CO_2-laser-driven wake-field accelerator with external injection

ATF experiment AE71

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Collaborators:
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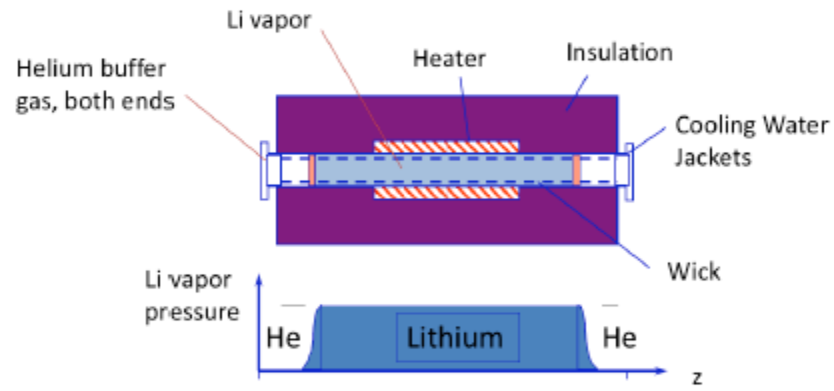
Basics

- We would like to explore large (e.g. psec or 0.5 mm) length of “bubble” in CO_2-laser driven plasma wake-field accelerator
- Matching injecting of an external high quality electron bunch with duration ~ 10 fsec and synchronizing it with the “bubble” should allow us to accelerate high quality electron beams with energy stability an spread reaching towards 10^{-4}
- CO_2-laser power upgrades are in progress at BNL, independently from this project
- Use visible diagnostics (since plasma is designed for CO_2-laser)
- Our project is devoted towards developing key components necessary for such experiment:
  - Plasma source with ramp-up and ramp-down density profiles
  - Electron bunch compressor to 10 fsec with emittance preservation
  - Visible laser diagnostics for the plasma

Looking towards ATF II with the 100TW CO_2 upgrade

CO_2 laser will drive bubble-regime wakes



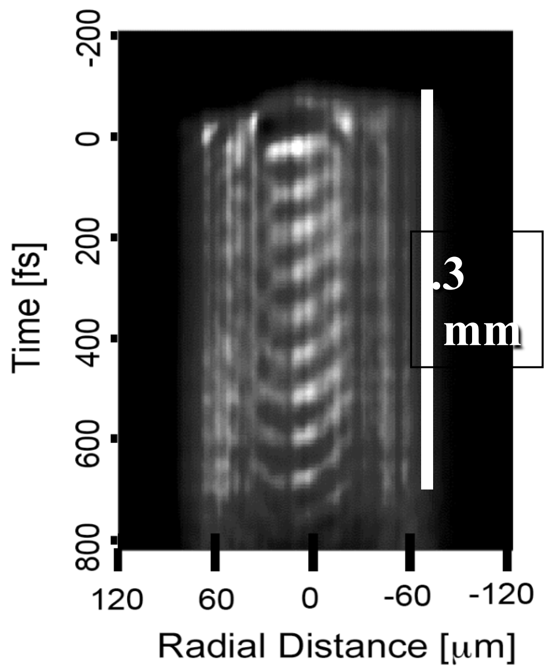
Experiments will be conducted in 10 to 100 cm long plasma source with density 5 x $10^{15} < n_e < 10^{17}$ cm^{-3} that will be built by C. Joshi team.

<u>Two parameter sets for LWFA at ATF II. (C. Joshi)</u>

Laser a_0	*Intensity (W/cm^2)*	*Dephasing Length (cm)*	*Energy Gain MeV*	*Spot w_0 (μm)*	*Matched-spot w_m (μm)*	*Rayleigh Length (mm)*
2	$4x10^{16}$	10	666	200	150	12.6
4	$1.6x10^{17}$	14	1332	100	212	3.1

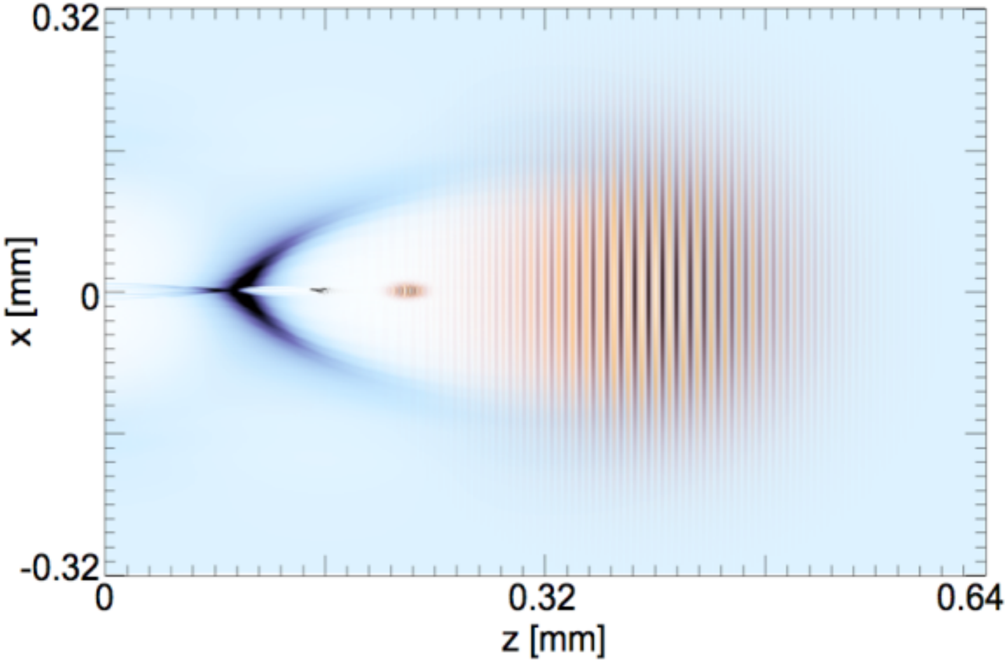
Comprehensive study of external injection of ~ 10fs x ~ 3μm bunches from the ATF linear accelerator into the plasma accelerator, operated below its self-injection threshold. Work will be supported by full simulations of all key processes in the proposed LFWA. (W. Mori)

Big advantage: our plasma is transparent for visible lasers



M.C. Downer, R. Zgadzaj, UT Austin

Example of the CO2-laser driven bubble



Simulated bubble in plasma density 1.1 x 10^{16} cm^{-3} ,driven by 500 fsec CO_2 laser with a_0 =1.4

