Science & Technology Facilities Council

Developments in Microtarget Fabrication to Meet Future Requirements of High Rep Rate High Power Lasers

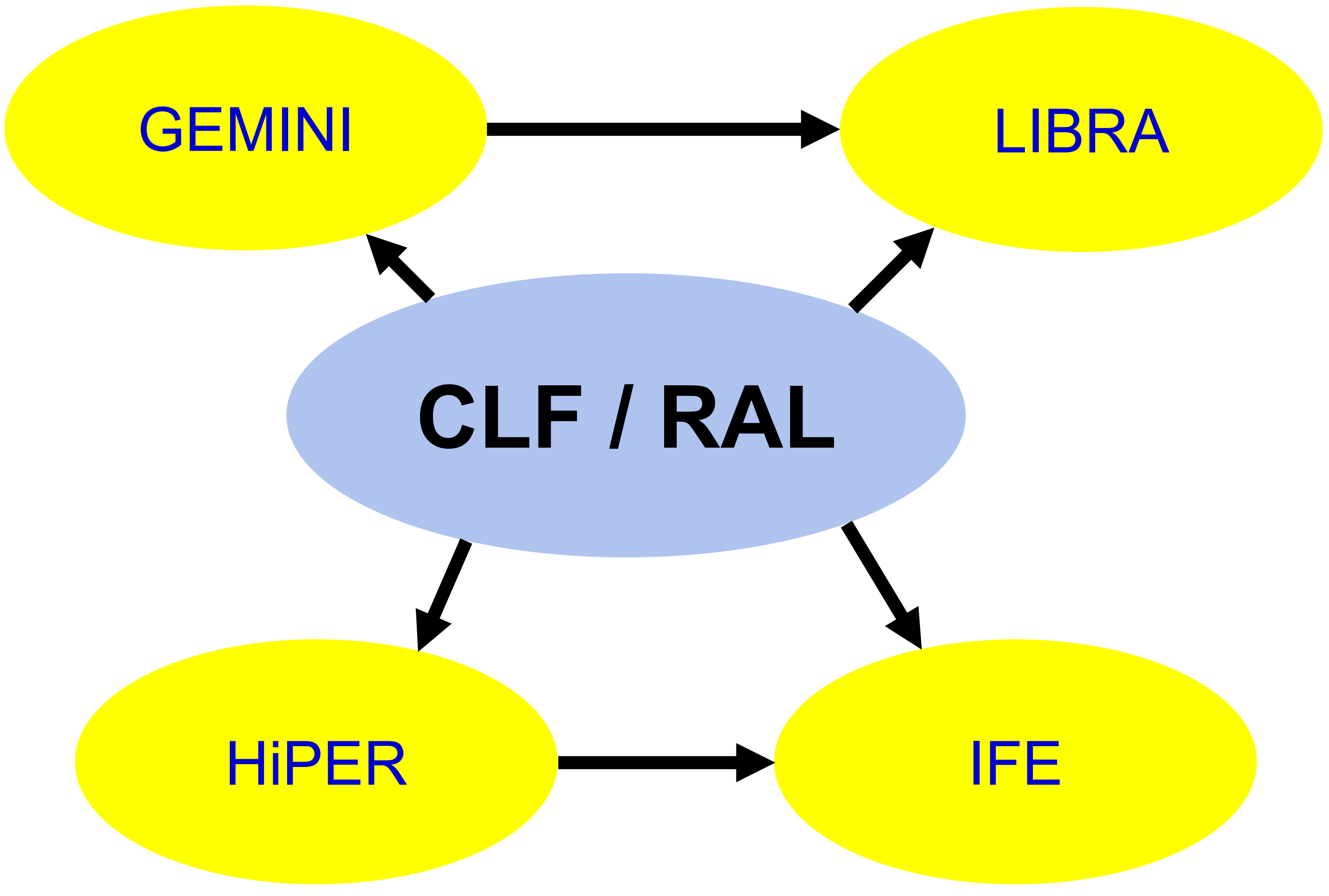
M. Tolley[1], J-P. Perin[2], N. Alexander[3], M. Beardsley[1], P. Hiscock[1], E. Koresheva[4], A. Malik [1], J. Spencer[1], C. Spindloe[1], R. Stevens[1]

1 STFC, Rutherford Appleton Laboratory, UK
2 Commissariat a L'Energie Atomique, Grenoble, France
3 General Atomics, San Diego, USA
4 Lebedev Physical Institute, Russian Academy of Sciences, Russia

m.k.tolley@rl.ac.uk

Science & Technology Facilities Council

Motivation



Motivation 1 - RAL

- The GEMINI upgrade of the Astra laser at RAL will have an experimental repetition rate of one shot per 20s with an energy of ~30J (giving ~0.5PW from two beams).

- This entails almost two orders of magnitude increase in the number of targets required for experiments. This is equivalent to the average annual HPL target production in 9 weeks!

- High repetition rate target production and insertion is also central to the RCUK (Basic Technology) funded LIBRA project (£5M).

- The work on both GEMINI and LIBRA is being leveraged and used as a test bed for the high repetition rate microtarget requirements of HiPER.

Motivation 2 - HiPER

2 major options:

- High yield (fast/shock ignition) demonstrator based on optimised NIF/LMJ technology

- High rep-rate fusion facility

  Burst mode: 10s full rep rate (~ 6-8 Hz) including some DT shots (T_0 + 7 years)

HiPER

Motivation 3 - IFE

In continuous operation at 6Hz one **IFE reactor** would require:

518 400 fuel capsules per day

189 345 600 fuel capsules per year

It is essential to remember that any technologies used for HiPER may need to be scaled up to meet IFE production numbers.

Outline

- Motivation
- GEMINI/LIBRA target types
- HiPER target types
- Mass production techniques (at RAL)
- Fielding solid targets
- HiPER targetry activity
- Conclusions

GEMINI / LIBRA Target Types

- The scheduled Gemini (LIBRA) experiment (Jan – Mar 2009) will require the delivery of ~ 3000 high specification targets.

- To meet the production numbers the targets will mostly be 2D:
  - a range of foils (different thicknesses and materials)
  - structured foils
  - 2D patterned
  - some 3D targets

- Fielding the targets with high placement accuracy at such high rates will require the introduction of novel Inserter technology.

