FACET

SLAC NATIONAL ACCELERATOR LABORATORY

LCWS2023 INTERNATIONAL WORKSHOP ON LINEAR COLLIDERS

A Compact Source of Positron Beams with Small Thermal Emittance arXiv:2305.00573

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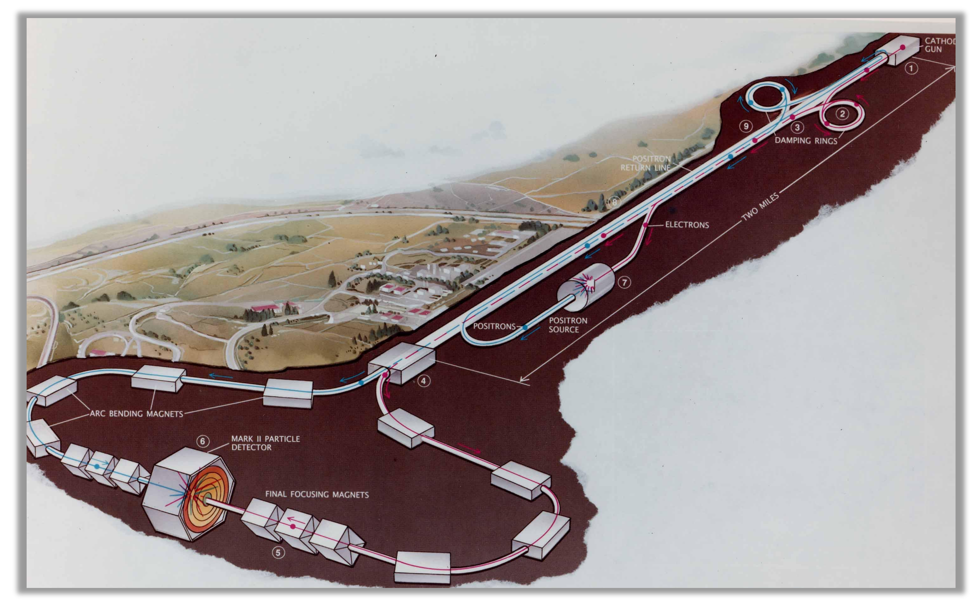
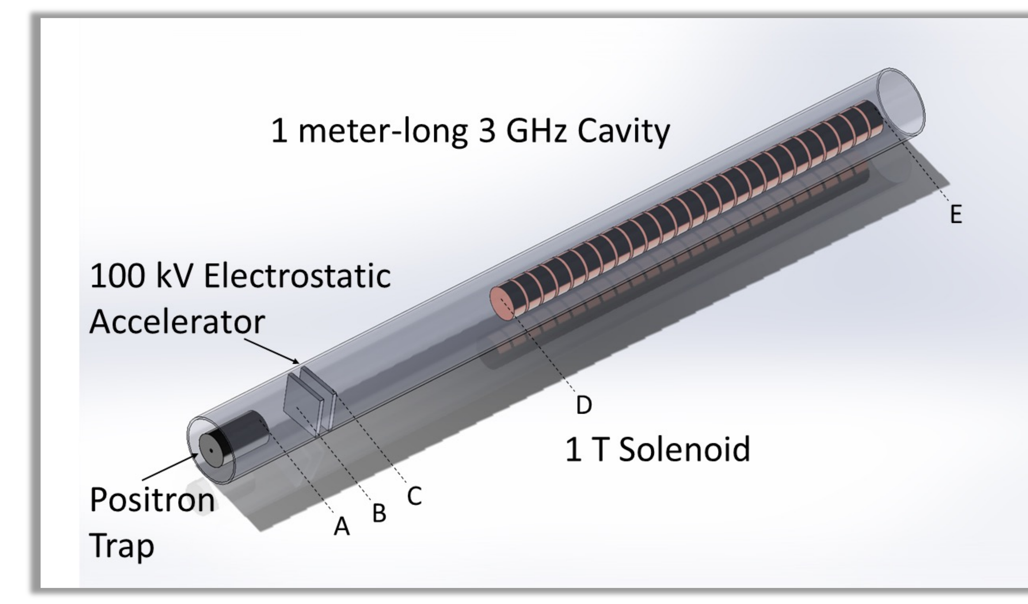
Abstract

We investigate electrostatic traps as a novel source of positron beams for accelerator physics applications. Penning-Malmberg (PM) traps are commonly employed in low-energy antimatter experiments. Positrons contained in the trap are cooled to room temperature or below. We calculate the thermal emittance of the positrons in the trap and show that it is comparable to or better than the performance of state-of-the-art photocathode guns. We propose a compact positron source comprised of a PM trap, electrostatic compressor, and rf accelerator that can be built and operated at a fraction of the cost and size of traditional target-based positron sources, albeit at a reduced repetition rate. We model the acceleration of a positron bunch up to an energy of 17.6 MeV with a final thermal emittance of 0.60 μm-rad and bunch length of 190 μm. This system may be useful for acceleration physics studies, such as investigations of flat-beam sources for linear colliders and positron plasma wakefield acceleration.

