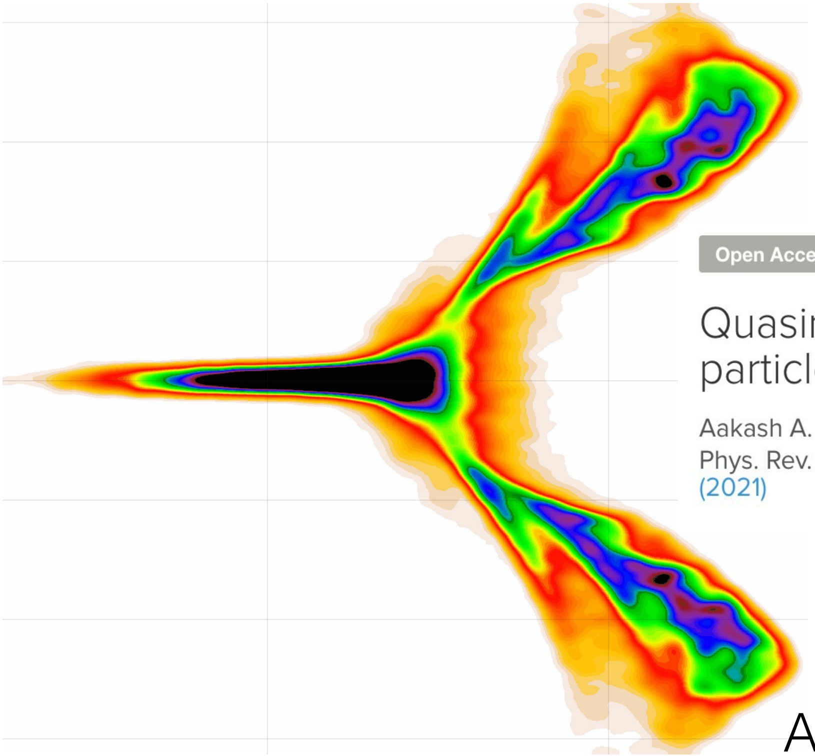
University of Colorado Denver

Tunable Laser Positron Source

NP-318679



Open Access

PRAB 21, 081301 (2018)

Quasimonoenergetic laser plasma positron accelerator using particle-shower plasma-wave interactions

Aakash A. Sahai
Phys. Rev. Accel. Beams **21**, 081301 – Published 8 August 2018; Erratum Phys. Rev. Accel. Beams **24**, 049902 (2021)

A. Sahai (PI), Kalyan T., CU Denver
D. Graham, Powerbeam Inc.
H. Chen, LLNL,
K. Kusche, M. Polyanskiy, I. Pogorelsky BNL

Funding source: DOE (applied)

US Patent 16,770,943: Method & apparatus for processing a particle shower using a laser-driven plasma

Objective

Key scientific goals

Tunable, collisionless variation of trapped positron properties

CO_2 laser-driven post-processing of ATF e-beam driven particle showers

- UNIQUE: long wavelength (mid-IR) CO_2 laser (compared to Ti:Sapphire/NIR):
  larger plasma structures – easier to physically overlay with the showers
  slower structures for a lower plasma density – laser velocity slower for same density

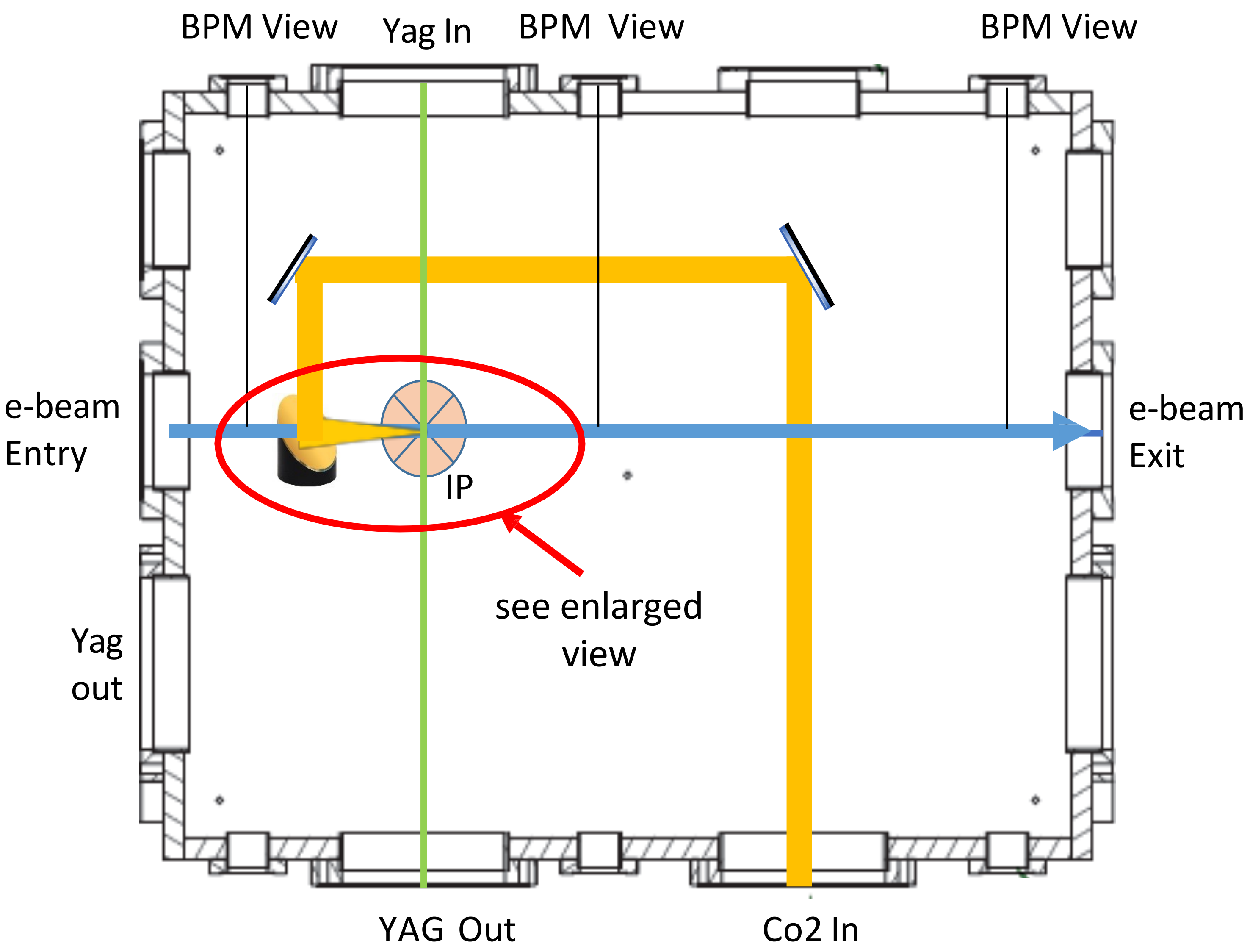
- UNIQUE: control the interaction – tunable laser, external electron beam and gas density

