ATF User Meeting
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LACARA: First Results and their Interpretation

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ACKNOWLEDGEMENT:

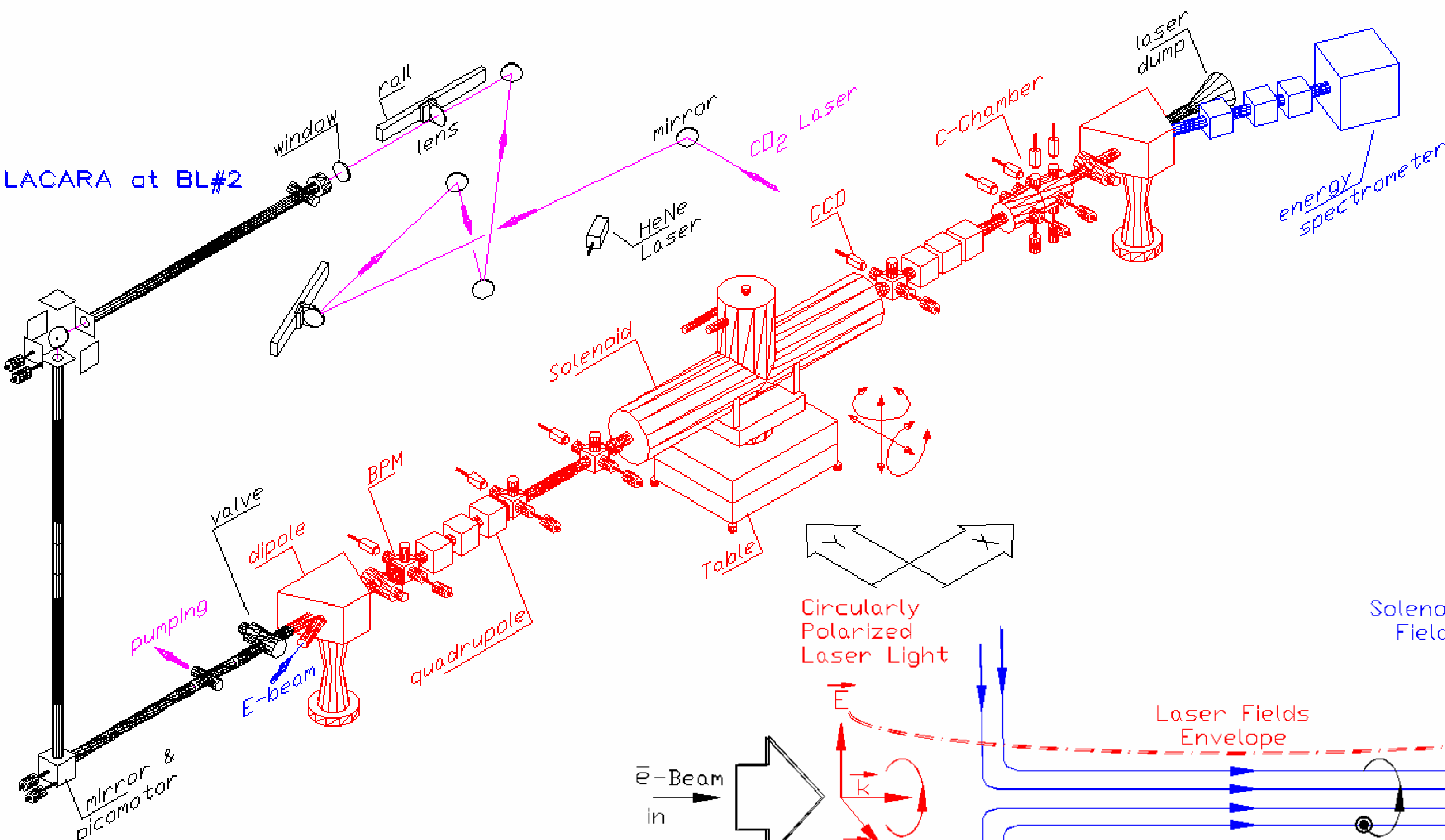
DoE Office of HEP

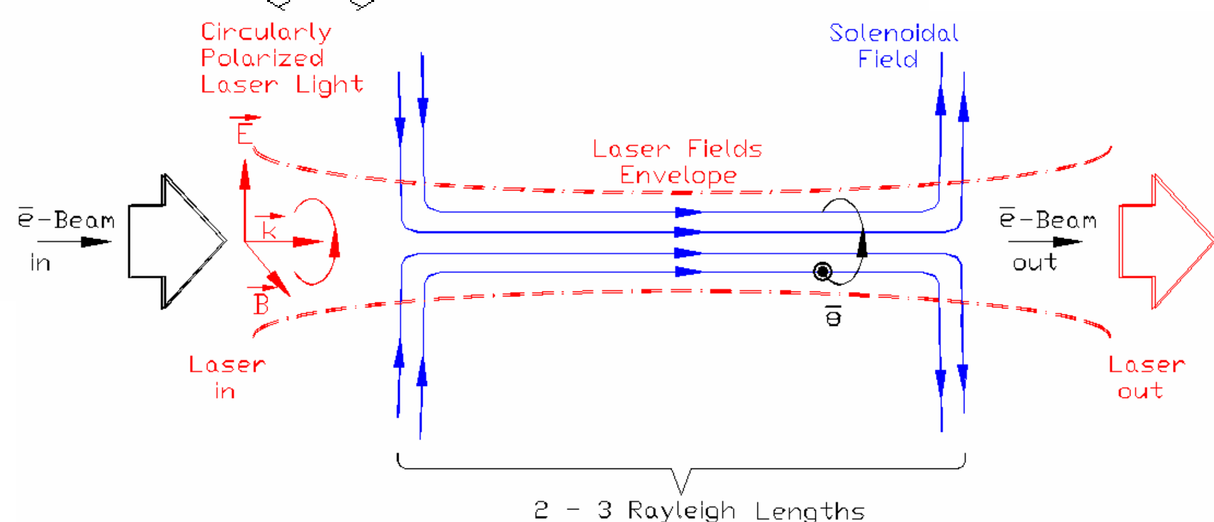
References:

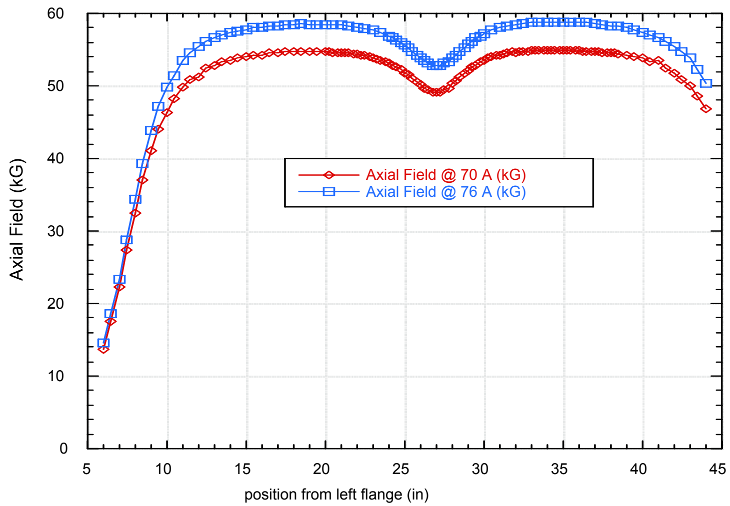
* J.L. Hirshfield, C. Wang, *Phys. Rev.* **E 61**, 7252 (2000).
* T. C. Marshall, C. Wang, J.L. Hirshfield, *Phys. Rev. ST Accel. Beams* **4**, 121301 (2001).
* S.V. Shchelkunov, T.C. Marshall, J.L. Hirshfield, C-B. Wang, and M.A. LaPointe, *AIP Conference Proceedings* **877**: 12th Advanced Accelerator Concepts Workshop, p. 880, eds: M. Conde and C. Eyberger (2006).

LACARA - Laser Cyclotron Auto-Resonance Accelerator

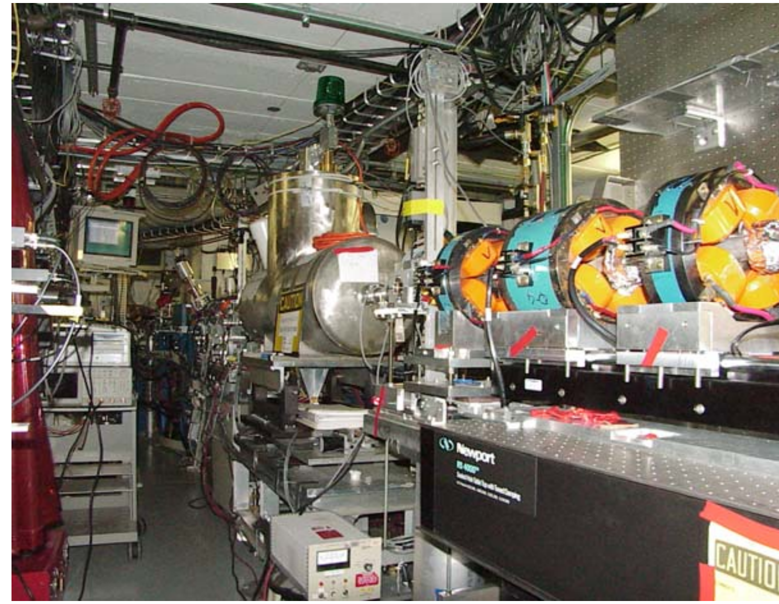
operates at the ATF-BNL experimental floor, 2nd beam line, (not to scale)







Magnetic field profile measured along the bore axis (marked by ‘squares’) compared to the calculated field presented by continues curves.

