A High Intensity Positron Source Based on a Superconducting Electron Linac

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Commercial Uses of Superconducting Electron Linacs

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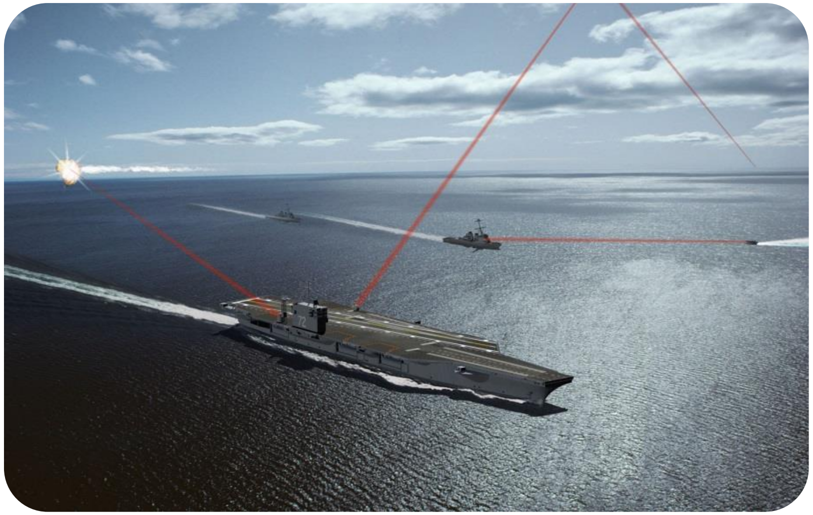
High Power X-Ray Sources

Radioisotope Production



Free Electron Lasers

High Flux Neutron Sources

Turnkey Linac Subsystems [1]

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Superconducting cavities
in specialized geometries

Cryomodules

Turnkey Linac Subsystems [2]

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Commercial 4 K refrigerators
(rugged piston-based systems,
100 W cryogenic capacity)

Industrial Accelerator Controls
(Programmable Logic Controllers with
PC interface)

Solid-state and tetrode
RF amplifiers
(up to 60 kW)

Project Overview

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- Applications of high-intensity positron sources
  - nuclear physics
  - materials science
- Positron Production System Design
  - 10 MeV Superconducting RF Electron Linac
  - High-power Beam Target Designs
  - Positron Capture and Transport Magnets
- Hardware Construction
- Experimental Results with Beam Target

Project Team

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- **Niowave, Inc.**
  - Terry Grimm, Chase Boulware, Mayir Mamtimin, James McCarter, and Valeriia Starovoitova
- **IAC**
  - Dan Dale and Tony Forest
- **JLab**
  - Joe Grames, Matt Poelker, and Mike Spata
- **LANL**
  - Stuart Maloy, Eric Olivas, and Keith Woloshun

Positrons for Nuclear Physics

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- Polarized positron collisions are an important program component at proposed next-generation lepton-ion colliders (JLEIC at JLab and eRHIC at BNL)
  - lepton polarization asymmetry in neutral current deep inelastic scattering
  - charged current deep inelastic scattering and charm production
  - physics beyond the standard model
- Transfer of polarization from a low-energy highly polarized electron beam has been demonstrated (PEPPo)

Positrons for Non-Destructive Testing of Materials [1]

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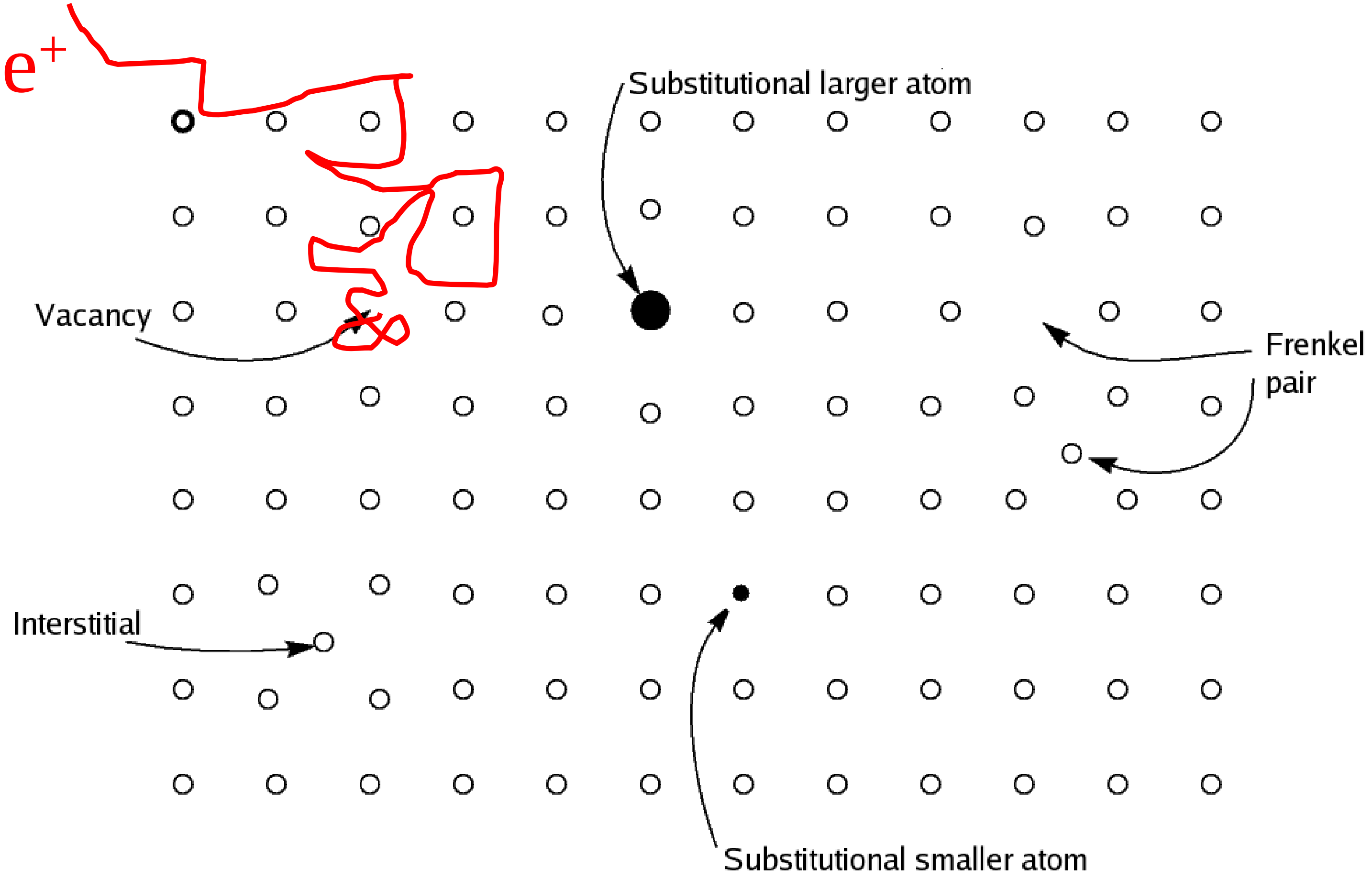

Positrons thermalize before annihilation with an electron, often becoming stuck in lattice defects.

