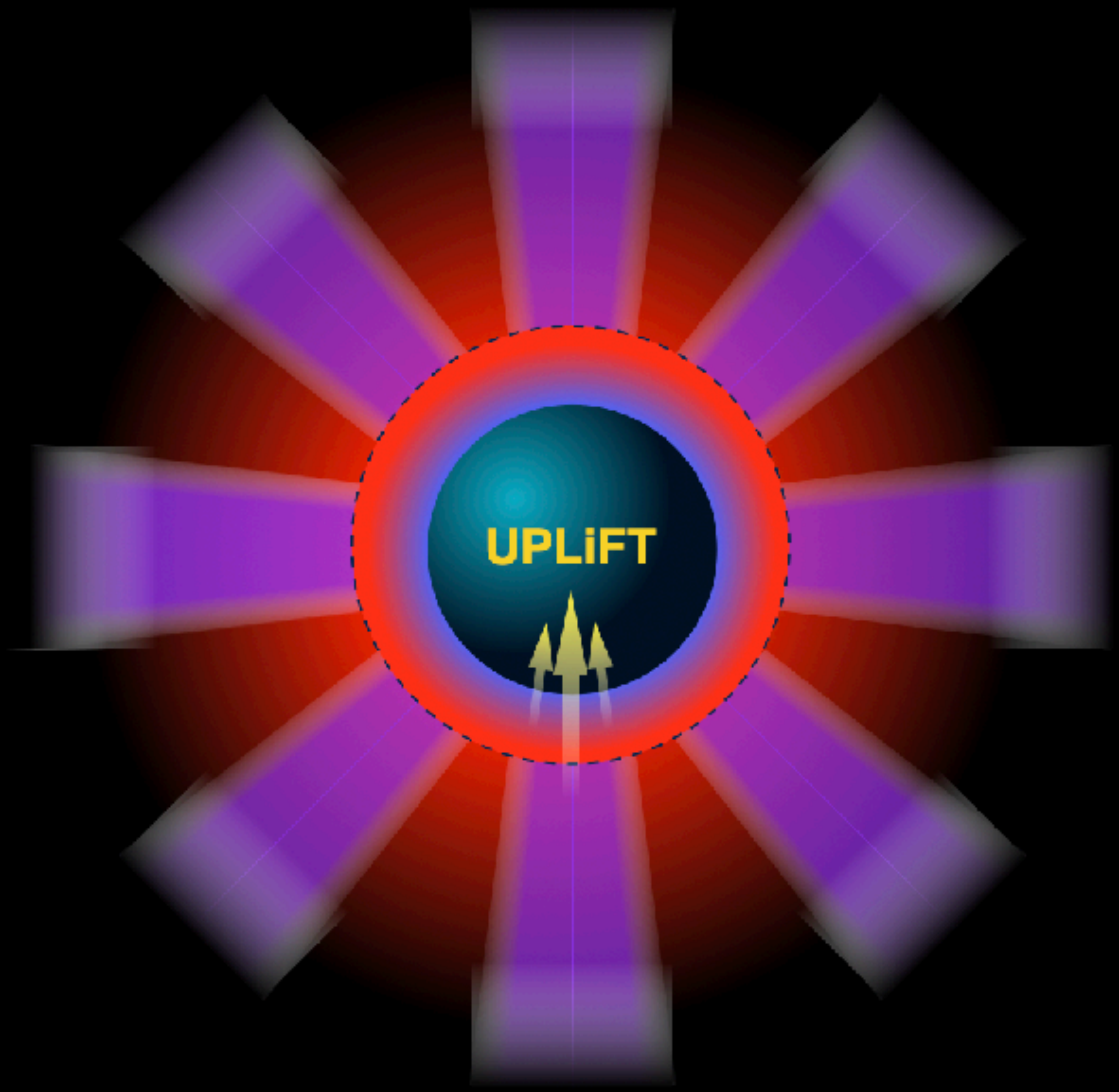
UK Programme of Laser inertial FusionTechnology for Energy



Dr Robbie Scott,
Senior Plasma Physicist, Central Laser Facility, STFC Rutherford Appleton Laboratory
Chair, UK Inertial Fusion Consortium

robbie.scott@stfc.ac.uk

UK Inertial Fusion Consortium

CLF central laser facility

UNIVERSITY OF OXFORD

Imperial College London

UNIVERSITY of York

AWE

University of Strathclyde Glasgow

WARWICK THE UNIVERSITY OF WARWICK

scitech PRECISION

QUEEN'S UNIVERSITY BELFAST

first light

Lancaster University

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  - Enabling collaboration: 11 UK institutions

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- www.inertial-fusion.co.uk

robbie.scott@stfc.ac.uk

UK Inertial Fusion Landscape

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UK Inertial Fusion Landscape

National Laboratories Researching Fusion

- **CLF:** World-class facilities, technologies, and expertise
- **AWE:** Deep Inertial Fusion expertise
- **UKAEA:** World-leading in fusion technology
  - Tritium handling and breeding
  - Fusion materials
  - Power-plant design

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  - Laser Inertial Fusion

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High Power Laser Facilities

- **Vulcan 20:20*** World's highest power laser, ~18kJ long pulse
- **Gemini:** 2 beams, ~30J, 25fs
- **EPAC*:** 2 short pulse beams @ 10 Hz (under construction)
- **Orion:** 10 long pulse beam (5kJ), 2 short pulse beams

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Inertial Fusion Technology & Industry

- **DiPOLE**: CLF's world-leading IFE laser technology
- **Scitech Precision**: Global exporters of laser targets
- **First Light Fusion**: Non-laser inertial fusion company
  - Prosperity partnership with academia

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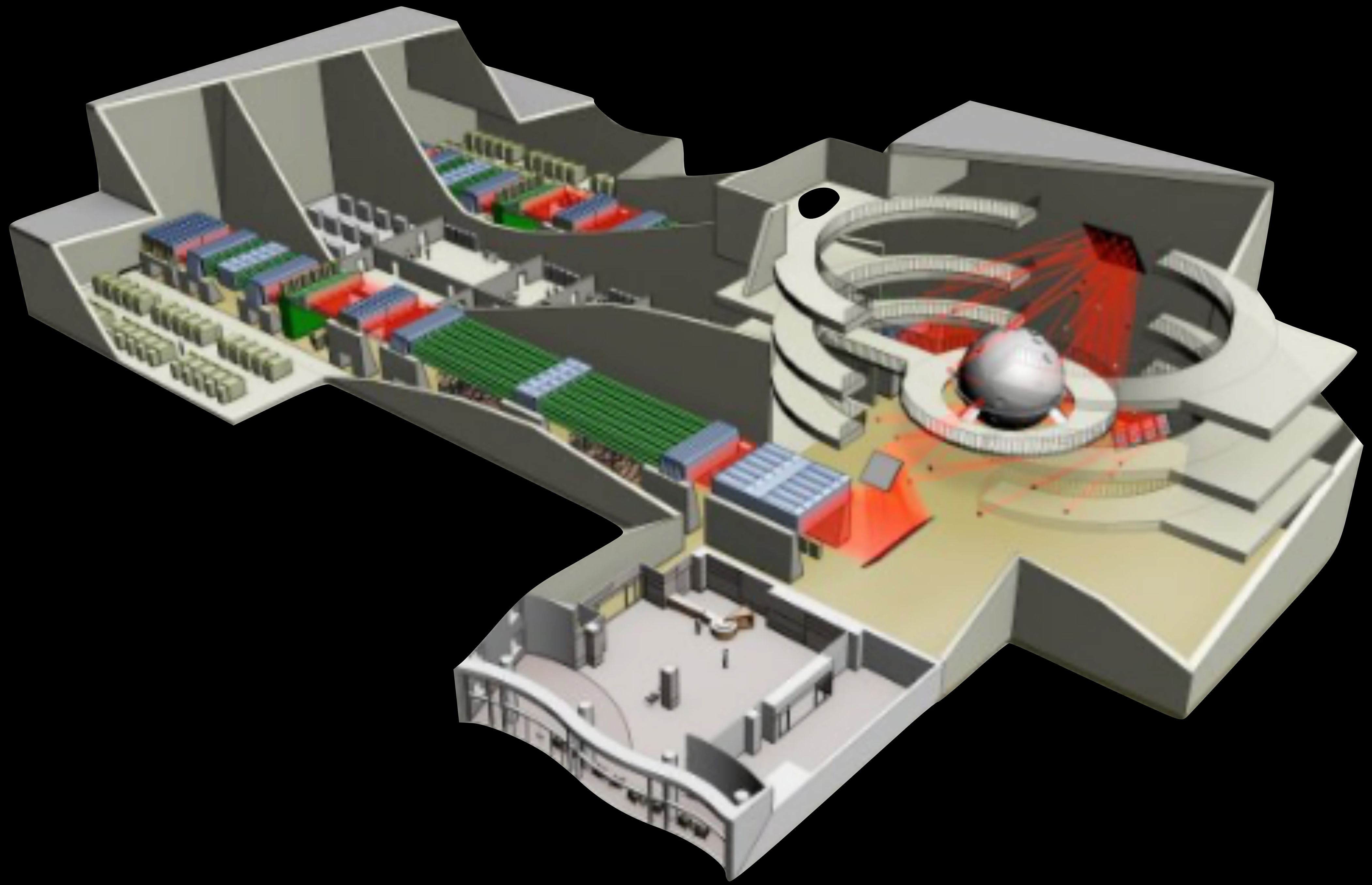
HiPER: A Pan-European Laser Fusion Project

- HiPER:
    - Laser Inertial Fusion Energy demonstration
    - CLF-led (2007-2013)
    - Was on European Strategy Infrastructure roadmap (ESFRI)
    - Ahead of its time: Predicated on NIF ignition & mothballed 2013
    - Outputs included:
        - Technology developments: e.g. DiPOLE lasers
        - Economic analyses of IFE
        - IFE chamber design
        - …



HiPER concept

robbie.scott@stfc.ac.uk

UK XFEL: Inertial Fusion Possibilities

- The conceptual design for a UK XFEL is being developed
- A laser-driven spherical compression facility: possible ‘end-station’:
  - Amazing inertial fusion, science, & defence capabilities
  - Globally unique

The EU XFEL

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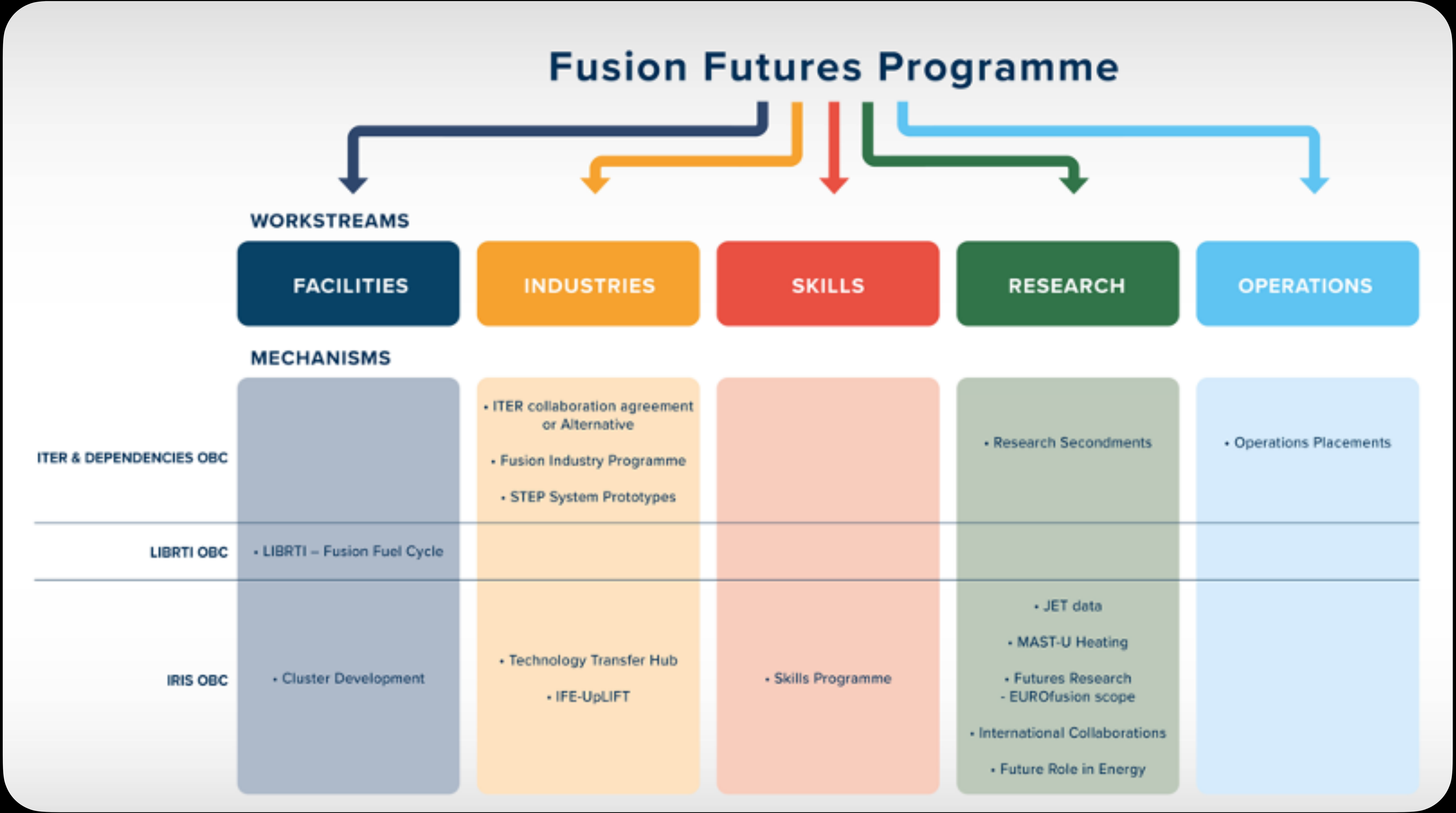
Fusion Futures



Fusion Futures Programme

WORKSTREAMS

MECHANISMS

	FACILITIES	INDUSTRIES	SKILLS	RESEARCH	OPERATIONS
ITER & DEPENDENCIES OBC		• ITER collaboration agreement or Alternative • Fusion Industry Programme • STEP System Prototypes		• Research Secondments	• Operations Placements
LIBRTI OBC	• LIBRTI – Fusion Fuel Cycle				
IRIS OBC	• Cluster Development	• Technology Transfer Hub • IFE-UpLIFT	• Skills Programme	• JET data • MAST-U Heating • Futures Research - EUROfusion scope • International Collaborations • Future Role in Energy	

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Fusion Futures training: UK Fusion PhDs

- 30 fusion PhDs
- Each PhD:
  - £40k funding from CCFE
  - £16k funding from the CLF
- 8 IFE PhD proposals were put forward
- Call anticipated to be annual

- How can we address some institutions' inability to find matching funds?