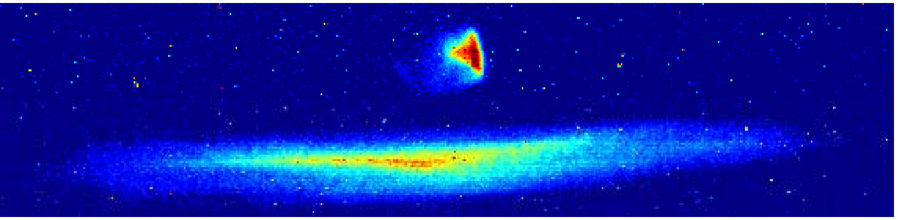


Requirements:

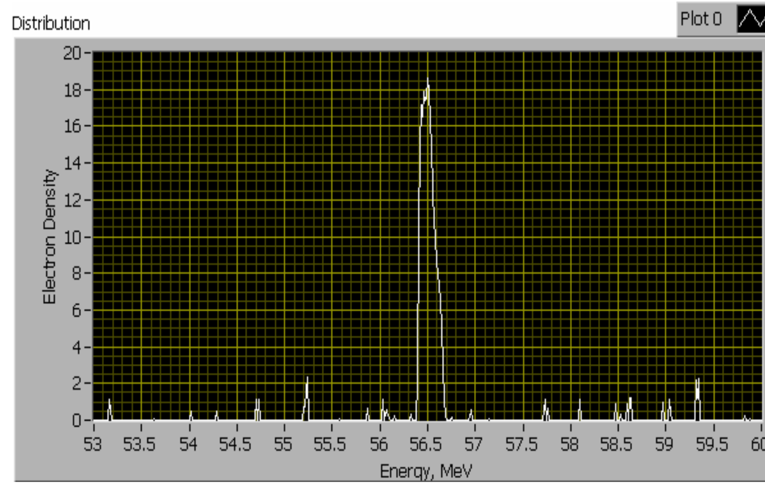
- ~5T solenoidal field (length ~1m, provided by a "dry" SC magnet.)
- Gaussian CO2 laser beam, $\lambda \approx 10.6\ \mu m$, Rayleigh length of ~70cm, power up to 1 TW

Expectations:

* acceleration of electrons in vacuum using the laser energy in a smoothbore structure
* using a not pre-bunched electron beam
* a ~50-60MeV bunch should be accelerated at 25 MV/m, provided ideal alignment
* acceleration is done by a nearly-gyro resonant interaction, and all the electrons of a bunch undergo the same acceleration ?



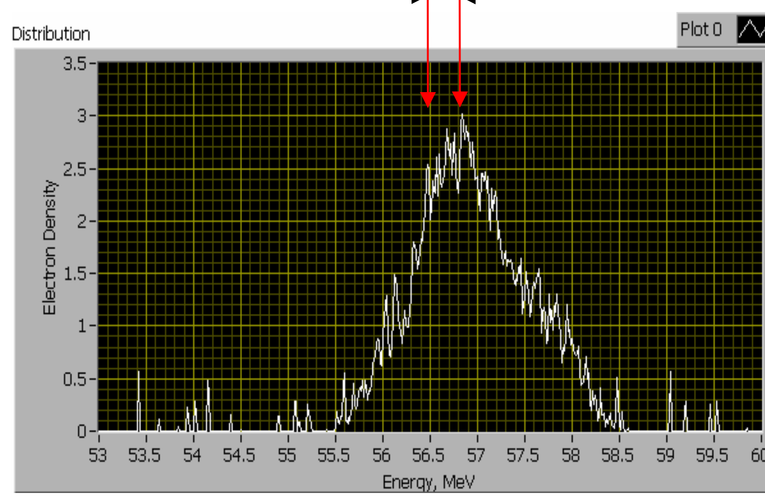
higher energy ←



initial beam energy ~56.5 MeV;
laser power ~220 GW; polarization ?
B-filed ~5T;
higher energy is on the left
Top trace: laser off.
Bottom trace: laser on.

~ 0.4 MeV

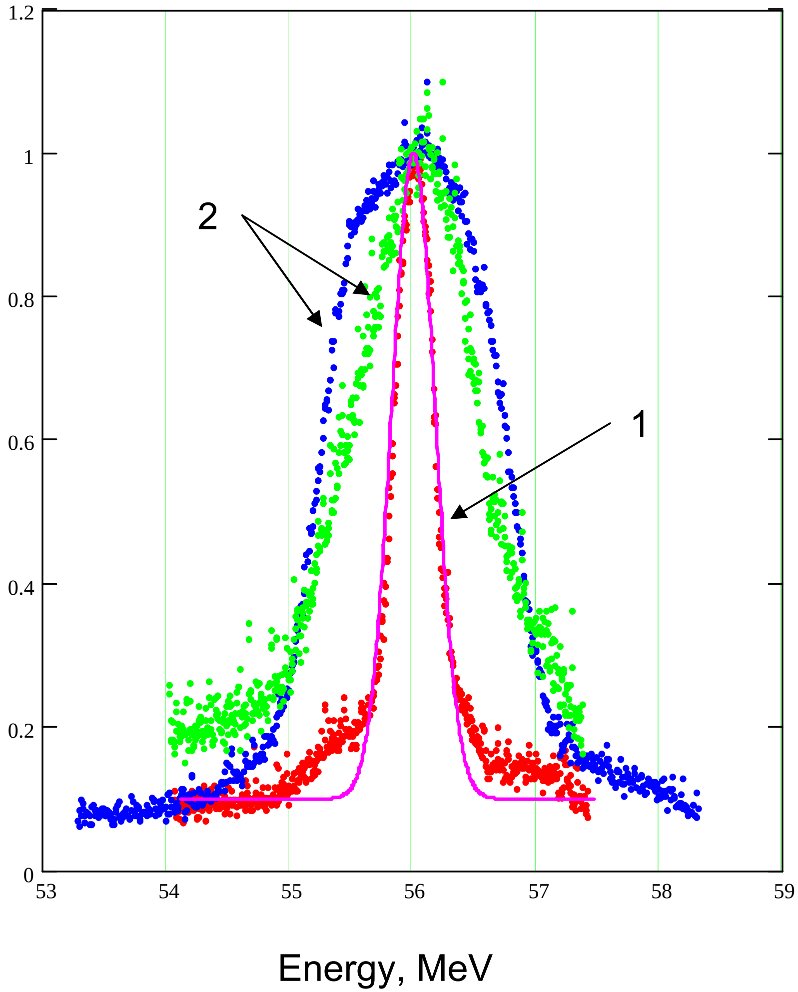
Electron distribution for non-accelerated and accelerated beams:



