Soft X-ray Self Seeding at LCLS

FEL14

D. Ratner on behalf of SXRSS team

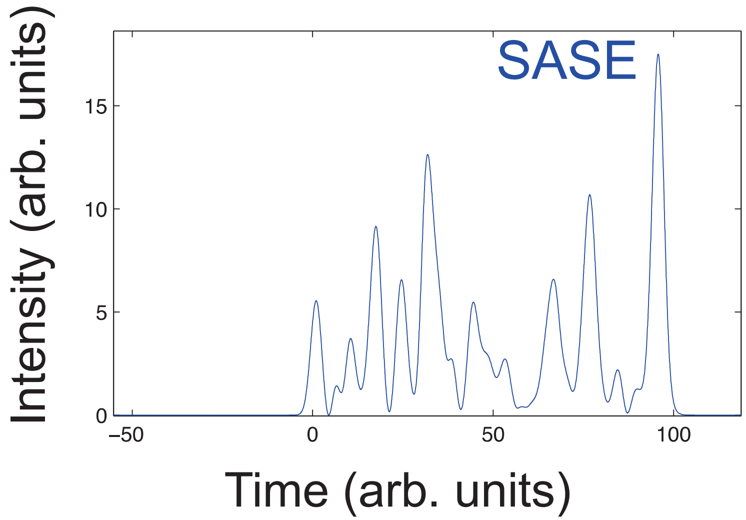
Aug. 26, 2014

Self-Seeded FEL Concept

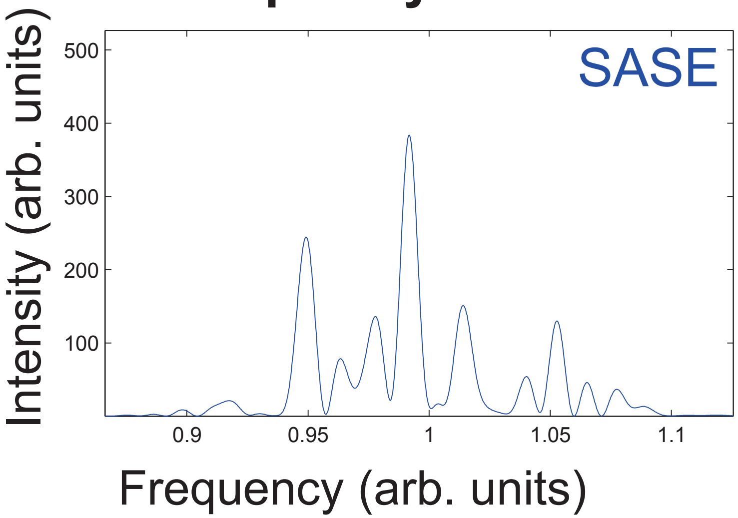
SLAC

SASE vs. Seeding

Time Domain



Frequency Domain



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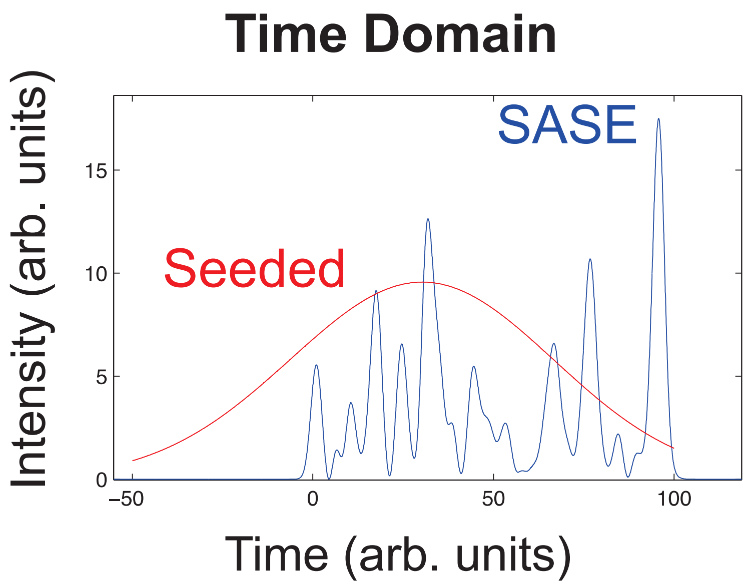
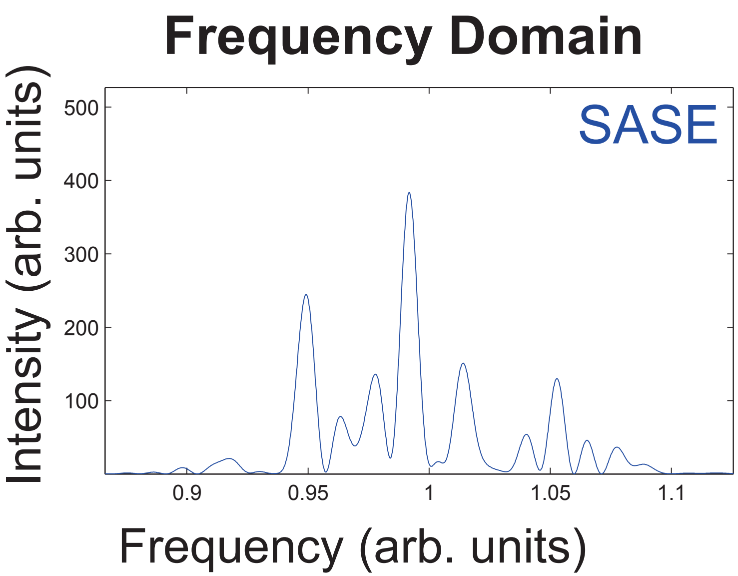
SASE vs. Seeding





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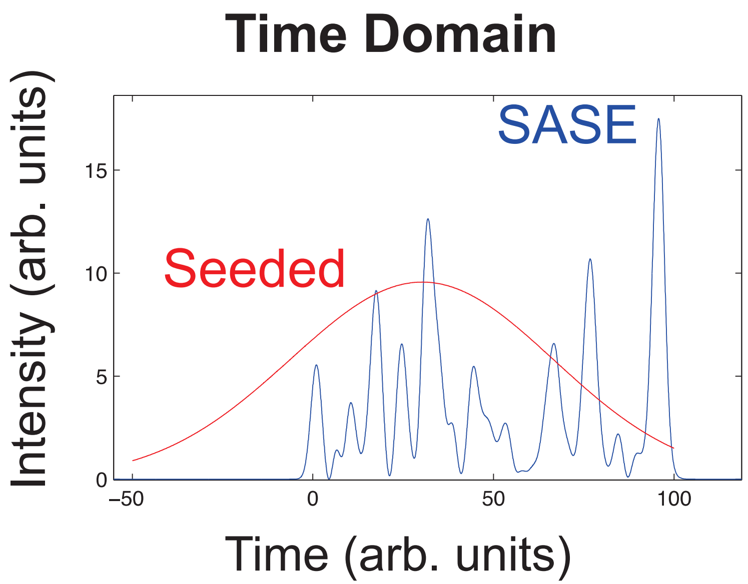

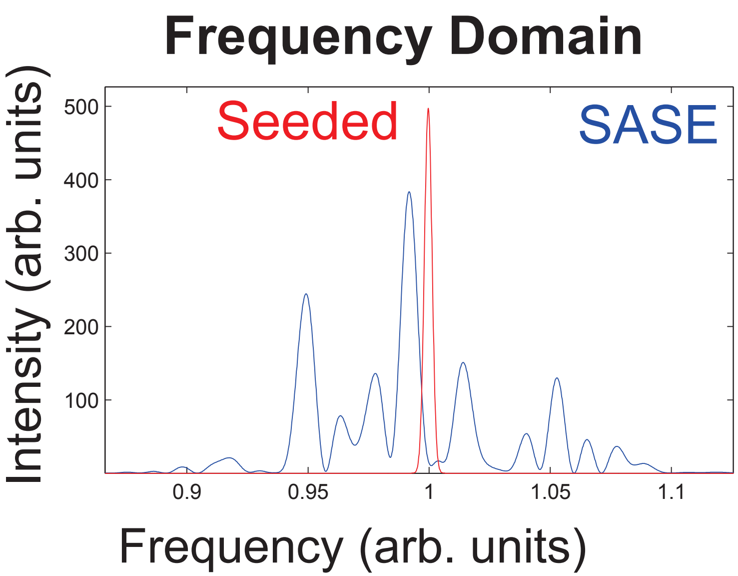

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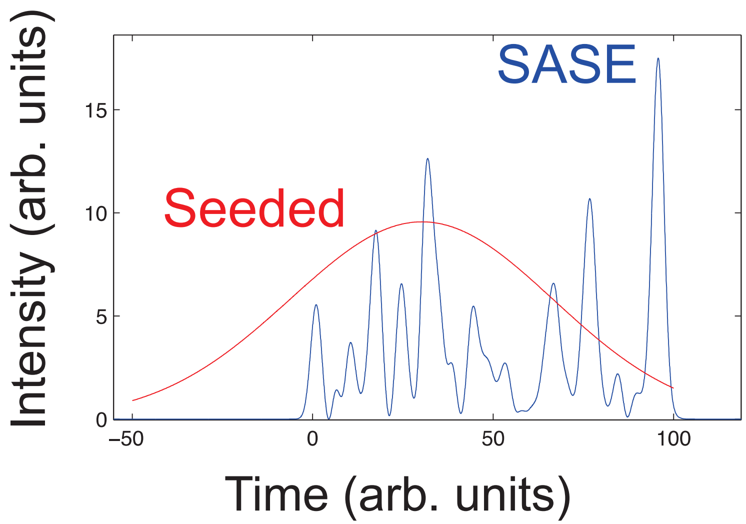

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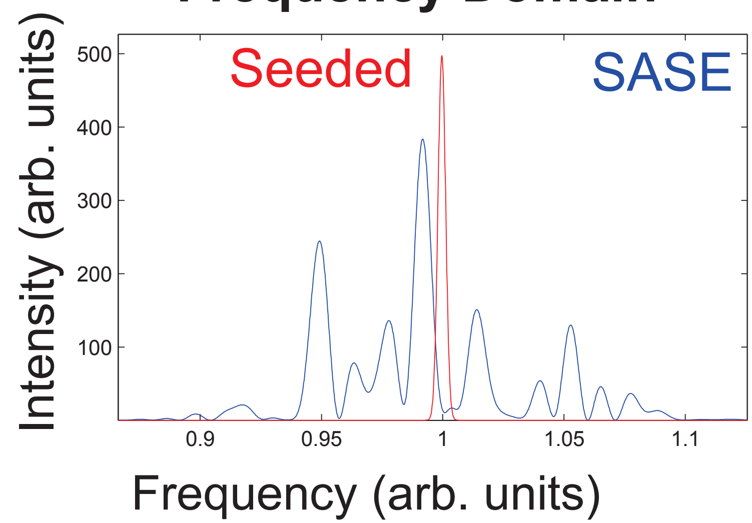

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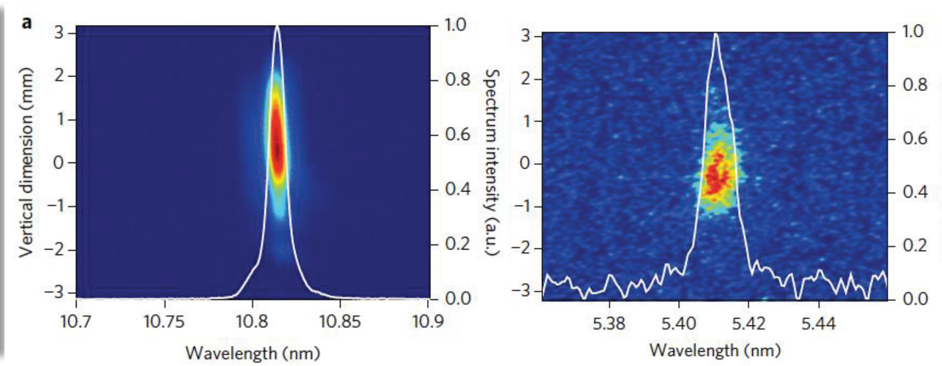

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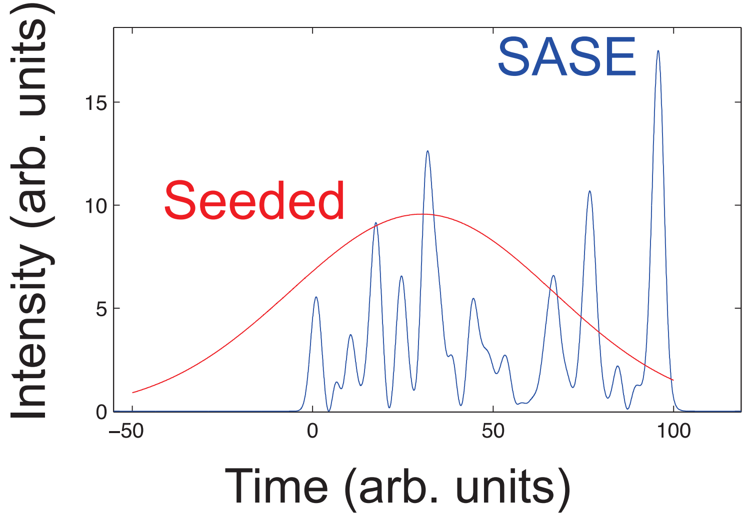

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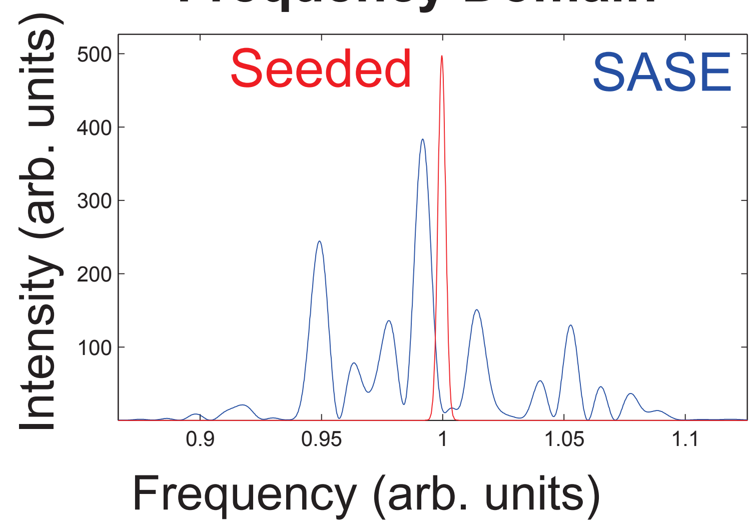

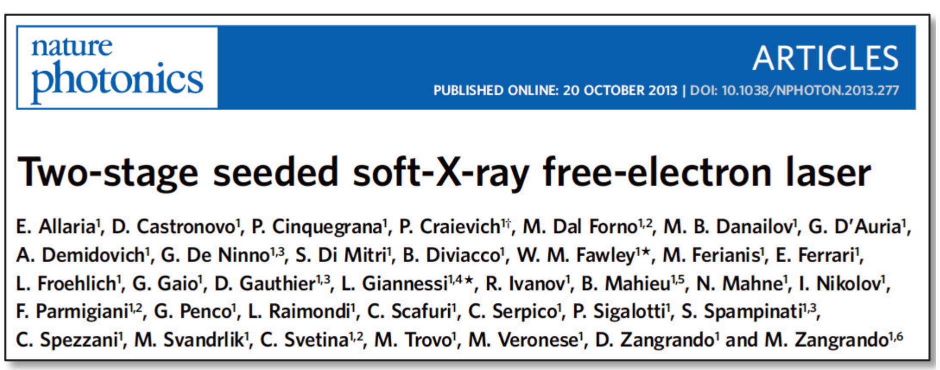

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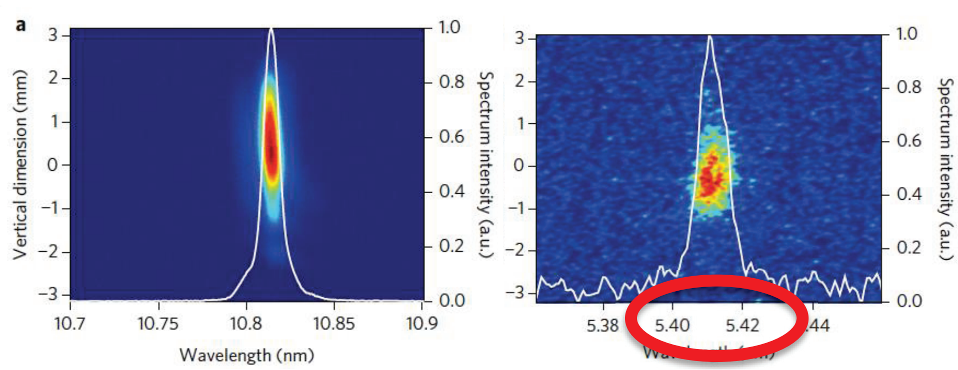

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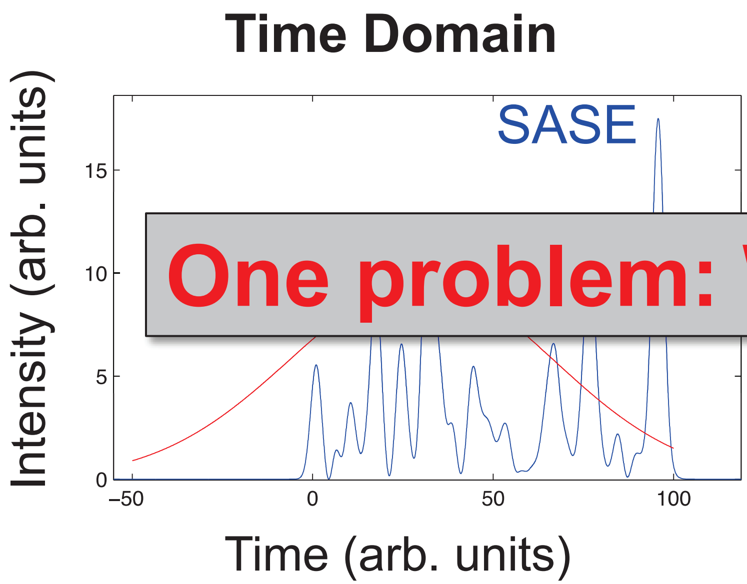

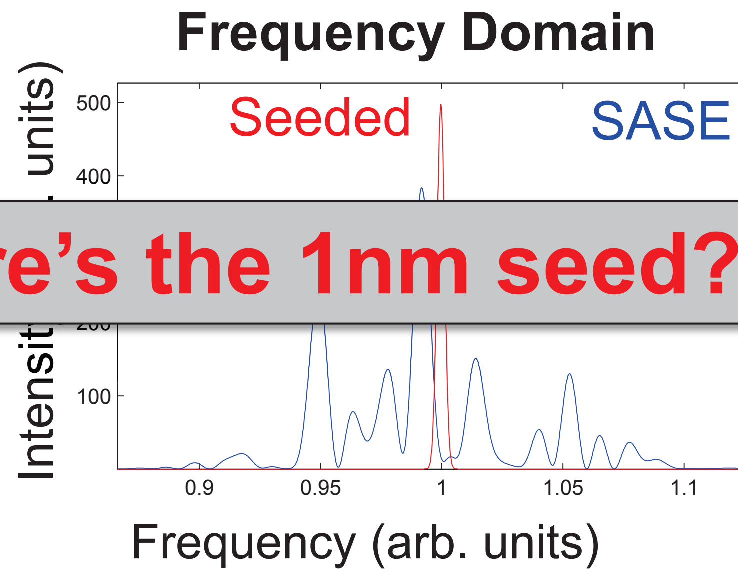

One problem: Where's the 1nm seed?

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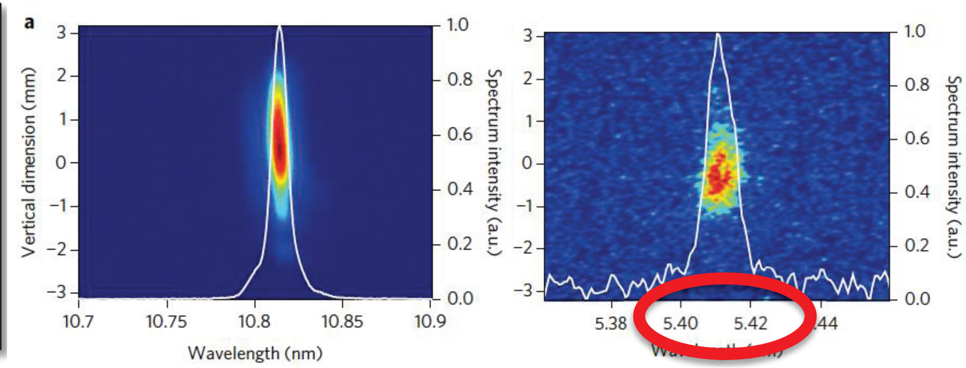

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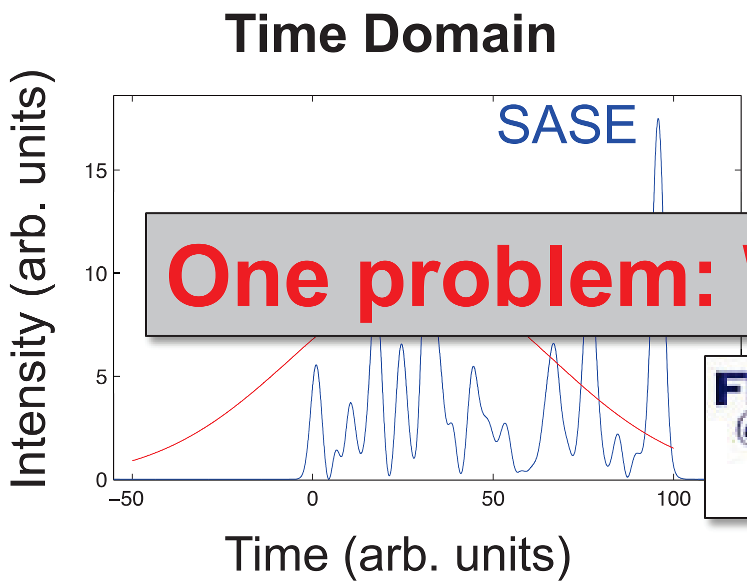
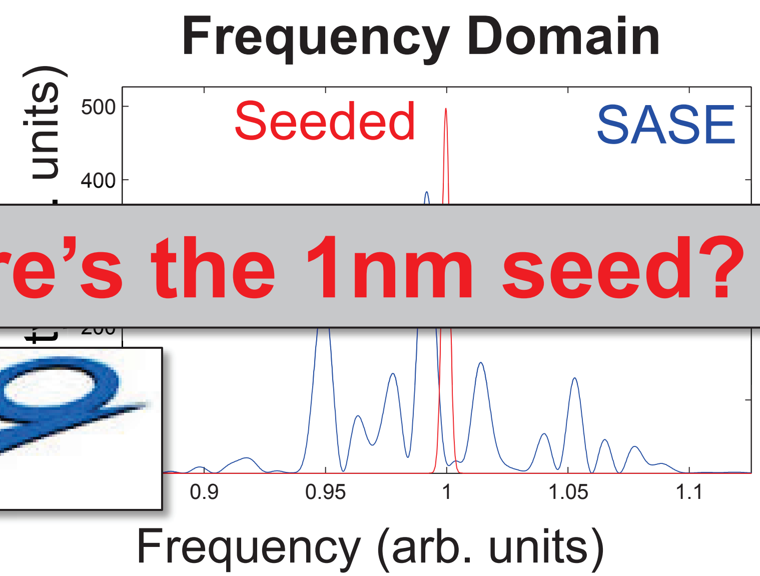
SASE vs. Seeding





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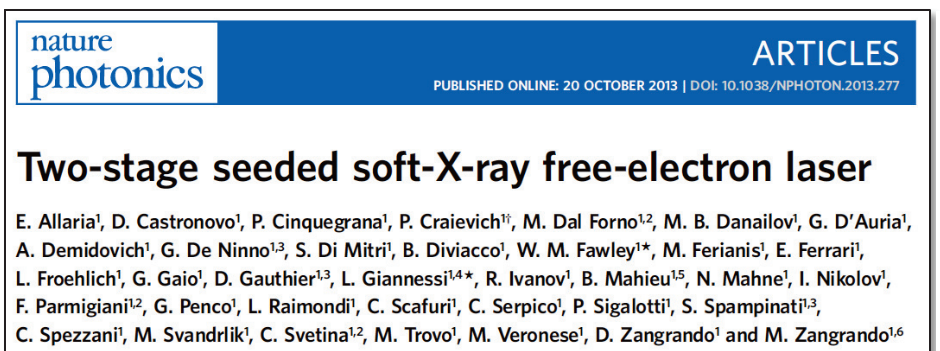
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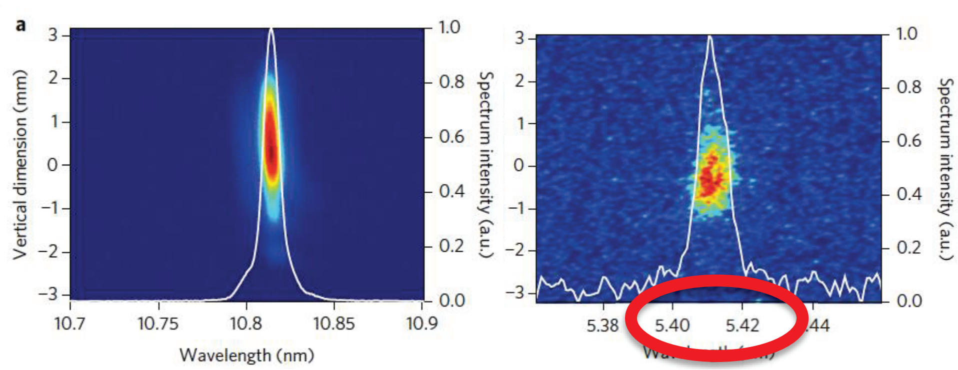

Self-Seeded FEL Concept

Self-Seeding: The FEL seeds itself!

