Progress of Novel Vacuum Laser Acceleration Experiment at ATF

Lei Shao

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Collaborators:

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- Y.K. Ho (Co-PI), Q. Kong, and P. Wang
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- I. Pogorelsky, V. Yakimenko, K. Kusche, J. Park, etc.
  BNL, USA

Approval letter for novel VLA experiment at ATF

Physics Department

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Professors David Cline and Y. K. Ho
Physics and Astronomy Department
University of California, Los Angeles
405 Hilgard Avenue
Los Angeles, CA 90024-1547

Dear Professors Cline and Ho:

Thank you for your proposal "Proof-of- principle Beam Test for Novel Vacuum Laser Acceleration at the ATF" presented at the ATF Program Advisory Committee (APAC) and ATF Users Meeting on October 17-18, 2005.

I apologize for the delay in this response. This is the second submission of this proposal, and although some questions were raised by the committee members, I am now giving the experiment a conditional approval. Congratulations! The approval is conditional on the demonstration that the ATF can run at the required low energy (below 20 MeV) and that the required peak laser power (2 ps at 10 J) is achieved. This is a very interesting concept, and it is my hope that the requirements will be successfully met and that the experiment can go forward.

Sincerely,

Robert Palmer

Robert Palmer

cc:
V. Yakimenko, BNL
S. Chattopadhyay, Jefferson Lab
M. Harrison, BNL
S. Milton, ANL
P. O'Shea, U. Maryland
R. Ruth, SLAC
T. Smith, Stanford U.

Outline

- Review of Theory behind and Previous Research
- Simulations Progress Based on Current ATF Experimental Conditions.
- Experimental Setup and Plans
- Summary

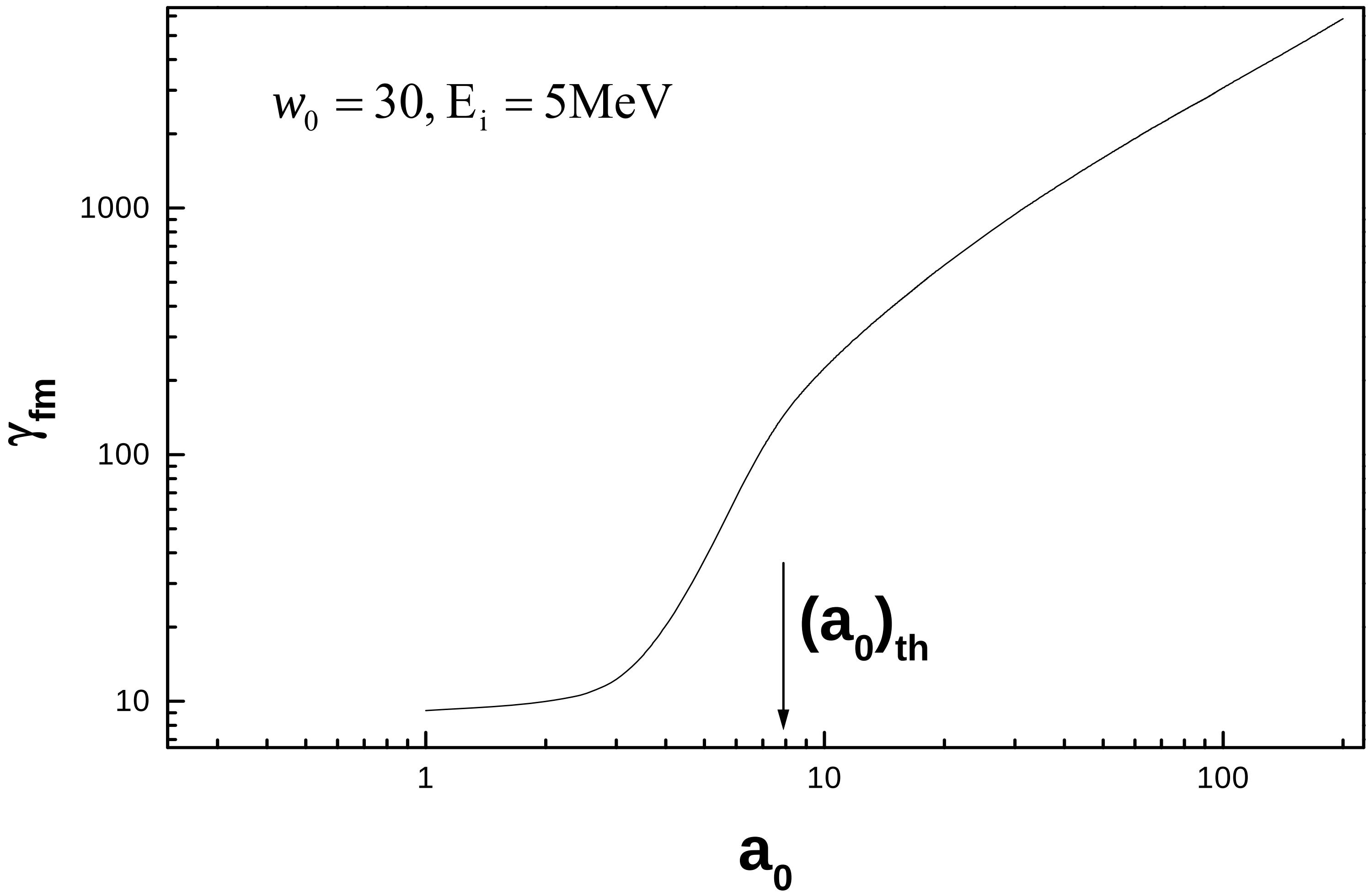
Review of Theory behind and Previous Research

- **Lawson-Woodward theorem**:

  In the plane wave V_φ >c, the electrons may experience the acceleration and deceleration phases alternately. Net energy gain is zero.

