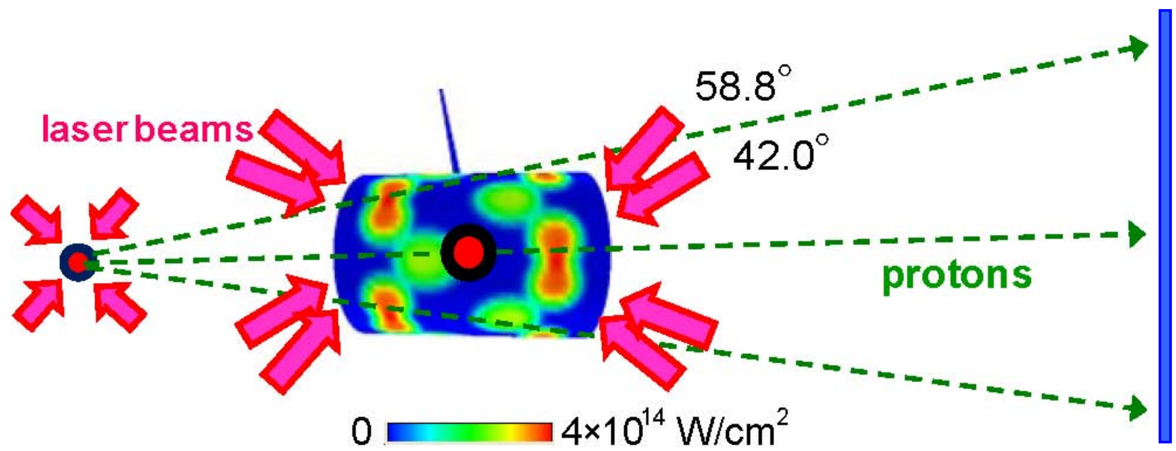
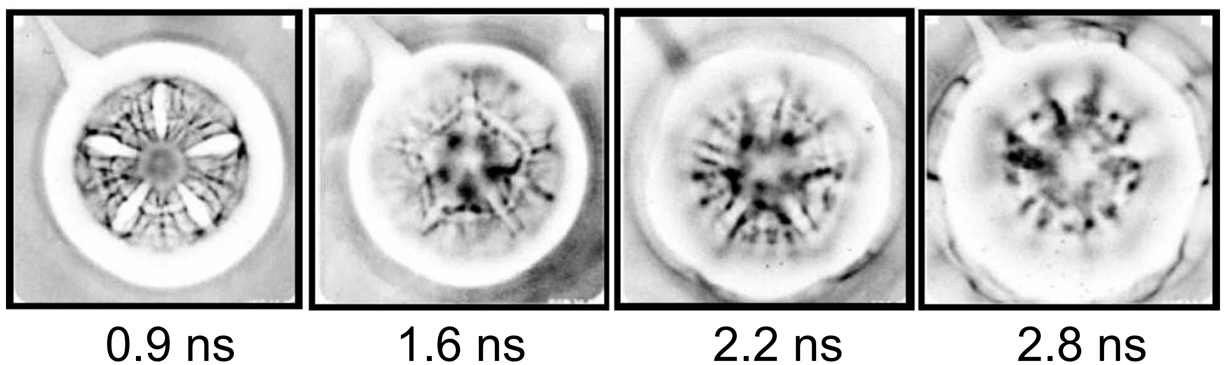
Charged-Particle Probing of X-ray-Driven Inertial-Fusion Implosions



Proton radiographs



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C. K. Li, MIT

OLUG workshop 2010

Summary

The first measurements of x-ray driven implosions with charged particles have resulted in unique and quantitative characterization of critical aspects of indirect-drive ICF

- Observations of three types of spontaneous electric fields differing in strength by two orders of magnitude (~ 10^8 -10^{10} V m^{-1}) the largest being nearly one-tenth of the Bohr field.
- Observations of self-generated megaGauss magnetic fields
- Observations of plasma flows and supersonic jets (~ Mach 4)
- Determinations of areal density (ρR) and implosion symmetry
- Demonstration of the absence of the stochastic filamentary pattern and striations that generally found in laser-driven implosions

