Composite gas targets for controlled injection and acceleration in laser plasma wakefields

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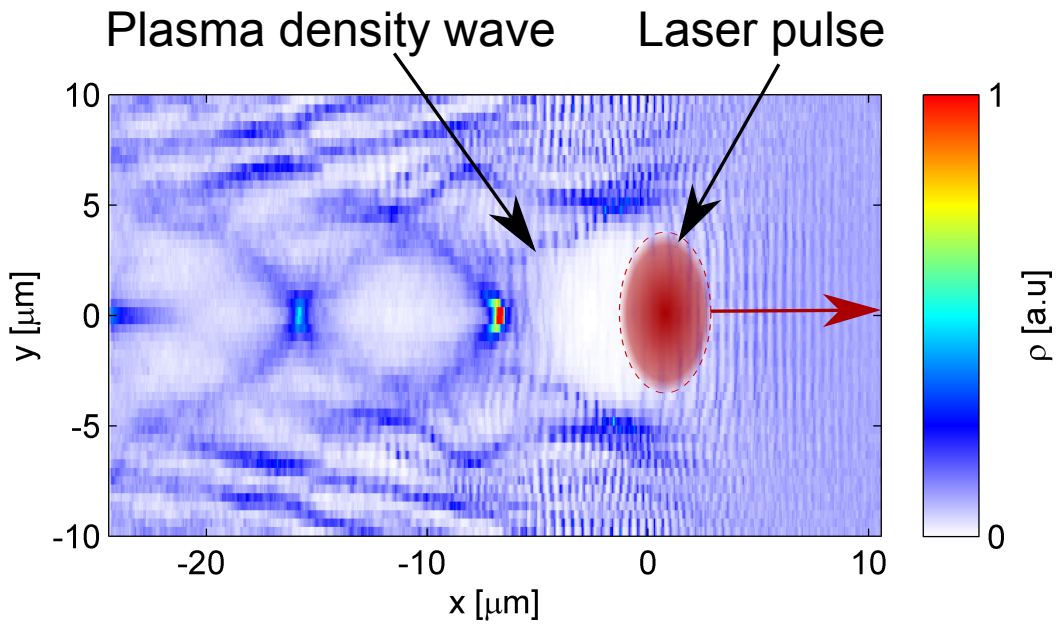
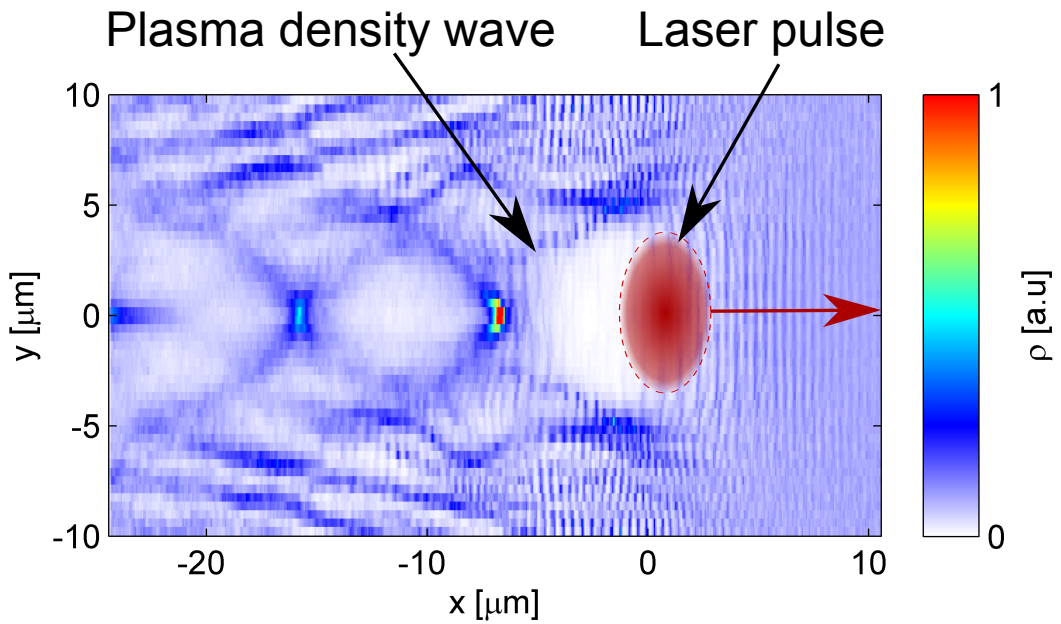
Laser wakefield acceleration



- High accelerating field – Small scale accelerators
- Intrinsically short electron bunches

Bulanov et al. Phys. Rev. E 58, R5257 (1998)
Gonsalves et al. Nature Phys. 7, 862-866 (2011)