Baseline Targets Types

Target will be a (part-)spherical shell mesostructure layered internally with cryogenic DT

There are 2 main target designs being considered (plus a few others)

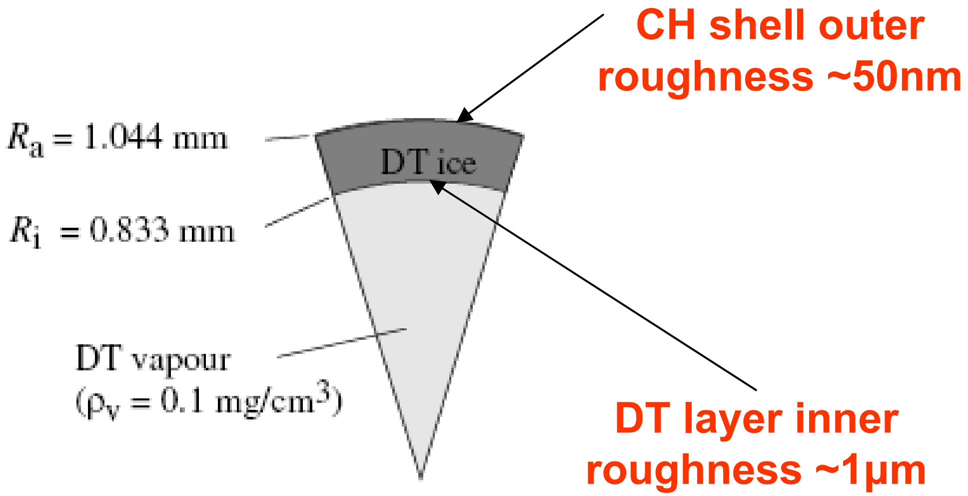
1 Fast Ignition: shell + cone

2 Shock Ignition: shell

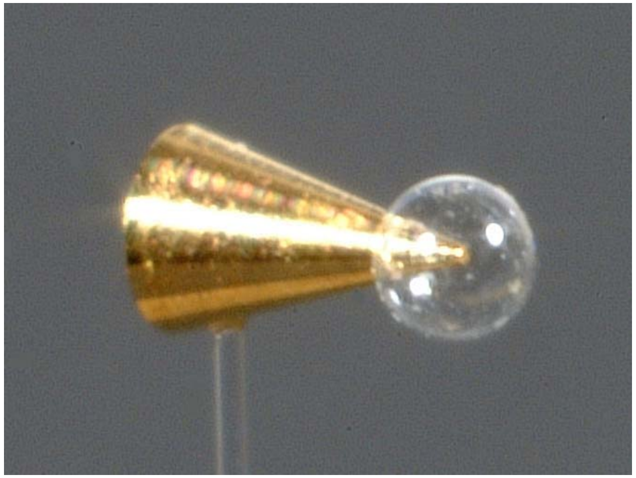
Baseline Target 1

Fast ignition target

CH shell (3μm thick): 2.088mm ID, 2.094mm OD
DT layer (211μm thick): 1.666mm ID, 2.088mm OD
Au Cone: 20μm wall thickness, 5μm tip wall, 20°-30° half angle
Cone to shell centre separation: 100-150μm
Fuel mass: ~0.6mg
Temperature: 16-19.6K



Shell cross-section



Baseline Target 2

Shock ignition target

CH shell (3µm thick): 2.040mm OD
Foam + DT layer (70µm thick)
DT layer (120µm thick)

CH shell outer roughness ~50nm

DT layer inner roughness ~1µm

Mat	R_{int}(µm)	Δr(µm)	R_{ext}(µm)	ρ_0
DT	0	830	830	1.e-4
DT	830	120	950	0.253
$CH(DT)_6$	950	70	1020	0.364
CH	1020	3	1023	1.05

Science & Technology Facilities Council

Precision Machining

Cone mass production scale-up strategy:

1) Direct micromachining

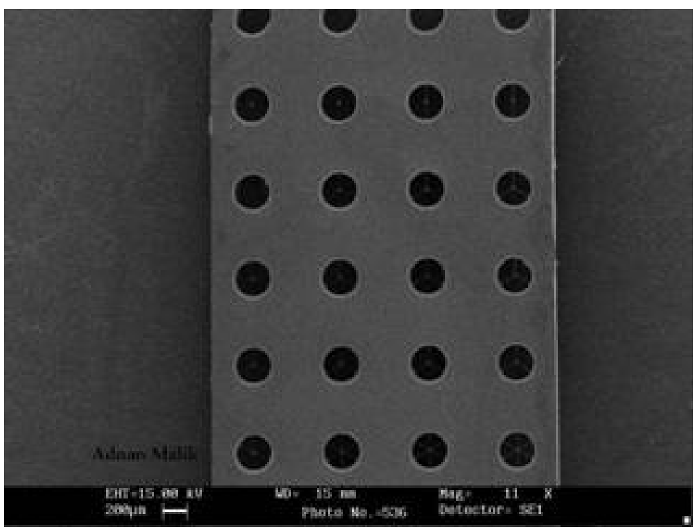
(J Spencer, M Beardsley, P Hiscock; PDF, RAL)

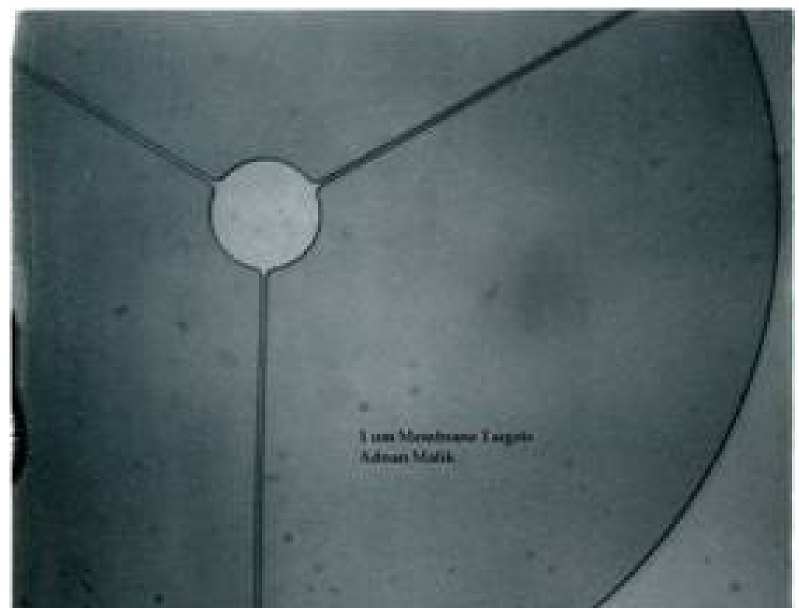
2) Leading to mould production for hot pressing

MEMS Techniques for Target Mass Production

- A programme is already significantly advanced using MEMS techniques to produce (mainly) 2D targets in sufficient numbers for the (Jan – Mar 2009) Gemini (LIBRA) experiment .

