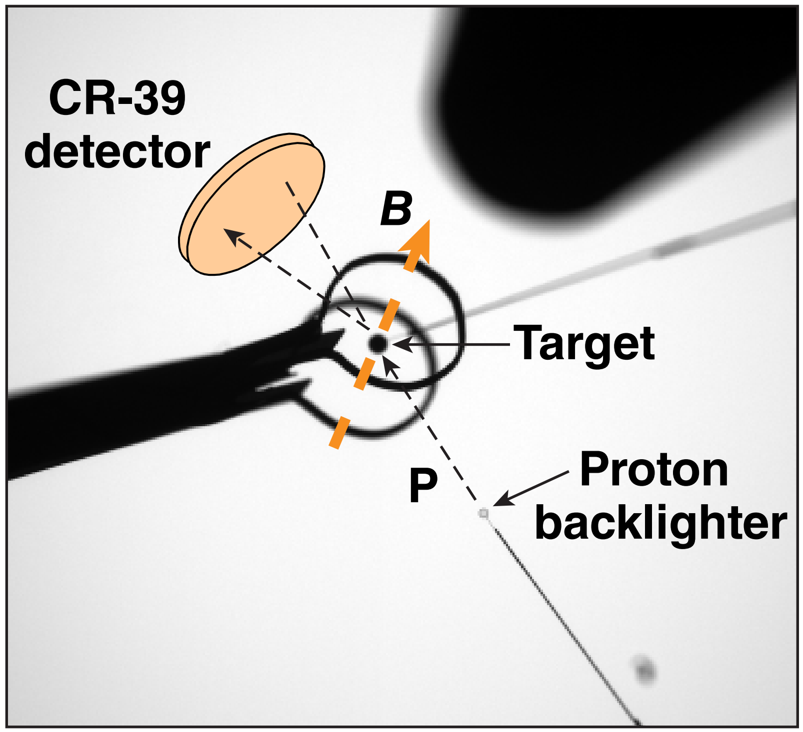
Magnetized Spherical Implosions on the OMEGA Laser



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Summary

An average compressed magnetic field of ~20 MG was observed in a spherical imploding target

- A seed field of 50 kG was compressed to 20 MG in spherical implosion experiments on OMEGA
- Expected neutron-yield enhancement and ion-temperature increase in spherical imploding targets from the 1-D simulation are small (~15% and ~8%, respectively) because of the open-field line geometry
- The shadow of the coil likely prevented conclusive observation of neutron yield or ion-temperature enhancement
- A single coil with polar drive will be used for future experiments to reduce the shot-to-shot variation and double the seed field

Collaborators

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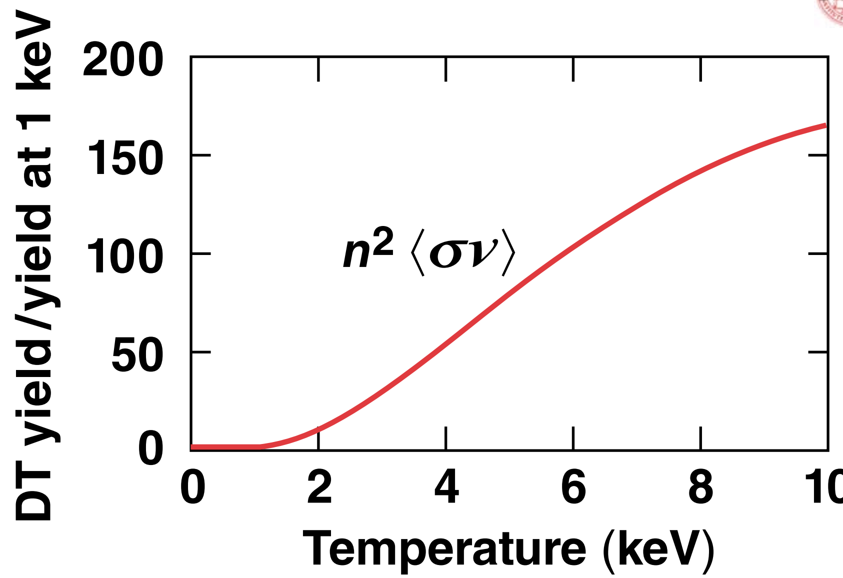
A strong magnetic field in the hot spot can be beneficial to the ignition condition

