Hard x-ray self-seeding stability experimental results and simulations

11. December. 2012

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Seeding and Self-seeding at New FEL Sources
Trieste, 10-12 december 2012

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U.S. DEPARTMENT OF ENERGY | Office of Science

Thanks to

- HXRSS Collaboration
- HXR Spectrometer team
- Operators team
- Seeding and Self-seeding at New FEL Sources

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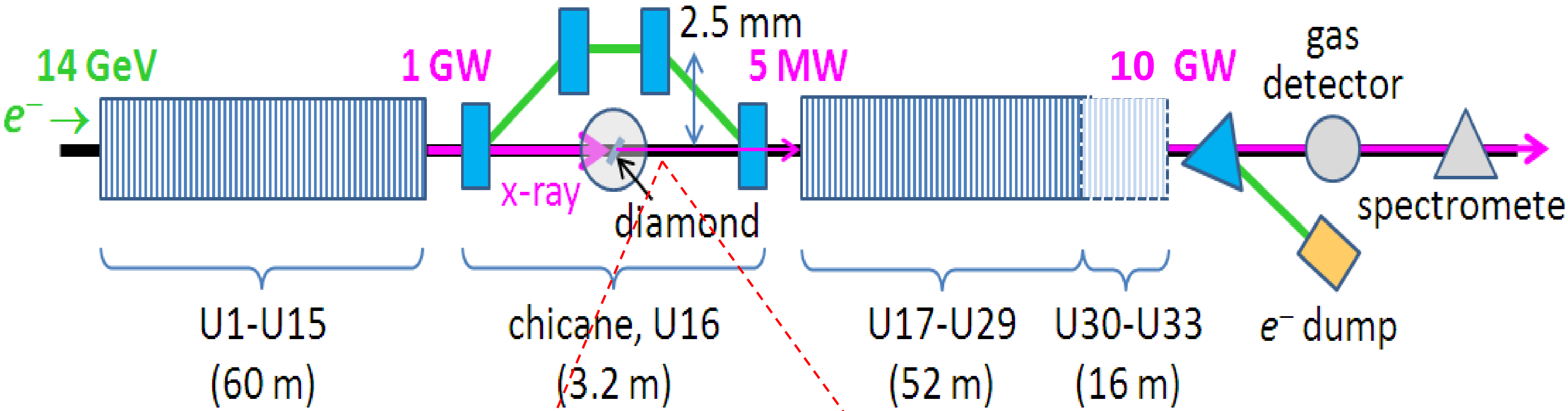
Talk outline

- Self seeding experimental results

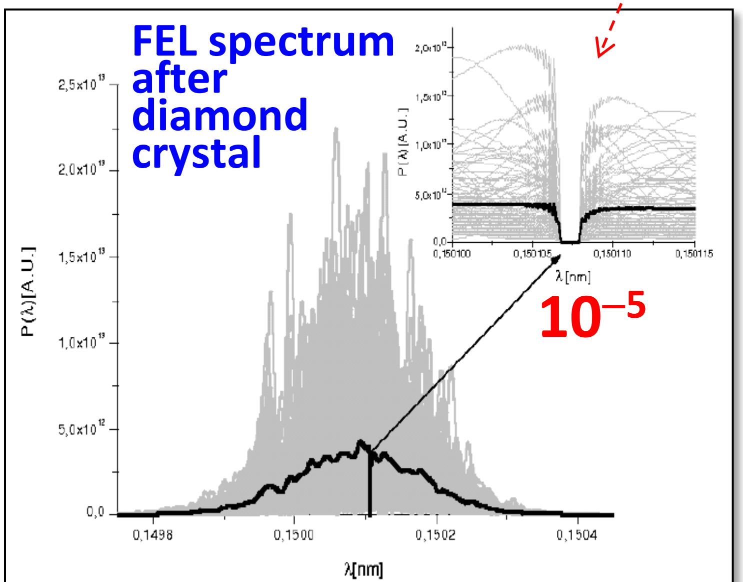
  Impact of machine jitters on performance

- Simulations with a 1D code compared to the experimental results.

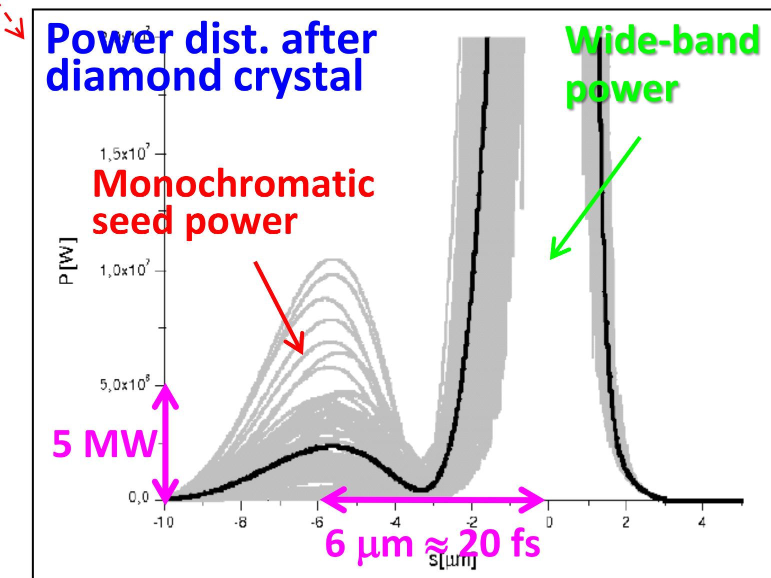
Hard X-ray Self-Seeding @ *LCLS*



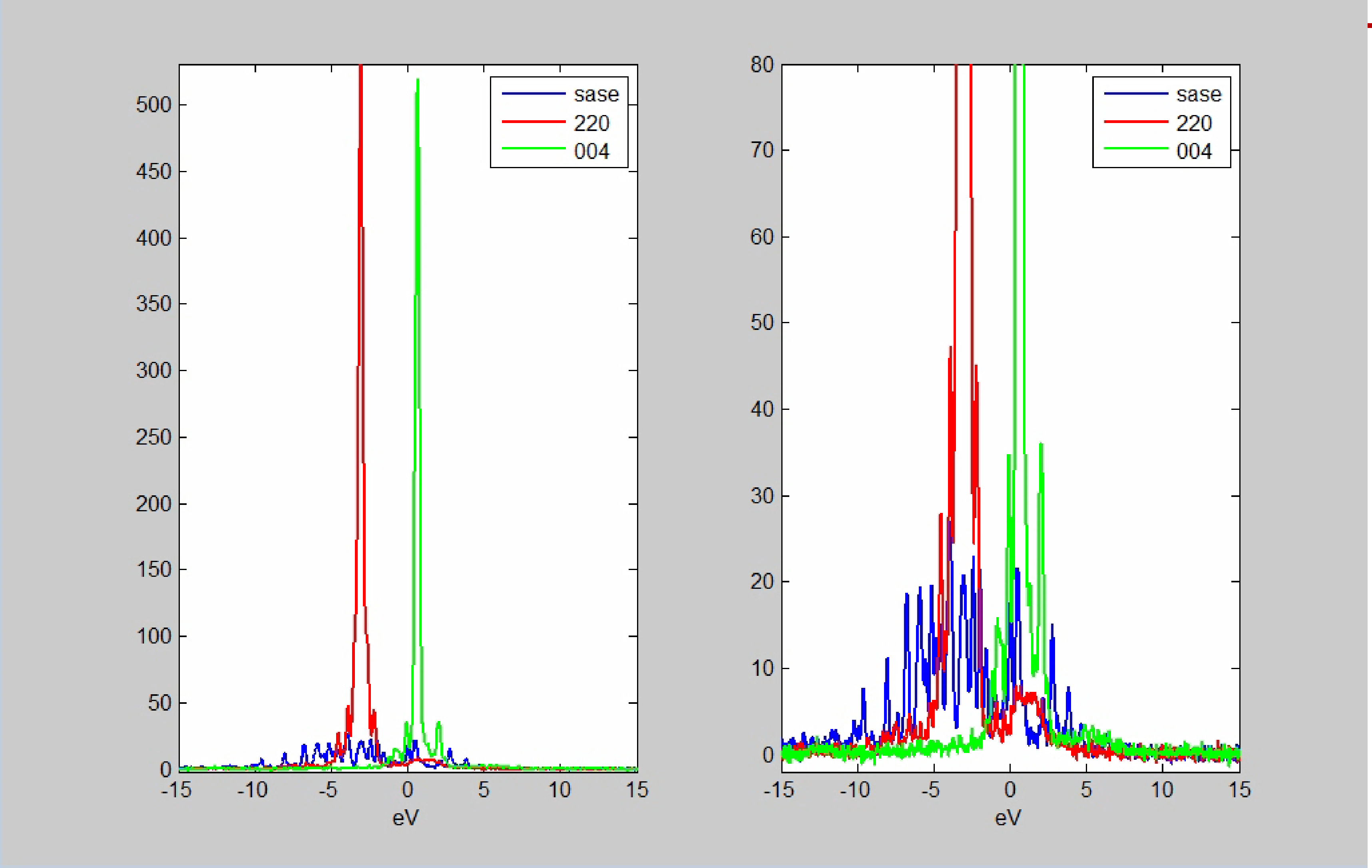
Geloni, Kocharyan, Saldin, *DESY 10-133*



Self-seeding of 1-μm e^- pulse at 1.5 Å yields **10^{-4} BW** with 20-pC mode



Single-Shots movie, Self seeded and SASE



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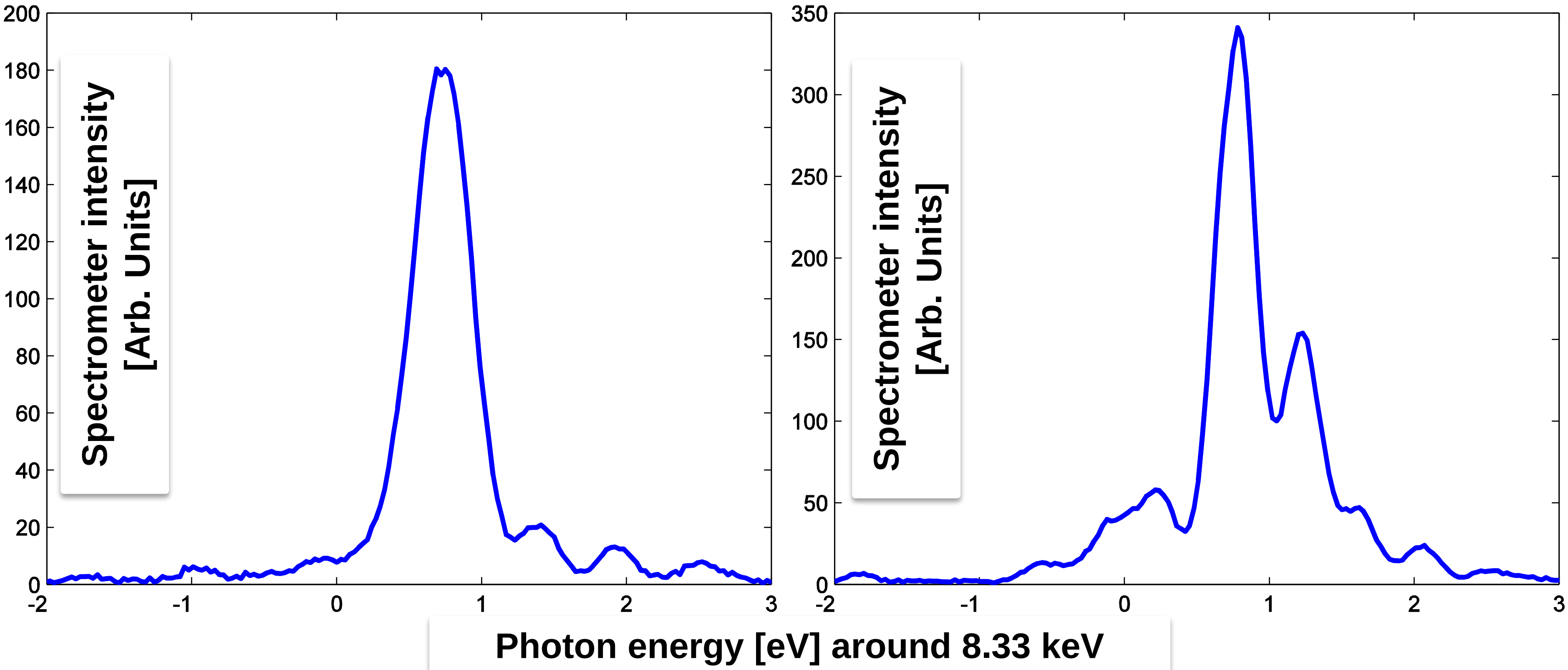
Photon energy [eV] around 8.33 keV

