Beam-plasma Physics Working Group Summary

P. Muggli, Ian Blumenfeld

Wednesday:

10:55, Matt Thompson, LLNL,
"Prospect for ultra-high gradient Cherenkov wakefield accelerator experiments at SABER"

11:25, Devon Johnson, UCLA,
"Plasma betatron radiation as a source for positron production" **

13:30, Mark J. Hogan, SLAC,
"Production of two bunches for PWFA experiments at SABER"**

14:00, Chengkun Huang, UCLA,
"QuickPIC simulations of the two-bunch operation regime for SABER"

15:20, Miaomiao Zhou, UCLA,
"Quasi-static simulations of self-ionized plasma wakefield acceleration by SABER relevant electron/positron beams"

16:30, Sven Reiche, UCLA,
"Inverse Compton scattering experiments at SABER"**

Thursday:

08:30, Erdem Oz, USC,
"Plasma dark current in self ionized plasma wakefield accelerators"

09:15, Gary Bower, SLAC,
"Plasma accelerator development project"

Beam-plasma Physics Working Group

Extension of the plasma work at FFTB: e^+

New experiments: Inversed Compton Scattering

Applications for the high e^- produced by plasma accelerator

Prospects for Ultra-High Gradient Cerenkov Wakefield Accelerator Experiments at SABER

Matthew C. Thompson

Lawrence Livermore National Laboratory

SABER Workshop – March 15, 2006

GigaWake Dielectric Accelerator Experiment Collaboration at FFTB

M. C. Thompson†, J. B. Rosenzweig, G. Travish, H. Badakov,
UCLA Dept. of Physics and Astronomy

M. Hogan, R. Ischebeck, N. Kirby, R. Siemann, D. Walz
Stanford Linear Accelerator Center

P. Muggli – University of Southern California

A. Scott – UCSB Dept. of Physics R. Yoder - Manhattan College

†Current Affiliation: Lawrence Livermore National Laboratory

Cerenkov Wakefield Experiments at SABER

The e^- and e^+ capabilities of SABER will provide unique opportunities for new dielectric wakefield experiments.

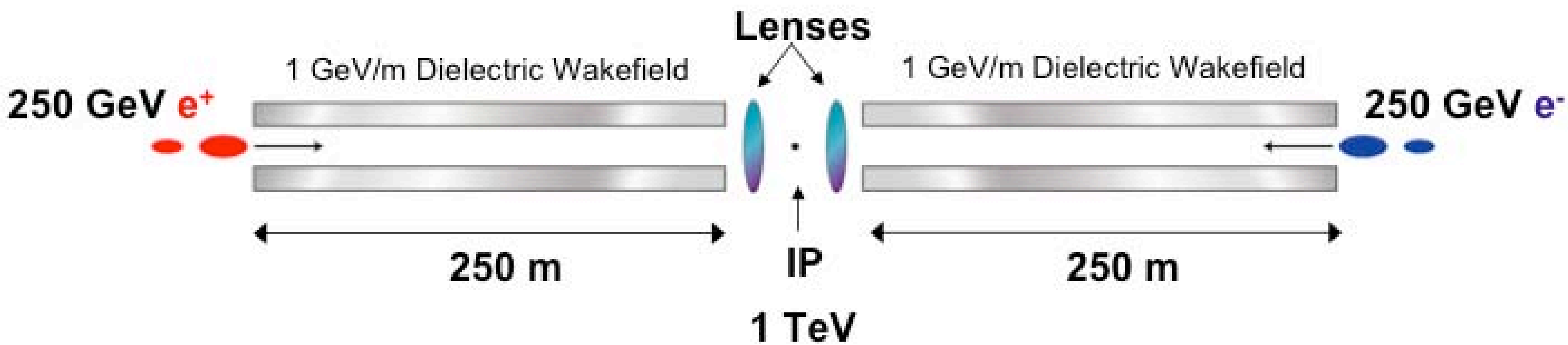
Chief Goals of a Dielectric Wakefield Experiment at SABER:

Demonstrate particle energy gain at GV/m fields.

$$E_{z,vac} = \frac{2Q}{a^2}$$

Demonstrate charge reversal symmetry.

Establish dielectric wakefield accelerators as a serious option for a **Linear Collider Afterburner** scenario immune to **ion collapse** and **electron/positron asymmetry** problems.



A Proposal for SABER

- We suggest an experiment to look at energy modulation of the drive beam as it passes through a 10 cm dielectric tube.
- This experiment can be done at SABER with electron and positron beam with identical parameters.
- The result should provide a clear measurement of the wakefields within the beam.
- This flexible set of experimental parameters can easily be optimized for a true drive / witness beam scenario or other situations.

Experimental Parameters

Beam Energy	30 GeV
Beam Energy Spread (FWHM)	< 0.25% (.075 GeV)
Beam Charge (e^- or e^+)	3×10^{10} (5 nC)
Beam Radius (σ_r)	10 μm
Beam Length (σ_z)	150 μm
Inner Dielectric Radius	100 μm
Outer Dielectric Radius	175 μm
Dielectric Permittivity	~ 3
Dielectric Length	10 cm
Peak Accelerating E_z	1.1 GV/m
Peak Surface Field	2.2 GV/m
Maximum Energy Gain	0.11 GeV

(Analytic Theory)

Need beam radius, but long bunches! Early SABER

Necessary SABER Capabilities and Features

From our previous experience as FFTB users, and our discussion of the possibilities at SABER, we developed the following suggestions:

Key FFTB Features Worth Preserving:

- **Highly skilled and cooperative technical support**
  - **Experiment A out; experiment B installed, running and removed in < 72 hrs!**
- **Physicists' playground**
  - **Windowed off vacuum area**
  - **Highly evolved beamline controls**
  - **Highly flexible experimental controls**
- **Minimal bureaucratic hassles**

Key SABER Features Worth Emphasizing / Adding:

- **Ample and dedicated experimental beamline space.**
- **Highly flexible focusing lattice to provide both short and long beta functions**
- **Flexible e^- and e^+ bunch production:**
  - **Variable bunch length**
  - **Split bunches**
- **Lots of built in diagnostics & controls**
- ***Real witness beams generated by an external injector.***

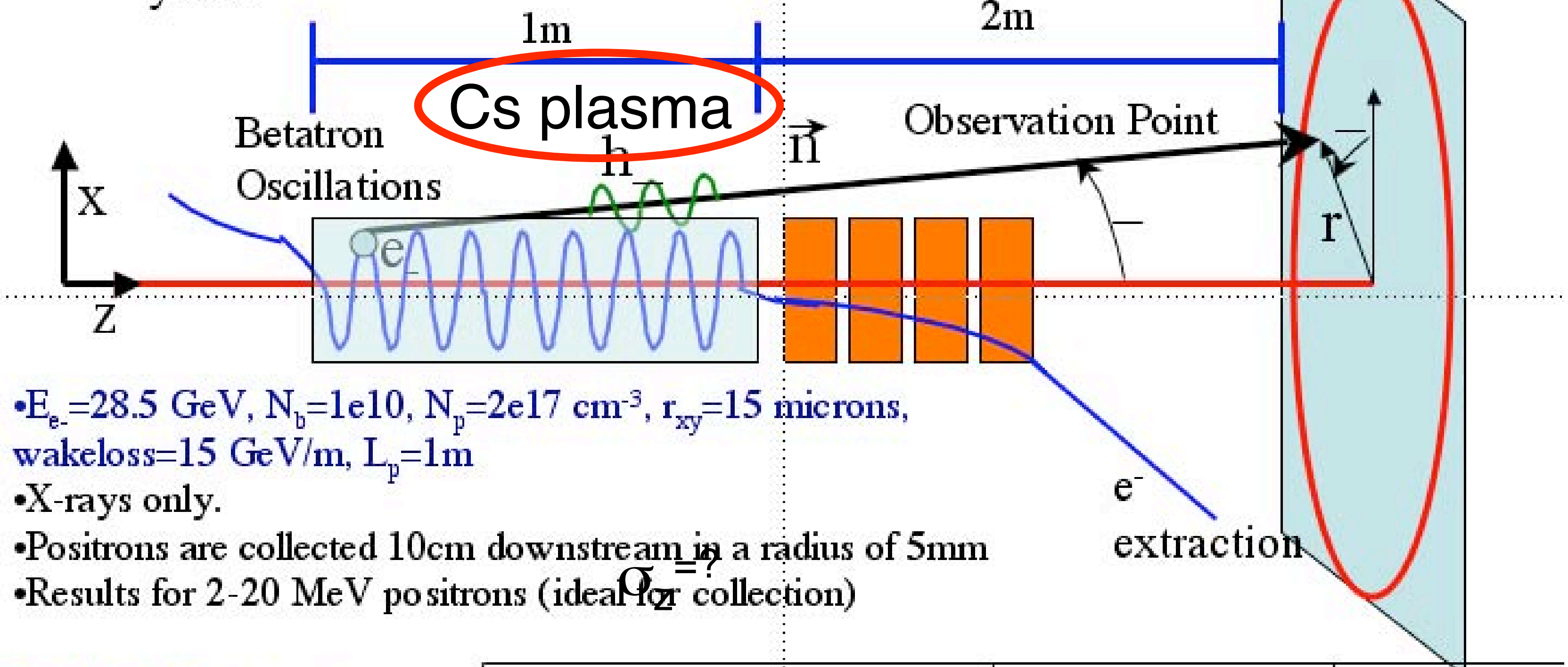
Positron Production Experiments at SABER

Presented by Devon K Johnson

3/15/06

Experiment #2

- Using a thin target (.5 rl W), can we get a comparable yield?



