# Inertial Fusion Energy at First Light Fusion

first light

Tackling Some Inertial Fusion Energy Challenges at the European XFEL
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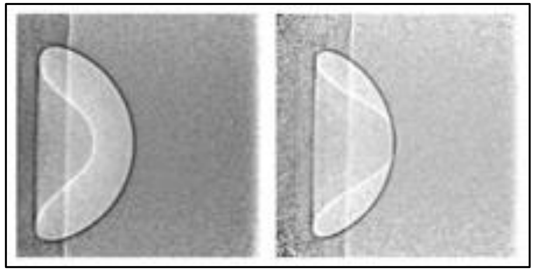
- Inertial Fusion research at FLF

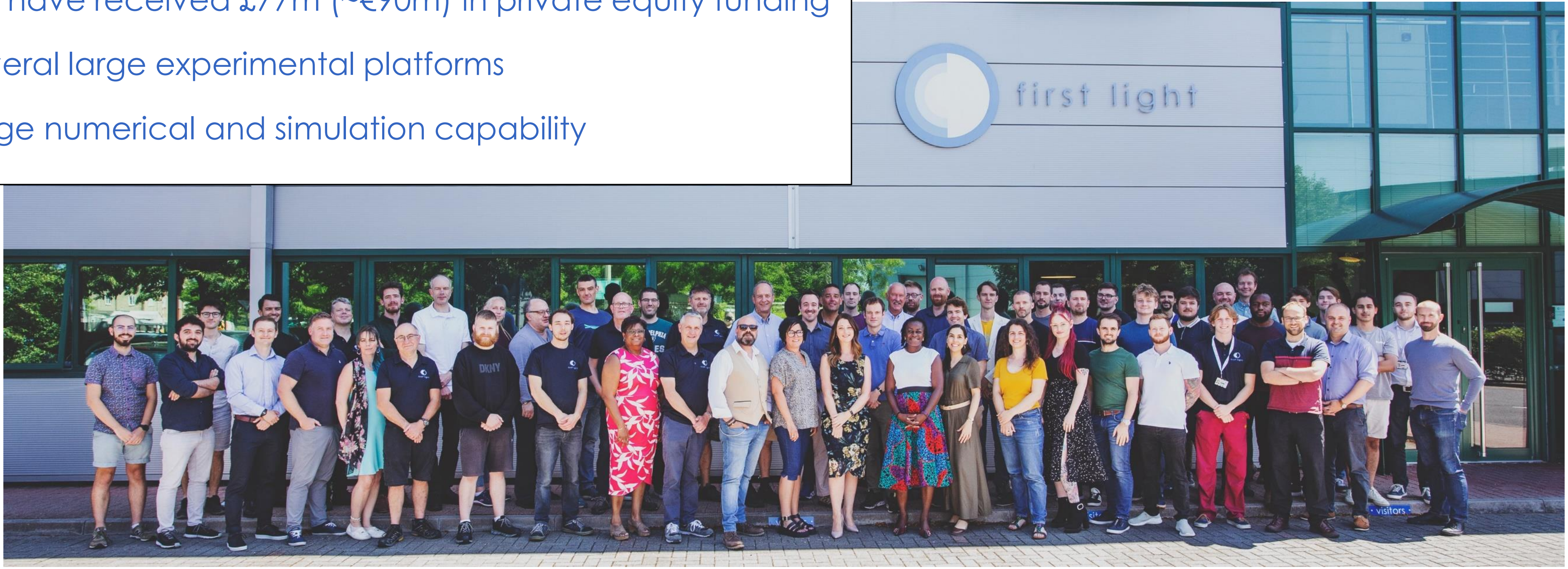


- Research prospects at EuXFEL

# A brief introduction to First Light Fusion

# First Light Fusion

- Spin out from Oxford University in 2011
- Today we are ~100 employees
- We have received £77m (~€90m) in private equity funding
- Several large experimental platforms
- Large numerical and simulation capability