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GENERAL ATOMICS

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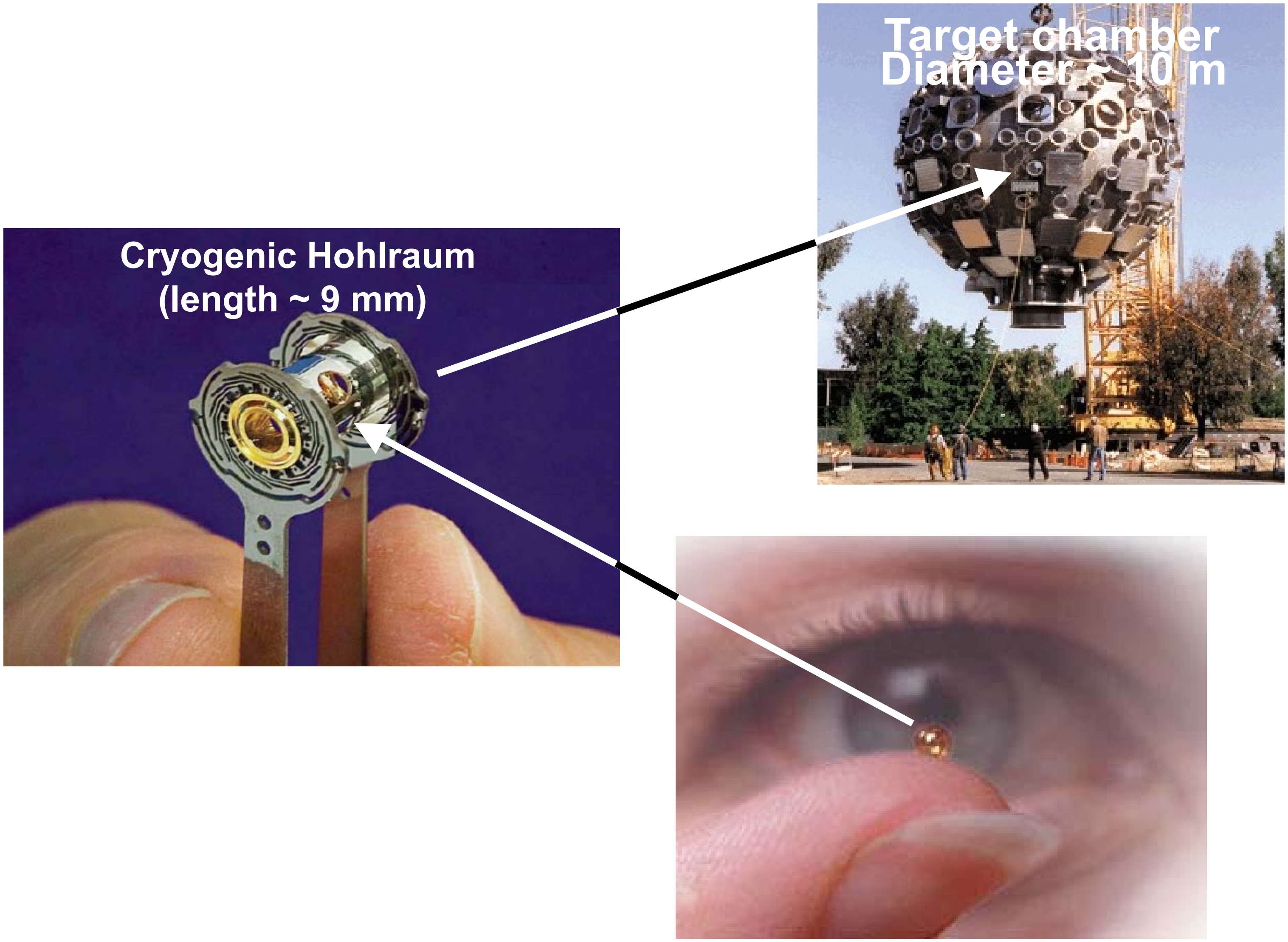
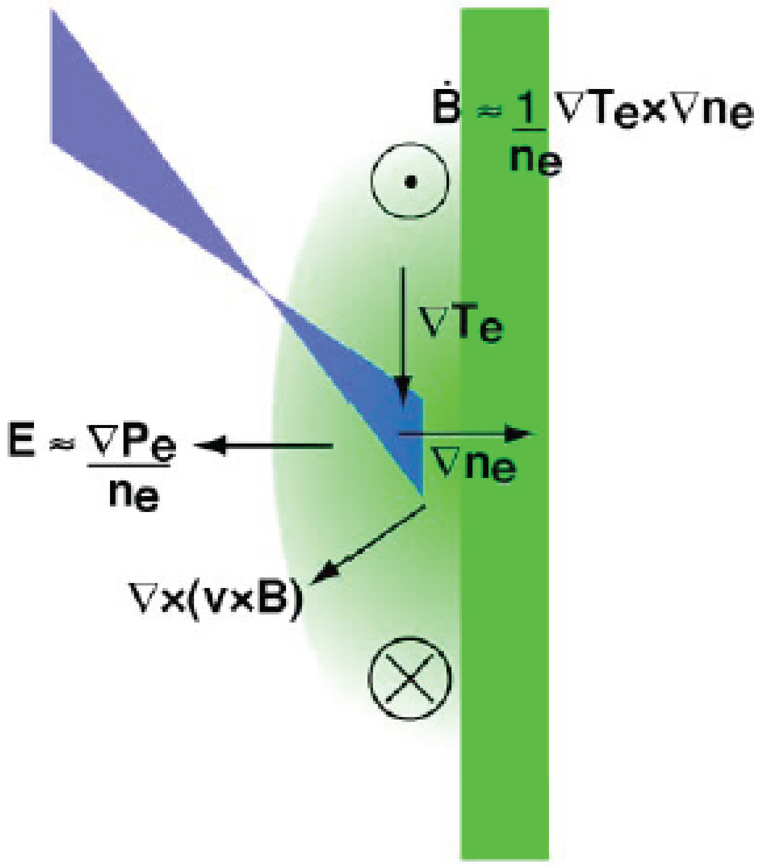
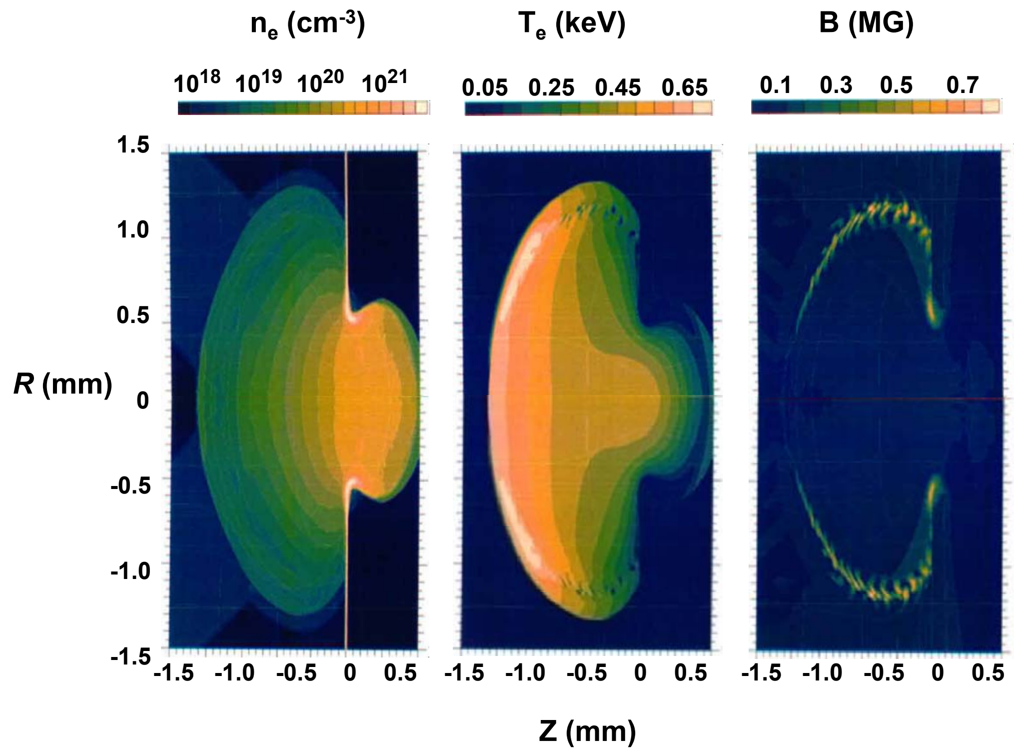
Fusion ignition will be explored with indirect drive ICF approach at the National Ignition Facility

