The National Ignition Laser Performance Status

JM. Di Nicola, T. Bond, M. Bowers, L. Chang, M. Hermann, R. House, K. Manes, G. Mennerat, B. MacGowan, R. Negres, M. Nostrand, B. Olejniczak, C. Orth, T. Parham, S. Rana, B. Raymond, M. Shaw, M. Spaeth, T. Suratwala, B. Van Wonterghem, W. Williams, C. Widmayer, S. Yang and P. Wegner

10th International Conference on Inertial Fusion Sciences and Applications

LLNL-PRES-738077

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

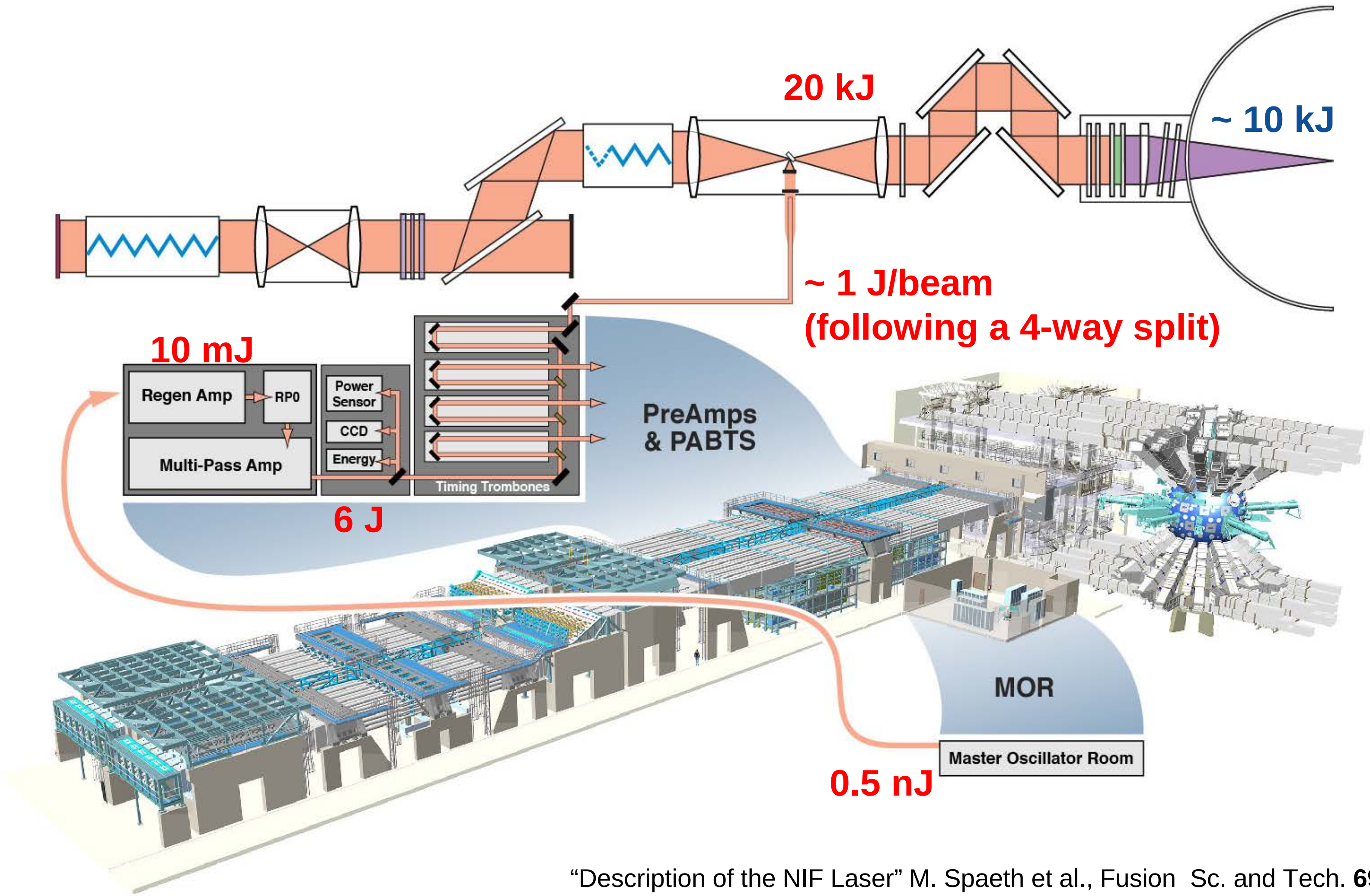
Lawrence Livermore National Laboratory

The National Ignition Facility – Lawrence Livermore National Laboratory, California

192 beams
- 1.8 MJ
- 500 TW
- 351 nm

4 CPA beamlets
- 1.2 kJ at 30 ps
- 1053 nm

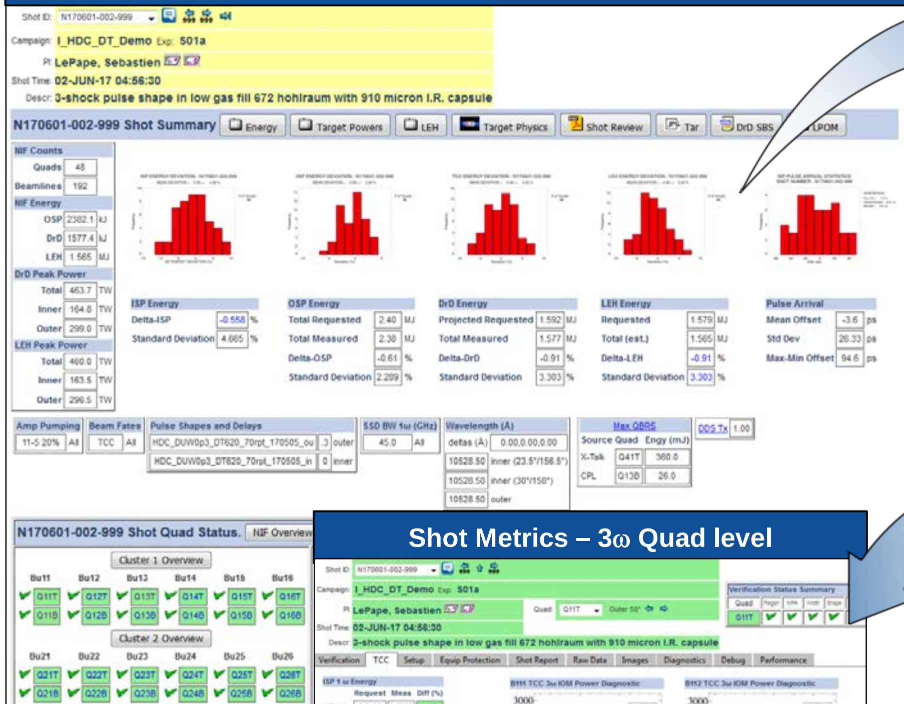
NIF laser beams are amplified and frequency converted from nJ to 10 kJ levels in the UV



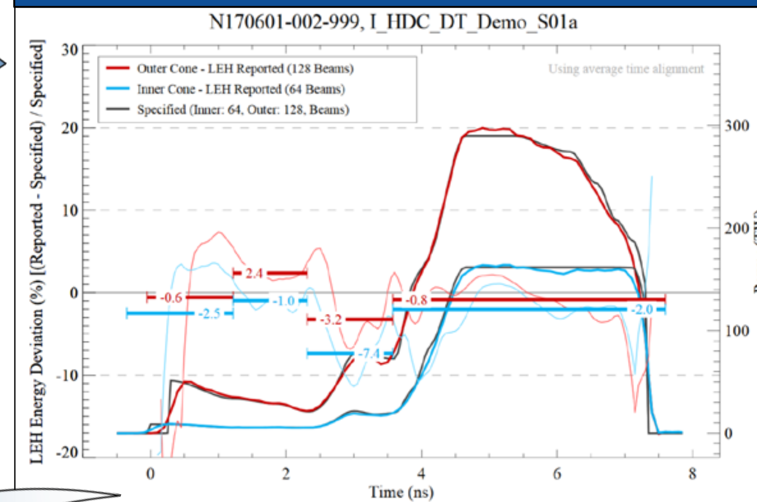
“Description of the NIF Laser” M. Spaeth et al., Fusion Sc. and Tech. **69** (2016)

NIF Laser Performance Operations Model is used to setup shots, perform post-shot data visualization and reporting

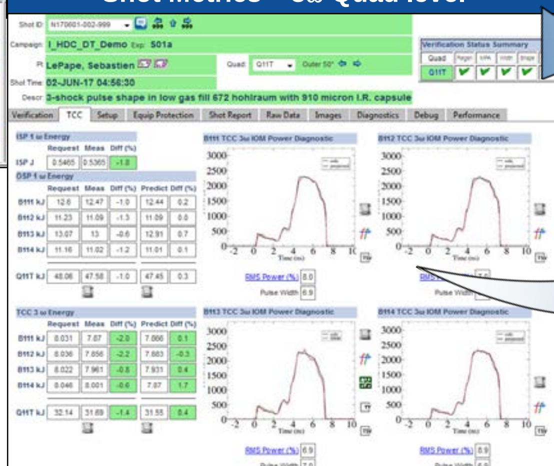
High Yield, shot HDC_DT_demo: 1.6 MJ UV / 465 TW
3ω delivered energy with -0.91% accuracy



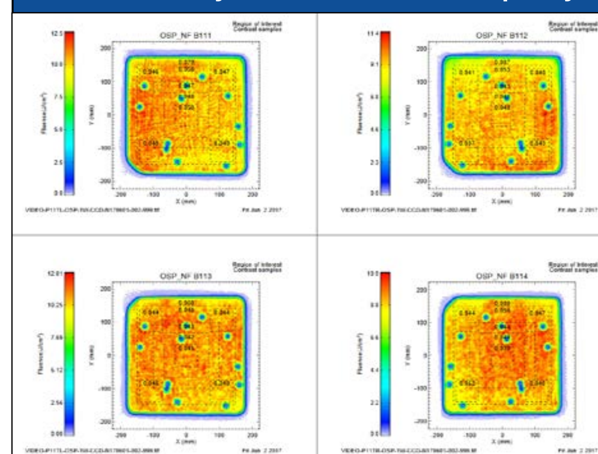
Shot Metrics – 3ω power accuracy, NIF & cone levels



