

Temperature Effects in Plasma-Wakefield Accelerators

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- 1. What is plasma wakefield acceleration?**
- 2. Why do we care about temperature?**
- 3. The FACET-II facility and experiment feasibility**
- 4. Outlook**

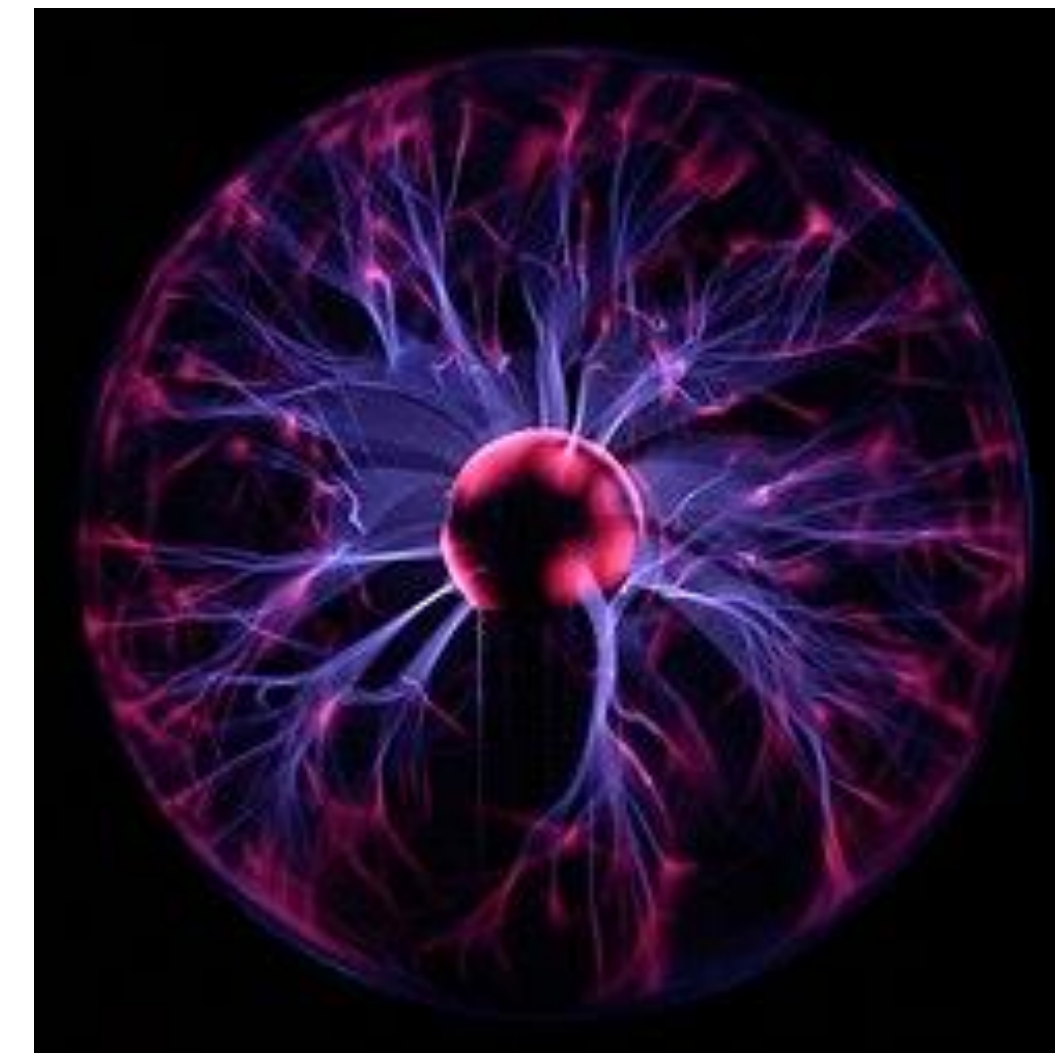
Why Plasma Wakefield Acceleration (PWFA)?

- Future collider designs are huge and expensive
- RF cavities can only sustain ~ 100 MV/m before breakdown

How to get around this?

