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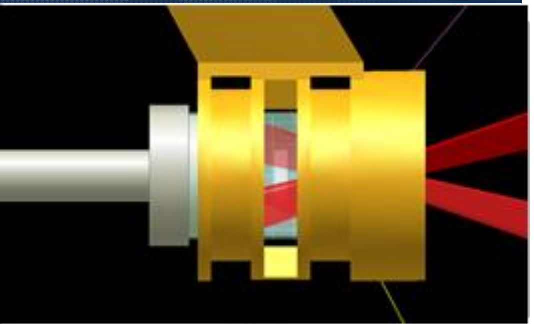

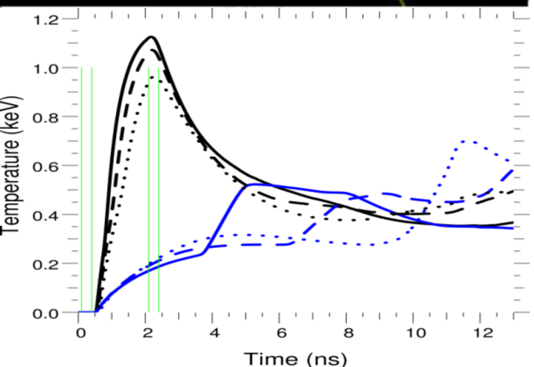

Laser-only experiments on OMEGA-EP in support of MagLIF

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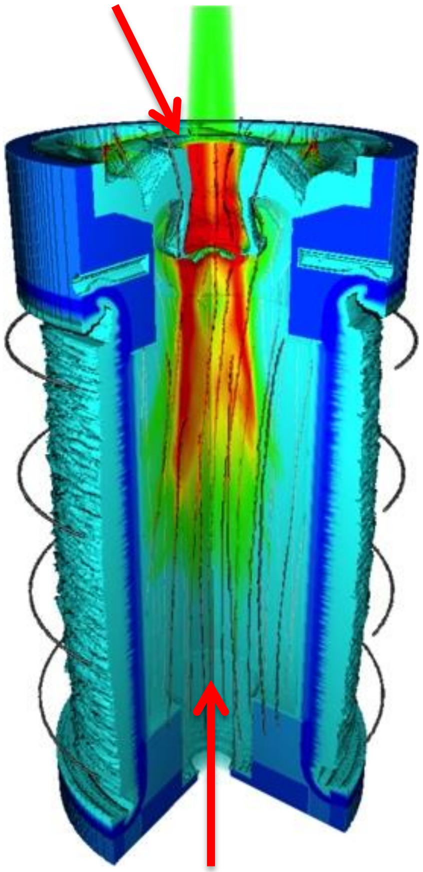
Laser-only experiments can address questions relating to preheat and magnetization

Laser preheat – transmission through LEH and coupling into gas



Applied B field - suppresses electron thermal conduction

- How do lasers deposit energy into underdense gasses and what factors affect this?
  - How does beam smoothing and magnetization affect energy coupling?
  - How is laser energy transmitted through laser entrance hole foils?
  - What is the best pulse shape for transmitting through LEH windows?
  - Does coupling laser energy into targets cause mix and how can this be mitigated?
- How well does an applied magnetic field suppress electron thermal conduction at MagLIF-relevant conditions?

Data is required to constrain and improve models in simulations

The OMEGA-EP facility has multiple, high energy, well characterized, DPP smoothed beams

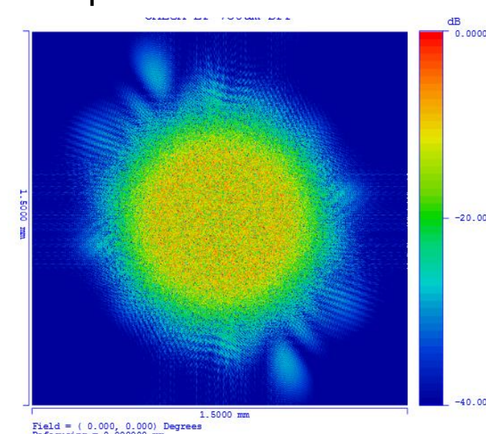
OMEGA-EP has characteristics ideal for MagLIF preheat studies

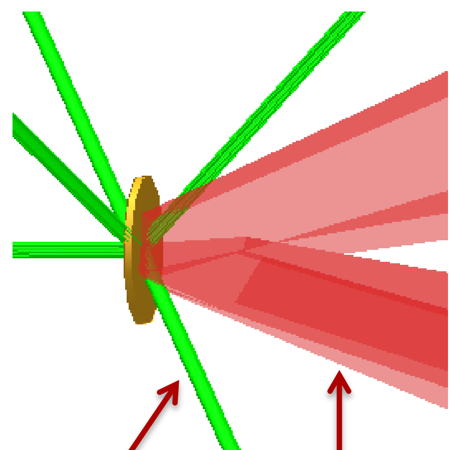
- High energies and powers in four beamlines
- Long duration beams – up to 10 ns
- Arbitrary pulse shape capability
- Range of DPP spot sizes (no SSD or polarization smoothing)
- Excellent energy stability (~3-4% for beams 3 and 4) and timing
- Pressure monitoring up to 20 atm.
- Good diagnostics including streaked spectrometers and x-ray framing cameras
- Magnetic field capability up to B=10T
- High shot rate – 7 shots per day per beam

Beam energies available on OMEGA-EP

Duration	Beam 1	Beam 2	Beam 3	Beam 4
1 ns	1250 J	1250 J	1250 J	1250 J
2 ns	1950 J	1950 J	2250 J	2200J
4 ns	2800 J	2800 J	3150 J	3100 J
10 ns	4400 J	4400 J	5000 J	4900 J

750 um DPP point spread function





TIM viewing angles

4 beamlines

OMEGA-EP is not a direct surrogate for ZBL – experiments addressed general preheat questions

- OMEGA-EP is 3ω (355 nm) ZBL is 2ω (532 nm)
- F# is 6.5 vs. 10 for ZBL
- Peak power is <1 TW and max $I\lambda^2$ is ~2.85e13 vs. ~6.8e13 for ZBL with 730 μm DPP

OMEGA-EP parameters put us in a benign regime where LPI shouldn't be an issue

Effect of B field on thermal conduction →

MagLIFEP_14A

- Measure how rapidly a MagLIF plasma cools after heating with and without a B field
  - Suppressing thermal conduction is most important aspect of applied B field and critical to preheat success

Laser propagation in underdense plasmas:

MagLIFEP_14B

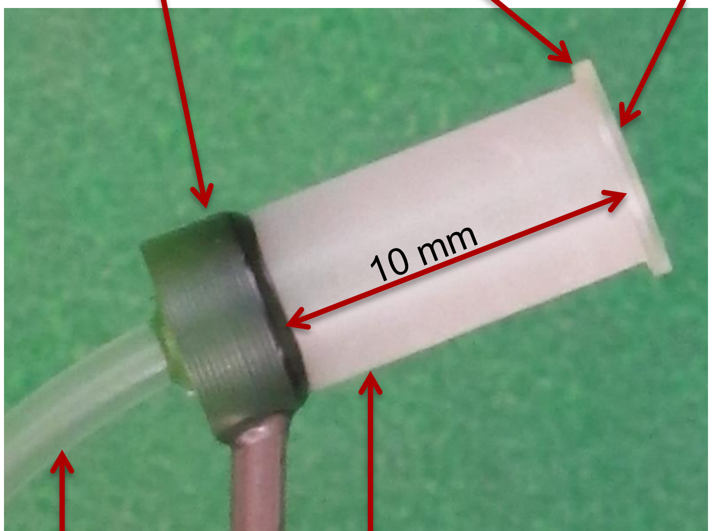
- Measure laser propagation in a pure Ar plasma and investigate factors that affect this (beam smoothing, energy, intensity, LEH thickness)

MagLIFEP_15A

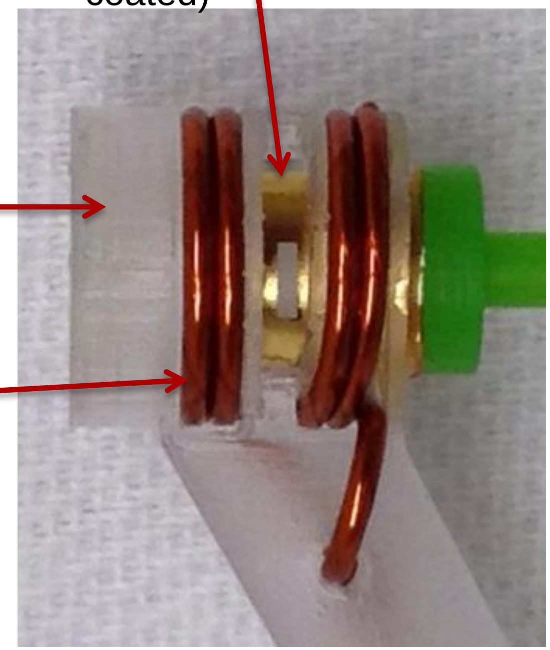
- Measure laser propagation in a dense (n_e~0.57n_c) D2 plasma, see how applied B field affects this

Targets use CH gas-filled pipes with LEH at one end

MagLIFEP_14B target



MagLIFEP_14A target

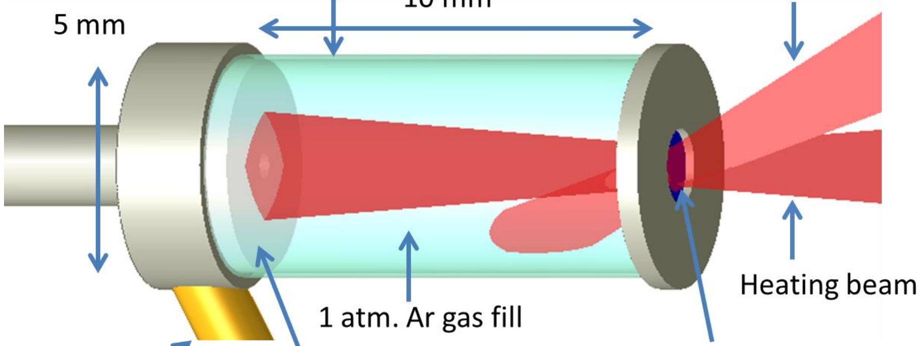


- Targets are robust – can hold pressures >20 atm.
- MIFEDS coils provide B fields from 4-10 T depending on geometry
- Targets developed by GA (P. Fitzsimmons, J. Fooks et al.,) and LUXEL

Experiments addressing: How do lasers deposit energy into underdense gasses and what factors affect this?

