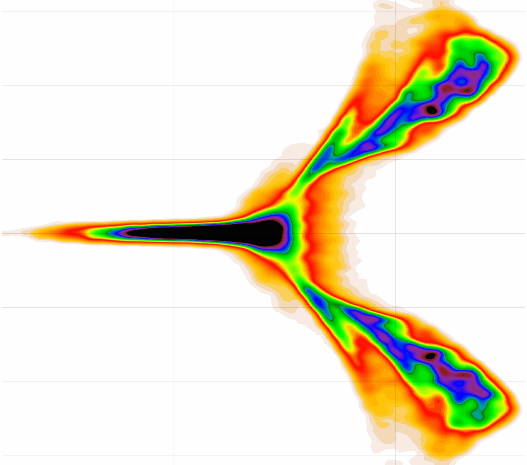
Tunable Positron Source

CO_2-Laser based post-processing of ATF e⁻ beam driven positron-electron jets



Lawrence Livermore National Laboratory

DENVER LYNX

A. Sahai (PI), CU Denver, **H. Chen (co-PI)**, LLNL
V. Harid, M. Golkowski, CU Denver
J. Resta-Lopez, Cockcroft Inst. & U Valencia
S. Palaniyappan, LANL, J. Cary, Tech-X & CU

TECH-X SIMULATIONS EMPOWERING YOUR INNOVATIONS

Los Alamos NATIONAL LABORATORY EST.1943

Funding source: CU multi-year grant (ongoing)
DOE (applied)

US Patent 16,770,943

Key scientific goals

- positron source with tunable properties - control the interaction
  CO_2 laser-driven post-processing of ATF e-beam driven particle showers

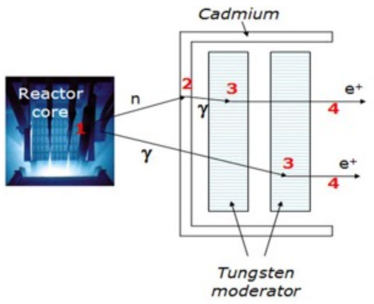
- **tunable yet collisionless moderator**

- **NOT** aimed at production of high-energy
  low-emittance positron beams for collider applications

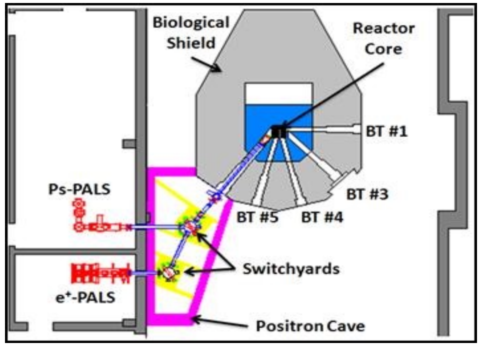
- long wavelength CO_2 laser (compared to Ti:Sapphire):
  larger plasma structures – easier to physically overlay with the showers
  slower structures for a lower plasma density – laser velocity slower for same density

- numerous applications benefit from a tunable positron beam

Current positron sources

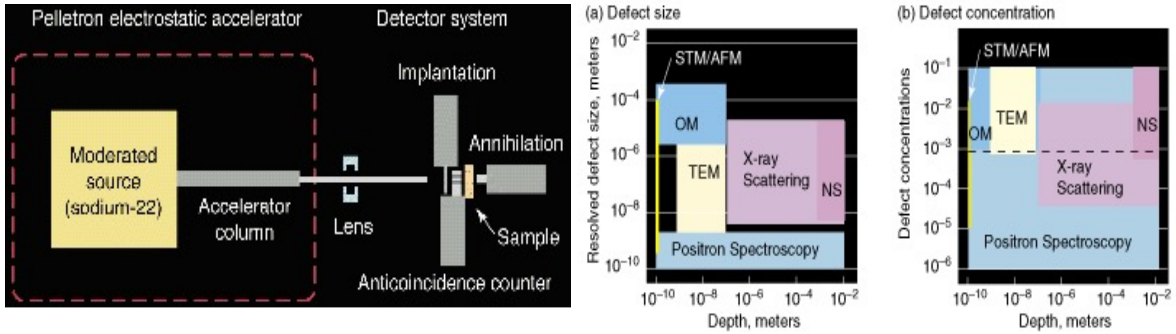


1. Neutrons (n) and gammas (γ) are emitted from fission reactions in the reactor core.
2. Neutrons react in the cadmium shroud producing additional gamma rays.
3. Gamma rays interact by pair production in the tungsten moderator to form positrons.
4. Positrons thermalize and are emitted from the tungsten surface with energies of a few electron volts (eV).



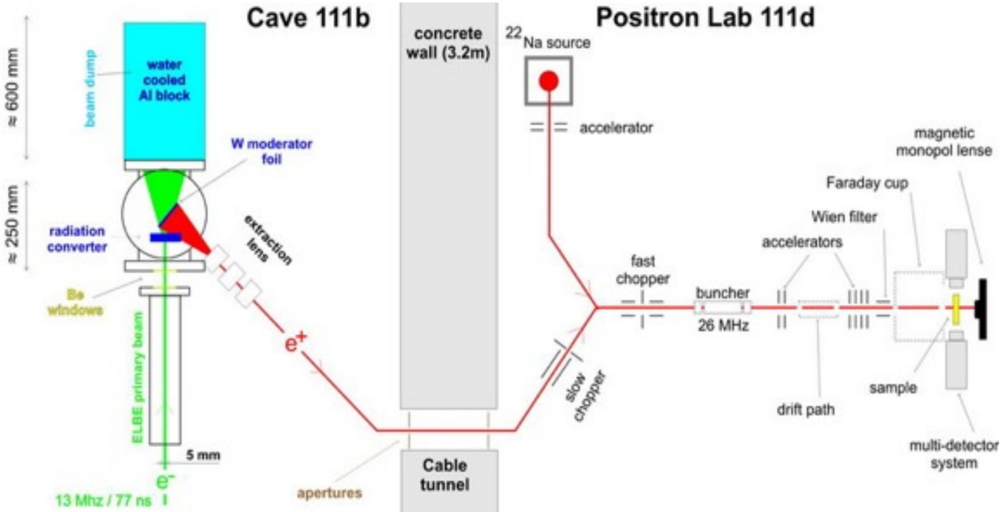
PULSTAR NCSU Fission reactor - positron source user-facility
[source: https://www.ne.ncsu.edu/nrp/user-facilities/intense-positron-beam/]

