Demonstration of Numerical Capability at First Light Fusion

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first light

Introduction

- First Light Fusion (FLF) is developing novel target designs for ICF experiments using shocks driven by high velocity projectiles
- Pulsed power machine M3 (right) has been commissioned, delivers ~8 MA over 1.5 μs to flyer plate load, providing projectile for fusion experiments.

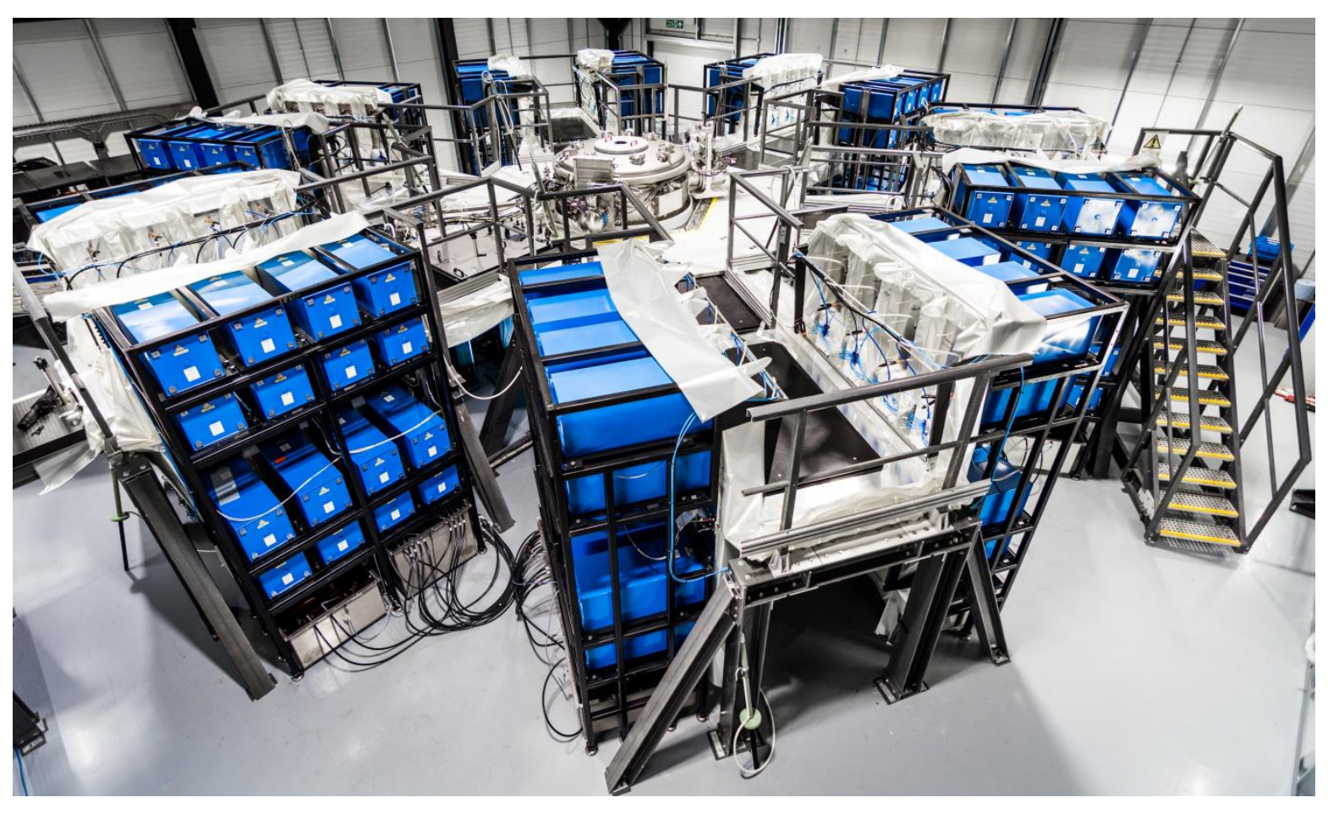


Fig. 1: M3 pulsed power machine at FLF

- FLF has developed two fluid codes: Hytrac, a 2D Eulerian code with AMR and front-tracking and B, a 3D MHD code with volume of fluid interface tracking. Both codes included subcycled thermal conduction, FEOS [1] equations of state and Lee-More transport [2].