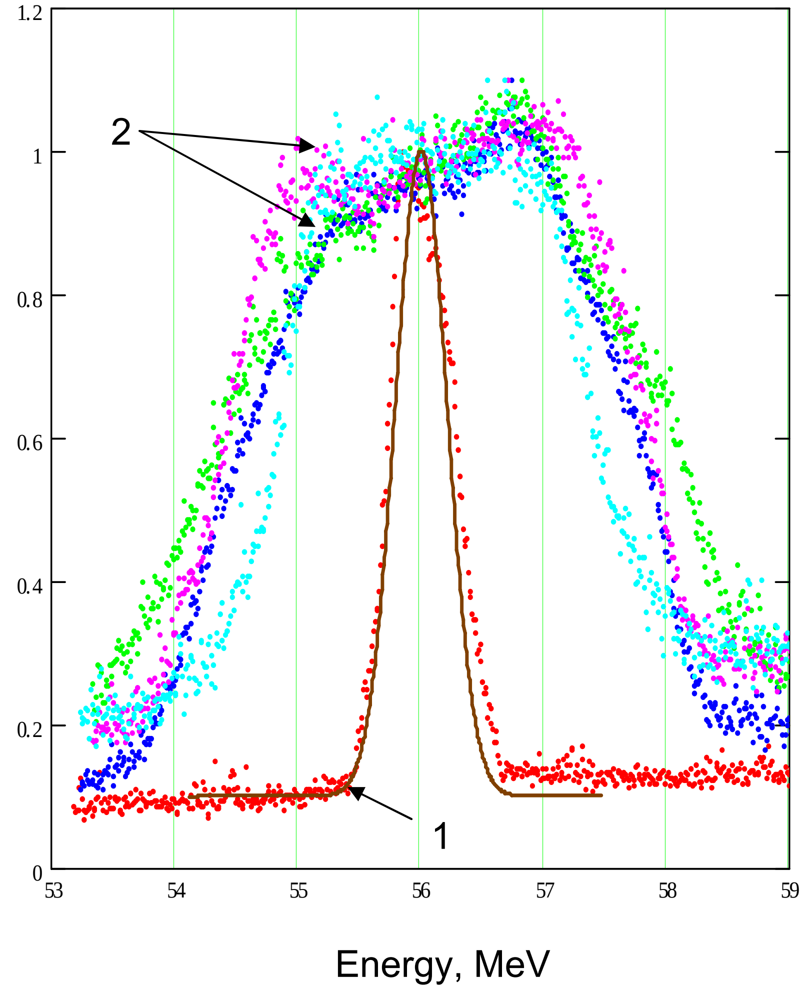
energy gain is up to 2 MeV;
energy loss is up to 1 MeV;
gain at peak of distribution ~ 0.4 MeV;
standard deviation ~0.7 MeV

*the results were reported at AAC 2008

More examples: initial beam energy 56.5 MeV; laser power ~220GW; polarization ~85% (1 - laser power off; 2 - with laser power on)



B ≈ -5T



B ≈ +5T

Parameter	Base value	Accuracy (range)	Deterioration in performance as compared to the energy gain for the base values			Time to measure	Time to tune
			5%	10%	15%		
Laser angle, μrad	0	+/- 300 μrad	**550**	**800**	**1000**	1/2 days	1 hr
Laser waist, mm	1.6	1.4-1.8 mm	**1.7**	**1.85**	**1.95**	2 days	?
Laser power, GW	~200 ?	**?**	**scales linearly with power**				
E-beam sigma σ, μm	200	+/- 35μm	**210**	**225**	**240**	minutes	days
Emittance, not-norm.,10^{-8} m-rad	1.5	1.5-2	**1.9**	**2.35**	**2.7**	<1 hr	?
E-beam shift, μm	0	Together result in +/- **500 μm** relative to the axis (inside solenoid)	**75**	**125**	**150**	1 day	days
E-beam angle, μrad	0		**125**	**190**	**230**	1 day	days

