An Introduction to First Light Fusion's Projectile Driven ICF

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First Light Fusion

First Light Fusion Ltd. is a privately funded company in Oxford, UK, researching projectile driven ICF. Targets are designed to utilise strong shocks from one-sided high velocity impacts.

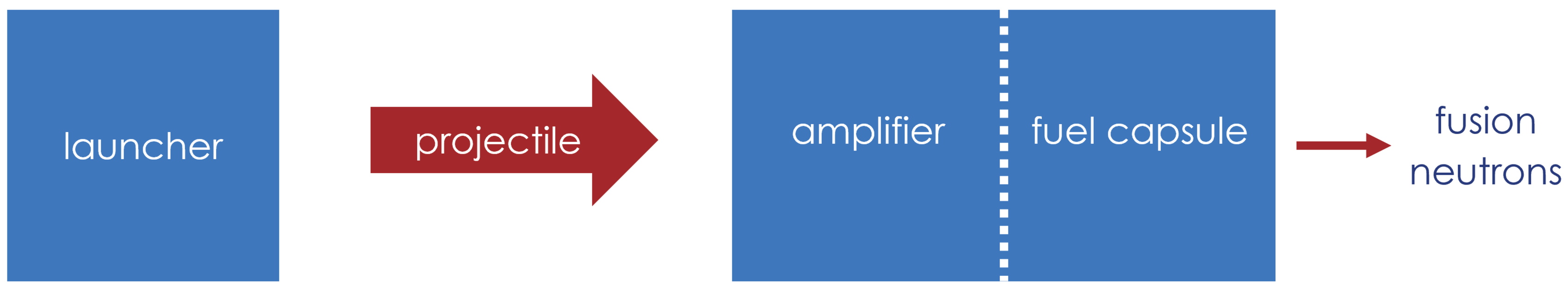

Fig. 1 : An overview of FLF's approach to inertial fusion.

In 2022, we demonstrated the production of fusion neutrons using our BFG gas gun. These results were validated externally by the UK Atomic Energy Authority [1].

Drivers

FLF's experimental facility has two types of drivers; two-stage gas guns and electromagnetic launchers, with the BFG and M3 being the largest in each category.

BFG: A 22m **two-stage gas gun** which shoots a 38 mm diameter, 100 g projectile up to 7 km/s.
The gun is loaded with 3 kg of gunpowder which pushes a piston that compresses hydrogen to high pressures, which provides the second stage launch power. A valve retains the pressure until it bursts and accelerates a sabot containing the projectile.