Hytrac

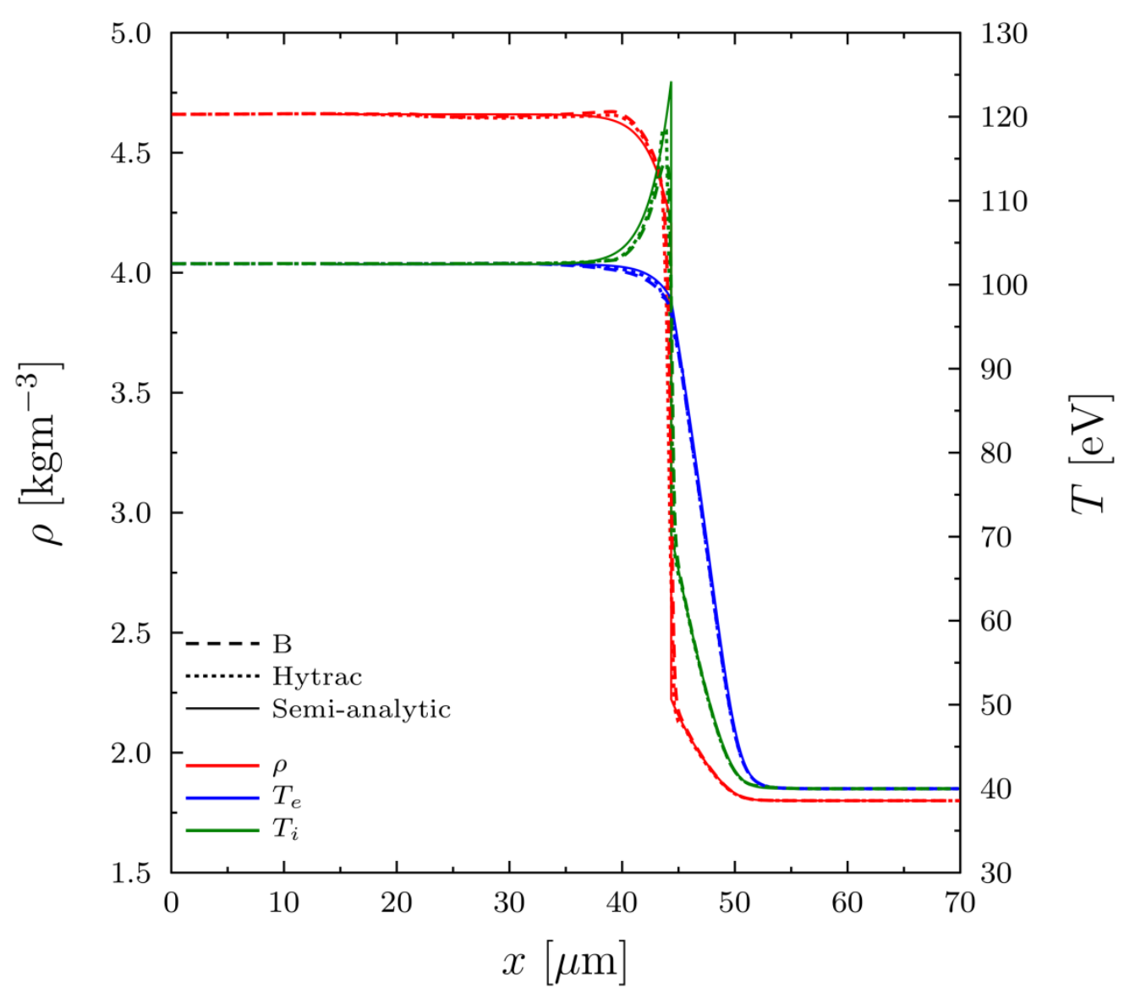
- Architecture uses two grids: Eulerian grid on which the hydrodynamics equations are solved and a Lagrangian grid tracking fluid interfaces.
- Eulerian grid includes AMR, allowing simulations over a range of scales
- Grid update through exact or approximate Riemann solvers.