- How does beam smoothing affect energy coupling?
- How does the laser power/intensity affect energy coupling?
- How much energy is lost to laser entrance hole foils?
- Does the laser push LEH material into the region of interest?

MagLIFEP_14B investigated factors affecting laser propagation in pure Ar



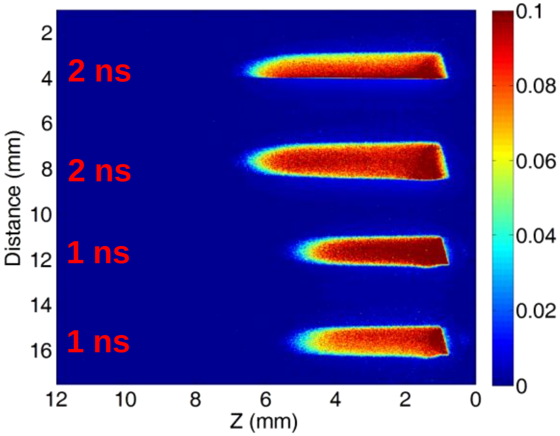
Experimental variables:

- Laser duration/power
- Phase plate smoothing vs. no phase plate smoothing
- 1 um and 2 um thick LEH windows
- Prepulse (250 J) vs. no prepulse

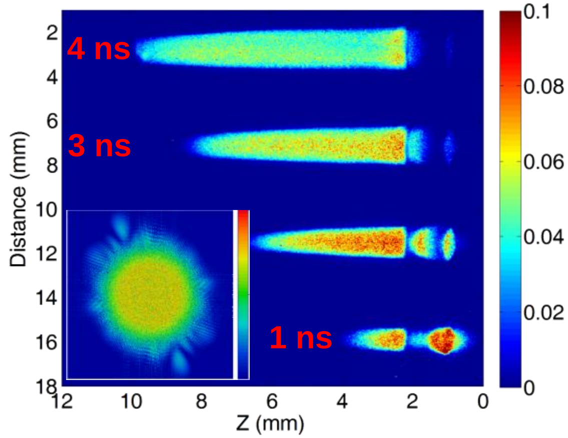
- Experiments tested beam propagation in 1 atm pure Ar ($n_e = 0.048\ n_c$ c.f. current MagLIF $n_e \sim 0.05\ n_c$)
  - Ar allows for good diagnostic signatures and low pressures for a given n_e
- X-ray framing cameras (XRFC), time resolved, spatially resolved spectrometer (MSPEC) and other diagnostics measured beam propagation
- Beams 3 and 4 were alternated to increase shot rate – 90 minute shot cycle reduced to minimum 45 minute cycle

XRFC images show how beam propagation varies with different conditions

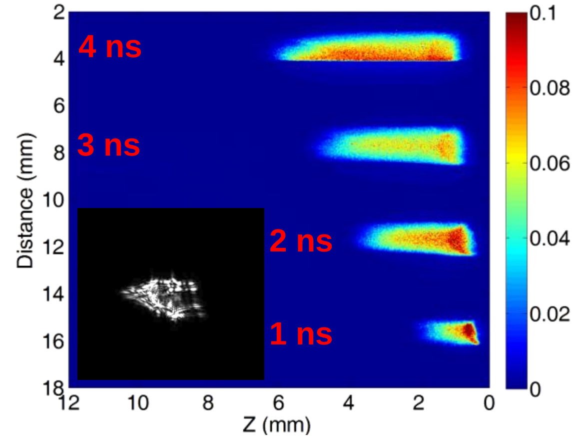
2 ns beam, 2.2 kJ, 1um LEH



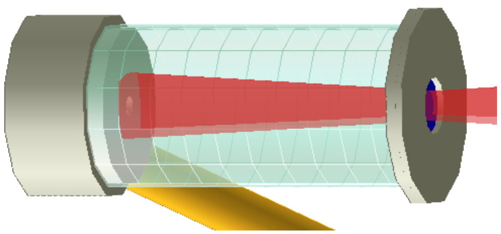
4 ns beam, 3.1 kJ, 2um LEH

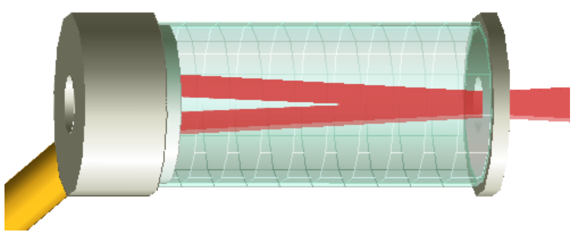


4 ns beam, 2.9 kJ, 2um LEH, No DPP



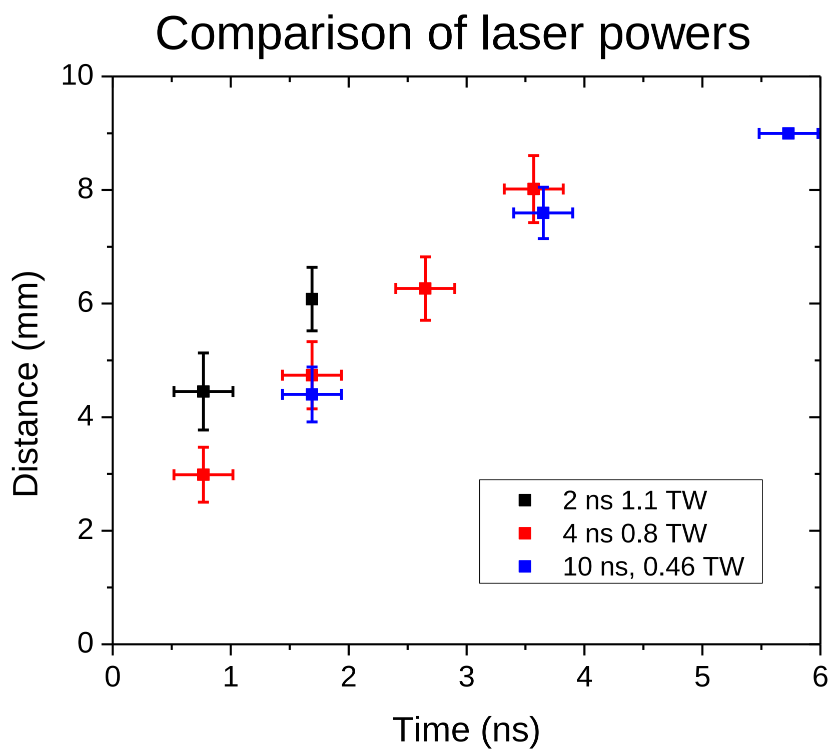
XRFC view is not orthogonal – geometry needs to be accounted for

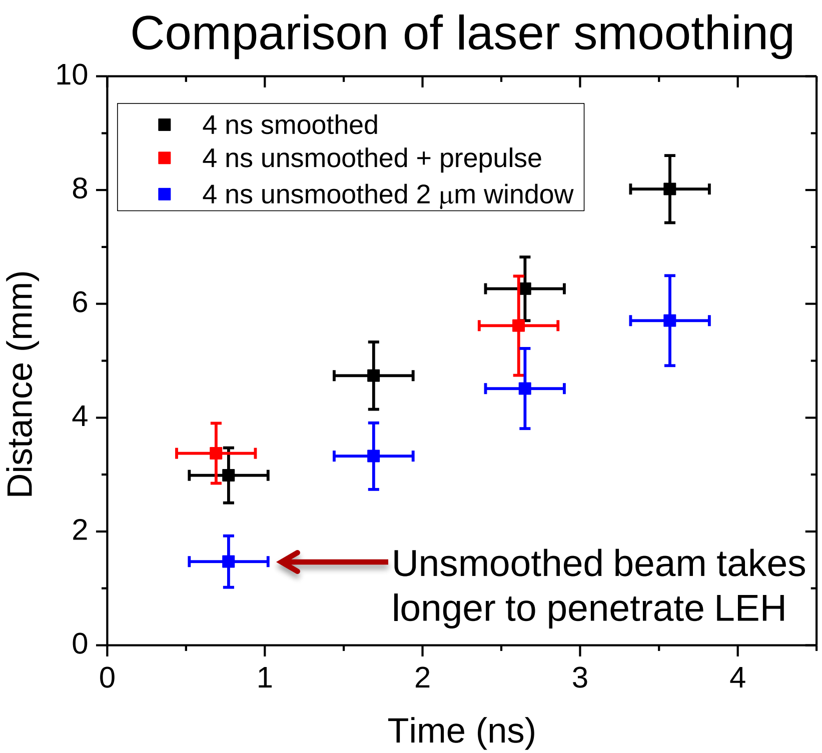




- Pure Ar gives high signal levels allowing propagation to be clearly seen
- Unsmoothed beam clearly propagates slower than smoothed beam
- Intensity is not well defined for unsmoothed beam – may reach intensity thresholds where LPI is important – OMEGA-EP does not have good diagnostics to detect this