robbie.scott@stfc.ac.uk

International Inertial Fusion Energy Landscape

US IFE hubs ($42M, 4 years):

- **LLNL:**
  - Power-plant compatible target designs
  - DPSSL lasers
  - Target manufacturing & injection and engagement
  - Power plant design
- **LLE:** Laser-plasma interactions
- **Colorado State University:** Fusion science and technology

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Taranis (France)

- Thales / CEA / academia /French investment bank
- €15M (for 2 years, starting now)
- €200M (in 2 years)
- €600M (in 5 years)
- Sebastian Lepape talk tomorrow

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- **2 Inertial Fusion Companies:**
  - **Focussed energy:** Proton Fast Ignition
  - **Marvel Fusion:** Unclear
- **Government backing:** Investing €1Bn in fusion

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HiPER+

- 9 European countries
- Draft roadmap published
- €3M ’INFRA-DEV’ funding application submitted:
  - Led by Dimitri Batani
- Seeking to be re-added to ESFRI in 2025/26
- Dimitri Batani’s talk tomorrow

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UK Programme: Laser Inertial Fusion Technology for Energy

**“the technological transition from energy-gain on NIF
to commercially viable Laser Fusion energy”**

UPLiFT

UK **P**rogramme: **L**aser **I**nertial **F**usion **T**echnology for Energy

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UPLiFT

Laser Drivers

Energy-efficiency (>10%)

Repetition rate (10 Hz)

Bandwidth (~1%)

Cheap (~£1000/J)

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Target Manufacturing

Mass-manufacturing

High quality

Economic

Cryogenics

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Direct Drive

Shock Augmented Ignition

Laser imprint, Laser-plasma physics, non-local transport

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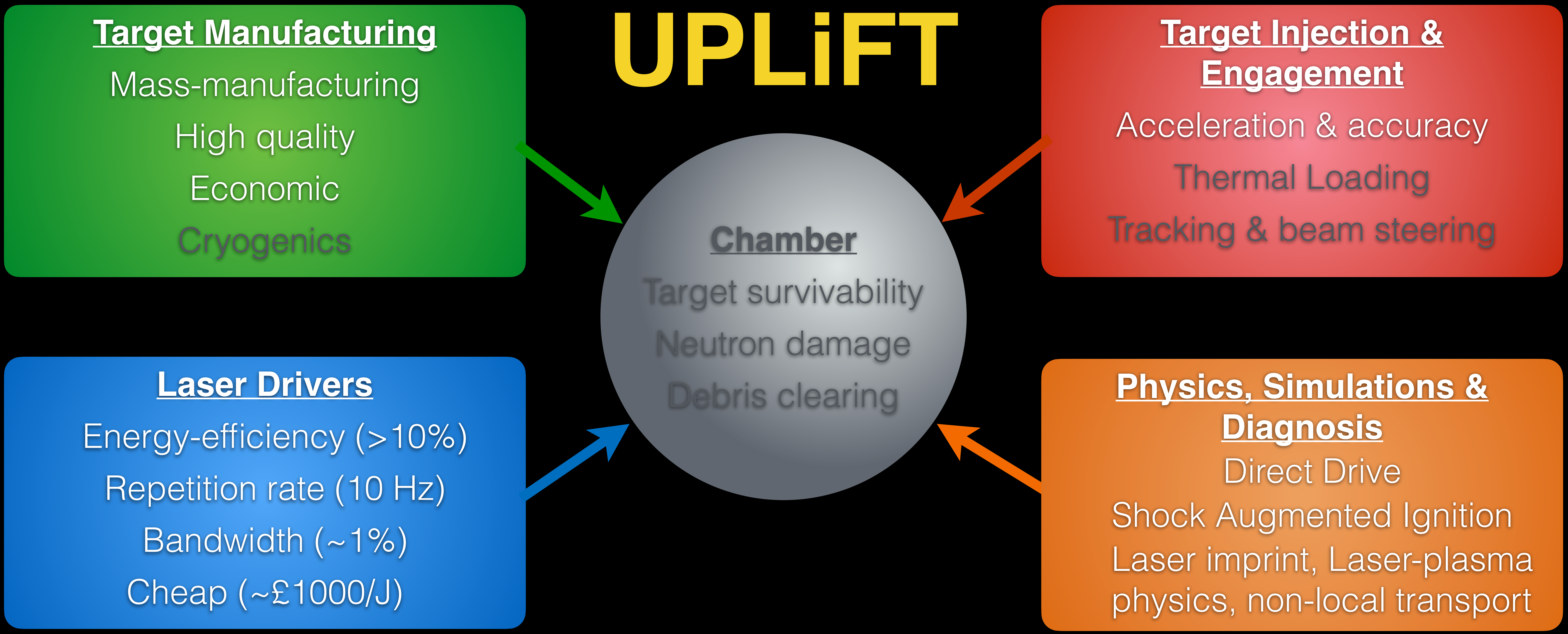

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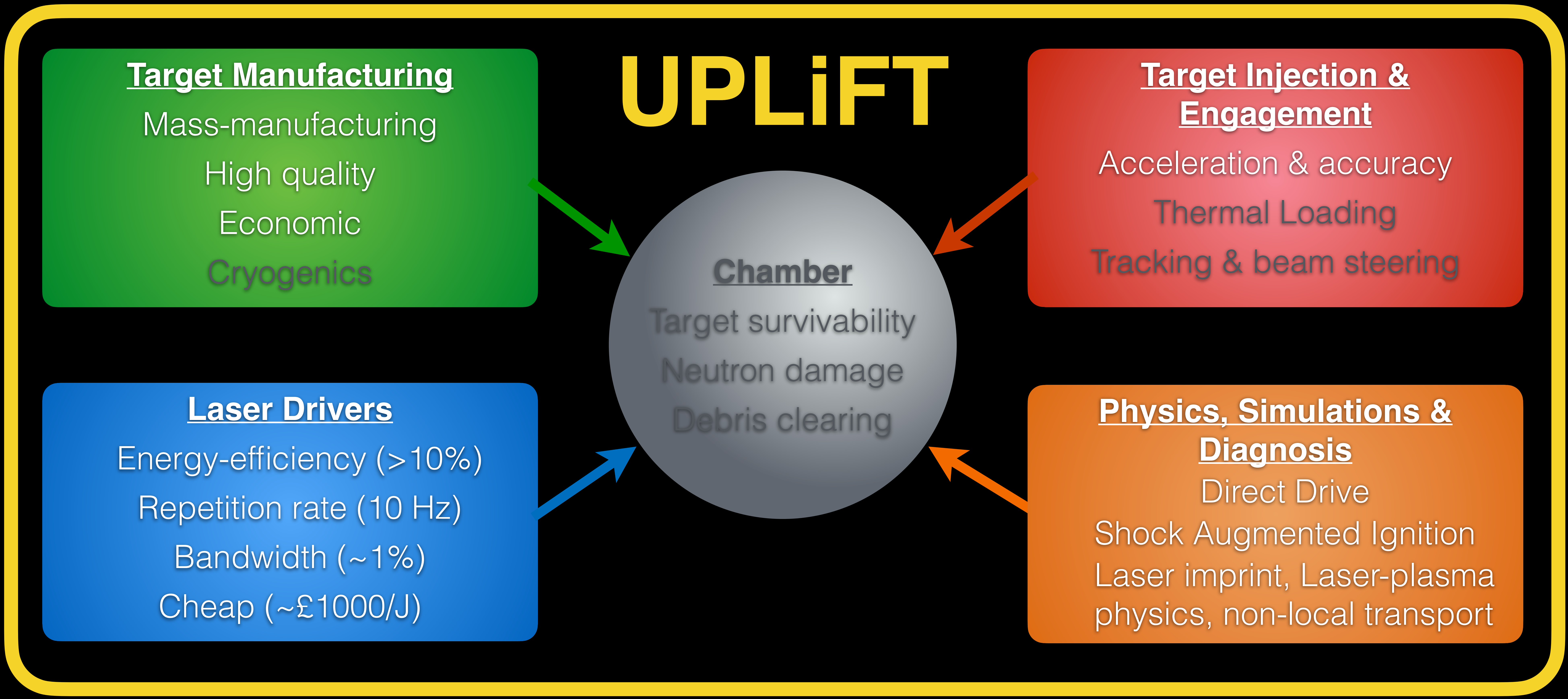

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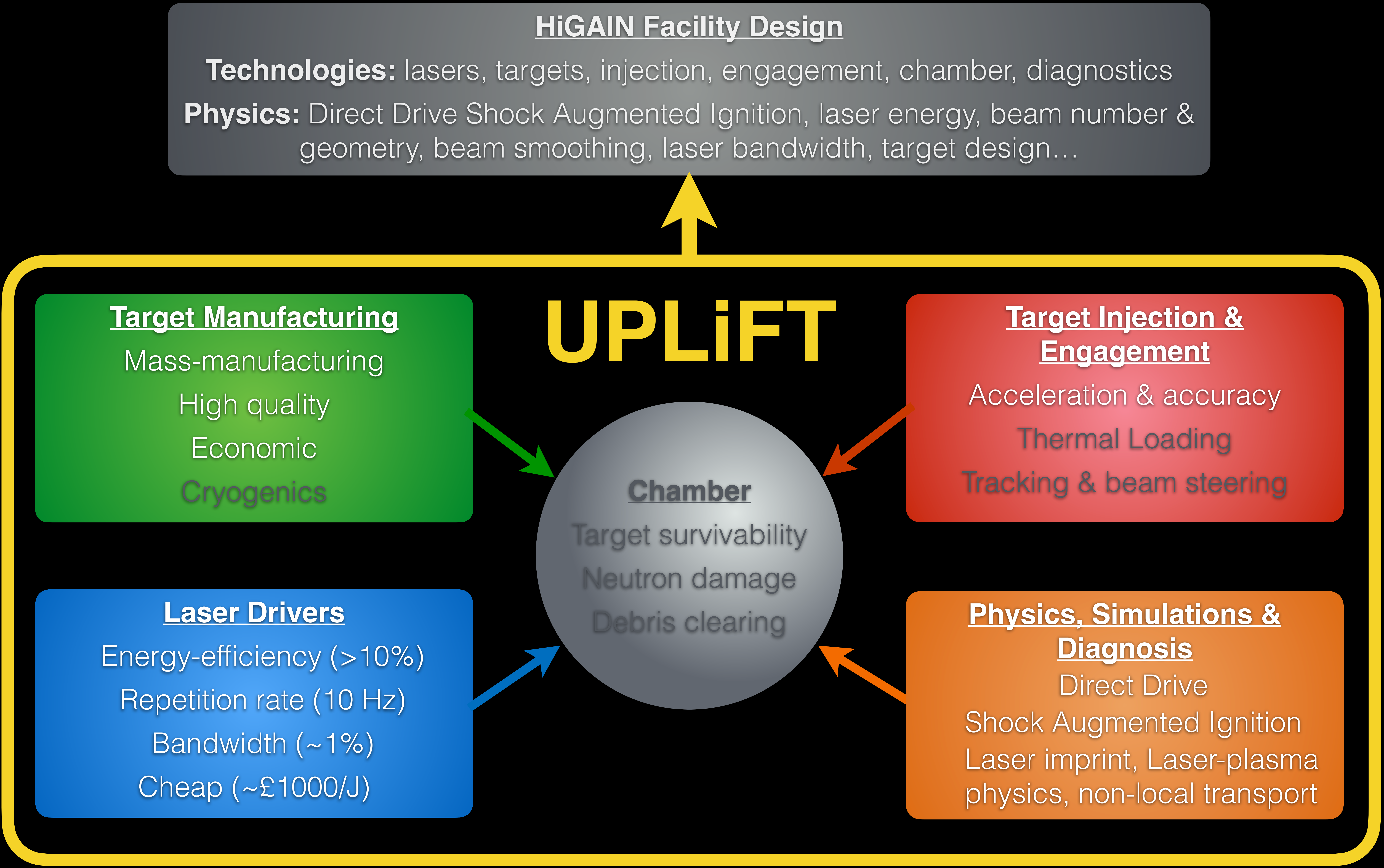

HiGAIN Facility Design

Technologies: lasers, targets, injection, engagement, chamber, diagnostics

Physics: Direct Drive Shock Augmented Ignition, laser energy, beam number & geometry, beam smoothing, laser bandwidth, target design…

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UPLiFT: Summary

- **Budget:** £10M (4 years, ~£2.5M / year)

- **Laser design & prototype construction:**
    - 6 people full time @ RAL
    - £2M capital

- **Implosion Capsule Targets:**
    - 5.5 people full time @ RAL
    - £715 capital (£300k for 2PP 3D printer)

- **High-Gain Physics:**
    - 7 post-doctoral research assistants (PDRAs)
    - 3 Omega experiments
    - Extensive Odin development
    - Diagnostic development (£500k capital)

- **Other:** £40k travel/annum, £25k computers, admin support

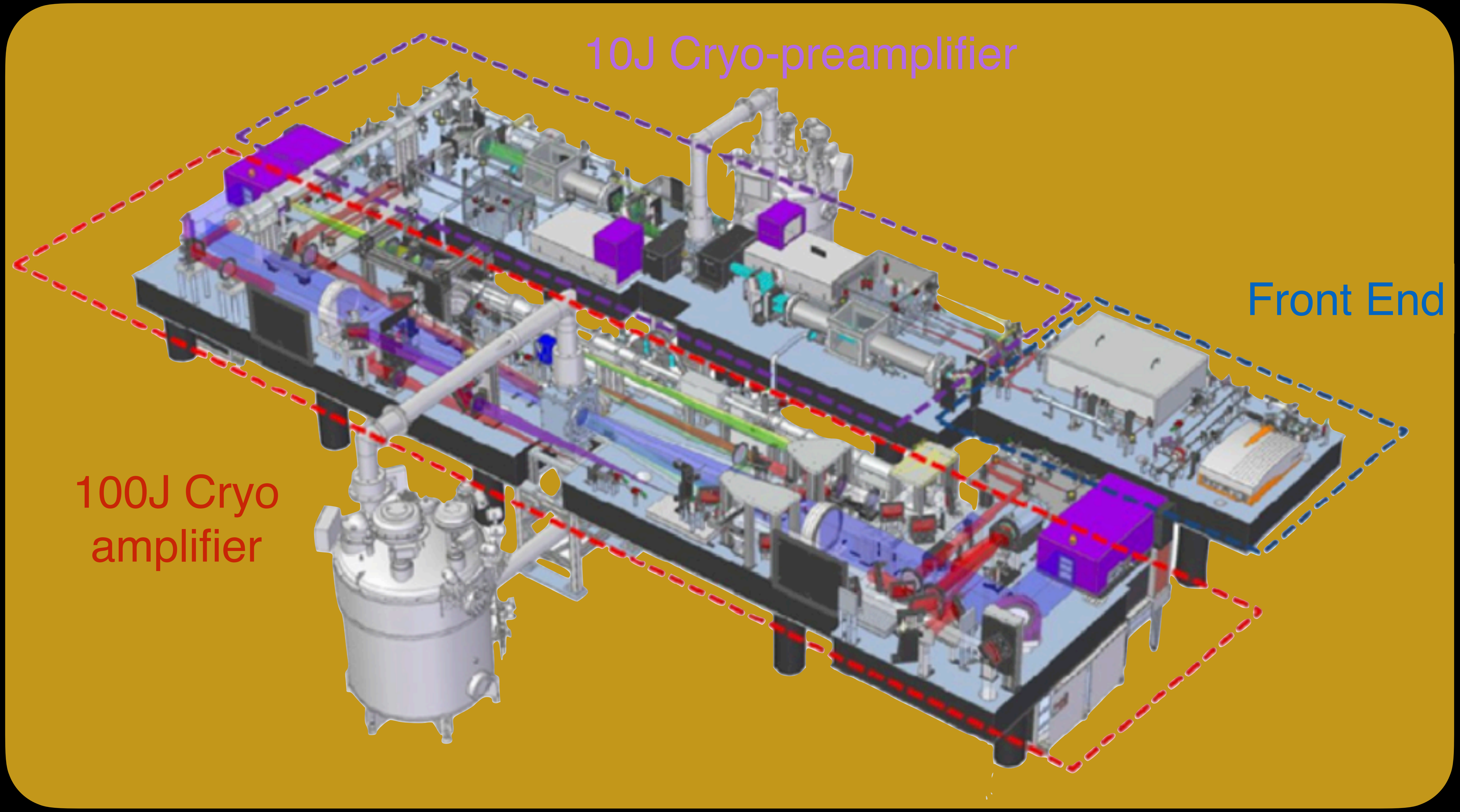
robbie.scott@stfc.ac.uk

DiPOLE: Energy Efficient Lasers for Fusion

- NIF's lasers are only **0.6% efficient**
  - Not feasible for power production

- DiPOLE*:
  - **10% efficient**
  - **30x** efficiency improvement
  - 10 Hz repetition rate

- UPLiFT:
  - Cheaper
  - Higher energy
  - Increased bandwidth



CLF's 150J, 10Hz, Diode-pumped 'DiPOLE' laser

*M. Divoky et al., "150 J DPSSL operating at 1.5 kW level," Opt. Lett., 46, 2021.

