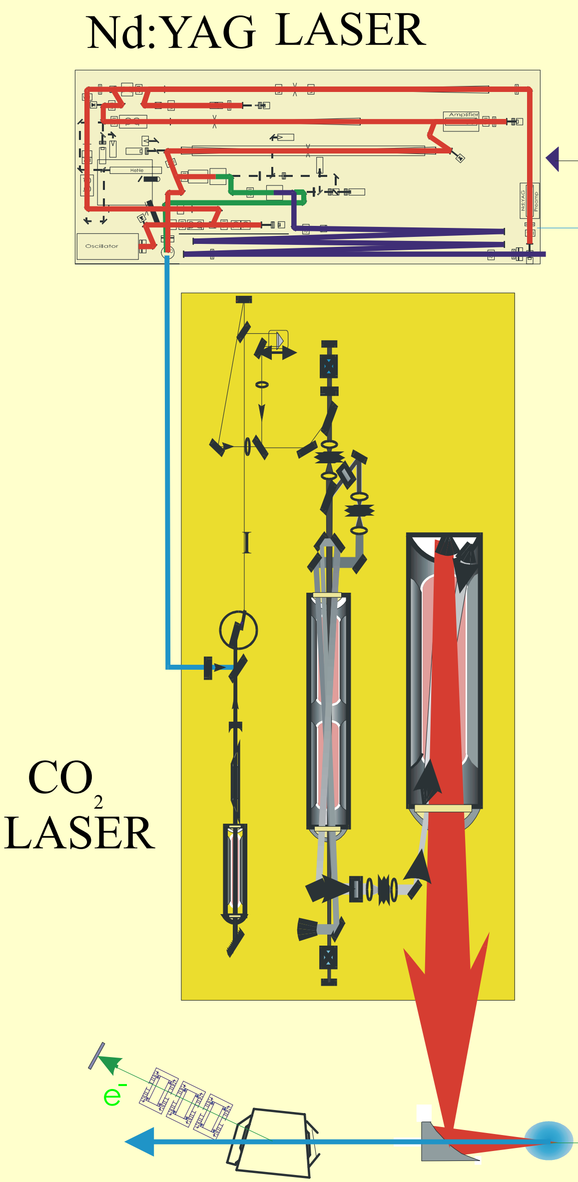
ATF LASERS

Igor Pogorelsky and Marcus Babzien

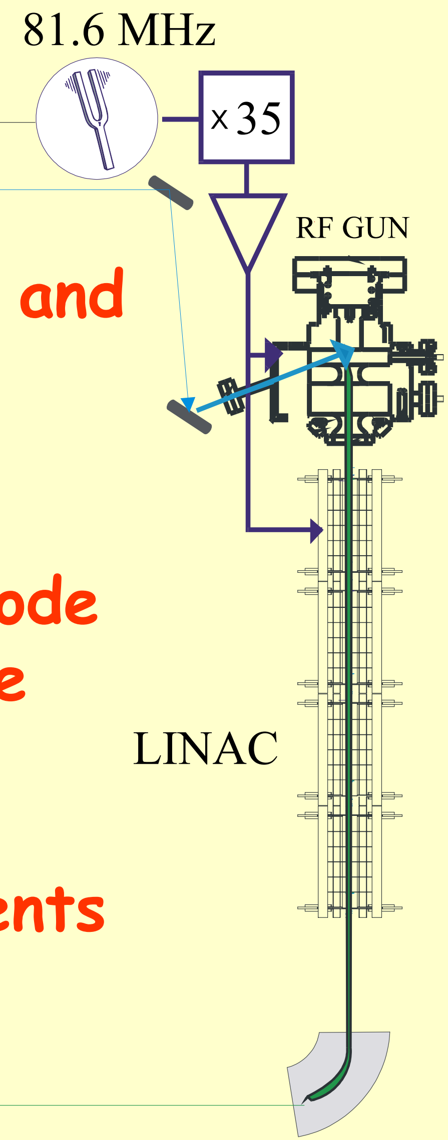
with special thanks to Igor Pavlishin

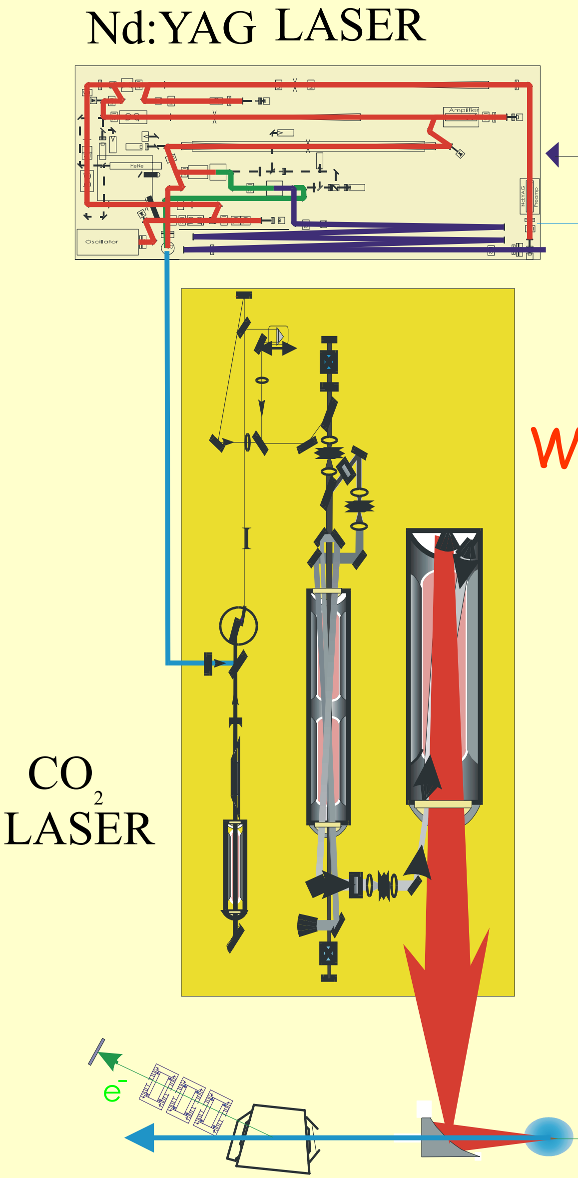


Synchronized to linac CO_2 and YAG Lasers are important components of the ATF

YAG: drives RF photocathode & slices ps CO_2 pulse

CO_2: drives laser/e-beam interaction experiments





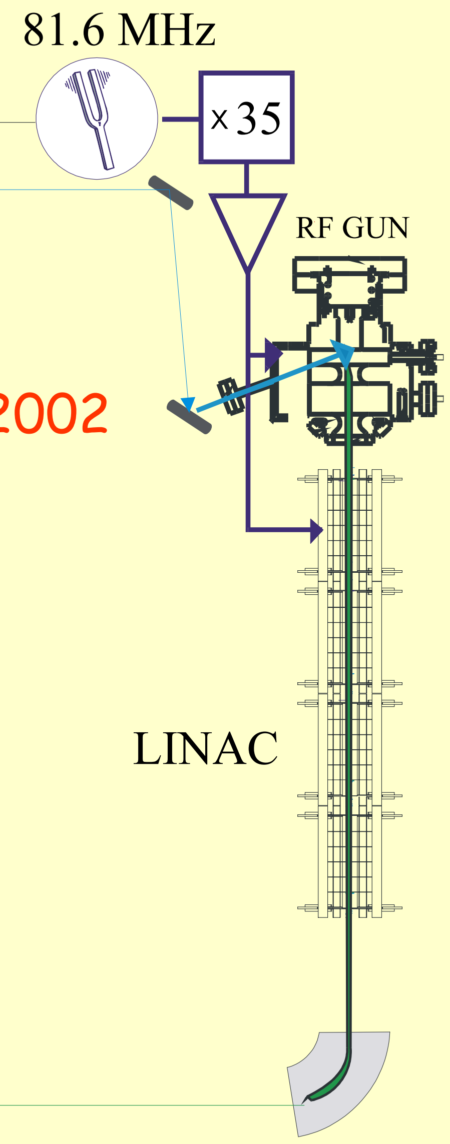
OUTLINE:

What is new since User's Meeting 2002

Status and perspectives

Special features

to meet user's requirements



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Brookhaven National Laboratory
Accelerator Test Facility

YAG Status - Overview

- YAG system now in very mature mode of operation – highly reliable, stable, flexible, and slowly improving.
- Since last users meeting, provided beam on 260 days and ~3000 hours. Average operating duration is >11 hours/day, which shows the usefulness of training experimental duty operators.
- Total shots since system was configured in its most recent form (ca. 1995) has now exceeded 100 million pulses!
- Upgrades ongoing, design of replacement underway.