- numerous applications benefit from a tunable positron beam

expt. design

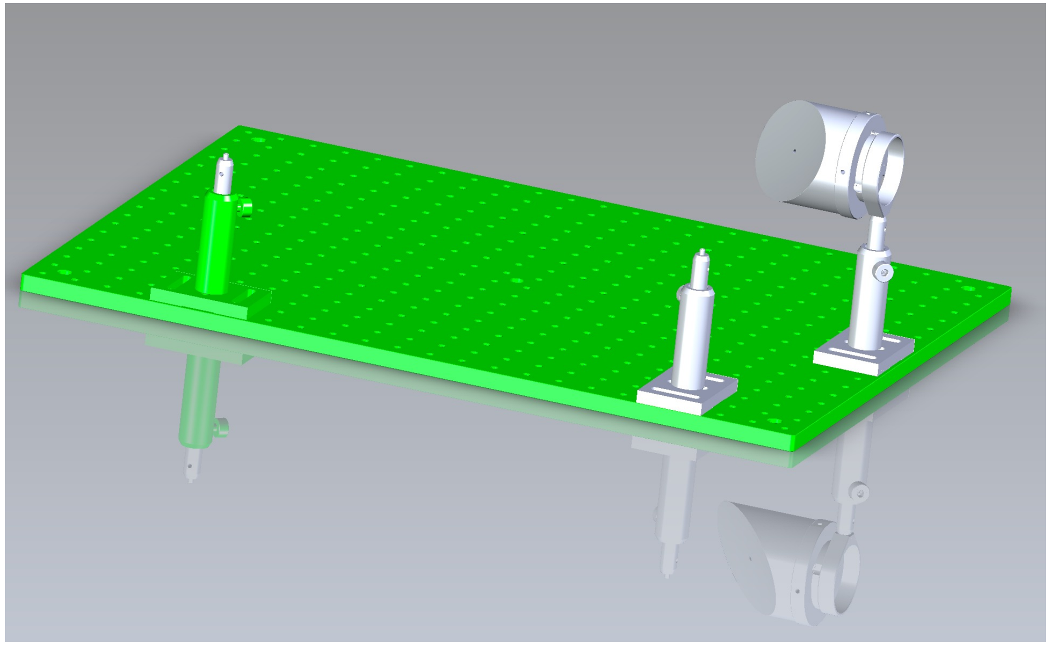
experimental layout

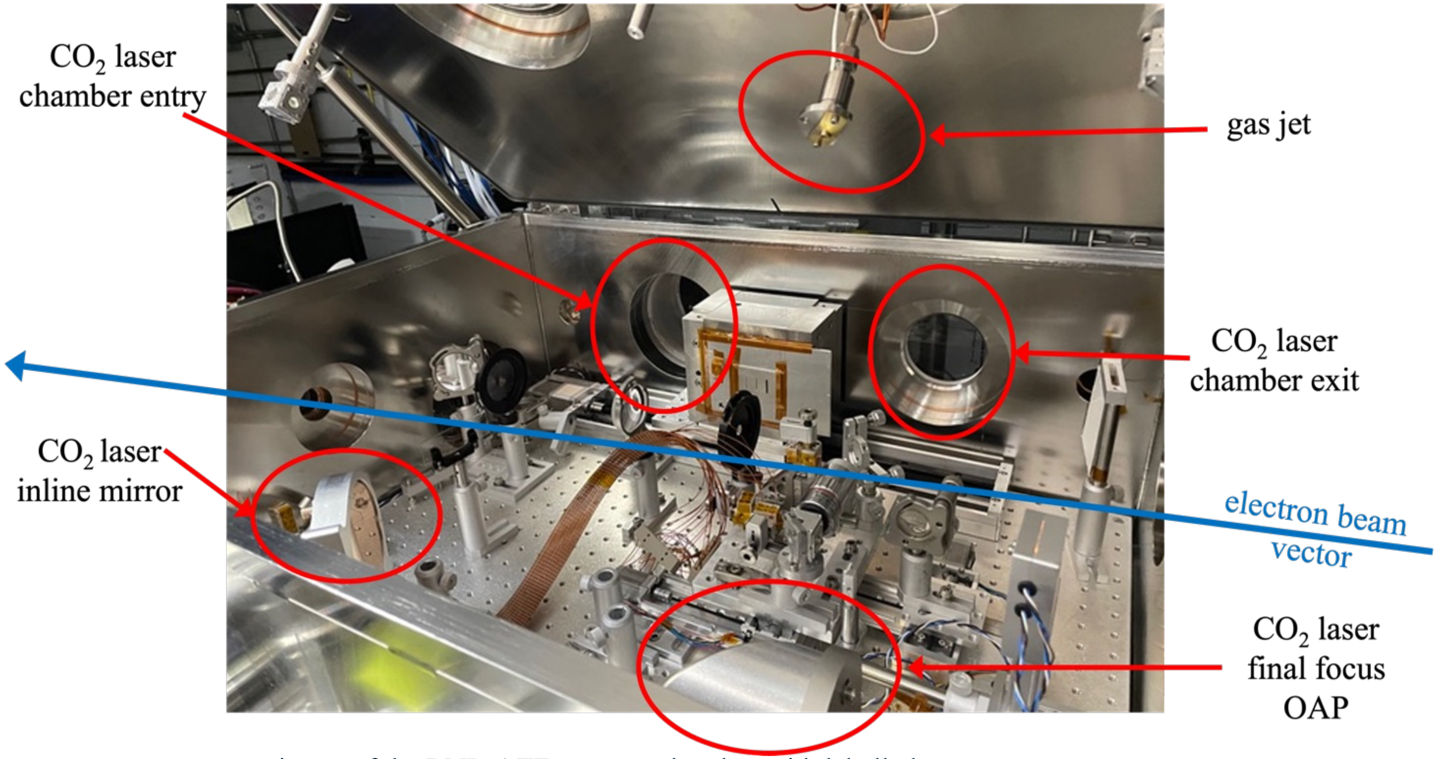
- BL# 1 vacuum chamber & gas jet
- vacuum chamber on BL#1 – space for REPPS spectrometer
- DOES NOT disturb the setup for ongoing experiments – remove and insert separate breadboard
- insert a high-Z target holder in the beam path (removable)



experimental layout - II

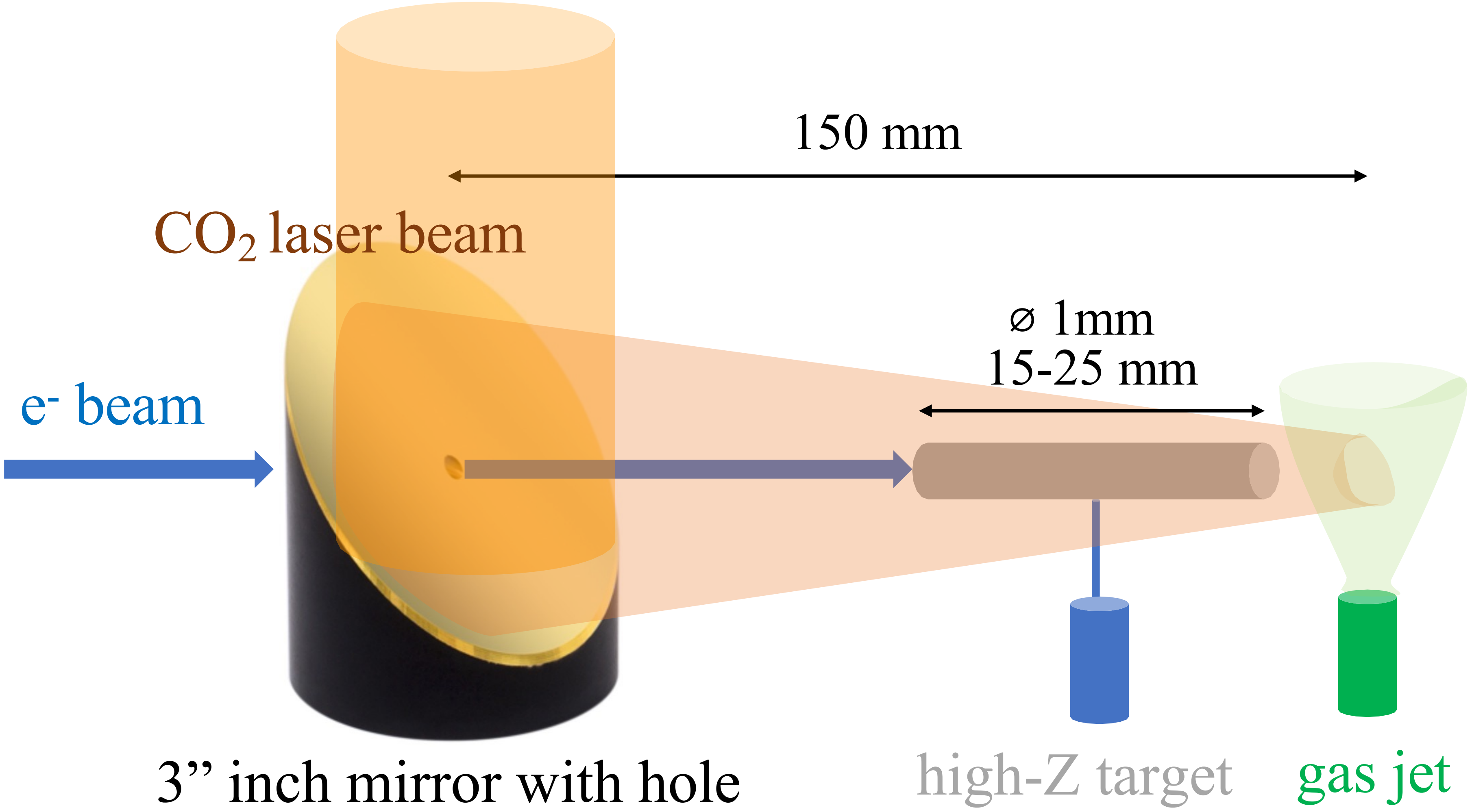
Setup on a separate breadboard
Two 90-degree turning mirrors ahead of the FF OAP
space from OAP to gas jet > focal length