Positrons for Non-Destructive Testing of Materials [2]

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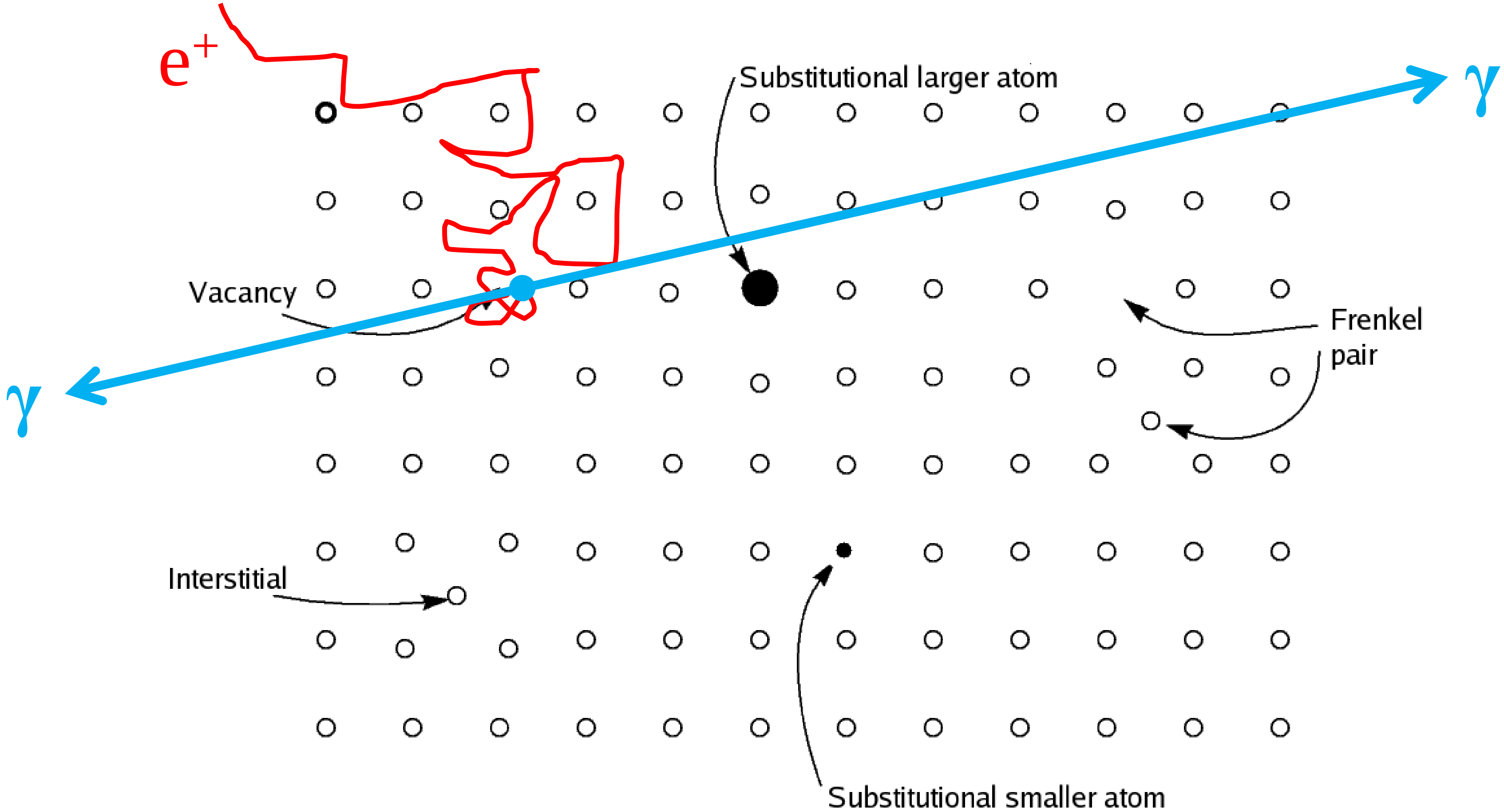
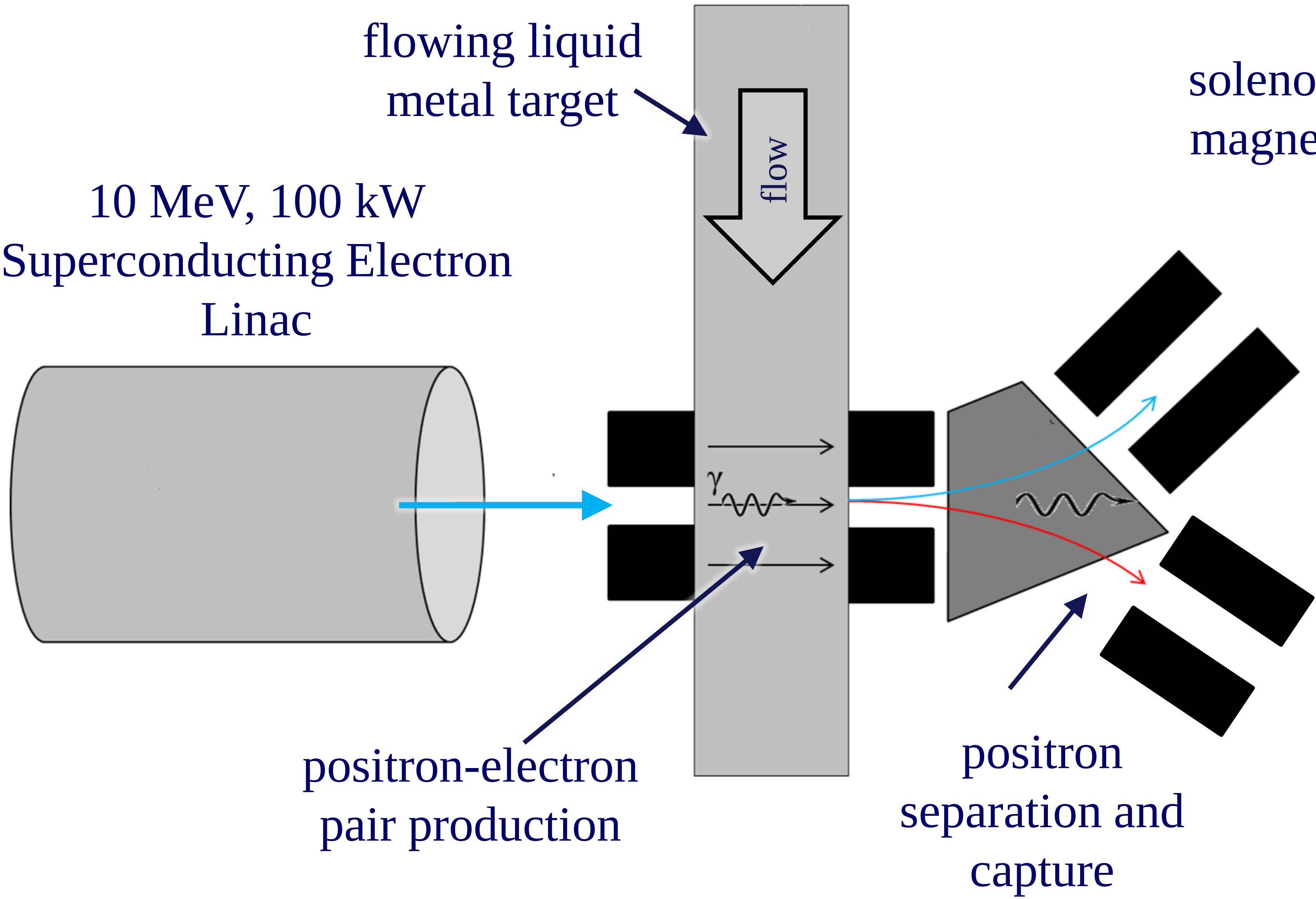
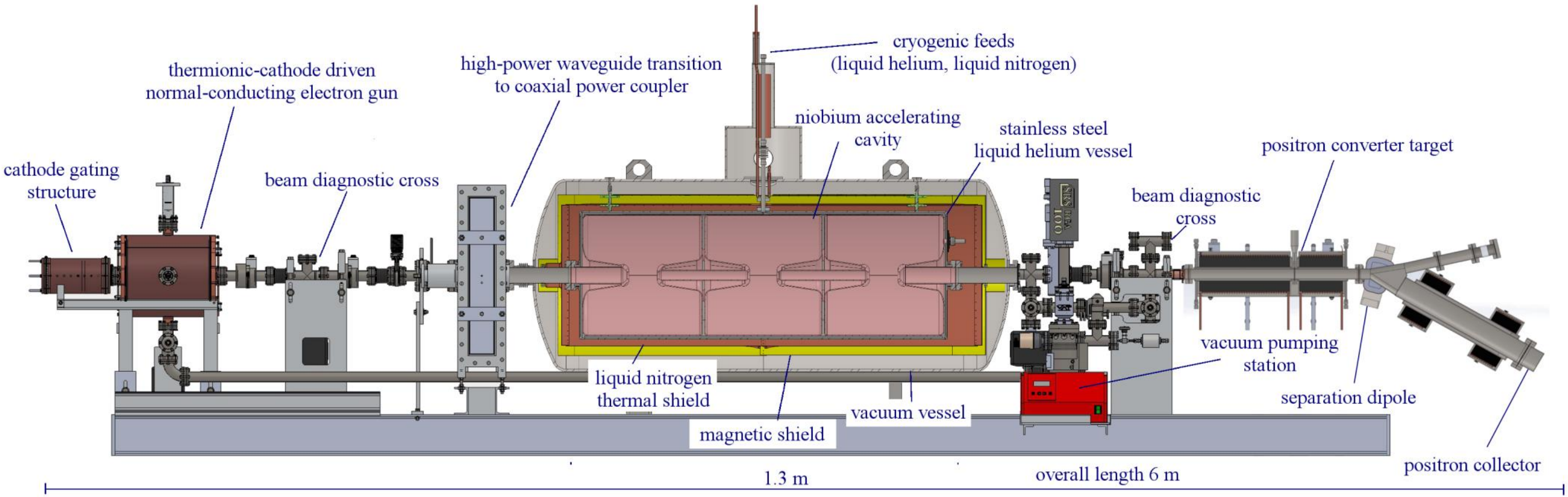


Gamma-ray emission from annihilation will come preferentially from the defect sites, locating them.