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UPLiFT Prototype IFE Beamline: Overview

Goal: Energy-scalable prototype laser fusion energy beamline

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- UPLiFT prototype laser beamline could be installed in EPAC:
  - 10Hz, multi-kJ (potentially), broadband
  - Interface with EPAC high-intensity beams and / or secondary sources
  - Address UPLiFT physics
  - Excellent CLF-user facility
  - Aligned with AWE's goals

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- White light interferometry
- ML-based characterisation

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Target Injection

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UPLiFT Physics: Key Challenges for Direct Drive

robbie.scott@stfc.ac.uk

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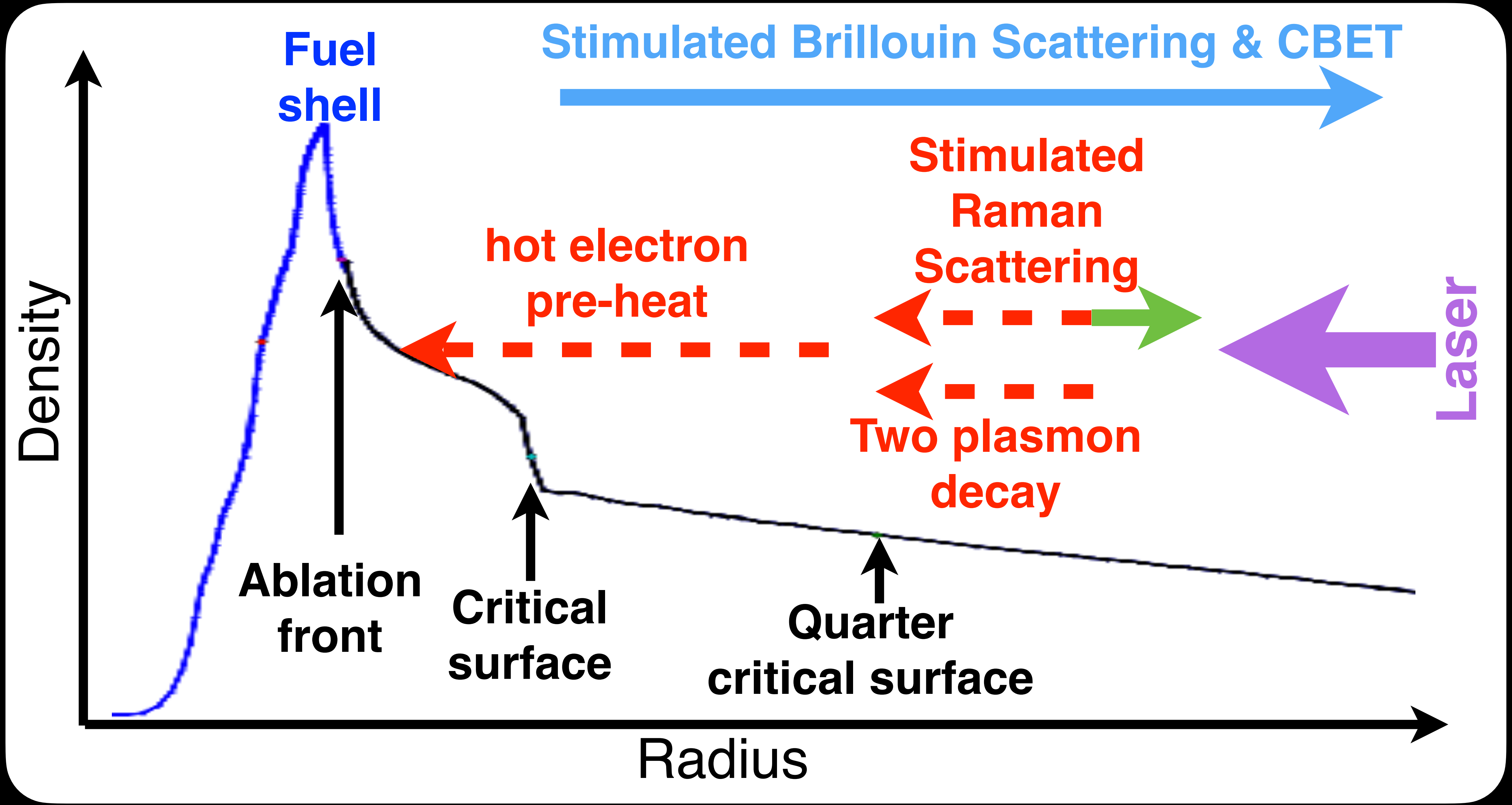

Laser-plasma instabilities can reduce energy coupling and cause fuel pre-heat

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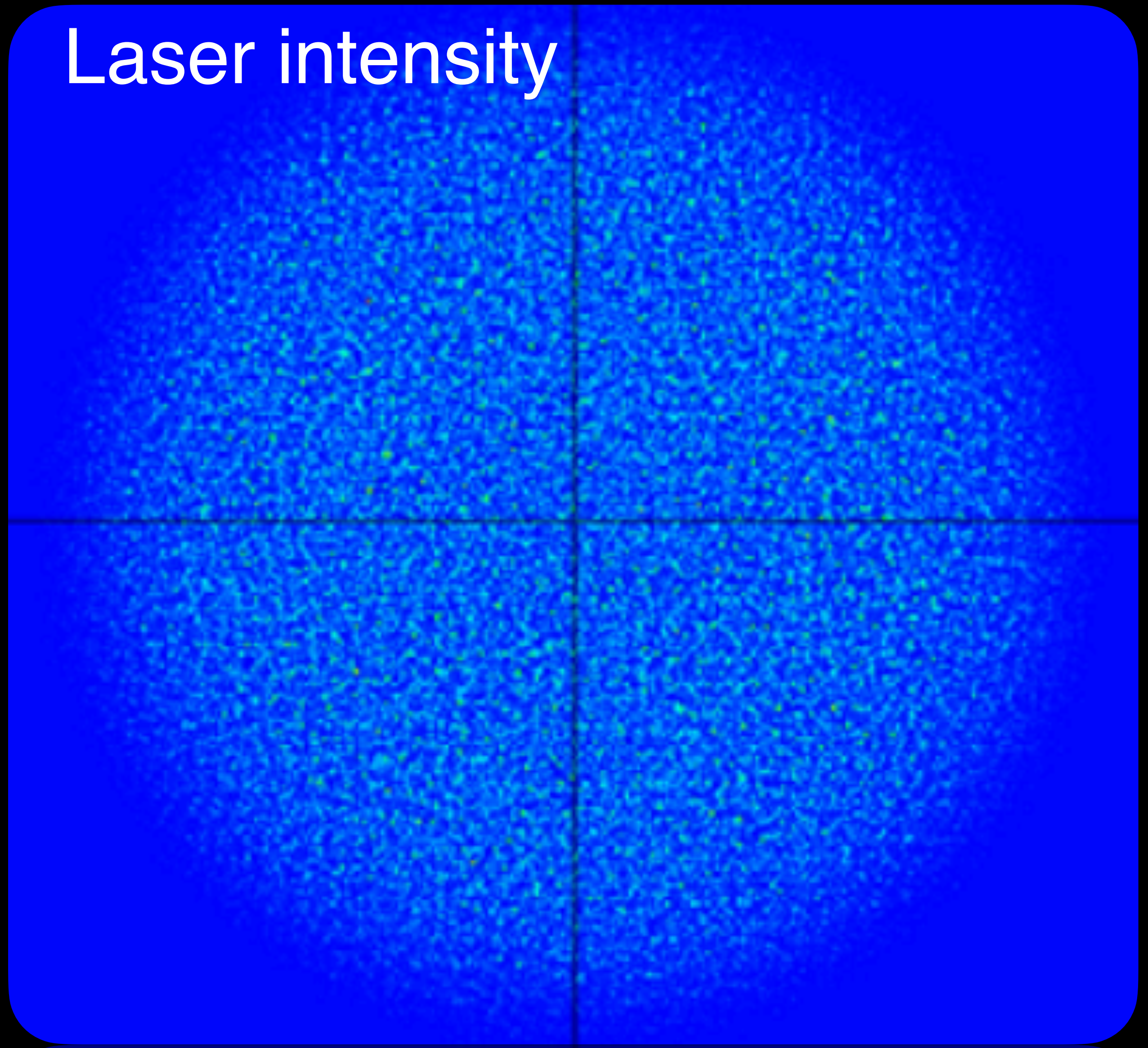
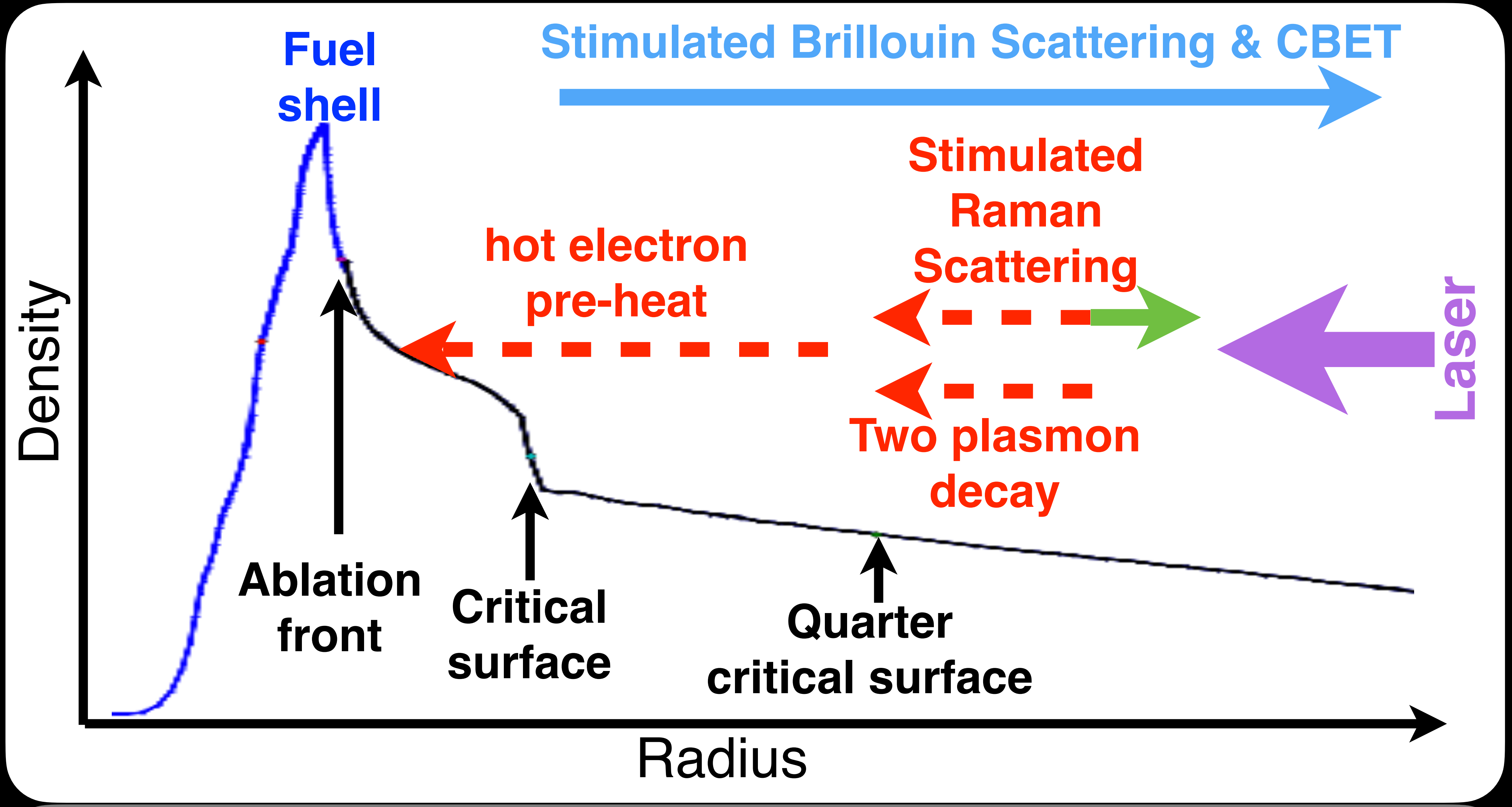


Laser speckles ‘imprint’ seeds for the Rayleigh-Taylor instability into the implosion capsule