Shot Metrics – 3ω Quad level

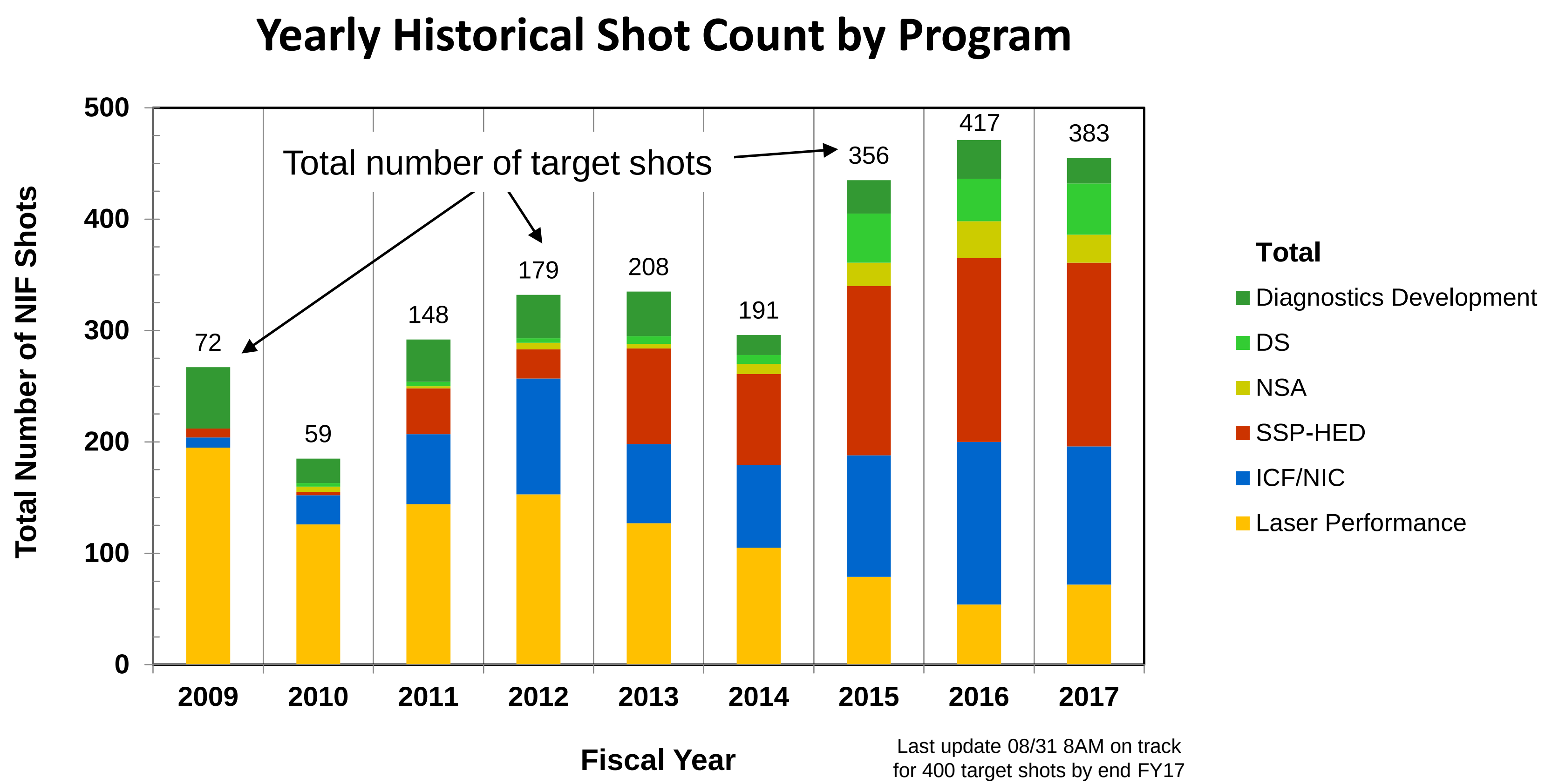


Detailed Analysis result – 1ω beam quality



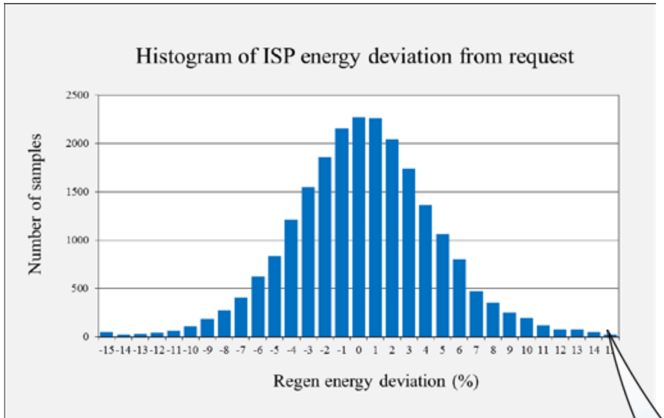
LPOM / Virtual Beam Line code are critical to maintain a high quality laser performance

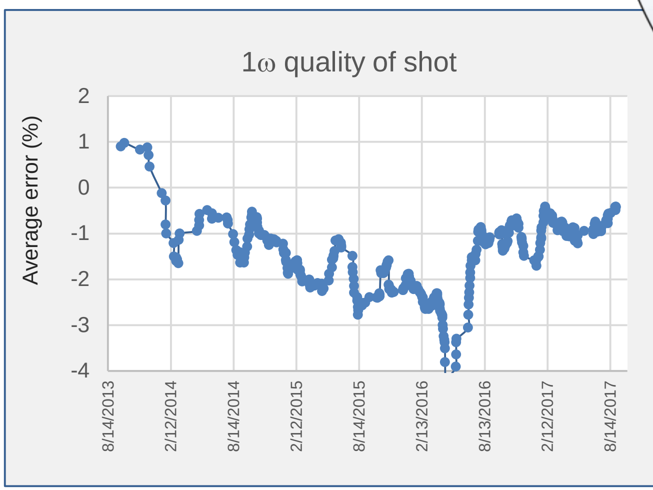
NIF target shot rate has doubled between 2012-2014 and 2015-2017 while maintaining high quality performance

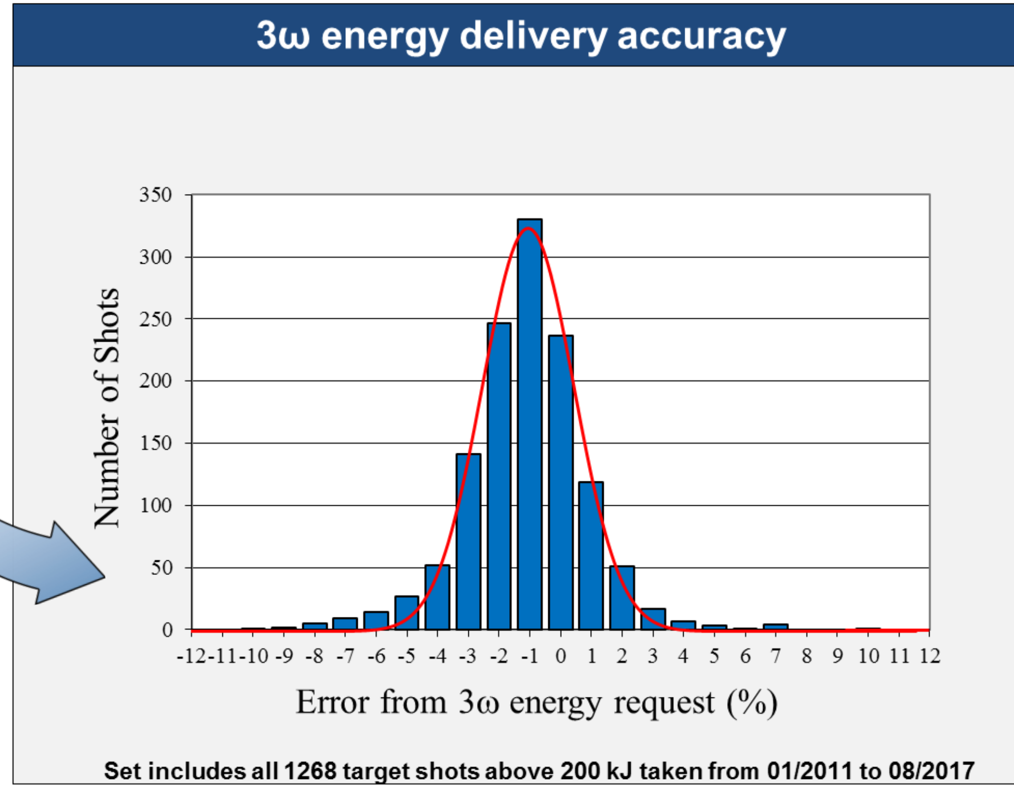


In FY17, >70 shots were dedicated to laser calibration and to the Power and Energy Performance quad campaign

Performance monitoring, trending and quality of models are key for high performance



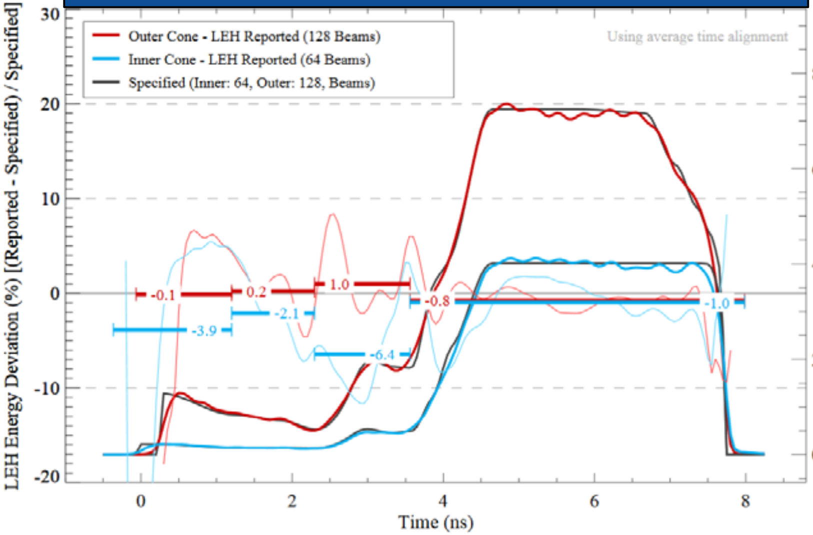




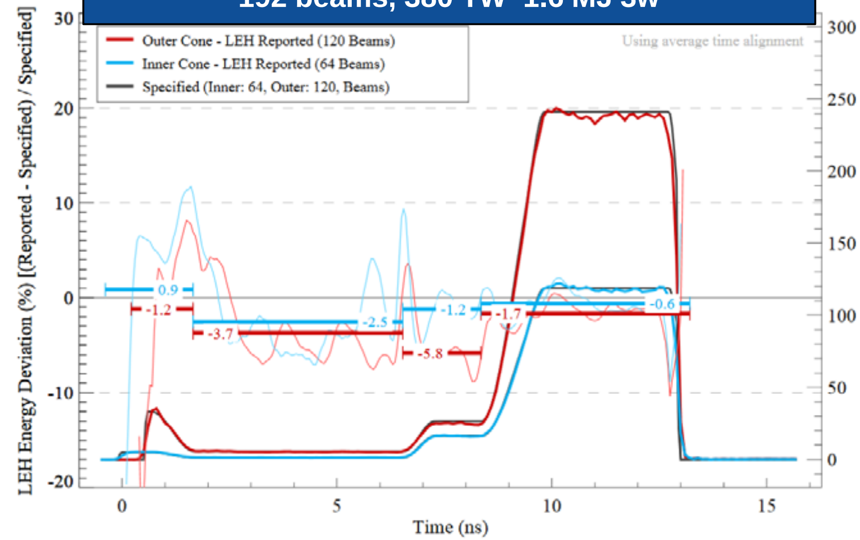
Main laser and frequency conversion models are updated when threshold is exceeded to compensate for slow drifts using calibration shots or information gathered on target shots

NIF laser continues to delivers high precision 3ω pulse shapes over a very wide operating range

