OMEGA EP UV Prediction Model for Enhanced Operational Performance

M. J. GUARDALBEN, M. SPILATRO, L. J. WAXER, and M. BARCZYS

University of Rochester, Laboratory for Laser Energetics

Summary

Accurate and rapid prediction of UV energy and pulse shapes has greatly enhanced OMEGA EP's agility on shot day

- The code *PSOPS* is used to predict the pulse shape, energy, and near-field beam-fluence distribution in the long-pulse beamlines of OMEGA EP
- Essential features of *PSOPS*
  - accurate, nearly real-time predictions of expected performance of all four OMEGA EP beamlines within a fraction of the OMEGA EP shot cycle
  - an intuitive, easy-to-use interface for laser operators
  - rapid optimization capability of the code between laser shots to fine-tune predictions based on shot performance
  - forward and backward prediction capabilities

The real-time UV prediction model *PSOPS* has enabled rapid and flexible response to Principal Investigator (PI) requests for increasingly complex pulse shapes that span a wide range of energies.

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PSOPS has provided greater shot-day flexibility by enabling rapid optimization in key areas

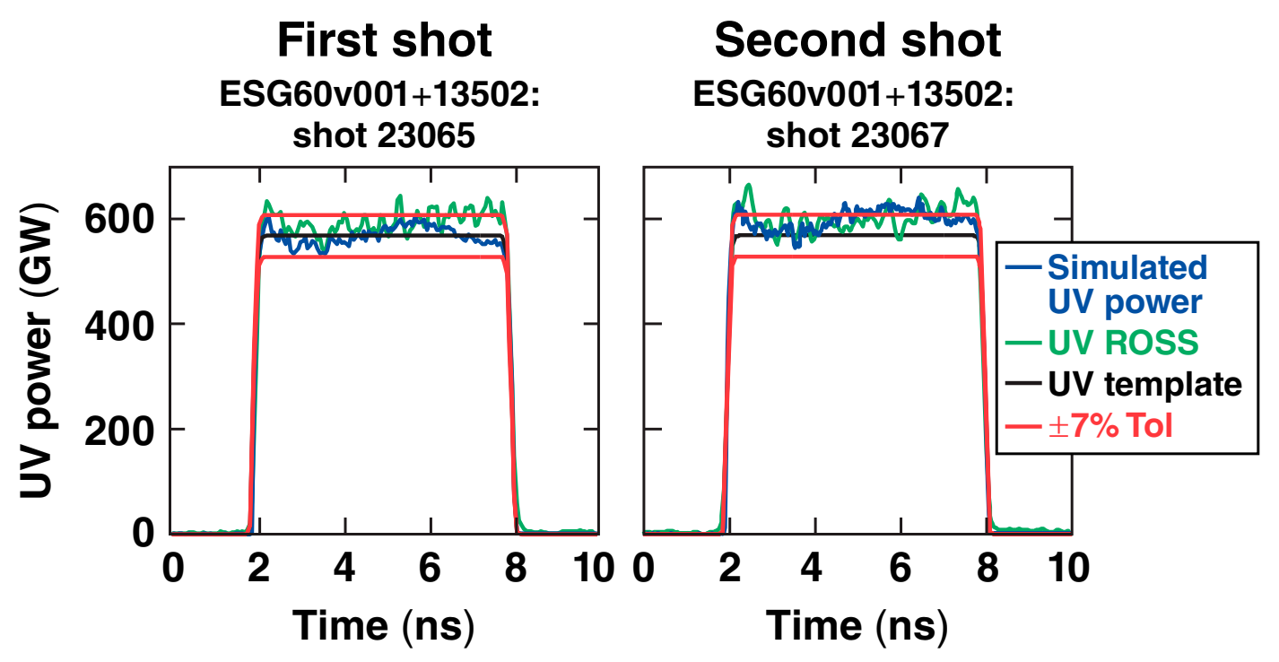
1) Rapid determination of front-end energy and pulse-shape modifications required to compensate for
   - loss of gain from amplifier flash-lamp degradation
   - spatial variations in saturated gain from changes in injected beam profile
   - spatiotemporal variations in regenerative amplifier performance
2) Fine-tuning of on-target energy and pulse shape based on real-time analysis of experimental data
3) Prediction can be optimized between shots based on measured pulse power
4) Prior to shot day, backward prediction is also used to design the required beamline-injected temporal pulse shapes that are needed to generate a wide range of UV pulse shapes on target

G10756

The prediction can be optimized between shots based on measured pulse power

Beam 1 recalibration on March 22, 2016

- Small changes in beamline gain and losses resulted in an ~5% discrepancy between measured and simulated UV energy on the first shot
- Optimized UV simulation was within ~1% of measurement on the second shot



		First shot	Second shot
IR switchyard energy (J)	Simulated	6570	6786
	Measured	6779	6842
UV on-target energy (J)	Simulated	3385	3570
	Measured	3564	3611

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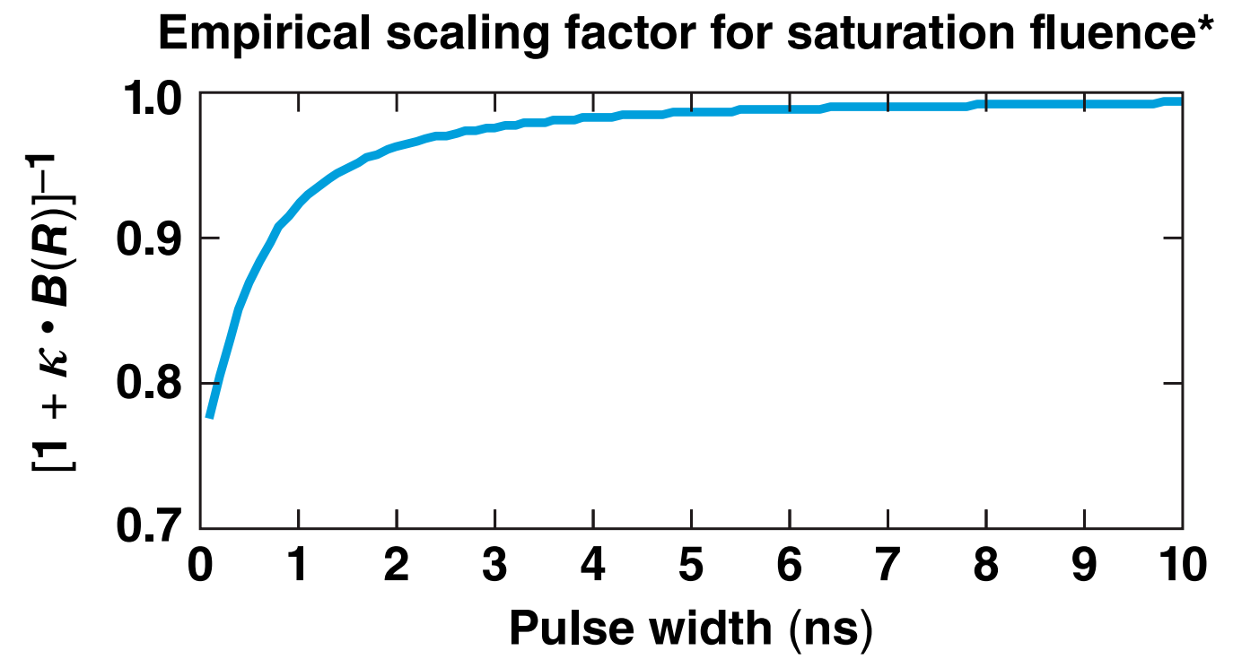
An empirical scaling factor is used for saturation fluence dependence on pulse width

Empirical scaling factor for saturation fluence*



- The terminal level of the laser transition has a finite lifetime
- At shorter pulse widths stimulated emission and absorption processes become competitive, causing re-excitation of the Nd-ion population into the upper-laser level
- The effective saturation fluence is reduced for shorter pulse widths per the empirical scaling factor shown

