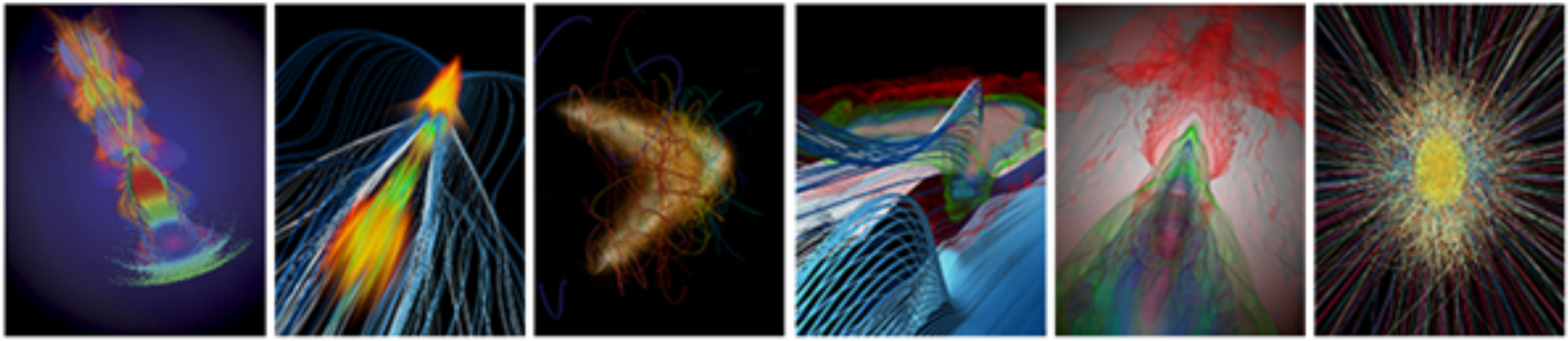

Positron Acceleration in the Electron Driven Plasma Wake Field

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FACET·II
Facility for Advanced Accelerator Experimental Tests

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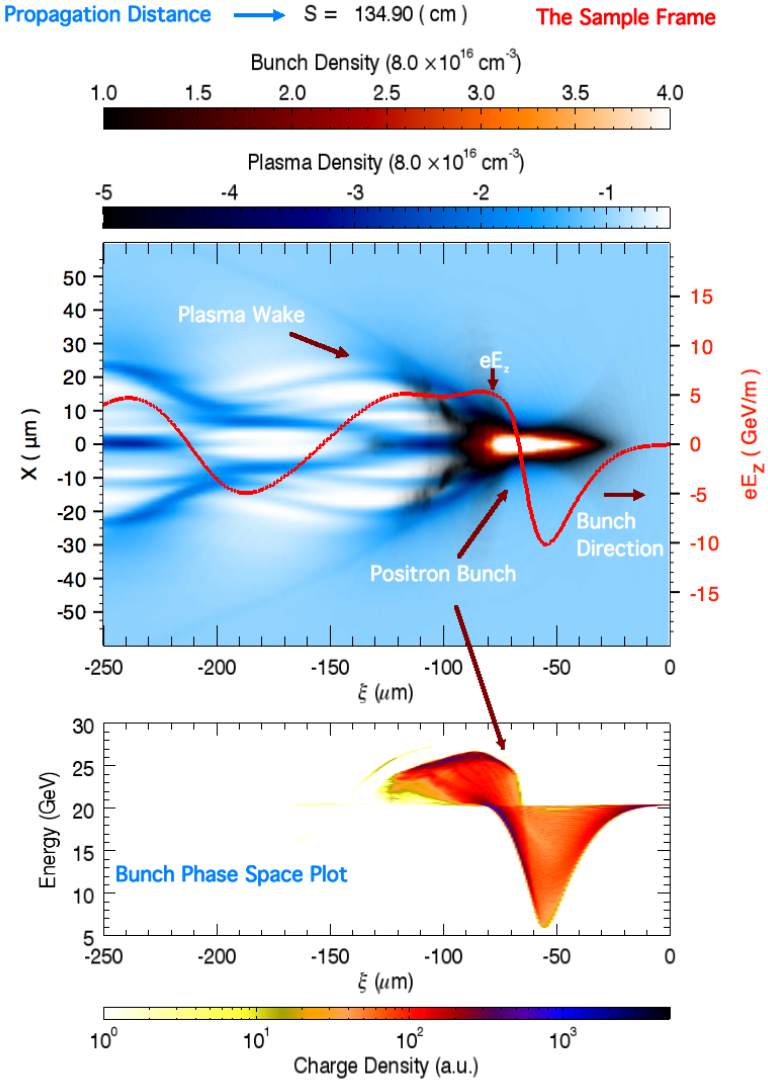
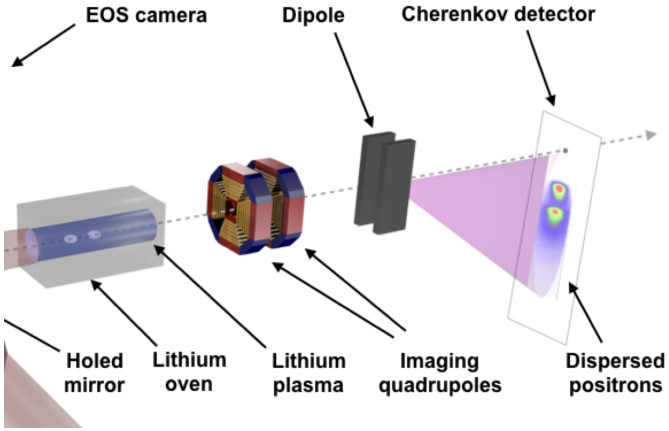
Positron Acceleration at FACET

1.Positron Self-loading



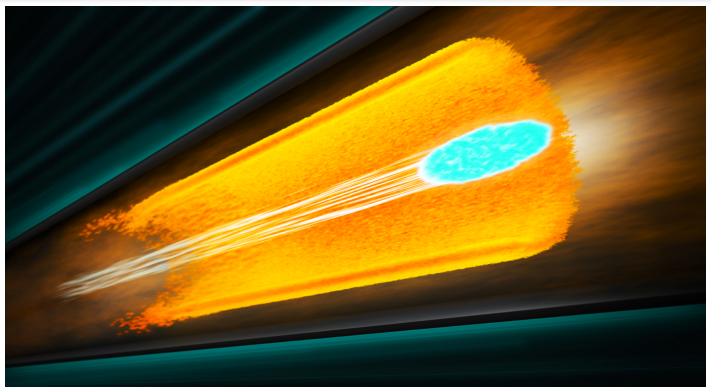
*S. Corde et. al, Nature 524, 442 (2015)

2.Two- Bunch Positron PWFA



*A. Doche et. al, Scientific Report, accepted (2017)

3. Positron in Hollow Channel



*S. Gessner et. al, Nature Comm. 7, 11785 (2017)

