# e-beam Driven (Plasma) Accelerators Working Group Summary

Presented by Patric Muggli, USC

Co-Chair: Johnny Ng, SLAC

# WG Charge:

The working group (WG) will identify the critical experiments that should be performed to study the feasibility of a plasma-based afterburner for a linear collider. These include, but are not limited to, two-bunch PWFA experiments, propagation in long plasmas leading to energy gains of the order of the incoming beam energy, stability of the propagation in long plasmas, erosion of the beam head when field ionizing over distances long compared to the incoming beam beta function, optimization of the transformer ratio and of the loading of the wake by the beam. The WG will also attempt to identify diagnostics appropriate for these experiments. Possible facilities where these experiment could be performed, and the generation of bunches suitable for PWFA experiments will be discussed. The WG will also discuss the necessary advances in computational toll required to design and optimize a full-scale afterburner. The WG will attempt to define the parameters of an afterburner for an existing (SLAC) or future (NLC) collider, and possibly for a future, higher energy collider. The parameters include the incoming beam, the plasma, and the expected beam parameters at the collision point. Issues specifically related to collisions in a particle detector, such as driver/witness beam separation, luminosity, background production will also be addressed.

Goals: 1)"Design" an afterburner for a future 1 TeV linear collider (NLC, TESLA, … upgrades)
2) Incorporate afterburner and accelerator design
3) Identify key PWFA/beam experiments for the afterburne

Organization: Invited speakers to present their work
1) Afterburner
2) PWFA experiments/simulations

Method: Talks serve a seeds for topical discussion about the afterburner

# nLC upgrade Parameters

| NLC and TESLA Parameters | | | | |
|---|---|---|---|---|
| | 2 TeV | | 2 TeV | |
| | NLC | AfterBurn | US SC | AfterBurn |
| CMS Energy (GeV) | 1000 | 2000 | 1000 | 2000 |
| **Linac Length (km)** | **14.1** | **0.13** | **30** | **0.21** |
| Repetition Rate (Hz) | 120 | 120 | 5 | 5 |
| **Bunch Charge ($10^{10}$)** | **1.5** | **1.1 / 0.4** | **2** | **1.5 / 0.5** |
| Bunches/RF Pulse | 96 | | 2820 | |
| Bunch Separation | 2.8 ns | 0.6 ps | 337 ns | 1 ps |
| **Eff. Gradient (MV/m)** | **52** | **4000** | **35** | **2400** |
| Plasma Density ($1/m^3$) | | 2.00E+22 | | 9.00E+21 |
| $\gamma\varepsilon_x$ at IP ($10^{-8}$ m-rad) | 360 | 360 | 960 | 960 |
| **$\gamma\varepsilon_y$ at IP ($10^{-8}$ m-rad)** | **4** | **4** | **4** | **4** |
| PI Lens Reduction | | 10 | | 11 |
| **$\sigma_x$ / $\sigma_y$ at IP (nm)** | **219 / 2.1** | **37 / 3.9** | **489 / 4.0** | **67 / 4.3** |
| $\sigma_z$ at IP (um) | 110 | 32 | 300 | 35 |
| $\Upsilon$ave | 0.27 | 5 | 0.11 | 3.5 |
| Pinch Enhancement | 1.4 | 1.1 | 1.7 | 1 |
| Beamstrahlung $\delta B$ (%) | 8.4 | 40 | 5.9 | 32 |
| Photons per e+/e- | 1.2 | 2 | 1.6 | 1.7 |
| **Luminosity (1033)** | 31 | 10 | 38 | 10 |

http://www.slac.stanford.edu/xorg/accelops/

- Based on upgrade of proposed next linear collider
- "Warm"=11.4 GHz
- "Cold"=1.3 GHz

# Invited Talks and Discussion Topics

Afterburner-related Issues for Linear Colliders, *T. Raubenheimer*
-Table of afterburner parameters

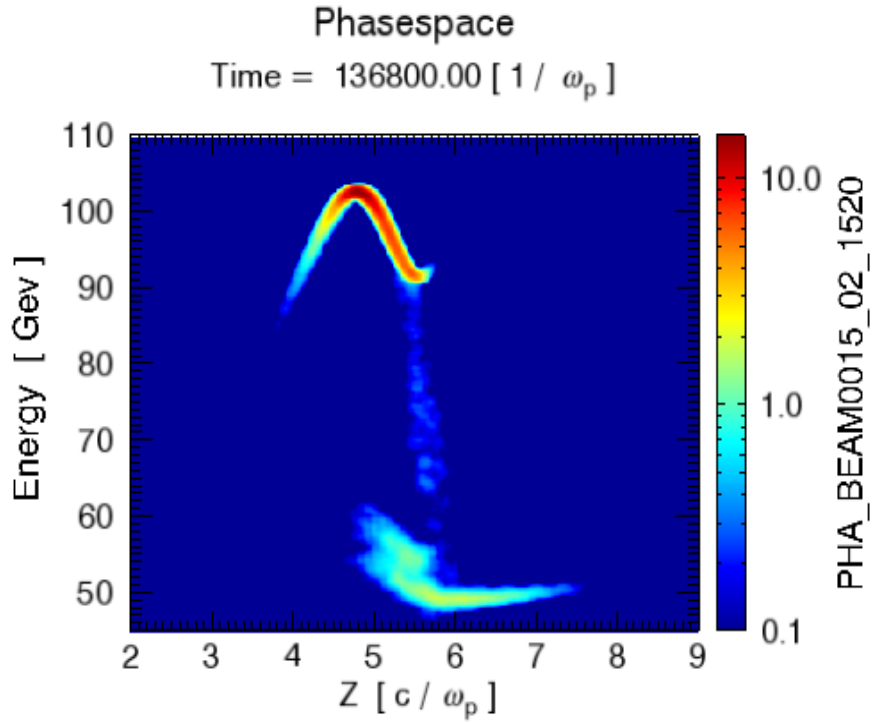
Simulation studies of an Afterburner Conceptual Design, *C. Huang*
-Simulation of SLC AB, 50GeV gain over 3 m, $\Delta E/E \approx 6\%$, hose oscillation of a few microns, preserve incoming emittance