G10762

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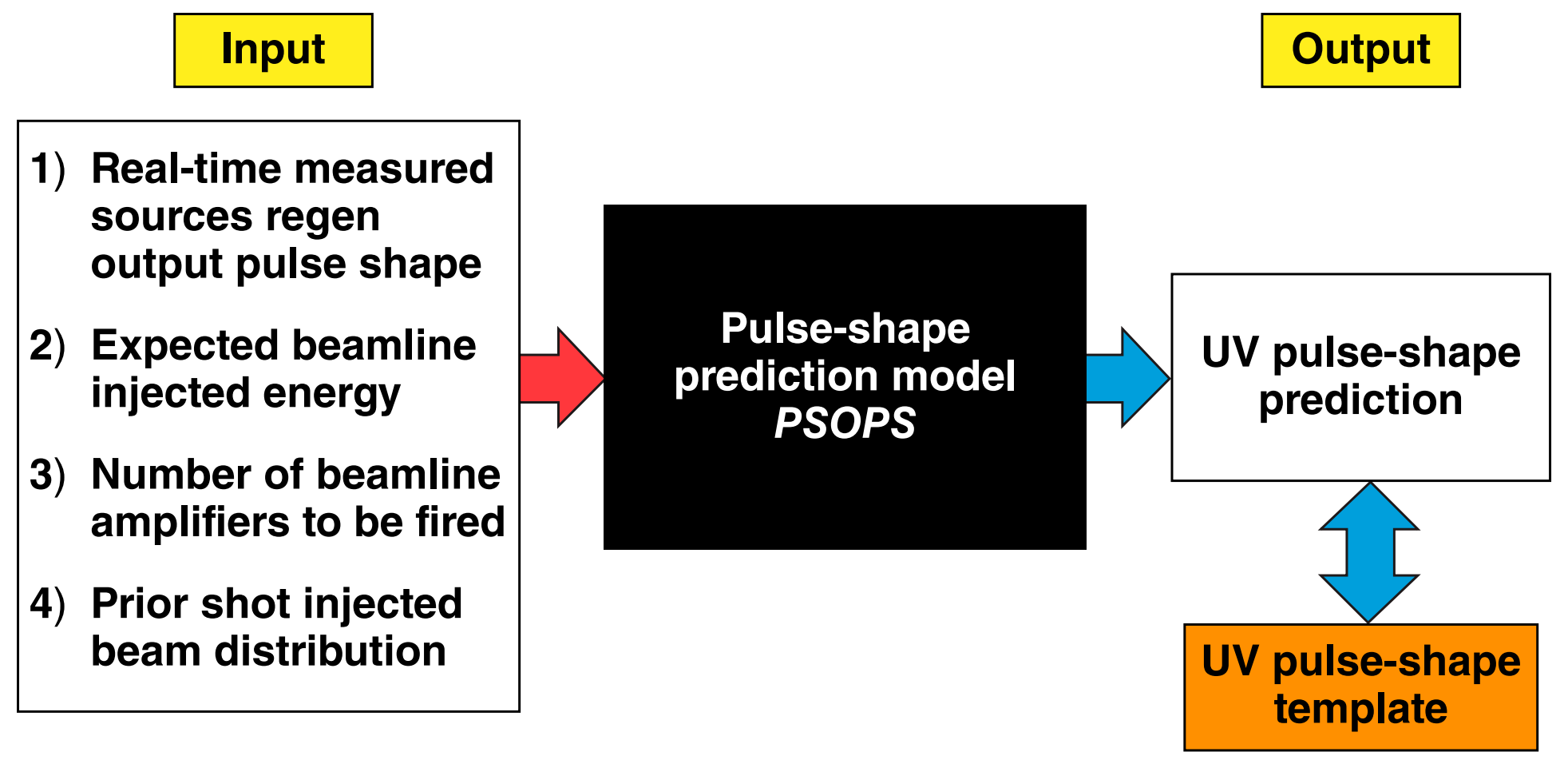
*C. Bibeau, J. B. Trenholme, and S. A. Payne, IEEE J. Quantum Electron. 32, 1487 (1996).

UV pulse power is predicted in nearly real time using inputs to amplifier chain and compared to requested UV pulse

Forward prediction



Input

1) Real-time measured sources regen output pulse shape
2) Expected beamline injected energy
3) Number of beamline amplifiers to be fired
4) Prior shot injected beam distribution

Pulse-shape prediction model *PSOPS*

Output

UV pulse-shape prediction

UV pulse-shape template

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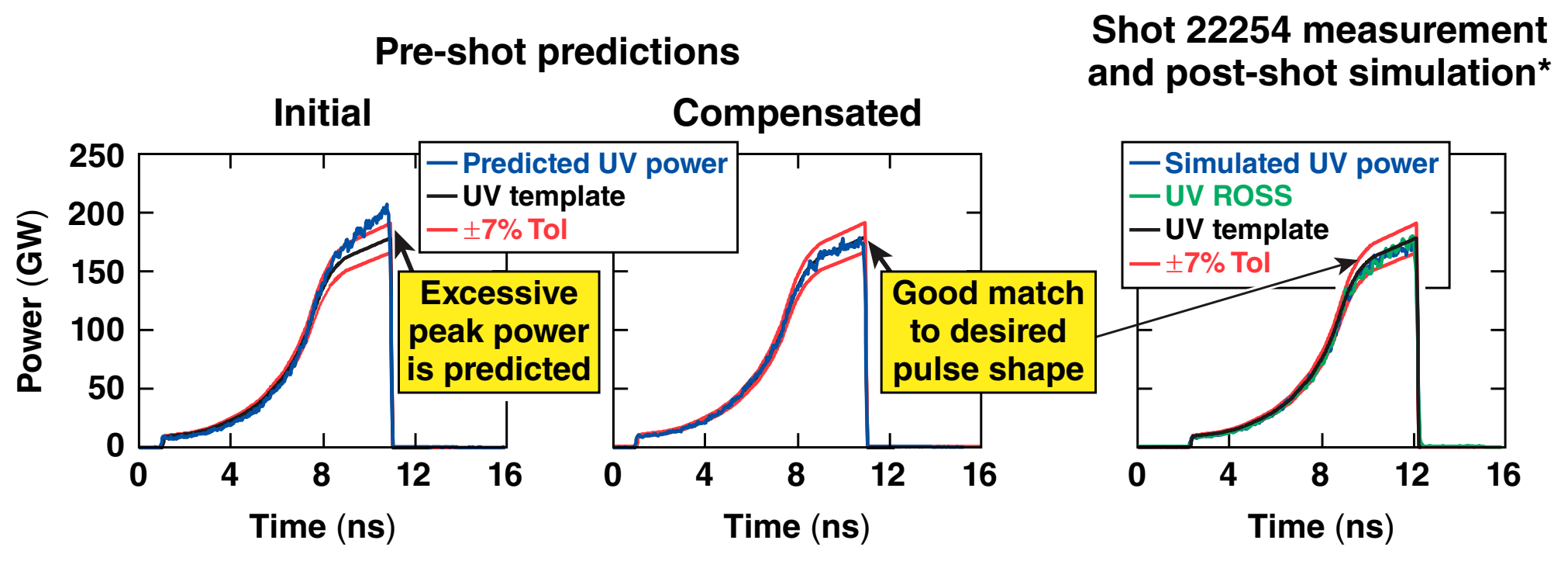
Rapid compensation can be made for small changes in system performance

Beam 3 UV pulse shape ERM99v021 + 31001
November 19, 2015



On-target UV energy (J)	
Requested	775
Measured	751
Post-shot simulated*	752

G10757

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*Simulated using measured beamline-injected energy and regen output pulse shape for shot 22254

Analytic solutions* to the rate equations for a homogeneously saturating thin slab are used for rapid predictions of beamline output

Forward prediction

$$I_{out}(t,x,y) = \beta^2 G_n(t,x,y)\, I_{in}(t,x,y)$$

$$G_n(t,x,y) = \frac{G_0}{G_0 - (G_0 - 1)\exp\left[-U_{in}(t,x,y)/U_{sat}\right]}$$

$$U_{in}(t,x,y) = \int_{t_0}^{t} \beta I_{in}(t,x,y)\,dt$$

Backward prediction

$$I_{in}(t,x,y) = I_{out}(t,x,y)/[\beta^2 G_n(t,x,y)]$$

$$G_n(t,x,y) = 1 + (G_0 - 1)\exp[-U_{out}(t,x,y)/U_{sat}]$$

$$U_{out}(t,x,y) = \int_{t_0}^{t} \left[I_{out}(t,x,y)/\beta\right]dt$$

$I_{in}(t)$ = input pulse of disk *n*
$I_{out}(t)$ = output pulse of disk *n*
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β = per-disk-surface scaling factor
G_0 = single-disk small-signal gain
σ = inferred emission cross section
$U_{sat} = h\nu/2\sigma$ (saturation fluence)