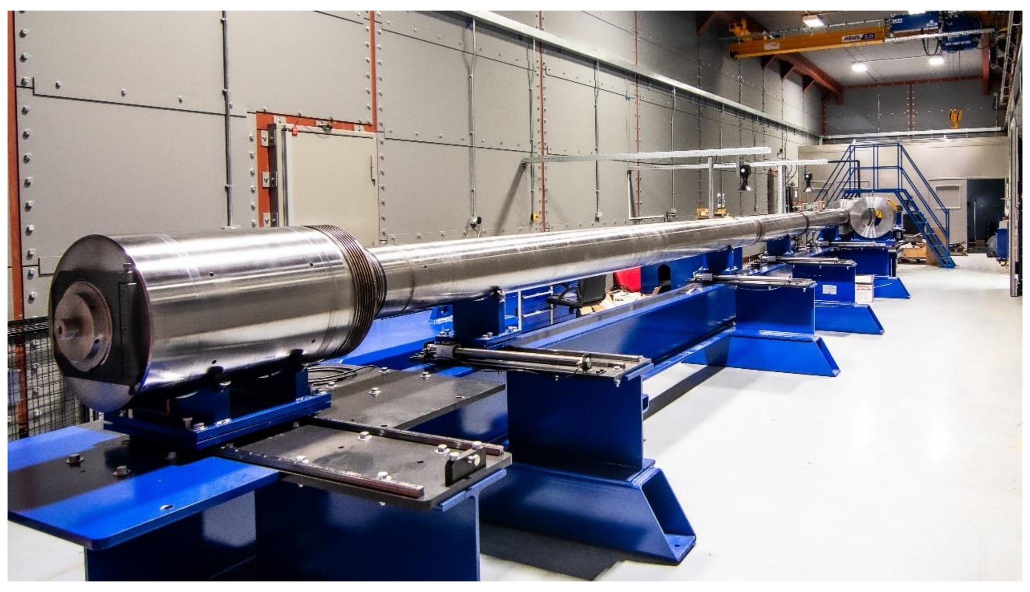

Fig. 5: The BFG (Big Friendly Gun) pointing into the diagnostics chamber.

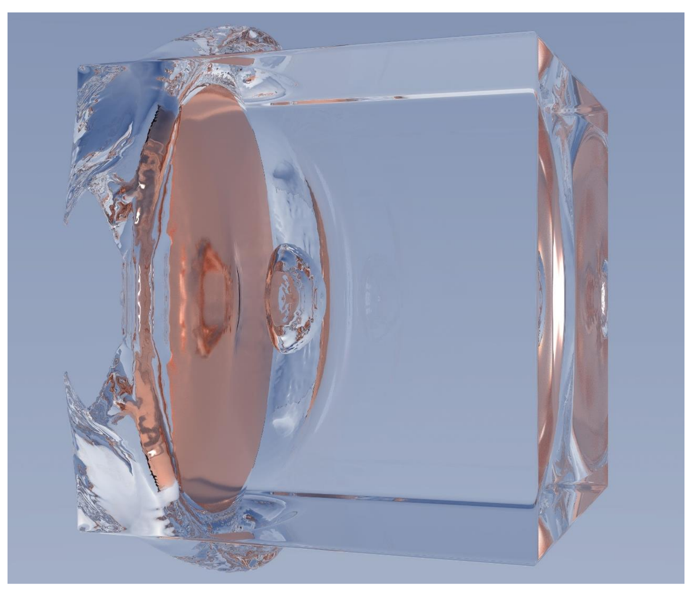

Fig. 6: A B2 Simulation of a projectile hitting a plastic target.

M3: One of the largest **pulsed power facilities** in the world and the largest in Europe.

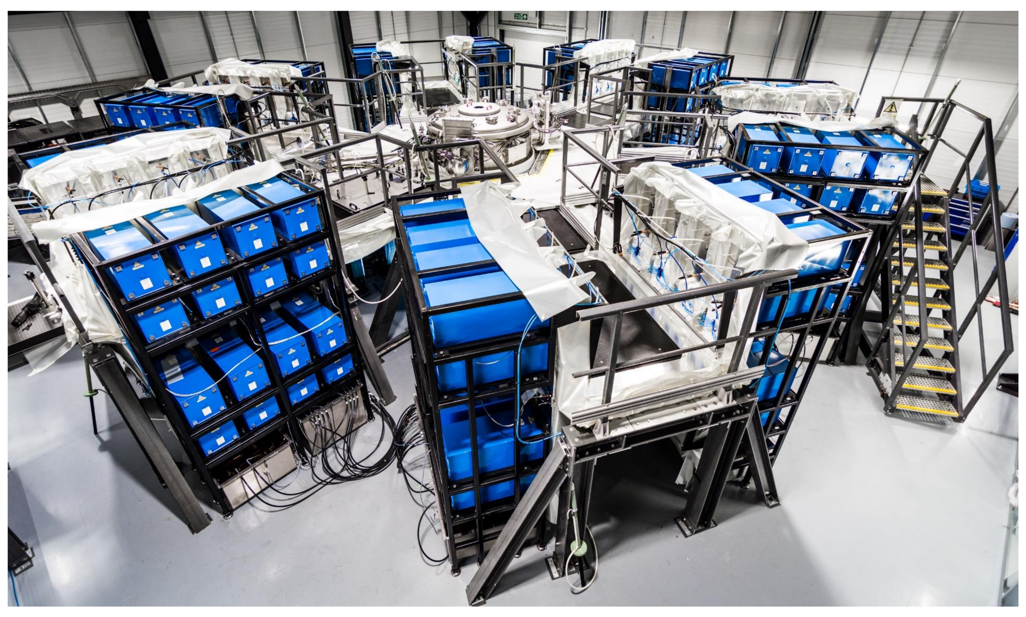

Fig. 7: M3, designed and built by First Light, uses extreme electromagnetic forces to launch projectiles at hypervelocities to test our fusion targets.