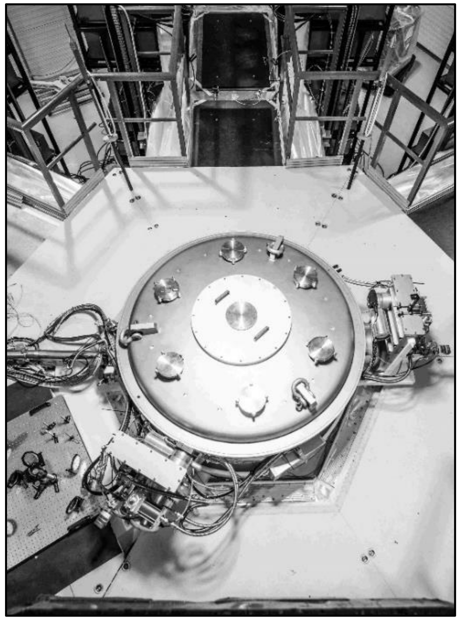


# First Light Fusion: Science departments

## Experimental

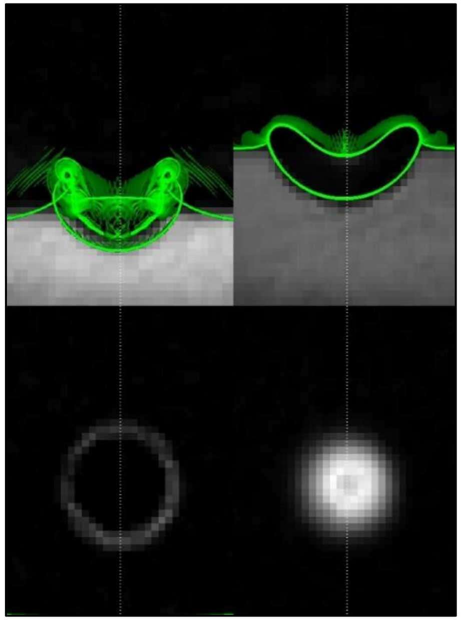
Diagnostics, experiment design/execution

## Pulsed Power



Electromagnetic launchers, system controls

## Computational Science and Engineering



In-house numerical codes, Data Science (Bayesian optimisation, UQ)