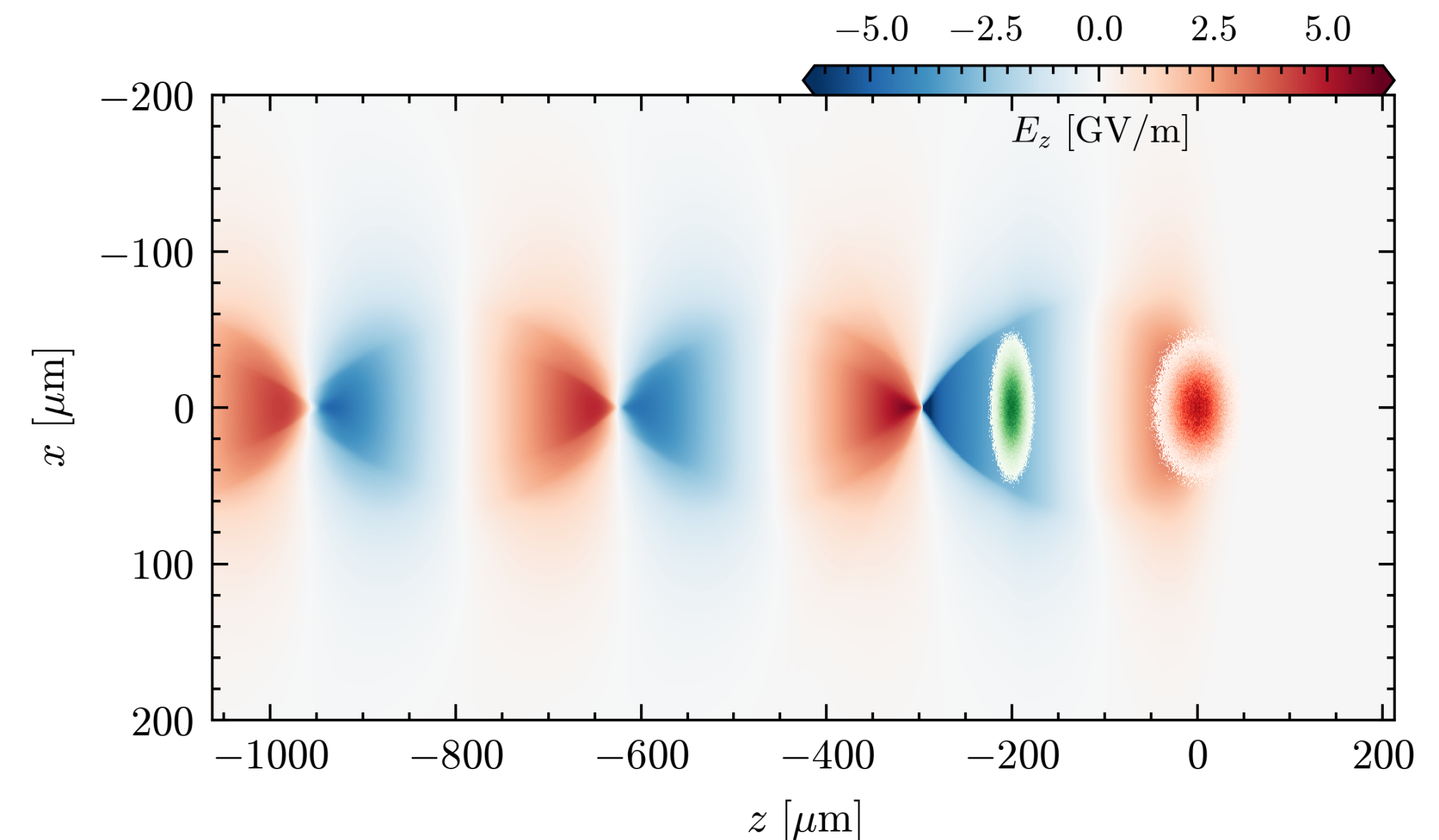
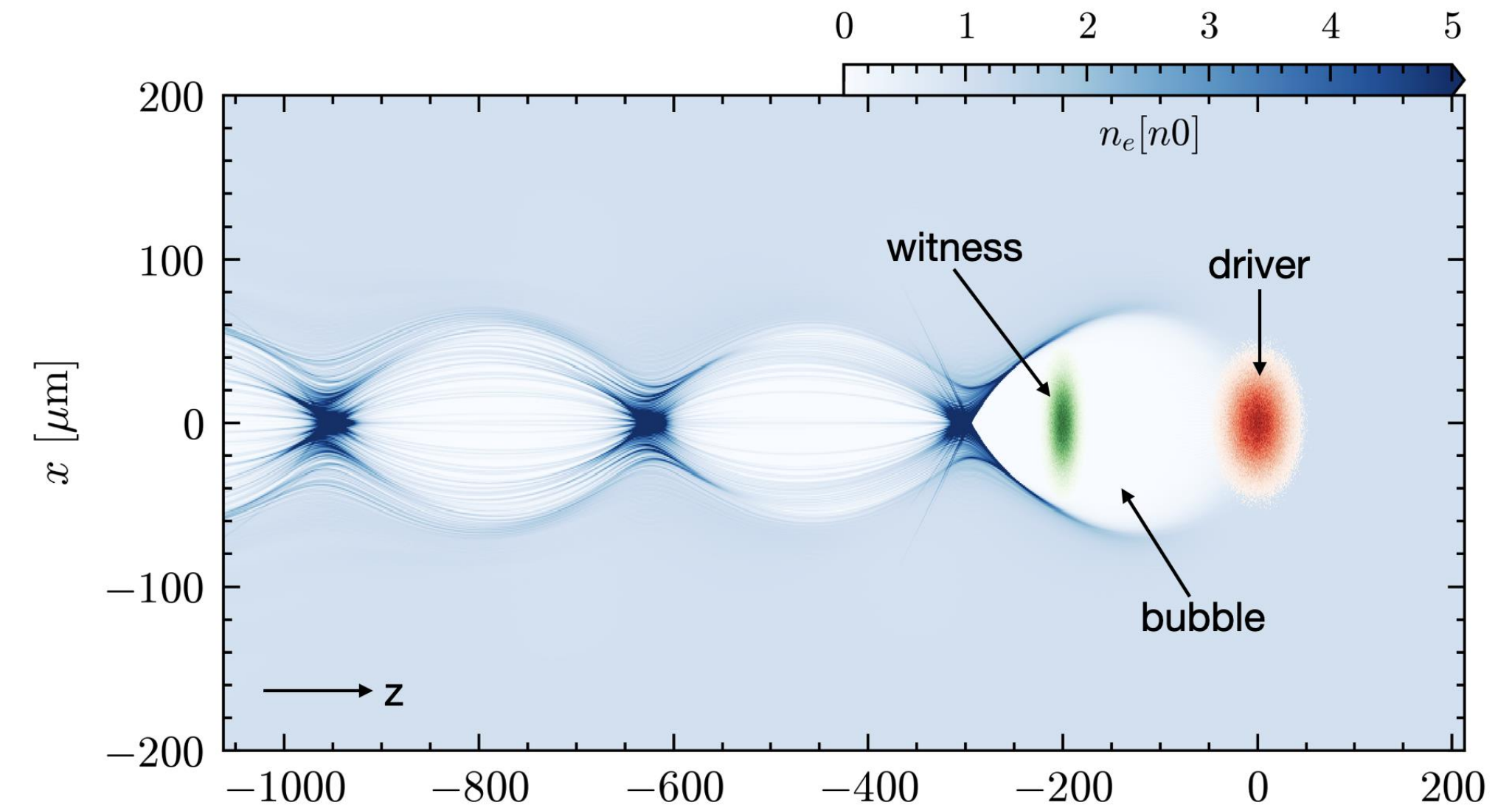
Use a medium which is already broken down...

