WEYB02

Hard X-Ray Self-Seeding at the Linac Coherent Light Source (*HXRSS at LCLS*)

P. Emma, for the HXRSS collaboration

May 23, 2012

SLAC National Accelerator Laboratory (Stanford, CA)

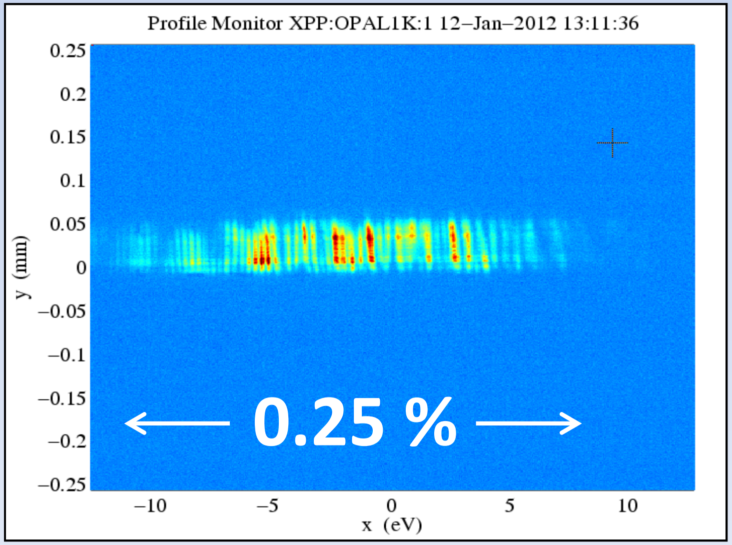
Advanced Photon Source, Argonne National Laboratory (Argonne, IL)

Technical Institute for Superhard and Novel Carbon Materials (Troitsk, Russia)

LCLS Operating in SASE Mode Since April, 2009

- FEL startup from noise produces wide, **noisy spectrum**
- Limited longitudinal **coherence**
- SASE FEL wavelength **jitter** of ~0.1% is typical
- Laser seeding **not possible** yet at 1-Å levels, but very attractive…

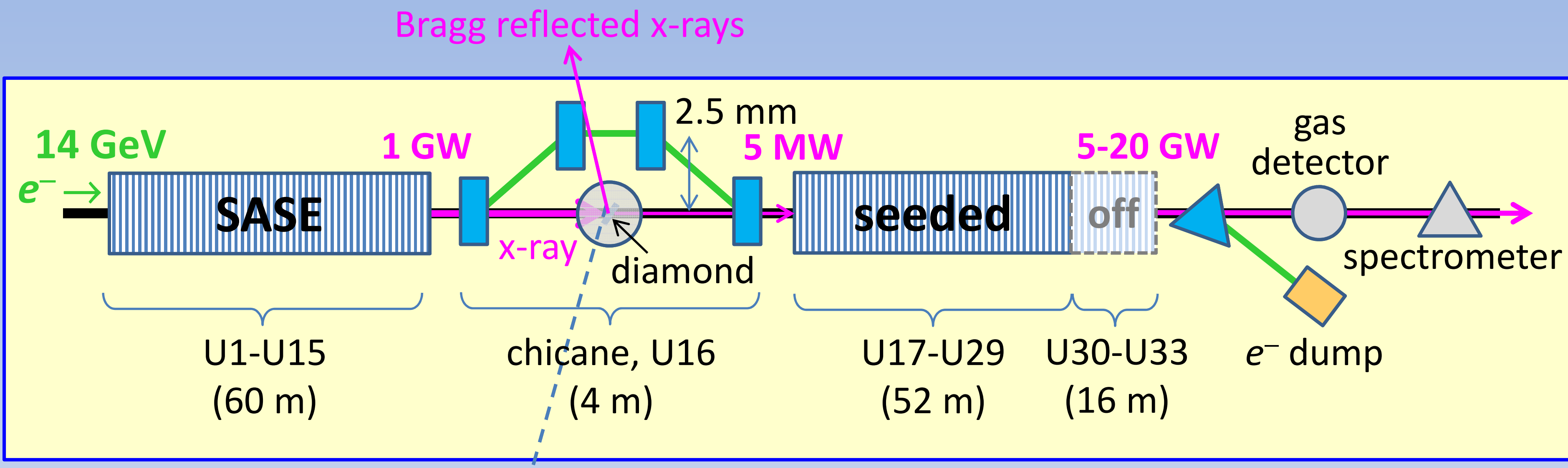
Measured SASE spectrum (LCLS)



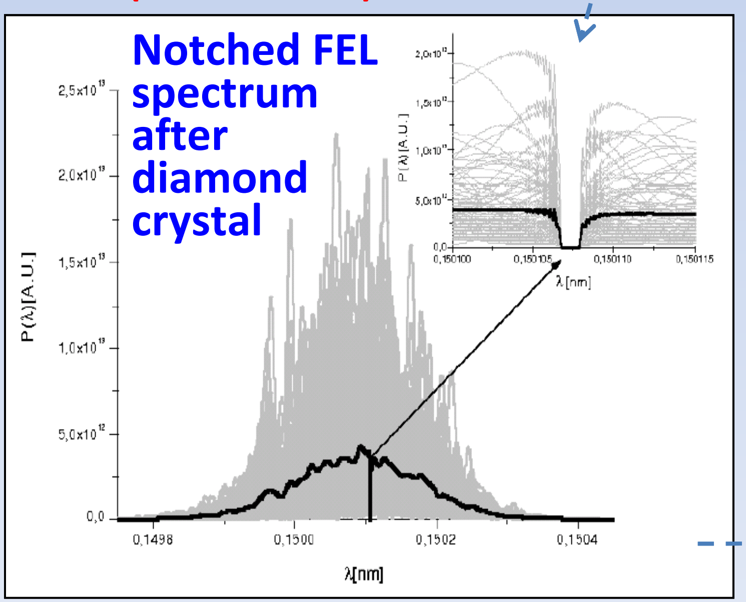
FEL Self-Seeding

- Great idea from ***DESY***:
  Geloni, Kocharyan, Saldin, *DESY 10-133*, Aug. 2010
- Remove 16^{th} 4-m undulator segment (of 33 total)
- Replace with 4-dipole chicane & diamond monochromator
- Transmitted (monochromatic) x-rays seed 2^{nd} half of FEL
- Generates $\mathbf{5\times10^{-5}}$ BW (narrowed by **50**) at 1.5 Å wavelength
- Switched **on** or **off** any time, allowing SASE or seeded mode
- Chicane also serves as phase shifter for SASE
- System installed Jan. 3-6, commissioned Jan. 7-12, 2012

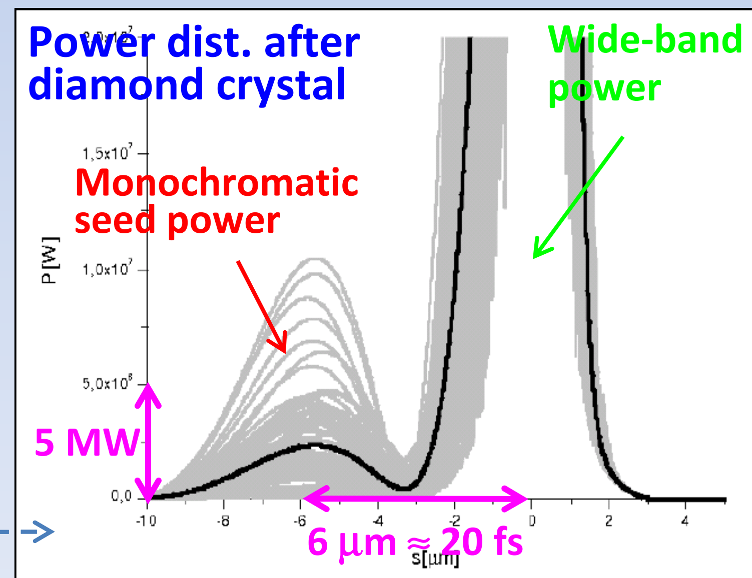
Self-Seeding Scheme @ *LCLS*



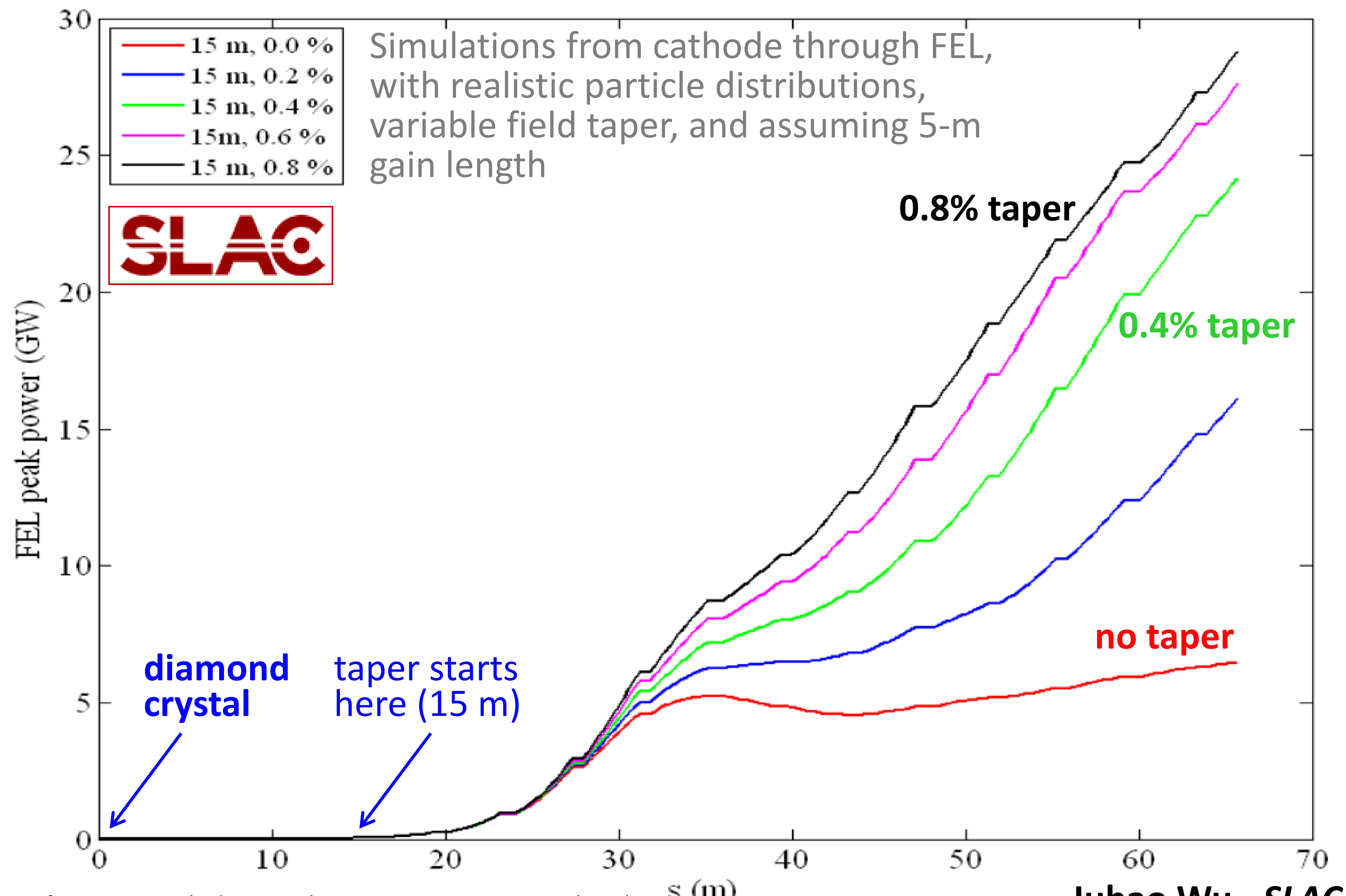
Geloni, Kocharyan, Saldin (*DESY 10-133*)



Use short, low-charge bunch to self-seed at 1.5 Å (20-40 pC)



