HiPER:
a laser fusion facility for Europe

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HiPER

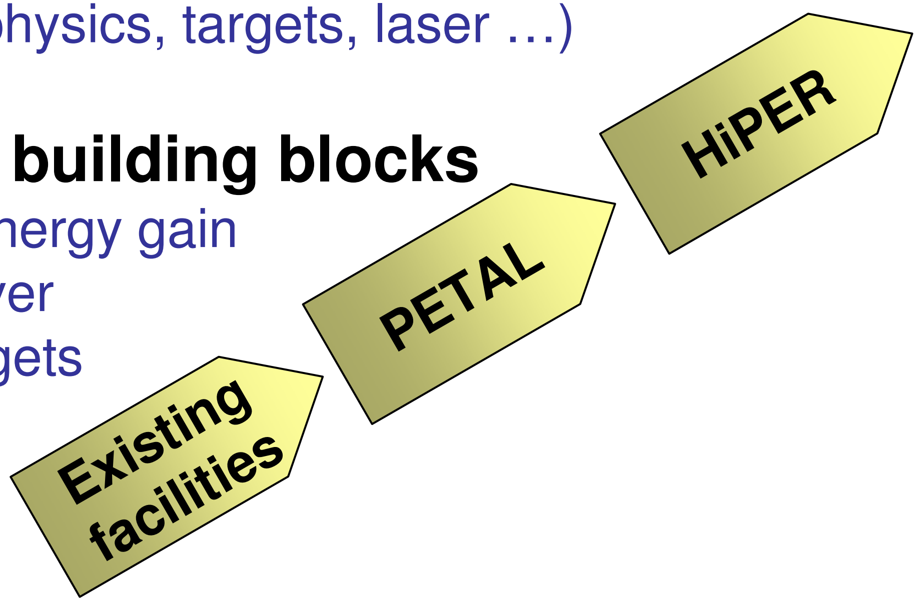
We are entering a new era

- Demonstration of IFE ignition within ~ 5 years
- Visibility of fusion via ITER (and IFMIF)

- **We need to ensure we take full advantage of these fundamental step-changes in our field**

- **International cooperation will be essential**
  - Staged approach: from existing facilities to PETAL then HiPER
  - Coordinated research (plasma physics, targets, laser …)

- **Parallel development of IFE building blocks**
  - Demonstration facility for high energy gain
  - High repetition rate, efficient driver
  - Mass production of complex targets
  - Laser fusion reactor design



HiPER The European proposal

Accepted onto the European large facilities roadmap (ESFRI) – October 2006

Countries involved to date:

UK, France, Spain, Italy, Germany, Poland, Portugal, Czech Republic, Greece, Canada

- 18 month conceptual design period

Next step:

- Detailed design and risk reduction (EC funded project proposal)

Meetings:

- Sep-06 (Cassis), Dec-06 (UK) to determine participation & scale of the next phase

physicsworld Science AAAS CORDIS News nature physics

Defining the specification for HiPER

HiPER Outcome of the conceptual study

- International scale laser is required to establish the route to affordable IFE
- Flexibility will be essential – to address emerging classes of fundamental science applications.
- Needs to offer a unique, competitive capability.
- Needs to be an unclassified facility (to be inclusive)
- FAST IGNITION approach chosen to meet these criteria
  - Scope set to allow multiple FI options
  - Scale set to produce robust high gain

HiPER Flexibility needed for a broad science base

- **Material Properties under Extreme Conditions**
  Unique sample conditions & diagnosis

- **Ultra-Relativistic Particle Acceleration**
  Novel diagnostics for high density matter
  High energy electron, proton, ion … sources

- **Nuclear Physics & Neutron Scattering**
  Access to transient & obscure nuclear states
  IFE based neutron scattering science?

