Fast Ignition-High Energy Density Physics and Fusion

Mike Campbell

Vice-President Fission,,Photonics and ICF
General Atomics
San Diego, California

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Fast Ignition is the "Fusion" application of the emerging field of Ultra-fast, Ultra-intense Lasers (UUL) and HEDP

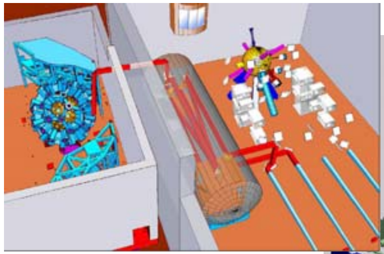
- Fast Ignition is a concept that is incorporates many HEDP topics :
  - Relativistic laser-plasma interactions and relativistic plasma production
  - Relativistic Electron transport and energy deposition with giga-amp/cm^2 current densities (I >>Alfven current)
  - Innovative low α "cold compressions" to high ρ and ρR fuel assemblies
- FI research contributes to techniques for creating and probing dense plasmas
  - Proton/ion beams for radiography and isochroic heating
  - High (hν >50 keV) x-rays
- Attracting world-wide talent to plasma physics
  - ~50% of the 70 HEDP PRLS from 2000-2004 were UUL related

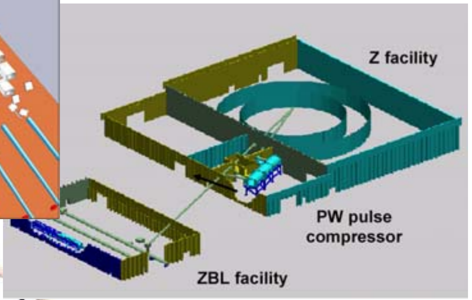
" Our fast ignition work is our current contribution to the emerging field of high energy density physics, an area that we hope to expand in the future. "
R Orbach OFES Feb 2004

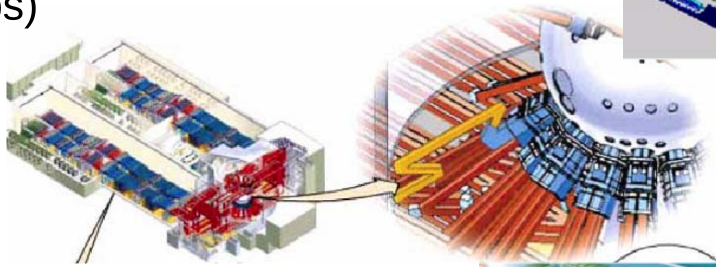
Investment in short pulse facilities by NNSA and overseas provides capability to develop and evaluate FI

NNSA plans to add multi-kilojoule Petawatts to HEDP Facilities in the 2006-2010 timeframe

- Omega-EP - 2 beams (~5 kJ/10psec)
- Z-PW - I beam (~2 kJ/5-10 ps)
- NIF-PW - ~4 beams (5 kJ/5-10ps)

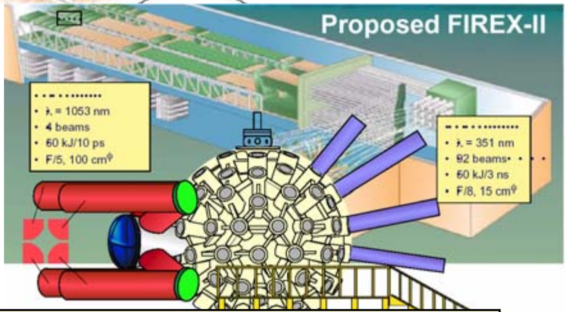






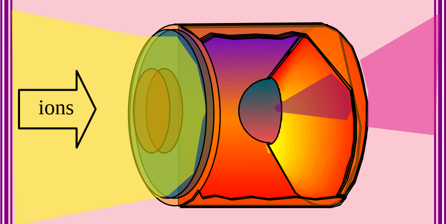
Japan

- Firex I - **FY06** 10 kJ/10ps, 10 kJ/2 ns

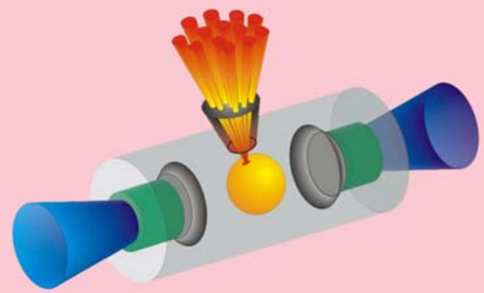


> **"The resources needed to reach this goal will require the involvement of the world scientific community…. We look forward to more closely coordinating FI research between Osaka and the OFES in the future to enable this innovative concept to be more rapidly evaluated**
>
> K Tanaka, ILE FI experimental leader, to A Davies, March 2004

