# Pulse duration reconstruction: based on FEL spectra

Svitozar Serkez,
Simulation of Photon Fields (SPF)

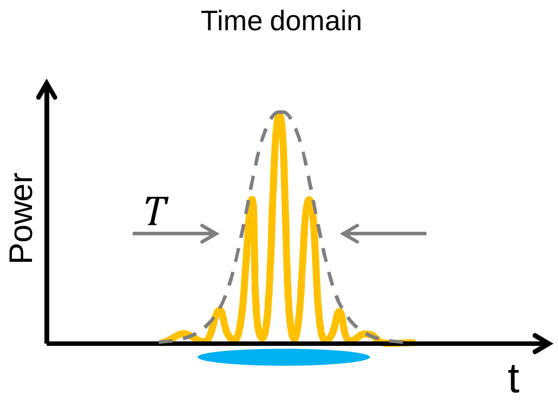
In collaboration with Naresh Kujala,
X-ray Photon Diagnostics (XPD)

# Outline

- Principle of spectrum-based FEL pulse measurement
- Present 2 methods
- HIREX data analysis
- Pulse length at XFEL.EU
- Conclusions

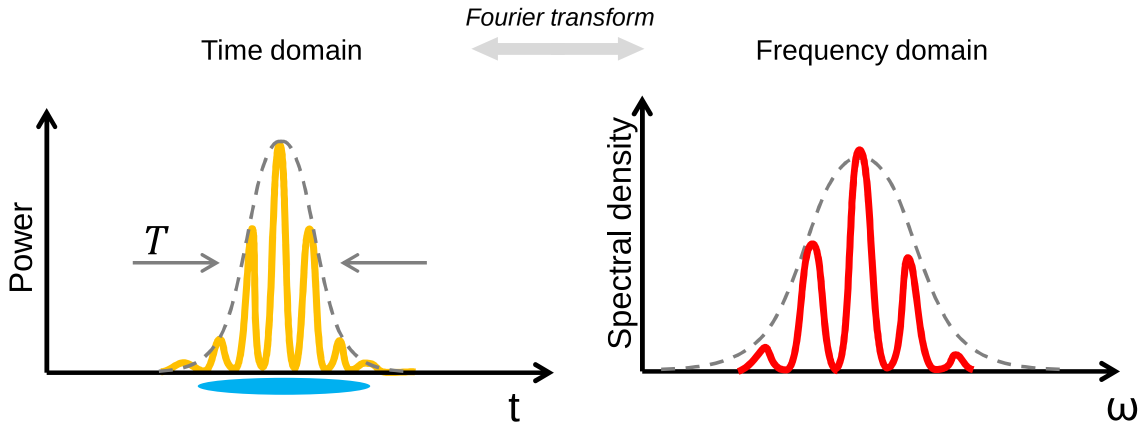
# Principle

- We want to know pulse duration
  - Hard to measure directly

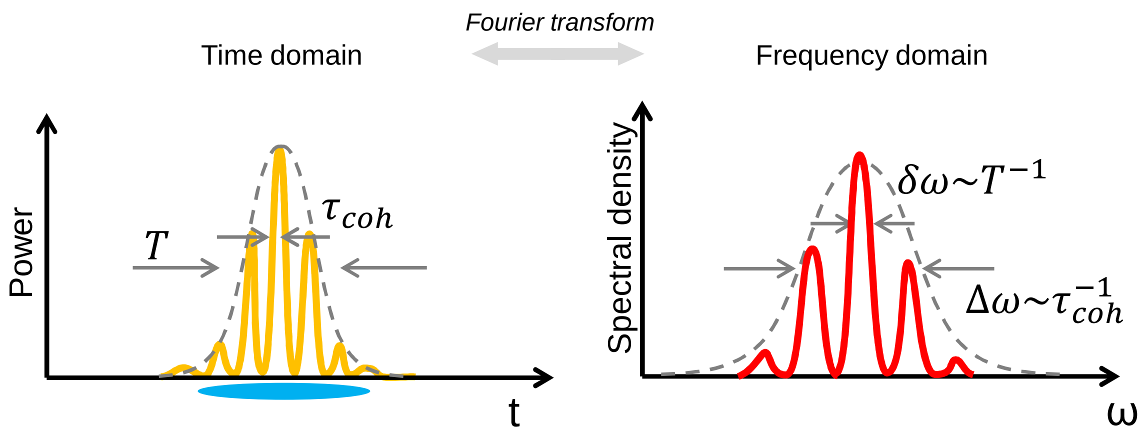


# Principle

- We want to know pulse duration
  - Hard to measure directly

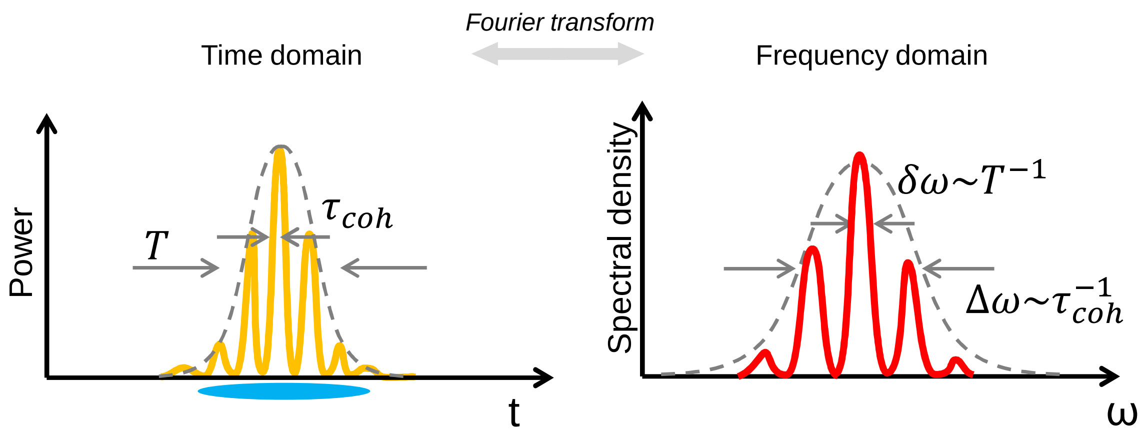


# Principle




- We want to know pulse duration
  - Hard to measure directly
- One can exploit connection between time and frequency domains:
  - With of spectral spikes is inversely proportional to pulse duration and vice-versa
  - Spectral correlation function is calculated

# Principle

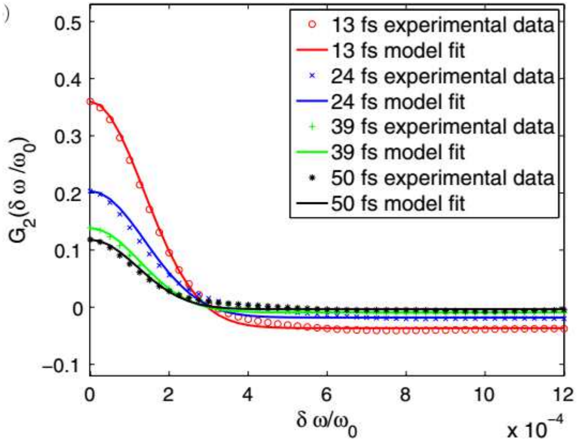



- We want to know pulse duration
  - Hard to measure directly
- One can exploit connection between time and frequency domains:
  - With of spectral spikes is inversely proportional to pulse duration and vice-versa
  - Spectral correlation function is calculated

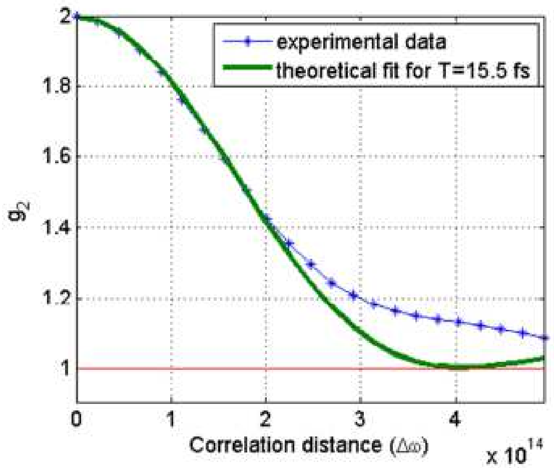
- Measure $g_2(\Delta\omega) = \frac{\langle I(\omega-\Delta\omega/2)\ I(\omega+\Delta\omega/2)\rangle}{\langle I(\omega-\Delta\omega/2)\rangle\ \langle I(\omega+\Delta\omega/2)\rangle}$
- Fit to theory

# It was done before

- at LCLS




- at FLASH




PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **15**, 030705 (2012)

**Femtosecond x-ray free electron laser pulse duration measurement from spectral correlation function**

A. A. Lutman,* Y. Ding, Y. Feng, Z. Huang, M. Messerschmidt, J. Wu, and J. Krzywinski

*SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*

(Received 11 July 2011; published 13 March 2012)

**Ivan Franko Lviv National University**

**Deutsches Electronen Synchroron**

**Analysis of statistical properties of FLASH radiation in spectral domain to characterize pulse duration**

**Master thesis**

**Svitozar Serkez**

**Supervised by:**

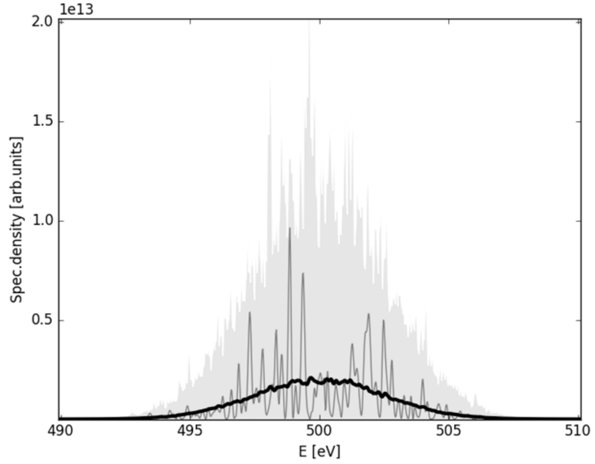
**Prof. Anatoliy Voloshynovskiy**

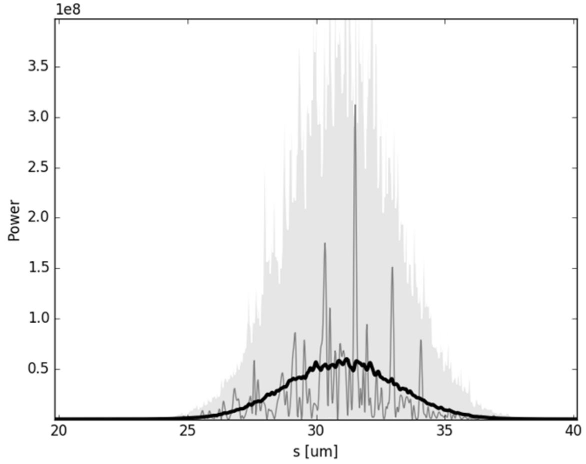
**Dr. Natalia Gerasimova**

**Lviv-Hamburg 2012**

# Simulation (SASE with Gaussian envelopes)

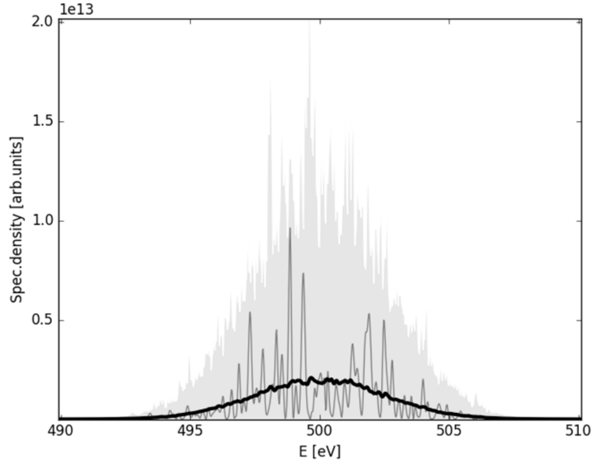
- Simulated Gaussian SASE pulse
  - 500 eV
  - Length 5 um (16.5 fs) fwhm
  - Bandwidth 6 eV
  - 500 events



# Simulation (SASE with Gaussian envelopes)

- Simulated Gaussian SASE pulse
  - 500 eV
  - Length 5 um (16.5 fs) fwhm
  - Bandwidth 6 eV
  - 500 events

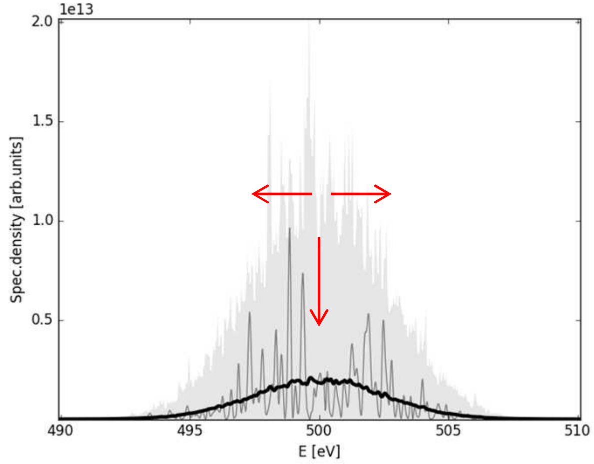


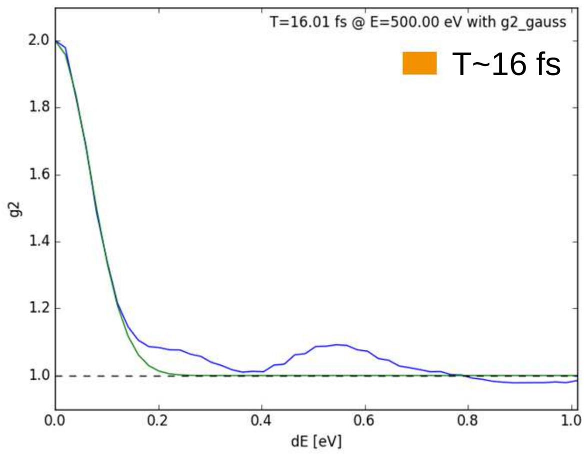

- $$g_2(\Delta\omega) = \frac{\langle I(\omega-\Delta\omega/2)\ I(\omega+\Delta\omega/2)\rangle}{\langle I(\omega-\Delta\omega/2)\rangle\ \langle I(\omega+\Delta\omega/2)\rangle}$$