- **Laboratory Astrophysics**
  Viable non-Euler analogues & diagnosis

- **Extreme Field Science**
  Speculative science, but source options exist

Fast Ignition: Scaling Law analysis

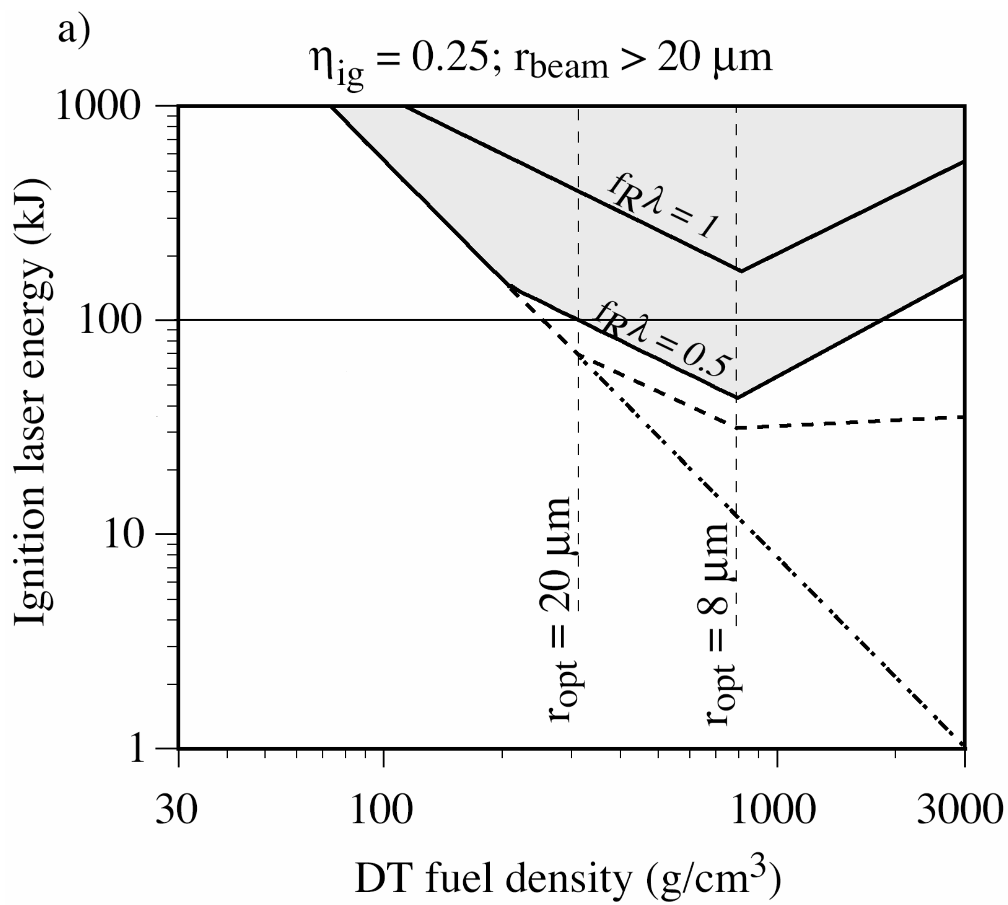
Atzeni et al

Require:
high density (> 300 - 400 g/cm³) and
either range smaller than classical
and/or short wavelength ignition laser

solid curves:
ignition energy at given $f_R\ \lambda$

dashed: ignition energy assuming no dependence on range

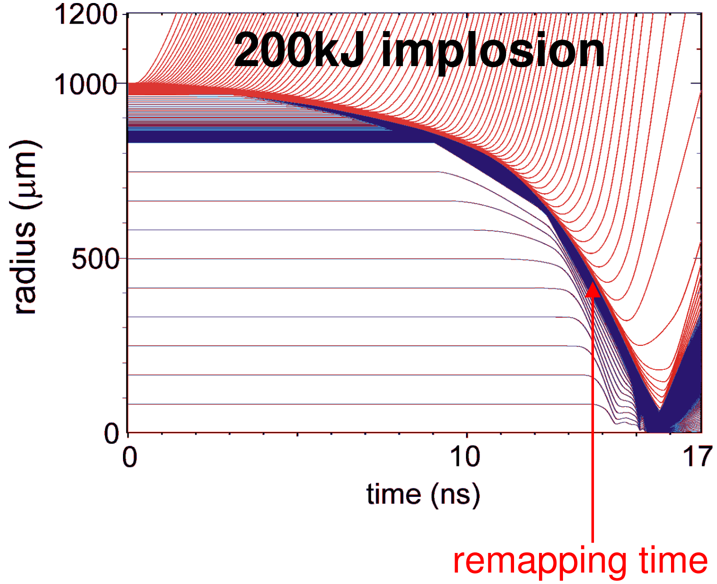
dot-dashed: no dependence on range; no limitation to beam radius



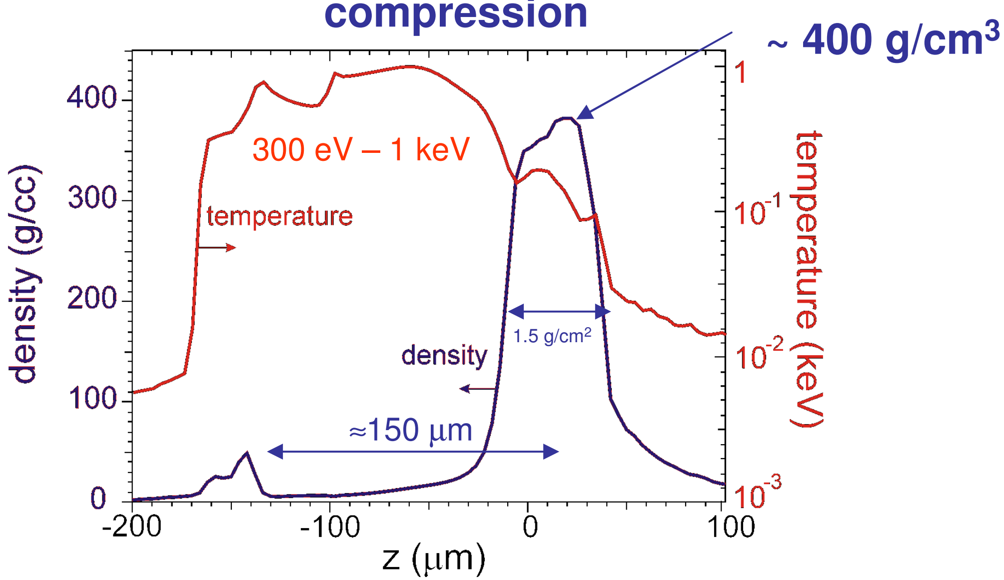
PPCF 47, B769 (2005)

