Plasma Dark Current in Self-Ionized Plasma Wake Field Accelerators

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What is Dark Current and Why is it Important?

• One of the fundamental limits to high accelerating gradients in conventional metallic particle accelerators (< 100 MeV/m)



•Lead to active research on Plasma Accelerators (10-100 GeV/m)

Is there a corresponding limit in Plasma Accelerators?





The wake grows from an instability, therefore the onset of trapping is not controllable

Experimental Setup Experimental Setup



Clear threshold at ~7 GV/m

Evindence For Particle Trapping Treshold



- Trapping above a threshold wake amplitude as measured by average energy loss or decelerating field: ≈7GV/m
- Excess charge of the order of the beam incoming charge (1.6x10¹⁰ e⁻)
- Evidence for two (or more) short bunches of trapped particles

Simulation of the Experiment with OSIRIS*



Parameters of OSIRIS Simulation For The Full PWFA Experiment

Beam Spot Size (σ_r) Gaussian	12 μ
Beam FWHM	70 μ
(non-Gaussian longitudinal distribution)	
Beam Energy	28.5 GeV
Number of Beam e ⁻	1.88 x 10 ¹⁰
Li Gas Density (n ₀)	1.6 x 10 ¹⁷ cm ⁻³
Number of Simulation Cells	500 x 600 moving
Beam Particles/cell	25
Gas Particles/cell	1
dt (1/ ω_p)	0.0286
Cell Size ∆z x ∆r	0.09 x 0.04 c/ω _p

OSIRIS Simulation: Real Space (r-z) Of Li & He Electrons



OSIRIS Simulation: Phase Space (P_z -z) Of Li & He Electrons and the on-axis line out of the E_z



He electrons do and reach energies up to 2.5 GeV

TRAPPING OF PLASMA e⁻



• High-energy, narrow $\Delta E/E$ trapped particle bunches

Courtesy of P. Muggli

CARTOON OF TRAPPING



Simulations Verify Theory and agrees well with Experiment

Vertical Lines are the analytic estimates each corresponds to a different simulation Constant of motion for a



Constant of motion for arbitrary wave potentials of the form, $A = A(z-ct), \Phi = \Phi(z-ct)$

$$\gamma mc - P_z + q \frac{\Psi}{c} = \text{const};$$

 $k^{'\,:}$ calculated from linear fits to ${\rm E_z}$ from simulations

Peak Field : calculated from simulations

Beam charge is varied from 0.4 to 1 times that of original beam from left to right

Trapped particles load the wake causing less energy gain



Plasma electrons are dragged out of the plasma by positron beam and can become as dense as the positron beam*



*T. Katsouleas et al. Phys Fluids b 1990