# Simulation (SASE with Gaussian envelopes)

- Simulated Gaussian SASE pulse
  - 500 eV
  - Length 5 um (16.5 fs) fwhm
  - Bandwidth 6 eV
  - 500 events

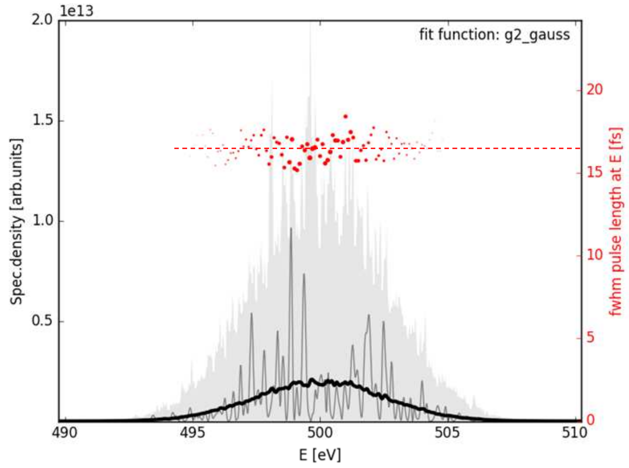
- $$g_2(\Delta\omega) = \frac{\langle I(\omega-\Delta\omega/2)\ I(\omega+\Delta\omega/2)\rangle}{\langle I(\omega-\Delta\omega/2)\rangle\ \langle I(\omega+\Delta\omega/2)\rangle}$$

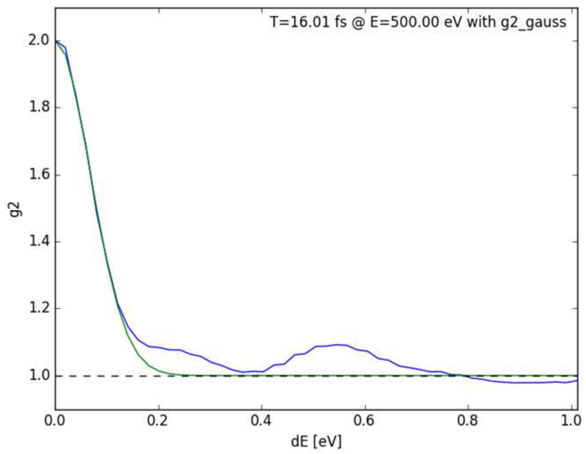


# Simulation (SASE with Gaussian envelopes)

- Simulated Gaussian SASE pulse
  - 500 eV
  - Length 5 um (16.5 fs) fwhm
  - Bandwidth 6 eV
  - 500 events



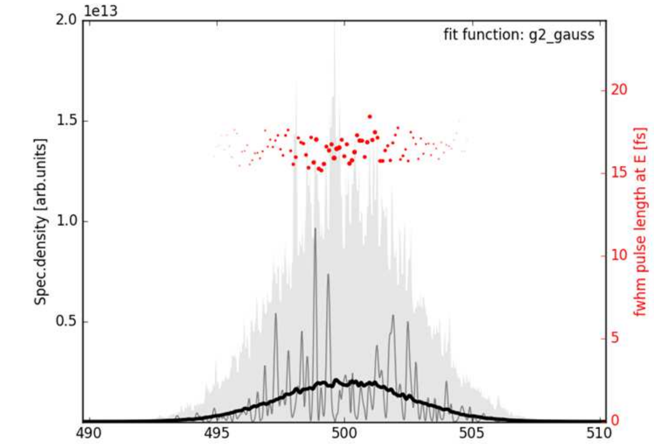

- $$g_2(\Delta\omega) = \frac{\langle I(\omega - \Delta\omega/2)\ I(\omega + \Delta\omega/2)\rangle}{\langle I(\omega - \Delta\omega/2)\rangle\ \langle I(\omega + \Delta\omega/2)\rangle}$$

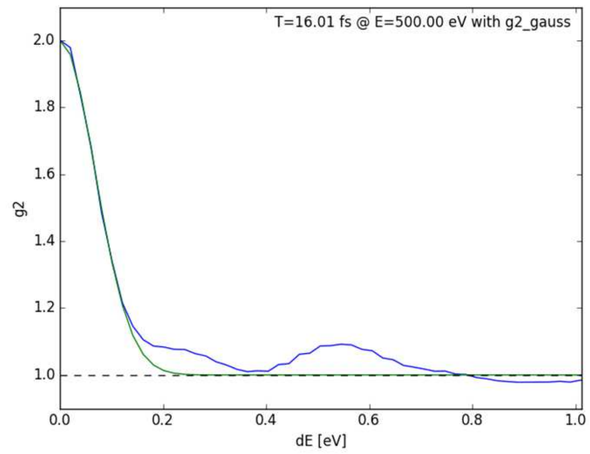
# Simulation (SASE with Gaussian envelopes)

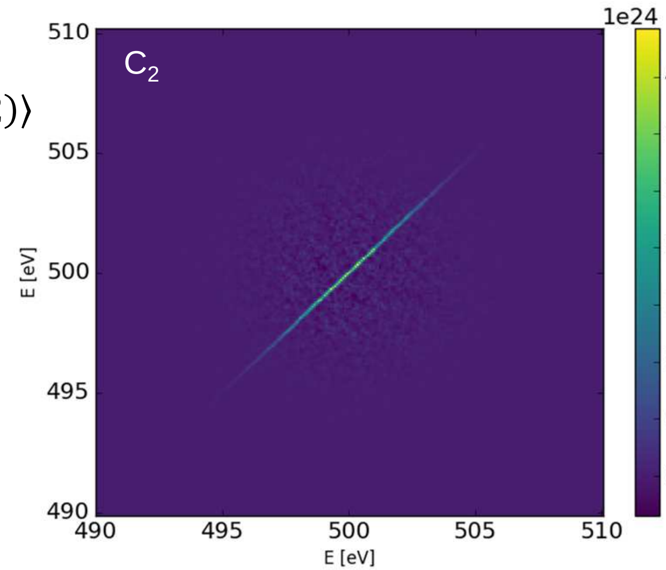
- Simulated Gaussian SASE pulse
  - 500 eV
  - Length 5 um (16.5 fs) fwhm
  - Bandwidth 6 eV
  - 500 events

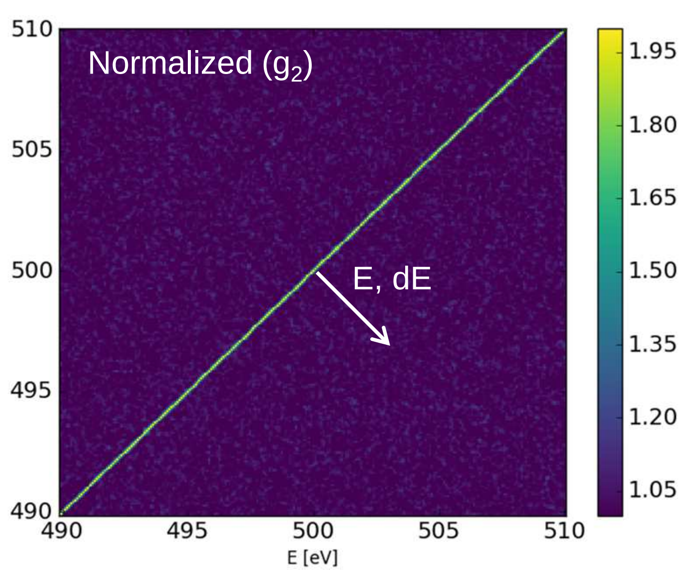
- $$g_2(\Delta\omega) = \frac{\langle I(\omega-\Delta\omega/2)\ I(\omega+\Delta\omega/2)\rangle}{\langle I(\omega-\Delta\omega/2)\rangle\ \langle I(\omega+\Delta\omega/2)\rangle}$$

- $$C_2(\Delta\omega) = \langle I(\omega-\Delta\omega/2)\ I(\omega+\Delta\omega/2)\rangle - \langle I(\omega-\Delta\omega/2)\rangle\ \langle I(\omega+\Delta\omega/2)\rangle$$



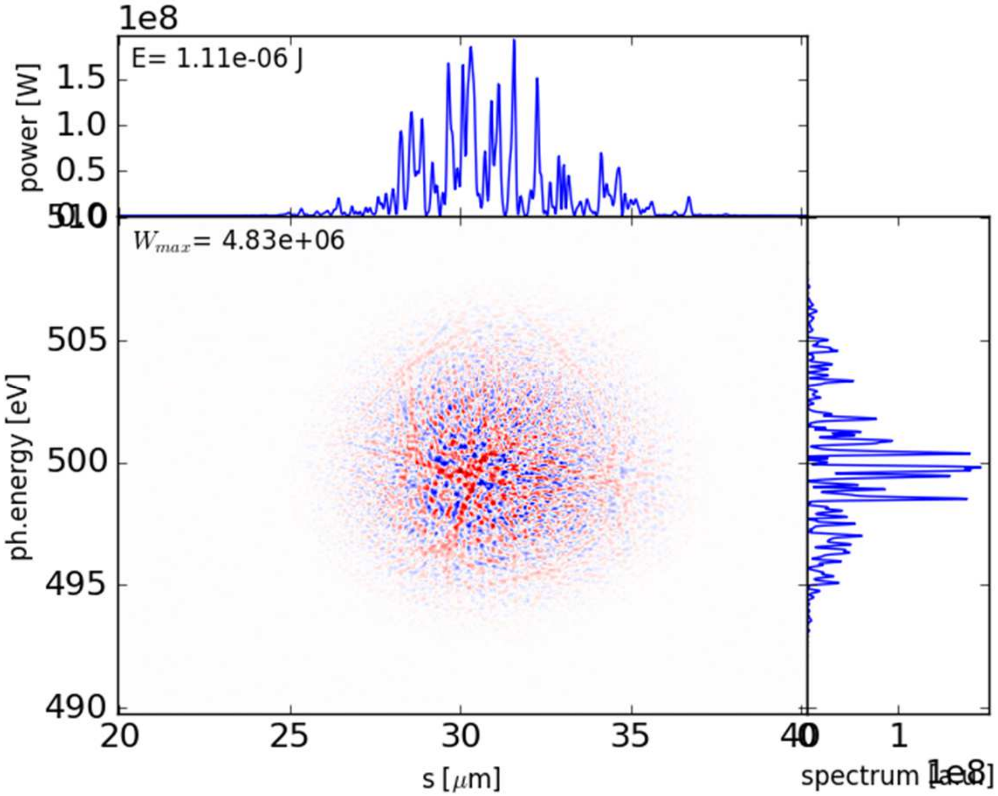



# Simulation (SASE with Gaussian envelopes)

- Wigner distribution (kind of spectrogram)

  - Single-shot

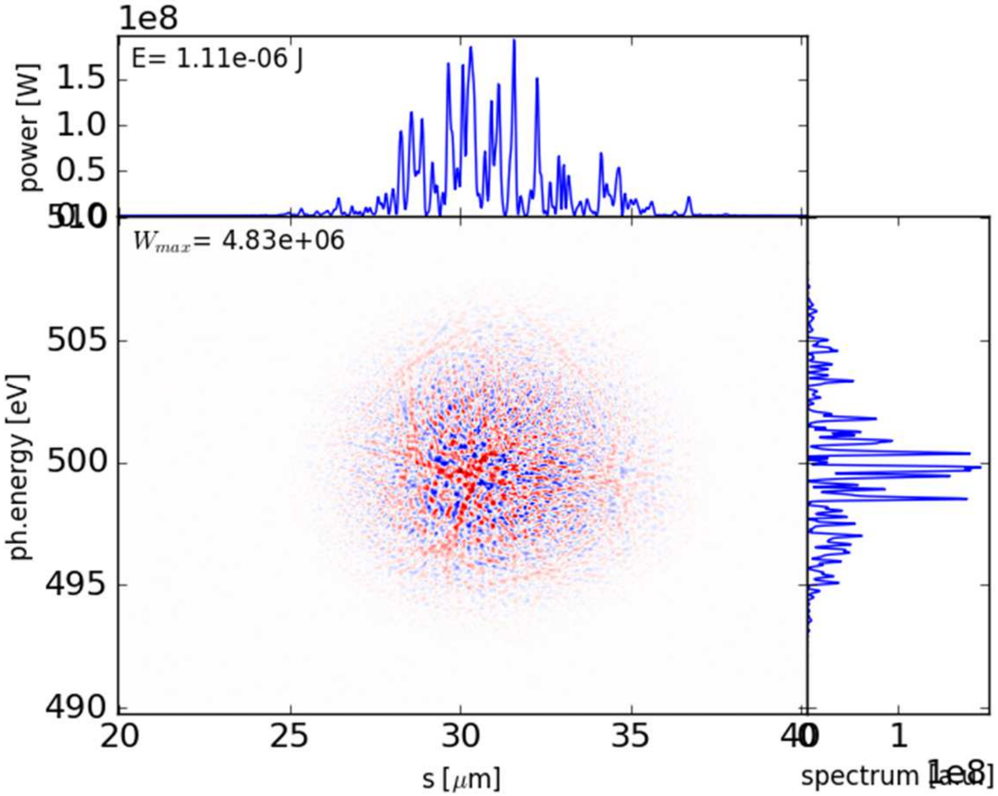



.