- Y_n is a strong function of T



- Laser energy required to achieve ignition can be reduced

  $E_{\text{laser-ignition}} \sim Y_n^{-1.3}$*

- A strong magnetic field will reduce the heat losses and improve hot-ion confinement

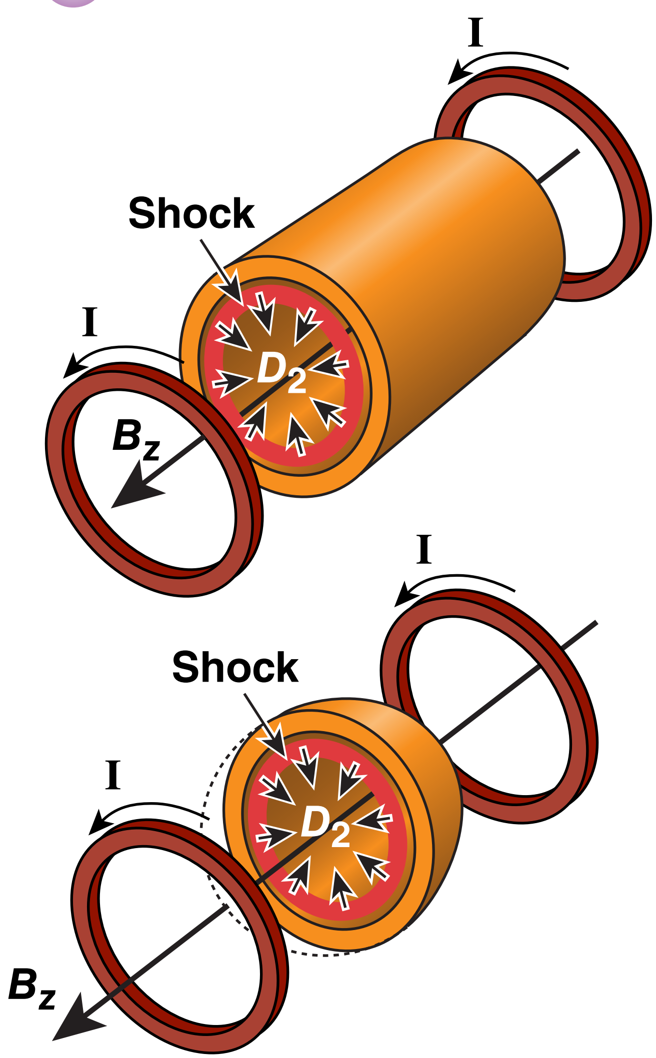
  NIF 1.5-MJ, polar-drive point design

  $\kappa_{\perp}/\kappa_{\parallel} \sim 0.2$ for $B = 10$ MG

  $r_{L\alpha} = 27\ \mu\text{m} \sim 1/2\ r_{HS}$ for $B = 100$ MG

*P. Y. Chang *et al.*, Phys. Rev. Lett. 104, 135002 (2010).

A new experimental setup was used to test the performance of spherical targets embedded in a magnetic field



Previous setup: cylindrical target

- Magnetic field of >30 MG observed in the cylindrical implosion experiment*
- Low ion density in the hot spot

