

Research on High Energy Density Science and Fusion at UC San Diego

Farhat Beg

Center for Energy Research

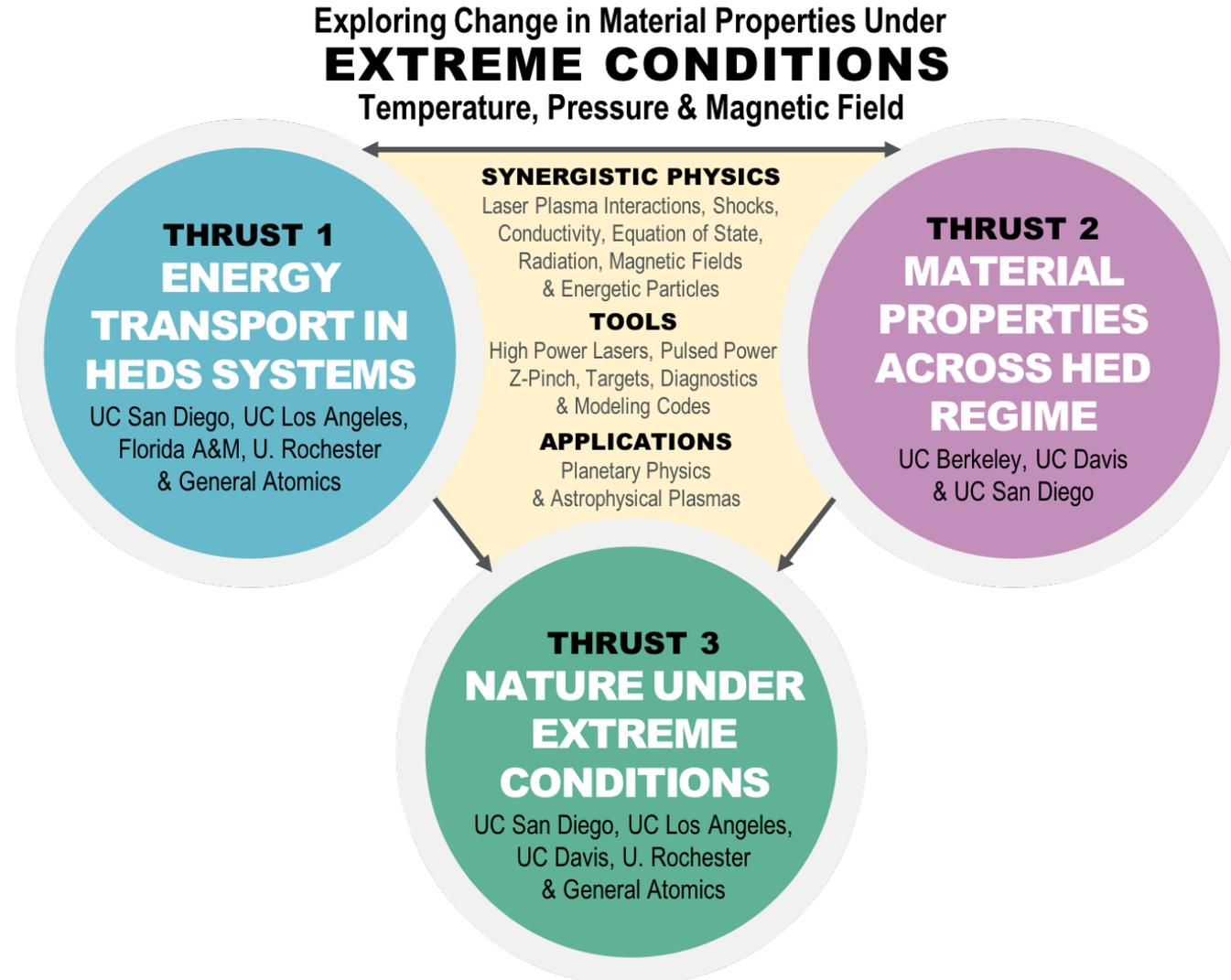
University of California San Diego

Fusion Power Associates Annual Meeting

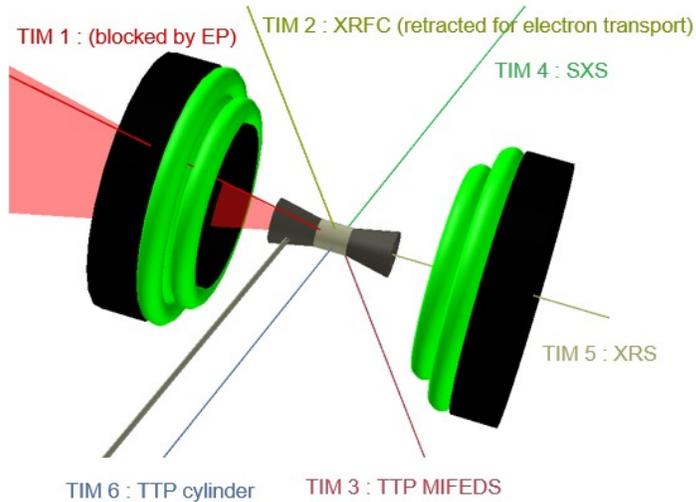
Washington DC, December 15-16, 2021

This work was supported by the NNSA/NLUF Grants DE-NA0003940 and DE-NA0003943

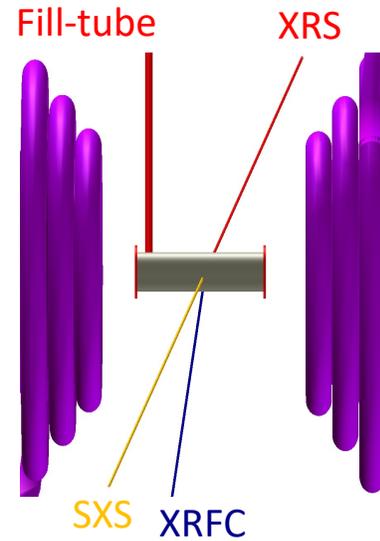
Overview of NNSA Center of Excellence



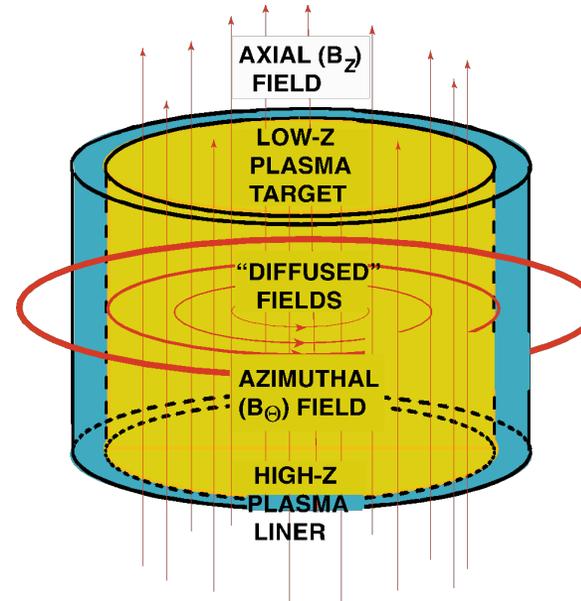
We Do Fundamental Research on Four Fusion Concepts