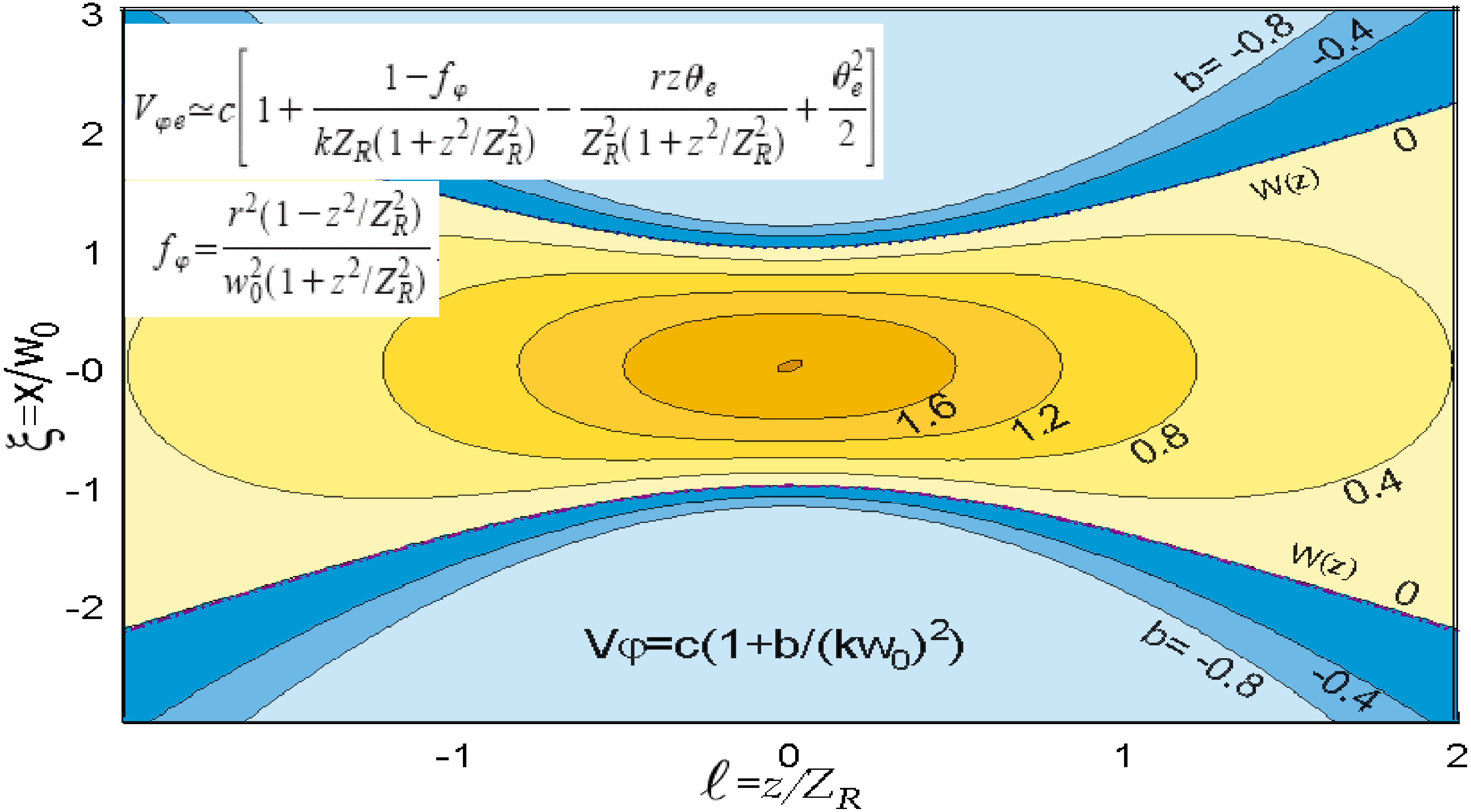
- **Novel VLA (CAS scheme)**:

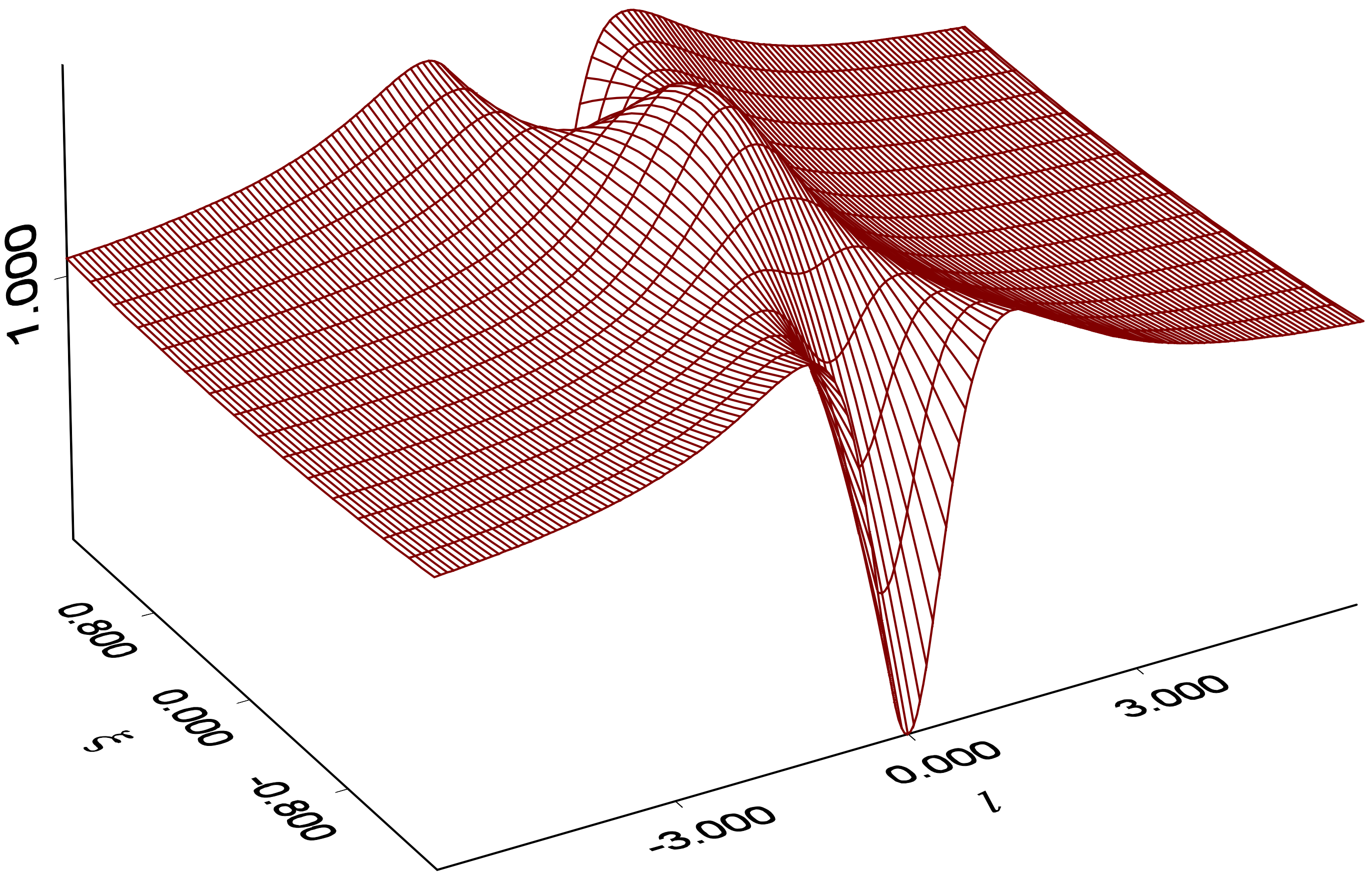
  The diffraction not only changes the intensity distribution of the laser, but also its phase distribution, which results in V_φ <c in some areas. Thus, in some special regions, which overlaps features of both strong longitudinal electric field and low laser phase velocity, electrons can receive high energy gain from the laser.