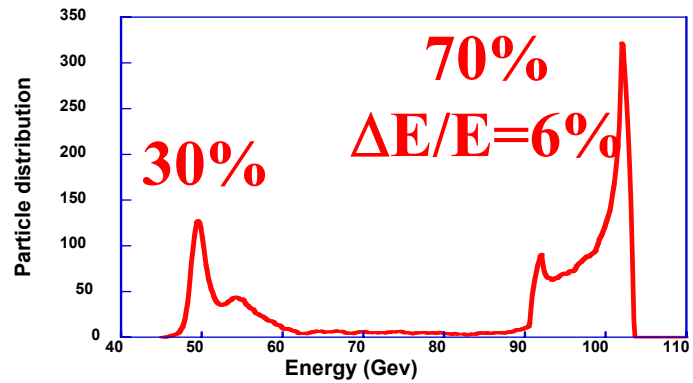
Field-ionization of a Neutral Li Vapor using a 28.5GeV e-beam, *C. O'Connell*
-Observation of ionization threshold, AB beam will ionize $H_2$

Energy Gain in E-164X, *M. Hogan*
-High gradient (≈40GeV/m), large energy gain (≈4GeV), PWFA scaling law, AB gradient feasible

Potential Beams at ORION, *E. Colby*
-Possible test bed for plasma lens experiments and ideal beams for 2-bunch experiments (60MeV+350MeV)

# *50 Gev energy gain in 3 meters !*




- Not optimized
-SLC-based
- Energy doubler!
- ΔE/E≈6%!

C. Huang

# *"Afterburner" simulation*

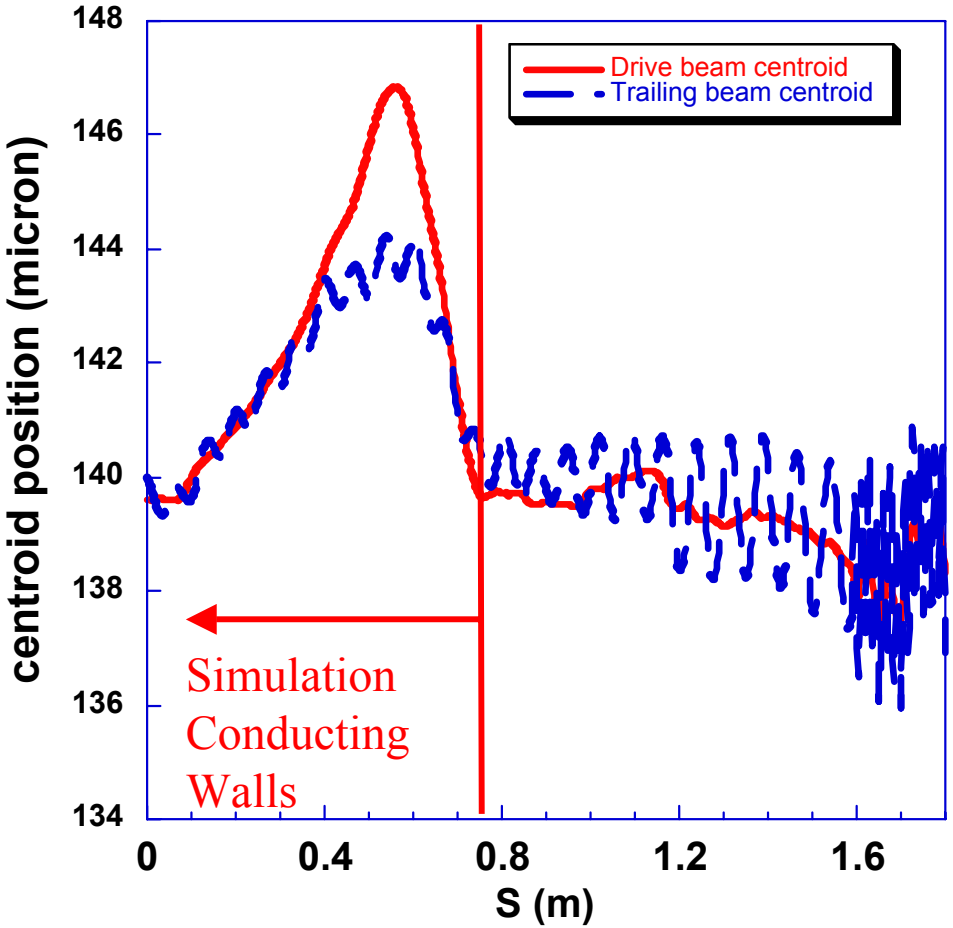
## *Emittance of the trailing beam*

**Some particles are lost, but no significant emittance growth.**

C. Huang

# *Hosing in "afterburner"*

Small hosing is observed for trailing beam while no hosing occurs in the drive beam




Large excursion for μm beam
Challenging for simulations:
<1μm beam and $c/\omega_p \approx 50\mu m$
But NEEDED!

