FUSION SCIENCE CENTER FOR EXTREME STATES OF MATTER AND FAST IGNITION PHYSICS

FSC

OVERVIEW and PLANS for 2008-09

FSC

R. Betti
for the Fusion Science Center team
UR, MIT, UCSD, OSU, UNR, UT, UCLA, GA, LLNL

DOE-OFES, FY09 Budget Planning Meeting
Gaithersburg, MD, March 13-14, 2007

FSC members are from ten institutions across the US

FSC

- → Participating Institutions: UR, MIT, UCSD, OSU, UNR, UT, UCLA, GA, LLNL
- → FY07 funding: DOE $1.088M, NYSERDA/LLE $150K, UR $81K
- → 16 faculty and senior scientists
- → 13 research associates and post-docs
- → 19 PhD students
- → 5 external advisors: Kilkenny (GA), Porkolab (MIT), Sheffield (U. Tenn), Tabak (LLNL), Town (LLNL)

FSC members interact through a monthly conference call and semi-annual meetings. The FSC produces an annual report.

FSC

- **Fusion Science Center Meetings**

  1st FSC Meeting: September 24, 2004, Cambridge MA
  2nd FSC Meeting: June 1-2, 2005, San Diego CA
  3rd FSC Meeting January 26-27, 2006, Rochester NY
  4th FSC Meeting August 28-29, 2006, Livermore CA
  5th FSC Meeting: February 28, 2007, Chicago IL

- **FSC Annual Report**

  Comprehensive activity reports have been produced for 2006 and 2007 and distributed to DOE and FSC advisors

FSC annual reports and meeting presentations are available on the FSC web site at fsc.lle.rochester.edu

FSC refereed publications and invited talks in 2006-07

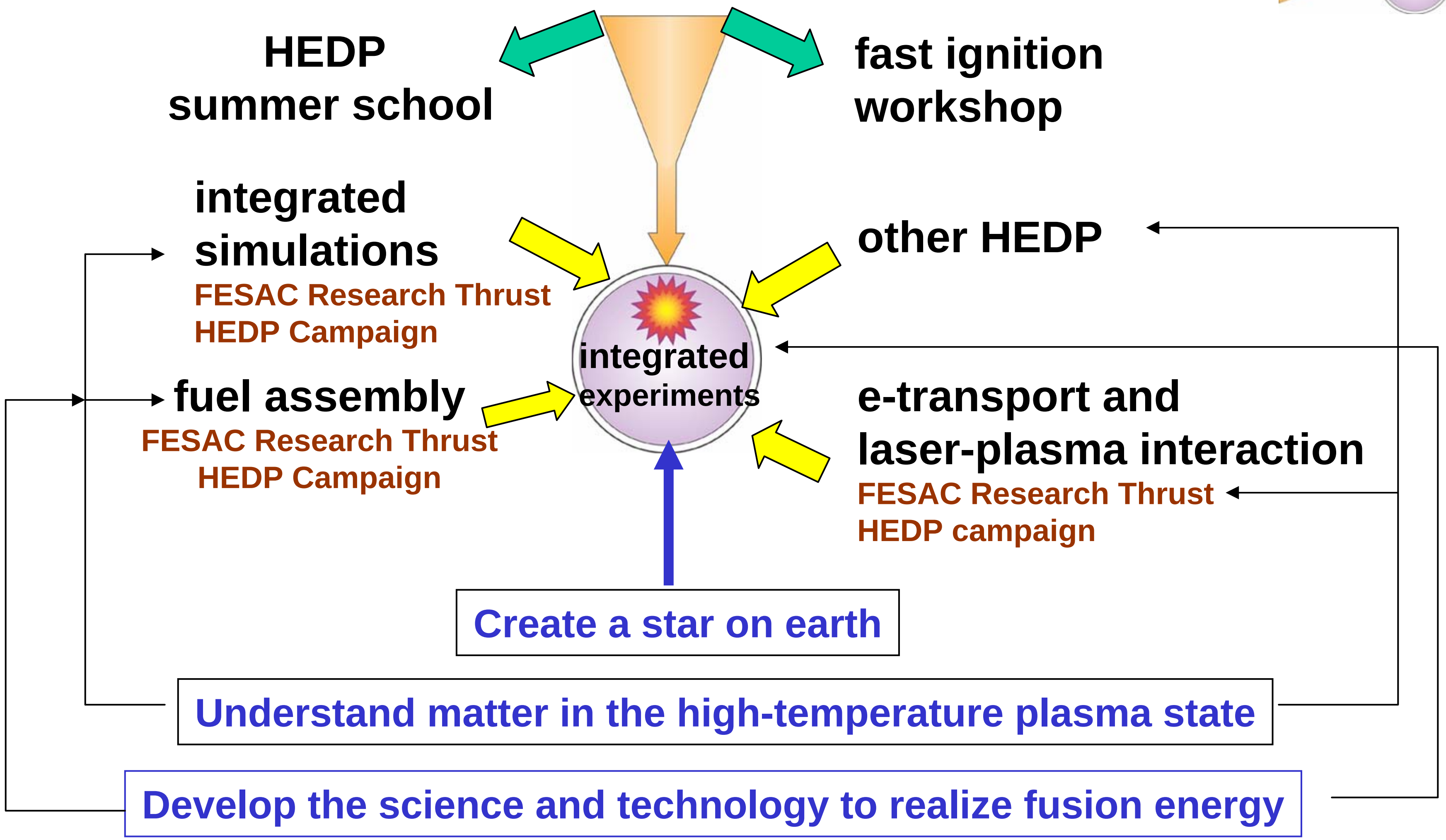
→ **20 papers published or submitted in 2006-07**

Phys. Rev. Lett. (5); Phys. Plasmas (8);
Phys. Rev. E (1); J. Phys. IV (4); J. Applied Phys. (1)
Plasma Phys. Cont. Fus. (1); Rev. Sci. Instrum. (2)

→ **13 invited talks in 2006-07**

EPS (1); APS (2); HTPD (1);
ICC Workshop (1); Fast-Ignition Workshop (3);
US Japan Workshop (3); Frontiers of Plasma Phys. (2)

HEDP research and education are the main goals of the FSC. Research activities are in line with FESAC priorities



FESAC priorities: overarching themes

FSC OUTREACH The FSC sponsored the 9th International Fast Ignition Workshop November 3-5, 2006, Cambridge, MA

K. Tanaka, recipient of the 2006 Excellence in Plasma Physics for first fast-ignition experiment

- 94 attendees from 8 countries
- 66 presentations

- Presentations available on FSC web site fsc.lle.rochester.edu

FSC EDUCATION The FSC is organizing its

2nd Summer School in High Energy Density Physics

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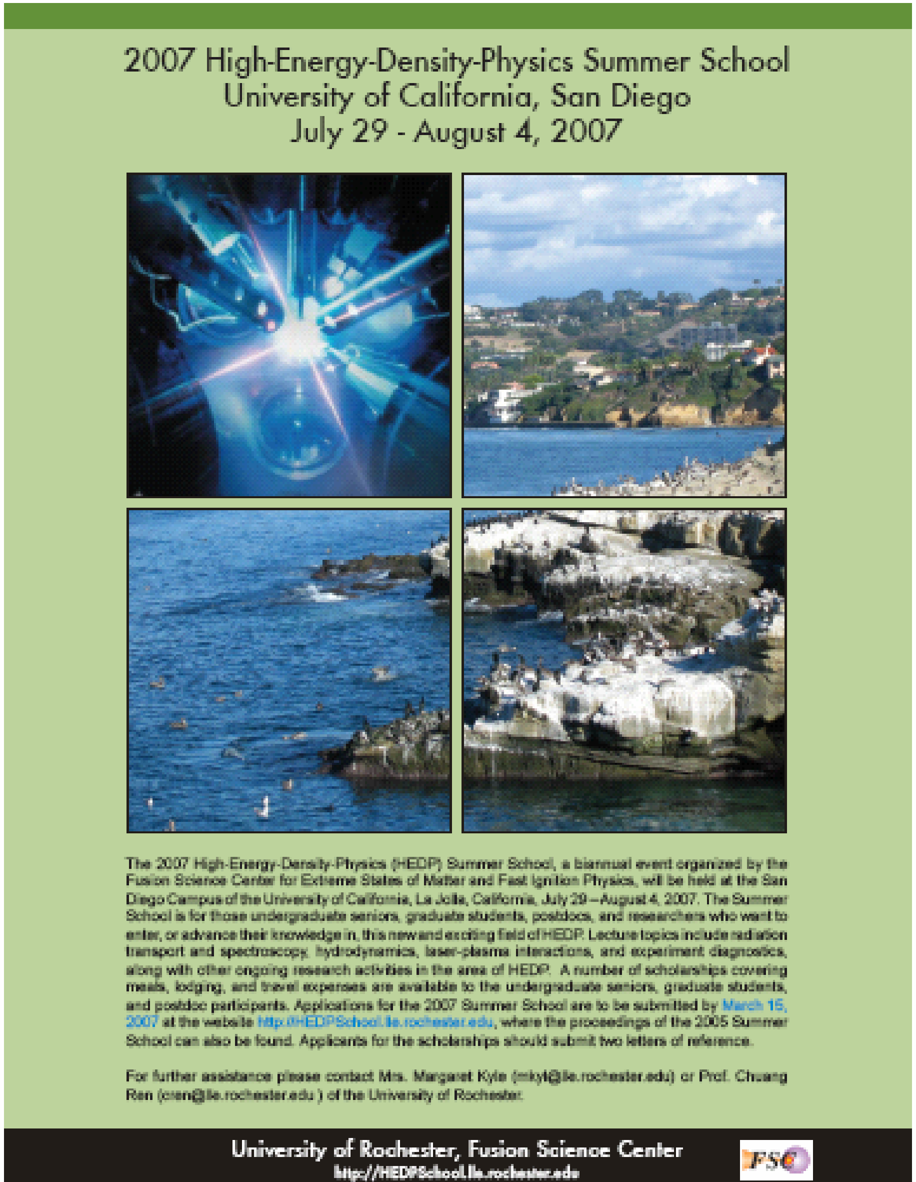
Scheduled lecturers and subjects