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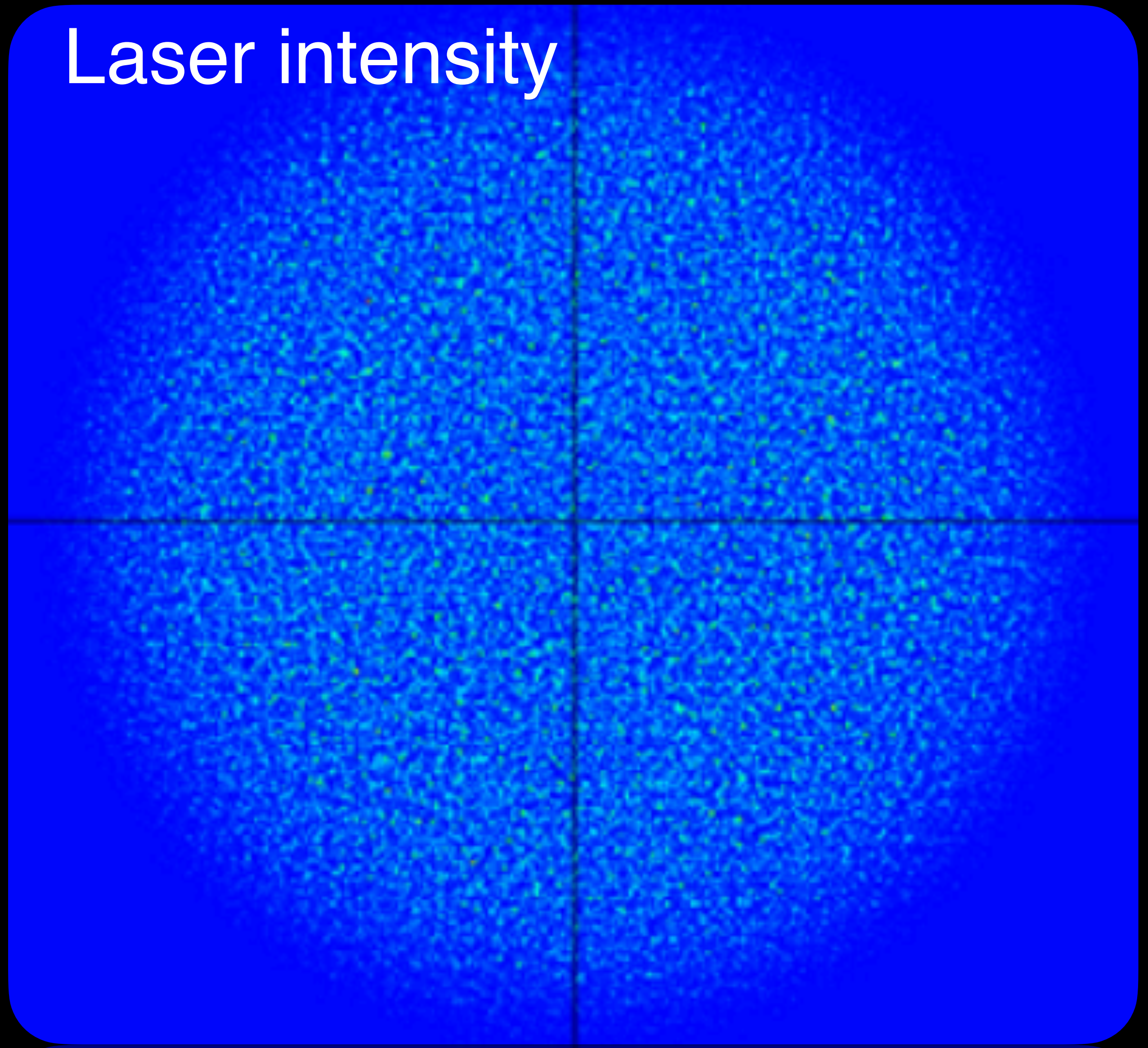

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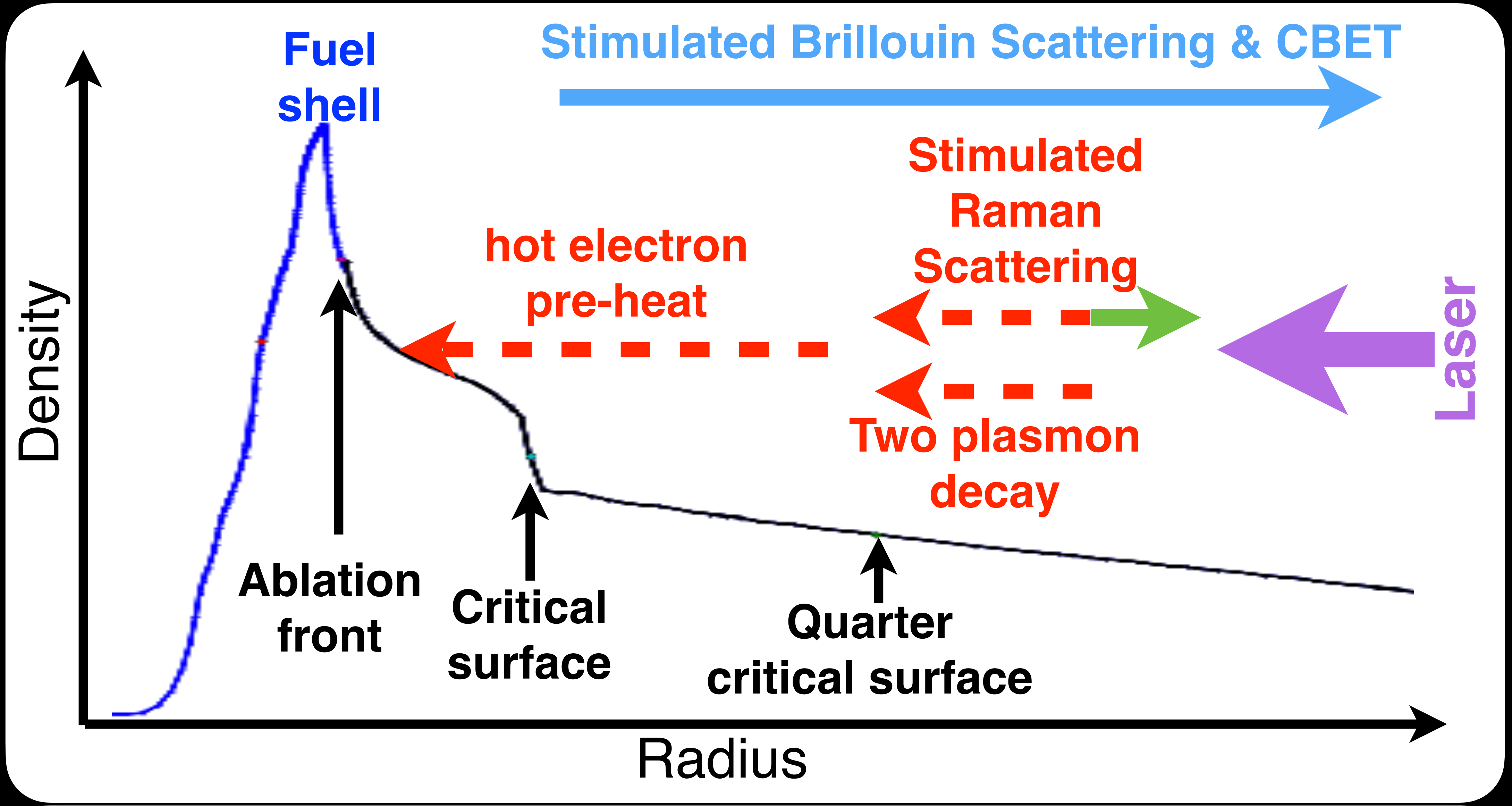

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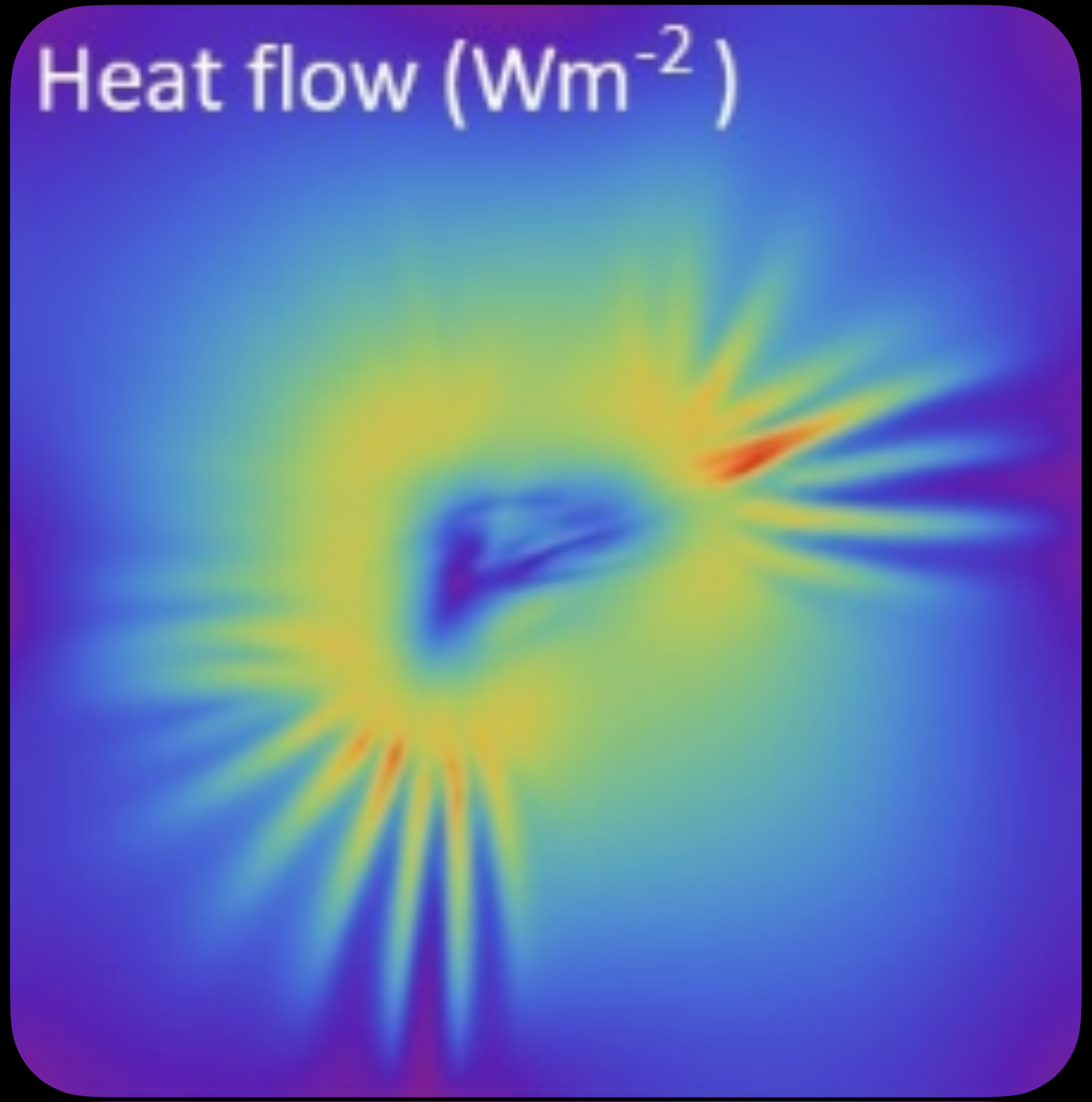

Non-local transport dictates heat flow, determining RT growth and ablation plasma conditions

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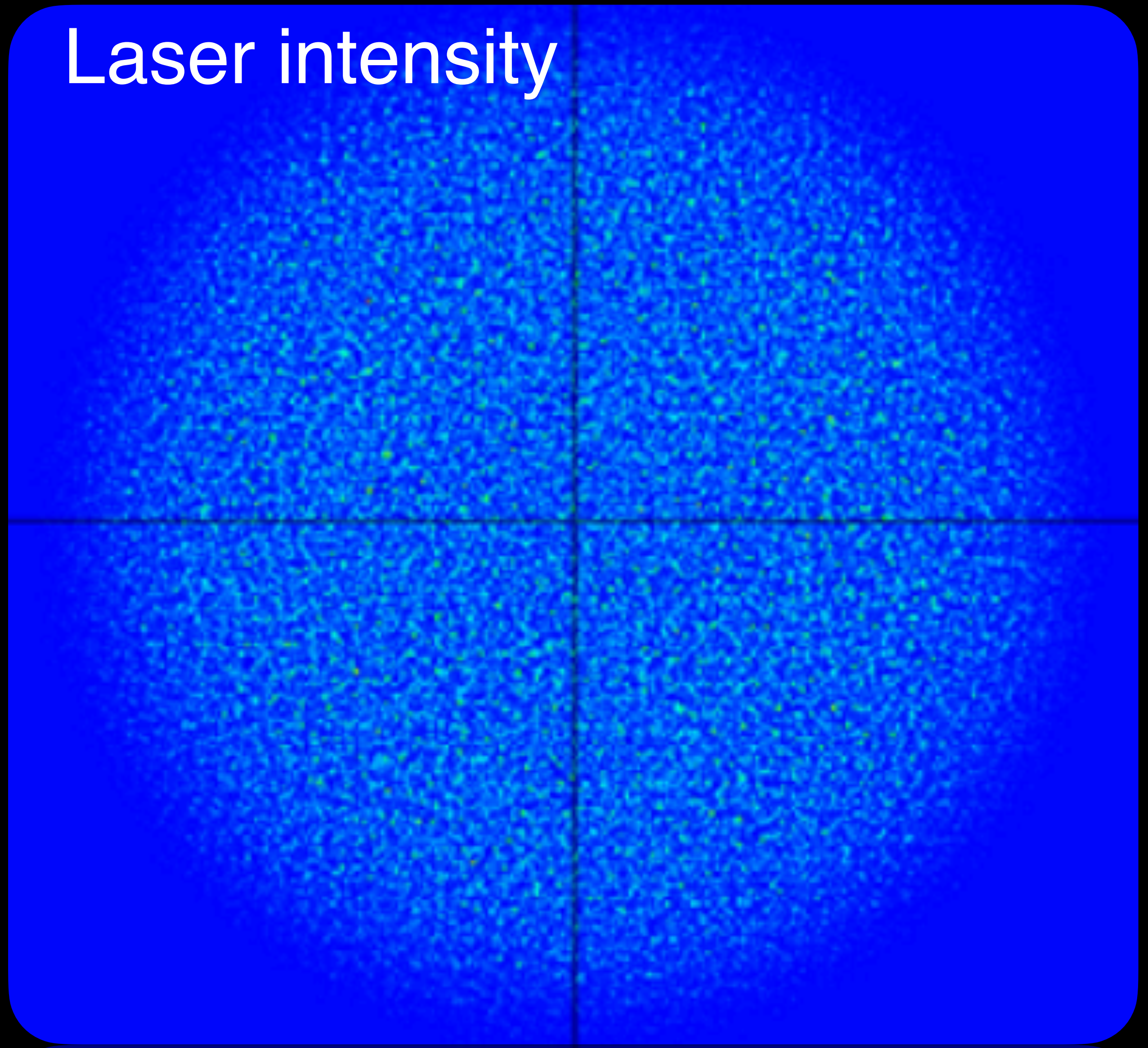