PLASMA!



What is Plasma Wakefield Acceleration?

- > 'Driver' electron bunch repels plasma electrons → charge separation behind the bunch
- > STRONG E-field gradient (10-100 GV/m)
- > Electrons pulled back on-axis by ions → plasma wake
- > 'Witness' bunch 'surfs' the wake and accelerates
- > 'Bubble' regime
 - > all plasma electrons expelled from behind driver
 - > radially uniform, focusing fields



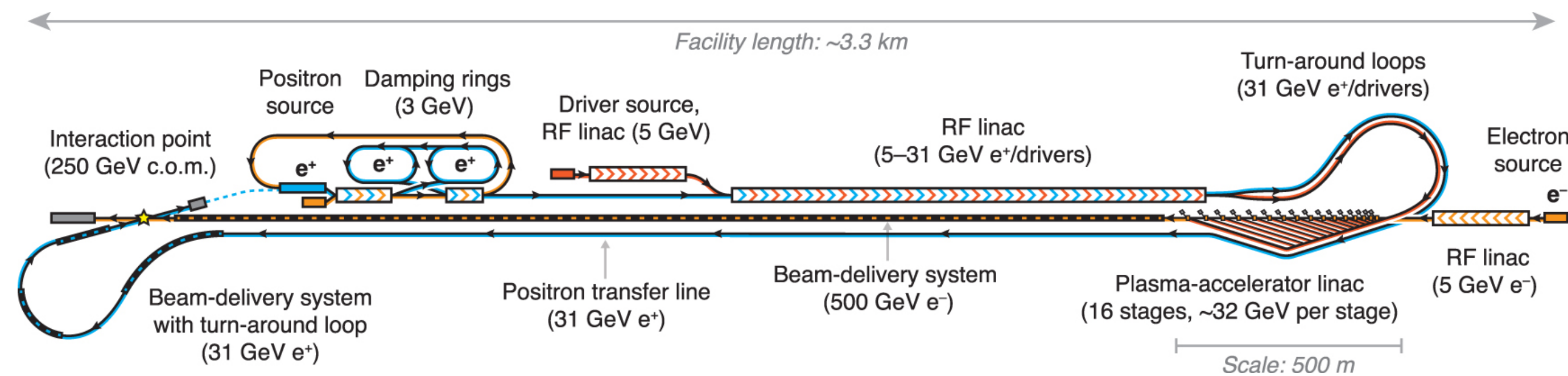
The Case For High Repetition Rate

$$L = \frac{N_1 N_2 f n_b}{4\pi\sigma_x\sigma_y}$$

Luminosity: HEP (e.g. HALHF)

