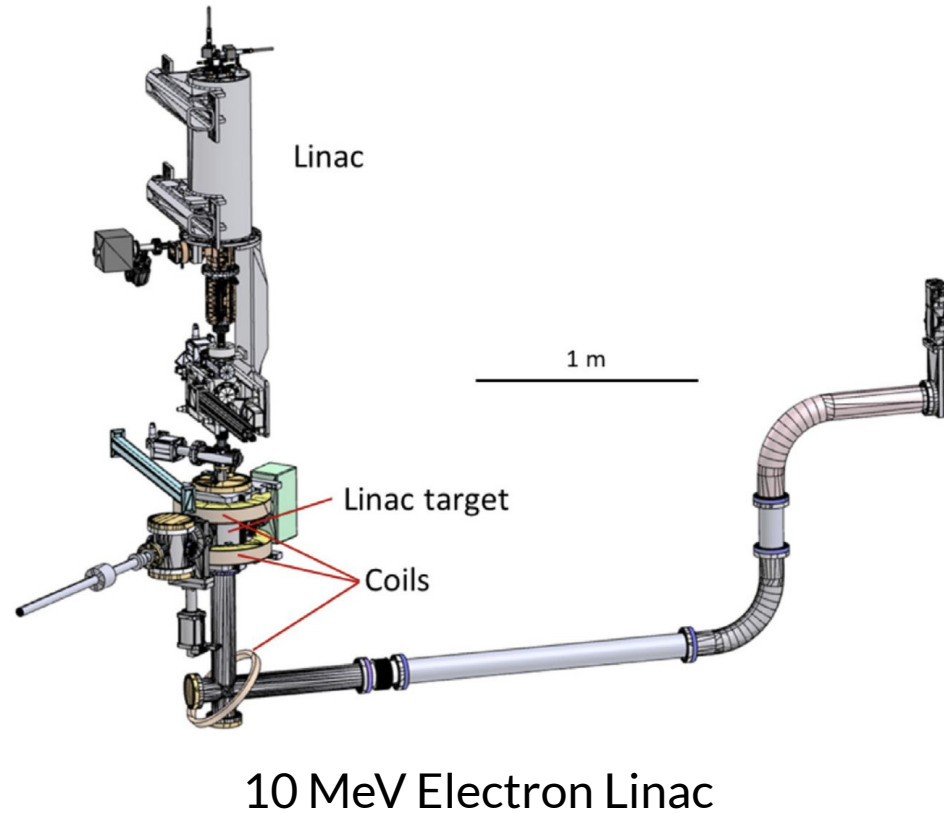
Seed of an Idea



A. Gorn et. al. *Phys. Plasmas* 25, 063108 (2018)



GBAR Experiment

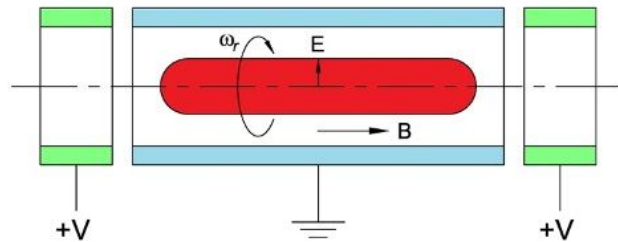


GBAR Positron Accumulator

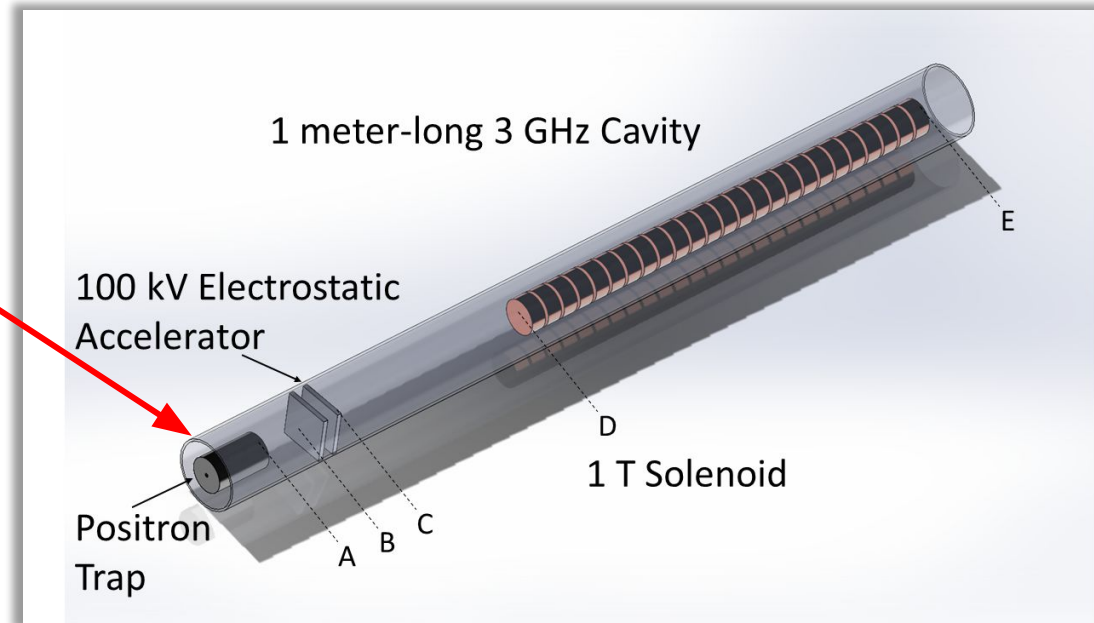
GBAR positron source is few-meter scale. Fits in AWAKE tunnel.

Positron Beams from Traps

Penning-Malmberg Trap

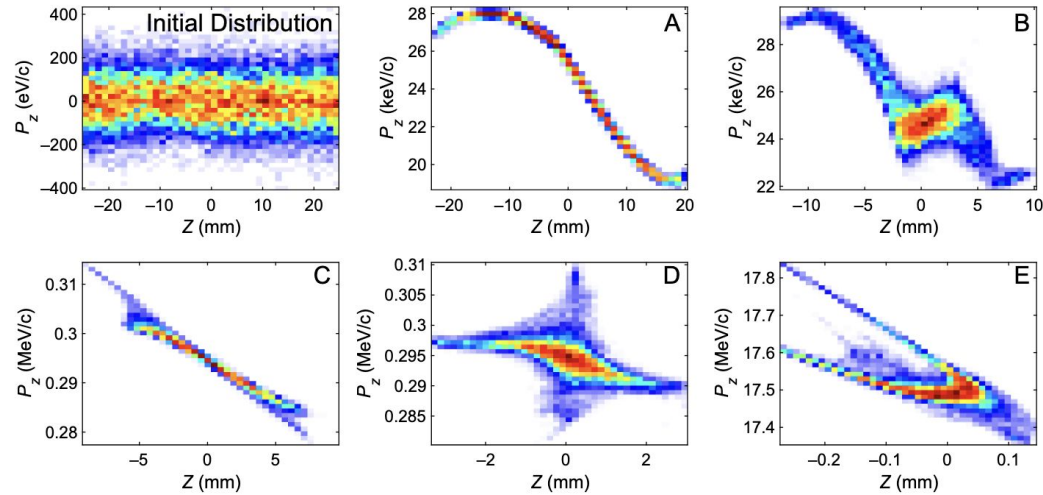


Compact Source of Positron Beams with Small Thermal Emittance.
R. Hessami and S. Gessner. Phys. Rev. Accel. Beams 2023.