Final energy changes as a function of a_0.

Contour of phase velocity in a tightly focused laser (Gaussian beam)





The distribution of the minimum phase velocity $v_{\varphi m}$ in $y = 0$ plane of a focused laser beam.

Quality factor and Acceleration Channel

$V_\varphi < c$

Intense E_z

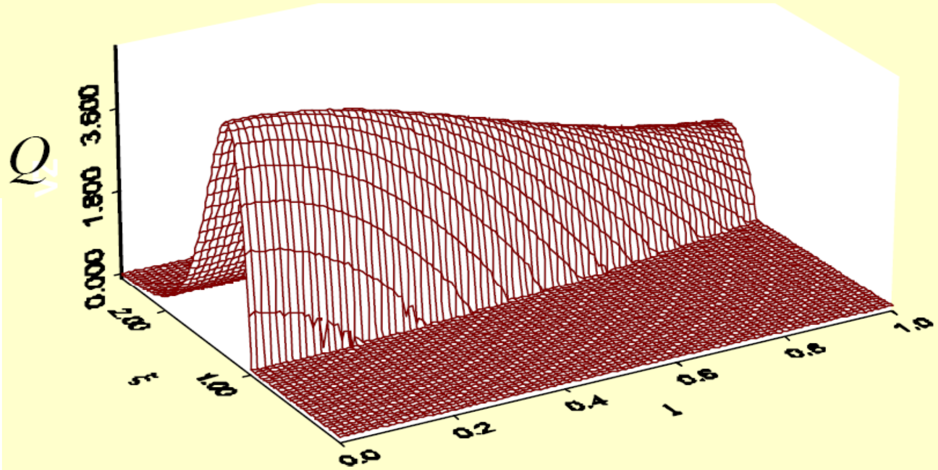
=> **Overlap region : good for acceleration**

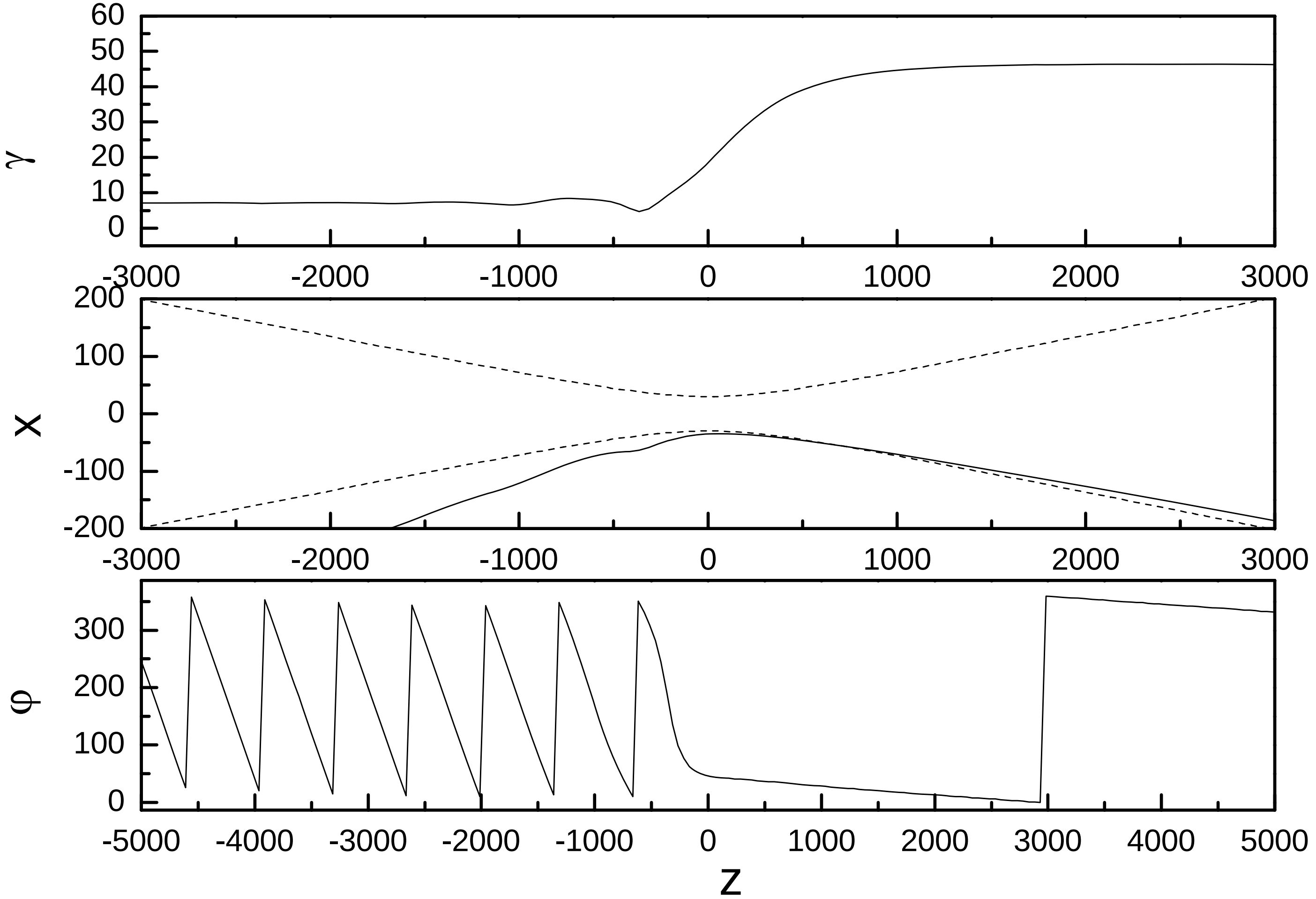
Quality factor:

$$Q = h(V_{\varphi m})\frac{x}{w(z)}\exp\left\{-\frac{x^2+y^2}{w(z)^2}\right\}$$

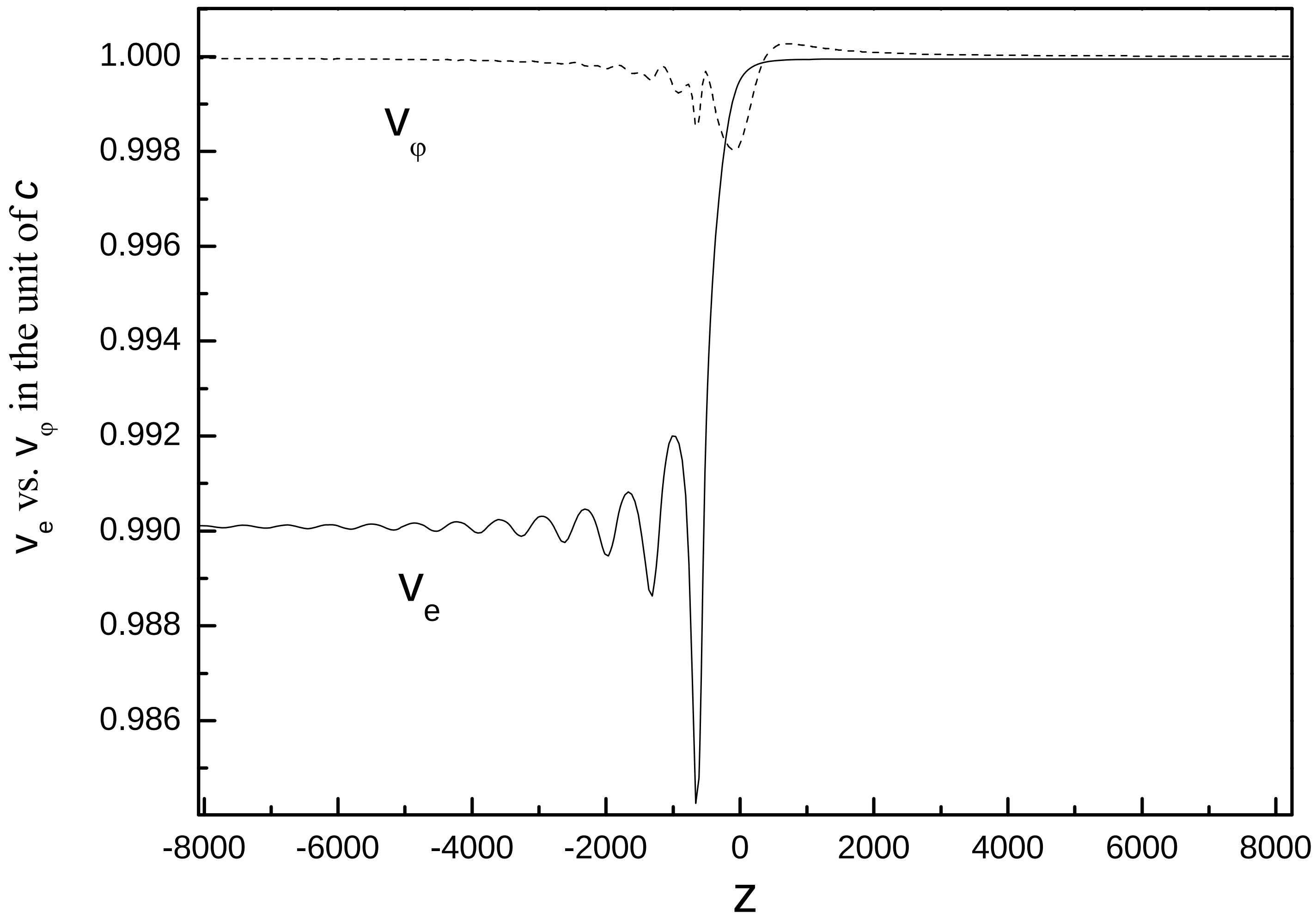
$$h(v_{\varphi m}) = \begin{cases} 1, & v_{\varphi m} < c \\ 0, & v_{\varphi m} > c \end{cases}$$

Acceleration channel (y=0)





$$a_0 = 5.0, \;\; w_0 = 30, \quad E_i = 5(\text{MeV}),$$



The comparison of electron velocity and phase velocity.

