LCLS Operation in Self Seeding Mode

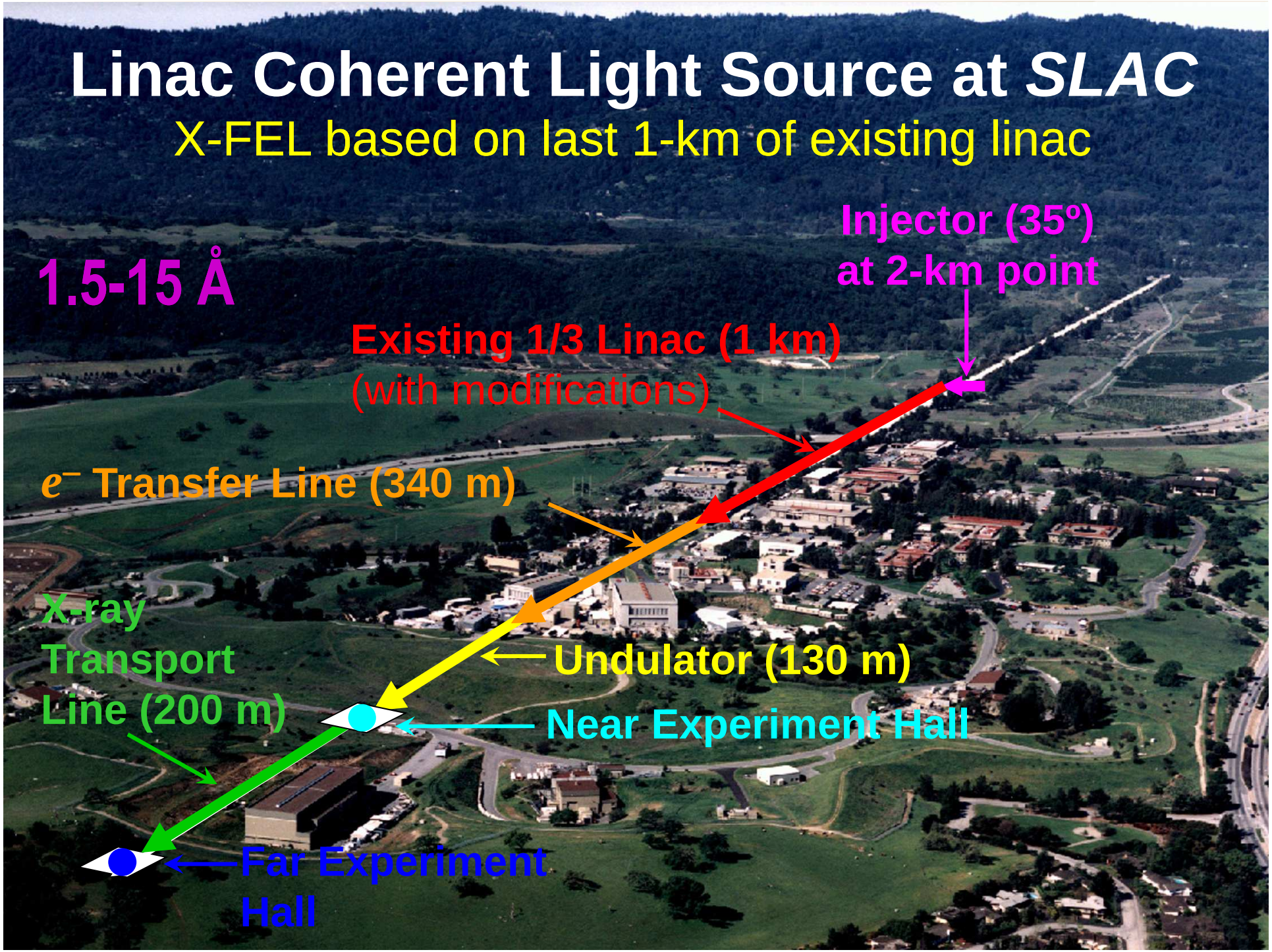
Franz-Josef Decker DESY, 25-Jun-2013

1. LCLS basics (Linac Coherent Light Source at SLAC)
2. Operational schedules
3. Self-seeding
4. More seeding lines than 004, 220 and 111
5. XTCAV (X-band transverse cavity)

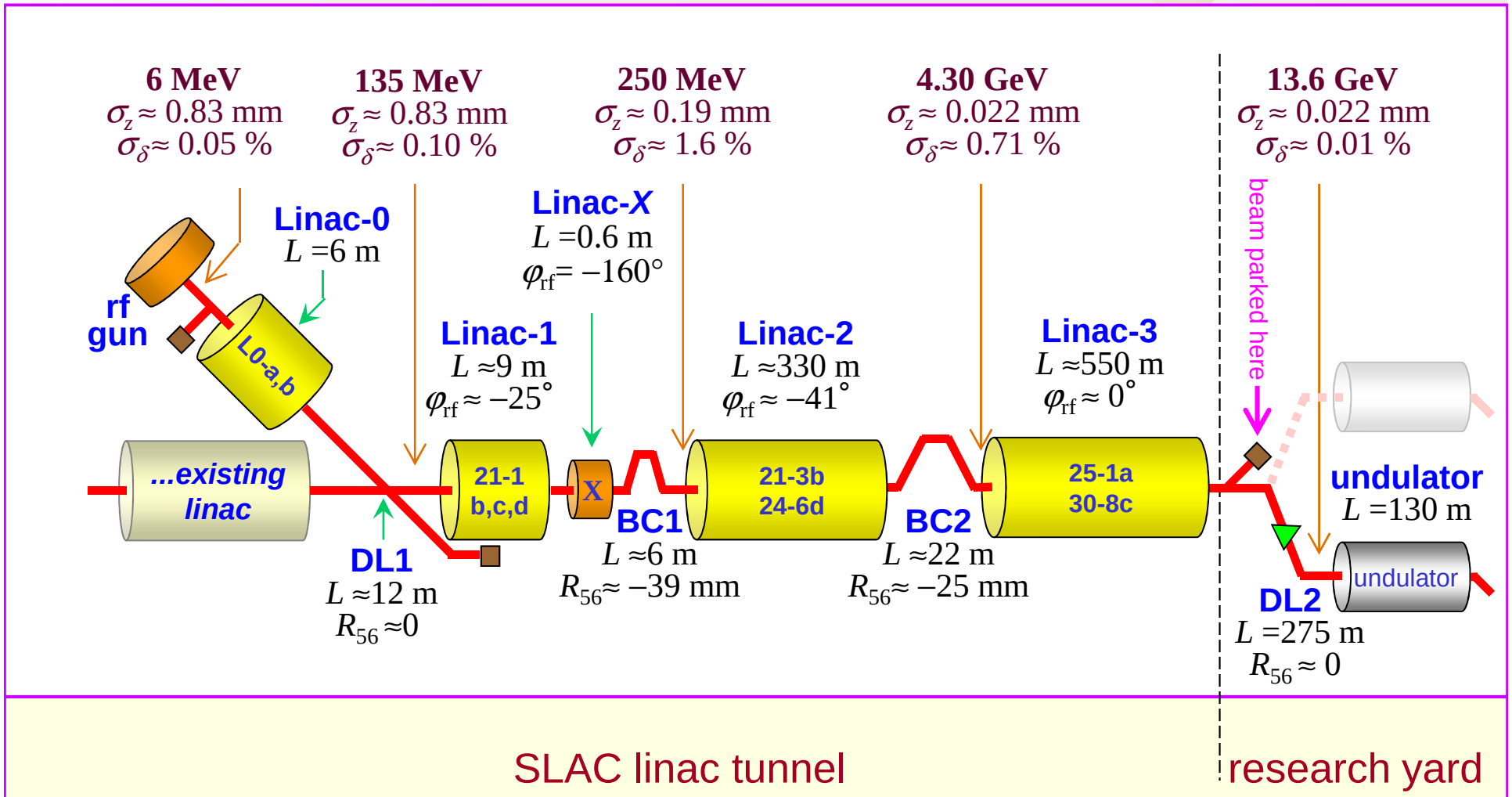
U.S. DEPARTMENT OF ENERGY
Office of Science
SLAC NATIONAL ACCELERATOR LABORATORY

Linac Coherent Light Source at *SLAC*

X-FEL based on last 1-km of existing linac



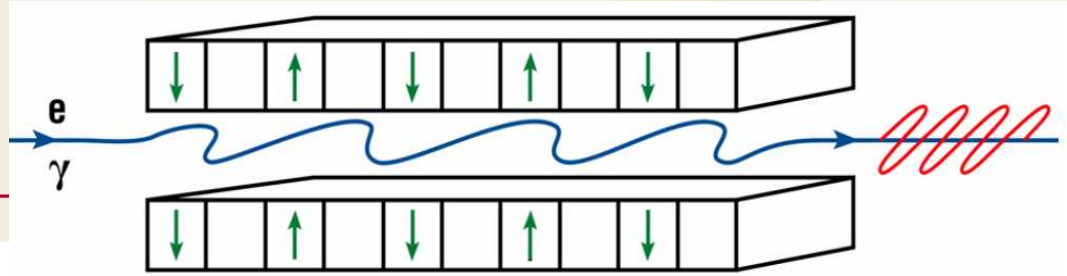
LCLS Accelerator Layout



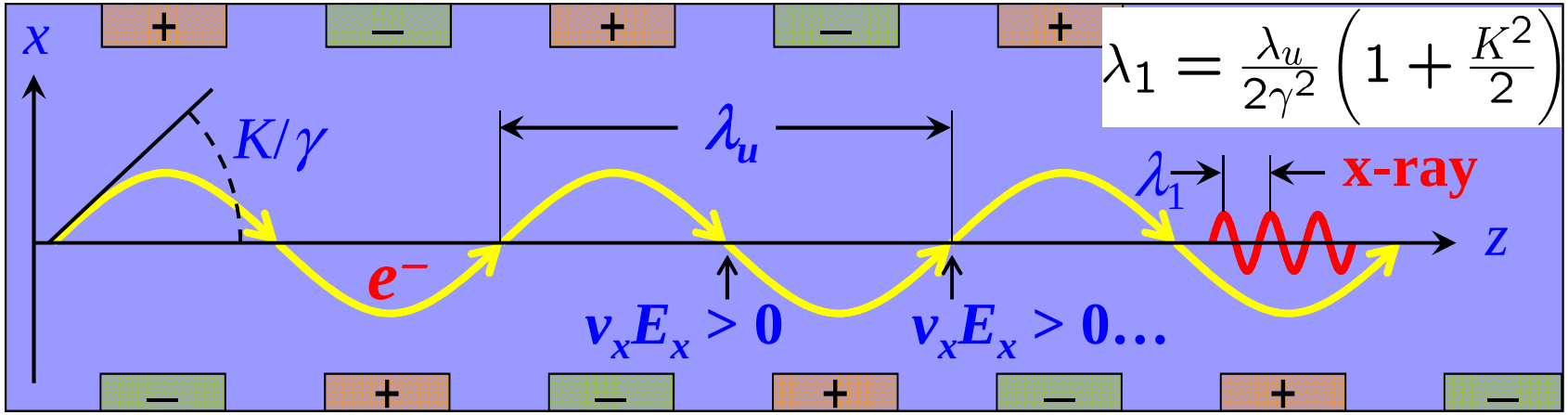
First Laser X-rays in April 10, 2009

FEL Principles

Z. Huang



- Electrons **slip** behind EM wave by λ_1 per undulator period (λ_u)



$$\lambda_1 = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

- Due to sustained interaction, some electrons lose energy, while others gain ➔ **energy modulation at λ_1**

- e^- losing energy slow down, and e^- gaining energy catch up ➔ **density modulation at λ_1 (microbunching)**

- Microbunched beam radiates coherently at λ_1, enhancing the process ➔ **exponential growth of radiation power**

LCLS 132 meters of FEL Undulator, straight to 10 μm

Operational Schedule

LCLS May - July Short Term Schedule

Important Dates:
Fri, Jul 19, 2013 09:00 Run 8 begins

Subject to Change

rev 21-MAY-13

May

		5	6	7	8	9	10	11	12	13	14	15	16	17	18
		Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
0900-2100	Day	Frank - L691		MD	PAMM	Hill - L710				MD	POMM	U Setup	Ravasio - L755		
2100-0900	Night	Dia.	MD	MD	Exp Setup	IH- Dev Moeller				MD	MD	Det. Dev.	Maia - L730		

June

		19	20	21	22	23	24	25	26	27	28	29	30	31	1
		Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
0900-2100	Day	Ravasio - L755	MD	MD	PAMM	IH - Comm Bozak					POMM	MD	L660		
2100-0900	Night	Maia - L730		MD	Exp Setup	Mankowsky - L731					MD	Exp Setup	Madsen - L729		

		2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
0900-2100	Day	L660	IH - CXI & XPP	MD	Beye - L657	Orville - L748			Orville - L748		MD	Hogue - L711			
2100-0900	Night	Madsen - L729		Exp Setup		MD	Beye - L657		MD	MD	Exp Setup	Hastings - L708			

		16	17	18	19	20	21	22	23	24	25	26	27	28	29
		Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
0900-2100	Day	Feng	MD	PAMM	Murphy - L751					Exp Setup	IH - Turner			IH XPP and XCS	
2100-0900	Night	L708	MD	Exp Setup	Soltis - L650			Two Color	MD	Exp Setup	Chapman - L669				

July

		30	1	2	3	4	5	6	7	8	9	10	11	12	13
		Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
0900-2100	Day	IH XPP and XCS		MD	PAMM	L639		MD	IH - Minitti			POMM?	Gafney - L695		
2100-0900	Night	Feng		MD	Exp Setup	Petrovic - L751						Exp Setup	Schlichting - L764		

		hutch
	AMO	1
	SXR	2
	XPP	3
	XCS	4
	CXI	5
	MEC	6
	Open	
	MD	

MD= Machine Development
POMM = Planned Operational Machine Maintenance
PAMM = Planned Accessible Machine Maintenance

POMM activities are generally coordinated with MD activities during the weeks when there is no PAMM

