Applications of a Compact Positron Source as a Source of Entangled Photons

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Acknowledgements

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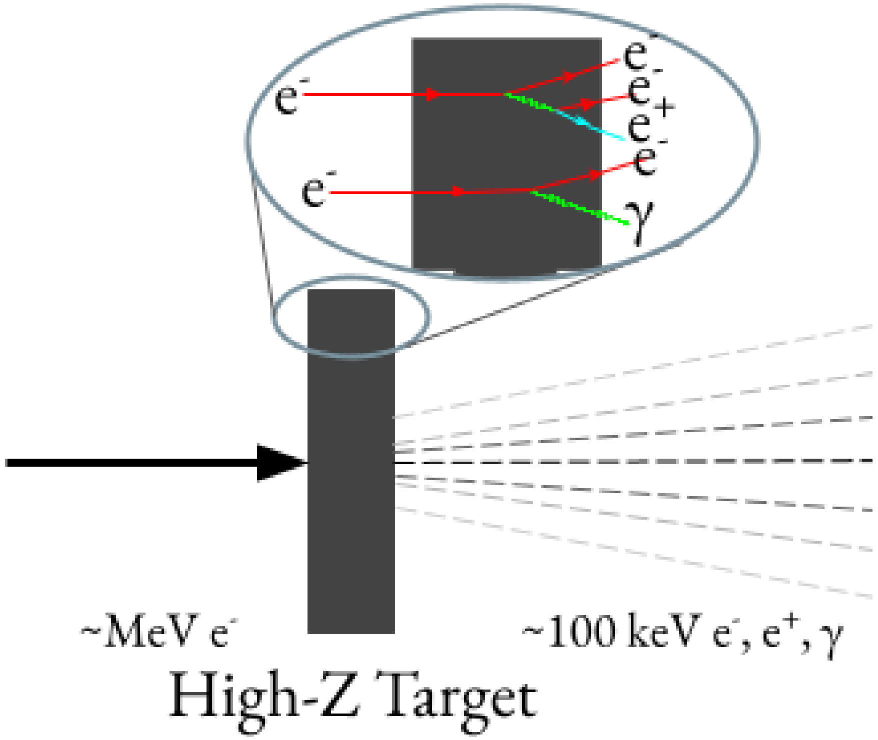
Outline

- Motivation
- Positron Generation at the XTA beamline at SLAC
- Near Term Experimental Opportunities



SLAC Once Hosted the World's Highest Intensity Positron Source

SLC Positron Target

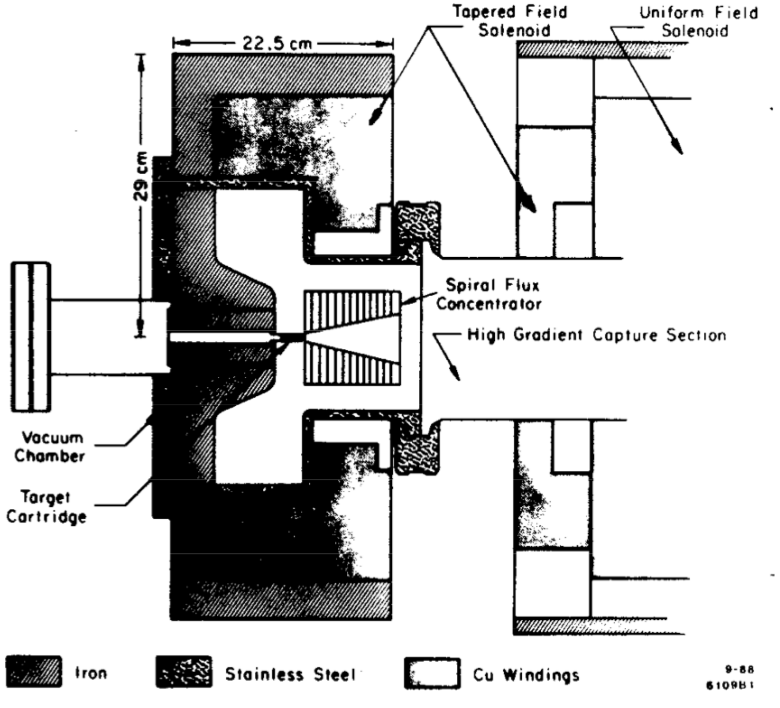


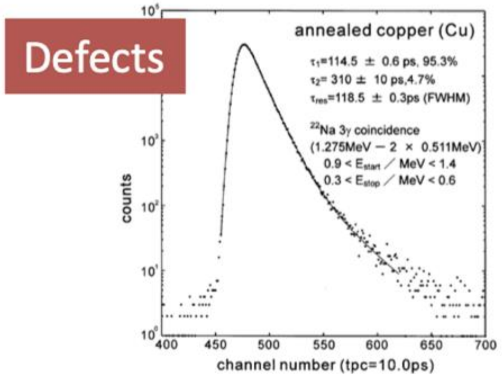
Fig. 1. Cross section of positron target assembly.

How can we leverage this expertise and apply it to new scientific challenges?

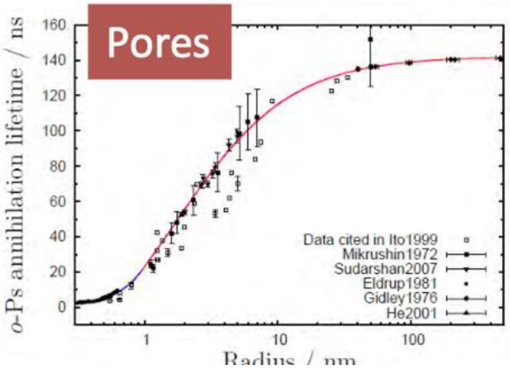
Positrons for Basic Research

Positron Annihilation Lifetime Spectroscopy

Saito, Hyodo et al., NIMA 487, 612 (2002)