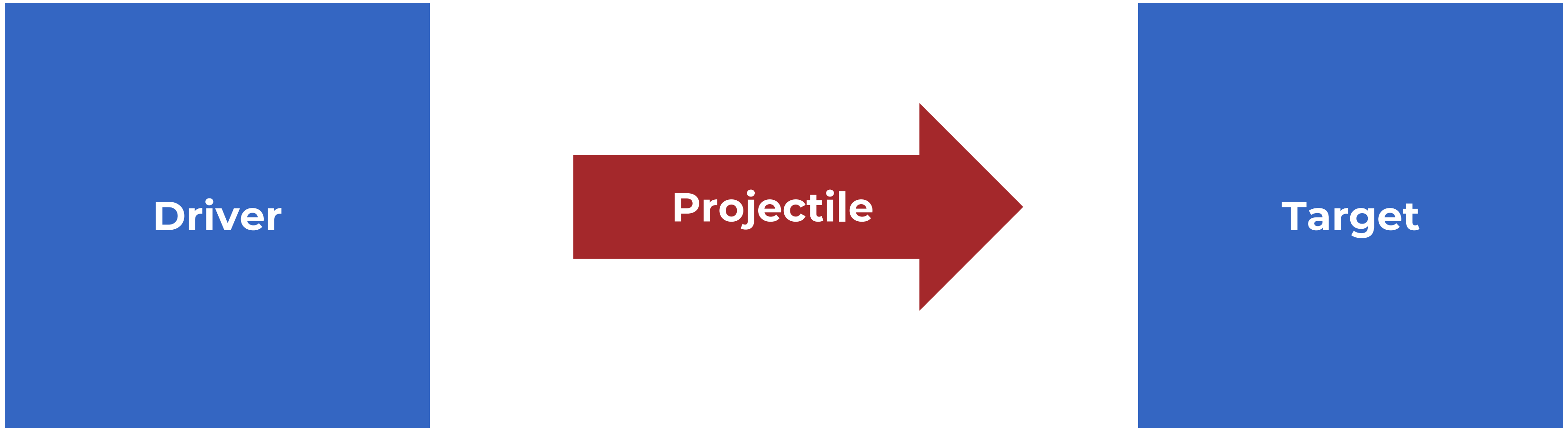
## Target Design

High-gain amplifier design and optimisation

## Power Plant

Energy cycle, neutronics, CFD

# We use a projectile driver, which is low cost and high energy, but low power; the target design compensates




Mechanical /
Electromagnetic /
**Other…?**

large but simple machine

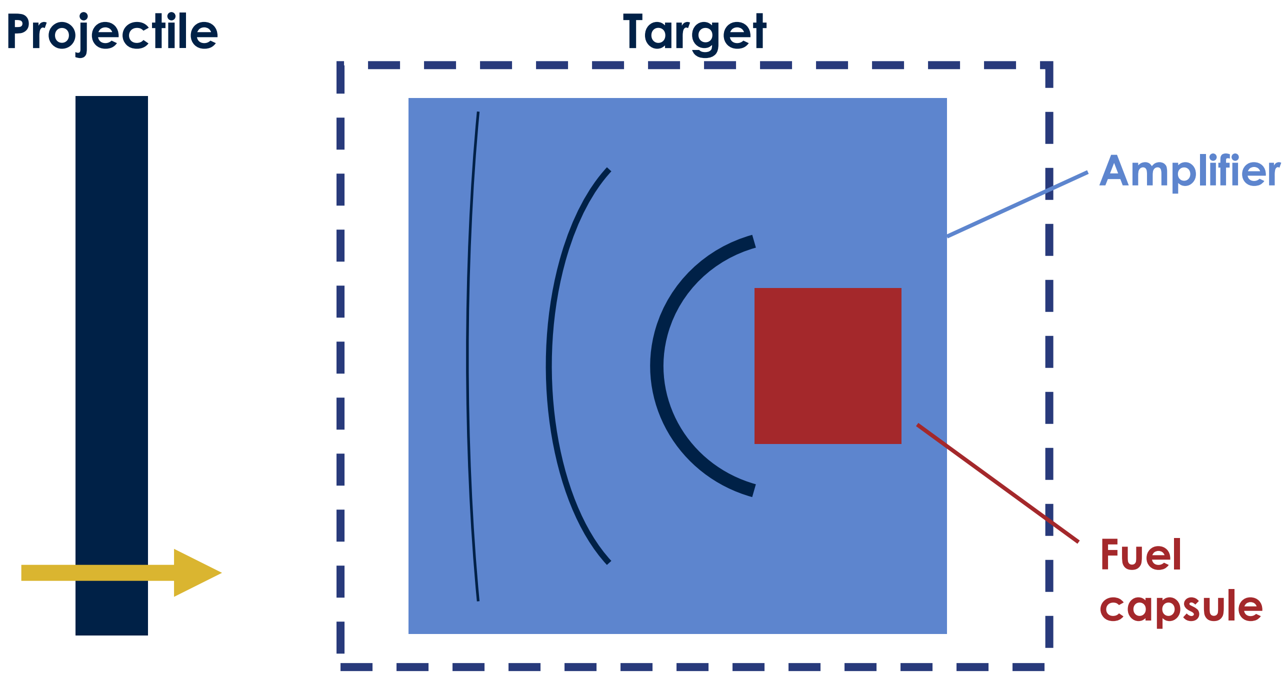
Velocity and energy
most important

Target impact

able to rapidly iterate design

# There is a key technology, the amplifier, which shapes and focuses the original shockwave

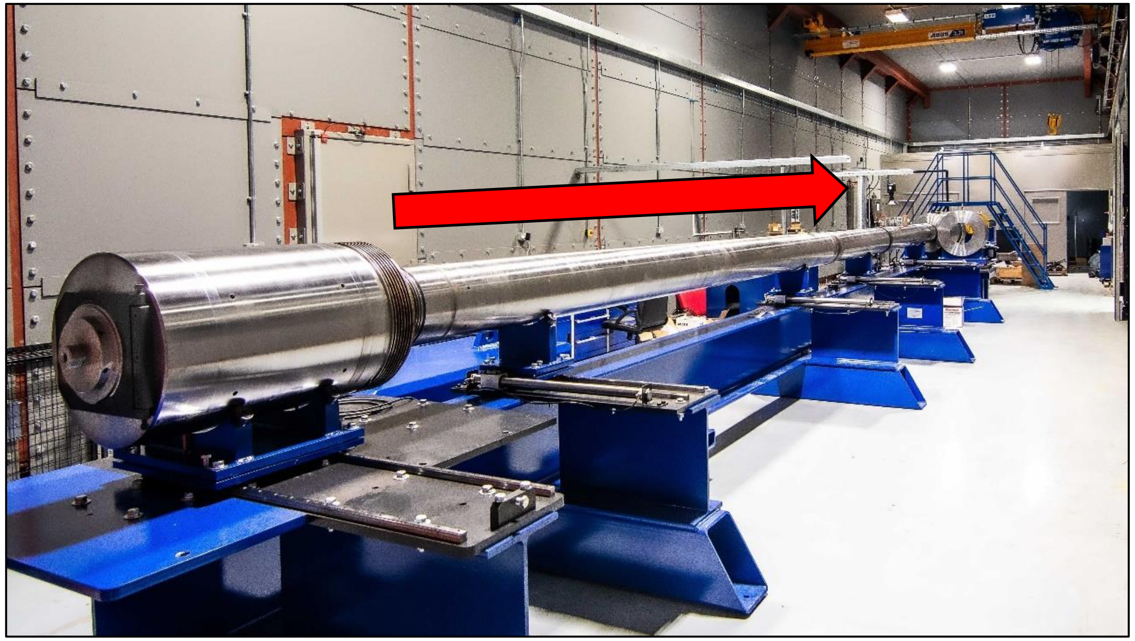
- Single-sided driver
- Planar input shock transformed to spherically-symmetric implosion ***(not shock ignition)***
  - Input ~80 GPa (0.8 Mbar) outputs ~1.2 TPa (12 Mbar)
  - Input 6.5 km/s impact gives a release of ~70 km/s
- **This amplifier technology is what makes projectile fusion viable**