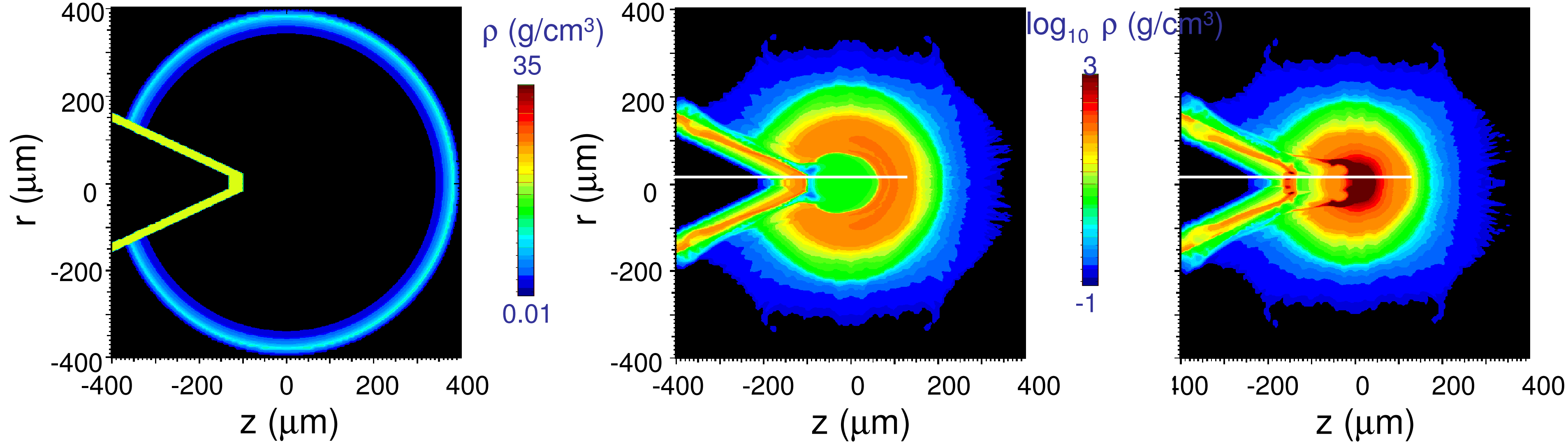
HiPER Simulations of fuel compression

Honrubia et al



profiles at peak compression





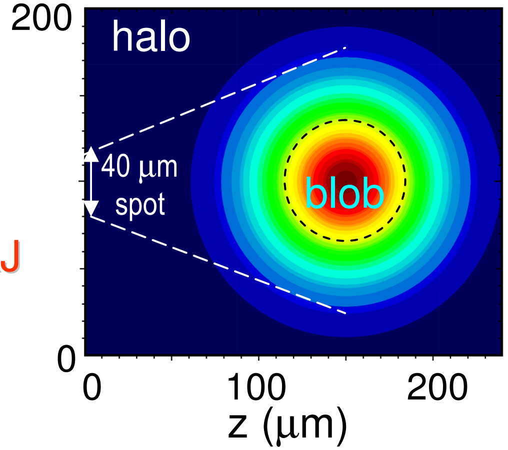
HiPER 3D Electron heating simulations

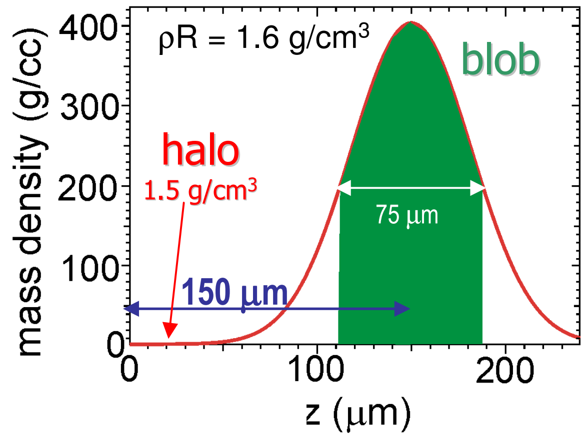
GIFI

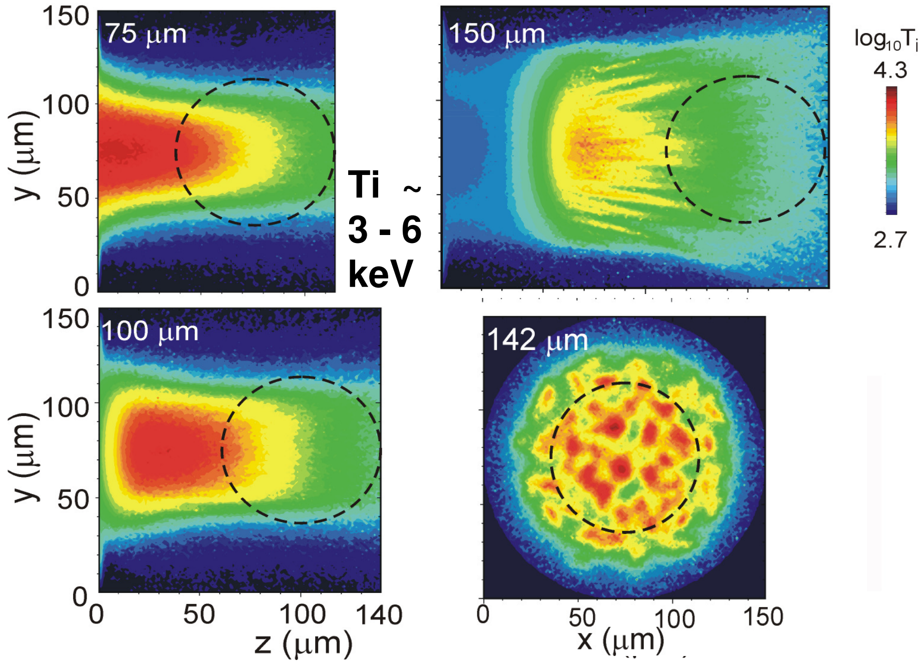
Honrubia et al