004, seeded spike structure



- Many shots show a substructure inside the self-seeded spike bandwidth

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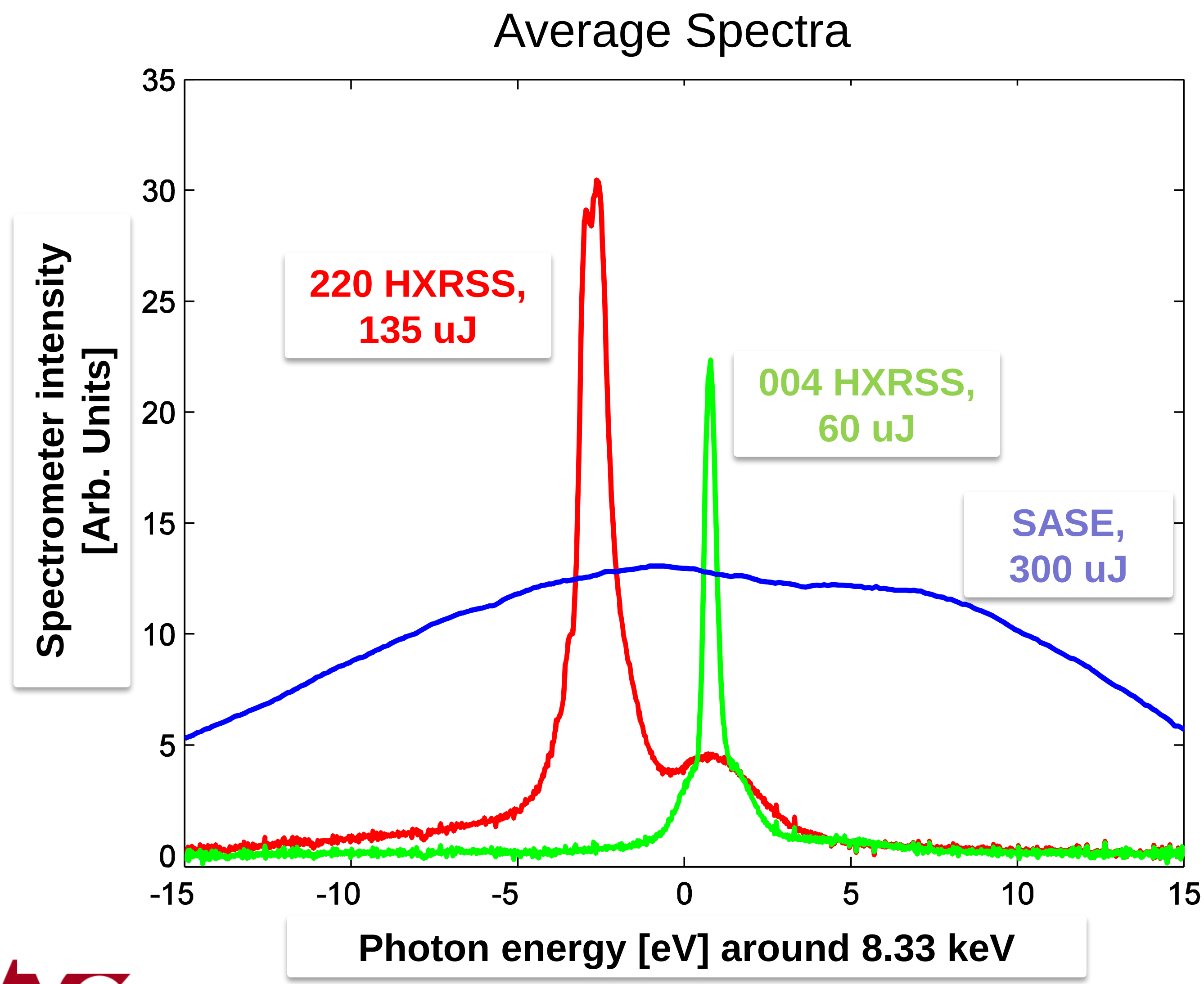
HXRSS vs SASE, bandwidth reduction



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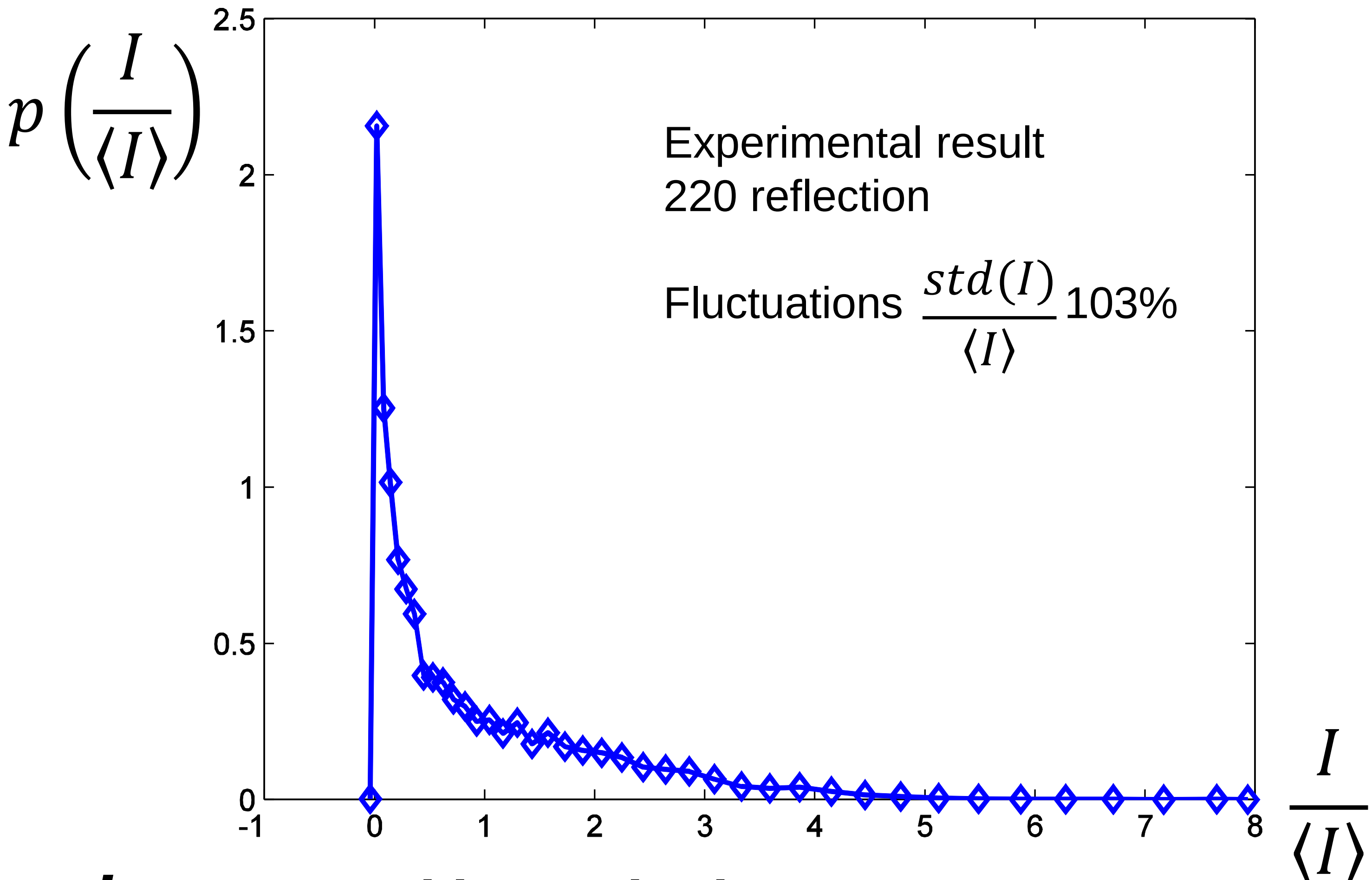
Normalized probability distribution



I **:Integrated intensity in 1.5 eV (from HXR spectrometer)**

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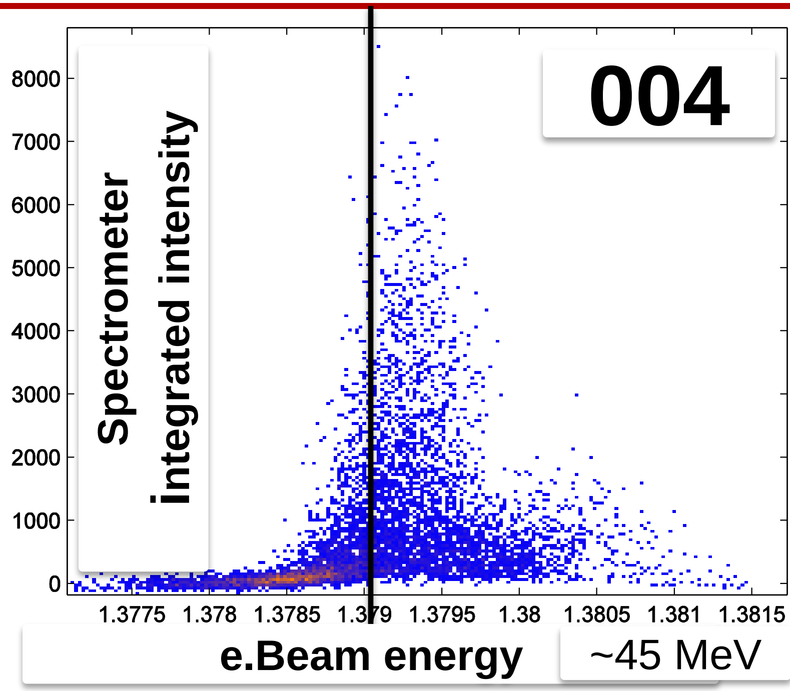
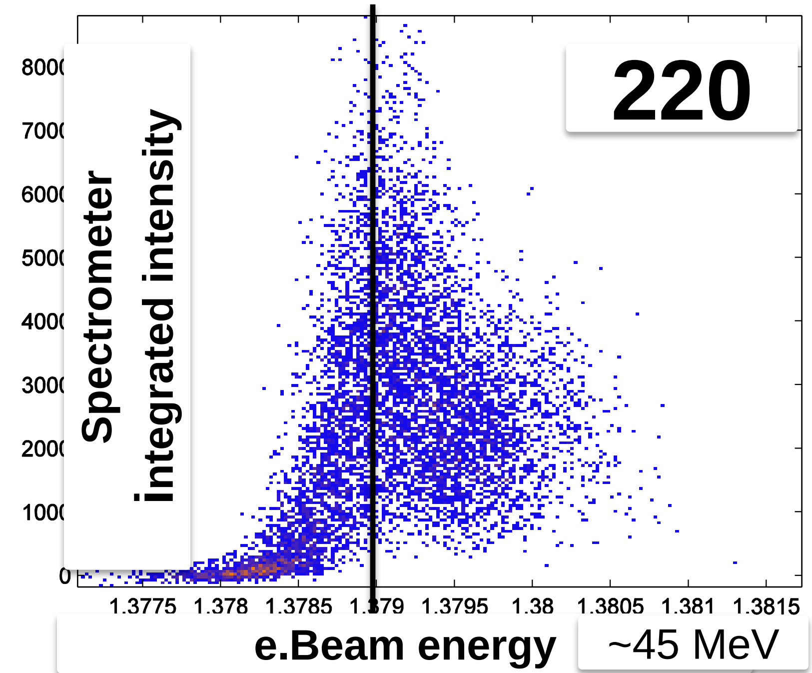
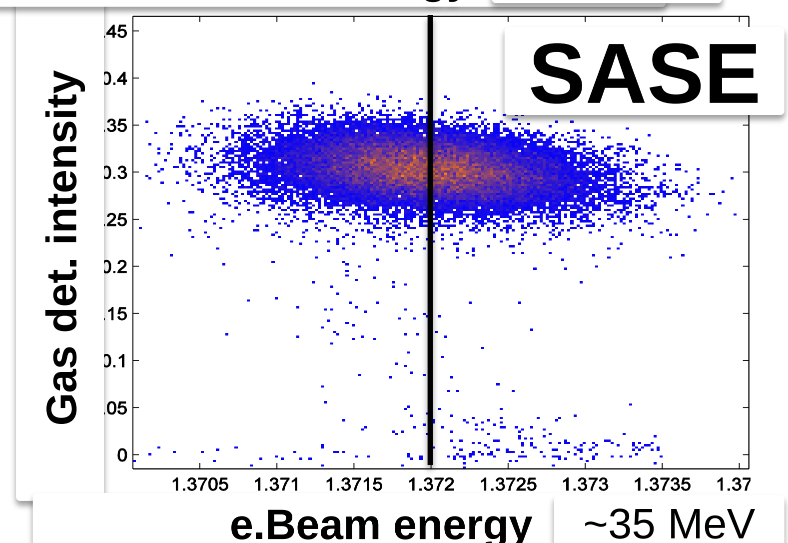
Correlation Intensity vs electron beam energy