GBAR positron bunch is too long → investigate bunch compression.

Positron Beams from Traps



Longitudinal phase space during bunch compression

TABLE II. Beam parameters at the end of the simulation.

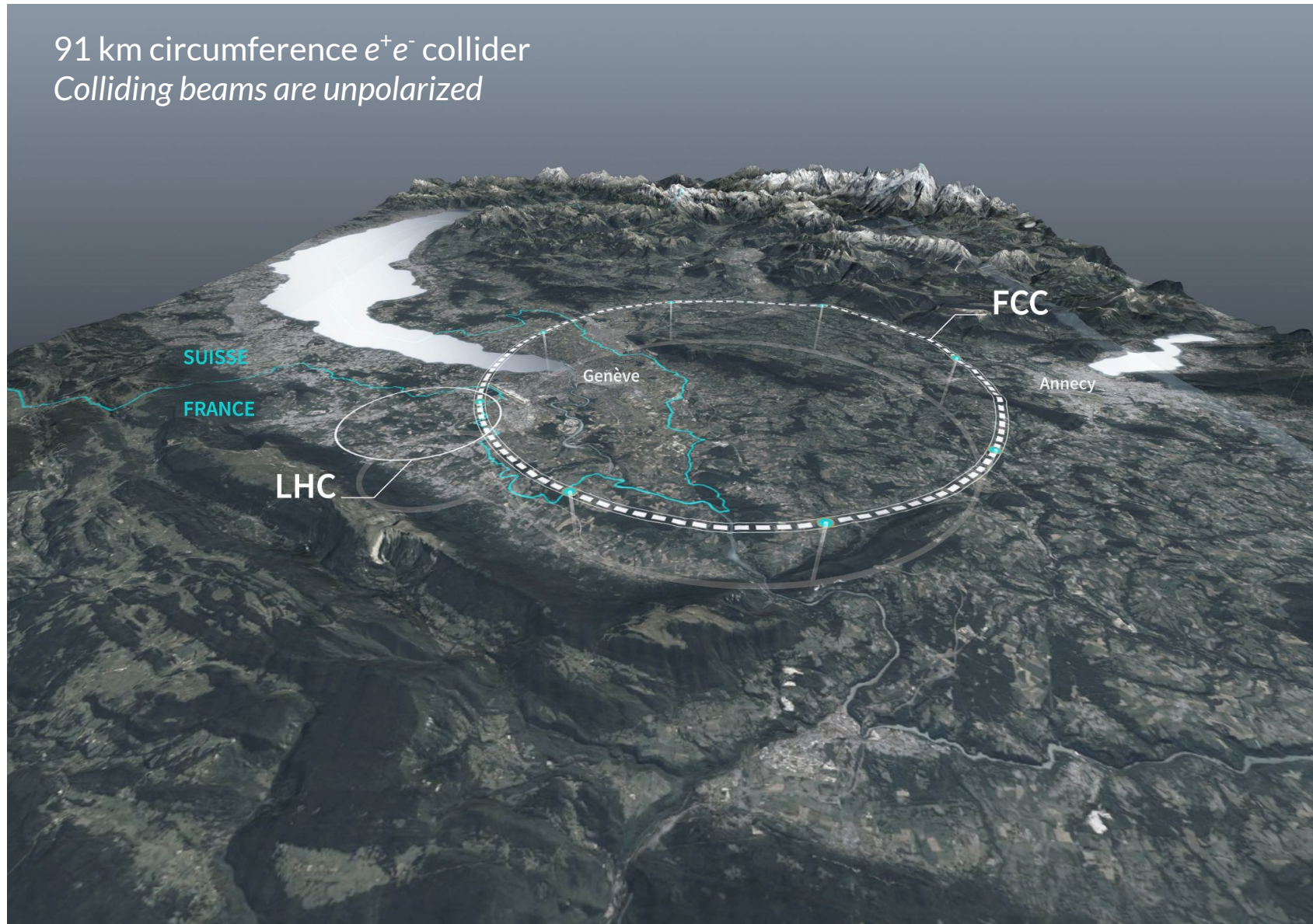
| Beam parameter | Value |
|----------------------|------------------------|
| Beam energy | 17.6 MeV |
| Beam charge | 15.43 pC |
| Bunch length (rms) | 190 μm |
| Energy spread (rms) | 0.76% |
| Transverse emittance | 0.60 $\mu\text{m rad}$ |

Final bunch length < 1 ps with 1E8 positrons.

AWAKE operates at 1 pulse every 30 seconds.
Implies 3.3E6 trapped positrons/second.
Consistent with GBAR parameters ✓

FCC-ee

91 km circumference e^+e^- collider
Colliding beams are unpolarized



FCC-ee Z-pole operation

Precision Measurements

J. Keintzel, CERN

Table 15: Calculated uncertainties on the quantities most affected by the center-of-mass energy uncertainties, under the final systematic assumptions.

| Quantity | statistics | ΔE_{CMabs} 100 keV | $\Delta E_{CMSyst-ptp}$ 40 keV | calib. stats. $200 \text{ keV} / \sqrt{N^i}$ | σE_{CM} $(84) \pm \mathbf{0.05} \text{ MeV}$ | |
|----------|--|-------------------------------|--|---|---|--|
| Z { | m_Z (keV) | 4 | 100 | 1 | – | Statistical precisions |
| | Γ_Z (keV) | 4 | 2.5 | 1 | 10 | 4 keV at Z |
| | $\sin^2 \theta_W^{eff} \times 10^6$ from $A_{FB}^{\mu\mu}$ | 2 | – | 0.1 | – | 100 keV per W |
| | $\frac{\Delta \alpha_{QED}(M_Z)}{\alpha_{QED}(M_Z)} \times 10^5$ | 3 | 0.1 | 0.9 | – | 0.05 |
| WW { | *) | | 300 keV | 150 keV | | Aim for same order of magnitude for systematic precision |
| | m_W (MeV) | 0.200 | (?) | 75 keV? | | |
| | Γ_W (MeV) | | (75?) | small | OK | |

*) further clarification/documentation needed for W uncertainties in WW studies (threshold meast, direct reconstruction)

EPOL working group aims at reducing the systematic error on the E_{CM} measurement



FCC-ee Z-pole operation

Precision Measurements

J. Keintzel, CERN

Table 15: Calculated uncertainties on the quantities most affected by the center-of-mass energy uncertainties, under the final systematic assumptions.

