Vacuum Laser Acceleration

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Brookhaven National Laboratory
Accelerator Test Facility

BROOKHAVEN NATIONAL LABORATORY
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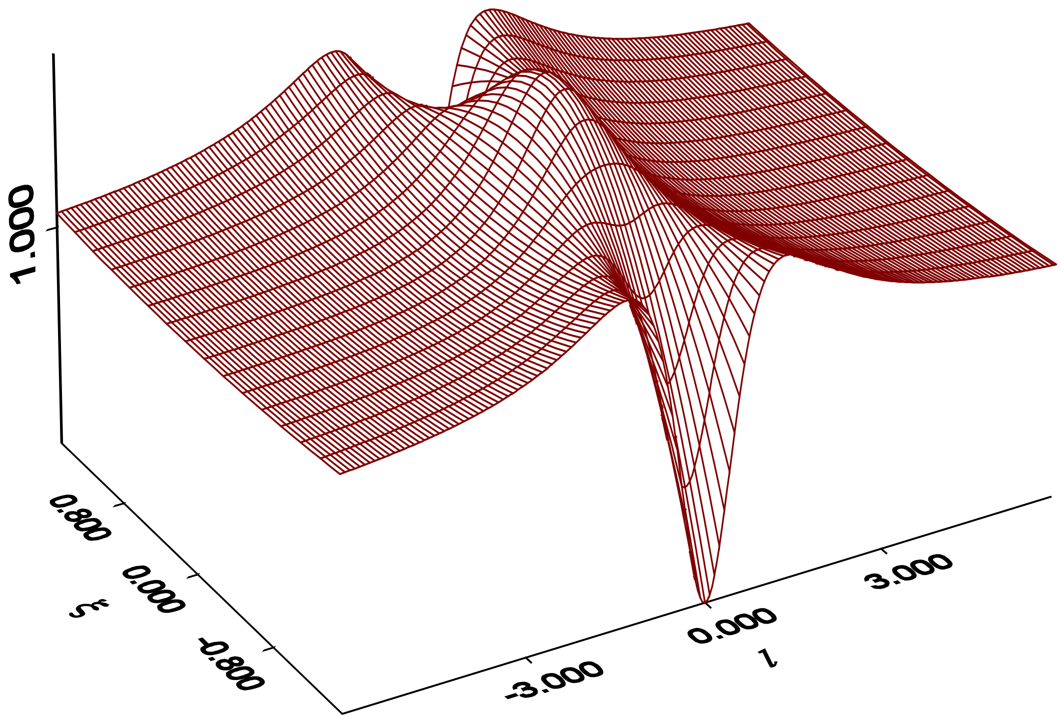
Outline

- Concept
- Current Measurement Status at ATF
- Future Prospect of VLA experiment
- Summary

Concept

- **Lawson-Woodward theorem is not applicable to tightly focused laser beam.** For tightly focused laser field, phase velocity doesn't have to be greater than *c* in some certain regions. This feature supports the key argument of Vacuum Acceleration.
- **CAS(Capture Acceleration Scenario)** use longitudinal component of the field as the main role for acceleration. Transverse components force are offset by each other.
- **The subluminuous regions** makes sure that relativistic electrons have a chance to catch up with the acceleration phase.

$$\partial\varphi/\partial t + v_\varphi \cdot \nabla\varphi = 0 \qquad \begin{cases} v_{\varphi z} = ck/(\partial\varphi/\partial z) \\ v_{\varphi m} = ck/|\nabla\varphi| \end{cases}$$

