Positron Source Concepts

C^3 Workshop

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October 13, 2022

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

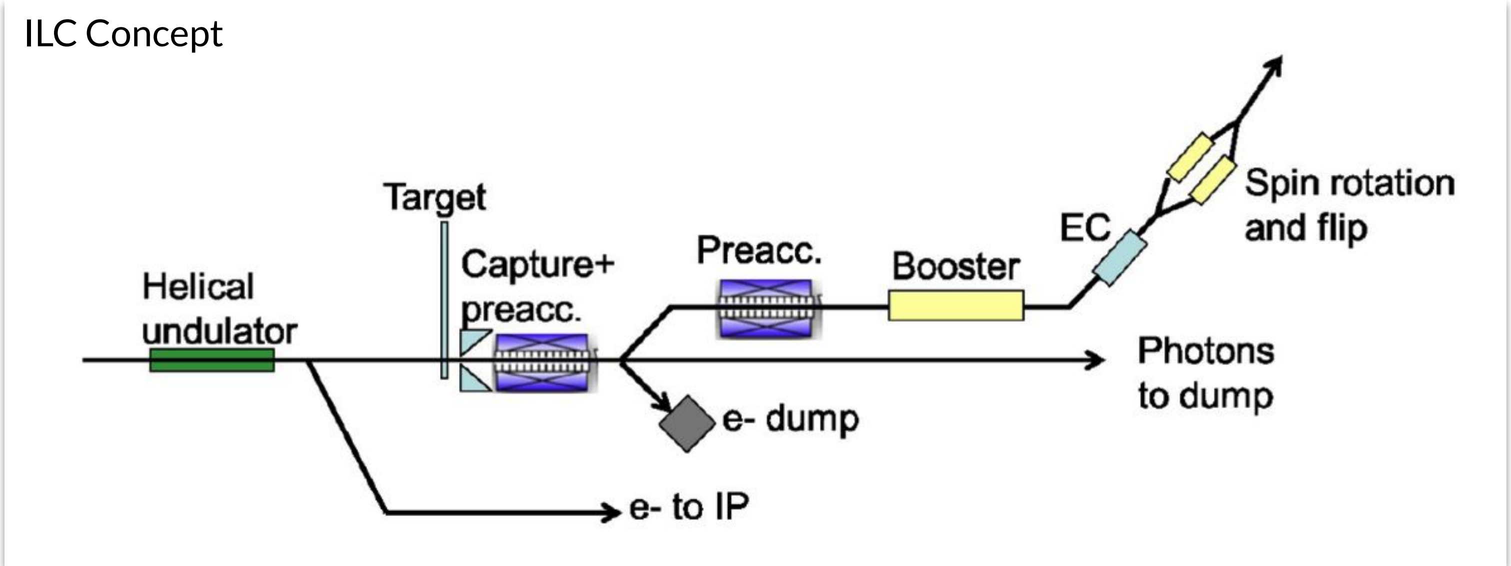
Overview

- Positron sources are a critical element of future Linear Colliders. The demand on the source is characterized by e^+/s required at the IP:
  - ILC-250: 1.3×10^{14} e^+/s
  - CLIC-380: 8.8×10^{13} e^+/s
  - C^3-250: 1.0×10^{14} e^+/s

- Polarized positron sources are challenging for 250 GeV CM energy.
  - Limited by beam energy in undulator (nominal 150 GeV).
  - Conventional (electron-driven) sources are considered as well.

- We can explore novel targets, sources, and schemes for positron generation in preparation for a future Linear Collider.

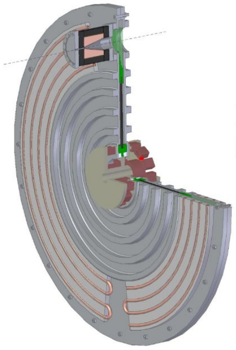
Polarized Positron Production



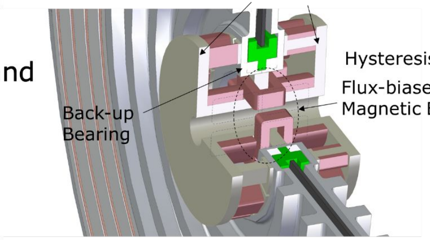
The undulator-based, polarized production scheme is the most challenging for the ILC target (highest peak power).

