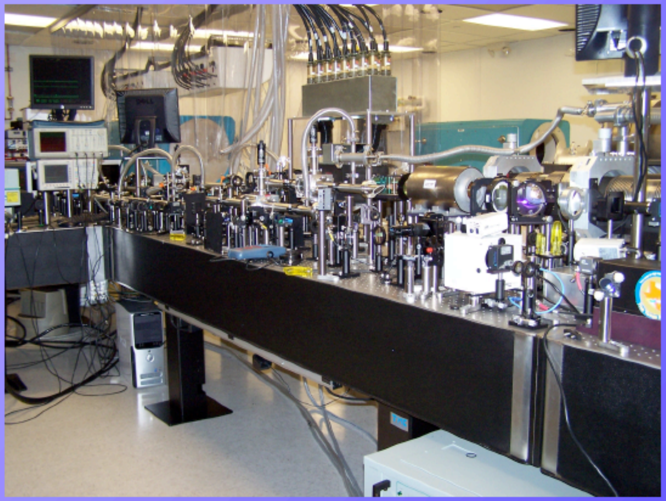
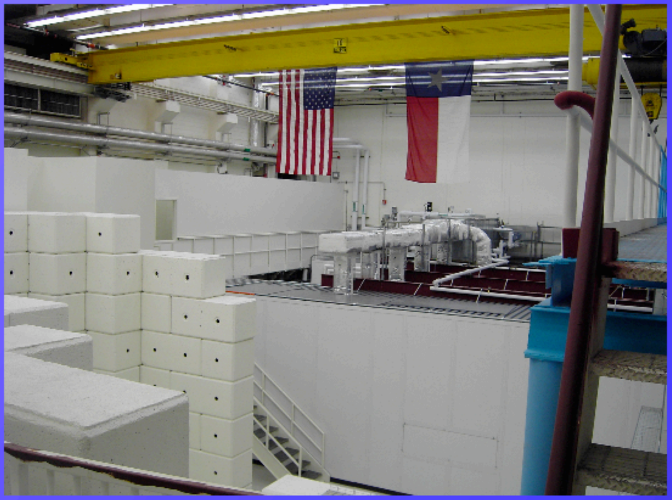
Overview of the Texas Petawatt Laser and Research in the Texas Center for High Intensity Laser Science





Presented by:

Aaron Bernstein

Texas Center for High Intensity Laser Science
Department of Physics
University of Texas at Austin

We have established a center at the University of Texas devoted to research in high intensity laser science

The Texas Center for High Intensity Laser Science (TCHILS) was established in July 2003 as an NNSA SSAA Center of Excellence under a cooperative agreement (DE-FC52-03NA00156). It was renewed for a further 5 years in 2008.

Principal missions of the Texas Center (TCHILS):

- **Conduct research in laser driven HED science and shocked materials science and attract new students into these areas**
- **Train US citizen graduate students in these two areas**
- **Train students in how to plan and execute experiments on large scale HED facilities**
- **Develop novel and "high risk" HED diagnostics that could ultimately be fielded on the large HED facilities (NIF, Z and Omega)**
- **Collaborate on many experiments with National Laboratory scientists to remain coupled to the labs and to expose students to the activities of the labs**
- **Partner with some of the DP labs on technical projects and some facilities development**
- **Leveraging large efforts in high intensity laser physics**
  - Ditmire, Downer and Keto groups
    → operating numerous high peak power lasers including two multi-terawatt lasers:
  - THOR laser: 0.7 J in 35 fs @ 10 Hz -- to be upgraded to 1 PW by early 2010
  - GHOST laser: 2.5 J in 110 fs (high contrast; 1 shot/30 sec)
  - 50 TW laser: 2.0 J in 40 fs @ 10 Hz

  ~25 students working on projects related to high power lasers and applications

TCHILS includes ~ 40 faculty, scientists, post-docs, students and staff

Center Faculty:

Roger Bengtson
Todd Ditmire
Mike Downer
John Keto
Michael Marder (CNLD)
Eric Taleff (Mech Eng)
Linn VanWoerkom (OSU)
Rick Freeman (OSU)

Center Senior Scientists:

Aaron Bernstein
Erhard Gaul
Gilliss Dyer

Collaborating Scientists

Jens Osterholz (Dusseldorf)
Alex Arefiev
Stephan Bless (IAT)
Boris Breizman
Charles Chiu
Richard Fitzpatrick
Wendell Horton
Gennady Shvets

Graduate students:

Woosuk Bang
Alexei Belolipetski
Joel Blakeney
Byong-Ick Cho
Irina Churina
Alan Dalton
Sam Feldman
Benjamin Erk
Intai Kim
Matt McCormick
Despina Milathianaki
Robert Morgan
Brendan Murphy
Juergen Schmidt
Johannes Rougk
Paul Scherek
Kristina Serrato

Post Docs:

Kay Hoffman
Hernan Quevedo

Collaborating TCHILS Alums

Aaron Edens (now at Sandia)
Matt Lane (now at Sandia)

Petawatt Laser Staff

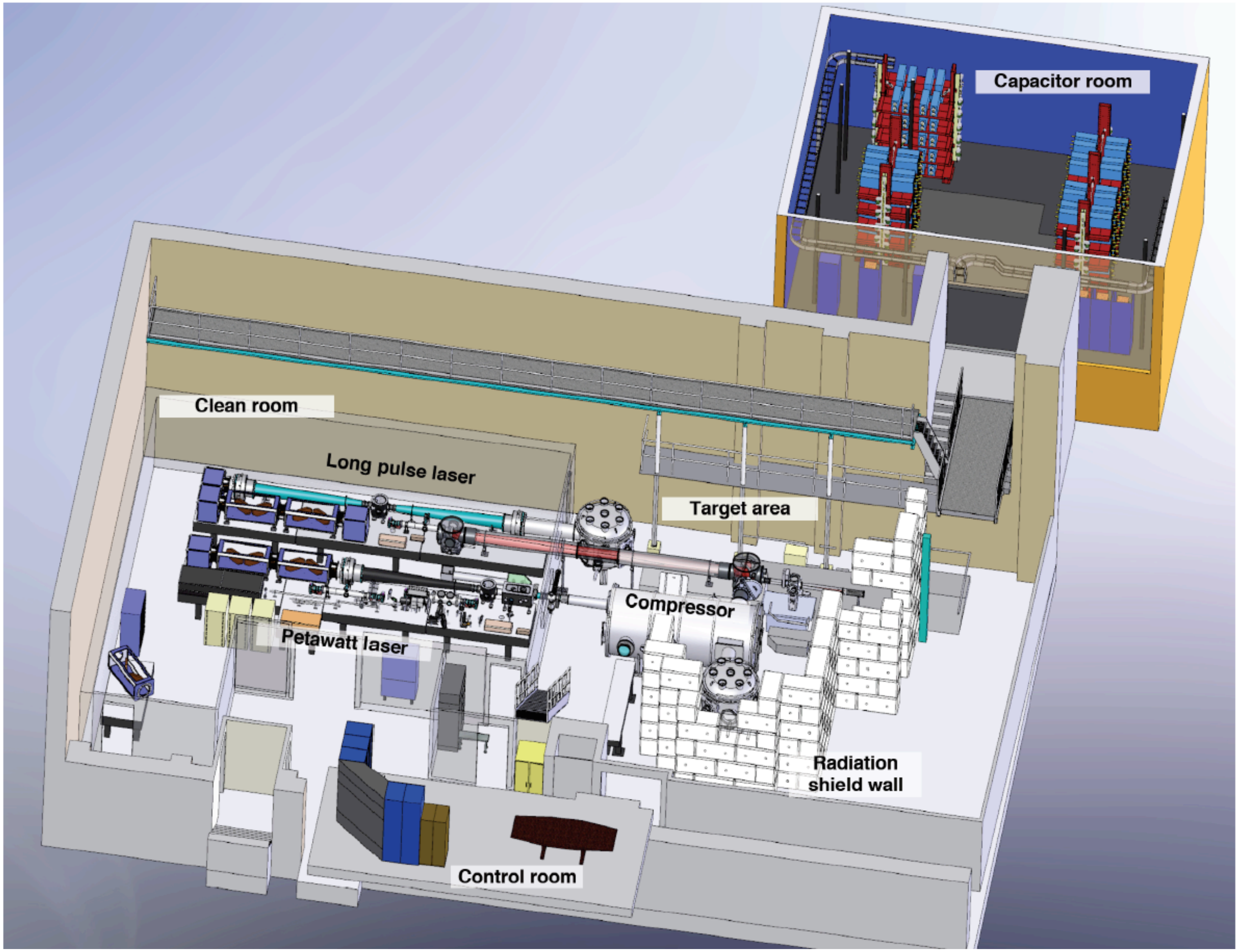
Erhard Gaul
Mikael Martinez
Ramiro Escamilla
Ted Borger
Doug Hammond
Srdjan Marijanovic
Marty Ringuette

Administrative Support Staff

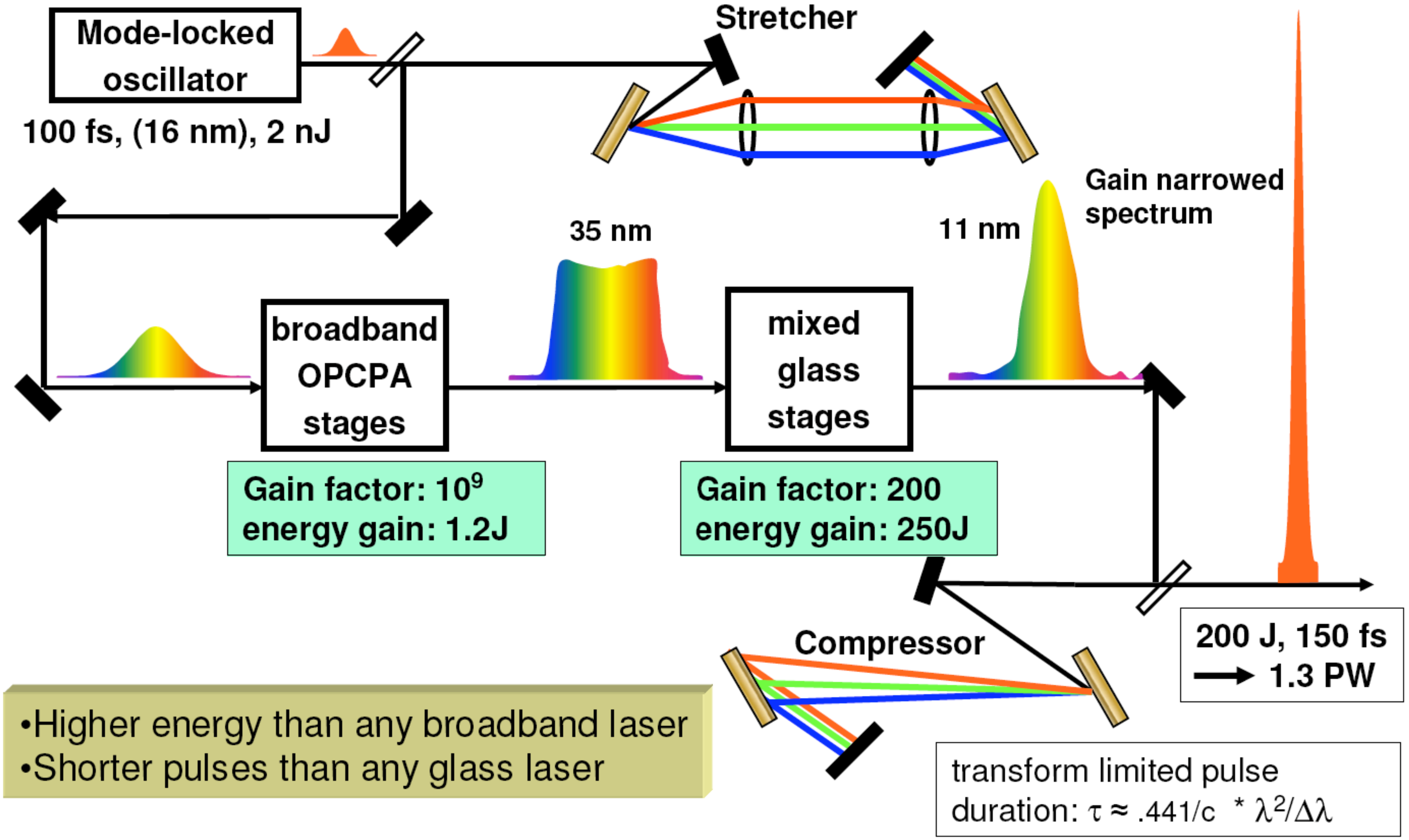
Maria Aguirre
Emily Hooks
Caryn Cluiss

We have successfully demonstrated PW operation of a hybrid laser chain

Layout of the Texas Petawatt Facility in the Robert Lee Moore Basement



The Texas Petawatt maintains broad bandwidth with a combination of OPCPA and mixed Nd:glass



Mode-locked oscillator

100 fs, (16 nm), 2 nJ

Stretcher

35 nm

11 nm

Gain narrowed spectrum

broadband OPCPA stages

Gain factor: 10^9
energy gain: 1.2J

mixed glass stages

Gain factor: 200
energy gain: 250J

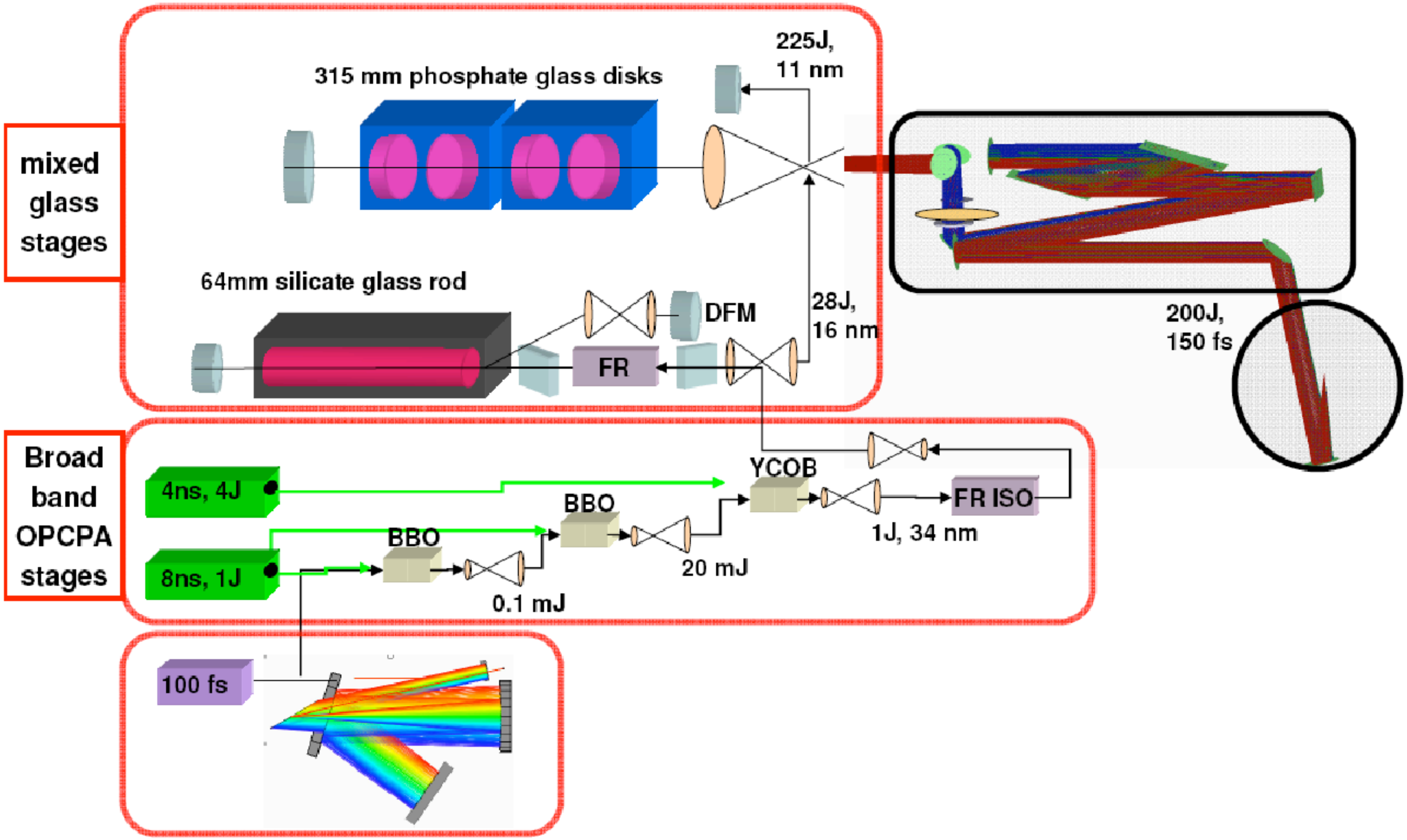
Compressor

200 J, 150 fs
→ 1.3 PW

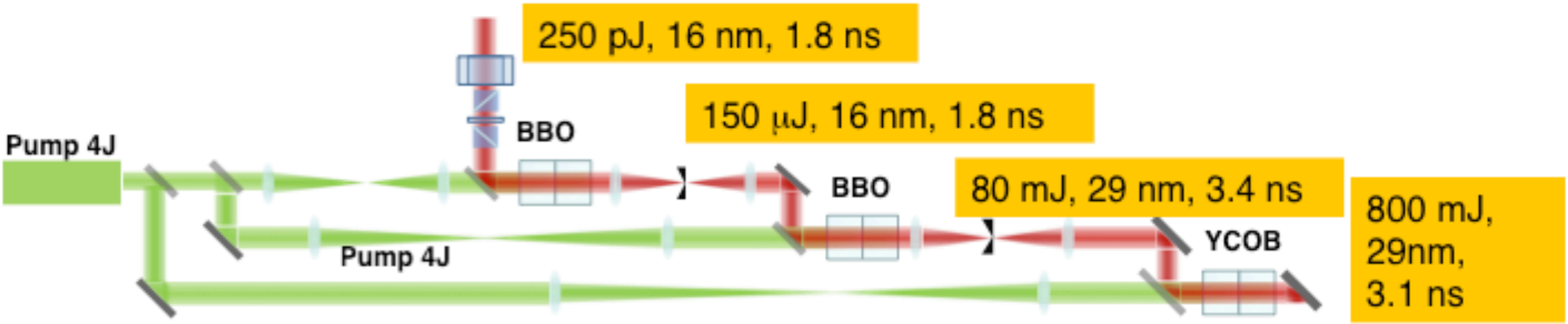
transform limited pulse duration: $\tau \approx .441/c * \lambda^2/\Delta\lambda$