- E_{e-}=28.5 GeV, N_b=1e10, N_p=2e17 cm^{-3}, r_{xy}=15 microns, wakeloss=15 GeV/m, L_p=1m
- X-rays only.
- Positrons are collected 10cm downstream in a radius of 5mm
- Results for 2-20 MeV positrons (ideal for collection)

Table 3: Positrons / incident e^- for plasma IN and OUT cases (2-20 MeV)

Case	e^+ at rear of target	e^+ collected
28.5 GeV in vacuum (6rl W)	26.1	1.3
28.5 GeV w/ plasma (.5 rl W)	???	???

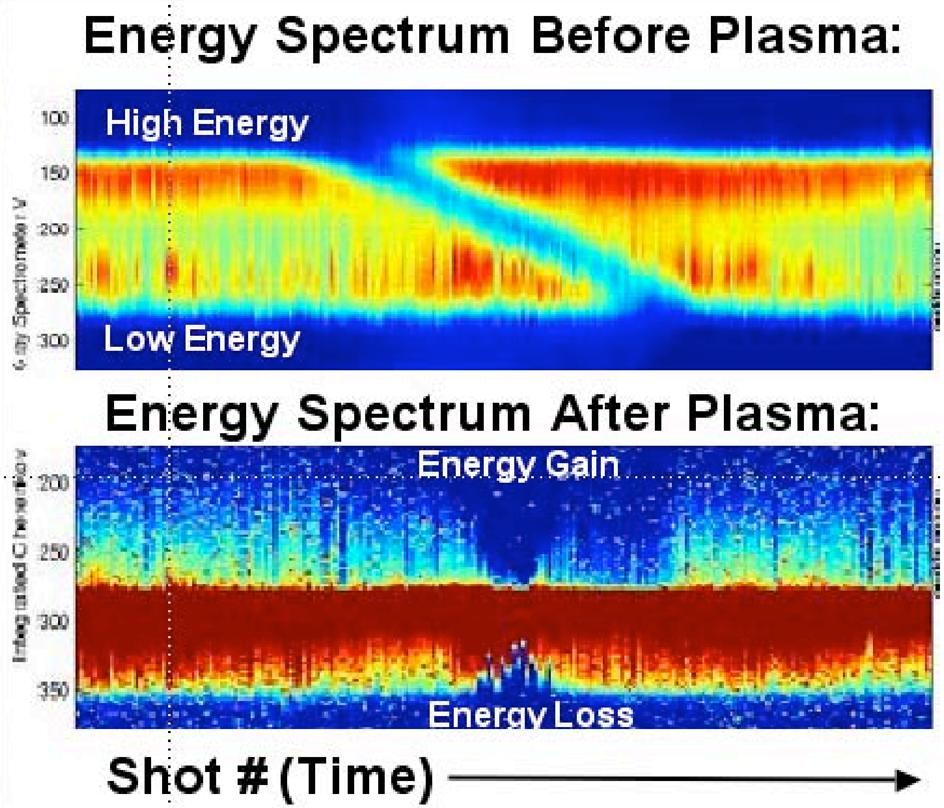
Relaxed beam parameters, early SABER?

Test of Notch Collimator - December 2005 & Prospects for SABER

- Why we would like two closely-spaced bunches
- How we are trying to make them with a notch collimator
- What we've seen so far
- What are the prospects for SABER

M.J. Hogan, SLAC

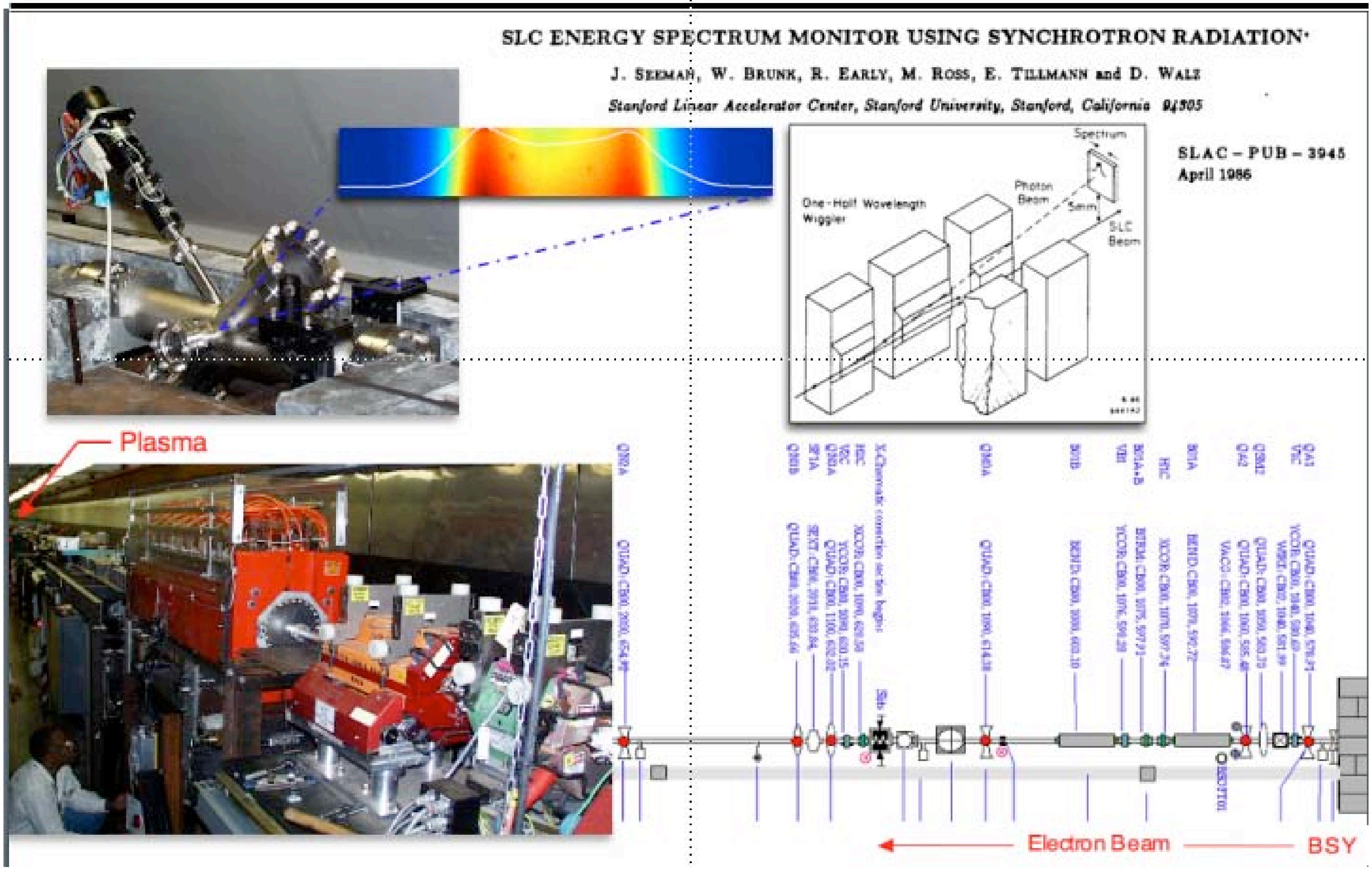
Test of Notch Collimator - December 2005



- Acceleration correlates with collimator location (Energy)
- No signature of temporally narrow witness bunch - yet!
- Other interesting phenomena also correlate (see next slide)
- Collimated spectra more complicated than anticipated