$$\frac{d}{dt} B_{6D} = \frac{Nf}{\epsilon_{nx}\epsilon_{ny}\epsilon_{nz}}$$

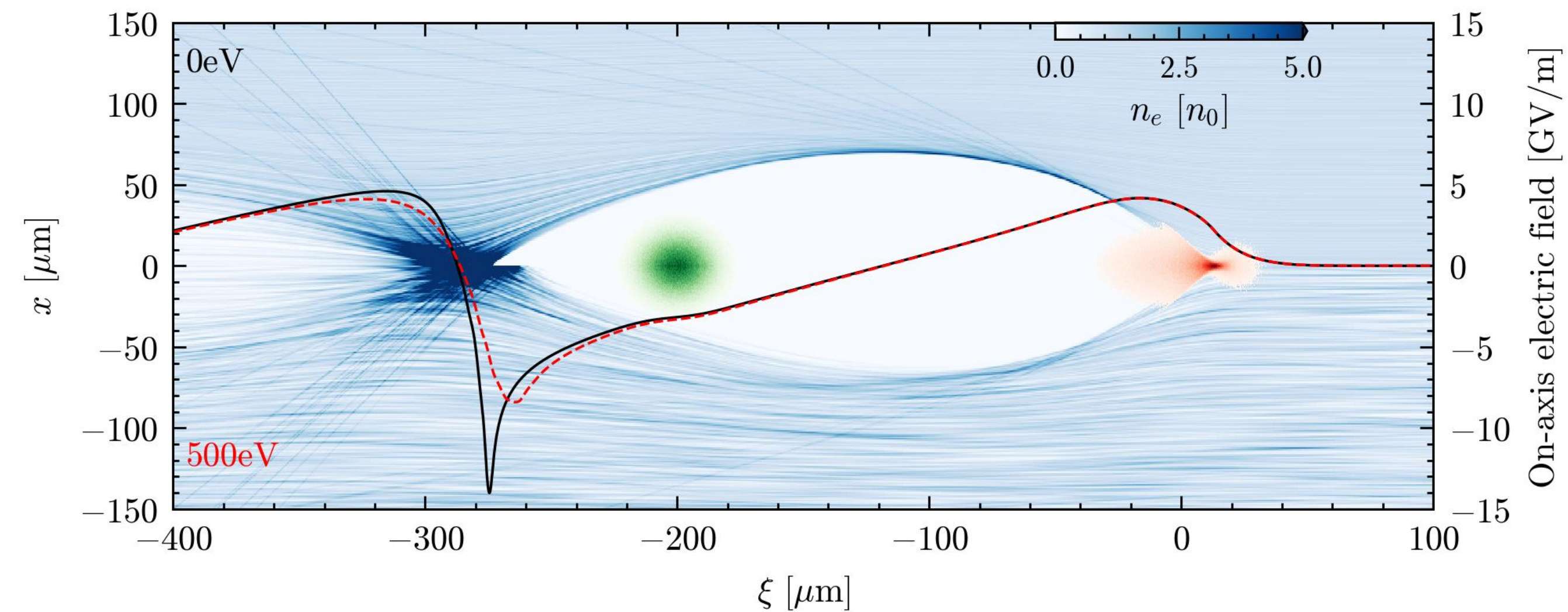
Integrated brightness: photon science (e.g. EuXFEL)



- Future collider designs e.g. *Hybrid Asymmetric Linear Higgs Factory (HALHF)*
- Require MHz repetition rates to be competitive with FCC, ILC
- Need to increase repetition rate

Plasma Temperature

- Energy transfer from the driver to the witness is not 100% efficient
- Significant energy remains in the plasma
- Increases KE (temperature) of plasma electrons
- Plasma heating (~ 20 eV per shot expected) modifies wakefield
- Significant at high repetition rate
- Bad for stable, repeatable acceleration
- ***Experimental studies of this have not yet been undertaken!***



- 1. How does the drive beam affect plasma temperature?**
- 2. How does an increase in plasma temperature affect subsequent plasma wake formation?**