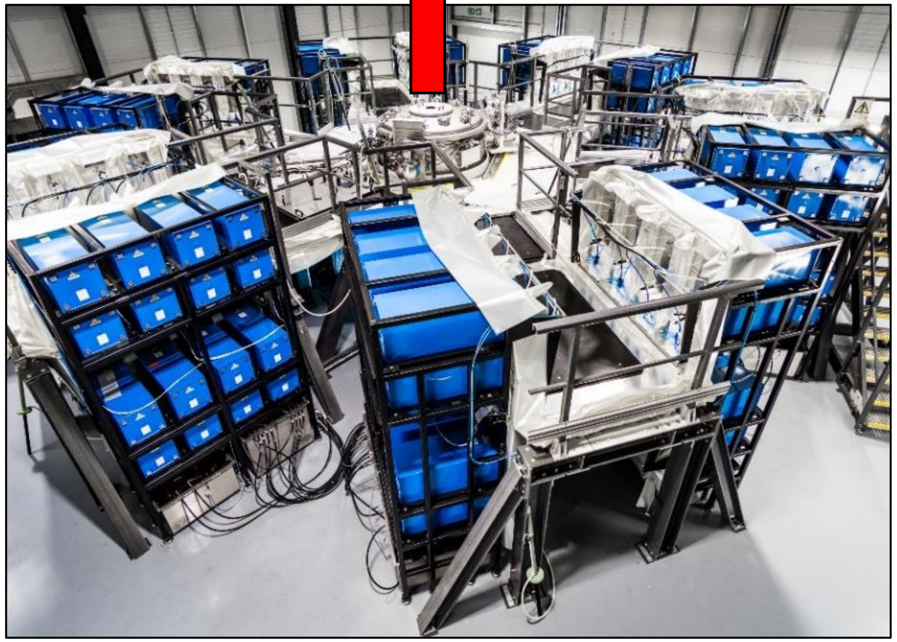



The planar output variant is called the **Endor amplifier**

**(*) Submitted paper currently under review**

# FLF’s in-house drivers: Gas-guns & pulsed-power





**BFG: ‘Big Friendly Gun’- Mechanical launch**

- 27 kg piston at 1 km/s
- Projectile ~7 km/s

**M3: ‘Machine 3’- Electromagnetic launch**

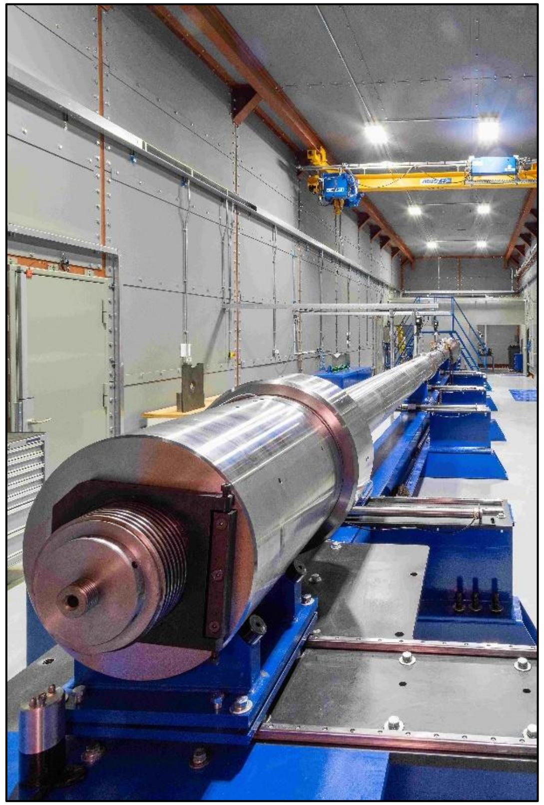
- 14 MA, 2 μs current pulse
- Projectile ~20 km/s

# Inertial Fusion Research at FLF

# End to End Science

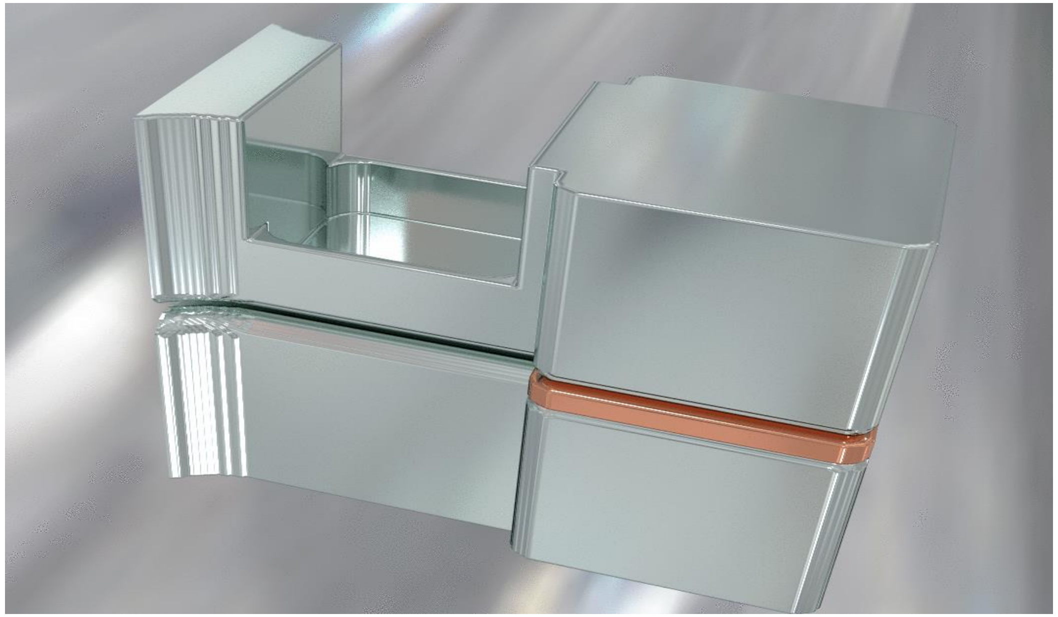
- Full in-house **experimental** and **numerical** capabilities