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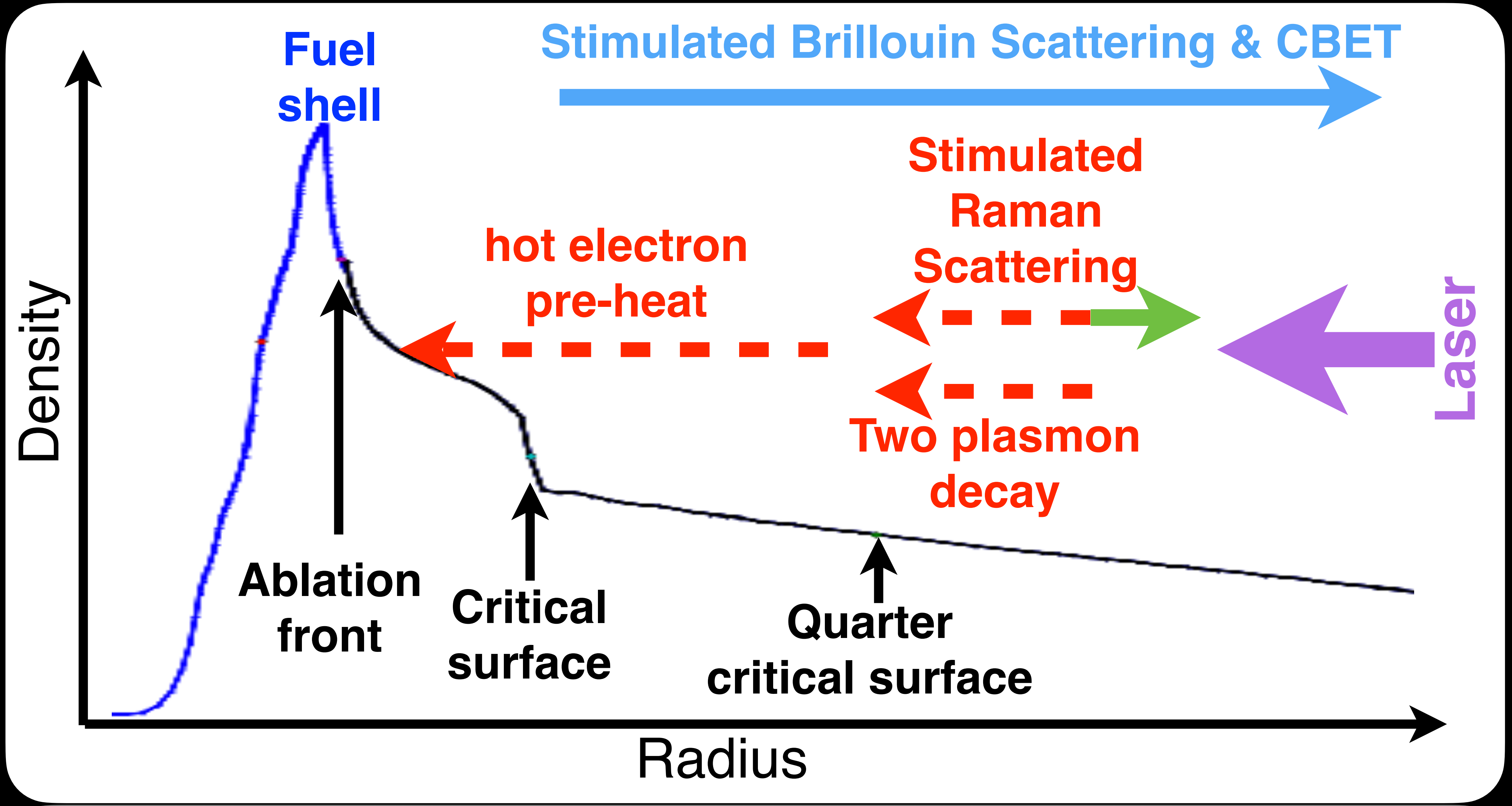
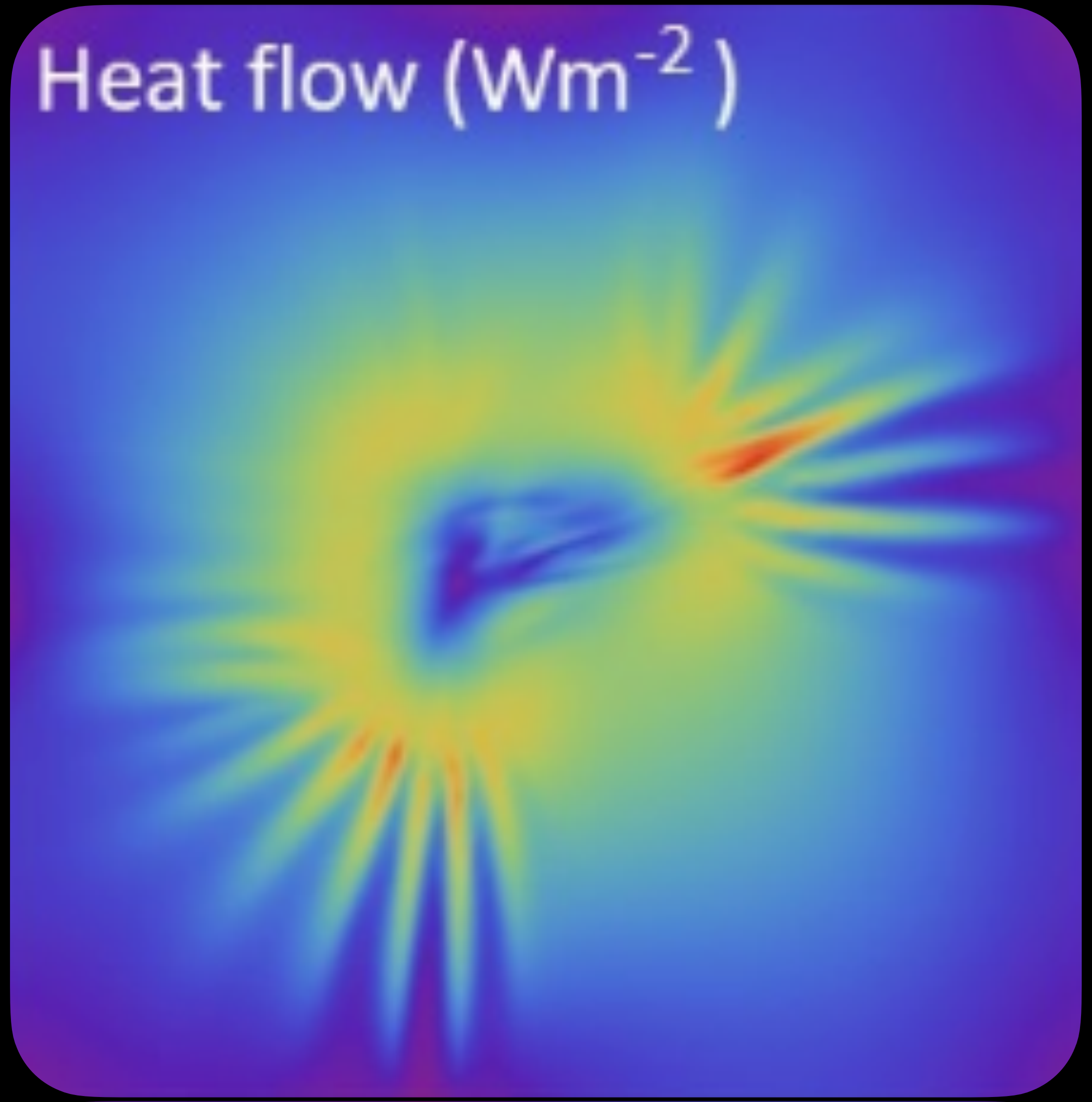


Laser-plasma instabilities can reduce energy coupling and cause fuel pre-heat

Implosion designs for next-generation facilities must accurately account for these physics



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Physics Overview

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Goals:

- 3D simulation capability(s):
  - Physics models for all key Direct Drive physics
  - Benchmarked against experiments
- High-gain implosion design(s)
  - Realistic
  - Robust
  - Set design basis for a future implosion facility

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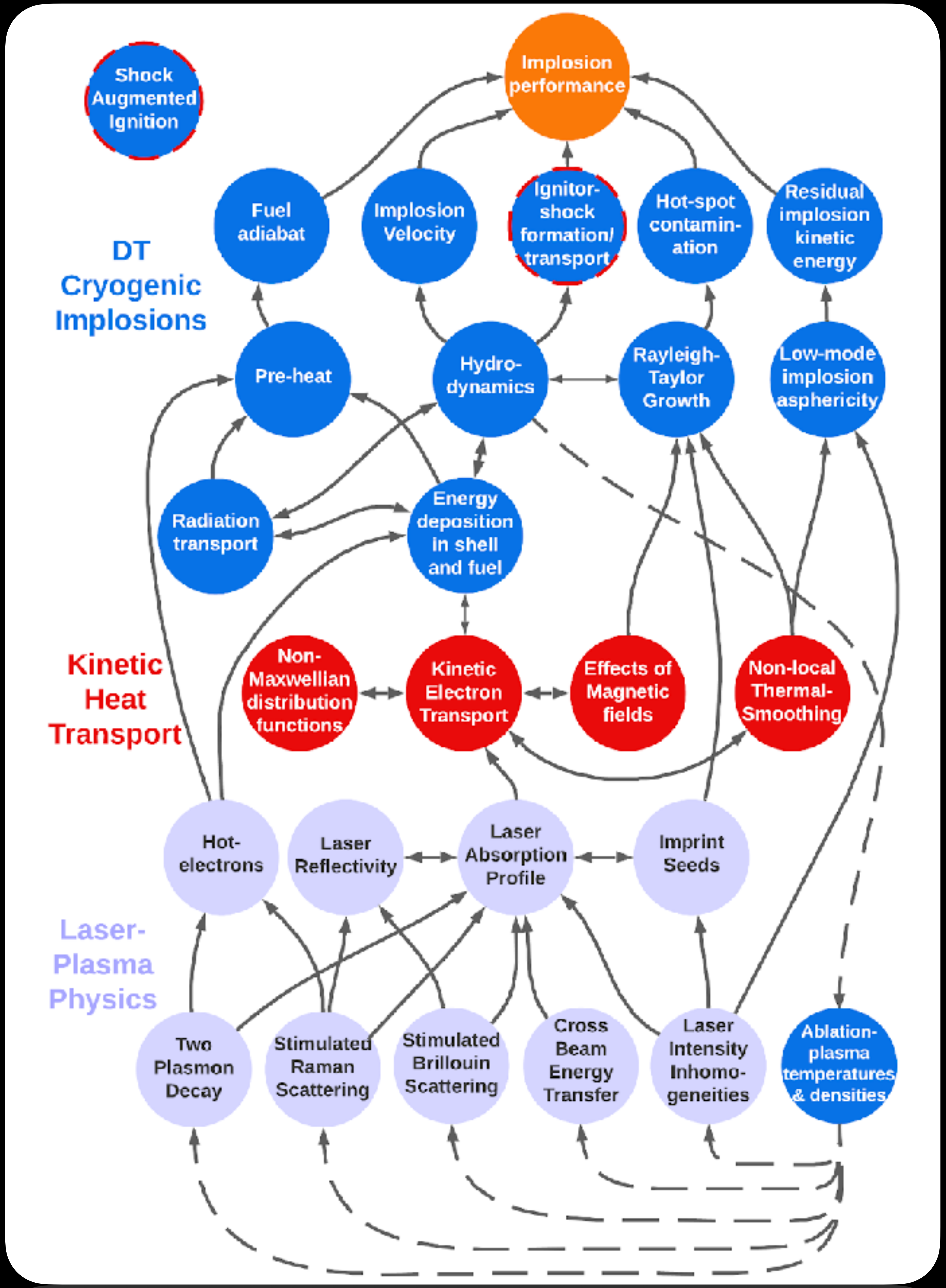

Inter-relationships of Direct Drive implosion physics

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4 Physics Work Packages (Direct Drive focussed):

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2. Laser imprint
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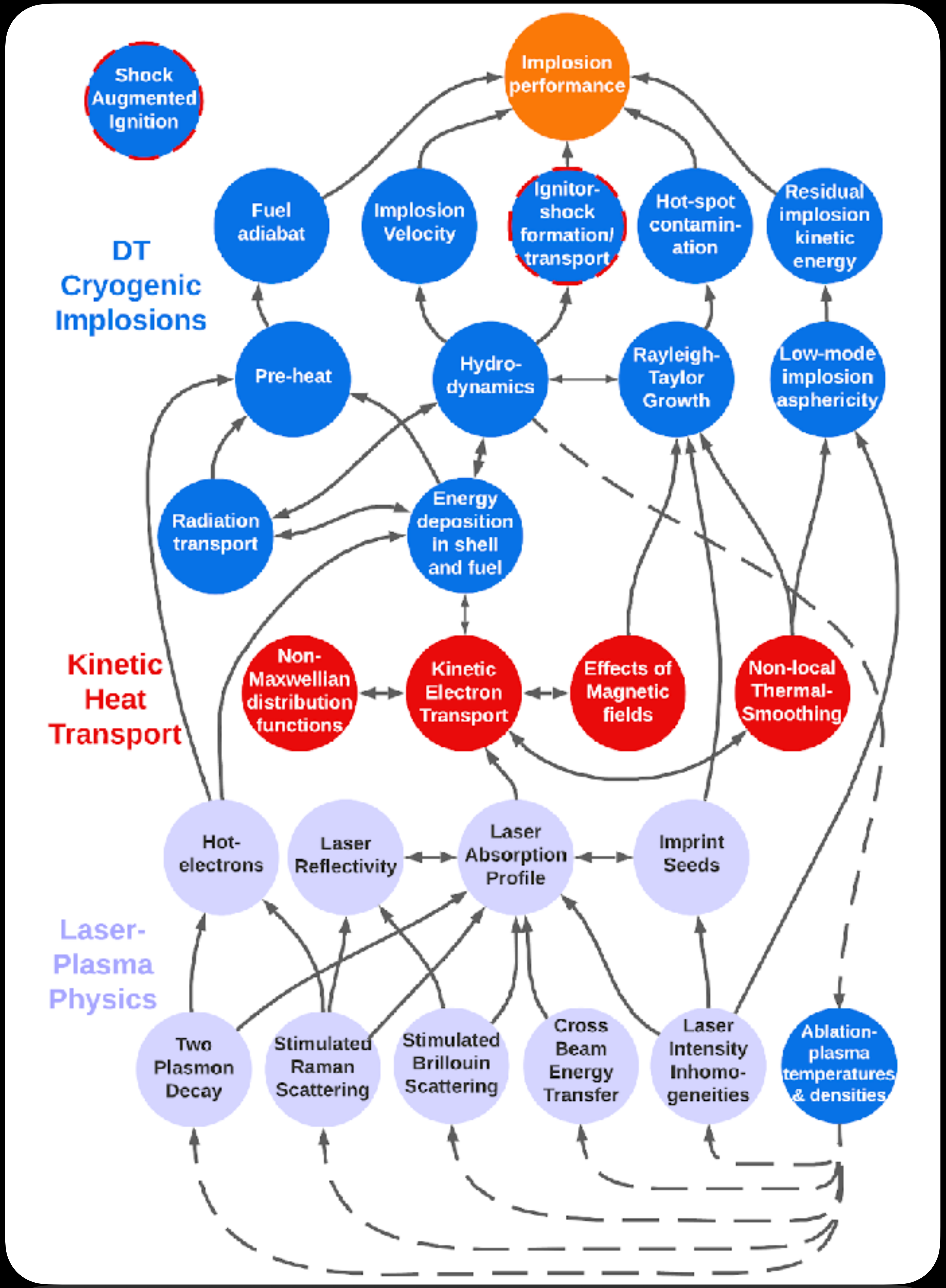