Part-per-million energy calibration!

| Quantity | statistics | ΔE_{CMabs} | ΔE_{CMSys}^{ptp} | calib. stats. | σE_{CM} | |
|---|--------------|--------------------|--------------------------|------------------------------|-----------------------------|--|
| | | 100 keV | 40 keV | $200 \text{ keV}/\sqrt{N^i}$ | $(84) \pm 0.05 \text{ MeV}$ | |
| Z { m_Z (keV) | 4 | 100 | 28 | 1 | – | Statistical precisions |
| Z { Γ_Z (keV) | 4 | 2.5 | 22 | 1 | 10 | 4 keV at Z |
| Z { $\sin^2\theta_W^{eff} \times 10^6$ from $A_{FB}^{\mu\mu}$ | 2 | – | 2.4 | 0.1 | – | |
| Z { $\frac{\Delta\alpha_{QED}(M_Z)}{\alpha_{QED}(M_Z)} \times 10^5$ | 3 | 0.1 | 0.9 | – | 0.05 | 100 keV per W |
| WW { *) | | | 300 keV | 150 keV | | Aim for same order of magnitude for systematic precision |
| WW { m_W (MeV) | 0.200 | (?) | 75 keV? | | | |
| WW { Γ_W (MeV) | | | (75?) | small | OK | |

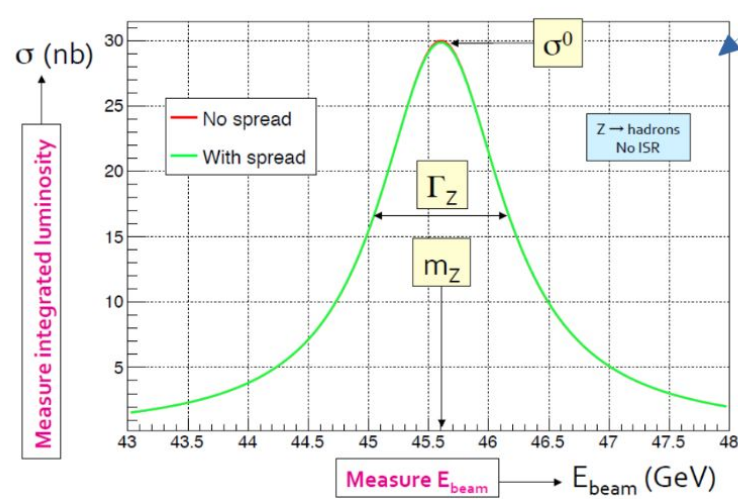
*) further clarification/documentation needed for W uncertainties in WW studies (threshold meas, direct reconstruction)

EPOL working group aims at reducing the systematic error on the E_{CM} measurement

FCC-ee Z-pole operation

A. Blondel

Scan Points

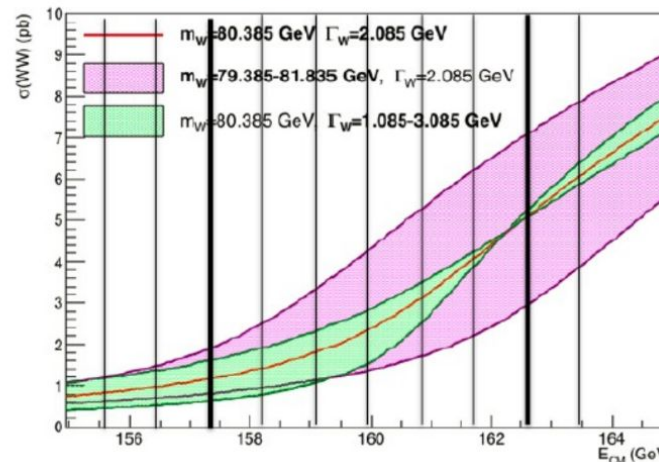
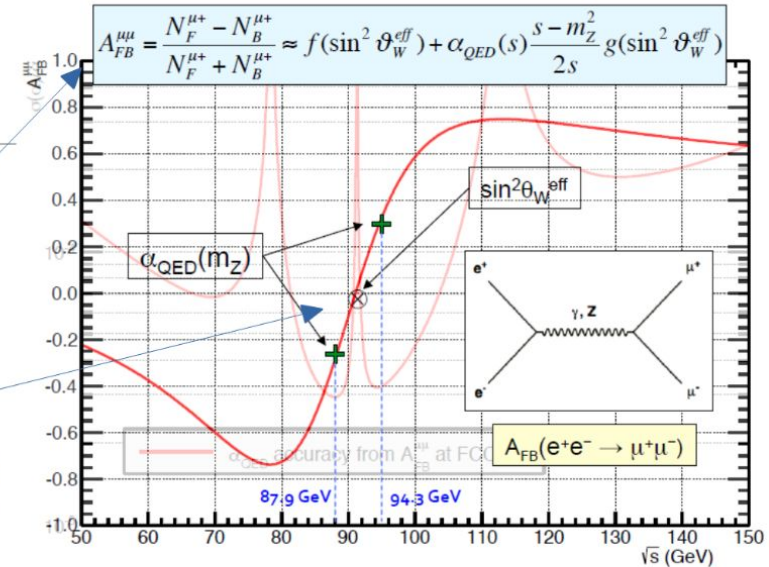


Z mass and width

Forward-Backward Assymetry links the weak coupling with the EM-coupling

To measure the slope around the Z resonance at $E_{CM} = 91$ GeV, a scan at different energies is proposed

| Scan point | \sqrt{s} (GeV) | E_b (GeV) | Spin tune |
|----------------------|------------------|-------------|-----------|
| $\sqrt{s_-}$ A | 87.69 | 43.85 | 99.5 |
| $\sqrt{s_-}$ Request | 87.9 | 43.95 | 99.7 |
| $\sqrt{s_-}$ B | 88.57 | 44.28 | 100.5 |
| $\sqrt{s_0}$ | 91.21 | 45.61 | 103.5 |
| $\sqrt{s_+}$ A | 93.86 | 46.93 | 106.5 |
| $\sqrt{s_+}$ Request | 94.3 | 47.15 | 107.0 |
| $\sqrt{s_+}$ B | 94.74 | 47.37 | 107.5 |



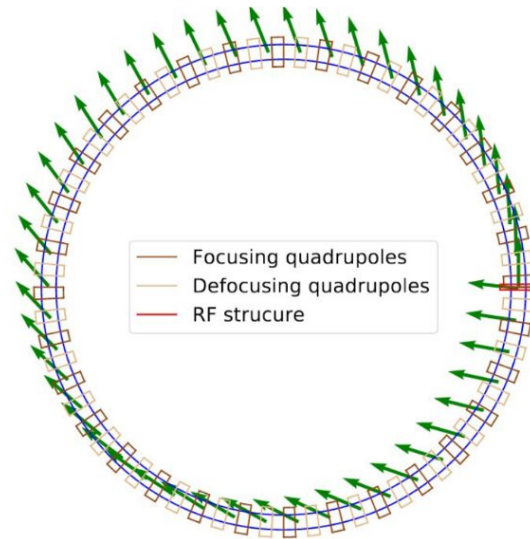
W mass and width have presently rather large uncertainties \rightarrow aim to be reduced

How to measure ppm energy changes?

