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Sandia National Laboratories' Z-Petawatt Laser Facility: A Progress Report

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Abstract

Sandia National Laboratories' long-pulse, multi-kJ, TW-class Z-Beamlet Laser (ZBL) [1] is presently being upgraded with the addition of a separate short pulse capability; the Z-Petawatt Laser (ZPW). Both systems will support x-ray imaging on the Z accelerator [2], which is currently being upgraded and will become operational again late 2007. The majority of the beam time, for either laser system, will be used for fundamental laser-plasma physics studies; laser-plasma accelerators, etc. Preliminary ZPW physics experiments at the 100-TW, 50-J level have been performed (Geissel *et al*. this conference); without interacting the ZBL beam.

ZPW begins with a Ti:Sapphire master oscillator generating an 80 MHz output of 250 mW, 100 fs @ λ=1053 nm ($\Delta\lambda$=16 nm). After stretching to 3 ns, the pulse is amplified to the 40 mJ level (10 Hz), via an optical parametric chirped pulse amplifier (OPCPA), with the bandwidth reduced to 8 nm. Double-pass amplification through 16 and 25 mm Nd:Phosphate rod amplifiers (to the J level) is followed by amplification to 225 J via a double-pass slab amplifier (14 cm FWHM beam size). Then, compression with commercially-available gold gratings leads to the 100-TW, 50-J pulse – limited by the grating damage thresholds. The beam has been focused to a 5 x 10^{19} W/cm^2 irradiance, allowing 30-MeV proton acceleration. With a 4-pass amplifier reconfiguration, and larger gratings - allowing the full amplifier aperture to be used – 2 kJ in 1-10 ps is expected in the near future.

[1] P. K. Rambo *et al*. Appl. Opt. **44,** 2421 (2005)
[2] M. K. Matzen *et al*. Phys. Plasmas. **12,** 055503 (2005)

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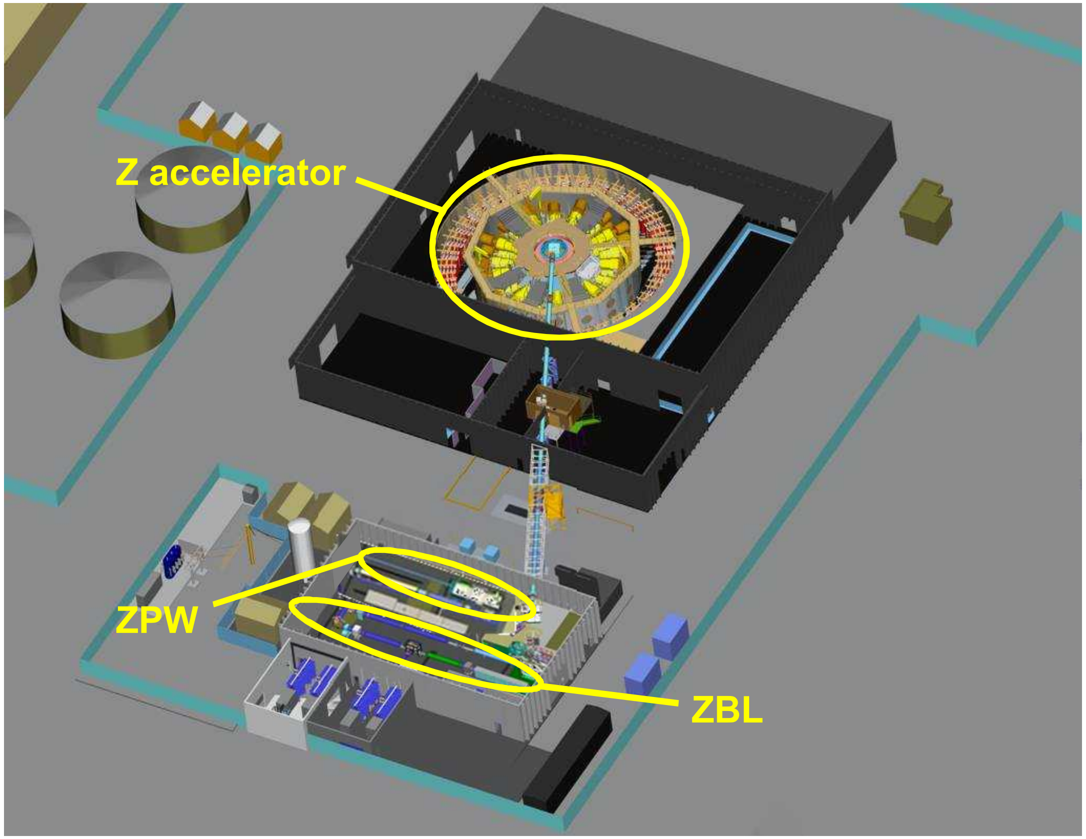
Facility overview

ZBL is a TW-class, multi-kJ, 526.57 nm Nd:glass laser

Historically, the first Z/ZBL experiments, *~6.7 keV point-projection imaging*, studied ICF capsule implosions [3,4]

ZPW, or rather the "100-TW" system at present, uses ZBL-type amplifier modules and the ZBL infrastructure



[3] G. R Bennett *et al*. Phys. Rev. Lett. **89,** 245002 (2002)
[4] R. A. Vesey *et al*. Phys. Rev. Lett. **90,** 035005 (2003)

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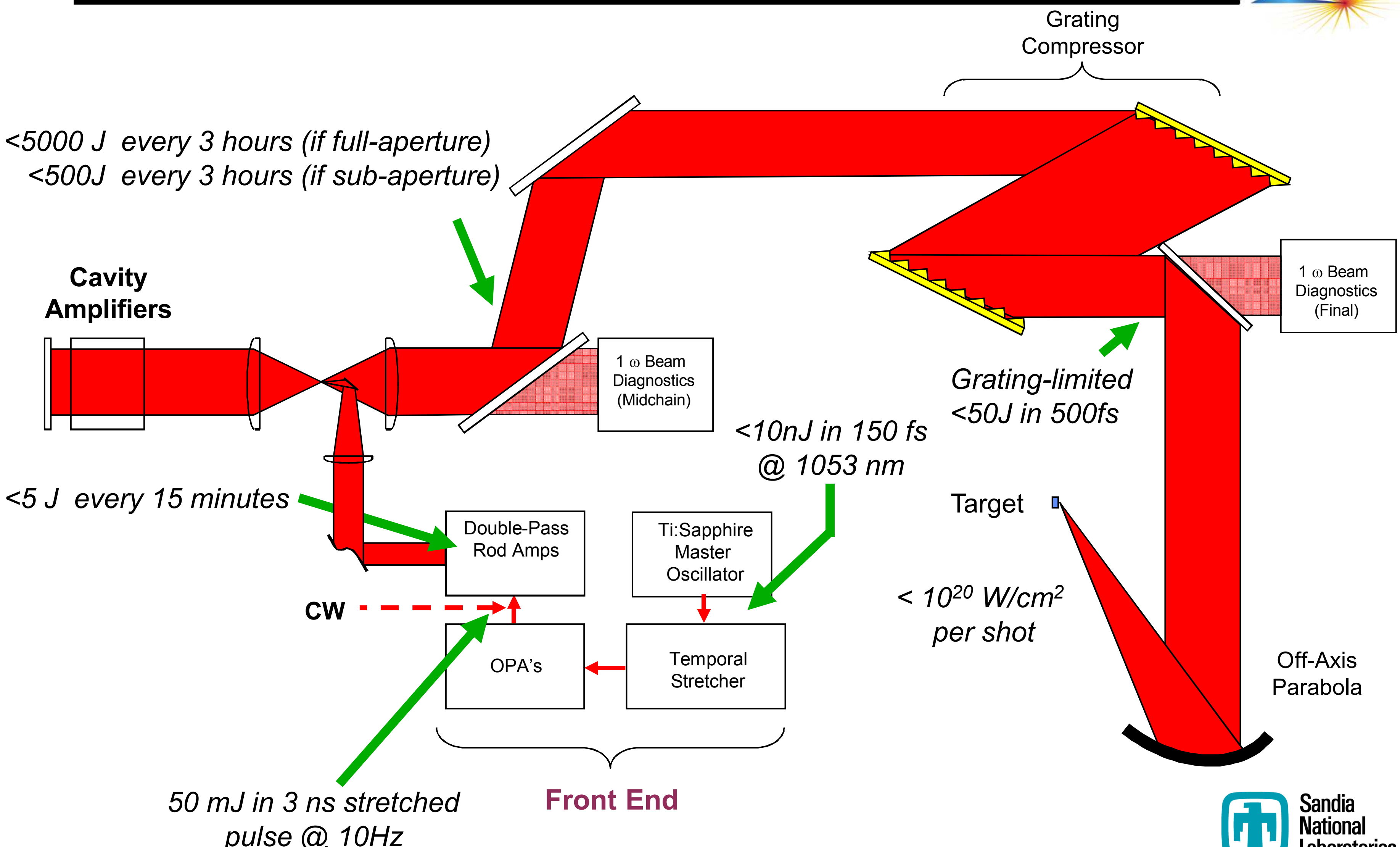
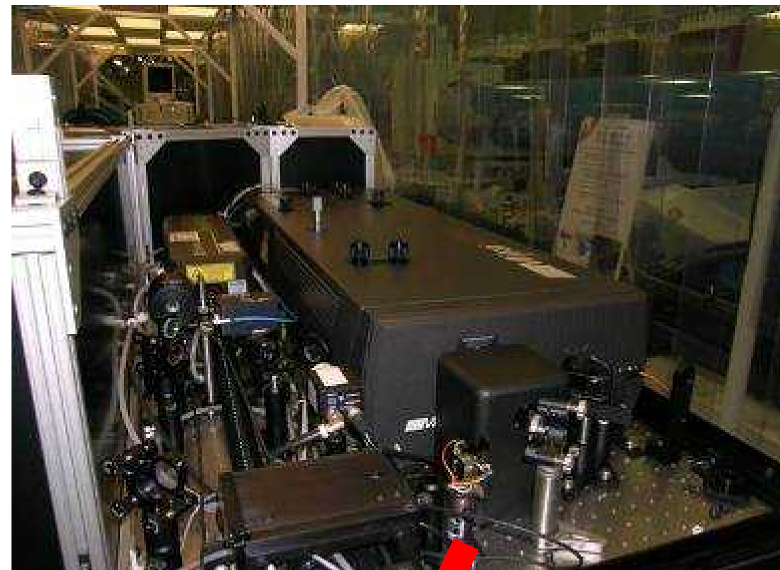
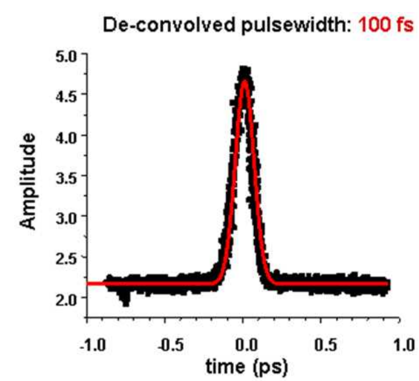
100-TW System

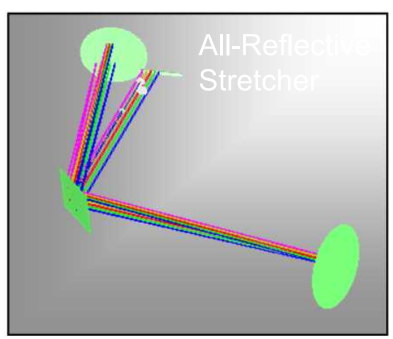


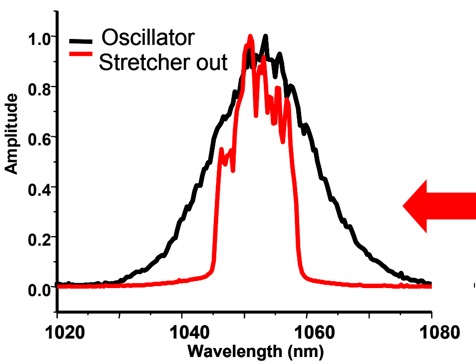
Seeder and stretcher

- Seeder: Coherent ***Mira*** Ti:Sapphire (pumped by a Coherent ***Verdi***).
  - **λ=1053nm, $\Delta\lambda$>16nm,**
  - **τ_p=100fs, 80MHz, 250mW**
- Compact all-reflective stretcher (Banks/Perry design)
  - **τ_{out}=3ns, $\Delta\lambda_{out}$=12nm (4nm/ns)**
  - **T=12%**