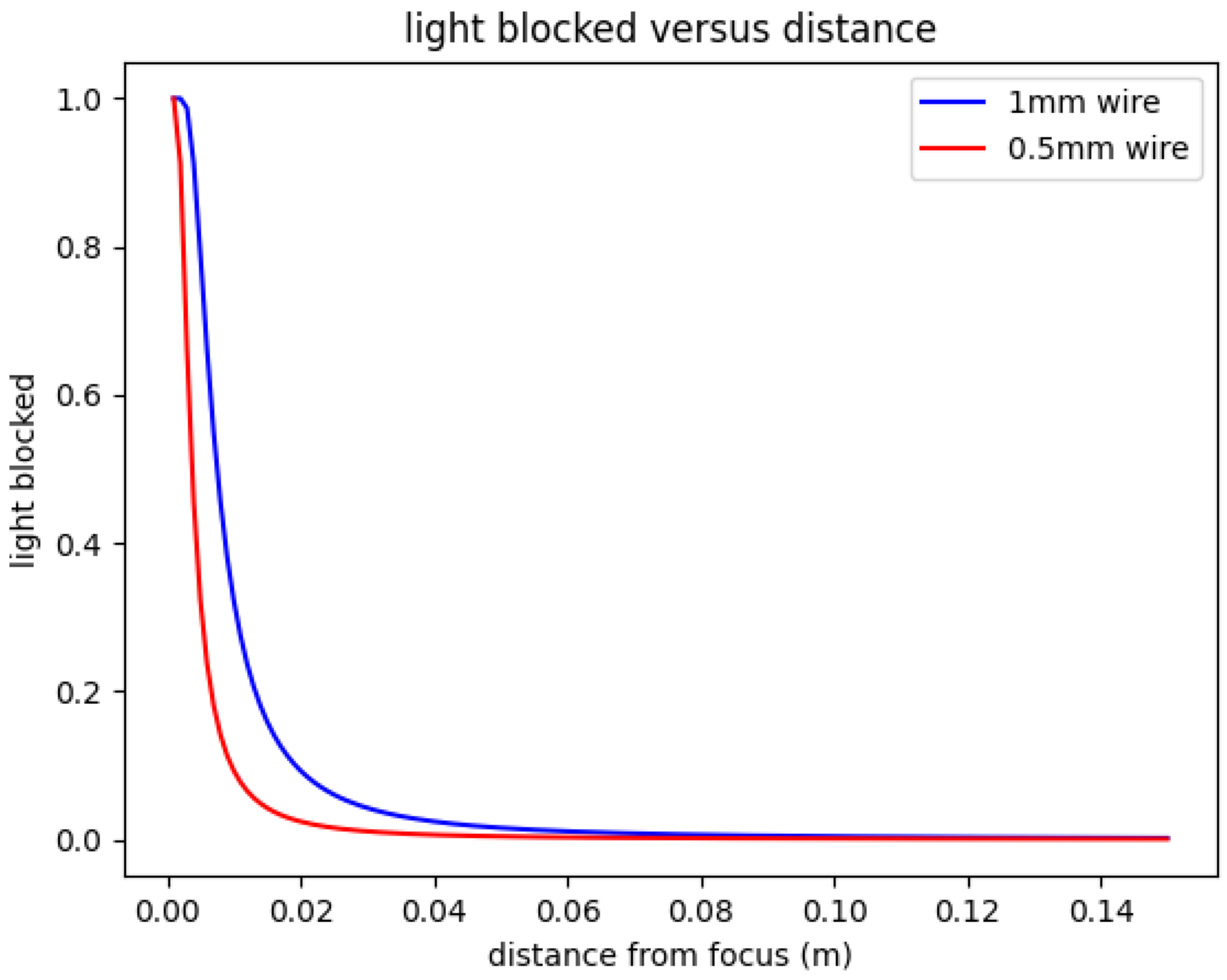


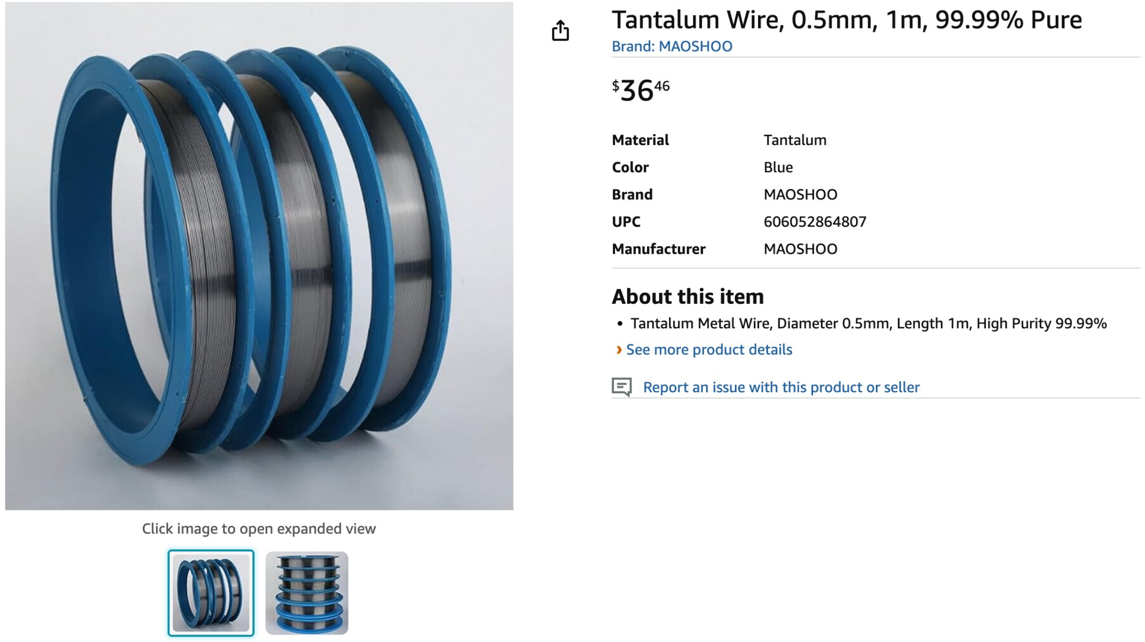
picture of the BNL-ATF vacuum chamber with labelled components