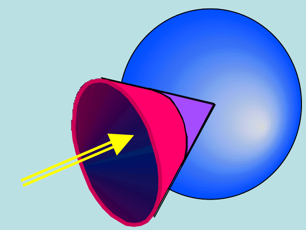
Fast Ignition is compatible with all "compression" drivers



Heavy Ion Beam Drive



Heavy Ion Beam Drive

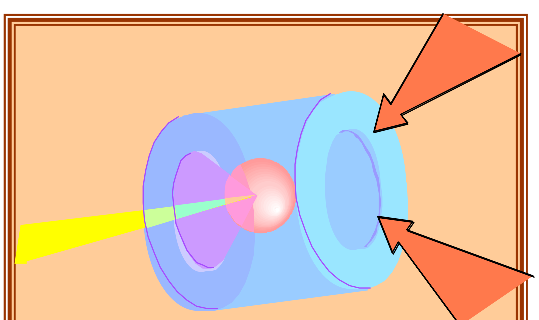


Direct Laser drive

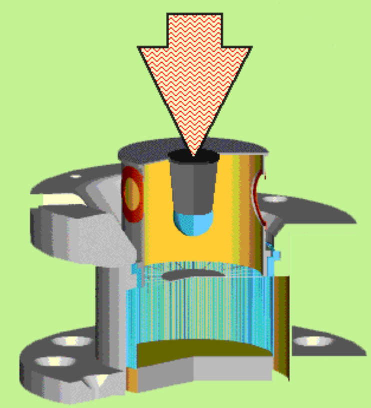
Innovative target designs are possible

BUT

Ignitor laser energy must be determined!



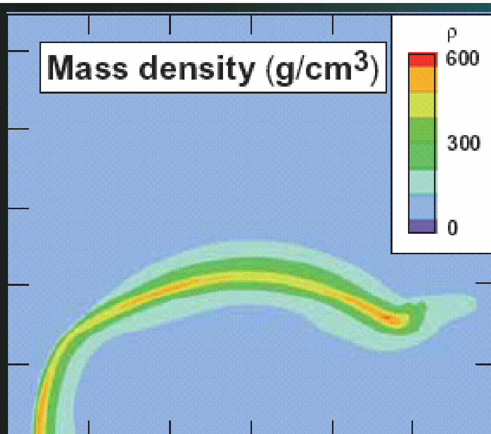
Indirect Laser drive

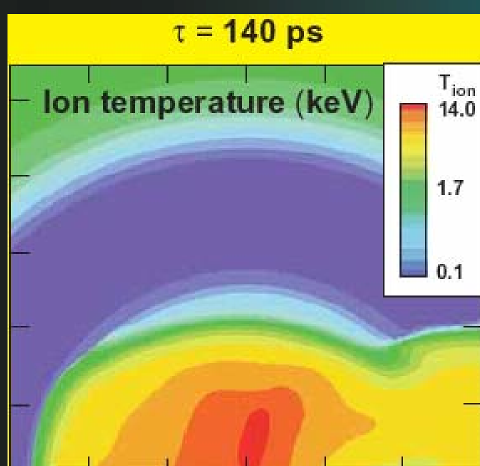


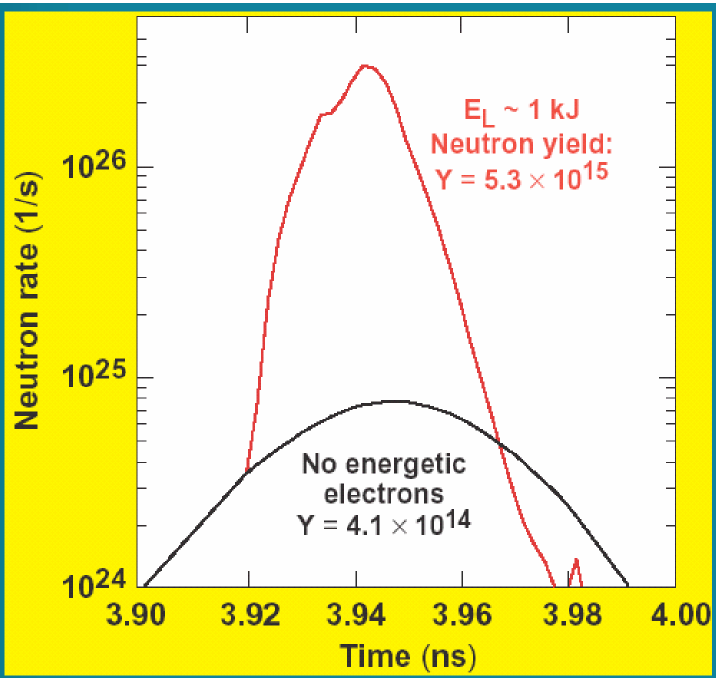
Z-pinch Drive

Proof of Principle Experiments are possible on US and Japanese facilities in the 2006- 2010 time frame

