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HEPAP MEETING
February 10, 2004

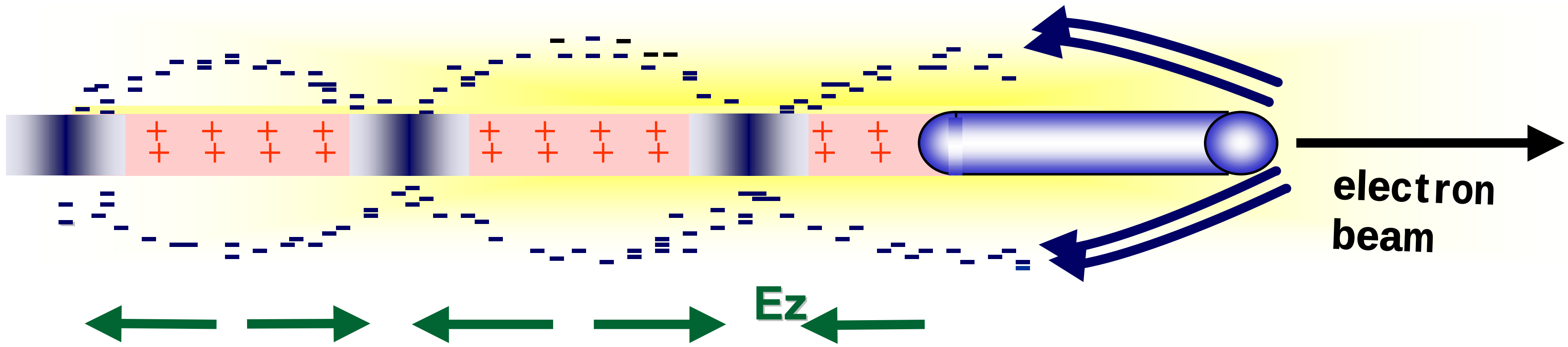
PARTICLE DRIVEN PLASMA WAKEFIELD ACCELERATORS

by
C. Joshi

University of California Los Angeles

Physical Principles of the Plasma Wakefield Accelerator

- Space charge of drive beam displaces plasma electrons



- Plasma ions exert restoring force => Space charge oscillations
- Wake Phase Velocity = Beam Velocity (like wake on a boat)
- Wake amplitude $\propto N_b / \sigma_z^2$
- Transformer ratio $E_{z,\ acell} / E_{z,\ decell}$

Brief History of PWFA

- Concept by P. Chen & J. M. Dawson et al. (1981)
- P.O.P expt at ANL-Wakefield Facility J.Rosenzweig, et al. (1988)
- Two line expts at KEK-Nakanishi et al. (1990)
- A_o expt at Fermilab-N. Barov et al. (Current)
- Recent work at BNL- V. Yakimenko et al. (2003)

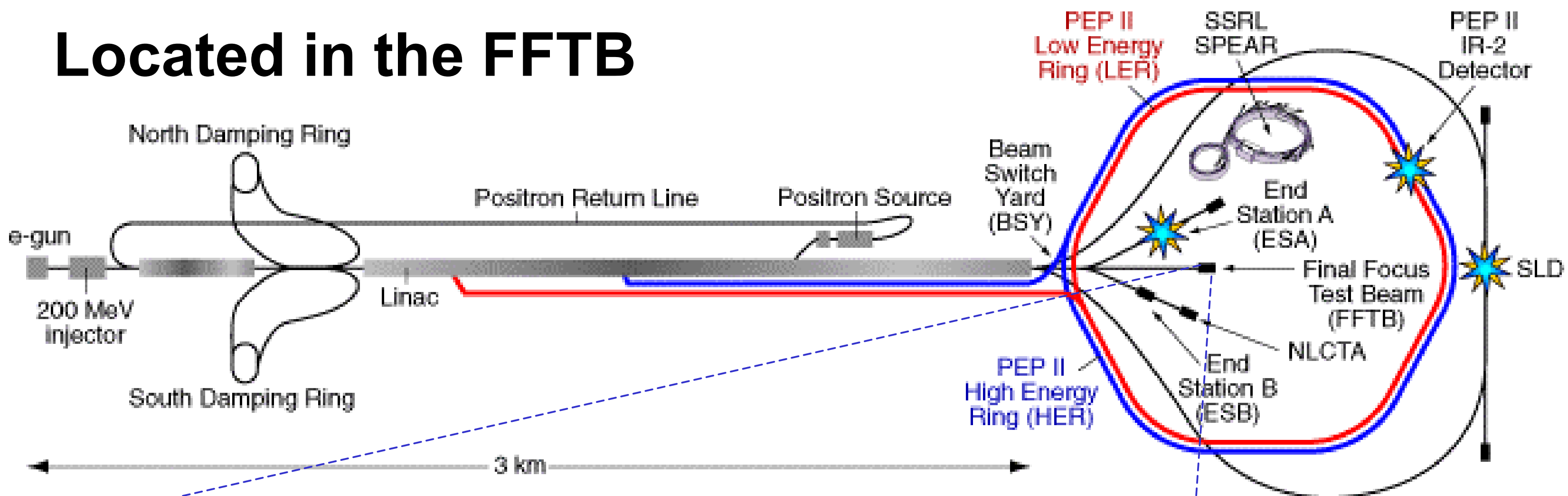
All these expts done using a low energy beam.

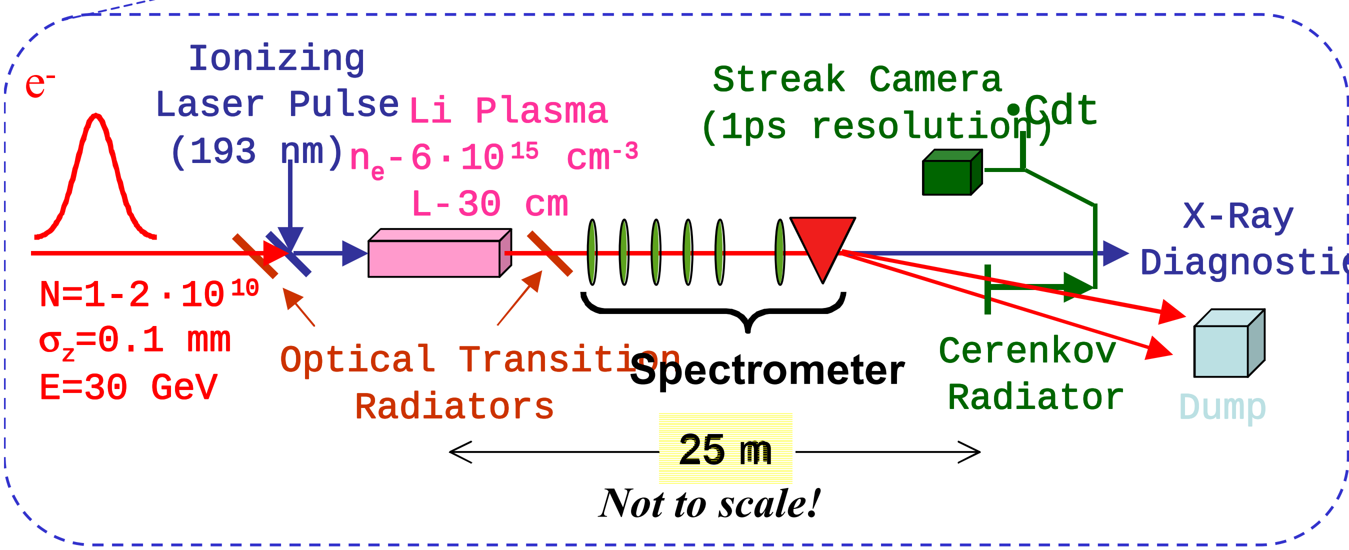
To increase the gradient and energy gain need a high energy beam : SLAC

SLAC is also the only place where there is suitable high energy electron and positron beams

PWFA Experiments @ SLAC
Share Common Apparatus

Located in the FFTB





E-162/E-164/E-164X

Collaborations:

C. Barnes, F.-J. Decker, P. Emma, M. J. Hogan, R. Iverson, P. Krejcik, C. O'Connell, P. Raimondi, R.H. Siemann, D. Walz

Stanford Linear Accelerator Center

B. Blue, C. E. Clayton, C. Huang, C. Joshi, D. Johnson, K. A. Marsh, W. B. Mori, W. Lu

University of California, Los Angeles

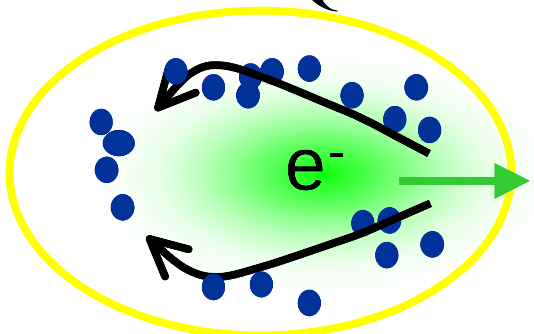
T. Katsouleas, S. Lee, P. Muggli, E. Oz

University of Southern California

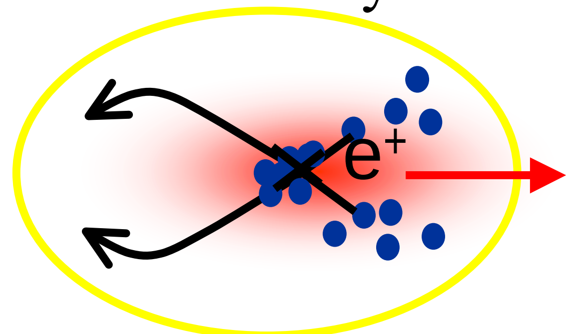
USC

e^- & e^+ Beam Neutralization

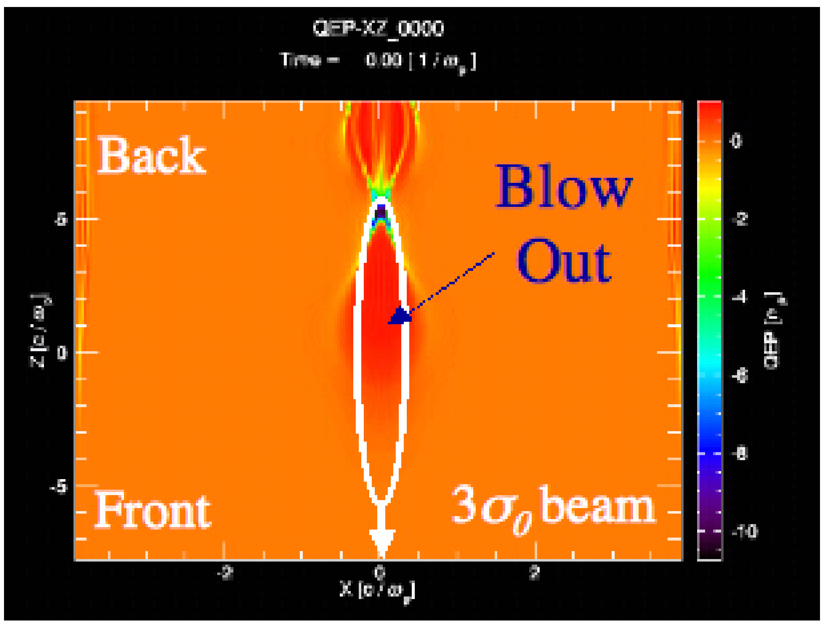
3-D QuickPIC simulations, plasma e^- density:



σ_r=35 μm
σ_r=700 μm
N=1.8×10^{10}
d=2 mm

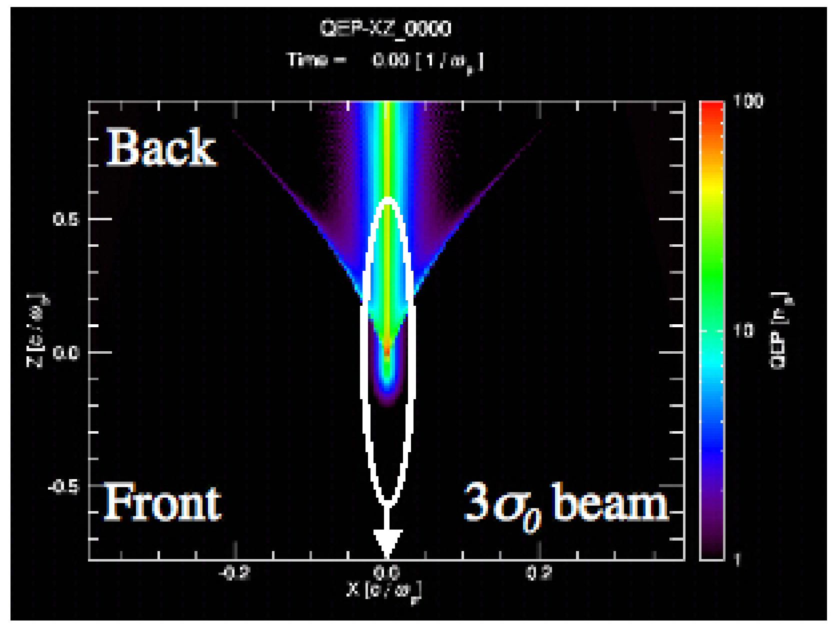


e^-: n_{e0}=2×10^{14} cm^{-3}, c/ω_p=375 μm



- Uniform focusing force (r,z)

e^+: n_{e0}=2×10^{12} cm^{-3}, c/ω_p=3750 μm



- Non-uniform focusing force (r,z)

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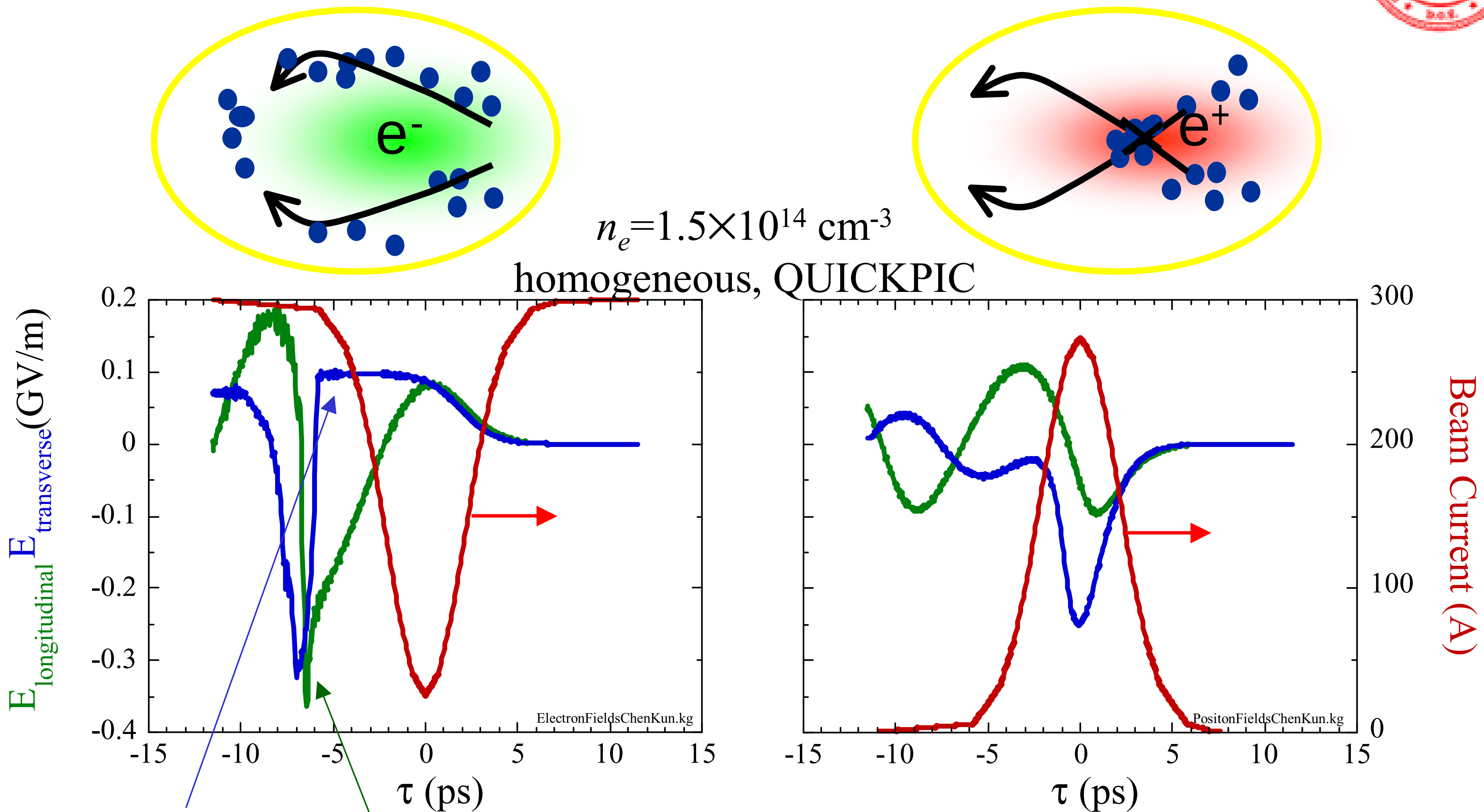
WAKEFIELD FIELDS for e^- & e^+



- Blow-Out
- Accelerating "Spike"

- Fields vary along r, stronger
- Less Acceleration

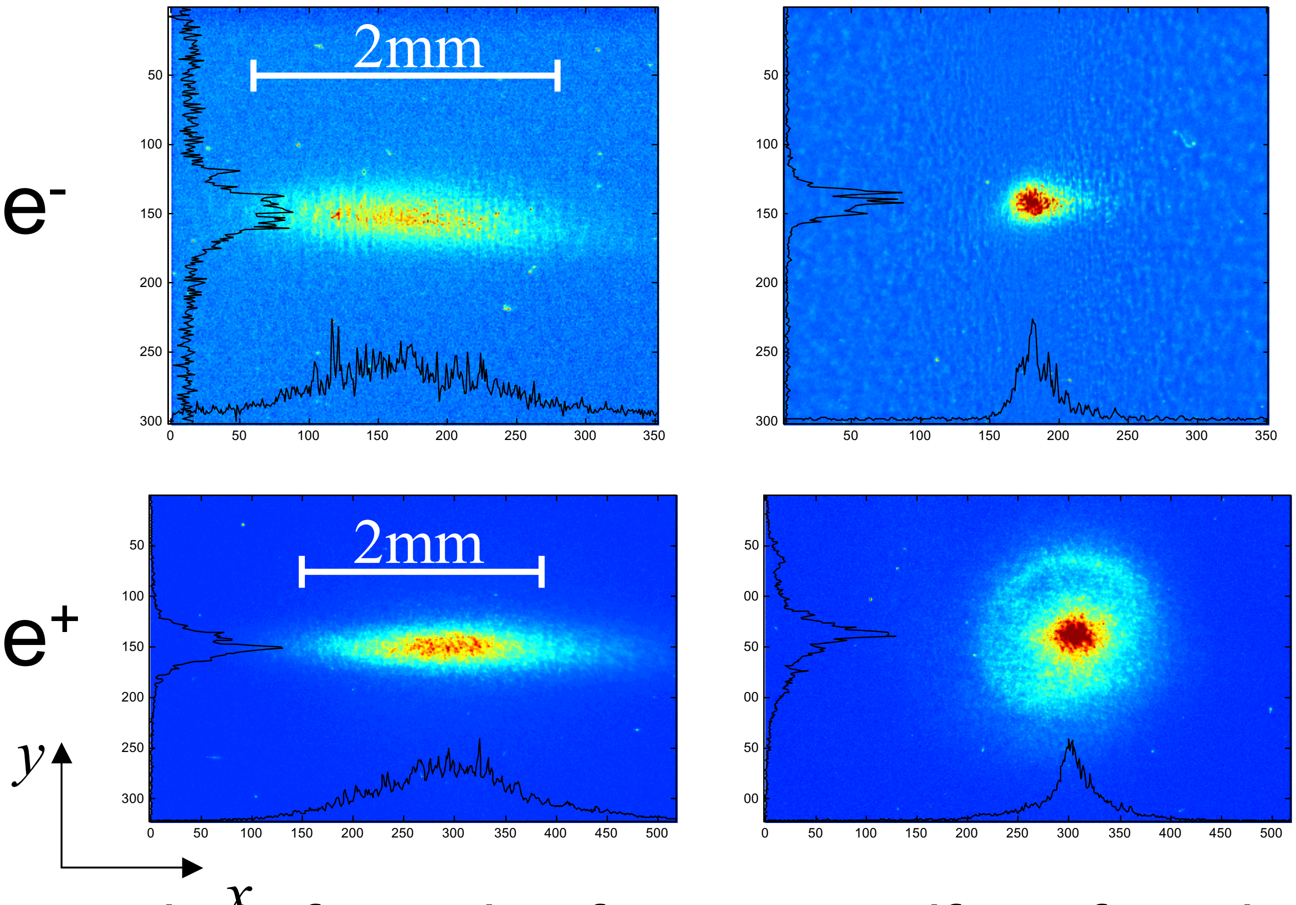
FOCUSING OF e^-/e^+

- OTR images ≈1m from plasma exit (ε_x ε_y)

