Optimization of Lasers in Electron Accelerator Applications (WEAO03)

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U.S. DEPARTMENT OF ENERGY Stanford University

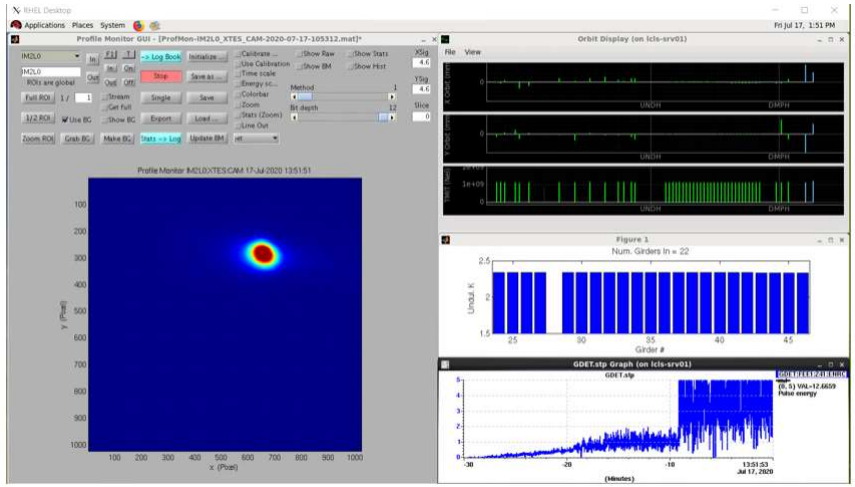
SLAC NATIONAL ACCELERATOR LABORATORY

Outline

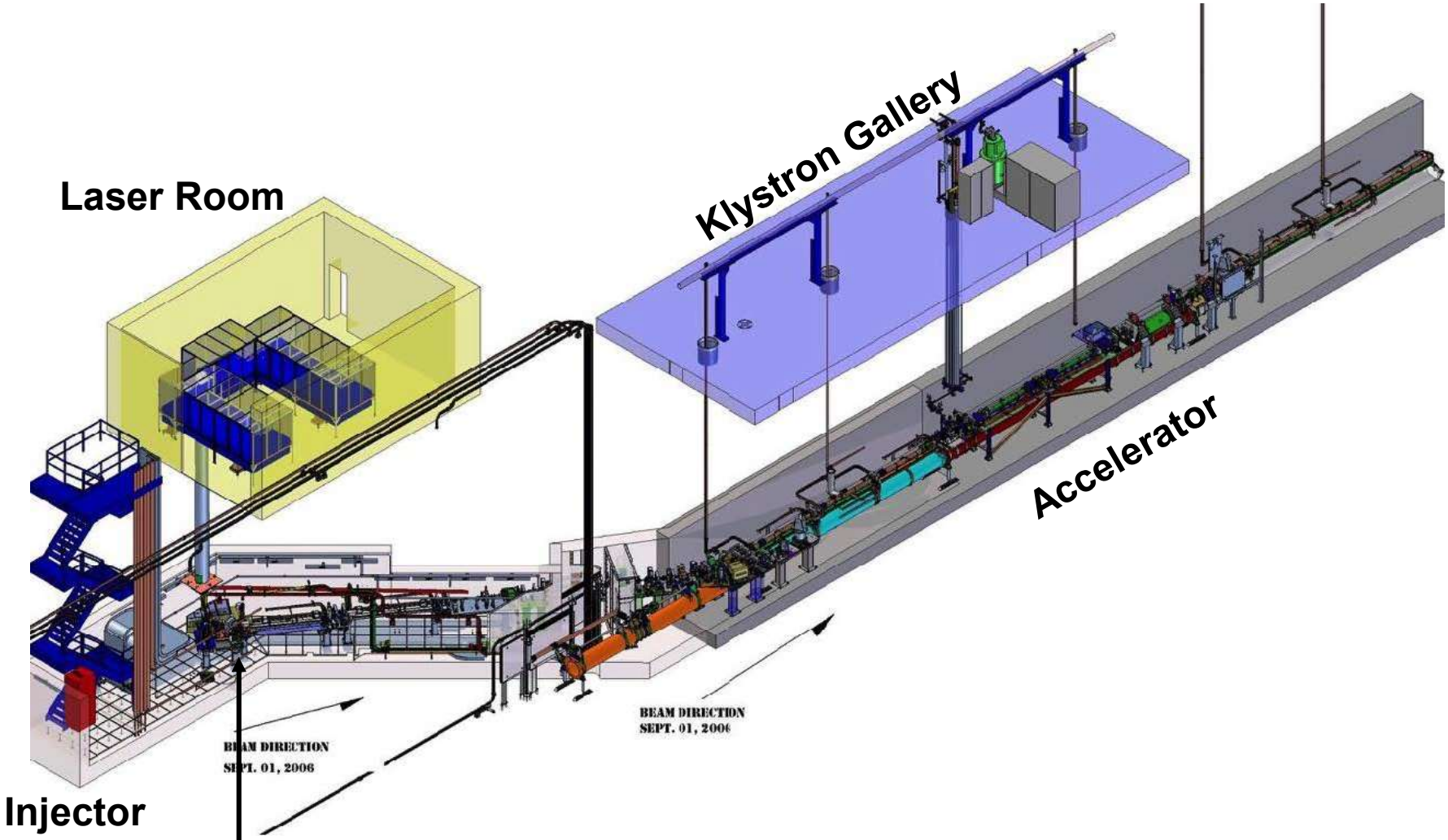
- SLAC's LCLS Photoinjector
- LCLS Laser System
  - Drive Laser System
  - Laser Heater System
- Laser and e-Beam Performance
- LCLS Operation and User Delivery
- Future Developments
  - xLEAP
  - LCLS II
  - Machine Learning

SLAC's LCLS Photoinjector

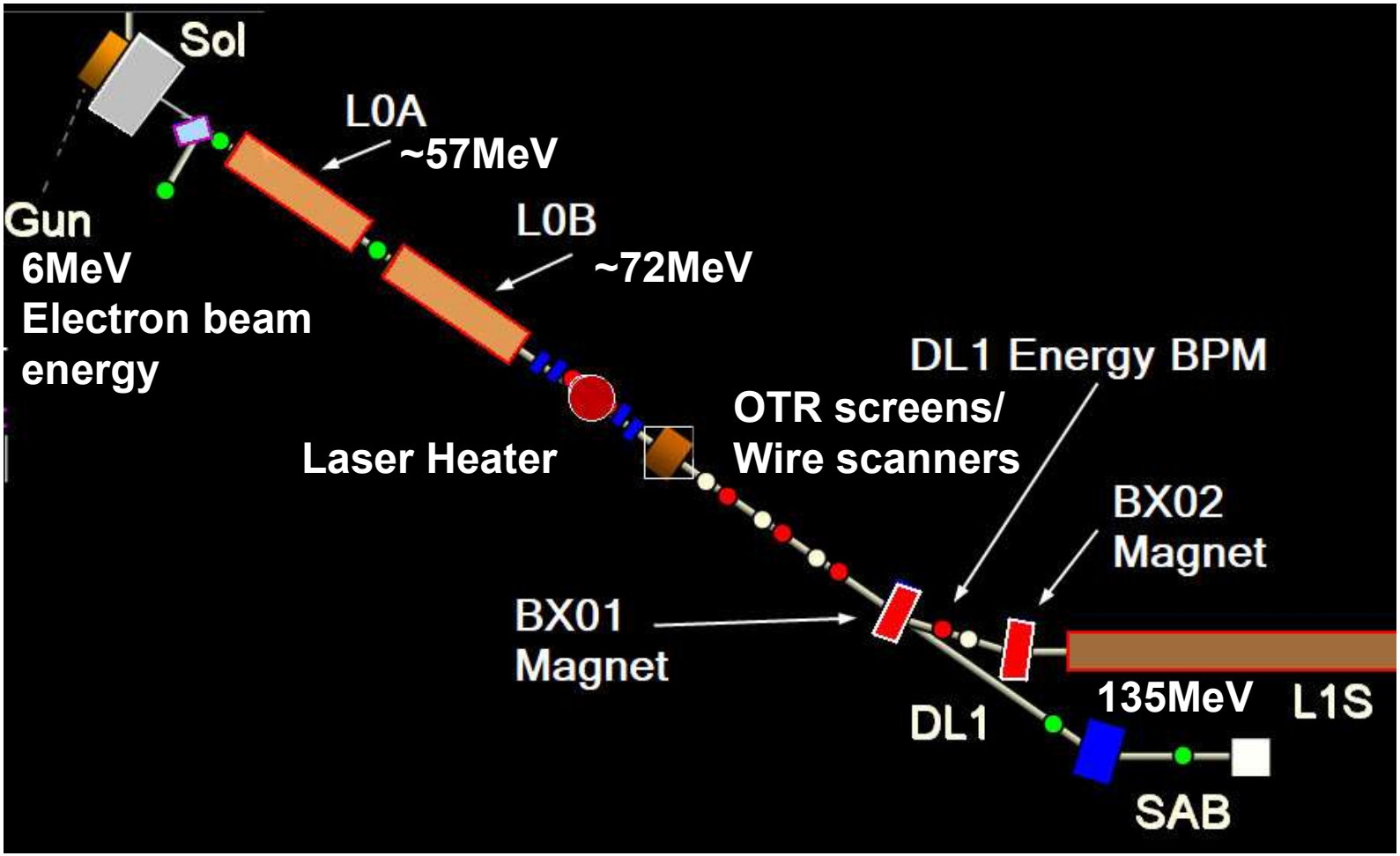
- LCLS 1 Laser Room and Injector Vault
- Located in the last 3rd of the 2 km LINAC
- First Light April 2009……and again in July 2020!



SLAC's LCLS Photoinjector

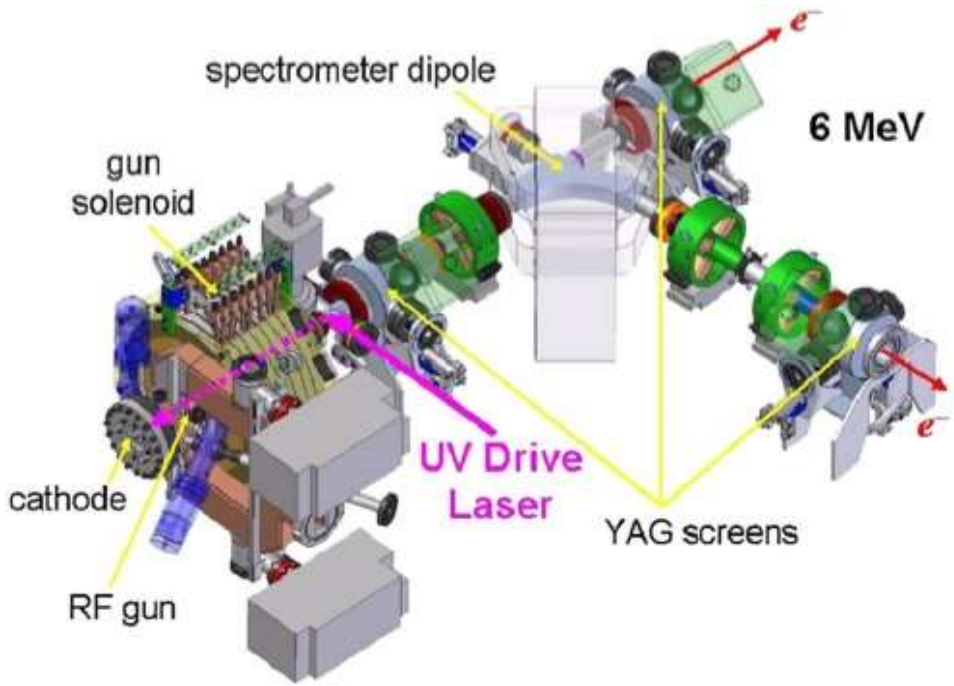


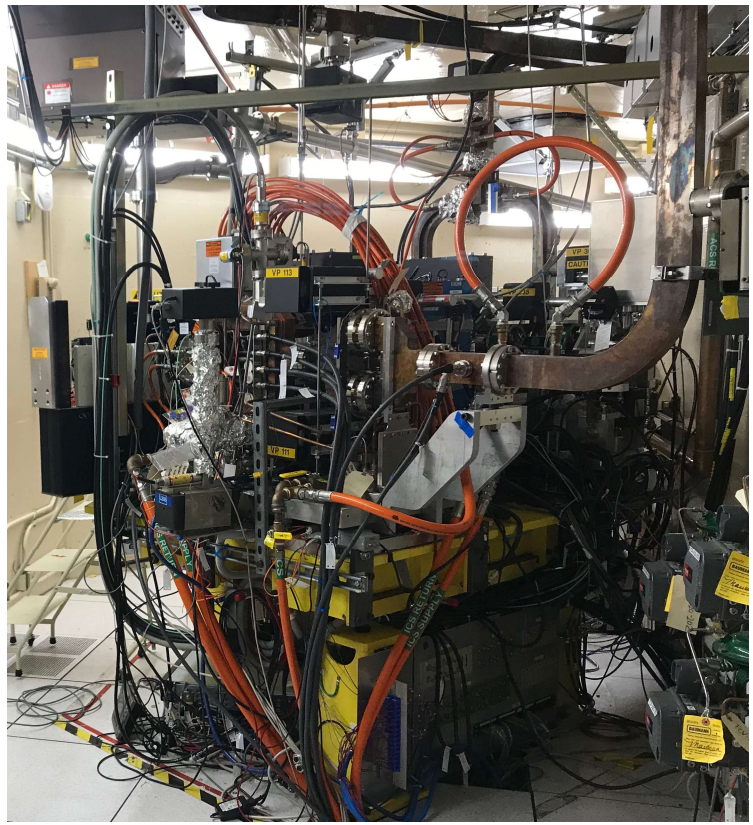
SLAC's LCLS Photoinjector



SLAC's LCLS Photoinjector

- LCLS 1 referred to as the Cu Linac or NC Linac
- Laser transport under vacuum, ~3.5 x 10^{-6} Torr

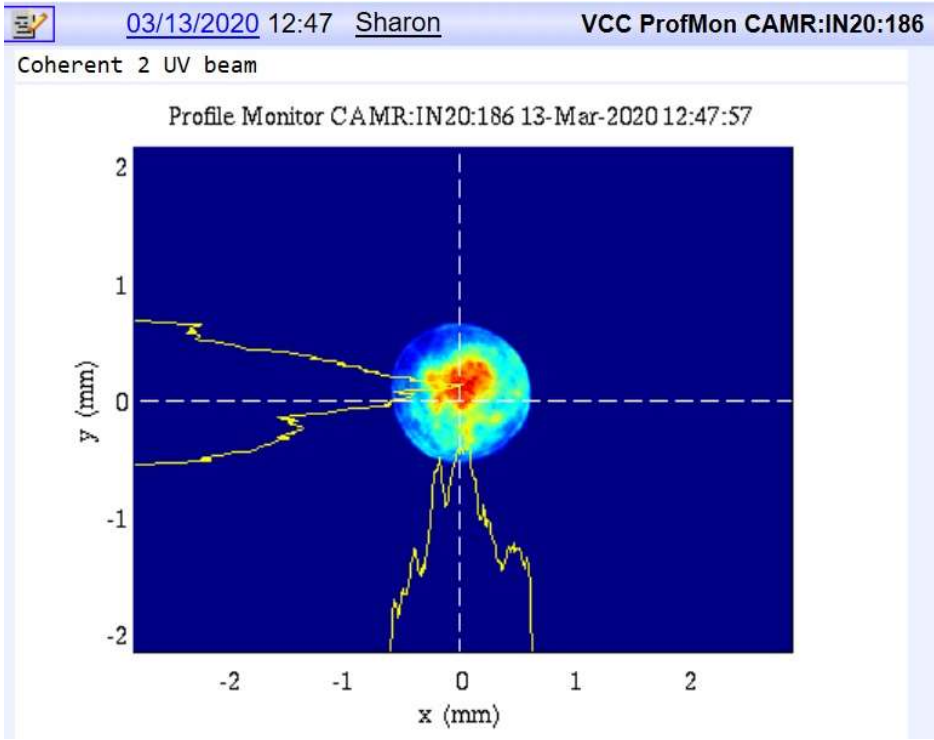


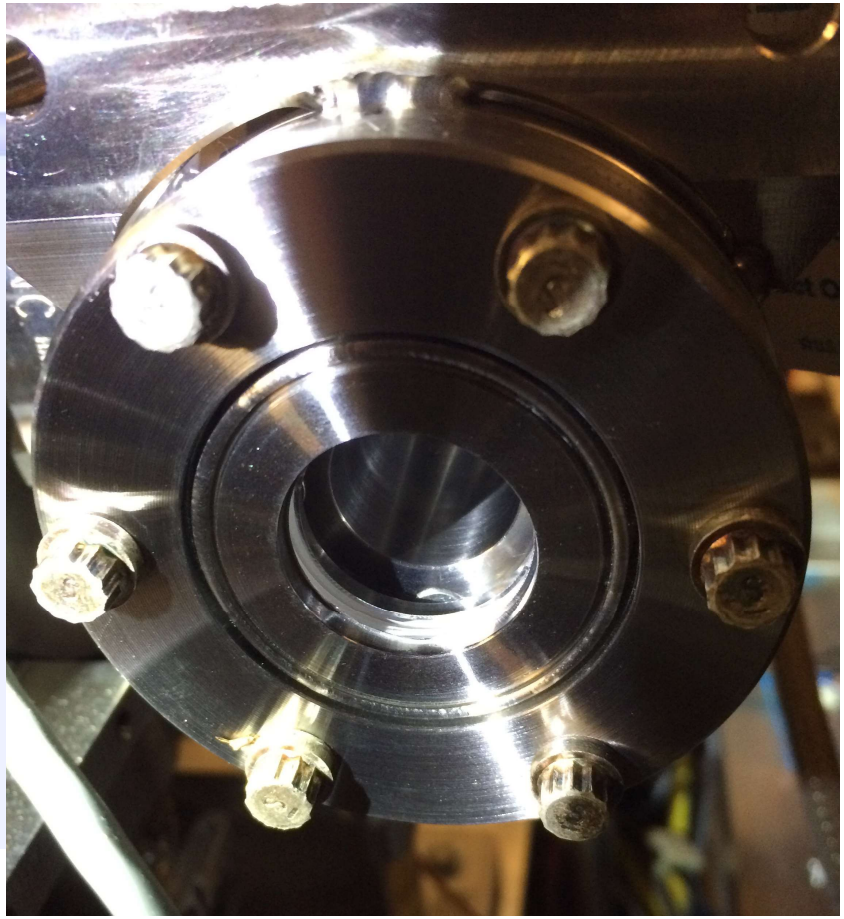


Ref: Akre et al, Phys.Rev.ST Accel.Beams 11, 030703 (2008)

SLAC's LCLS Photoinjector

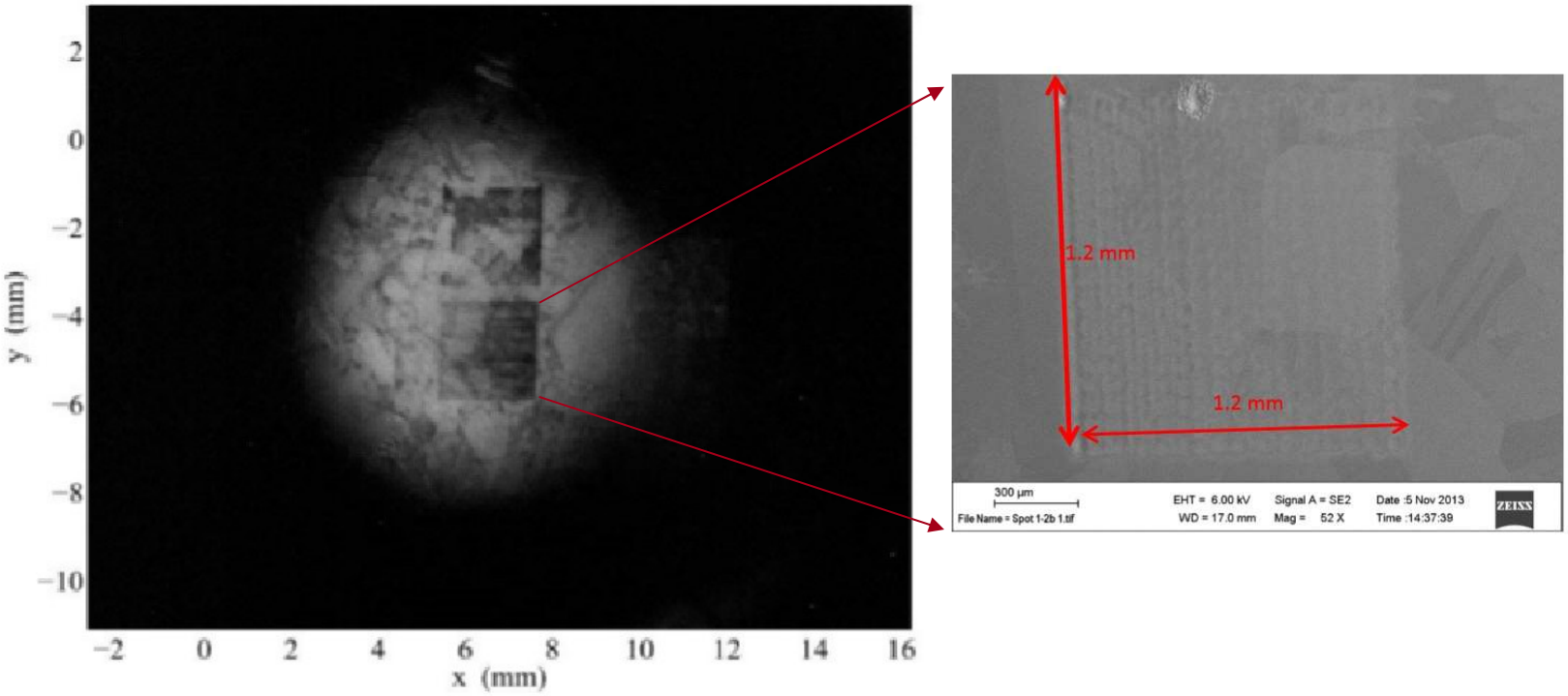
- Virtual Cathode Camera (VCC) – Pulnix camera, in vault next to gun higher radiation area
- Window to Cathode





