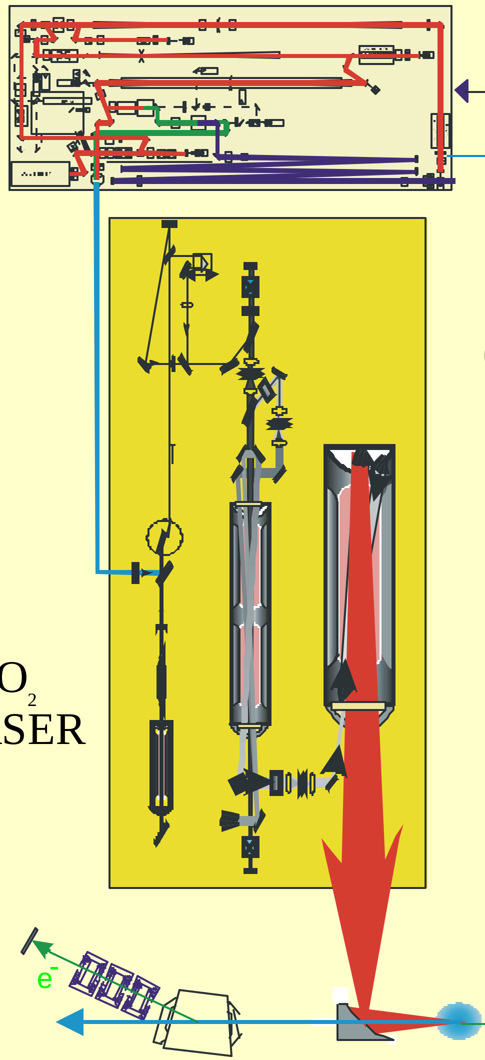
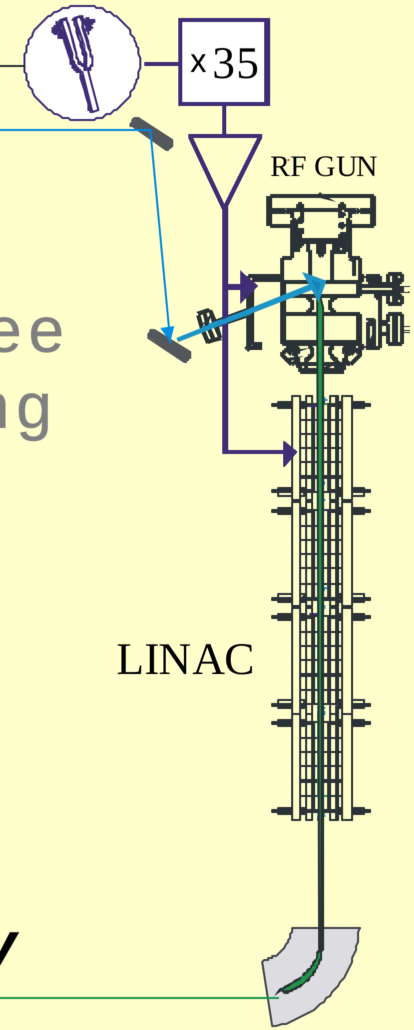
ATF Lasers





Report to

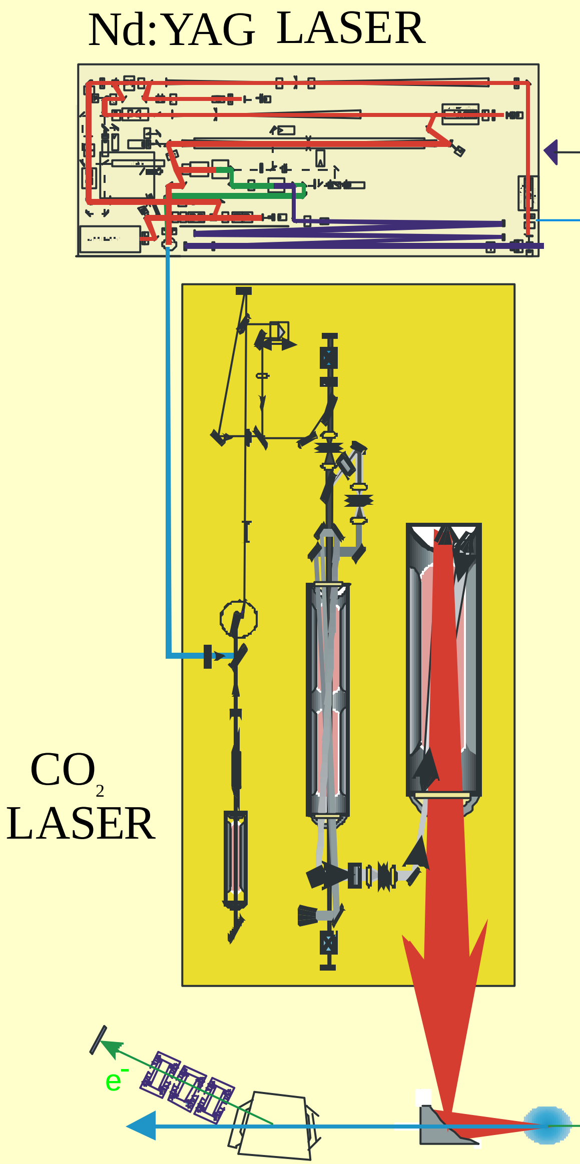
CAP Steering Committee
and ATF User's Meeting