expt. layout – interaction region

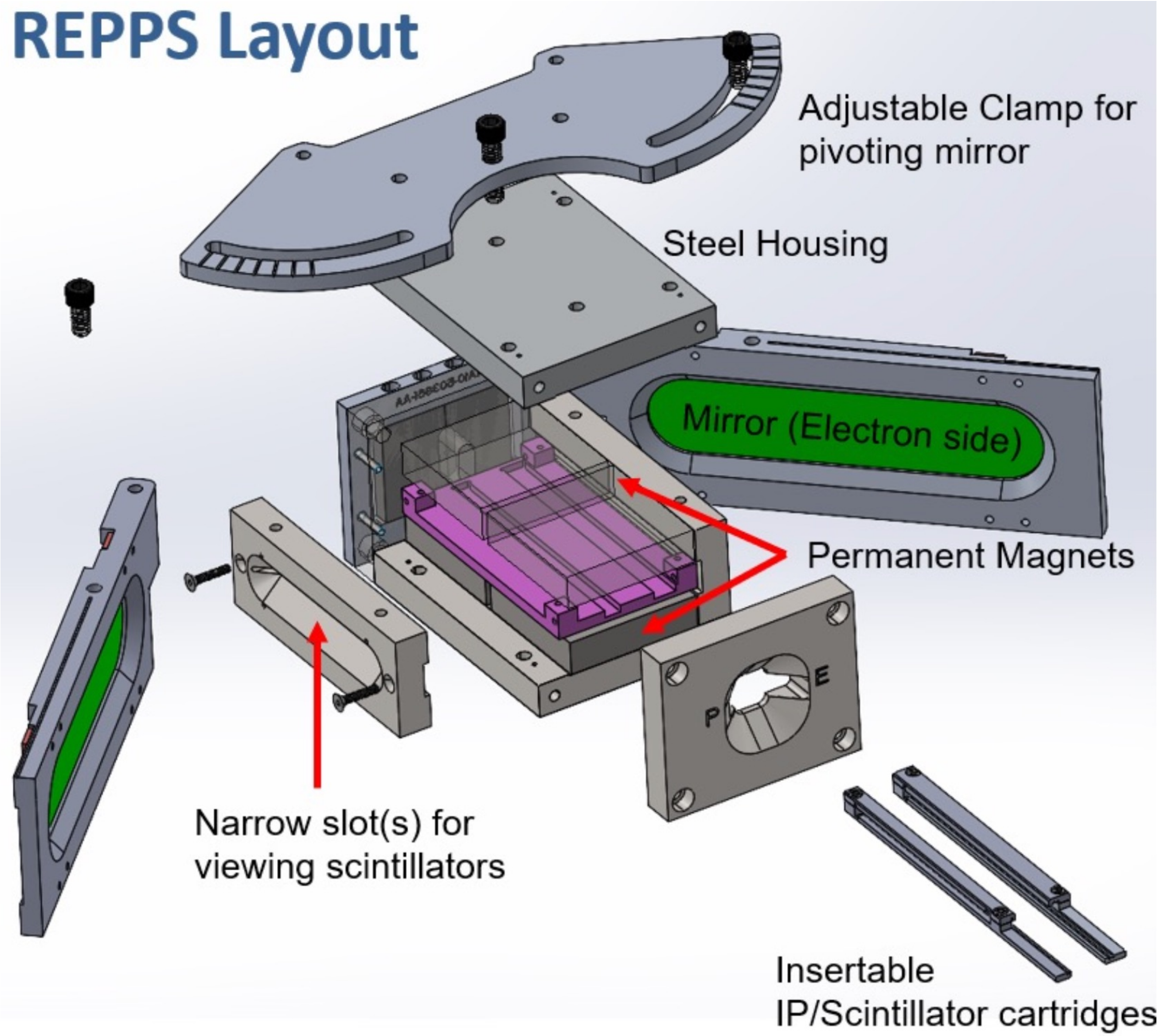


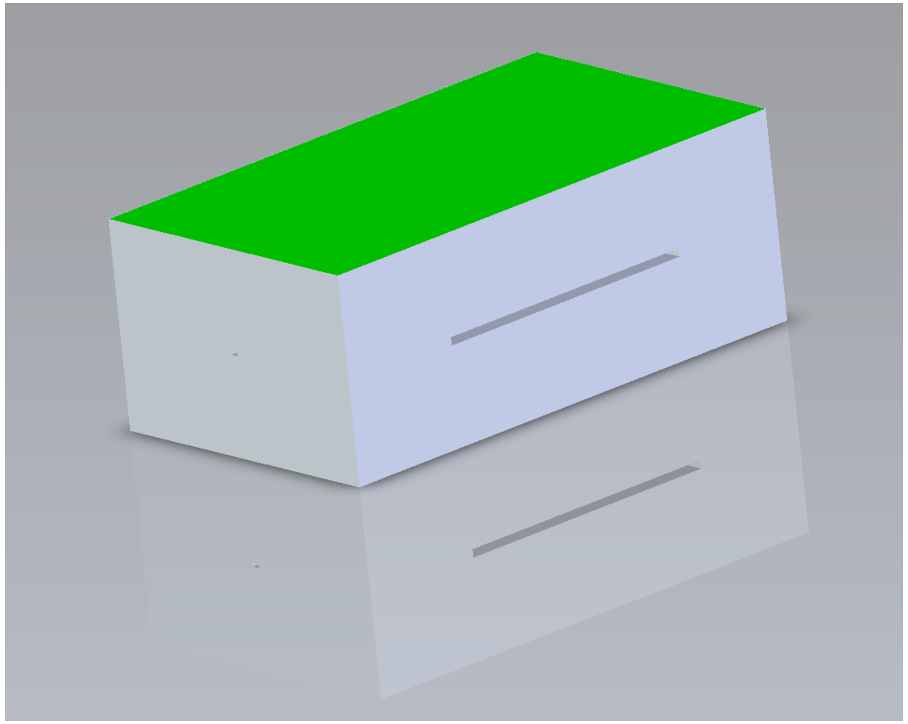
interaction region – target wire





REPPS – LLNL positron spectrometer



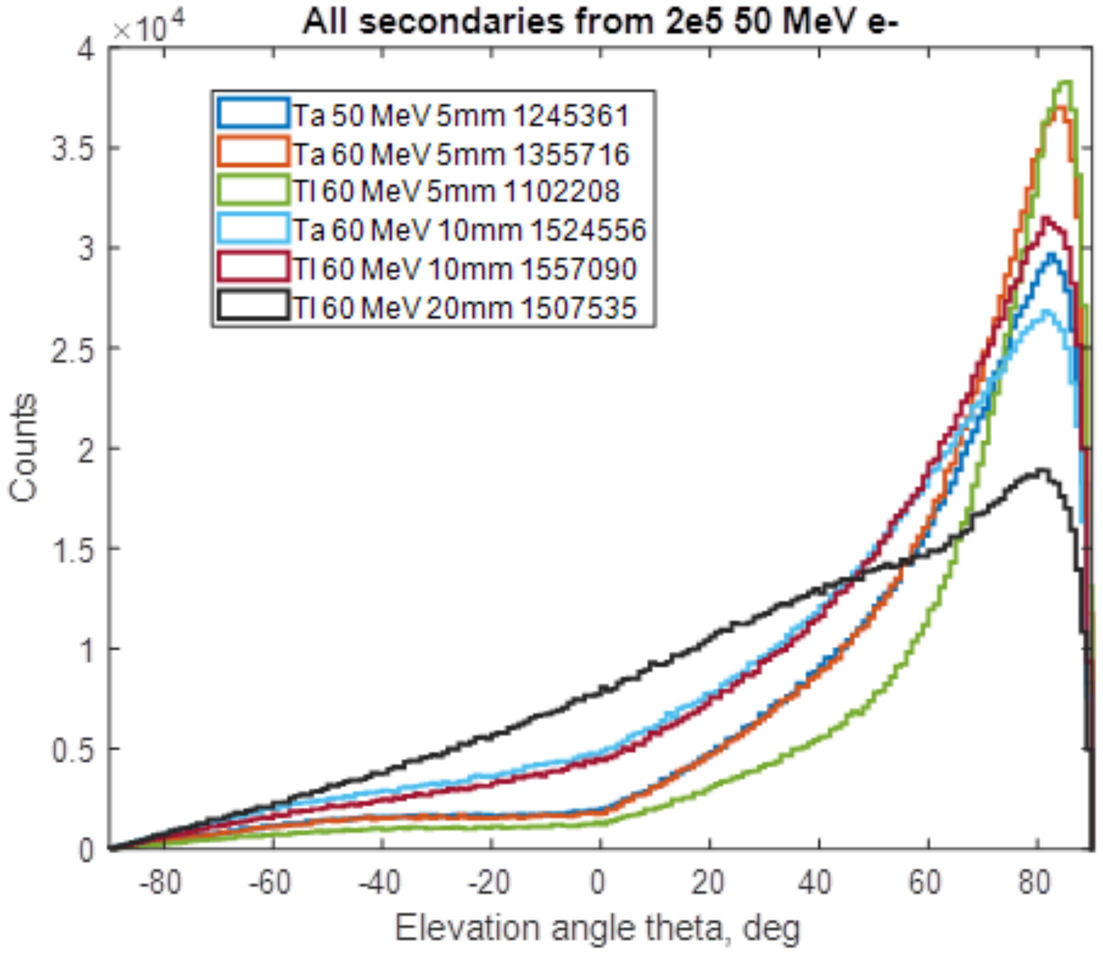


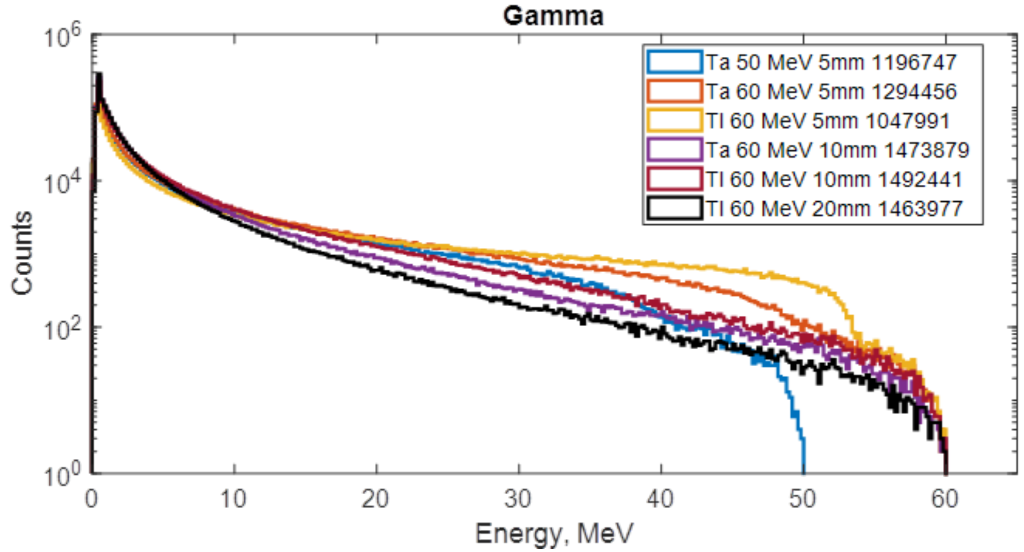
REPPS – sufficient space on the optical breadboard to fit the LLNL spectrometer in the space after the interaction region.

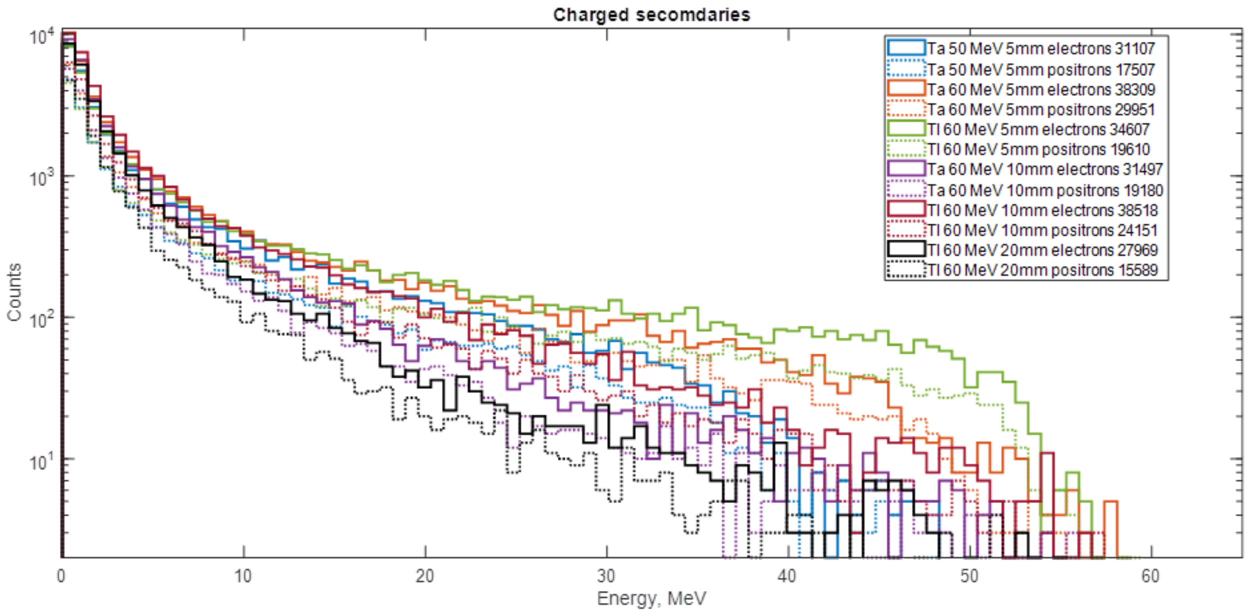
BNL ATF simulations

University of Colorado Denver

e-beam driven positron-electron showers







GEANT4 Acknowledgement:
J. Resta-Lopez, V. Rodin (CI) and LLNL

PIC modeling of electron-positron showers

- Shower properties determined using GEANT4
- Initialize a long shower ~ 2.5 ps
- Pair-plasma analytical model when produced by a relativistic electron beam - bremsstrahlung and pair-production.

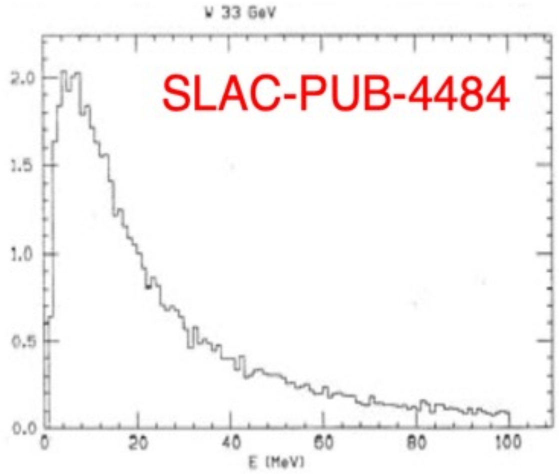
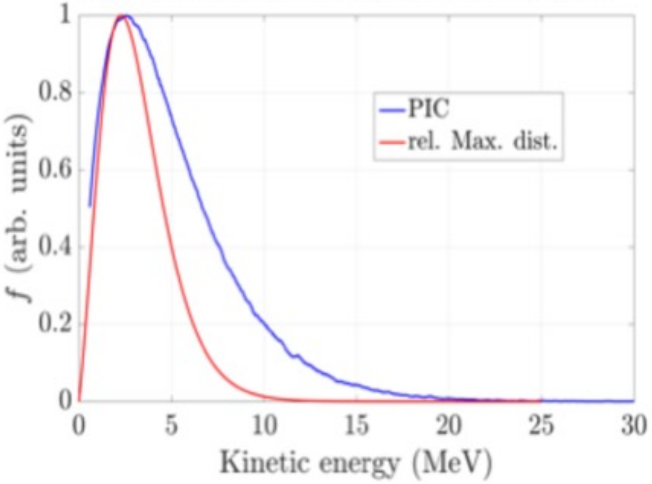


Fig. 3. Yield per 1-MeV energy (E) bin versus E at $z = 6$ radiation lengths.

