Fast electron source and transport in laser-driven shock heated warm dense matter

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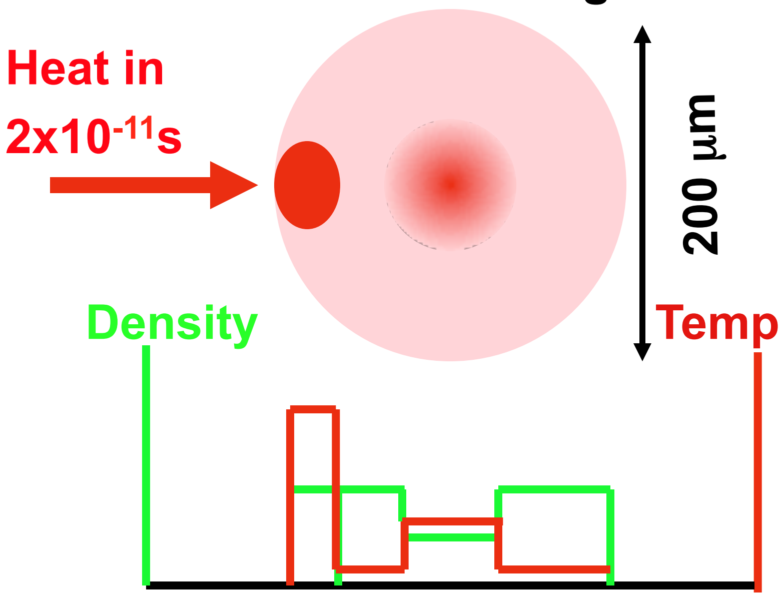
Outline

- Motivation
- Electron source and transport using 150 J, 0.7 ps laser
- PICLS modeling of the source and transport
- Electron transport in large volume warm dense plasma using 1 kJ, 10 ps laser
- Summary

What is Fast Ignition (FI) & Why fast Ignition?

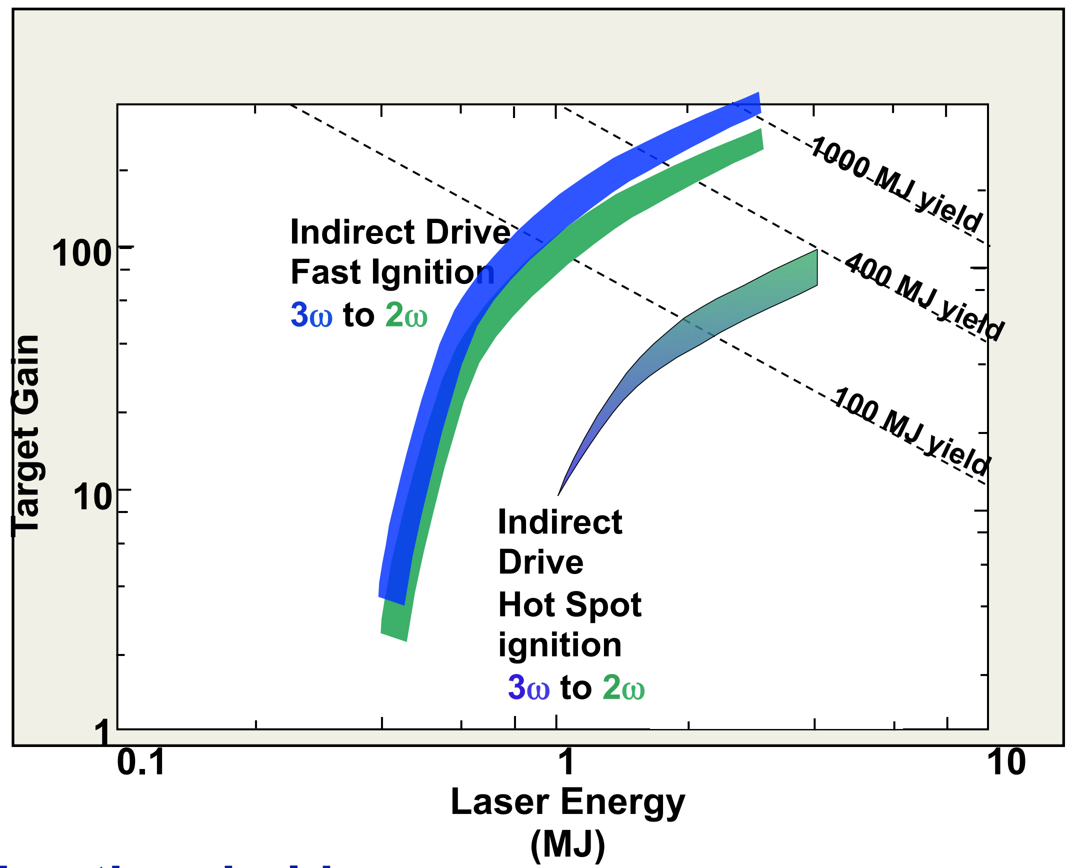
Fast Ignition (FI)
Isochoric - fast heating



Fuel 300 gcm^{-3}

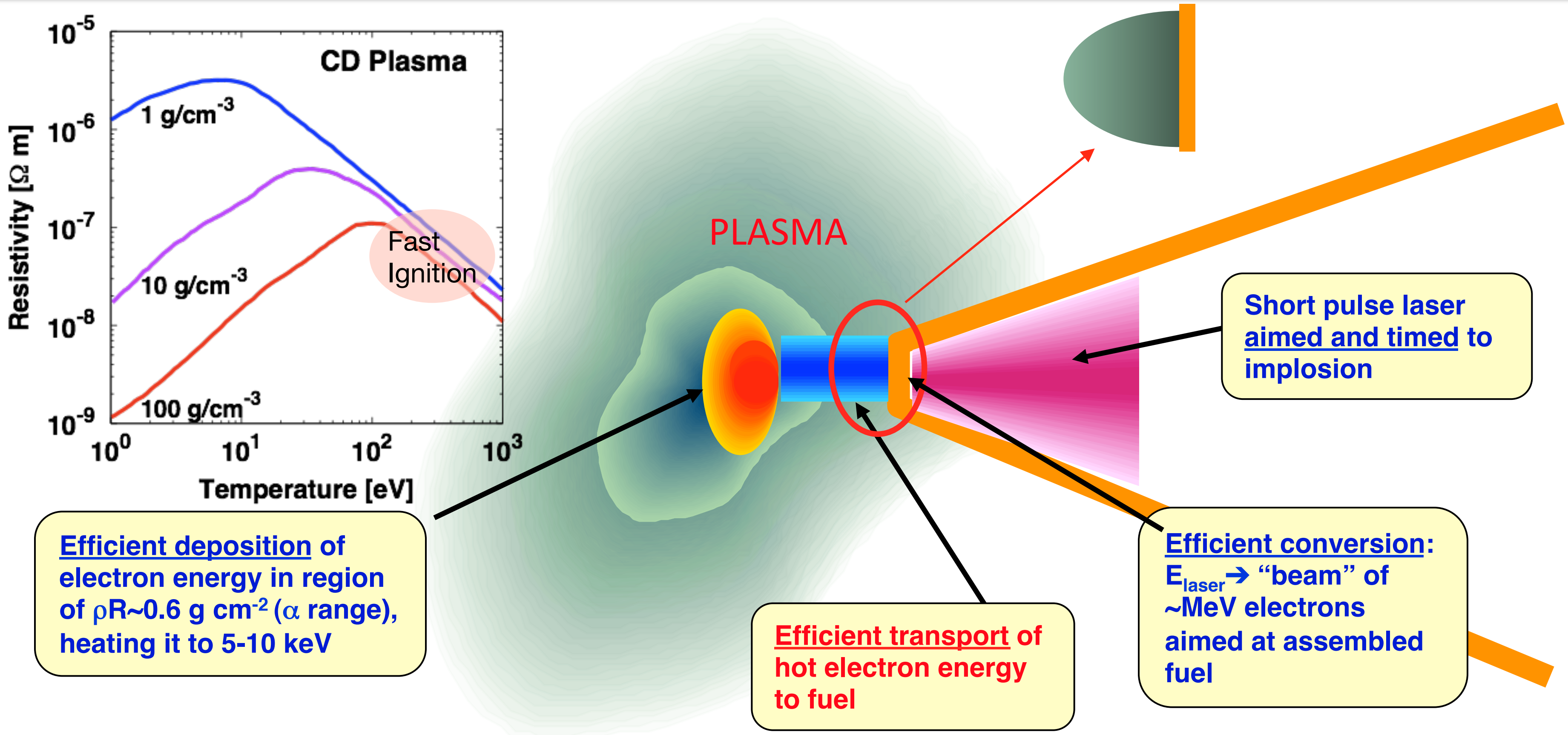
Spark 300 gcm^{-3}

* M. Tabak et. al., Fusion Science and Technology v 49 2006



- **Higher gain and lower ignition threshold**
- **Less stringent symmetry requirement**
- **Low energy driver suitable for IFE power plant**

Critical issues in cone guided FI



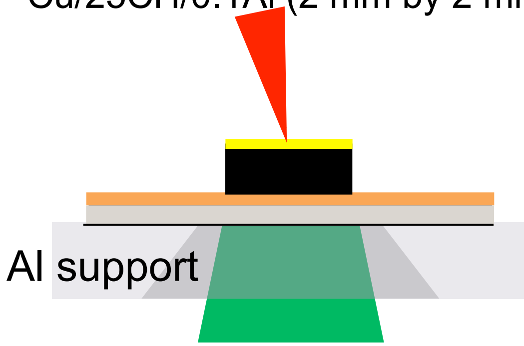
- FI requires efficient energy coupling from ignition laser to the compressed fuel.
- Cone tip physics is complicated and extremely important to FI.
- Transport from the source (high Z cold Au) into solid density PLASMA targets is not well understood - current experiments are mostly performed with cold solid targets.

