Enhancing multi-keV line-radiation from laser-driven, non-equilibrium plasmas through application of external magnetic fields on the OMEGA laser facility

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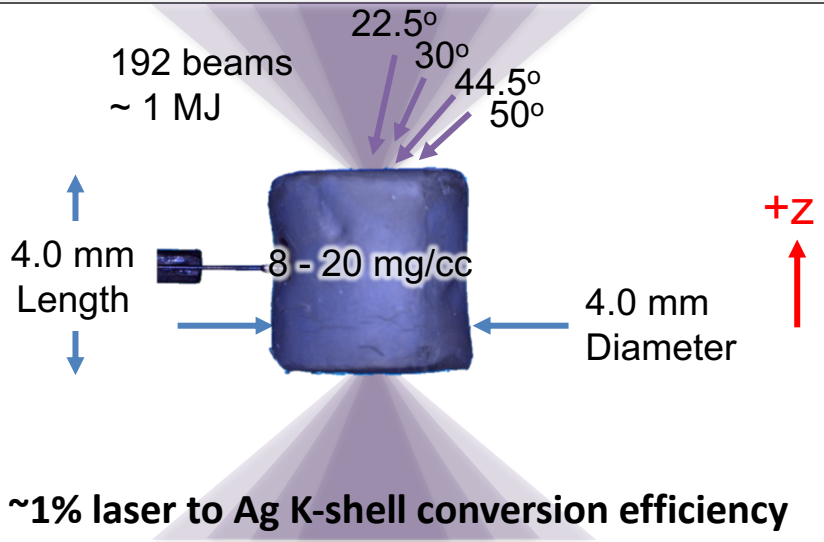
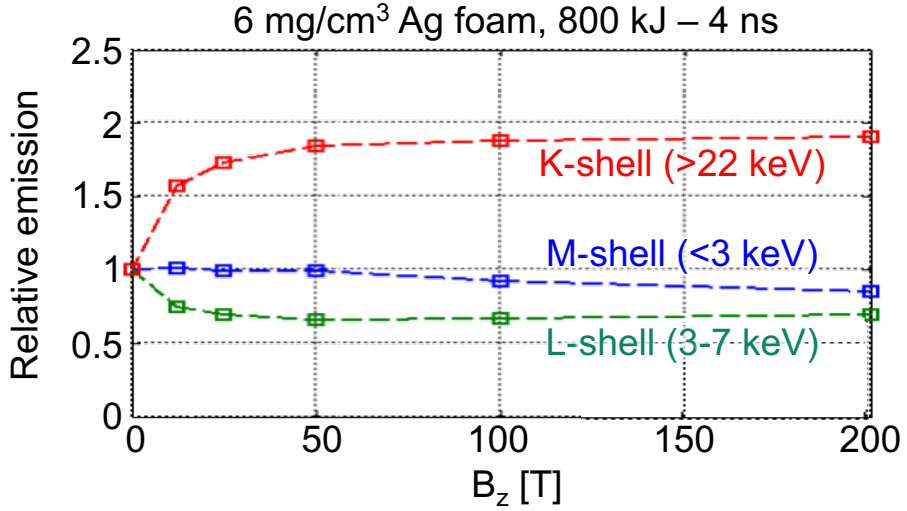
Can electron thermal transport inhibition from external B-fields enhance multi-keV x-ray emission from laser-driven targets?

Ag nano-wire foams are being developed[1] as novel sources of multi-keV line-radiation at the National Ignition Facility



~1% laser to Ag K-shell conversion efficiency

MHD rad-hydro simulations[2] with HYDRA[3] suggest ~2X increases in Ag K-shell may be possible with external B_z = 50 T



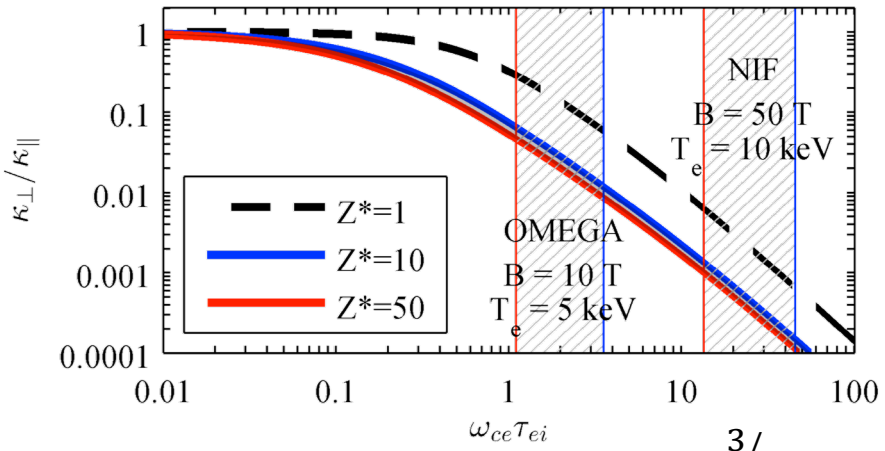
We have an LDRD* to obtain benchmarking data for V&V of the HYDRA model

