Texas Petawatt: Status and Prospects

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- Laser capabilities
- Laser construction
- Target areas and detector capabilities
- Theory support
- Simulations

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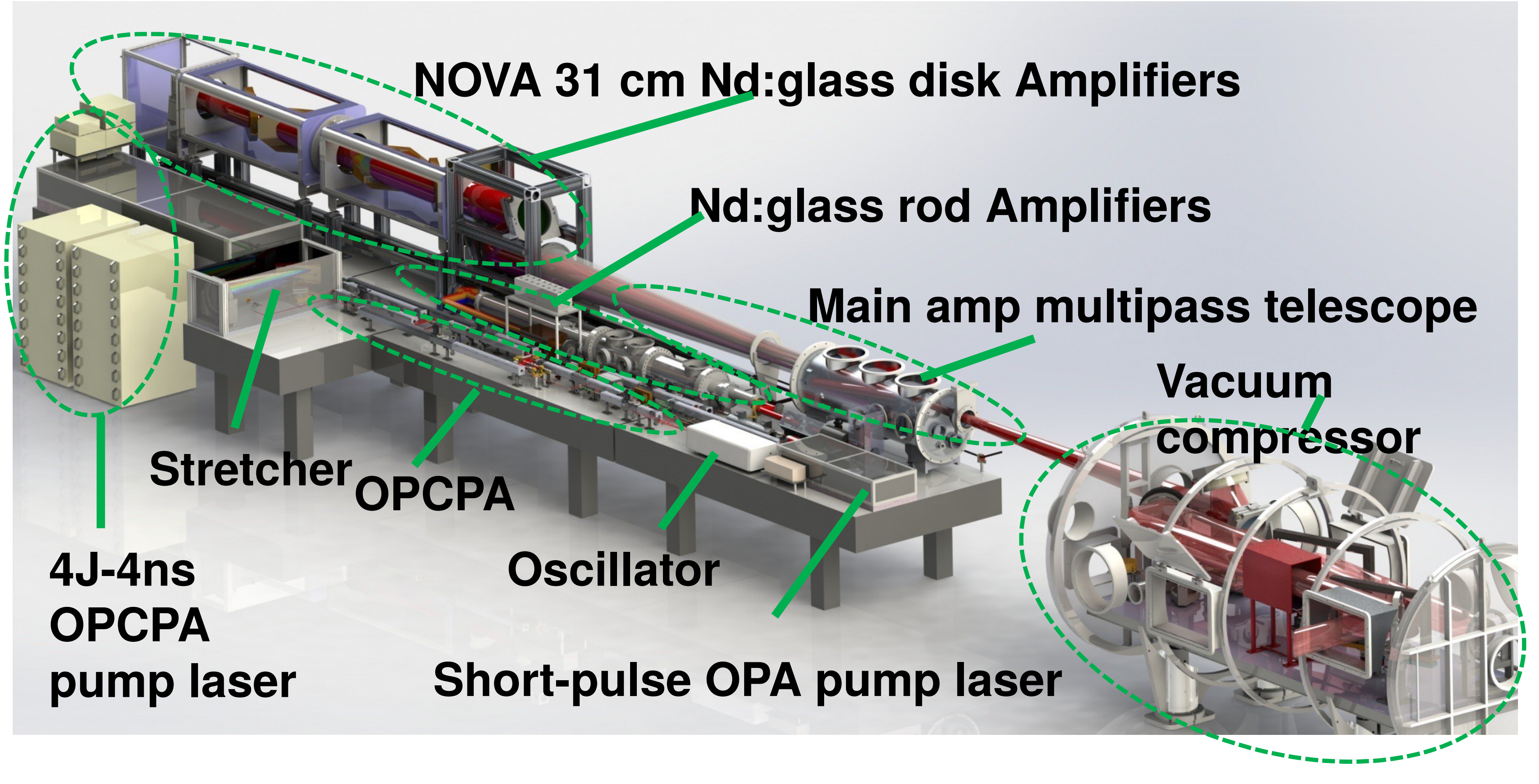
Laser infrastructure

