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Study of the Polarization Dependence of Two Beam Interactions

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Study of the Polarization Dependence of Two Beam Interactions

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CEA

Workshop on
Multi-Beam Laser Plasma Interaction Experiments and Related Physics
IEEE International Conference on Plasma Science
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Monterey Ca.

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Energy Transfer Experiments Investigate the Effect of Beam Polarization on Multi-beam Interactions

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- **Previous experiments in CH and Al foil plasma have demonstrated a power transfer between beams in a flowing plasma and shown evidence of non-linear saturation of the simulated ion waves causing the power transfer. This has led to a plan for controlling energy transfer in NIF with frequency shifted beams.**

- **Initial experiments in CH plasmas investigating the <u>importance of the relative polarization</u> of the two beams to further control multi-beam interactions show:**
  - **The polarization of the probe beam is rotated when it is amplified, consistent with models.**
  - **The backscatter of the pump beam is dependent on relative polarization of the probe, as may be explained by non-linear interactions between waves driven by the different beam.**

Two Beams in a Flowing Plasma Will Stimulate Ion Waves That Scatter Energy Between the Beams

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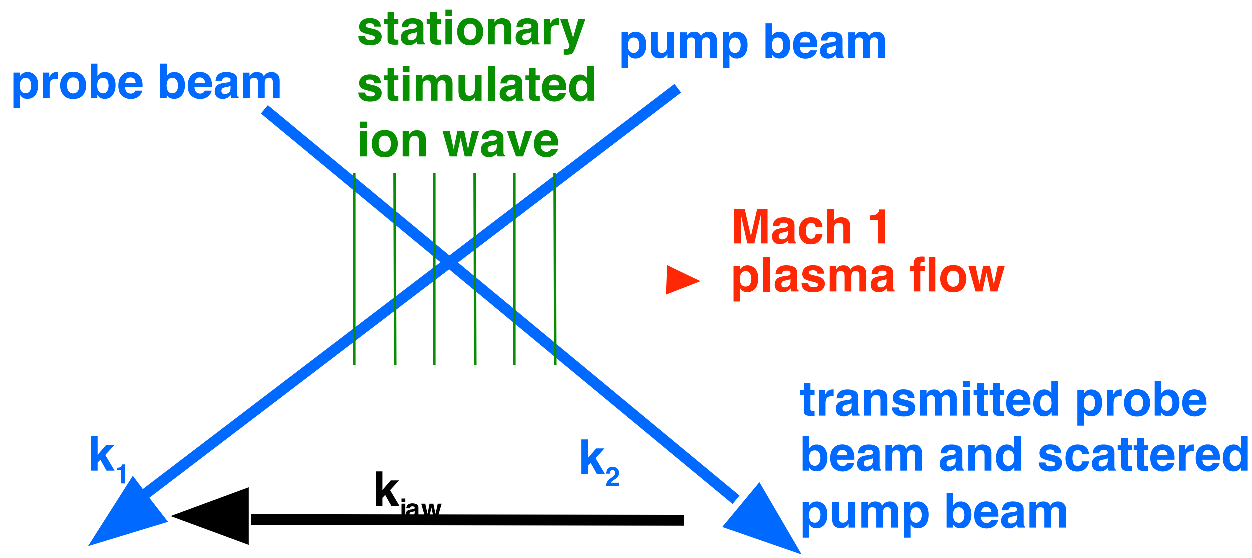

A stationary intensity profile is produced by two beams that has a spatial frequency component determined by the difference in the two wave vectors.

$$\mathbf{k}_{iaw} = \mathbf{k}_1 - \mathbf{k}_2$$

When a Mach 1 flow is present a stationary ion acoustic wave ($w_{ia} = 0$) is resonant with the intensity profile and grows to large amplitude.

$$w_{ia} = c_s |\mathbf{k}_{ia}| + \mathbf{v}_o \cdot \mathbf{k}_{ia} \sim \mathbf{0}$$

The ion wave forms a 3D diffraction grating that scatters power from one beam to the other.

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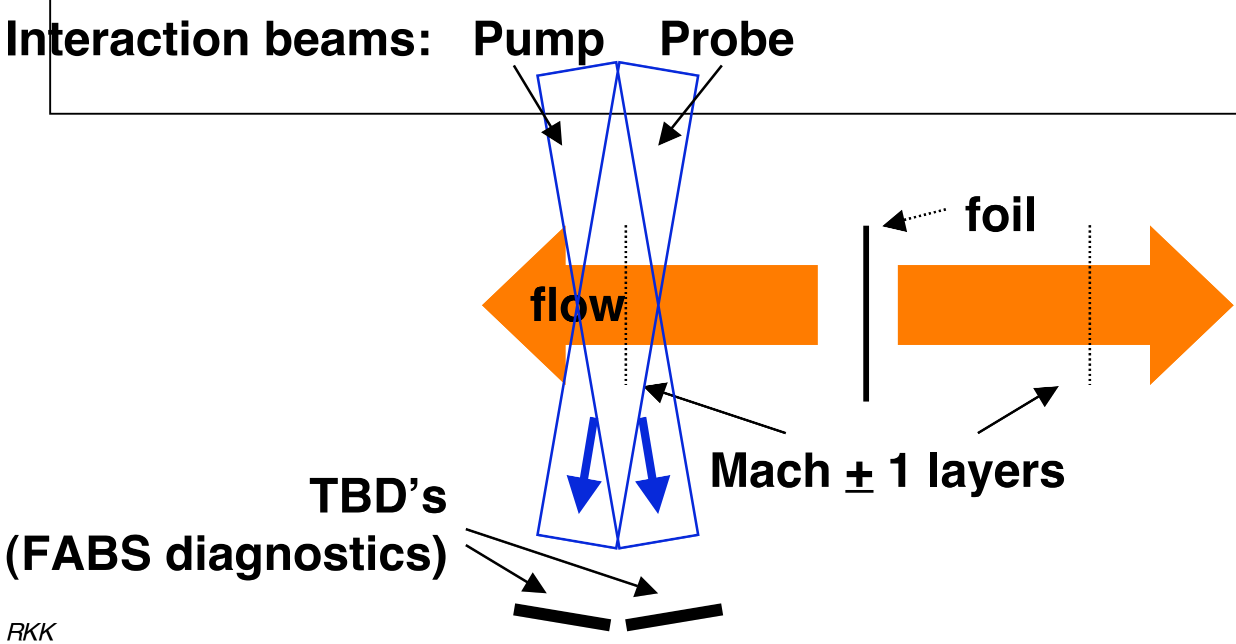
Omega Experiments have Simulated the Crossing Geometry and Plasma Flow of a Laser Entrance Hole in a Hohlraum