C. Back–GA,	***Material Science and ICF***
R. Betti–UR,	***Implosion Hydrodynamics***
M. Campbell–GA,	***Fusion Energy***
T. Ditmire – UT,	***HEDP***
R. Freeman –OSU,	***Fast-Electron Transport***
D. Hammer – Cornell U,	***HEDP with Z-Pinches***
C. Joshi – UCLA,	***Plasma Accelerators***
M. Key – LLNL,	***Fast Ignition***
M. Marinak –LLNL,	***Hydrodynamic Simulations***
D. Meyerhofer– UR,	***HEDP Diagnostics***
W. Mori – UCLA,	***Laser-Plasma Interaction***
E. Moses – LLNL,	***National Ignition Facility***
B. Remington- LLNL,	***Introduction to HEDP***
M. Rosen, LLNL,	***Inertial Confinement Fusion***

2nd FSC summer school in HEDP, UCSD campus, July 29-August 4, 2007



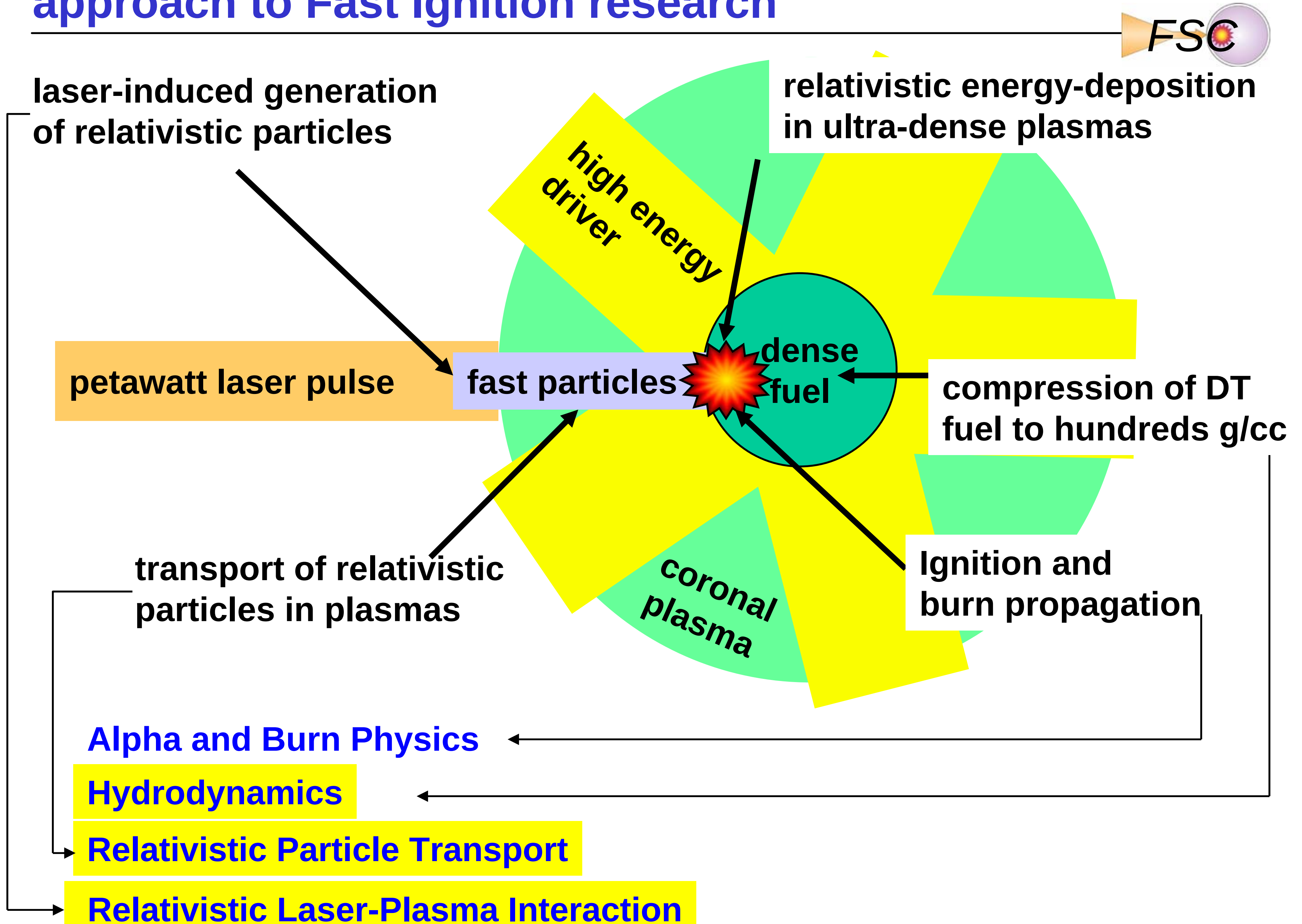
→ **Sponsors:**
- **FSC**
- **ILSA**
- **IMDEC**

→ **50 scholarships to Grad/UnderGrad students**

→ **Application deadline is March 15**

→ **Preliminary program is available online fsc.lle.rochester.edu**

The FSC provides coordination to a multi-disciplinary approach to Fast Ignition research



FSC activities on the hydrodynamics for Fast Ignition: Theory Simulations Experiments

FESAC priorities – HEDP campaign – Research thrust

Design targets and carry out implosion experiments to identify the optimum assembly of HEDP plasmas at densities of hundreds g/cc.

The hydro-theory of FI implosions is developed by the FSC. Low velocity, low adiabat implosions are optimal for fast ignition.

$$\rho R \sim E_L^{0.33} / \alpha^{0.55}$$

$$\text{Gain} \sim \frac{1}{V_i^{1.2}} \frac{\rho R}{7 + \rho R}$$

$$\rho \sim V_i / \alpha$$

Fast ignition implosion for given laser energy E_L:

- Low velocity V_i
- Low adiabat α
- Large mass

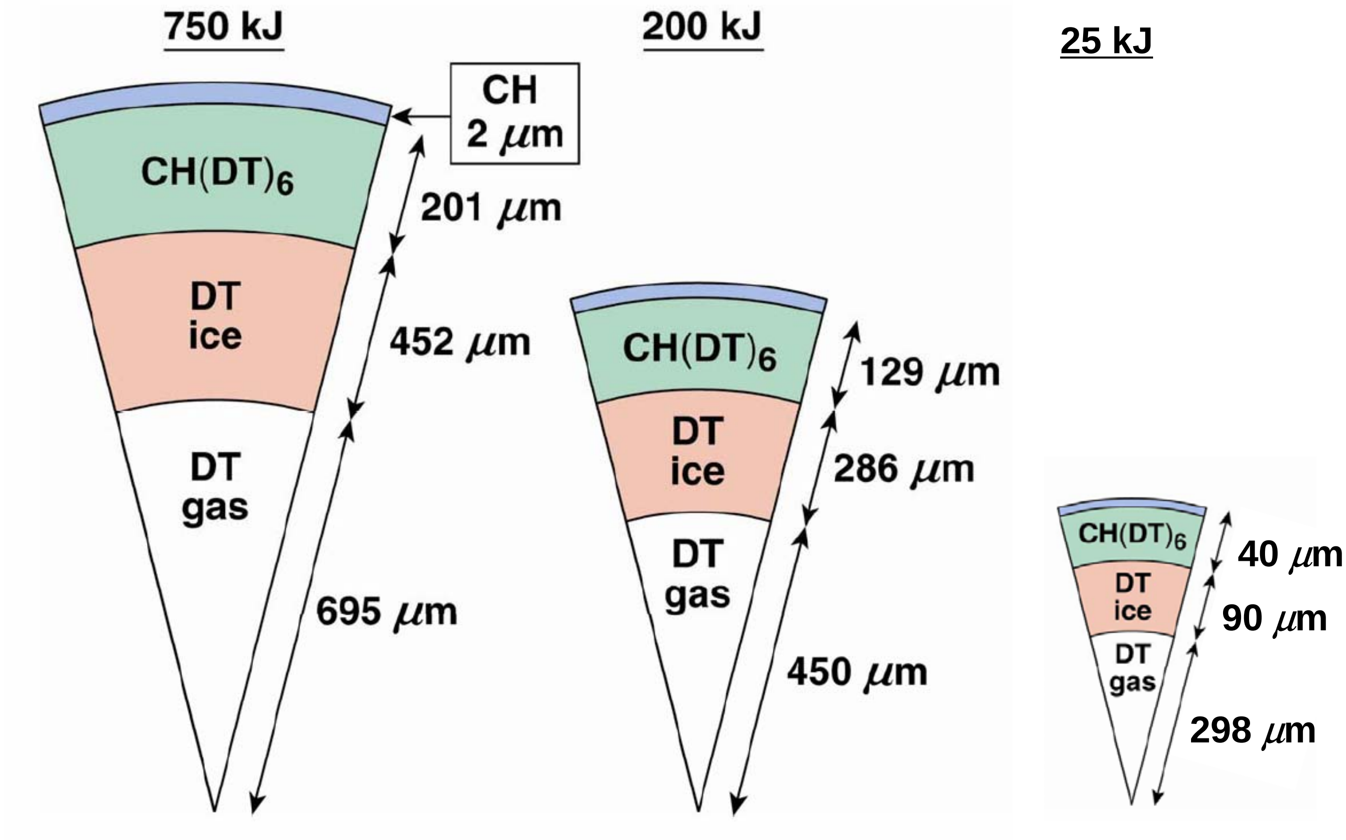
$$< \rho > \approx 300 - 500 g / cc$$

$$\rho \sim uniform$$

Optimum density for fast ignition

R. Betti and C. Zhou, Phys. Plasmas 12, 110702 (2005);
R. Betti et al, Plasma Physics Cont. Fusion 48, B153 (2006)
R. Betti and C. Zhou, J. Phys. IV 133, 59 (2006)
C. Zhou and R. Betti, submitted to Phys. of Plasmas