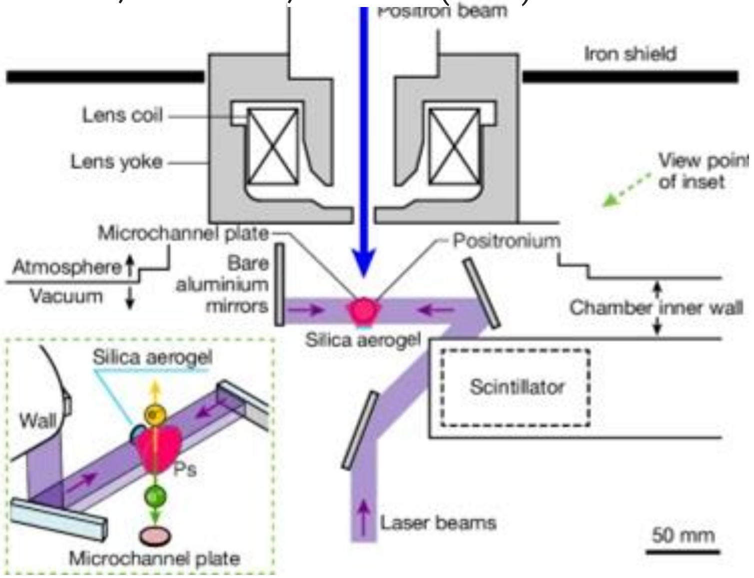


K. Wada and T. Hyodo,
J. Phys. Conf. Ser. 443, 012003 (2013)



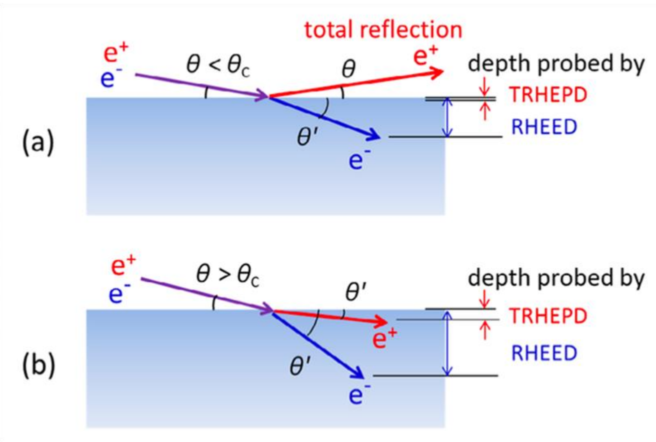
Laser Cooled Positronium

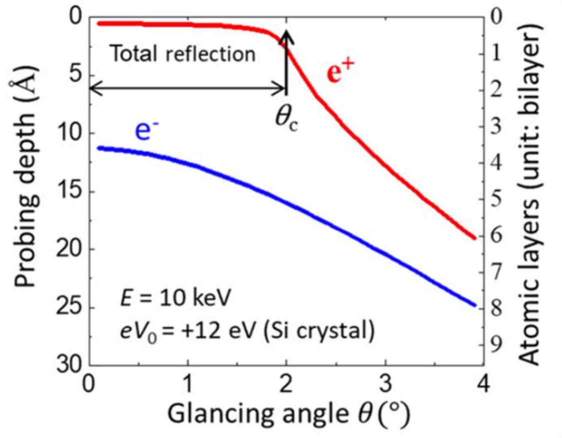
K. Shu et al., *Nature* 633, 793–797 (2024)

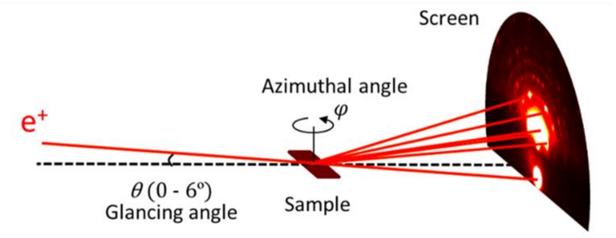


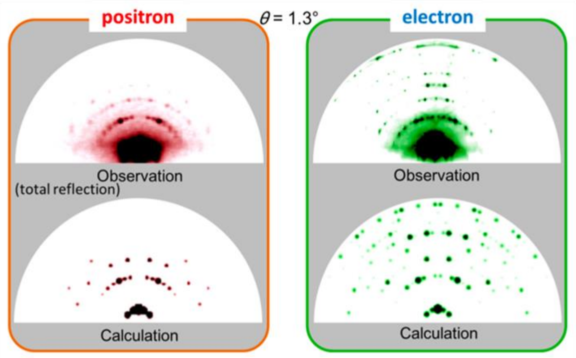
Total Reflection High Energy Positron Diffraction

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









Positrons enable exciting scientific opportunities, but positron sources have limitations.

Current Positron Sources are Limited by Efficiency

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

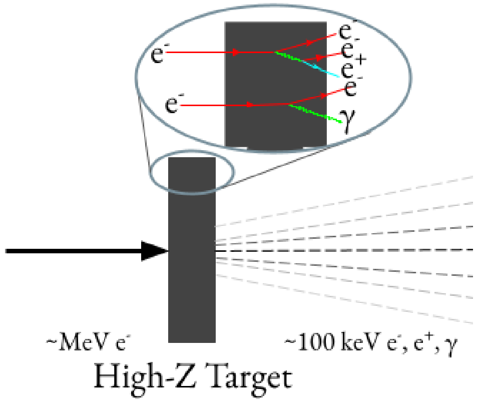
Table 1
Performance of linac-based positron sources.

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~~ 10	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

* This is just linac sources, but you get the idea

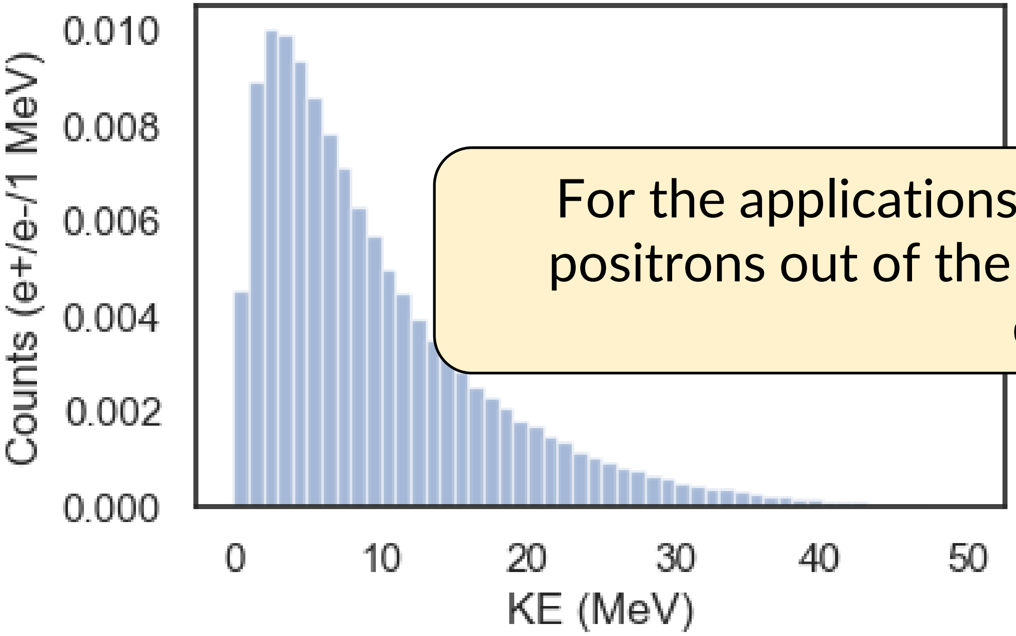
- Arguably the biggest issue in having accessible positron sources is that the yield of e+/e- is extremely low
- The reason for this is *moderation*, which takes a beam with large energy and divergence and produces a quasi-monoenergetic beam with large spot size and low divergence