- Previous Experiments have Demonstrated:
- 1) Energy and Power transfer between same frequency beams crossing near to parallel (q = 25°, forward scatter) similar to the inner and outer cones on NIF (q = 14.5°- 26.5°)
- 2) That the Amplification of the probe beam is non-linearly saturated when the probe power approaches the pump and plasma scale lengths are small.



The forward scatter geometry has flow perpendicular to beams. (beams parallel to foil)

Energy is transferred from pump to probe; in the direction of the flow !

Reversed effect is obtained on opposite side of foil.

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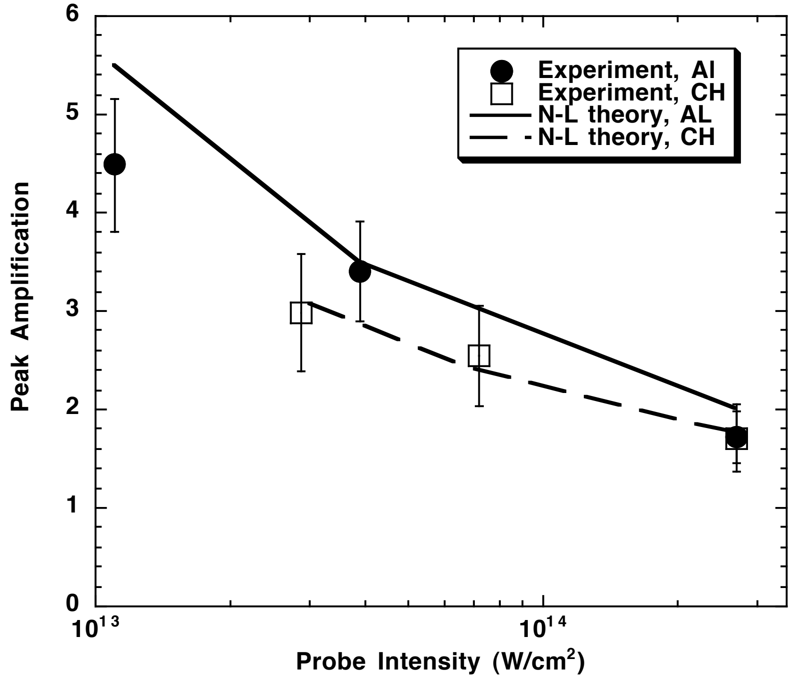
Measured 'Peak Amplification' Indicates Peak Ion Wave Amplitude and Shows Saturated Scaling with Probe I in both CH and Al Consistent with Modeling in Short Scale Length Plasmas



Amplification is averaged over 200 ps and peak values show no significant dependence on plasma material or the damping rate of the ion acoustic wave

The reduced amplification at high probe intensity is consistent with saturation by wave frequency detuning in both Al and CH as shown on plot. Local pump depletion may also play a role in saturation.

Future Improvements to the model:

1) Add gradients to the 1D model (presently a slab)