- The Target Fabrication group collaborates closely with the Micro and Nanotechnology Centre (MNTC) at RAL.





Science & Technology Facilities Council

Associated and Integrating microtarget technologies

- Wide range (thermal evaporation, e-beam, sputtering) of thin film coating techniques.
- Chemical etching of lithographically patterned substrates to mass-produce 2D components.
- High precision electroplating of microcomponents, especially in gold.

Fielding Solid Targets for High Rep Rates - 1: Target Wheels

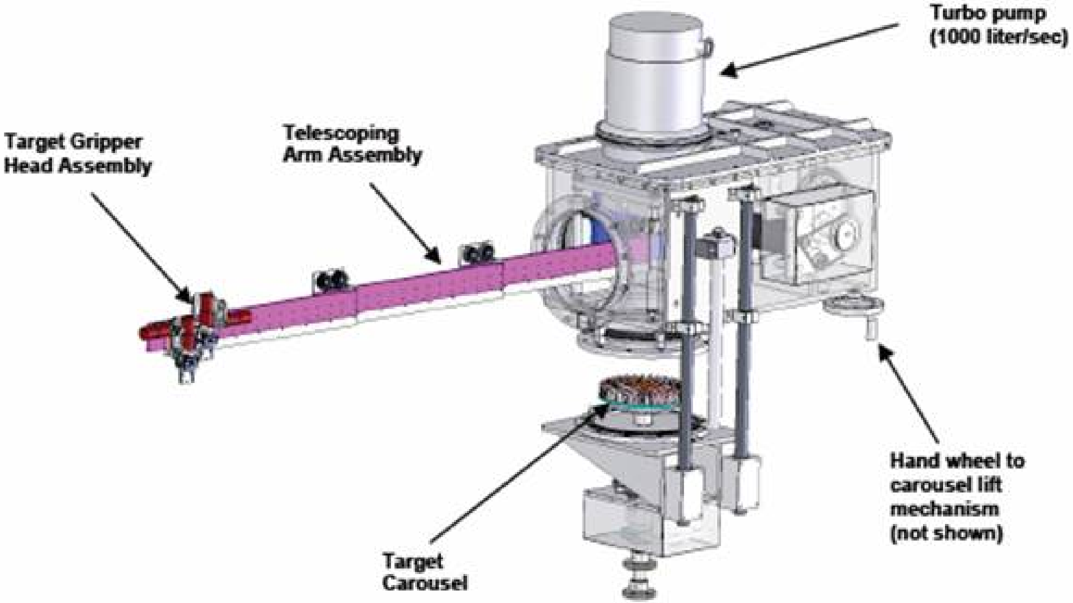
- To meet the near-term requirement for high rep rate solid target placement a nanoposition wheel is being constructed which will drive one or more discs populated with targets.

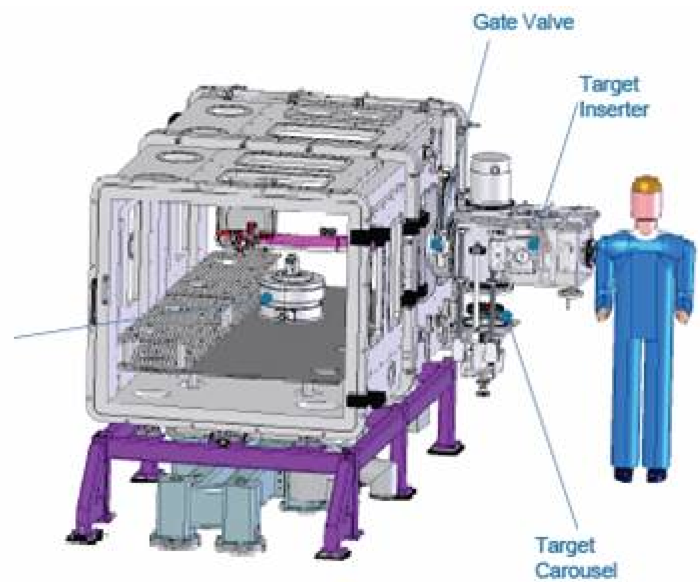
- Experimental time has been allocated in the commissioning phase of GEMINI to ascertain the necessary separation between targets to ameliorate collateral damage effects.

200 shot microtarget wheel with
sub-micron positional accuracy

Fielding Solid Targets for High Rep Rates - 2: GA Target Inserter

General Atomics are working collaboratively with RAL to make a target Inserter capable of inserting one target every 60s.





The GA designed Target Inserter for use on Gemini and LIBRA experiments

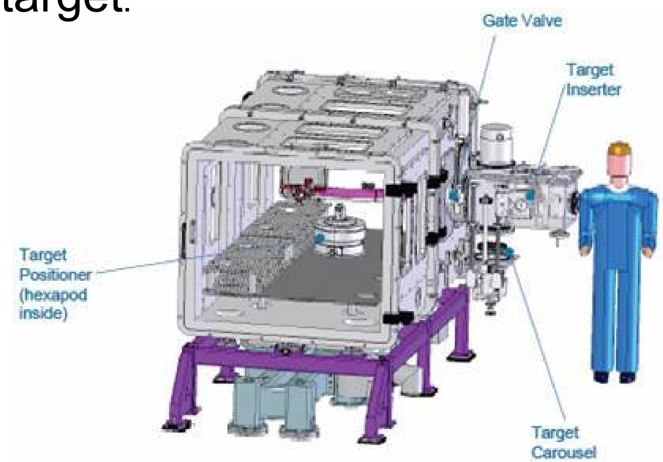
Science & Technology Facilities Council

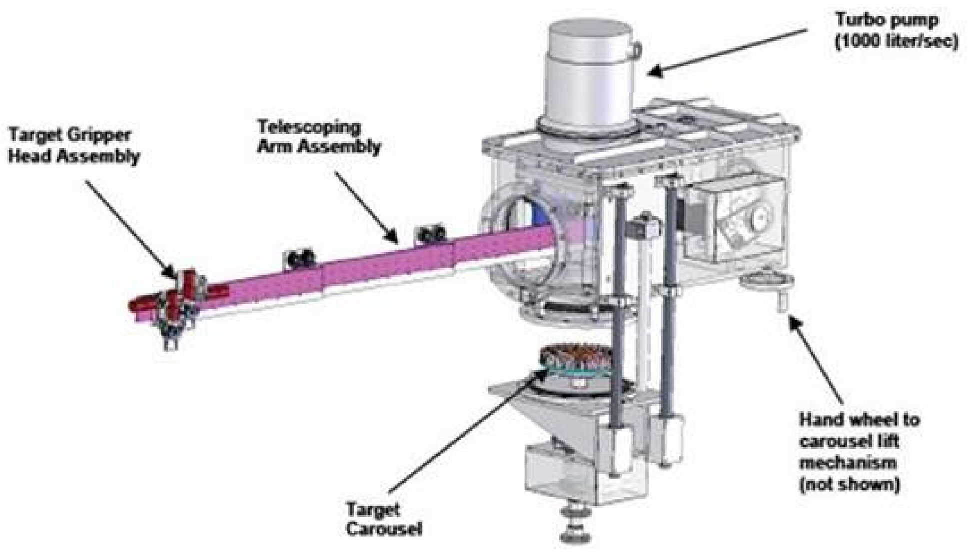
Fielding Solid Targets for High Rep Rates - 2: GA Target Inserter

The load locked system accepts carousels populated with targets mounted on individual carriers.