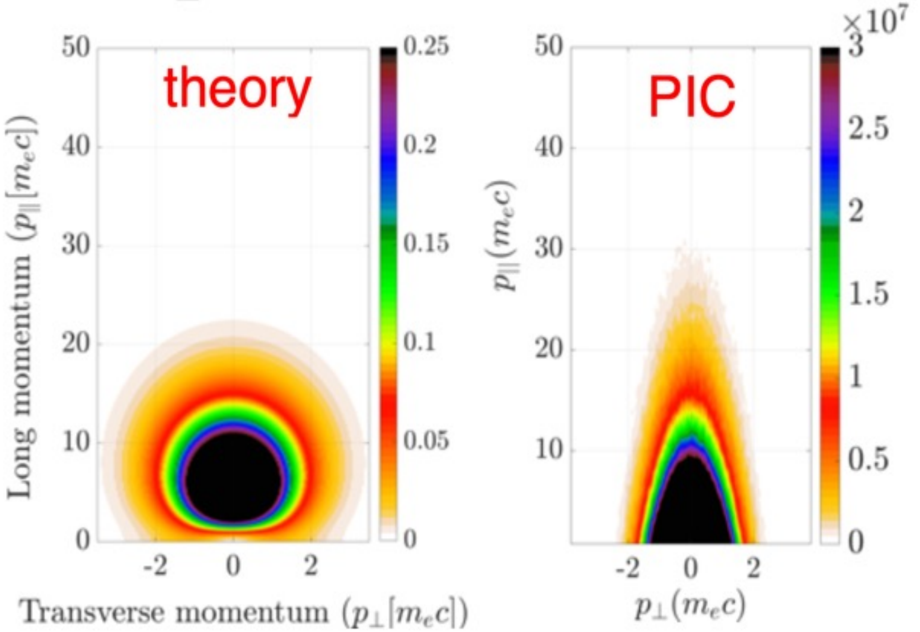


anisotropic relativistic Maxwellian

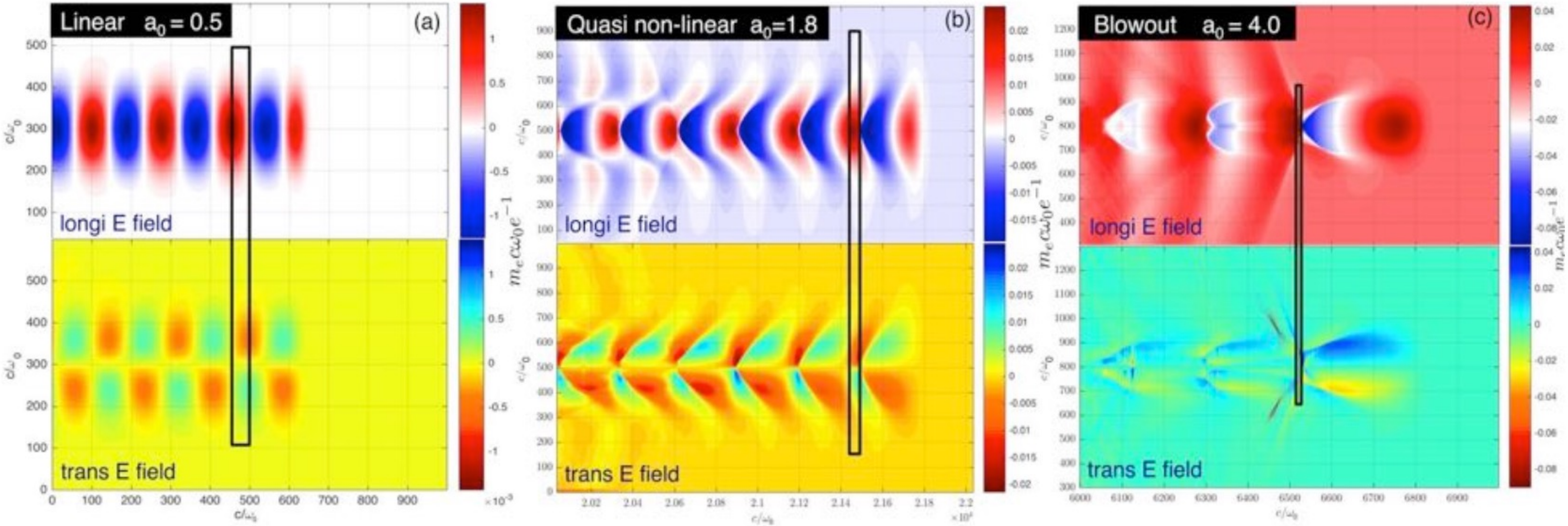
$$f(\mathbf{p}) = C\,(p_\perp^2 + p_\parallel^2)\,\exp\left[-\beta_\perp\sqrt{1 + p_\perp^2 + A\,p_\parallel^2}\,\right]$$

$$\beta_\perp = m_e c^2\, T_\perp^{-1},\ A = T_\parallel T_\perp^{-1}$$

$$T_\perp = 0.2\ \text{MeV}\quad A = 25$$



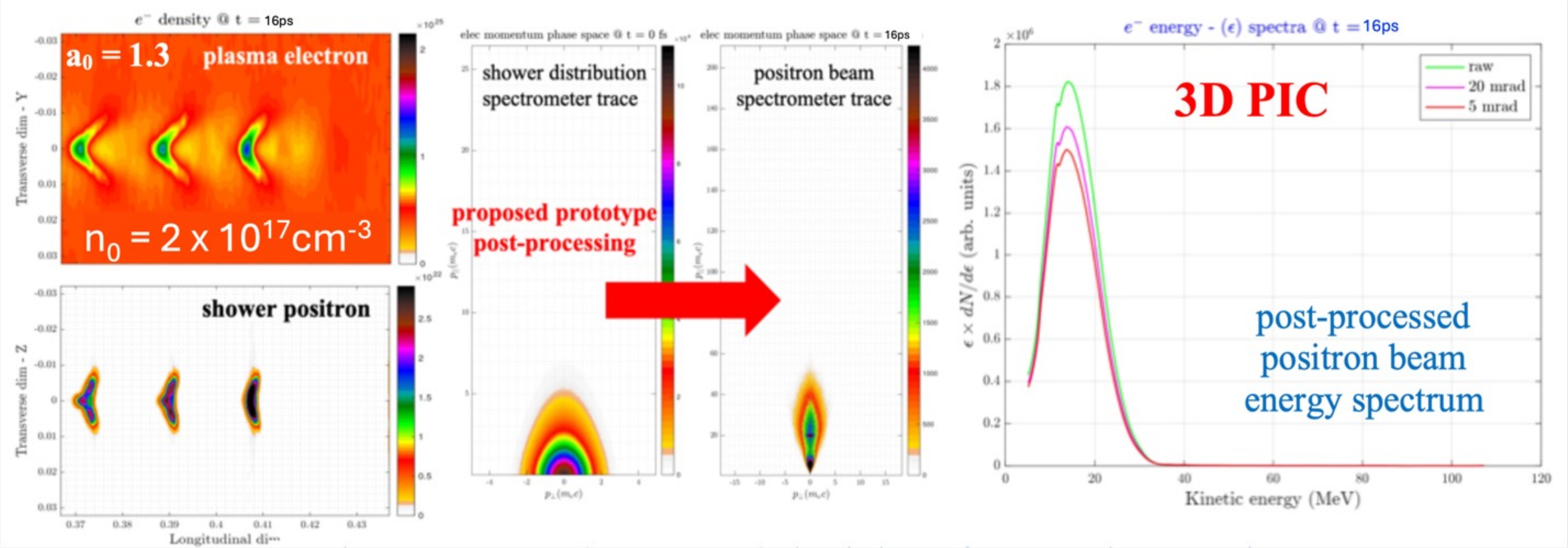
Physics behind the interaction



- Linear regime – interaction or overlap distance is LIMITED
- Blowout regime – positron focusing region is limited and can change – destroying the trapped positron
- Quasi-linear regime – optimal interaction distance and large enough focusing region to trap positrons

PIC modeling of the interaction

- pair-plasma waist-size of 50 microns and longitudinally spans the entire box
- 3D cartesian grid - resolves λ_0 = 9.2 microns with 25 cells inn longitudinal / 10 cells in transverse
- Gaussian envelope of length 250fs, laser waist of 50 microns and a_0 = 1.3



3D PIC (EPOCH) simulations of the interaction between pair-plasma and laser-driven plasma demonstrating the trapping and production of positron bunches.

Milestones

University of Colorado Denver

Proposed Milestones

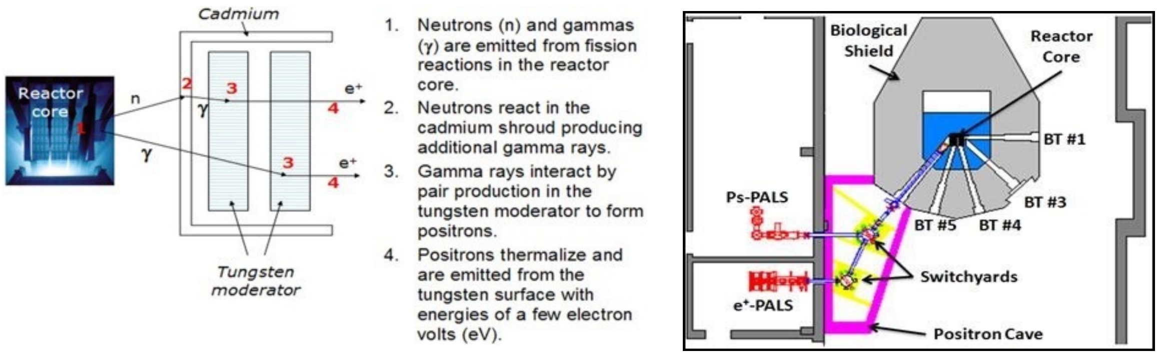
Year 1 – electron beam and low-power CO_2 laser
characterization of positron-electron jet production in solid target using REPPS, over the sub-ps electron beam parameter-space (spot-size, charge, current) and its interaction with gas and low-power (0.5TW) plasma.