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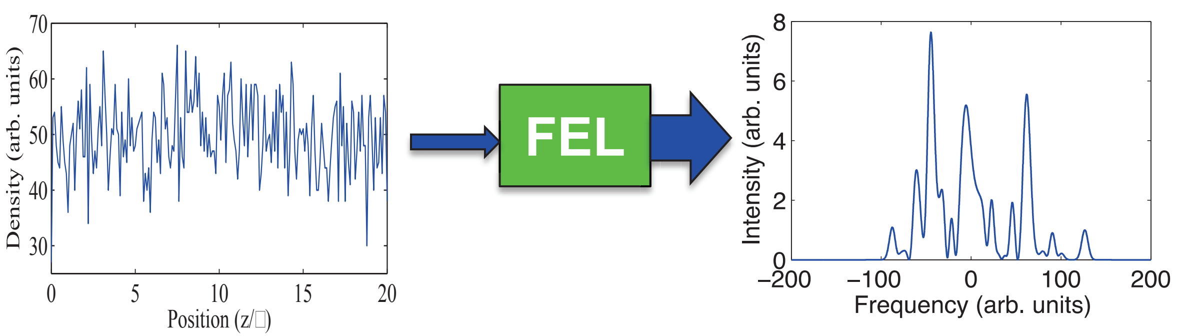

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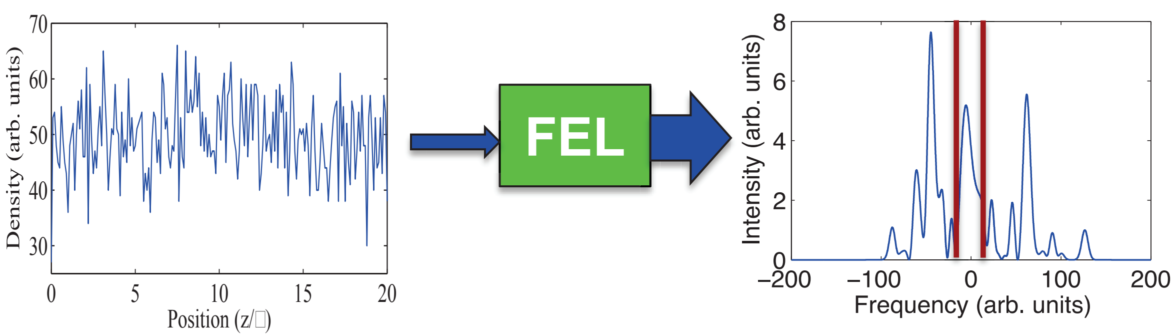
Two components:

a) Monochromator selects narrow-bandwidth seed



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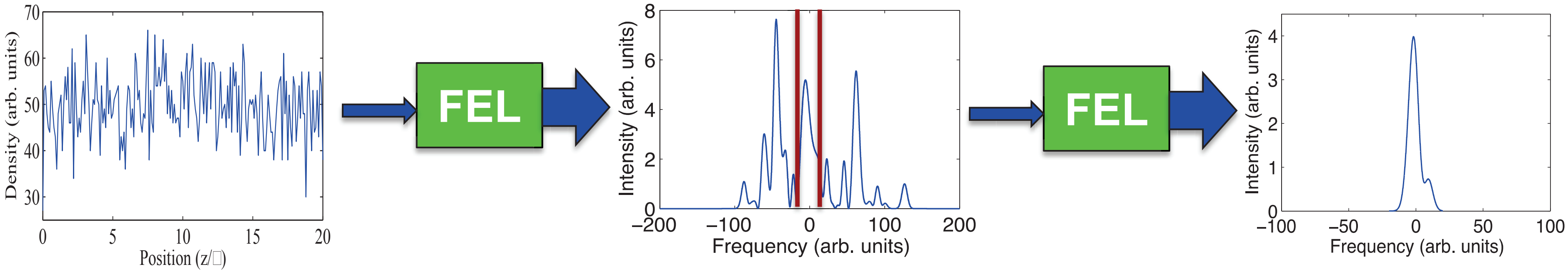

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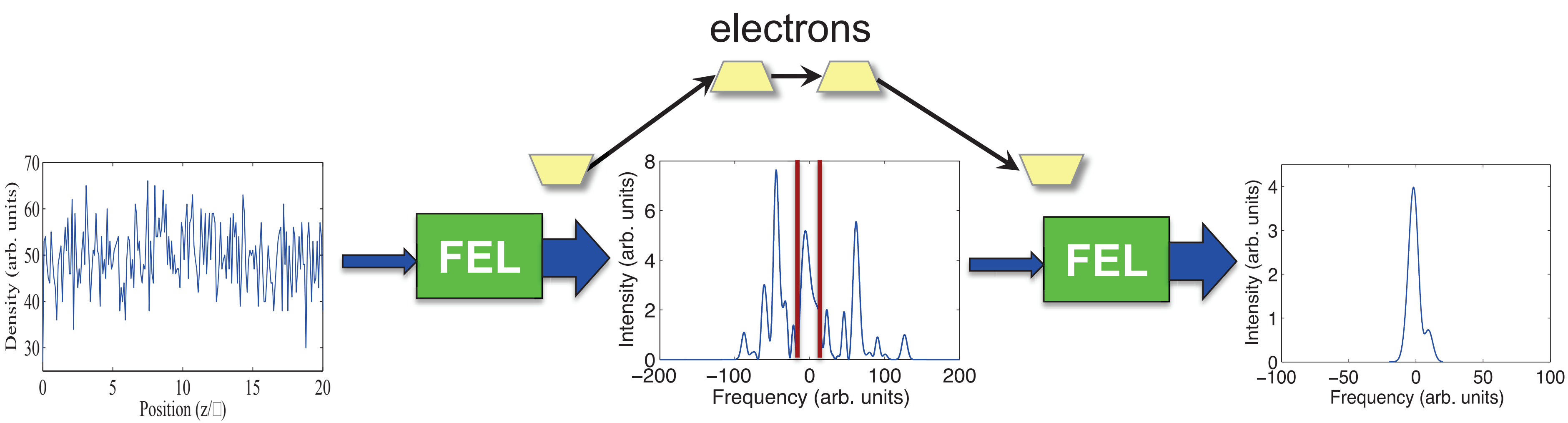
Two components:

a) Monochromator selects narrow-bandwidth seed
b) Chicane resets electron bunch to shot noise, matches delay of x-rays, and steers e- around optics



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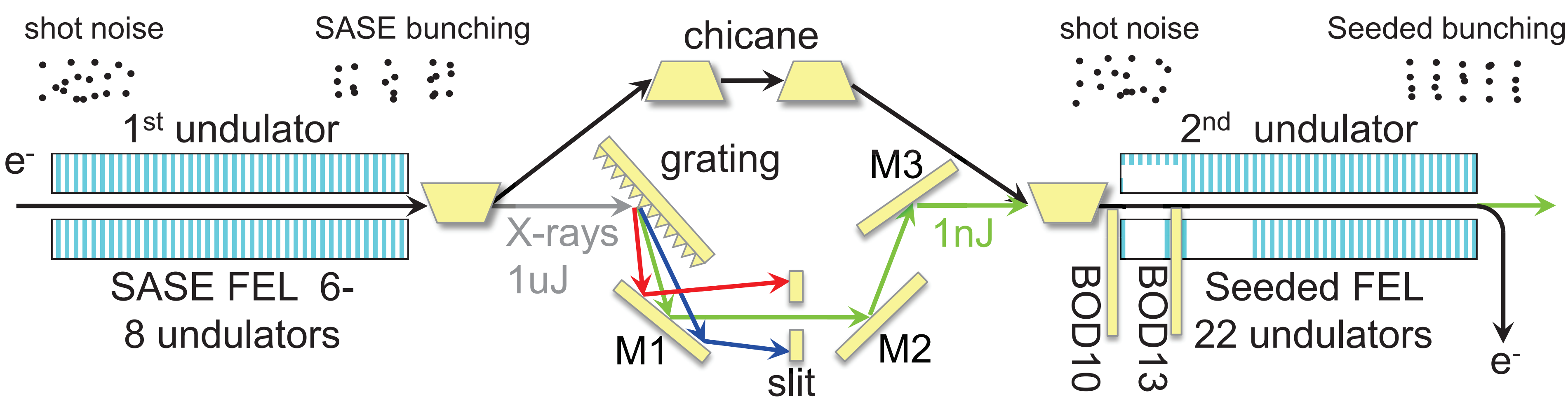
Soft X-ray Self-Seeding Design



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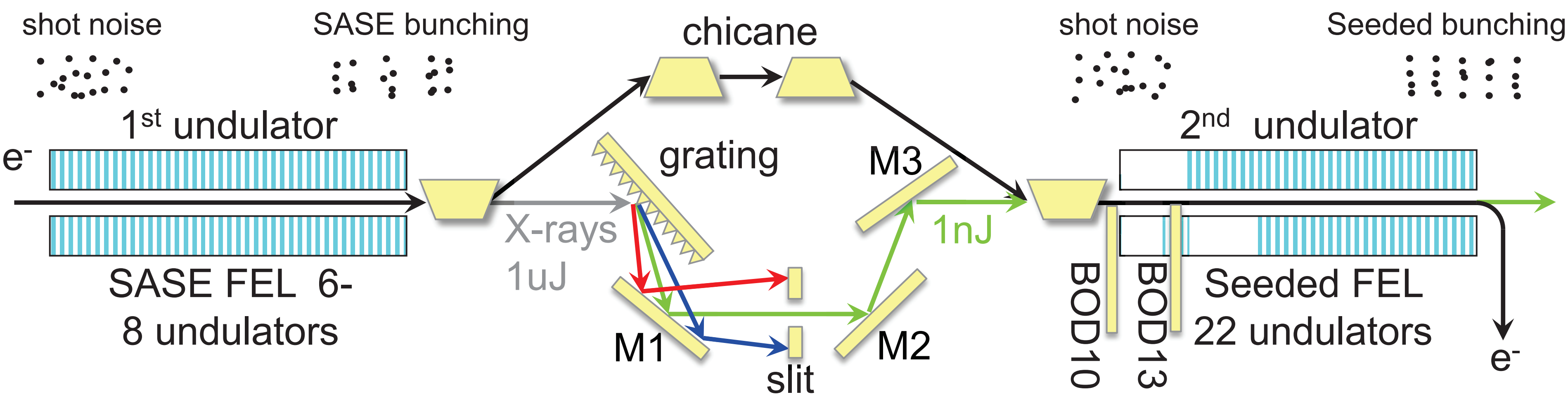

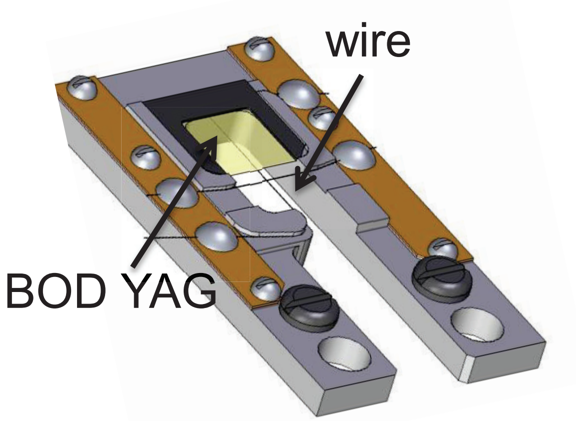

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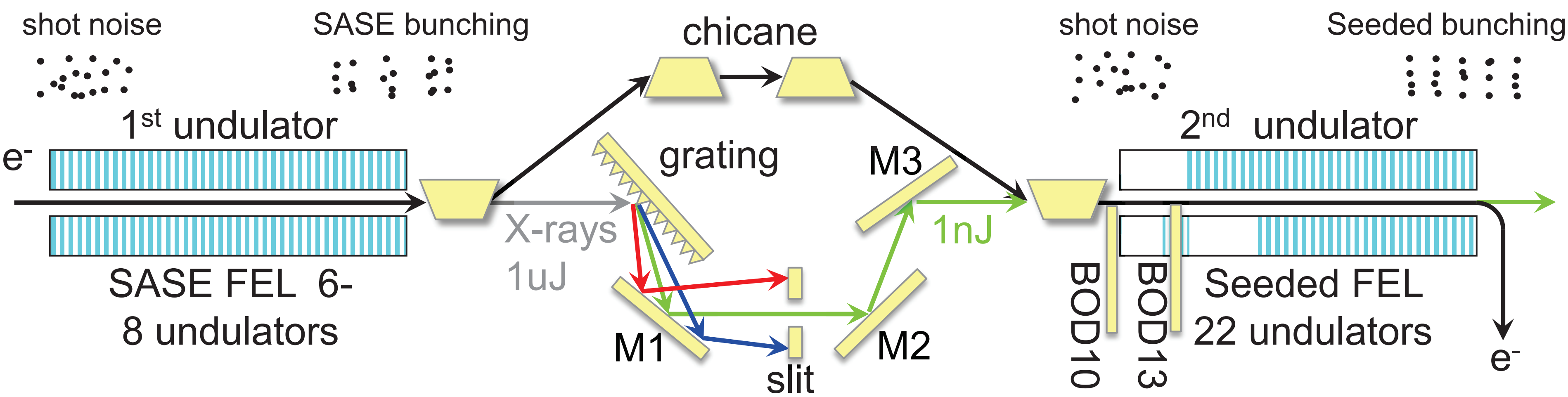

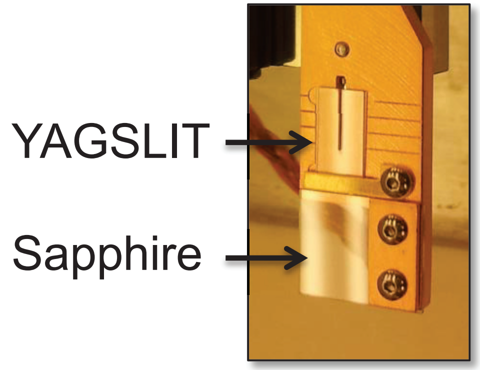

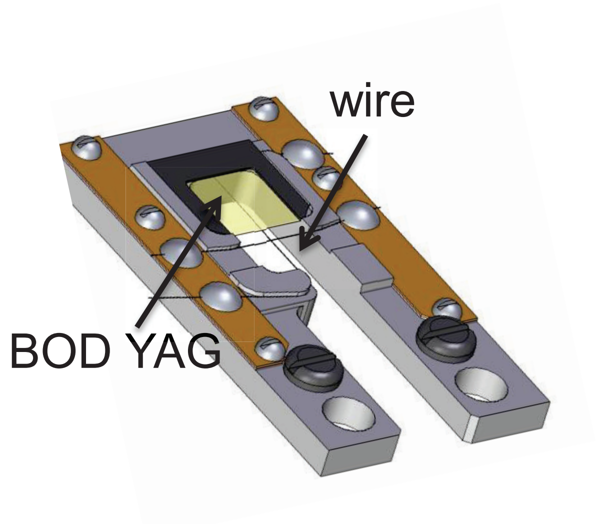

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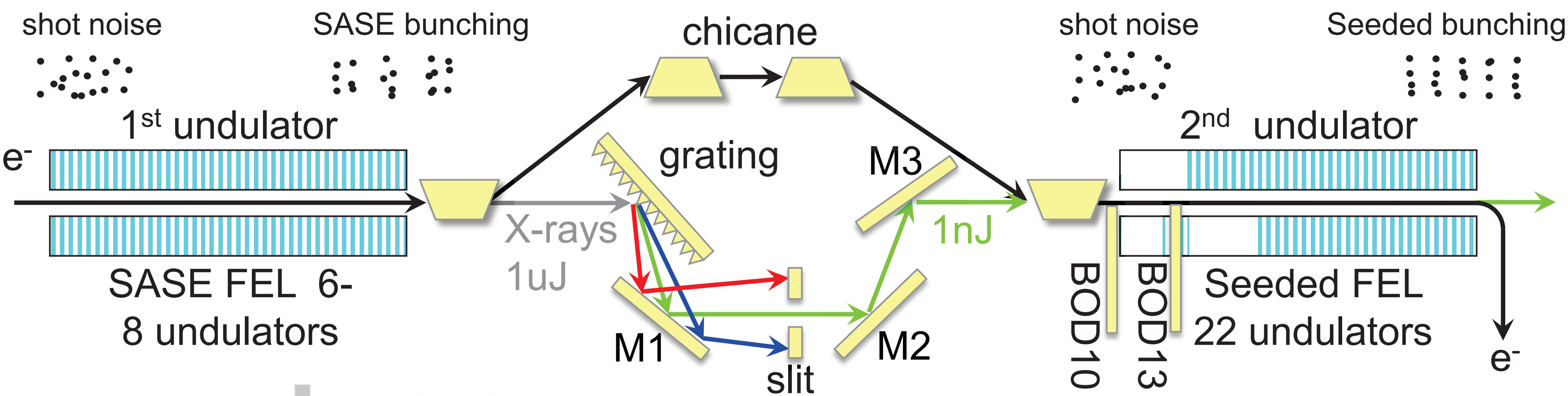

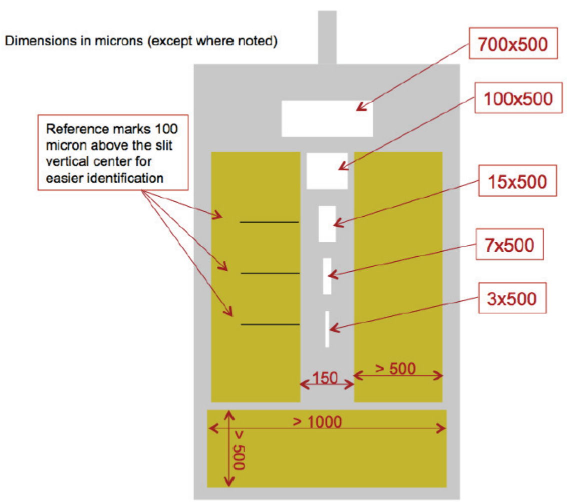

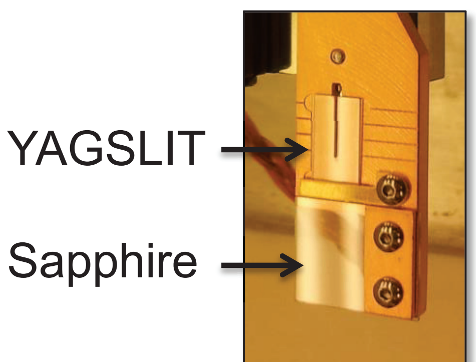

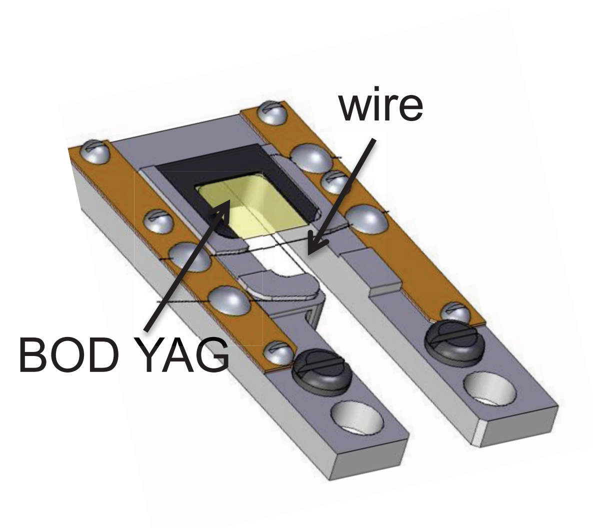

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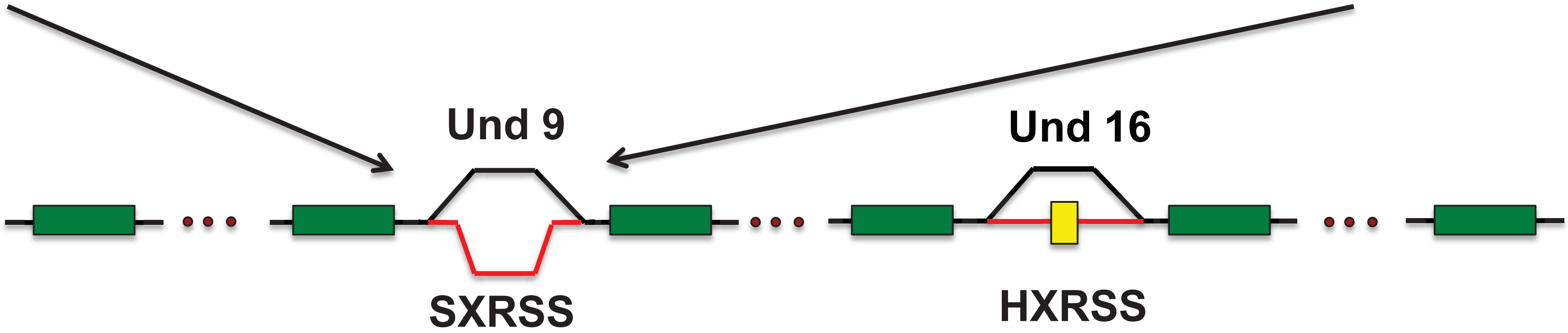
Physics requirements for SXRSS

Physics and Location Constraints for Mono:

1) Provide resolving power greater than or equal to 5000
2) Energy range 500-1000 eV
3) Fit mono in 4m space (single undulator)
4) X-rays delayed less than 1 ps (to fit chicane)



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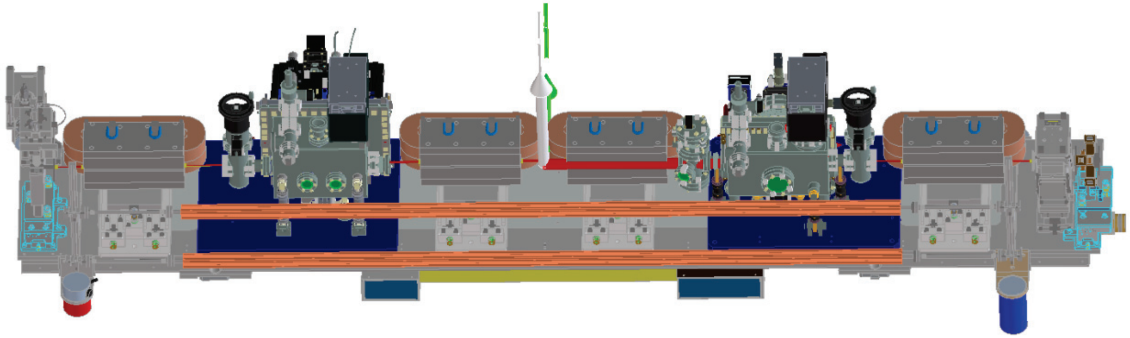
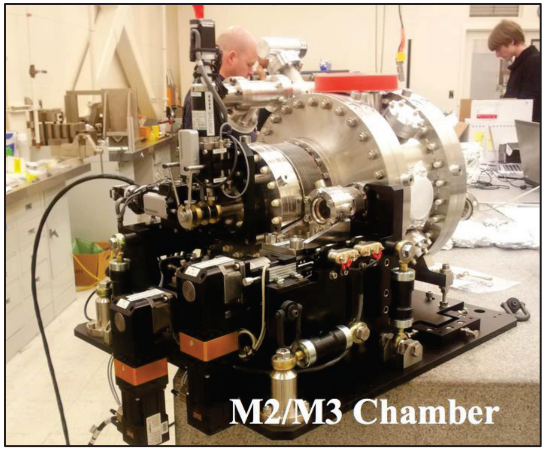
Physics requirements for SXRSS