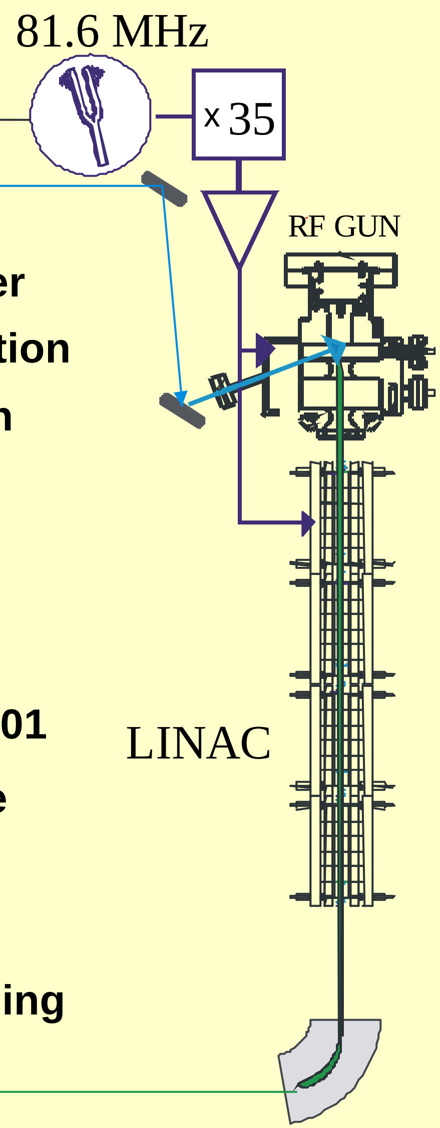
January 31, 2002

Igor Pogorelsky
Marcus Babzien

Accelerator Test Facility

Overview





- **ATF lasers since 2000 User's Meeting**
  - **Improved YAG photocathode driver**
  - **CO_2 high-power amplifier in operation**
  - **Continued user's experiments with improved ATF lasers**
- **Ongoing developments and upcoming capabilities**
  - **CO_2 Advisory Panel September 2001**
  - **TW CO_2 laser completion schedule**
    - **new front end**
    - **new preamplifier**
  - **Plasma channel for CO_2 laser guiding**
  - **Shortening photocathode driver**

YAG Laser System

Overview

· **Enables core functions of ATF: electron beam and high power CO_2 light generation and synchronization.**

· **Is designed for state-of-the art operation of the facility by virtue of the unique operational parameters:**

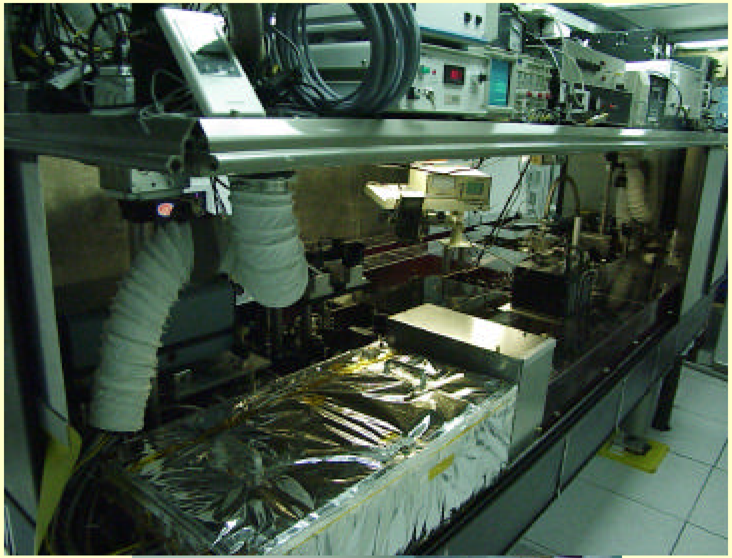
-energy stability on cathode down to 1% level (rms at 266 nm)

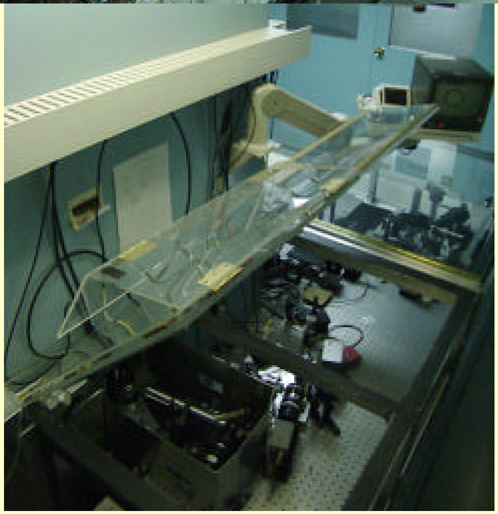
-arbitrary gating and amplification of 81.6 MHz pulses: single pulse up to 3 μs train

-system capable of normal operation at up to 1W P_{avg} @1μm

-dependable operation with quick, simple turn-on and low down time

· **Upgrades still possible and ongoing**





YAG Laser System
Operational Status

· **Photocathode and CO_2 slicing fully available on-demand.**

· **Electron beam-synchronized optical pulses available for users:**

5 mJ, 14 ps @ 1064 nm in laser lab (exclusive of slicing)
50 μJ, 10 ps @ 532 nm in laser lab or FEL room (not yet implemented)
50 μJ, 8 ps @ 266 nm in gun hutch and laser lab

· **Delivered light on 245 days since last user's meeting (June 1, 2000) average ~10 hours/day.**

Turn-on time usually 15 minutes, including daily performance characterization. Gun operations typically underway by 9:30 AM

Demonstrated YAG Laser Performance

Energy (dual pulse mode)

