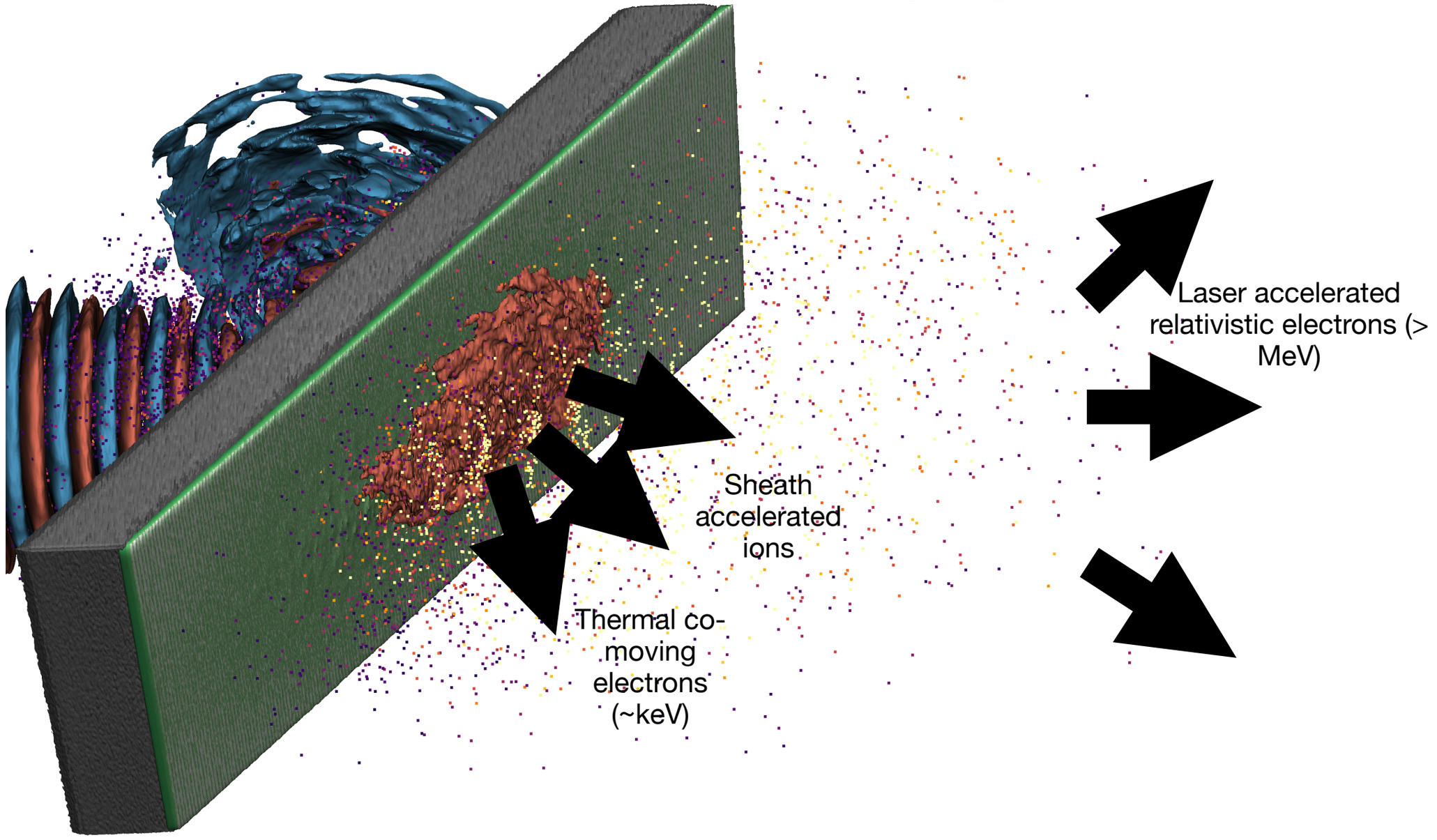
Electron emission from laser driven ion source

31-10-24

Two electron populations:

- “fast” electrons -> ~MeV thermal, moves ahead of protons, *centred along laser axis*
- “comoving” electrons -> ~keV thermal (?), moves with protons, *centred along target normal*