Alone result in 1/6 drop In energy gain

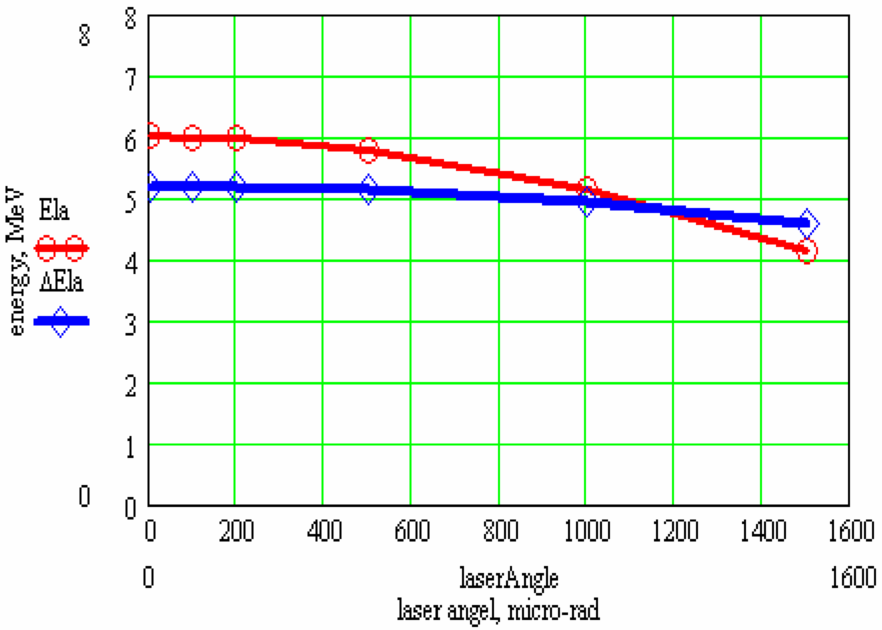
together result 12% of deterioration in energy gain

together result 25% of deterioration in energy gain

together result 35% of deterioration in energy gain

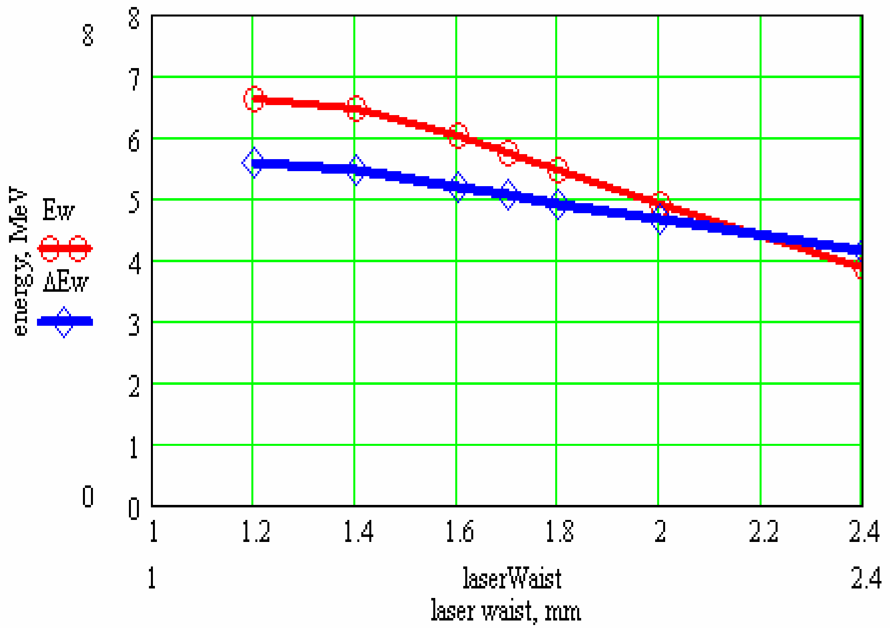
This misalignment + the other contributions [see green column], result in the gain drop by ~ 85%, leading to energy gain ~ 0.65MeV at ~200-250GW (instead of ~4MeV).
The observed value ~0.4 MeV is close, but perhaps can be further explained by lesser laser power of ~ 130-150 GW.

Red – average energy gain (MeV) and blue – energy spread (std, MeV) vs. Laser Angle relative to the solenoid (μrad) - parameter that does not inflict much the performance.



The curves are given for 300GW laser power (simulation). One may conclude that the loss in gain is 5% for 550 micro-rad , 10% - for 800 micro-rad, and 15% - for 1000 micro-rad (note that calculation is done for a discrete set of points [marked])