FSC target designs for direct-drive fast ignition use massive wetted foam shells insensitive to fluid instability



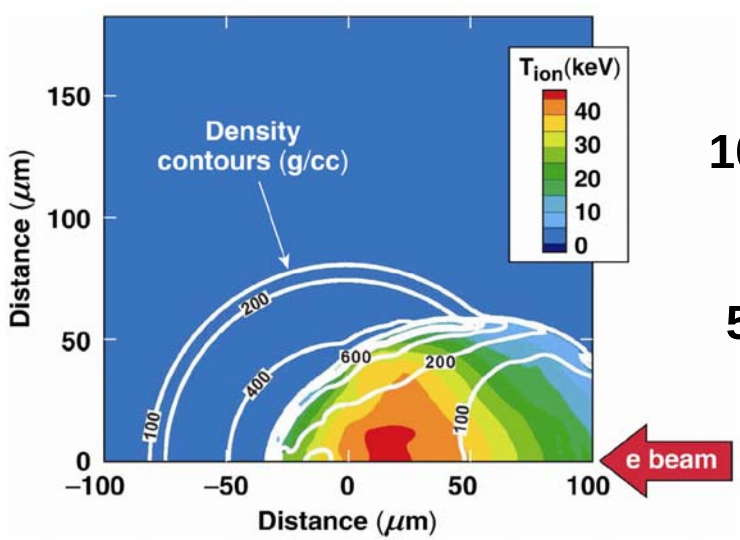
$\rho R \approx 3 g/cm^2$ $\rho R \approx 1.9 g/cm^2$ $\rho R \approx 0.7 g/cm^2$

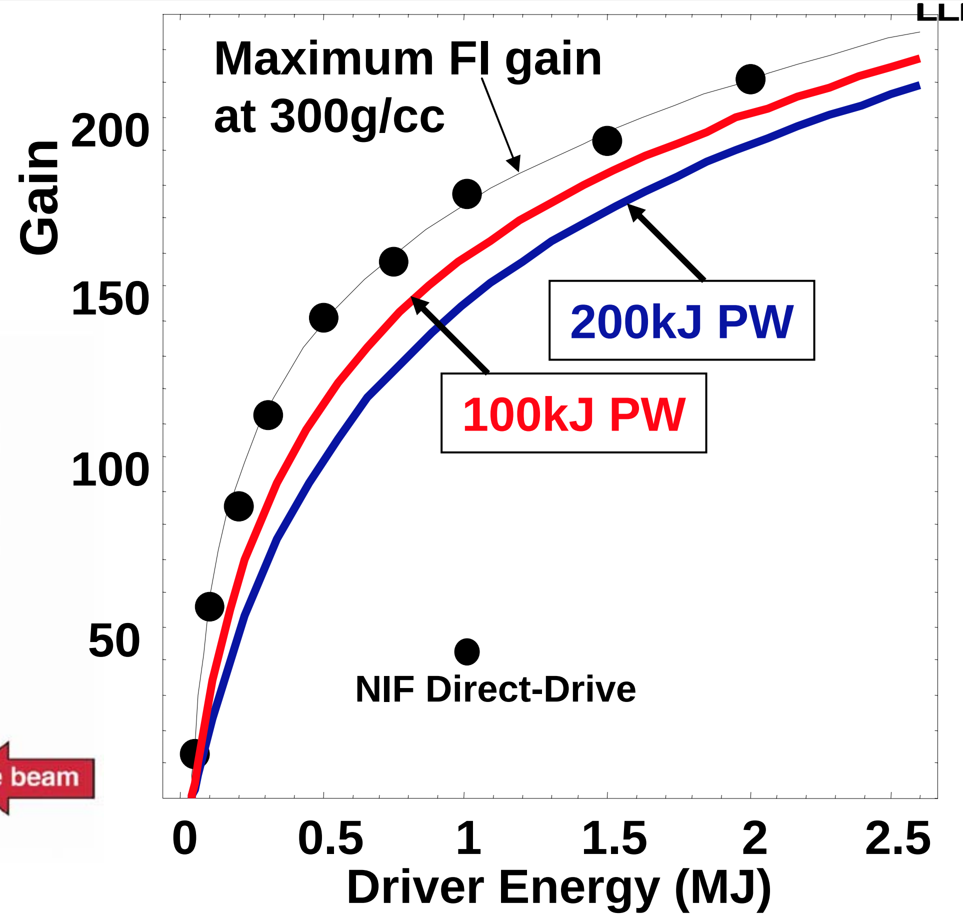
$<\rho> \approx 300\text{-}500 g/cm^3$

R. Betti, A.A. Solodov, J.A. Delettrez, C. Zhou, Phys. Plasmas 13, 100703 (2006)

2D simulations of ignition by fast electrons and burn propagation yield fast ignition gain curves

- 2D simulations of ignition and burn by 15kJ, 2MeV, 20µm, 10ps e-beam



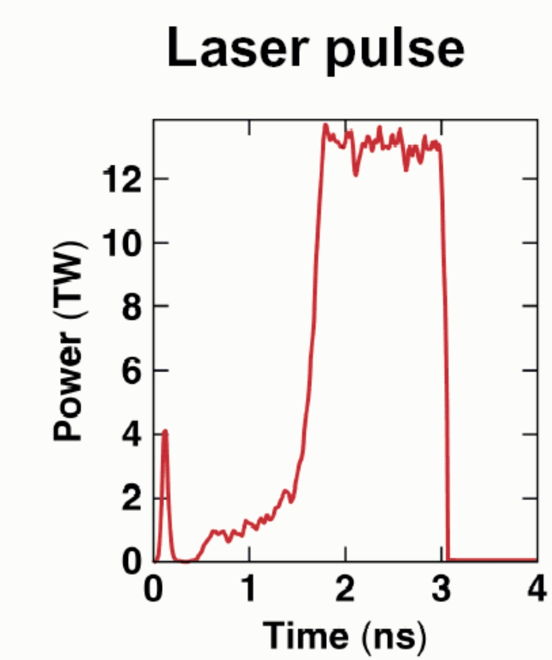


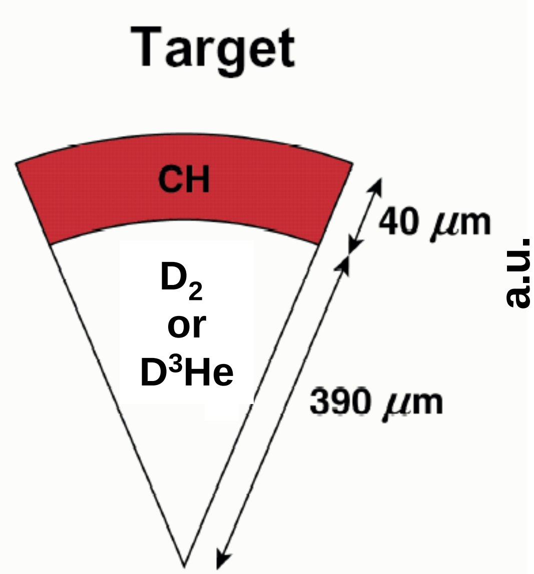
FI allows for significant gains with a few hundred kJ laser driver

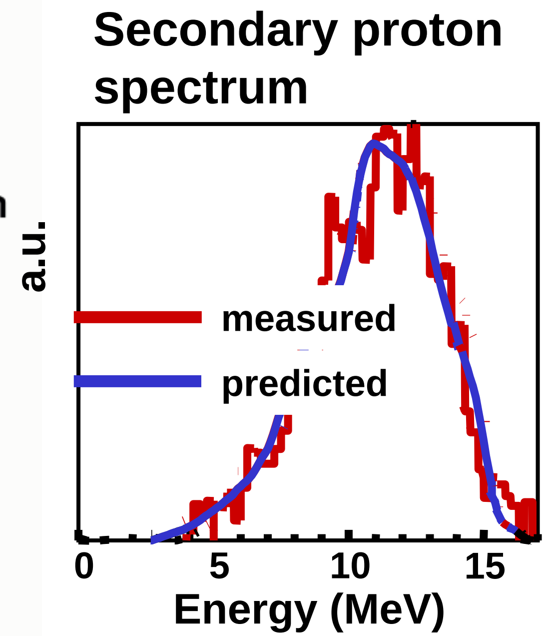
R. Betti, A.A. Solodov, J.A. Delettrez, C. Zhou, Phys. Plasmas 13, 100703 (2006)