Injection in density gradients

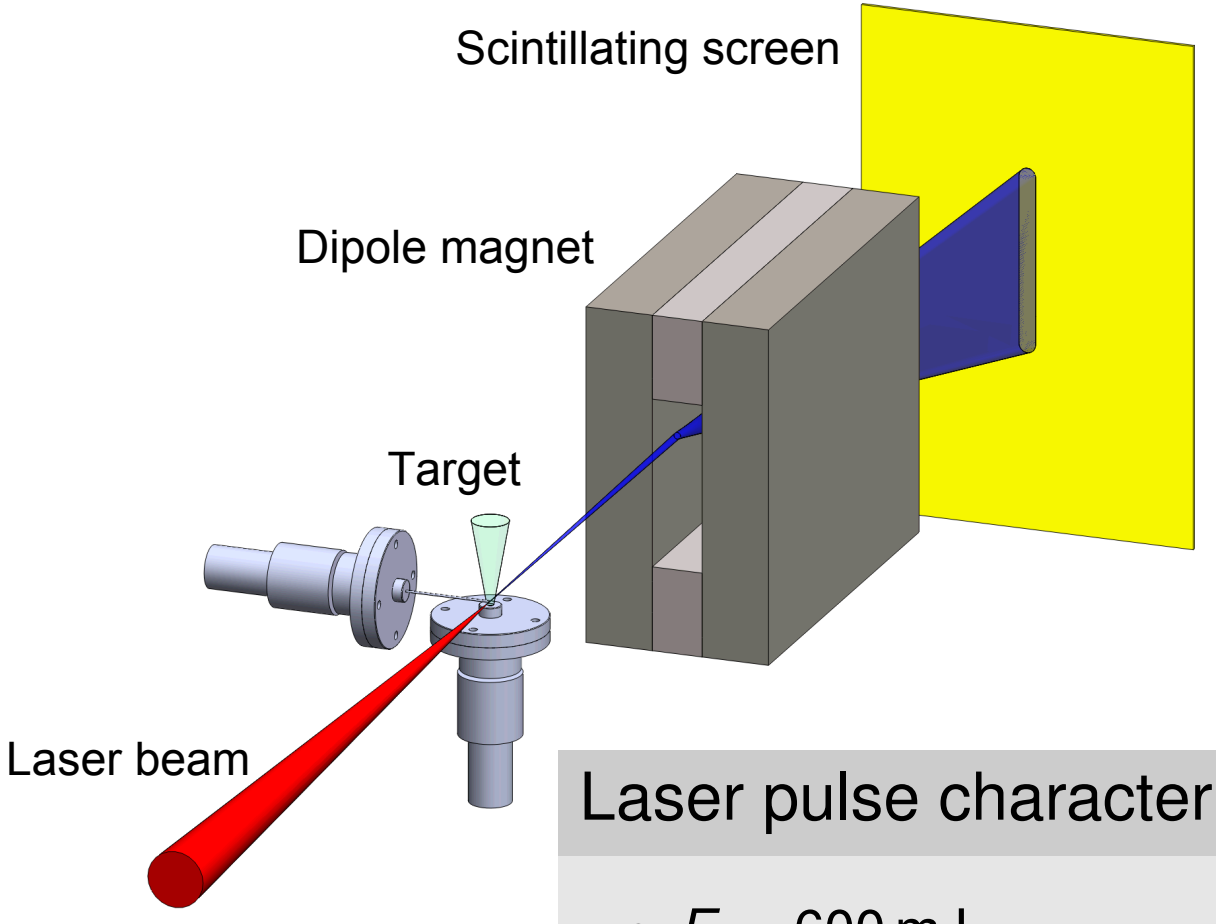


- Wave-breaking as the particle velocities approaches the phase velocity of the wake
- Wake phase velocity decreases behind the laser pulse in a density downramp

$\Rightarrow$ Lower threshold for self-injection

Bulanov et al. Phys. Rev. E 58, R5257 (1998)
Gonsalves et al. Nature Phys. 7, 862-866 (2011)

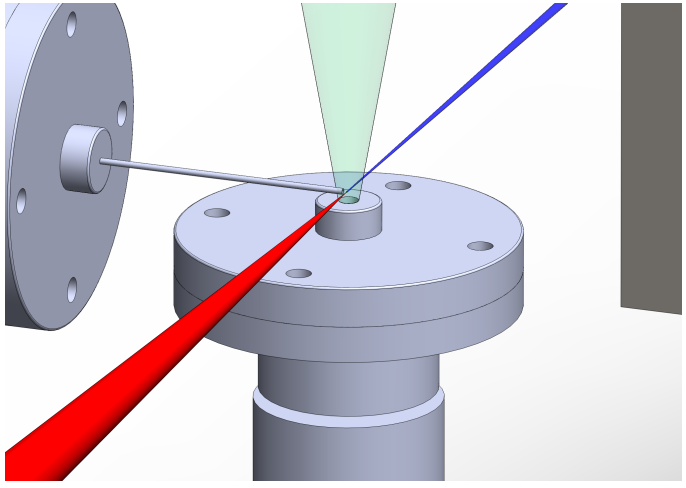
Experimental set-up



Laser pulse characteristics

- $E = 600\,\mathrm{mJ}$
- $T_{\mathrm{FWHM}} = 40\,\mathrm{fs}$
- $\lambda = 800\,\mathrm{nm}$
- $D_{\mathrm{FWHM}} = 19\,\mu\mathrm{m}$
- $I = 4 \cdot 10^{18}\,\mathrm{W/cm^2}$
- $a_0 = 1.3$

Experimental set-up



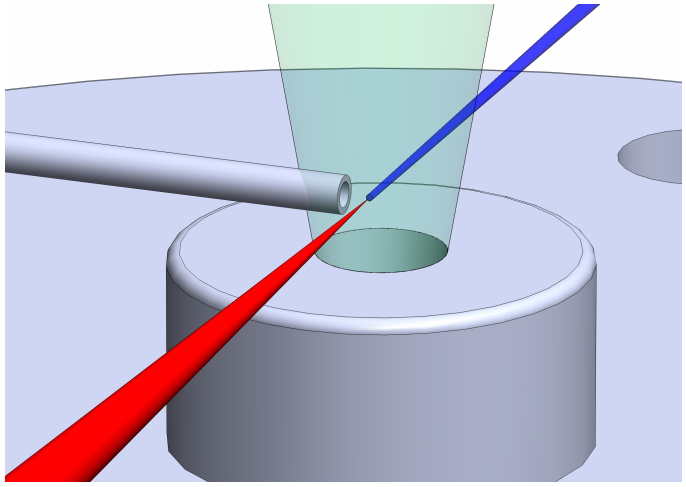
Gas target

Two nozzles supplying gas:

- Two regions of different density
- Gradient between the regions
- Freedom to move the gradient