4. Two-Bunch Positron in Hollow Channel

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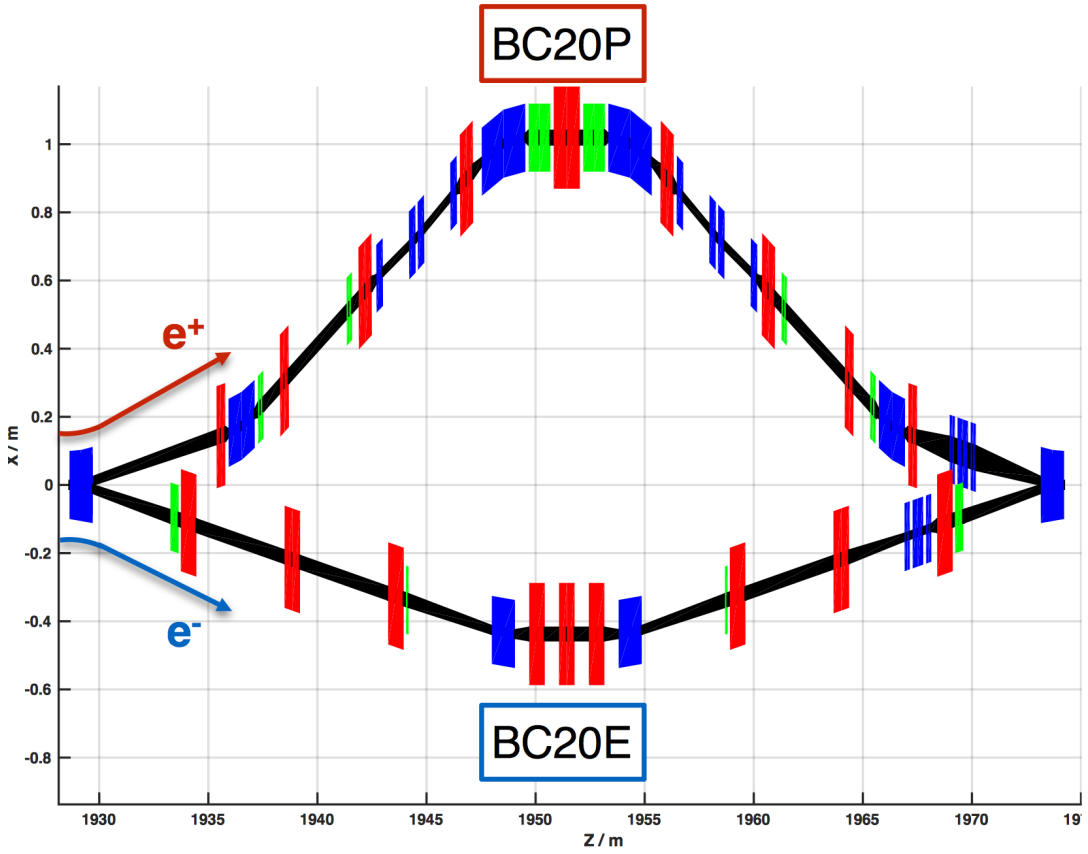
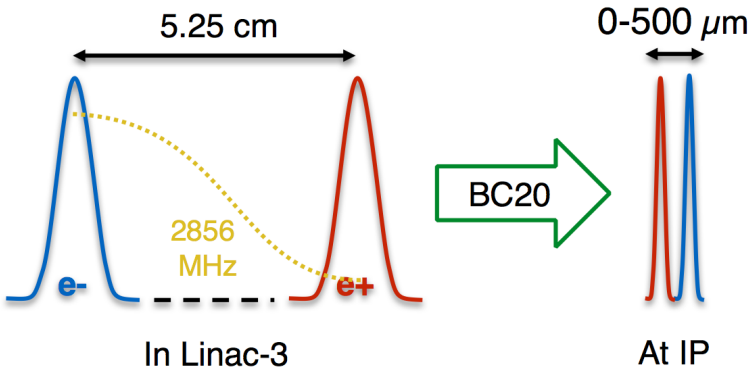
Electron and Positron Beam from the Sailboat Chicane

New BC20 Layout (Stage-III)



*Glen White



Drive Beam (Electron):
N =1.25 x 10^{10} (2.0 nC), I_{peak}=15 kA
σ_z = 16 μm, E = 10 GeV

Trailing Beam (Positron):
N =6.25 x 10^{9} (1.0 nC), I_{peak}=6 kA
σ_z = 20 μm, E = 10 GeV

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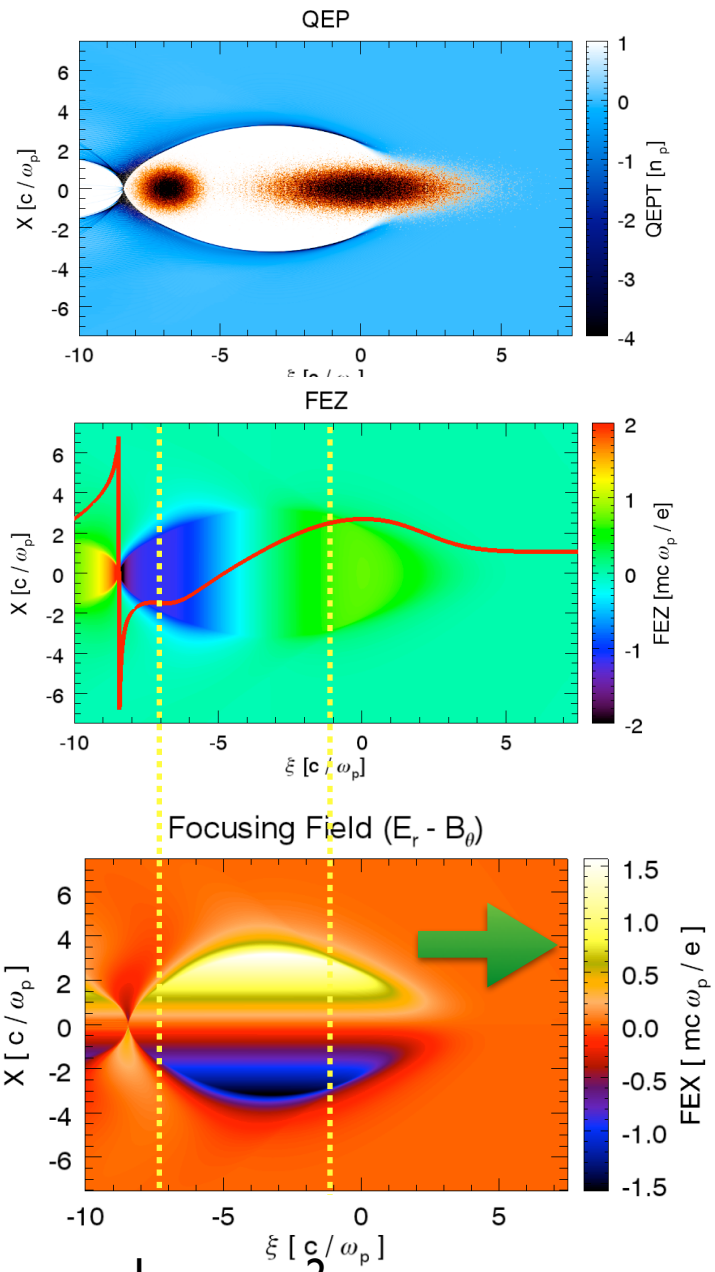
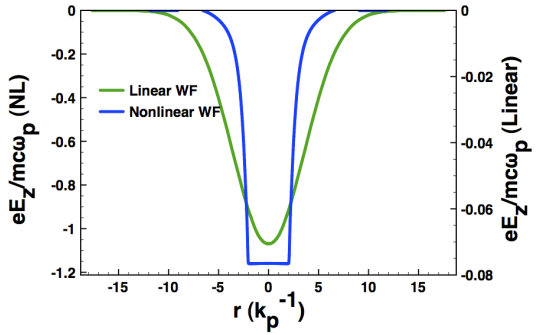
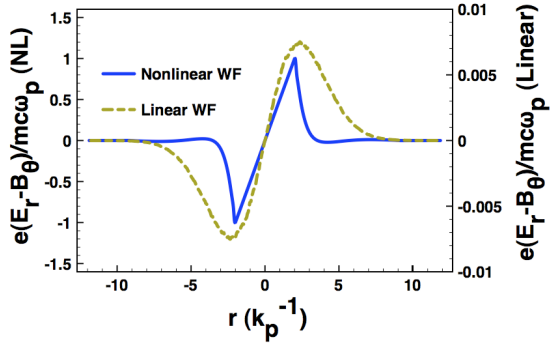
Nonlinear Plasma Wake Field



1





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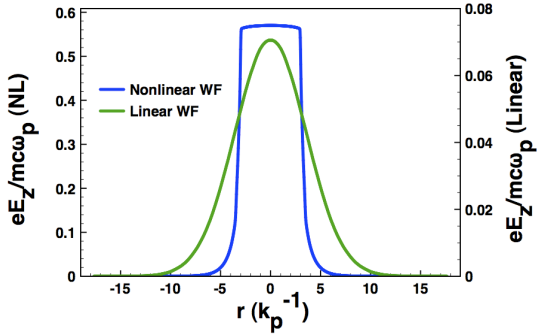

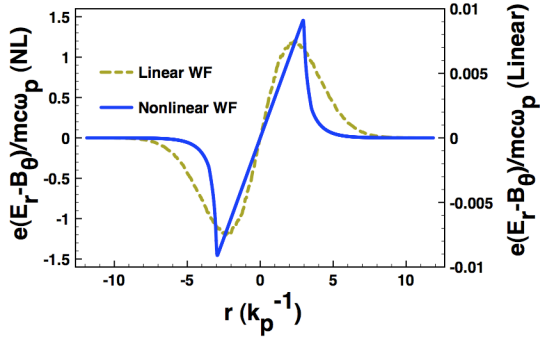

The linear case shown here is using different parameters.