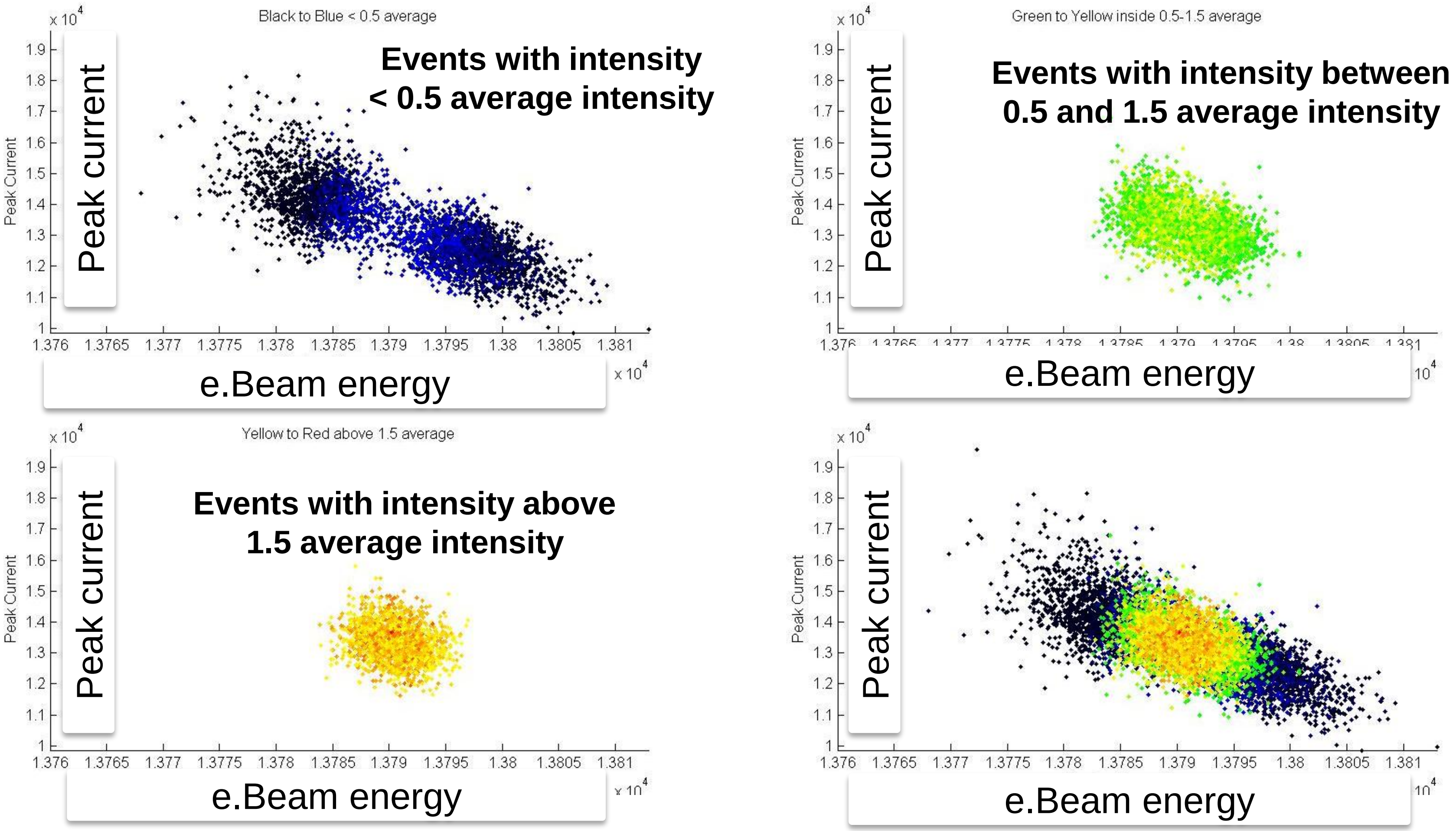




- Self-seeding more demanding than SASE for electron beam energy stability
- Electron beam energy distribution has Gaussian shape, with 6.8 MeV rms (5 x 10^{-4})



More machine jitters: intensity vs peak current vs electron beam energy



220 – Intensity in 1.5 eV around peak (from HXR spect.)

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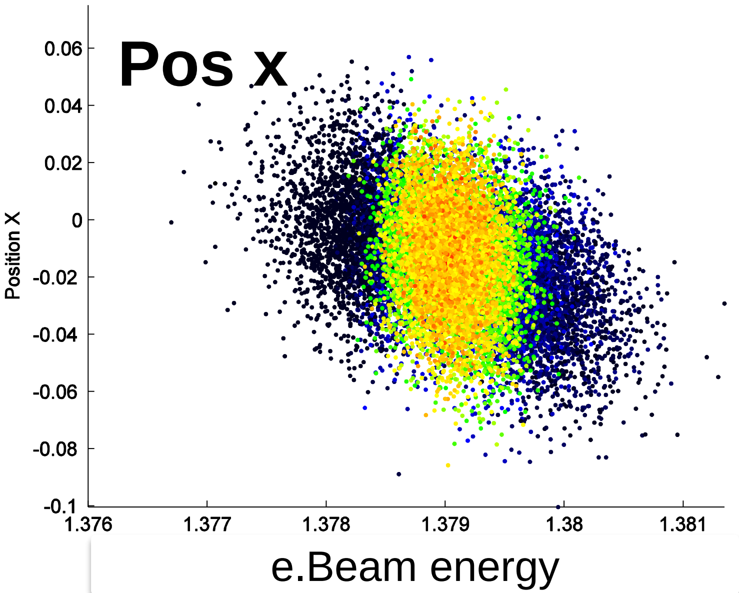
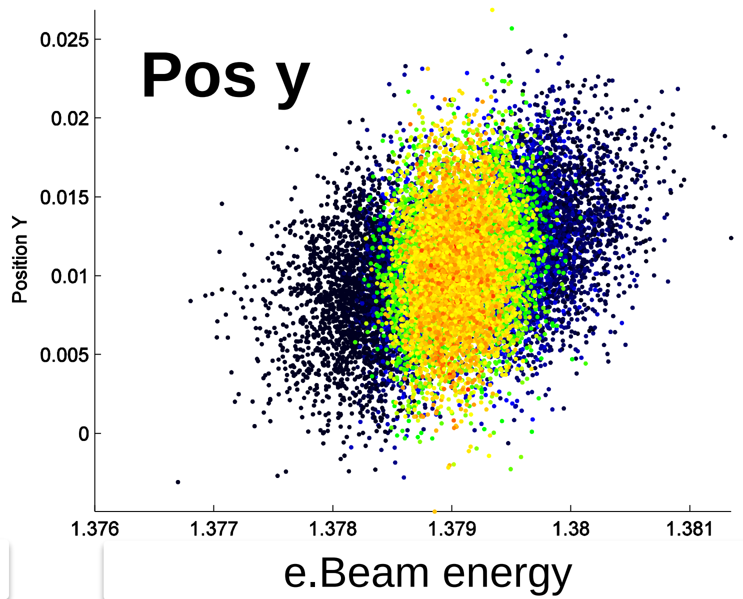
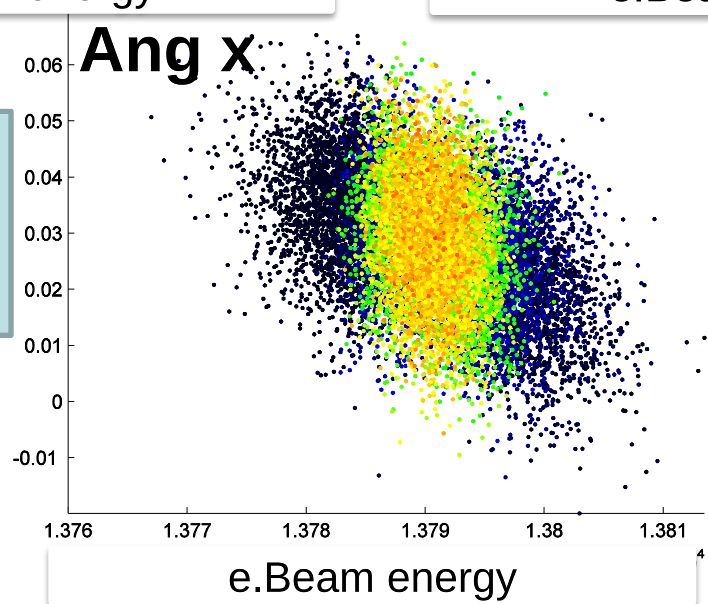
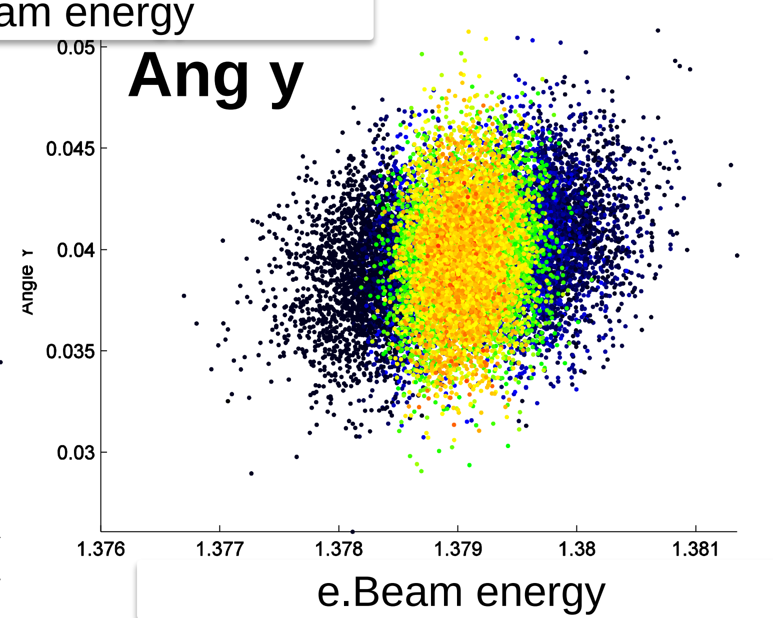
Correlation with shot-to-shot beam parameters (other than beam erngy)