Schedule can change
without notice

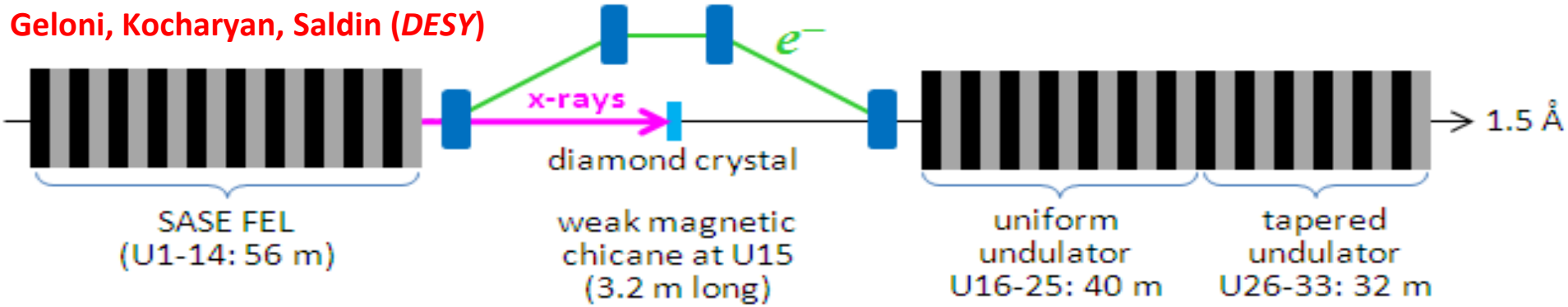
Questions to: Mike Sullivan

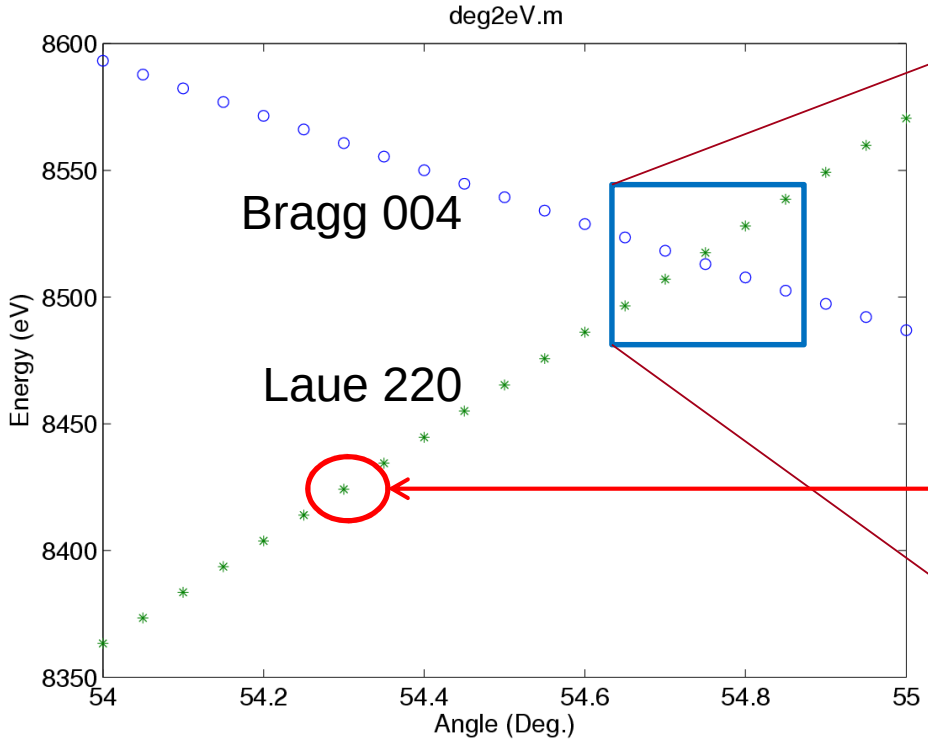
MD Schedule

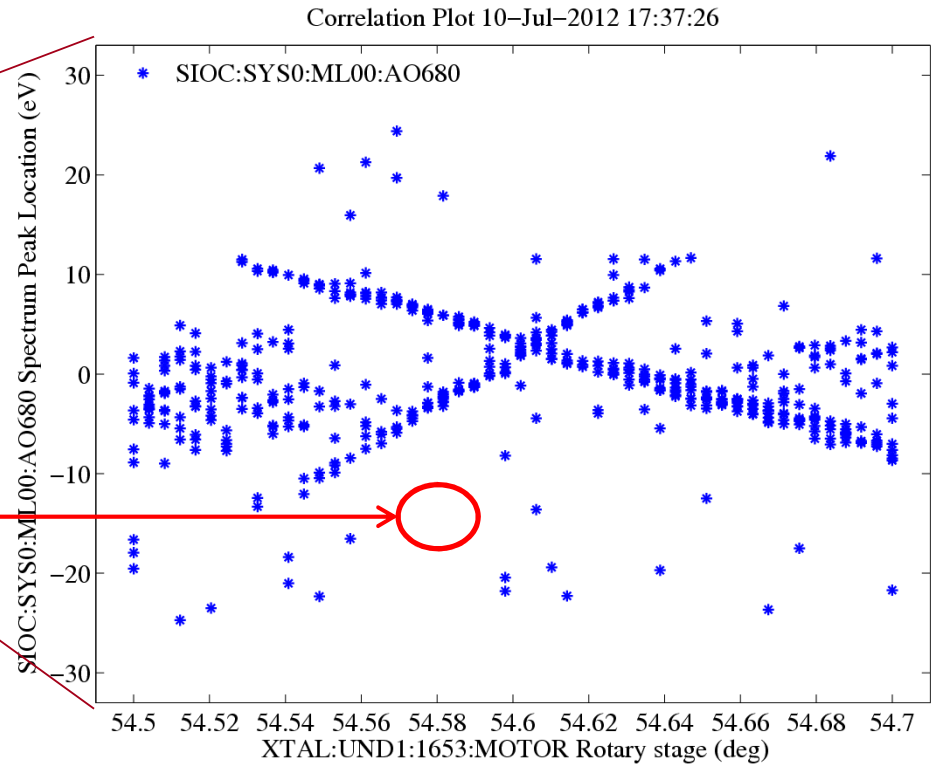
2013	Monday, May 13	Tuesday, May 14	Wednesday, May 15
all-day			
1 AM		Photon MD, CXI, 7.4keV, SASE and Seeded, Boutet et al.	OPS Prepare for Expt.
2 AM		1:00 AM OPS Max SASE FEL, parameters from Colocho, beam to FEE	
3 AM			
4 AM			
5 AM			4:30 AM BCS Checks
6 AM			6:00 AM XTCAV PPS Cert., Belt
7 AM			
8 AM			8:00 AM Ops continue to Prepare for Expt.
9 AM	9:00 AM Low energy matching into Undulator, Loos, Turner	9:00 AM POMM	
10 AM			
11 AM			
Noon		12:00 PM Girder angle and taper study, Welch	
1 PM	1:00 PM Beam setup, tune 7.4keV, Ops		1:00 PM Photon MD, 7.1keV, CXI, MEC beam sharing tests, Boutet, Nagler et al.
2 PM		2:00 PM 250pC on LTU BLEN, xray distribution, dump wire, Decker, Welch, Colocho, Iverson	
3 PM			
4 PM			
5 PM	5:00 PM Photon MD, CXI, 7.4keV, SASE and Seeded, Boutet et al.		
6 PM			
7 PM			
8 PM		8:00 PM OPS Prepare for Expt.	
9 PM			
10 PM			
11 PM			

Hard X-Ray Self-Seeding at LCLS (HXRSS)

Geloni, Kocharyan, Saldin (*DESY*)







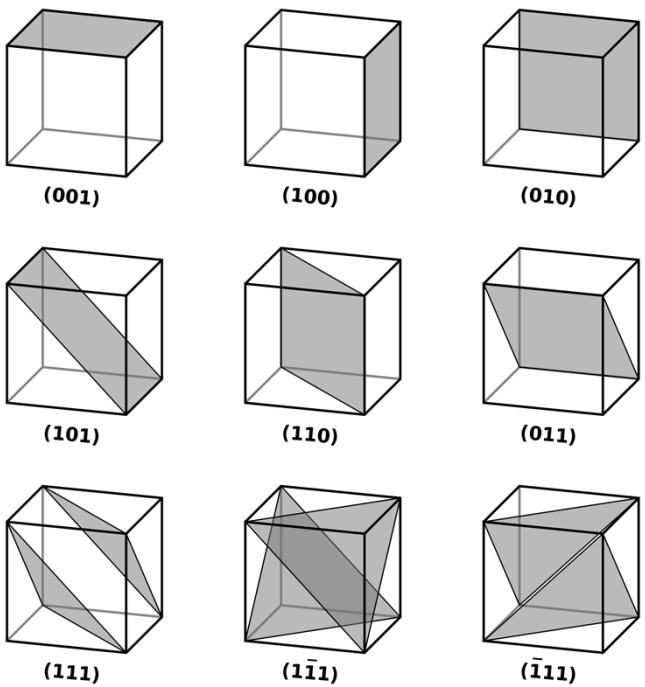
[0 0 4], L[2 2 0], [1 1 1], and [1 1 3]

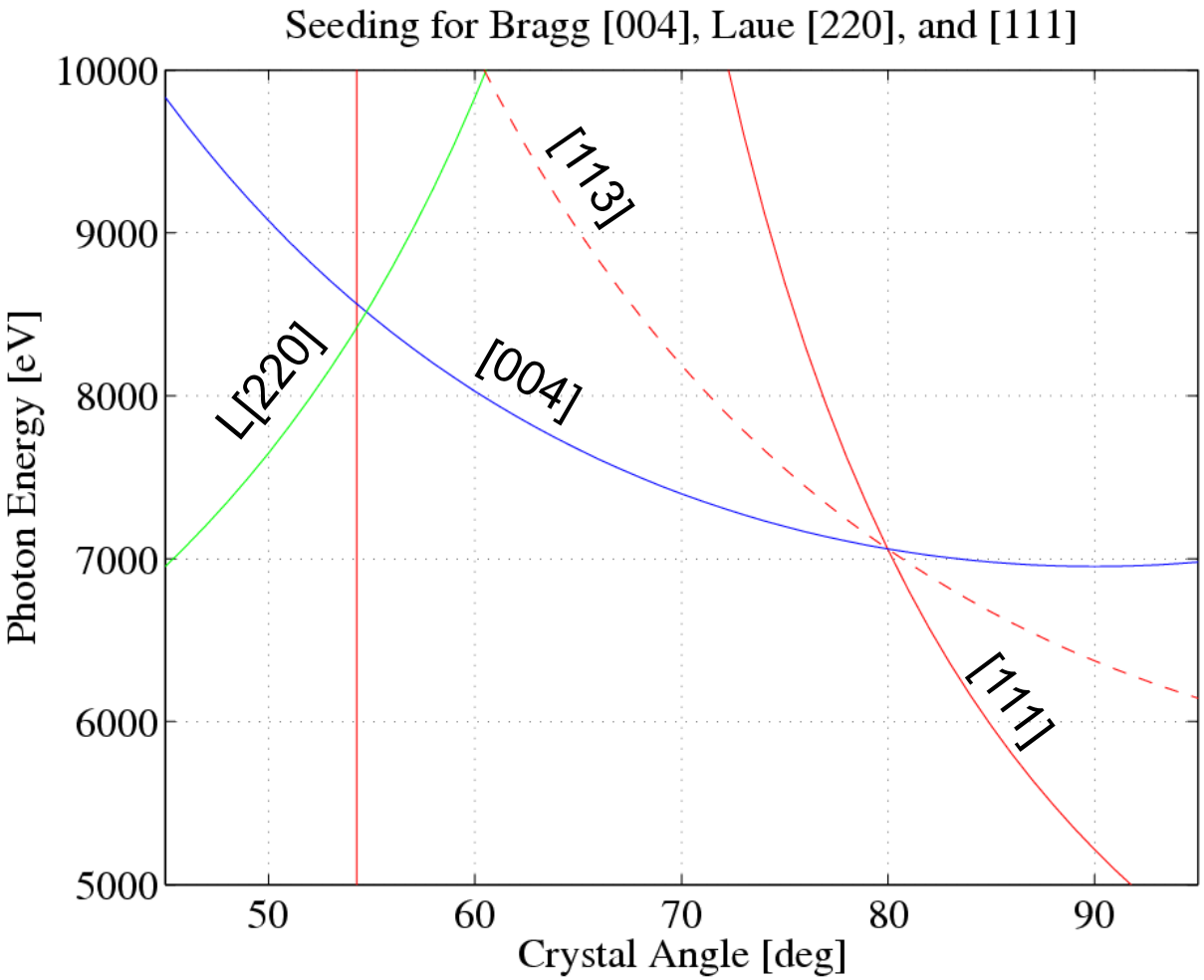
What we (I) knew about crystal angles and energies

Rules:

Any odd o.k

Even divide by 4





There are more lines: Long crystal angle scan 7.2 keV using gas detector

Bragg: ____,

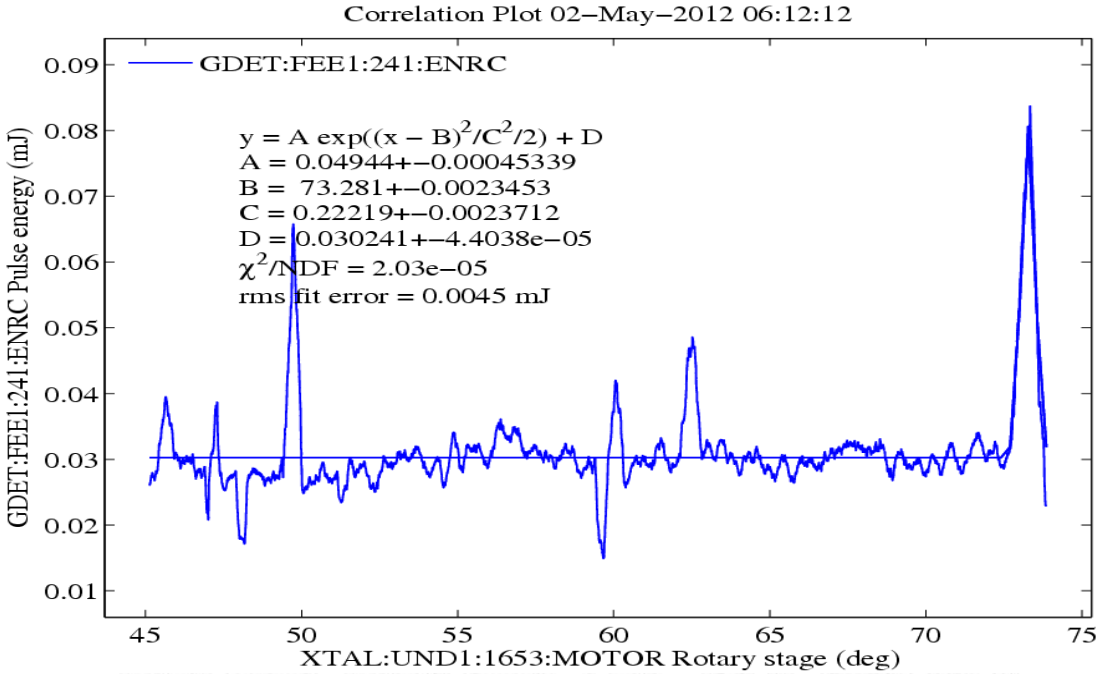
minus planes [-1-11] dashed: - - - ,

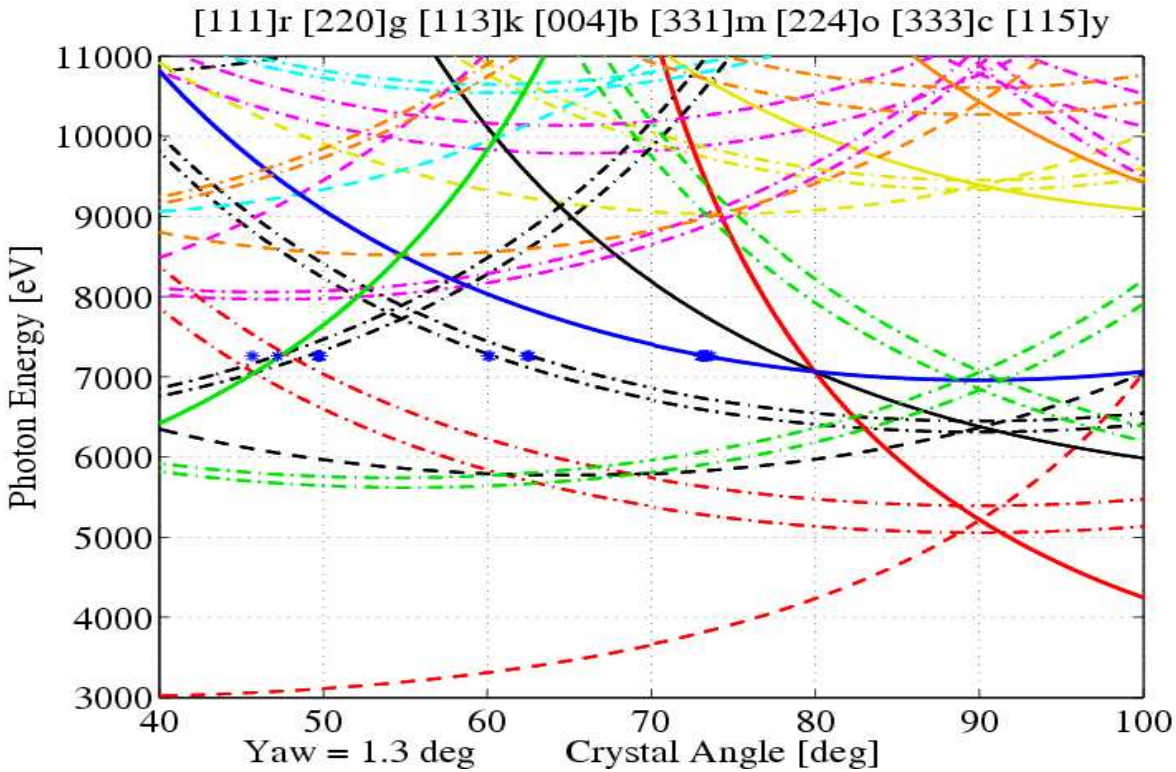
[out-of-plane lines: dash-dotted: - . - . -]

Minimum energy for lines below 11 keV:

<111> -1-11	red	3.010 keV
[1-11] [-111]		
<220>	green	4.916
<113> -1-13	black	5.764
<004>	blue	6.952
331	magenta	7.576
224	orange	8.514
333	cyan	9.031
115	yellow	9.031
440 …	violet	9.832

Not perfect agreement at 50 deg and 7.2 keV



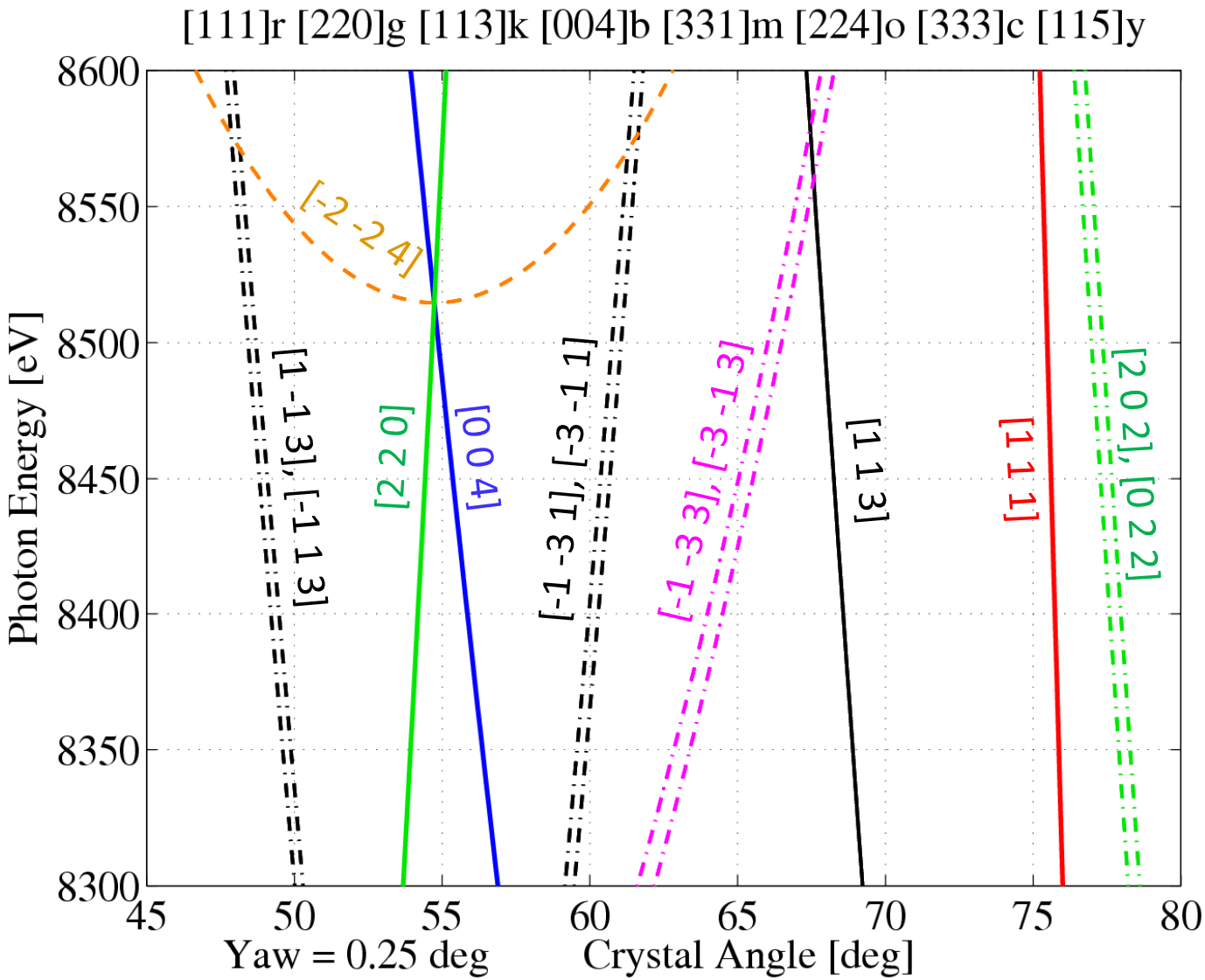


Seeding 12 Bragg Crystal Lines at Spectrometer Energy of 8.45 keV

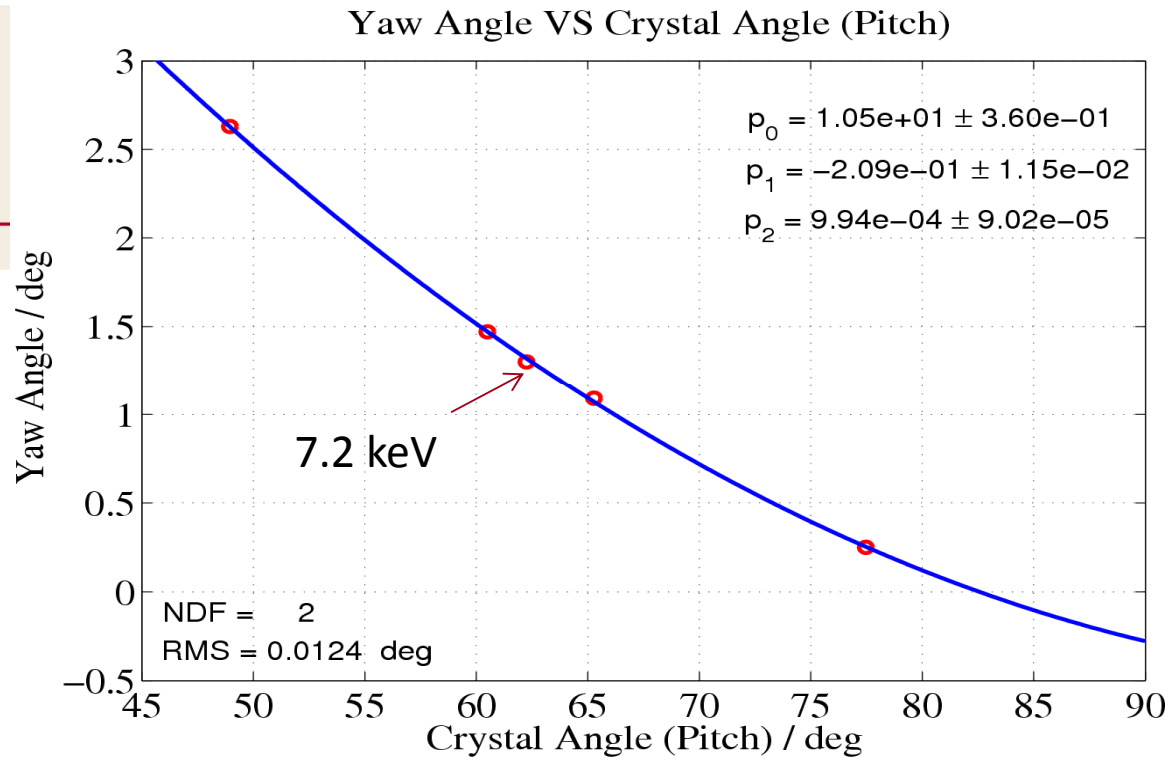
Solid: in-plane

Dash: first two minus

Dash-dotted: out-of-plane (will split with yaw (or roll) angle)

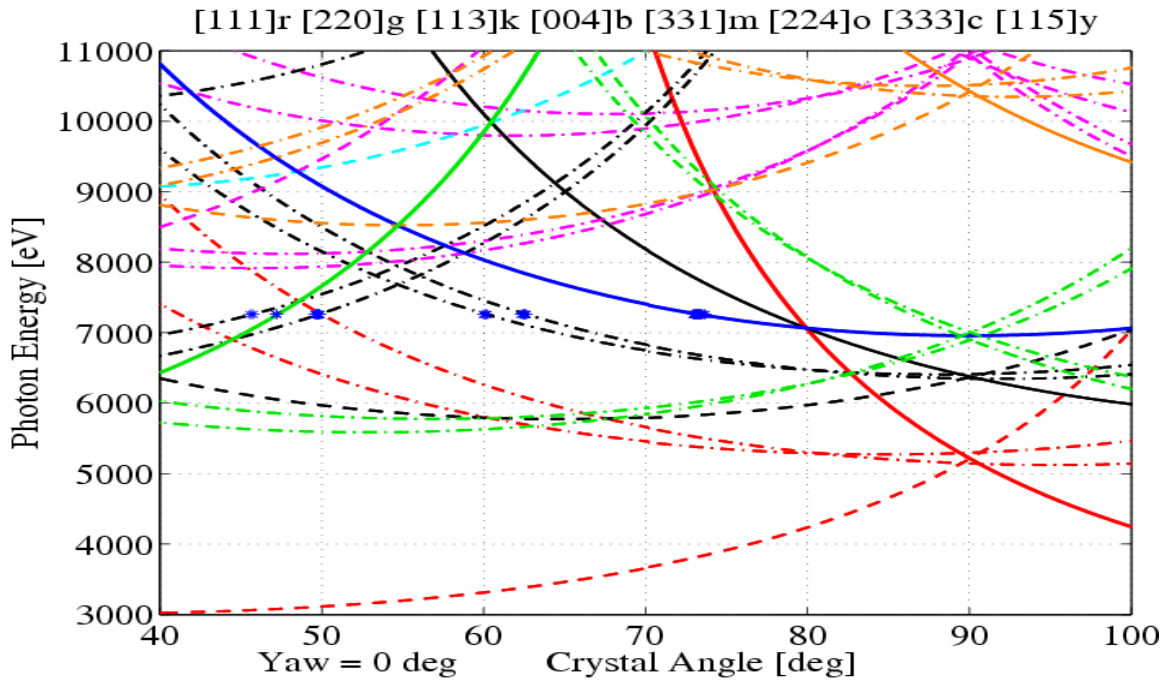


Yaw angle to put off-planes on top

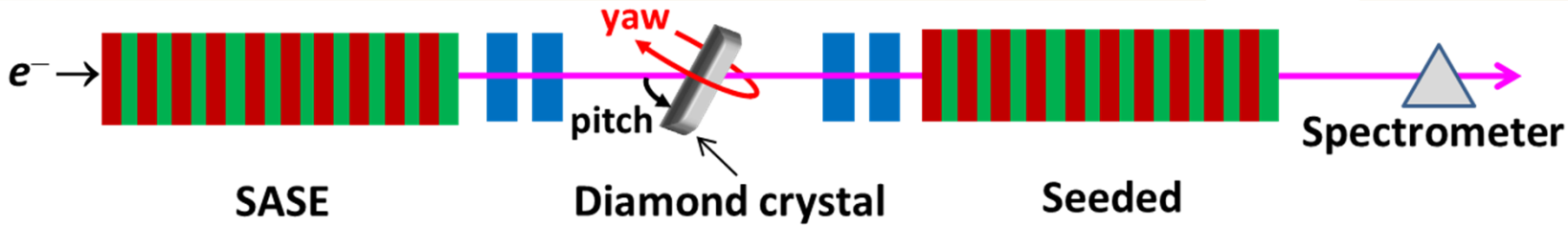


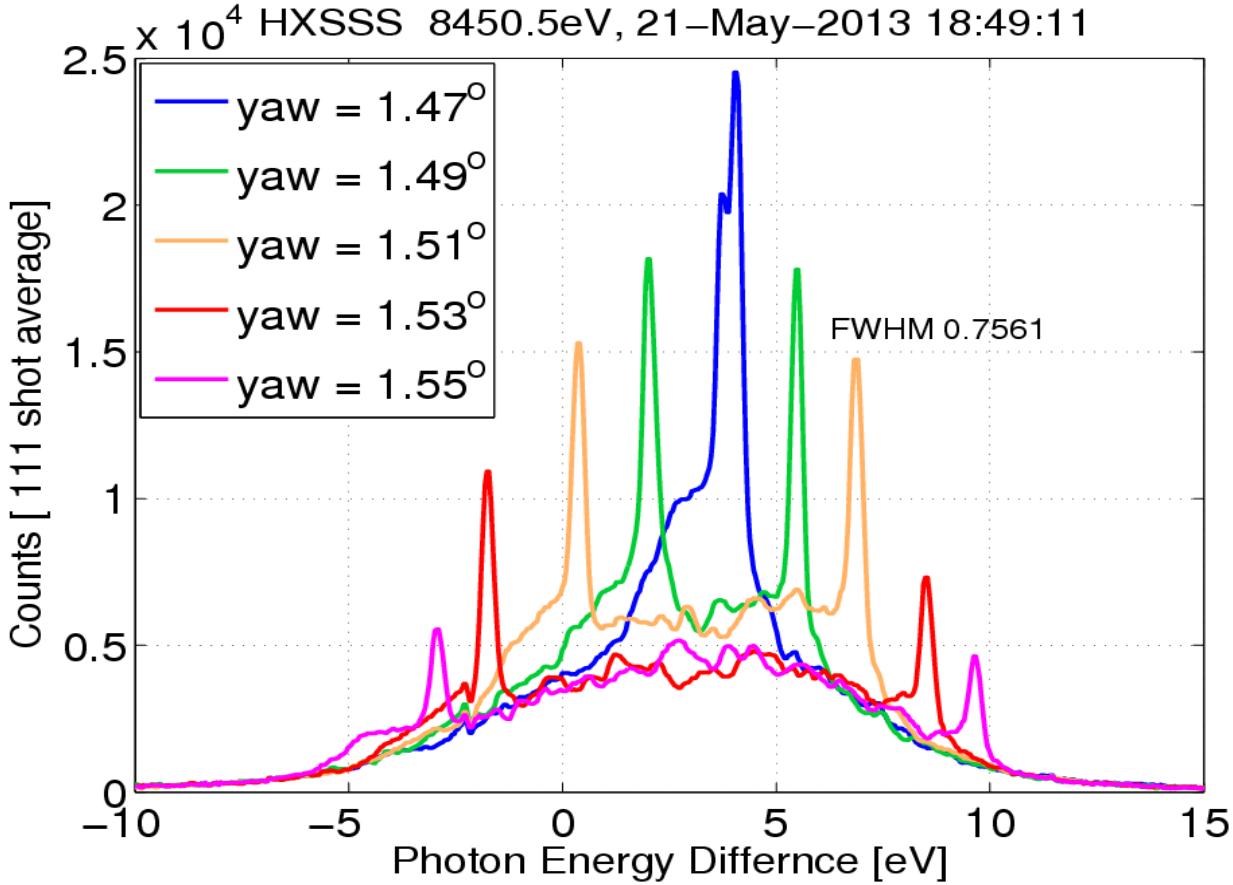
Final model:
roll angle = -3.73 deg
yaw angle offset = 0.61 deg

