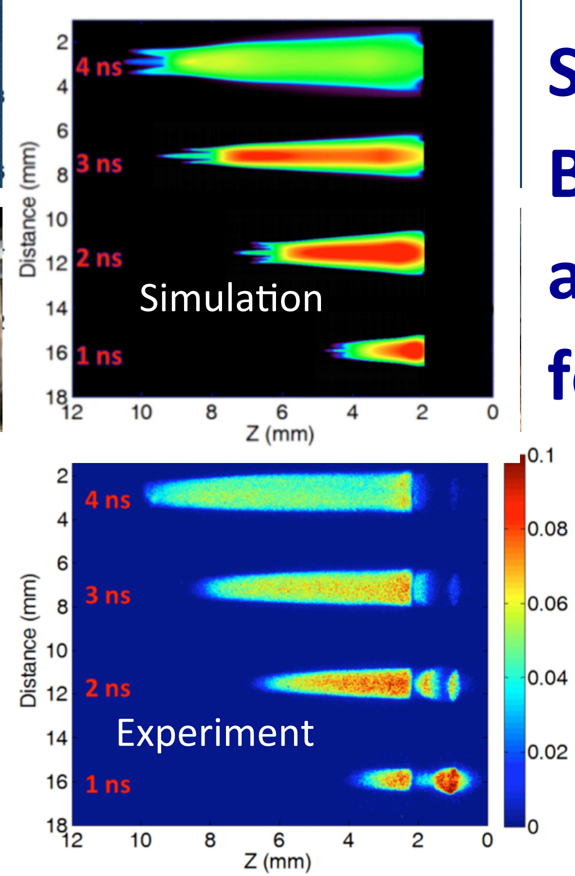

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Study of Laser Power, Duration and Beam Smoothing on Laser Propagation and Heating in an Underdense Plasma for MagLIF using the OMEGA EP Laser

SAND2016-1714PE

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Omega Laser Facility Users Group Workshop
April 22 – 24, 2015, Rochester NY

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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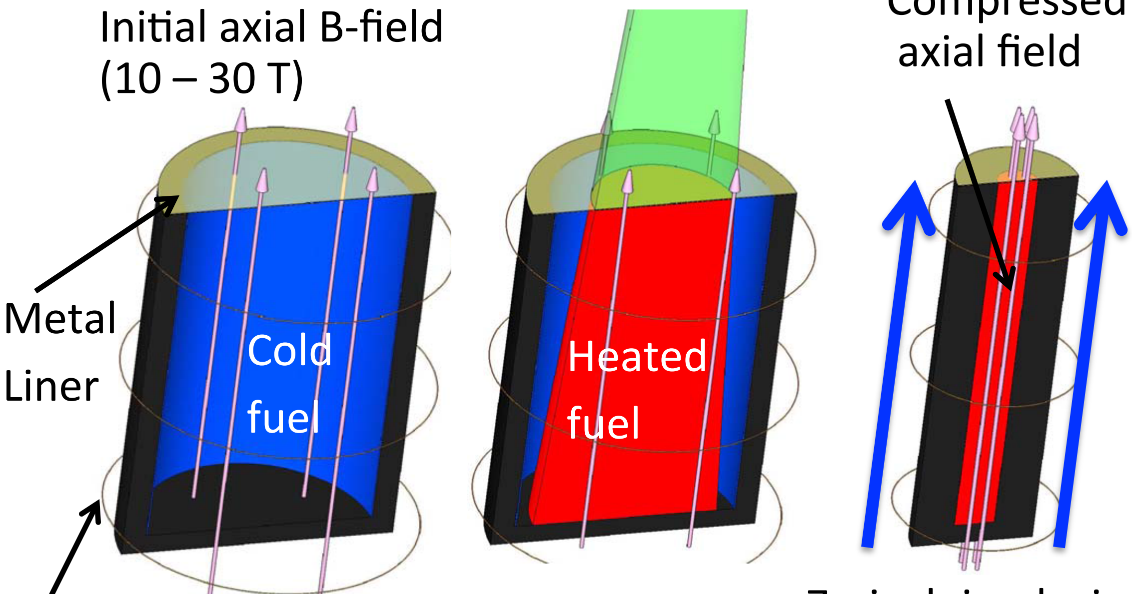
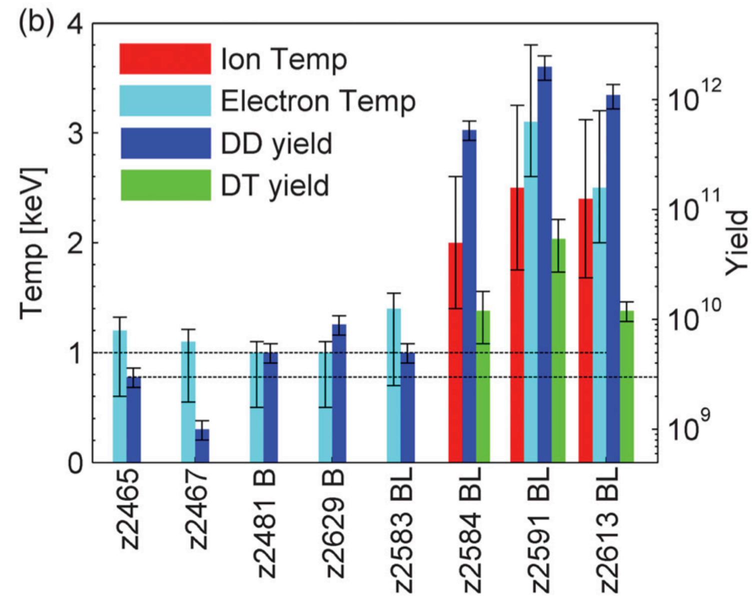
MAGnetized Liner Inertial Fusion(MagLIF*) is a 3-step process – has potential to achieve significant fusion yield with slow implosions and modest radial convergence

*S.A. Slutz et al., PoP 17, 056303 (2010)

#M.R. Gomez et al., PRL 113, 155003(2014)



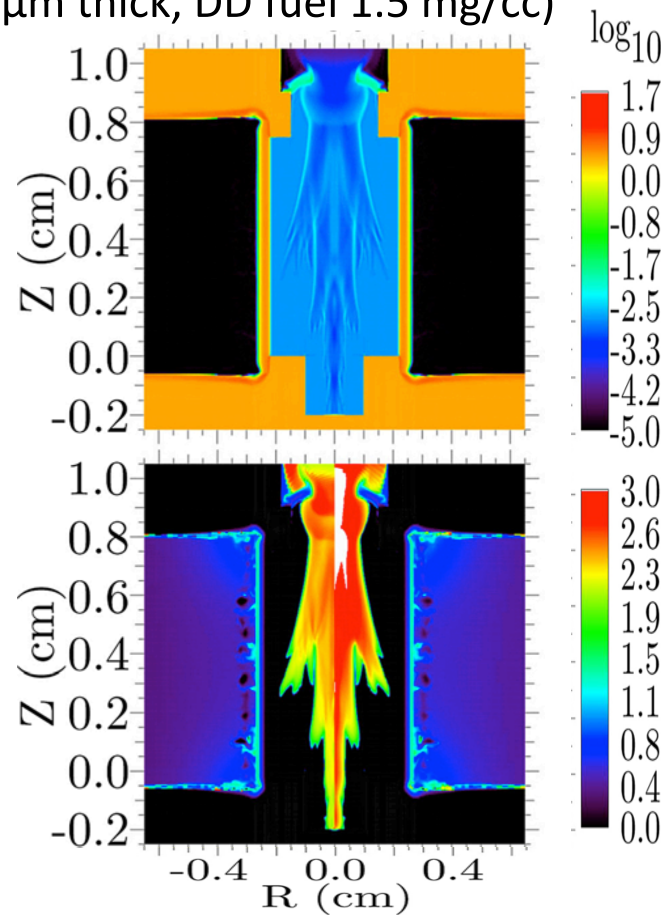


- **Magnetization suppresses thermal conduction and enhance α-particle heating**
- **Preheating the fuel (100's eV) can reduce the implosion velocity and convergence requirements**
- **First integrated experiment# has been successfully demonstrated at Z**

ZBL laser was used to preheat a D2 gas contained in a cylinder in integrated MagLIF experiments performed at Z

HYDRA simulated preheat* by ZBL laser

(2.2 kJ/2ns heating beam with a prepulse, LEH 2 μm thick, DD fuel 1.5 mg/cc)