2) Add non-linear frequency shifts due to electrons

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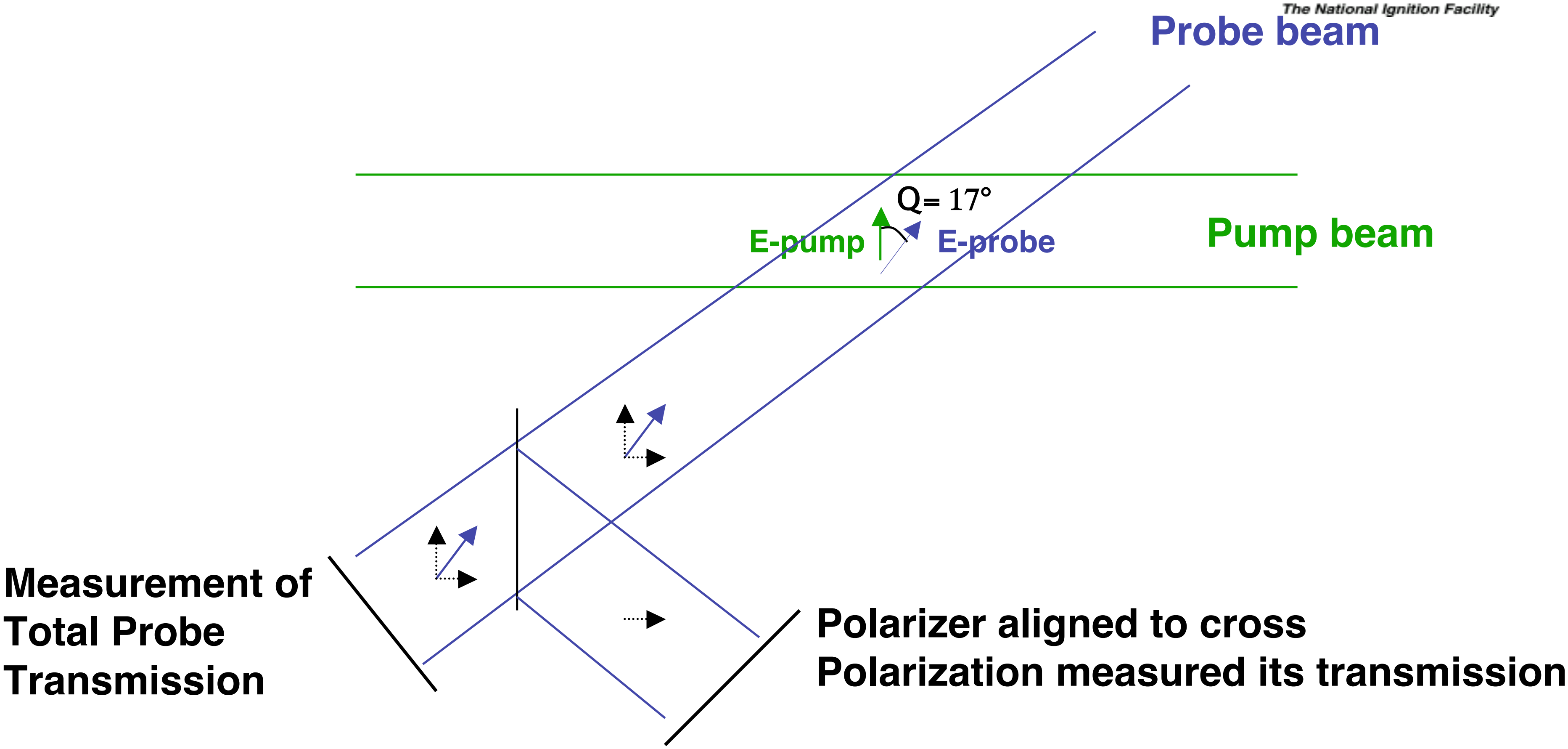
Polarized Detectors Now Measure the Cross Polarized Component of Probe to Show The Effect of Amplification on Polarization



The small fraction of power in the cross polarization is monitored separately from the total transmitted power.

This cross polarization component should experience only plasma absorption, and the large component aligned to pump is amplified by stimulated ion wave scattering of pump.

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Transmission of Cross Polarized Component is Less Than Transmission of Amplified Total Power

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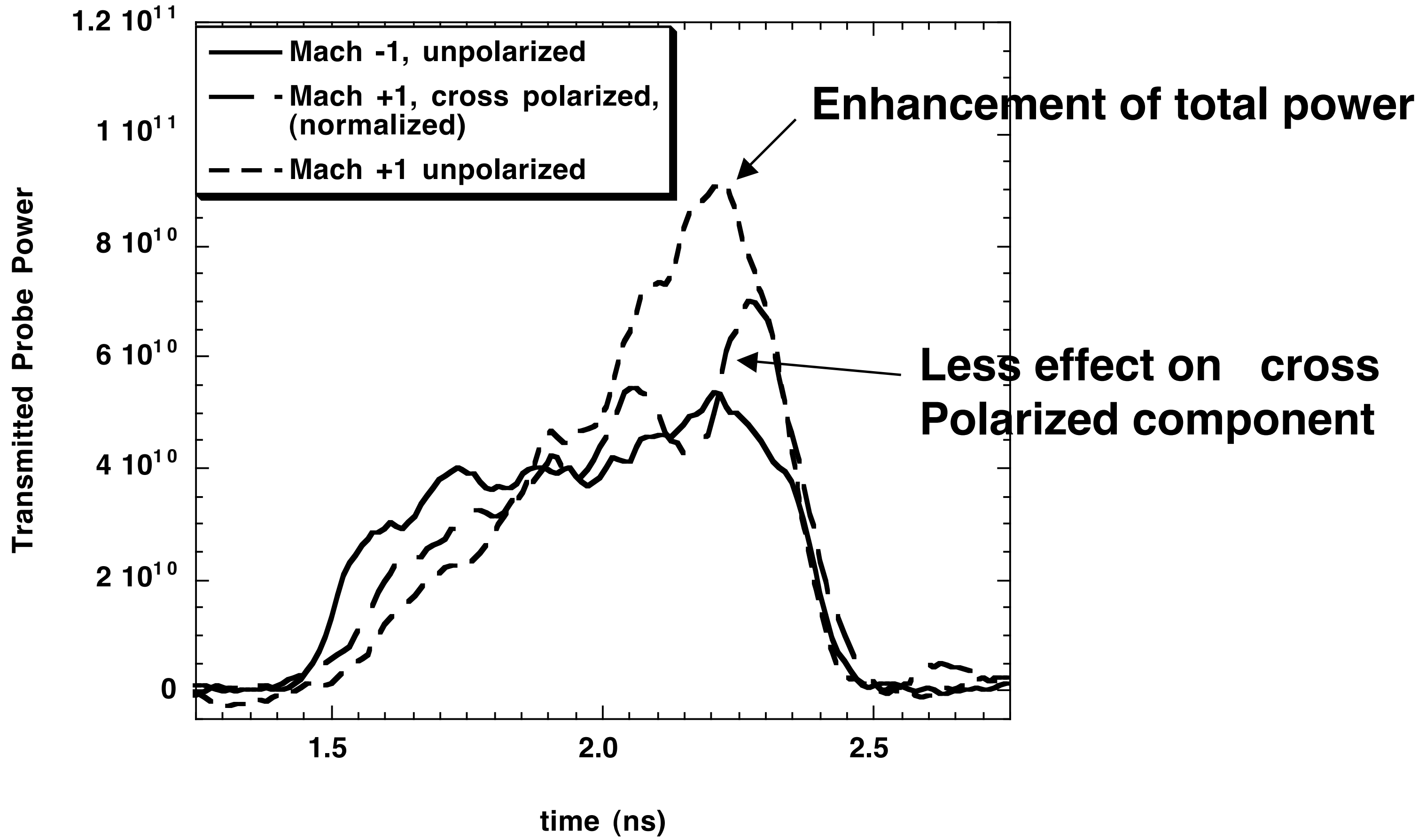