Roll angle can be compensated with jaw angle at certain energies

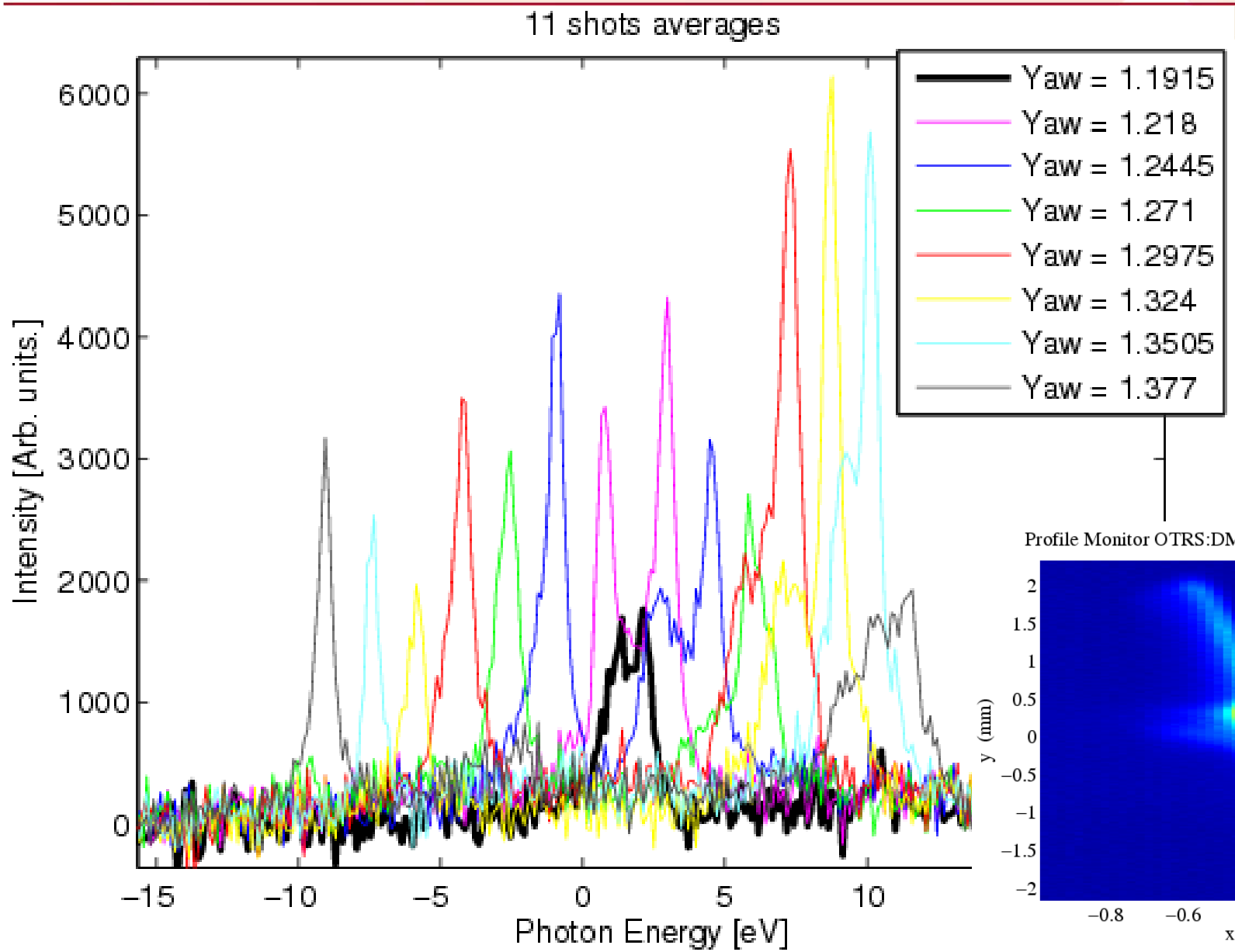


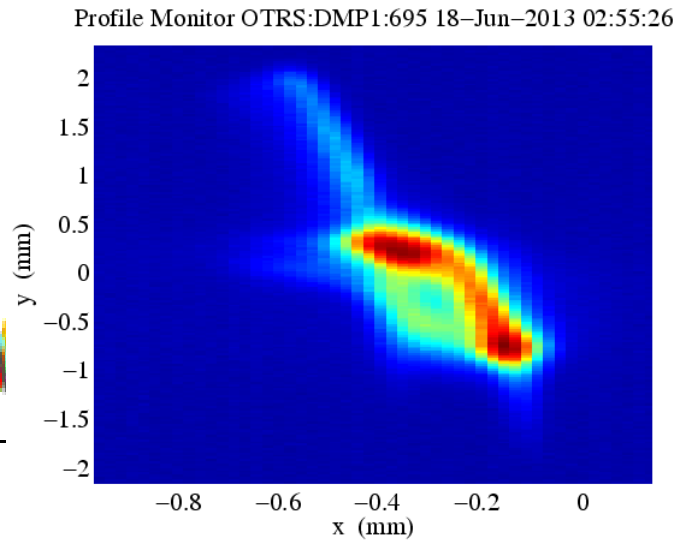
Seeding Chicane Side View





Two colors around 7.1 keV





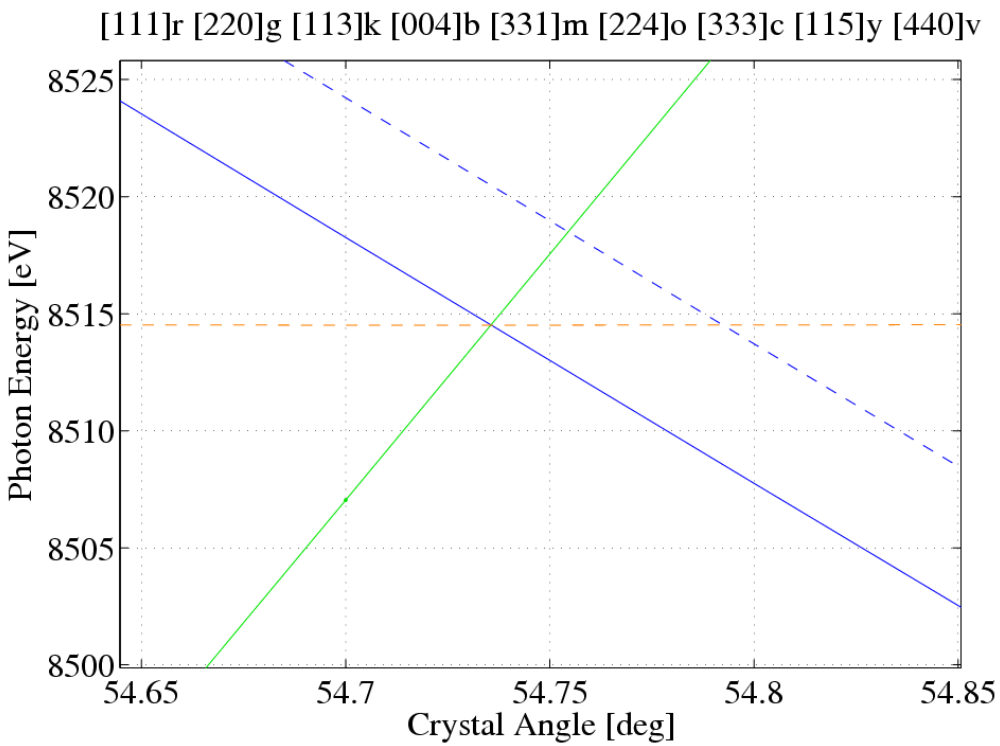
Three way crossing:

Three lines:

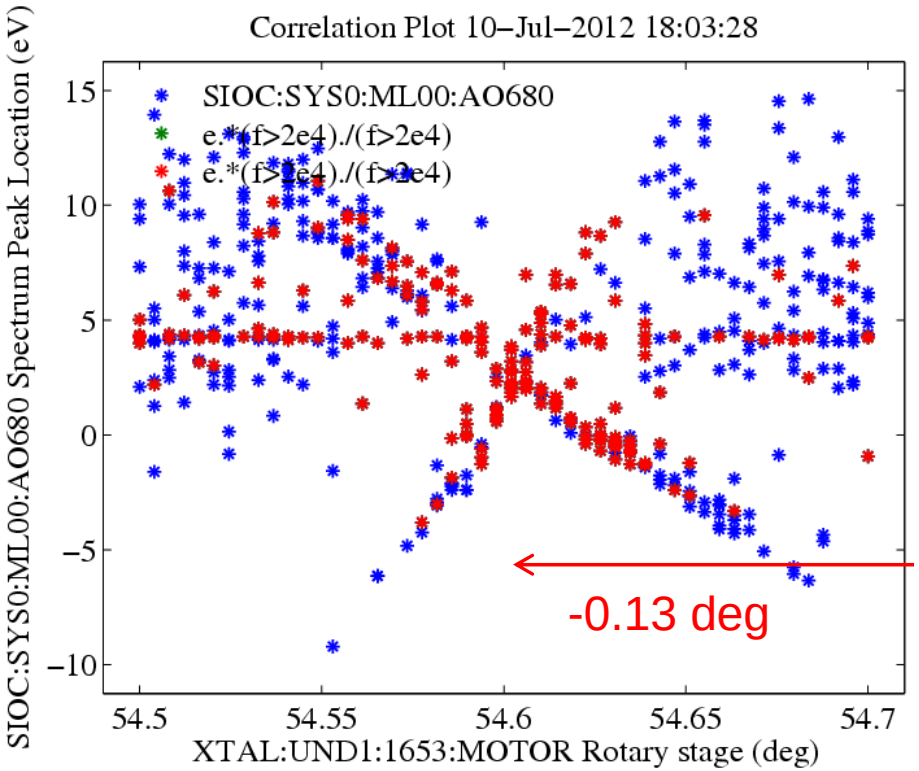
Bragg [004] down blue, (dashed: 2 % yaw angle)

Laue [220] up green,

Bragg [-2-24] flat orange



"40 MeV energy vernier"



Different Mode of Operation

1. Blue: “Background” SASE with delay, crystal out
2. Red: Seeded 220 (tuned)
3. Green: Seeded 004
4. Magenta: Seeded 220 over-compressed (less SASE?)

Typical:

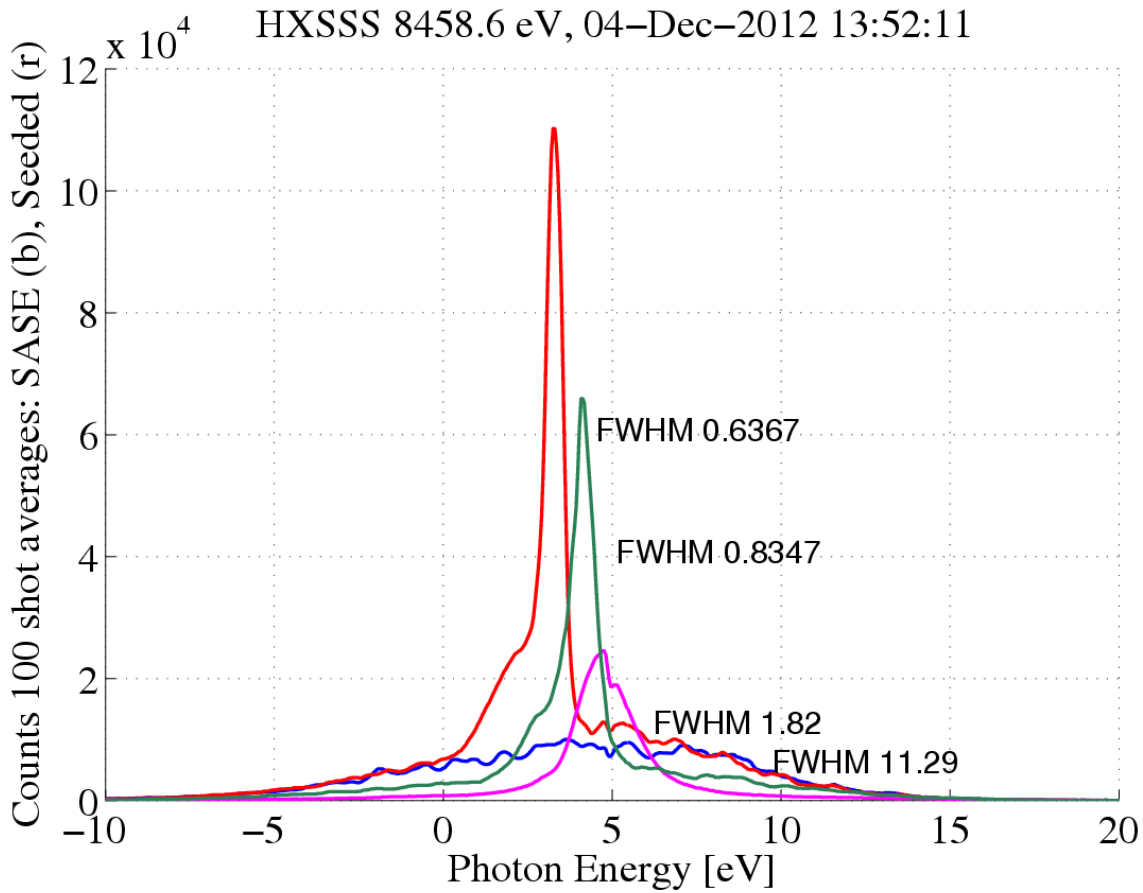
220: 0.8 eV

004: 0.5 eV

220 o-c: 2.0 eV

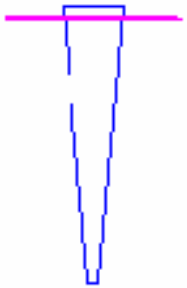
SASE: 20.0 eV

(Spectrometer cuts to 11.0 eV)