Need further study of MagLIF laser preheat:

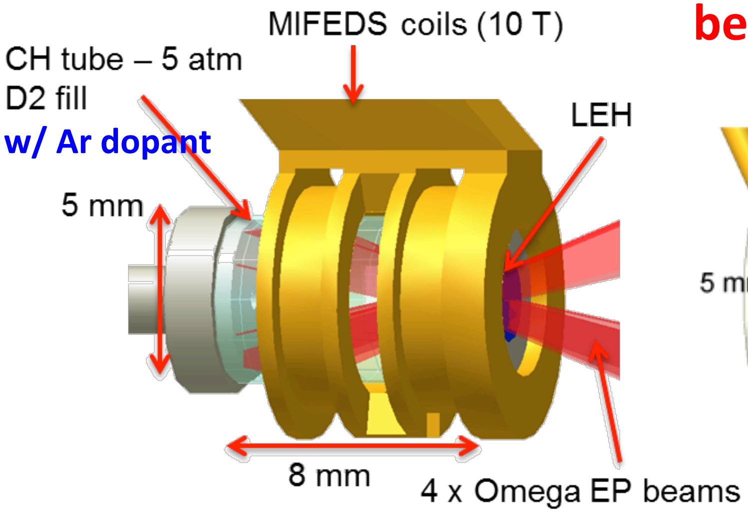
- ZBL laser preheat in integrated MagLIF experiment showed unexpected low energy coupling (100-300 J coupled to D2)
- D2 gas needs to be at high pressures (1-5 mg/cc, 5 – 30 atm.) – thick laser entrance hole (LEH) foils required if non cryo
- Laser hitting walls/end causes mix and instabilities
- ZBL laser was unsmoothed and may filament at regions of high intensity – hydro codes don't capture this
- Scientific breakeven point design requires >8 kJ energy into D2 fuel in 10 mm long cylinder

* A.B. Sefkow et al., PoP 21, 072711 (2014)

A new platform on OMEGA EP for MagLIF laser preheat study with multi-kJ lasers, B-fields and a suite of x-ray diagnostics

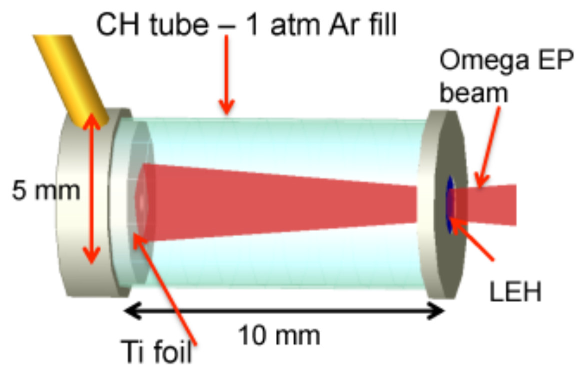
Target/experimental configurations evolving with improved capabilities and understanding

14A w/ and w/o B-field, smoothed beams

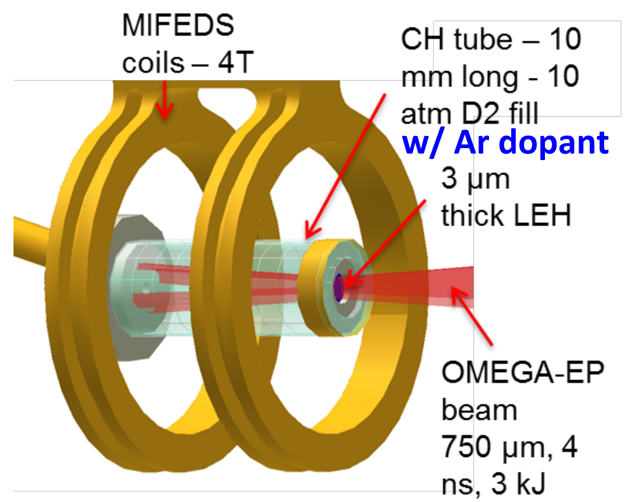


14B - this poster

w/o B-field, w/ and w/o beam smoothing



15A w/ and w/o B-field, smoothed beam



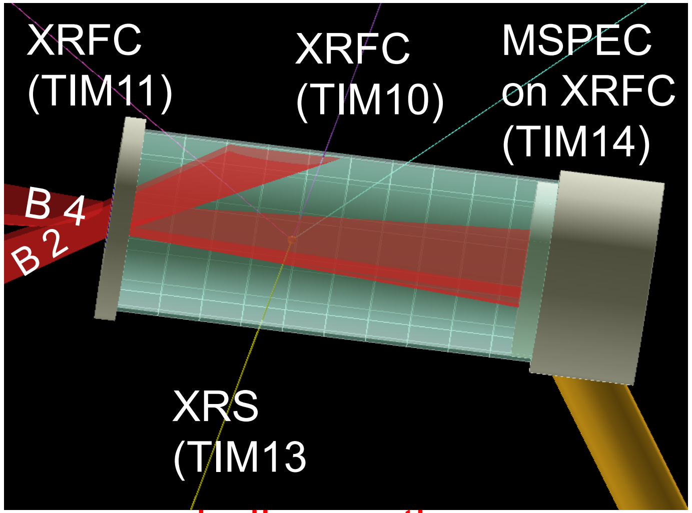
See Harvey-Thompson's poster for 14A and 15A results

MagLIFEP experiments aim to test:

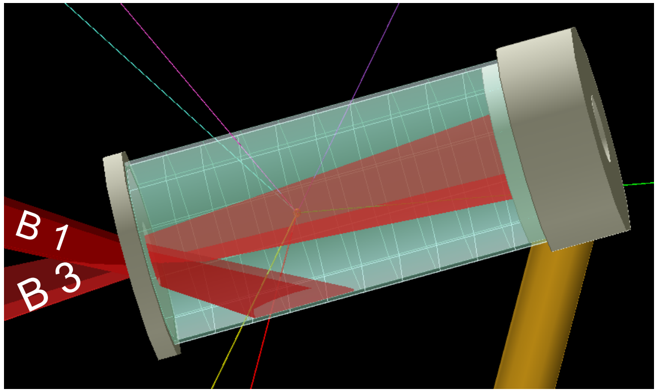
- **Laser energy deposition and plasma heating in MagLIF-relevant conditions**
- **The effect of applied magnetic field on thermal conduction/the cooling rate of the plasma**
- **Laser propagation and heated plasma conditions diagnosed by measuring x-ray emission and x-ray spectroscopy**

MagLIFEP_14B tested laser propagation through LEH and absorption in pure Argon gas ($n_e=0.048n_c$) 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:

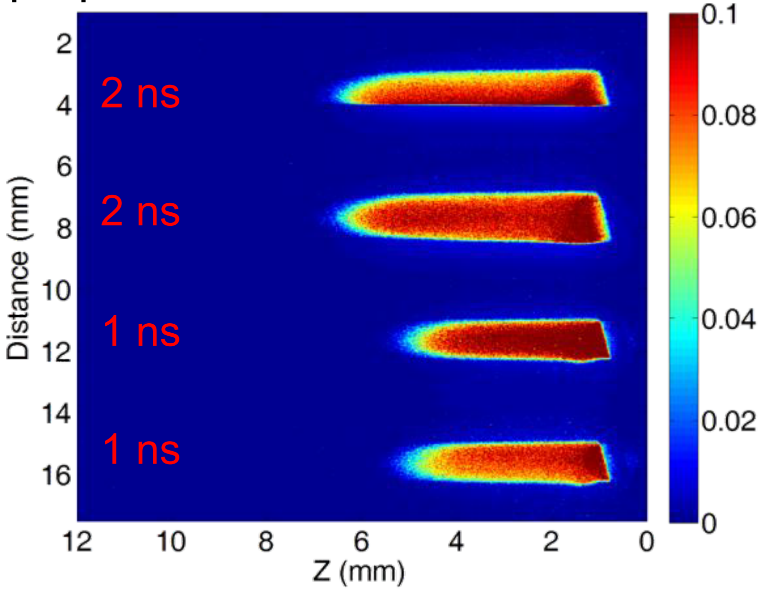
- Main interaction beam (aligned to the tube axis) with **<u>different pulse durations/powers</u>**
  - 2 ns (2. 2 kJ, 1.1 TW)
  - 4 ns (3 kJ, 0.75 TW)
  - 10 ns (4.5 kJ, 0.45 TW)
- Interaction beam **<u>w/ and w/o DPP</u>** <u>(750 μm)</u>
- Prepulse 0.25ns (250 J), 1 ns before main beam
- Main diagnostics: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