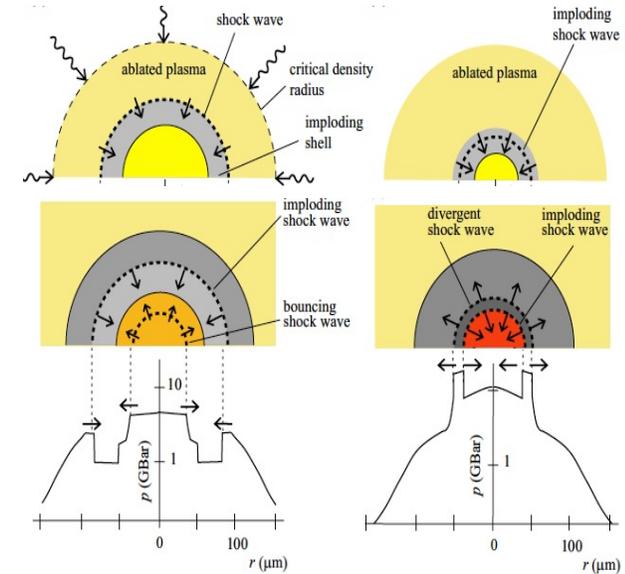
Fast Ignition 2.0



MagLIF

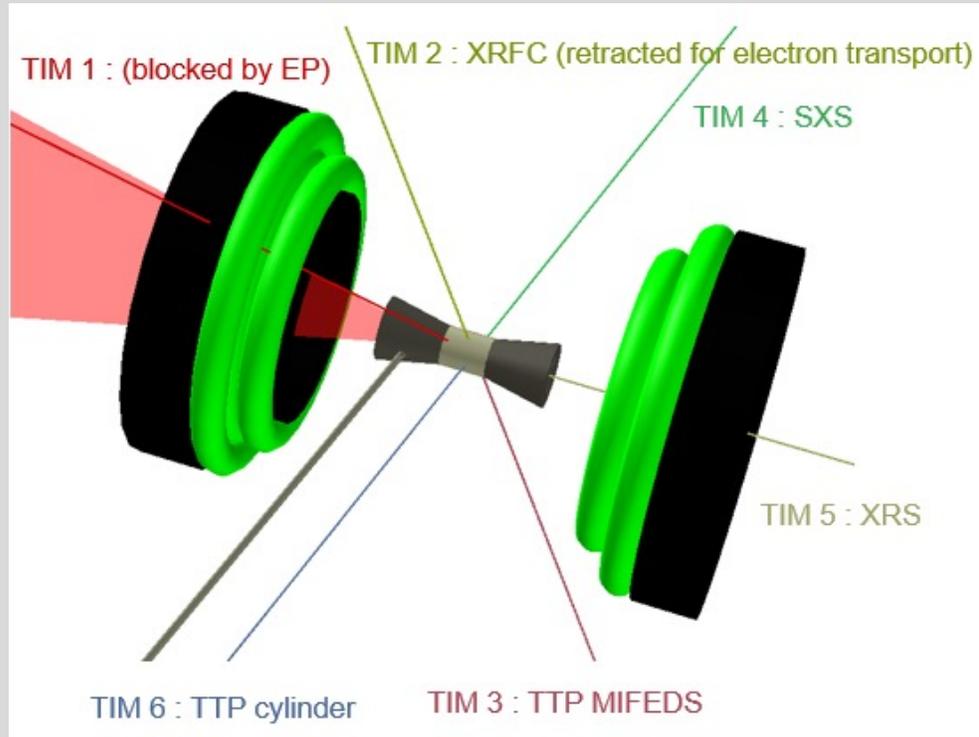


Liner on target Z-pinch

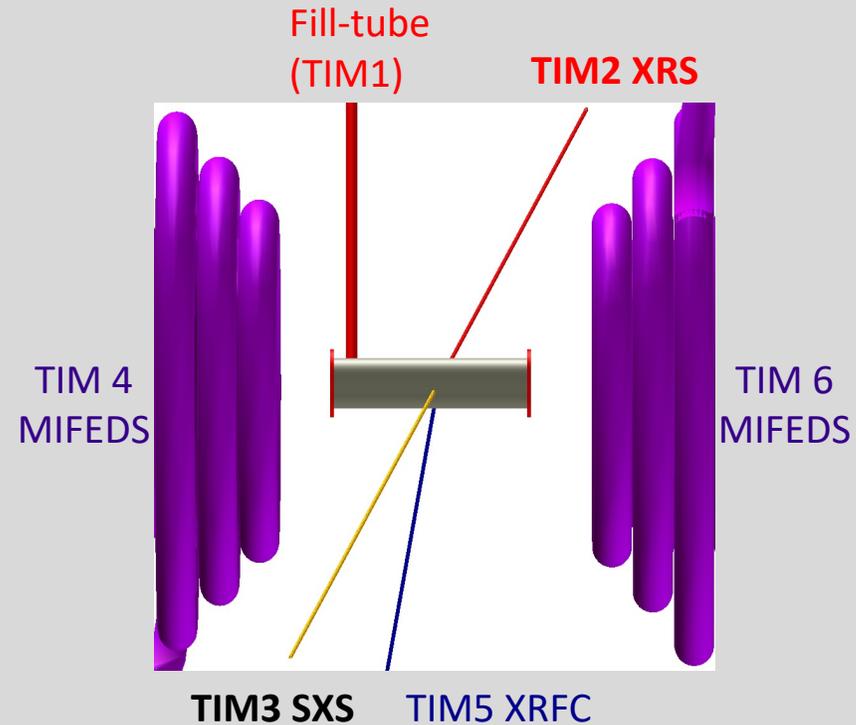


Shock ignition

Fundamental Research on Two Fusion Concepts

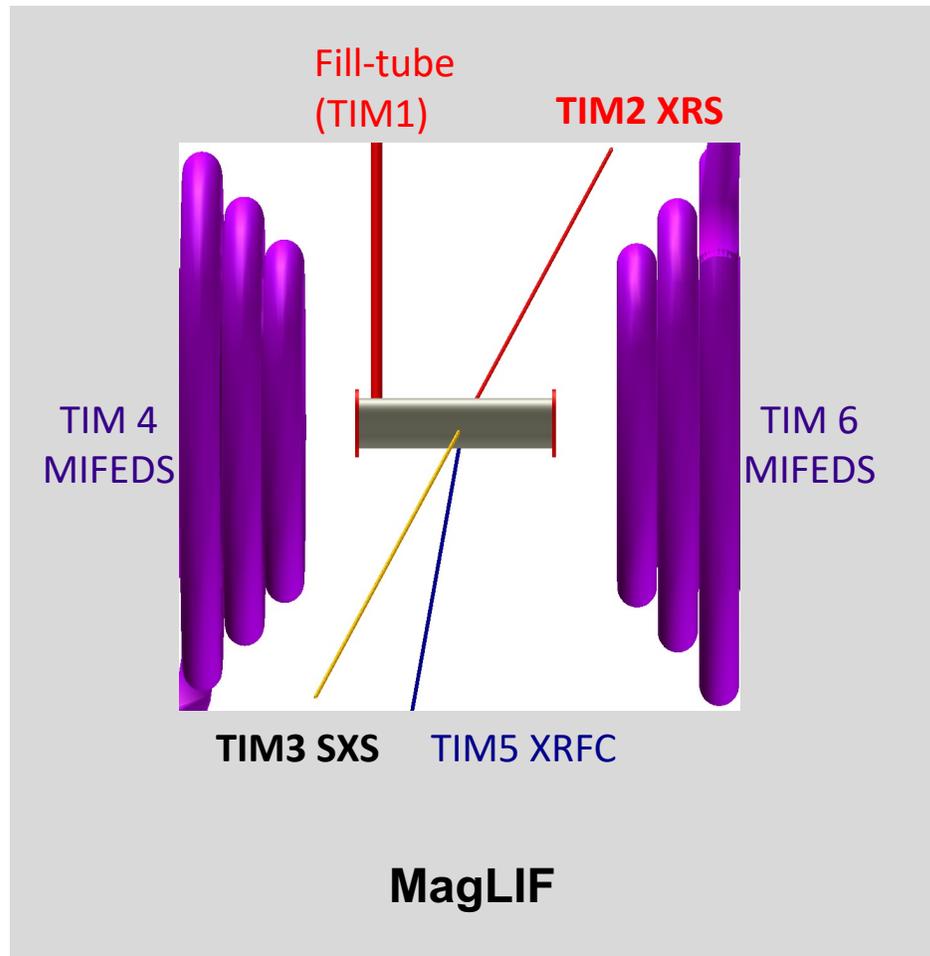
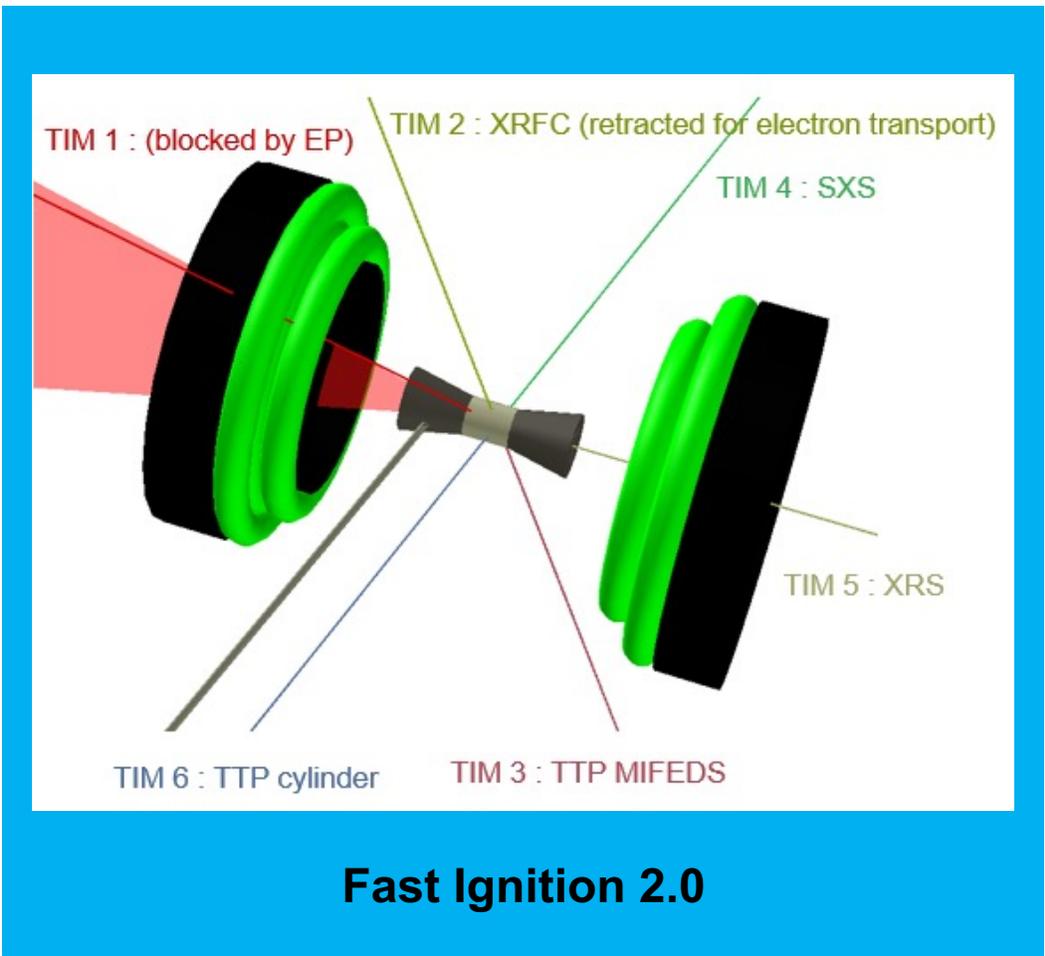