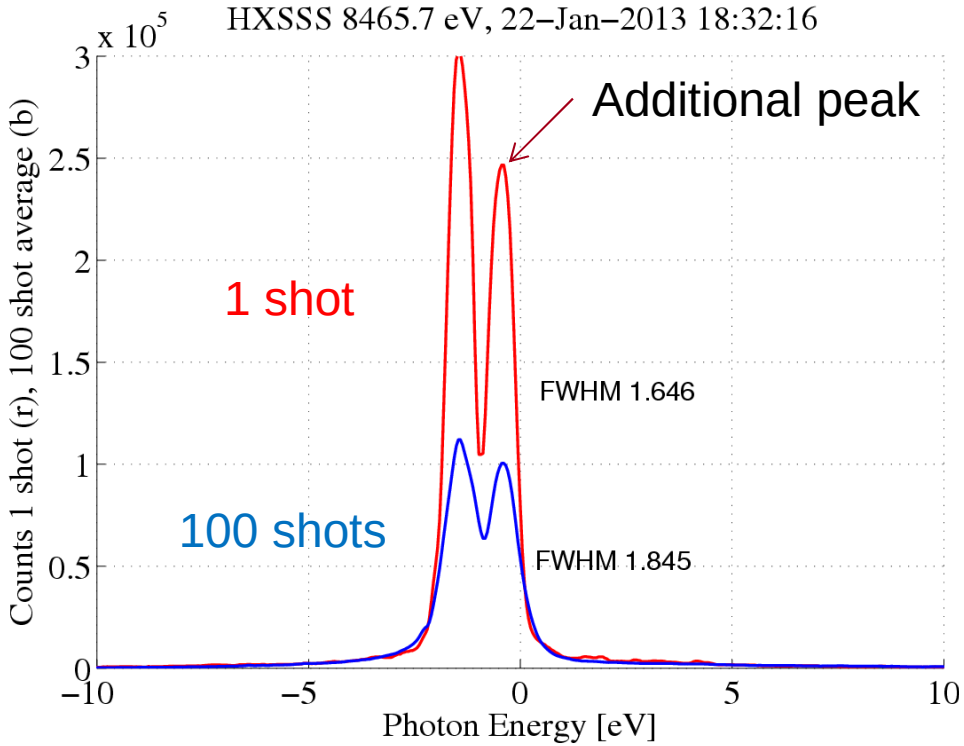


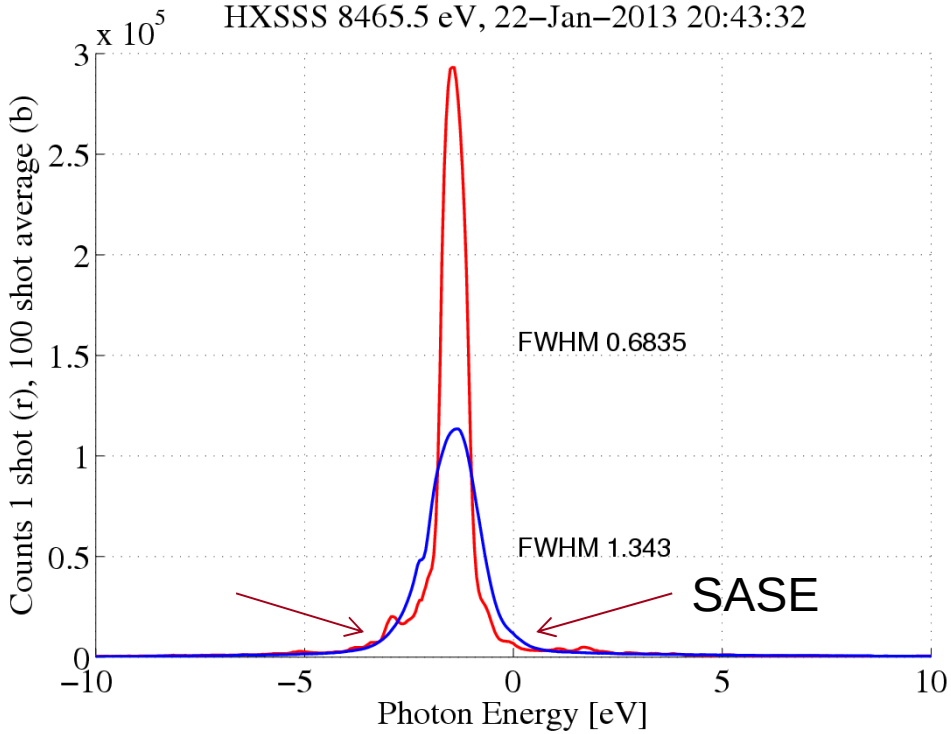
To avoid tuning up on the horns: Cut them with Slotted Foil

Foil out



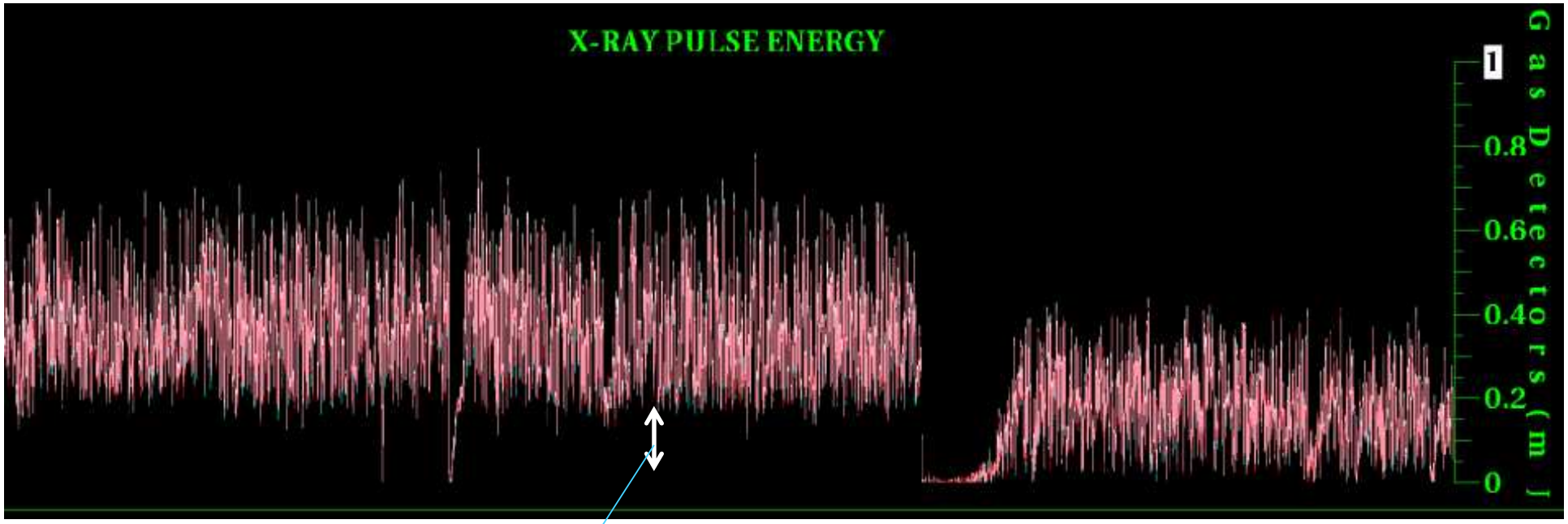
Foil in (tuned)





Gas detector: FEL intensity vs time

- Slotted foil: out and in

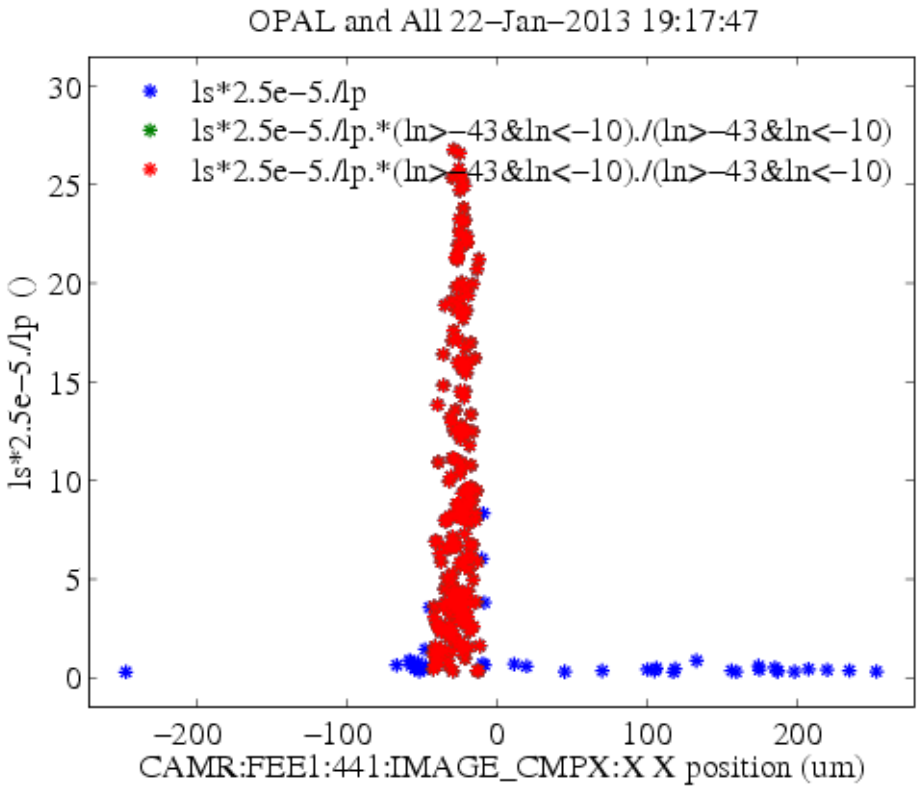


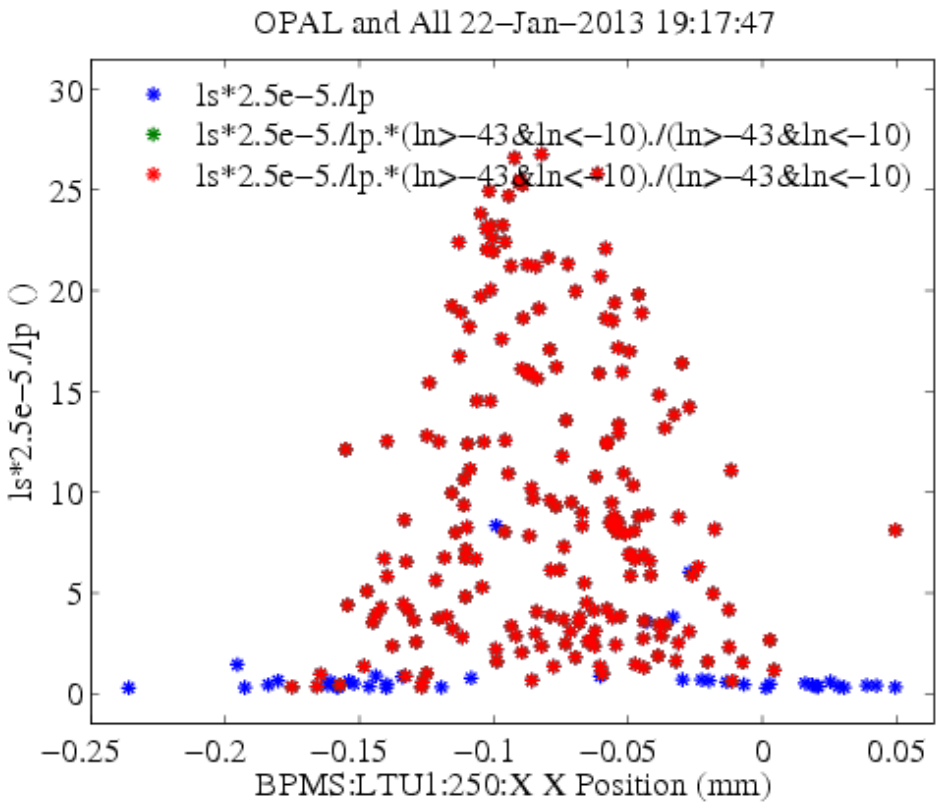
- 0.2 to 0.70 mJ 0.0 to 0.4 mJ

(SASE) or multiple spikes ?

Correlation Plot Data with Spectrometer Profile (Foil in)

- Peak (= area/sigma*2.5) vs x (= photon energy)
- Peak vs x (= e-beam energy)

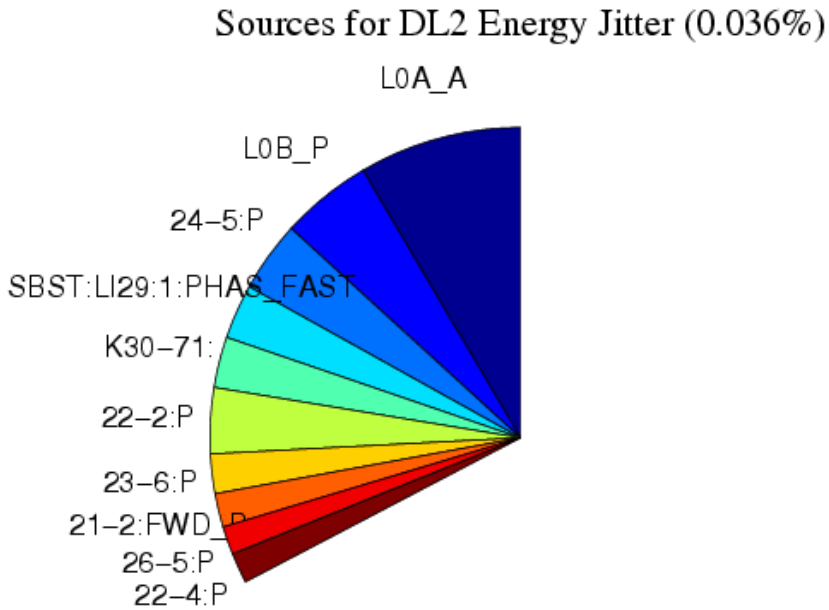




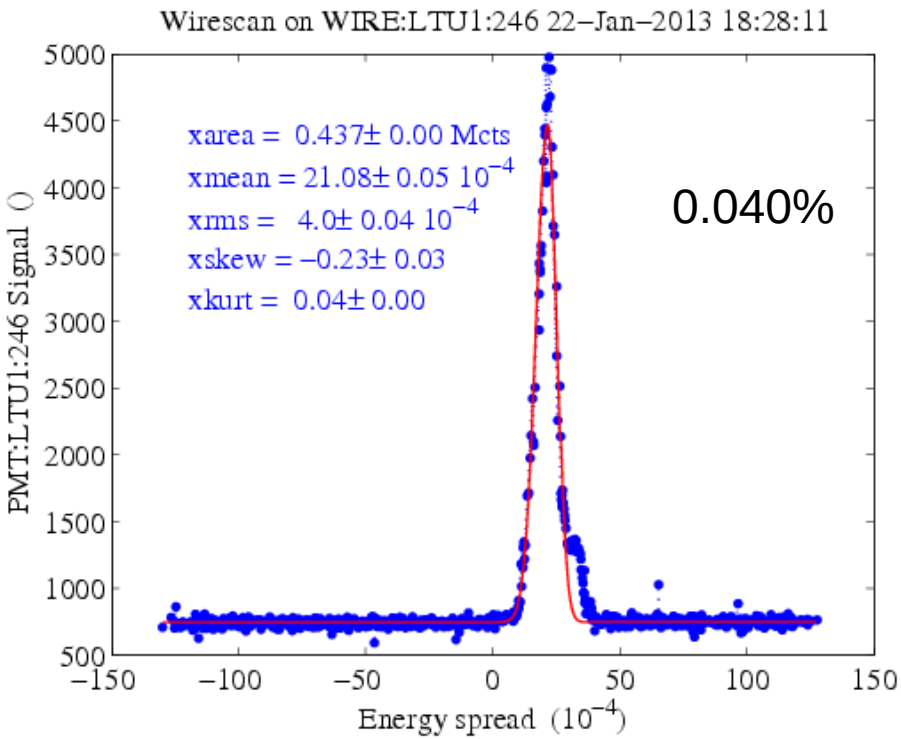
Three Different Energy "Widths"