B

- 3D resistive MHD code, MHD equations subcycled within hydro solve.
- Volume of fluid method is cheap and simple, allowing arbitrary number of materials with some diffusion at interfaces.

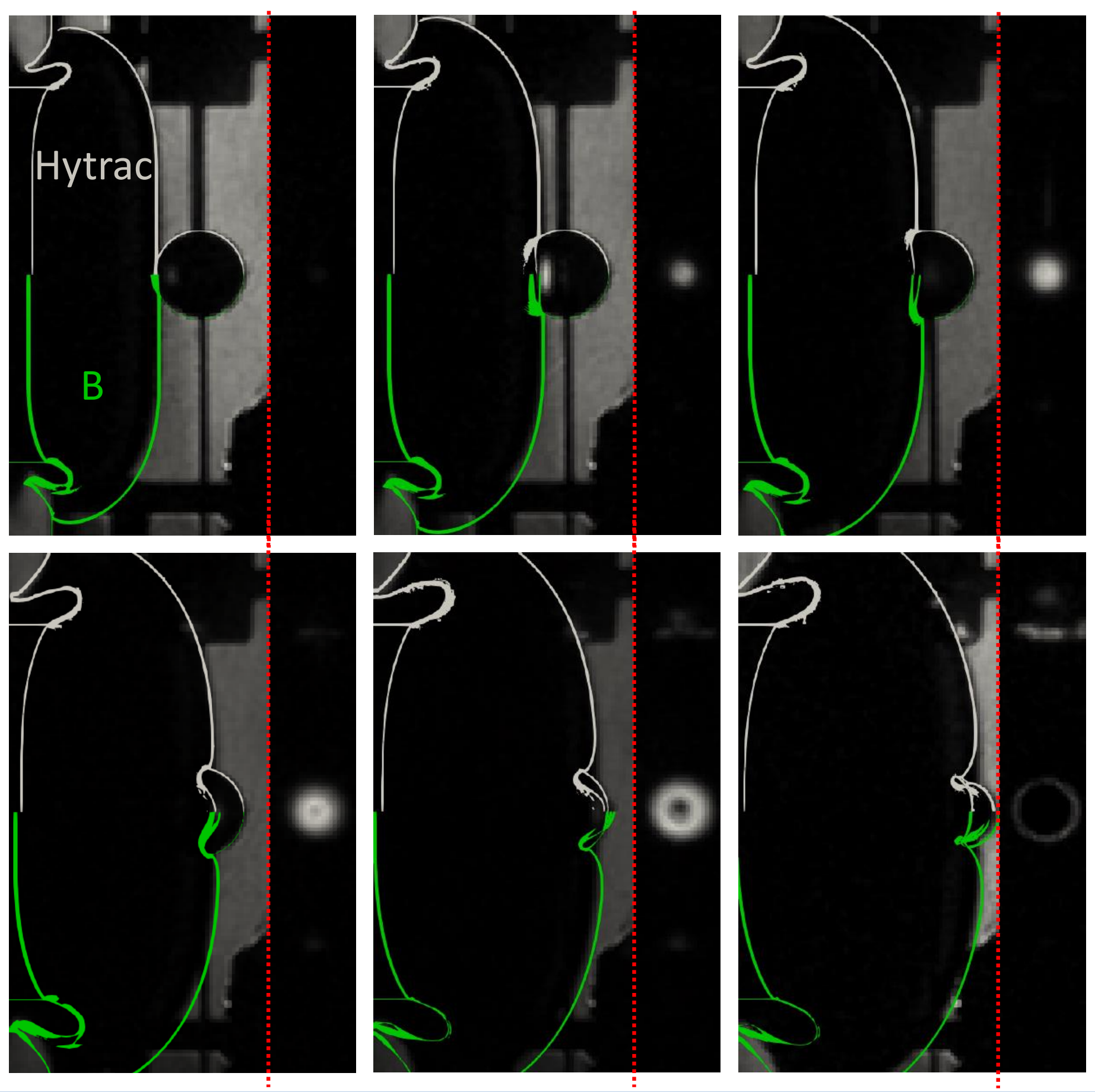
1D and 2D benchmarking

Fig. 2: 1D Shafranov test [3]



Shafranov test [3]: a strong shock is initialised in helium and allowed to evolve using hydrodynamics and thermal conduction. Unshocked material is preheated due to electron thermal conduction. Hytrac and B agree well with semi-analytic solution (ODE solve).