nuclear reactor



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

radioactive nuclei



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

electron linac

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

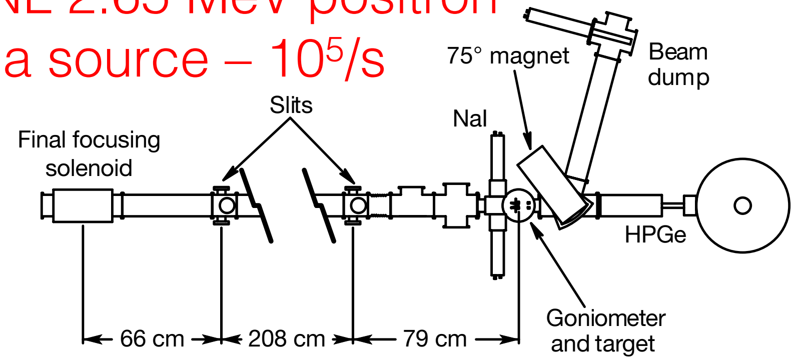
P. Asoka-Kumar,[1] M. Alatalo,[1] V. J. Ghosh,[1] A. C. Kruseman,[2] B. Nielsen,[1] and K. G. Lynn[1]
[1]*Brookhaven National Laboratory, Upton, New York 11973*
[2]*IRI, Delft University of Technology, Mekelweg 15, NL-2629JB Delft, The Netherlands*

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



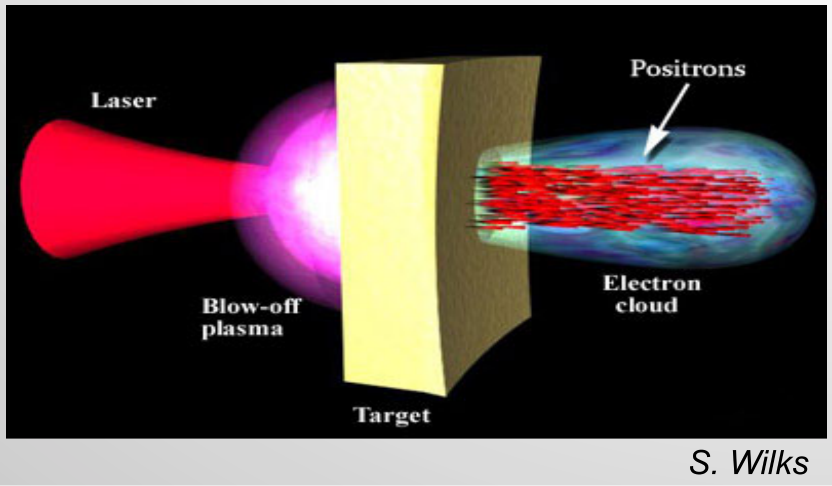
…development of practical atomic-scale channeling measurements of electronic spin densities, and momentum profiles in addition to valence and bonding e⁻ density maps.