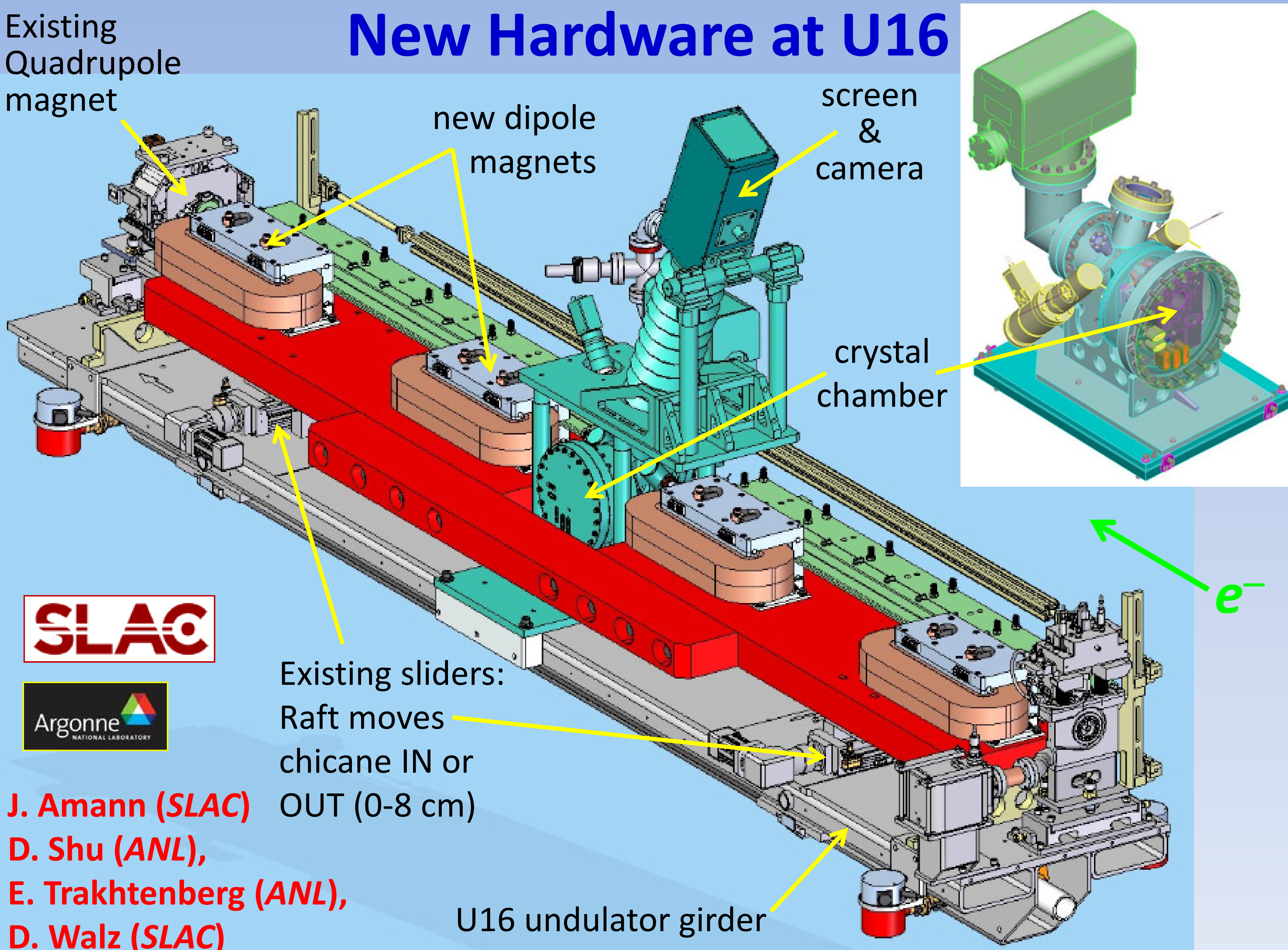
Start-to-End HXRSS Simulations (U17-U33)



performance may be better – this is a worst case 5-m gain length

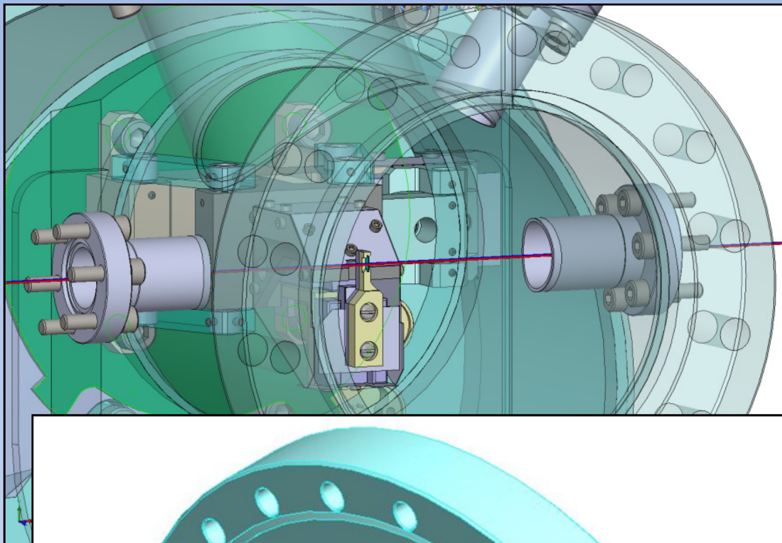
Juhao Wu - *SLAC*

New Hardware at U16



J. Amann (*SLAC*)
D. Shu (*ANL*),
E. Trakhtenberg (*ANL*),
D. Walz (*SLAC*)

The Diamond Crystal and Positioning System



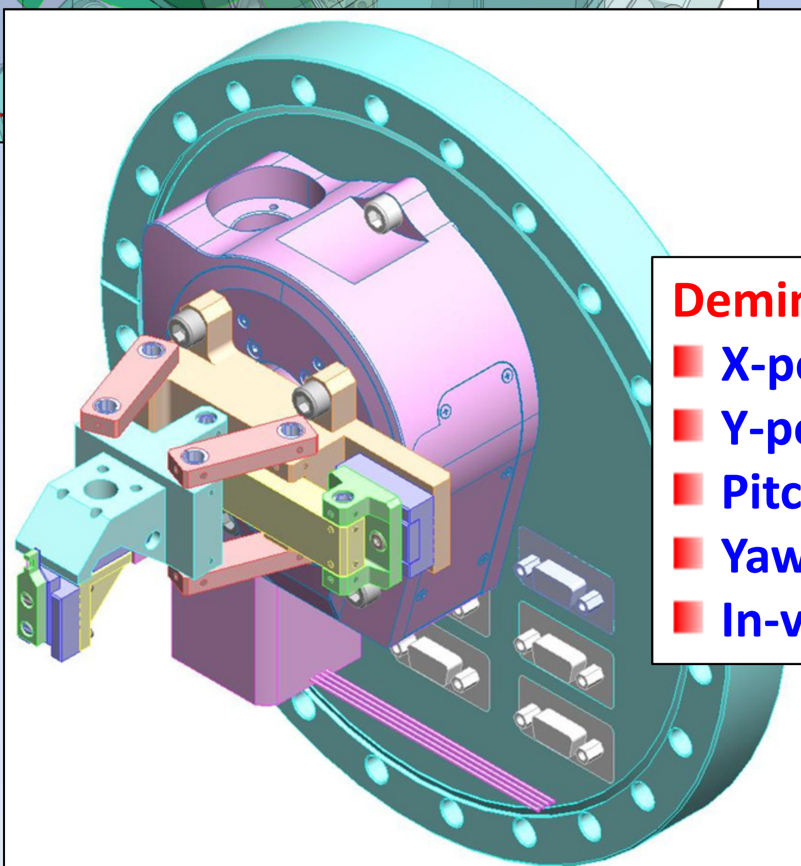
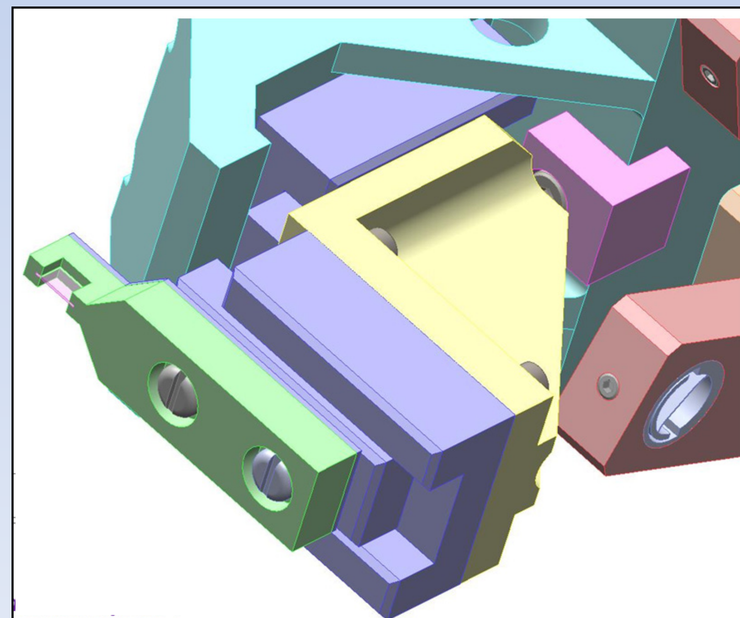


Table 6. Crystal chamber, YAG diagnostic, and crystal positioning parameters.

parameter	value	units
x and y position full control range	±2	mm
x and y position settability (rms)	<0.05	mm
crystal extraction range (approx).	0 - 10	mm
crystal pitch angle full control range	45 - 95	deg
pitch angle settability (rms)	<0.005	mrad
crystal yaw (optional) angle control range	±3	deg
crystal yaw (optional) angle settability (rms)	<0.010	mrad
crystal temperature stability	~1	degC
screen and camera position resolution	<0.02	mm
expected rms spot size on screen	30-50	μm
max. camera update rate	≥10	Hz

Deming Shu (*ANL*)

- **X-pos control**
- **Y-pos control**
- **Pitch angle ctrl**
- **Yaw angle ctrl**
- **In-vac. stages**