- Each disk is treated as a thin slab and equations are applied iteratively per disk
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- Frequency conversion to the third harmonic uses look-up tables from *MIXER* calculations
- Optimization to measured power adjusts β and σ

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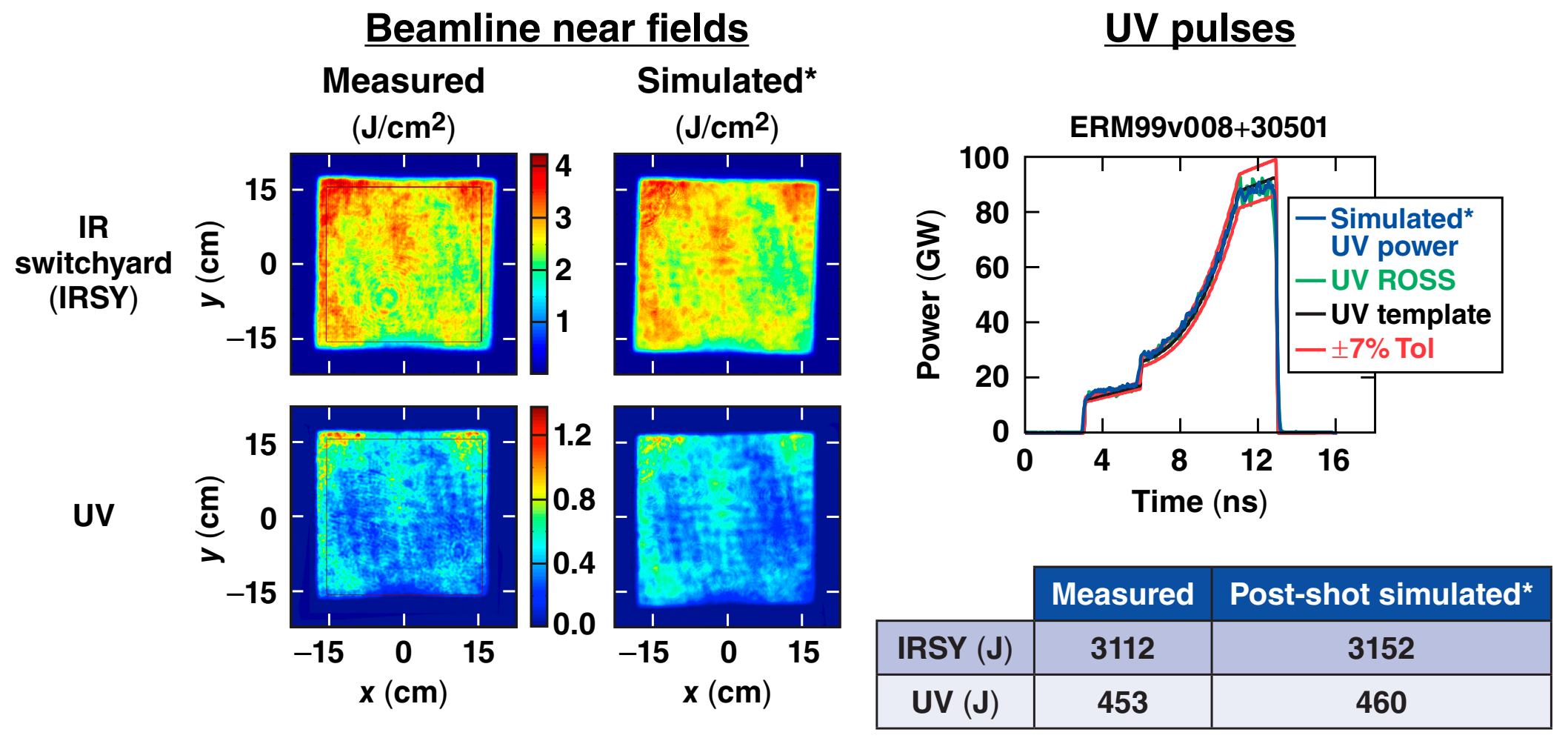
*A. E. Siegman, *Lasers* (University Science Books, Mill Valley, CA, 1986), Chap. 10.

Spatial and temporal simulations are in excellent agreement with measurements

Beamline 3 shot 20678
April 16, 2015



	Measured	Post-shot simulated*
IRSY (J)	3112	3152
UV (J)	453	460

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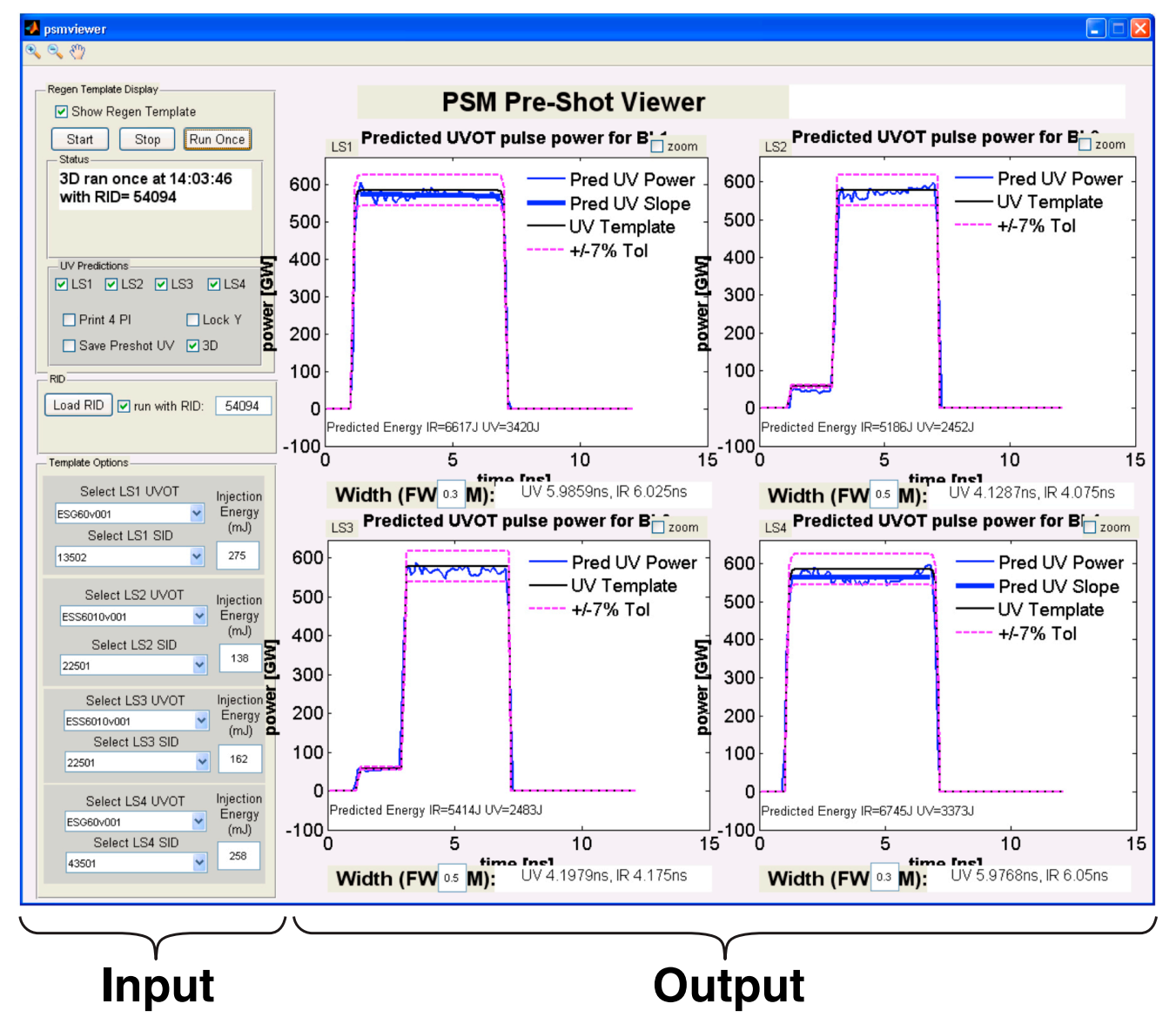
*Simulated using measured beamline-injected energy and regen output pulse shape for shot 20678