- Different gas species

Experimental set-up



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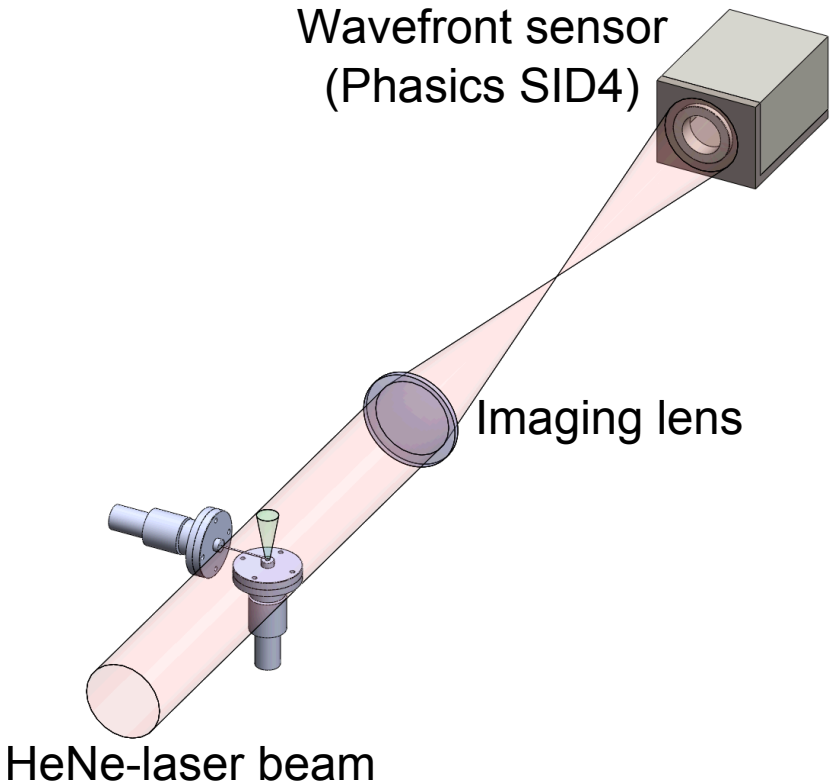
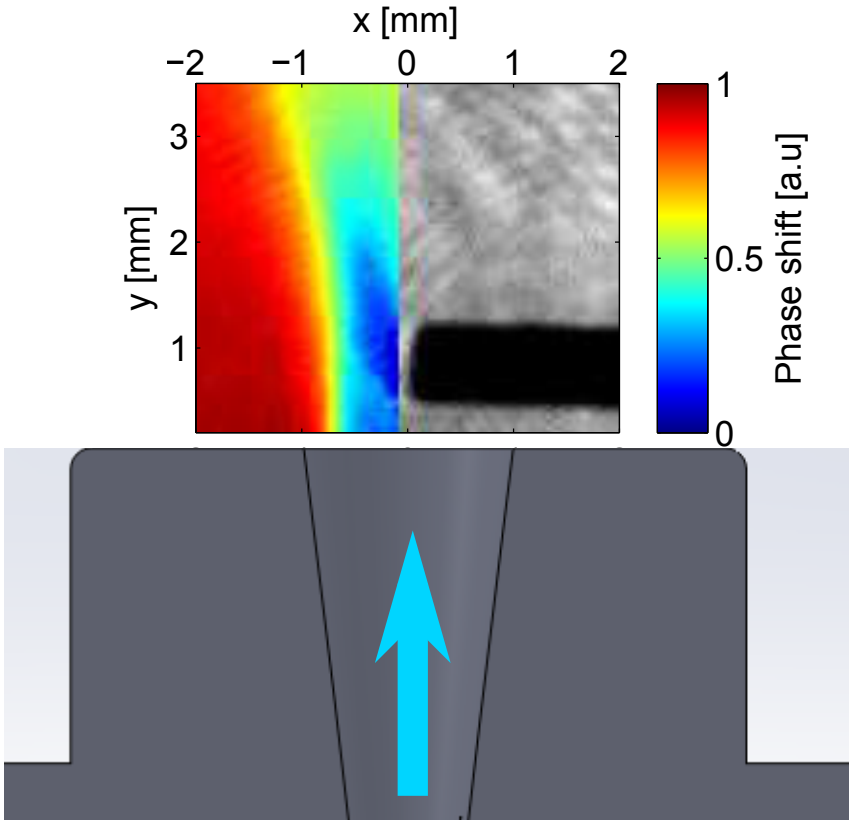
Target characterization



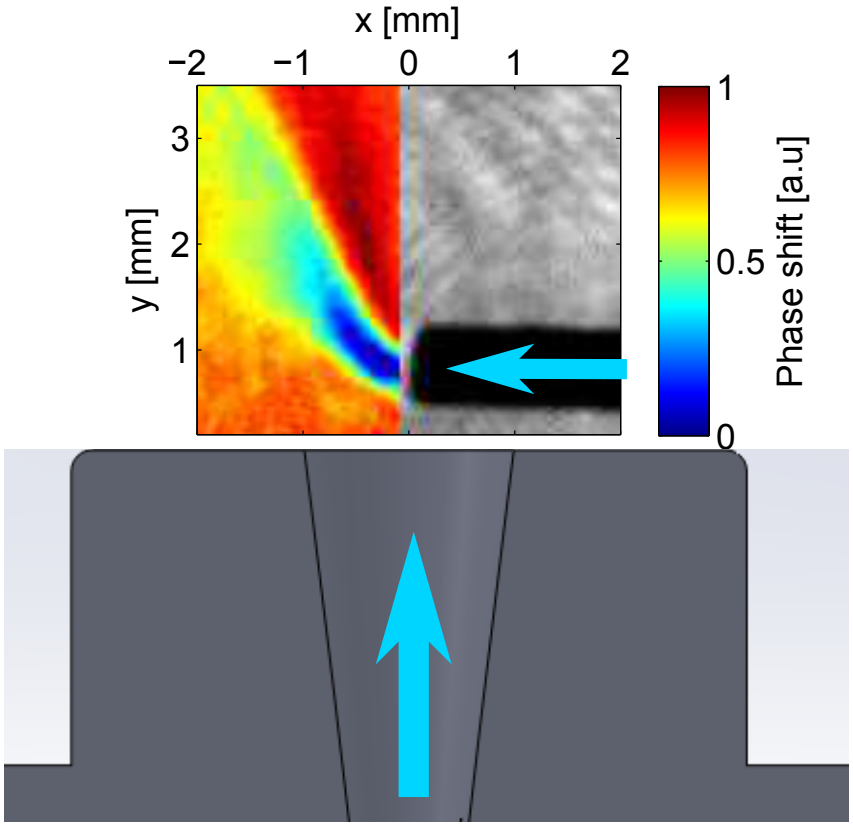
- Gas target introduces phase shifts in probe beam
- Phase shifts measured using wavefront sensor

Plateau et al. Rev. Sci. Instrum. 81, 033108 (2010)