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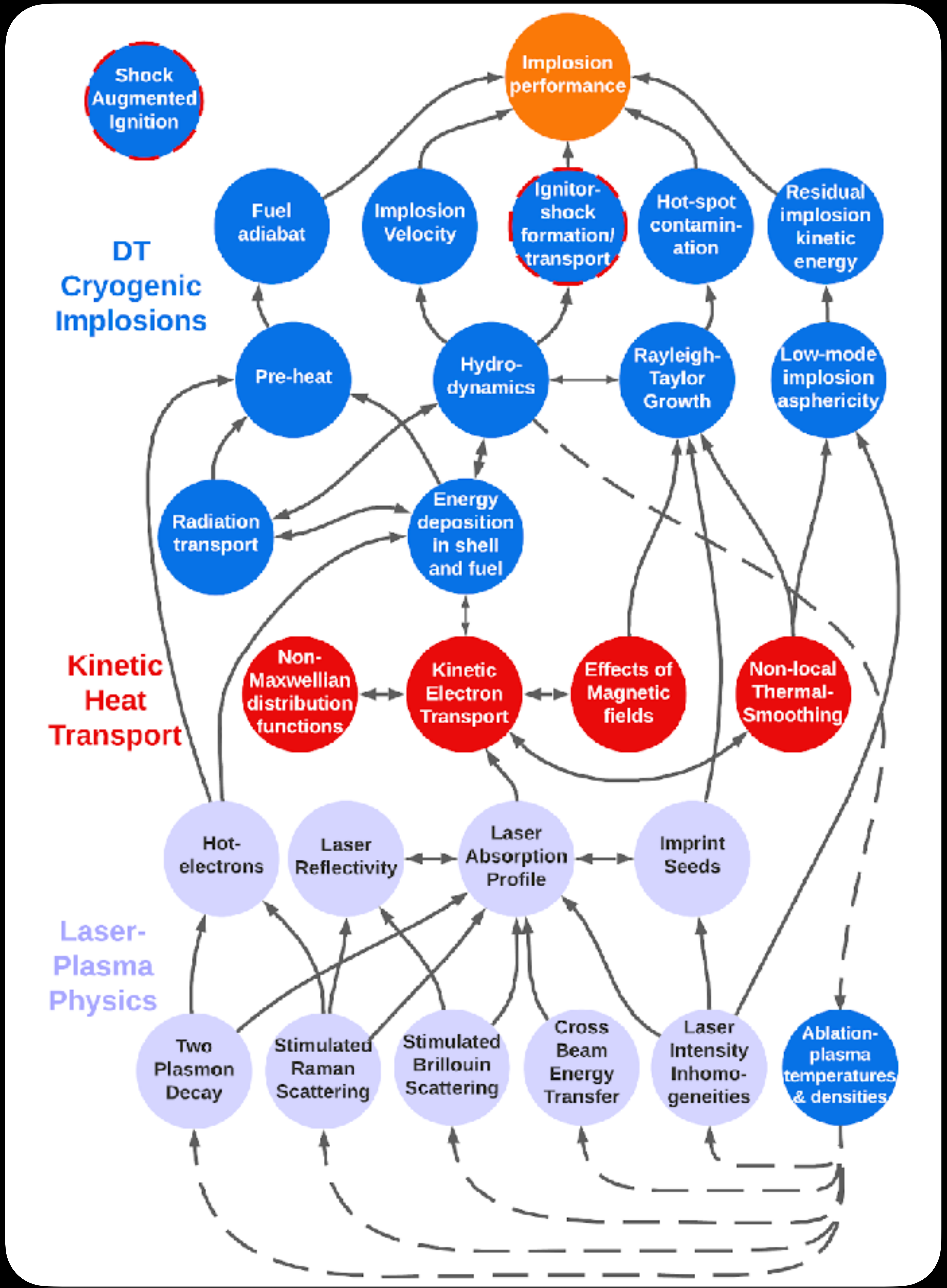

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Laser Plasma Interactions: energy coupling to implosion & imprint seeds

Schematic of non-linear Direct Drive implosion dynamics

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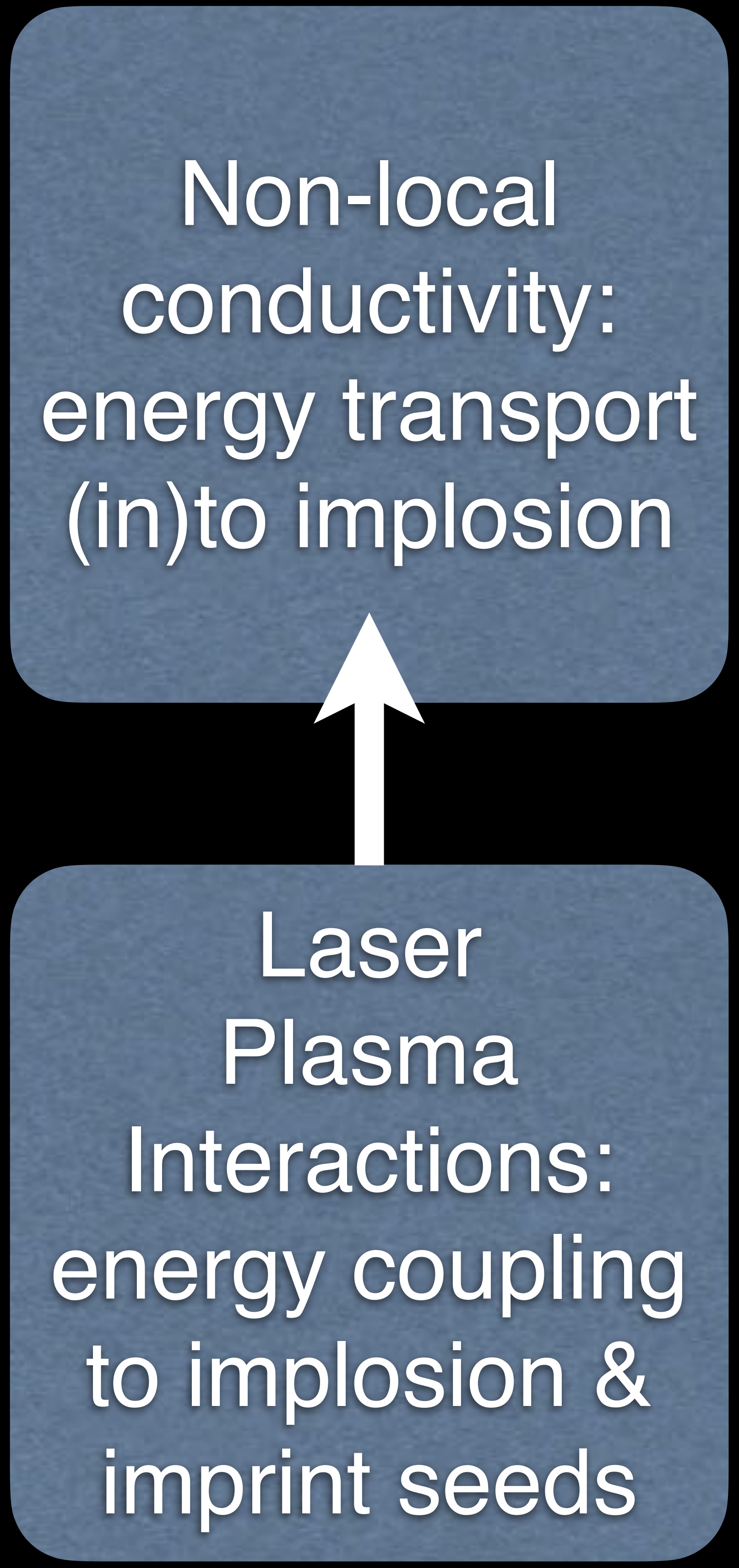

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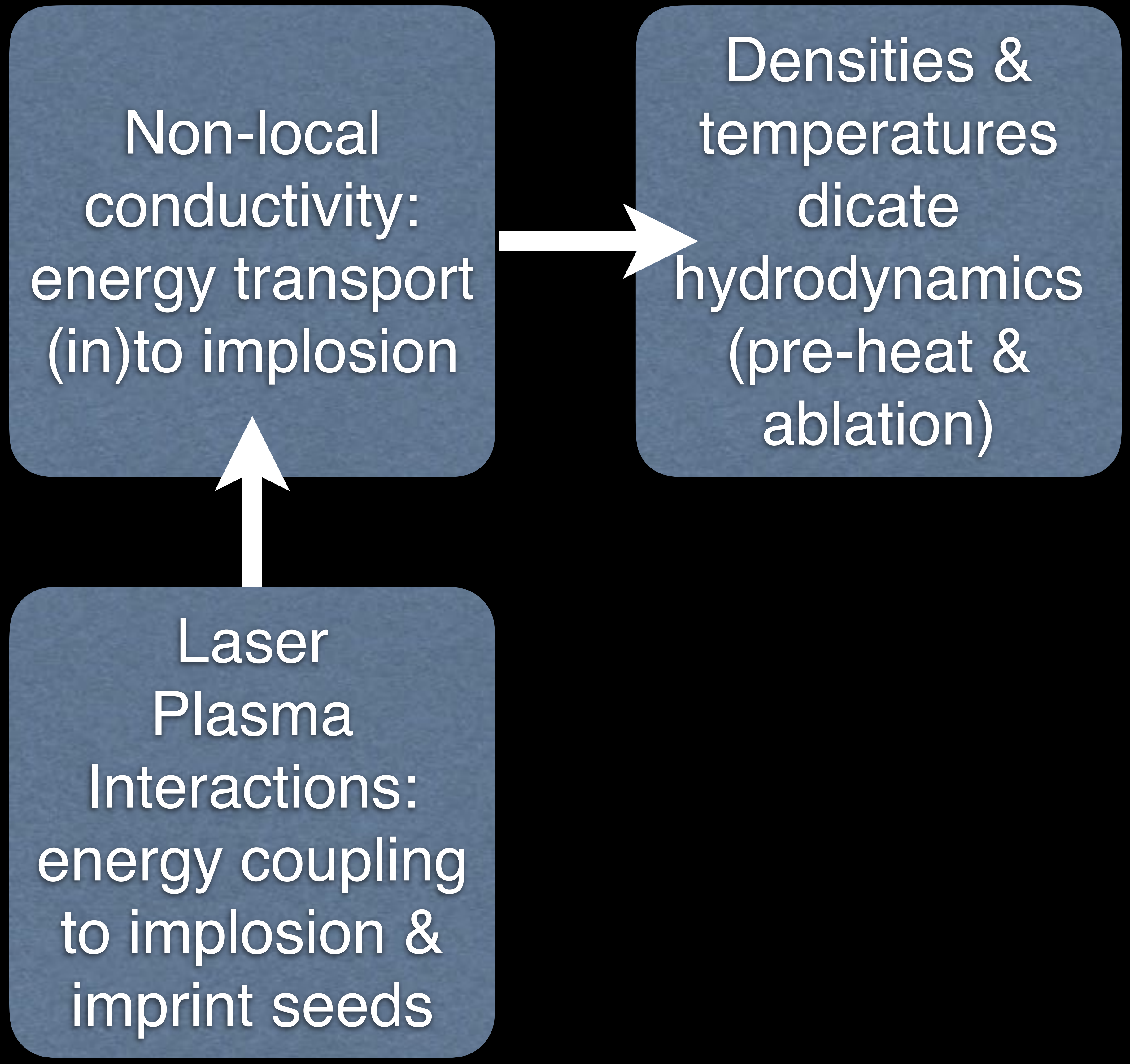

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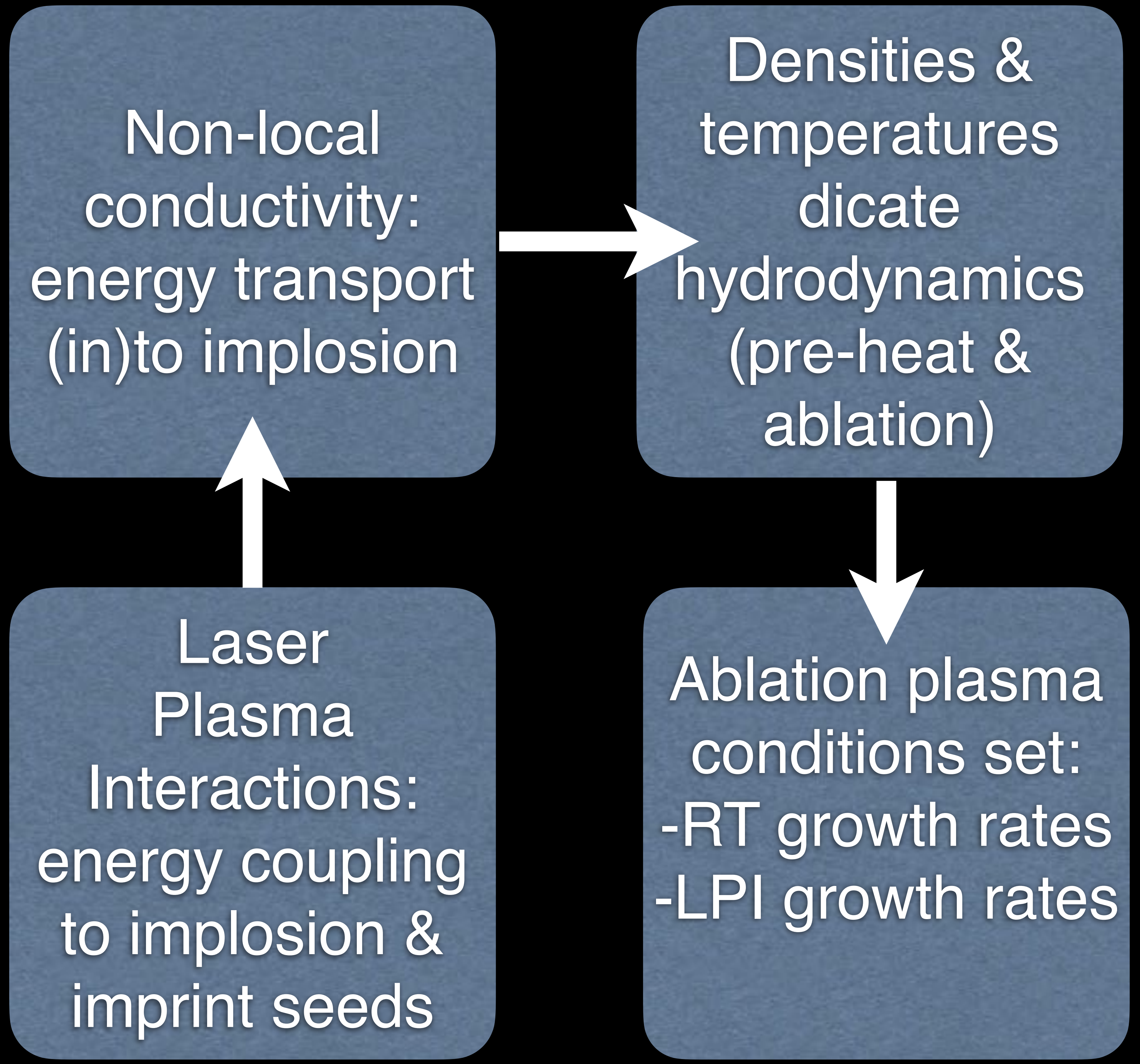

