Generation of a spectrally two-component electron beam in a laser-wakefield accelerator

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Outline

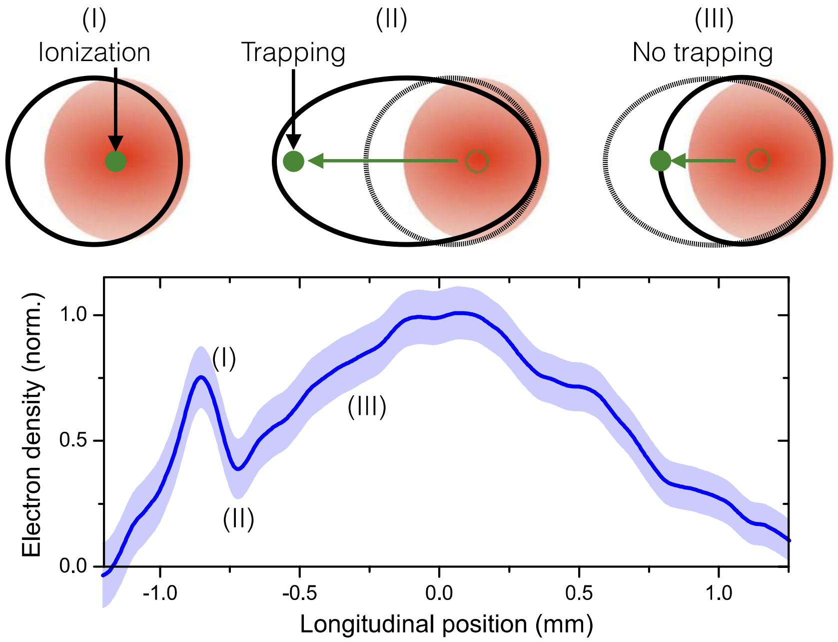
- Goal of the experiment
- Experimental setup
- Electron beams with one jet
- Electron beams and X-rays with two jets
- Summary and outlook

Experiment goal

In short: hybrid LWFA-PWFA, boosting a witness bunch in a second stage

1. Generate two distinct electron bunches within the same bubble

Shock-assisted ionization injection
(C. Thaury et al., Sci. Rep. 5, 16310 (2015))



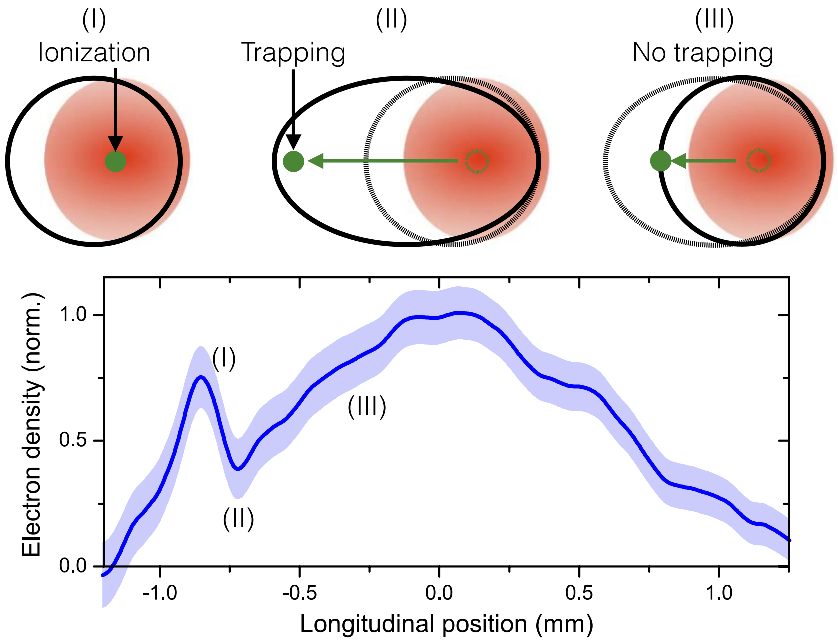
Experiment goal

In short: hybrid LWFA-PWFA, boosting a witness bunch in a second stage

1. Generate two distinct electron bunches within the same bubble

   Shock-assisted ionization injection
   (C. Thaury et al., Sci. Rep. 5, 16310 (2015))

2. Send them into a second, higher-density gas jet and boost witness

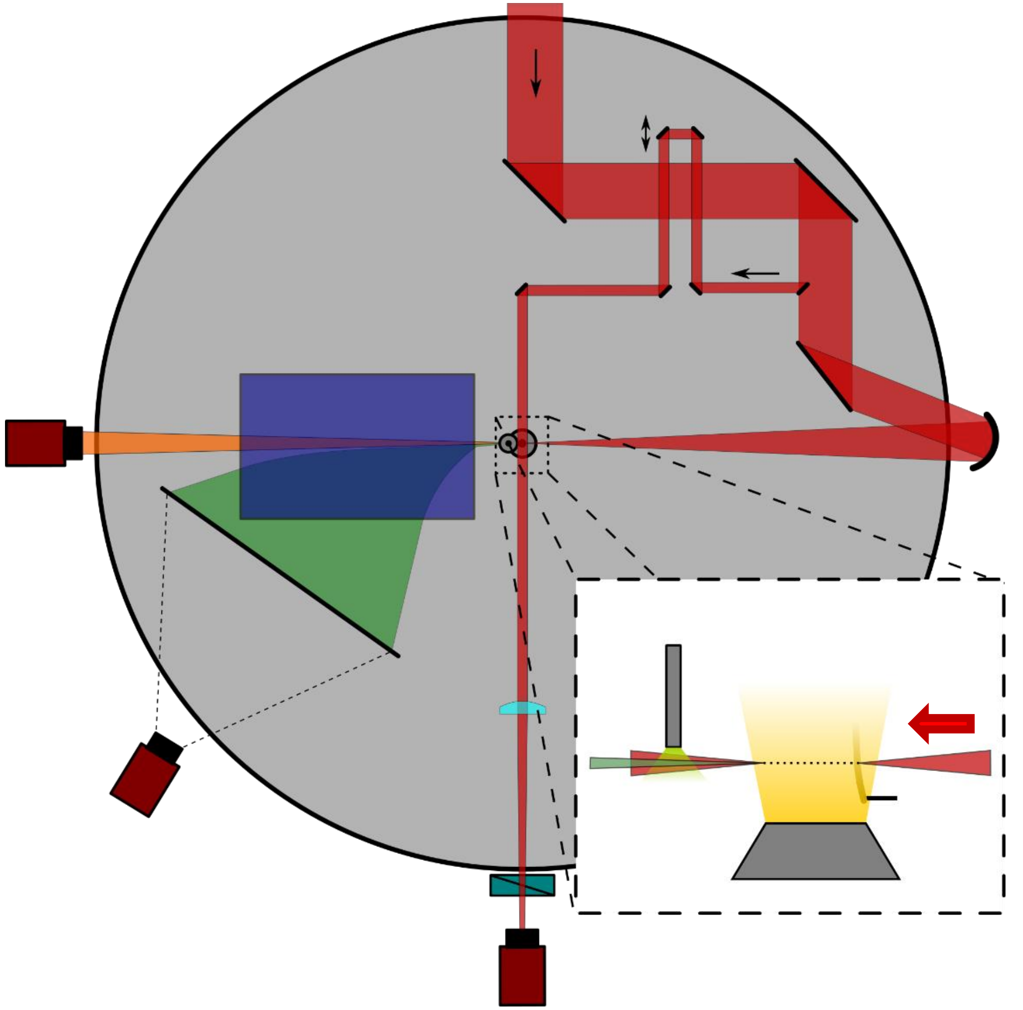


Experimental setup

- Combine shock-front injection and ionization injection (99 % He, 1 % N_2)
- Insert second jet with pure N_2 (to reach high plasma density)
- Look for effects in electron spectrum and X-rays

Laser parameters:

1 J on target, 32-37 fs fwhm duration, 14 µm fwhm focal spot size, $a_0 \approx 2.1$



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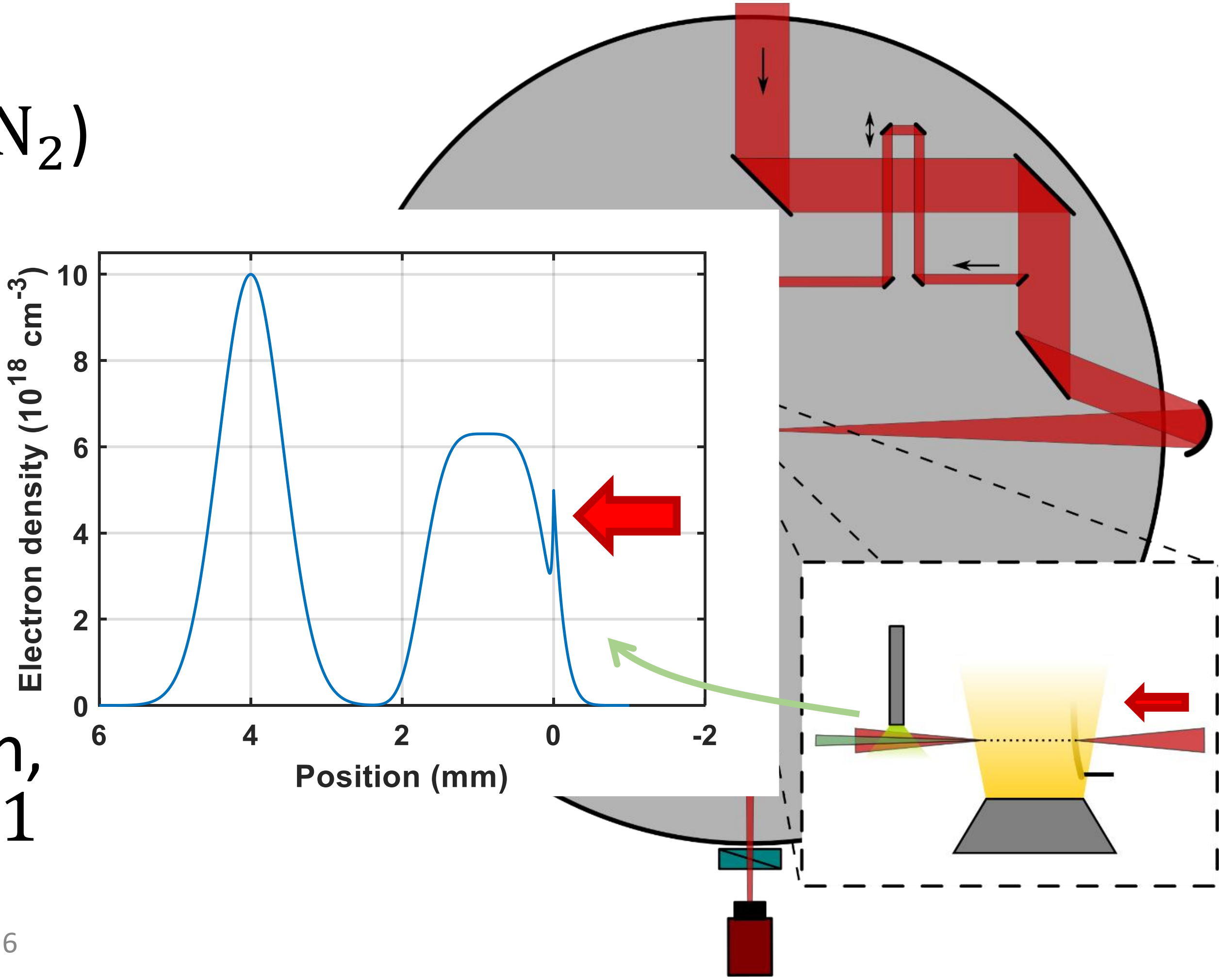
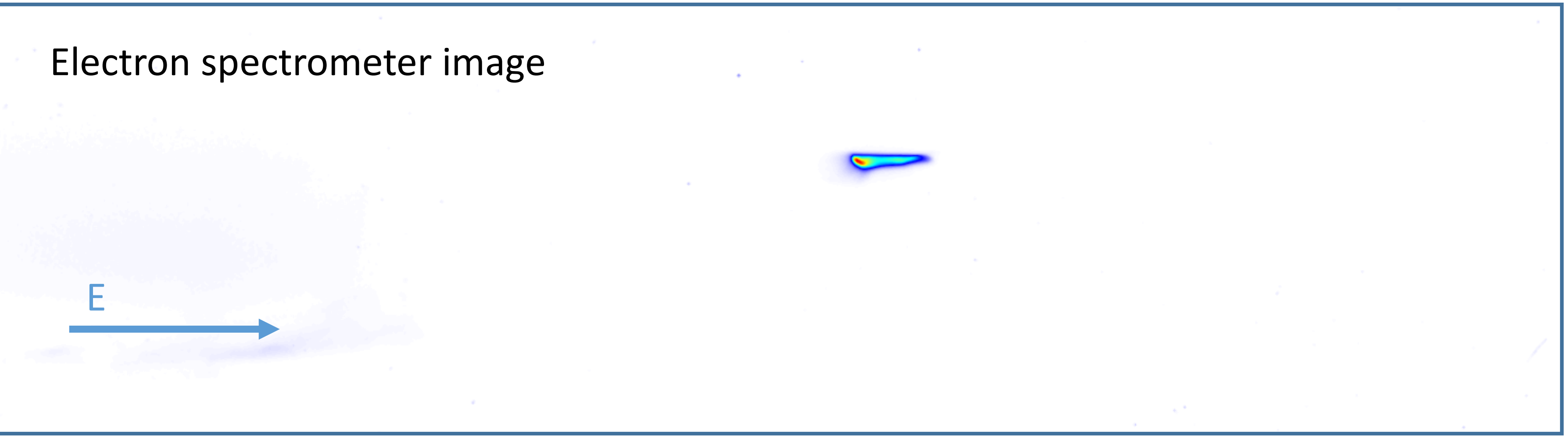
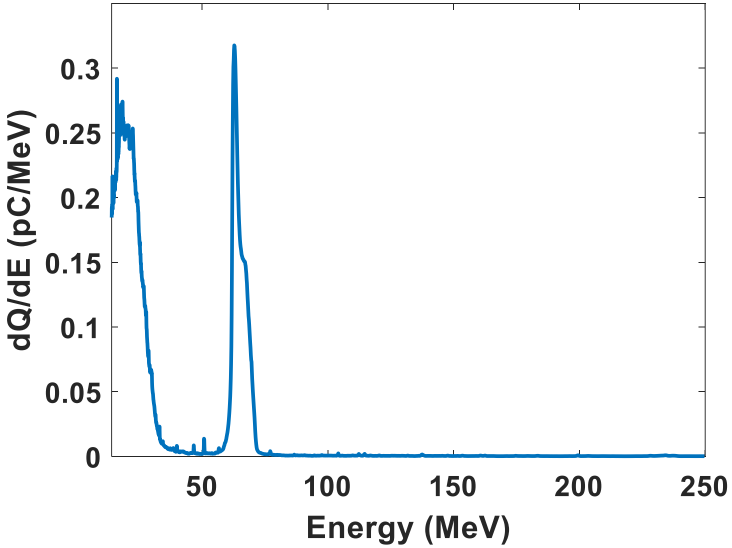