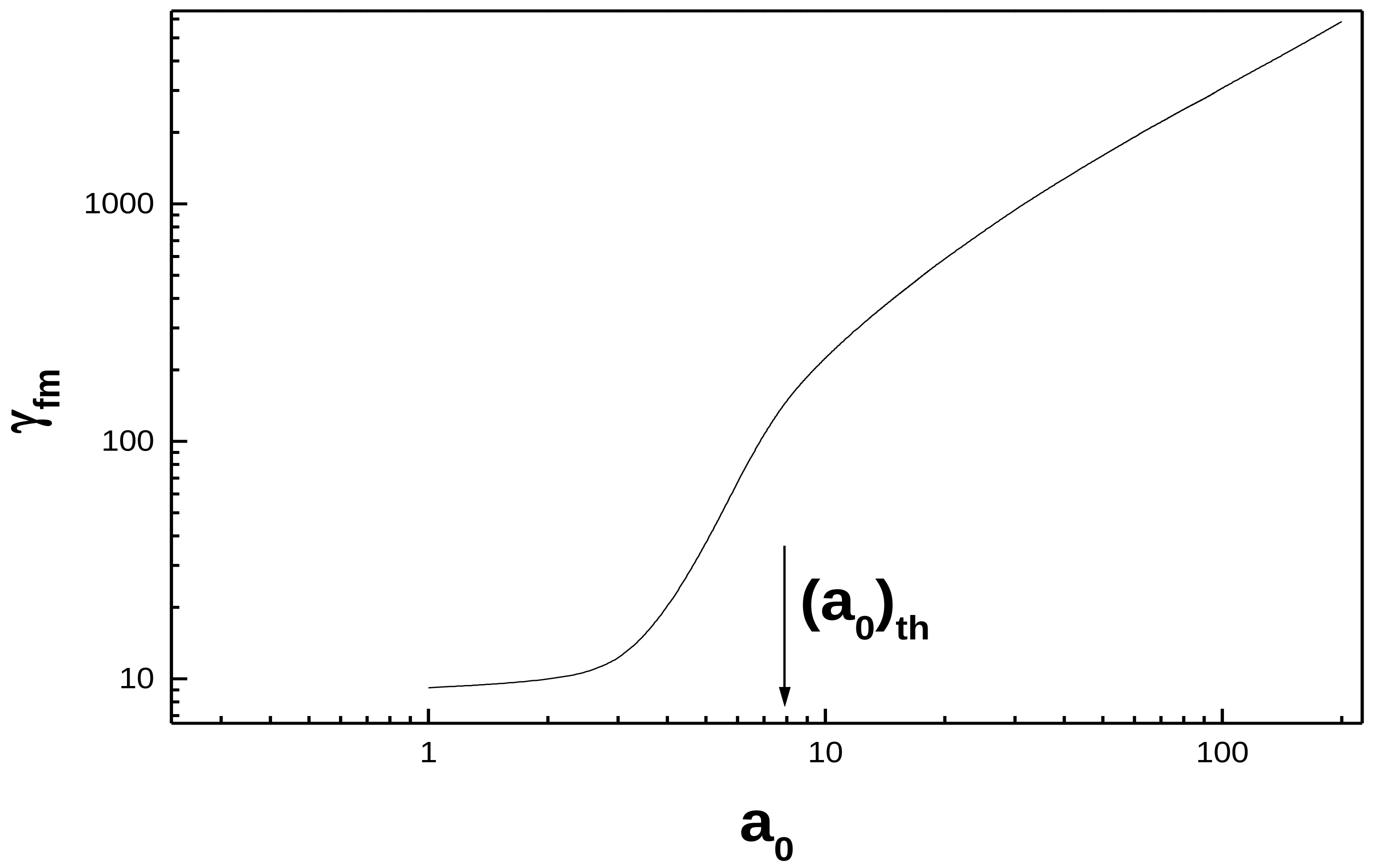


- This is a very important feature of tightly focused beam. This theory is first discovered by our cooperator Fudan group.

- Different radii of different wave fronts cause this feature. Along with different trajectories, the phase velocities are different. It doesn't have to be always equal or great than *c*.

Fig 1. The distribution of the minimum phase velocity $v_{\psi m}$ in the *y=0* plane of a focused laser beam with kw_0=30. The value $v_{\psi m}$ is given in unite of *c*, $\xi=x/w_0$, and $l=z/Z_R$.

- CAS requires high laser intensity
  - In fig 2. parameters we can see the threshold is around $a_0=5$



Initial e-beam 5MeV, w_0=40μm, γ_{fm} is the maximum final energy.

- Our simulation also shows that with relatively lower laser intensity a_0~1 the e-beam still gets accelerated with net energy gain. However the signal is less significant than CAS cases.
- The simulation results with current ATF experiment condition parameters show as following:

- ATF current parameters:

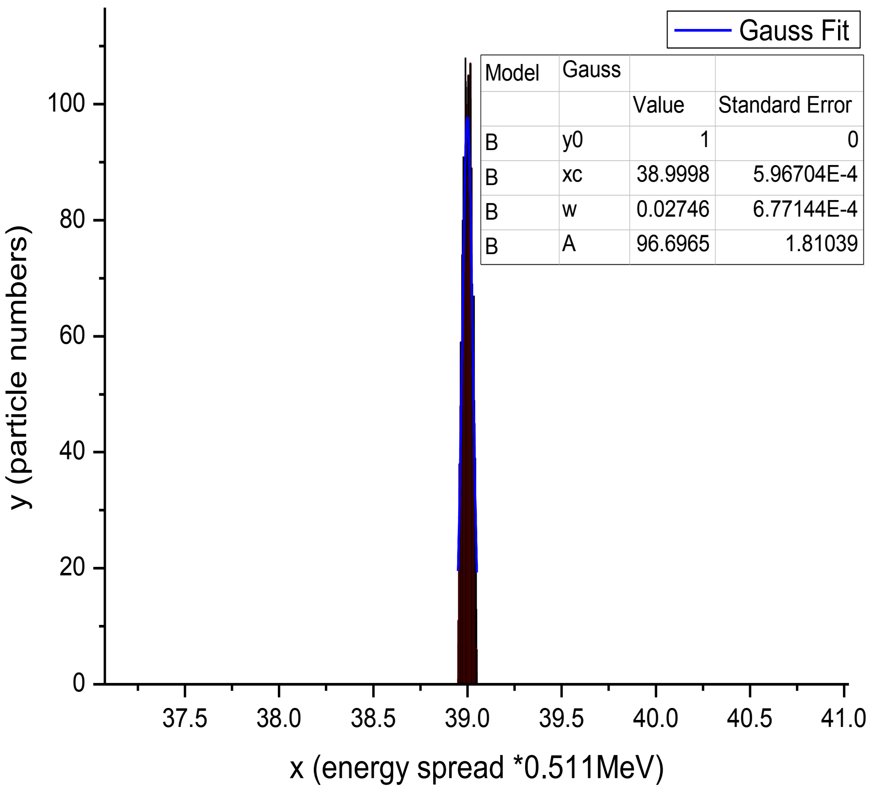
CO2 Laser:

Energy	5J
Pulse Length	5ps
Spot Size	40μm
Wave Length	10.6μm
a_0	~0.9

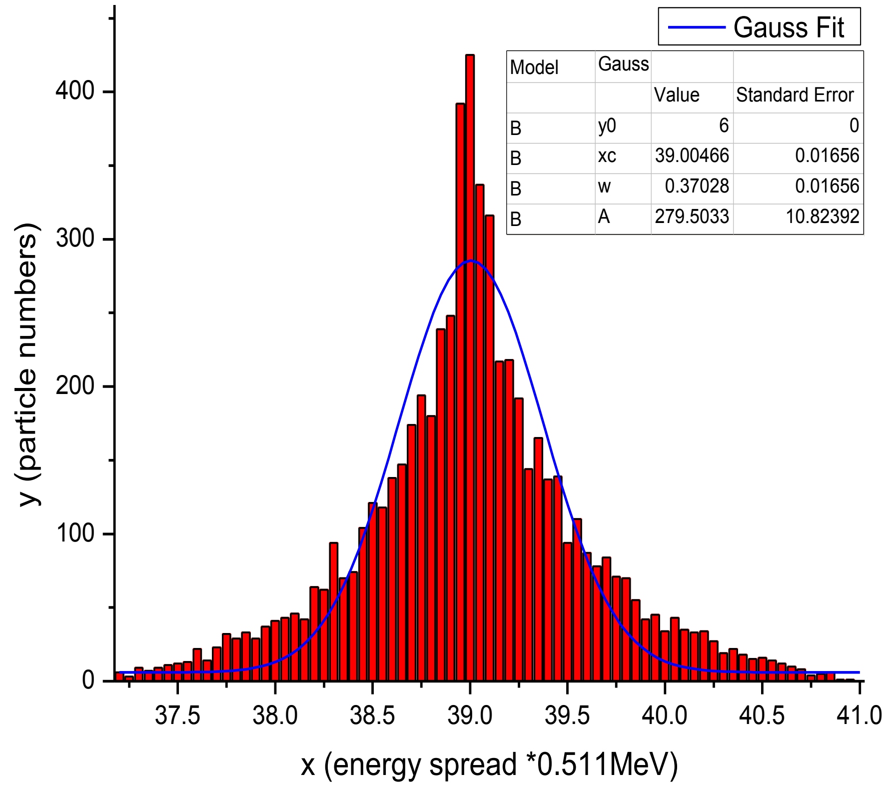
Electron beam:

Initial Energy	20MeV
Initial Emittance	~1.2 mm·mrad
$\Delta E_i/E_i$	$\sim \times 10^{-3}$
Spot Size	30μm
Pulse Length	5ps

