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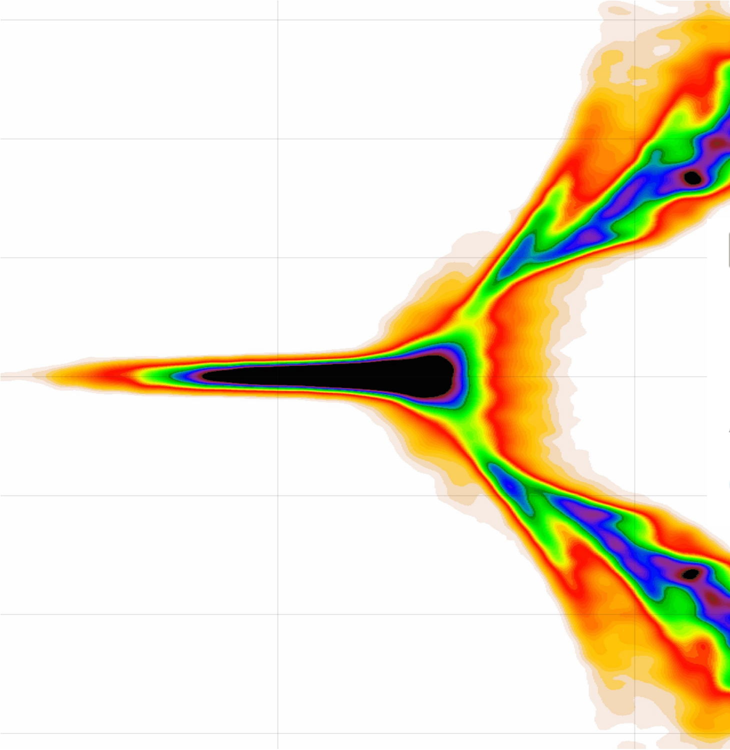
Denver

Tunable Laser Positron Source

NP-315765




Open Access

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)

PRAB 21, 081301 (2018)

A. Sahai (PI), CU Denver,
H. Chen, LLNL, K. Kusche, M. Polyanskiy, 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

Motivation

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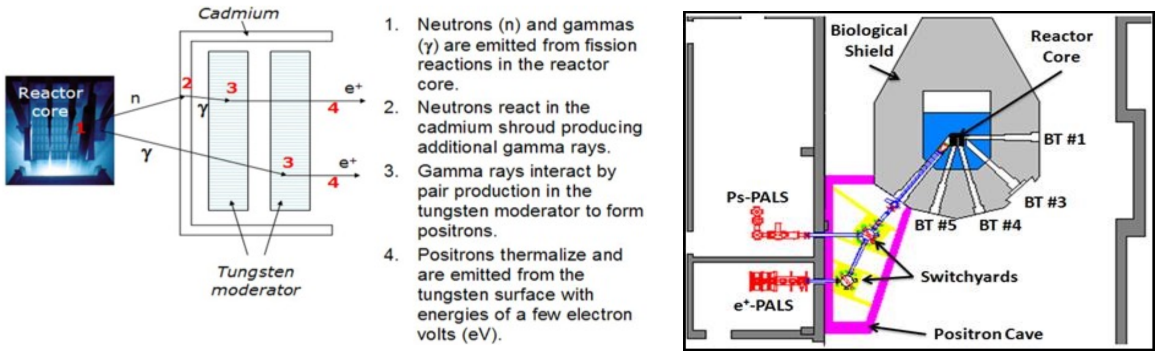
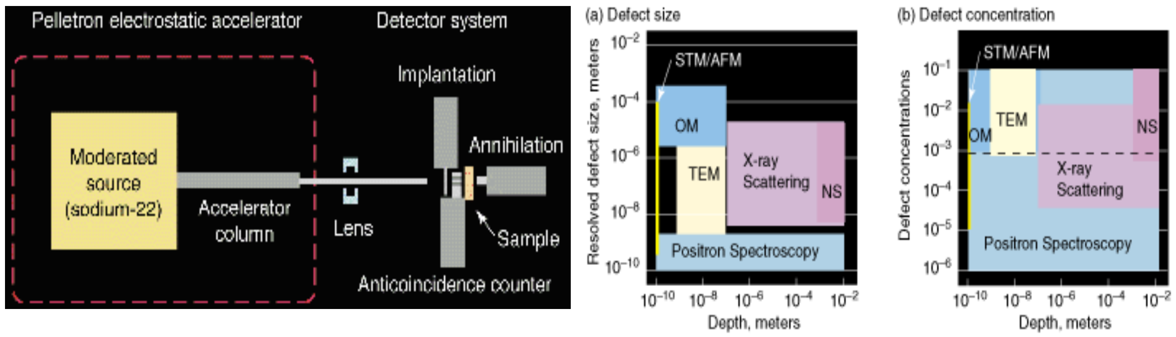
existing positron sources



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).

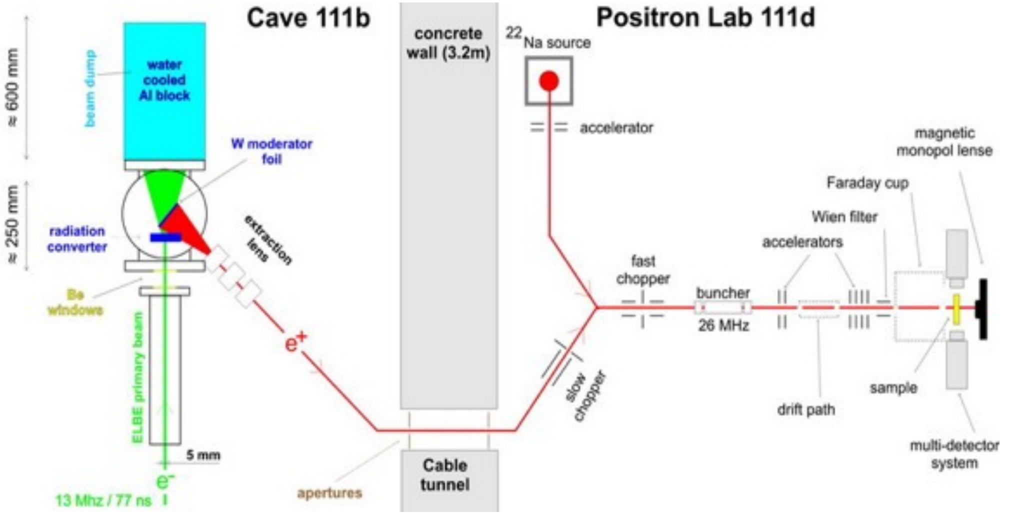
PULSTAR NCSU Fission reactor - positron source user-facility
[source: https://www.ne.ncsu.edu/nrp/user-facilities/intense-positron-beam/]