Target:

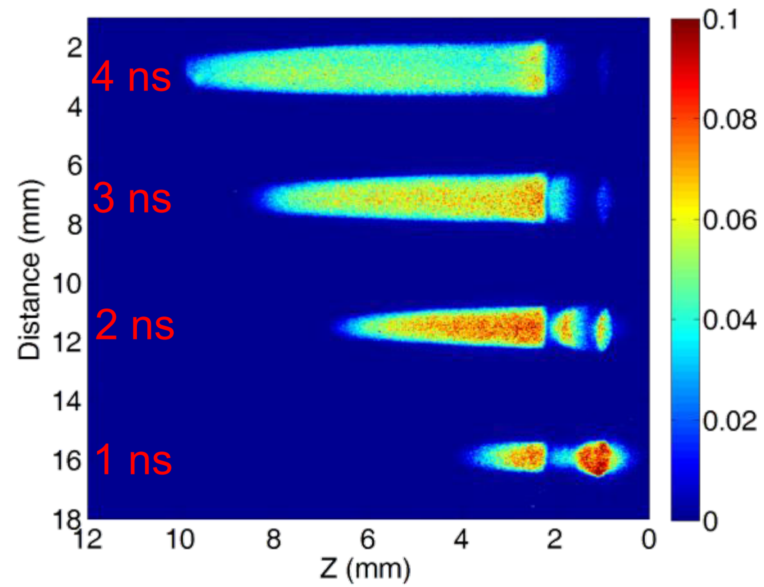
- Argon gas (~ 1 atm, $n_e=0.048n_c$) filled plastic tube (10 mm long, 5 mm diam. 75 μm wall thickness)
  - Good diagnostic view of targets
- Laser entrance hole polyimide window (1.7 mm diam., **1 or 2 μm thick**)
- 1 μm thick Ti coating on end plug
  - as a witness layer

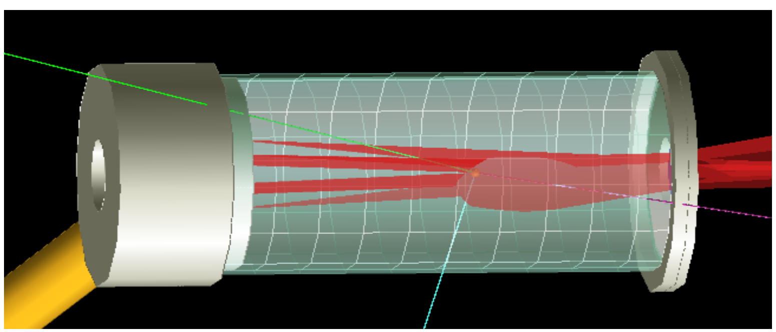
Laser Propagation dependence on Pulse length and power – measured by XRFC

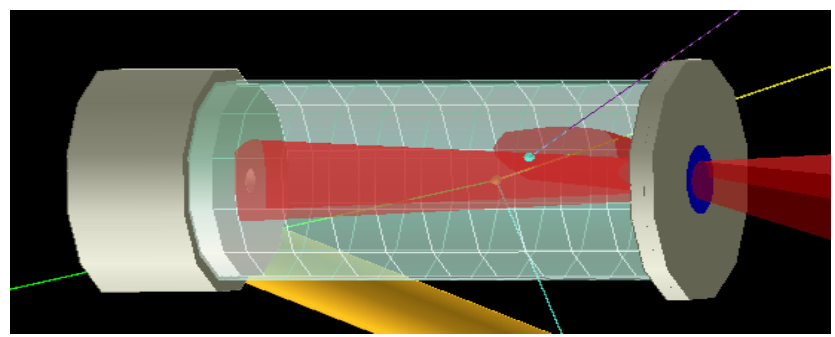
2 ns /2.2 kJ (1.1 TW), 1 µm LEH, no prepulse



4 ns/3.1 kJ (0.78TW), 2 µm LEH, no prepulse

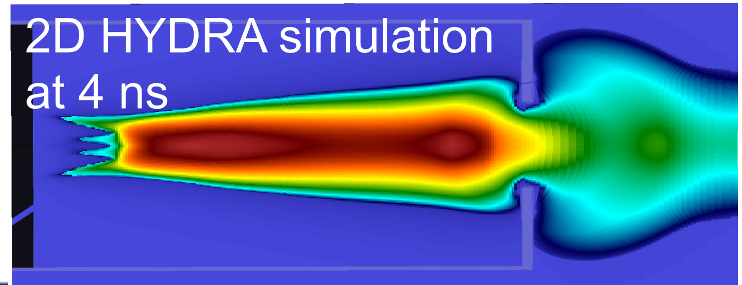




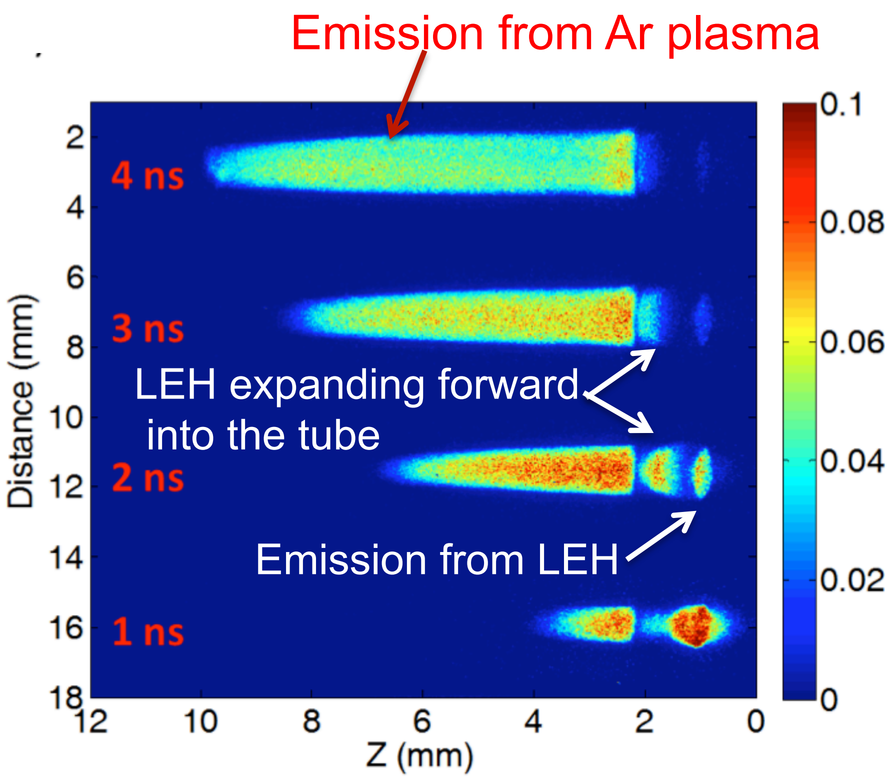


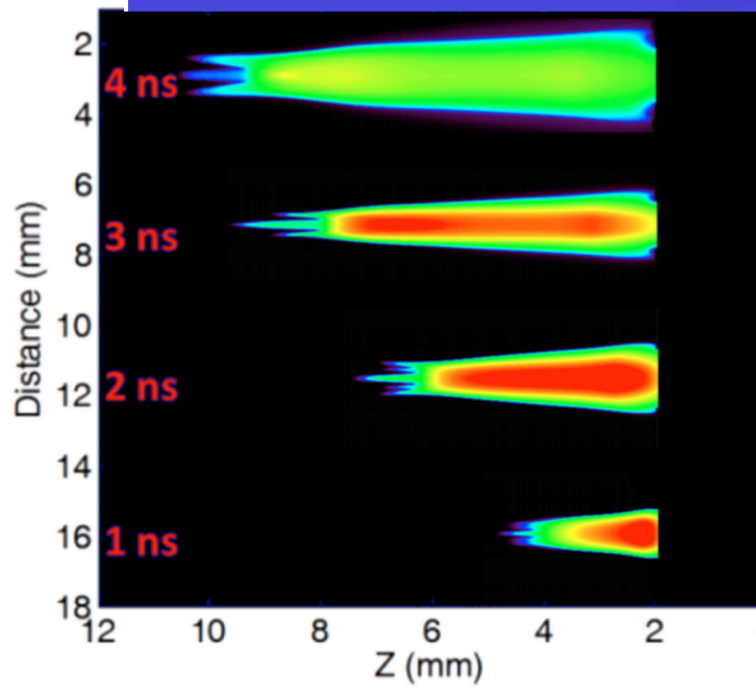
- **Compared to 4 ns case, 2 ns heating beam showed brighter emissions, but a shorter propagation distance**