e-beam energy spread



laser off

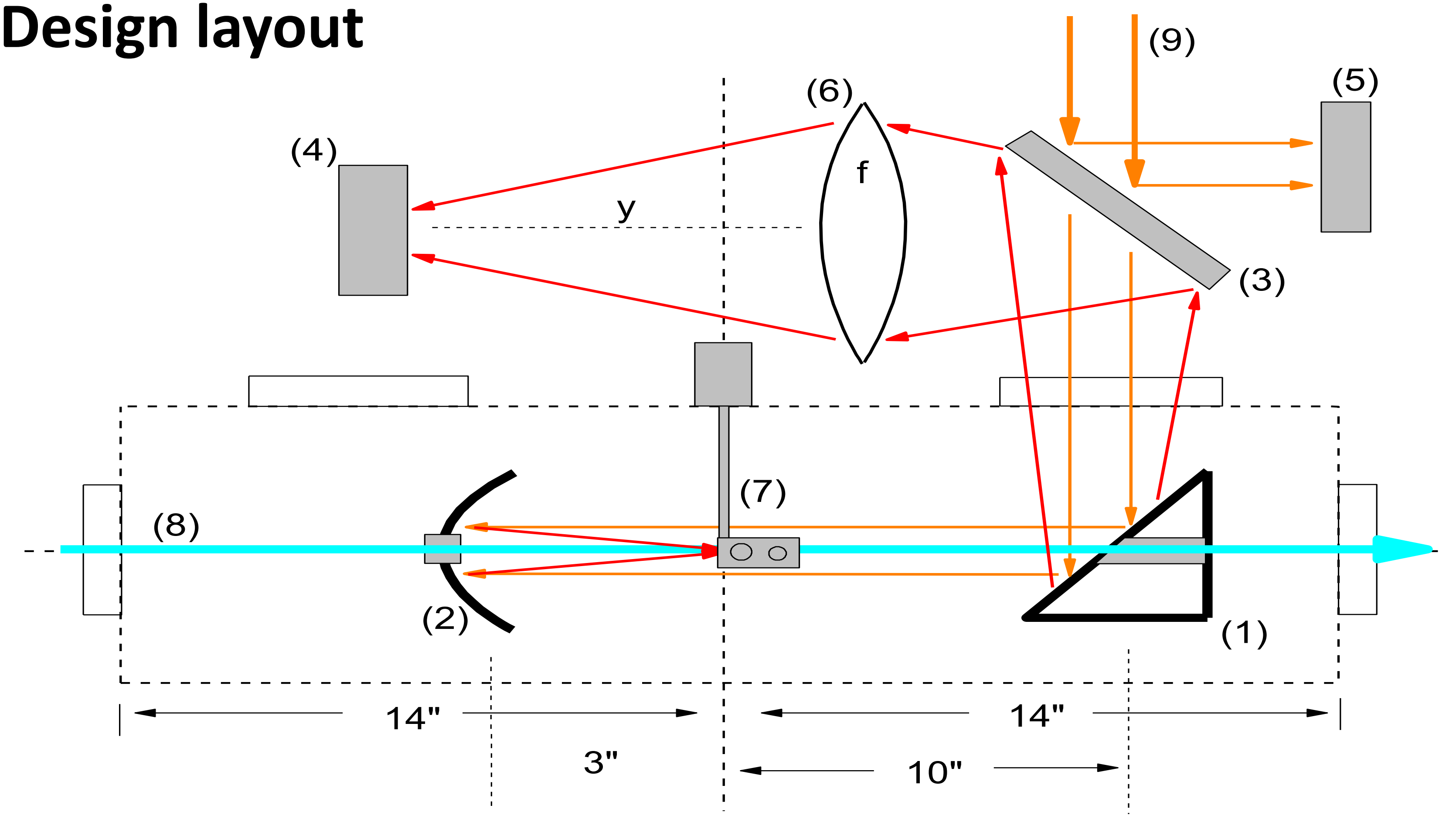


laser on

Energy spread increased to 10^{-2} from initial 10^{-3}, which is expected to be seen by ATF spectrometer.

Current Measurement Status at ATF

Design layout



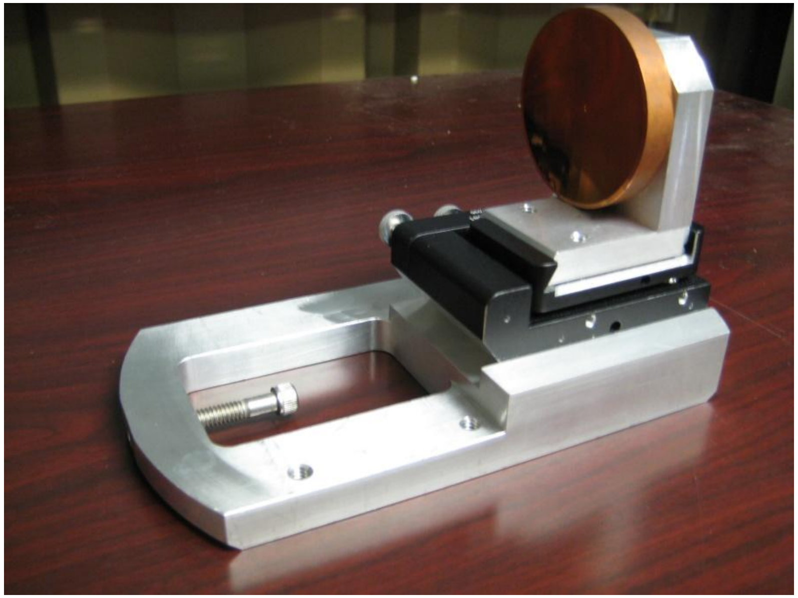
This is the layout for our VLA experiment

•The optics system will be set up on the platform next to beam line one for guiding CO2 laser into the interaction chamber.

•The parabolic mirror inside the chamber is used to focus CO2 laser at the interaction spot. The focus length is 3”.

•The flat mirror inside the chamber is used for guiding the CO2 laser in and out.

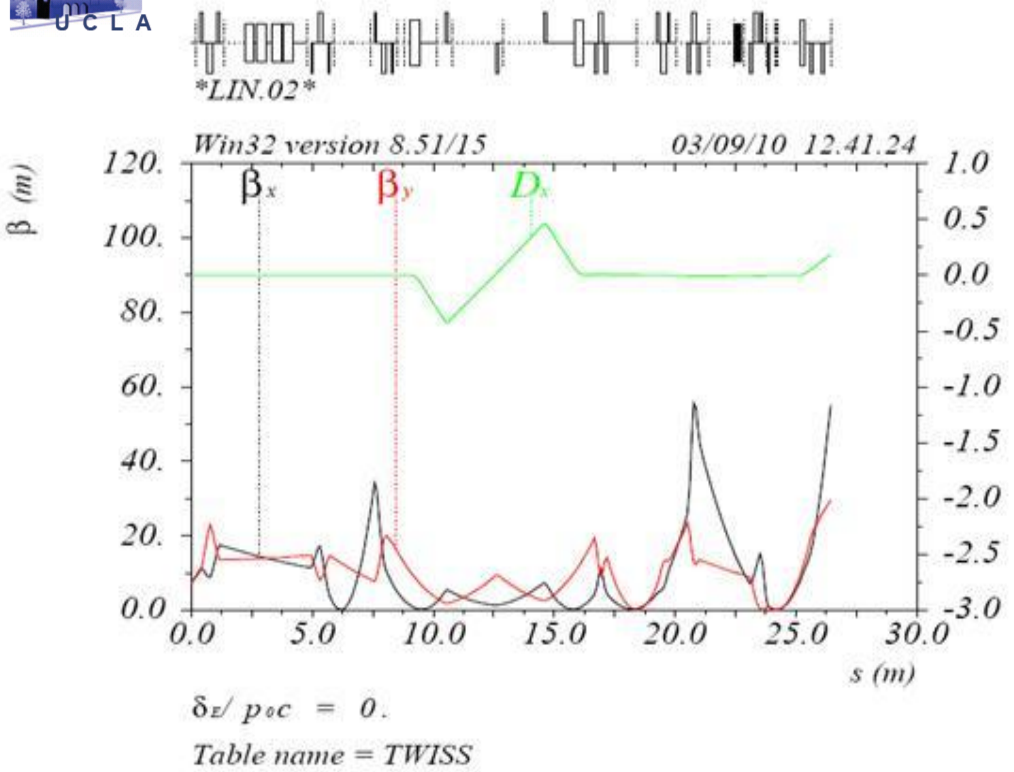
•The flange mounted target is composed by a Pin hole and Germanium plate, which is respectively used for alignment and synchronization of e-beam and laser beam. The position is just located at the laser focus spot.



