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High Energy Electron Transport in Solids

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High Energy Electron Transport in Solids

R.B. Stephens, General Atomics

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Biarritz, France

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IFT/P2005-082

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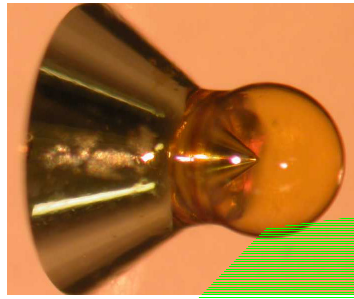
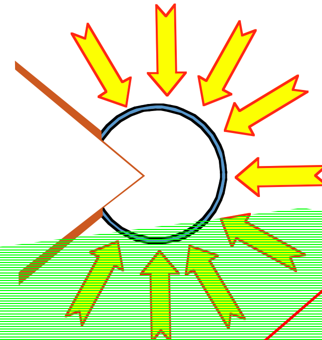
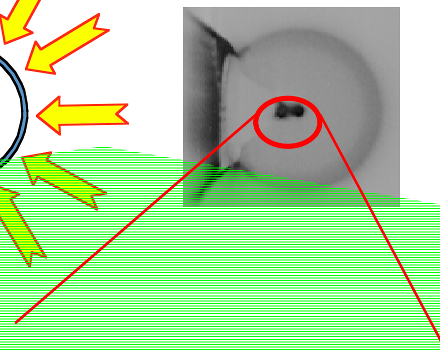
Studying transport for fast ignition application

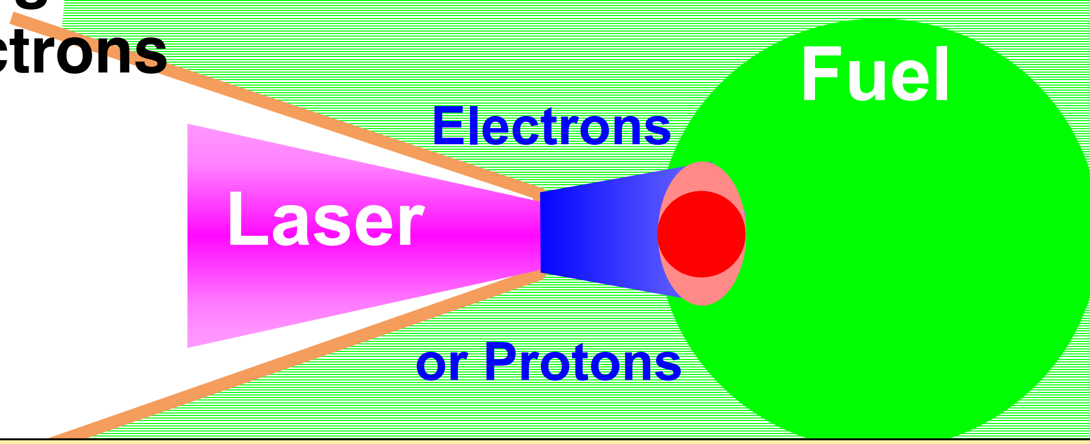
1) Drive lasers compress the fuel







2) A Petawatt laser generates energetic (MeV) electrons

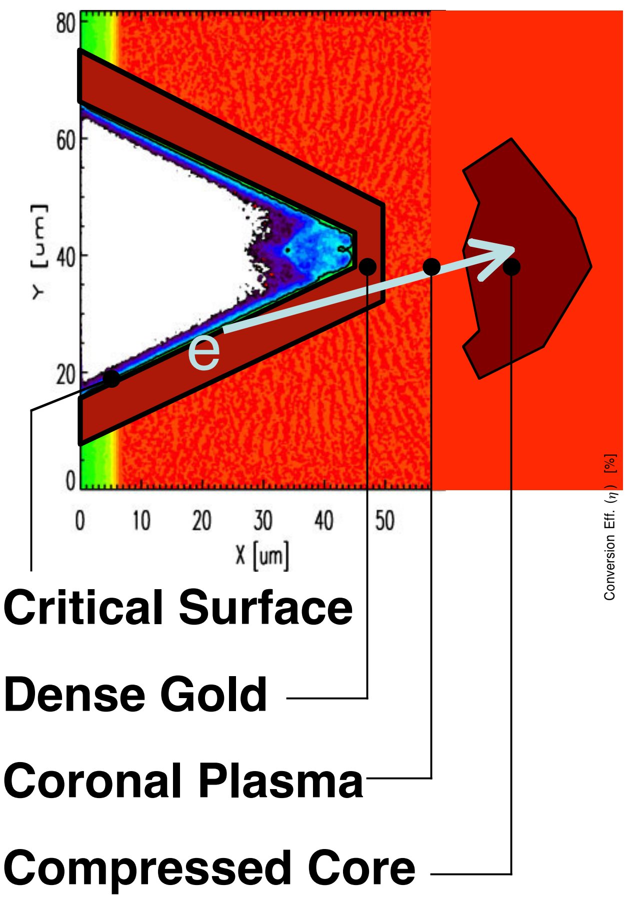


3) The electrons transport the ignition energy to the core

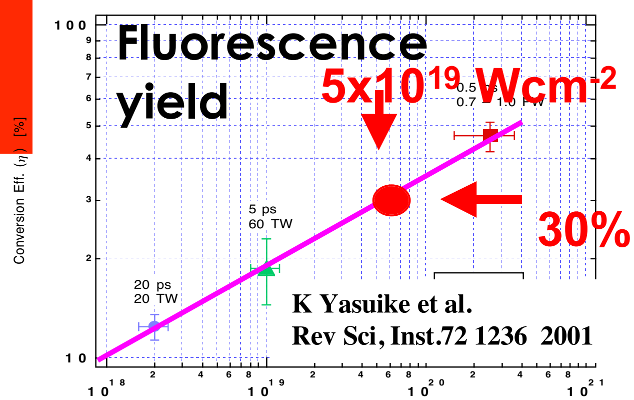
Experiments are approaching huge currents required