2-D simulation of Omega-EP using 25kJ compression, 1 kJ ignitor e-beam







Simulation shows Q≤0.5:

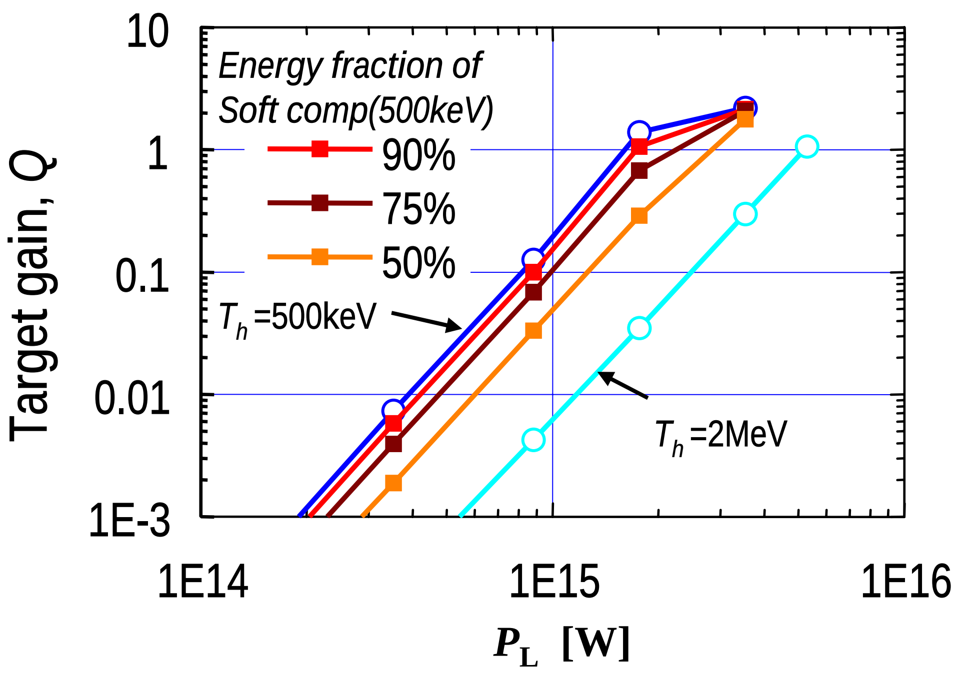
ρ~300 g/cc, T_{ion} up to 14 keV, n~5x10^{15}

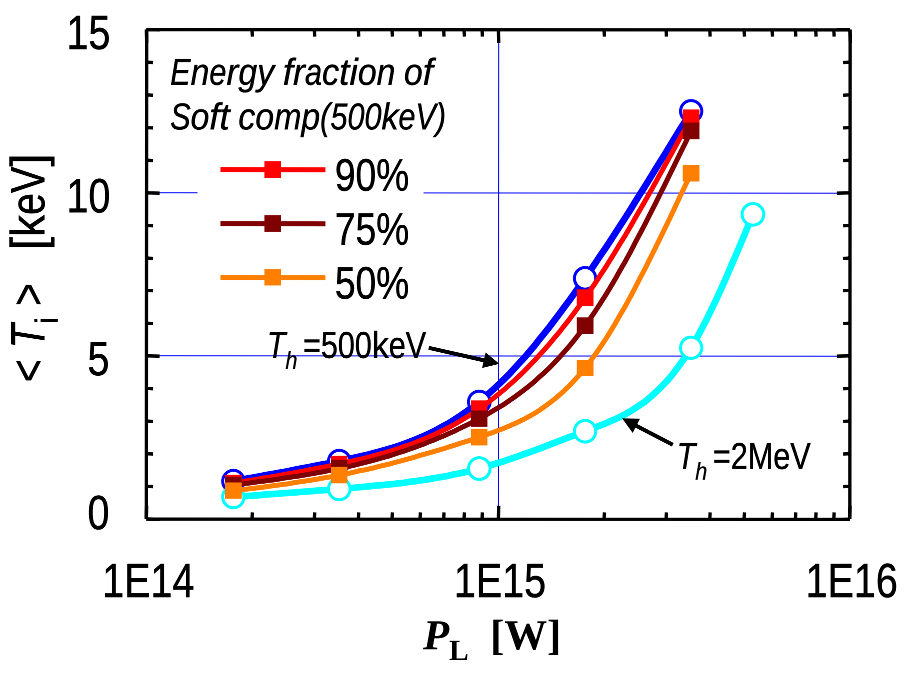
Energetics and F-P modeling indicate "PoP" regimes for FIREXI