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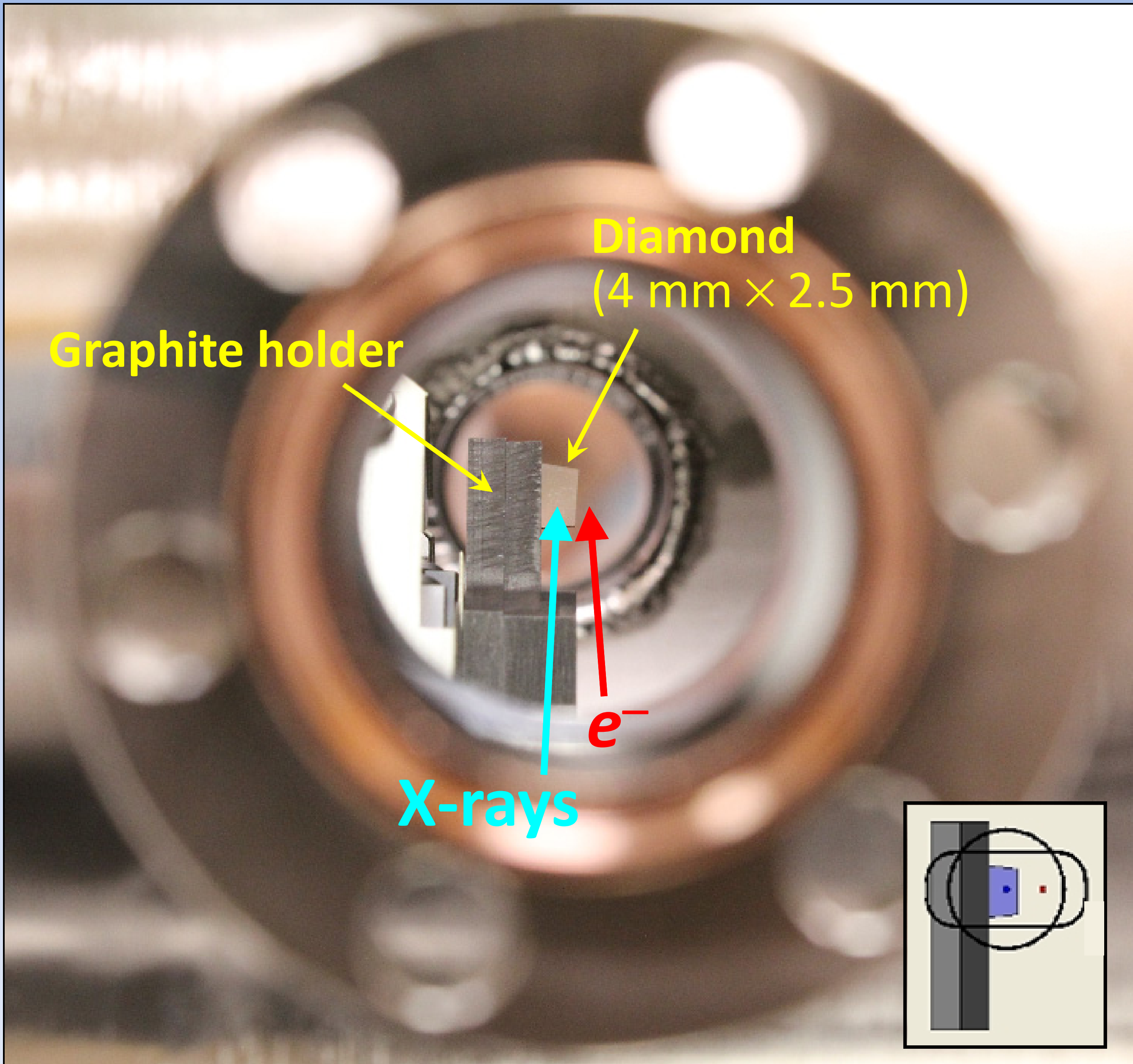
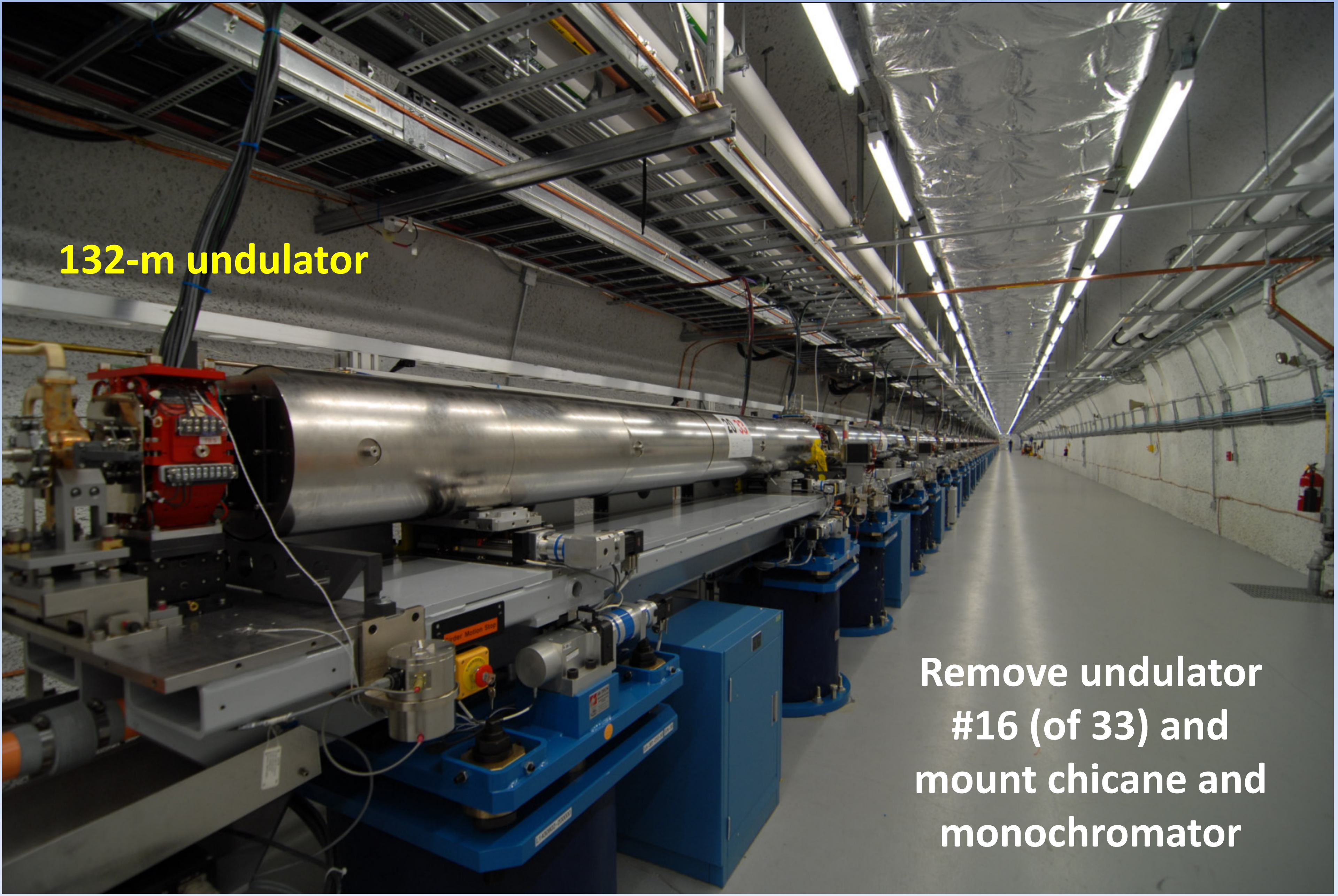
Diamond & Holder Seen Through Beam Pipe



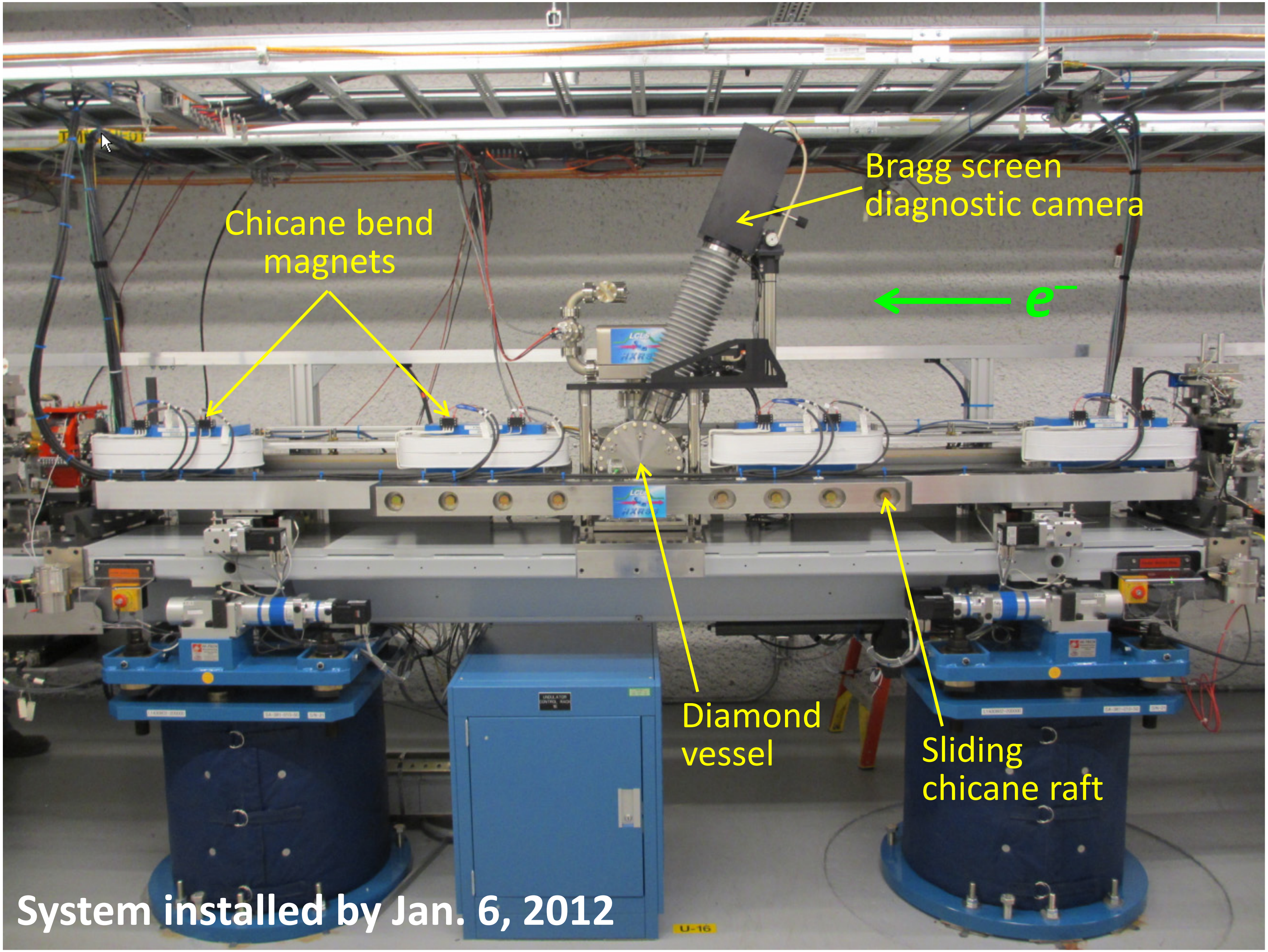
Crystal is high quality 110-μm thick type-IIa diamond crystal plate with (004) lattice orientation.

Grown from high-purity (99.9995%) graphite at the *Technological Institute for Super-hard and Novel Carbon Materials* (**TISNCM**, Troitsk, Russia) using the temperature gradient method under high-pressure (5 GPa) and high-temperature (~1750 K) conditions.

LCLS Undulator (33 4-m segments, 132 m long)

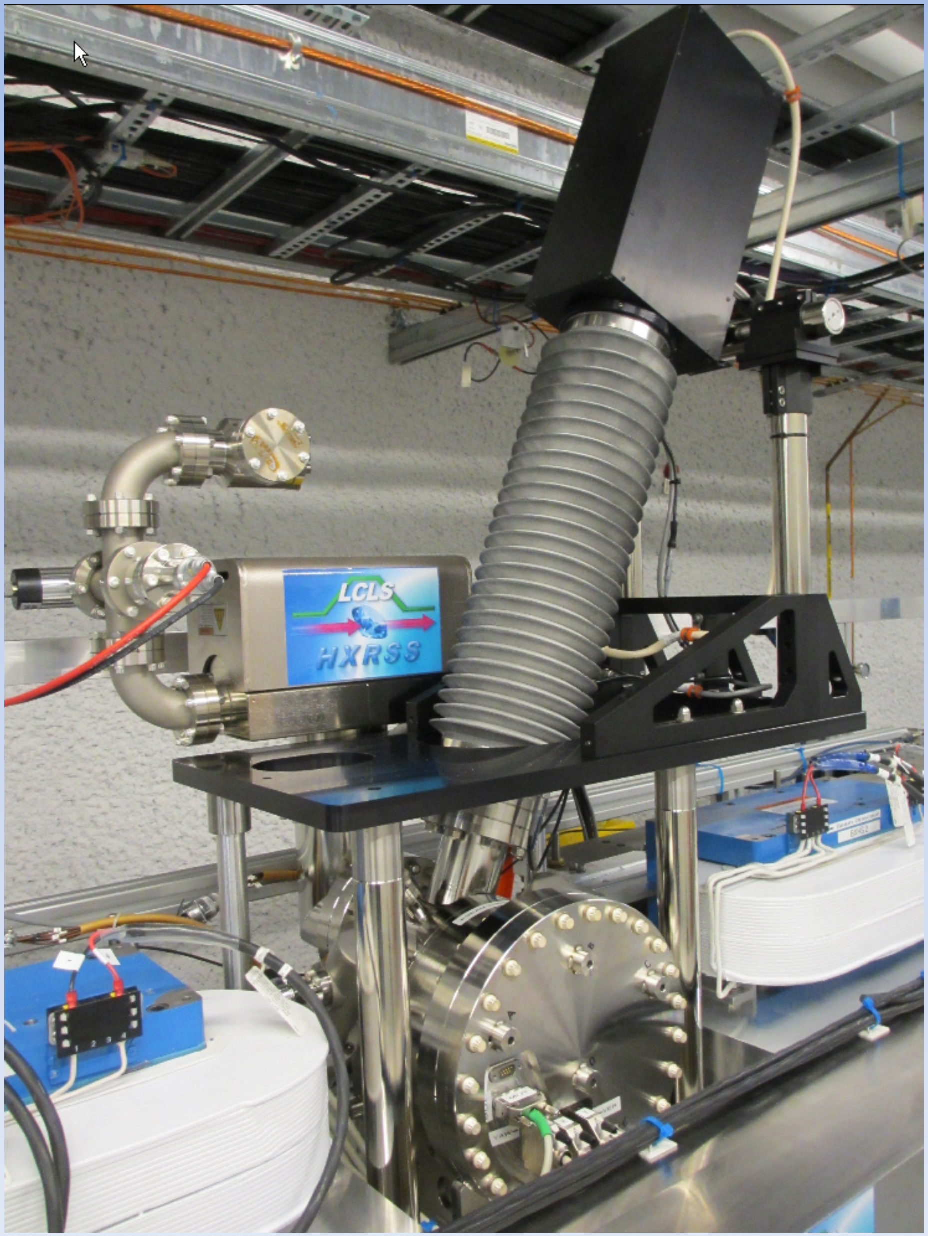


Chicane and Monochromator at Undulator #16 (of 33)

