In Situ Measurement of Electron Energy Evolution in a Laser-Plasma Accelerator.

Thomson scattering as *in-situ* diagnostic

Phys. Rev. Lett. 129, 244801, 2022

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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DESY.

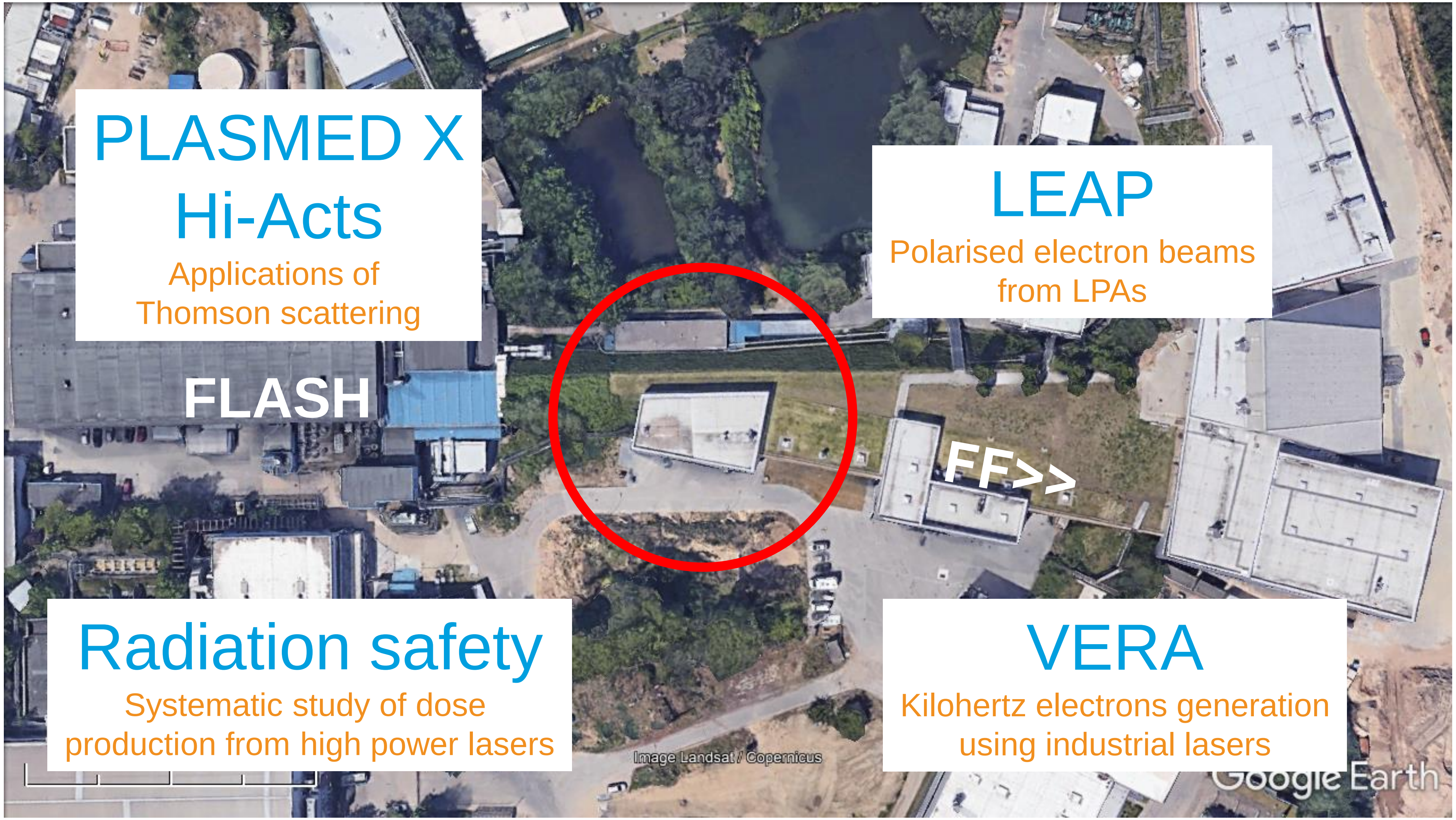
Study of Laser-Driven Plasmas & Applications

Fundamentals of LPAs for industrial and medical applications

M. Meisel
Tunable x-ray source
Mo. 17:05

S. Bohlen
Cavity based charge meas.
We. 19:30

S. Bohlen
Radiation generation
We. 19:30



PLASMED X
Hi-Acts
Applications of Thomson scattering

LEAP
Polarised electron beams from LPAs

Radiation safety
Systematic study of dose production from high power lasers

VERA
Kilohertz electrons generation using industrial lasers

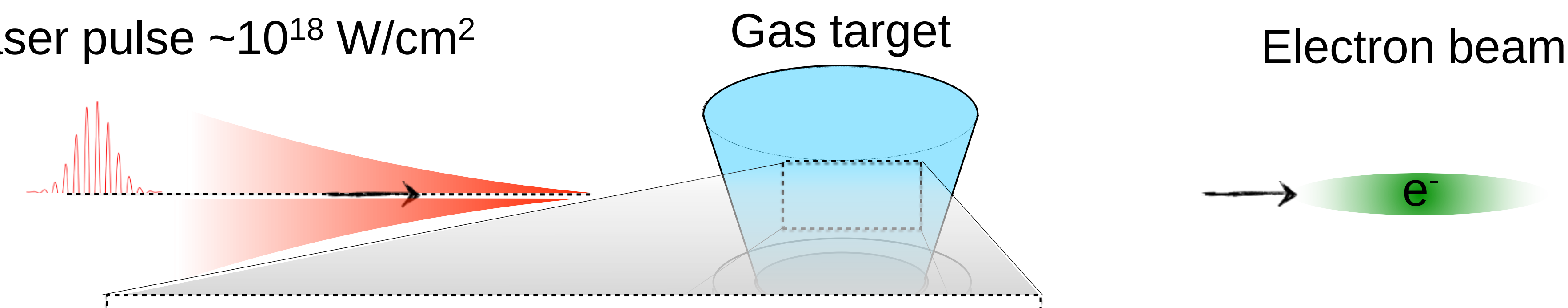
F. Stehr
Overview of LEAP
Mo. 19:00

K. Poder
High-quality polarised e-
Tu. 17:45

B. Farace
Towards first electrons
We. 19:30

Acceleration of electrons using high gradients

Working principle of laser-plasma acceleration (LPA)[1]

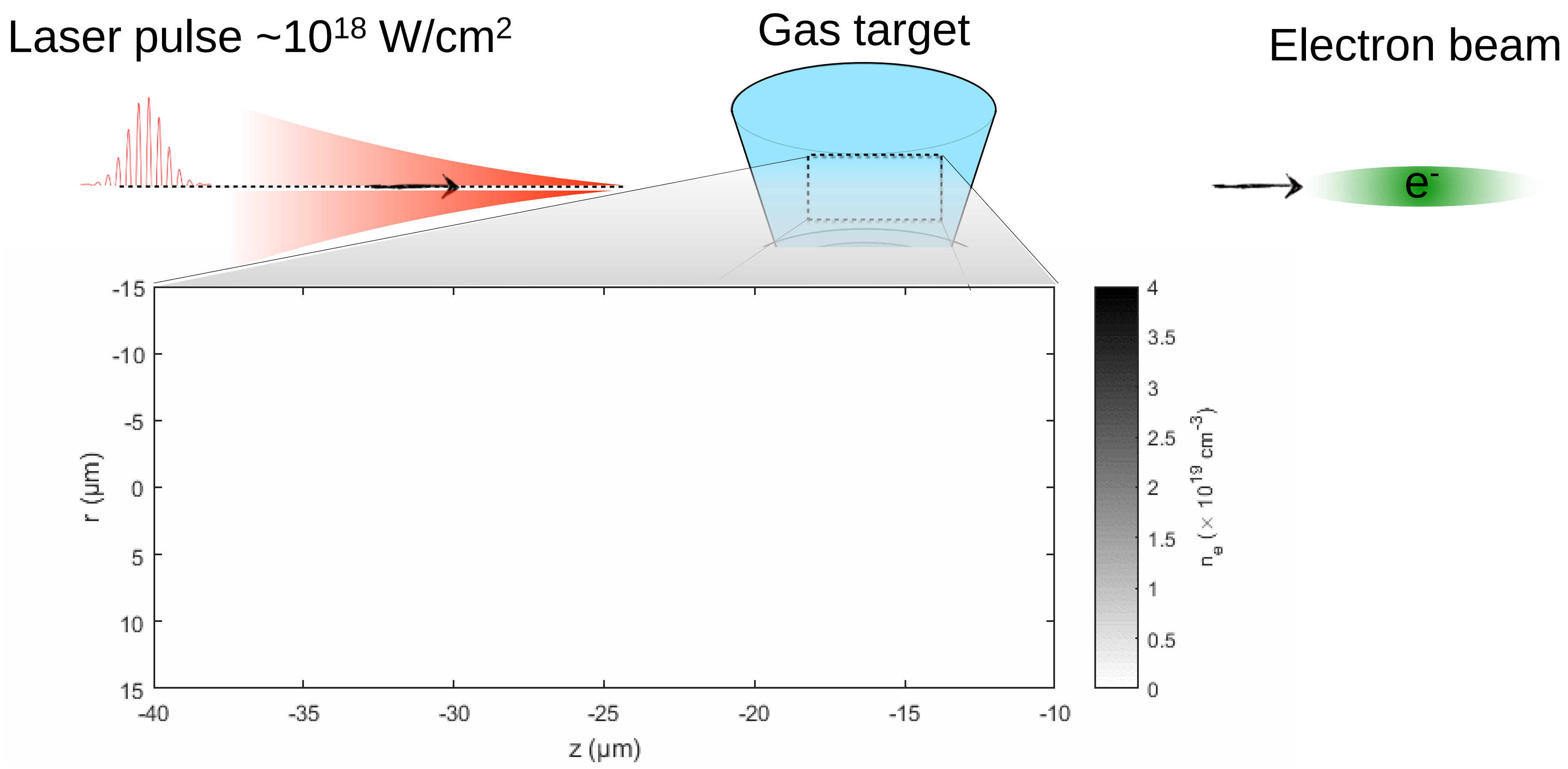


- Electrons pushed by ponderomotive force
- Longitudinal fields reach more than 100 GV/m
- Electrons at the back of the wakefield can be accelerated to high energies on mm scales

[1]Tajima, T. and Dawson, J. M., Phys. Rev. Lett., 43(4), 267-270, (1979)