nuclear reactor



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

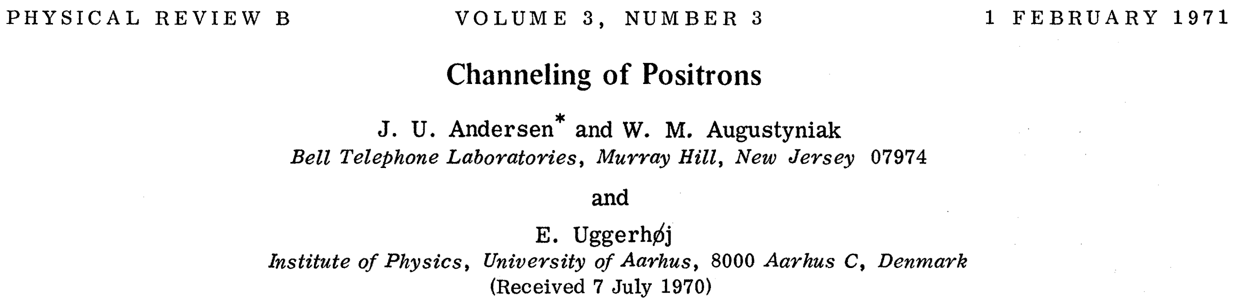
radioactive nuclei



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

electron linac

Numerous positron applications



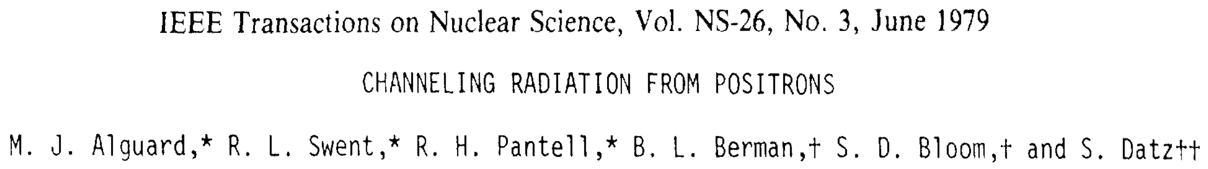
PHYSICAL REVIEW B VOLUME 3, NUMBER 3 1 FEBRUARY 1971

Channeling of Positrons

J. U. Andersen* and W. M. Augustyniak
Bell Telephone Laboratories, Murray Hill, New Jersey 07974

and

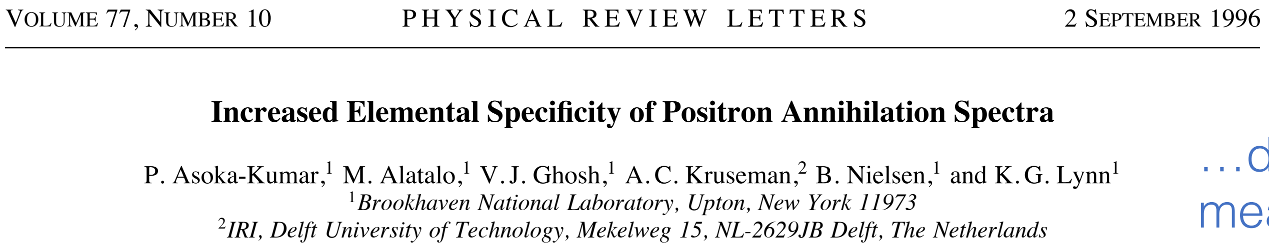
E. Uggerhøj
Institute of Physics, University of Aarhus, 8000 *Aarhus C, Denmark*
(Received 7 July 1970)



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

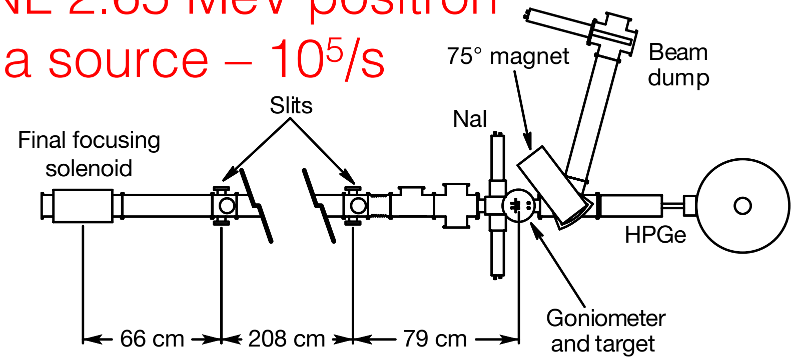
P. Asoka-Kumar,[1] M. Alatalo,[1] V. J. Ghosh,[1] A. C. Kruseman,[2] B. Nielsen,[1] and K. G. Lynn[1]
[1]*Brookhaven National Laboratory, Upton, New York 11973*
[2]*IRI, Delft University of Technology, Mekelweg 15, NL-2629JB Delft, The Netherlands*

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.