Engineering Challenges

1. 3 optics chambers, 2 diagnostic chambers, 9 motors
2. Tight machine, alignment, and motion constraints
3. 'Challenging' schedule



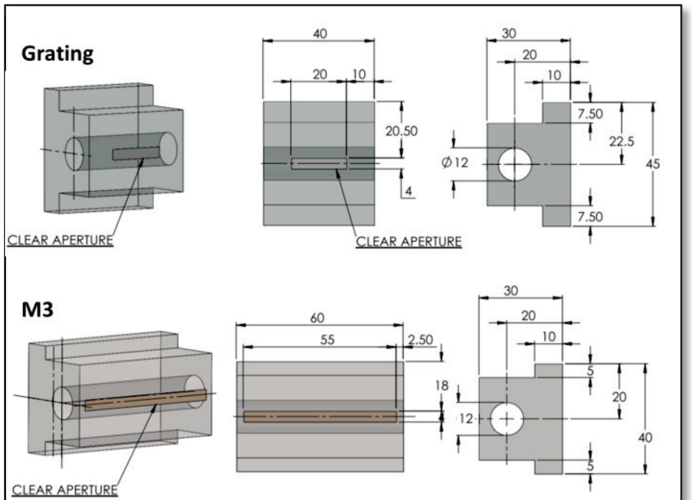


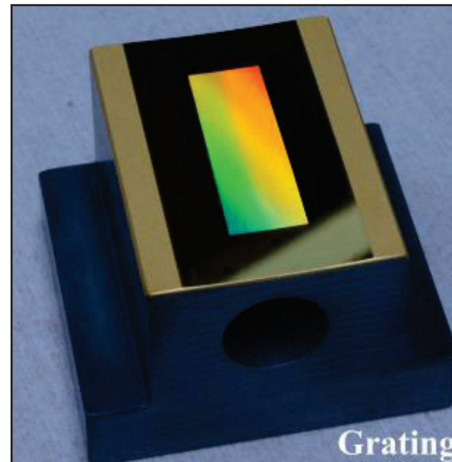
Big thanks to N. Rodes, K. Chow, P. Montanez and the machine, tech, and alignment teams that made this possible

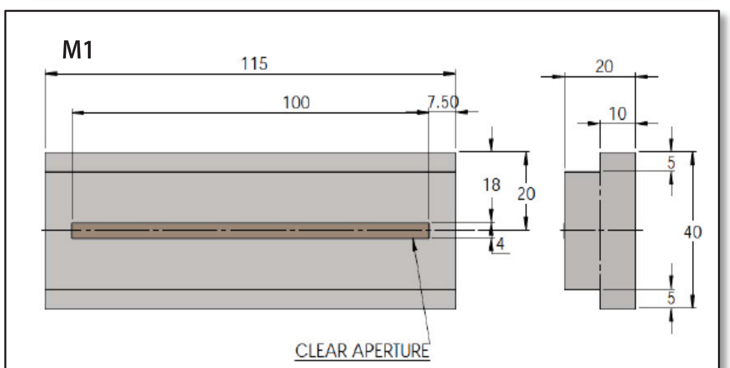
Optics design for SXRSS

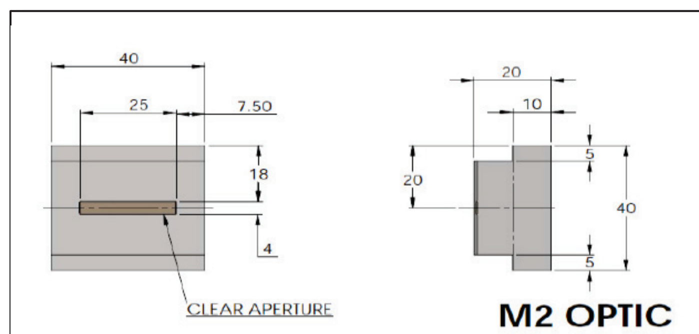
SLAC

Optics designed by PSI, manufactured in Germany



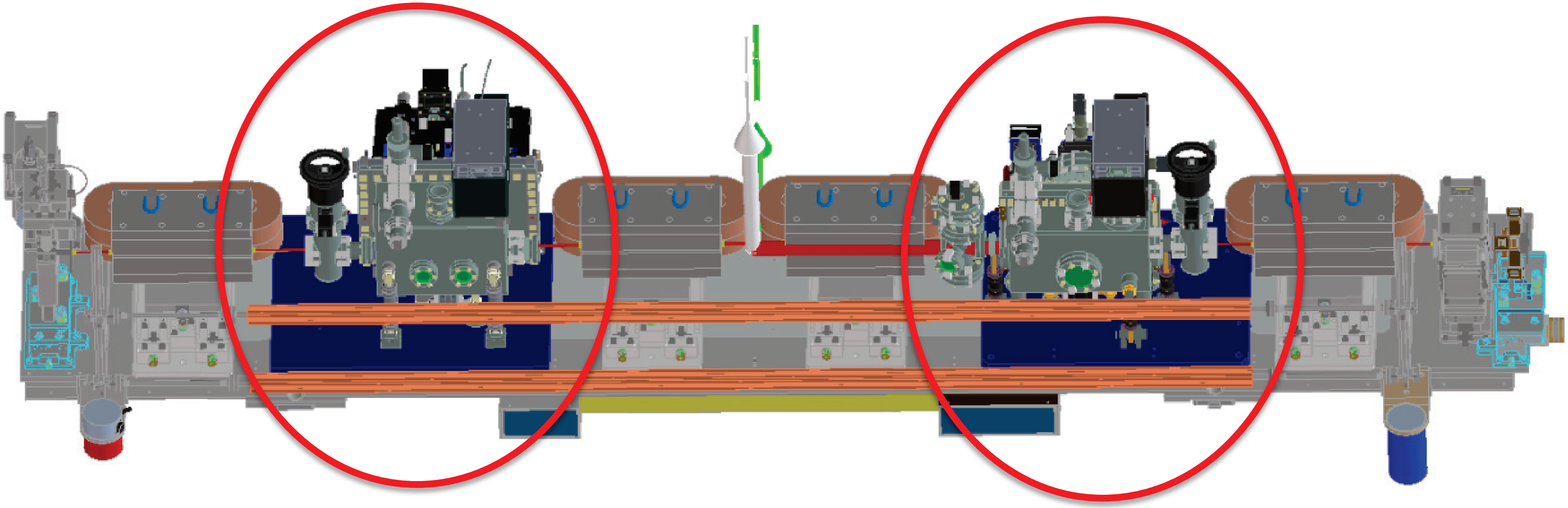






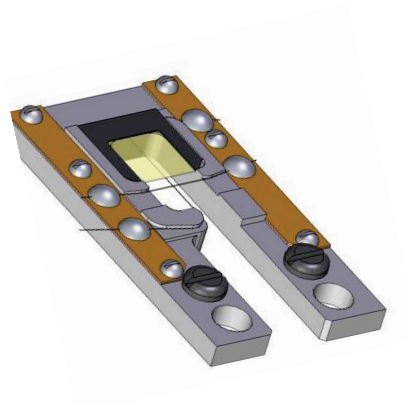
Mechanical design for SXRSS

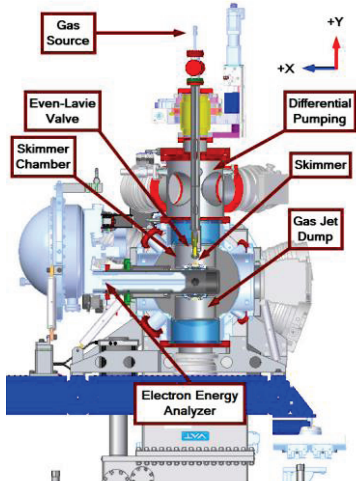
Optics chambers designed by LBNL

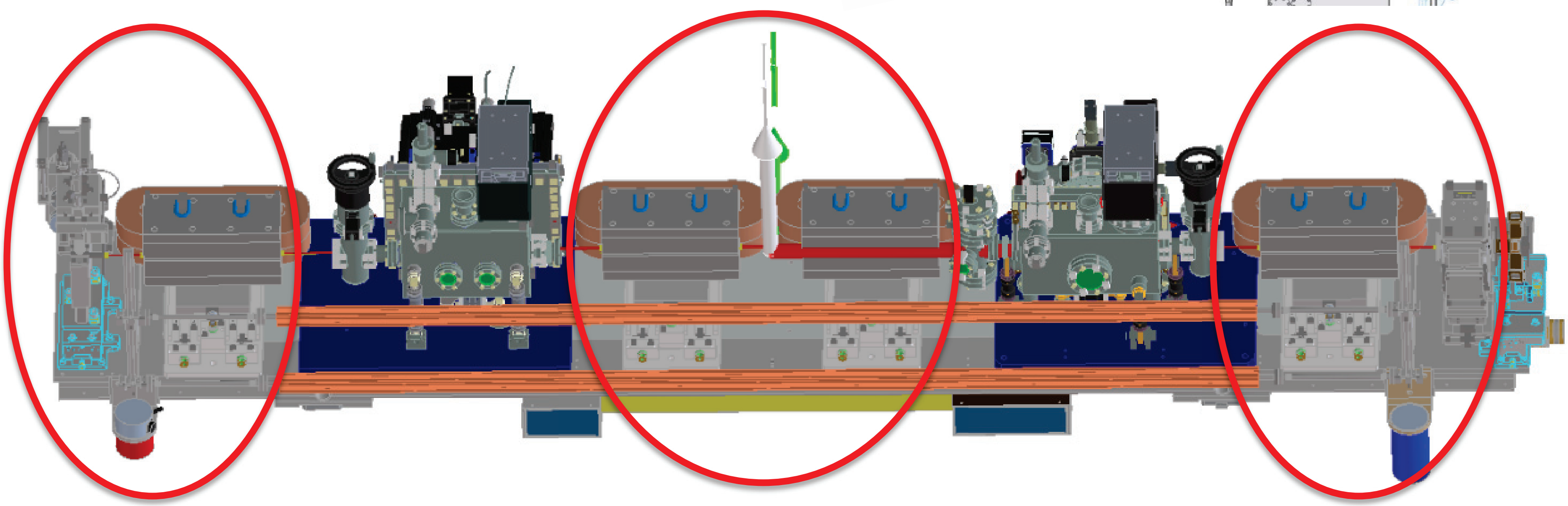


Mechanical design for SXRSS

Chicane and beam overlap designed at SLAC



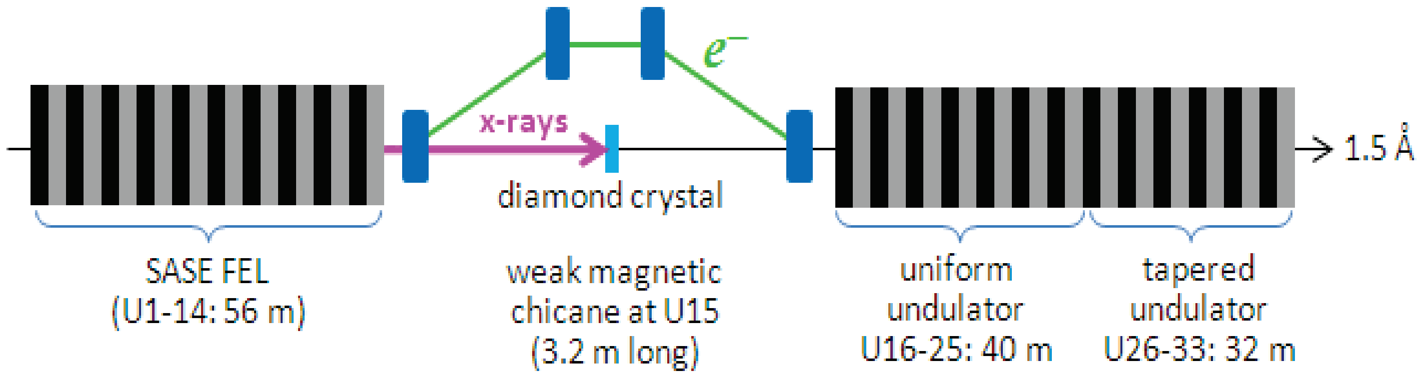




Commissioning

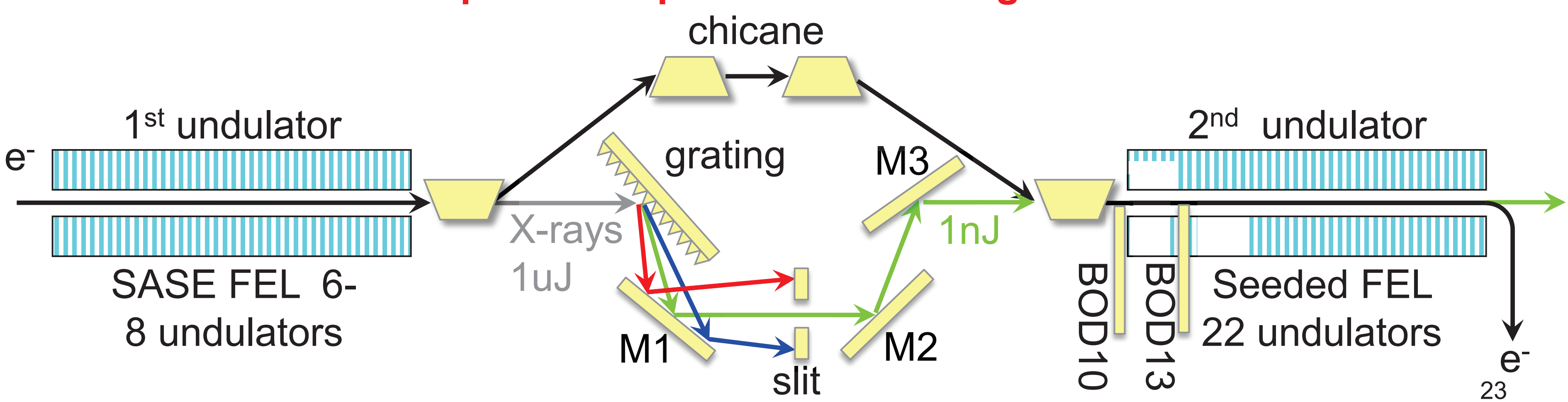
HXRSS

1 optical component



SXRSS

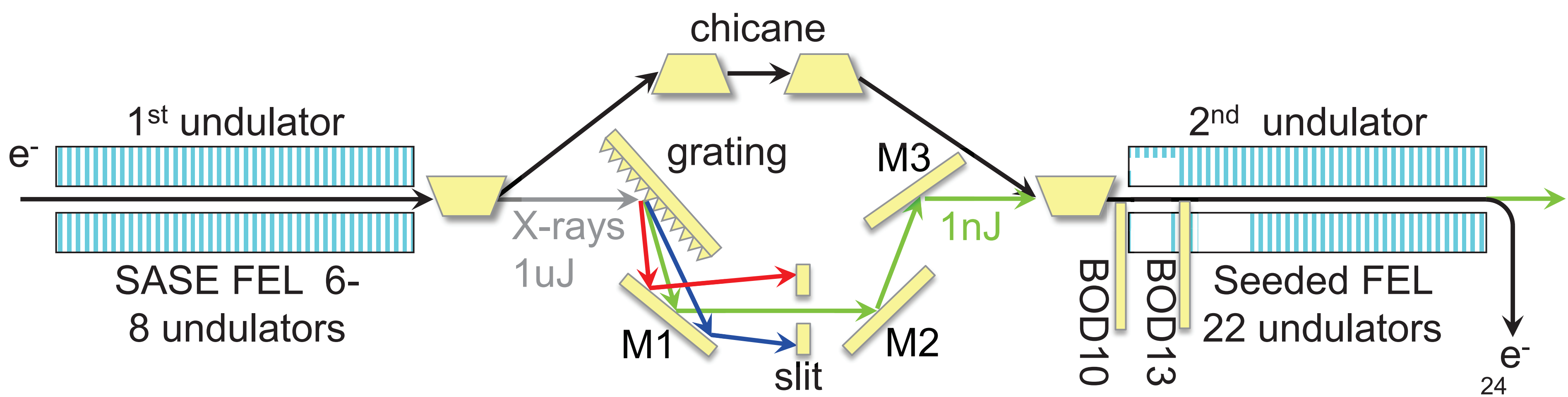
5 optical components and 2 diagnostics



SLAC

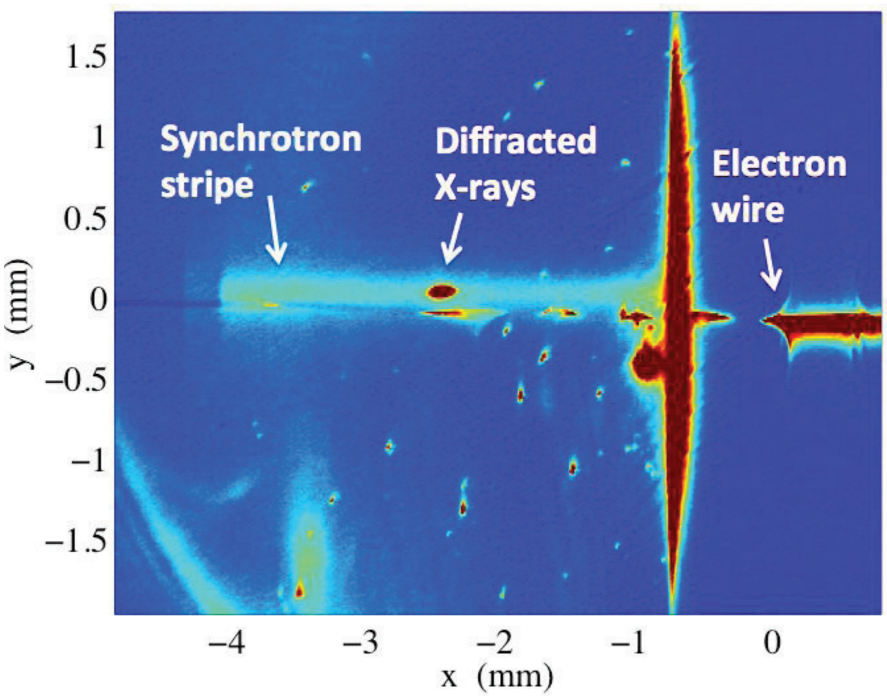
Commissioning Challenges

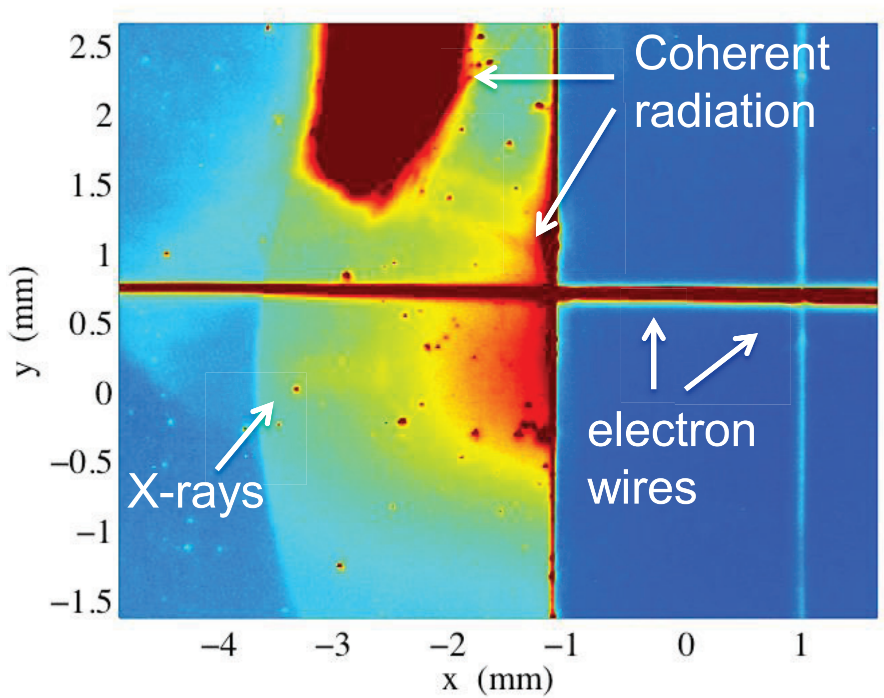
1. Setup SASE FEL in first section (not too much, not too little)
2. Track X-rays through the 5-component Monochromator
3. Measure positions of both electrons and X-rays
4. Overlap X-rays and electrons transversely
5. Overlap X-rays and electrons temporally



Commissioning Challenges

Coherent radiation an obstacle for overlap diagnostics

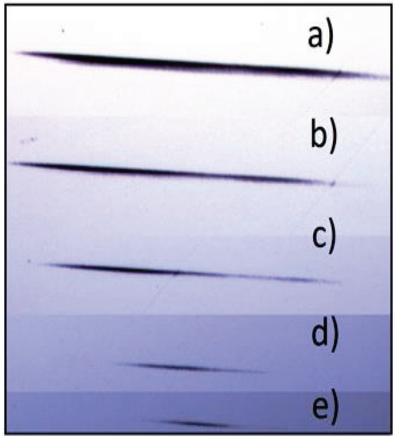




Damage concerns

Compromise between need to seed, and damage threshold

To much pulse energy destroys grating



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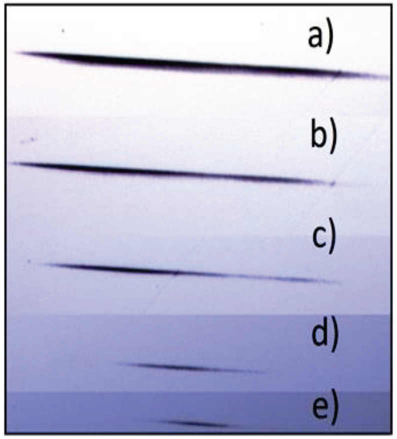