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The FACET-II Facility

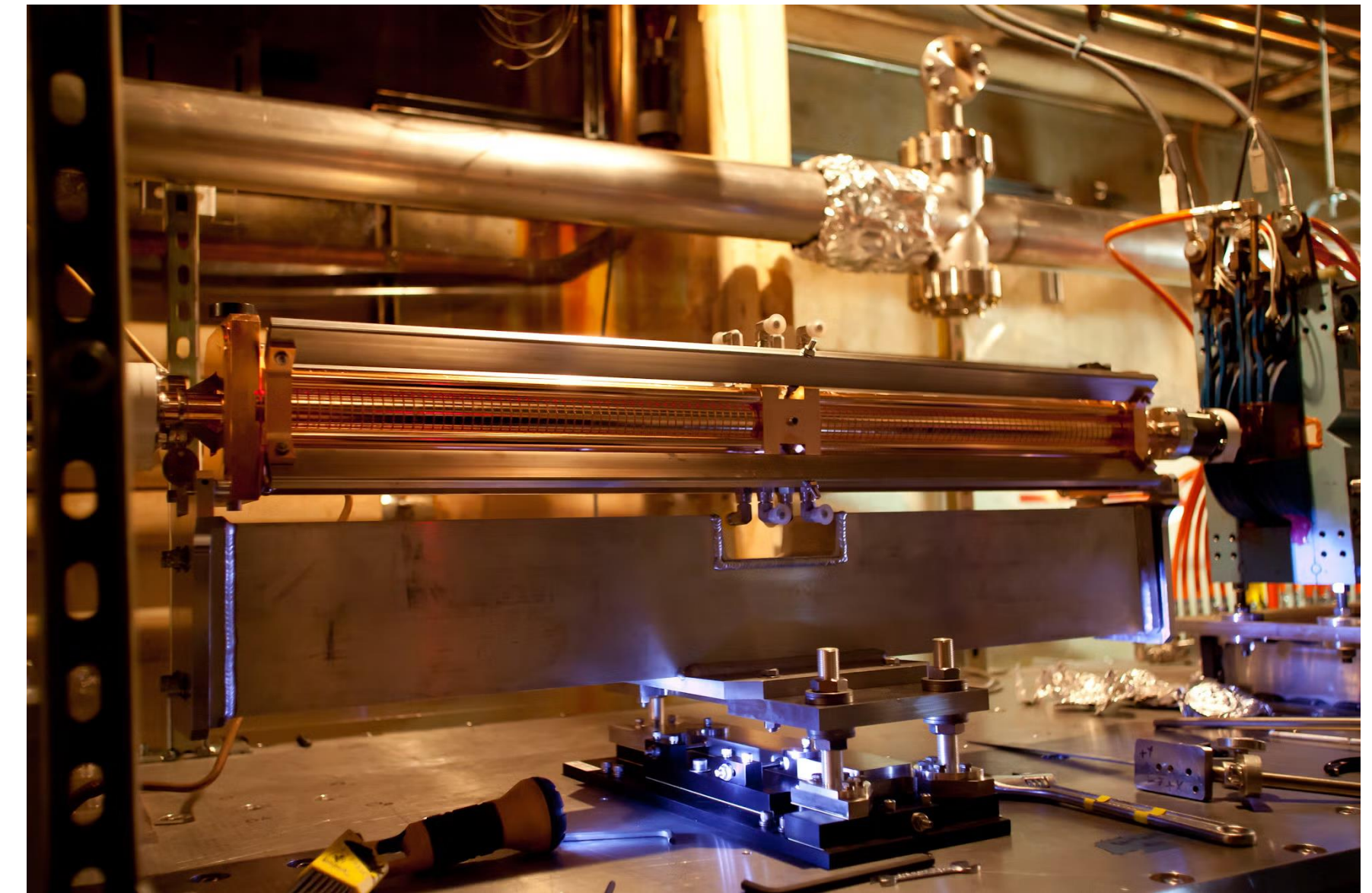
> SLAC linac