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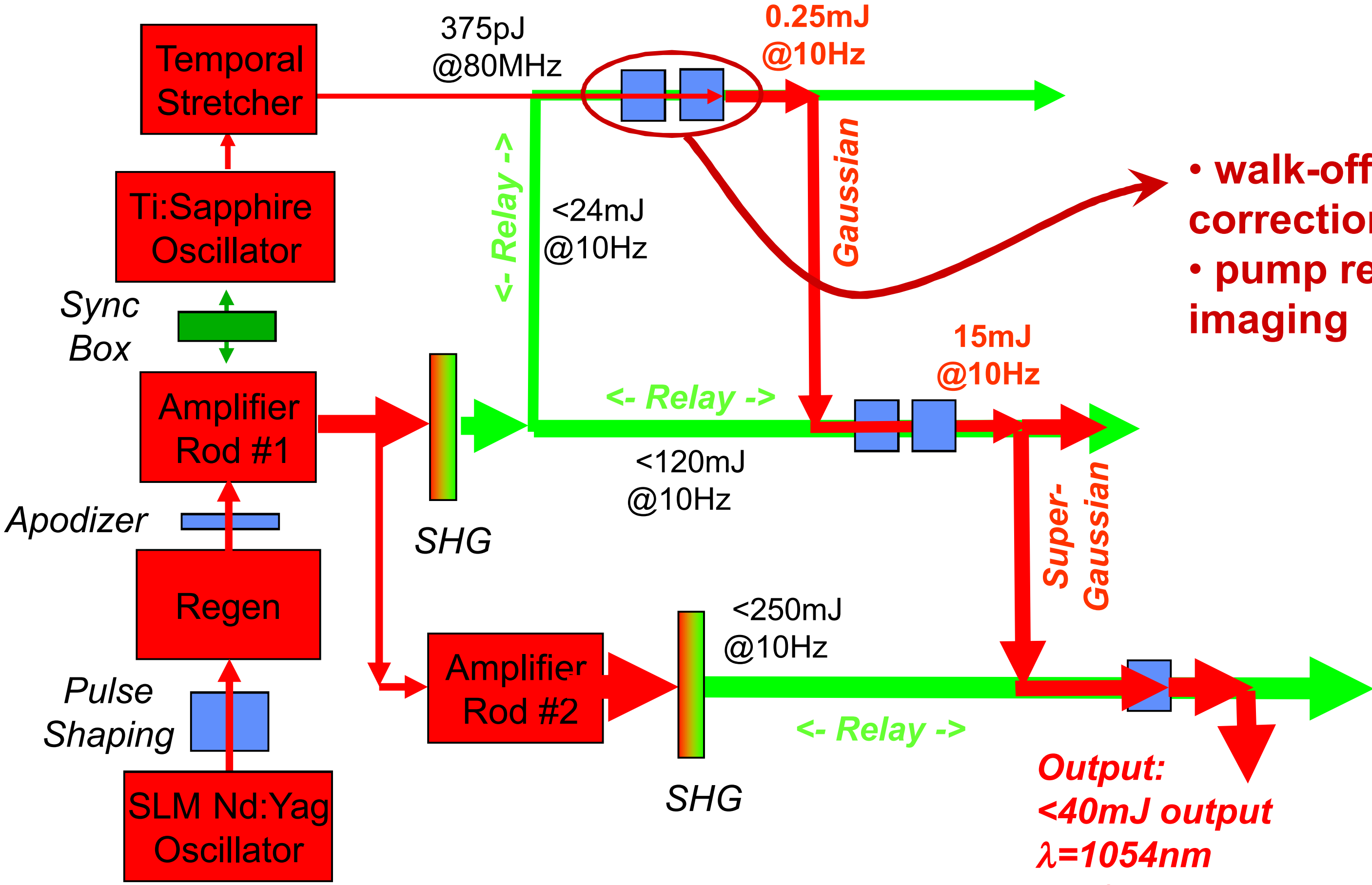
Optical Parametric Chirped Pulse Amplifier (OPCPA) front-end



- **walk-off correction**
- **pump relay imaging**

Output:
<40mJ output
λ=1054nm
δλ=8nm
δt=2ns
Rep rate=10Hz

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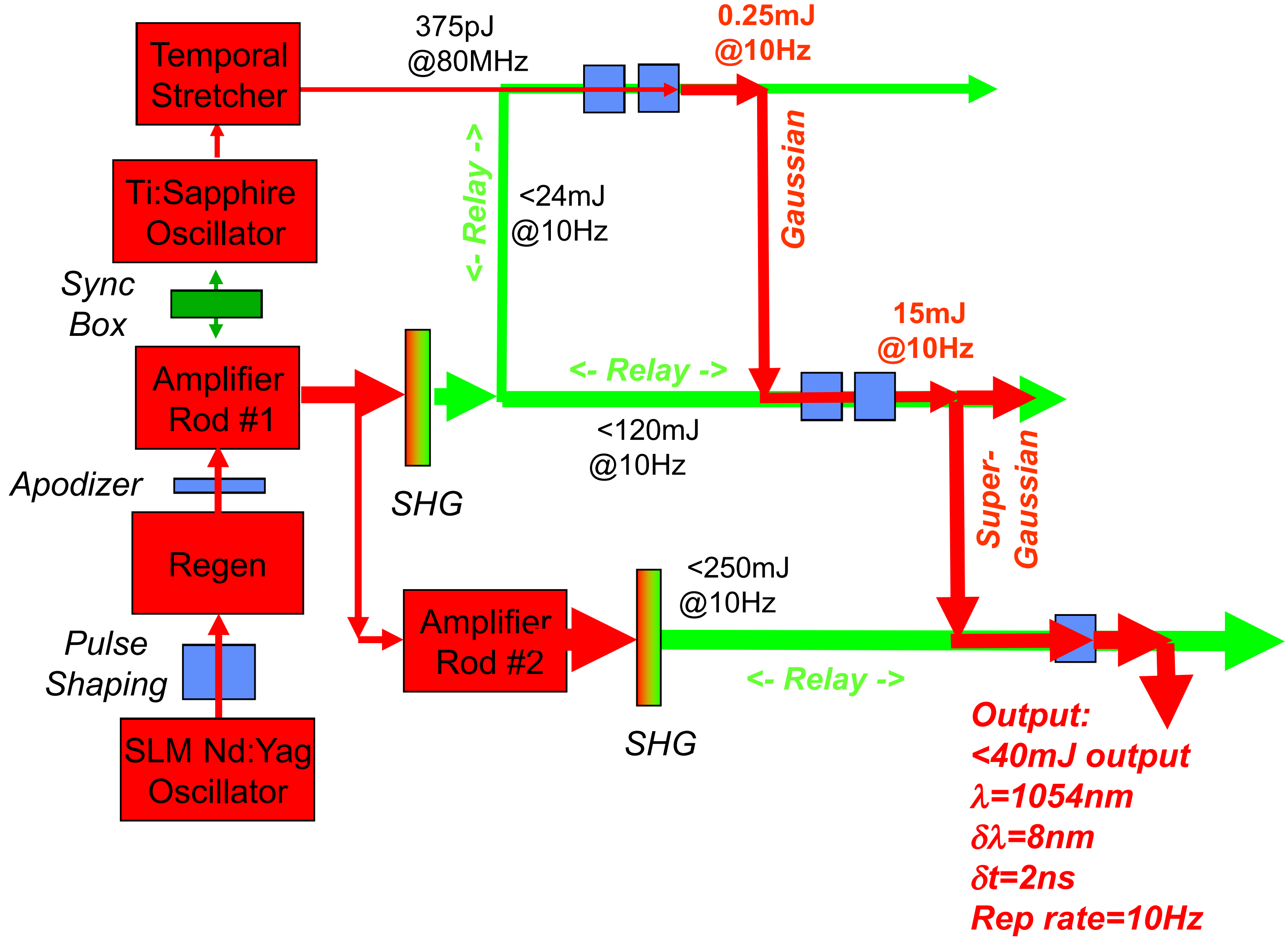
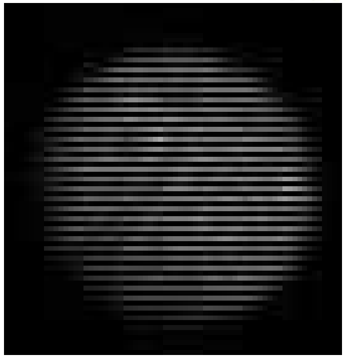
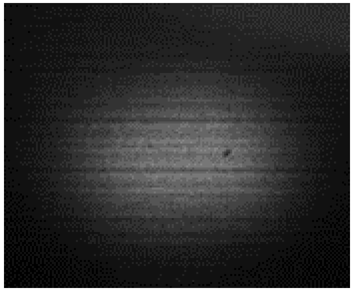
Optical Parametric Chirped Pulse Amplifier (OPCPA) front-end