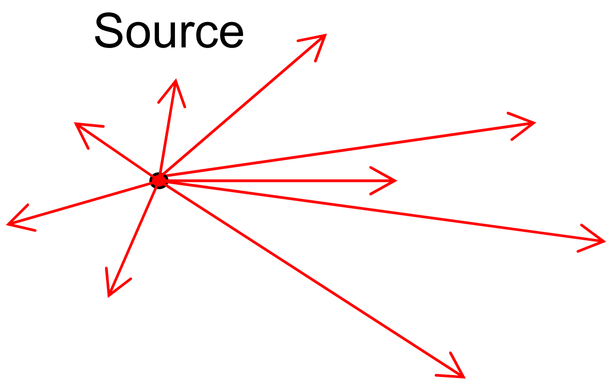


For long-pulse, low-intensity laser light, the dominant source for *B*-field generation is $\nabla n_e \times \nabla T_e$, and the dominant source for *E* fields is ∇P_e



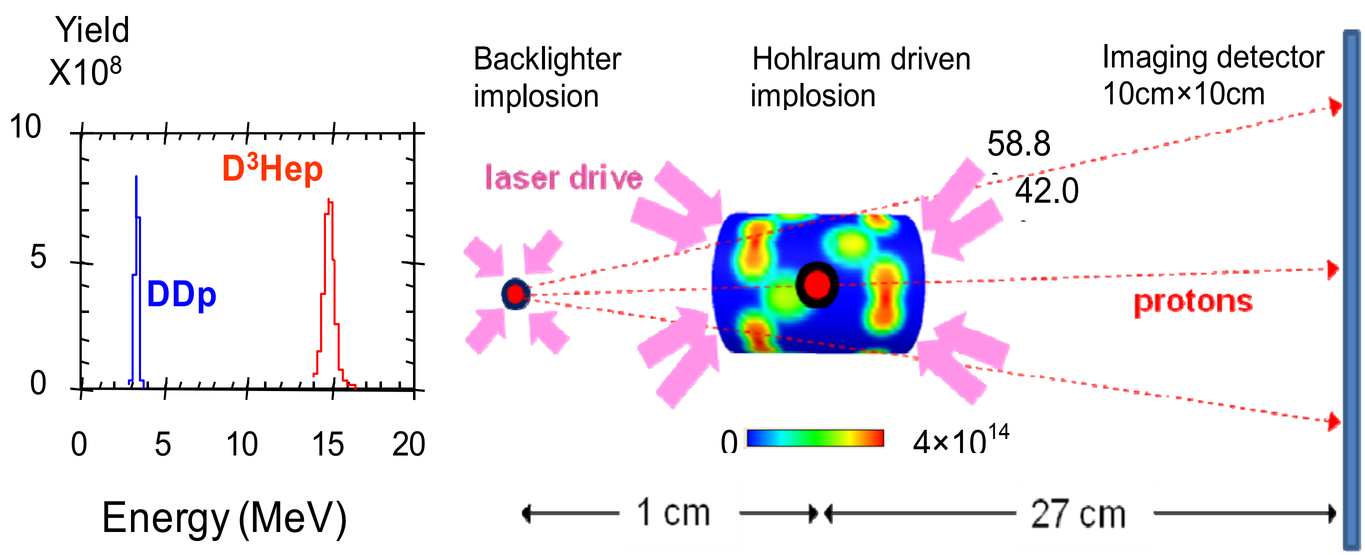


Simultaneous imaging with two or more discrete proton energies breaks any inherent degeneracy between *E* and *B*