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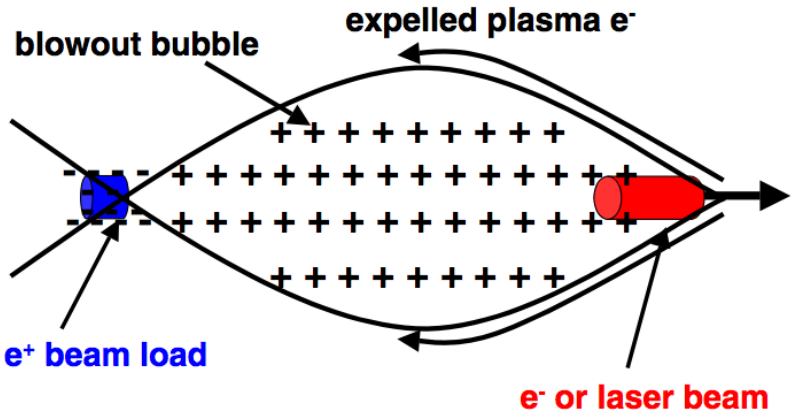
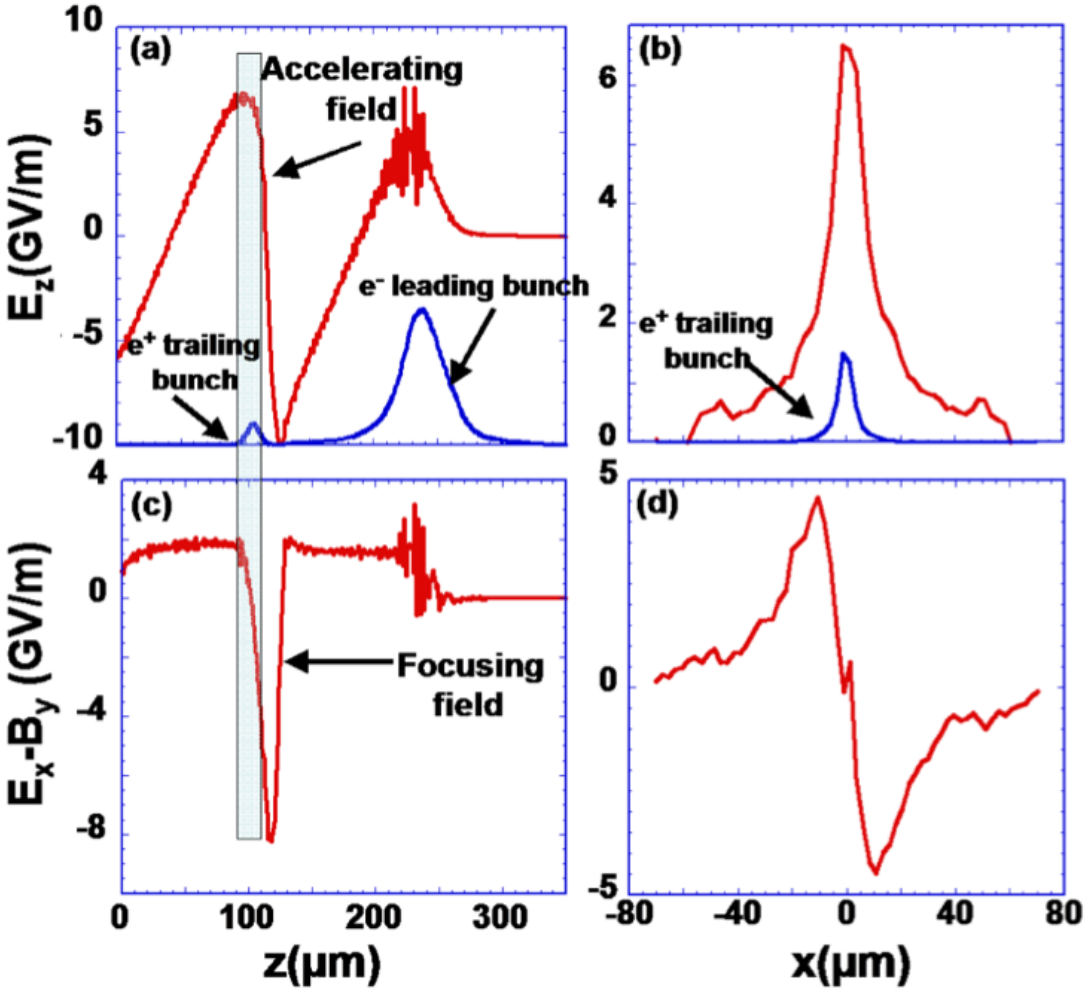
Positron Acceleration in Nonlinear Plasma Wake Fields



*X. Wang et. al, PRL 101, 124801(2008)



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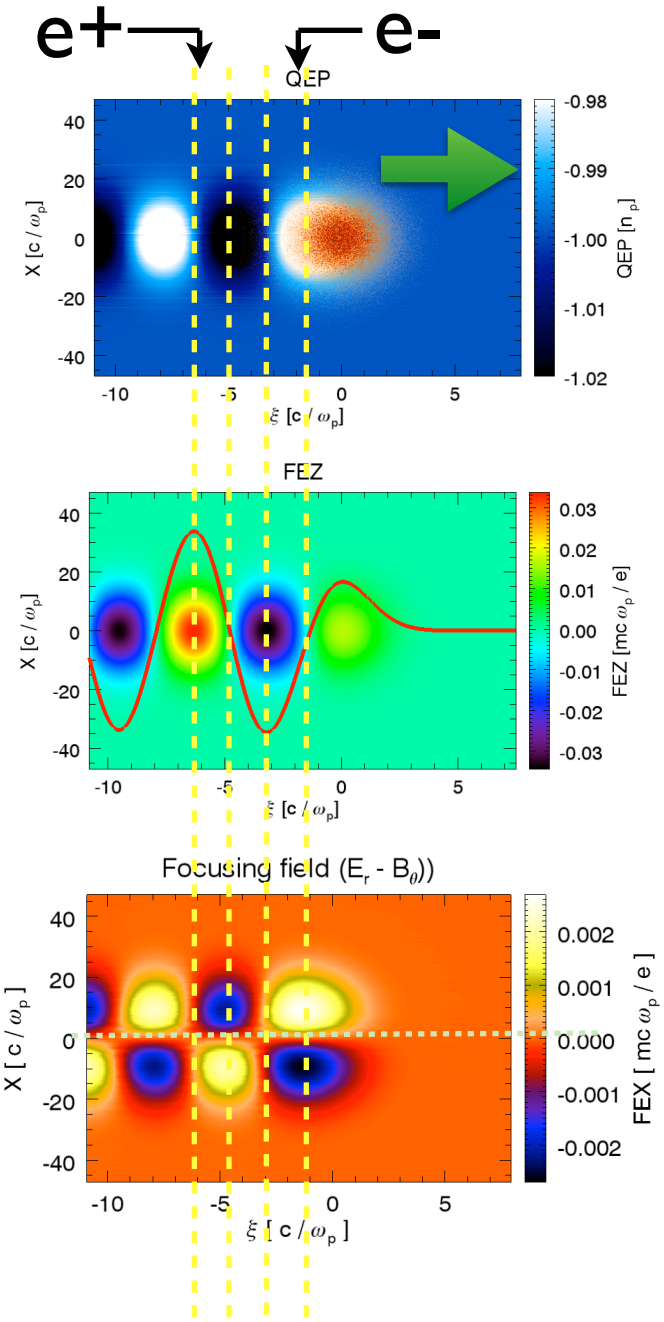
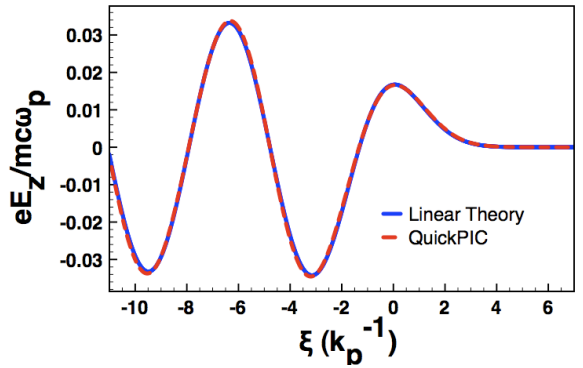
Linear Plasma Wake Field