Positrons can be Produced by Colliding a High Energy Electron Beam on a Dense Target

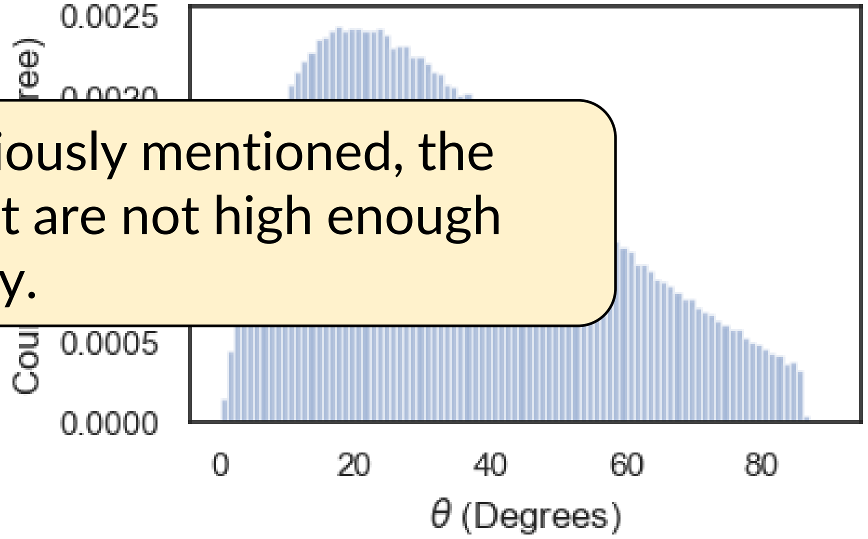


For an incident 65 MeV e- Beam:

Positron Energy After Target

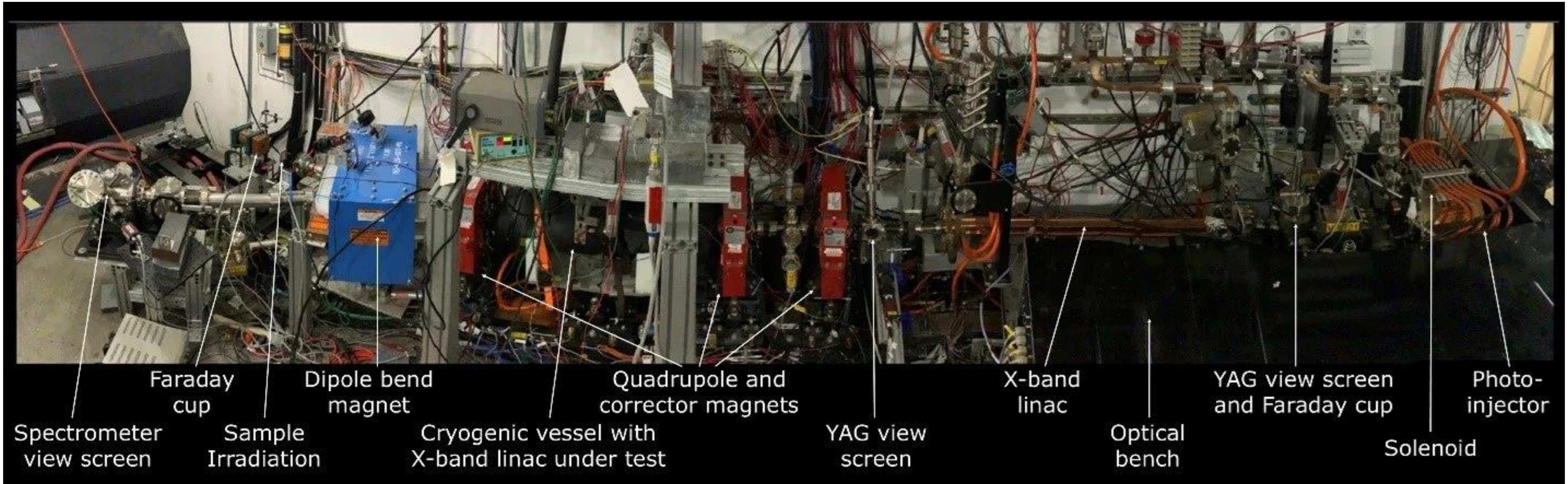


Positron Divergence After Target



For the applications previously mentioned, the positrons out of the target are not high enough quality.

The XTA Accelerator at SLAC is an Ideal Testbed for Positron Research



Photograph of the XTA beamline (~7 m long). Electron beam propagates from right to left.

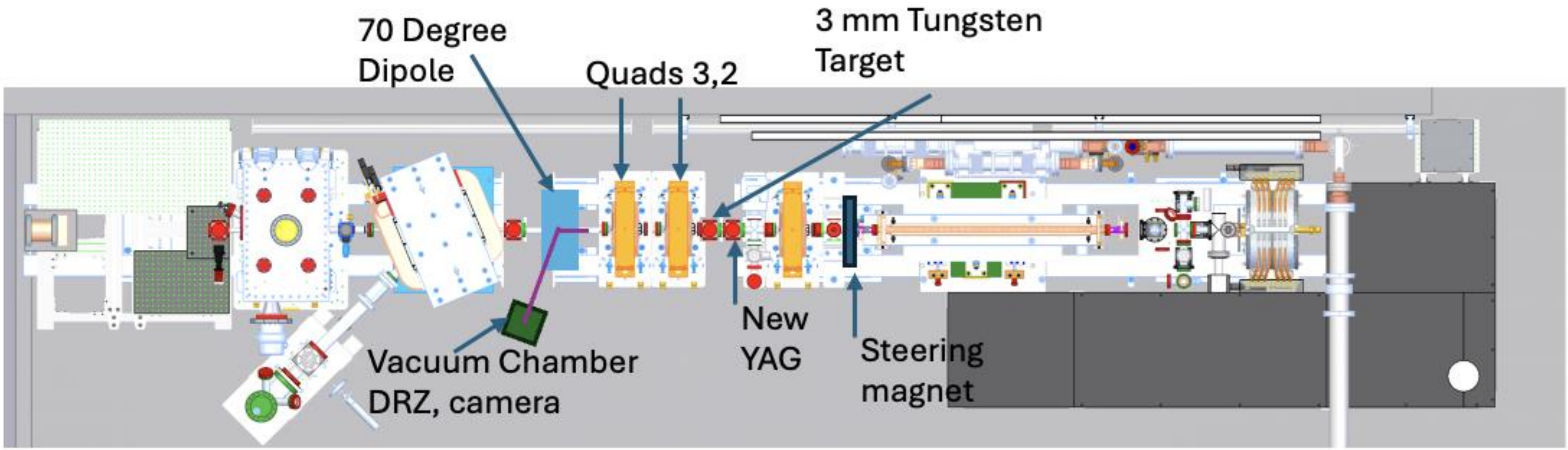
XTA can provide a 65 MeV, 100 pC, 30 Hz e- beam with <10ps pulse length