YAG Status - Safety

- Lab-wide stand-down issued Sept. 10, 2003
- ATF lasers first at BNL to be back online on Sept. 23
- All personnel retrained as per director’s mandate
- All aspects of laser safety at ATF found to be in order: training, controls, eyewear, postings, and documentation met or exceeded requirements for restart

- Minimal operational impact to linac users!

- Laser experiments slower to receive restart approval

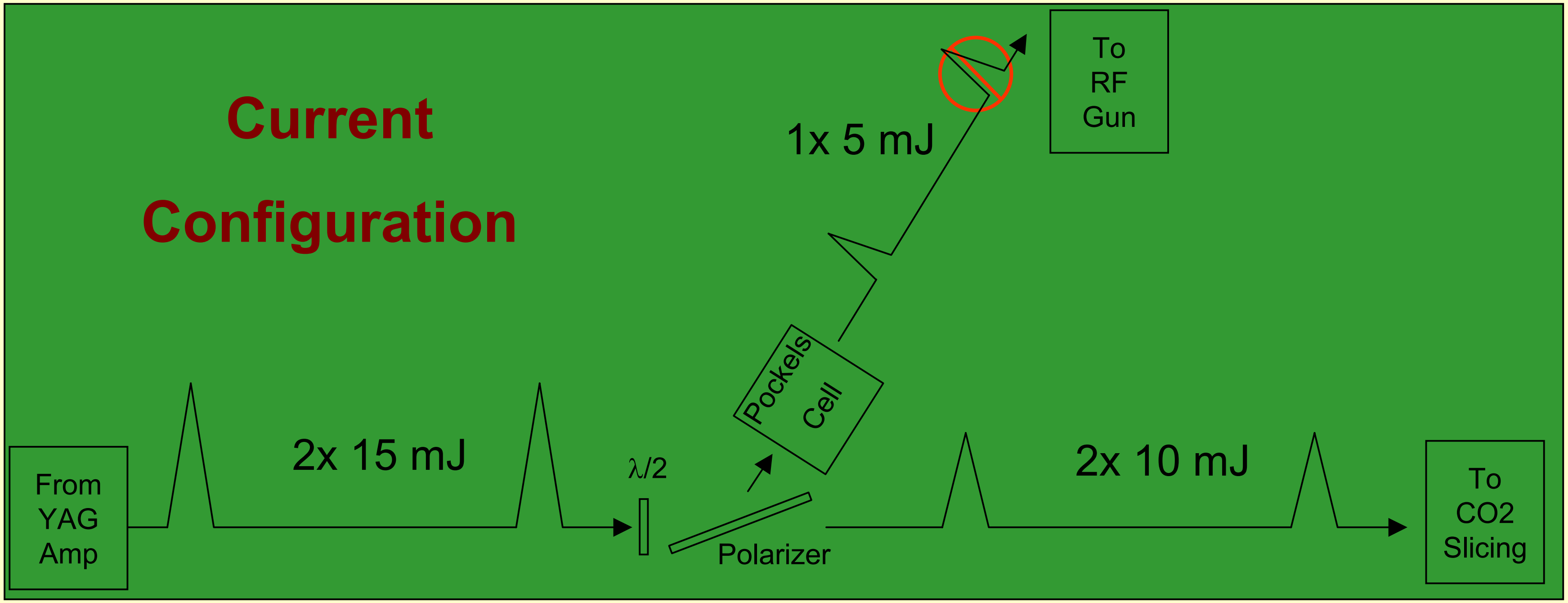
YAG Status - Demonstrated Performance

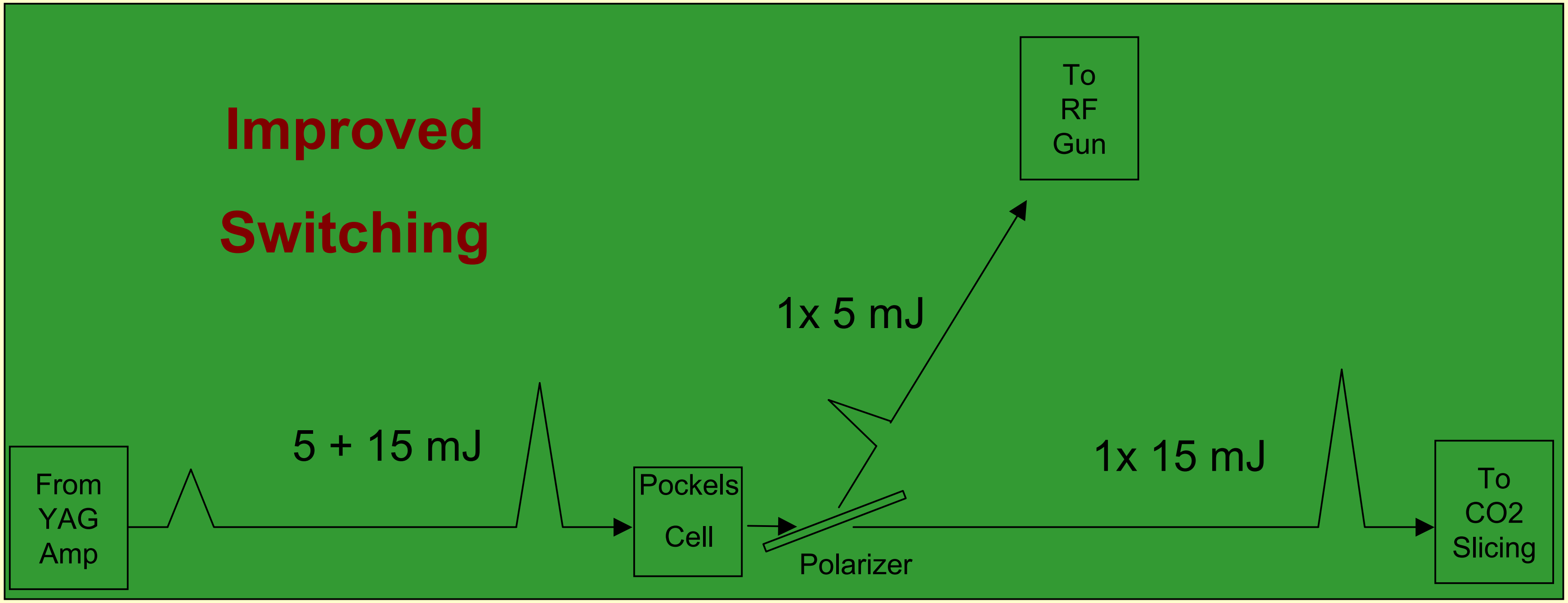
See also:http://www.bnl.gov/atf/systems/lasers/NdYAG/YAG_stats.htm

Energy: (dual pulse mode)	
UV on cathode	0-10 μJ
IR at CO2 table	5 mJ
Laser output: total IR	30 mJ
IR to gun	5 mJ / pulse
Green	1 mJ / pulse
UV	200 μJ
Repetition rate	1.5, 3 Hz
Pulse duration (FWHM):	
Oscillator IR	7 ps
Amplified IR	14 ps
Green	10 ps
UV	8 ps
Range of beam size on cathode (Ø)	0.2 - 3 mm
Top-Hat Beam Profile Modulation (P-P)	<20%
Shot-to-shot stability (rms):	
Timing	<0.2 ps
Energy	2 %
Pointing (fraction of beam Ø)	<0.3%
Drift (8 hour P-P)	
Timing	<1ps
Energy	<15 %
Pointing (fraction of beam Ø)	<1%

YAG Status – CO_2 Slicing Improvements

- Measured second harmonic compression from 1 micron to 532 nm with pulse duration decreasing 3-4x in a 10 cm long KD*P crystal.
- Energy available at 532 nm is ~ 100 μJ, now limited by input energy.
- Multi-stage semiconductor slicing using both 1 micron & green pulses will allow few ps CO2 pulse generation for TW operation.
- New Pockels cell is on order to more efficiently utilize 1 micron energy between gun and CO2 slicing