Slow implosions with low adiabat were tested on OMEGA D-^{3}He fusion proton energy loss measured the high ρR

E_L≈20kJ   P≈25-34atm   α≈1.3   V≈2•10^{7}cm/s







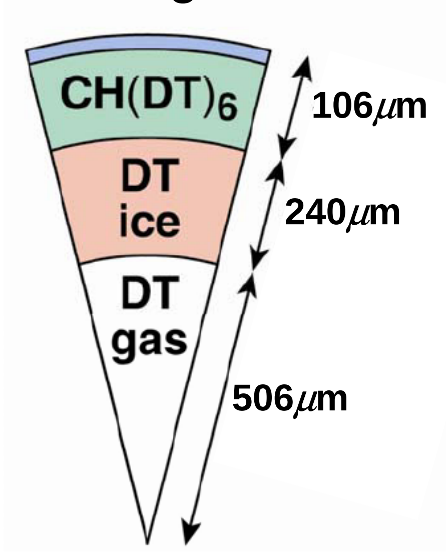
- Peak ρR is 0.26g/cm,^{2} the highest ρR to date on OMEGA
- Empty shells would achieve ρR≈0.7g/cm^2 and stop 4MeV electrons

Warm (CH) thick-shell cone-target implosions in '08

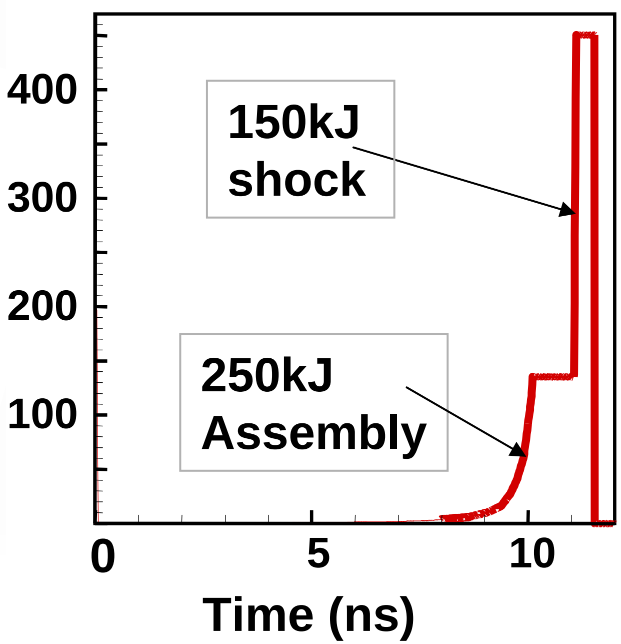
C. Zhou, W. Theobald, R. Betti, P.B. Radha, V. Smalyuk, *et al*, Phys. Rev. Lett. 98: 025004 (2007)

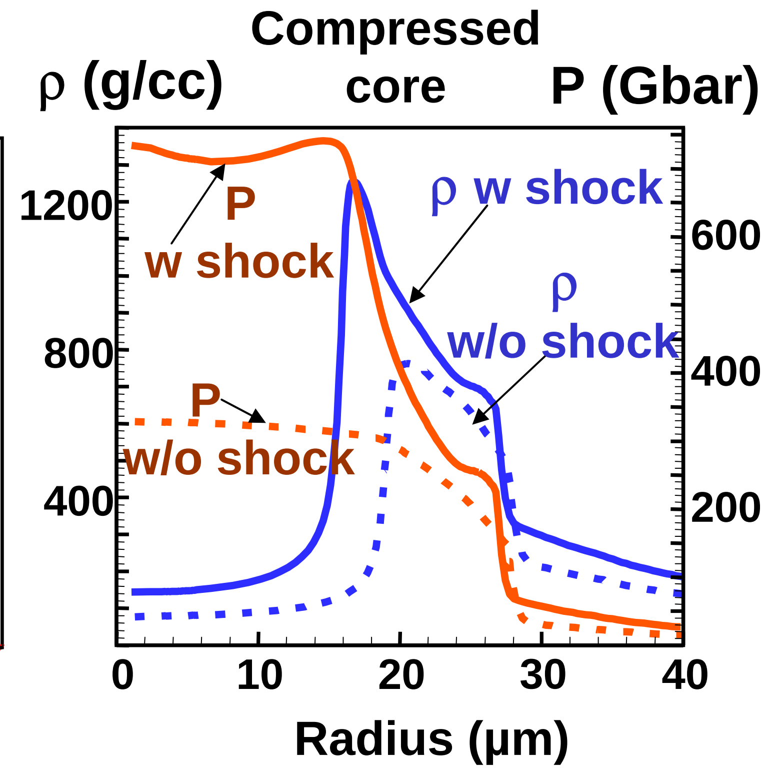
Thick wetted-foam targets can also be ignited by a spherically convergent shock

Target



Laser Power (TW)



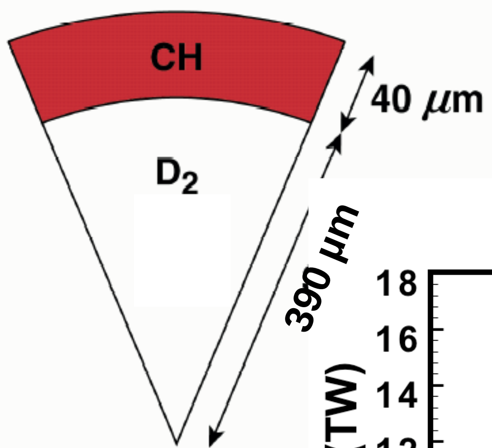


2D simulations of shock ignition in '07-'08

R. Betti, C. Zhou, K. Anderson, J. Perkins, A. Solodov, in press in Phys. Rev. Lett.

The shock ignition concept has been tested on OMEGA

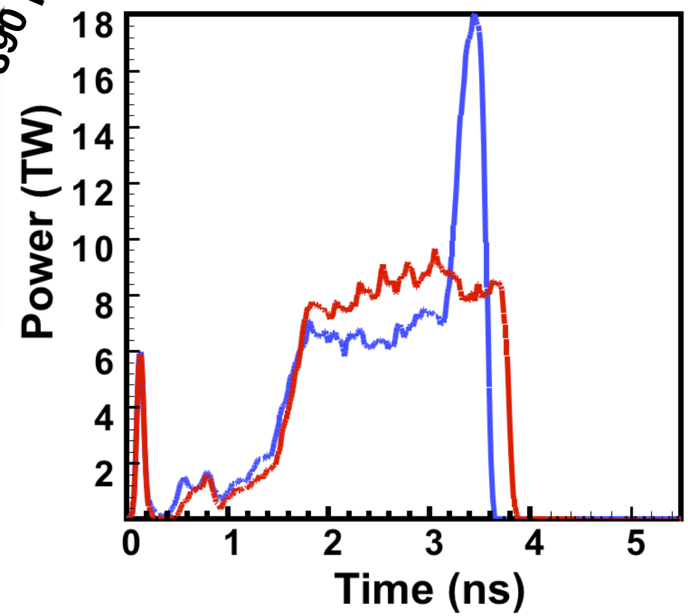
Target

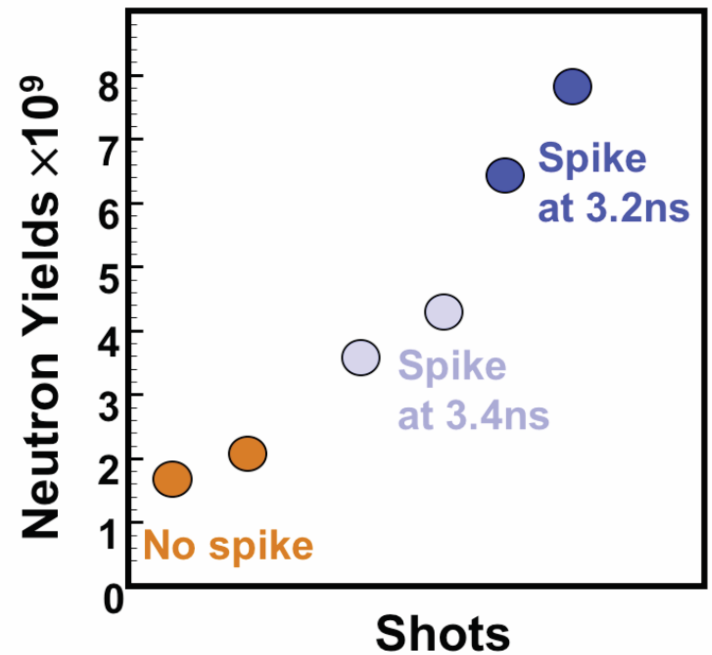


E_L=17-18kJ
$\alpha \approx$1.3

W. Theobald,
R. Betti,
C. Zhou,
C. Stoeckl
(UR-LLE)

Pulse shape with and without shock spike





The neutron yield increases considerably when a shock is launched at the end of the pulse