Positron Production Conceptual Design



10 MeV Accelerator with Positron Target



Electron Source

- 350 MHz, 100 kV normal-conducting resonant cavity
- integrated, gated thermionic cathode

10 MV superconducting cryomodule

- 3-cell, 350 MHz niobium resonator
- thermal and magnetic shields

10 MeV Linac in Tunnel

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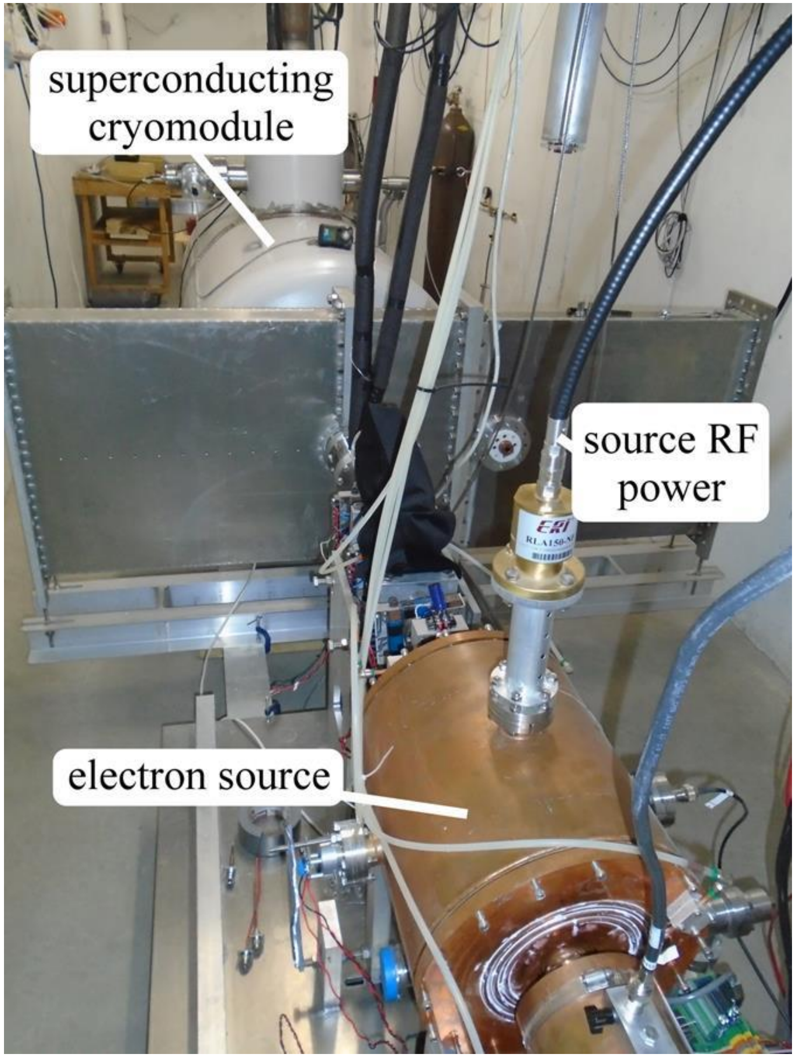
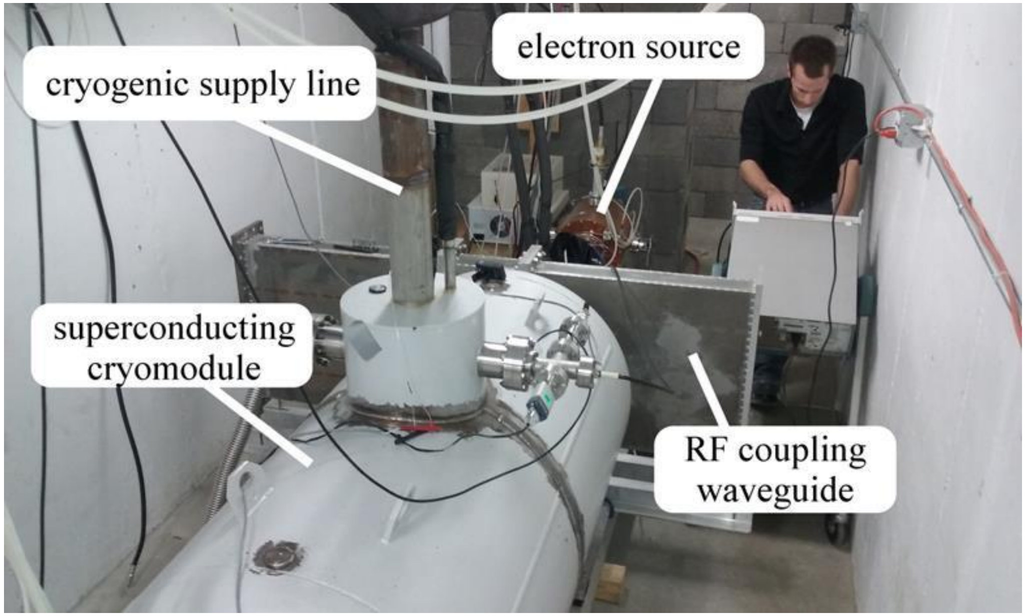


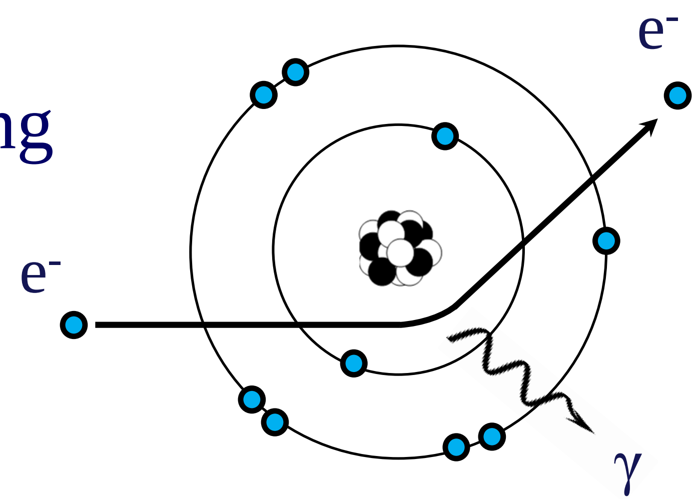


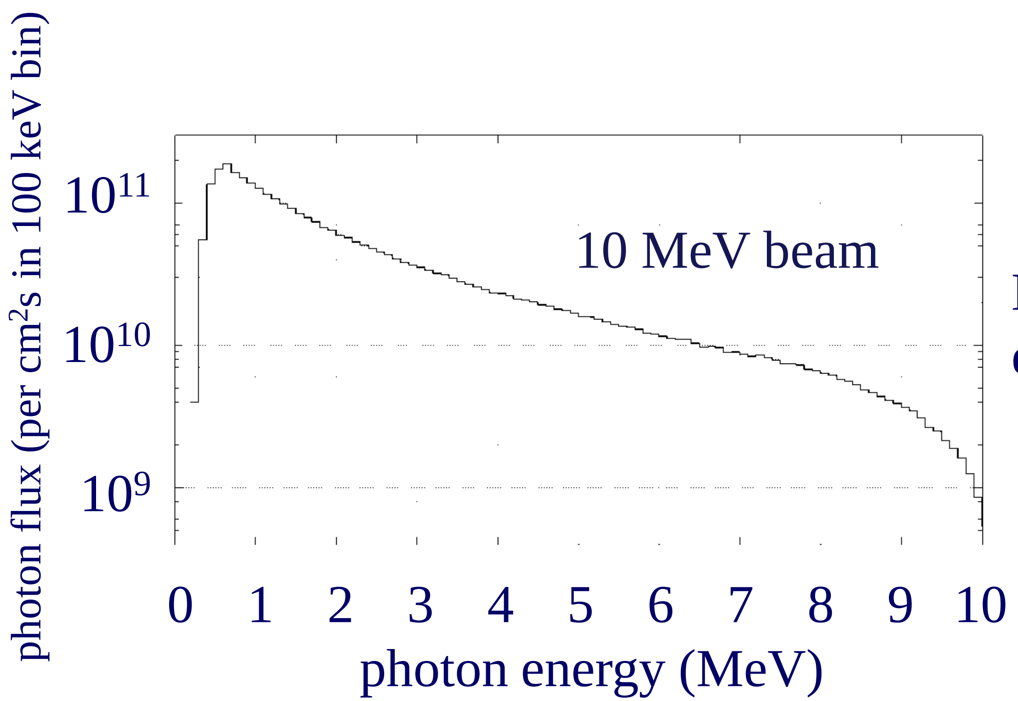
System currently being commissioned for sterilization and cargo scanning demonstrations.