Particle-in-cell (PIC) simulations to understand LPA

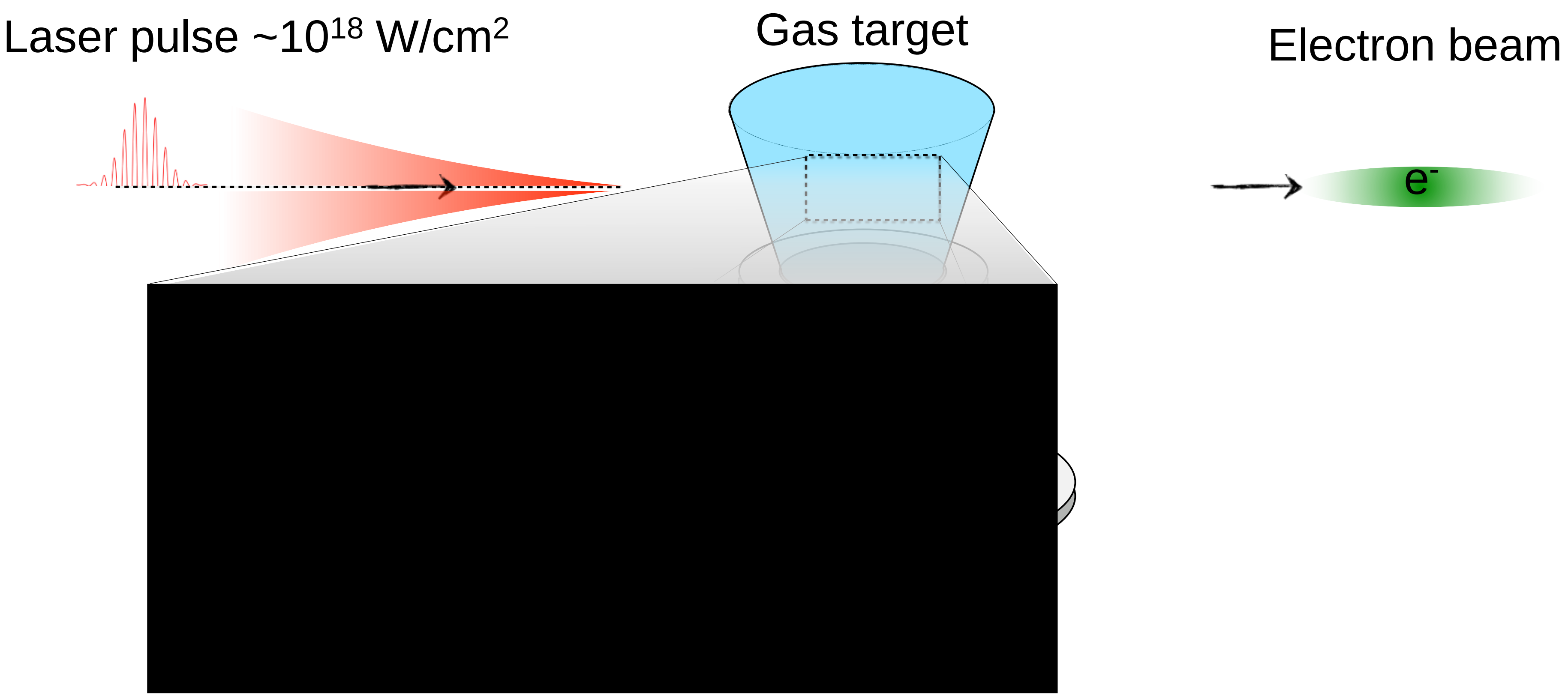
Simulation of the acceleration process using FBPIC[2]



[2]Lehe, R. et al. (2016). *CPC* 203, P. 66-82

Experimental knowledge about electrons in plasma

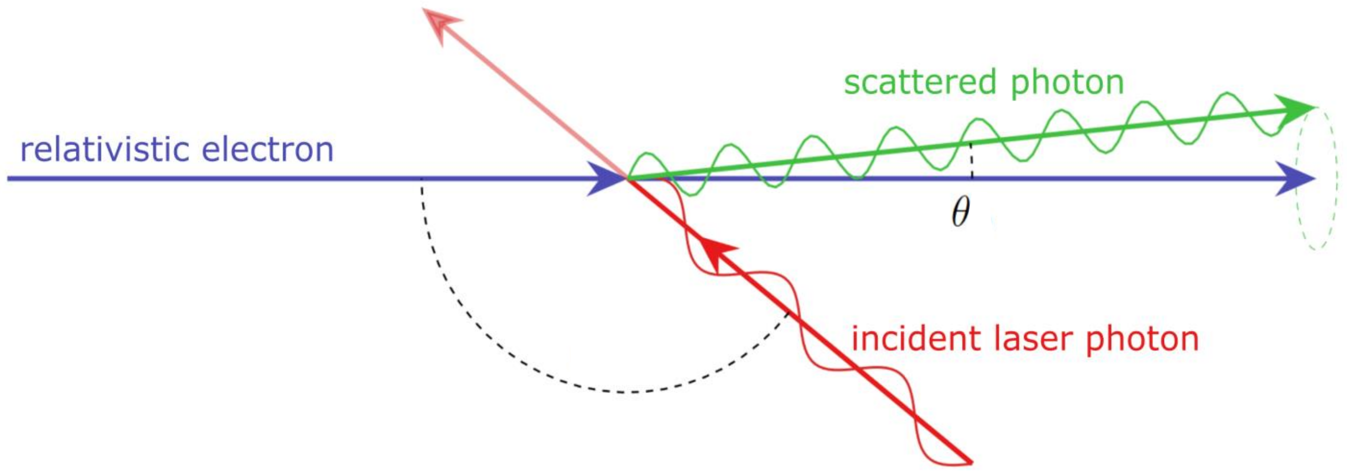
For many parameters, we never measured how electrons evolve inside the plasma



» Can we measure directly what happens inside the gas target?

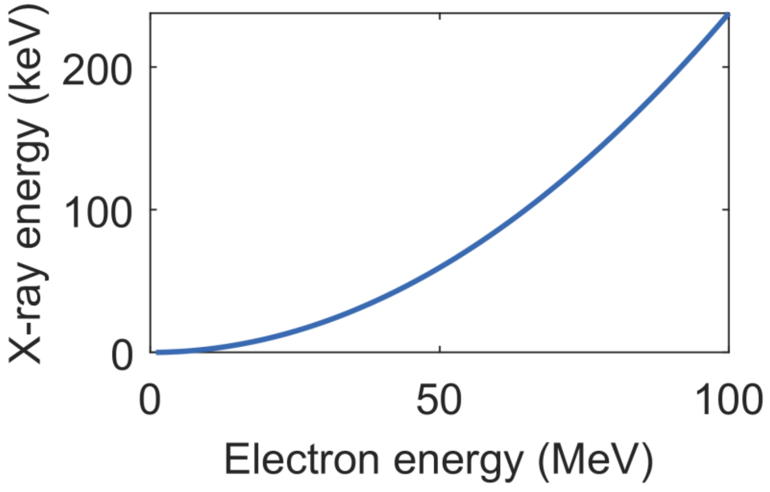
Can we measure how the electrons evolve inside plasma?

Electrons imprint information on x-rays



Energy of scattered photons:

$$E_\gamma \approx \frac{4\gamma_e^2 * E_{Laser}}{1 + \gamma_e^2\theta^2 + a_0^2/2}$$