M3 stores 2.5 MJ in a capacitor bank at ±70kV with a 14 MA peak current, which can launch projectiles at a measured impact speed of 20 km/s.
A flyer plate is the most used projectile on M3. A high current density is passed through the top and bottom electrodes with a thinner section, this thin flyer section experiences the same $J \times B$ force and is accelerated upwards, figure 8.

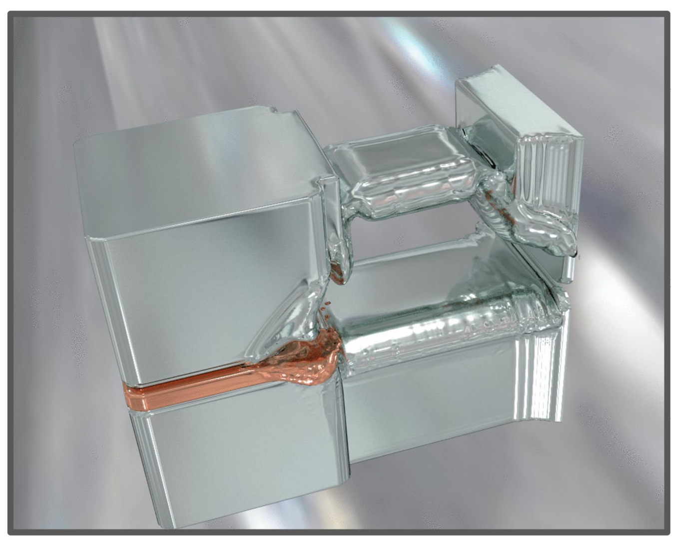

Fig. 8: A flyer plate launch simulation, in B2, mid-trajectory showing the top and bottom electrodes and the shim between the two electrodes.

Current Diagnostics Techniques:
VISAR, Active shock breakout, Shadowgraphy, Schlieren and X-ray back-lighting.

M4: The gain demonstrator [3], M4 will be the worlds largest pulsed power driver at approximately 75 m in diameter. With a storage capacity of around 100 mega joules of electrical energy, M4 will have the capability of launching projectiles at over 60 km/s, three times faster than M3.

Once developed, the aim is for fuel gain of 100 or more on Machine 4, but with the core principle of de-risking the physics of self-heating.
The focus is on the physics of the burning plasma, rather than the efficiency of the drivers or equipment.

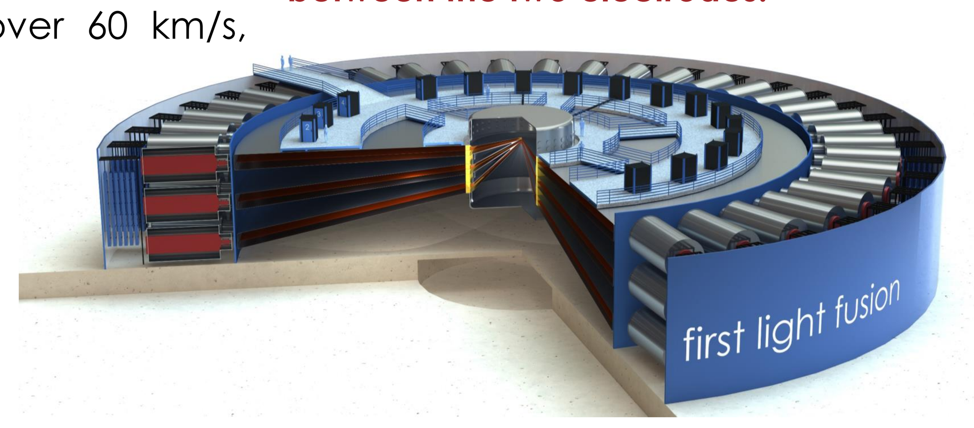

Fig. 9: A concept design of M4 illustrating the 3 layers, 42 modules per layer, and the oil-filled, water-filled and vacuum sections.