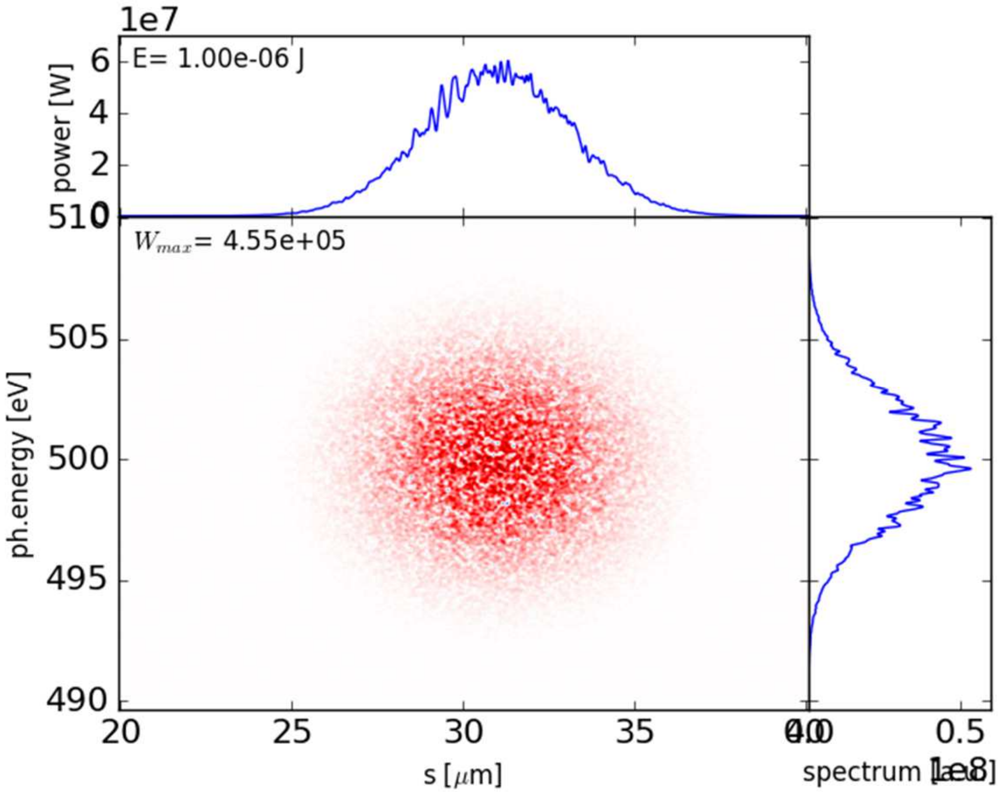
# Simulation (SASE with Gaussian envelopes)

- Wigner distribution (kind of spectrogram)

- Single-shot



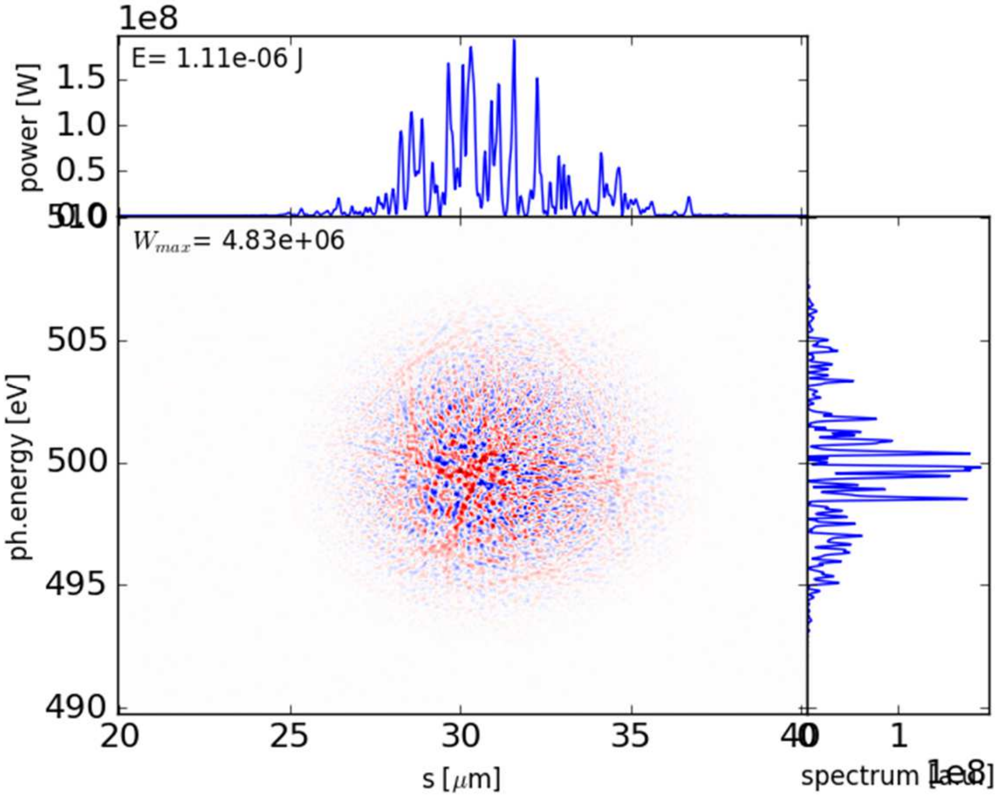

- Averaged



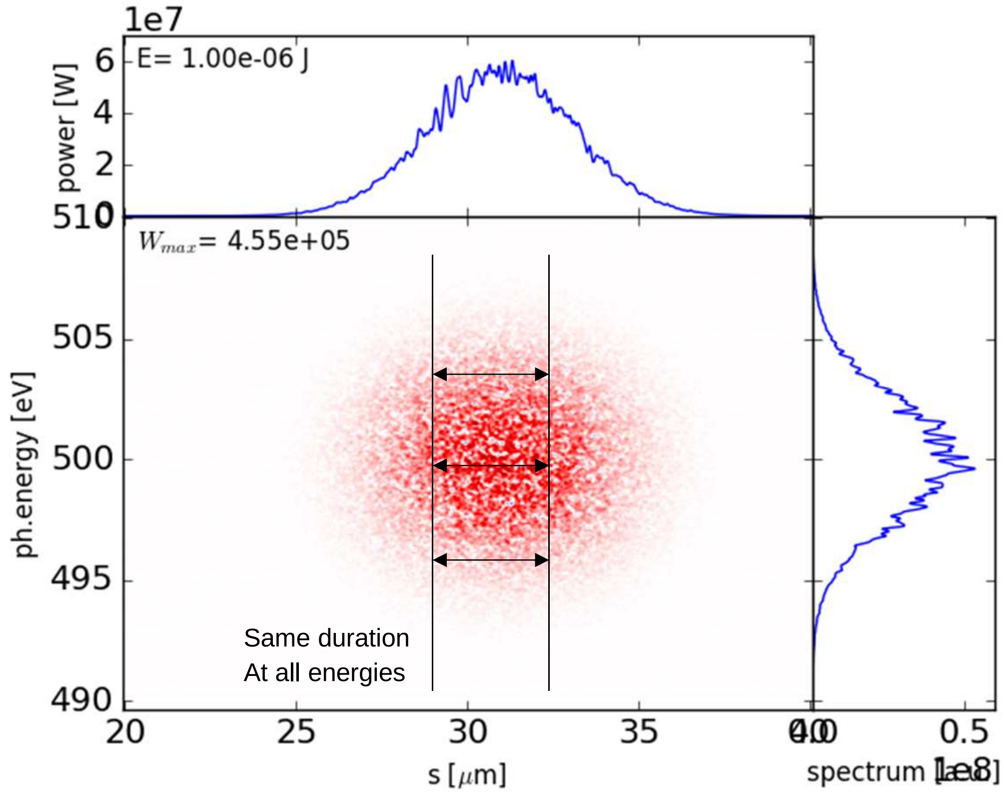
# Simulation (SASE with Gaussian envelopes)

- Wigner distribution (kind of spectrogram)

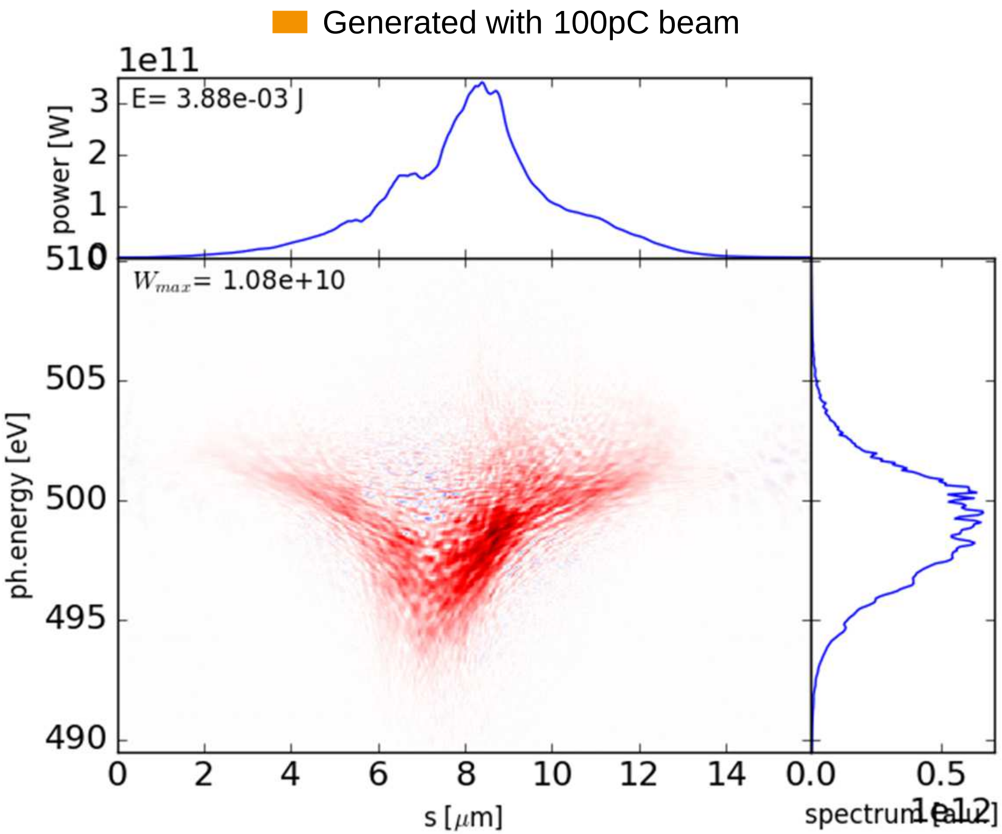
- Single-shot

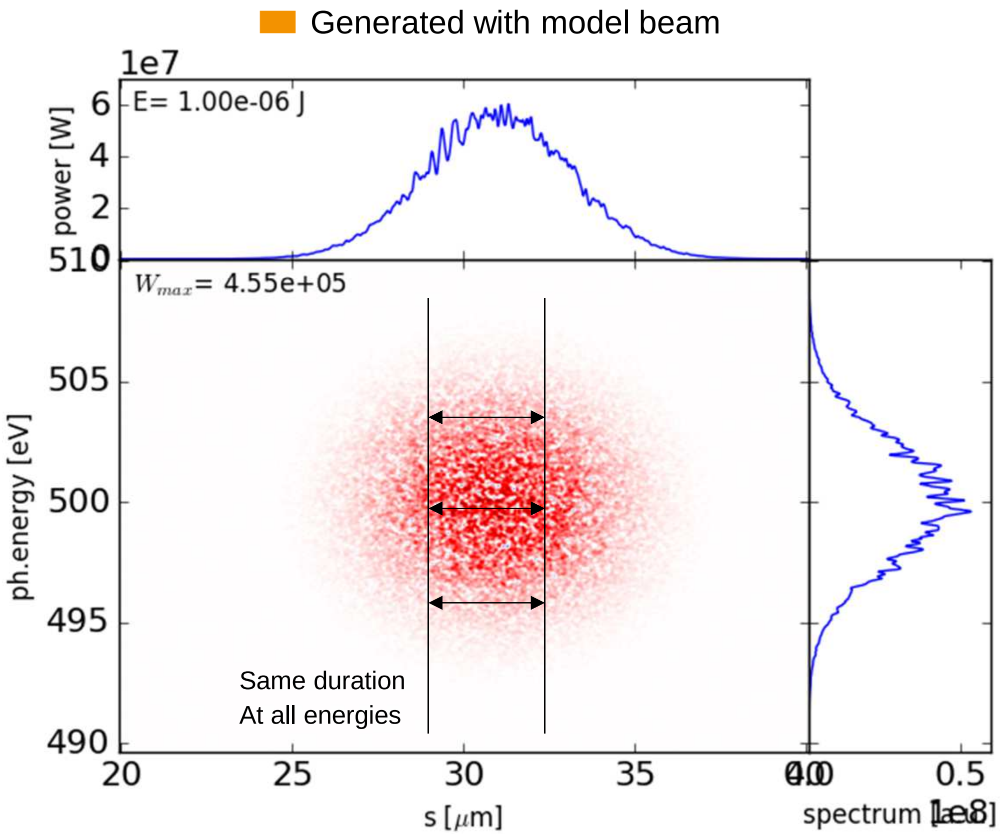



- Averaged



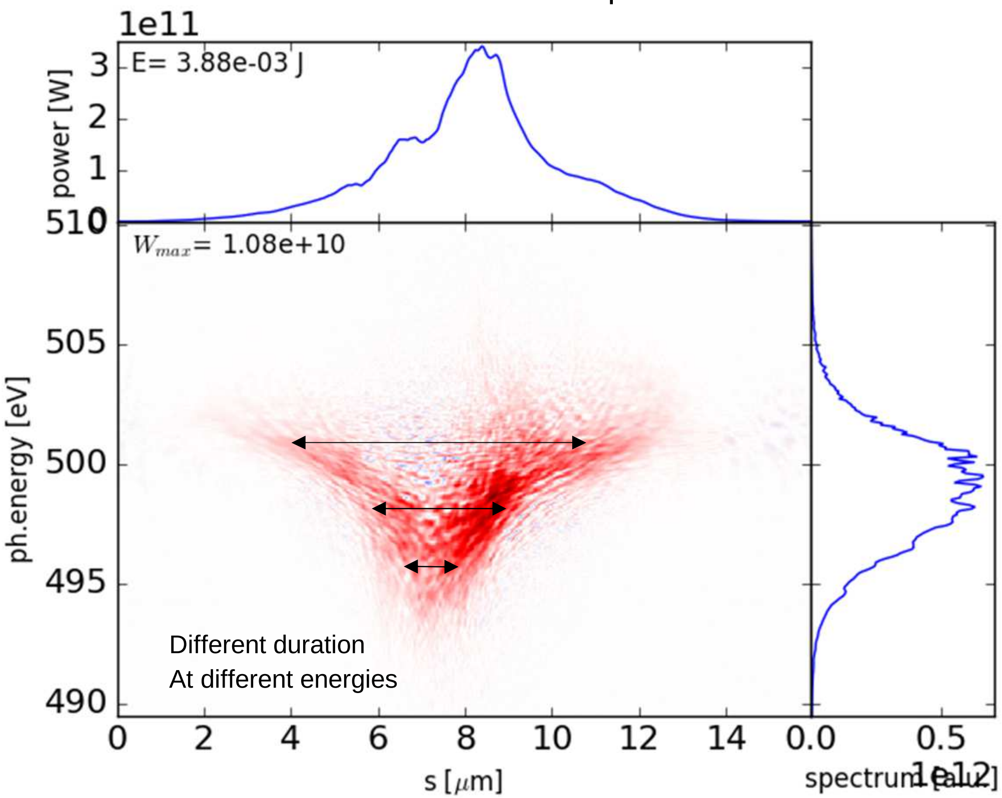
# Simulation (SASE with 100pC beam)