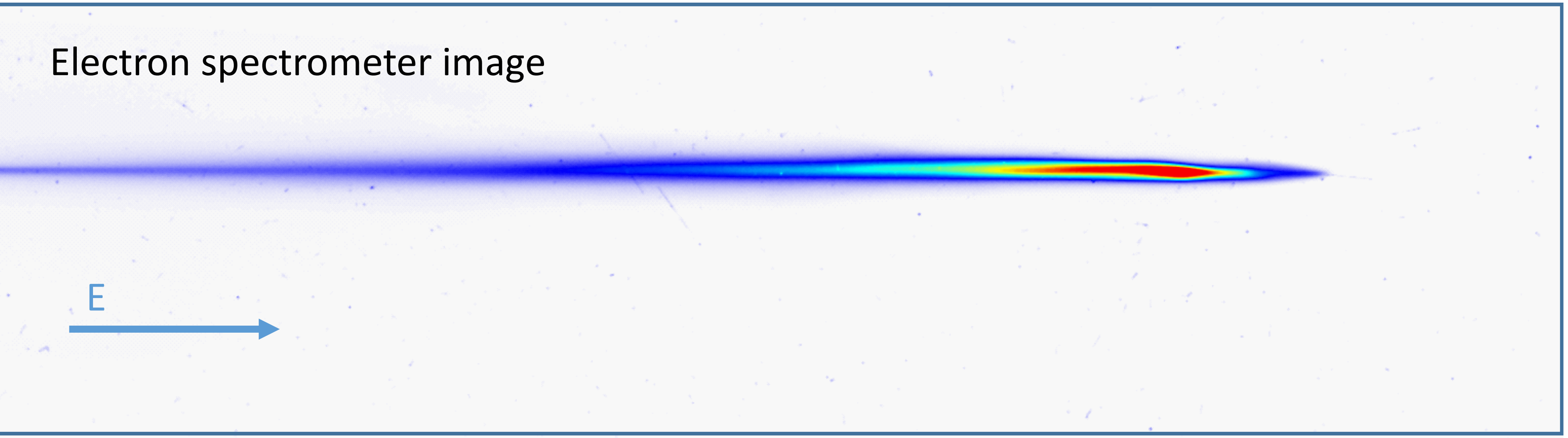
Single jet – injection mechanisms

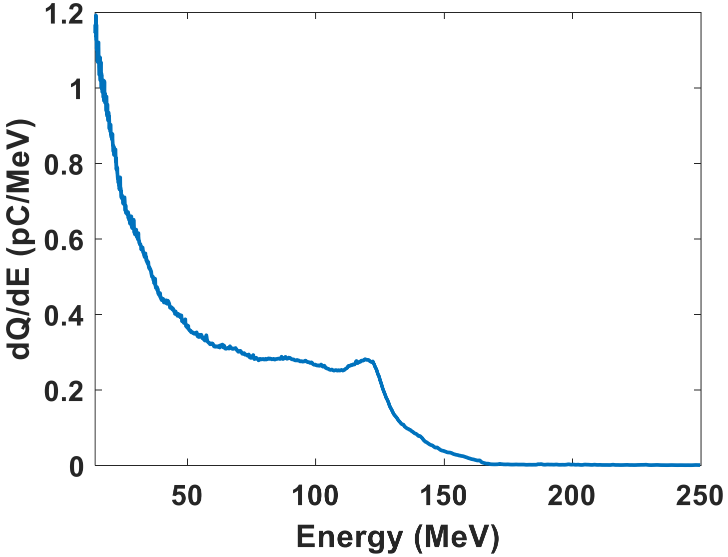




- Shock-front injection with pure He
  - 60-70 MeV
  - Few % fwhm energy spread
  - Few pC charge
  - ~4 mrad fwhm divergence

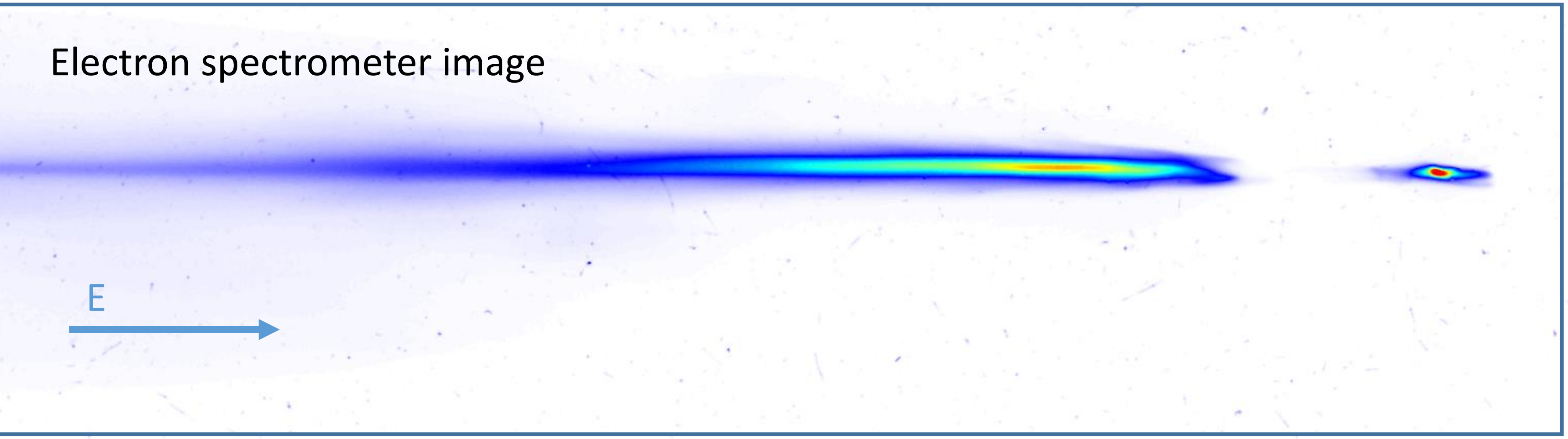
Single jet – injection mechanisms

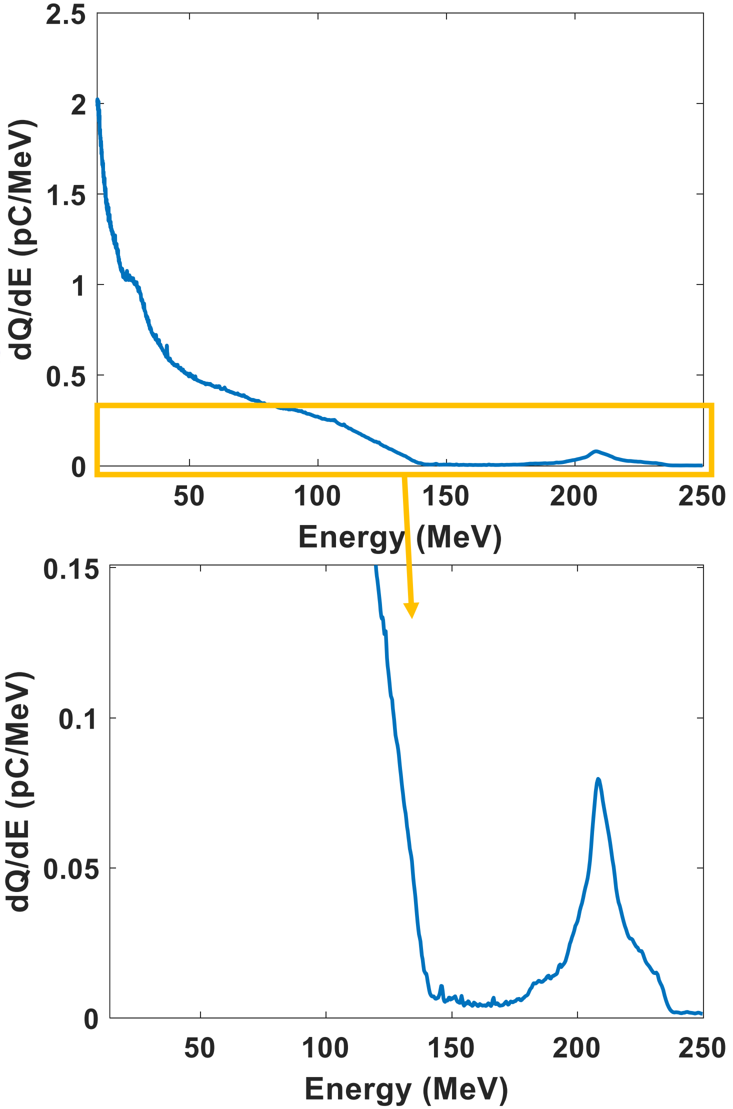




- Ionization injection with 99 % He, 1 % N_2
  - Broadband spectrum, ~150 MeV cutoff
  - 10's of pC charge
  - ~8 mrad fwhm mean divergence