3.5 MeV fast electrons

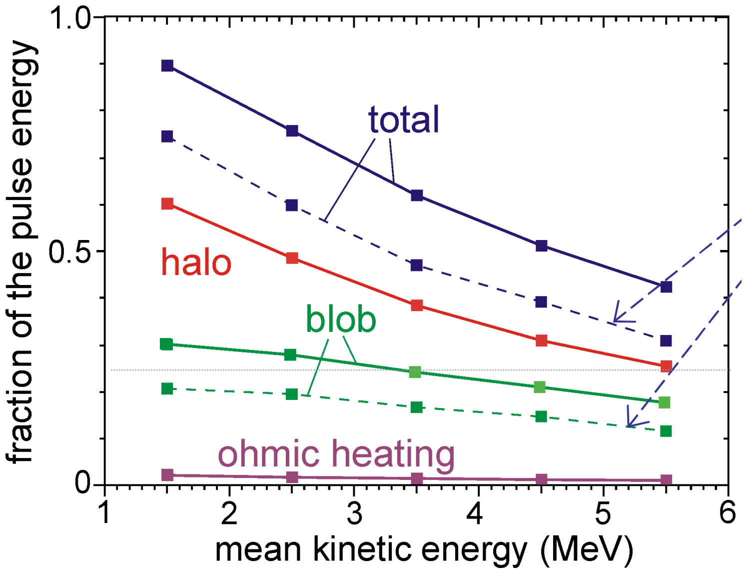
3 PW, 10 ps, 30 kJ





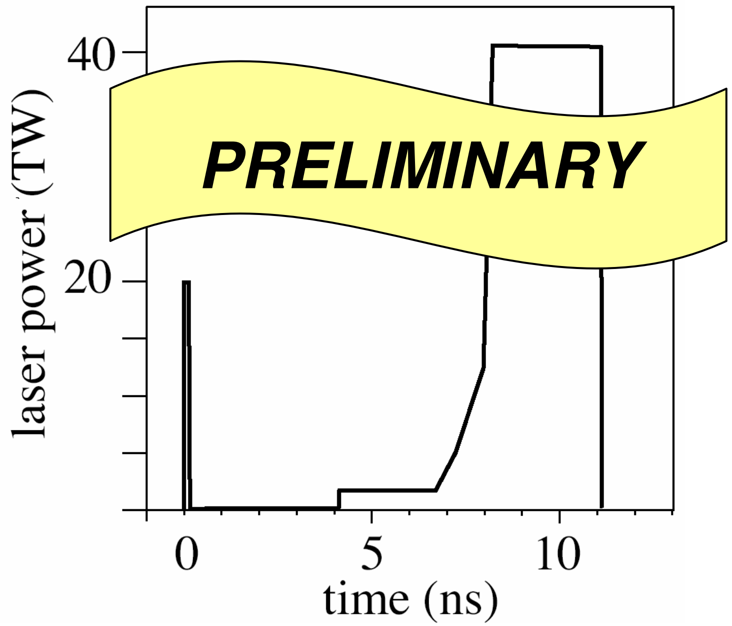


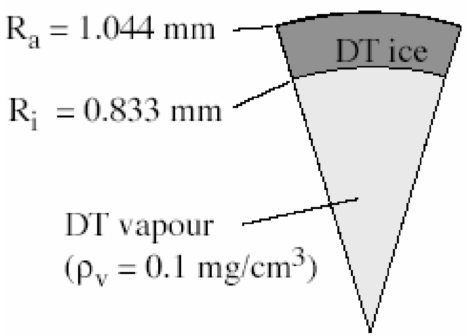
Full 3D simulation



HiPER Scoping the target performance

Recent modelling with a shaped adiabat (Atzeni, Bellei, Schiavi)