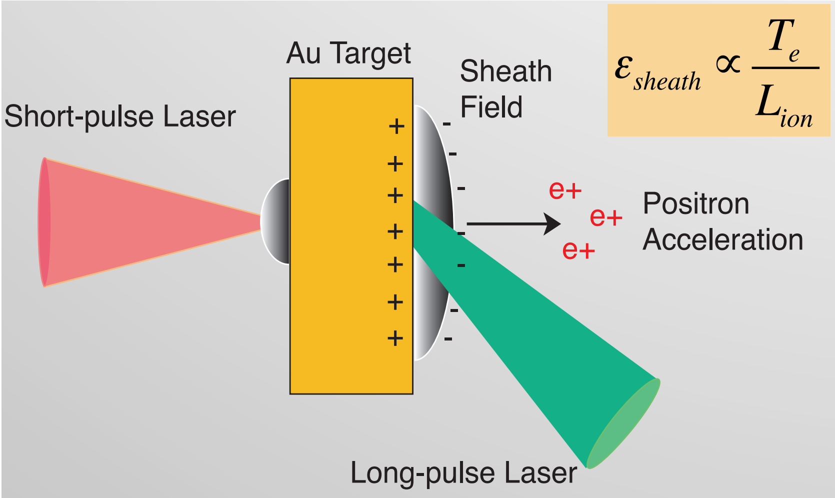
LLNL – kJ laser positron-production

University of Colorado Denver

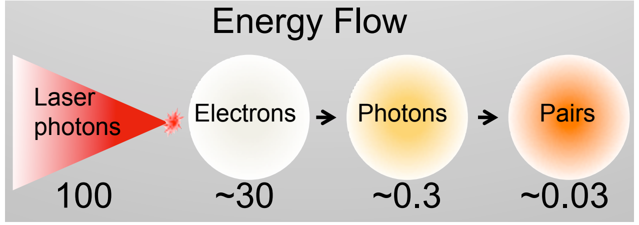
BROOKHAVEN NATIONAL LABORATORY

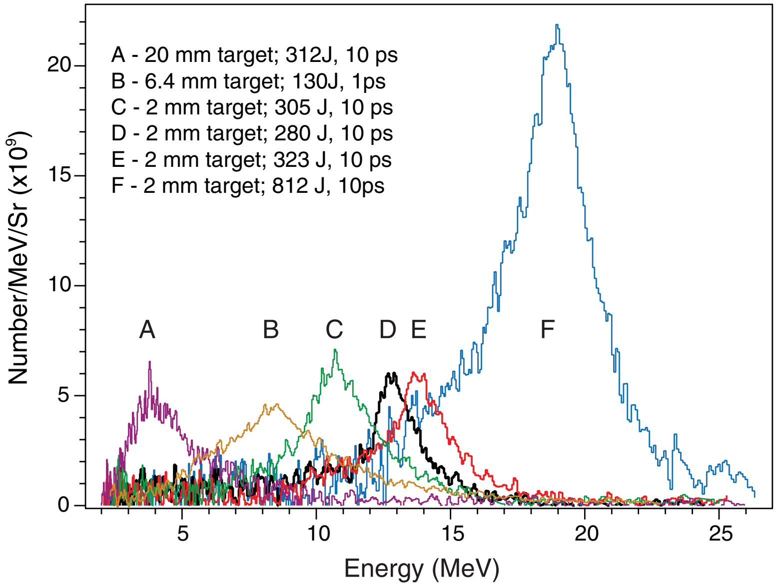
LLNL

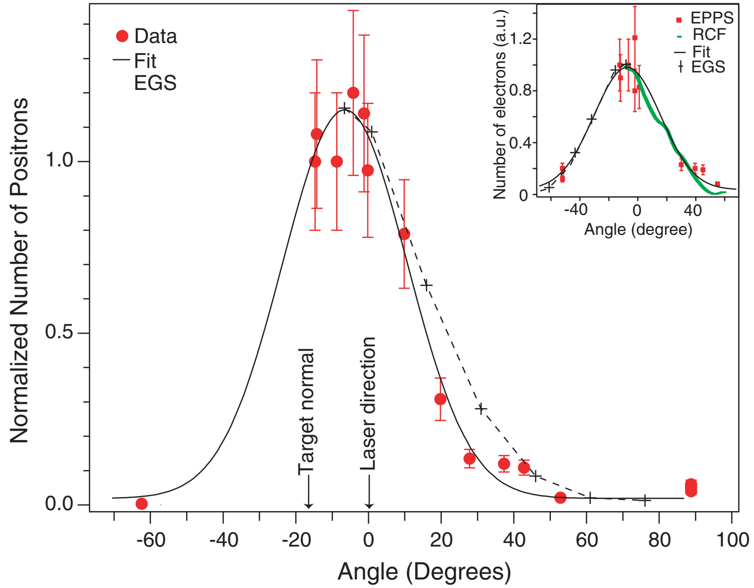




H. Chen et. al.
PRL 105, 015003 (2010)







Laser shower production

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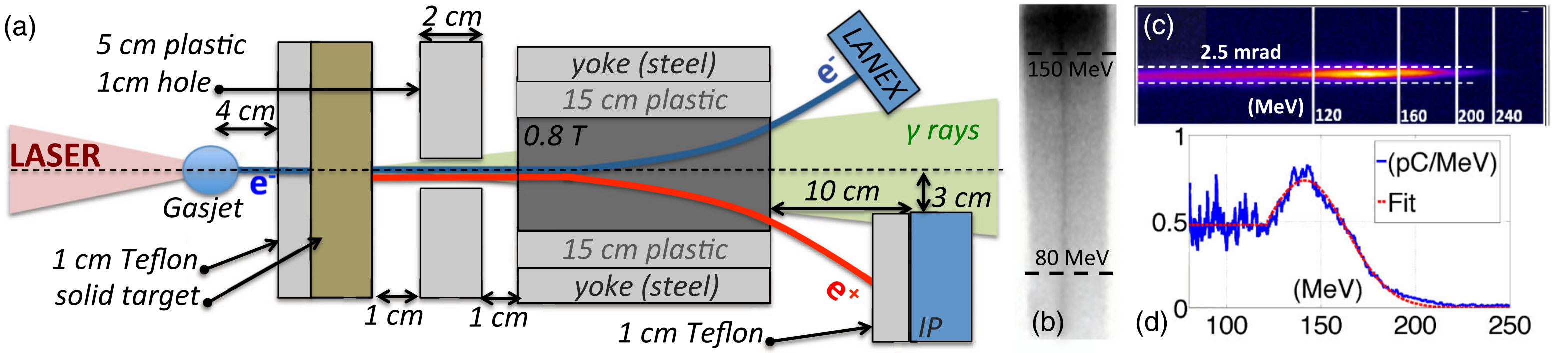
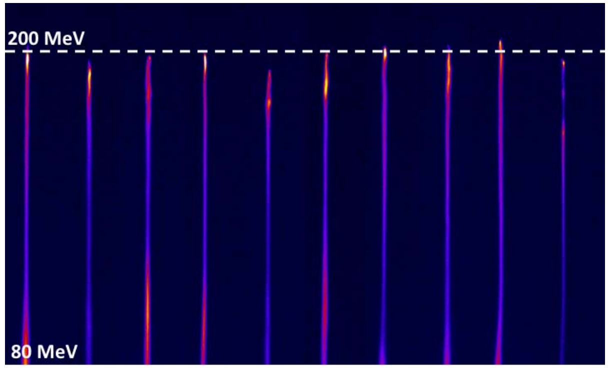




Supplementary material Figure 1: Typical series of ten spectra of the laser-accelerated electron beam, as recorded on the LANEX screen before the insertion of the solid target. The overall electron beam charge fluctuated within less than 10% and the peak electron energy was consistently of the order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

Laser shots NOT consistent !