- Electron beam energy jitter dominates the other jitters





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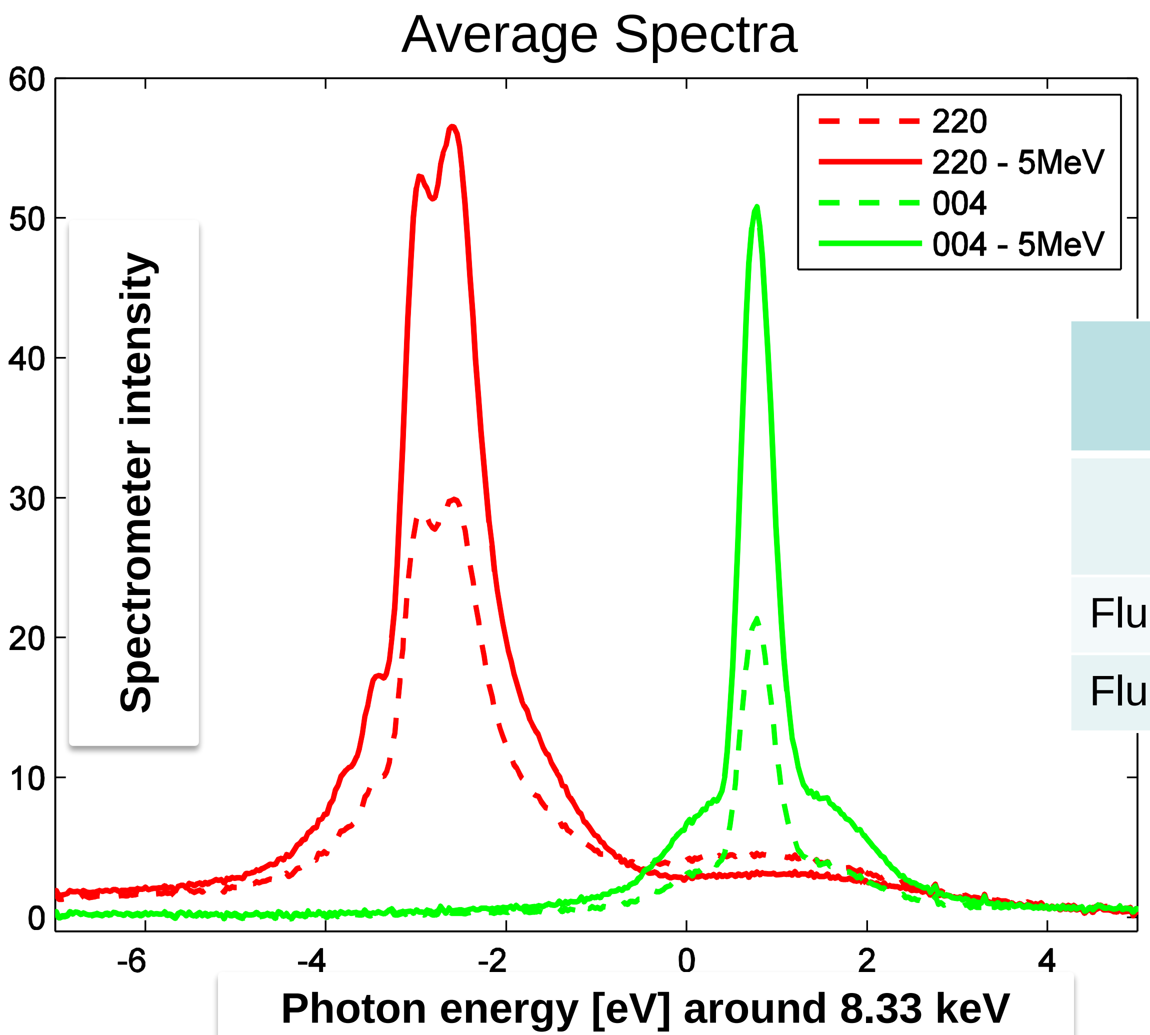
Filtering data on electron beam energy



	Spectral intensity in 2x FWHM Bandwidth	
	All e.beam energies	5 MeV e.b. energy cut
Fluct-220	103%	61%
Fluct-004	185%	110%

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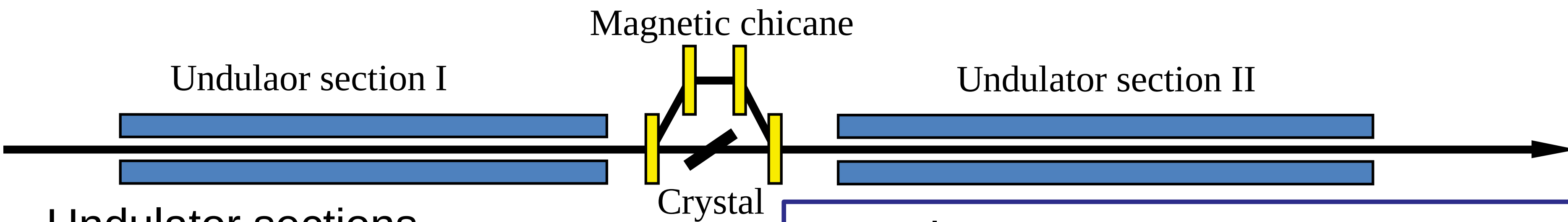
1D FEL simulation



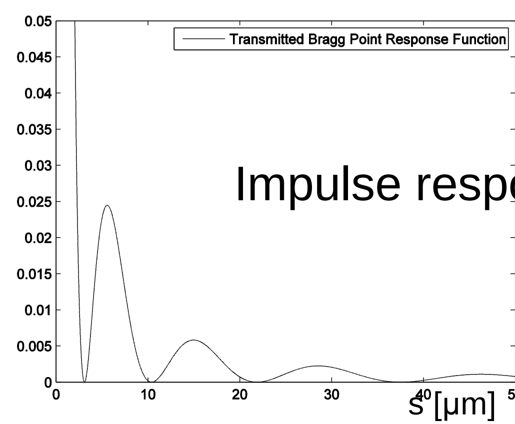
Undulator sections

- 1D FEL code
- Current profile
- Energy profile
- Slice energy spread profile
- Undulator taper

Bunch length	20 fs
current (flat top)	2 kA
Central energy	13695 MeV
Central energy relative deviation	ρ (5×10^{-4})

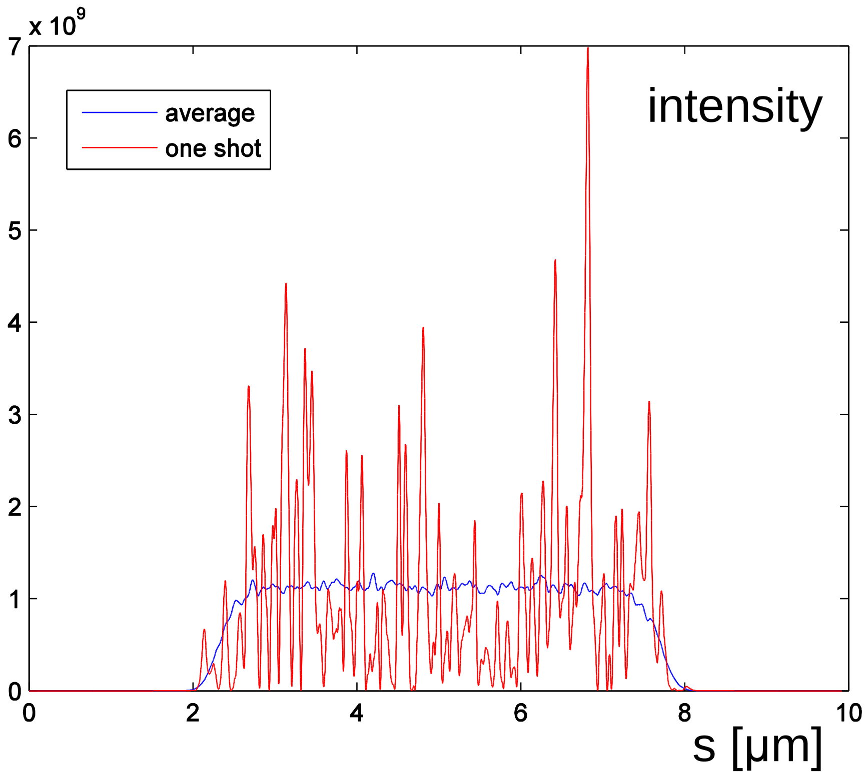
Crystal

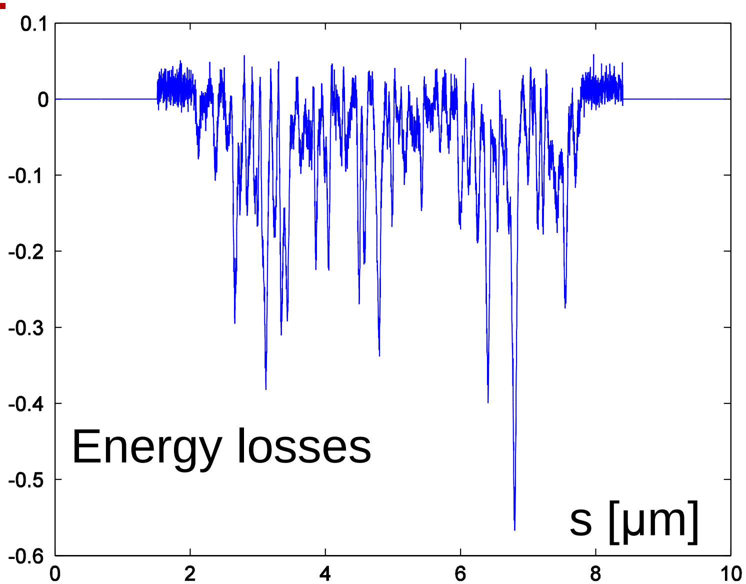
- Uses Yuri Shvyd'ko time-domain formula for forward Bragg diffracted beams (Spatiotemporal response of crystals in x-ray Bragg diffraction P.R. ST AB 2012)
- Crystal thickness 104 μm
- 004, symmetric Bragg @8.333 keV

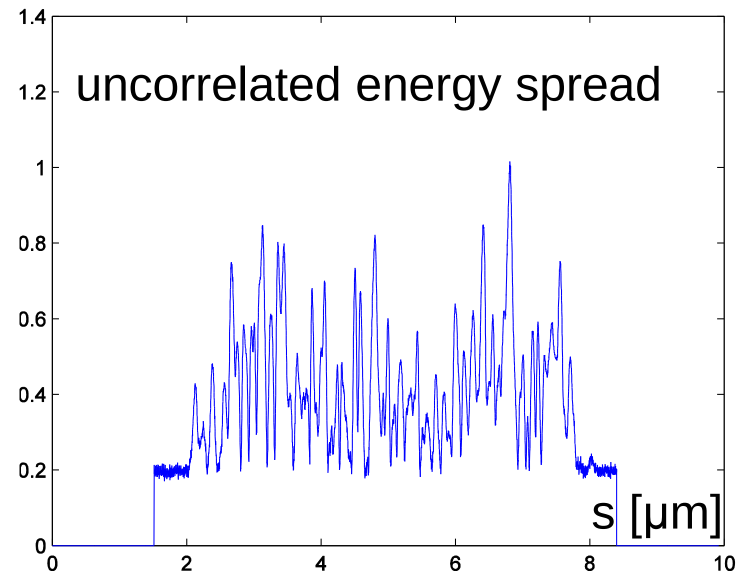


Impulse response function

First undulator section, one single shot







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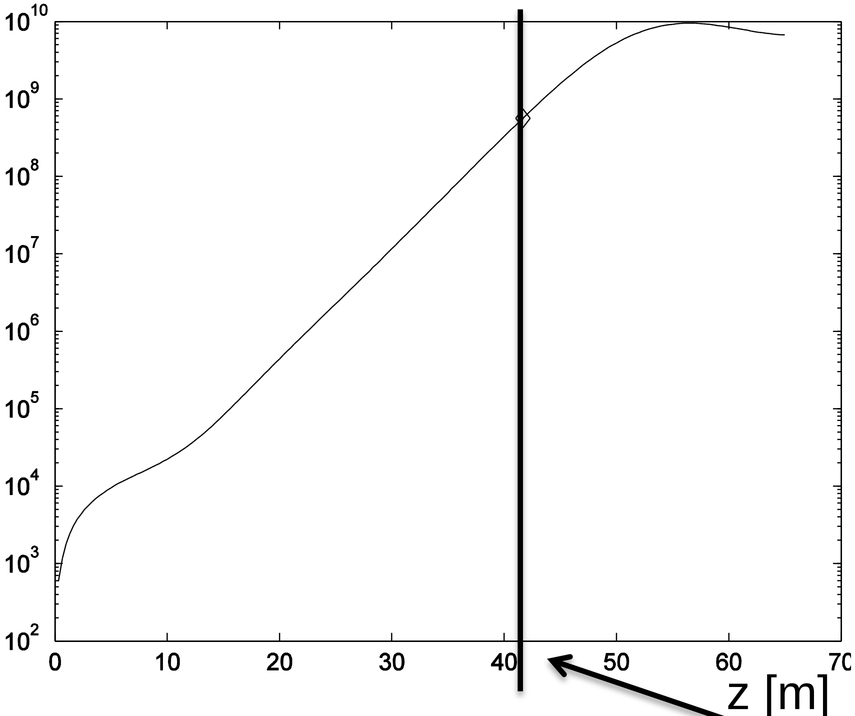
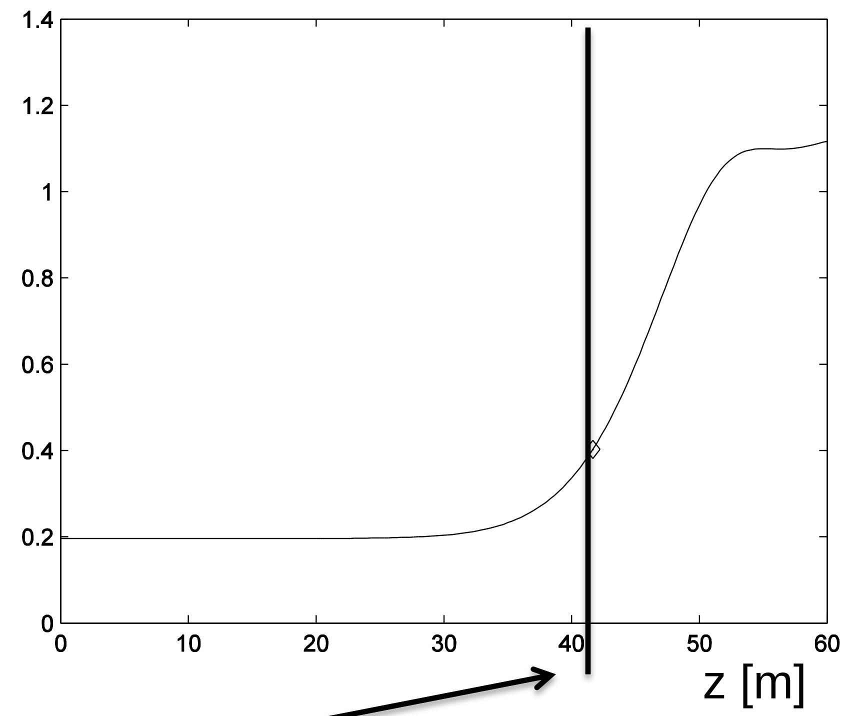
First undulator section, growth curve