Wei Lu

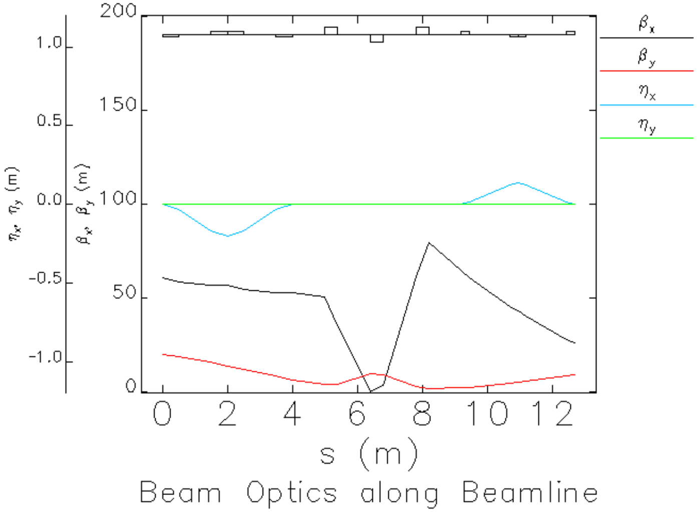
The “bubble”, or ion cavity, will have typical lateral dimension ~ 300+ μm, time duration ~1+ psec for $n_e = 10^{16}$ cm^{-3}.

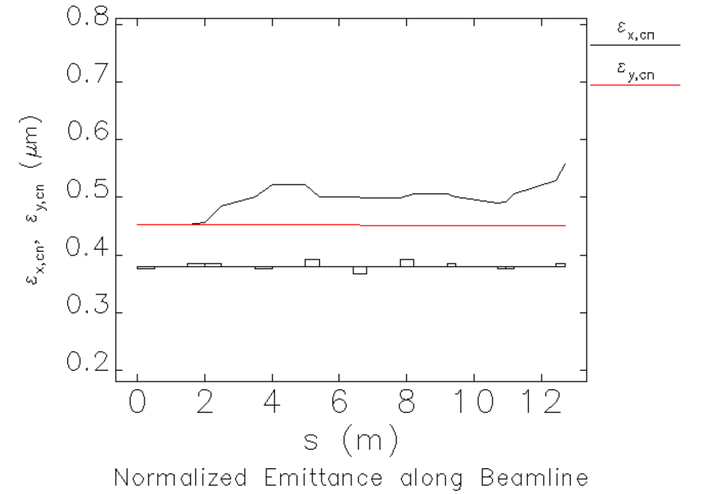
Its large size will allow unprecedented detail in the visualization of the bubble structure, its shot to shot variations, and evolution.