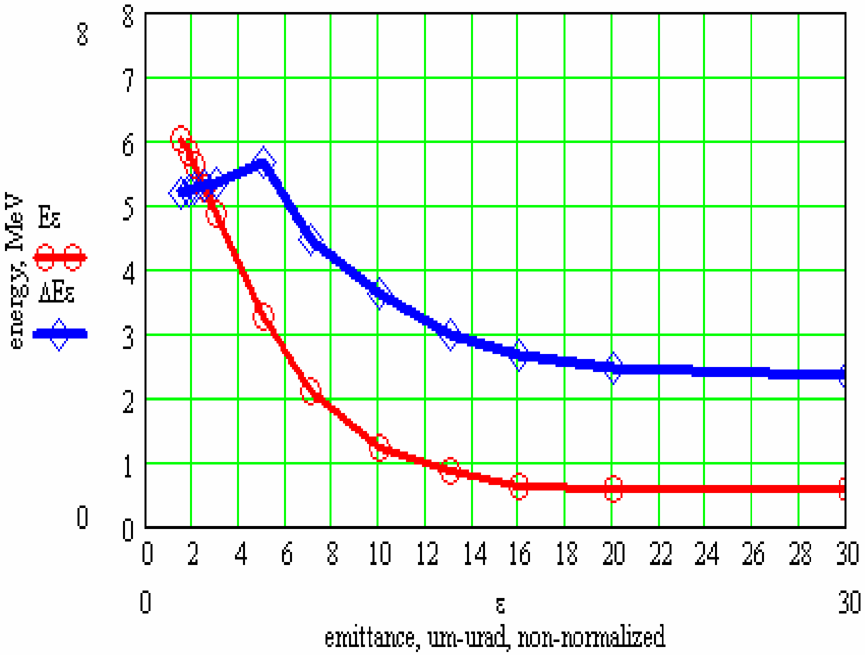
Red – average energy gain (MeV) and blue – energy spread (std, MeV) vs. Laser Waist W_x = ~W_y (mm, reasonably well known parameter)

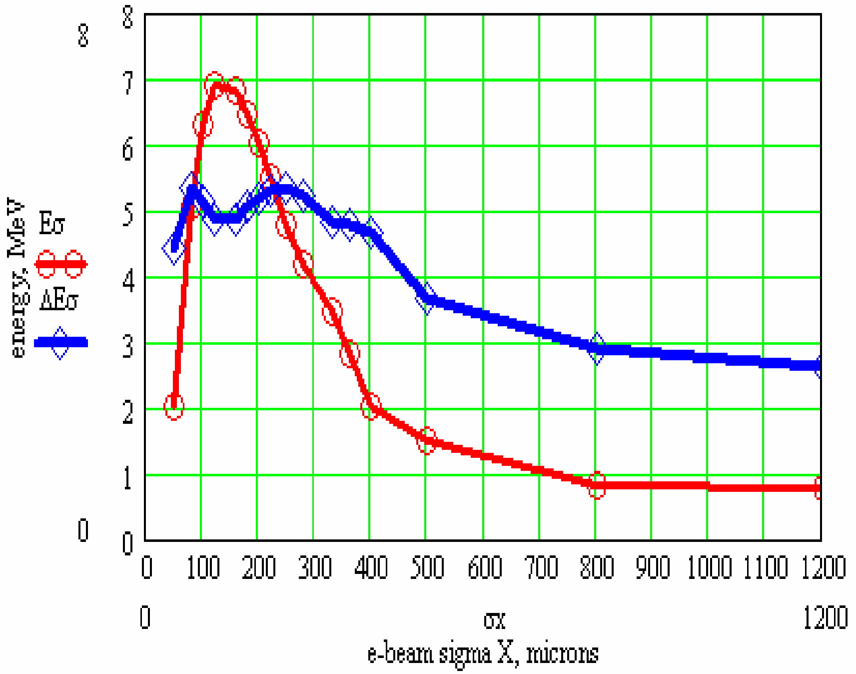


The curves are given for 300GW laser power (simulation). One may conclude that the loss in gain is 5% for 1.7 mm, 10% - for 1.85 mm, and 15% - for 1.95 mm, all compared to the gain at the expected Wx = ~Wy = 1.6 mm (note that calculation is done for a discrete set of points [marked])

Red – average energy gain (MeV) and blue – energy spread (std, MeV) vs. initial e-beam emittance (non-normalized, μm – μrad, well known parameter)

Red – average energy gain (MeV) and blue – energy spread (std, MeV) vs. initial e-beam sigma σx = ~σy (μm, well controlled parameter)