Average Power (logscale)



Uncorrelated average energy spread



end of first undulator section

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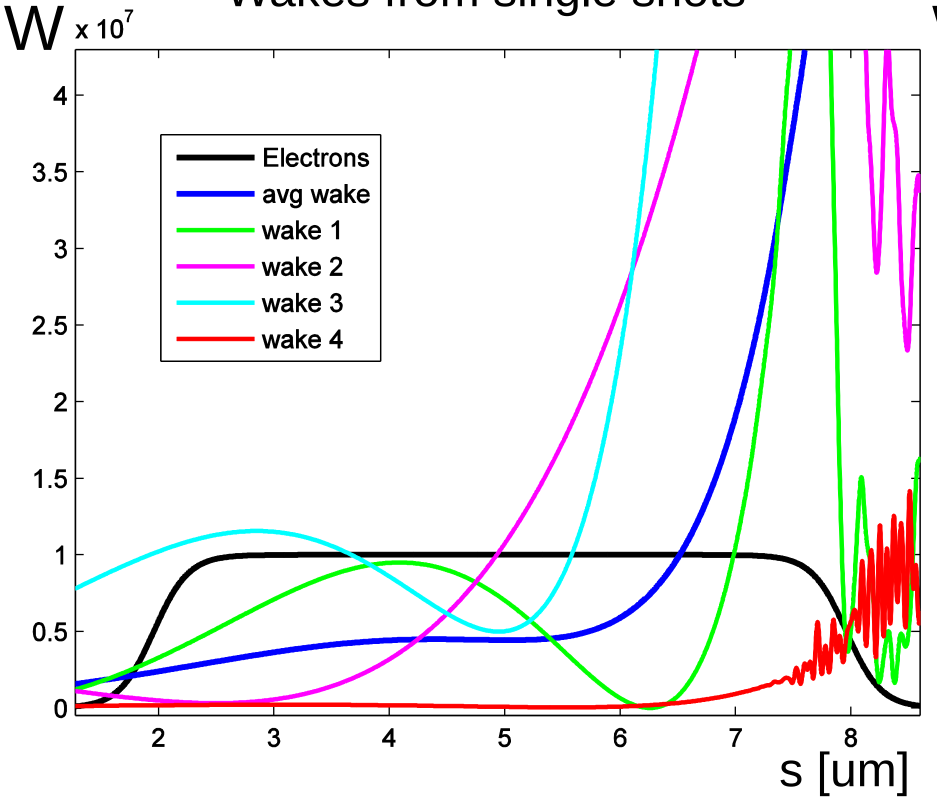
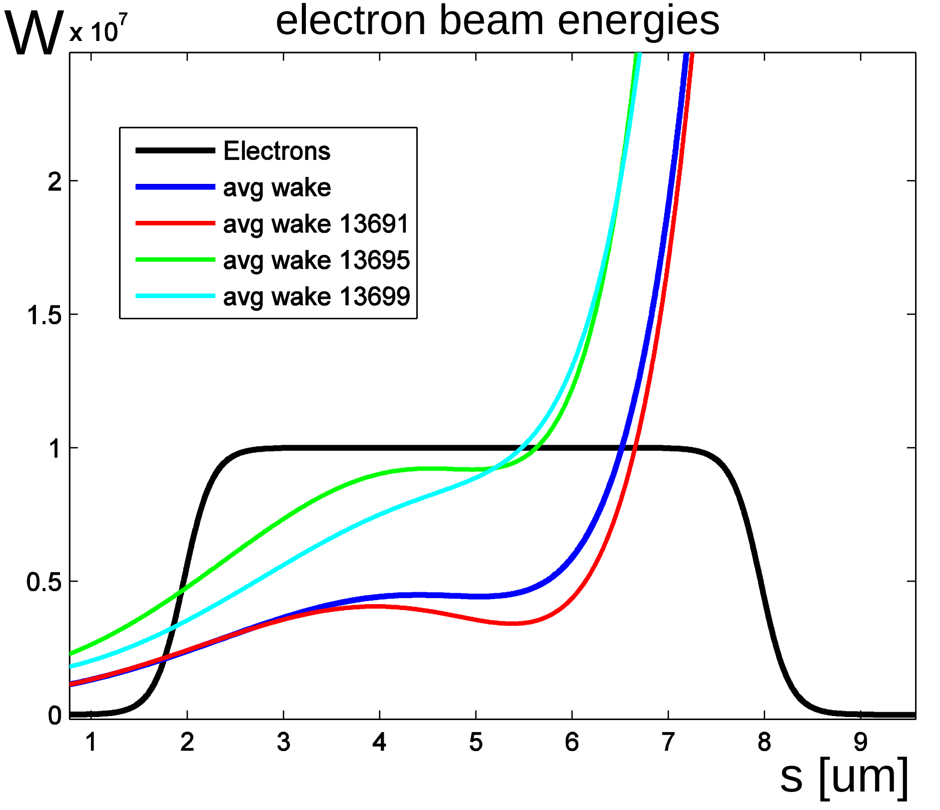
After the crystal

Wakes from single shots



Average wakes around different electron beam energies



- Wake shape changes from shot to shot
- Besides the intensity, the wake is not correlated with electron beam energy

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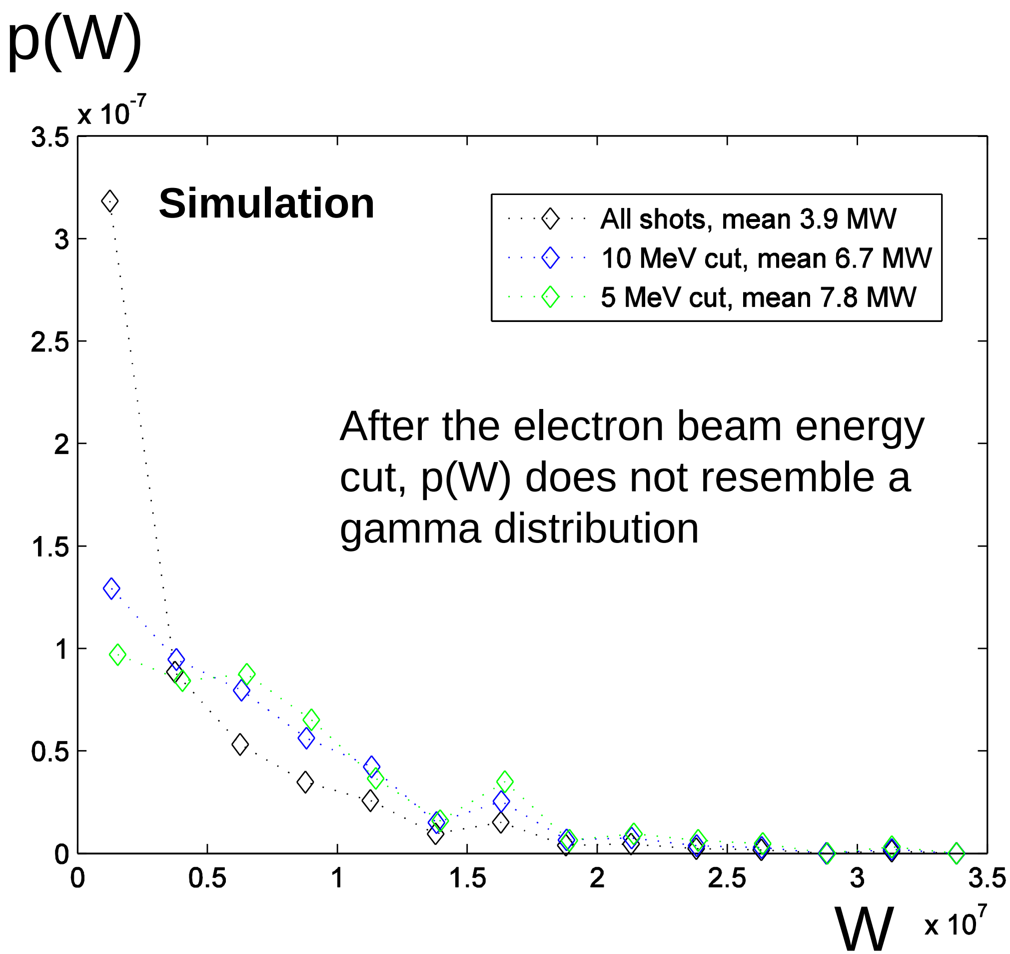
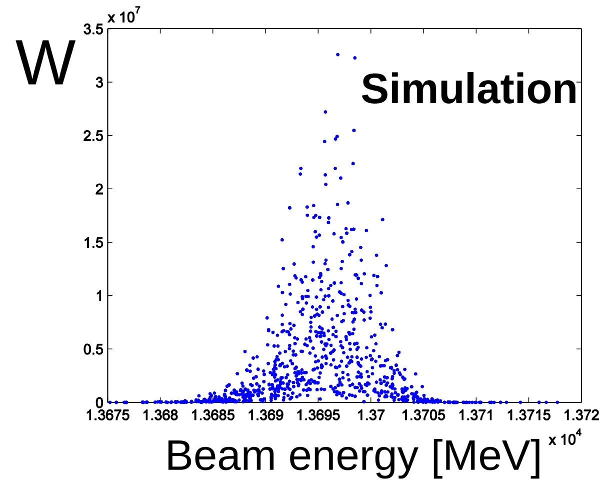
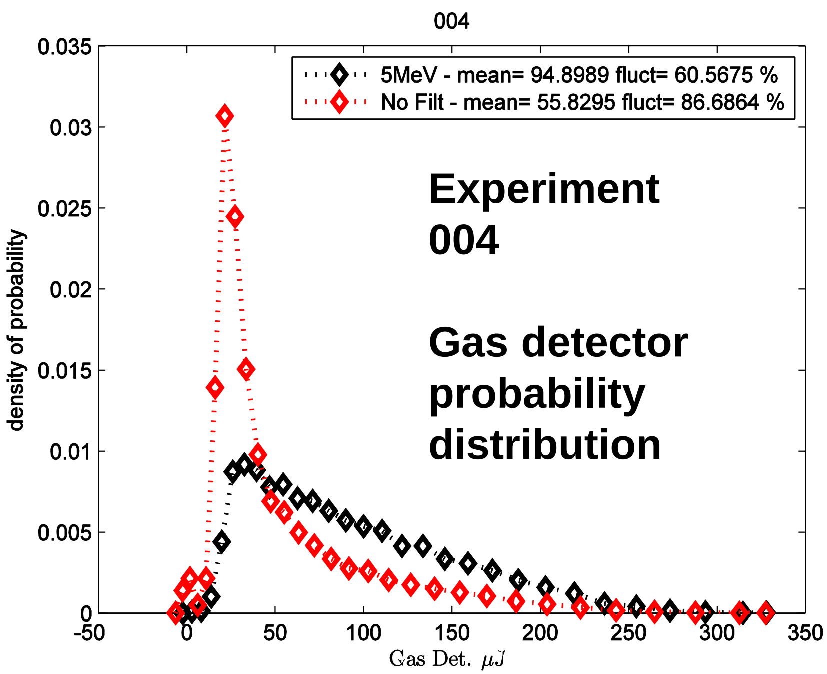
Monochromatic wake, probability distributions