A. Bogomyagkov, V. Caudan, E. Gianfelice-Wendt

Beam Energy and Spin Tune

- Beam energy is closely related to the spin tune ν



Precession of spin over one revolution in ideal machine with spin tune of about 0.25

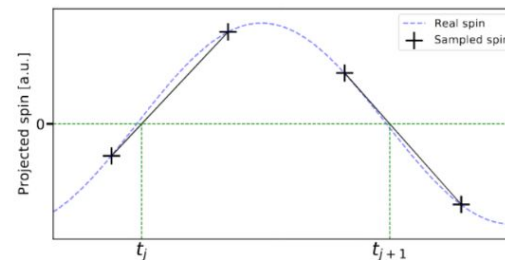
Measurement of spin tune will yield the beam energy
 → To be performed for the electron and the positron beam

E ... energy
 m ... mass
 c ... speed of light
 ν ... spin tune
 a ... anomalous magnetic dipole moment

$$E = mc^2 \left(\frac{\nu}{a} - 1 \right)$$

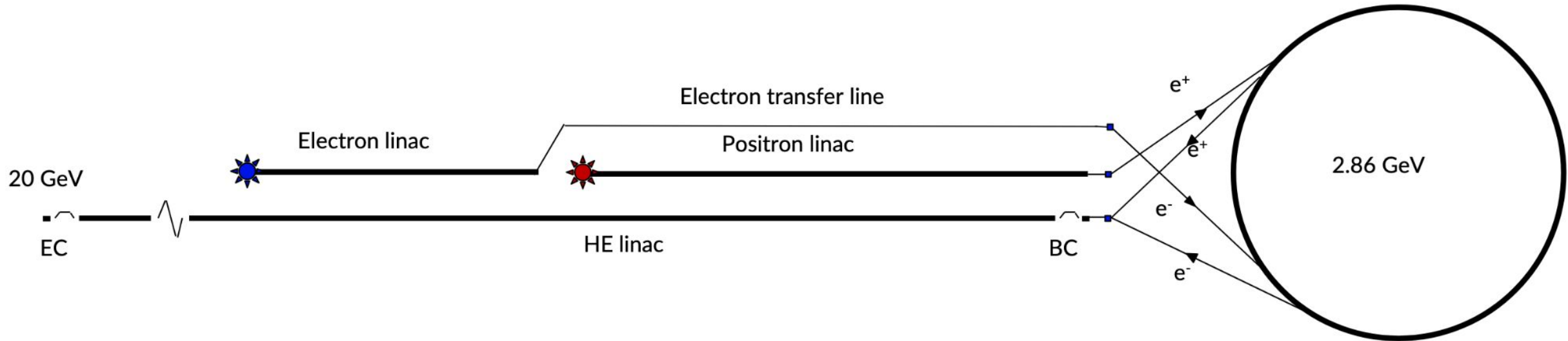
Spin tune measurement might not be exact beam energy measurement, e.g. **shift due to vertical or longitudinal magnetic fields** → to be studied in detail

Various contributions on the average beam energy estimated



| | | |
|--|-------------------------|---------------------|
| synchrotron oscillations | $\Delta E/E$ | $-2 \cdot 10^{-14}$ |
| Energy dependent momentum compaction | $\Delta E/E$ | 10^{-7} |
| Solenoid compensation | | $2 \cdot 10^{-11}$ |
| Horizontal betatron oscillations | $\Delta E/E$ | $2.5 \cdot 10^{-7}$ |
| Horizontal correctors*) | $\Delta E/E$ | $2.5 \cdot 10^{-7}$ |
| Vertical betatron oscillations **) | $\Delta E/E$ | $2.5 \cdot 10^{-7}$ |
| Uncertainty in chromaticity correction | $O(10^{-6}) \Delta E/E$ | $5 \cdot 10^{-8}$ |
| invariant mass shift due to beam potential | | $4 \cdot 10^{-10}$ |

Polarized Positrons at FCC?



Option 1: Inject unpolarized positrons into FCC ring and wait for them to polarize via Sokolov-Ternov Effect.

Problem: Polarization is 250 hours without wigglers and 12 hours with wigglers. Too long!

Option 2: Pre-polarize positrons in 2.86 GeV damping ring. This is CERN's baseline design.

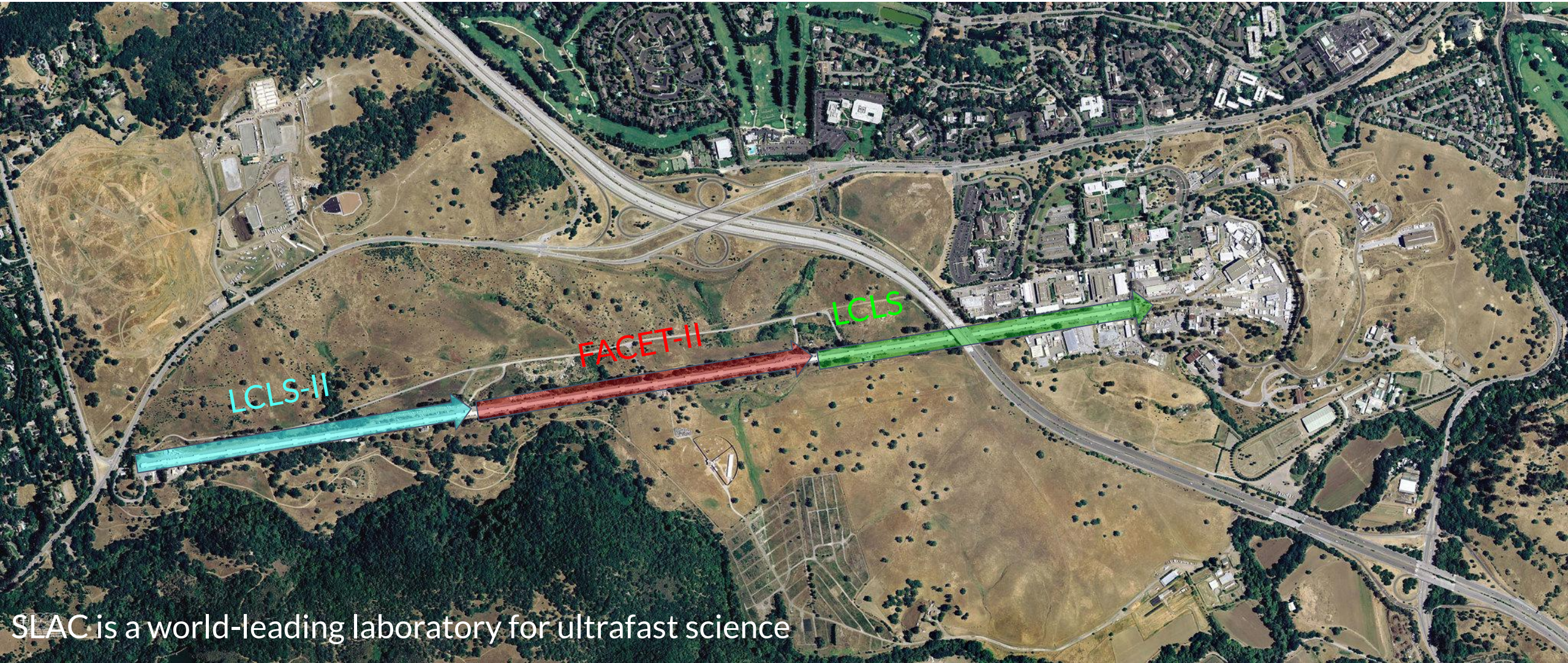
Problem: Damping ring adds significant cost to experiment. Not needed for electrons!