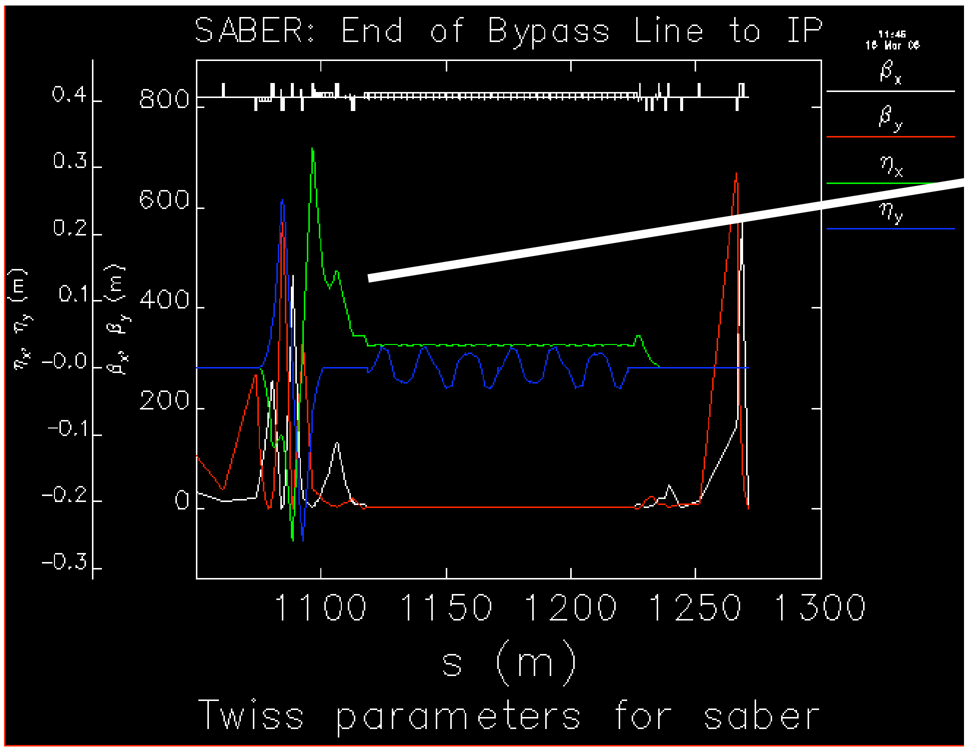
Work in progress! Need to transfer to SABER!

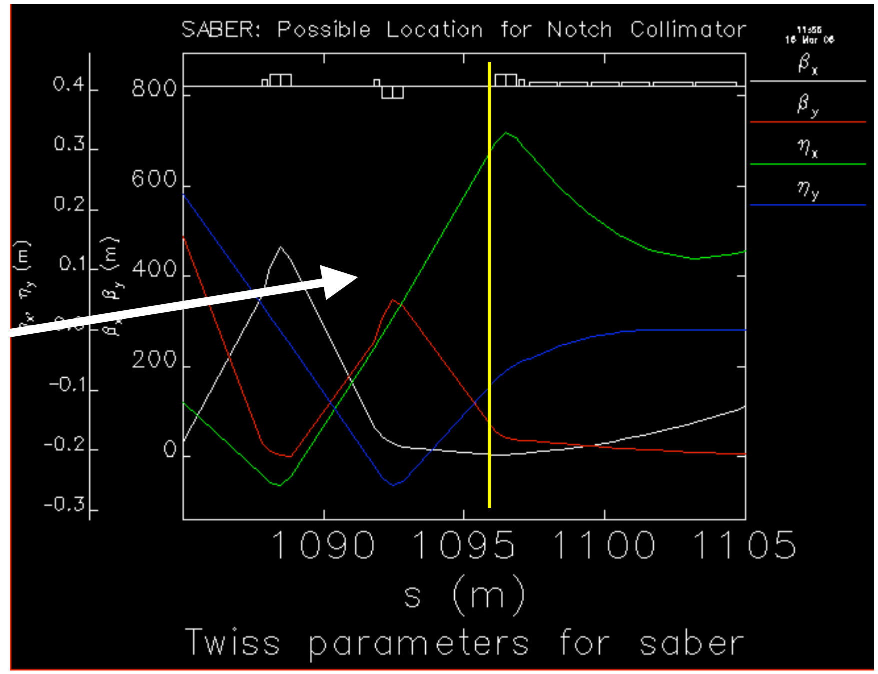
Non-Invasive Energy Spectrometer Upstream of Plasma

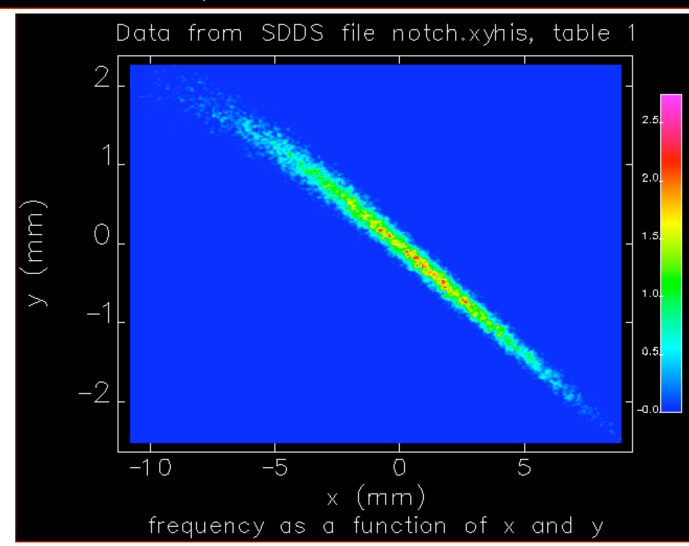


Need to transfer to SABER!

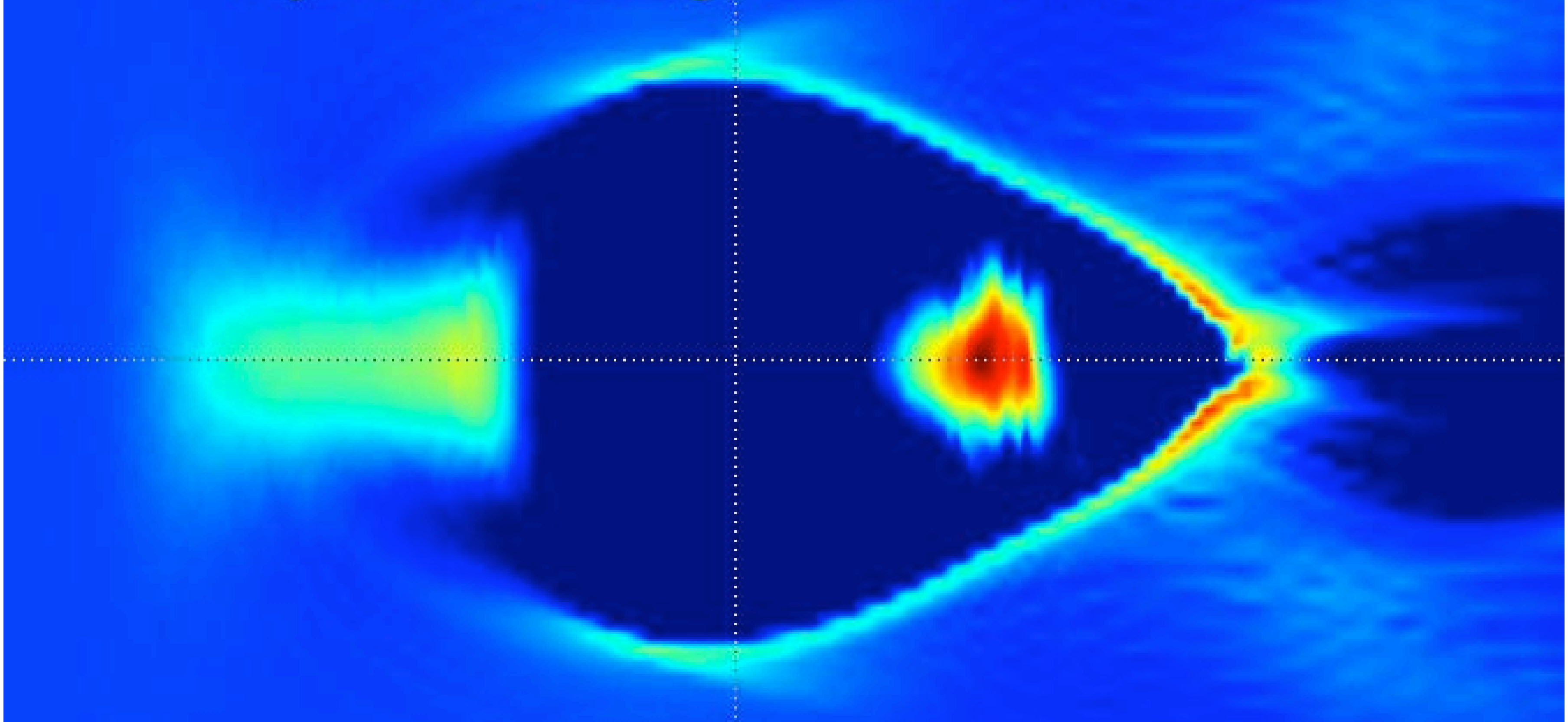
Possible Location for
Notch Collimator & X-ray Stripe SABER