Positron Conversion Process [1]

Positrons are created in a two-step process

- Electrons emit Bremsstrahlung photons





Bremsstrahlung (braking radiation) energy depends on:

- incident electron energy
- directness of collision with target nucleus

Positron Conversion Process [2]

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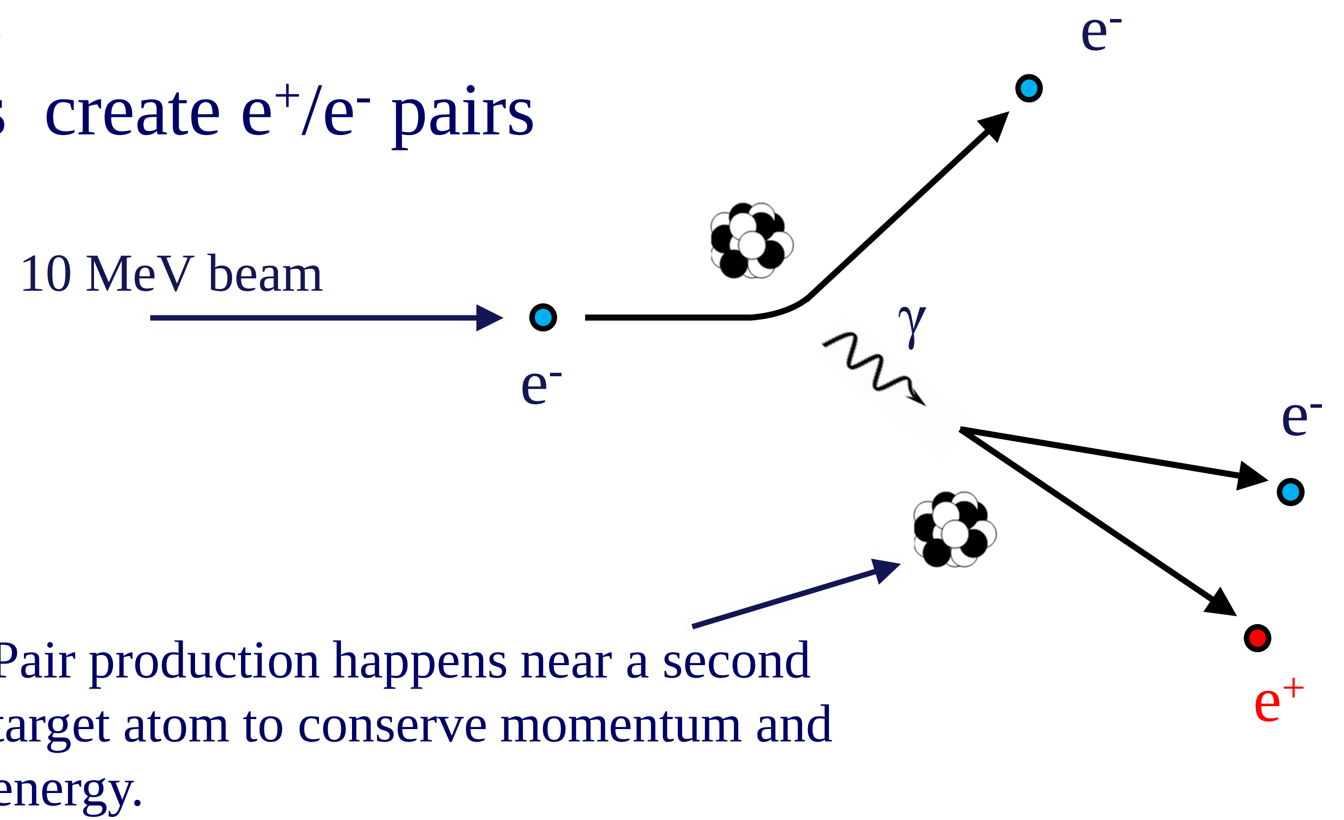
Positrons are created in a two-step process

- Electrons emit Bremsstrahlung photons
- Photons create e^+/e^- pairs



Positron System Schematic

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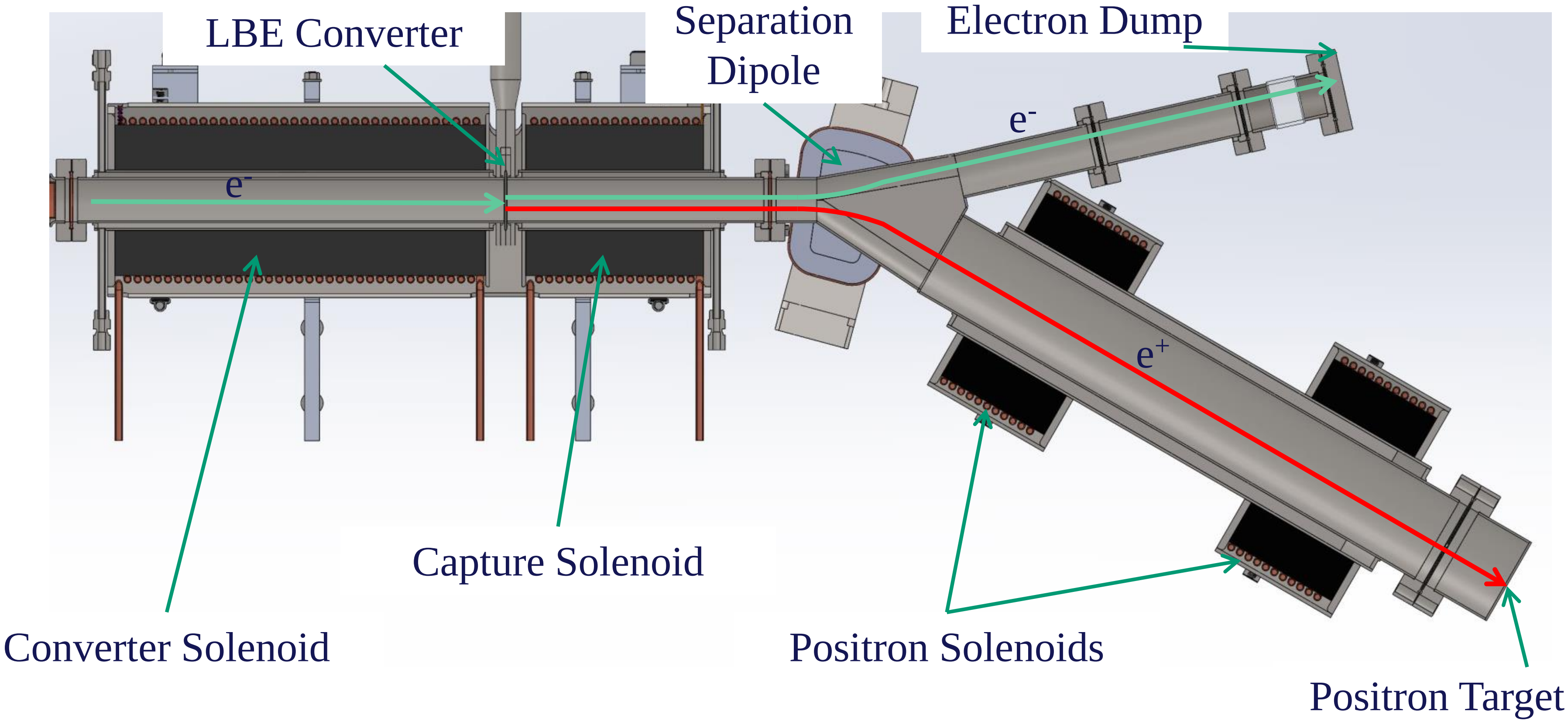