Data shows clear effect of smoothing and intensity/duration on beam propagation

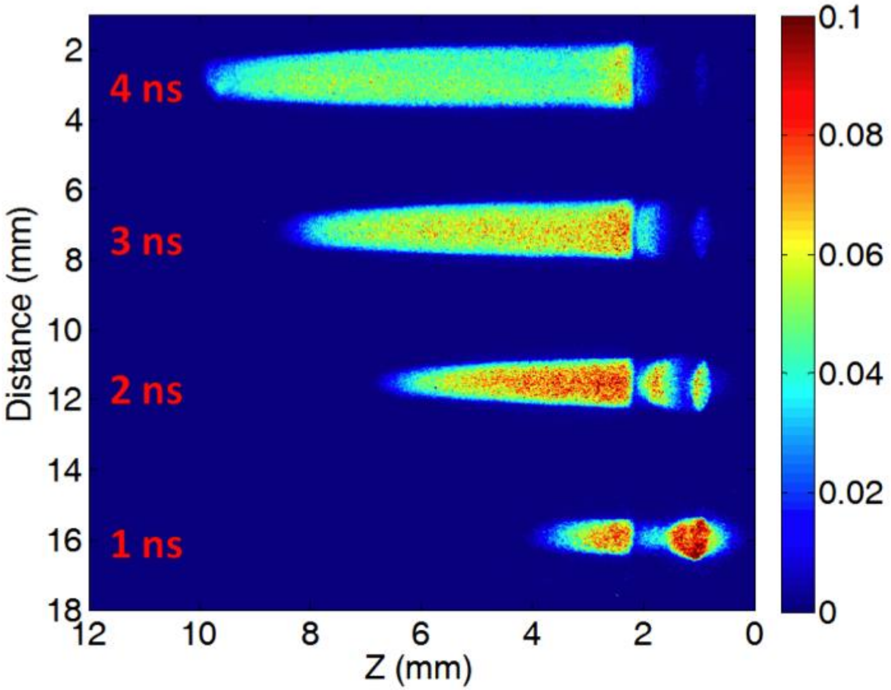


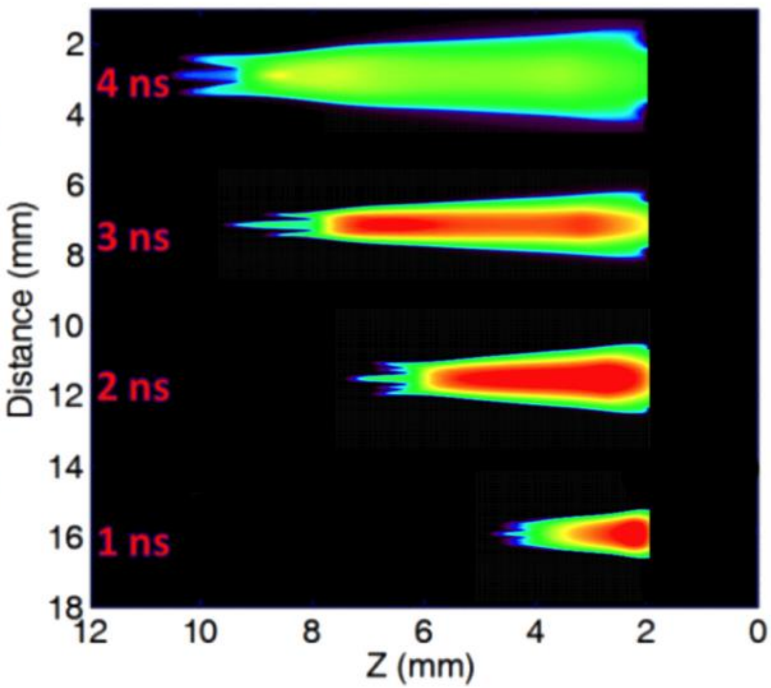


- Propagation velocity only weakly dependent on beam intensity
- Unsmoothed beams propagate slower through the plasma and take longer to penetrate LEH

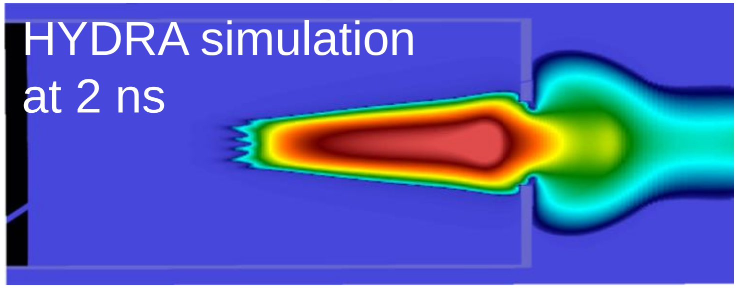
HYDRA simulated laser propagation/plasma heating with a smooth beam agrees with the experiment

Experiment with 4 ns heating beam

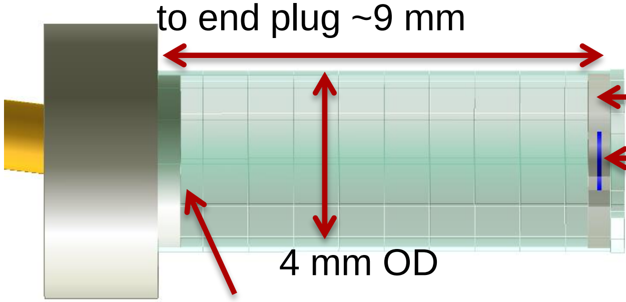


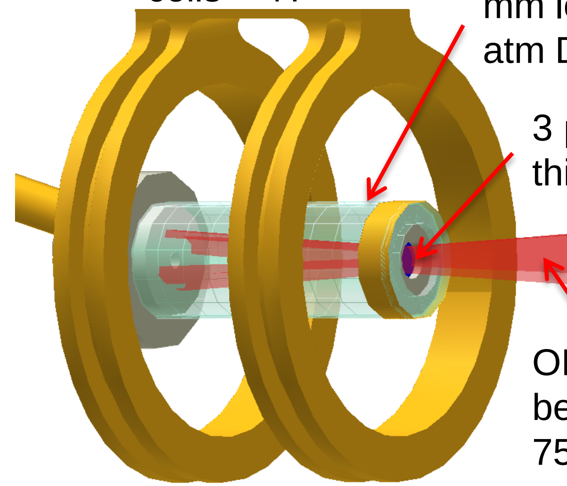


- Generally excellent agreement allows energetics to be accounted for (e.g. energy lost to LEH)



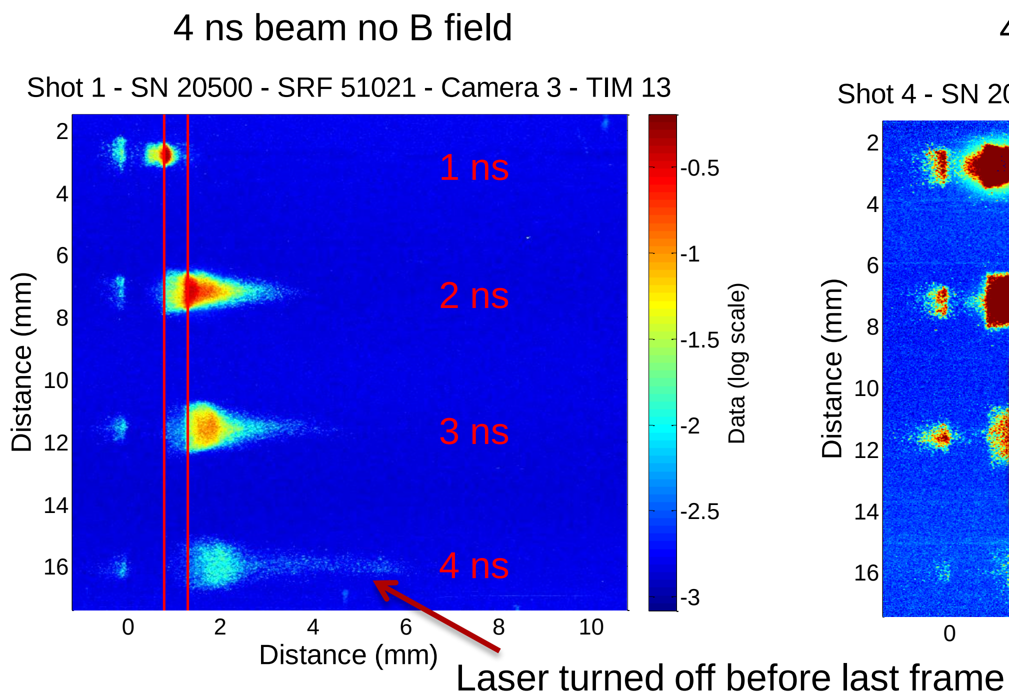
MagLIFEP_15A aimed to take propagation data in dense, magnetized D2 gas with Ar dopant