Laser output: total IR	30 mJ
IR into 2ω	5 mJ / pulse
Green	1 mJ / pulse
UV	200 µJ
UV on cathode	0-20 µJ
IR at CO_2 table	7 mJ

Repetition rate 1.5, 3 Hz

Pulse duration (FWHM):

Oscillator IR	7 ps
Amplified IR	14 ps
Green	10 ps
UV	8 ps

Beam Æ on cathode 0.2 - 3 mm

Top-Hat Beam Profile Modulation <15%

Shot-to-shot stability (rms):

Timing	<0.2 ps
Energy	<2%
Pointing (fraction of beam ∅)	≤0.3%

Drift (8 hour P-P)

Timing	<1 ps
Energy	<15 %
Pointing (fraction of beam ∅)	<1%

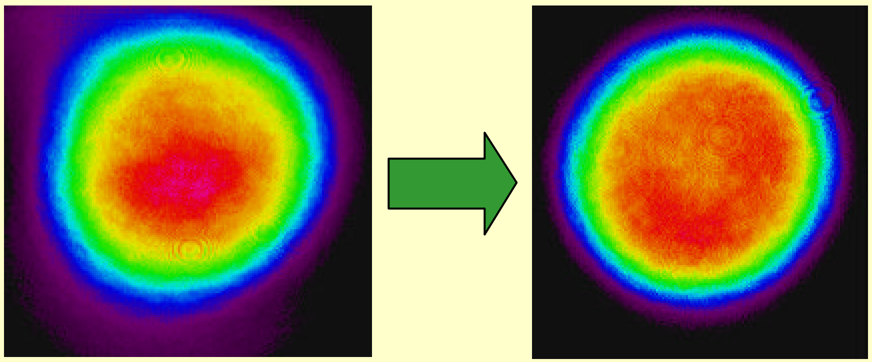
YAG Laser System

Future Prospects

Short Term:

· **Continue transverse beam shaping work:**

-Gaussian mirror in use for flatter IR profile:



Next, active shaping for better UV profile.

· **Extend temporal diagnostics to harmonics**

-Received green autocorrelator; starting work on UV device

·Implement pulse shortening

-Saturable absorber ready for testing

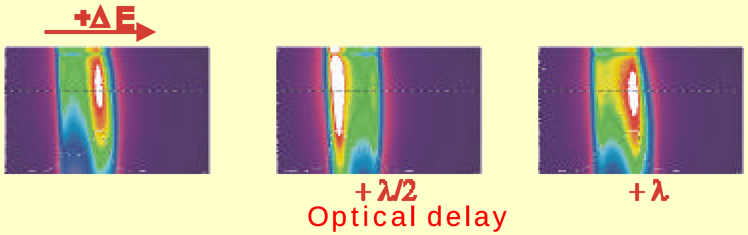
Long Term:

· **Drive laser replacement:** Retain the present optical synchronization philosophy and develop an advanced drive laser that will serve gun, CO_2, and experiments simultaneously. Study has already begun on an Ytterbium-based system to exceed the reliability and stability of the current laser and provide greater gain bandwidth.

Benefits of using long-wavelength (10μm) CO_2 laser:

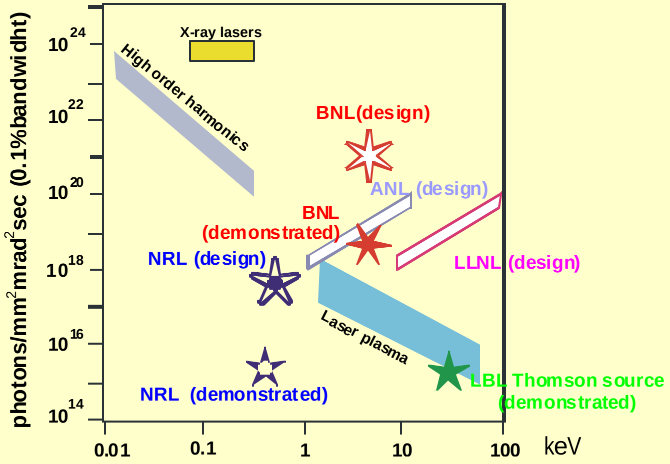
•**Combines advantages of high-quality conventional RF accelerators and high-gradient optical accelerators (favorable phasing and structure scaling).**

Illustrated by STELLA - the first two-stage laser accelerator



•**Ponderomotive potential that controls x-ray production, plasma wake generation and other strong-field phenomena is proportional to l^{2}.**