BFG gas-gun driver

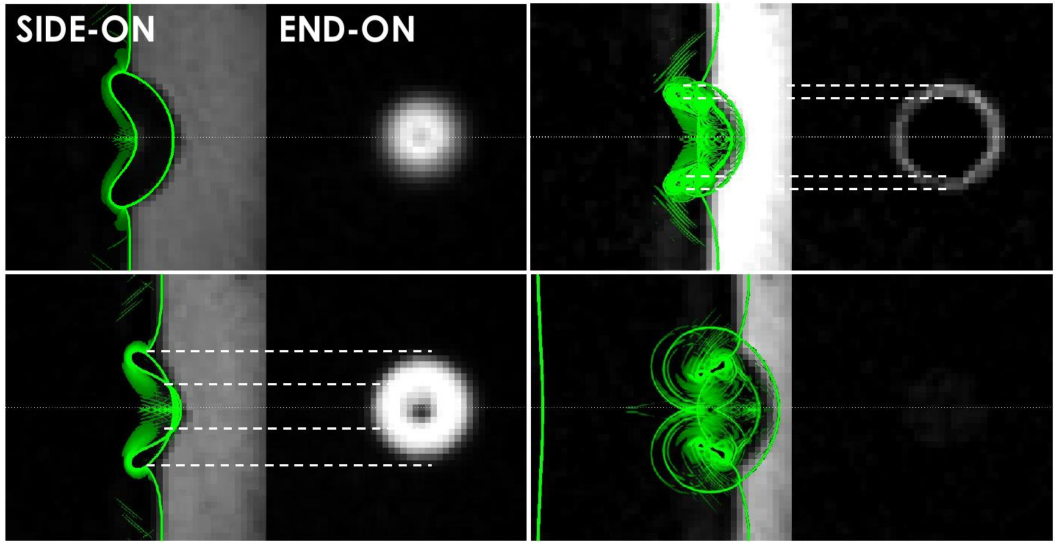


M3 pulsed-power driver

3-D MHD simulation of a flyer plate projectile on M3



Synthetic diagnostic from a target simulation

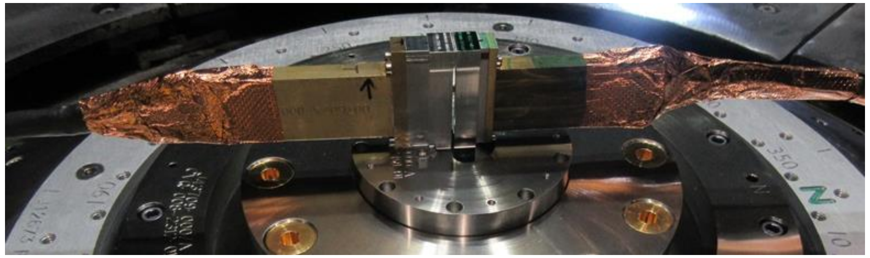


# FLF's IFE research is driven by collaborations

- **US National labs** (Sandia)

Amplifiers on the STAR gas-gun

Amplifiers on the Z-machine



- New pressure record in quartz (1.85 TPa)
- **First amplifier paper under review**
- Currently developing an EoS platform using our amplifiers

- **UK universities** (Imperial College, Oxford, York)
- **European research facilities** (ESRF)

# IFE research with UK universities and industry

AMPLIFI Prosperity Partnership

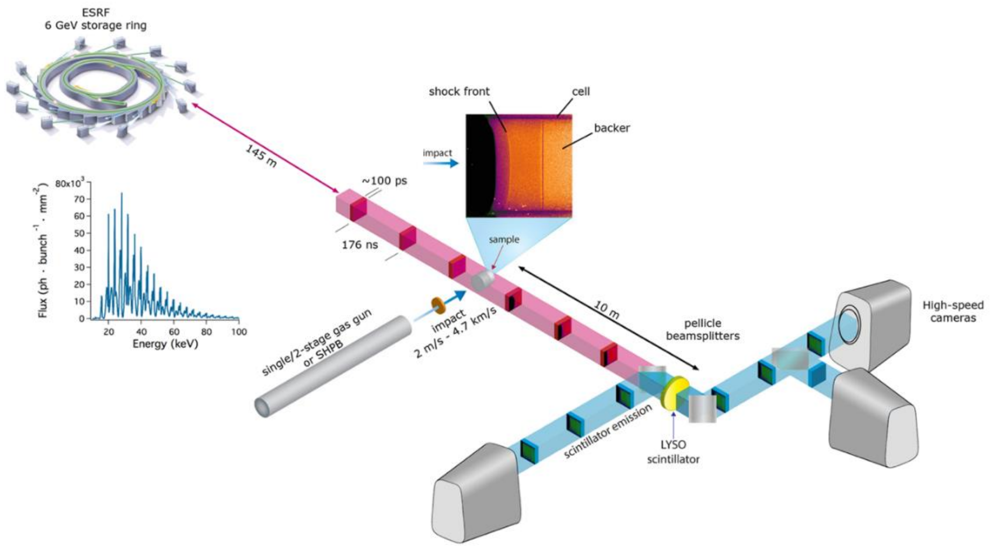
- **AMPLIFI:** 5-year programme for **business-led research in collaboration with UK academics**
- Total of **£12M (~€14M)**, £6M from UK EPSRC + **£6M from FLF**
- Funding for **11x PhD students, 14x Postdoctoral researchers, 40x Summer interns**
- Explore **fundamental physics of complex IFE targets (hydrodynamics, radiation, heat transport)**