In the high intensity CH case amplification relative to Mach -1 is only significant in Total power, indicating no significant amplification of cross polarized component. (This indicates the probe polarization rotates toward alignment with the pump)

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The effect of the Polarization of the Probe Beam on the Backscatter of the Pump has also been Studied

Initial studies in gas bag targets with single frequency beams, put beam crossing volume in region of large Langmuir waves produced by SRS backscatter of the pump to study the non-linear coupling with waves produced by the beat of the two beams. (Energy transfer ion waves may not be resonant in this case, fluctuations driven by filamentation, and SRS Langmuir waves of the probe may also play a role)

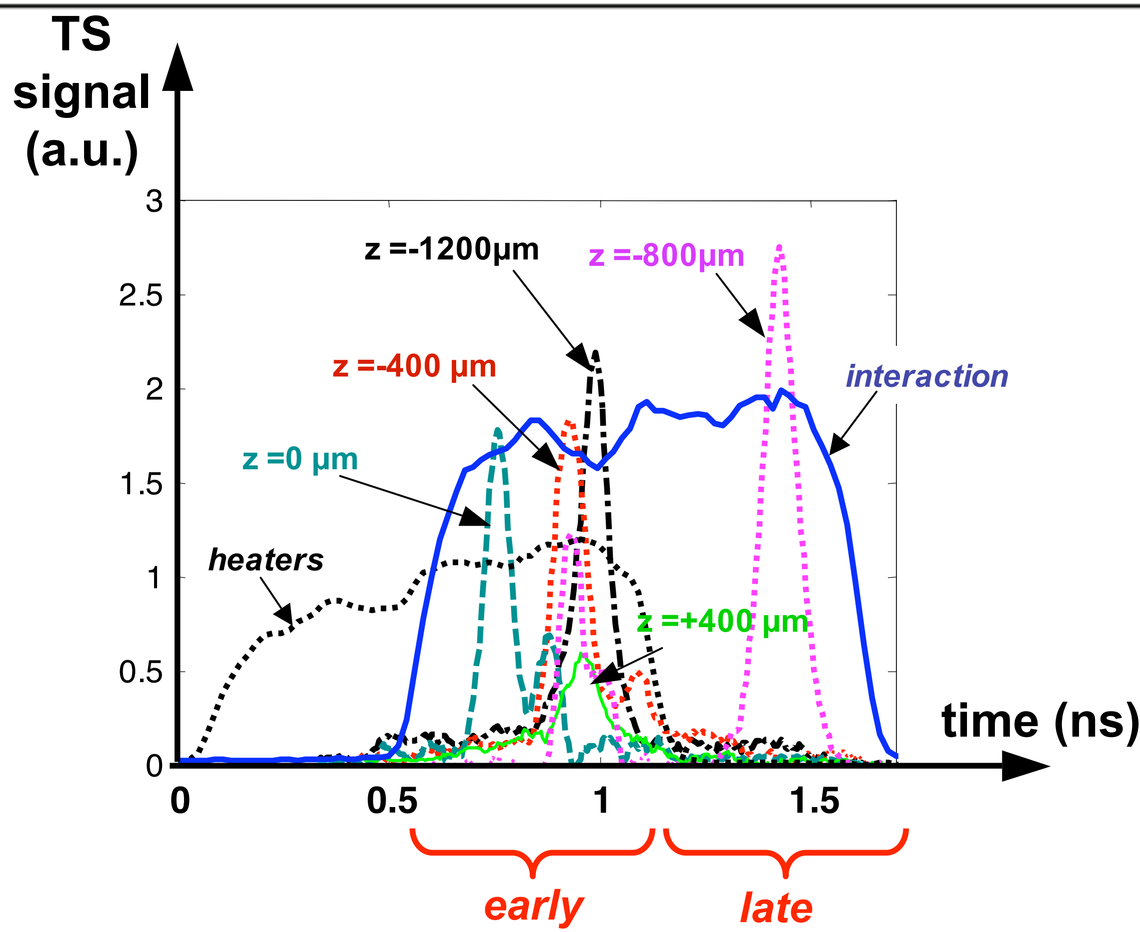
SRS was studied in 3 cases at 5.8% critical density and *without SSD smoothing*:

1) With a single pump beam
2) With a pump and crossing probe beam with polarizations *aligned*.
3) With a pump and crossing probe beam with polarizations *crossed*.

SRS was studied in 2 cases at 6.8% critical *with SSD smoothing*:

1) With a pump and crossing probe beam with polarizations *aligned*.
2) With a pump and crossing probe beam with polarizations *crossed*.