Option 3: JLab bremsstrahlung-based polarized positron source.

Opportunity: FCC needs relatively few polarized positron bunches. Save money and provide new physics capabilities!

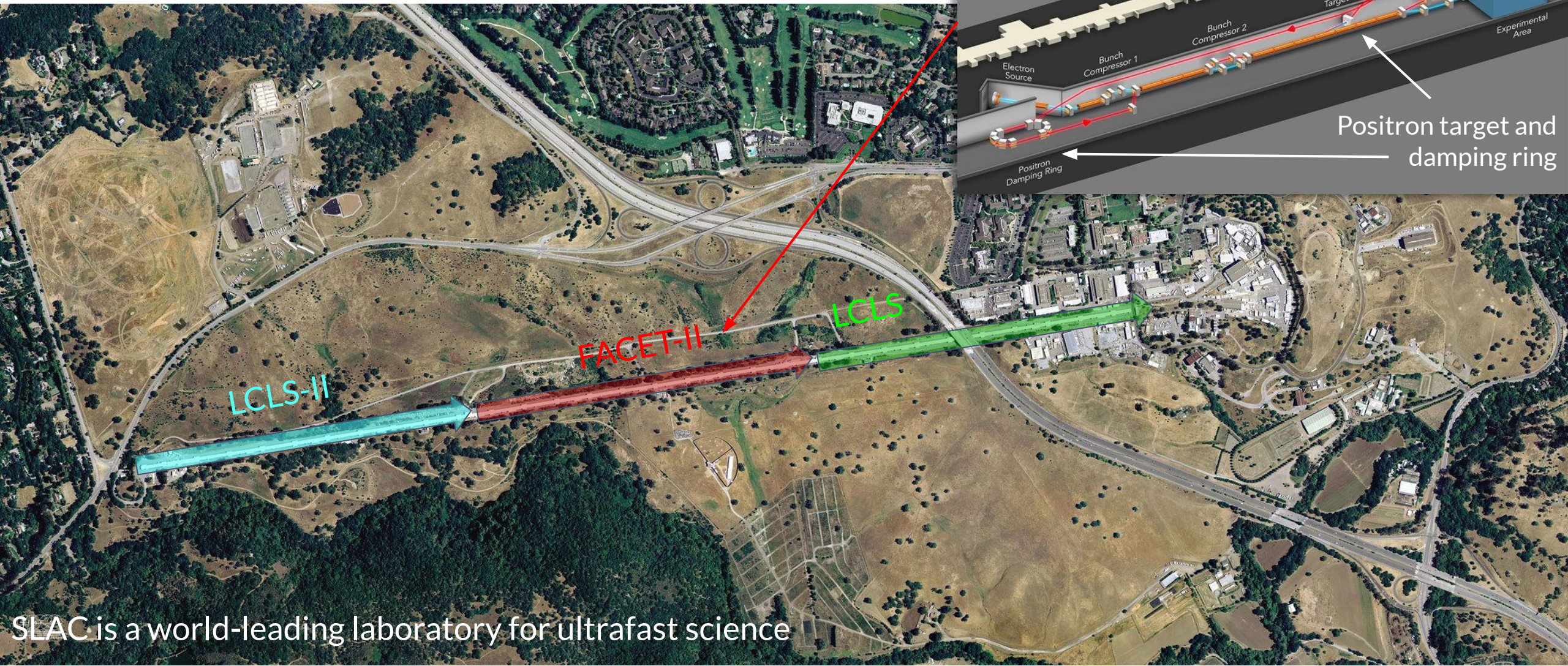
US HFCC program can provide seed-funding for polarized positron design effort at JLab.

Back to SLAC



SLAC is a world-leading laboratory for ultrafast science

Back to SLAC



SLAC is a world-leading laboratory for ultrafast science

LDRD: Multi-Disciplinary Science with Compact Positron Source

Accelerator R&D

Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

Report of the 2023 Particle Physics Project Prioritization Panel Executive Summary

An upgrade for FACET-II e^+ is uniquely positioned to enable study of positron acceleration in high-gradient plasmas.

A strategic plan for the High Energy Physics Advisory Panel

Advanced Accelerator Physics

PHYSICAL REVIEW ACCELERATORS AND BEAMS

Highlights Recent Accepted Special Editions Authors Referees Sponsors

Open Access Review Article

Positron acceleration in plasma wakefields

Gevy J. Cao, Carl A. Lindström, Erik Adli, Sébastien Corde, and Spencer Gessner
Phys. Rev. Accel. Beams **27**, 034801 – Published 5 March 2024

Article References No Citing Articles PDF HTML Export Citation

Laboratory Astrophysics

Physics of Plasmas PERSPECTIVE scitation.org/journal/php

Review Article

Perspectives on relativistic electron-positron pair plasma experiments of astrophysical relevance using high-power lasers

Cite as: Phys. Plasmas **30**, 020601 (2023); doi:10.1063/5.0134819
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Ultrafast Materials Science

Article | Open access | Published: 22 June 2022

Many-body theory of positron binding to polyatomic molecules

Jaroslav Hofbauer

PHYSICAL REVIEW LETTERS **130**, 263001 (2023)

Nature **606**, 7359 Access

Many-Body Theory Calculations of Positron Scattering and Annihilation in H_2 , N_2 , and CH_4

C. M. Rawlins,
¹Centre for Light-Matter

ELSEVIER ScienceDirect

Available online at www.sciencedirect.com

Surface Science Reports 71 (2016) 547–594

surface science reports

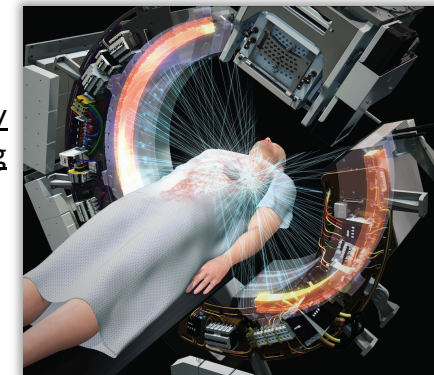
Positrons in surface physics[☆]

Christoph Hugenschmidt

FIM II and Physik-Department E21, Technische Universität München, Lichtenbergstraße 1, 85748, Germany
Received 9 June 2016; received in revised form 9 June 2016; accepted 24 September 2016
Available online 4 October 2016

Stanford Medicine first to try out novel tumor-targeting radiation therapy machine

Novel Treatment Modalities



Proposal aligns with SLAC's strength as an ultrafast science laboratory.

Challenges

Challenge #1

Produce, capture, and cool a record number of slow positrons

Challenge #2

Compress and accelerate positrons from trap while preserving the beam quality.

Production Rate Challenge

The positron trap provides high-quality beams, but at relatively low rate. The current state-of-the-art is around $1 \times 10^8 e^+/s$.