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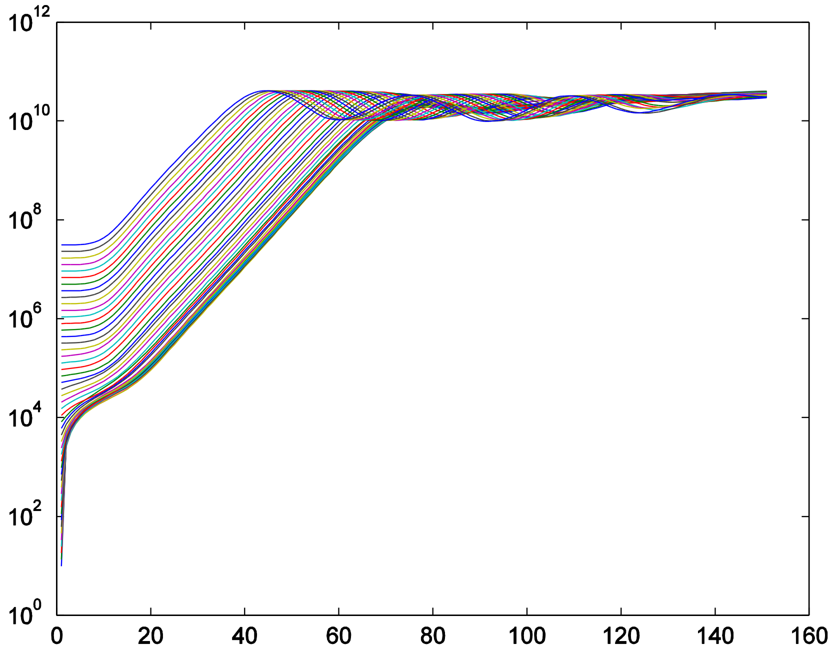
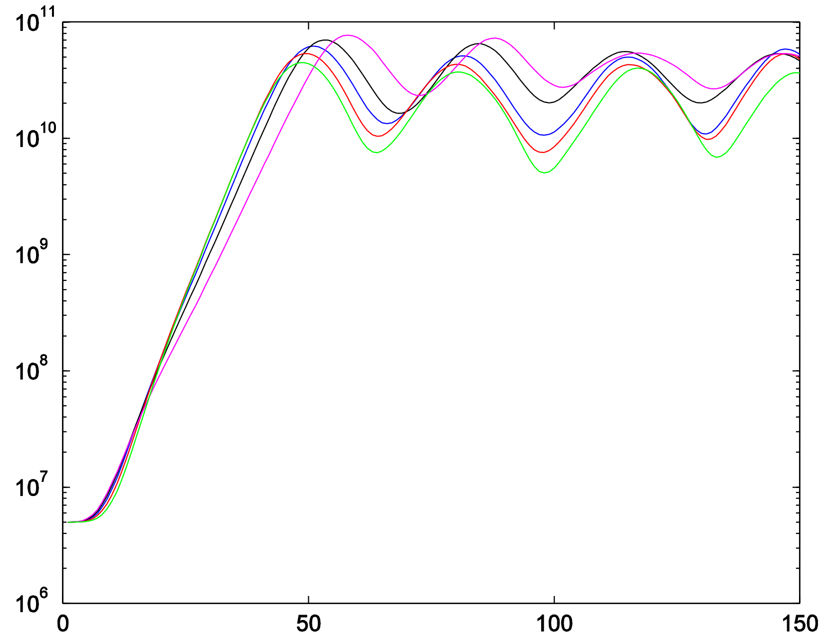
Different seed power, same electron beam energy



Undulator Distance
[Arb. Units]

Same seed power different electron beam energy



Undulator Distance
[Arb. Units]

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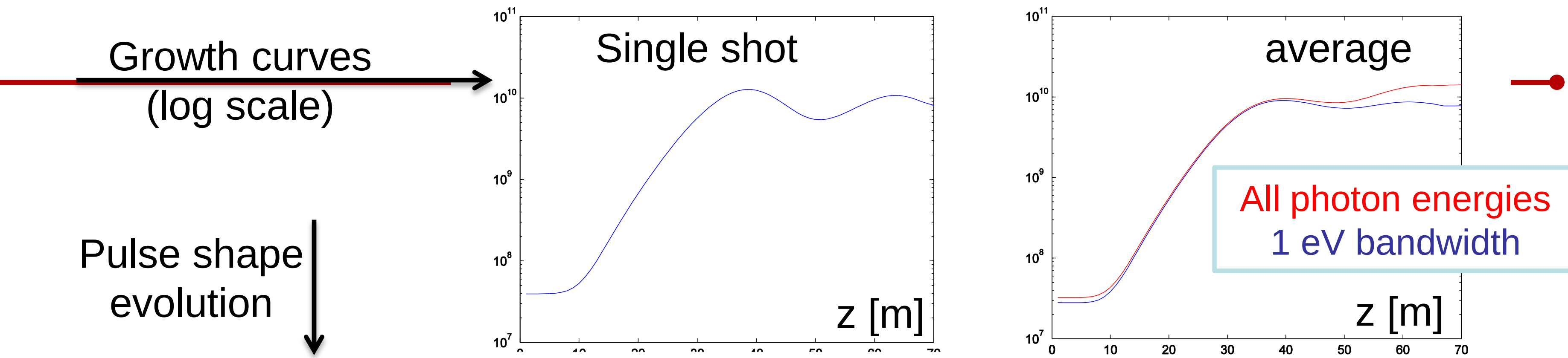
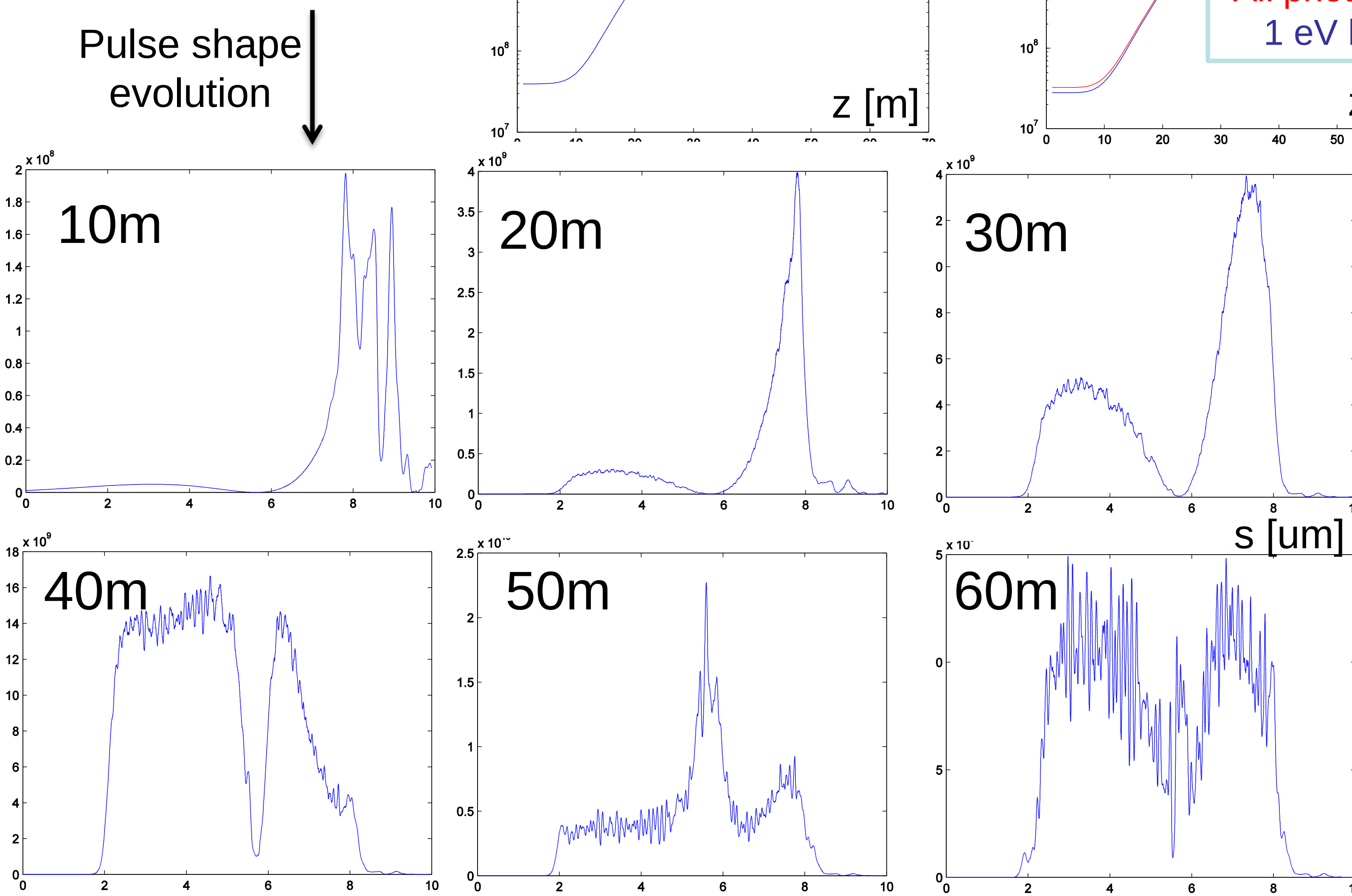
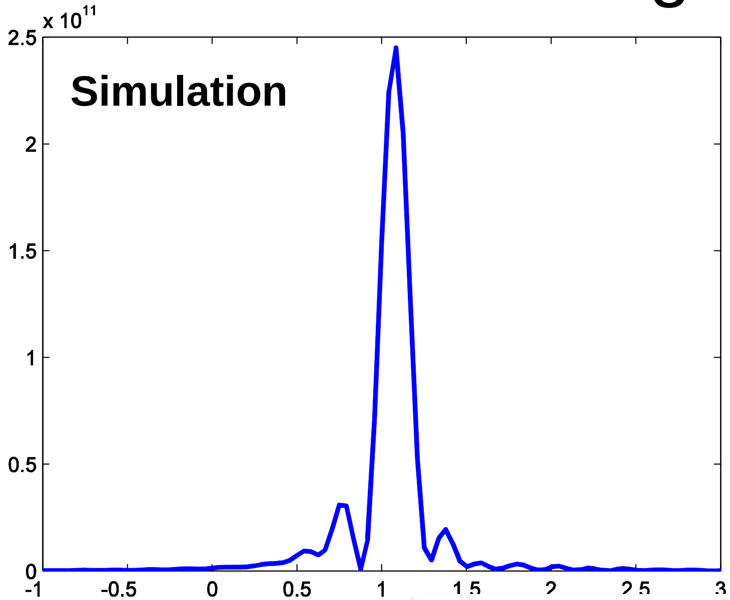
Second undulator section (untapered)

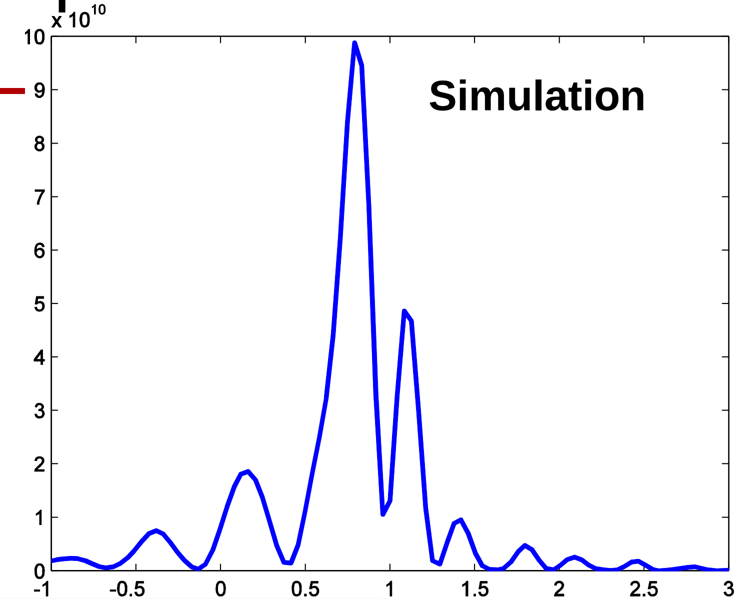




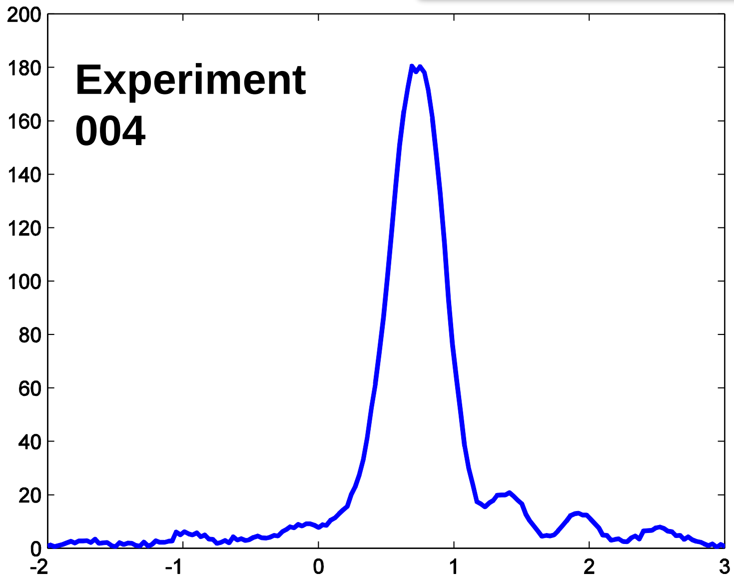
- Profile shape strongly dependent on distance
- Pulse duration seen can be affected