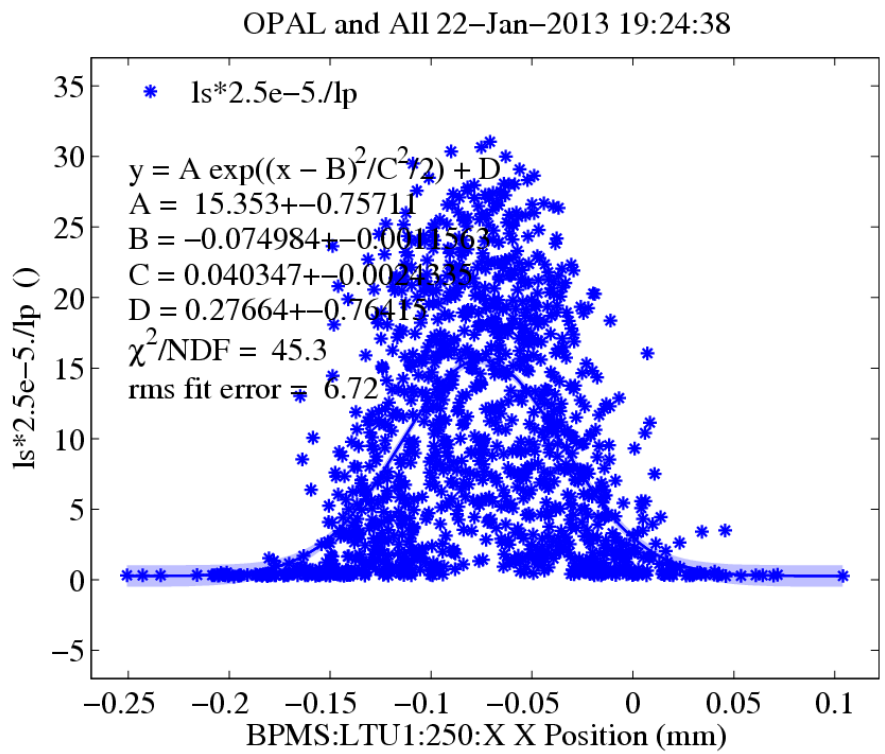
- DL2 wire scan: 0.040%
- DL2 energy jitter: 0.036%
- Undulator acceptance: 0.032%

  all about the same

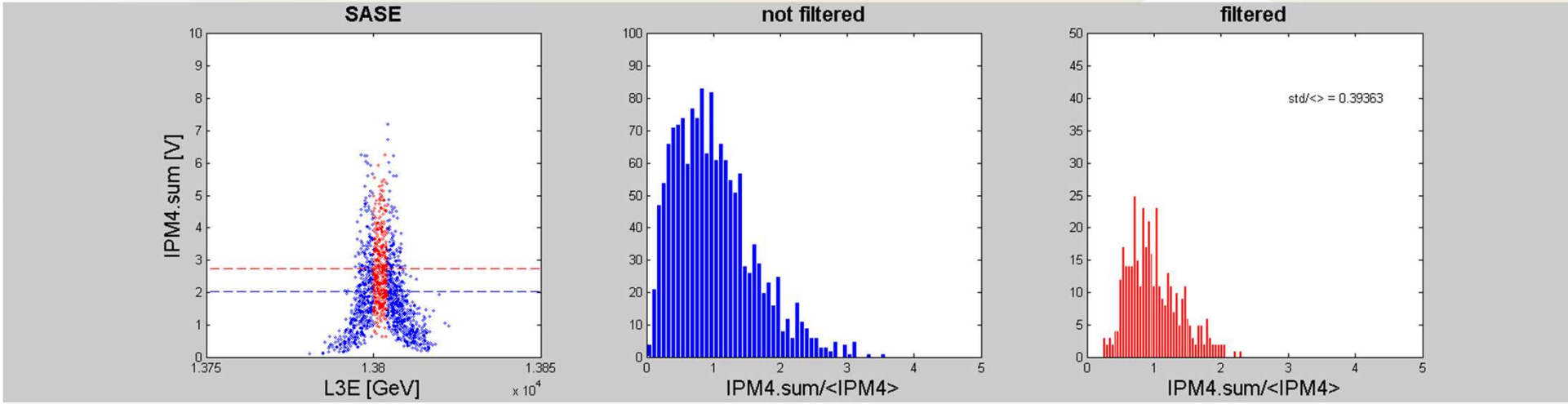


Need to reduce E-jitter or increase acceptance (0.022-0.042% ?)

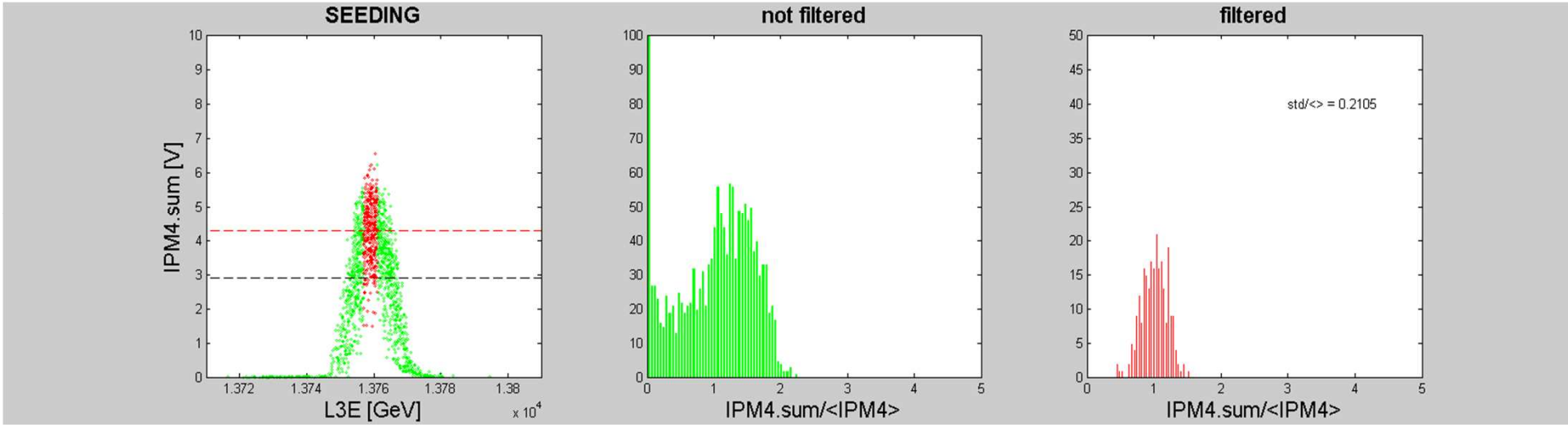




Seeding vs. SASE with Si(111) in XCS (Aymeric Robert)



Gain: Seeded / SASE: 3.4 / 2 / 0.7 = 2.4 (0.7 FEE spectrometer throughput)



Seeded up to 1mJ, 11-Jul-2012

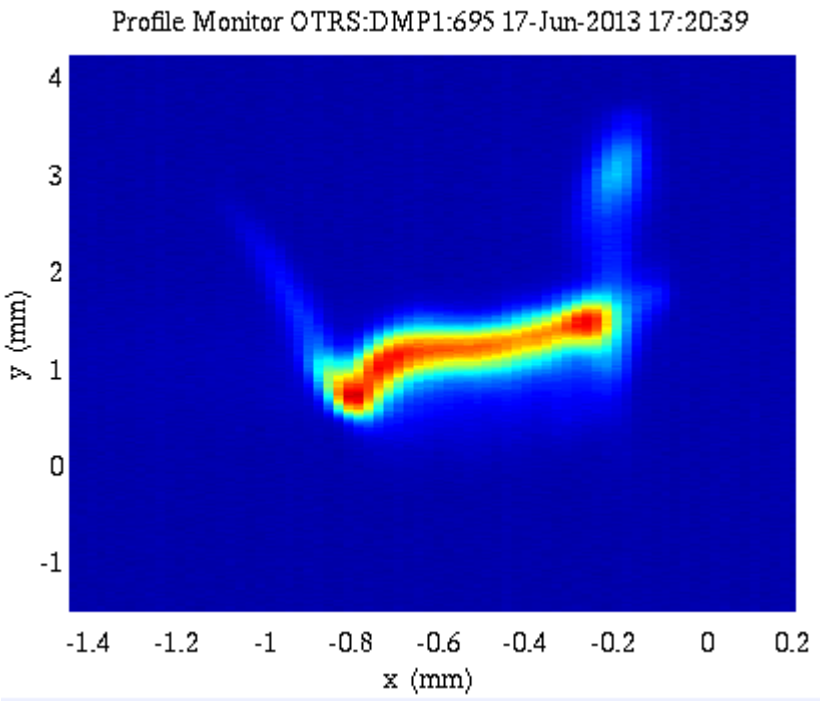

LCLS XTCAV

XTCAV (X-band transverse cavity)