Current setup: spherical target

- High ion density in the hot spot

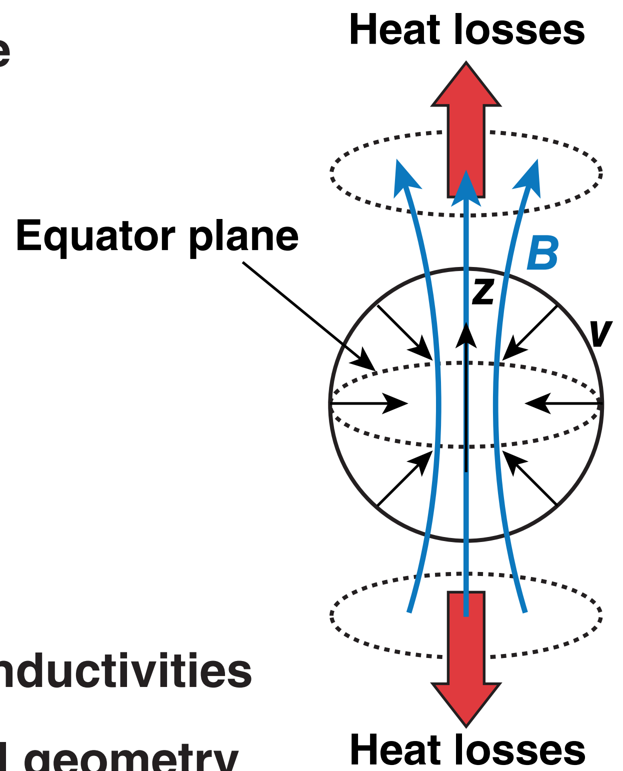
TC8998

*O. V. Gotchev *et al*., Phys. Rev. Lett. 103, 215004 (2009).

Heat losses are reduced by half in spherical geometry

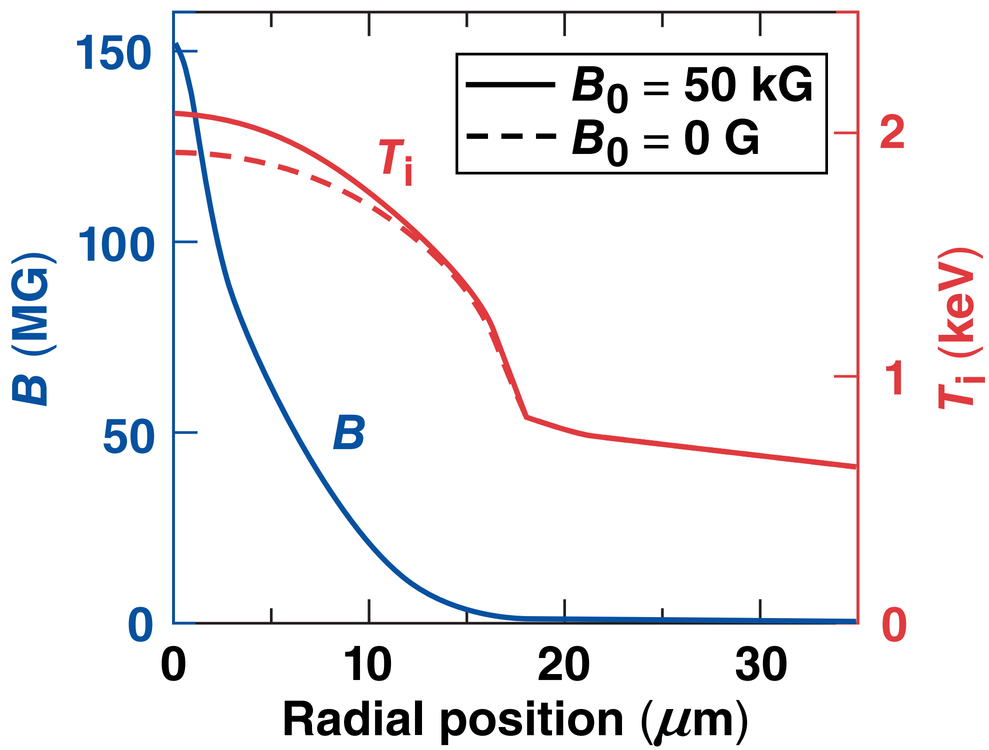
- 1-D *LILAC*-MHD code is used to simulate the spherical implosion on the equator plane
- Induction equation on the equator plane in spherical geometry

$$\frac{\partial \vec{\mathbf{B}}}{\partial t} = \hat{\mathbf{z}}\left[\underbrace{-\frac{1}{r}\frac{\partial}{\partial r}\left(r\nu_r B_z\right)}_{\text{Convection}} + \underbrace{\frac{1}{r}\frac{\partial}{\partial z}\left(rD_\eta \frac{\partial B_z}{\partial r}\right)}_{\text{Diffusion}}\right]$$