Positron Sources Diagrams



SLC Positron Source
2 km long



Compact Positron Source
1.5 m long

Benefits and Challenges

Benefits:

- Inherently low emittance.
- Compact footprint.
- Natural polarization.

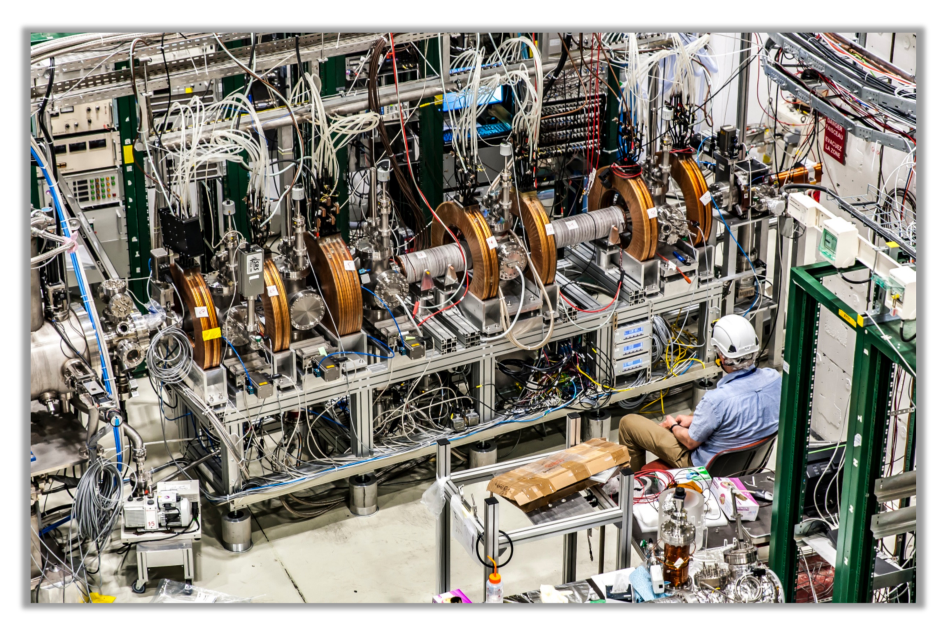
Challenges:

- Low repetition rate.
- Long bunches.
- Radionuclide sources.

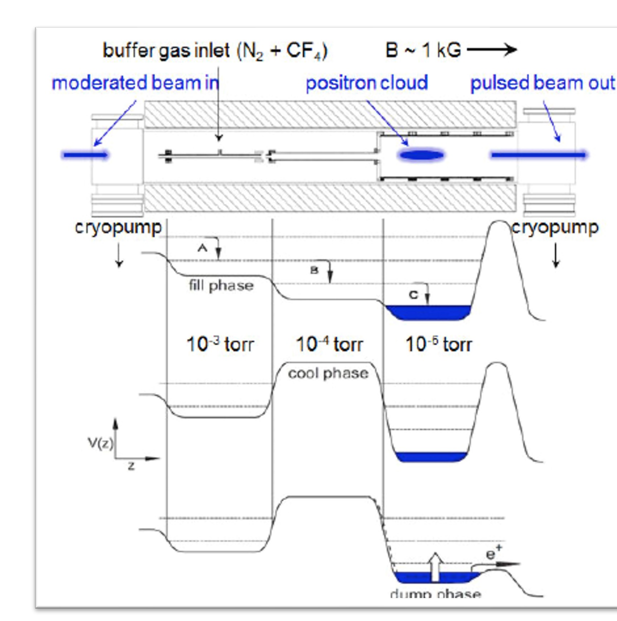
Key Technologies

Fig. 3. The closed capsule (small design). The welding of the front ring is visible. The post has got a 6–32 UNC thread with a length of 6.3 mm.

UHV Sodium-22 Source
https://doi.org/10.1016/j.nimb.2004.03.049



GBAR Positron Trap



Buffer Gas Trap

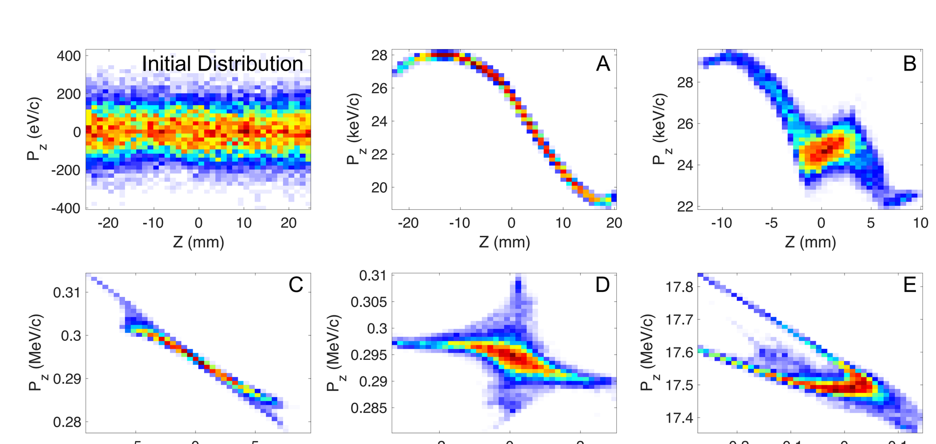
The core technologies for the compact positron source include: a radionuclide, UHV-compatible positron source, a Penning-Malmburg trap, and a buffer gas or alternative cooling system.