beamNetUS
accelerating beam-based research

The new call for proposals is open!

Submit your proposal by September 4th. Check out our User Handbook and the recording of our Virtual Townhall where we discussed our facilities' capabilities and the proposal process. We will also hold a number of office hours, the first one on August 6th at 9am-10am Pacific time, where we welcome your questions regarding this new call for proposals. **Subscribe to our mailing list and follow us on LinkedIn for updates!**

Initial XTA Facility Positron Upgrade



Positron Energy: 1-5 MeV (@ central energy 3 MeV, +-200 keV)
Spot Size: 5 mm x 50 mm
Pulse length: <100 ps (@ central energy 3 MeV, 40 ps)
Charge: 1 fC/s - 30 fC/s

Comparison of positron sources

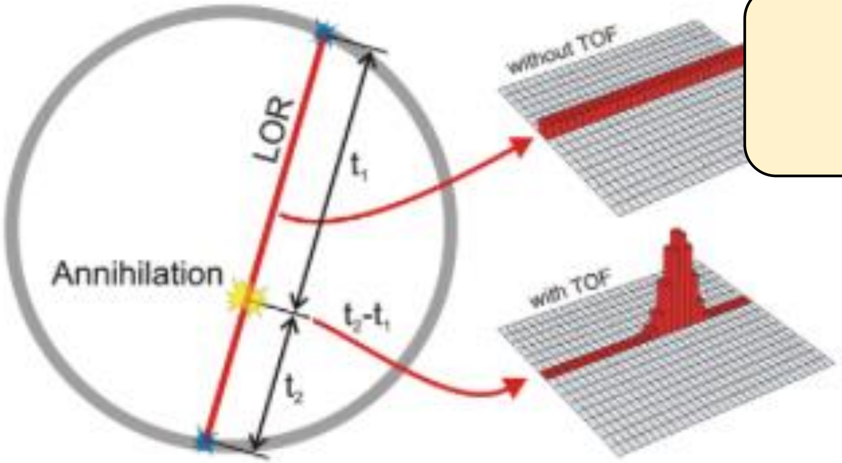
	e+ energy	Positron Flux 10^7 e+/s	Bunch Length ps
Radioisotope (typical)	<30 keV	0.001	>500
KEK	<35 keV	10	1000
NEPOMUC	<30 keV	100	150
Compact SLAC Design	0.6-5 MeV	0.1	10-100

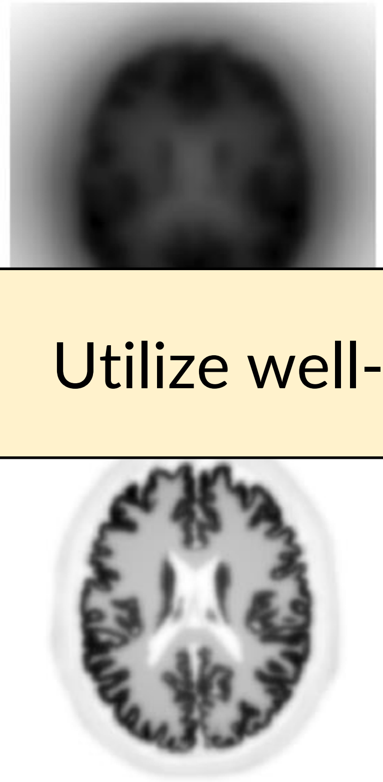
Ultrashort positron bunches will enable new science.

First Science with the SLAC Compact Positron Source

Time of Flight PET Detectors

- 10 ps Time of Flight resolution for PET detectors would enhance the SNR, enabling lower dose and quicker measurements