C. Huang

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e164 & e164x

PLASMA WAKEFIELD ACCELERATOR EXPERIMENT

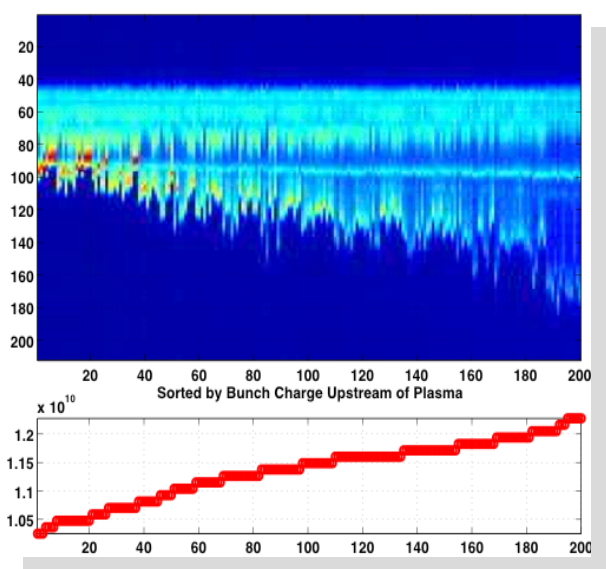
# ENERGY LOSS ASSOCIATED WITH FIELD IONIZATION

USC
SLAC
UCLA
C. O'Connell

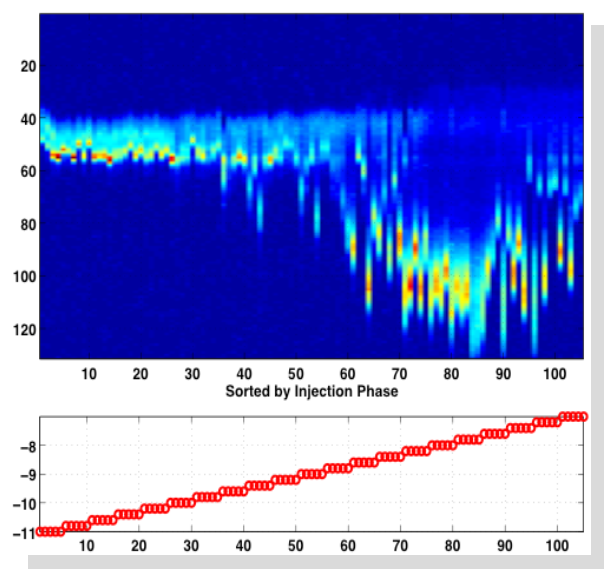
$$W_{Li}\left(s^{-1}\right) \approx \frac{3.60 \times 10^{21}}{E_r^{2.18}\left(\frac{GV}{m}\right)} exp\left(\frac{-85.5}{E_r\left(\frac{GV}{m}\right)}\right)$$