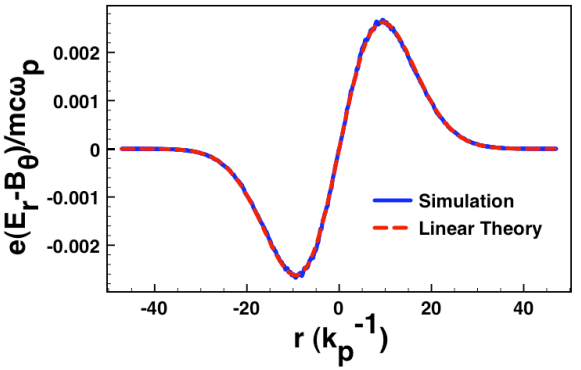


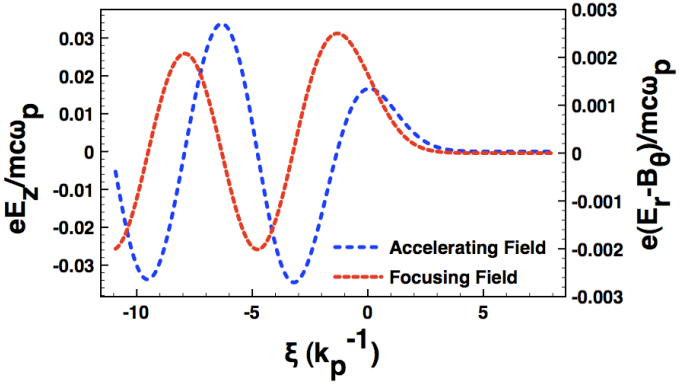
Beam Parameters: σ_r = 200 μm = 9.4 k_p^{-1} σ_z = 30 μm = 1.414 k_p^{-1}

N = 3.0 x 10 ^{10}, n_b / n_p = 0.025

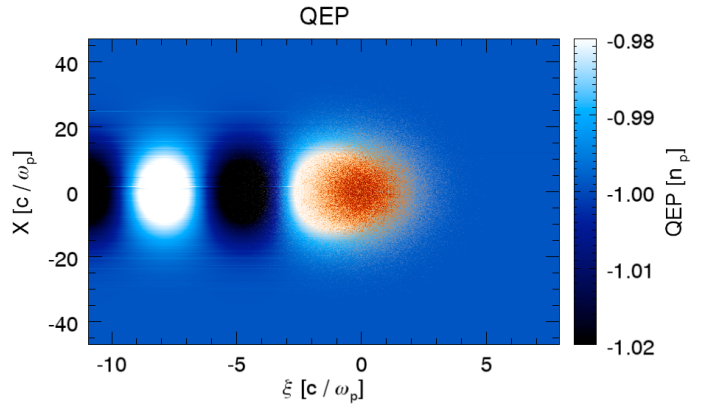
Plasma density: 6.3 x 10 ^{16} cm^{-3}

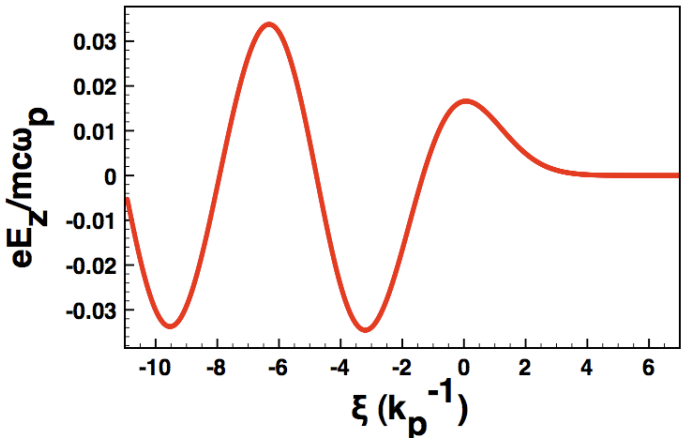


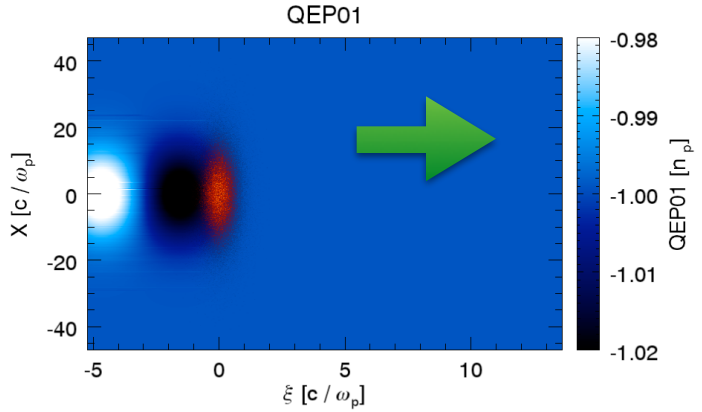


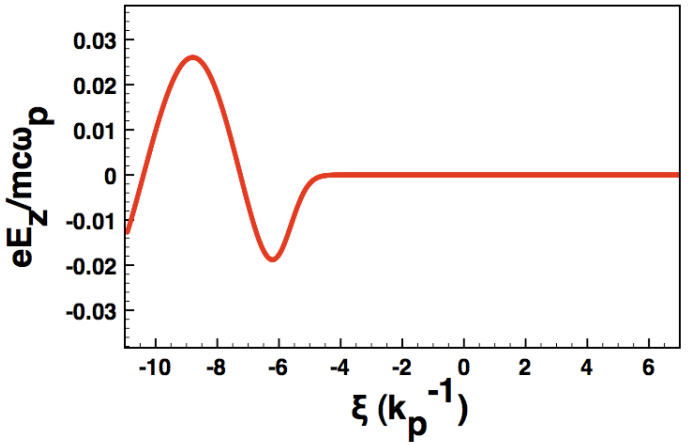


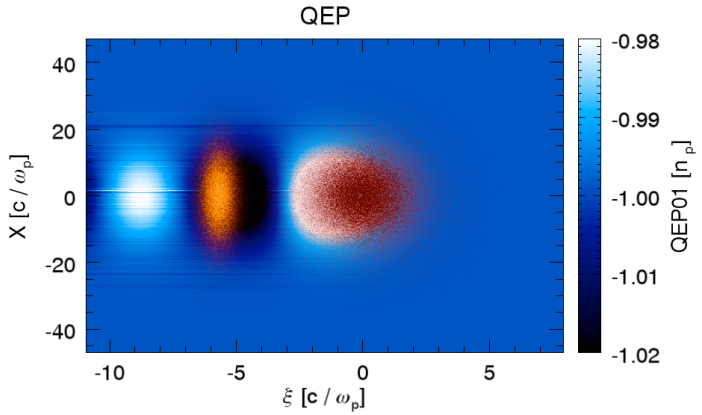
Accelerating a Positron Beam in the Linear Plasma Wake Field

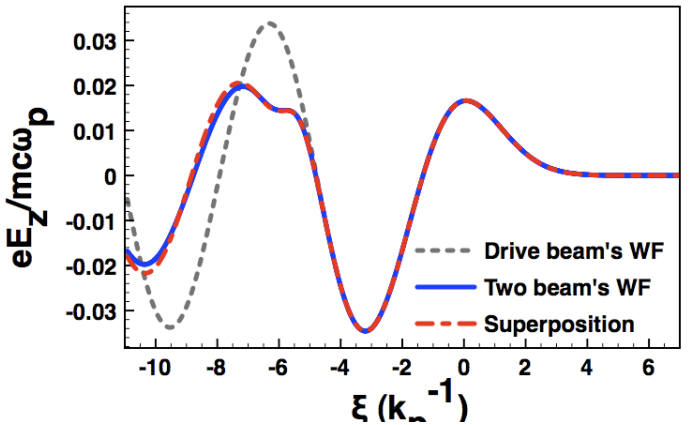












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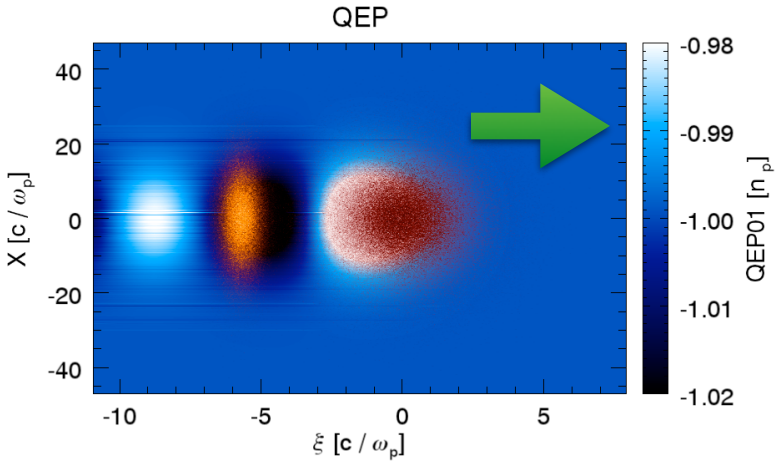
E-P PWFA at FACET II

Goal

Linear or Weakly Nonlinear Regime



Drive Beam (Electron):
N =1.25 x 10^{10} (2.0 nC), I_{peak}=15 kA
σ_z = 16 µm, E = 10 GeV

Trailing Beam (Positron):
N =6.25 x 10^{9} (1.0 nC), I_{peak}=6 kA
σ_z = 20 µm, E = 10 GeV

Basic parameters are still missing.