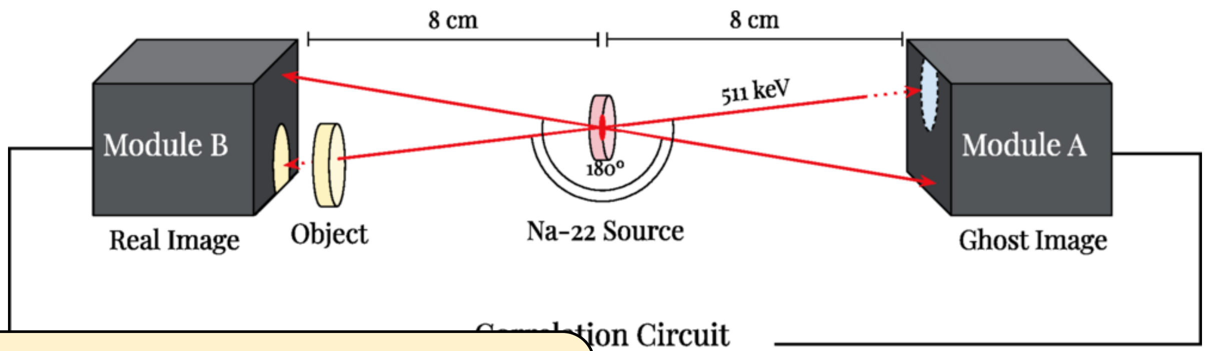




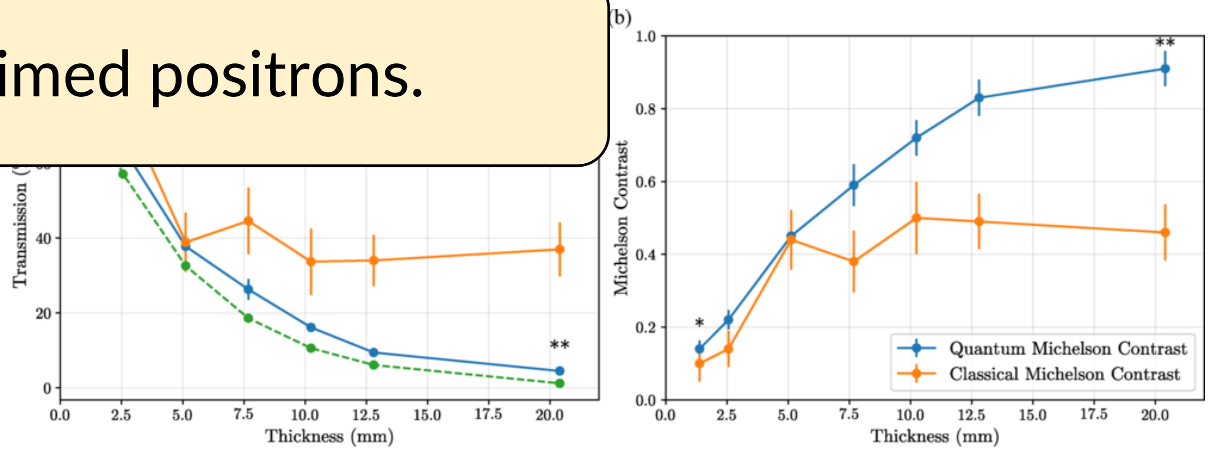
TOF back-projection with 10ps FWHM CTR

Ghost Imaging with Gamma Rays

- Utilizing the entangled nature of the emitted gamma rays enables imaging of dense materials

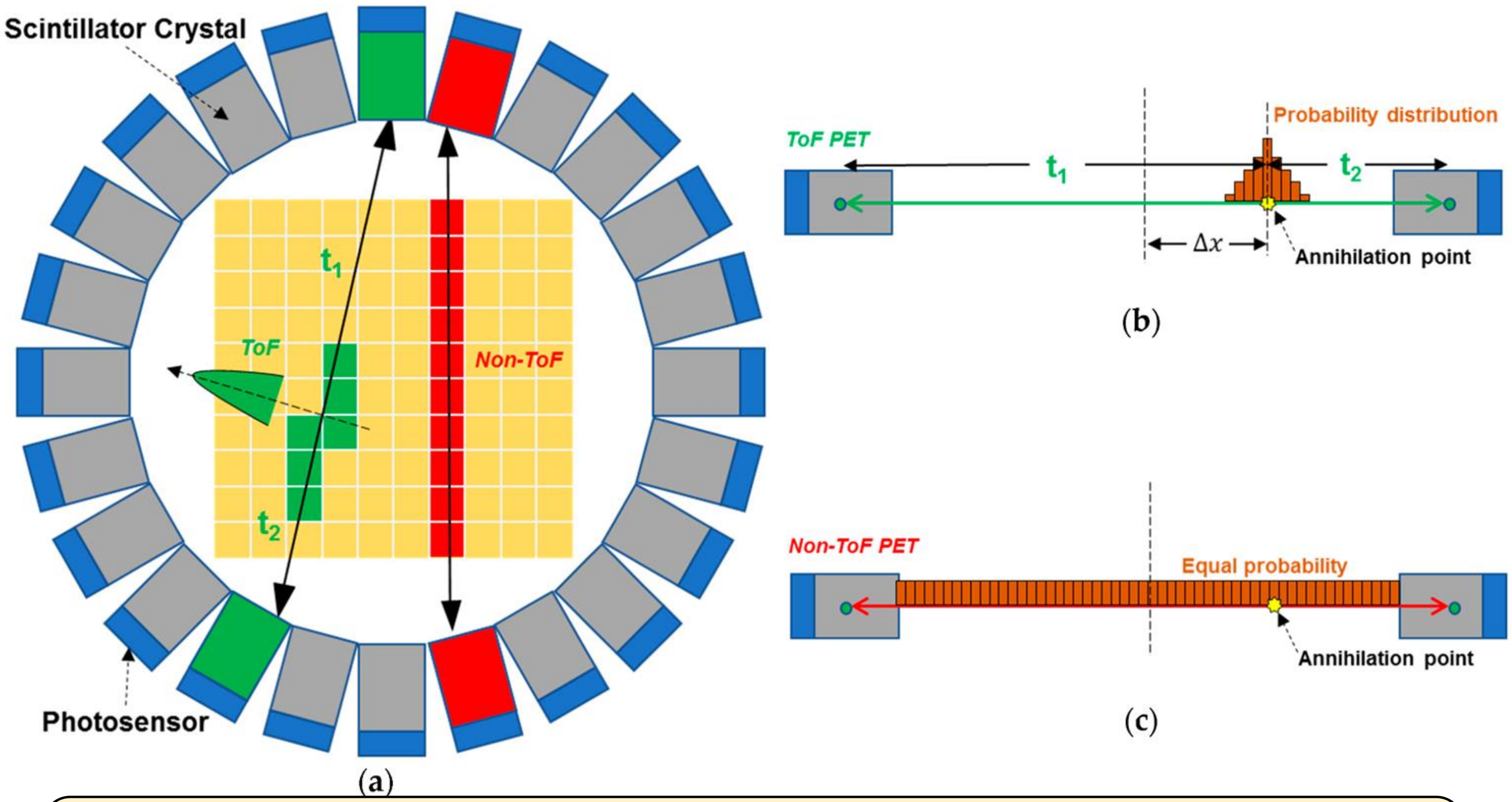


Utilize well-timed positrons.



Schneider et al., Phys. Rev. A 113, 013715 (2026)