An arm places a new target on the mount in the interaction chamber and then removes the previous used carrier.

External metrology in combination with a hexapod inside the chamber will lead to a placement accuracy of better than 2 μm in x, y and z for every target.





Fielding Solid Targets for High Rep Rates - 3: Target Injector

RAL has recently acquired an electrostatic injector.

The feasibility will be assessed of integrating the Injector with the LIBRA target delivery programme.

Electrostatic Injector

Targetry Workpackage Contributors

STFC: Central Laser Facility, Rutherford Appleton Laboratory, UK

CEA: Commissariat a L'Energie Atomique, Grenoble, France

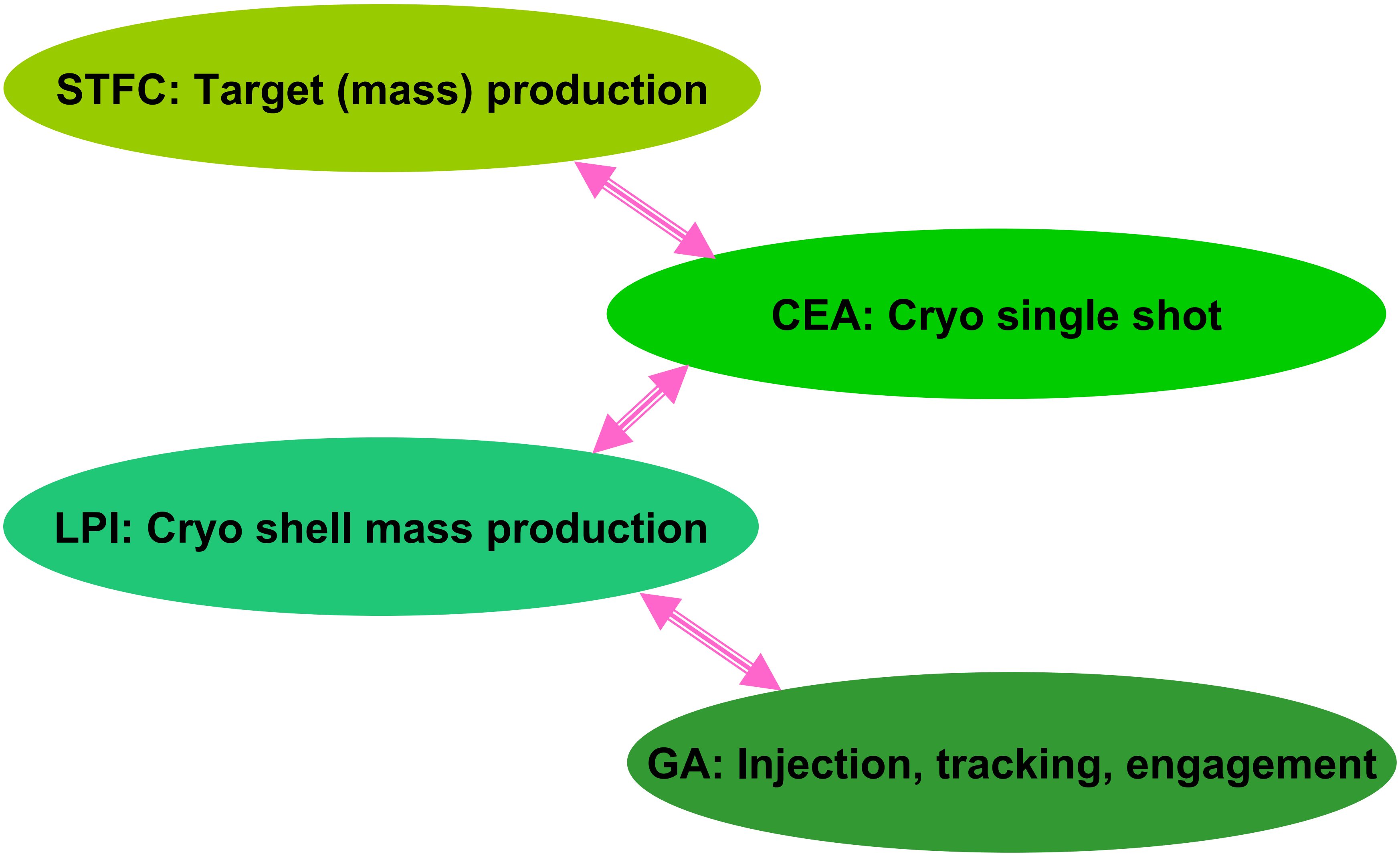
LPI: Lebedev Physical Institute, Russian Academy of Sciences, Russia