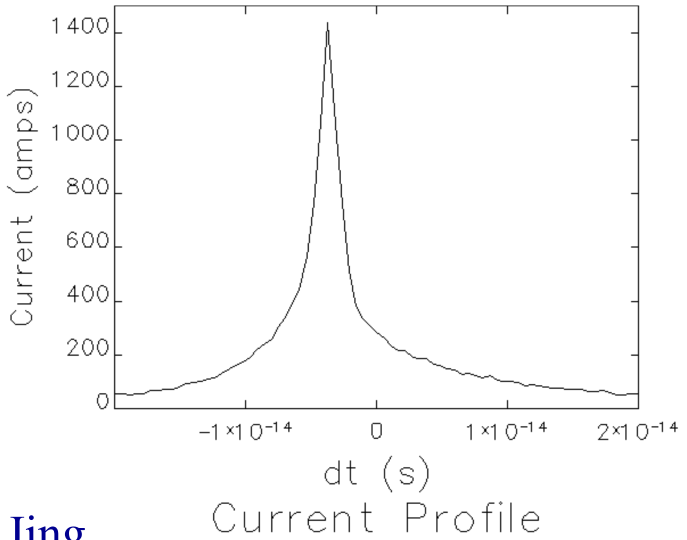
ATF II

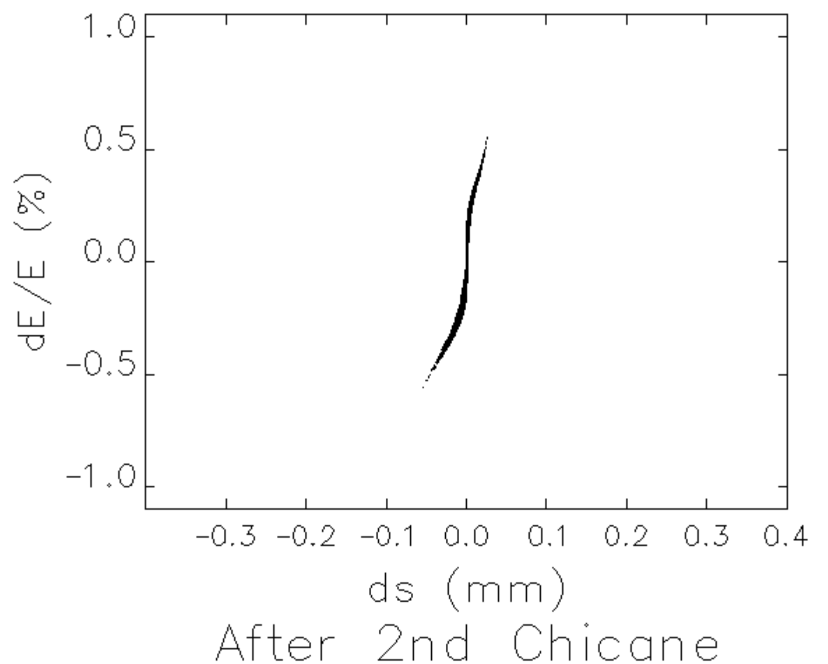
ZigZag compressor
Taking care of CSR

Energy, MeV	150
Bunch length, fsec	≤10







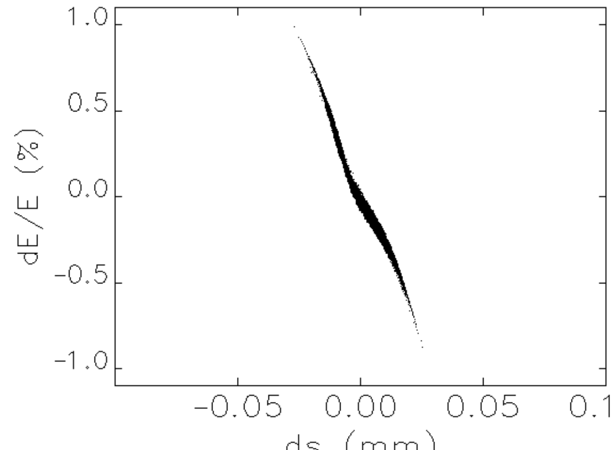


Y. Jing

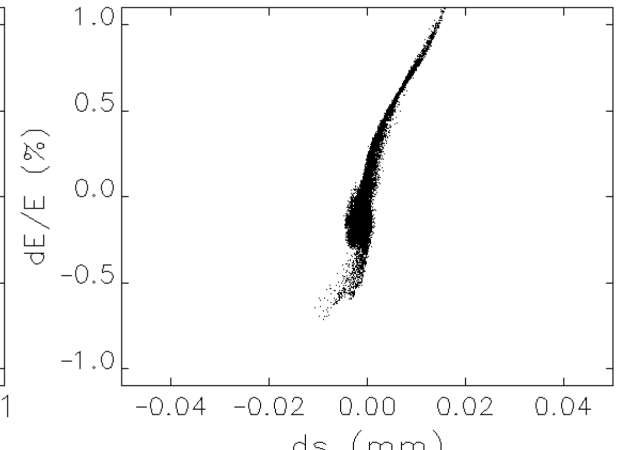
Bunch Compression: existing ATF beam

New Zig-Zag type compressor will be installed in ATF to compress bunches to 12fs

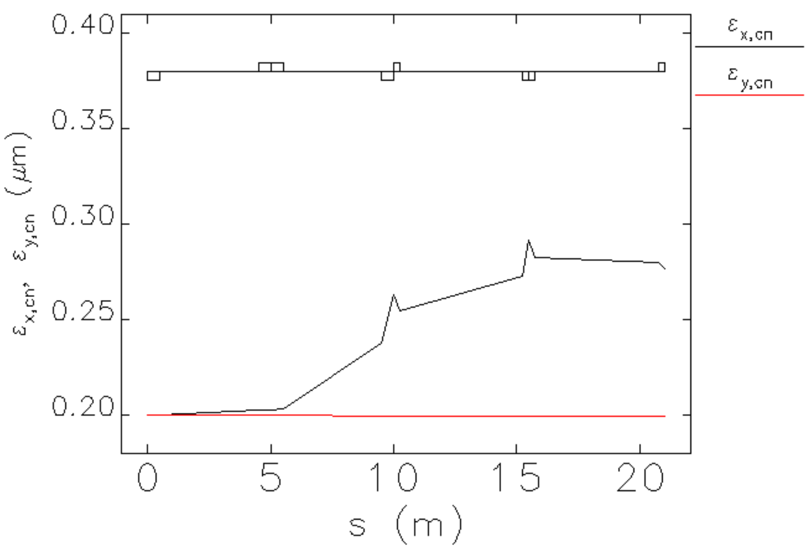
Energy, MeV	70
Bunch length, mm	0.06
Chirp, m^{-1}	20
Bunch length, rms, fsec	12



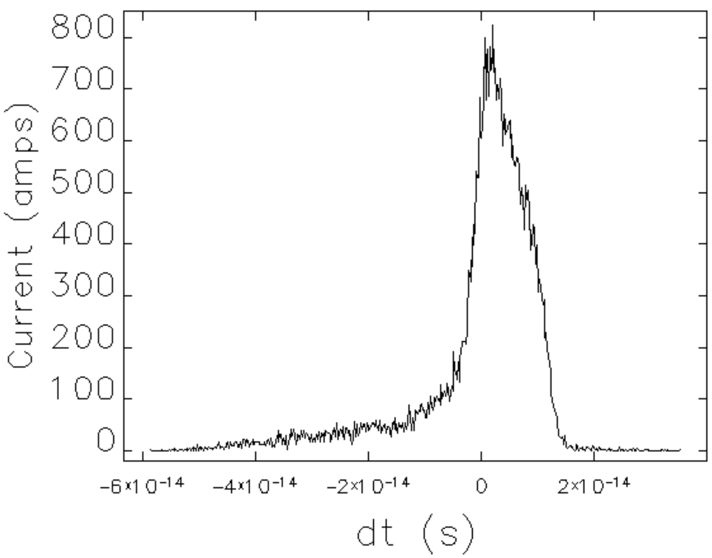
Before 2nd Chicane



After 2nd Chicane



Normalized Emittance along Beamline



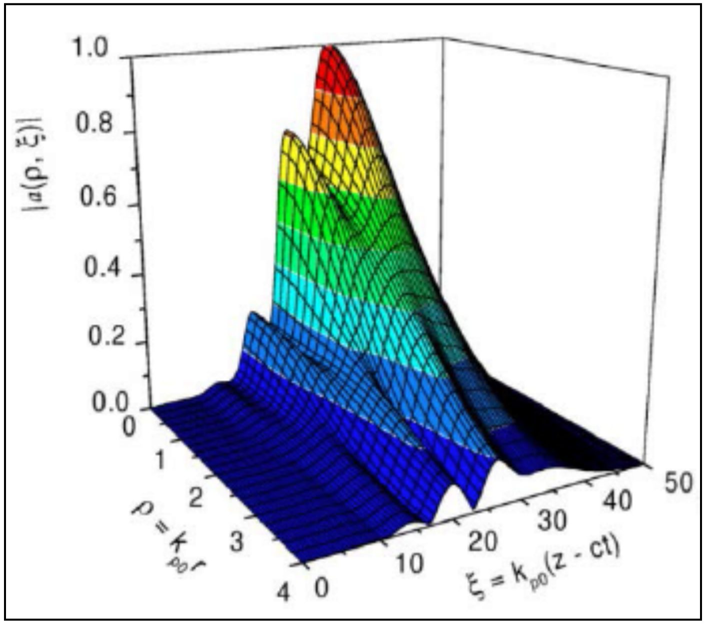
Current Profile

Y. Jing

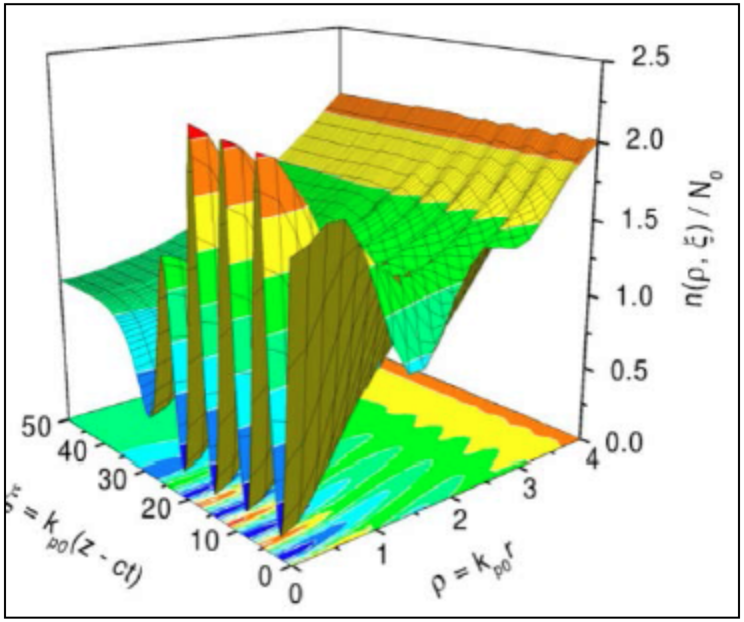
Near term plans

- Experimental demonstration of CO_2 laser driven wake-field in the self-modulation regime (2TW 2 psec CO_2 laser pulses)
  - With shorter pulse (1ps, 1-2TW) it is possible to observe self-injected mono-energetic electron beams
- Direct snapshot of the CO_2 laser wakefield and its evolution (and injection process) using the short electron beam from ATF linac
  - such a scheme for 800nm LWFA has recently been demonstrated by Tsinghua/NCU/UCLA team

Self-modulated wakes with current ATF I CO_2 laser parameters



Normalized laser field



Normalized plasma density

2.5TW, 2ps pulse, after 6.7cm of propagation in 1×10^{16} cm^{-3} plasma. The laser pulse self modulates, its peak intensity grows by more than 50%, and a strong wake is produced, with wake amplitude greater than 1GV/m.