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

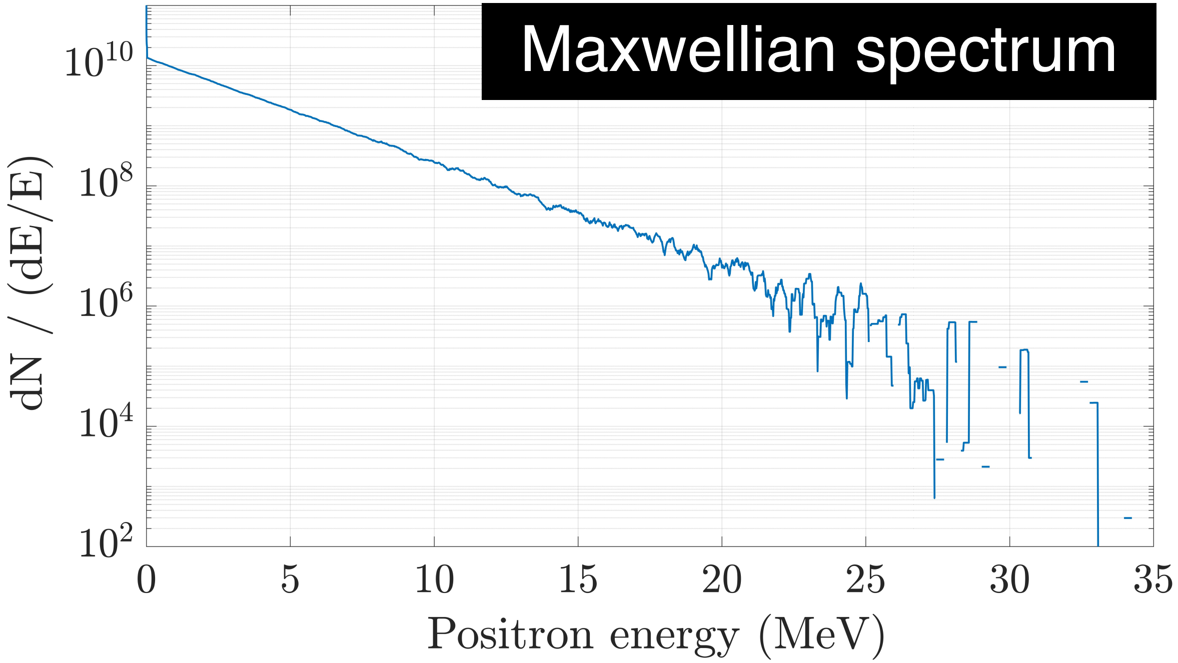
Table-Top Laser-Based Source of Femtosecond, Collimated, Ultrarelativistic Positron Beams

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]