Fast Ignition 2.0



MagLIF

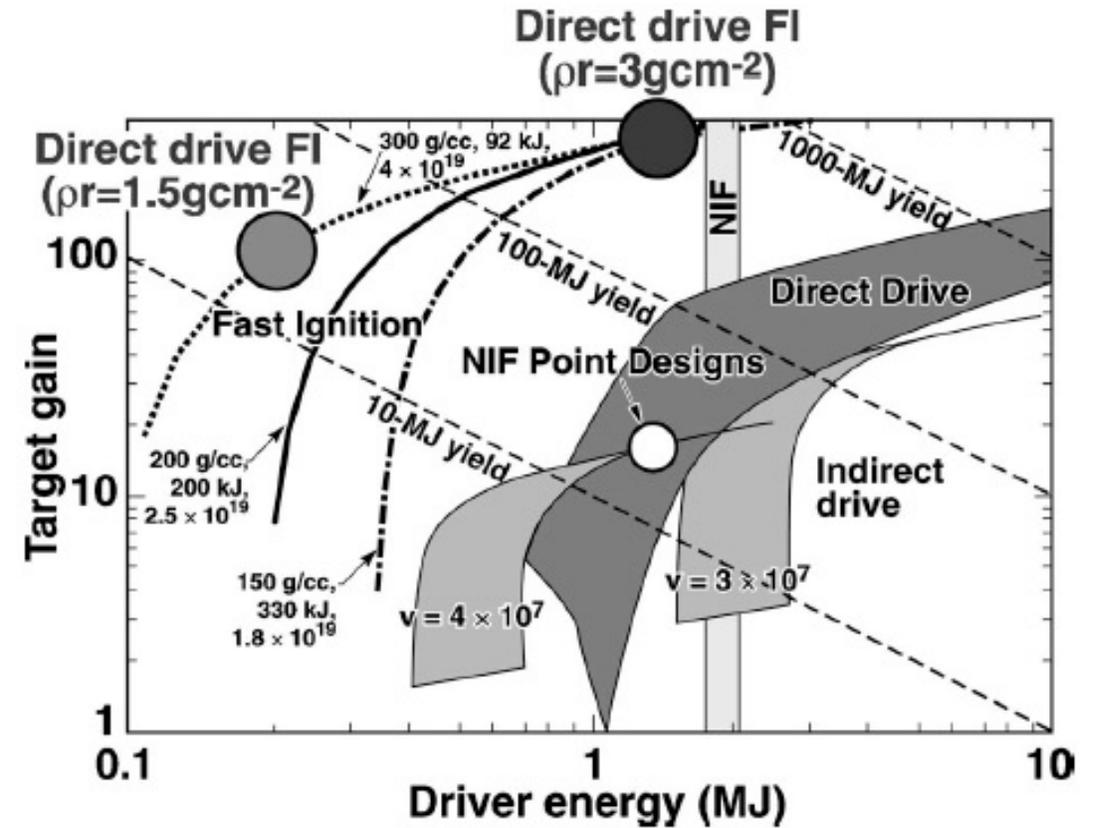
Fundamental Research on Two Fusion Concepts has Been Pursued



Why Fast Ignition?

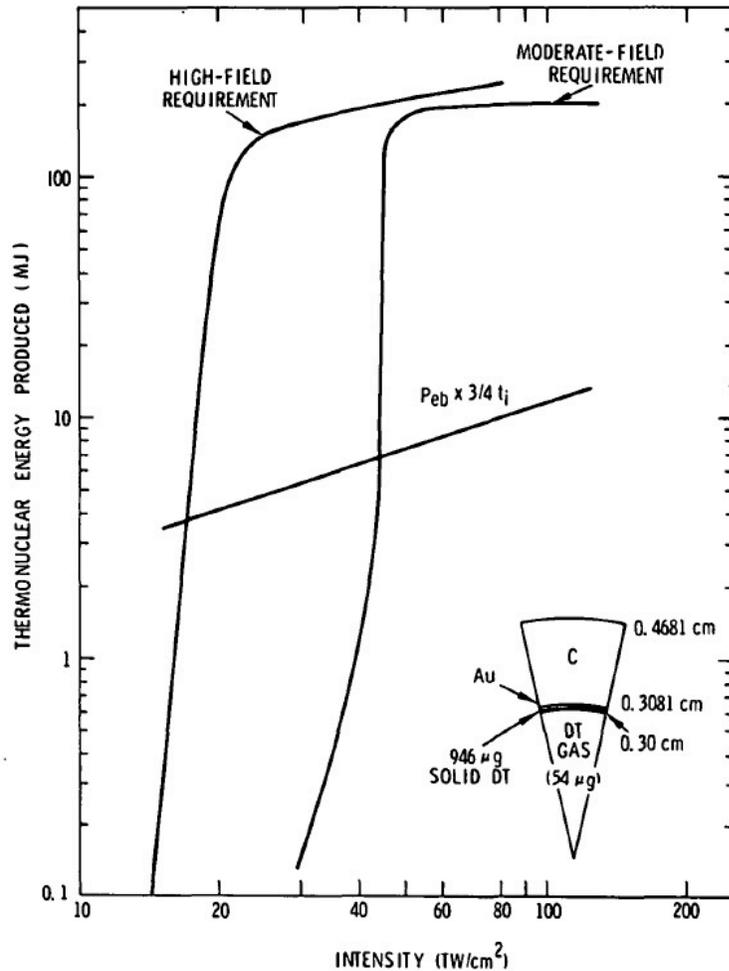


- Higher gain and lower ignition threshold
- Less stringent symmetry requirement
- Stand off distance is challenging



M. Key *et al.*, Physics of Plasmas **14**, 055502 (2007)

Fuel Heating by a Relativistic Electron Beam



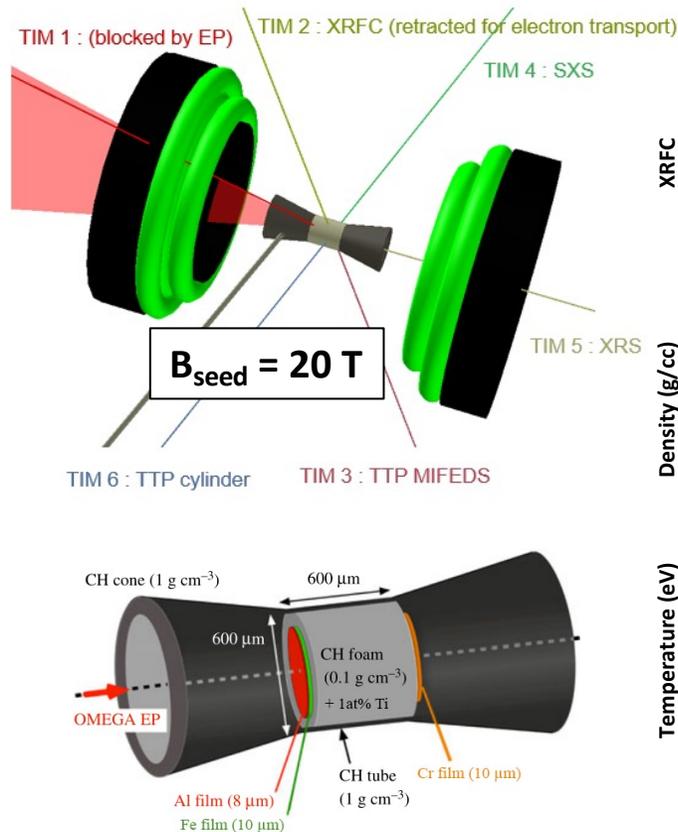
- In 1981, Sweeney *et al.** considered a class of high-gain ICF targets driven by electrons or light ions with strong external B-fields.
- Energy gains of **20–40** in the compressed density of 10 g/cm³ are expected using 1 MeV electron beam injection with an intensity of **~50 TW/cm²** and initial B-fields of **30–60 T**.



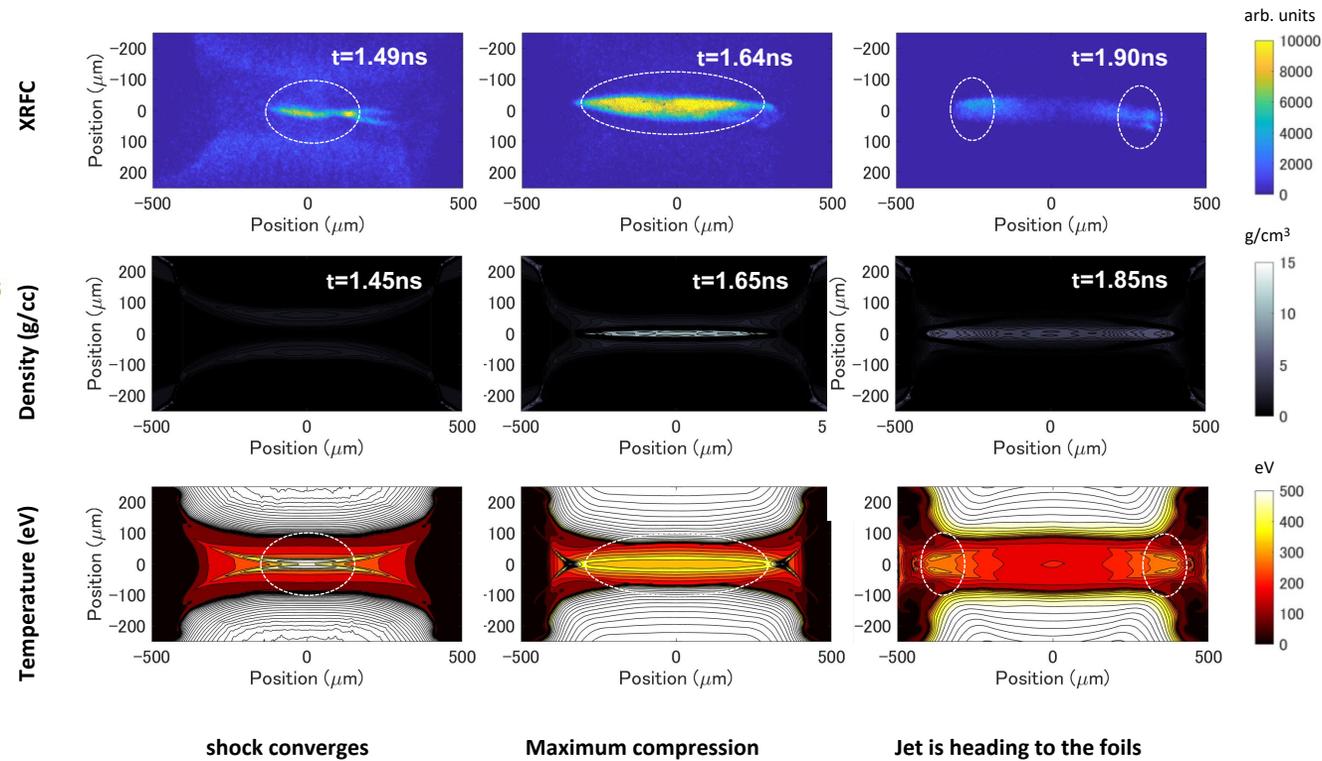
- ✓ We can now perform demonstration experiments with high-power short pulse lasers coupled with implosion laser drivers (OMEGA, NIF).
- ✓ It is also possible now to realistically simulate magnetized implosions (magneto-hydrodynamic, electron transport).