Non-local conductivity: energy transport (in)to implosion

Densities & temperatures dicate hydrodynamics (pre-heat & ablation)

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Ablation plasma conditions set:
-RT growth rates
-LPI growth rates

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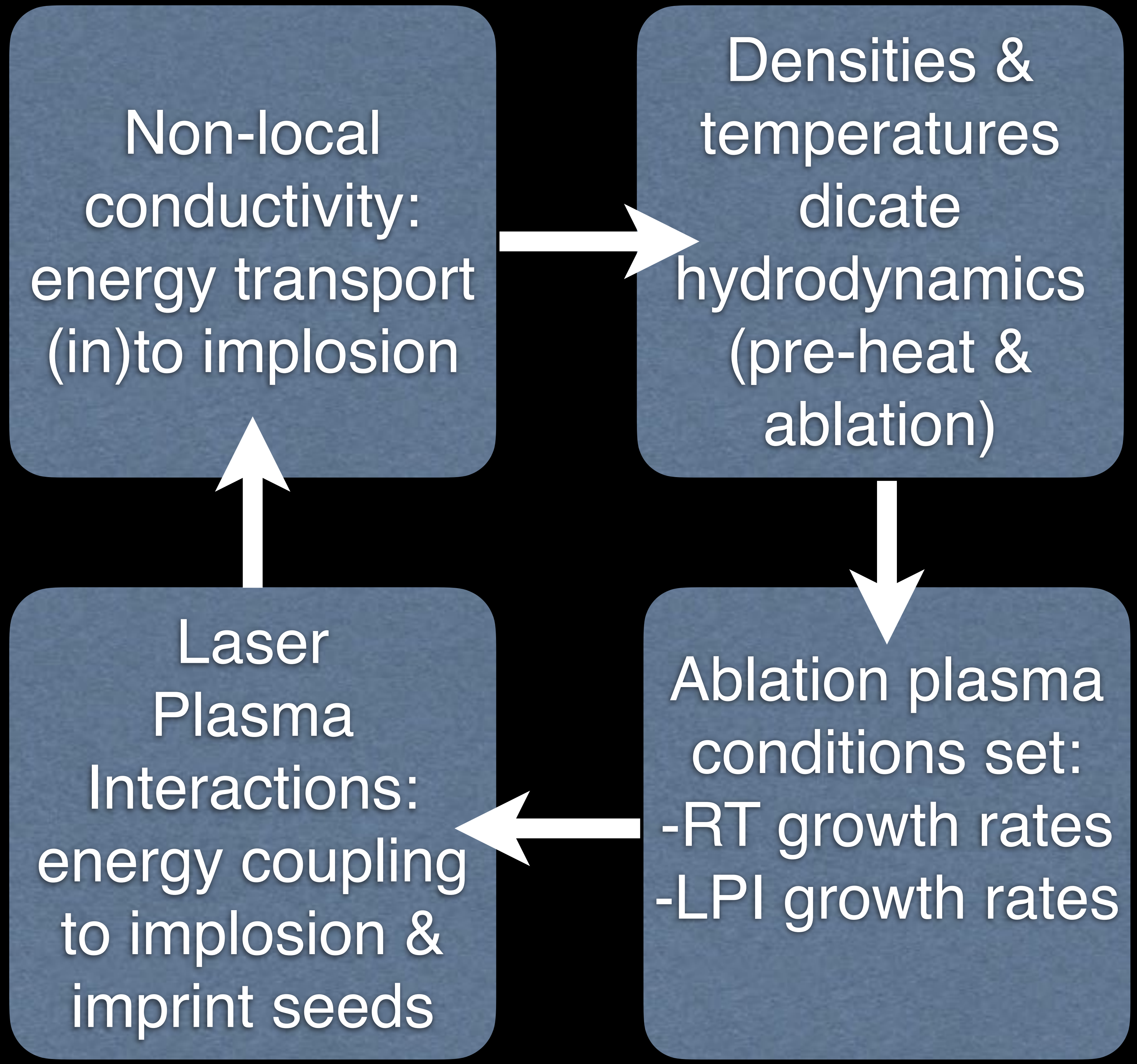

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Physics Work Packages: Detail 1

Each work package will have:

- 1 Theory PDRA
- 1 Experimental PDRA
- 1 Omega experiment

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robbie.scott@stfc.ac.uk

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- Theory PDRAs:
  - Development of inline models for Odin (& Chimera)
  - Benchmarking
  - Experiment design simulations / analysis

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1 Theory PDRA

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- Theory PDRAs:
  - Development of inline models for Odin (& Chimera)
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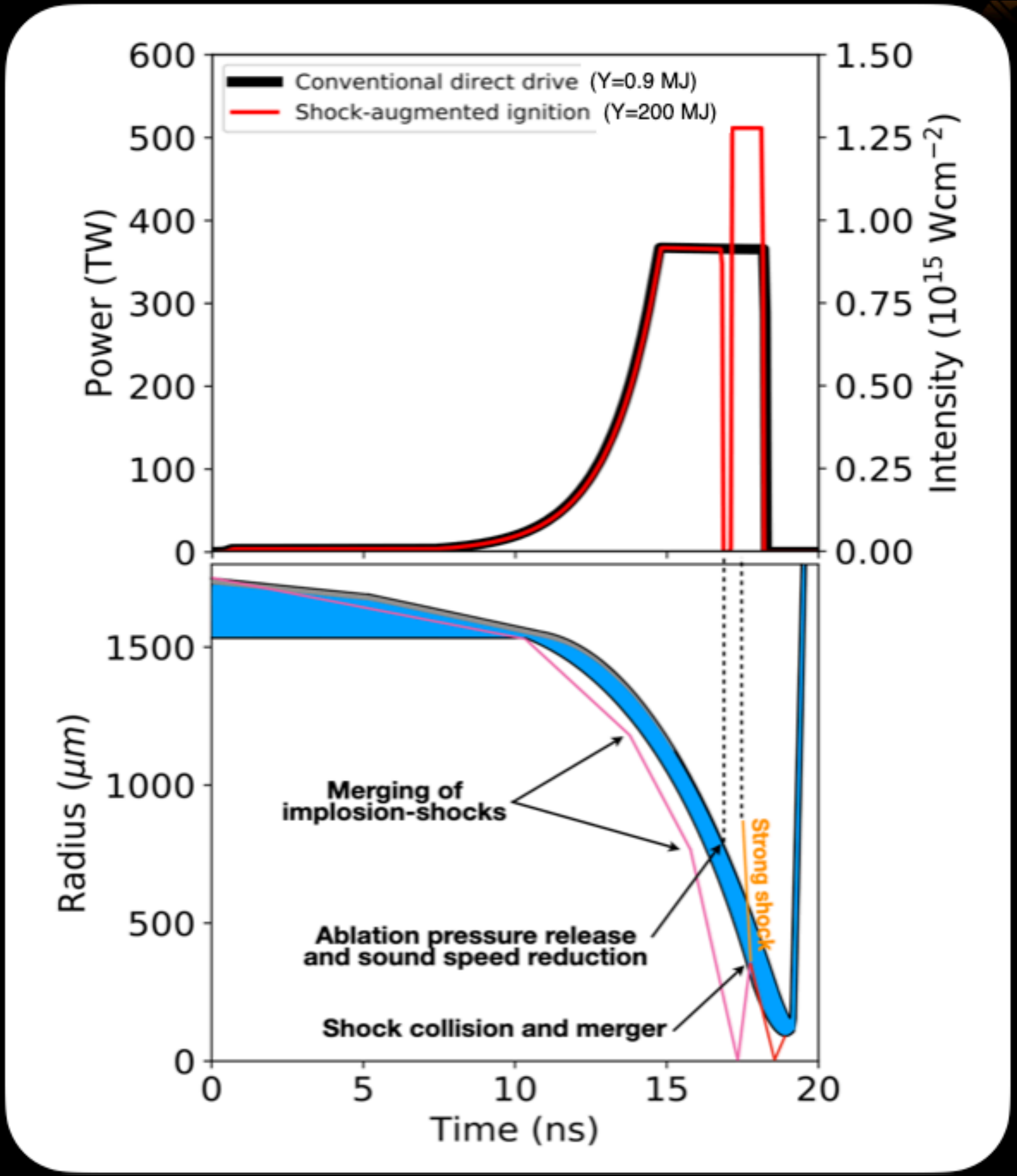
- Experimental PDRAs:
  - Proposals
  - Experiment design
  - Execution
  - Analysis

robbie.scott@stfc.ac.uk

Physics Work Packages: Detail 2

4. High-gain Direct Drive implosion design:
   a) 1 & 2D modelling PDRA
   b) 3D modelling PDRA
   c) Implosion Diagnostics PDRA:
      - Develop TIM based diagnostic for Omega DT cryo implosions:
         - £500k capital budget + engineering design effort
         - UK buy-in to US experiments

- ODIN development:
   - Tom Goffrey and Keith Bennett funded at >= 50%



- Shock-Augmented Ignition's Potential:
   - Higher gain (>100)
   - Increased robustness to instabilities

robbie.scott@stfc.ac.uk

UPLiFT Schematic

robbie.scott@stfc.ac.uk

UPLiFT Schematic

Laser Imprint

robbie.scott@stfc.ac.uk

UPLiFT Schematic

Laser Imprint

Laser Plasma Interactions

robbie.scott@stfc.ac.uk

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UPLiFT Schematic

Experimental

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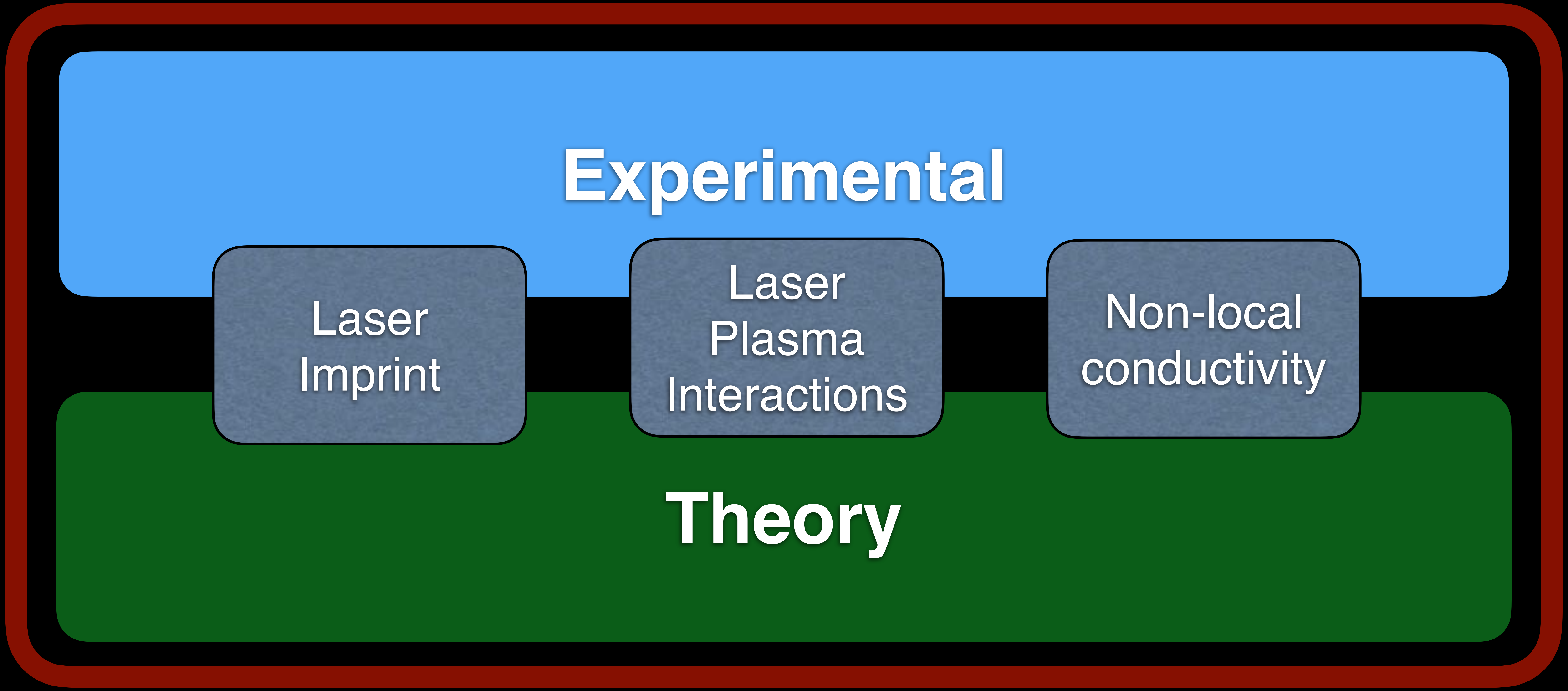