The copper parabolic mirror mounted on the stage. There is a small hole in the center of the mirror for e-beam passing through. The stage can be adjusted horizontally and tilt the mirror axis.

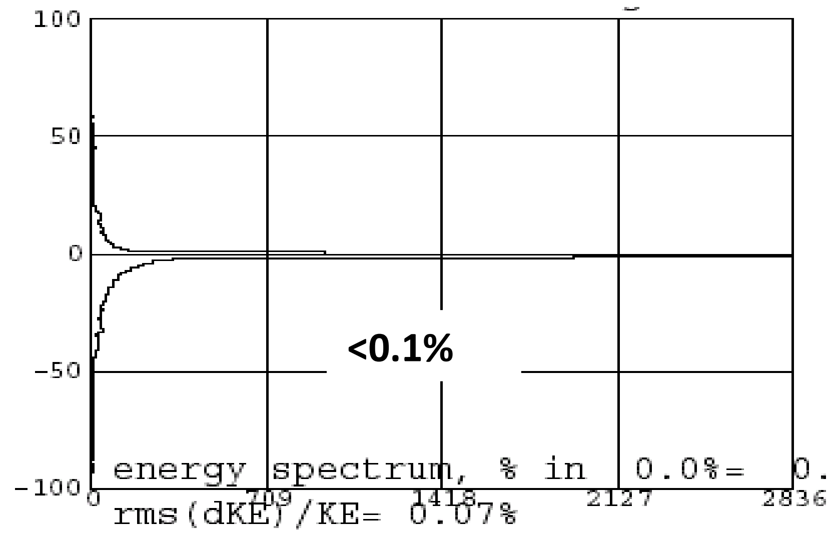
The target is mounted on the flange which offers 3-D adjustment. The step motor can be remotely controlled to insert and retract the target for e-beam going through

Tune the electron-beam to 20MeV



BPM position	βx	βy	Xmax (μm)	Ymax (μm)
Up stream	0.171	0.160	56	54
Center	0.125	0.105	47	43
Down stream	0.171	0.160	56	54