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

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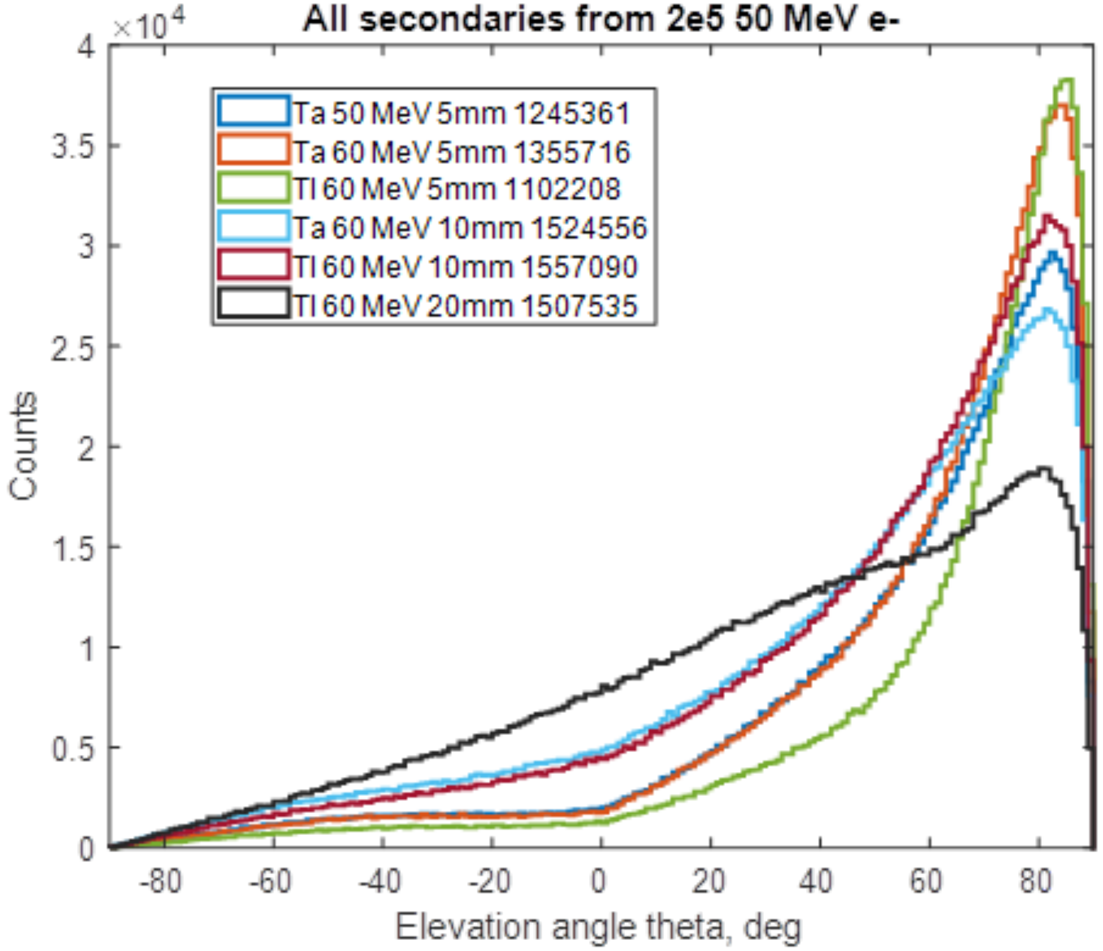
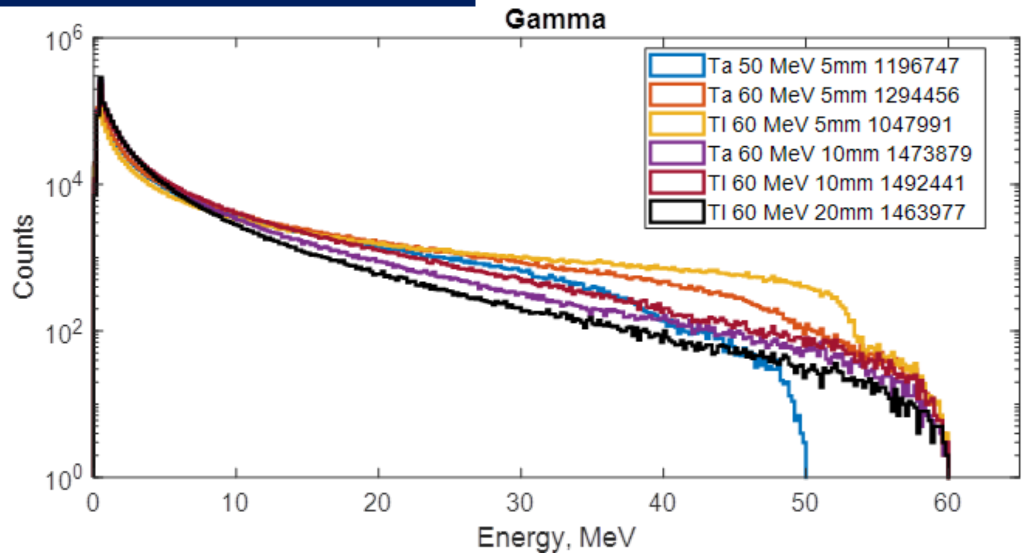
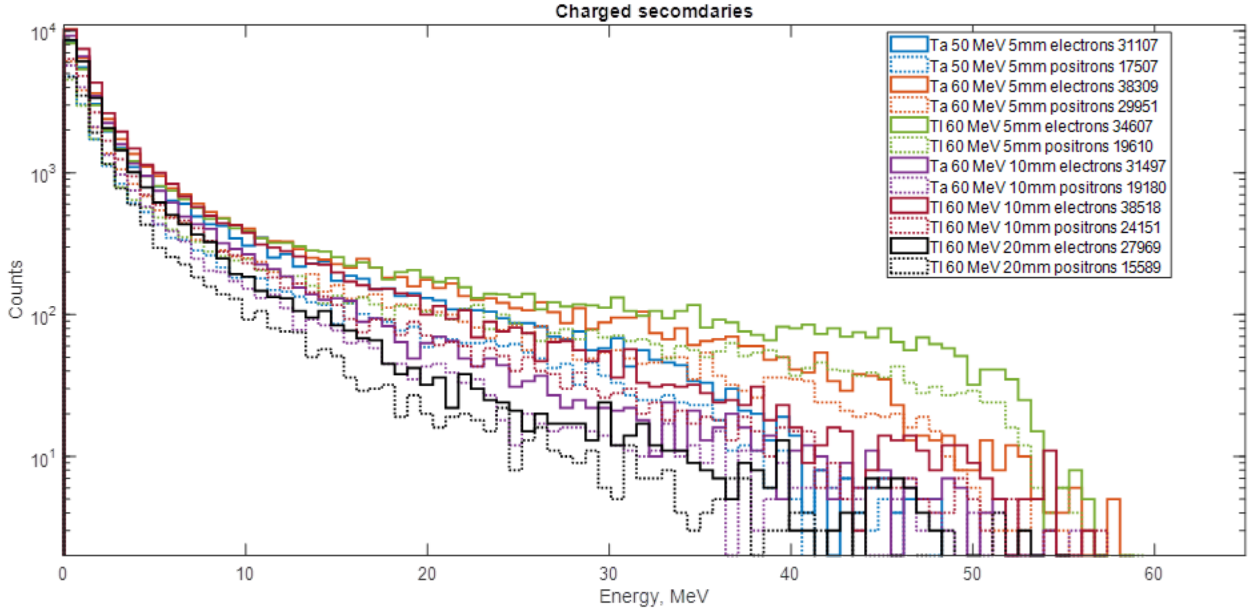
simulations of ATF-beam driven positron-electron showers







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

Expt scheme - CO_2 laser driven post-processing

- Parabola with hole for re-directing the electron beam
- 3” diam parabolas with 5 mm hole available at ATF
- ATF has different parabolas with F varying between 100-250 mm. They are between 3-4” dia. But only 3” dia have holes

- Axicon pair telescope to split, expand and combine the laser beam
- Axicon pair is already in-stock at ATF
- The axicon pair cannot be used for our full power