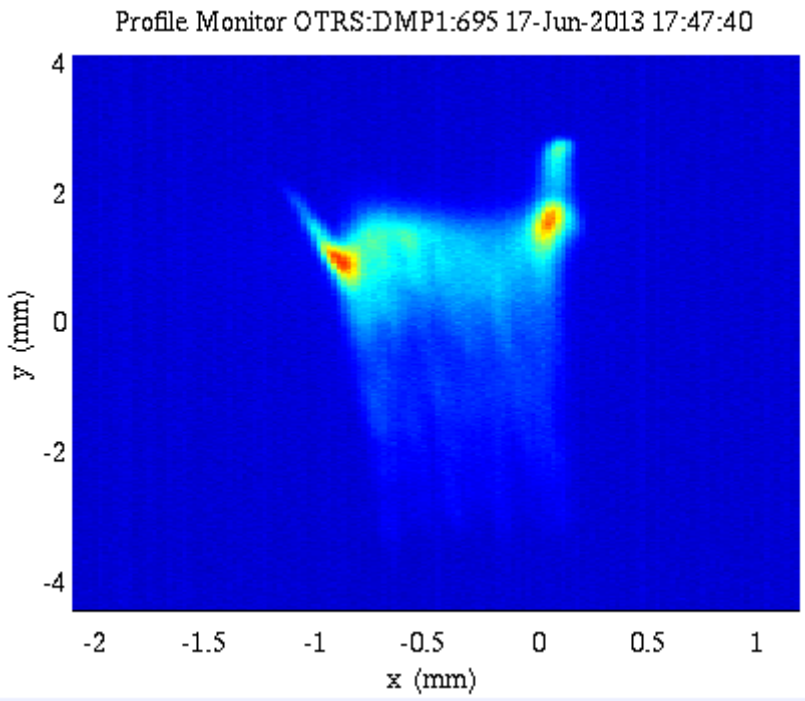
Y. Ding, P. Krejcik, C. Behrens

Beam gets bend down: y-axis is energy

and streaked horizontally: x-axis is longitudinal



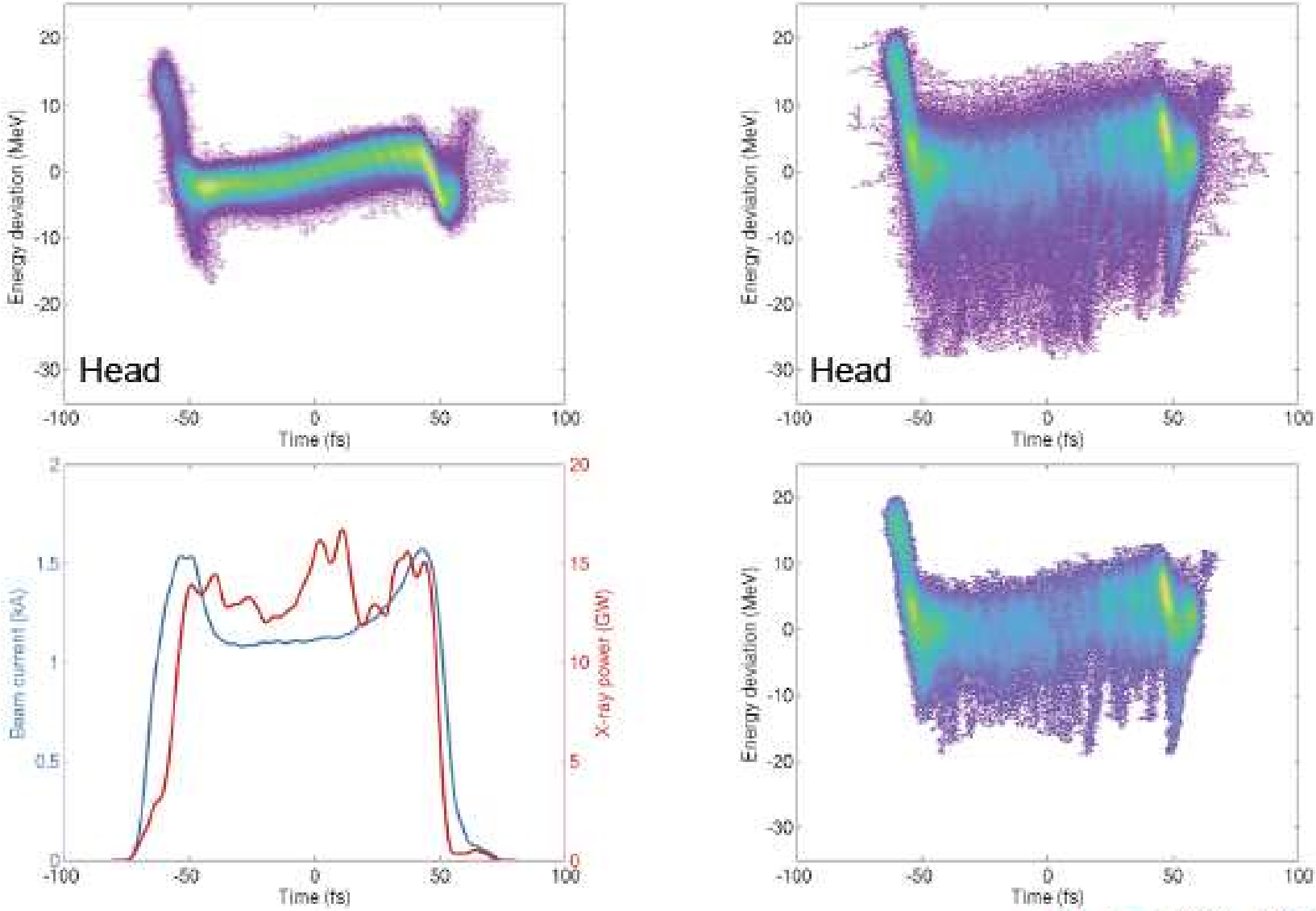
FEL off



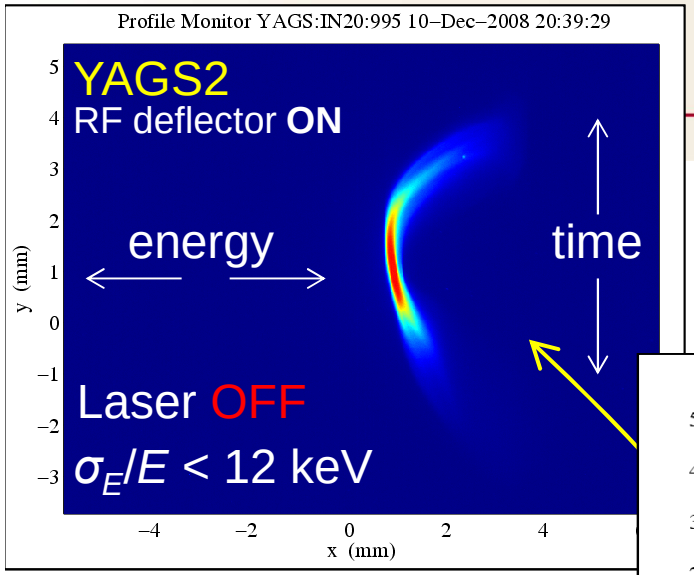
FEL on

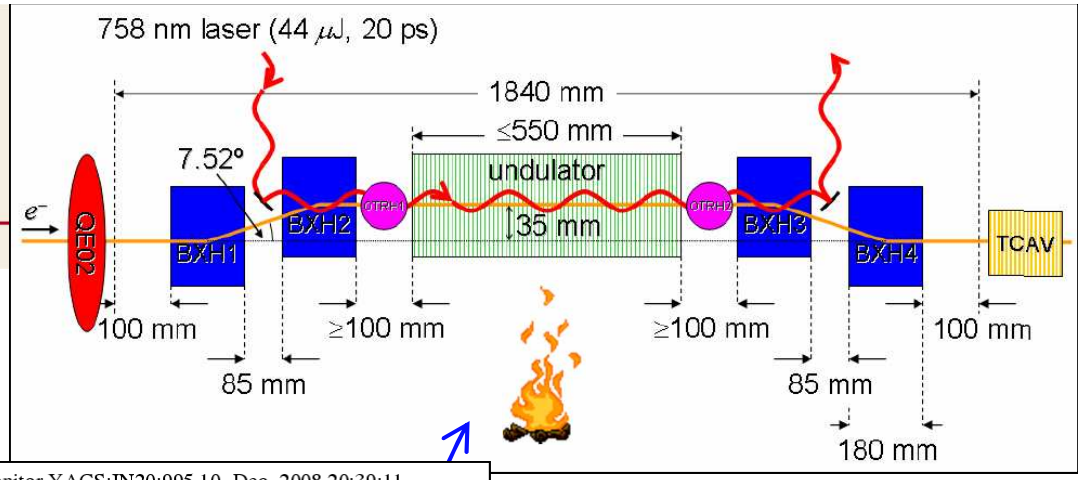
TREX at ~1kA, 3453MeV, and 150pC

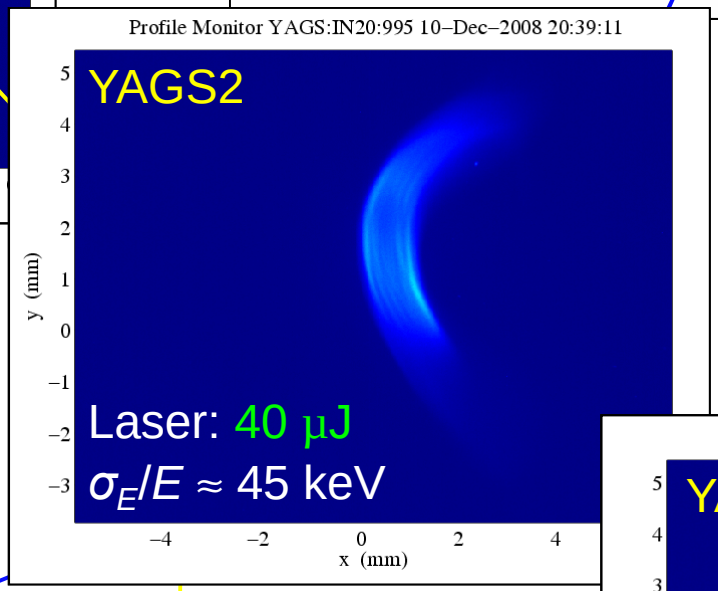
Temporal Reconstruction of Electron and X-ray Pulses