SLAC's LCLS Photoinjector

- QE ~4 x 10^{-5} (–e/photon)
- Cu cathode – third cathode since 2007 (First: 2007-Jul 2008, Second: Jul 2008 – May 2011, Third: May 2011 – present)
- Accelerator Structure Test Area (ASTA) program – cathode cleaning



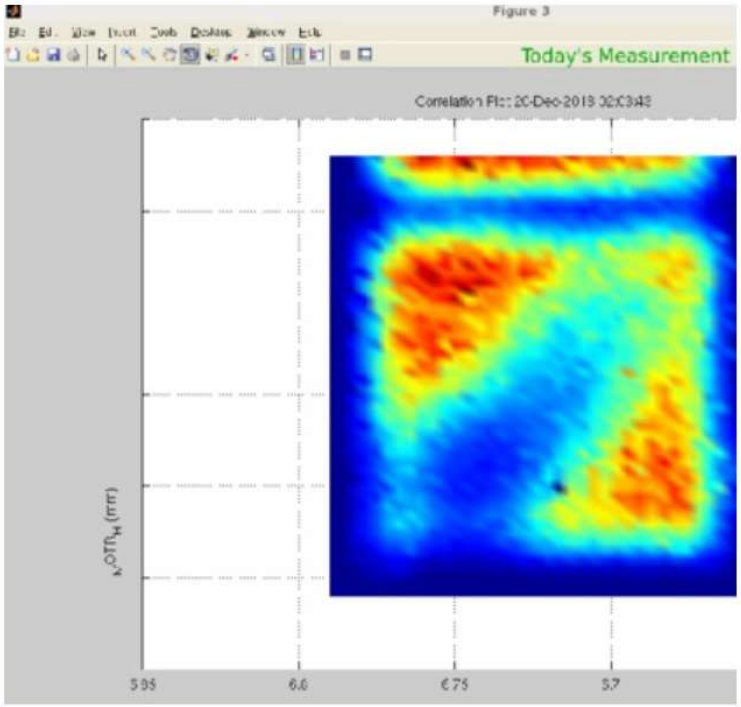
Ref: SLAC-PUB-16439

SLAC's LCLS Photoinjector

- QE mapping of the Cu Cathode

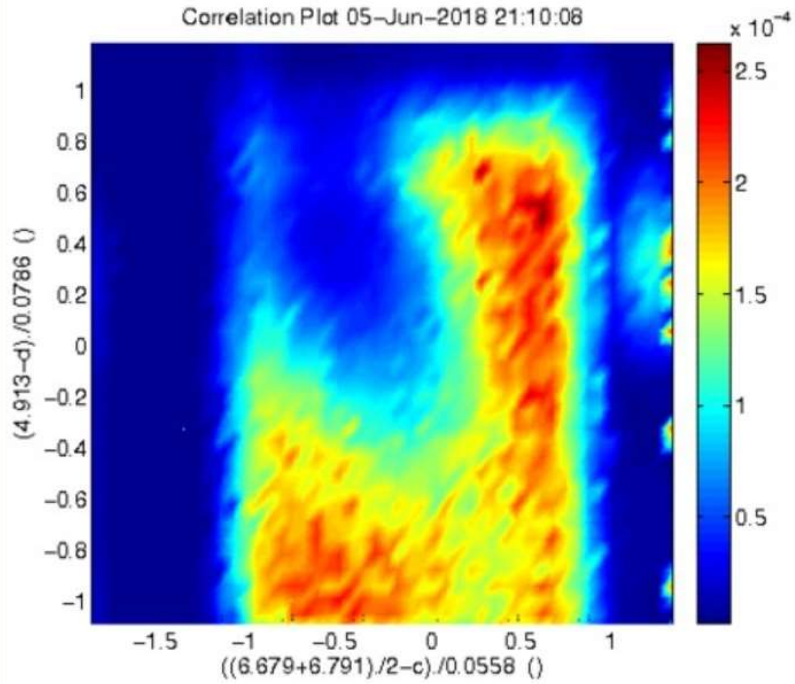
12/20/2018 03:28 Gibbs, Shtalenkova **Comparison of tonight's scan vs. the one done in August**

(Thumbnail is broken, click for full image)
Comparison of tonight's scan vs. the one done in August. Generally the same shape, but the low QE 'canyon' is growing.



06/06/2018 14:05 Zhou, Sheppard, (Maxwell) **Scaled QE scan**

With scaling from John, here see the QE map with axes in mm of position on VCC.



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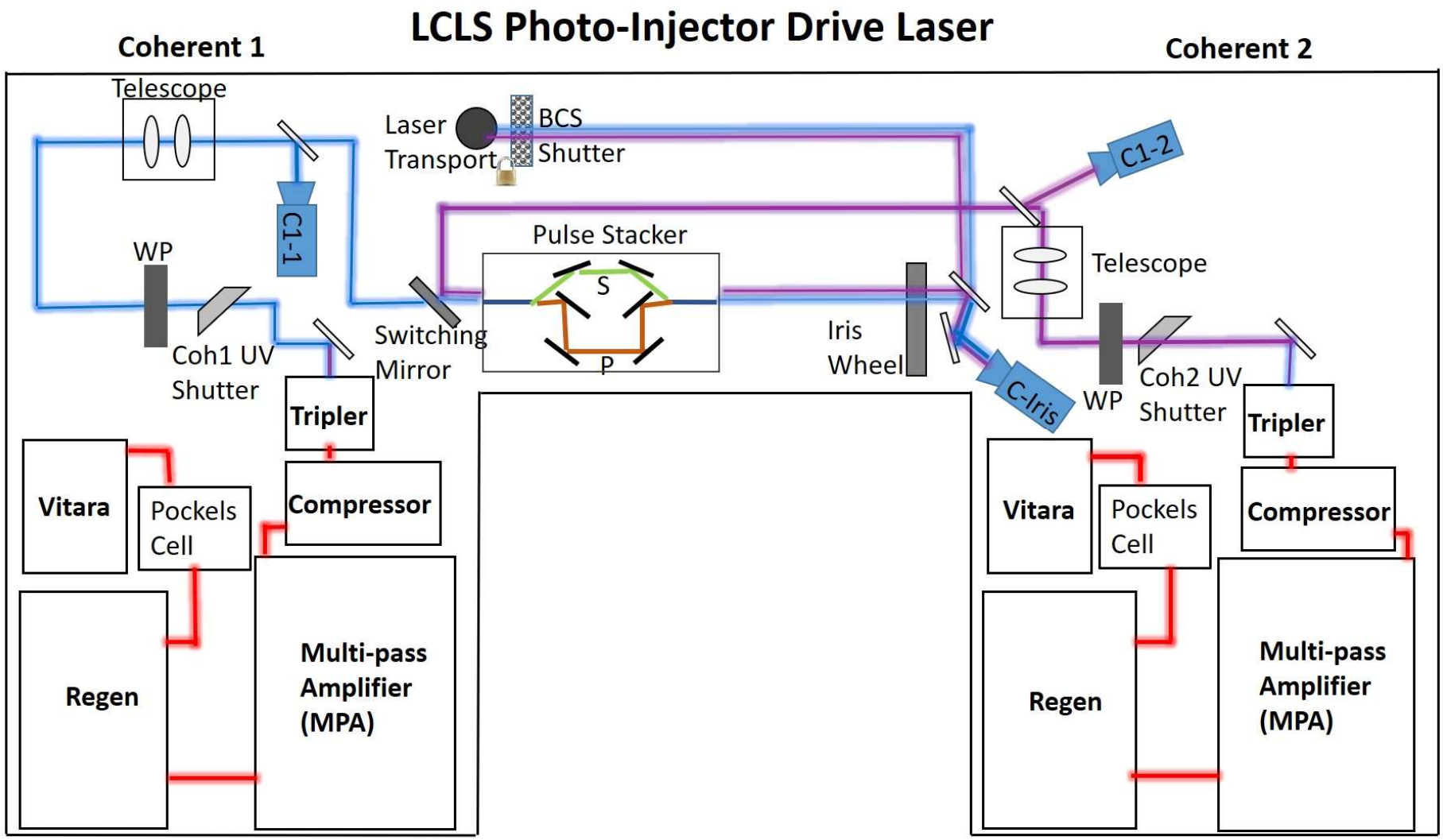
LCLS Laser System - Drive Laser System



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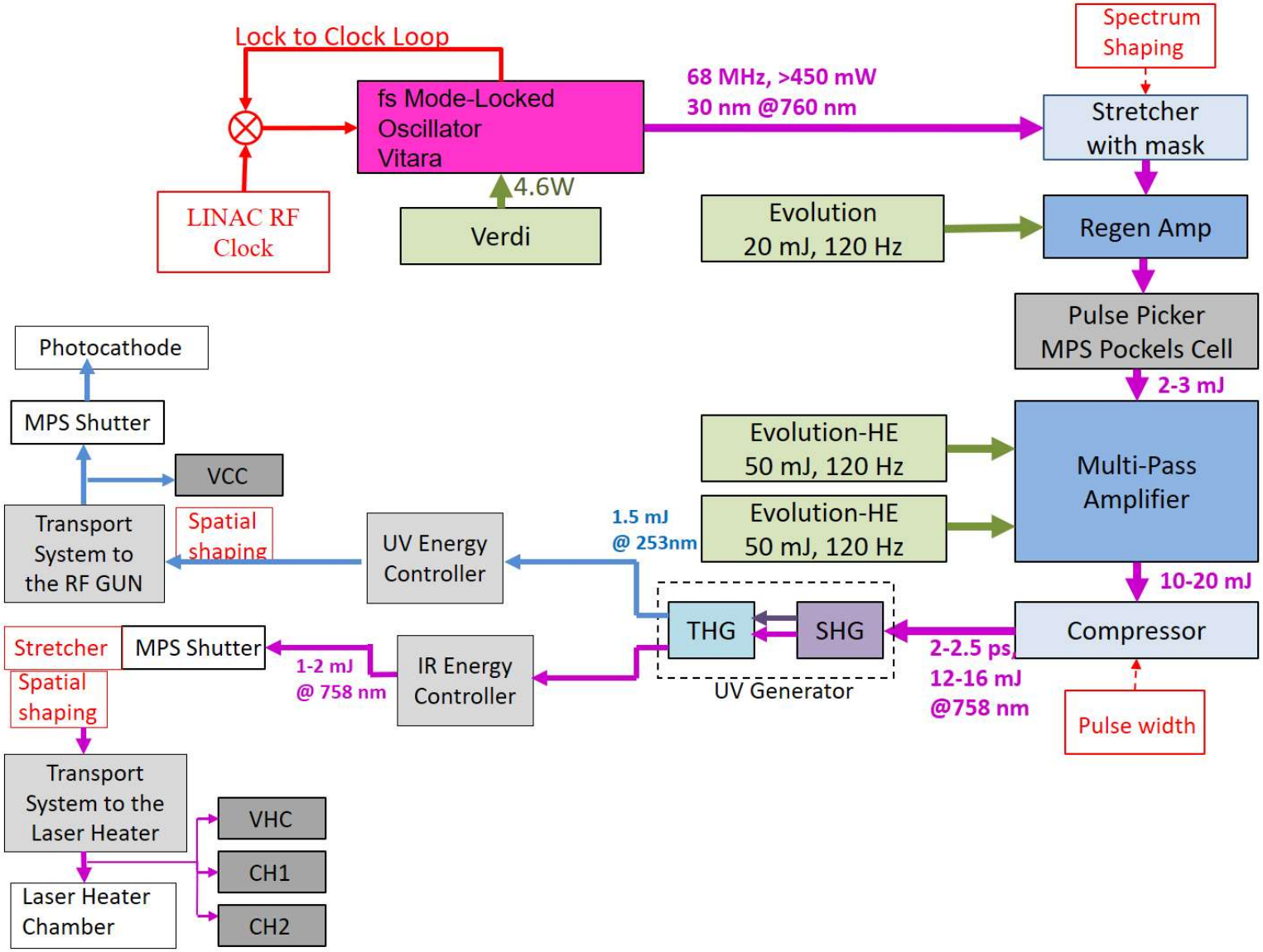
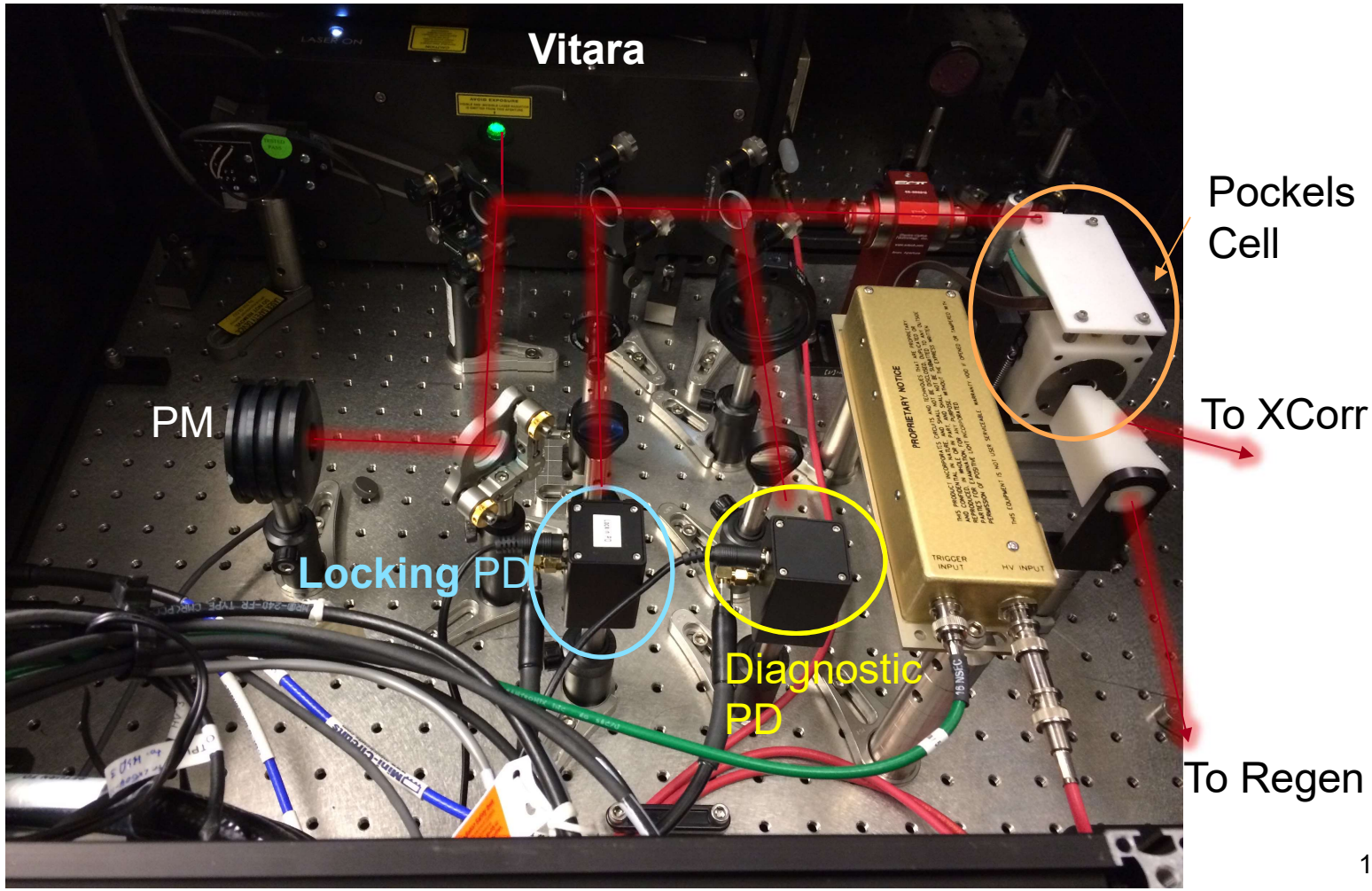