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Laser Imprint

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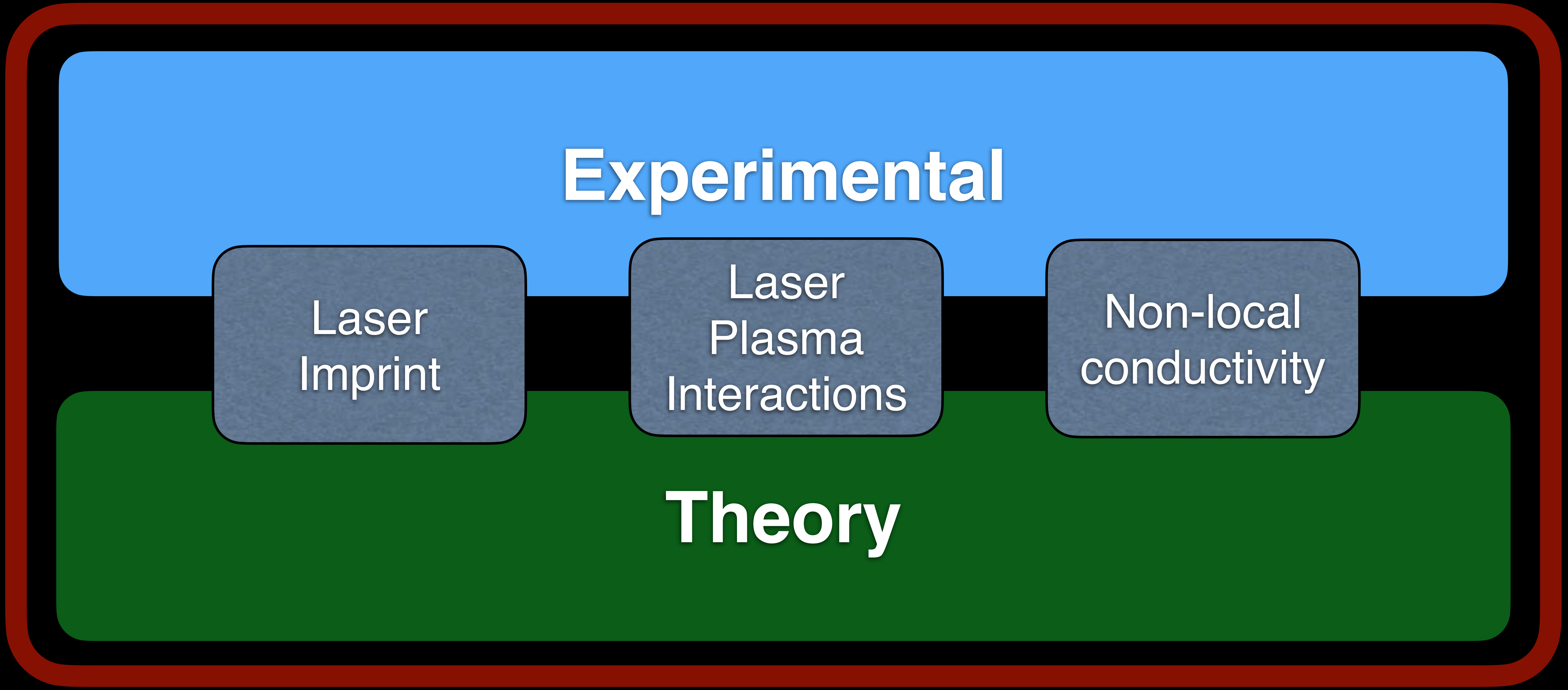
UPLiFT Schematic

Lasers: Efficiency > 10%, 10Hz repetition rate, cheap



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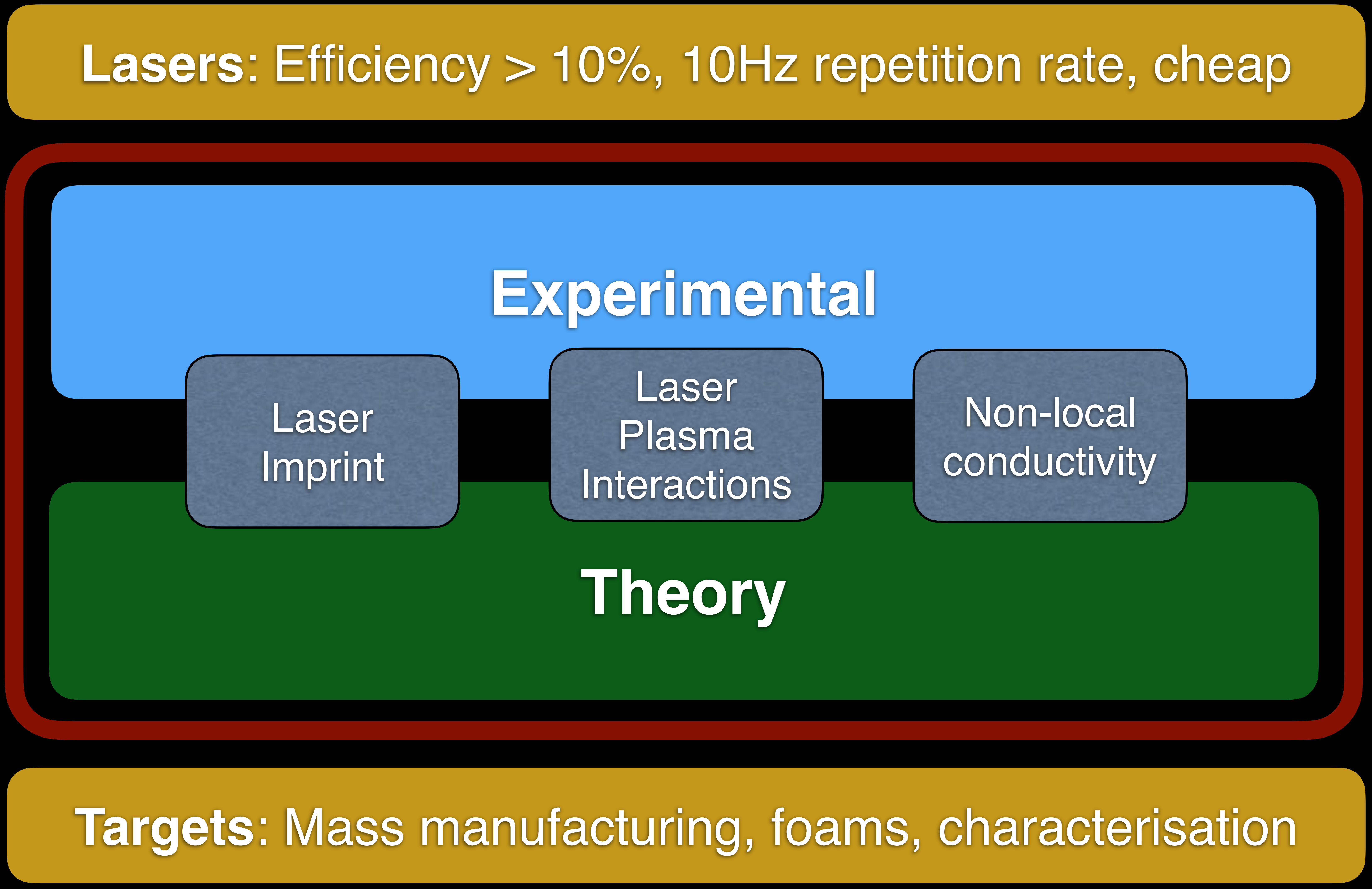

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Targets: Mass manufacturing, foams, characterisation

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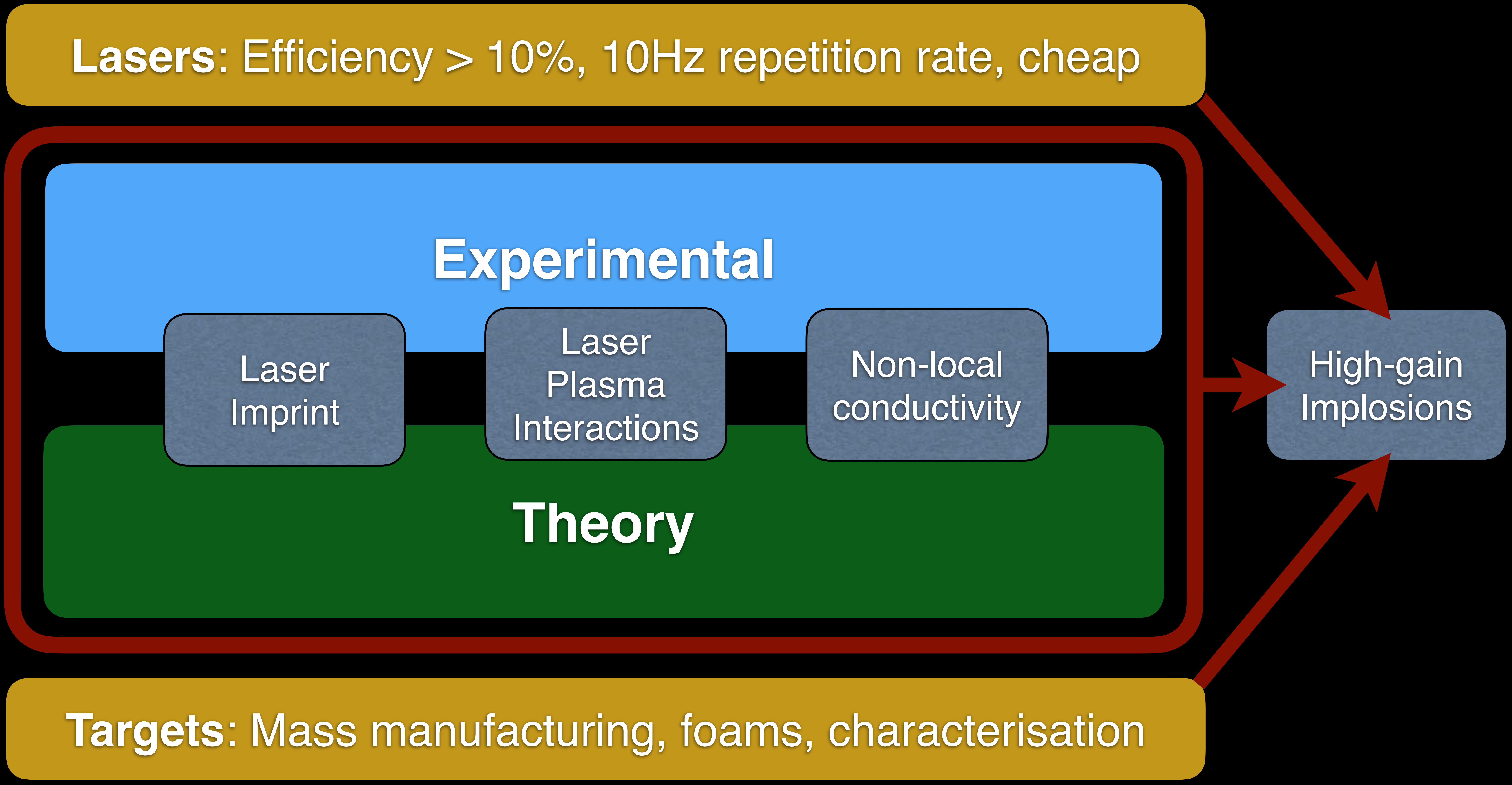

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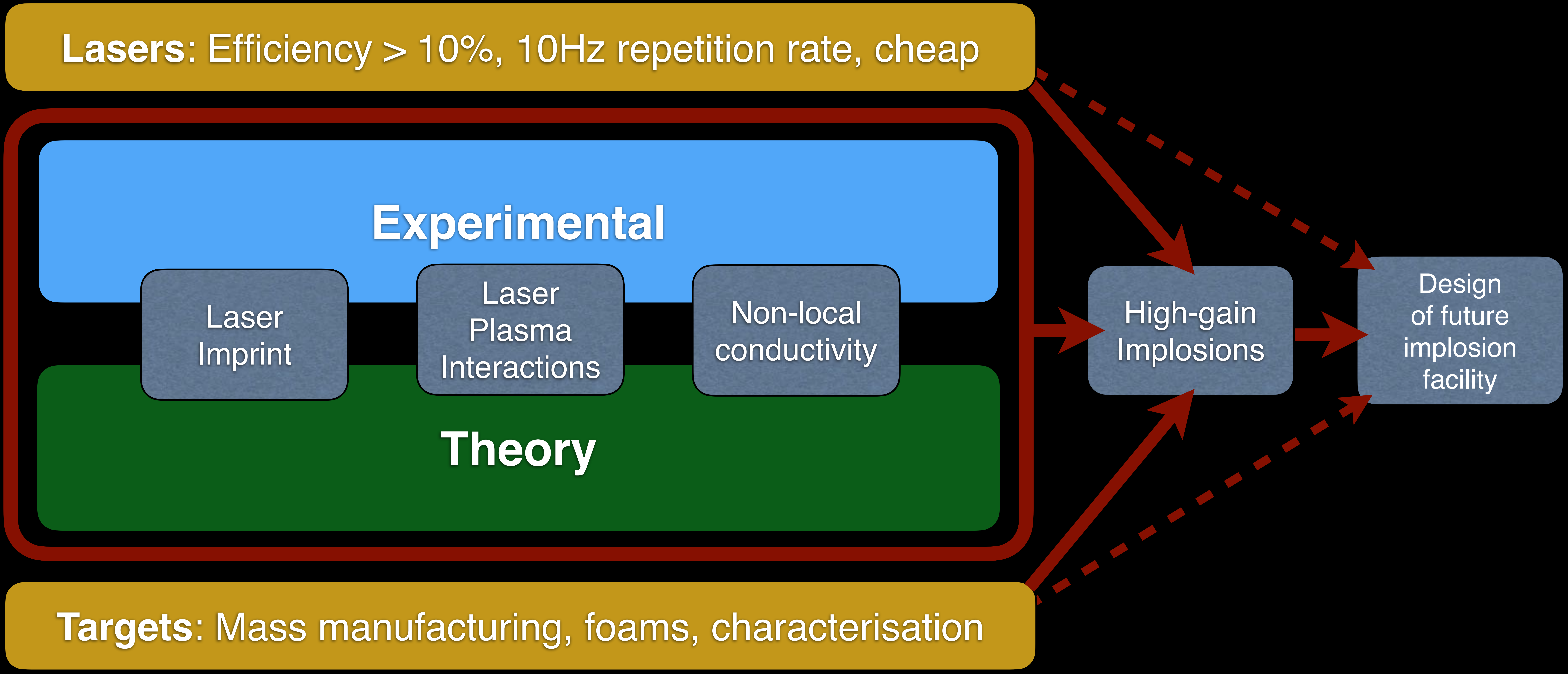

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Laser Imprint

Laser Plasma Interactions

Non-local conductivity

Theory

High-gain Implosions

Design of future implosion facility

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Timeline

2025 2030 2035 2040

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Timeline

- UPLiFT:
  - Phase 1: Lasers, target shells, Direct Drive physics
  - Phase 2: += cryo targets, target injection, facility design

2025 **2030** **2035** **2040**

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- HiGAIN:
  - Spherical Direct Drive Laser Fusion implosion facility
  - High fusion-energy-gain
  - No power production

HiGAIN

Construction

UPLiFT

UPLiFT

Phase 2

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HiGAIN

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HiGAIN

Operations

UPLiFT

UPLiFT

Phase 2

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- GRiD (2nd target chamber):
  - Re-use HiGAIN’s beams
  - Power generating target chamber

GRiD

Construction

HiGAIN

Construction

HiGAIN

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UPLiFT

UPLiFT

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robbie.scott@stfc.ac.uk

Summary

robbie.scott@stfc.ac.uk

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- **Laser Fusion works**

robbie.scott@stfc.ac.uk

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robbie.scott@stfc.ac.uk

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- At **$40 Tn*,** Fusion Energy has **huge projected commercial potential**

*Bloomberg, 2021.

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- Laser Fusion is a **highly credible** approach to fusion energy with **distinct advantages**
- UPLiFT provides an opportunity to take the first steps

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