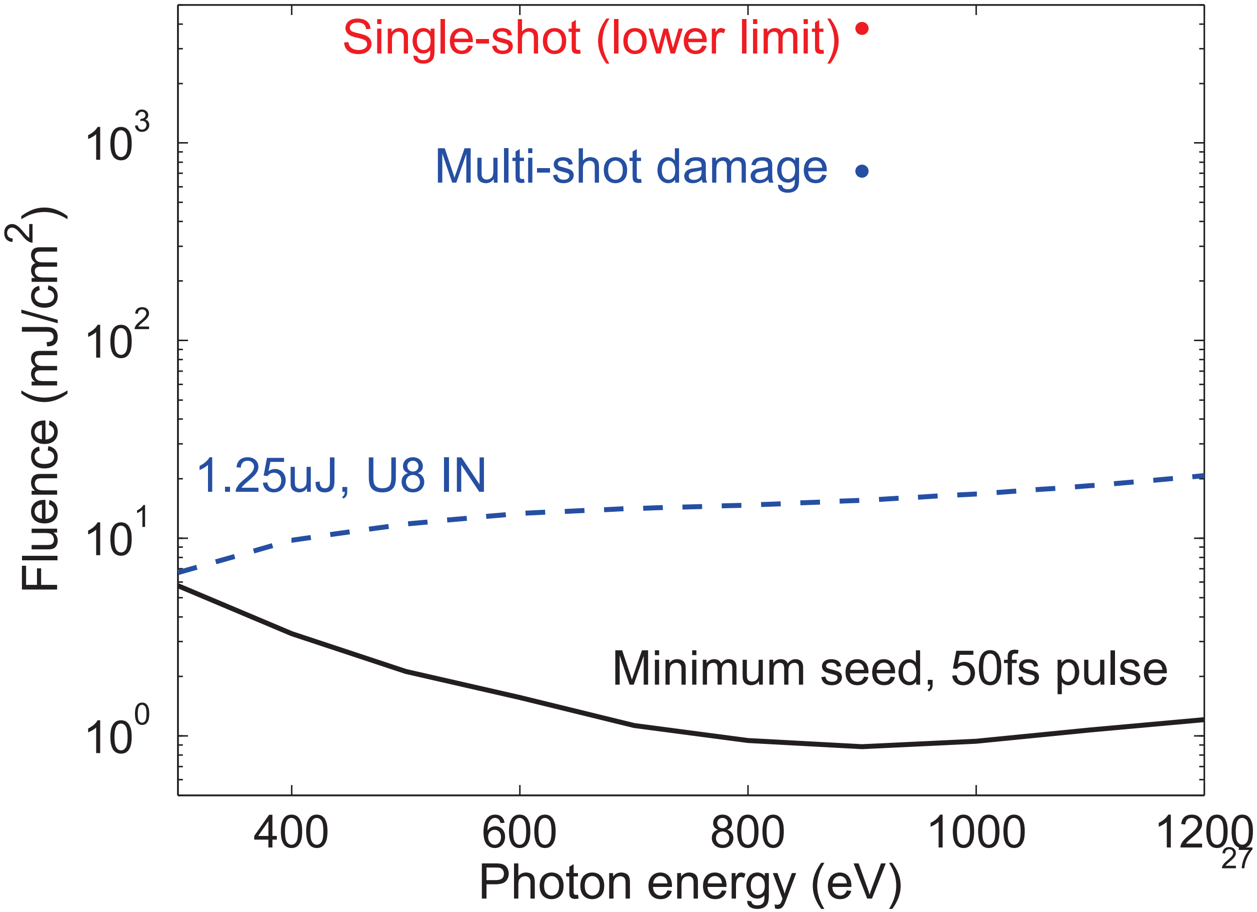

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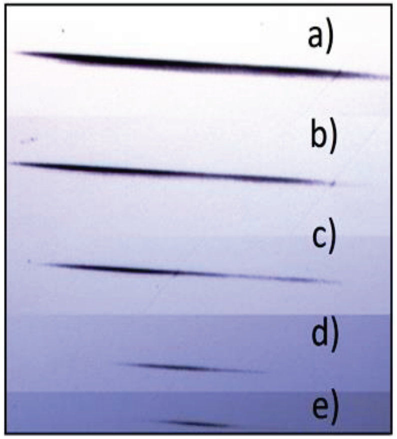
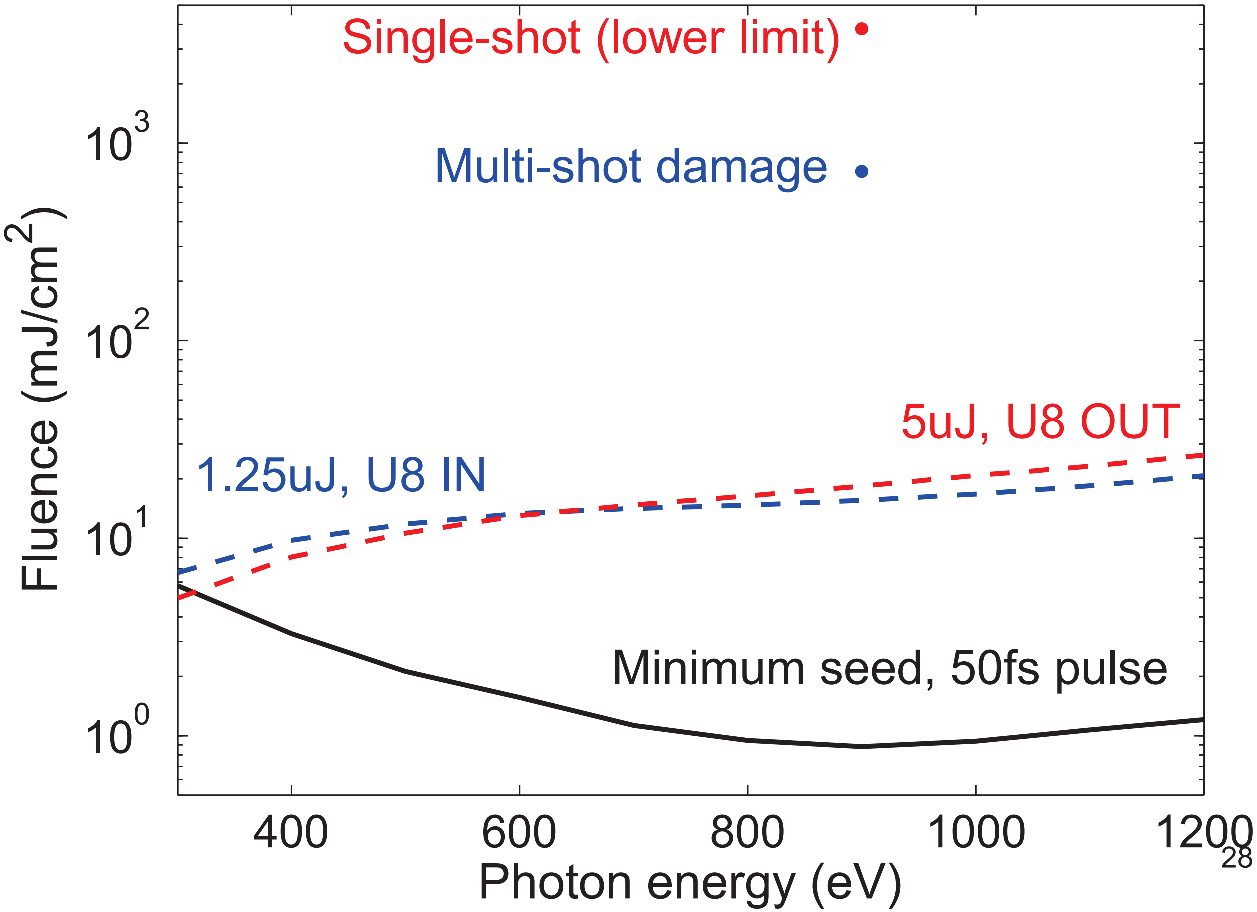
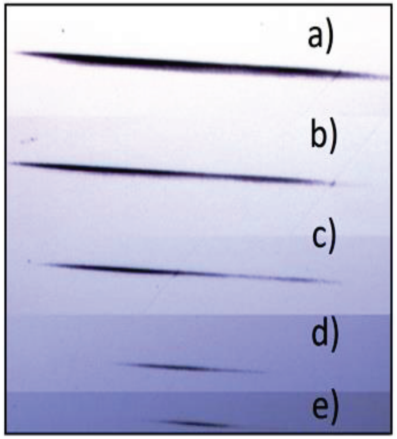


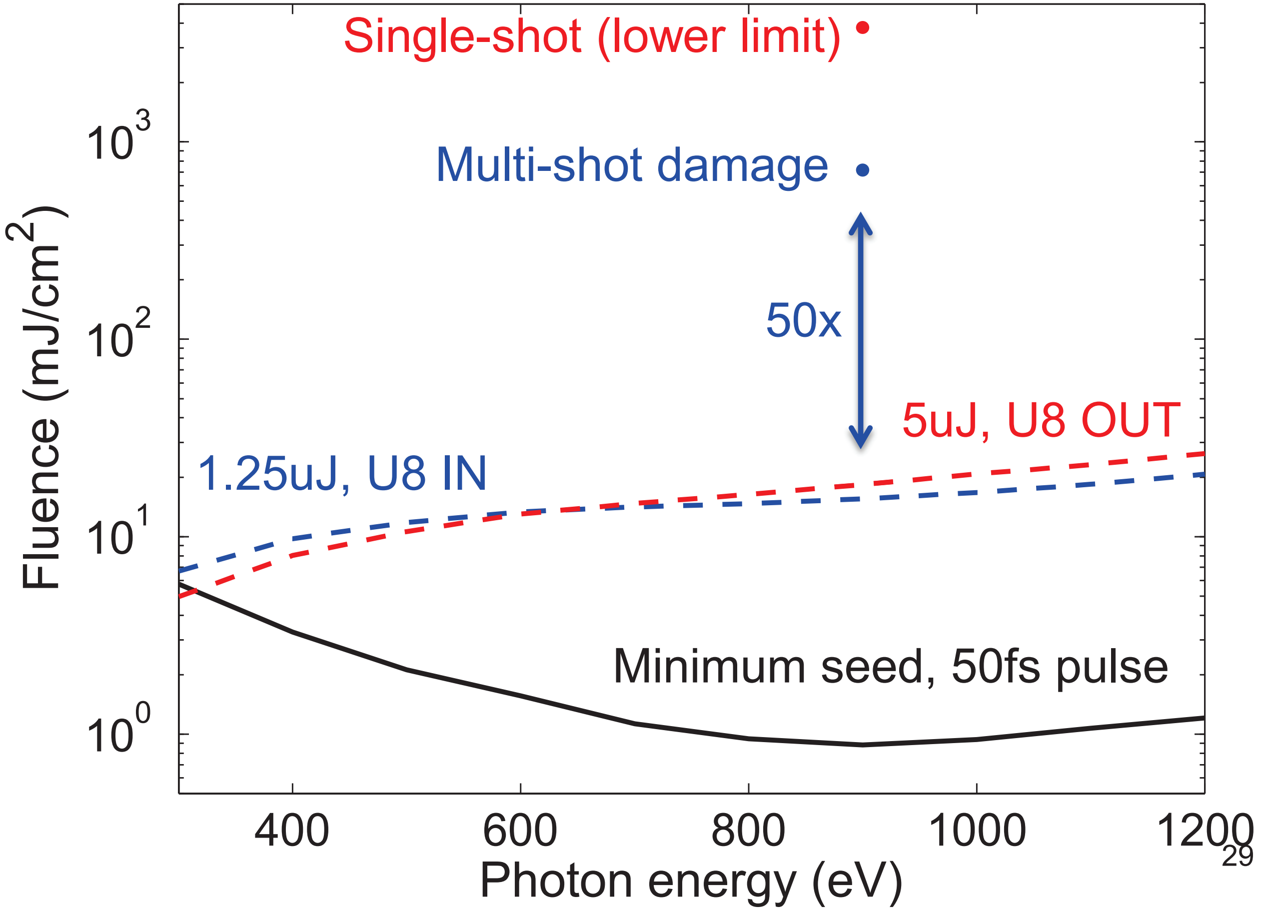


Damage concerns

Compromise between need to seed, and damage threshold

To much pulse energy destroys grating



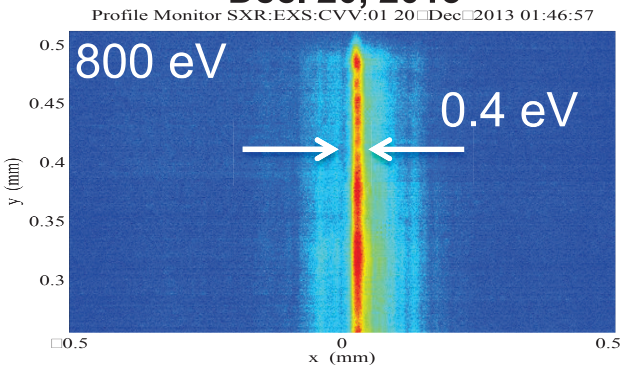


Commissioning

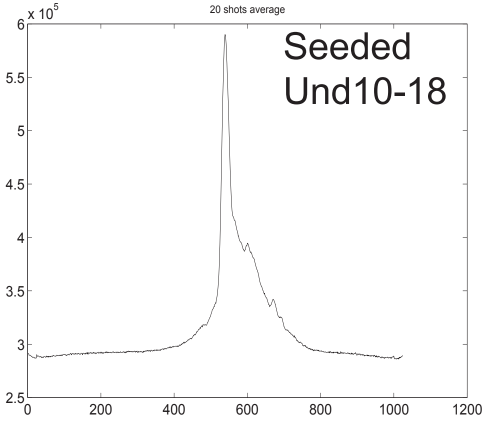
First seeding!

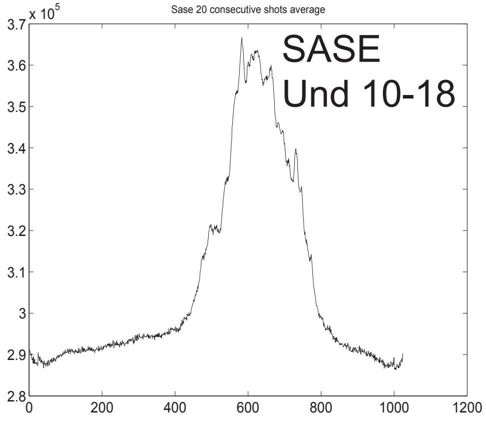
SXR spectrometer, 800 eV (resolution limited)

Dec. 20, 2013



Bandwidth (arb. units)



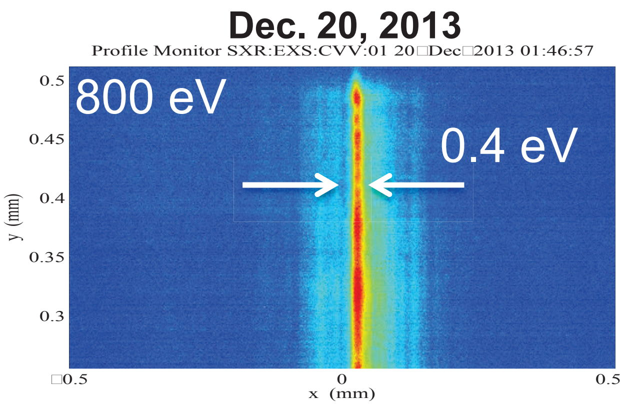


Commissioning

SLAC

First seeding!

SXR spectrometer, 800 eV (resolution limited)



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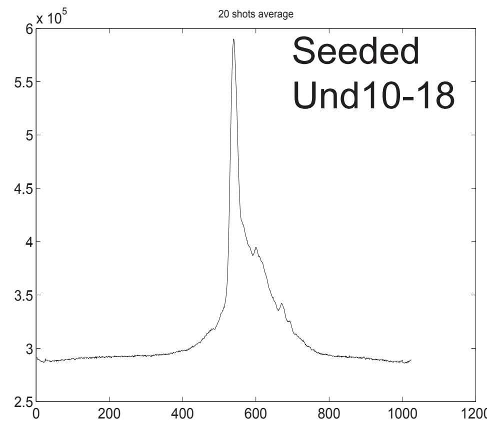
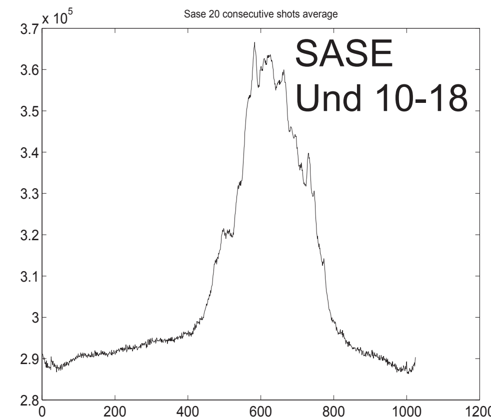
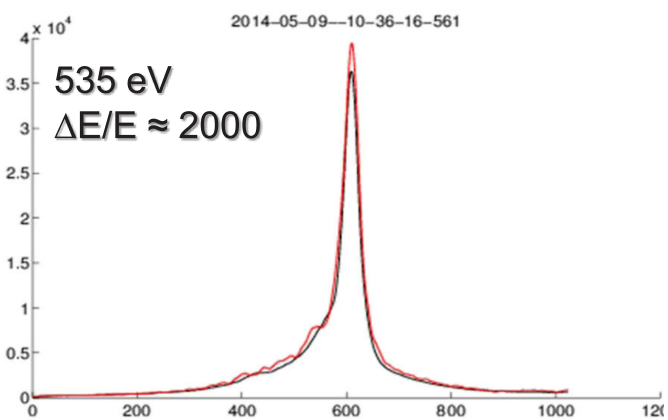
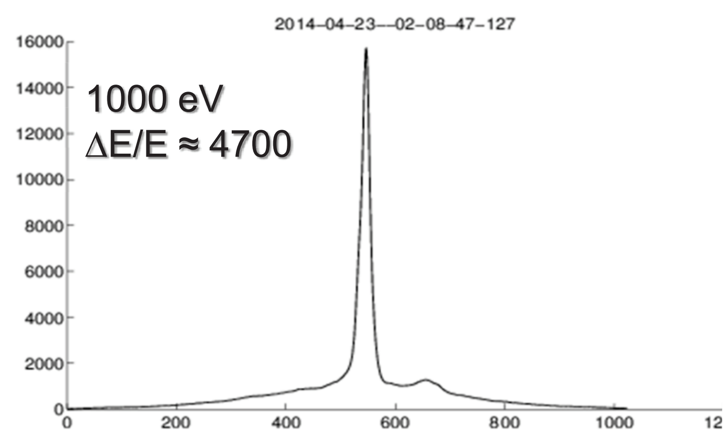


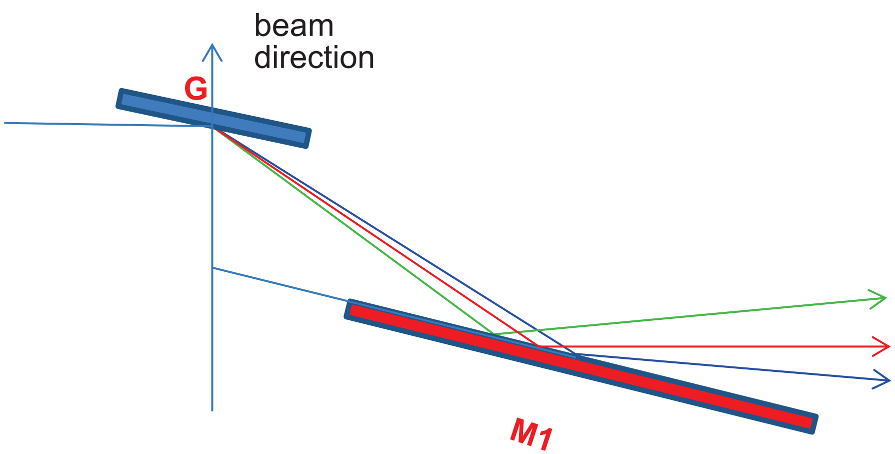


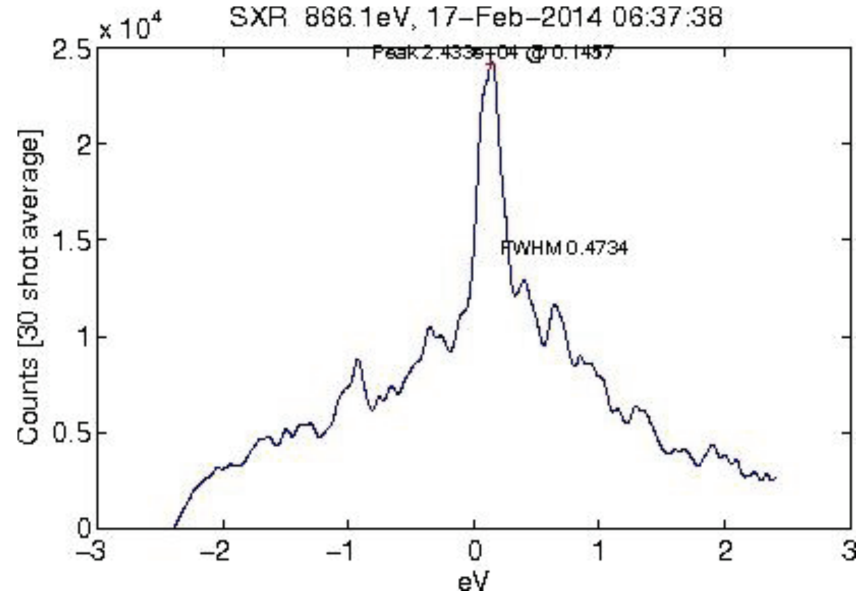


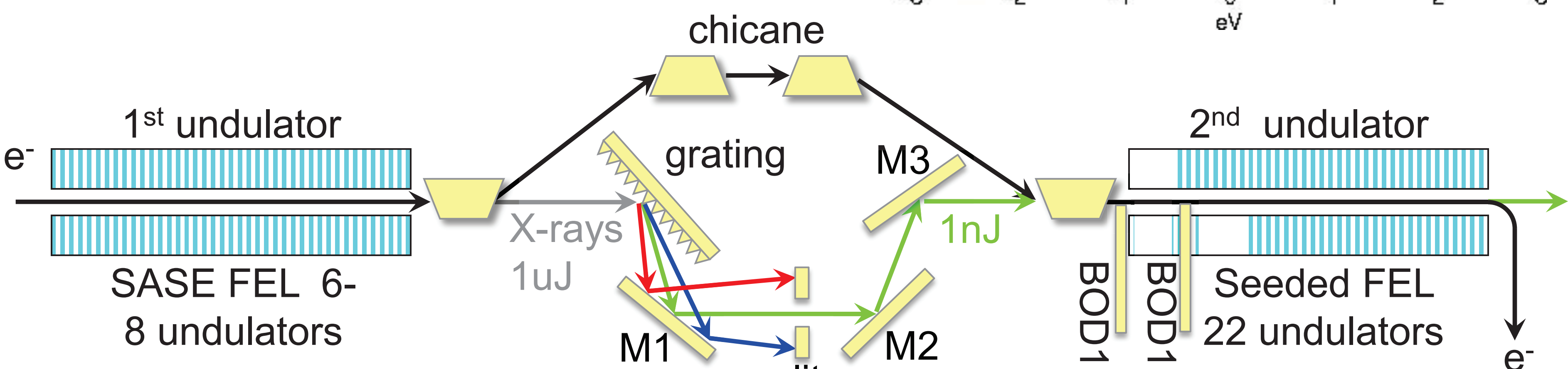


Commissioning

Seeding with 2nd order diffraction







Commissioning

SLAC

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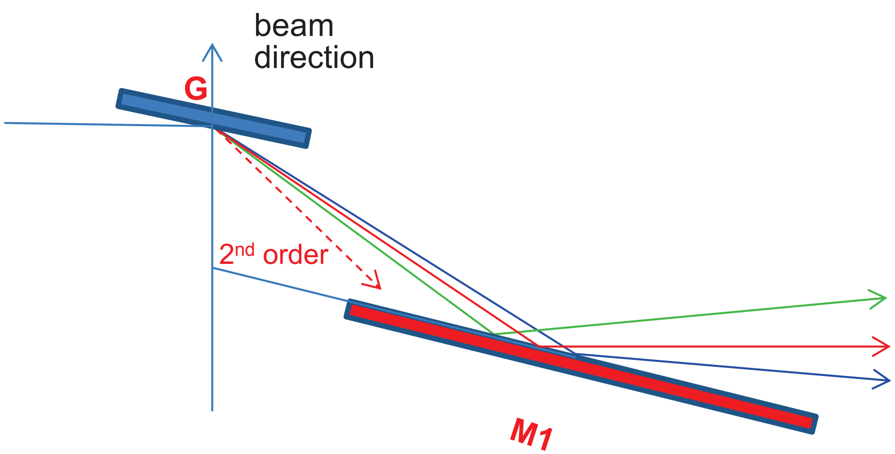