$$E_r \sim \frac{N}{\sigma_r \sigma_z}$$

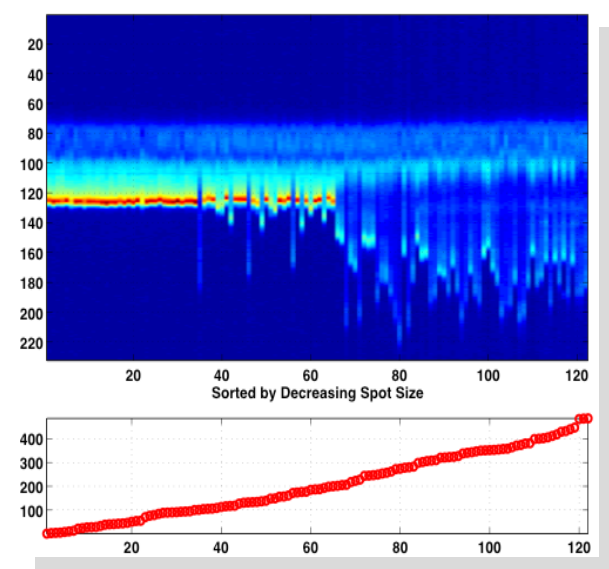
**CHANGING CHARGE**




**CHANGING BUNCH LENGTH**




**CHANGING SPOT SIZE**



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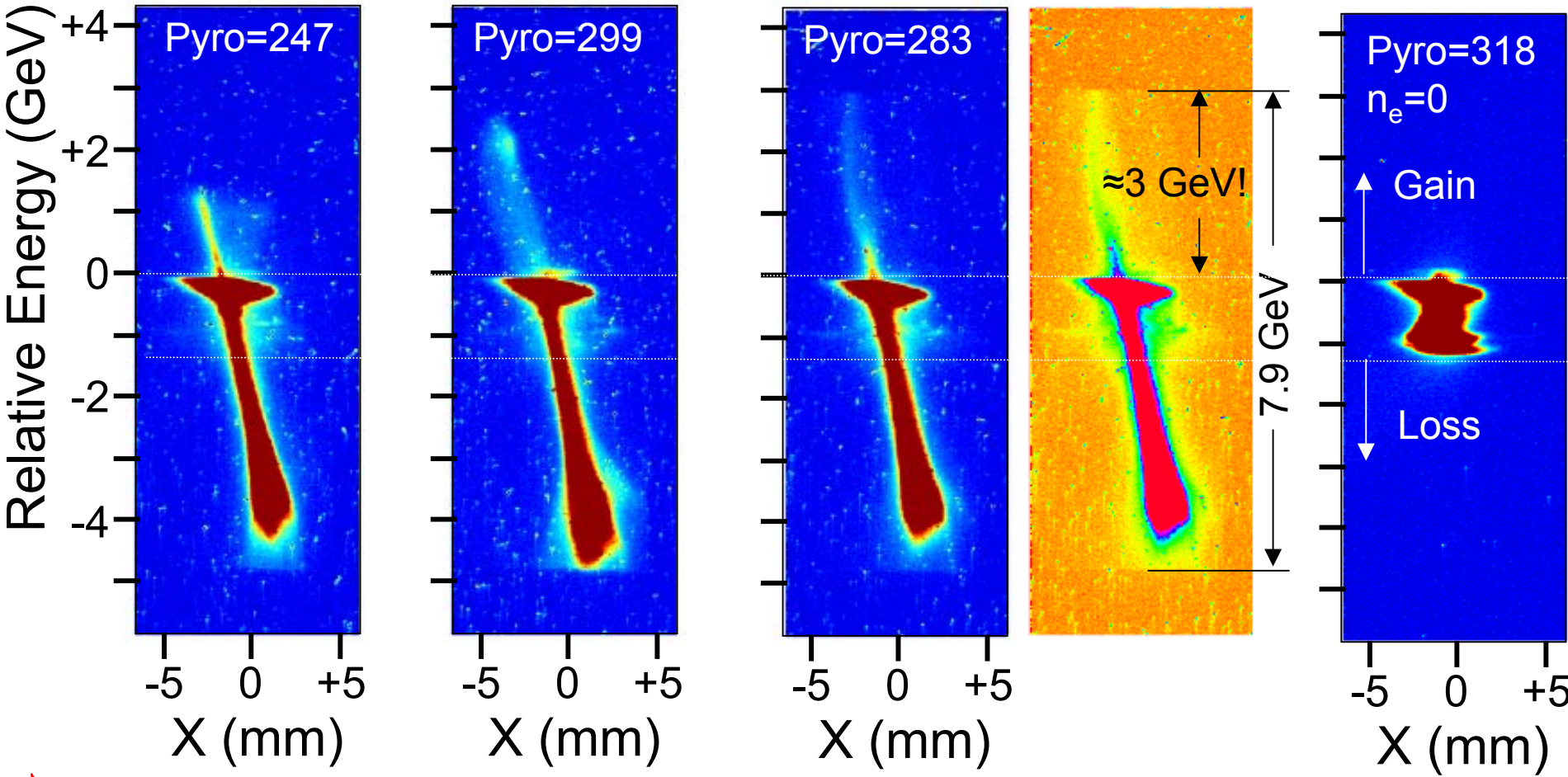
# $n_e \approx 2.55 \times 10^{17}$ cm$^{-3}$ RESULTS

L≈10 cm, N≈ $1.8 \times 10^{10}$




➡ Energy gain reaches ≈4 GeV, over ≈10 cm or ≈40 GeV/m

M. Hogam

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# Invited Talks and Discussion Topics (2)