Simulation Codes

Hytrac: a 1D/2D Eulerian radiation hydrodynamic, with Lagrangian front-tracking code designed for high interface fidelity and high-accuracy compressible flow solvers. It utilises the Godunov FVM with various flux mechanisms and face reconstruction.
The grid uses gradient based AMR with n-multifluid nodes, singular points of >2 material contacts, and has the capability of planar, axial and spherical geometries.
A two-temperature adiabatic electron fluid treatment is prescribed and allows the multiphysics options of; conduction, multigroup radiation transport, viscosity, local alpha heating, and thermal relaxation.
Employs HPX thread-based parallelism.

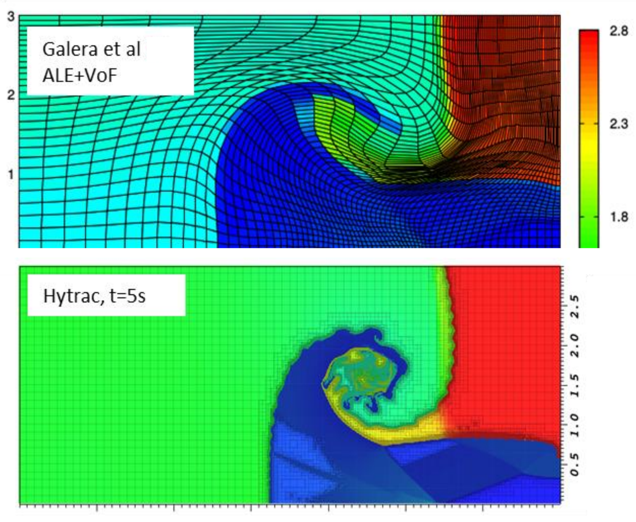

Fig. 2 : Comparison of Hytrac to an ALE+VoF code (Galera et al.[2]) on a shocked three material (3 fluid node) test problem, front tracking is numerically less diffusive than VoF approaches at the interface.

B2: an Eulerian 1D/2D/3D n-materials resistive MHD code that employs Lagrangian-remapping and varying order flux reconstruction. B2 also has the capability of planar, spherical and axial geometries.
It utilises a two-temperature conservation scheme, custom SLIC-VoF interface tracking, unified 2T EOS and microphysics closures with Hytrac.
Contains multiphysics options of; conduction, multigroup radiation, laser heating, depletive alpha heating, material strength, thermal relaxation, and electron inertia.
Employs MPI domain decomposition.

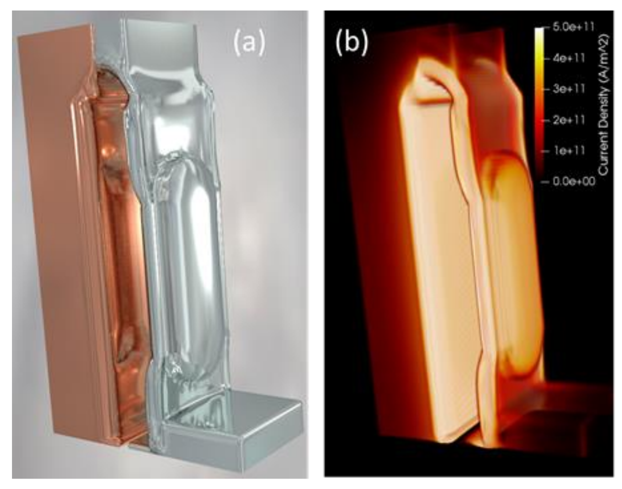

Fig. 3 : A B2 simulation of a flyer showing the material density (a) and the current density (b).