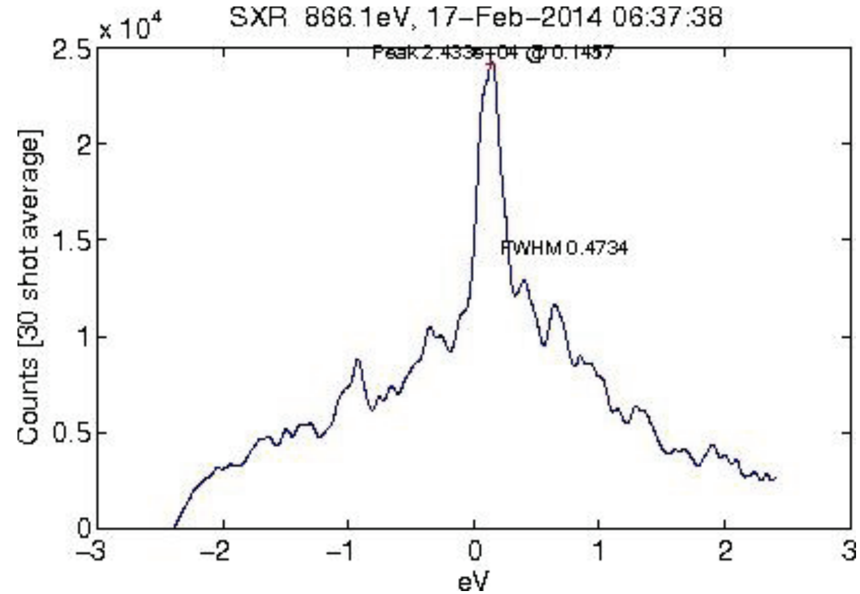

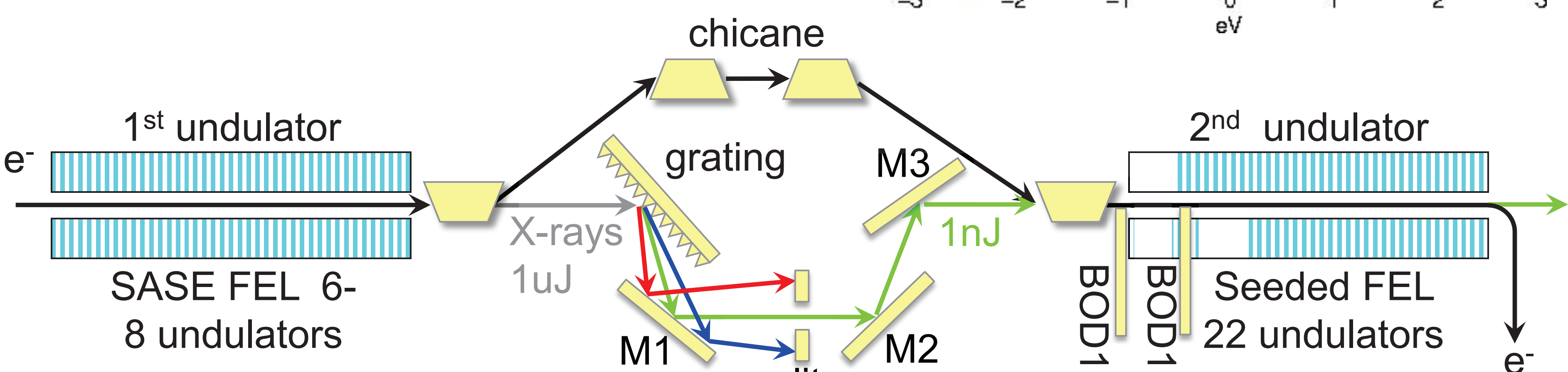

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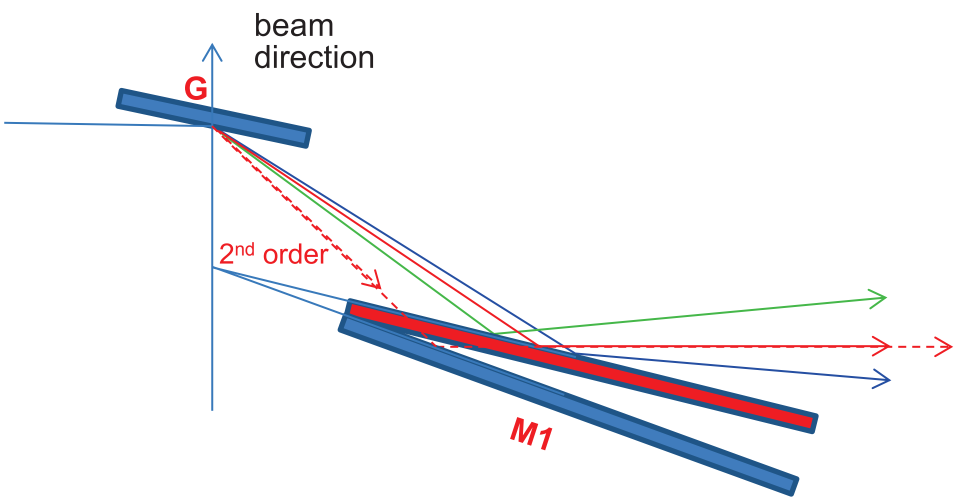
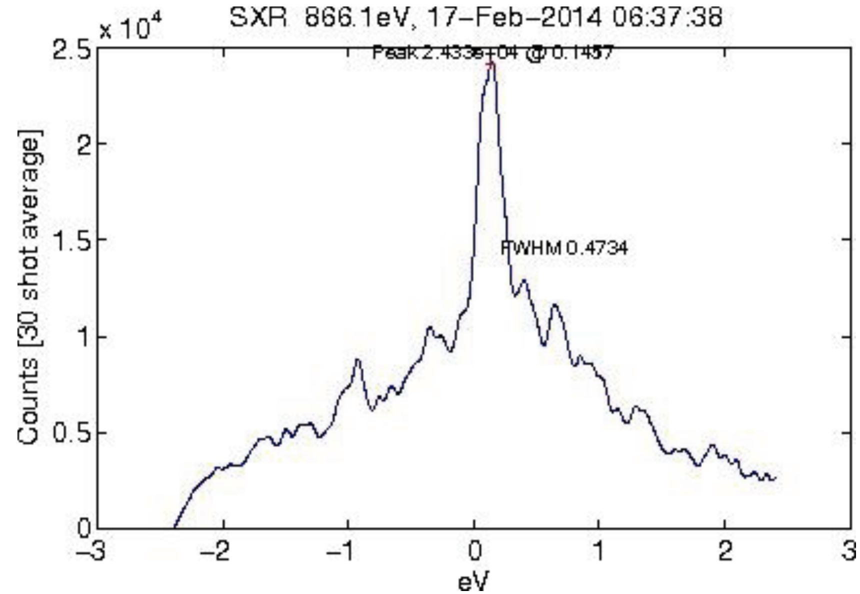
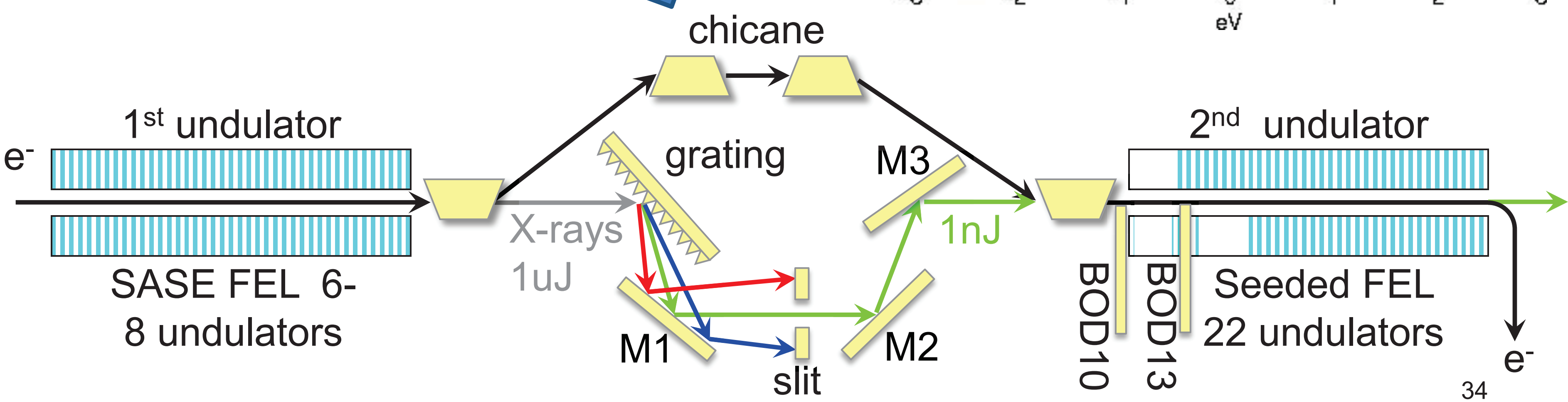






SXRSS Limitations

Why isn't everything perfect?

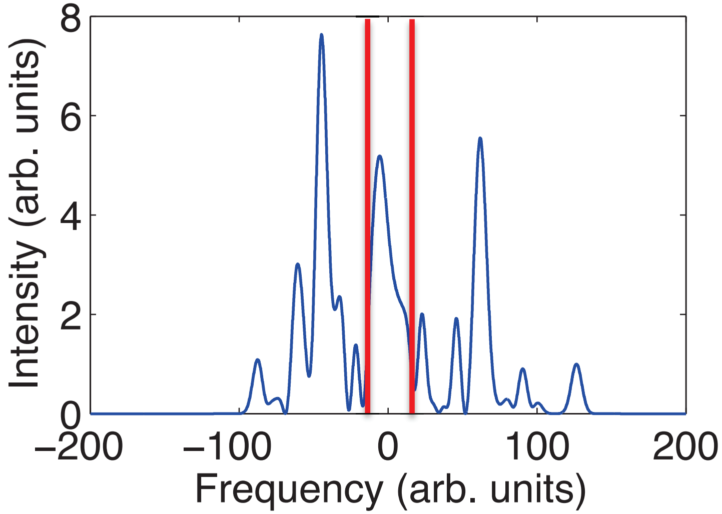
It's all the accelerator's fault:

a) Fundamental SASE jitter
b) Electron energy jitter
c) Electron orbit jitter
d) Nonlinear phase space of electron bunch
e) Jitter of electron bunch phase space

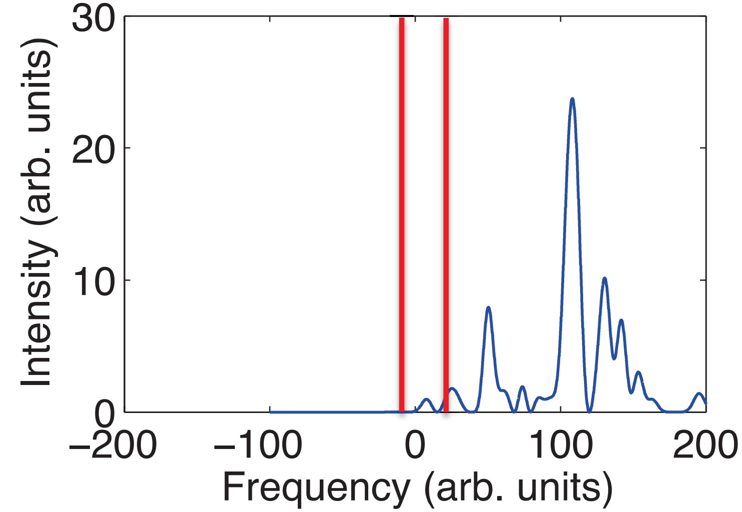
SXRSS Limitations

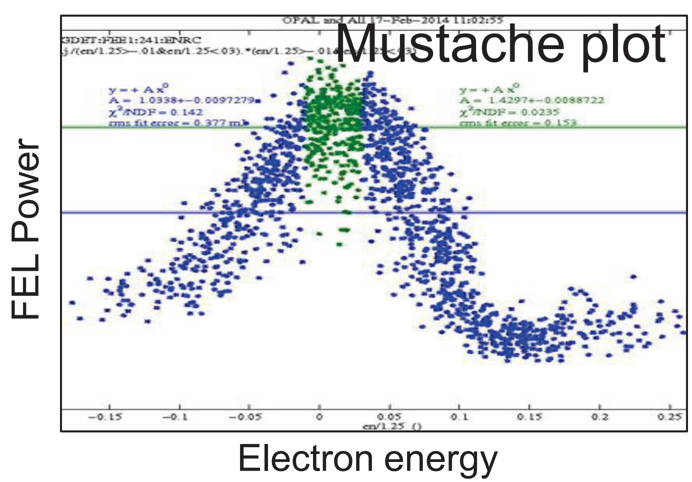
Jitter Issues

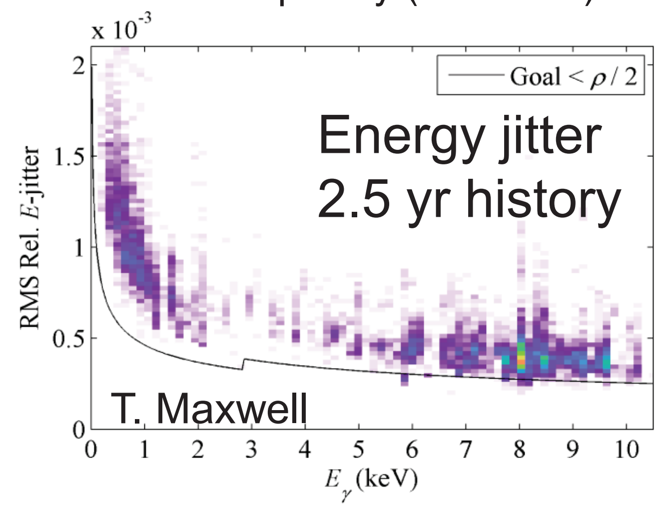
SASE Jitter



Electron Energy Jitter

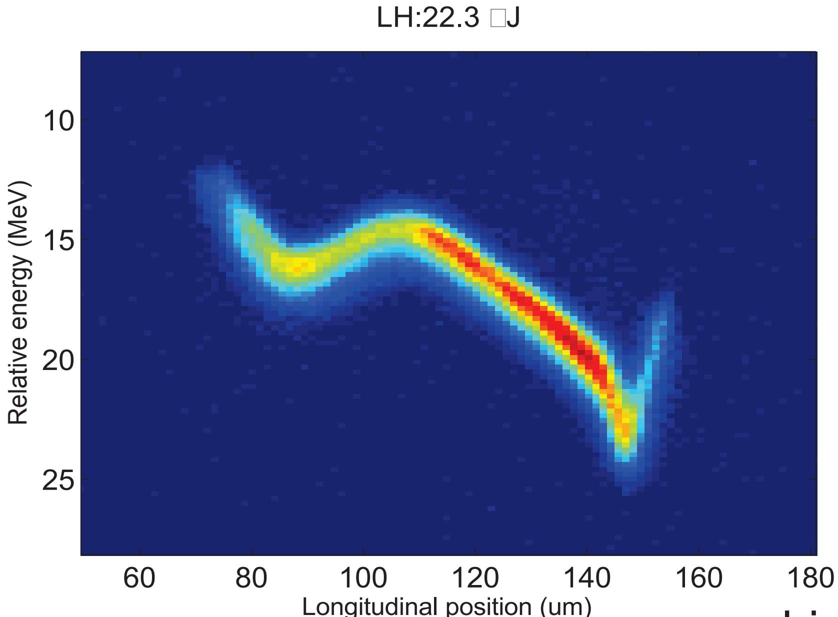


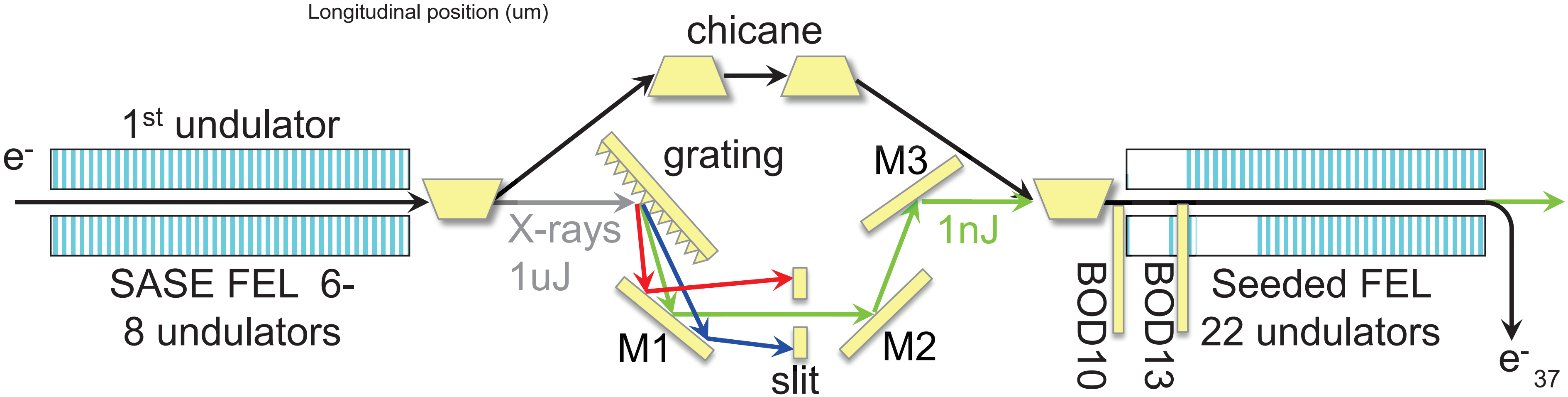




SXRSS Limitations

Electron Phase Space

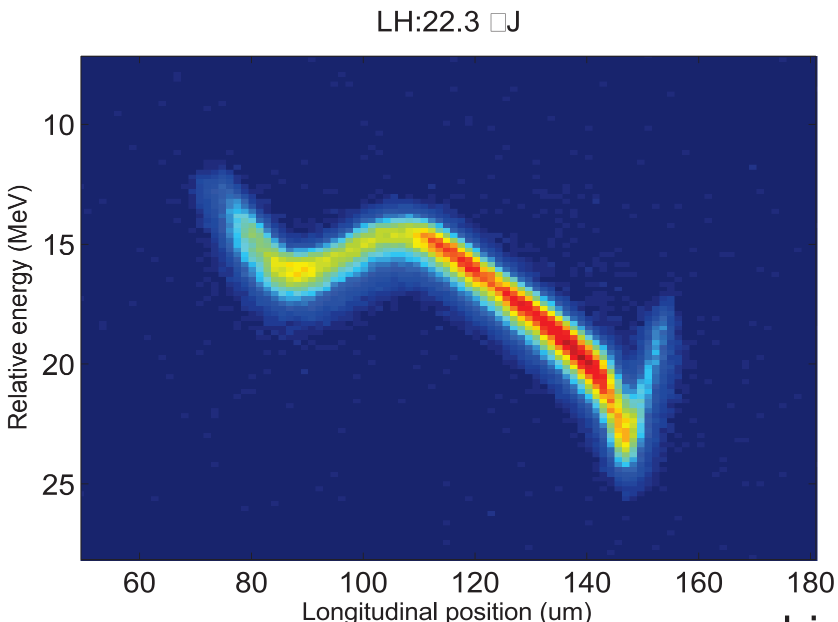




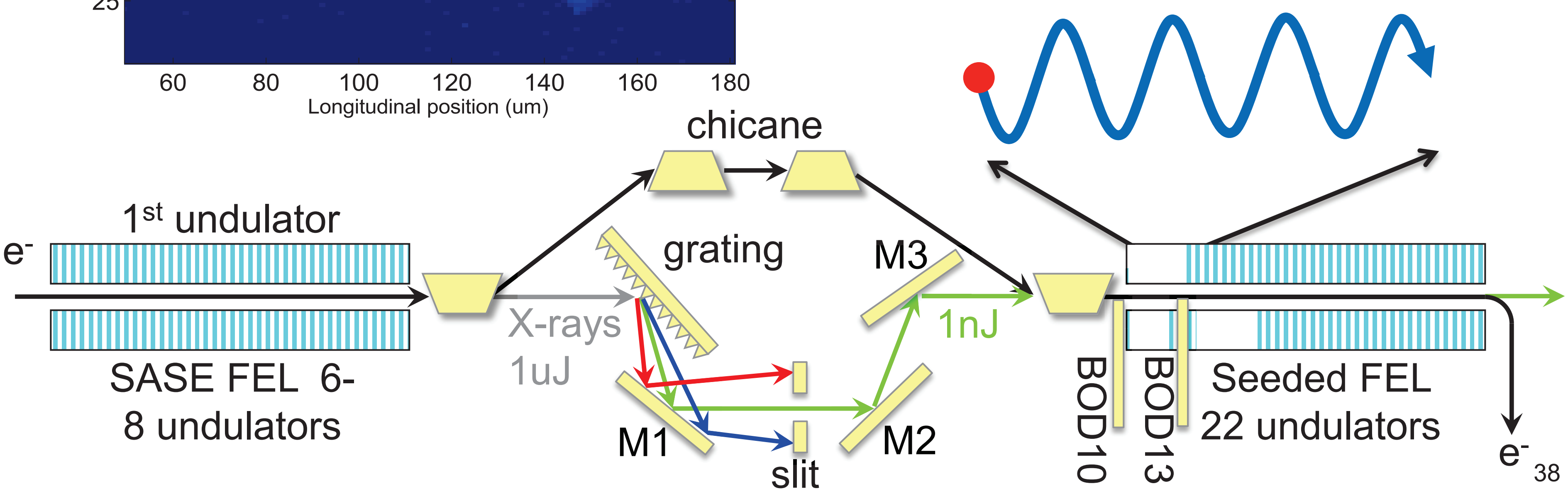
SXRSS Limitations

SLAC

Electron Phase Space



Acts like chicane ➔ $R56 = 2\lambda N_u$



SXRSS Limitations

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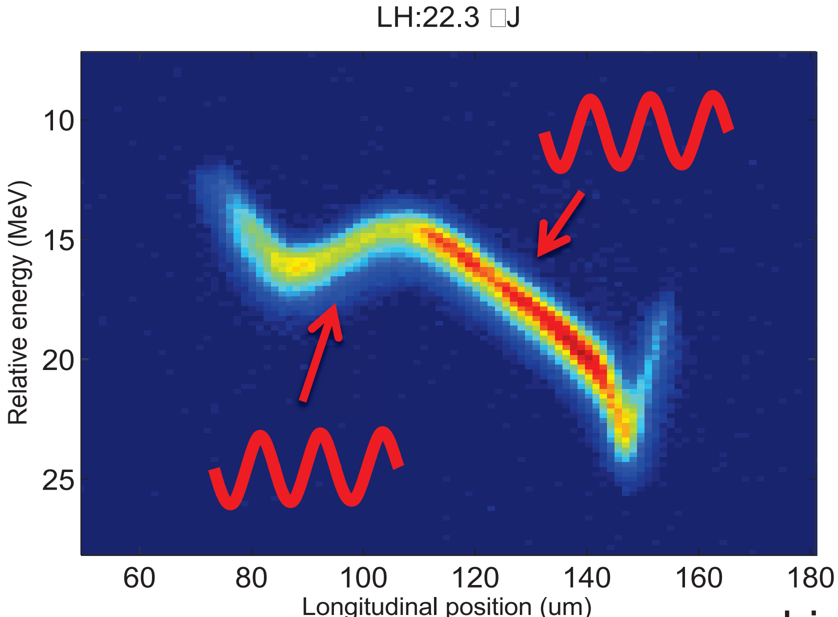

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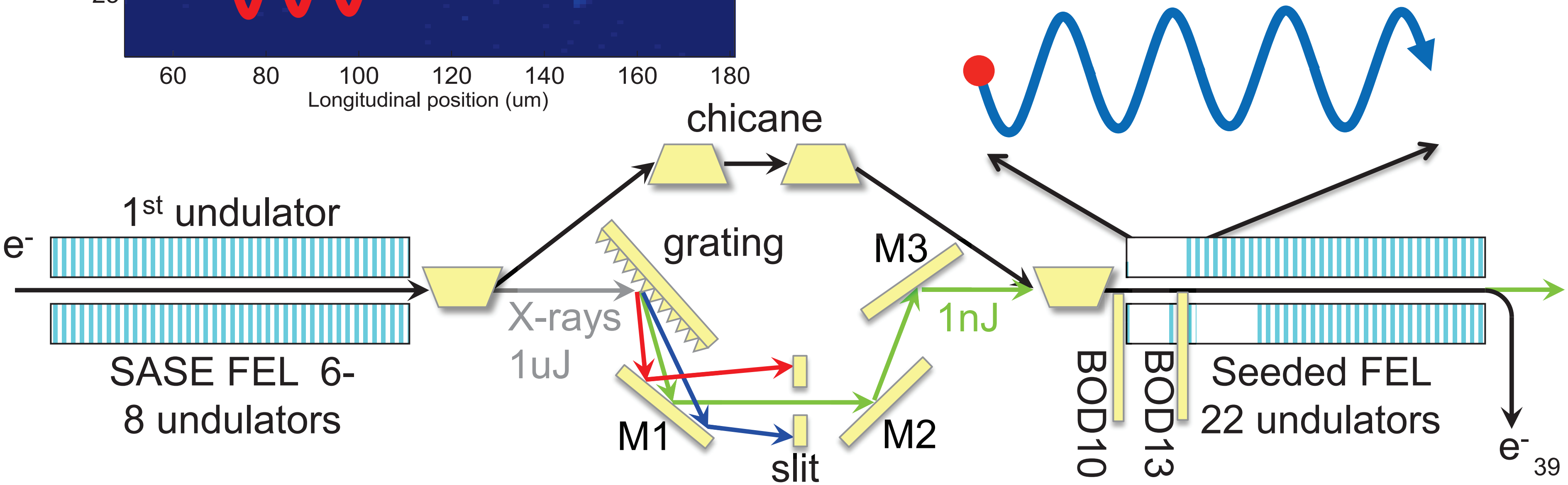