Target characterization

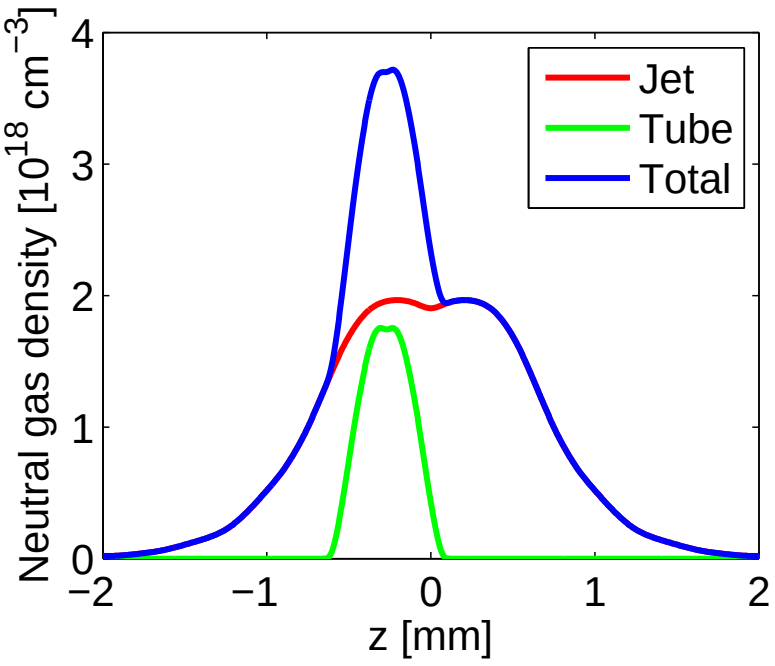


Phase map and shadowgram



Residual phase shift due to gas from narrow tube

Target characterization



Density distribution calculated from phase shift measurements

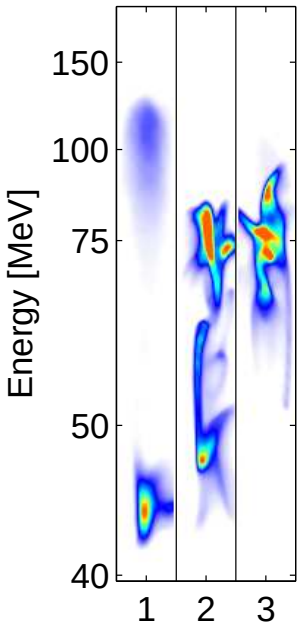
Two separate gas sources

- Two regions of gas
- Gradient between the regions

Degrees of freedom

- Peak density
- Plateau density
- Gradient position

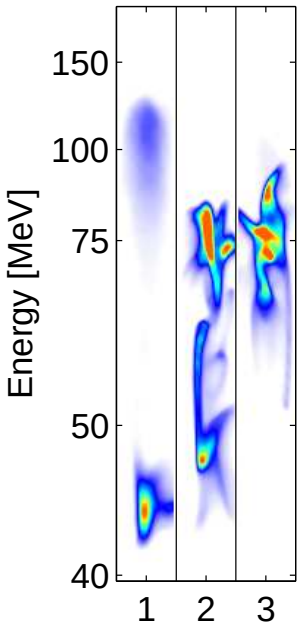
First results



2 mm nozzle

Plateau density:
$13 \cdot 10^{18}\,\mathrm{cm}^{-3}$

First results



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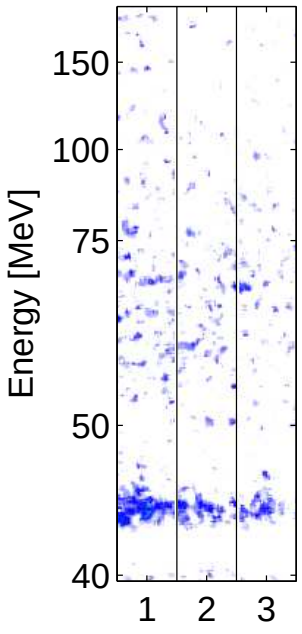
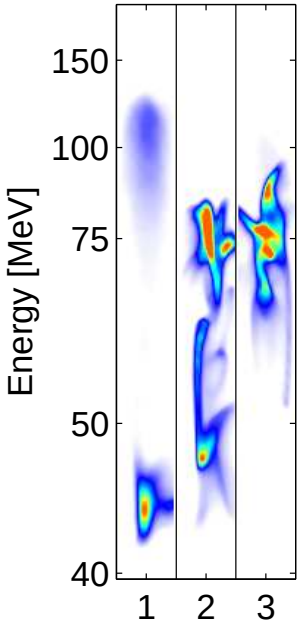


2 mm nozzle

Plateau density:
$4 \cdot 10^{18}\,\mathrm{cm}^{-3}$

First results



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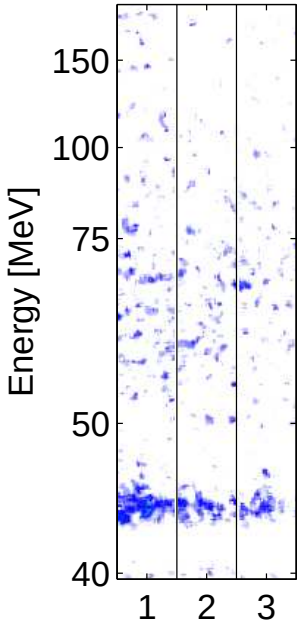

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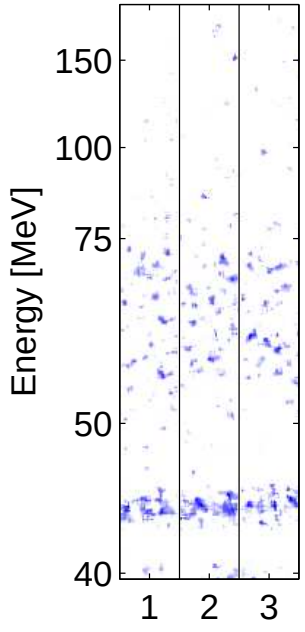
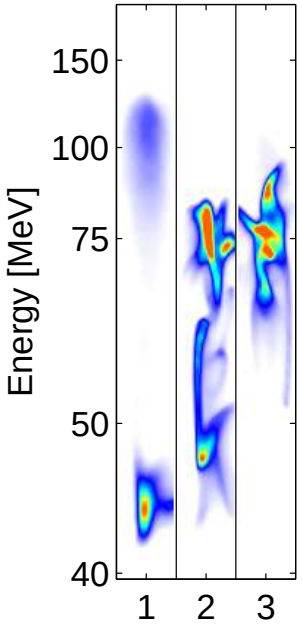


400 μm tube

Peak density:
$8 \cdot 10^{18}\,\mathrm{cm}^{-3}$

First results



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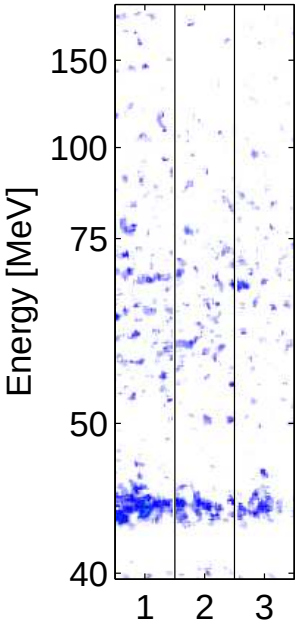

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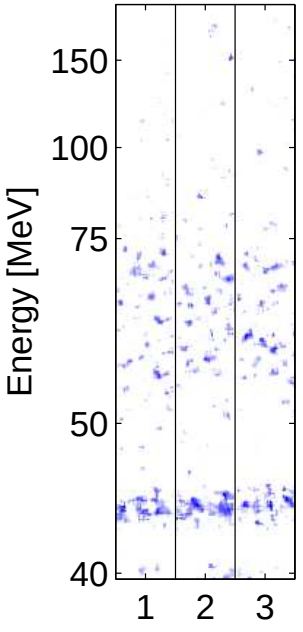