[1] M. J. May, et al., APS DPP 2017, CI3.00002
[2] G. E. Kemp, et al., Physics of Plasmas **23**, 101204 (2016)
[3] M. M. Marinak, et al., *Physics of Plasmas* **8**, 2275 (2001)

* 17-ERD-027

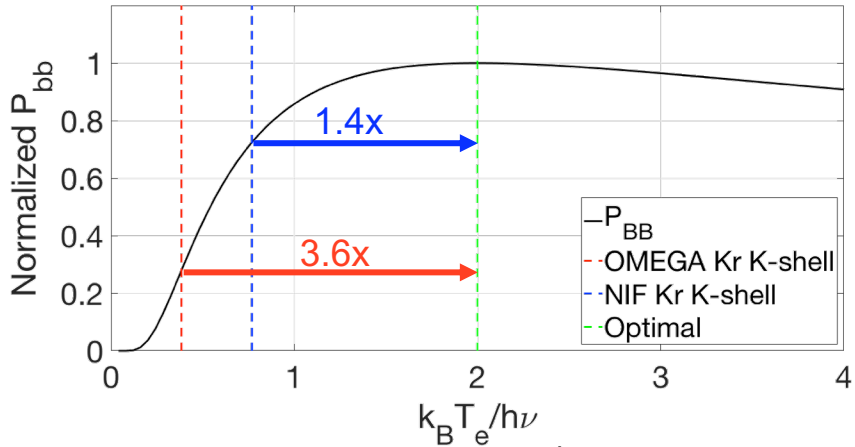
Magnetic fields can increase electron temperatures through thermal transport inhibition

Electron heat flux, $\vec{Q}_e$ is inhibited perpendicular to magnetic field lines[1]



$$\vec{Q}_e = -\kappa \nabla T_e \qquad \omega_{ce}\tau_{ei} \propto \frac{BT_e^{3/2}}{Z\, n_e ln\Lambda_{ei}}$$

Bound-bound line-radiation power[2], P_{bb}, is optimal around $k_B T_e \sim 2\ h\nu$



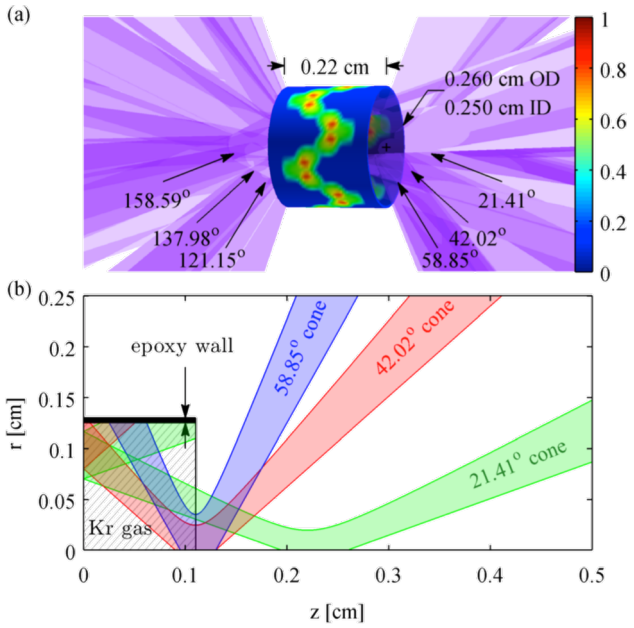
$$P_{bb} \propto n_e n_i \frac{e^{-h\nu/k_B T_e}}{\sqrt{k_B T_e}}$$

Thermal transport inhibition will be most beneficial for otherwise sub-optimal plasmas

[1] E.M. Epperlein and M.G. Haines, Physics of Fluids **29**, 1029 (1986)
[2] H.R. Griem, Principles of Plasma Spectroscopy, 1997

Magnetized plasma benchmarking experiments were performed on the OMEGA laser facility with Kr gas-pipe targets