The graphical user interface allows laser operators to rapidly adjust pulse shapes between shots



☑ Show Regen Template

3D ran once at 14:03:46 with RID= 54094

☑ LS1 ☑ LS2 ☑ LS3 ☑ LS4
☐ Print 4 PI ☐ Lock Y
☐ Save Preshot UV ☑ 3D

☑ run with RID: 54094

		Injection Energy (mJ)
Select LS1 UVOT: ESG60v001	Select LS1 SID: 13502	275
Select LS2 UVOT: ESS6010v001	Select LS2 SID: 22501	138
Select LS3 UVOT: ESS6010v001	Select LS3 SID: 22501	162
Select LS4 UVOT: ESG60v001	Select LS4 SID: 43501	258

LS1: Predicted Energy IR=6617J UV=3420J; Width (FW 0.3 M): UV 5.9859ns, IR 6.025ns
LS2: Predicted Energy IR=5186J UV=2452J; Width (FW 0.5 M): UV 4.1287ns, IR 4.075ns
LS3: Predicted Energy IR=5414J UV=2483J; Width (FW 0.5 M): UV 4.1979ns, IR 4.175ns
LS4: Predicted Energy IR=6745J UV=3373J; Width (FW 0.3 M): UV 5.9768ns, IR 6.05ns

- Predicted UV power is compared to the requested UV pulse-shape template
- Predicted on-target UV energy and IR beamline energy are also displayed

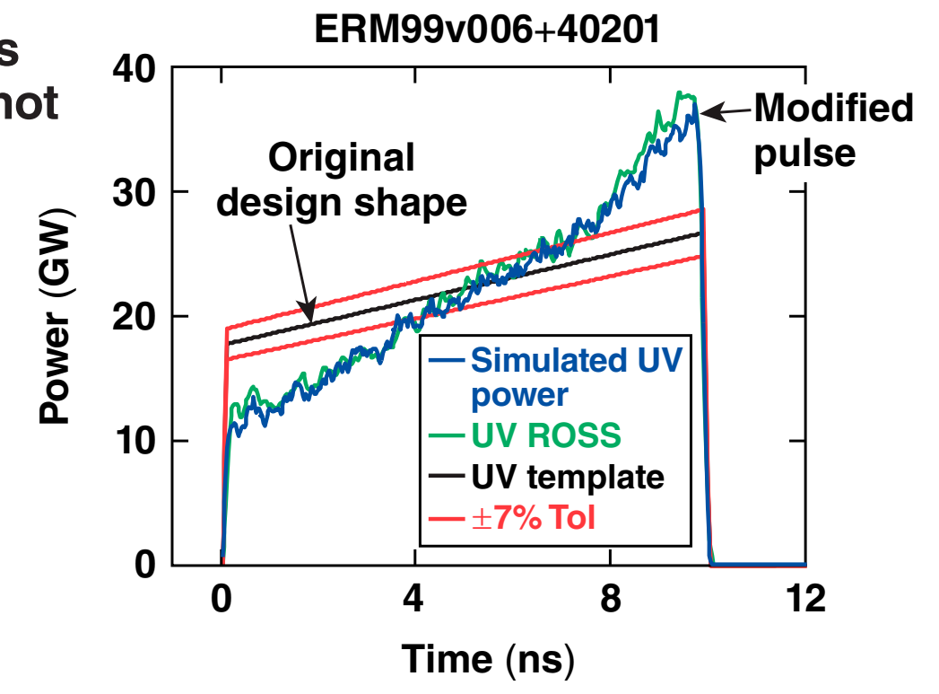
G10755

PSOPS has enabled fine-tuning of on-target UV pulse shape and energy between laser shots

- Based on analysis of data from previous shot, a significant increase in the slope of the UV pulse was desired while maintaining 220-J UV on-target energy
- Front-end pulse shape and throttles were adjusted per the *PSOPS* pre-shot prediction
- The post-shot *PSOPS* simulation closely matched the measured UV-ROSS on-target pulse power

On-target UV energy (J)	
Requested	220
Measured	222
Post-shot simulated	217

UV pulses
Beam 4 Shot 20647
April 14, 2015



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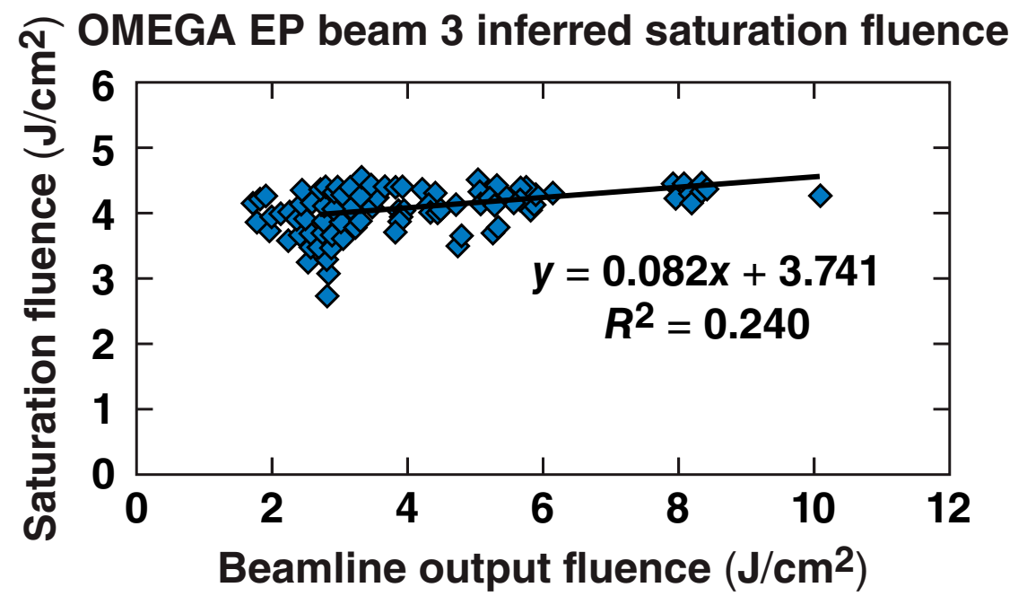
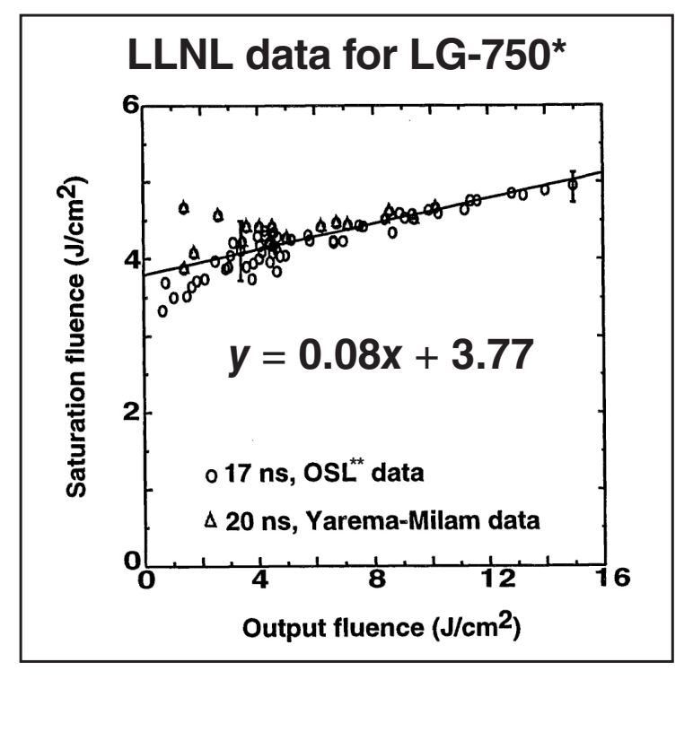
Dependence of saturation fluence on beamline output fluence is taken into account

