Neutron emission from light-gas gun projectile driven targets

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Our approach to fusion

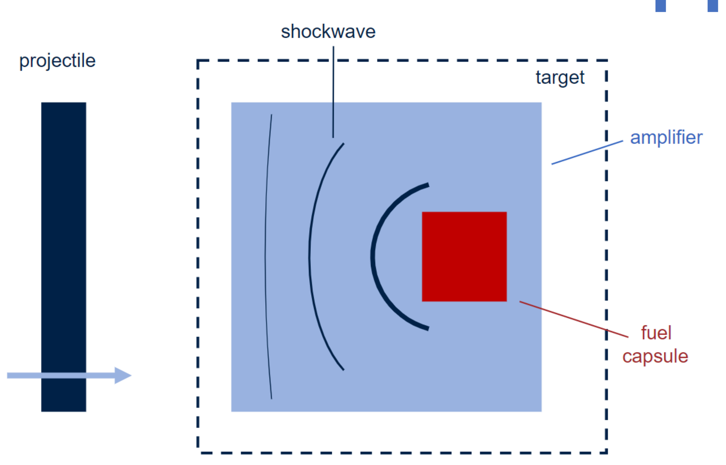

Fig. 1: FLF approach to inertial fusion

First Light Fusion Ltd. is a privately funded company researching energy generation via inertial confinement fusion (ICF), using intense shock waves driven by a high-velocity projectile impact (one-sided pressure drive).

Fig. 2: The large light gas gun facility

- Two-stage light gas gun is used to accelerate projectiles up to 6.5 km/s
- The initial drive pressure (~100 GPa) is amplified about 10 times and the shock exiting the amplifier with velocity of more than 30 km/s compress a capsule with DD or DT gas mixture to densities and temperatures relevant to achieve fusion
- The target design is a key aspect in FLF approach and is optimized using magneto-hydrodynamics 2D and 3D codes developed at FLF (B and Hytrac)

Experimental layout

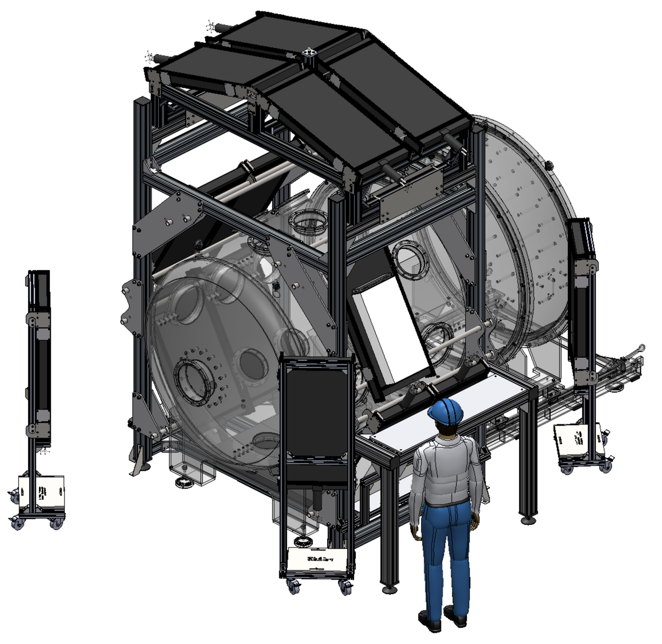

Fig. 3: Detector framework around the experimental chamber

Neutron detectors

- 16 large format EJ-200 plastic scintillators (1000 × 500 × 50 mm), intrinsic efficiency ~30% for DD neutrons
- 12 arrays of He-3 proportional counters, embedded in a 690 × 330 × 95 mm polyethylene moderator, intrinsic efficiency ~11%
- Detectors are positioned at multiple distances (~1m, 1.5 m and 2 m) to perform n-TOF measurement

Projectile diagnostics

- Shimadzu HPV-X2 fast camera (50 ns exposure, 100 ns inter-frame) was used to image the projectile in flight and determine its velocity.
- Dynasen ionization pins were position around the amplifier's effective area and difference in the impact time is used to estimate projectile tilt