- The e^+ beamline is designed to be dispersion free at positron target location, so that different energy positrons arrive at the same point
- 0.2 Tesla solenoid collects ~20% of e^+ produced at converter
- ~$4x10^{-4}$ e^+ leave the capture solenoid per incident 10 MeV e^- on the converter

Liquid Metal Target with Natural Circulation

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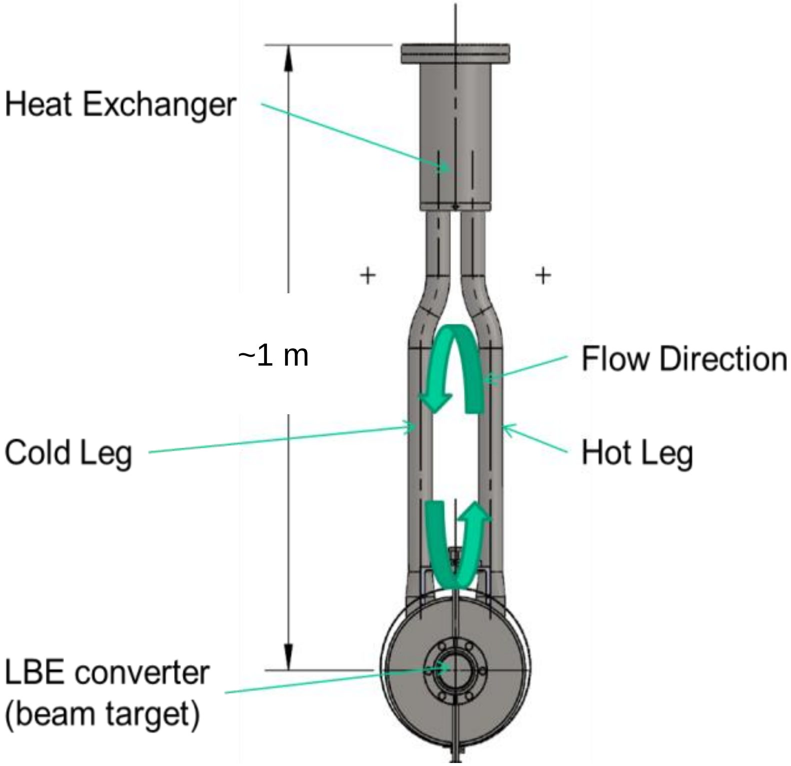

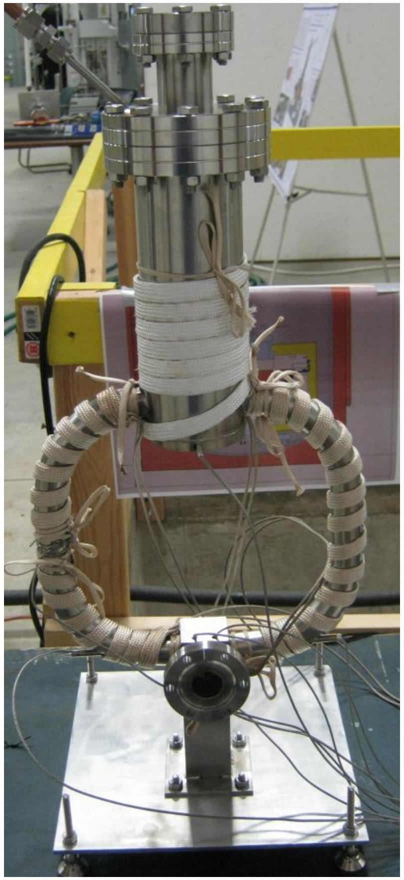

- Density differential between hot and cold leg drives flow
- Heat input from beam goes into hot leg
- Heat exchanger removes heat at reservoir on top

- Lead-bismuth eutectic
  - Low melting point: 124°C
  - High boiling point: 1670 °C
  - Z = 82, 83

Liquid Metal Target with Mechanical Pumping

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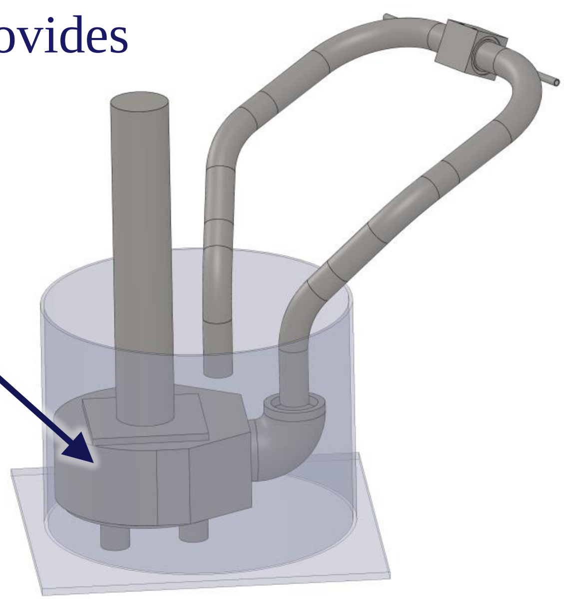
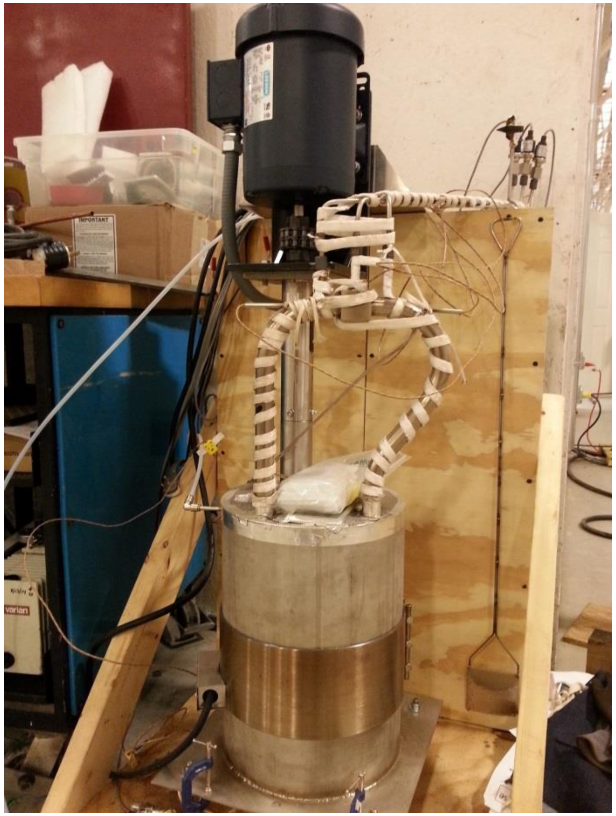
Mechanical pumps can also be used with lead-bismuth eutectic to increase and control the flow rate.

More flow allows for better cooling of the target, and handling of more beam power.

Spinning impeller provides liquid metal flow.





Liquid Metal Target with Electromagnetic Pump

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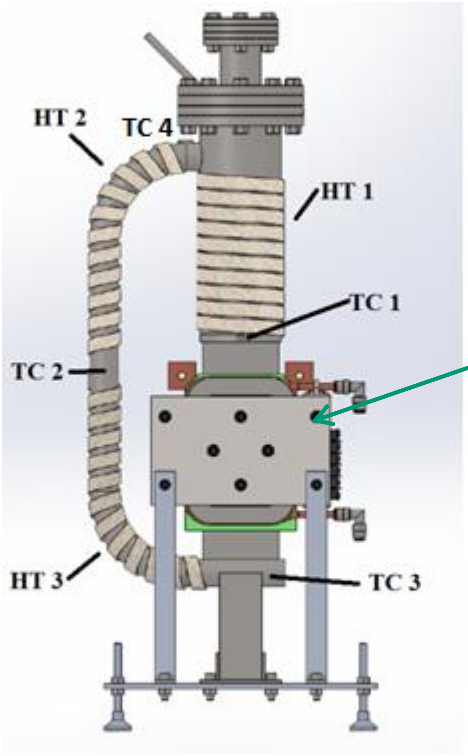
Active pumping of the liquid metal with electromagnetic pump (no moving parts) has also been prototyped and tested.