D + ^{3}He → ^{4}He + p (14.7 MeV)
D + D → T + p (3.0 MeV)

Spatial resolution: ~ 40 μm (FWHM)
Energy resolution: ~ 3%
Temporal resolution: ~ 80 ps



The Lorentz force is used to identify and measure *E* and *B*

(1) Proton trajectory bending is due to the Lorentz force $F = q\left(E + \frac{v \times B}{c}\right)$

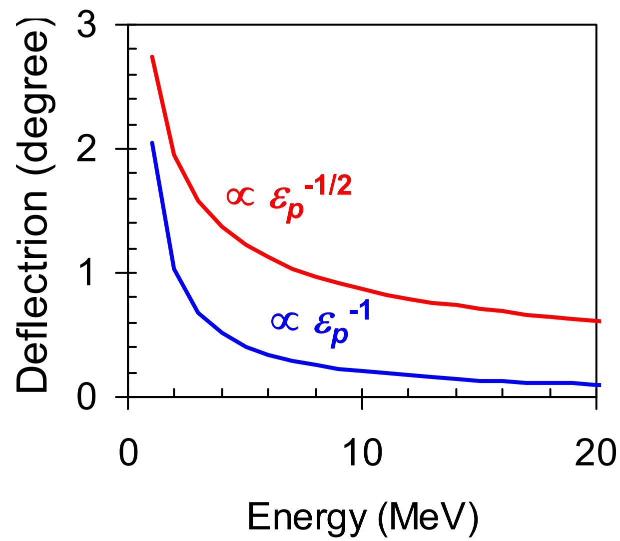
(2) Proton deflection angle *Θ* is proportional to

$\propto \mathcal{E}_p^{-1} \int E \times d\ell$ **and/or** $\propto \mathcal{E}_p^{-1/2} \int B \times d\ell$

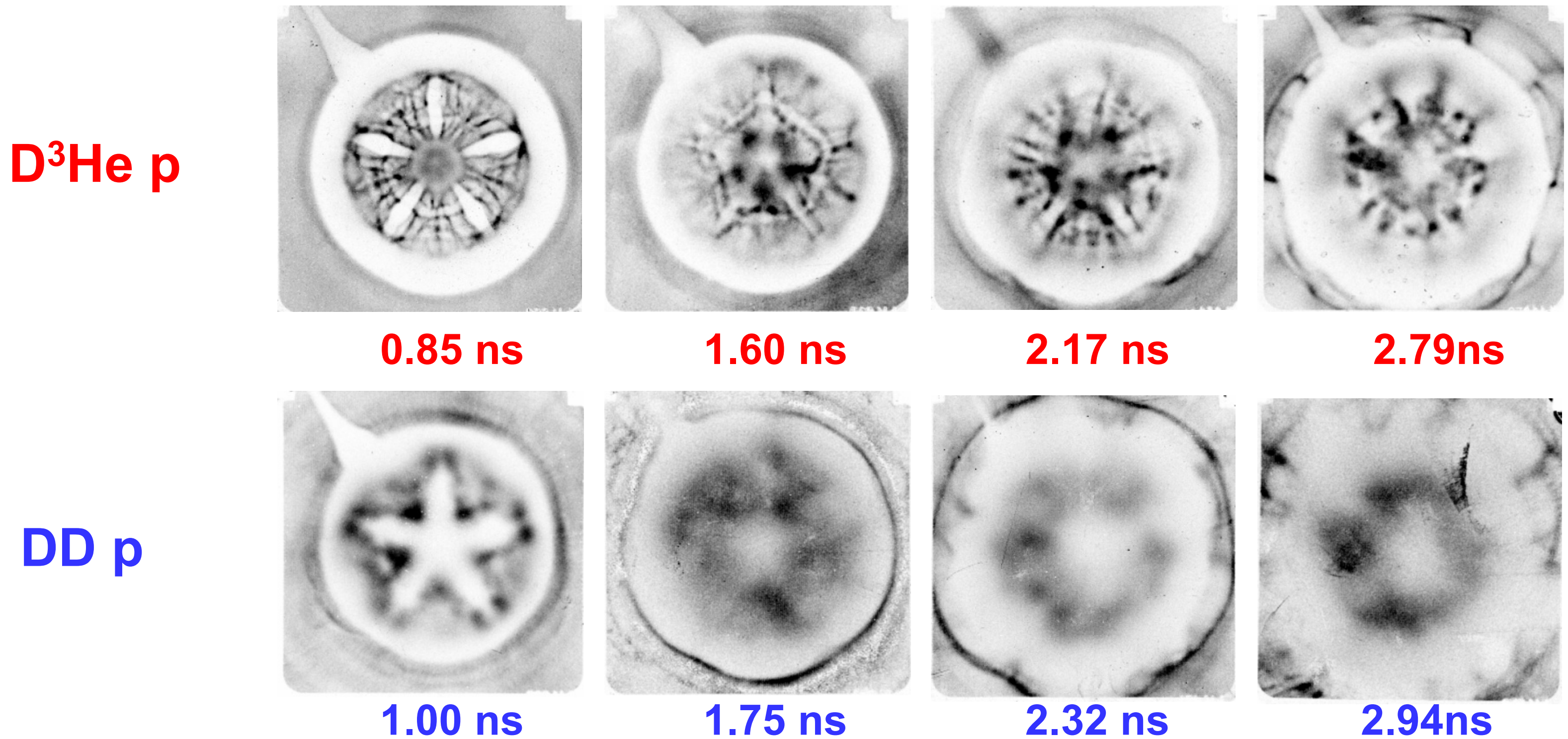
(3) Proton deflection due to collisional scattering is also proportional to