Two experiments have been performed to study cone plasma interface effects and transport in warm dense plasma

Experiment on Titan laser

SP: 150 J, 10μm spot, 0.7ps

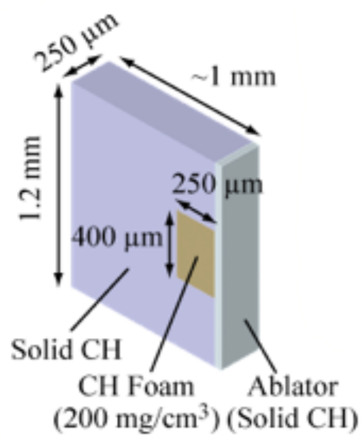
Foam package target:
Au/CRF (W:600μm, H:1mm)
Cu/25CH/0.1Al (2 mm by 2 mm)

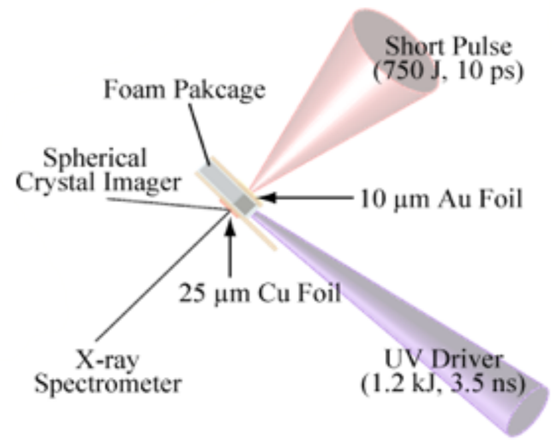


LP:**300 J**,600μm spot, **3 ns**

Experiment on OMEGA EP laser

SP: 800 J, 40μm spot, 10 ps





LP:**1250 J**,100μm spot, **3.5 ns**

- **On Titan laser, foam was shock compressed and heated with 300 J, 3 ns laser**
  - 1.3 g/cc, 5-10 eV, 15 μm thick (rad-hydro calculations)

- **On OMEGA EP, the foam was shock heated with 1.2 kJ, 3.5 ns laser pulse**
  - ~150 (50) mg/cc, 40-50eV, 360 μm thick (rad-hydro calculations)

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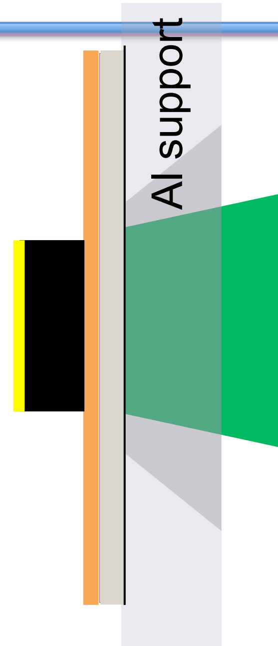
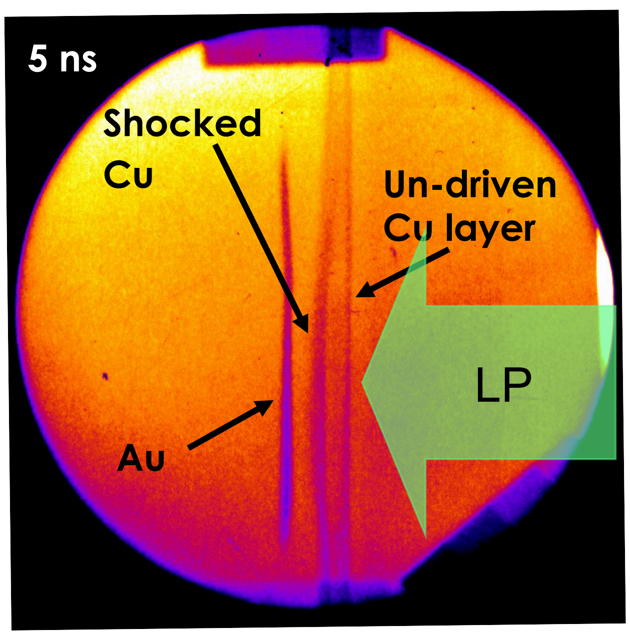
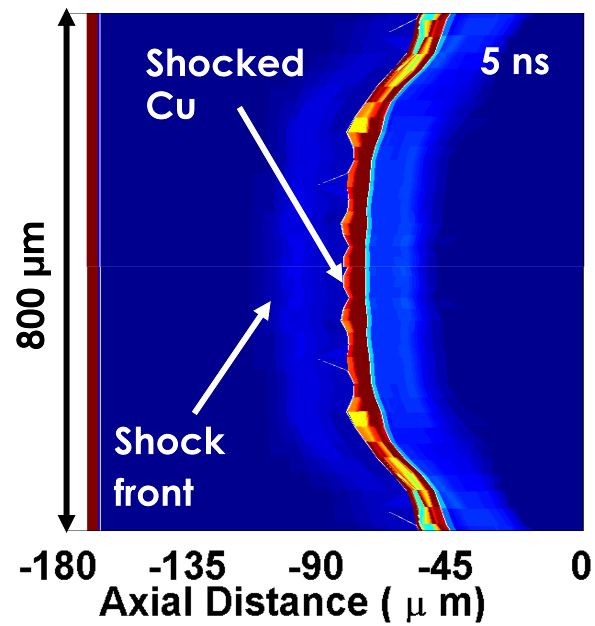
Radiography data and h2d rad-hydro simulations show shocked Cu propagation in foam targets

Foam package target:
Au/CRF (W:600μm, H:1mm)
Cu/25CH/0.1Al (2 mm by 2 mm)