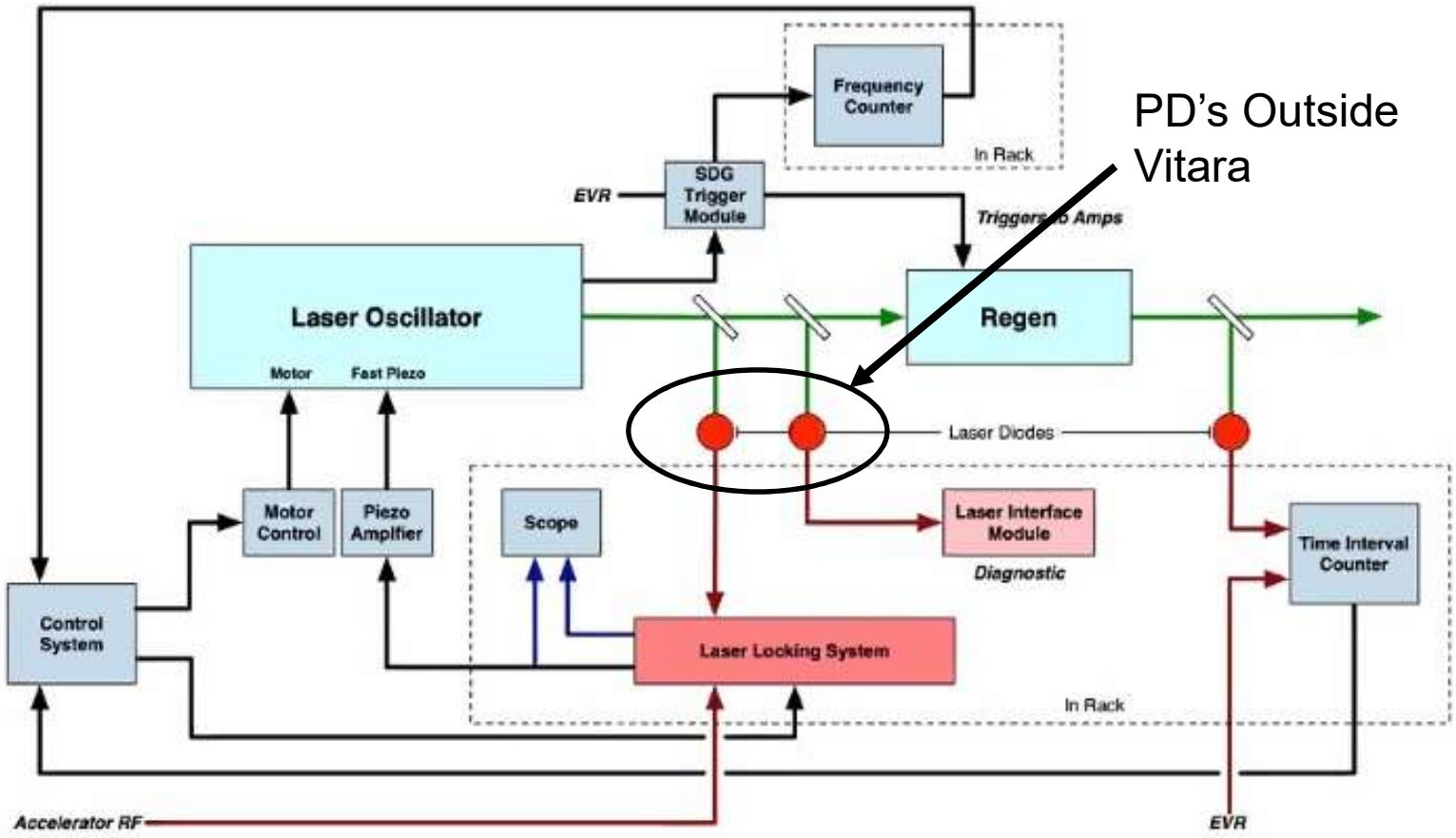
LCLS Laser System - Drive Laser System

- Vitara output – Pulse picker and timing diagnostics



LCLS Laser System - Drive Laser System

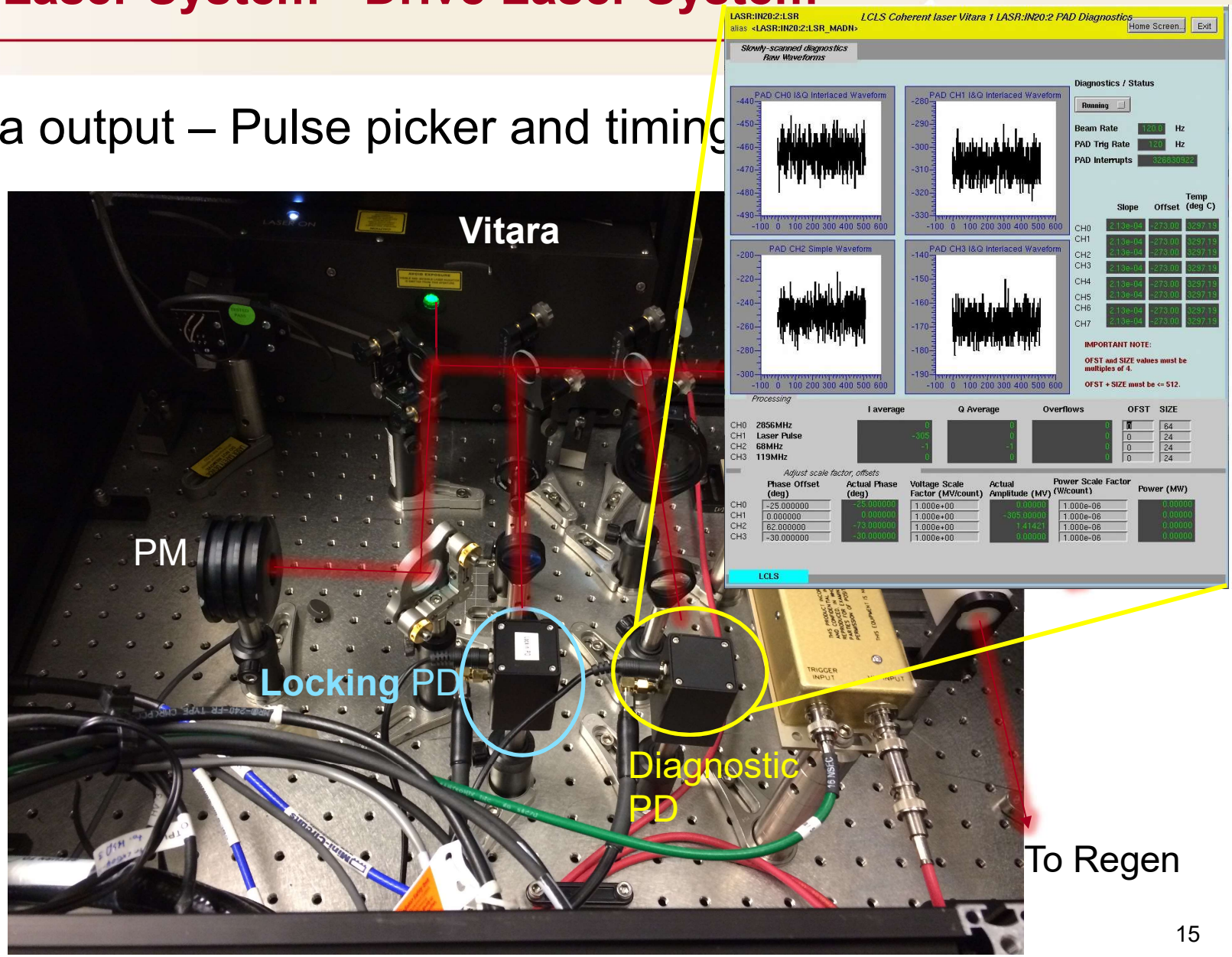
- Vitara output –timing diagnostics



Courtesy of Justin May

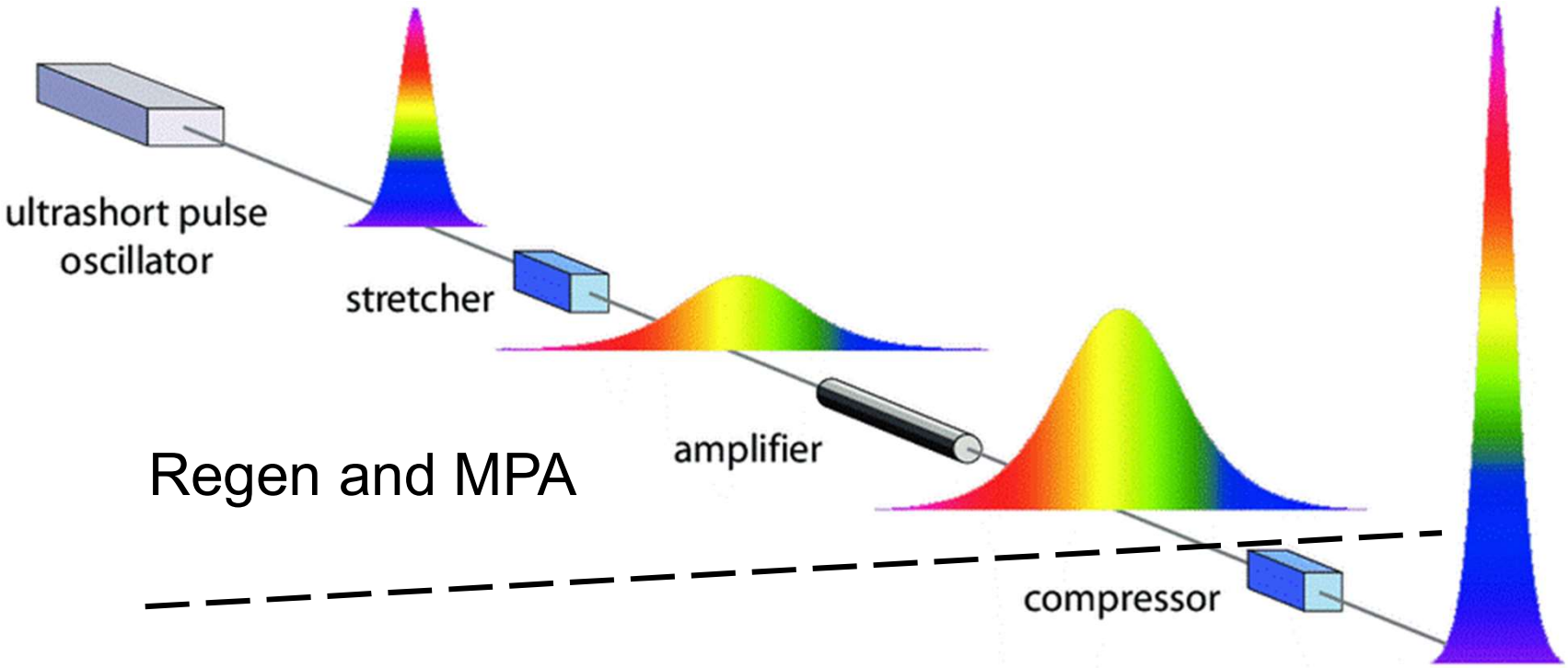
LCLS Laser System - Drive Laser System

- Vitara output – Pulse picker and timing



LCLS Laser System - Drive Laser System

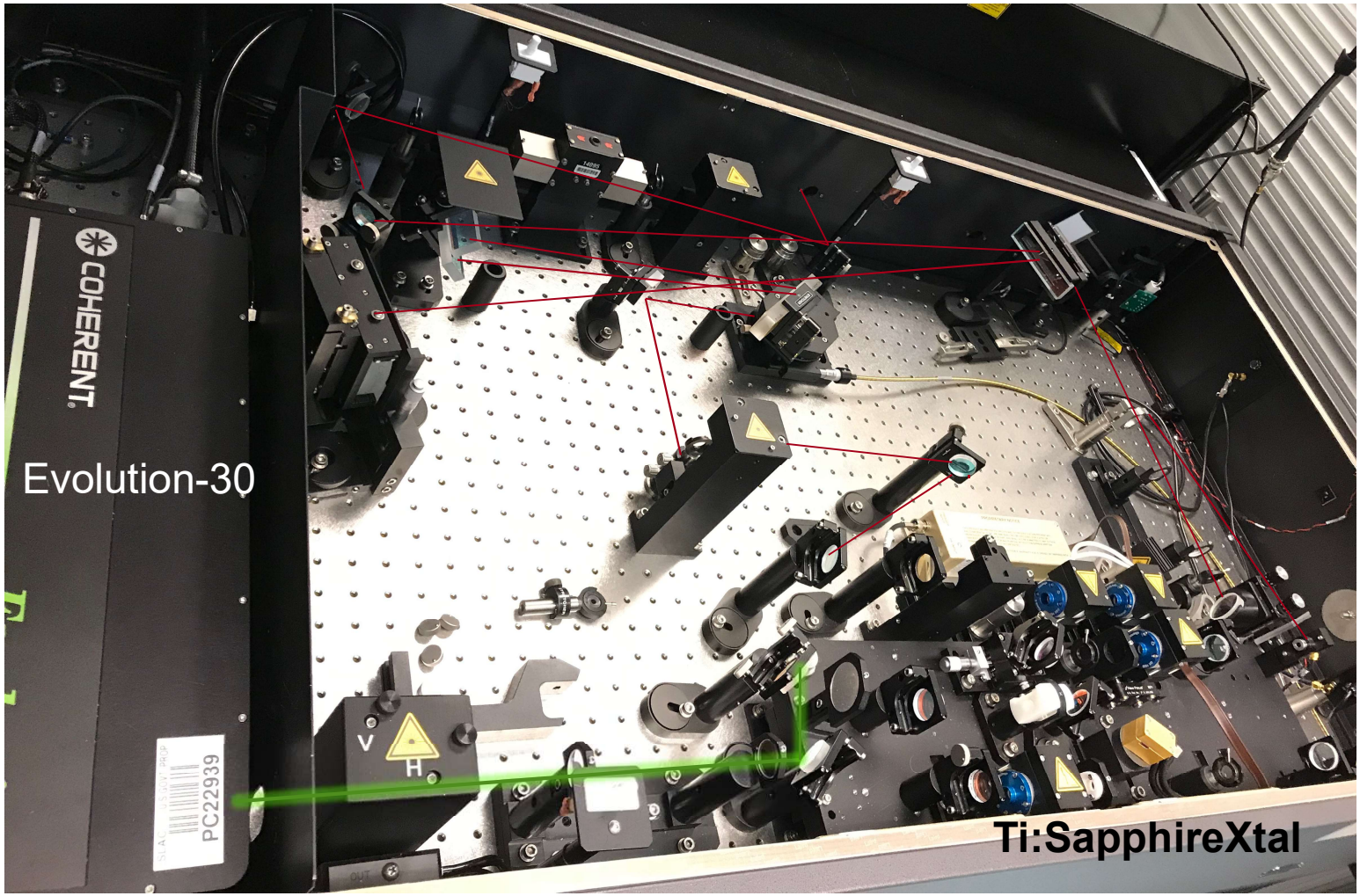
- Chirped Pulse Amplification – Strickland and Mourou, 2018 Nobel Prize



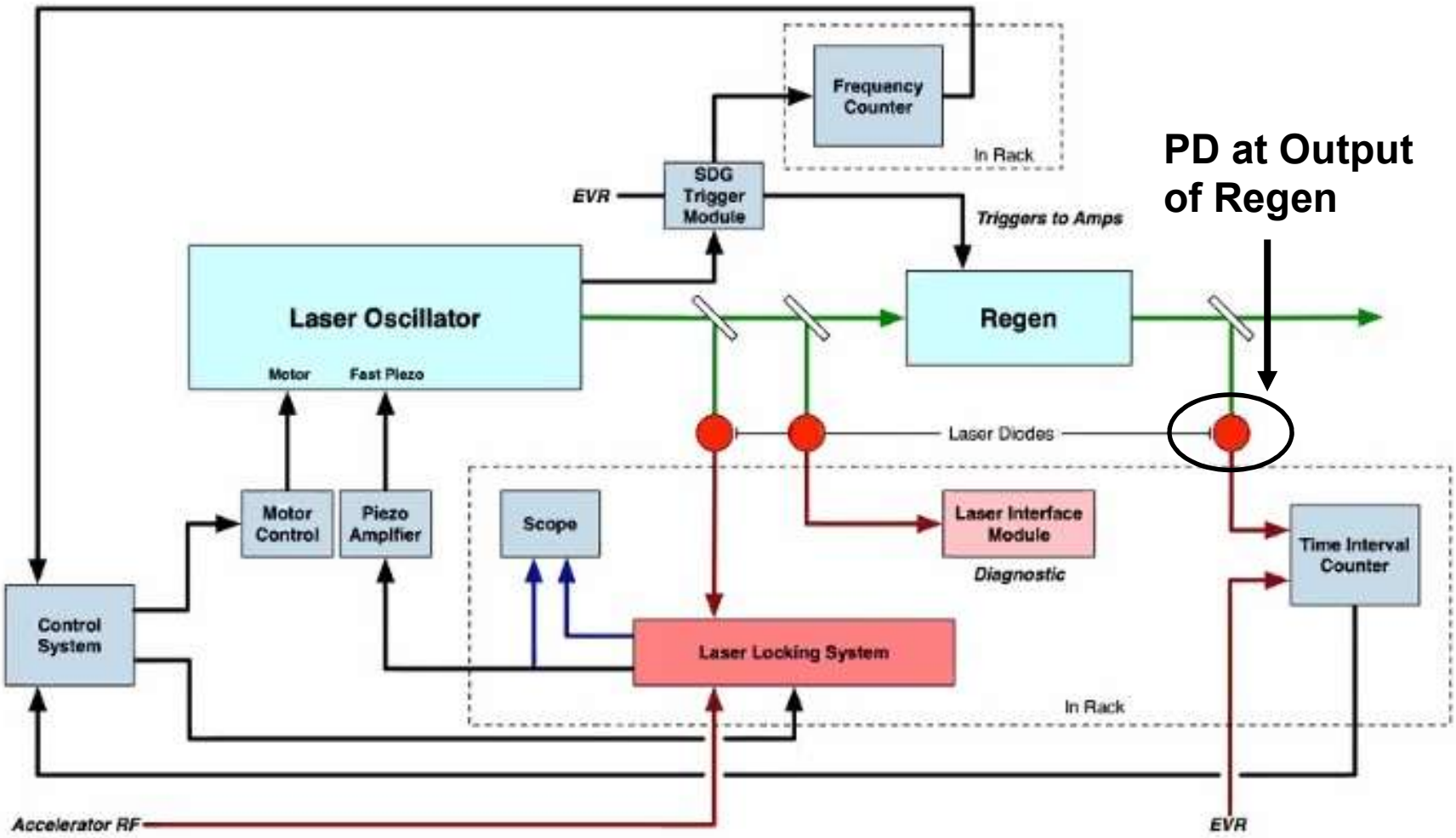
Courtesy of ResearchGate.net

LCLS Laser System - Drive Laser System

- Regenerative Amplifier (Regen) aka Legend



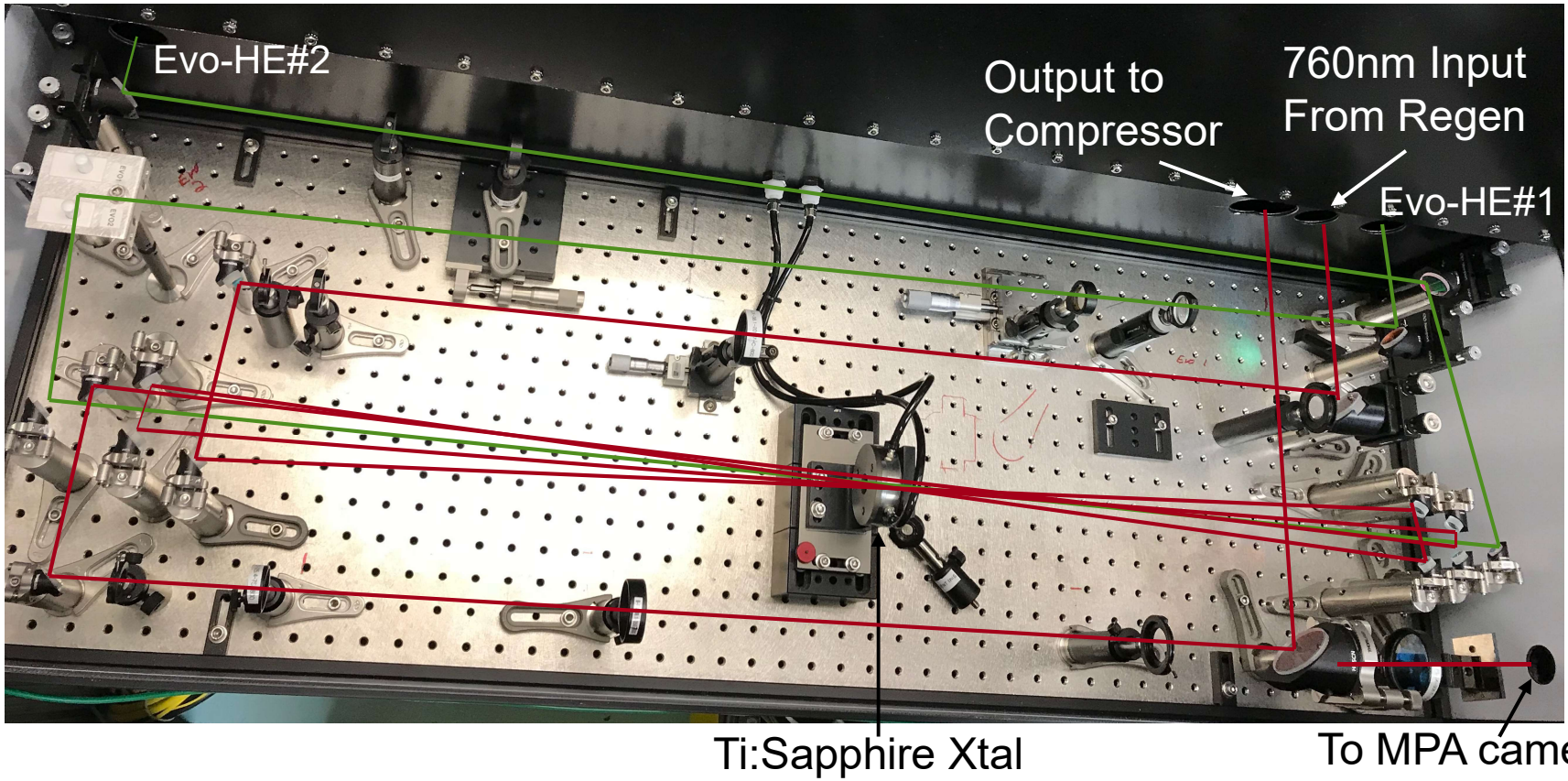
LCLS Laser System - Drive Laser System



Courtesy of Justin May

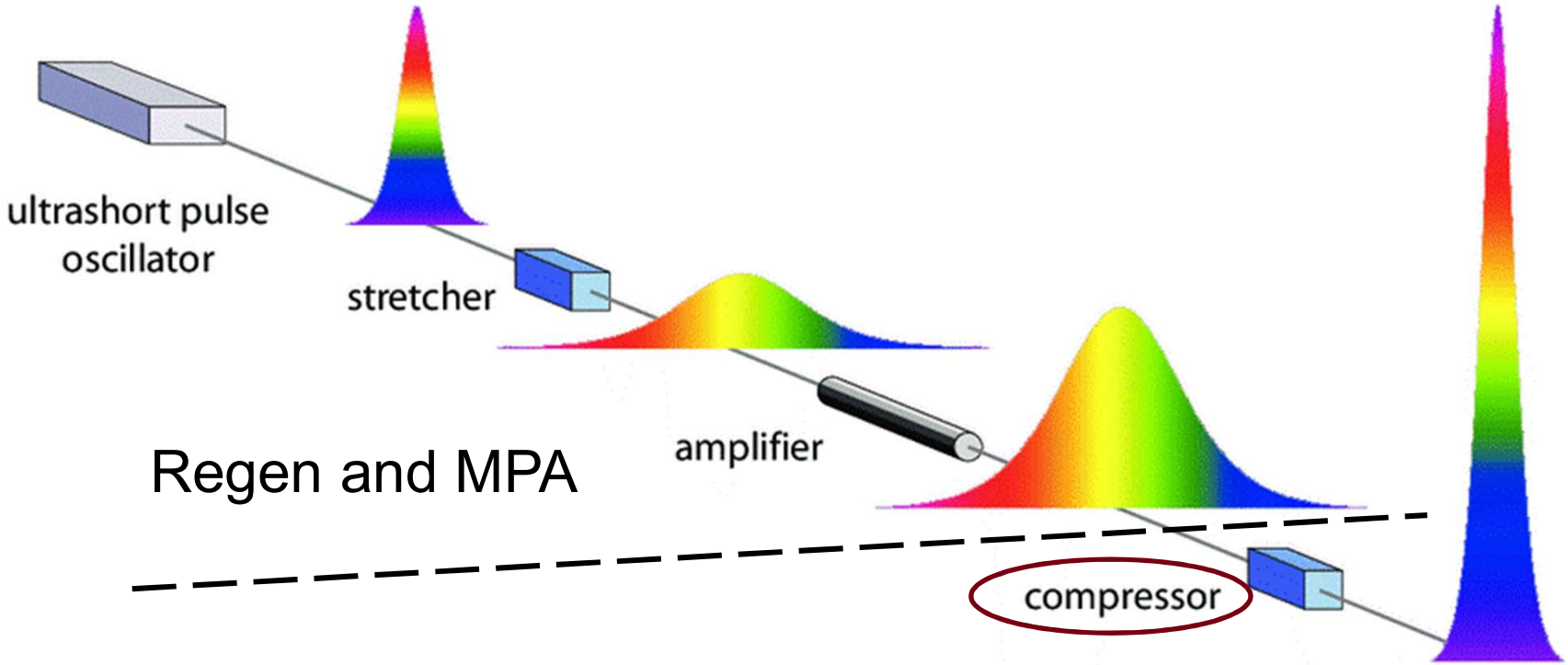
LCLS Laser System - Drive Laser System

- Multi-Pass Amplifier (MPA)