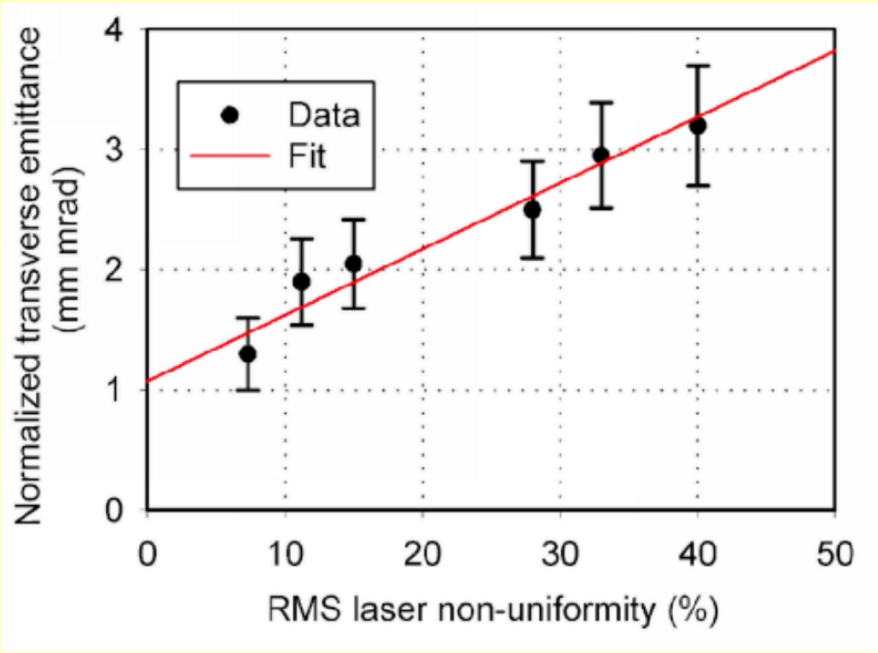

Current
Configuration
From YAG Amp
2x 15 mJ
λ/2
Polarizer
Pockels Cell
1x 5 mJ
To RF Gun
2x 10 mJ
To CO2 Slicing

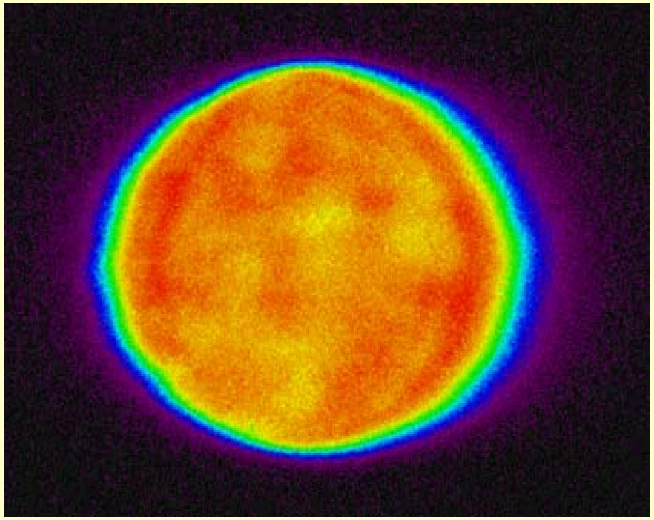

Improved
Switching
From YAG Amp
5 + 15 mJ
Pockels Cell
Polarizer
1x 5 mJ
To RF Gun
1x 15 mJ
To CO2 Slicing

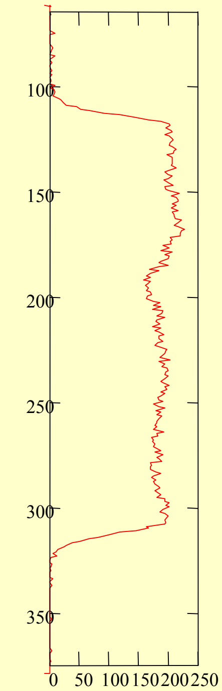
YAG Upgrades – Beam Profile

Uniformity of electron emission from photocathode affects emittance.

Laser uniformity is limited by phase errors in optical elements that are transferred to the intensity domain as the beam propagates to the photocathode.

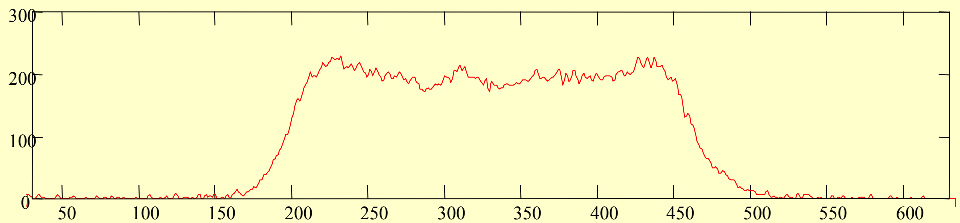






Some elements such as non-linear crystals and Pockels cells are not easily fabricated to such tight tolerances (<λ/20).

Therefore it is very challenging to passively improve the uniformity of the beam.



YAG Upgrades - Active Profile Shaping

- A micromirror array consisting of a 1024x768 grid of 13 micron square mirrors is commercially available.
- Mirrors can be controlled individually to one of two tilt states. A group of mirrors smaller than the resolution limit of the laser transport optics provides discrete control of intensity at on point in the beam profile.
- The large number of mirrors will allow both high resolution and ~ 100:1 dynamic range in intensity over the entire beam profile. This should allow beam uniformity to be adjusted to within 1%.
- Sample arrays have been tested with the ATF laser and meet the requirements for damage threshold and reflectance control.
- A development version with computer control is on order for further testing.

Future Prospects – Advanced Drive Laser Design

GOALS:

- **100 uJ available UV on cathode**
  (currently ~ 10-20 uJ)
- **Energy jitter 0.2% rms ~ 1% p-p**
  (currently ~ 1% rms)
- **Timing jitter < 200 fs rms**
- **Profile uniformity ≤ 5% p-p from desired arbitrary profile**
  (currently ~20%)
- **Pointing Jitter ≤ 1% p-p**
  (currently < 0.3%)
- **Retain desirable characteristics of current system:**
  - **Fast turn-on**
  - **High Reliability**
  - **Simple operation (~turn-key)**

APPROACH:

- **Rely on diode pumping**
- **Choose efficient 1 μm materials (e.g. Ytterbium:glass Yb:S-FAP)**
- **Integrate high-level commercial components in-house**
- **Provide capability for optical synchronization of facility by seeding additional amplifiers**
- **Design system as a photocathode driver from the beginning!**

ATF user's experiments with CO_2 laser

completed experiments:

- Inverse Cherenkov Accelerator
- IFEL Accelerator
- Staged Electron Laser Accelerator (STELLA I and II)
- High Gain Harmonic Generation (FEL)

currently active experiments:

- Compton Scattering of ps Electron and CO_2 Beams
- Laser Driven Cyclotron Autoresonance Accelerator (LACARA)
- Structure-based Laser Driven Acceleration in Vacuum

more to come

CO_2 laser status and perspectives

- Until recently, operated at the 180 ps 30 GW level. The relatively long pulse duration was due to a narrow bandwidth of a preamplifier.

- Advisory panel (September 2001) outlined practical steps to attain ~1 TW primarily by shortening pulse duration:

  Generation of ~3 ps SH of YAG laser in a KD*P crystal

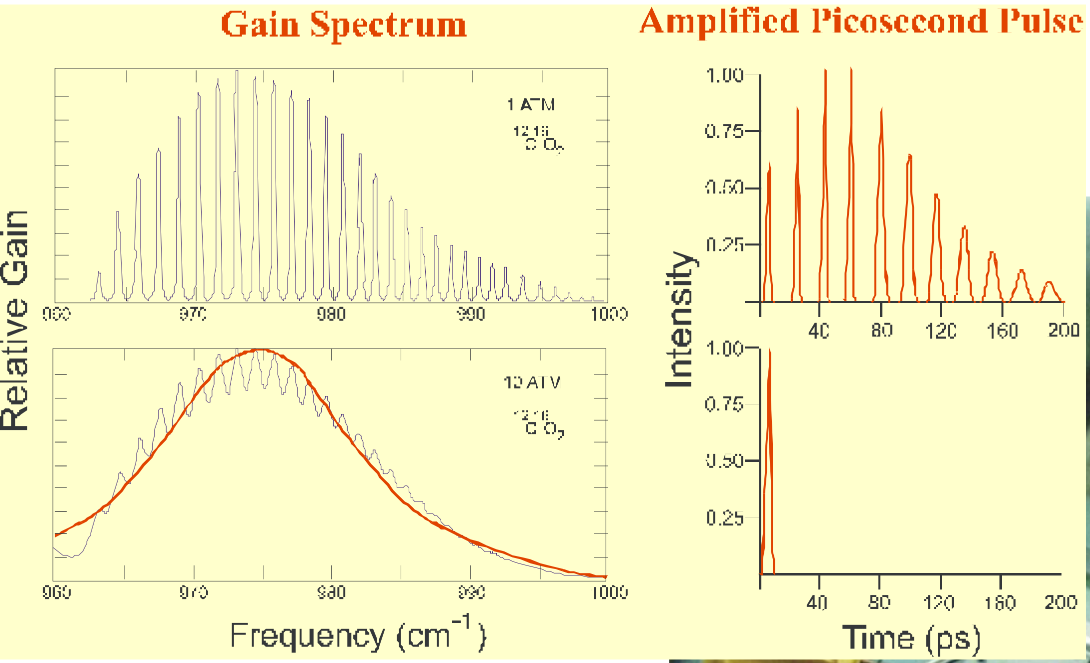
  Gate ~3 ps CO_2 pulse with a fast semiconductor or Kerr switch controlled by YAG SH

