MeV Electron Generation and Transport using Second Harmonic Laser Pulses for Fast Ignition

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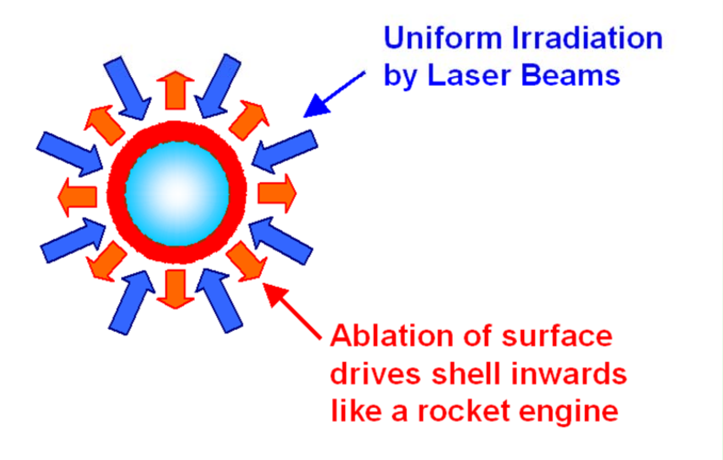
Laser Fusion

Direct Drive

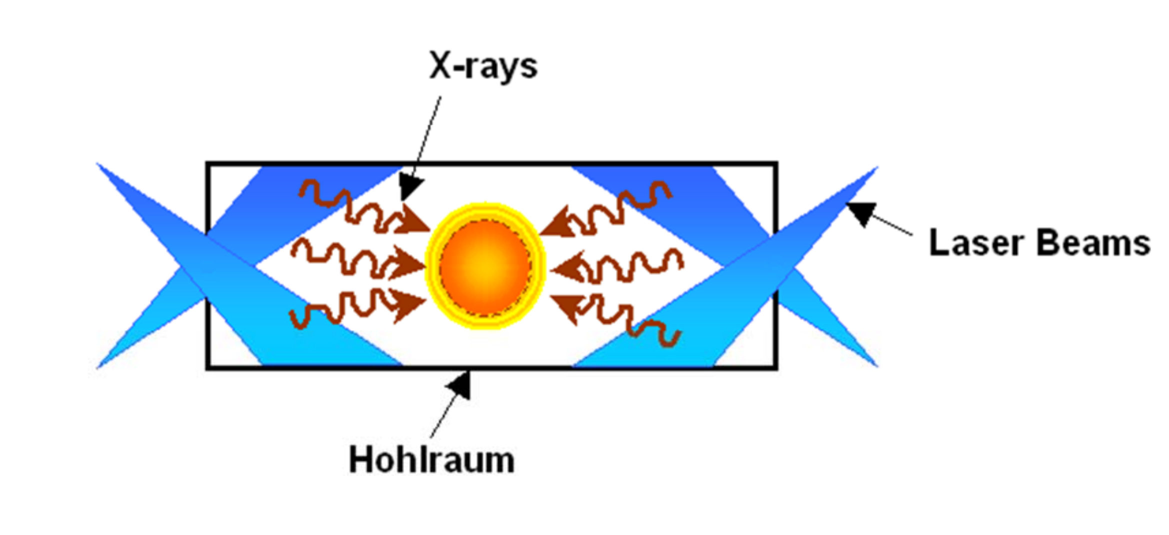


Ignition Conditions

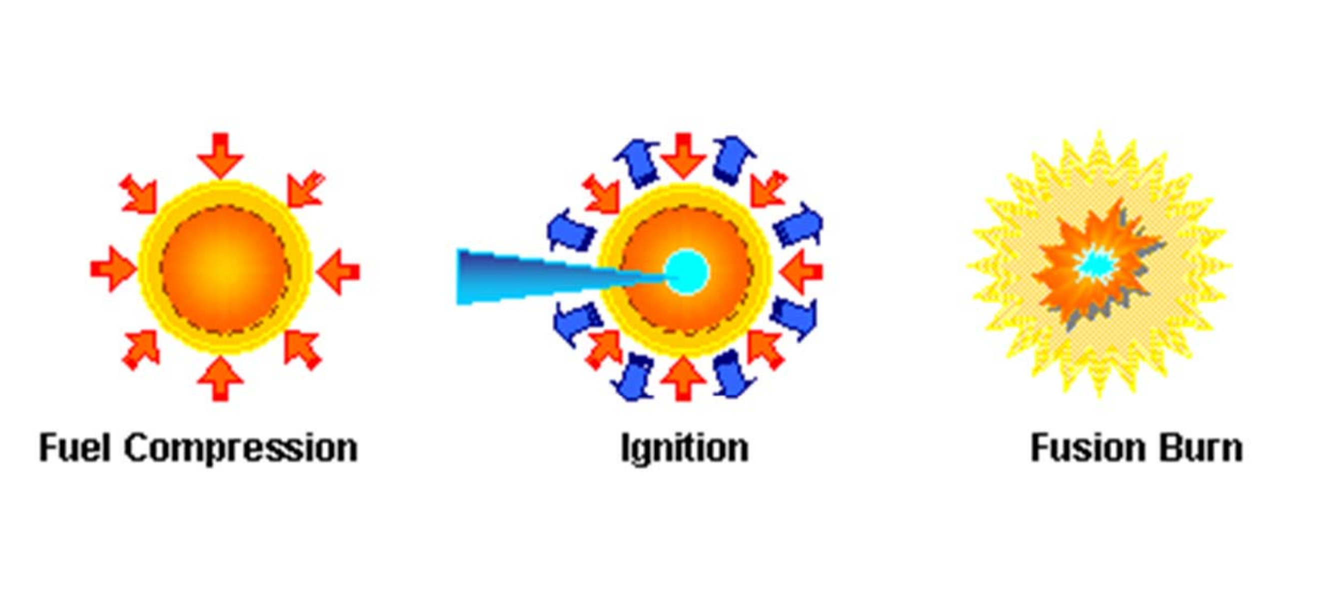
$\rho \sim 500 \text{ g cm}^{-3}$

$T \sim 10 \text{ keV}$

Indirect Drive



Fast Ignition



Requires electrons or ions to carry the energy from the laser absorption region to the compressed core

Ignition Requirements

$\rho \sim 300$ g cm^{-3}

$\tau_{dep} \sim 20$ ps

$D_{dep} \sim 40\ \mu$m

$E_{dep} \sim 20$ kJ

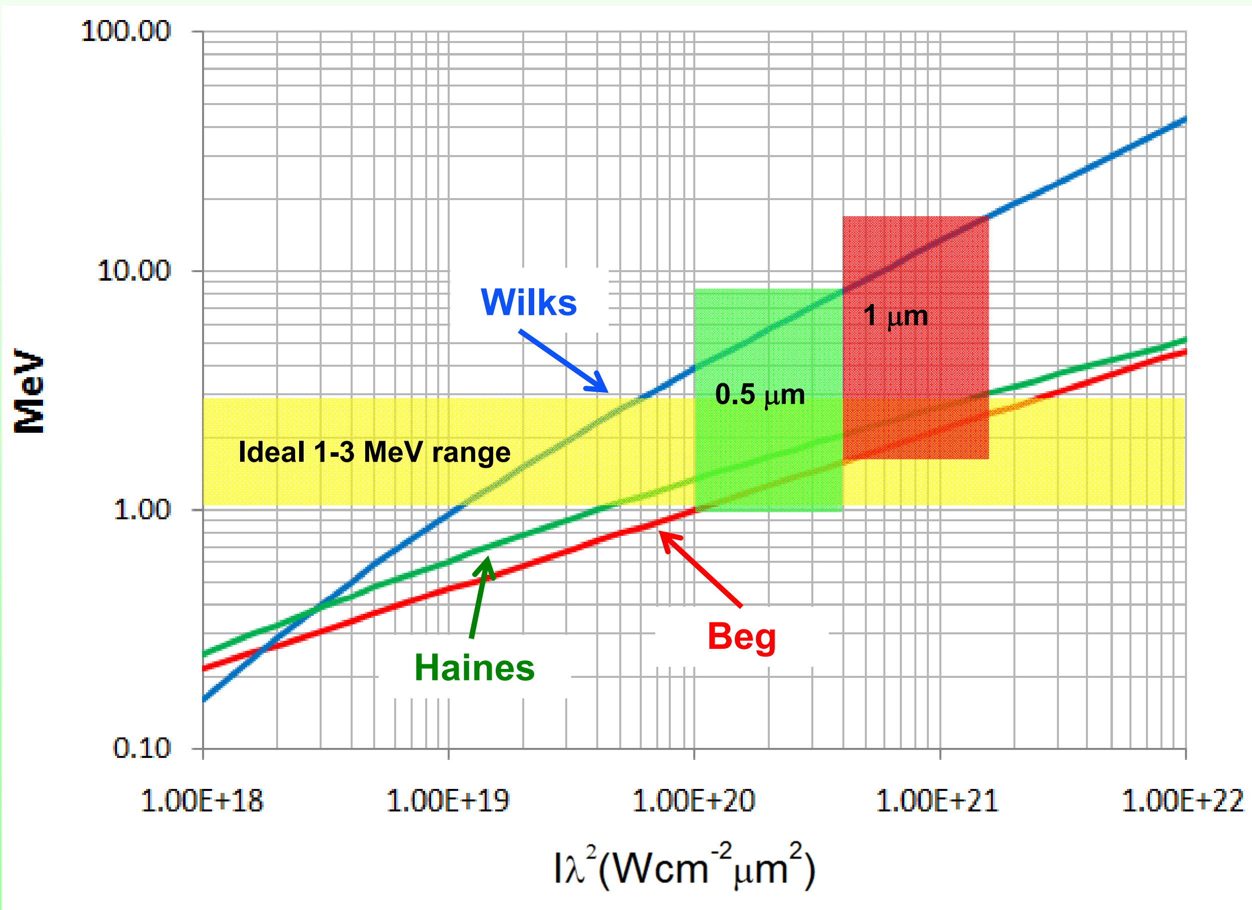
$E_{laser} \sim 100$ kJ

$\phi_{laser} \sim 20 - 40\ \mu$m

$I_{laser} \sim 0.4 – 1.6 \times 10^{21}$ W cm^{-2}

Electron Energy Scaling

Required electron energies ~ 1-3 MeV



Scaling Laws:

Wilks (Ponderomotive)
PRL 69, 1383 (1992)

Beg (Exp Bremsstrahlung)
Phys.Plasmas 4,447 (1997)

Haines (Energy/Momentum)
PRL 102, 045008 (2009)

2ω Experiment Objectives

Determine scaling at 2ω for hot electron generation

Measure

- **T_{hot}**
- **Electron generation efficiency**
- **Divergence**
- **Specular Beam reflection and chirp**

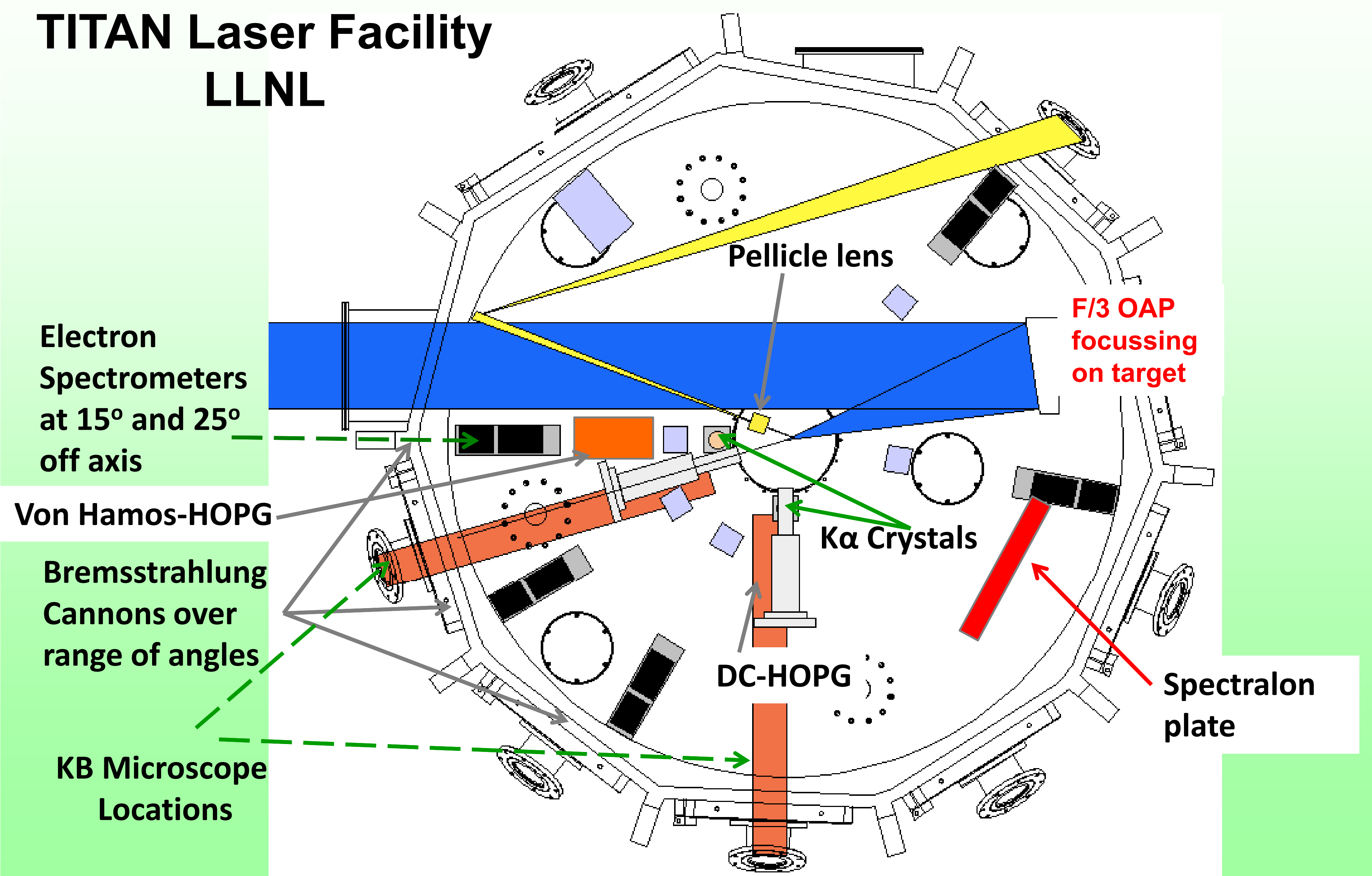
Geometries

- **Flat Foils with Cu tracer layer**
- **Buried Cones with Cu tracer layer**
- **Cone wire**