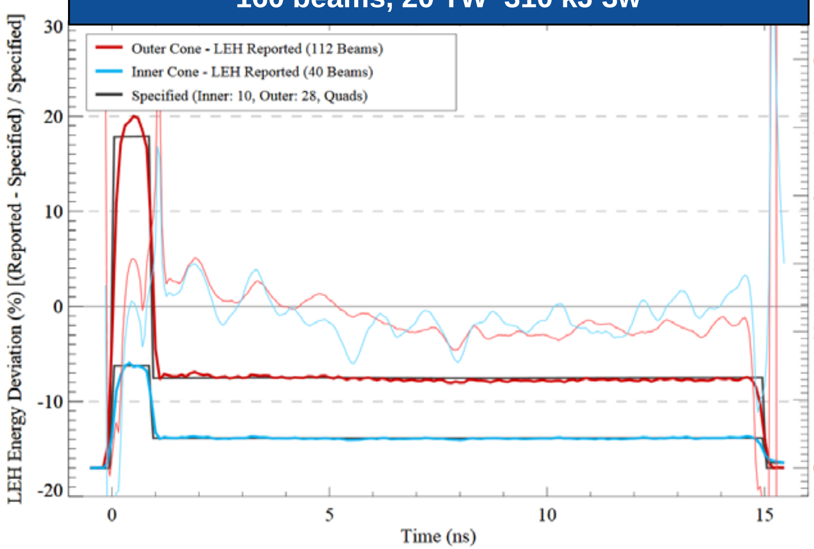
N170827-002-999, I_Int_DT_HDCScaleUp_S01a
192 beams, 460 TW 1.8 MJ 3w



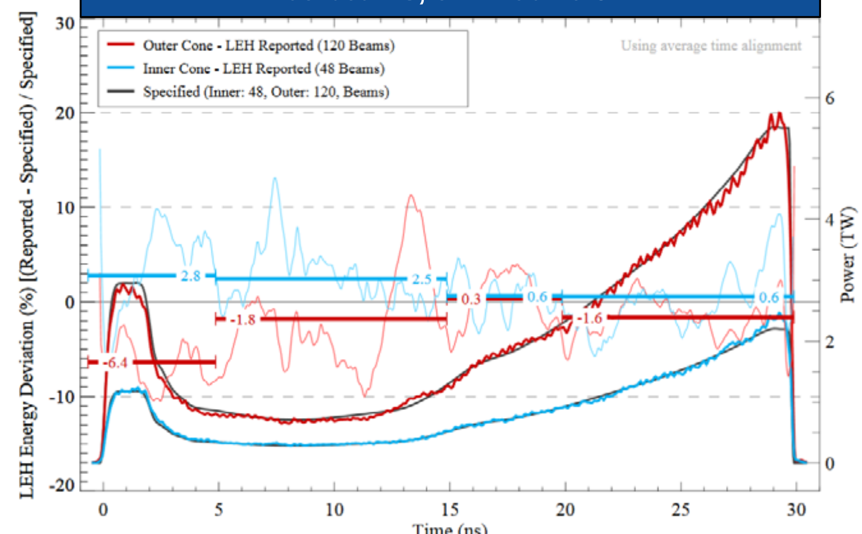
N170205-001-999, I_CH_2DConA_cap0p9_S01a
192 beams, 380 TW 1.6 MJ 3w



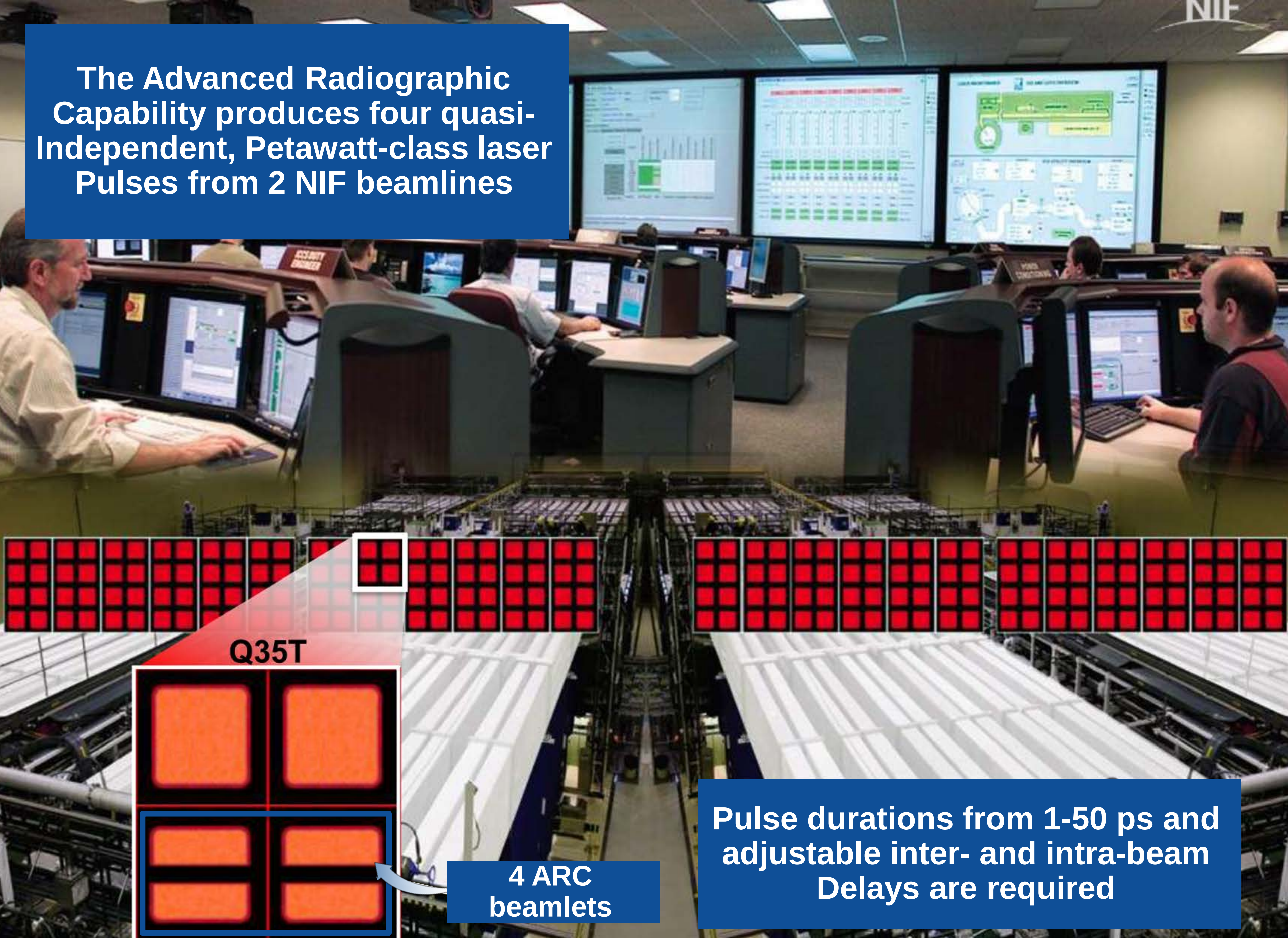
N170215-002-999, D_Astro_Cshoc_TDYNO_S09a
160 beams, 20 TW 310 kJ 3w