Single jet – injection mechanisms





- Combining ionization and shock
  - Beams keep main characteristics, peak E increased
  - Peak: Few pC, $\Delta E/E < 10\ \%$, 4 mrad
  - Broadband beam: 60-100 pC, 8 mrad divergence

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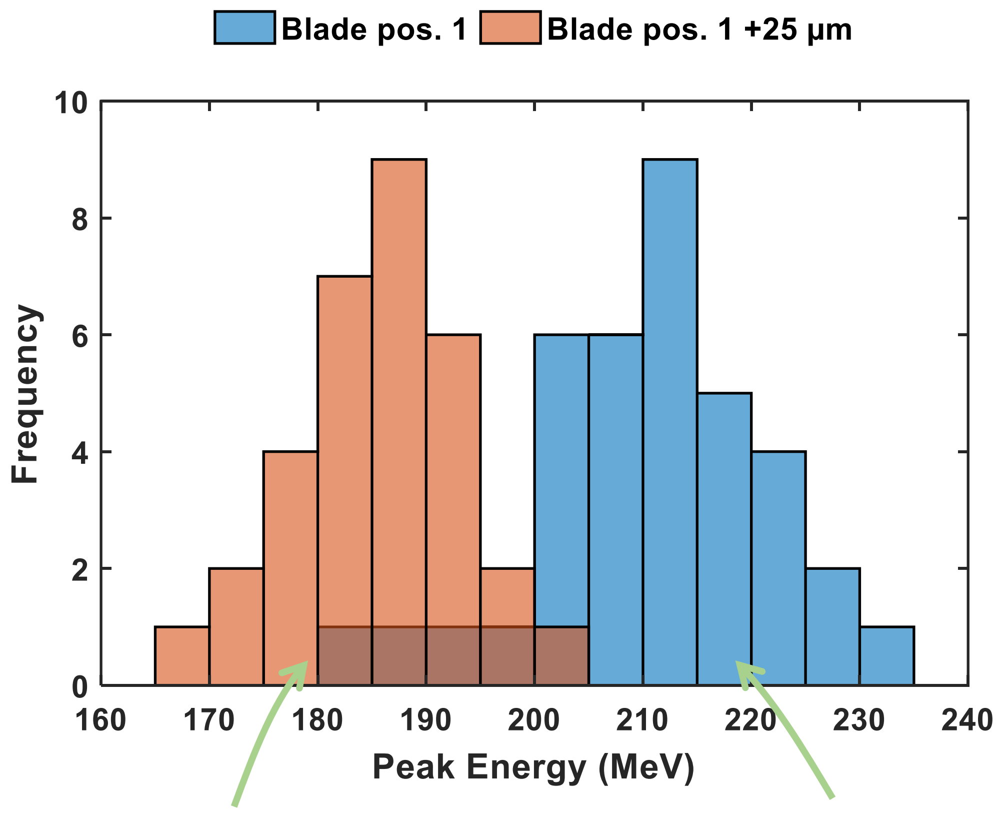
Single jet - tuneability

- Tuneable energies by blade position
- Tuneable peak charge by N_2 conc.
  - 1 % N_2 → ~2 pC; 5 % N_2 → ~ 5 pC



185 MeV ± 8 MeV (4.2 %) rms

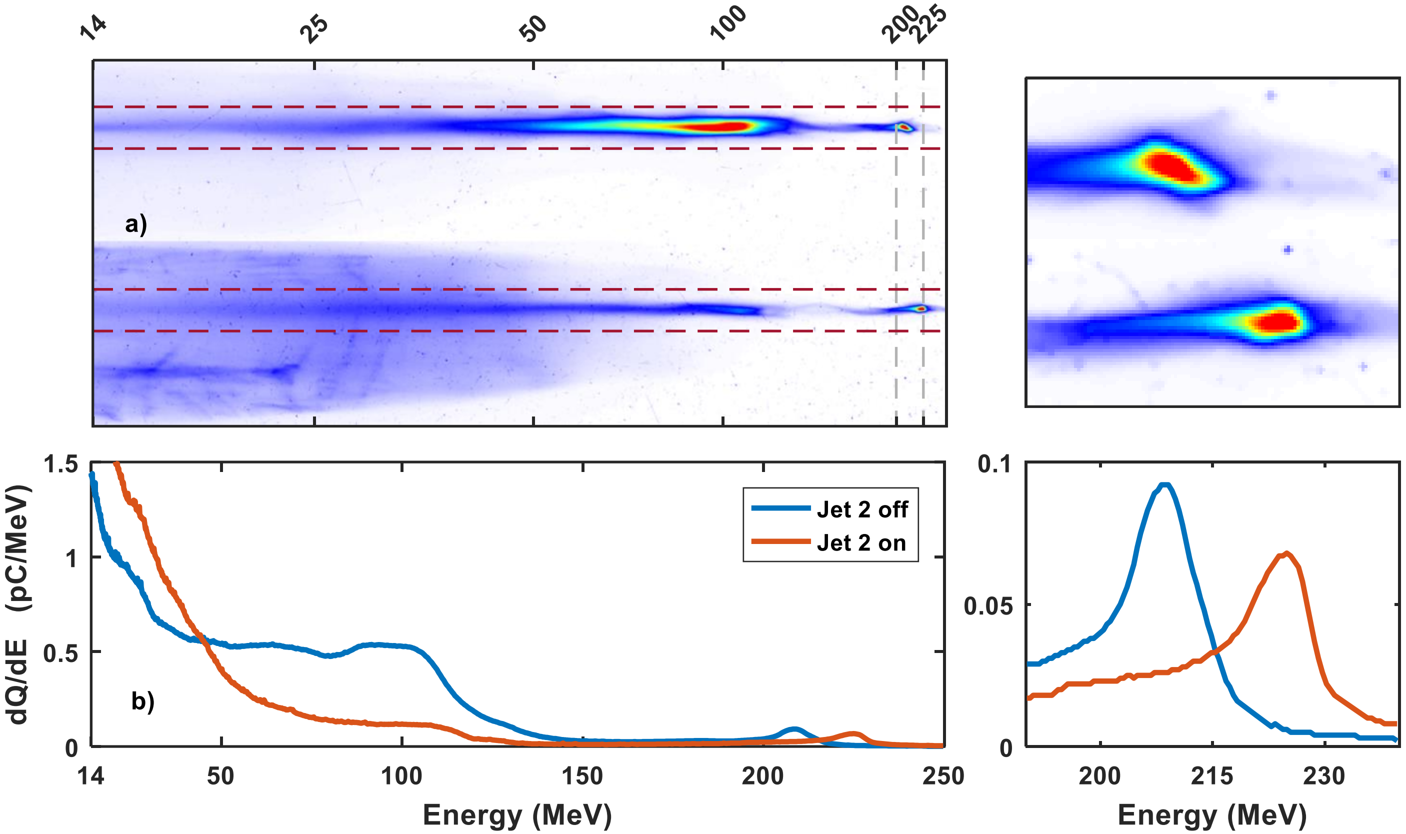
211 MeV ± 11 MeV (5.1 %) rms

Adding a second jet: electrons

Broadband	Mean E (MeV)	Mean div. (mrad)
Jet 2 off	63	8
Jet 2 on	45	47

Peak	Mean E (MeV)	Mean div. (mrad)
Jet 2 off	206	4
Jet 2 on	219	3

Depends on pressure and jet 2 position



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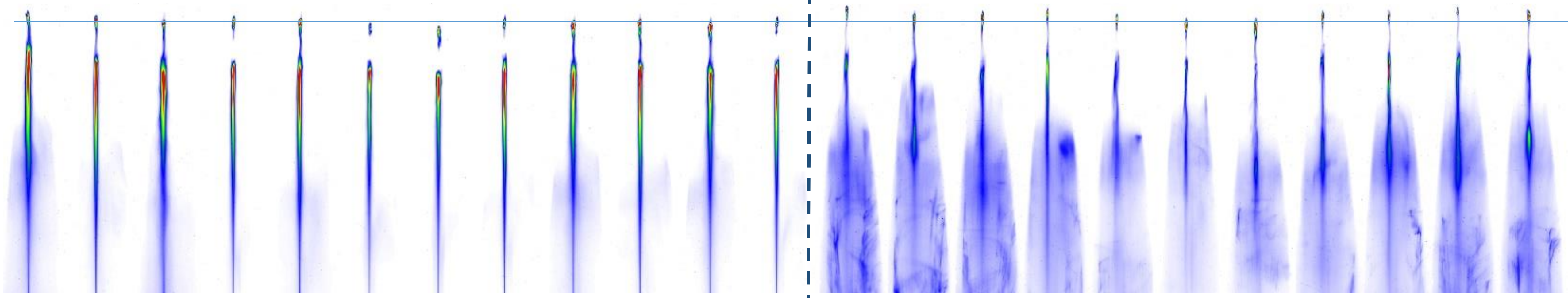