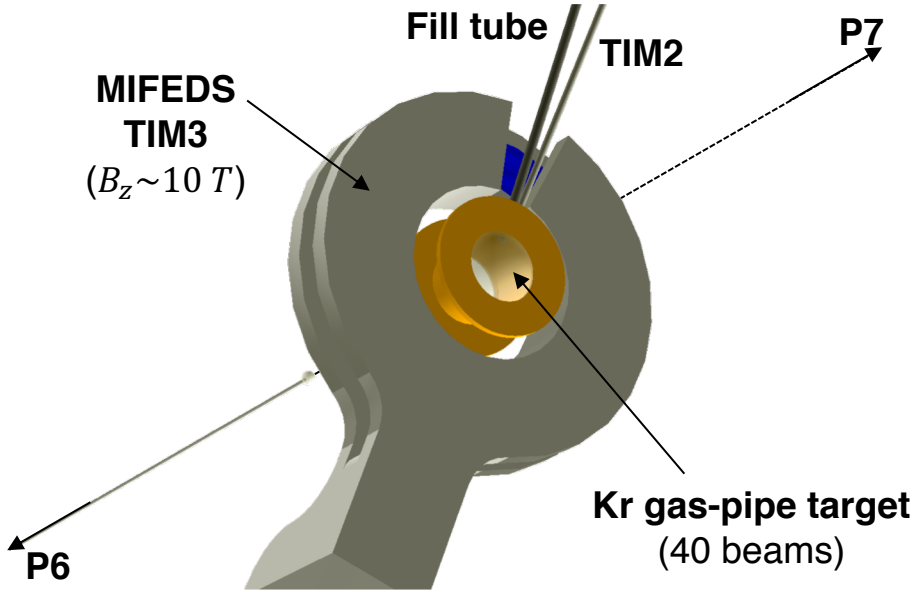
Interaction geometry



Thin-wall gas-pipe
1.5 atm Kr

40 beams
20 kJ
1 ns square pulse
3 drive cones

Experimental layout for MagXRSA-18A



Radial electron thermal energy transport is inhibited in this geometry

The design and preshot predictions were performed with the multi-physics radiation-hydrodynamics code HYDRA[2]

HYDRA model[2]

2D cylindrical geometry

Arbitrary Lagrangian-Eulerian (ALE)

3D laser-ray tracing (no SRS *or* SBS)

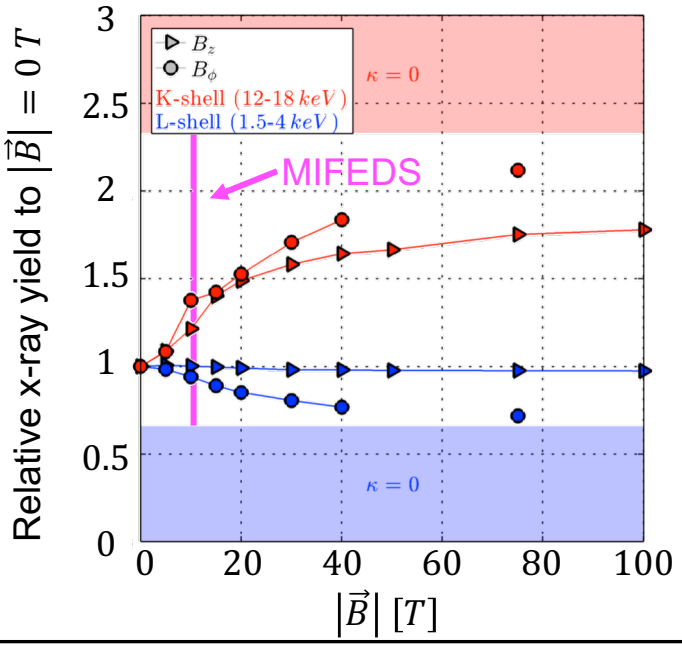
Implicit Monte Carlo (IMC) photonics

Inline non-LTE, opacities (CRETIN)

Flux-limited, Epperlein-Haines conductivity

Resistive-MHD package (no Biermann, Nernst *or* Righi-Leduc)