Target Wheel

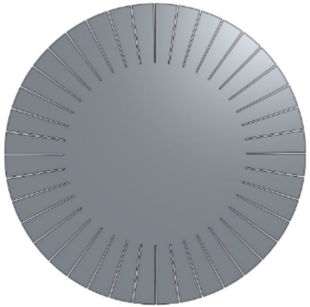
A Positron Target Concept for the ILC,
M. Breidenbach et al, ICHEP 2016

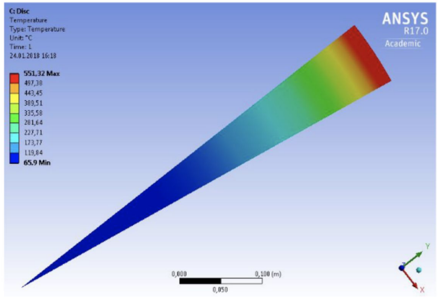


Magnetic Drive and Suspension



The ILC positron target cooled by thermal radiation,
S. Riemann et al, arXiv:1801.10565

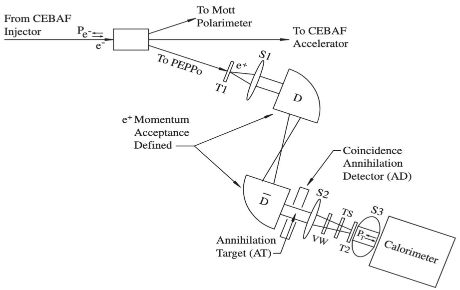


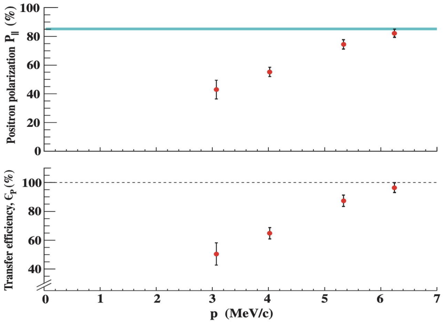


The titanium target wheel in the undulator scheme is well-studied, but there are open topics, such as demonstration of the magnetically-levitated target.

Alternative Polarized-Positron Schemes

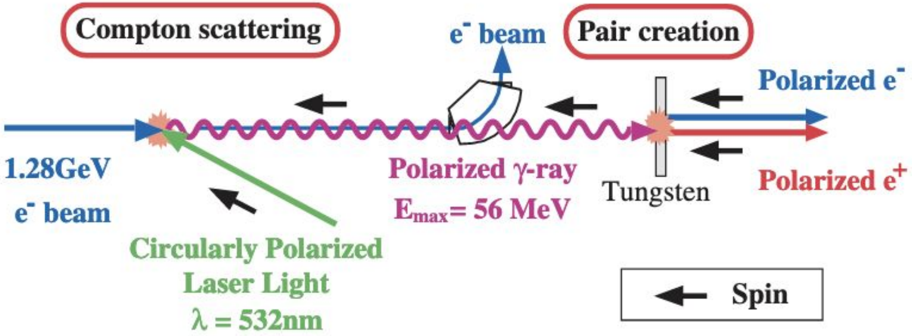
Polarized Bremsstrahlung





Production of Highly Polarized Positrons Using Polarized Electrons at MeV Energies, D. Abbott et al. (PEPPo Collaboration) PRL (2016)

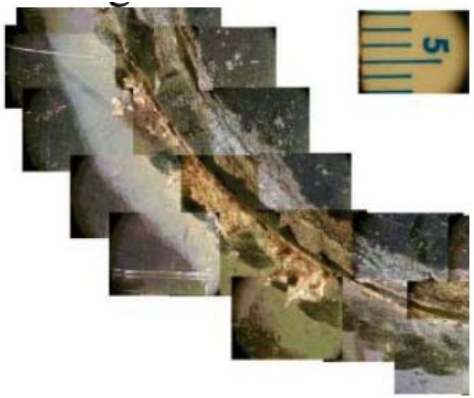
Laser Undulator



Efficient Propagation of Polarization from Laser Photons to Positrons through Compton Scattering and Electron-Positron Pair Creation, T. Omori et al. PRL (2006)

New Ideas for Targets

- Targets are characterized by their ability to withstand powerful beam fluxes.
- The key figure-of-merit is Peak Energy Deposition Density (PEDD).
  - For solid targets, PEDD should be less than 35 J/g.
- The cooling mechanism is a key to long-term survivability.
- Liquid metal targets can withstand large PEDD, but they are difficult to work with (toxic).