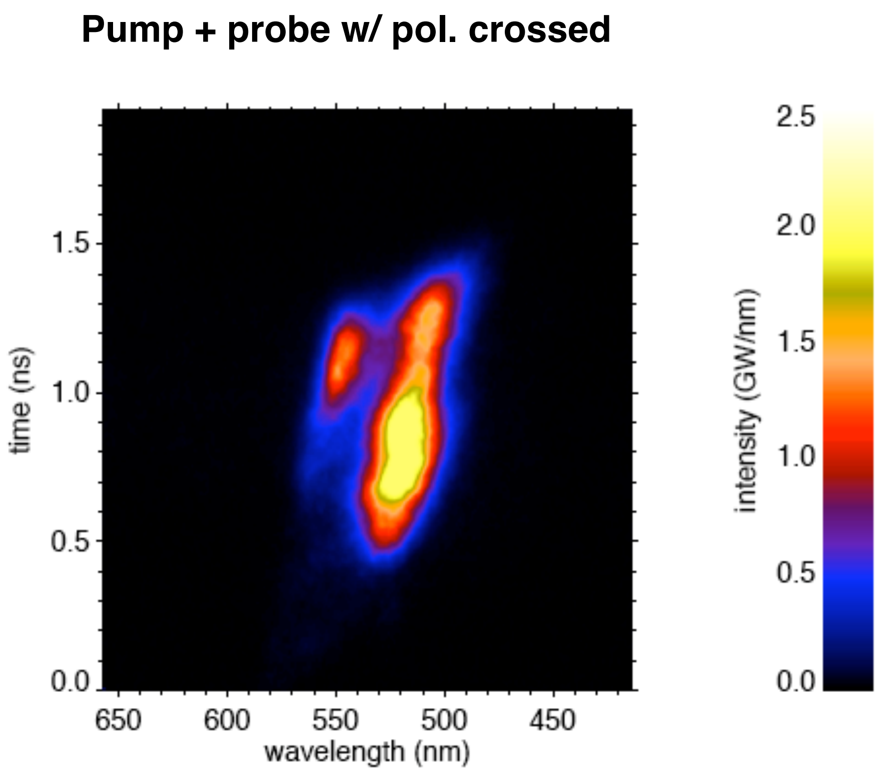
Thomson Scattering Experiments (with CEA) Show Langmuir Waves driven by a Single Pump beam in the Beam Crossing Volume in a Gas Bag are Large at Early Time

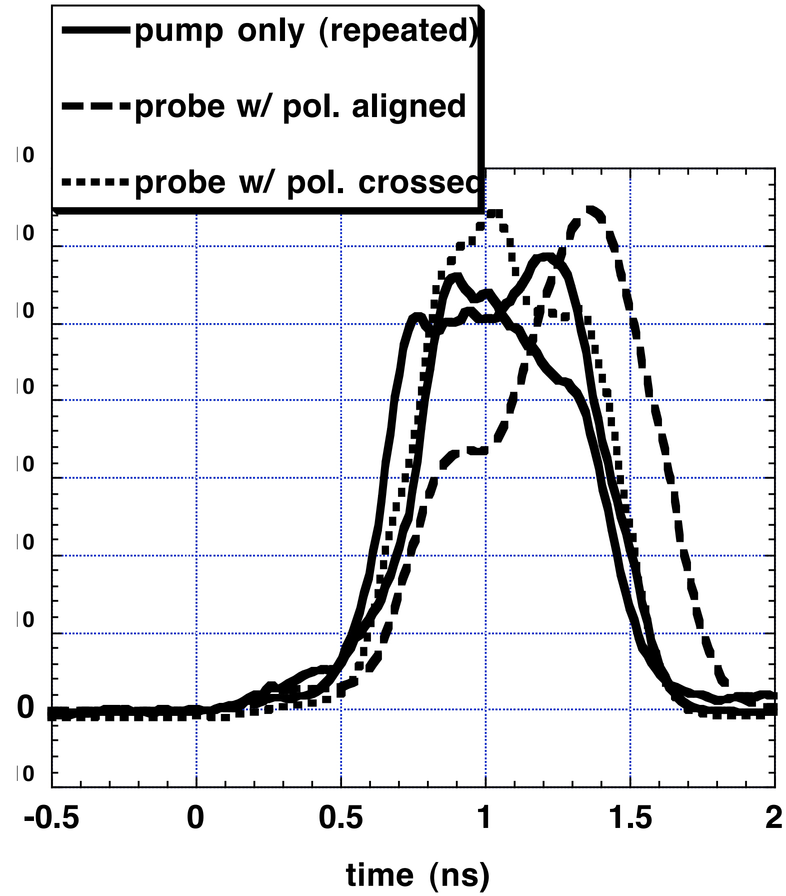


Thomson measurements[1] show the largest wave amplitudes in the beam crossing volume at early time (0.5-1.0 ns), where the potential for affecting the Large SRS scattering of the pump with the probe beam is greatest.

RKK [1] S. Depierreux, et. al. In preparation.

Experiments at 5.8% Critical Density and No (SSD) Beam Smoothing Show a Crossing Beam with Aligned Polarization Reduces SRS at Early Times





This Experiment was done at ~5.8% critical with No SSD

Early time SRS appears suppressed only when E_probe dot E_pump is large.