Diagnostics

- **HOPG CU K_{α} x-ray spectrometers**
- **Electron spectrometers**
- **X-ray Bremsstrahlung versus angle**
- **Cu K_{α} imaging crystals**
- **KB x-ray microscope**
- **Specular Imaging and FROG**

Experimental Diagnostic Layout



2ω Titan Run Parameters

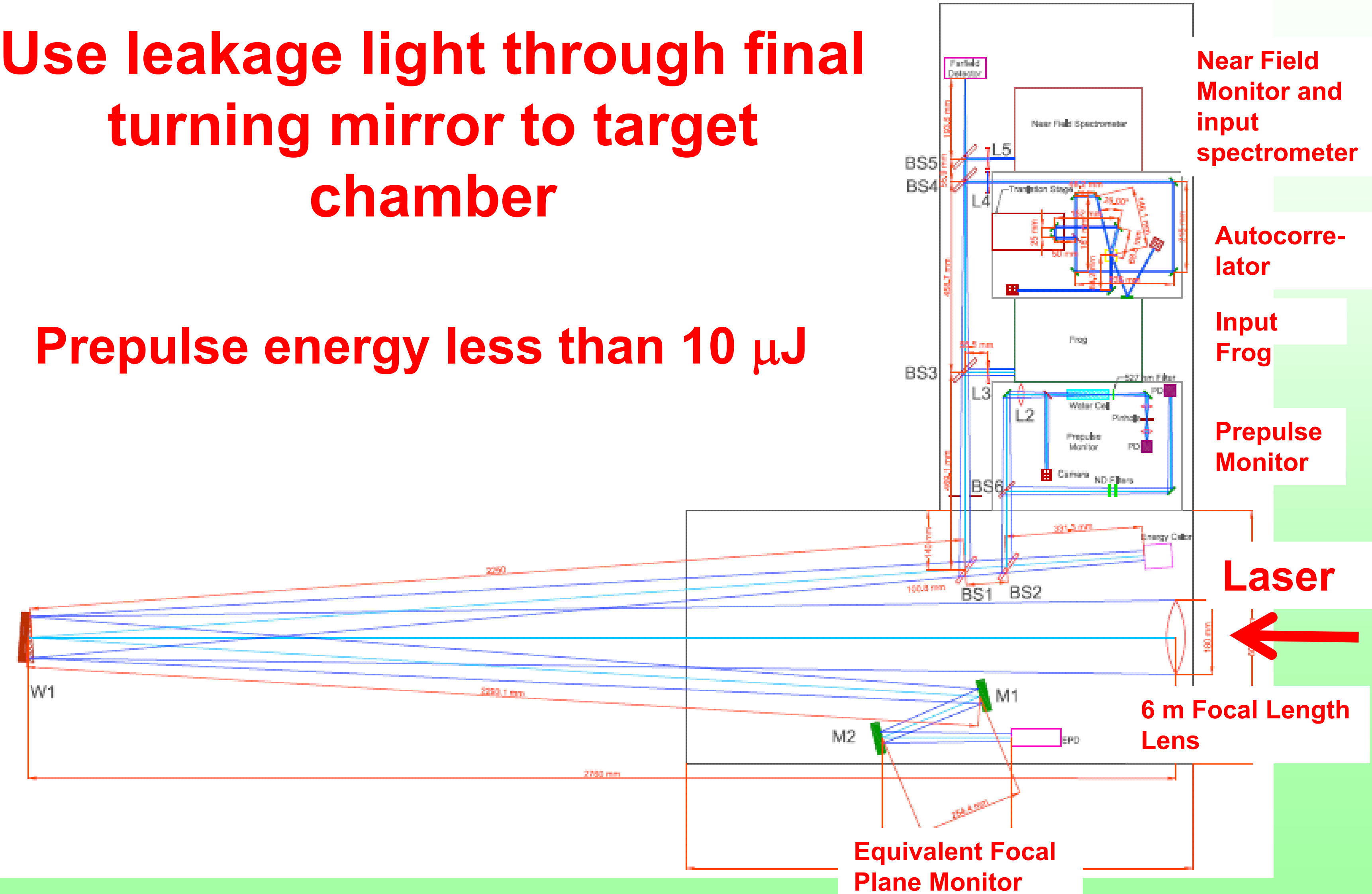
50 J
700 fs
0.53 μm
5×10^{19} W cm^{-2}

Planar Foil Targets
Buried Cone targets
Cone foil Targets
Cone Wire Targets

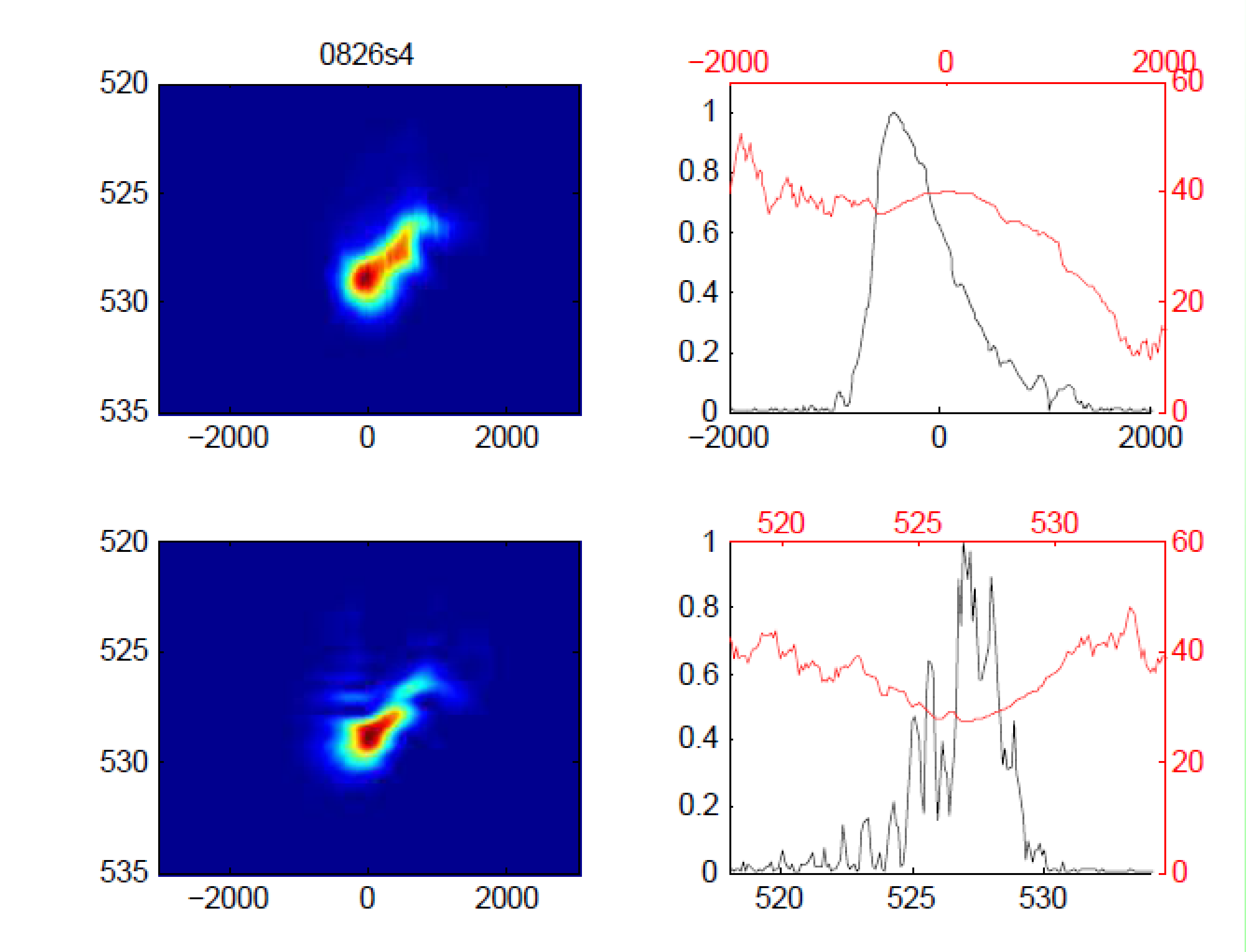
Laser Diagnostic Layout - 2ω

Use leakage light through final turning mirror to target chamber

Prepulse energy less than 10 μJ



Input FROG Signals



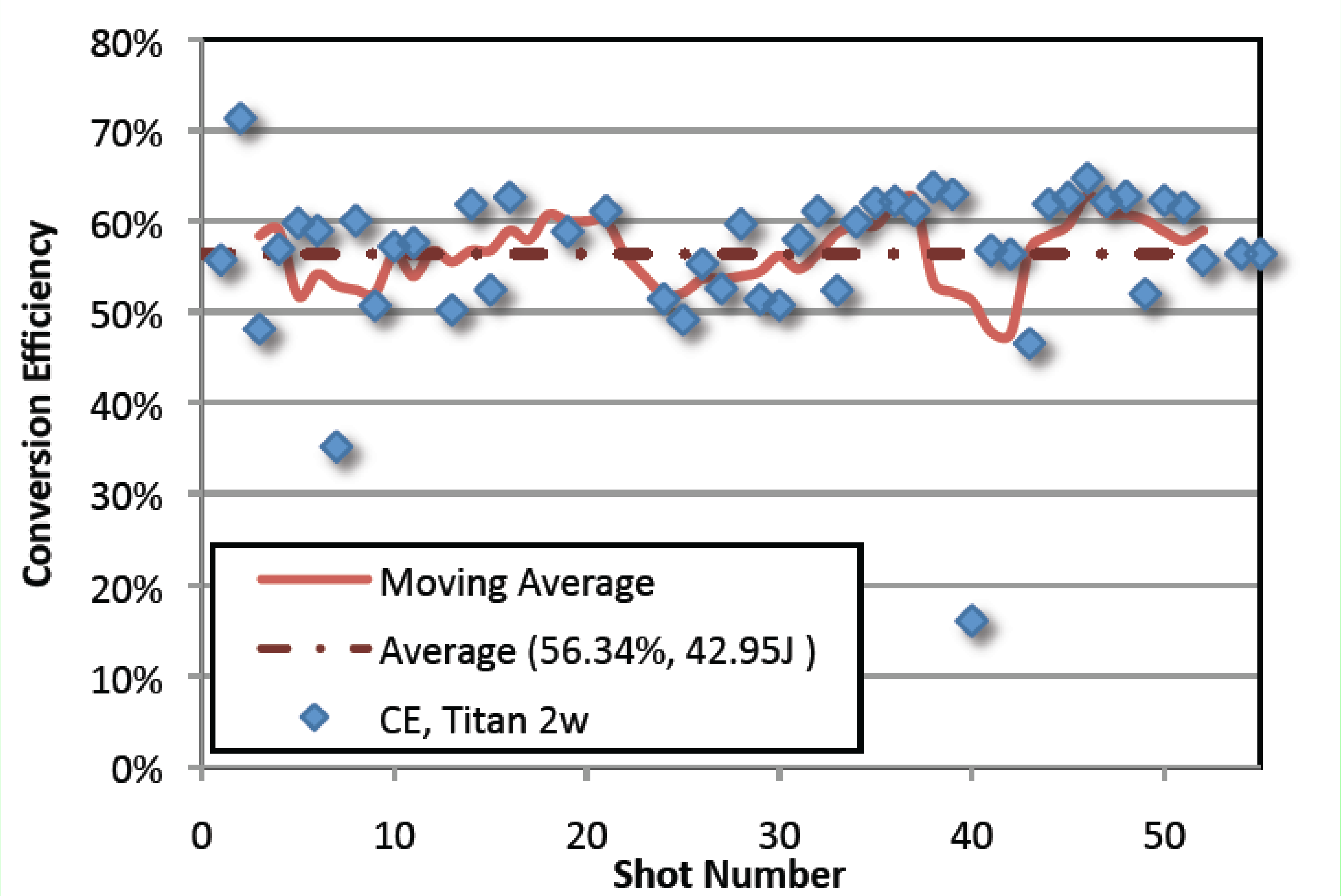
Duration and Phase

710 fs FWHM

Spectrum and Phase

710 fs pulse duration with slight chirp

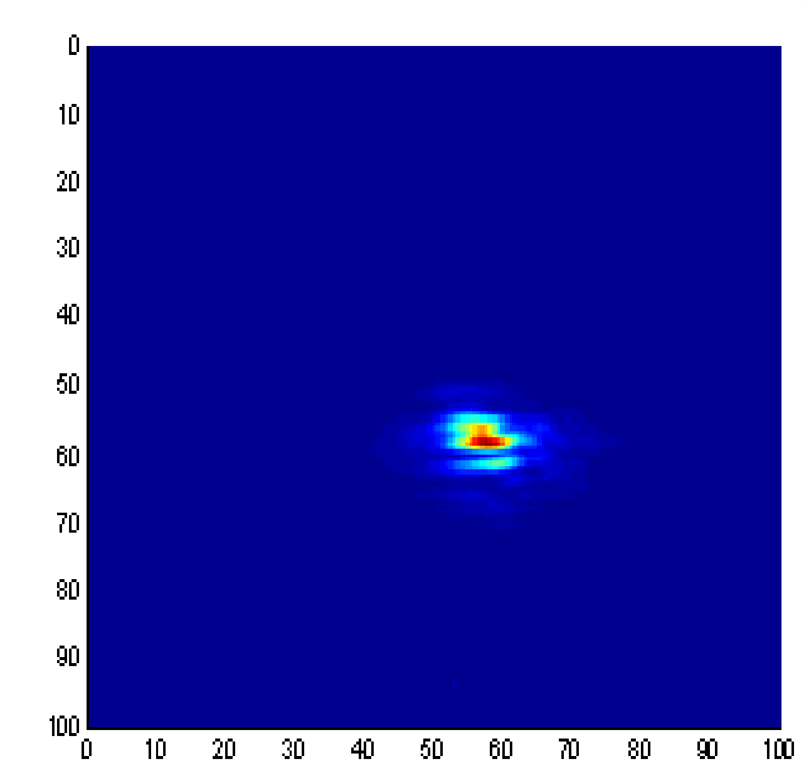
Conversion Efficiency



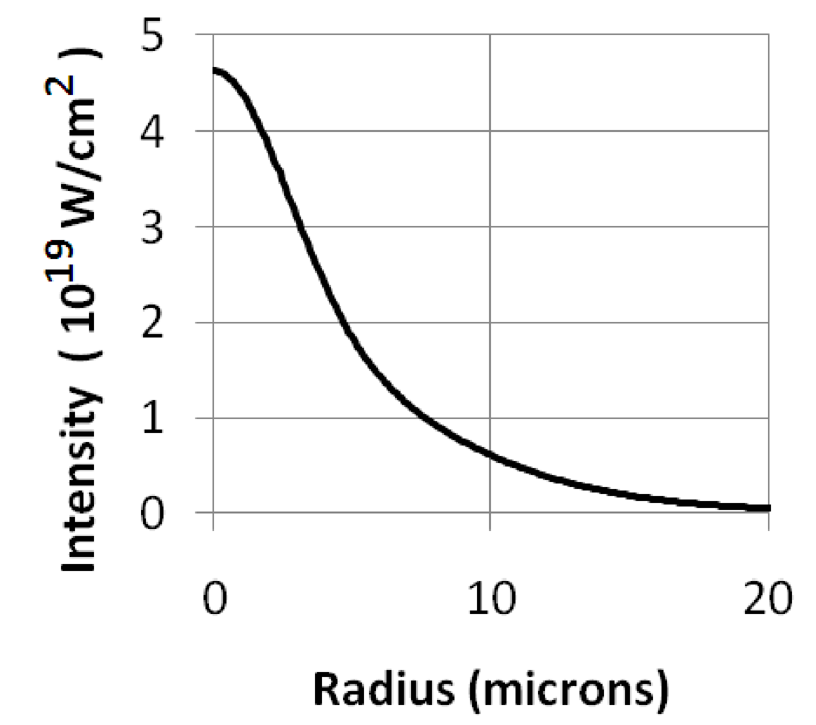
Peak Conversion efficiencies of over 60% obtained - 2mm KDP crystal