400 μm tube

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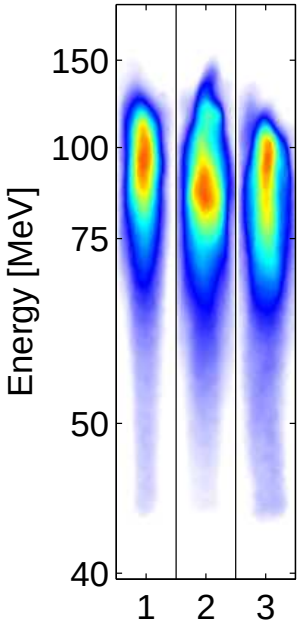
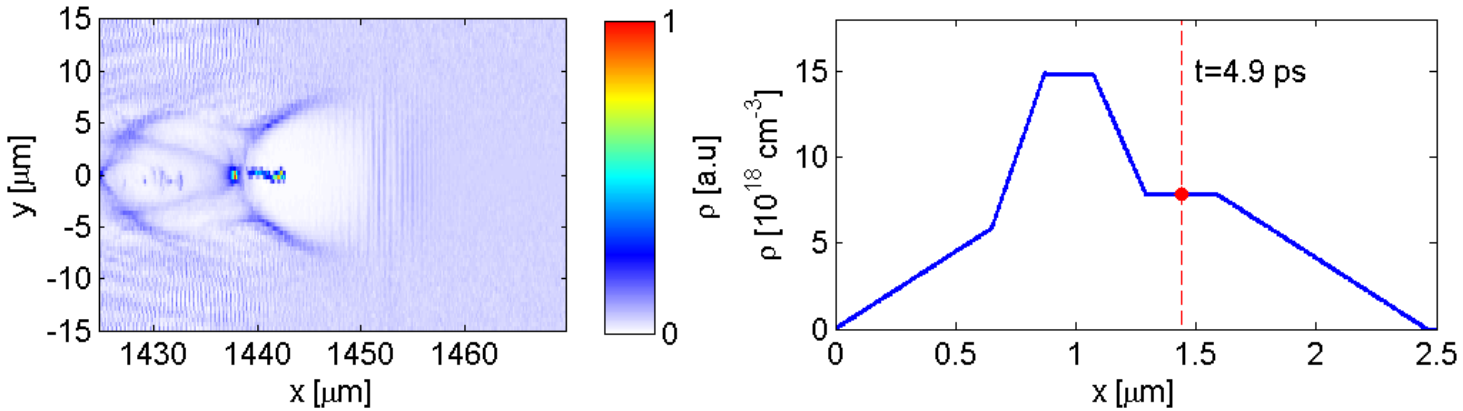


Combined target

Peak density:
$12 \cdot 10^{18}\,\mathrm{cm}^{-3}$
Plateau density:
$4 \cdot 10^{18}\,\mathrm{cm}^{-3}$

