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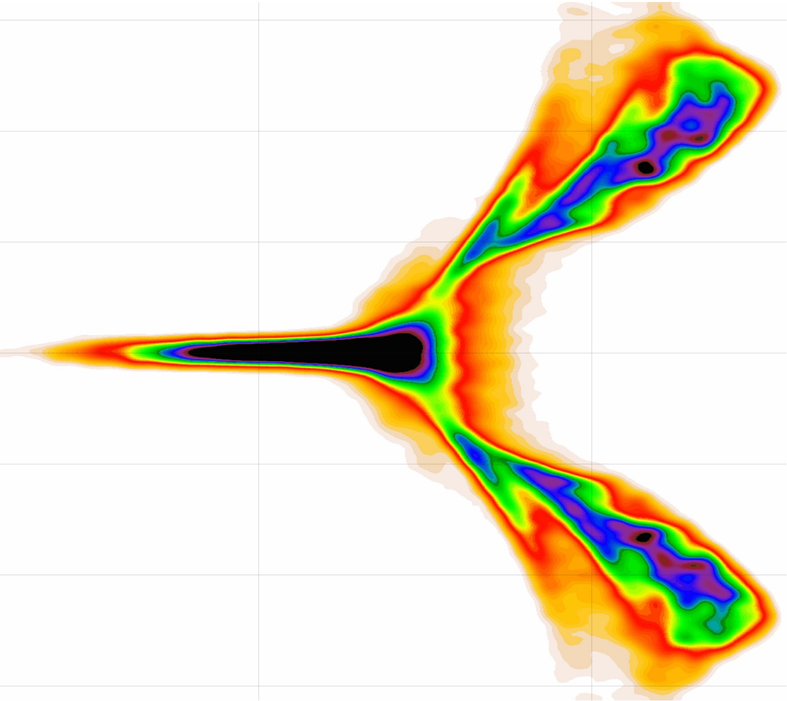
Tunable Laser Source of Exotic particles



PRAB 21, 081301 (2018)

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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)

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Schemes of laser muon acceleration: Ultra-short, micron-scale beams

Aakash A. Sahai, Toshiki Tajima, and Vladimir D. Shiltsev

https://doi.org/10.1142/S0217751X19430085 | **Cited by:** 6 **(Source: Crossref)**