- Higher energy than any broadband laser
- Shorter pulses than any glass laser

The Texas Petawatt design is based on a 3-stage OPCPA amp and a mixed glass chain



The OPCPA section provides 10^{10} gain, yielding seed pulses with energy near 1 J and bandwidth of ~30 nm

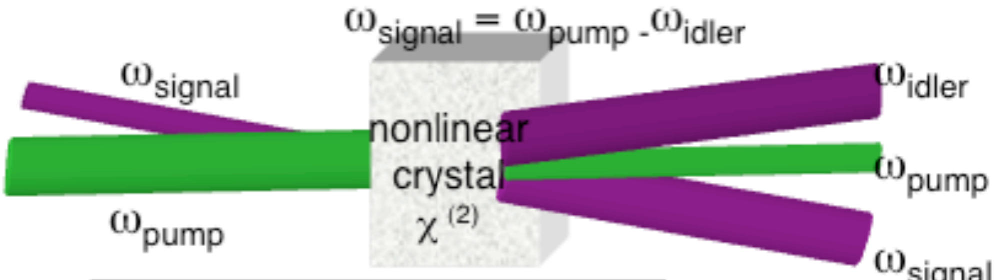


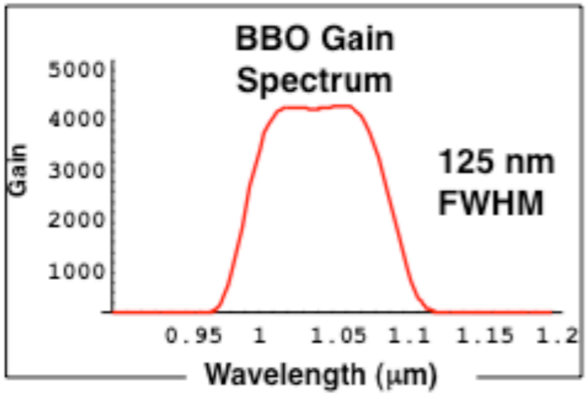
250 pJ, 16 nm, 1.8 ns

150 µJ, 16 nm, 1.8 ns

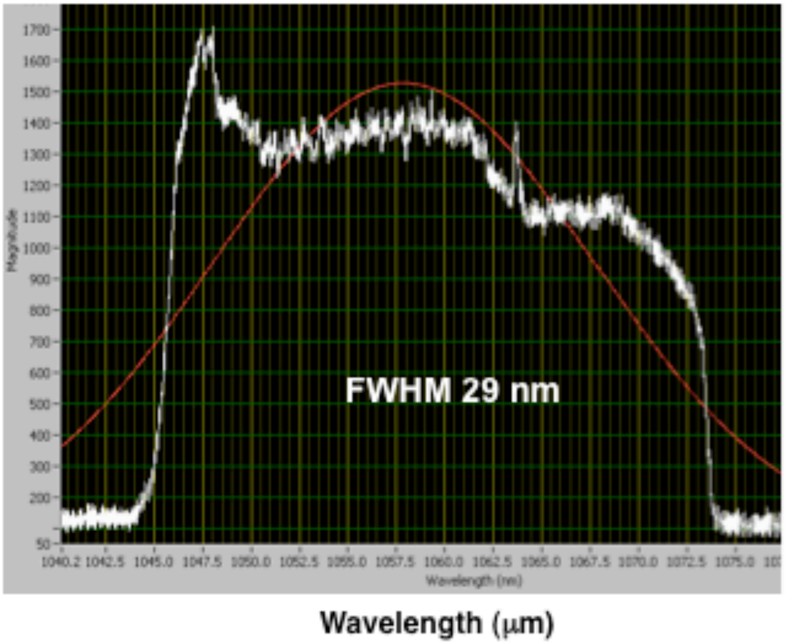
80 mJ, 29 nm, 3.4 ns

800 mJ, 29nm, 3.1 ns





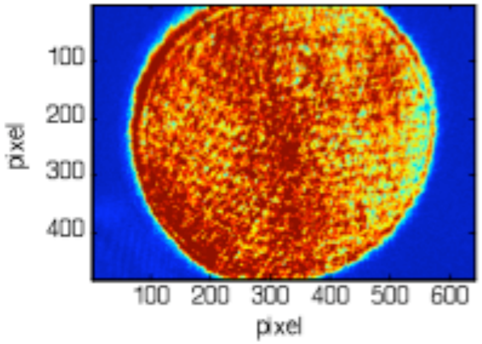
125 nm FWHM



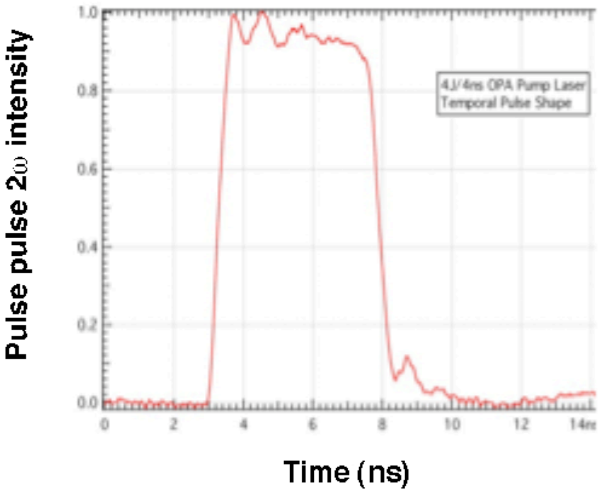
FWHM 29 nm

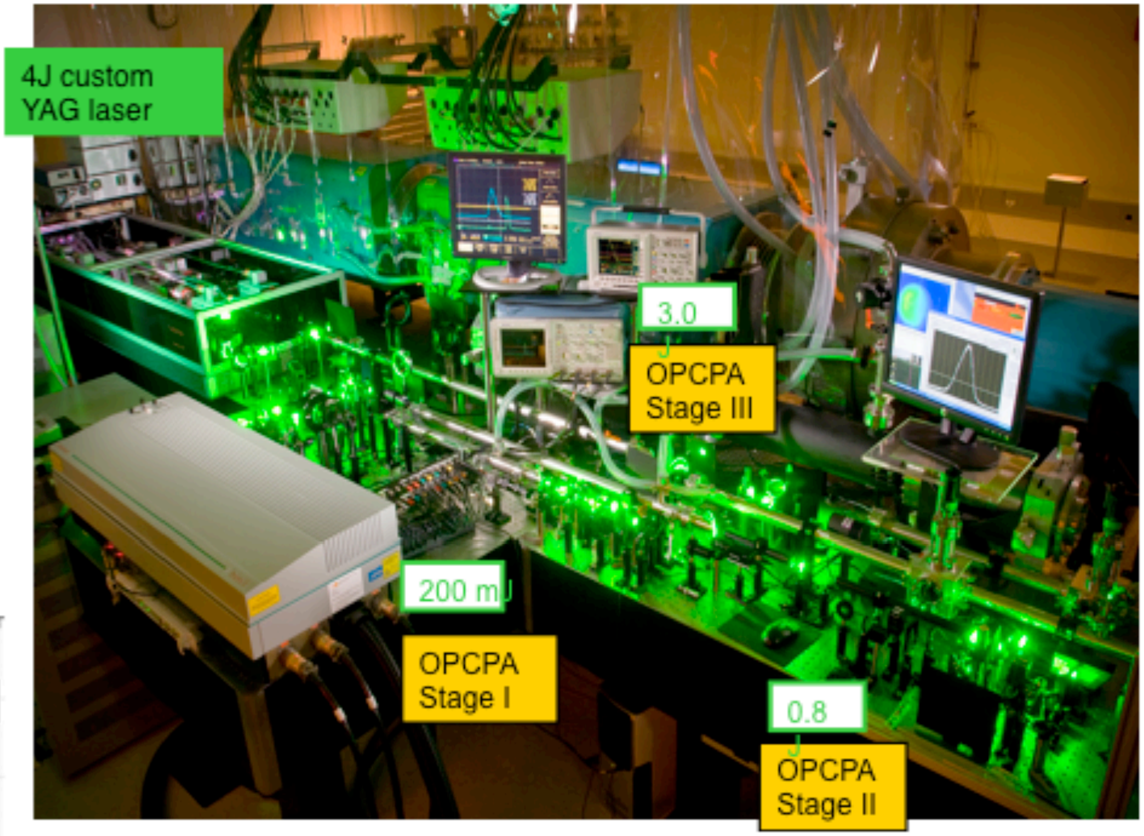
A key to high performance OPCPA operation is pulse laser pulses well shaped in time and space

Nearfield image



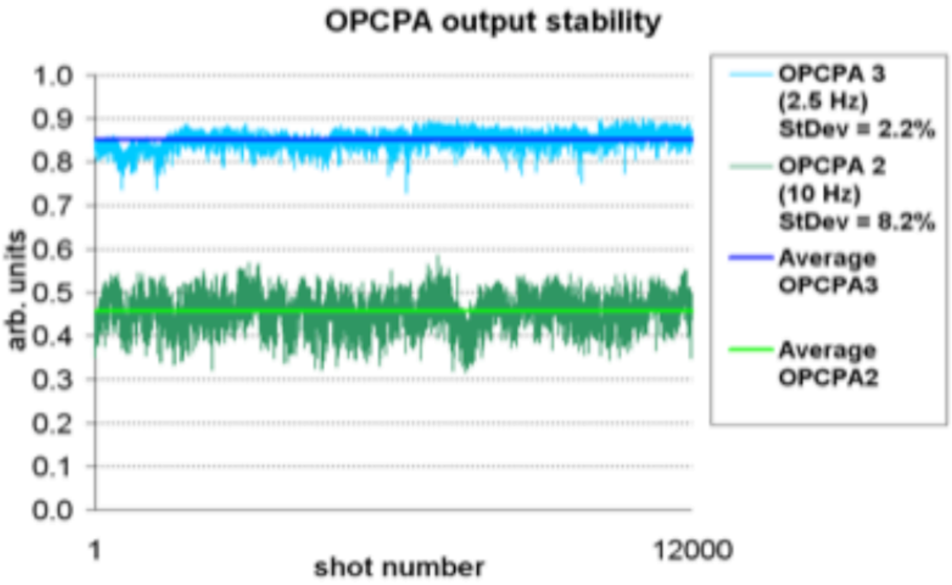
τ = 4.1ns timing <100 ps

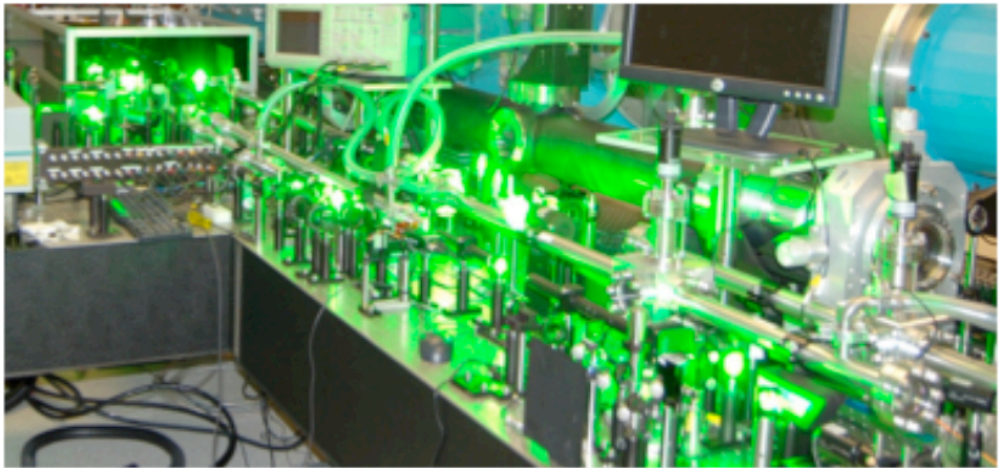




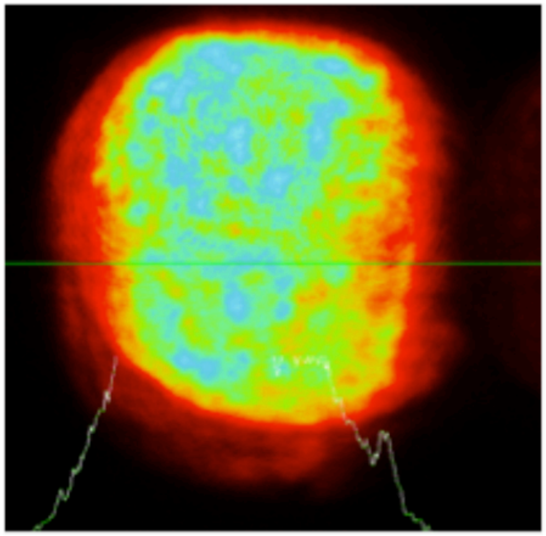
- Temporal profile of pump laser can be adjusted to control the OPA output spectrum.
- Tophat profile of pump laser shapes the output of the OPA .