Experimental Comparison: comparison between in-house simulation codes and experimental data is regularly performed to test the physical nature of our codes.
A like-to-like comparison between simulation and the diagnostics of a release of a shock from an amplifier into a block is shown below in figure 4.

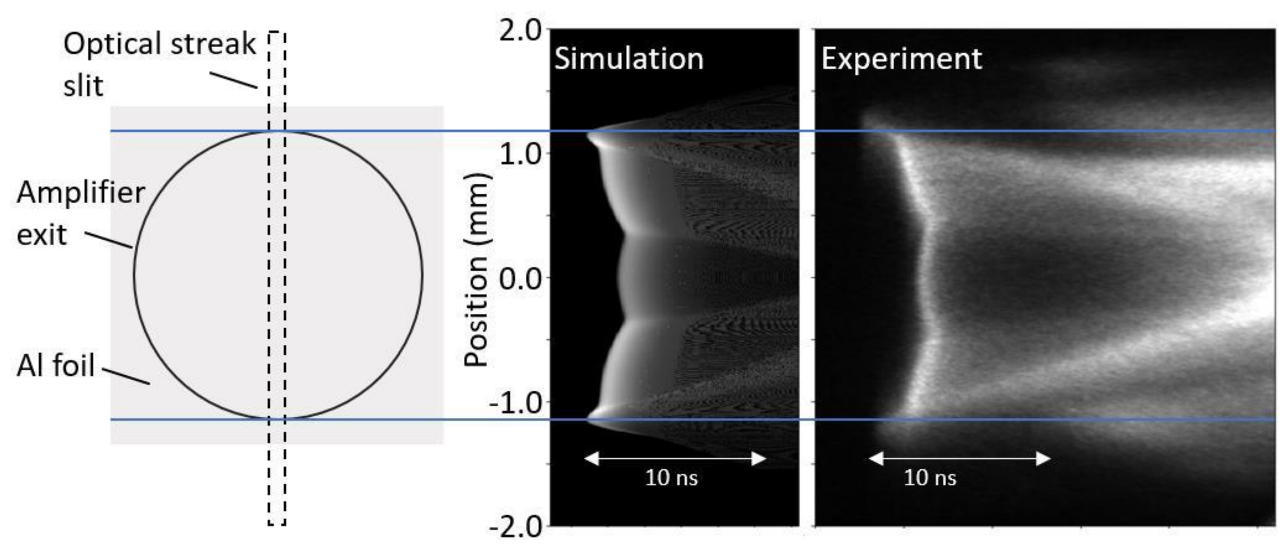

Fig. 4 : B2, was used to create a synthetic image of the brightness emitted as the shock breaks through the foil on the streak camera.

Targets

FLF's innovative shock amplification system increases the pressure from a projectile impact by a factor of 15. This results in TPa pressures over mm spatial scales to drive a quasi-spherical collapse.

A projectile driven by the BFG impacts the amplifier at 6.5 km/s with an 80 GPa impact pressure. This is increased to 1200 Gpa and 80 km/s release velocity into the fuel.
This amplifier technology has been demonstrated and validated using numerous experiments on FLF's pulsed power machines and light gas guns.

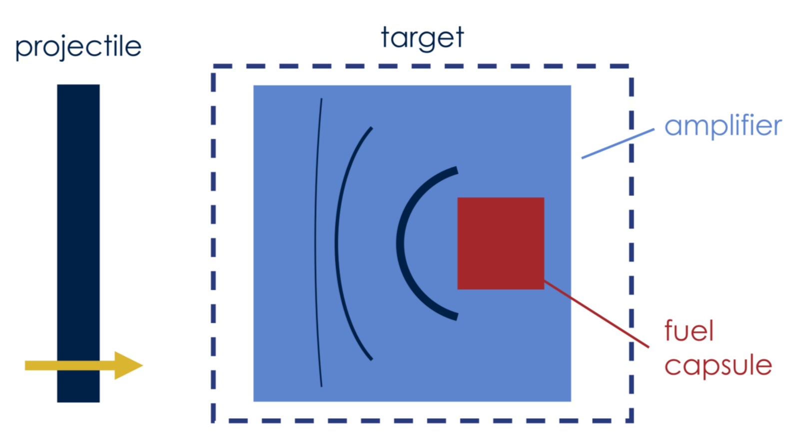

Fig. 10: A diagram illustrating the basic concepts of an amplifier shaping and concentrating a shock onto a fuel collapse.

