

Tunable Laser Source of Exotic particles

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

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

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

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Schematic

 $\mathcal{S}_{\mathcal{A}}$, so state of laser-plasma post-produced (photo-meson and BH muon and BH m

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

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

pair-production) ⇡*±*-*µ±* Hadronic shower driven by *e±* beam in a target. Aakash A. Sahai, Univ of Colorado Denver, Adv. Acc. Concepts 2024 3 3

Tunable, collisionless variation of trapped positron / muon properties

 $CO₂$ laser-driven post-processing of ATF e-beam driven particle showers:

- UNIQUE: long wavelength (mid-IR) CO₂ 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

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raw positron-electron showers

shower \neq beam pair-plasma ≠ beam

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

Maxwellian spectrum 10^{10} / (dE/E) 10^8 10^6 $\overline{\rm dN}$ $10^4\,$ $10²$ $\overline{5}$ 10 15 20 25 30 35 $\overline{0}$ Positron energy (MeV) orders-of-magnitude roll-off at high-energies

Laser-driven plasma + particle shower

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1st-stage – positron-production stage Maxwellian momentum distribution function in p-space where position production diago $M_{\rm{max}}$ momentum distribution function function in p-space \sim $\bm{\vartheta}$ $-$ positron-production stage \parallel gation axis [26, 27], ¹ st</sup>-stage – positron-produ proverse *position* product and $\frac{1}{2}$ beinverse versus and **manufacturers** p.824 (1957) plorado **1**st-stage – positron-production stage pp. 83-112 (1934); H. J. Bhabha, W. Heitler, Proc. of the transverse *poolitica production* $\bf e$ H. Bethe, W. Heitler, Proc. of the Royal Society A 146, $\bf e$

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

The above laser-driven particle-shower parameters are

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p.824 (1957)

pp. 83-112 (1934); H. J. Bhabha, W. Heitler, Proc. of the

p.824 (1957)

p.213 (1938)

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Royal Society A 159, iss. 898, p.432 (1937); L. Landau,

G. Rumer, Proc. of the Royal Society A 166, iss. 925,

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 $\mathcal{L}_{\mathcal{A}}$

sh]

e+-LPA regime - interaction physics requirements to the accelerate positions and the accelerated **e** T analytically derived. The minimum kinetic energy, *E*sh = (sh 1) mec² (lab-frame momen t benver and the distribution in et-LPA regime - interaction physics

laser-driven plasma-wave $\beta_\phi = \left[1 - \omega_{\rm pe}^2/\omega_0^2\right]$ $\frac{1}{2}$ laser-driven plasma-wave $\beta_\phi = \left[1 - \omega_\mathrm{pe}^2/\omega_0^2\right]^{\frac{1}{2}}$ **phase-velocity** P^{φ} if \mathbf{r}_{pe} and \mathbf{r}_{pe} laser-driven plasma-wave β , $=$ \lceil 1 \ldots , 2 $/$, 2 $\rceil^{\frac{1}{2}}$ \textbf{p} has e-velocity in the distribution in eq. 1. The Lorentz transition is transitional lower-limit of transition in the \textbf{p} can be a set of transformed lower-limit of transformed lower-limit of transformation **P**¹¹40
مونیا مامنا سمبین
<mark>-veloc</mark>i sh (1 ^k sh) 1 $\overline{}$

lab-frame shower particle kinetic-energy \sim (in the set of $(2, 2)$ $\frac{1}{2}$ and $\frac{1}{2}$ simulation. And $\frac{1}{2}$ simulations below the luminos below $\frac{1}{2}$ simulations below the luminos of $\frac{1}{2}$ **lab-frame** shower particle kinetic-energy $\mathcal{E}_{\text{sh}} = (\gamma_{\text{sh}} - 1) \, \text{m}_{\text{e}} \text{c}^2$

wave-frame shower particle kinetic-energy
$$
\mathcal{E}'_{\text{sh}} = \left(\frac{\omega_0}{\omega_{\text{ne}}} \gamma_{\text{sh}} (1 - \frac{\omega_0}{\omega_{\text{ne}}})\right)
$$

wave-frame shower particle kinetic-energy
$$
\mathcal{E}'_{\text{sh}} = \left(\frac{\omega_0}{\omega_{\text{pe}}}\ \gamma_{\text{sh}}\ (1-\beta_{\text{sh}}^{\parallel}\beta_{\phi}) - 1\right)\ \text{m}_\text{e}c^2
$$

wave-frame trapping condition
\nshower particle trapped in plasma wave
\n
$$
e\Psi'\geq\mathcal{E}'_{\mathrm{sh}}
$$