The OPCPA front end exhibits excellent stability and beam quality

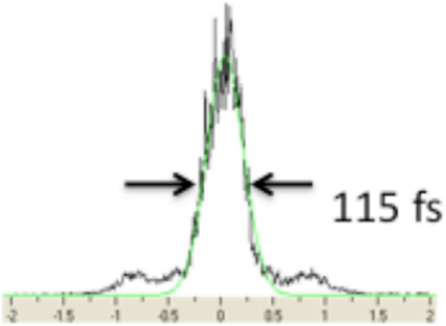

OPCPA output stability



Nearfield stage III

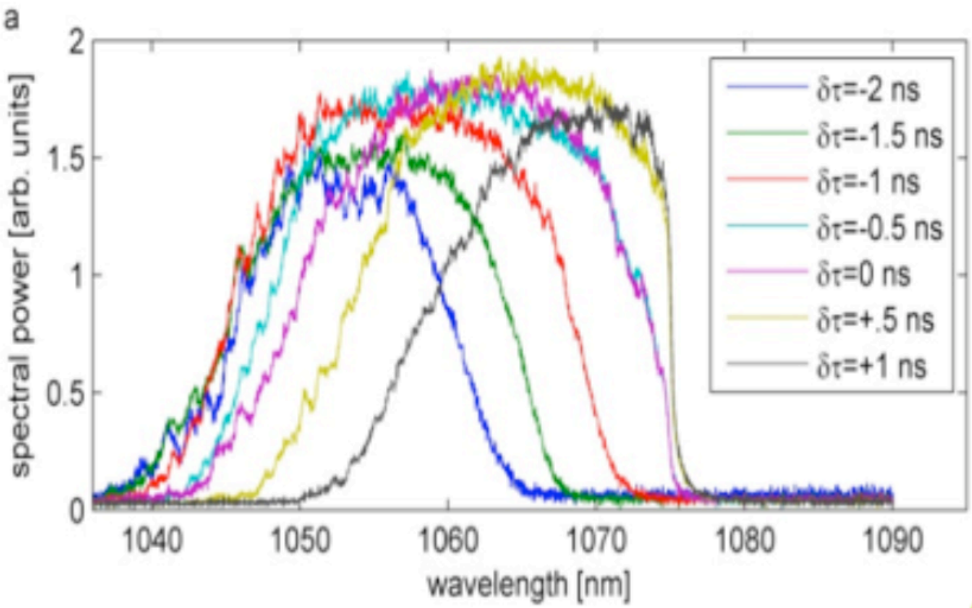


Compression of OPCPA output in large compressor

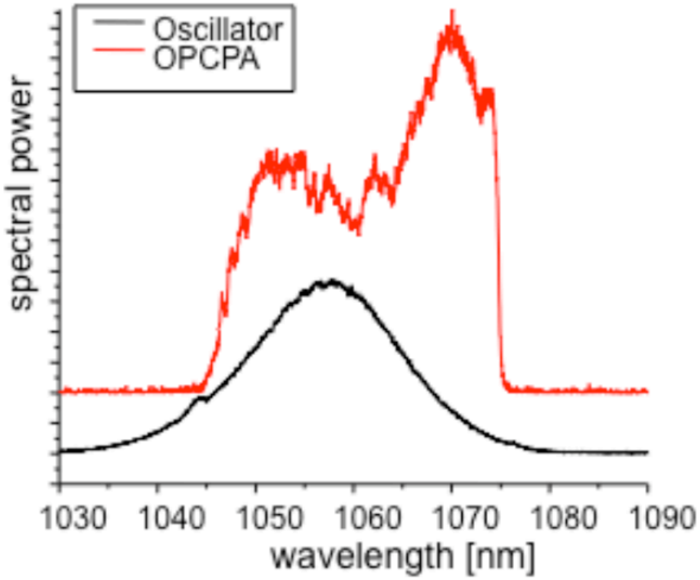


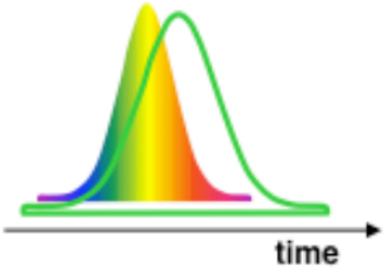
Spectral shaping in the OPCPA stage enables very broadband seeding of the Nd:glass amplifiers

Spectral saturation in stage II and shifting due temporal overlap with the pump pulse.



Spectral preshaping or the pulse due temporal control of the 4 J pump pulse.

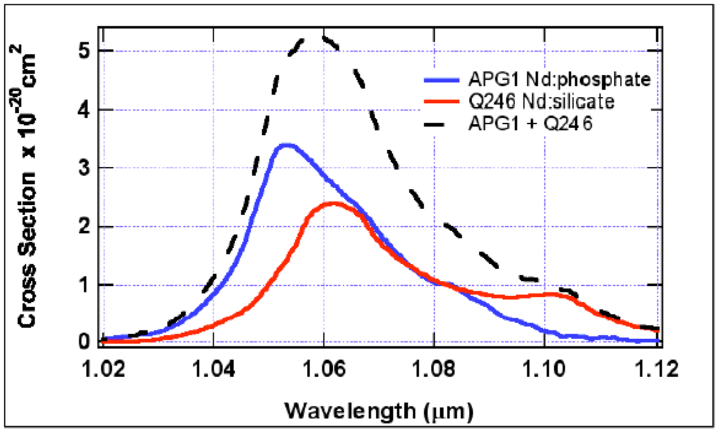




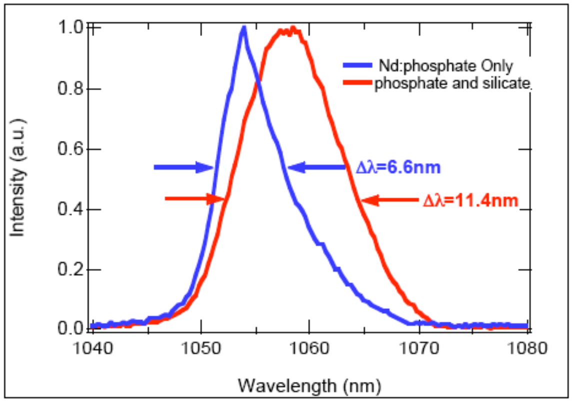
We have chosen a route to 1 PW by mixing glasses and aiming for ~ 100 fs pulses

Mixed glasses combine to yield a broader amplification spectrum.

Combined Gain Cross-Sections of Nd:silicate and Nd:phosphate glasses



Mixed Glass Amplified Spectrum vs. Nd:phosphate Amplified Spectrum

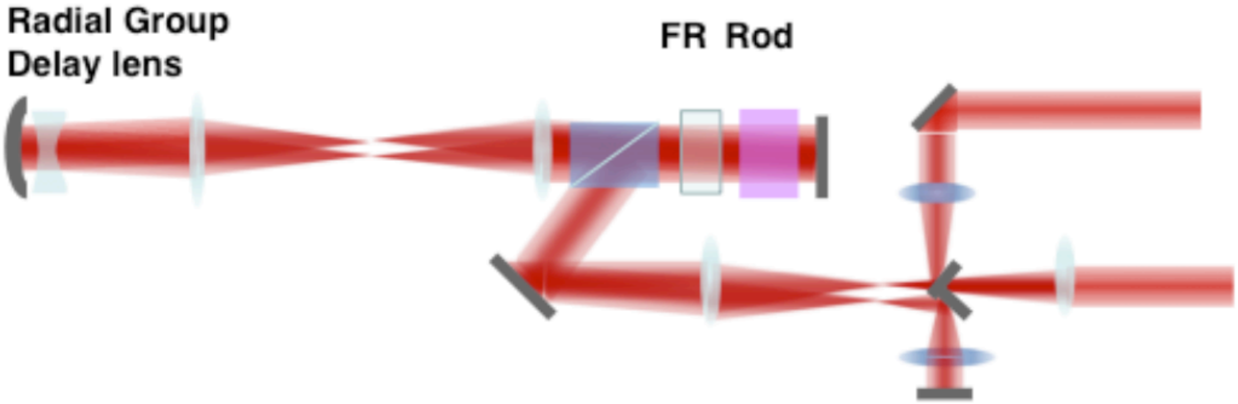


•Seed Bandwidth	10.2 nm FWHM
•Seed Wavelength	1057 nm

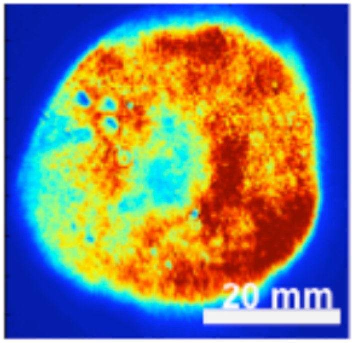
Nd:glass amplification

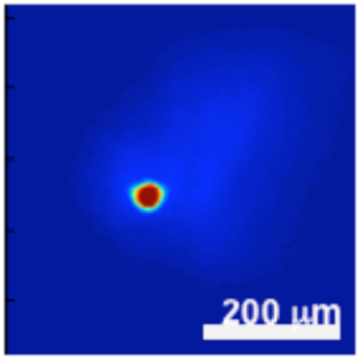
- **Limit glass amplification to 2 orders of magnitude to minimize spectral gain narrowing.**
- **What is the optimum gain ratio between the 2 glasses?**
- **At what wavelength should the amplifier be seeded?**

An 8-pass 64 mm silicate Nd:glass rod amplifier increases pulse energy to 20 J



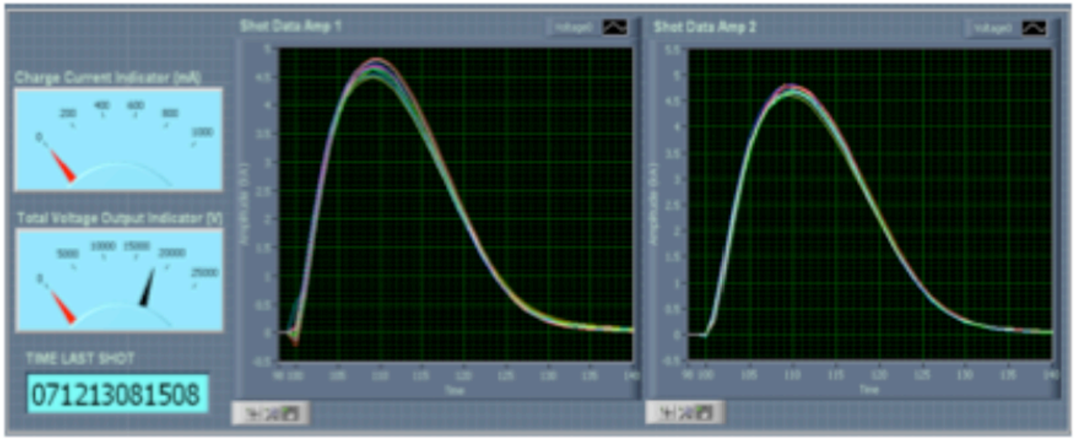
- Up to 27 J achieved,
- 15-18 J goal for compression and low (<.6) B-integral
- 8% energy stability





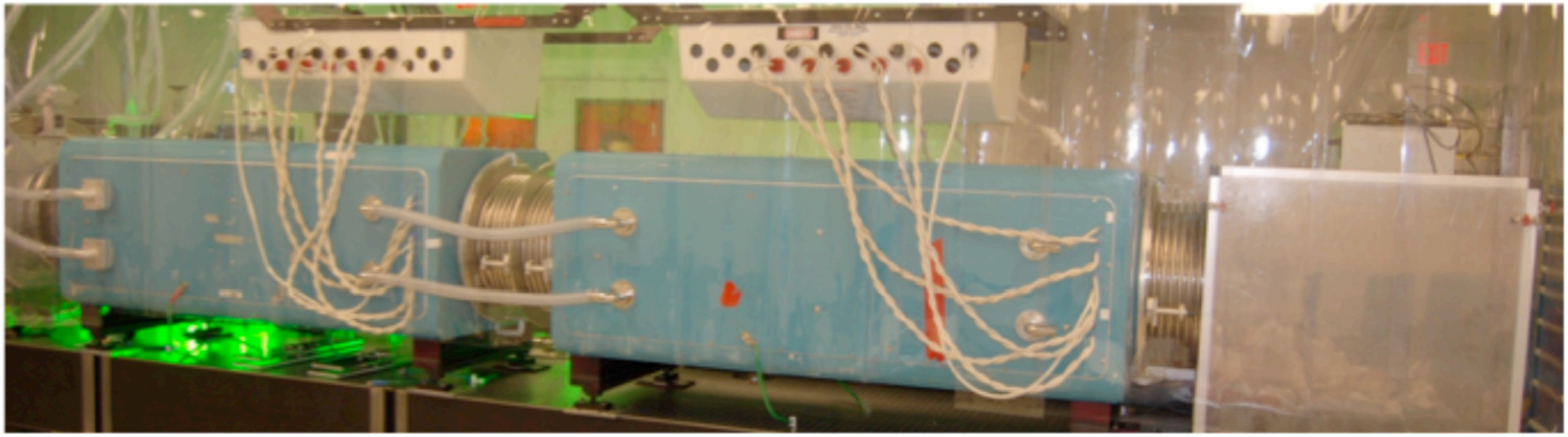
Two NOVA 31 cm disk amplifiers employing phosphate Nd:glass provide final amplification to >200 J

- up to 248 J achieved, with 80% charge voltage
- Energy limited by gratings, not by gain.
- Labview control for system shots and diagnostic

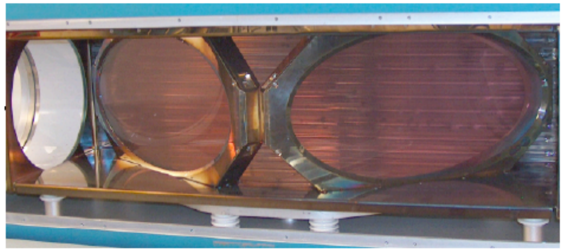


TIME LAST SHOT: 071213081508

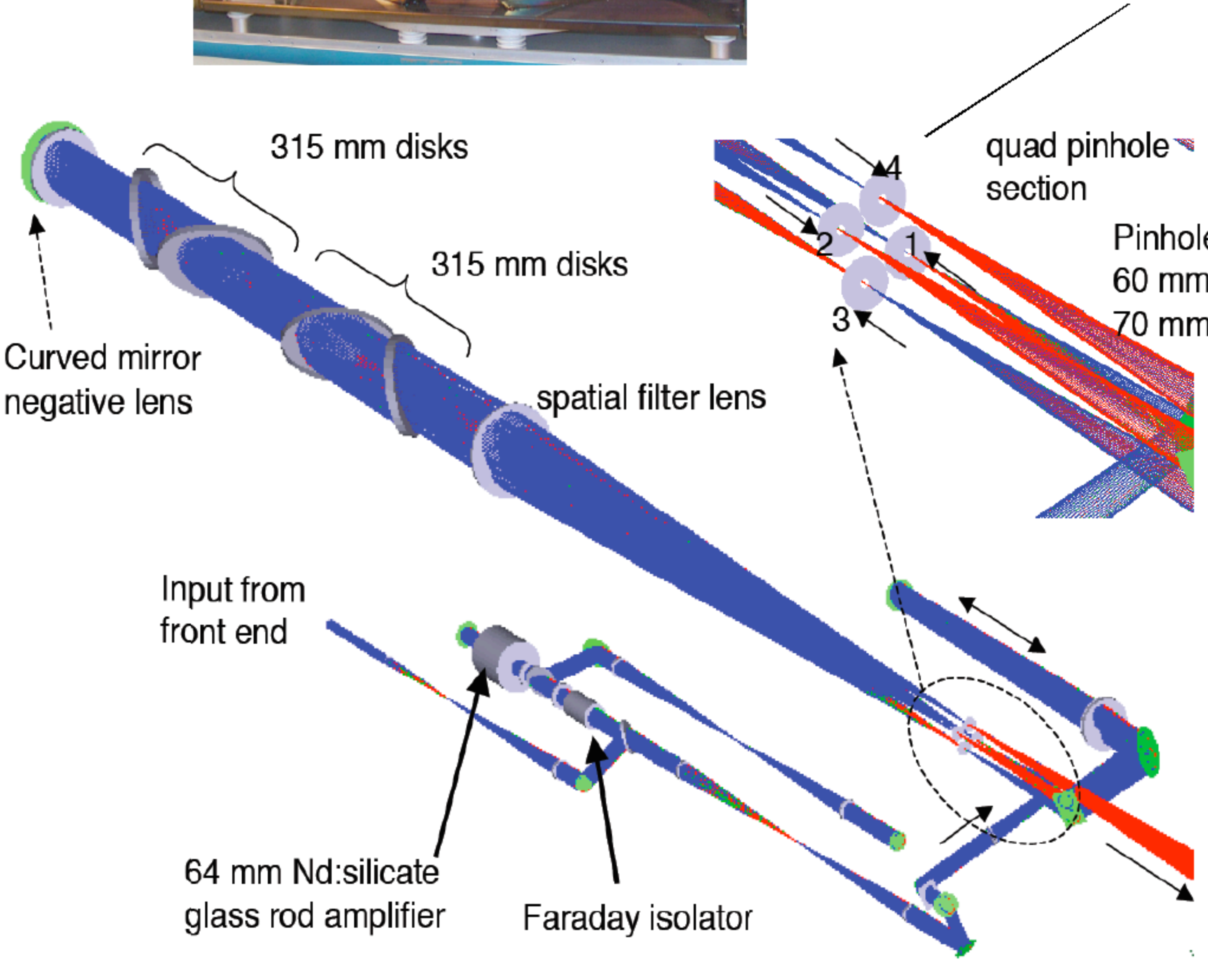
315 mm Phosphate Nd:glass disk



The final stage of the TPW beam line is a four-pass of two 315 mm disk amplifier heads