Typical Low Energy Focal Spot on Target

Low Intensity Focal Spot at TCC



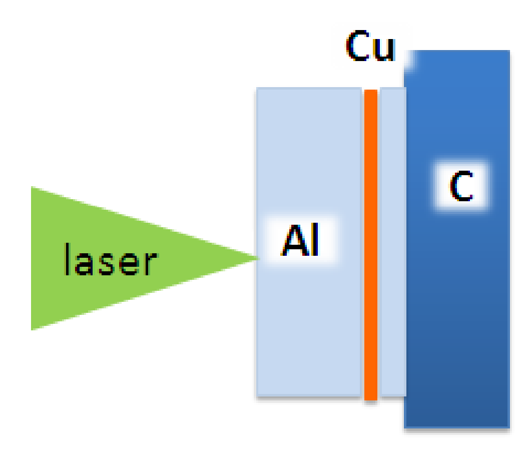
Estimated Radially Symmetric Target Intensity Distribution for 50J 700 fs



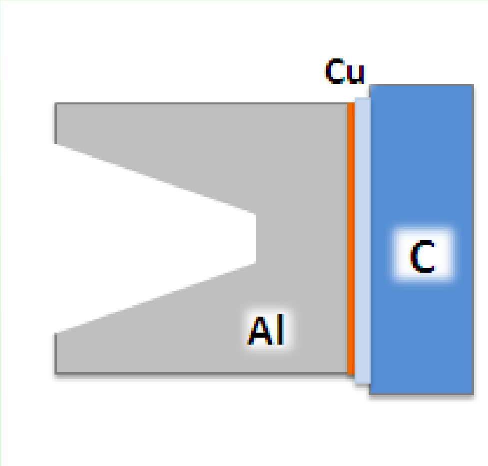
Equivalent FWHM Spot Diameter = 8 μm

Targets used

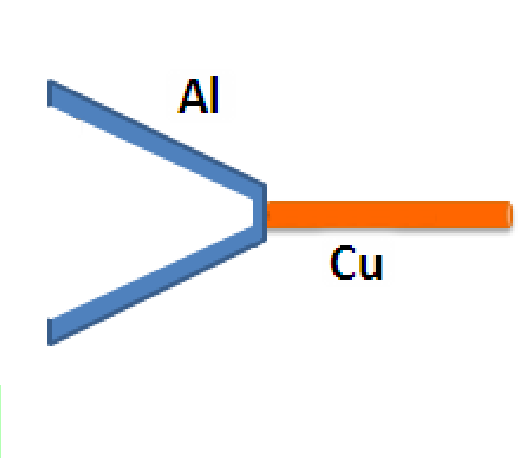
Planar with buried
Cu tracer layer



Solid Al cone with
buried
Cu tracer layer

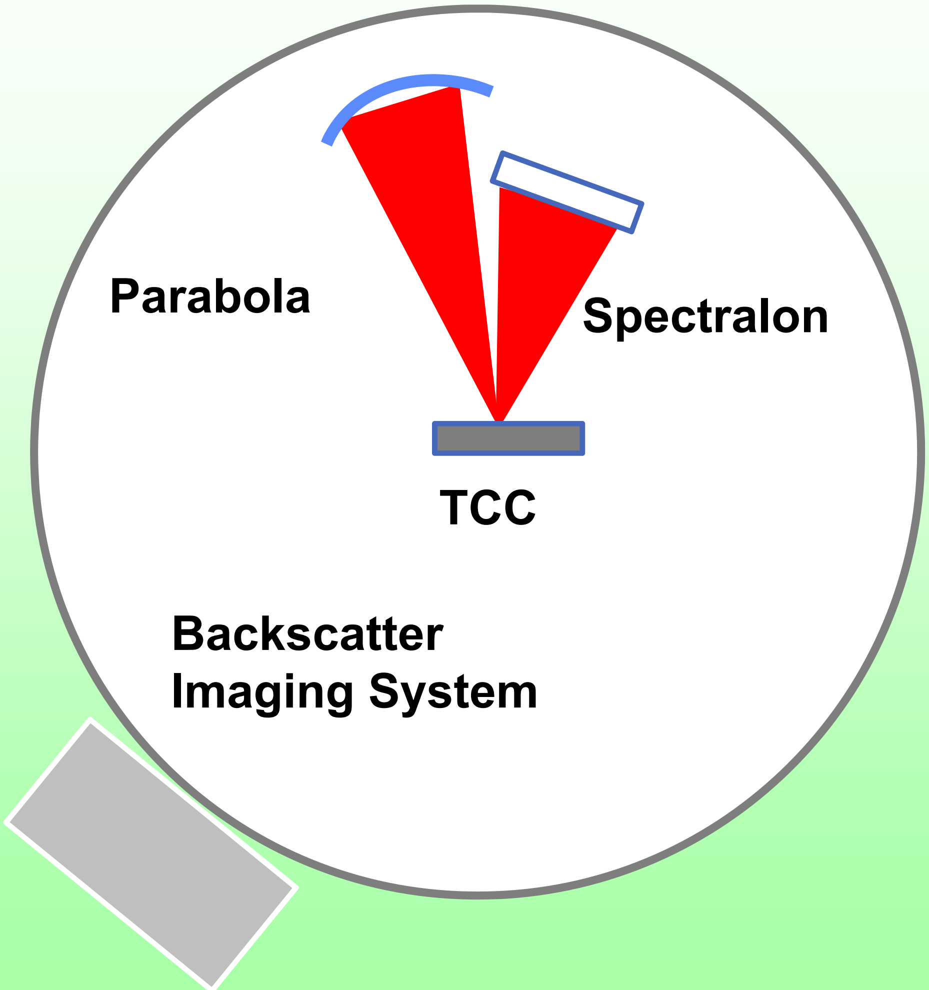


Thin Al cone
Cu wire



Shots taken with no prepulse ($<10\ \mu J$)
or with injected 3mJ 3ns 2ω prepulse

Spectralon Reflectivity Mesurement Setup



Imaging System

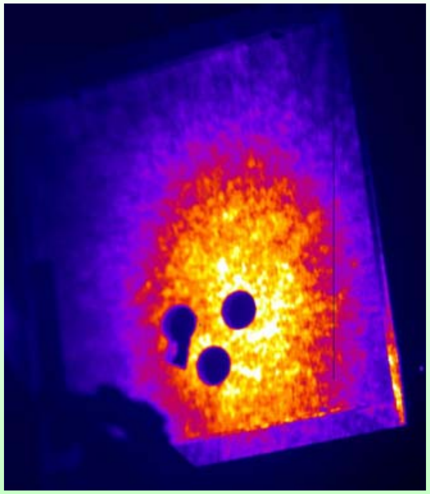
- On Door H
- Looking through Port H1

Spectralon

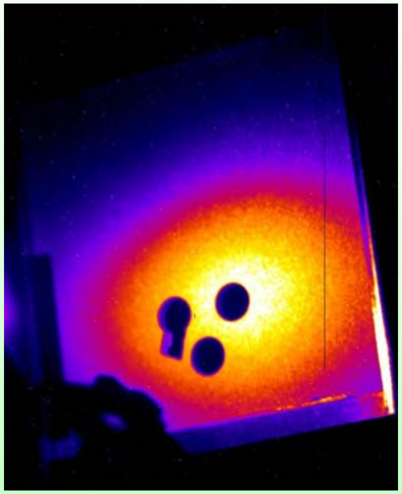
- 10” x 10” spectralon
- In front of Door E
- Holes aligned to allow FROG through port E2
- F/1.5 beam collection

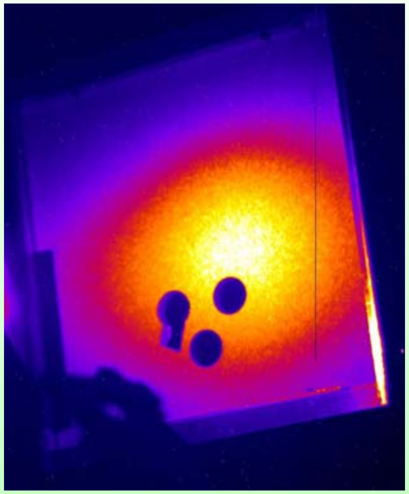
Specular Reflectivity Images
Titan 2w run

No prepulse



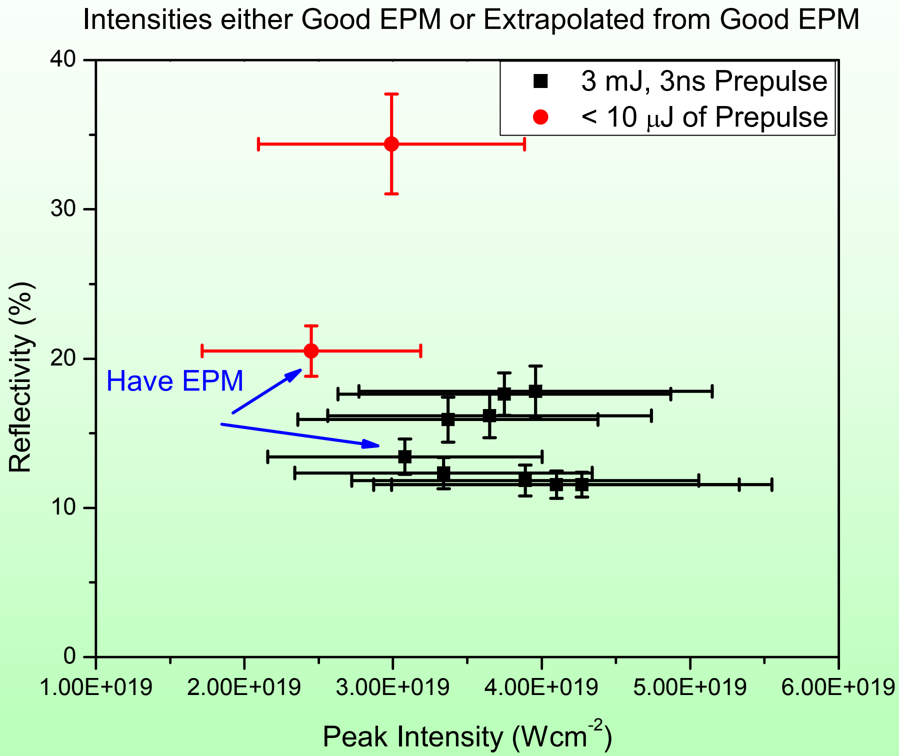
3mJ prepulse



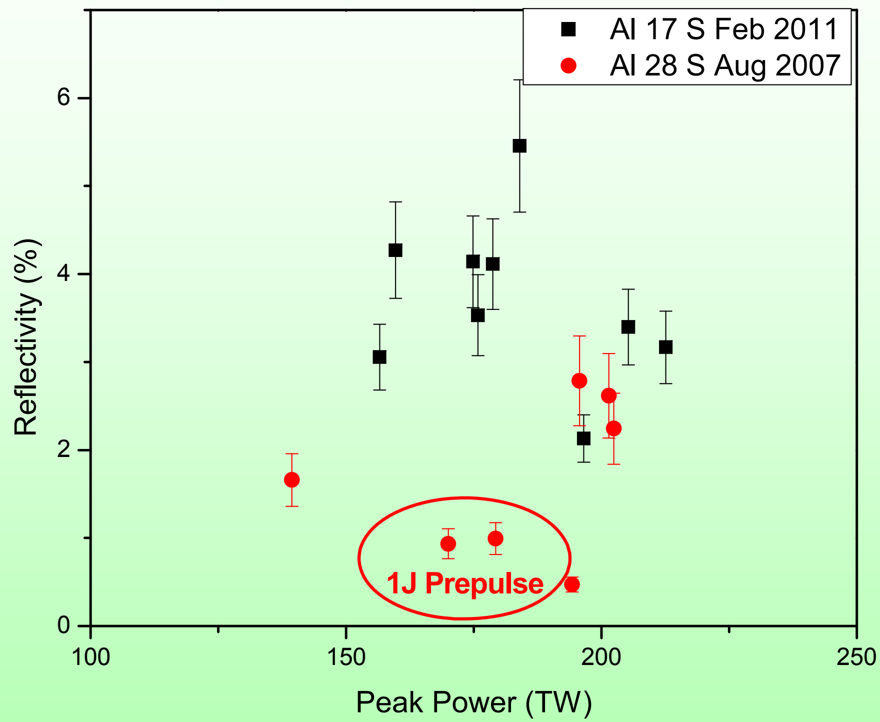


- Speckle pattern seen from no prepulse shots –
  perhaps speckle from surface roughness
- Smooth pattern seen for shots with prepulse –
  smoothing from preplasma