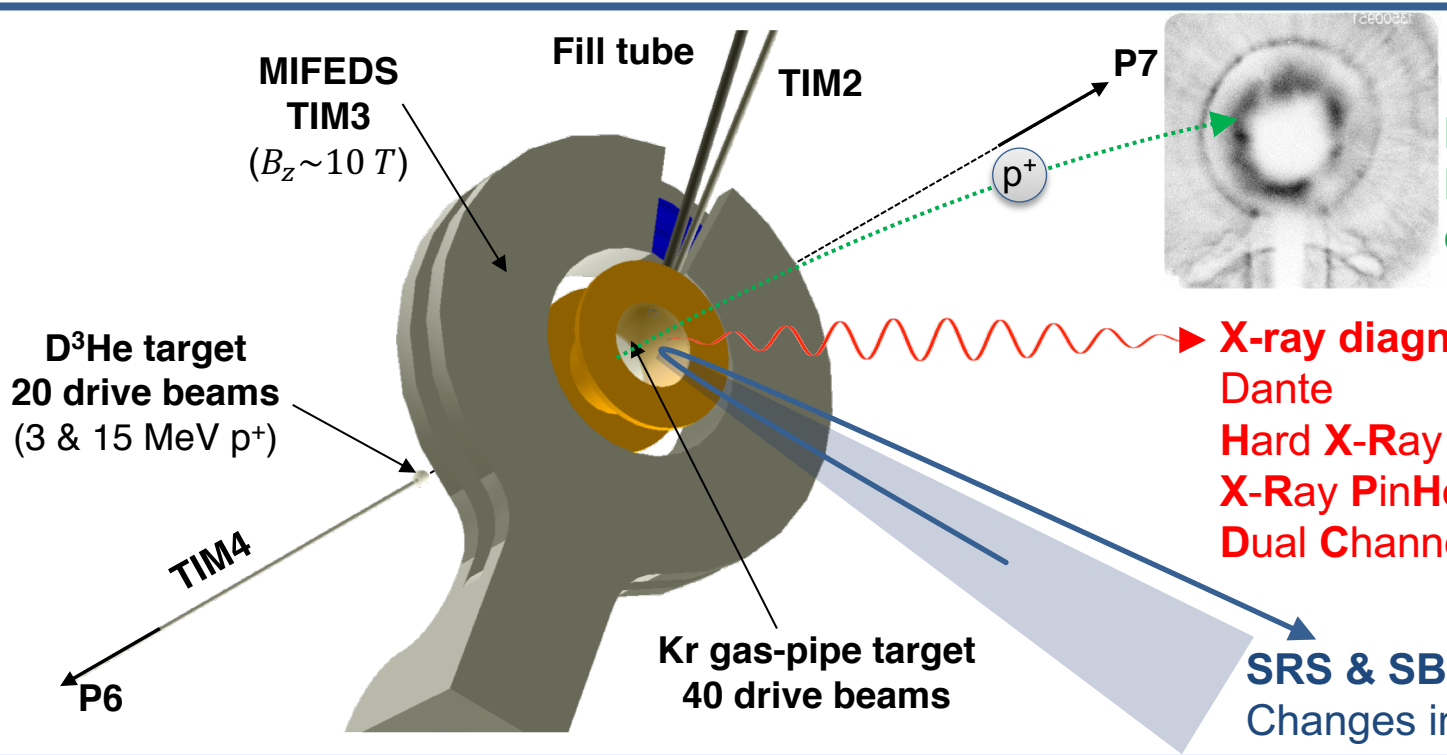
Kr line-radiation sensitivity to B-field



Simulations suggest ~20% enhancement in Kr K-shell emission possible with MIFEDS

[1] G. E. Kemp, et al., Physics of Plasmas **23**, 101204 (2016)
[2] M. M. Marinak, et al., *Physics of Plasmas* **8**, 2275 (2001)

Changes in the emitted x-ray performance was the primary indicator of the B-field influence



Proton Radiography:
B-field generation & evolution

X-ray diagnostics:
Dante
Hard **X**-**R**ay **D**etector (HXRD)
X-**R**ay **P**in**H**ole **C**amera (XRPHC)
Dual **C**hannel **S**pectrometer (DCS)

SRS & SBS laser backscatter:
Changes in plasma conditions

X-ray, laser backscatter, and proton radiography data were simultaneously collected

12 shots taken for MagXRSA-18A exploring proton timing, B-field strength, and material dependence

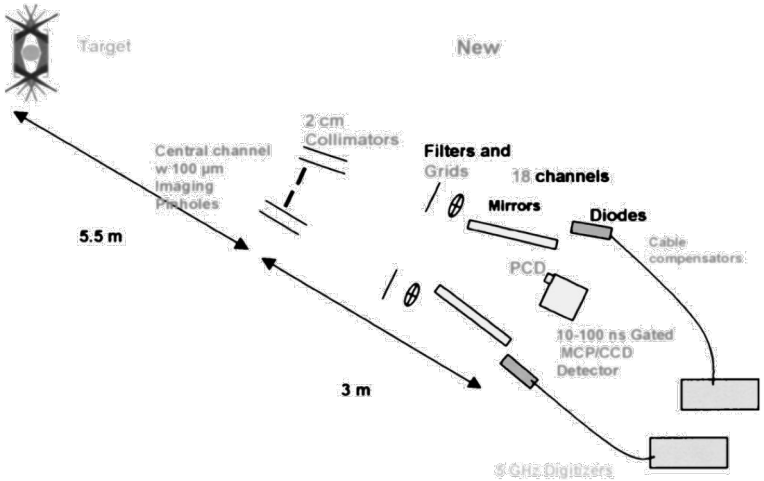
Shot number	SRF	Target	Proton timing (14.7 MeV)	B-field strength
87769	65393	Kr gas-pipe (1.5 atm)	t_o + 0.6-0.8 ns	0 T
87771	65394	Kr gas-pipe (1.5 atm)	t_o + 0.6-0.8 ns	10 T (max)
87772	65395	Kr gas-pipe (1.5 atm)	t_o + 0.4-0.6 ns	0 T
87773	65396	Kr gas-pipe (1.5 atm)	t_o + 0.4-0.6 ns	10 T (max)
87774	65397	Kr gas-pipe (1.5 atm)	t_o + 0.2-0.4 ns	0 T
87775	65398	Kr gas-pipe (1.5 atm)	t_o + 0.2-0.4 ns	10 T (max)
87776	65399	Cu cavity	t_o + 0.4-0.6 ns	0 T
87777	65400	Cu foam	t_o + 0.4-0.6 ns	0 T
87778	65401	Cu cavity	t_o + 0.4-0.6 ns	10 T (max)
87779	65402	Cu foam	t_o + 0.4-0.6 ns	0 T (mistimed)
87780	65403	Cu foam	t_o + 0.4-0.6 ns	10 T (max)
87781	65404	Cu foam	t_o + 0.4-0.6 ns	10 T (max)