Pinhole multi-passing scheme



quad pinhole section

Pinhole spacing:
60 mm horizontally
70 mm vertically

315 mm disks

315 mm disks

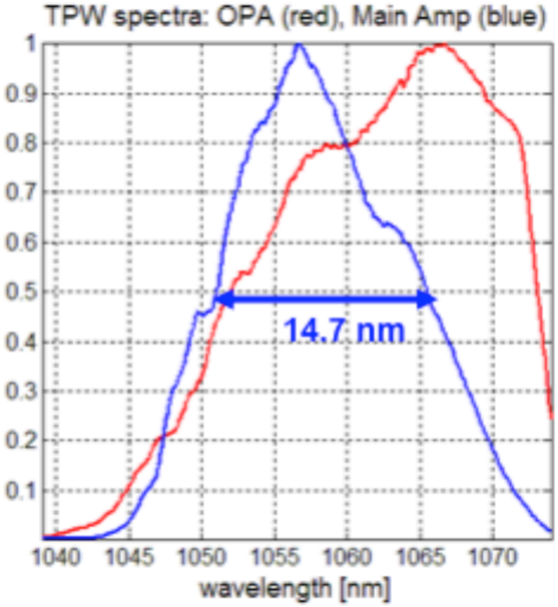
Curved mirror negative lens

spatial filter lens

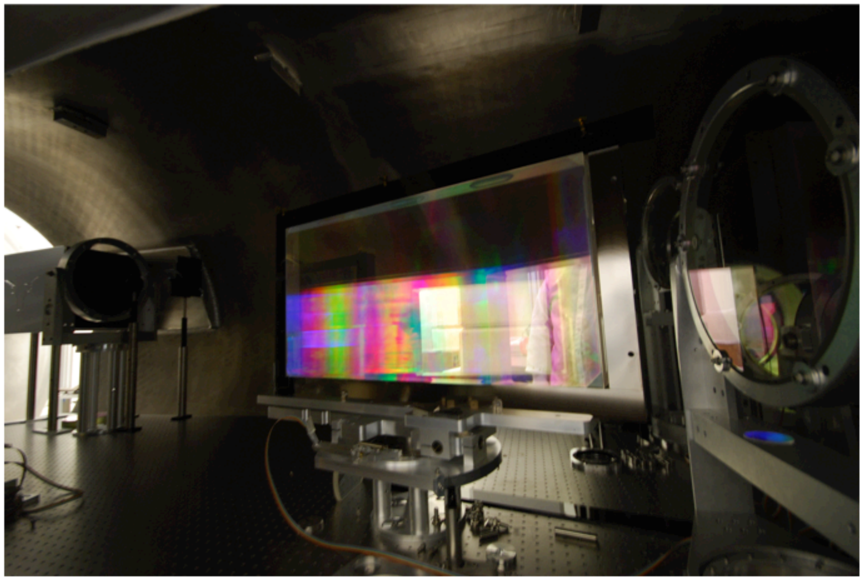
Input from front end

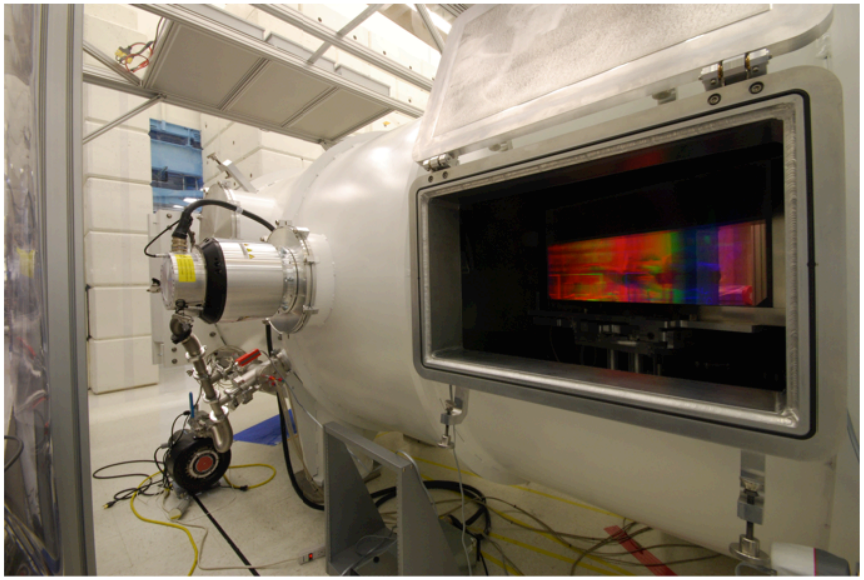
64 mm Nd:silicate glass rod amplifier

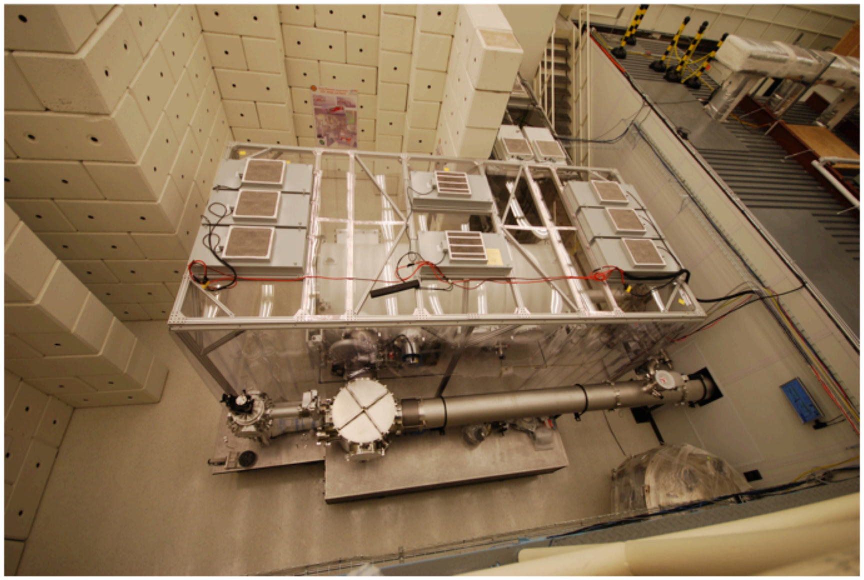
Faraday isolator



The pulse compressor utilizes large scale dielectric gratings housed in a vacuum tank

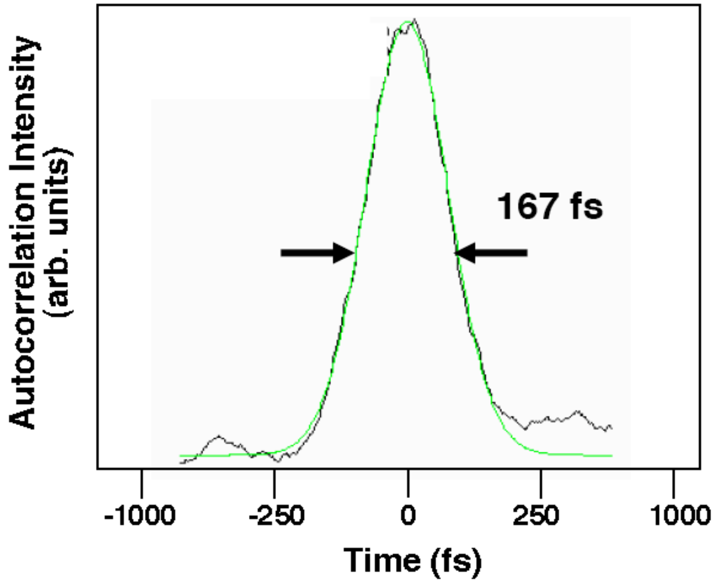




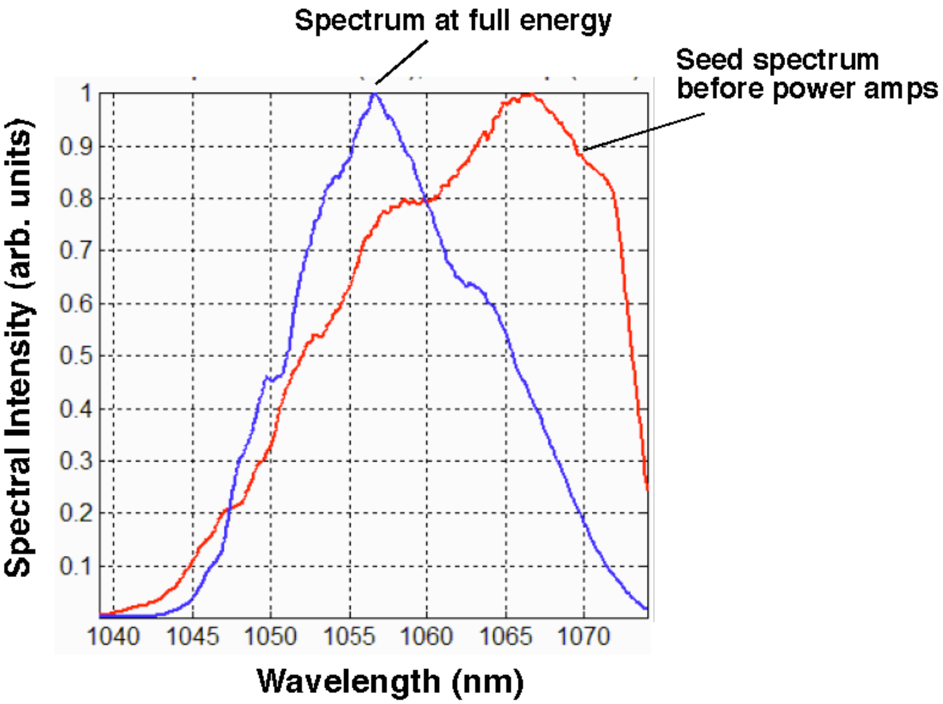


We have compressed nearly 200 J from the final amplifiers

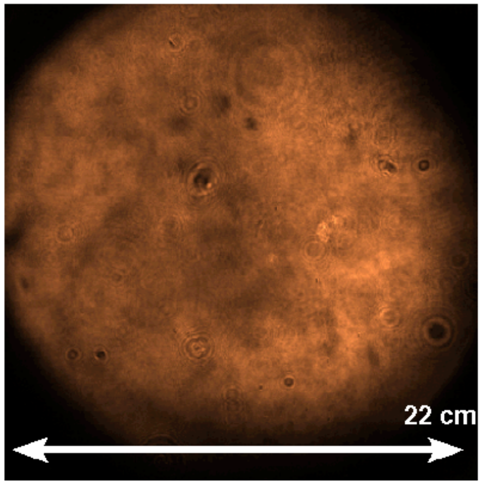
Pulse duration measurement at full power



Pulse spectrum



Beam profile measurement at full power



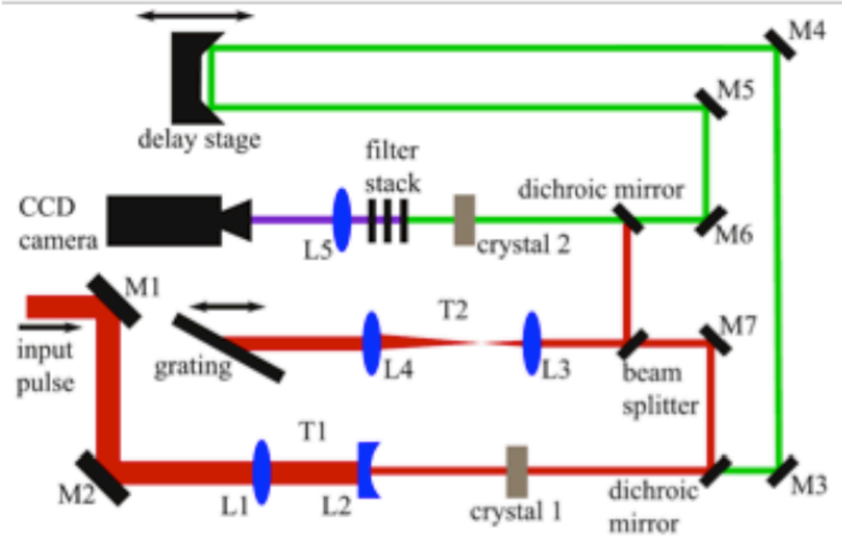
Current power level achieved:

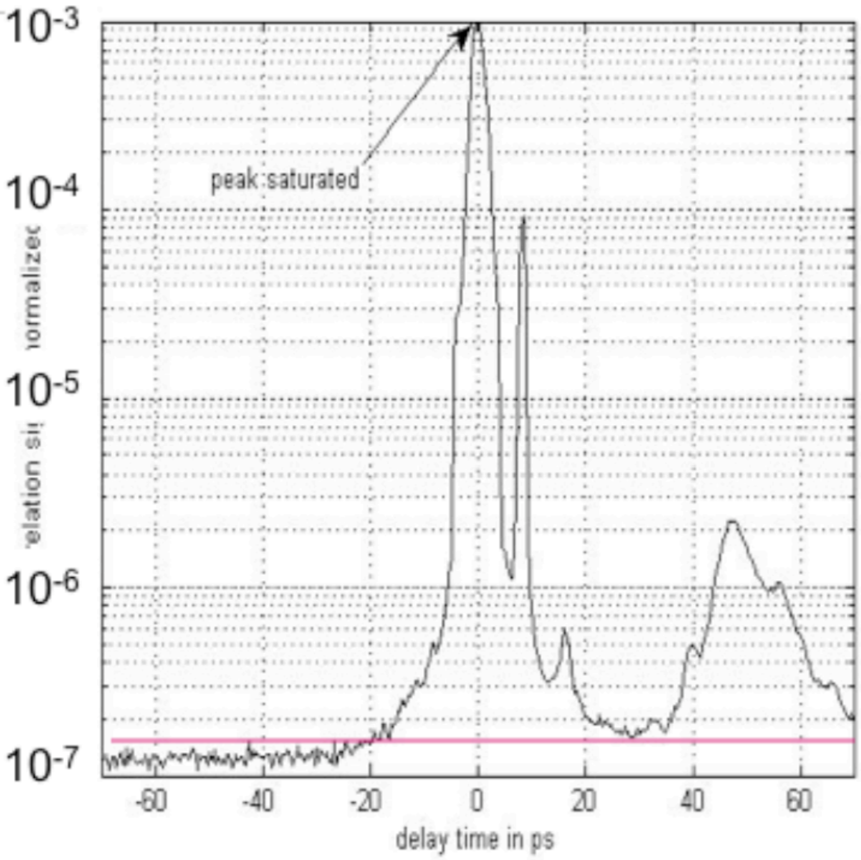
190 J compressed to 170 fs

= 1.1 PW

Prepulse characterization of high energy PW lasers must be performed single shot to ensure correct results

Single shot third order autocorrelator





- **data taken on OPCPA - mixed glass laser (GHOST: 50mJ OPA, 3 J Glass) at UT by J. Schmidt *et al***
- **Contrast better than 10^7 at 20ps**
- **Parasitic Fluorescence level is typically lower on the TPW despite higher gain**

We have assessed the intensity and focusing required for a number of planned experiments on the TPW