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

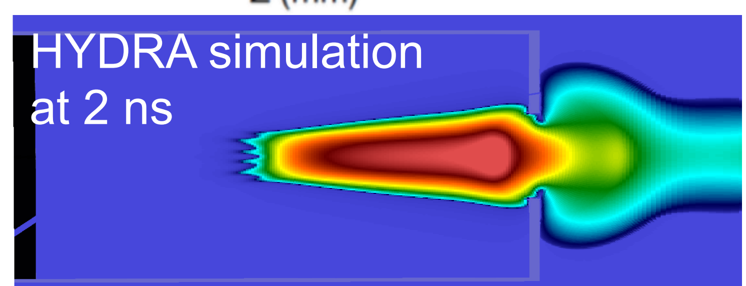


Experiment with 4 ns heating beam

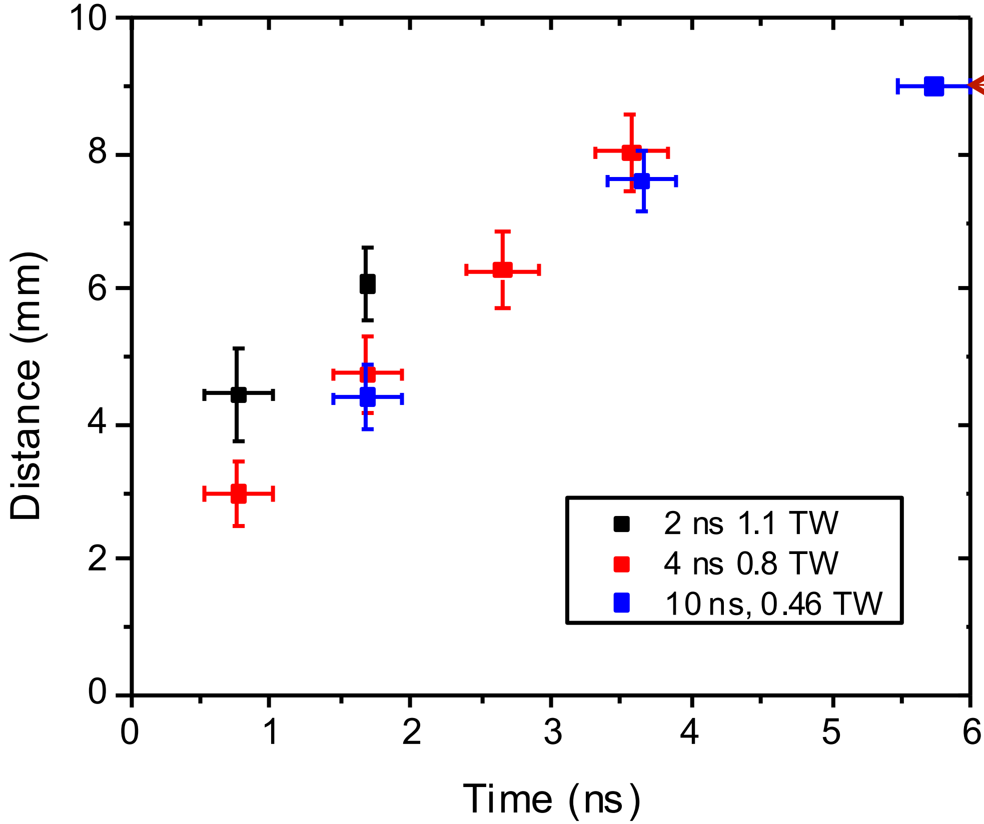




- **Some discrepancies occurred in LEH region and also at the heating front**
  - **3D simulations are underway**



XRFC measurements quantified laser propagation distance

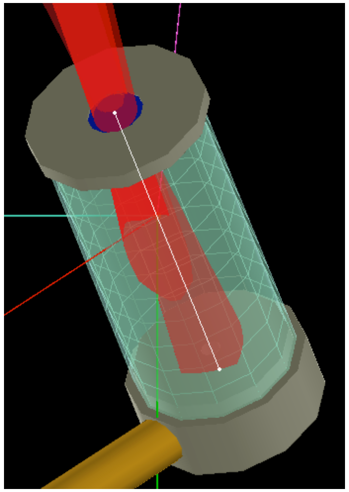


End of tube
(only 9 mm long due to viewing angle)

- **Propagation velocity appears to depend on laser power**
  - **2 ns beam with the highest power (1.1 TW) had the fastest propagation velocity, but stopped at a shorter distance**

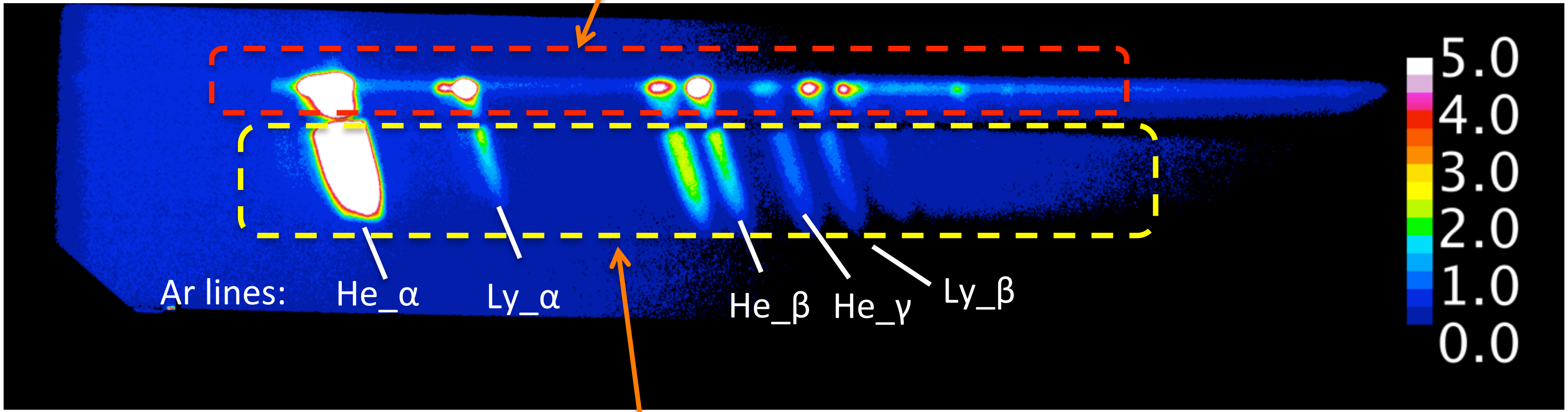
Measured Argon spectra showed Ar He-α line emission dominating plasma radiation and energy loss at LEH

XRS view



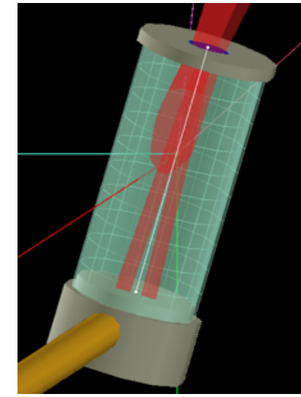
XRS data with B3 configuration,
B3 only (4 ns, 3.139 kJ, 0.785 TW), 2 μm LEH

Strong Ar line emissions from LEH region



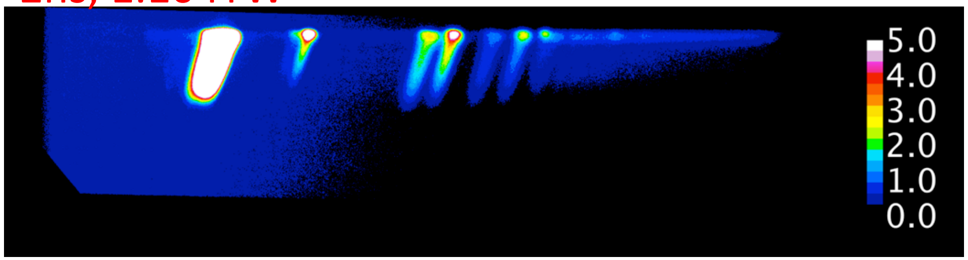
X-ray radiation from the heated Ar plasma inside the tube was dominated by Ar He-α emission