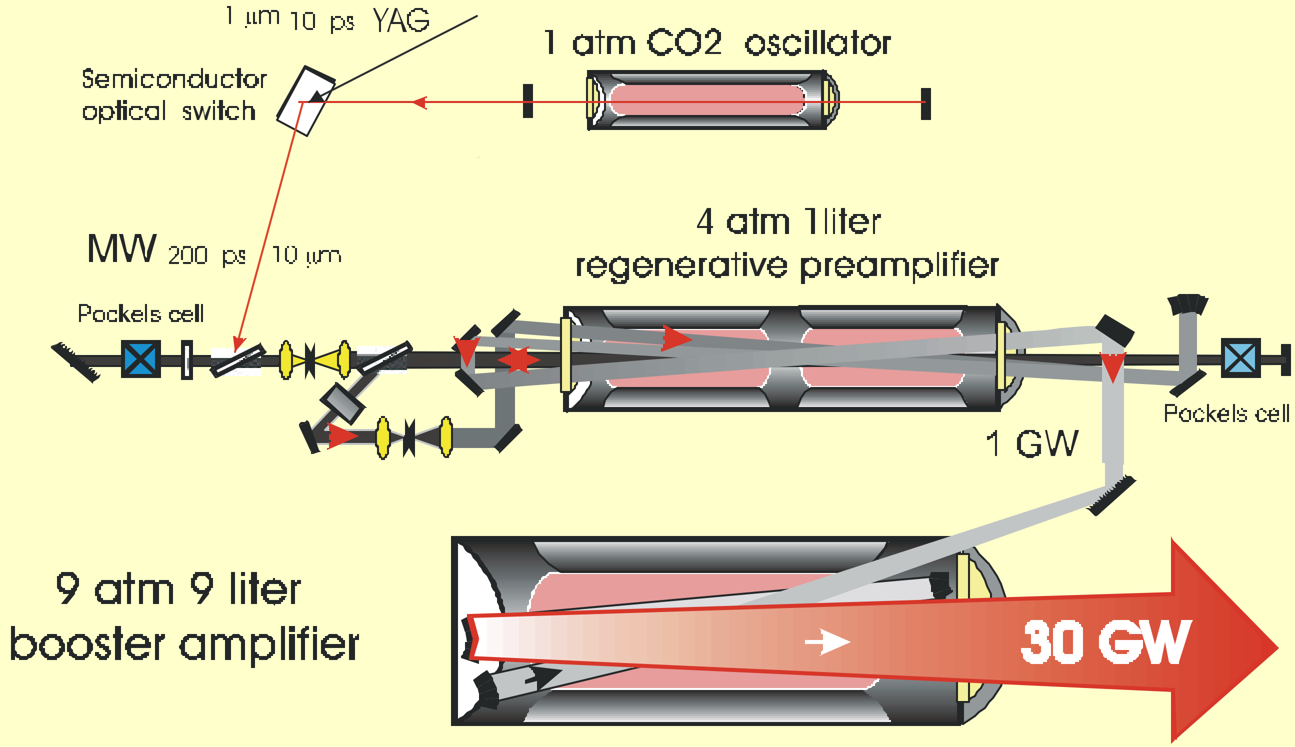
Illustrated by Thompson scattering experiment – presently the brightest Thomson x-ray source. This was achieved at the ATF with only modest laser power.



BROOKHAVEN NATIONAL LABORATORY

Brookhaven National Laboratory
Accelerator Test Facility

Presently operational ATF CO_2 laser system provides 30 GW @ 180 ps



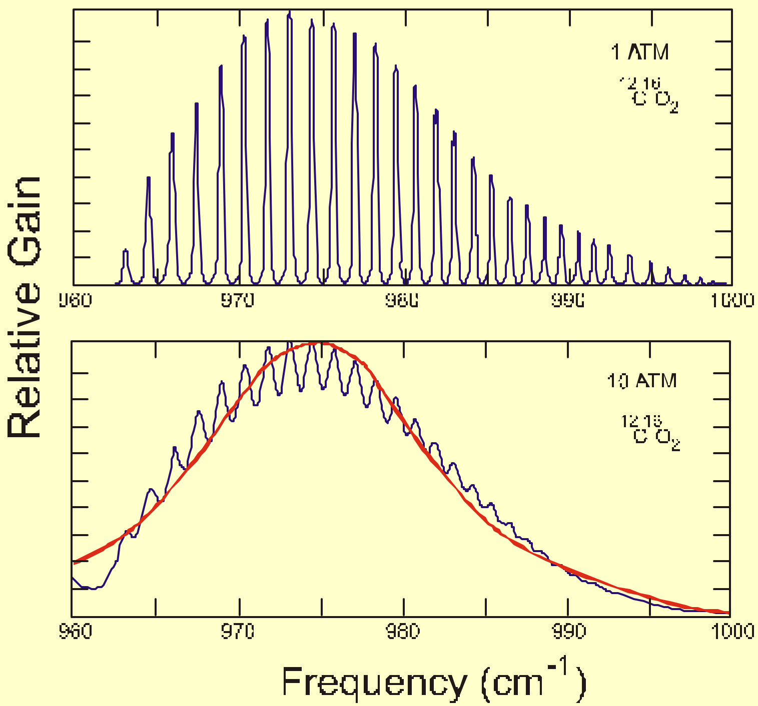
Present ATF CO_2 laser system includes:

- hybrid 1-atm oscillator
- semiconductor optical switch controlled by 14-ps YAG laser
- UV-preionized regenerative 4-atm 1-liter preamplifier with 1/200 ps^{-1} bandwidth
- x-ray preionized 9-atm. 9-liter amplifier with 1ps^{-1} (1 THz) bandwidth potentially allows amplification of 1 ps pulses

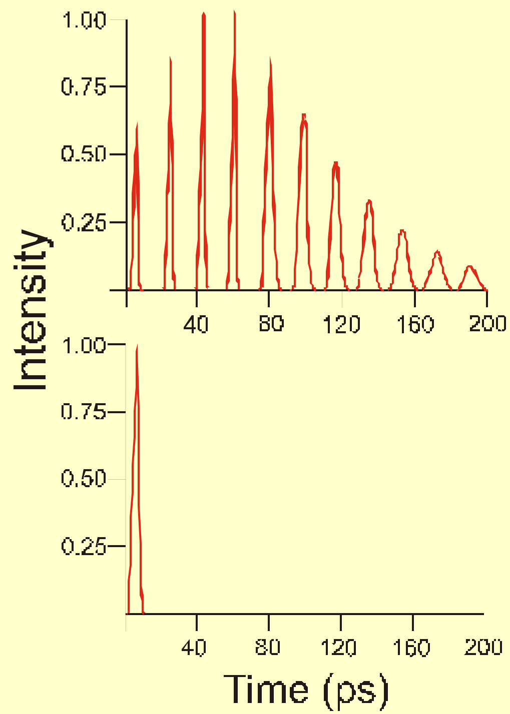
Brookhaven National Laboratory
Accelerator Test Facility