UKRI Engineering and Physical Sciences Research Council

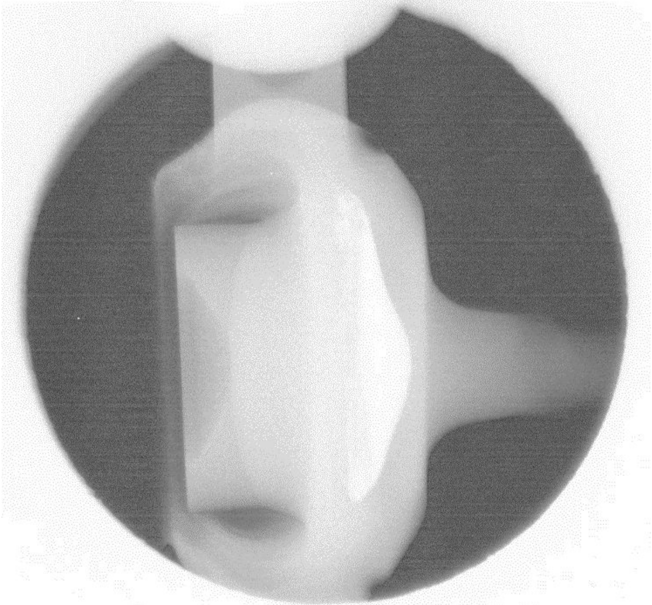
| Imperial College London | University of Oxford | University of York | Machine Discovery |
|---|---|---|---|
| HED with pulsed-power, laser ICF, MHD, diagnostics | HED with lasers, XFELS, gas-guns, atomic physics | HED with lasers, XFELs, molecular dynamics, kinetic simulations | Code optimisation through machine learning |

- Ranges of ρ, T, P from WDM regimes to burning plasma. Instabilities, mixing…
- Research kicked off only recently!

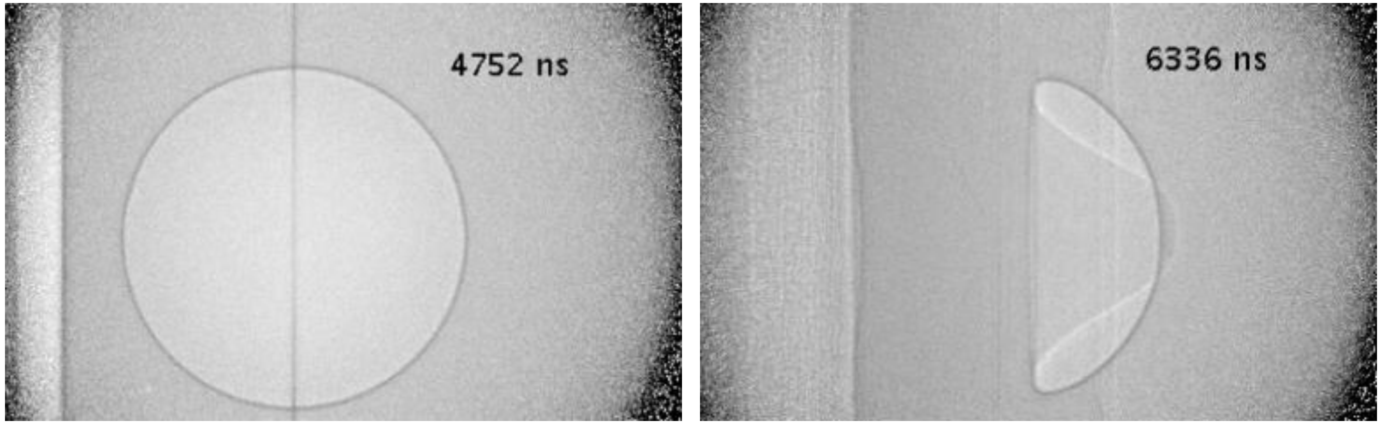
# X-ray phase contrast imaging at ESRF




- **Research led by Oxford Engineering (D. Eakins)**
- First use of 5 km/s portable gas gun on ESRF
- Allows comparison to hydrodynamic simulations
  → push to higher velocities and rep. rate