SXRSS Limitations

SLAC

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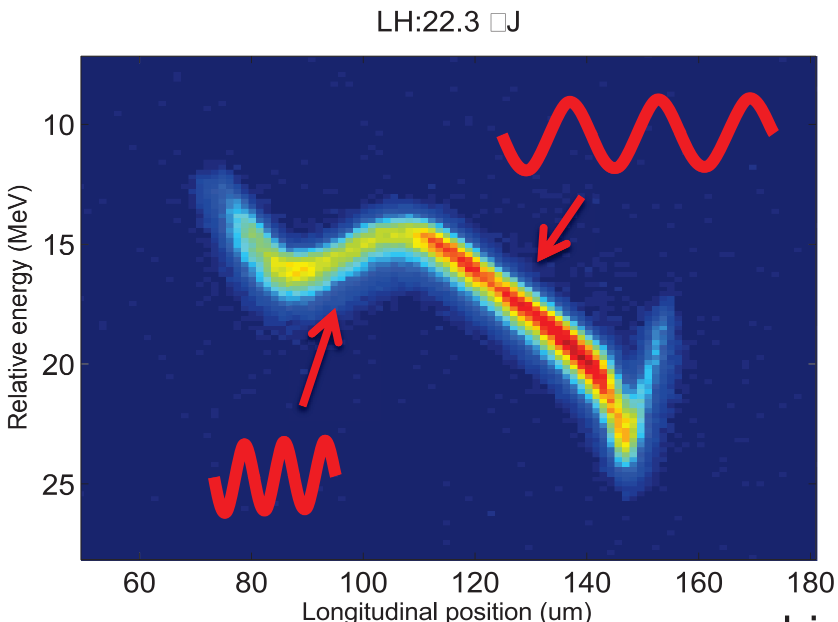

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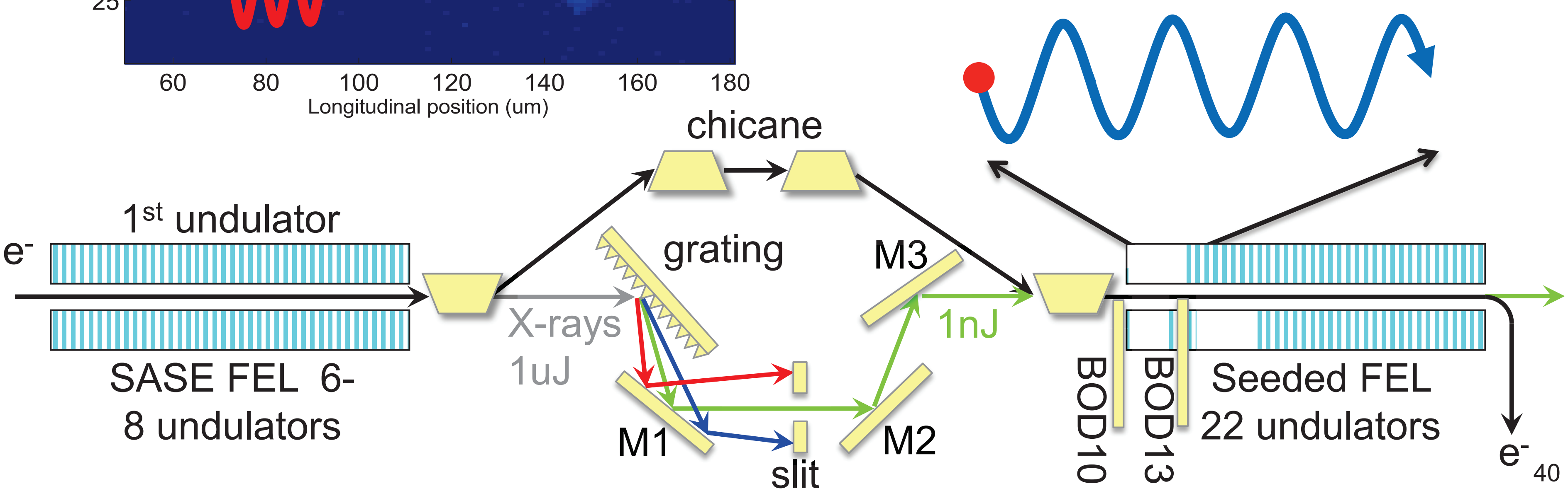
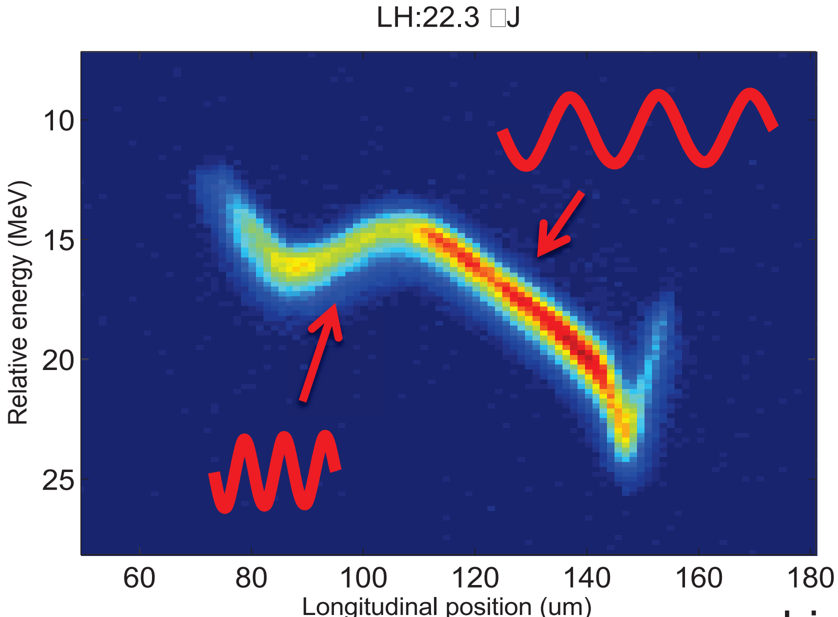
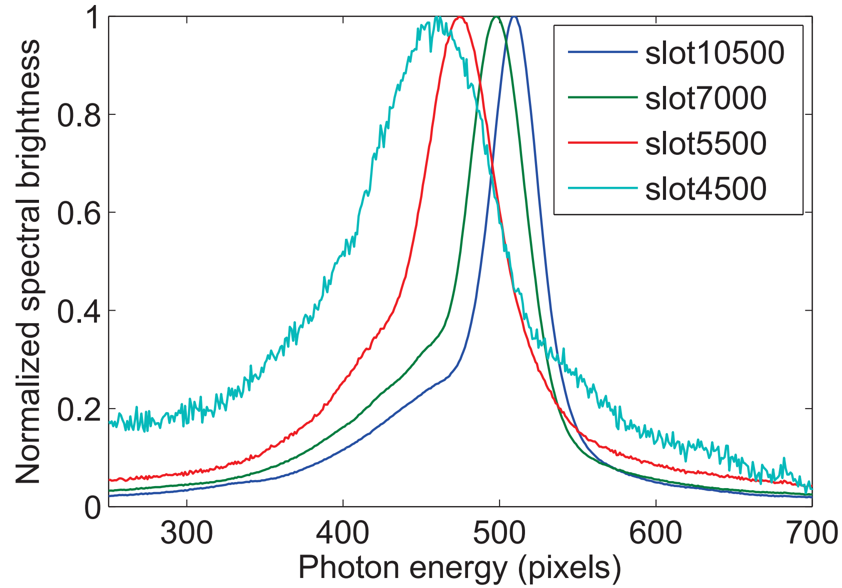


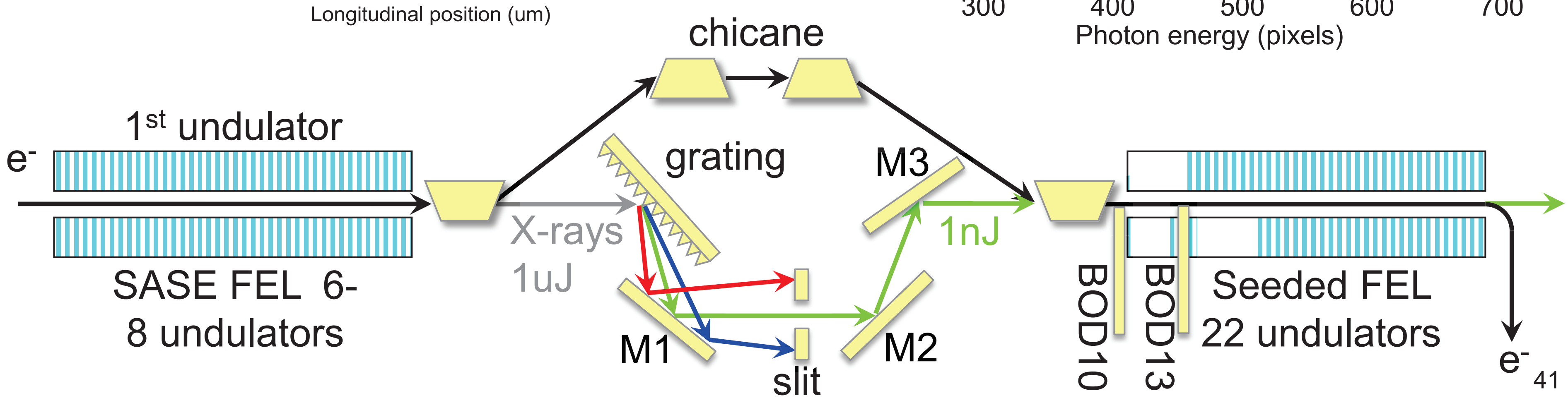
SXRSS Limitations

Electron Phase Space



Slotted foil selects part of the beam





SXRSS Limitations

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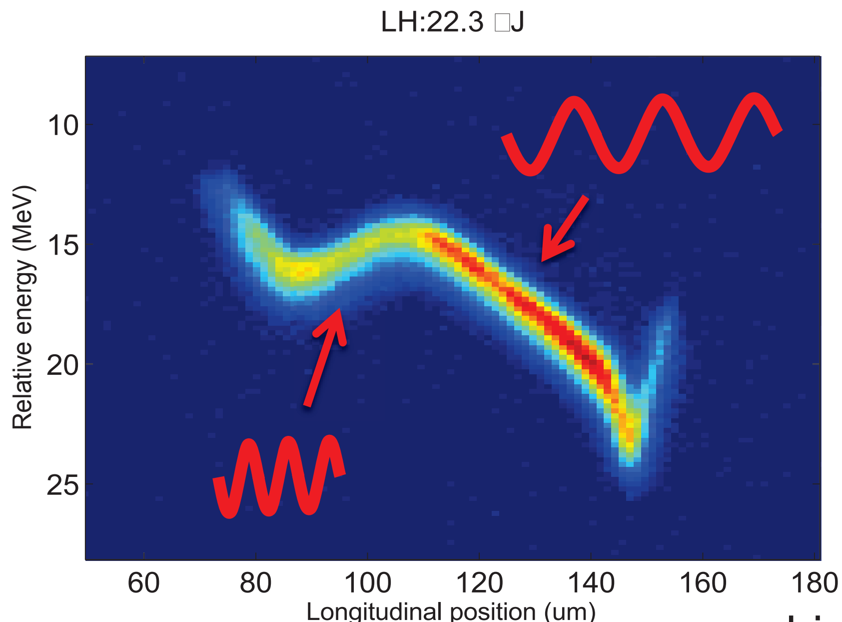
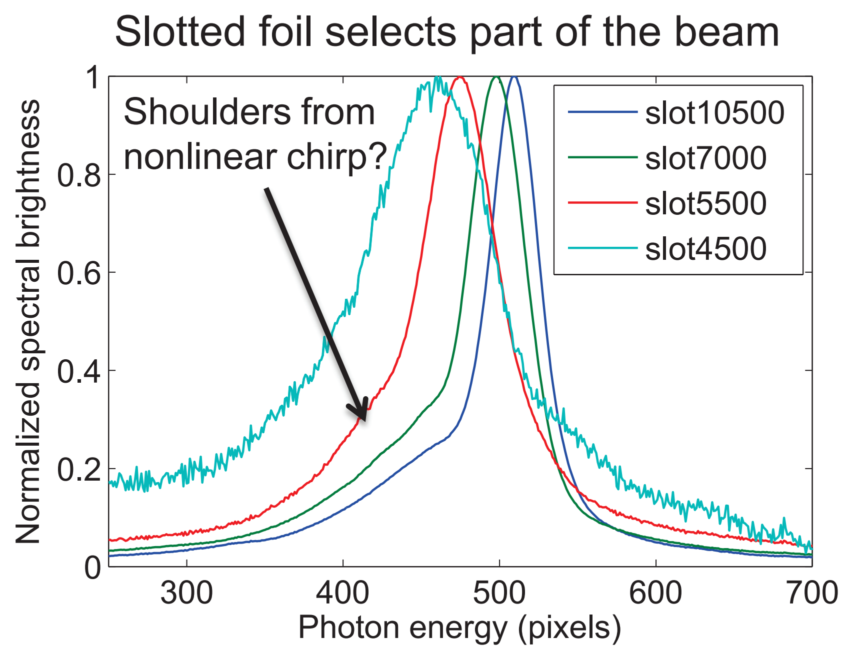
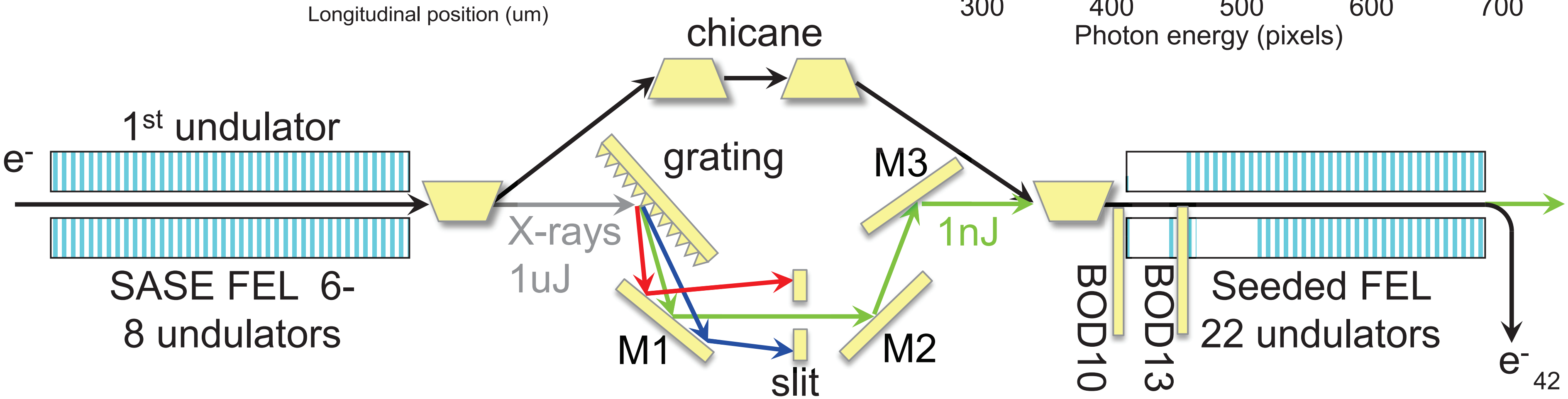




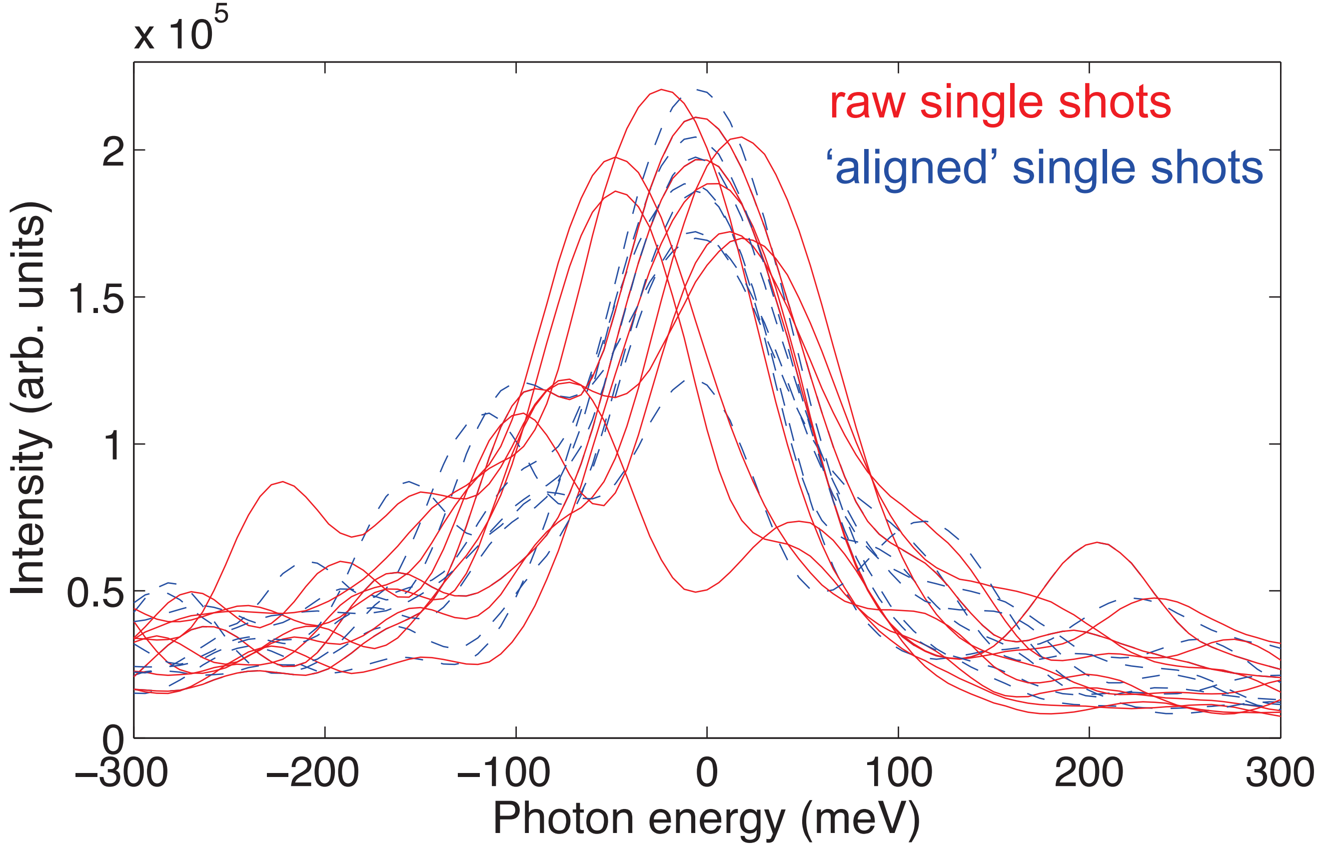


SXRSS Limitations

Seeded wavelength stability

Wavelength is stable to around 10^{-4}

…but still widens average bandwidth by ~15%



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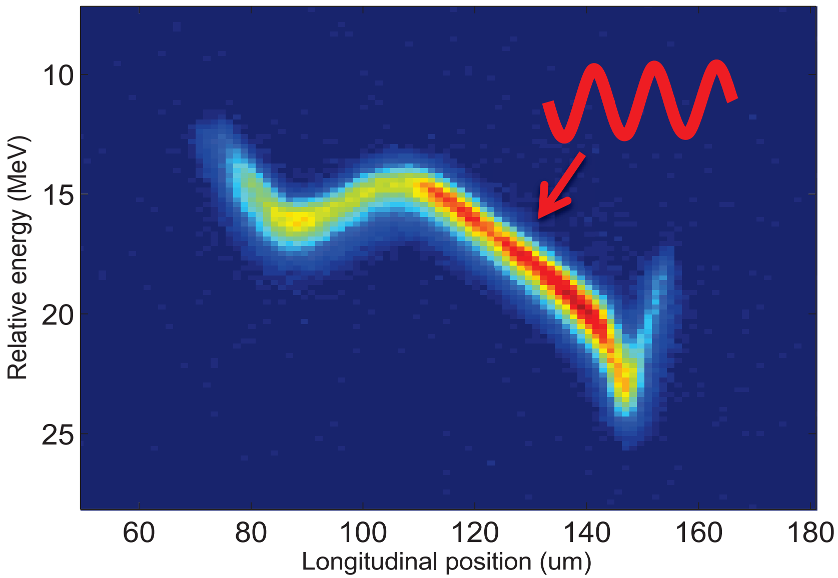
Chirp changes shot-to-shot



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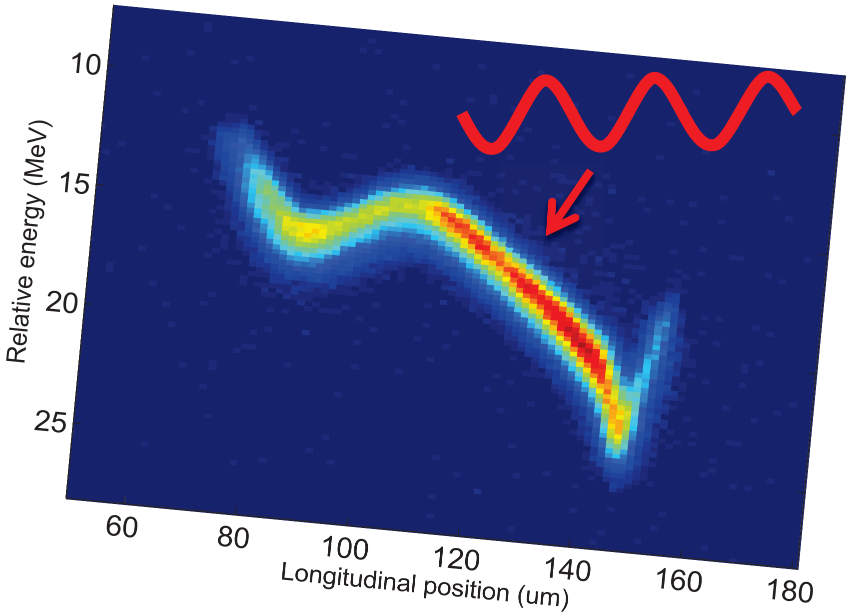

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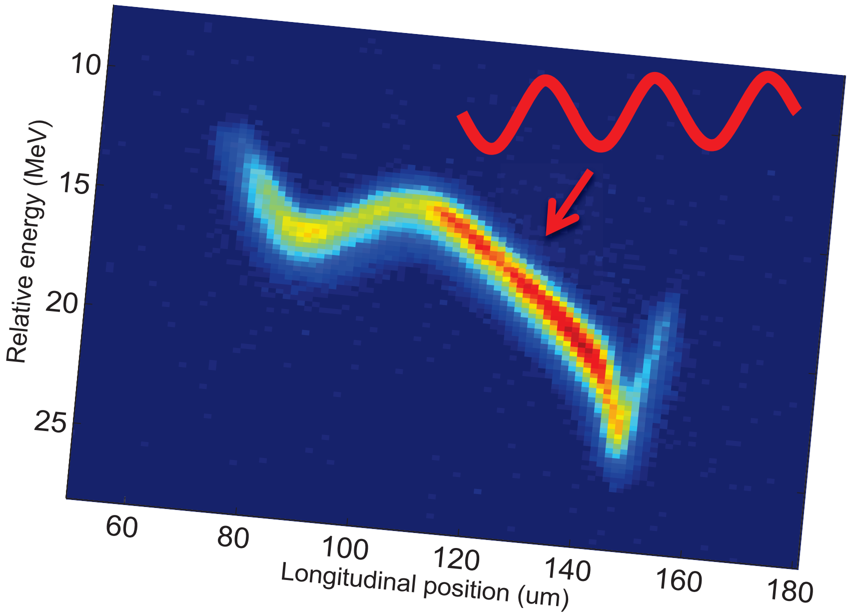
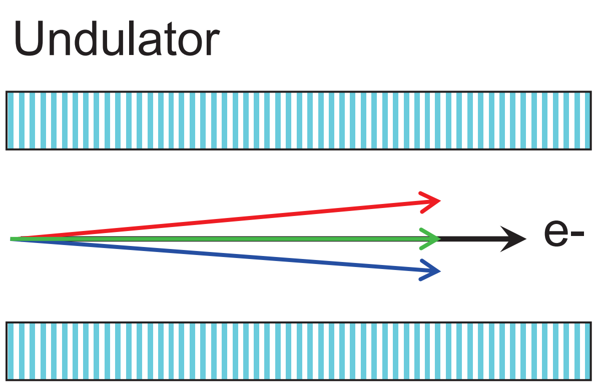