Current through liquid metal in magnetic field drives LBE down towards target, where it heats and then rises to exchanger

Liquid Metal Target Design

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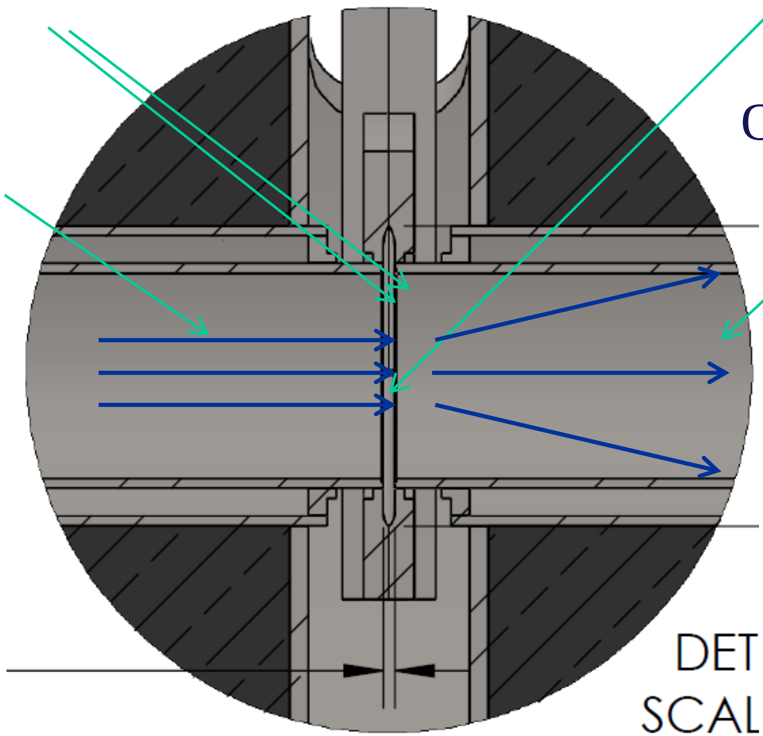
Input electron beam passes through:

- 0.25 mm SS
- 2 mm LBE, chosen for highest rate of production of e^+ using 10 MeV e^- ($\sim 2\times10^{-3}$ e^+/e^-)
- 0.25 mm SS



Momentum of e^+ and e^- after Converter

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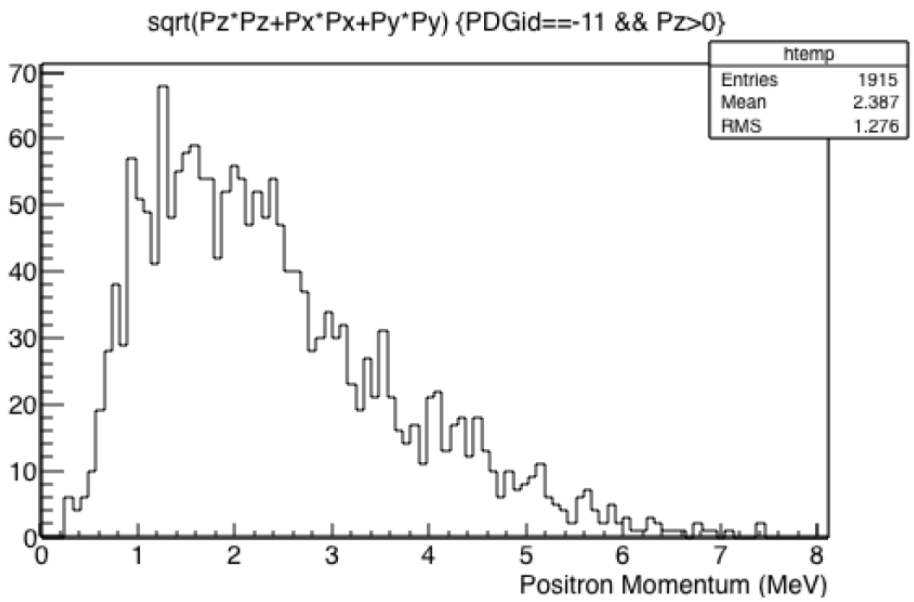
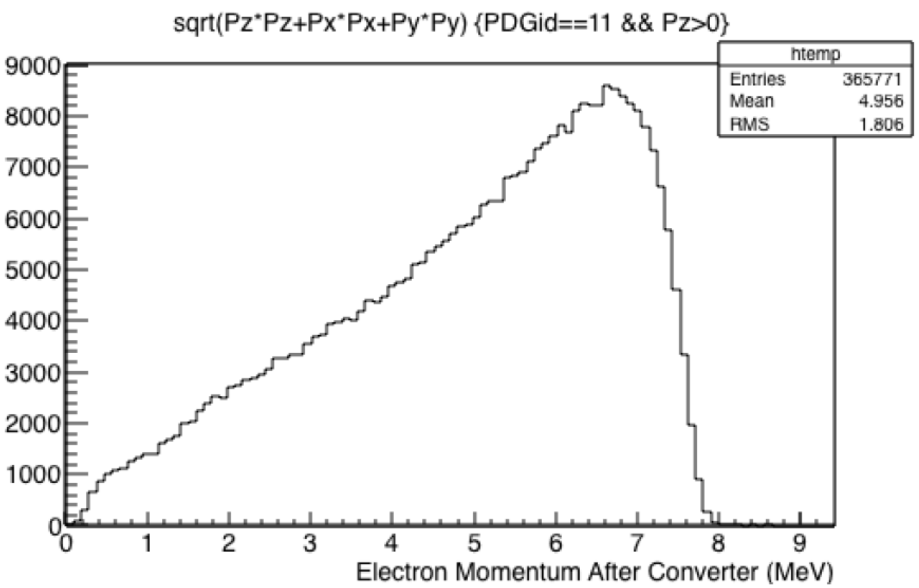
- Positron and electron momenta distributions using 10 MeV beam (simulated by IAC)
  - Peak of e^- at ~7 MeV
  - Peak of e^+ at ~2 MeV





System Power Handling

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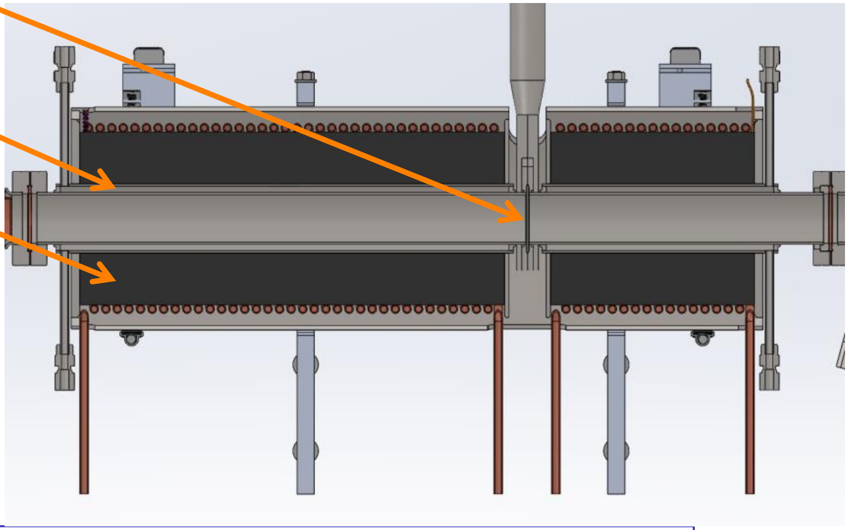
Total power deposited into various beamline components by e^- and γ as a percent of input beam power of 10 MeV e^- beam

Part Description	Percent of Power Deposited
LBE Converter	52 %
Beampipe (water cooled)	27 %
Solenoids (water cooled)	20 %
Leaving System	1 %



Coupled with analysis by LANL, this indicates that the natural circulation liquid metal converter can handle up to 10 kW of incident beam power.