Consistent with ion waves, driven off resonance causing detuning of SRS

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Further Experiments at higher density and with SSD show the effect of crossing beam polarization at late time

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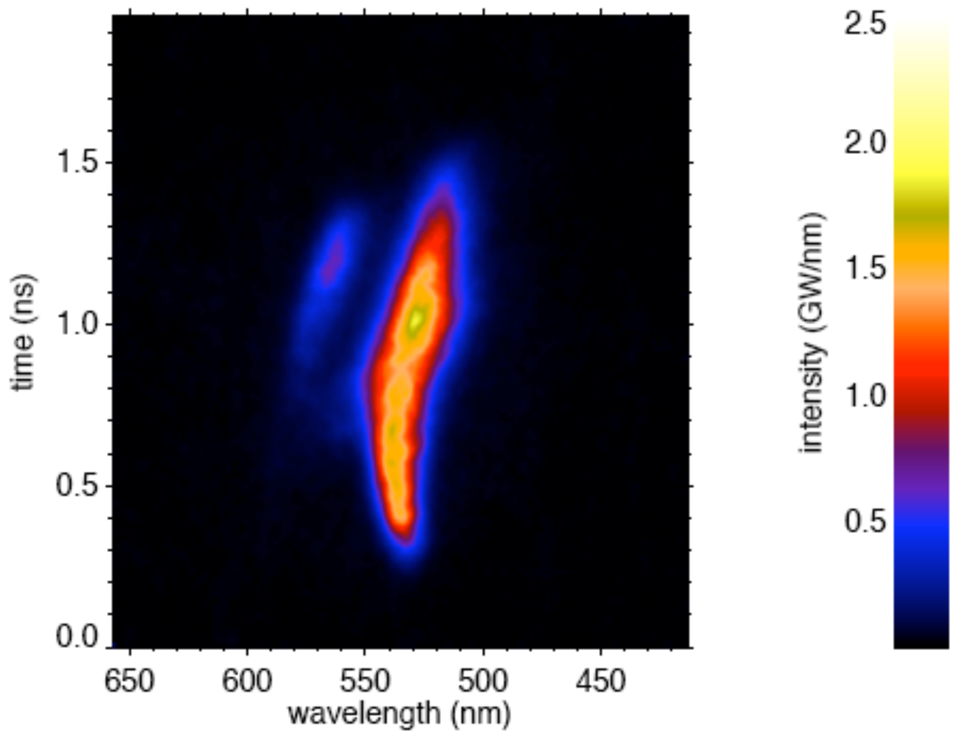
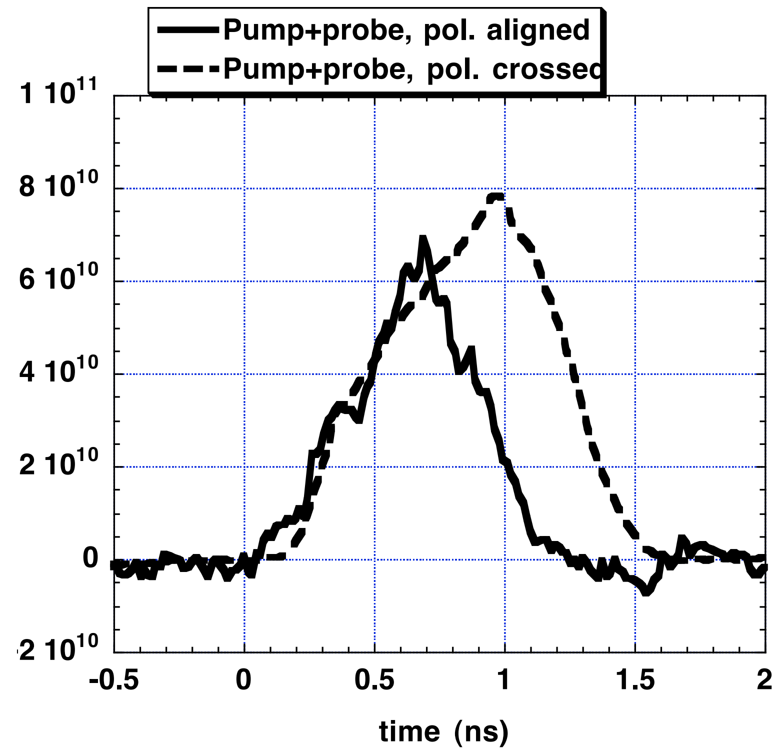
Pump + probe w/ pol. crossed





~6.8% critical density

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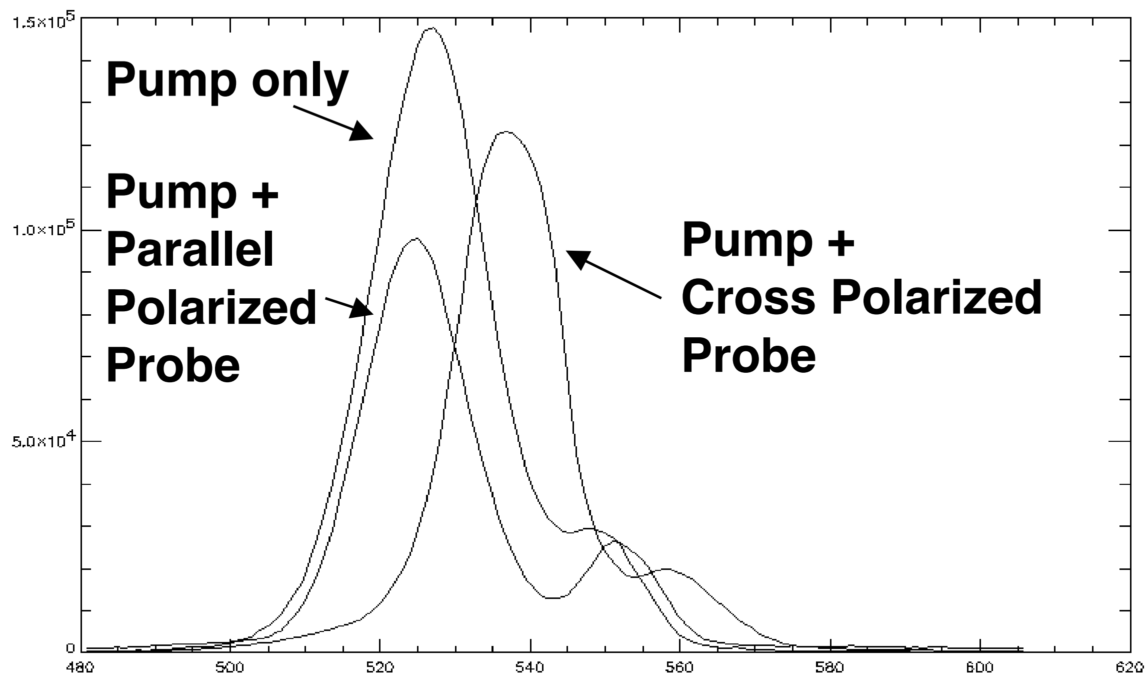
Conclusions on Polarization Effects in Multi-Beam Interactions