* M.A. Sweeney, A.V. Farnsworth, Nucl. Fusion 21, 41–54 (1981)

Well-Characterized Magnetized Cylindrical Implosions at OMEGA modeled with the FLASH code

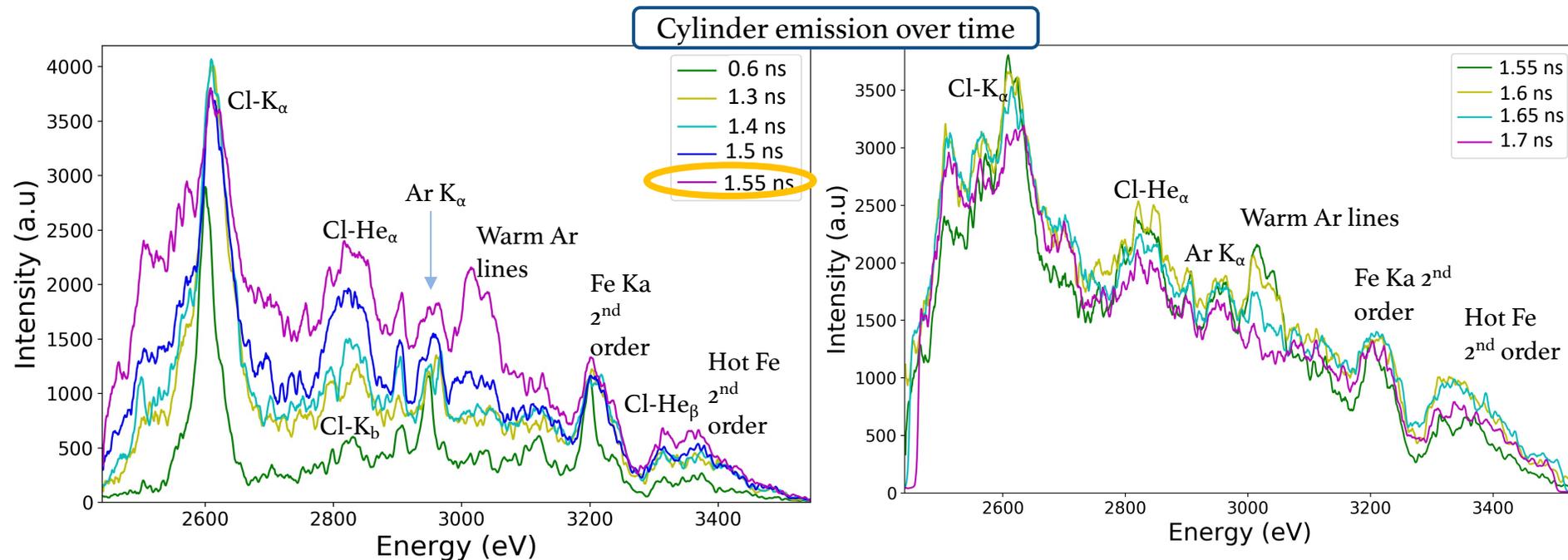


Implosion with $B_{seed} = 20$ T and no EP



- At stagnation, the compressed core density is ~ 10 g/cm³, the electron temperature is ~ 500 eV.

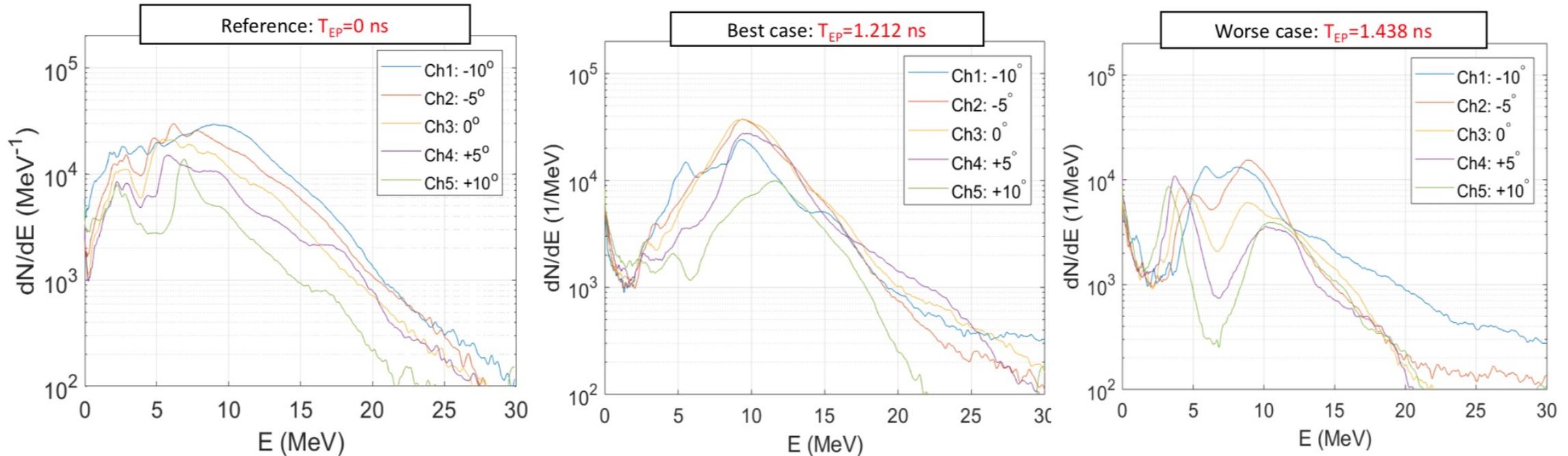
Emission Spectra Show the Dynamics of the Implosion Consistent with FLASH Simulations



- Lines get broader and the continuum intensity keeps on increasing until 1.55 ns when the shock reaches the center of the foam. This corresponds to the highest temperature.
- Duration of the stagnation emission predicted with FLASH is similar to the experimental spectra, 200 ps and 150 ps respectively.
- Continuum slope gives a temperature estimation of about 400 eV, which is consistent with FLASH simulations.

Experimental Data Shows Stopping of Fast Electrons in the Cylinder

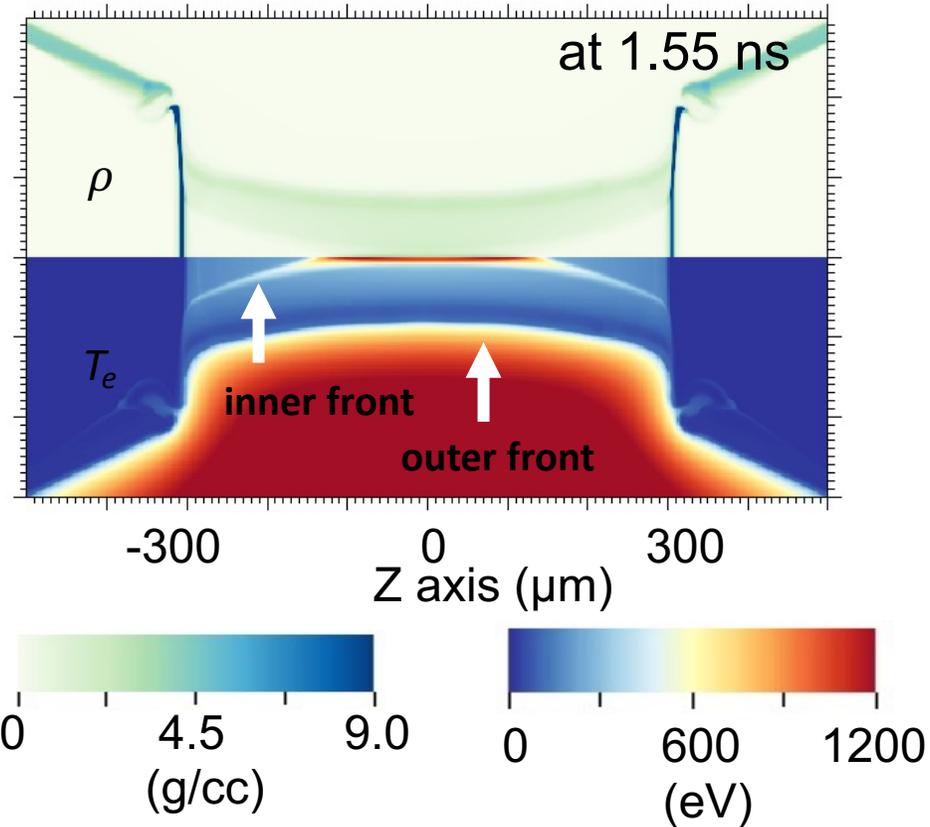
OUESM data



- Only a small number of fast electrons are stopped in cylinder at early time.
- As the magnetic field grows, more fast electrons are stopped with dips at 2 and 7 MeV.