$\propto \mathcal{E}_p^{-1}$

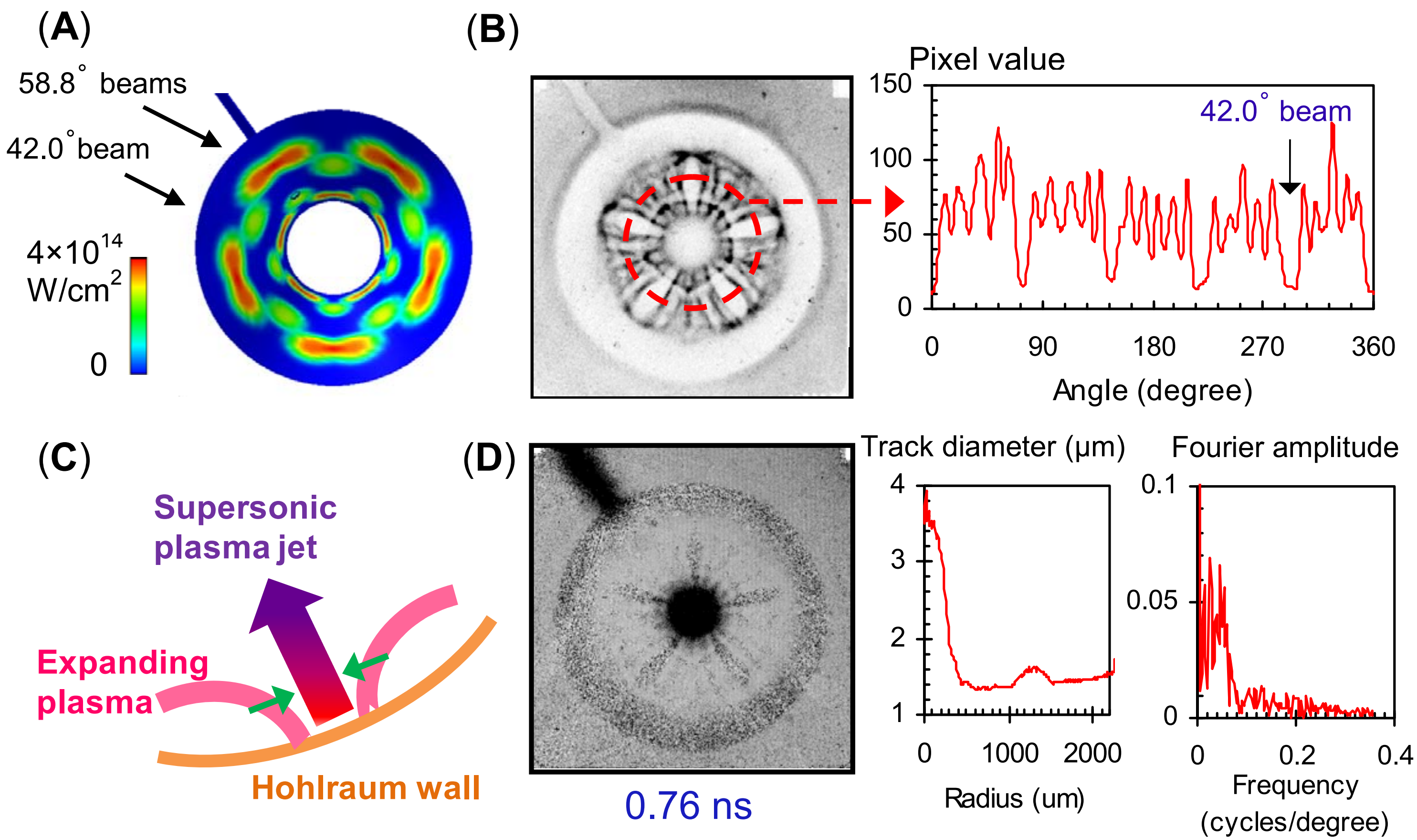
But this process always accompanies with energy loss