Pulse length of the trailing beam

Plasma Density: 10^{16} cm^{-3}

Spacing: ~300 µm

Beam Spot Sizes?

n_b / n_p ~ 0.1

σ_r ~ 200 µm

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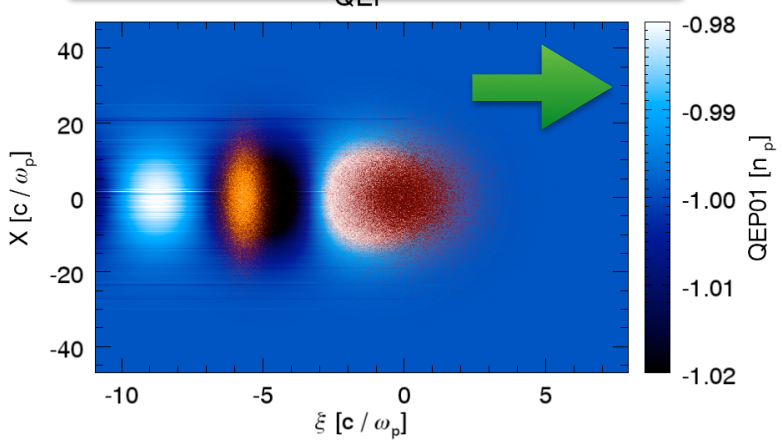
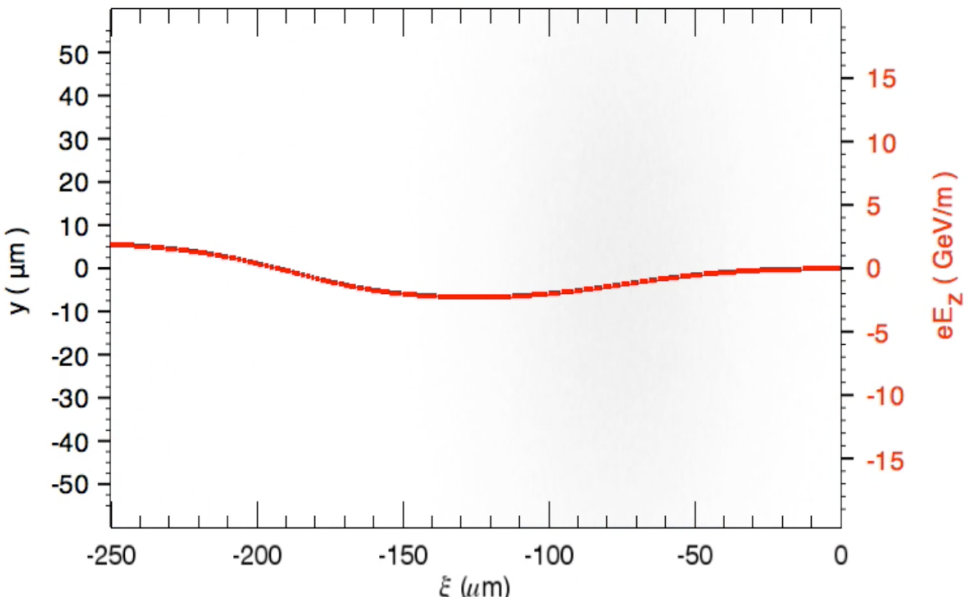
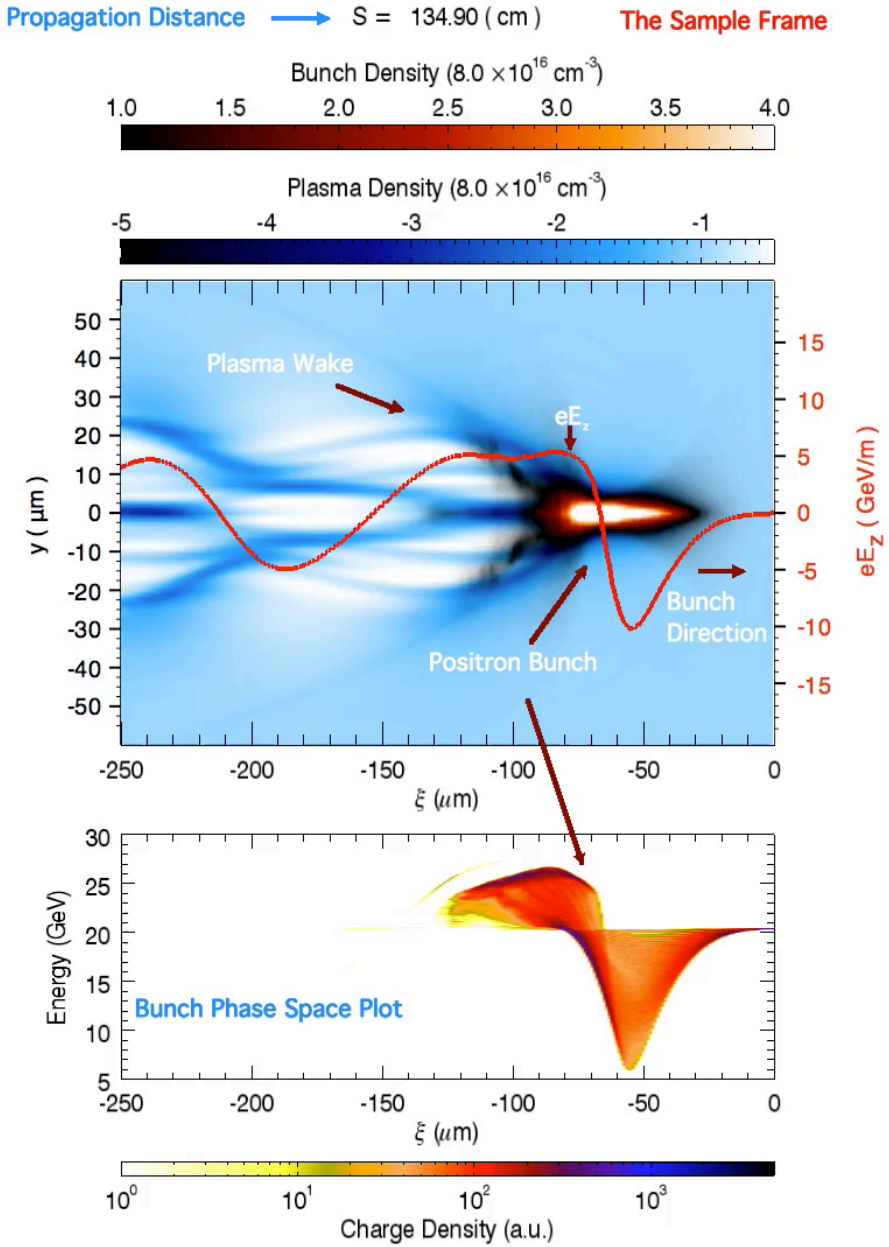
E-P PWFA at FACET II

Beam Emittances?



Drive Beam: σ_r = 70.0 μm , σ_z = 30.0 μm,
N =1.4 x 10^{10} , ε_N = **(50,200) mm·mrad**
Plasma Density: 8.0 x 10^{16} cm^{-3}





*S. Corde et. al, 524, 442 Nature (2015)

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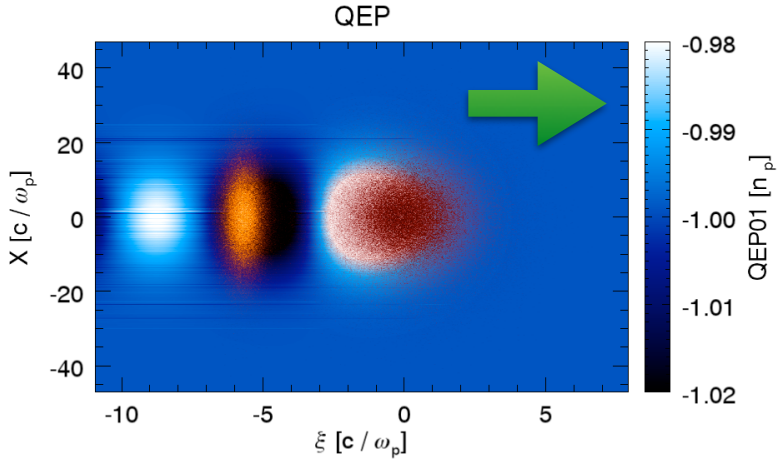
E-P PWFA at FACET II

Beam Emittances?