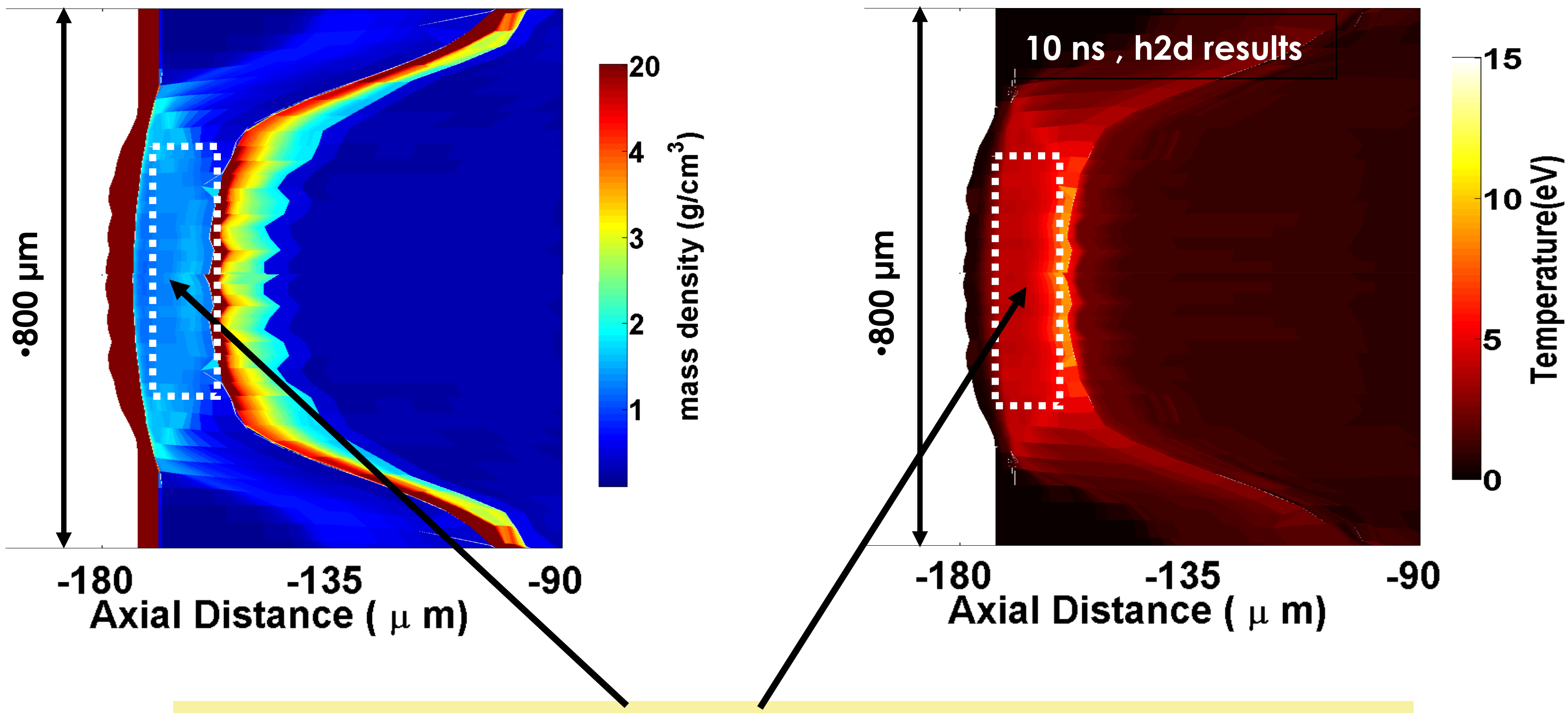


LP:**300 J**,600μm spot, **3 ns**



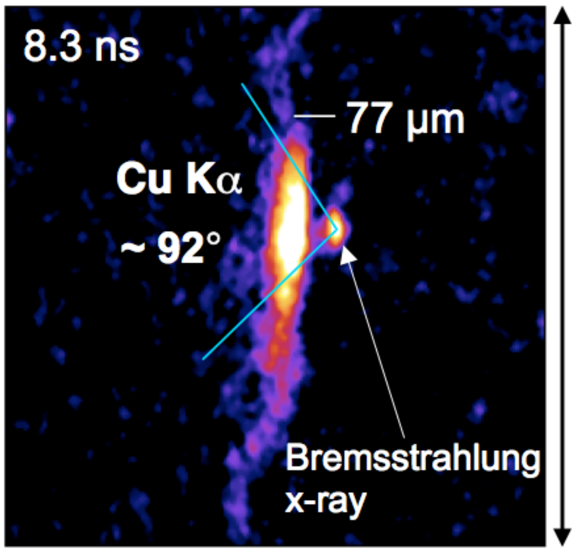


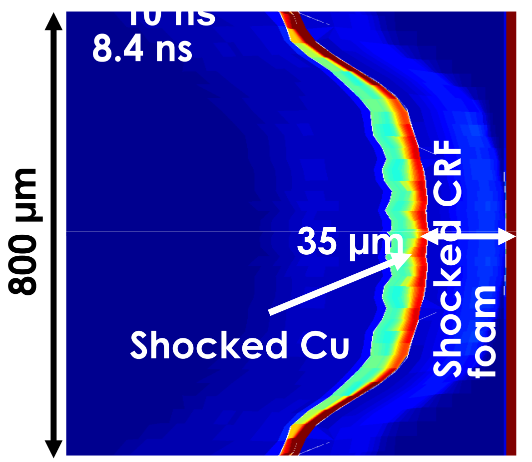
h2d rad-hydro simulations suggest WDM parameters of a few eV and 1.3g/cc at the maximum compression

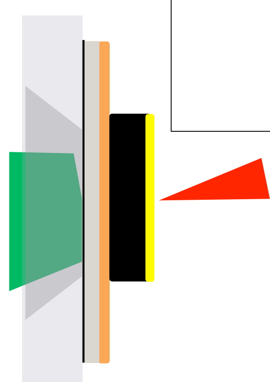


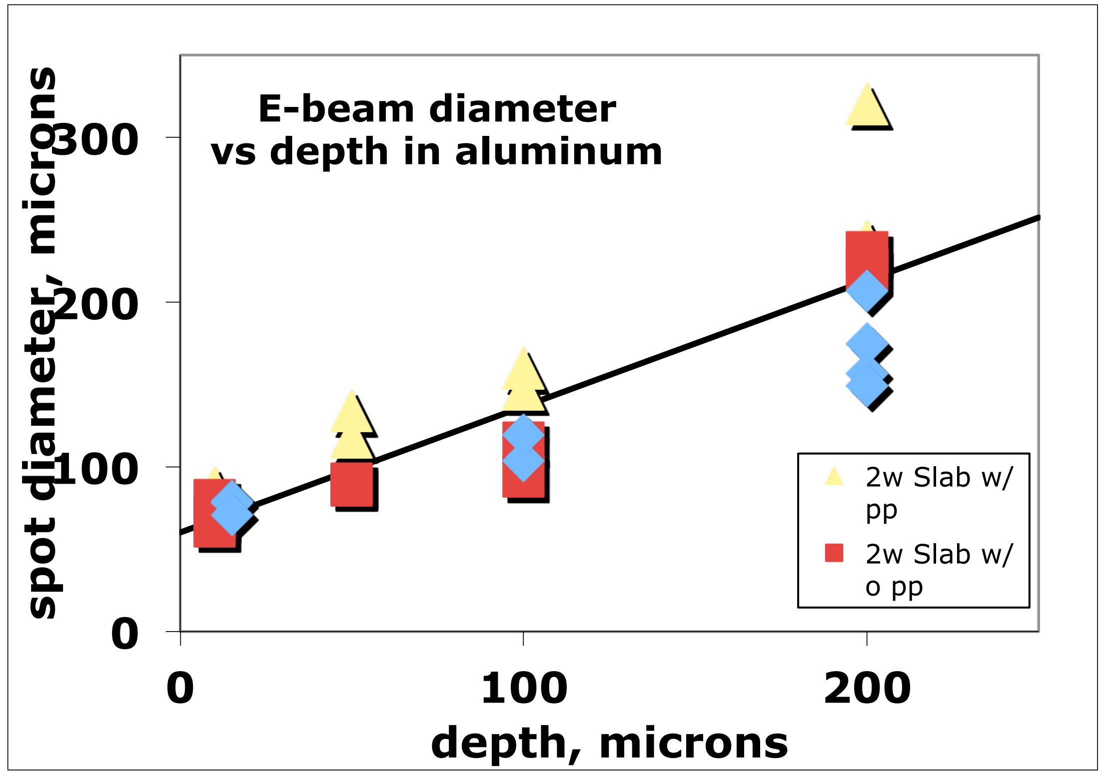
Region of interest at maximum compression: ~ 1.3 g/cc, 5-10 eV, ~15 µm thick and ~400 µm in height

Large extended Cu Kα spot was consistently observed in WDM targets suggesting a large angular spread of fast electrons









R.Stephens *et al.*, Phys. Rev. E 69, 066414 (2004)

SP only or LP only or LP+SP (with 3ns delay) shots did NOT produce such a large extended spot in the same type of foam package targets