$n_e=0$ | $n_e\approx10^{14}$ cm^{-3}

e^-

e^+

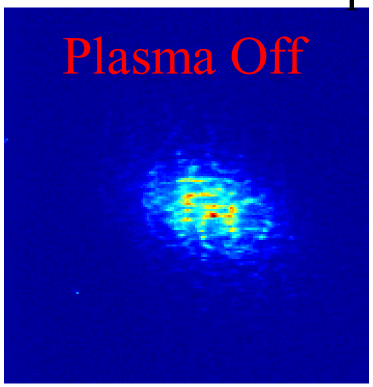


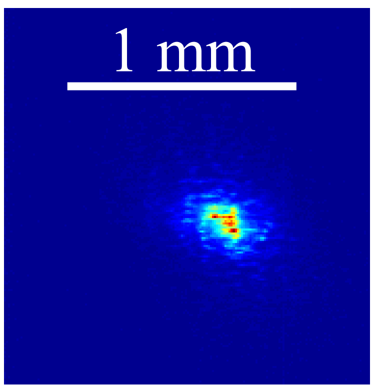
- Ideal Plasma Lens in Blow-Out Regime
- Plasma Lens with Aberrations

- e^+: halo formation from non uniform focusing (focusing abberations)

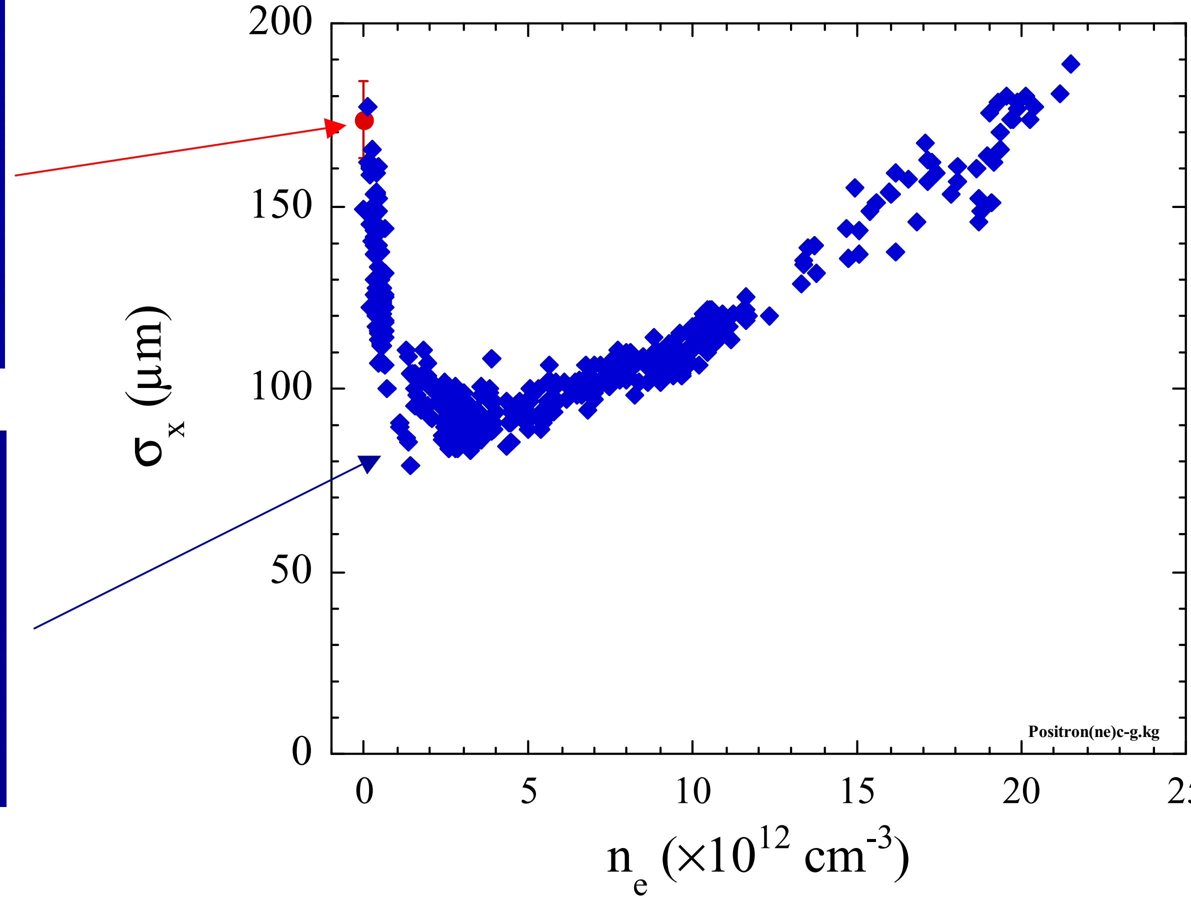
FOCUSING OF e^+

OTR Images
(≈1m downstream from plasma)





N=1.9×10^{10}, ε_N>5×10^{-5} m-rad

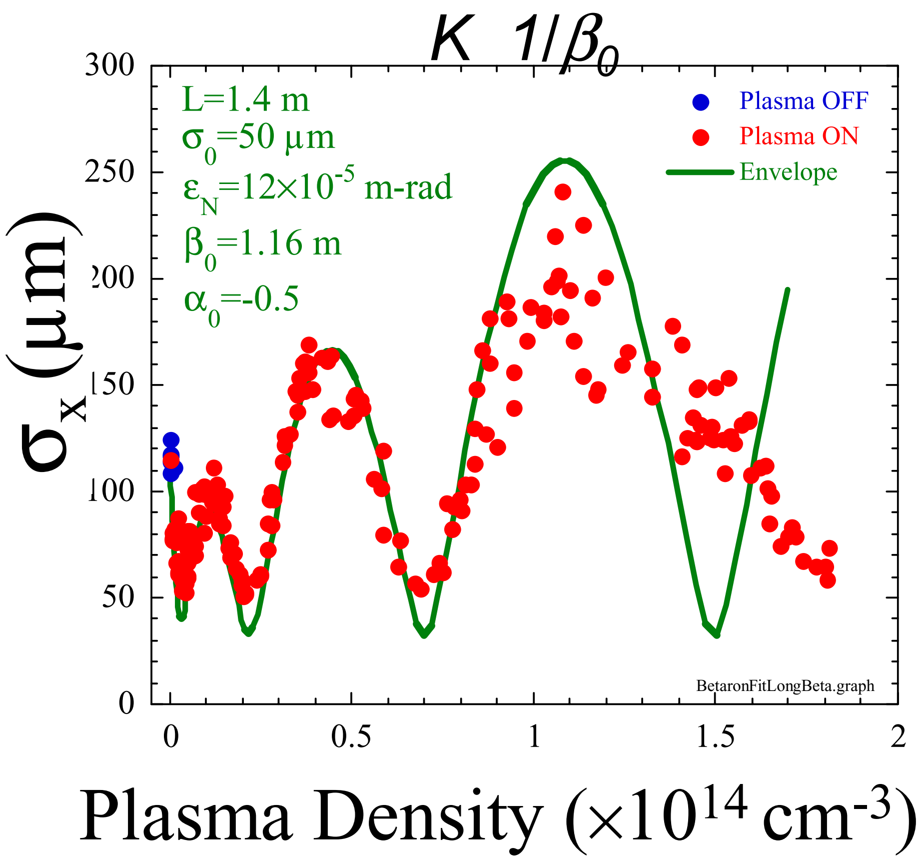


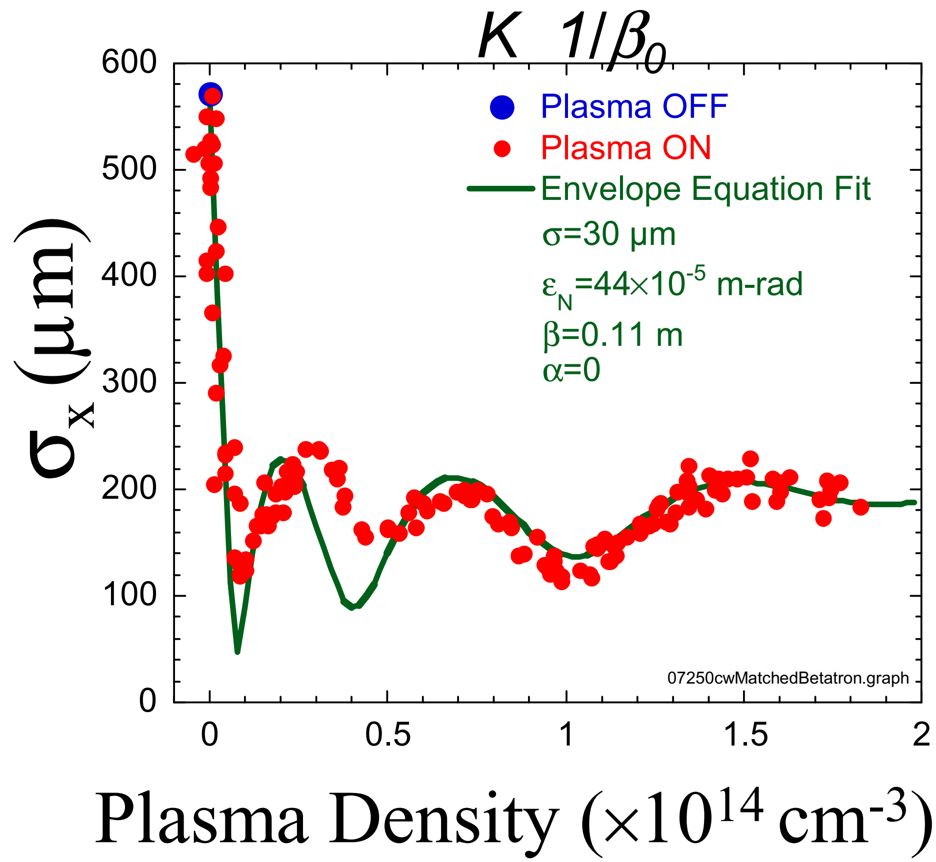
- Overall focusing at low plasma densities

M.J. Hogan *et al.*, PRL, 2002

FOCUSING OF e^-

OTR Images ≈1m downstream from plasma





- Focusing of the beam well described by a simple model ($n_b>n_e$):
  Plasma = Ideal Thick Lens
- Channeling of the beam over 1.4 m or >12β_0