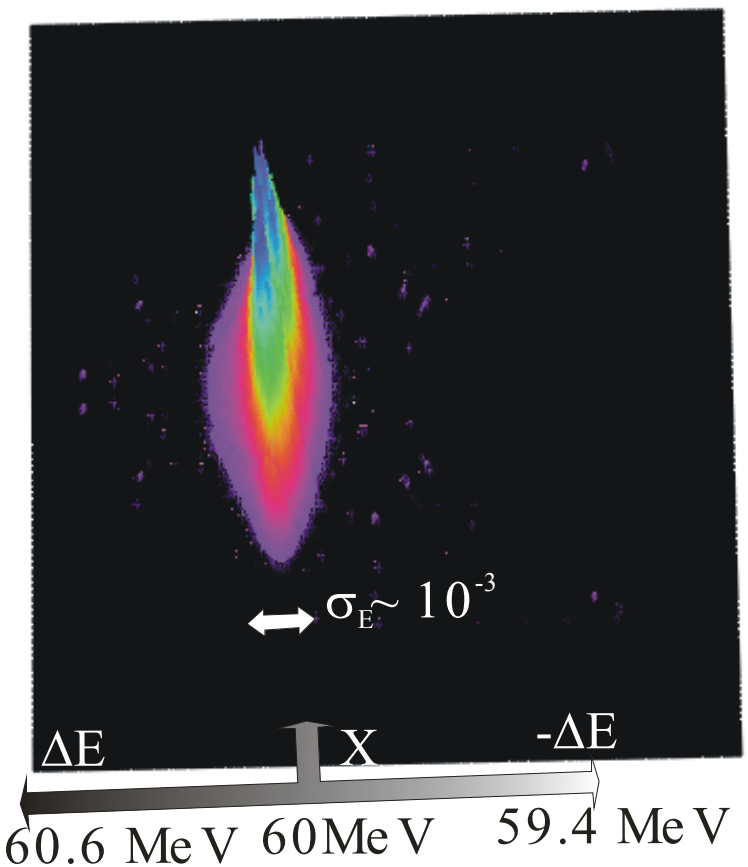
Acceleration and focusing of relativistic Electrons in Overdense Plasmas,
*V. Yakimenko*
-Phase between longitudinal and transverse wake fields
-Micro-Bunch train PWFA experiment planned

The UCLA/NICADD Plasma Density Transition Trapping Experiment
*M. Thompson*
-Density trapping as a source of ultra-short bunches

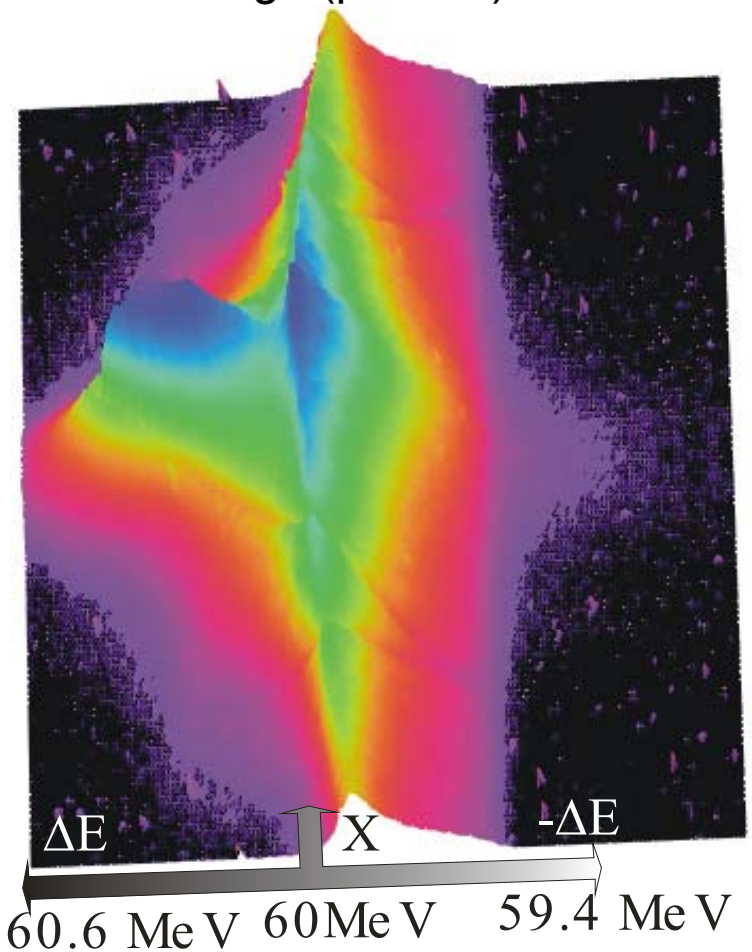
Joint session with the Computational Accelerator Physics WG
(*J. Rosenzweig, D. Bruhwiler, D. Dimitrov*)
-AB with $\sigma_r \approx 1\,\mu m$ $c/\omega_p \approx 30\,\mu m$ is a challenge for simulations and may not be in the linear regime of the PWFA
-Effort to include impact-, field-ionization, scattering and radiation in PIC codes
-Field ionization also works for positron PWFA
-Web interface/submission for OOPIC

# The picture

Discharge (plasma) off




Discharge (plasma) on




Energy distribution and transverse beam phase space dramatically changed after a 60 MeV, 0.5 nC, 3 ps (FWHM) e-beam passes through 17 mm of ~$10^{17}$ plasma.