Reflectivity 1ω vs 2ω



2ω Data



1ω Data

2ω Reflectivty

R_{npp} ~ 27%

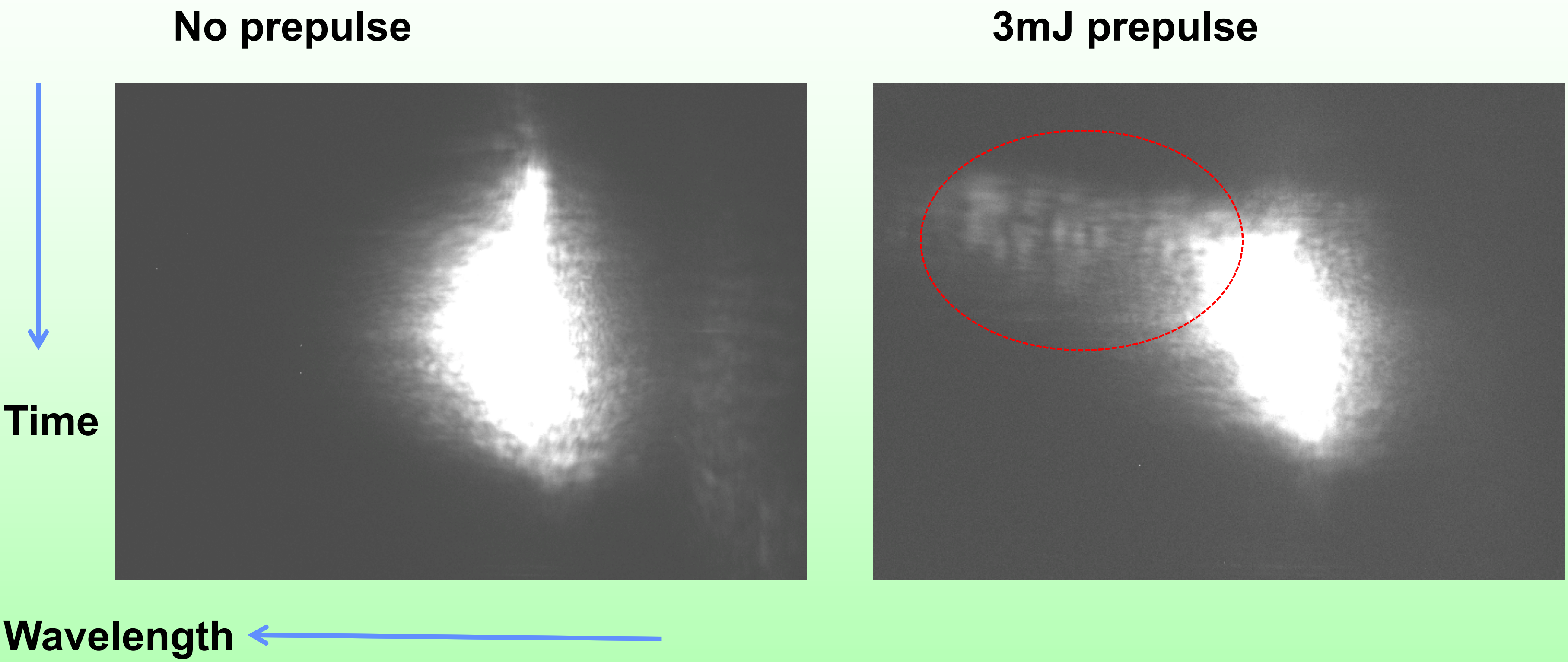
R_{wpp} ~ 14%

2ω vs 1ω with pp

$R_{1\omega}$ ~ 4%

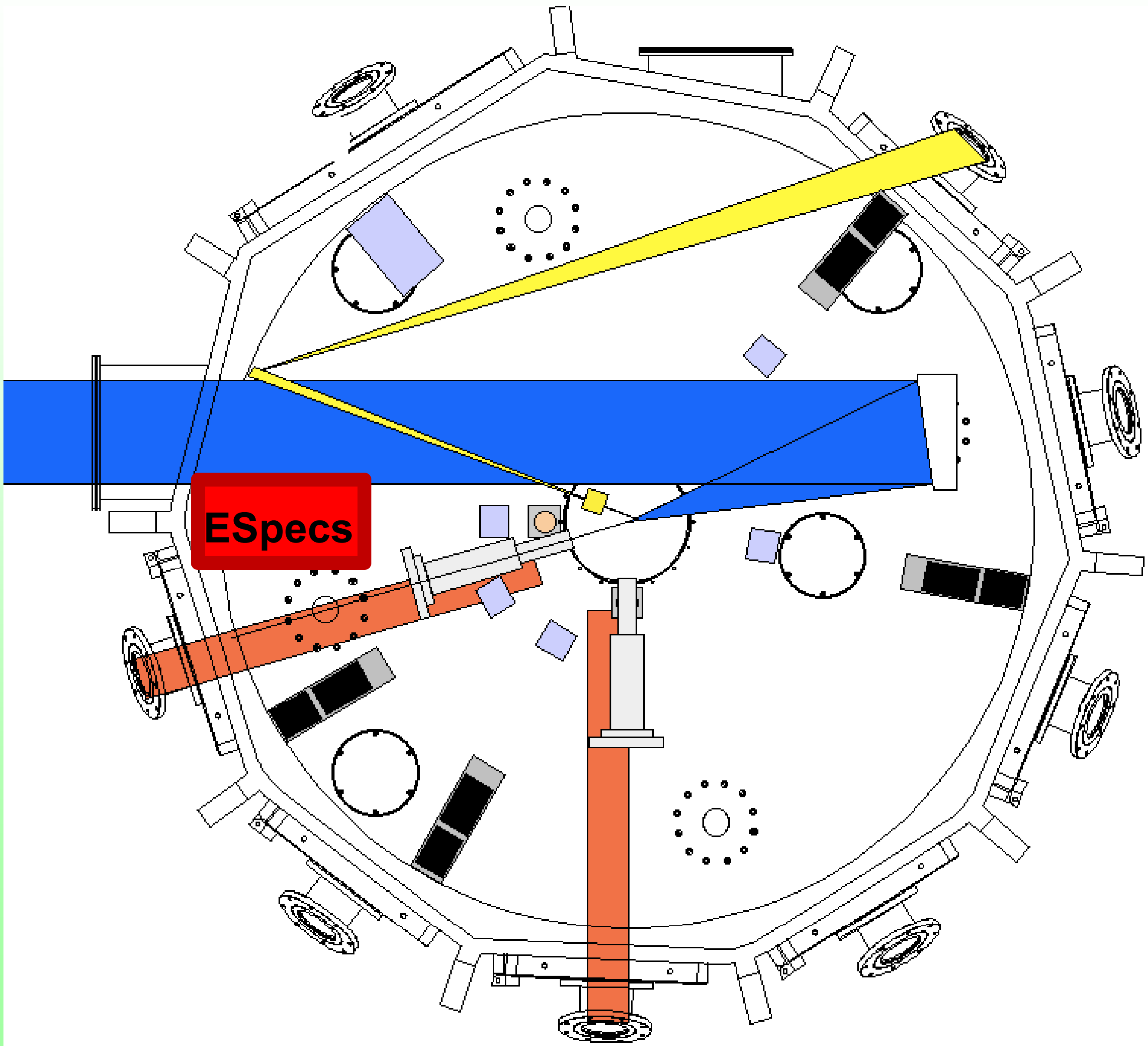
$R_{2\omega}$ ~ 14%

FROG data shows prepulse effect



- Large red shift at the beginning: due to pushing in of preplasma?
- Very reproducible

Electron Spectrometer Setup

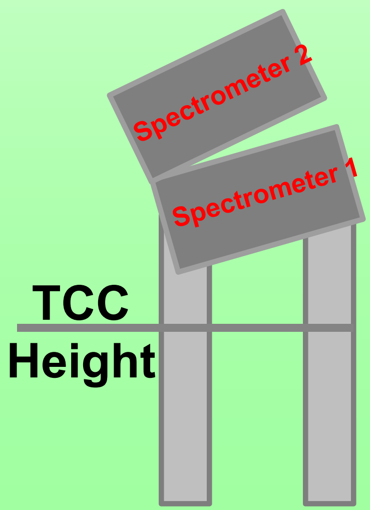


Especs
Located Above Cannon 1

Horizontal Angles
- 0 wrt Target Normal
- 16° wrt to Laser Axis

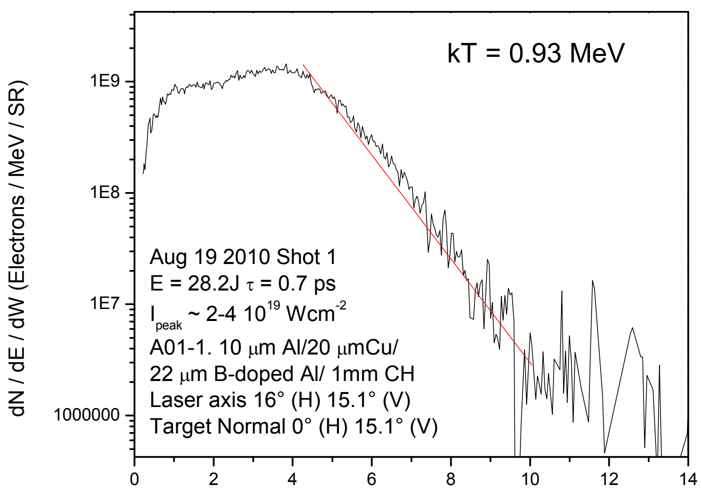
Vertical Angles
- 15° out of the plane
- 25° out of the plane
- plane, looking down to TCC

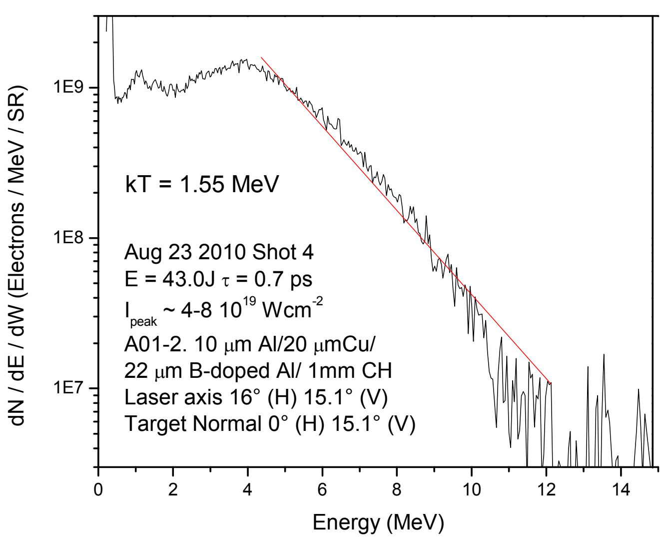
Distance
- center of slit 80 cm from stalk at TCC