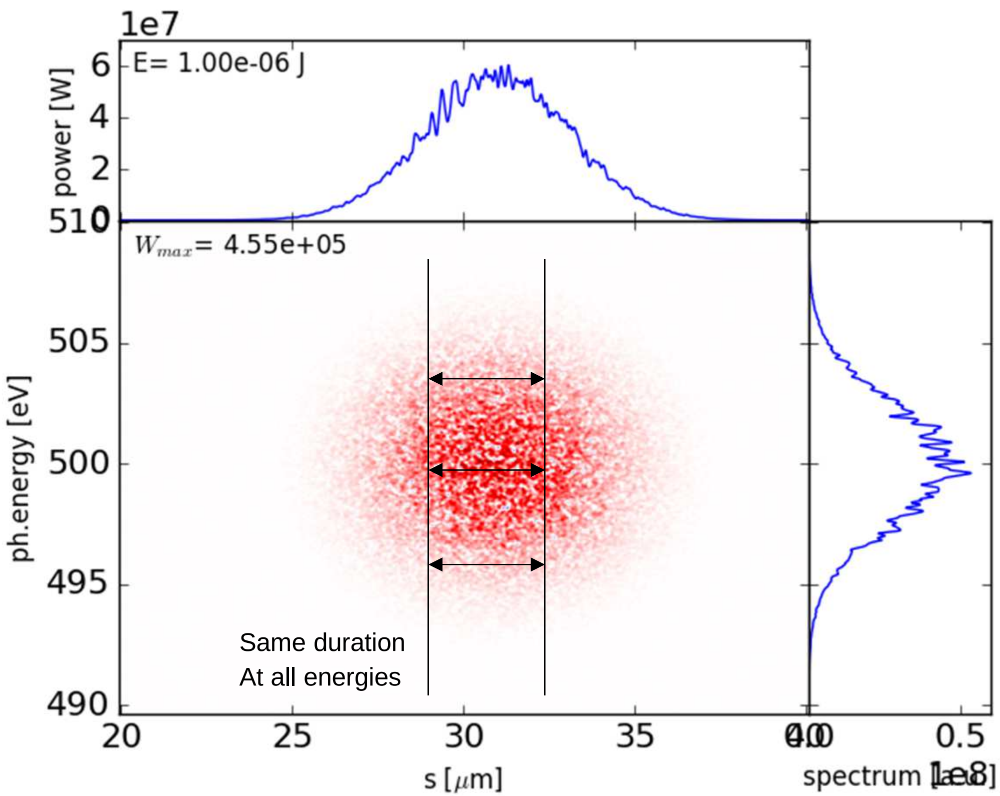



# Simulation (SASE with 100pC beam)

Generated with 100pC beam

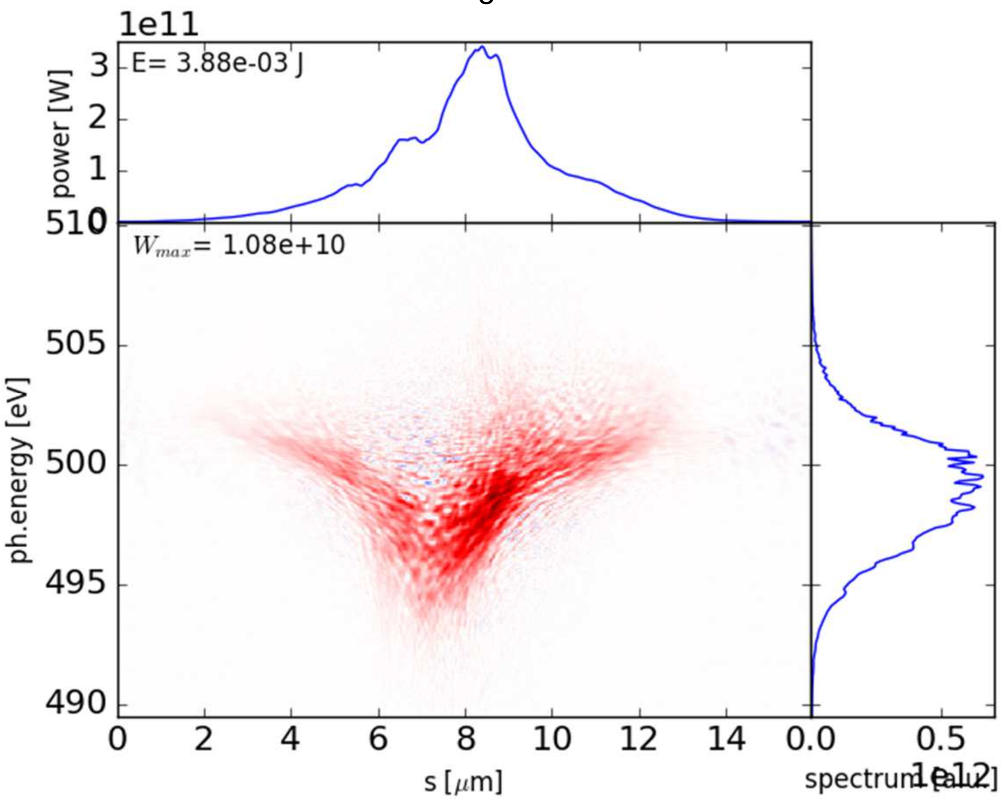



Generated with model beam

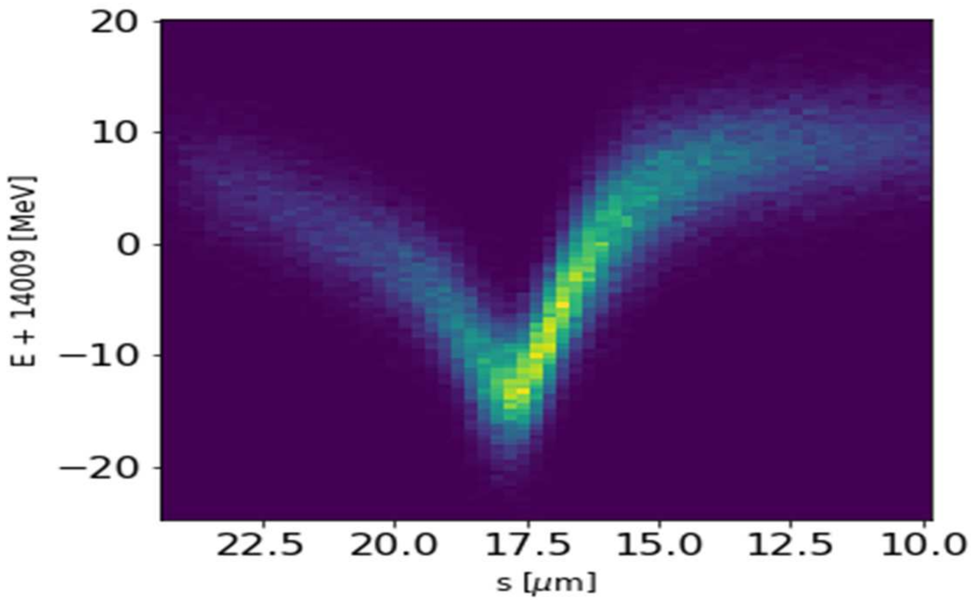


# Simulation (SASE with 100pC beam)

- Wigner



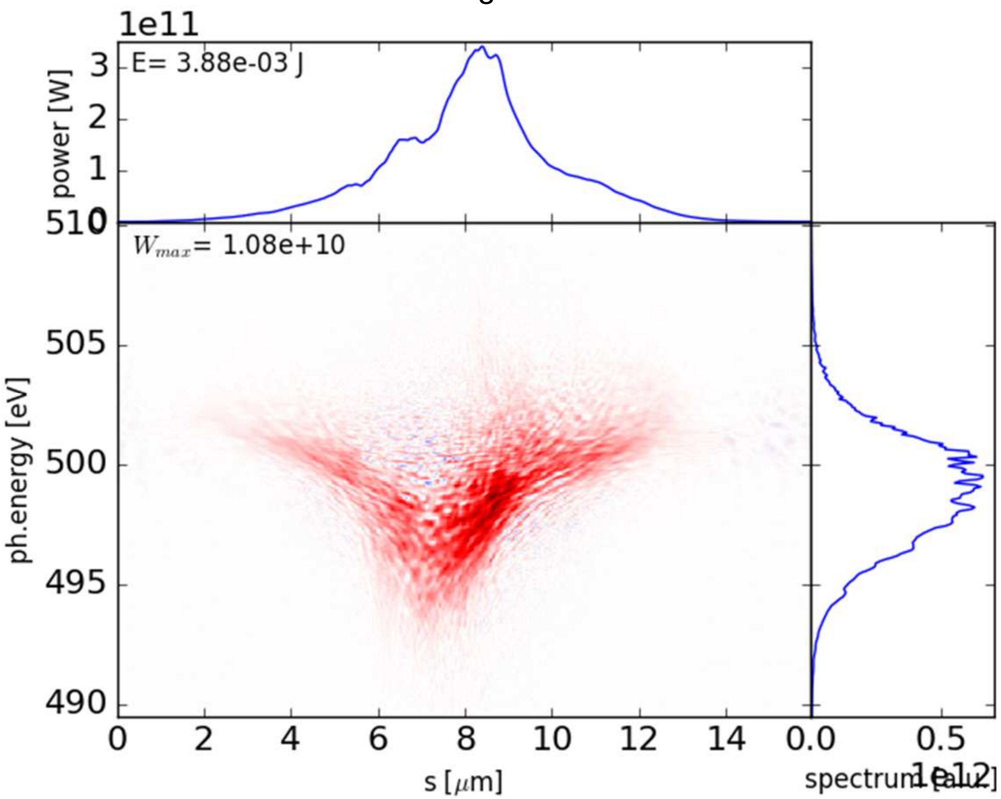

- 100 pC electron beam



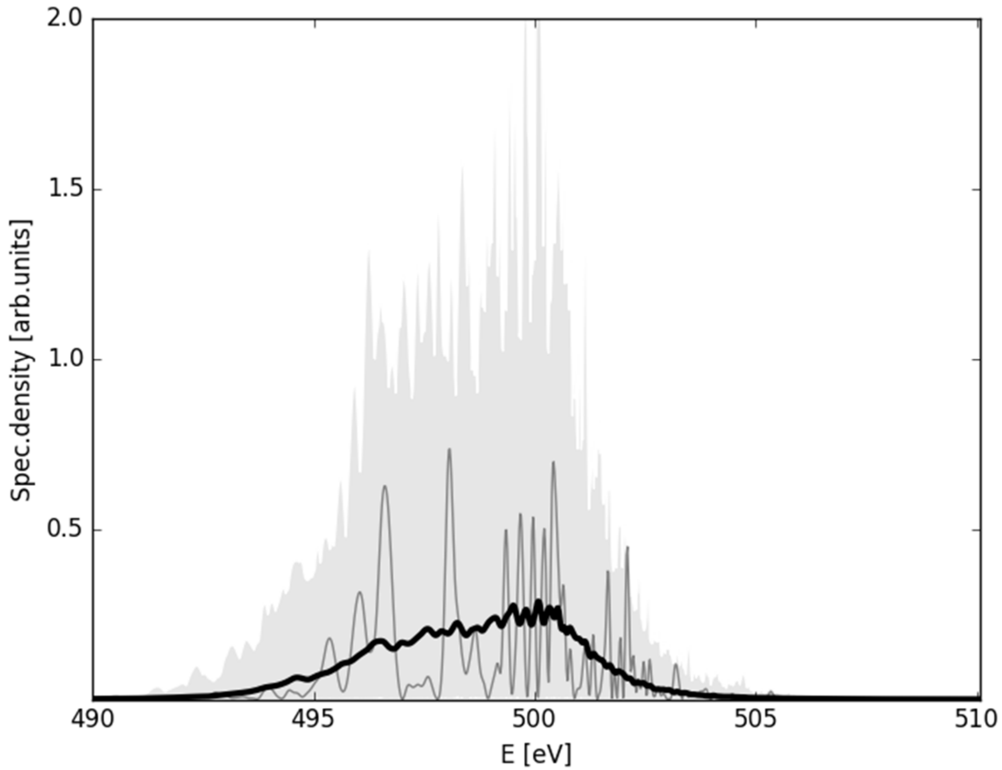