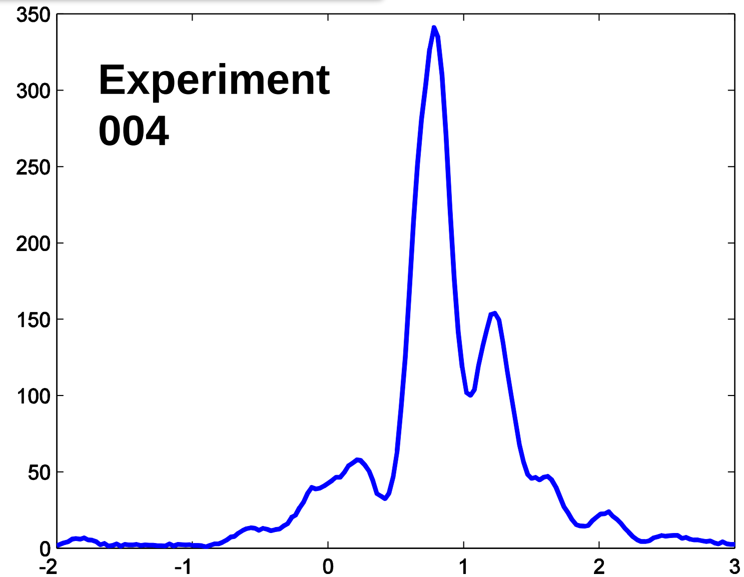
Single shot spectra





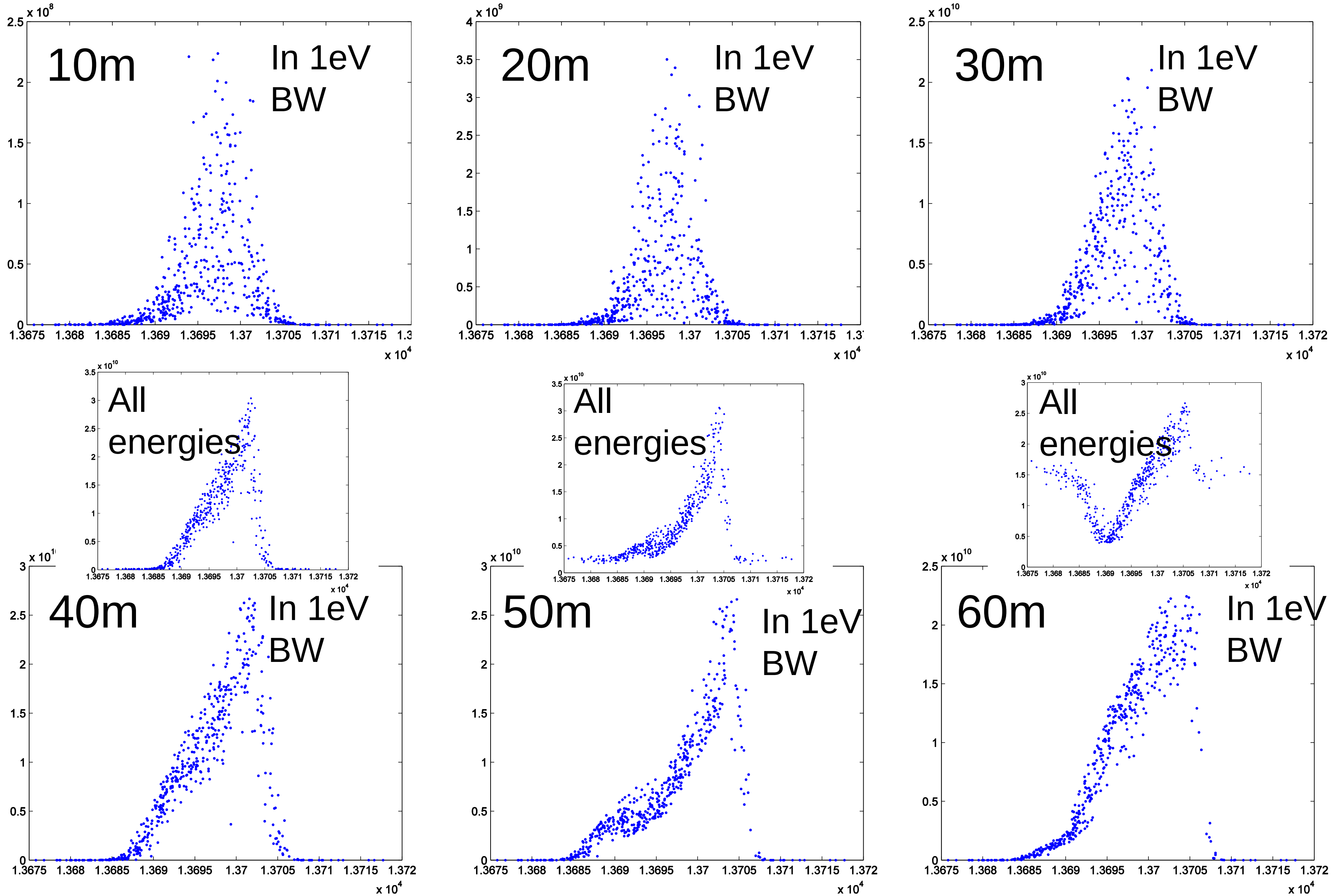
Photon energy [eV] around 8.33 keV





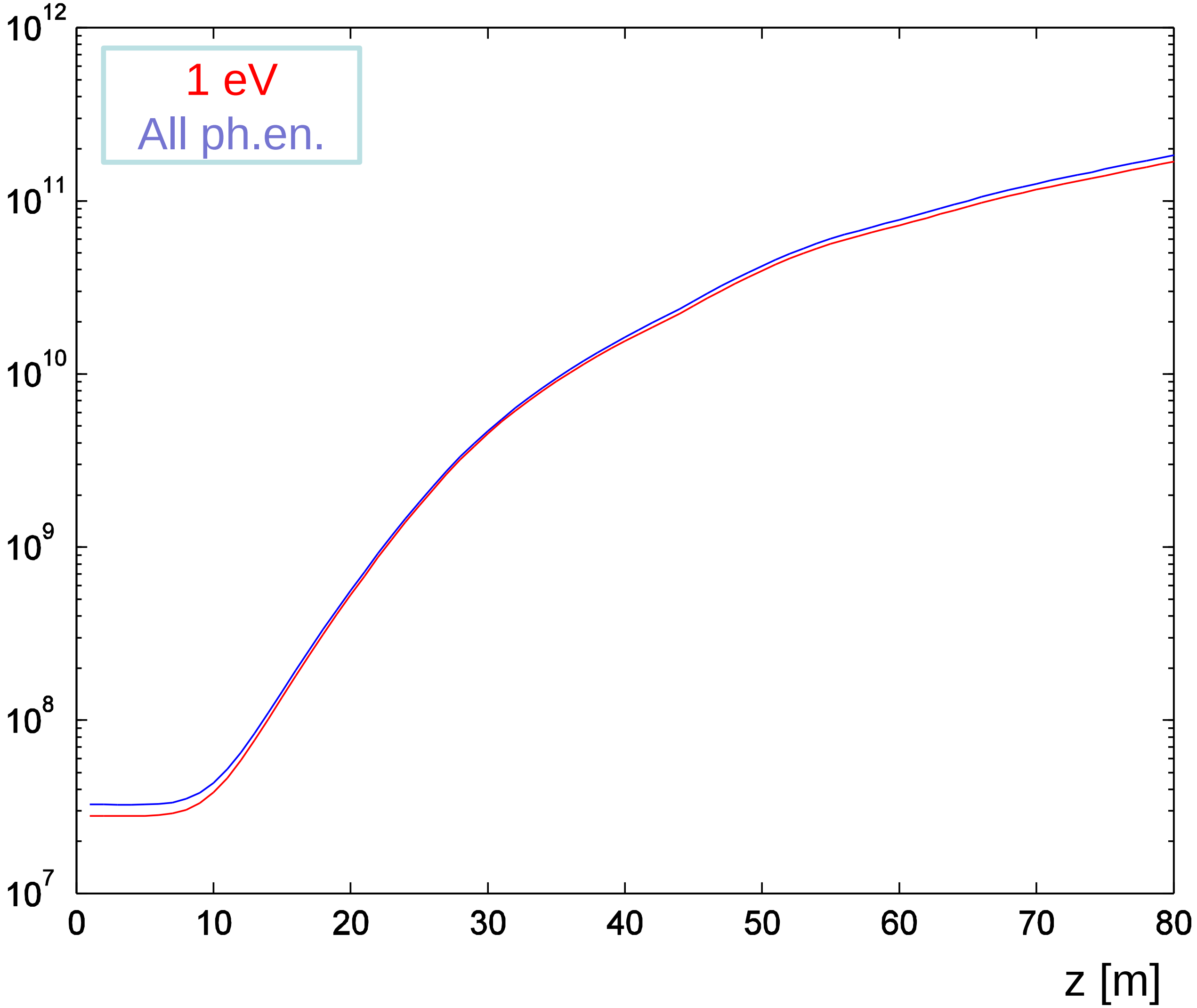
Photon energy [eV] around 8.33 keV

Beam energy vs Self seeded intensity evolution (untapered)



Tapered Radiator

Average Power (logscale)



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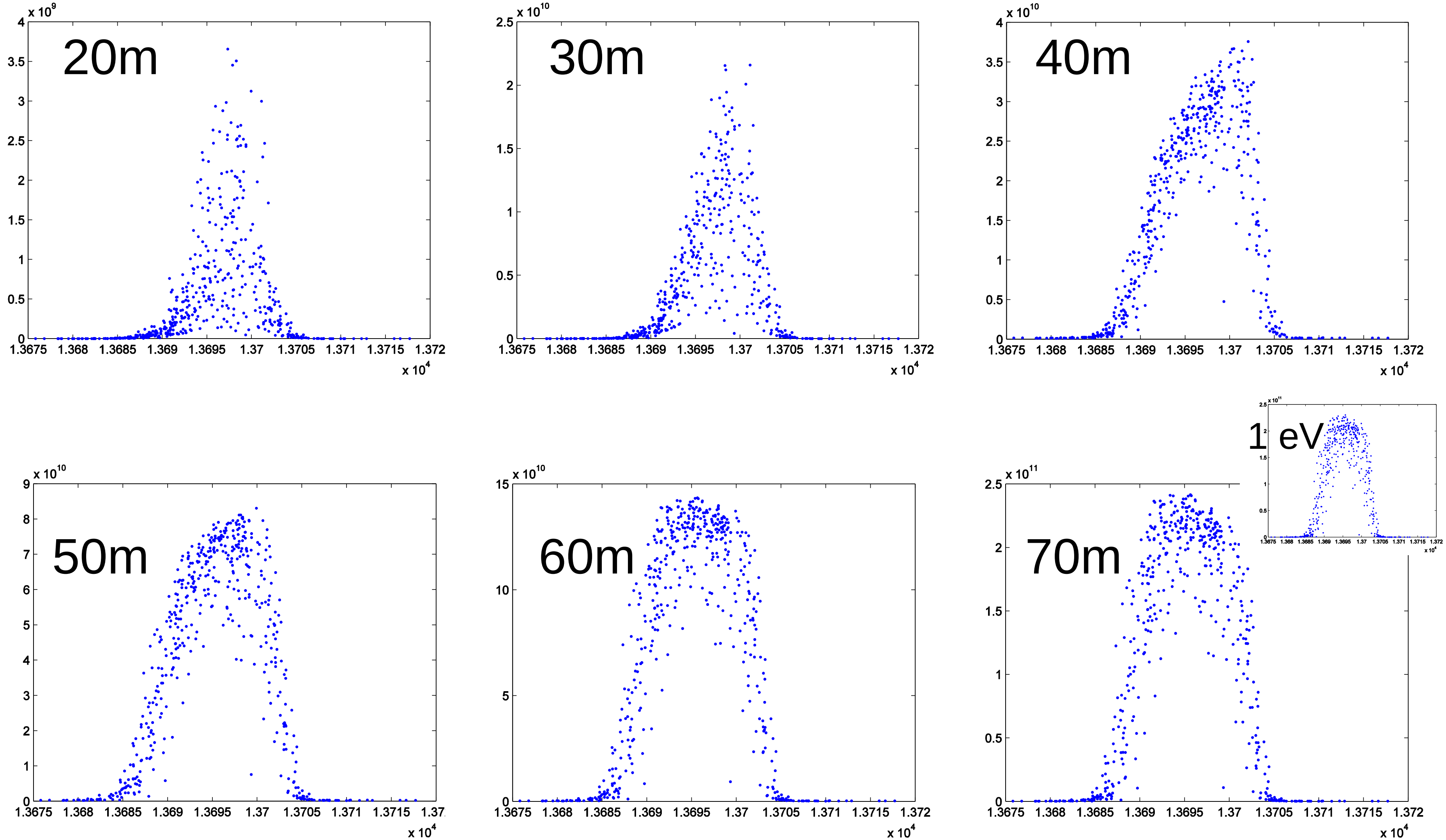
Beam energy vs Self seeded intensity evolution (tapered)