LCLS Laser System - Drive Laser System

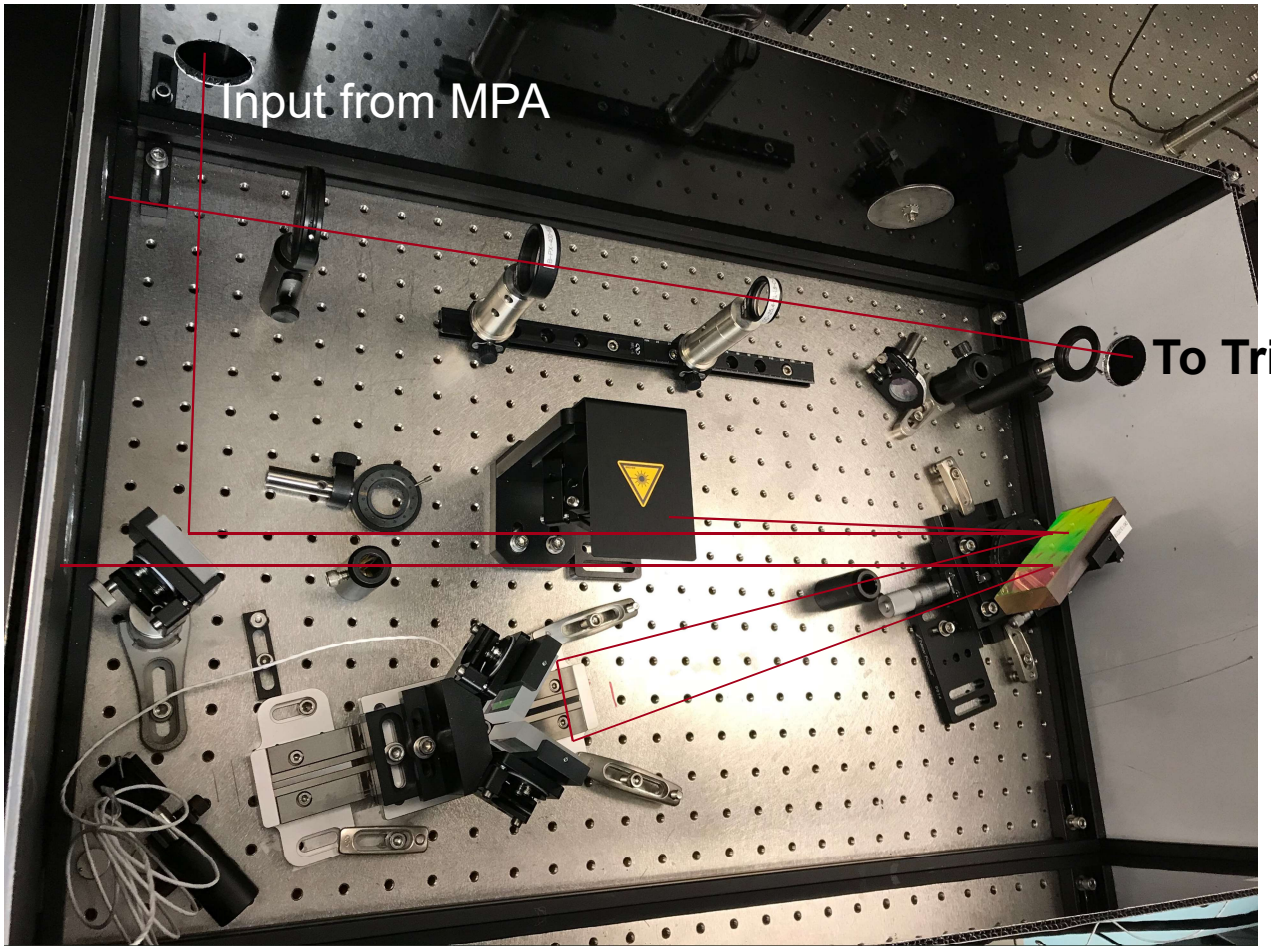
- Chirped Pulse Amplification – Strickland and Mourou, 2018 Nobel Prize



Courtesy of ResearchGate.net

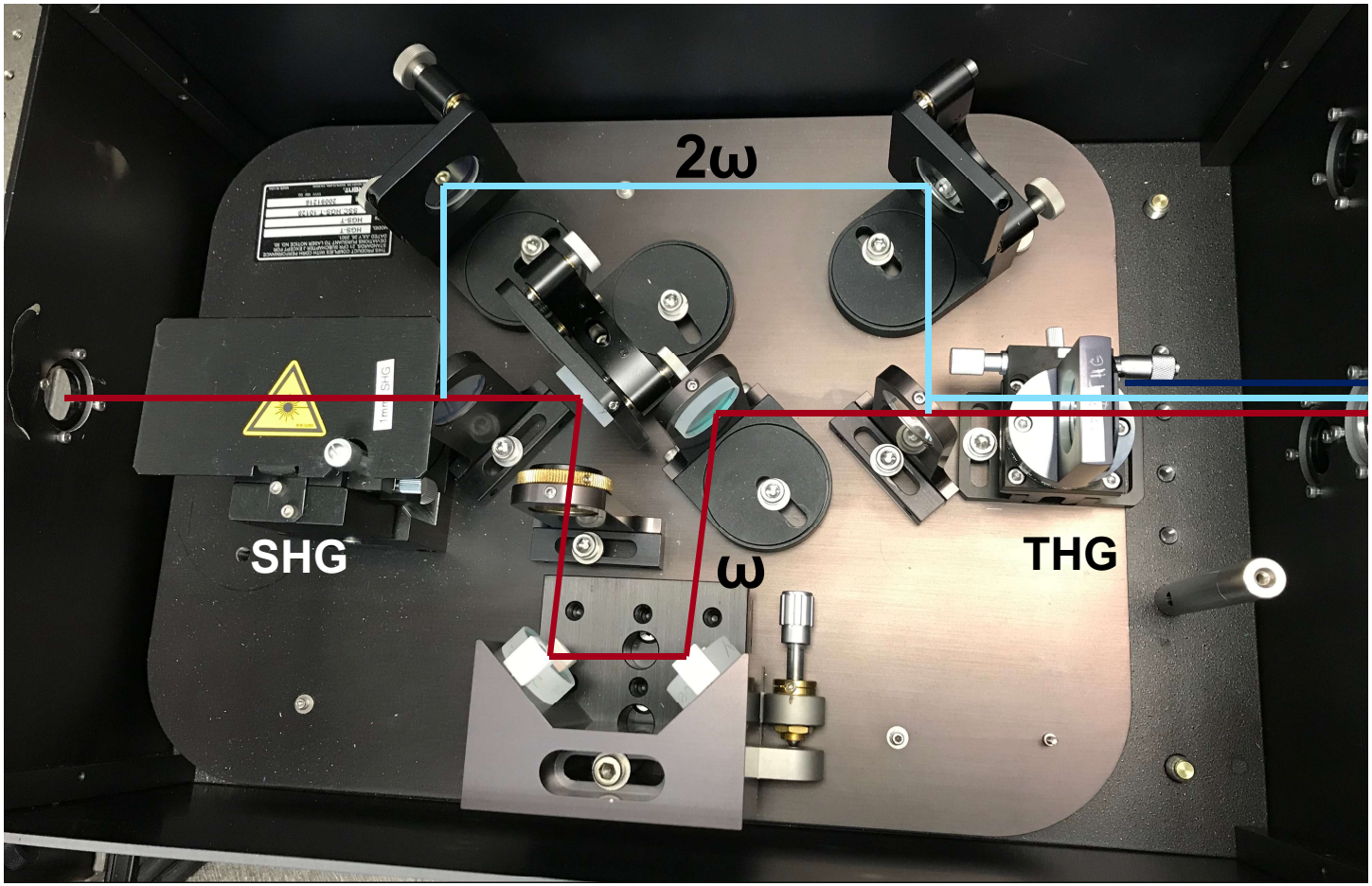
LCLS Laser System - Drive Laser System

- Compressor – specification of 2-2.5ps UV pulse length



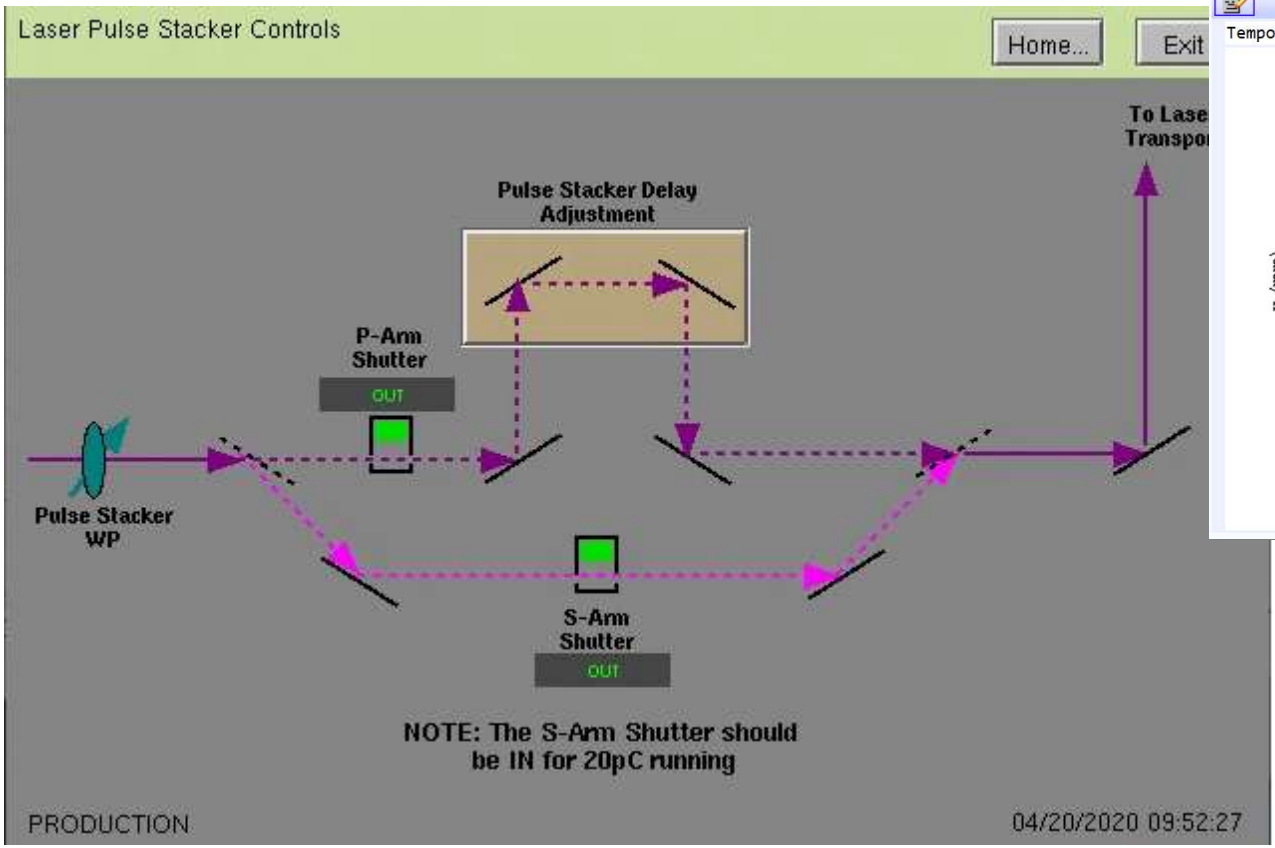
LCLS Laser System - Drive Laser System

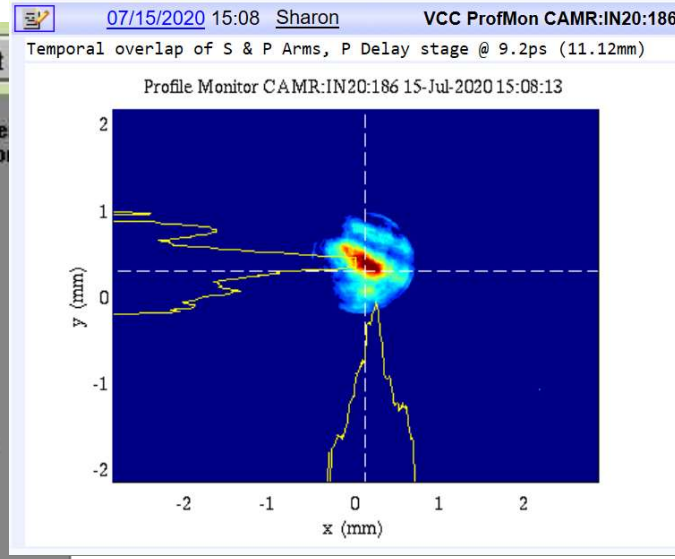
- Tripler – BBO crystals to achieve 253nm, ~10% efficiency



Laser Room Layout – Drive Laser System

- Pulse Stacker – temporal profile requirement for the cathode, ~2ps stacked pulses provides ~4 ps (sharper rise/fall times) and better projected cathode emittance



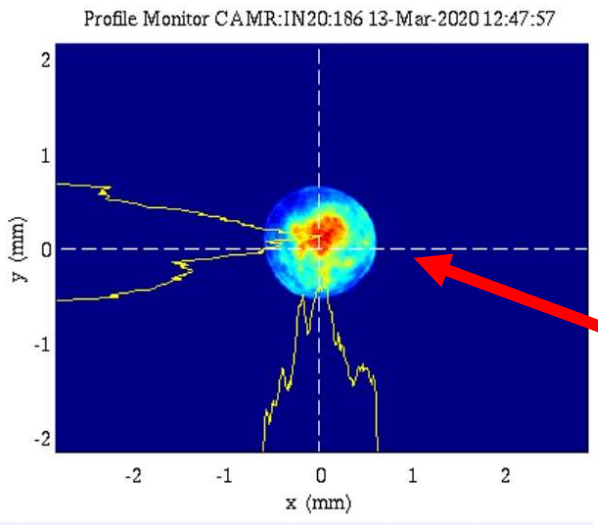


Fringe pattern – Temporal overlap

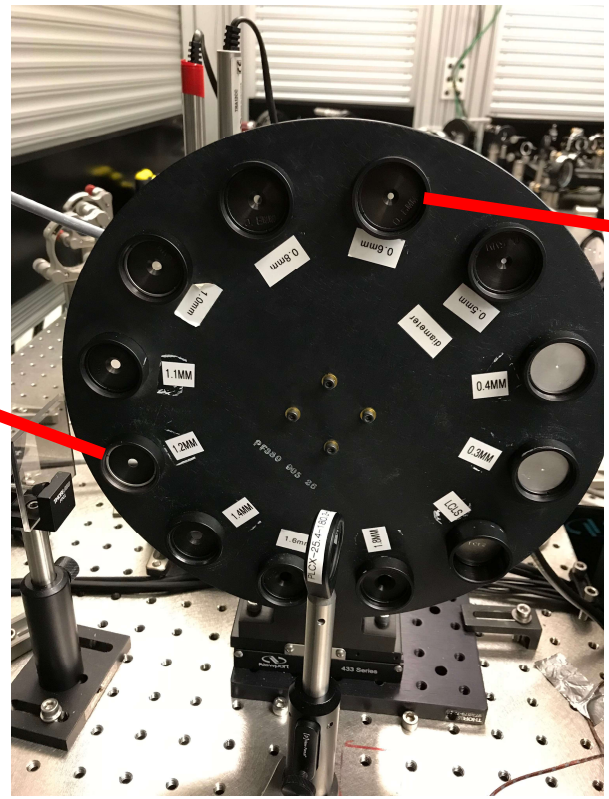
LCLS Laser System - Drive Laser System

- Iris Wheel – Imaging system to the cathode (4:1)
- Nominal charge of 250pC, iris size 1.2mm
- Lower charge such as 20pC, smaller iris size