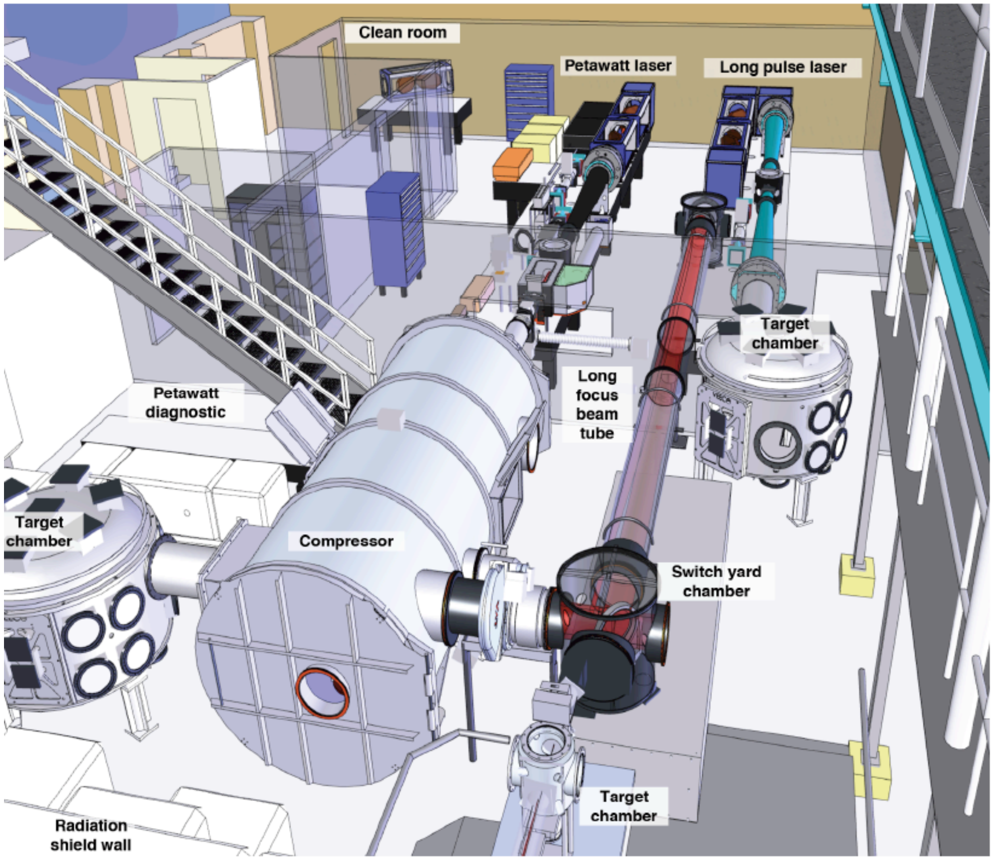
Pulse duration: 150 fs; Energy: 200 J; B-integral <1

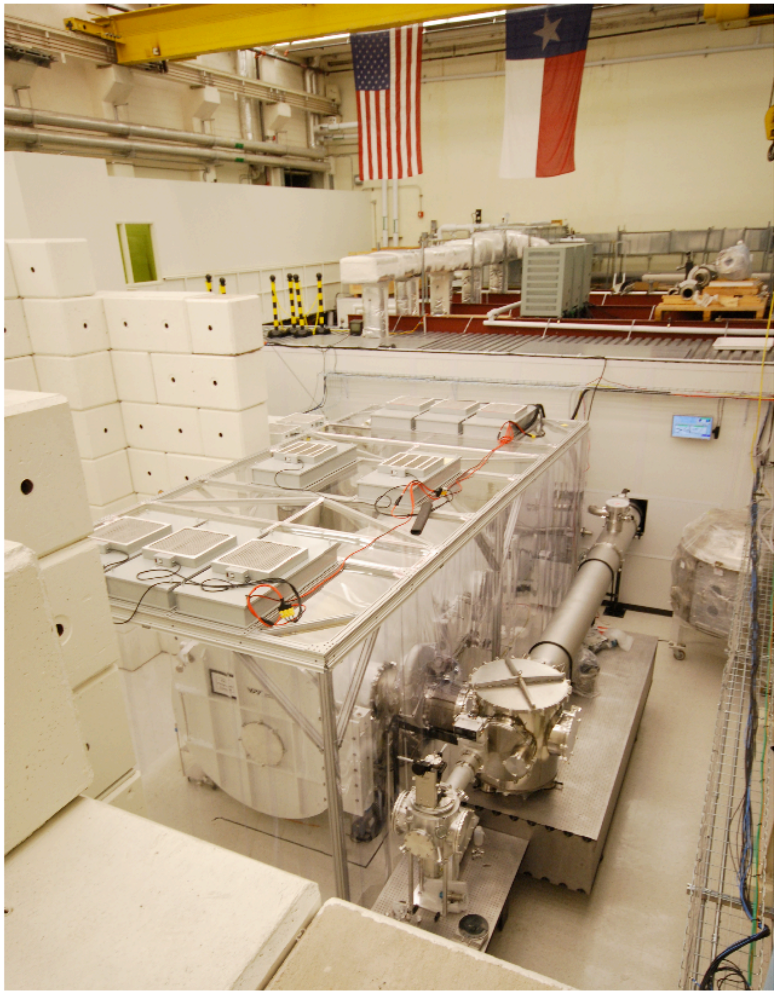
Long F# Target 2

Experiment	Spot size [μm]	Focusing geometry (F#)	Pointing accuracy [μm]	Peak irradiance W/cm2
Solid target/ isochoric heating	100	50	<50	10^{18}
Cluster fusion	50-200	25	<100	10^{18}
Wake field acceleration	100-200	80-150	<30	10^{18}
Radiation blast wave		20-100	<100	10^{17}
High harmonic generation		25-50	<200	10^{14}
Raman amplification	100	50-150	<30	10^{16}
MeV proton source	<20	4-5	<50	10^{20}
Ultra intense physics/ High field ionization	<10	1-4	<50	$>10^{21}$

Short F# Target 1

The Texas Petawatt Laser now has a long f/# beam line for fusion neutron production and HHG





The Texas Petawatt will have a limited capacity for outside experimenters

The Texas Petawatt has features which make it internationally unique

1) High Energy PW laser with ~ 100 fs pulse duration
- **Short pulse ideal for some classes of experiments**

→ laser cluster interactions; linear wakefield generation

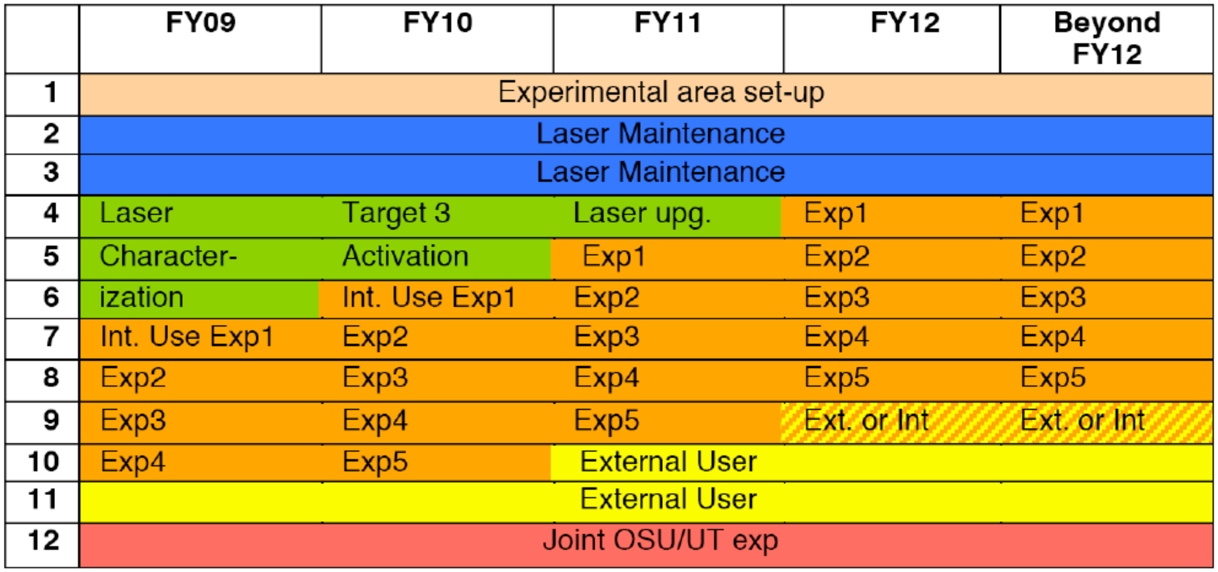
2) Very long f/# capability
- **Hardware in place for f/40 and f/20 experiments**

→ may allow NIF ARC style experiments

3) Soon to have a 100 T capability
- **Sandia now constructing a compact 1 MA pulser for installation at the TPW**

→ may permit experiments on hot electron transport in B-fields

Vision for use of the Texas Petawatt in the coming 4 years



	FY09	FY10	FY11	FY12	Beyond FY12
1	Experimental area set-up				
2	Laser Maintenance				
3	Laser Maintenance				
4	Laser	Target 3	Laser upg.	Exp1	Exp1
5	Character-	Activation	Exp1	Exp2	Exp2
6	ization	Int. Use Exp1	Exp2	Exp3	Exp3
7	Int. Use Exp1	Exp2	Exp3	Exp4	Exp4
8	Exp2	Exp3	Exp4	Exp5	Exp5
9	Exp3	Exp4	Exp5	Ext. or Int	Ext. or Int
10	Exp4	Exp5	External User		
11	External User				
12	Joint OSU/UT exp				

Points of Contact:
Target Experiments
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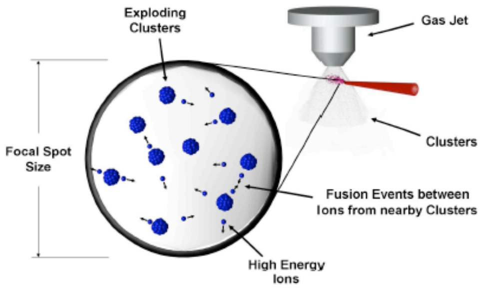
TPW Laser
Dr. Erhard Gaul
TPW Lead Laser Scientist
gaul@physics.utexas.edu

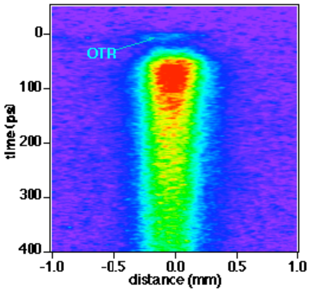
Access to the Texas Petawatt will be coordinated through the Joint Institute of High Energy Density Science operated jointly by Sandia and UT System

Some research directions we are pursuing on the TPW Laser:

1) Producing intense bursts of fusion neutrons

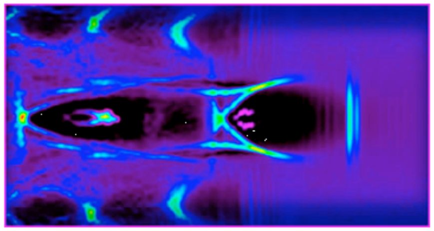


2) Creating and measuring the properties of hot, dense plasma with protons

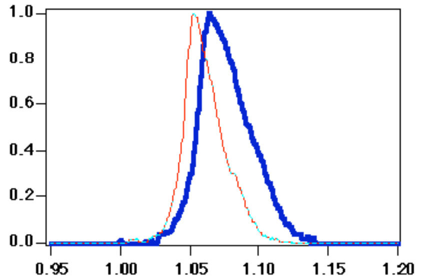


3) Study of plasmas in strong magnetic fields

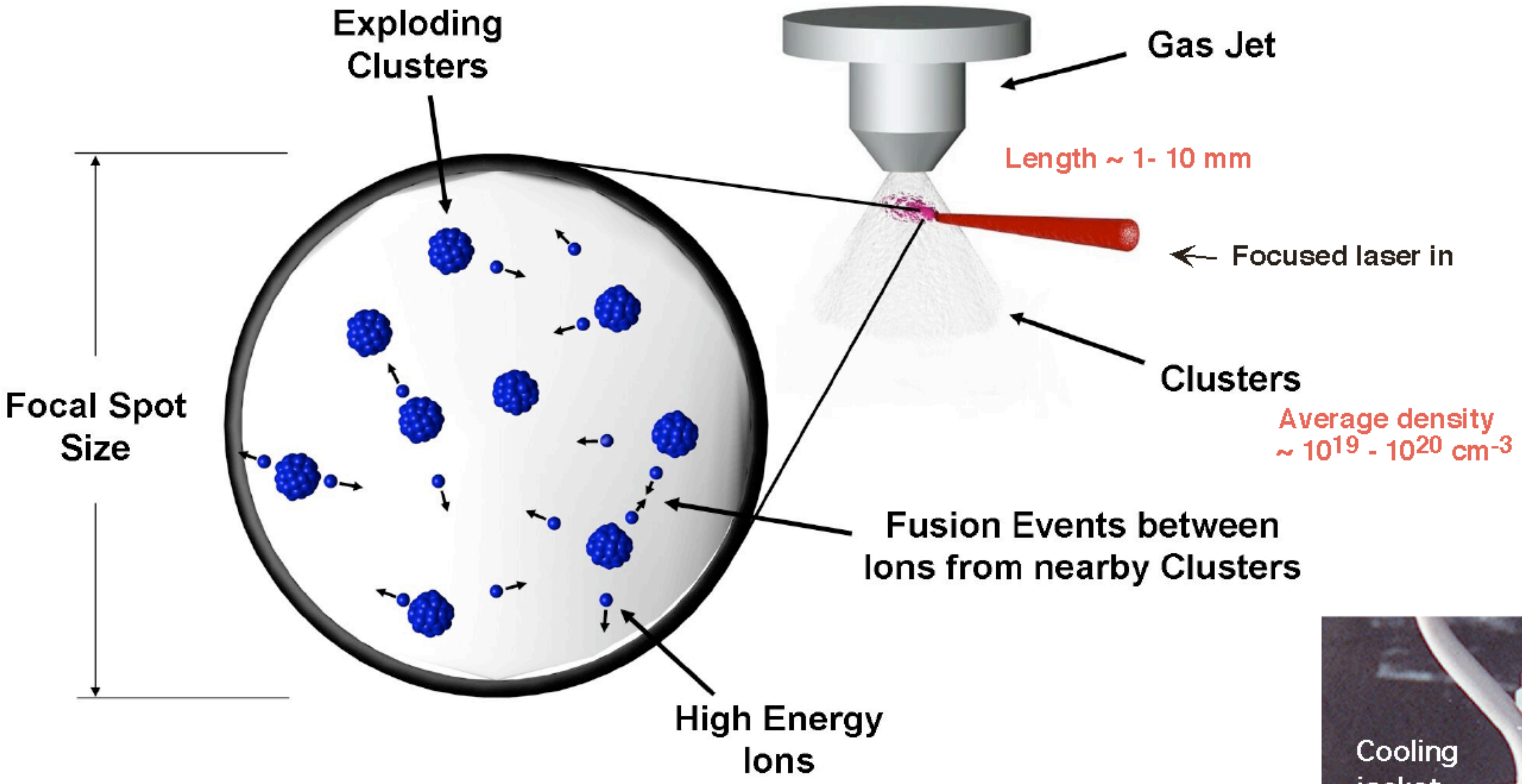
4) Wakefield acceleration to multi-GeV energies