C.E. Clayton *et al.*, PRL, 2001

P. Muggli


PHYSICAL REVIEW LETTERS

1 April 2002

Volume 88, Number 13

Member Subscription Copy
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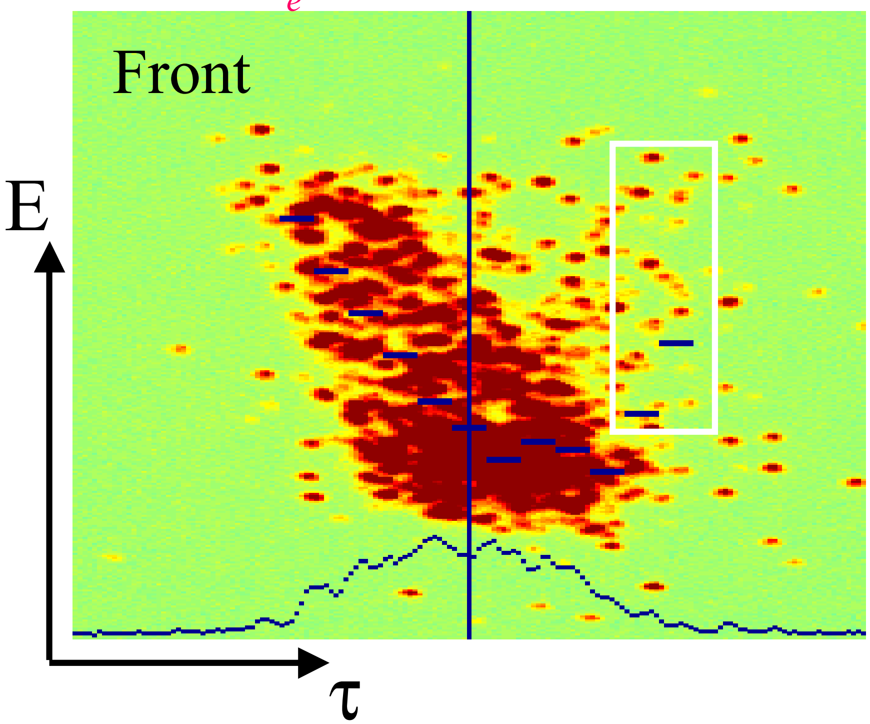
APS Published by The American Physical Society

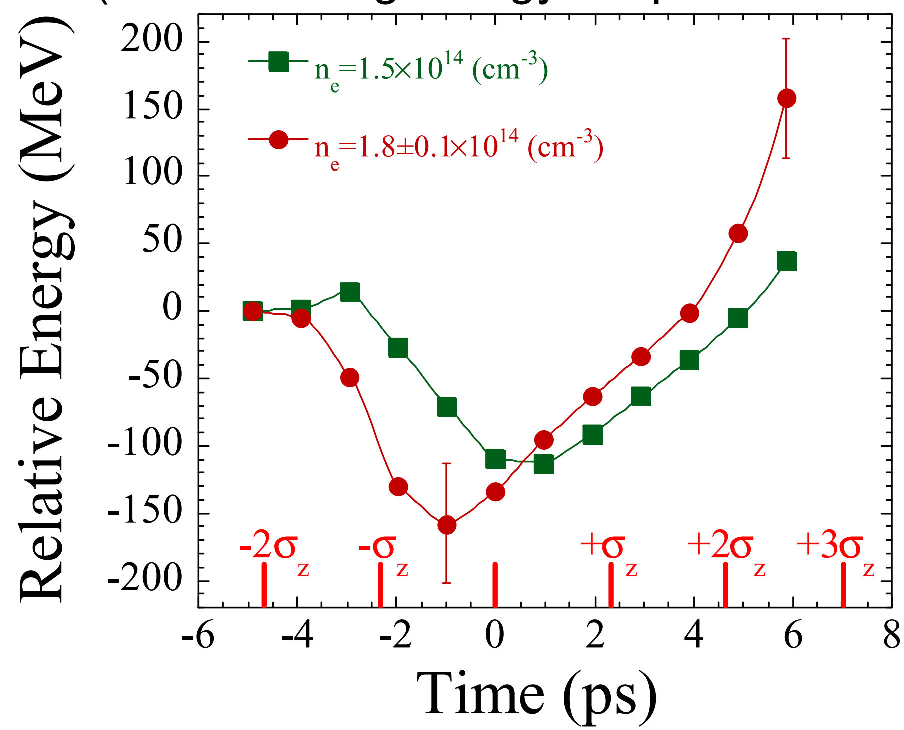
e^- ENERGY GAIN/LOSS

ps slice analysis results

$n_e=1.8\times10^{14}$ cm^{-3}



(with incoming energy chirp subtracted)



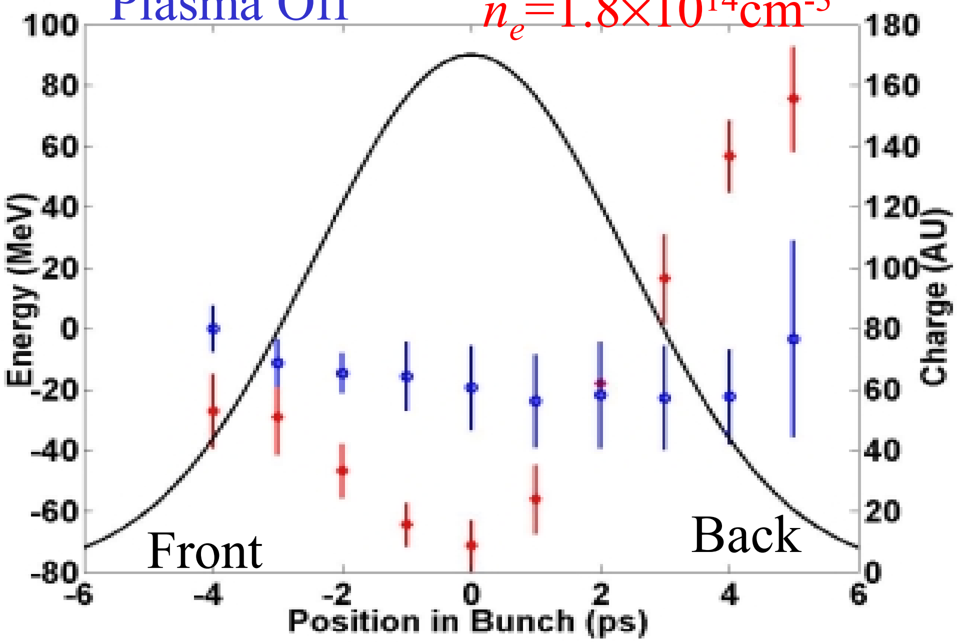
- Energy gain by particles ≈279 MeV in the last (-6 ps) 1 ps slice
- Peak accelerating gradient ≈200 MeV/m (L=1.4 m)

P. Muggli *et al.*, submitted to PRL, 2003

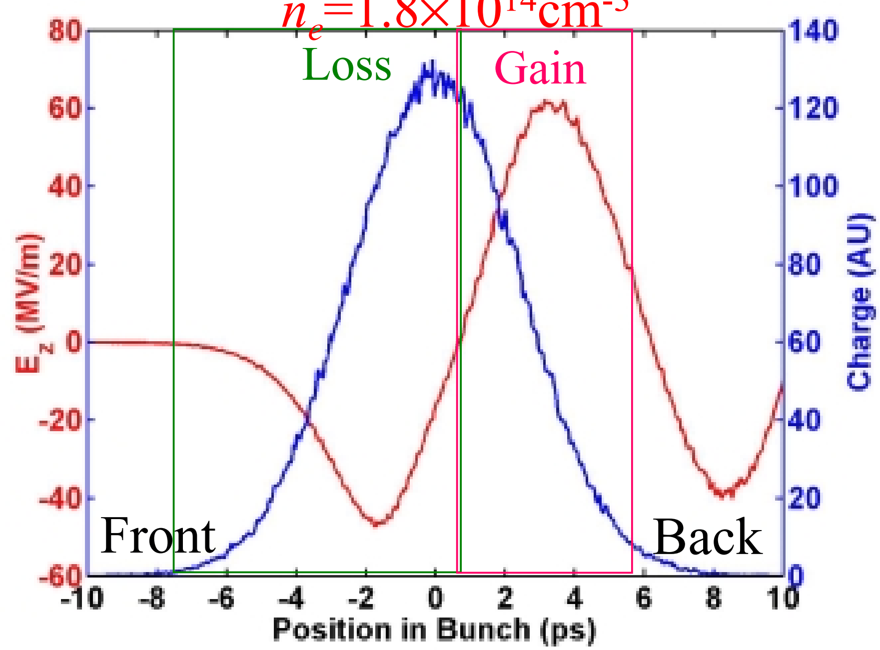
ENERGY LOSS/GAIN LOW CHARGE e^+

N=1.2×10¹⁰ e⁺

Experiment



2-D Simulation



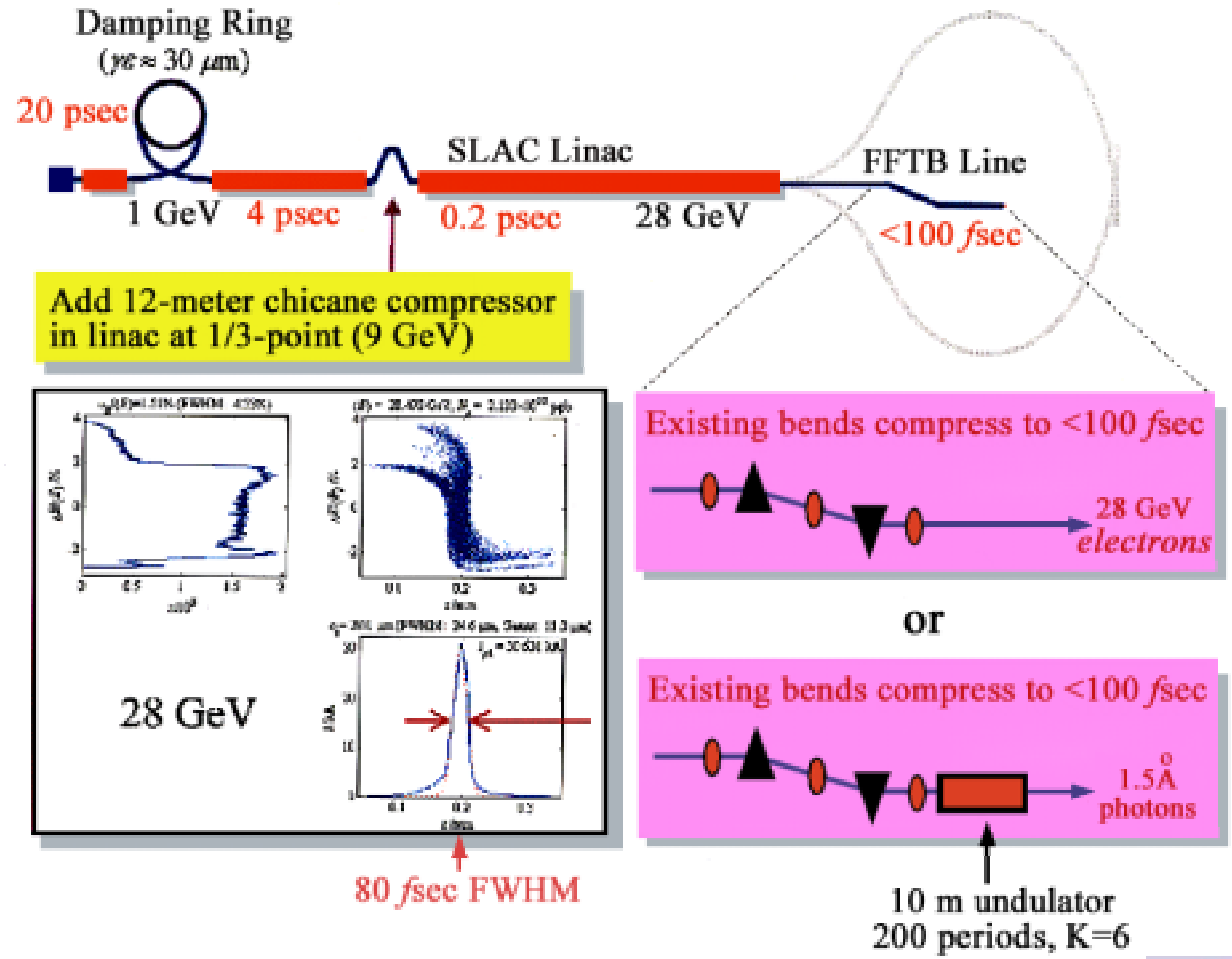
- Loss ≈ 70 MeV
- Gain ≈ 75 MeV

(over 1.4 m)