Bandwidth-limited amplification of ps CO_2 laser pulses

Gain Spectrum



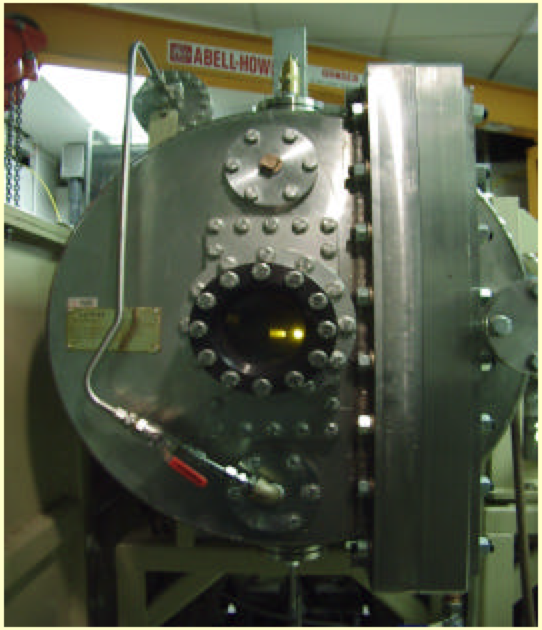
Amplified Picosecond Pulse



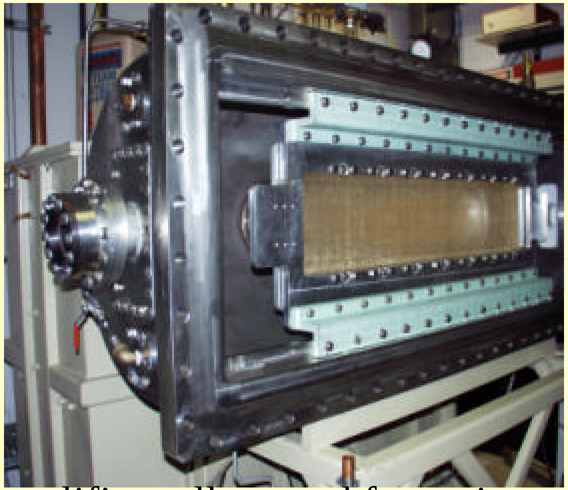
Strongly modulated rotational line structure of the CO_2 gain spectrum modifies the frequency content of picosecond pulses, changing their temporal structure.

At 10 atmospheres, collisional broadening produces overlap of the rotational lines into the 1 THz wide quasi-continuous gain spectrum, and pulses as short as 1 ps can be amplified without distortion.

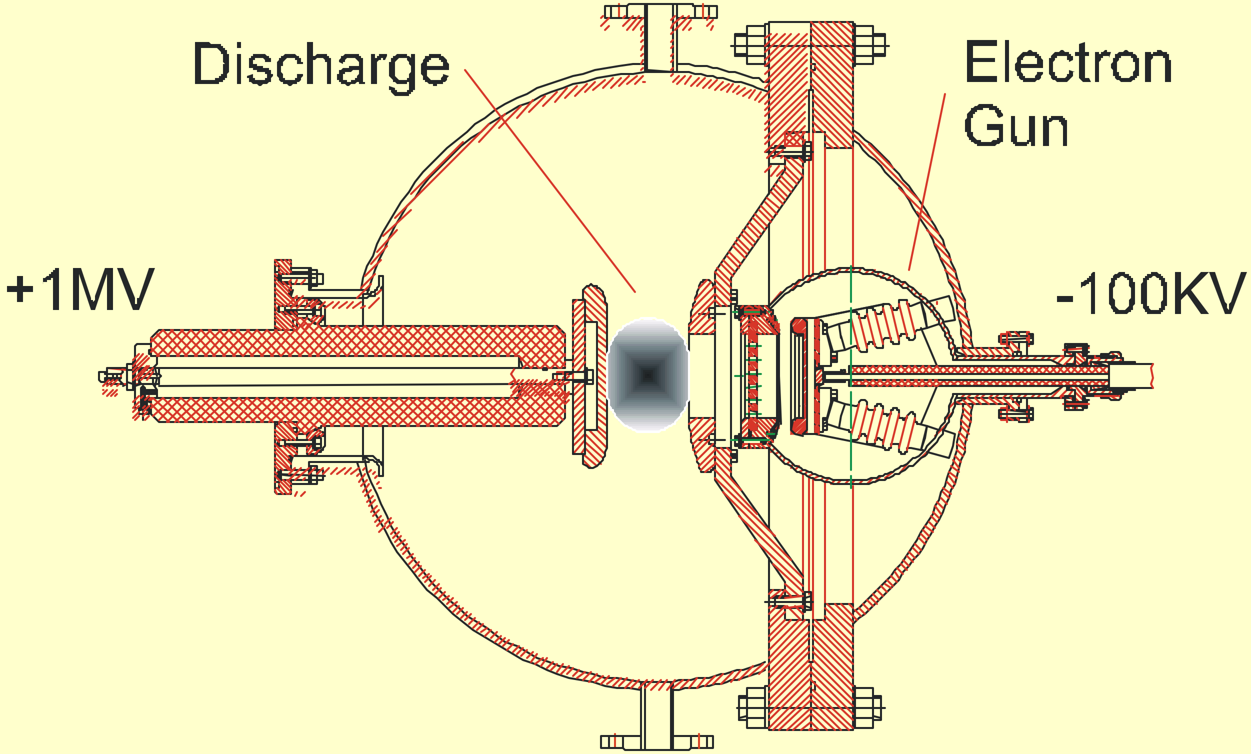
High-power amplifier put in operation in 2001



10 cm output window



Amplifier cell opened for maintenance



Amplifier cross-section diagram

CO_2 status and prospects

•Presently we operate at the 180 ps 30 GW level. The relatively long pulse duration is due to the narrow bandwidth of the preamplifier.