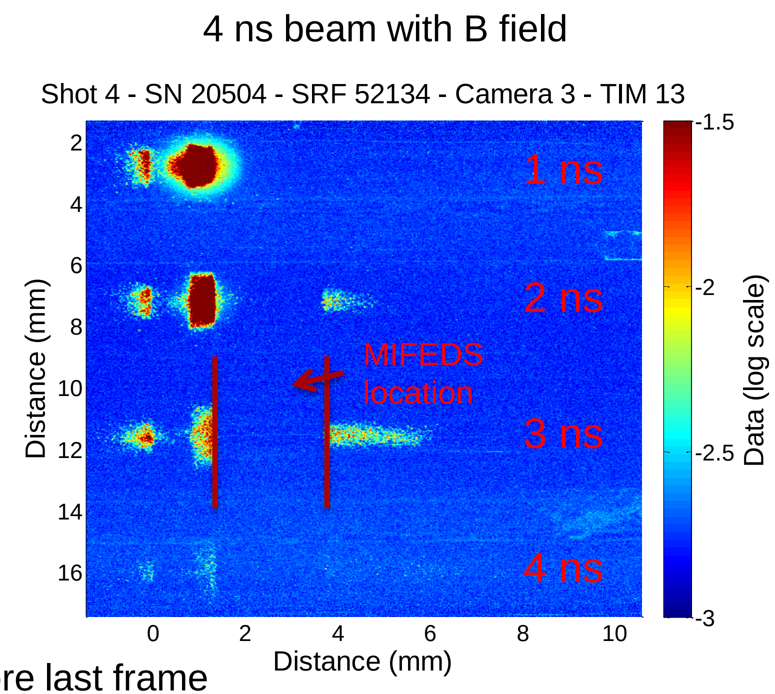




- MIFEDS design allowed for improved access but reduced B field to 4 T ($\omega\tau$~2)
- Target design allowed for 10 atm D2 gas fill with 0.25% Ar dopant (n_e=0.058n_c)
- 1.3 mm diameter LEH window – 3 um thick
- Ti coating on inside of LEH allowed propagation of window material to be viewed
- Single 4 ns heating beam (2 ns in some shots), 750 um DPP spot size, ~3.2 kJ energy

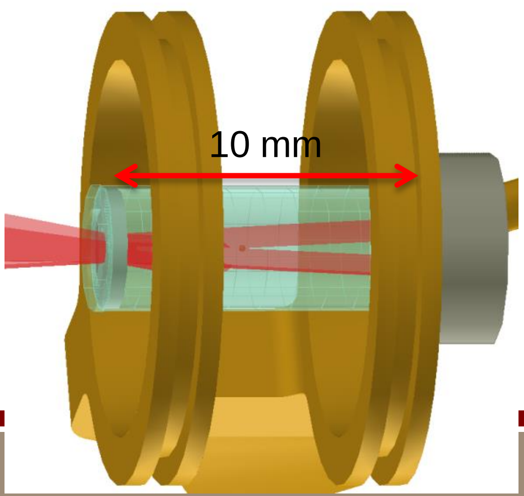
XRFC images show propagation of laser energy in targets





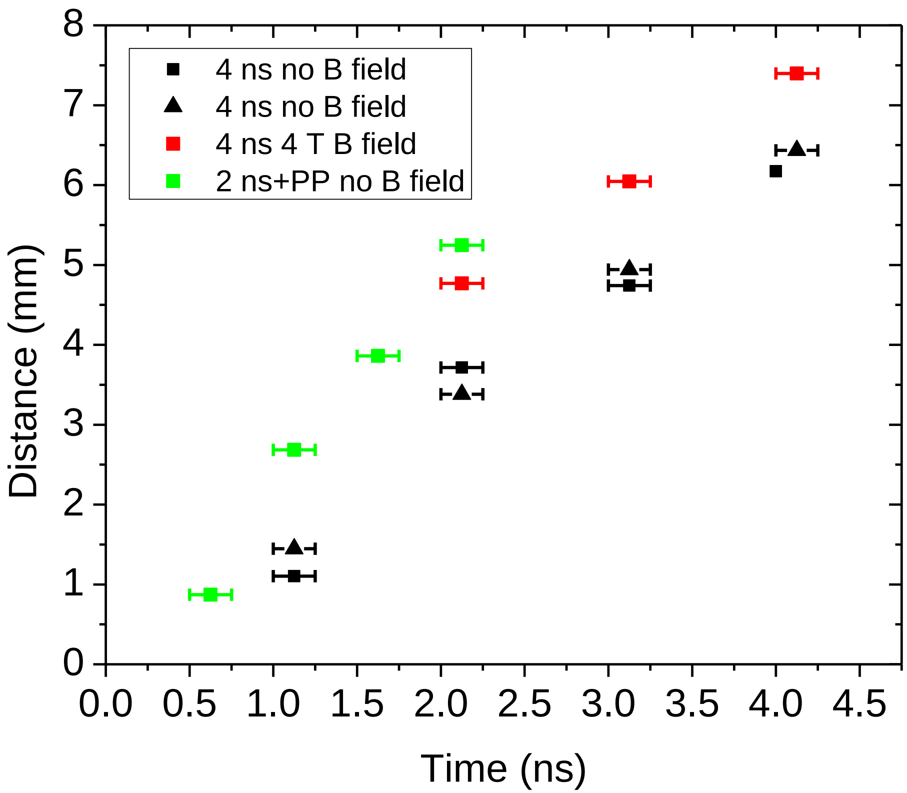
- Images show beam propagation with and without B field during laser heating
- Emission decays rapidly after laser turns off- final frame just after laser has low signal
- We are exploring using crystal imager and reducing phase plate spot size to increase signal levels

XRFC view of target

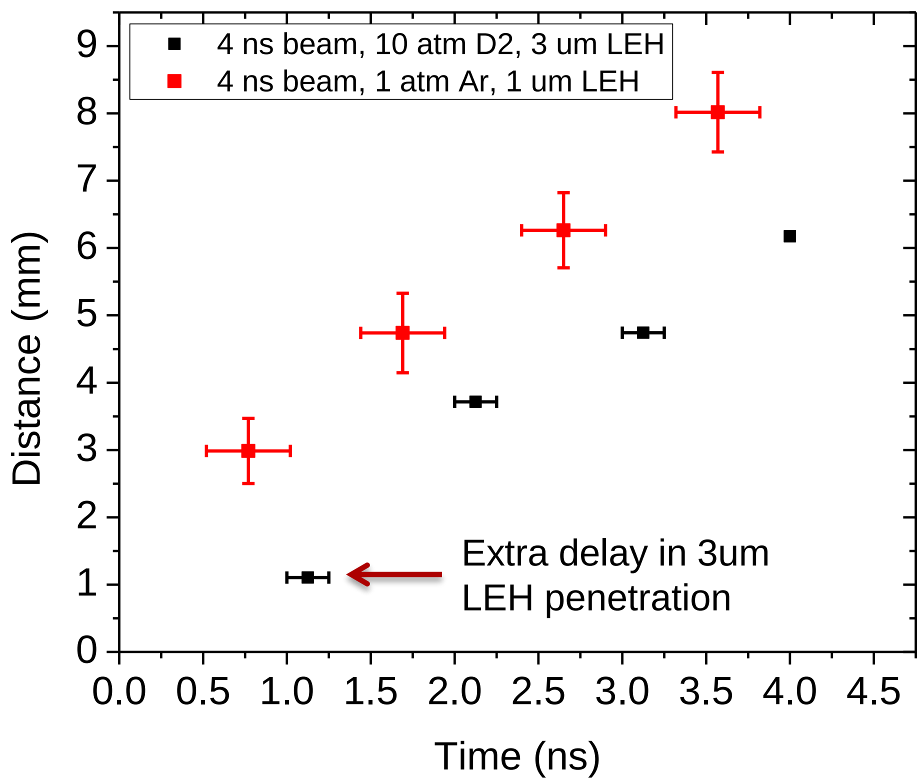


Preliminary analysis shows beam progression in targets

Comparison of MagLIFEP_15A



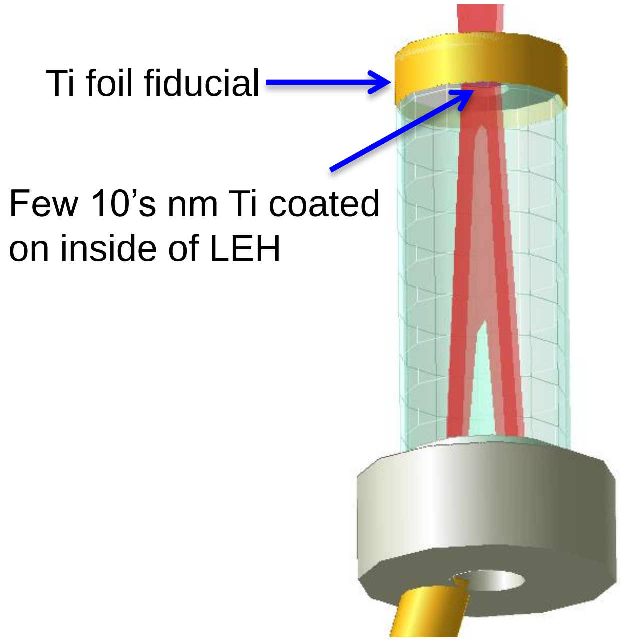
Comparison of MagLIFEP_15A D2 propagation and 14B Ar propagation for 4 ns beams