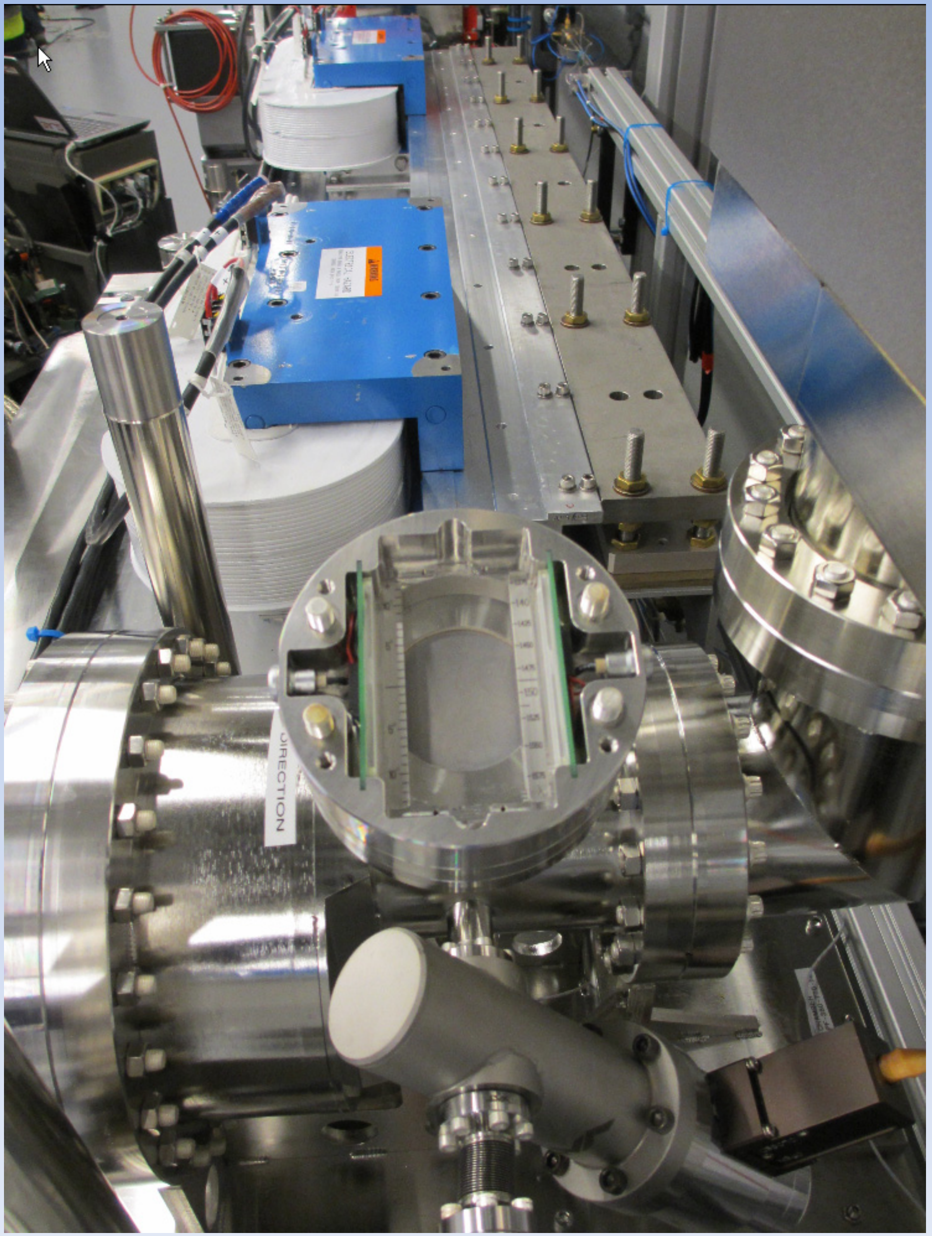


Chicane and Monochromator at Undulator #16 (of 33)

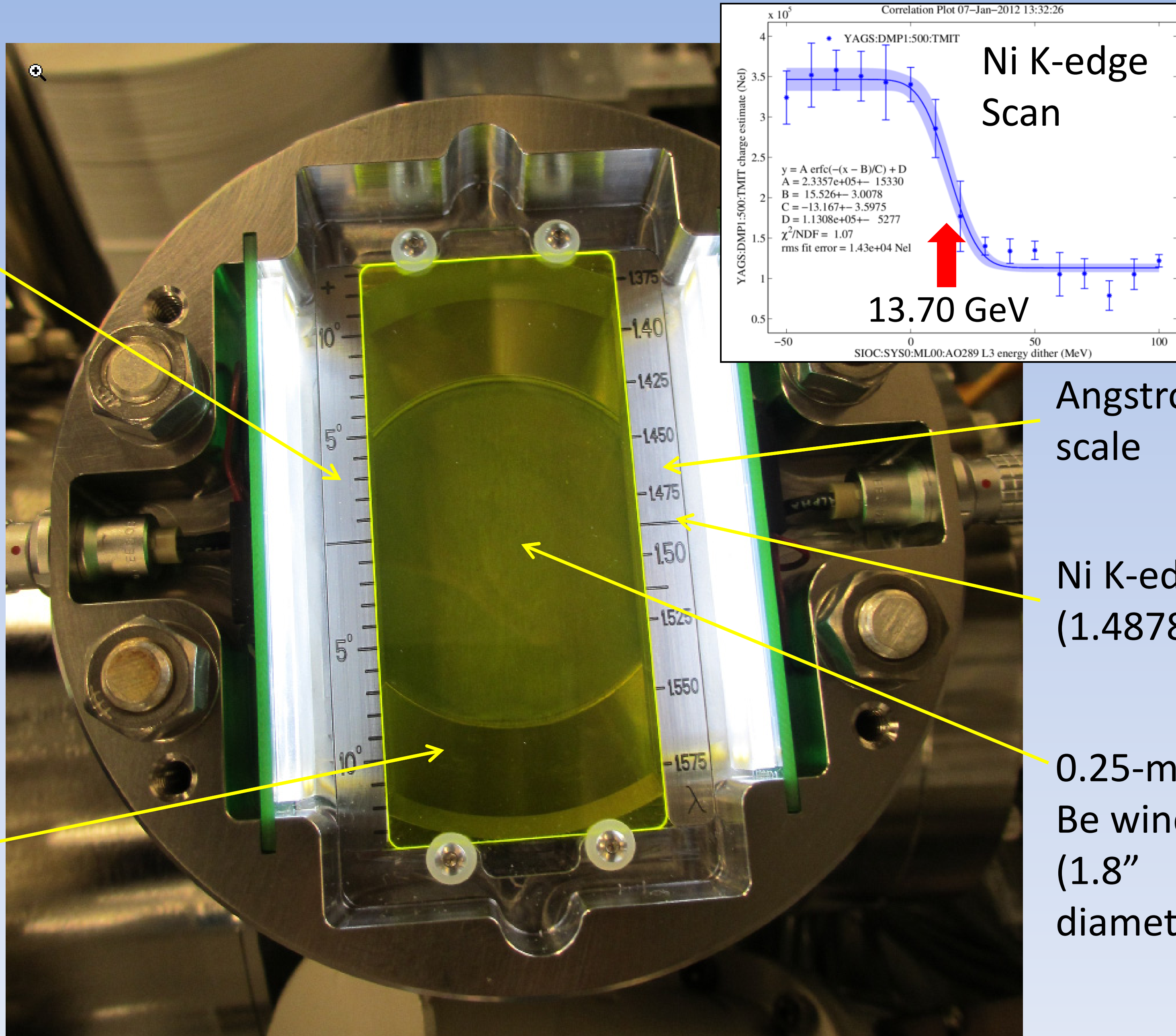
Bragg diagnostic with camera in place



Bragg diagnostic with camera removed



Bragg Diagnostic Screen (suggested by Geloni, et al)



Angle scale

YAG screen (36 mm x 80 mm)

Angstrom scale

Ni K-edge (1.4878 Å)

0.25-mm Be window (1.8" diameter)

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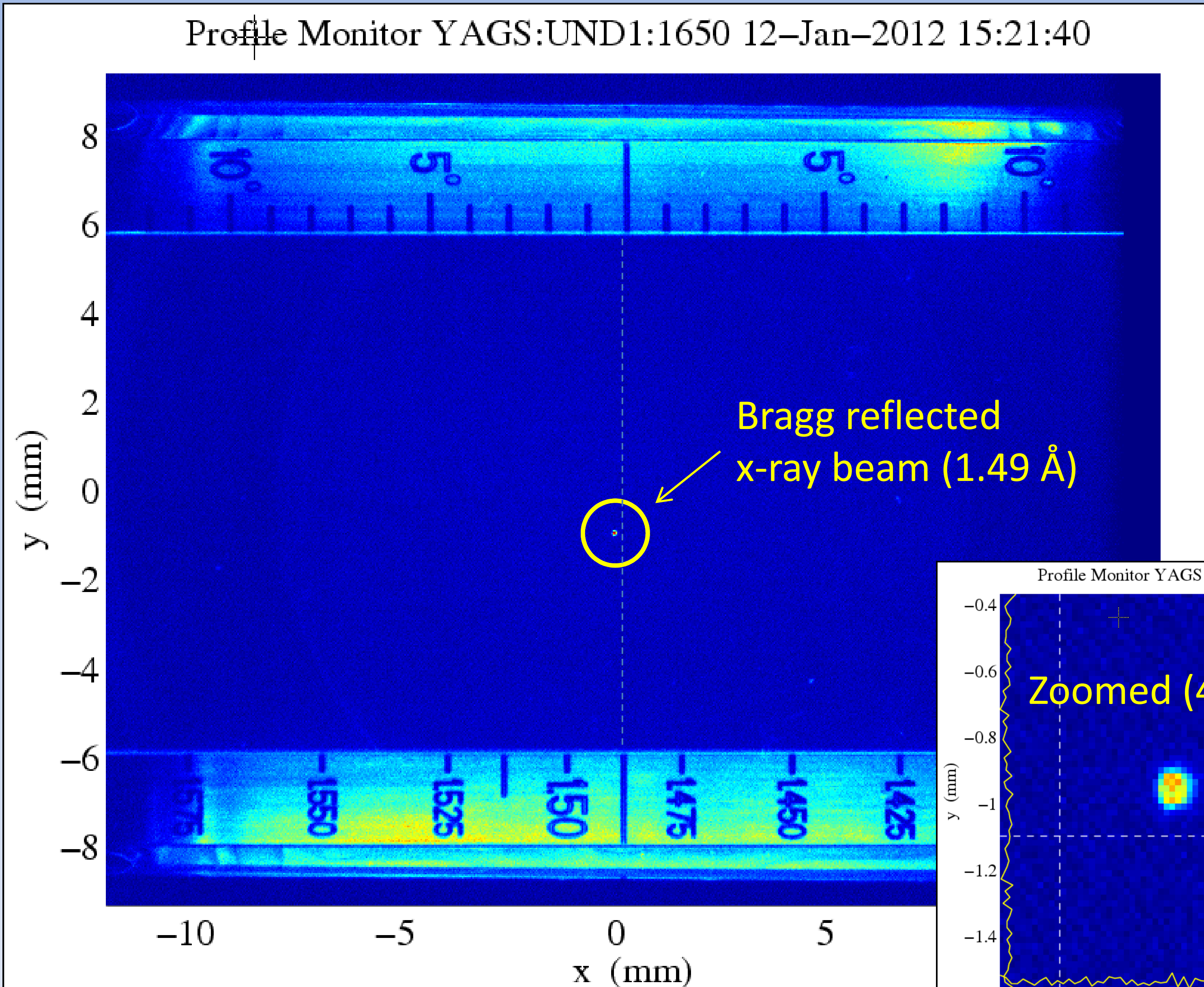
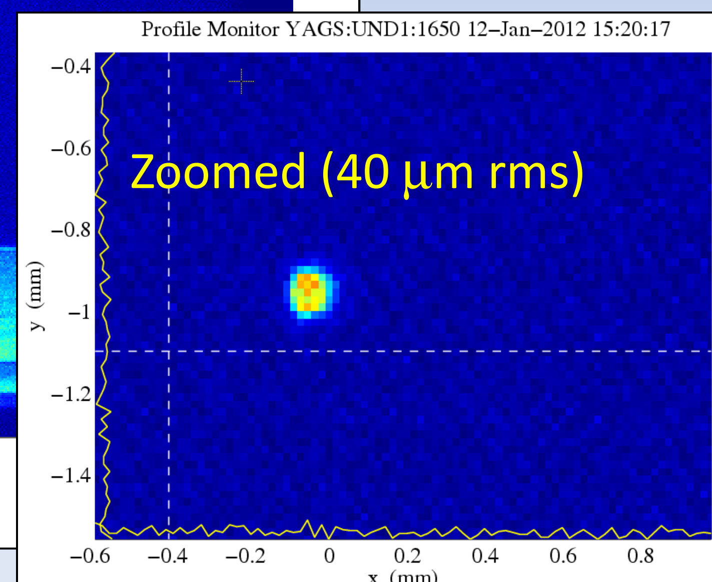
Bill Berg (*ANL*)