- Braginskii coefficients are used for heat conductivities
- Heat losses are reduced by half in spherical geometry
  – ratio of area of open-field lines to target surface area $= \dfrac{2 \times \pi r^2}{4\pi r^2} = \dfrac{1}{2}$

15% neutron-yield and 8% ion-temperature enhancements are expected in spherical imploding targets with magnetic fields



- A flux average magnetic field of ~20 MG in the hot spot is expected in the simulation for OMEGA targets
- A higher seed field would enhance the increase in yield and temperature

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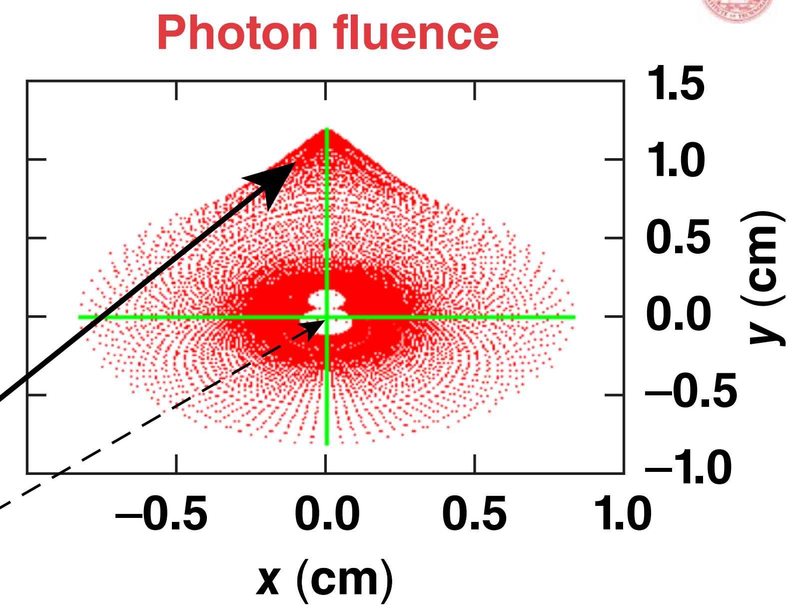
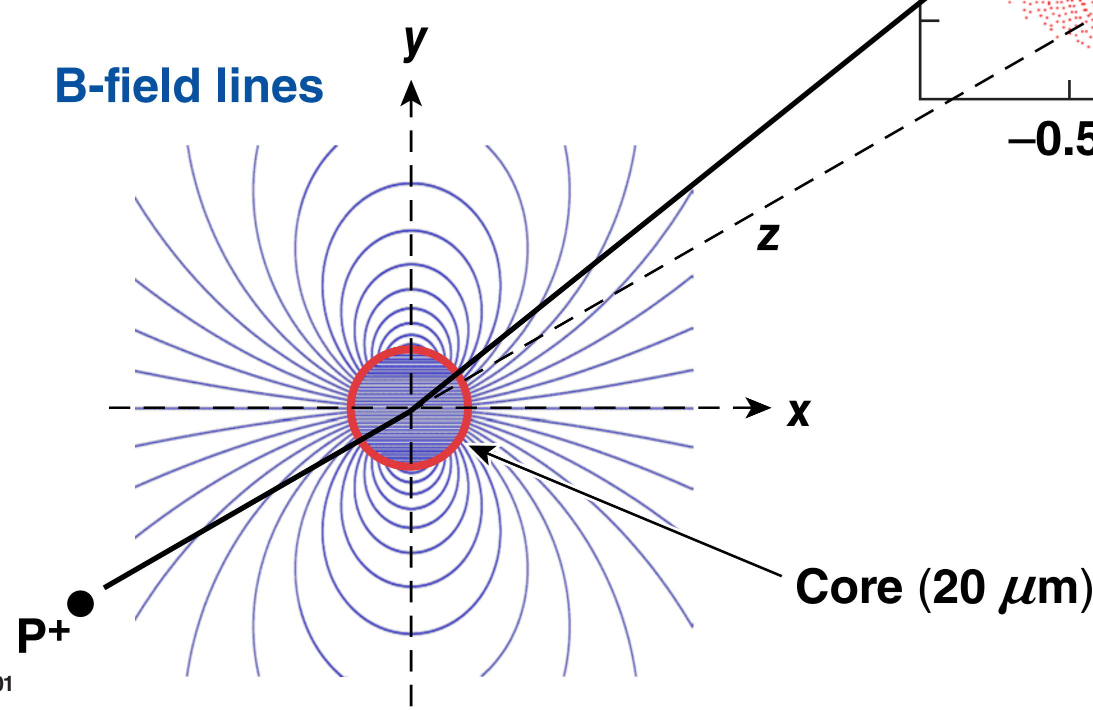
Particle-tracing simulation indicates a deflection peak related to the compressed magnetic field in proton radiography