In-house hemispherical cavity jet formation image

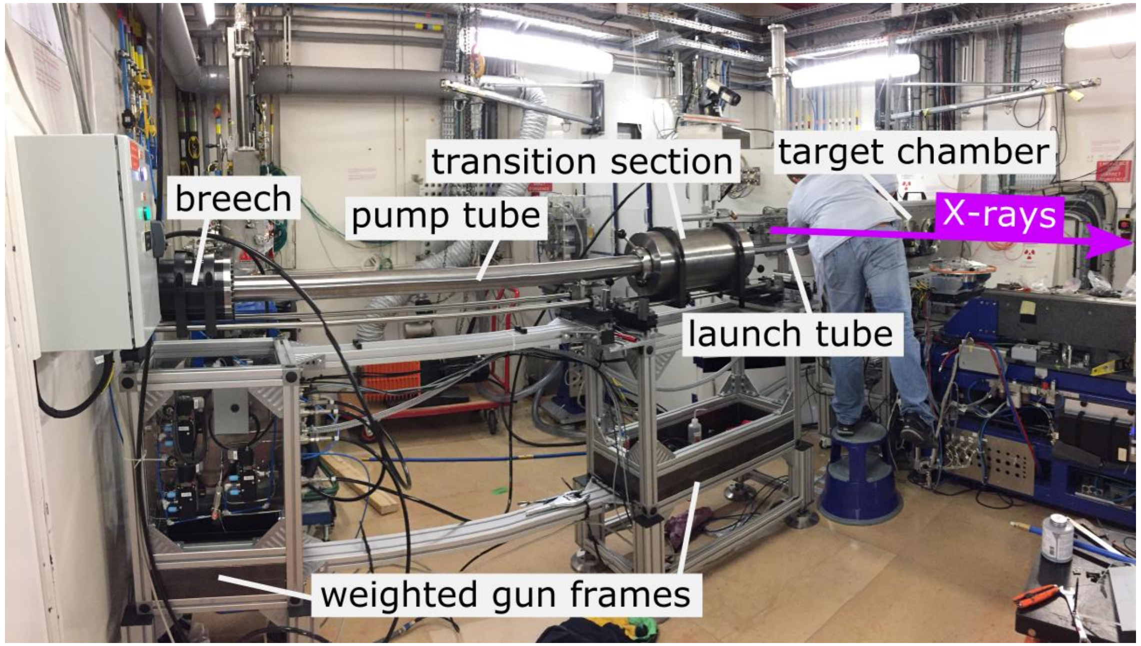



ESRF spherical cavity imaging

E. Escauriza *et al.*, ‘Collapse dynamics of spherical cavities in a solid under shock loading’, Sci. Reports (2020)

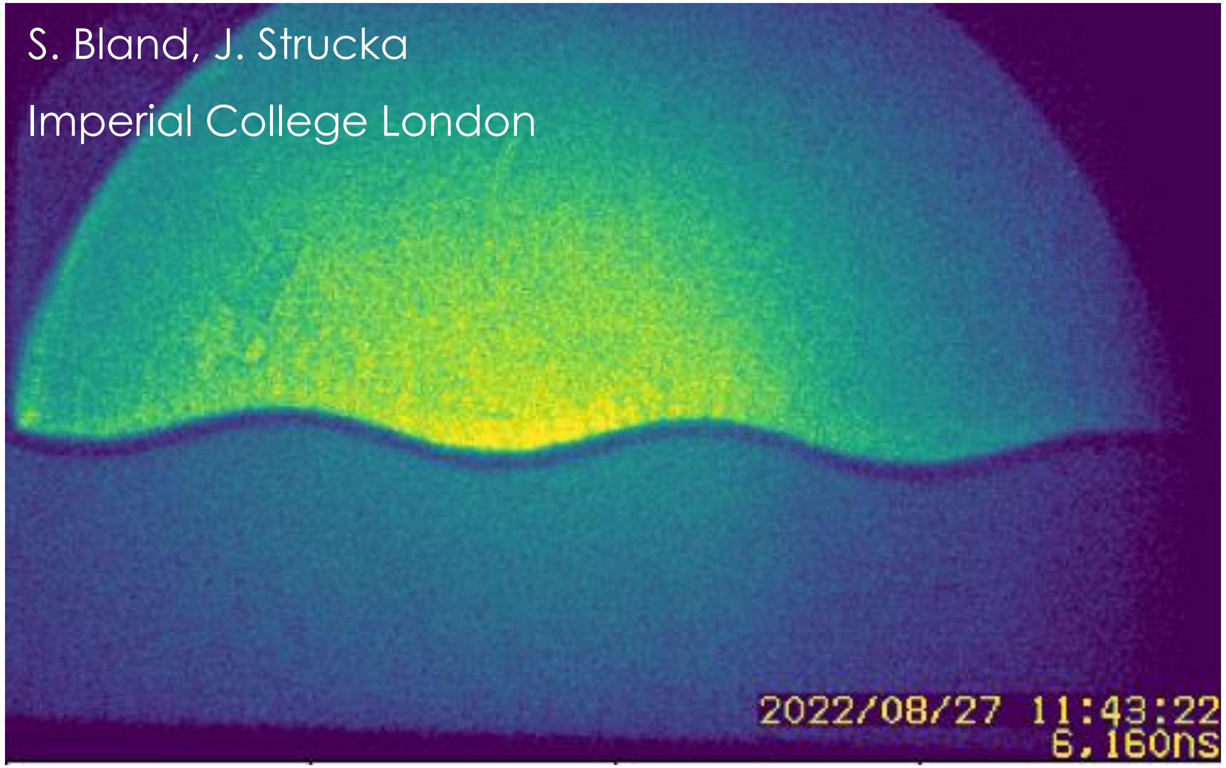
# A new gas-gun platform for ESRF's ID19