Effective saturation fluence is higher at higher beamline fluences, owing to an inhomogeneous broadening effect*





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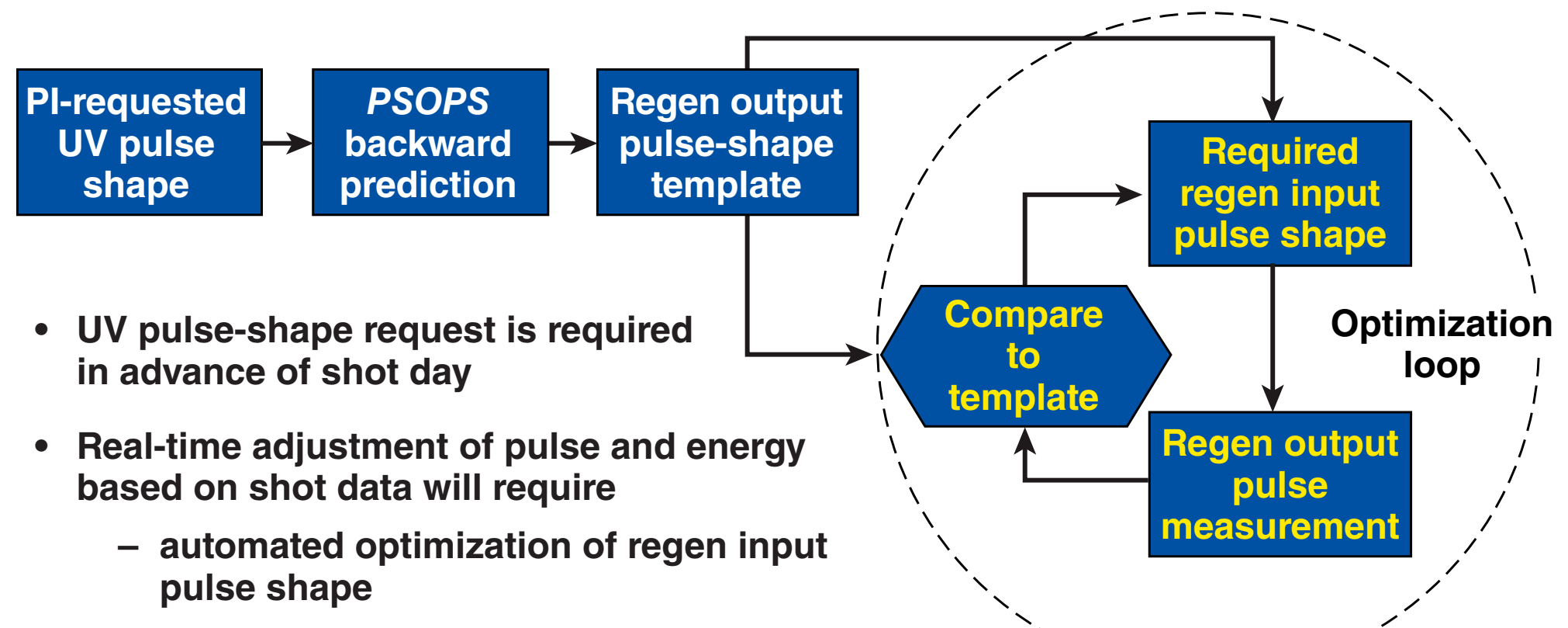
*D. M. Pennington, D. Milam, and D. Eimerl, Proc. SPIE 3047, 630 (1997). Plot shown on the right is Fig. 5(b). OMEGA EP's LHG-8 glass (Hoya), has similar glass composition to LG-750 (Schott).

**OSL: Optical Sciences Laser at Lawrence Livermore National Laboratory (LLNL)

Future Work

PSOPS is a first step toward offering greater flexibility to refine energy and pulse shape on shot day



PI-requested UV pulse shape

PSOPS backward prediction

Regen output pulse-shape template

Required regen input pulse shape

Compare to template

Regen output pulse measurement

Optimization loop

- UV pulse-shape request is required in advance of shot day
- Real-time adjustment of pulse and energy based on shot data will require
  - automated optimization of regen input pulse shape
  - range of safe energy and pulse-shape adjustment identified
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***PSOPS* has provided a foundation for offering real-time energy and pulse-shape refinements on OMEGA EP.**

G10795

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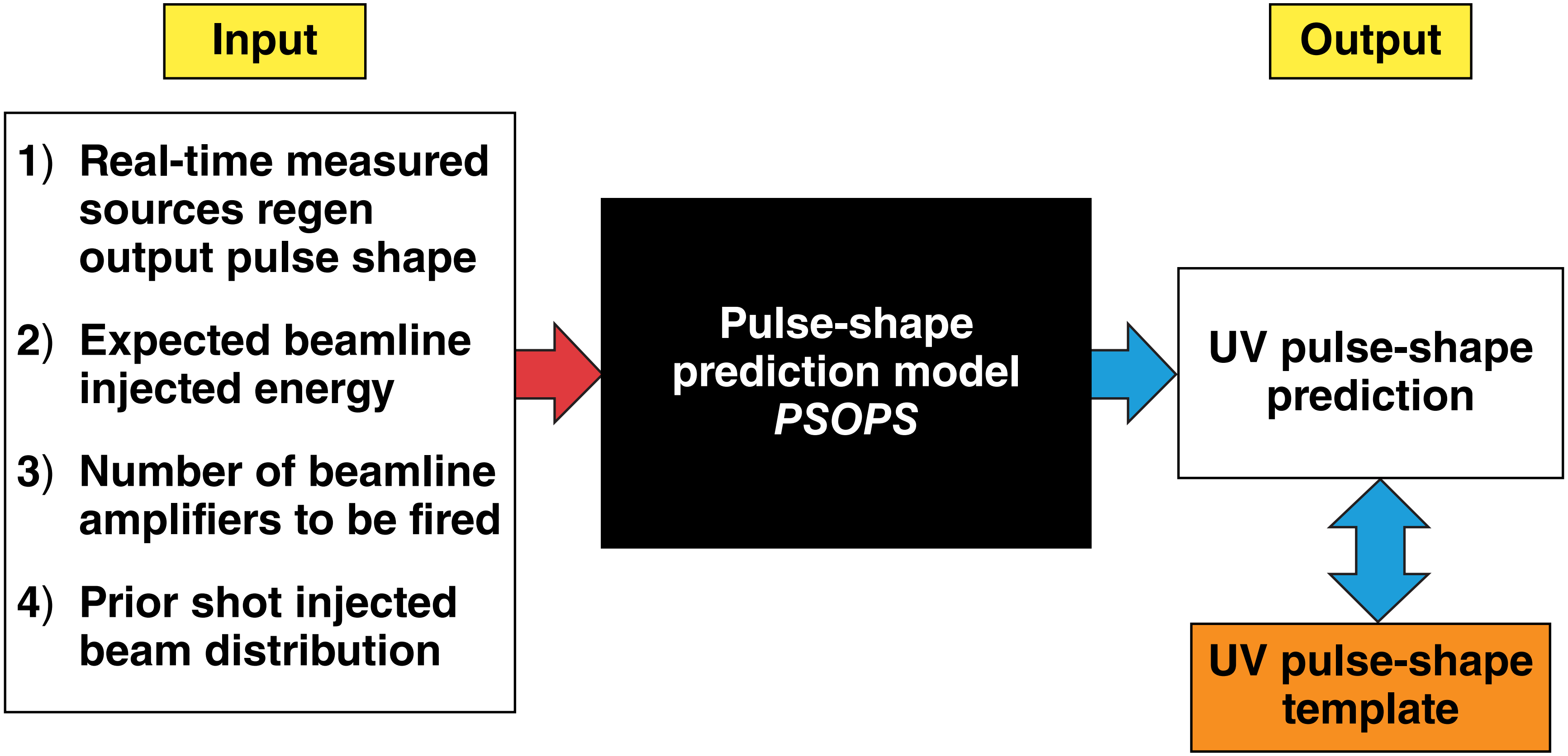
UV pulse power is predicted in nearly real time using inputs to amplifier chain and compared to requested UV pulse