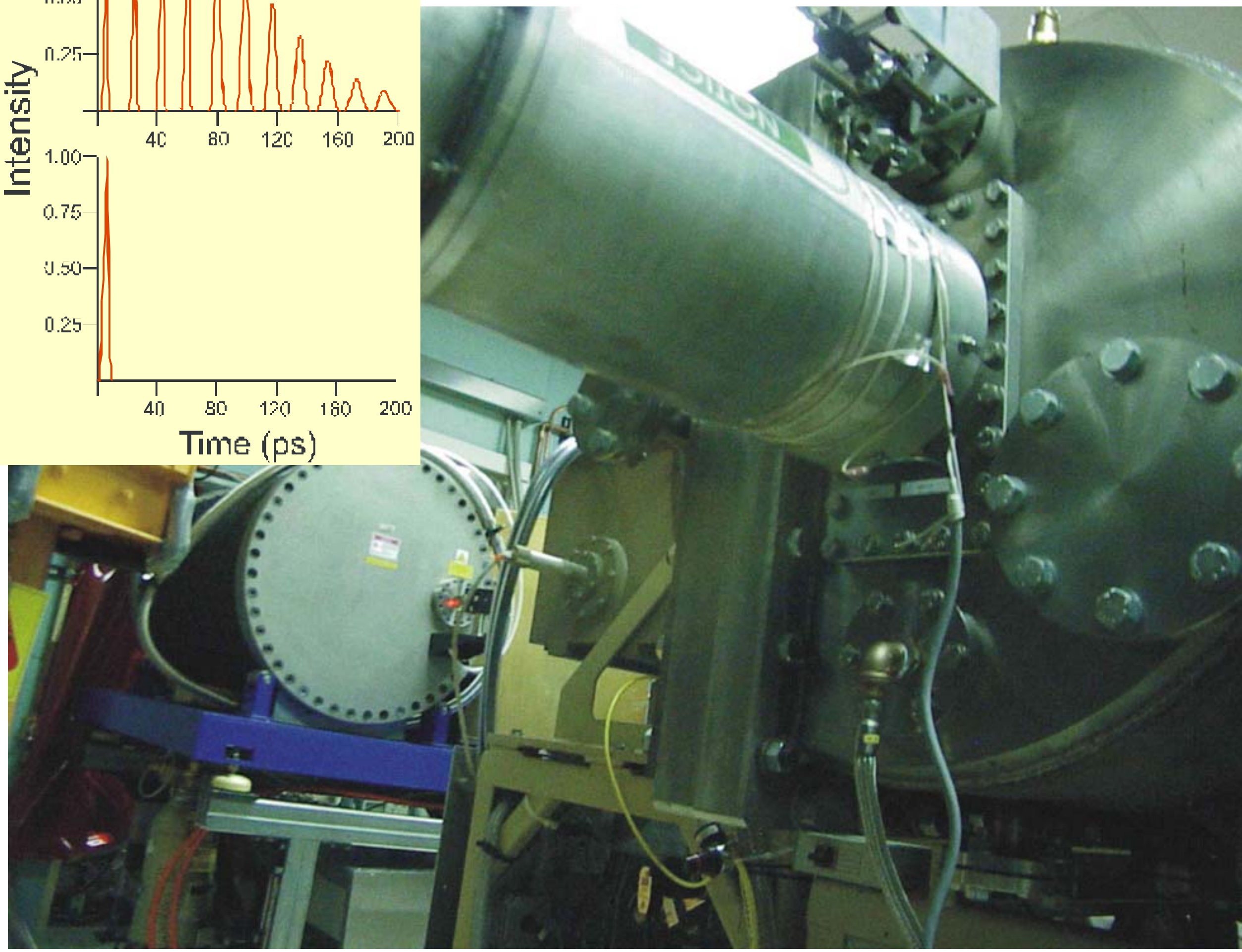
  Acquire 10-atm preamplifier

- Presently, all these hardware upgrades are completed and integrated into the system that operates at 30 ps 0.5 TW (to be confirmed).

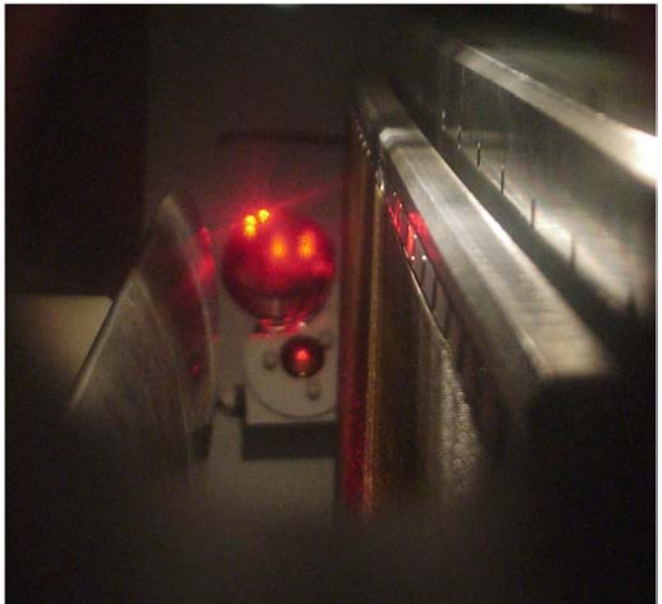
- We will proceed with a gradual improvements leading to a shorter pulse and higher peak power by optimizing the YAG and CO_2 setup.