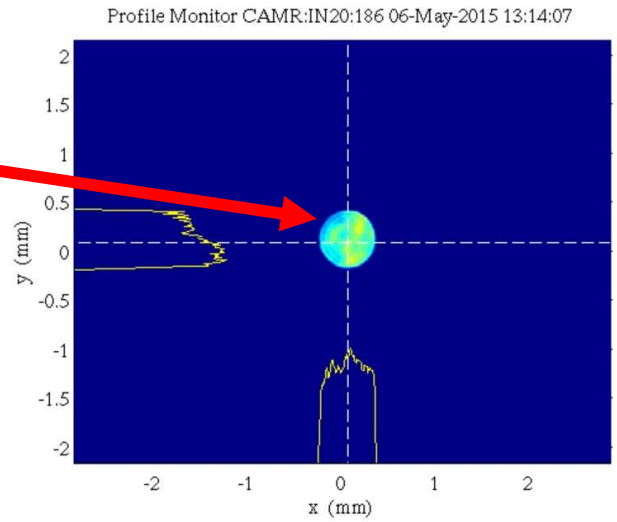
1.2mm Iris



VCC



0.6mm Iris



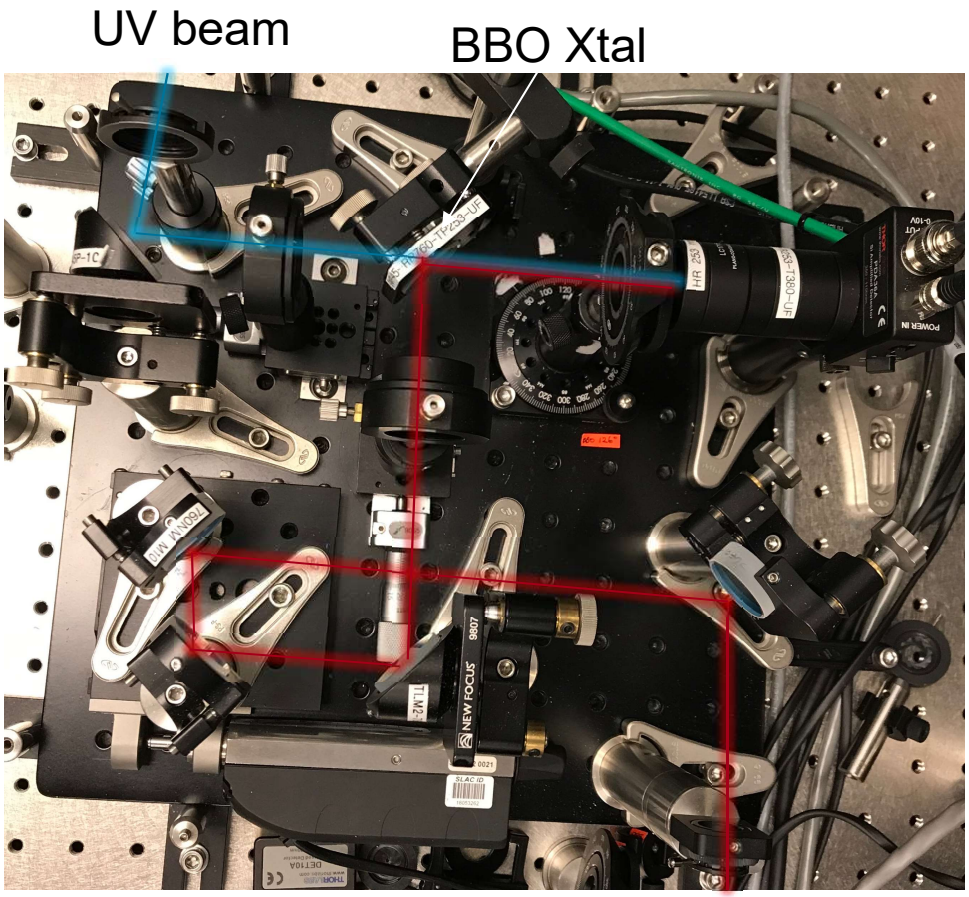
VCC

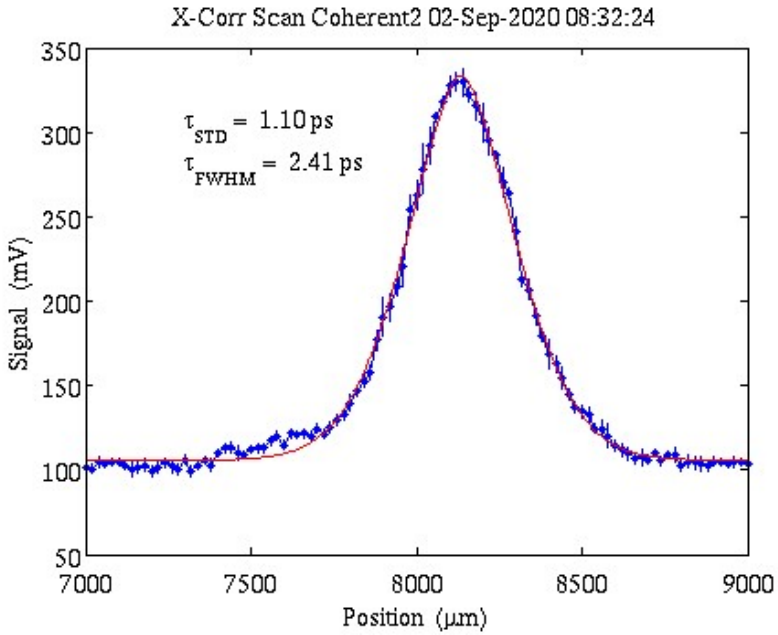
LCLS Laser System - Drive Laser System

- Cameras – Manta cameras, Pulnix cameras in Vault for VCC, CH1 & VHC
- Power Meters- Coherent

LCLS Laser System - Drive Laser System

- Cross-Correlator – measurement of UV pulse length





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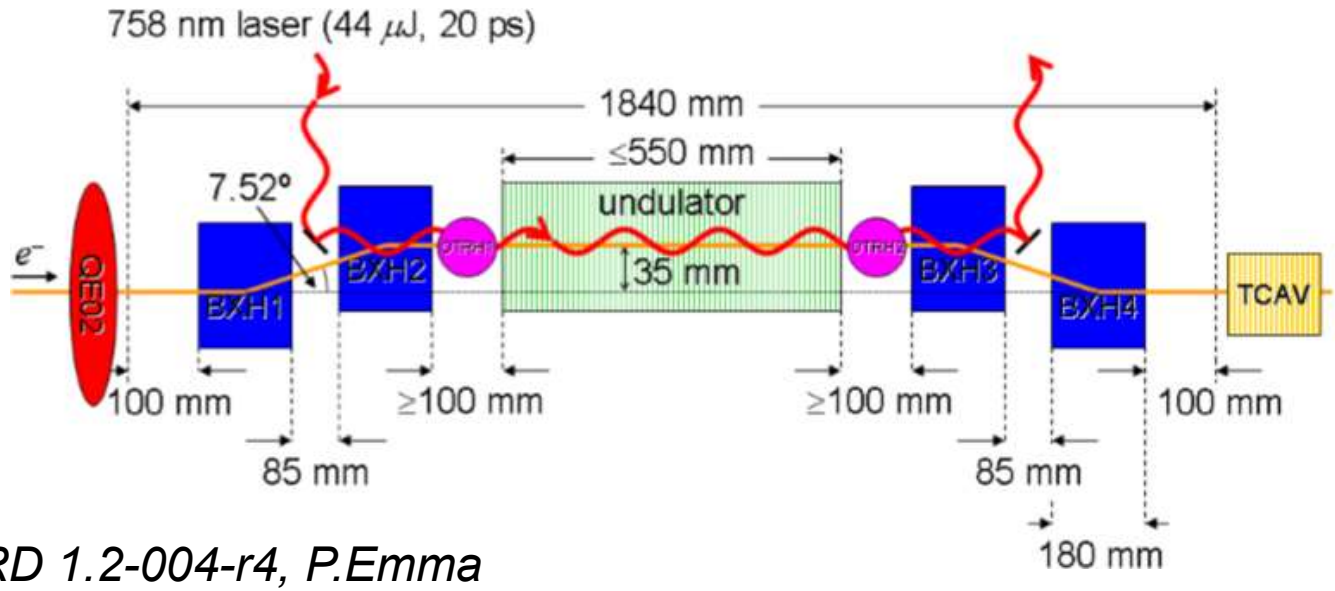
LCLS Laser System – Laser Heater System

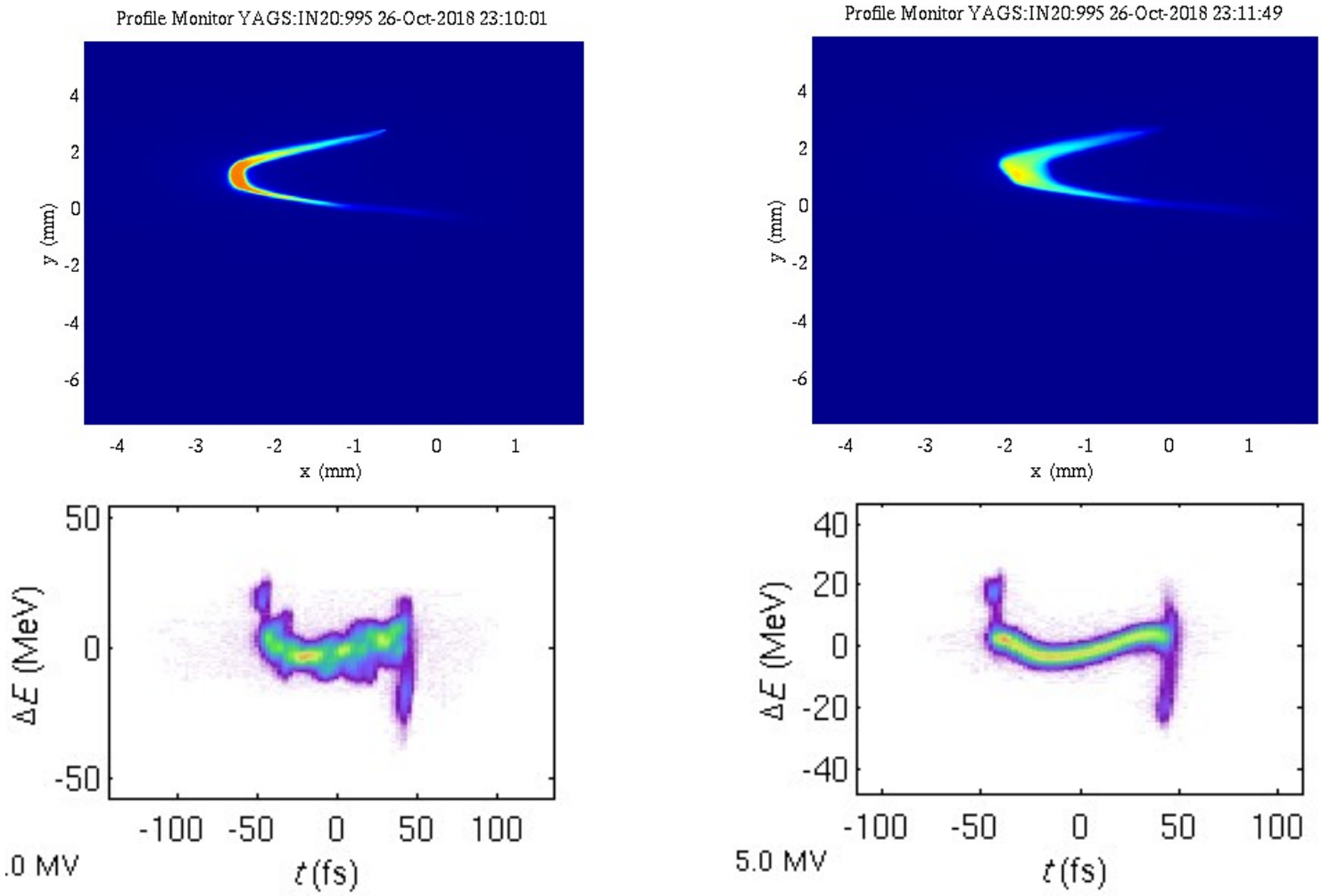
- Why do we need the laser heater?
- Microbunching instabilities (MBI)
- Overlap of laser and electron beam gives energy modulation
- growth of slice energy spread to suppress instabilities and make the longitudinal phase space more manageable



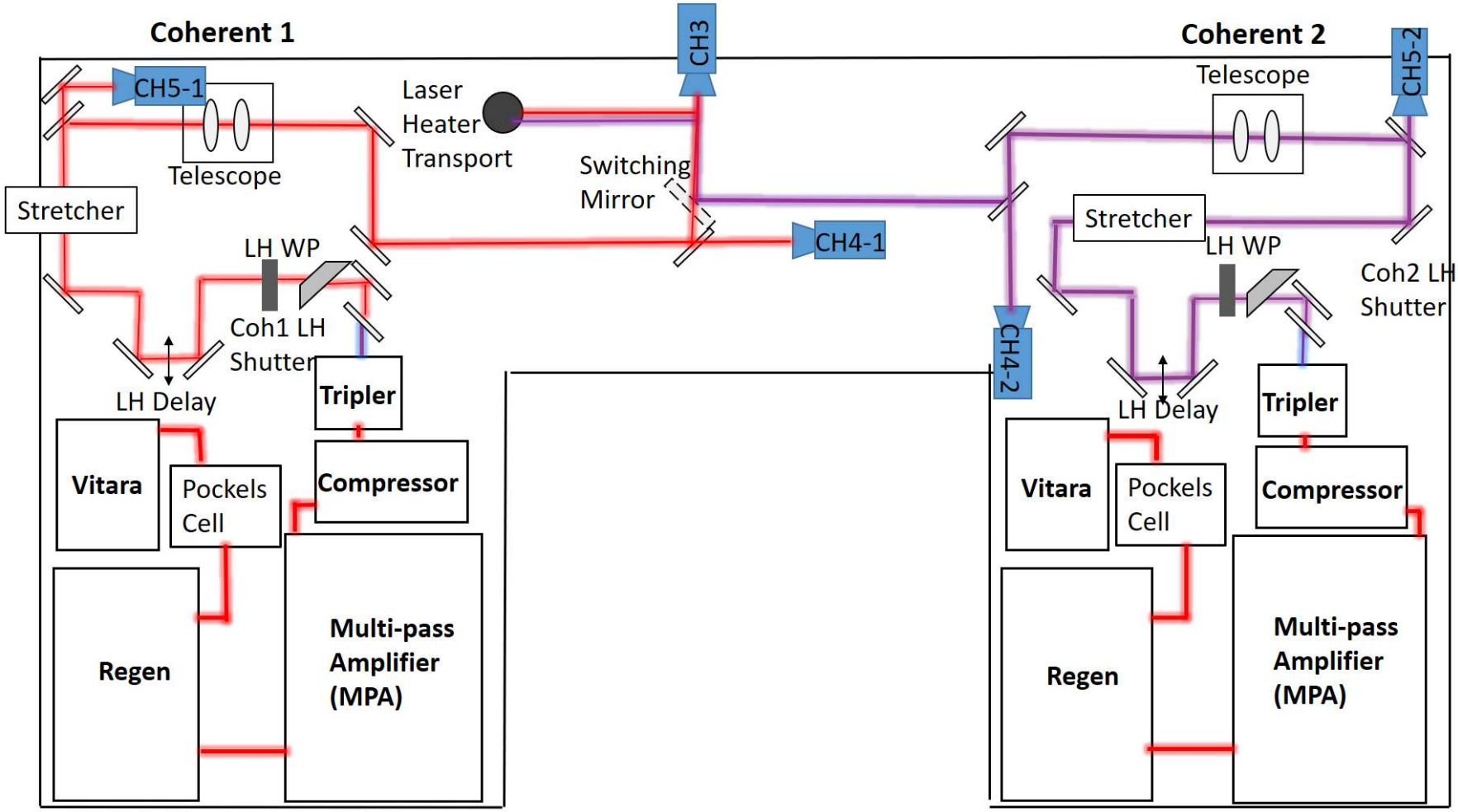
Ref: PRD 1.2-004-r4, P.Emma

LCLS Laser System – Laser Heater System

- Laser Heater OFF vs Laser Heater ON

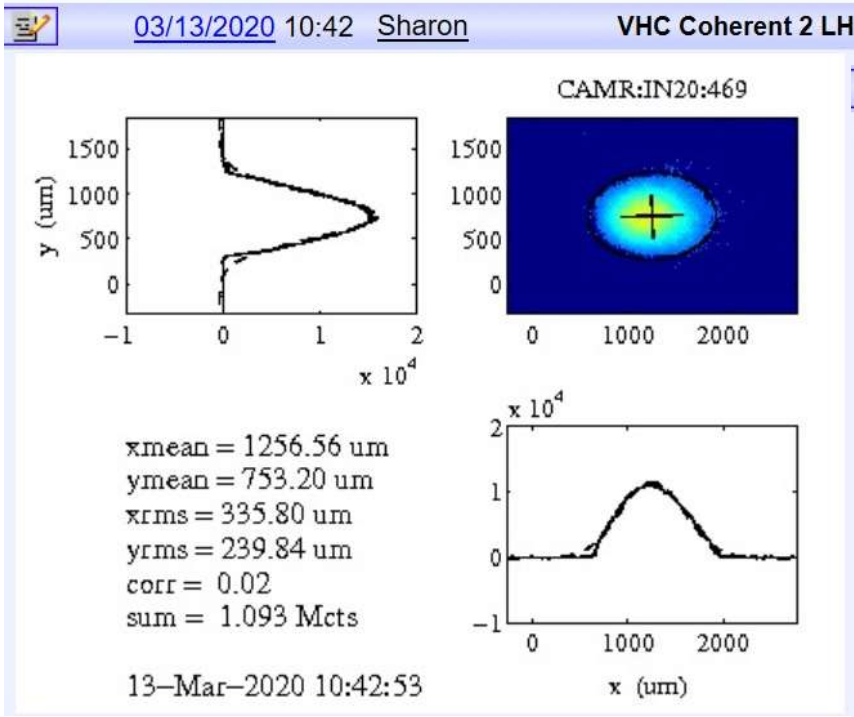


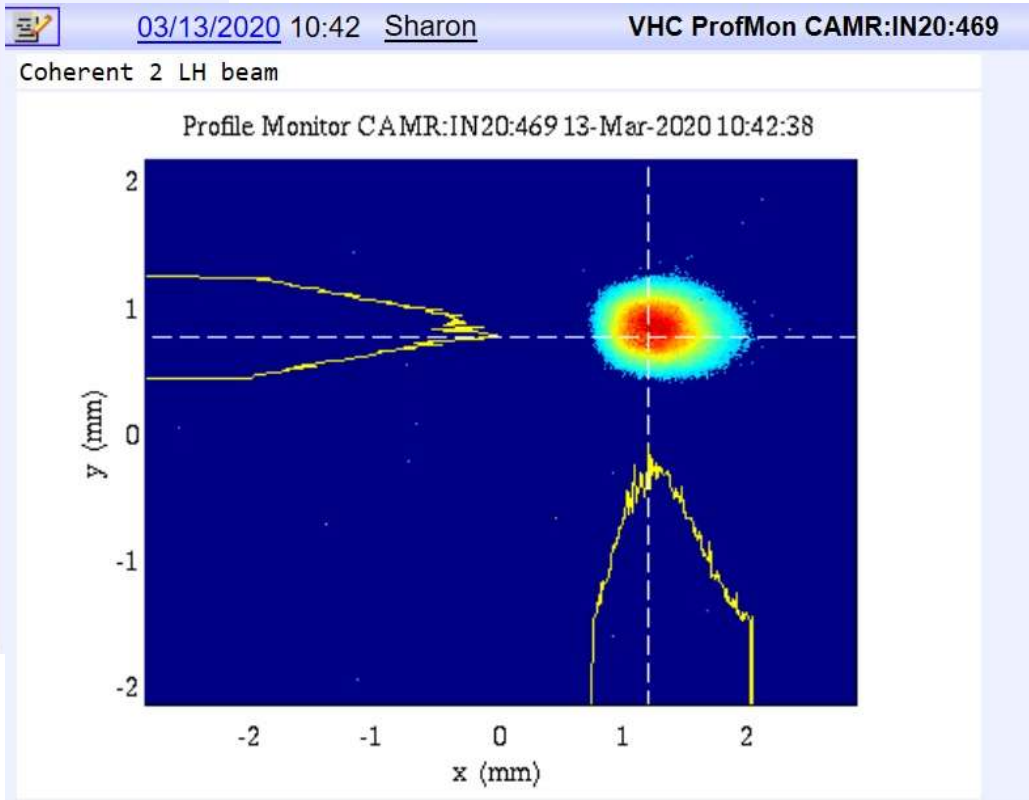
LCLS Laser System – Laser Heater System



LCLS Laser System – Laser Heater System

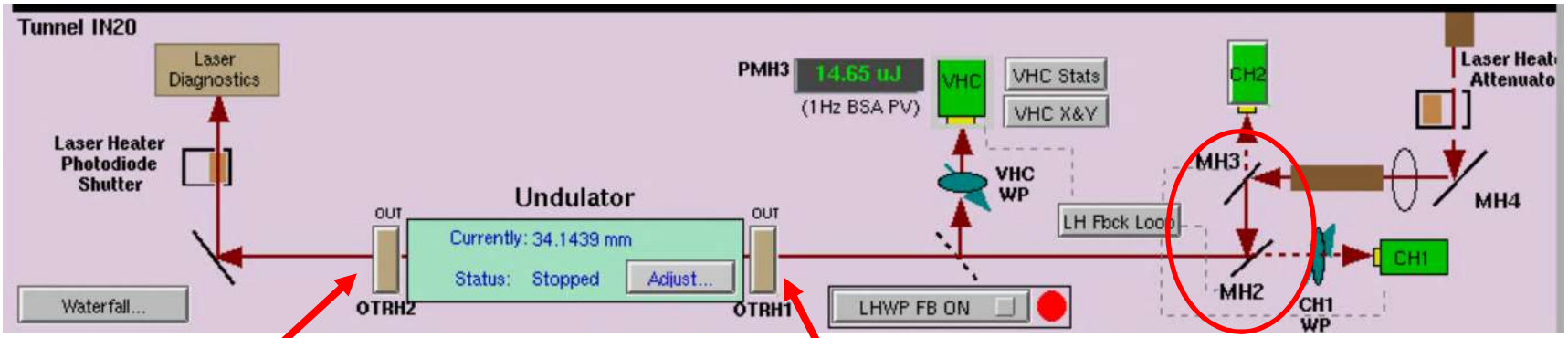
- VHC – Image of beam inside the undulator