- > Delivers 10 GeV, 1.6 nC beams at 10Hz (can be split into driver and witness beams)

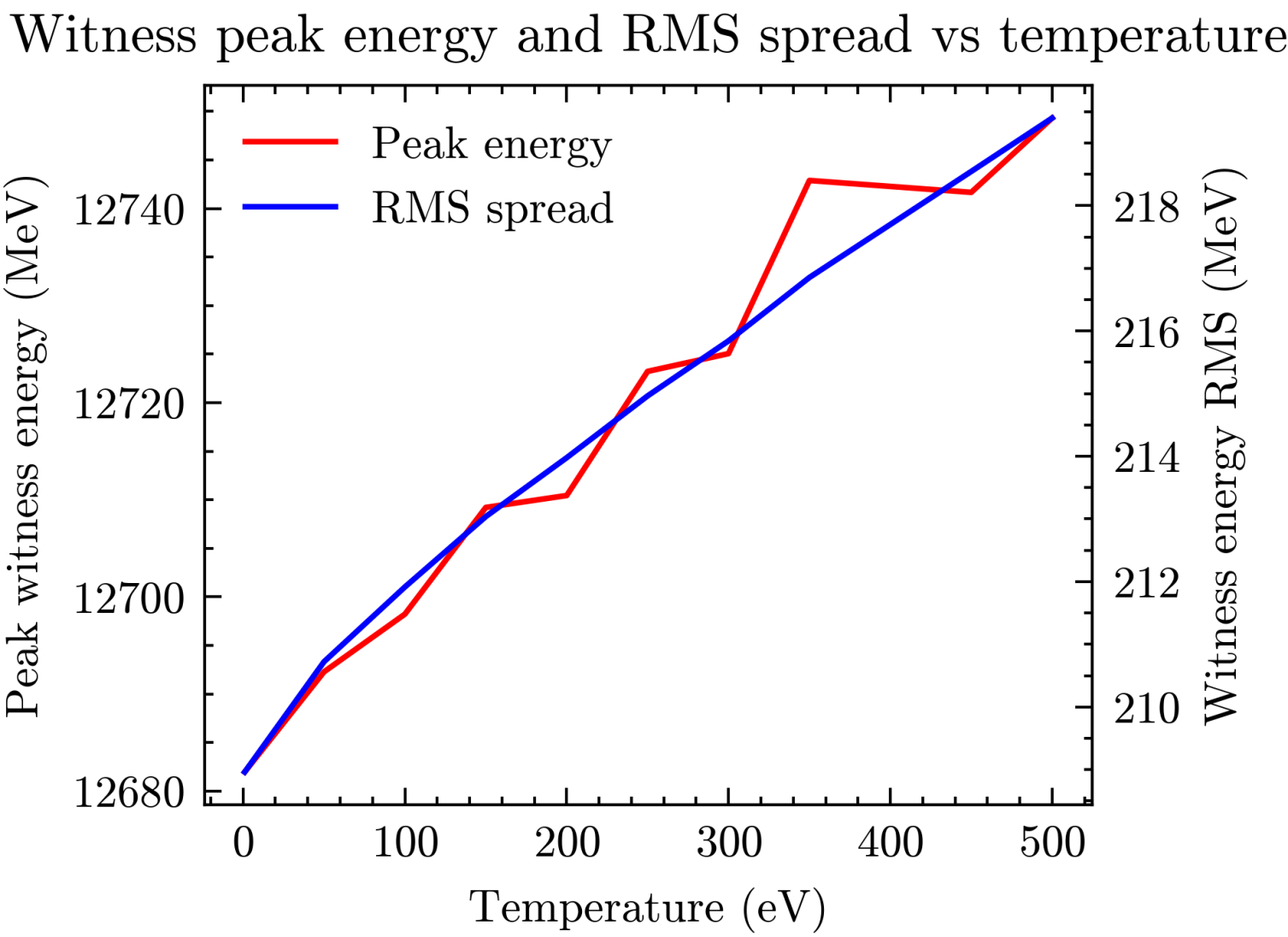
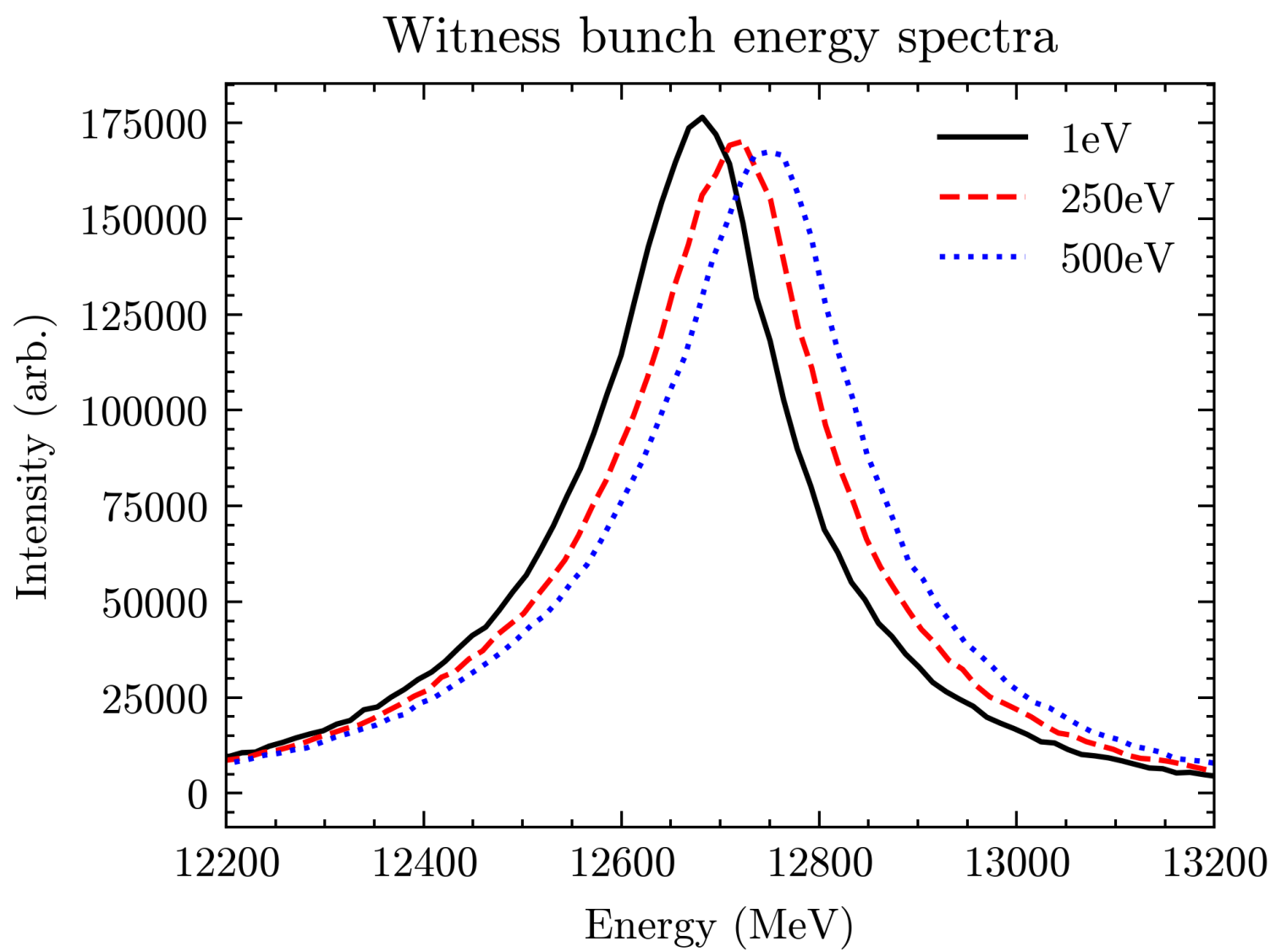