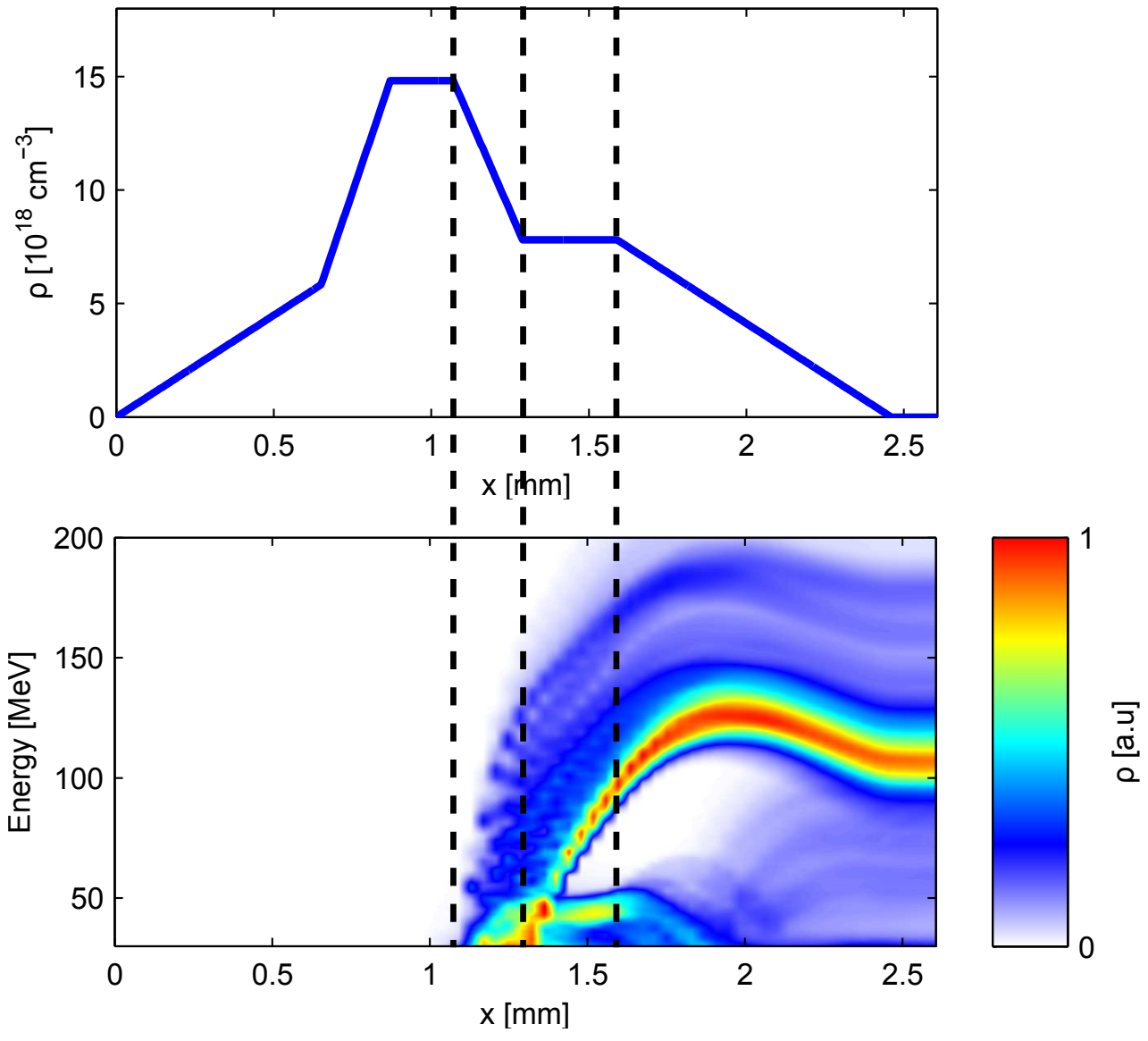
Simulations



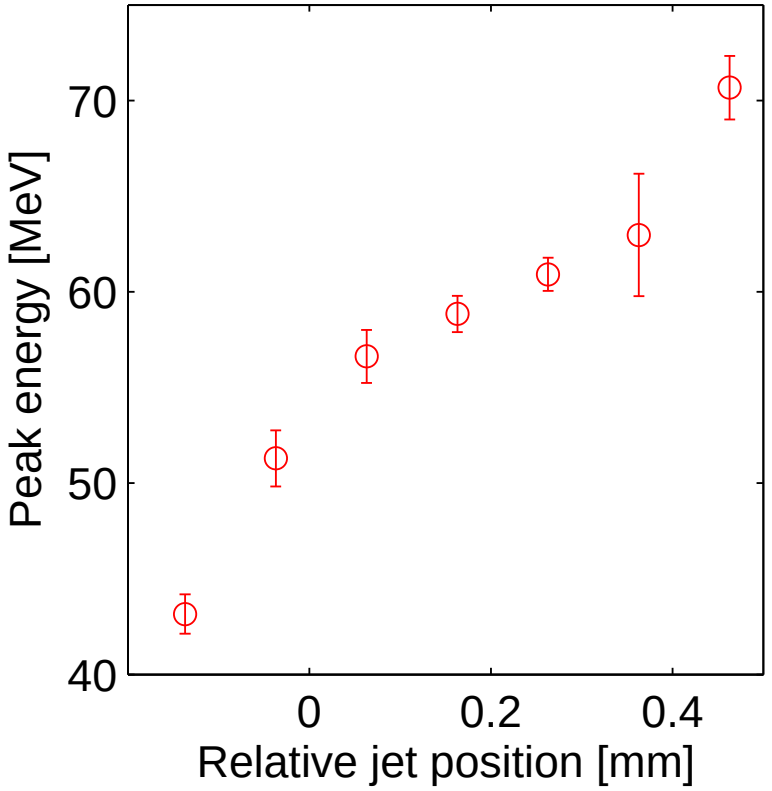
Simulations using CALDER-CIRC[1]

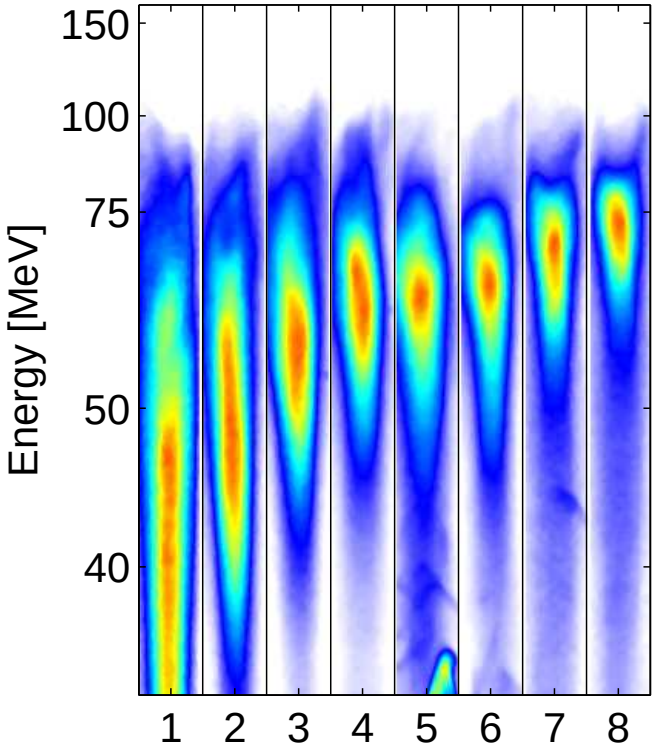
[1] Lifschitz et al J. Comput. Phys. 228, 1803-1814 (2009)

Simulations



Tuning the acceleration length



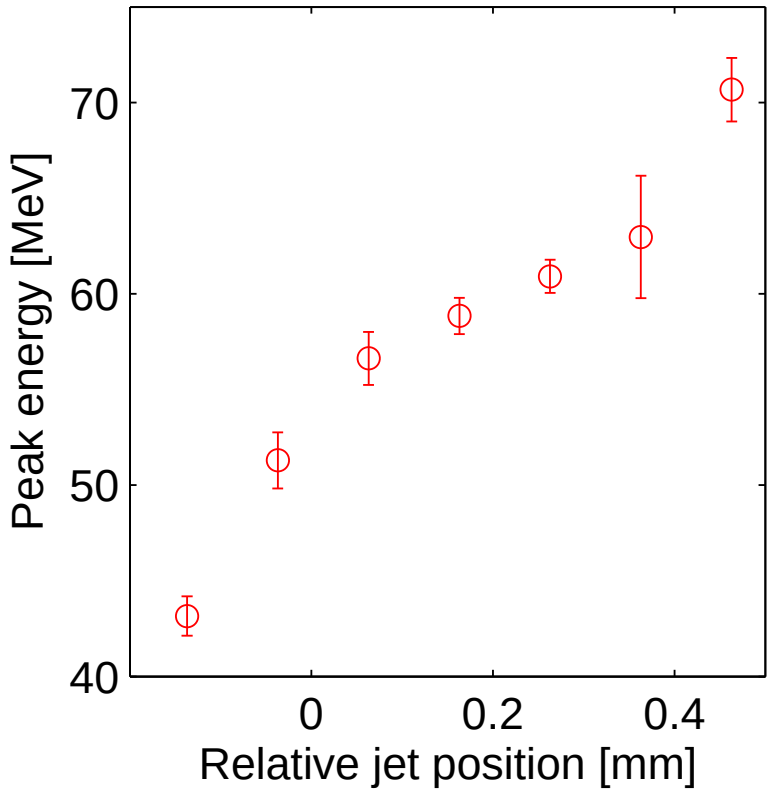


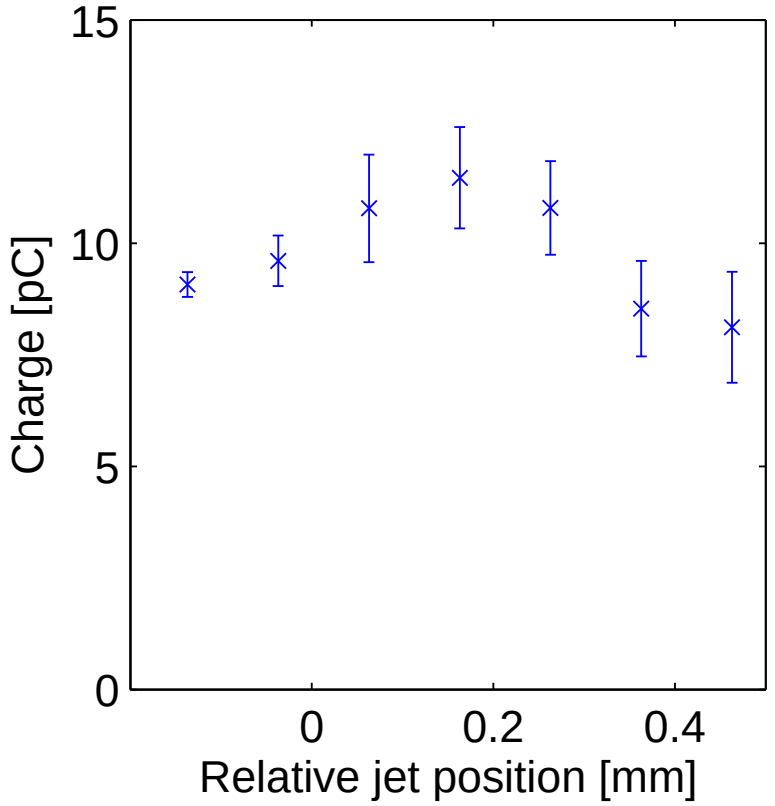
Peak density: $10 \cdot 10^{18}\,\mathrm{cm}^{-3}$
Plateau density: $3 \cdot 10^{18}\,\mathrm{cm}^{-3}$