QuickPIC simulations of the two-bunch operation regime for SABER

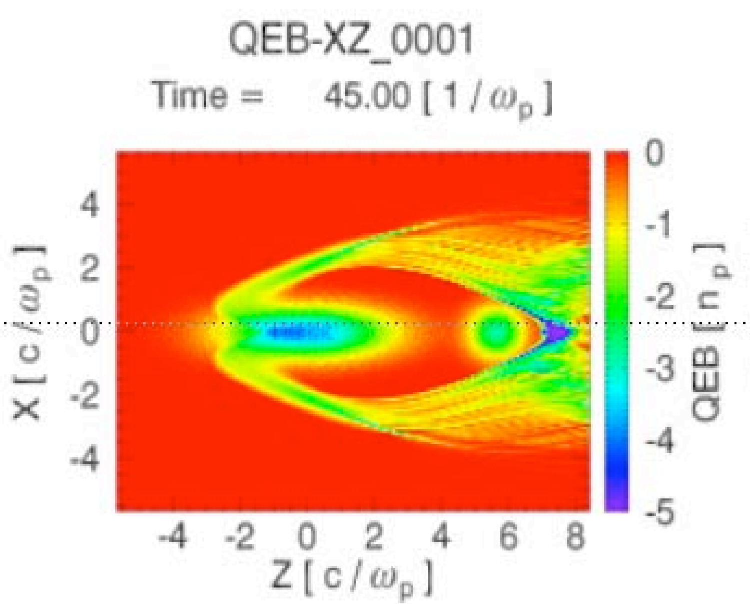


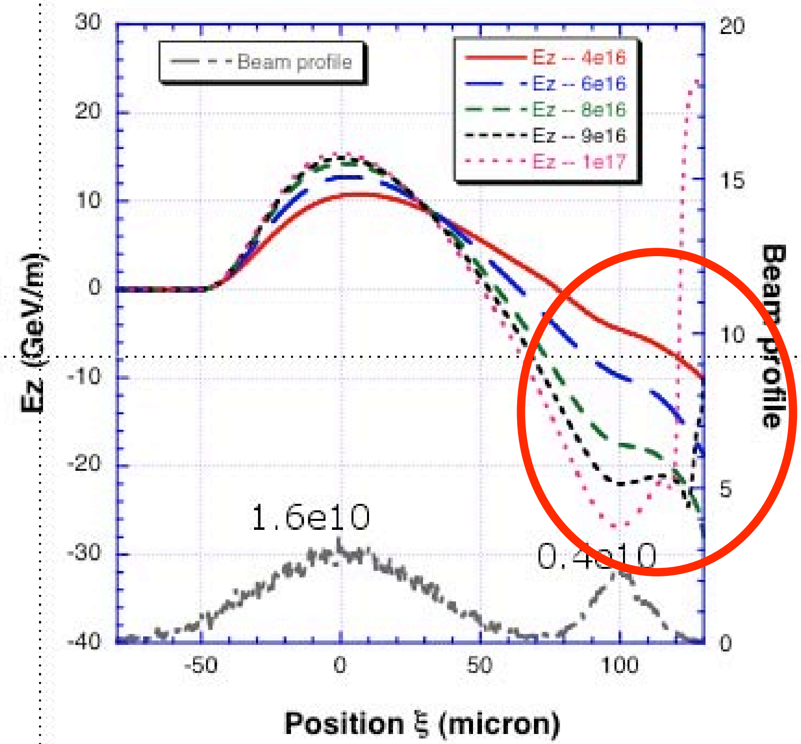
Chengkun Huang

Presented at SABER Workshop

03/15/06

An example

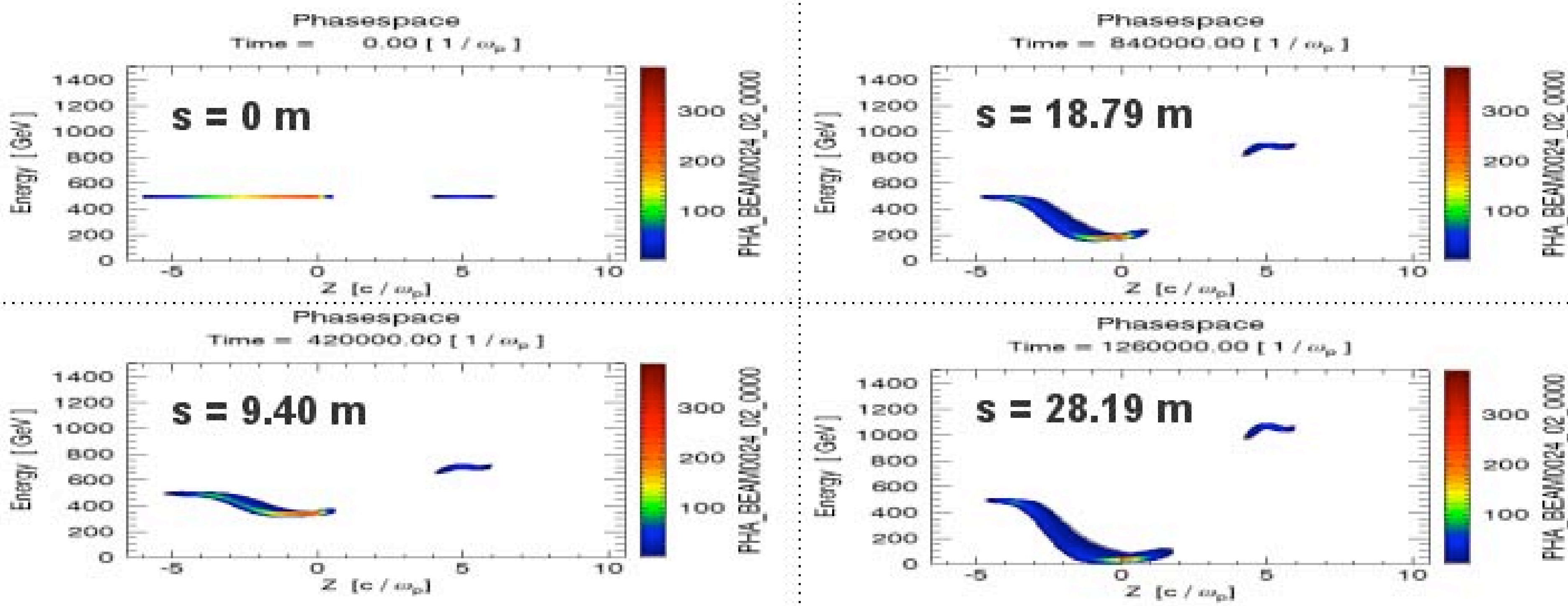




Two bunches with $_z$=30 _m, 10 _m respectively and the charge ratio is 4:1.
The separation is 100 _m. The plasma density is 8~9E16 cm^{-3}.

Look for 2-bunch parameters that lead to small ΔE/E
(Beam loading)
Optimzation similar to that in conventional accelarators

500 GeV energy gain!



500 GeV energy gain in 25m!

Quasi-static simulations of self-ionized plasma wakefield acceleration by SABER relevant electron/positron beams

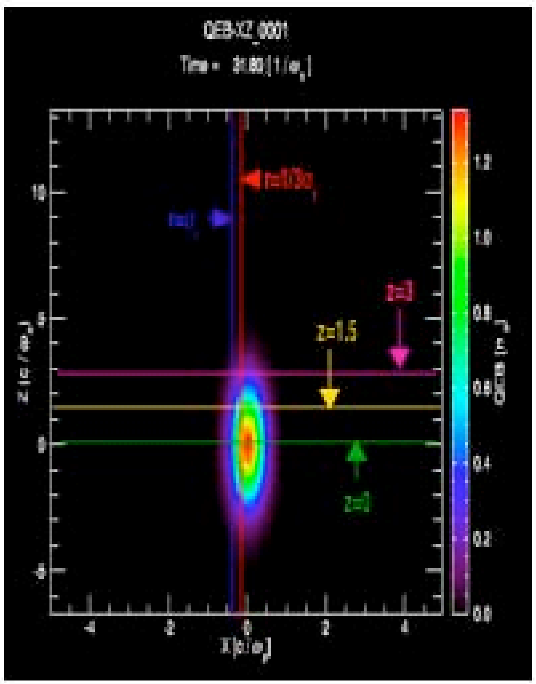
Presented by Miaomiao Zhou (UCLA)