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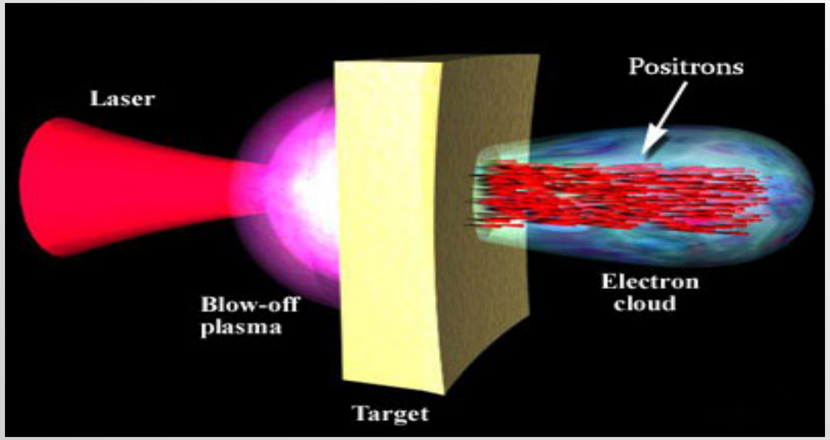
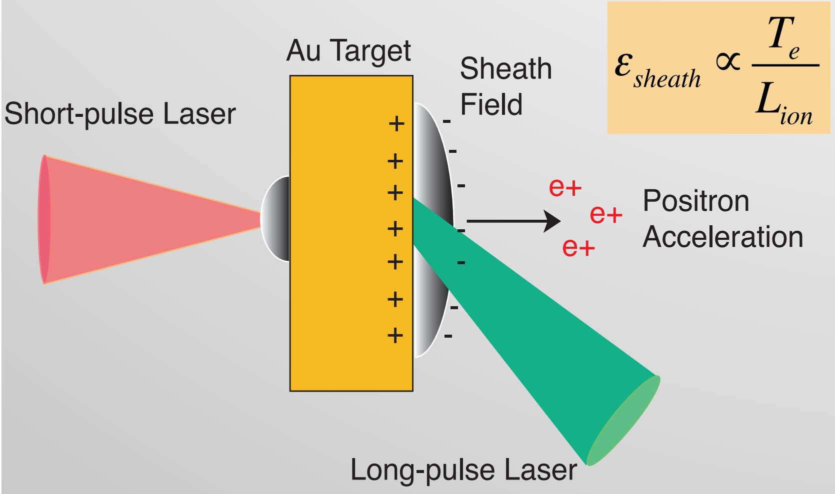
kJ laser-based positron-production

LLNL

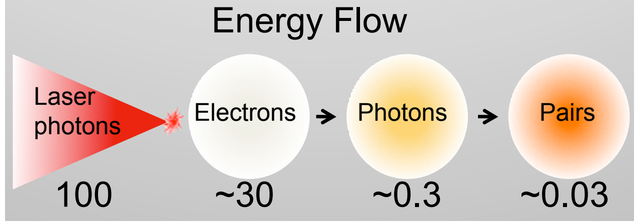


S. Wilks



$$\varepsilon_{sheath} \propto \frac{T_e}{L_{ion}}$$

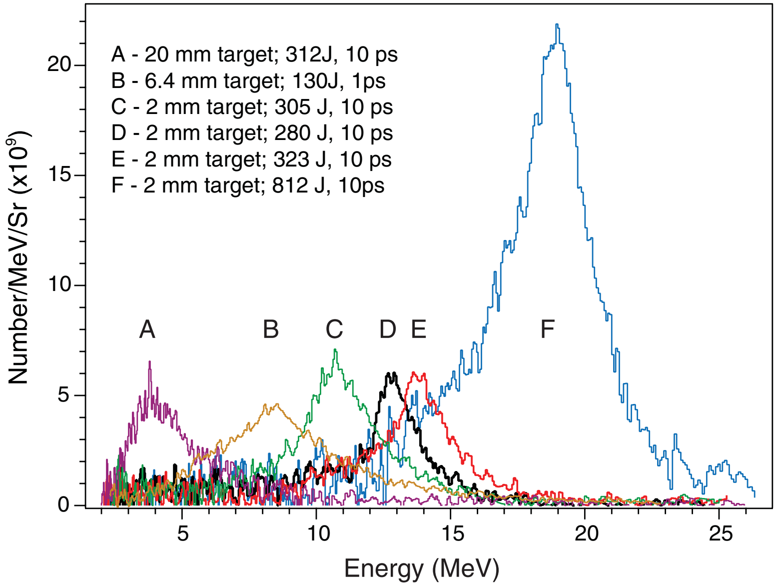
H. Chen et. al.
PRL 105, 015003 (2010)