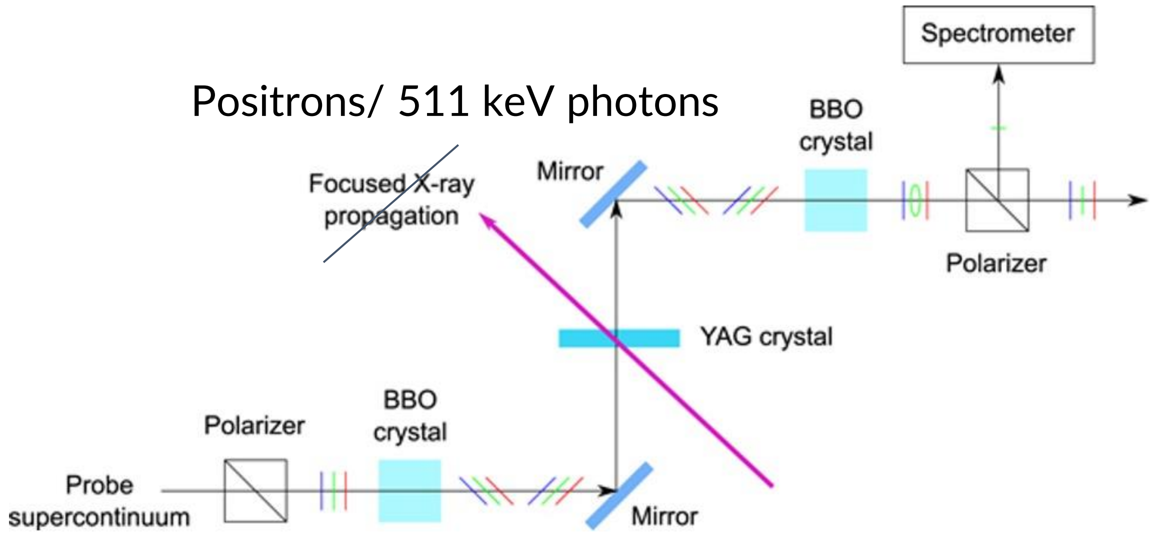
Time of Flight (ToF) Positron Emission Tomography

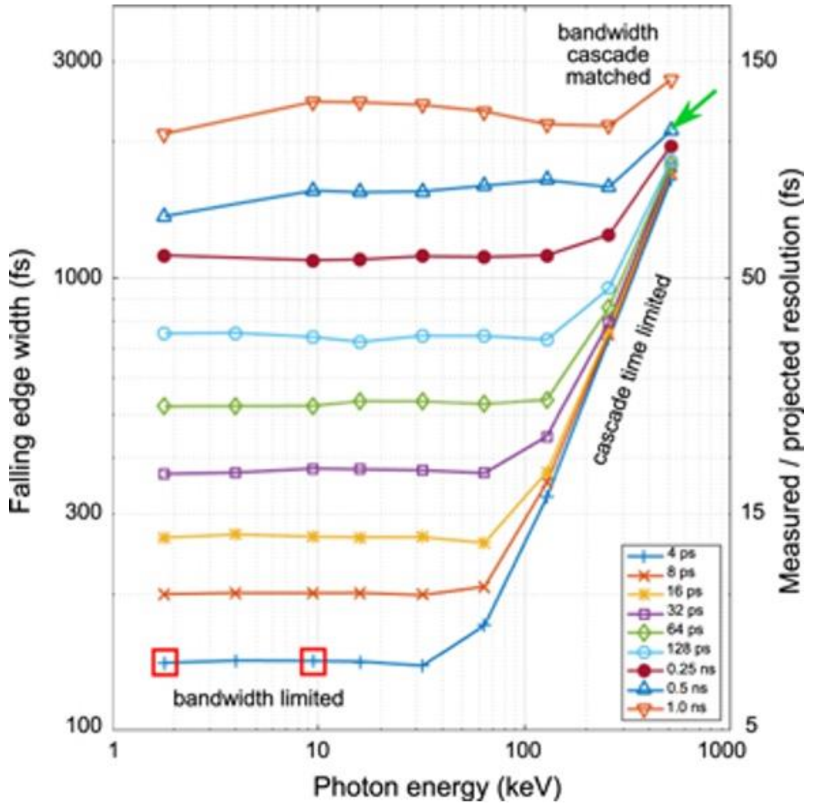


Gamma Ray Timing Resolution → Spatial Resolution

Novel Laser Based Gamma Ray Detector Could Enable High Resolution PET

Traditional detectors are scintillator based, but novel laser scheme could enable resolution <100 ps





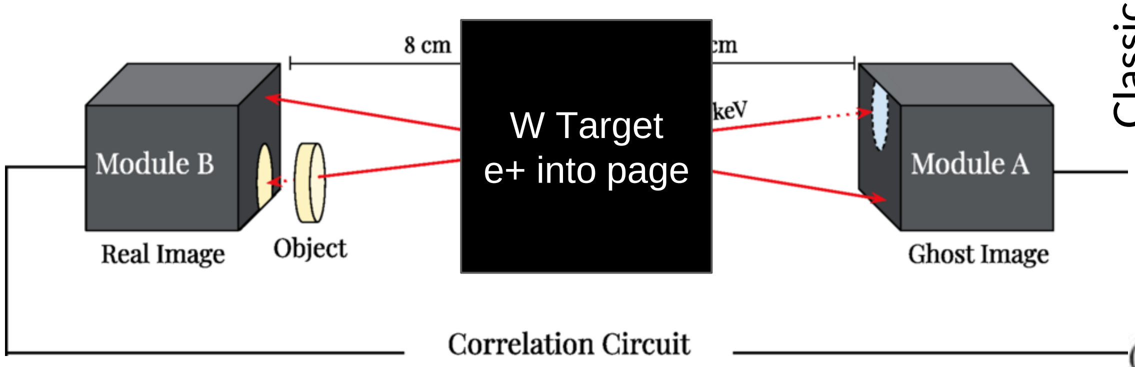
Unlike radioisotope based source, the XTA linac source is inherently laser timed.

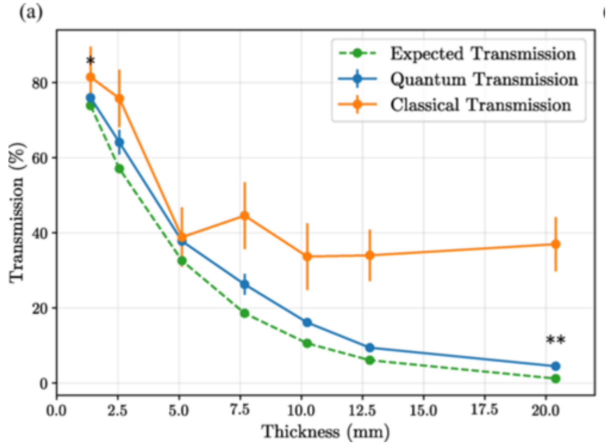
Currently discussing with C. Levin (Stanford), R. Coffee (SLAC)