Laser wavelength λ=1.058 μm

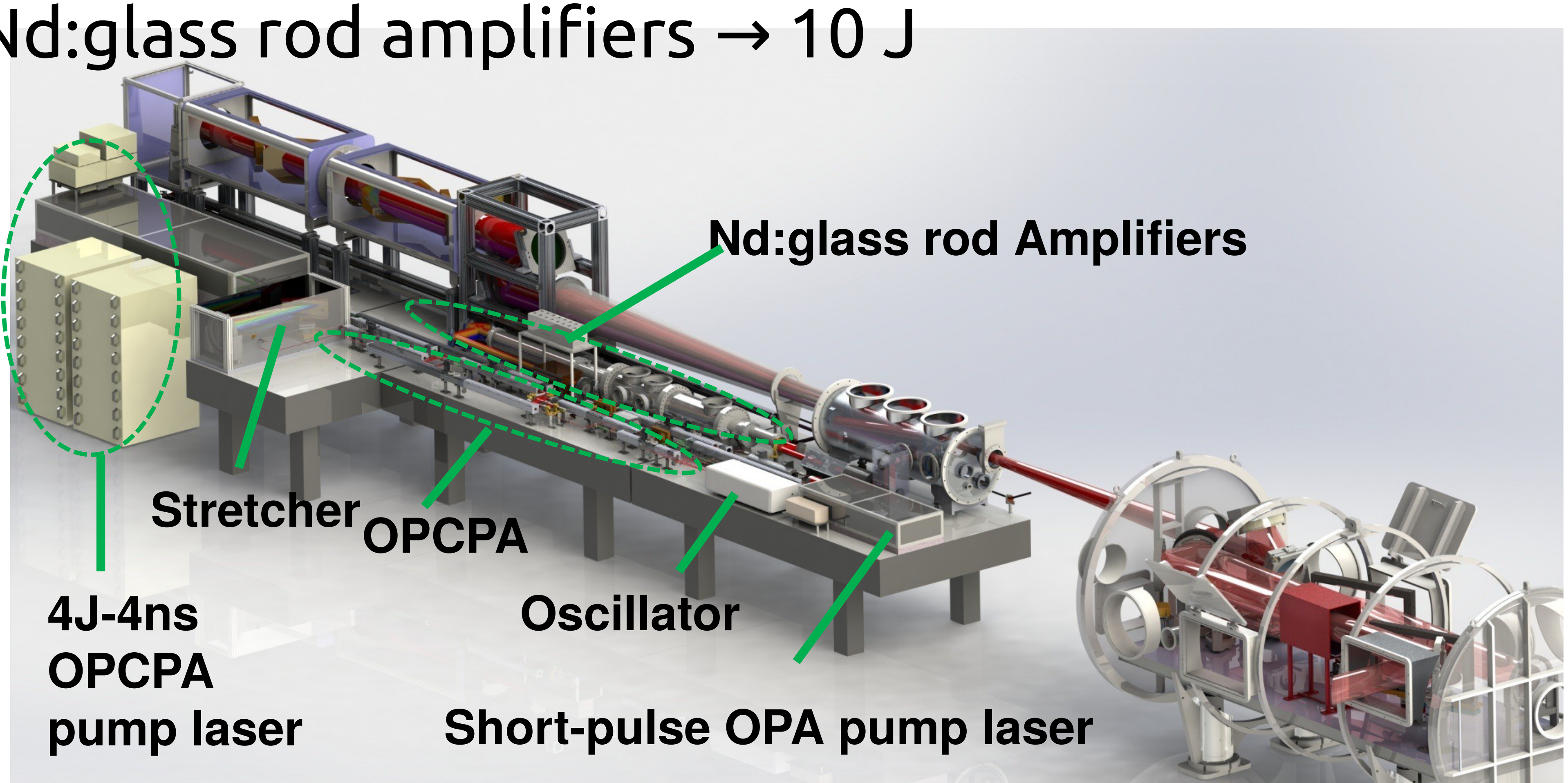
Full power: 150-170 J / pulse

Repetition rate at full power: ~ 1 / hour

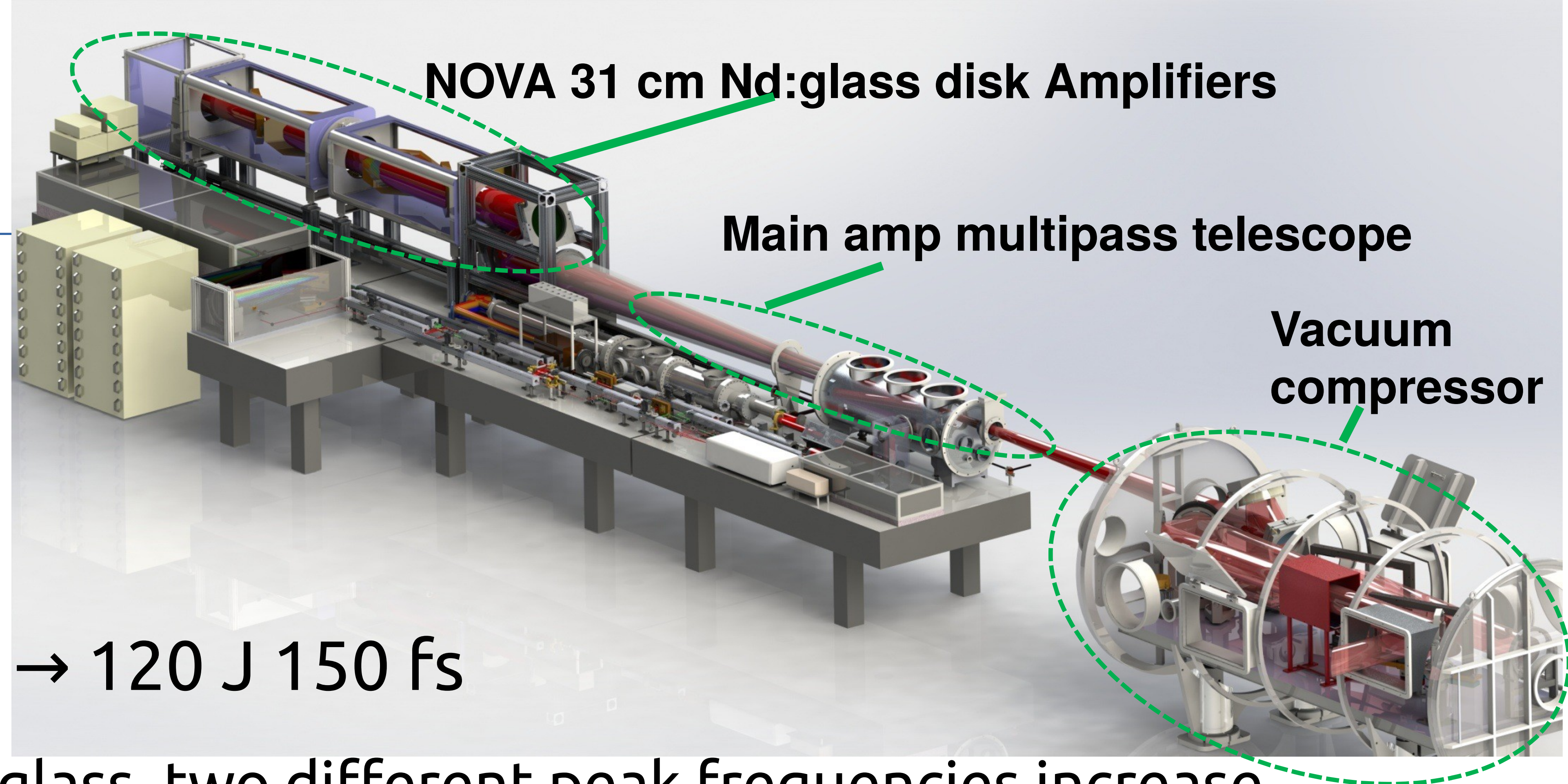


Operation outline

1. Oscillator produces nJ, <100 fs pulses at ~70 MHz repetition
2. 2 Short-pulse OPA stages deliver 500 μJ (pumped by 20 mJ, 10 ps using YLF crystal at 2ω)
3. Stretch to 2 ns, matching to 4ns 4J pump of next OPA stages (BBO and LBO crystals) → 0.5 J 2ns 2.5 Hz
4. 2- and 4-pass Nd:glass rod amplifiers → 10 J



Operation outline



5. Main amplifier → 120 J 150 fs

   * P, Si doped Nd:glass, two different peak frequencies increase amplified bandwidth, improves compression capability

   * Adaptive mirror corrects thermal inhomogeneities in pump glass

6. Compressor

   * Adaptive mirror before gratings corrects wavefront for final optics

7. Chamber 1 : f/1 or f/3 parabola for High intensity/high energy experiments

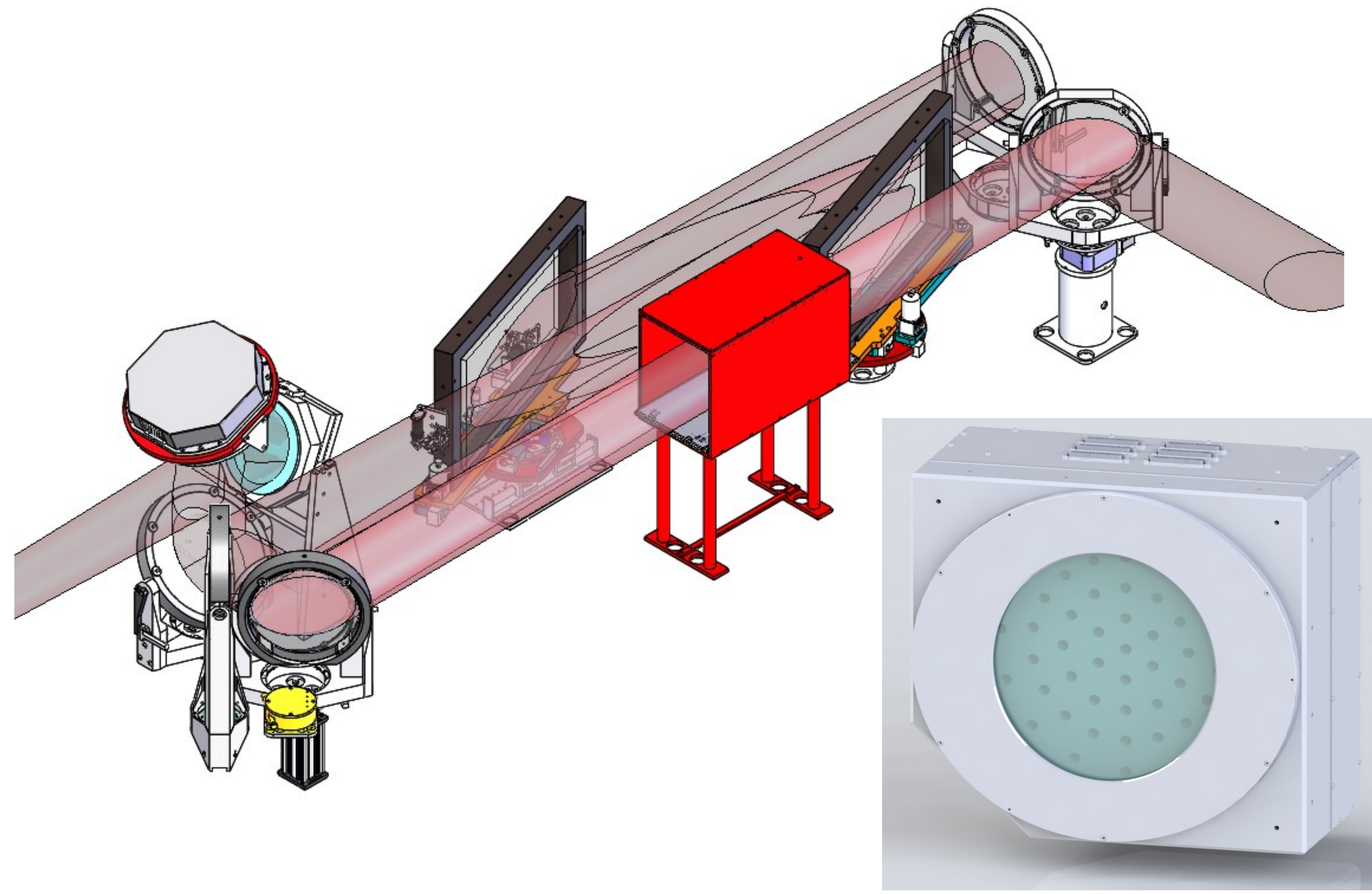
   Chamber 2 : f/45 spherical mirror for wakefield