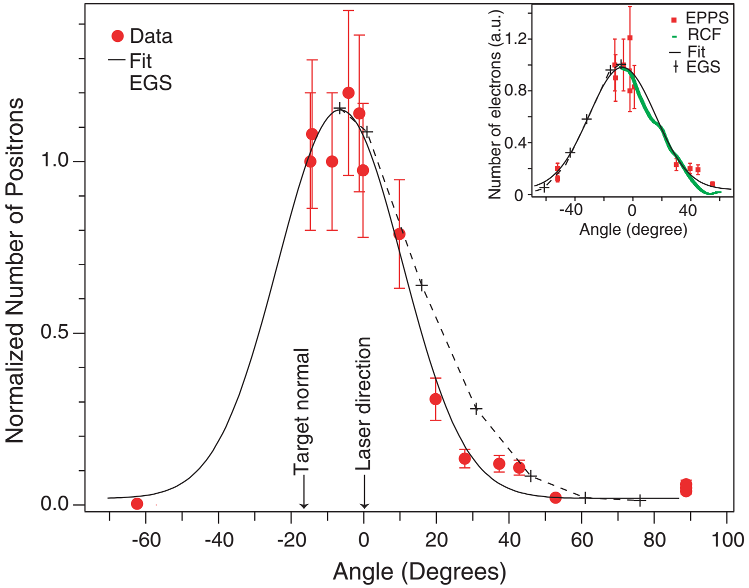


Energy Flow

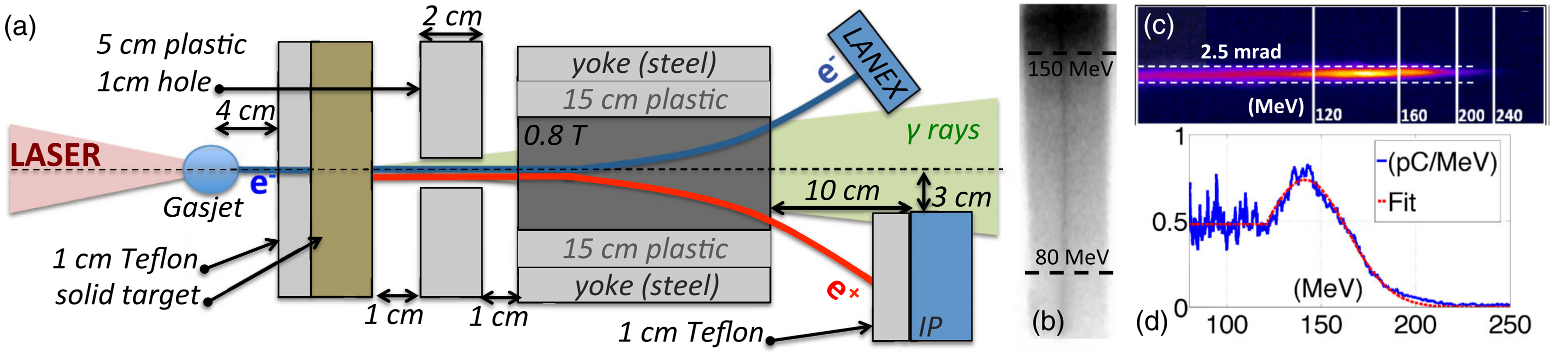
Laser photons → Electrons → Photons → Pairs

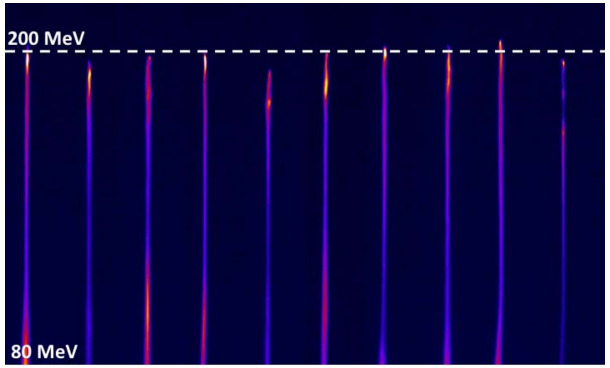
100 ~30 ~0.3 ~0.03



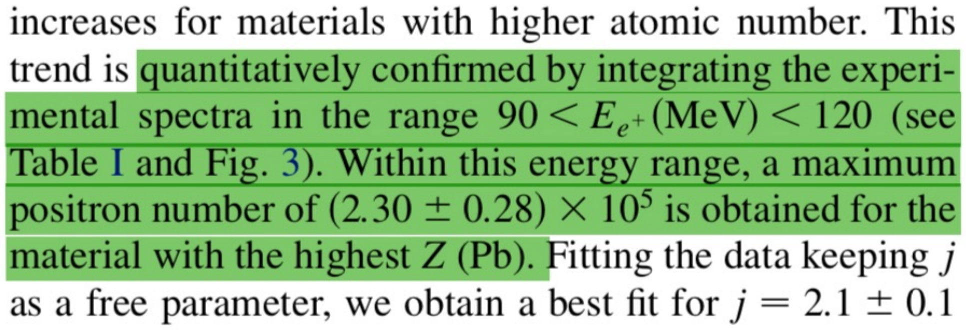


Laser driven e-beam shower production





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 $j = 2.1 \pm 0.1$

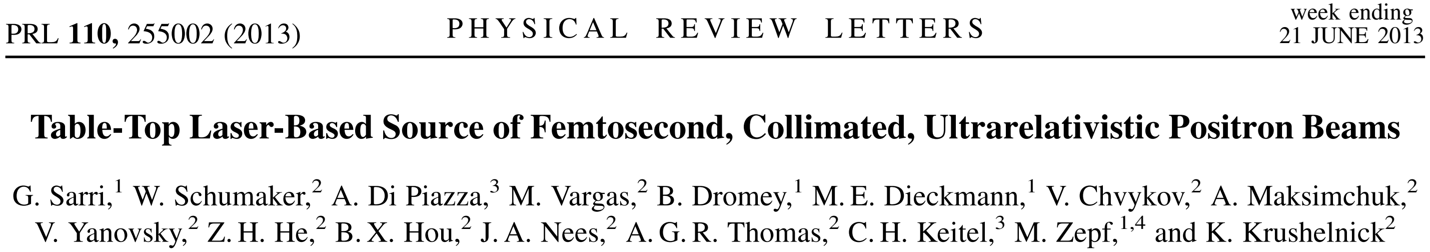

PRL **110,** 255002 (2013) PHYSICAL REVIEW LETTERS week ending 21 JUNE 2013

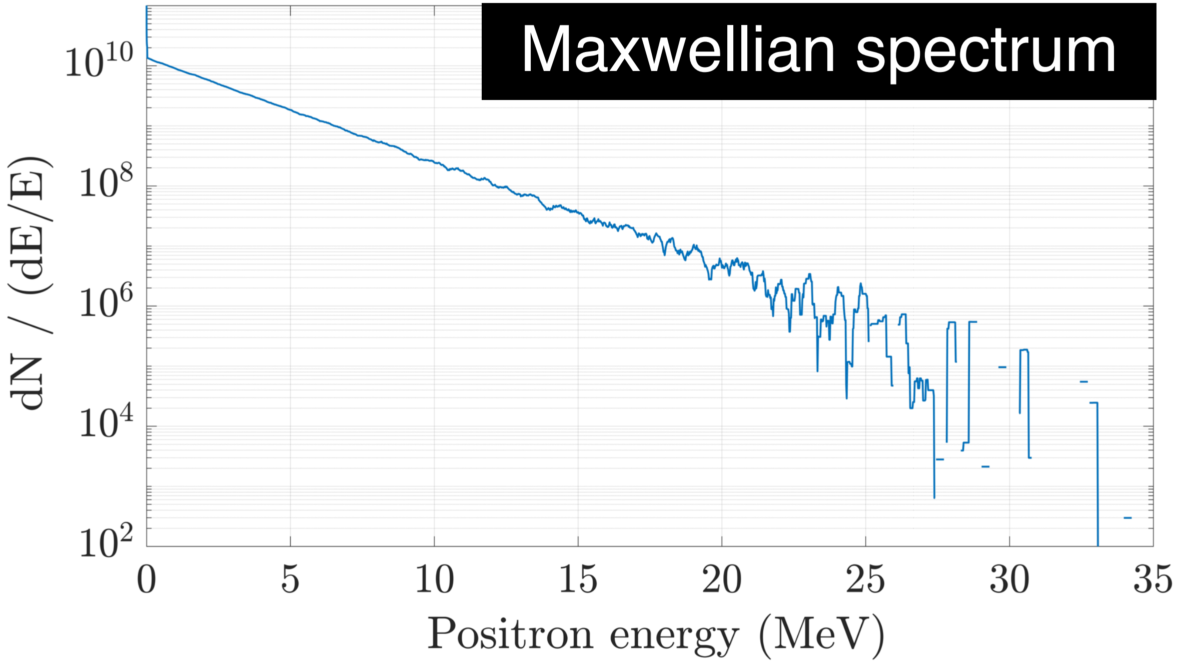
Table-Top Laser-Based Source of Femtosecond, Collimated, Ultrarelativistic Positron Beams