Radiation Detectors for Positron Production

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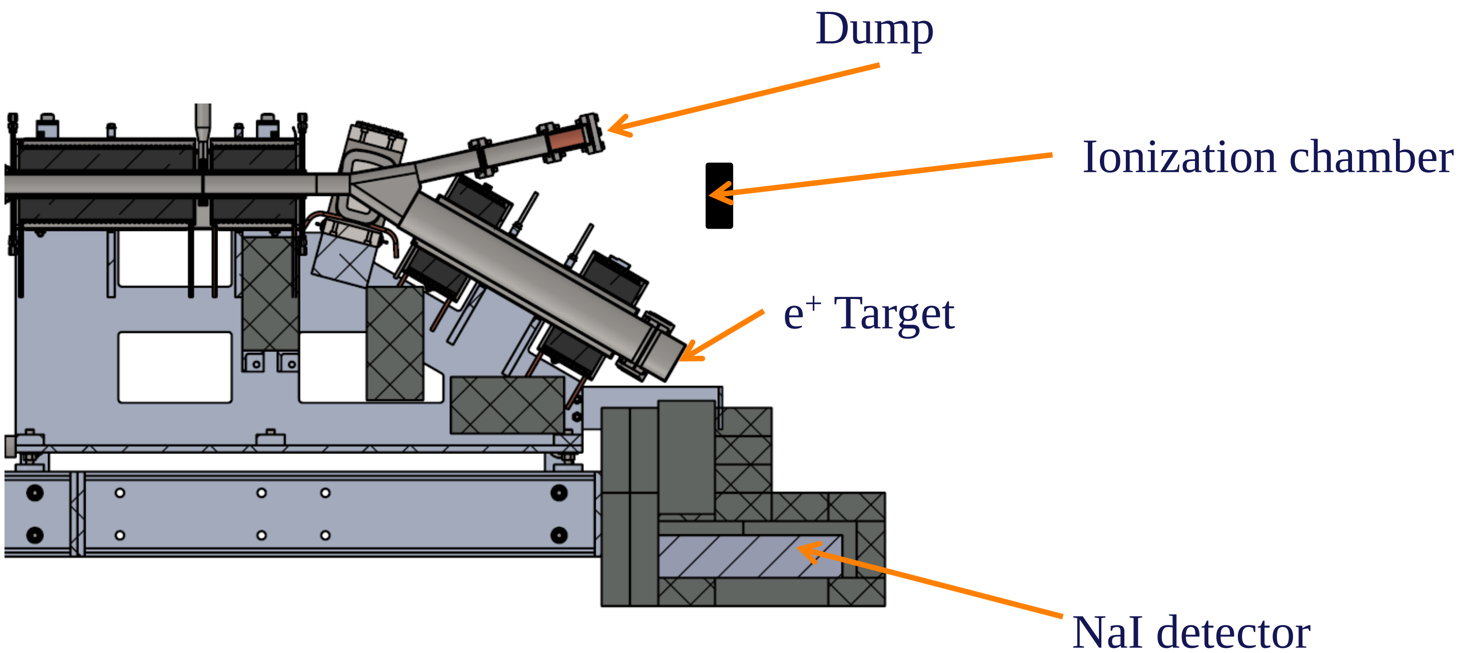
Radiation from the beam is monitored at two locations

- ionization chamber along the beam axis
- NaI detector near the target to record annihilation gammas



Positron System Hardware

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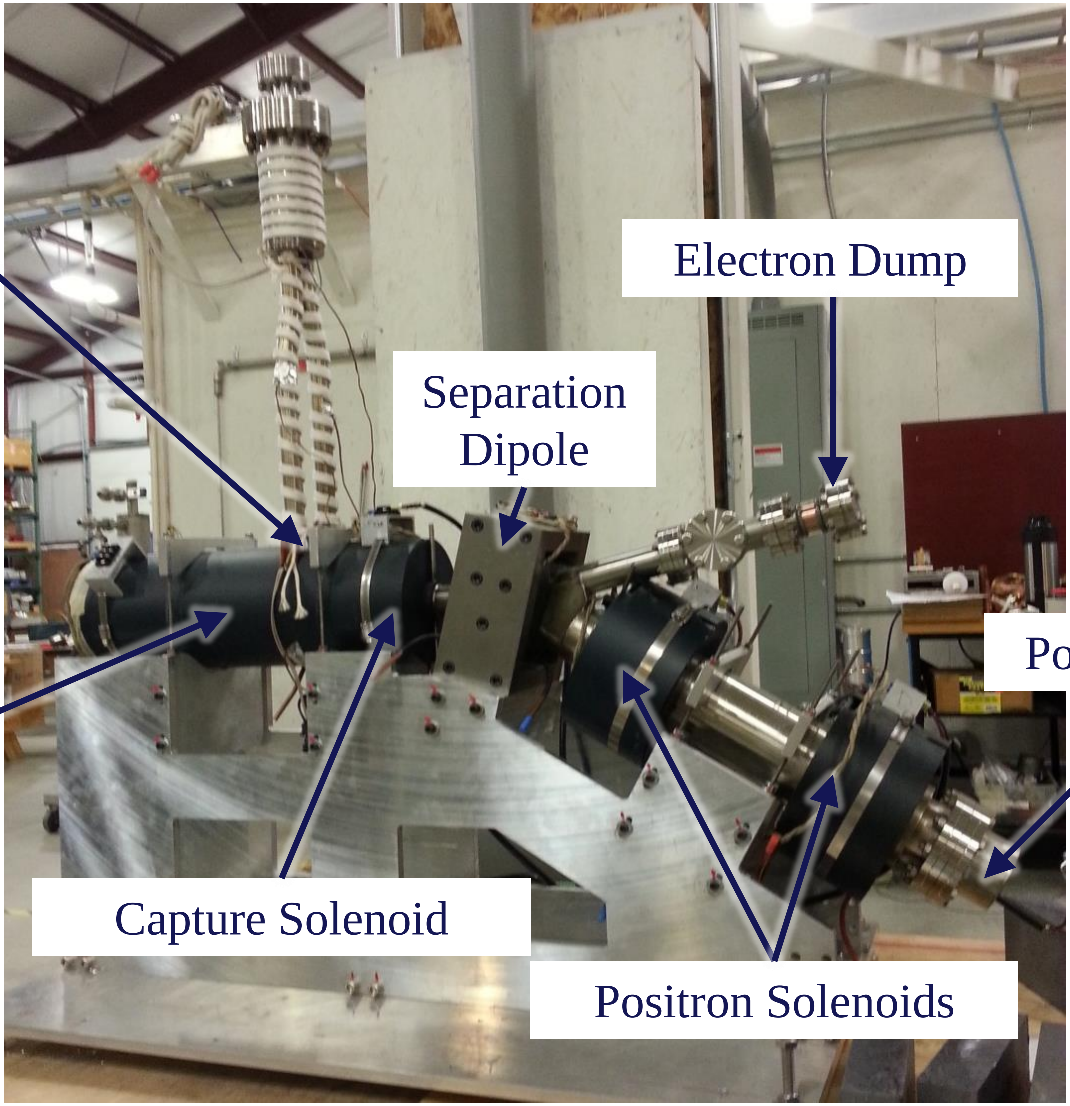

Converter-Only Testing

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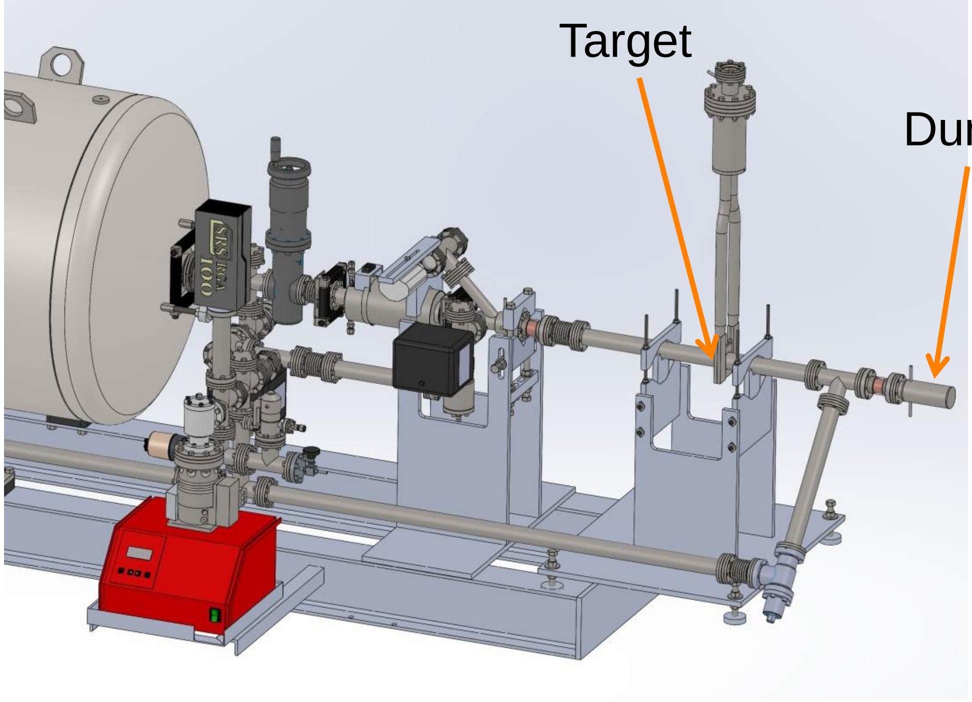
Completed testing a simplified target region, a bare beampipe with the LBE target