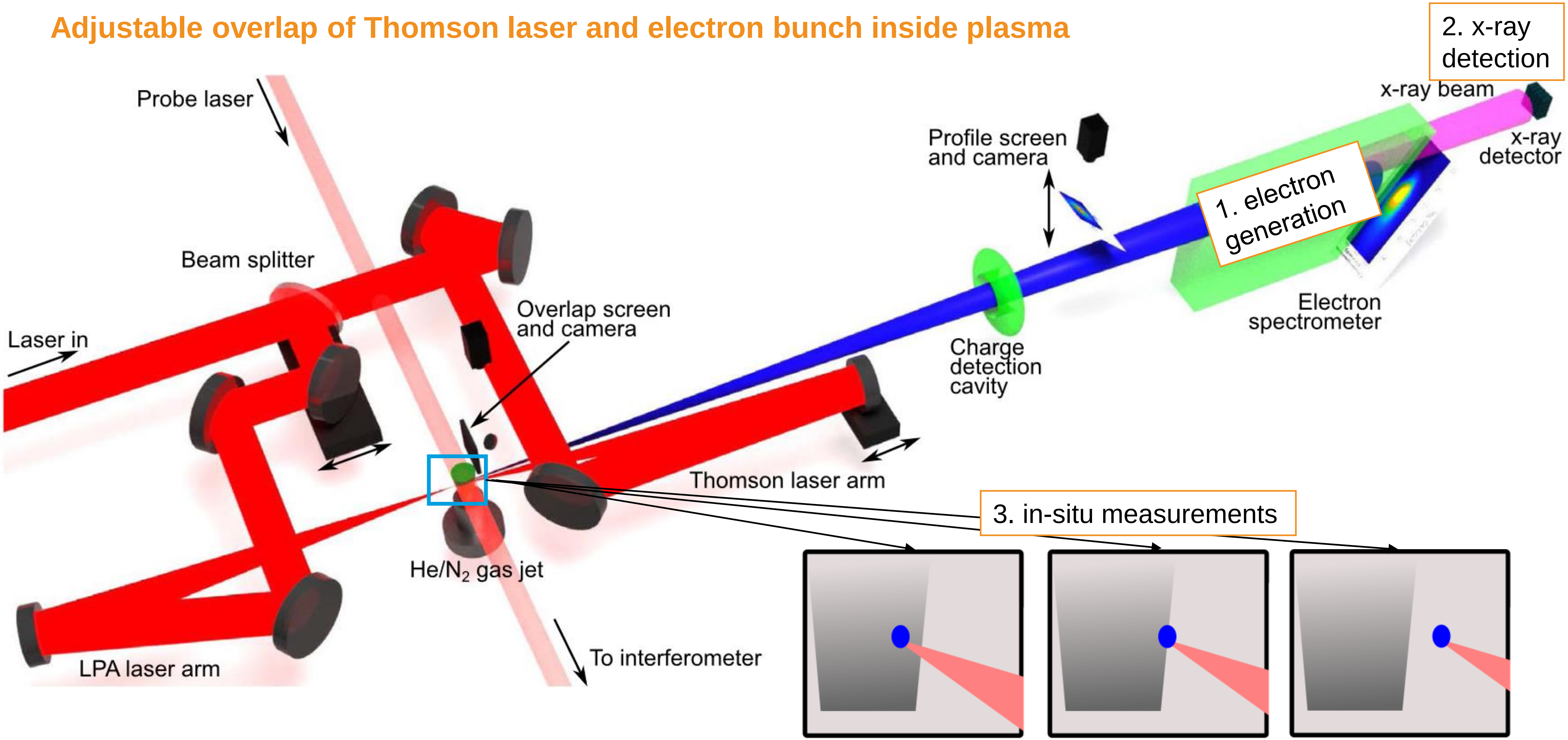


1) Scattered x-ray parameters depend on electron bunch properties

2) X-rays can leave the plasma and be detected outside

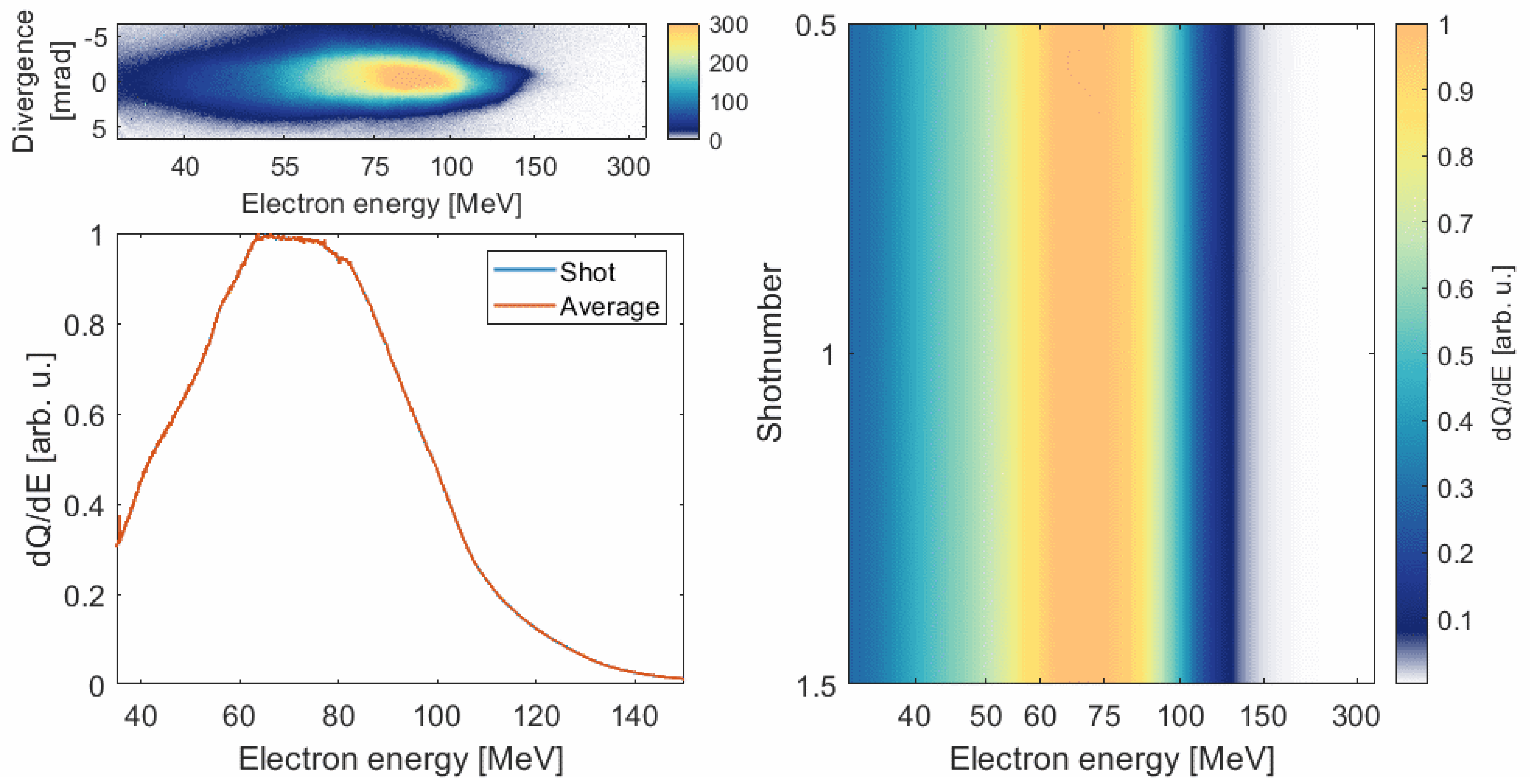
Experimental setup for Thomson scattering

Adjustable overlap of Thomson laser and electron bunch inside plasma



Stable electron beams with ionisation injection[3]

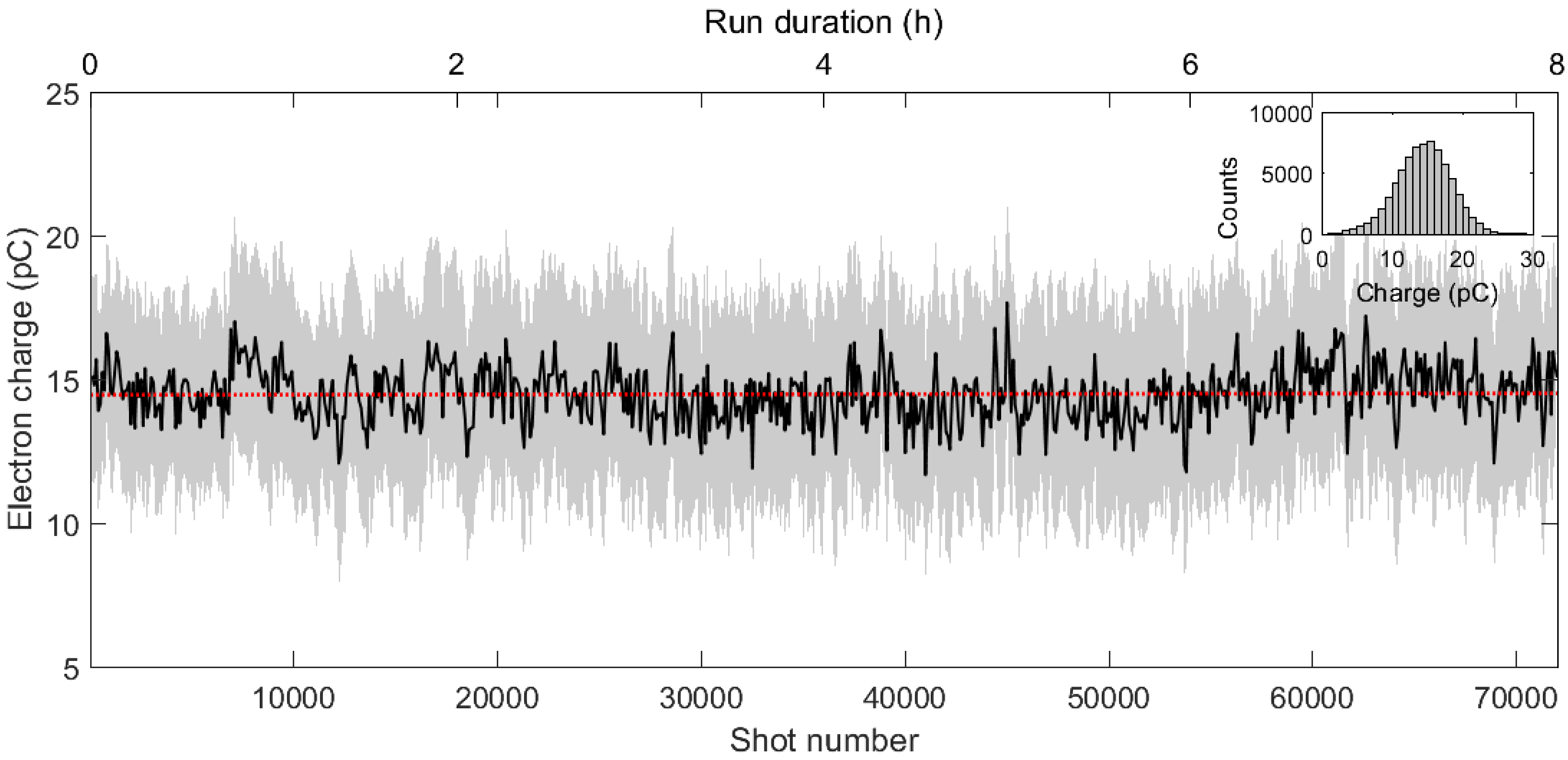
Spectral stability at repetition rate of 2.5 Hz



[3]S. Bohlen et al., Phys. Rev. Accel. Beams **25**, 031301, 2022

Stable electron beams with ionisation injection[3]

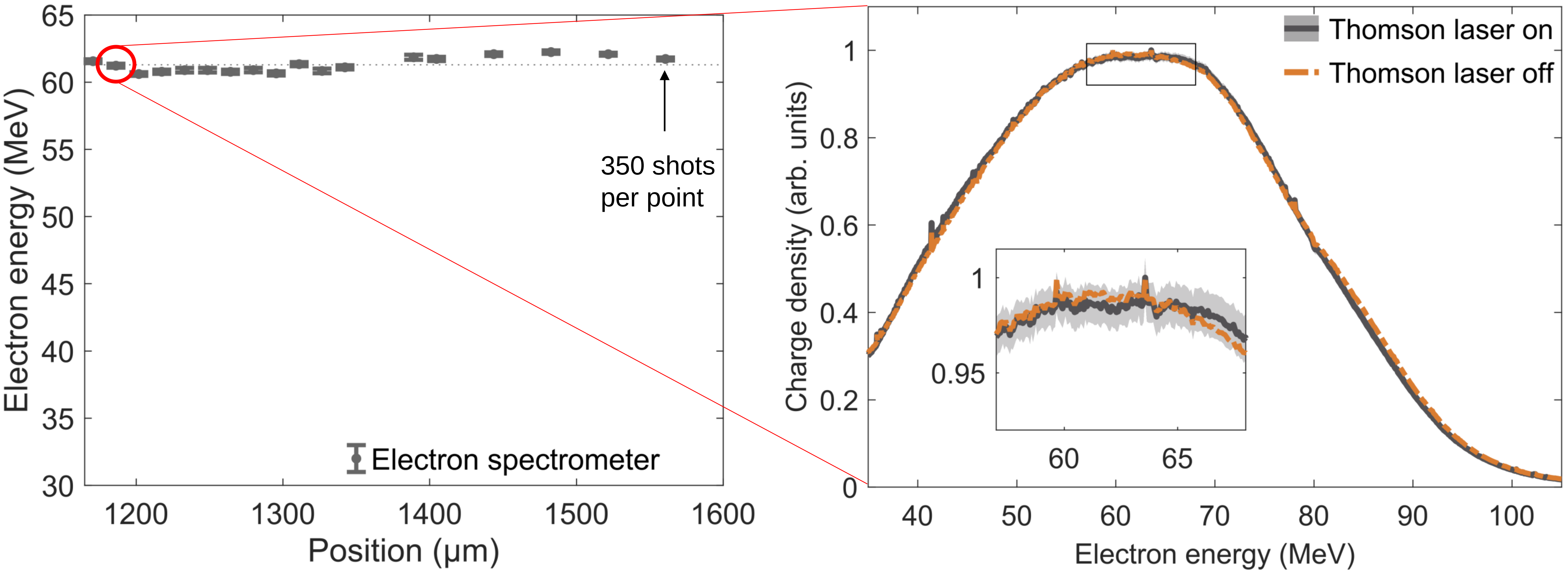
Average charge: $14.5 \pm 3.8\ pC$; constant over 8 hours, 100% injection