$$\vec{B} = \begin{cases} \hat{x} & \left|\vec{r}\right| < 1 \\ \dfrac{1}{2}\dfrac{3\left(\hat{x}\cdot\vec{r}\right)\vec{r} - \hat{x}\left|\vec{r}\right|^2}{\left|\vec{r}\right|^5} & \left|\vec{r}\right| > 1 \end{cases}$$

Normalized by R = 20 μm and B = 20 MG





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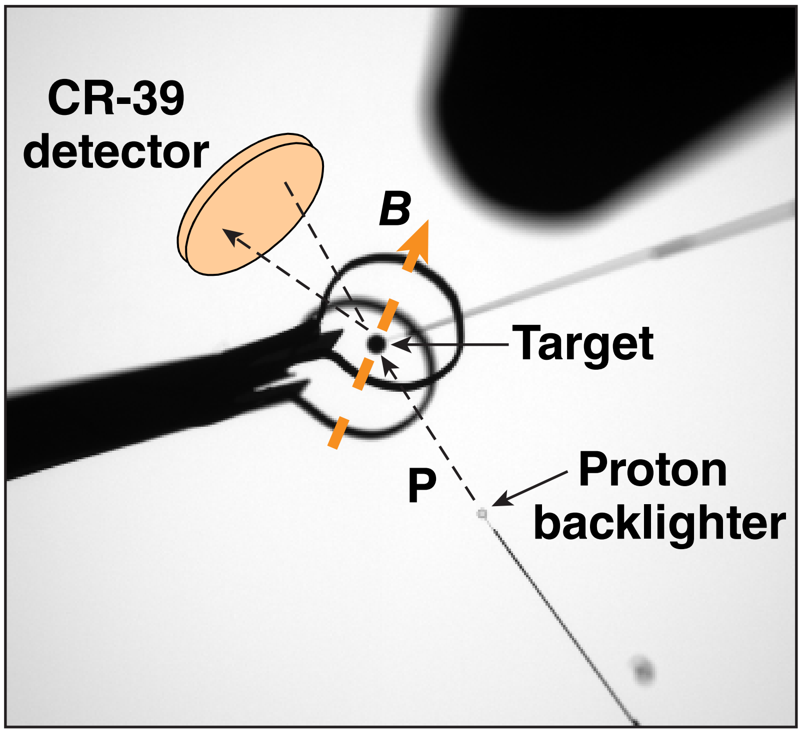
The compressed field was measured using proton radiography on OMEGA