•Advisory panel (September 2001) outlined measures to attain ~1 TW, primarily by shortening pulse duration.

•Main steps of the ongoing upgrade:

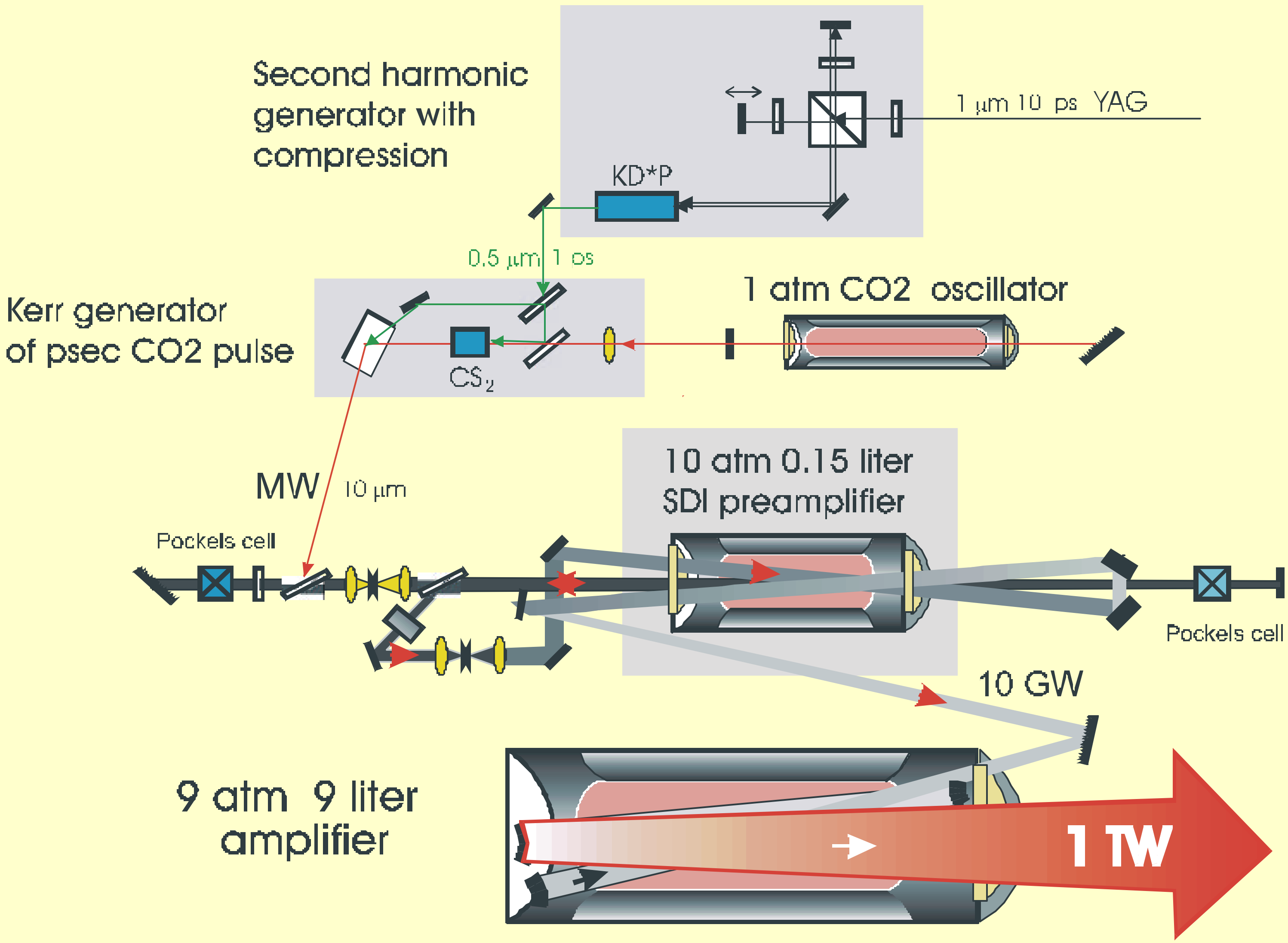
Generation of ~1 ps SH of YAG laser in KD*P crystal