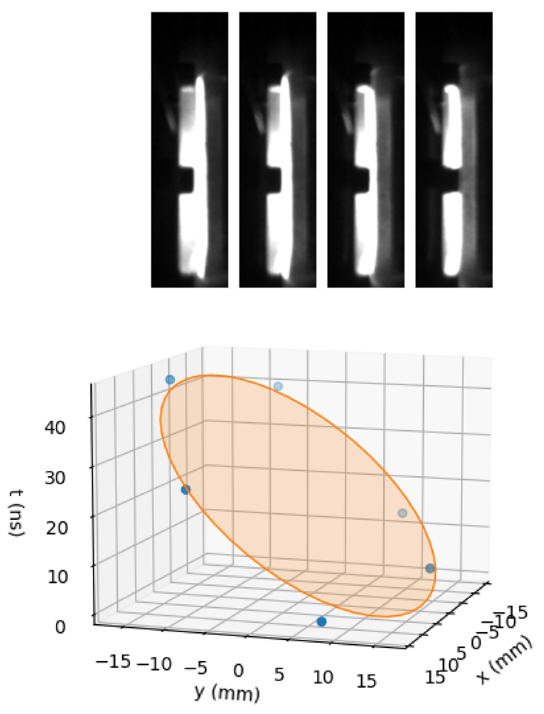

Fig. 4: Projectile diagnostics: image of the projectile in flight recorded with a Shimadzu HPV-X2 camera (top, the projectile is coming from the right) and projectile tilt plane reconstructed using ionization pins triggering time (bottom).

Neutronics model

- Radiation transport codes (MNCP, OpenMC, Geant4) were applied to evaluate the temporal and total response of the FLF neutron detection setup
- Neutrons tracking is combined with a Bayesian method to generate a sampled posterior distribution of the source model parameters (including yield). The neutron transport simulation was used to account for scattered neutrons and detectors correlation

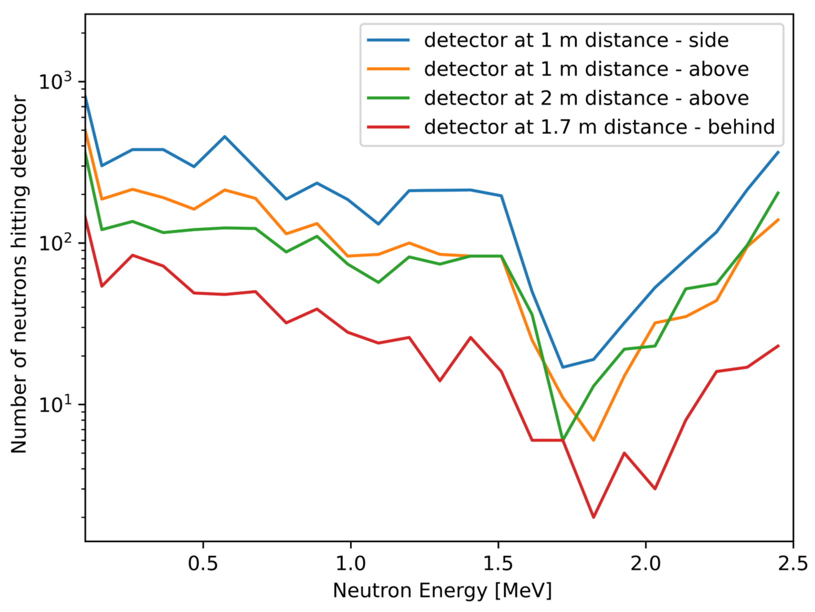

Fig. 5: OpenMC simulation of energy distribution of neutrons interacting with selected detectors

Validation of fusion neutrons

We achieved a major milestone in 2022 and demonstrated production of DD fusion neutrons