GA: General Atomics Inc, San Diego, CA, US

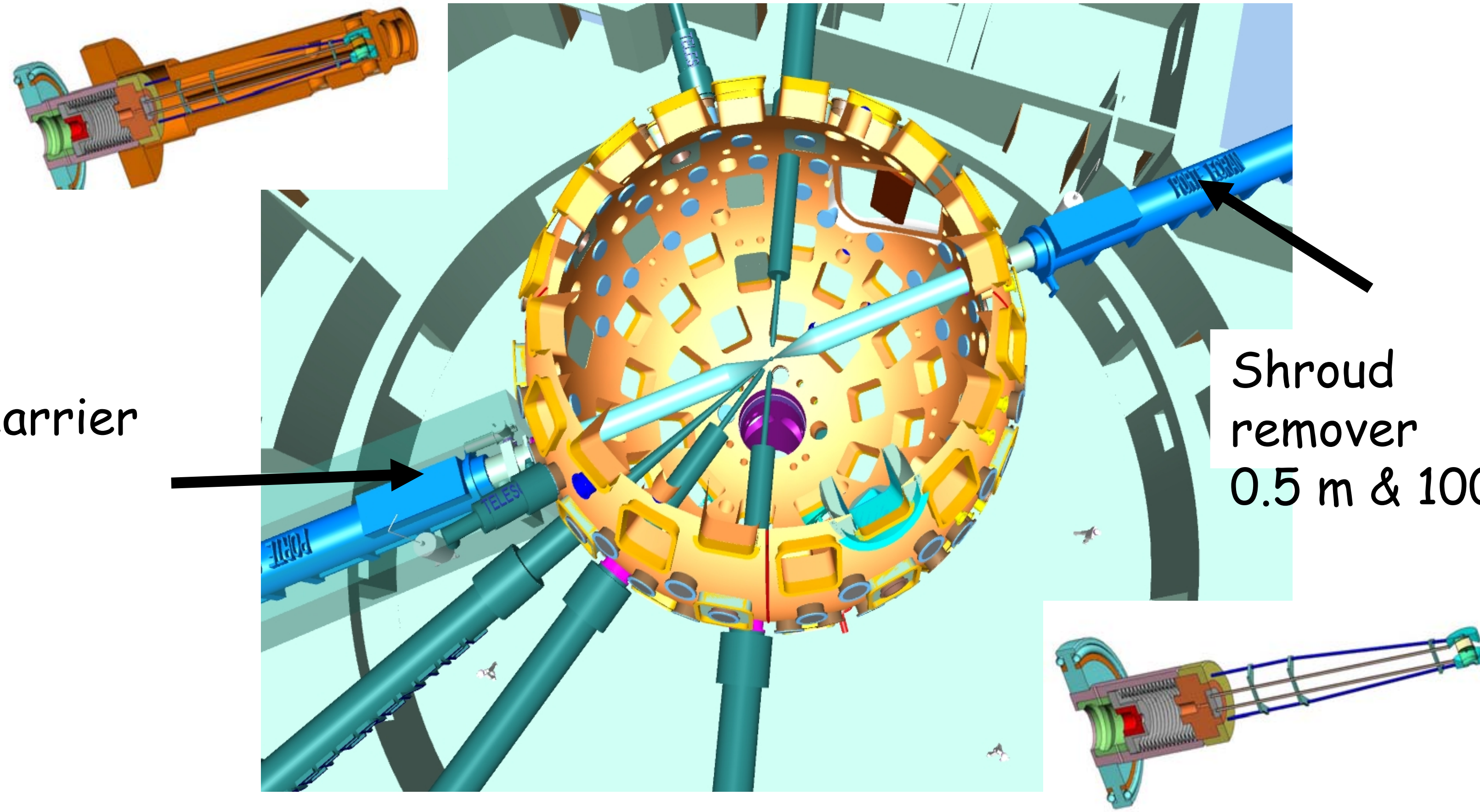
UPM: Universidad Politecnica de Madrid, Spain