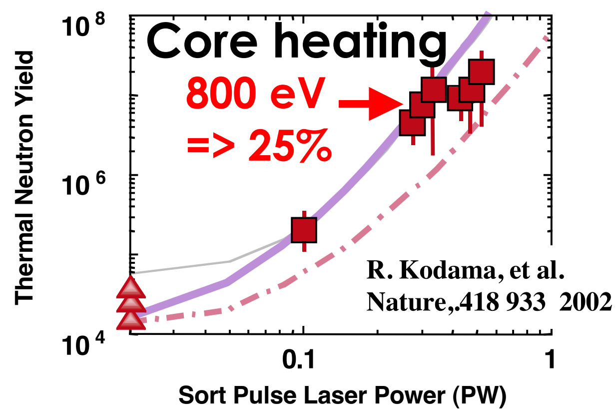
- Igniting 200 g/cc DT to 10 keV
- Requires 40KJ -> $2e^{17}$ e^- @1 MeV

$\Rightarrow$ 200 MA, 15 ps



- Energy conversion ~ 30% demonstrated





- With laser energy up to 300 J

$\Rightarrow$10-20 MA, 1 ps in our targets

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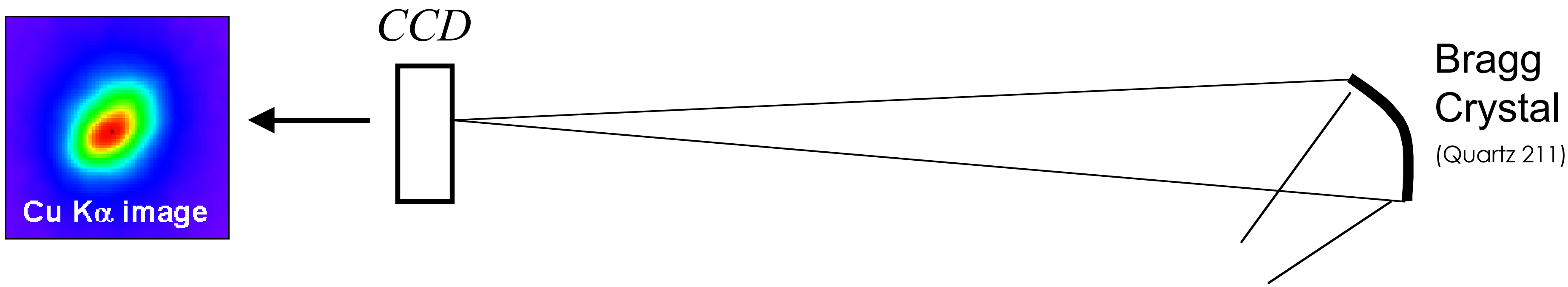
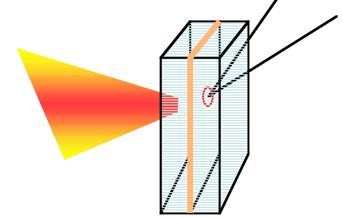
We use room temp metal to stand in for DT plasma

- **Cu-K_α fluorescence shows electron propagation**
  - A Bragg mirror images the fluorescence emission
  - Observe propagation in slab and wire geometries
- **Basic findings**
  - e^- spread is independent of energy
  - Energy deposition is proportional to energy
  - Propagation length is approx the same in all
  - Largest deposited energy requires corrections
    - Temperature reduces mirror efficiency
    - Resistance is limiting current
  - Indications of surface bottleneck?
- **Have developed new diagnostics to show local temperature, starting to give a handle on details.**

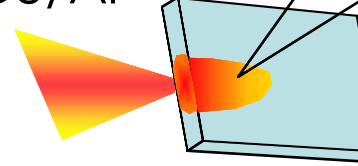
We use K_α imaging to see electron transport in Al

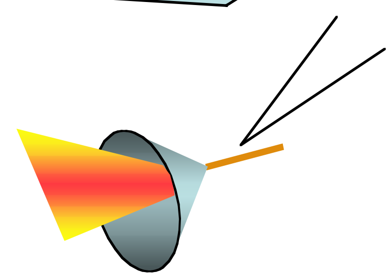


- **With Cu-K_α (8 keV) can see ~ 100 µm into Al**
- **Use three geometries**



  - **Buried layer**: cross section of prop in Al/Cu/Al
  - **Alloy**: Side view of prop thru Al:Cu
  - **Wire**: transport confined to Cu wire