N170703-001-999, H_Mat_EOS_EOSSn _S02a
168 beams, 8 TW 90 kJ 3w

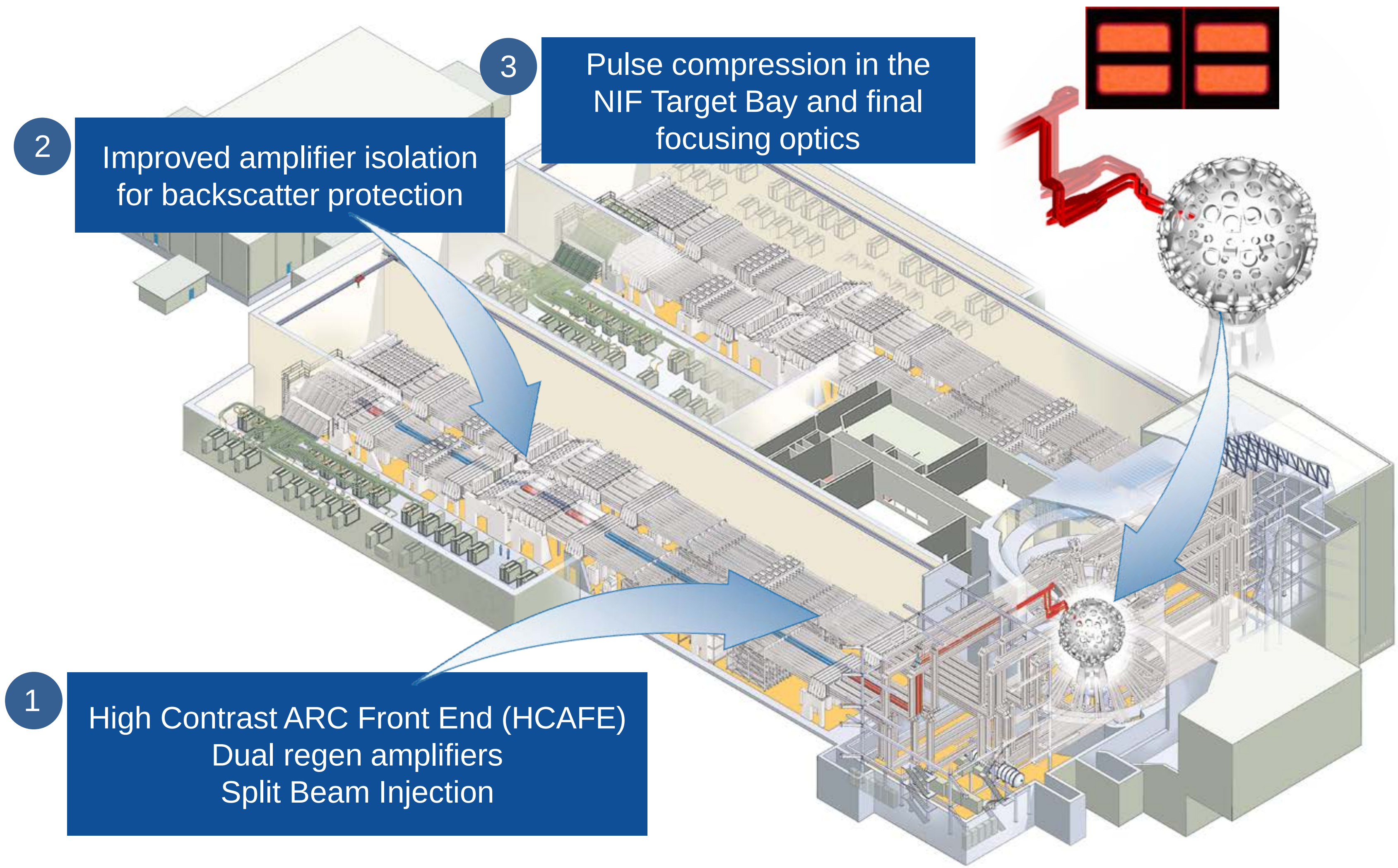


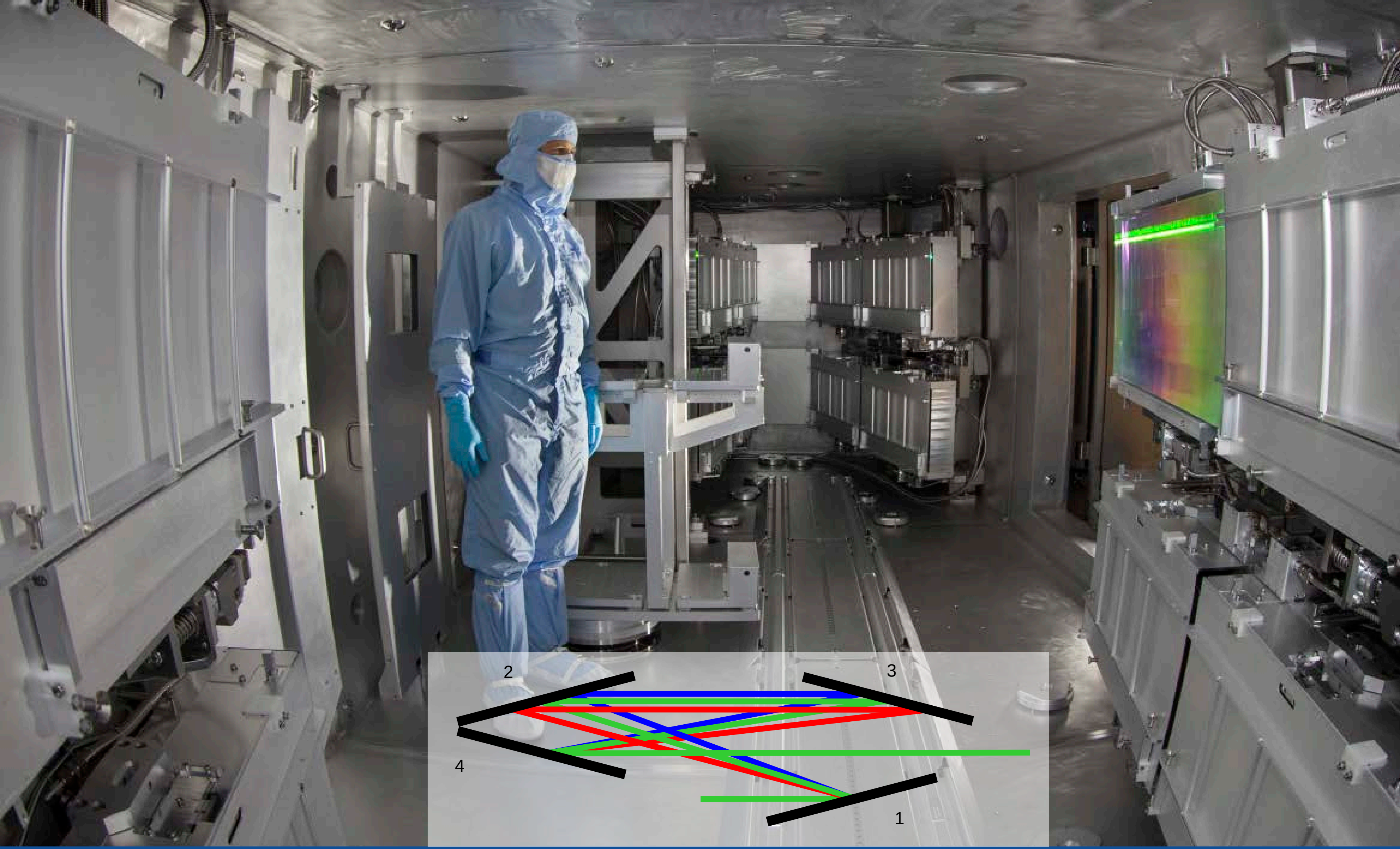
The Advanced Radiographic Capability produces four quasi-Independent, Petawatt-class laser Pulses from 2 NIF beamlines



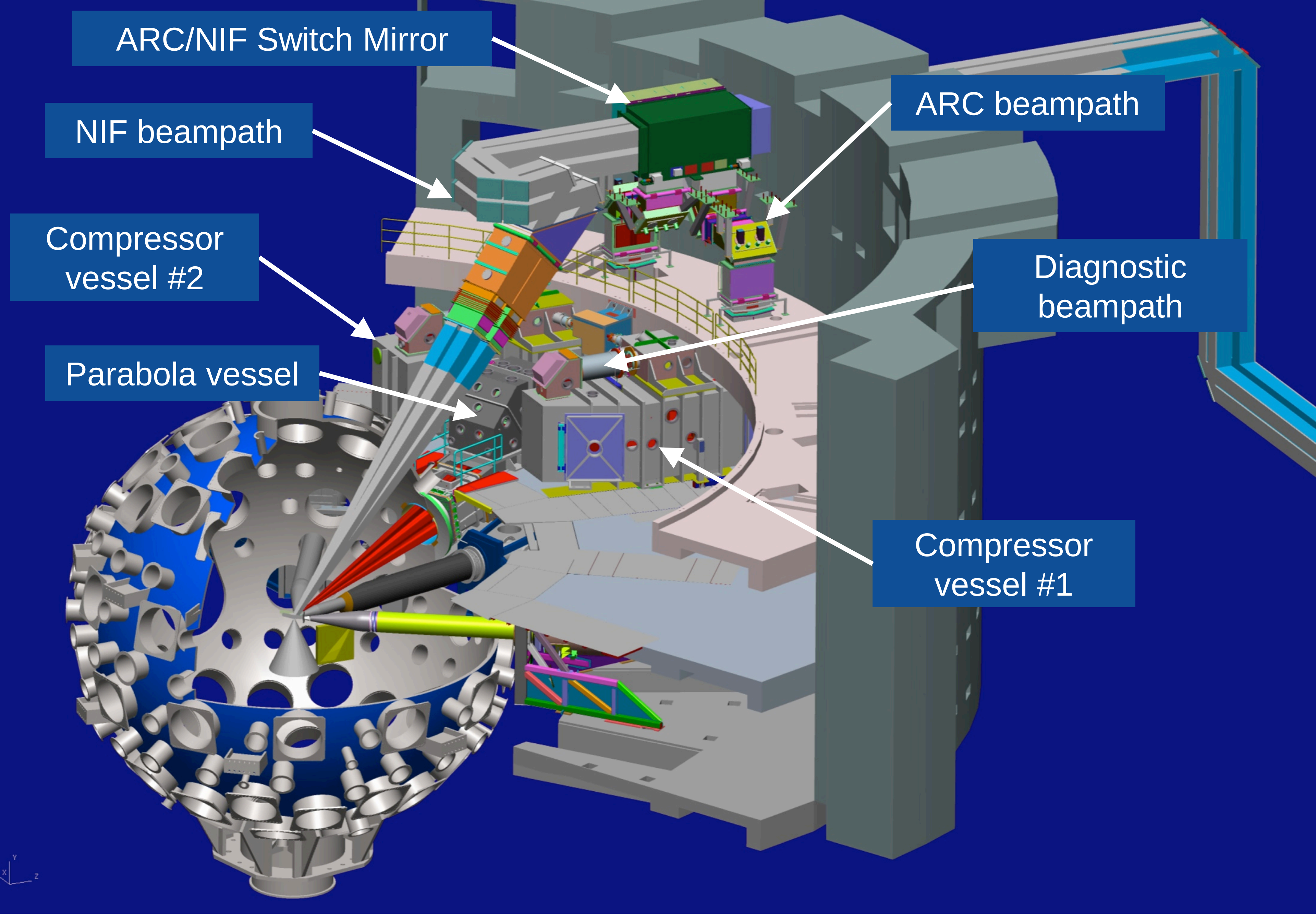
Pulse durations from 1-50 ps and adjustable inter- and intra-beam Delays are required

Conversion of NIF beamlines to ARC high-intensity, picosecond operation required 3 top level changes

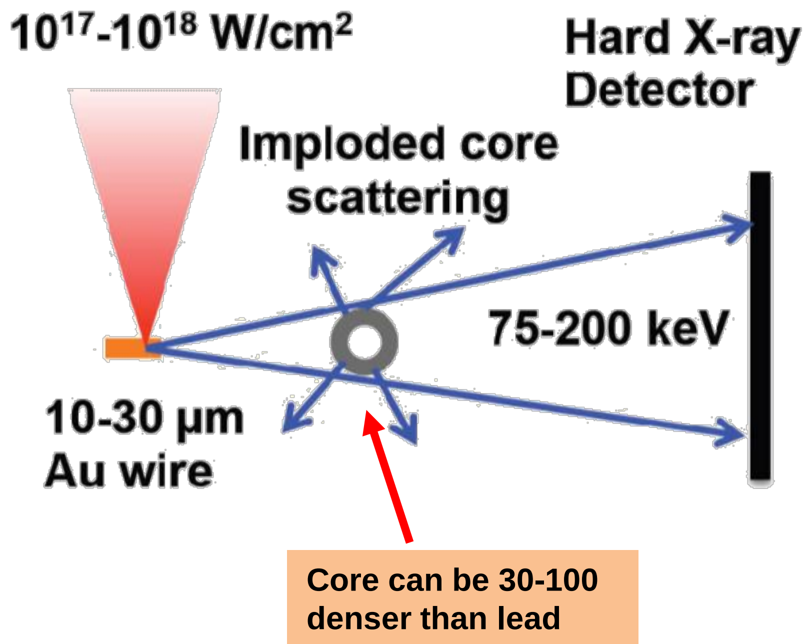


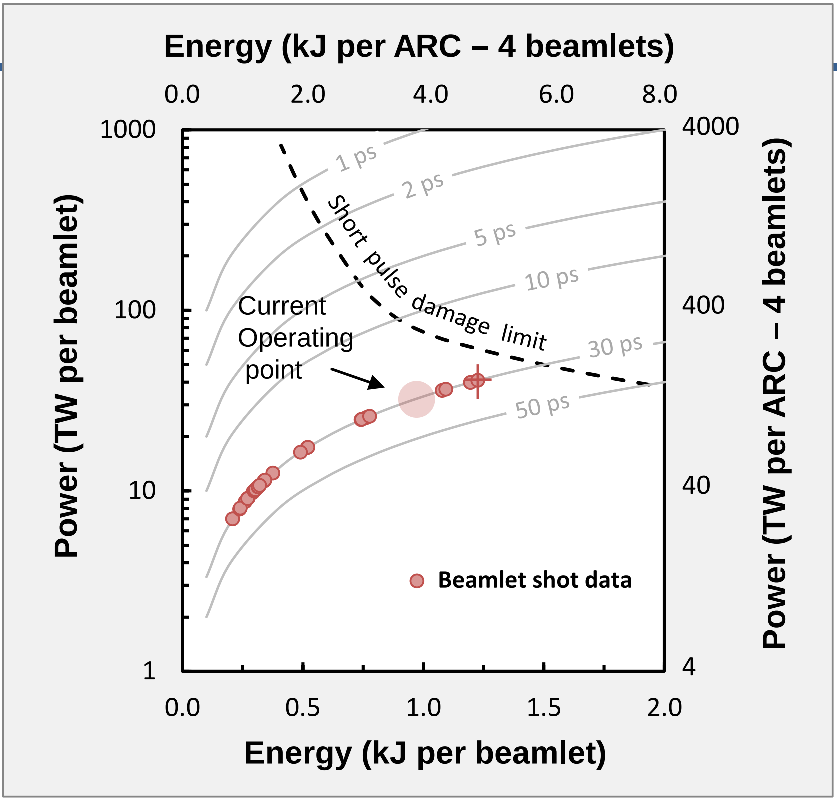


A compact folded compressor uses 16 large-scale gratings to compress the ARC 4 beamlets


ARC/NIF Switch Mirror
NIF beampath
ARC beampath
Compressor vessel #2
Diagnostic beampath
Parabola vessel
Compressor vessel #1