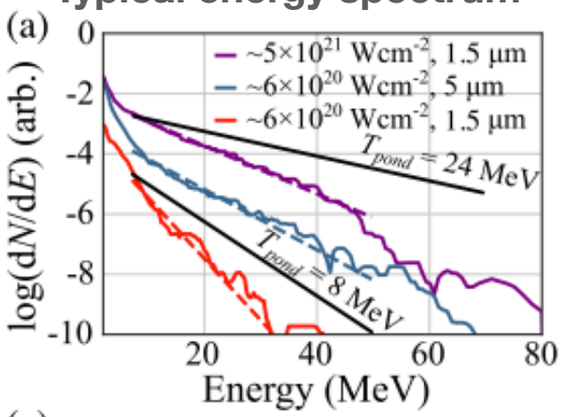


“Fast” electrons

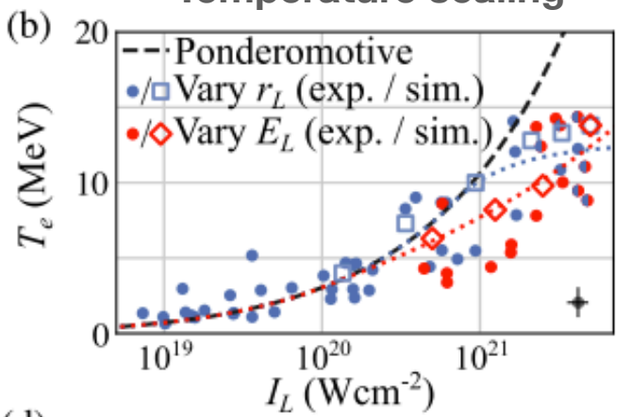
- Properties depend on laser-plasma interaction, e.g.:
  - Laser intensity
  - Laser spot size
  - Laser contrast
  - Target angle with respect to laser axis
- LhARA: E_L ~10 J, ~3 micron focus, 30 fs pulse -> intensity ~ 1x10^{21} W/cm^2
- From previous studies T_e ~10 MeV, possibly also bimaxwellian with 0.5 MeV component
- Divergence (FWHM of emission cone) ~30~40 degrees
  - Beam centred on laser axis; currently planning target irradiation at 30 degrees so “fast” electrons likely to go into capture system

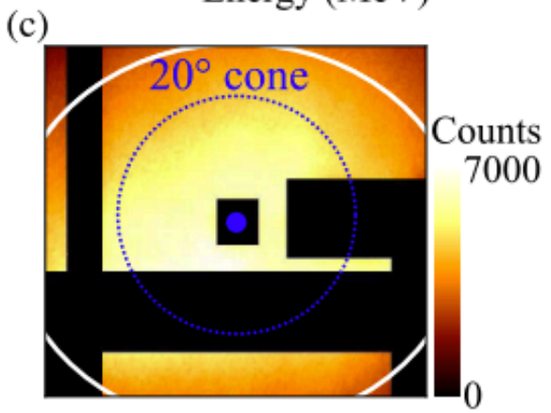
From Dover et al. PRL 124, 084802 (2020)