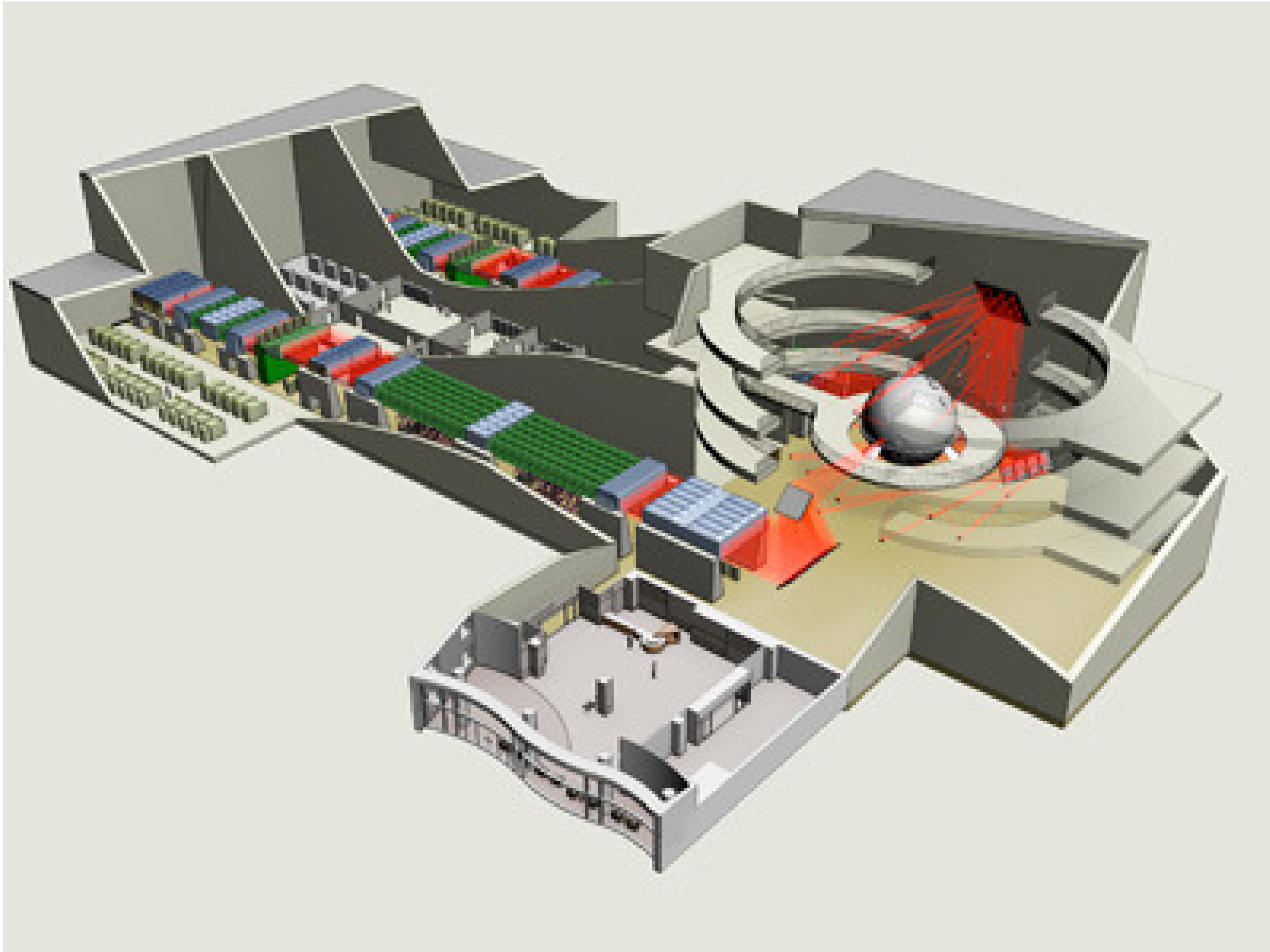
		Reference target	
Compression driver energy (kJ)	90	**132**	270
Imploded fuel mass (mg)	0.19	**0.29**	0.58
peak density (g/cm^3)	510	**500**	510
ρR (g/cm^2)	1.33	**1.58**	1.98
Ignition driver energy (kJ), assuming η_{ig}=0.25	80	**80**	80
Fusion yield (MJ)	5 (estimate)	**13 (2D simulation)**	35 (estimate, based on previous simulation of similar targets
GAIN	30	**61**	100

Based on theoretical and experimental work by Betti *et al* (LLE)

Baseline specifications

1. **Implosion energy:**
   200 kJ in 5ns
   10 m chamber
   40 beam irradiation?
   2ω or 3ω?