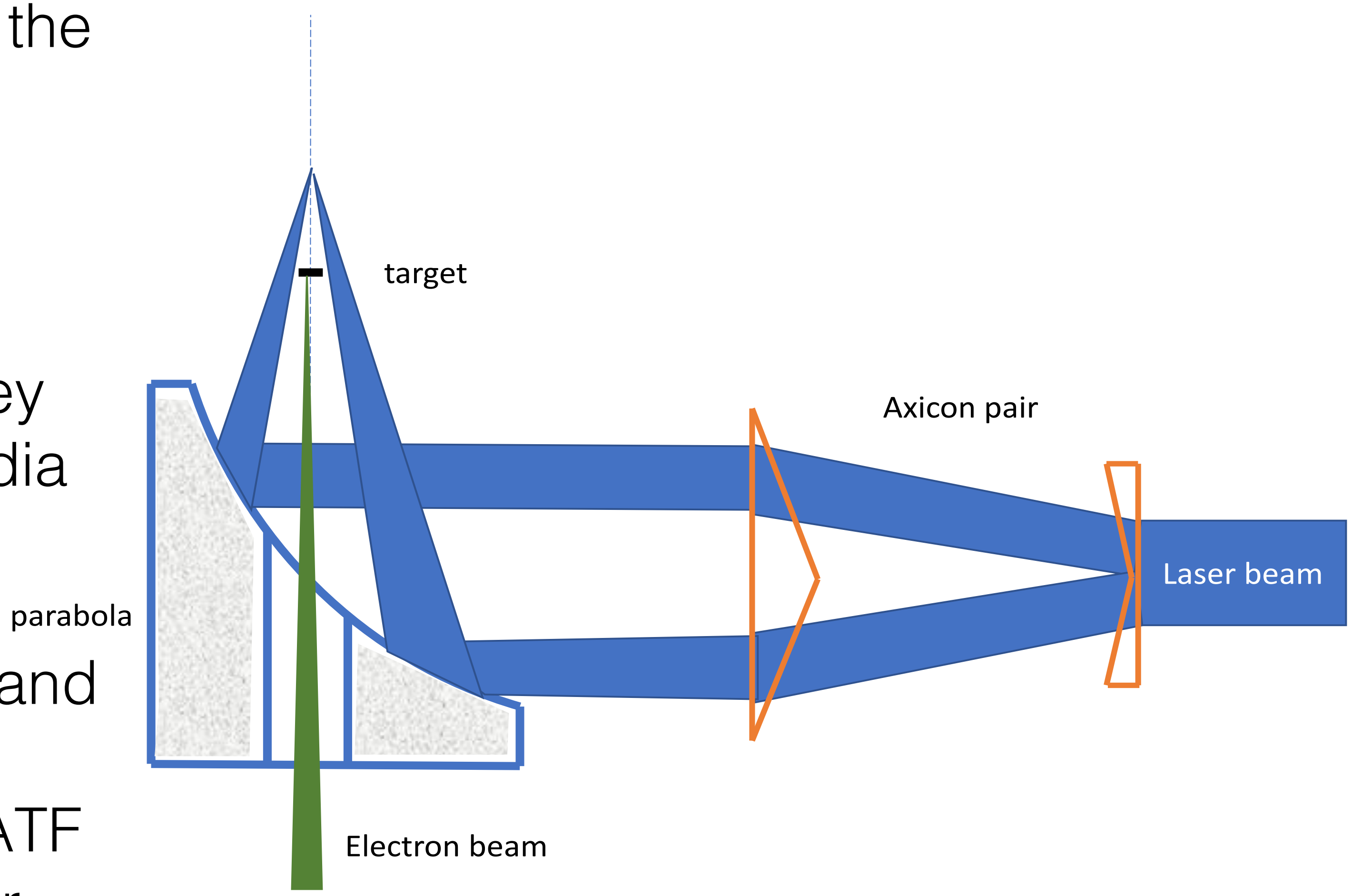


Figure 7: Parabola with hole and axicon-pair setup for laser delivery

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Sim of CO_2 laser driven plasma processing

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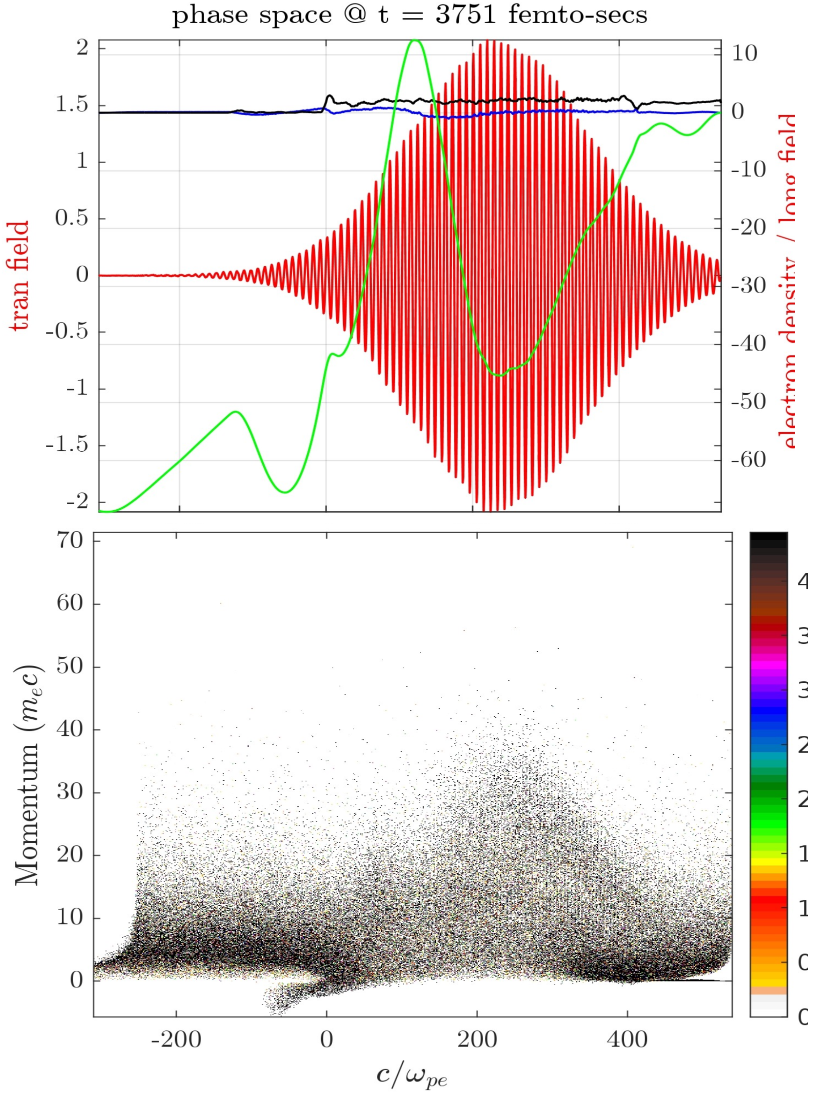
- 2D PIC EPOCH simulations – CO2 laser-driven post-processing of ATF beam-driven showers
- Shower properties determined using GEANT4
- Initialize a long shower ~ 2.5 ps
- CO_2 Laser-driven structures – can trap and slow-down positrons