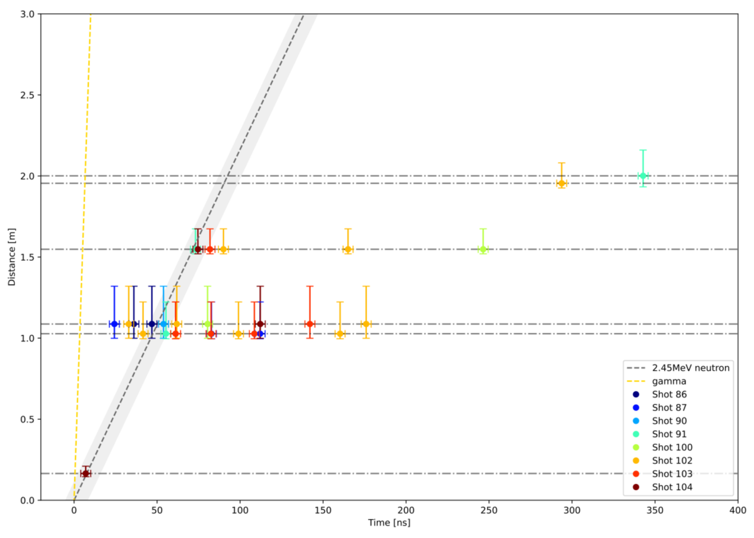

Fig. 6: Aggregated n-TOF (x – t) plot for all DD experiments with scintillator hits. Scintillator data are plotted from t = 0 (fusion event time) to 400 ns.

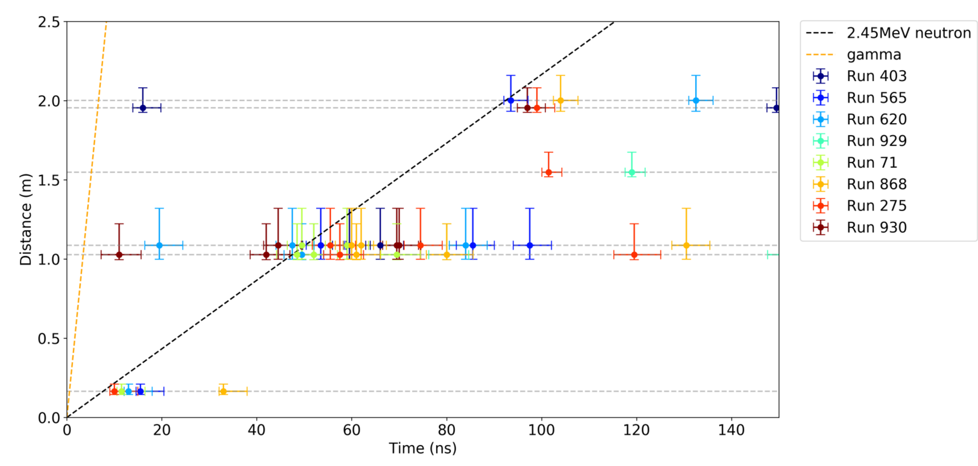

Fig. 7: 1000 MCNP simulations with a source yield of 100 neutrons using our detector geometry. 8 simulations were randomly selected and plotted for comparison with our experimental data.

- Simulation of the Nevarro target predicts that neutrons are emitted from a region of plasma with average density 2500 kg/m3, ion temperature 240 eV and a volume equivalent to a sphere of radius 2.2 um [2]
- Simulated yield (~40) is in agreement with the experimentally determined yield of 47 neutrons (95% credible Interval from 12 -124) [1]
- External validation was done by UKAEA:
  - measured particle time-of-flight (TOF) to confirm consistency with 2.45 MeV neutrons
  - detected hits on He-3 detector which have a better discrimination for neutrons
  - results are supported by MCNP neutron tracking simulations

Tilt dependence and DD fuel pressure scan

- Endor amplifier and Corellia fuel capsule were used in these shots as they yield more neutrons in comparison to Navarro targets
- We repeated 7 shots under the same conditions (projectile velocity and fuel pressure) to establish the yield dependence on a random projectile tilt at impact: we found a strong dependence on the projectile tilt, which can be attributed to the non-uniform pressure drive which causes an asymmetric fuel collapse (see TP11.00075)