2. **PW beamlines:**
   70kJ in 10ps
   wavelength?
   number of beams?



3. Future OPCPA options to provide 150 PW beam (probe) and/or 2 EW (driver)

4. Enhanced support infrastructure & cooperation required throughout Europe

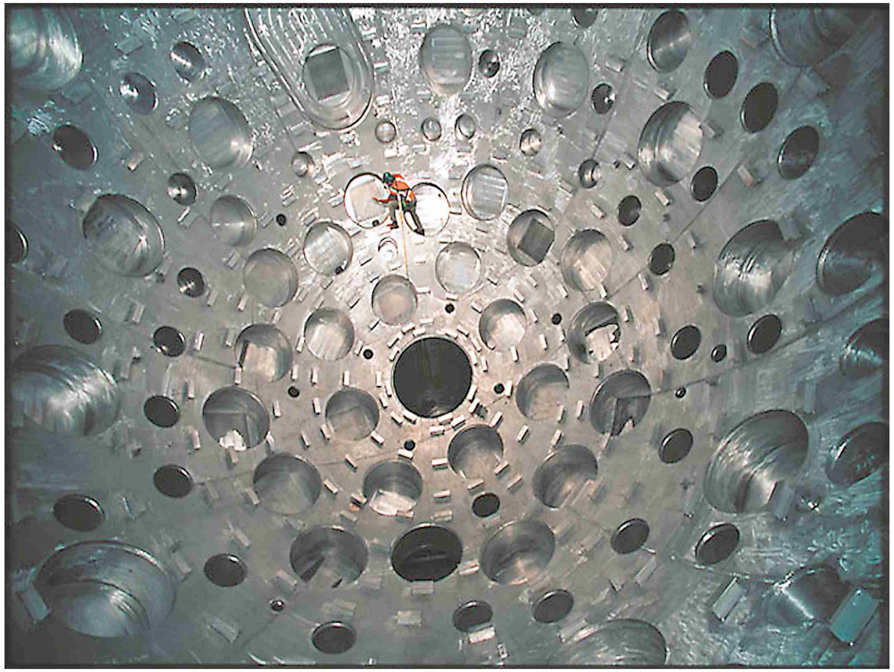
HiPER Four target areas are envisaged

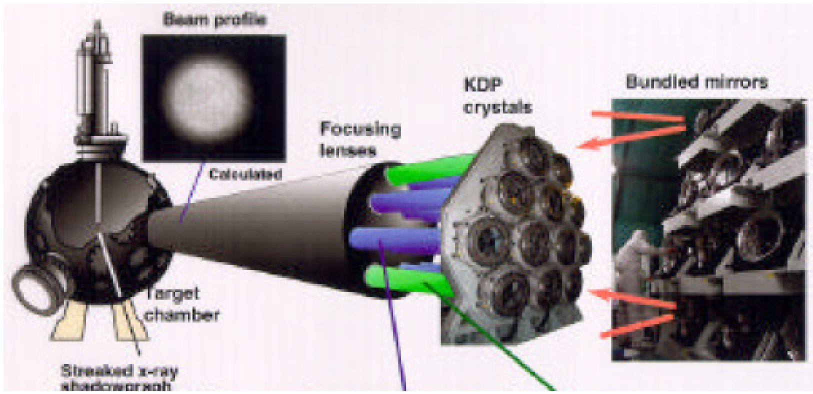
1. **High gain fusion chamber** (all beams)

2. **Flexible science area**
(100kJ long + 70kJ short)
Cluster configuration

3. **High repetition rate diagnostics** and technique development area
(**10kJ / 1Hz or 1kJ / 10Hz**)