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

Objective

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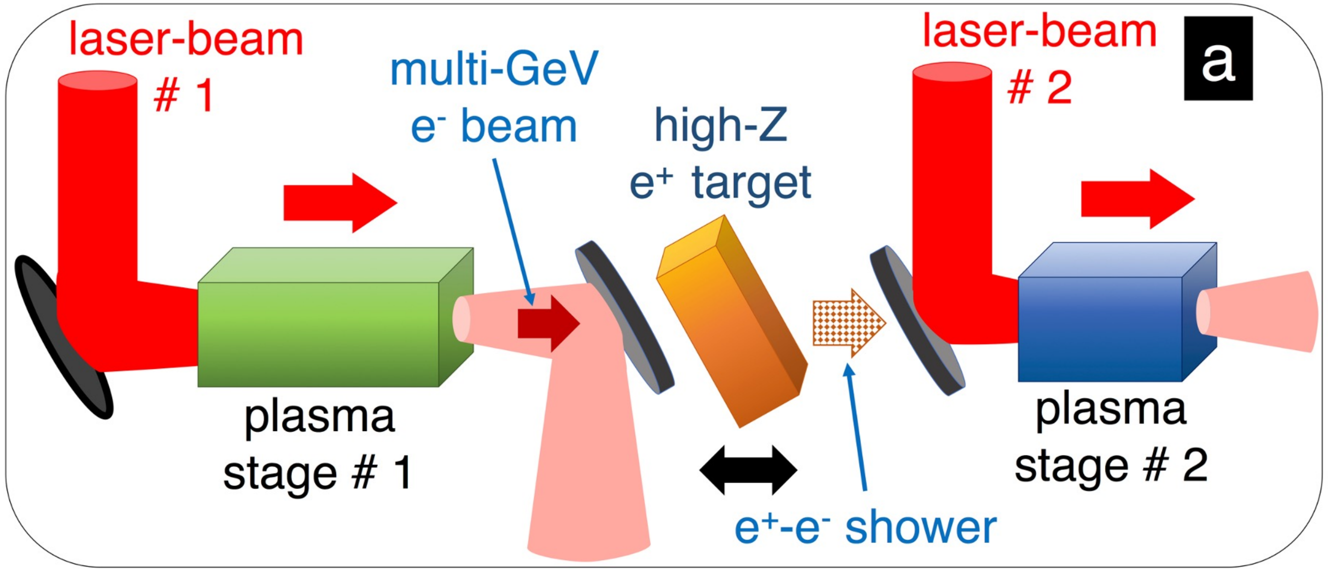
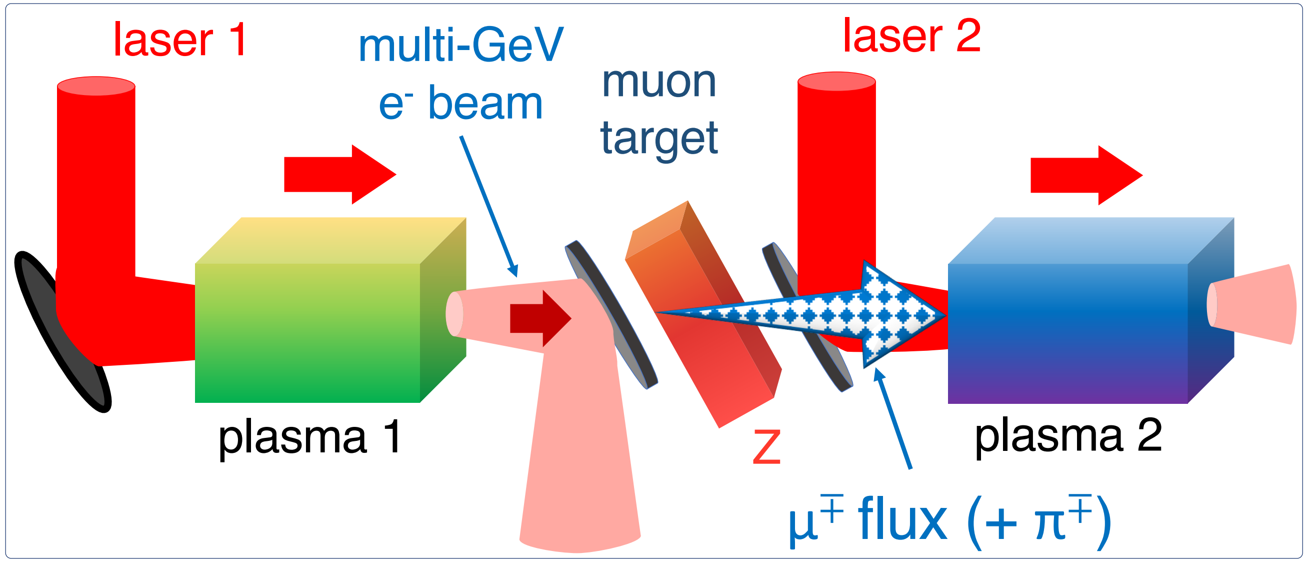
Schematic



Laser positron source (acc./dec. & focusing of e⁻-e⁺ shower)



Laser muon source (acc./dec. & focusing of μ⁻-μ⁺ shower)