Laser Heater

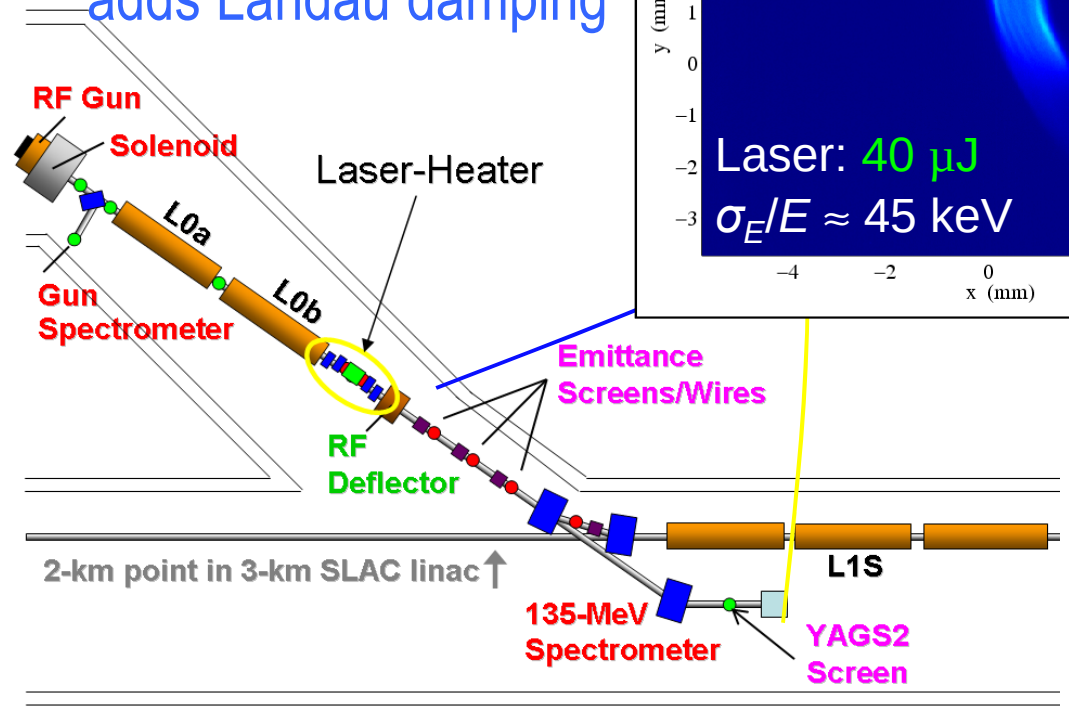


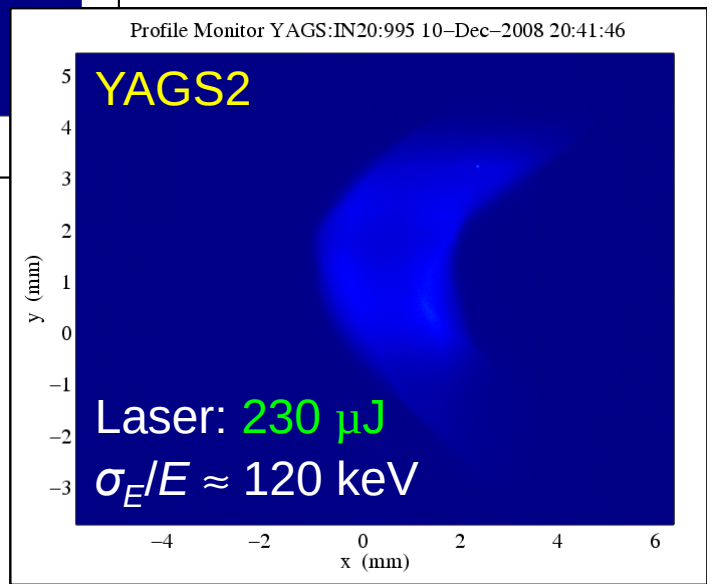




It's Working Well

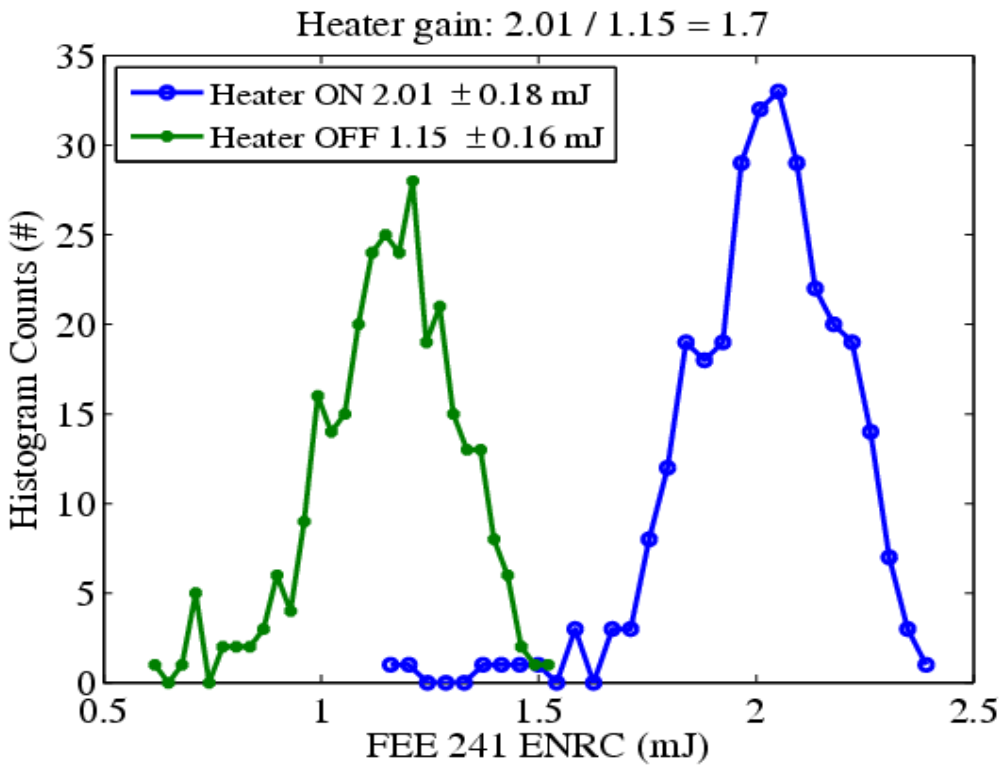
adds Landau damping

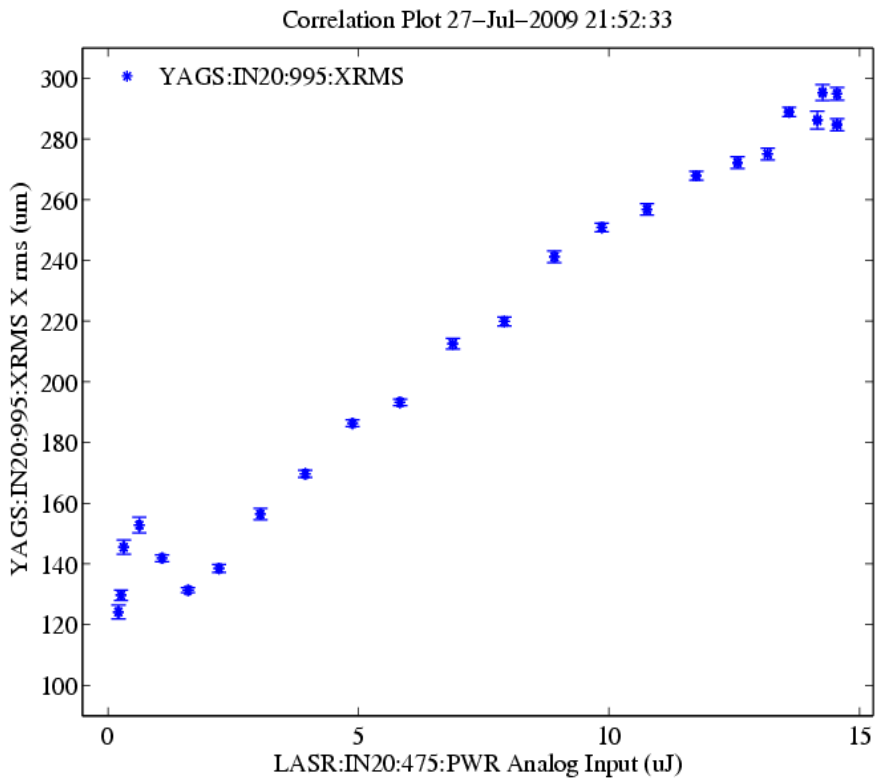




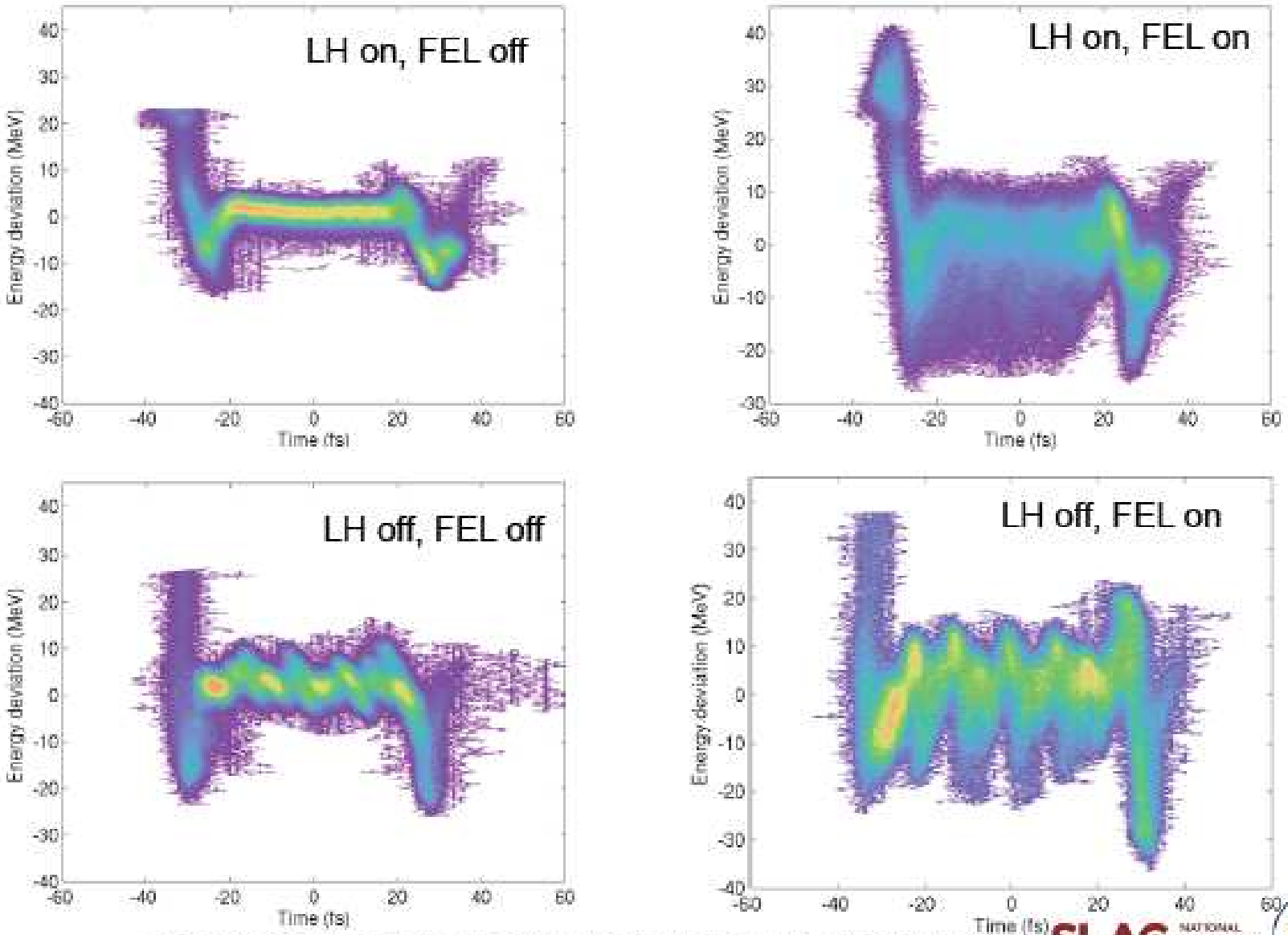
Laser Heater Gain and Trickle heating curve

Laser heater gain typical: 1.5 – 2.0





Laser heater impact & microbunching



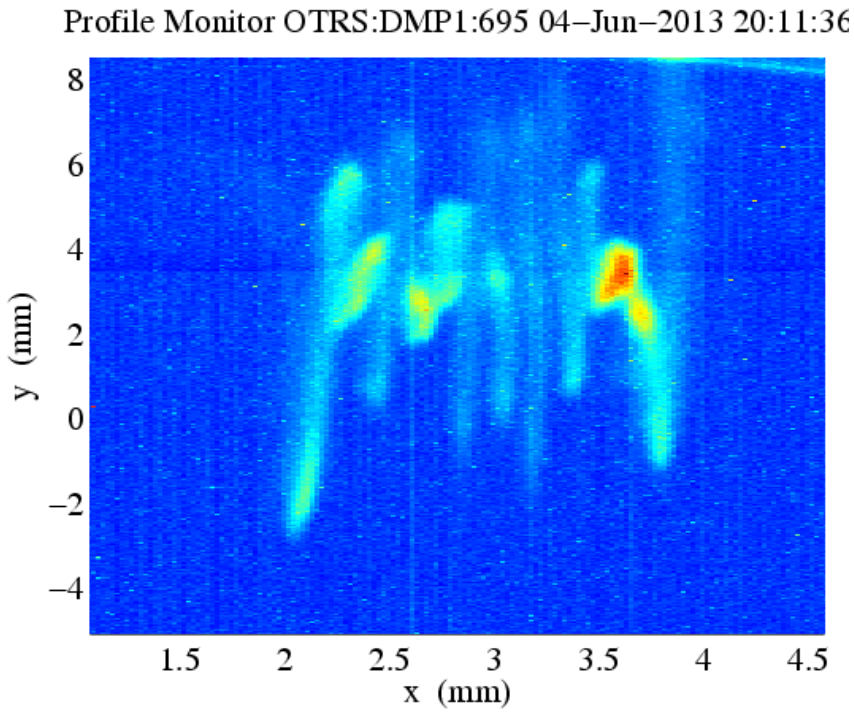
Trickle Heating, 2 μJ (normal 14 μJ)

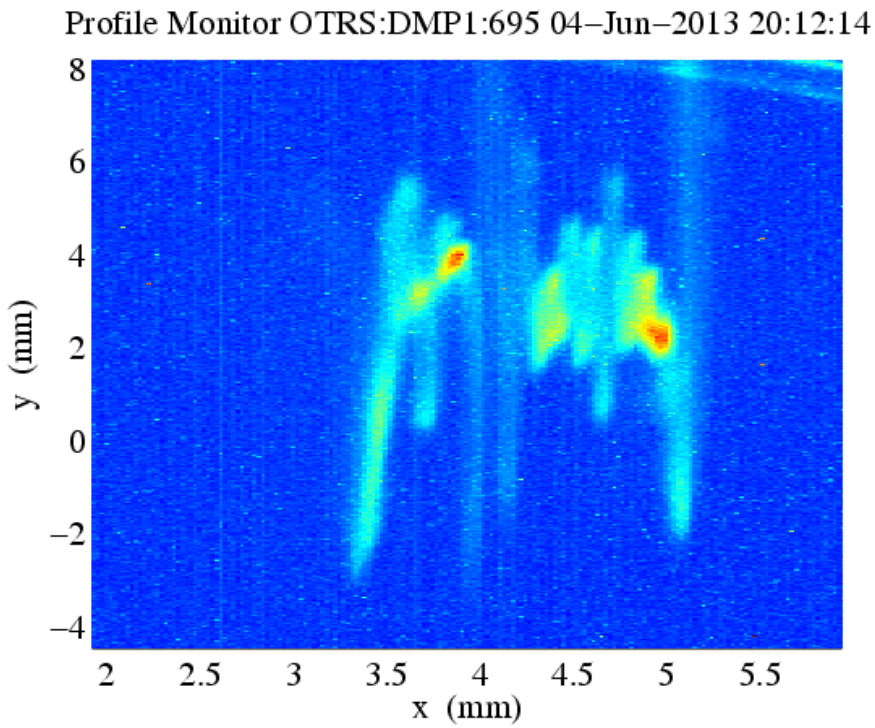
Three shots, same condition,

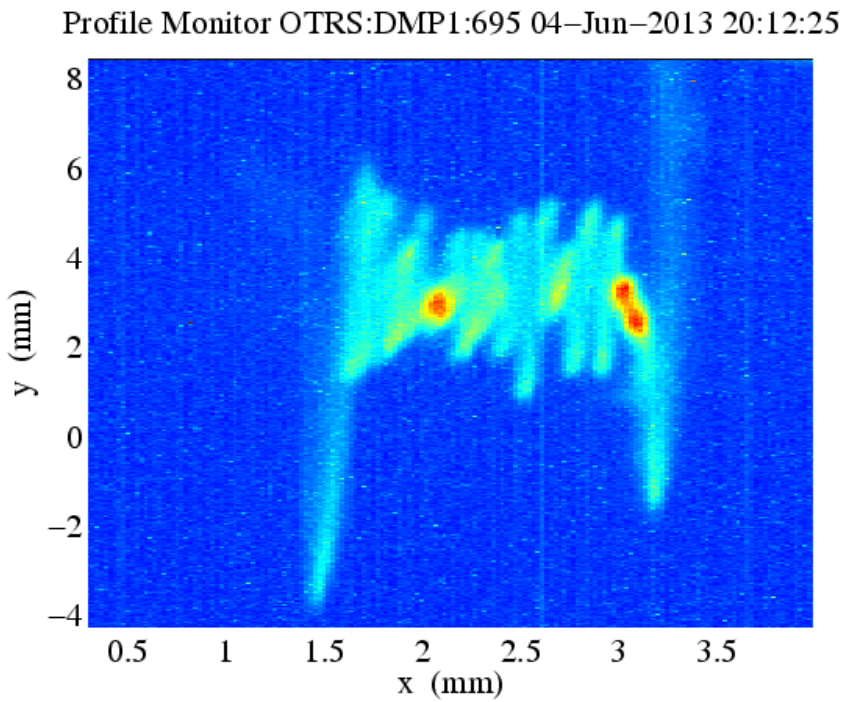
no FEL, wild energy spreads

within parts of bunch,

8-12 “bunchlets”





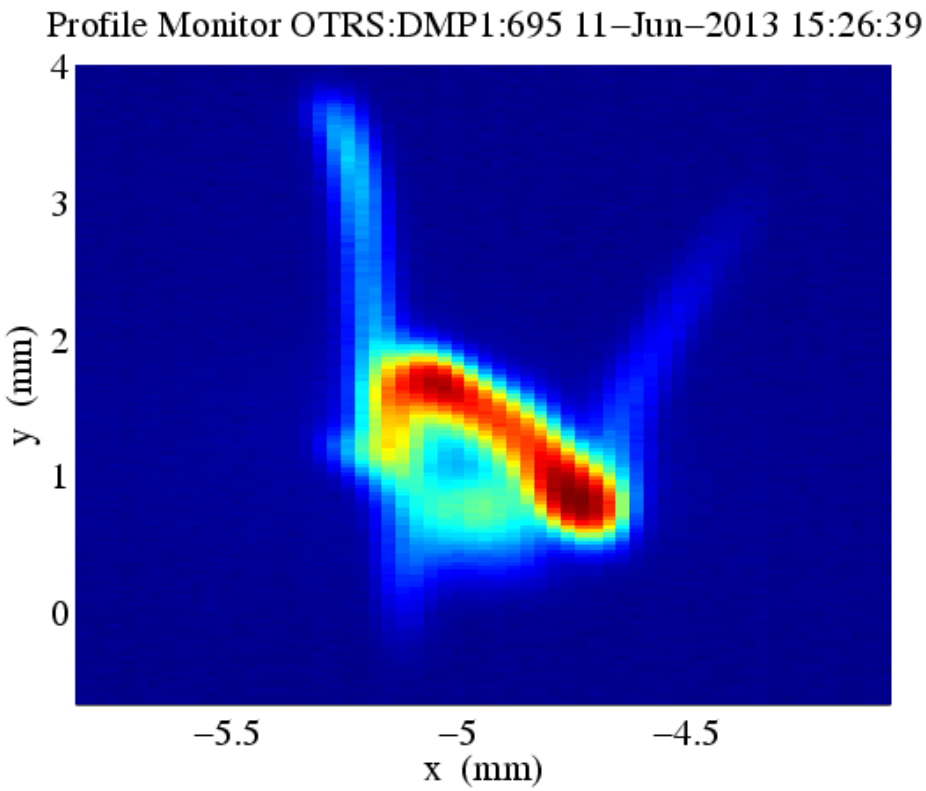


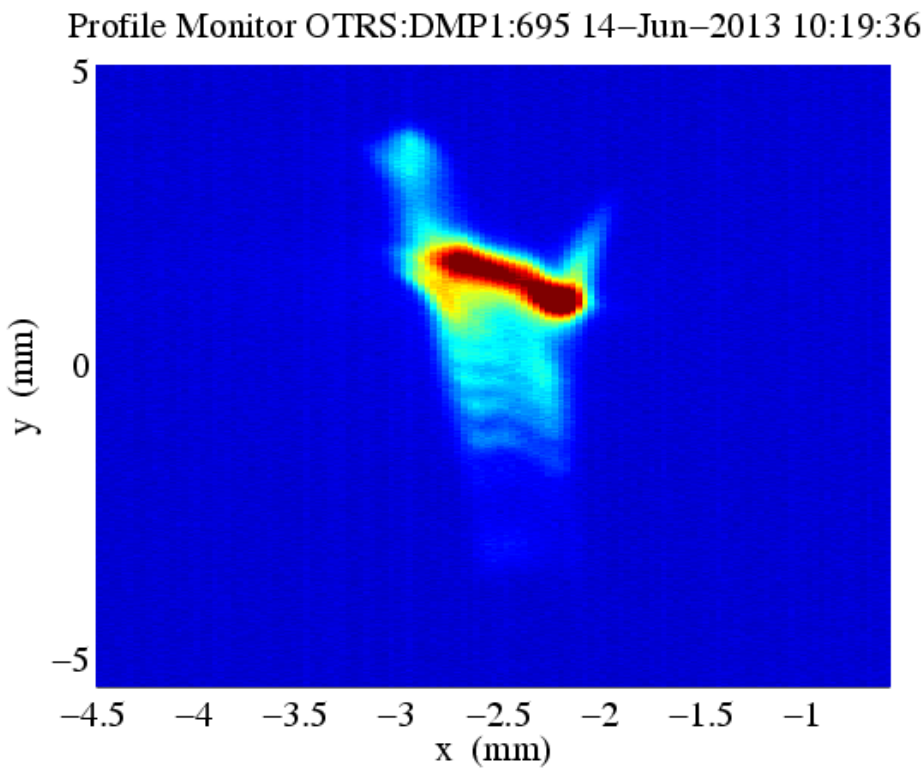
XTCAV with Seeding

Part of the electron loose

same energy (separation)

[multiple energies ??]





Study list with xtcav:

Lasing evolution and control

- 150pC, 4.3GeV and 13.6GeV, different BC2 current 1-3 kA.
- lasing evolution along undulator;
- Taper effects on the pulse shape;
- DL2 R56 effects on horns;
- L1X and L1S effects on chirp and horns
- Under-compression versus over-compression

20pC, low & high energy

Self-seeding

slice energy spread vs. laser heater etc.

micro-bunching

benchmark with TCAV3, and SPARO spectrometer.

slotted foil.

BC1/BC2 collimation (remove double horns).

Synchronized data between FEE spectrometer and xtcav, Phase retrieval (Lutman, Maxwell)

undulator chamber wake fields

…

Summary

- Basics of the LCLS (Linac Coherent Light Source)
- Operational schedules
- Seeding reduces spectral width from 20 to 0.5 eV
- Seeding with 004, 220, and other lines
- Two color seeding
- Over-compressed beam
- Tuning strategies for seeded beam
- Longitudinal phase space visible with XTCAV
- Electron AND photon distribution with TREX