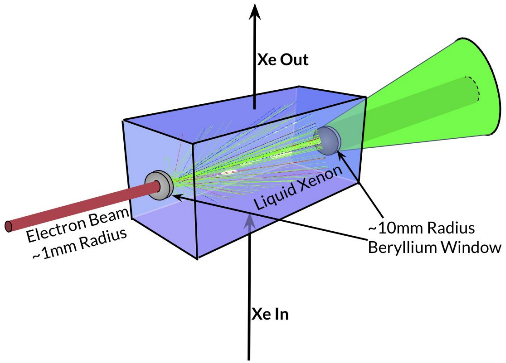
Degraded section of SLC positron target
V. Bharadwaj, et al. WPAH019 PAC 2001

Is there a safe alternative to liquid metal targets?

Liquid Xenon Targets (with M. Varverakis, CalPoly)

Why liquid Xenon (LXe)?

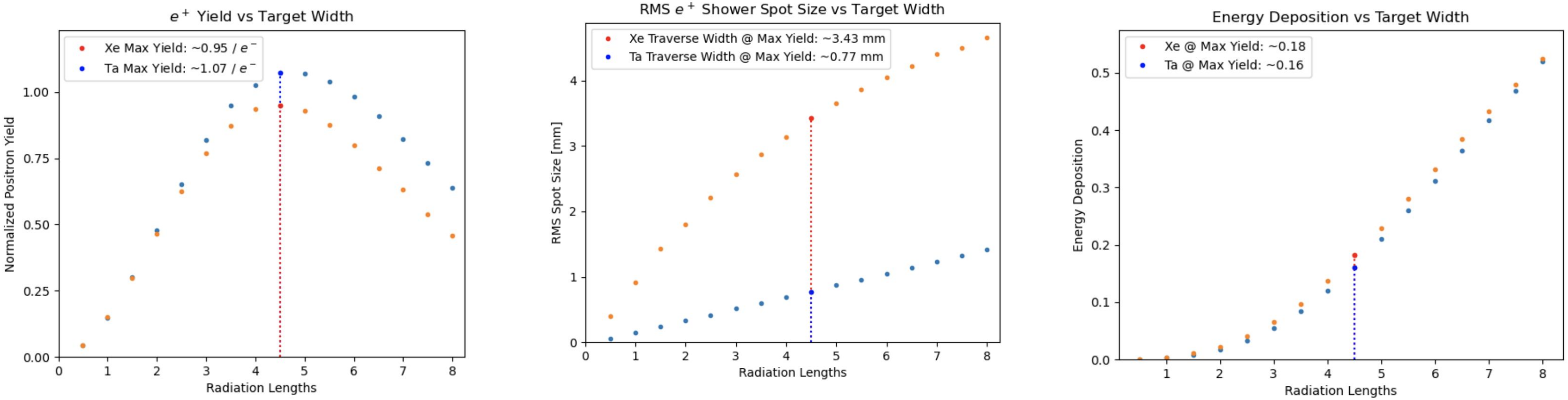
- Very dense liquid with modest radiation length.
- The maximum PEDD is determined by the Heat of Vaporization.
  - ΔH = 12.6 kJ/mol → PEDD_{max} ~ 100 J/g
  - Roughly 3X PEDD for solid targets!
- Built in cooling mechanism.
  - LXe temperature = 161 K
  - Required flow rate for ILC parameters (conventional) is 0.3 L/s
- Also, we have LXe experts at SLAC. . .



LXe target schematic

LUX-ZEPLIN Detector

GEANT Simulations for LXe (M. Varverakis, CalPoly)