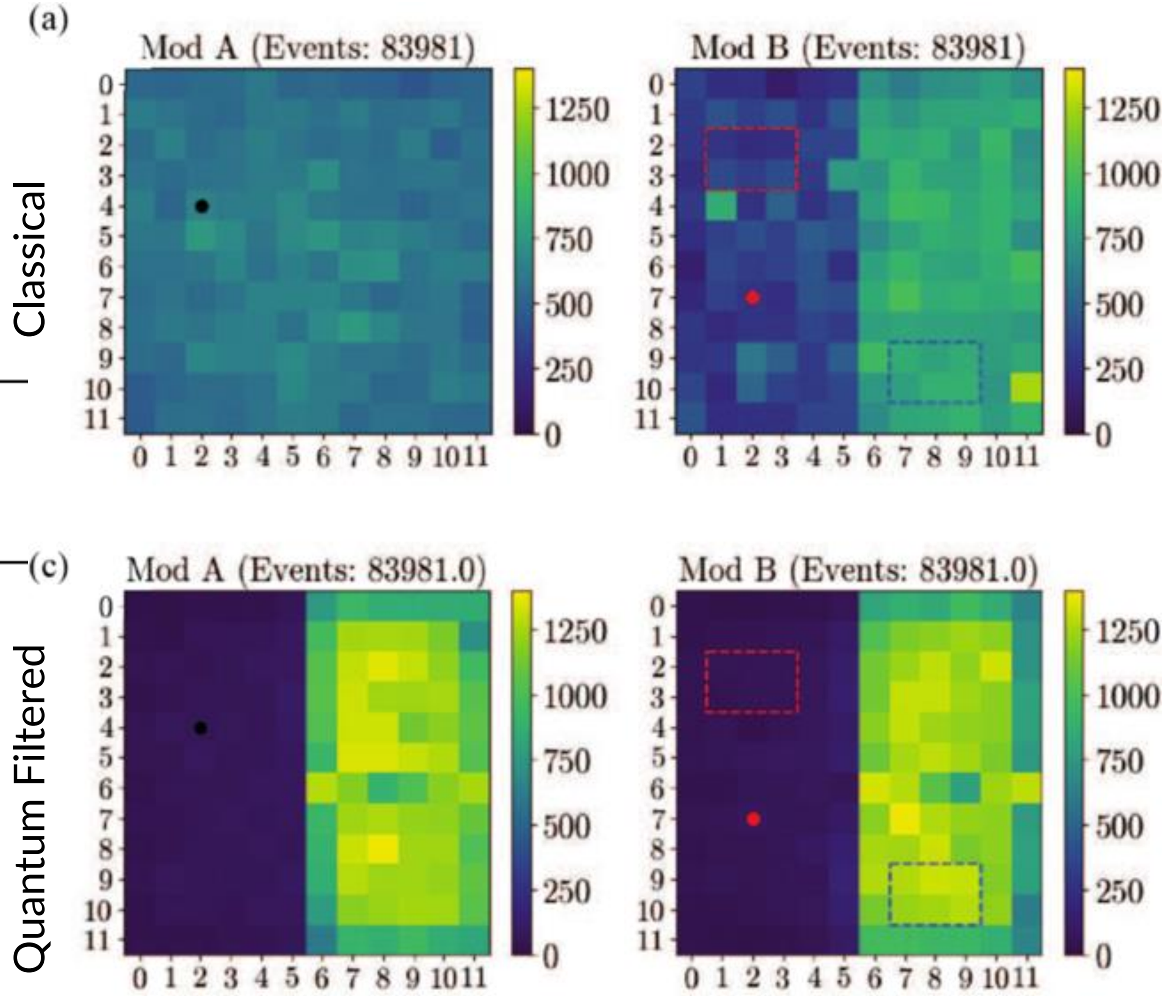
Li Tao et al 2021 Phys. Med. Biol. 66 045032
D. Jeong et al. Nature Photonics volume 20, pages 686–692 (2026)

Quantum Ghost Imaging for Dense Materials

Early experimental results indicate ghost imaging can make significant improvements to SNR in the imaging of dense objects

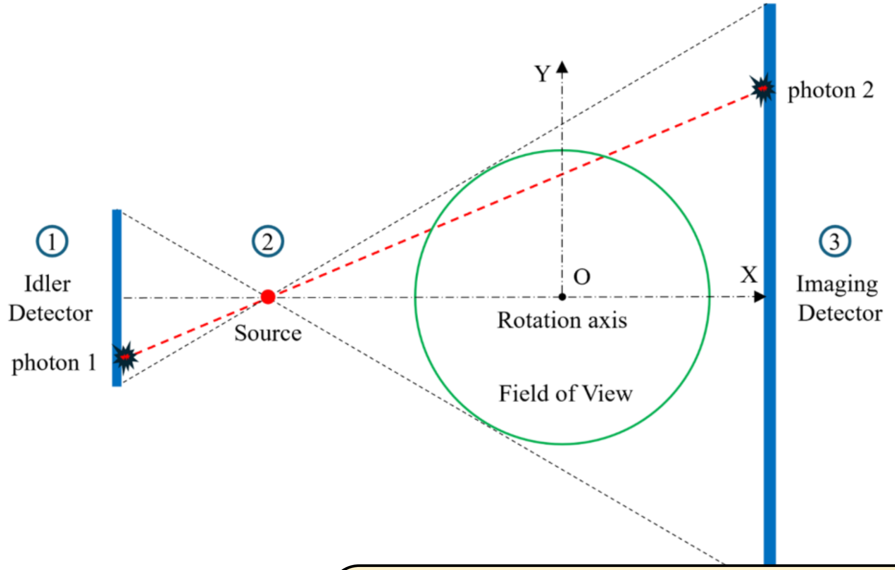






Schneider et al., Phys. Rev. A 113, 013715 (2026)

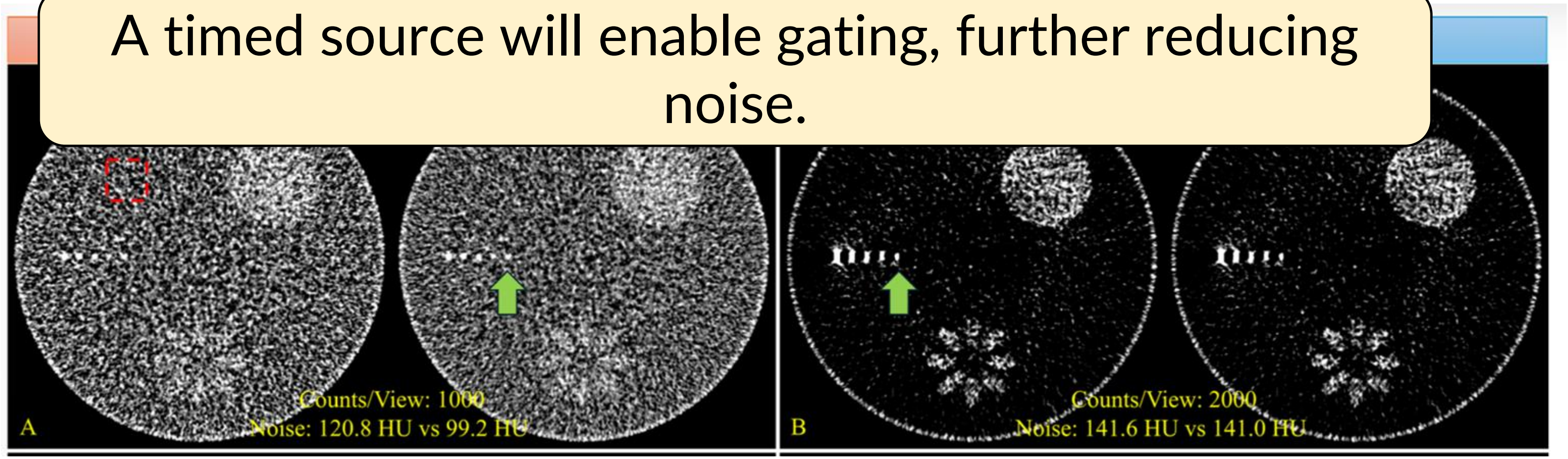
Ghost Imaging for Direct Breast Tomography