Recent experiments show:

Polarization measurements show probe beam amplification is only significant for probe field component that is aligned to the pump field, **indicating the amplification produces the expected rotation of the polarization, and suggests that adjusting beam polarization can control energy transfer.**

Initial backscatter measurements show polarization controls the effect of the two beam interaction on SRS.

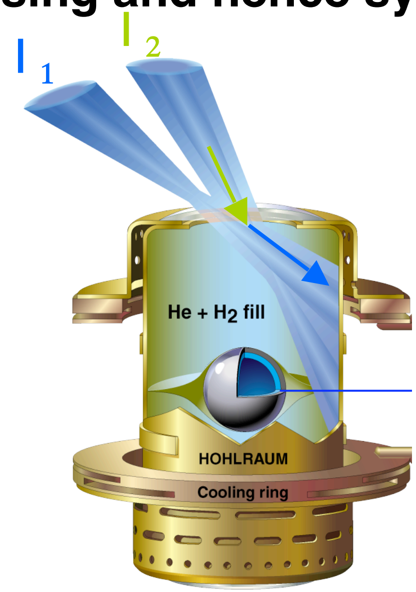
Early Time SRS Data is Consistent with Waves Produced by The Beating of the Two Beams Affecting SRS Backscatter



The probe beam reduces the early time SRS of the pump most significantly when Its polarization is aligned to the pump.

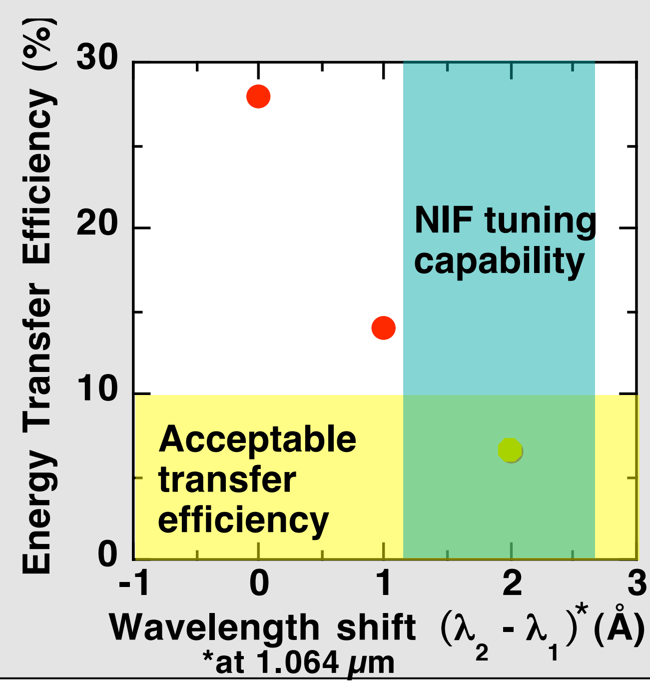
Cross-beam energy transfer will be controlled on NIF by wavelength detuning the inner cone beams ("2-color operation")

Issue is energy transfer from inner to outer beams changing power phasing and hence symmetry



Experiments at NIF-relevant laser intensity at Omega and Nova have measured < 20% *on-resonance* energy transfer consistent with simulations

Calculated NIF cross-beam energy transfer efficiency



Shift of + 2Å should reduce total NIF energy transfer to the < 10% level needed for symmetry

Backlit foamballs will be used to optimize wavelength detuning and tune out any residual asymmetry swings

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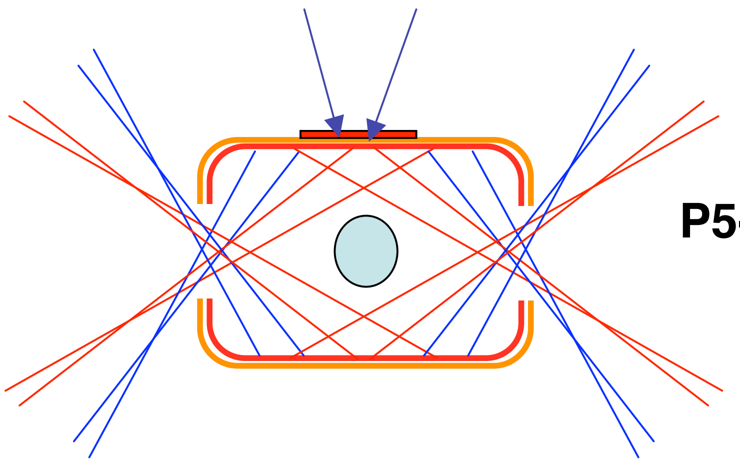
Future Work

To further validate the NIF '2-color' plan to frequency shift the inner cone Beams to control illumination symmetry, a series of implosion experiments are Planned [1]

C1 and C2 (different color) May use DPP



P5-P8

20 beam drive

Foamballs Thinwall imaging

The present Omega laser system can frequency shift nearly one entire inner cone Of beams, and modifications may allow frequency shifting of both inner cones.