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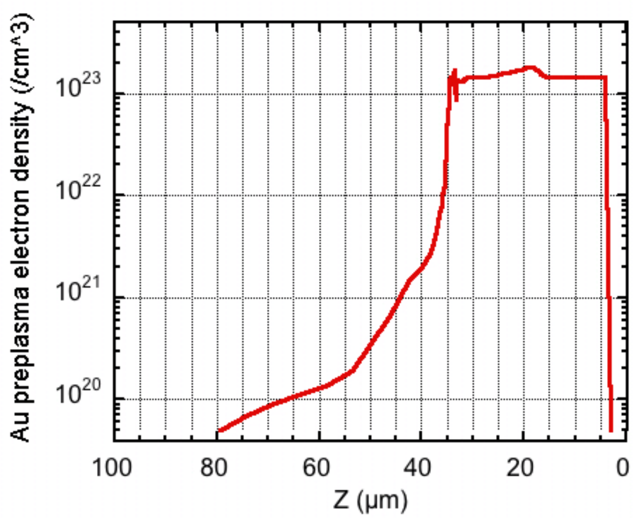
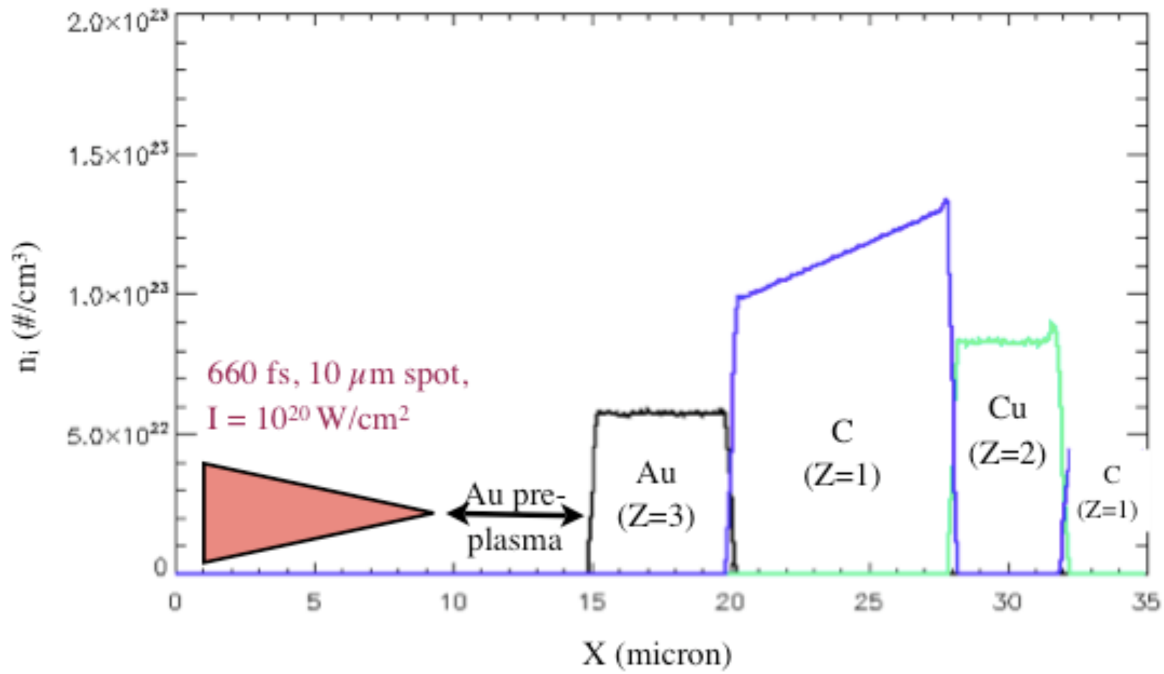
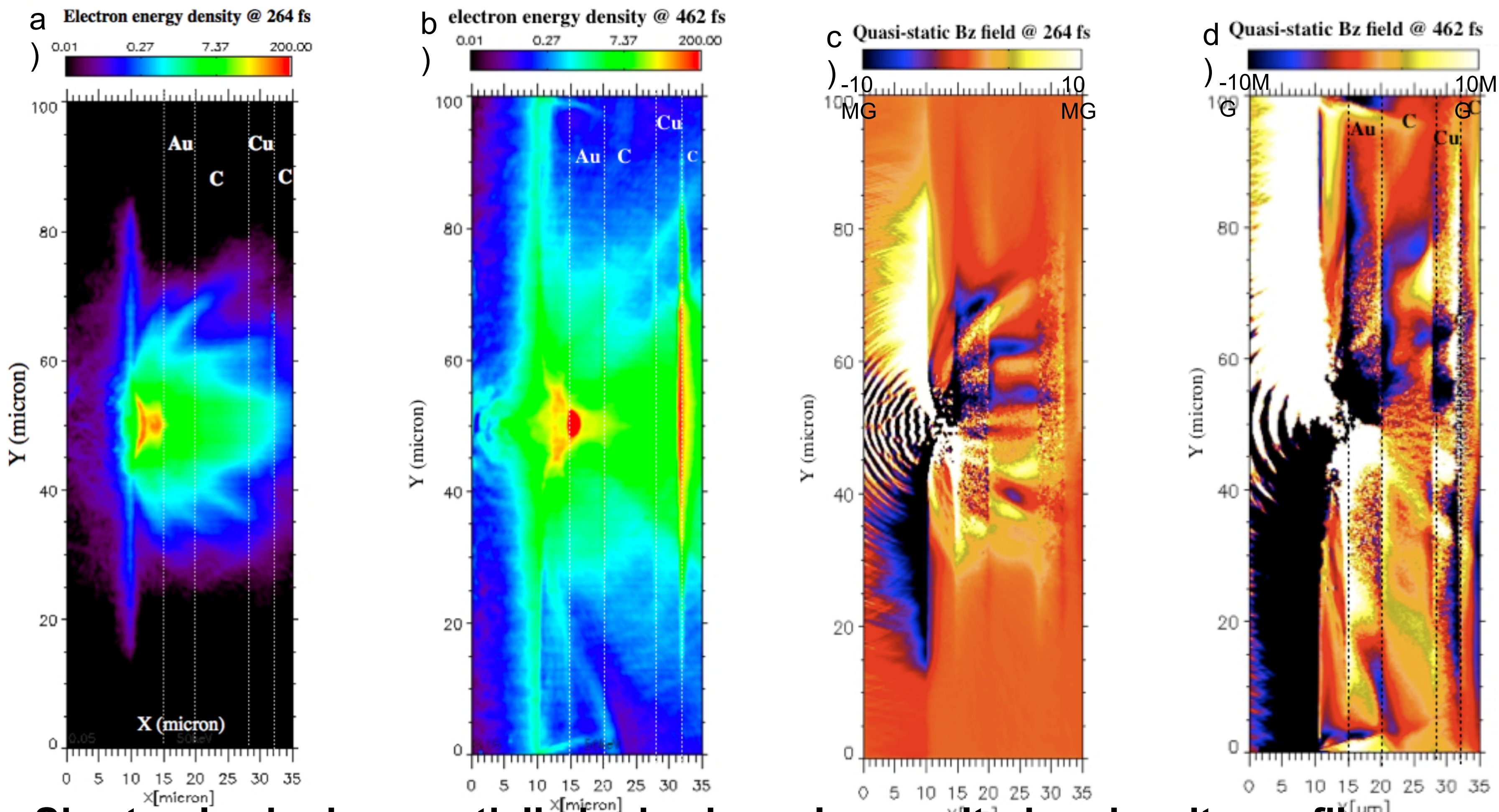
PIC code PICLS has been used to validate experimental observations





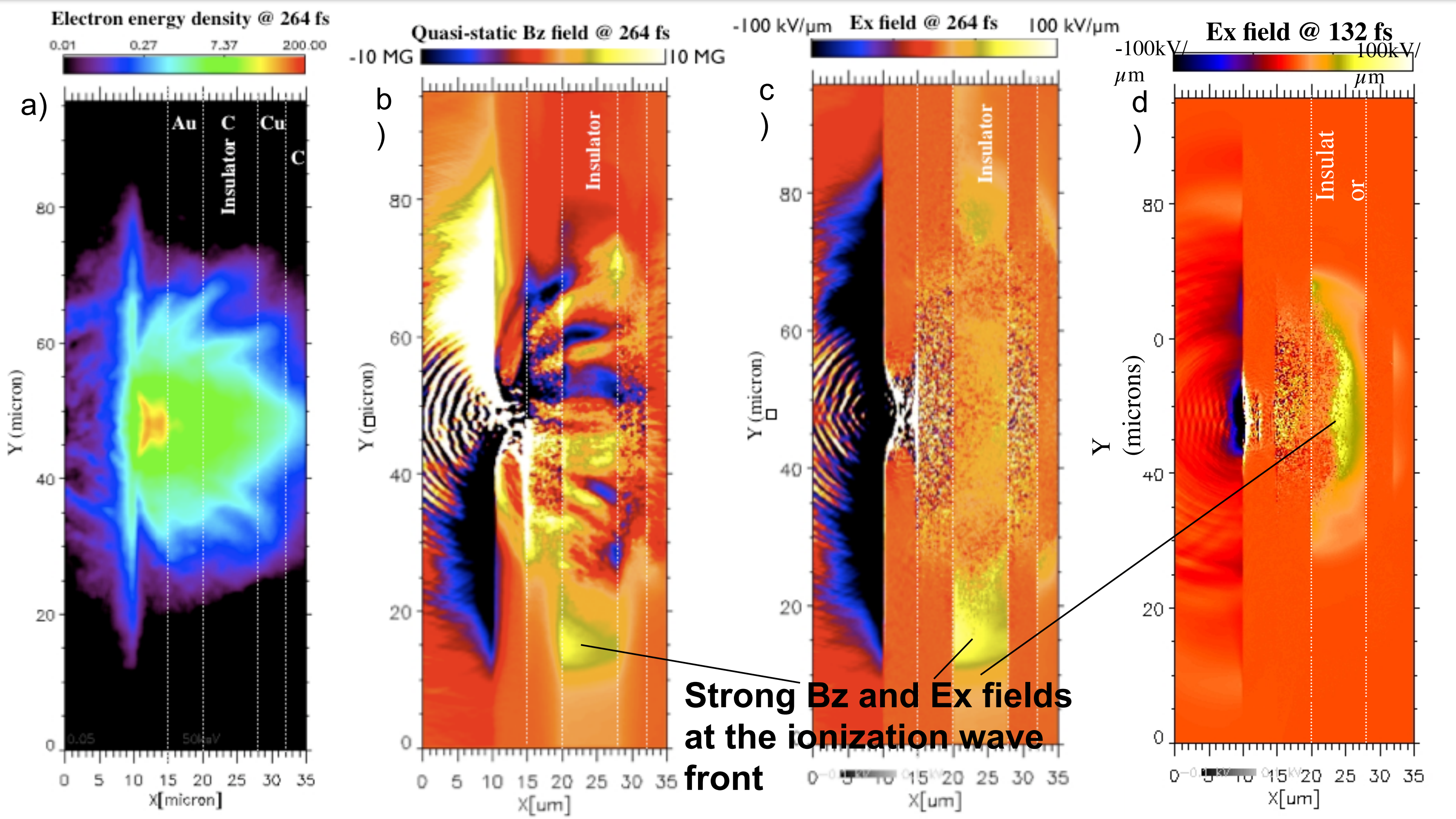
- Gold preplasma due to intrinsic prepulse (2.5 ns, 17 mJ) was simulated with Hydra.
- Initial target conditions are obtained with rad-hydro h2d code.
- In experiment, a large pre plasma was created, only 5 μm was considered in modelling.
- PIC simulations were performed in Cartesian coordinates.
- Collisions and dynamic ionization were included.
- Absorbing boundaries were used to avoid refluxing.
- Two cases were considered: partially ionized dense plasma and an insulator for middle layer.