Linear Plasma Wake Field

$$(\frac{\partial^2}{\partial \xi^2} + 1)(\nabla_\perp^2 - 1)\psi = \rho_b$$

Pseudo Potential ψ

$$F_\parallel = E_z = \partial\psi/\partial\xi \text{ and } F_\perp = \vec{E}_\perp + \hat{z} \times \vec{B}_\perp = -\nabla_\perp \psi$$

$$\psi = \frac{1}{2\pi}\int_0^{2\pi} d\theta' \int_0^\infty r' dr' \tilde{\rho}_e(\vec{r}') K_0(|\vec{r} - \vec{r}'|)$$

Long Pulse (Adiabatically)

$$\partial_\xi^2 << 1$$

$$\frac{\partial^2 R_x}{\partial s^2} - \frac{q_b < xF_x >}{m_b \gamma R_x} - \frac{\epsilon_{Nx}^2}{\gamma^2 R_x^3} = 0$$

Wide Beam

$$\nabla_\perp^2 << 1$$

$$\frac{\partial^2 R}{\partial s^2} + \frac{q_b^2 \Lambda_b}{4 m_b \gamma R^3} - \frac{\epsilon_N^2}{\gamma^2 R^3} = 0$$

$$\psi = -\rho_b$$

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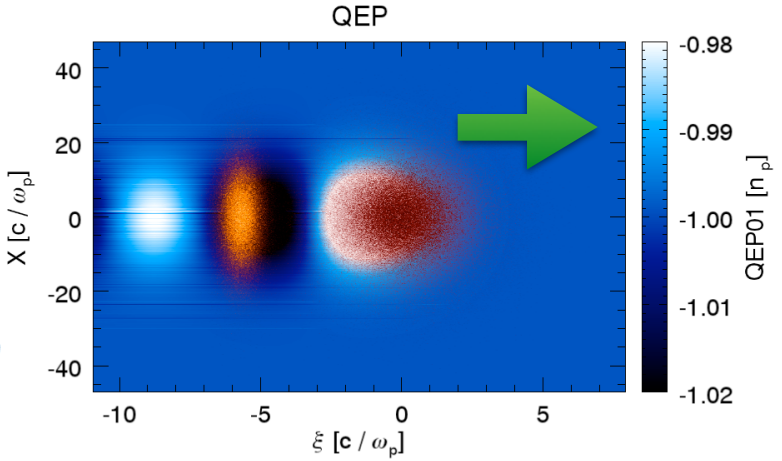
E-P PWFA at FACET II

Beam Emittances?

Pseudo Potential ψ

$$\psi = -\rho_b \qquad F_\perp = \vec{E}_\perp + \hat{z} \times \vec{B}_\perp = -\nabla_\perp \psi$$



Envelop Equation

$$\frac{\partial^2 R_x}{\partial s^2} - \frac{q_b < xF_x >}{m_b \gamma R_x} - \frac{\epsilon_{Nx}^2}{\gamma^2 R_x^3} = 0 \Rightarrow \frac{\partial^2 R}{\partial s^2} + \frac{q_b^2 \Lambda_b}{4 m_b \gamma R^3} - \frac{\epsilon_N^2}{\gamma^2 R^3} = 0$$

Steady State

$$\frac{\partial^2 R}{\partial s^2} = 0 = \left(\frac{\epsilon_N^2}{\gamma^2} - \frac{q_b^2 \Lambda_b}{4 m_b \gamma}\right)\frac{1}{R^3}$$

e⁻ and e⁺

$$\epsilon_N^2 > \frac{\gamma \Lambda_b}{4}$$

ε_N > 5000 μm rad

Plasma Density: 10^{16} cm^{-3}

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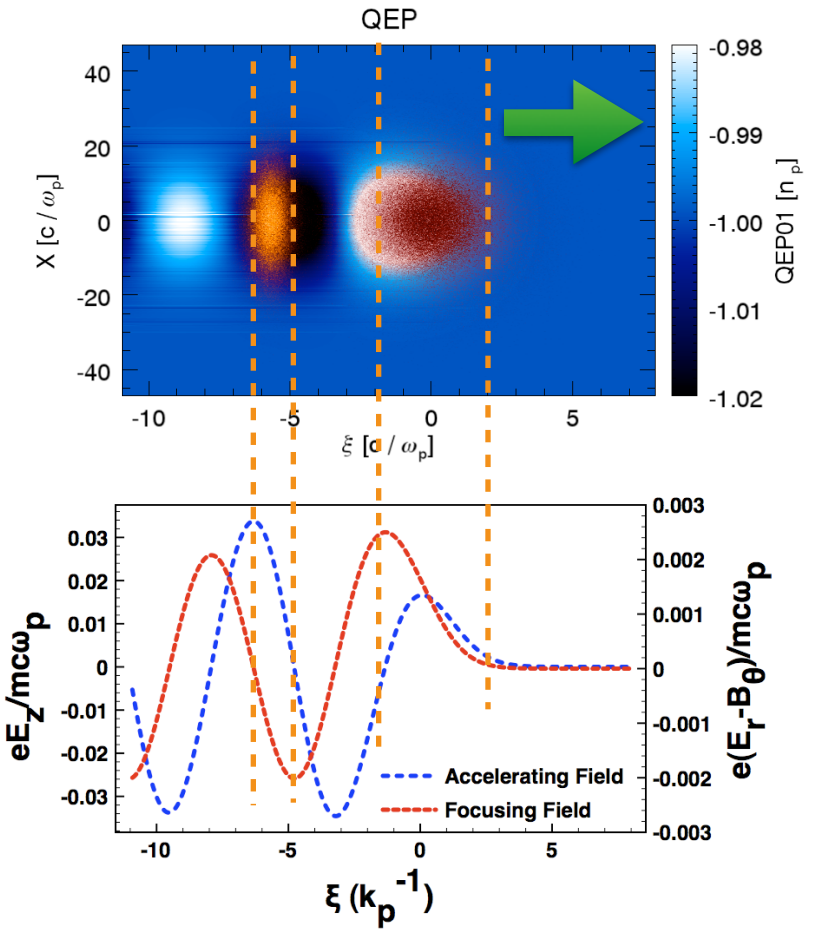
E-P PWFA at FACET II

Beam Emittances?