Plasma parameters	1TW	2TW
Density	2×10^{17} cm^{-3}	
Critical Power (P_c)	1.1 TW	1.1 TW
P/P_c	0.88	1.87
matched-w_0	32 μm	36 μm
a_0	1.52	1.95
λ_β	1.45 mm	1.45 mm
Z_R (matched-w_0)	0.32 mm	0.4 mm
σ_r/w_0	0.9	0.8

Strongly Mismatched Regime of Nonlinear Laser–Plasma Acceleration: Optimization of Laser-to-Energetic Particle Efficiency
10.1109/TPS.2019.2914896



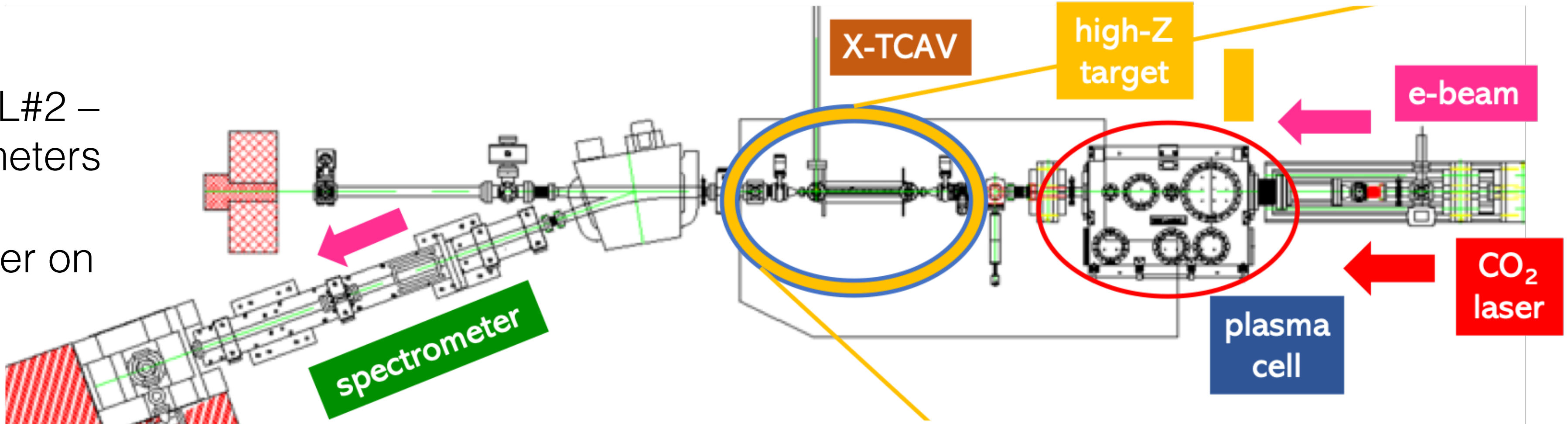
2D PIC simulation of CO2 laser driven post-processing of shower

NSF

XSEDE
Extreme Science and Engineering Discovery Environment

experimental layout

- initially use BL# 2
- vacuum chamber on BL#2 – space for our spectrometers
- however, need CO_2 laser on BL#2
- can we get Ti:Sap or Nd:YAG on BL#2 ?