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(2021)

 $\sin \theta$ ($\sin \theta$)

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e+-LPA regime - interaction physics - 2 Lorentz transformation of the four potential (⁰ *,* A⁰ $\overline{}$ to the label to the label to the label to the label potential and threshold potential and threshold potential
The threshold potential and the threshold potential and the threshold potential and the threshold potential an e⁺-LPA regime - interaction physics - 2

lab-frame trapping condition $\Phi = \frac{\Psi}{\omega_0} \Phi + \Phi \cdot \mathbf{A} \cdot \mathbf{A} \cdot \mathbf{A}$ shower particle trapped in plasma wave LONGITUDIN.

lab-frame trapping condition
$$
\Psi = \frac{\omega_{\text{pe}}}{\omega_0} \ \Psi' + \mathbf{c} \ \mathbf{A} \cdot \boldsymbol{\beta}_{\phi}
$$

 th sh (1 ^k sh) !pe !0 *,* = e ^mec² *,* ^A^k = 0*.* mentum contracts and the average particle energy in the shower frame is *k*BT?. Thus, the

shower particle trapped in plasma wave l_a T $(m_a c^2)$ -1 **lab-frame** trapping condition **TRANSVERSE**

$$
\begin{array}{ll}\text{frame trapping condition} & e \Psi'' \geq \alpha \,\, k_{\mathrm{B}} \mathrm{T}_\perp \\ & \text{trapped in plasma wave} \\ & \text{TRANSVERSE} \quad \, \psi_{\mathrm{th}} \geq \alpha \,\, \frac{k_{\mathrm{B}} \mathrm{T}_\perp (m_{\mathrm{e}} c^2)^{-1}}{1+\mathcal{E}_{\mathrm{sh}} (m_{\mathrm{e}} c^2)^{-1}} \end{array}
$$

mentum contracts and the average particle energy in the shower frame is *k*BT?. Thus, the $\frac{1}{2}$ trapping particles with $K \square$ up to a fow keV \triangle **patential** \therefore 1 trapping particles with K.E. up to a few keV \rightarrow potential \sim 1

> the different comparison of the solid of the set of the solid of the solid of the solid μ in the **electron compression phase** of the wave

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shower momentum s

BNL ATF expt. design

Yr. 1 - experimental layout

■ BL# 1 vacuum chamber & gas jet

• vacuum chamber on $B_L\#1$ – 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

sim of CO₂ laser driven plasma processing

- 2D PIC EPOCH simulations $-$ CO₂ laser-driven Passed Fig. 2 and Summation $S = CO_2$ rased for mean 1.5 T beforeting the theoretical model of the theoretical model of the set of th
- Shower properties determined using GEANT4
■ ag obted to the size of the siz
- **•** Initialize a long shower ~ 2.5 ps $\qquad \qquad$ \qquad \q
- down positrons at 2 Plasma Undulator *Plasma Undulator Plasma Undulator Plasma* University at 2 Plasma University at 2 \bullet $CO₂$ Laser-driven structures – can trap and slow- $\begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix}$

Strongly Mismatched Regime of Nonlinear Laser–Plasma Acceleration: Optimization of ²⁰⁰ P_{H} $\begin{bmatrix} P_{\text{H}} & P_{\text$ Laser-to-Energetic Particle Efficiency $\left(\frac{10.1109}{\text{TPS}} \cdot 2019.2914896 \right)$

here. The process of laser slicing uncovered here is signifi-

 T identities that Damar, Dimensional Undulated **Aakash A. Sahai. Univ of Cold** Aakash A. Sahai, Univ of Colorado Denver, Adv. Acc. Concepts 2024 27 However, a wide range of well-known groundbreaking

Thanks \rightarrow any questions