ILE OSAKA

- Beam electron energy spectrum : slope temperature (1comp. or 2comp.)
- REB duration = 10ps
- Compresed core at 300 g/cm^3 and 0.2 keV
- By assuming 30μmϕ beam spot and 40% coupling efficiency from laser to REB

Heating Laser power, $P_{Lh} = I_{REB} \times \pi r_b^2 / \eta_h$





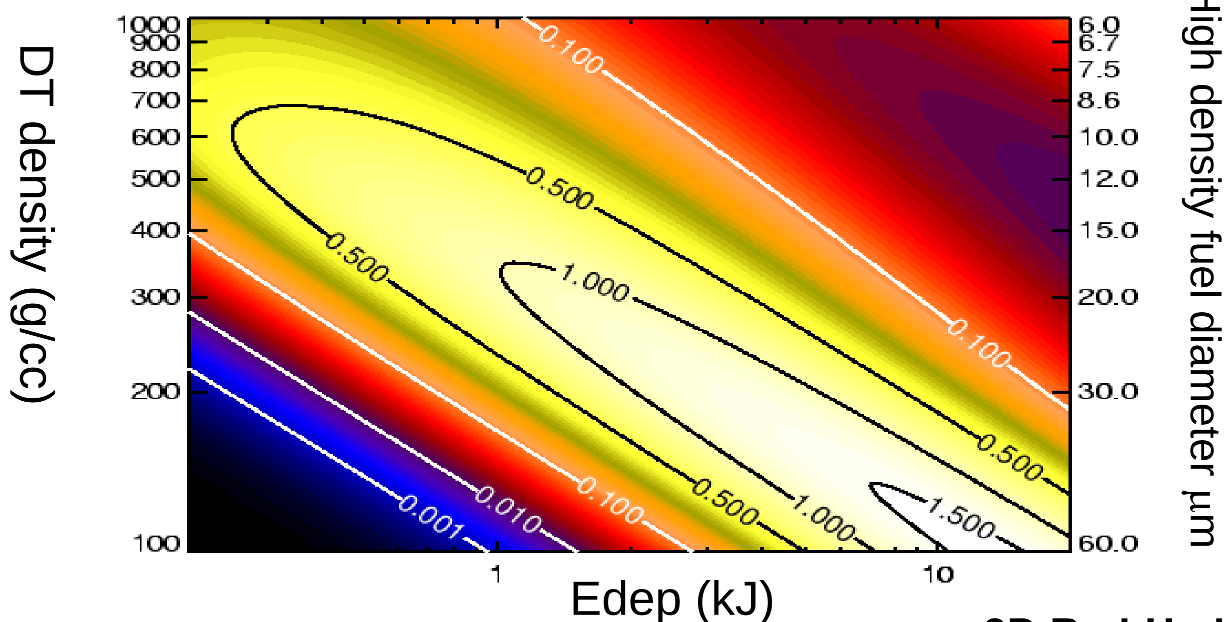
Q ~ 0.1 may be possible !

SNL is exploring FI target designs and beginning fuel assembly experiments

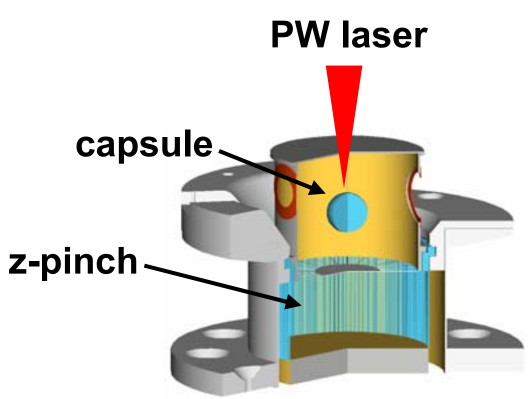
Sandia National Laboratories

$\rho R = 0.6$, $\tau_p = 5ps$

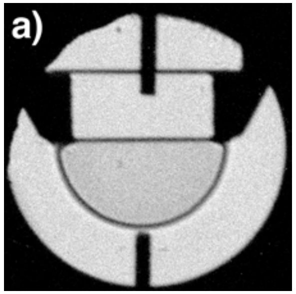
Calculated $Q = E_{tn} / E_{dep}$



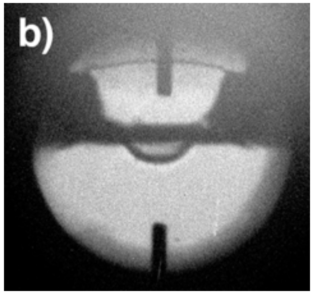
Fast Ignitor ICF target driven by a single sided z-pinch