The views of the spatial structure and temporal evolution of both the laser drive in a hohlraum and implosion properties provide essential insight into x-ray-driven ICF

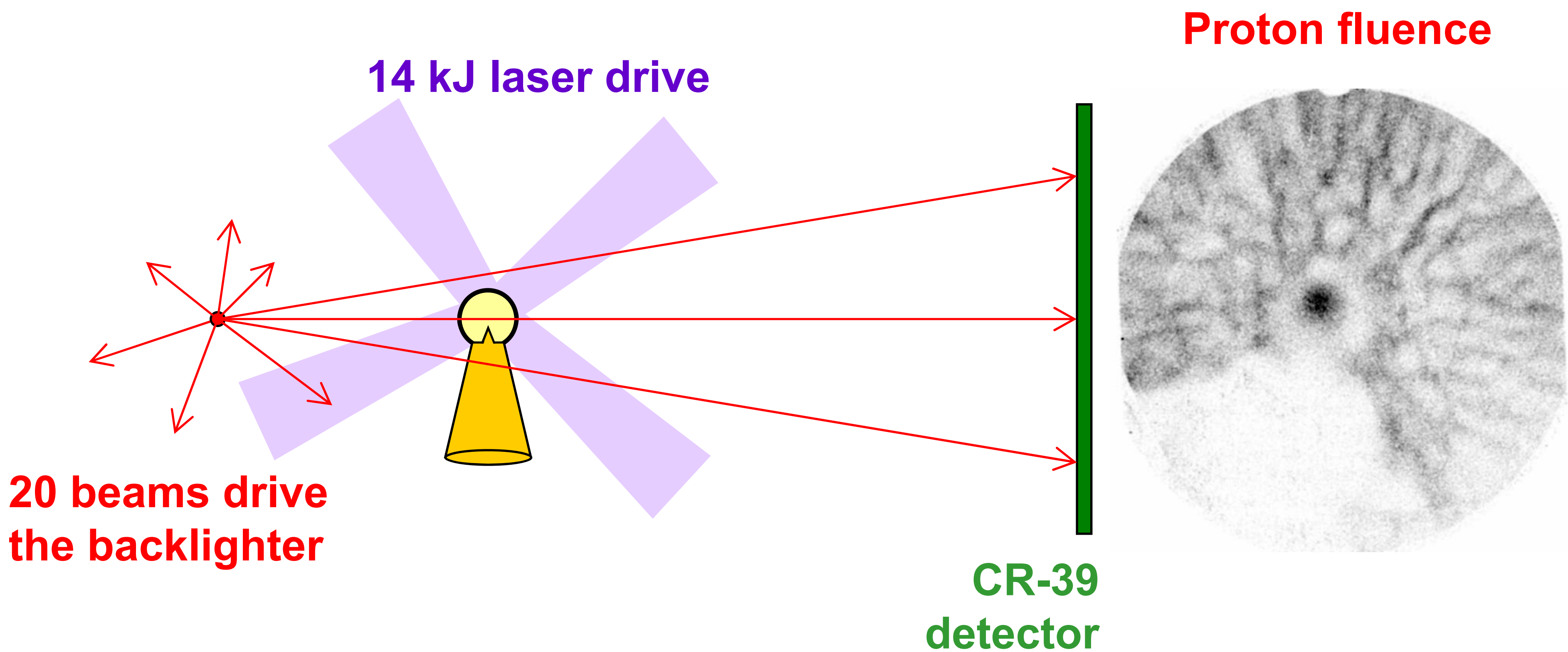


A striking feature shown in both fluence and energy images is a five-pronged asterisk-like pattern surrounding the imploding capsule.



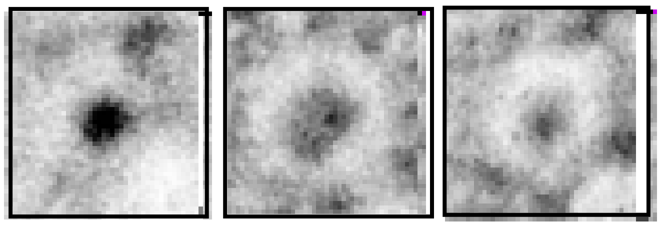
C. K. Li *et al.*, *Science* (2010)

A common feature of the direct-drive implosions is the presence of striations around the imploded capsule

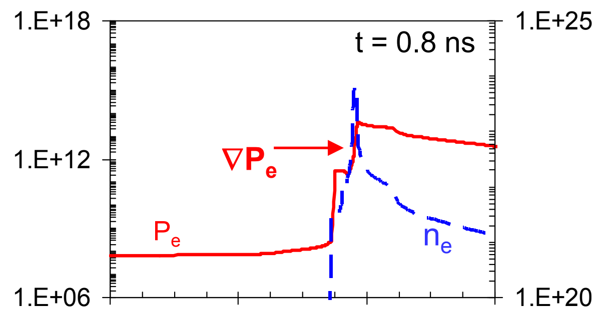


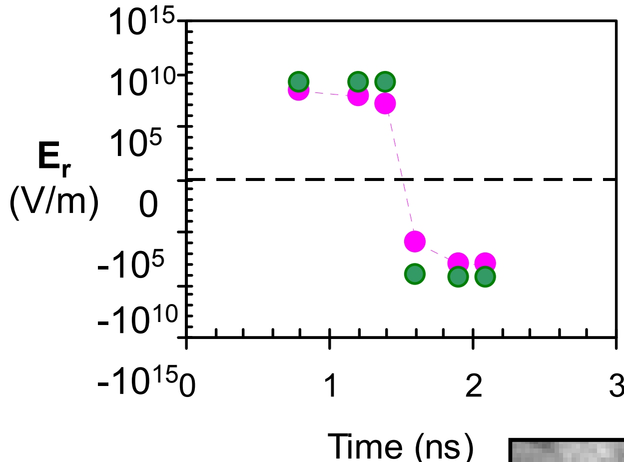
R. Rygg *et al*., *Science* (2008)