- Loss ≈ 45 MeV/m × 1.4 m=63 MeV
- Gain ≈ 60 MeV/m × 1.4 m=84 MeV

B. Blue *et al.*, PRL 90, 2003

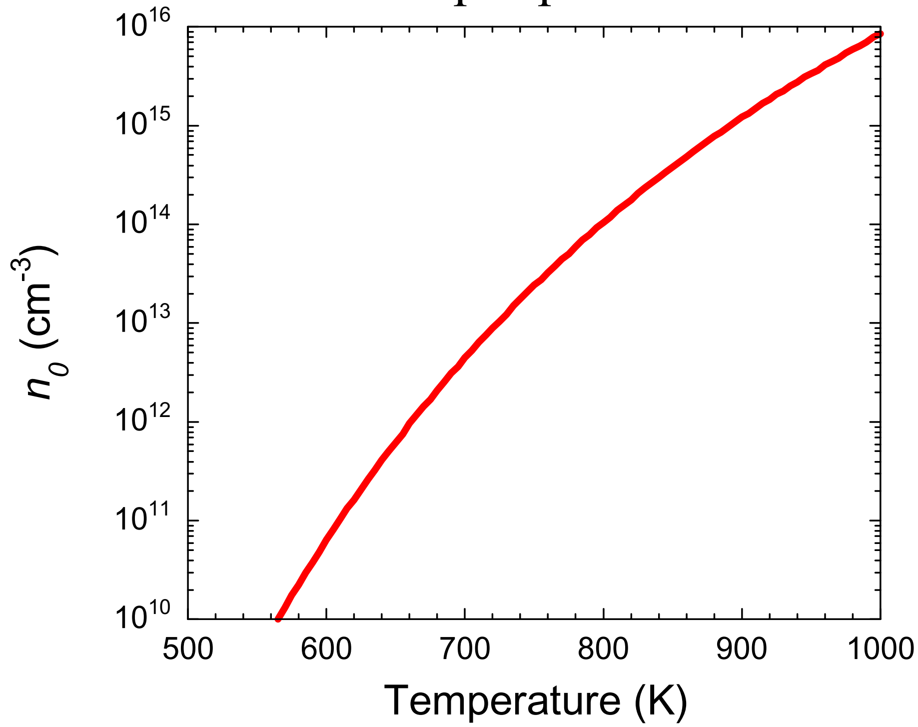
Sub-Picosecond Pulse Source



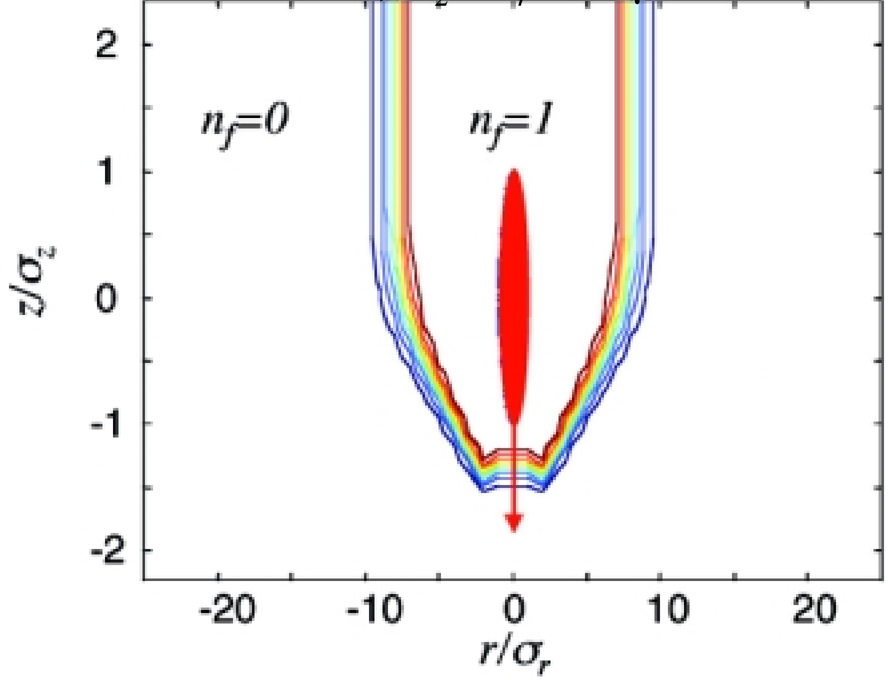
BEAM-IONIZED PLASMA

- Short bunch, $E_r \approx 5.2\times10^{-19} N/\sigma_z\,\sigma_r$ (GV/m) > tunneling field (Kyldish, ADK)