Experimental 6.7 keV backlit capsule images on Z

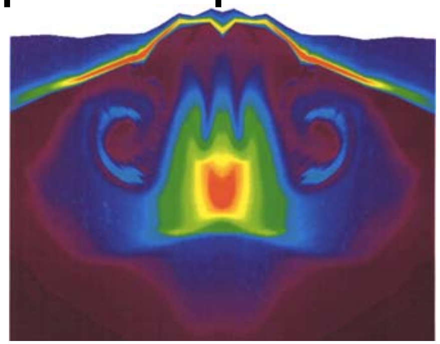


initial



$C_r = 3$

2D Rad-Hydro simulation of capsule compression on Z



max density = 135 g/cm^3
max ρz = 1.1 g/cm^2

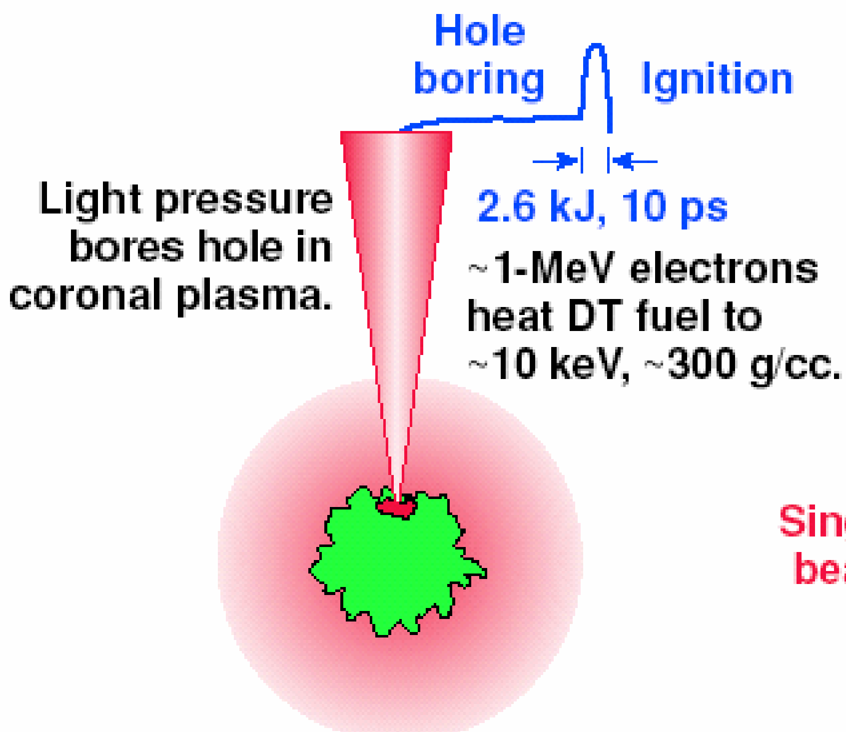
An enhanced FI OFES is required to develop the scientific foundations to exploit emerging capabilities

- Relativistic Laser-matter interaction with ~10 psec pulses with “imploded target” (including cone plasma)
- e-transport in dense plasmas of varying resistivity
- Self-consistent imploded target design suitable for “high gain”

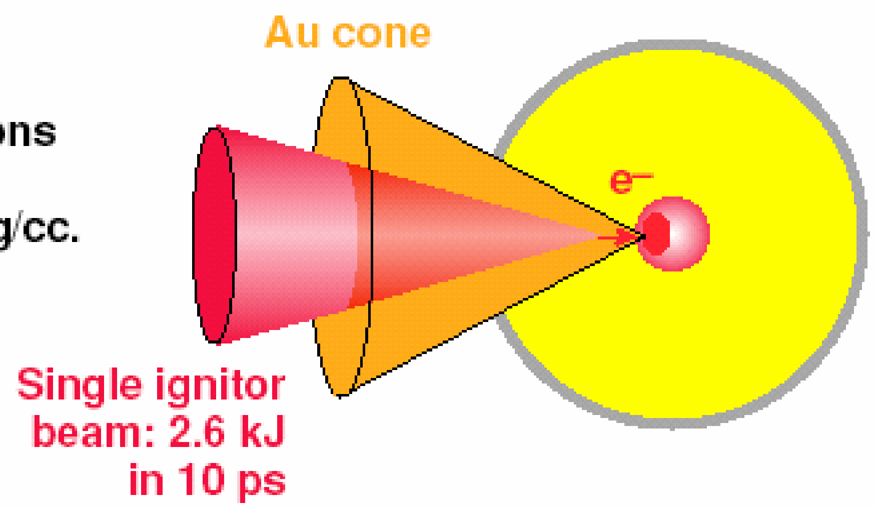
OFES supports the science and NNSA and Japan construct and operate the facilities!