One jet

Two jets

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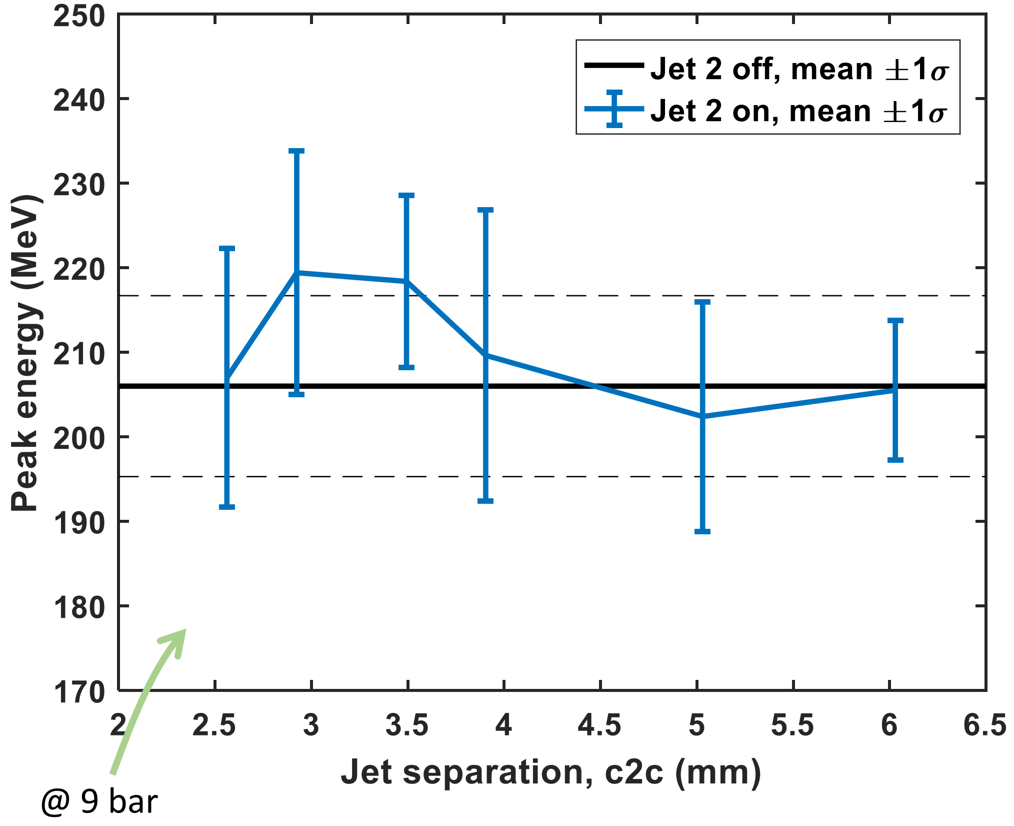
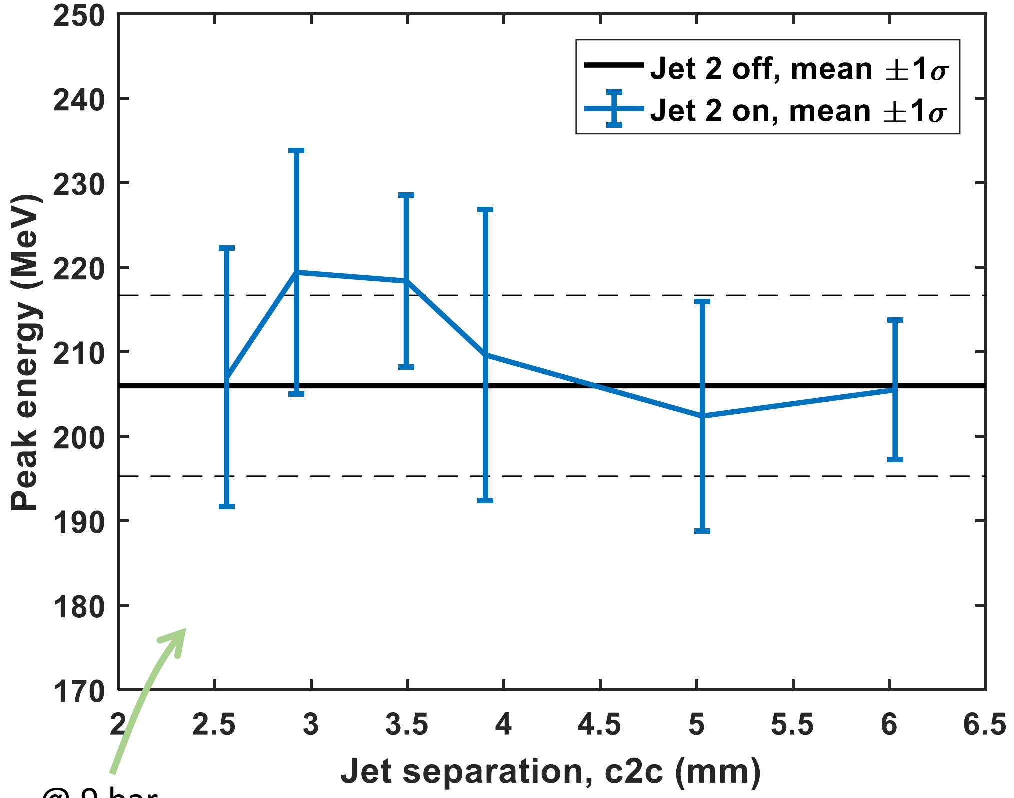
Adding a second jet: electrons