V. Yakimenko

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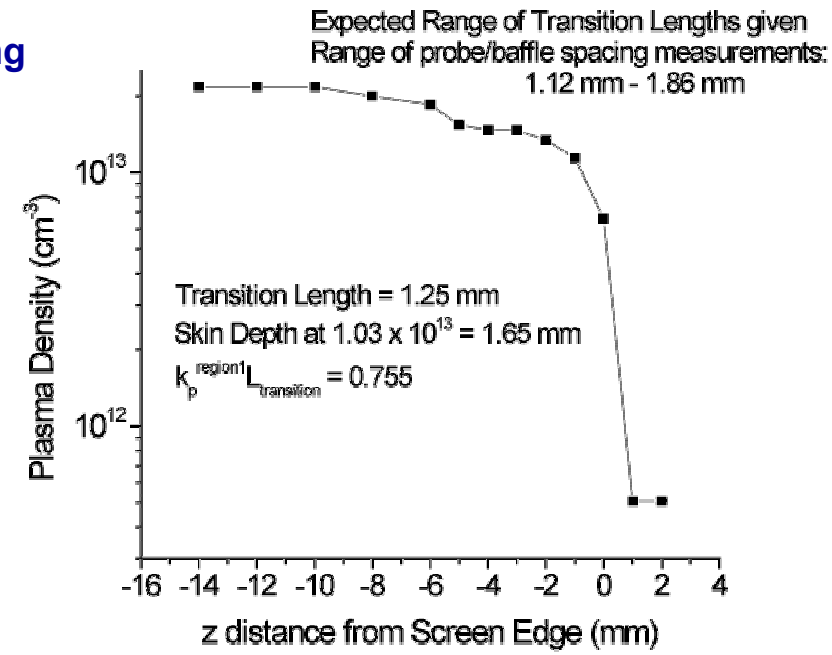
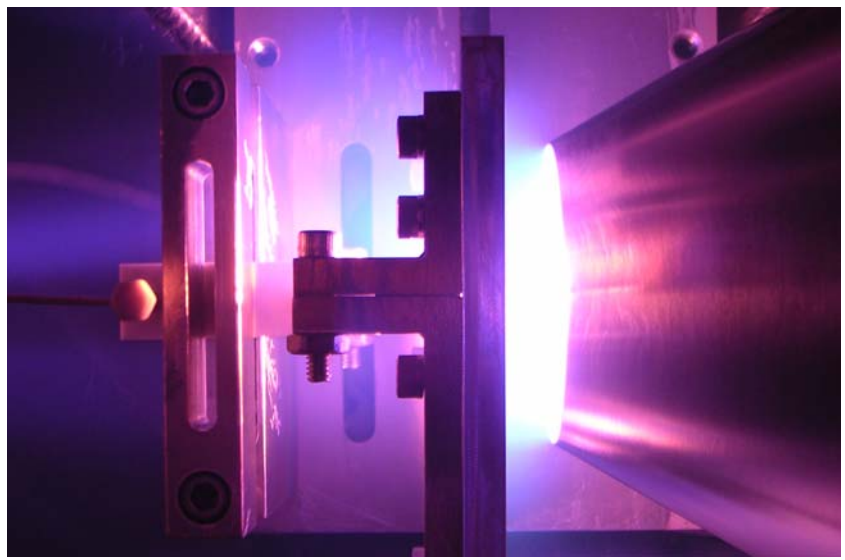
## The UCLA/NICADD Plasma Density Transition Trapping Experiment M.C. Thompson, et al.




- Suitable Density Transition Produced
- First commissioning run January 2004 to May 2004
- Still working to achieve all the experimental parameters.
- Second run to start September 2004

| | |
|---|---|
| Beam Energy | 1.5 MeV |
| Beam Charge | 130 pC |
| Beam Duration $\sigma_t$ | 0.3 ps |
| Beam Radius $\sigma_r$ | 100 $\mu$m |
| Normalized Emittance | 16 mm-mrad |
| Energy Spread (rms) | 4 % |

Simulated Captured plasma electron beam parameters.



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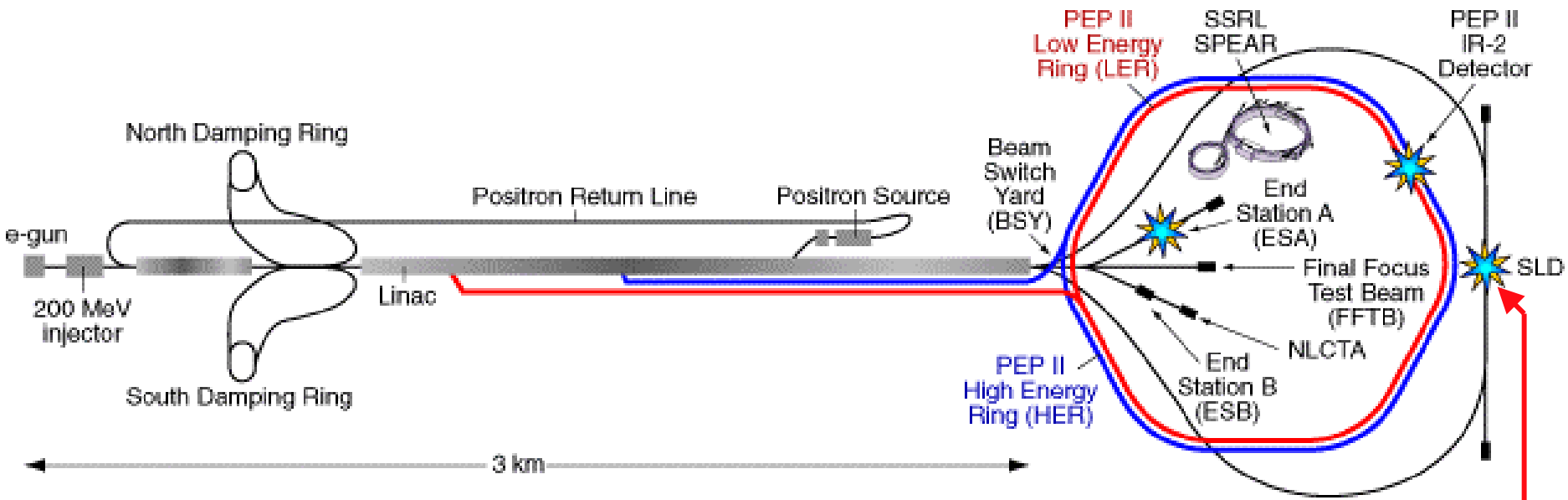
# Energy Doubler for a Linear Collider (SLC)