Fig. 3: Frames from spherical cavity collapse experiment on FLF gas gun [4], compared to Hytrac (white) and B (green)



Spherical cavity collapse: FLF gas gun [4] driven projectile initiates cavity collapse. Images show side (left of red line) and end (right of red line) on optical images. Forms bright torus of emitting plasma.

- Numerical Schlieren overlaid for Hytrac (white) and B (green), shows good agreement with experiment.

Additional 2D benchmarking done using the Richtmeyer-Meshkov instability (see M. Read's poster).

Gap correction and comparison to Z

- Comparison made to 45 km/s flyer experiments (Lemke et al) [5]. Magnetic field in gap given by: $B = \dfrac{\mu_0 I}{w + g(t)}$ **(1)**
- New method developed to self-consistently determine evolving gap g(t): use total stored magnetic energy with width and length of stripline plate (2). For uniform magnetic field in cuboidal region, gives (3):

$$E_{mag} = \int_V \frac{B^2(x,y,z,t)}{2\mu_0}\,\mathrm{dV} \quad \textbf{(2)} \qquad E_{mag} = \frac{B^2}{2\mu_0} \times w \times l \times g(t) = \frac{1}{2} L(t) I^2(t) \quad \textbf{(3)}$$

The total inductance is calculated in B by summing the magnetic field over the simulation volume; combining (1) with (2) gives a quadratic in g(t), which can be easily solved: $L(t) = \dfrac{\mu_0}{[w + g(t)]^2} \times w \times l \times g(t)$ **(4)**

This calculation is carried out dynamically throughout the simulation.

3D B simulation using gap correction gives excellent agreement with experimentally measured velocity without requiring any fudge factors