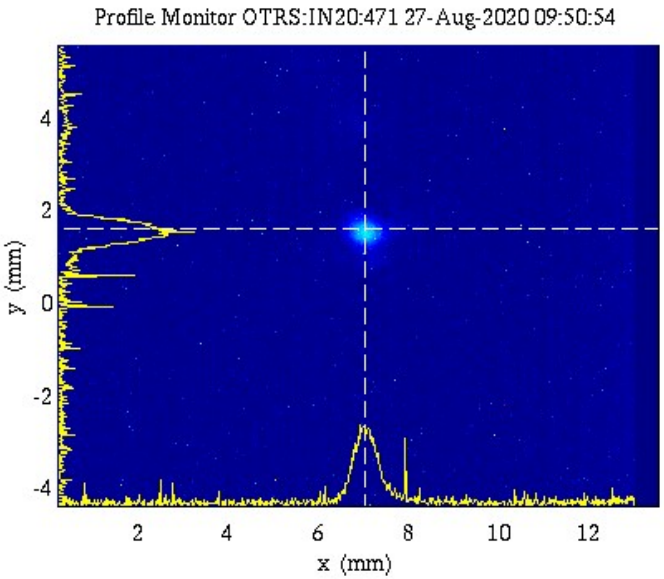


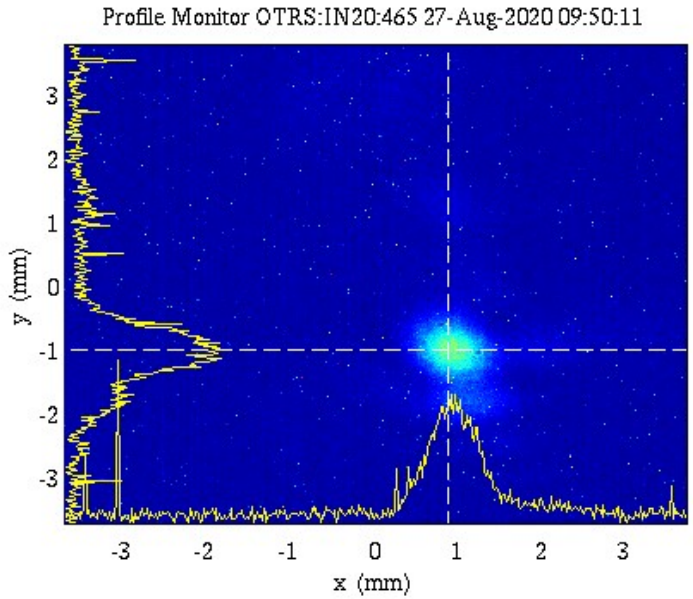


LCLS Laser System – Laser Heater System

- Laser Heater Transverse alignment

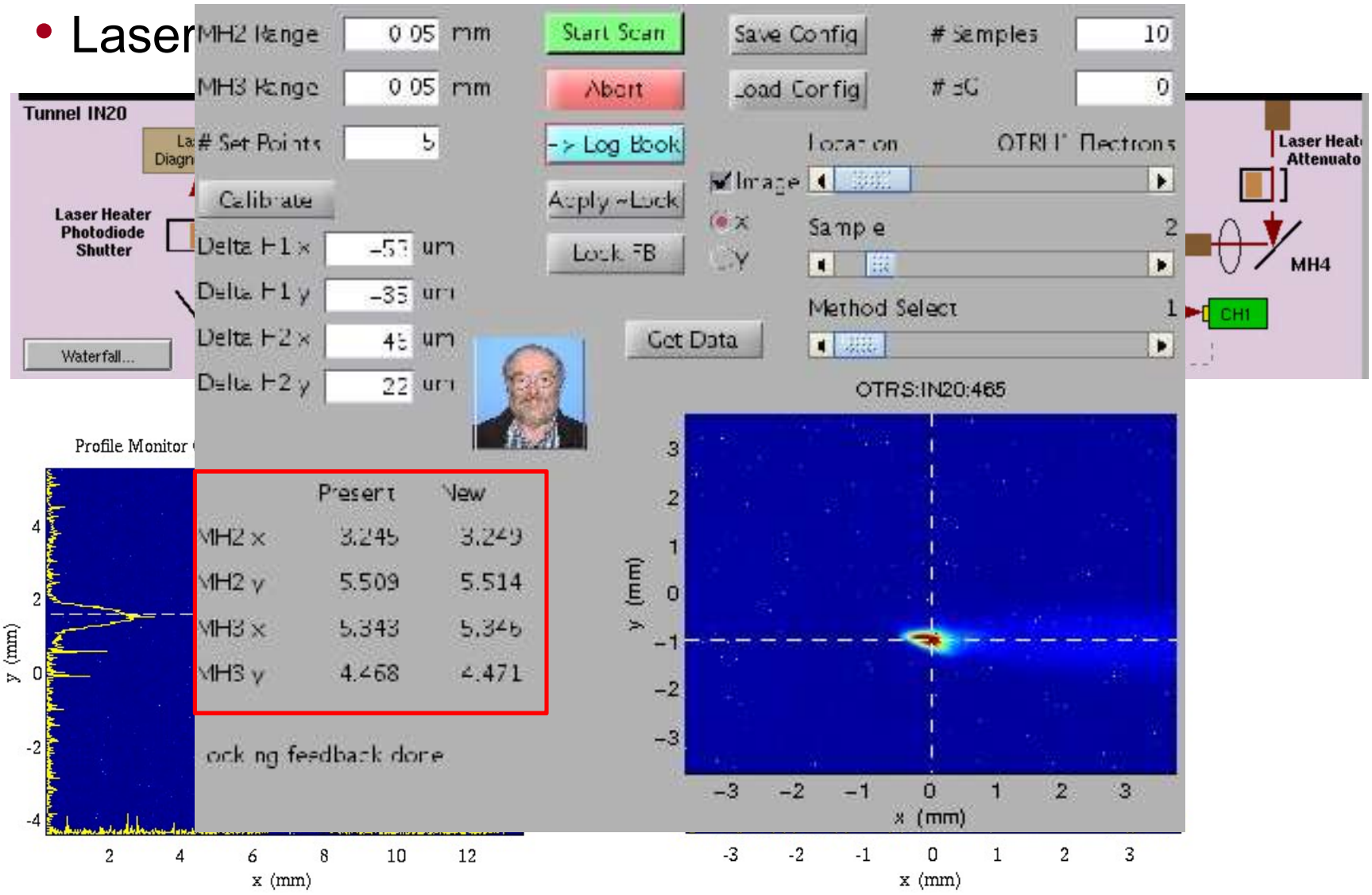






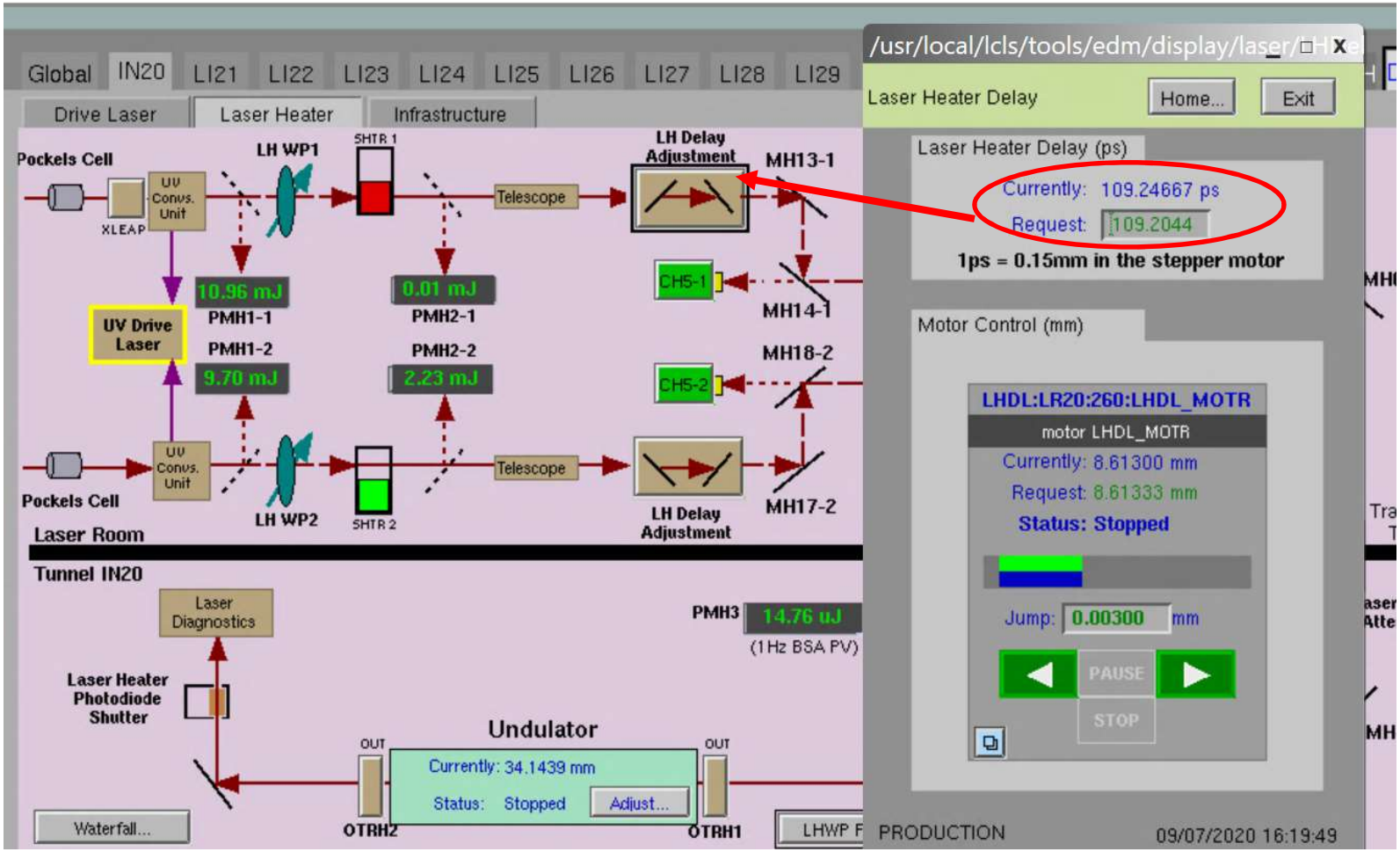
LCLS Laser System – Laser Heater System

- Laser



LCLS Laser System – Laser Heater System

- Laser Heater Temporal alignment



LCLS Laser System – Laser Heater System

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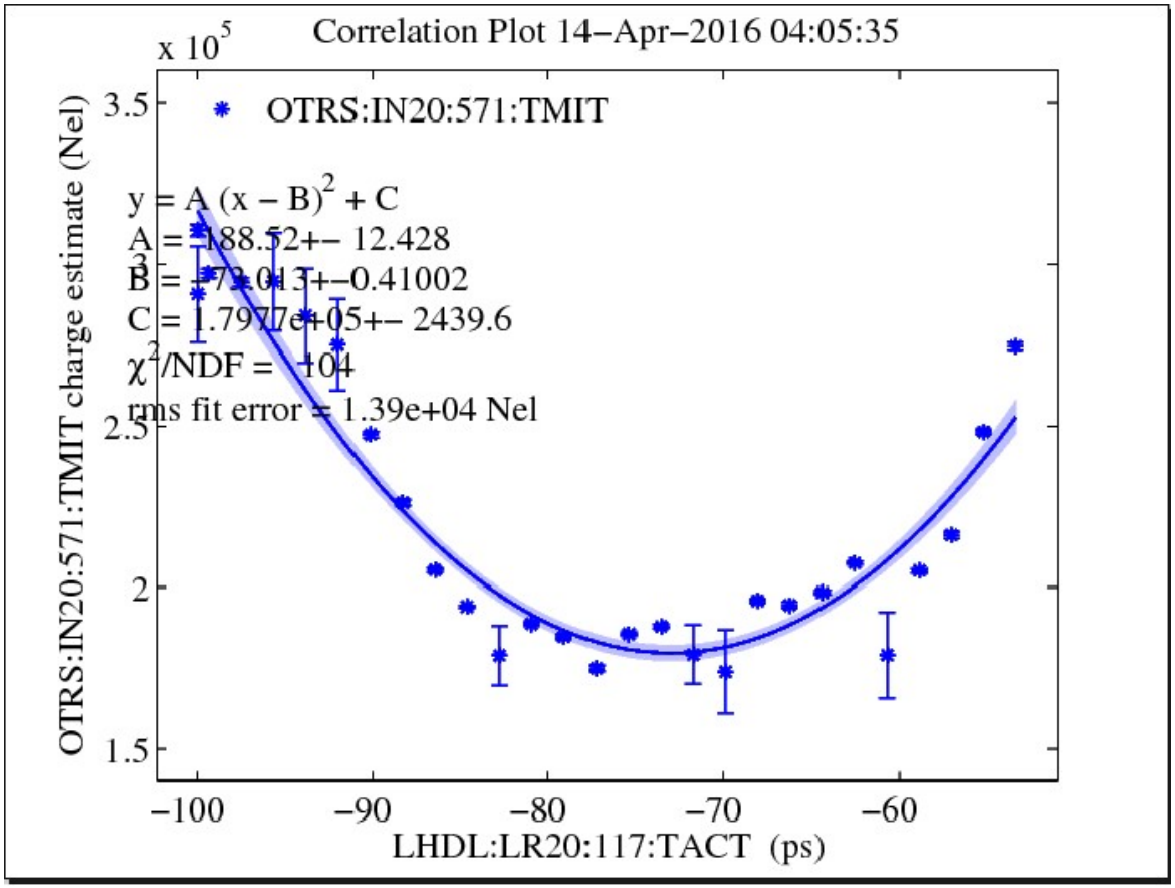

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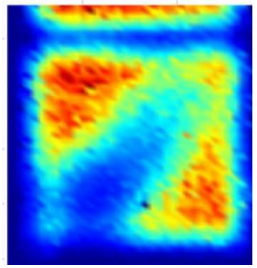
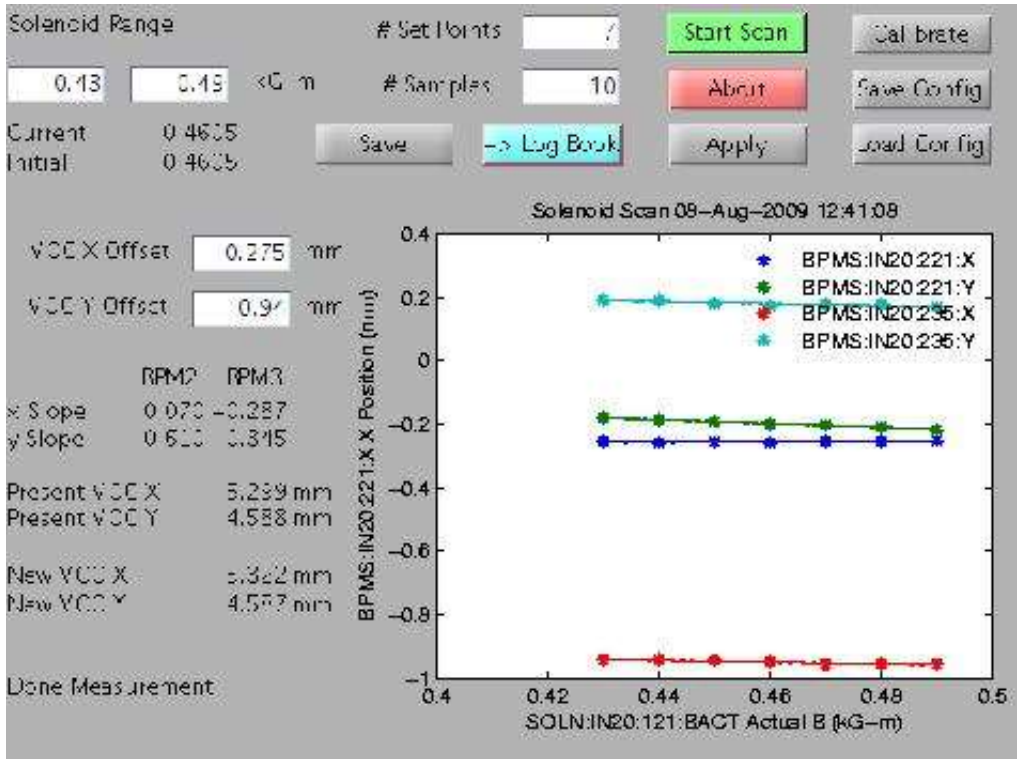
Laser and e-Beam Performance

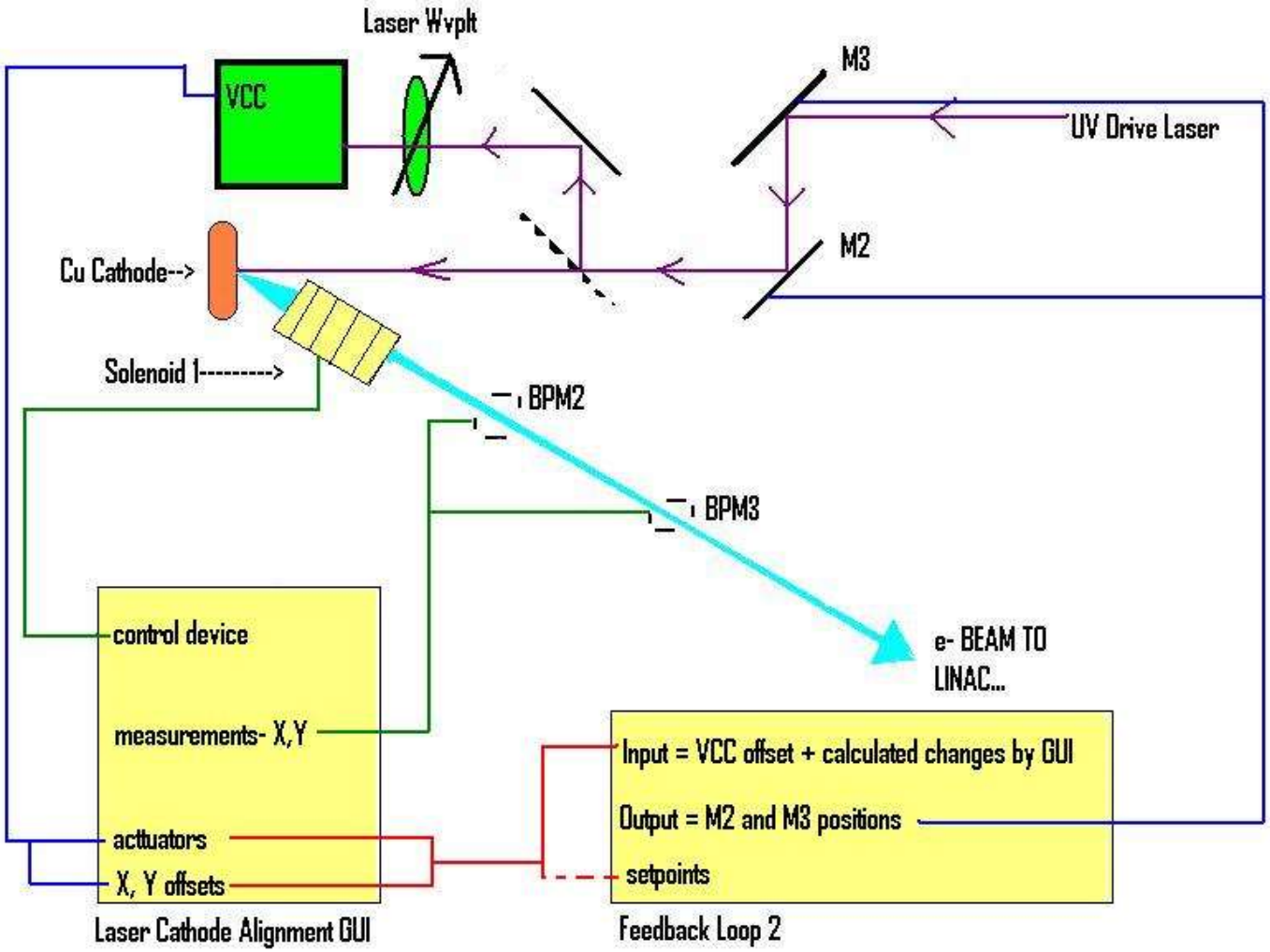
- Cathode alignment
  - Laser position on the cathode in an area with good QE performance



  - Electron beam position using BPM's and the solenoid strength, when the drive laser is well-aligned, the electron beam will be in the middle of the solenoid (no transverse field)