*S. Lee et al., PRSTAB 5, 011001 (2002)*

50 GeV $e^-/e^+$ -> $100^+$ GeV $e^-/e^+$



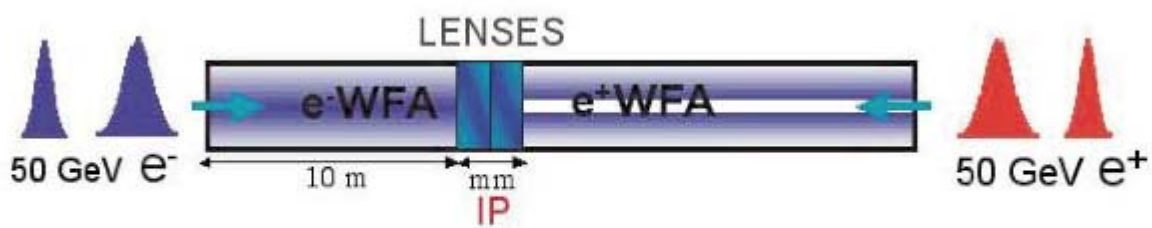
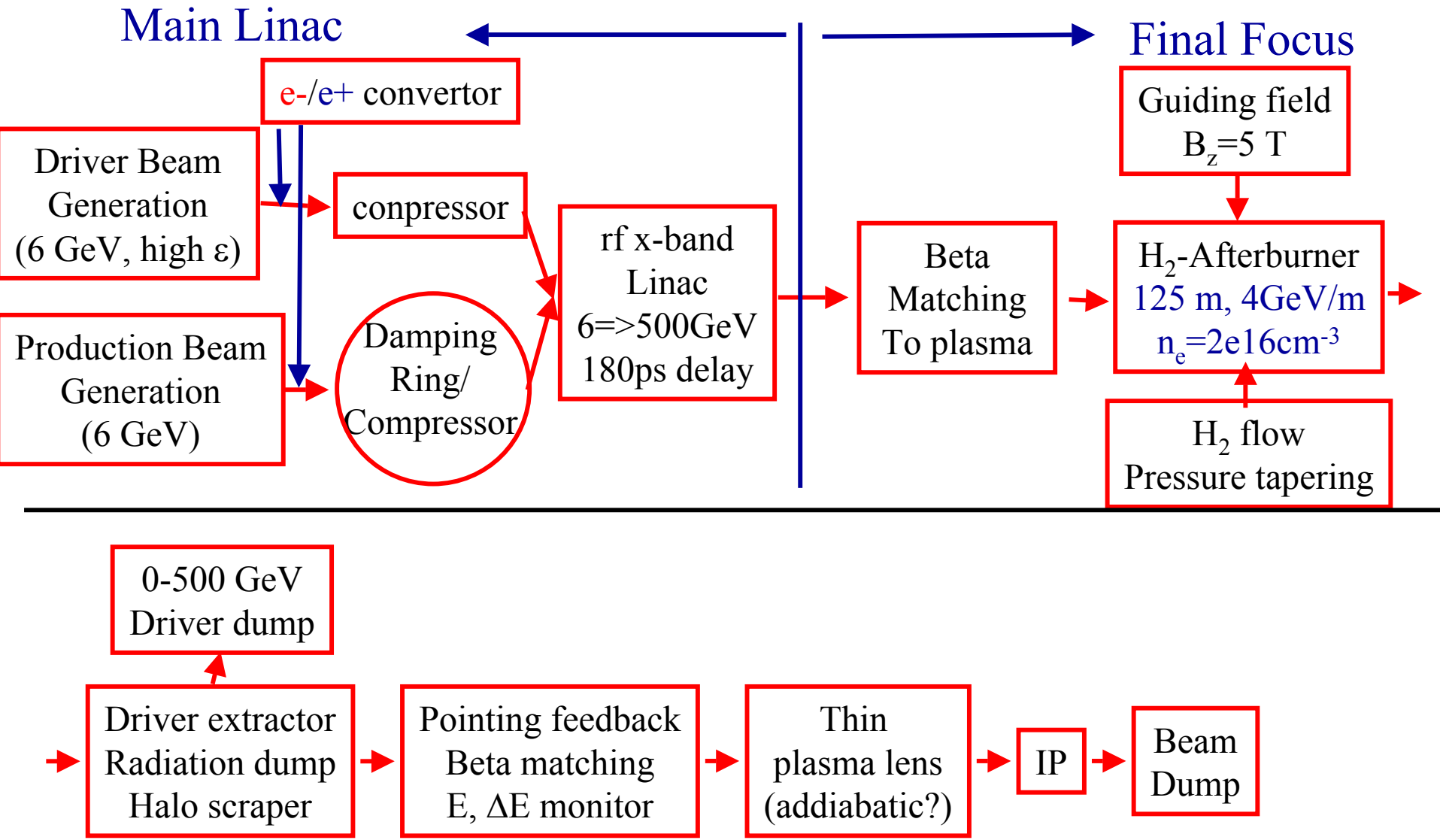