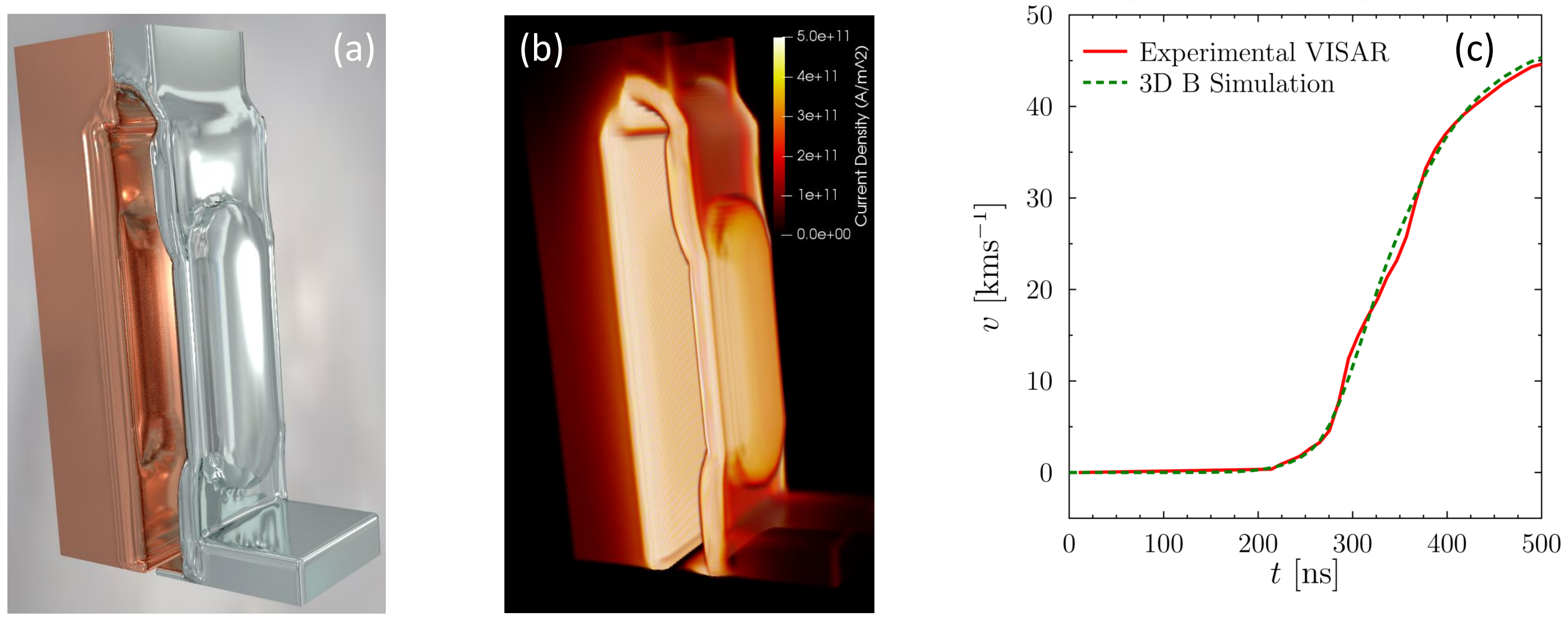


Fig. 4: Simulation results for 45 km/s flyer on Z [5]: density surfaces (a), volumetric current density (b) and experimental VISAR vs. synthetic VISAR (c)

B simulation of flyer plates on M3

Three different simulation domains: full volume requires fewest assumptions, pier only allows highest resolution.