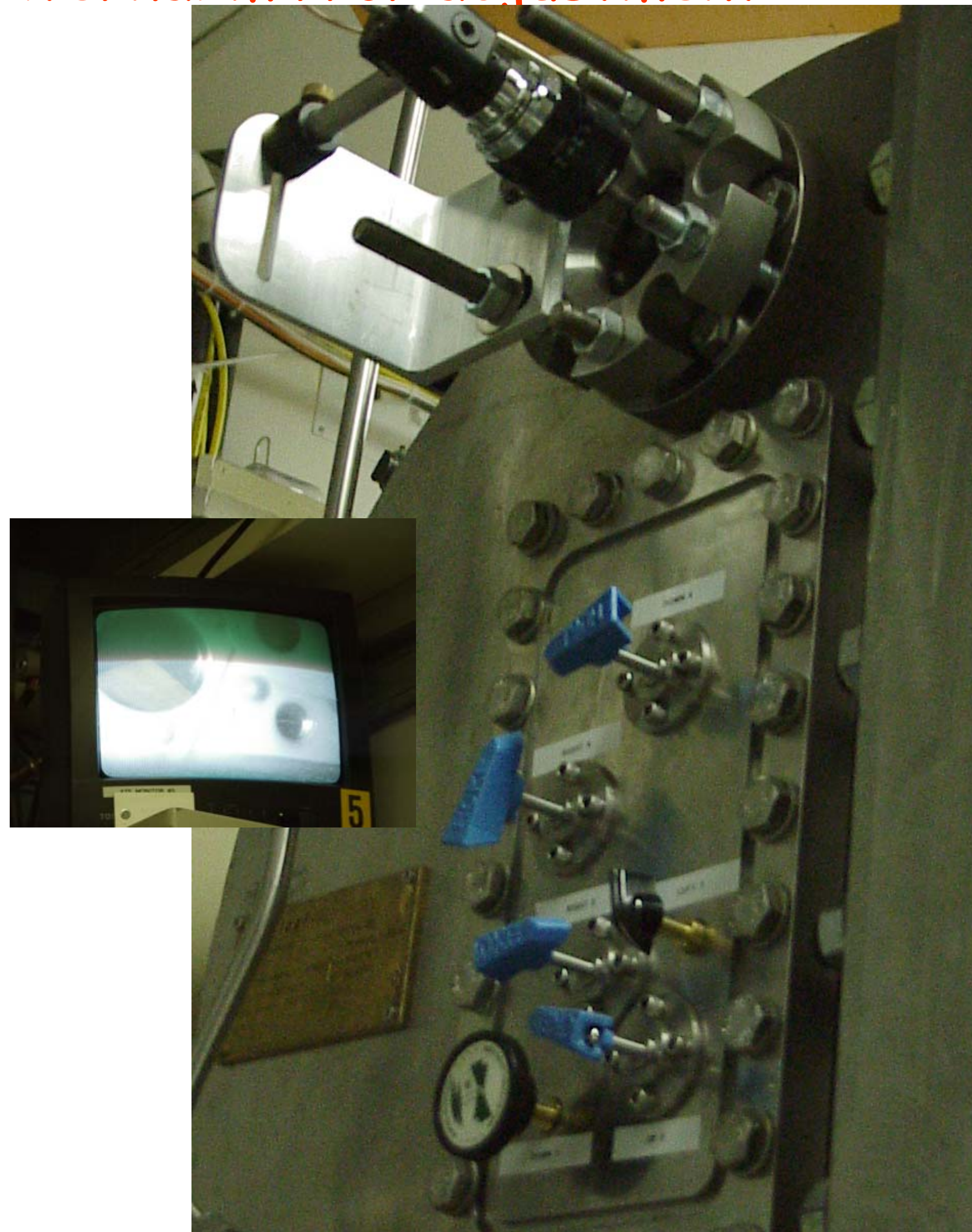
High-Pressure CO_2 Amplifiers



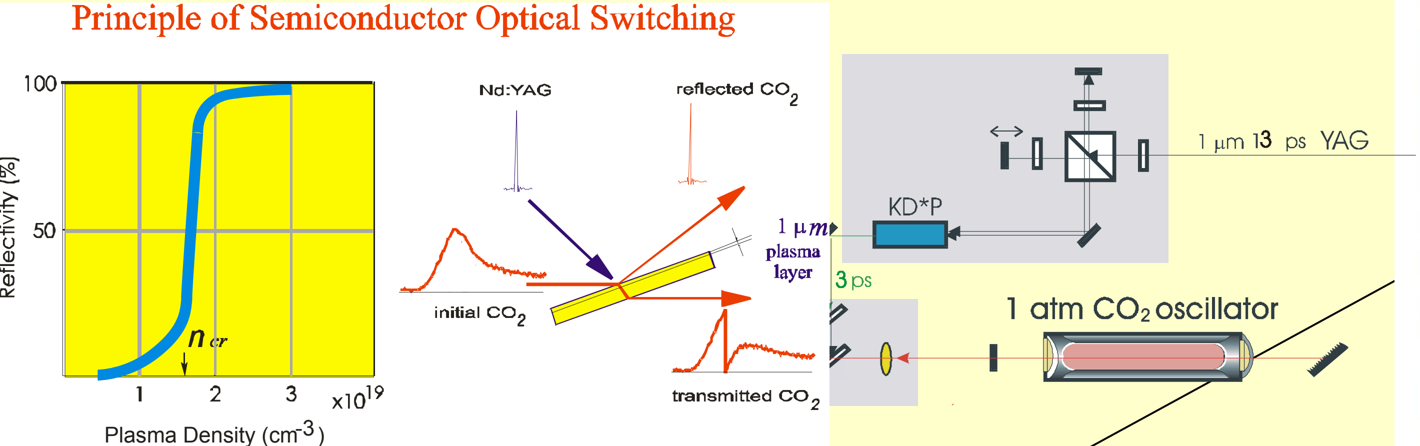


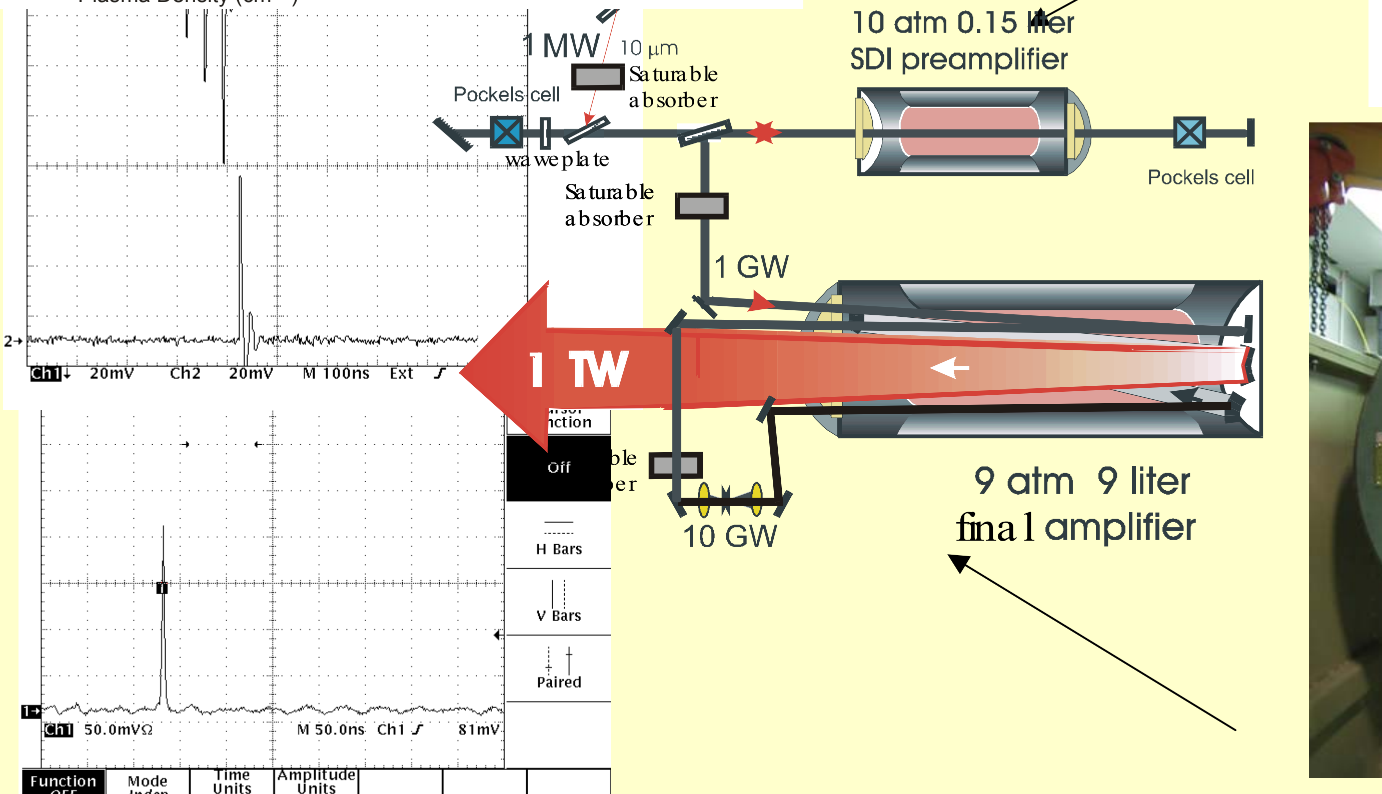
Final CO_2 amplifier is upgraded with adding extra 2 passes (6 total) and external mirror adjustment