The FACET-II positron source based on the SLC target system with a new damping ring can provide $3 \times 10^{10} e^+/s$.

We can pursue high-impact accelerator R&D with only $1 \times 10^9 e^+/s$, a ten-fold improvement over the current state-of-the-art.

Requires kW-scale drive linac.

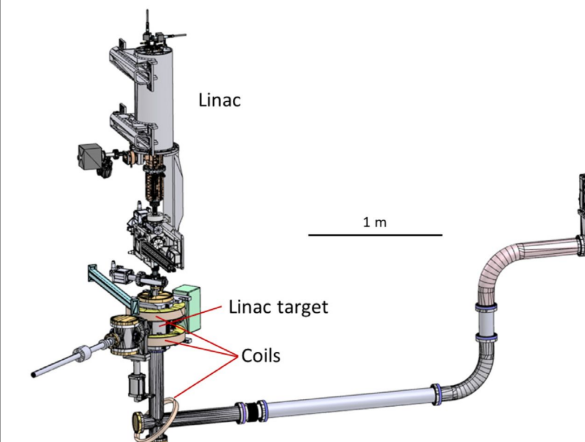
Nuclear Inst. and Methods in Physics Research, A 985 (2021) 164657

Table 1
Performance of linac-based positron sources.

| Linac | e ⁻ energy MeV | e ⁻ beam power W | Slow e ⁺ flux 10 ⁷ e ⁺ /s | Efficiency 10 ⁻⁷ e ⁺ /e ⁻ |
|------------------------|------------------------------|--------------------------------|---|---|
| Oak Ridge [33] | 180 | 55 000 | 10 | 0.53 |
| Livermore [34] | 100 | 11 000 | 1000 | 16 |
| ETL, Japan [35] | 75 | 300 | 1.0 | 6 |
| KEK [36] | 55 | 600 | 5 | 7.3 |
| Ghent [37] | 45 | 3800 | 2 | 0.4 |
| Giessen [38] | 35 | 3500 | 1.5 | 0.2 |
| Mitsubishi, Japan [39] | 18 | 16 | 0.077 | 1.35 |
| GBAR, CERN | 9 | 2500 | 5 | 0.28 |
| Saclay, CEA [40] | 4.3 | 300 | 0.2 | 0.05 |

M. Charlton, J.J. Choi, M. Chung et al.

GBAR Source



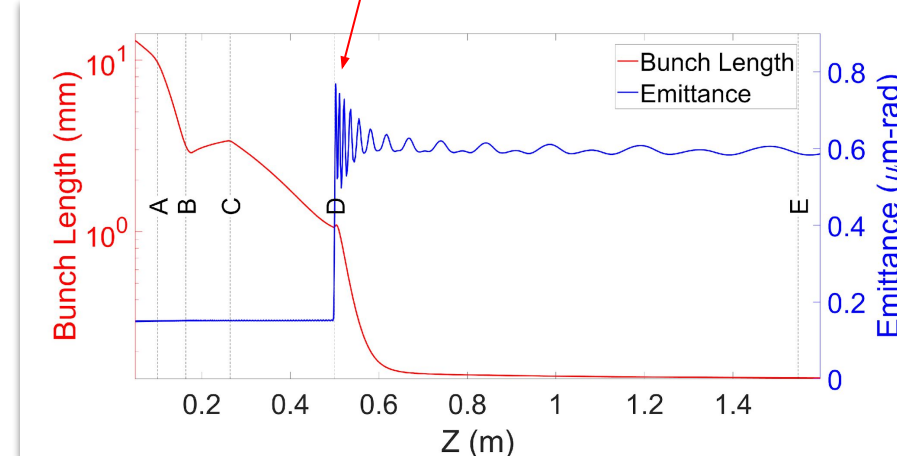
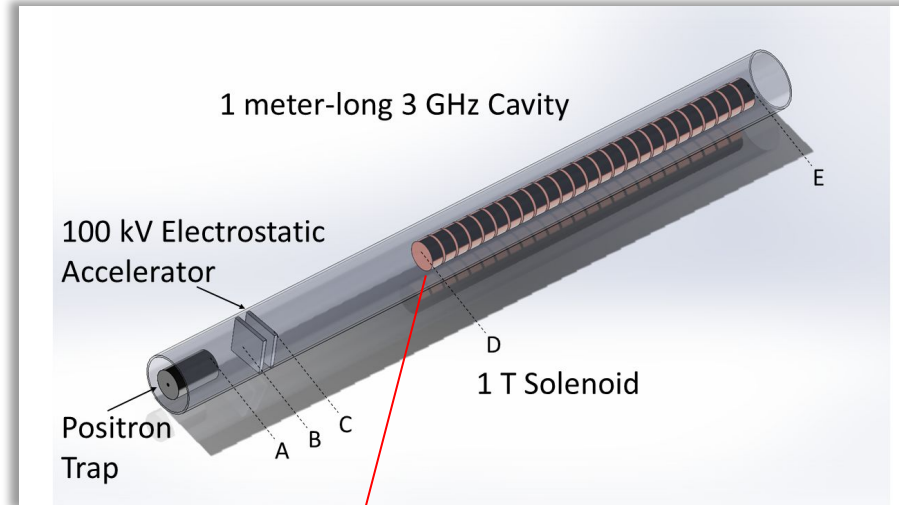
Compression and Emittance Growth

How do we compress low-energy beams while preserving beam quality?

$$\mathcal{L} = \frac{\langle xp_y - yp_x \rangle}{2} = \frac{eB\sigma_r^2}{2mc}$$

$$\Sigma_{4D} = \begin{bmatrix} \langle x^2 \rangle & \langle xp_x \rangle & \langle xy \rangle & \langle xp_y \rangle \\ \langle xp_x \rangle & \langle p_x^2 \rangle & \langle p_x y \rangle & \langle p_x p_y \rangle \\ \langle xy \rangle & \langle p_x y \rangle & \langle y^2 \rangle & \langle yp_y \rangle \\ \langle xp_y \rangle & \langle p_x p_y \rangle & \langle yp_y \rangle & \langle p_y^2 \rangle \end{bmatrix}$$