> Laser-ionised plasma source

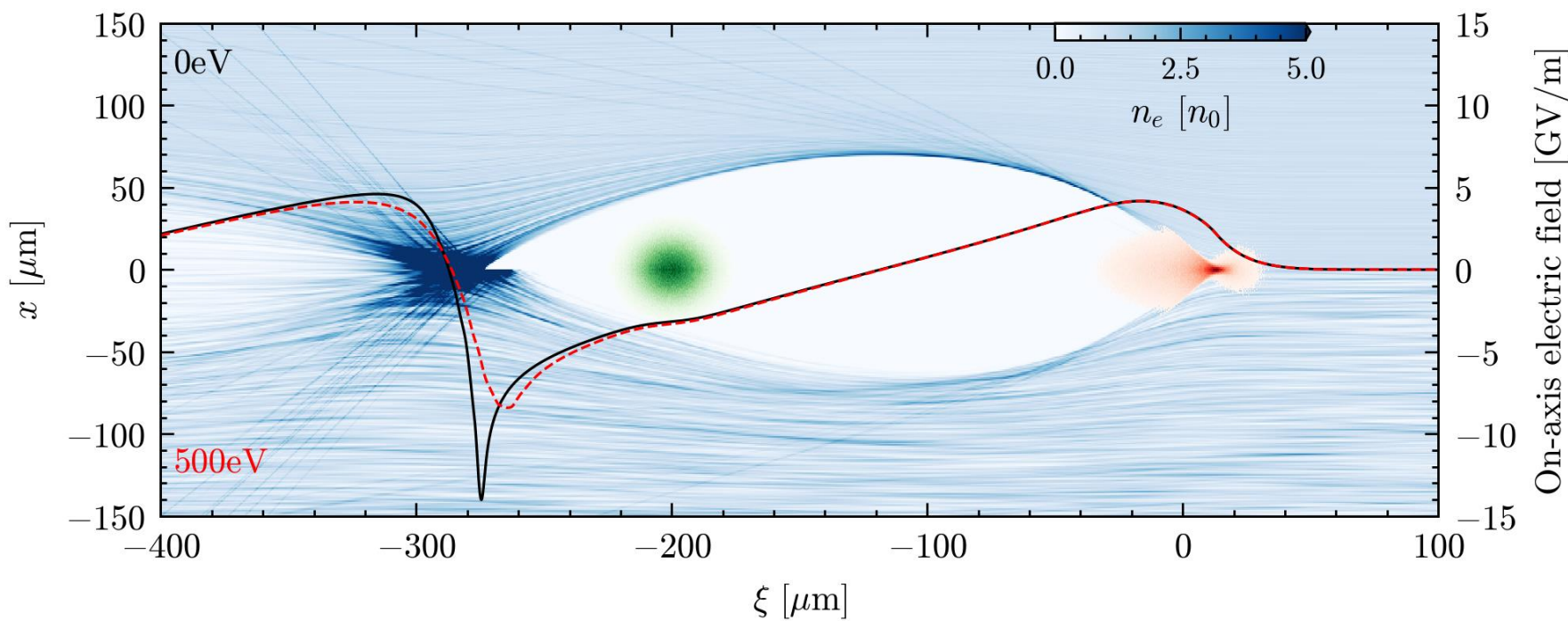
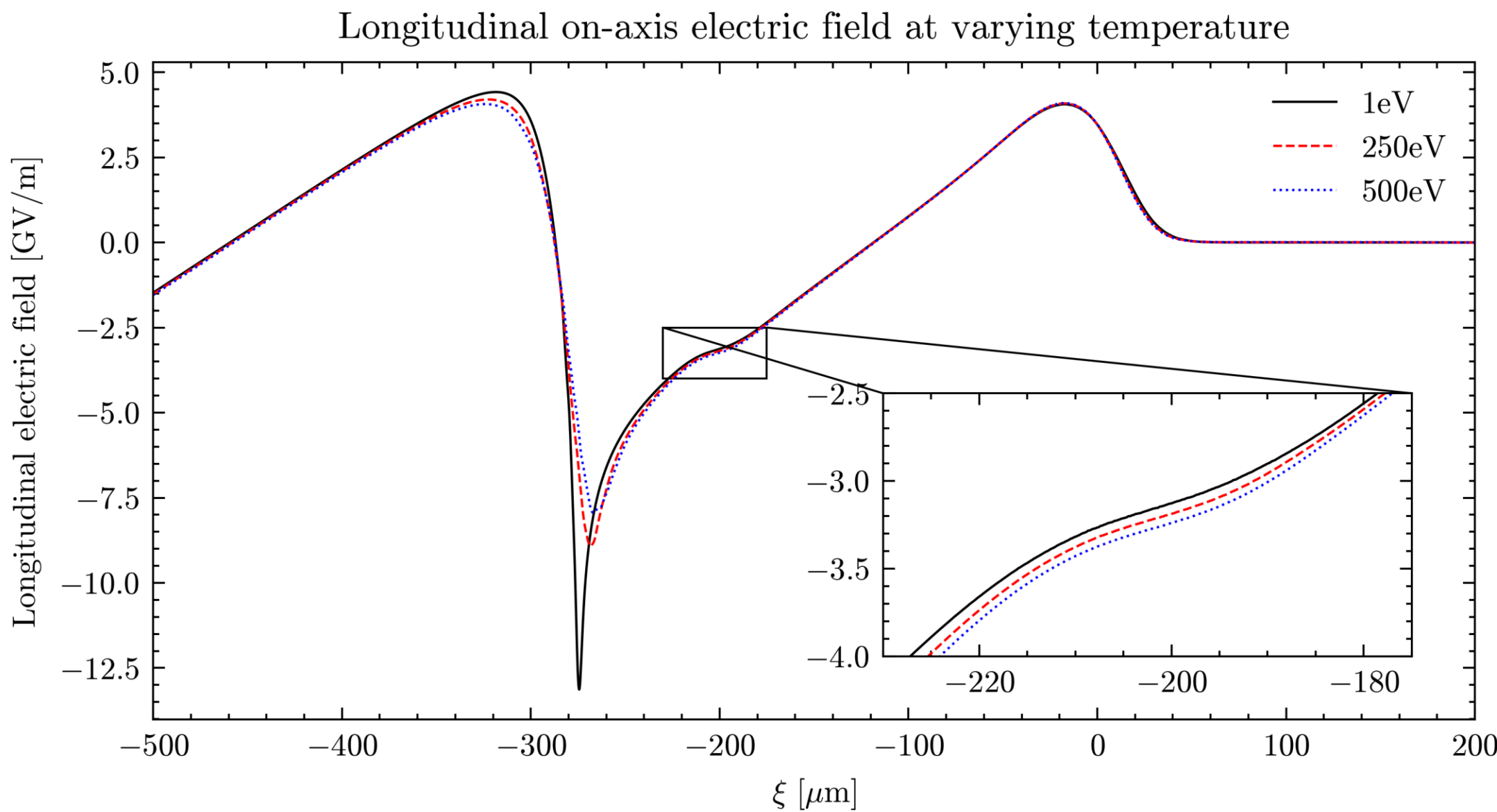
- > 85 cm capillary
- > Adjusting polarisation of ionising laser from linear to circular should allow control over plasma temperature