Electron orbit changes shot-to-shot



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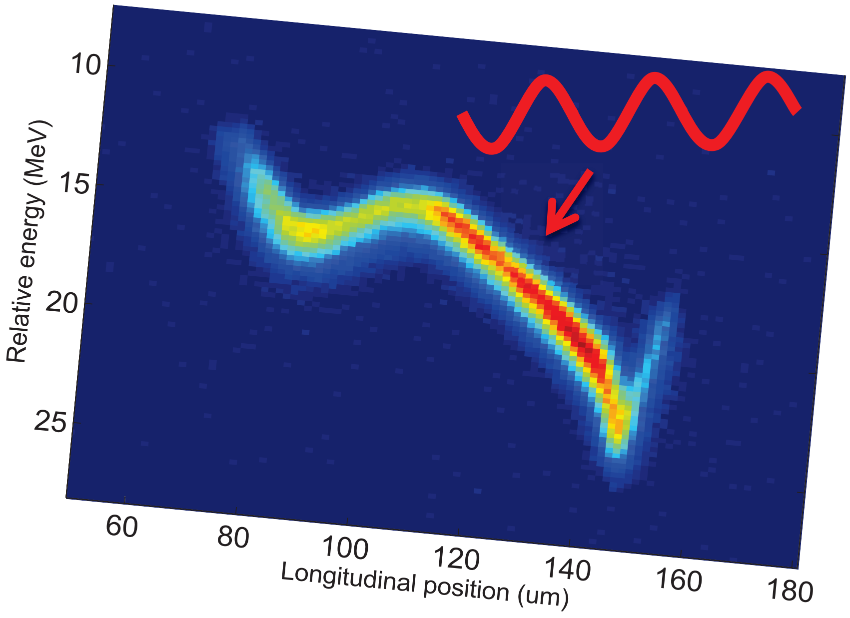

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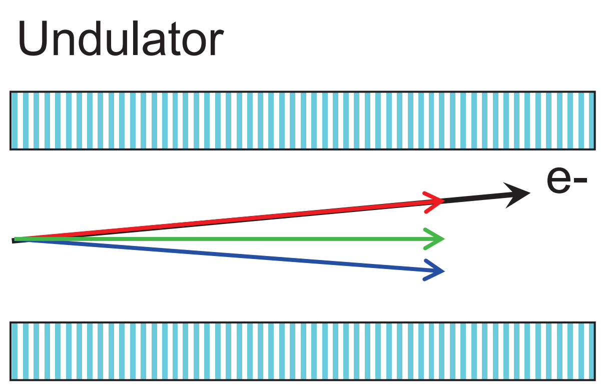
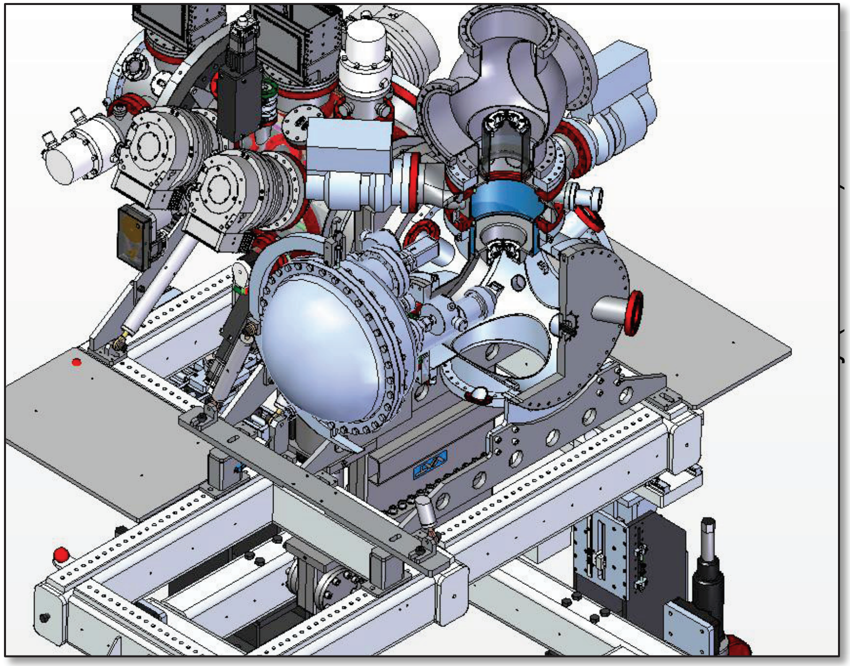
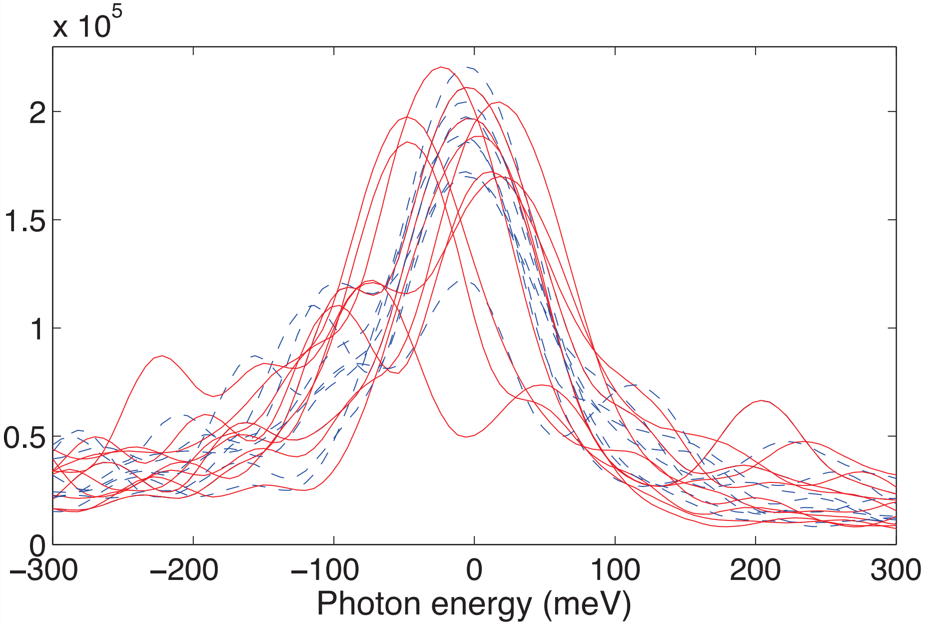


SXRSS Limitations

SLAC

Need robust, available X-ray diagnostics:
➔ Transmissive SXR Spectrometer

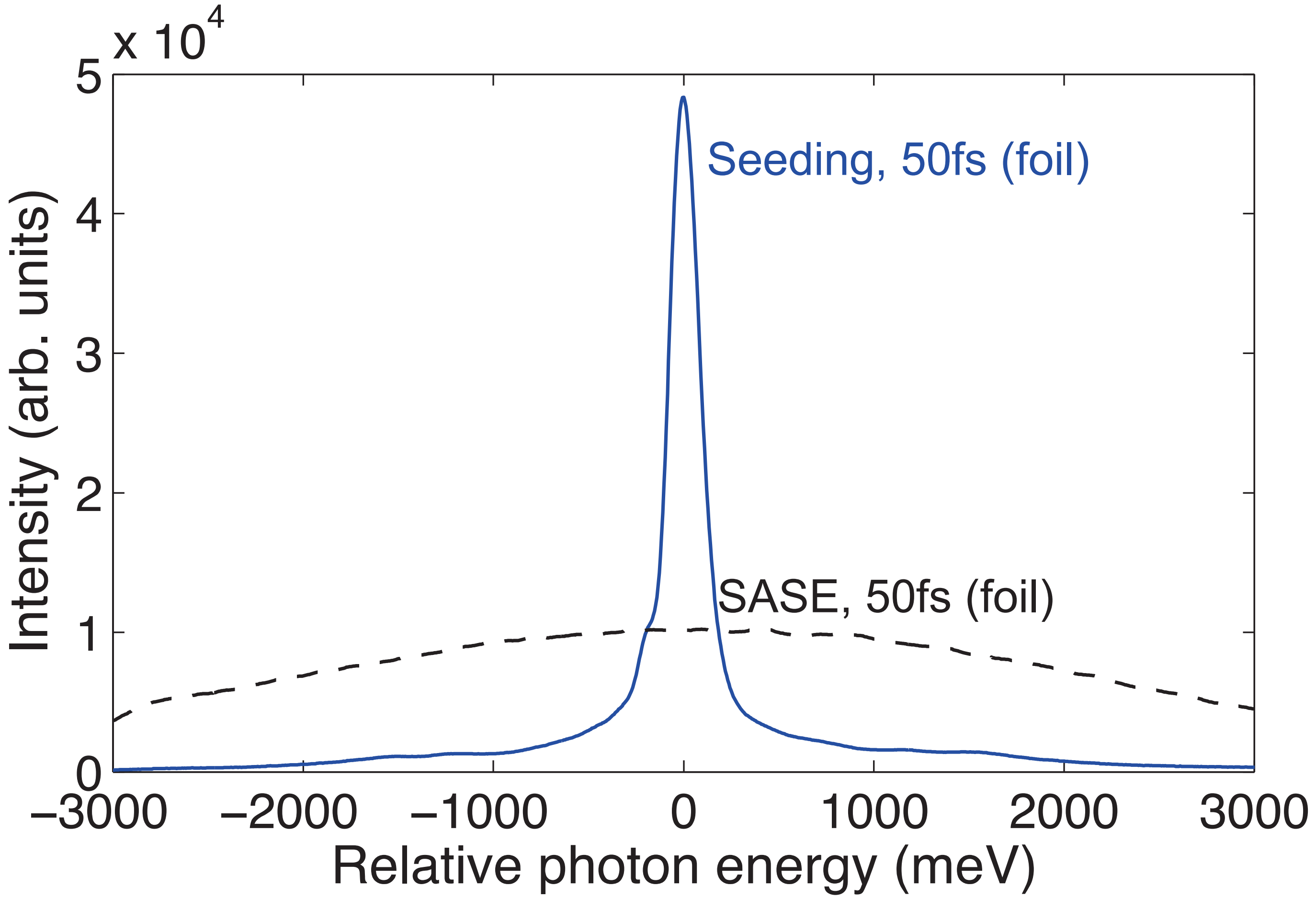




July 29th, 930 eV

Latest Seeding Results

(Undulators 10-25 inserted for seeding)



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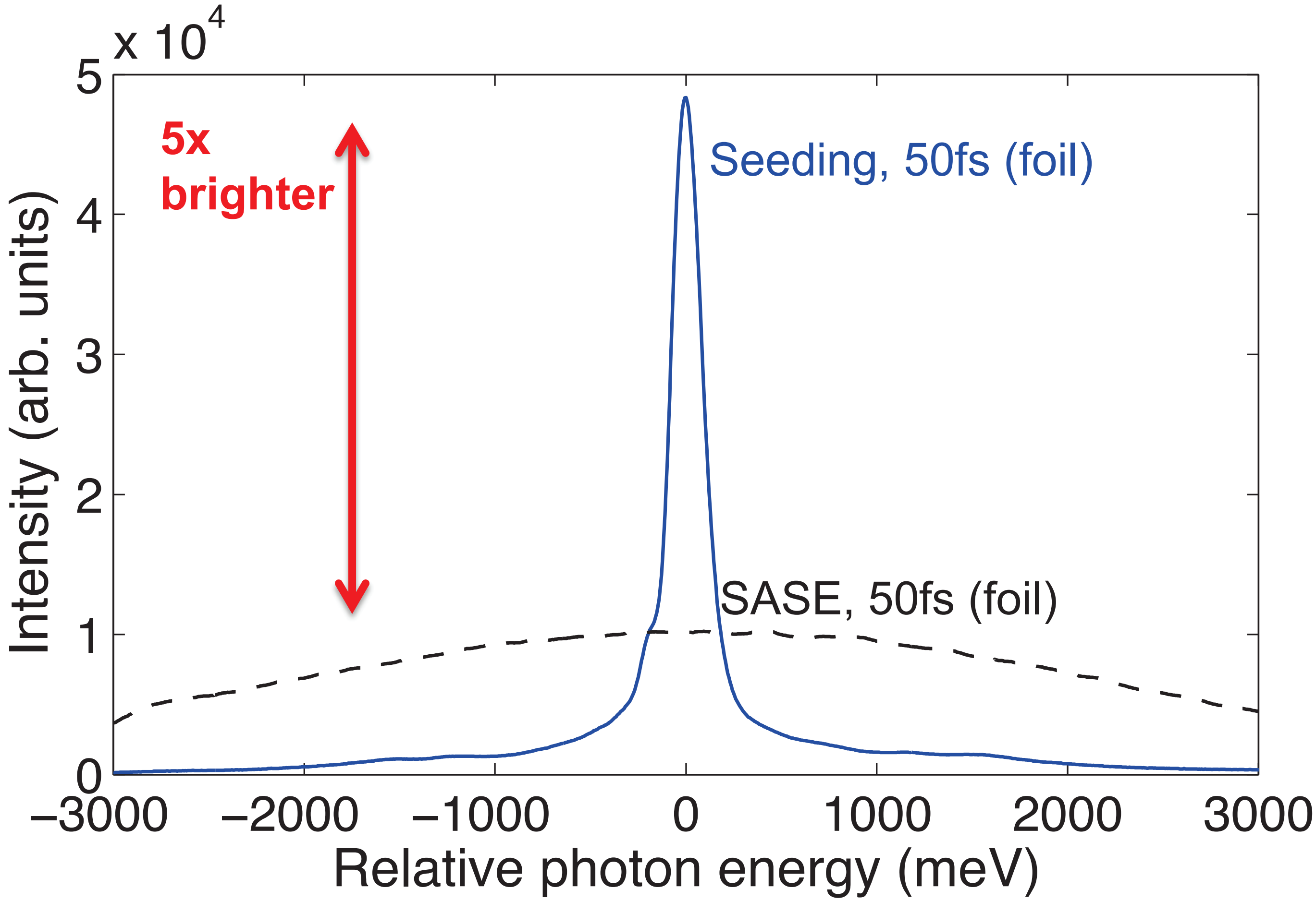

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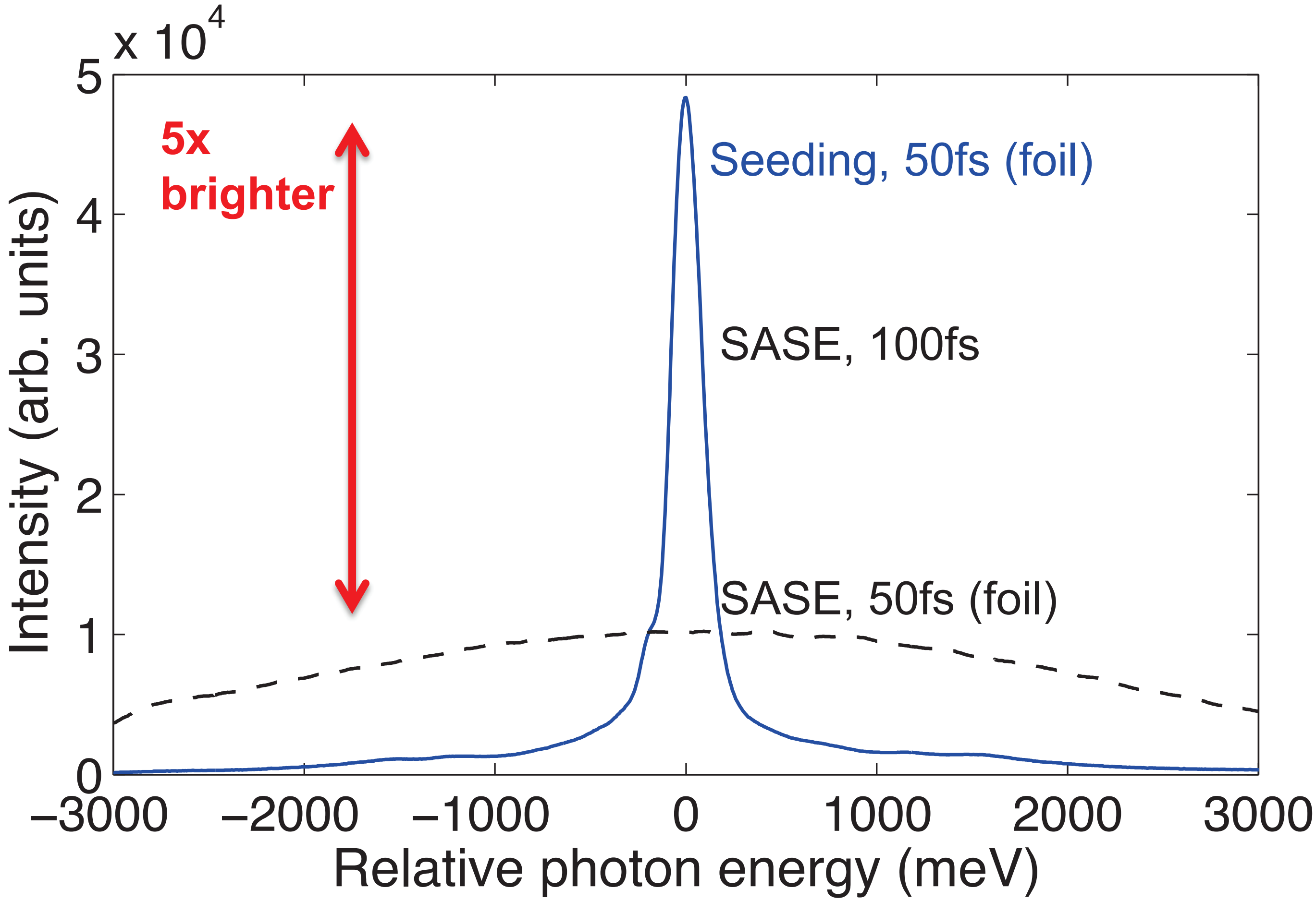

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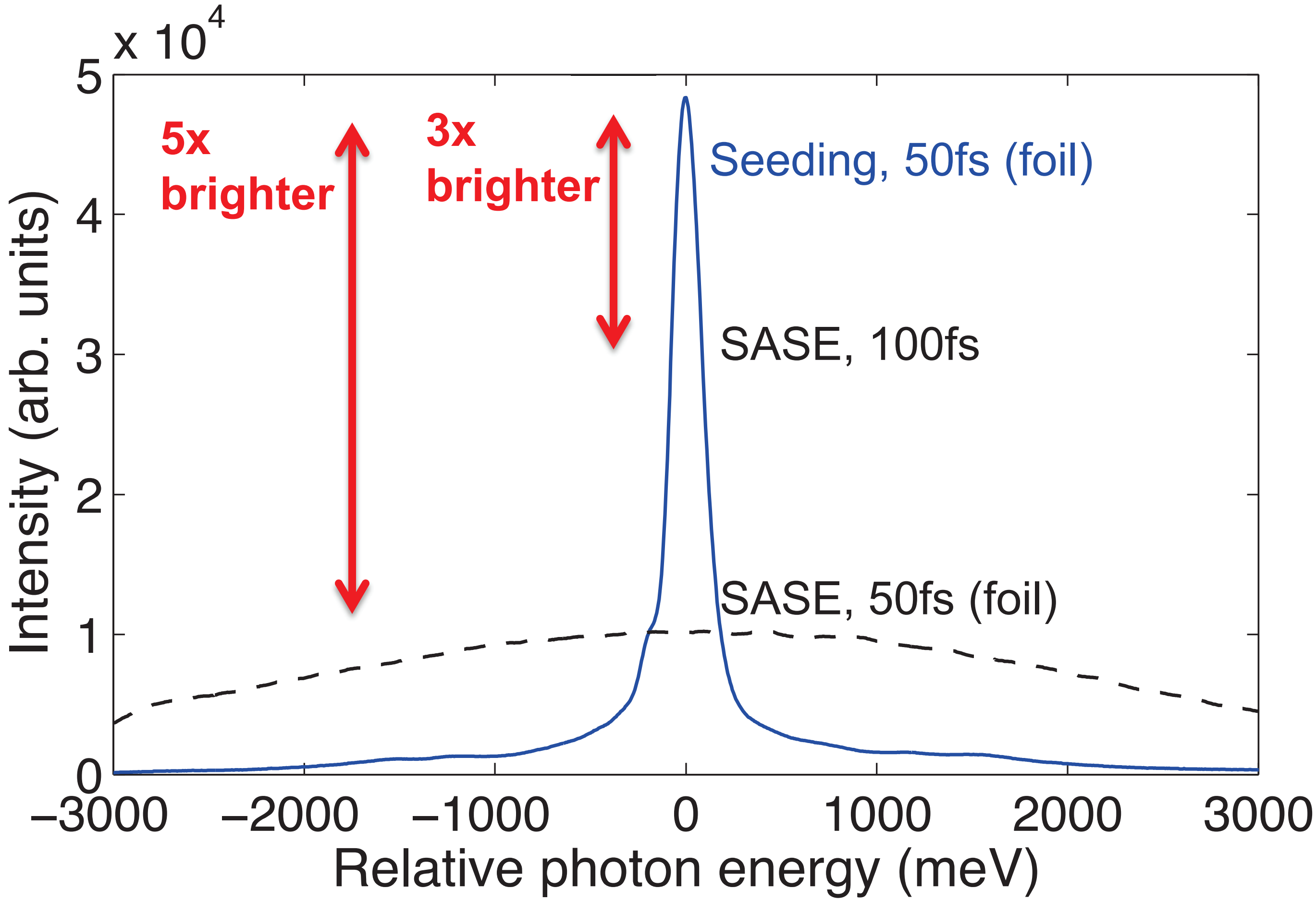
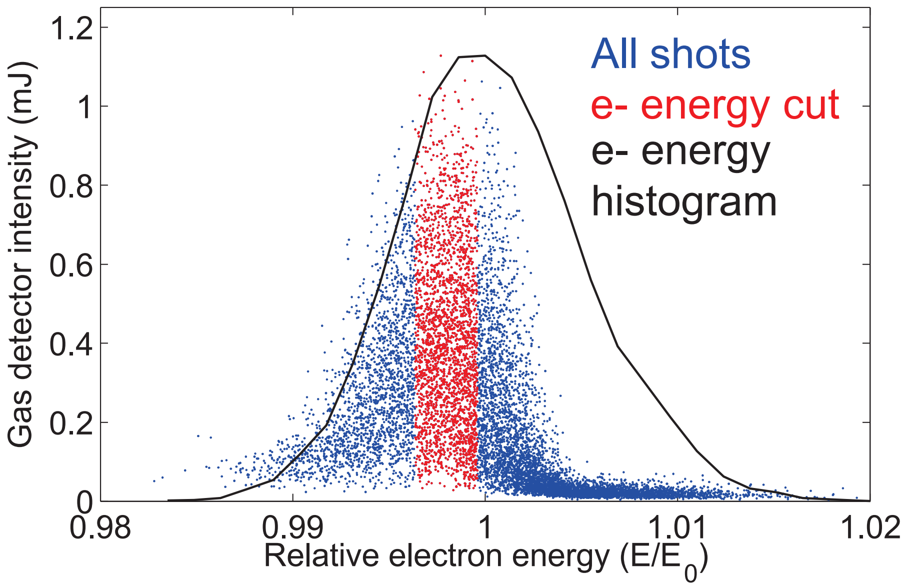