[3]S. Bohlen et al., Phys. Rev. Accel. Beams **25**, 031301, 2022

Stable peak electron energy of 61.3 ± 0.5 MeV

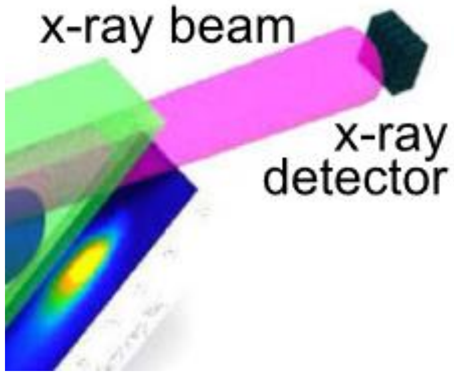
The Thomson laser had no measurable effect on the final electron spectrum



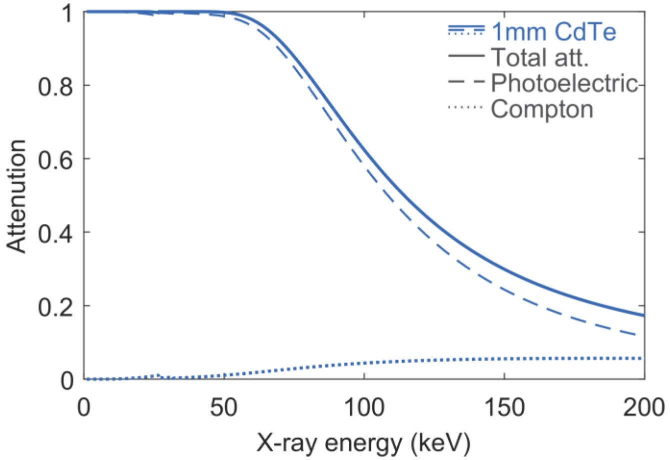
Understanding x-ray detection

The Hexitec[4,5,6] detector for x-ray measurements

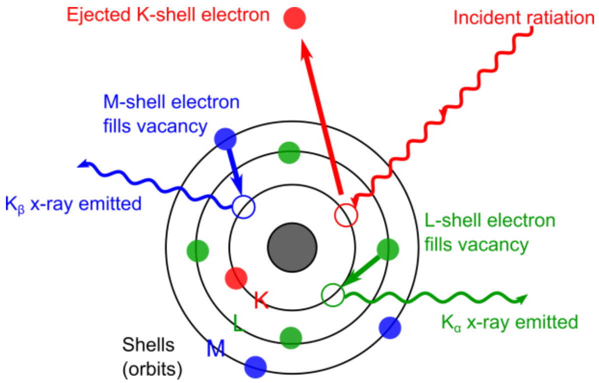
- CdTe detector, 0.8 keV energy resolution
- 80x80 pixels, 250 µm x 250 µm x 1mm



Attenuation in beamline



Detection probability



X-ray detection

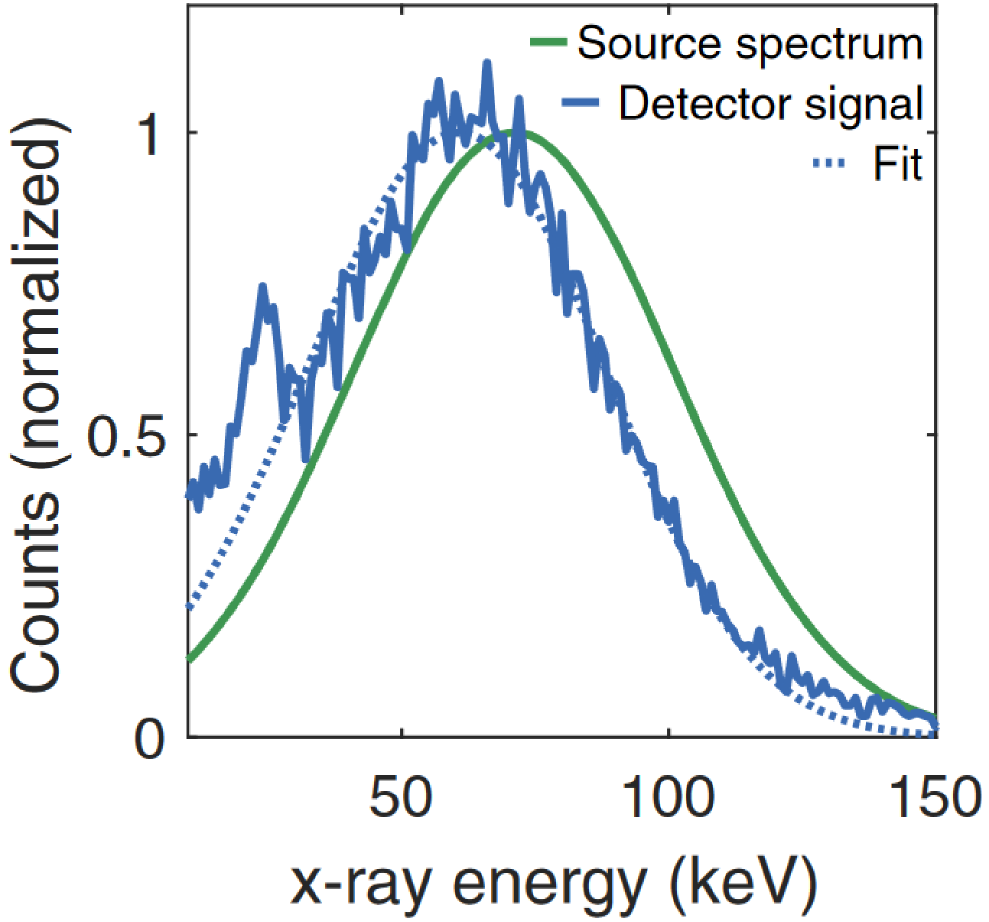
[4]Kindly loaned from CLF @ STFC
[5]P. Seller *et al.*, J Instrum. 6 (2011)
[6]M. C. Veale *et al.*, Synch. Rad. News 31, 28 (2018)

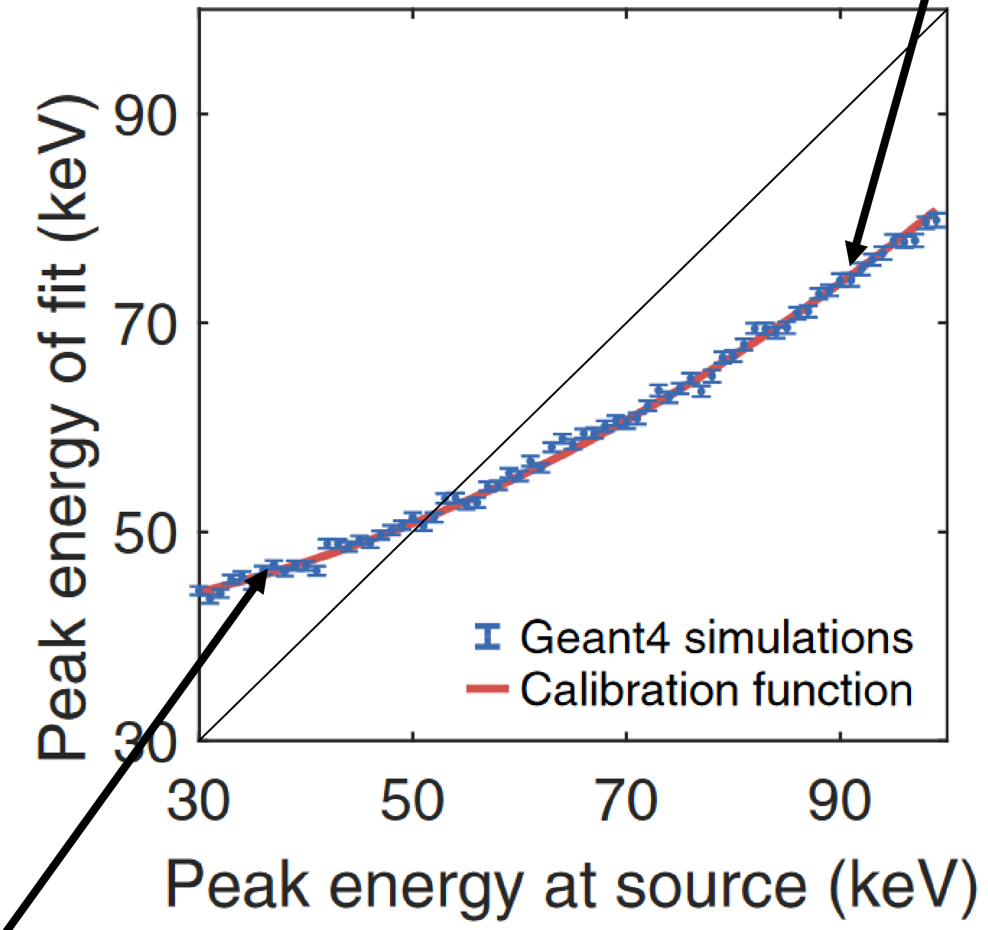
Used in G. Golovin et al., *Sci*. *Rep*. **6**, 24622, (2016)