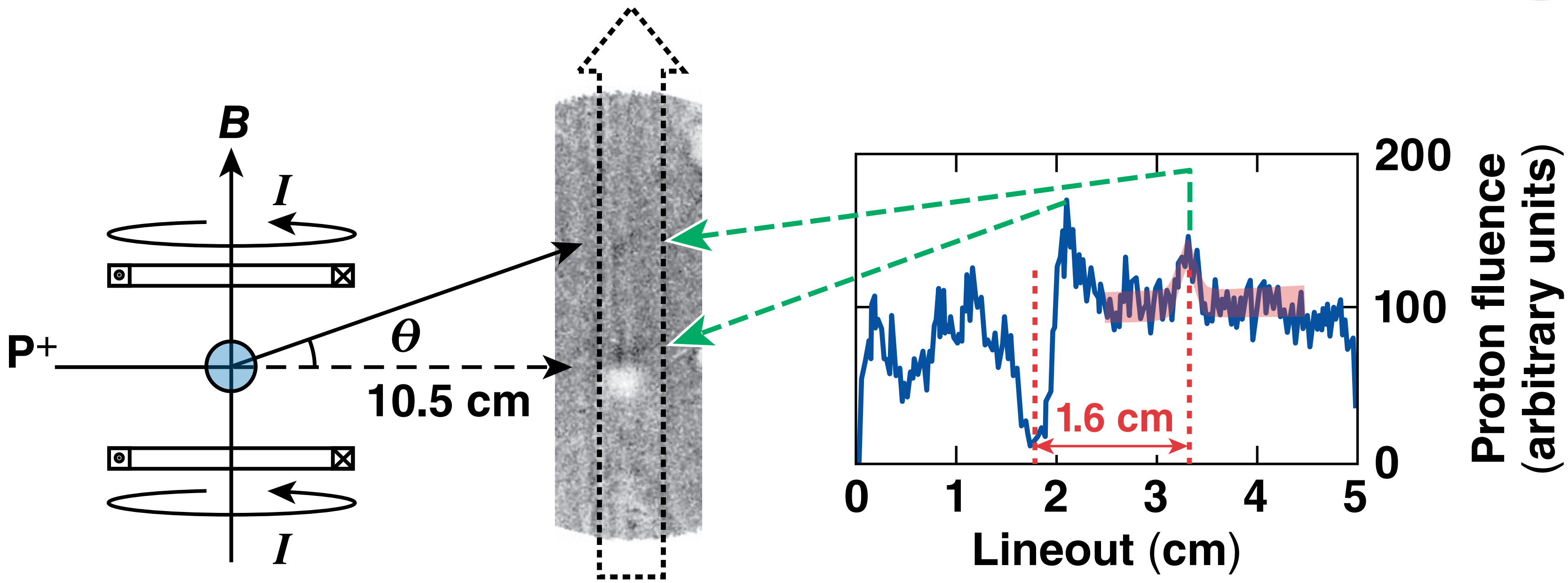


D + ^{3}He $\rightarrow$ ^{4}He + p (14.7 MeV)

- Main Target
  - D_2-filled CH
  - P = 3/5/10 atm
  - r_{D_2} = 406 μm
  - d_{CH} = 24 μm
  - 18.9 kJ (42 beams)
- Backlighter
  - D^3He-filled SiO_2
  - 9 mm away from TCC
  - 5.4 kJ (12 beams)