$$\mathcal{L} \approx 250 \mu\text{m-rad}$$



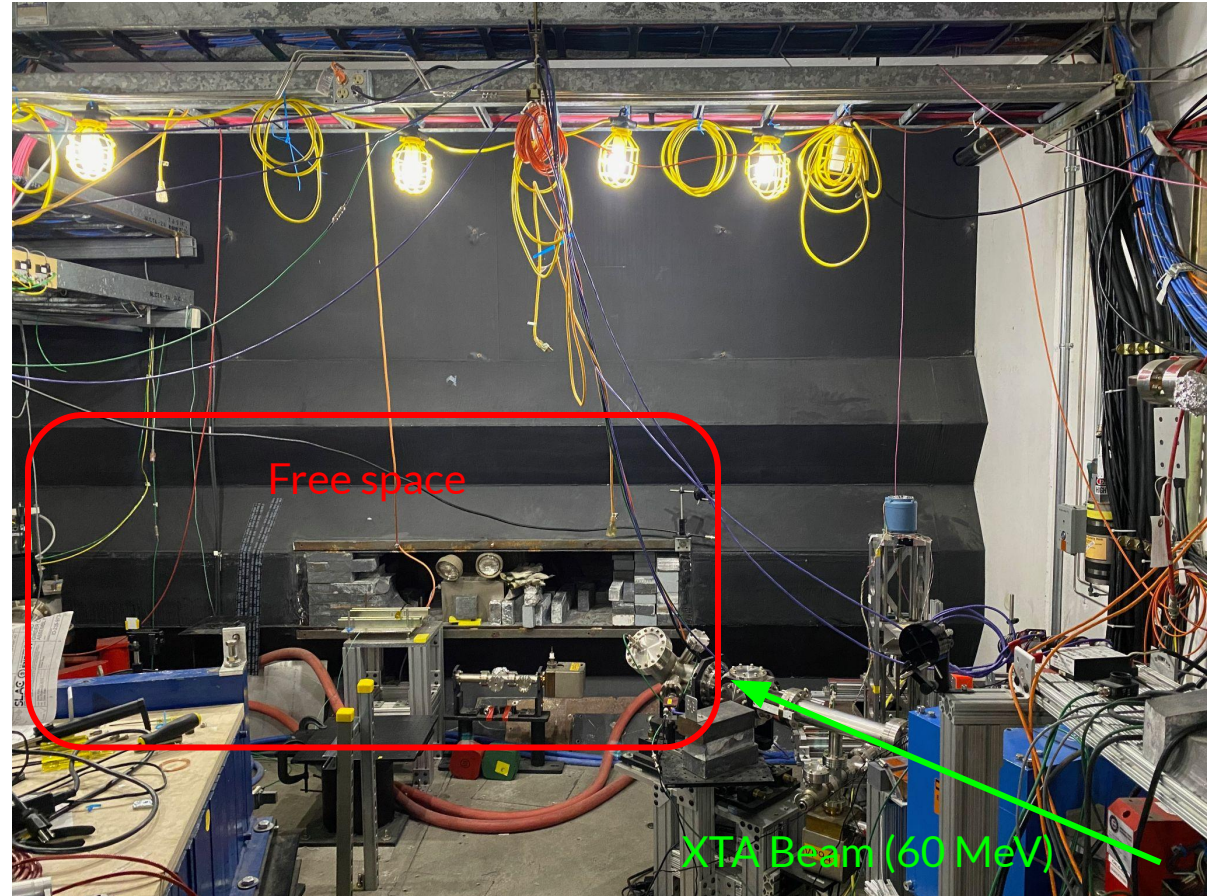
Test Area: XTA Linac at NLCTA

LDRD proposal requests 1 kW beam at 100 MeV to generate 10^9 e⁺/s

XTA can provide 60 MeV beam with ~1 Watt of beam power.

Fewer positrons per second, but option to start immediately and test out components.

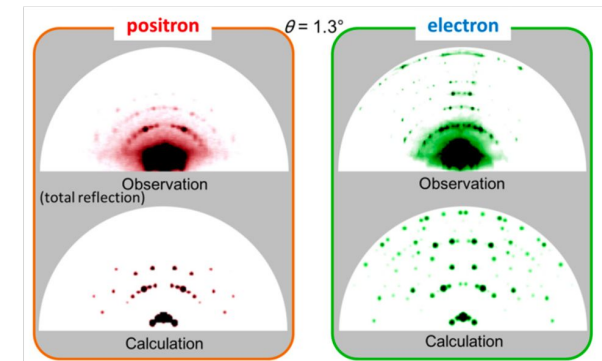
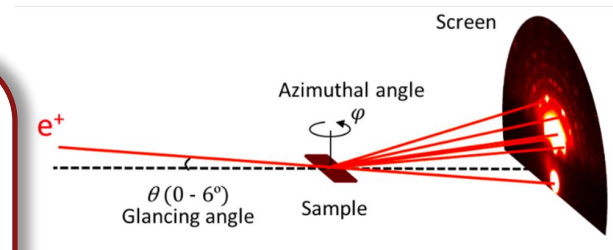
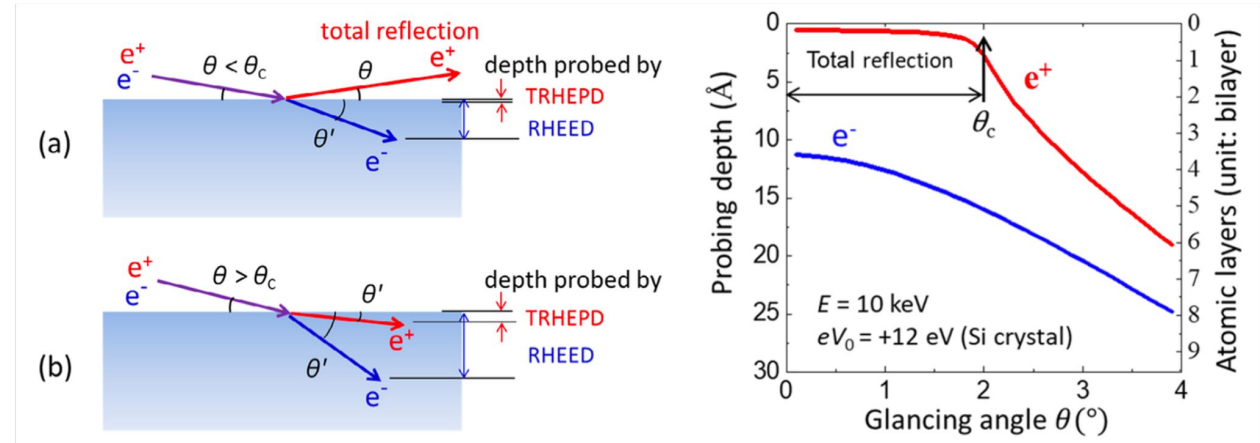
Details in Sophie's talk.



Questions: Ultrafast Science with Positron Beams

- Positron beams interact *differently* with the surface of materials than electron beams.
- This allows for direct probes of surface dynamics .
- Partnering with Aaron Lindenberg (SLAC) on first opportunities with short bunch positron diffraction.

Y. Fukaya, J. Phys. D: Appl. Phys. 52, 013002



Can we compress positron bunches to sub-picosecond duration and synchronize with external laser?

Opportunities: Science with single, well-timed positrons

We are partnering with experts from Stanford Medicine and SLAC to provide single positrons for Time-of-Flight Positron Emission Tomography (ToF-PET) detector testing.

Other opportunities include:

- Well-timed positrons for PALS with Farida Selim and Sami Tantawi (ASU)
- Ghost imaging with entangled gammas from annihilations.
- Entangled gammas to probe qubit decoherence with Noah Kurinsky (SLAC).