10 shots for each position

Extending the density plateau after the density ramp increases the electron bunch energy

Tuning the acceleration length





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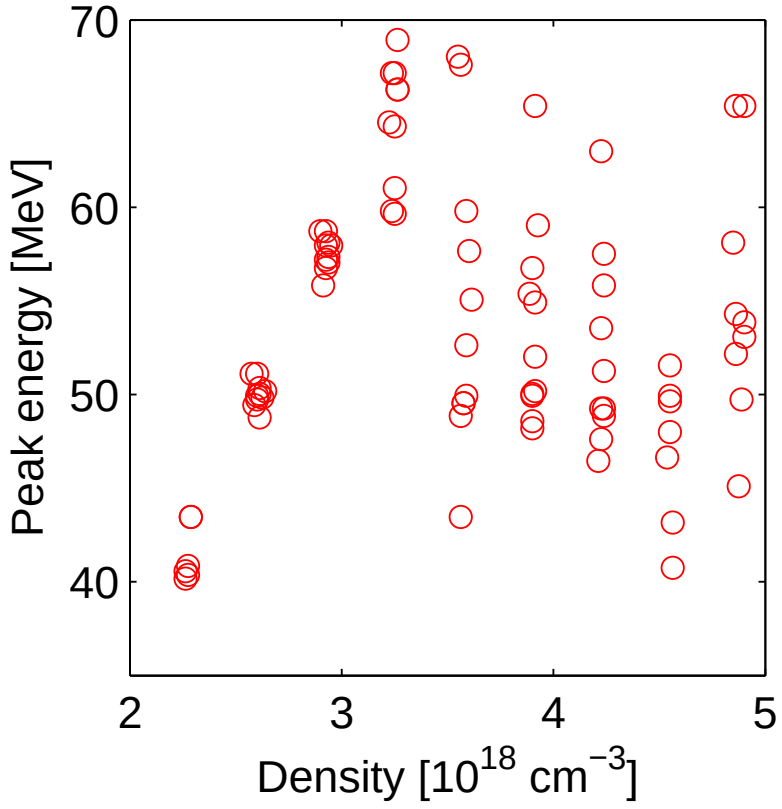
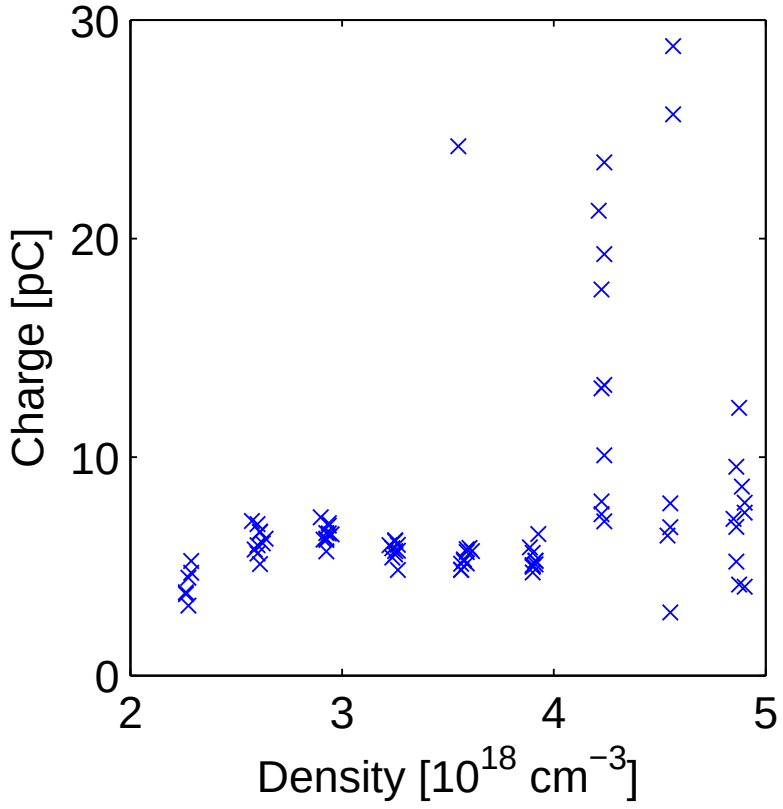
10 shots for each position

Extending the density plateau after the density ramp increases the electron bunch energy