More experiments with CH targets in '07-'08, cryo-targets in '09

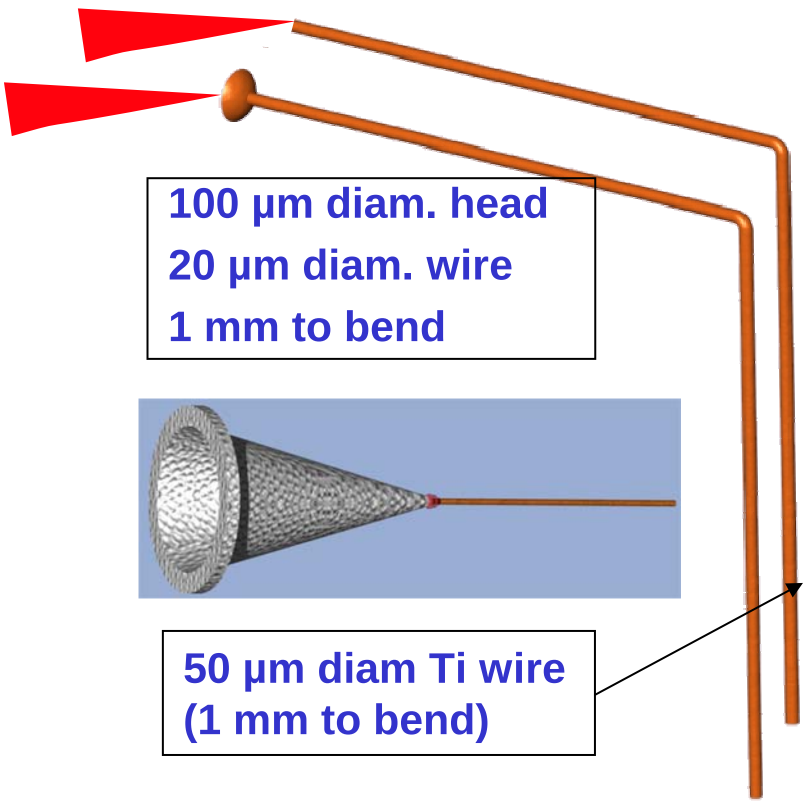
FSC activities on electron generation and transport : experiments and simulations

FESAC priorities – HEDP campaign – Research thrust

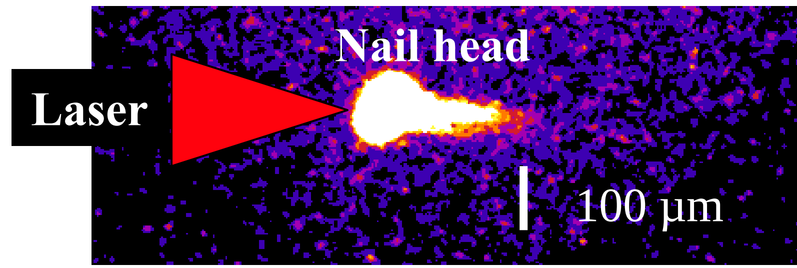
- Develop a basic understanding of the transport and stopping of particle beams in HEDP plasmas using PIC codes, coupled with experiments.
- Develop basic understanding of hole boring and fast particle generation for relevant intensities and pulse lengths

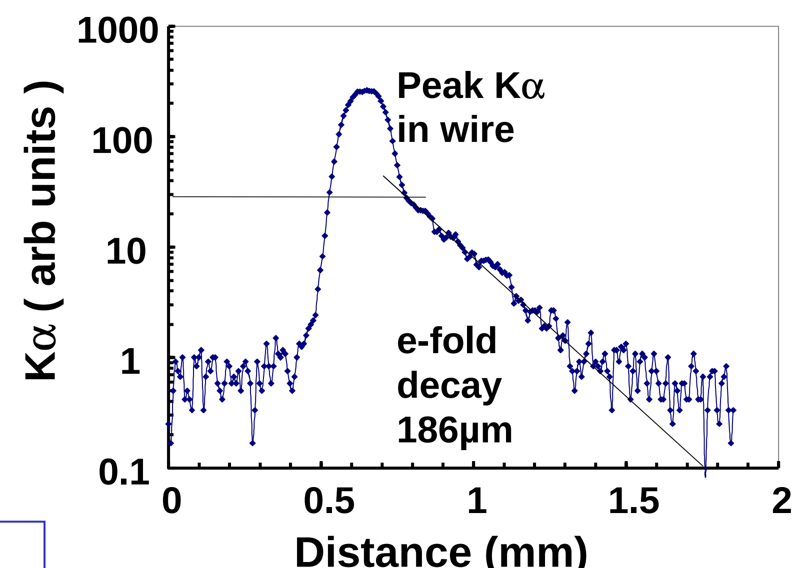
FSC experiments at RAL and TITAN study hot-electron transport in wires

FSC | The Ohio State University College of Mathematical and Physical Sciences | UCSD | General Atomics



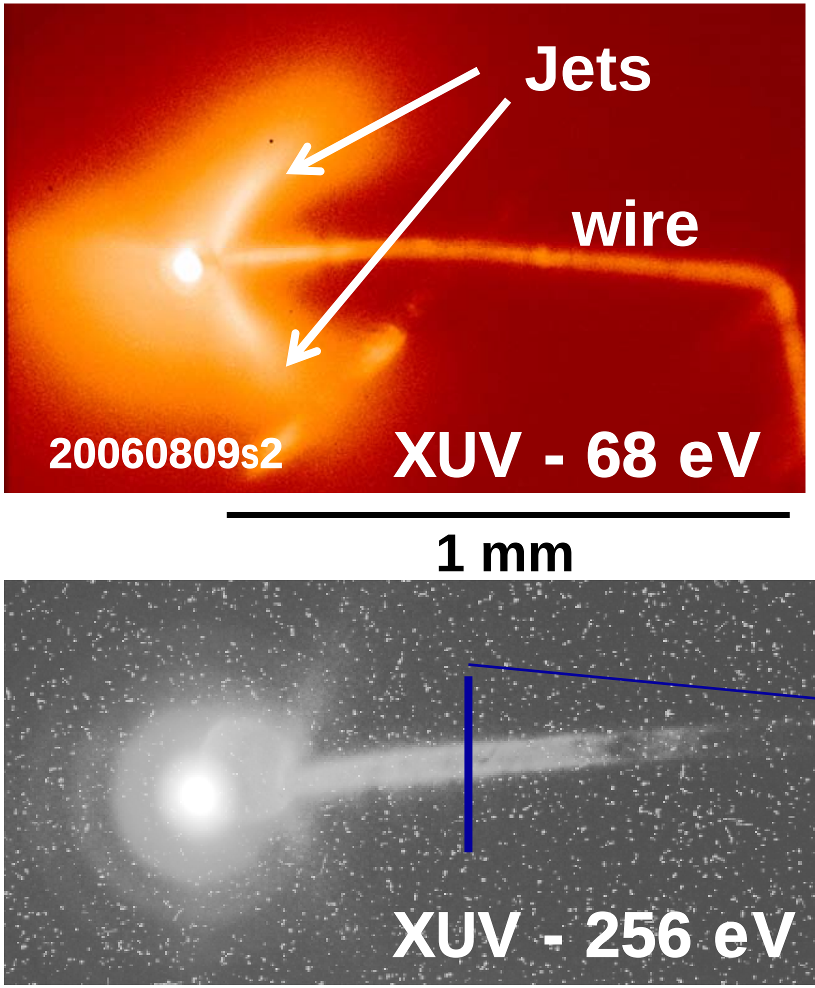
Cu-K$_\alpha$ images

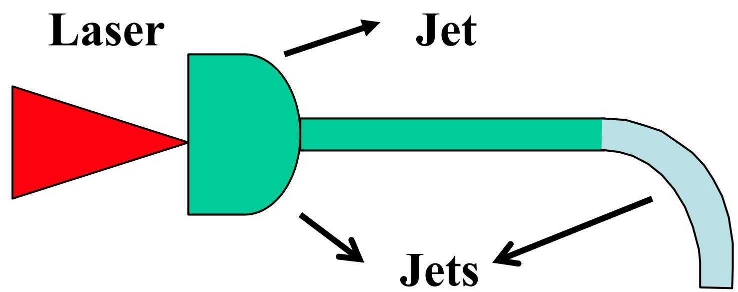




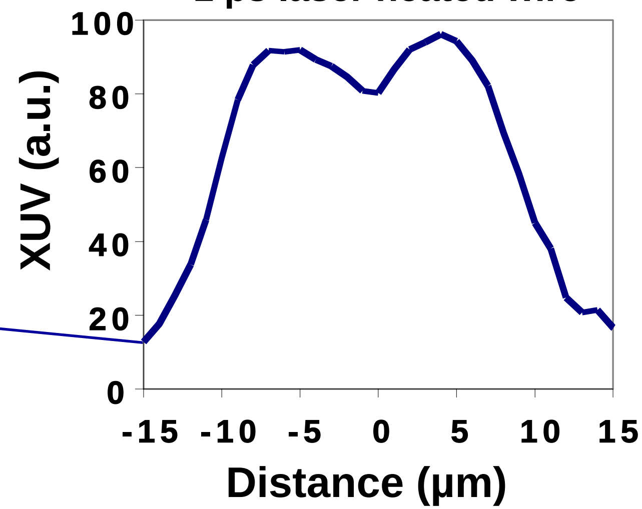
1ps pulse, I =1.7•10^{20}W/cm^2, 10µm spot