XRS measured Ar line spatial profiles showed similar trend of propagation on laser duration/power observed by XRFC

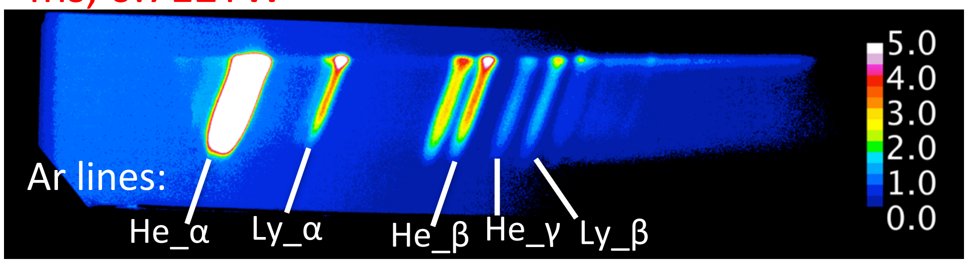


Raw data from the B4 configuration, B4 only, 1 µm LEH

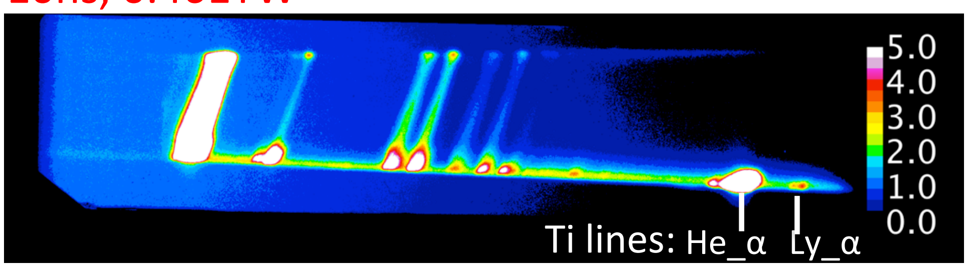
2ns, 1.104TW



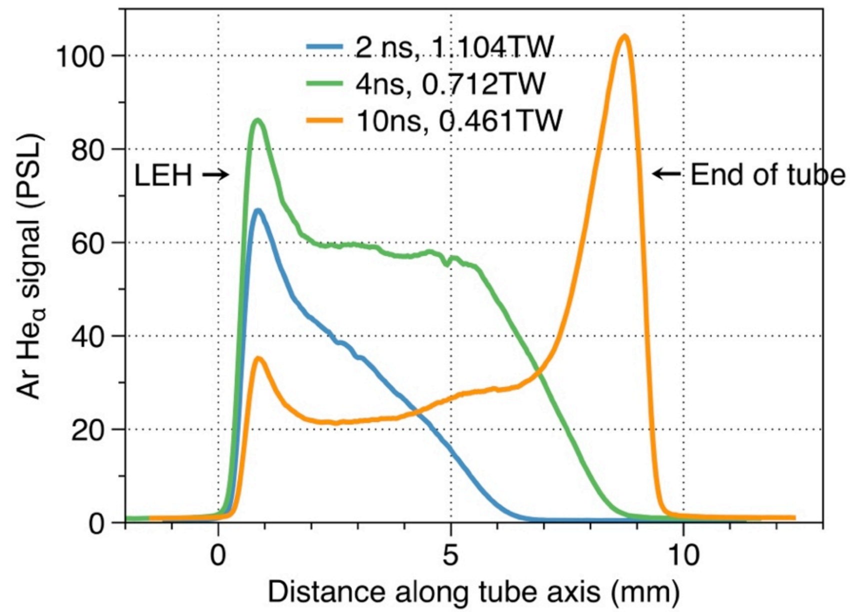
4ns, 0.712TW



10ns, 0.461TW



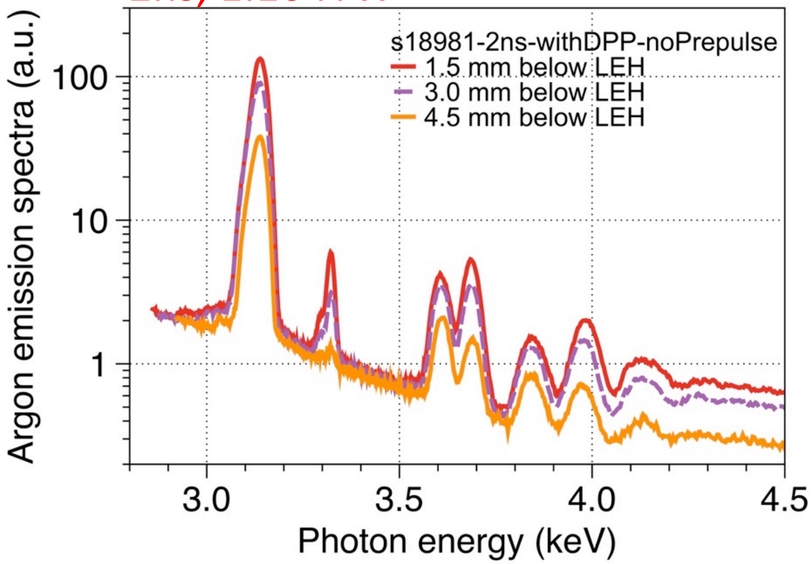
Ar He-α emission along the tube axis



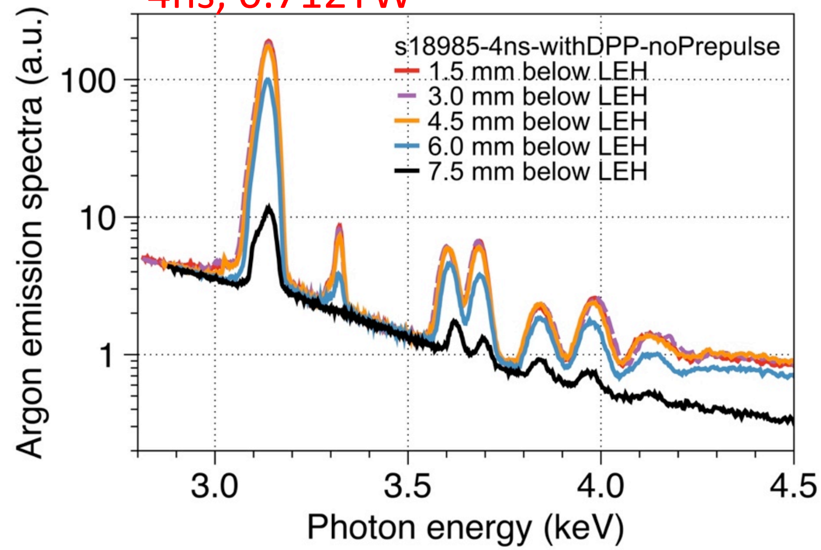
- **Peaked emission from LEH region dropped quickly in ~ 1 mm distance**
- **Emission from the heated plasma inside the tube strongly depends on pulse duration and power**
  - **2 ns case had the shortest propagation distance**
  - **4 ns case showed a quite flat profile with higher signal and longer propagation distance**
  - **10 ns case had less heating at LEH and inside the tube, most of energy deposited at the end**

Measured Ar spectra at various axial distances revealed laser heating dependence on beam duration/power