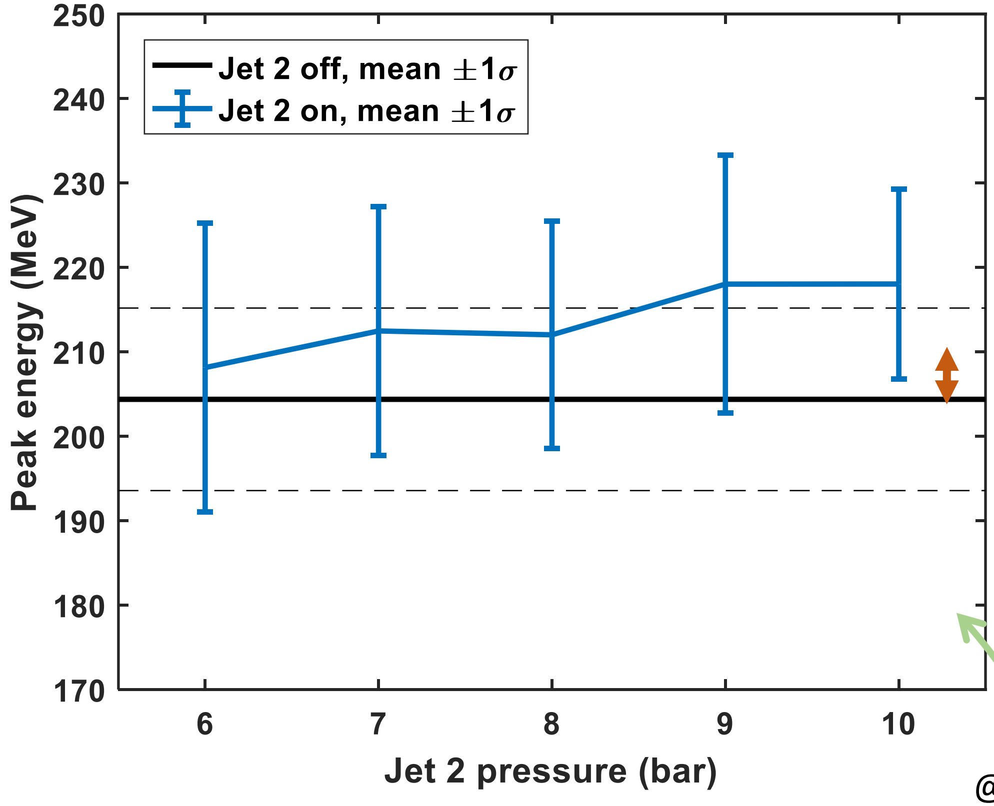


- Energy gain? Small but statistically significant

Adding a second jet: electrons



@ 9 bar

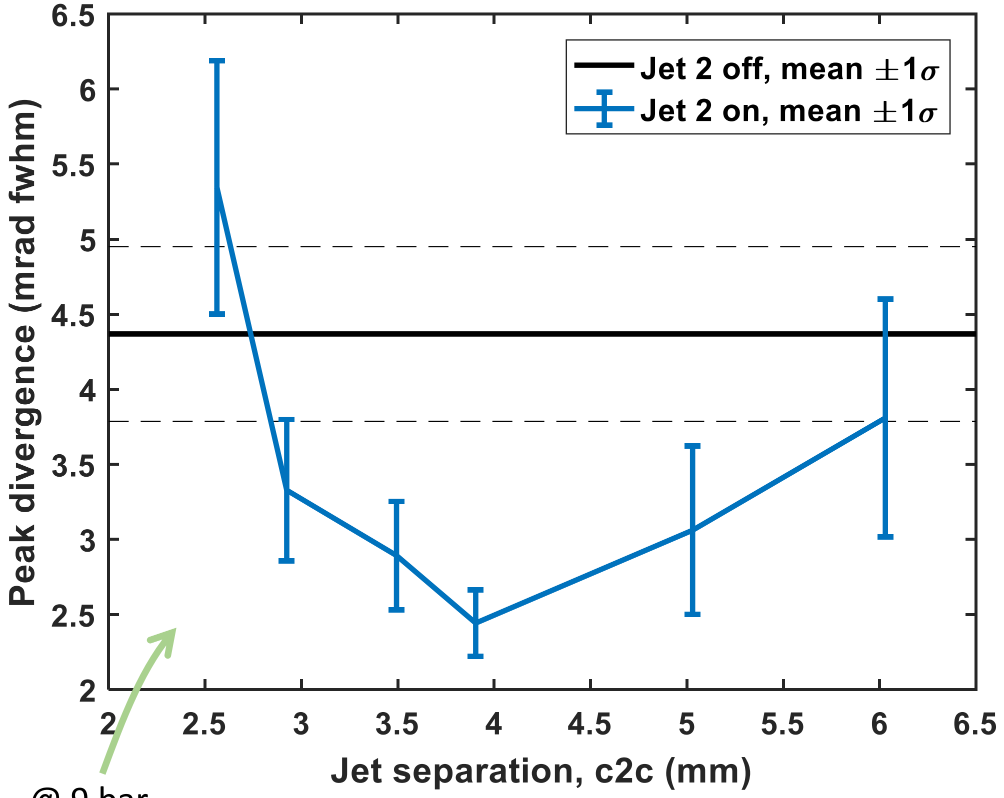


Pure shock beam boost

@ 3 mm sep.

- Energy gain? Small but statistically significant

Adding a second jet: electrons

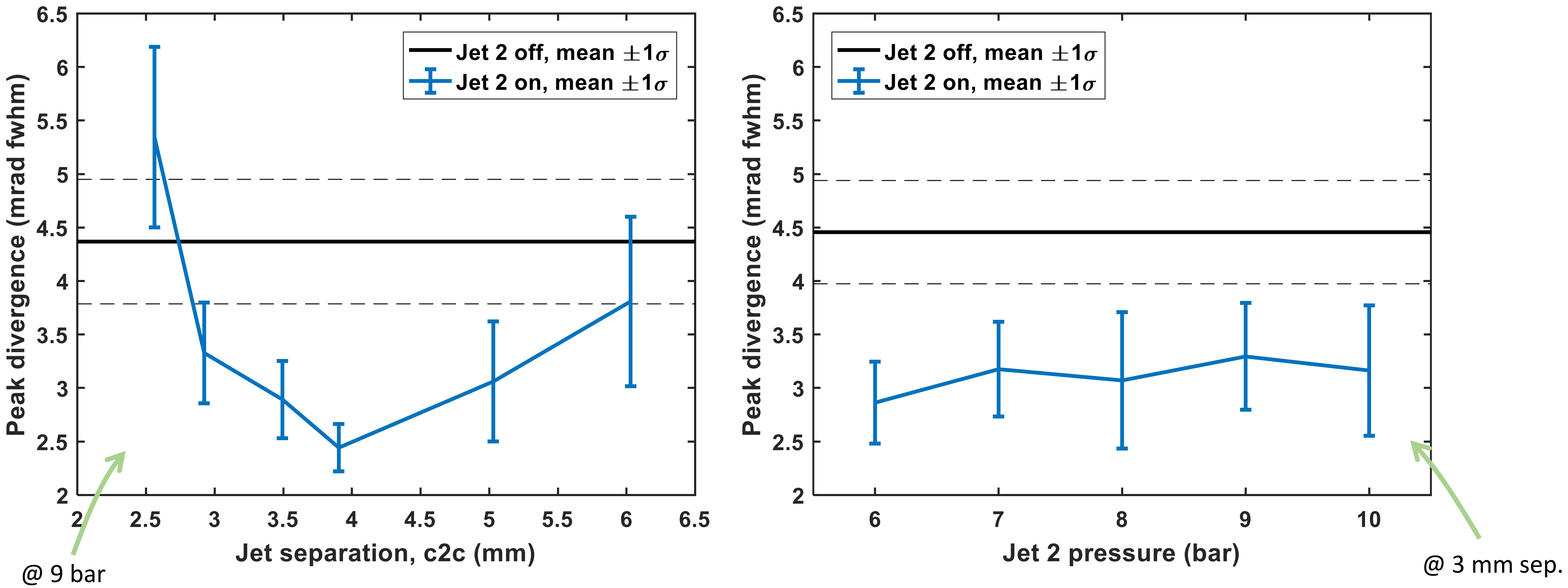


@ 9 bar

✓Focusing

(see *Demonstration of relativistic electron beam focusing by a laser-plasma lens*, C. Thaury et al., 2015, DOI: 10.1038/ncomms7860)