Tuning the accelerating field



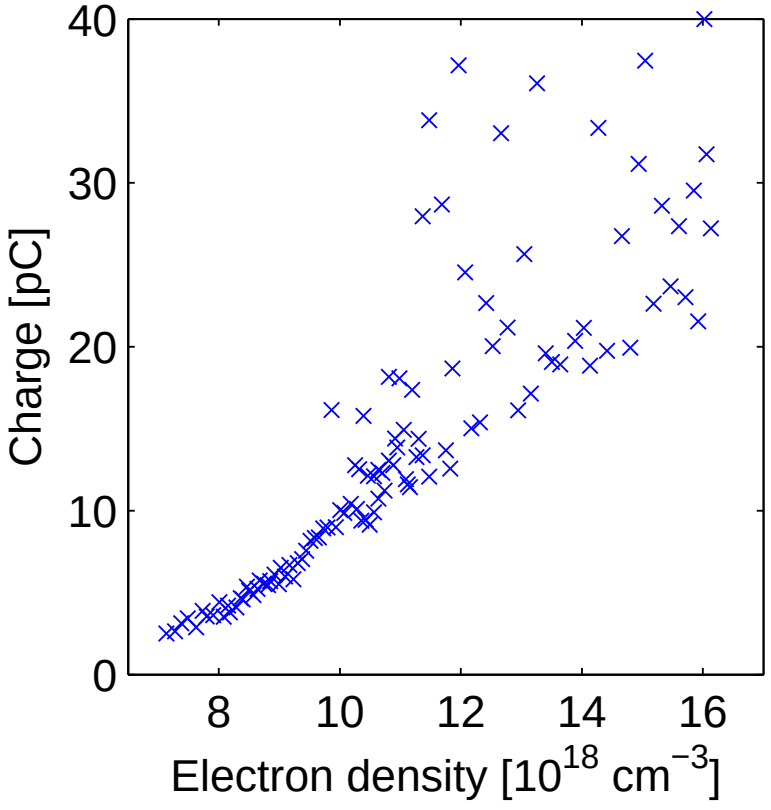


Peak density: $10 \cdot 10^{18}\,\mathrm{cm}^{-3}$

10 shots for each position

Increasing the plateau density
increases electron bunch energy

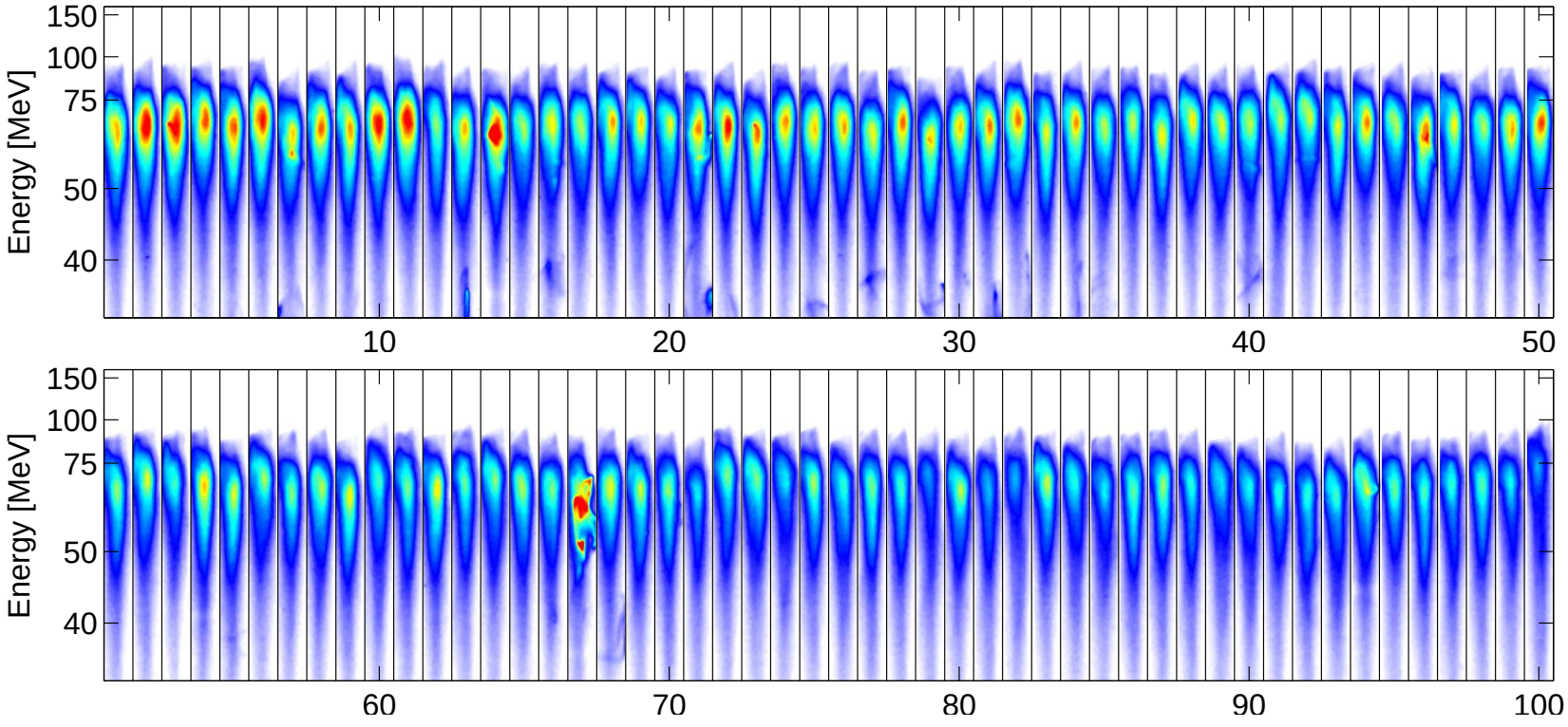
Tuning the electron bunch charge



Plateau density: $3 \cdot 10^{18}\,\mathrm{cm}^{-3}$

Increasing the peak density
increases the electron bunch charge

Stability



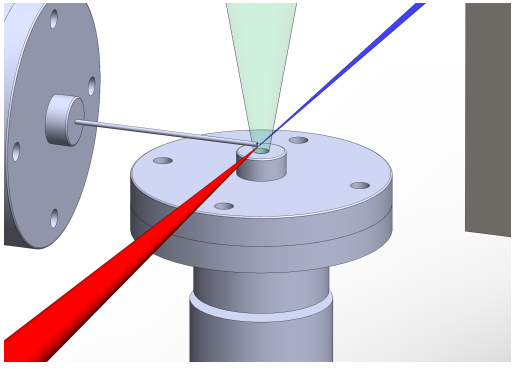
Average peak energy: 62 MeV $\pm$ 5%
Average bunch charge: 7 pC $\pm$ 13%

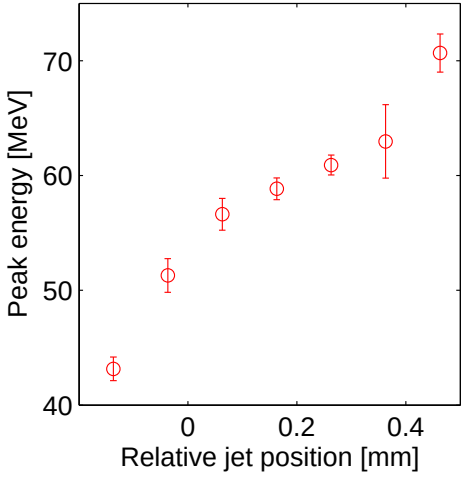
Peak density: $10 \cdot 10^{18}\,\mathrm{cm}^{-3}$
Plateau density: $3 \cdot 10^{18}\,\mathrm{cm}^{-3}$

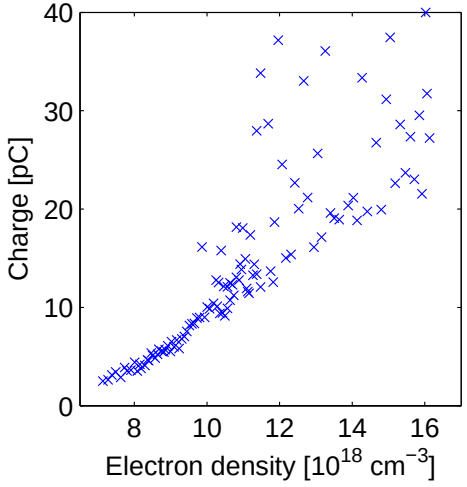
100 consecutive shots
17 minutes

Summary

- Composite target for density down-ramp injection
- Electron energy control by:
  - Down-ramp position
  - Density in accelerator region
- Electron bunch charge control by:
  - Peak density







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