Forward prediction



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UV pulse-shape template

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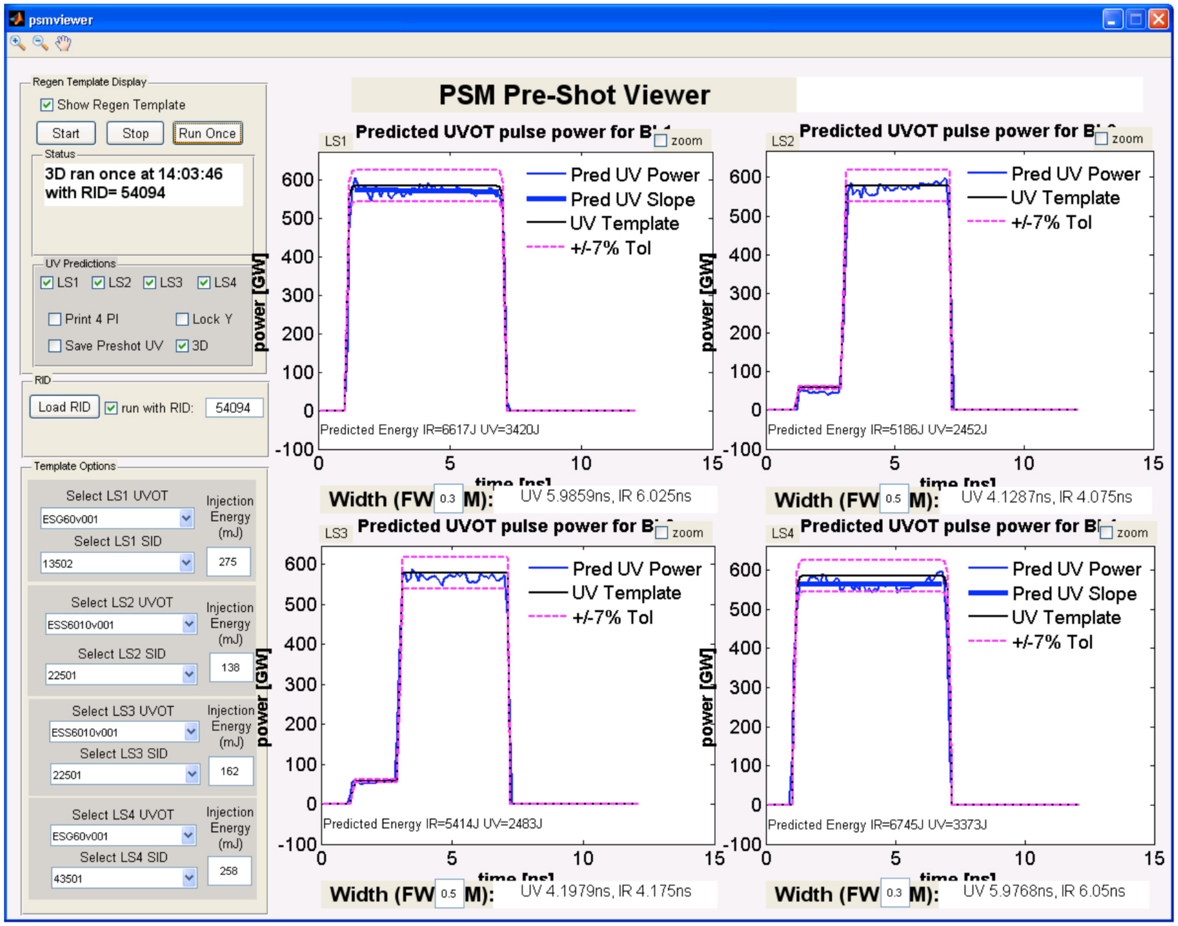

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UV Predictions: ☑ LS1 ☑ LS2 ☑ LS3 ☑ LS4

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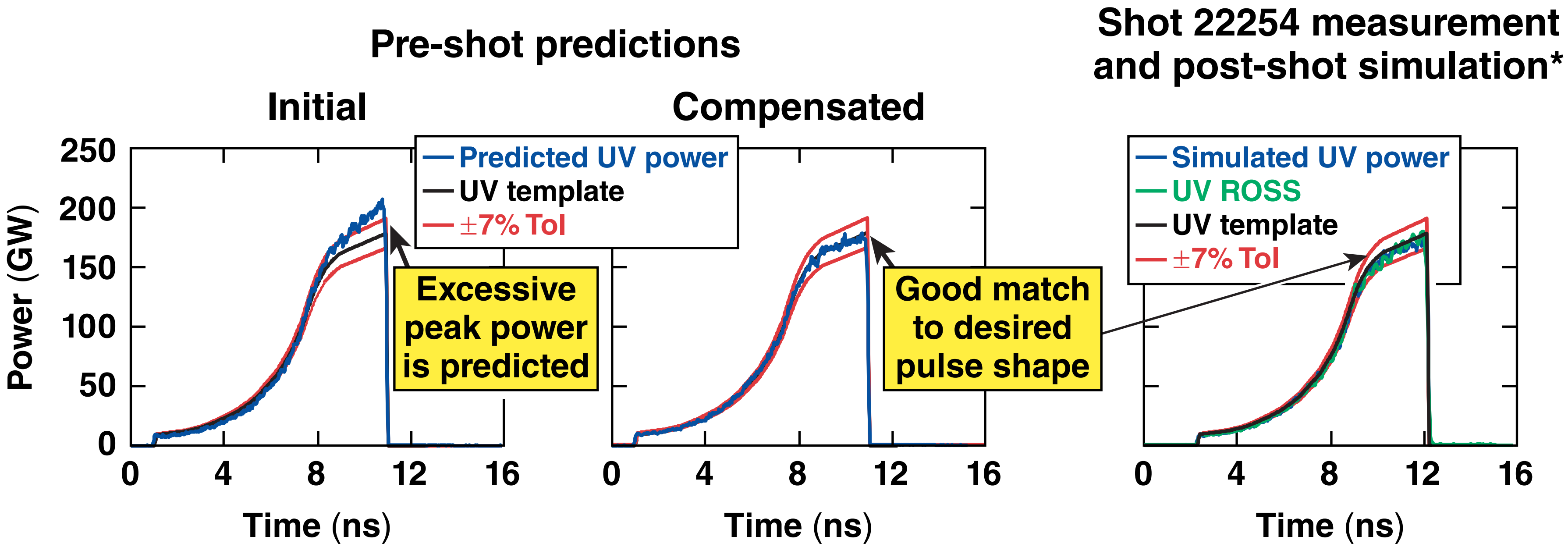
November 19, 2015



Pre-shot predictions

Initial

Compensated

Shot 22254 measurement and post-shot simulation*

Excessive peak power is predicted

Good match to desired pulse shape

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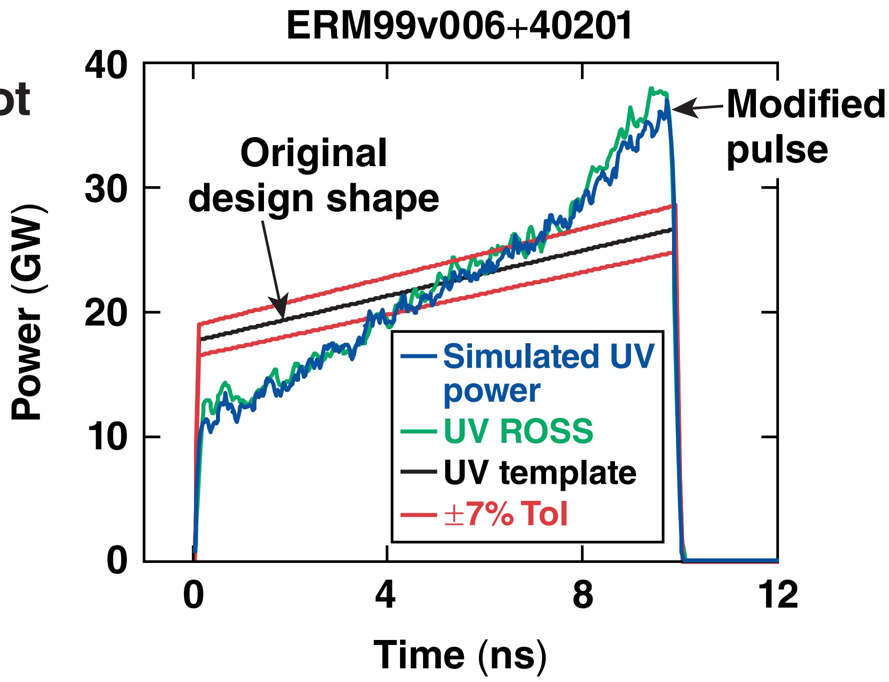
Beam 4 Shot 20647
April 14, 2015