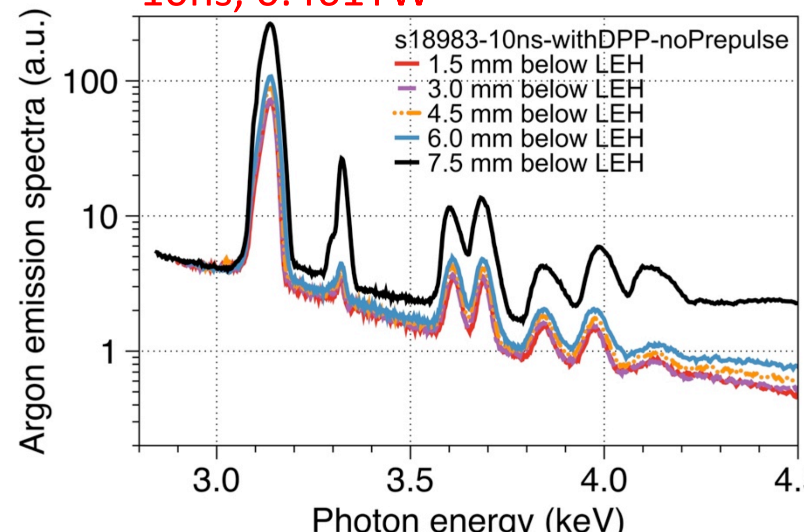
2ns, 1.104TW



4ns, 0.712TW

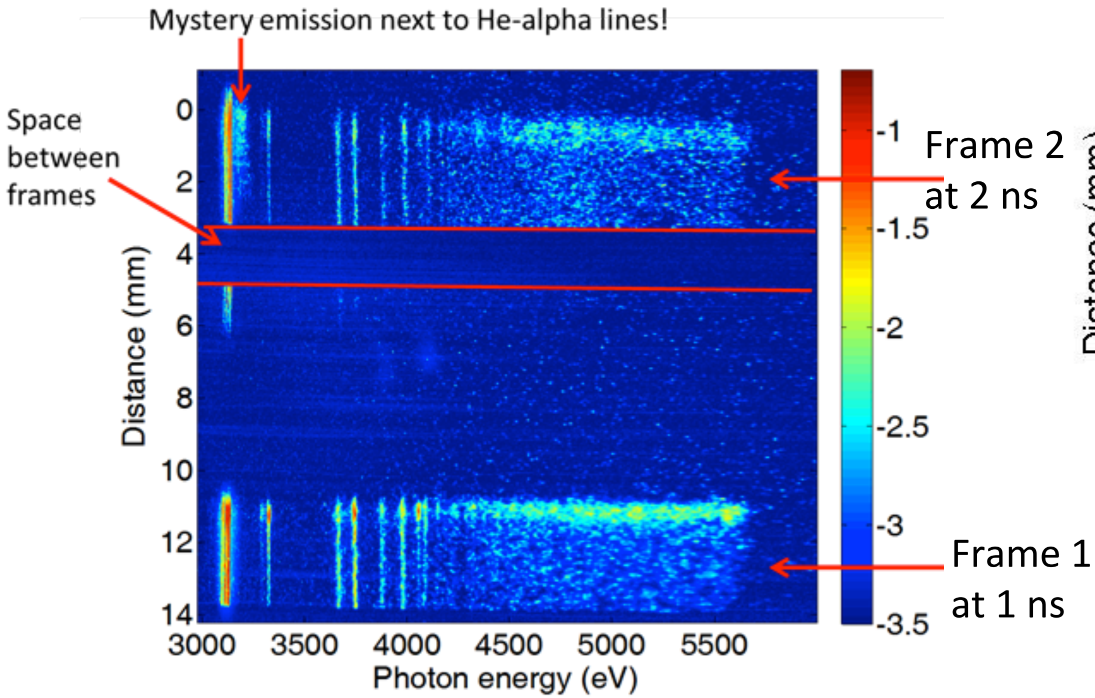


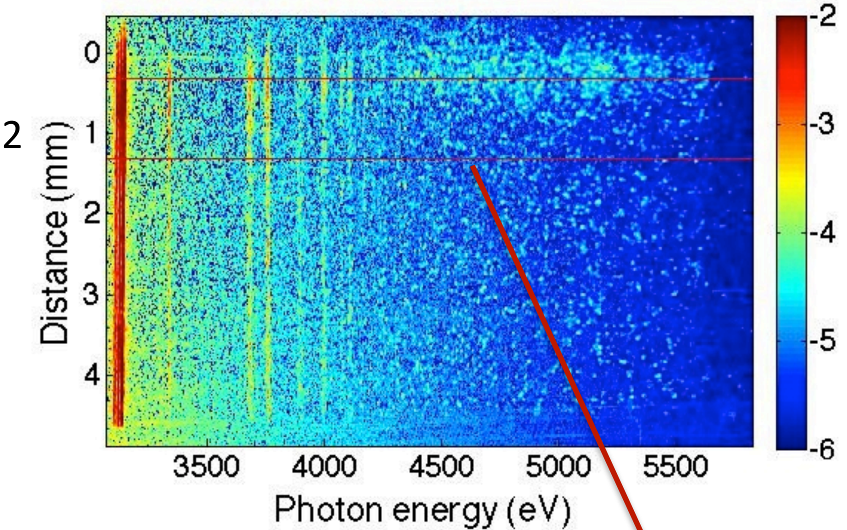
10ns, 0.461TW

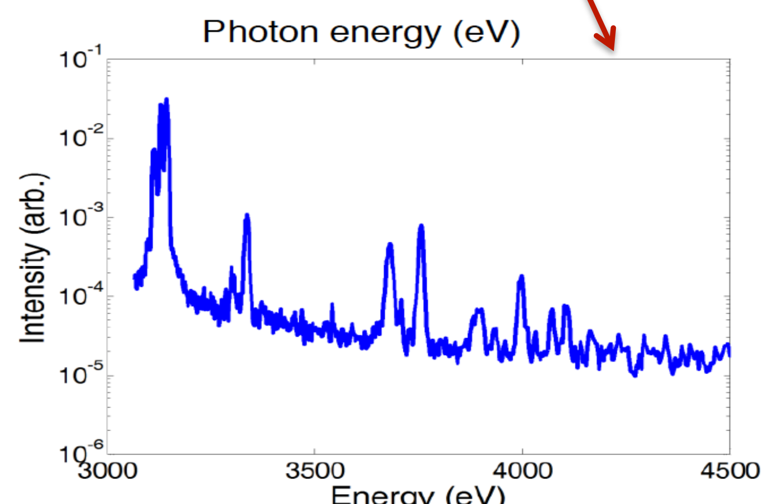


- **4-ns case showed uniform heating over a significant distance**
  - Identical emission spectra from heated Ar plasma for > 5 mm beneath LEH
- **2-ns pulse stopped in a shorter distance**
  - Ar Ly-α line disappeared at ~4.5 mm
- **10-ns case showed strongest heating at the back of the tube**
  - Due to reflected shocks?

We have also obtained temporally and spatially resolved Ar emission spectra using the MSPEC coupled to XRFC



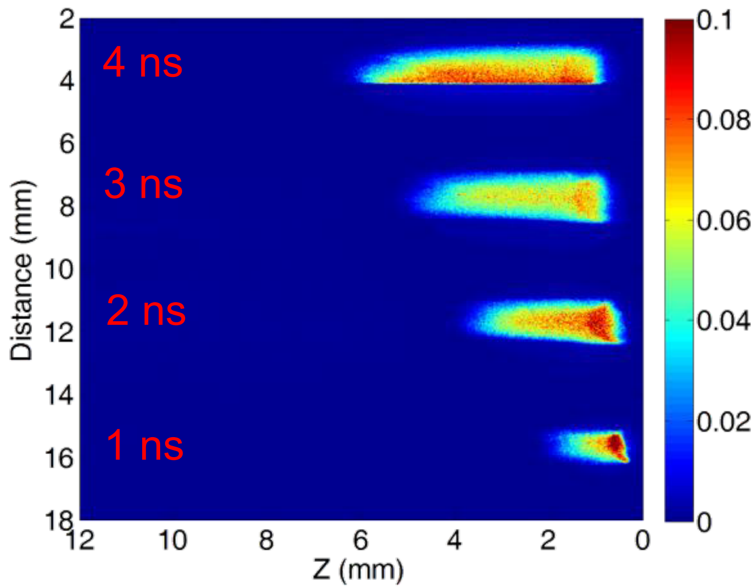




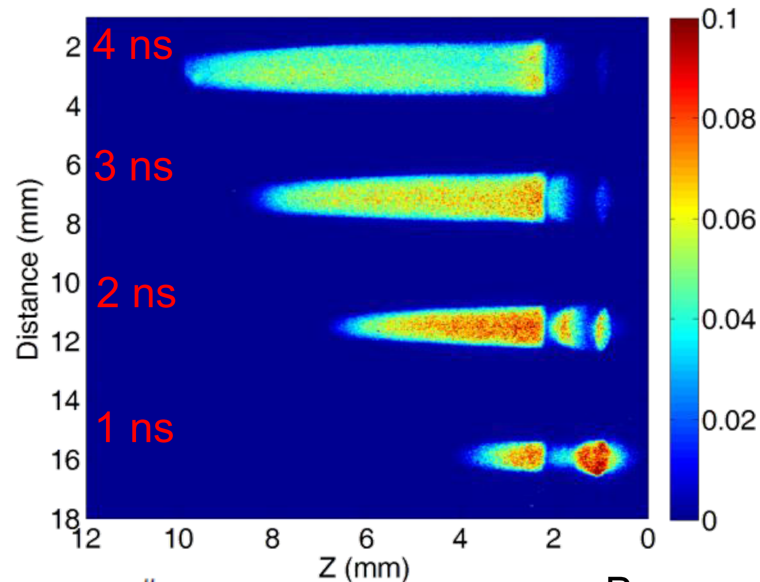
- **Time and spatially resolved spectroscopy give details of plasma temperature**
  - **Analysis of MSPEC data and comparison with HYDRA/SPEC3D modeling is ongoing**
- **MSPEC has limited field of view about 6 mm**
  - Aligned to measure heated plasma in front half of the tube