We will focus on the Kr data in this work

Dante was the primary x-ray diagnostic for Kr K-shell ehnancement

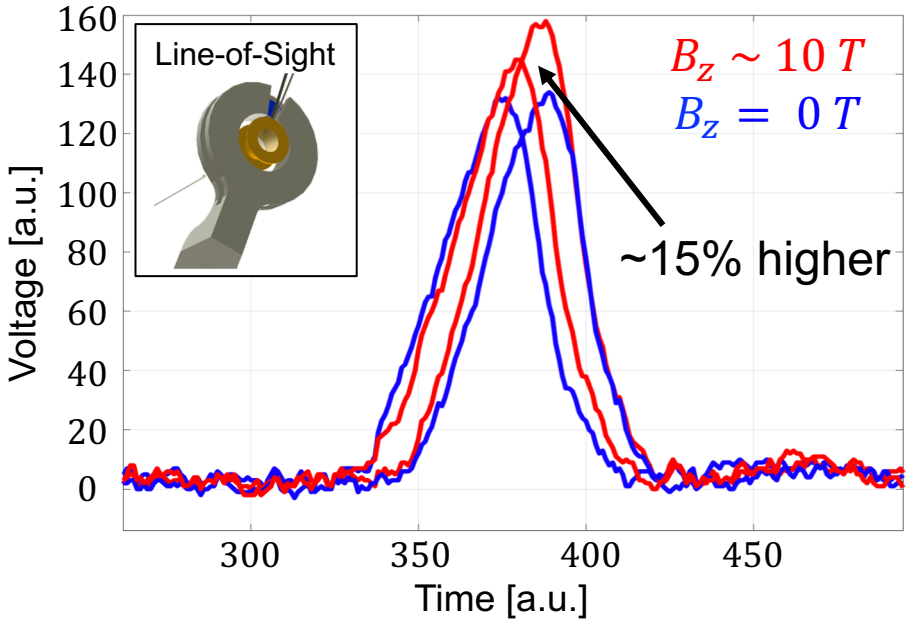
Dante

18 channel, time-resolved, filtered, x-ray diode array spectrometer (broadband, $< 20\ keV$)



E.L. Dewald, et al., Review of Scientific Instruments **75**, 3759 (2004)

Channel 18 is sensitive to Kr K-shell

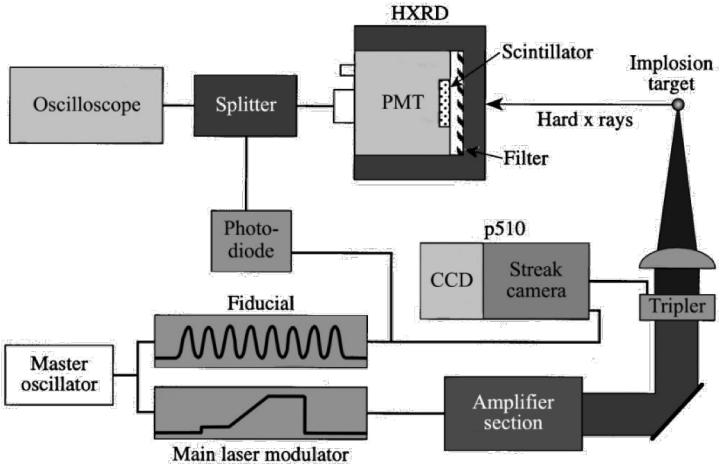


Marginal (but consistent) increase in Kr K-shell yield with external B-field

Hard x-ray detectors recorded continuum x-ray emission above the K-shell

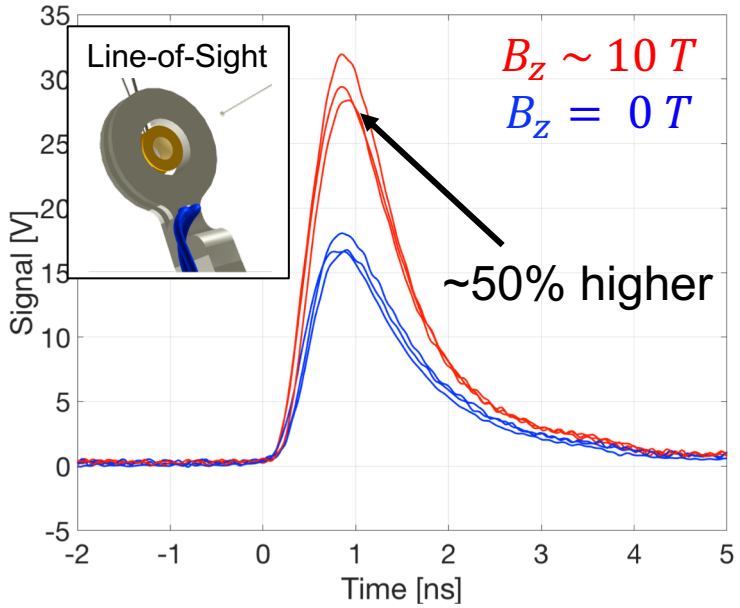
Hard X-Ray Detectors (HXRD)