4. High repetition rate area for **fusion technology development**





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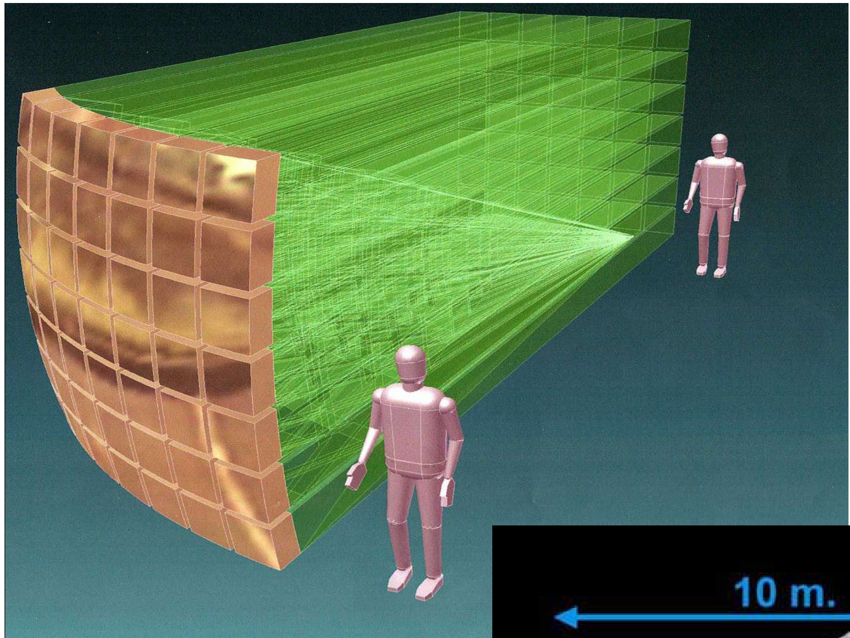
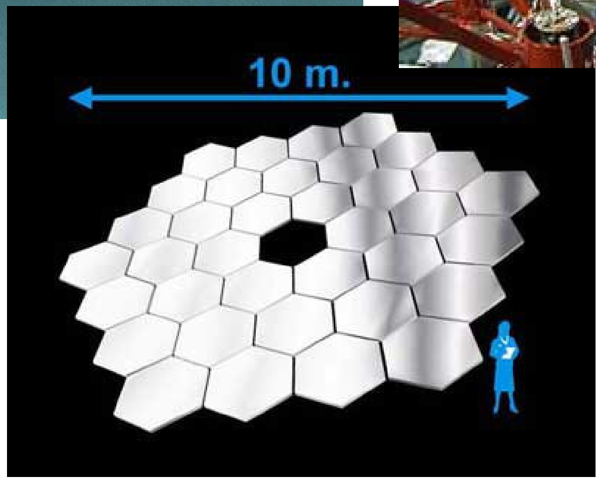
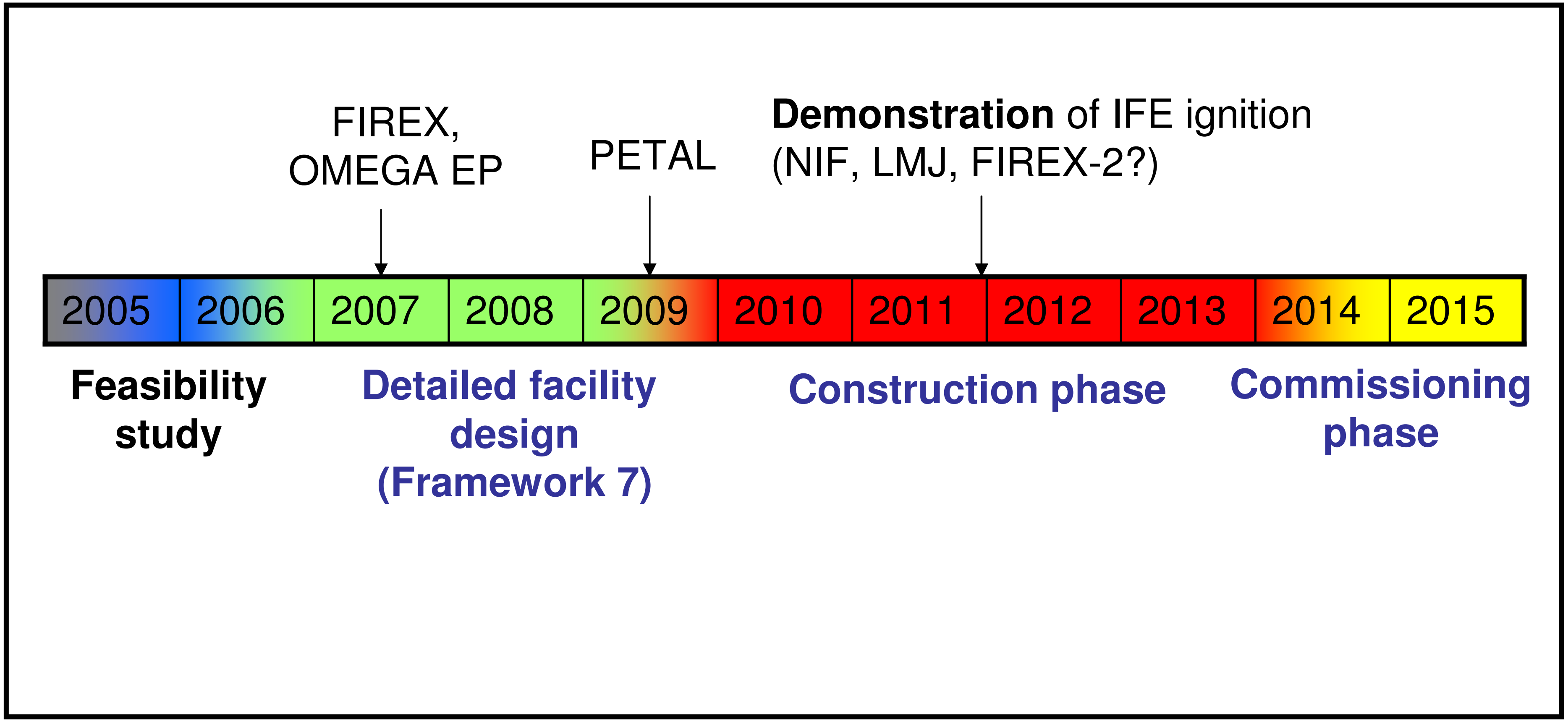
Focusing the high power laser beams