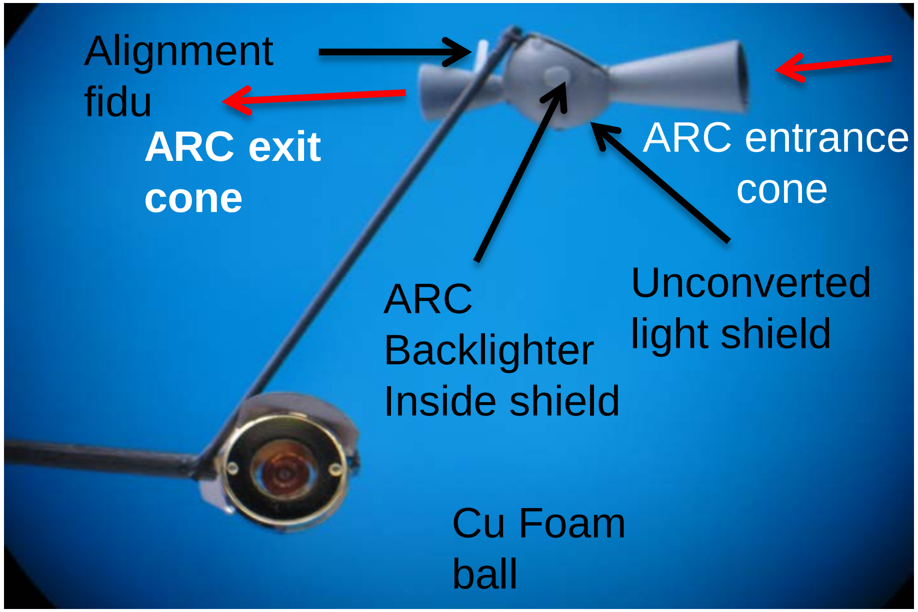
ARC enables point-projection high-energy (>75keV) radiography for probing cold materials at high pressure

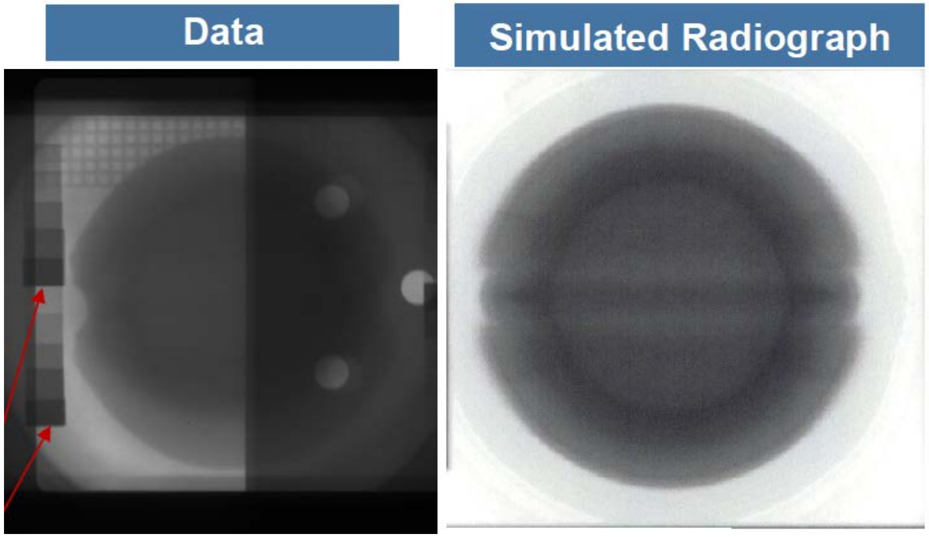




Description	Ignition Need	HED Need	Initial Performance
Peak irradiance/sub-aperture beam	≥10^{17} W/cm^2	≥10^{17} W/cm^2	≥10^{17} W/cm^2 @ 30 ps
Pulse energy/sub-aperture beam	1.5 kJ	≥ 1 kJ	< 1200 J
Pulse width	30 ps	≤100 ps	30 ps

We successfully integrated ARC with NIF and obtained the first data in support of the HED program



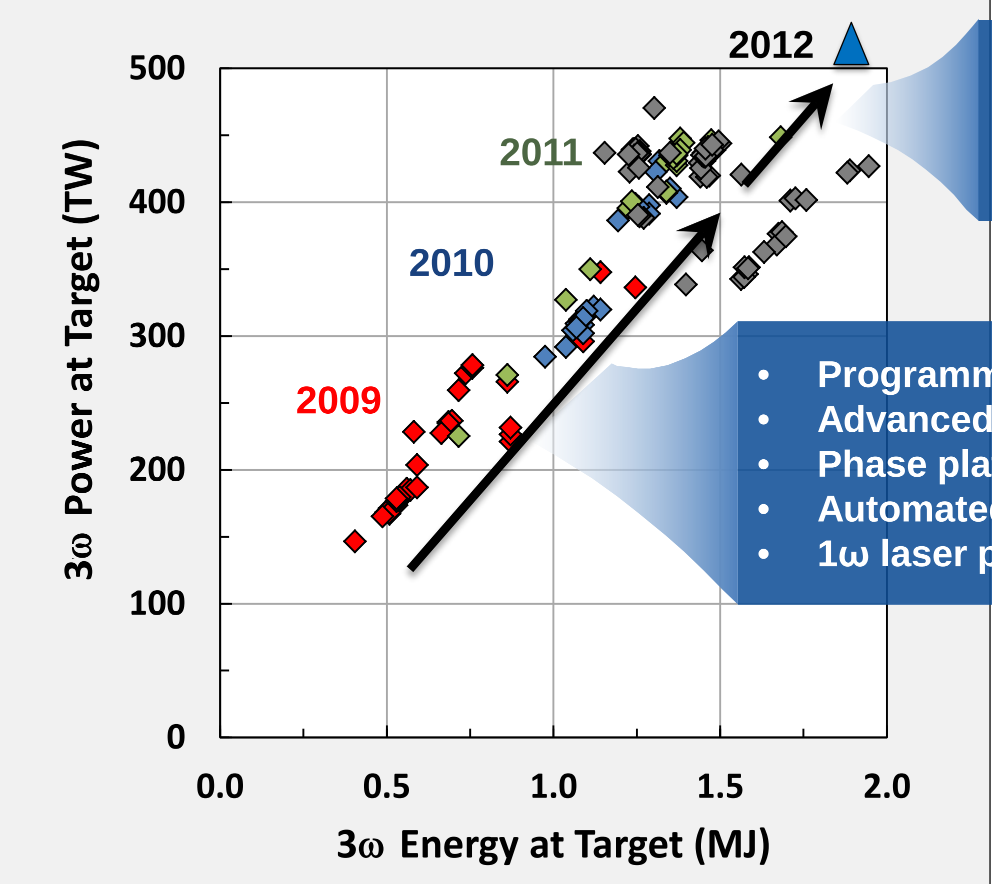


- **ARC operations and experimental team has addressed a number of integration issues, front-end stability, pre-pulse, unconverted light, background issues, new detectors**
- **ARC platforms and shots are now delivering a consistent performance**

ARC has now started operations at 10 ps

Between the initial commissioning (2009) and the end of the ignition campaign (2012) NIF steadily increased its laser energy & power available for experiments

Shaped pulses up to 1.9 MJ, 520 TW delivered to cryogenic implosion targets



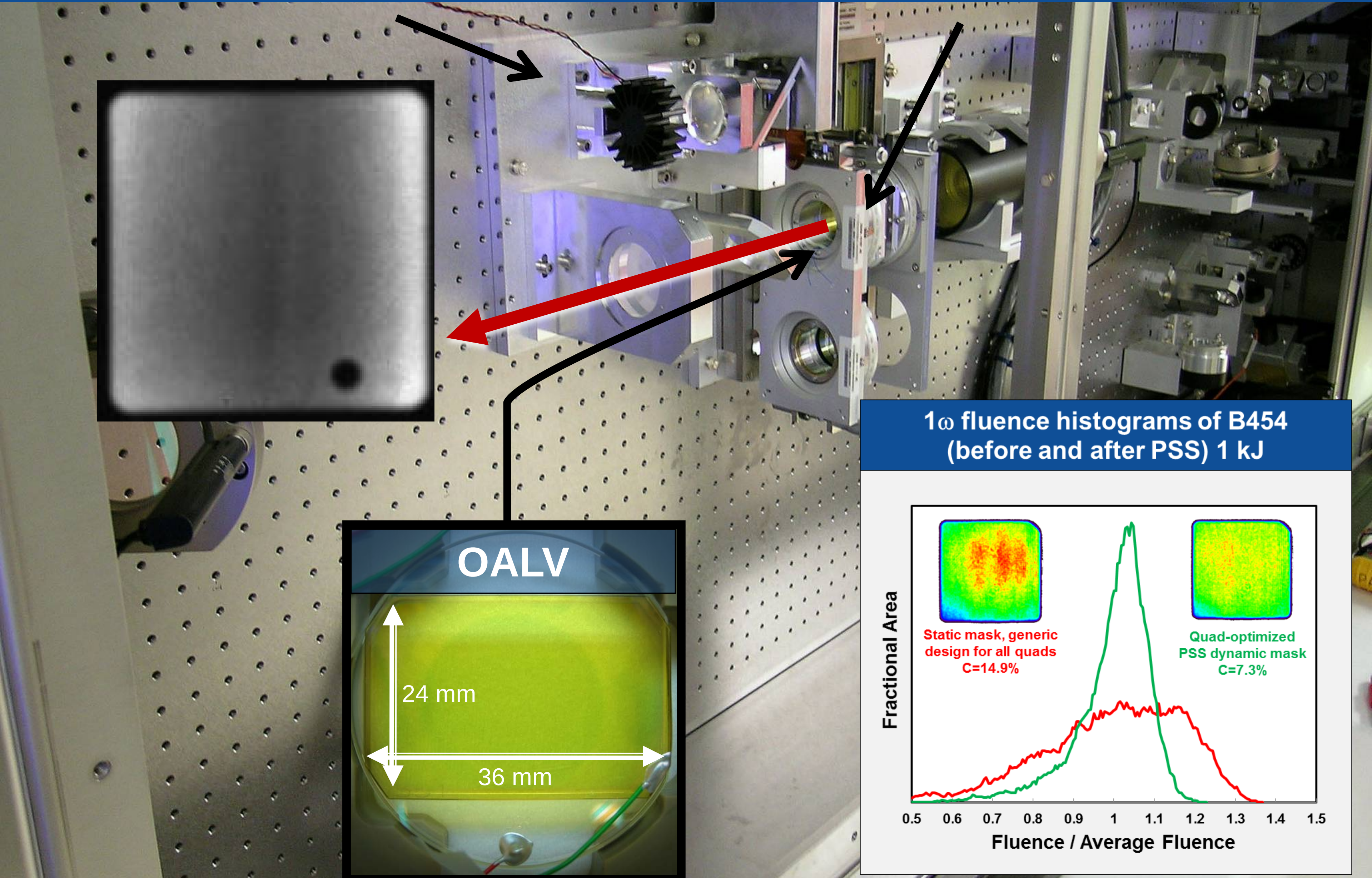
- Beam size optimization
- FM-AM control optimization
- Full optics recycle capacity
- Advanced-process 3ω debris shields