Typical 2ω Electron Spectra 15°

No Prepulse | **With Prepulse**



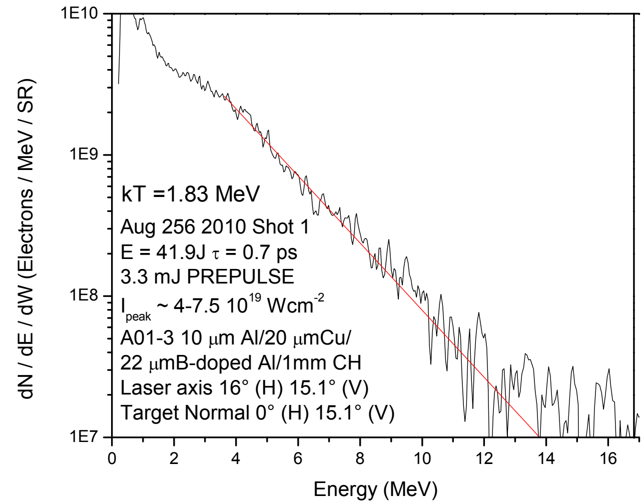


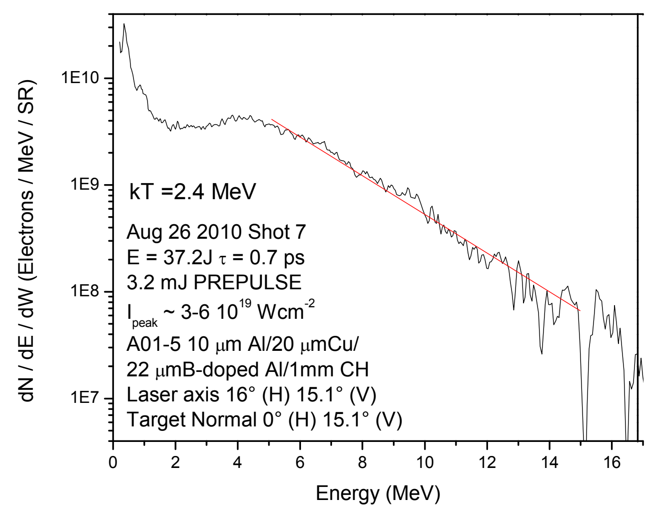
2 ω

T_{hnpp} ~ 1.5 MeV

T_{hwpp} ~ 1.9 MeV

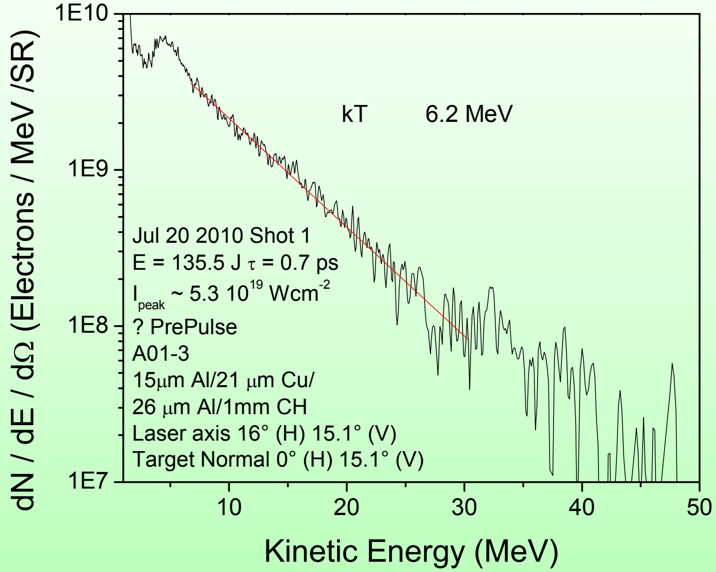
T_{hnpp} ~ 0.8 T_{hwpp}

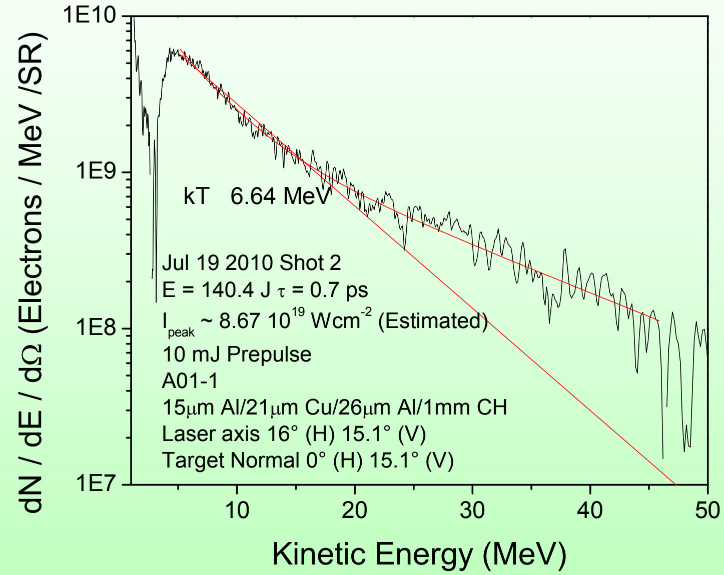




Typical 1ω Electron Spectra 15º

Measured with the same spectrometer and similar targets



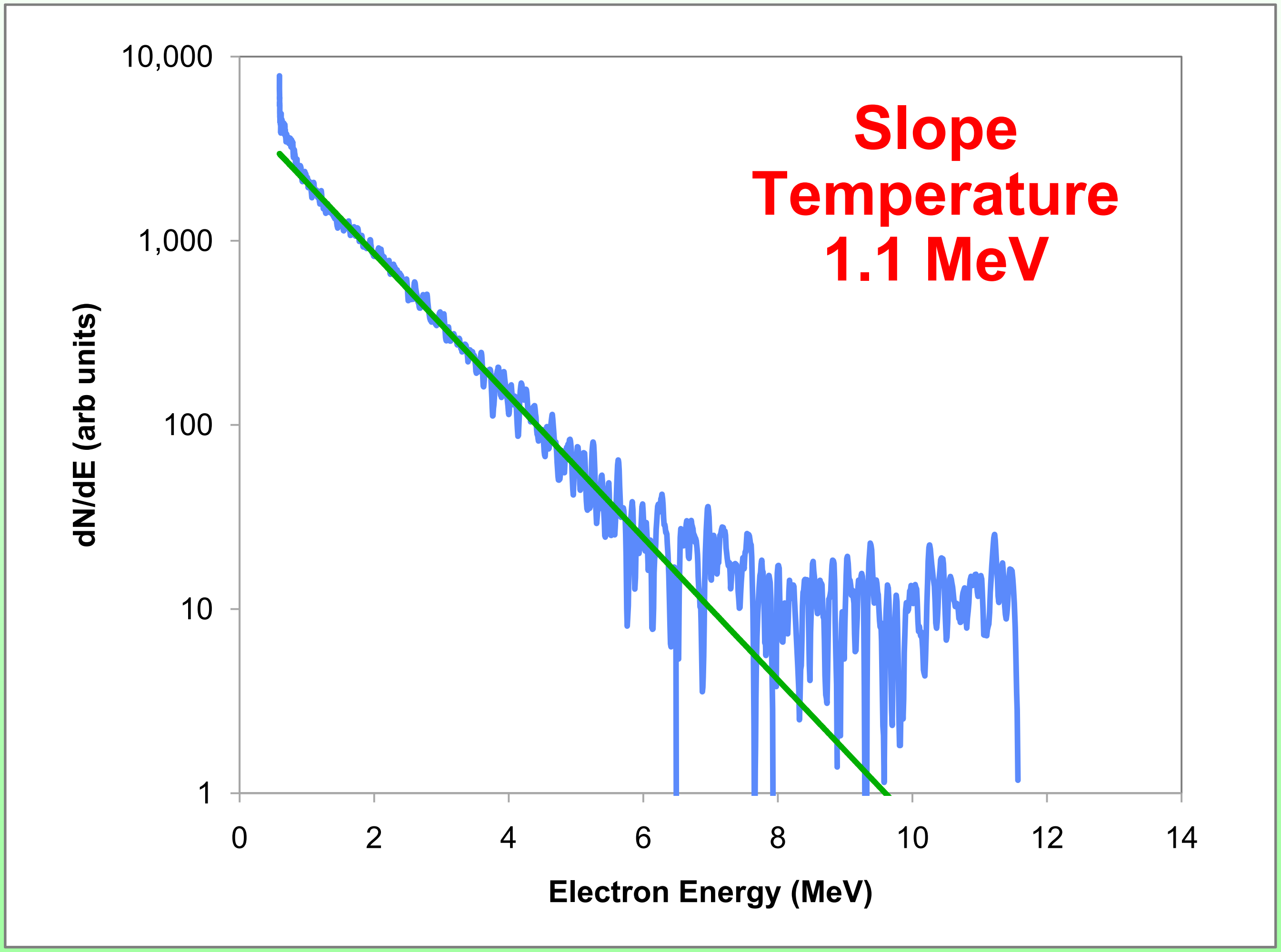


T_{hot} ~ 6 MeV

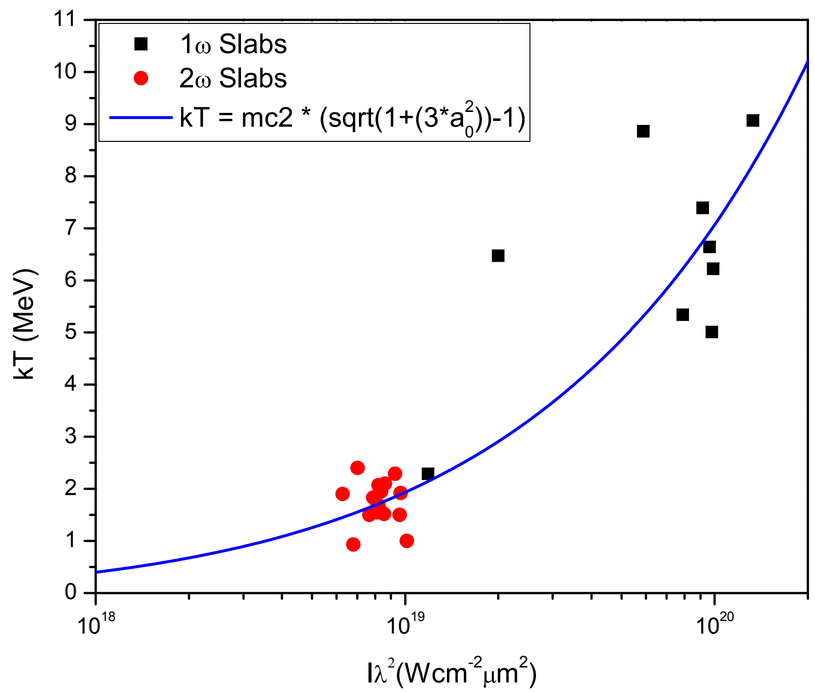
at 1 ω

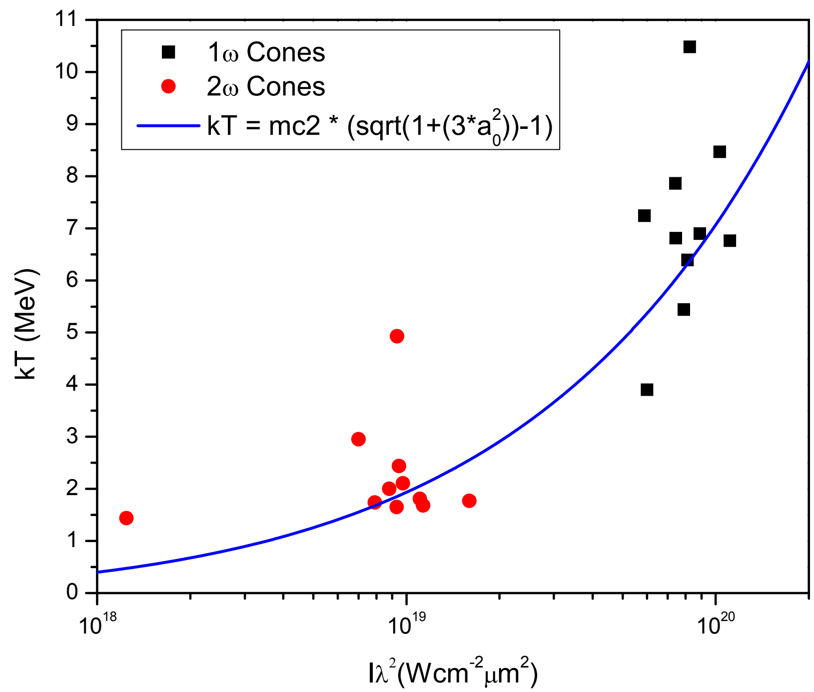
Electron Spectrometer 25° off axis

T_h at 25° ~ 0.6 x T_h at 15°



Electron Spectrometer Summary 1ω vs 2ω

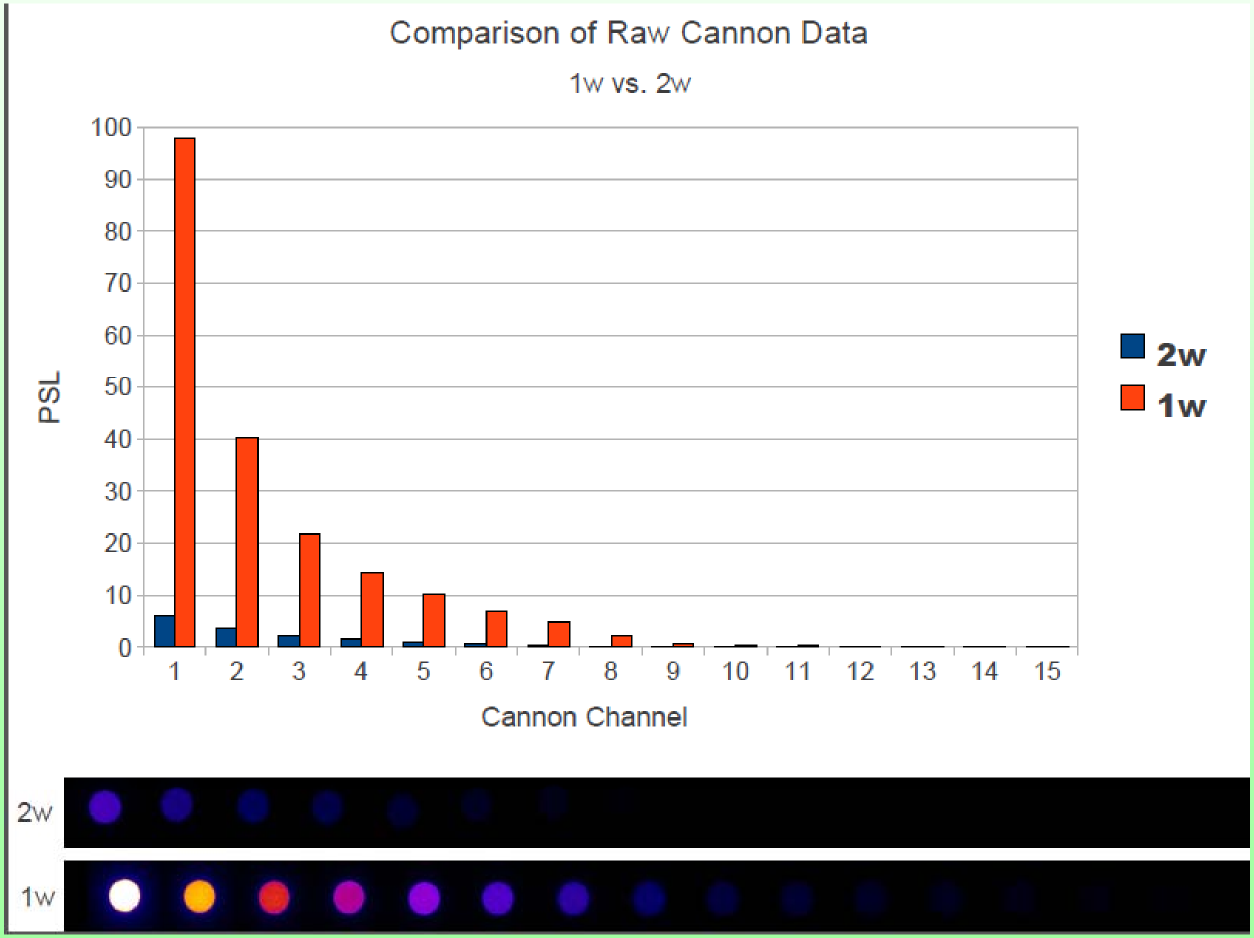




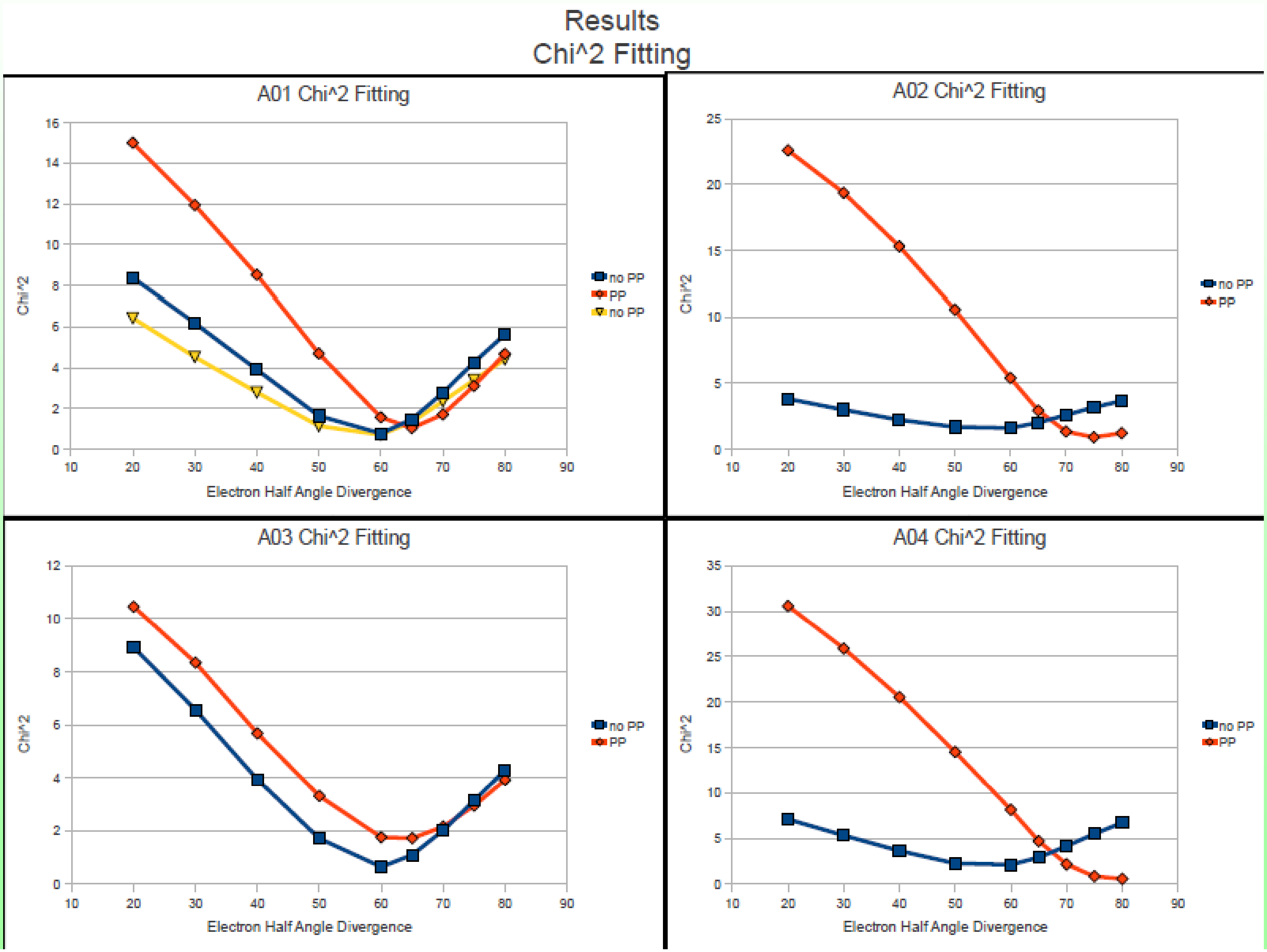
T_h fits modified Pondermotive scaling law
($T_h \sim 1.7\ T_{PM}$)