BL#2 optics and diagnostics block diagram

BL#2 optics and diagnostics design to show the location of our experiment

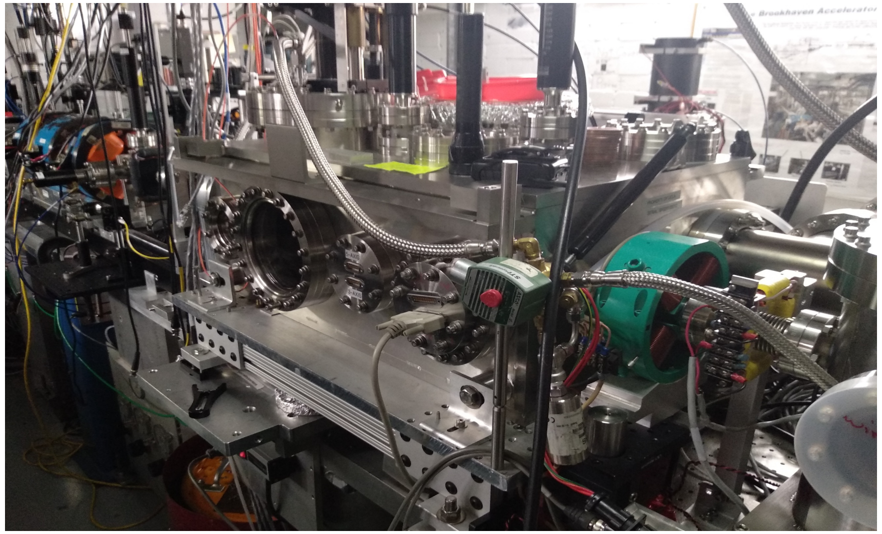
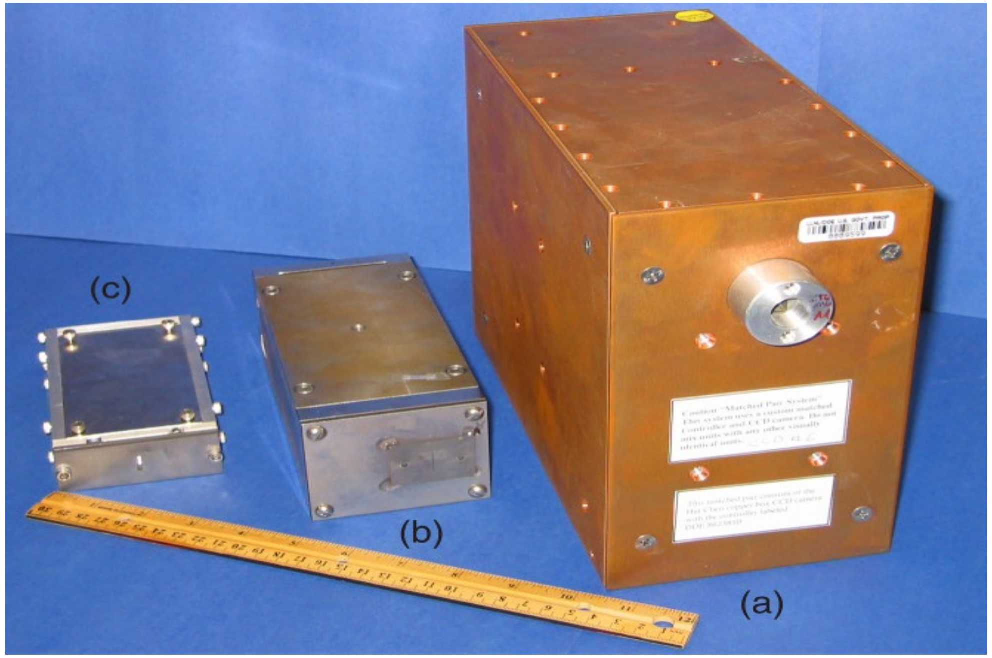


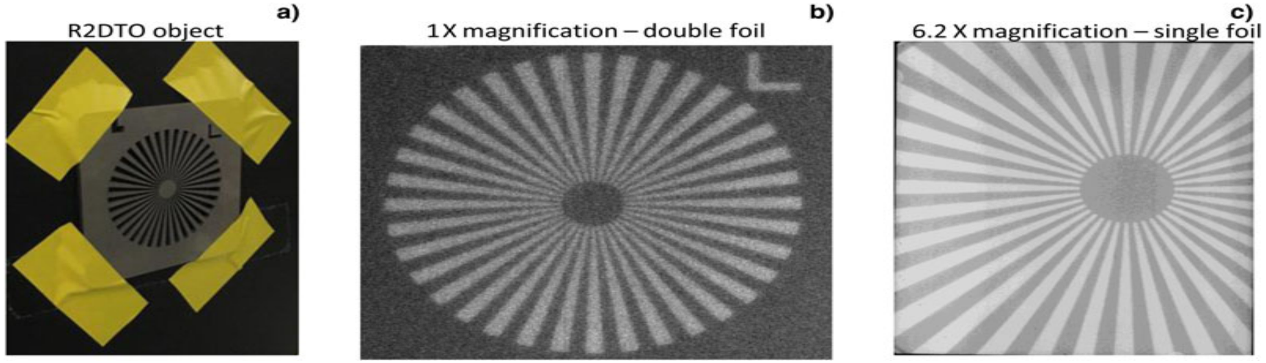
Photo of beamline # 2 setup

our diagnostics



LLNL positron spectrometer

Rev. Sci. Instrum. **79**, 10E533 (2008)



LANL gamma-ray diagnostics

Laser and Particle Beams **36**, 502–506. (2018)

Proposed Milestones

Yr. 1 – *ONLY electron beam*
characterization of positron-electron jet production in solid target, over the sub-ps electron beam parameter-space (spot-size, charge, current) and its interaction with laser-ionized plasma

Yr. 2 – **demonstration of spatio-temporal overlap** between a high-power CO_2 laser pulse within the plasma-cell along with positron-electron jets

Yr. 3 – demonstration of **tuning of the characteristics of positrons** by scanning over electron beam, CO2 laser and plasma properties.

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*	*0.1 - 1ps* *(10fs 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* *Can we get the PMQ triplet setup used earlier at BNL ?*
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.*	

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CO_2 Laser Requirements

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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		*2 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*	*linear*

Special Equipment Requirements and Hazards

- Electron Beam
    - plasma capillary discharge system

Experimental Time Request

CY2021 Time Request

Capability	Setup Hours	Running Hours
Electron Beam Only	*24*	*80*
Laser* Only (in Laser Rooms)		
Laser(s)* + Electron Beam		

Time Estimate for Remaining Years of Experiment (including CY2021)

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	*80*	*300*

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