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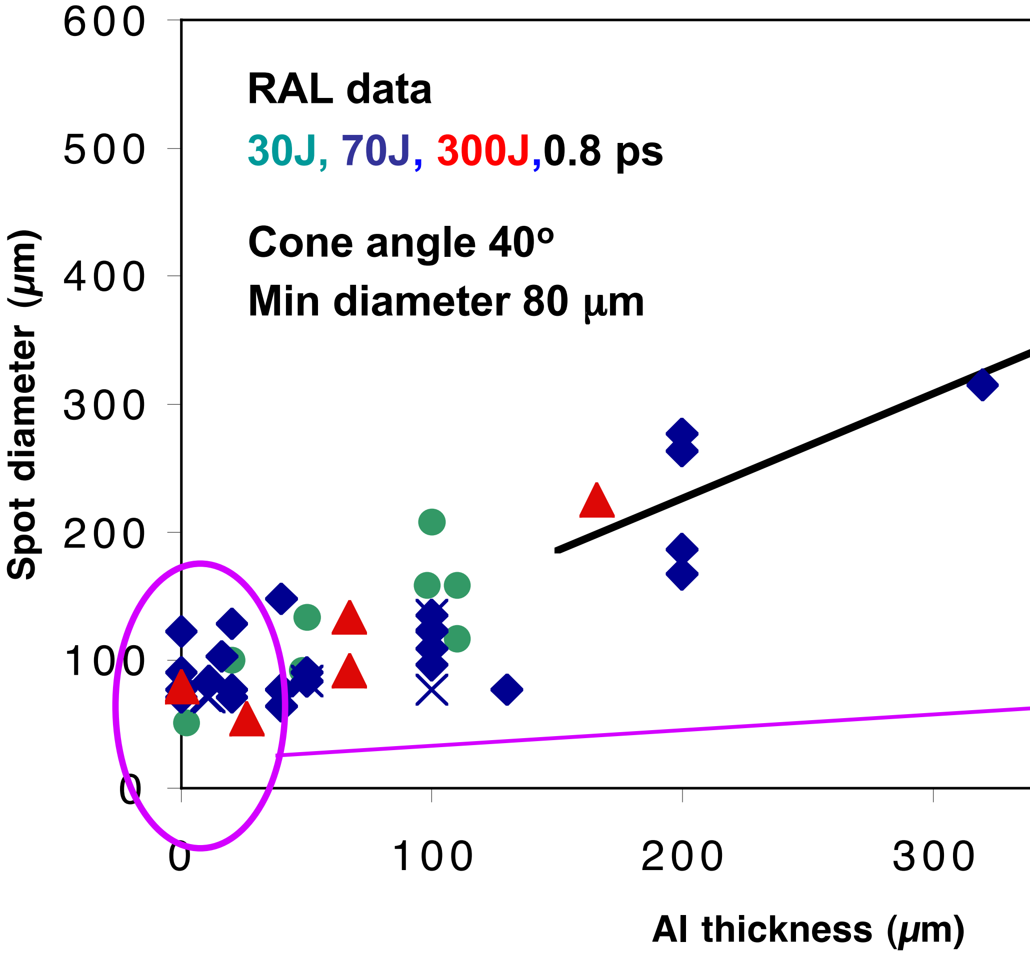
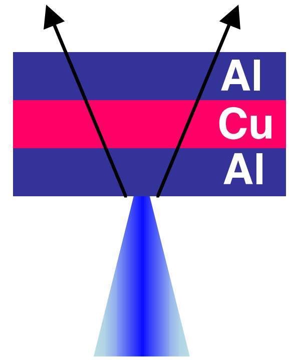
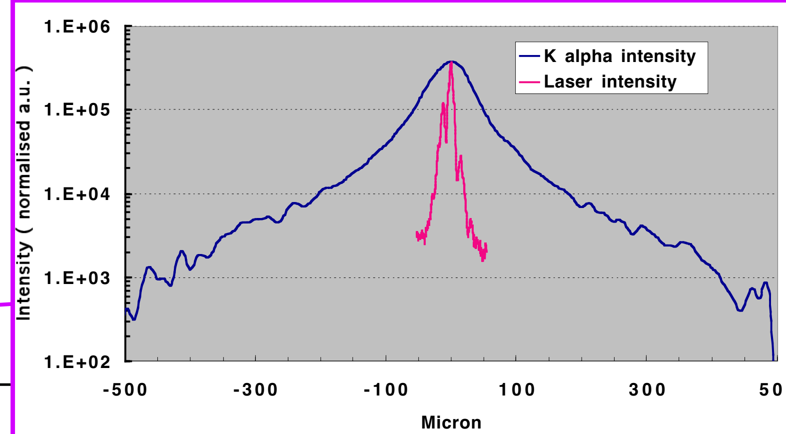
Electron beam spread in Aluminum is independent of energy (30J, 70J, and 300J)







Note initial spread -- starting spot size is ~ 5X laser spot size

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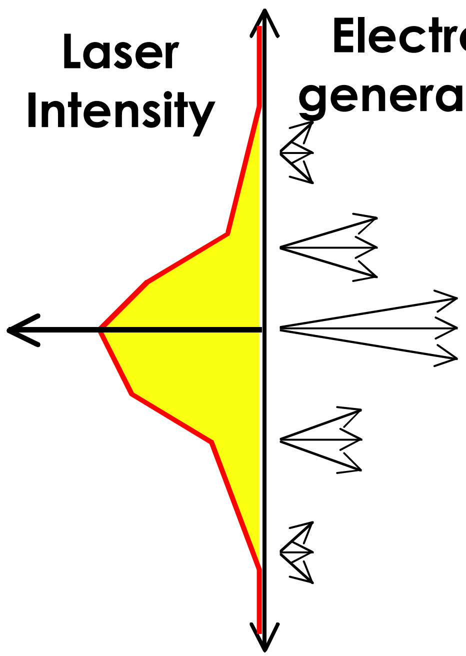
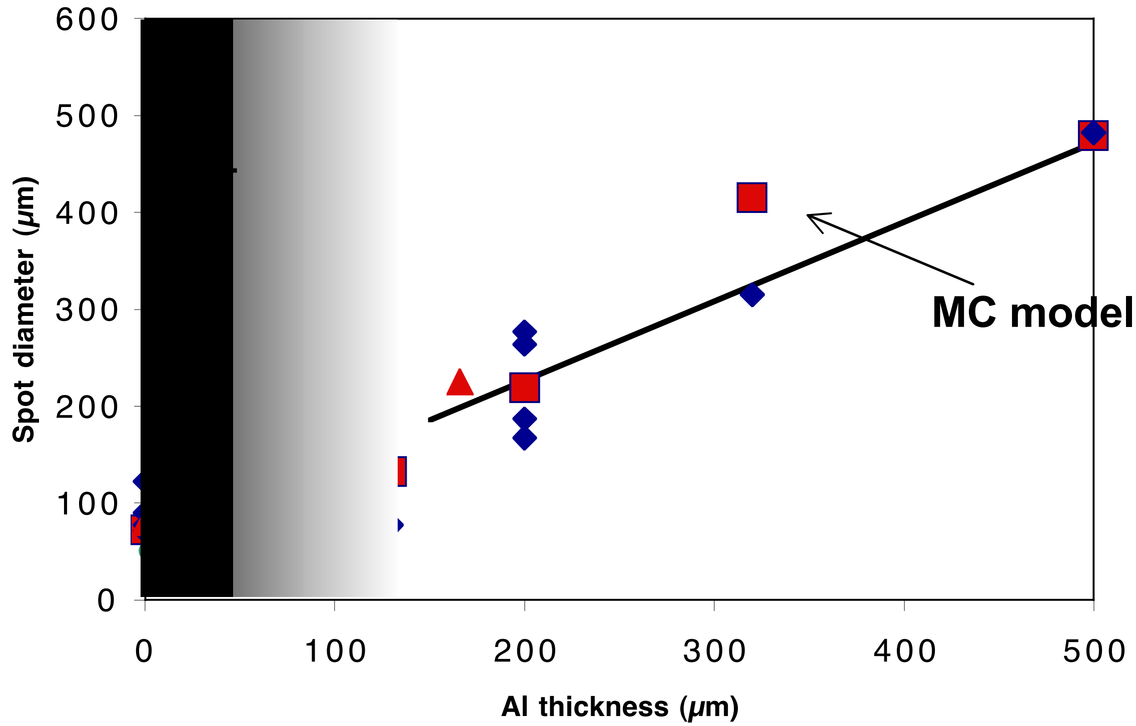
R Stephens et al. Phys Rev E,69, 066414 (2004)

Spread well described by heuristic Monte-Carlo model





- e^- generation efficiency & energy from local intensity (Beg scaling)
- Random transverse momentum independent of location