Bragg Diagnostic Screen Shows First Reflected X-ray Beam

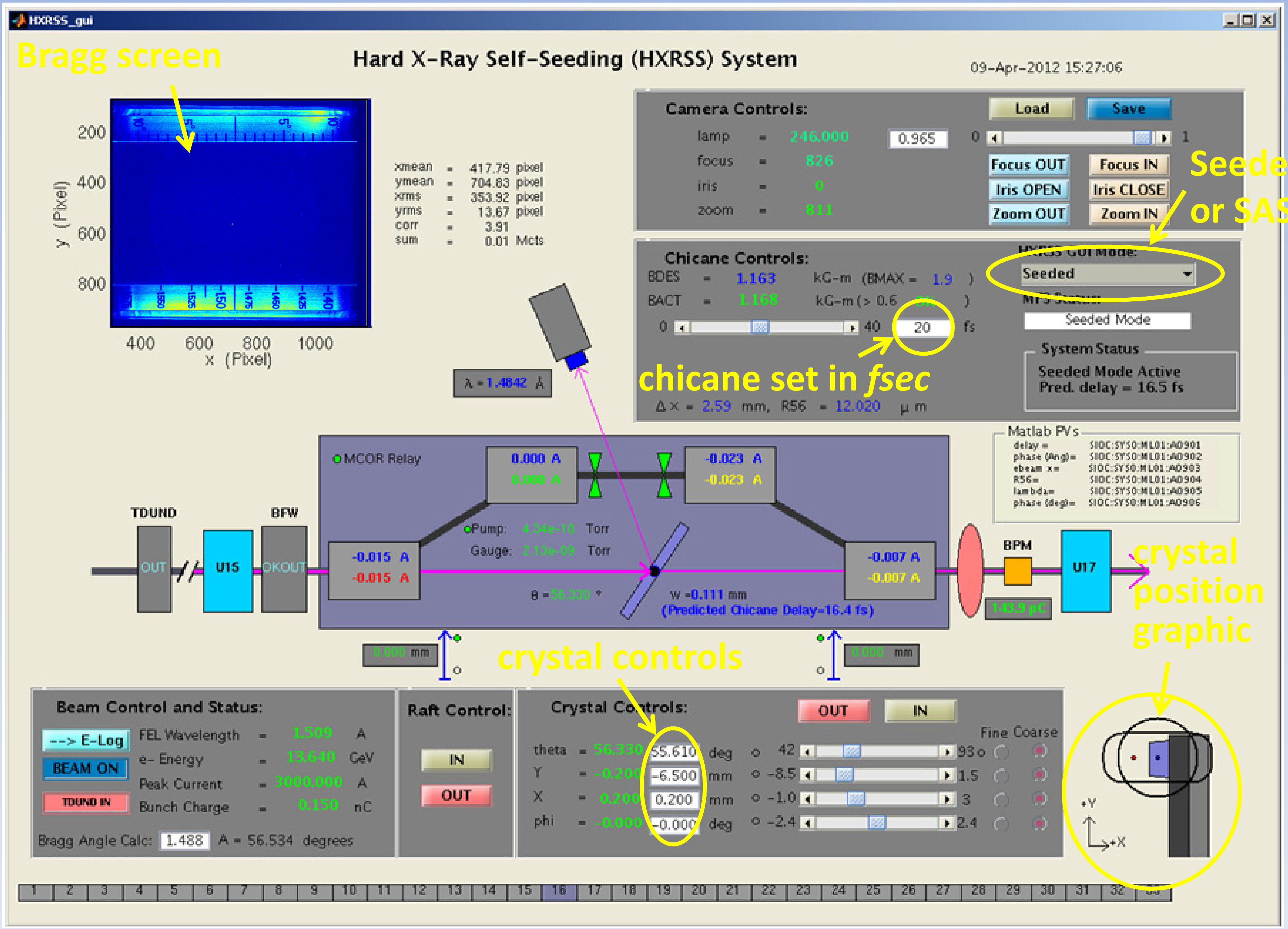




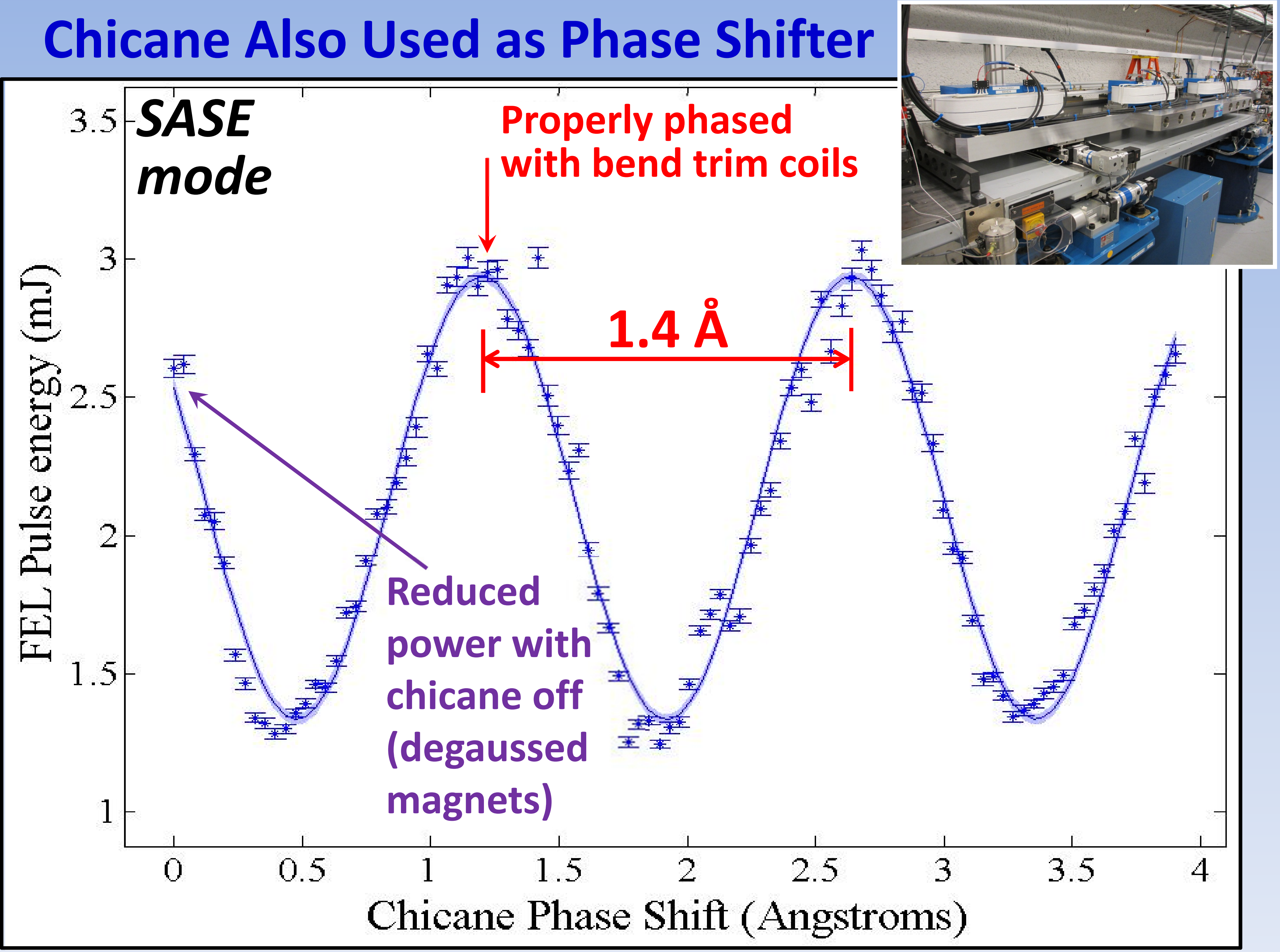
Intensity jitter here is 100% (not saturated and only narrow band is reflected)