- Relevance to FLF work requires accessing **more extreme** regimes
- **New** 2-stage gas-gun is needed, with impact **velocities >6 km/s**




- First amplifier validation experiments at ESRF granted July 2024
- **Submitted Industrial Long-Term Proposal (public-private partnership)**

# Hydrodynamic instabilities are critical for IFE




t=7.5μs → individual cylindrical shock waves interact
t=8.2μs → a merged planar shock wave is formed
t=13.3μs → pressure due to shock reflection forms cavities
t=22.8μs → initial interface inverts due to RMI, shock wave detaches

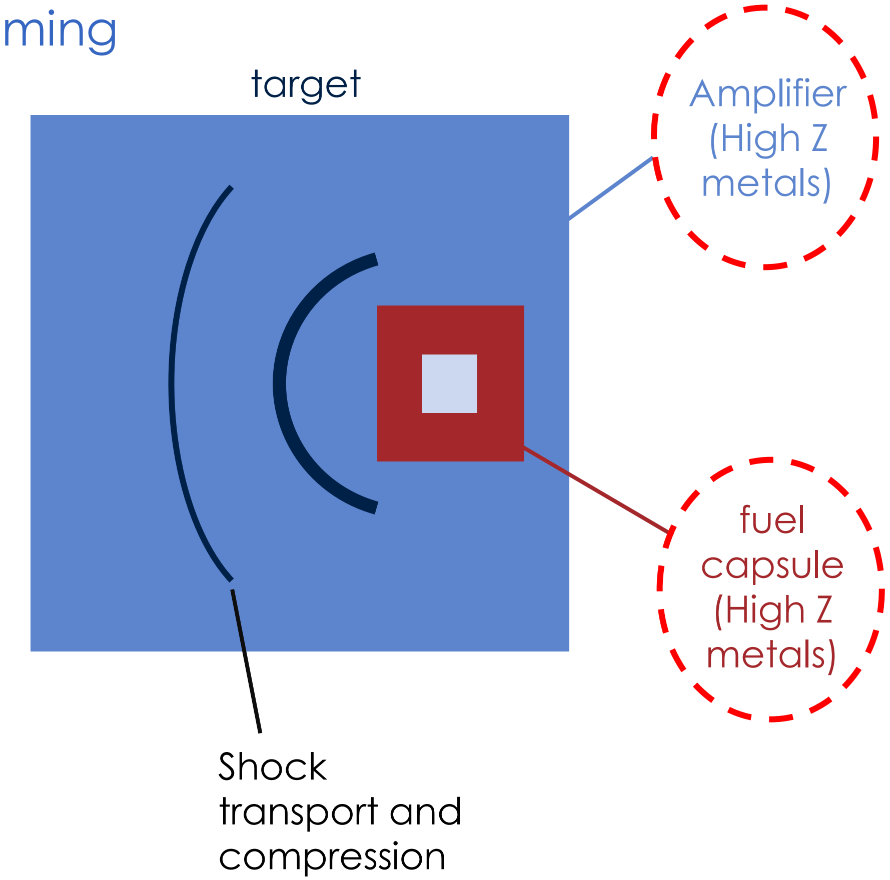
- Richtmyer-Meshkov instability experiments at the ESRF **Research led by Imperial College (S. Bland, J. Strucka)**
- Coupled portable pulsed-power driver to synchrotron

- Complements laser experiments but with larger volumes, longer timescales. Pulsed-power allows flexibility in driver geometries.
- First LCLS proposal accepted: Electrothermal instability experiments
- Proposal to EuXFEL submitted….

# Research prospects at EuXFEL

# Core physics applications for XFEL

1. **Image > TPa (10s Mbar) pressure release, with any instabilities, into fuel**
   - Needs high energy, high resolution, multi-frame, accurate timing
   - Need a method of achieving these pressures on XFEL
2. **Material properties of fuel capsule metal**
   - Need 'boring' high fidelity information
3. **Properties of compressed fuel, especially WDM regime**
   - Needs novel techniques for temperature and density



# IFE challenges for XFELs - Summary

- **Collaboration is the way forward for IFE**
  - Public-private partnerships (BMBF proposal)
- **Driver: High-energy, high-repetition laser would be a unique tool for IFE research**
  - Reach higher pressures relevant to amplifiers
  - But consider other combos: "simpler", portable alternatives e.g. pulsed power or gas guns
- **Faster detectors**
  - Aiming for 3 ns interframe on ESRF, but minimum scintillator decay is ~30 ns. Need development, novel solutions, facility time for testing
- **Amplifiers: Higher energy photons with large field of view**
  - >1 mm while keeping ~1 $\mu$m resolution
- **Current and future capabilities at EuXFEL are aligned with key fundamental physics relevant to IFE / FLF: instabilities, mix, strength, EoS, shocks, microphysics…**

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# Thank you for your attention
# Please get in touch

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