Lithium vapor pressure curve

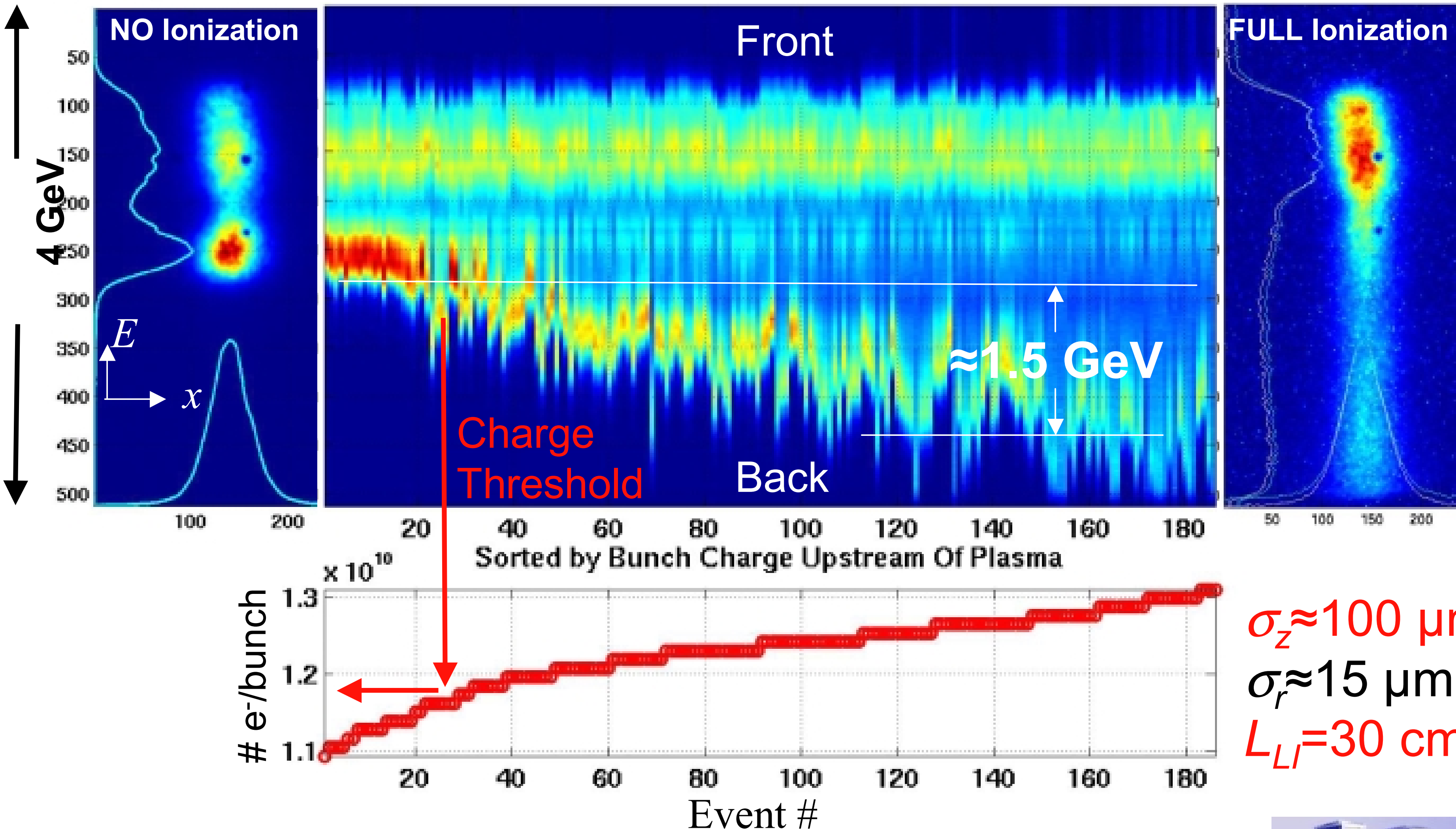


N=10^{10} e$^-$, σ_z=σ_r=20 μm in Cs



e^--BEAM FIELD-IONIZATION

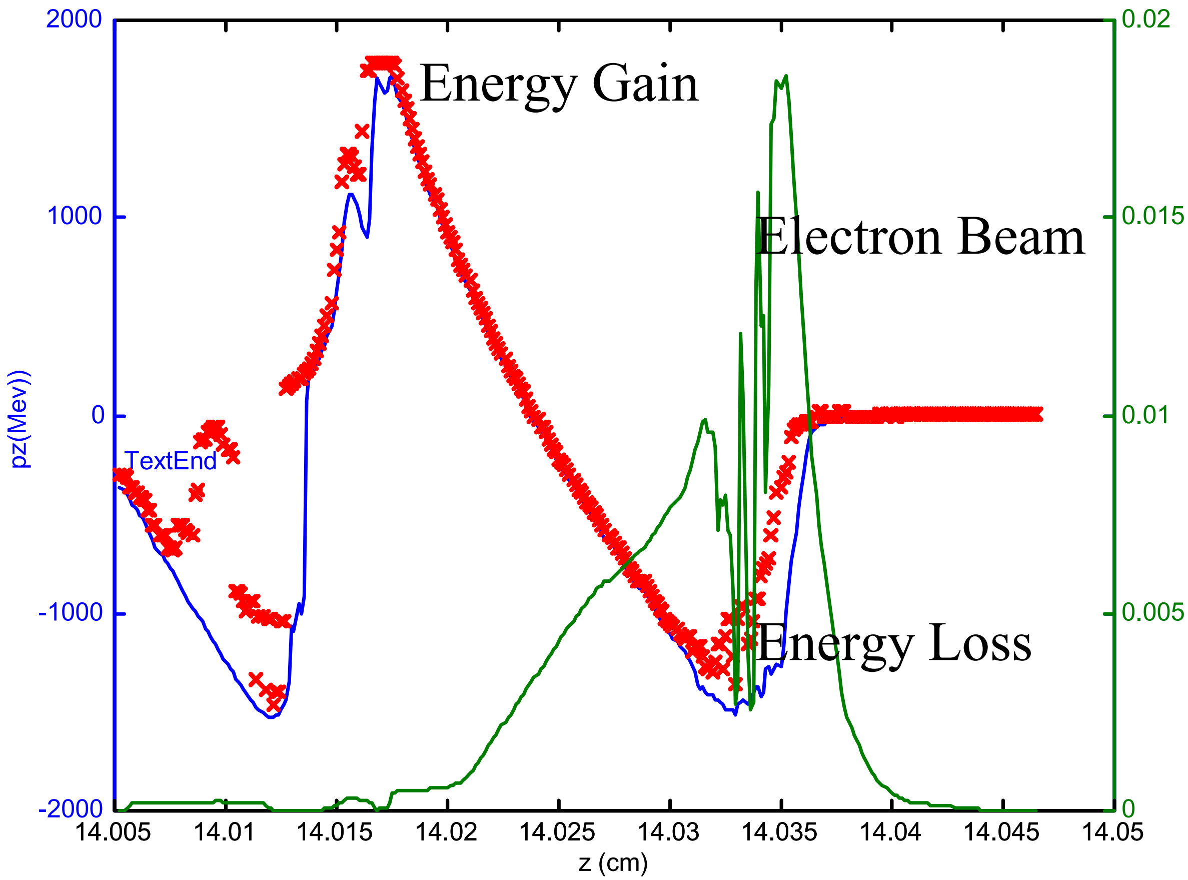
Beam images dispersed in energy



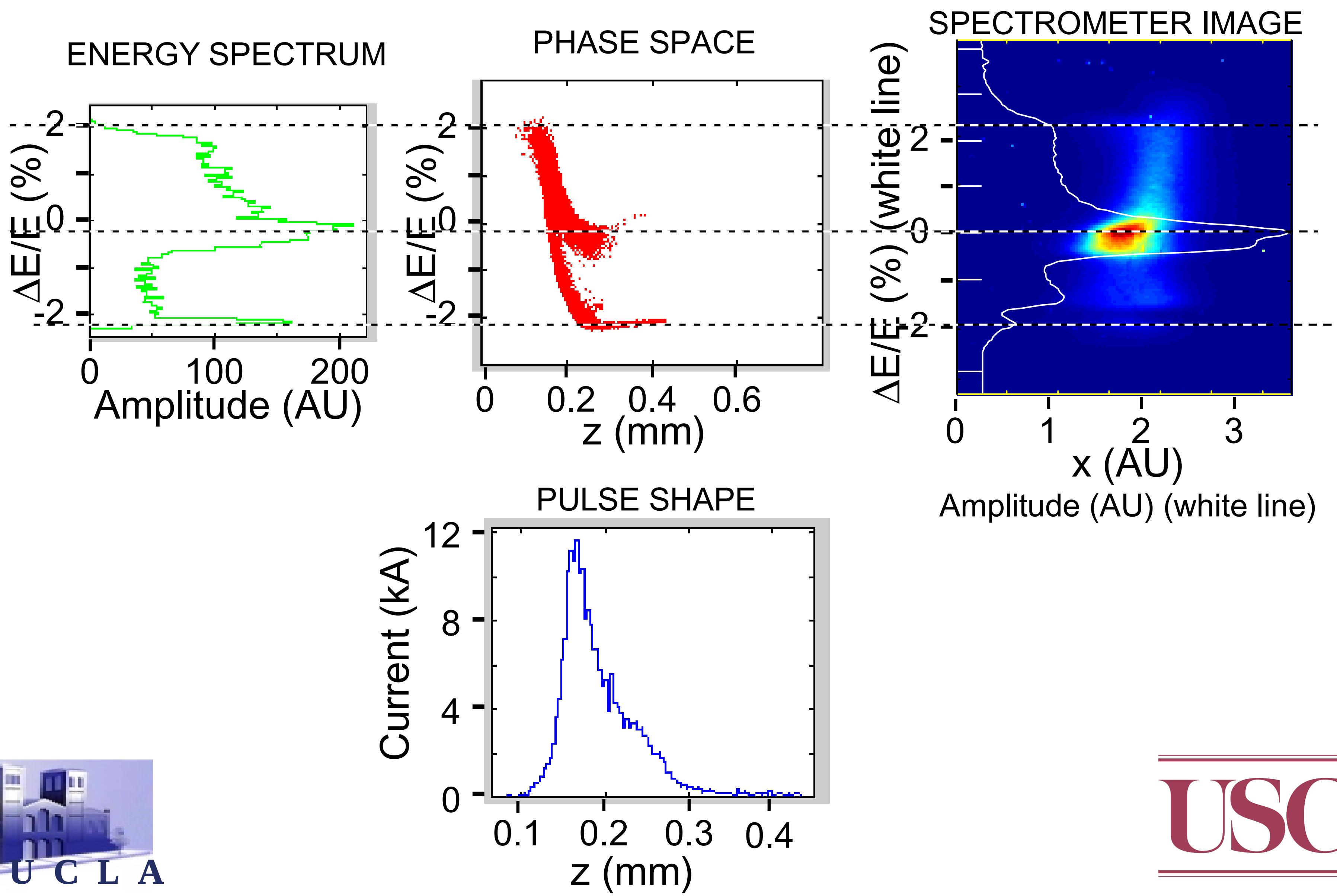
σ_z≈100 µm
σ_r≈15 µm
L_{LI}=30 cm

- \> 4 GeV/m Energy Loss in Beam Ionized Plasma
(near threshold)

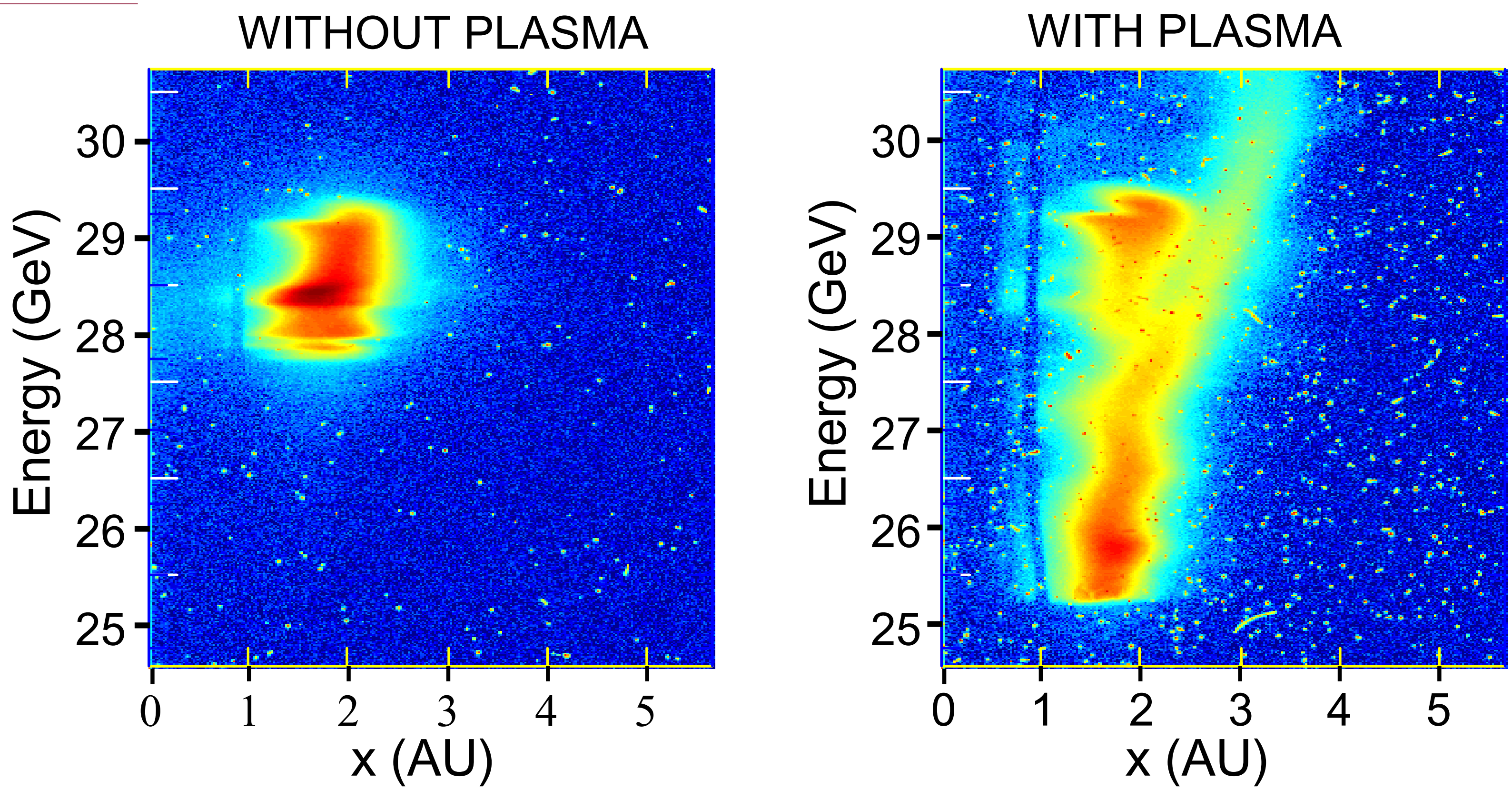
3D PIC Simulations of E164 Run II



EXPERIMENTAL BEAM-IMAGE AGREES WELL WIT SIMULATION OF SUBPICOSECOND BEAM



Preliminary Results from E-164 (Run II)



$n_e = 3 \times 10^{16}\ cm^{-3}$, L = 15 cm, N = 1.8×10^{10}

- Energy loss of ~ 2.5 GeV seen.
- Tail motion consistent with energy gain.