J. Rzepiela
TUPPP080

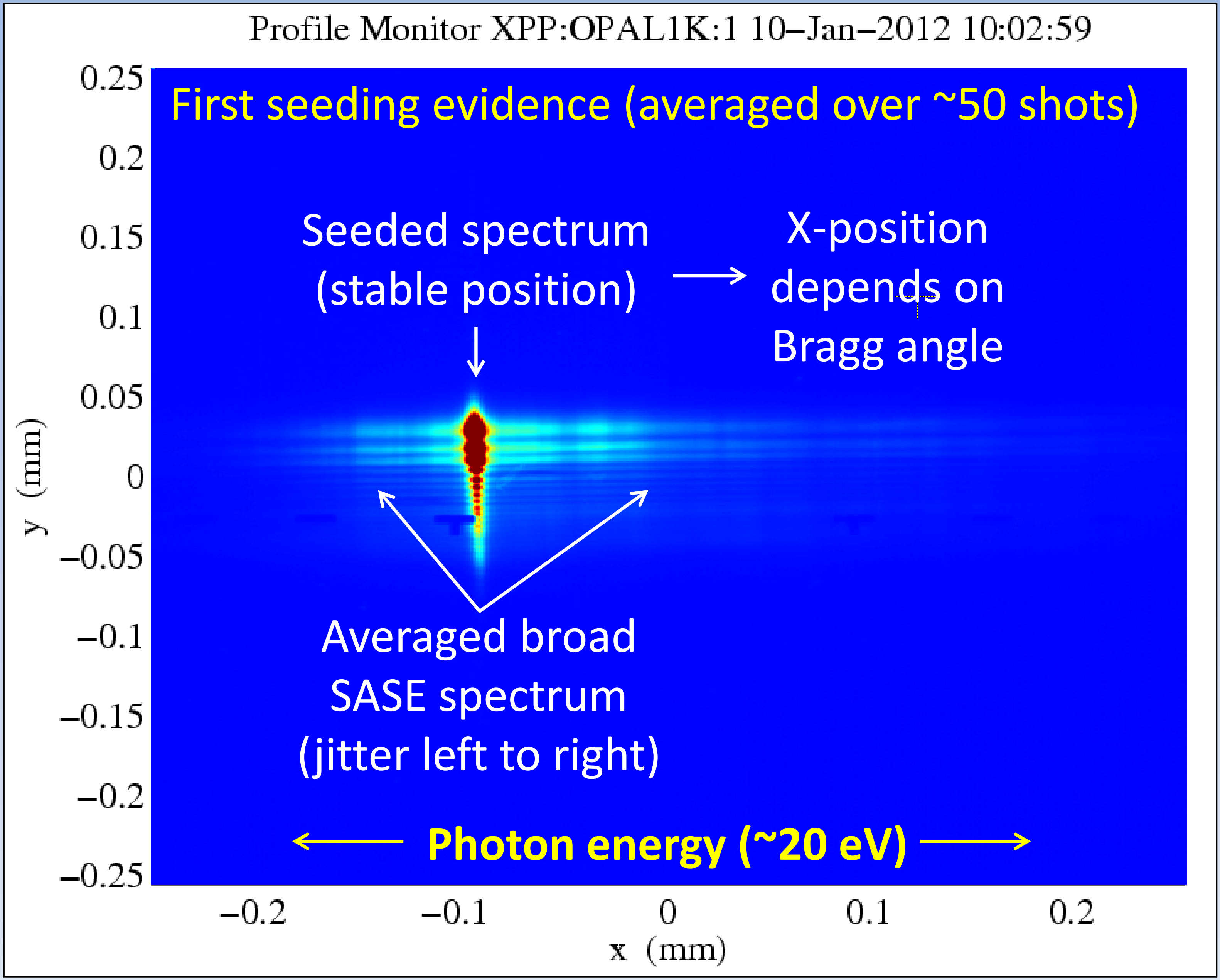
HXRSS Control GUI



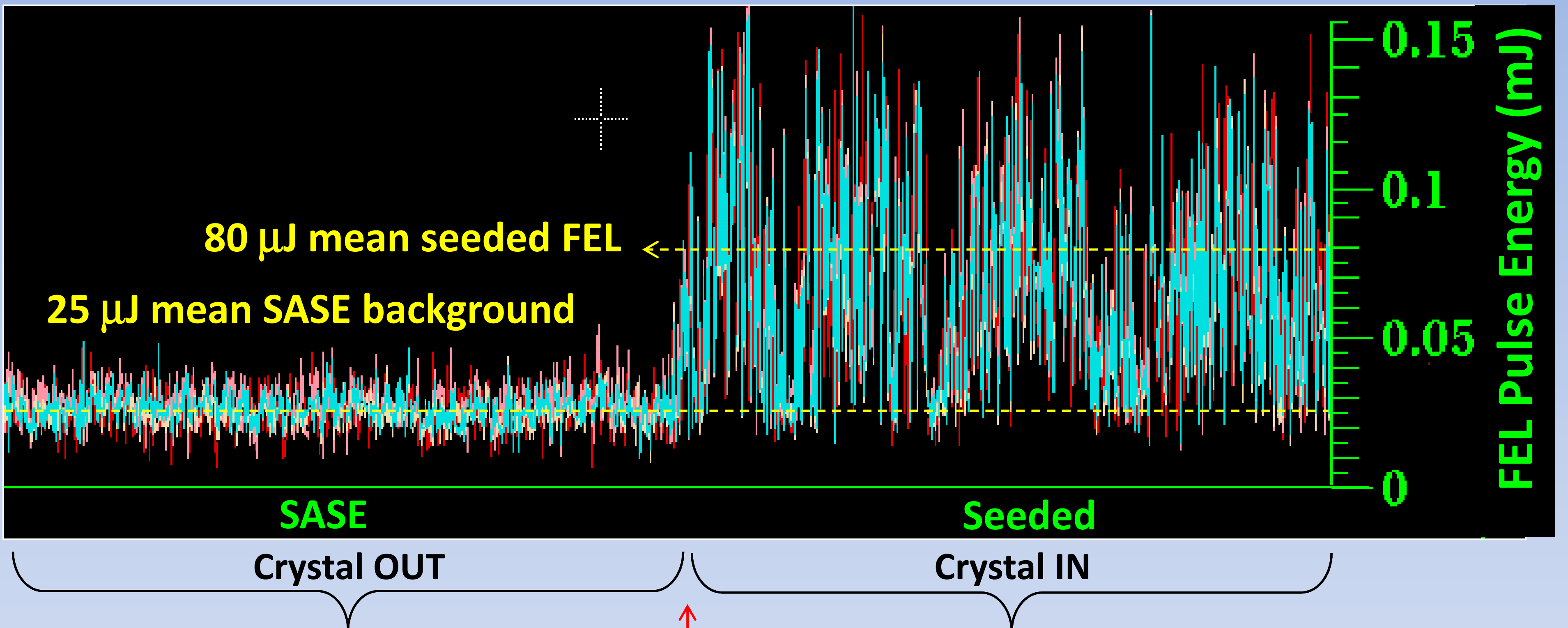
Chicane Also Used as Phase Shifter

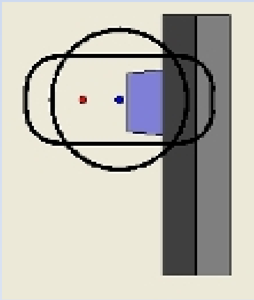


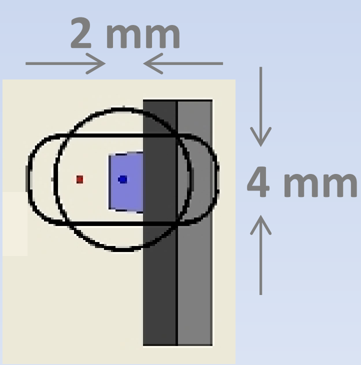
Averaged Spectrum: SASE + Stable Seeded Pulse



Seeded Power & SASE Power (40 pC, well tuned, U1 OUT)





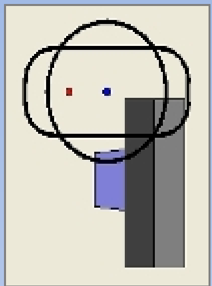


Crystal inserted here (1.5-mm position change)
[chicane is always ON in this plot]