Plasma Temperature Experiment Feasibility



- Simulated witness bunch energy spectrum after plasma source at varying temperatures
- Increasing temperature increases witness bunch energy and energy spread
- Use witness bunch spectrum to diagnose differences in longitudinal E-field with temperature



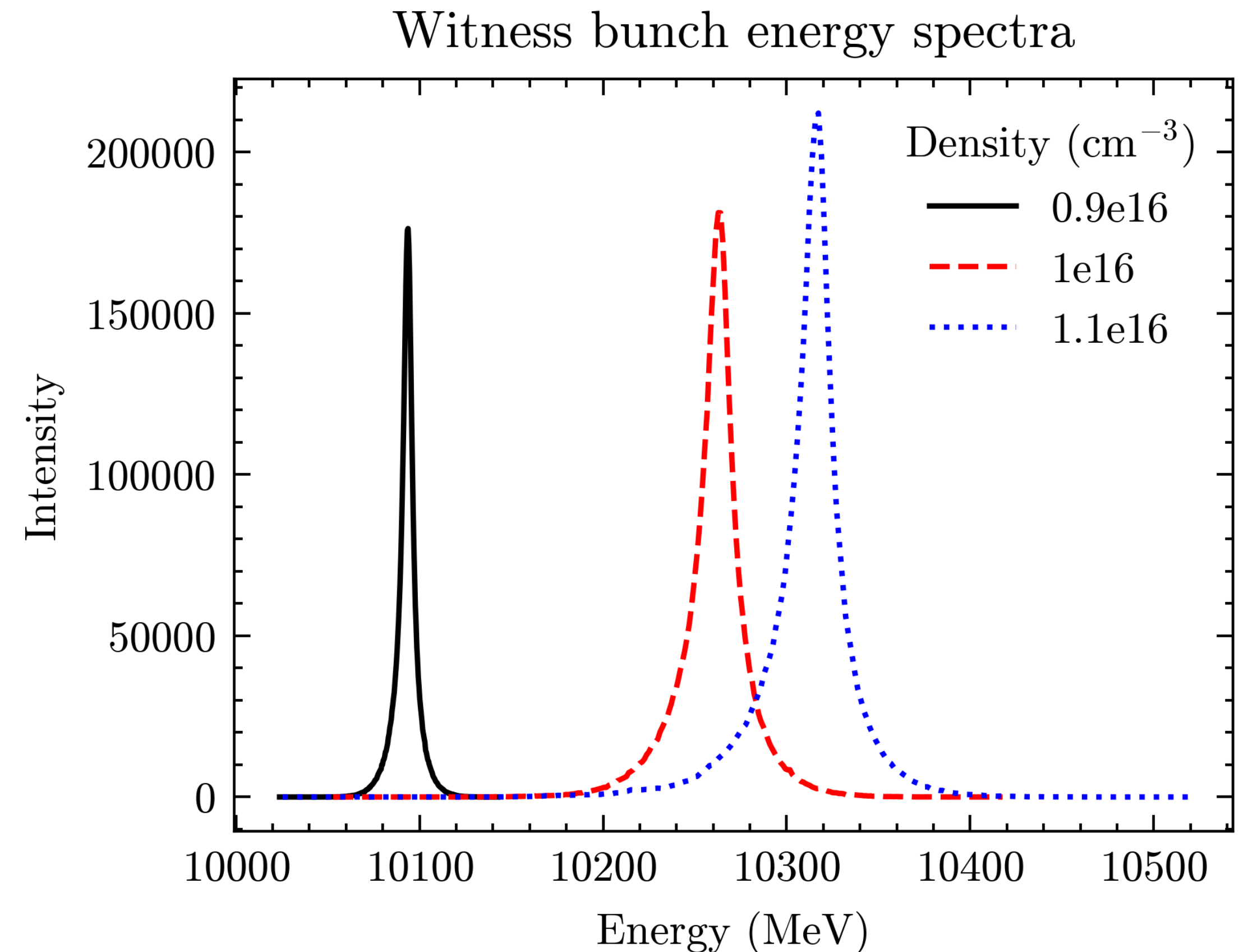
Remaining Challenges

> Density Effects

- > Simulate effect of changing polarisation of ionising laser on both plasma density and temperature

> Numerical Effects

- > Need convergence scans for number of particles per grid cell at higher temperatures
- > Likely underestimating witness peak energy at higher temperatures
- > Simulation time scales with particles per cell



Conclusions and Outlook

- **More work needed to ensure feasibility of this experiment at FACET-II**
- **Plasma temperature and density diagnostics are being developed in the lab**
 - Directly measure temperature and density of FACET-II laser-ionised plasma source
 - Plan to measure increase in plasma temperature from high repetition rate acceleration (other facilities)
- **Answer both questions to develop more complete understanding of temperature effects in plasma accelerators**
- **Understanding and control of plasma heating will be essential for application of plasma accelerators to future colliders and light sources**