TUD: Technische Universität Darmstadt, Germany

WP11 Critical Deliverables Strategy



CEA: LMJ cryosystem

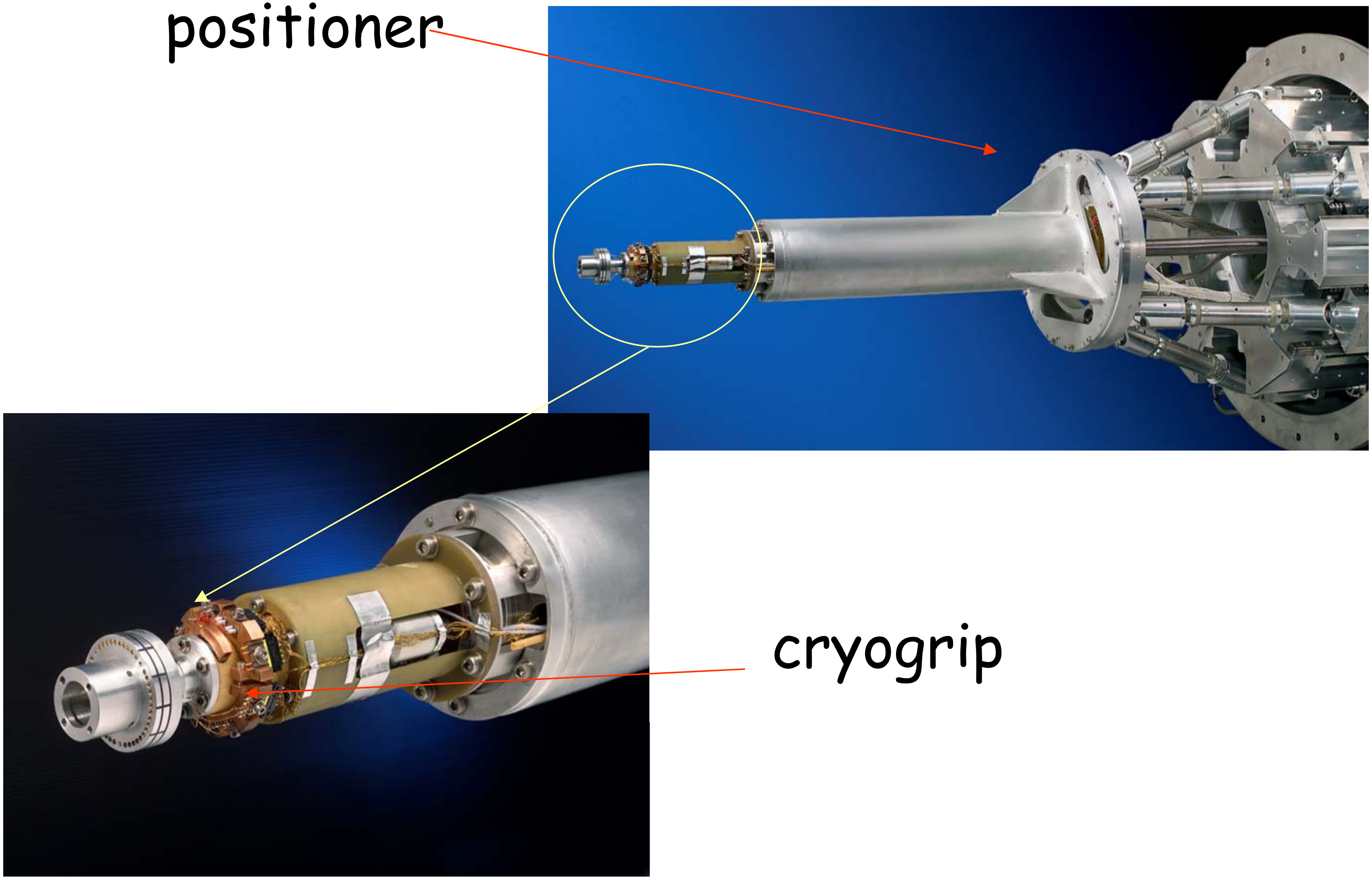


Cryo carrier

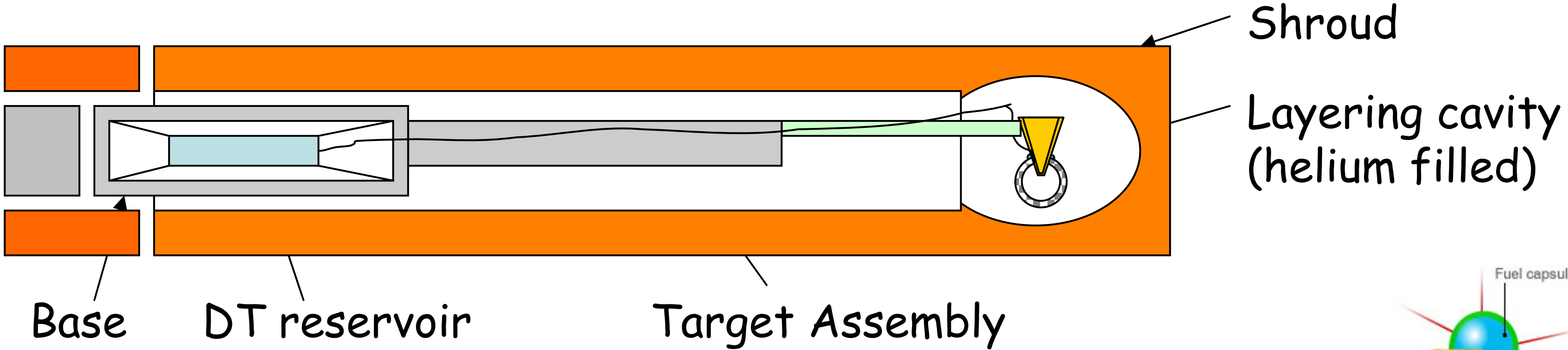
Shroud remover
0.5 m & 100ms

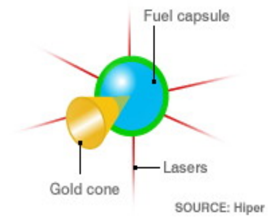
Target life time 180 ms (numerical simulation)

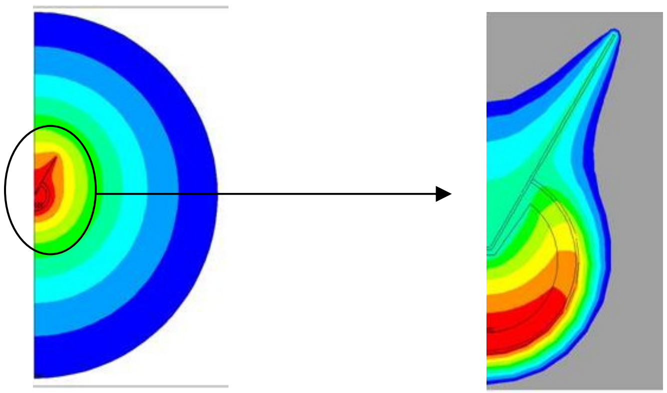
CEA: Cryo target single shot



CEA: Cold source



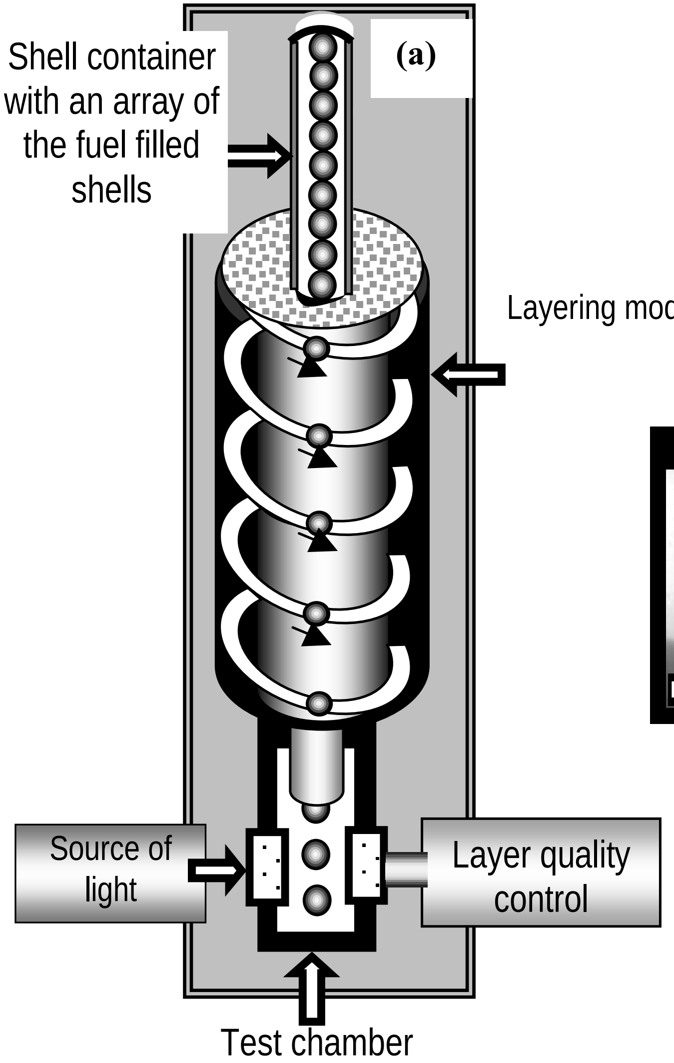


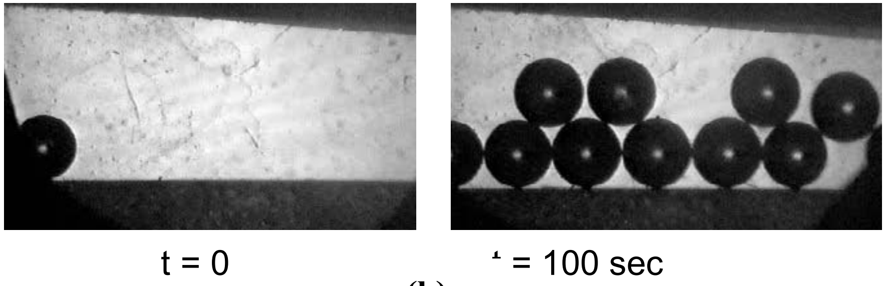


HiPER extension: concepts for layering in inserter and the target assembly due to the non-uniform cooling with a cone