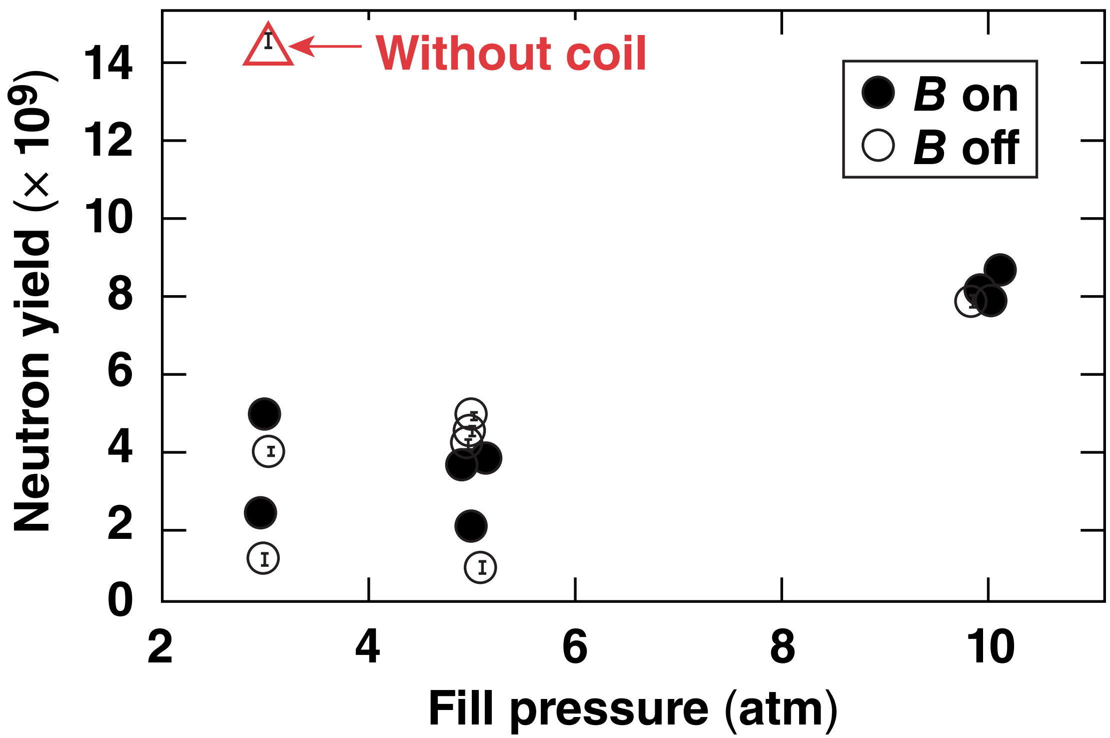
An average magnetic field of ~20 MG was estimated in the hot spot of the spherically imploded targets

Proton maps at t_0 + 1.8 ns (shot 59300)



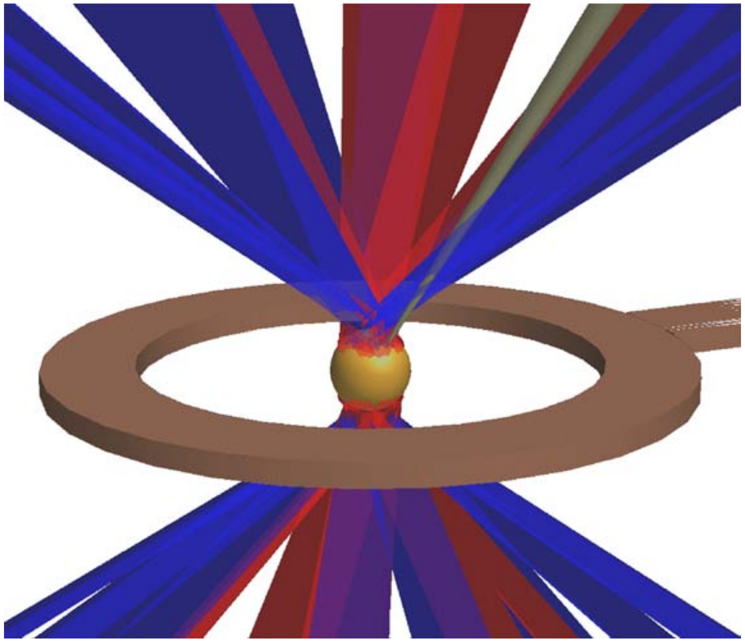
- The displacement between the minimum and the second peak in proton fluence is 1.6 cm
- The displacement gives $\int B \times \mathrm{d}r = \frac{\sqrt{2m_p E_p}}{q} \tan\theta = 860\ \mathrm{MG}\ \mu\mathrm{m}$
- Hot-spot radius of ~20 μm is predicted by *LILAC* simulation

Shadowing of coil may have prevented observation of neutron-yield or ion-temperature enhancement



- Two shots with and without coils (both without fields) produced yields that differed by a factor of ~3

A single coil with polar drive (PD) will be used to increase the magnetic field and reduce shot-to-shot variation



<u>Benefits of the new design</u>

- Higher seed magnetic field (~100 kG)
- Less chance of interference between the laser beams and the coil (2-mm tolerance for coil fabrication and positioning)
- Experimentally optimized laser uniformity on targets*

*F. J. Marshall *et al*., J. Phys. IV France <u>133</u>, 153 (2006).
Related talk: B05.00006

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