http://www.desy.de/fel-beam/s2e/xfel.html

# Simulation (SASE with 100pC beam)

Wigner

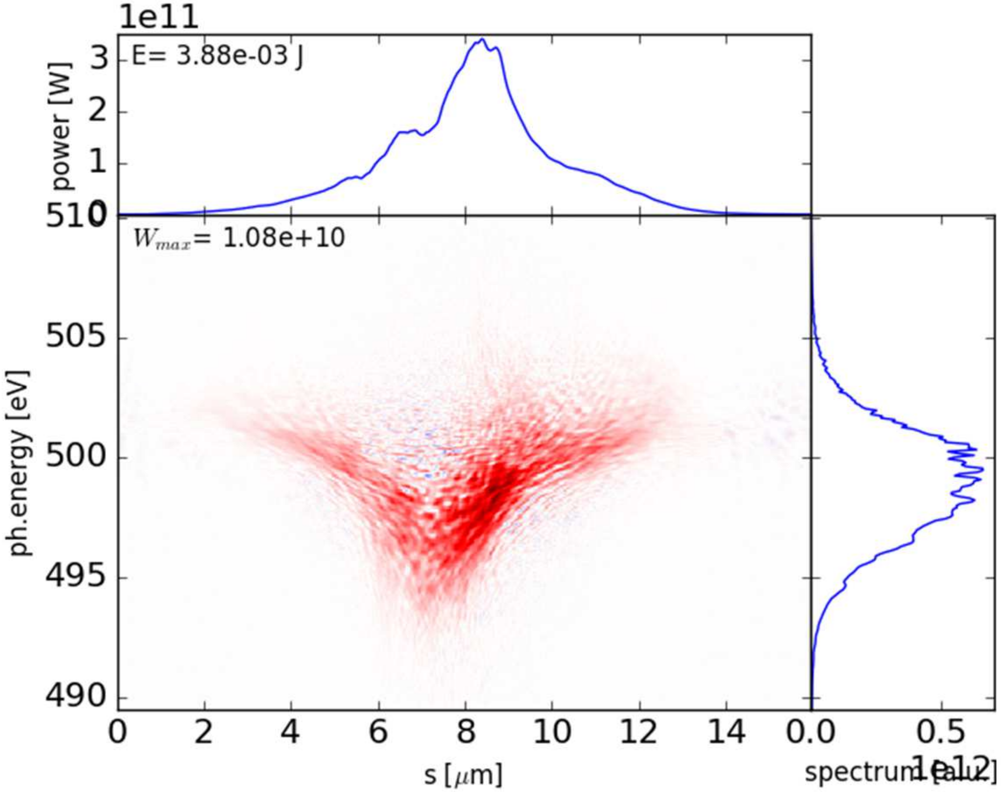



Spectrum

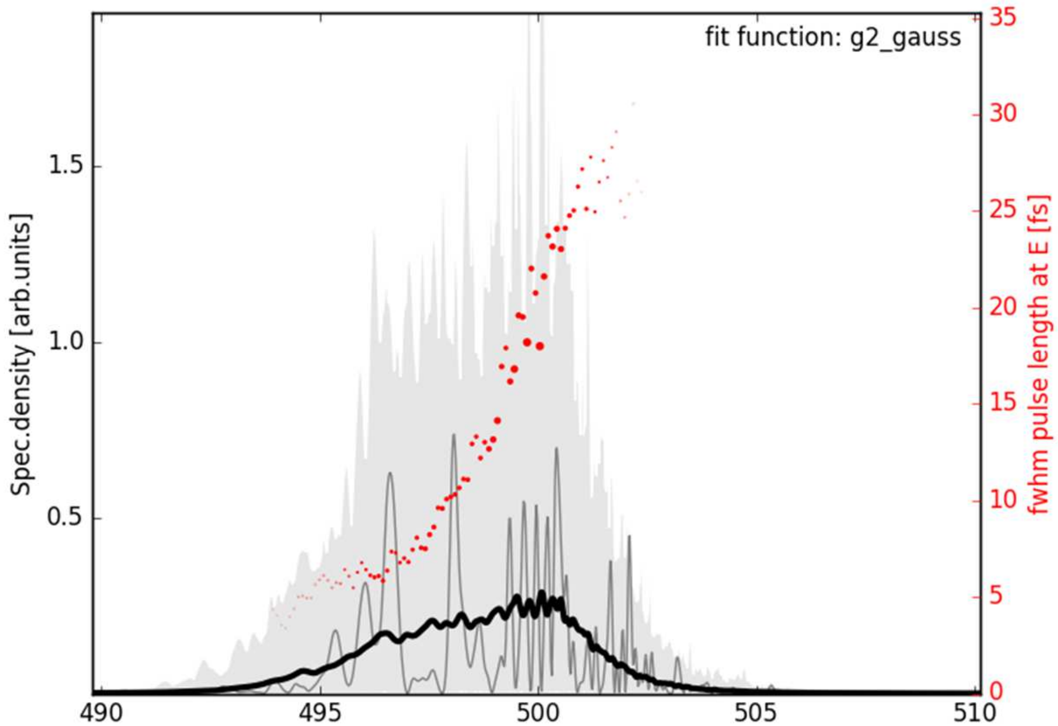


# Simulation (SASE with 100pC beam)

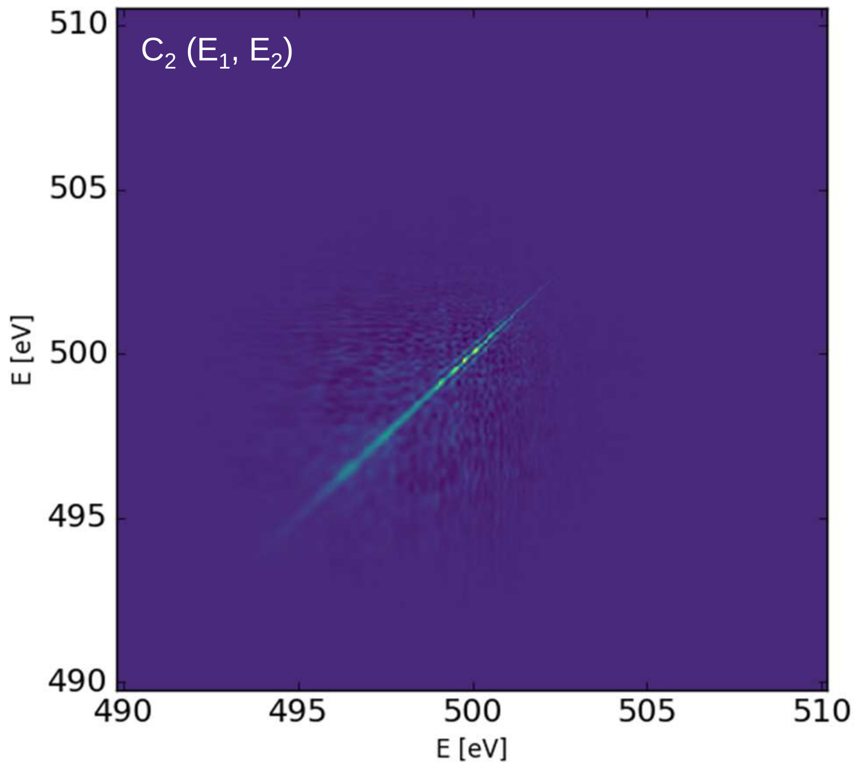
Wigner



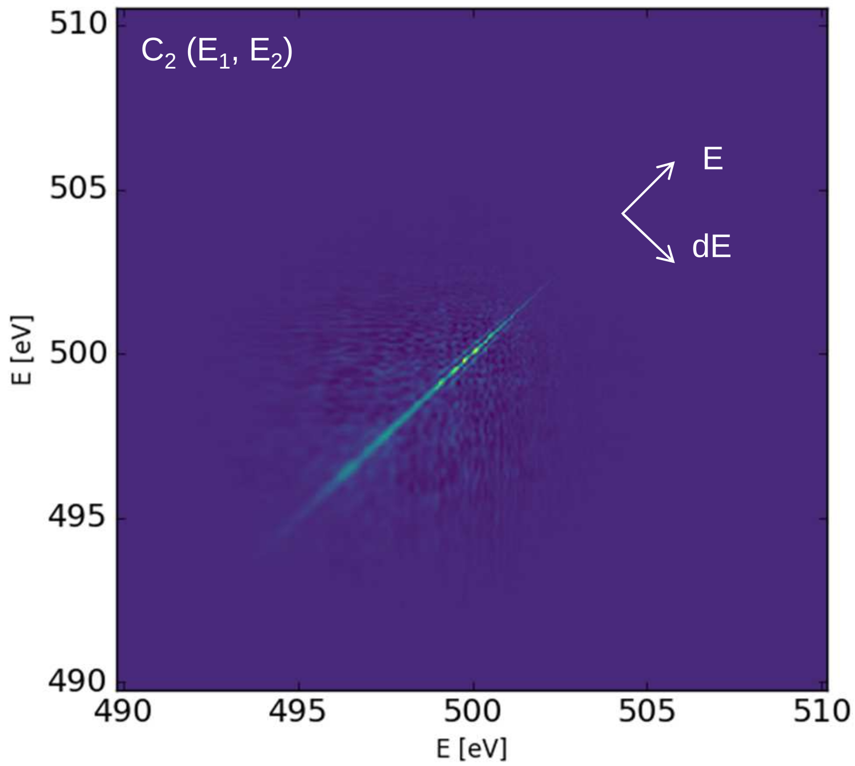

Spectrum



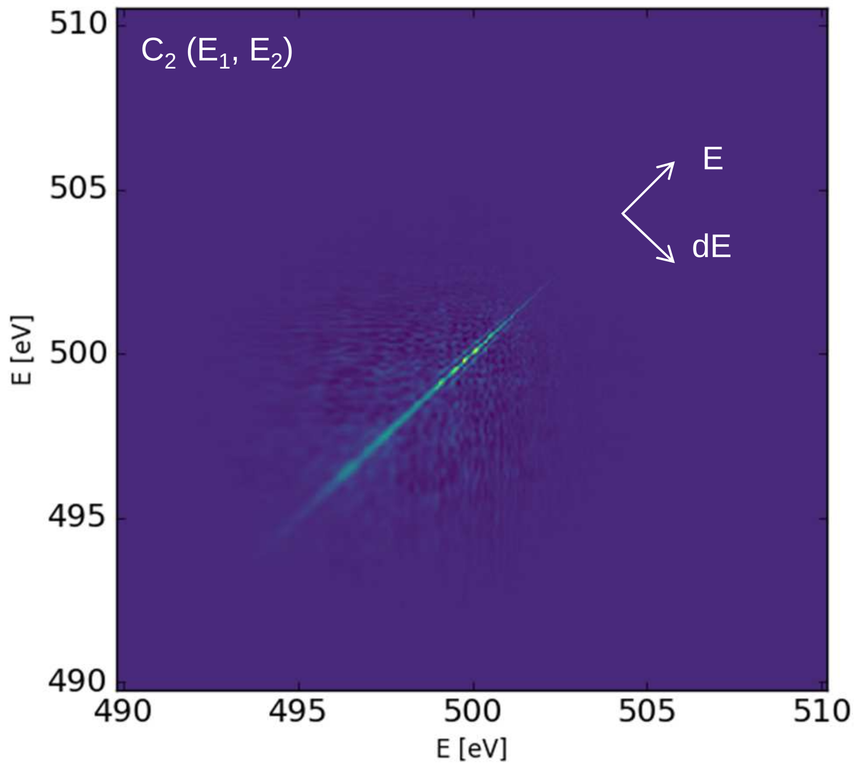
# Simulation (SASE with 100pC beam)