Upgrade Contrast and Intensity

Goal: >2x10^22 W/cm^2

Focusing:

- 2nd adaptive mirror in compressor
- full aperture
- f/1 off-axis parabola



$\Rightarrow \mathbf{I}_{ave} > 10^{22}$ W/cm^2 for ~50 cycles

$\Rightarrow \mathbf{I}_{peak}$ (Airy) $>1 \times 10^{23}$

	Generated WF µm PTV	Residual (nm RMS)		Used Dynamic (%)	
		Absolute	Relative	Absolute	Relative
active flatness	-	34	-	34%	-
focus	6	33	8	35%	1%
astig	5.8	34	8	34%	1%
astig45	5.95	33	9	33%	2%
comaX	5.83	40	20	31%	5%
comaY	5.87	34	12	37%	4%
trefoil	5.94	35	10	36%	4%
trefoil30	5.94	34	14	37%	4%
AS	2.97	47	25	38%	9%
astig2	3.78	39	23	35%	7%
astig2_45	3.9	37	19	34%	7%
tetrafoil	3.9	38	22	34%	7%
tetrafoil22,5	3.95	38	15	40%	6%

Baseline experiment:

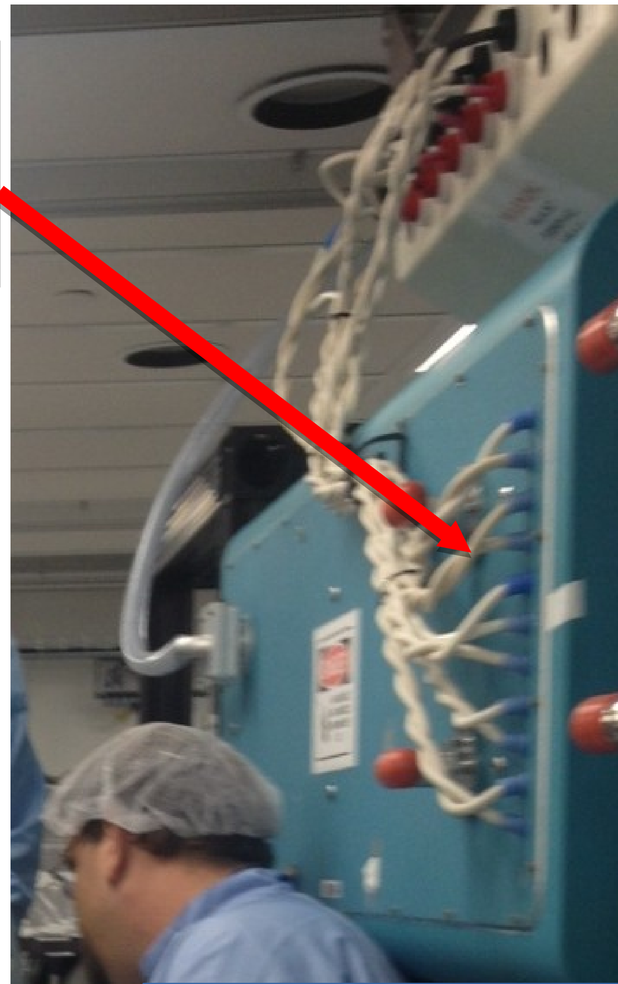
f/3 optic $\Rightarrow \mathbf{I} \geq 10^{21}$ W/cm^2

Pulse/wavefront upgrades

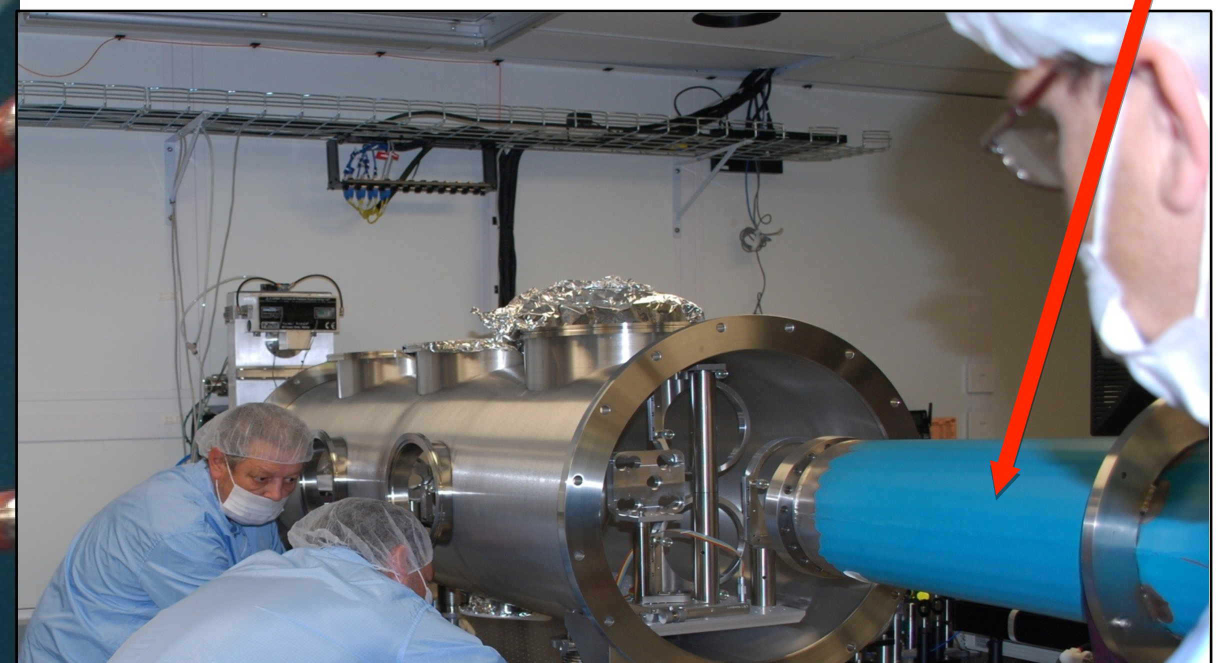
- ✔ Shorter pump laser before OPA
  - * reduces pedestal length
- ✔ Replace all transmission optics with reflection
  - * eliminates pencil beams, but more difficult pointing
- ✔ Install adaptive optics systems
  - * Corrects thermal changes inside pump glass
  - * Installation complete, set for testing later this year