PICLS simulations show a large fast electron divergence in dense plasma target originating from laser plasma interaction



- Short pulse ionizes partially ionized preplasma altering density profile.
- Ponderomotive pressure bow shapes interface resulting in a wider divergence of fast electrons at their birthplace consistent with experimental observations.
- Resistive filamenation occurs inside overdense plasma.

Transport in insulator target is dominated by ionization front

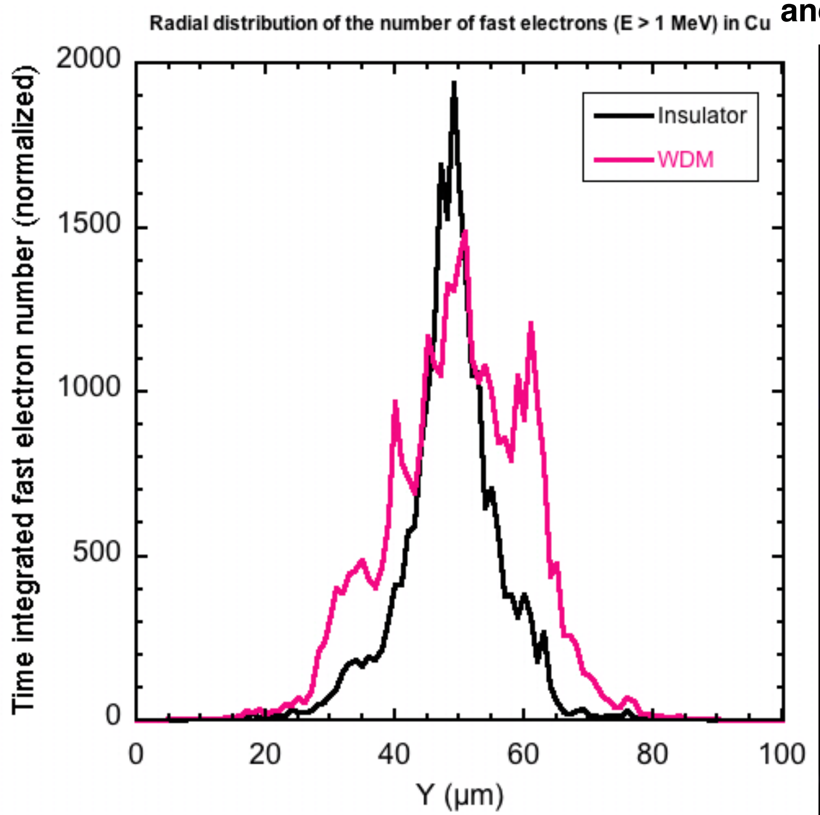


- Strong electric and magnetic fields are observed at the ionization front.
- Magnetic field at the front deflects fast electrons towards center.

B. Frolov, S. Krasheninnikov, A. Kemp, T. Cowan, New J. Phys 8, 134 (2006)]

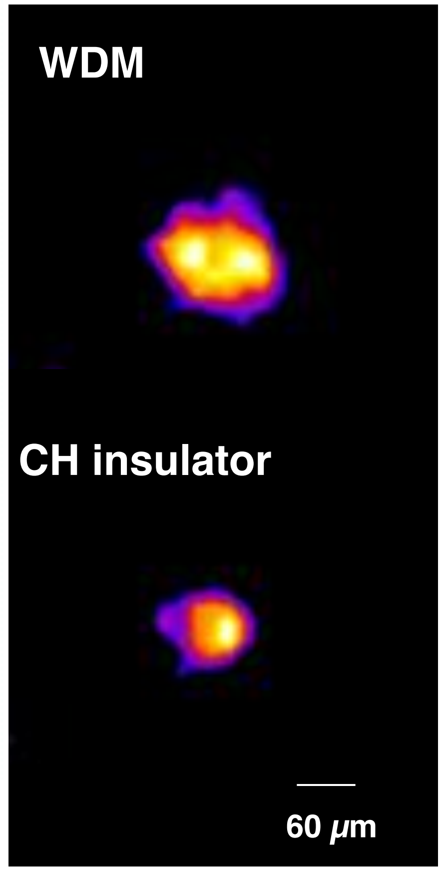
Spatially broader fast electron radial distribution in the WDM case compared to the insulator transport medium

PICLS results

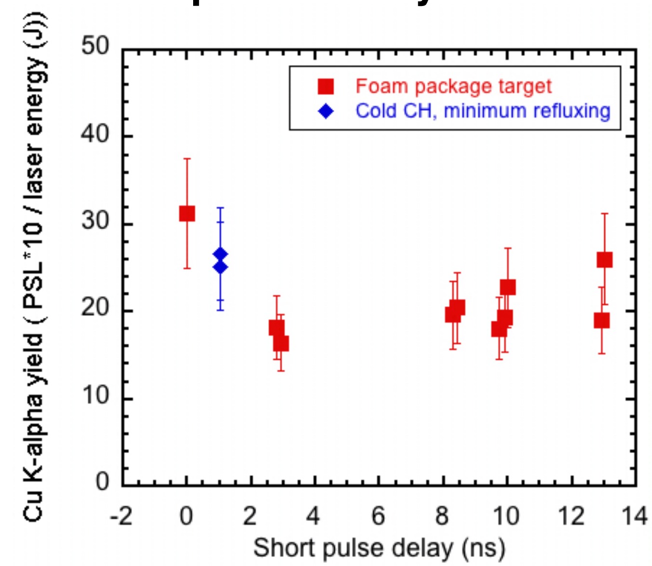


Exp: Kα spot size from the rear imager

Same spatial scale,background subtracted and the signal normalized to the peak value



Exp: total Kα yield



- **PICLS simulations show similar fast electron number counts in the Cu layer, but with a broader radial distribution in the WDM compared to the insulator case**
  - **– consistent with the experimental observation**