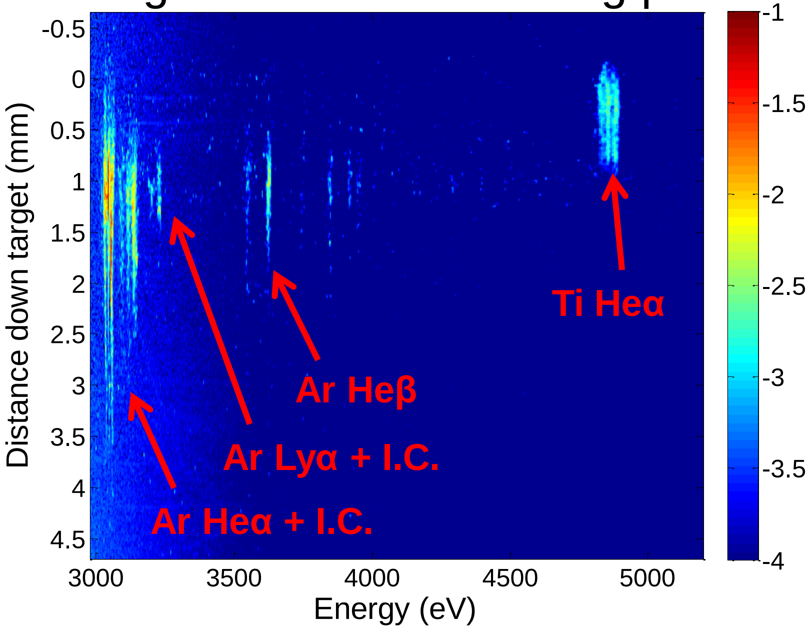
- Results show slightly increased propagation distance with 4T B field
- Propagation velocity is similar for 10 atm D2 ($n_e = 0.058\ n_c$) and 1 atm Ar ($n_e = 0.048\ n_c$)
- Significant delay in penetrating the 3um thick LEH (~1 ns)

MSPEC shows heating of gas and propagation of Ti coating

MSPEC view of target



Spectrum from unmagnetized target at 2 ns into heating pulse

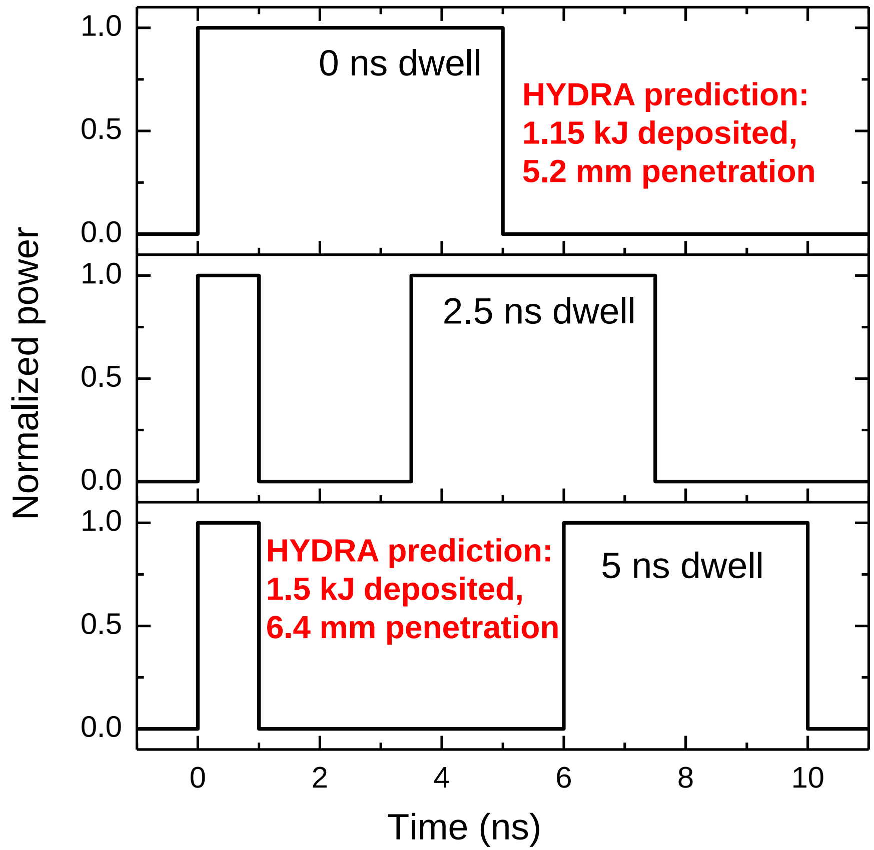


- MSPEC is a TIM-based elliptical crystal spectrometer coupled to a two-frame MCP camera – allows time and spatially resolved spectrum
- Ar dopant (0.25%) lights up allowing for temperature analysis (still in progress) – emission is relatively optically thin
- Ti coating on underside of LEH lights up showing propagation of window material into gas region – interesting for determining mix contribution

Planned future experimental series and new capabilities

- MagLIFEP_15B (July 28th) will investigate laser heating of higher density D2 fuel (18 atm, n_e=0.1n_c) and higher B fields (~7 T)
- MagLIFEP_16A aims to test effects of pulseshaping (prepulse followed by main pulse) on LEH transmission and propagation in high density Ar gasses (n_e~0.2n_c)
- Three more series planned in FY16 aim to test heating of D2 using spherical crystal imager and smaller spot size phase plate to increase signal levels

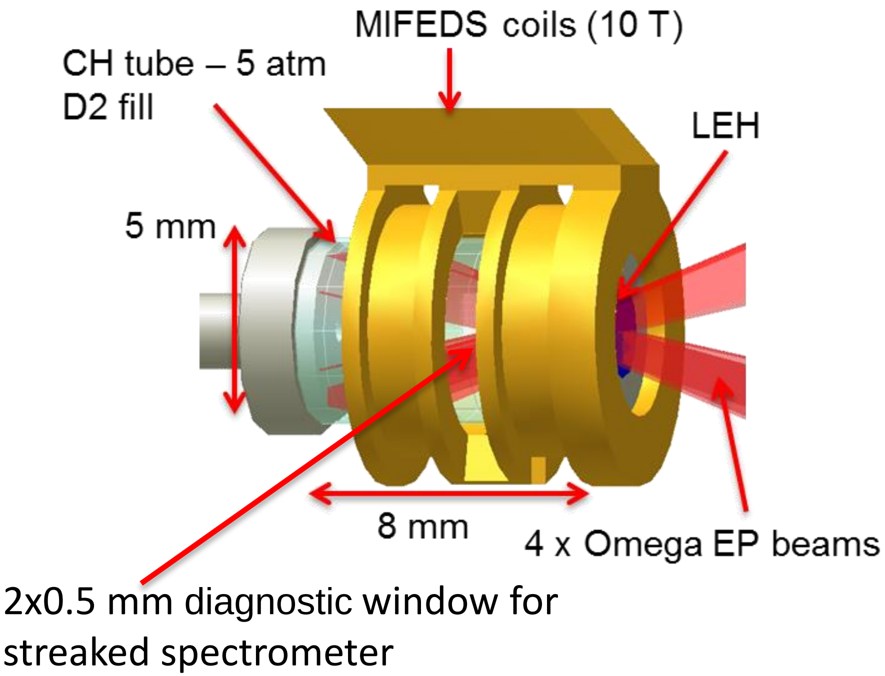
MagLIFEP_16A Requested pulse shapes

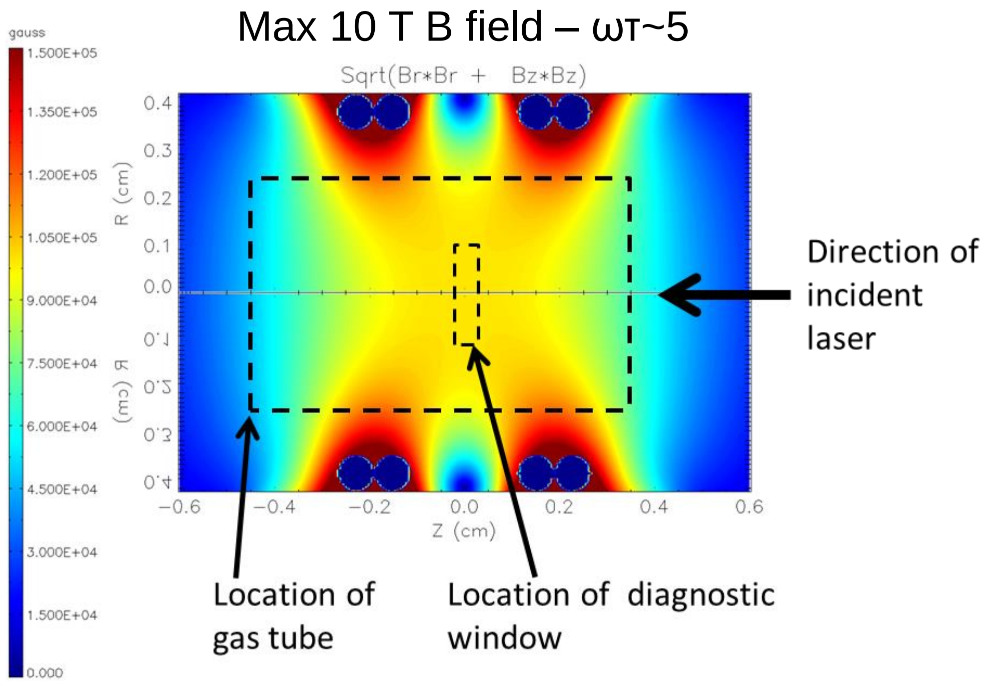


Experiments addressing:
How well does an applied magnetic field suppress electron thermal conduction at MagLIF-relevant conditions?