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]

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

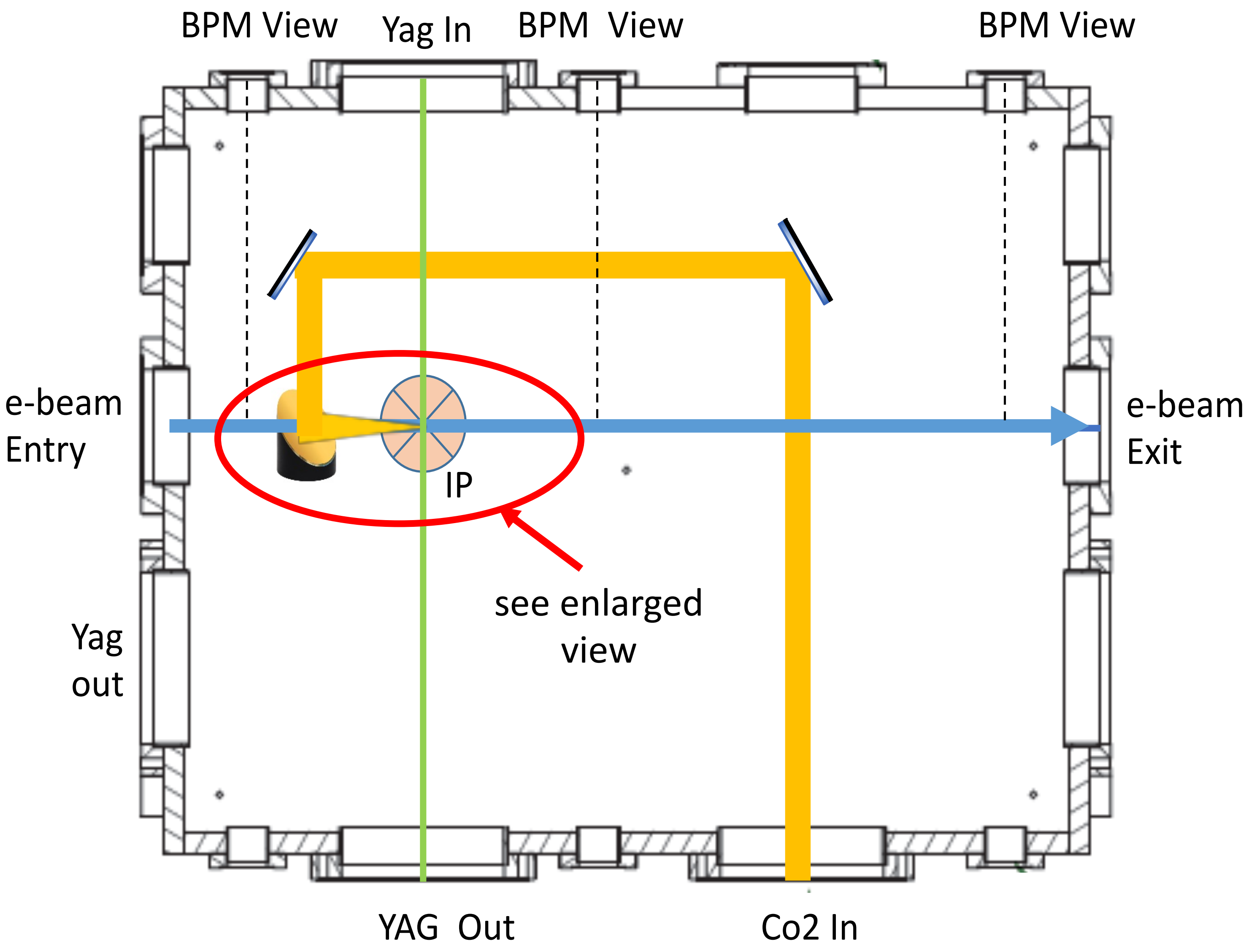


orders-of-magnitude
roll-off at
high-energies

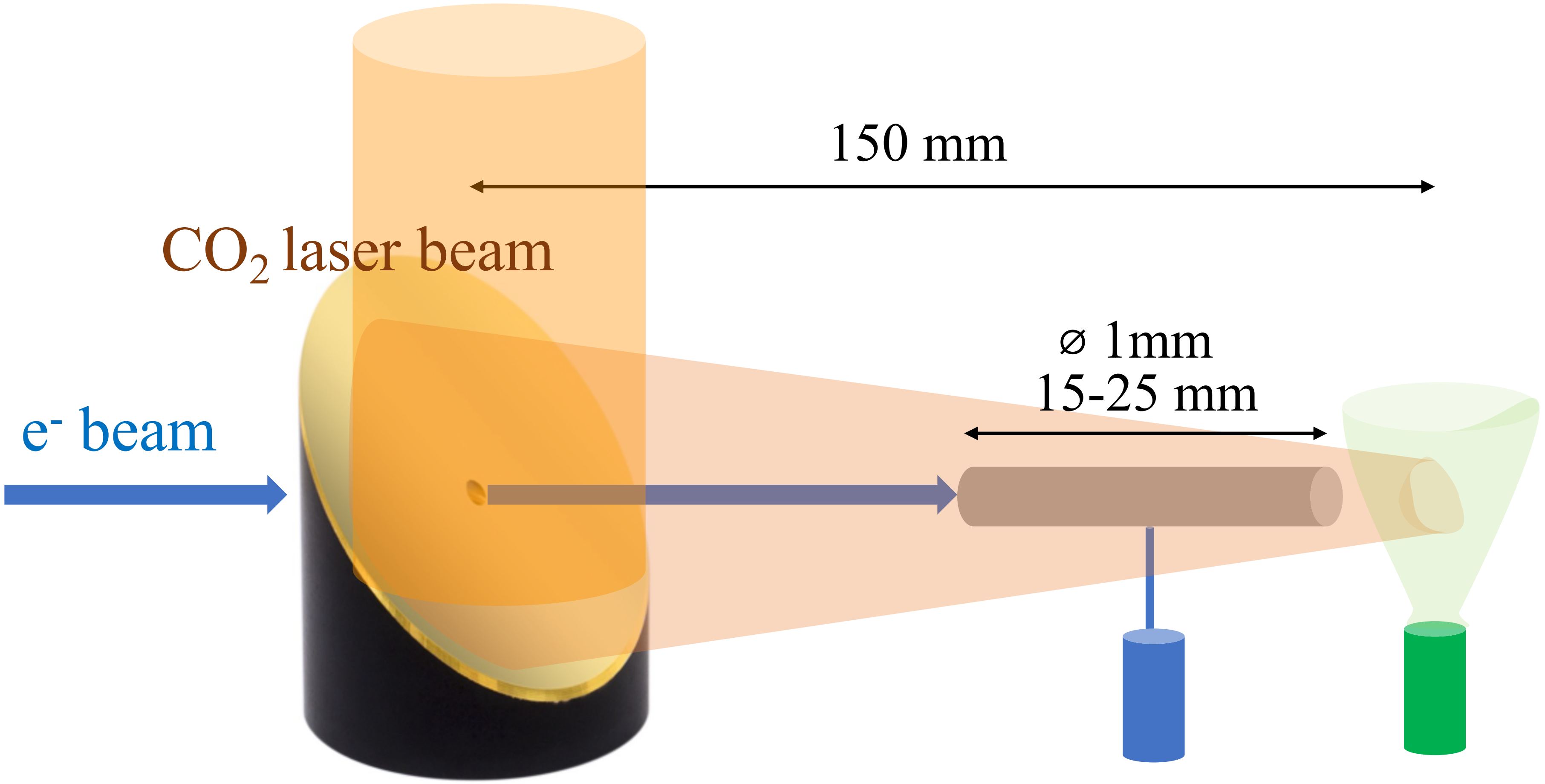
BNL ATF expt. design