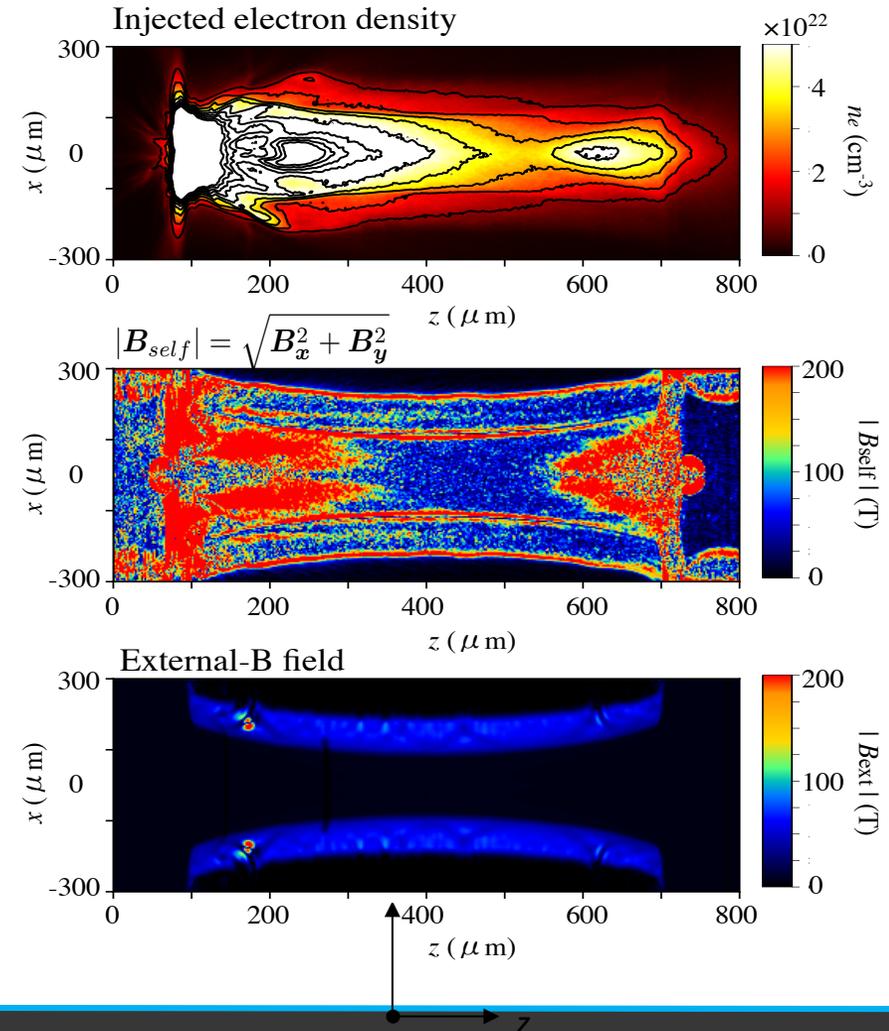
Fast Electrons Guiding by Self Generated B-fields before stagnation

FLASH Simulation for compression



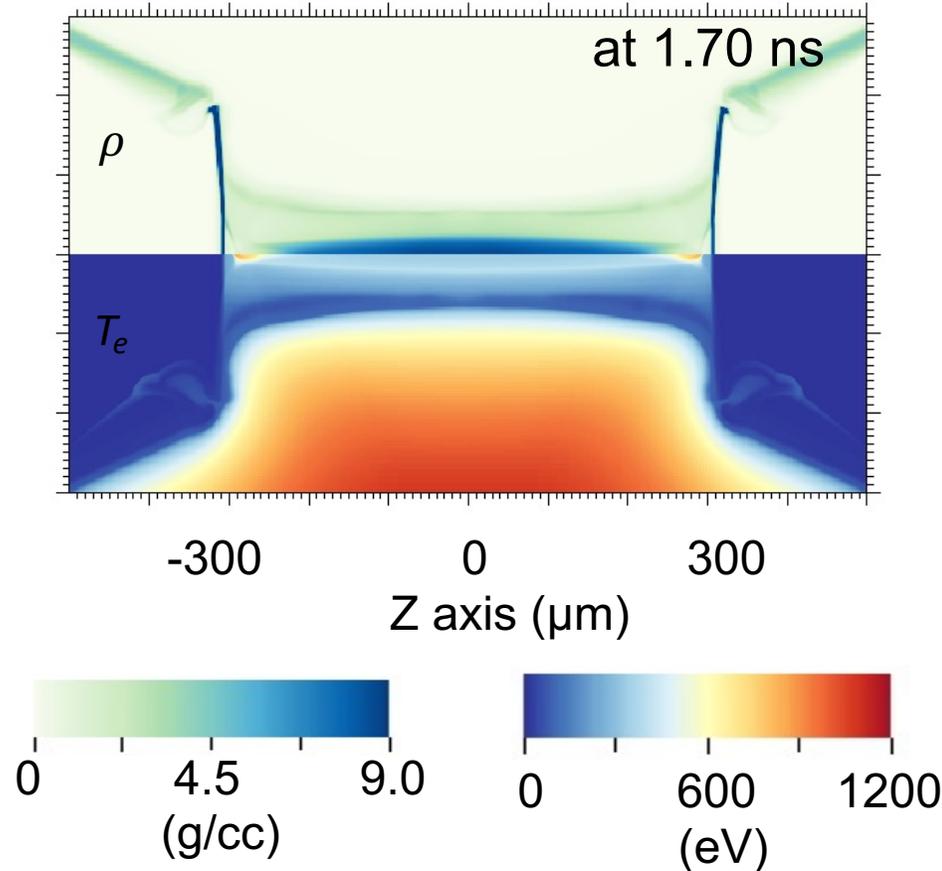
$$\frac{\partial \vec{B}}{\partial t} = -\nabla \times \left(\frac{\eta}{\mu_0} \nabla \times \vec{B} \right) + (\nabla \eta) \times \vec{j}_f + \eta (\nabla \times \vec{j}_f)$$

Hybrid PIC for electron transport

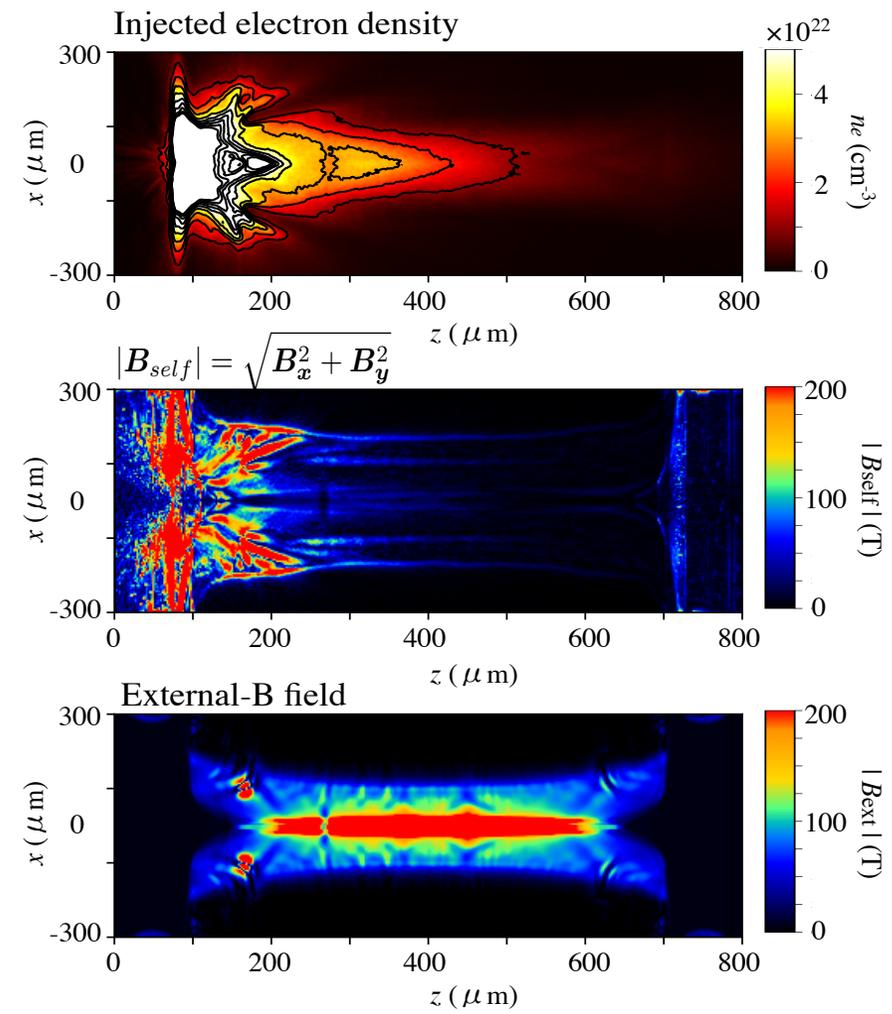


Fast Electrons Reflection by Self Generated Magnetic Mirror Effect at stagnation

FLASH Simulation for compression



Hybrid PIC for electron transport



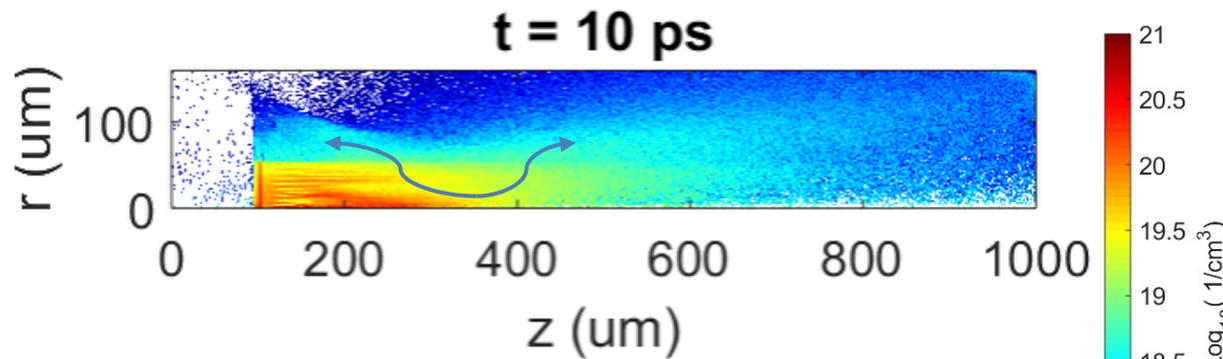
M. Dozières *et al.*, Physics of Plasmas **27**, 023302 (2020)