Adding a second jet: electrons



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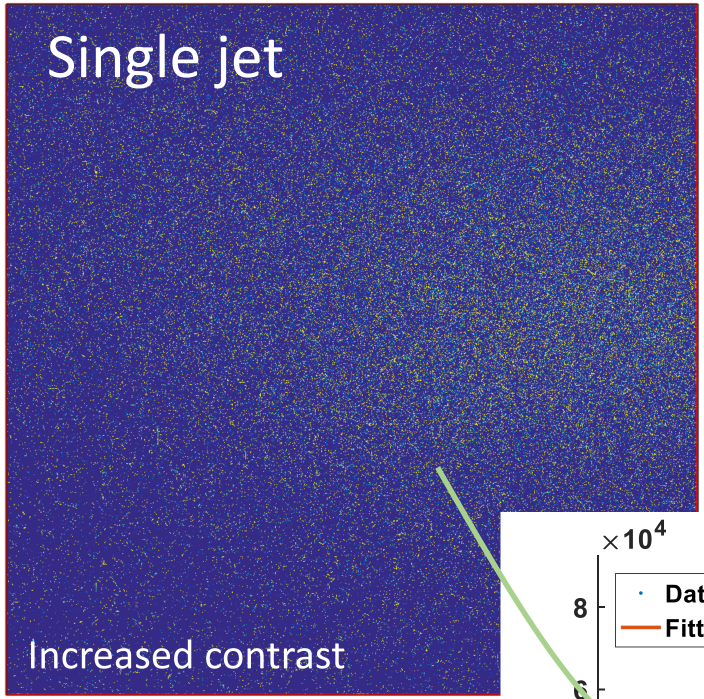
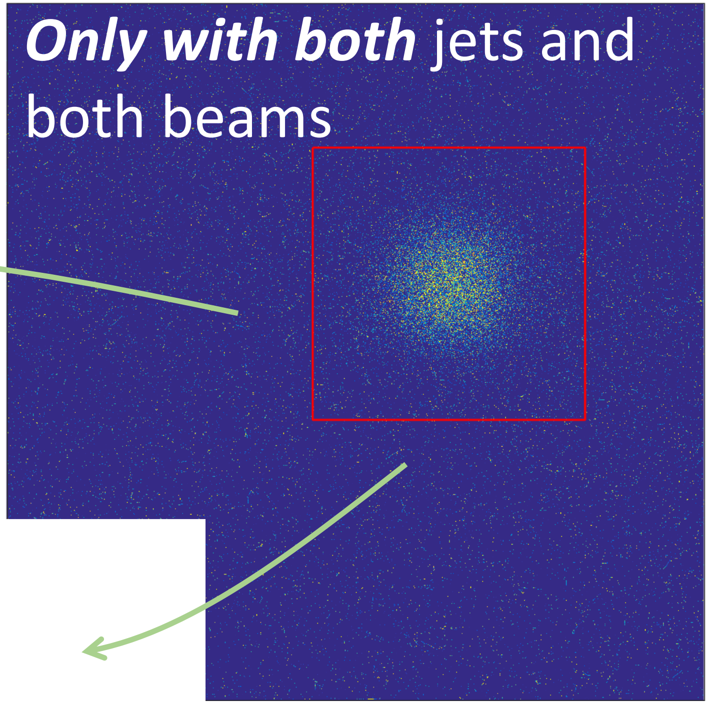
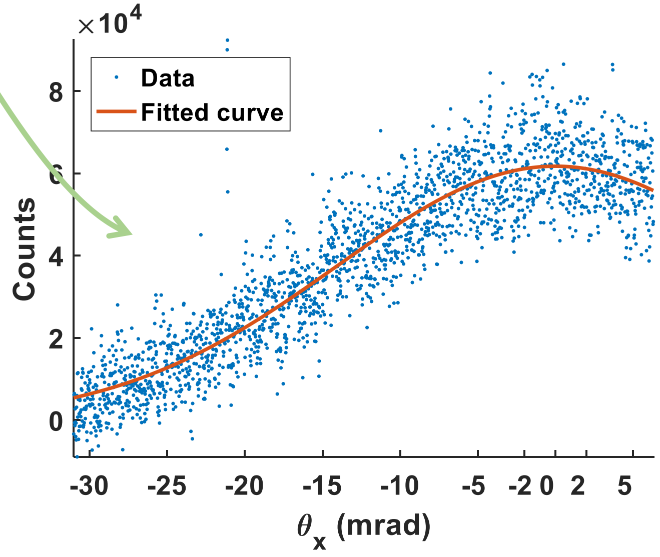
Adding a second jet: X-rays