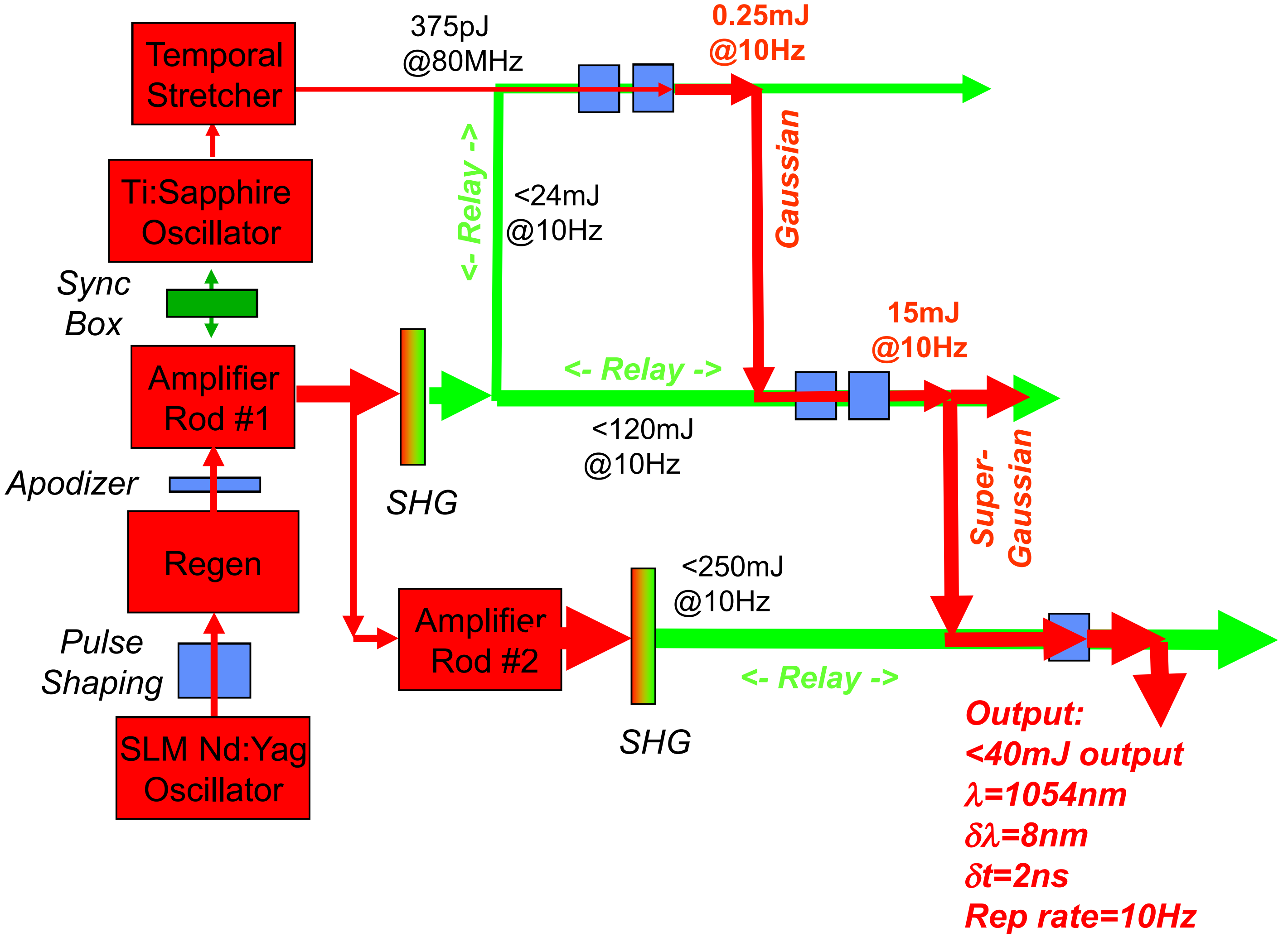


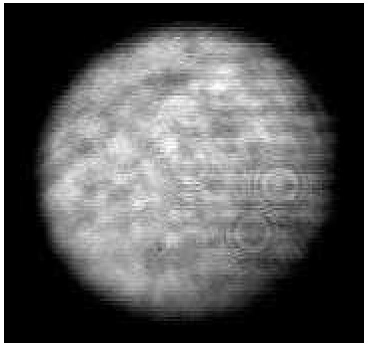
OPA1 pump



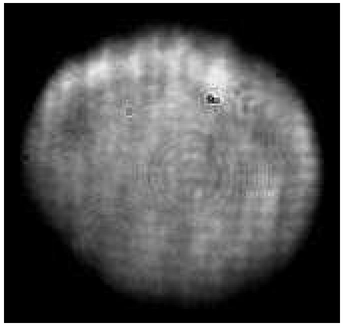
OPA1 output

Optical Parametric Chirped Pulse Amplifier (OPCPA) front-end



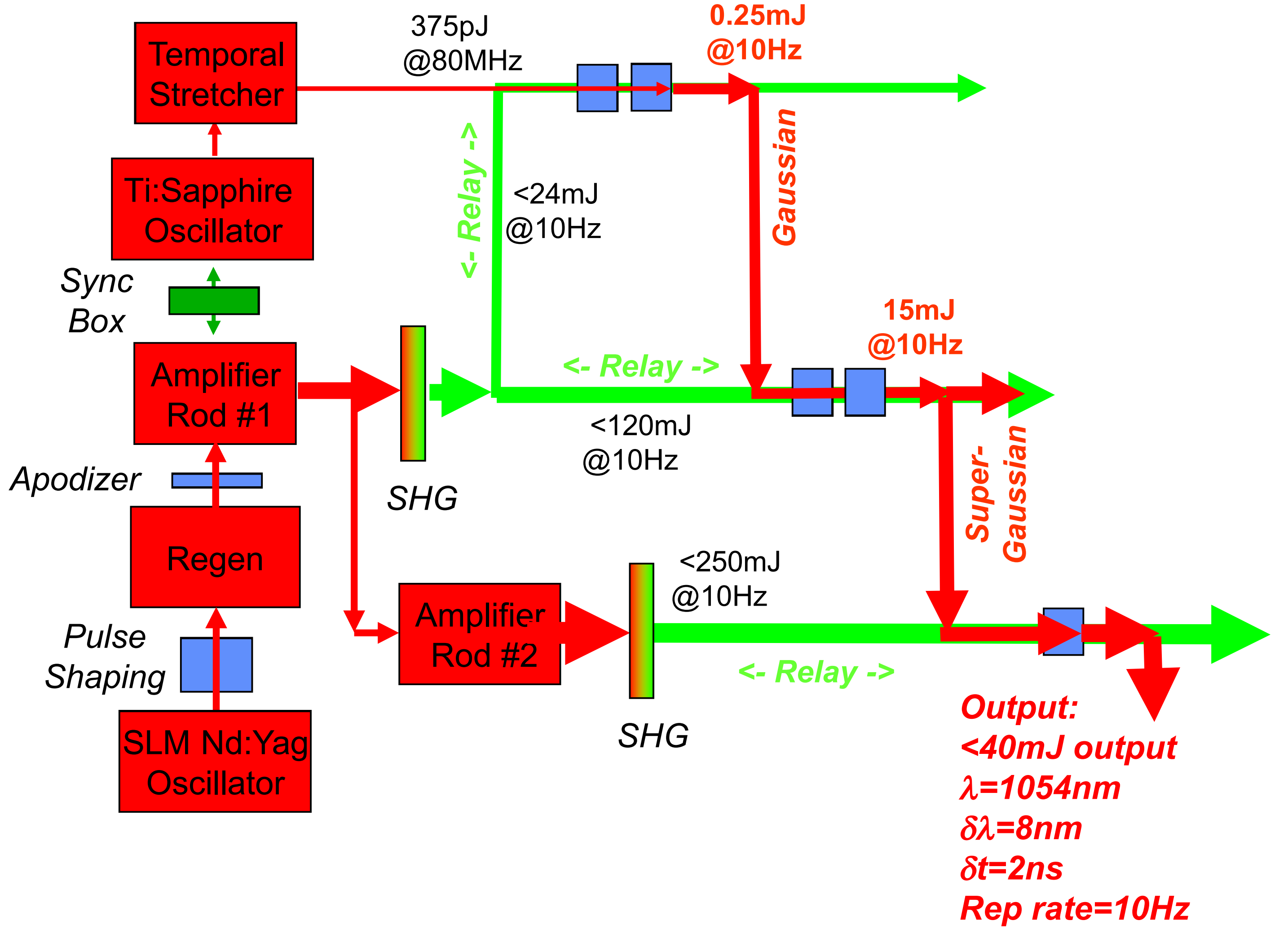


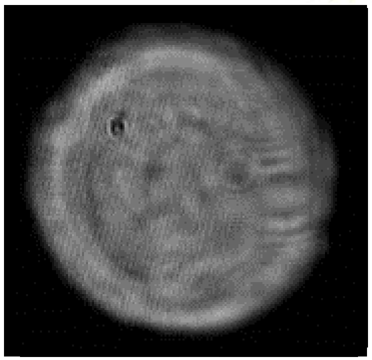
OPA 2 pump



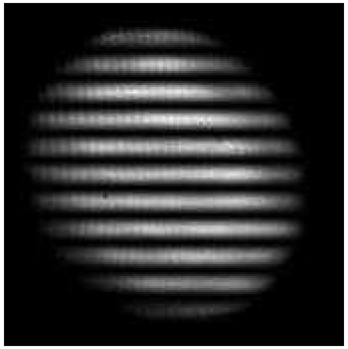
OPA 2 output

Optical Parametric Chirped Pulse Amplifier (OPCPA) front-end





OPA 3 pump



OPA 3 output

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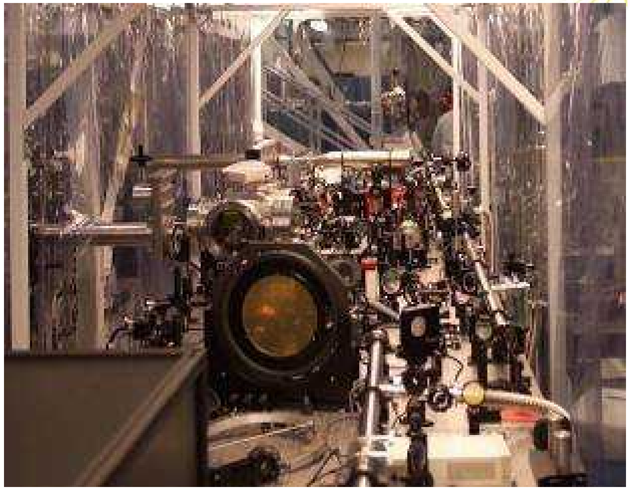
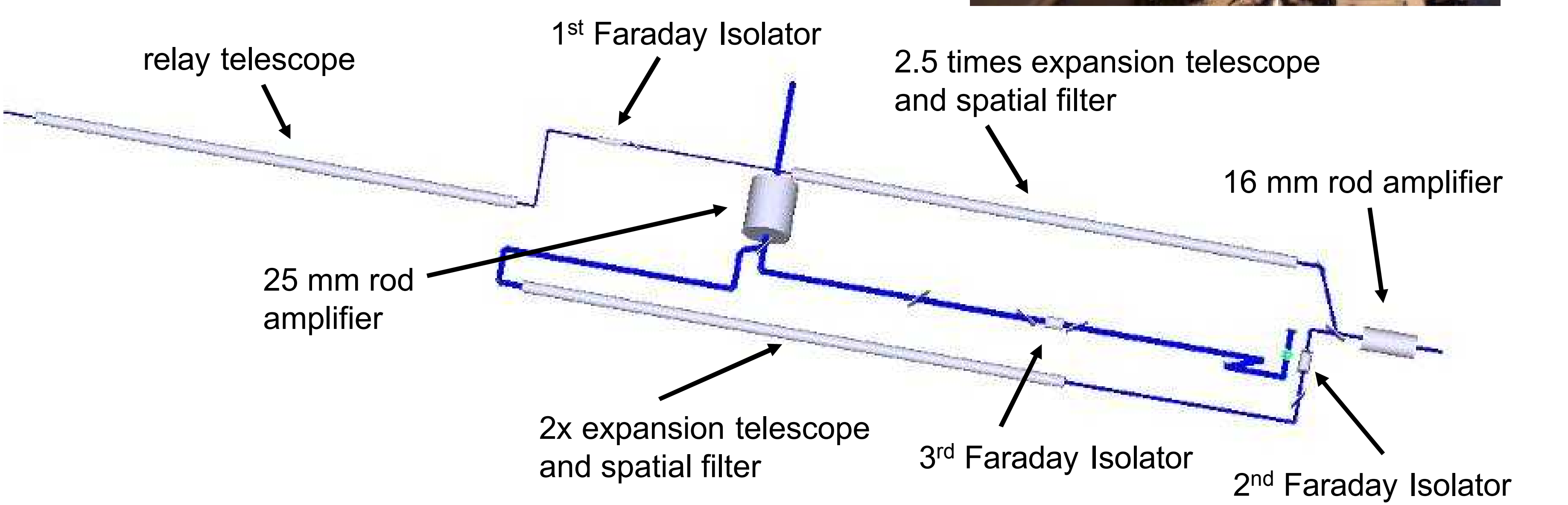
Rod amplifiers

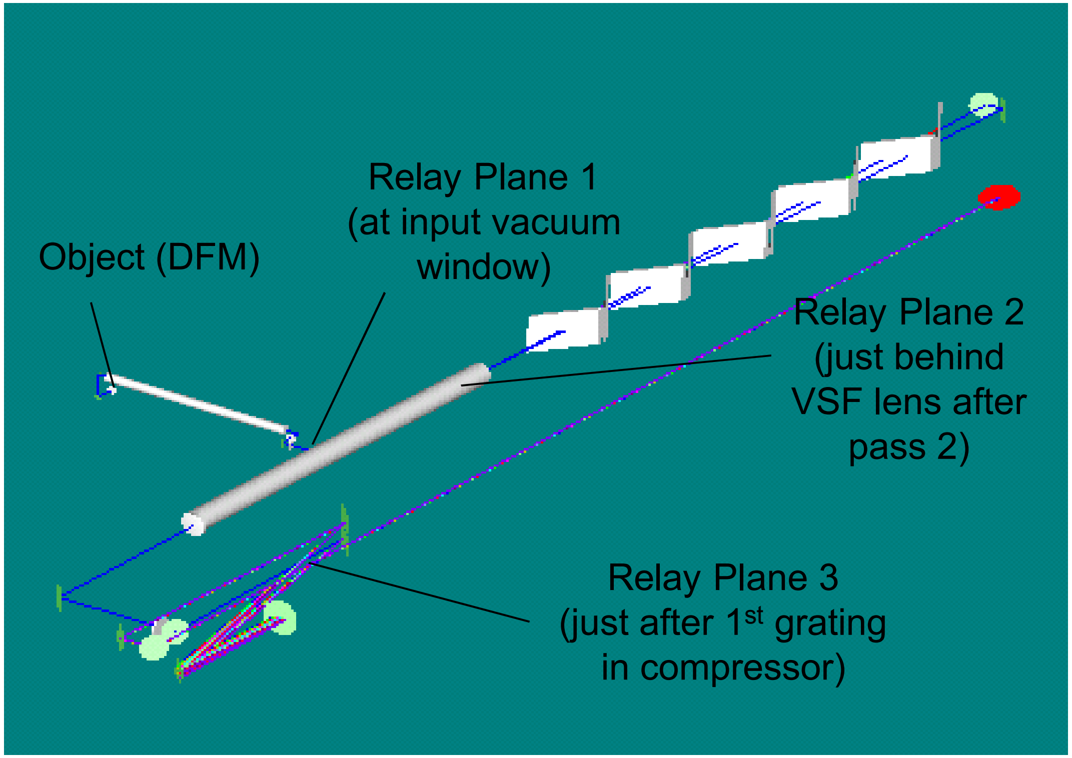
- 16mm, 2-pass + 25mm, 2-pass
  → <5J @ 15min rep rate, $\Delta\lambda\sim$6nm
- Custom AO thermal lens correction

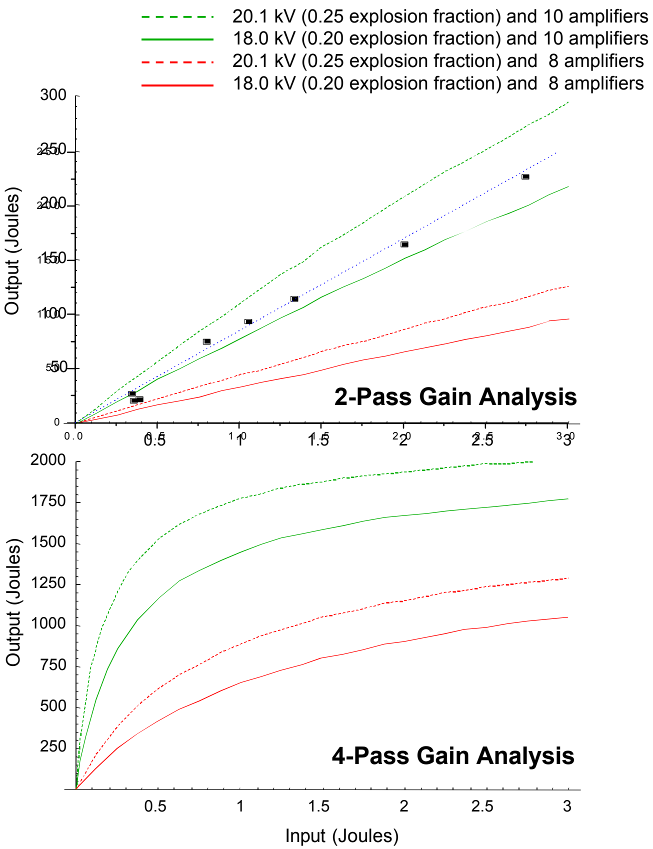




Optical layout, main system

- Baseline amplifier design: Double-pass of a 14.5cm beam (~80X gain in energy)
- Compressor design: Double-pass design 1480 line/mm HJY gold gratings (10 nm bandpass)
- Relay imaging still applies until the compressor.