Typical energy spectrum

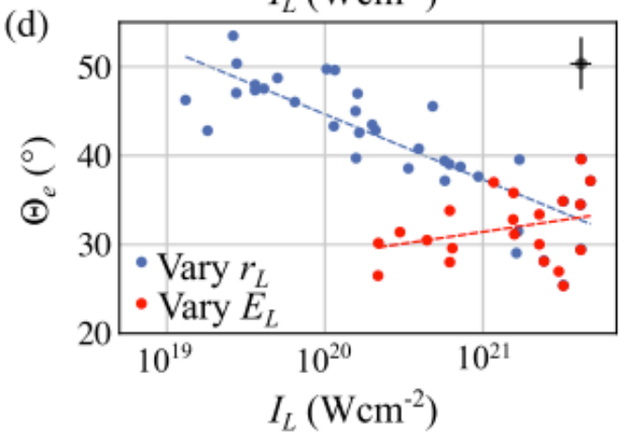


Temperature scaling





Beam profile



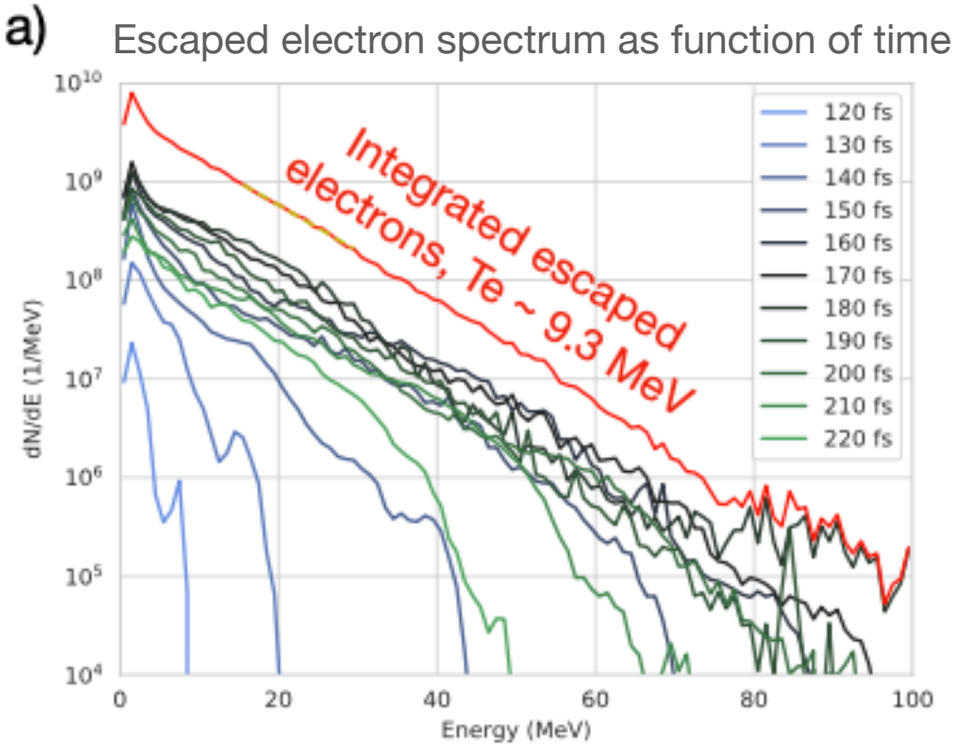
Angular divergence scaling

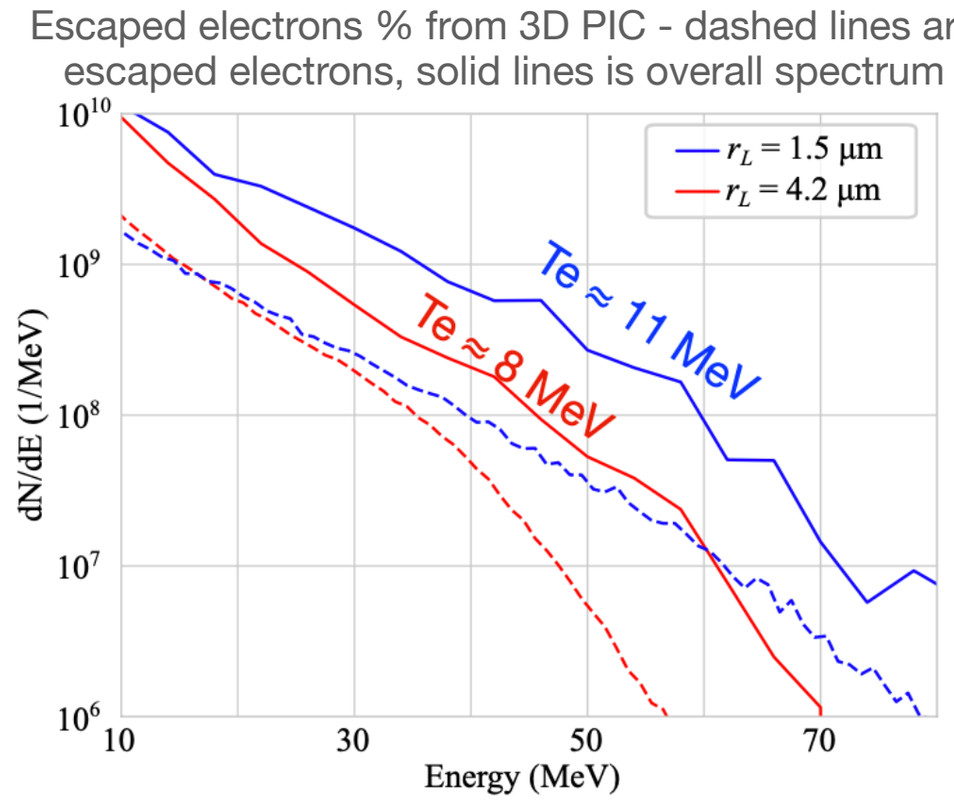
Estimating number of “fast” electrons going to capture system