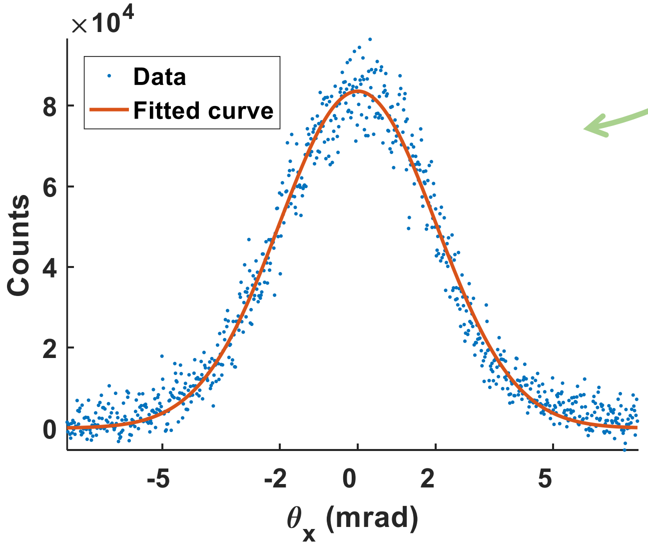


$$\theta = \frac{K}{\gamma} \rightarrow K = \theta\gamma < 1$$





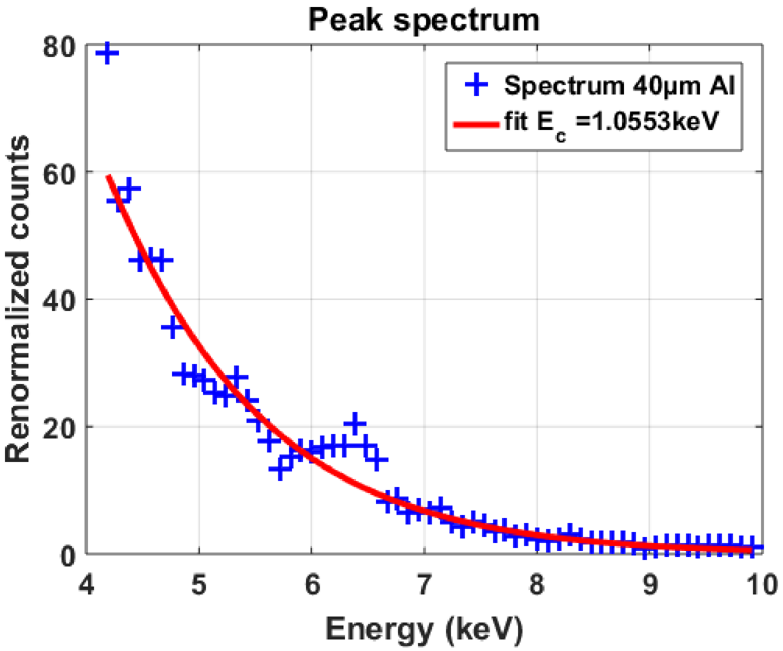
20x12 mrad rms

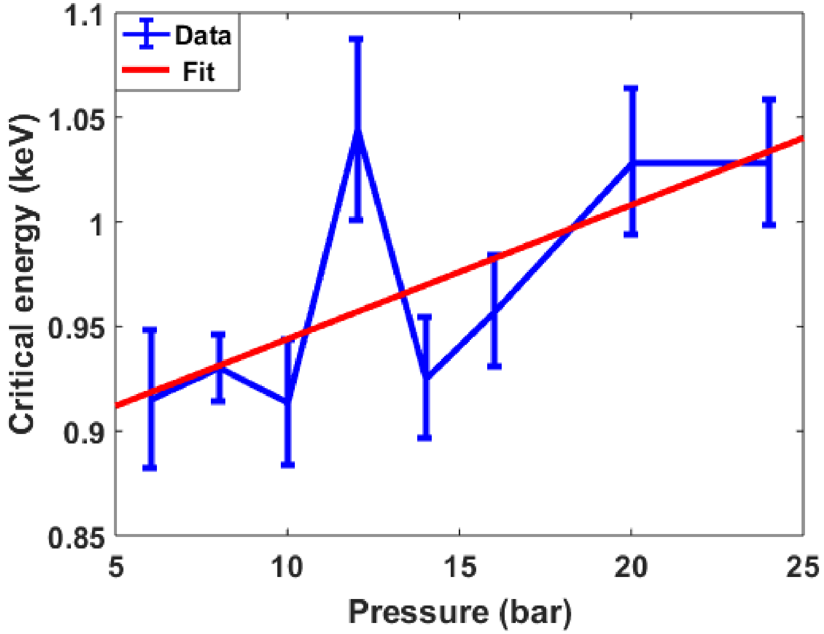


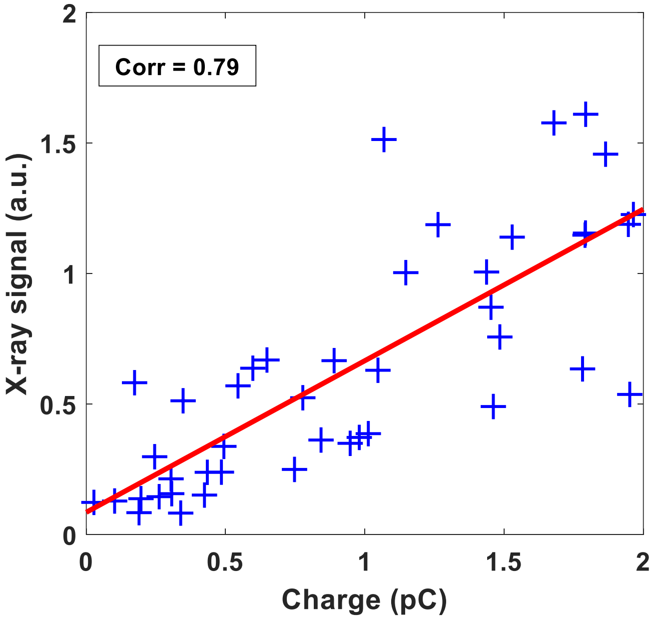
2.7x2.7 mrad rms

6.4x6.4 mrad fwhm

Adding a second jet: X-rays



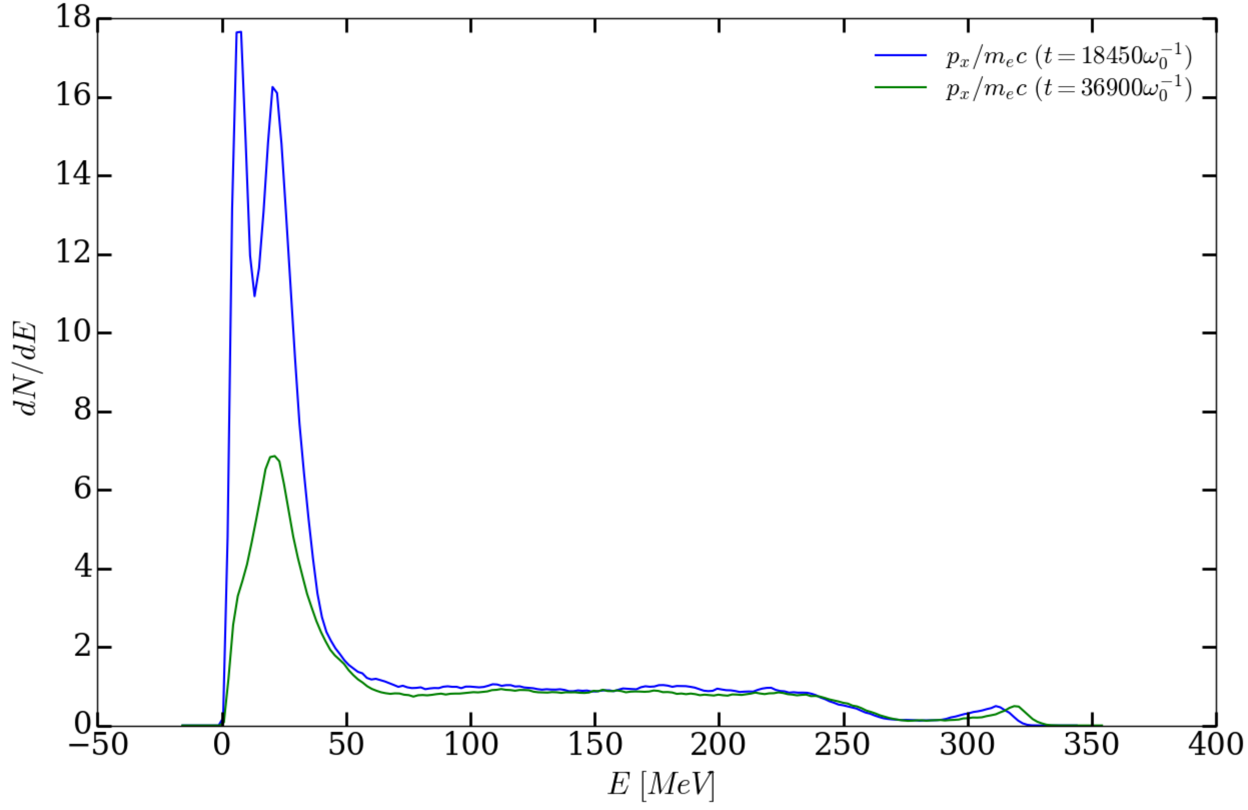




- Spectrum fit appears synchrotron-like, $E_c \approx 1$ keV
- Normally 2-4 keV when optimized for X-rays
- Precision hampered by use of X-ray filters (little data below 4 keV)

Simulations – single jet

- Simulations qualitatively recreate electron spectrum
- Currently a work in progress



Summary and outlook

- Stable electron beam generation using SAII
- Focusing of electrons and collimated X-ray generation
- Apparent gain under the right conditions (beyond laser-driven)

Future:

- Measure time structure with CTR
- Improve X-ray spectral measurements
- More simulations to understand dynamics

Summary and outlook

Thanks for your attention!

Collaborators:

Department of Physics, Lund University, Lund, Sweden

Jonas Björklund Svensson, Diego Guénot, Isabel Gallardo González, Henrik Ekerfelt, Kristoffer Svendsen, Anders Persson and Olle Lundh

Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

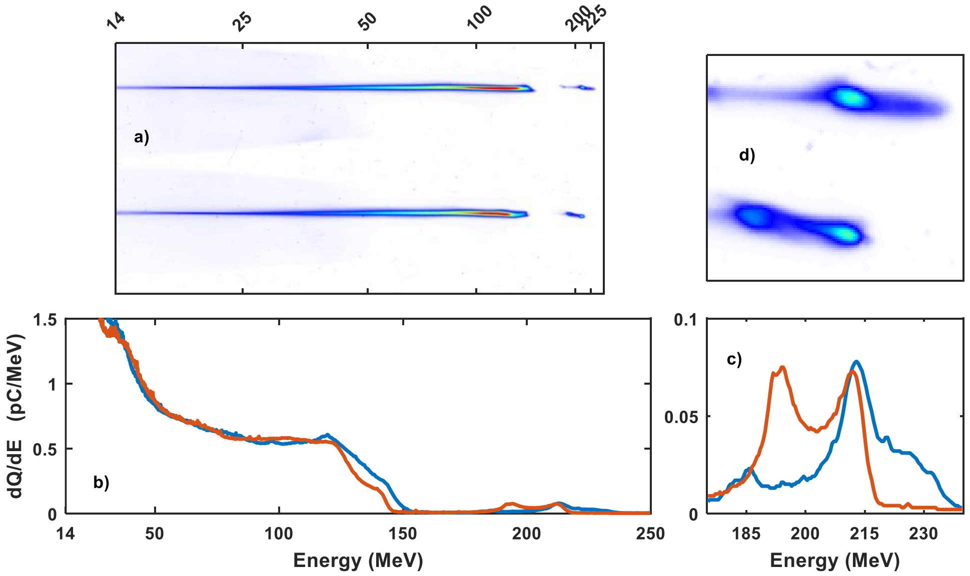
Julien Ferri

X-ray setup

- X-ray deep-depletion CCD (Andor Ikon-L)
- Single-photon counting, requires low flux
- 3 µm Al (laser block), 50 µm Kapton (vac. window), 3 cm air, 40 µm Al (flux reduction), 250 µm Be (vac. window)
- → not difficult to reduce amount of filters and increase source-camera distance to improve measurement in the future

Peak spectrum

- Many shots exhibit unusual peak spectral structure with double peaks
  - Beam loading?
- Low-energy charge injection when 2 jets?
- For high jet 2 pressures, broadband beam disappears while peak remains



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