ERM99v006+40201

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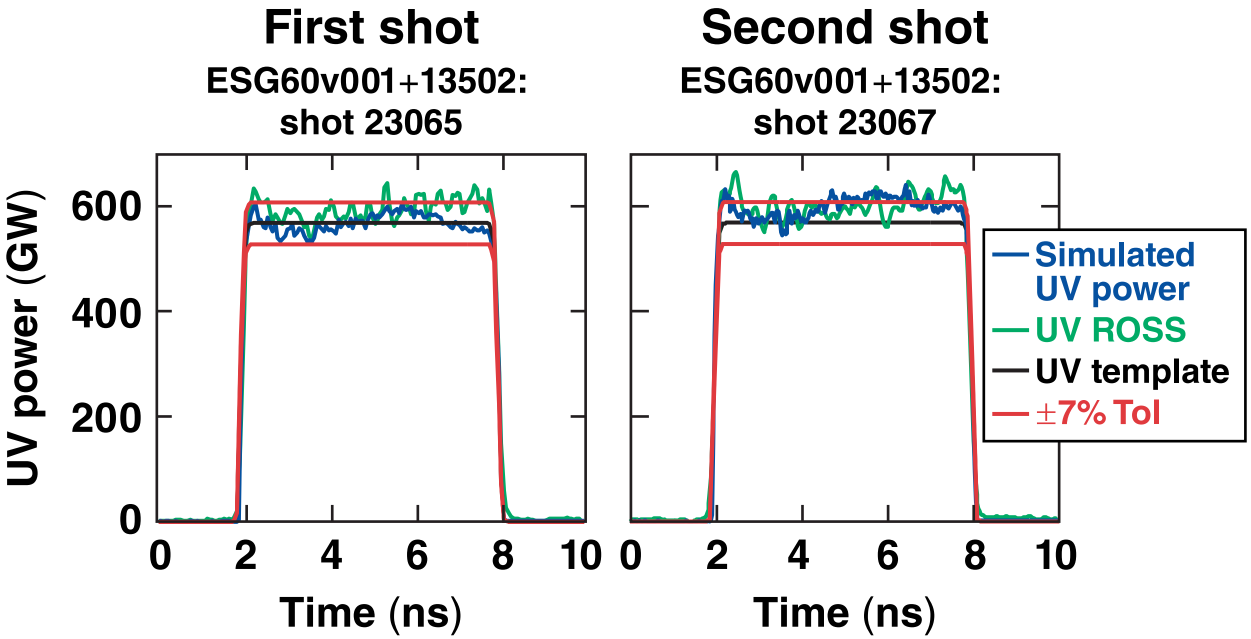

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G10759

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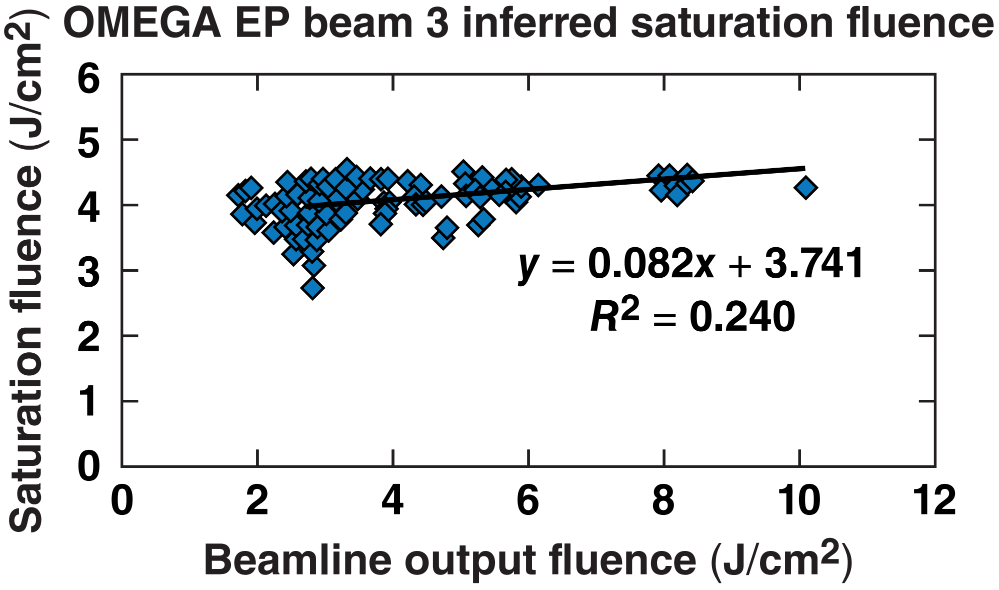
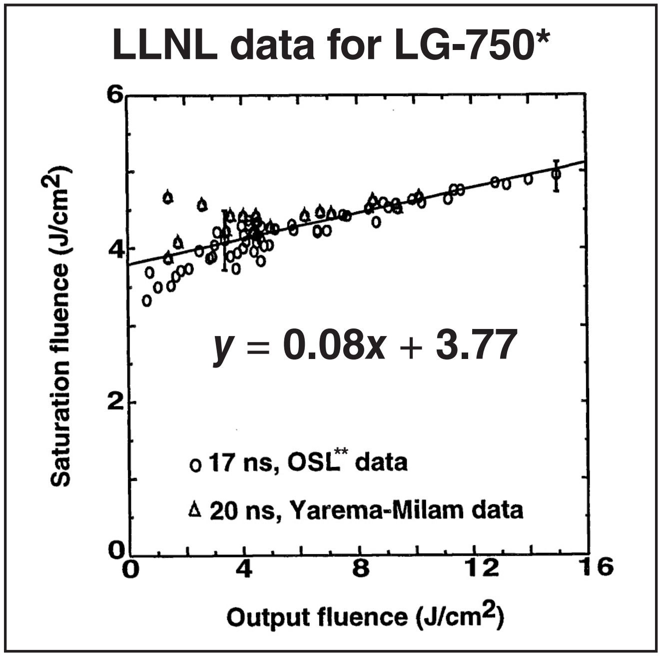

OMEGA EP beam 3 inferred saturation fluence


LLNL data for LG-750*

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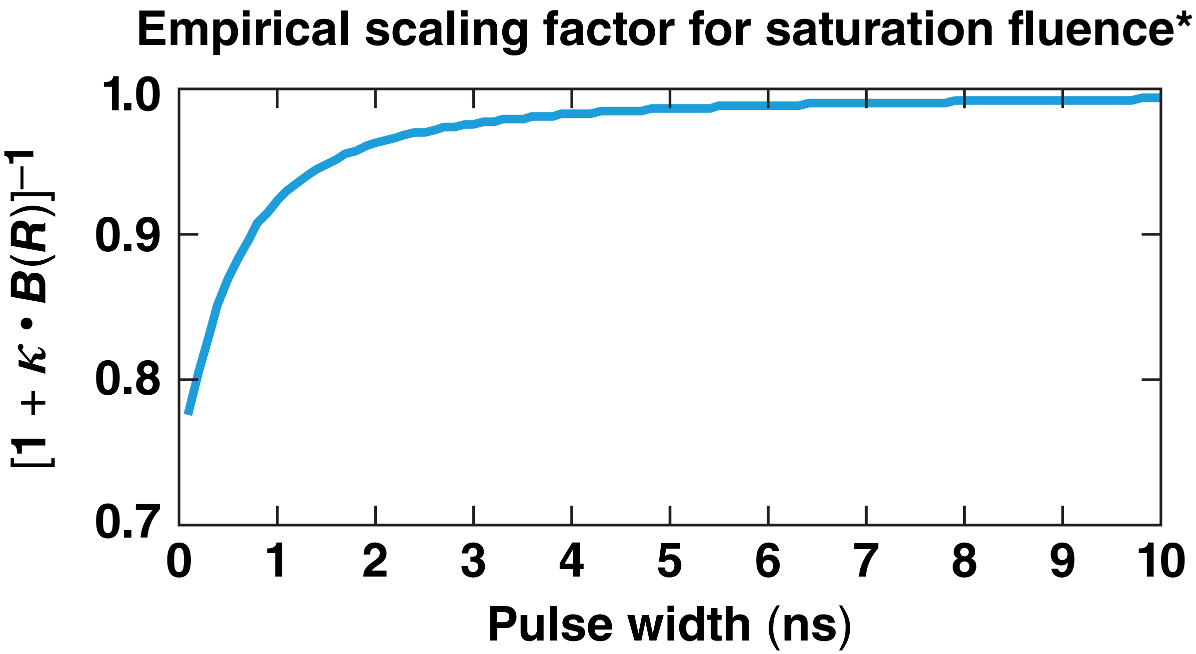