Key scientific goals

Tunable, collisionless variation of trapped positron / muon properties

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

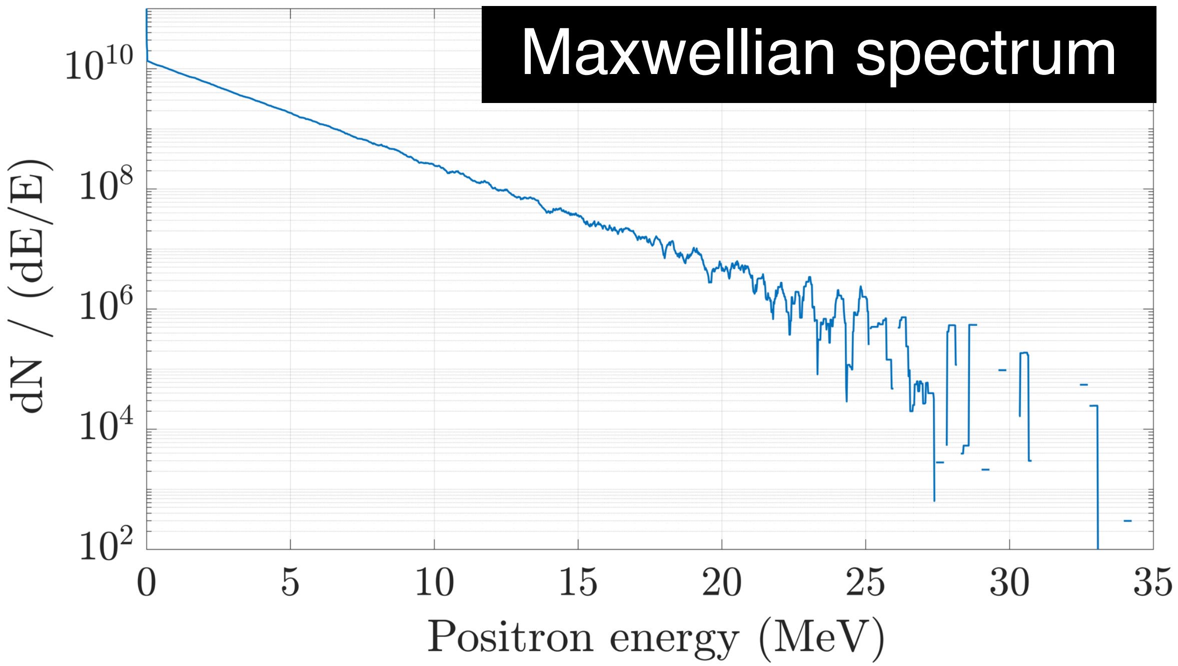
- **UNIQUE:** long wavelength (mid-IR) CO_2 laser (compared to Ti:Sapphire/NIR):
  larger plasma structures – easier to physically overlay with the showers
  slower structures for a lower plasma density – laser velocity slower for same density
- **UNIQUE:** control the interaction – tunable laser, external electron beam and gas density
- numerous applications benefit from a tunable positron / muon beam

Motivation

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

Laser-driven plasma + particle shower

1st-stage – positron-production stage

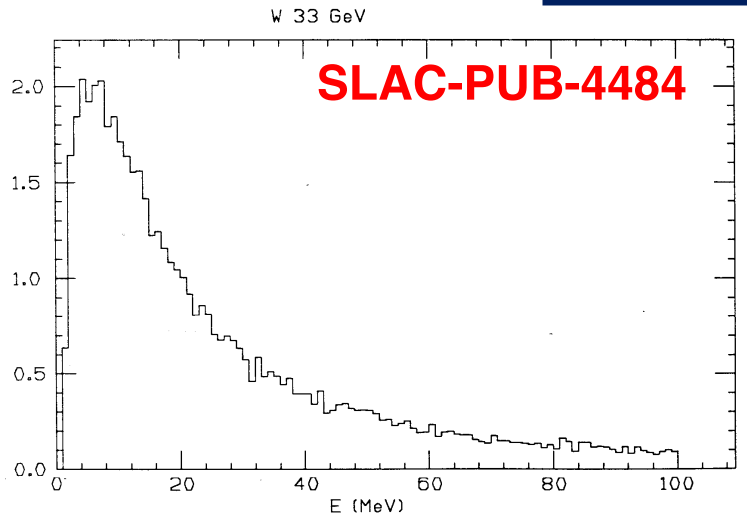


Fig. 3. Yield per 1–MeV energy (E) bin versus E at $z = 6$ radiation lengths.