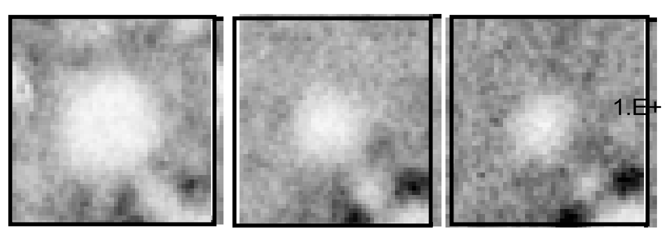
Proton fluence focusing and its reversal are caused by the direction change of a self-generated radial *E* field



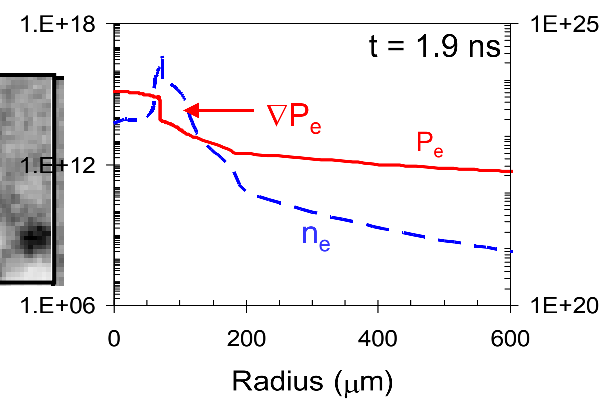
0.8 ns **1.2 ns** **1.4 ns**





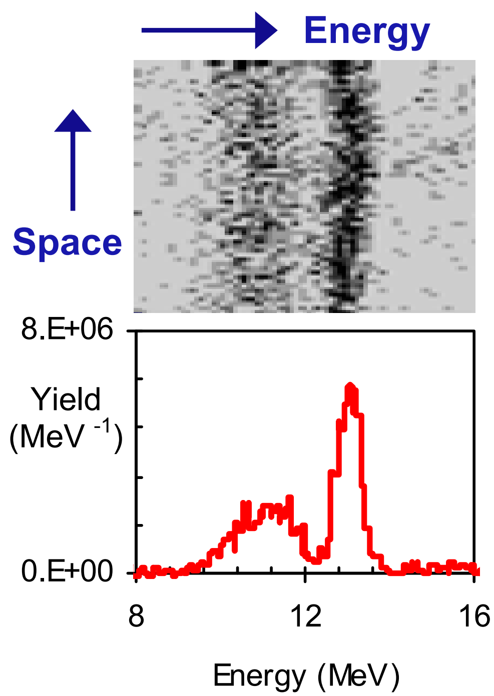


1.6 ns **1.9 ns** **2.1ns**

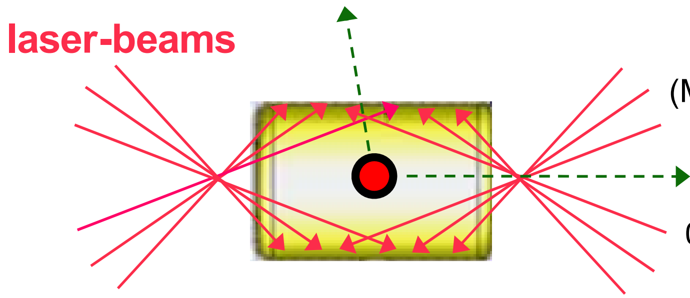


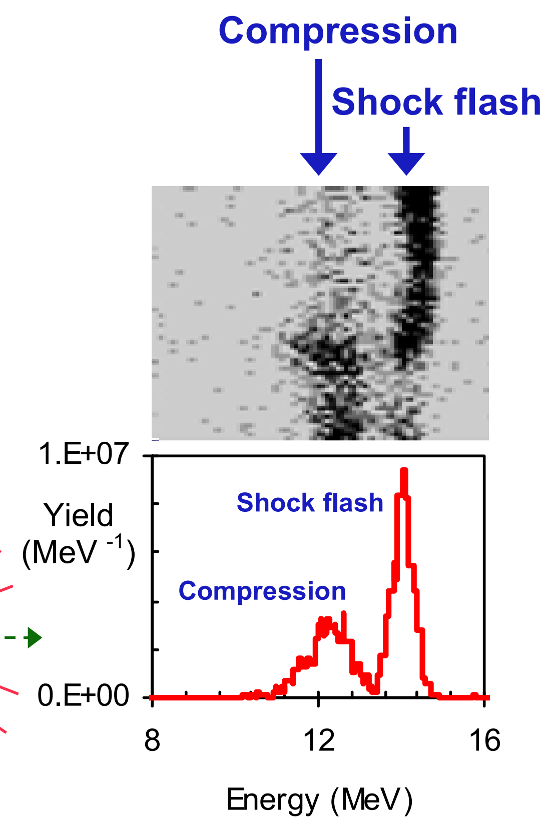
C.K. Li et at, *PRL* (2008)