⇒ High energy e- are forward directed, low energy e- spread out

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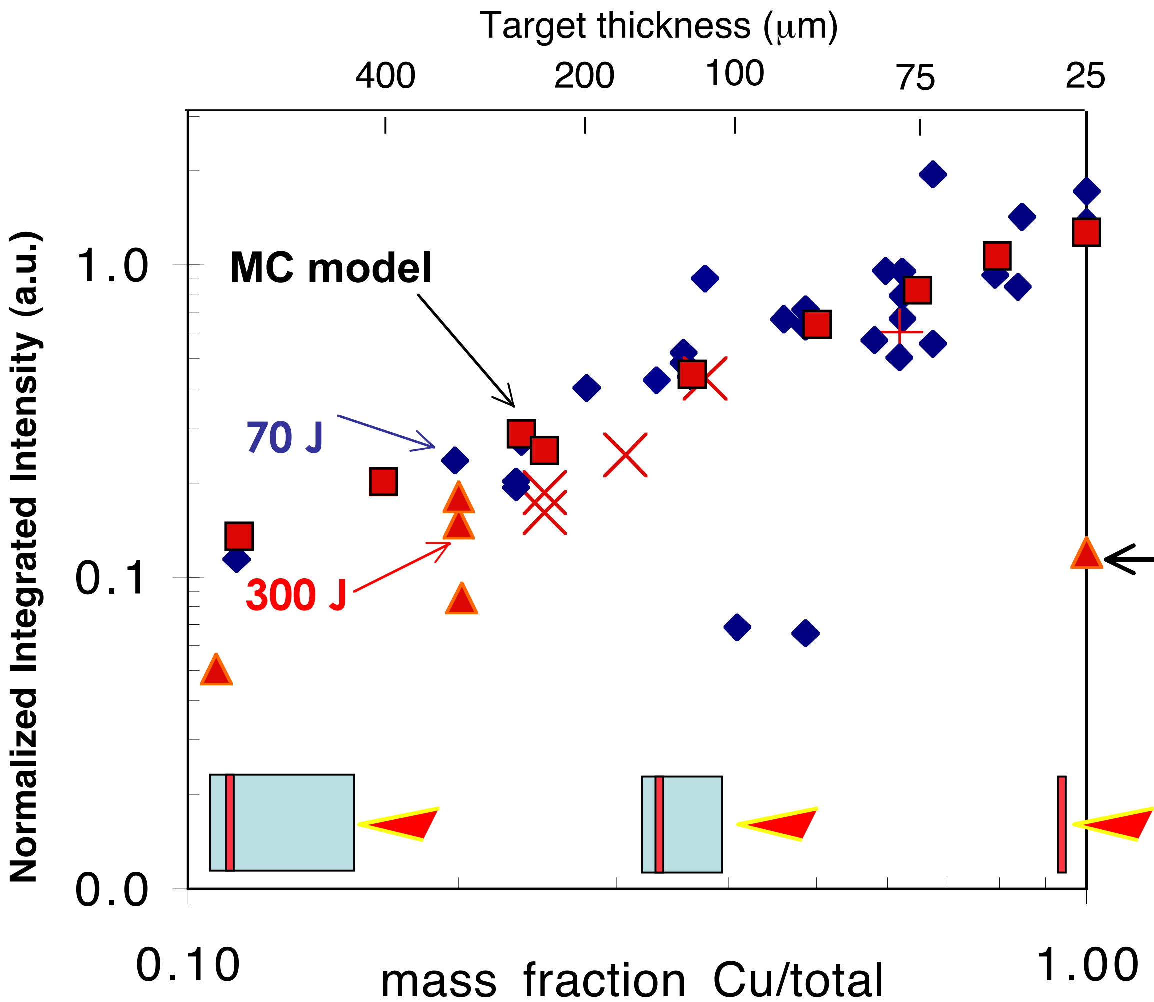
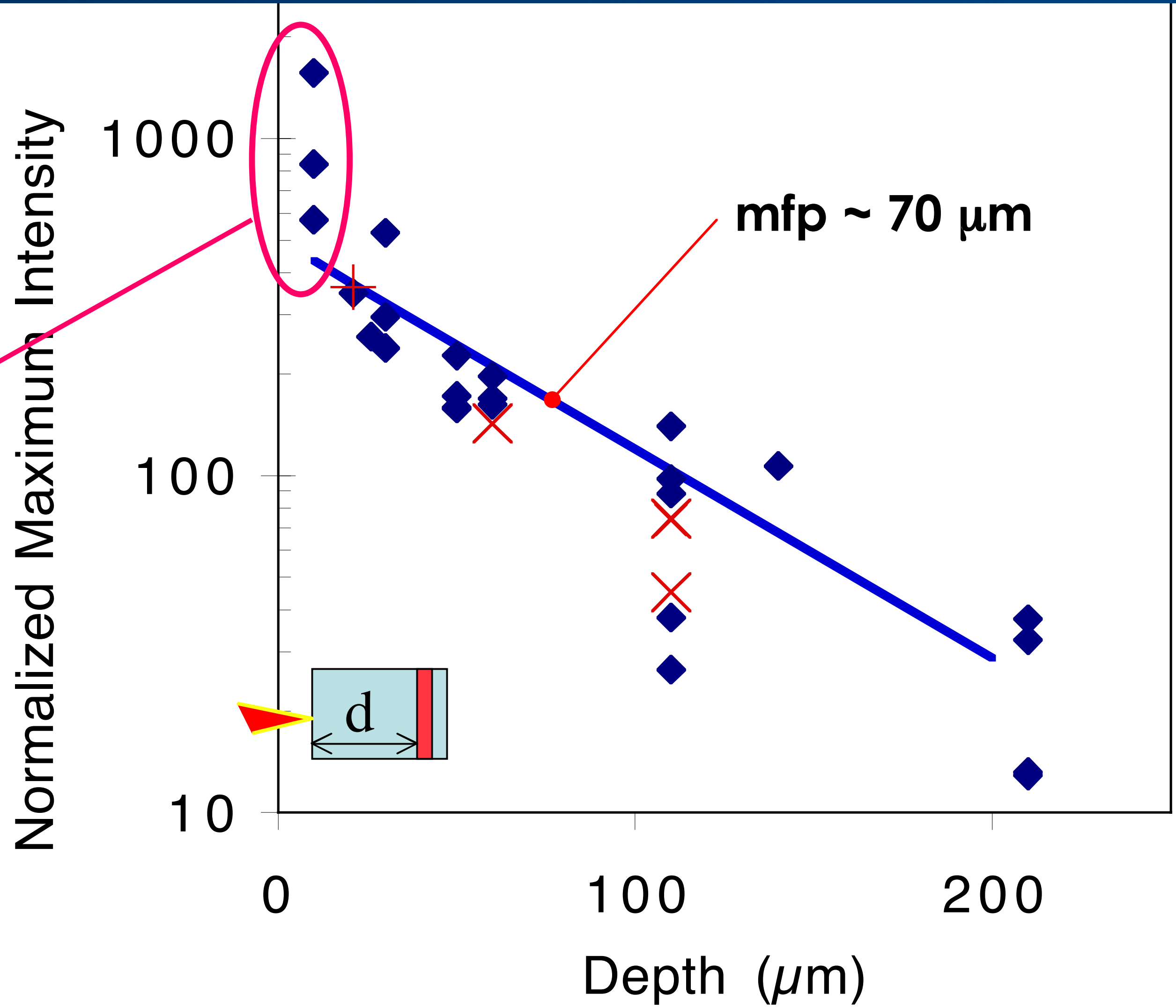
Fluorescence ∝ Laser energy and Cu fraction