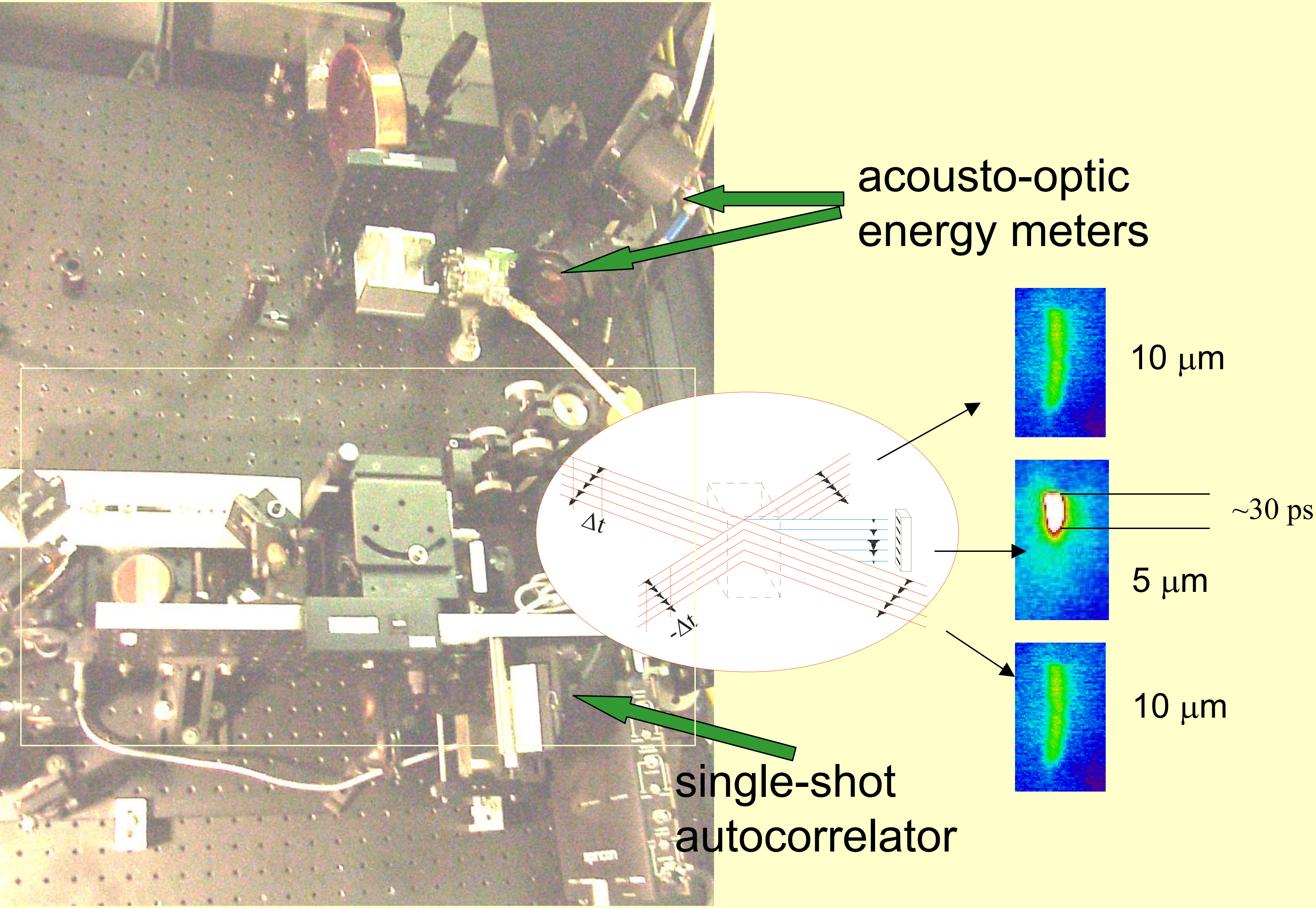


After upgrade the ATF CO_2 laser system will be capable to 1 TW peak power



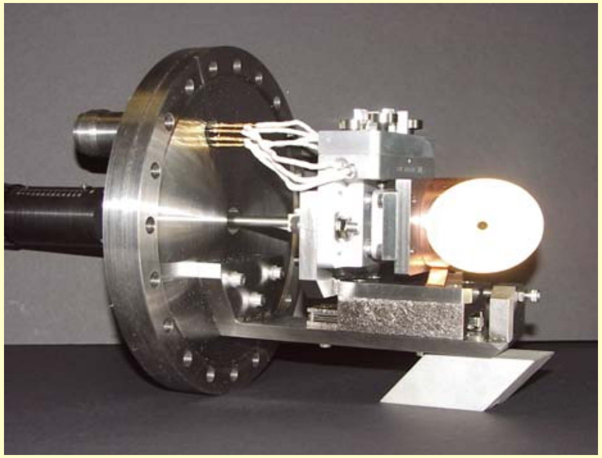


On-line diagnostics



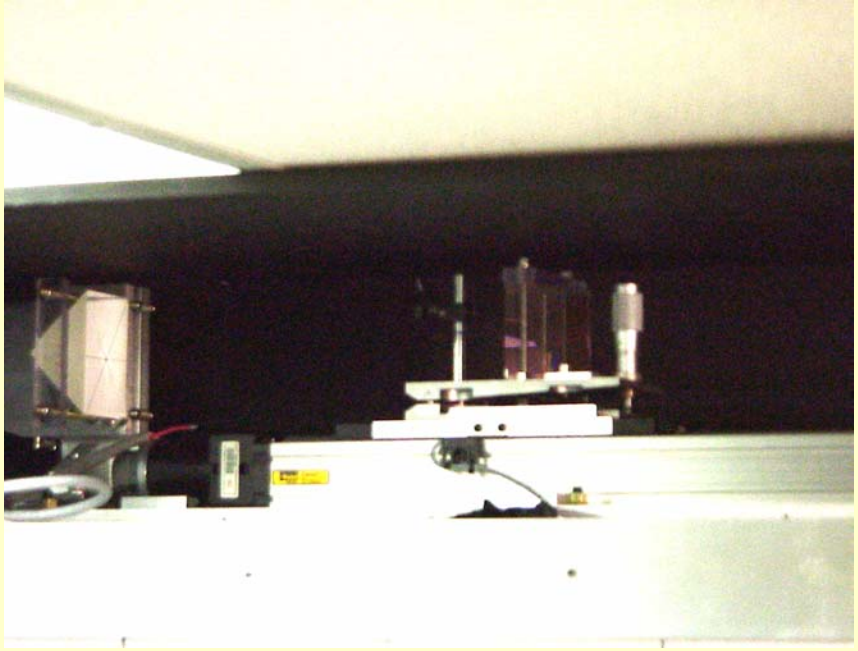
Demonstrated and prospective CO_2 laser performance

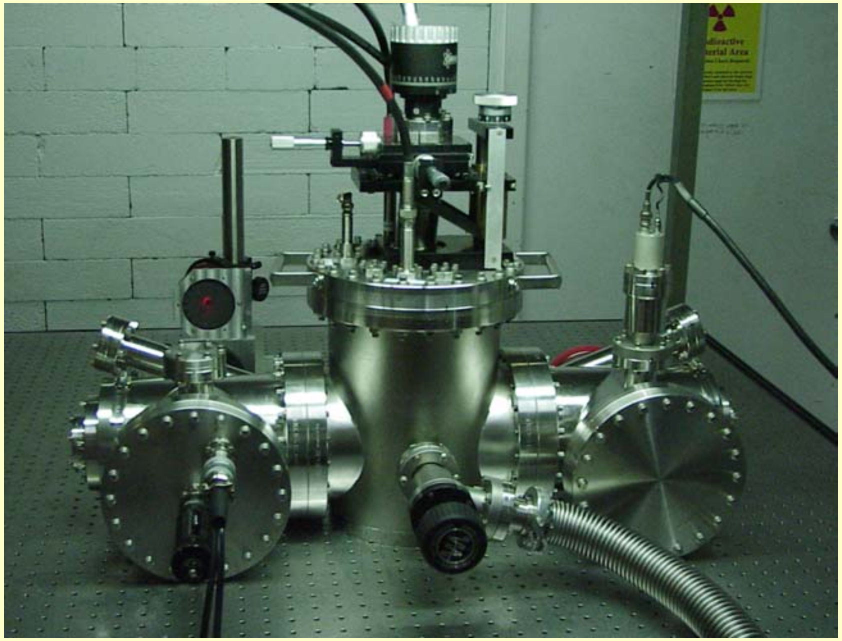
	preamplifier	final amplifier
Pulse length	30-180 ps	(3ps)
Energy	10 mJ	15 J
Repetition rate	1 Hz	1 / 20 Hz (limited by power supply)
Peak power	1 GW	0.5 TW (>1 TW)
Focal spot (σ)		32 μm (~10 μm)
Laser strength (*a*)		0.1 (>2)
Beam size (on transport mirrors)		50 mm