Contrast upgrades

Pinhole Assembly

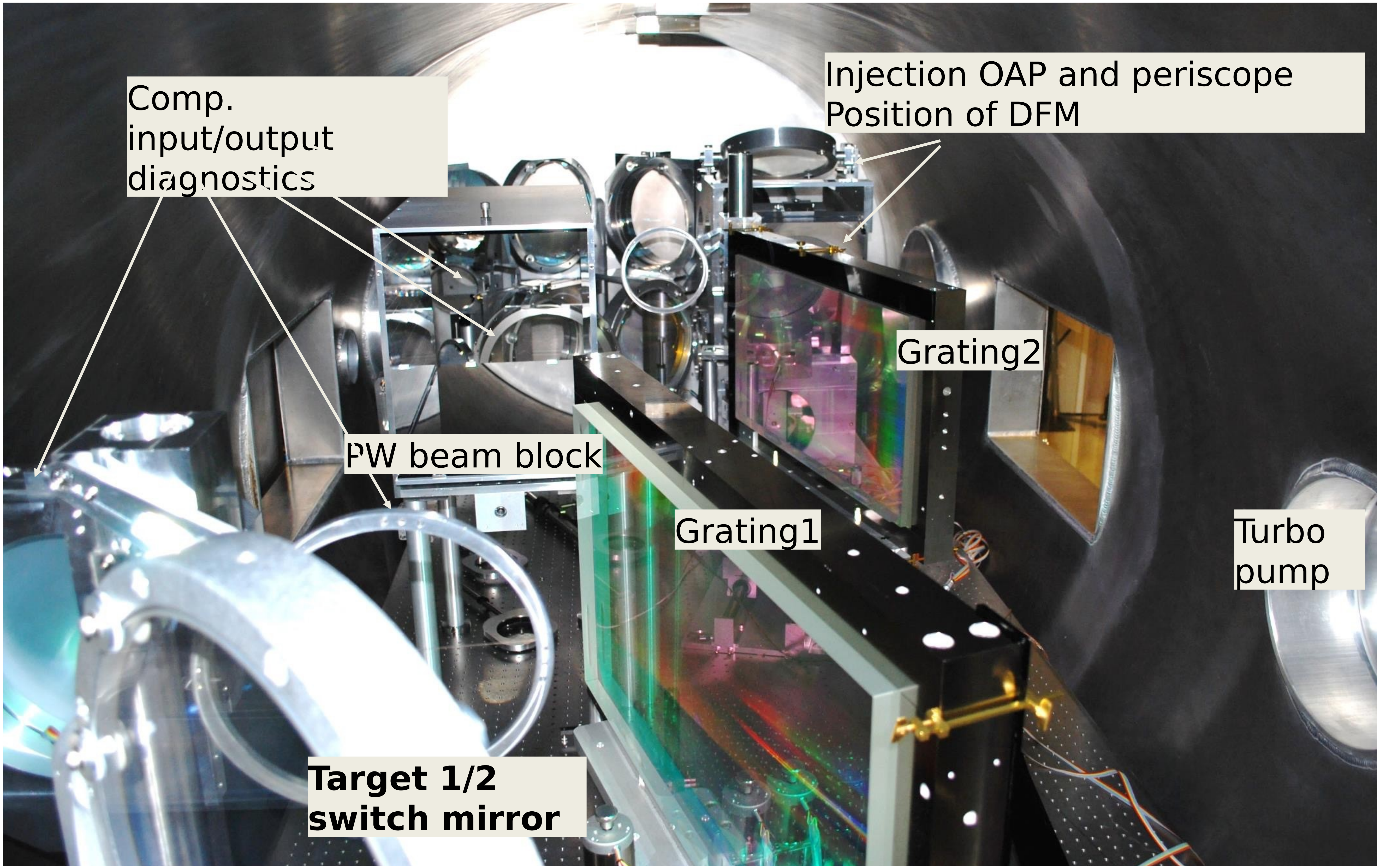


Vacuum transport tube from pinhole



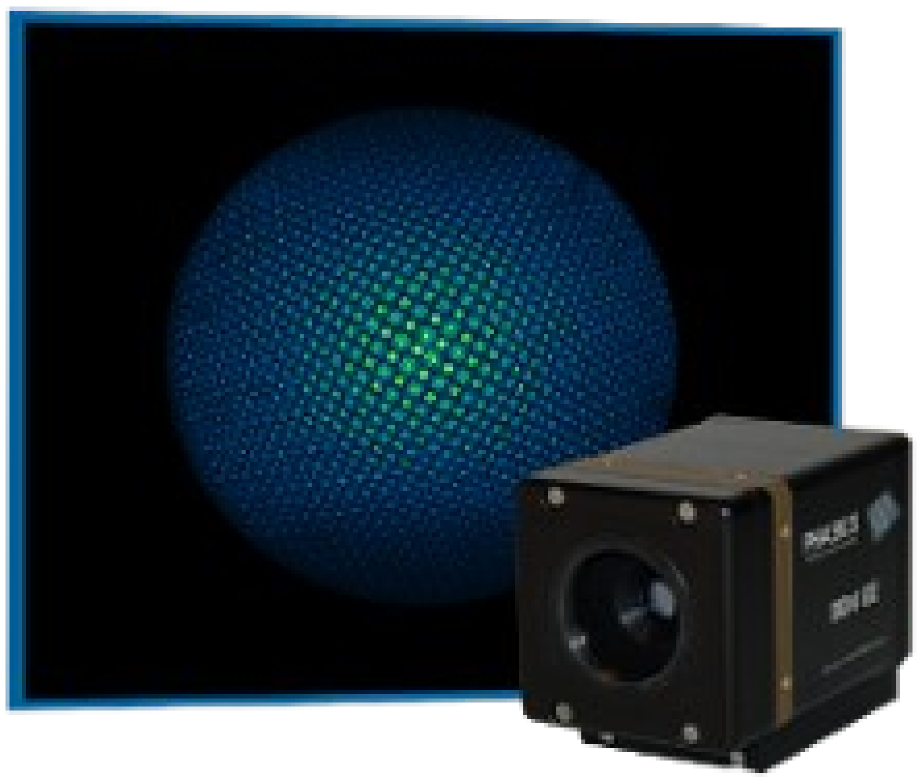
All reflective optics for beam transitions

Dynamic Focus Mirror installation: compressor completely rebuilt and ready for DFM

