Some of M.King Papers Main Points

Near-100 MeV protons via a laser-driven transparency-enhanced hybrid acceleration scheme by Higginson et al.

- Paper on experimental results with Vulcan laser at RAL achieved proton energies $> 94\,\text{MeV}$.
  - $\lambda_L = 1.053\,\mu\text{m}$
  - $\tau_L = (0.9 \pm 0.1)\,\text{ps}$
  - $E_L = (210 \pm 40)\,\text{J}$
  - Thickness: $10\,\text{nm}$ to $1.5\,\mu\text{m}$
- Experimental results show that significant transmission of laser energy (due to too early relativistic induced transparency (RIT) such as too thin a thickness $< 100\,\text{nm}$) is detrimental to proton acceleration.
  - Strong signal for 94 MeV achieved with a $90\,\text{nm}$ plastic foil.
- EPOCH simulations show an agreement with trend, but absolute values are higher than measurements due to 2D dimensionality.
  - Used shorter pulse duration used in simulation compared to experiments ($0.9\,\text{ps} \to 0.4\,\text{ps}$)
- Before peak of pulse interacts with target, electron density along laser propagation axis decreases below critical density making target relativistically transparent.
  - High-energy electron jet extends beyond TNSA ion front.
  - Highest energy proton brunch observed within vicinity of electron jet.
- Acceleration dominated by dual-peaked electrostatic field:
  - One is the TNSA sheath field.
  - Other is produced later by laser radiation pressure giving RPA.
  - Eventually broadens at late times when dual-field structure decays.
- RIT enhances the magnitude of both peaks.
- Early in interaction, proton beam centred on target normal axis.
  - Eventually, a ring-like density distribution emerges at relatively low proton energies.
  - After RIT occurs, part of protons gain energy faster than rest.
- For short pulses, different regimes of hybrid acceleration occurs.
- Tuning target thickness can tailor proton spectrum to produce RPA-driven spectral peak, or enhance proton energies at expense of energy width of peak.

Effect of rear surface fields on hot, refluxing and escaping electron populations via numerical simulations by Rusby et al.

- Studies temporal and spectral characteristics of refluxing and escaping electrons with EPOCH simulations.
- Simulation parameters:
  - Spatial resolution of $20\,\text{nm}$.
  - Target thickness of $25\,\mu\text{m}$.
  - Electron density of $50 \times n_{\text{crit}}$.
  - PPC of 30.
  - Laser pulse duration (FWHM) of $175\,\text{fs}$, incident at $0°$.
  - Laser intensities varied by changing laser energy, keeping constant focal spot size.
- Two peak field structures at different velocities: fast field from fast escaping electrons, and slow field from plasma expansion.
- Equation of the change in energy of electrons at rear sheath show overall temperature of electrons should reduce by 2%, but a cooling effect of up to 40% is seen.

  - One process for cooling is electrons lost and another process is some energy goes into creation and driving of sheath field
  - For 10^{20} W/cm^2 simulations, 61% of refluxing electrons lose energy at an average of $\sim 0.23\,\text{MeV}$ and 80% electrons gain or lose $< 0.5\,\text{MeV}$.

- Refluxing electrons comprise 95% of initial hot electrons, with the remaining 5% either escape, are trapped, or below the threshold of analysis ($< 250\,\text{keV}$).

- Electrons with highest energies most likely to escape target.
  - There are escaping electrons that ballistically escape target at near the speed of light, leaving simulation relatively early.

- Most electrons lose energy leaving the target in order to overcome the electric field.
  - The point where the internal-escaping electrons and internal electrons are the same gives a threshold energy where electron guaranteed to escape.
  - This threshold energy increases with the peak field on the rear surface which increases with the intensity.

- Ballistic electrons are a small percentage of population outside target, about 1% of the initial internal hot-electron population.

- Experimentally, escaping electrons are about 15% of initial internal hot-electron population due to the vast number of plasma/sheath electrons.

Energy absorption and coupling to electrons in the transition from surface- to volume-dominant intense laser-plasma interaction regimes by Williamson et al.

- Reports measurements of energy absorption from interactions from surface-dominated (tens-of-microns) to volume-dominated (tens-of-nanometres), and finding optimum thickenss for total energy absorption.
  - PIC simulations indicate significant direct laser acceleration of electrons in volumetric-dominated interaction regime.

- Experiments using PHELIX laser at GSI:
  - $\lambda_L = 1.053\,\mu\text{m}$
  - $\tau_L = (0.7 \pm 0.1)\,\text{ps}$
  - $E_L = (80 \pm 5)\,\text{J}$
  - Incident at $0°$
  - Thickness: $40\,\text{nm}$ to $20\,\mu\text{m}$

  2D simulations with EPOCH with:
  - $\tau_L = 0.55\,\text{ps}$
  - $\phi_L = 5\,\mu\text{m}$
  - Peak intensity $= 6 \times 10^{19}\,\text{W cm}^{-2}$
  - Thickness: $20\,\text{nm}$ to $6\,\mu\text{m}$ with fixed $10\,\text{nm}$ contaminant protons

- Comparison of absorption good overall agreement, giving an optimum thickness ($l \sim 380\,\text{nm}$) where target does not become relativistically transparent.
  - Escaping electron number increases with decreasing target thickness until a threshold of when RSIT occurs.
  - Surface absorption mechanisms less efficient at coupling energy to fast electrons.
  - Electron distribution becomes narrow and more peaked for thinnest targets.