Yr. 1 - experimental layout

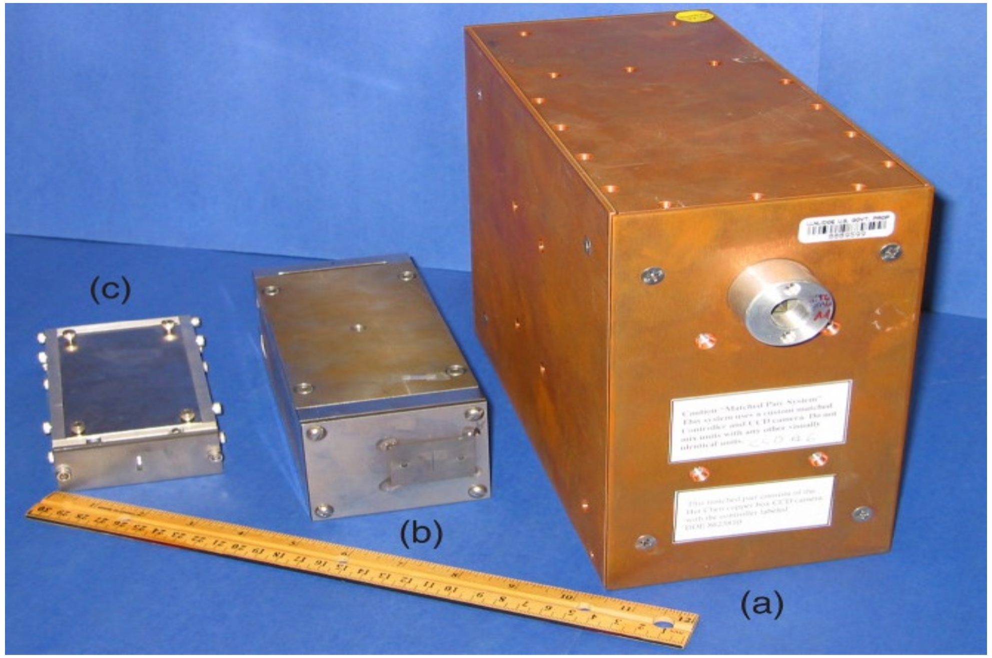
- BL# 1 vacuum chamber & gas jet
- vacuum chamber on BL#1 – space for our spectrometer
- DOES NOT disturb the setup for ongoing experiments
- insert a high-Z target holder in the beam path (removable)