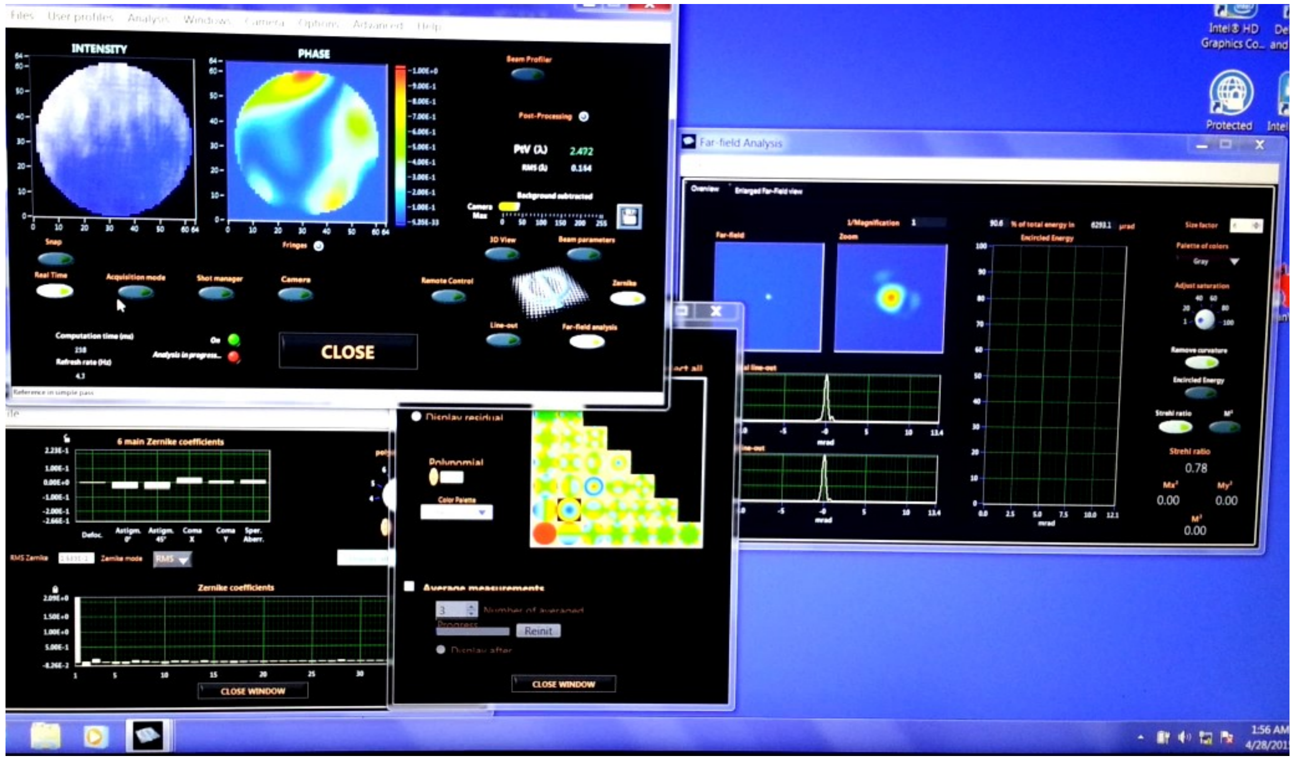


Wavefront optimization

- New lensless Off-Axis Parabola architecture
- Phasics SID-4 wavefront sensors (in TC and on diagnostic table for use when on target)
- corrects the laser wavefront before the compressor down to λ/4 error.

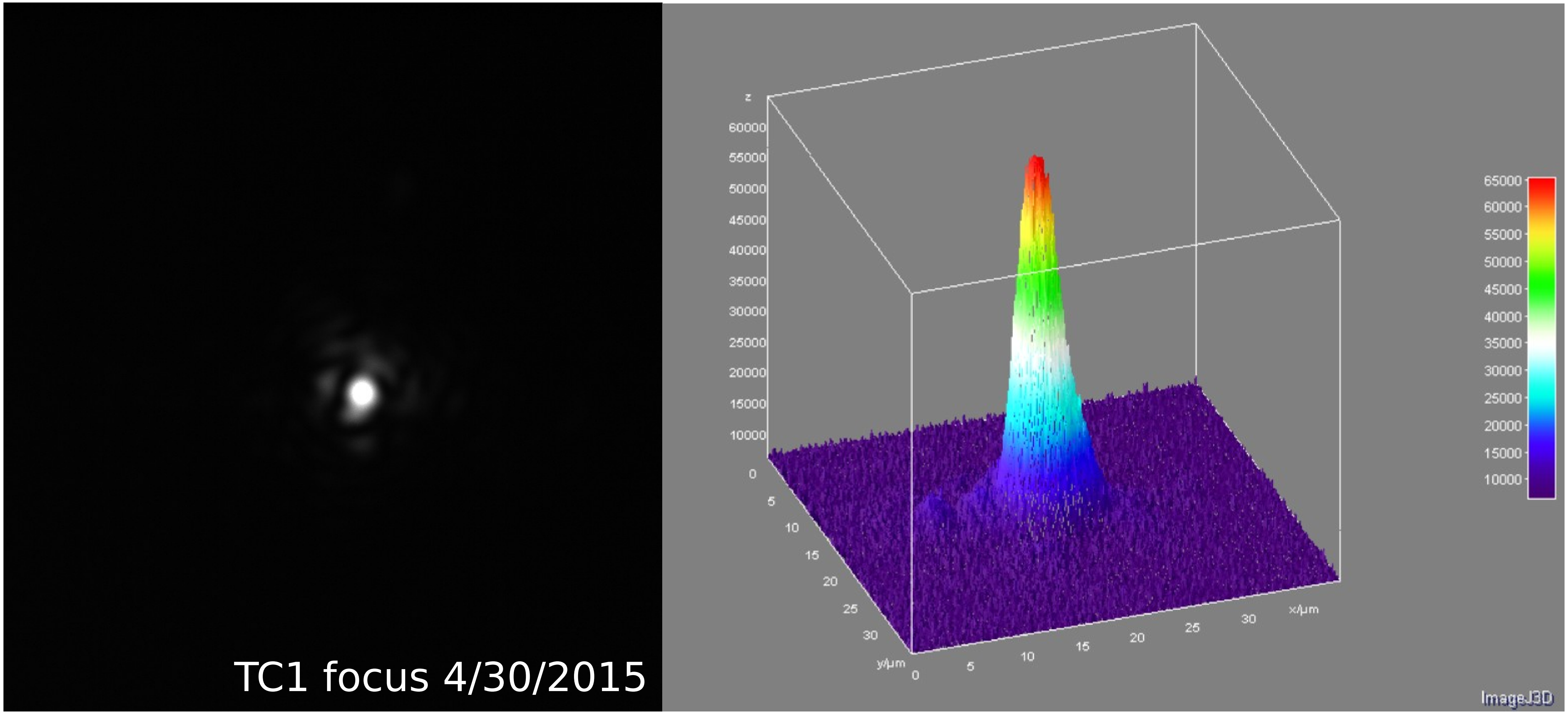


SID-4 Sensors



SID-4 program interface showing λ/4 residual error measured at compressor input

With DFM active-feedback loop : Strehl ratio > 0.8



Focal quality without DeFormable Mirror

The compressed OPCPA pulse focused to 3.9um FWHM with f/3 OAP.
The compressor and final focusing optics preserve beam quality.
OPA pulses have been compressed to 110 fs.

Pulse/focal properties

New and improved!

$$I(\theta) = I_0 \left(\frac{2J_1(kasin\theta)}{kasin\theta} \right)^2$$

flat top near field

d_{beam} = 23 cm

Airy transverse profile

$$I_{Peak} = \frac{P_0 A}{\lambda^2 f^2} = 1.8 \times 10^{23} W/cm^2$$

$$w_{foc}^{top-hat} = 2.44\lambda \frac{f}{d_{beam}} = 2.56\mu m$$

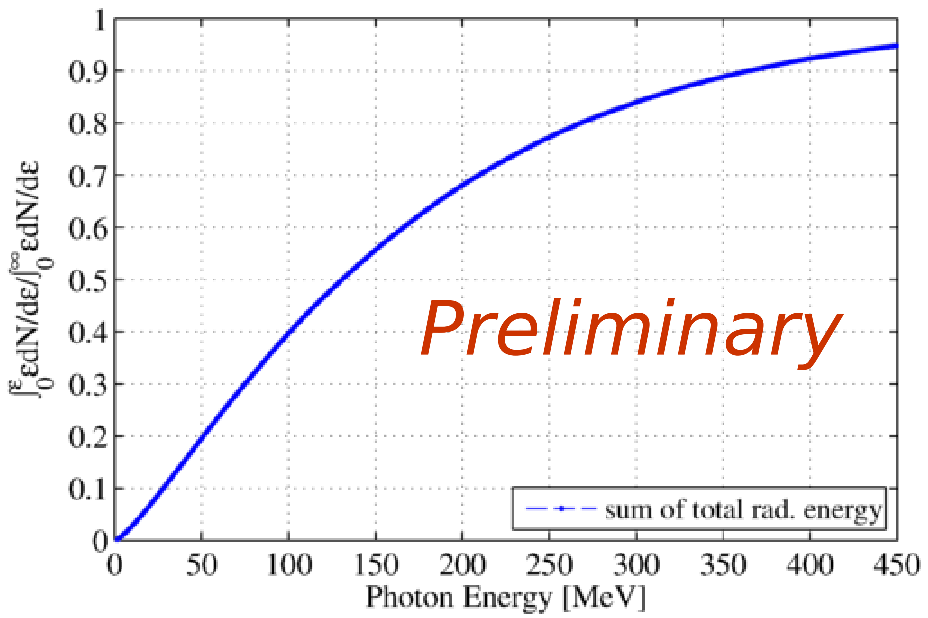
with f/1 final focusing optic:

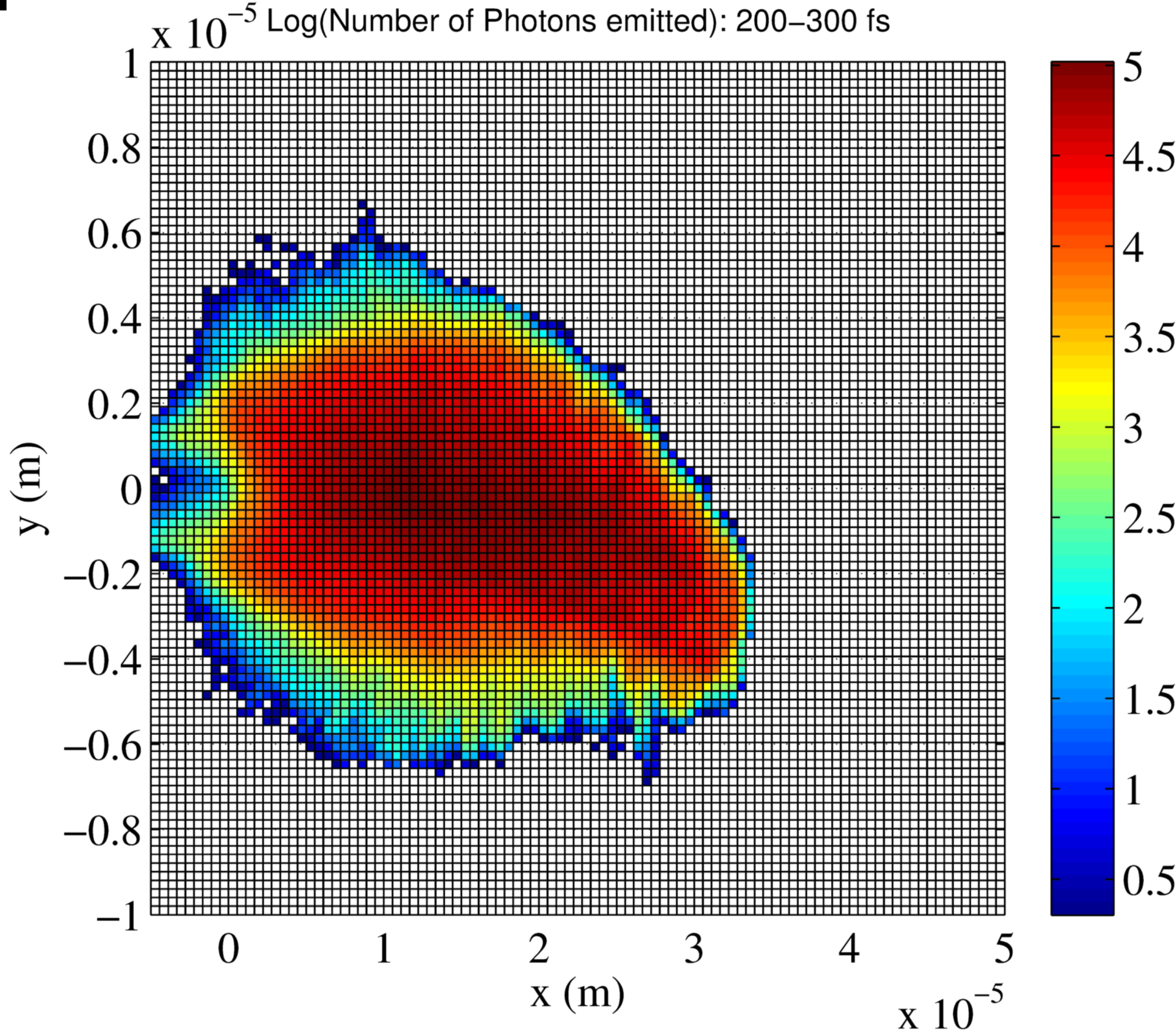
I(FWHM) = 1.6 x 10^{22} W/cm^2 (a_0=150)

I(Peak) = 1.8 x 10^{23} W/cm^2 (a_0=350)

Observables and diagnostics:

- Laser-matter interaction at >10^{22} W/cm^2 expected to generate high energy gamma photons
- simulations predict that the radiation pattern is not collimated but found in 10-15 degree spread from the laser axis
- Diagnostics should either cover a broad angular range or be employed at different angles with respect to the laser axis





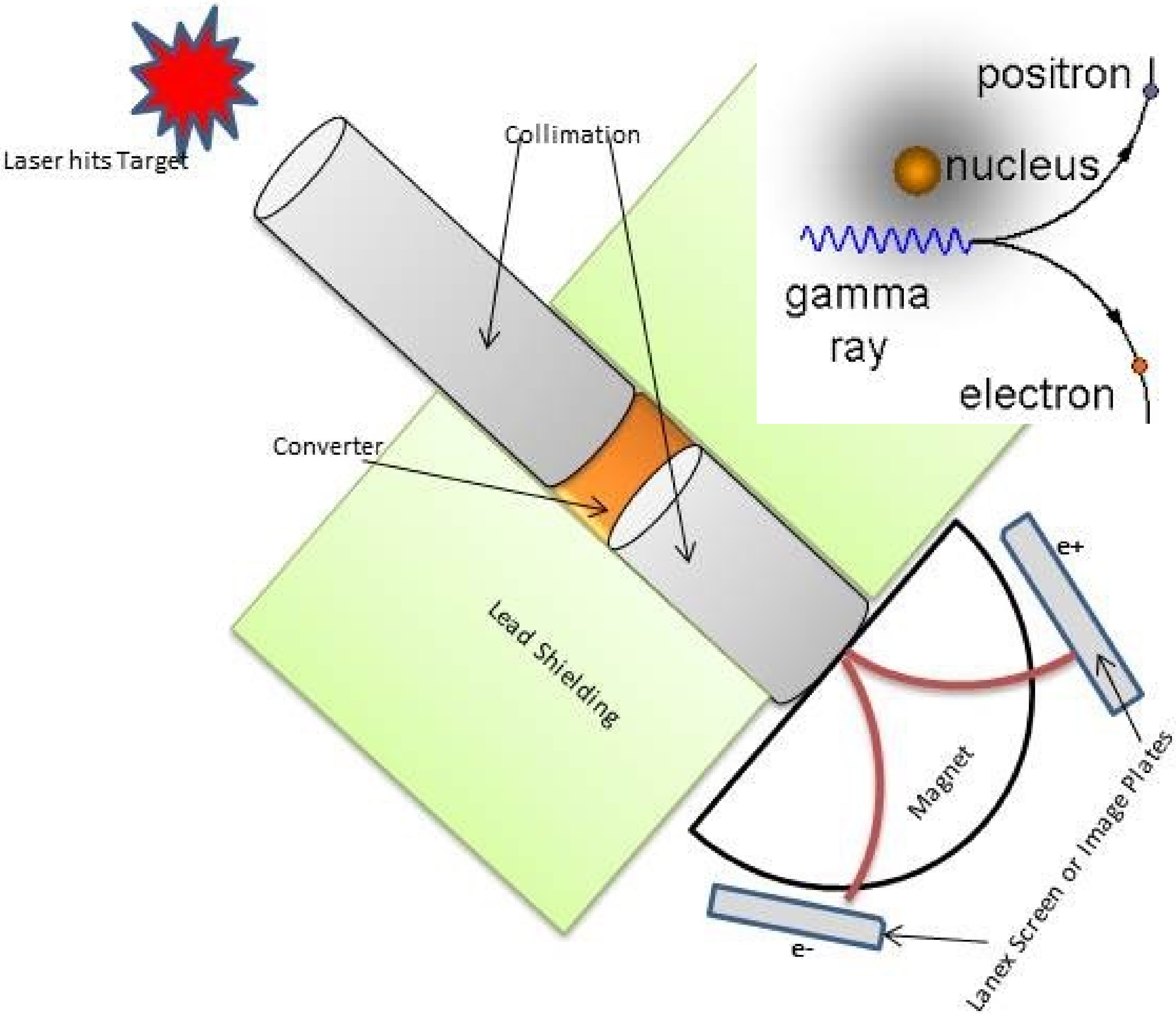
Epoch 2D PIC simulation by D. Stark & A. Arefiev