Bremsstralung Cannon Data

Filtered image plate stack with Pb collimator sensitive up to 500keV



Bremsstralung Cannon Data Fits vs Electron source Divergence



Bremsstralung Cannon Preliminary Summary

	Half Width	T_{hot}	Conversion Efficiency
Planar no pp	60°	0.37 MeV	11 %
Planar with pp	71°	0.50 MeV	17 %

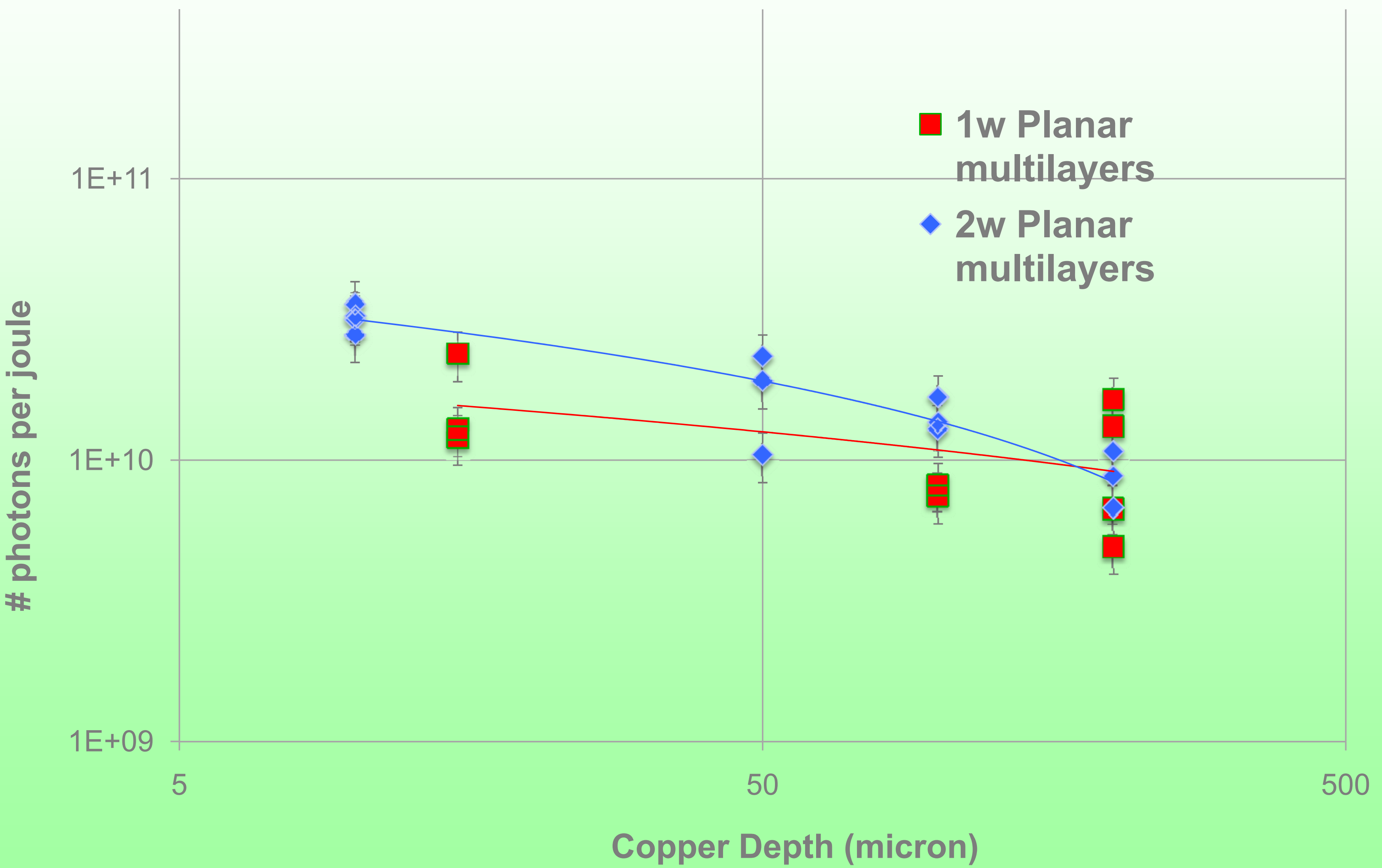
Compare to 1ω data for Ag target (Westover APS 2010):

- Electron Divergence ~ 60° (HW)
- Conversion Efficiency ~ 32%-38%

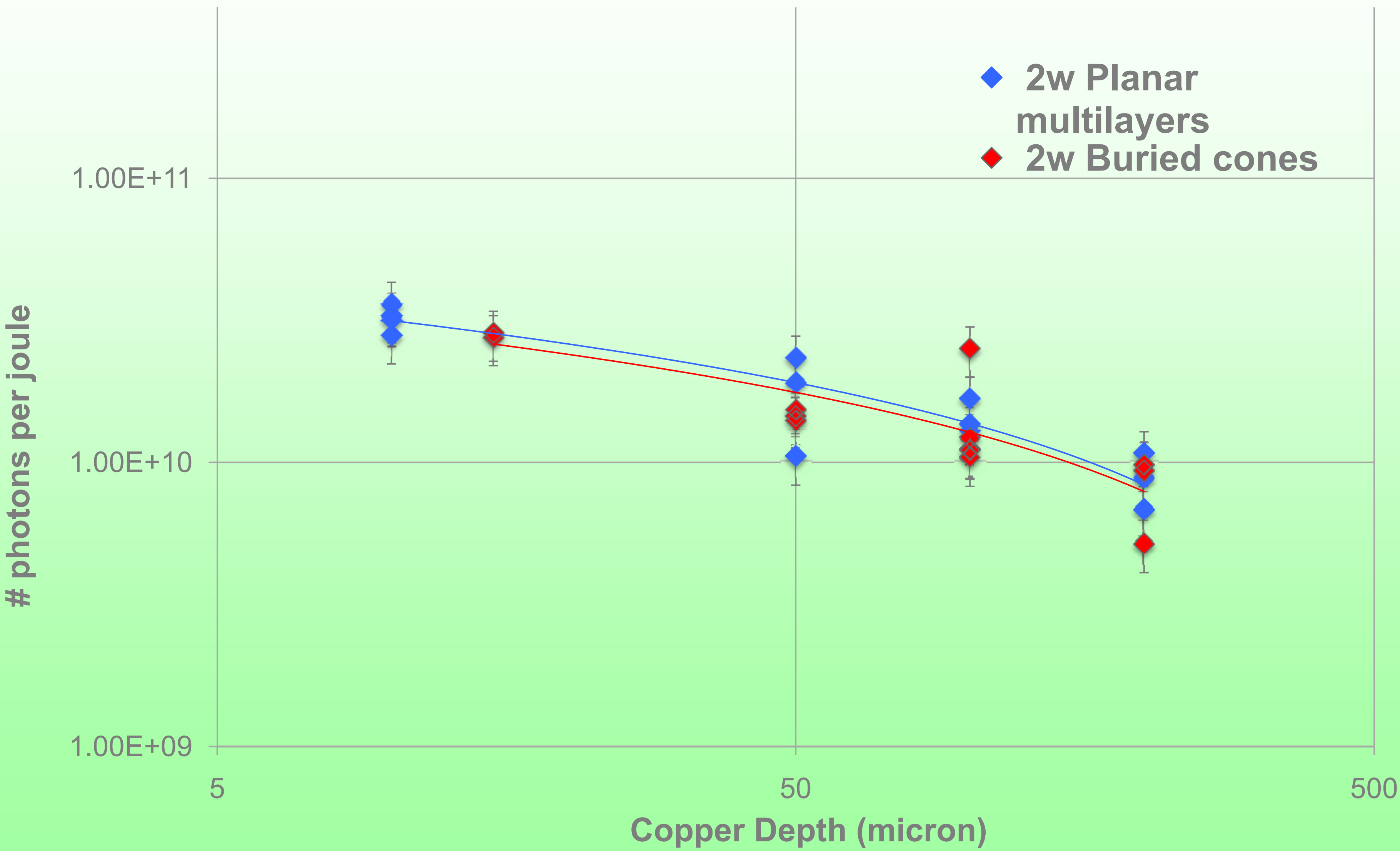
Compare to 1ω data for Al target (Chen PoP 16, 082705 2009):

- T_{hot} ~ 1.3 MeV
- Conversion Efficiency ~ 20-40%

Cu K_α HOPG Data: 1ω vs 2ω - Planar

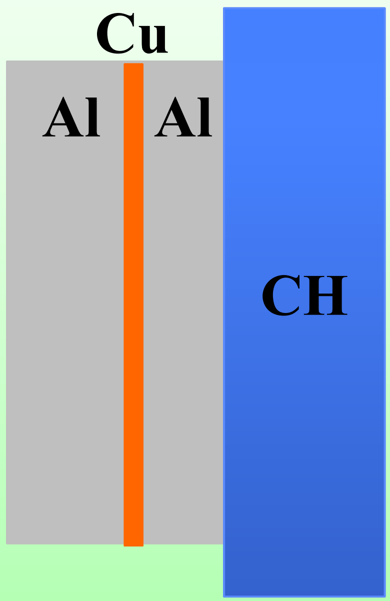


Cu K_α HOPG Data: Buried Cones vs Planar (2ω)



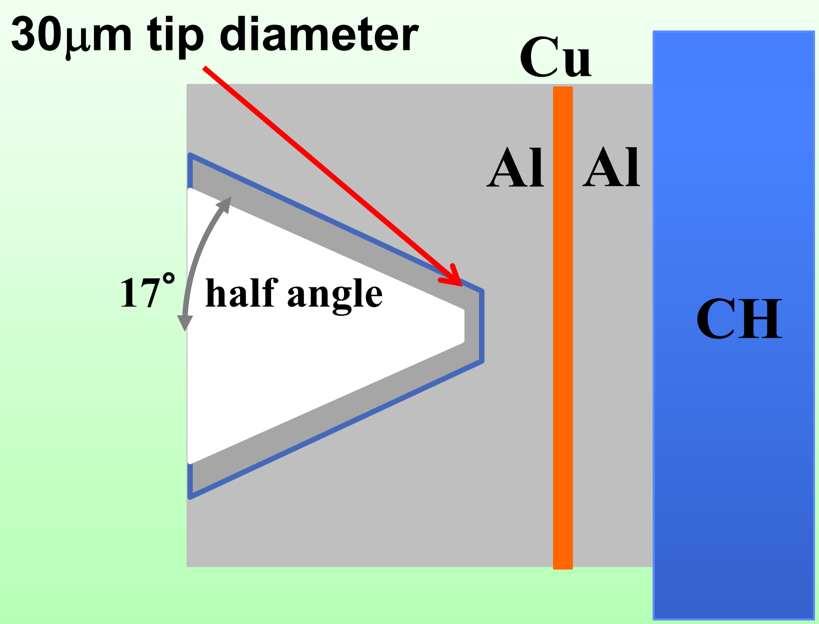
Electron Imaging Divergence Measurements