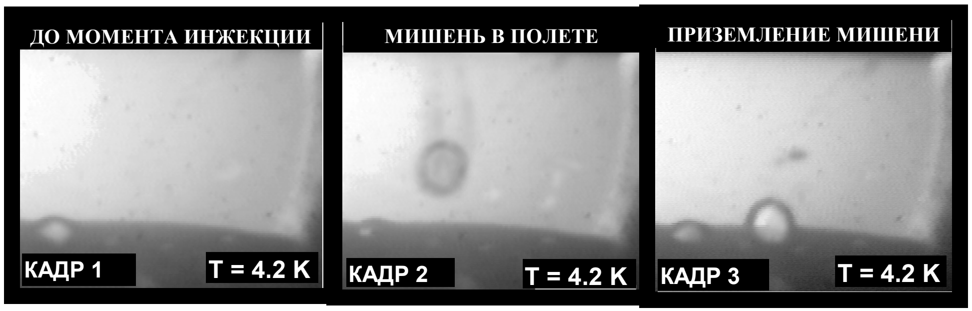
Numerical simulation have to be done to reach the layer shape for fast ignition

LPI: Cryo shell target mass production





(b)



(c)

Fig.2. Continuous fabrication of the free-standing targets using the FST technology. (a) Schematic of the layering module, (b) targets injection from the layering module into the test chamber at T=4.2 K with the rate of 0.1 Hz, (c) injected target flight inside the test chamber of cryostat

LPI: Cryo shell target mass production

FST LAYERING MODULE

Experimental facility for cryogenic layering study

References:

1. I.V.Aleksandrova, E.R.Koresheva, I.E.Osipov, *et al. Free-Standing Target Technologies for ICF.* 2000 Fusion Technology 38 No1 p.166

2. I.V.Aleksandrova, S.V.Bazdenkov, V.I.Chtcherbakov et al. *An efficient method of fuel ice formation in moving free standing ICF/IFE targets.* J.Phys.D: Appl.Phys. **37**, 1-16, 2004

3. I.V.Aleksandrova, S.V.Bazdenkov, V.I.Chtcherbakov, E.R.Koresheva, I.E.Osipov. *Extension of free-standing technologies on IFE requirements.* 2002 in: Inertial Fusion Science and Application, State of the art 2001 (ELSEVIER) p.762

LPI: Cryo shell target mass production

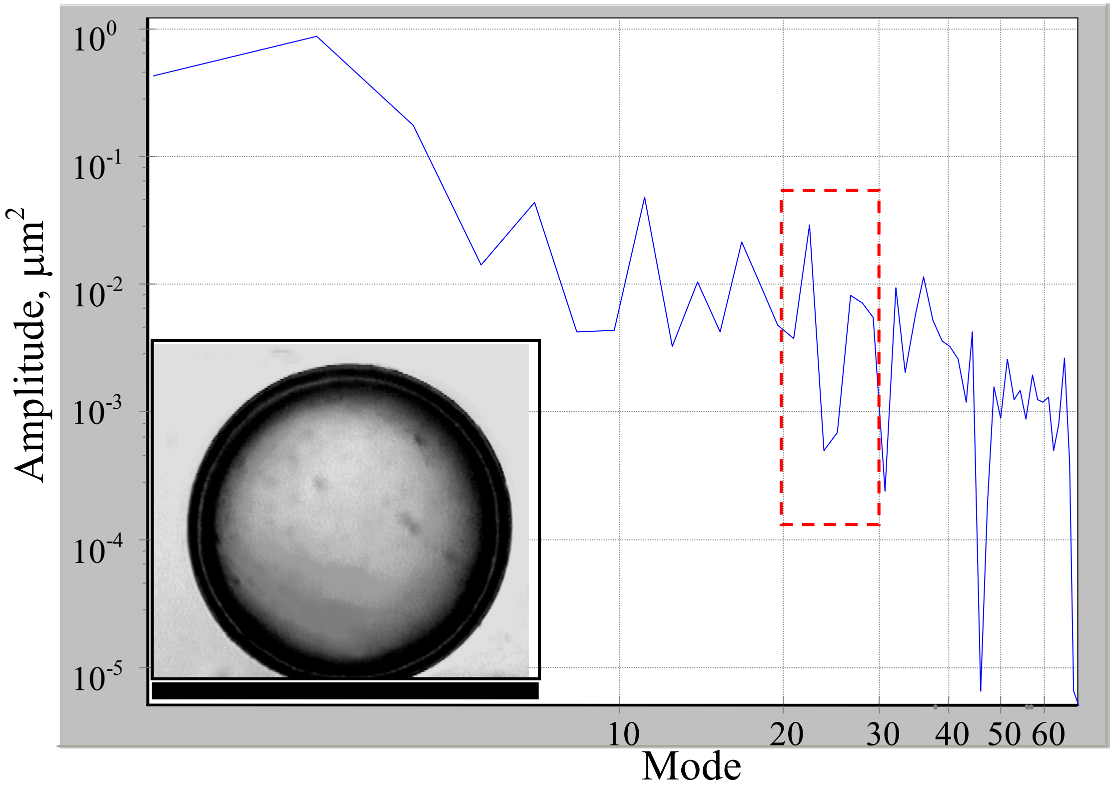


Fig.3. The results of the FST – layering: fourier-spectrum of bright band shows that layer roughness does not exceed 0.15 μm for modes 20-30

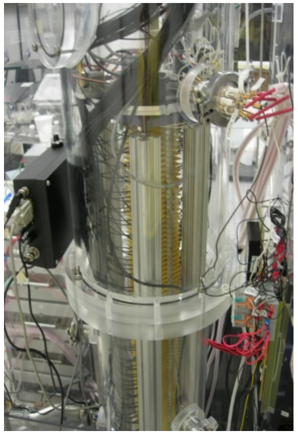
Target parameters: CH shell 1230 μm-diam. filled with 80%D_2/20%Ne mixture up to 275 atm at 300 K; cryogenic layer is 41μm- thick.