- Programmable spot blockers (1 per quad)
- Advanced-process 3ω lenses
- Phase plates moved to 2ω slot
- Automated disposable debris shields
- 1ω laser protection from target-area stray light

The NIF laser has capability for higher performance

- Substantial increases in performance are possible through improvement in beam uniformity (fill factor) and reductions in passive losses alone
  - Quad-optimized beam flattening with the programmable spatial shaper system (PSS)
  - Installation of deuterated vs un-deuterated KDP polarization rotators in the final optics
  - Application of anti-reflection coating on the 3w diagnostic sampling grating in the final optics
- Continued efforts to improve UV optics quality with the goal of lowering NIF operating costs also enable higher performance
  - AMP3 quality fused silica in the final optics
- The fielding and integrated testing of these improvements has recently been completed on a single NIF Quad (“Performance Quad”) to:
  - Re-assess the performance limits of the laser and update laser performance models
  - Extend exisiting optics damage models to higher fluence to better predict cost of operation at increased energy and/or power

The NIF Programmable Spatial Shaper (PSS) is installed in the PAM and allows for dynamic spot blocker <u>and</u> quad-based beam flattening



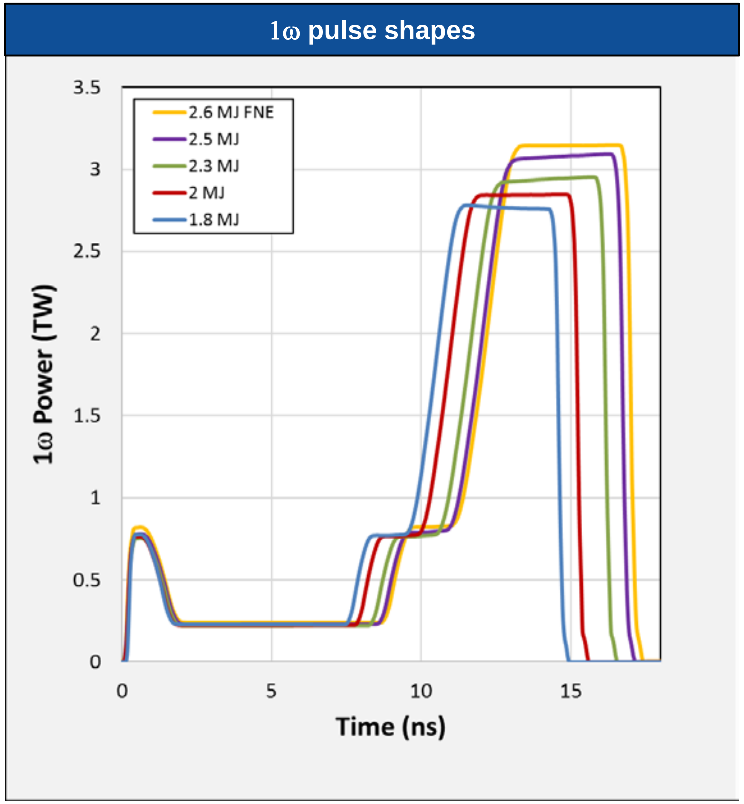
"National Ignition Facility Laser System Performance" M. Spaeth et al., Fusion Sc. and Tech. **69** (2016)

The Performance Quad Power and Energy (PE) campaign was conducted in 3 phases

1ω PE campaign

- Phase I **(8 shots)**
  - Preparation of the 1ω Main Laser
  - Ramp up to 21 kJ/beam pulse shapes consistent with 2.6 MJ, 480 TW full-NIF
  - Calibrate 1ω detectors against calorimeters
  - Demonstrate PSS quad-based beam flattening
  - Demonstrate 1ω energy and pulse shape consistent with the 3ω requirements
  - Validate 1ω model at elevated energy

Target physics-relevant pulse, hydro-scaled high-foot pulses (9.3e15 neutron yield class)

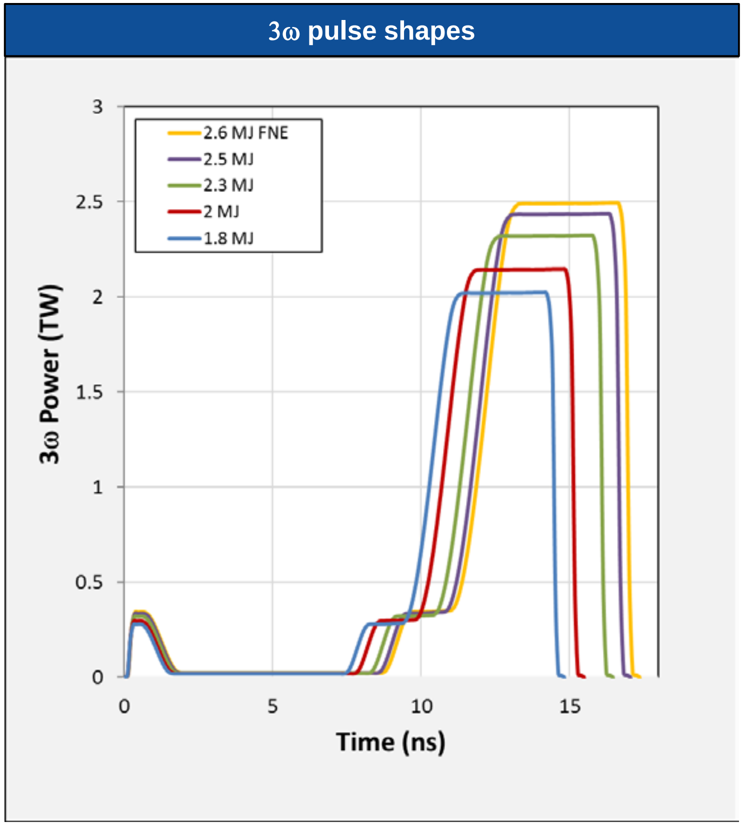


The Performance Quad Power and Energy (PE) campaign was conducted in 3 phases (cont'd)

3ω PE campaign

- Phase II **(5 shots)**
  - **5 shots:** shots to ramp-up and condition optics (1ω transport mirrors and frequency conversion crystals) to the highest fluence levels corresponding to 2.6 MJ.
  - Validate the 3ω model fidelity at TCC up to 2.6MJ, 480 TW NIF equivalent
- Phase III **(6+6 shots)**
  - Sustained shots at elevated energy interleaved with 1 MJ "cleaning shots"
  - Perform assessment of optics impact & update damage/lifetime models

Target physics-relevant pulse, hydro-scaled high-foot pulses (9.3e15 neutron yield class)

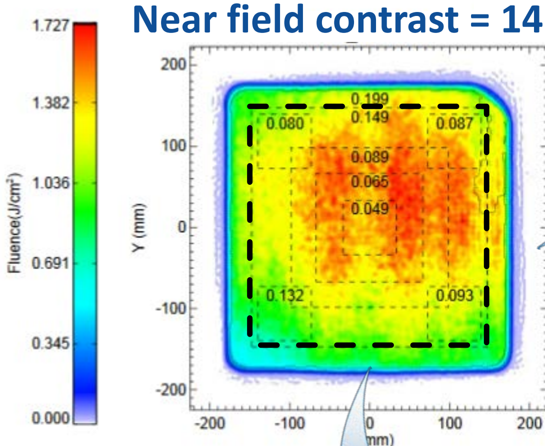


Beam flattening at main laser output was optimized at low energy and verified at high energy

No beam flattening | **With beam flattening**

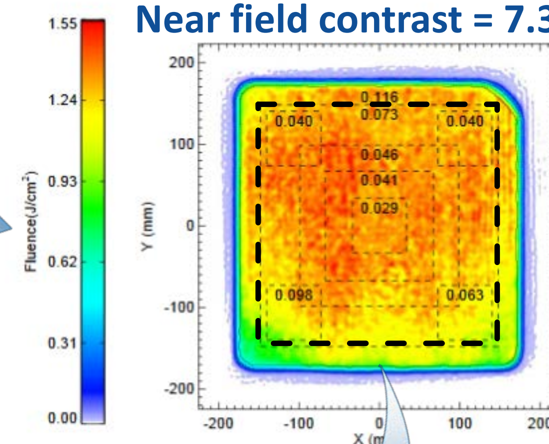
Low Energy
1.5 kJ/beamline

Near field contrast = 14.9%



PSS

Near field contrast = 7.3%

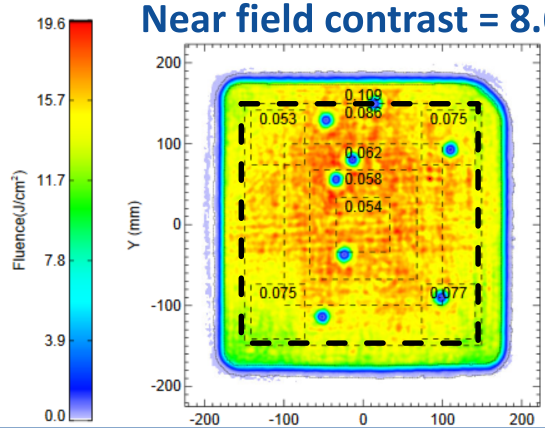


2012

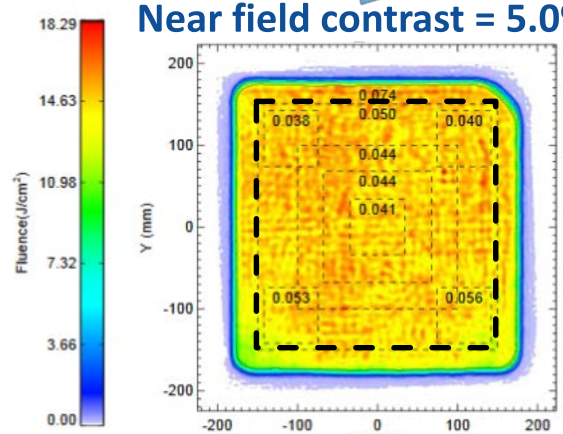
2017

High Energy
18 kJ/beamline 1ω
(3ω 1.9 MJ / 500TW)

Near field contrast = 8.6%*



Near field contrast = 5.0%



* Spot blockers are excluded from analysis not to bias the contrast

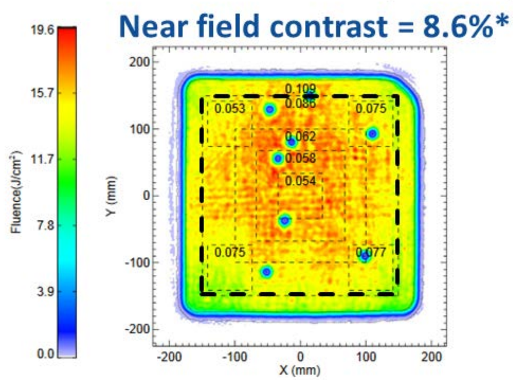
Substantial improvements are also demonstrated in saturated regime

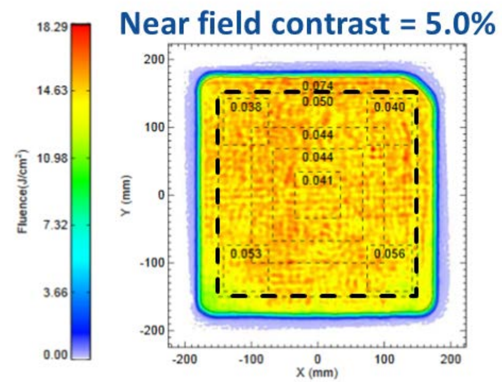
Substantial improvement achieved in the tail of the fluence distribution for 1.9MJ / 500TW conditions