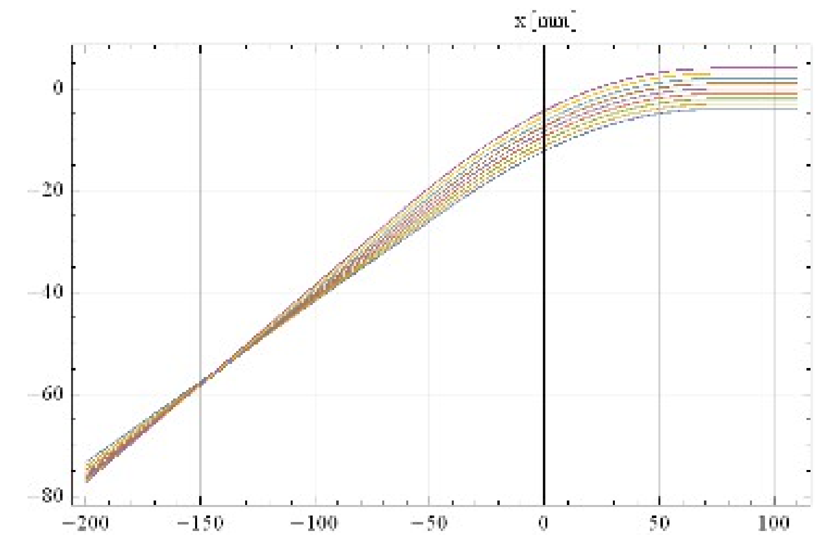
Target Chamber 1 Diagnostics

Diagnostic	*angular range*	*mobility*
electron spectrometer	***limited***	***very high***
ion/proton spectrometers	***1. Ion Wide Angle Spectrometer 2. Thomson parabolas (narrow)***	***high low at several fixed ports***
gamma spectrometers	***narrow***	***low at several fixed ports (depends on energy range)***

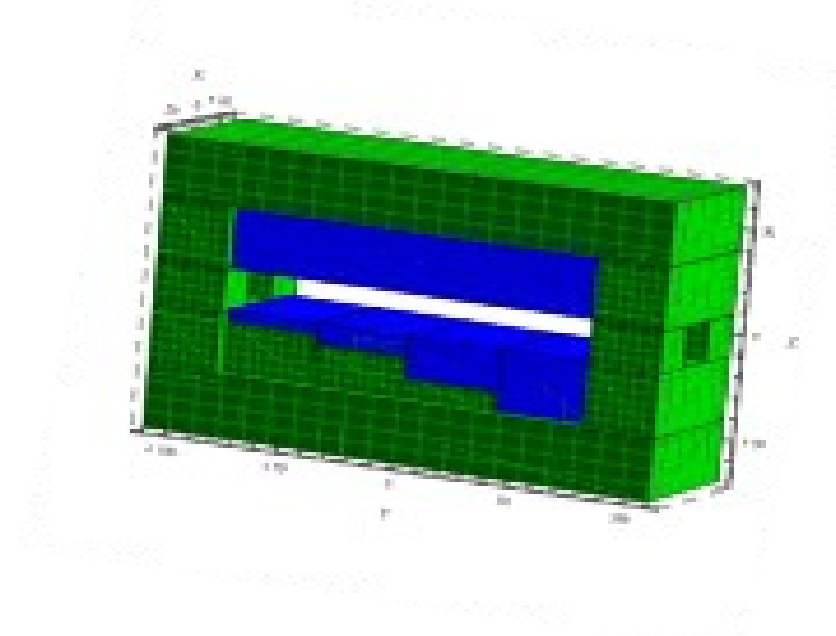
✔ On going theory and simulation work to determine best locations for diagnostics, particularly gamma spectrometers

Gamma to Electron Positron Magnetic Spectrometer





Preliminary designs



Develop tailored to TPW/TC1 experiments by G. Tiwari, grad student

Theory + Simulations support

- Effective field theory for laser-electron interactions (LL, forthcoming)
  - Allows more precise calculations of observables and accounting for experimental cuts
  - Can be combined with classical PIC simulations for full quantitative predictions
- Updated PSC code ported to *SuperMUC* (Munich) and ***Stampede*** (UTAustin)
- First EPOCH simulations executed on *Stampede* (Arefiev+Stark, forthcoming)
  - reveal challenges in simulations due to intensity dependent resolution criterion

Summary – Texas Petawatt Status

- Texas Petawatt Laser Upgrade is well underway.
  - Installation and Testing of adaptive optics has been scheduled by TPW to commence in September
- New high energy gamma diagnostic design well underway (10-200 MeV)
  - collaboration with LANL (M. Espy, J. Kim) for Compton spectrometer (0.5-25 MeV) and Gas Cherenkov detector (NIF, absolute numbers >15 MeV)
  - collaboration with Peking University: high sensitivity bubble chamber
- First experiments on electron dynamics in under dense plasma fields successfully executed, analysis ongoing.
- First Experiments at ultrahigh intensity with AO and F/3 has been scheduled for 3rd quarter 2015.
- First Experiments at ultrahigh intensity with F/1 has been scheduled for 1st quarter 2016.