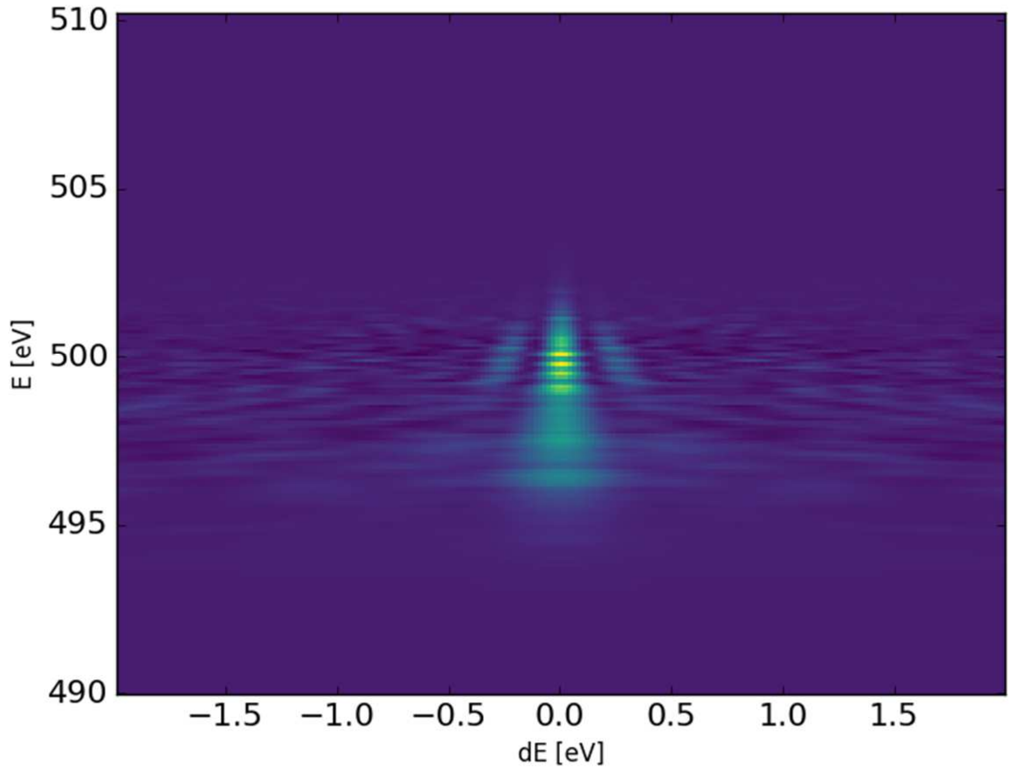


# Simulation (SASE with 100pC beam)



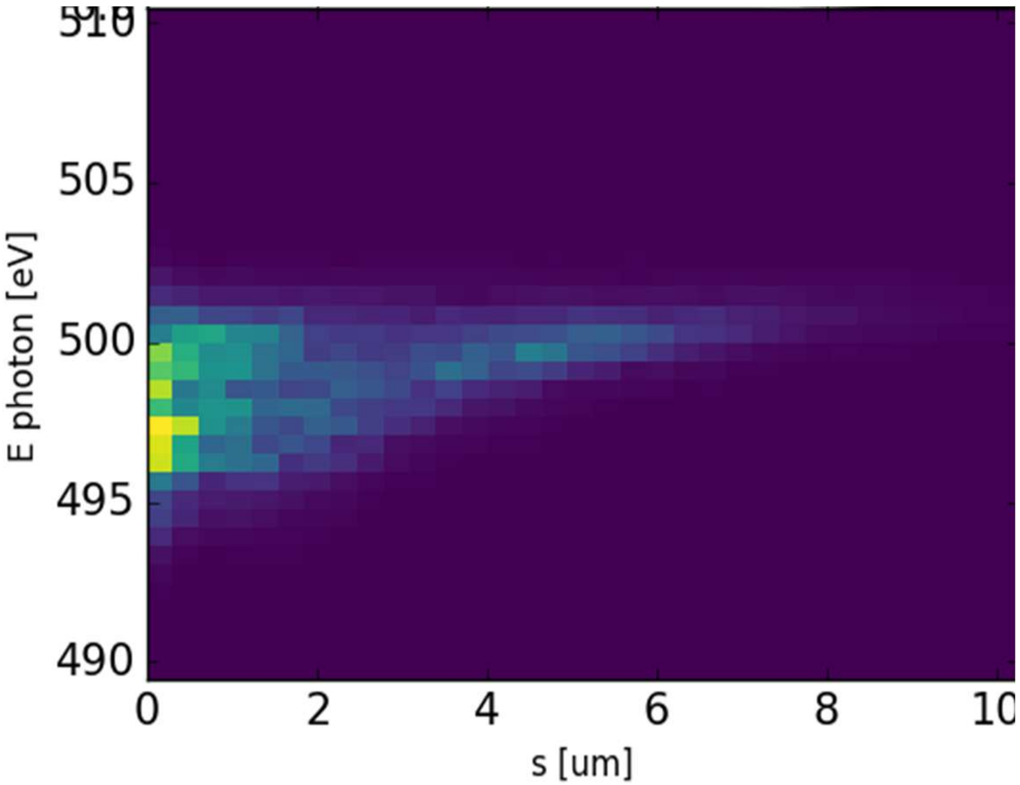
# Simulation (SASE with 100pC beam)

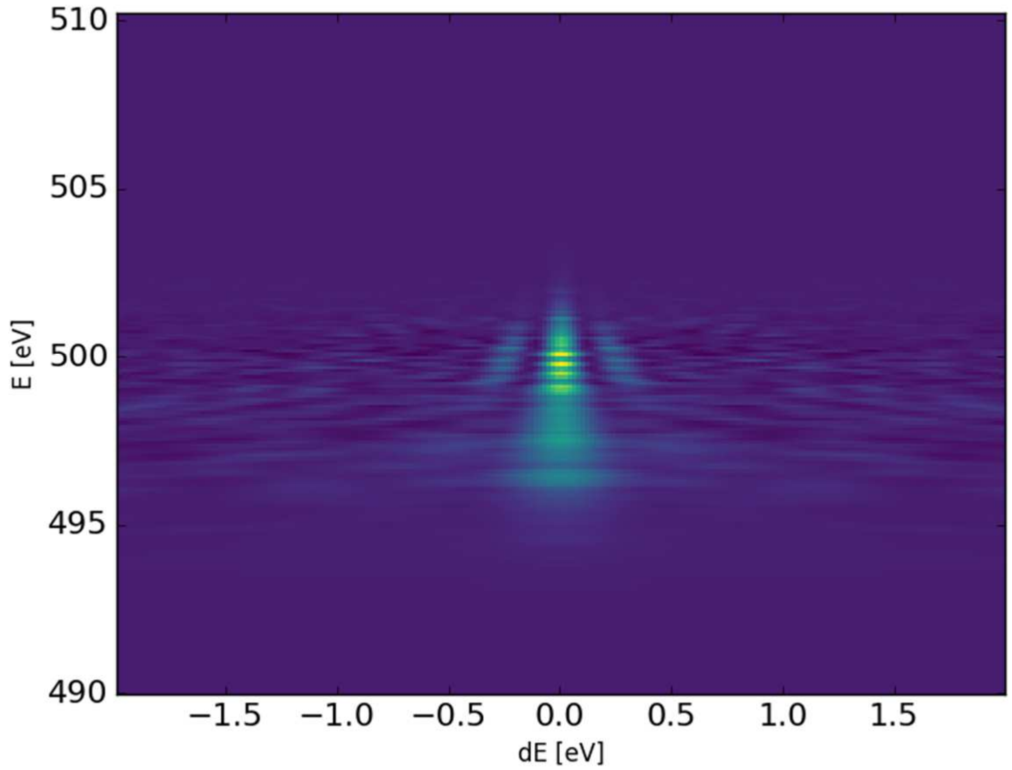


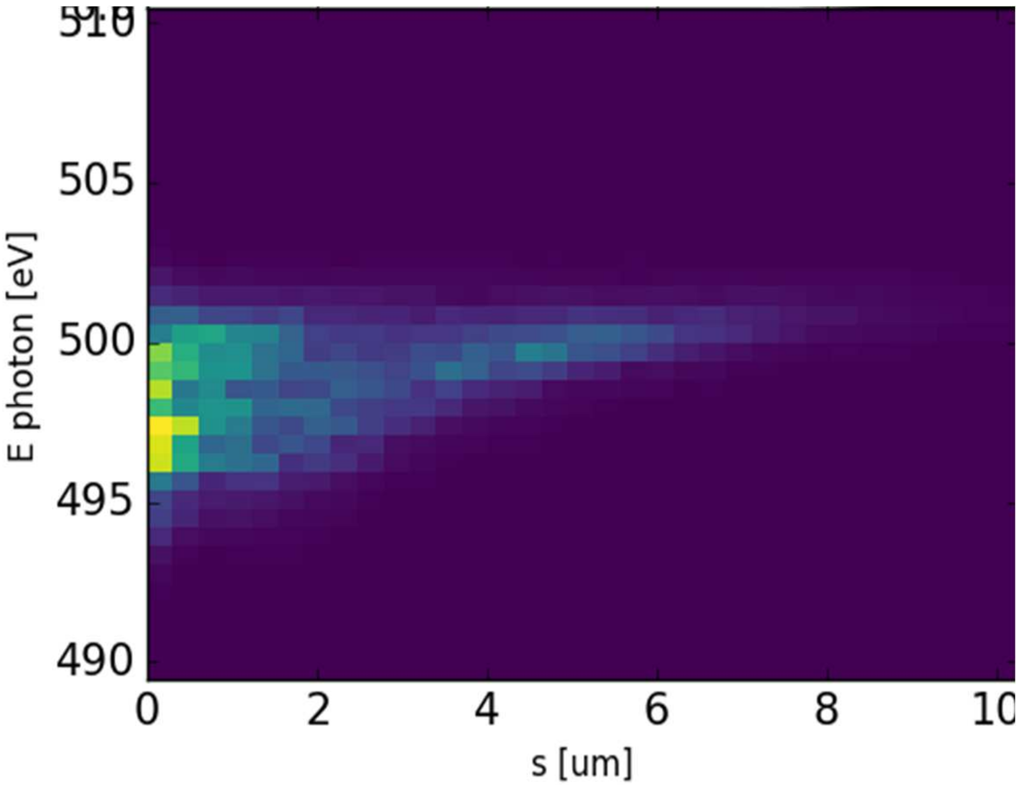
# Simulation (SASE with 100pC beam)

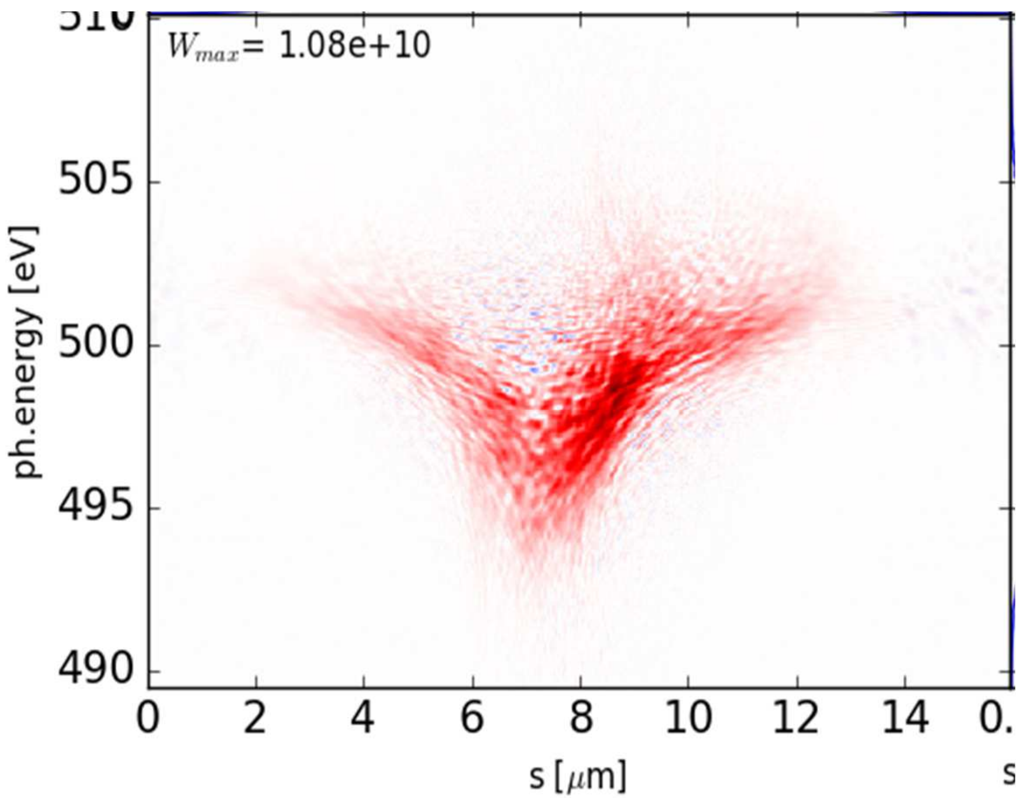
Fourier Transform over dE



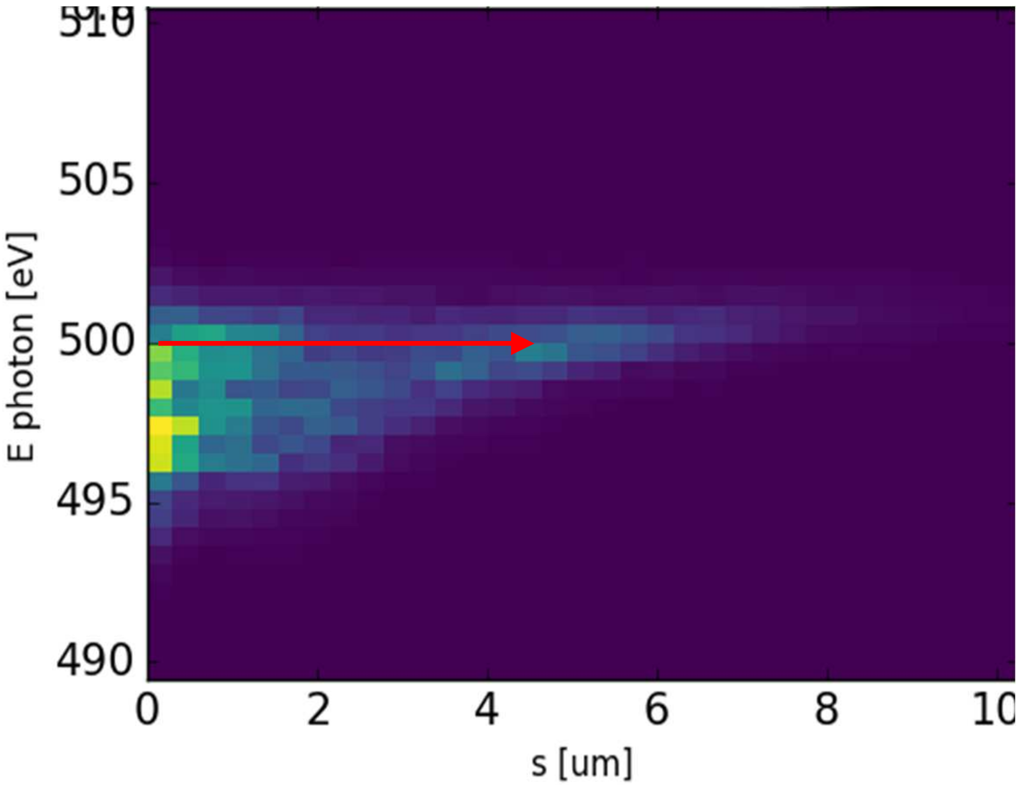



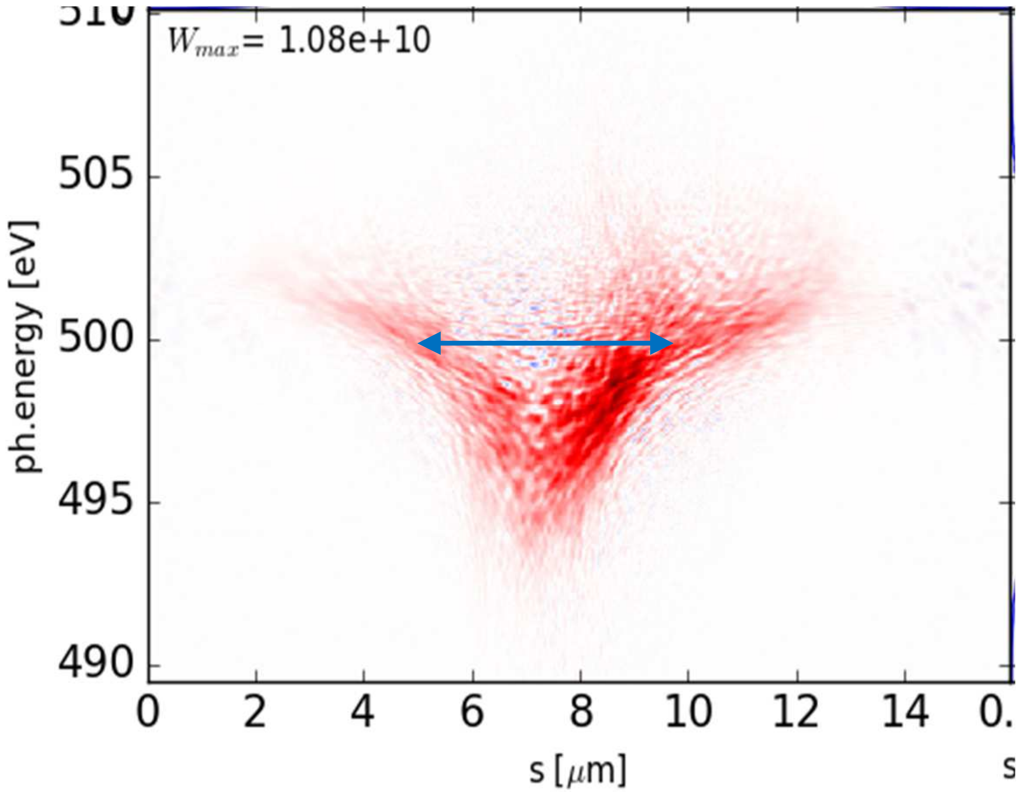
# Simulation (SASE with 100pC beam)