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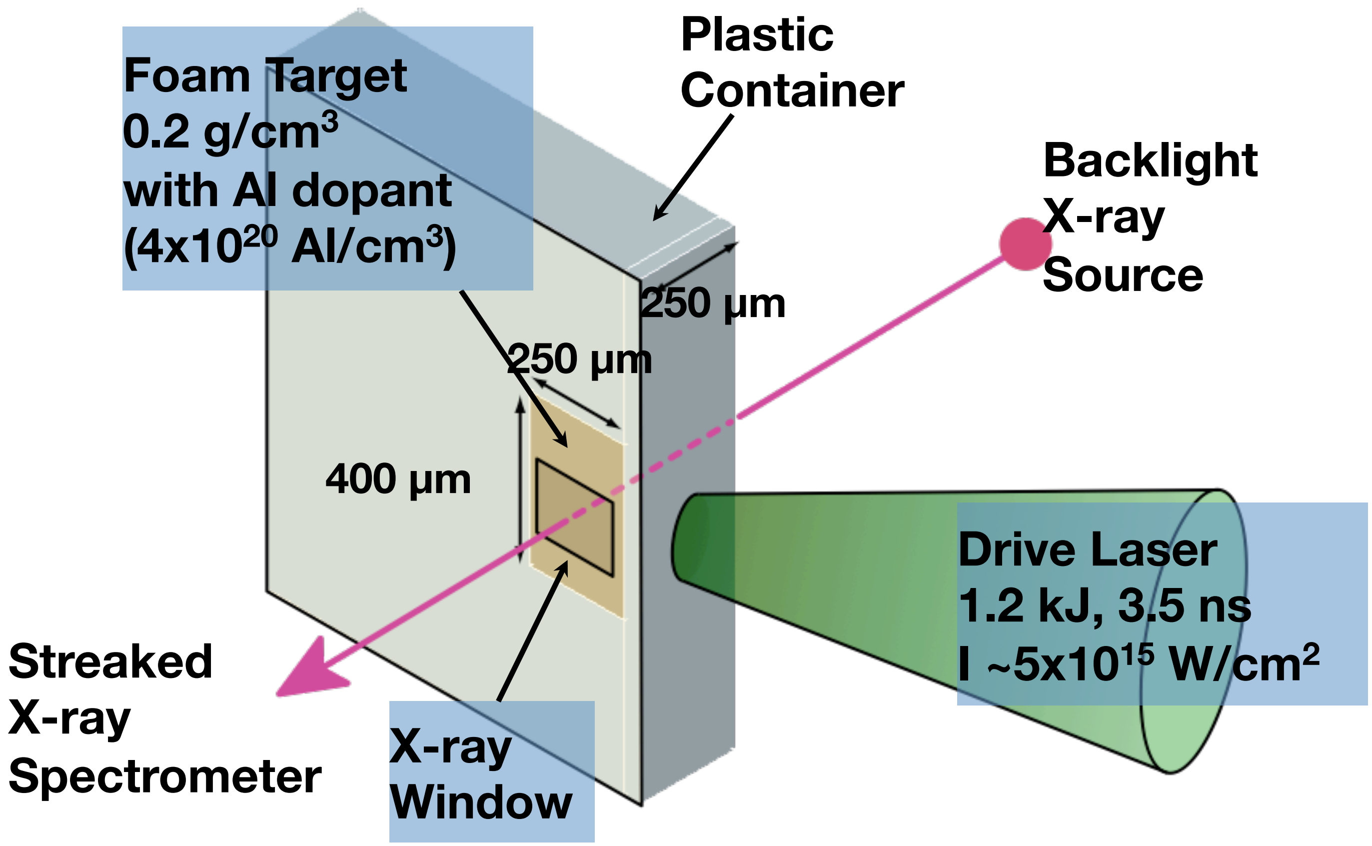
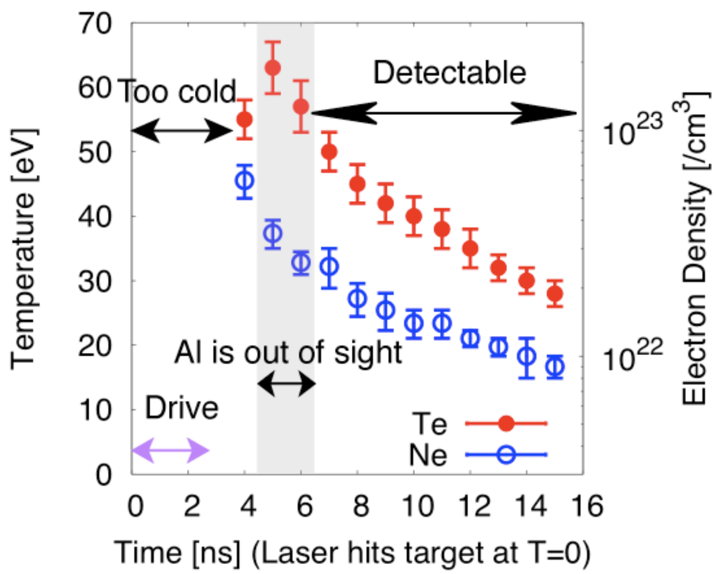
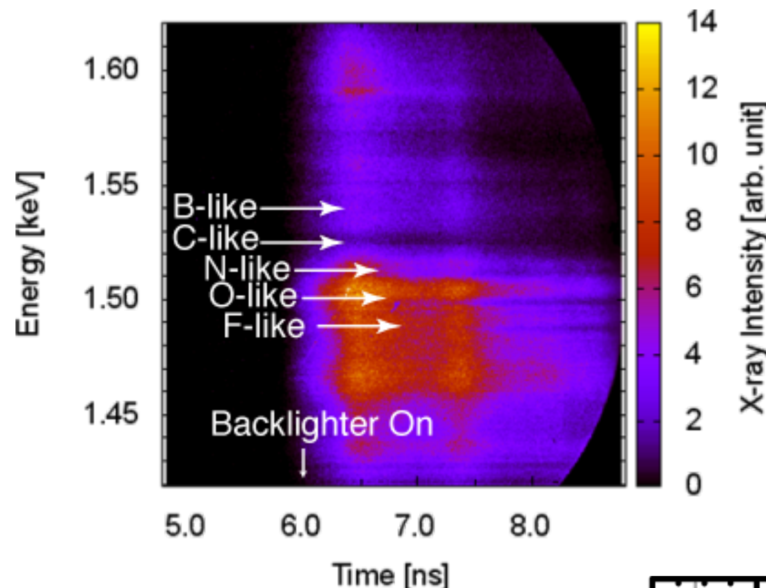
Large volume warm dense plasma was created and characterized at OMEGA EP

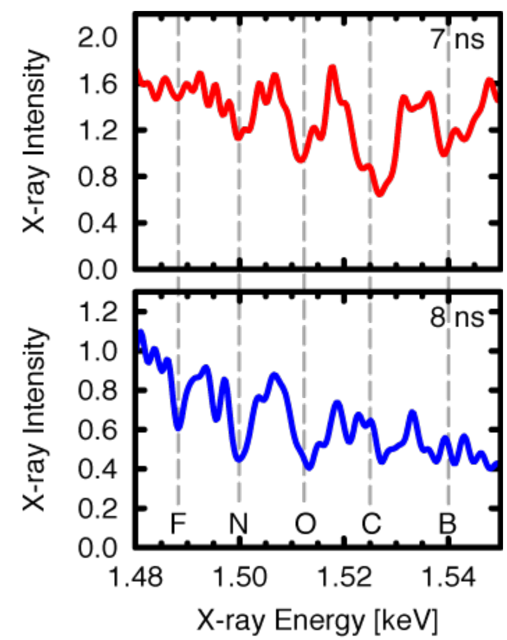


- Absorption spectroscopy was used to extract temperature from aluminum doped foam using Sm backlighter.

A large volume, 40 eV plasma was created

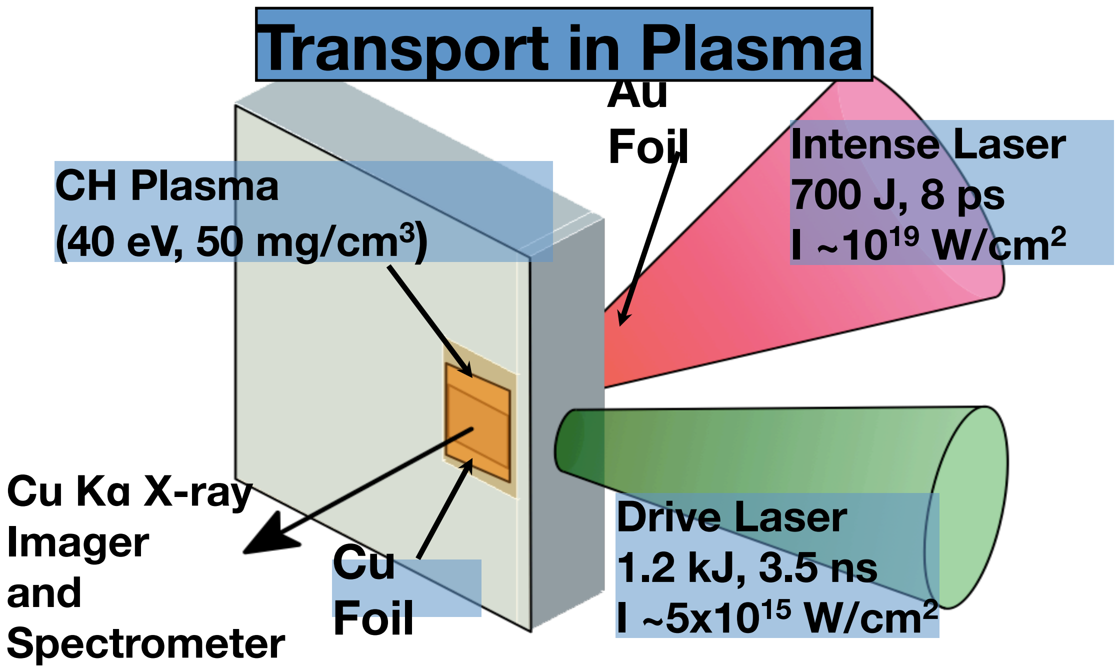






- **Rad-hydro calculations using DRACO code shows temperature of 40-50 eV and density of 150 mg/cm^{-3}.**
- **Suitable conditions for absorption spectroscopy after 6 ns.**
- **X-ray streak clearly shows absorption lines after 6 ns from drive good agreement with modeling prediction. However, the density was lower than predicted.**