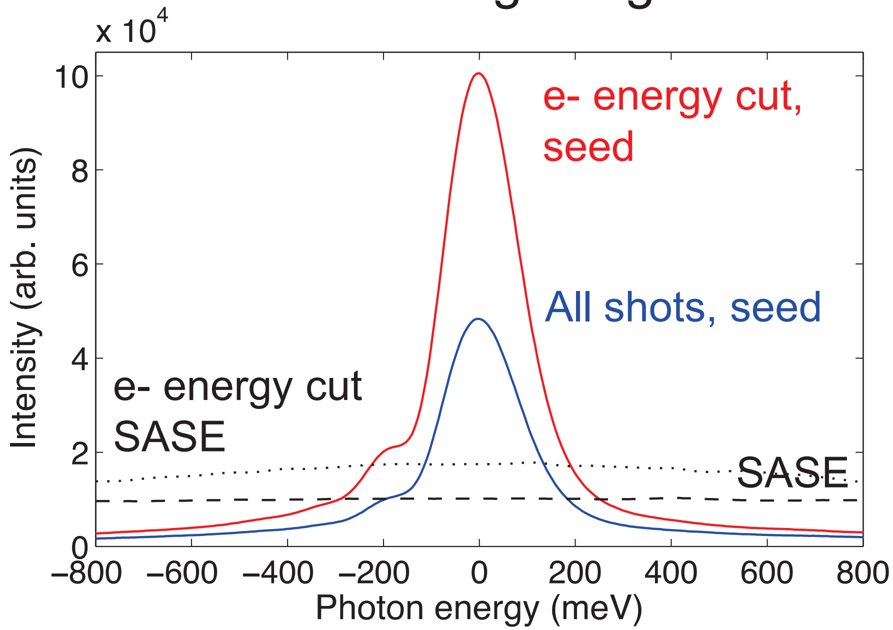
Latest Seeding Results

Electron energy jitter limits seeding performance

e- jitter > gain bandwidth



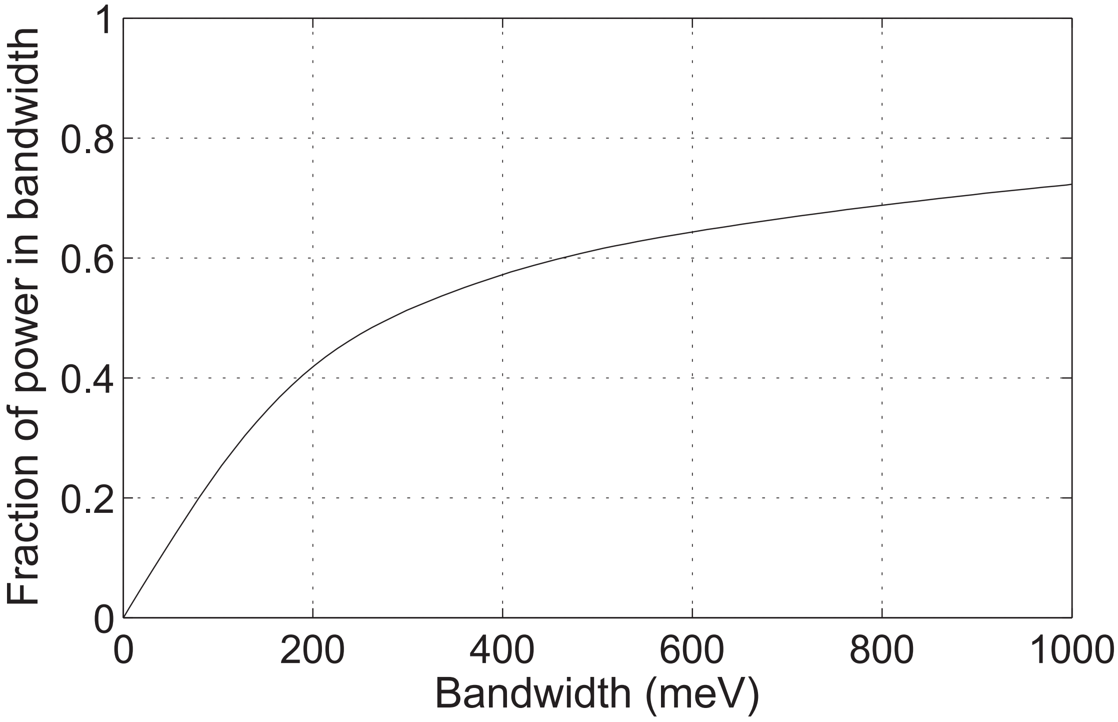
Reducing jitter can double average brightness

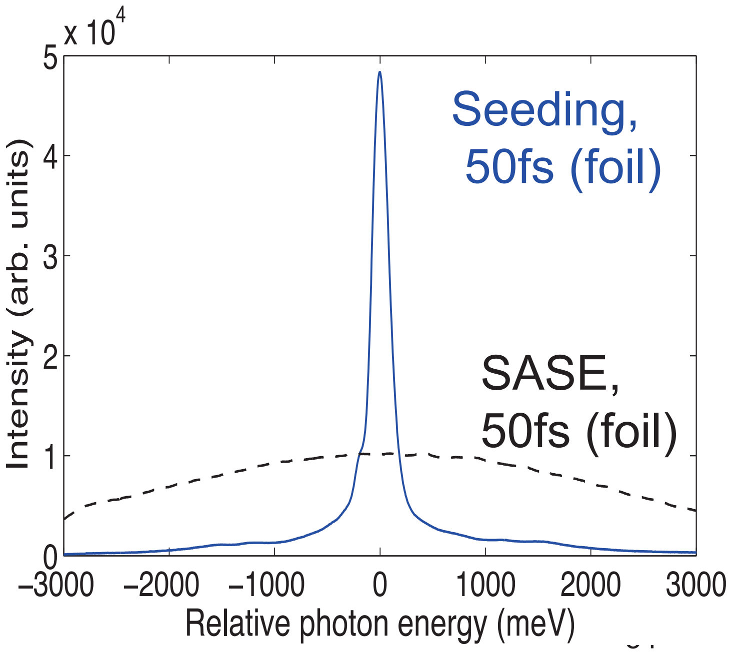


July 29th, 930 eV

Avoiding Hutch Mono

Undulators 10-25 inserted





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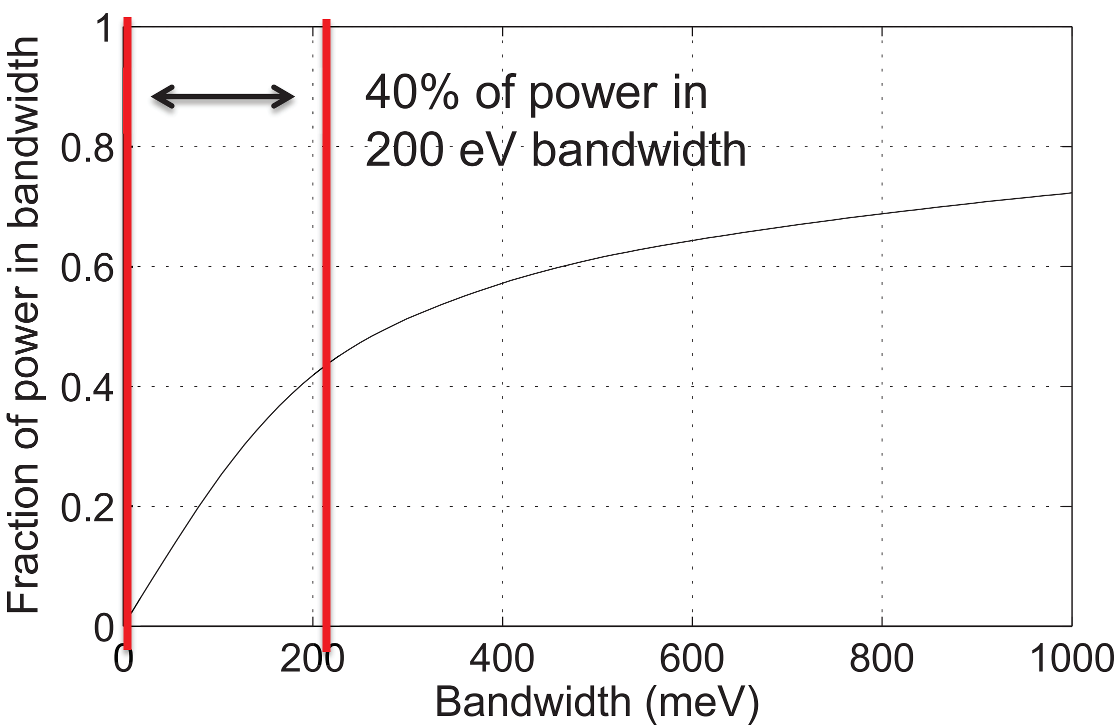
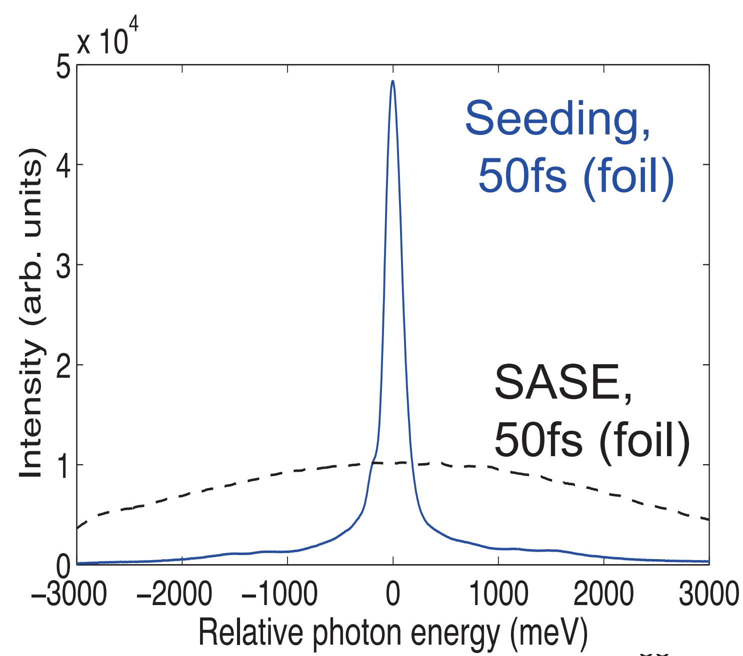


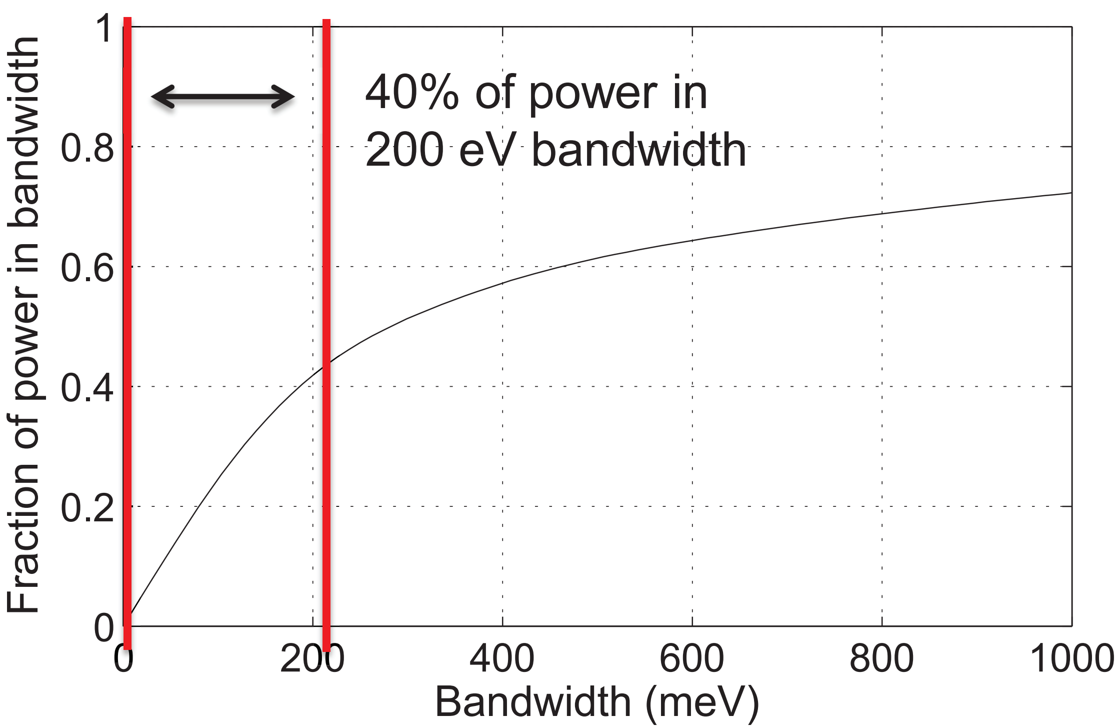


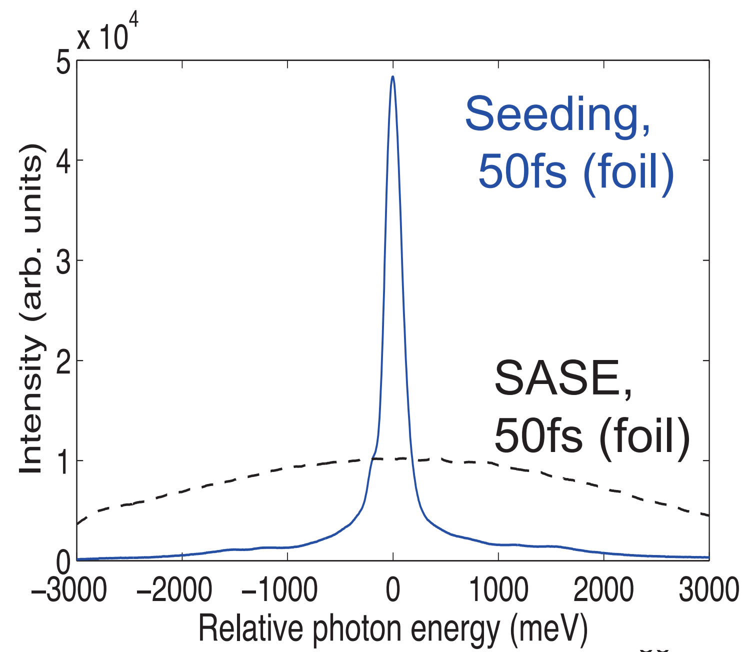
July 29th, 930 eV

Avoiding Hutch Mono

Hutch monochoromator loses factor of 10 or more in brightness → Avoid mono and brightness increases factor of >50!

Undulators 10-25 inserted

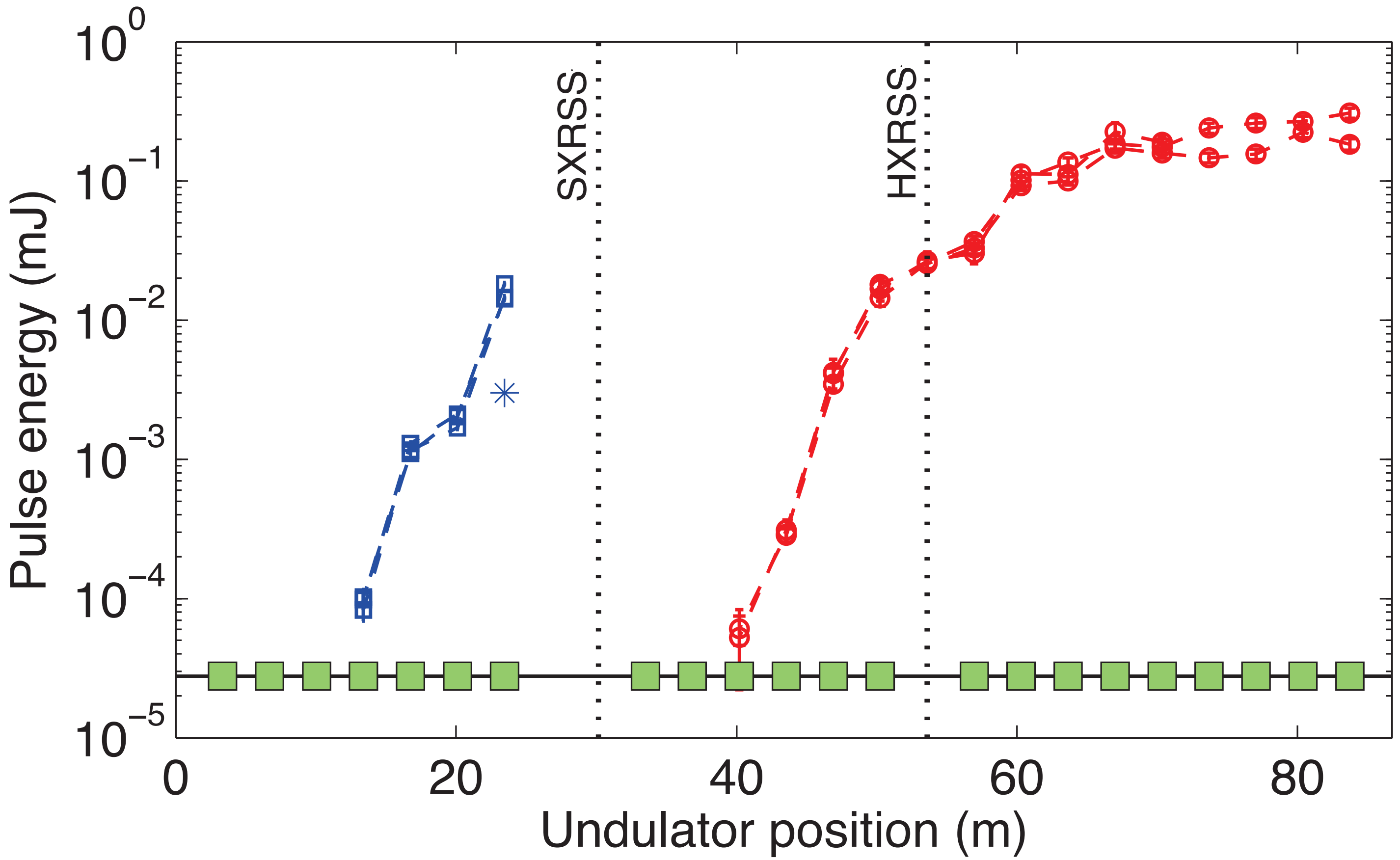




July 29th, 930 eV

Seeded gain length (930 eV)

Gain length ~ 2m



July 29th, 930 eV

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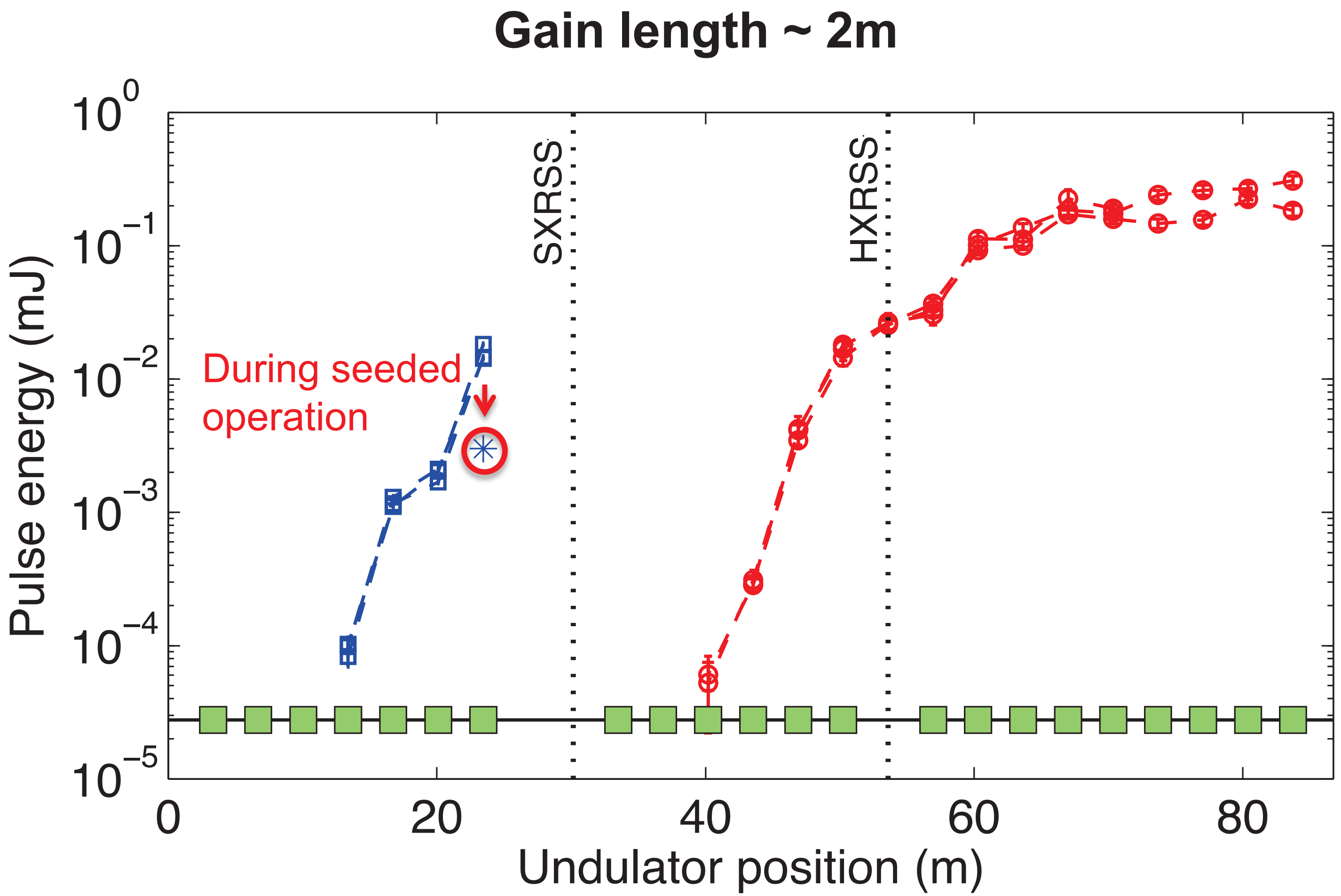

Next Steps

Accomplished Goals:

1. Achieved self-seeding at soft X-rays
2. Demonstrated seeding across 500-1000 eV range
3. Observe up to factor of ~5-50 increase in average brightness
4. Reach up to ~5000 resolving power
5. Wavelength stability of 10^{-4}

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Still to do:

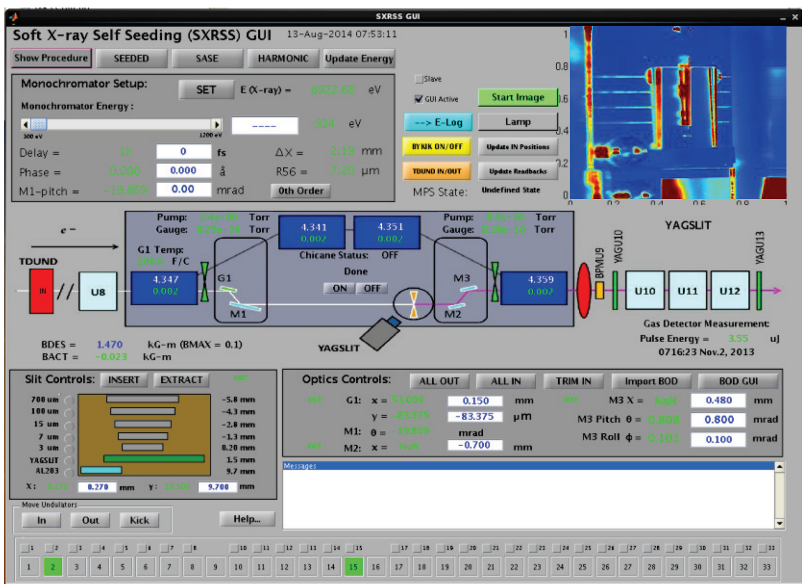
1. Study optimal seeding conditions (vs. seed power, slit size, etc.)
2. Optimize taper to maximize seeding vs. SASE
3. Improve setup to reduce time, improve stability, and attract users

Next Steps

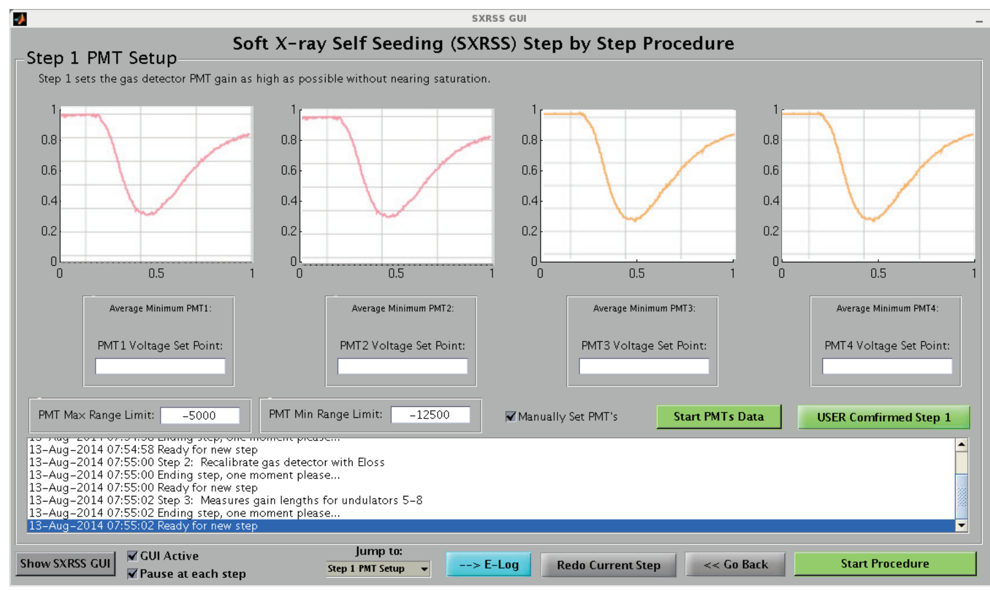
Reducing setup time

Target: Less than 30 minutes to switch from SASE to seed

Low level GUIs to organize components



High level programs to guide operators



Thanks!

On behalf of SXRSS team:

Thanks to the enormous group of people who made this project possible!