GA: Target injection, tracking and engagement

- Apply direct drive injection techniques to HiPER
  - Spherical targets (shock-ignition)
  - Gas gun, mechanical, coil gun, electro-static accelerator
- Develop injector for cone and shell FI targets
  - Prime concepts: Gas gun, and induction accelerator with sabots
- Apply developments in in-flight steering to improve placement accuracy
  - Potential for HiPER to not need beam steering for burst mode
    - 10 μm placement demonstrated at low velocity and 0.5 m stand-off
  - May be possible for burst mode (short stand-off, modest number of shots)

*From HAPL and FTF programs and in collaboration with UCSD

Gas Gun*

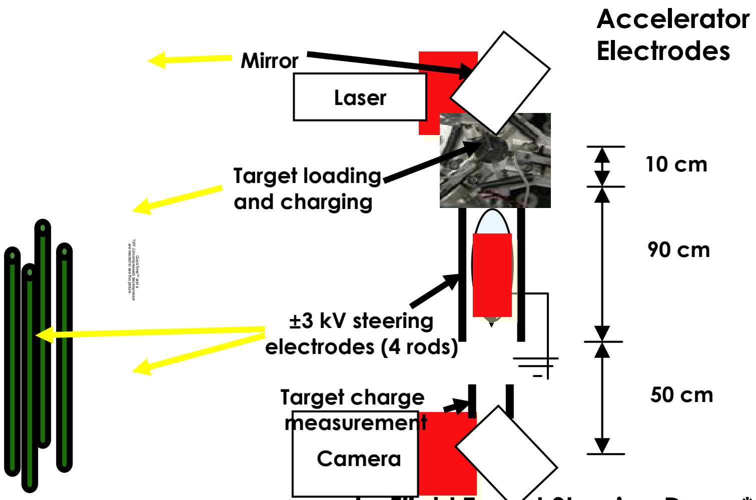


Electrostatic Accelerator*

Demonstrated

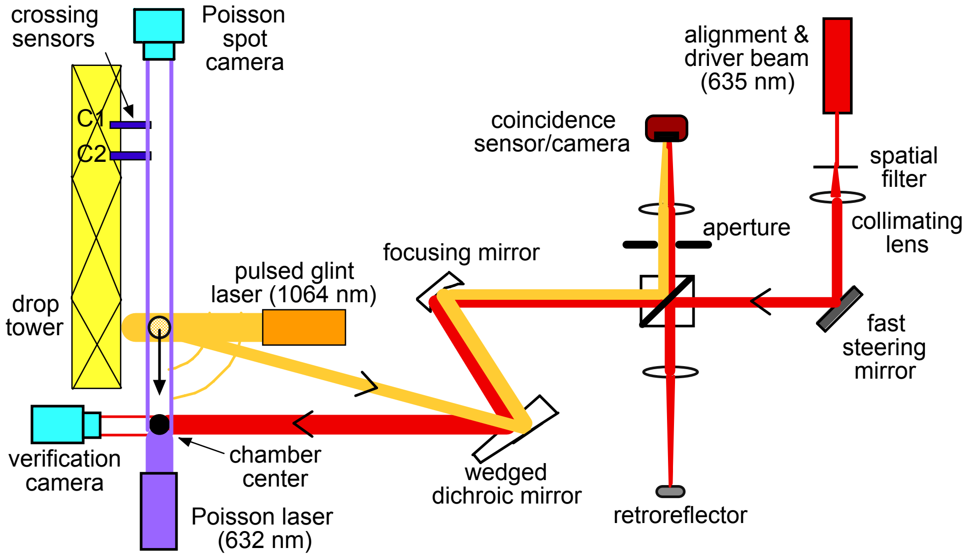
Gas Gun: ≥400m/s, 10 mm accuracy at 17m

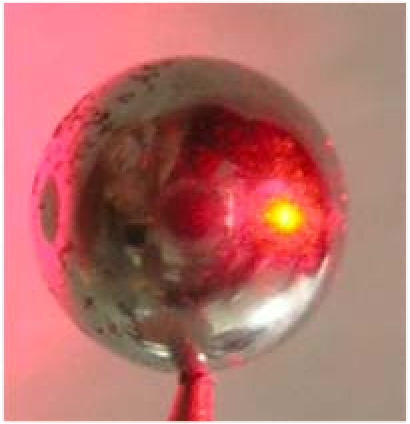
Mechanical: ≥75m/s, 4mm accuracy at 17m



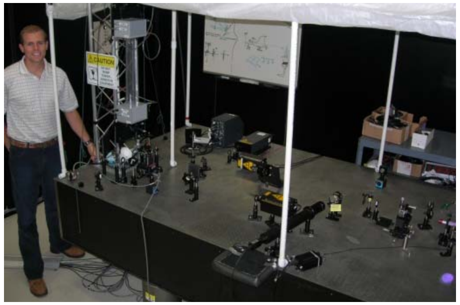
In-Flight Target Steering Demo*

GA: Target injection, tracking and engagement



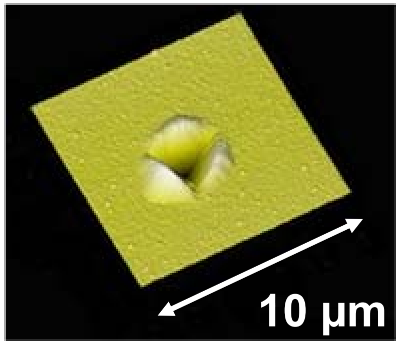


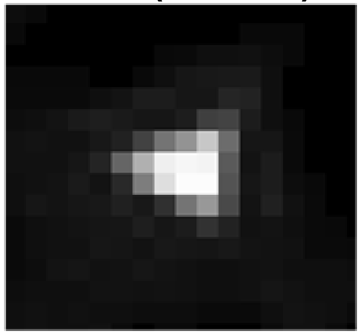
Glint off target



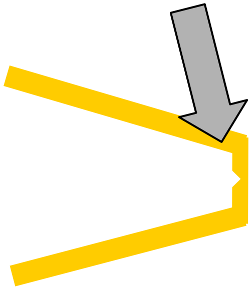
Direct Drive Table top tracking and engagement demo* (v~5m/s)

- Approach: Laser return off of target can be used to track target
  - Glint of spherical surface for direct drive, fast ignition, and shock ignition targets
  - A micro-corner cube may be employed in cone for ignition beam
  - To tracking signal is generated from a glint pulse directed off of a dichoric wedge into a coincidence sensor
    - Pulse shortly before target reaches chamber center
  - Fast steering mirror directs the drive beam to target





Optical return off of micro-corner cube



*From HAPL program and in collaboration with UCSD

Summary

High repetition rate target production and delivery will be one of the main limiting/enabling factors for high rep rate HPL facilities.

There is already a need to increase production/delivery rates by 2 orders of magnitude at RAL and this will soon be the case at others facilities.

Significant results have already been achieved in many institutions.

There is a lot more work to do in targetry to enable the full exploitation of high rep HPL systems.