Self-emission, spectrally resolved one-dimensional images and energy spectra reveal a strong, rapidly-changing, asymmetric field structure near the hohlraum axis

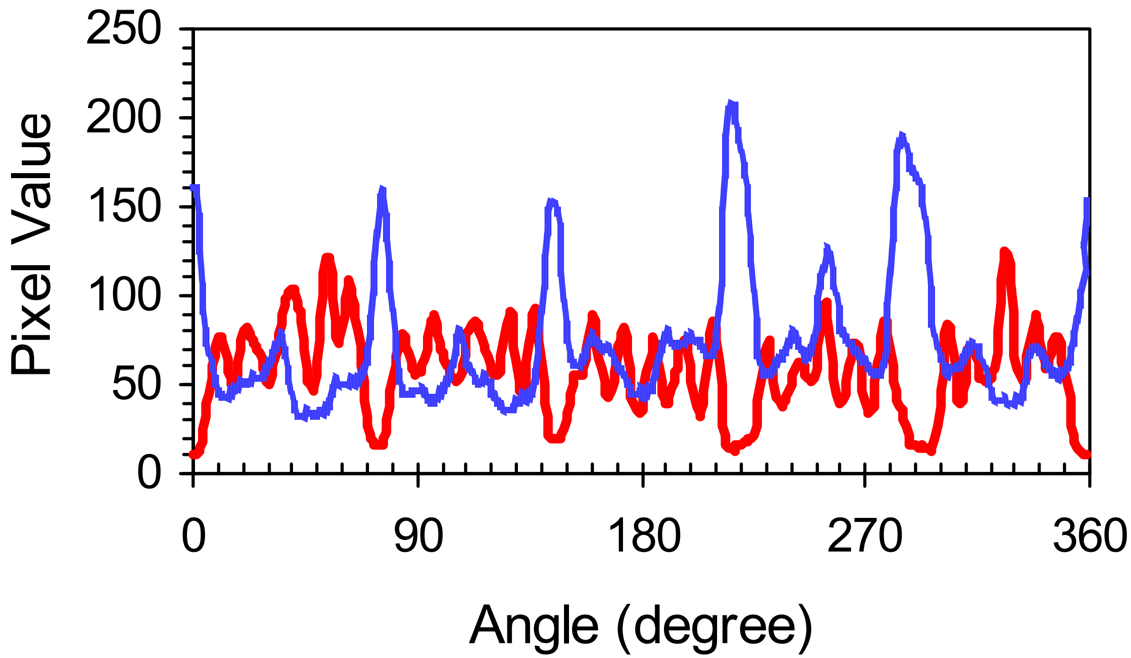


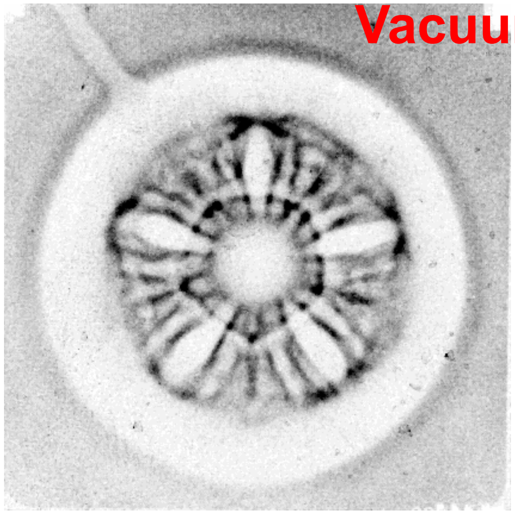
$$\frac{\partial \boldsymbol{B}}{\partial t} = -\nabla \times \boldsymbol{E}$$

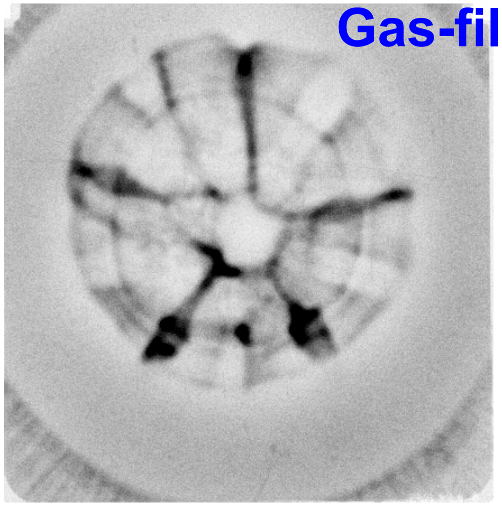




The preliminary data from the first proton backlighting gas-filled hohlraum-driven implosions indicate that the gas inhibits plasma flow and jet formation







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