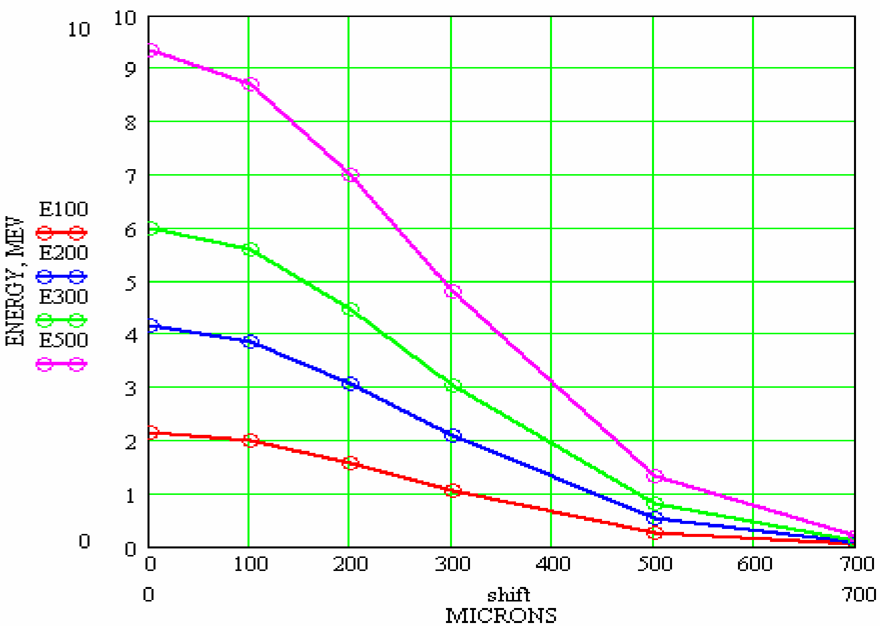


The curves are for 300GW laser power (simulation). One may conclude that the loss in gain is 5% for 1.9 μm-μrad, 10% - for 2.35 μm-μrad, and 15% - for 2.7 μm-μrad, all compared to the gain at the expected εx= ~εy =1.5 μm-μrad (note that calculation is done for a discrete set of points [marked])

The curves are for 300GW laser power (simulation). One may conclude that the loss in gain is 5% for 210 μm, 10% - for 225μm, and 15% - for 240 μm, all compared to the gain at the expected σx = ~σy = 200 μm (note that calculation is done for a discrete set of points [marked])

Parameter (s) that inflict much the performance (simulation)

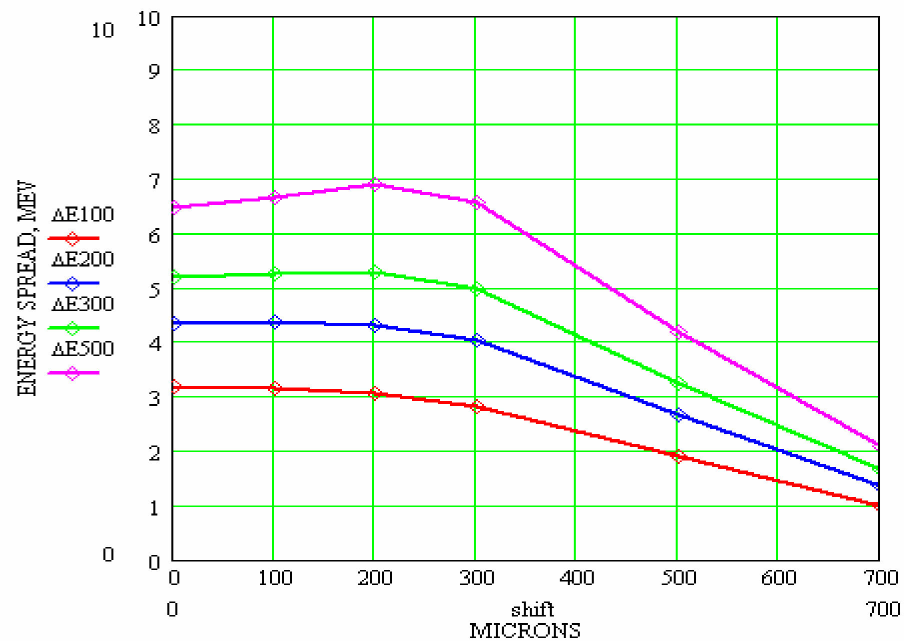
Average energy gain (MeV) vs. **initial e-beam shift (μm)**



The curves are for different **laser powers:** red – 100 GW, blue – 200 GW, green – 300 GW and magenta – 500GW (calculation is done for a discrete set of points [marked])
The interesting thing to note is that energy gain scales directly proportional to the laser power for up to 500 GW,