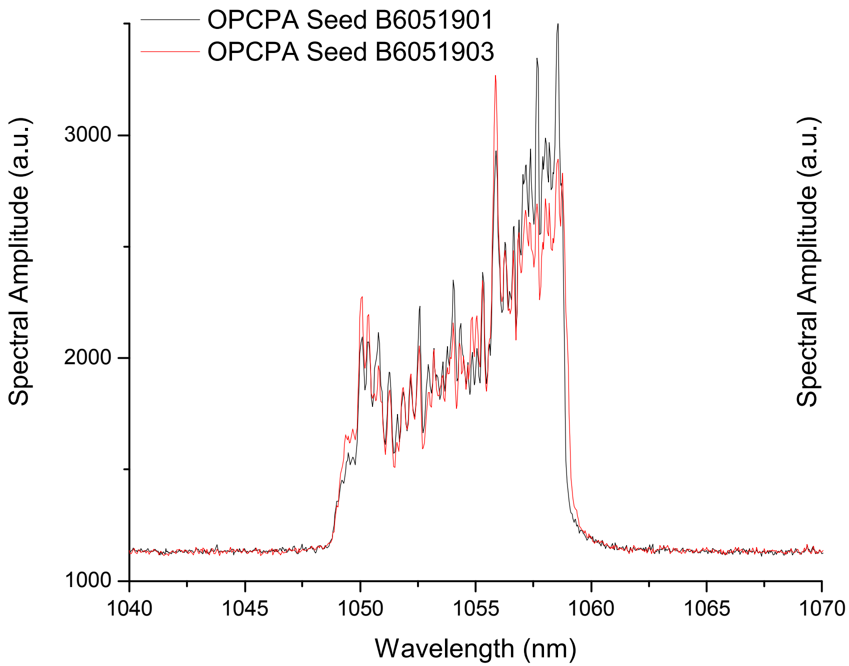


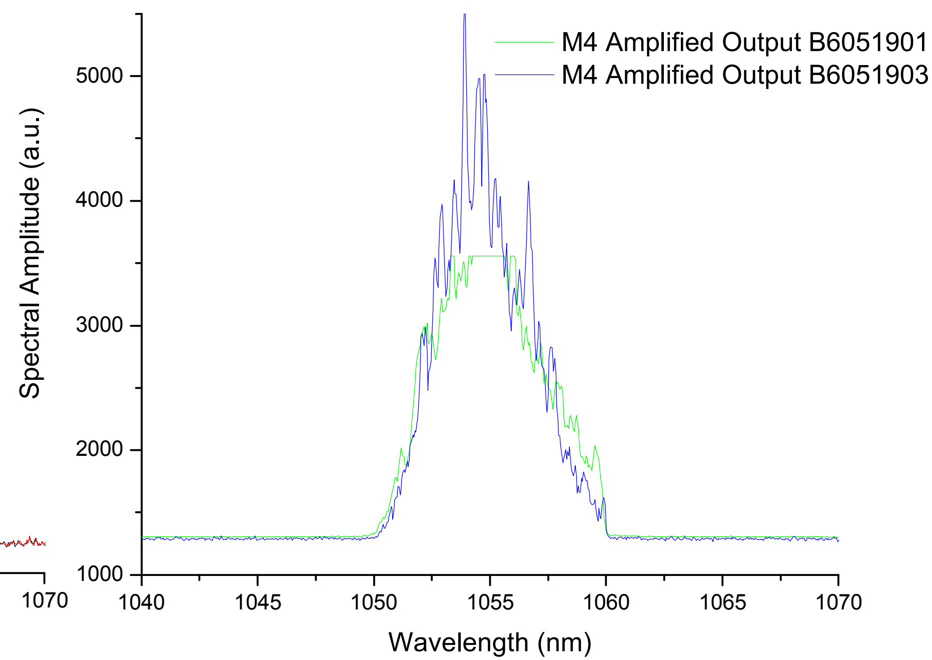


Spectral data

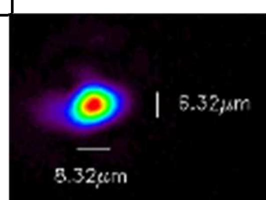
- OPCPA provides a relatively stable seed with 9.0nm FWHM

- M4 amplified spectra also appears relatively stable shot-to-shot with 4.8nm FWHM
- BW limit = 340fs

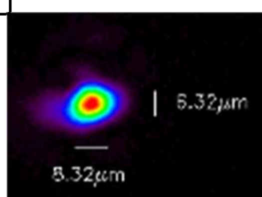
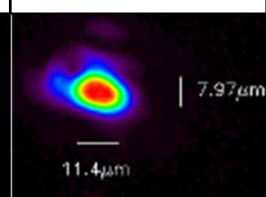




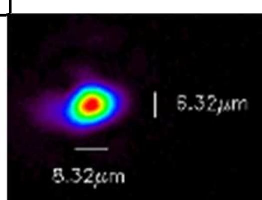
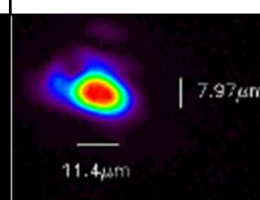
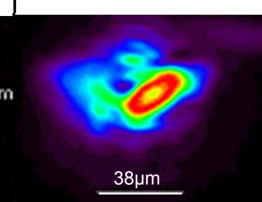
Focusability

Shot type	CW alignment	OPCPA 10HZ	Rod shot no AO	Rod shot with AO	Full system shot
FWHM x	8.3				
FWHM y	6.3				
Strehl ratio	0.39				
Encircled energy 1	63.4% R=6.9				
Encircled energy 2	90.4% 16.3				
Image					

Focusability

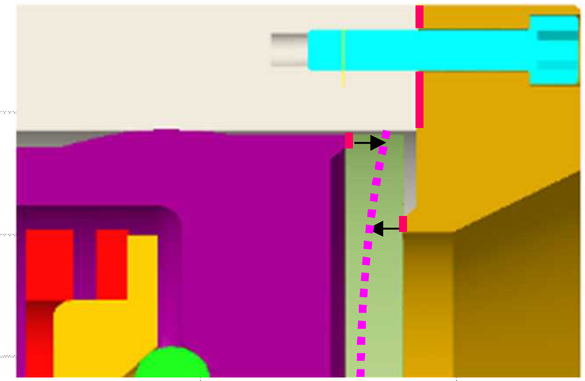
Shot type	CW alignment	OPCPA 10HZ	Rod shot no AO	Rod shot with AO	Full system shot
FWHM x	8.3	11.4			
FWHM y	6.3	8.0			
Strehl ratio	0.39	0.23			
Encircled energy 1	63.4% R=6.9	66.6% R=7.7			
Encircled energy 2	90.4% 16.3	92.9% 12.0			
Image					

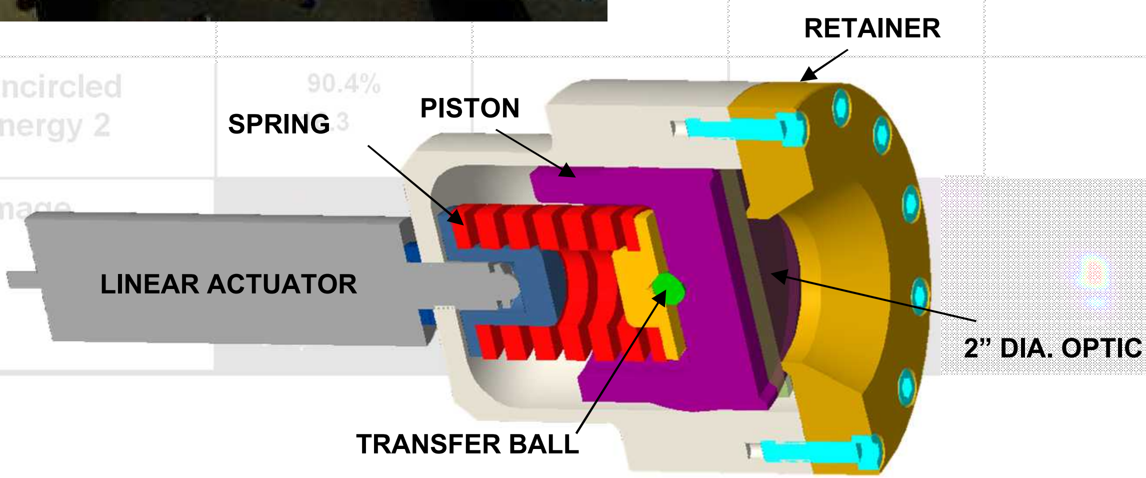
Focusability

Shot type	CW alignment	OPCPA 10HZ	Rod shot no AO	Rod shot with AO	Full system shot
FWHM x	8.3	11.4	38 m		
FWHM y	6.3	8.0	24		
Strehl ratio	0.39	0.23	0.03		
Encircled energy 1	63.4% R=6.9	66.6% R=7.7	60.6% R=21.5		
Encircled energy 2	90.4% 16.3	92.9% 12.0	90.3% R=42.1		
Image					

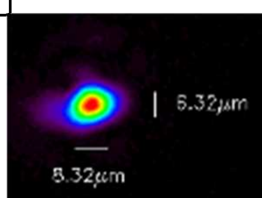
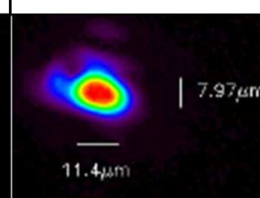
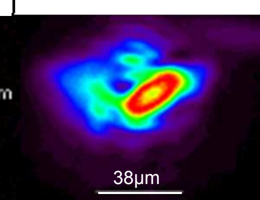
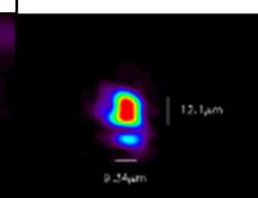
Focusability

Thermal lens correction



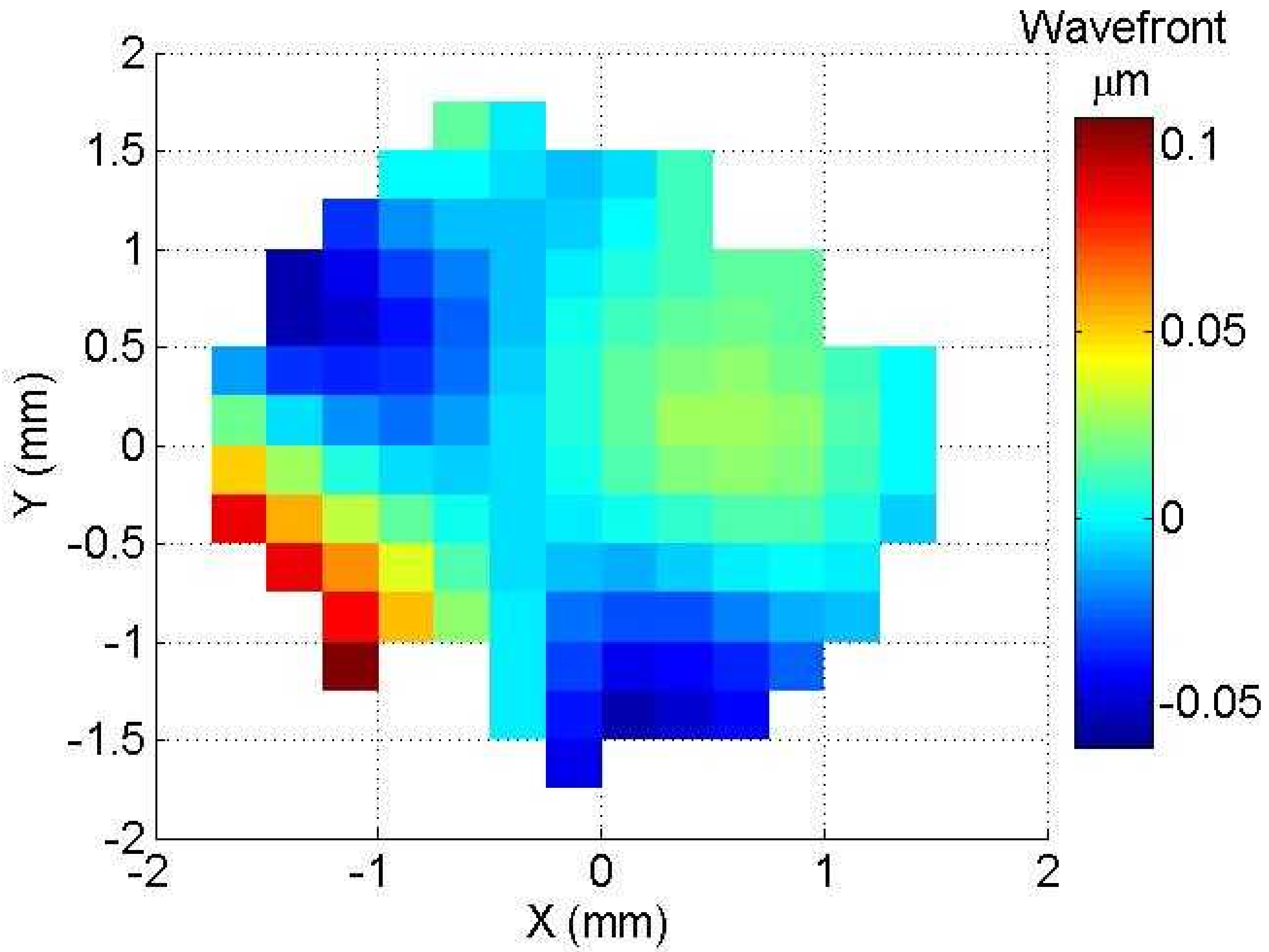


Focusability

Shot type	CW alignment	OPCPA 10HZ	Rod shot no AO	Rod shot with AO	Full system shot
FWHM x	8.3	11.4	38 m	9.4	
FWHM y	6.3	8.0	24	12.1	
Strehl ratio	0.39	0.23	0.03	0.21	
Encircled energy 1	63.4% R=6.9	66.6% R=7.7	60.6% R=21.5	61.2% R=6.9	
Encircled energy 2	90.4% 16.3	92.9% 12.0	90.3% R=42.1	90.4% R=12.9	
Image					