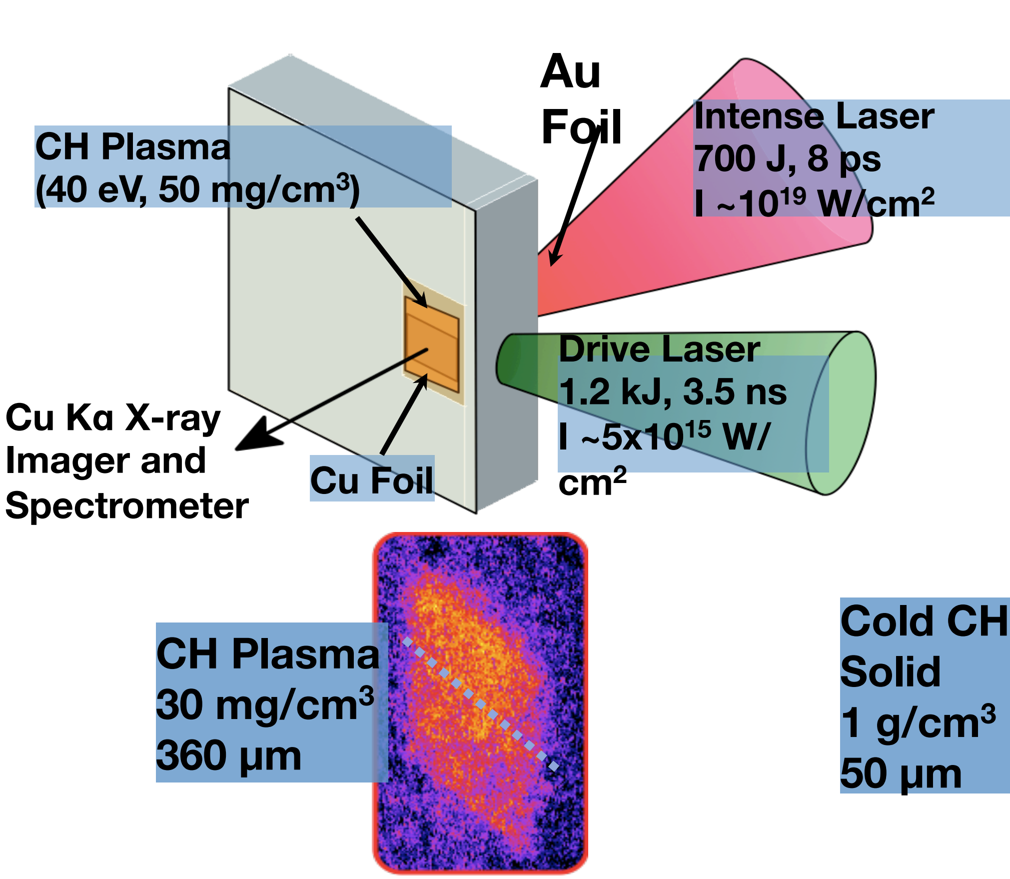
Fast electron transport was studied in ~40 eV plasma with 750 J/10 ps laser pulse



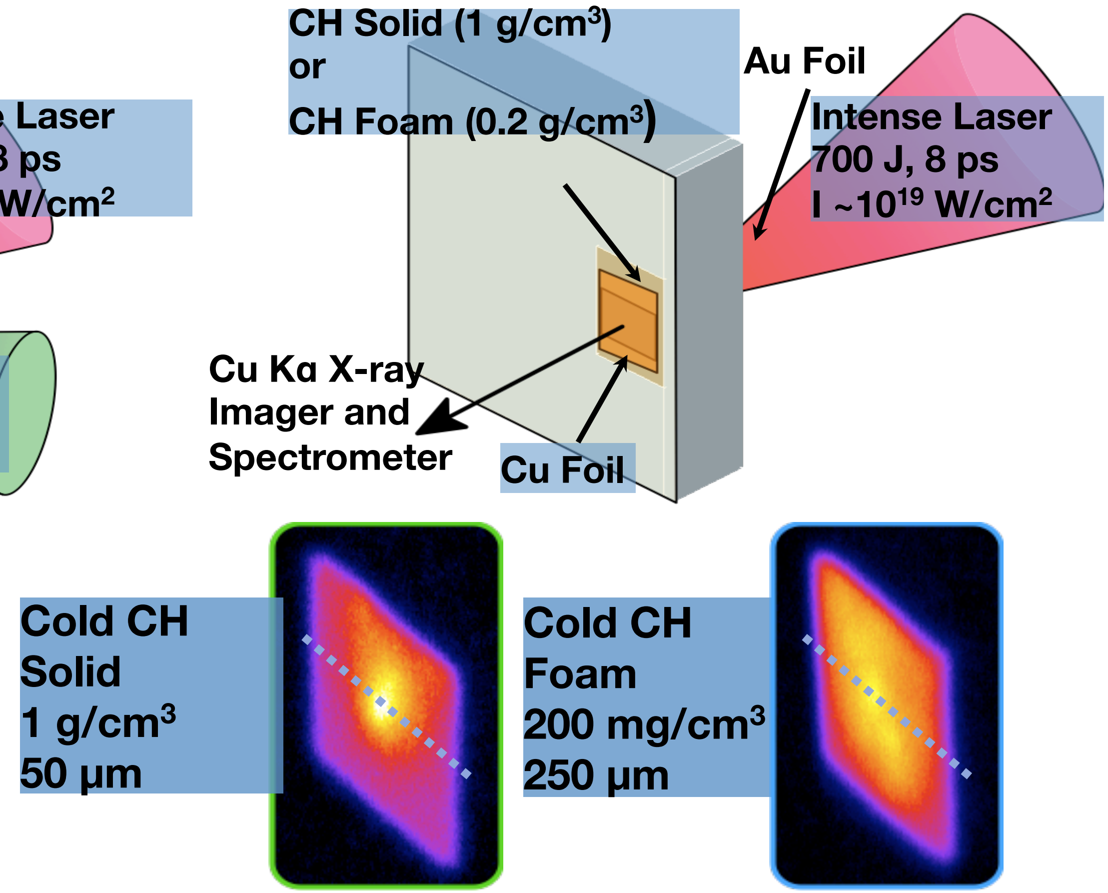
- Short pulse laser was focused onto gold foil with energies of 750 J in 10 ps pulse duration.
- Kα emission from Cu foil due to fast electrons after they propagate in characterized WDM was monitored with a crystal imager and a spectrometer.