Operation outline

1. Oscillator produces nJ, <100 fs pulses at ~70 MHz repetition
2. Split:

    Amplify 10% up to 20 mJ, 10 ps using YbF crystal at 2ω

    Send 90% through Dazzler to remove phase errors

3. Stretch to 2 ns, matching to 4ns pump, amplified in BBaO and LiBaO (OPA) crystals

    → 0.5 J 2ns 2.5 Hz

4. Select single pulse by shutter
5. 2 pass glass rod amplifier → 1 J
6. 4 pass rod amplifier → 10 J
7. Focusing optics and pinhole clean up profile

    → add adaptive mirror here, corrects thermal variations in pump glass

8. Main amplifier → 120 J 150 fs

    P, Si doped Yag glass, two materials with different peak frequencies to increase amplified bandwidth → improves compression capability

9. Compressor → 2^{nd} adaptive mirror and gratings
10. Switch yard after compressor:

    TC1 : f/1 parabola for High intensity/high energy experiments

    TC2 : f/45 spherical mirror for wakefield experiments

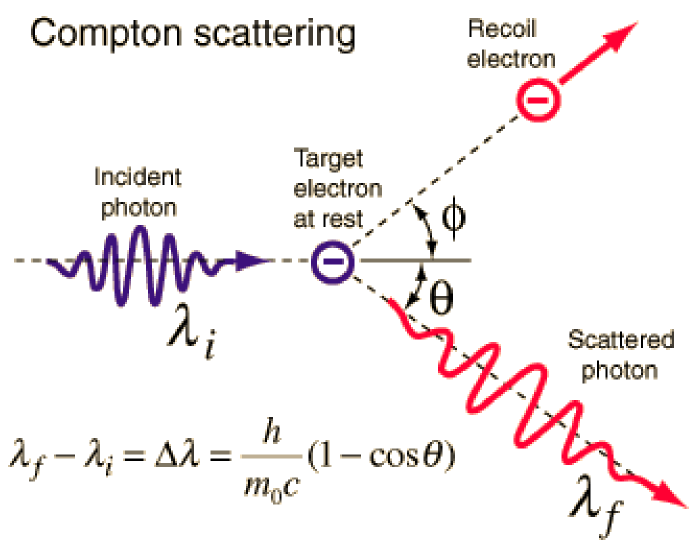
Gamma to Electron Positron Magnetic Spectrometer

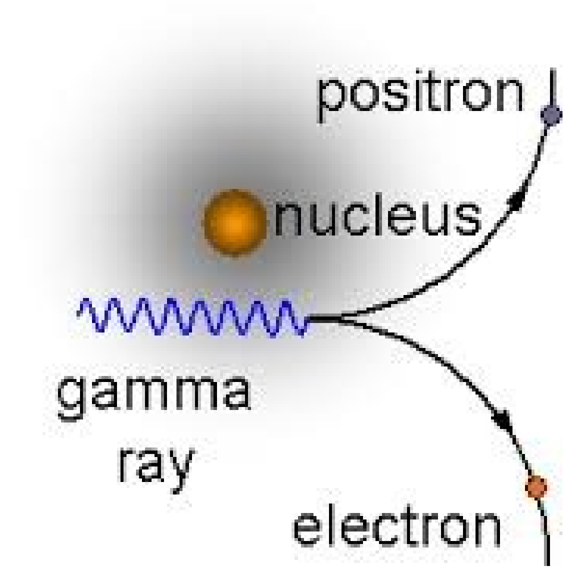
Simulations predict high energy photons: E >1 MeV

Dominant energy-loss mechanisms in a medium:

1. Compton Scattering dominates up to 10 or 20 MeV (depending upon the converter)

2. Pair-Production remains the active process of scattering up to 1 for Titanium as a converter.

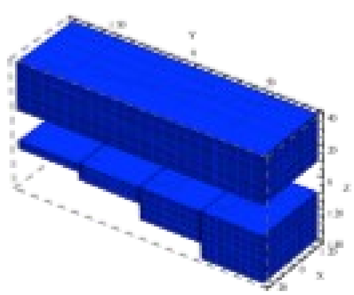




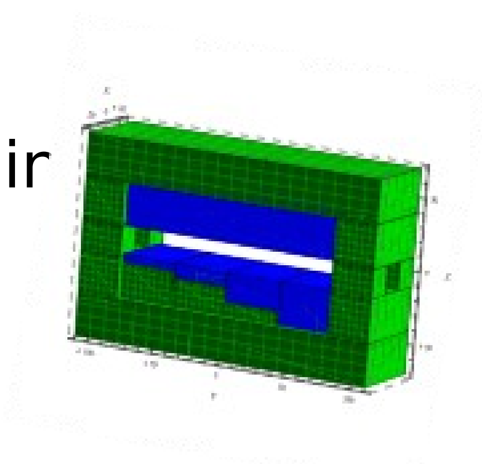
Tailoring a GEPMS to TPW: Resolution and Efficiency balance

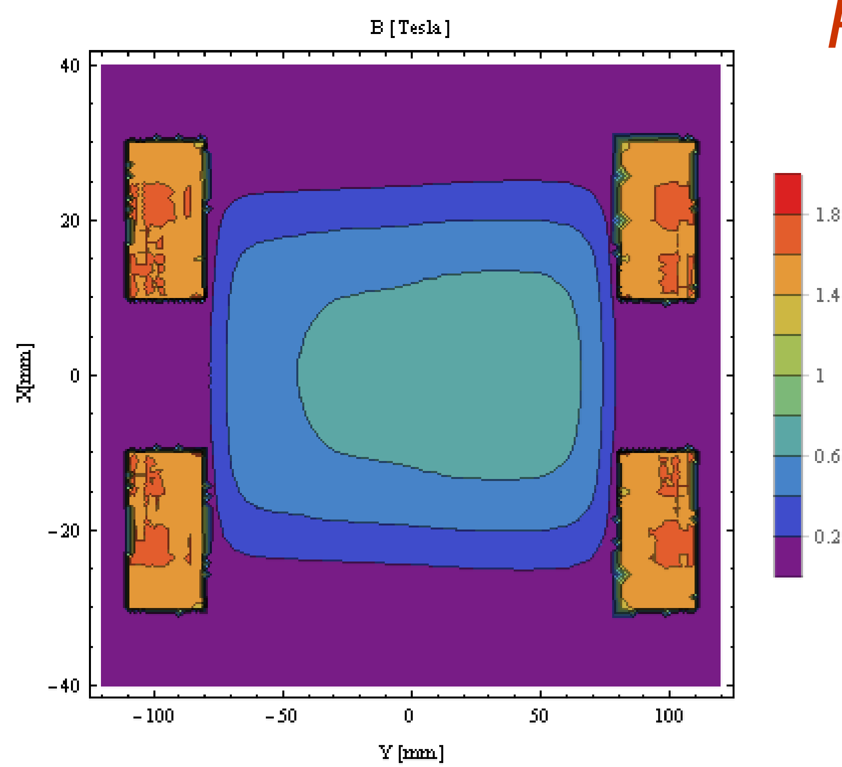
- Converter Thickness and Energy Resolution
- Expected Signal Calculation with Titanium Converter
- Magnetic Rigidity and Magnetic Field Configurations
- RADIA and Chase calculations for an Efficient GEPMS

magnet



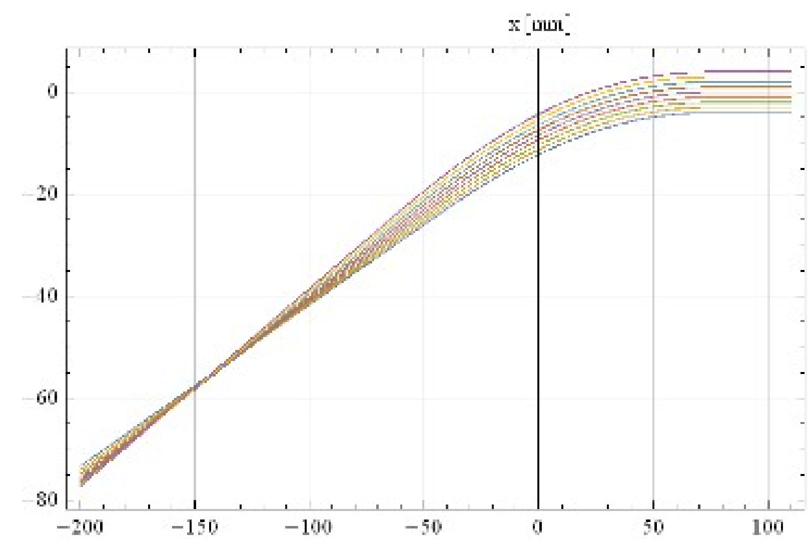
magnet in yoke





field topology

Preliminary designs



Focusing of a 70 MeV electrons