Year 2 – demonstration of spatio-temporal overlap between a high- power (>1 TW) CO_2 laser pulse propagating within the plasma formed by laser-ionized flow from the gas jet and the positron- electron jets excited in the wire target by the electron beam propagating along the laser axis.

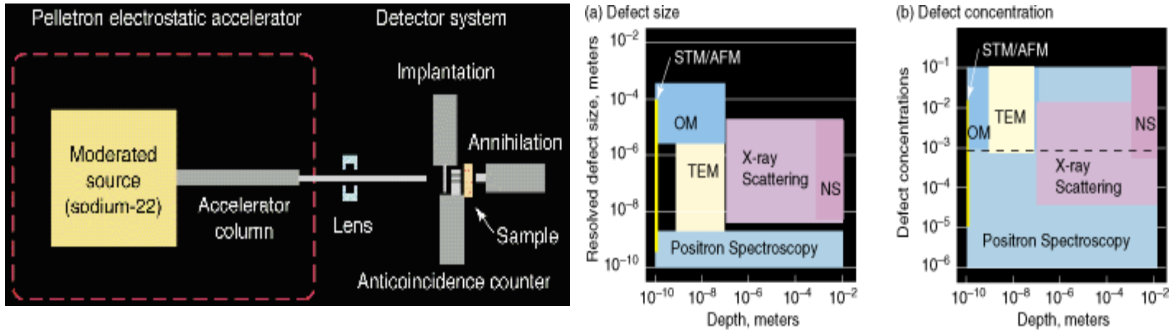
Year 3 – demonstration of tuning of the characteristics of positrons
by scanning over electron beam, CO_2 laser and plasma (gas jet) parameters.

Motivation

existing positron sources



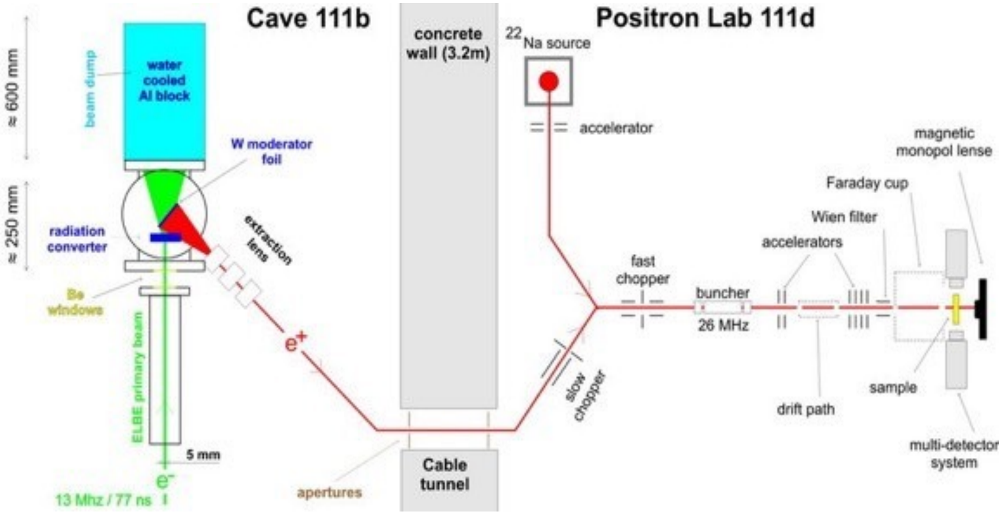
PULSTAR NCSU Fission reactor - positron source user-facility
[source: https://www.ne.ncsu.edu/nrp/user-facilities/intense-positron-beam/]



LLNL Na-22 beta plus positron source and positron spectroscopy
[source: https://str.llnl.gov/str/Howell.html]

nuclear reactor

radioactive nuclei



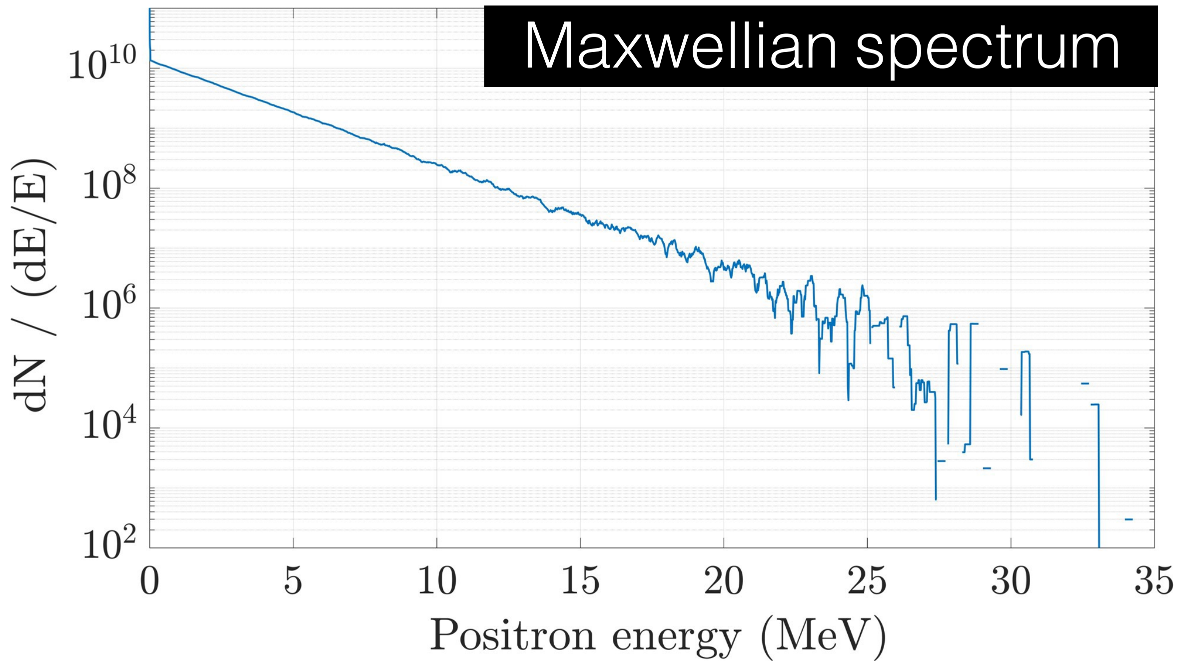
HZDR Germany - ELBE Positron (EPOS) facility
[source: http://positron.physik.uni-halle.de/EPOS/]

electron linac

raw positron-electron showers

shower ≠ beam
pair-plasma ≠ beam

- showers > MeV electrons on converter target
- positrons NOT isolated
- positrons still divergent
- un-localized in momentum space



orders-of-magnitude roll-off at high-energies

Numerous positron applications

PHYSICAL REVIEW B VOLUME 3, NUMBER 3 1 FEBRUARY 1971

Channeling of Positrons

J. U. Andersen* and W. M. Augustyniak
Bell Telephone Laboratories, Murray Hill, New Jersey 07974
and
E. Uggerhøj
Institute of Physics, University of Aarhus, 8000 *Aarhus C, Denmark*
(Received 7 July 1970)

IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

CHANNELING RADIATION FROM POSITRONS

M. J. Alguard,* R. L. Swent,* R. H. Pantell,* B. L. Berman,† S. D. Bloom,† and S. Datz††

VOLUME 77, NUMBER 10 PHYSICAL REVIEW LETTERS 2 SEPTEMBER 1996

Increased Elemental Specificity of Positron Annihilation Spectra

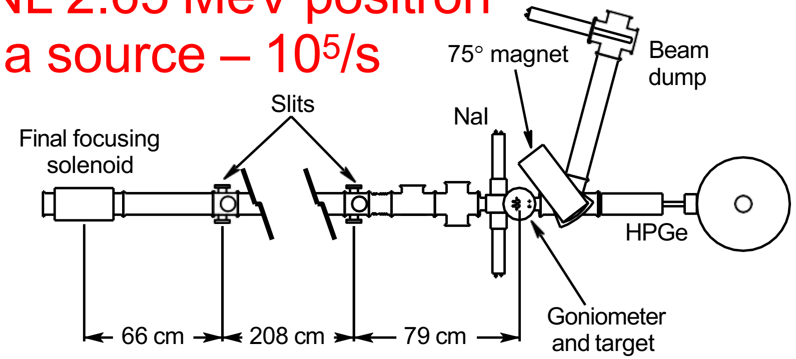
P. Asoka-Kumar,[1] M. Alatalo,[1] V. J. Ghosh,[1] A. C. Kruseman,[2] B. Nielsen,[1] and K. G. Lynn[1]
[1]*Brookhaven National Laboratory, Upton, New York 11973*
[2]*IRI, Delft University of Technology, Mekelweg 15, NL-2629JB Delft, The Netherlands*

Spatial sampling of crystal electrons by in-flight annihilation of fast positrons

A. W. Hunt*†, D. B. Cassidy*†, F. A. Selim‡, R. Haakenaasen§, T. E. Cowan†, R. H. Howell†, K. G. Lynn‖ & J. A. Golovchenko*†#