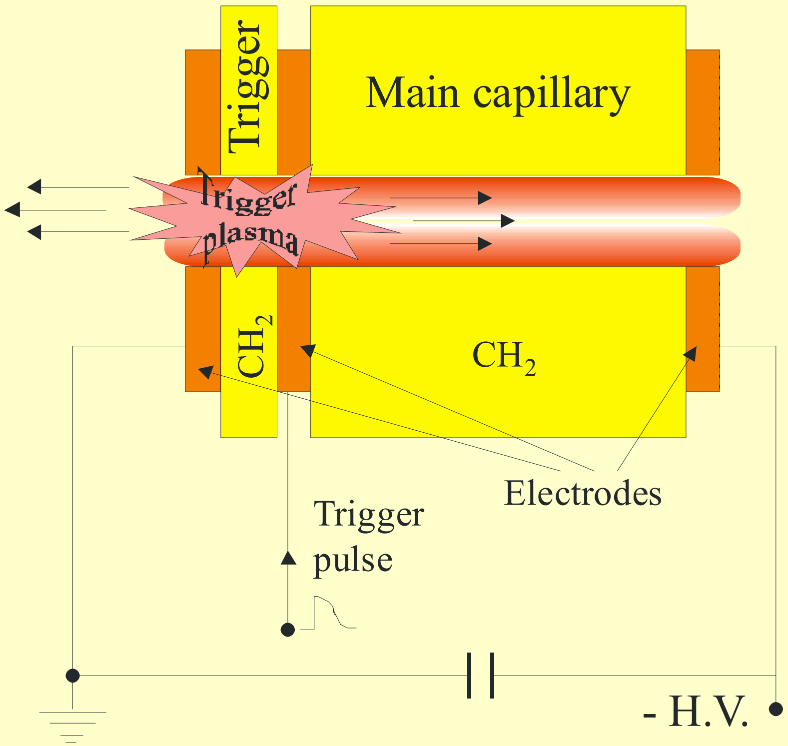
We send 2" dia laser beam to Experiment hall

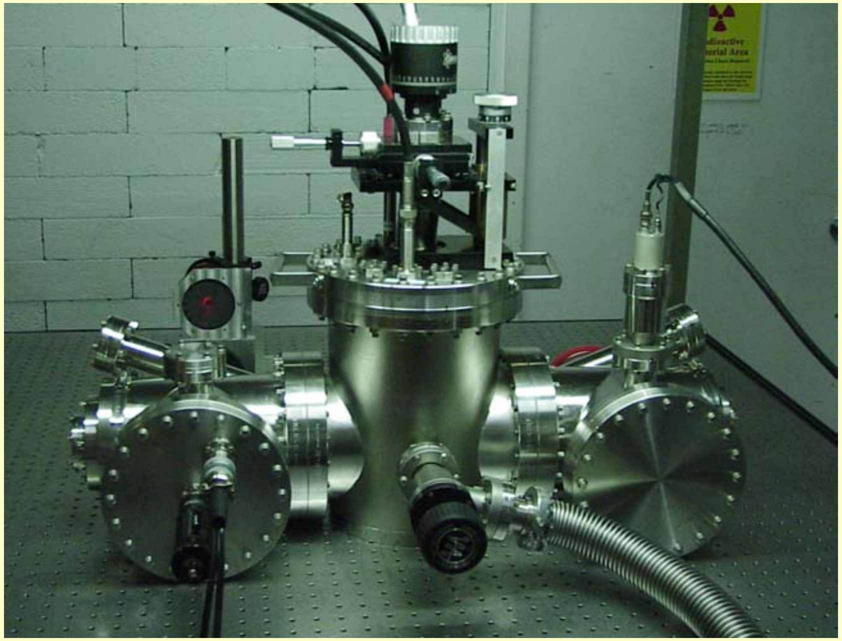
6-foot motorized optical delay stage
and
another universal laser/e-beam interaction cell to be installed in beamline #2 will facilitate and speed up installation of new experiments



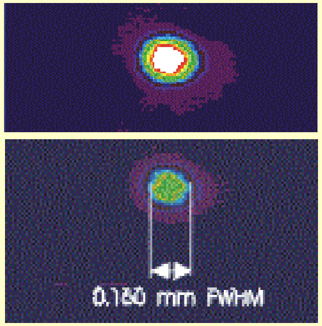


CO_2 laser has been channeled in capillary discharge

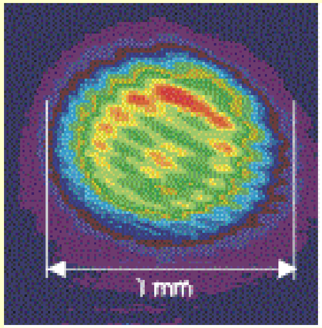




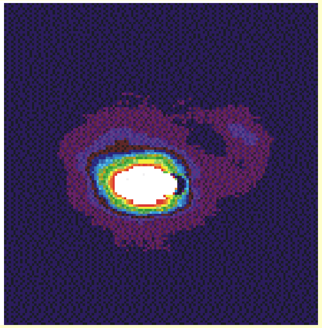
This enables a new generation of experiments on laser/e-beam interaction in plasma



laser beam at the focal point



17 mm downstream from the focus in the free space



at the exit from the 17 mm plasma discharge

Summary
on CO_2 laser progress and new developments since the last User's meeting and the next plan

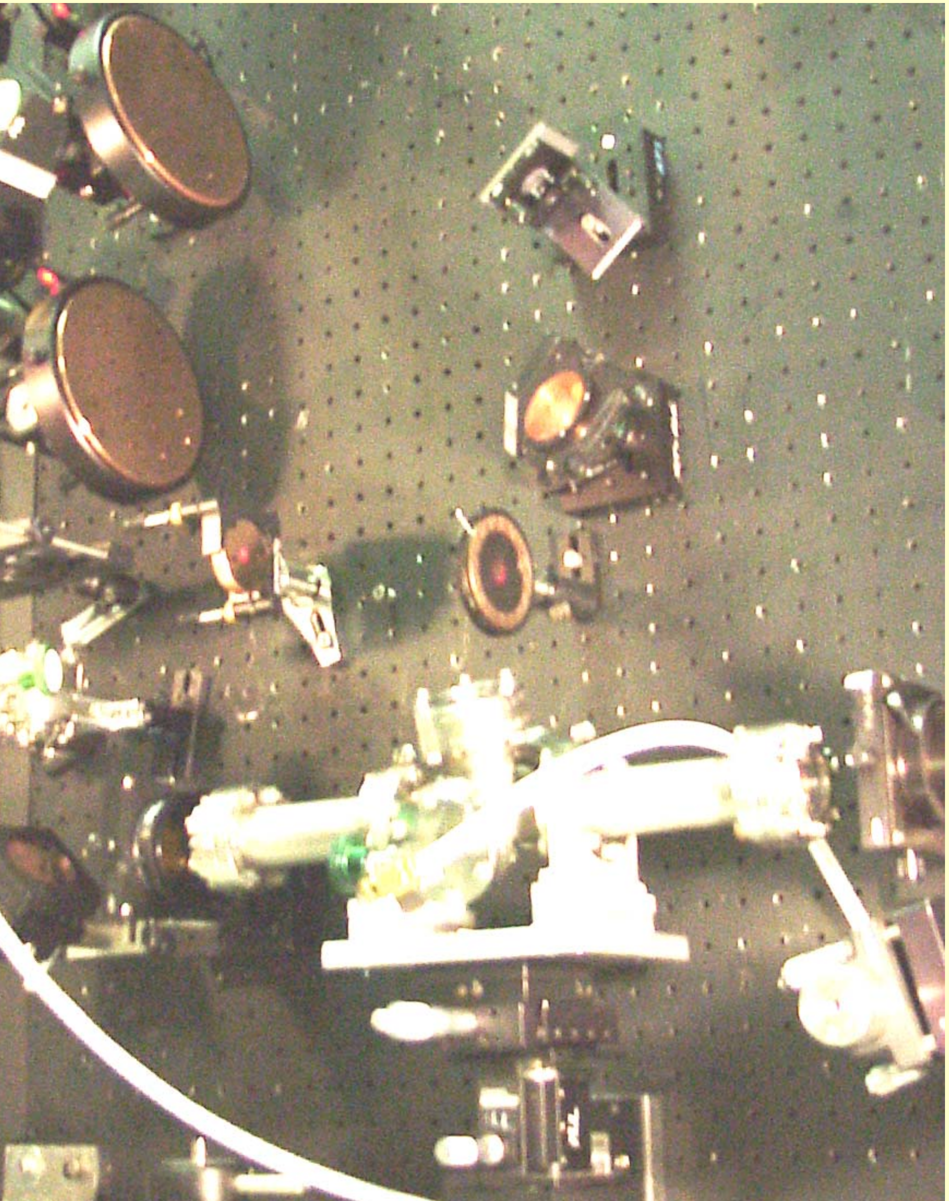
•Recent hardware upgrades (new 10-atm preamplifier, 3 ps YAG SH) allow a short-pulse Terawatt regime.
Presently, the system operates at 15 J with the pulse adjustable between 30-180 ps.