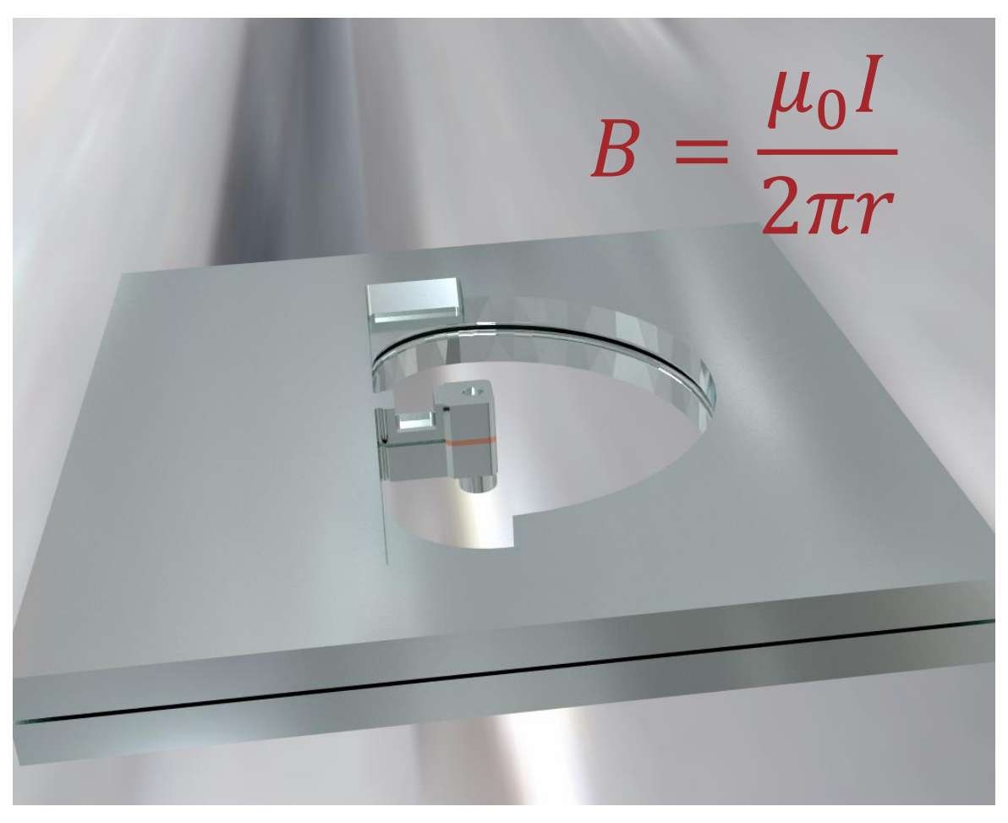


Fig. 5a: Full volume

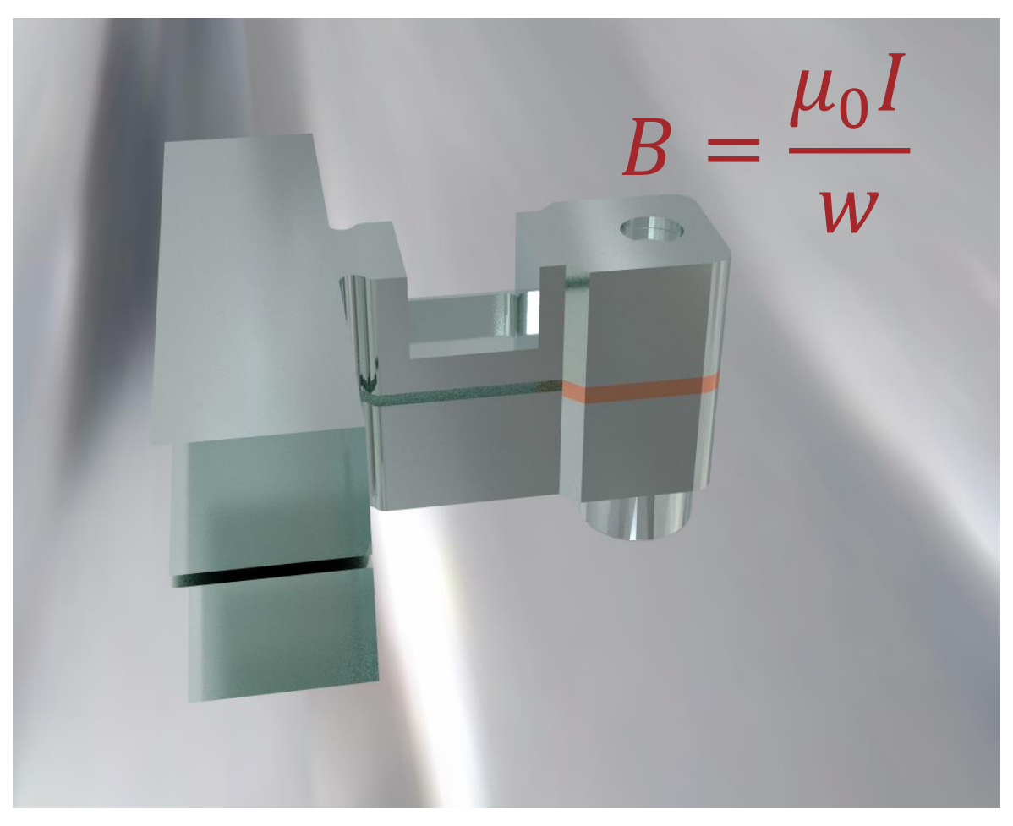


Fig. 5b: Pier plus electrode

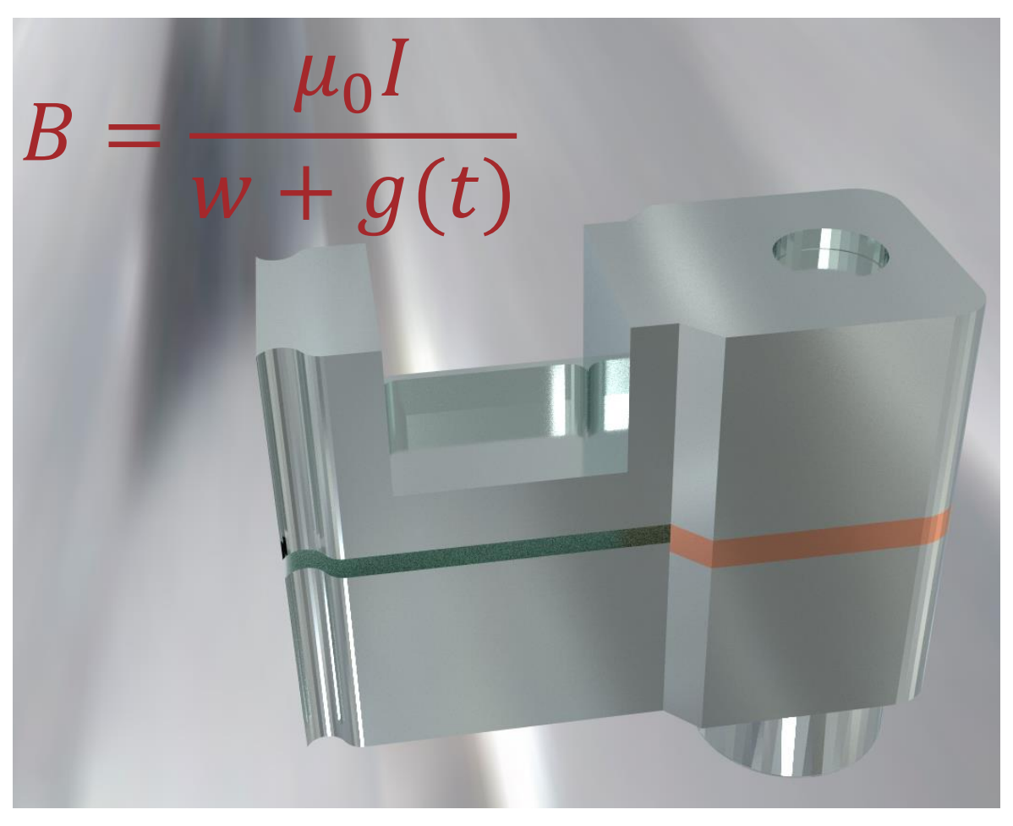


Fig. 5c: Pier only

Inductance correction applied for (b) and (c) by running a static B