$$E_{gain} \sim P_{laser} \quad (1)$$

Energy spread (std, MeV) vs. **initial e-beam shift (μm)**

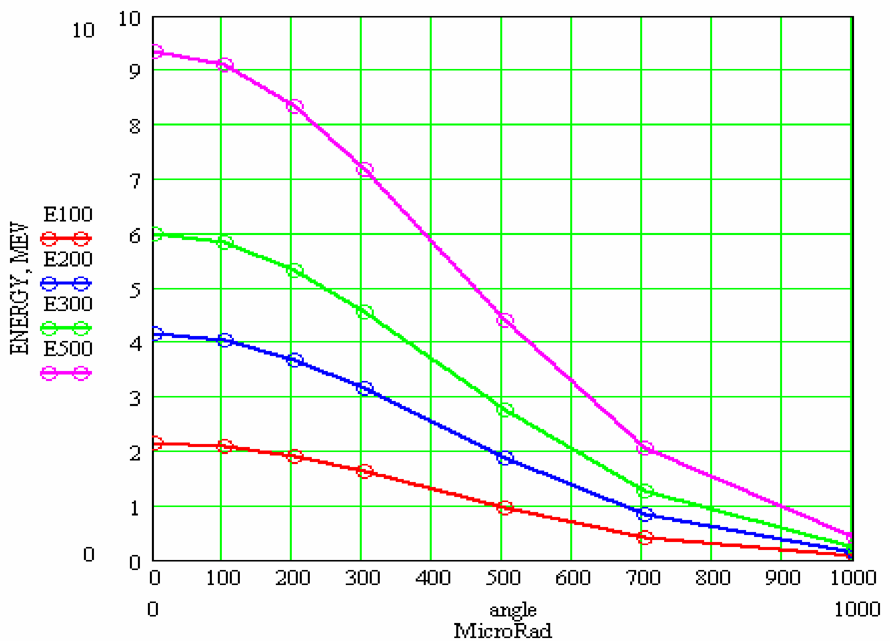


The curves are for different **laser powers:** red – 100 GW, blue – 200 GW, green – 300 GW and magenta – 500GW (calculation is done for a discrete set of points [marked])
The interesting thing to note is that energy spread scales directly proportional to the square root of laser power for up to 500 GW,

$$\Delta E_{spread} \sim \sqrt{P_{laser}} \quad (2)$$

Parameter (s) that inflict much the performance (simulation)

Average energy gain (MeV) vs. **initial e-beam angle (μrad)**

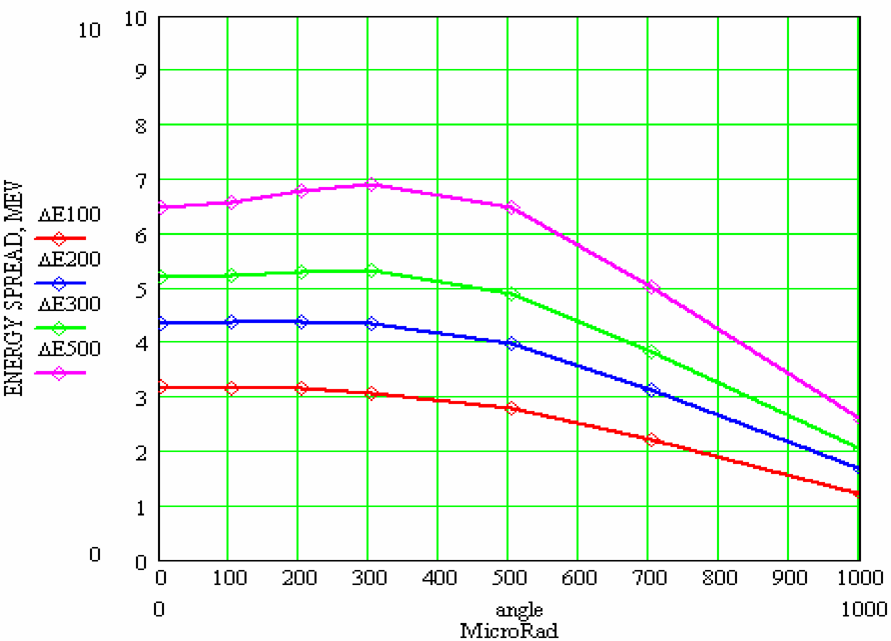


The curves are for different **laser powers:** red – 100 GW, blue – 200 GW, green – 300 GW and magenta – 500GW (calculation is done for a discrete set of points [marked])

The interesting thing to note is that energy gain scales directly proportional to the laser power for up to 500 GW,

$$E_{gain} \sim P_{laser} \qquad (1)$$

Energy spread (std, MeV) vs. **initial e-beam angle (μrad)**



The curves are for different **laser powers:** red – 100 GW, blue – 200 GW, green – 300 GW and magenta – 500GW(calculation is done for a discrete set of points [marked])

The interesting thing to note is that energy spread scales directly proportional to the square root of laser power for up to 500 GW,

$$\Delta E_{spread} \sim \sqrt{P_{laser}} \qquad (2)$$

Things to do:

a) Measuring the laser power:

a.1) relatively straightforward to measure the total energy
a.2) proven to be difficult to know the pulse shape – presently ATF is doing work on that, and we solely rely on their progress

b) Improving the alignment between the e-beam and the solenoid

b.1) present procedure, where we align the solenoid with e-beam, is lengthy in duration and has poor convergence
b.2) poor convergence may be because of deviation of the solenoid axis from the straight line at high field
b.3) a new procedure, where we will align the e-beam with the solenoid (not vice versa) is being considered and is under development

c) Improving the simulation code:

c.1) to include known, but not accounted by it parameters (the laser beam shift relative to the solenoid axis)
c.2) to solve legacy issues. i.e. the absence of output of the detailed distribution (histograms) of electrons after or in the process of acceleration

Summary:

- First experimental results from LACARA at BNL-ATF were obtained July 14-22, 2008 by Yale/ATF team.

- Both energy gains and energy losses were observed, with either linear-or circularly-polarized laser light, and for both directions of B-field.

The magnitude of energy changes agrees with theory; the complex physics involved in the interaction process is understood.

- Experimental arrangement require refinement, e.g.

improved alignment of laser and magnetic field axes and e-beam;
improved accuracy of synchronization, and laser power measurements.

- In order to explore better operation (and better data) of LACARA, and based on our experience, we conclude that we need at least 8 run session (~ 1-2 years of operation at ATF). Productivity can be greater if support for a postdoc can be obtained.