Pulse energy spikes up to 300 μJ observed, but jitter is ~50%

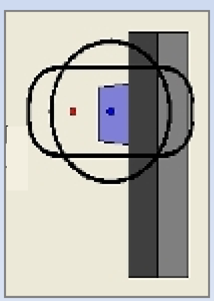
Bandwidth Before and After

8.3 keV

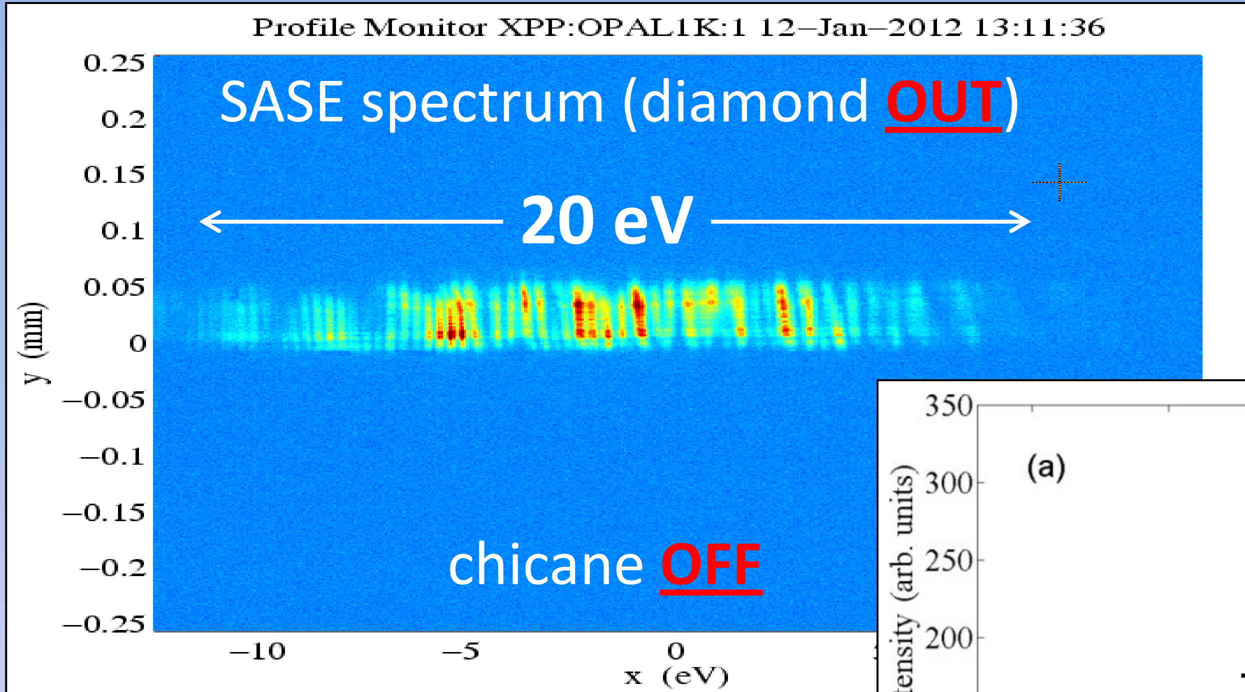


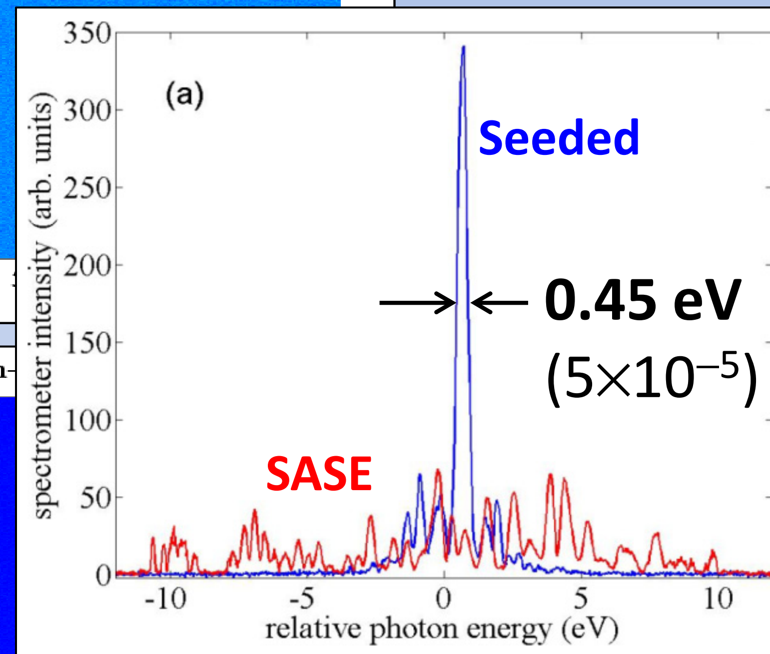
SASE

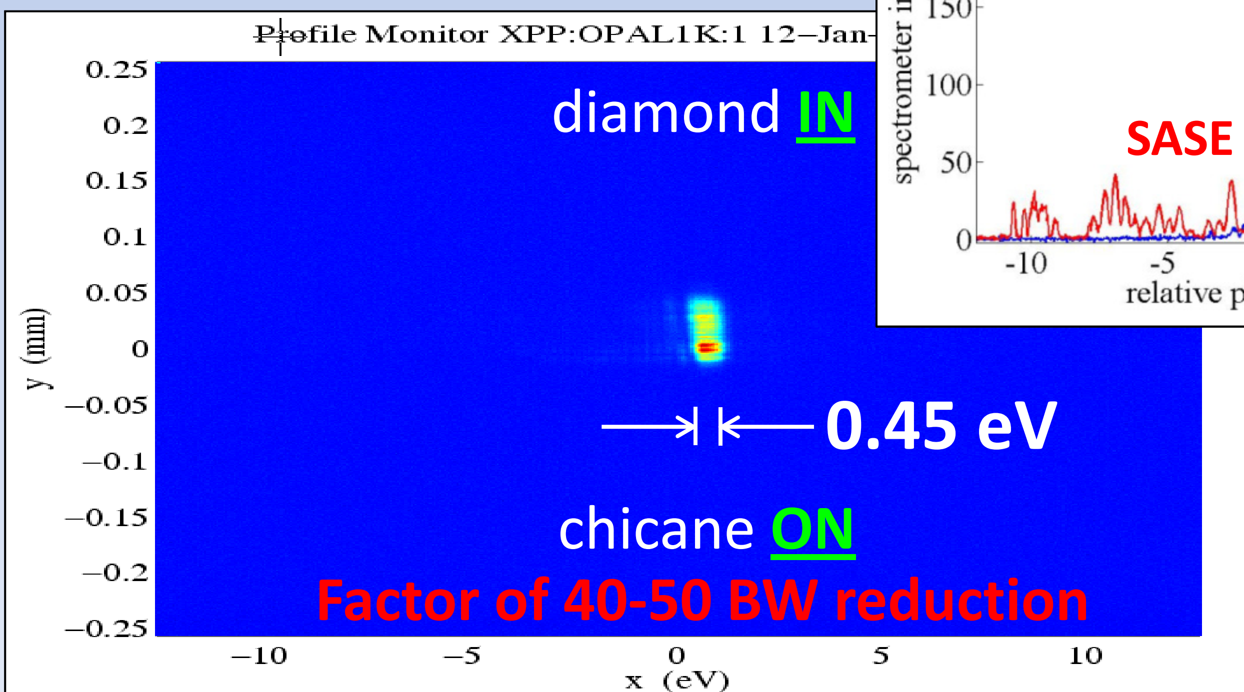
insert diamond & turn on chicane



seeded



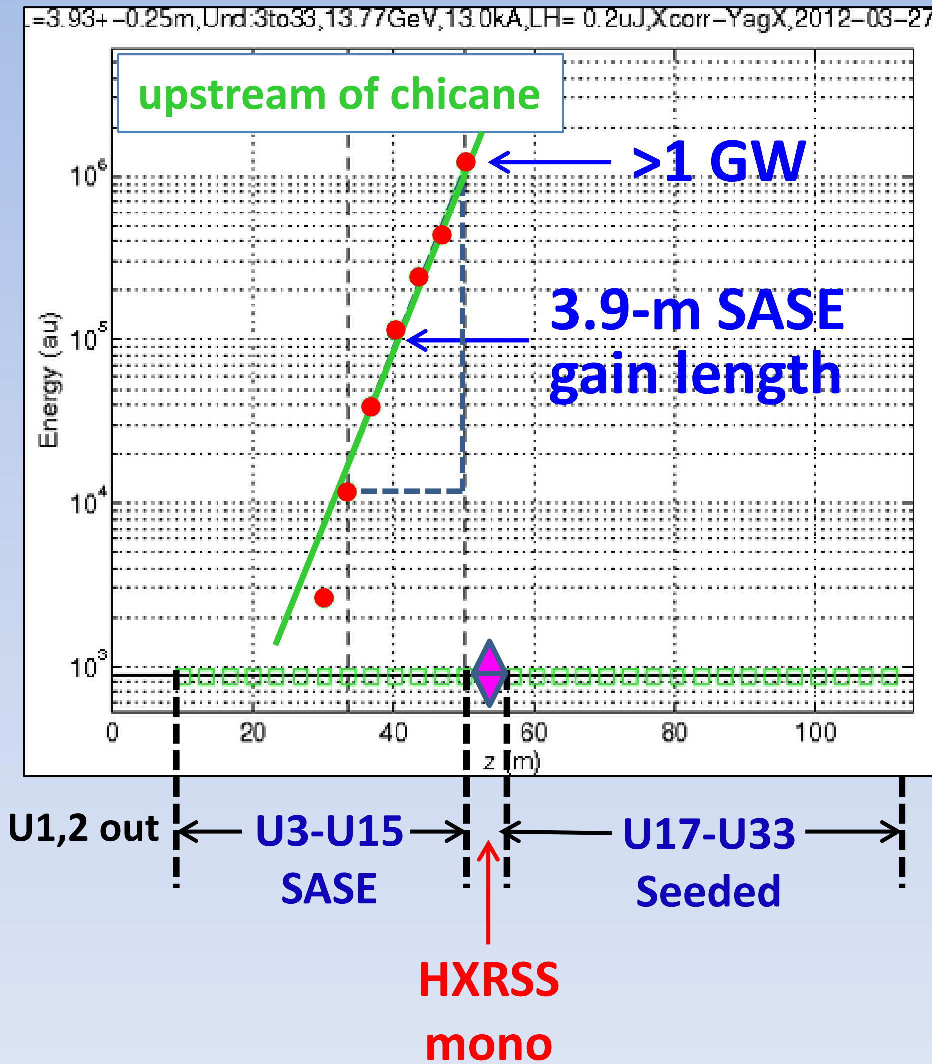




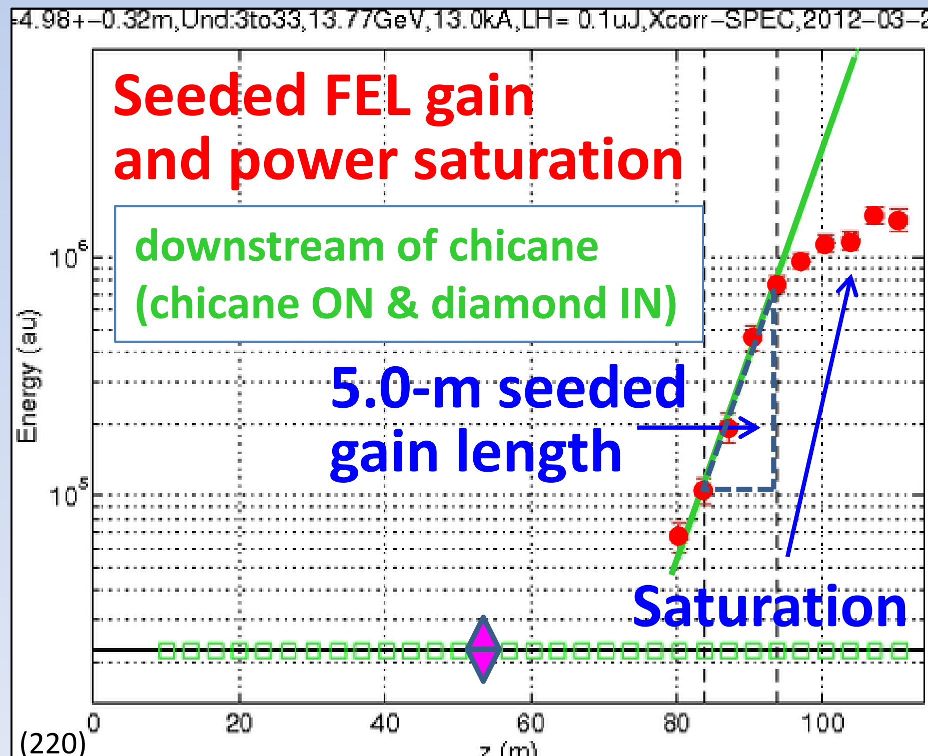
A well seeded pulse (not typical)