5) Exawatt Laser Science



A gas of exploding deuterated clusters can produce a burst of fusion



Exploding Clusters

Gas Jet

Length ~ 1- 10 mm

Focused laser in

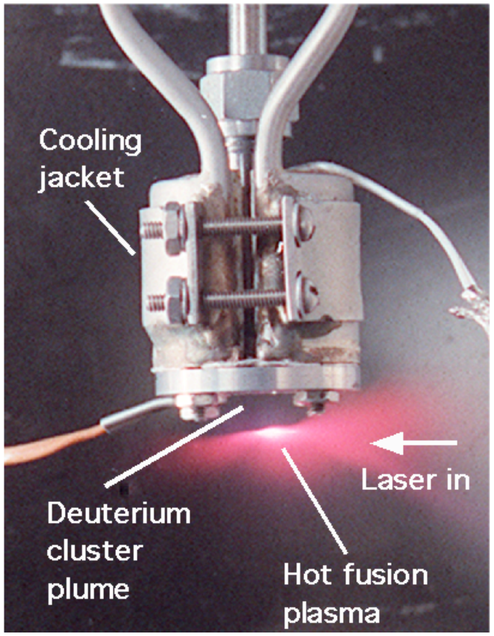
Focal Spot Size

Clusters

Average density ~ 10^{19} - 10^{20} cm^{-3}

Fusion Events between Ions from nearby Clusters

High Energy Ions

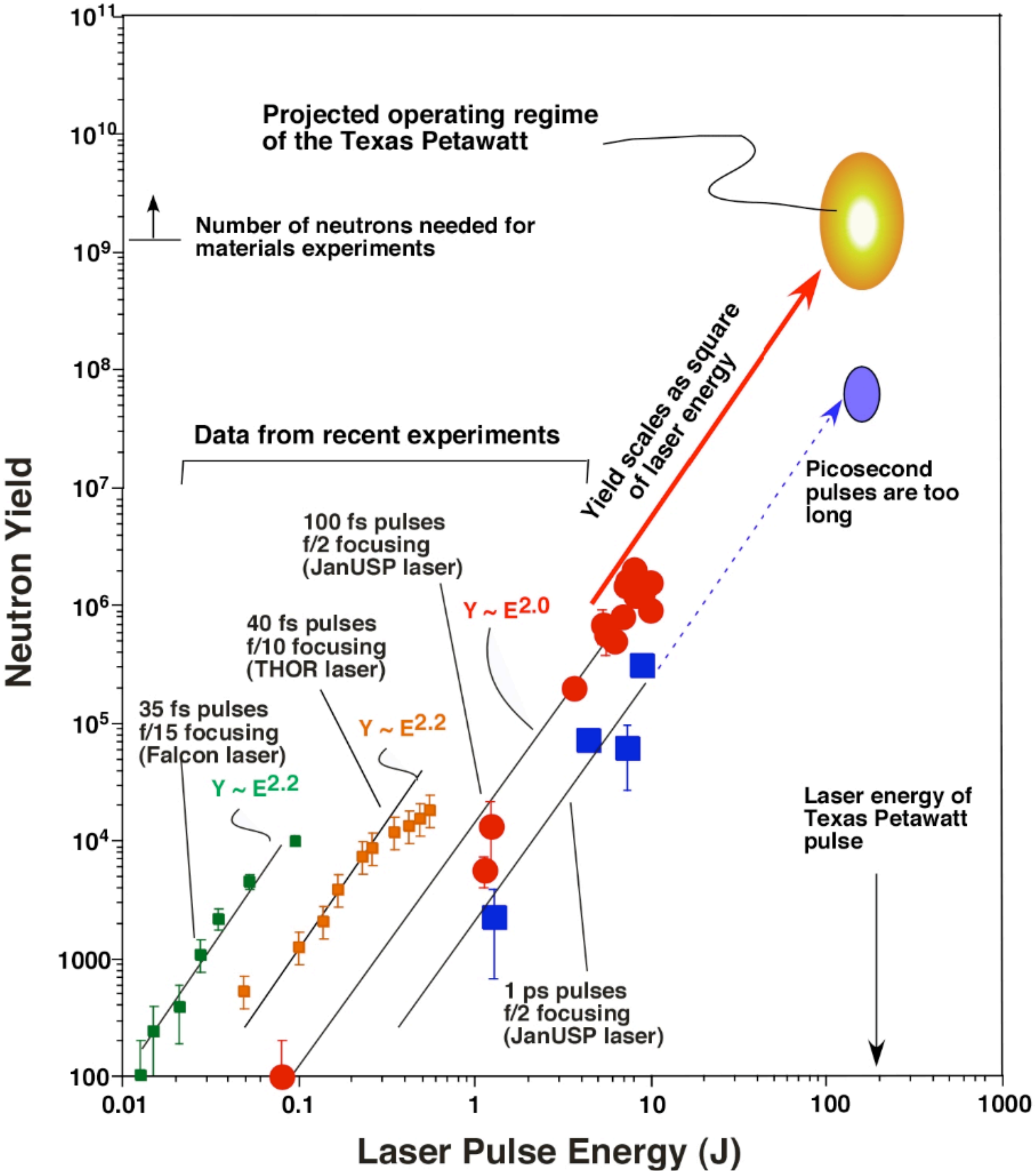


Relevant fusion reactions:

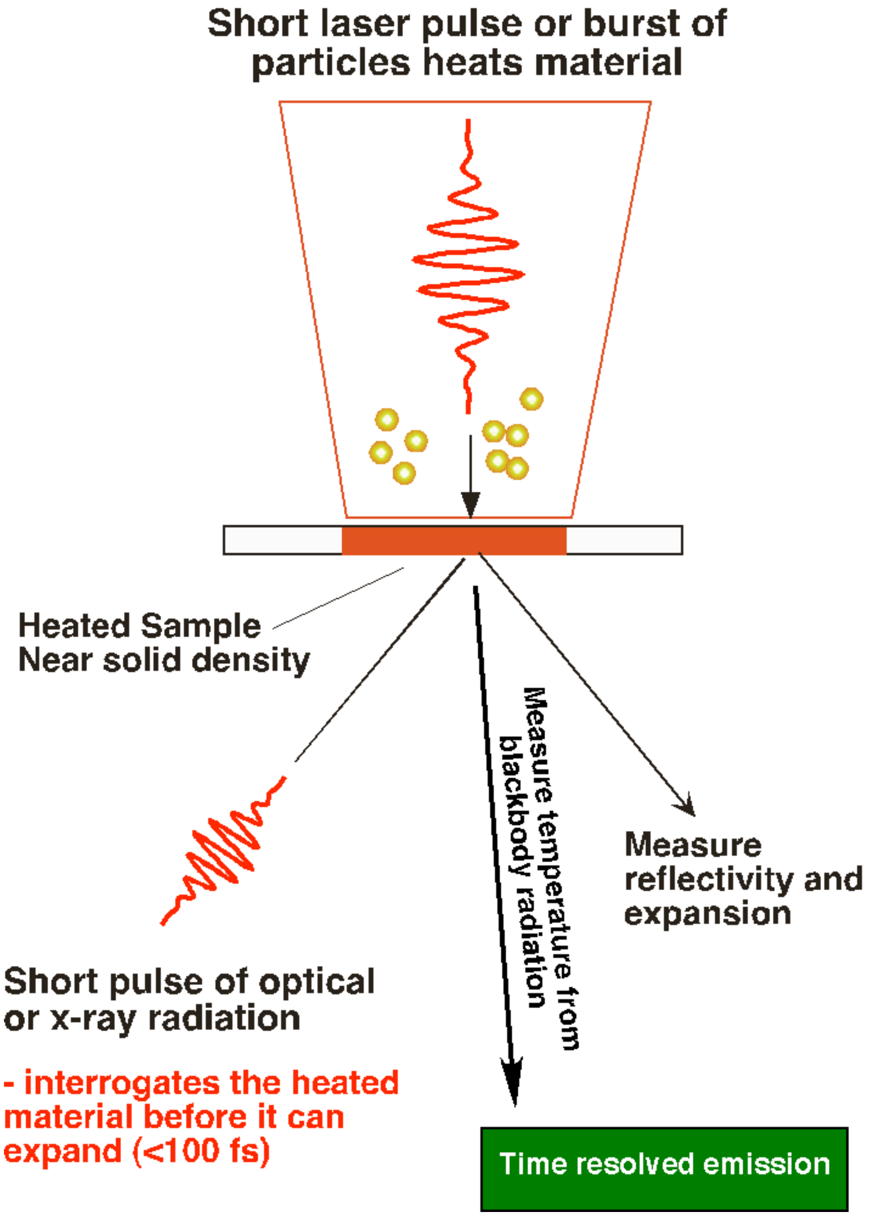
$D + D \rightarrow He^3$ (0.82 MeV) + n (2.45 MeV)

$D + T \rightarrow He^4$ (3.5 MeV) + n (14.1 MeV)

A petawatt class laser may make possible neutron induced materials damage experiments



A short pulse laser can isochorically heat materials to high temperature and pressure



Short laser pulse or burst of particles heats material

Heated Sample
Near solid density

Measure temperature from blackbody radiation

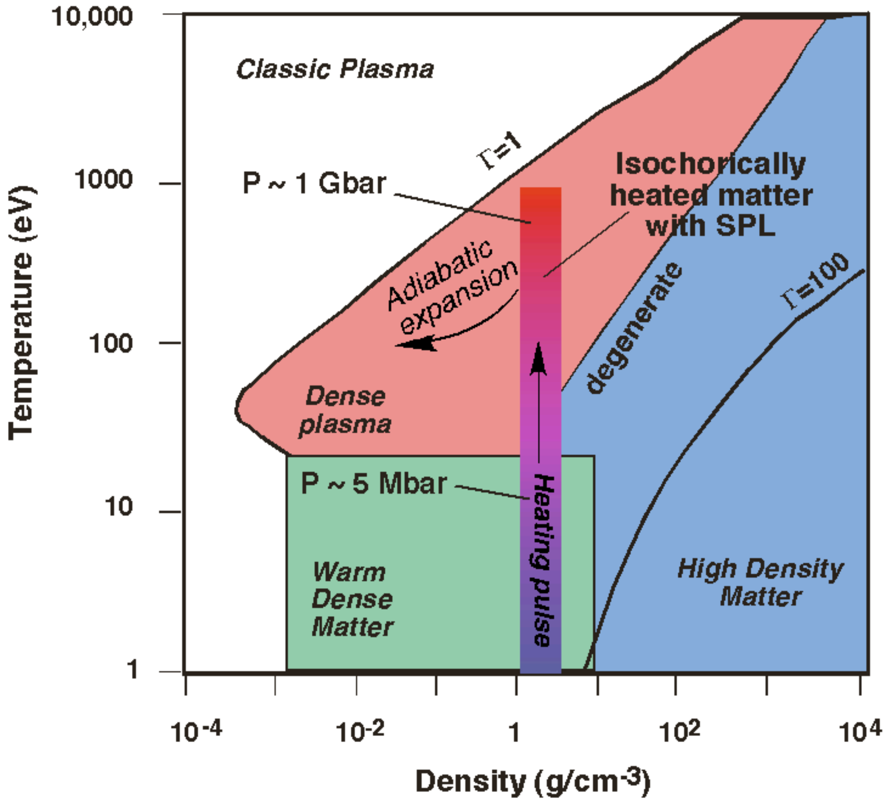
Measure reflectivity and expansion

Short pulse of optical or x-ray radiation

- interrogates the heated material before it can expand (<100 fs)

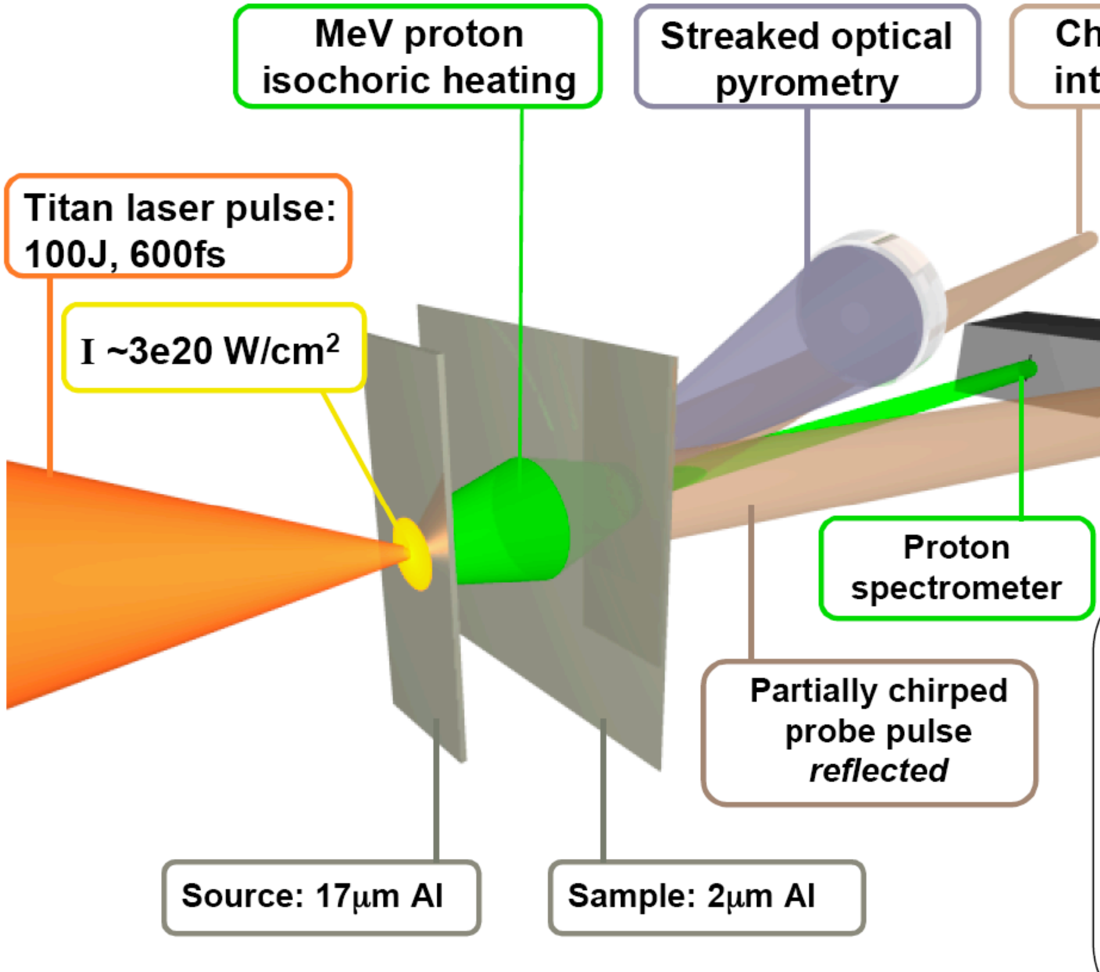
Time resolved emission

Aluminum ρ - T diagram



Target expands ~ d/c_s
~ 1 μm/ 5 x 10^6 cm/s
(for 100 eV Al)
~ 20 ps

We have implemented this proton heating EOS experiment on the LLNL Titan laser



MeV proton isochoric heating

Streaked optical pyrometry

Chirped-pulse interferometry

Titan laser pulse: 100J, 600fs

I ~3e20 W/cm^2

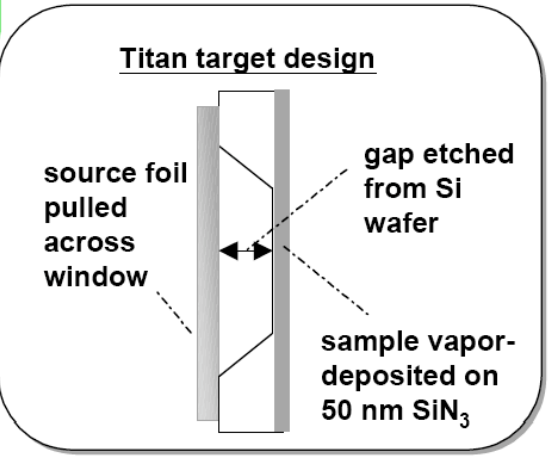
Proton spectrometer

Partially chirped probe pulse *reflected*

Source: 17μm Al

Sample: 2μm Al

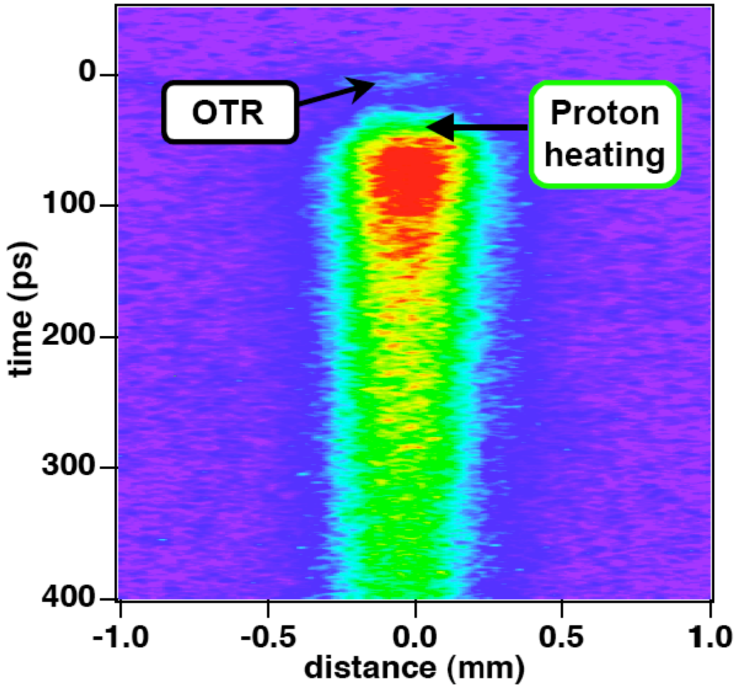
- **Single shot time resolved thermal measurement (SOP)**
- **Single shot time-resolved expansion measurement (CPI)**