Shack-Hartman data at M9

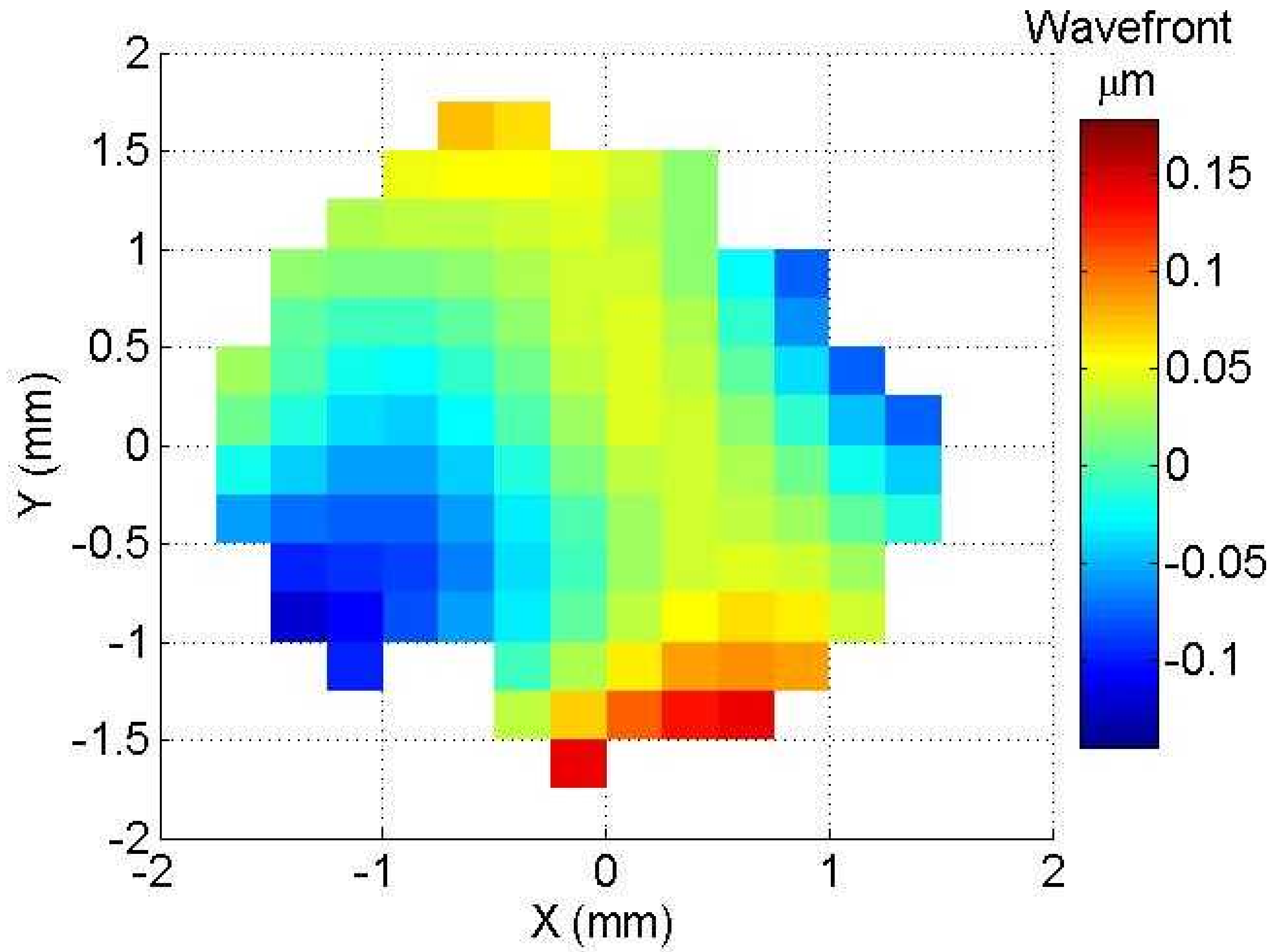
OPCPA baseline:
PV: 0.21 μm
RMS: 0.04 μm



Shack-Hartman data at M9

OPCPA baseline:
PV: 0.21 μm
RMS: 0.04 μm

16 mm amp shot:
PV: 0.64 μm
RMS: 0.14 μm

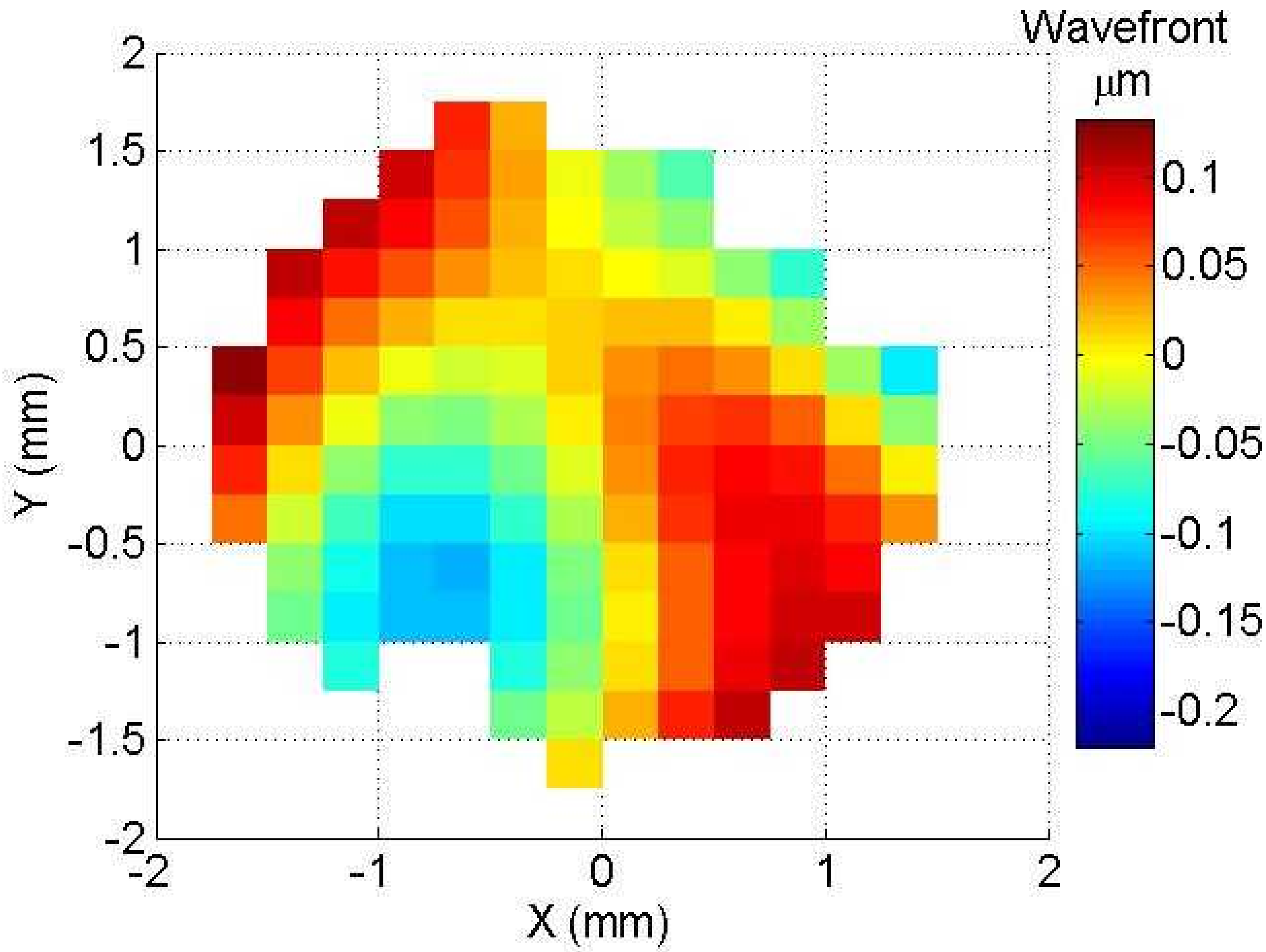


Shack-Hartman data at M9

OPCPA baseline:
PV: 0.21 μm
RMS: 0.04 μm

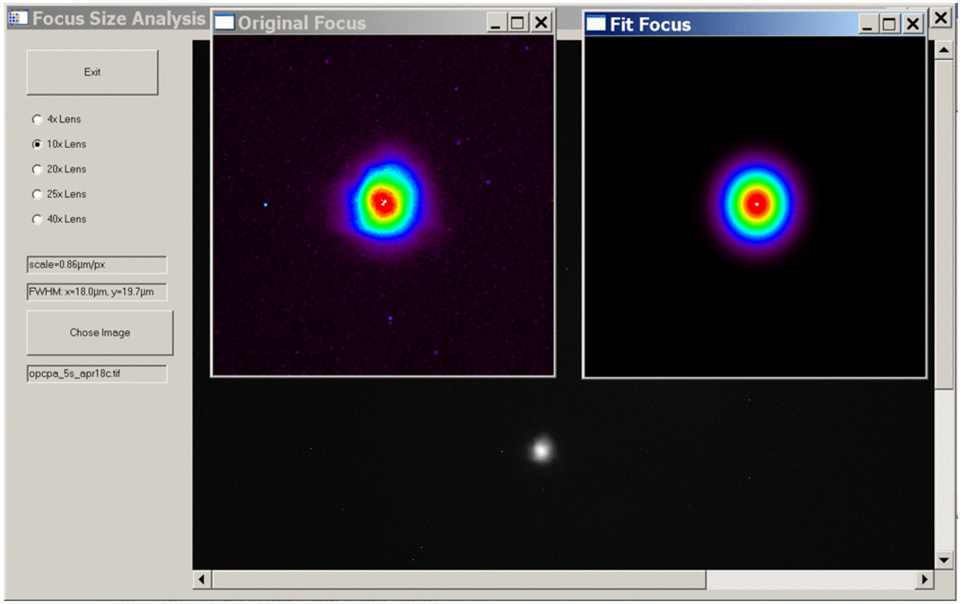
16 mm amp shot:
PV: 0.64 μm
RMS: 0.14 μm