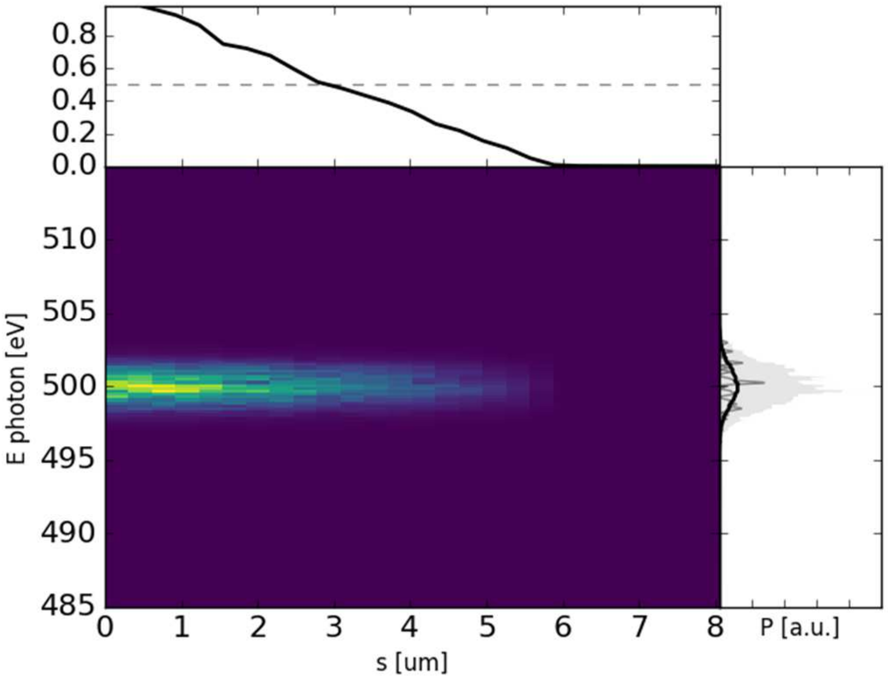



# Simulation (SASE with 100pC beam)

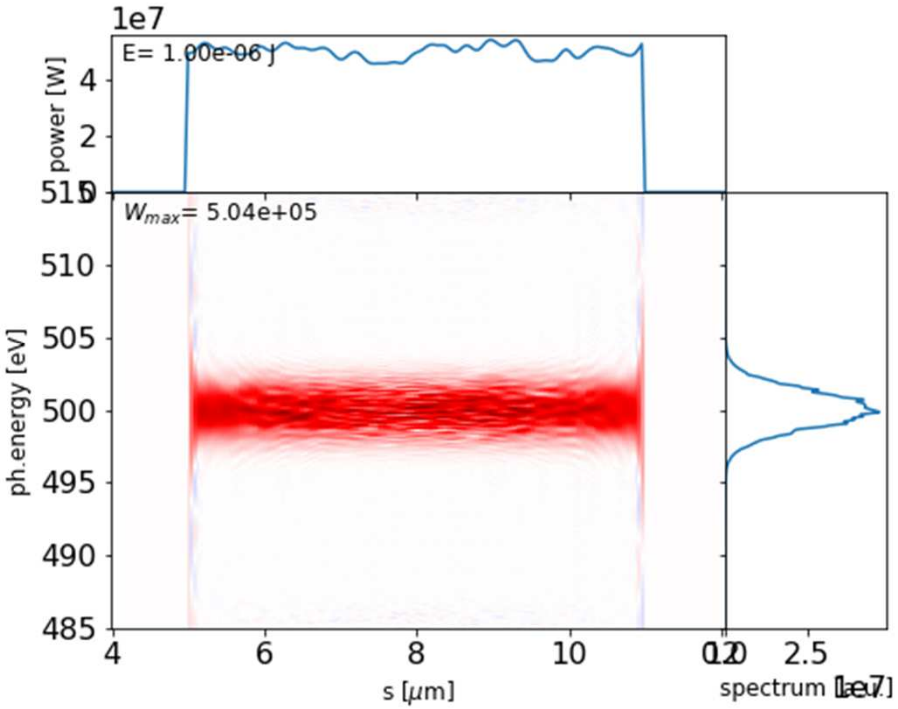


# Autocorrelation of Wigner (SASE with flat-top beam)




6 um (20fs)



# Autocorrelation of Wigner

- $$C_2(\omega, \Delta\omega) = \langle I(\omega - \Delta\omega/2)\ I(\omega + \Delta\omega/2)\rangle - \langle I(\omega - \Delta\omega/2)\rangle\ \langle I(\omega + \Delta\omega/2)\rangle$$

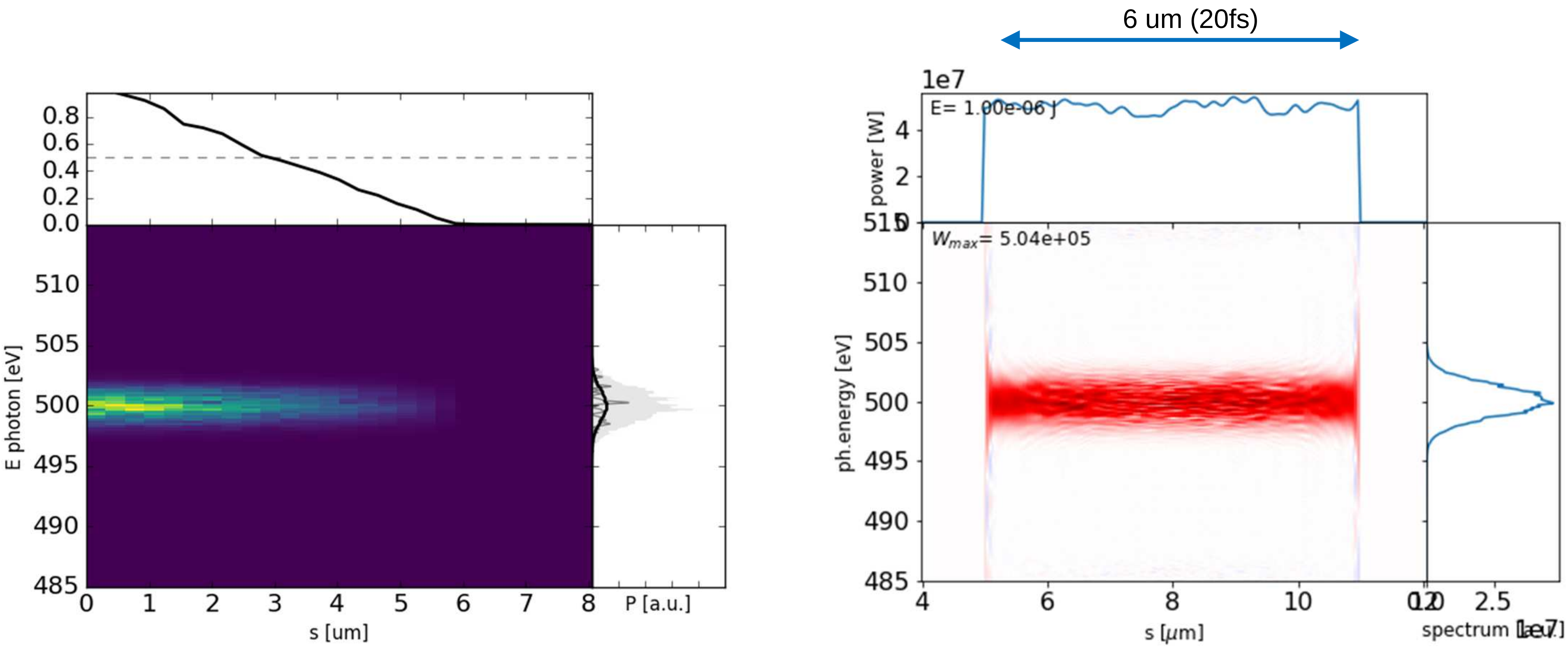
  *(assuming Gaussian random process)* $$= \langle E(\omega - \Delta\omega/2)E^*(\omega + \Delta\omega/2)\rangle\ \langle E(\omega - \Delta\omega/2)E^*(\omega + \Delta\omega/2)\rangle^*$$

- $$\mathcal{F}_{\Delta\omega}\{C_2(\omega, \Delta\omega)\} = \mathcal{F}_{\Delta\omega}\{\langle E(\omega - \Delta\omega/2)E^*(\omega + \Delta\omega/2)\rangle\ \langle E(\omega - \Delta\omega/2)E^*(\omega + \Delta\omega/2)\rangle^*\}$$

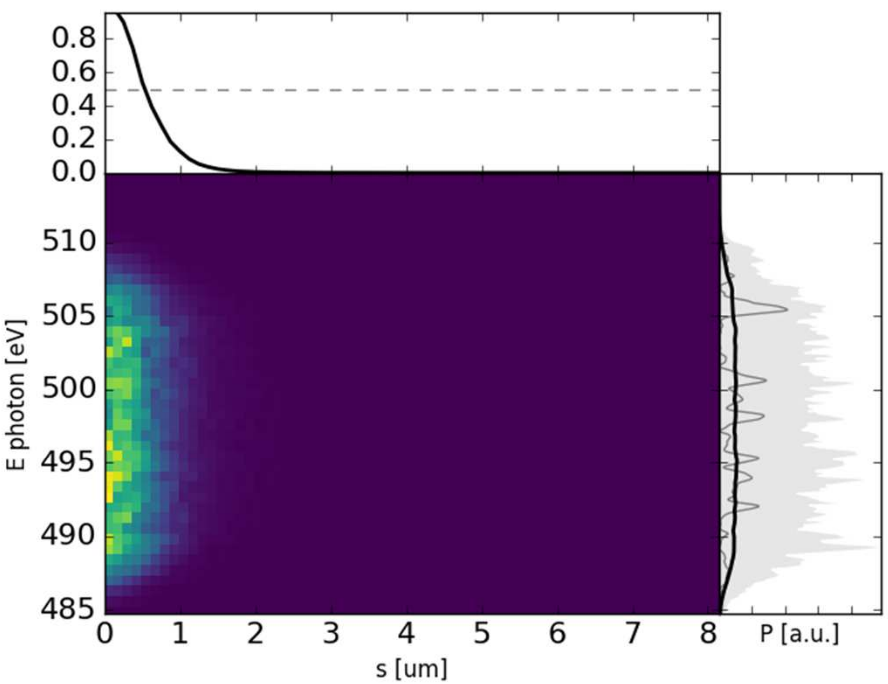
  *(using convolution theorem)* $$= \mathcal{F}_{\Delta\omega}\{\langle E(\omega - \Delta\omega/2)E^*(\omega + \Delta\omega/2)\rangle\} * \mathcal{F}_{\Delta\omega}\{\langle E(\omega - \Delta\omega/2)E^*(\omega + \Delta\omega/2)\rangle\}^*$$

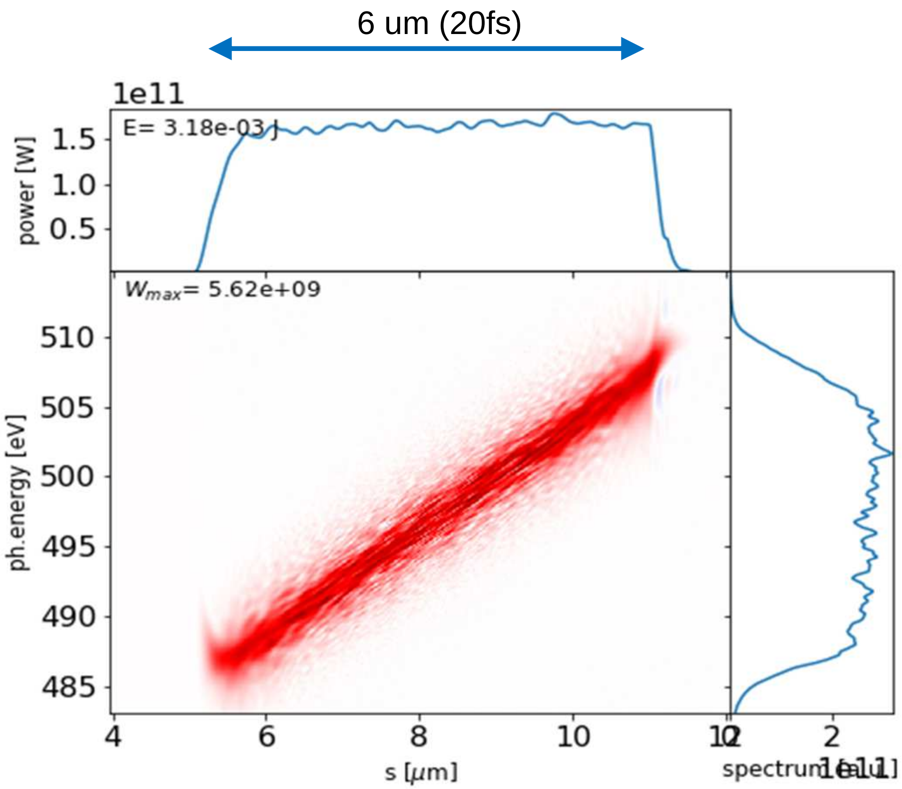
  *(by definition)* $$= \langle W(\omega, \tau)\rangle * \langle W(\omega, \tau)\rangle^*$$