The two fast-ignition concepts share fundamental issues: hot-electron production and transport to the core

Channeling concept

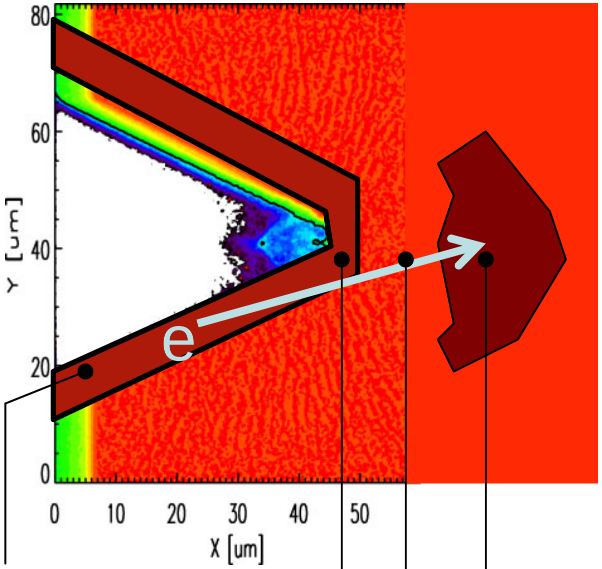


Cone-focused concept



OMEGA-EP can explore both concepts

Electron transport to target crosses many regimes



Critical Surface

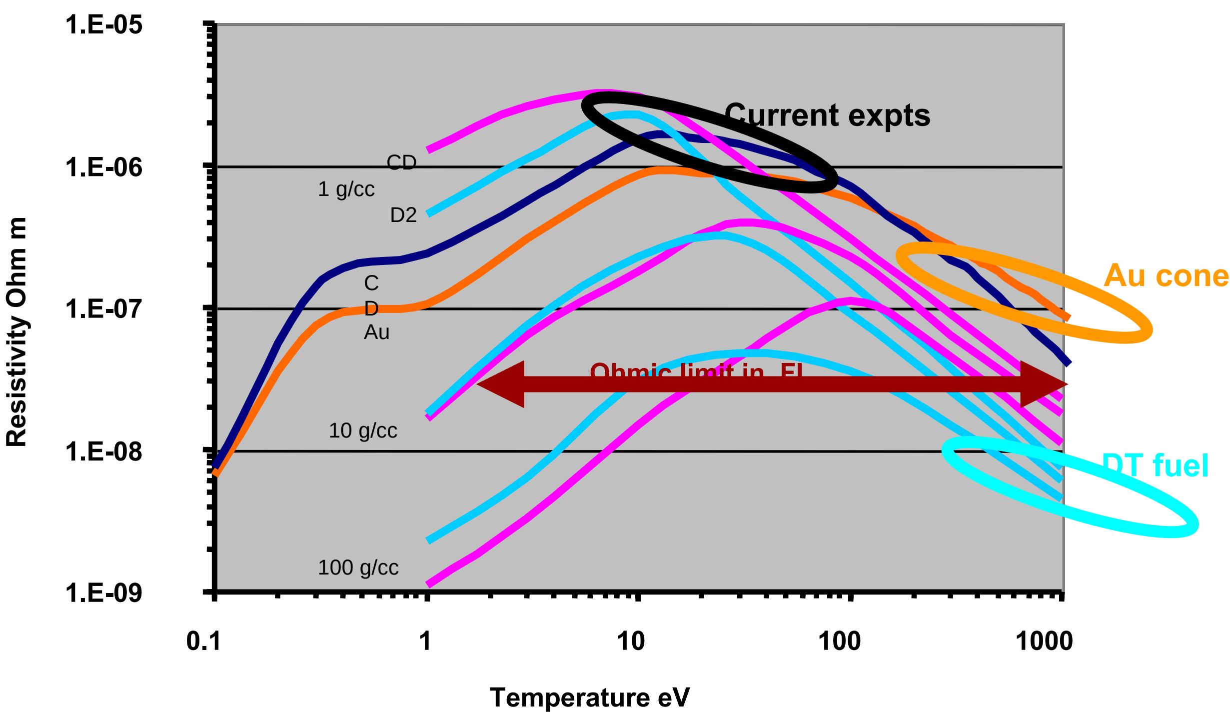
Dense Gold

Coronal Plasma

Compressed Core

Plasma resistivity is important

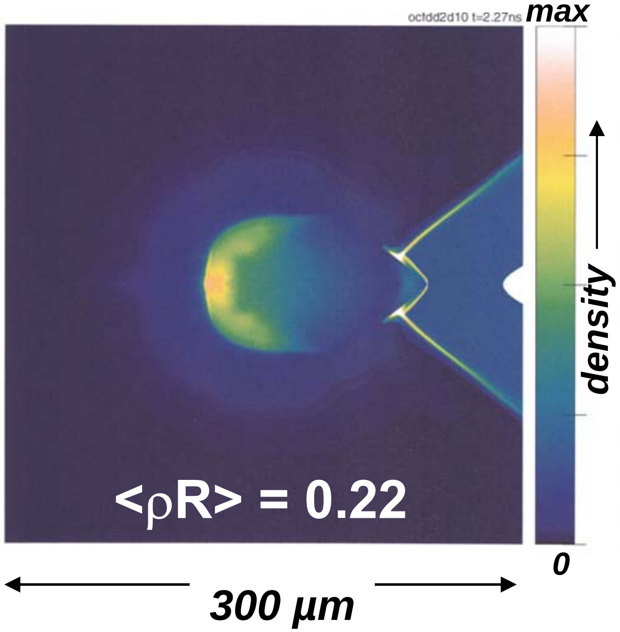
- R(T, Z, ρ) changes dramatically in transit
- Reactive fields couple REB with cold electrons