Return currents and surface heating are observed in the XUV images





X-ray emission from
1 ps laser heated wire



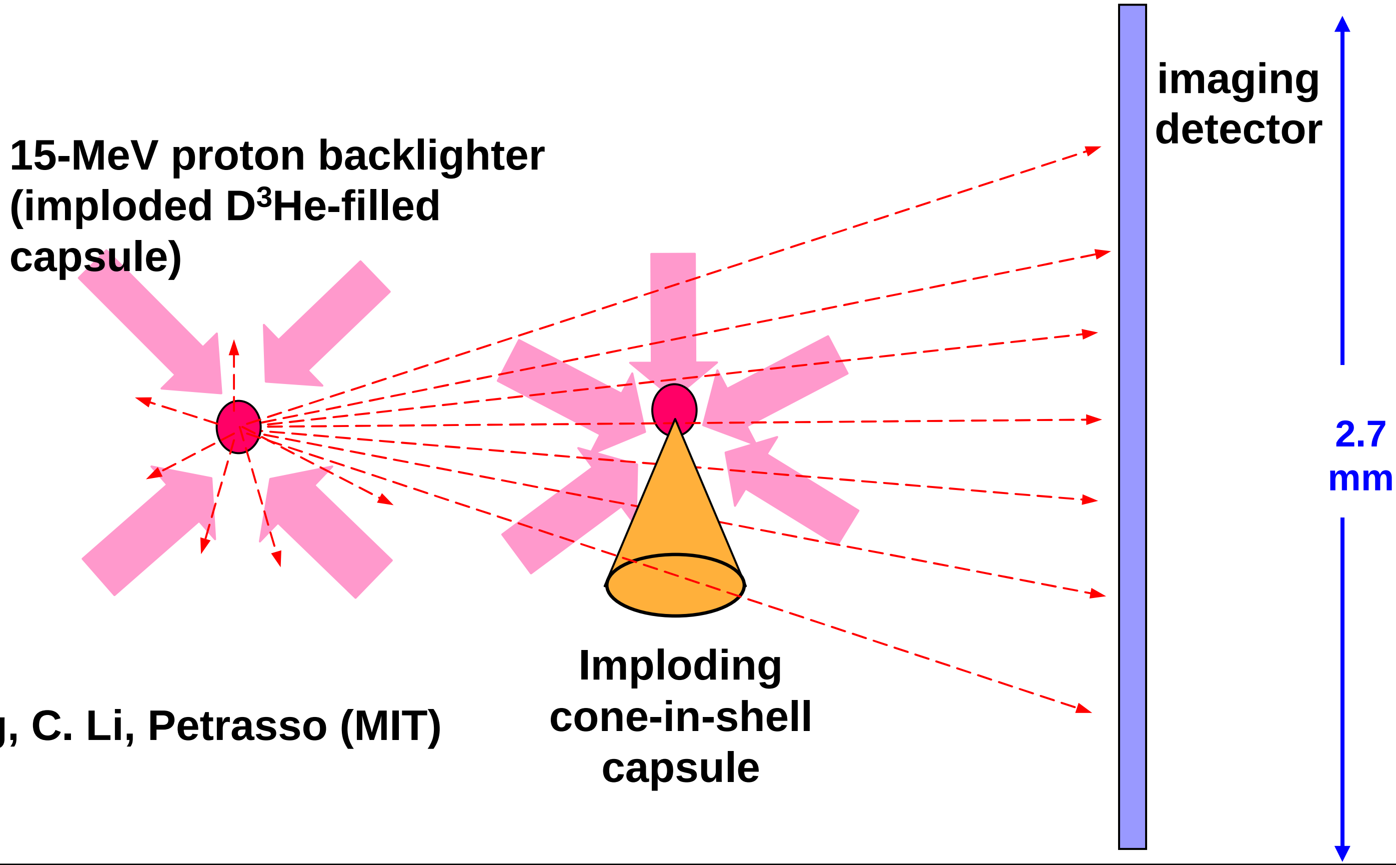
Beg,
Stephens
Freeman
Van Woerkom
Pasley
Wei

e-transport experiments in solids, WMD and plasmas on Titan, Z-PW, Ω-EP ('06-'09)

Proton radiography is used to measure E and B fields and areal densities in FI implosions on OMEGA

FSC — MIT

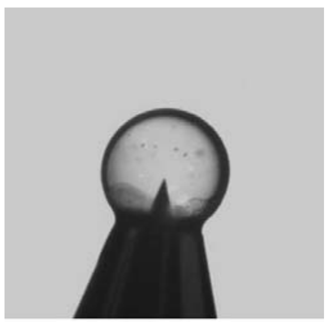
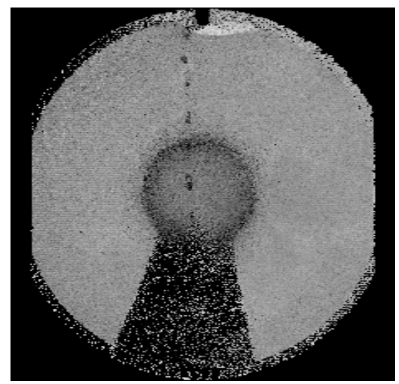
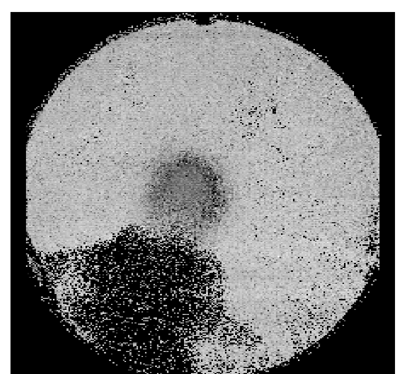
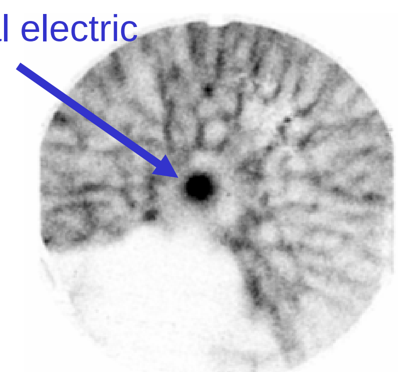
Motivation: EM fields affect the hot-electron transport



Rygg, C. Li, Petrasso (MIT)

P-radiographs of cone-target implosions on OMEGA ('07-'08)

First radiograph of a cone-target implosion. Proton fluence images reveal the presence of large EM fields

	Visible light photograph	Proton energy image (darker means lower energy, higher $\int \rho \, dl$)	Proton fluence image (darker means more protons)
Before implosion:			
During implosion (1.5 ns):			

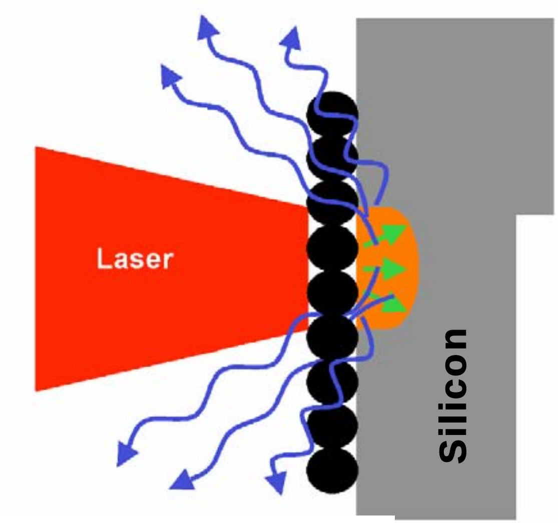
Time

Strong proton collimation due to radial electric fields

2.7 mm

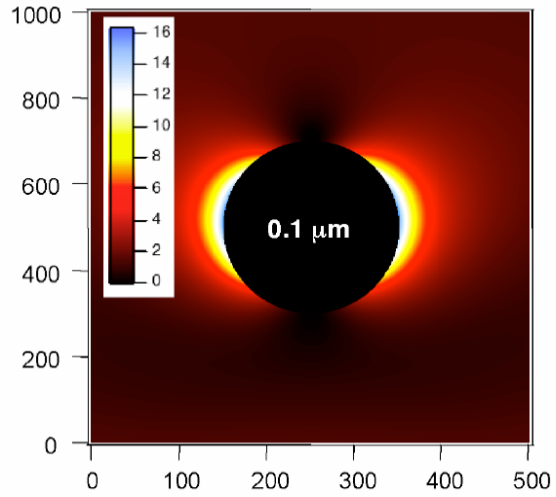
Rygg, C. Li, Petrasso (MIT)

Experiments on THOR show that fast electron generation is enhanced in sphere coated targets