4 channel, time-resolved, filtered, calibrated, hard x-ray detector $(20 - 500\ keV)$



C. Stoeckl, et al., Review of Scientific Instruments **72**, 1197 (2001)

Channel 4 is sensitive to $> 80\ keV$ x-rays

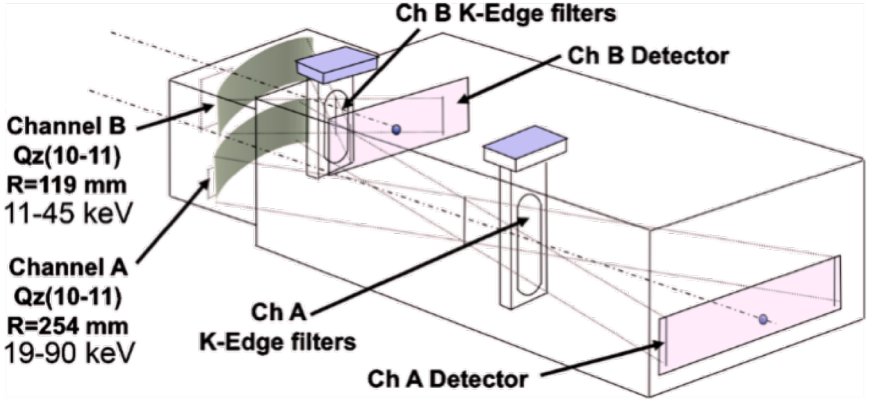


~50% higher signal levels observed for $> 80\ keV$ continuum

The Dual Channel Spectrometer provided high resolution, time-integrated K-shell spectra

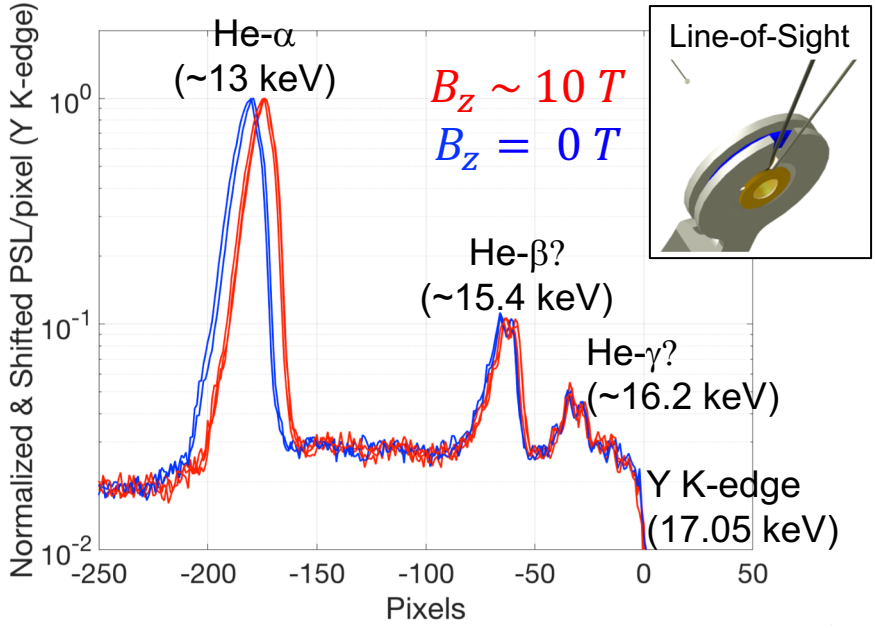
Dual Channel Spectrometer (DCS)

2 channel, time-integrated, spectrometer
$(11 - 45\ keV\ \&\ 19 - 90\ keV)$



C.I. Szabo, et al., Review of Scientific Instruments **81**, 10E320 (2010)