- Change in total absorption varies weakly with target thickness, but dynamics of accelerated electrons varies strongly.
  - The larger number of electrons available for thicker targets can enable higher overall energy coupling to electrons in the case of ultra thin targets.

- Simulations also performed with target pre-expanded by defining target with a Gaussian profile with overall trends staying the same.

Role of magnetic field evolution on filamentary structure formation in intense laser-foil interactions by King et al.

- Paper demonstrates that filamentary structures from nanometre foils can depend on formation of azimuthal magnetic field filaments, through Weibel instability.
- For ultra thin targets pressure perturbations during RPA can induce unstable wave behaviour associated with Rayleigh-Taylor instability at critical surface.
  - This leads to filamentary structures.
  - For thicker targets, a long-density scale length plasma at the rear surface can induce a Weibel instability.
  - This results in the growth of transverse electromagnetic perturbations that form localized magnetic field structures, leading to filamentary structures in background electron population.
- Experiment used Vulcan laser at RAL:
  - $\lambda_L = 1.053\,\mu\text{m}$
  - $\phi_L = 7.3\,\mu\text{m}$ (FWHM)
  - $\tau_L = (1 \pm 0.2)\,\text{ps}$ (single-pulse) and $(1.5 \pm 0.1)\,\text{ps}$ (split)
  - $E_L = (200 \pm 15)\,\text{J}$
  - Thickness: 10 nm to 40 nm
- When temporal intensity profile modified with addition of significant second pulse, filamentary structures appear in lower energy component of proton beam.
  - As intensity of first pulse increased, degree of structure reduces.
  - For thick targets, degree of structure is significantly lower.
- Simulations conducted to investigate initial seeding of this behaviour:
  - Spatial resolution in longitudinal direction is at sufficient resolution to resolve skin depth.
  - Second pulse is defined with same duration and diameter of first pulse, separated by 1 ps.

  When electrons are injected into target, a fast current is drawn to counter fast electron propagation.
  - This results in counter-streaming electron populations leading to growth of Weibel instability, leading to magnetic field perturbations.
  - For thicker targets, collisions act to suppress the growth of this instability.
  - The formation of sheath fields at the front and rear reflect electrons back into target which allow Weibel instability to grow.
- For the magnetic field structure to influence accelerated protons, it has to form early enough before proton layer has significantly expanded.
  - As intensity of first pulse is increased, the proton layer expands such that it is outside the influence of magnetic field structure.
  - There is a parameter space where the degree of structure in proton beam is maximized for least amount of initial proton layer expansion and fastest azimuthal magnetic field formation.
- Through two controllable laser pulses, the degree of structure in the proton beam can be varied.

Enhanced laser-energy coupling to dense plasmas driven by recirculating electron currents by Gray et al.

- Paper displays a different scaling of absorption scaling with laser intensity depending on whether pulse energy or focal spot size is varied.
- For a dense plasma, the dominant laser coupling mechanisms are sensitive to laser polarisation, intensity, angle of incidence, and density scale length of plasma.
- Previous results demonstrate laser absorption scales with intensity by varying pulse energy, but the influence of focal size and pulse duration not well characterised.
- Experiment performed with PHELIX laser at GSI:

  - $\tau_L = (700 \pm 100)\,\mathrm{fs}$
  - $E_L = 4$ to $180\,\mathrm{J}$
  - $\lambda_L = 1.053\,\mu\mathrm{m}$
  - Incidence angle = $0°$
  - Thickness = 6 to $20\,\mu\mathrm{m}$

- Measurements are in good agreement with empirical model (Davies model) when intensity scaled by varying the pulse energy.
  - For thinner targets, a different scaling can be expected due to volumetric interaction processes.
  - But when intensity is scaled by varying the focal size, the scaling is considerably slower.

- EPOCH simulations used to investigate underlying absorption physics by varying the focal size.
  - $\tau_L = 550\,\mathrm{fs}$
  - Thickness = 6 to $50\,\mu\mathrm{m}$

- Simulations are consistent with experiments in that larger spot sizes ($50\,\mu\mathrm{m}$) gives a higher total energy of electrons compared to small spot sizes ($4\,\mu\mathrm{m}$) for the same peak intensity.
  - This is not accounted for by established electron temperature scaling laws.
  - Investigations show that target thickness does not significantly change electron spectra for small focal size.
  - By contrast, for larger spot size the thinnest target gives the highest electron temperature and energies.
  - Reducing the pulse duration reveals recirculation of electrons within target plays an important role in laser-energy coupling dynamics.

- A geometric model is presented to illustrate the parameter space where recirculation-enhanced absorption is relevant.