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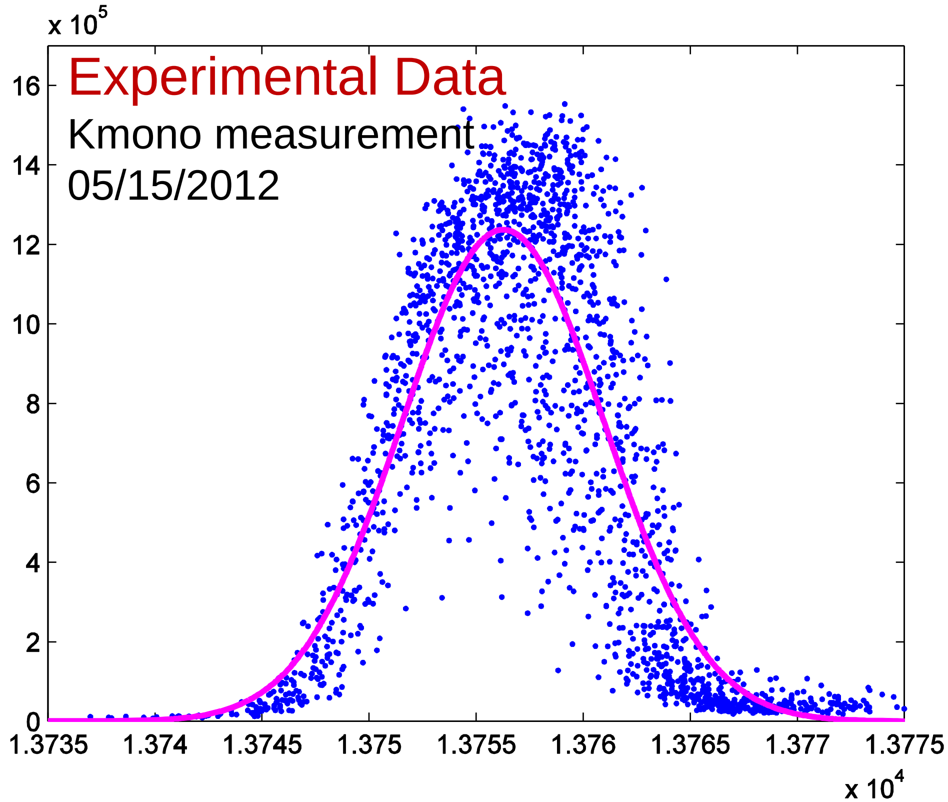
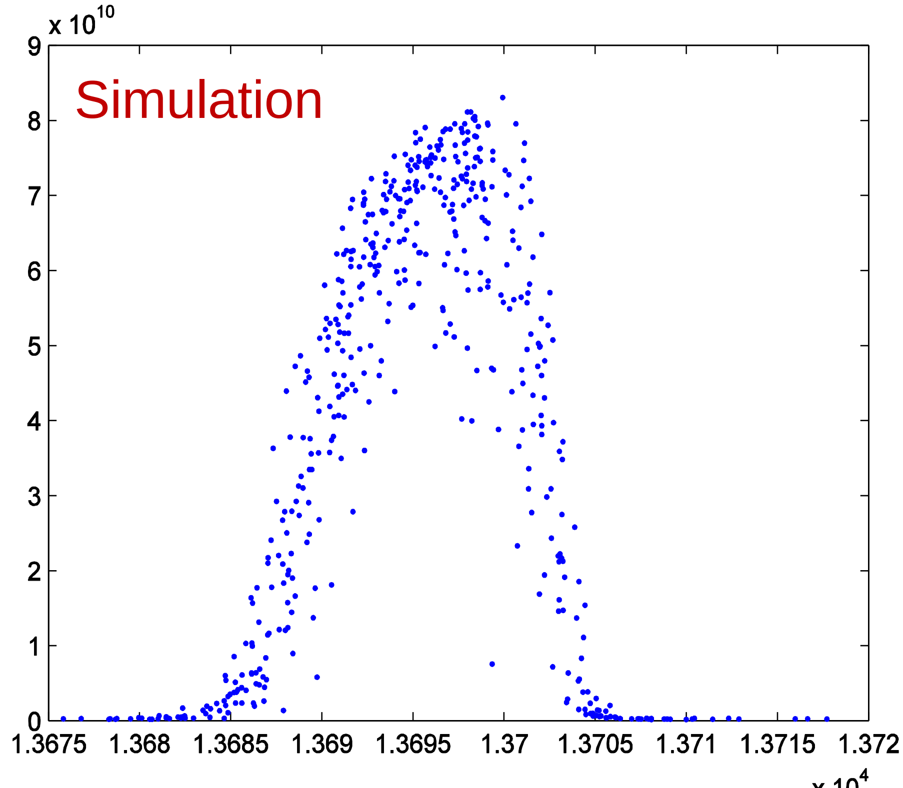
Experiment and simulation comparison





Relative energy rms 7.2 x 10^{-4}

Fluctuations 72%

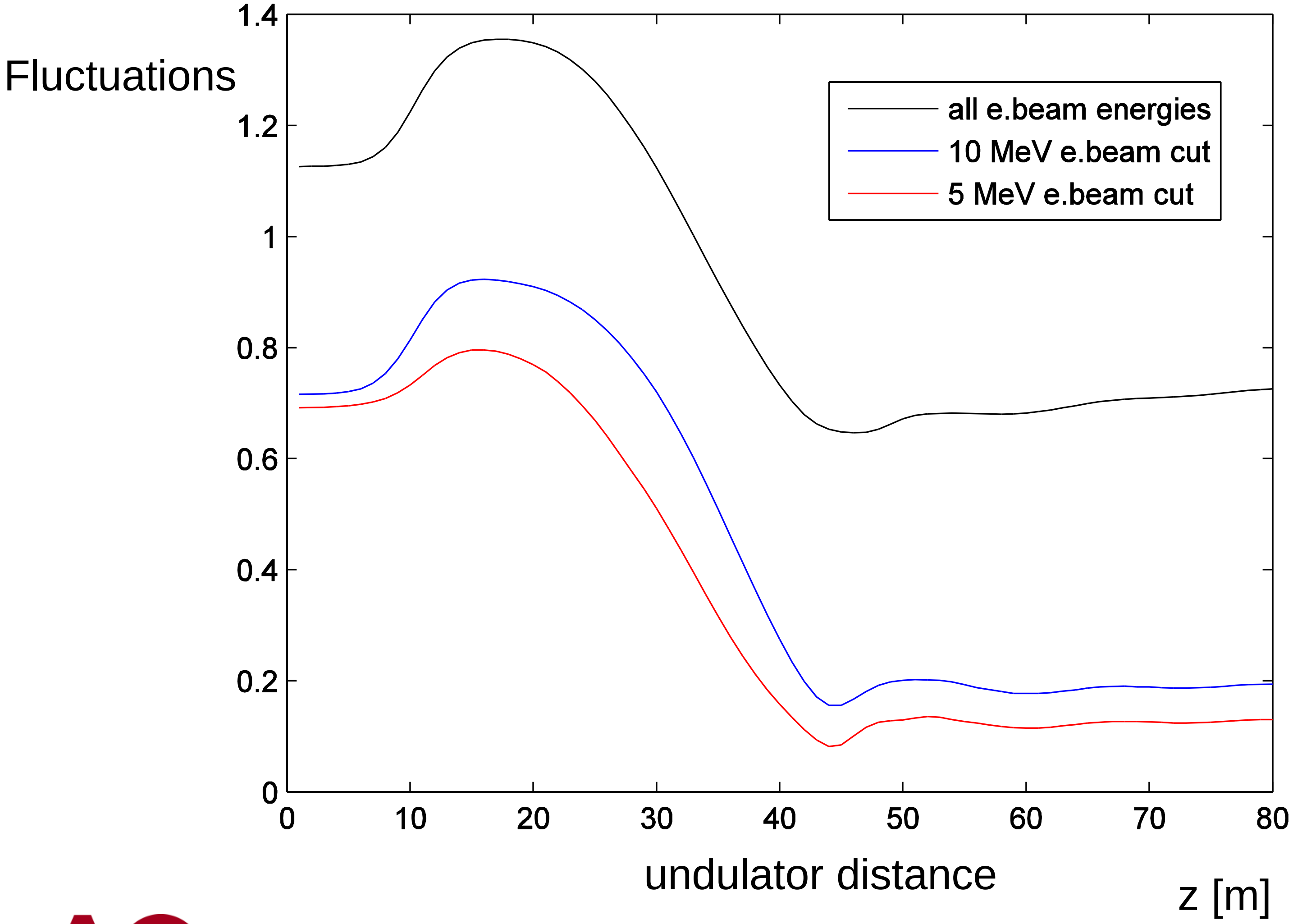
Rho = ~7 x 10^{-4}

Relative energy rms 5 x 10^{-4}

Fluctuations 67%

Rho = 5 x 10^{-4}

Fluctuations vs undulator distance (tapered)



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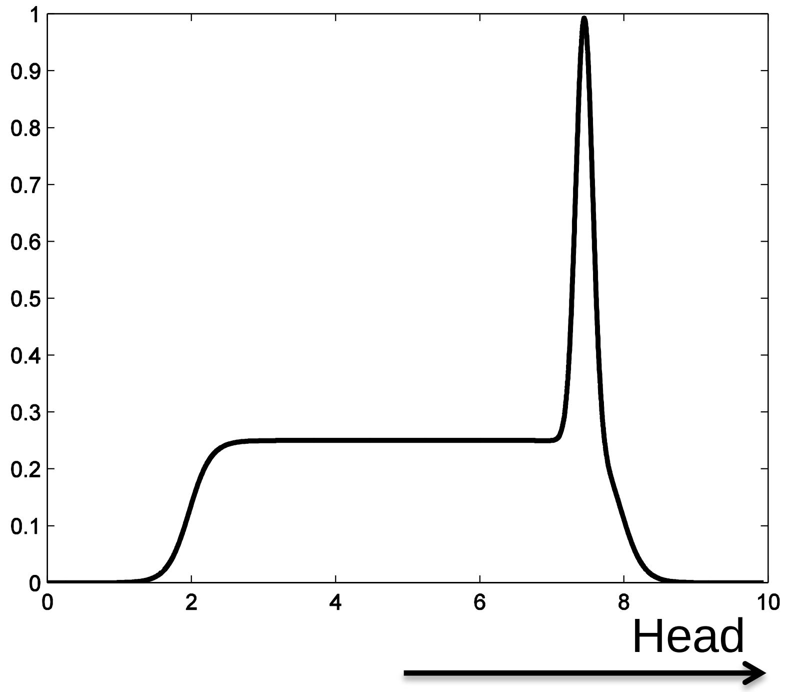
Shaping the electron beam



Big spike draws SASE to saturation in first undulator section.

Pulse duration before the chicane is short, compared to the width
of the “bumps” of the forward Bragg diffraction response function.

The wake shape is the same for different shots.

The spike area has too large energy spread in the second undulator to lase.

Flat tail can produce a clean self seeded spike in the second undulator section.

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Summary

- HXR Self Seeding allows to deliver beams with more photons in a narrow bandwidth compared to SASE.

  Intensity stability is not as good as for SASE.
  Often the spectrum consists of more than a single spike.

- Electron beam energy jitter dominates other measured jitters for HXRSS @LCLS.

- Simple 1D simulation code can reproduce well the experimental results.