NATURE | VOL 402 | 11 NOVEMBER 1999

LLNL 2.65 MeV positron
^{22}Na source – 10^5/s

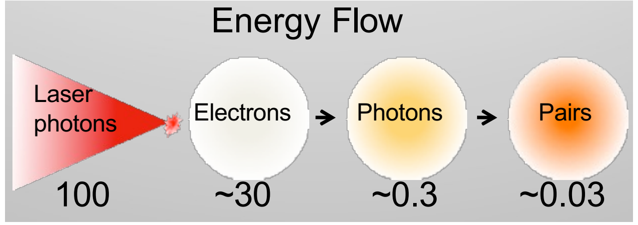


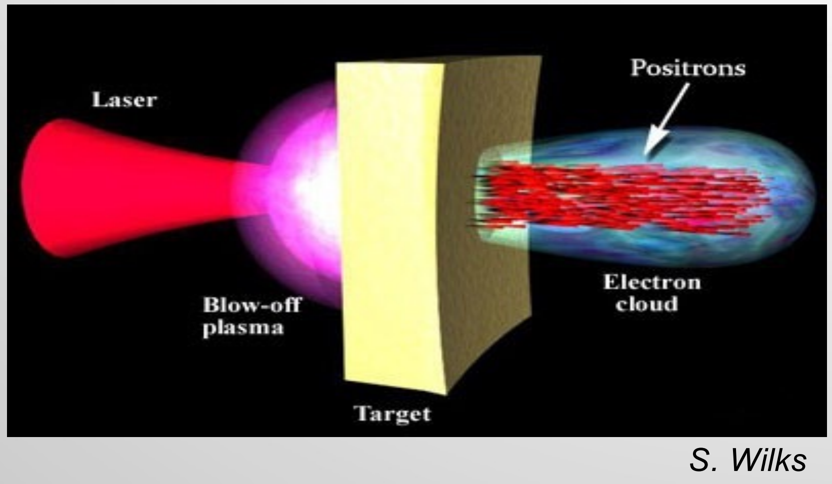
…development of practical atomic-scale channeling measurements of electronic spin densities, and momentum profiles in addition to valence and bonding e$^-$ density maps.

kJ laser-based positron-production

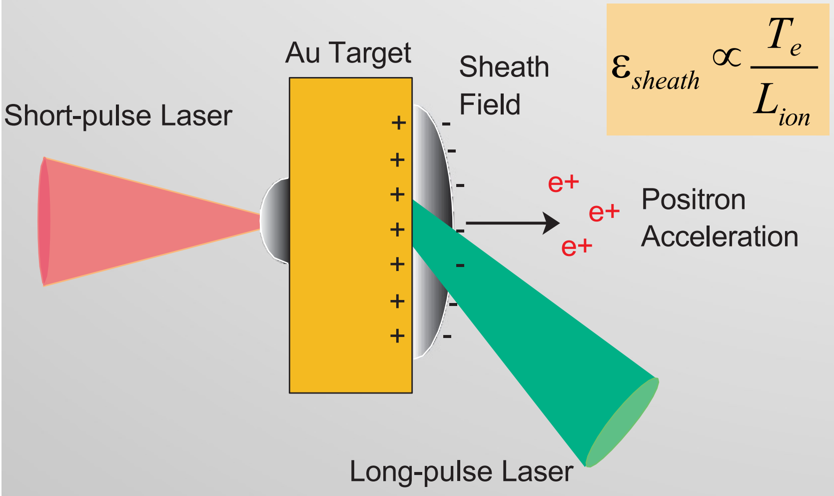
LLNL

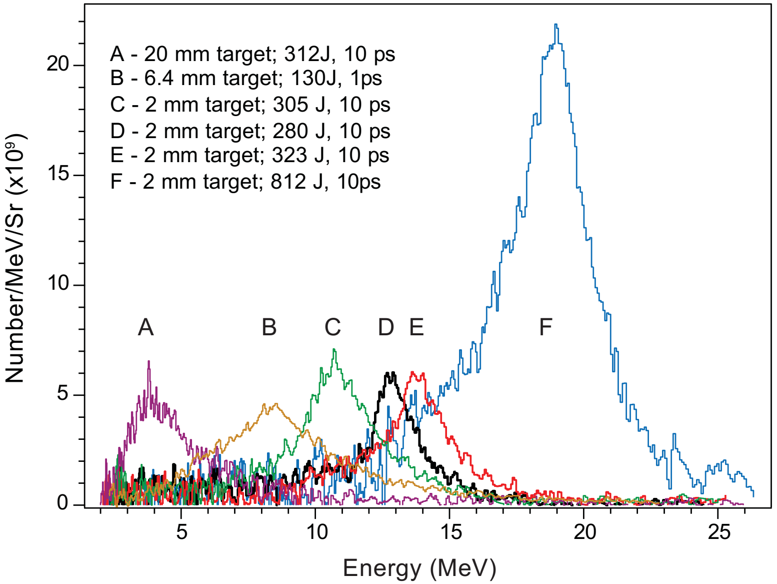
H. Chen et. al.
PRL 105, 015003 (2010)

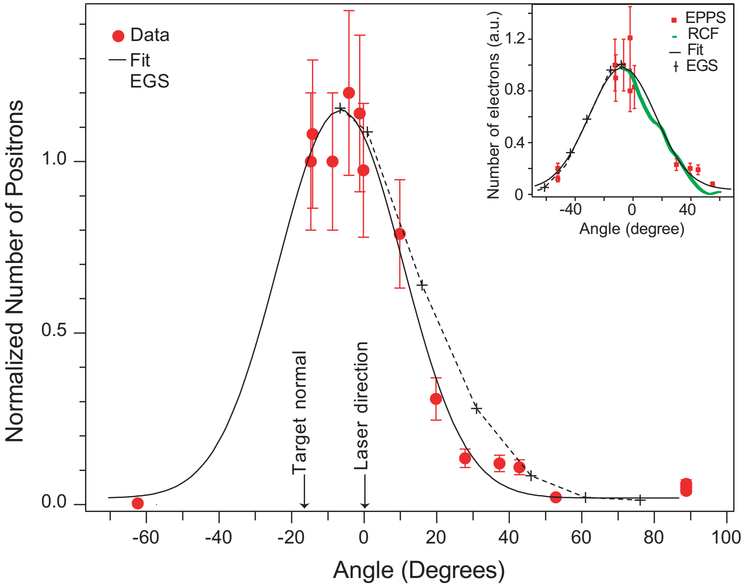




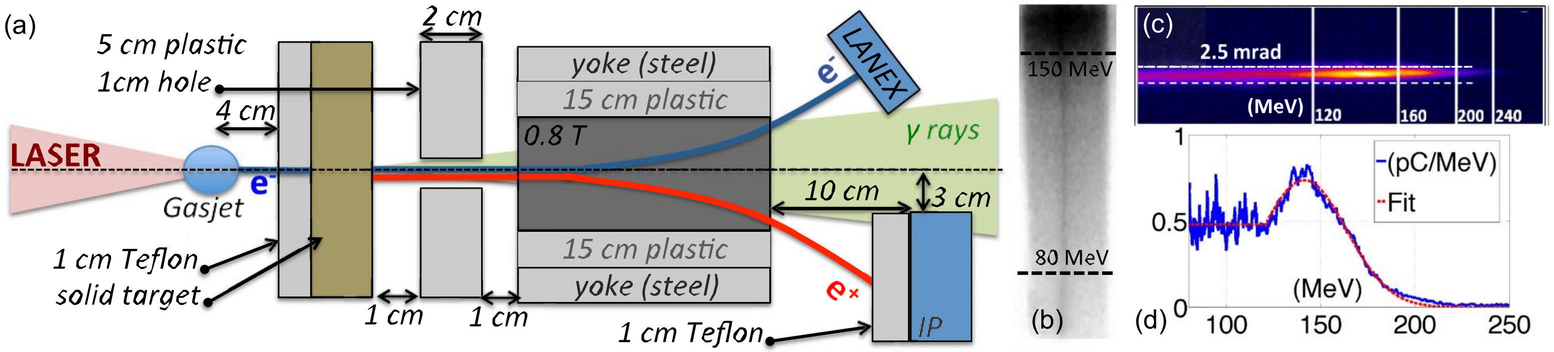
S. Wilks

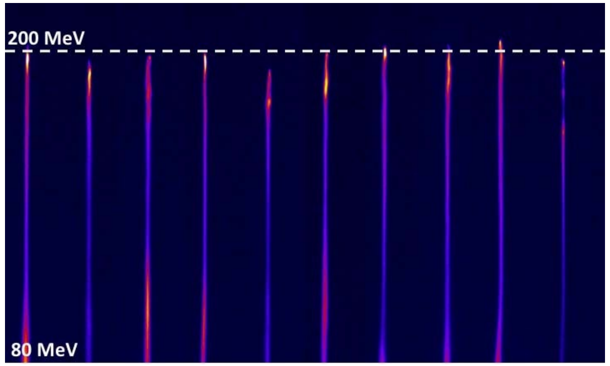






Laser driven e-beam shower production





Supplementary material Figure 1: Typical series of ten spectra of the laser-accelerated electron beam, as recorded on the LANEX screen before the insertion of the solid target. The overall electron beam charge fluctuated within less than 10% and the peak electron energy was consistently of the order of 200 MeV.

increases for materials with higher atomic number. This trend is quantitatively confirmed by integrating the experimental spectra in the range $90 < E_{e^+}(\mathrm{MeV}) < 120$ (see Table I and Fig. 3). Within this energy range, a maximum positron number of $(2.30 \pm 0.28) \times 10^5$ is obtained for the material with the highest Z (Pb). Fitting the data keeping j as a free parameter, we obtain a best fit for $j = 2.1 \pm 0.1$