simulation with a short at the boundary, to determine the extra inductance from the neglected portion of electrode.

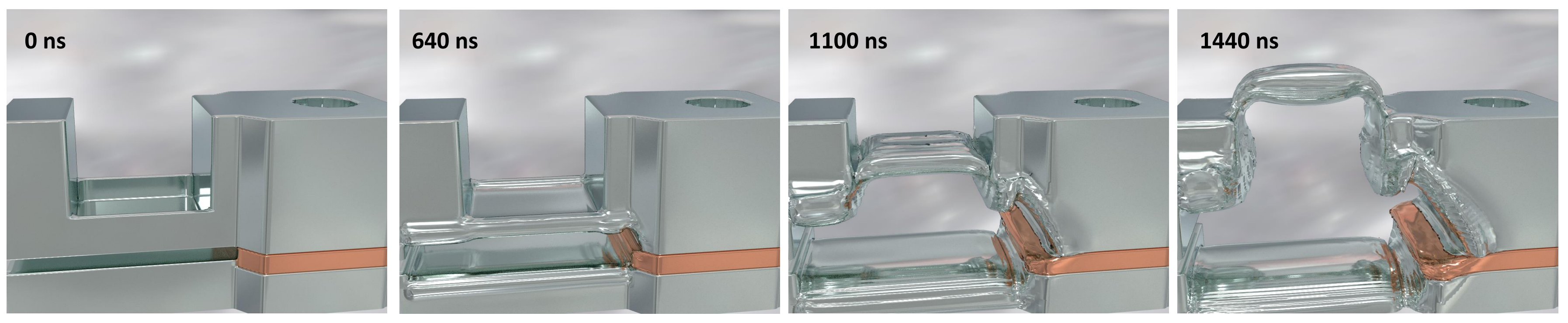


Fig. 6: Time series of flyer density from 3D B simulation, showing flyer launch and opening of stripline gap.