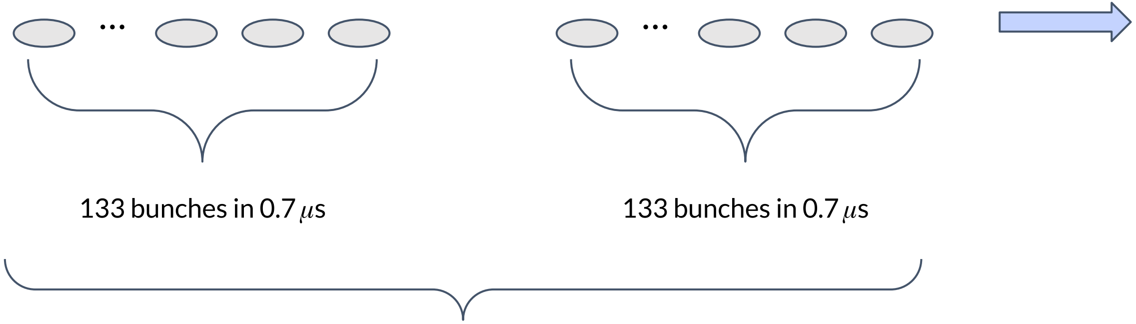


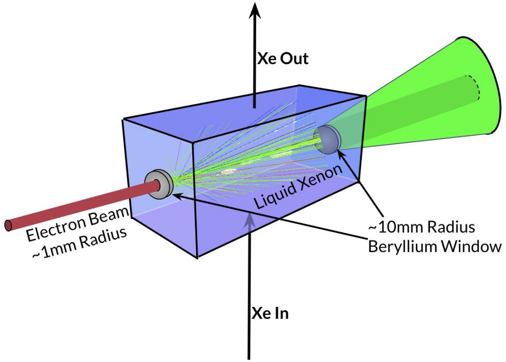
Possible to match yield of conventional targets with 4.5 radiation lengths of LXe.

LXe Flow Rate Considerations for C^3

A single C^3 train deposits 20 J/g PEDD in the LXe.

- 5 bunch trains required to hit PEDD limit.



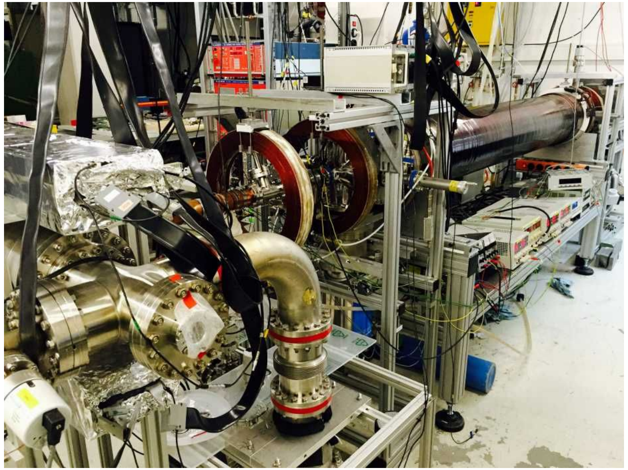


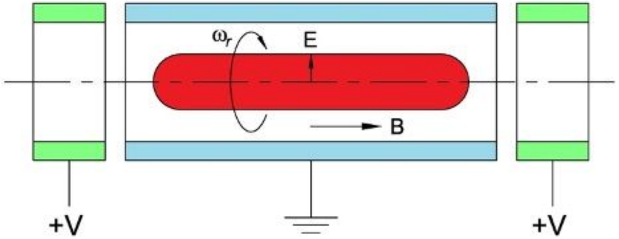
Minimum flow rate (replace LXe every 5 trains) = 0.06 L/s
Maximum flow rate (replace LXe every train) = 0.3 L/s

Compact Positron Sources (with R. Hessami, Stanford)

- It's not easy to get positron beams for testing, but compact positron sources for non-HEP applications exist!
- A Penning-Malmberg trap is used to accumulate and cool positrons from a radioactive source.
- The positrons are naturally polarized because they are produced by β-decays of an ^{22}Na source.

ETH Lab for Positronium Physics

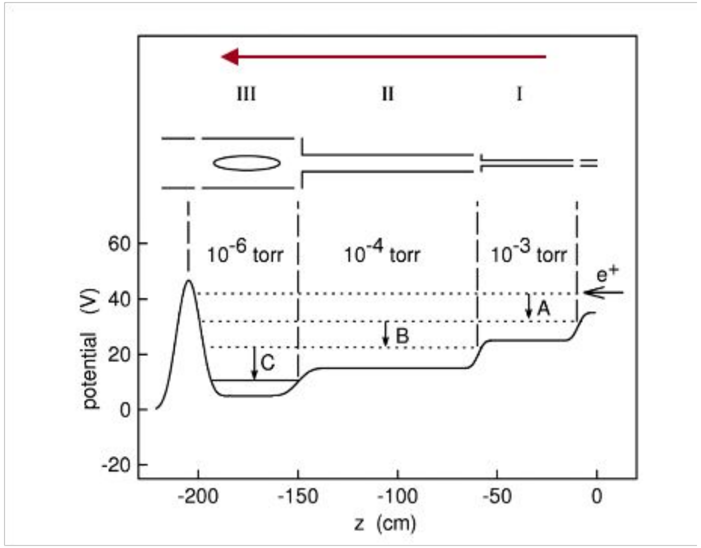




Penning-Malmberg Trap

Compact Positron Sources (with R. Hessami, Stanford)