Except for PW shot onto thin target

Fluorescence gets more complicated for high pulse energy

Propagation distance obtained from the peak K_α image brightness vs depth



Current seems to drop quickly near front surface

These are 70 J shots for which temp corrections aren't needed

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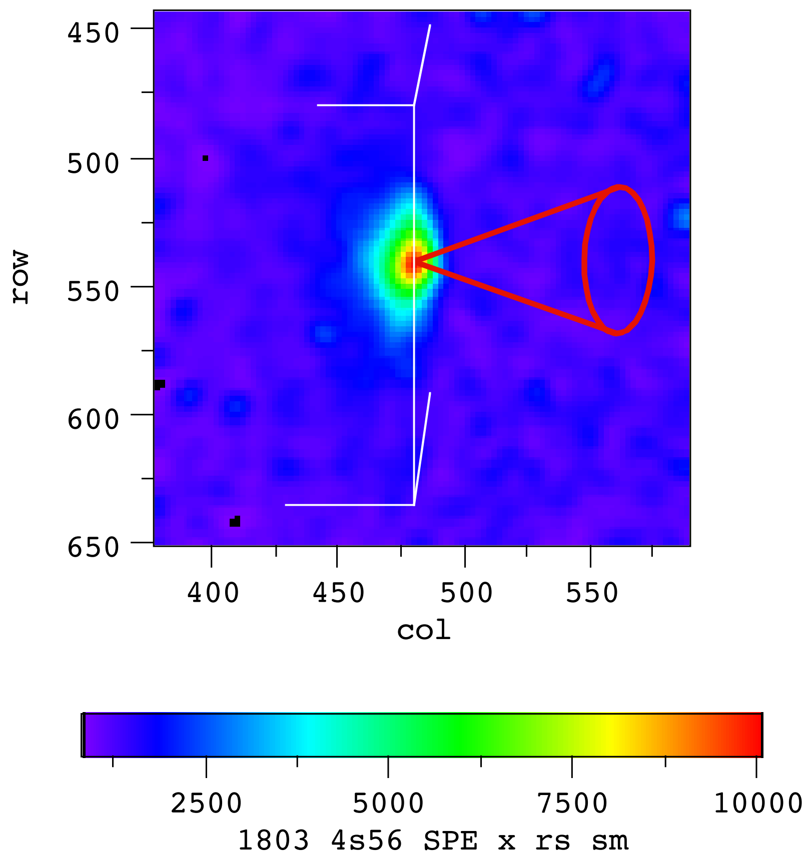
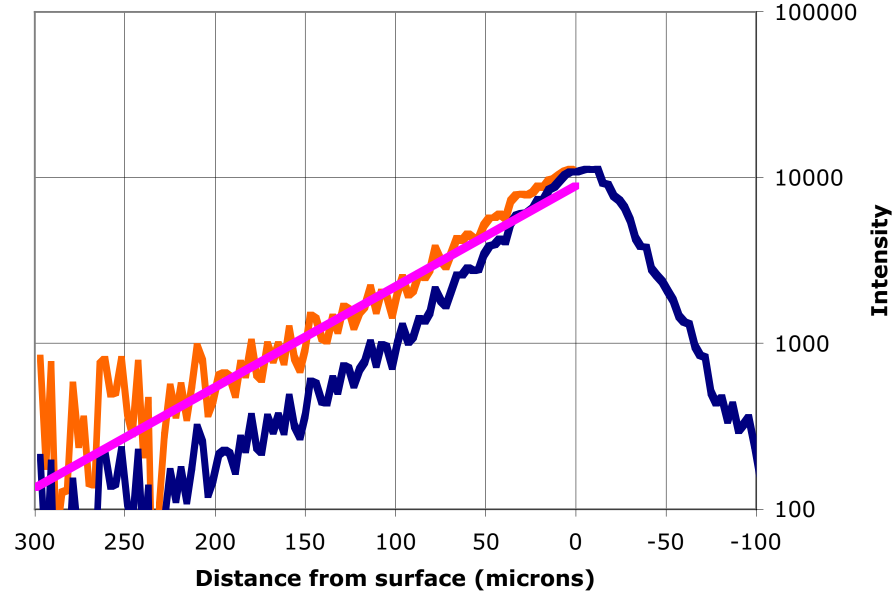
Side view of CuAl gives the same result - spreading at entry surface and ~ 70 μm mfp