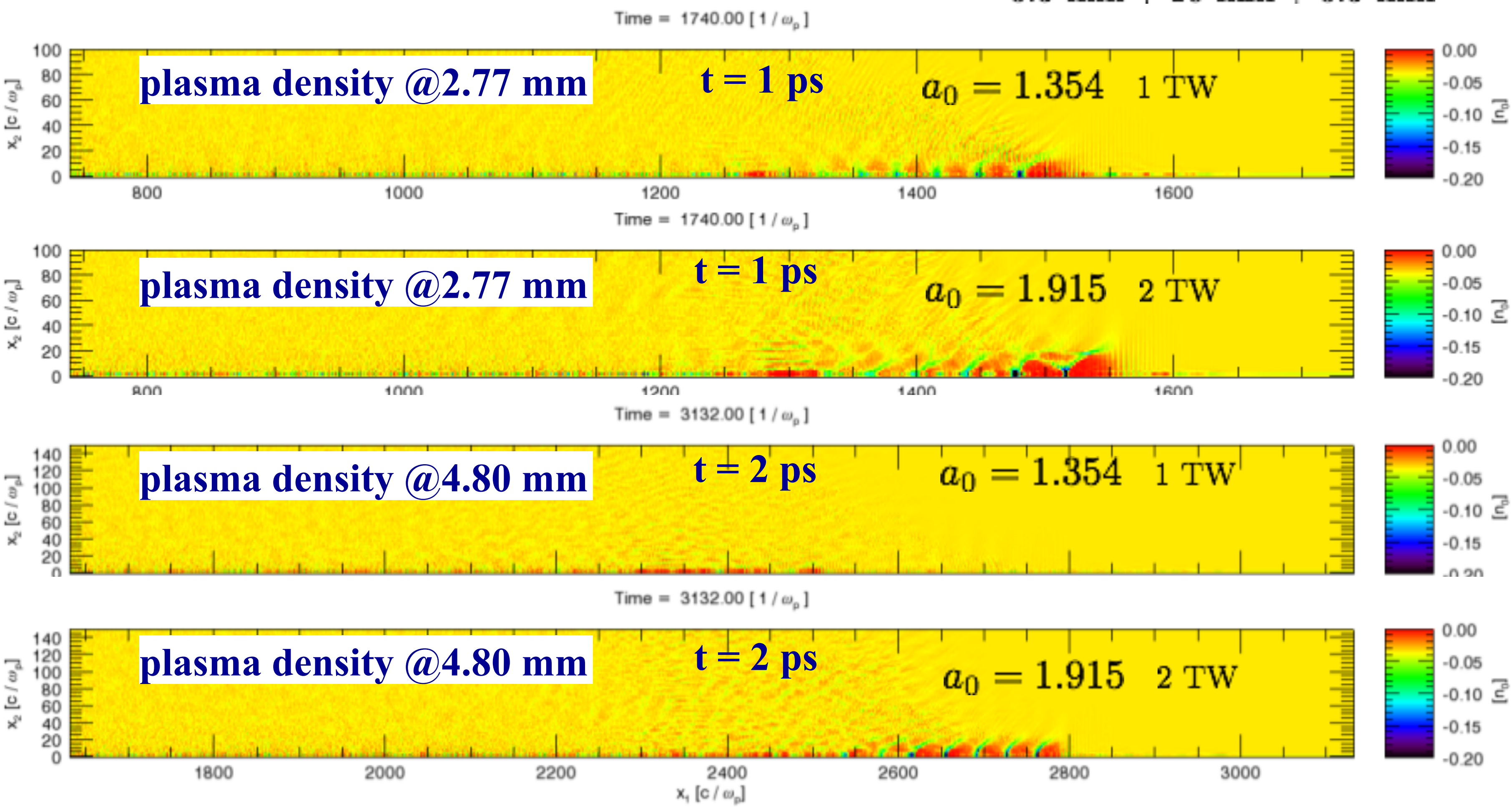
N.Andreev

Quasi-3D simulation for SMLWFA by CO2 laser

w0 = 50 um

$n_p = 3.87 \times 10^{17}\ \mathrm{cm}^{-3}$

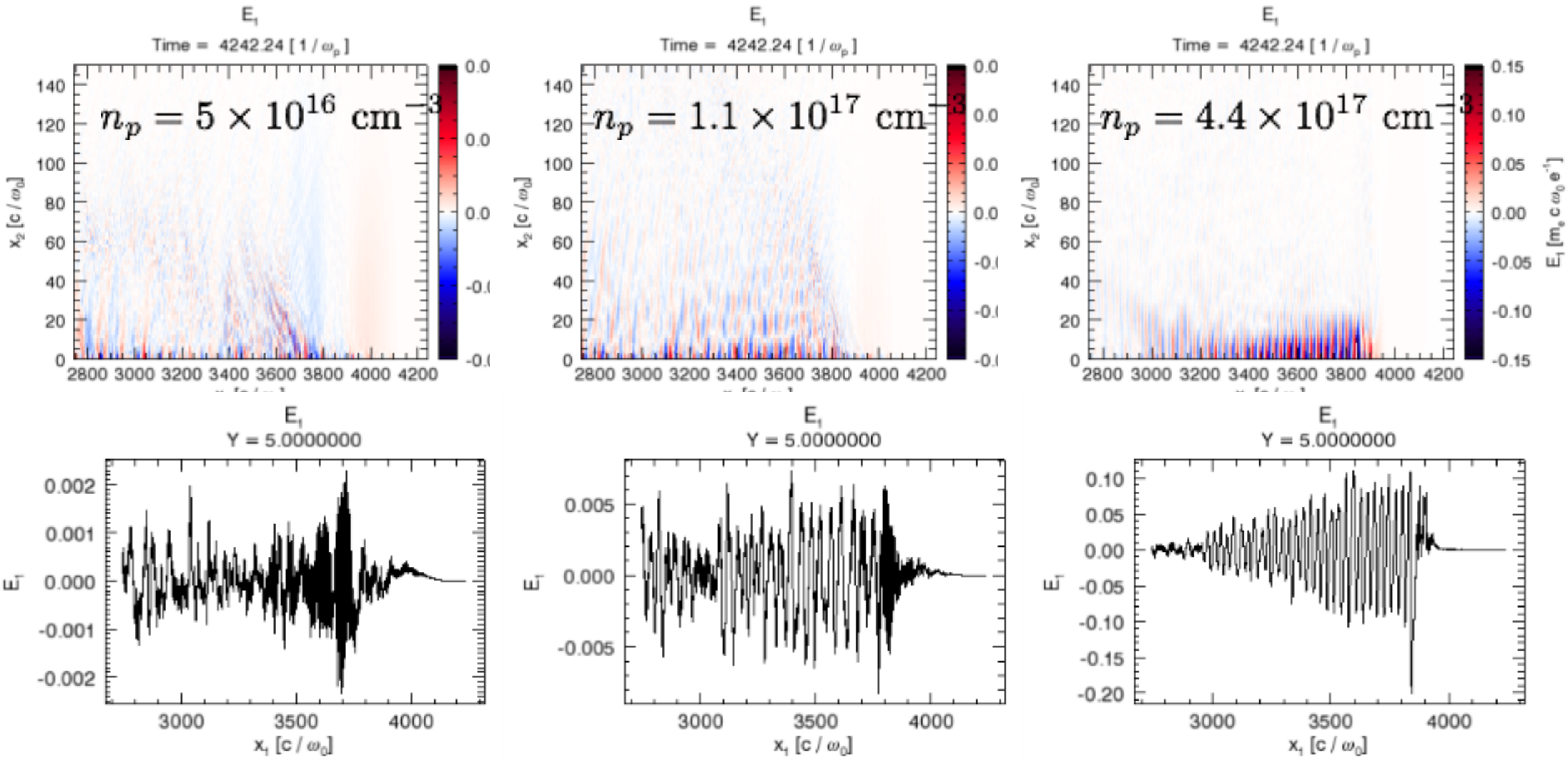
$0.5\ \mathrm{mm} + 10\ \mathrm{mm} + 0.5\ \mathrm{mm}$