Required Parameters for CAS to emerge

- **Extra Strong Laser Intensity**

$$a_0 \geq 5$$

$$I > 1\times10^{19} W/cm^2 \quad for \quad \lambda \approx 1\mu m$$

$$I > 1\times10^{17} W/cm^2 \quad for \quad \lambda \approx 10\mu m$$

- **Initial Electron Beam Energy** (5 ~ 15MeV)

Simulations Progress Based on Current ATF Experimental Conditions.

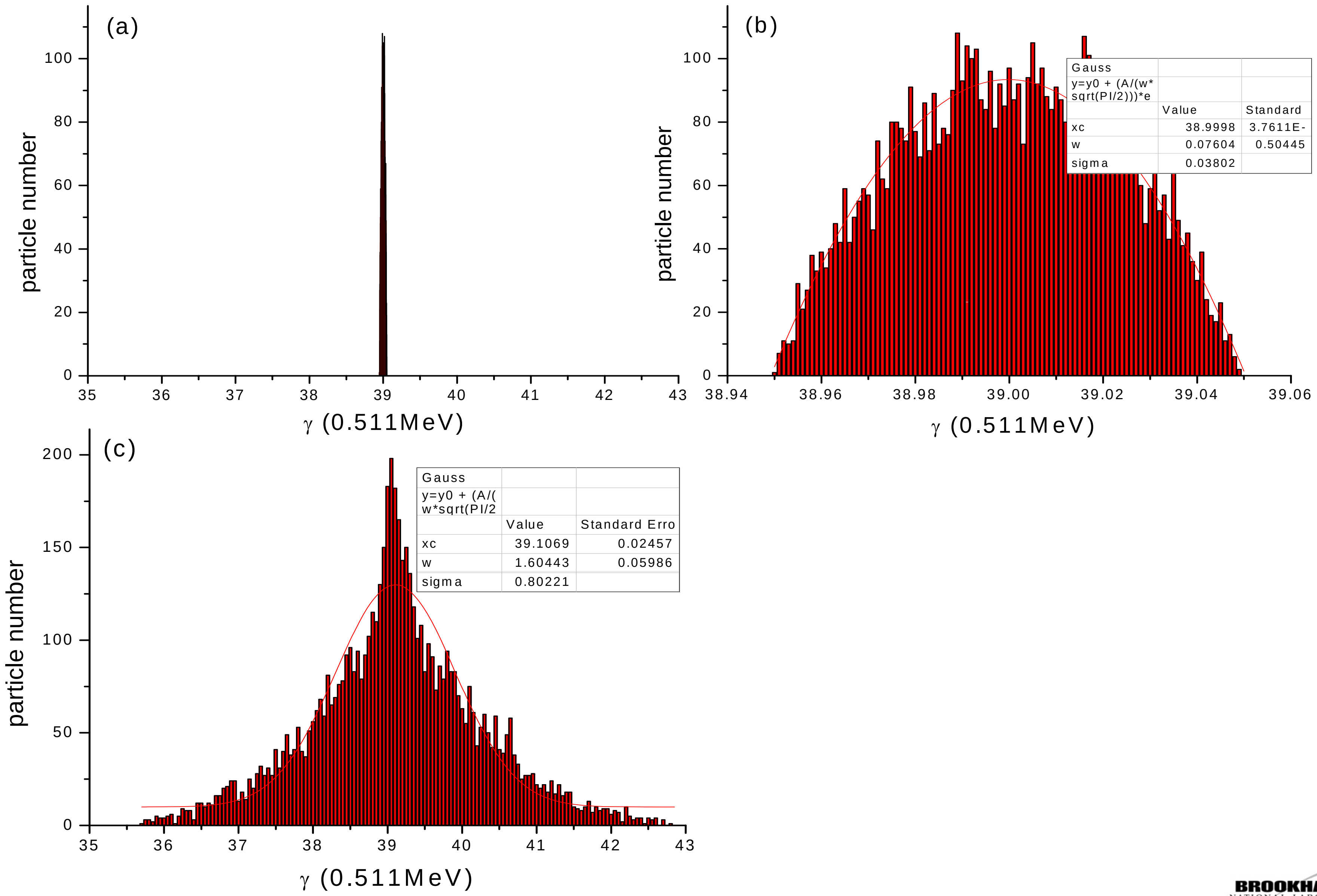
- 20 MeV electron beam at 200pC has been successfully tuned to the end of Beam Line 1 (BL1) by Feng Zhou with normalized transverse emittance below 3.5 μm and energy spread smaller than 0.15%.
- 10.6 μm CO_2 laser with 5J and 5ps, 1TW level is available; 3TW will come soon
- Higher resolution and wider energy acceptance energy spectrometers with 90^0 and 4^0 dipoles, respectively.