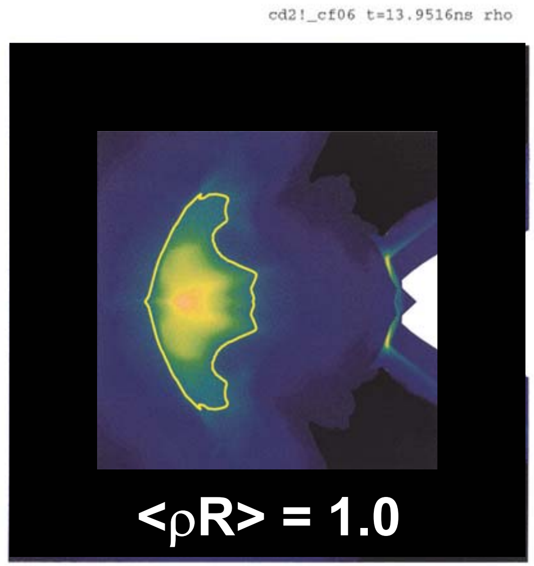
Experiments are evolving toward high temperature regime

FI Relevant Fuel assemblies (hotter,denser plasma cores) can be studied at NNSA facilities

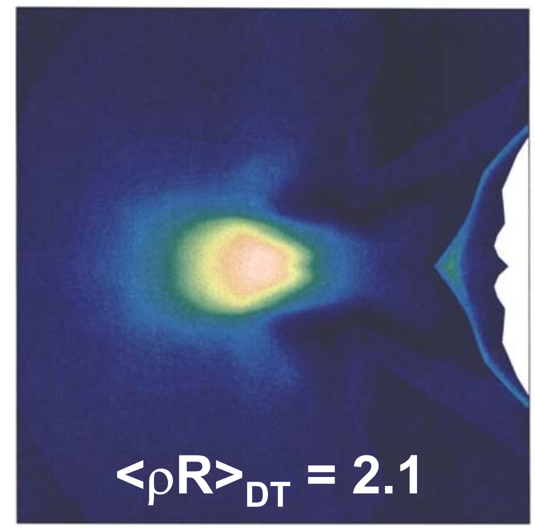
Omega scale CD



Early (2007) NIF scale CD



Full NIF scale DT



- **Requires penetrating diagnostics (petawatts!)**
  - **Proton beam radiography**
  - **High energy K_a backlighting**

Expand the Science to match the expanding experimental capability

FY05 FY06 FY07 FY08 FY09 FY10

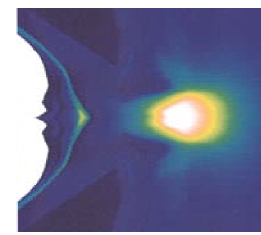
Concept Exploration
E_{comp}~10kJ, E_{heat}~1 kJ

Proof of Principle
E_{comp}~10 kJ E_{heat}~10 kJ G= 0.1-0.5

Performance Extns’n
E_{comp}~100 kJ
E_{heat}~100 kJ
G ~1

Transport	Hi Ω	Hot lo-Z	Dense lo-Z	Core heating
Fuel assy	Cone geometry	Integrated	pure DT	
Target	Wetted foam	Layered ice		
Diagnostic	E,B-fields	Core x-ray	Localized n	
Modeling	Benchmark	Laser-cone	Integrated	