SLAB Targets



Variable Cu fluor depths for divergence calculation

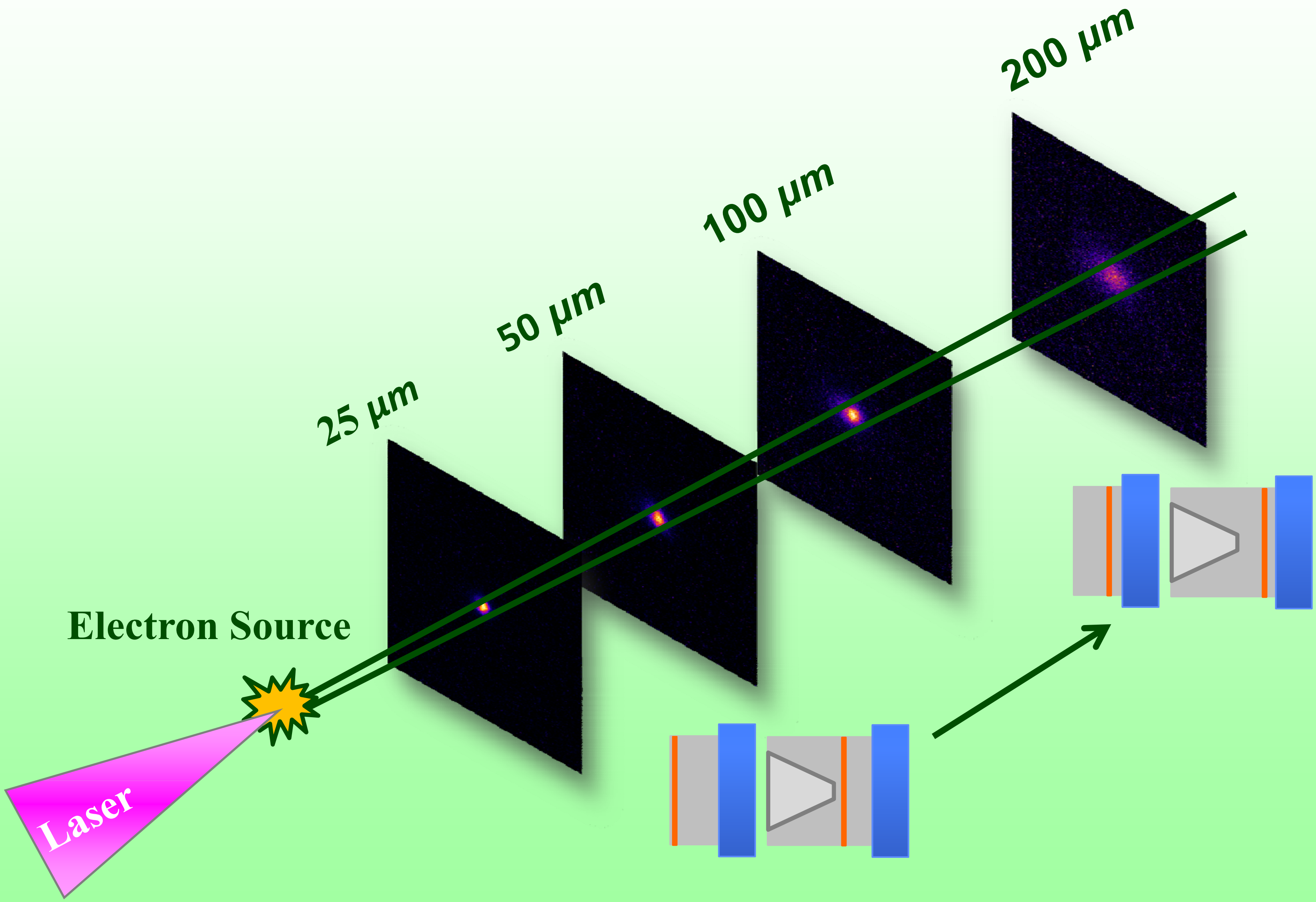
Buried Cone Targets



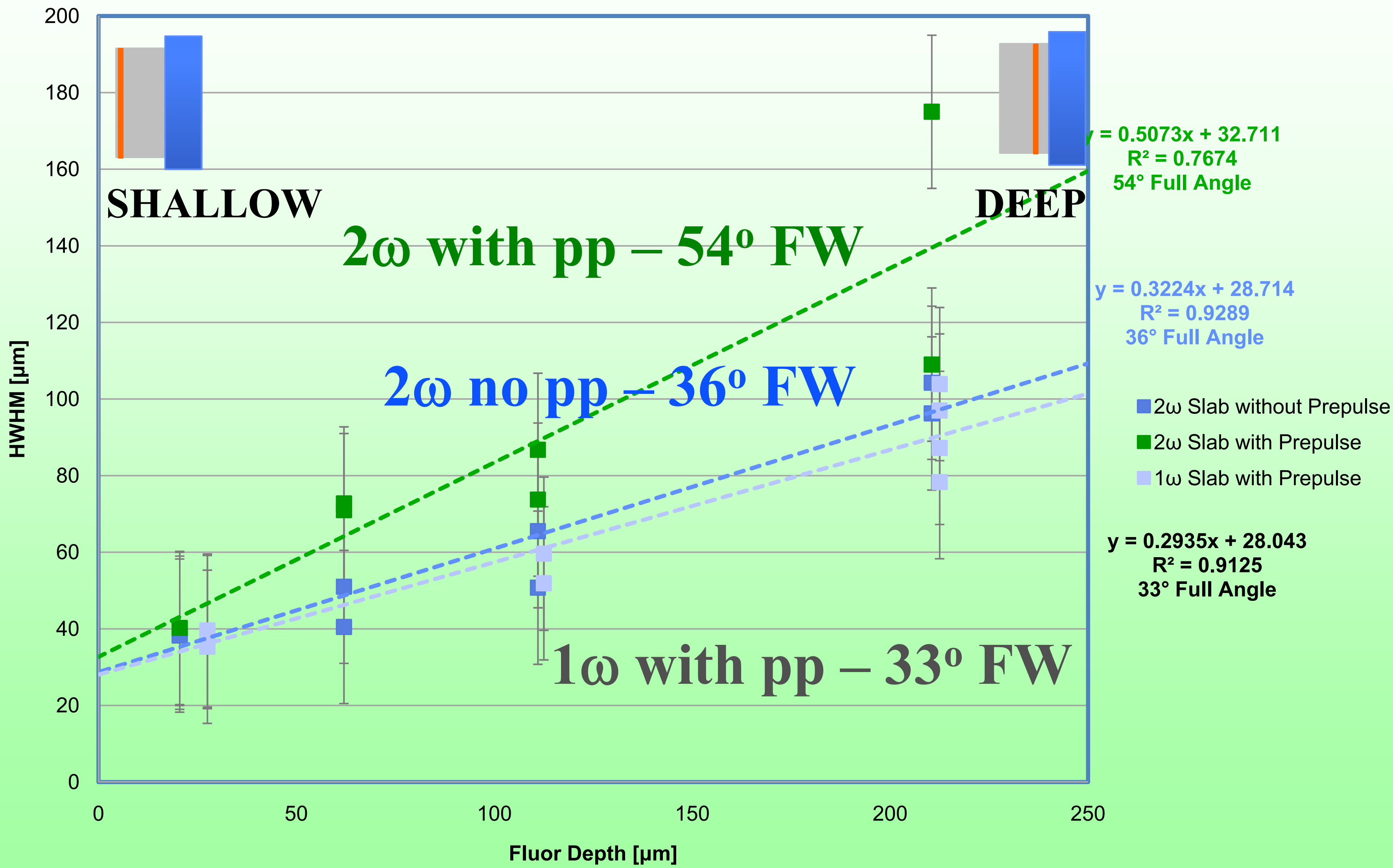
Surrogate for a cone surrounded by a conducting plasma

Thick 1mm CH layer to avoid electron refluxing

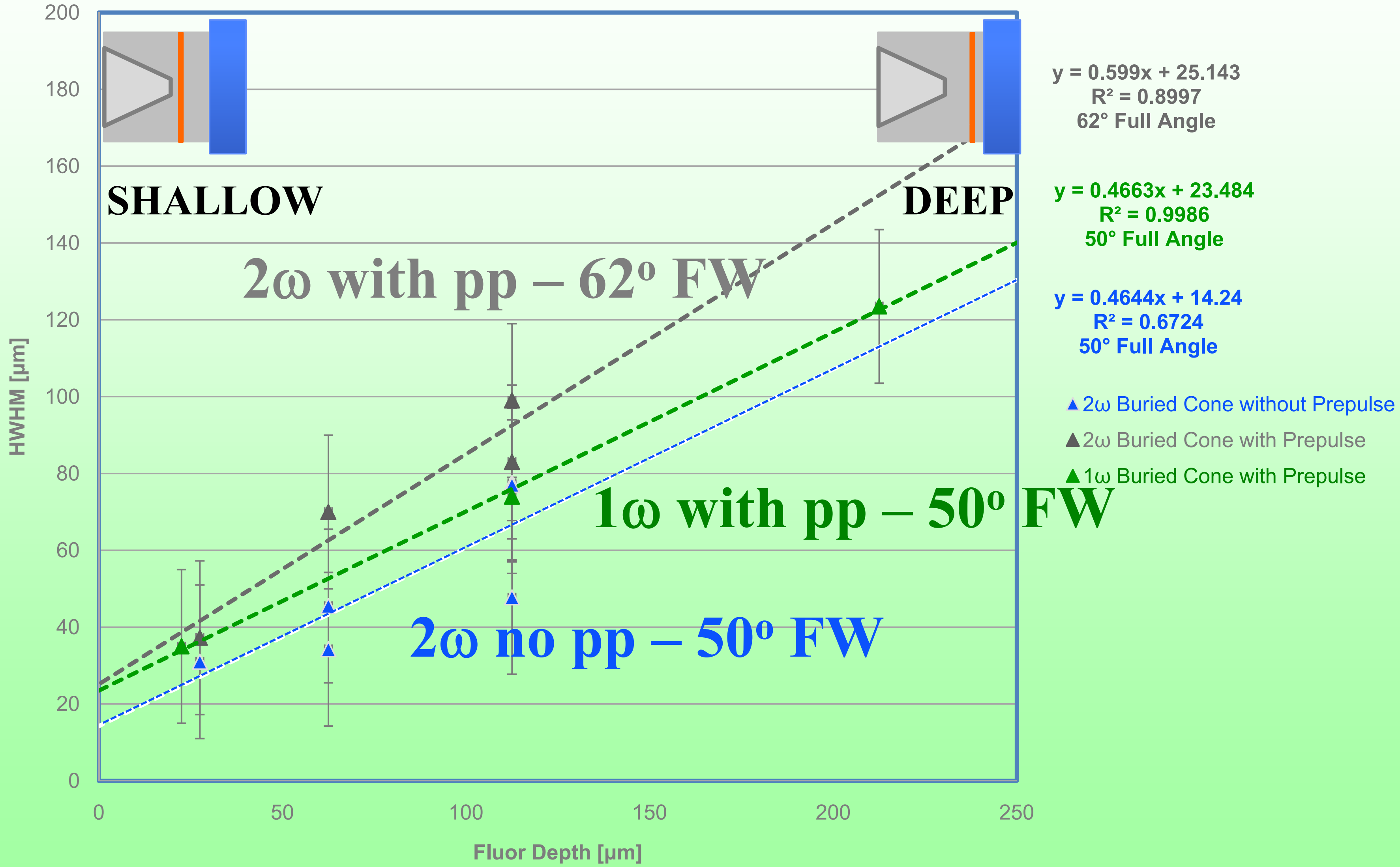
Electron Beam Divergence from K_α images



Preliminary Electron Beam Divergence - Planar

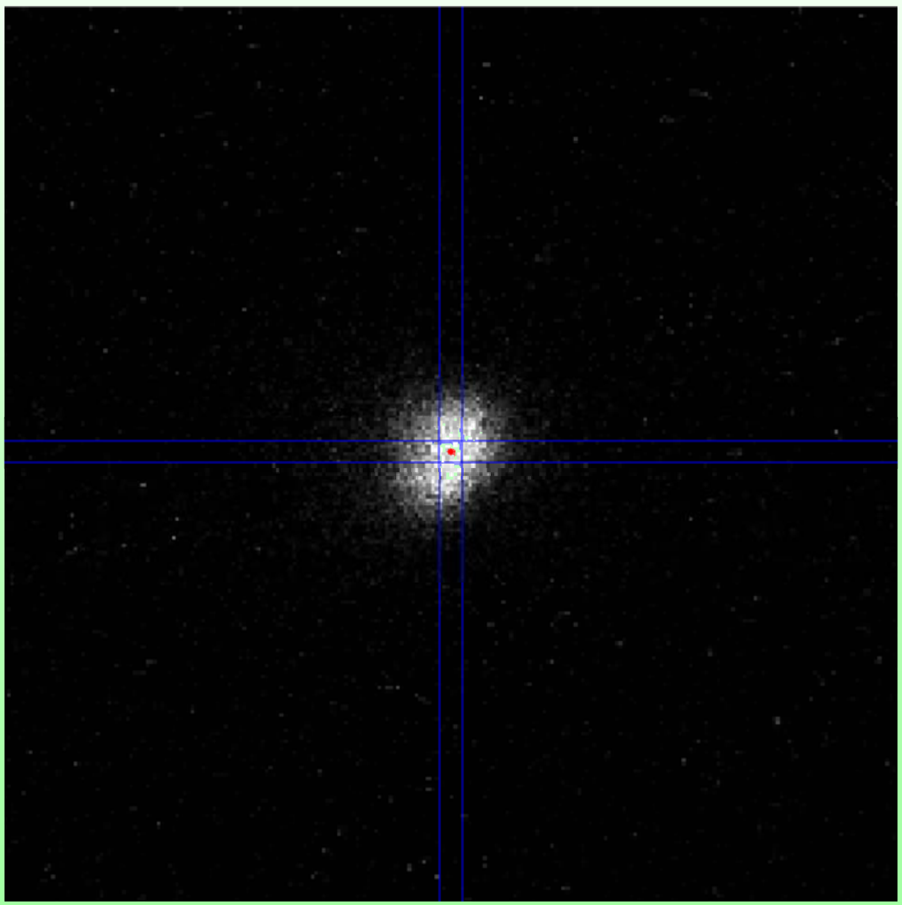


Preliminary Electron Beam Divergence – Buried Cones

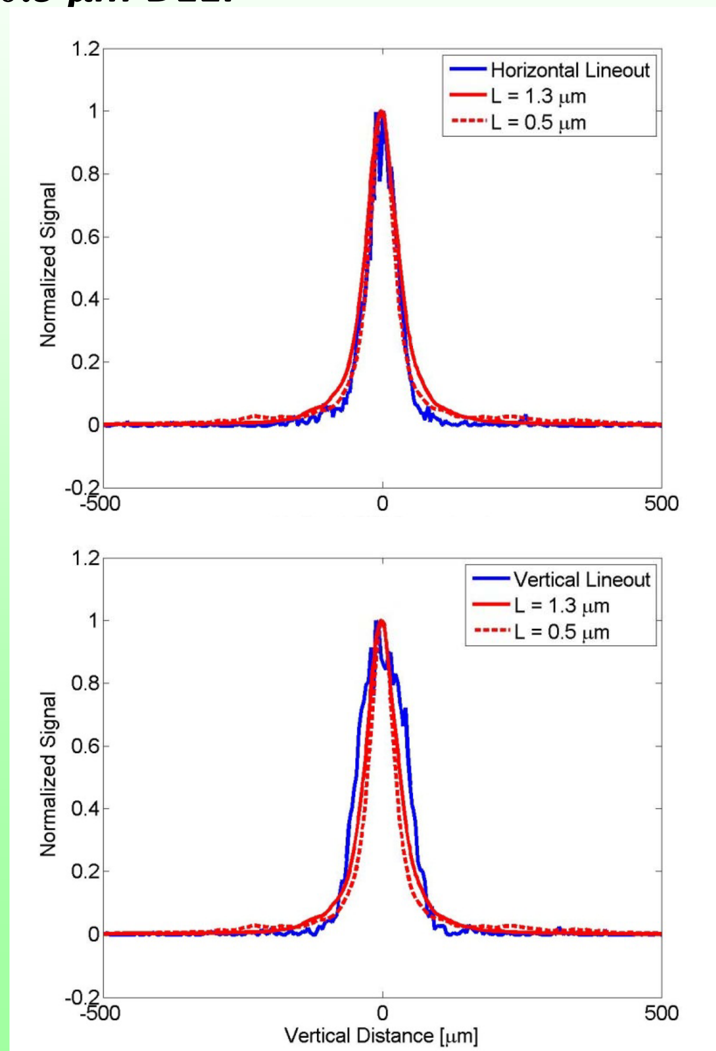


Initial LSP simulations with Laser Plasma Interaction Physics – Comparison to Data