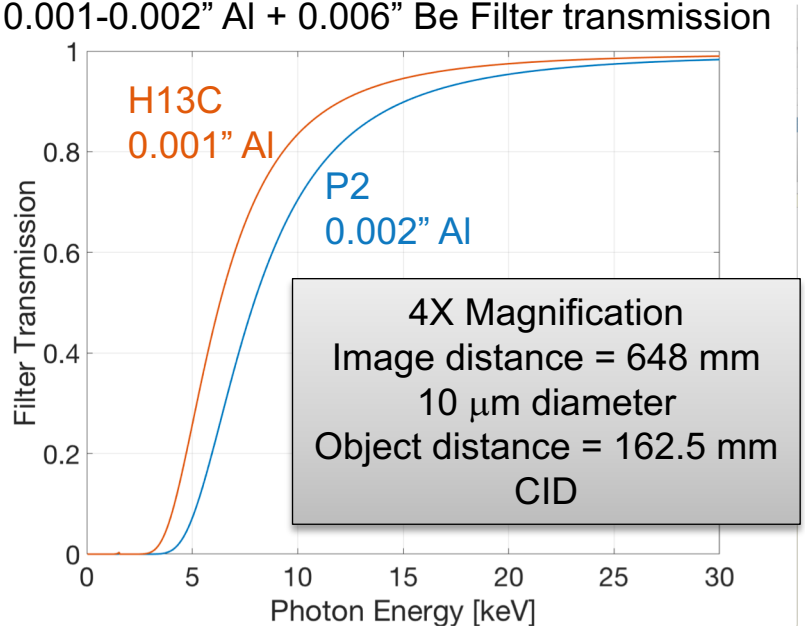
Kr K-shell was recorded on Channel B



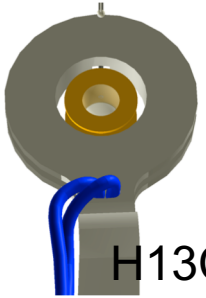
No obvious changes in line-ratios/widths – spectral shifts or dispersion effect?

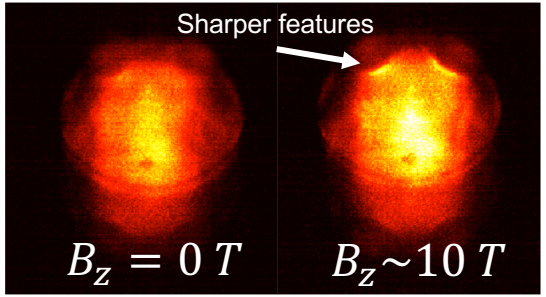
X-ray pinhole cameras provided time-integrated, spatially resolved emission distribution

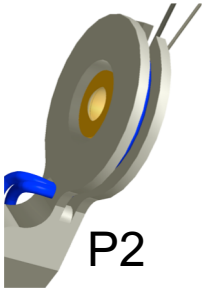
X-Ray PinHole Cameras (XRPHC)

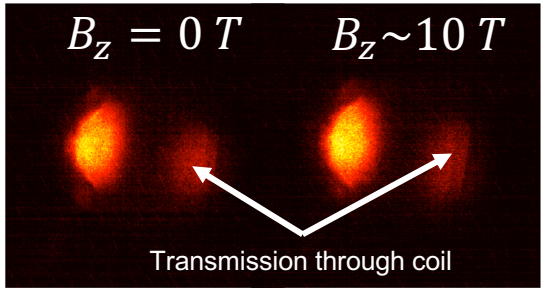


XRPHCs show brighter sources with B_z







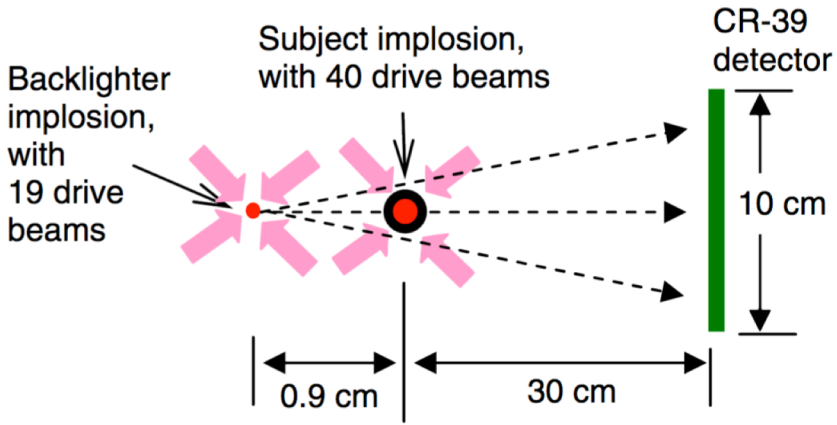


10-30% brighter multi-keV signals with ~10 T fields

Proton radiography was intended to diagnose the evolution of the B-field structures