1/e decay length
~ 70 μm



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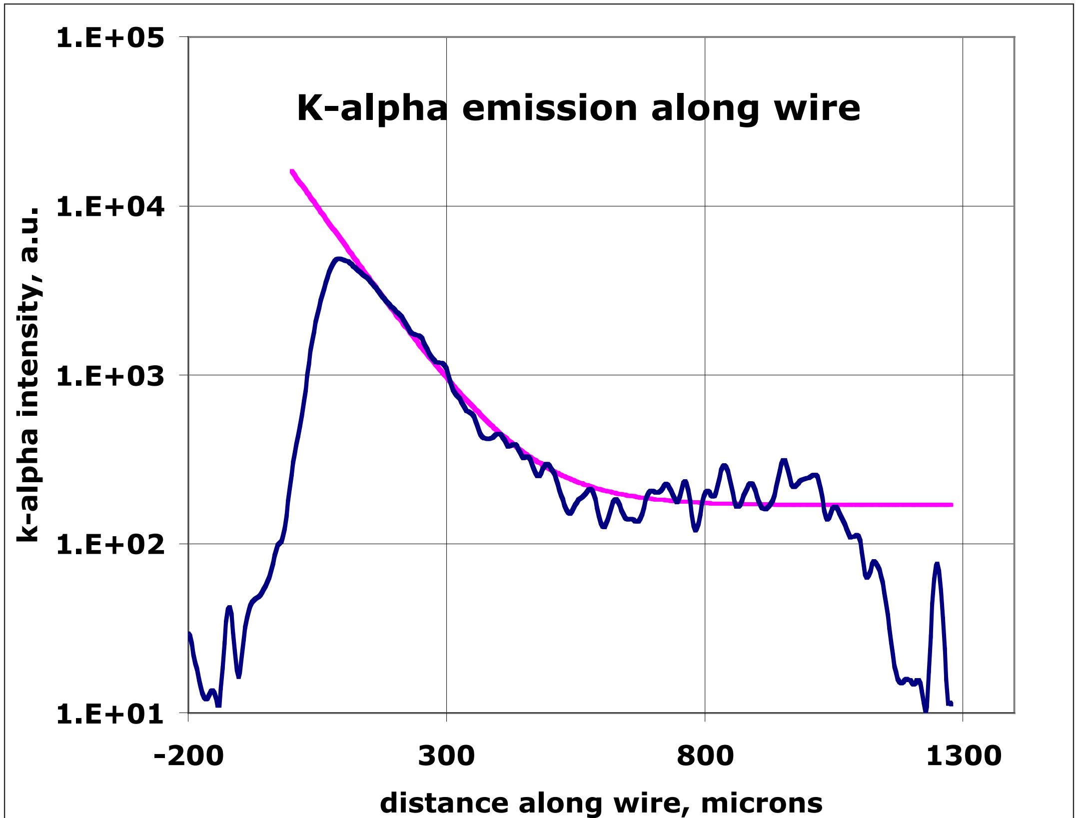
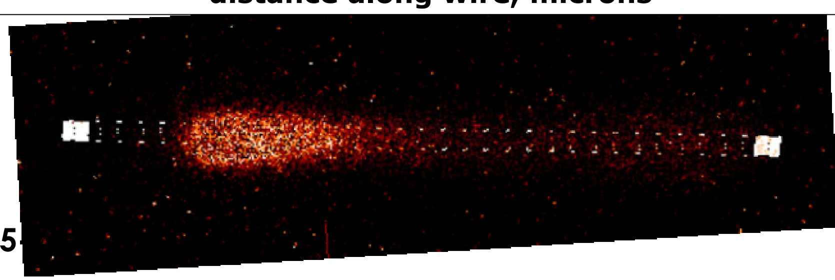
And in Cu wires where the current can't spread





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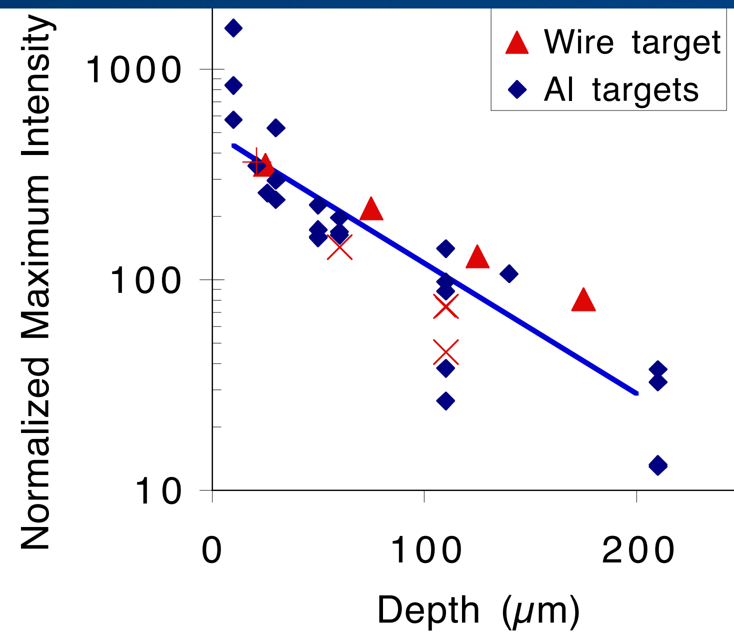


Normalized current density and mfp are similar to slab geometry

Cross section is much smaller, so total energy into wire is ~ 2% of beam energy

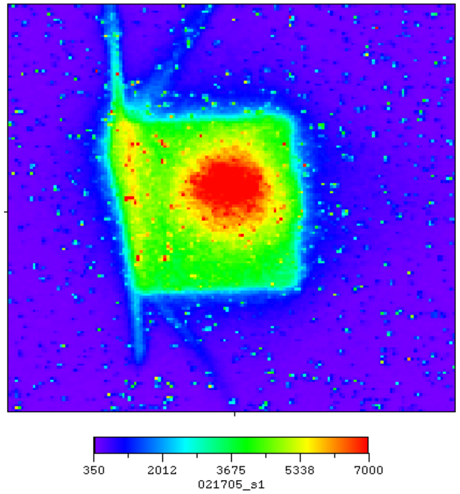
With increasing current we are getting into complications

- **Reached current densities that require more sophisticated diagnostic**
  - Must account for temperature
  - Resistance limitations become important
- **Challenge is in understanding the laser-plasma interface region**

Have added HOPG spectrometers for better understanding of temperature gradients

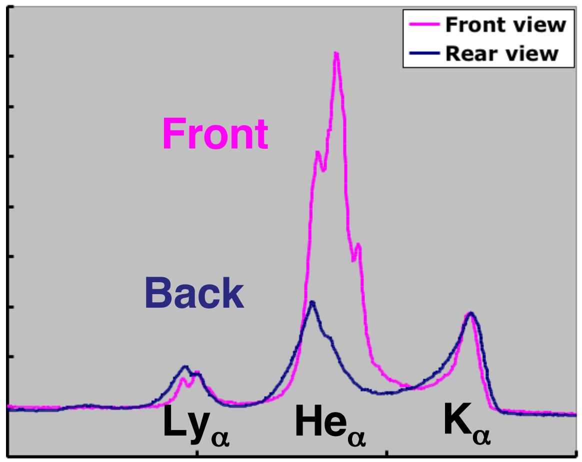
- 0.5 μm Al/5 μm Cu target
- 500 μm x 500 μm size
- 0.5 ps, 300J irradiation