- Probably ~50 to 80% of laser energy absorbed by high energy electrons, i.e. ~5 J.
- Most are confined to the target or lose energy in the target. ~10% escape. i.e. 500 mJ of electrons.
- Average KE ~10 MeV, so ~3x10^{11} electrons
- For divergence 40 degrees FWHM, equivalent average # per solid angle is ~6x10^{10} electrons/sr
- If nozzle has aperture of i.e. 15 msr, approx 1x10^{9} electrons enter capture
- If source to nozzle distance is e.g. 12 cm, fast electrons arrive ~2 ns before ions
- **Electron pulse length < 1 ps -> beam density could be > 10^{16} m^{-3}**

Final rough estimate

Electron parameters:
1x10^{9} electrons arriving in < 1 ps (<100 fs?)
Maxwellian, T_e~10 MeV
Arrive 2 ns before protons

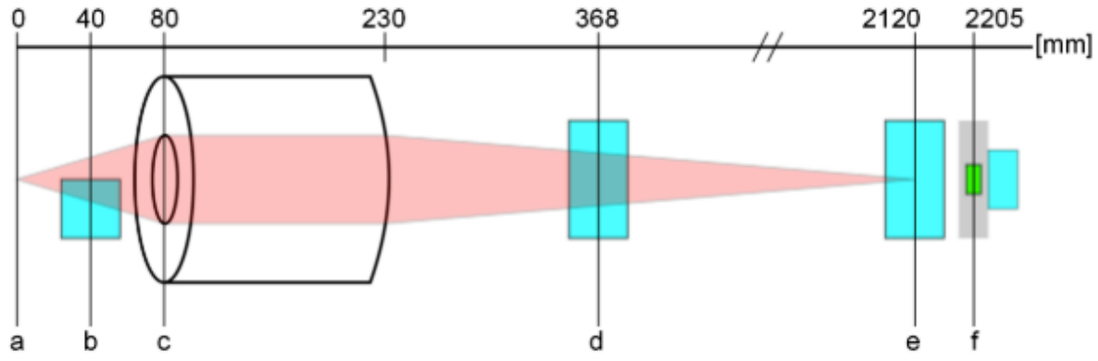




“Comoving” electrons

- Considerably less work done on co-moving electrons - rarely measured directly
- Initially hot, before adiabatically cooling while giving energy to the ions
- **At collimator, ~same numbers and velocity spectrum as ions**
- Proton velocity @ 15 MeV is ~0.2c, so approx electron T_e is ~10 keV
- Will arrive over many nanoseconds, with same time structure as protons

Experimental observation of comoving electrons in solenoid capture system - Busold et al. PRAB 16, 101302 (2013):



Electrons focused by solenoid onto axis, creating a larger-than-expected focusing field for protons

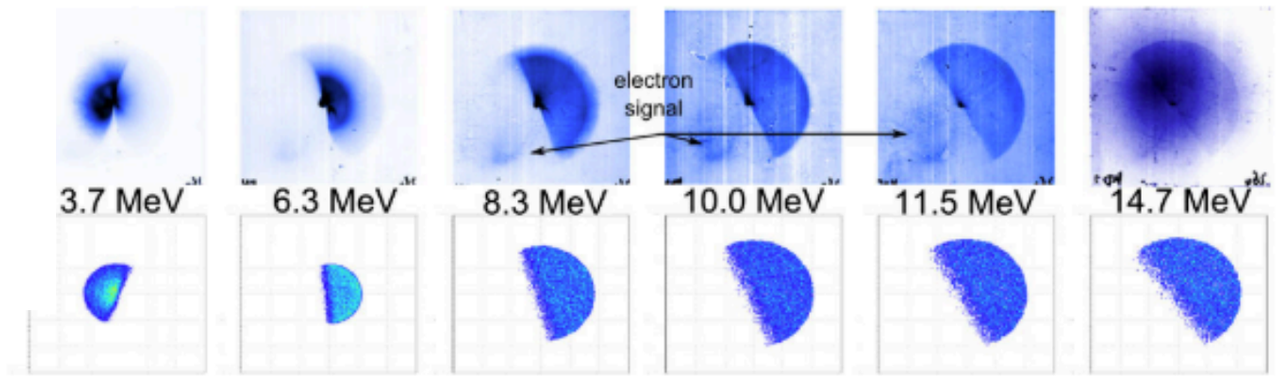


FIG. 3. Proton imprint in the RCF stack at 36.8 cm behind the source: experimental (upper) and simulation (lower sequence) results. In both cases the size of a single film is 60 mm × 60 mm. Additionally, an electron signal can be seen in the experimental data in the lower left quarter.