Yr. 1 – expt. layout – interaction region

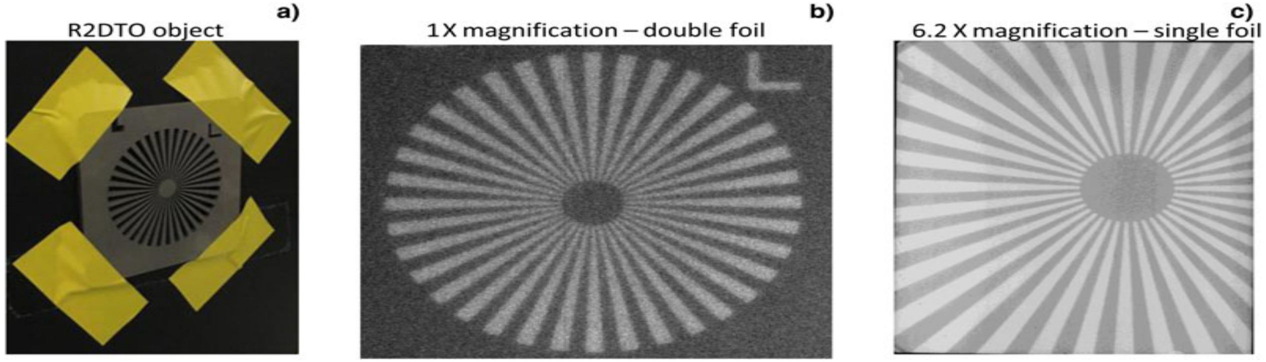


our diagnostics – positron & γ-ray



LLNL positron spectrometer

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

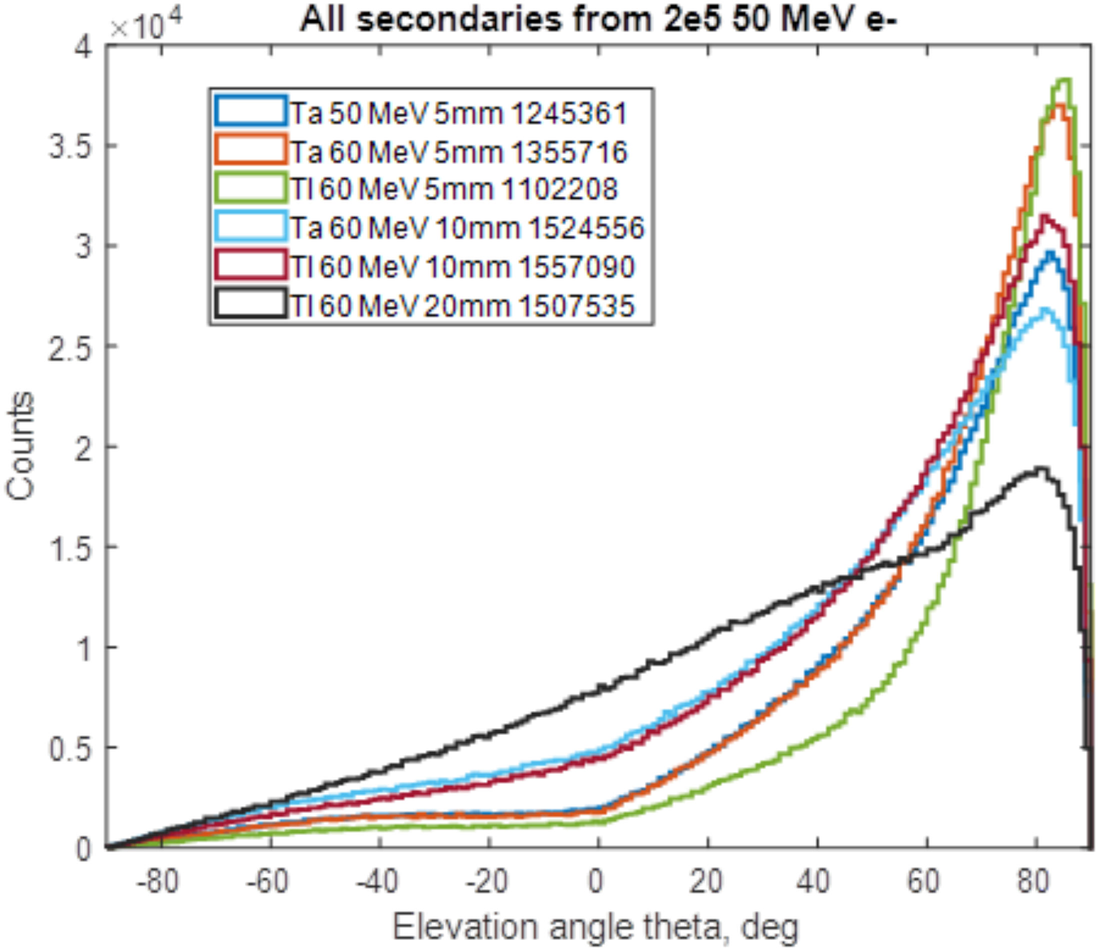


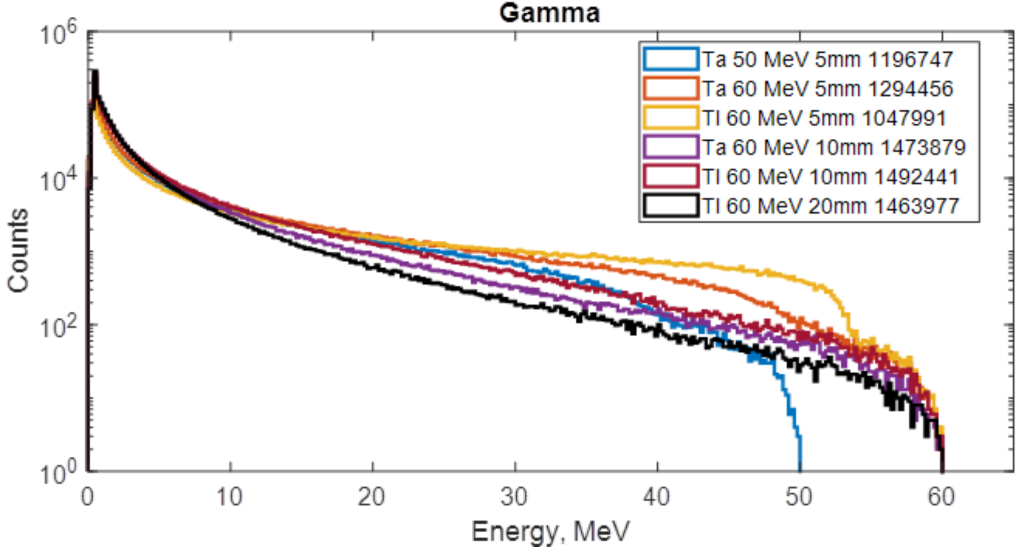
LANL gamma-ray diagnostics

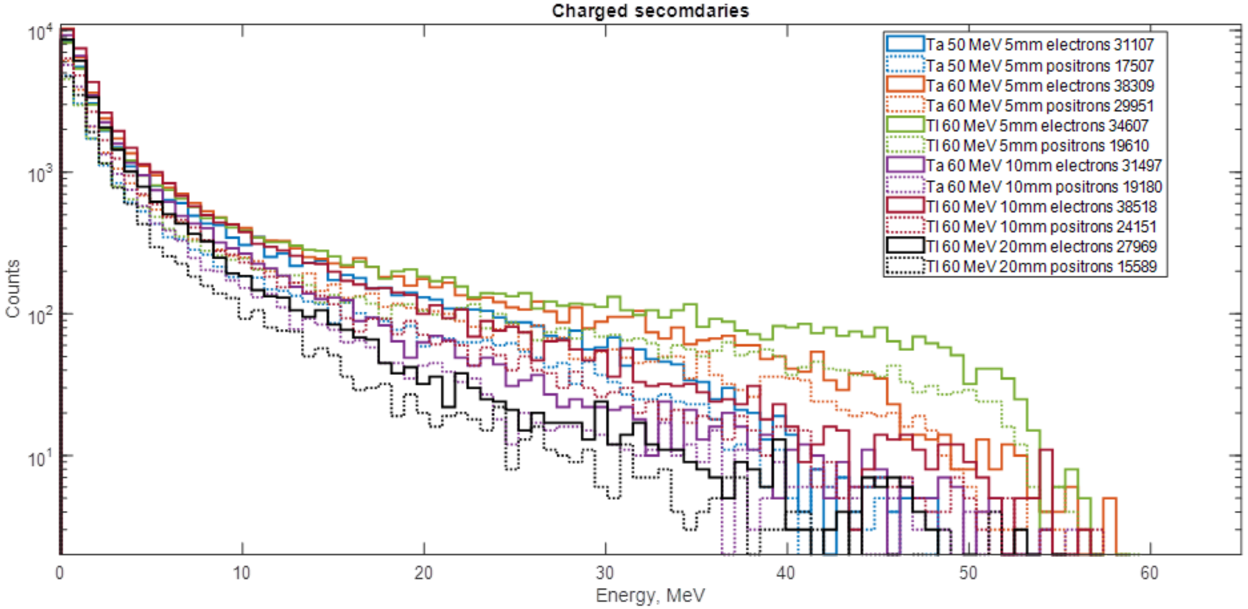
Laser and Particle Beams **36**, 502–506. (2018)

BNL ATF simulations

simulations of ATF-beam driven positron-electron showers







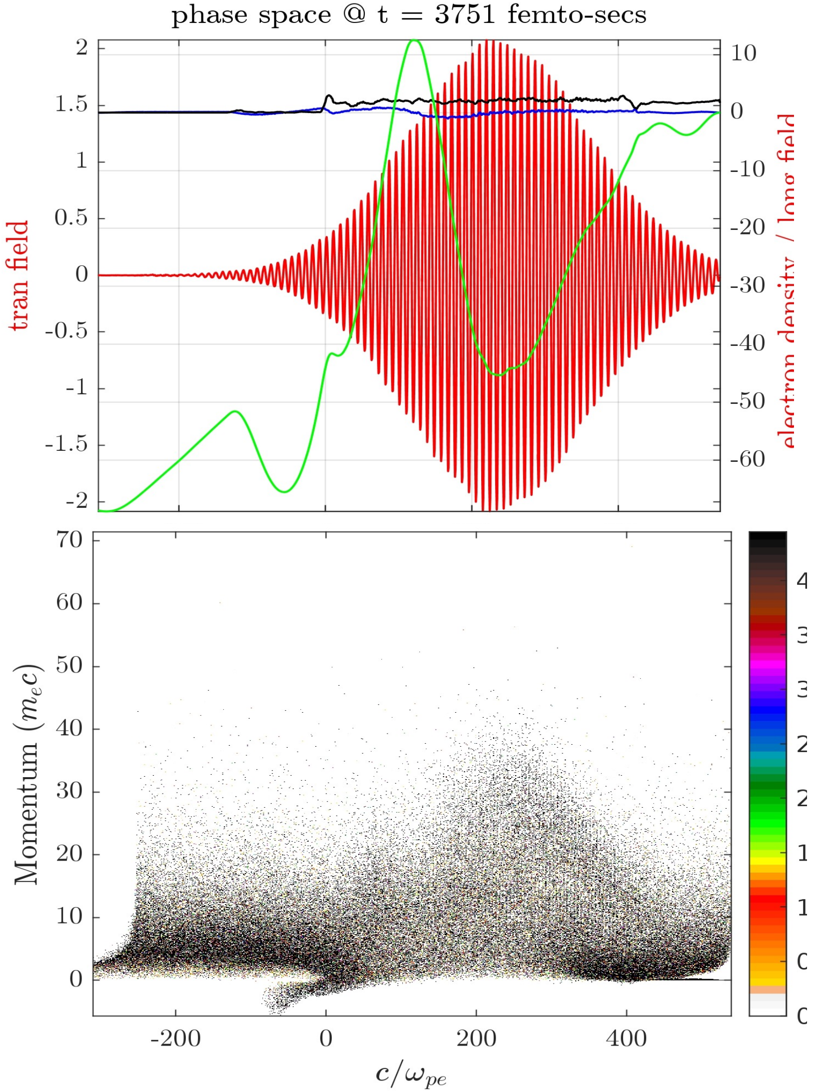
GEANT4 Acknowledgement:
J. Resta-Lopez, V. Rodin (CI) and LLNL

sim of CO$_2$ laser driven plasma processing

- 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

XSEDE
Extreme Science and Engineering Discovery Environment

Milestones

Proposed Milestones

Run 1 – *electron beam and low-power CO_2* laser
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 gas and ***low-power (0.5TW)*** plasma

Run 2 – **demonstration of spatio-temporal overlap** between a ***high-power (>1 TW)*** CO_2 laser pulse within the plasma-cell along with positron-electron jets

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

Experimental Time Request

CY2023 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 CY2023)

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