Gain Curve Shows Seeded Power Saturation

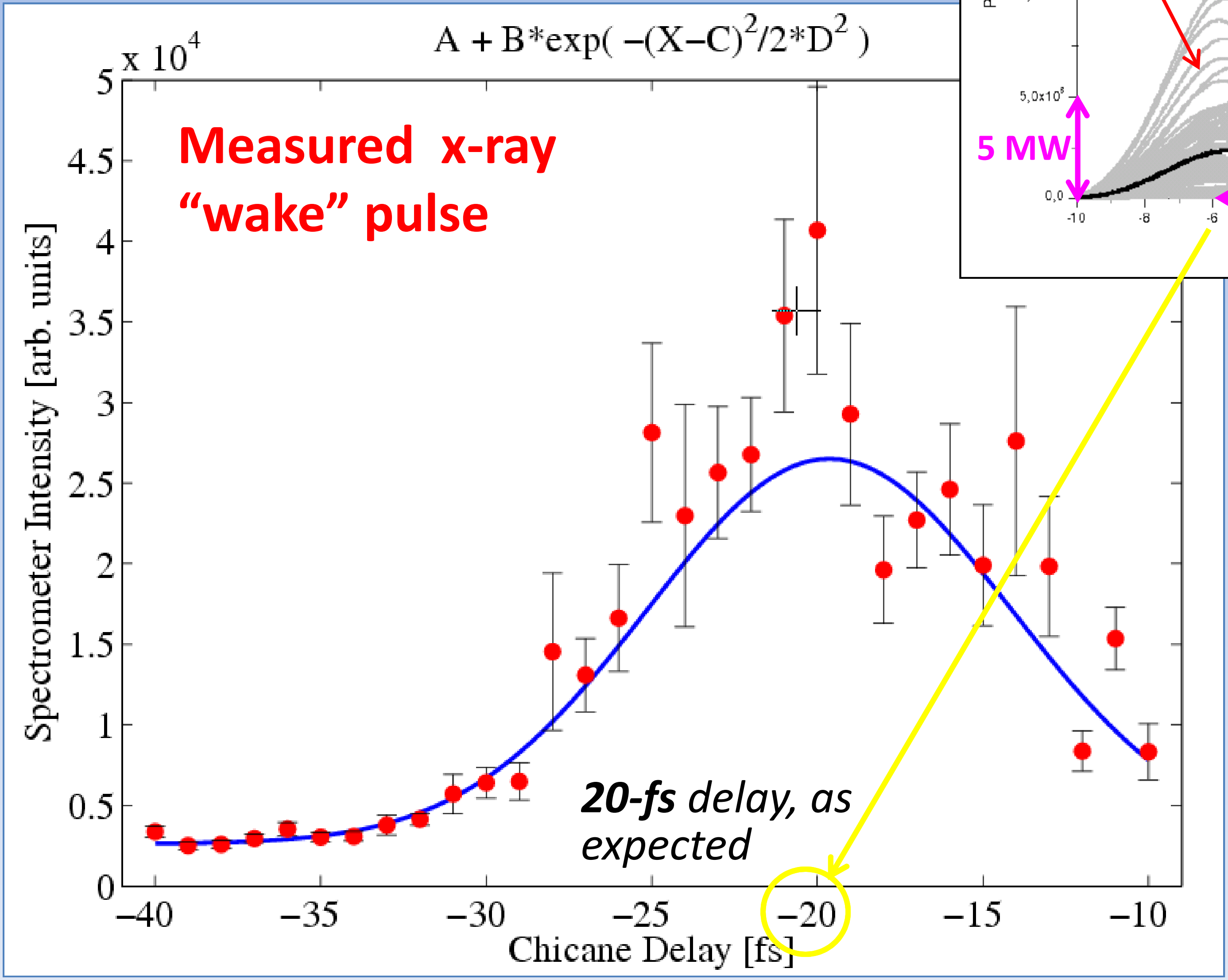
U3-U15 SASE gain length: 3.9 m

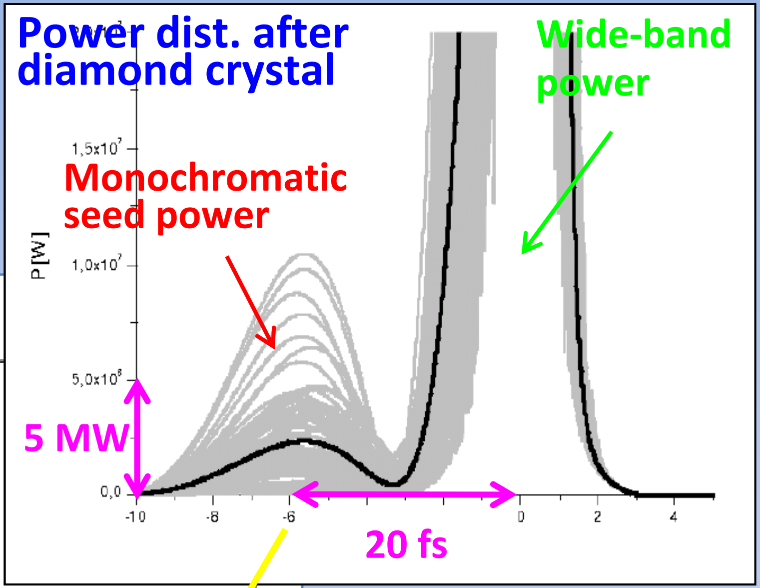


U17-U33 Seeded gain length: 5.0 m



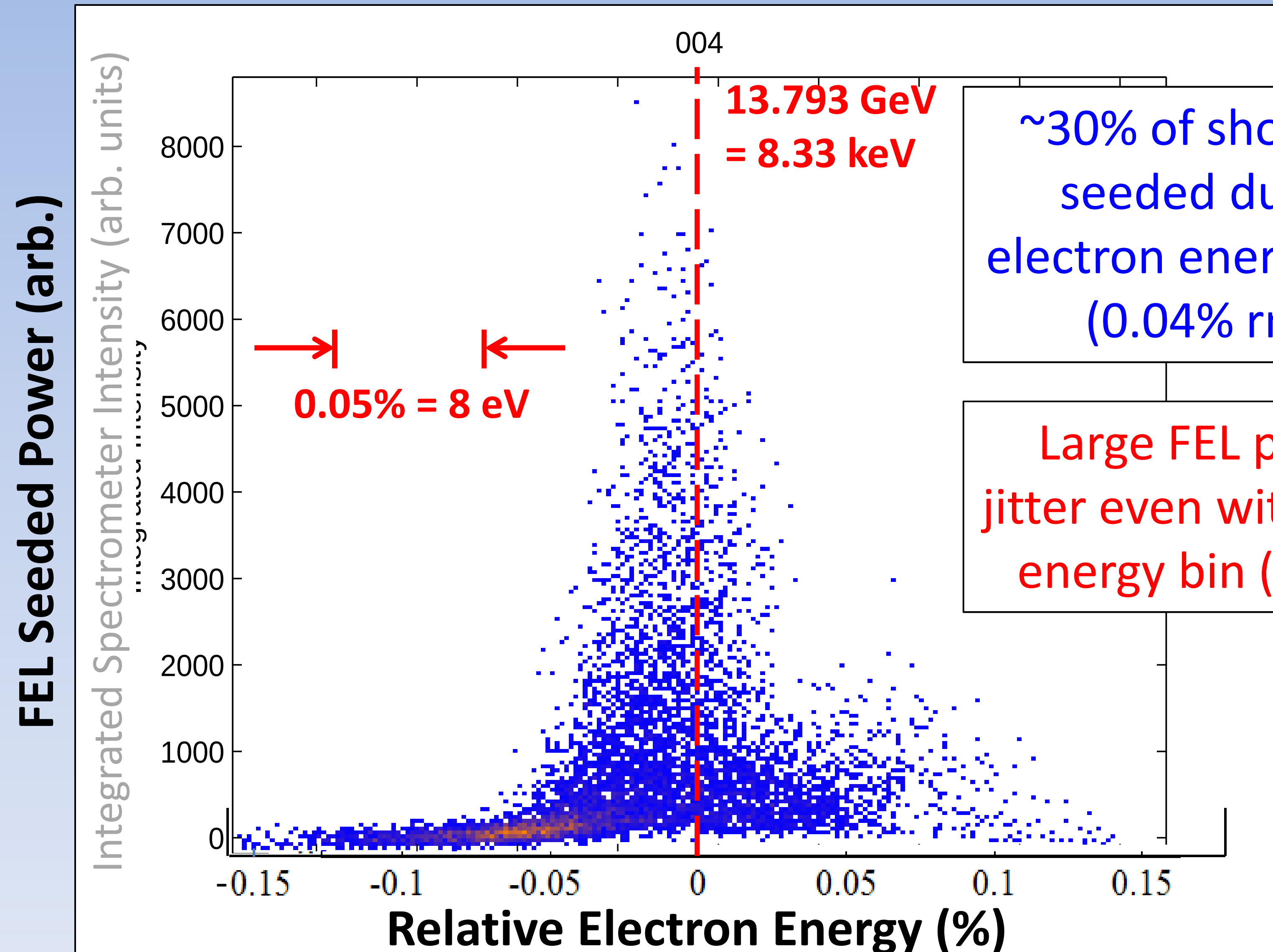
Chicane Delay Scan Shows X-Ray Wake Pulse (40 pC)





Geloni, Kocharyan, Saldin (*DESY 10-133*)

Seeded FEL Power Jitter vs. e^- Beam Energy Jitter

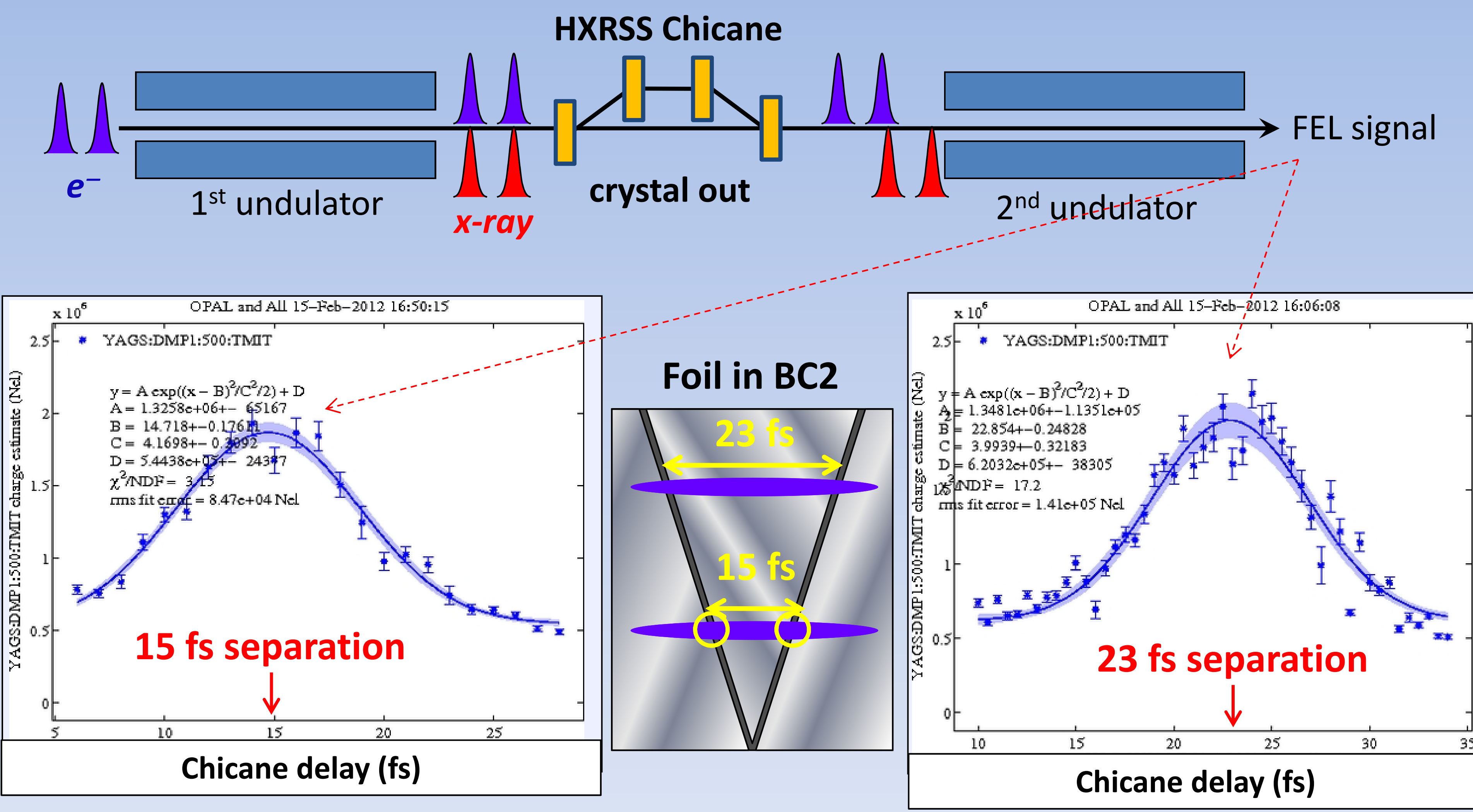


~30% of shots **not** seeded due to electron energy jitter (0.04% rms)

Large FEL power jitter even within one energy bin (worst)

A. Lutman

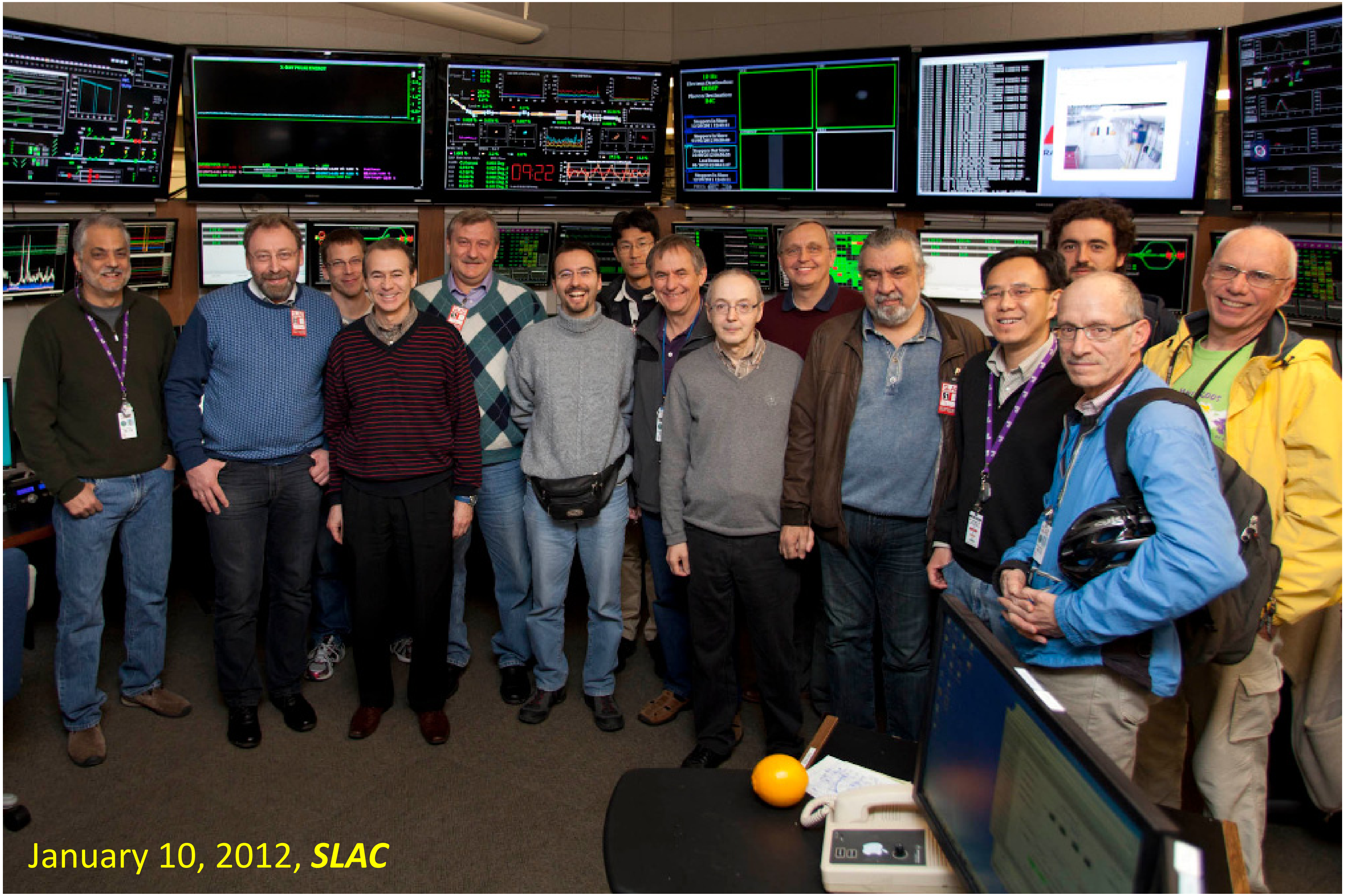
Diagnostic: Cross-correlation of e^- and x-ray pulses



Y. Ding

measured rms pulse duration is 3-4 fs

Self-Seeding Commissioning Team (partial)



Summary

- Self-Seeding **works**, producing 5×10^{-5} FEL BW at 8-9 keV
- **Low charge** (40 pC) mode needed for <10 fs pulse lengths
- Electron energy jitter (RF) contributing to FEL power **jitter**
- FEL saturated power **jitter** ~50% rms – 1/2 due to energy jitter
- First steps toward **TeraWatt-FEL** (aggressive tapering)
- ***LBNL*** now collaborating with ***SLAC*** on Soft X-Ray Self-Seeding at ***LCLS*** for use in ***NGLS***!

TUPPP070

THANKS!

Thanks to ***SLAC*** teams (alignment, controls, engineering, operations)

Thanks to ***ANL/APS*** (A. Zholents) and a great team

Thanks to V. Blank and S. Terentyev (*TISNCM*) for high quality diamonds

free