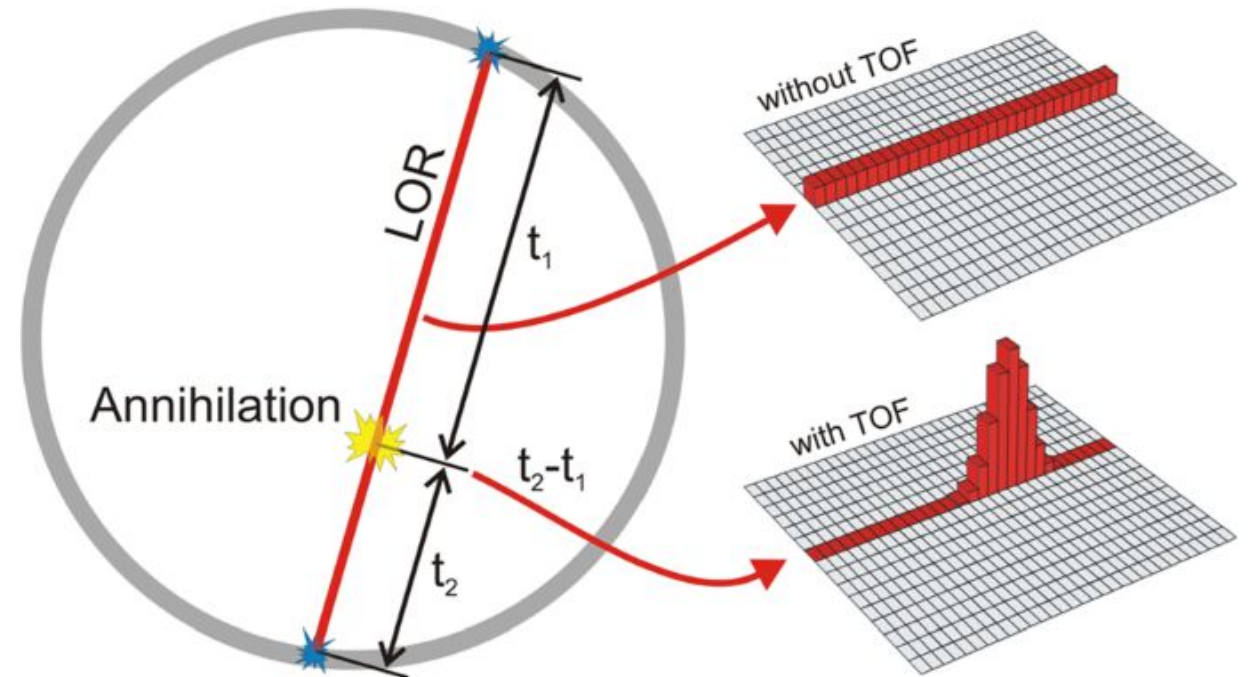
Do *some* science soon.
Enable *more* science later.



Craig Levin, Stanford Medicine
Radiology
PET Expert

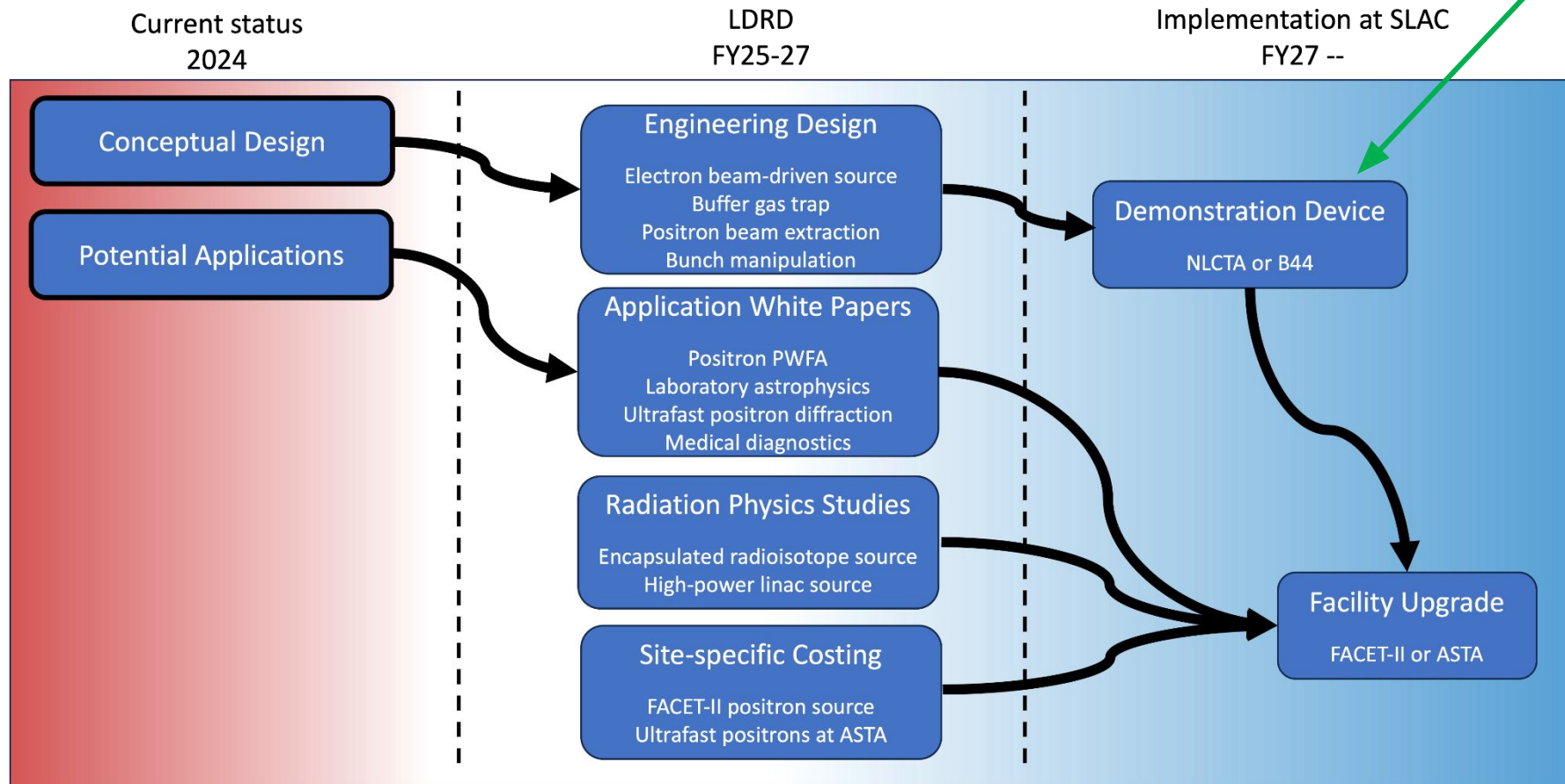


Ryan Coffee, SLAC
LCLS
Detector Expert



Research Roadmap

We are here!



Conclusions

SLAC is pursuing a compact positron source for science with ultrashort positron beams.

Ultrashort positron beams will enable new opportunities in:

- Detector physics
- Materials science
- Health and medicine
- Accelerator physics

SLAC's work on targets, moderators, and beam physics is aided by collaboration with KEK and synergistic with JLab's aims.

The JLab positron source can provide unique opportunities for positron plasma acceleration R&D and FCC-ee polarized positron source.

We are excited to continue our partnership with JLab on electron-driven positron sources and the exciting science case for low-energy positrons!