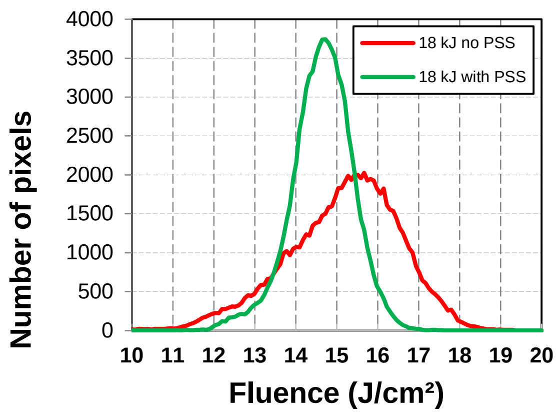
High Energy

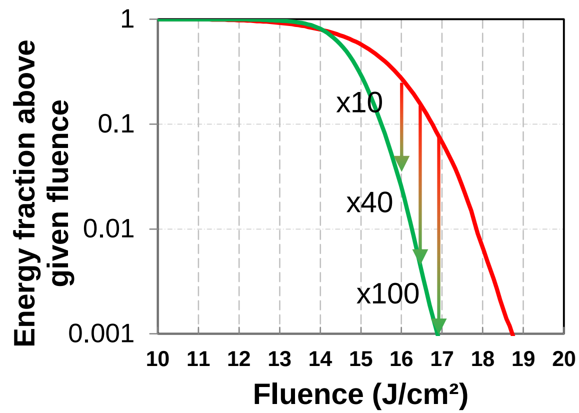
18 kJ/beamline 1ω

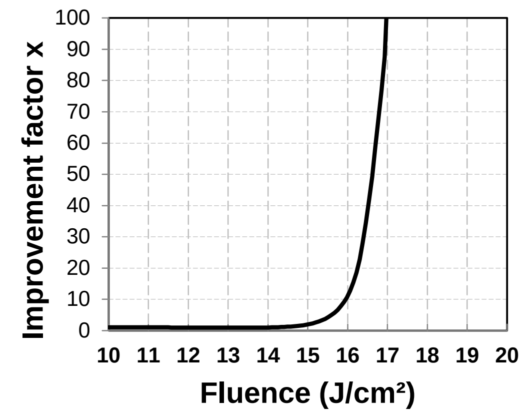
(3ω 1.9 MJ / 500TW)











* Fluence was compensated
for spot blockers obscuration

Without PSS ~ 10% energy above 16 J/cm²

**Without PSS Beam non-uniformity persist even at very saturated regimes.
PSS beam flattening is able to reduce the high fluence tail**

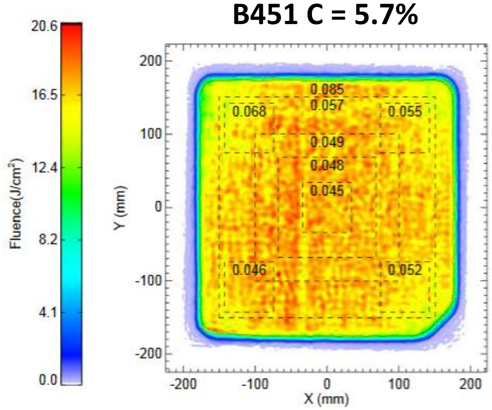
1ω beam quality of 5-6% contrast was consistently achieved on all four beams in the performance quad

High Energy

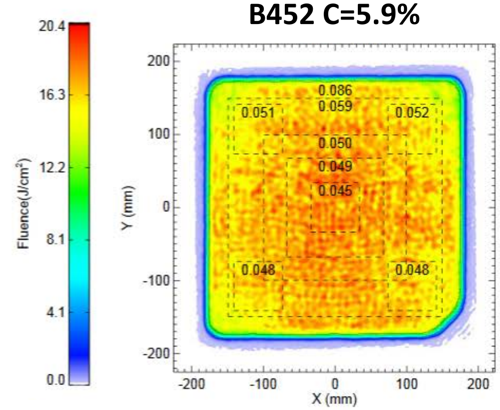
20-21 kJ/beamline 1ω

(3ω 2.6 MJ / 480TW full-NIF)

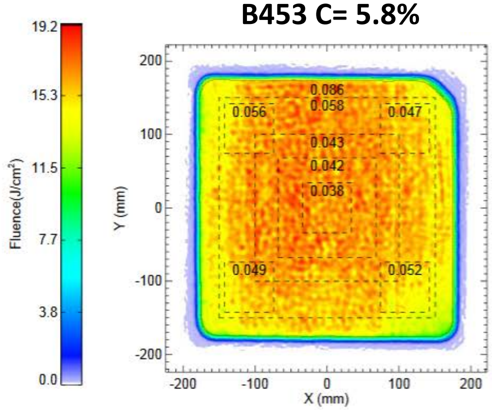
B451 C = 5.7%



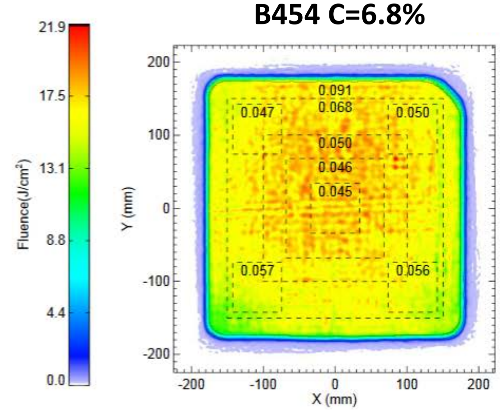
B452 C=5.9%



B453 C= 5.8%



B454 C=6.8%



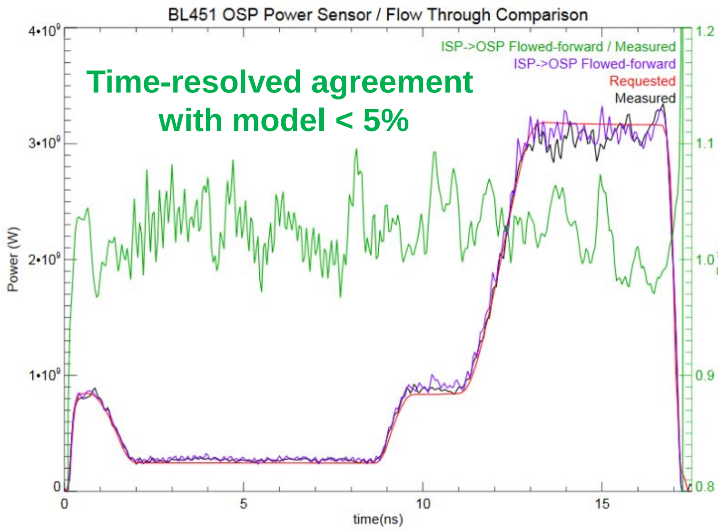
High quality beams are obtained, lowering machine safety risks at elevated fluence

Models match measured performance 1ω to a high degree of accuracy

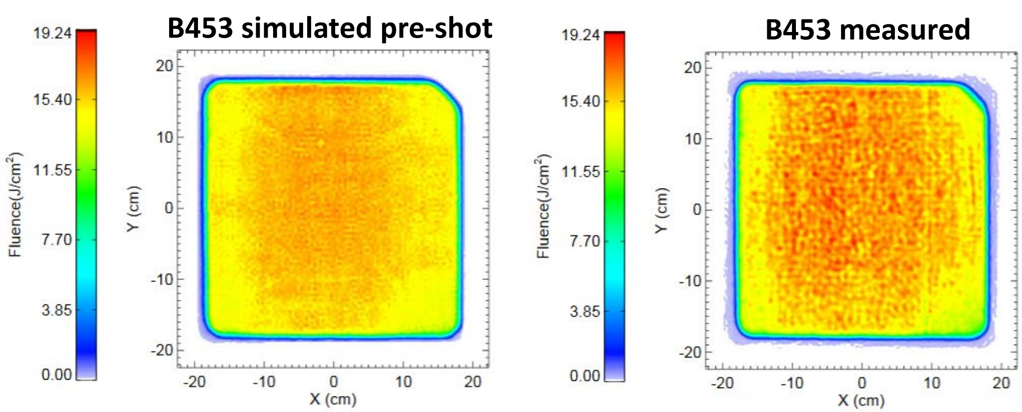
Energetics 1ω

Beam	OSP req. (kJ)	OSP meas. (kJ)	Diff (%)
B451	20.89	20.75	-0.7
B452	20.42	20.32	-0.5
B453	19.81	19.73	-0.4
B454	20.89	20.62	-1.3