We will proceed with the system optimization towards a shorter laser pulse and higher peak power.

Demonstrated laser channeling in plasma expands the ATF capabilities opening a new class of User's experiments .

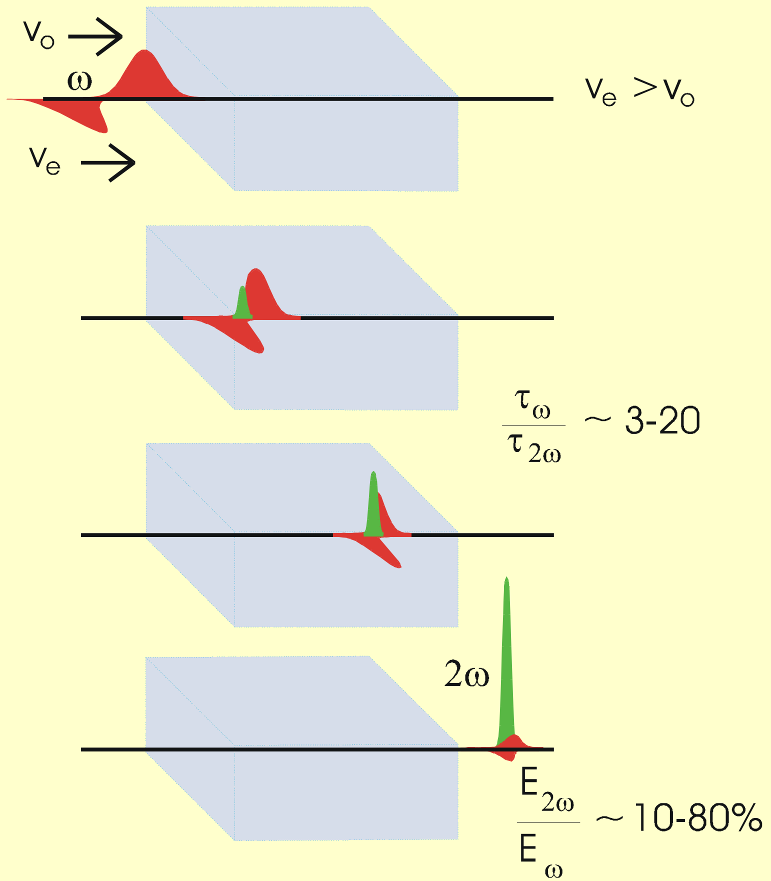
Improved e-beam/laser synchronization tune, universal interaction cell, and an extra site for interaction experiments are getting available to users.

CO_2 output beam optics

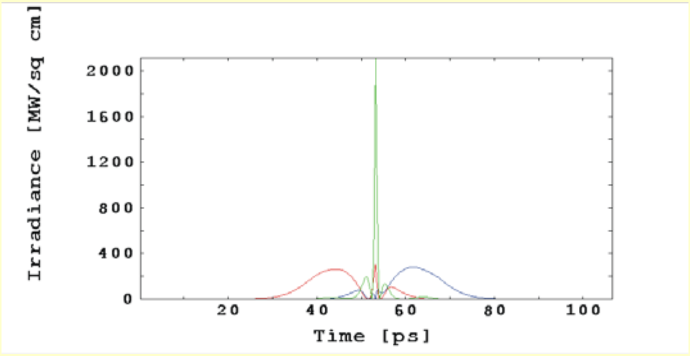


SH compression in KD*P crystal

Starting with the existing long pulses (14 ps) from the ATF YAG laser, second-harmonic compression* can be used to generate ps to sub-ps green pulses.



SNLO code simulations of 1064 to 532 nm conversion in 10 cm crystal with group velocity mismatch.



- Measured compression from 1 micron to 532 nm with pulse duration decrease of 3-4x in a 10 cm KD*P doubler.
- Energy available at 532 nm is ~ 100 mJ, now limited by input energy.
- New Pockels cell is on order to more efficiently utilize 1 micron energy between gun and CO2 slicing.
- Multi-stage semiconductor slicing using both 1 micron & green pulses will allow few ps CO2 pulse generation for TW operation.

*Y. Wang, and R. Dragila, Phys. Rev. A **41**, 5645 (1990)

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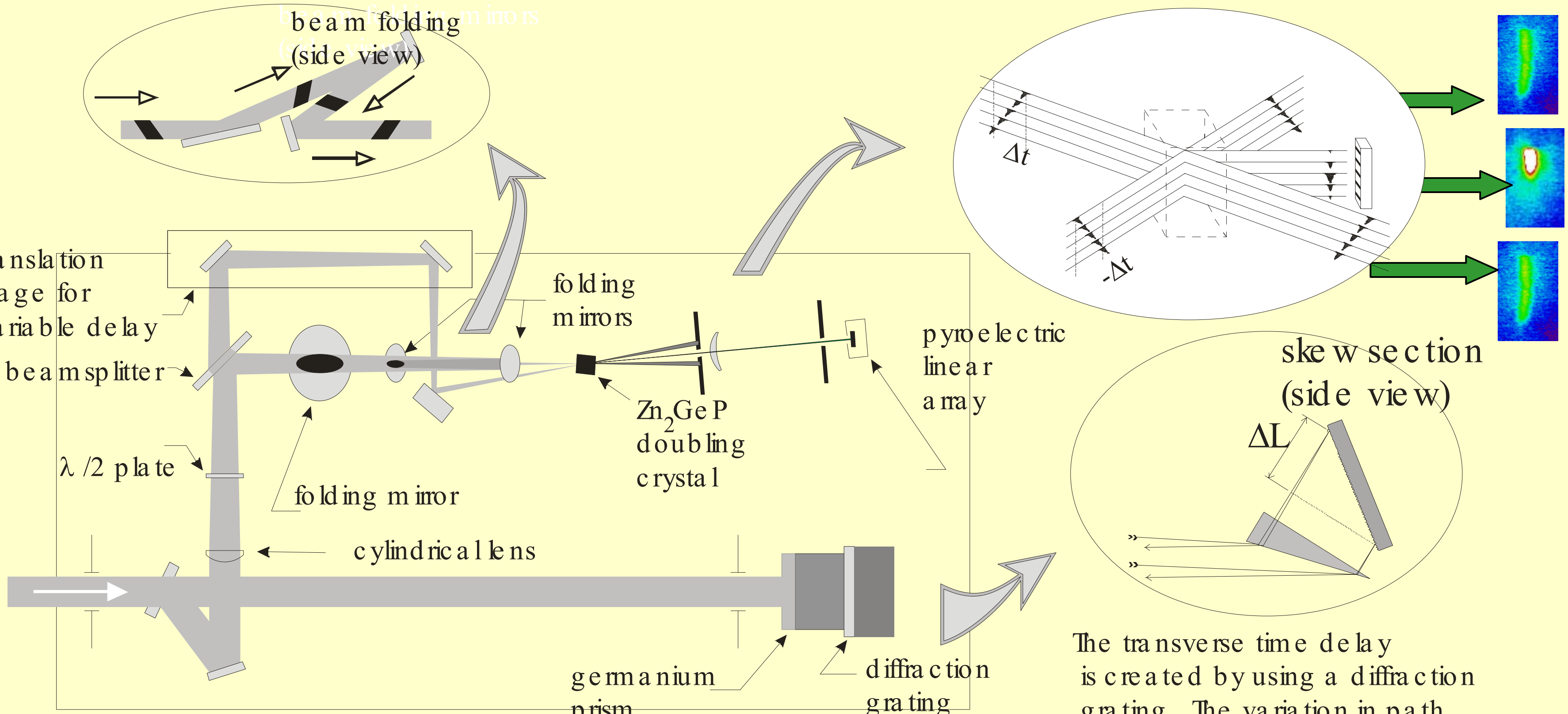
Brookhaven National Laboratory Accelerator Test Facility ATF

Single shot autocorrelator

This folding inverts one beam and thereby causes the beams to intersect in the doubling crystal with opposite transverse time delays

single-shot, background-free autocorrelation by non-collinear second harmonic generation



The transverse time delay is created by using a diffraction grating. The variation in path length across the beam produces a total range of 2ΔL/c.