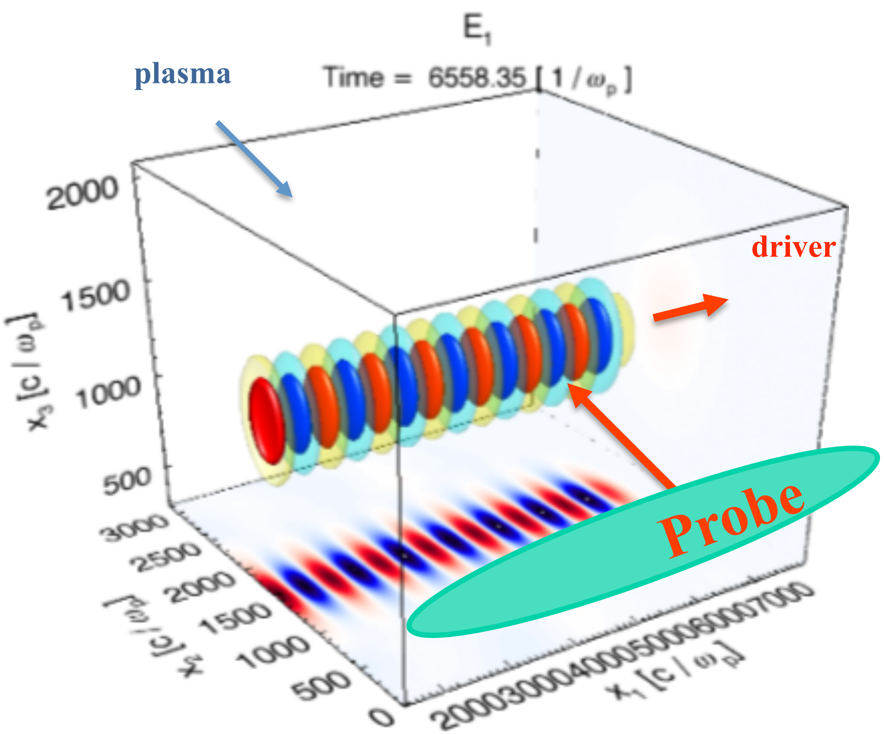
Self-modulation vs. plasma density

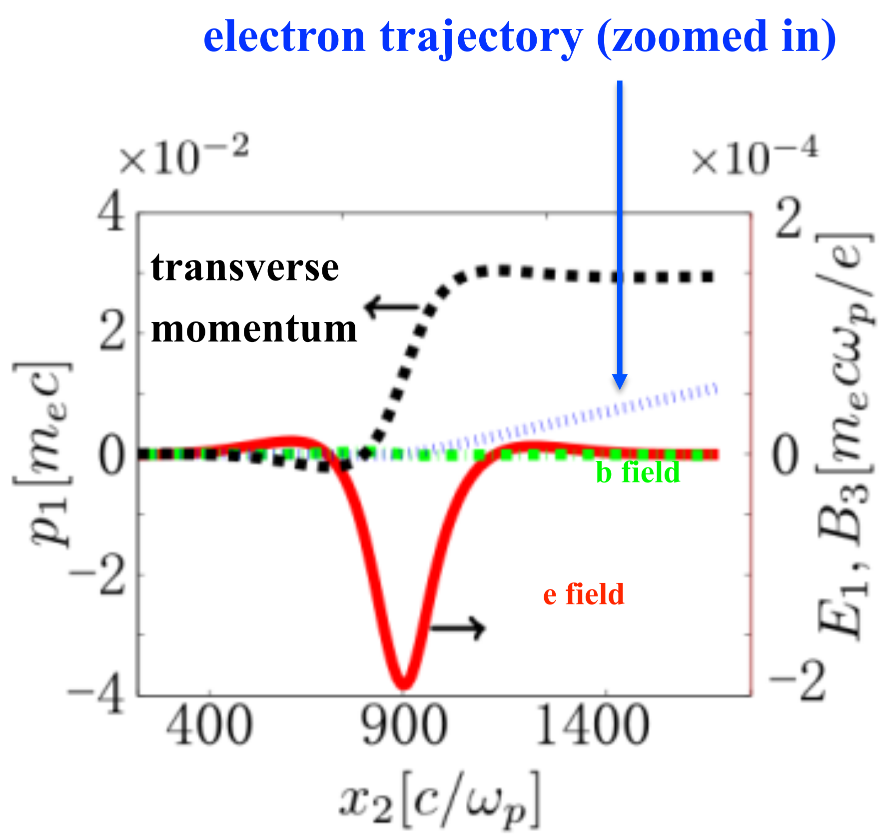
For a given 2 ps, 1 TW laser with 100 um spot size, higher plasma density leads to stronger modulation and more intense accelerating fields.