Full system shot:
PV: 0.74 μm
RMS: 0.18 μm

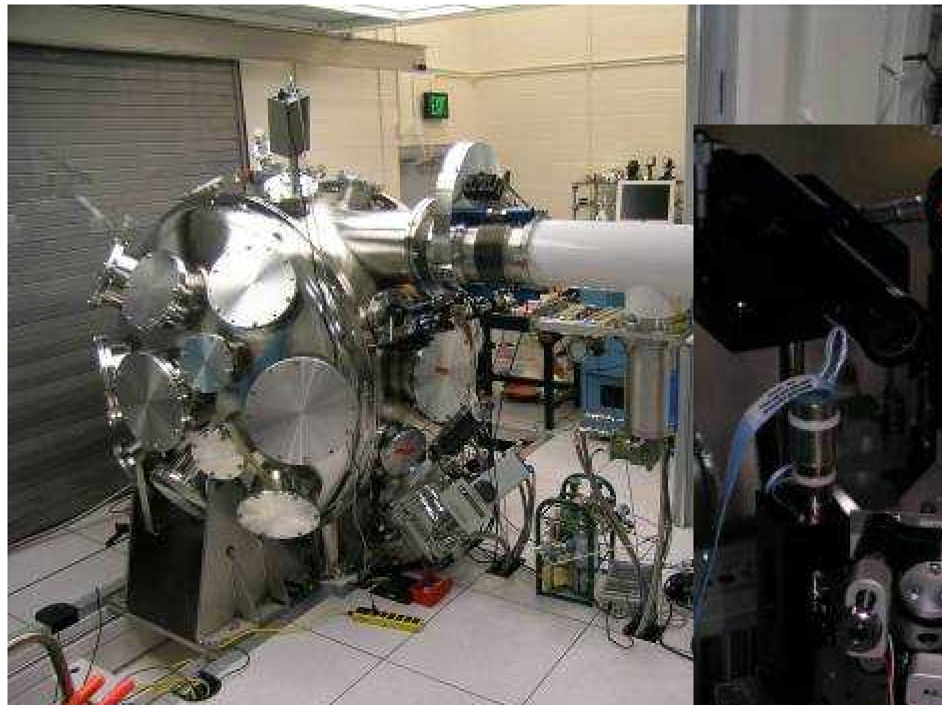


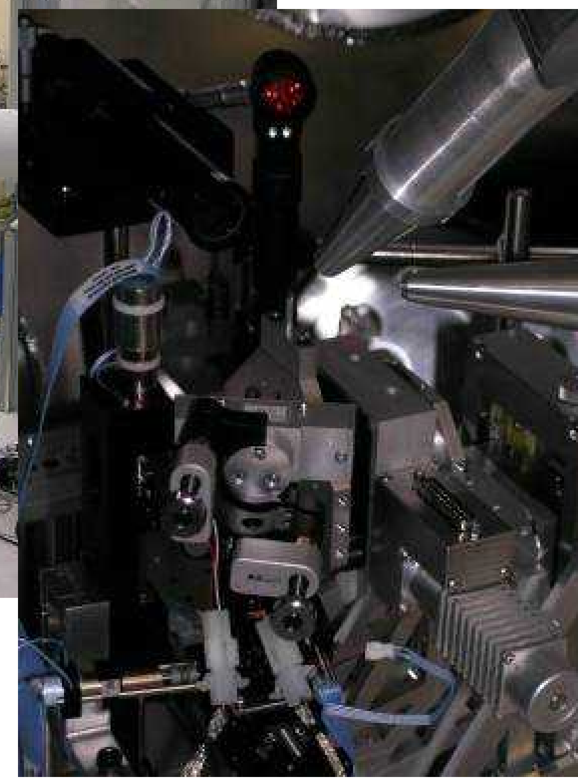
Pointing stability

• Pointing of 10Hz OPCPA focal spot integrated over 5s shows spot confined to 18μm X 20μm



100-TW target area





- Variable rad-shielding
- Mid 10^{-7} Torr
- RGA, EMI-cabinets, 5D-target positioner, movable domes, interior optical table

Diagnostics include:
- X-ray Spectrometers
- Pinhole Cameras
- Optical Probes
- RCF
- Cu k-α Bent Crystal Imager
- Thompson Parabola
- Streak Cameras (2 optical, 1 x-ray)

Collaborators:
UT, UCSD/GA, OSU, UNR

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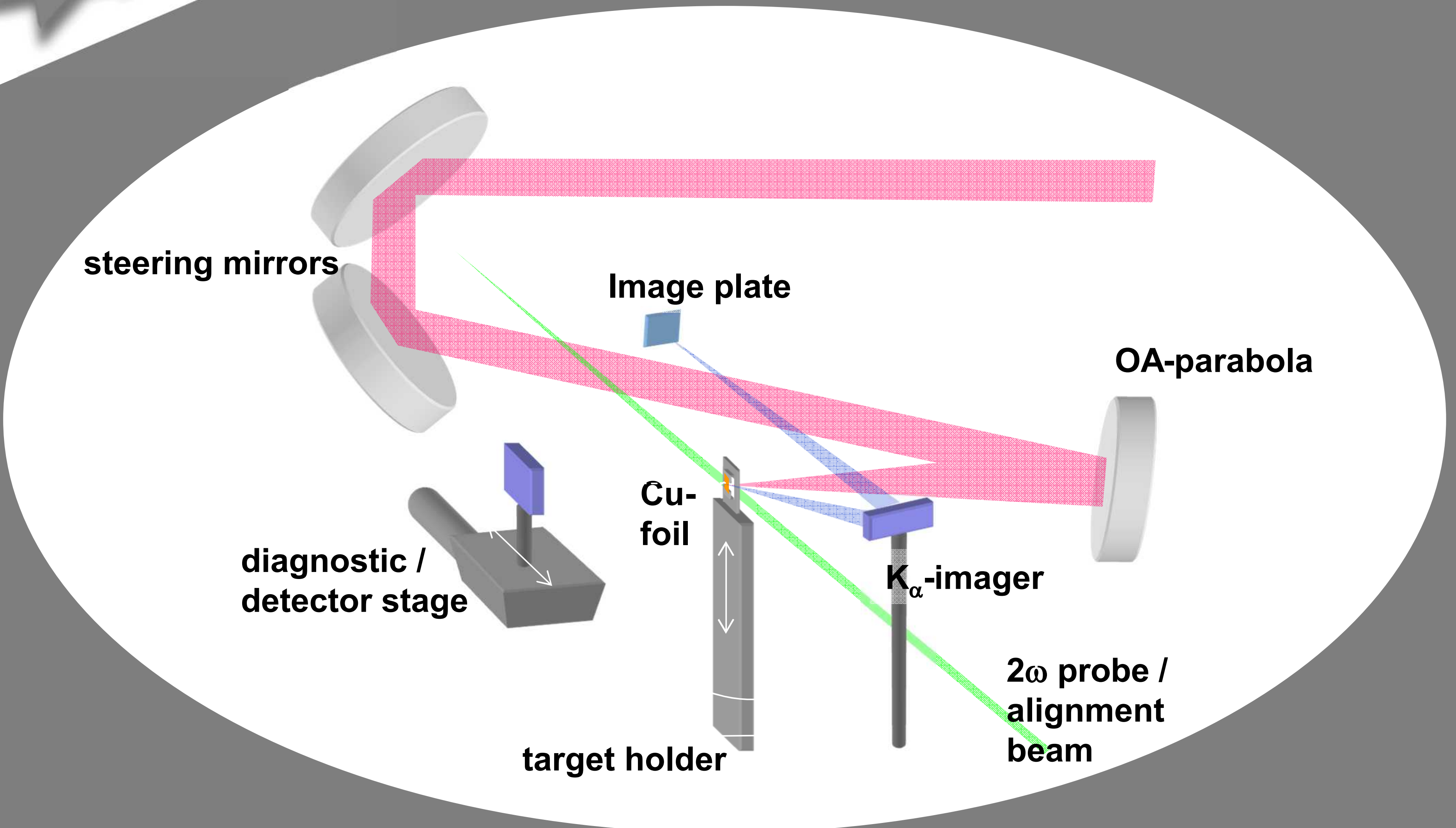
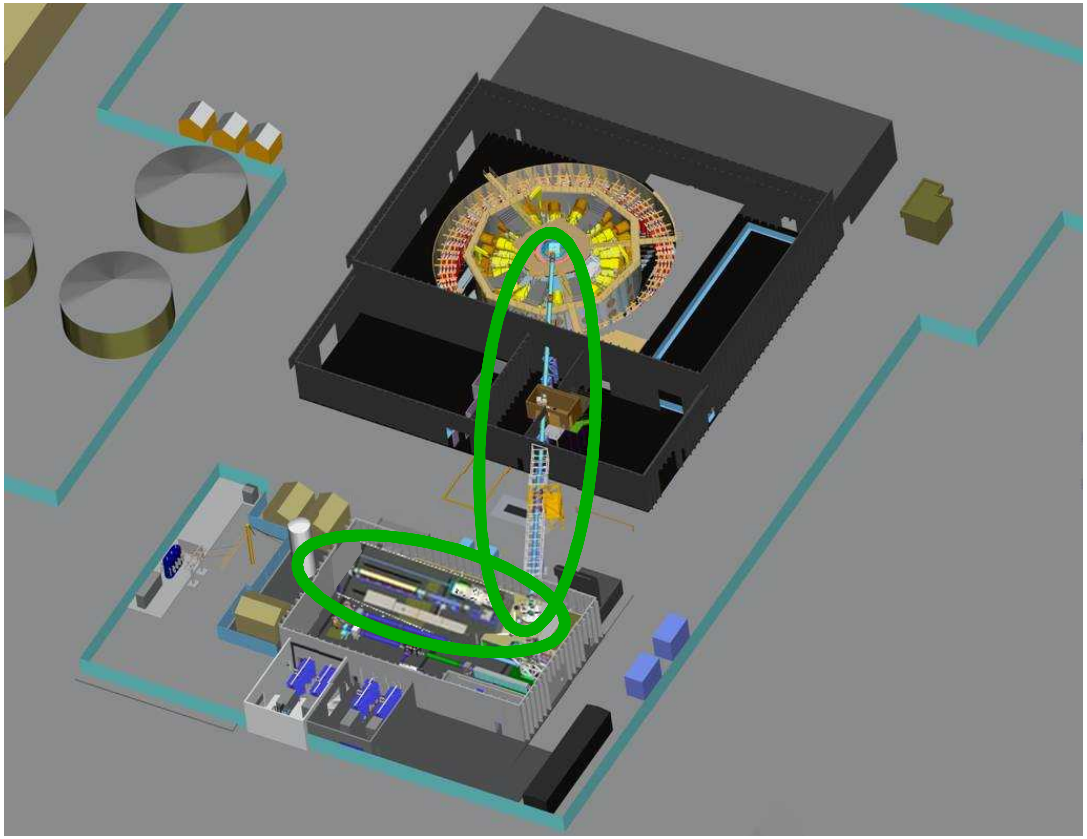
Target Chamber



With harder pumping (and an extra slab) at the main cavity amps, the beam will be transported to Nova gold grating compression in the Z building



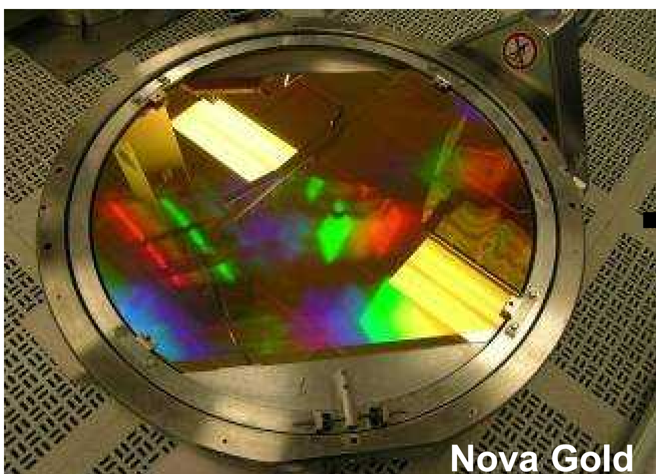
Compression grating options for future 2 kJ ZPW

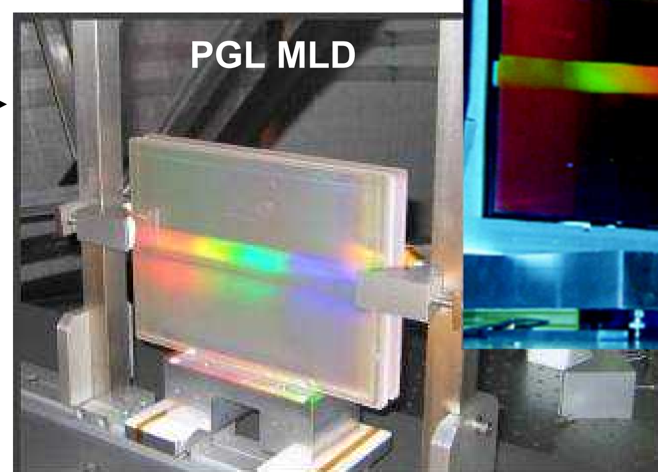
- **Use Nova Gold Gratings to achieve ZPW 500J/500fs operation (Limited due to LIDT)**

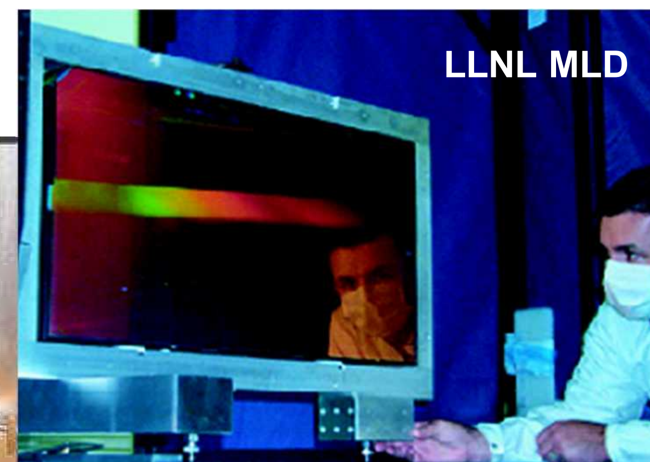
- **Later enhance ZPW to HEPW:**
  To increase energy, MLD's will have to be employed. For large but produceable meter-class gratings (no tiling), MLD options are:

  LLNL/Britten: Has already produced 80cmX40cm 1780l/mm MLD's;
  Smaller samples show: up to 98% D.E.; ~4.6J/cm^2 at 10ps at 76.5° (Rt.σ)