TIME INTEGRATED CU Kα DISTRIBUTIONS – NO PREPULSE
CU FLUOR DEPTH 20.5 *μm* DEEP

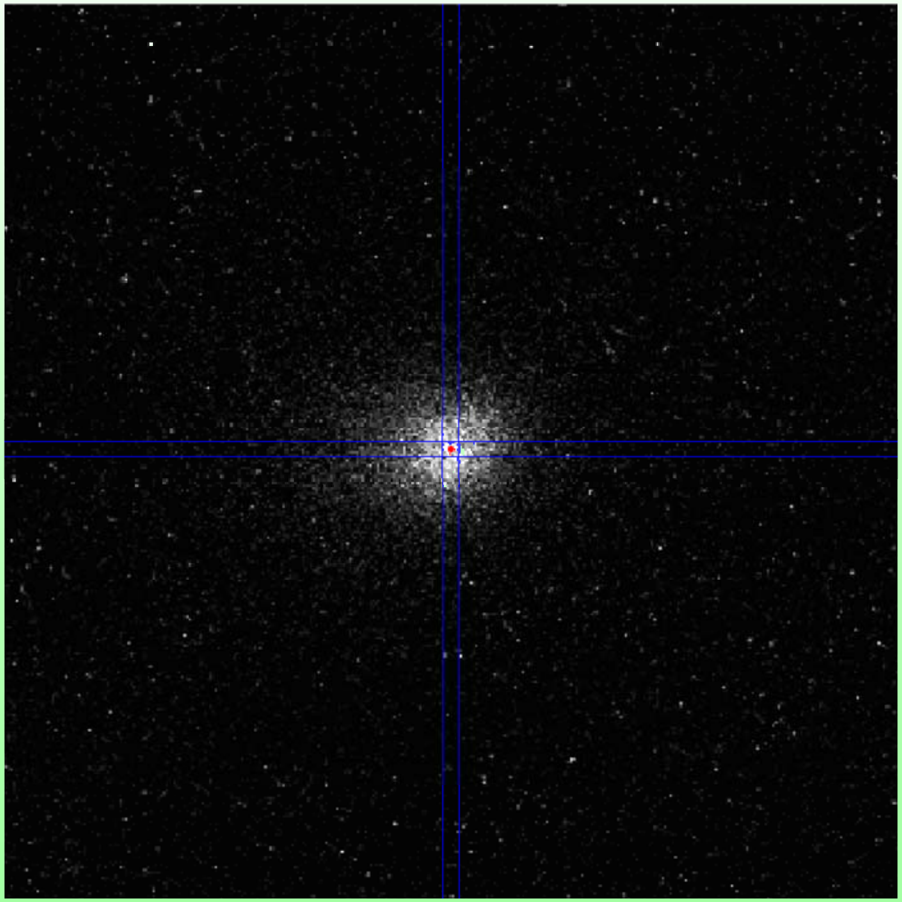


20100819_s01_CuKaSouth

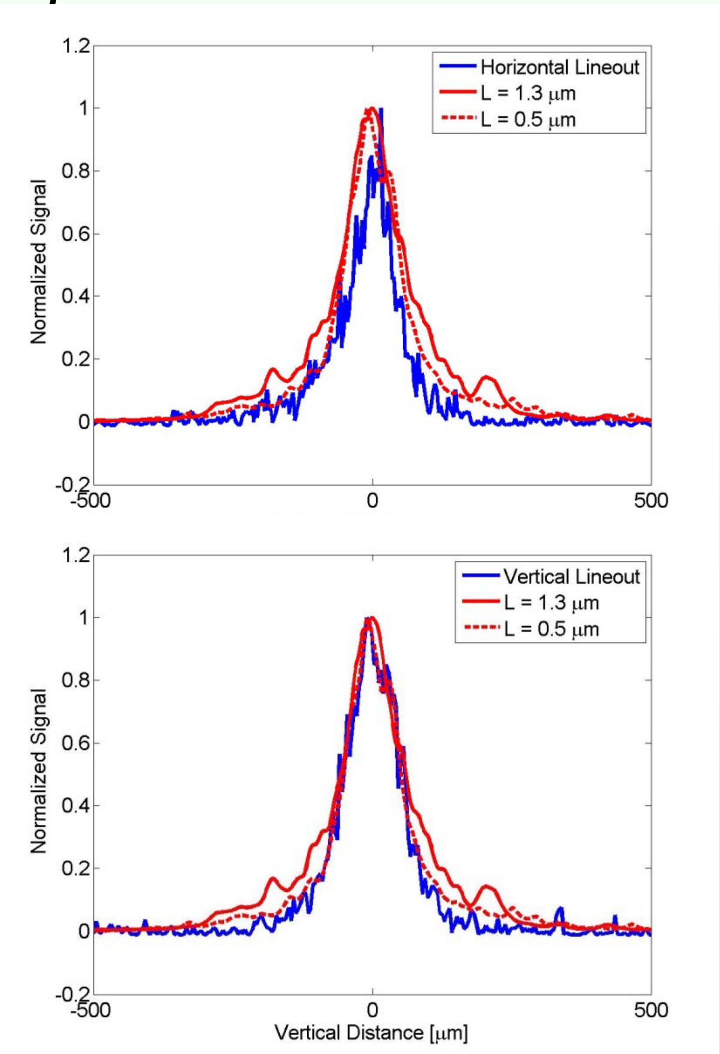


Initial LSP Code Comparison to data

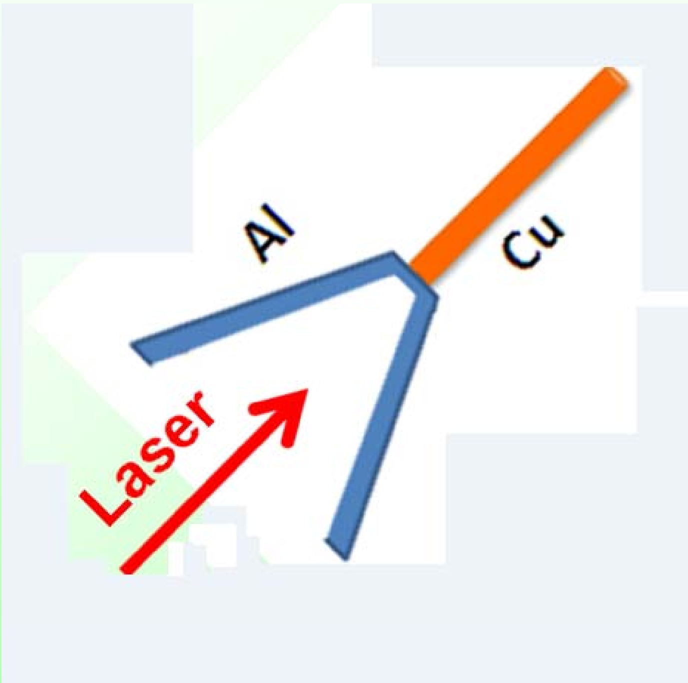
TIME INTEGRATED CU Kα DISTRIBUTIONS – NO PREPULSE
CU FLUOR DEPTH 111 μm DEEP



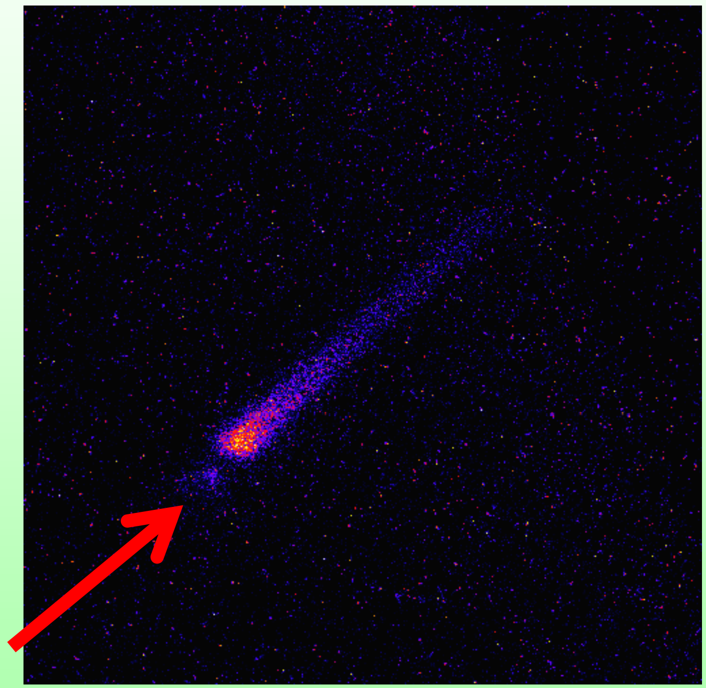
20100824_s06_CuKaSouth



Cone Wire Target – KB Image with no Prepulse



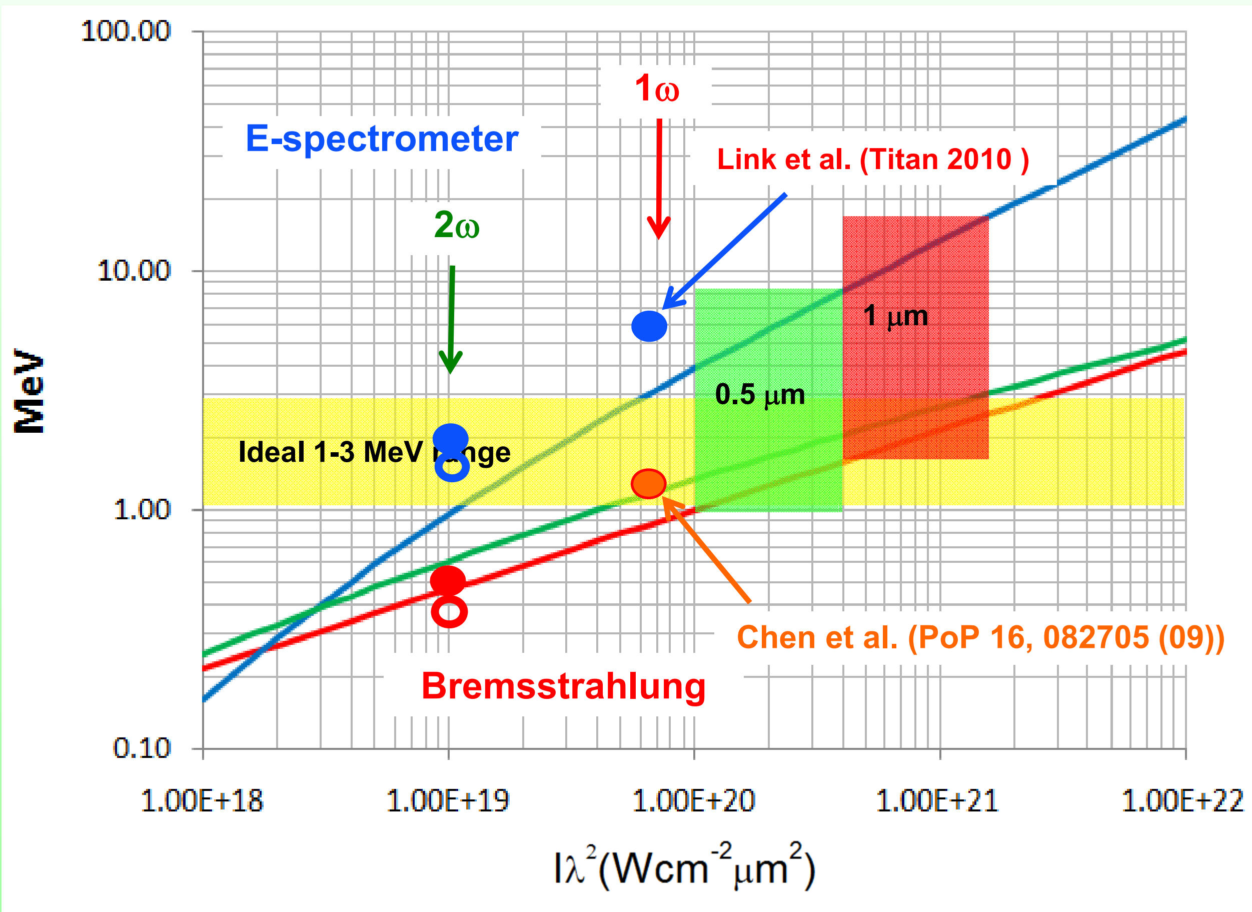
Viewed at approximately 45^o angle



Laser

Summary - Electron Energy Scaling

Experimental Results



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PRL 69, 1383 (1992)

Beg (Exp Bremsstrahlung)
Phys.Plasmas 4,447 (1997)

Haines (Energy/Momentum)
PRL 102, 045008 (2009)

Summary

- Successful implementation of 2ω target experiments at 50J 700fs level at the TITAN facility
- Conversion efficiencies over 60% obtained
- Intrinsic prepulse less than 10 μJ
- Controlled injection of prepulse of 3ns 3mJ
- Preliminary analysis of the experimental results carried out thus far
- Initial electron temperatures colder than 1ω as expected from $I\lambda^2$ scaling

  T_{hot} ~ 0.37 – 0.50 MeV (Bremsstrahlung)
  ~ 1.5 – 1.9 MeV (escaping hot electrons)

Summary

- Initial divergence angles similar to 1ω
- Difference seen between angularly resolved Bremsstrahlung and Kα imager angles
  - FW ~ 120^o – 142^o Bremsstrahlung
  - FW ~ 36^o – 62^o K_α imaging
- Buried Cones show slightly larger divergence angles
- Absorption and electron yield lower than 1ω as expected for lower Iλ^2
  - η_{e-} ~ 11 – 17 %
  - R ~ 27 – 14%
- Red shift and smoothing seen in specular reflection with prepulse indicating preplasma effects
- Extensive modeling under way to better understand the results

End