D. Kawahito *et al.*, Philosophical Transactions of the Royal Society A **379**, 20200052 (2020)

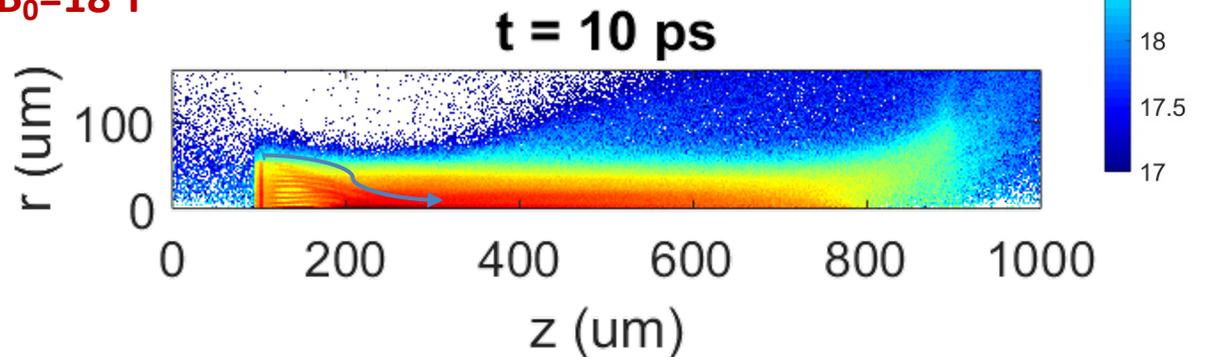
Compressed Magnetic Field can Guide the Fast Electrons and increase Energy Deposition (if $>$ self-B)

Hybrid-PIC simulations (LSP)

$B_0=0$ T

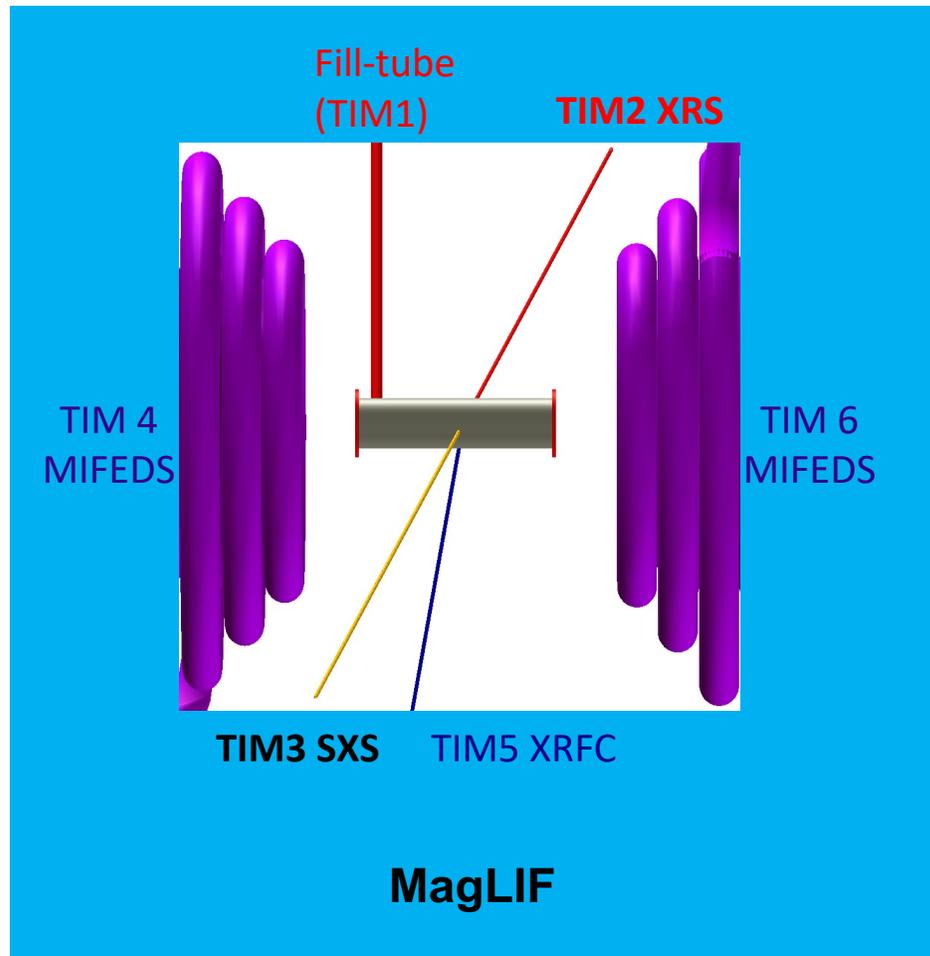
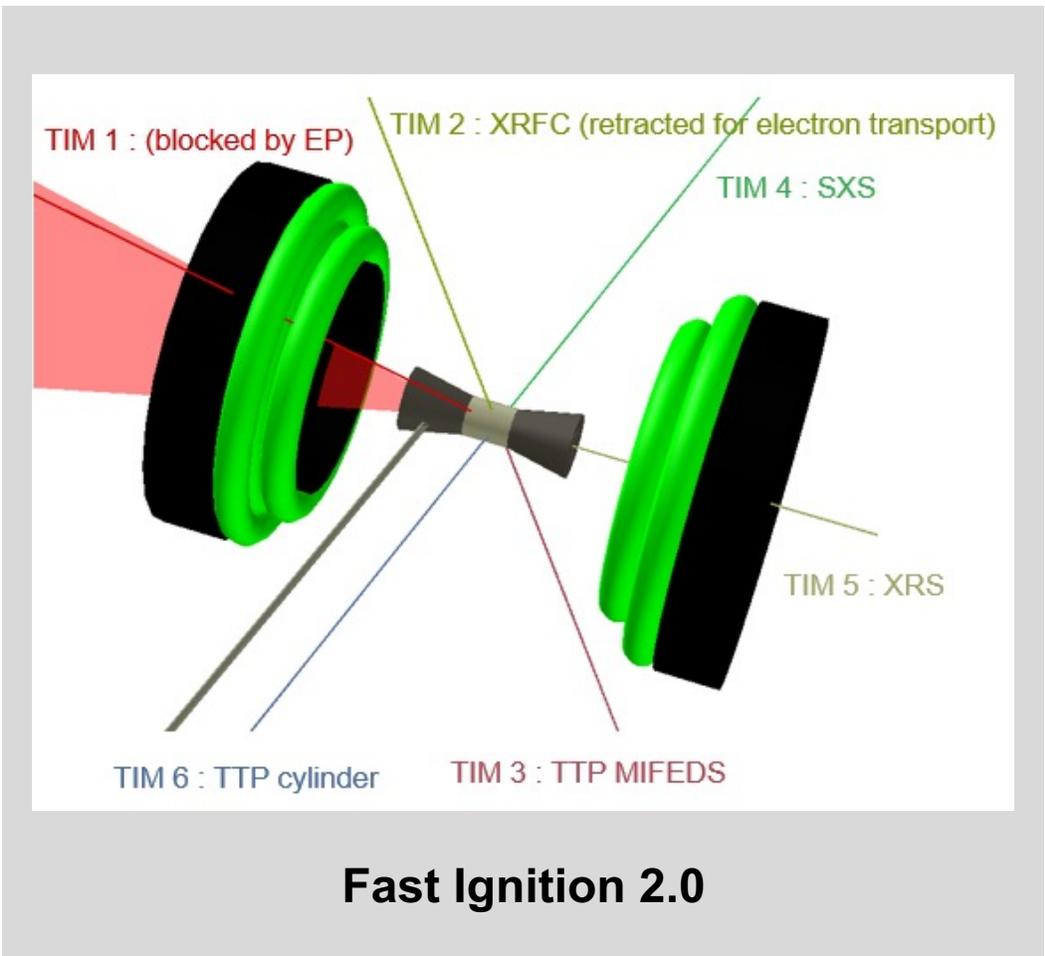


$B_0=18$ T

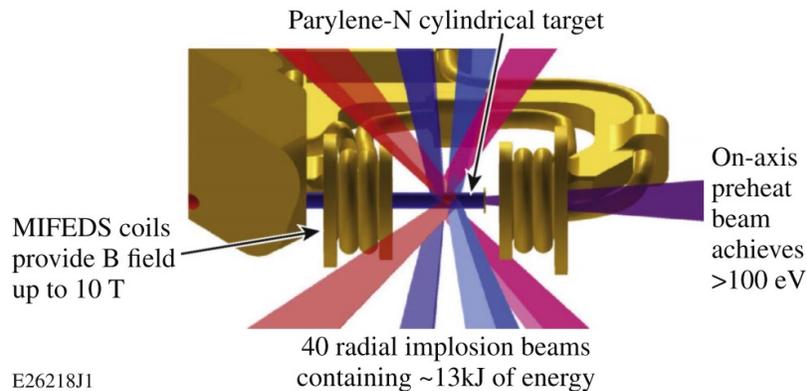


- The fast electrons are mirrored or scattered near the compressed core edges and propagate through the low-density outer part of the cylinder (at higher radii)
 - Low energy deposition in the compressed core.
- The fast electrons are guided by the compressed magnetic field along the cylinder axis.
 - Enhanced energy deposition in the compressed core.