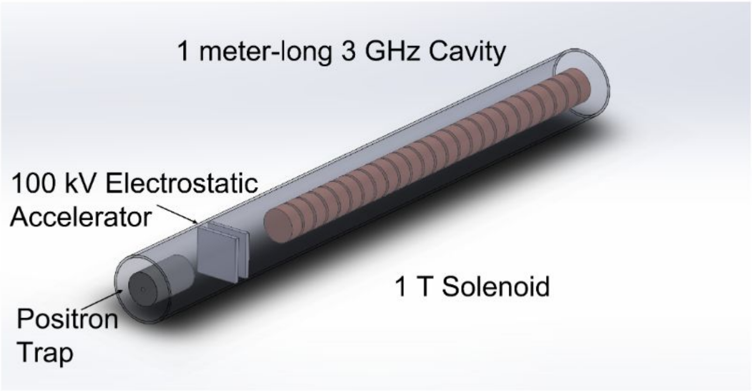
- PM traps are divided into stages and use a buffer gas to cool the positrons.
- The intrinsic emittance is proportional to positron temperature in the trap.
    - Possible to reach 100 nm-scale emittance at room temperature.
    - Lower emittances are possible with cryo-cooling.
- The beam is “magnetized” because the cooling occurs in a solenoid field.
    - Naturally gives flat-beam emittance.

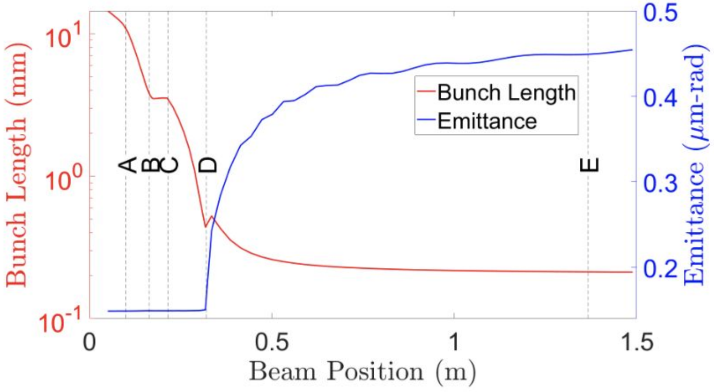


$$\epsilon_{th} = \frac{1}{mc}\sqrt{\frac{qNmk_BT}{8\pi\epsilon_0 B\omega_r L_p}}$$

Compact Positron Sources (with R. Hessami, Stanford)

- Can we preserve the low emittance of the beam after extraction from the trap?
- Can we compress the beam temporally for injection into an accelerator?



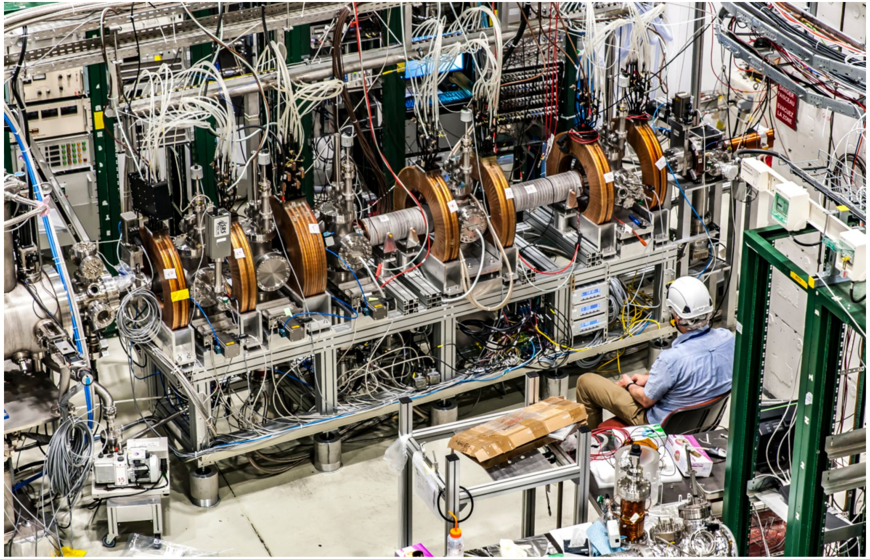


Challenge for the Compact Source

- Only 10^7 e^+/s from the ^{22}Na source.
- GBAR achieves 10^{10} e^+/s by generating positrons with a target before trapping them.
    - The drawback is that there is no positron polarization.