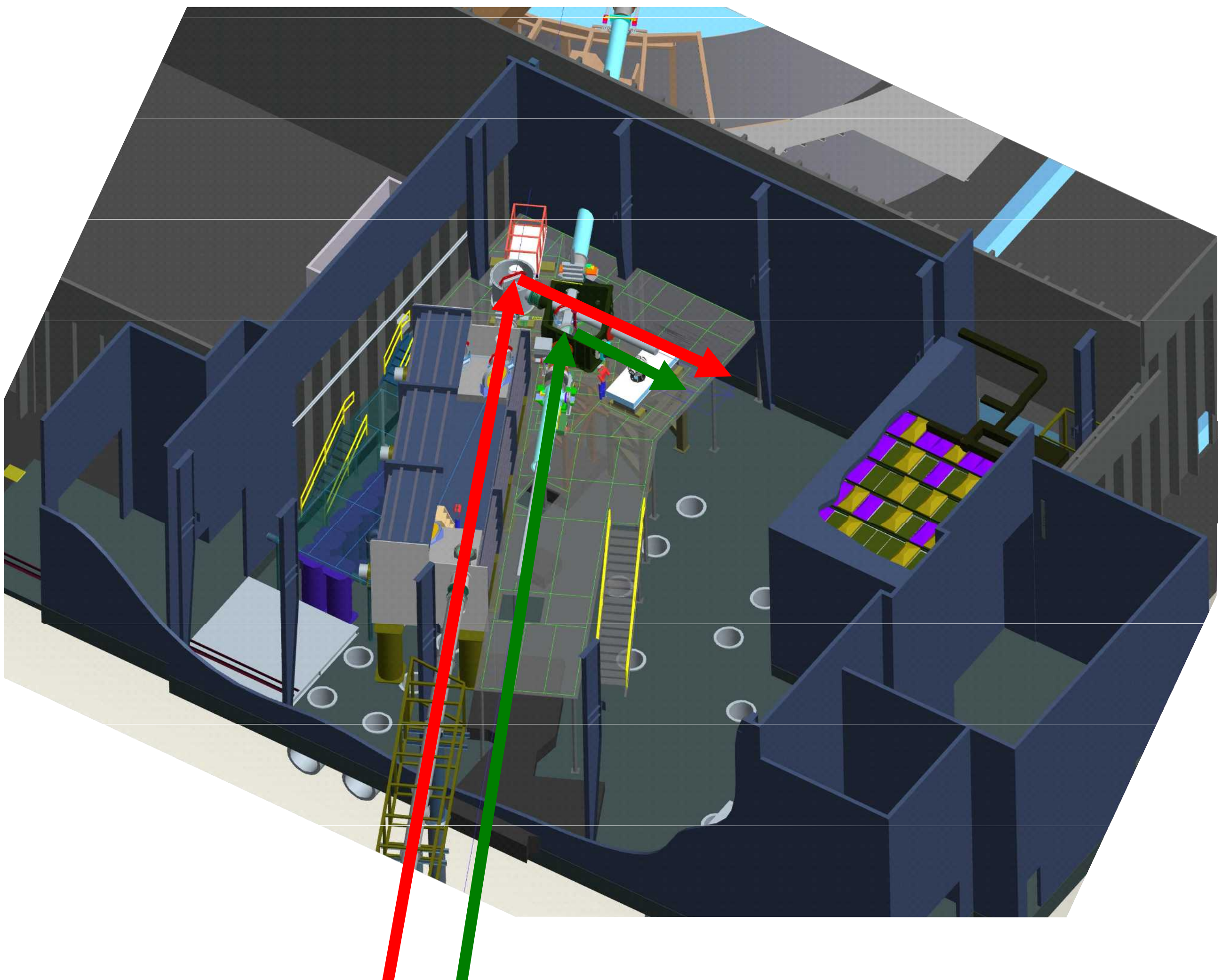
  PGL: Has already produced 16.5cmX22cm 1740l/mm MLD's
  Smaller samples show: up to 97% D.E.; ~5.9J/cm^2 at 10ps at 72° (Rt.σ)







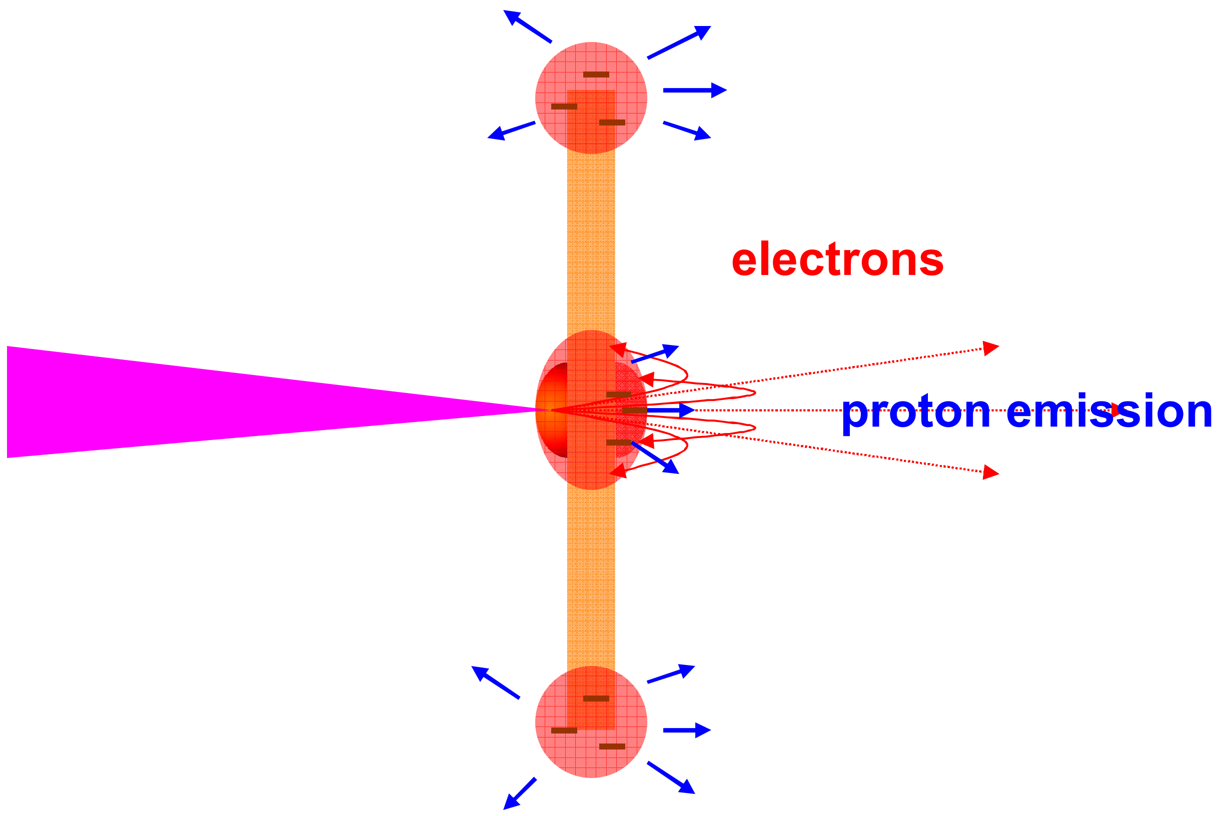
ZPW and ZBL beams will eventually be brought together in a dedicated target chamber



Eventual ZPW compressor vessel containing MLD gratings

Edge Emission

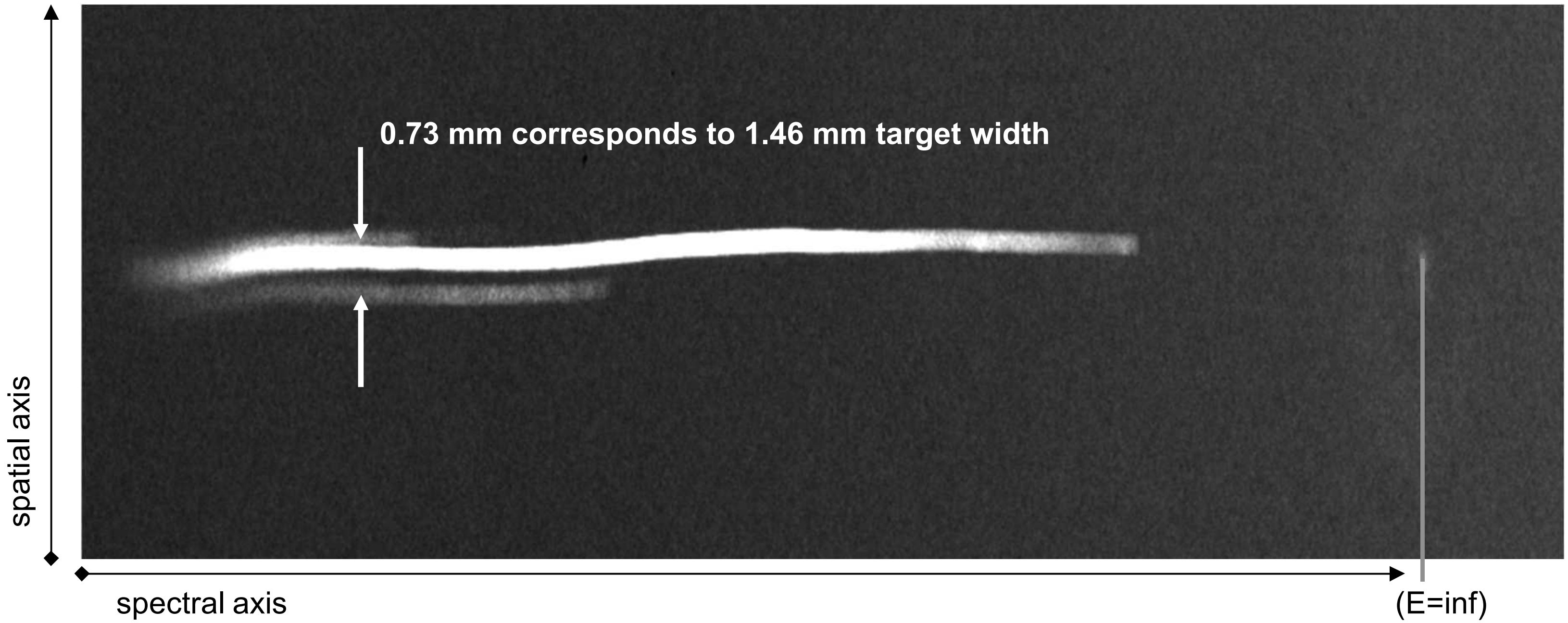
(Concept: McKenna et al.: PRL 98, 145001, 2007)



Recent results from our 100-TW facility:
Laser generated ion beams (*Geissel et al.*)

Edge Emission

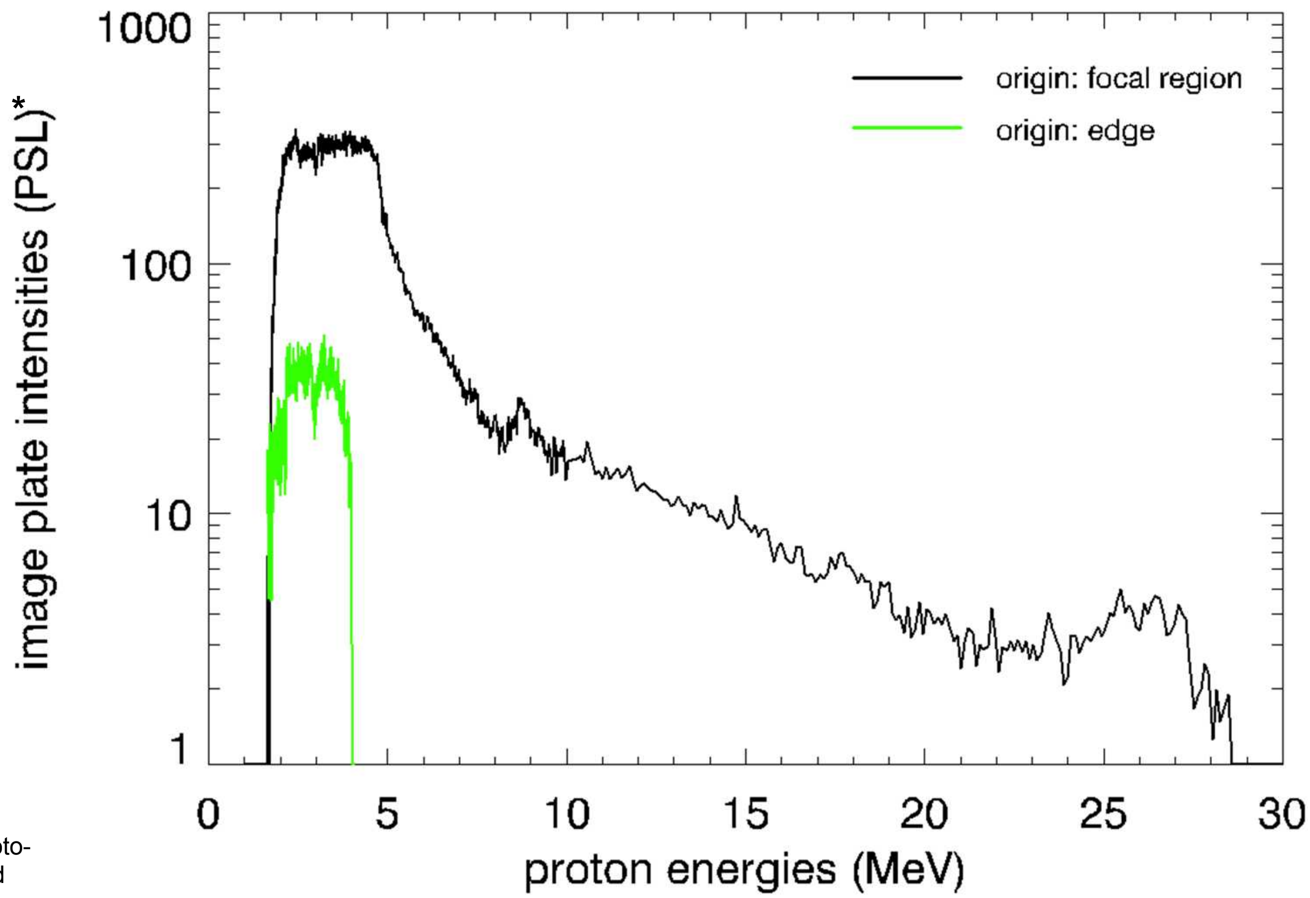
Proton Traces on B-Spectrometer



Low energy protons are emitted from the edges of the target foil and leave parallel ghost images on the image plate behind the Thomson parabola. Similar to X-ray emission, the intensity is substantial due to field enhancement at an edge. The entrance pinhole of the spectrometer projects a 1:2 demagnified 1D-image of the source.