anisotropic relativistic Maxwellian

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

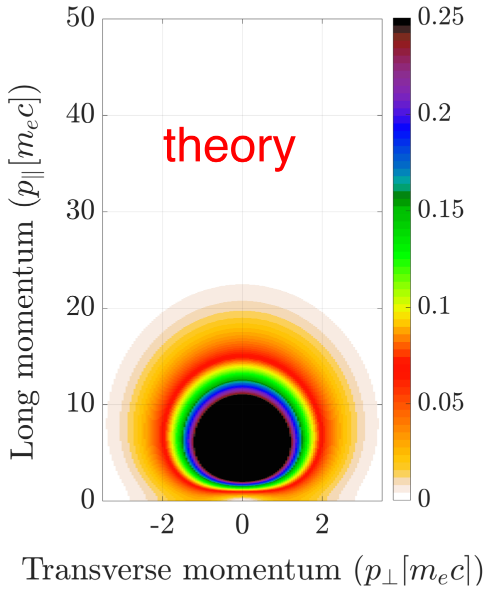
$$\beta_\perp = m_e c^2\,T_\perp^{-1},\ A = T_\parallel T_\perp^{-1}$$

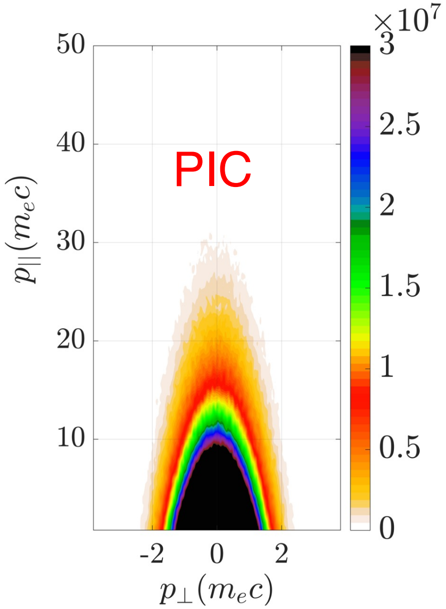
$$T_\perp = 0.2\ \mathrm{MeV} \quad A = 25$$

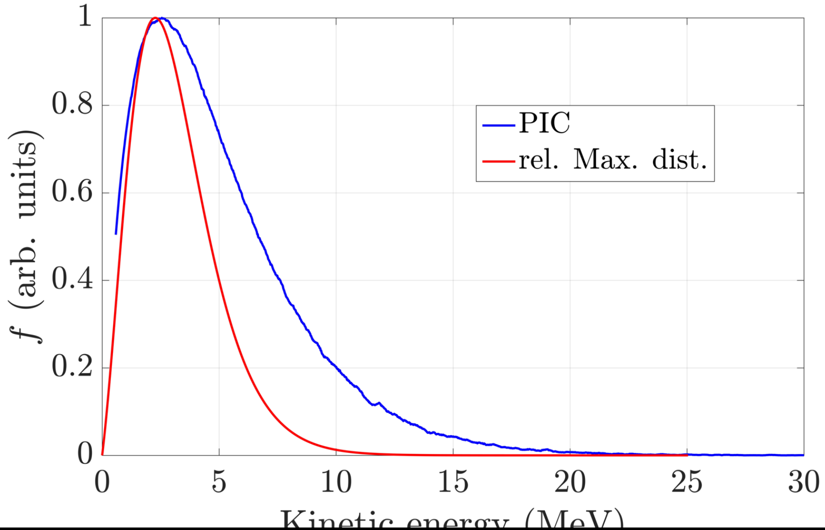
peak ~ **2.5 MeV**

temperature
~ 200keV

shower **e+** density
1-10 × 10^{16} cm^{-3}







e^+-LPA regime - interaction physics

laser-driven plasma-wave
phase-velocity

$$\beta_\phi = \left[1 - \omega_{\rm pe}^2/\omega_0^2\right]^{\frac{1}{2}}$$

lab-frame shower particle kinetic-energy
to be trapped

$$\mathcal{E}_{\rm sh} = (\gamma_{\rm sh} - 1)\,{\rm m_e c^2}$$

wave-frame shower particle kinetic-energy
to be trapped

$$\mathcal{E}'_{\rm sh} = \left(\frac{\omega_0}{\omega_{\rm pe}}\,\gamma_{\rm sh}\,\left(1 - \beta_{\rm sh}^{||}\beta_\phi\right) - 1\right)\,{\rm m_e c^2}$$