256 eV XUV image



Peak temp 2x general temp
-> strong heating from initial beam

Cu K shell spectrum



3:1 front:back intensity ratio in He_α
-> strong axial temp gradient
-> front surface ~ 2 keV

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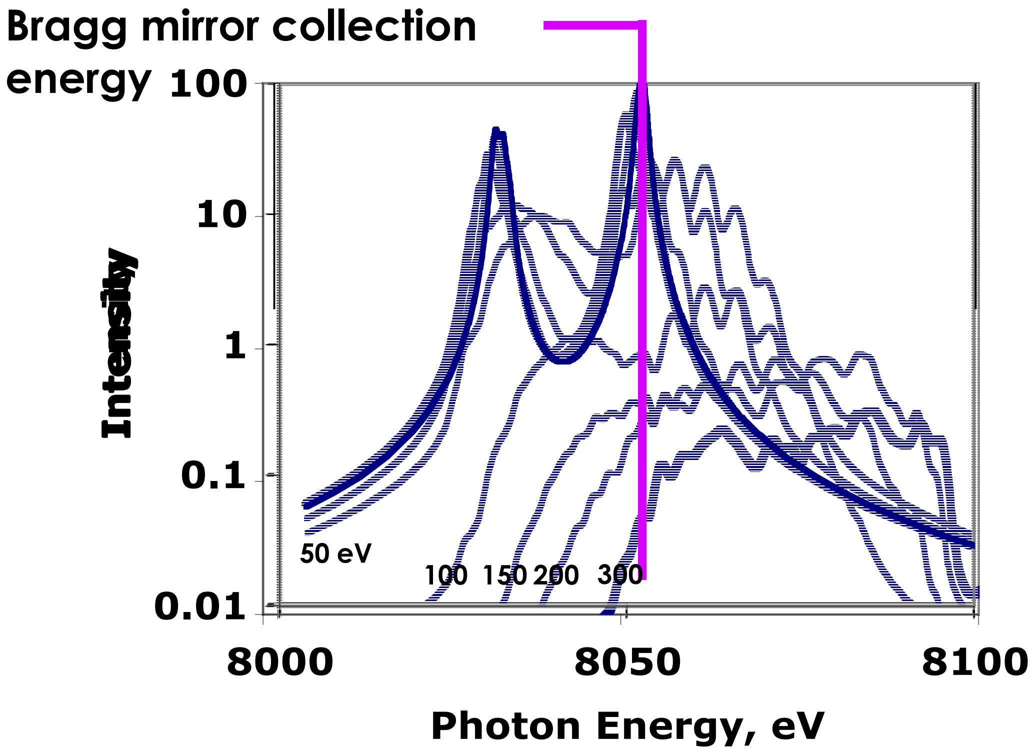
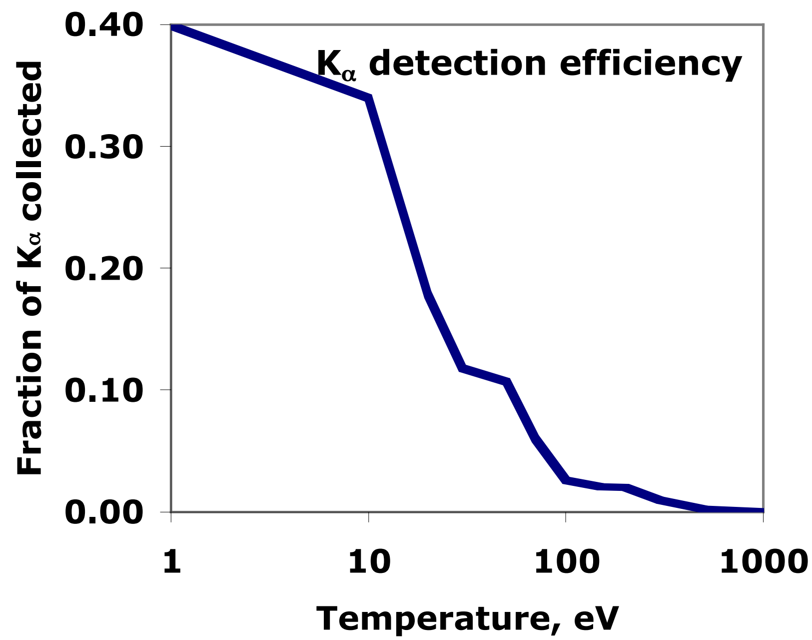
Fluorescence collection efficiency decreases with temperature