Titan target design

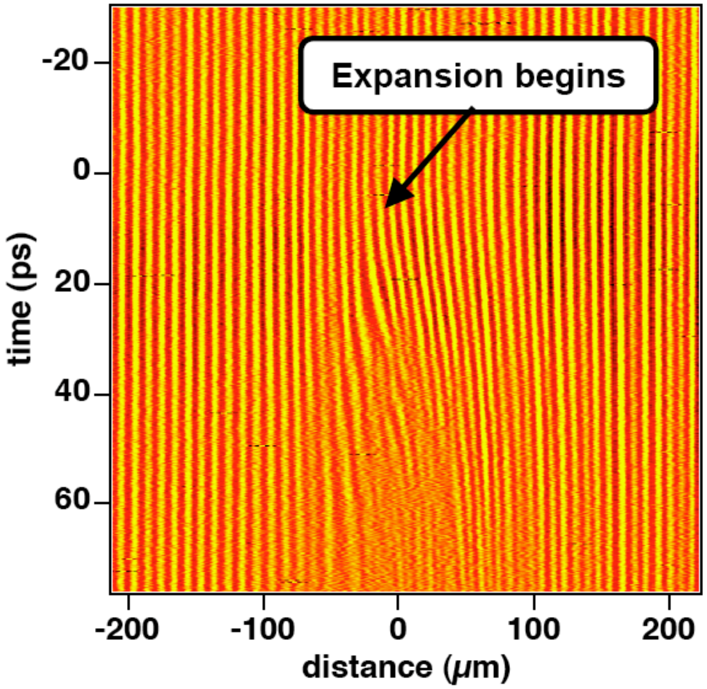
The time history of the temperature and expansion of the heated Al slab was measured on every shot

SOP: Time-resolved temperature



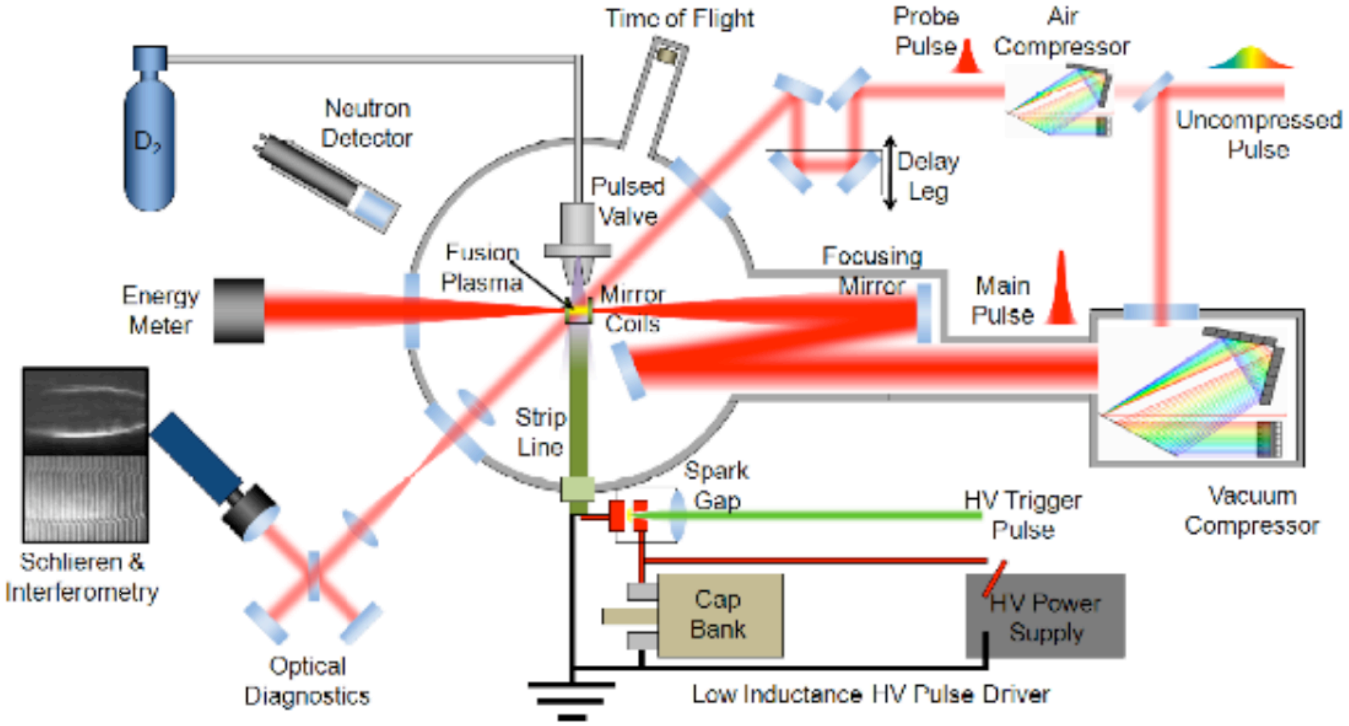
- Peak temperature ~ 25 eV
- Optical transition radiation signal at t_0

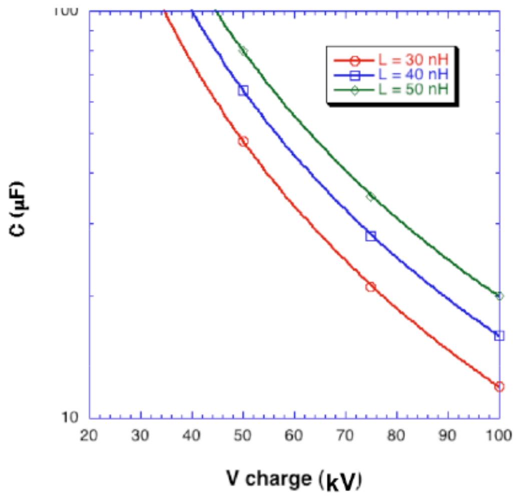
CPI: Time-resolved expansion

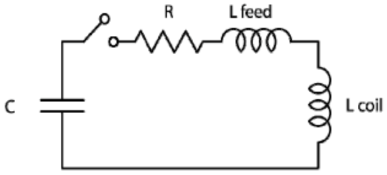


- Fourier analysis of bending fringes → phase shift → expansion in time

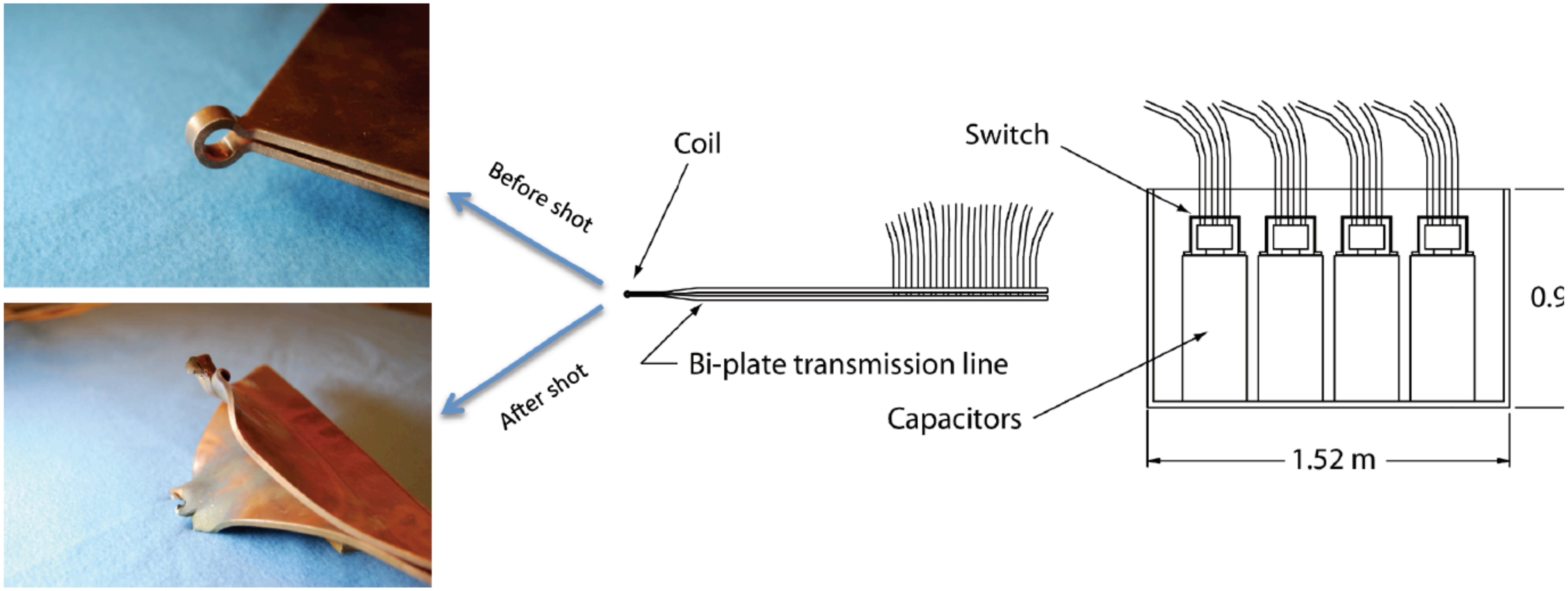
In a joint Sandia-funded LDRD project, we will be fielding a 200 T pulsed magnet on the Texas Petawatt







Sandia have developed a design for a compact 2 MA pulser to drive small coils to fields of ~ 200 T



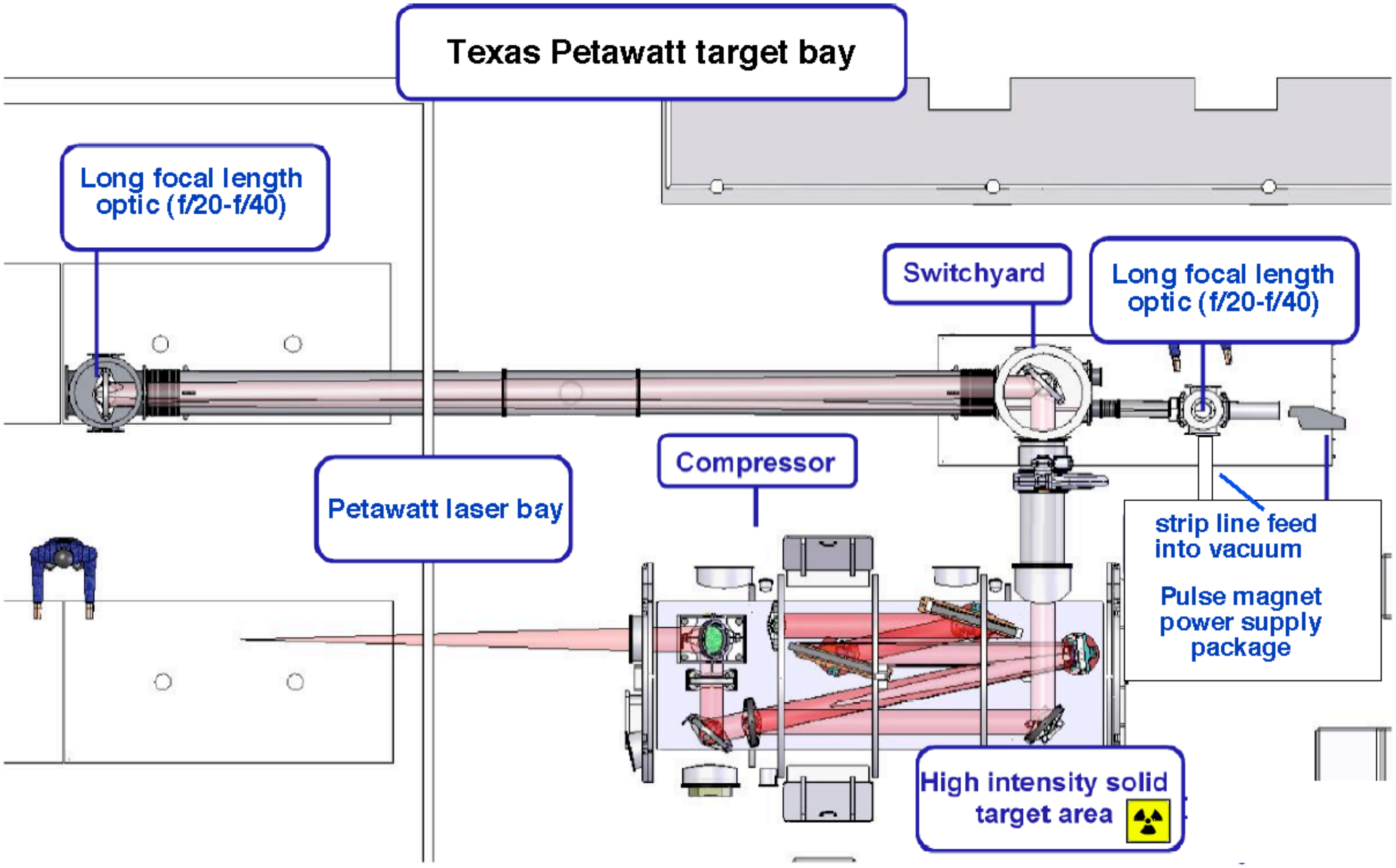
Peak magnetic field vs. current

V_o (kV)	I_{peak} (MA)	B_{peak} (T) 5 mm radius coil	B_{peak} (T) 3 mm radius coil
25	0.5	45	76
50	1.0	90	150
75	1.5	140	230
100	2.0	180	310

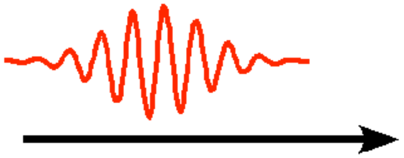
Driver parameters

C	24.8 μF
L	50 nH
R	5 mΩ
Peak I	2.0 MA
Peak V_o	100 kV
Peak E	120 kJ
$\tau (= L/R)$	10 μs
T_{peak}	1.7 μs

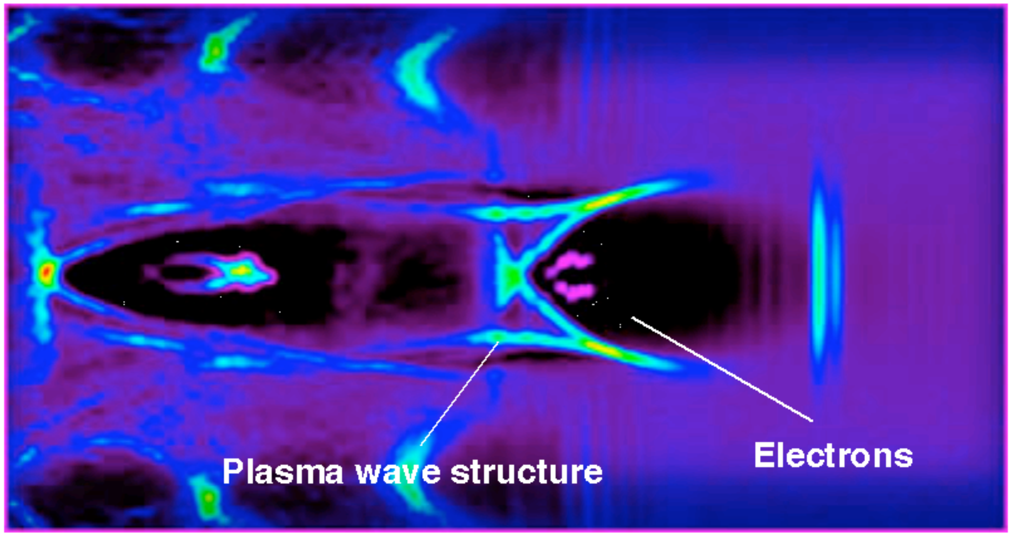
The Sandia-built pulsed magnet will be installed in the TPW bay on the long focal length chamber