Laser Parameters:

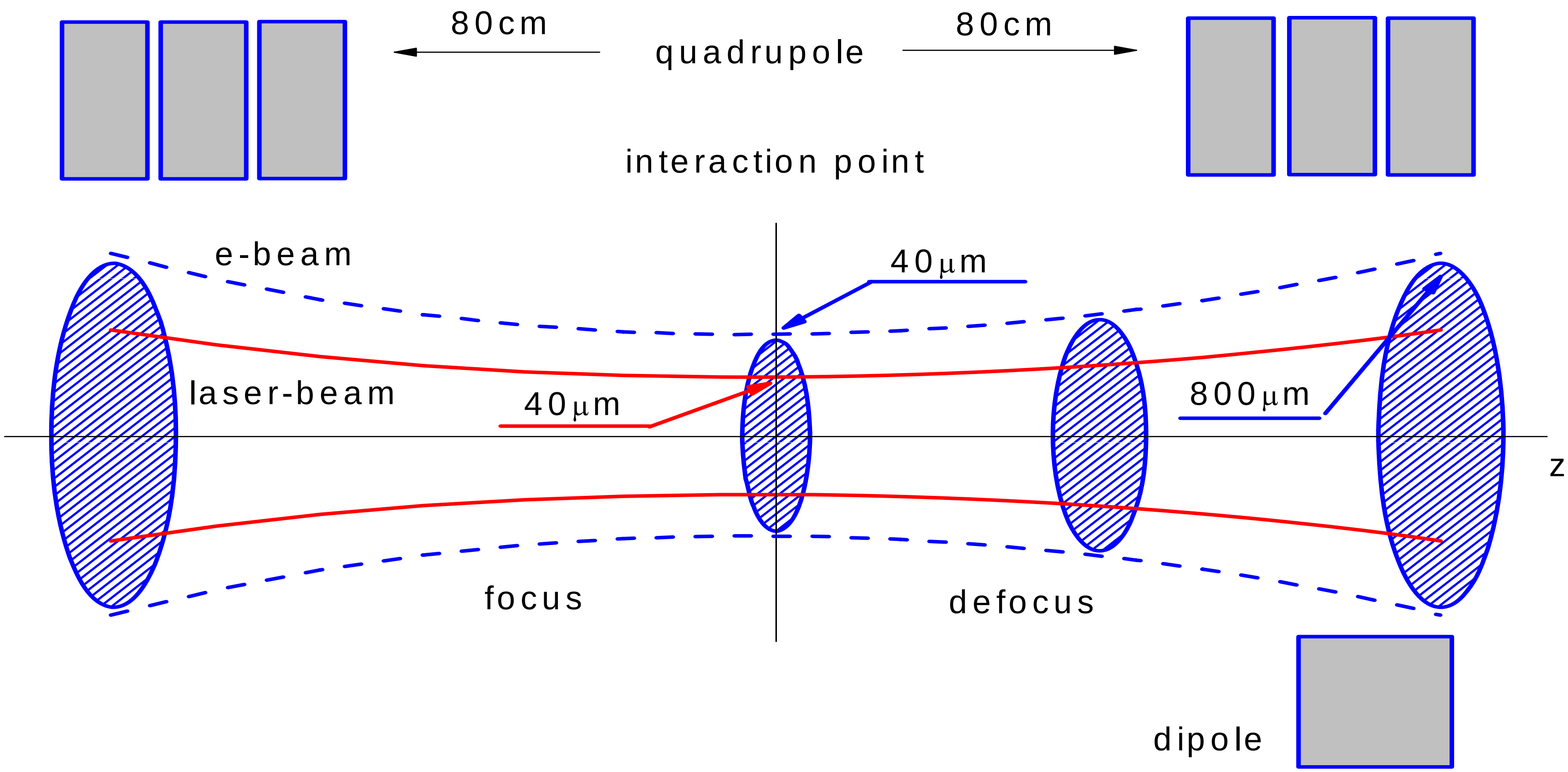
energy	5J
pulse length	5ps
power	1TW
spot size (radius)	$\sim 40\mu m$
wave length	$10.6\ \mu m$
a_0	1.3

e-Beam Parameters:

Initial energy	20MeV
Initial Emittance	~1.2
Energy Spread	$\sim 10^{-3}$
spot size	$\sim 40\mu m$
Pulse length	5ps



(a)
particle number
γ (0.511MeV)
(b)
particle number
γ (0.511MeV)
Gauss
y=y0 + (A/(w*sqrt(PI/2)))*e
Value
Standard
xc
38.9998
3.7611E-
w
0.07604
0.50445
sigma
0.03802
(c)
particle number
γ (0.511MeV)
Gauss
y=y0 + (A/(w*sqrt(PI/2
Value
Standard Erro
xc
39.1069
0.02457
w
1.60443
0.05986
sigma
0.80221


80cm
quadrupole
80cm
interaction point
e-beam
40μm
laser-beam
40μm
800μm
z
focus
defocus
dipole

beam line 2

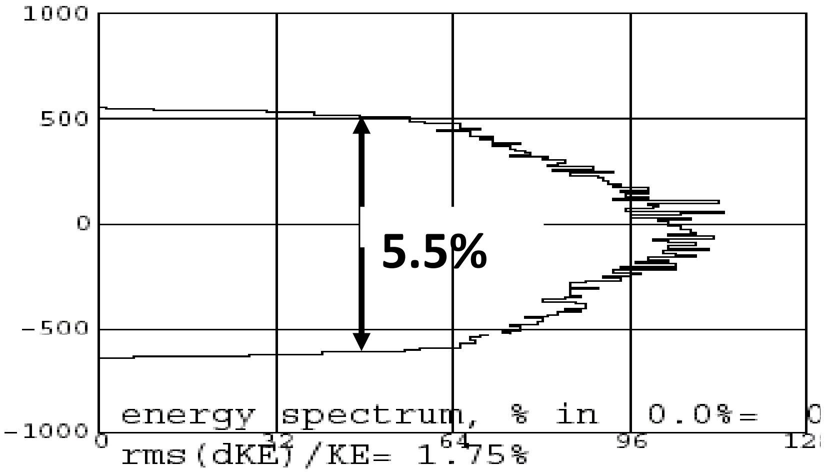
Conclusions

- In BNL-ATF, the current spectrometer can distinguish 0.1% accuracy and tell 0.05% accuracy. So this interaction can be detected by ATF diagnostic system. Since the original e-beam is at 20MeV and 0.1% energy spread, which gives 20keV width; and the final e-beam energy center is at around 20MeV too, and the 2% energy spread gives 400keV width, which is obvious enough to observe. ATF spectrometer's vertical axis represents vertical size of e-beam and the horizontal axis represents energy spread. Therefore, we are supposed to see the signal of energy gain from the spectrometer.