wave-frame trapping condition
shower particle trapped in plasma wave

$$e\Psi' \geq \mathcal{E}'_{\rm sh}$$

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e+-LPA regime - interaction physics - 2

lab-frame trapping condition
shower particle trapped in plasma wave
LONGITUDINAL

$$\Psi = \frac{\omega_{\rm pe}}{\omega_0}\ \Psi' + {\rm c}\ \mathbf{A}\cdot\boldsymbol{\beta}_\phi$$

$$\psi_{\rm th} \geq \gamma_{\rm sh}\ (1-\beta^{||}_{\rm sh}\beta_\phi) - \frac{\omega_{\rm pe}}{\omega_0},\ \ \psi = \frac{{\rm e}\Psi}{{\rm m_e c^2}},\ \ {\rm A}_{||} = 0.$$

lab-frame trapping condition
shower particle trapped in plasma wave
TRANSVERSE

$$e\Psi'' \geq \alpha\ k_{\rm B}{\rm T}_\perp$$

$$\psi_{\rm th} \geq \alpha\ \frac{k_{\rm B}{\rm T}_\perp({\rm m_e c^2})^{-1}}{1+\mathcal{E}_{\rm sh}({\rm m_e c^2})^{-1}}$$

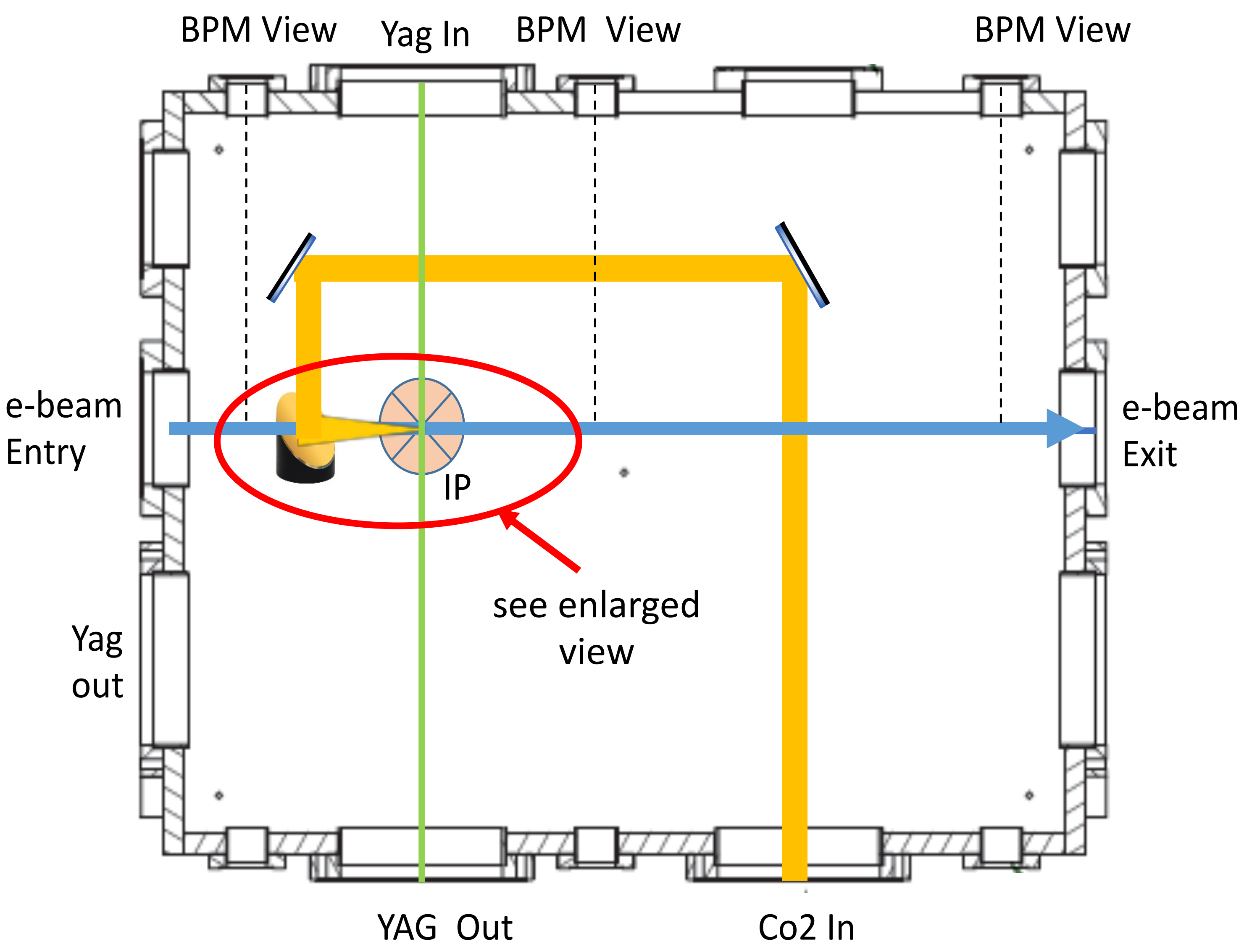
trapping particles with K.E. up to a few keV → **potential ~ 1**