- Measurement of temperature time history during and after heating with and without applied B field

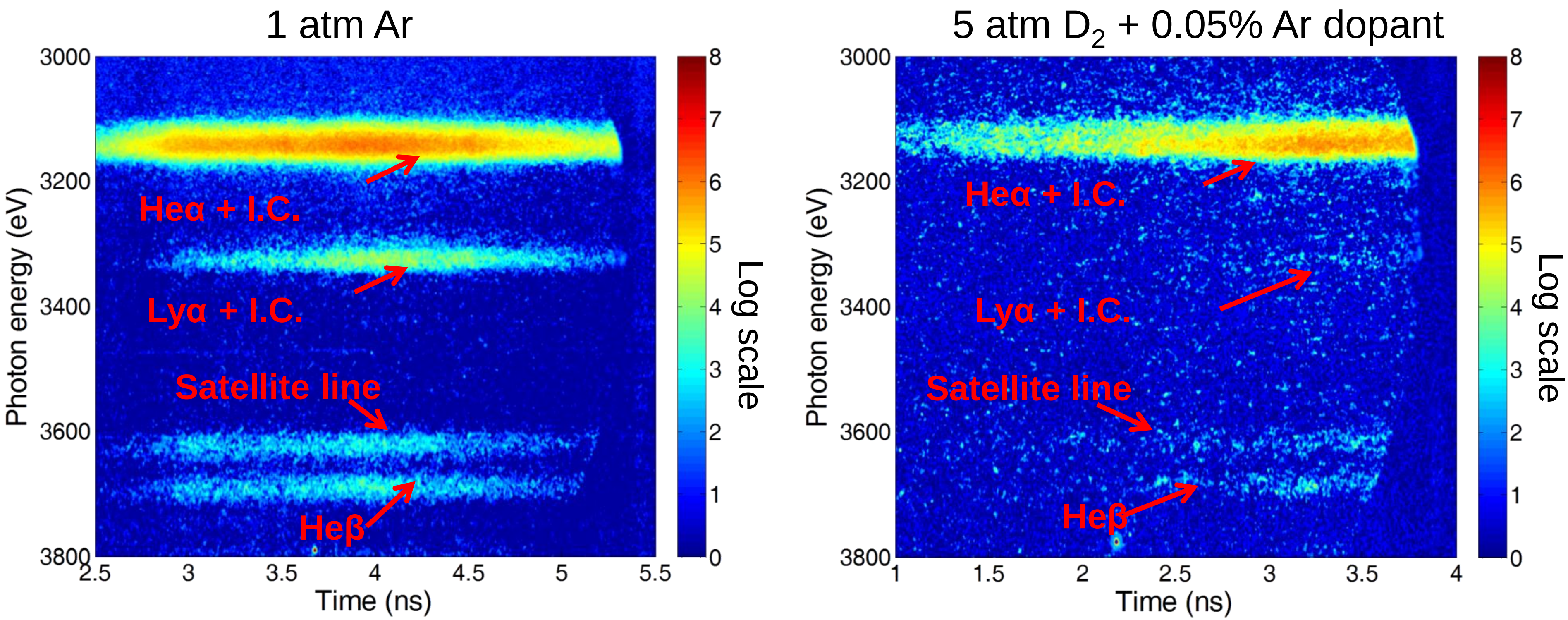
MagLIFEP_14A aimed to diagnose the temperature time history of magnetized D2 plasmas





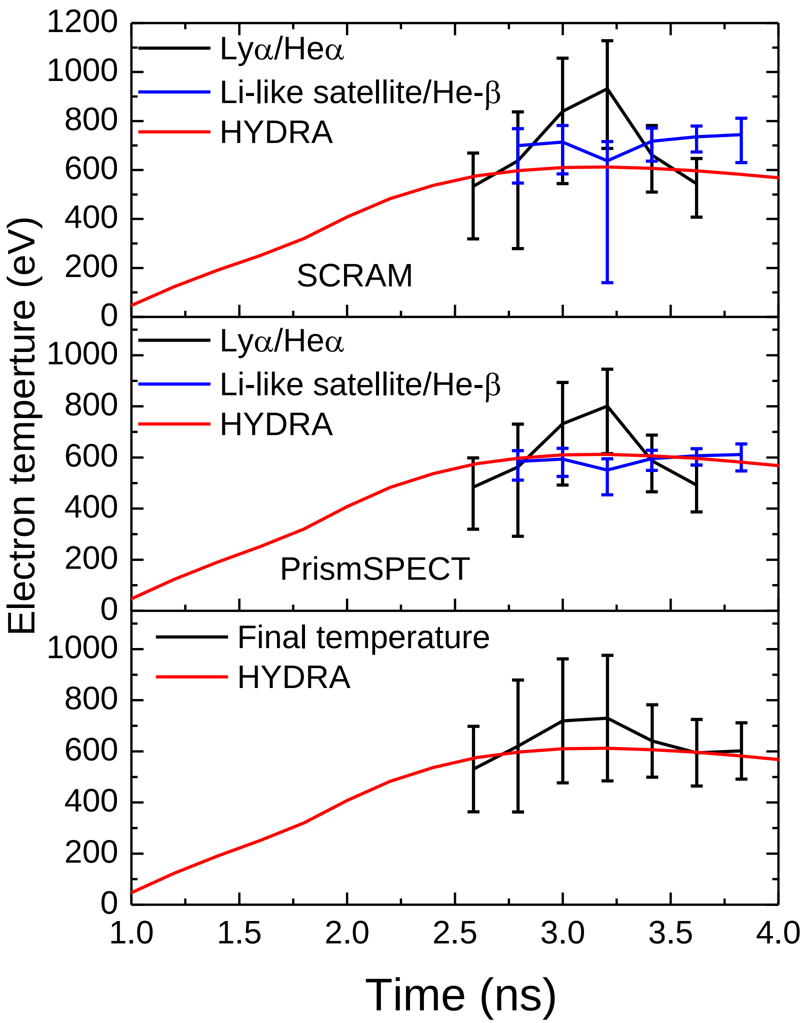
- Target design allowed 5atm D2 fill (n_e=0.028n_c) – not ideal for energy coupling
- Four beams used (4 ns, square pulse, 9 kJ energy) to increase heating/signal levels
- MIFEDS design allowed for high B fields (10 T) and diagnostic access through 2x0.5 mm window between coils on side of target
- Primary diagnostic - streaked spectrometer (4 ns streak) looking at Ar K shell emission

Streaked spectrometer data shows heating of unmagnetized pure Ar and magnetized D2 gasses



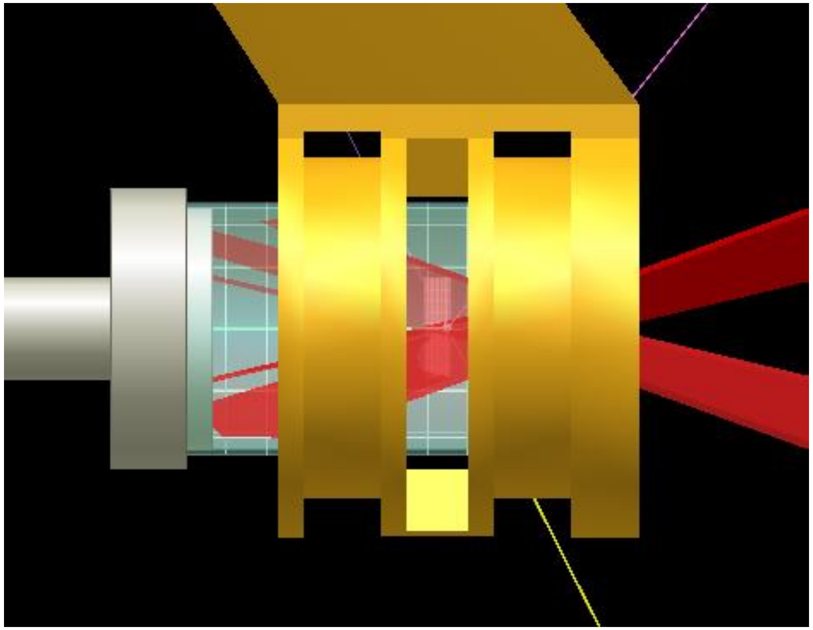
- Line emission from pure Ar gives good signal but is very optically thick (He-α~150!)
- Signal levels for doped D2 are very weak even at peak heating – measurements after heating require higher signal levels
- Unmagnetized D2 shot did not return data – T_e may have been too low

HYDRA shows reasonable fit to D2 data – but error bars are large due to low signal levels



- 0.1% Ar dopant is optically thin – can be modelled simply with PrismSPECT and SCRAM to infer T_e
- Peak T_e = 690±140 eV inferred
  - Error bars are large due to low signal levels and some discrepancy between models
- To reduce errors need to increase signal level, can be done by:
  - Increasing gas pressure
  - Increasing laser intensity
  - Moving to lower Z dopant, e.g. Neon, that is better suited for diagnosing lower T_e and has lower impact on cooling