Use similar approach to the large area optical telescope community





HiPER Preliminary timescale



HiPER **Project – timescale & contacts**

Development of the HiPER preparatory phase study:

Timescale:

- **June-Sept 06**: specification of design study milestones
- **Sept-Dec 06**: integration of the milestones; institutional commitment; division of labour
- **Early 07**: submission to FP-7

Team Leaders:

- Fusion science case: Stefano Atzeni (Rome)
- High energy density science case: Michel Koenig (LULI)
- High power science case: Luis Silva (Lisbon)
- Laser design: Bill Martin (RAL)
- Experimental & Diagnostic issues: Dimitri Batani (Milan)
- Fusion Technology Manolo Perlado (Madrid)

HiPER Objectives for this proposal phase (2006)

(1) Agree a balanced project plan

(2) Identify which institutions will participate

We are developing **a project plan which will:**

- provide sufficient **design** detail to allow adequate costing
- execute a detailed **risk mitigation** plan to address the key risks to the main project phase
- establish sufficiently robust **scientific confidence** in Fast Ignition that we can reasonably expect high gain and a future reactor programme
- pull together a trans-national **political commitment** and associated legal framework

HiPER Developments needed in the design phase

- Enhanced research into Fast Ignition and scientific applications is needed to refine the HiPER specification
  - Coordinated ongoing research programmes
- R&D required to address key issues
  - Implosion effectiveness at 2ω
  - Ignitor operation at 2ω or 3ω ?
  - OPCPA at high power
  - High repetition rate beamline approach
  - Target supply
- Increase in community size and breadth
  - Significant training of new scientists and technicians
  - Coordination between international partners
- Political decision to proceed
  - Purpose of the Framework 7 "preparatory phase" design study

Links to other developments (1)

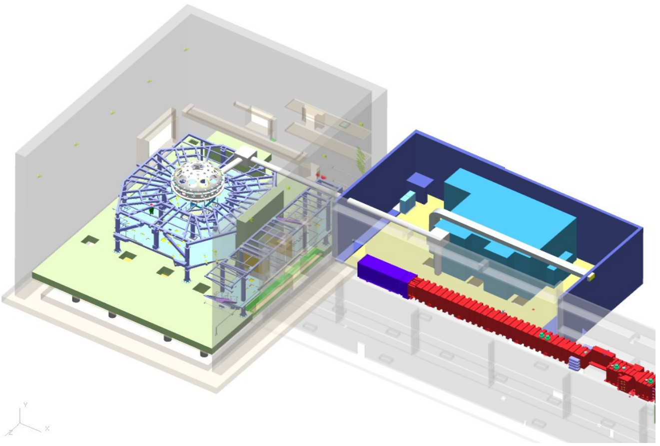
1. A single approach to IFE within Europe is planned

Common strategic theme, with phased facility development:

– PETAL: Integration of PW and high energy beamlines

– HiPER: High yield facility

Coordinated scientific and technology development between the major European laser laboratories



3.5 kJ	60 kJ
0,5 – 10 ps	8 beams
Up to 7 PW	ns , 3ω

The PETAL scientific program is under the Institute Lasers and Plasmas (ILP) which coordinates high intensity lasers activities in France

HiPER Links to other developments (2)

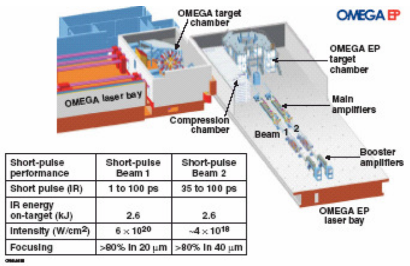
2. Lessons from emerging generation of facilities (FIREX, EP, …)

3. Activities to ensure growth of the European laser community

- via national and other international projects
- via Laserlab-Europe I3.

4. Coordination with other international partners

- USA, Japan, Canada, Korea, China, Russia, …



Short-pulse performance	Short-pulse Beam 1	Short-pulse Beam 2
Short pulse (IR)	1 to 100 ps	35 to 100 ps
IR energy on-target (kJ)	2.6	2.6
Intensity (W/cm^2)	6×10^{20}	$\sim 4 \times 10^{18}$
Focusing	>80% in 20 μm	>80% in 40 μm

2007 OMEGA EP laser, USA
5.2kJ PW + 30kJ $3\omega_0$

2007 FIREX-I laser Japan 10kJ PW + 10kJ $2\omega_0$
FIREX-II: 50kJ + 50kJ

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Conclusions

- We are entering a new era for Fusion Energy
- Fast ignition risks are high but a coordinated 3-year program seems sufficient to assess future viability
- Timely planning for the next generation is essential
- Concept now included on national & European roadmaps
- Next stage is detailed facility design and risk reduction

This is the Fast Ignition Workshop

If we believe that FI has a chance then we need to coordinate our work