Further confirmation and scaling planned in Run III (Feb ‘04)

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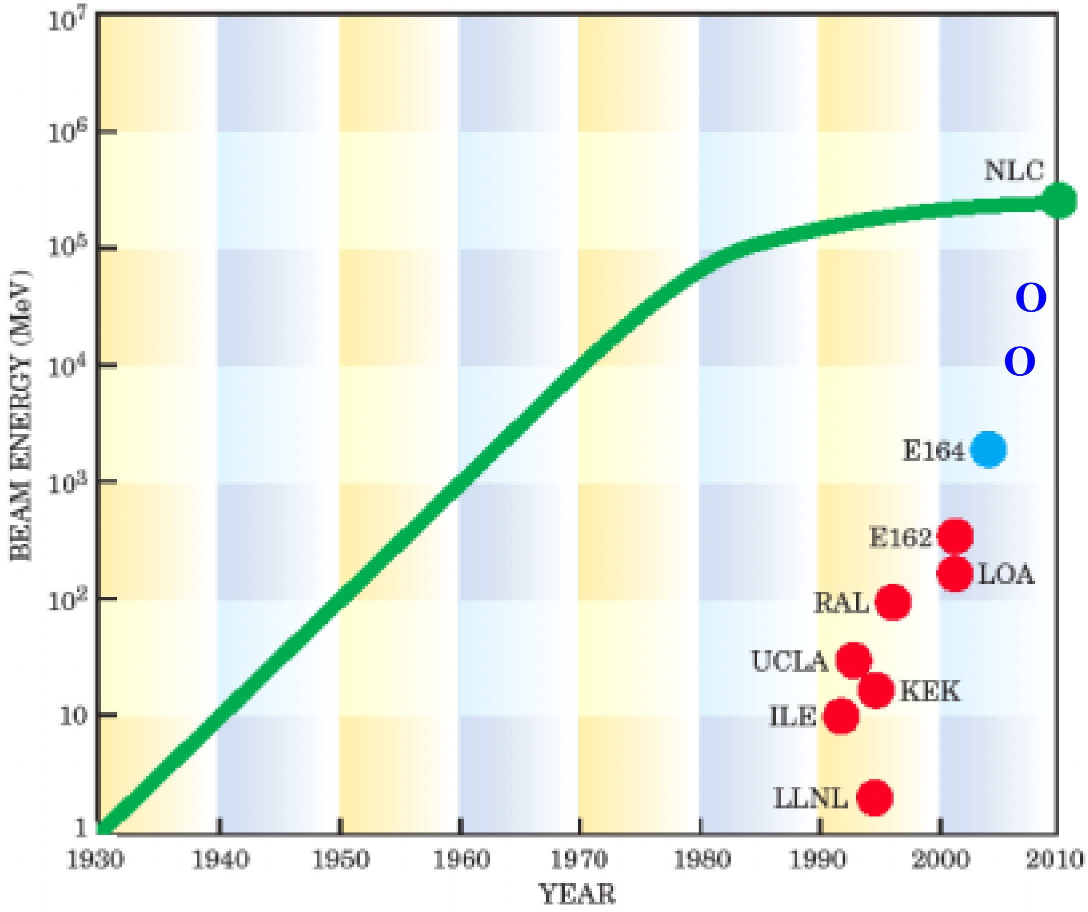
Plasma Accelerators and the Livingston Curve



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Critical Issues

- Bunch Length Scaling Law
- Beam Loading
- Large Transformer Ratio
- Transverse Beam Dynamics
  - Betatron, hosing, lensing
- Positron Acceleration
- Plasma Source Development
- Modeling

THE ORION CENTER

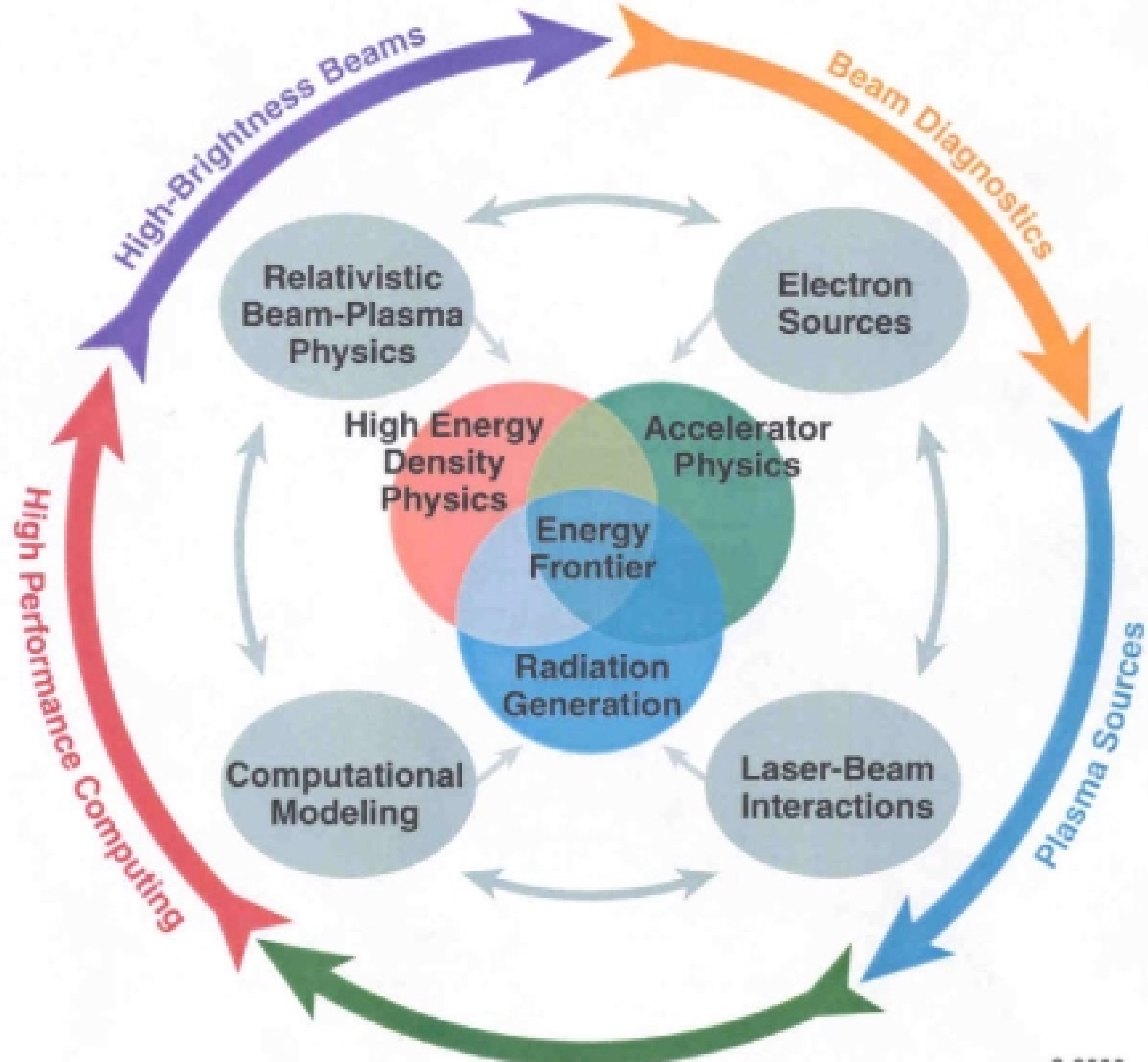
UCLA

Chan Joshi
Warren Mori
James Rosenzweig

USC

Tom Katsouleas

Bob Byer
Bob Siemann



3-2002
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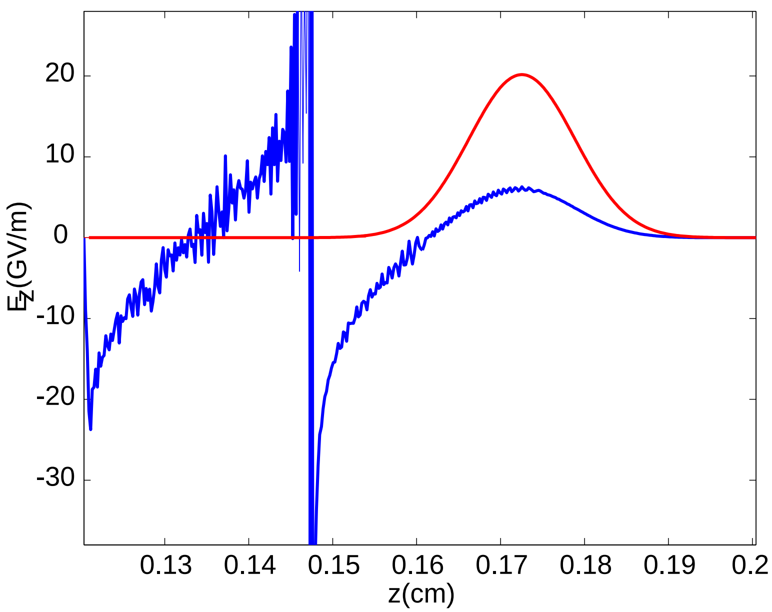
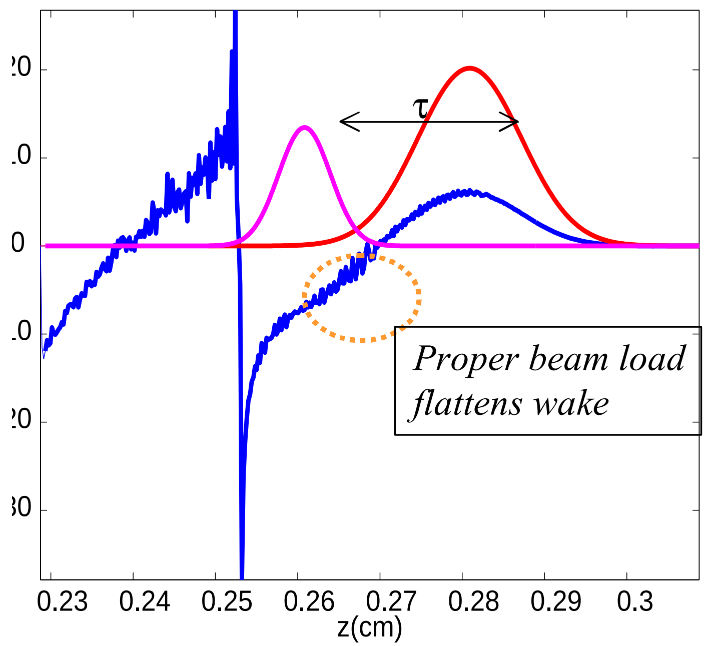
PIC Simulation of 2 bunch Afterburner Experiment

Hi beam quality requires specialized infrastructure of ORION beamline

(shorter 2nd bunch, precise phasing τ)