Fundamental Research on Two Fusion Concepts has Been Pursued

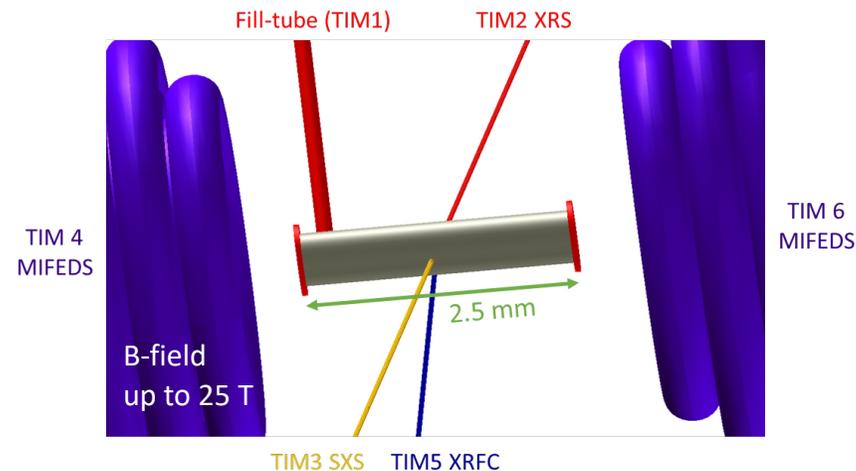


Magnetized Implosions: What Happens to the Compressed Plasma in Presence of Strong Magnetic Fields?



Laser-driven MagLIF (MiniMagLIF) setup

D.H. Barnak *et al.*, Phys. Plasmas 24, 056310 (2017).
 J.R. Davies *et al.*, Phys. Plasmas 24, 062701 (2017)
E.C. Hansen *et al.*, Plasma Phys. Control. Fusion 60, 054014 (2018)
 E.C. Hansen *et al.*, Phys. Plasmas 27, 062703 (2020)



**BCoilCompress campaign setup
(our platform)**

- Magnetization appears as a possible route towards higher fusion yield.
- Treatment of **magnetized hot dense plasmas** requires understanding of complex mechanisms such as magnetic flux compression and extended MHD effects, as well as induced currents and nonlocal electron transport.

Aim is to produce and characterize strongly magnetized hot dense plasmas (high Hall parameter and low plasma β).

Platform to Characterize Cylindrical Compressions with $> 10,000$ T Compressed Magnetic Fields

PI: Mathieu Bailly Grandvaux

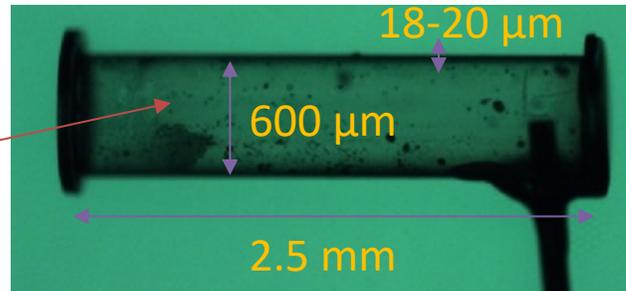
40 UV beams, $I_0 \sim 10^{15}$ W/cm²

total energy ~ 14.5 kJ

1.5 ns square pulse

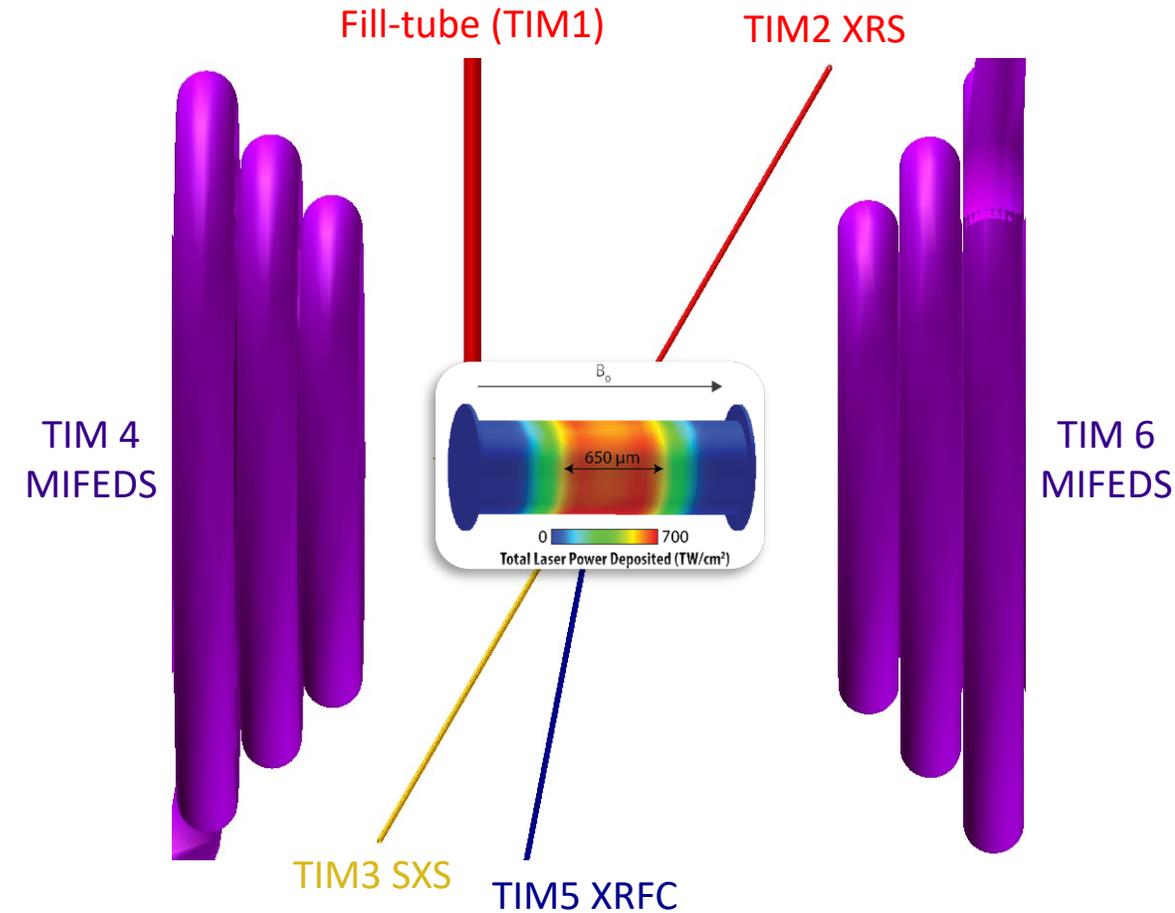
300 μ m radius phase-plate (R98%)

D₂@11 atm
(0.15 atomic % Ar)



Parylene-N filled-tube

- The seed (initial) B-field generated by pulsed-power coils is $B_0 \sim 25$ T at the target location, and it is amplified by the compression to $> 10,000$ T.