Understanding x-ray detection

Extracting source spectrum using simulations

Shift due to detector efficiency

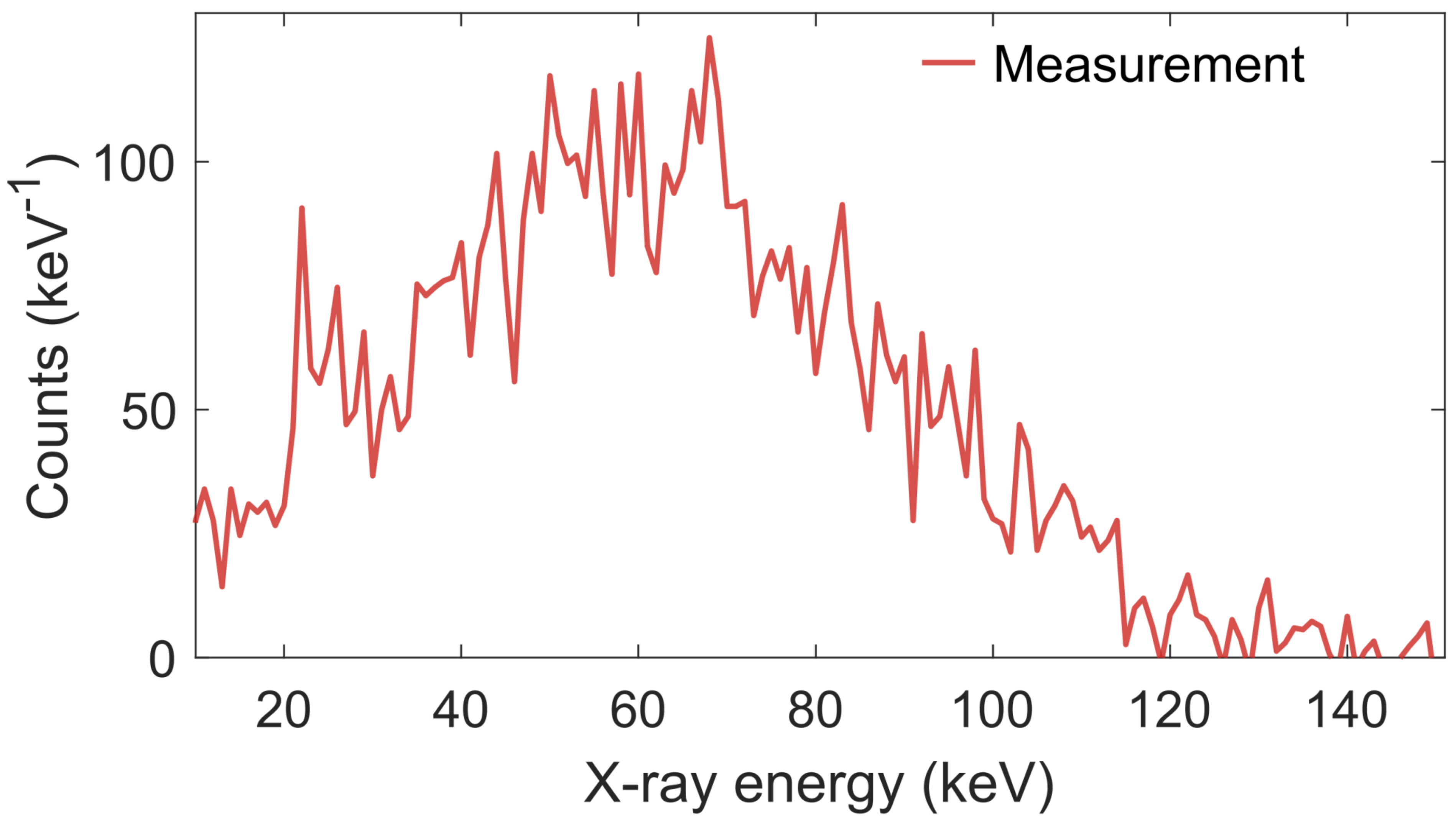




Attenuation in Aluminium

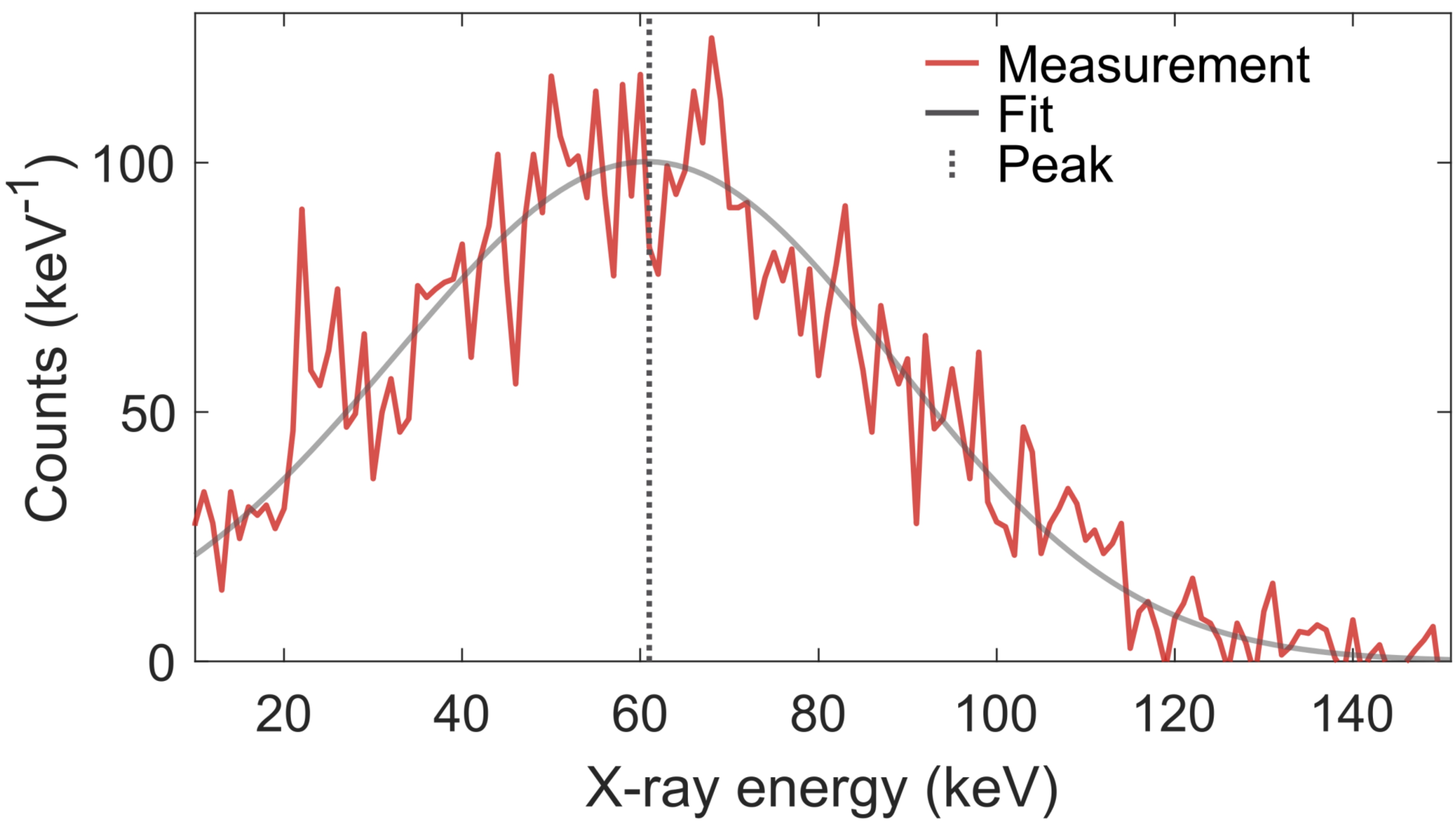
Understanding x-ray detection

Example of x-ray detection in the experiment



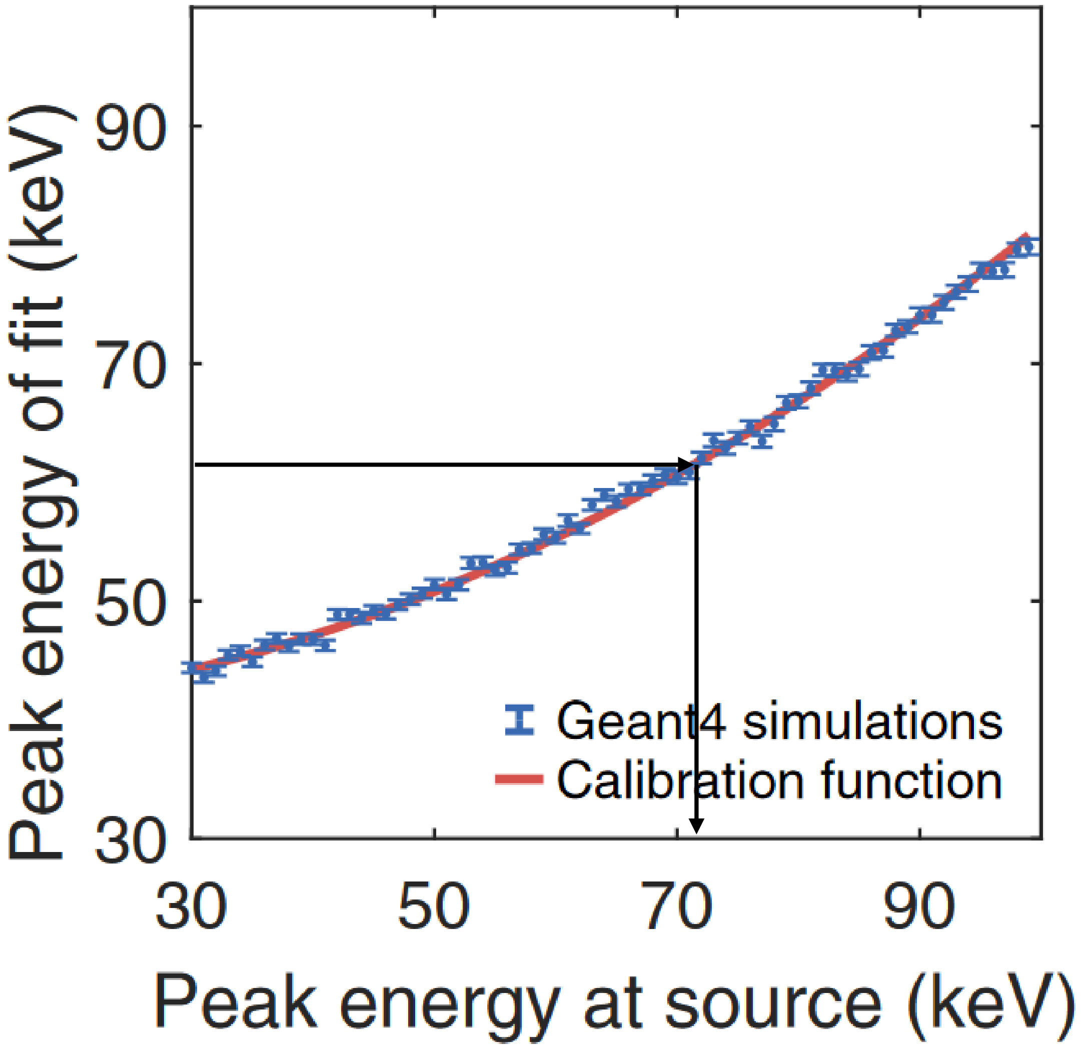