Other long term objective – measure effect of B field on thermal conduction as in MagLIFEP_14A



- Apply large magnetic field (>10T) to target
- Measure T(t) with MSPEC/streaked spectrometer at a single Z during/after heating
- Use gas fill that is optically thin – Ar fraction ~0.5%
- Measure temperature after heating as plasma equilibrates

Principle difficulty in taking this measurement concerns signal levels at T_e<500 eV

- Increase laser power by reducing spot size – 450 μm diameter DPP being developed
- Use different/more sensitive diagnostics (e.g. Thomson scattering, crystal imager etc.)
- Use lower Z dopants – currently no capability to observe Ne/F emission

ARPA-E funding will allow capabilities to be extended over next few years

Summary: OMEGA-EP is a flexible platform that allows questions about preheat and magnetization to be addressed

- A platform has been developed on OMEGA_EP to study the preheat stage of MagLIF
  - Density (ne=0.05-0.1nc), magnetization (ωτ~2-5), scale length (10 mm), and intensity (Iλ2 ~ 1014 watts-μm2 /cm2) all relevant to MagLIF

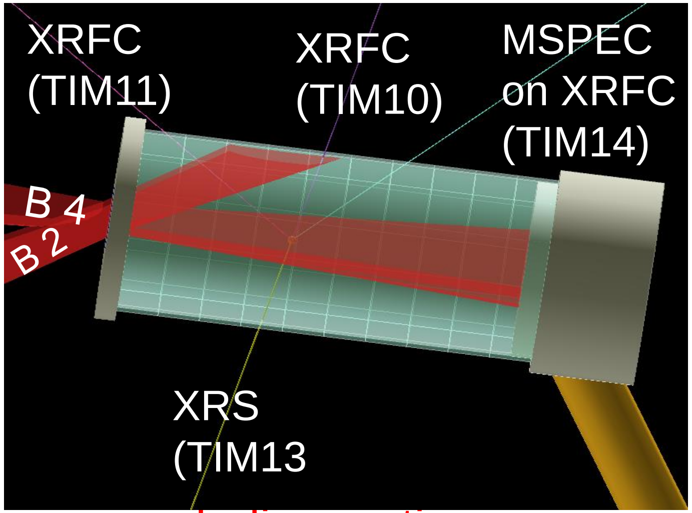
- Results show effect of B field, laser smoothing and laser power/intensity on energy deposition

- Investigating effect of magnetization requires more sensitive measurements – diagnostics are being developed to enable this

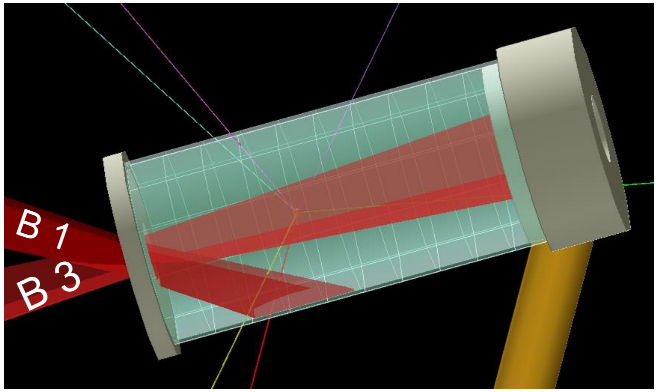
Extra slides

MagLIFEP_14B tested laser propagation through LEH and absorption in pure Argon gas targets to validate modeling codes

Main configuration with beam 4 (beam 2 as prepulse)



Additional configuration with beam 3 (Beam 1 as prepulse)



Beams and diagnostics:

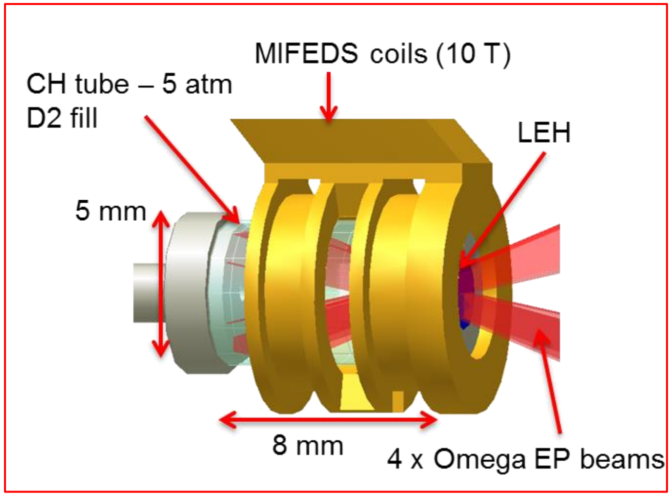
- Main interaction beam (aligned to the tube axis) with **<u>different pulse durations/powers</u>**
  - 2 ns (2. 2 kJ, 1.1 TW)
  - 4 ns (3 kJ, 0.75 TW)
  - 10 ns (4.5 kJ, 0.45 TW)
- Interaction beam **<u>w/ and w/o DPP</u>** <u>(750 µm)</u>
- Prepulse 0.25ns (250 J), 1 ns before main beam
- Main diagnostics: **XRFCs, XRPHCs, MSPEC, XRS**

Target:

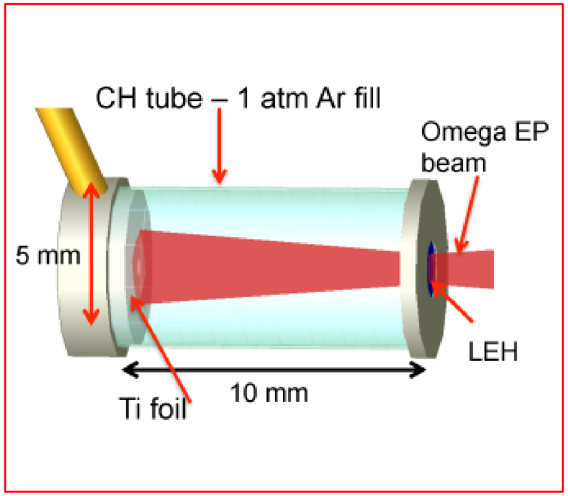
- Argon gas (~ 1 atm, n_e=0.048n_c) filled plastic tube (10 mm long, 5 mm diam. 75 µm wall thickness)
  - Good diagnostic view of targets
- Laser entrance hole polyimide window (1.7 mm diam., **1 or 2 µm thick**)
- 1 µm thick Ti coating on end plug
  - as a witness layer

MagLIF_EP experiments seek to test magnetization and preheat at conditions relevant to MagLIF

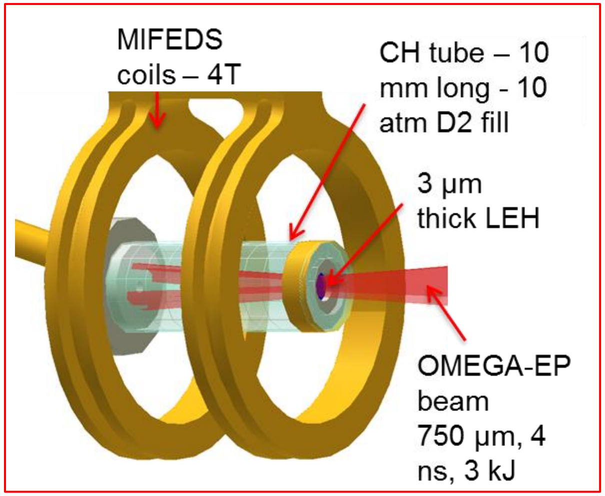
MagLIFEP_14A (04/09/14)



MagLIFEP_14B (07/29/14)



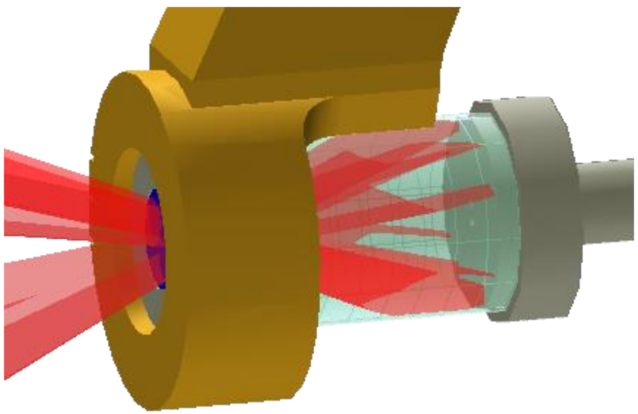
MagLIFEP_15A (03/10/15)