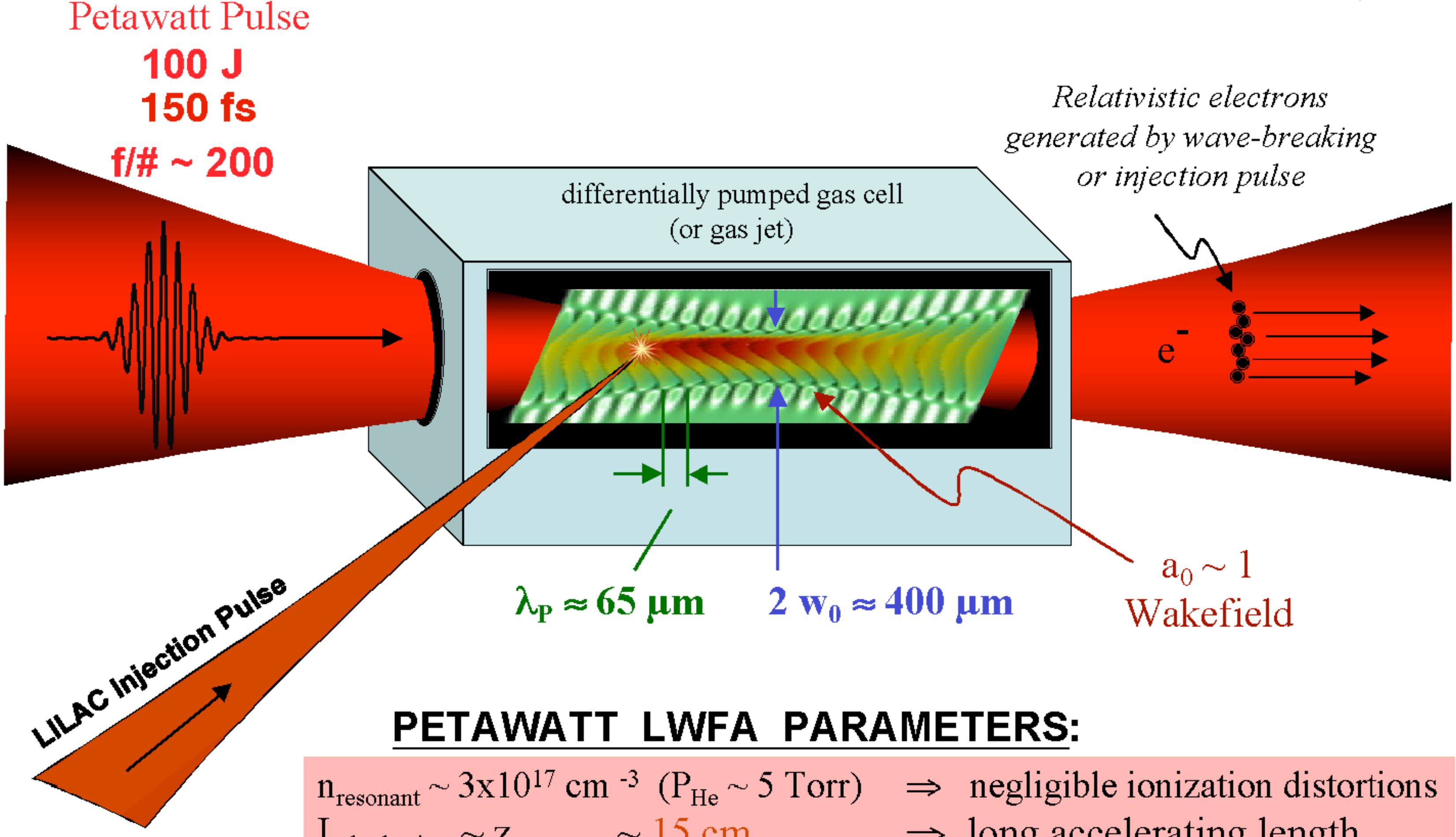
An intense laser pulse can be used to make a wake in a plasma which will accelerate electrons



Intense light focused into plasma



The 100 fs TPW will allow flat-field resonant, multi-GeV laser wakefield acceleration of electrons



Petawatt Pulse

100 J

150 fs

f/# ~ 200

differentially pumped gas cell
(or gas jet)

Relativistic electrons generated by wave-breaking or injection pulse

e^-

$\lambda_P \approx 65\ \mu m$

$2\ w_0 \approx 400\ \mu m$

$a_0 \sim 1$
Wakefield

LILAC Injection Pulse

Umstadter, PRL ('96)

PETAWATT LWFA PARAMETERS:

$n_{resonant} \sim 3x10^{17}\ cm^{-3}$ ($P_{He} \sim 5$ Torr) ⇒ negligible ionization distortions

$L_{dephasing} \sim z_{Rayleigh} \sim 15$ cm ⇒ long accelerating length

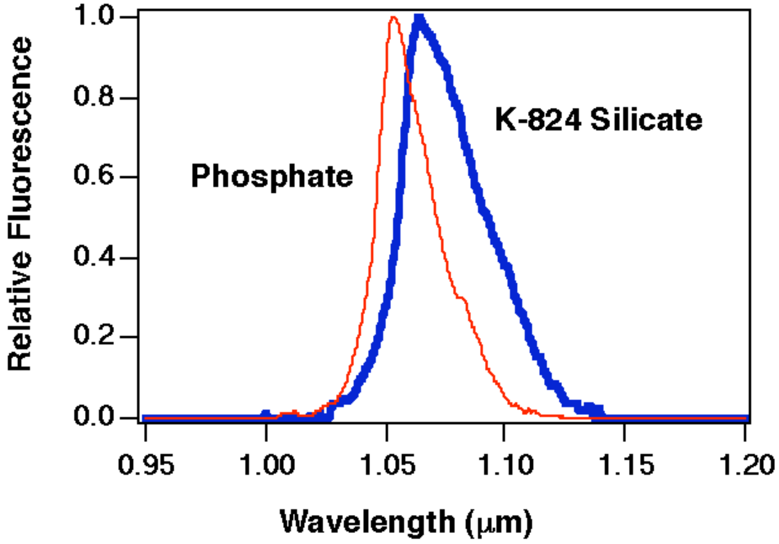
$E_z \sim 0.5$ GV/cm ⇒ largex accelerating field

Linear wakefield best driven by fs pulses

Accelerating gradient ~ $n_e^{1/2}$ ⟶ $n_e \sim (1/\Delta t_{pulse})^2$

We have isolated two candidate glasses which have a broad gain spectrum and reasonable gain properties

K-824 Tantalate/Silicate glass



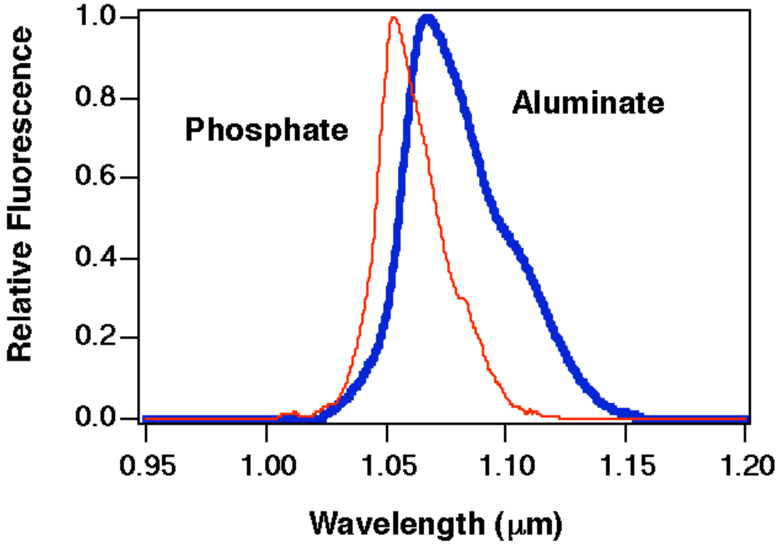
Peak Wavelength: 1065 nm

Peak cross section: 2.4 x 10^{-20} cm^2

Linewidth (FWHM): 38.2 nm

Ta_2O_5	57%
SiO_2	17%
MgO	10%
BaO	15%
Nd_2O_3	~1%

L-65 Aluminate glass



Peak Wavelength: 1067 nm

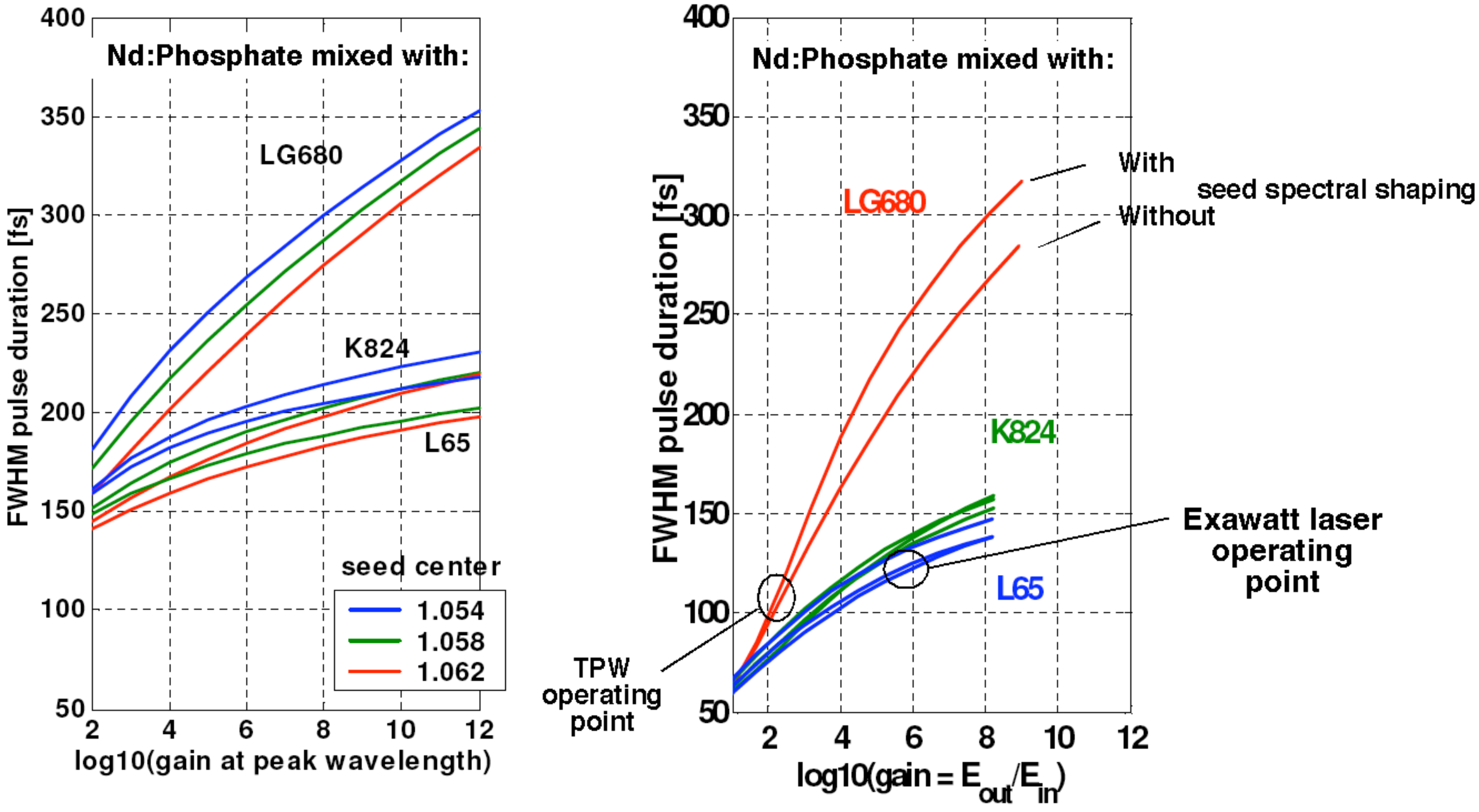
Peak cross section: 1.8 x 10^{-20} cm^2

Linewidth (FWHM): 41.2 nm

Al_2O_3	42%
CaO	38%
BaO	10%
SiO_2	8%
Nd_2O_3	~4%

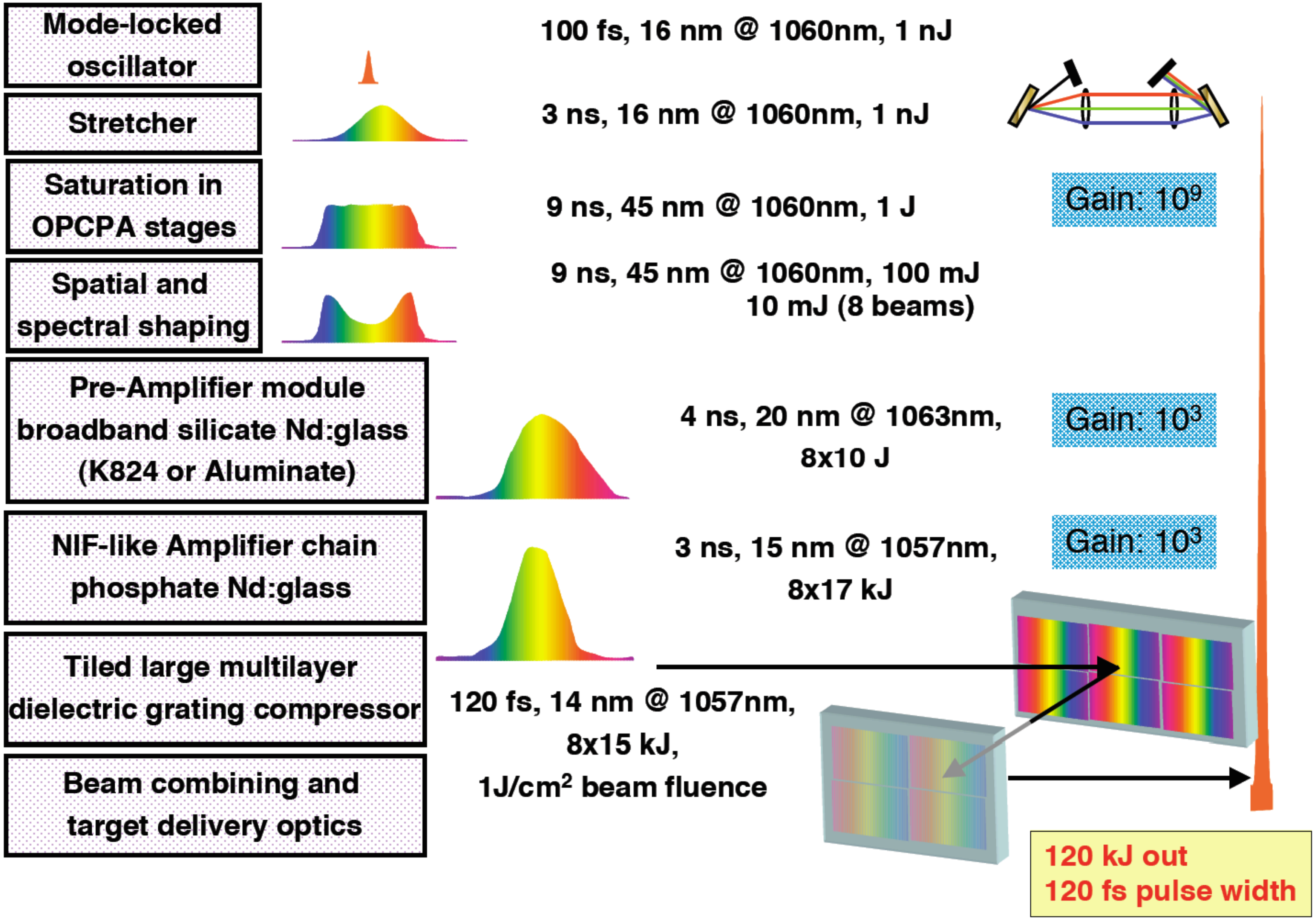
High integrated gain will be possible with mixtures of these novel glasses while retaining short pulses

Final pulse duration calculated as a function of peak and total (spectrally integrated) gain



Using a mixture of Phosphate and Aluminate glass amplifiers, bandwidth sufficient for near - 100 fs pulses will be achievable with integrated gain of $>10^5$

A good approach to achieving an exawatt would be to implement an OPCPA seed into mixed glass



Mode-locked oscillator

100 fs, 16 nm @ 1060nm, 1 nJ

Stretcher

3 ns, 16 nm @ 1060nm, 1 nJ

Saturation in OPCPA stages

9 ns, 45 nm @ 1060nm, 1 J

Gain: 10^9

Spatial and spectral shaping

9 ns, 45 nm @ 1060nm, 100 mJ
10 mJ (8 beams)

Pre-Amplifier module broadband silicate Nd:glass (K824 or Aluminate)

4 ns, 20 nm @ 1063nm,
8x10 J

Gain: 10^3

NIF-like Amplifier chain phosphate Nd:glass

3 ns, 15 nm @ 1057nm,
8x17 kJ

Gain: 10^3

Tiled large multilayer dielectric grating compressor

120 fs, 14 nm @ 1057nm,
8x15 kJ,
1J/cm^2 beam fluence

Beam combining and target delivery optics

120 kJ out
120 fs pulse width

UT Tower, August 28th, 2008