Unsmoothed laser beam (without distributed phase plate) showed a noticeable shorter propagation distance

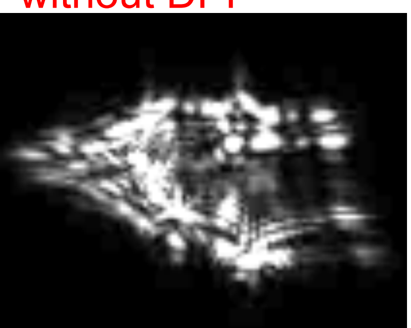
4 ns/2.93 kJ, 2 μm LEH, no prepulse
without DPP



4 ns/3.1 kJ, 2 μm LEH, no prepulse
with DPP



Beam profile (representative)
without DPP

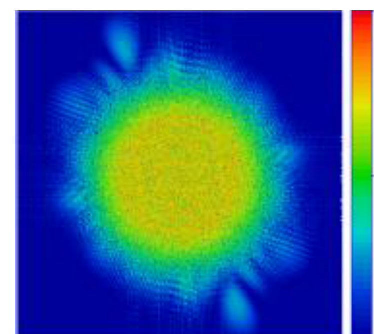


$$\text{FFOM} = \frac{I_p \lambda_0^2}{10^{13}} \left(\frac{n_e}{n_{cr}}\right)\left(\frac{3}{T_e}\right)\left(\frac{f^{\#}}{8}\right)^2,$$

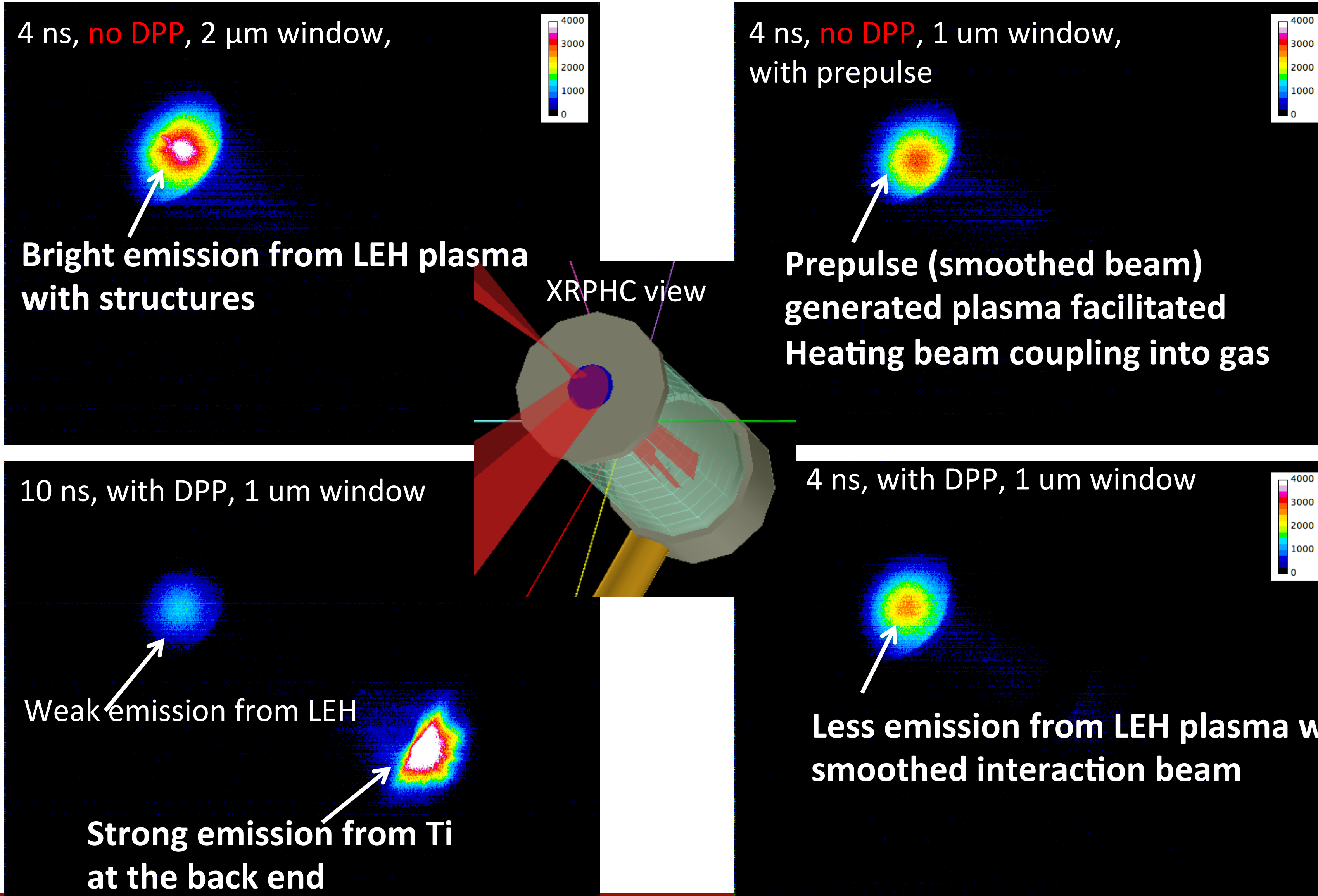
* D. Froula et al., PoP 14, 055705(2007)

- DPP smoothed beam was below filamentation threshold (FFOM* < 1)
- Removing DPP put hot spots in beam above FFOM and led to filamentation causing the beam to stop faster in the gas
- Results helped motivate the addition of phase plates to ZBL at SNL for integrated MagLIF study

Beam profile
with DPP

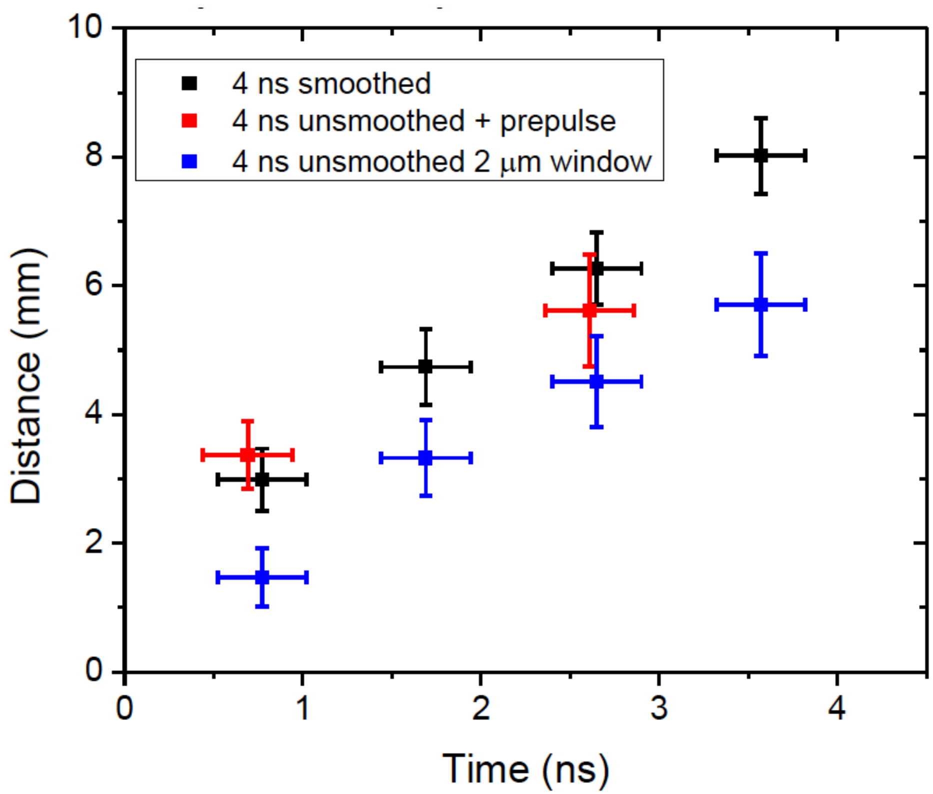


Stronger x-ray radiation with structures observed from the LEH region in interaction with unsmoothed beam without prepulse