Ignited Plasma



Japan Gekko | Firex I | FirexII

US Omega, Z | Omega EP, Z-R | NIF

Modest OFES support is required to meet these goals over the next several years

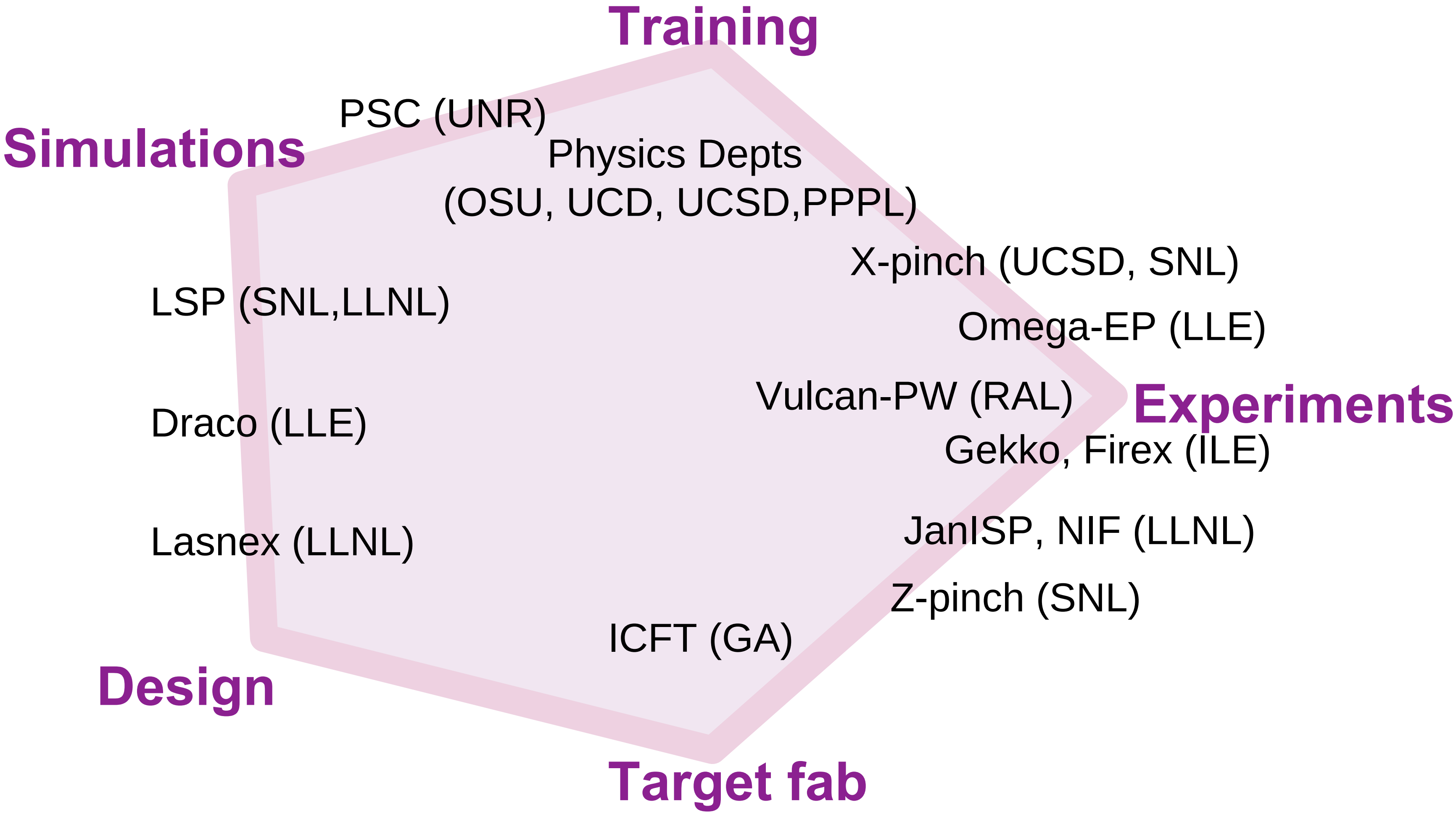
Effort (FTE)	FY06	FY07	FY08	
Transport	3	5 (cryo)	9 (cryo)	~2 exptl campaigns/yr
Fuel assy	3	3		~2 exptl campaigns/yr
Target dev	2	2		
Diagnostic	2	2	2	incl~$1M equip costs
Modeling	3	4	5	
Approx Cost	$4.5M	$5.0M	$5.5M	
	(FTE~$0.3M/yr, expt ~$0.5M, cryo expt ~$2M)			

Existing program ~ $2M/y ($0.8M OFES, $1M internal)

Added cost	**$2.5**	**$3.0**	**$3.5**

Facility modifications for FI and operations are NOT funded by OFES

This program is a cooperative effort with Universities, National Laboratories and Industry



Many of these institutions have been working together for 3 years

Fast Ignition is an exciting Scientific challenge that combines HEDP and fusion

- **Timely**:
  - New short pulse capabilities added to “implosion facilities provide access to extreme plasmas relevant to FI
- **Rich science that expands our capabilities:**
  - strong interaction of “extremes
- **International collaboration:**
  - Japan is a world leader in FI research
- **OFES and NNSA collaboration:**
  - Highly leveraged OFES activity

Proposed Activity enables an serious exploration of Fast Ignition while contributing to HEDP Science

- **Addresses physics issues:**
  - Transport, fuel assembly,target science, modeling tools, diagnostics
- **Develops the capability to integrate them**
  - Self-consistent, physics-based target design and experimental validation

A pathway to take FI to concept to Proof of Principle and beyond is possible