for SABER Workshop

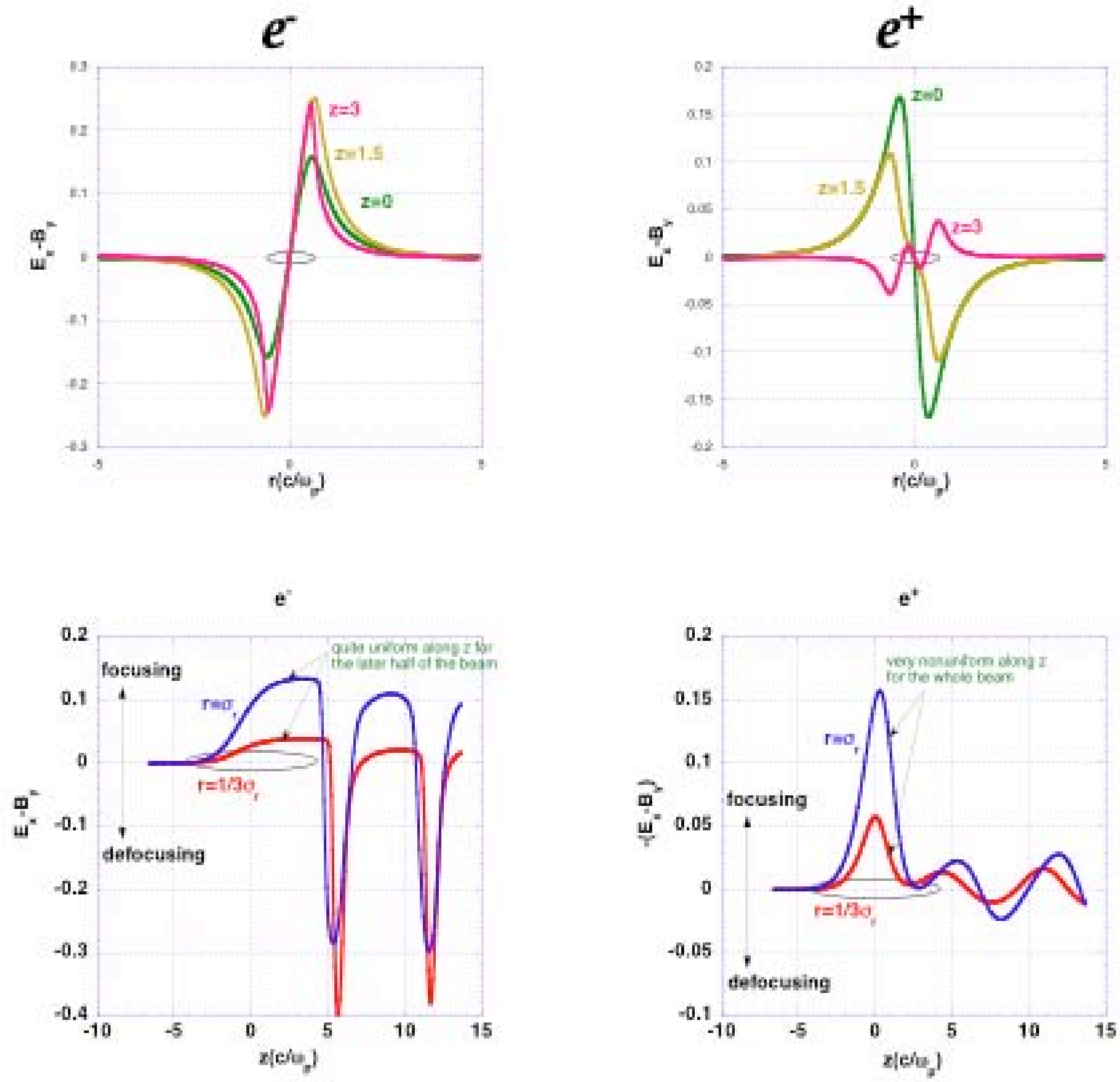
03/15/2006

Modeling positron wakefield acceleration
(I) Properties of a bi-gaussian positron beam wakefield

In the wake of a *bi-gaussian* positron beam, the **longitudinal field** is normally **smaller** than that in a similar electron wake. The **focusing forces** are **neither linear** in r, **nor uniform** along z.

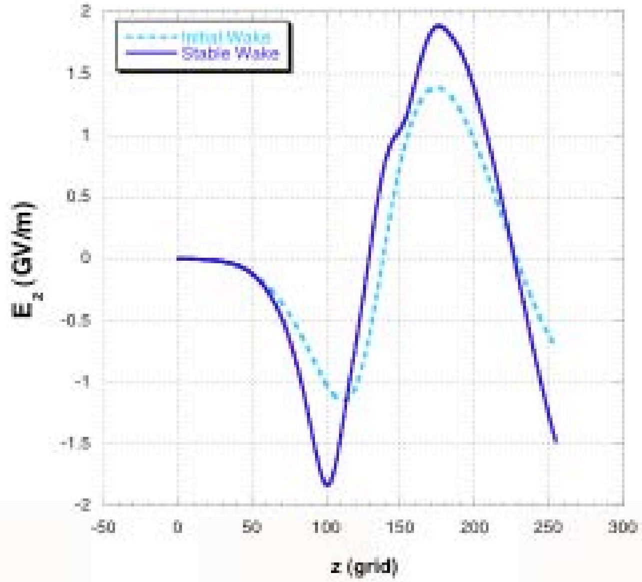


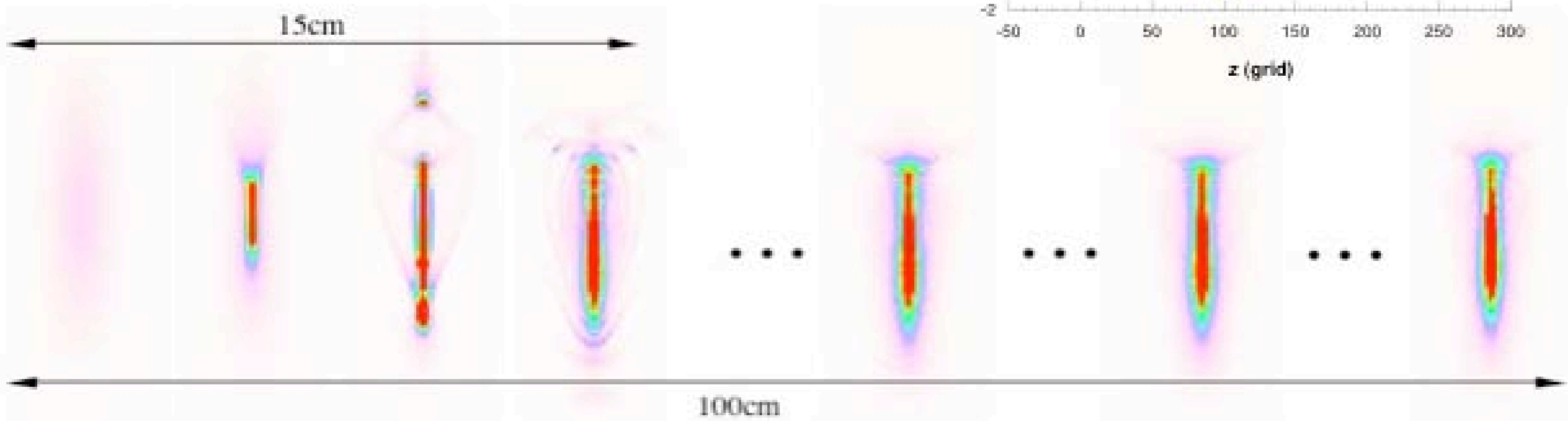
Focusing force comparison



Modeling positron wakefield acceleration
(II) Beam/wake evolution (pre-ionized plasma)

However, positron beams tend to **modulate dramatically** in their own wakefields **before** they reach a **stable envelope** (in both pre-ionized and self-ionized plasmas).