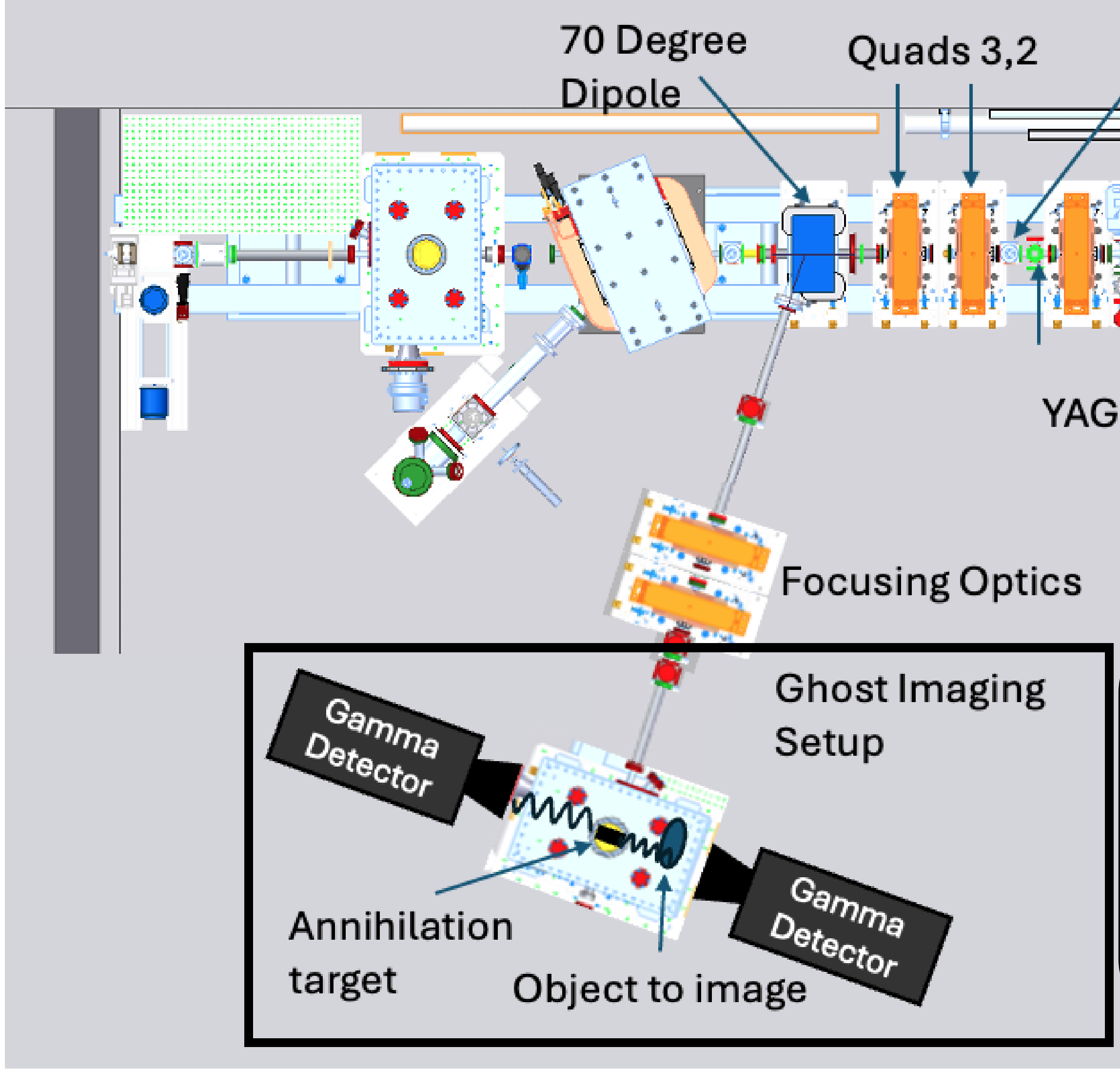
Simulations indicate that ghost imaging with 511 keV photons could reduce noise by 22%.

Yu et al., Proc. SPIE 13924, Medical Imaging 2026: Physics of Medical Imaging, 139241D (2 Apr 2026)

A timed source will enable gating, further reducing noise.



Ghost Imaging at XTA



XTA can be a testbed of novel gamma ray detectors and imaging enabling technology

Roadmap for a SLAC Positron Facility

Phase 1: MeV Positron Source	Phase 2: Ultrashort Positron Bunches	Phase 3: Ultrashort, High Brightness Positron Facility
Utilize existing infrastructure to generate 100 ps positron bunches. Enable PET detector, ghost imaging, and basic positron studies. **This talk!**	Utilize magnetic and RF bunching to create sub-picosecond positron pulses. Enable pump-probe positron science.	Utilize historic SLAC infrastructure to enable average power, high peak power positron source. Enable pump-probe positron diffraction, laser-cooled positronium electron positron pair plasma studies.

Conclusion

- Positrons are for more than colliders!
- At the XTA beamline at SLAC, we can produce a positron source of up to 1e6 e+/s, 10x more than radioactive source capabilities, in an ultrashort pulse
- In the near term, positron production at SLAC will enable testing of novel PET detectors, high SNR ghost imaging, and the optimization of positron sources for basic science

Thanks for your attention!

Background Depends on Incident Positron Energy

If we stay below 800 keV e+,>10x as many 511 keV gamma rays as not

SNR = (# 511 keV)/(total photons)

*assumes 1:1 signal/photon regardless of energy