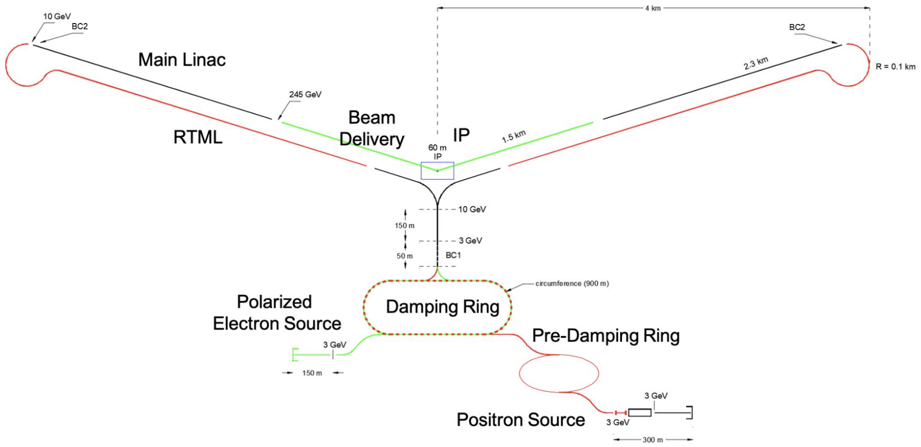
- Can we recover polarization using the polarized bremsstrahlung concept?
- Can we multiplex the devices to achieve the desired number of e^+/s?

GBAR Experiment at CERN



C^3 without Damping Rings?

C^3 : A "Cool" Route to the Higgs Boson and Beyond, M. Bei et al. arXiv:2110.15800 (2021)



	Sub-Domain	%	%
Sources	Injectors	8	35
	Damping Rings	12	
	Beam Transport	15	
Main Linac	Cryomodule	10	33
	C-band Klystron	23	
BDS	Beam Delivery and Final Focus	8	13
	IR	5	
Support Infrastructure	Civil Engineer	5	19
	Common Facilities	11	
	Cryo-plant	3	
Total	3.7B$	100	100

SLAC

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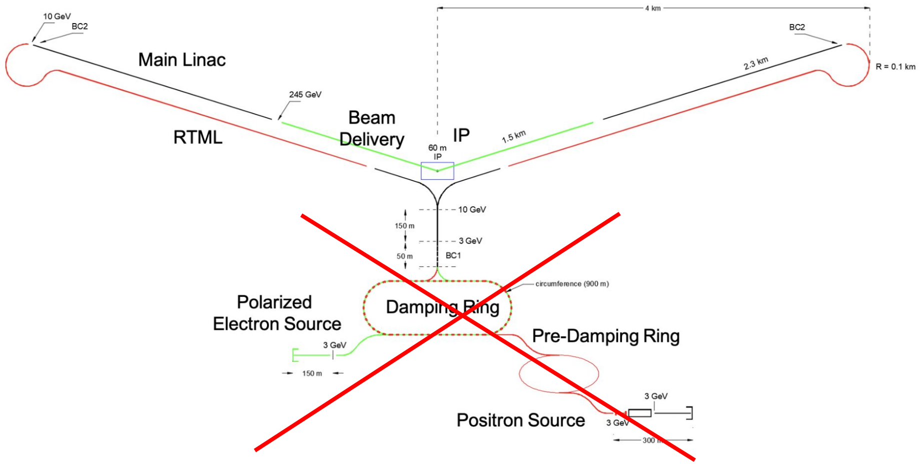

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Total	3.7B$	100	100

Cost savings of roughly ⅓ of the project!

Conclusion

- Further development of positron source technology can aid a future collider in ways both small and large.
- We have the opportunity to do some of this work at SLAC, either as standalone projects or as part of a C^3 demo facility.

Thanks!