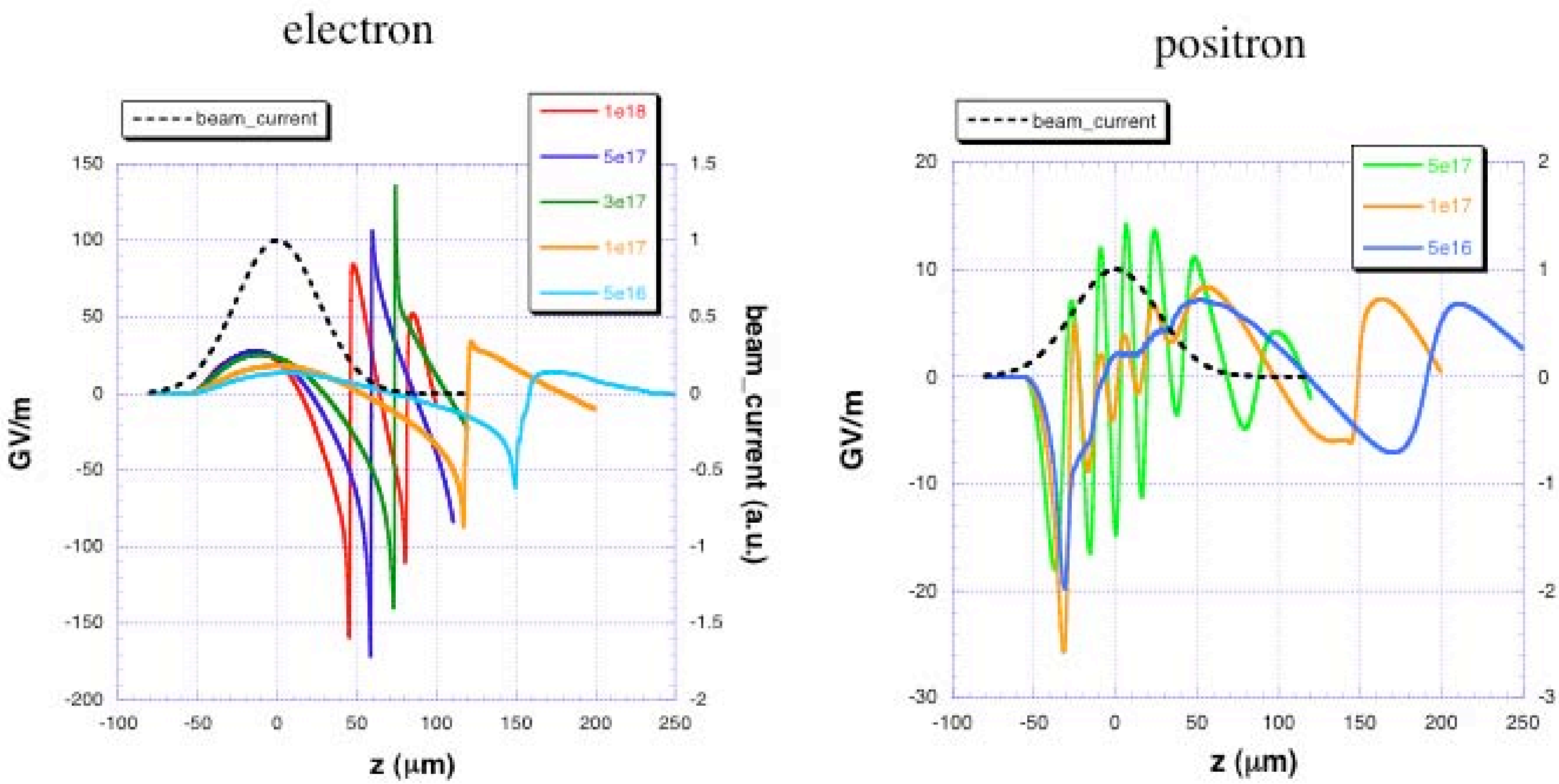


Evolution of a positron beam and its wakefiled in a **pre-ionized** plasma

$$N_b = 2\times 10^{10}, \sigma_r = 11\mu m,\ \sigma_z = 58.66\mu m,\ n_p = 2\times 10^{16} cm^{-3}$$

Wakes for SABER beam parameters

$$N_b = 2\times 10^{10}, \sigma_r = 5.3\mu m, \sigma_z = 26\mu m$$



For e^+ there is a narrower parameter space for good wakes than for e^-

Plasma Dark Current in Self-Ionized Plasma Wake Field Accelerators

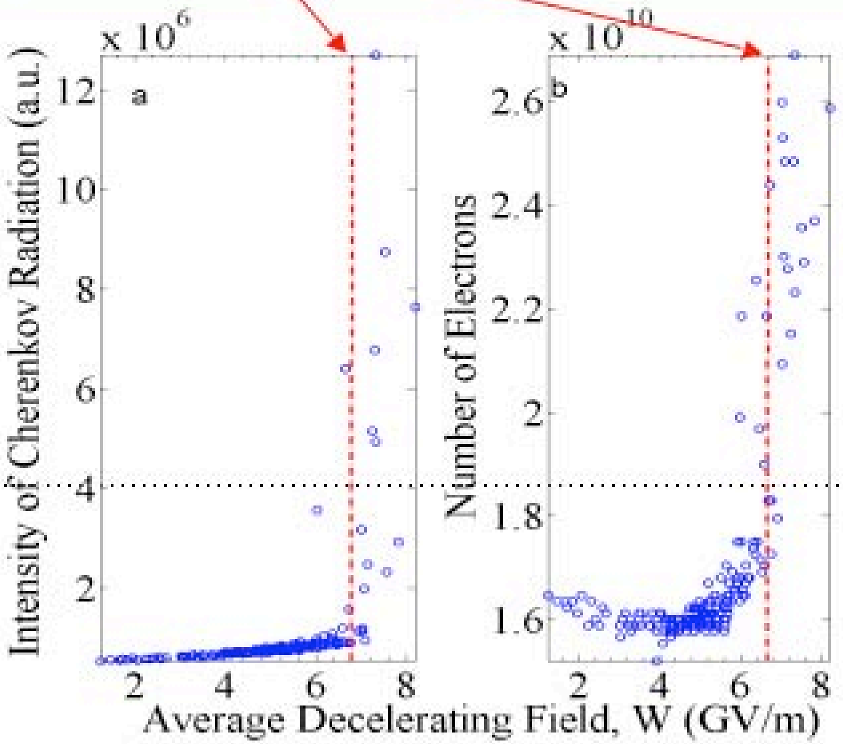
Erdem Oz* USC

E-164X,E167 Collaboration

*eoz@usc.edu

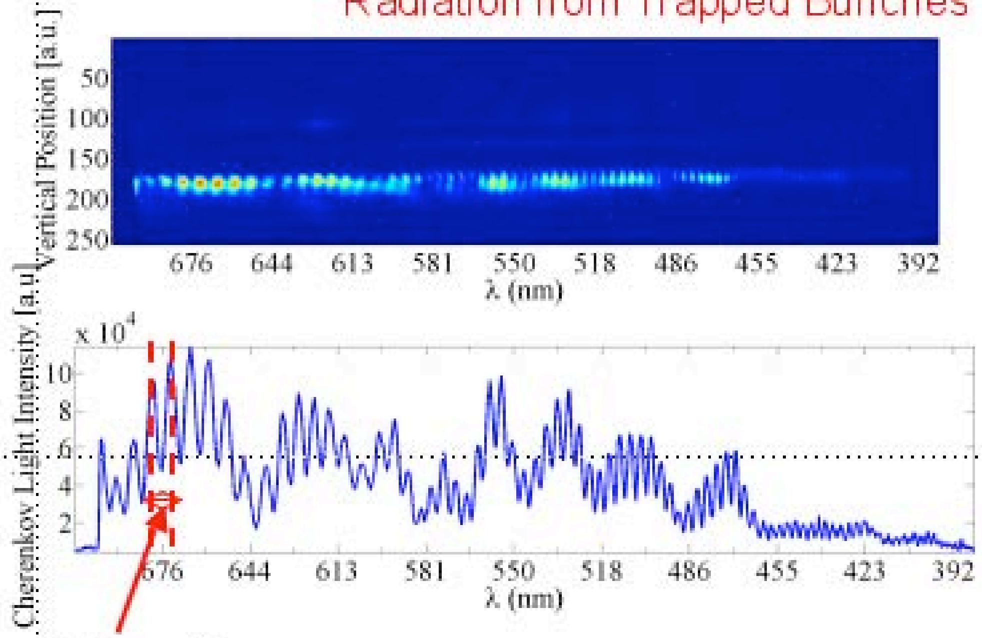
Evindence For Particle Trapping Treshold

Clear threshold
at ~7 GV/m



Density=$1.6\times10^{17}\,cm^{-3}$

Interference of Coherent
Radiation from Trapped Bunches



$\tau\Delta\omega = 2\pi$

Bunch Spacing $= c\tau \approx 70\ \mu$,

plasma wavelength, $\lambda_p = 64\ \mu$.