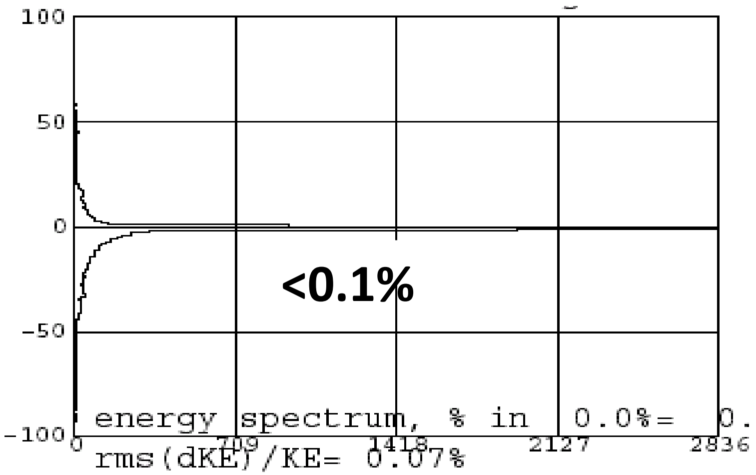
- Also ATF's spectrometer's lens for capturing image is 1.5cm. The e-beam in our simulation shows that the beam size will be around several hundred microns, more than 10^2 orders smaller than the spectrometer scope range. To make sure that e-beam image would be in the effective range of spectrometer, after the interaction chamber we have four quadrupoles which can be used to tune the beam size down along the stream and the dipole there bend e-beam to spectrometer.

Experimental Setup and Plans.

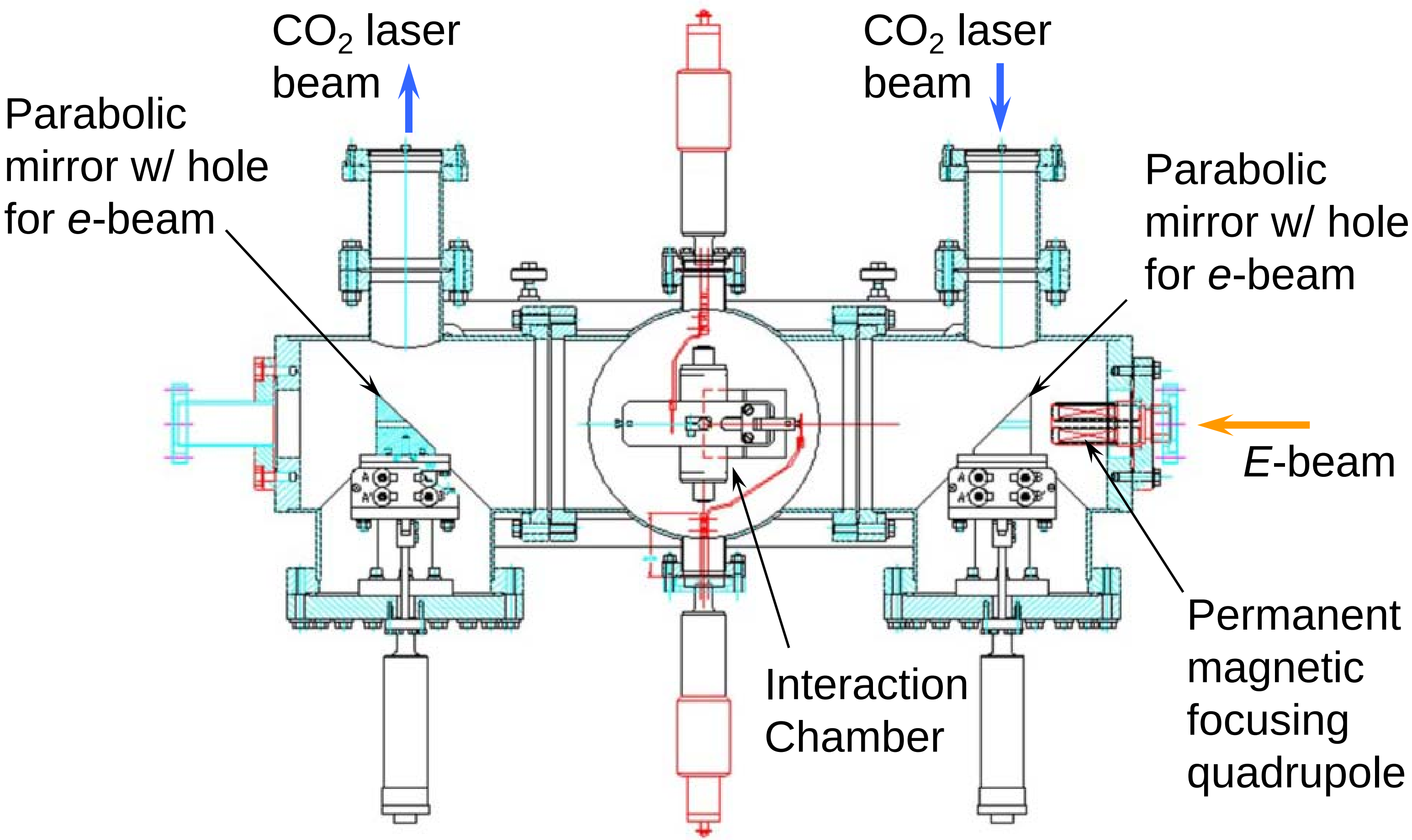
- ATF routinely operates at higher energy >40 MeV to avoid space charge effects. Running at 5-20 MeV may need to investigate:
  - *Transport ~30 m to experimental station*
  - *All power supplies were designed for higher-energy beam*
- 20-MeV e-beam study - PARMELA show that the emittance and energy spread can be preserved 2 μm and 0.3%, respectively; real beam was successfully tuned to the end of the beam line;