Simulations show good agreement between each other and with the experimental flyer velocity ("Pier only" under-estimates L late in time)

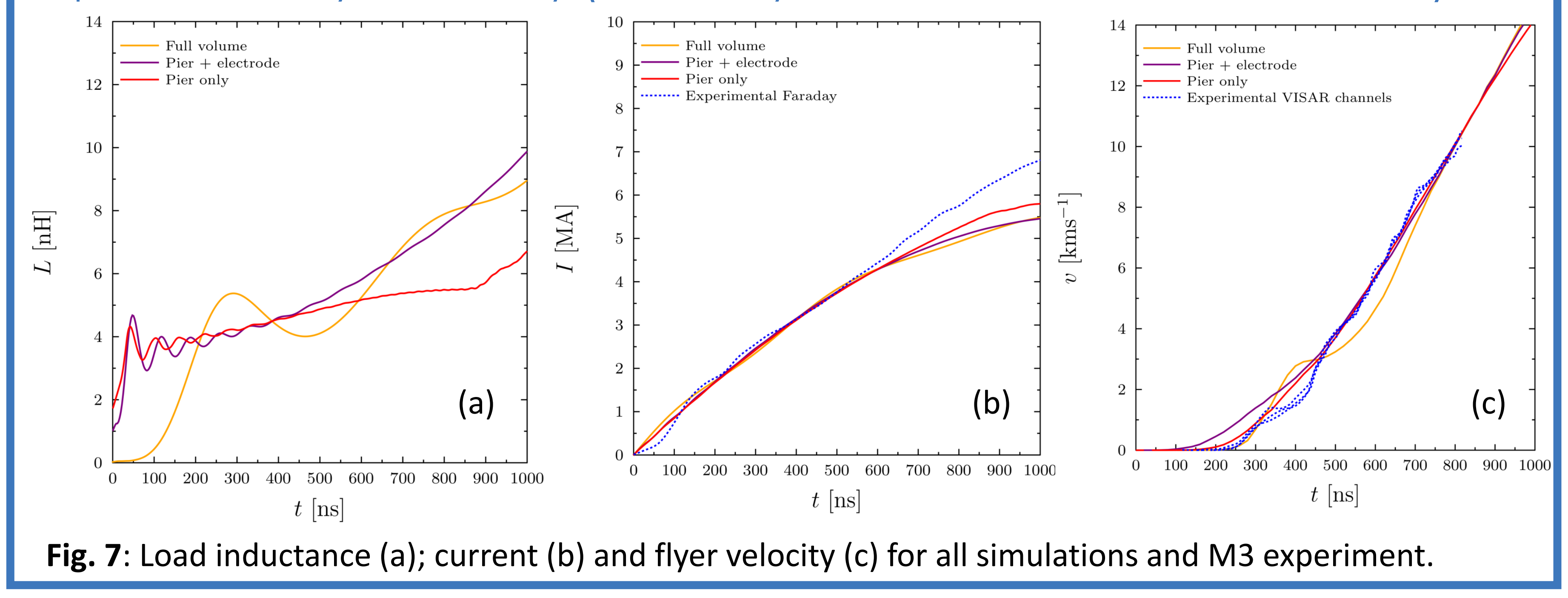


Fig. 7: Load inductance (a); current (b) and flyer velocity (c) for all simulations and M3 experiment.

Conclusions and future work

FLF has developed and benchmarked world class numerical tools to provide predictive capability for in-house experiments. Development of new techniques for simulation of magnetically-driven flyer plates maintains excellent agreement with experiment while reducing numerical effort, allowing faster and higher fidelity simulations. Efforts are continuing to further optimise flyer launch, aiming towards achieving higher flyer velocities and impact pressures.

References

1. Faik et al, HEDP 8, 349-359, 2012
2. Lee and More, PoF 27, 1273 (1984)
3. Shafranov, JETP 5, 6, 1183-1187 (1957)
4. Ringrose et al, Proc. Eng. 204, 344-351 (2017)
5. Lemke et al, Int. J. Impact Eng. 38, 480-485 (2011)

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