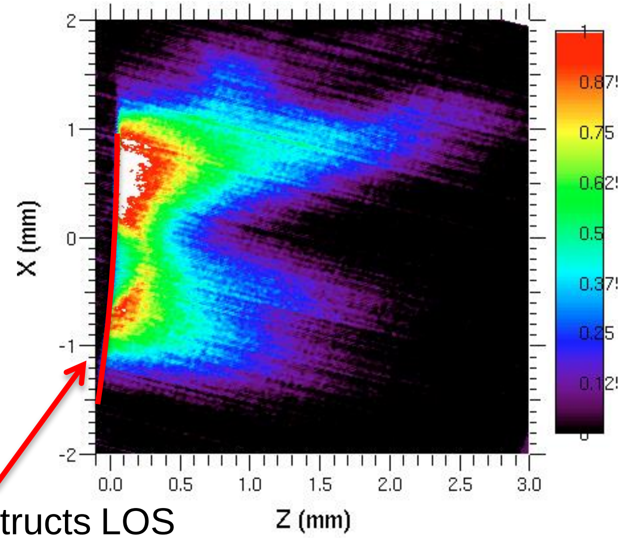
- MagLIFEP experiments aim to address questions important to preheat at conditions relevant to MagLIF
  - Density (n_e=0.05-0.1n_c), magnetization (ωτ~2-5), scale length (10 mm), and intensity ($I\lambda^2 \sim 10^{14}$ watts-µm^2 /cm^2) all relevant to MagLIF
- OMEGA-EP has several advantages over experiments at Z including: Well characterized beams and an appropriate suite of diagnostics
- Poster will focus on investigation of magnetized D2 gasses – MagLIFEP_14A and 15A
  - See M.S. Wei's poster for discussion of MagLIFEP_14B experiments

Time integrated pinhole imaging shows beam propagation in unmagnetized Ar

XRPHC target view

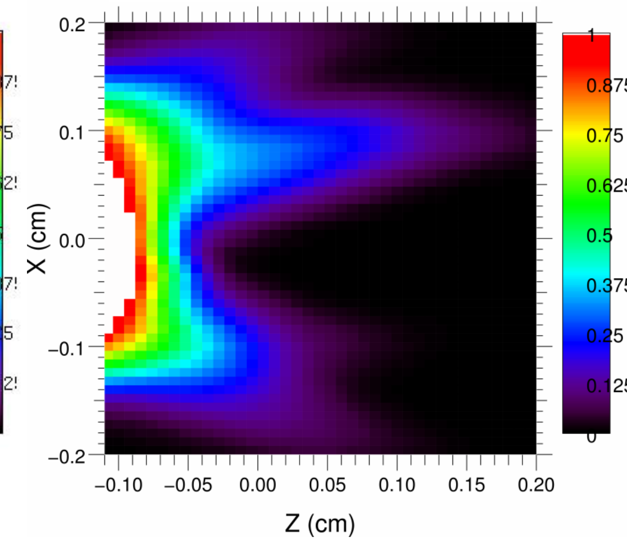


Time integrated XRPHC

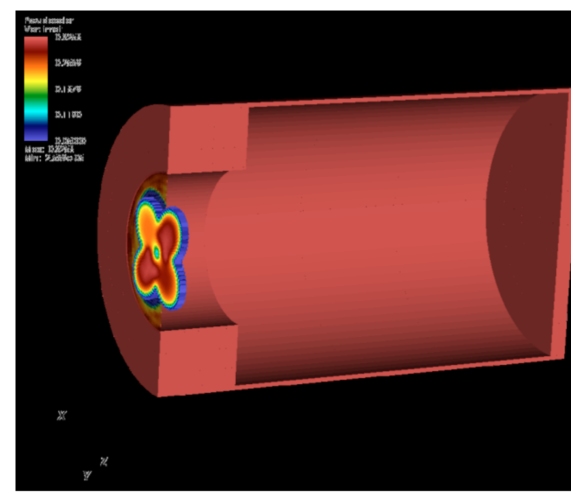


MIFEDS coil obstructs LOS

HYDRA synthetic emission image



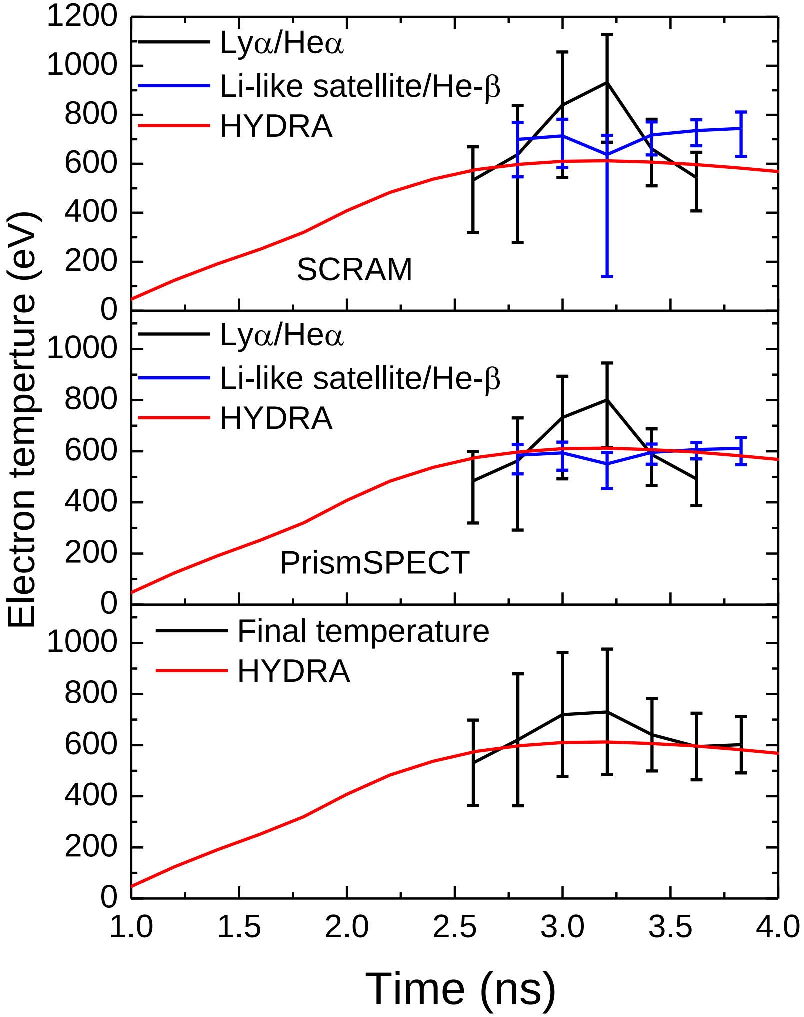
HYDRA sim setup



- 3D HYDRA modelling of 1 atm unmagnetized Ar target shows good agreement with deposition
- Actual beam energies and spot sizes used (1.7-2.5 kJ, 4 ns, square pulse, 750 um spot size)
- 4 laser spots are not of equal energy – sims. include this and match observed asymmetry

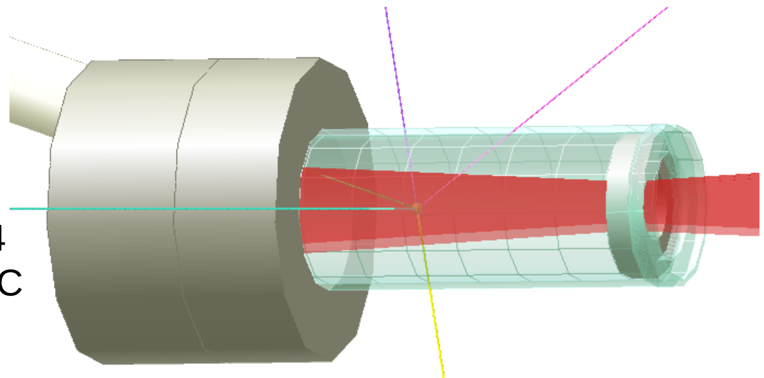
For more data and comparisons on laser heating see poster by M.S. Wei

HYDRA shows reasonable fit to data – but error bars are large due to low signal levels



- 0.1% Ar dopant is optically thin – can be modelled simply with PrismSPECT and SCRAM to infer T_e
- Peak T_e = 730±245 eV inferred
  - Error bars are large due to low signal levels and some discrepancy between models
- To reduce errors need to increase signal level, can be done by:
  - Increasing gas pressure
  - Increasing laser intensity
  - Moving to lower Z dopant, e.g. Neon, that is better suited for diagnosing lower T_e and has lower impact on cooling

MagLIFEP_15B (July 29th 2015) aims to test increasing gas density up to 20 atm ($n_e = 0.114\ n_c$) with >5T B field



Modifications to target design to allow 20 atm pressure:

- Smaller diameter (3 mm OD)
- Thicker walls (115 um rexolite)
- Gas plug modified – greater gluing surface area

- Single heating beam – 4, 6, or 10 ns depending on simulation results
- Aim to use 0.1% Ar dopant (optically thin) – may have to use 0.5% Ar dopant for signal levels
- Ti coating on inside of LEH, possible $CaCl_2$ coating on LEH interior
- MIFEDS coils (to be designed) aim to apply >5 T, need to consider target view and B field uniformity

Summary

A platform has been developed on OMEGA_EP to study the preheat stage of MagLIF

- Density (n_e=0.05-0.1n_c), magnetization (ωτ~2-5), scale length (10 mm), and intensity ($I\lambda^2$ ~ 10^{14} watts-μm^2 /cm^2) all relevant to MagLIF

Results show laser propagation in Ar and magnetized D_2 gasses

- 3D HYDRA sims of propagation in Ar match the data closely
- Analysis and simulations of MagLIFEP_15A D_2 propagation data is still underway

Results show heating of the D_2

- MagLIFEP_15A diagnosed propagation T_e = 730±245 eV
- Neutrons measured in these experiments – 3.01±0.3×10^8 in MagLIFEP_14A and 1.5-5×10^6 in MagLIFEP_15A.
  - Neutrons produced by shock behind LEH, factor 10 greater than HYDRA sims – discrepancy still being invesitgated

We are near the limit of diagnostic sensitivity for Ar doped D_2 – we need to find a way to increase heating and/or diagnostic sensitivity moving forward