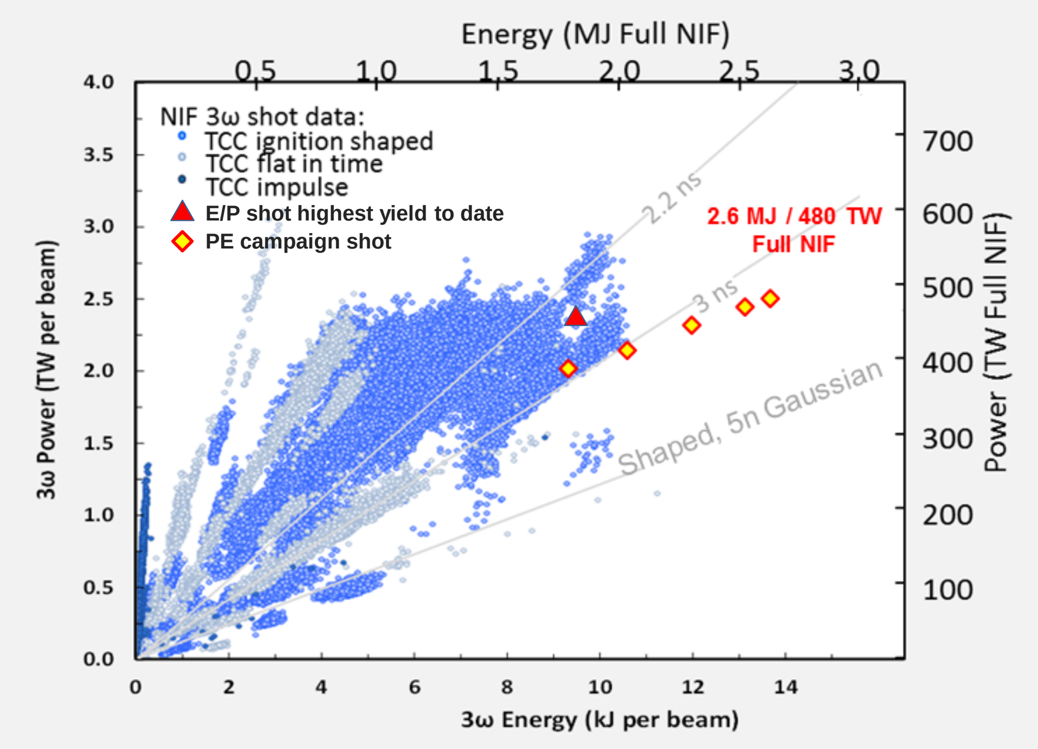
1ω pulse shape

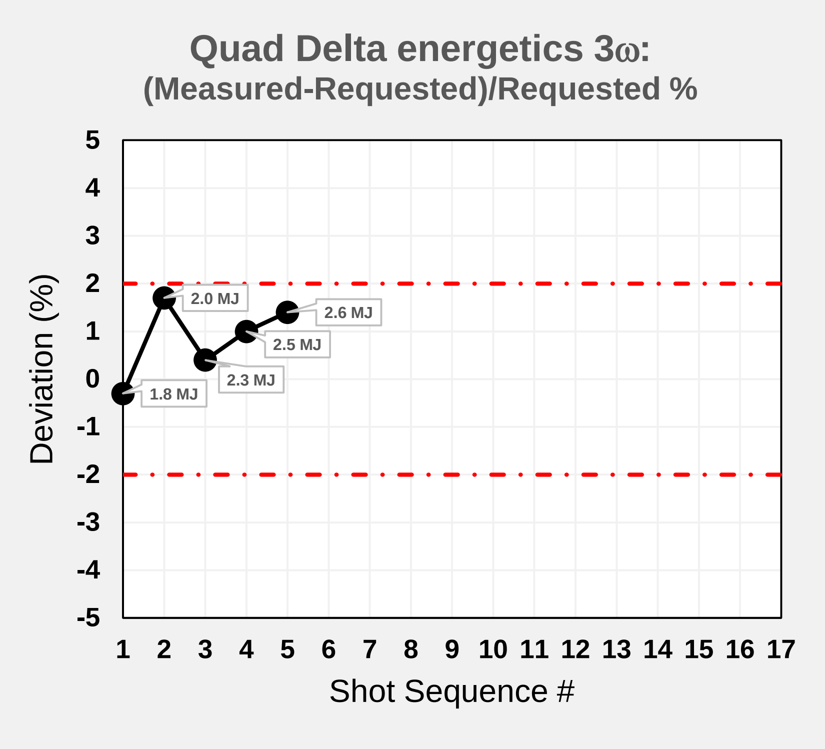


Near fields 1ω



Performance quad 3ω ramp to 13.7 kJ/beam (2.6 MJ full-NIF equivalent) successfully completed on March 9th





Highest 3ω energy on a single laser aperture to date

Highest NIF 3ω energy to date for a beam (14.04 kJ) and a quad (54.61 kJ) representing 2.62 MJ full-NIF

Shot ID: N170309-001-999

Campaign: Fa_LSR_PerfPE_Quad3w Exp: S06a

PI: Mennerat, Gabriel

Quad: Q45T Outer 44.5°

Shot Time: 09-MAR-17 10:48:35

Descr: PerfPE Quad Exp. #5: Q45T ramp-up conditioning shot to TCC at 2.6 MJ FNE using OH1HiFt_2.502_468_Out

Verification | TCC | Setup | Equip Protection | Shot Report | Raw Data | Images | Diagnostics | Debug

ISP 1 ω Energy

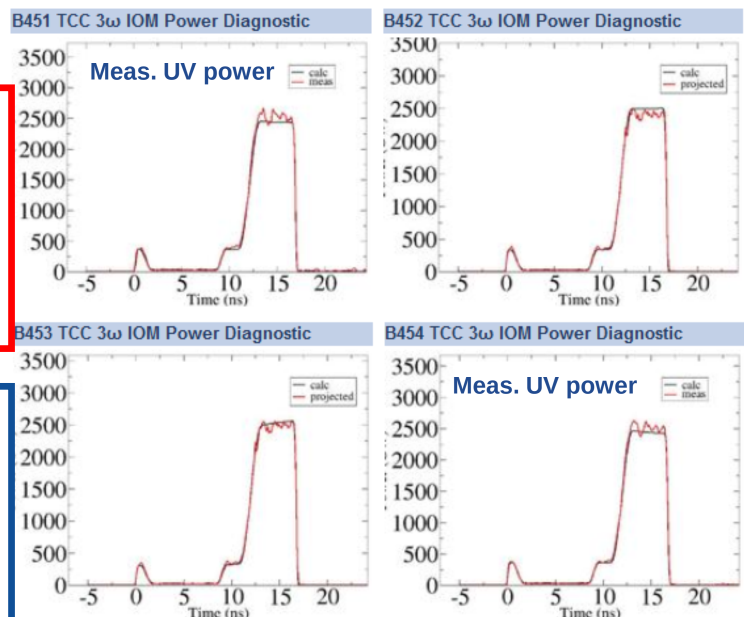
	Request	Meas	Diff (%)
ISP J	2.053	2.13	3.7

Delivered 1ω Energy

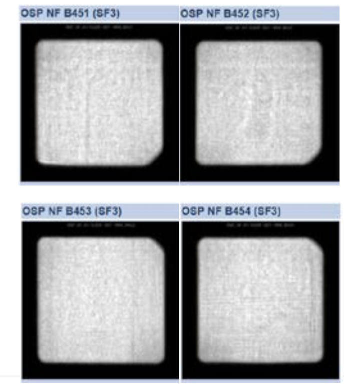
	Request	Meas	Diff (%)	Predict	Diff (%)
B451 kJ	20.9	20.87	-0.2	21.18	-1.5
B452 kJ	20.43	20.47	0.2	20.71	-1.1
B453 kJ	19.78	19.81	0.2	20.06	-1.2
B454 kJ	20.89	20.84	-0.3	21.17	-1.6
Q45T kJ	82	81.99	-0.0	83.12	-1.4

Delivered 3ω Energy

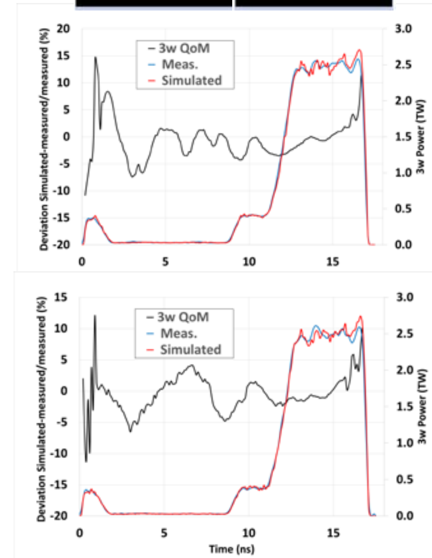
	Request	Meas	Diff (%)	Predict	Diff (%)
B451 kJ	13.45	14.04	4.4	13.47	4.3
B452 kJ	13.49	13.22	-2.0	13.56	-2.5
B453 kJ	13.51	13.48	-0.2	13.58	-0.7
B454 kJ	13.4	13.87	3.5	13.44	3.2
Q45T kJ	53.85	54.61	1.4	54.05	1.0



Measured IR near fields

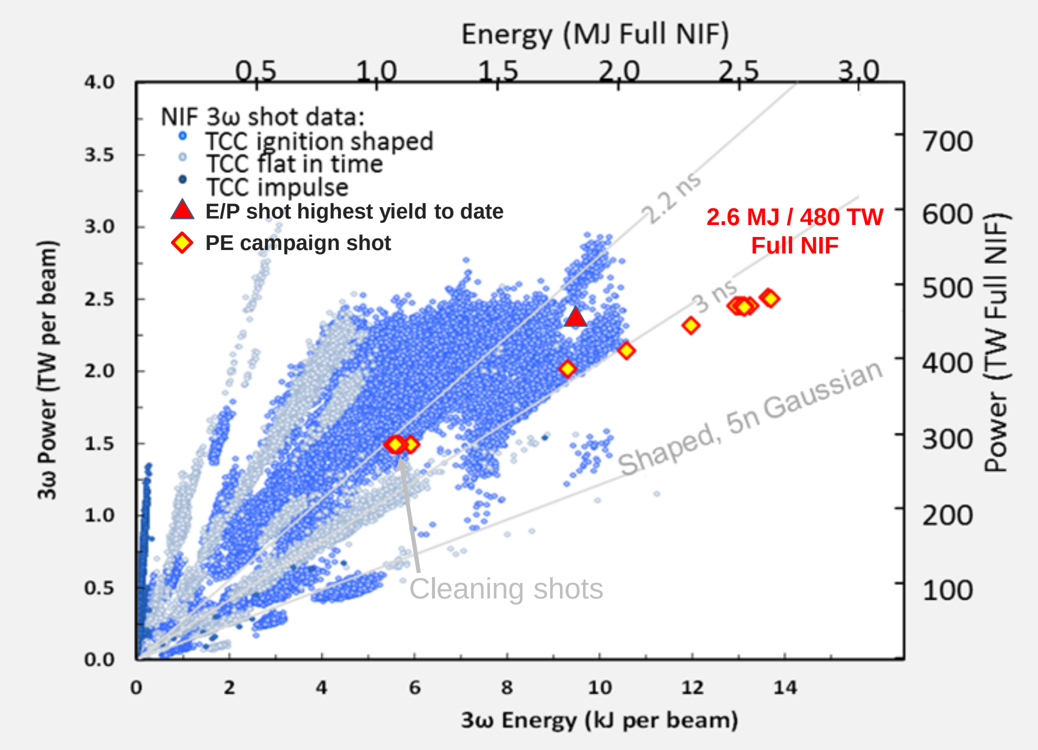


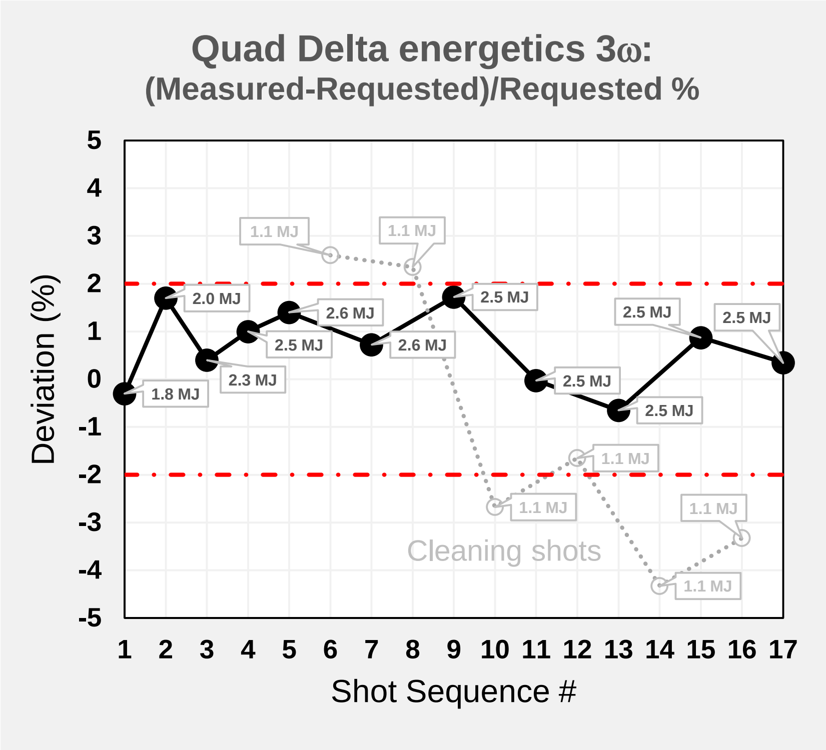
3ω Time-resolved quality of model



Excellent laser performance: Quad energy 1.4% from request Ignition quality 3w pulse shapes

Sustained series of shots at elevated 3w energy completed for UV optics testing





- Optics damage results are highly encouraging and will be reported elsewhere
- Spot blocker shape and beam edge still require some optimization for increased margin at elevated power and B-integral