FIG. 1. (Color) Schematic of the plasma afterburner concept. Plasma wake field acceleration (WFA) sections are placed at the interaction point (IP); short plasma lens sections of higher density further focus the beams before collision. Note that the WFAs are not symmetric; the positron section may be longer to reach the same energy and may have a channel to enhance the wake.

# Energy Doubler for a nLC (Afterburner)

*E.D.A. Working Group et al., PRSTAB 1, 1*

1 TeV $e^-/e^+$ -> 2 TeV $e^-/e^+$



# Afterburner: 500 GeV+500 GeV => 1 TeV+1 TeV

| NLC and TESLA Parameters * | | | | |
|---|---|---|---|---|
| | 2 TeV | | 2 TeV | |
| | NLC | AfterBurn | US SC | AfterBurn |
| CMS Energy (GeV) | 1000 | 2000 | 1000 | 2000 |
| **Linac Length (km)** | **14.1** | **0.13** | **30** | **0.21** |
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| Photons per e+/e- | 1.2 | 2 | 1.6 | 1.7 |
| **Luminosity (1033)** | 31 | 10 | 38 | 10 |

***Tor Raubenheimer***

- -2, 6GeV linacs
- -Train of bunch pairs 64μm+32μm @ 180μm
- -Charge split ≈3:1
- -AB in the final focus section
- -$H_2$ field ionized plasma
- -$n_e$=2e16 $cm^{-3}$, L=125m
- -4 GeV/m
- -Matched beam ($\beta_x$=$\beta_y$)
- -Preserve linac emittance
- -Split PWFA-plasma lens
- -Lower luminosity

# AB numbers:

-Energy deposited in the plasma: $E_d$<560J/bunch pair

-Power deposited in the plasma:

$$P_d=96\text{bunches}*120\text{Hz}/125\text{m}*E_d<52\text{kW/m}$$

-Betatron radiation loss <100 MeV/m ($\sigma_r \approx 1\mu m$)

-Efficiency $N_p/N_d$=37% (increases if $R=E_{acc}/E_{decc.}>1$)

-AB preserves incoming emittance (scattering negligible), polarization

-<200m long, fits in the final focus section of nLC

-Luminosity lower by≈3 upon energy doubling

# Options/Alternatives:

-Double bunch pair spacing, cold nLC with large bunch spacing

-CLIC-like, AB: 13, 10m-long, 50 GeV driver beam sections

- More efficient driver beam generation
- Beam pointing feedback
- Increase in complexity
- Longer, lower mean gradient AB, does not fit in final focus section

-$e^-$-driver for $e^+$-PWFA: requires 2 linacs on the $e^+$ side

# Key experiments for afterburner:

Large energy gain / large gradient over long distances

Possible in the SLAC/FFTB in the next 2 years, but requires modified beam dump line

L≈30-100cm available!

Two-bunch experiments
- Beam acceleration
- Beam quality
- Beam loading

Experiments may be possible in the SLAC FFTB.

Demonstration at MeV energies: ideal location=SLAC/ORION,A0, or …

Example: 100μm driver, 25μm witness, variable delay 100-300μm, 1+0.3nC, >100MeV

Bunch shaping
- $R=E_{acc}/E_{decc.}>1$
- Head erosion
- Hose stability

Hosing

Scaled to lower energy or longer bunch, same # of β-tron oscillations

$L=125m$, $n_e=2e16m^{-3}$, $\gamma=1e6$, $\lambda_{\beta 0}\approx 17cm$, $N_{\beta 0}\approx 750$!

Measure displacement ≈1μm (or miss collision in AB!)

# Key experiments for afterburner: (2)

Plasma lens focusing to <1 μm sizes

Need demonstration of <μm generation by plasma lens

Demagnification 5-10, use LCLS high quality beam?

Plasma sources development ($H_2$)

Deposition of large amount of heat by the driver bunch

Positrons

Do all experiments with $e^+$

In addition:

Simulation tools and simulations are critical

# WG Conclusions

The afterburner (AB) is a viable energy doubler for a nLC

We have "designed" an AB based on existing nLC designs

3 steps towards the afterburner since AAC'02:

-Field ionized plasma source => $n_e=10^{16}$ $cm^{-3}$ over L=10-125m possible
-Demonstration of >10 GeV/m, >1 GeV gain in a PWFA (SLAC $\sigma_z$)
-Progress towards reduced algorithm numerical codes that could model a full scale AB

More experiments are needed (PWFA, beam), low and high energies
There are still major challenges such as positron AB and final focus
Need an AB-class facility such as FFTB
Need to involve the whole accelerator community!

Thank you to all speakers, contributors, and organizers!