MAD8 result for 20MeV on beam line #1

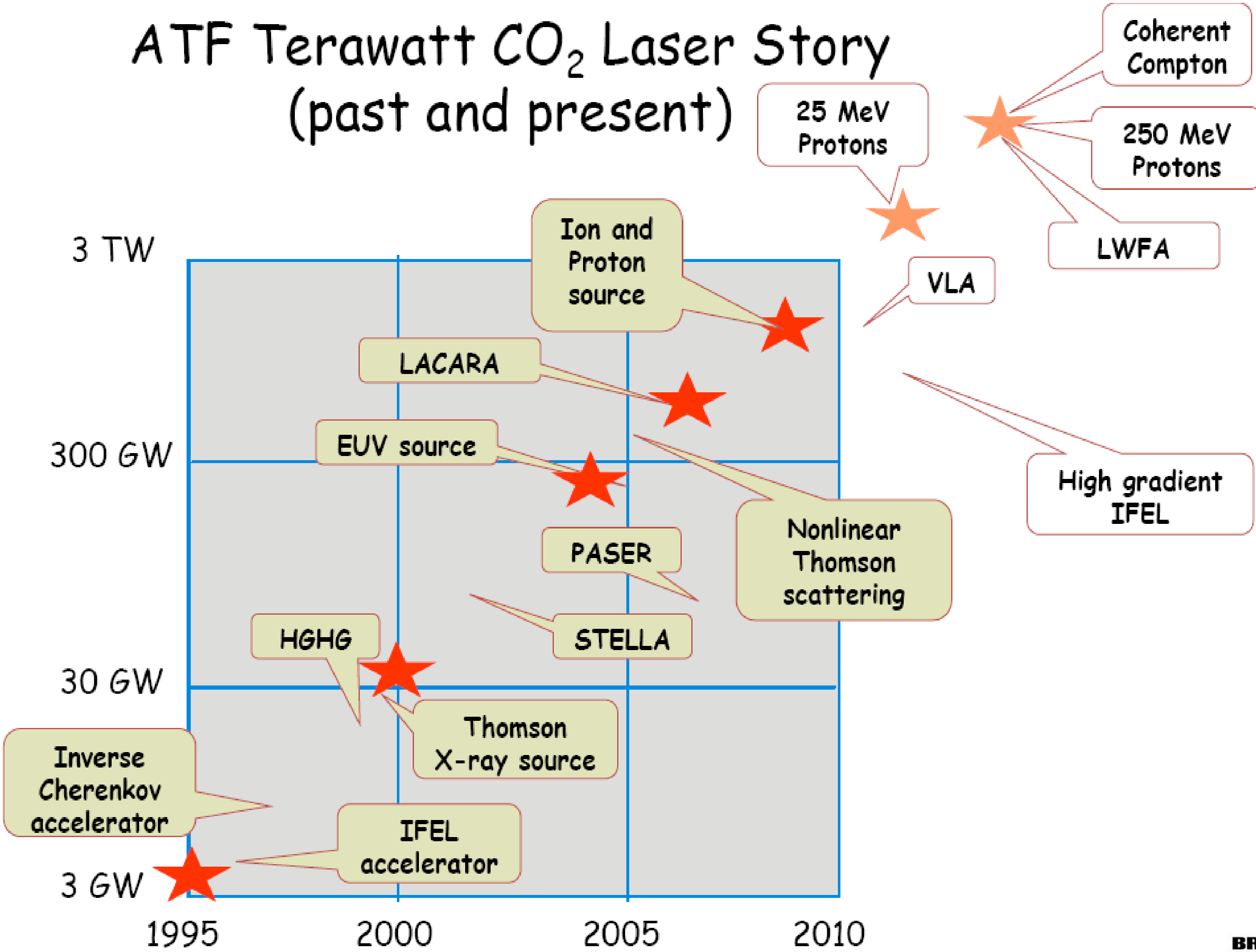


PARMELA simulation for beam energy spectrum at 20MeV

Experiment step and current status

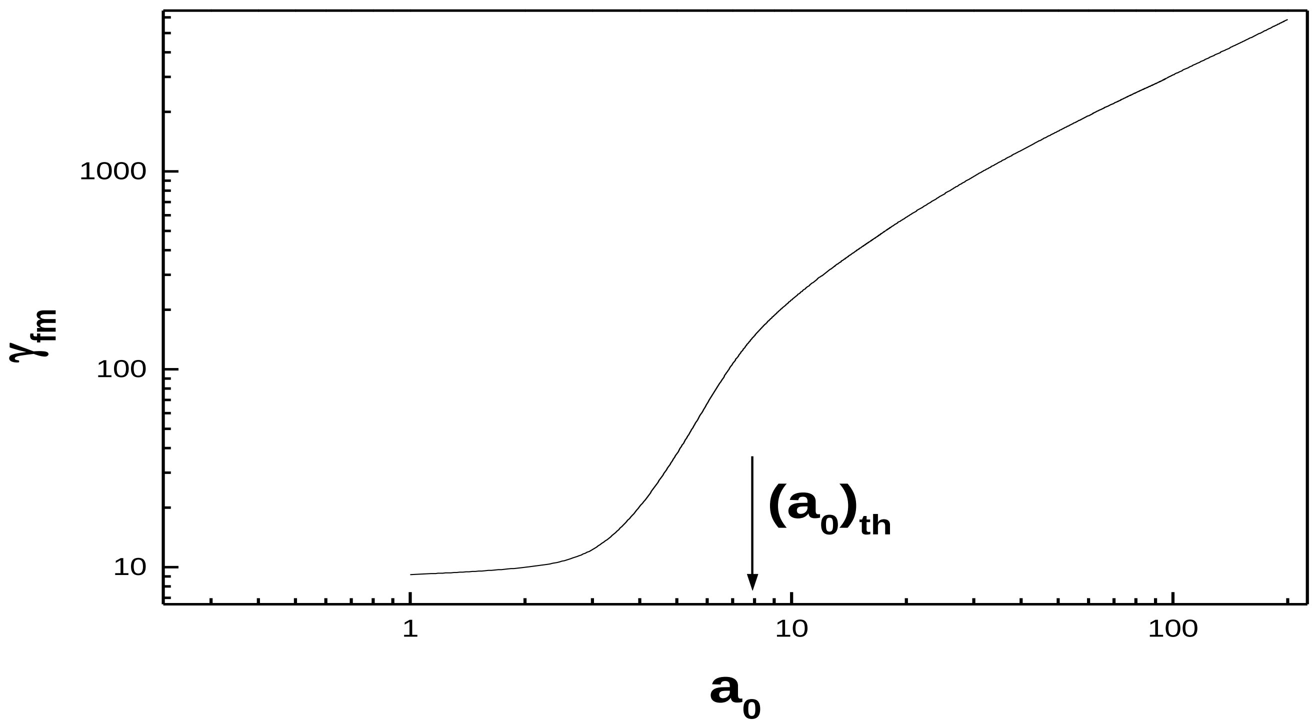
Step	Content		Stat	Note
1	Simulation	we expect to see energy spread expand from 10^{-3} to 10^{-2} with current ATF experiment condition	Check	Laser at ATF upgraded, which gives better expected results.
2	e-beam MAD8 study	MAD8 is run on Beamline #1 and gives the analysis of the chamber position. e-beam size around ~50µm.	Check	
3	BPM/Image System	1.Phosphor resolution~20-40 µm 2.Optics resolution ~12-30 µm 3.Camera CCD Cell ~10µm	Check	existing sys can measure the e-beam
4	Optics/Diagnostics	1.parabolic mirror 2.diagnostics target Modified and installed	Check	
5	Alignment	Use local Hi-Ne laser and CO2 to do the alignment for parabolic mirror and diagnostic target	Next	1 week
6	Synchronization	Use Germanium plasma feature to synchronize laser and e-beam	Next	1 week
7	e-beam tuning and beam time	1.tune 20MeV e-beam 2.experiment beam time	Next	1 week