in the **electron compression phase** of the wave

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)



BNL ATF simulations

simulations of ATF-beam driven positron-electron showers

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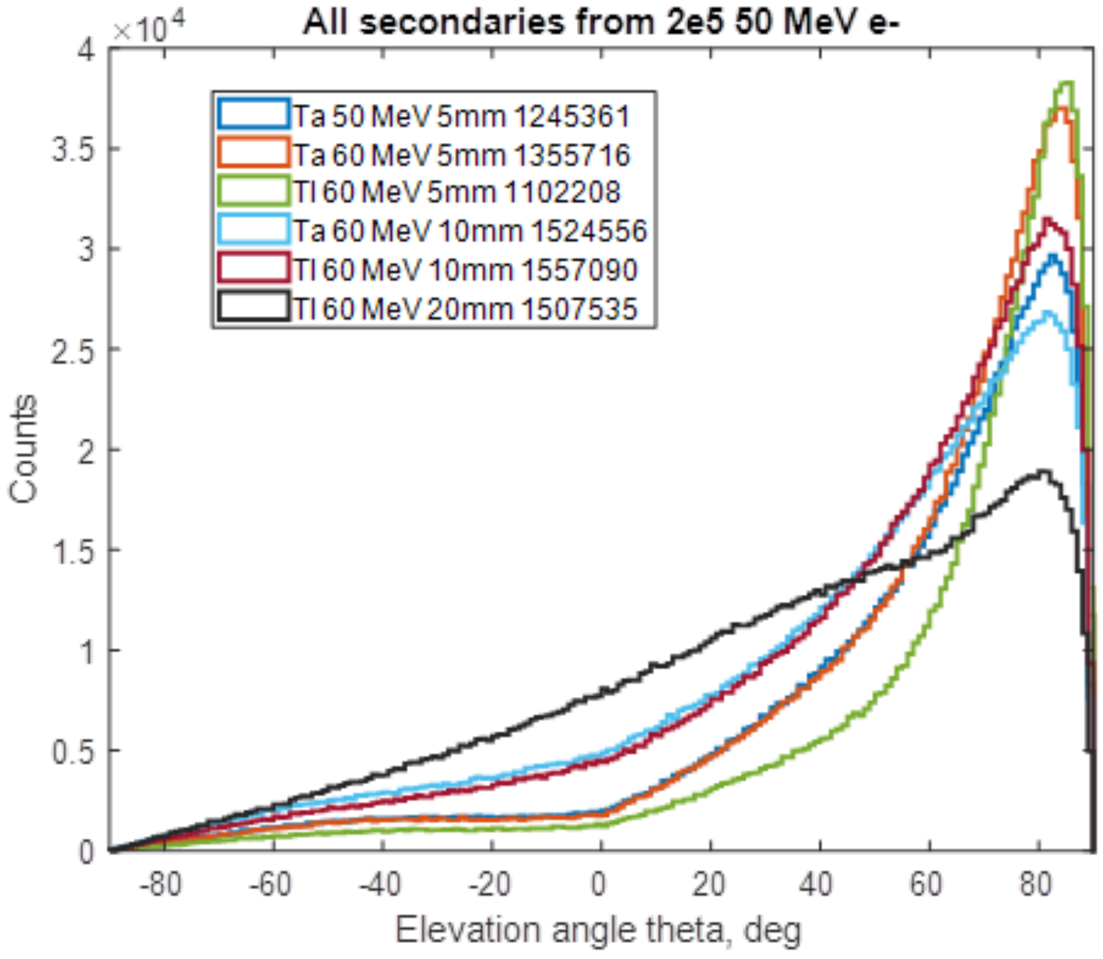
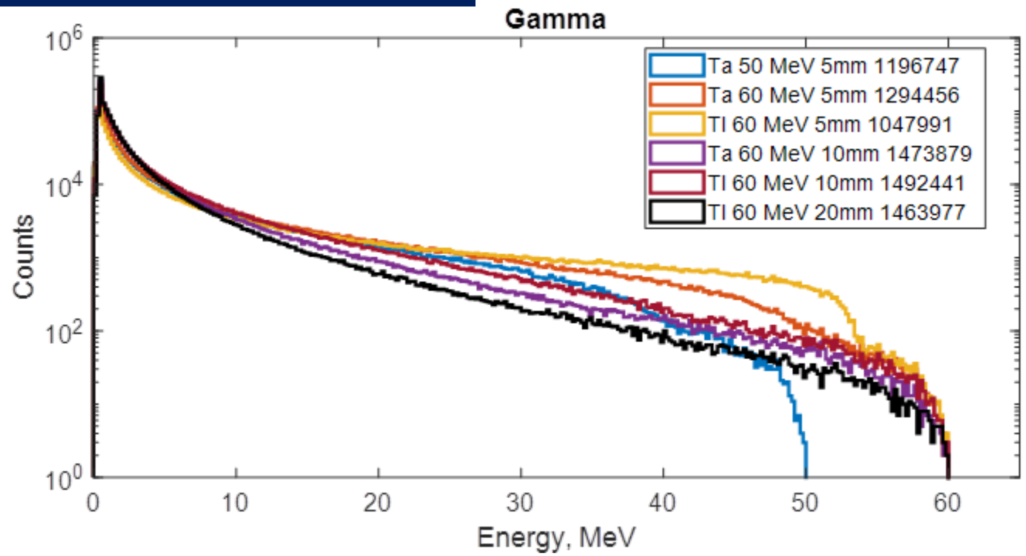
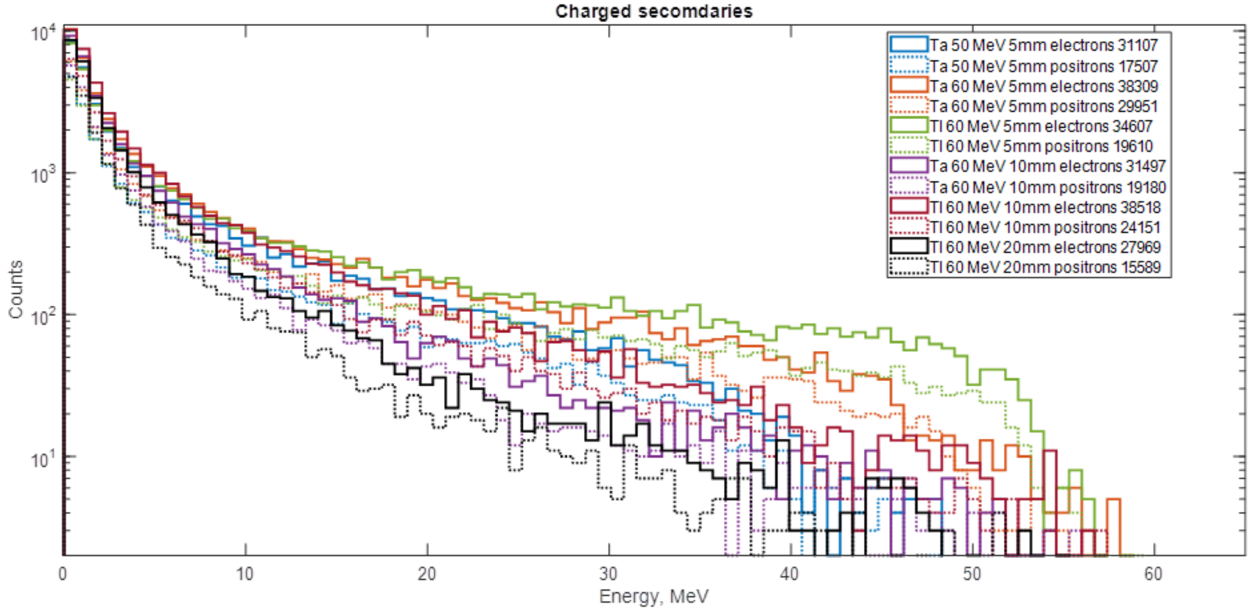