# Autocorrelation of Wigner (SASE with flat-top beam)

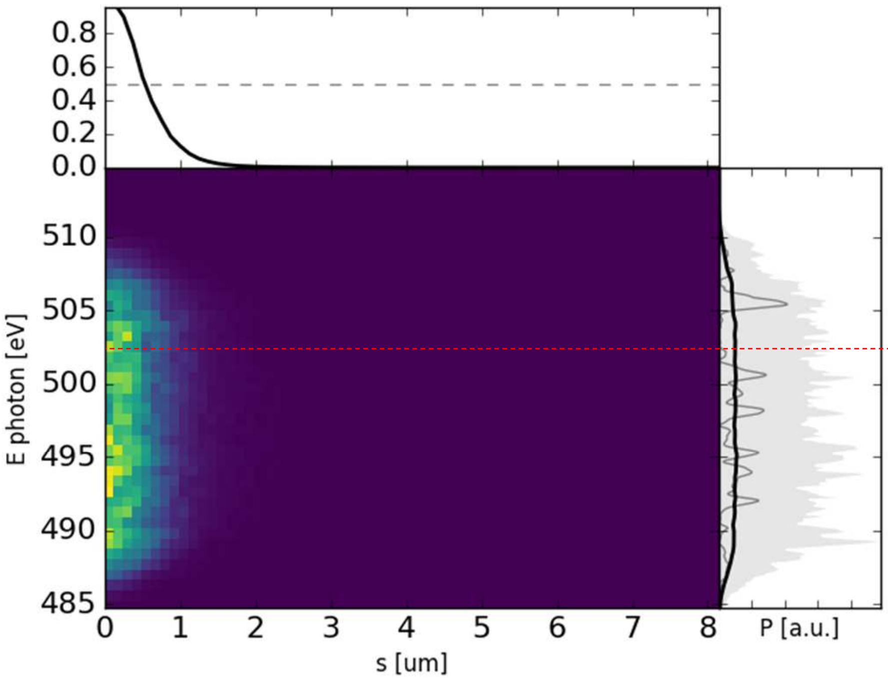


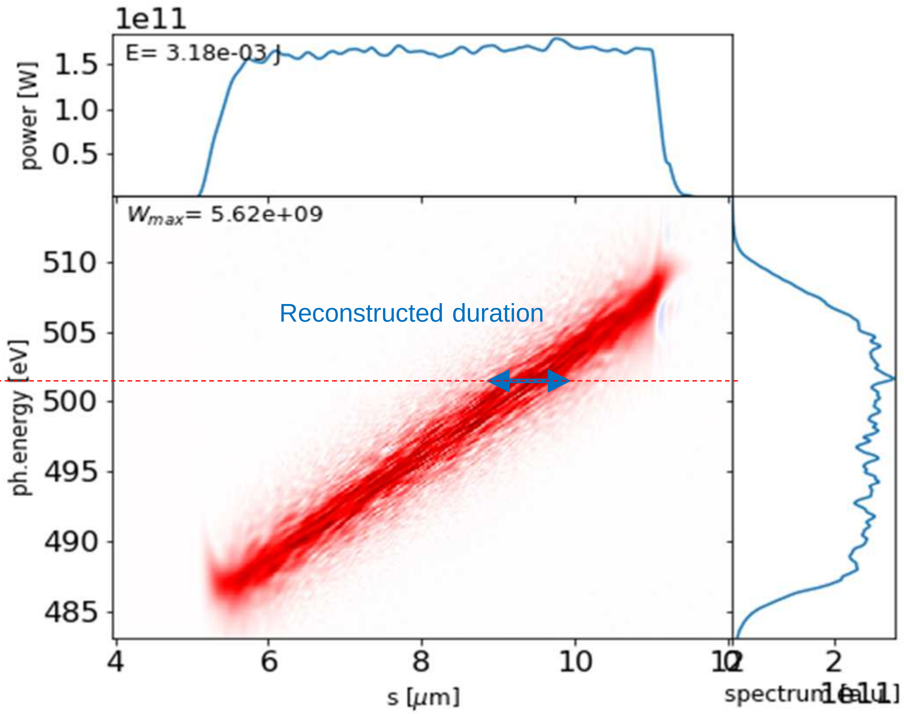
# Autocorrelation of Wigner (SASE with chirped flat-top beam)



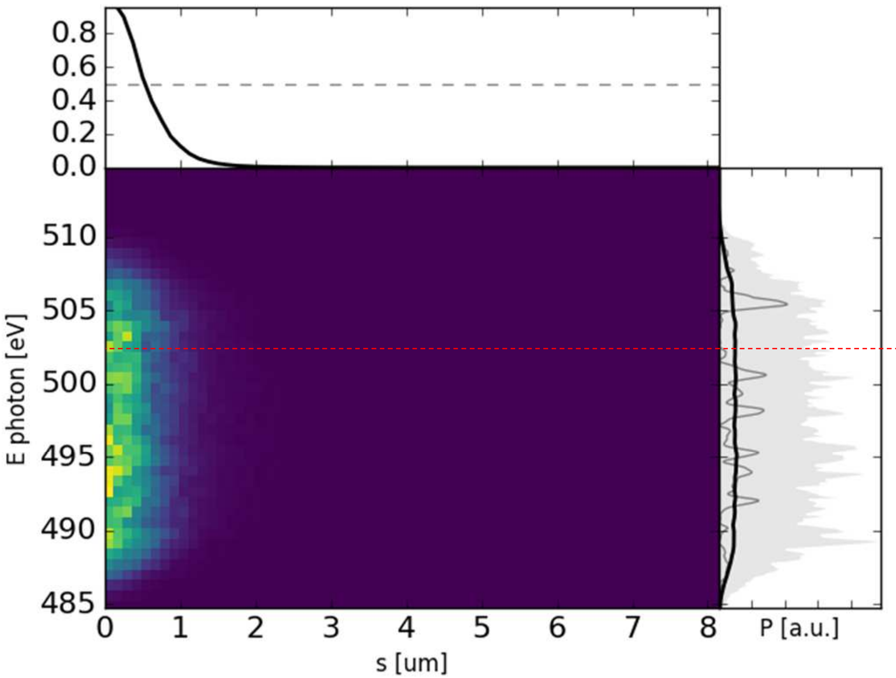



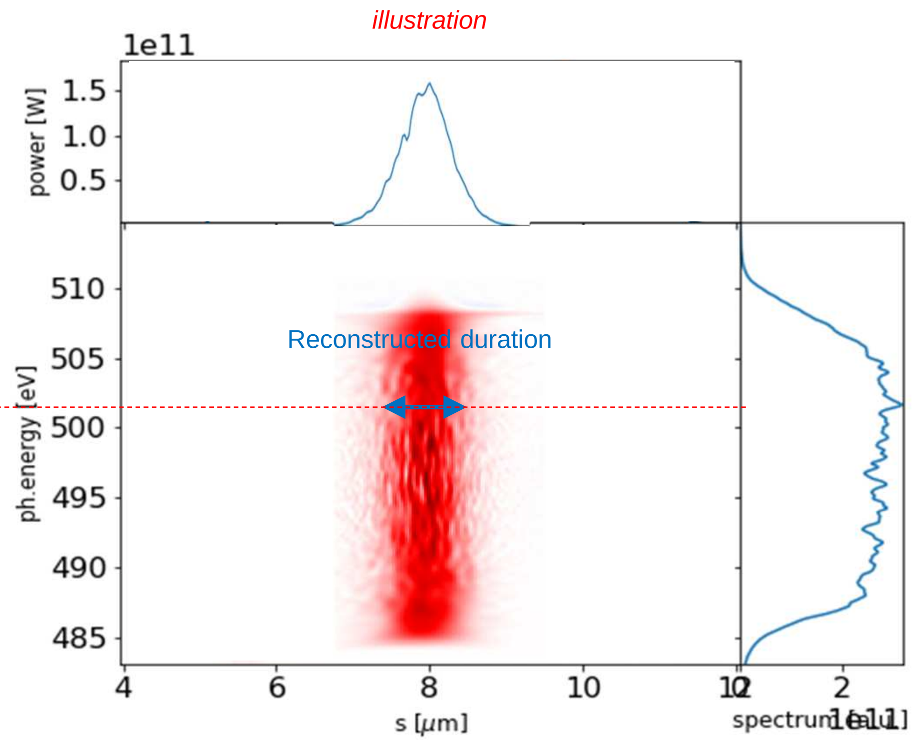
# Autocorrelation of Wigner (SASE with chirped flat-top beam)



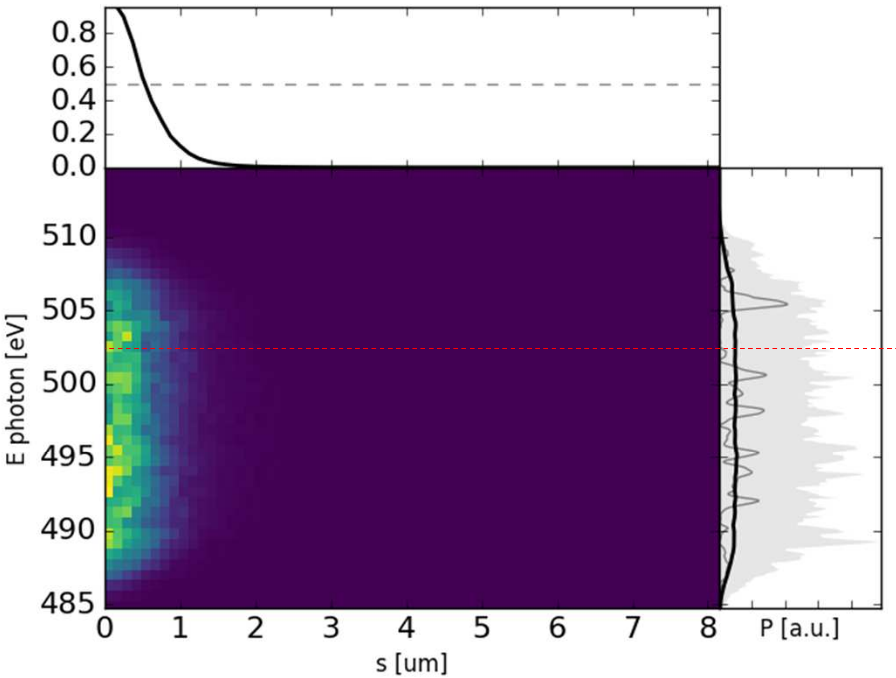



# Autocorrelation of Wigner (SASE with chirped flat-top beam)

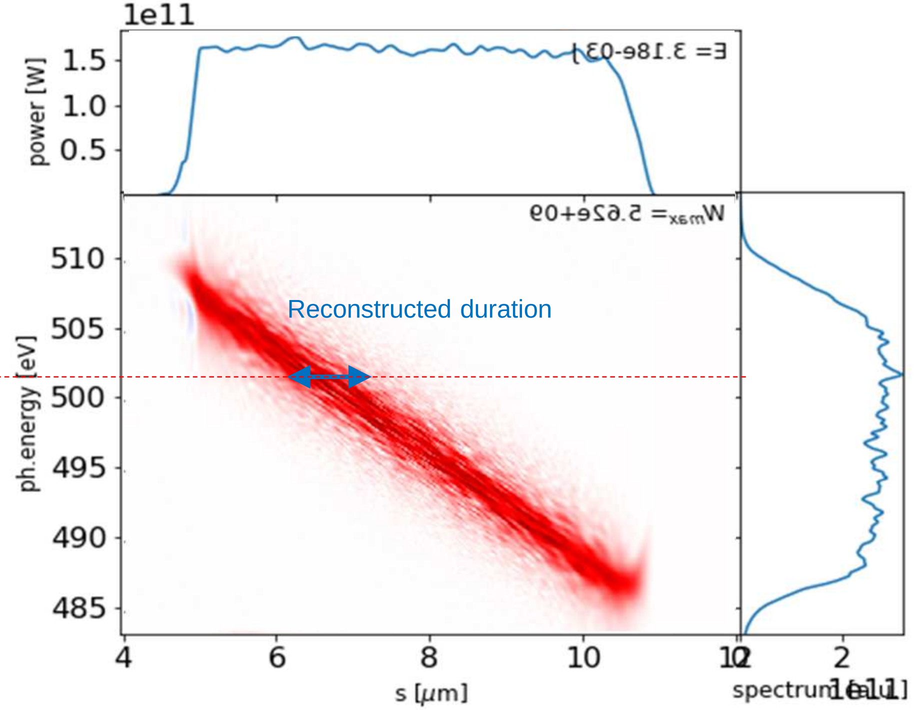


# Autocorrelation of Wigner (SASE with chirped flat-top beam)




*illustration*



**The following slides were intentionally removed, since they contained unpublished experimental results**

# Thanks

- *Gianluca Geloni, Takanori Tanikawa, Sergey Tomin*
- *Naresh Kujala, Jia Liu, Jan Gruenert*
- *Natalia Gerasimova, Oleg Gorobtsov*
- *Liubov Samoylova, Harald Sinn*
- *Igor Zagorodnov, Andrey Sorokin, Bohdana Sobko*
- ***Whole commissioning team!***