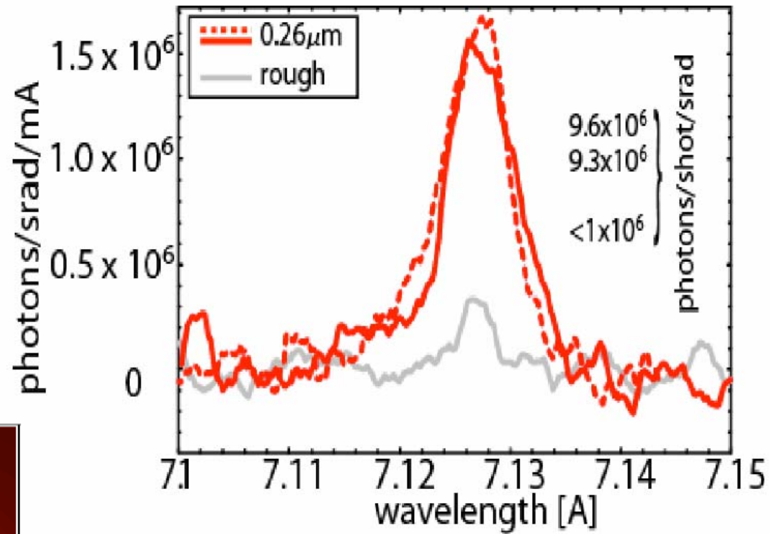


Silicon K_{α} emission at 7.1A

X16 field enhancement



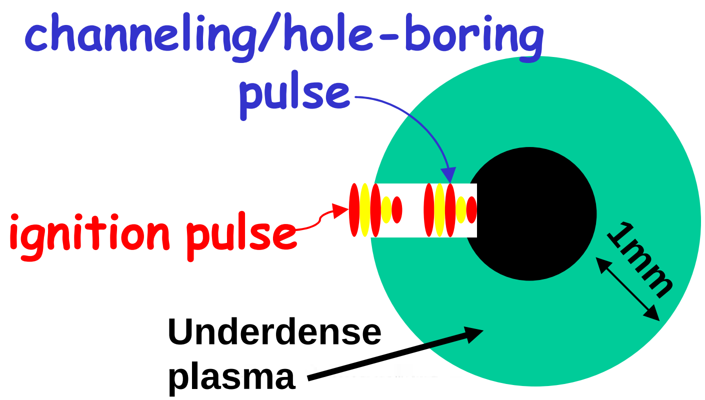
Kα emission

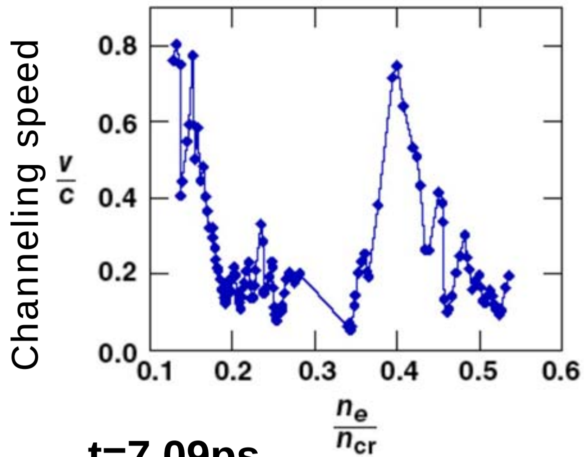


Ditmire,
Cho,
Dyer,
Sumeruk,
Edens,
Grisby
(U Texas)

Theoretical analysis in progress ('07-'08)

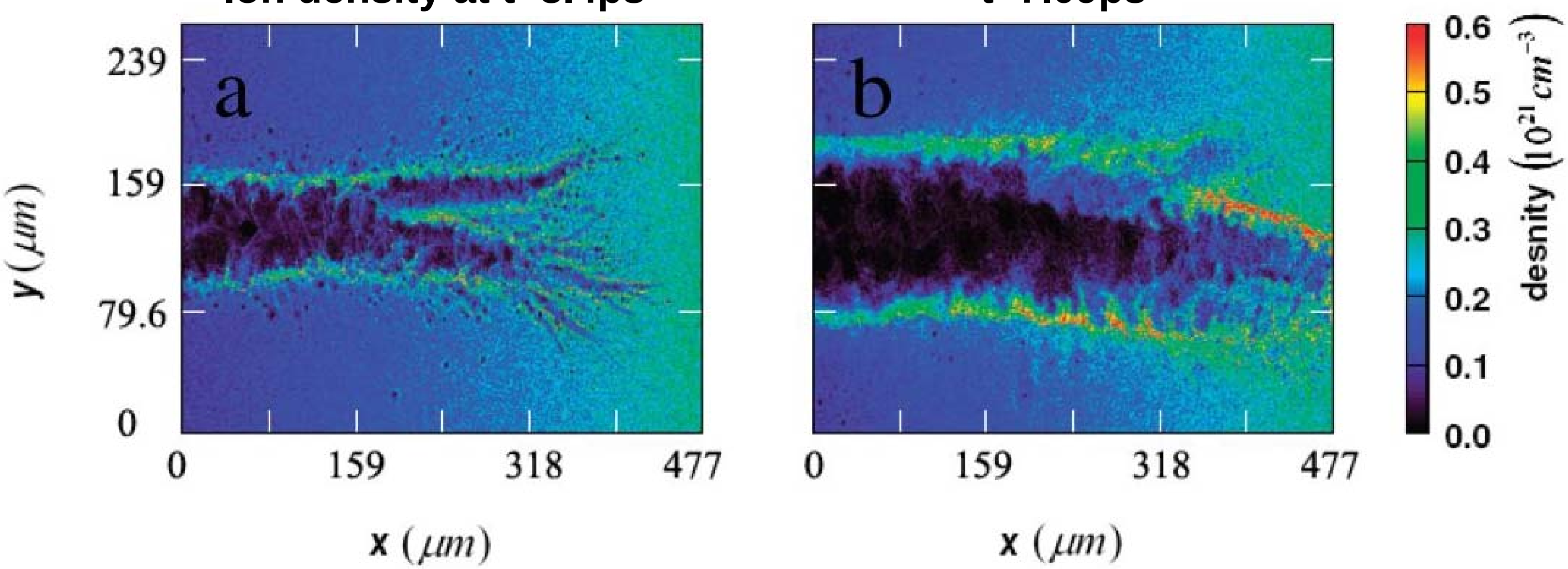
First PIC simulation of channeling in mm-size underdense plasmas with the code OSIRIS





Ion density at t=3.4ps

t=7.09ps

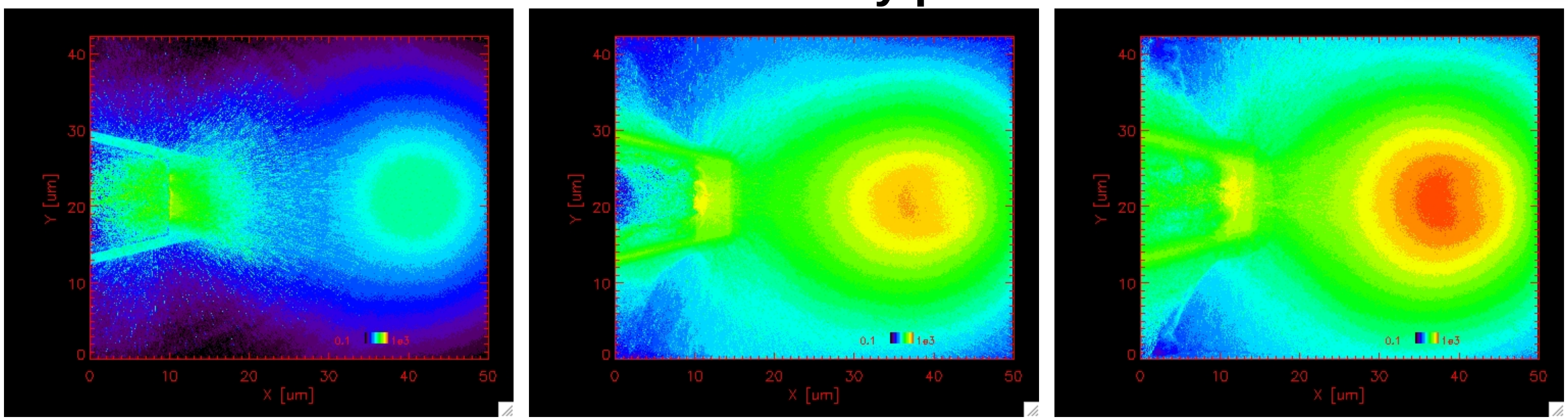


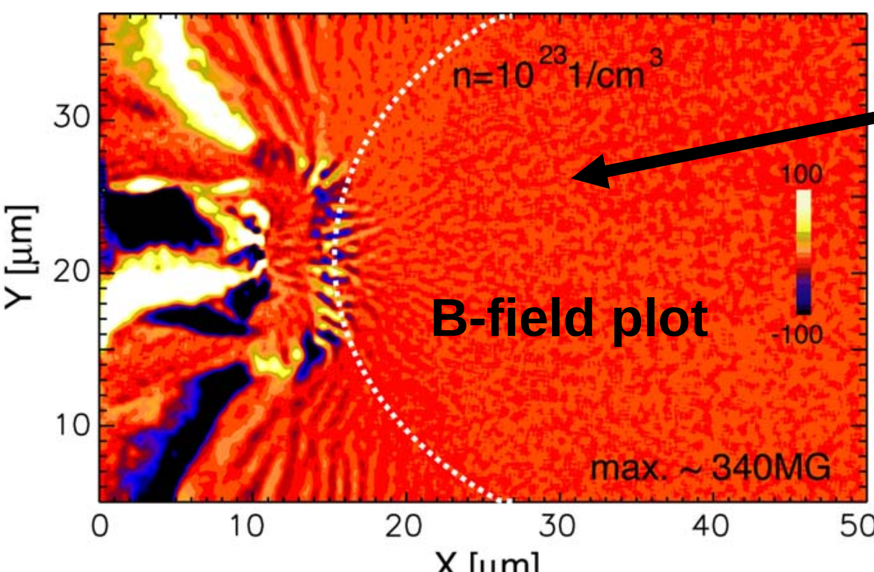
Experimental verification on OMEGA-EP ('08-'09)

Ren and G. Li (UR)

First fully-integrated simulations of cone-guided fast ignition are carried out with PICLS

Electron density plots





No large magnetic fields are present in the dense plasma. The hot electron stopping is collisional.