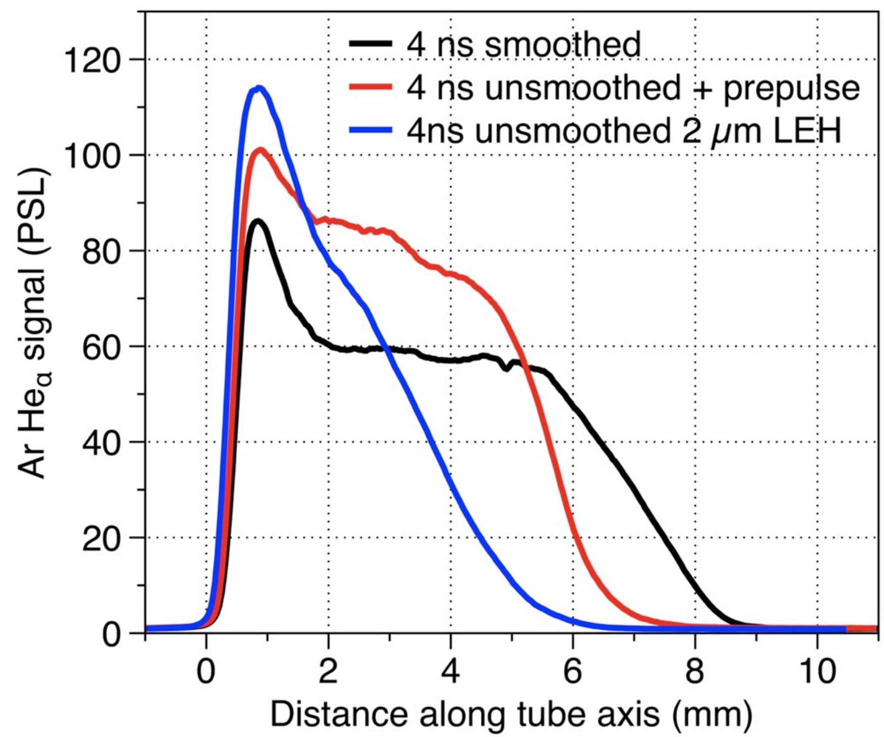


XRFC and XRS both showed clear reduction in propagation distance without beam smoothing

XRFC measured propagation distance

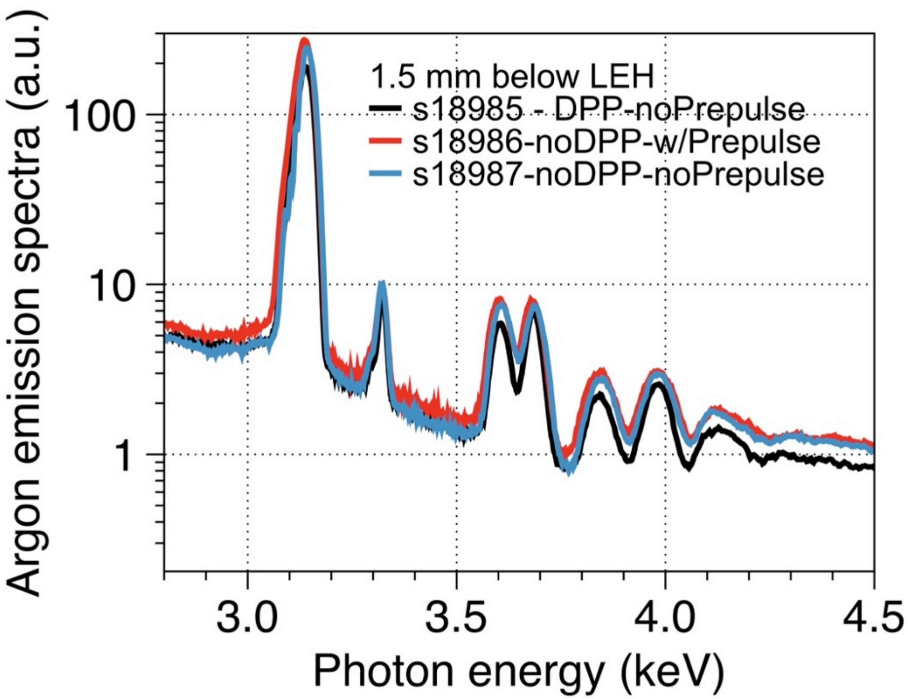


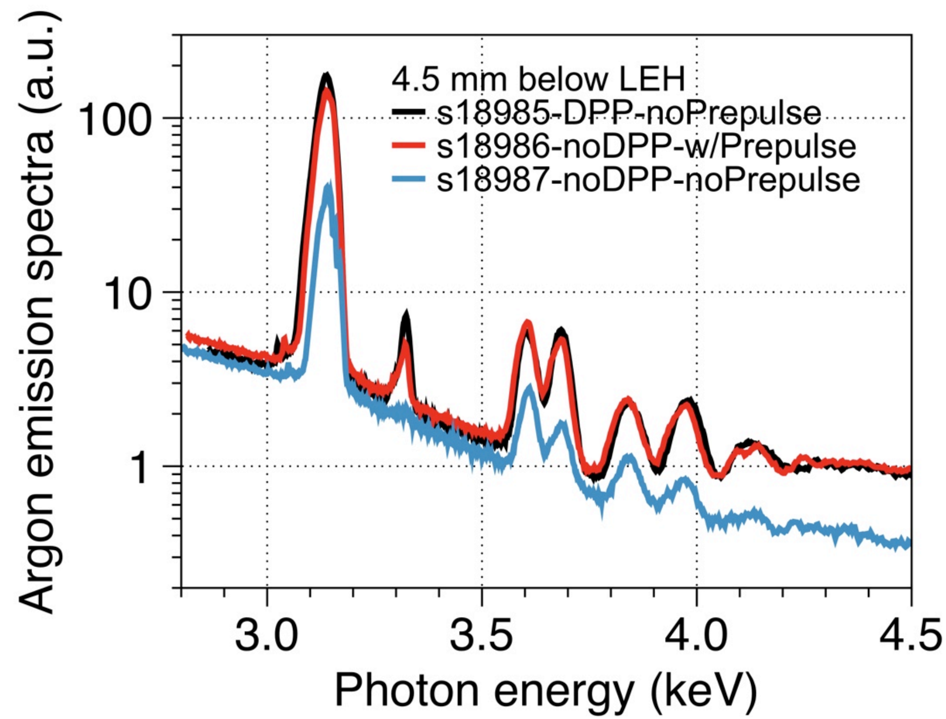
XRS measured propagation distance



- **Prepulse facilitated unsmoothed beam energy coupling through LEH into gas inside the tube**
  - **Also showed stronger heating of Ar plasma beneath LEH with prepulse**

Measured Ar emission spectra suggested a large Te gradient in axial direction with the unsmoothed beam without prepulse





- **Ar plasma was cold 4.5 mm below LEH and beyond (Ar Ly_a line, sensitive to temperature, was not observed)**
  - **Similar emission spectra from the heated Ar plasma close to LEH (e.g. 1.5 mm below LEH)**
- **Optical depth in Ar plasma complicates Te analysis – under investigation**

Summary and Future (including on-going) work

- Experiments showed strong dependence of laser energy absorption on laser duration and power
  - Propagation velocity appears to increase with laser power – 2ns (1.1 TW) showed the fastest propagation, but stopped at a shorter distance with non-uniform heating
  - 4 ns (0.8 TW) pulse showed uniform heating over 5 mm distance; while 10 ns (0.42TW) reached the end of the 1 cm long target with low heating at the front and strong heating at the back
- Good comparison with HYDRA simulations for the smoothed beam in 4 ns case
  - Experimentation data validating simulation codes for predictive capability
- Observed a much shorter propagation distance with the unsmoothed beam
  - Removing phase plates led to filamentation causing the beam to stop faster in the gas
  - Adding a prepulse helped the unsmoothed heating beam energy coupling through LEH into D2 gas
- Detailed analysis of Ar emission (images and spectra) and comparison with HYDRA and SPECT3D modeling are underway
- Future experiments will study laser preheat with and without axial B-fields in high density D2 gas (with 0.1% Ar dopant)