Future Prospect of VLA experiment

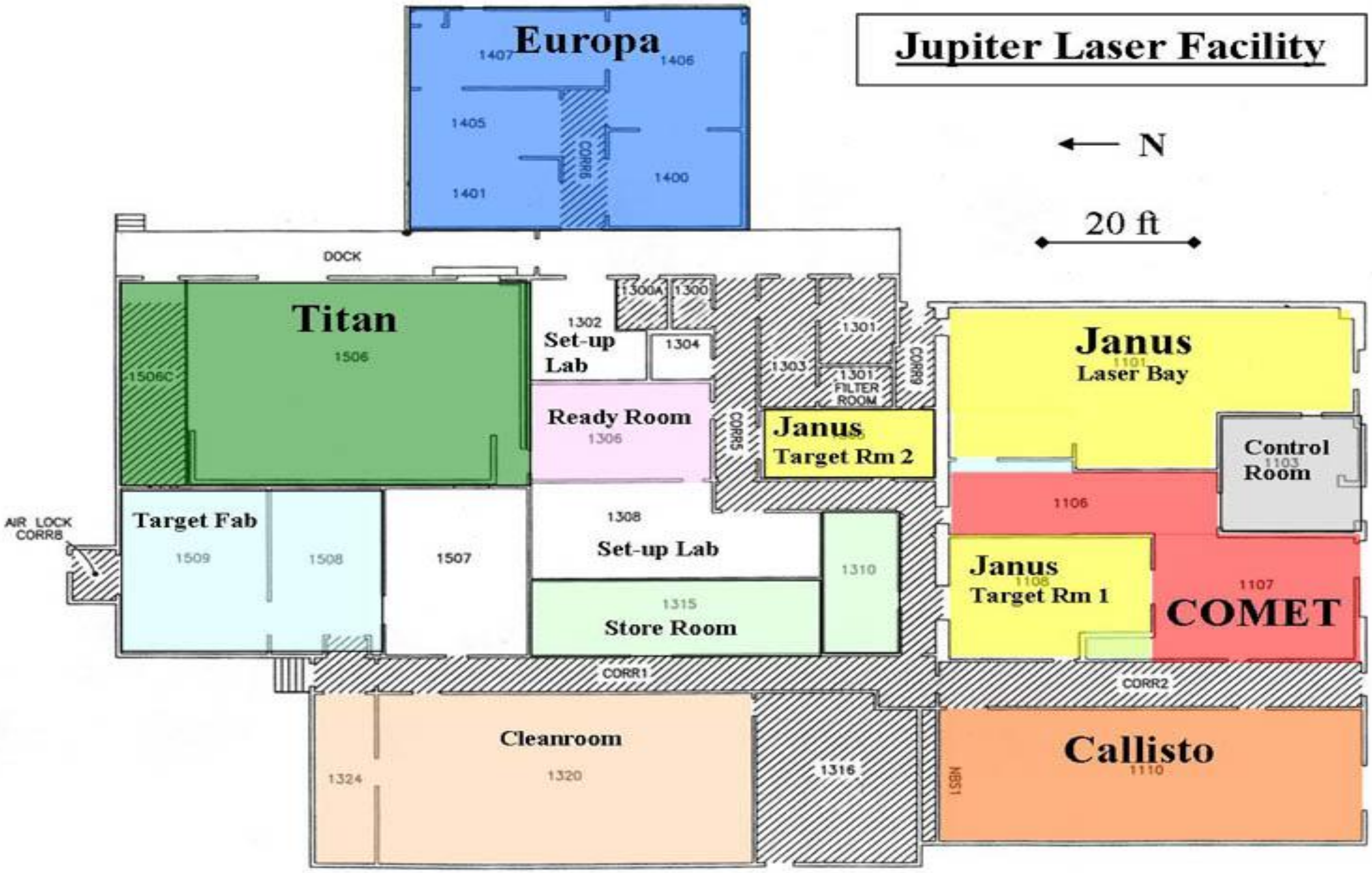


CO2 upgrade path

		Apr.2009	Feb.2010	Nov.2010	Nov.2011	???
Energy	[J]	5	5	5	10 (IV)	25 (V)
Duration	[ps]	2 x 5 (I)	5 (II)	5	2 (IV)	0.5 (V)
Power	[TW]	0.5	1	1	5	50
a_0		1.2	1.7	2.2 (III)	5	16
E_p	[MeV]	1.5		5	25	250



Multi-laser platform at JLF-LLNL. With the same seed, different rooms have different laser system.