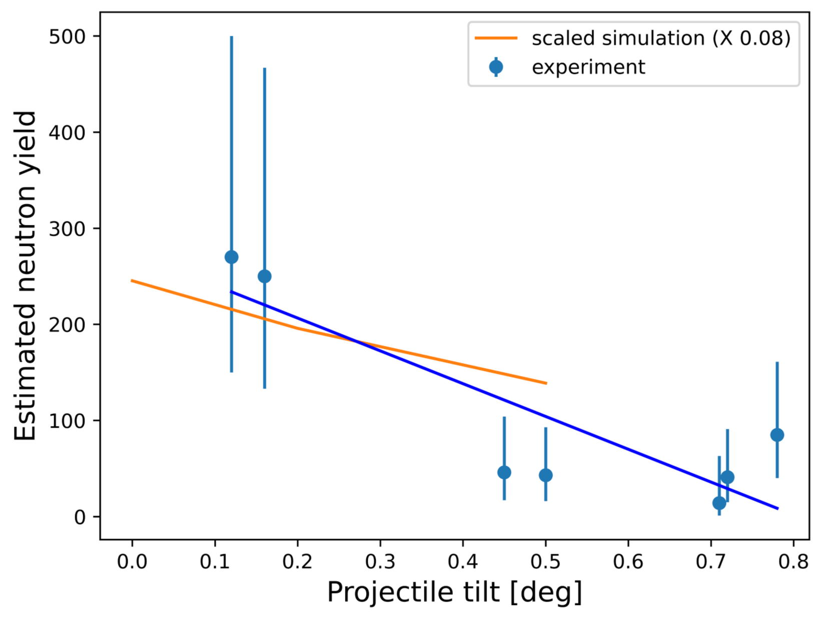

Fig. 8: Yield dependence on projectile tilt. All shots were performed with 40 bar fuel pressure and projectile velocity of 6.5 +/- 0.2 km/s. The simulation results are arbitrary scaled by factor 0.08

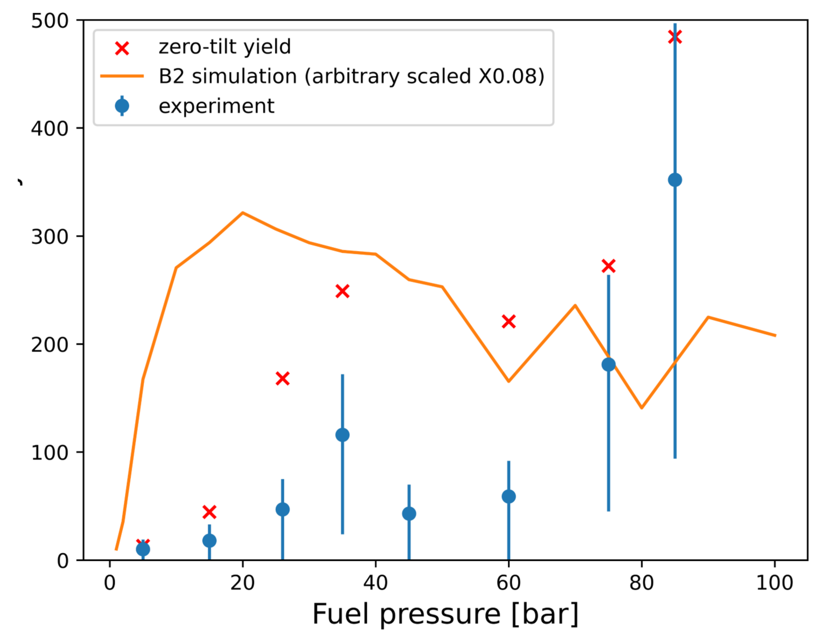

Fig. 9: Neutron yield dependence on the fuel pressure (preliminary analysis). The linear fit of yield vs. tilt data in Fig. 7 provides a extrapolation function to "zero-tilt yield"

- We performed a fuel pressure scan from 5-85 bar. The simulated yield increases sharply with fill pressure, and begins to drop at relatively slower rate, the trend being determined by the initial density, ability to heat the fuel and radiation losses
- The experimental yield is normalized using measured yield vs. tilt dependence (Fig. 7) and the zero-tilt yield is compared with the simulation
- The preliminary analysis indicate that the yield is about 10-15 times lower than the simulation predicts and that maximum yield occurs at higher fuel pressures

Summary

- We achieved a major fusion breakthrough and demonstrated projectile fusion by using unique target technology
- Parameter scans (tilt and pressure) show a broad agreement with simulations

References

1. G. C. Burdiak et al (2022), Validate Production of Neutrons from Gas Gun-Driven Targets, FLF White Paper, https://firstlightfusion.com/science-hub/validate-production-of-neutrons-from-gas-gun-driven-targets
2. J. D. Pecover et al (2022), Simulation of the Nevarro Target, FLF White Paper, https://firstlightfusion.com/science-hub/simulation-of-the-nevarro-target