Edge Emission

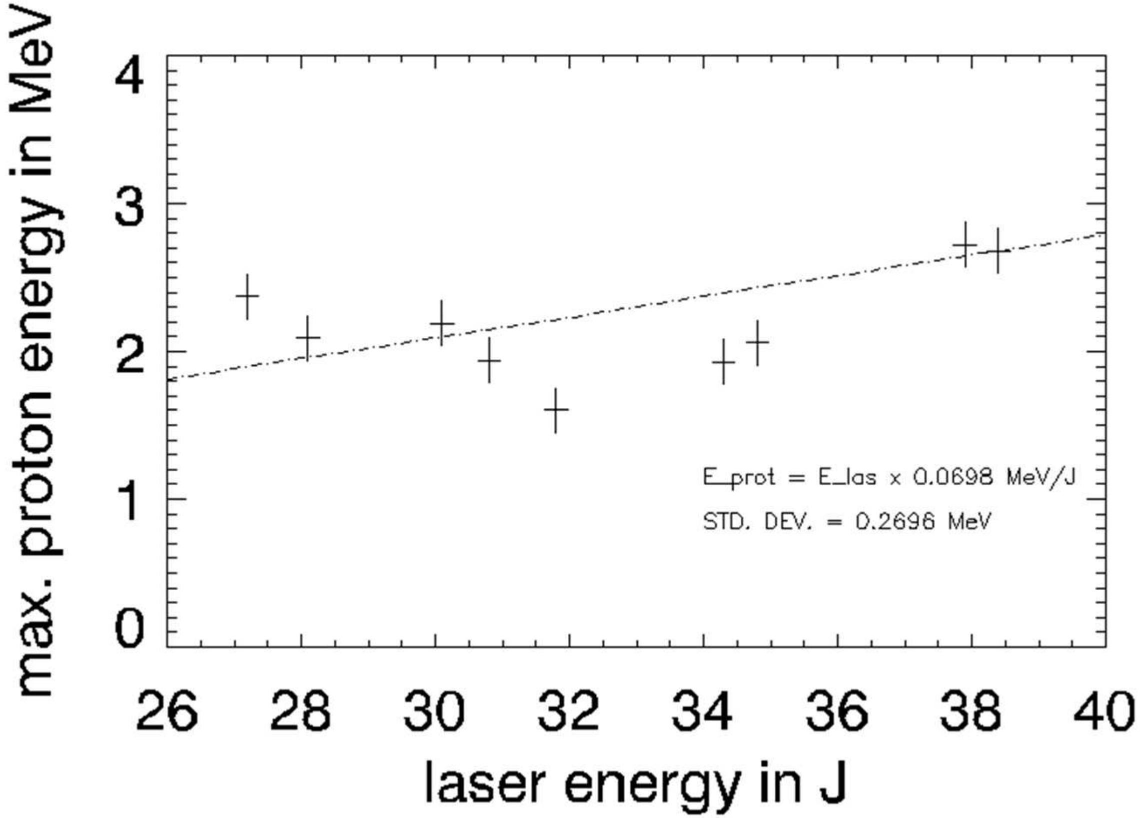
Comparison with Main Proton Trace



*PSL: photo-stimulated luminescence

Edge Emission

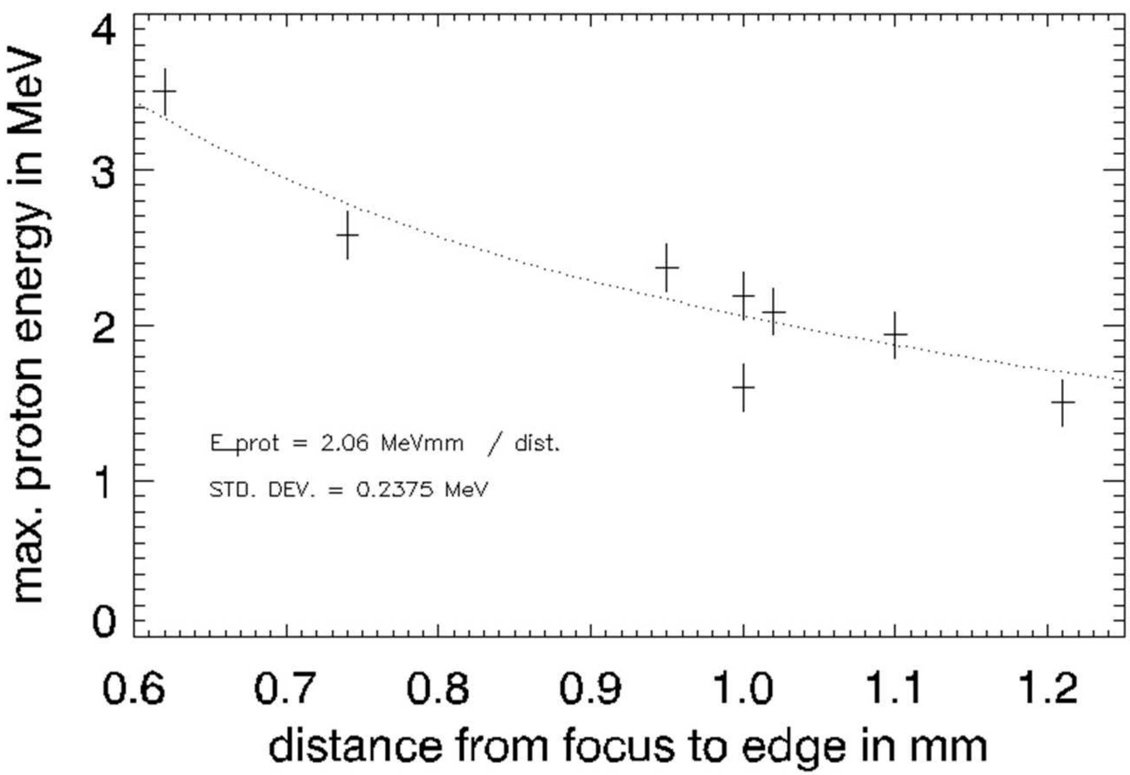
Dependence on Laser Energy



Evaluation of shots with a distance from focus to edge of 1mm ± 10%

Edge Emission

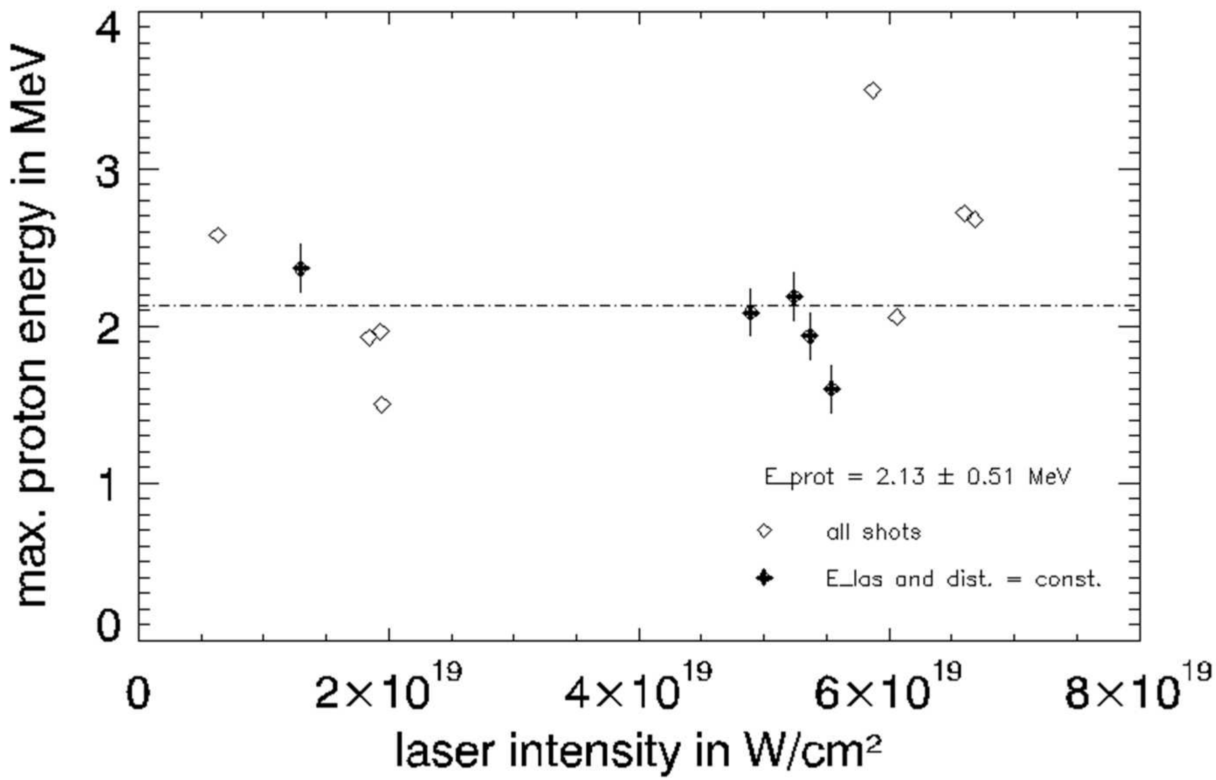
Dependence on Focus Position



Evaluation of shots with a laser energy of 30.5 J ± 10%

Edge Emission

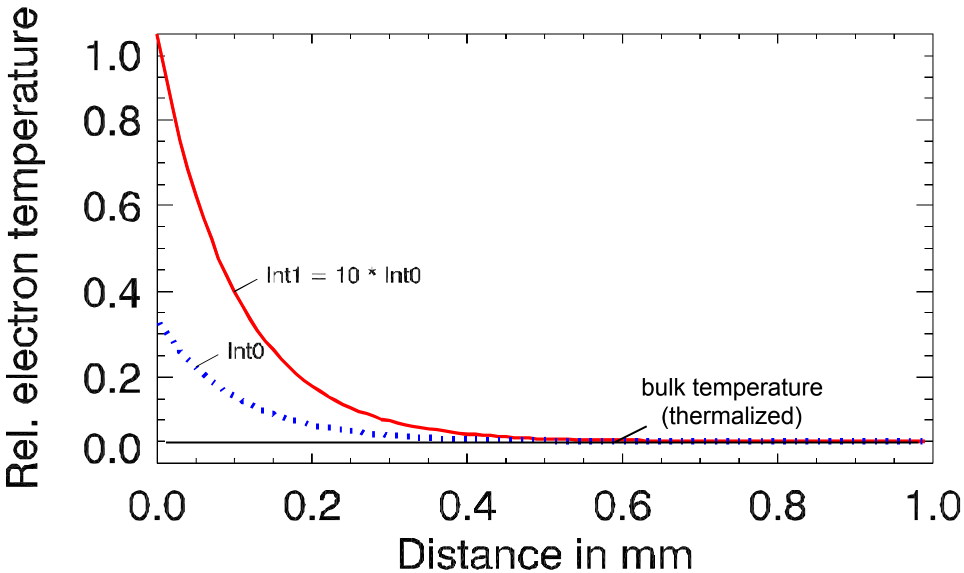
Dependence on Laser Intensity



No obvious dependence of max. proton energy on laser intensity!

Edge Emission

Explanation: Thermalized electrons ?



Electrons cool along the target:

$$T_e \infty T_0 * e^{-x/c} + T_{bulk}$$

This example: $c = 0.1$ mm

$T_{bulk} = 0.05$

$E_{max}(p^+) = F(T_e, n_e)$

T_e: electr. temp.

n_e: electr. density

$E_{max}(p^+)$ is:

- independent of $T_{e,0} \infty I^{½}$
- proportional to $n_e \infty E_{laser}$
- proportional to $n_e \infty 1/d$
- dependent on T_{bulk} (∞ E_{las}?)

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