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Simulation Results based on LLNL practical parameters

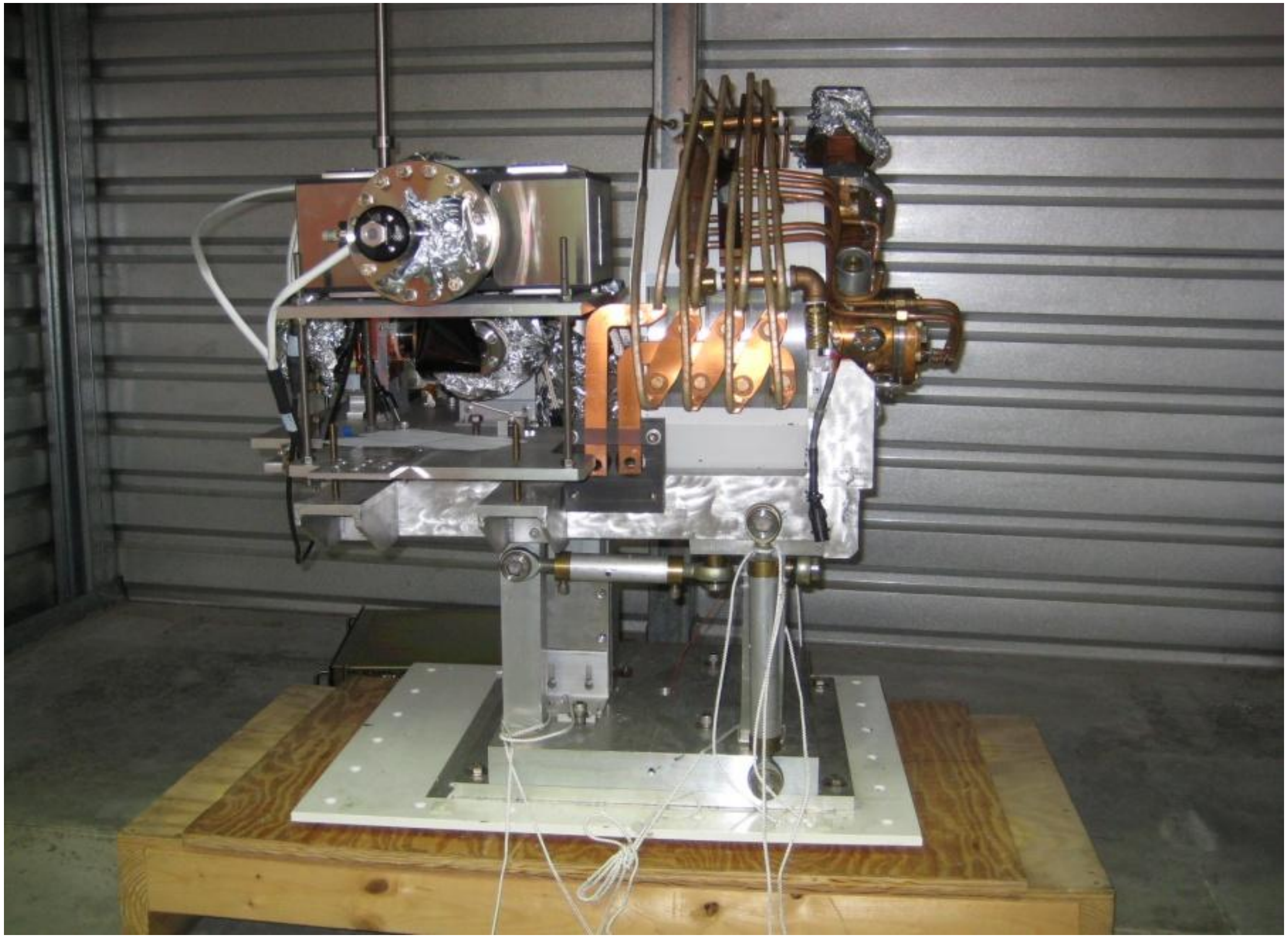
Case	Energy (J)	Pulse duration (fs)	λ Wave length (nm)	Spot size (μm)	Power (TW)	a_0	γmax (*0.511MeV)
I	20	60	800	15	330	4.6	118
II	20	60	800	5	330	14.07	722
III	20	60	800	3	330	23.45	750
IV*	20K	5000	1054	10	4000	32.06	~1000

Initial electron energy is around 5MeV.

Proposal submitted to LLNL for future experiment

Abstract

The UCLA/BNL team proposes to carry out the study of a GeV Vacuum Laser Accelerator (VLA) with Jupiter Laser Facility (JLF) and National Ignition Facility at (NIF) at the LLNL. This is a whole new idea of VLA of charged particles and this is unique. Taking advantage of the super-strong laser field available at NIF/JLF ($a_0 \geq 20$), the expected energy gain of the proposed VLA should be higher than 400 MeV. Preliminary simulation shows that GeV output electron can be expected with a laser beam intensity . The acceleration gradient could be ~GeV/cm. In VLA the output electron beam is easy to control. And it has much less confinement of Interaction Region (IR) and optics damages. A 2856 MHz BNL photocathode RF gun will be used as an injector for the proposed VLA, simulation will be performed to optimize the electron beam injector for the VLA performance. We have identified some key hardware components needed for the 5MeV electron accelerator. It has a laser driven photo cathode and will provide a low emittance electron beam.



The electron-gun we acquired for future potential collaboration with LLNL

Summary

What we are looking for (for optimal situation):

Stage #1, at BNL-ATF, we are planning on a proof-of-principle experiment to prove that laser driven vacuum acceleration is achievable.

Stage #2, with higher laser intensity we are expecting significant CAS acceleration results, which could yield acceleration gradient ~GeV/m. ATF's next year laser upgrade and LLNL NIF/JLF laser system can be used to perform this innovative acceleration scheme.

Application and Prospection:

This acceleration scheme could be a revolution in high energy physics. If this experiment can be performed and further get improved on beam alignment controlling and staging, such for an example, a small table size accelerator with *GeV* output energy can be in any lab, or even office for researching work anywhere.

Thank you!