Focusing Force Felt by the Beams

Beam	Head	Tail
Electron	Weak	Strong
Positron	Strong	Weak

Electron Drive Beam

ε_N = 1000 mm·mrad

Positron Trailing Beam

ε_N = 4000 mm·mrad

Focusing force is not uniform along ξ

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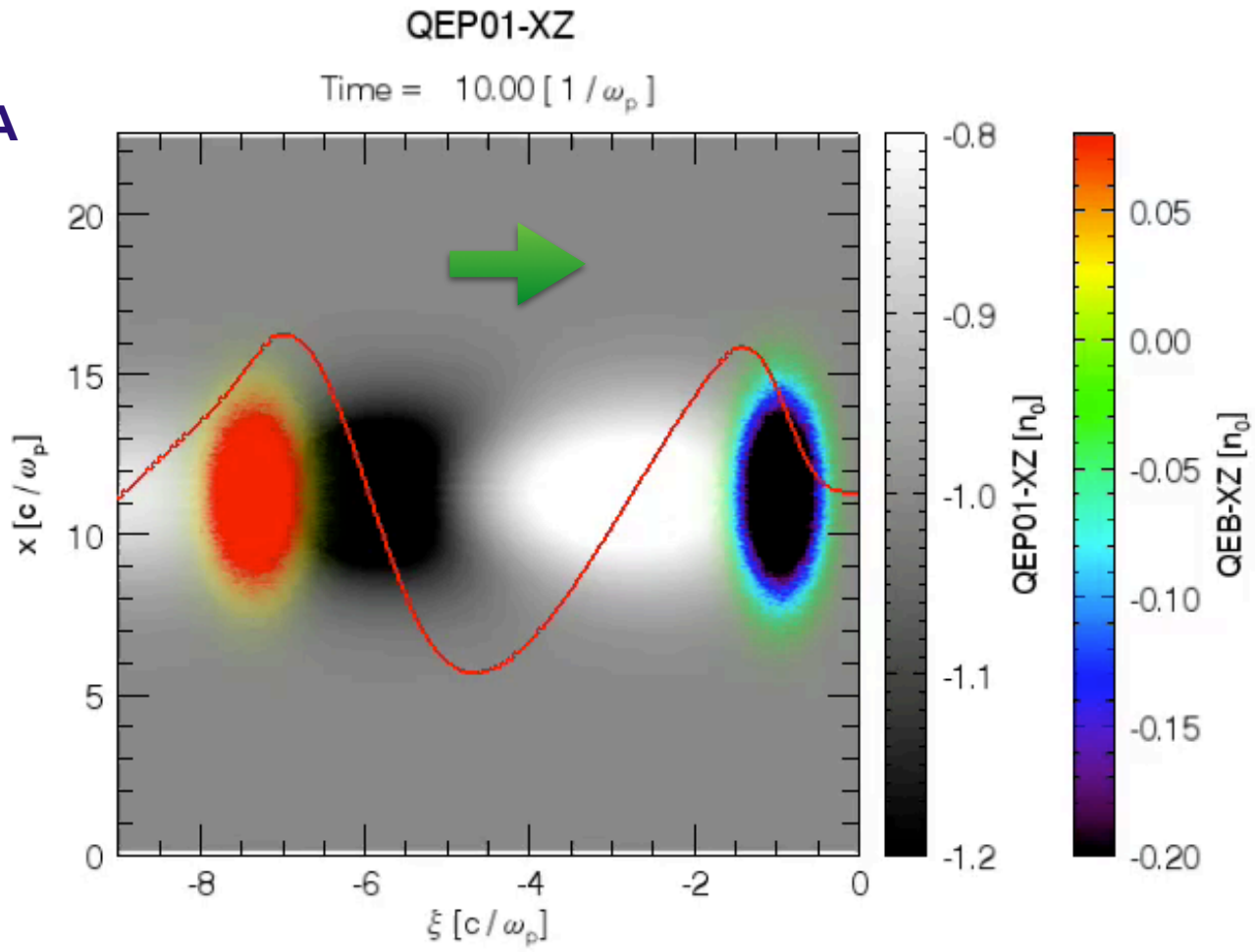
E-P PWFA at FACET II

Drive Beam (Electron):
N =1.25 x 10^{10} (2.0 nC), I_{peak}=15 kA
σ_z = 16 μm, E = 10 GeV
σ_r = 100.0 μm, ε_N = 1000 μm rad

Trailing Beam (Positron):
N =6.25 x 10^{9} (1.0 nC), I_{peak}=6 kA
σ_z = 20 μm, E = 10 GeV
σ_r = 100.0 μm, ε_N = 4000 μm rad

Distance between two bunches:
340 μm

Plasma Density: 1.0 x 10^{16} cm^{-3}



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E-P PWFA at FACET II

Drive Beam (Electron):
N =1.25 x 10^{10} (2.0 nC), I_{peak}=15 kA
σ_z = 16 μm, E = 10 GeV
σ_r = 100.0 μm, ε_N = 1000 μm rad

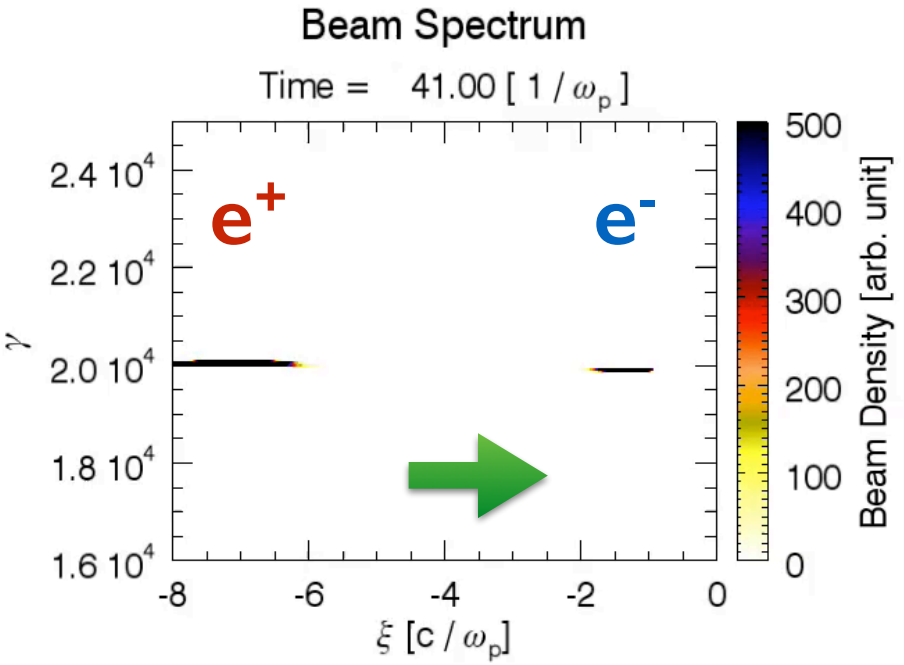
Trailing Beam (Positron):
N =6.25 x 10^{9} (1.0 nC), I_{peak}=6 kA
σ_z = 20 μm, E = 10 GeV
σ_r = 100.0 μm, ε_N = 4000 μm rad

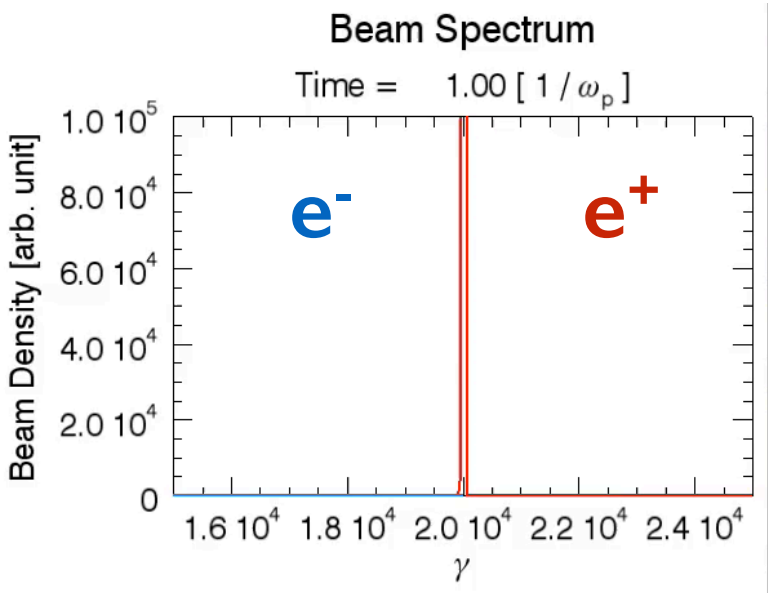
Distance between two bunches:
340 μm

Plasma Density: 1.0 x 10^{16} cm^{-3}
~ 1 meter long

Positron Beam

Peak Energy: 11 GeV





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E-P PWFA at FACET II

Drive Beam (Electron):
N =1.25 x 10^{10} (2.0 nC), I_{peak}=15 kA
σ_z = 16 μm, E = 10 GeV
σ_r = 100.0 μm, ε_N = 500 μm rad