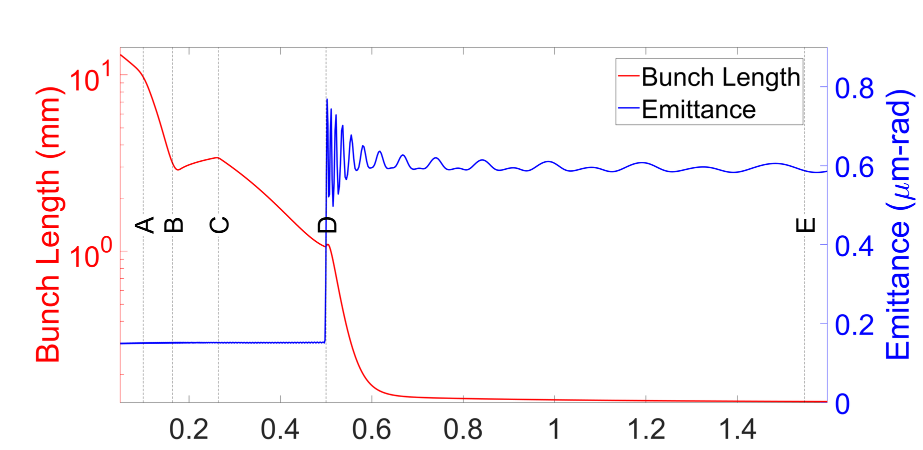
Beam Physics Considerations

Penning-Malmberg Traps provide beams with excellent emittance, but the bunches are long. Our study examines the beam physics of bunch compression with emittance preservation.

$$\epsilon_{th} = \frac{1}{mc}\sqrt{\frac{qNmk_BT}{8\pi\epsilon_0 B\omega_r L_p}}$$

Parameter	Symbol	Value
Trap radius	r_w	4 cm
Trap length	l_w	10 cm
Magnetic field	B	1 T
e^+ plasma radius	r_p	1.3 mm
e^+ plasma length	r_l	5 cm
Temperature	T	273 K
Number of positrons	N	10^8
Space charge potential	$\Delta\phi$	22.4 V
Debye length	λ_D	60.6 μm
Cyclotron frequency	Ω_c	175.6 GHz
Rotation frequency	ω_r	3.2 MHz
Transverse emittance	$\varepsilon_{x,y}$	0.11 μm-rad



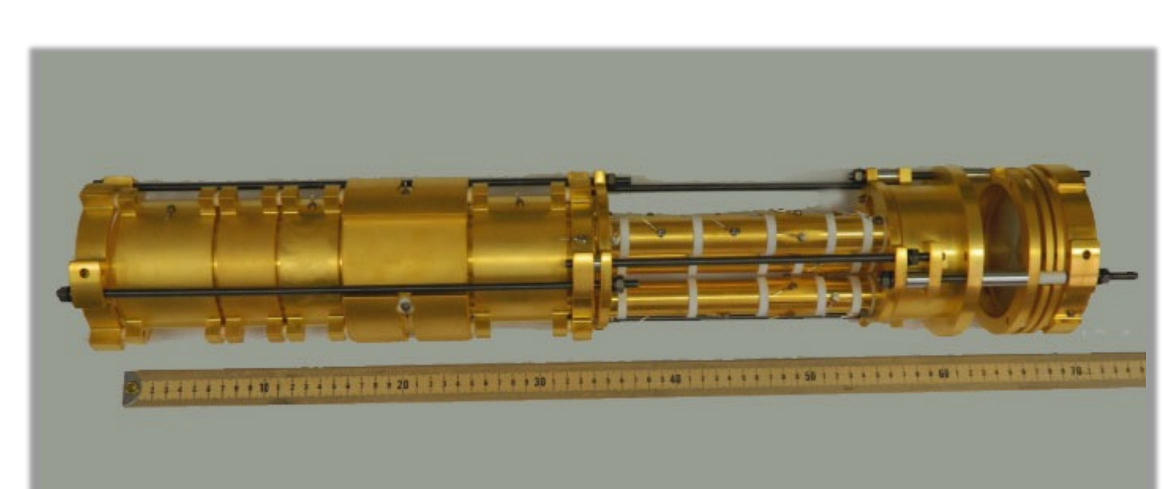


Top: Evolution of the longitudinal phase space of the positron bunch throughout the accelerator.
Bottom: Evolution of the bunch length and emittance throughout the accelerator. There is a jump emittance at the start of the RF acceleration cavity.

Applications and Future Directions

In the near-term, compact positron sources can enable materials science studies with low emittance positron beams and allow for positron plasma acceleration research.

Future work will seek to improve the repetition rate of the device by multiplexing the chamber and allowing for accumulation of multiple positron beams.



A multiplexed positron trap designed by the Surko group at UCSD. N. Hurst et al. Phys. Plasmas (2019)