laser: $w_0 = 100\ \mu\mathrm{m} \qquad P = 1\ \mathrm{TW}$



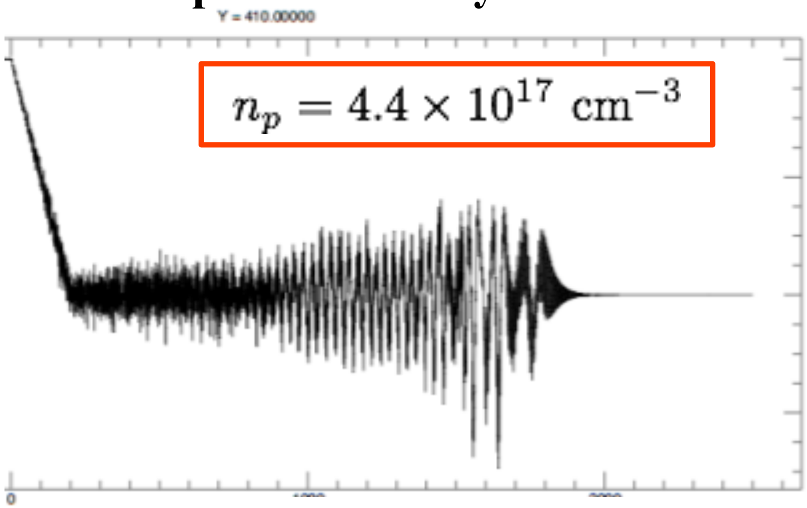
Electron-beam probe sketch



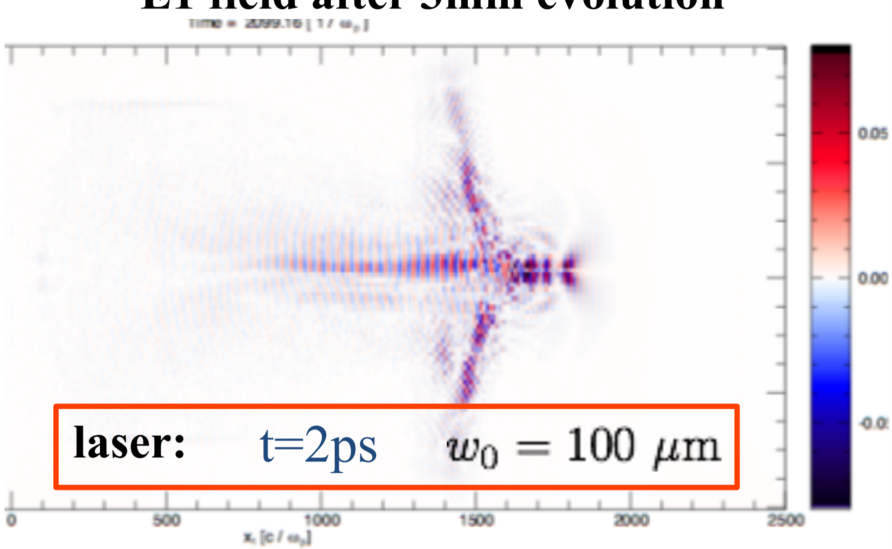


Electron probe snapshot of self-modulated wake (simulations)

plasma density lineout



E1 field after 3mm evolution

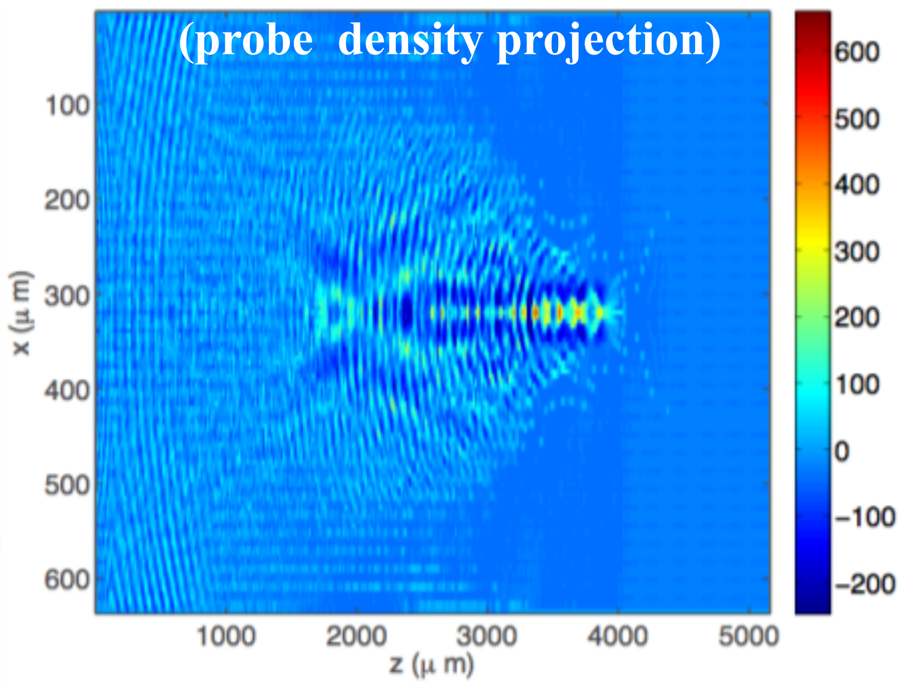


ATF linac can be used to study the self-modulated wake generation and evolution.

electron probe parameters:

E=80 MeV, T=100 fs, Q=20 pC

snapshot of the wake



Plans/Conclusions

- Develop plasma source for the experiment
- Start using existing ATF system
  - CO_2 laser parameters (2 TW, 2 psec) for self-modulation experiment
  - Compress electron beam below 100 fsec
  - Use electron beam for plasma diaganostics
- Simulate the processes including injection into the plasma
- Develop initial plasma diagnostics
- Design and test bunch compressor suitable for external injection
- When CO_2 laser operates at necessary peak power – attempt to inject the beam into the plasma accelerator

- We acknowledge support from US DoE HEP office - grant #215125

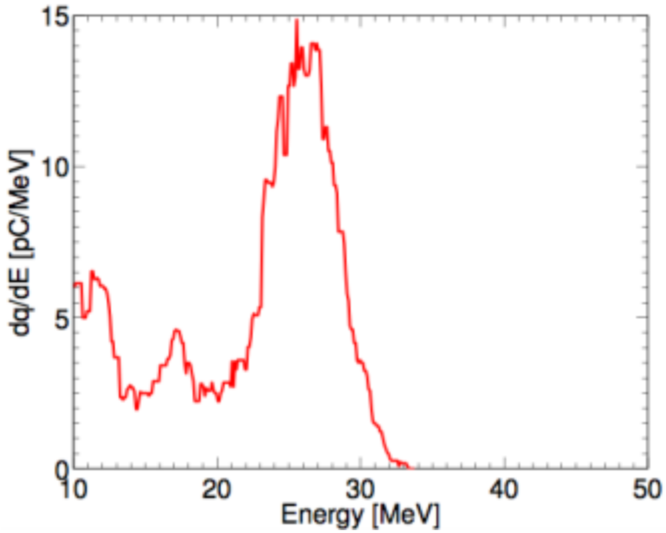
Energy spectrum of injected bunch

Injection and acceleration occurs for proper laser and plasma parameters.