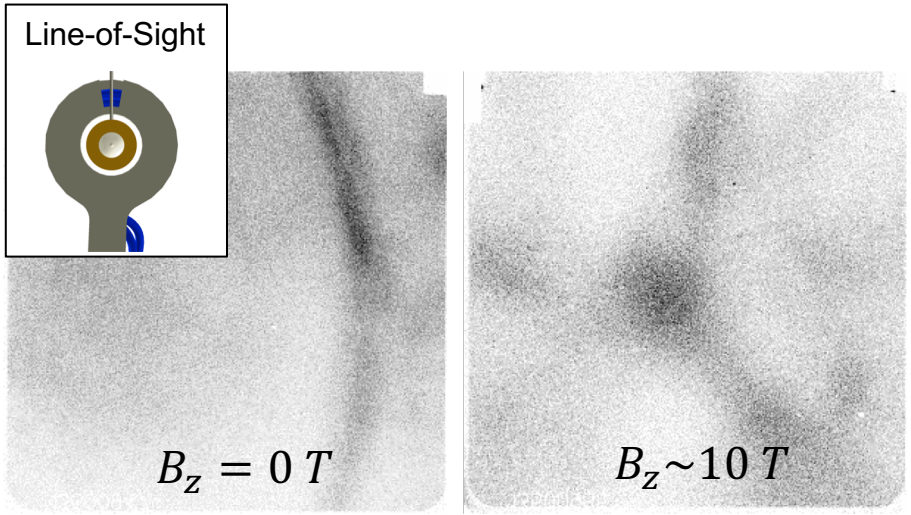
D^3He Proton Radiography

Monoenergetic 3 and 15 MeV p^+ source



C.K. Li, et al., Phys. Rev. Lett. **100**, 225001 (2008)

3 MeV proton radiographs at t_o+300ps



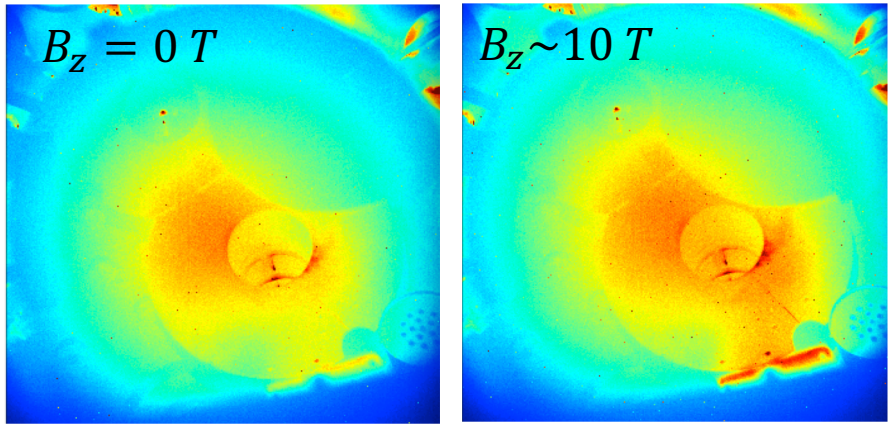
Dark features indicate higher proton fluence

Deflections of 3 MeV protons likely too significant to infer B-field topography

Stimulated Raman and Brillouin backscatter data was collected with the Near Backscatter Imaging (NBI) diagnostic

Stimulated Raman Scattering (SRS)

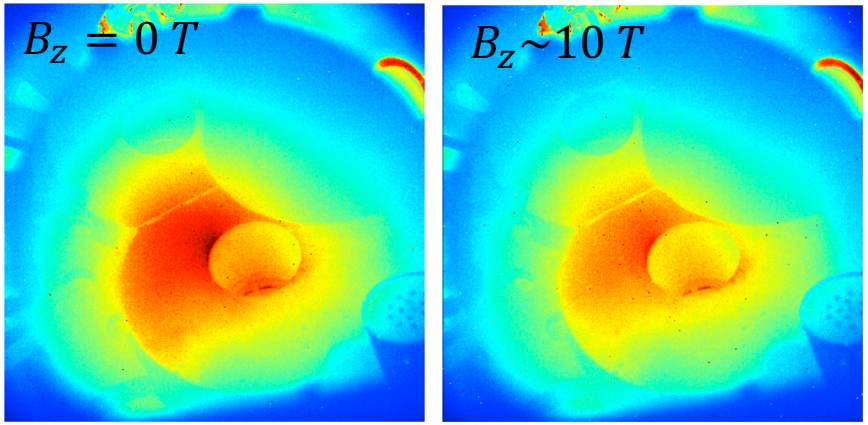
Inelastic scattering of laser off electron plasma waves



~3% more SRS

Stimulated Brillouin scattering (SBS)

Elastic scattering of laser off ion acoustic waves



~10% less SBS

Changes in backscatter may be due to changes in collisional and Landau damping

[1] D.S. Montgomery, et al., Physics of Plasmas **22**, 010703 (2015)

Summary and future work

We are developing a magnetized x-ray source platform for OMEGA using MIFEDS to improve multi-keV x-ray source conversion efficiency and provide benchmarking data for the HYDRA modeling

Initial results are encouraging, consistent with ~20% increase in Kr K-shell emission from the preshot simulations

- Exploring sensitivity to various MHD terms and thermal transport models

We are exploring a dual MIFEDS setup w/ improved proton radiography measurements for FY19

- Pushing to >20 T fields

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