- Temperature along beamline pipe, for power deposition
- Collected current at dump, for e^- transmission through LBE
- X-ray detection, for radiation doses



Test Results – Charge Transport

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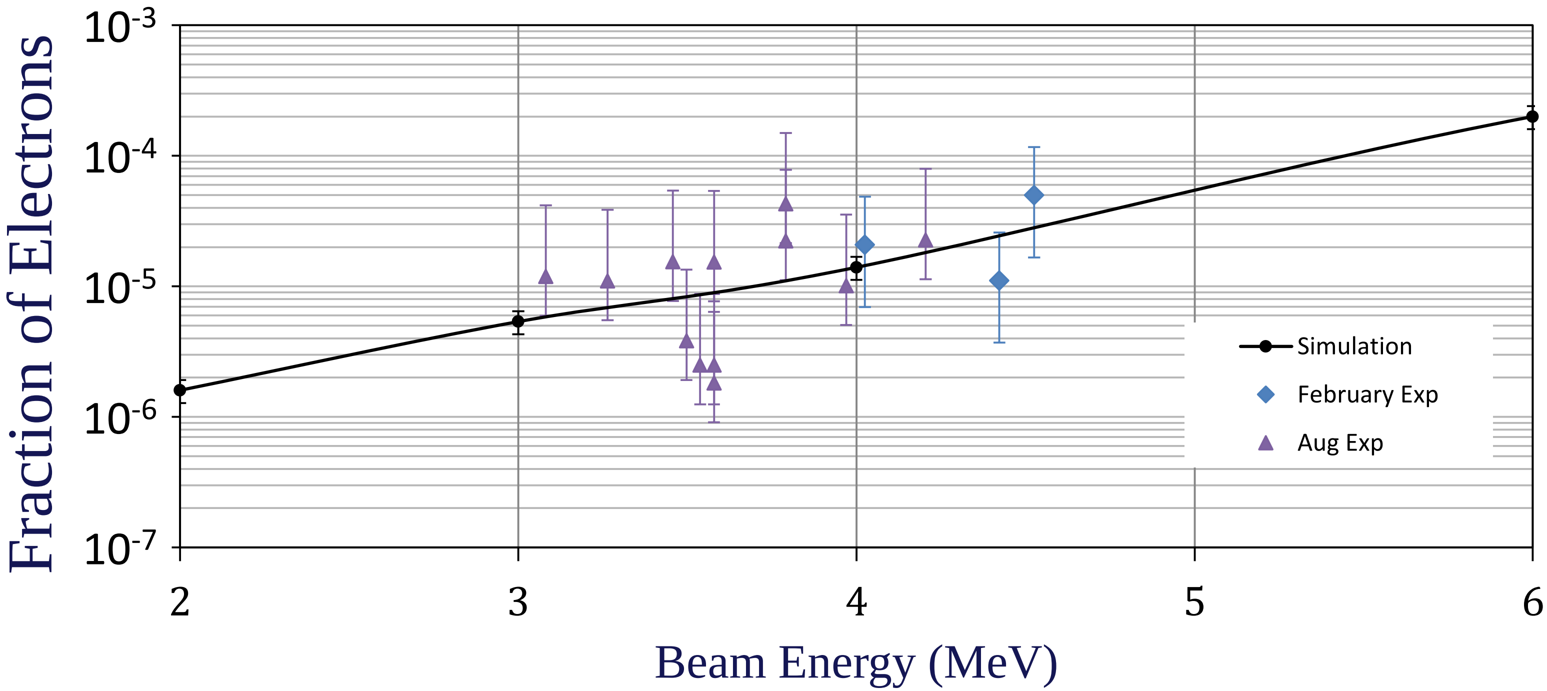
- Used MCNPX to simulate charge transport of electrons through the liquid metal target to a beam dump with no magnetic focusing
- Two beam tests were run with the accelerator and converter-only setup, giving reasonable agreement with the simulation

Electron transport from to beam dump (after liquid metal target)



Test Results – Radiation Spectrum

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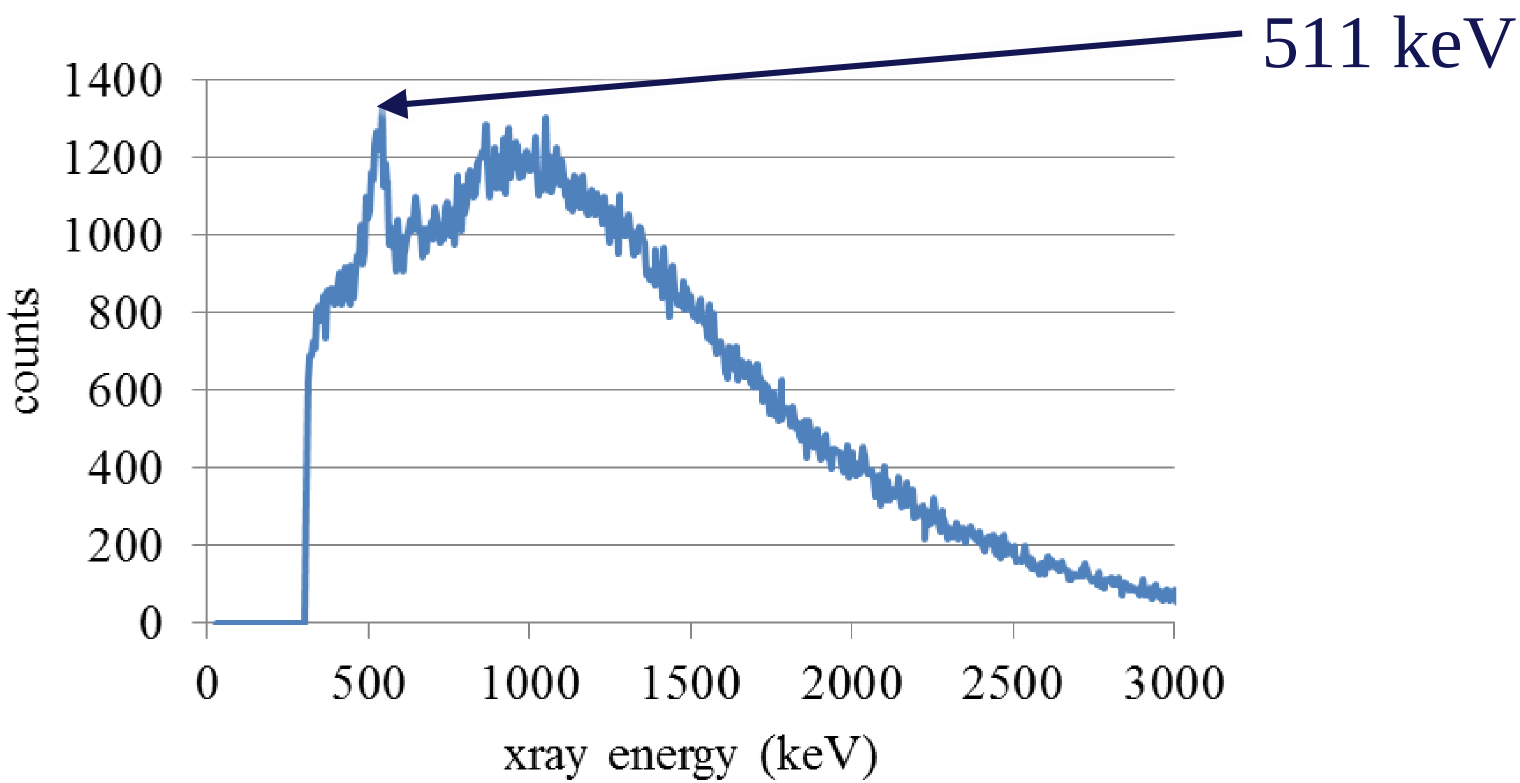
The NaI detector was able to clearly resolve the positron annihilation peak even without magnetic capture (this spectrum includes positrons generated all along the beamline).



Project Summary

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- A robust, industrial positron source is needed for both nuclear physics and materials science applications
- This SBIR project has developed and built a positron production system
  - 10 MeV superconducting electron accelerator
  - high-power liquid metal target
  - magnetic capture and separation systems
- Full testing with high-energy beam and positron detection planned for late 2016