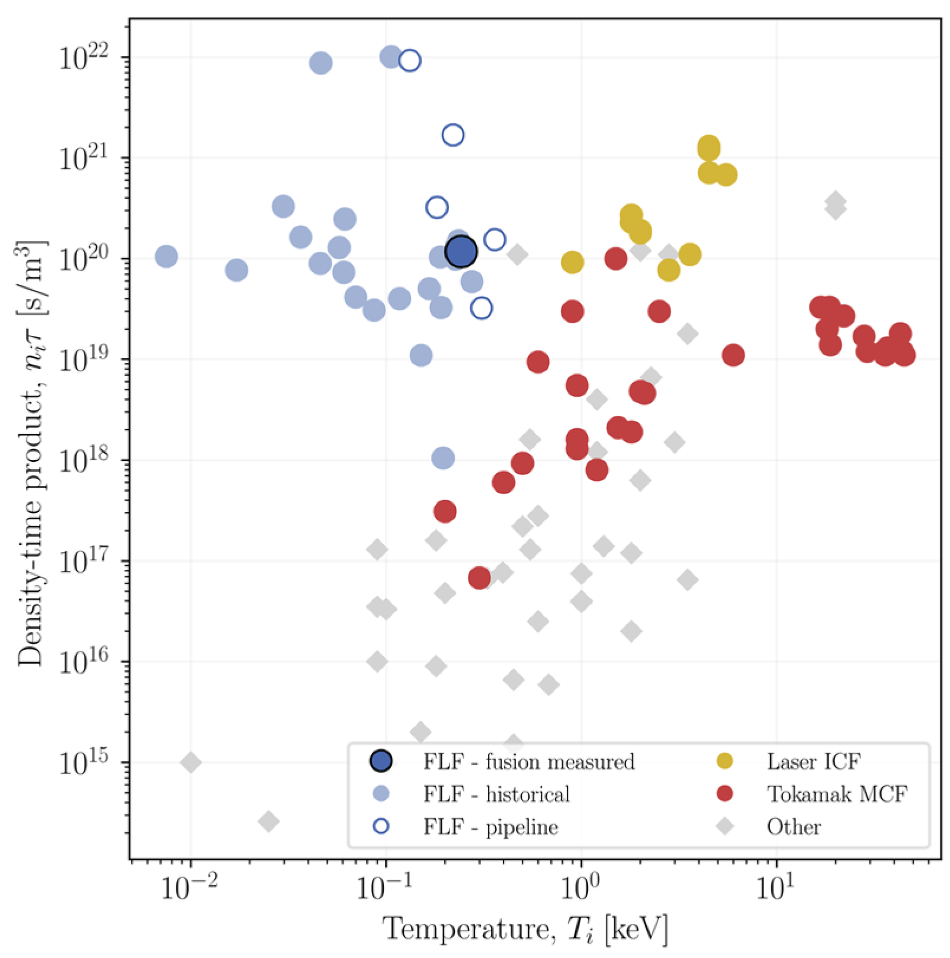

Fig. 11: A graph showing FLF's parameter space within the triple product in comparison to other methods of fusion.

References

1. FLF science hub - *"Validate Production of Neutrons from Gas Gun Driven Targets"*
2. *Galera et al., (2011), "A two-dimensional VOF interface reconstruction in a multi-material cell-centered ALE scheme", Int. J. Numerical Methods in Fluids, 65: 1351-1364*
3. FLF Website – technology/m4