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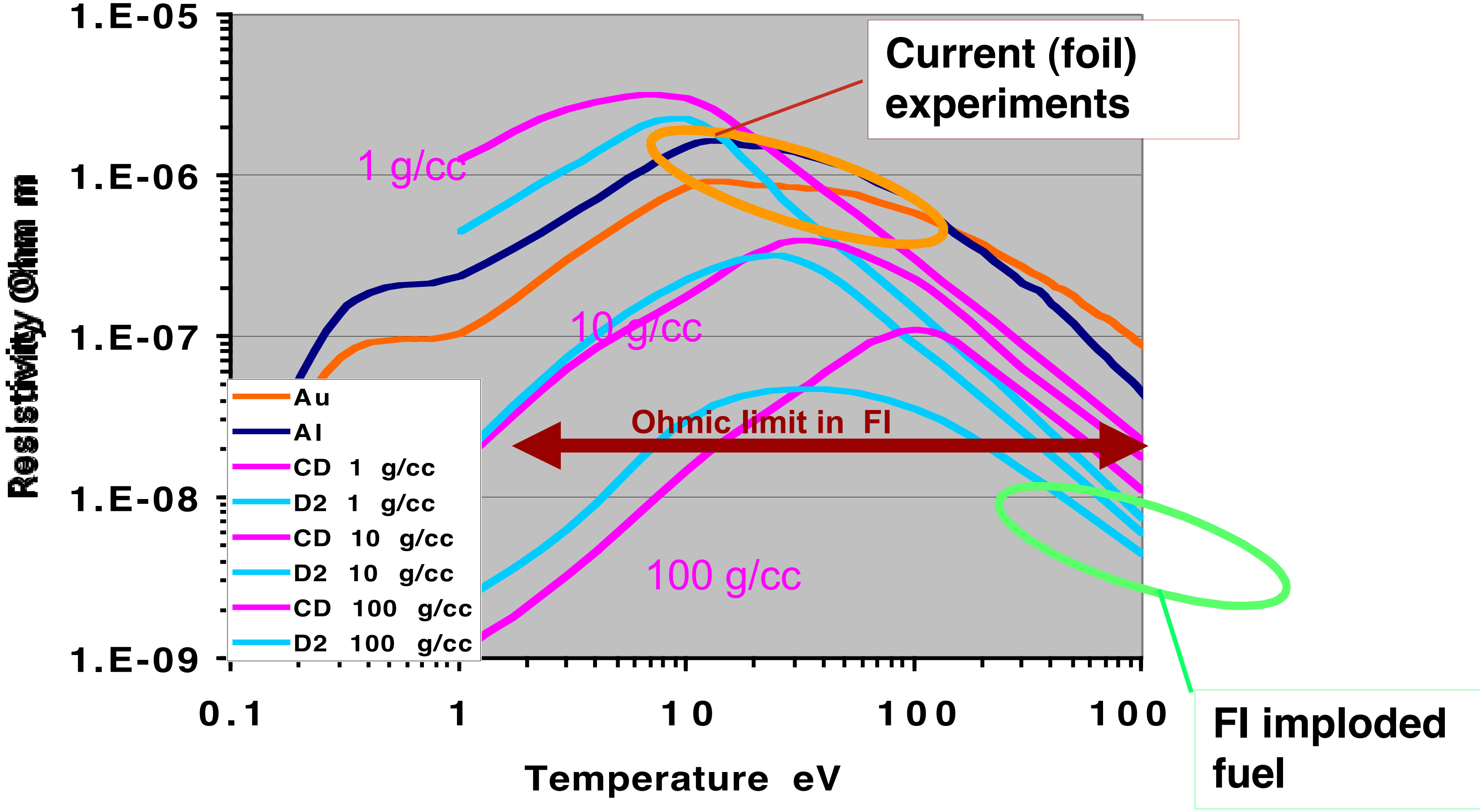
Resistivity limits propagation at high current density



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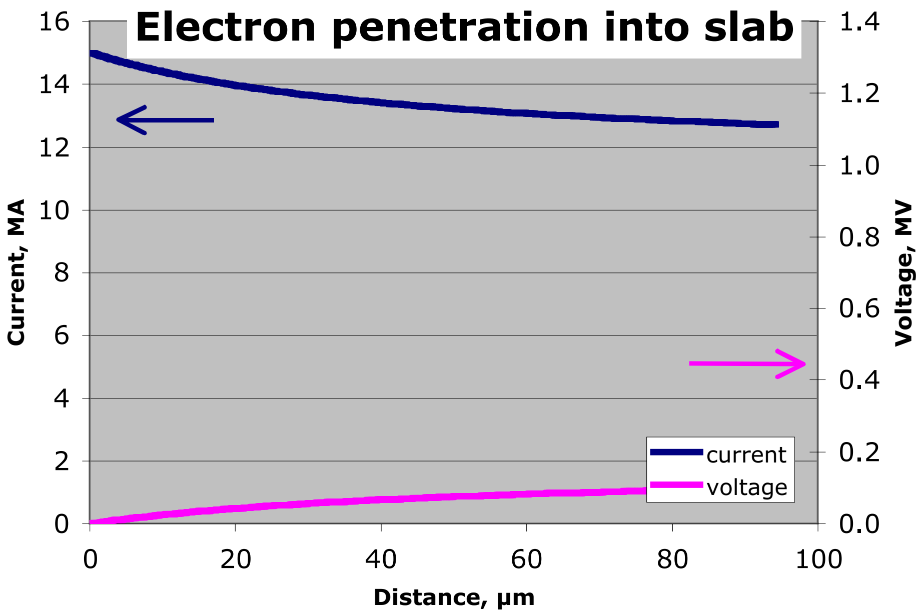
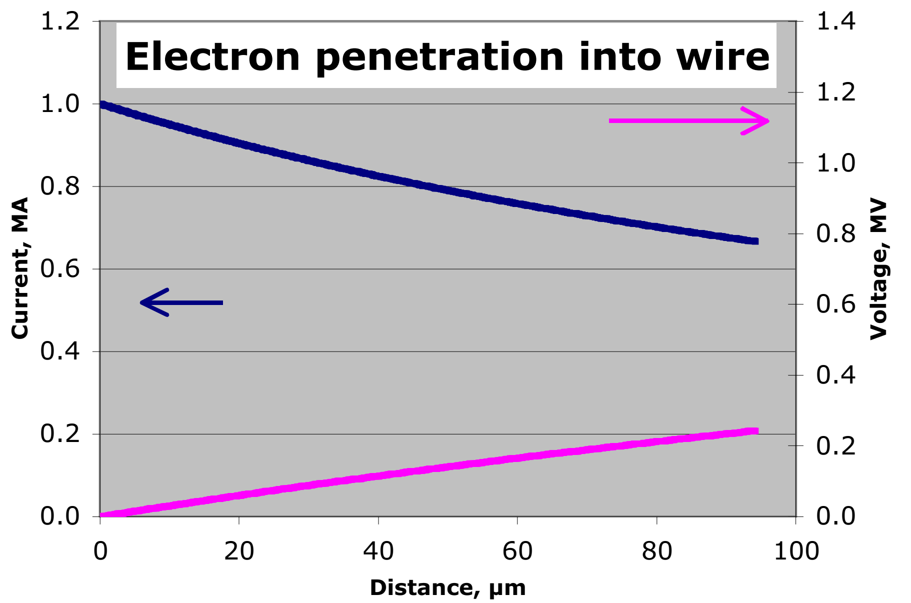
Higher current would cause stronger limitations.





Current into the wire was limited so fields aren't too bad

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Summary

- **Currents are still scaling with increasing intensity**
- **Propagation lengths are appropriate - ~ 100 μm**
- **Reached current densities that require more sophisticated diagnostic**
  - HOPG spectrometers for current and temperature
- **Resitivity may be limiting wire current**
- **Challenge is in understanding the laser-plasma interface region**
  - Created diagnostics and analyses to probe that area
  - Adding packages to LSP for self-consistent electron creation in plasma