Understanding x-ray detection

Example of x-ray detection in the experiment



Understanding x-ray detection

Example of x-ray detection in the experiment



Understanding x-ray detection

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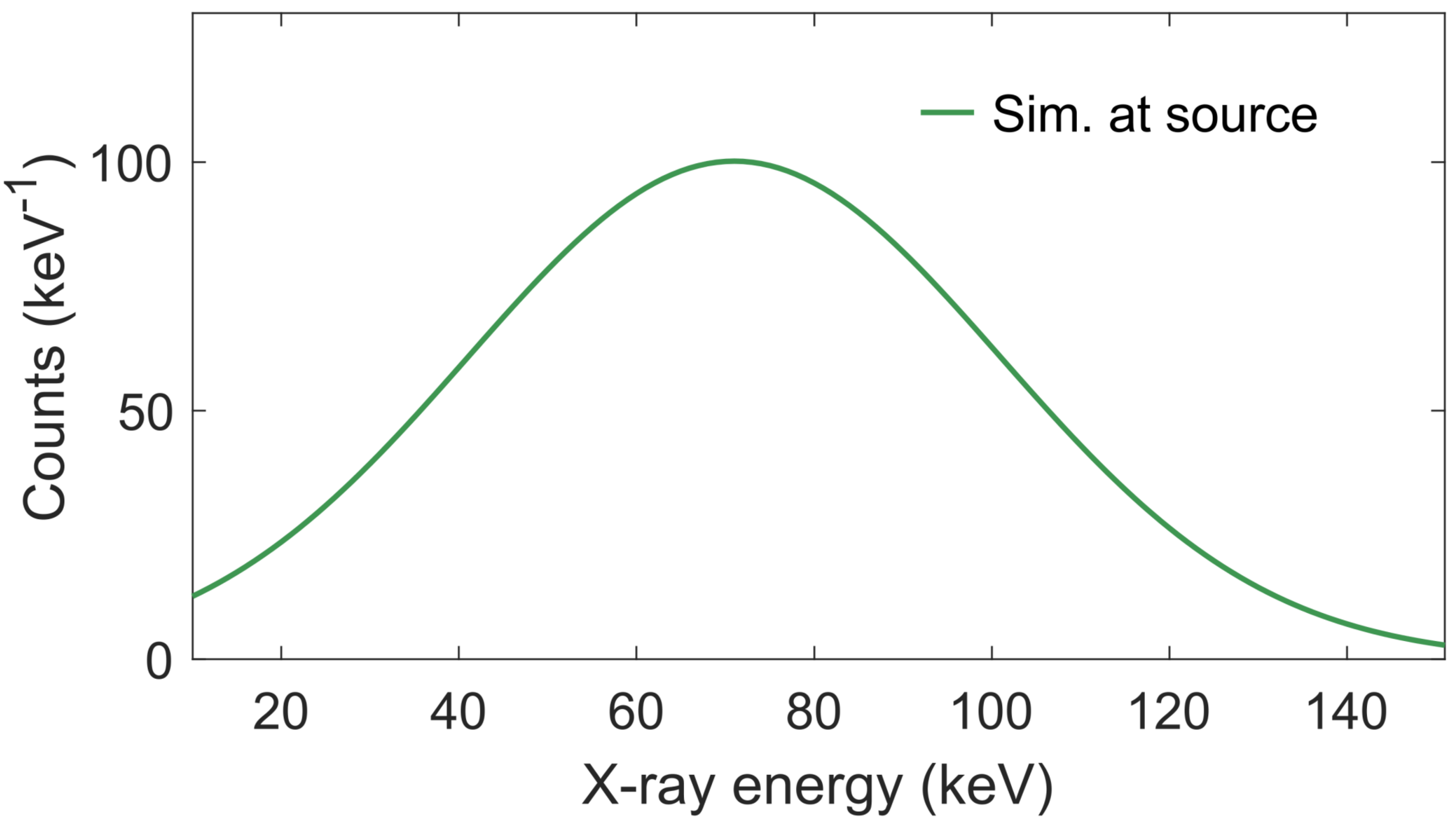
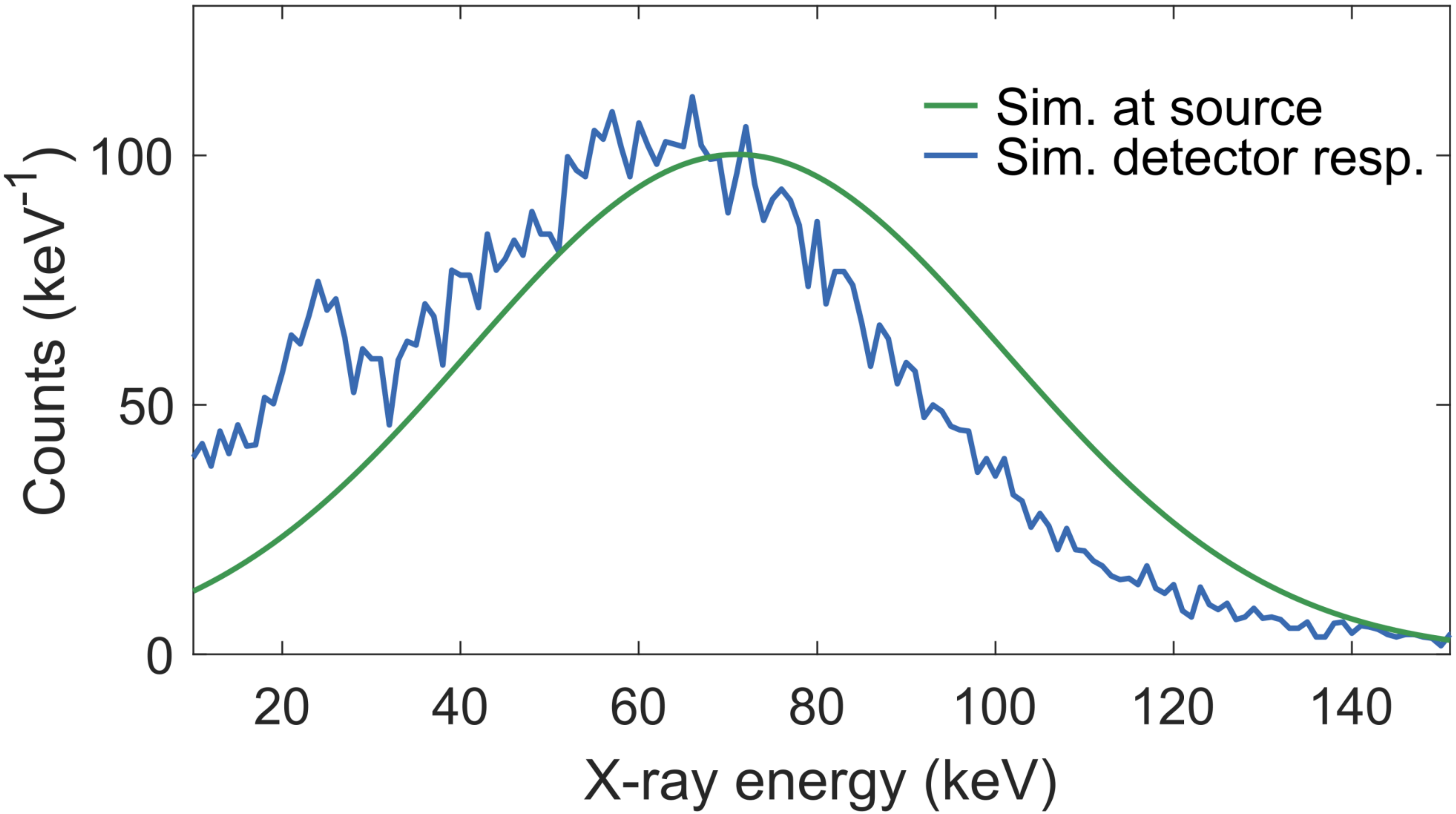