Acceleration + deceleration

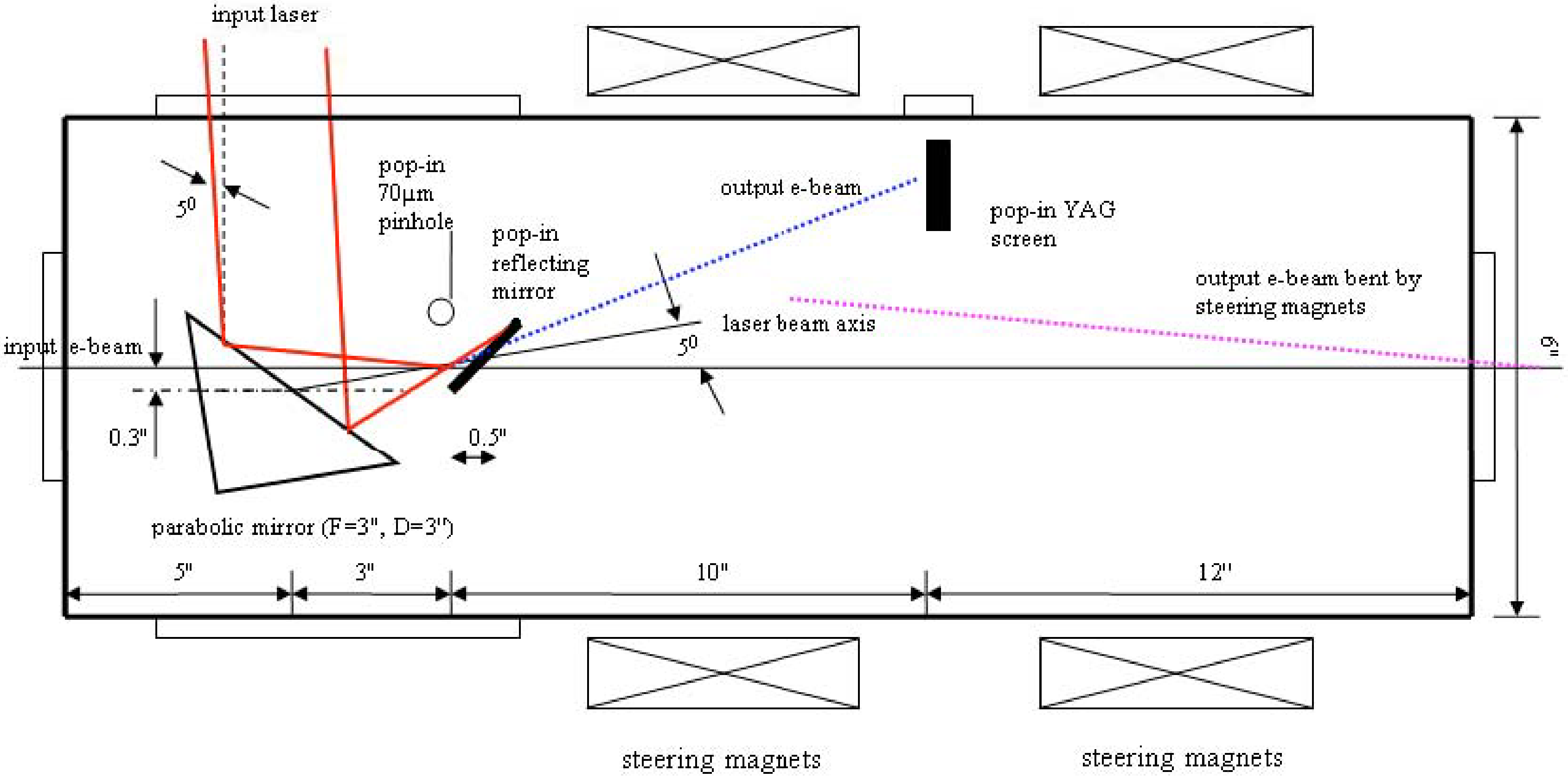


Acceleration + acceleration



CO_2 laser beam
CO_2 laser beam
Parabolic mirror w/ hole for *e*-beam
Parabolic mirror w/ hole for *e*-beam
E-beam
Interaction Chamber
Permanent magnetic focusing quadrupole

Experiment Layout Design



Measurements

- **Angular particle distribution**:
  - electrons were ejected parallel to the laser axis
  - an off-z-axis (along x-direction) pop-in BPM, which is located at 12-cm from IP(~1000 Z_R);
  - its intensity 0.2-J/cm^2 <YAG screen damage threshold 1-J/cm^2

- **Maximum energy gain**: using correctors to correct beam to the original axis and then measured energy spectrum with energy spectrometer, 90^0 or 4^0-dipole spectrometer.

Experiment plan

- **Phase I: Proof-of-principle based on the current ATF conditions**

  - *Engineering designs for the laser injection system*
  - *Engineering designs for the output electron diagnostics to measure angular particle distribution*
  - *Design and fabricate a particular VLA chamber*
  - *Measure angular electron distributions*
  - *Continue to optimize parameters for measurements of angular electron distributions.*
  - *Modify the steering magnets to meet the VLA requirements*
  - *Measure energy gain*

- **Phase II: to demonstrate novel VLA – CAS under higher laser intensity**

  - *Continue efforts to tune e-beam at 15-MeV and lower energy*
  - *Adjust laser optics to make laser having an incident injection to e-beam*
  - *Measure angular distribution and energy gain*

Summary

•Proof-of-Principle experiment

This is a new concept for vacuum laser acceleration

•Man power

Collaboration between USA and China. Dr. Pingxiao Wang from Fudan University is coming to ATF for co-working on this project, which is funded by China

•Experiment Equipments

The existing equipments can be used. No need to build more devices, but only some re-configuration.

•Future Prospects

With the laser improvement in future, we can perform much higher energy gain experiments.

Thank You!

and

Thanks to every one at ATF