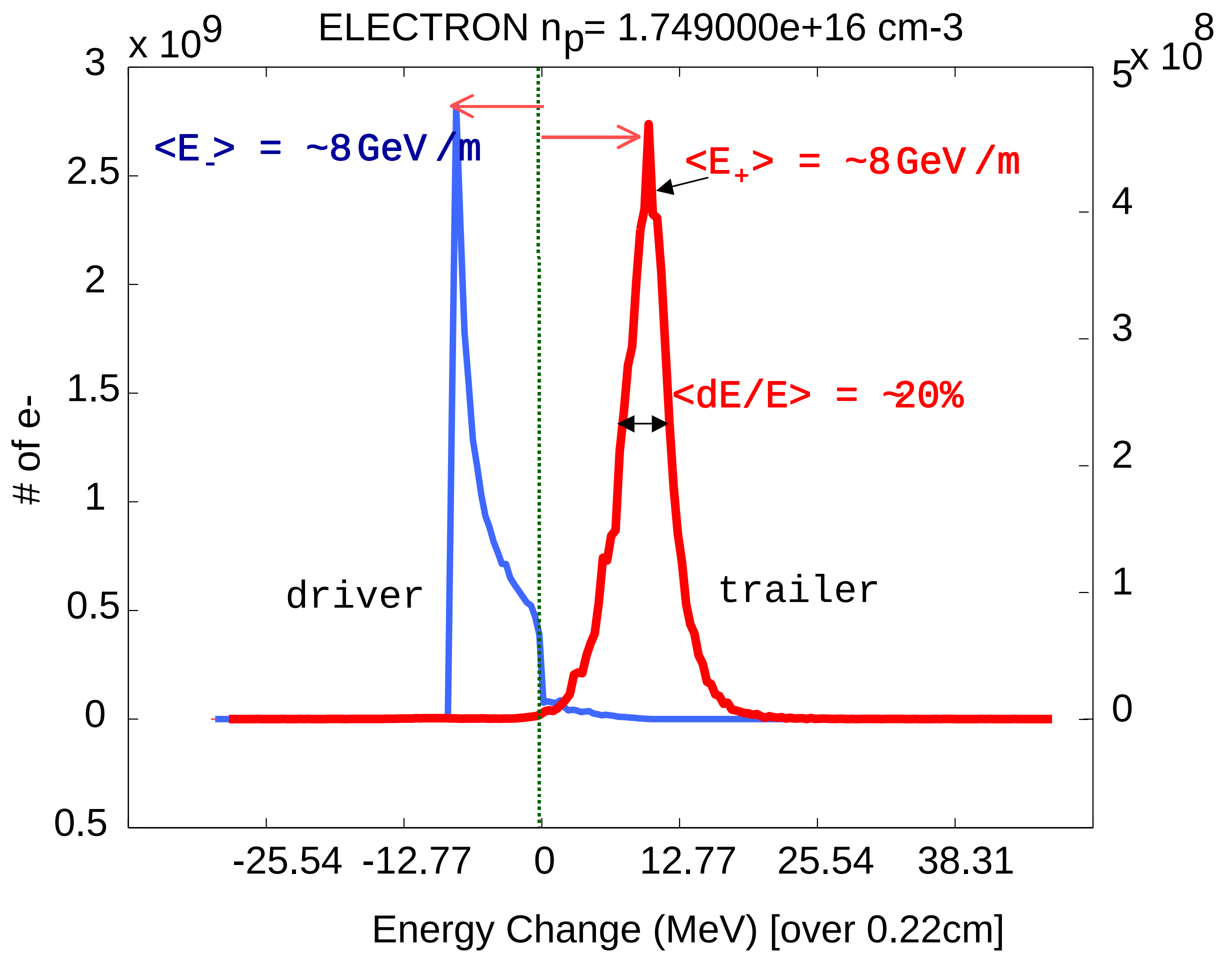
Driving bunch only



Driving bunch N=3×10^{10} σ_z=0.063mm

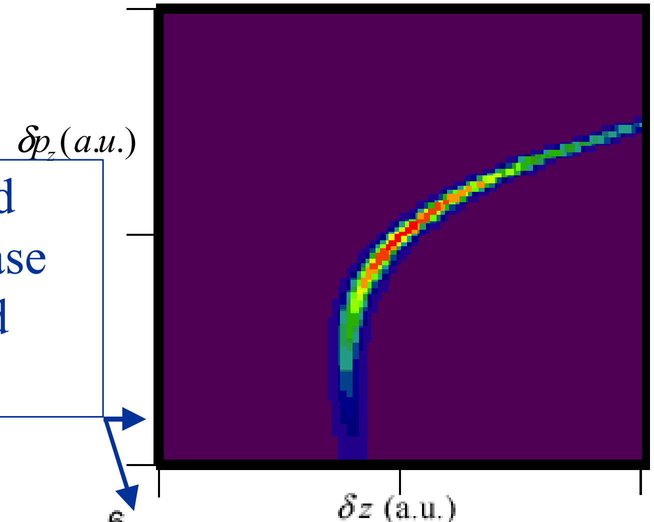
Trailing bunch N=1×10^{10} σ_z(trailing)=σ_z/2

Energy distribution of driver & trailer

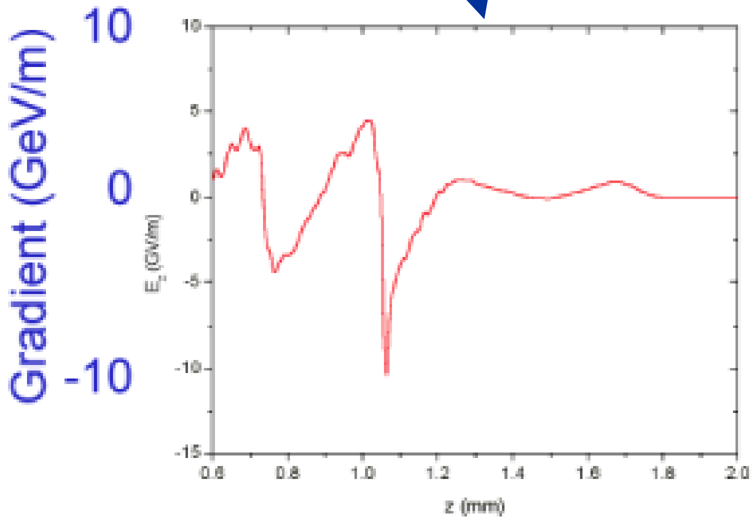


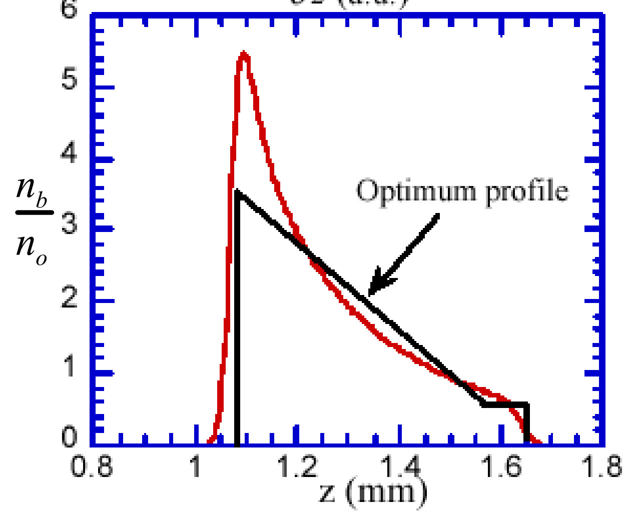
Shaped bunch PWFA can be studied at ORION

Simulated beam phase space and shape



Simulated Wake





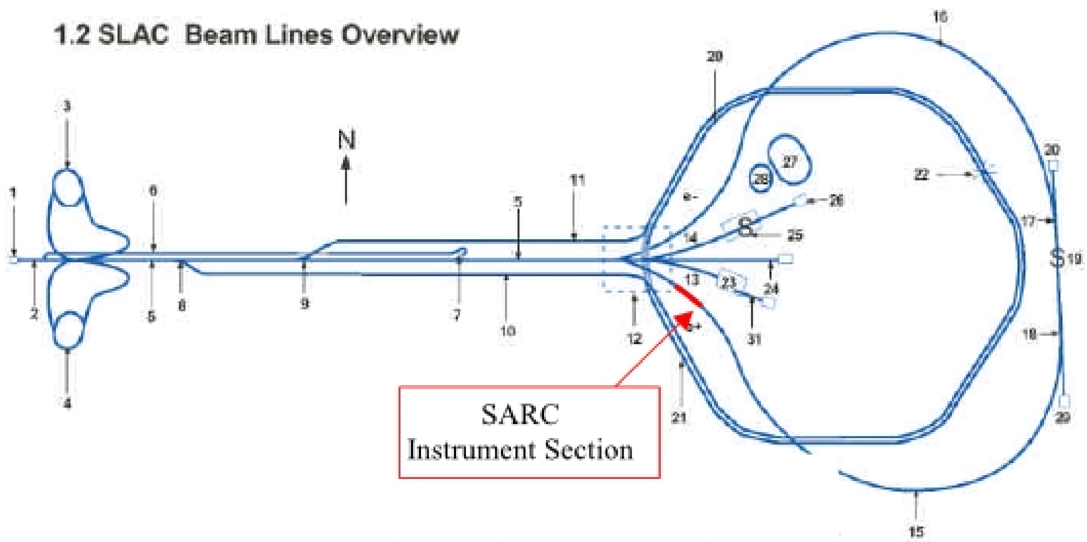
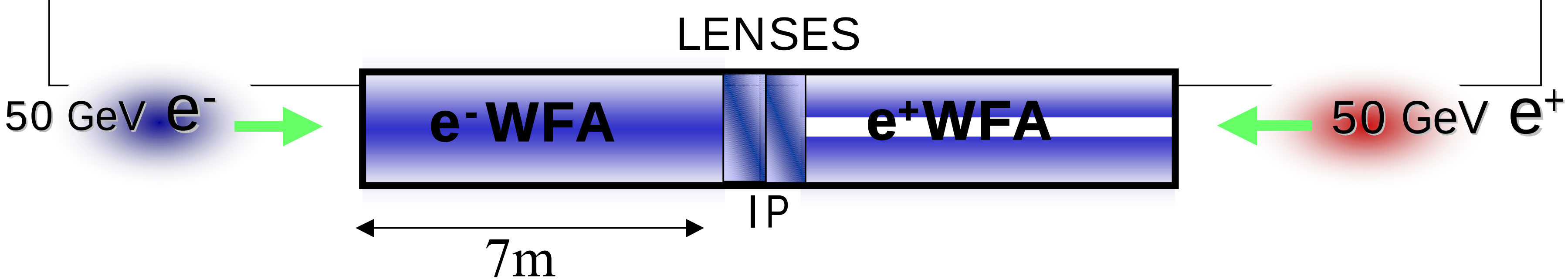


Figure 1. Location of the Instrument Section close to the beginning of the SARC

Courtesy P. Krejcik, P. Emma

PLASMA AFTERBURNER

- Double the energy of Collider w/ short plasma sections before IP
- 1^{st} half of beam excites wake --decelerates to 0
- 2^{nd} half of beams rides wake--accelerates to 2 x E_o
- Make up for Luminosity decrease $\propto N^2/\sigma_z^2$ by halving σ in a final plasma lens



S. Lee *et al.*, PRST-AB (2001)