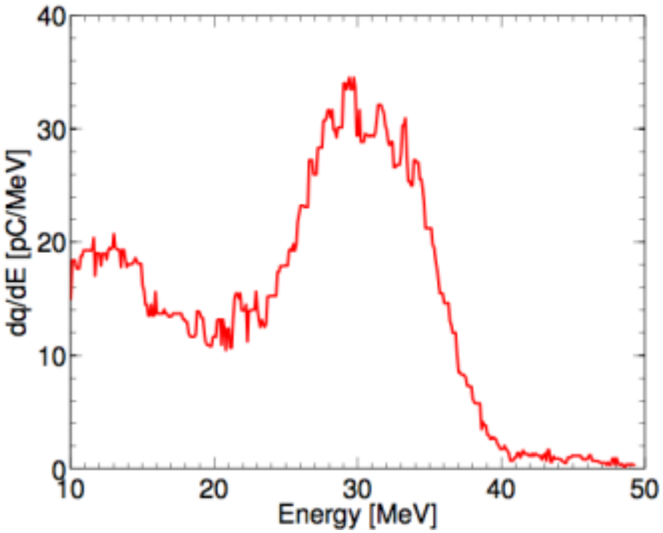
laser: $w_0 = 50\ \mu m$ $\tau = 1$ ps

plasma: $n_p = 3.87 \times 10^{17}\ \mathrm{cm}^{-3}$ $0.5\ \mathrm{mm} + 10\ \mathrm{mm} + 0.5\ \mathrm{mm}$

1ps, 1TW, @5.4 mm



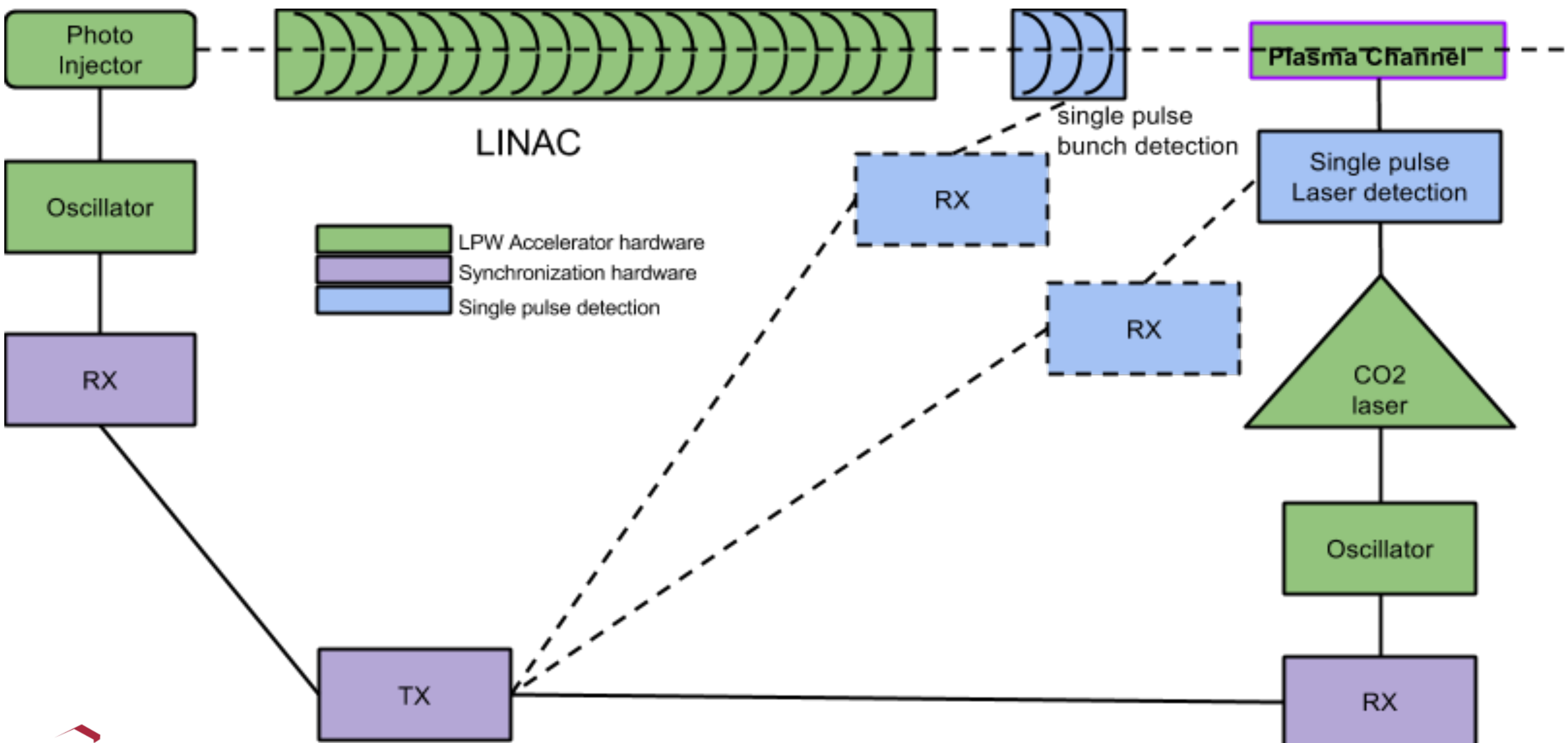
1ps, 2TW, @4.8 mm



THANK YOU FOR YOUR ATTENTION

Synchronization is currently is not in the scope

Scheme developed in LBNL to achieve laser and e-bunch synchronization to 10-20fs.
Currently we do not have funds to pursue its implementation – it would be future step.