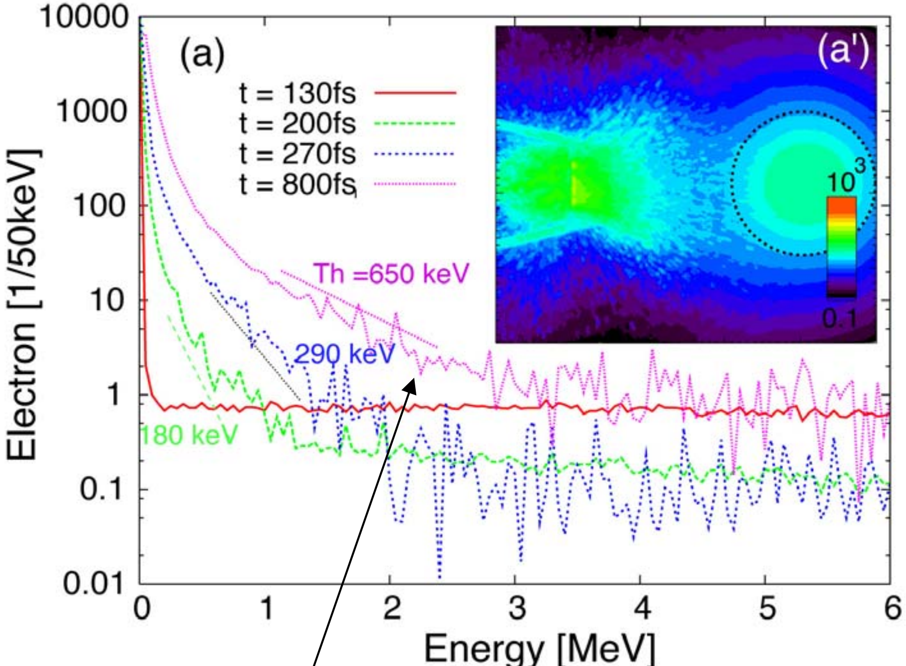
Integrated simulations of ignition-scale FI cone-targets ('08-'09).
Integrated experiments on Ω-EP ('09)

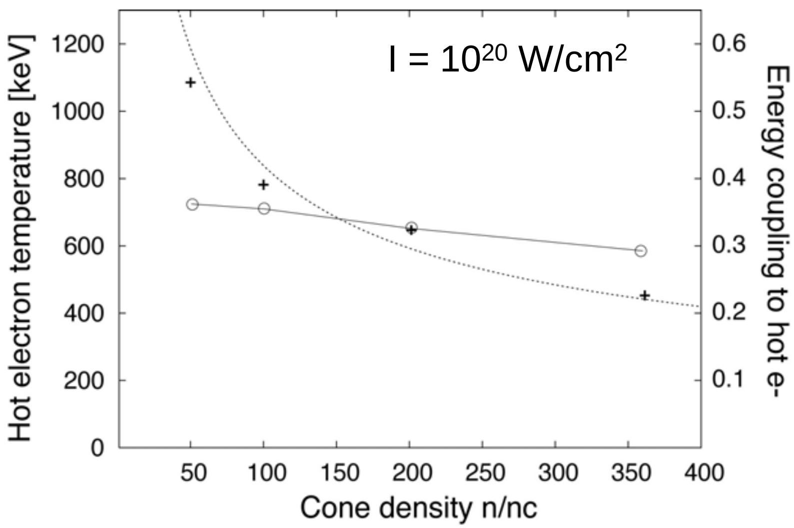
Sentoku, Cowan, Crisman (UNR)

PICLS simulations show that the hot-electron energy is less than predicted by the ponderomotive scaling

FSC

Nevada Terawatt Facility





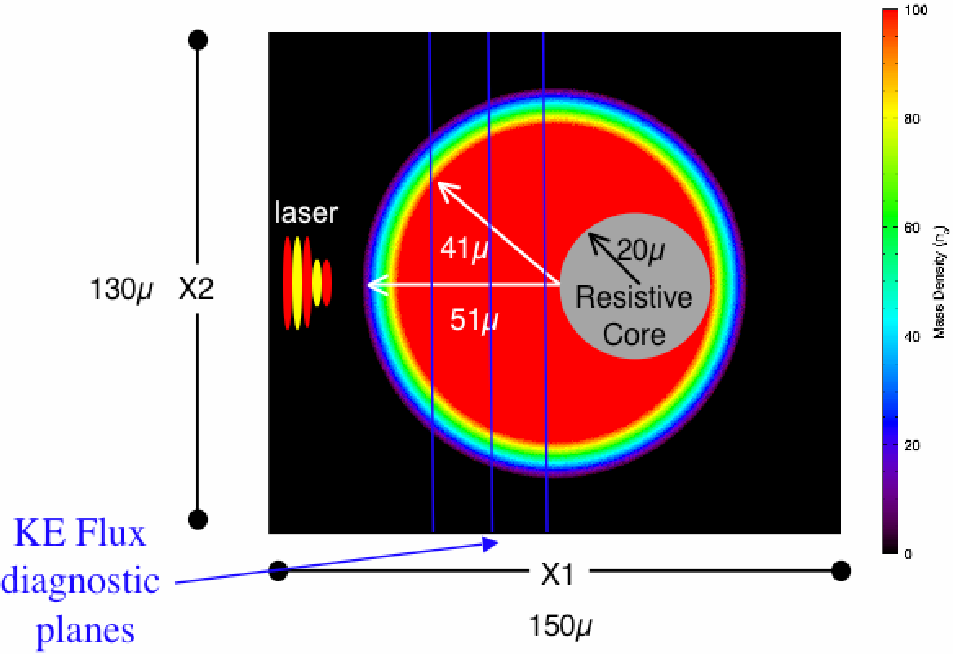
The energy of the hot-electrons reaching the core is ≤ 1MeV

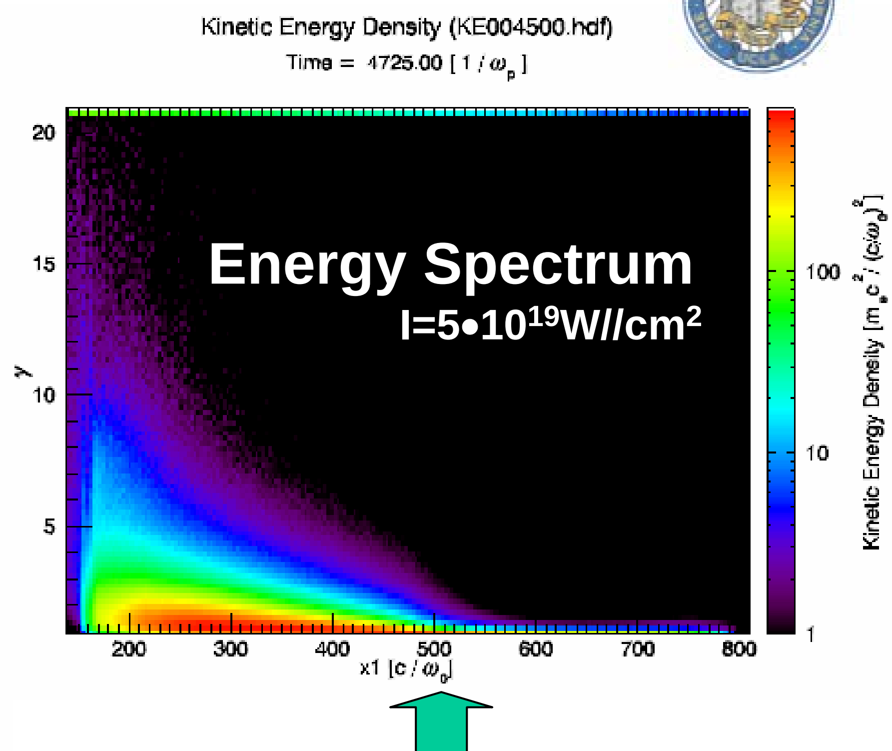
Higher cone densities lead to less energetic electrons

Sentoku, Cowan, Crisman (UNR)

Experimental verification ('08-'09)

Integrated PIC simulations with OSIRIS also show low energy ≤ 1MeV electrons reaching the core





Largest OSIRIS simulation of fast ignition to date

19000×16400 grids

Grid size: 0.05 c/ω_0

9×10^4 time steps

10^9 particles

Tonge, Mori (UCLA)

The electron reaching the core have relatively low energy ≤ 1MeV

Larger scale, higher core-density simulations ('07-'09)

FSC EDUCATION AND OUTREACH: SUMMARY AND PLANS

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1st FSC HEDP Summer School
Berkeley, CA, August 7-13, 2005

2st FSC HEDP Summer School
La Jolla, CA, July 29-August 4, 2007

3rd FSC HEDP Summer School
TBD, 2009

2005 and 2006 Annual Reports are available on FSC web site fsc.lle.rochester.edu

9th International FI Workshop organized by the FSC
Cambridge, MA, November 3-5 2006 (fsc.lle.rochester.edu)

12th International FI Workshop
TBD, 2009

FSC RESEARCH: SUMMARY AND PLANS