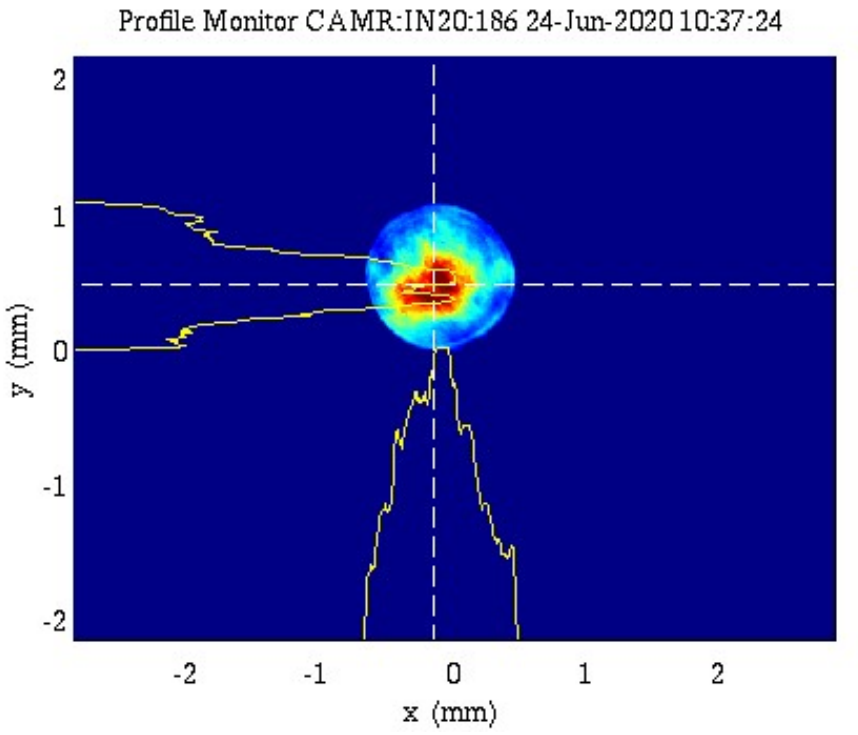


Laser and e-Beam Performance



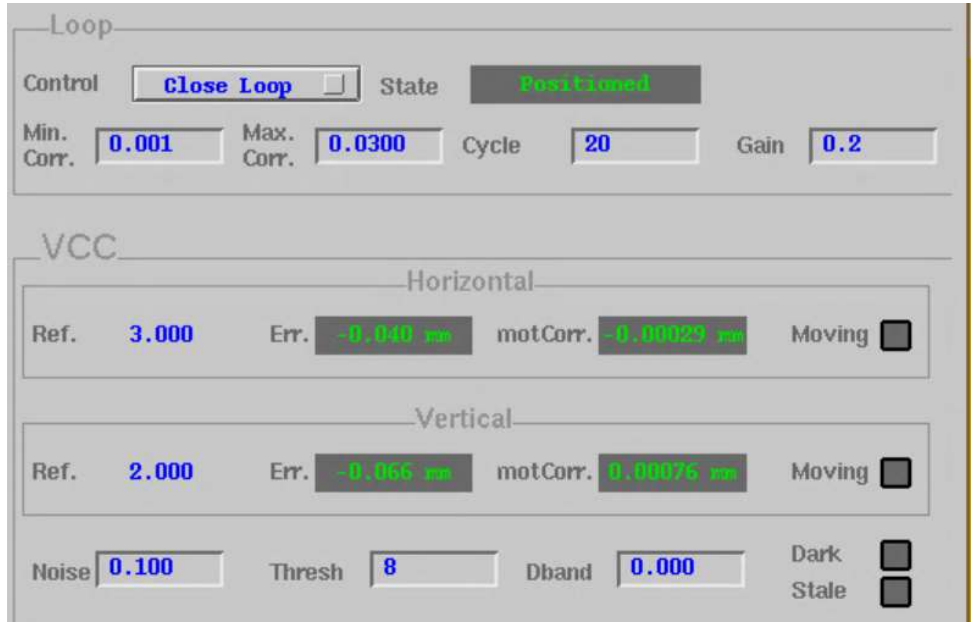
Courtesy of Eric Tse

Laser and e-Beam Performance



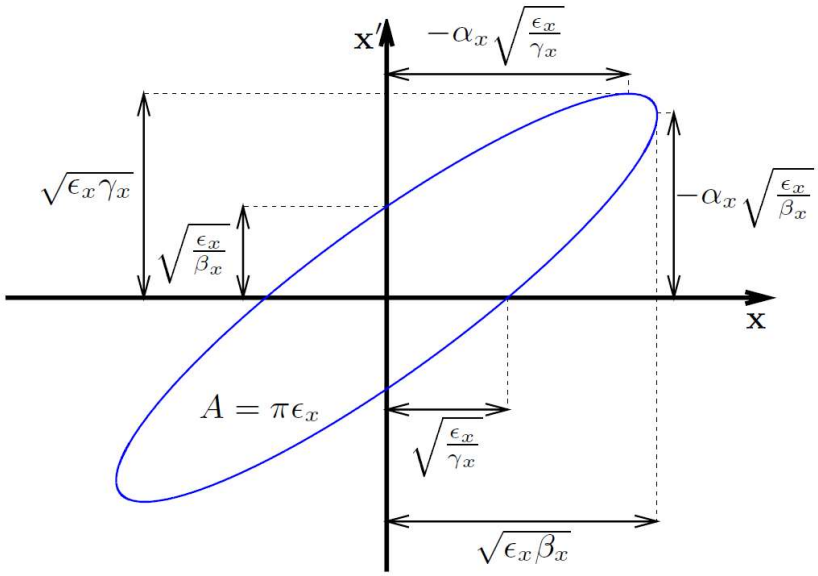
- Laser Profile – cut-Gaussian
- Filling the iris with a uniform beam, lose lots of laser energy

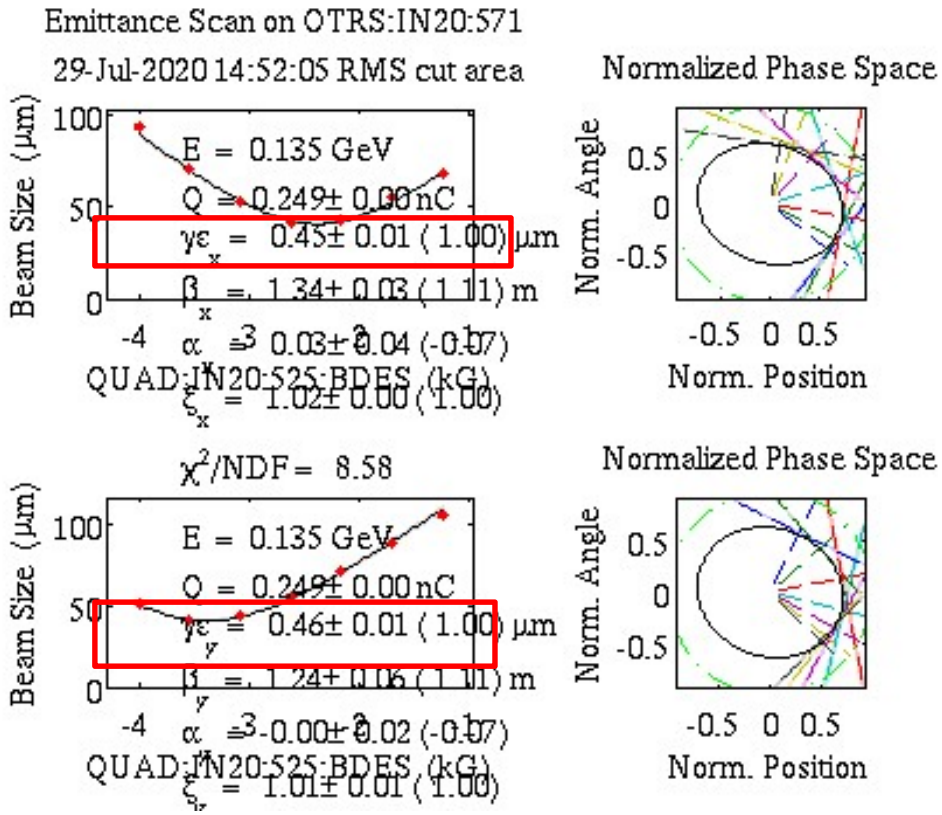
- Laser Feedback to maintain beam position on cathode



Laser and e-Beam Performance

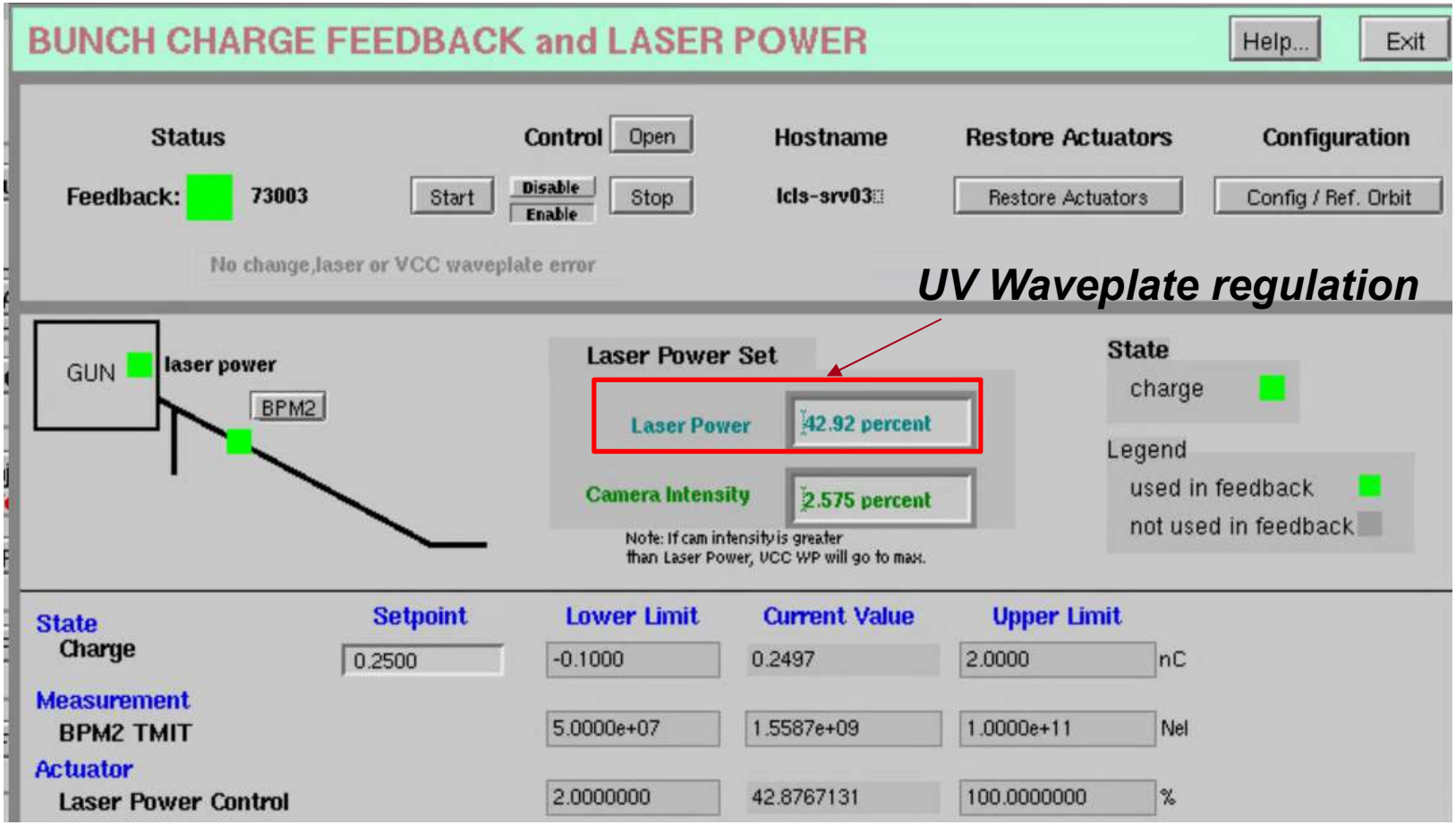
- Emittance measurements – aim for $\varepsilon_{x,y} \sim 0.4\mu m$
- Beam orientation described by the Twiss parameters (α, β, γ)





Laser Room Layout – Drive Laser System

- Bunch Charge Feedback and the Laser Percentage



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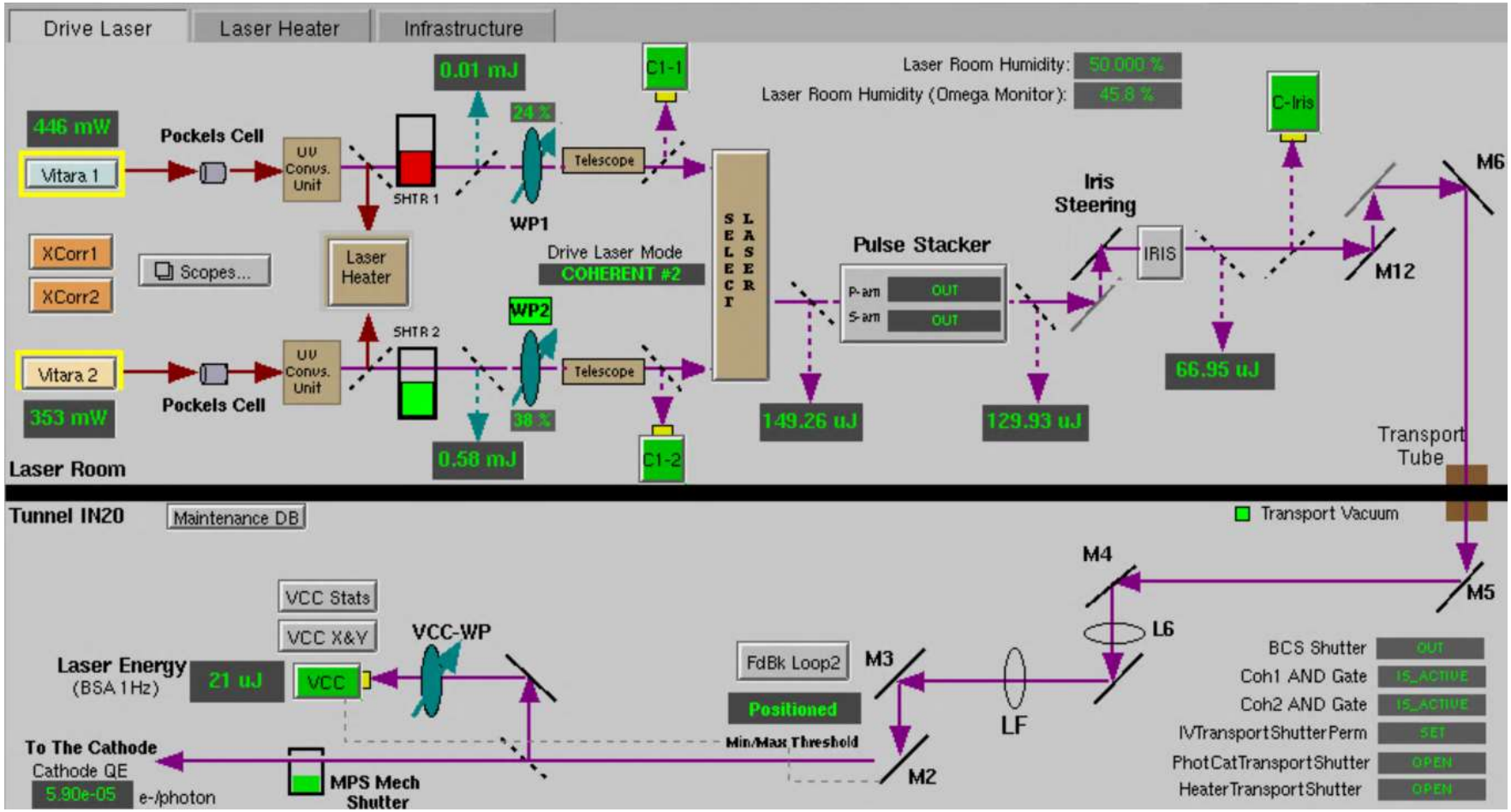
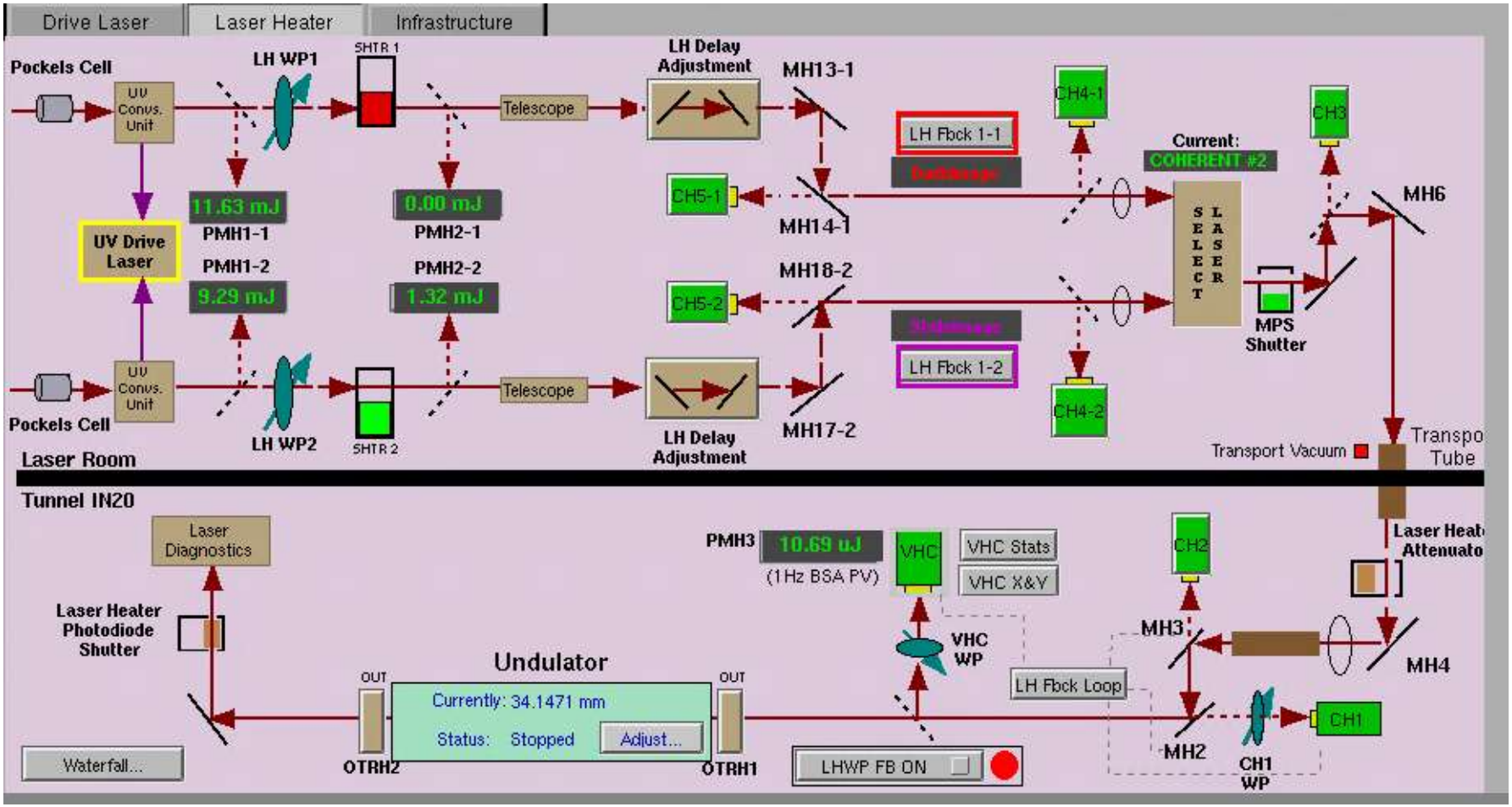
LCLS Operation and User Delivery

- User Delivery schedule typically Thurs-Mon, User Run 18 started August 11th with an emphasis on Coronavirus experiments
- MD and Maintenance times Tues/Wed/Thurs
- Laser support 24/7, with shifts DAY 9am-9pm/NIGHT 9pm-9am
- Potential to switch lasers if needed to minimize downtime
- So what gets monitored during delivery? Power, laser spatial shape on the cathode, pulse length