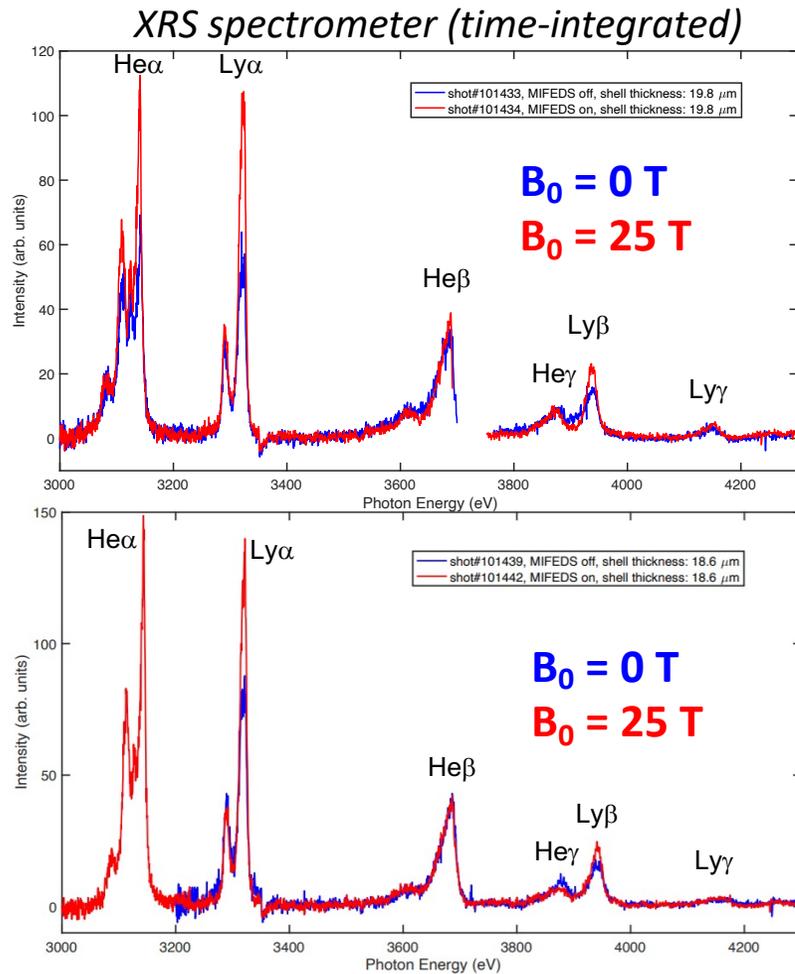
XRS: X-Ray Spectrometer

XRFC: X-Ray Framing Camera

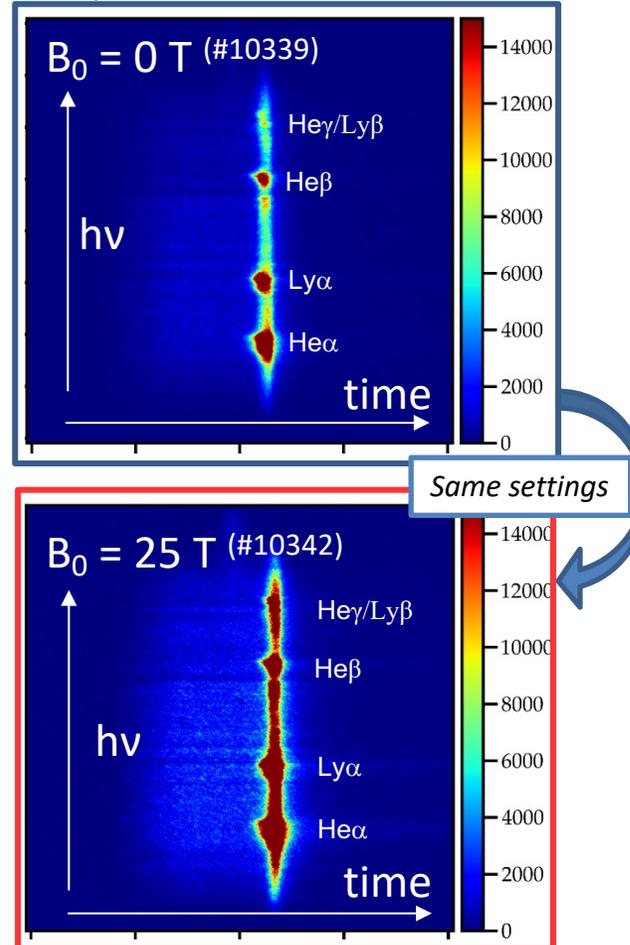
SXS: Streaked X-ray Spectrometer

MIFEDS: (pulsed-power coils)

What are the Effects of the Applied Magnetic Field on the Assembled Core Conditions?



SXS spectrometer (time-resolved)



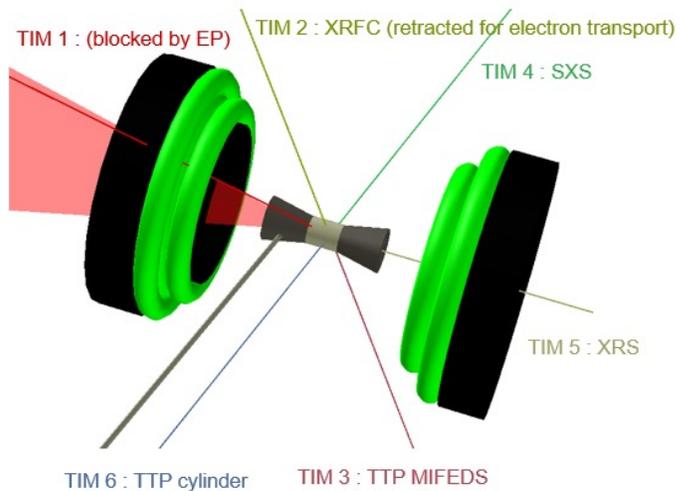
XRS

- No matter which pair of shots with MIFEDS on/off we take, we observe a **systematic behavior**.
- For the **magnetized case**, the $\text{Ly}\beta/\text{He}\beta$, $\text{Ly}\alpha/\text{He-like sat.}$ and $\text{He}\alpha/\text{Li-like sat.}$ are higher:
 \Rightarrow **higher electron temperature.**
- The effect on density needs further analysis to be identified.

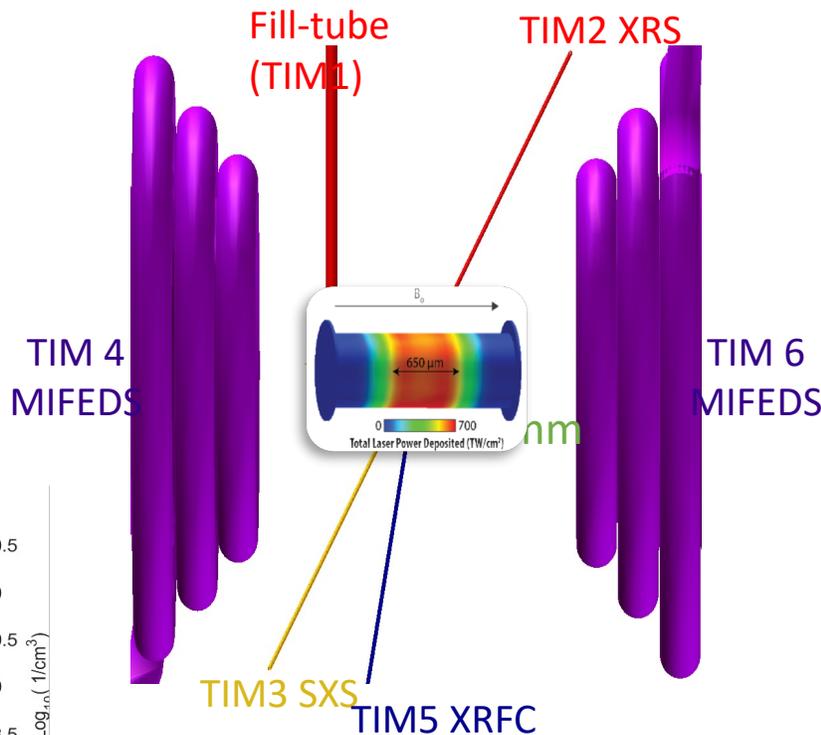
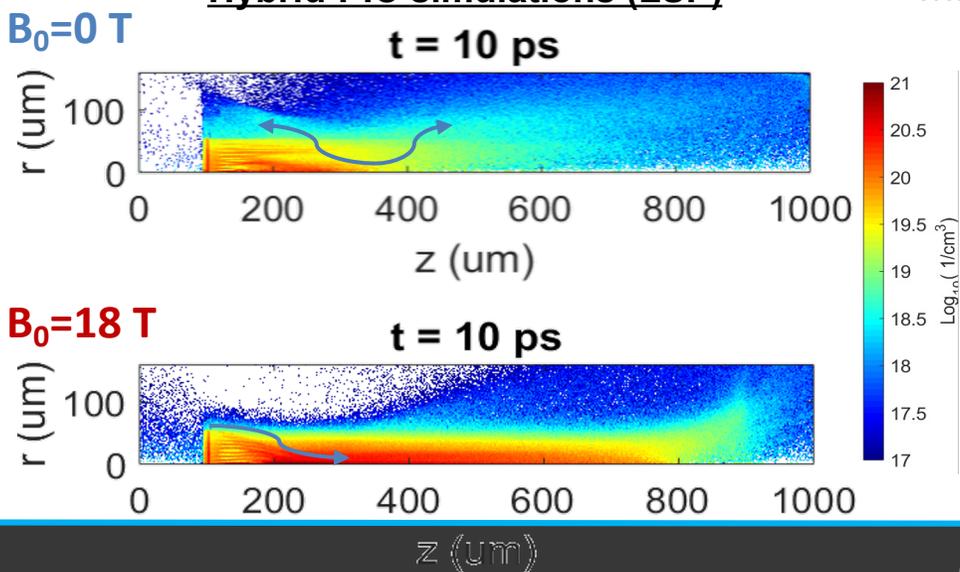
SXS

- The Ar spectra is **dominated by the core emission at stagnation**.
- This indicates that the XRS data can be used to infer conditions at maximum compression.

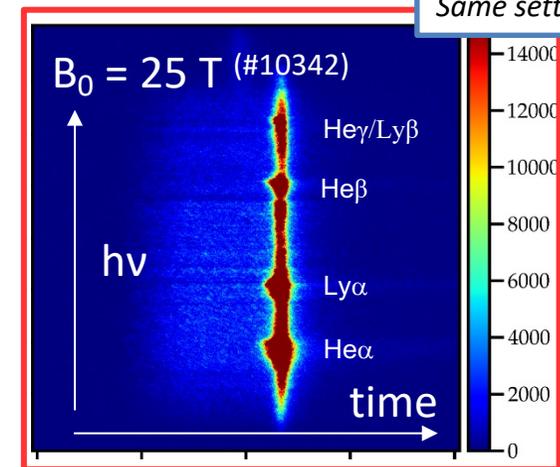
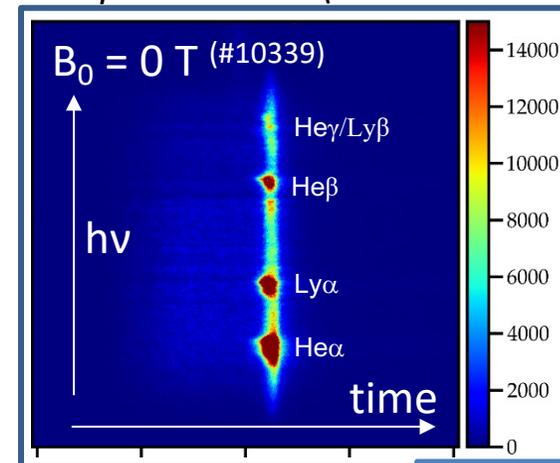
Summary



Hybrid-PIC simulations (LSP)



SXS spectrometer (time-resolved)



Same settings