GEANT4 Acknowledgement

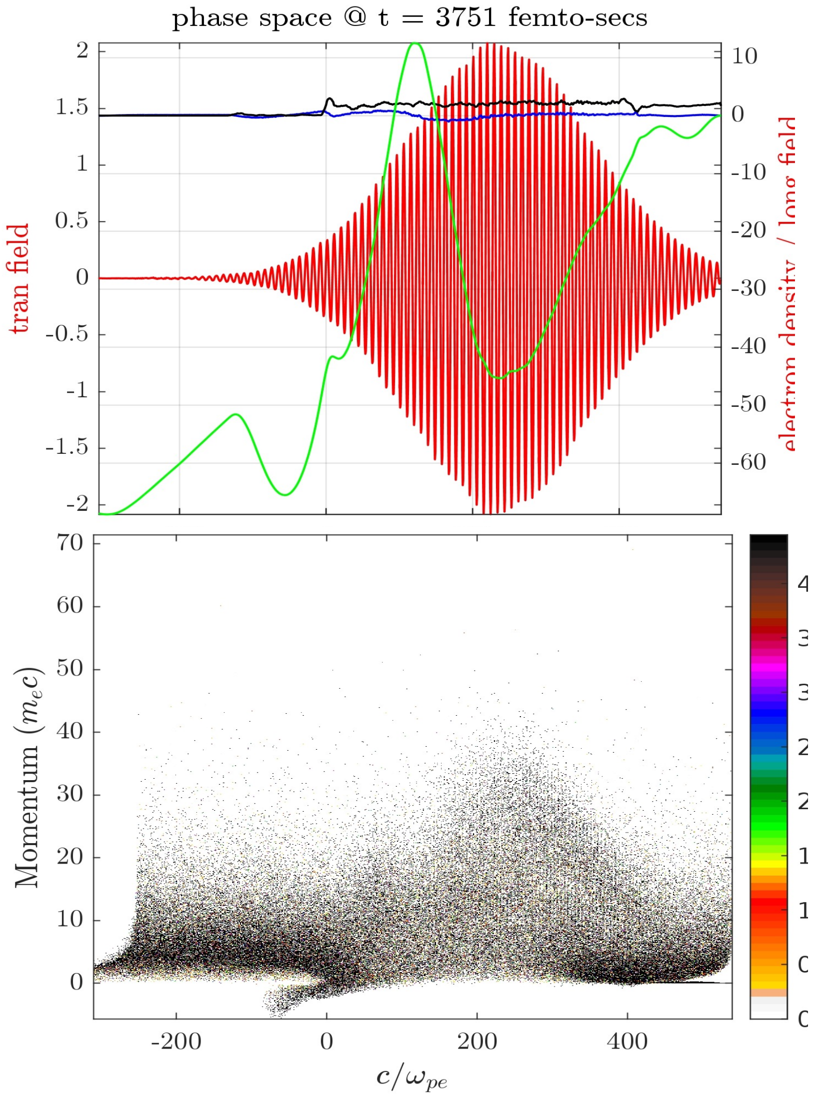
sim of CO_2 laser driven plasma processing

- 2D PIC EPOCH simulations – CO_2 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

Thanks → any questions