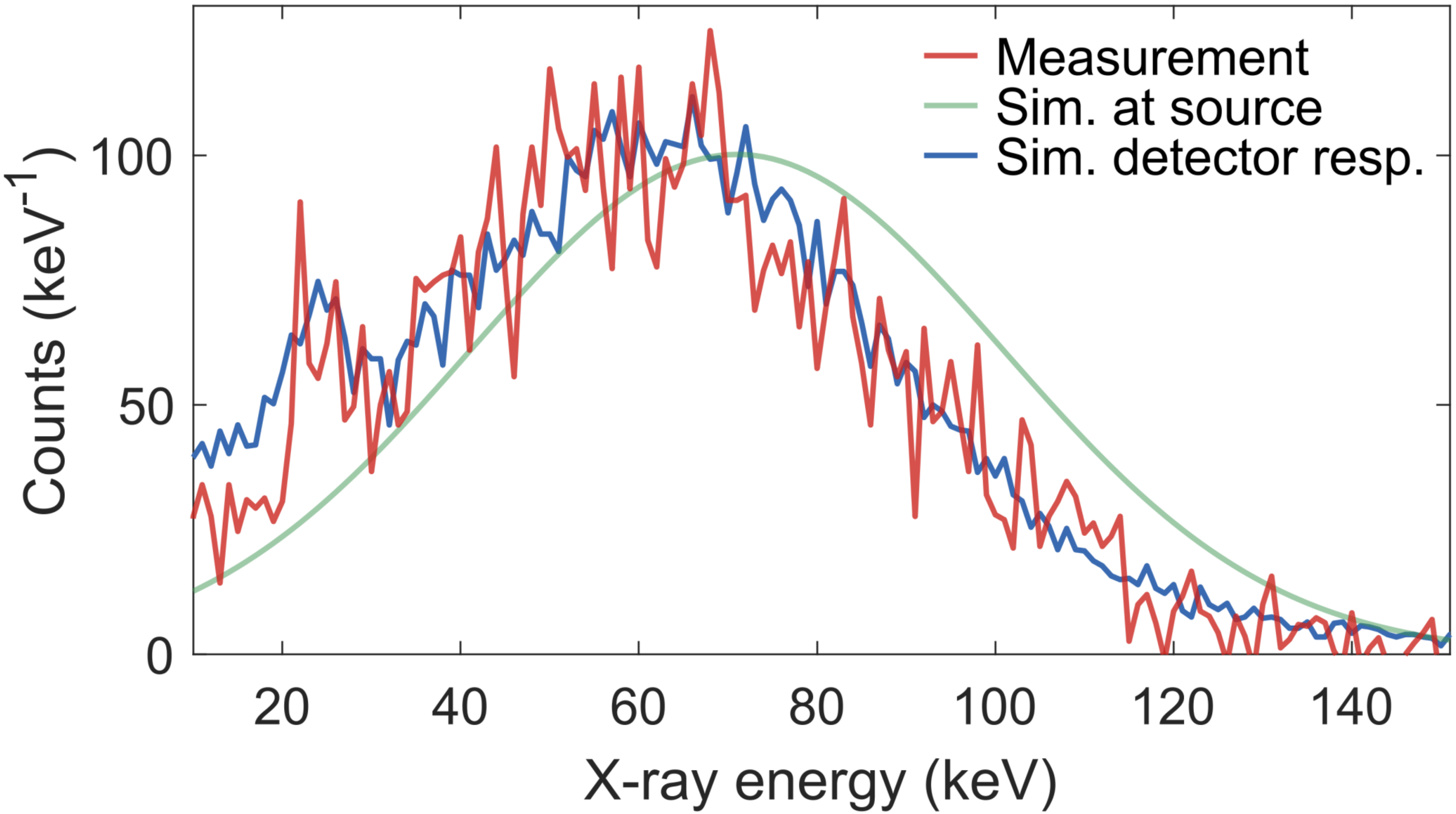
Understanding x-ray detection

Example of x-ray detection in the experiment



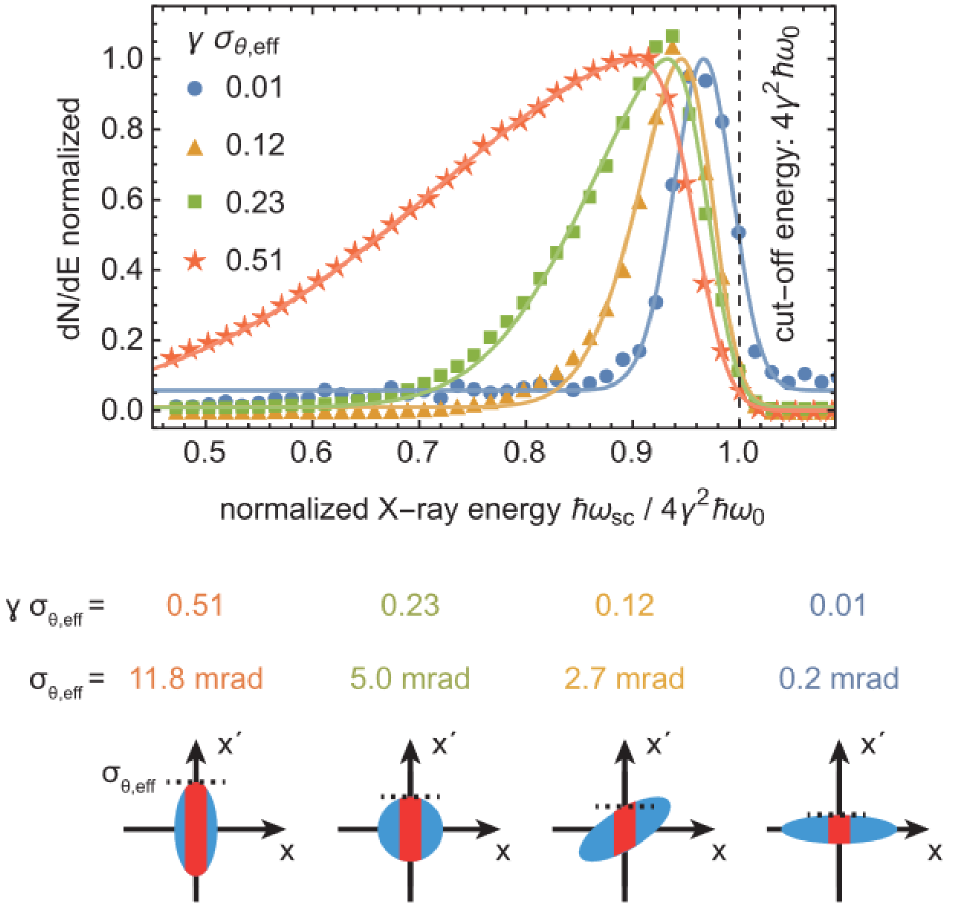
Understanding x-ray detection

Example of x-ray detection in the experiment



Understanding x-ray generation[7,8] and detection

Braodening and shifting effects from Thomson scattering need to be considered



From: J. M. *Krämer et al., Scientific Reports* **8**: 1398 (2018)

Energy of scattered photons:

$$E_\gamma \approx \frac{4\gamma_e^2 * E_{Laser}}{1 + \gamma_e^2\theta^2 + a_0^2/2}$$

Energy of scattered photons:

$E_\gamma \approx 4\gamma_e^2 * E_{Laser} * \Lambda$ [8]

[7] S G Rykovanov *et al., J. Phys. B: At. Mol. Opt. Phys.* **47** 234013 (2014)
[8] J. M. *Krämer et al., Scientific Reports* **8**: 1398 (2018)

Experimental knowledge about electrons in plasma

- Can we measure directly what happens inside the gas target?

Yes!

In our setup:

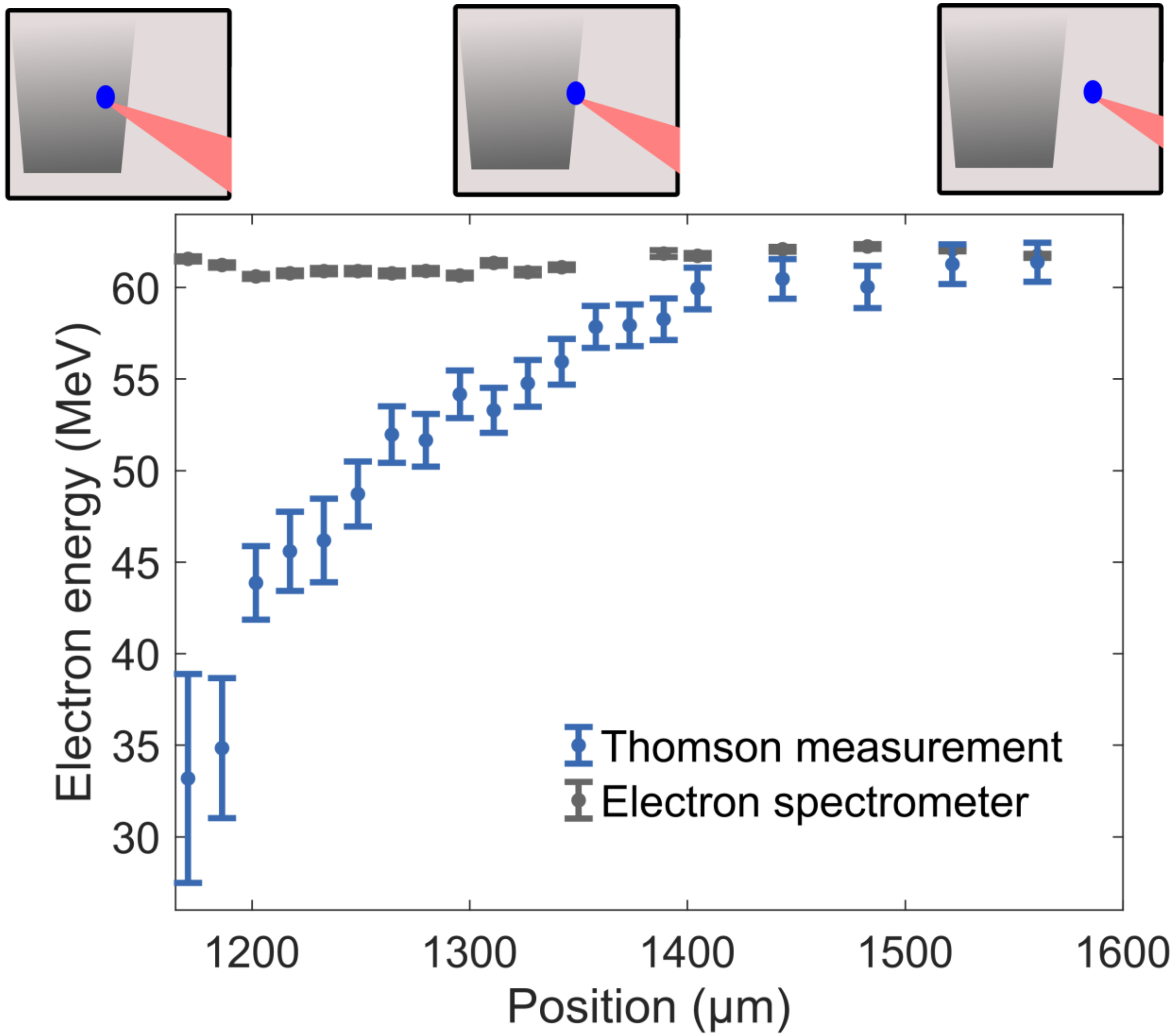
- Measure x-ray spectrum (E_γ)
- Correct for measurement effects ($E_{\gamma,Source}$)
- Adjust for Thomson Theory (Λ)
- Calculate electron peak energy