Gate ~1 ps CO_2 pulse Kerr switch controlled by YAG SH

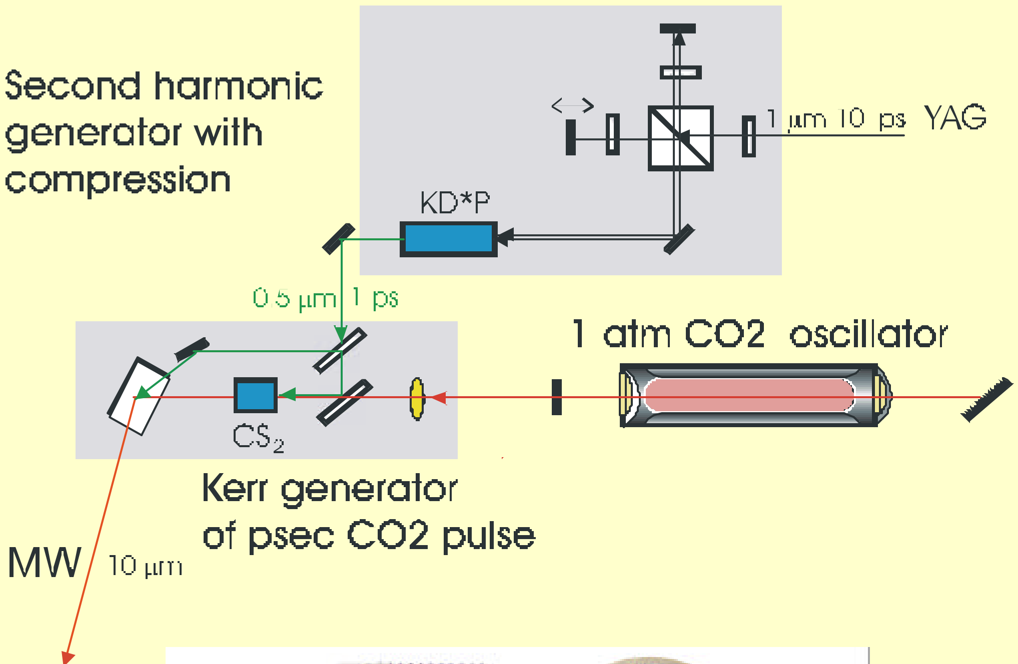
10-atm preamplifier (ordered)

Integrate new components into the system before the end of 2002

After upgrade to be completed in 2002 the ATF CO_2 laser system will be capable to 1 TW @ 3 ps



TW CO_2 laser upgrade plan



To meet demands of advanced accelerators and x-ray sources the ATF is upgrading CO_2 laser to 3 ps pulse duration and 1 TW peak power.
Upgrade includes:

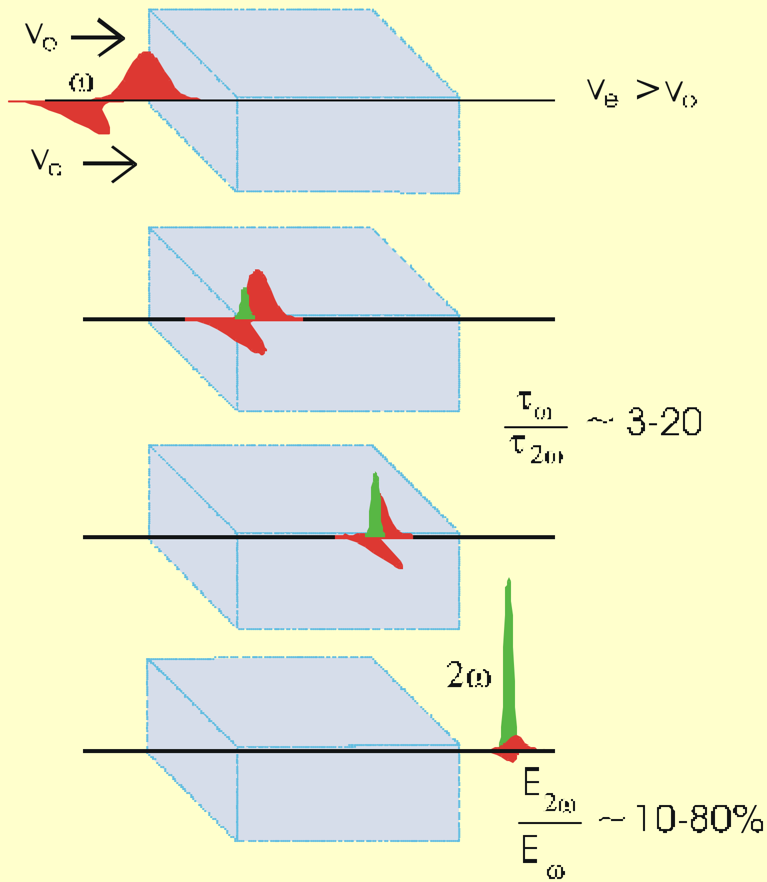
generator of ~1 ps 2nd harmonic of YAG

Kerr switch to produce 3 ps CO_2 pulse

10-atm preamplifier to match the present booster amplifier in bandwidth

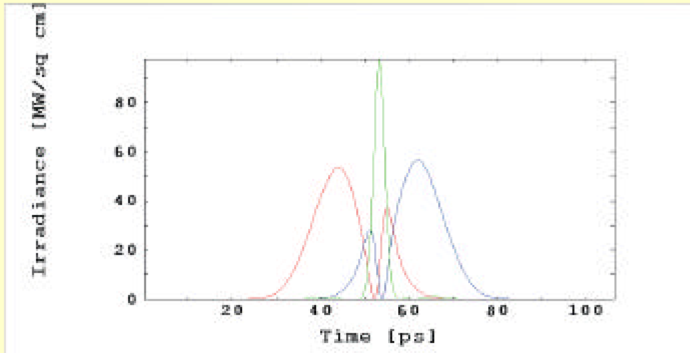
SHG in Long KD*P crystal

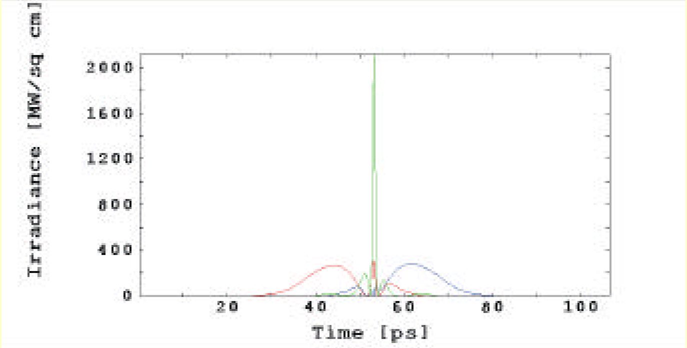
Starting with the existing long pulses (14 ps) from the ATF YAG laser, second-harmonic compression* can be used to generate ps to sub-ps green pulses.