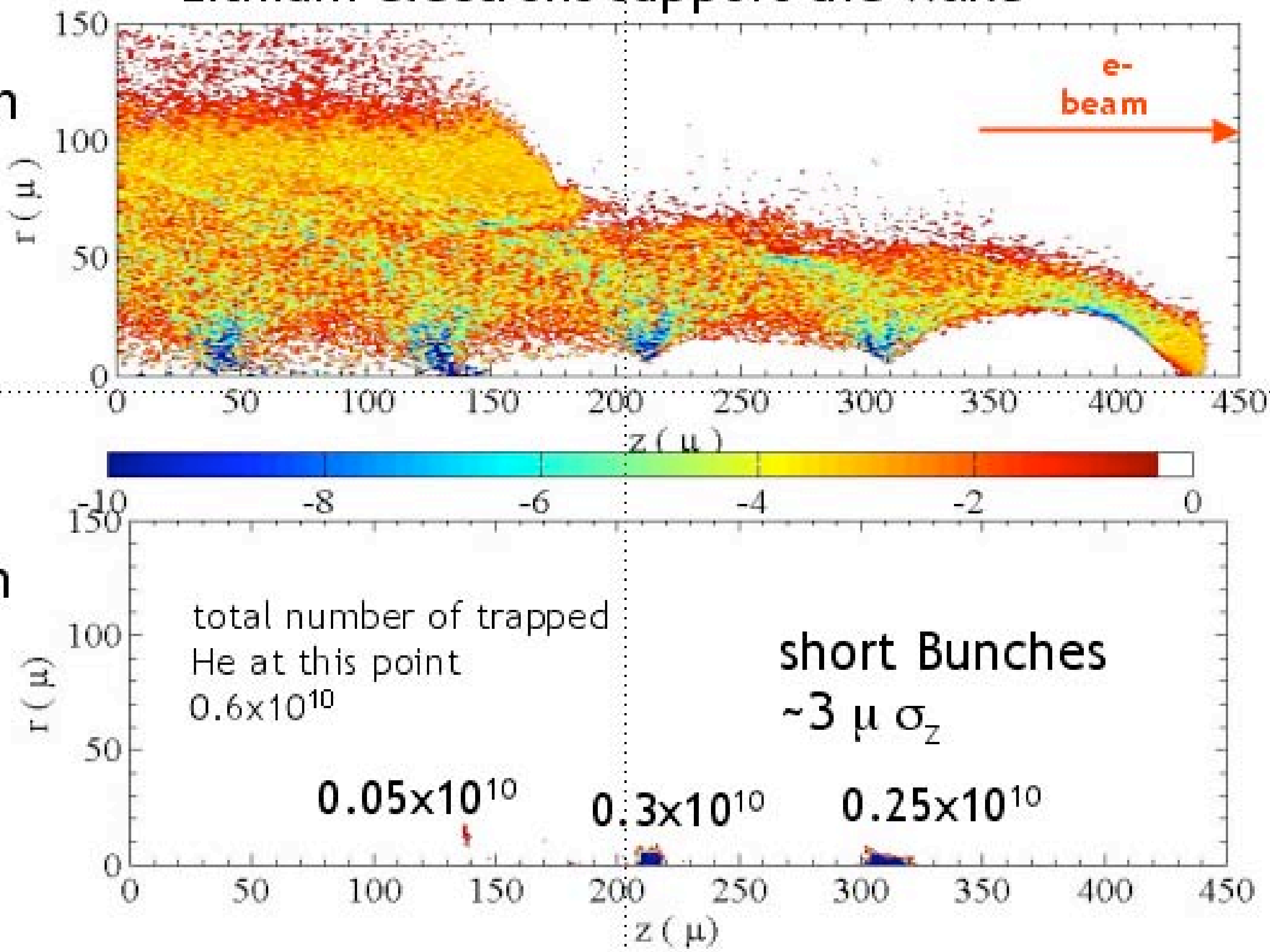
- Trapping above a threshold wake amplitude as measured by average energy loss or decelerating field: ≈7GV/m
- Excess charge of the order of the beam incoming charge ($1.6\times10^{10}\ e^-$)
- Evidence for two (or more) short bunches of trapped particles

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

Lithium electrons support the wake

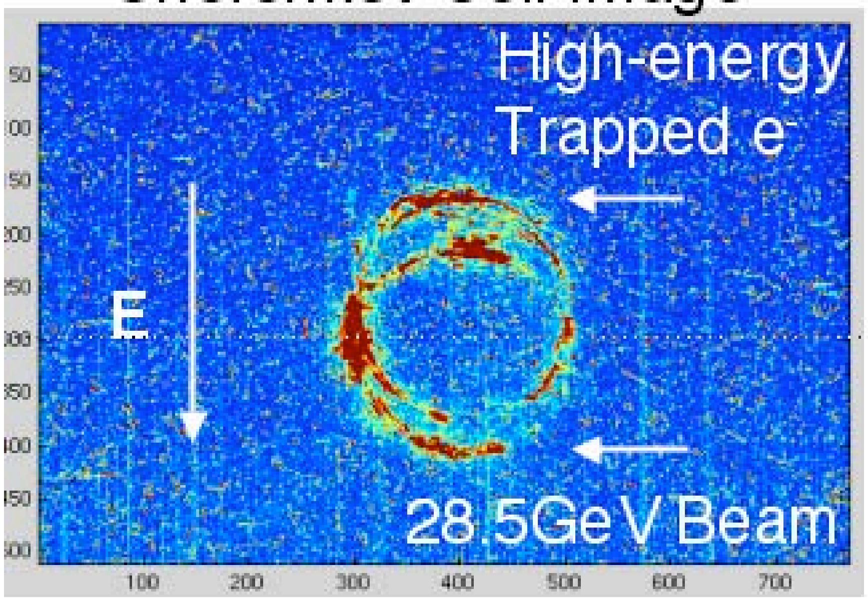
Li at
z=11.3 cm

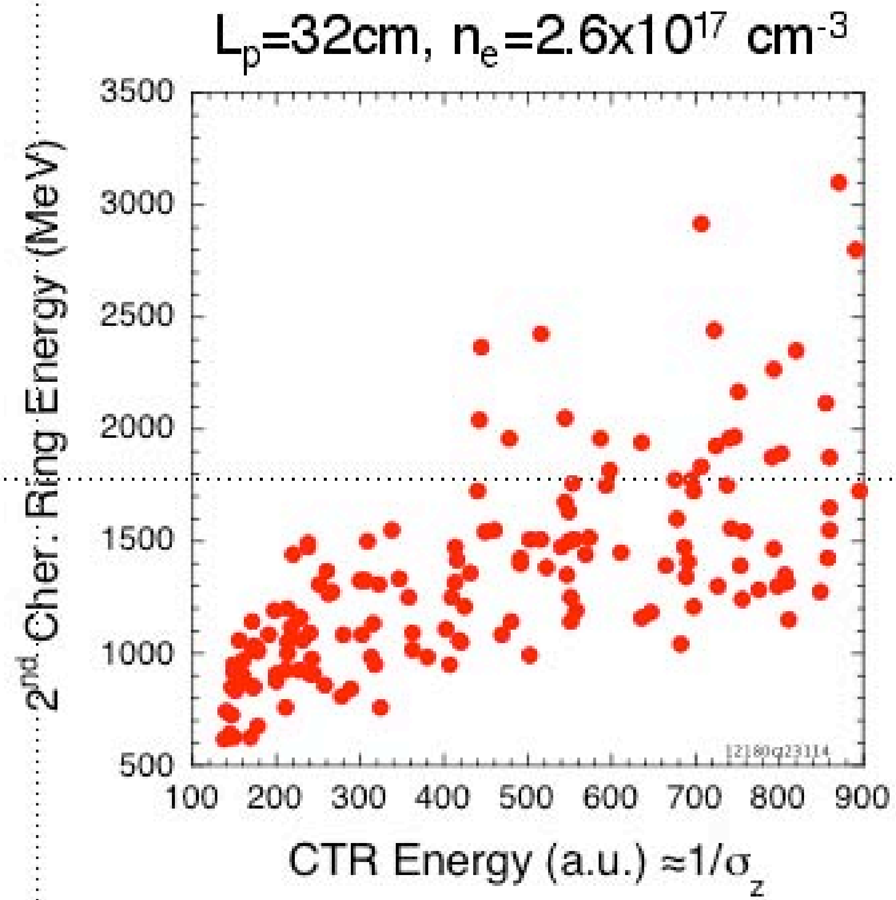
He at
z=11.3 cm



He electrons trapped inside the wake

TRAPPING OF PLASMA e⁻





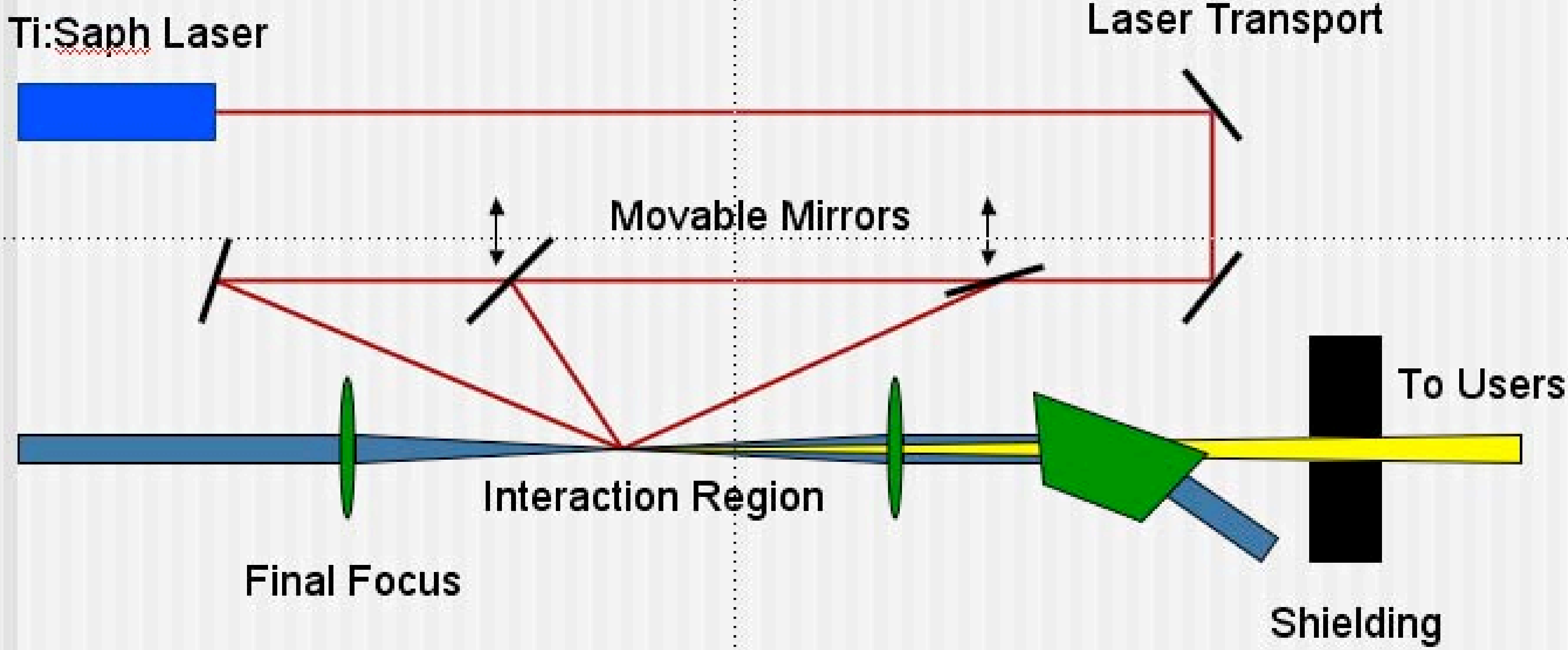
- High-energy, narrow ΔE/E trapped particle bunches