Energy of scattered photons:

$$E_{\gamma,Source} \approx 4\gamma_e^2 * E_{Laser} * \Lambda$$

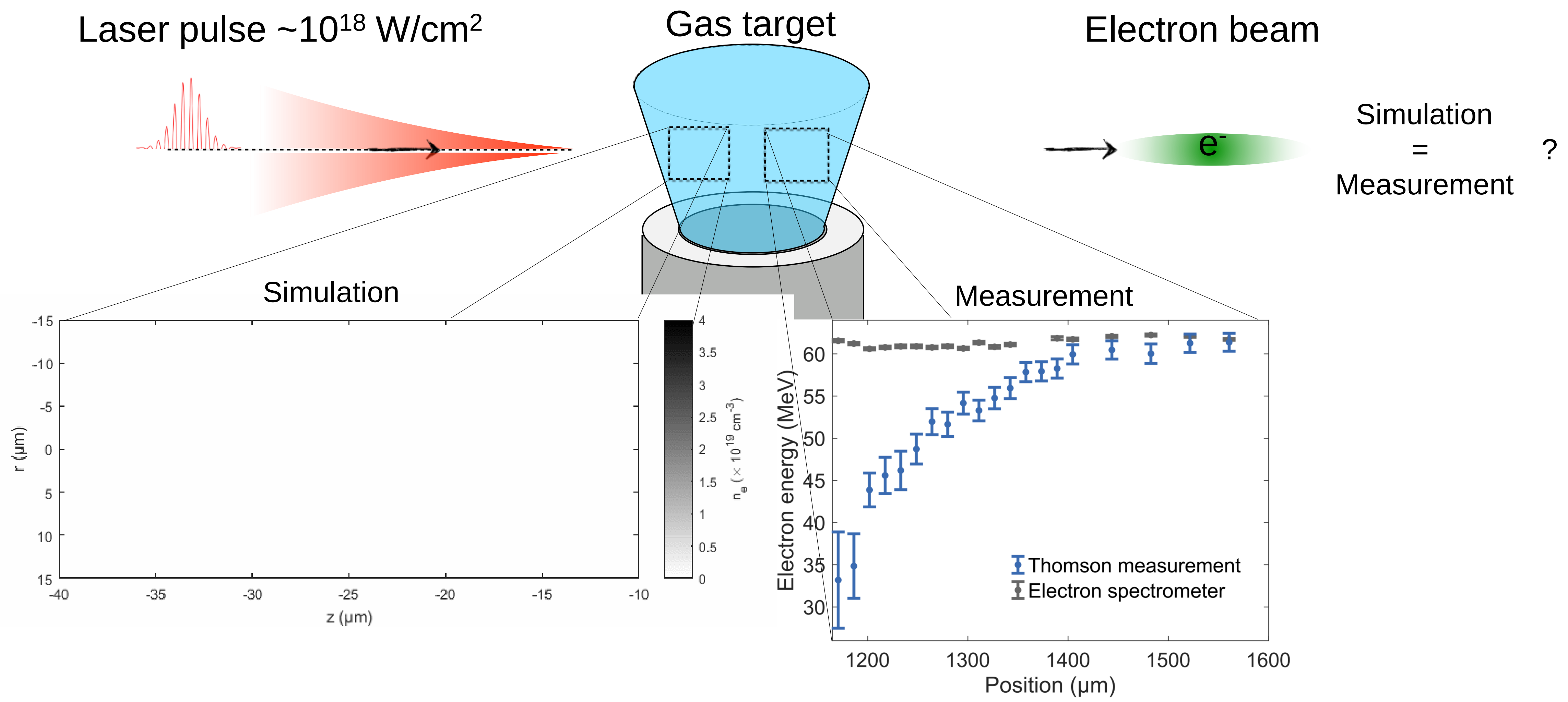
Measurement of the electron energy evolution in the plasma

Thomson scattering enables non-invasive *in-situ* measurement of the electron energy



Particle-in-cell (PIC) simulations to understand LPA

Study of laser wakefield acceleration using Particle-In-Cell (PIC) simulations



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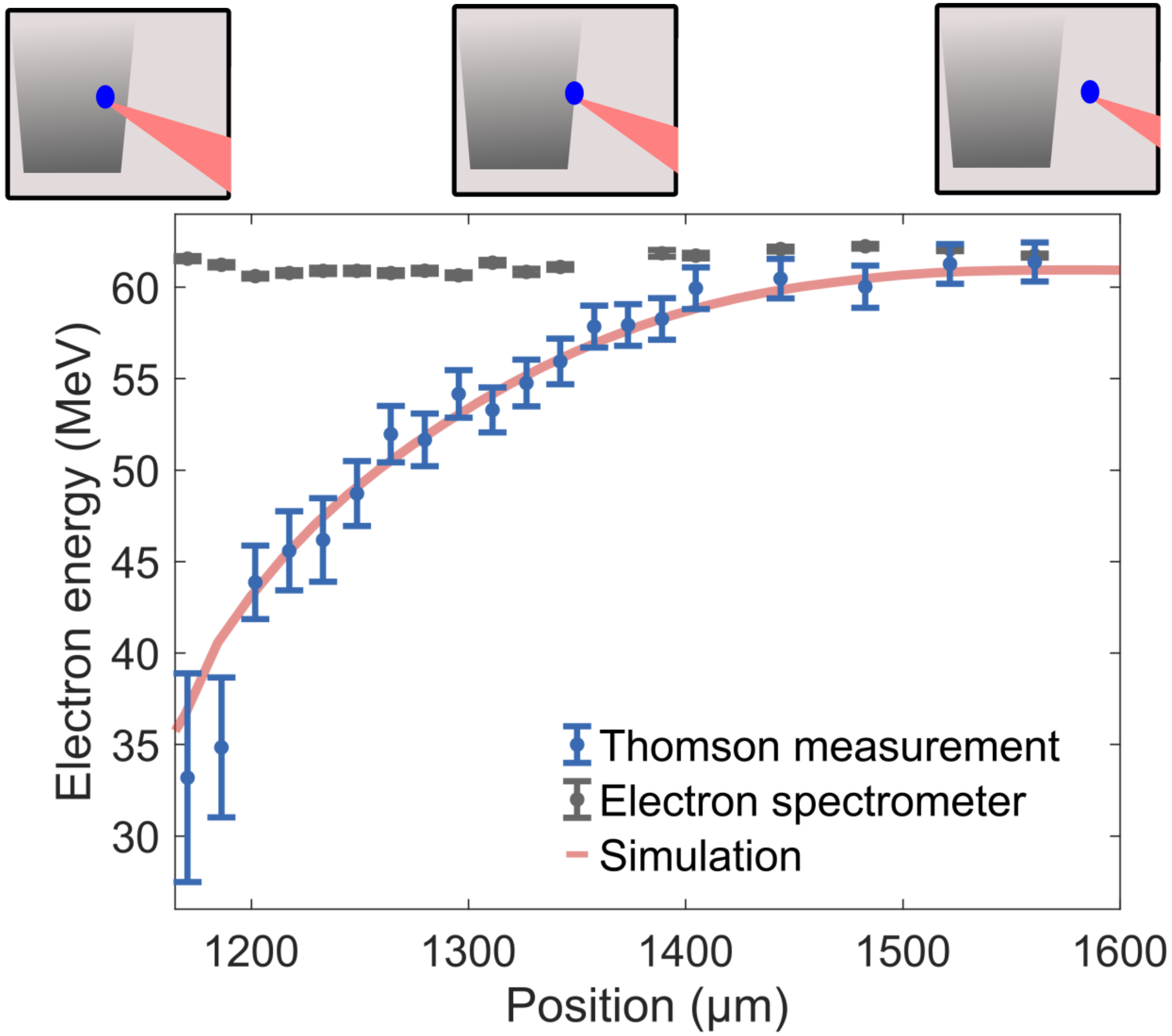

Measurement of the electron energy evolution in the plasma

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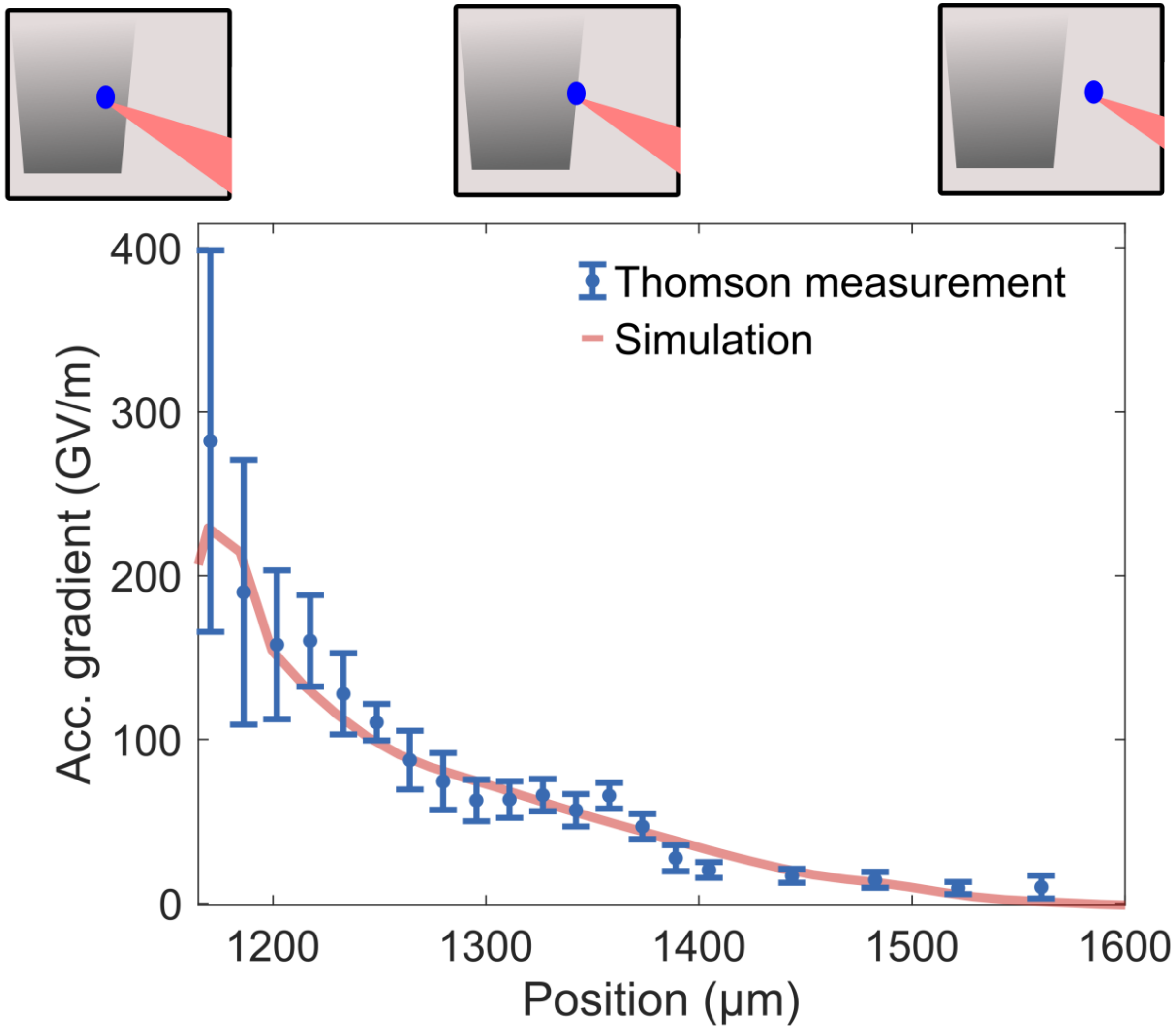

Summary

In Situ Measurement of Electron Energy Evolution in a Laser-Plasma Accelerator

- Experimental demonstration of new multi-shot diagnostic based on Thomson scattering

- First measurement of the electron energy evolution inside a plasma accelerator

- Non-invasive: No effect on final electron parameters

- Energy measurement enabled measurement of longitudinally resolved electric field at position of the electron bunch

- Understanding of X-ray generation and detection necessary for precise measurements