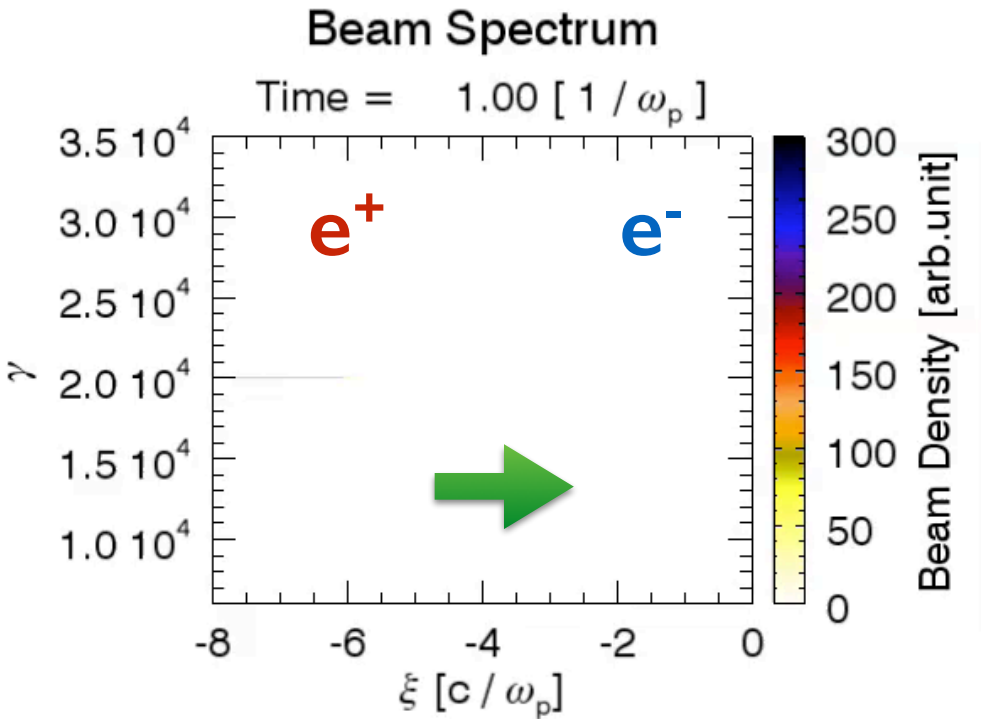
Trailing Beam (Positron):
N =6.25 x 10^9 (1.0 nC), I_{peak}=6 kA
σ_z = 20 μm, E = 10 GeV
σ_r = 100.0 μm, ε_N = 3000 μm rad

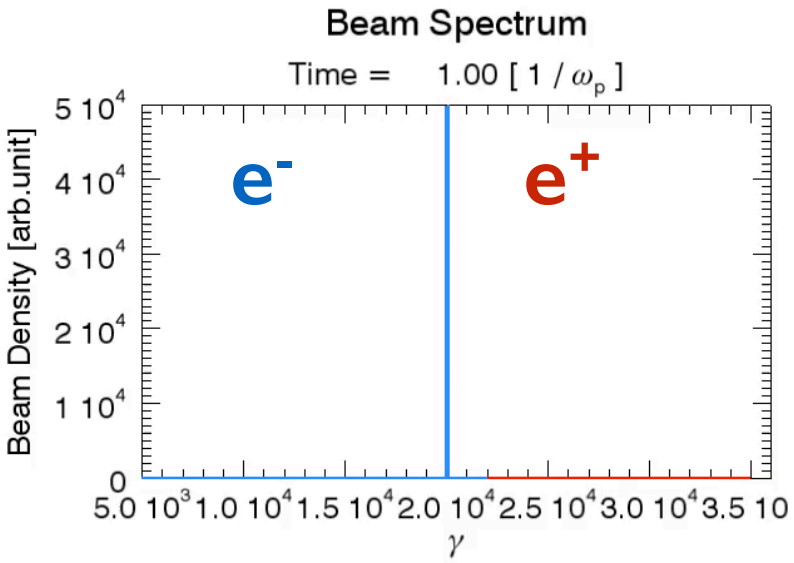
Distance between two bunches:
340 μm

Plasma Density: 1.0 x 10^{16} cm^{-3}
~ 2 meter long

Positron Beam

Peak Energy: 13.5 GeV





E-P PWFA at FACET II

Scaling Law

T	ω_0^{-1}
L	k_0^{-1}
E	$m_e c\omega_0/e$
B	$m_e c\omega_0/e$
ρ	en_c
Q	$en_c k_0^{-3}$
J	$en_c c$
v	c
M	m_e
n	n_c
A	$m_e c^2/e$
ϕ	$m_e c^2/e$

n	D/T	Q (nC)	σ (μm)	I (kA)	σ (μm)	ε (μm)	Spacing (μm)	L (cm)
10 cm	e	2.0	16	15	100	500	340	200
	e	1.0	20	6	100	3000		
10 cm	e	0.2	1.6	15	10	50	34	20
	e	0.1	2	6	10	300		

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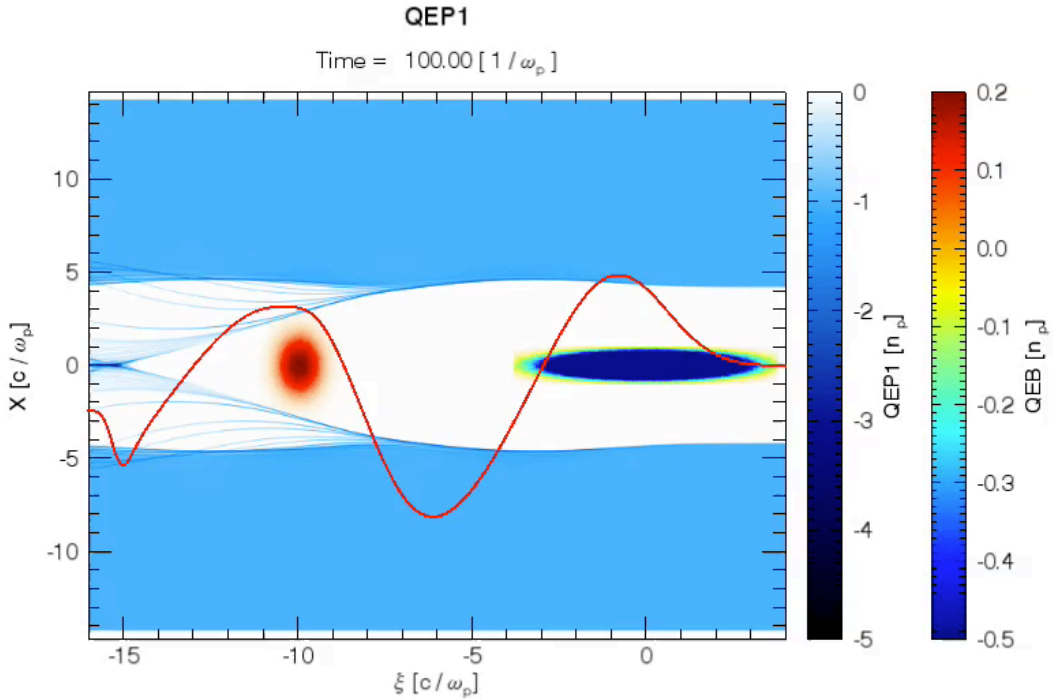
E-P PWFA in Hollow Channel

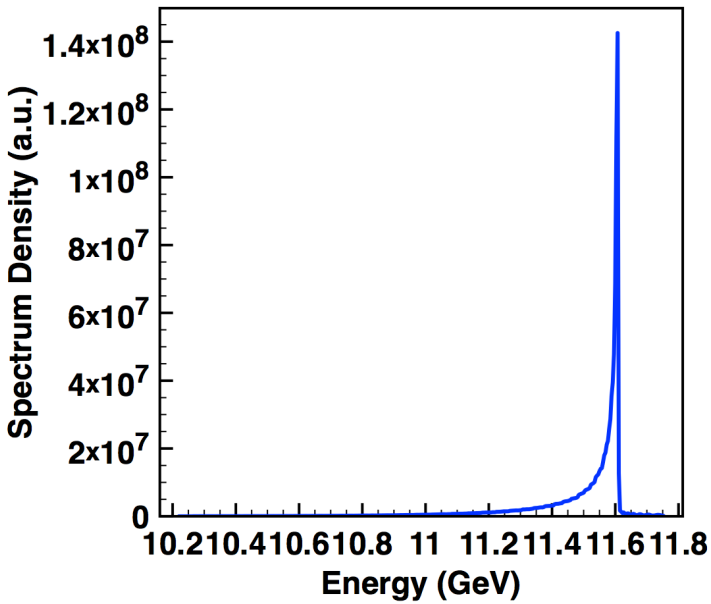
Drive Beam (Electron):
N =1.25 x 10^{10} (2.0 nC), I_{peak}=8 kA
σ_z = 30 μm, E = 10 GeV
σ_r = 7.91 μm, ε_N = 1 μm rad
β = 1.25 m, α = 0.5 (β^* = 1.0 m)

Trailing Beam (Positron):
N =1.0 x 10^9 (0.16 nC), I_{peak}=1.92 kA
σ_z = 10 μm, E = 10 GeV
σ_r = 25.0 μm, ε_N = 10 μm rad
β = 1.25 m, α = 0.5 (β^* = 1.0 m)

Distance between two bunches:
237 μm

Plasma Density: 5.0 x 10^{16} cm^{-3}
R_c = 100 μm, 1 meter long





1.6 GeV Energy Gain in 1 meter
0.2% Energy Spread (Initial E.S. is 0)