LCLS Operation and User Delivery



Normal Operation and User Delivery



LCLS Operation and User Delivery

SLAC

Laser Maintenance GUI

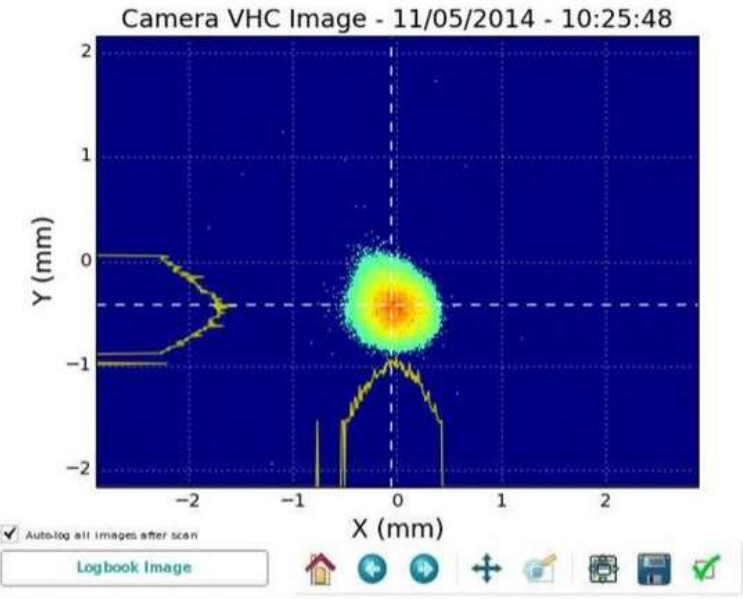
Current Laser: Coherent 2

Abort | Run Full | Get Noninvasive

	Status	Run Timestamp	Action Performed	Data Collected	PV used
1	Complete	11/05/2014 - 10:25:46	Current laser name	Coherent 2	MIRR:LR20:111:M19_STATE
2	Complete	11/05/2014 - 10:25:46	Mode-Locked Power for Vitara 1	450.325927734	PMTR:LR20:20:PWR
3	Complete	11/05/2014 - 10:25:47	Mode-Locked Power for Vitara 2	386.401367188	PMTR:LR20:10:PWR
4	Complete	11/05/2014 - 10:25:47	Pulse Stacker Waveplate Angle	124.0	WPLT:LR20:117:PSWP_ANGLE
5	Complete	11/05/2014 - 10:25:47	Pulse Stacker S Arm Position	OUT	SHTR:LR20:117:SARM_STS
6	Complete	11/05/2014 - 10:25:47	Iris Diameter	1.0 mm	IRIS:LR20:118:CONFG_SEL
7	Complete	11/05/2014 - 10:25:47	Camera VCC Image	...0 0 0 ..., 0 0 0]	CAMR:IN20:186:IMAGE
8	Complete	11/05/2014 - 10:25:47	Camera C_IRIS Image	...1 1 1 ..., 0 0 0]	CAMR:LR20:119:Image:Array
9	Complete	11/05/2014 - 10:25:47	Camera C1 Image	...1 0 1 ..., 0 0 0]	CAMR:LR20:113:Image:Array
10	Complete	11/05/2014 - 10:25:47	Camera C2 Image	...2 2 0 ..., 0 1 0]	CAMR:LR20:114:Image:Array
11	Complete	11/05/2014 - 10:25:47	Camera CH1 Image	...0 0 0 ..., 0 0 0]	CAMR:IN20:461:IMAGE
12	Complete	11/05/2014 - 10:25:48	Camera CH2 Image	...2 2 3 ..., 1 1 3]	CAMR:IN20:423:Image:Array
13	Complete	11/05/2014 - 10:25:48	Camera CH3 Image	...0 0 0 ..., 0 0 0]	CAMR:LR20:120:Image:Array
14	Complete	11/05/2014 - 10:25:48	Camera VHC Image	...0 0 0 ..., 0 0 0]	CAMR:IN20:469:IMAGE

	Status	Run Timestamp	Action Performed	Data Collected	PV used
1	Complete	11/05/2014 - 10:26:26	PM1 power average	0.497	PMTR:LR20:112:AVG
2	Complete	11/05/2014 - 10:26:26	PM1 power standard deviation	0.006	PMTR:LR20:112:STDE
3	Complete	11/05/2014 - 10:26:53	Drive laser WP at 100% laser power	59.6	WPLT:LR20:116:WP2_
4	Complete	11/05/2014 - 10:26:53	PM2 power	0.135154724121	PMTR:LR20:117:PWR
5	Complete	11/05/2014 - 10:27:09	PM3 power	0.0597267150879	PMTR:LR20:119:PWR
6	Complete	11/05/2014 - 10:27:25	Cathode power	42.6583007812	LASR:IN20:196:PWR
7	Complete	11/05/2014 - 10:28:00	Heater WP angle at 50% transmission	117.5	WPLT:LR20:117:LHWF
8	Complete	11/05/2014 - 10:27:37	LH PM1 power	5.64994812012	PMTR:LR20:115:PWR
9	Complete	11/05/2014 - 10:28:00	LH PM2 power	0.595092773438	PMTR:LR20:118:PWR
10	Complete	11/05/2014 - 10:28:16	LH PM3 power	52.5819702148	LASR:IN20:475:PWR

Open DB | Data to Database | Operator: Sharon | Comment: During some RF Hut Water work



	Log Timestamp	Log Message
123	2014-11-05 10:28:14	Starting clock to wait 2 seconds
124	2014-11-05 10:28:16	PMH3 power = 52.5819702148
125	2014-11-05 10:28:16	Moving heater waveplate to start position: 101.5 degrees
126	2014-11-05 10:28:17	CAPUT: WPLT:LR20:117:LHWP_ANGLE: 101.5
127	2014-11-05 10:28:17	Checking status for PV changes: Timeout = 15 seconds...
128	2014-11-05 10:28:23	Change complete, all PVs converged in 6.192 seconds
129	2014-11-05 10:28:23	CAPUT: TRIG:LR20:LS01:TCTL: 1
130	2014-11-05 10:28:24	Invasive scan sucessfully completed

Developed by Chris Zimmer

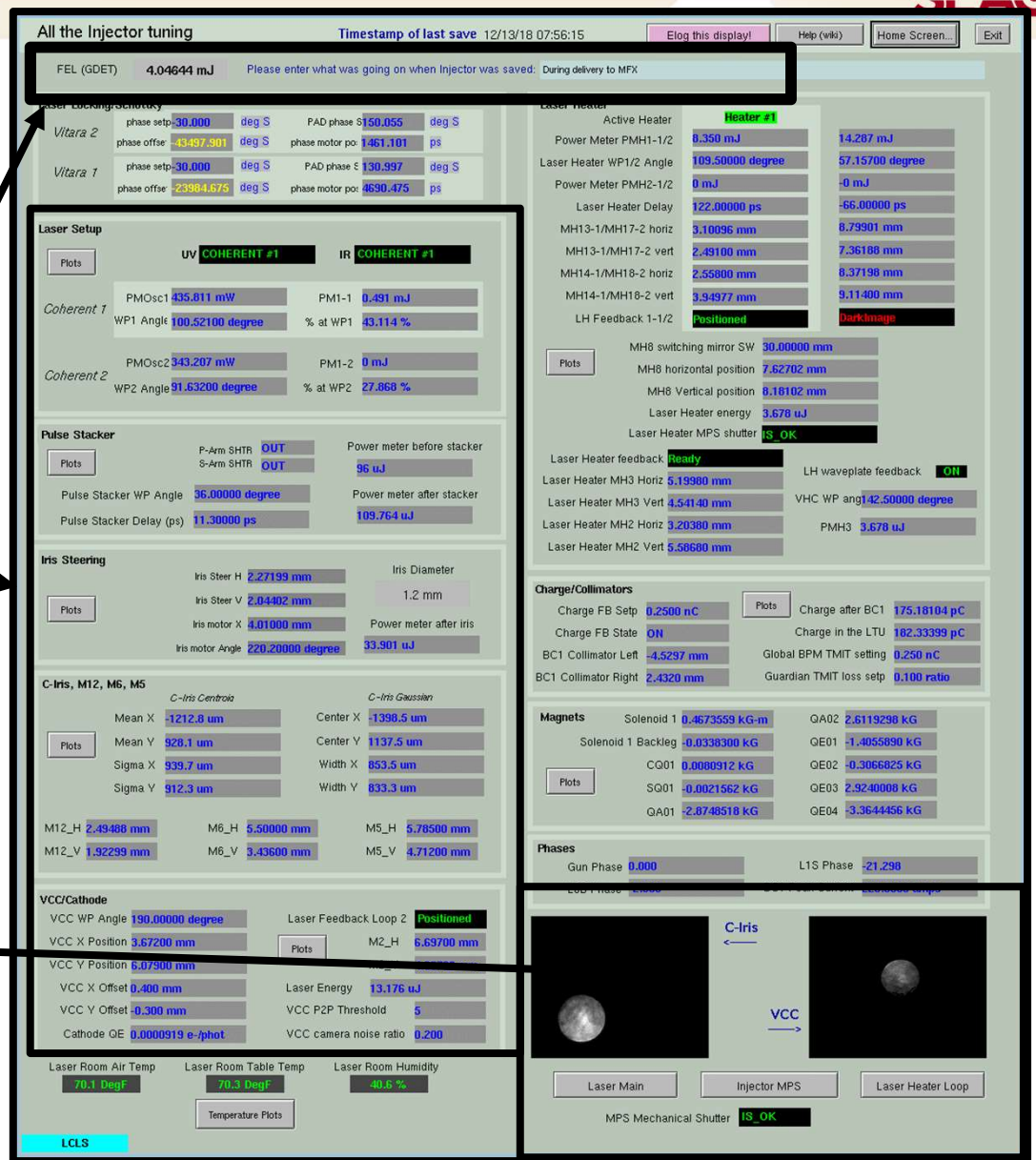
LCLS Operation and User Delivery

Snapshot of the machine
Created by Tonee Smith

FEL performance
and User Delivery

Drive Laser and setup

VCC and C-Iris Images

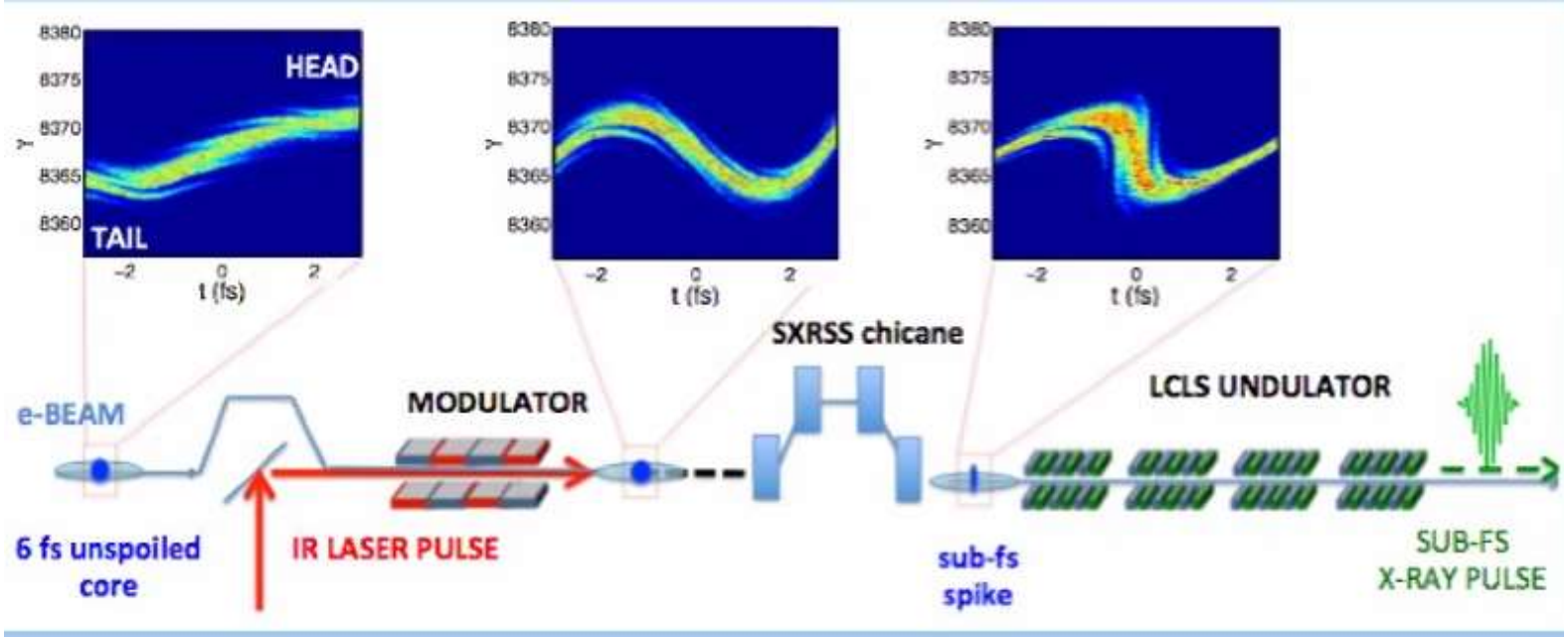


Outline

- SLAC's LCLS Photoinjector
- LCLS Laser System
  - Drive Laser System
  - Laser Heater System
- Laser and e-Beam Performance
- LCLS Operation and User Delivery
- **Future Developments**
  - **xLEAP**
  - **LCLS II**
  - **Machine Learning**

Future Developments
xLEAP

- XLEAP – X-Ray Laser Enhanced Attosecond Pulse Generation



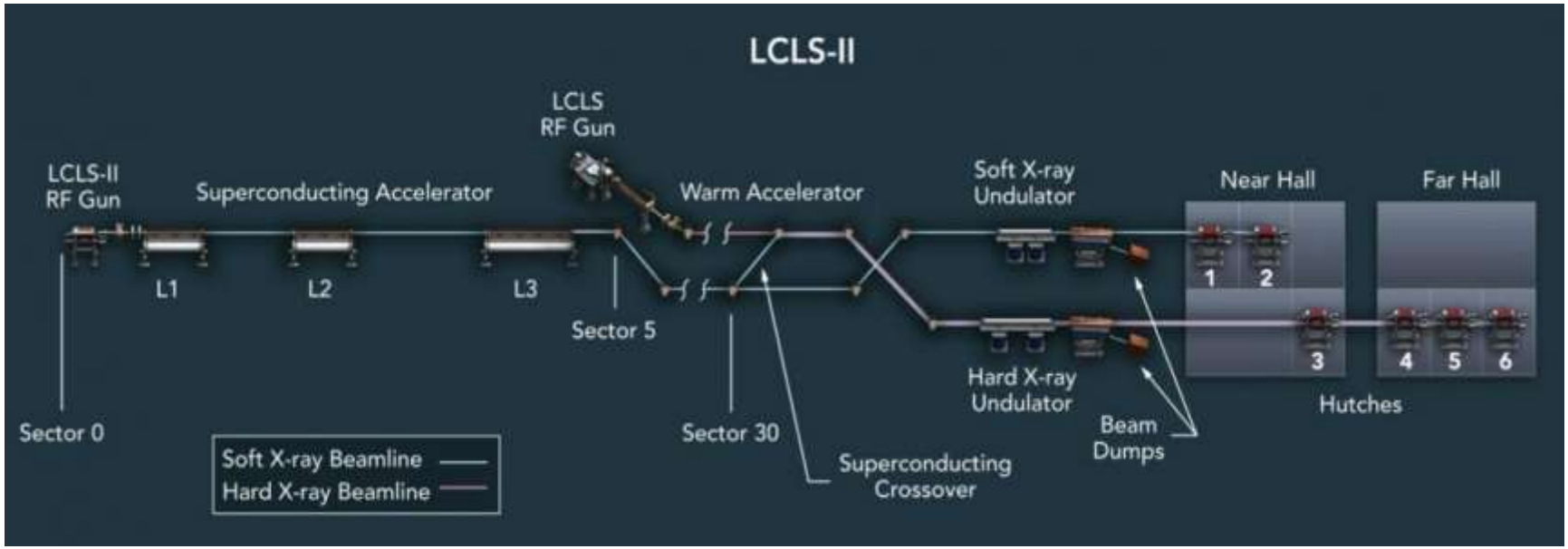
- Ago Marinelli and Joe Duris using the xLEAP wiggler to produce sub-fs X-Ray pulses

Future Developments
LCLS II

SLAC

Cs_2Te cathode, ~1 MHz Operation

LCLS II laser system is an Amplitude fiber oscillator and amplifier ~50 W of class IV IR (1030 nm) radiation with UV conversion to produce the 4th harmonic (257.5 nm) of the IR beam



Future Developments
Machine Learning

- Advances into Machine Learning at SLAC for Accelerator Operations

ML-at-SLAC Initiative

Daniel Ratner
Initiative Lead

ML Steering Committee

Ryan Coffee
LCLS Science

Audrey Therrien
LCLS/TID

Apurva Mehta
SSRL

Kazuhiro Terao High Energy Physics

Xiaobiao Huang
Accelerator

- Nicole Neveu, Auralee Edelen, Lipi Gupta, William Lou, Chris Mayes, Aashwin Mishra…and many others!

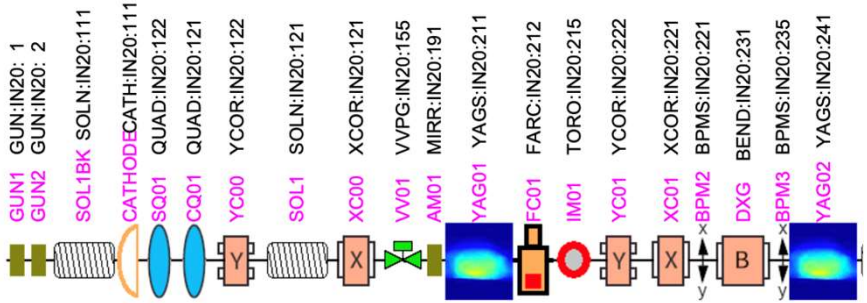
Lisa Kaufman
Nuclear Physics

Jana B. Thayer LCLS
Data Systems

Mariano Trigo
Energy Science

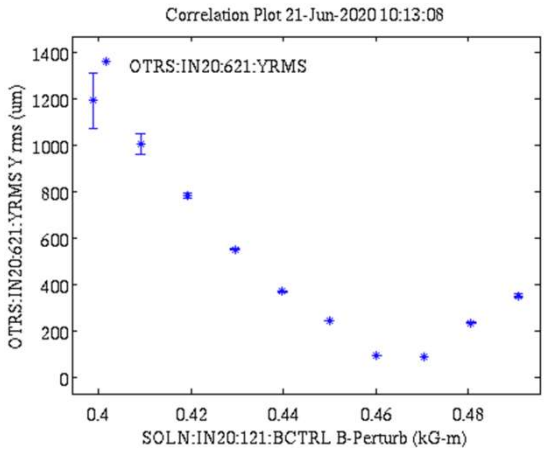
Future Developments
Machine Learning

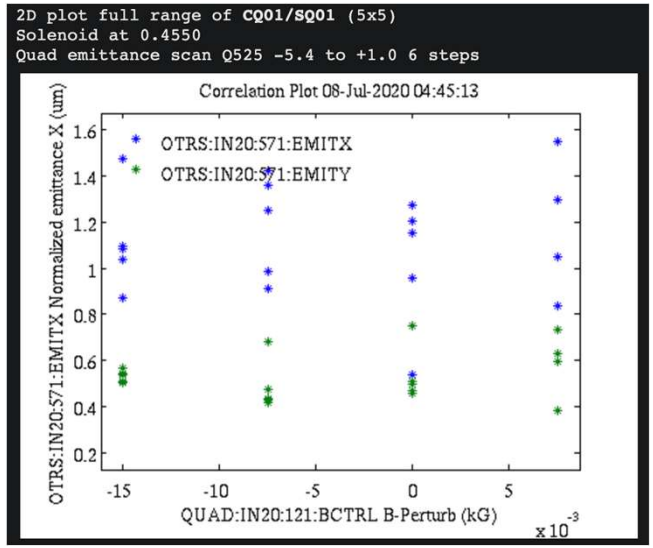
- Example of datasets collected on Injector tuning for simulations and ML models

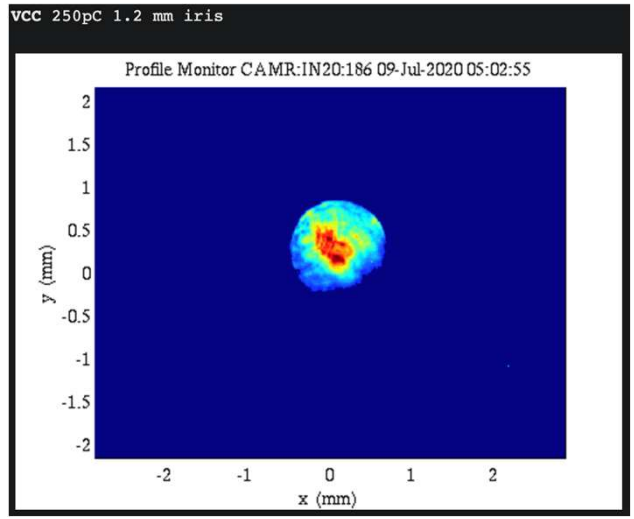


Injector

Variables	MAD Name	PV Name
Iris diameter		IRIS:LR20:130:MOTR_ANGLE
Solenoid	SOL1	SOLN:IN20:121:BDES
Corrector quad	CQ01	QUAD:IN20:121:BDES
Skew quad	SQ01	QUAD:IN21







Courtesy of Nicole Neveu

Summary

Optimization of Lasers in Electron Accelerator Applications

Hope you have a better understanding of the LCLS 1 Injector Laser System and Photoinjector

Appreciation LCLS Operation for User Delivery

Future developments for LCLS with Attosecond X-Ray pulse generation, LCLS II and Machine Learning


THANK YOU!
Sept 16th, WEAO03
SLAC