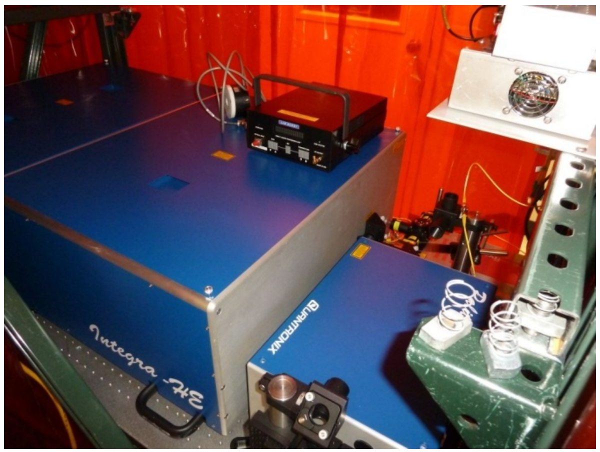
TX : Transmitter; RX: Receiver
Single e-bunch detection: high freq. cavity or electro-optical modulator
Single CO_2 pulse detection: Develop optical ring-down cavity

J. Byrd , L. Doolittle , G. Huang , R. Wilcox (LBNL)

BERKELEY LAB

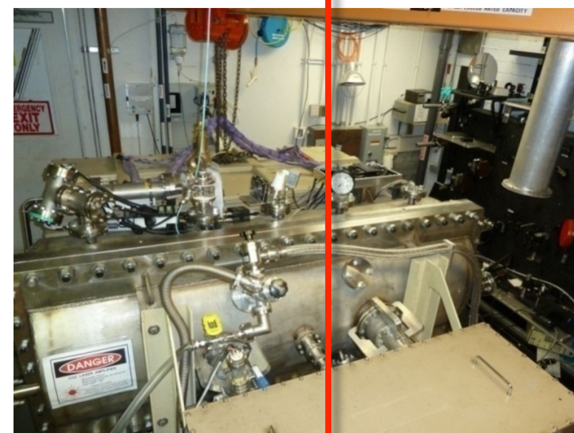
2 TW BNL CO_2 laser system

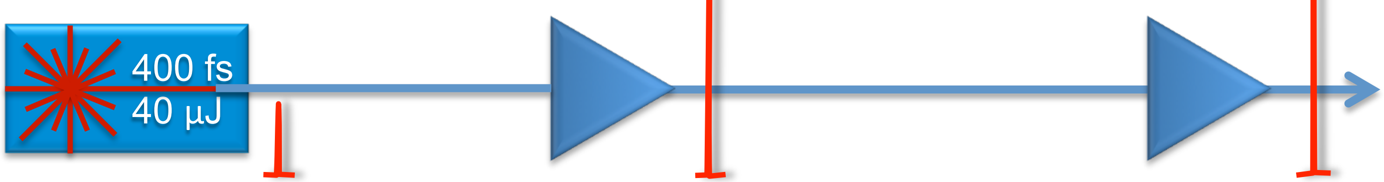
SOLID-STATE OPA INJECTOR



REGENERATIVE ISOTOPIC AMPLIFIER

MAIN AMPLIFIER



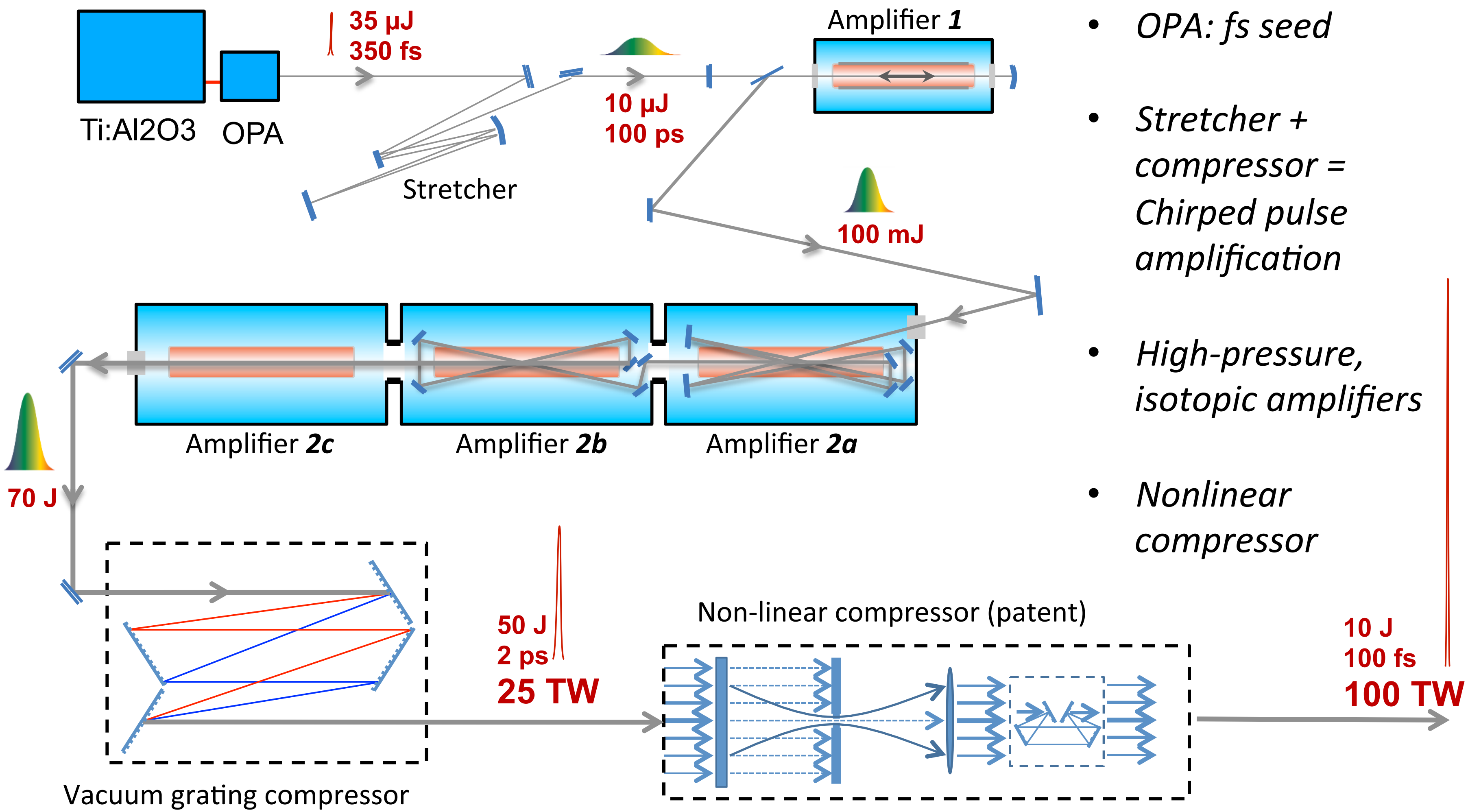


2 ps
10 mJ

3 ps
6 J

I. Pogorelsky

New concept of 100TW CO_2 laser



Collection of innovations:

- *OPA: fs seed*
- *Stretcher + compressor = Chirped pulse amplification*
- *High-pressure, isotopic amplifiers*
- *Nonlinear compressor*

I. Pogorelsky