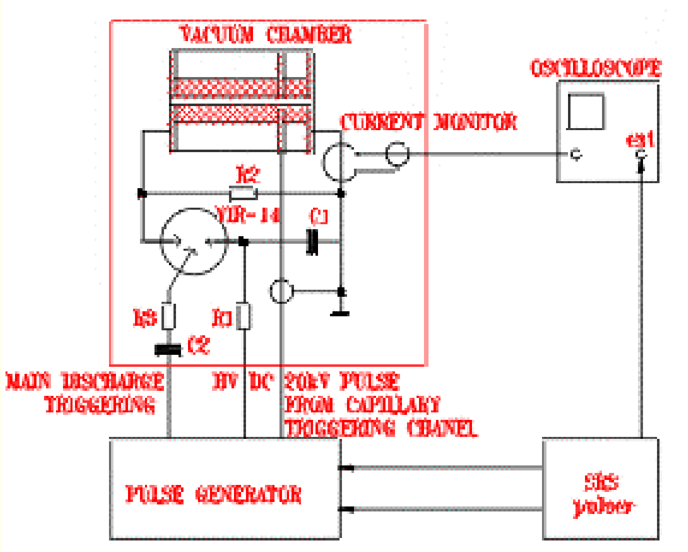
*Y. Wang, and R. Dragila, Phys. Rev. A **41**, 5645 (1990)

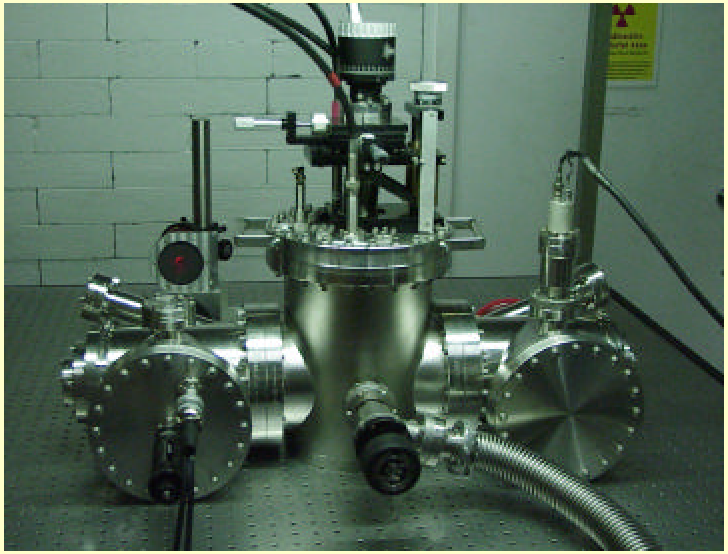
SNLO code simulations of 1064 to 532 nm conversion in 10 cm crystal with group velocity mismatch. Under ATF input parameters, significant pulse compression can be achieved with either small satellite production (top), or maximum compression (bottom).

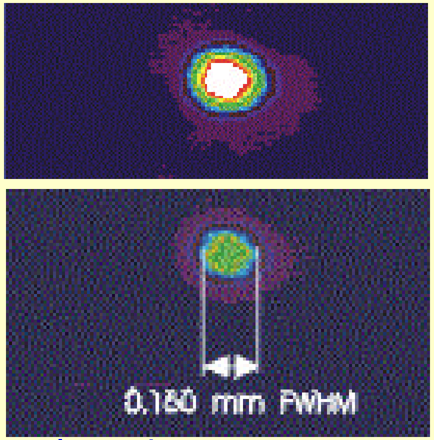




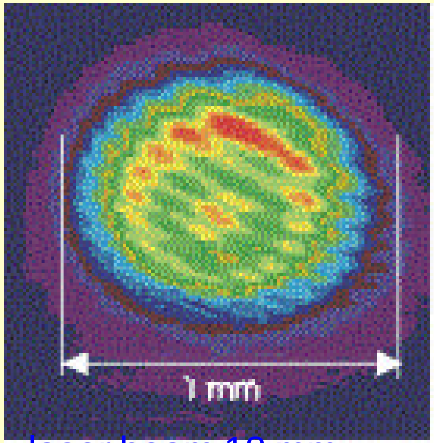
Channeling of CO_2 laser in capillary discharge



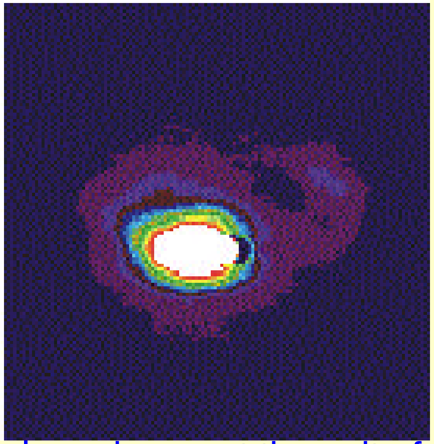




laser beam at the focal point



laser beam 18 mm downstream from the focus in the free space



laser beam at the exit of the 18 mm plasma discharge with the capillary entrance placed at the focal point