PRL 110, 255002 (2013) PHYSICAL REVIEW LETTERS week ending 21 JUNE 2013

Table-Top Laser-Based Source of Femtosecond, Collimated, Ultrarelativistic Positron Beams

G. Sarri,[1] W. Schumaker,[2] A. Di Piazza,[3] M. Vargas,[2] B. Dromey,[1] M. E. Dieckmann,[1] V. Chvykov,[2] A. Maksimchuk,[2] V. Yanovsky,[2] Z. H. He,[2] B. X. Hou,[2] J. A. Nees,[2] A. G. R. Thomas,[2] C. H. Keitel,[3] M. Zepf,[1,4] and K. Krushelnick[2]

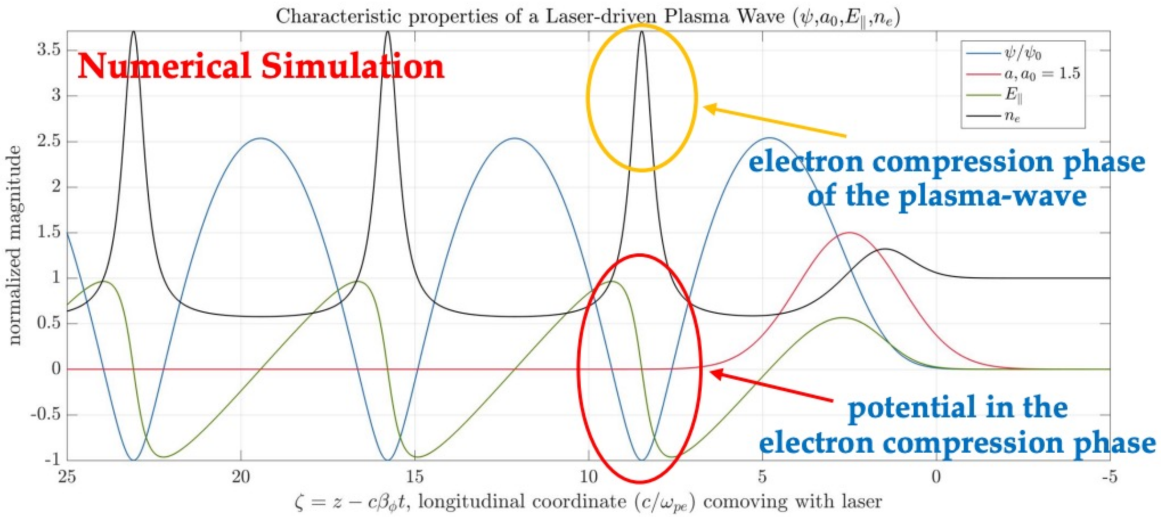
Summary

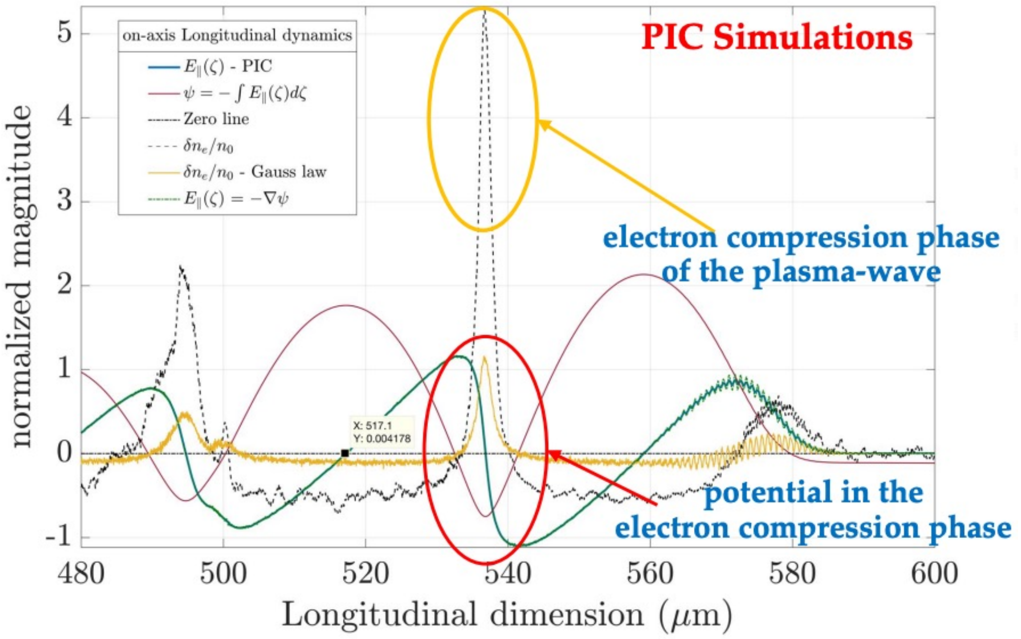
Simulations

- Proof-of-Principle - 3D simulation of the interaction undertaken (futuristic) – 10-20MeV quasi-mono-energetic positron bunch
- analysis using 2.5D simulations to demonstrate trapping in longer pulses but larger energy spreads

Experimental layout

- Optical transport for spatiotemporal overlap of laser and electron beam
- Shadowing of laser pulse by electron-positron wire target characterized
- REPPS integration studies





requested facility parameters

University of Colorado Denver

Electron Beam Requirements

Parameter	Units	Typical Values	Comments	Requested Values
Beam Energy	MeV	50-65	*Full range is ~15-75 MeV with highest beam quality at nominal values*	*60 MeV*
Bunch Charge	nC	0.1-2.0	*Bunch length & emittance vary with charge*	*1nC*
Compression	fs	Down to 100 fs (up to 1 kA peak current)	*A magnetic bunch compressor available to compress bunch down to ~100 fs. Beam quality is variable depending on charge and amount of compression required.* *NOTE: Further compression options are being developed to provide bunch lengths down to the ~10 fs level*	*1000 - 10^4fs* *(500fs will be highly desirable when available ?)*
Transverse size at IP (σ)	μm	30 – 100 (dependent on IP position)	*It is possible to achieve transverse sizes below 10 um with special permanent magnet optics.*	*30-50 μm*
Normalized Emittance	μm	1 (at 0.3 nC)	*Variable with bunch charge*	
Rep. Rate (Hz)	Hz	1.5	*3 Hz also available if needed*	
Trains mode	---	Single bunch	*Multi-bunch mode available. Trains of 24 or 48 ns spaced bunches.*	

CO_2 Laser Requirements

Configuration	Parameter	Units	Typical Values	Comments	Requested Values
CO_2 Regenerative Amplifier Beam	Wavelength	μm	9.2	*Wavelength determined by mixed isotope gain media*	*9.2 μm*
	Peak Power	GW	~3		*3 GW*
	Pulse Mode	---	Single		
	Pulse Length	ps	2		*2 ps*
	Pulse Energy	mJ	6		*6 mJ*
	M^2	---	~1.5		
	Repetition Rate	Hz	1.5	*3 Hz also available if needed*	
	Polarization	---	Linear	*Circular polarization available at slightly reduced power*	
CO_2 CPA Beam	Wavelength	μm	9.2	*Wavelength determined by mixed isotope gain media*	*9.2 μm*
Note that delivery of full power pulses to the Experimental Hall is presently limited to Beamline #1 only.	Peak Power	TW	2	*~5 TW operation is planned for FY21 (requires further in-vacuum transport upgrade). A 3-year development effort to achieve >10 TW and deliver to users is in progress.*	*0.5 – 2 TW*
	Pulse Mode	---	Single		
	Pulse Length	ps	2		*1 ps*
	Pulse Energy	J	~5	*Maximum pulse energies of >10 J will become available in FY20*	*1-5 J*
	M^2	---	~2		
	Repetition Rate	Hz	0.05		
	Polarization		Linear	*Adjustable linear polarization along with circular polarization will become available in FY20*	*linear*

Other Experimental Laser Requirements

Ti:Sapphire Laser System	Units	Stage I Values	Stage II Values	Comments	Requested Values
Central Wavelength	nm	800	800	*Stage I parameters are presently available and setup to deliver Stage II should be available summer 2025*	
FWHM Bandwidth	nm	20	13		
Compressed FWHM Pulse Width	fs	<50	<75	*Transport of compressed pulses will initially include a very limited number of experimental interaction points. Please consult with the ATF Team if you need this capability.*	
Chirped FWHM Pulse Width	ps	≥50	≥50		
Chirped Energy	mJ	10	200		
Compressed Energy	mJ	7	~20	*20 mJ is presently operational with work underway this year to achieve our 100 mJ goal.*	
Energy to Experiments	mJ	>4.9	>80		
Power to Experiments	GW	>100	>1000		

Nd:YAG Laser System	Units	Typical Values	Comments	Requested Values
Wavelength	nm	1064	*Single pulse*	
Energy	mJ	100		
Pulse Width	ps	14		
Wavelength	nm	532	*Frequency doubled*	
Energy	mJ	0.5		
Pulse Width	ps	10		

Experimental Time Request

CY2025 Time Request

Capability	Setup Hours	Running Hours
Electron Beam Only	*40*	*120*
Laser* Only (in Laser Rooms)		
Laser(s)* + Electron Beam		

Total Time Request for the 3-year Experiment (including CY2025-27)

Capability	Setup Hours	Running Hours
Electron Beam Only	Good for year 1 (but pre-amp CO2 level would be very useful)	
Laser* Only (in FEL Room)		
Laser(s)* + Electron Beam	*120*	*360*

* Laser = Near-IR or LWIR (CO_2) Laser

Special Equipment Requirements and Hazards

Electron Beam

- Beam termination within the chamber
- Gas jet in the vacuum chamber @ beamline 1
- RePPS spectrometer inside the vacuum chamber on beamline 1

CO_2 laser

- Small fraction of the focusing CO_2 laser overlaps with a wire target
- CO_2 laser needs to be redirected out before the RePPS chamber