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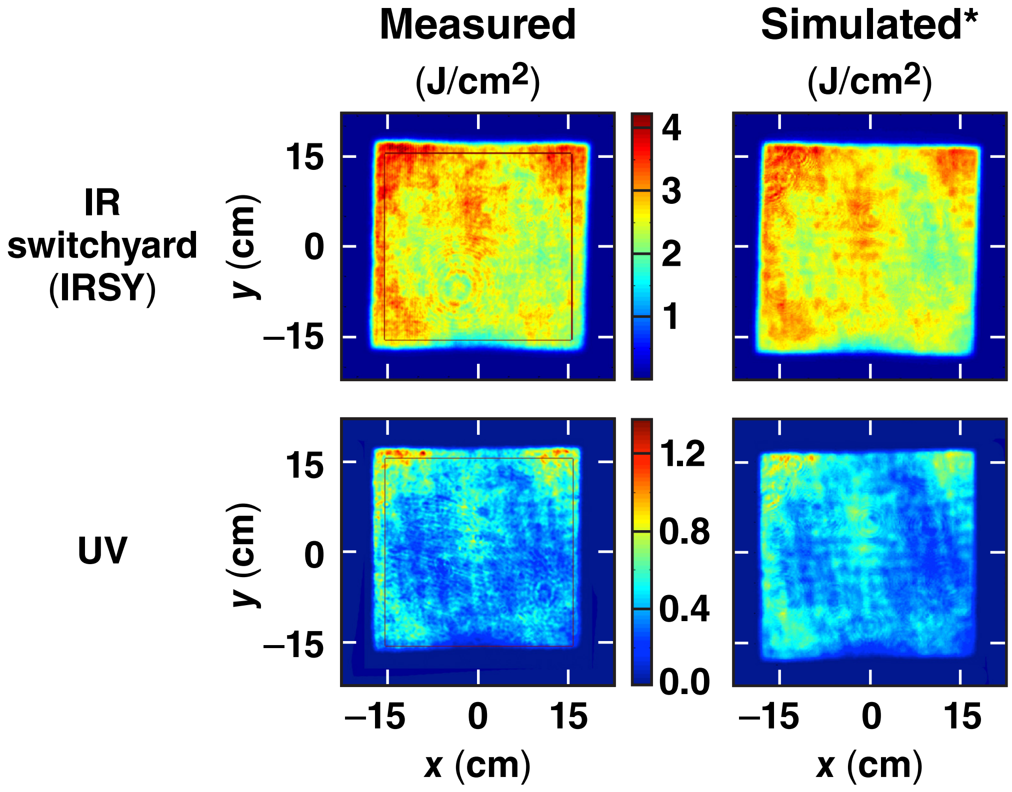
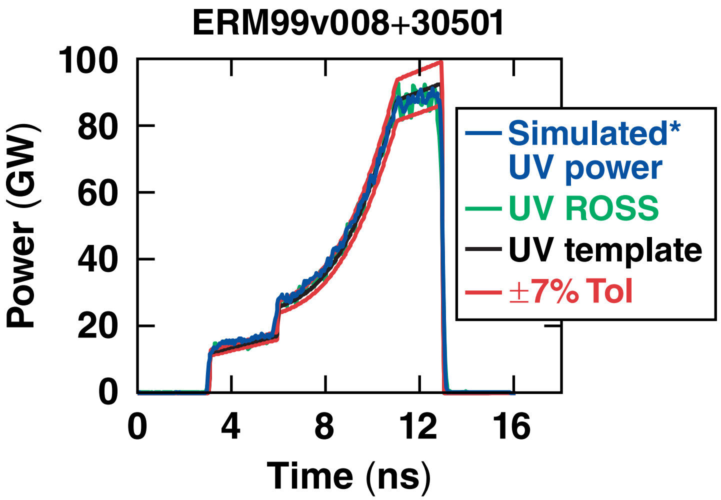
Beamline 3 shot 20678

April 16, 2015

Beamline near fields



UV pulses



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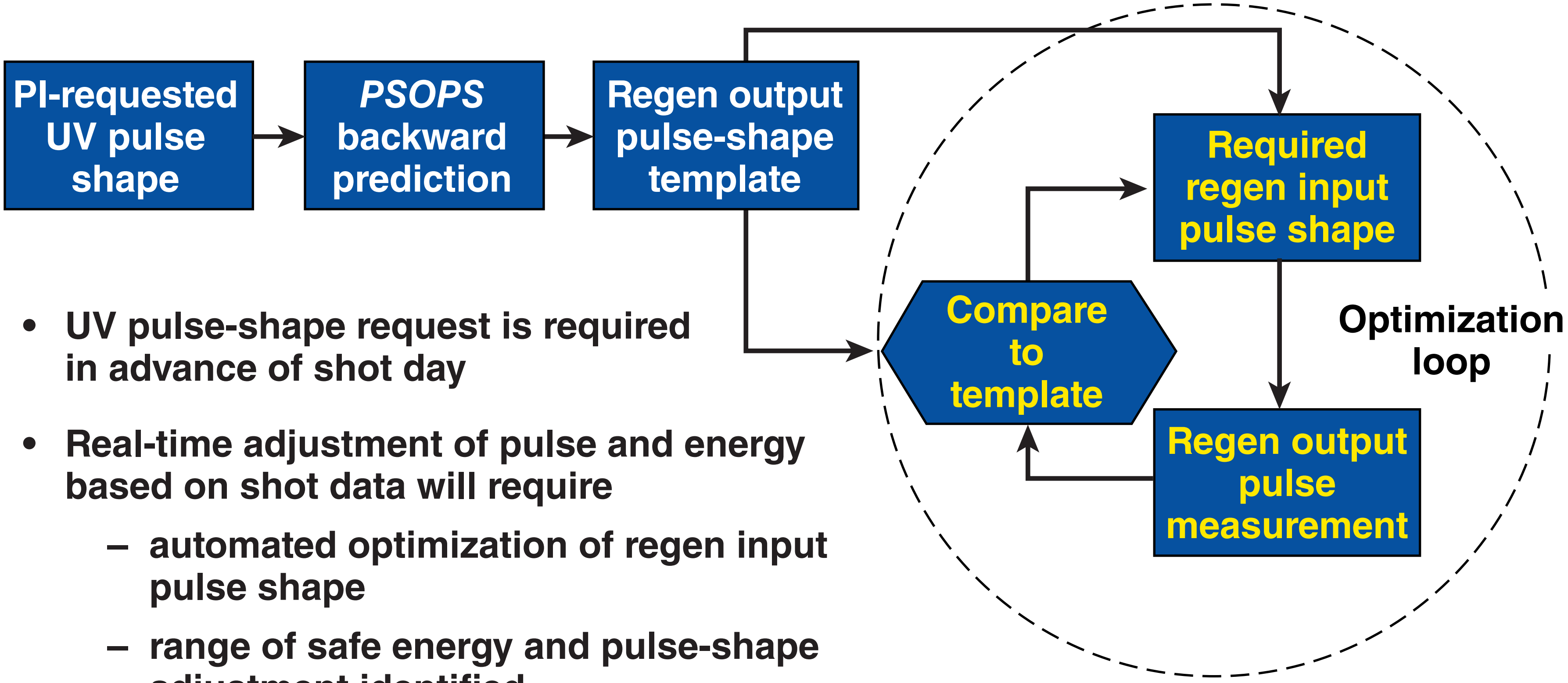

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