Inverse Compton Scattering Experiments at SABER

Sven Reiche

Saber Workshop - 3/15/06

Schematic Layout



Sven Reiche
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Expected Performance

Normalized field *a* should be < 0.1 to reduce red shift and improve spectral brightness

Incident Angle	Photon Energy*	Comments
180°	2.5 - 15 GeV	Highest energy
45°	0.25 - 2 GeV	Shortest pulses
10°	20 - 200 MeV	Lowest energy

* Electron Beam Energy : 10 - 30 GeV

Sven Reiche
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Beam Parameter Demands for ICS

- Beam size 10 microns
- Beam charge > 1nQ
- Beam energy 10 - 30 GeV
- Beam Current ~ 1kA (though of low importance)
- Energy Spread ~ 1% (though of low importance)
- Timing at IP ~ 1 ps (head-on collision)
- Laser ~ 1J (scales linearly with photon count)
- Laser spot size at IP: $w_0 \sim 20$ microns
- Laser intensity: a < 1 preferred.

Standard SABER beam, but need a laser, timing!

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A Plasma Accelerator Development Project

SABER Workshop at SLAC

3/16/06

Gary Bower

First customer for a plasma accelerator!

SLC afterburners application

- Goals:
  - 2 x 45→ 80 GeV (WWbar)to get a W factory.
  - 2 x 45 → 175 GeV (ttbar)to get a top quark factory.
  - 2 x 45 → (90 + Hmass)/2 (ZH) to get a Higgs factory.
    - If Higgs exists, Hmass is expected to be < ~ 190 GeV.
  - Polarized beam(s) are a big plus.
  - Need SLC sized spots.
  - > 10**10/bunch, _E/E small.
- Challenges:
  - Expensive project, certainly > $50 million.
  - Several years down the road.
- Question – How much higher can we push the linac and what energy will the SLC arcs sustain to reduce the energy multiplication required?

Long term!

Fixed target application - physics

- Gluon nuclear spin measurement:
  - See E161 proposal for details
    - Pursue only the two muon final state case.
  - Series of beam energy steps up from 25 GeV to as high as possible.
  - 1 x polarized e- beam
  - Spots < 1"!!
  - ~ 10**8/bunch OK!, _E/E < ~ 10%
  - ESA experiment – good "clean" QCD physics.
    - Important QCD test.
    - Extends understanding of hadronic matter.

Doable at End Sation A?

Fixed target application – test beam

- ILC test beam
  - Electromagnetic calorimeters, luminosity monitors, polarimeters, beam energy spectrometers.
    - See the ILC report on test beams for details.
  - Energy – can use whatever is possible.
  - ~ 1/bunch! for some applications.
  - Polarization required for some applications.
  - Test beam in SABER.

SABER! Nedd a collaboration!

Some important beam-plasma physics questions that could be answered at SABER:

- Can e^+ be accelerated with high-gradient to large energies in plasmas?
- Can an afterburner for a linear e^-/e^+ collider be built? Plasma or Cherenkov wake?
- Can PWFA produce ultra-bright electron beam by self-trapping? Is there an application for these? (FEL, magnetic measurements)
- Can we measure extremely high energy photons produced by Inverse Compton Scattering? (25MeV-15GeV)
- Can a plasma wiggler be used as a positron source for a linear collider? Polarized?
- Can a plasma accelerator produce electron with high enough energies for W, Higgs factory, top, …
- Can we develop a plasma accelerator for fixed target applications at SABER?

SABER parameters/features required for beam-plasma Physics:

- Parameters similar to FFTB for PWFA of e^+
- N=2e10part./bunch, I_{peak}>10kA, $\sigma_r \approx 10\mu m$, $\sigma_z < 30\mu m$
- Longer bunches (600-100μm) can be used for Cherenkov wakefield accelerator and production of e^+ from plasma wiggler radiation
- 2-bunch structure for e^- and e^+ for PWFA and Cherenkov wakefield accelerator: driver: 60-100μm, witness, 30-100μm
- Which 2-bunch formation technique? Beam manipulation/notch collimator? RF photo-injector gun?
- Ti:sapphire laser system (1J) for Inverse Compton Scattering experiments, magnetic materials, EO? (timing system, …)
- Soft-chicane and notch collimator in dispersive region
- Large acceptance energy spectrometer/dump/focusing?
- Flexible beam parameters (e^-/e^+, beam size and length, …)
- Ample experimental area space (larger tunnel at IP0?)

Thank you to:
all speakers
participants and contributors
organizers

For the very exciting workshop!

See you all at SABER!

Summary

- The proposed SABER plasma wakefield experiments in the two-bunch regime are intvestigated using quasi-static PIC code, QuickPIC. Two sets of parameters are used in the simulations. One with 50 microns bunch separation and a higher plasma density and the other set with 100 microns bunch separation and a lower plasma density.

- The plasma density and the charge ratio of two bunches are fine-tuned in each set of simulations to minimize energy spread. 4:1 charge ratio is found to be the best for both cases. The optimal plasma density in the 50 microns separation case is 4E17 cm^{-3} and in the 100 microns separation case is 9E16 cm^{-3}.

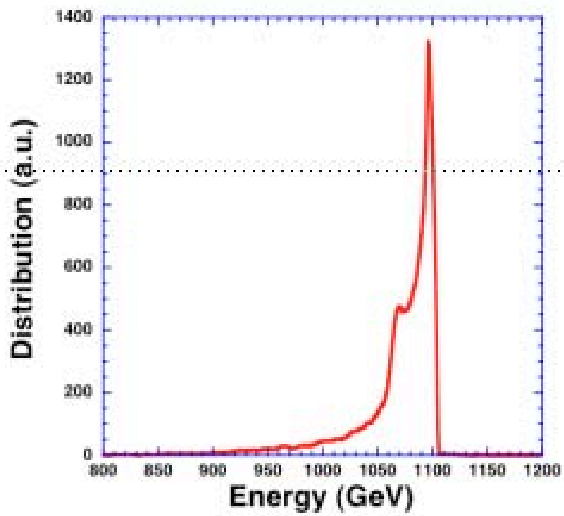
- The 100 microns separation case has an energy spread less sensitive to the variations in experiment condition. The effect of bunch misalignment is also studied.

- 1 TeV afterburner stage is demonstrated in simulation for relative lower plasma density.

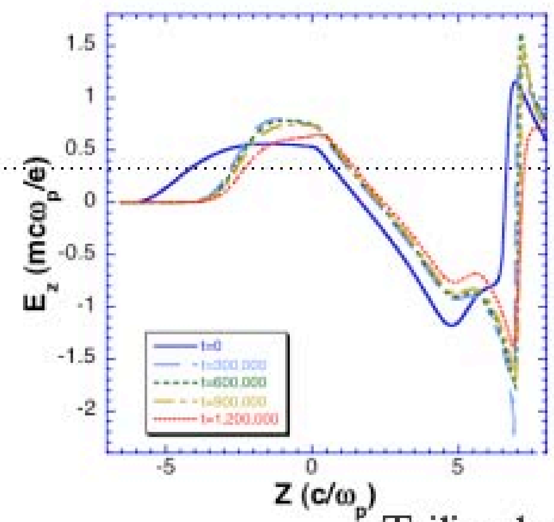
Need to transfer FFTB soft chicane and notch collimator to SABER

Energy spread

Final energy 1.05~1.1 TeV
Energy spread ~ 5%



Wakefield evolution



Tailing beam location

The plateau region in the longitudinal wakefield contributes to the relatively small energy spread. This spread can be further reduced by using shorter trailing bunch.

Wake evolution, driver head erosion