Fast electron transport has been studied in the characterized plasma

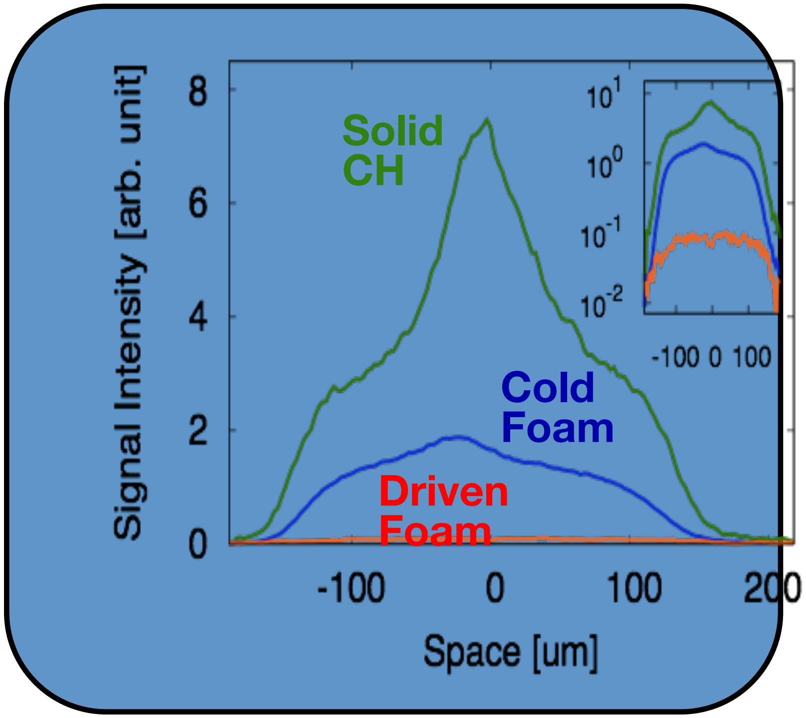
Transport in Plasma

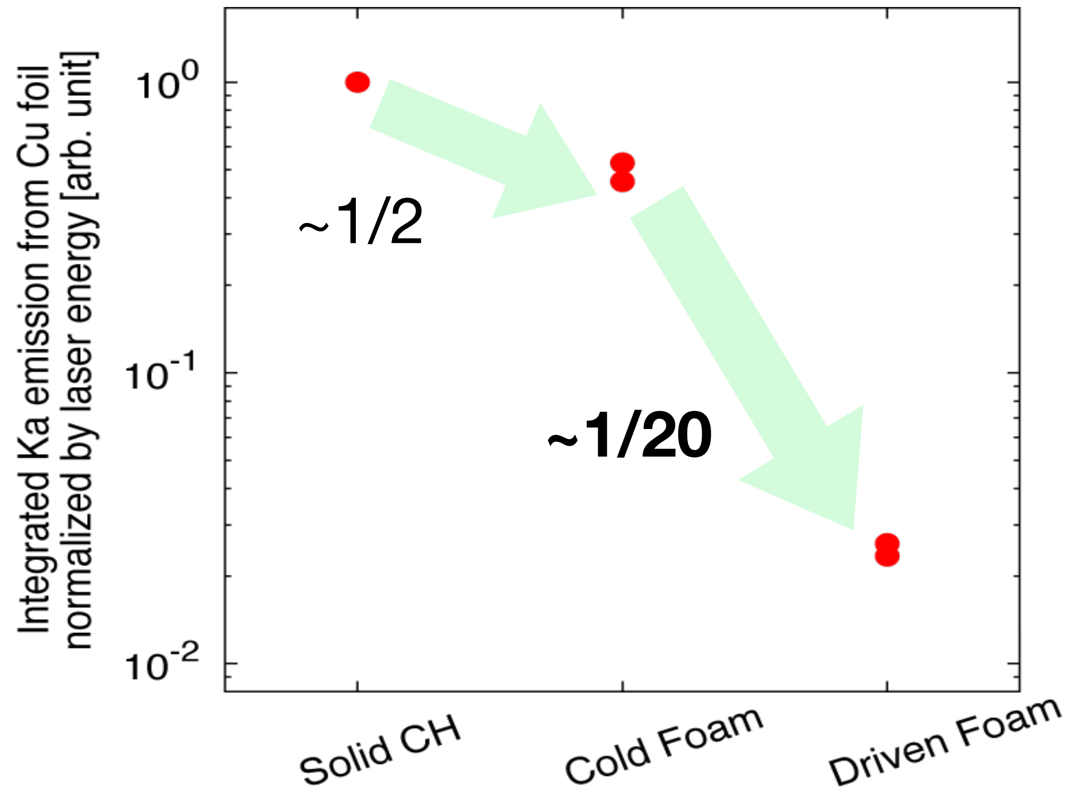


Transport in Cold Targets



Significant signal reduction between cold and driven foams



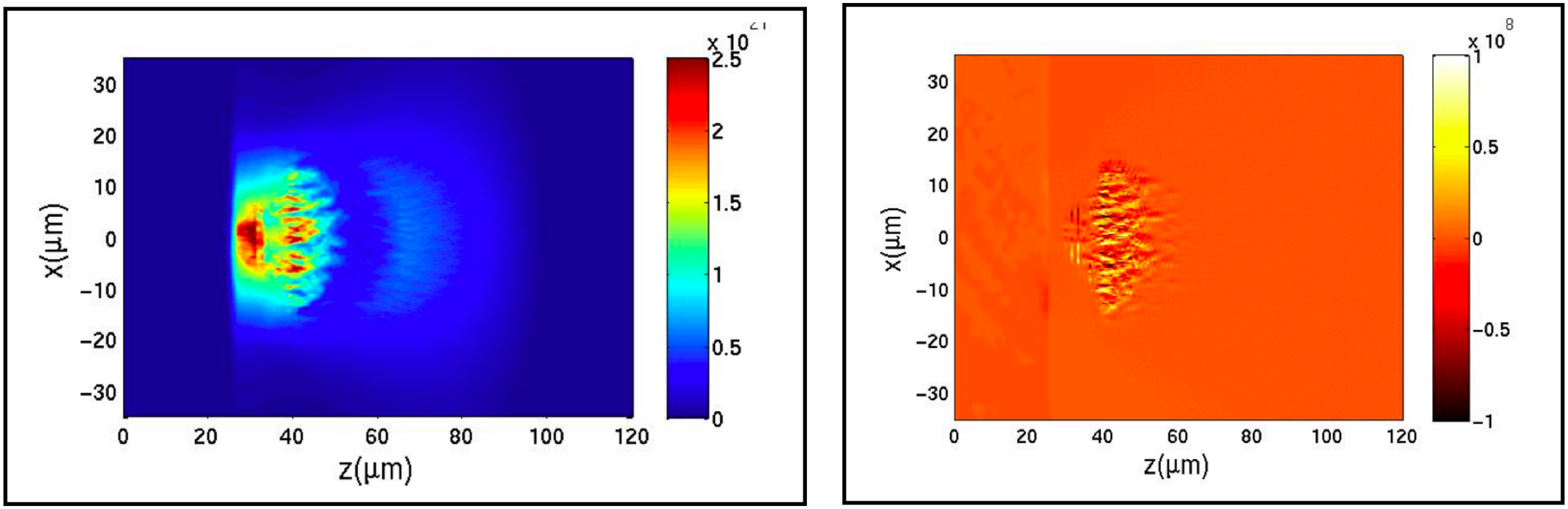


- **Assuming ~100˚ divergence in driven foam case, the solid angle of Cu foil can cover 20% of the electron beam, which means 5x smaller signal. However, reduction is 20x, which gives divergence of 160⁰.**
- **Fast electron stopping in foam is likely reason being investigated using**

  LSPmodeling

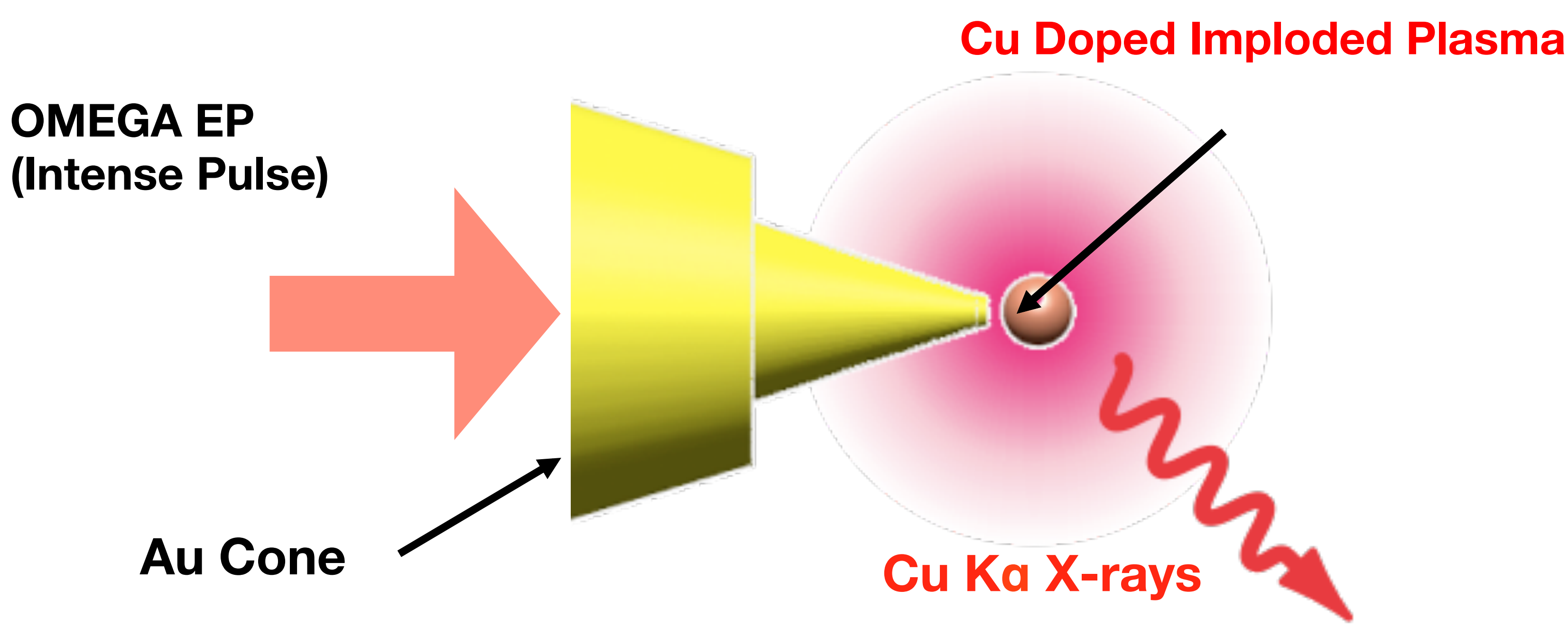
Preliminary LSP simulations show strong Weibel magnetic field stopping the fast electrons in the target

0.25 ps



- **Electron beam is injected in a plasma slab of 10 μm with a density of $5x10^{22}$ cm^{-3}, which decreases linearly to 10^{22} cm^{-3} over 5 μm and then stays constant at Z>40 μm**
- **The beam becomes Weibel unstable generating strong magnetic fields inhibiting the transport of electrons.**
- **Simulations breakdown at 0.35 ps.**

Future Work: Electron transport will be studied in FI relevant Plasma on OMEGA



- Fast ignition relevant plasma (~ 1 keV and ~ few 100's g/cm^3) will be created by the implosion using OMEGA long pulses (54 beams).
- Cu dopant in the shell will provide information of fast electron spatial distribution and coupling efficiency in the imploded plasma.
- To date, all we can do is to measure plasma temperature from neutron spectrum.

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Summary

✓ We have successfully created two conditions (1.3 g/cc and 5-10 eV, 50 mg/ cc and 40 eV)) for electron transport study by shock compression and heating of foam targets.

✓Fast electron transport through Au foil into fully shocked foam shows a large angular spread (~ 100°).

✓ PICLS code shows a large divergence of electrons originating from the LPI region due to the deformation of interacting surface by ponderomotive pressure.

✓ In insulator targets, fields created at the ionization front deflect the electrons to the center.

✓ Large volume plasma on EP laser shows significant spreading of fast electrons and low coupling due to stopping in foam.