Foamball thinwall imaging experiments can demonstrate the effect of frequency shifting on implosion symmetry.

[1] E. A. Williams et. al. these proceedings

Initial Work Used CH Foil Targets Designed to Produce Mach = 1 Flows with Minimum Refraction and Absorption

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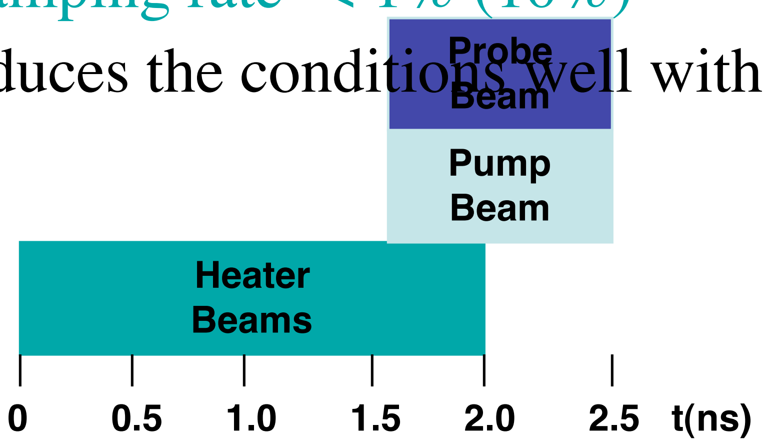
Lasnex simulations of a 4 micron thick Al(CH) foils with 2.5 kJ of heater energy in a 2 ns pulse gives, at t = 2.0 ns and z = 350 microns:

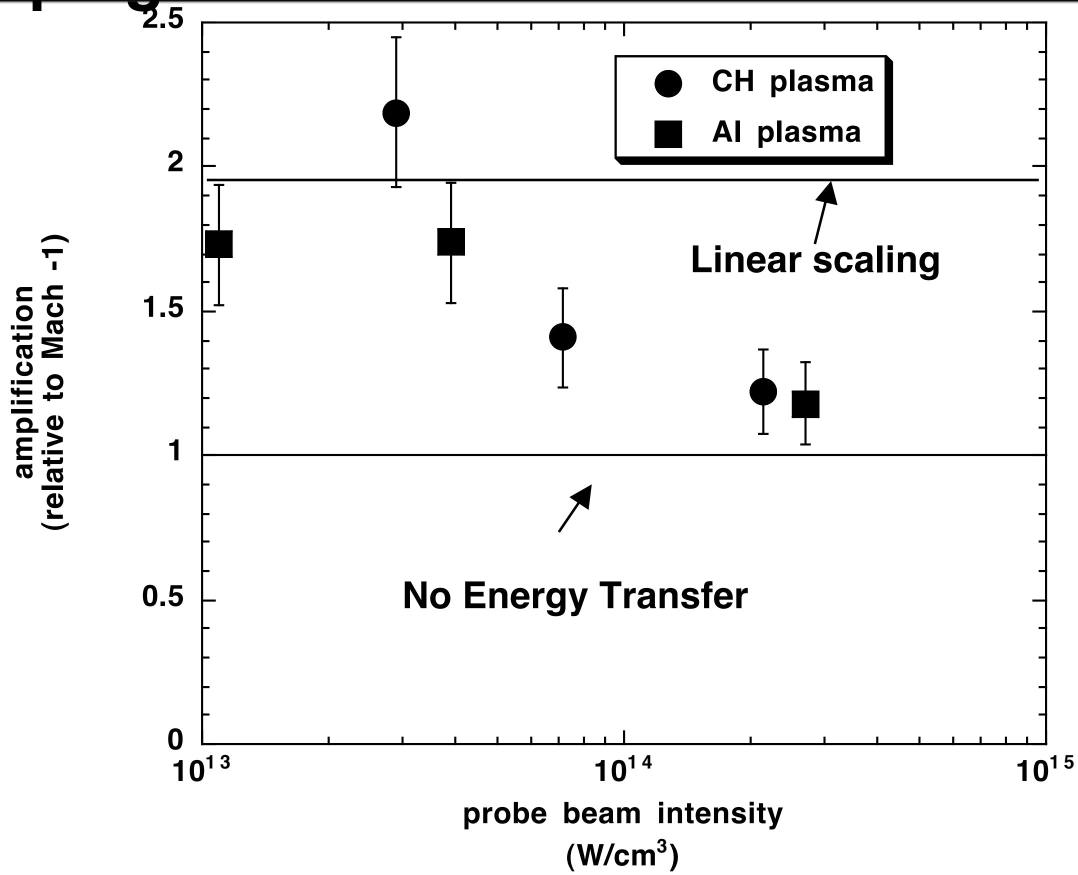
- Flow Velocity = Mach ~1
- n_e = 5% critical (6.5%)
- T_e = 1.6 keV (1.2 keV)
- Plasma length ~ 750 μm (same)
- Ray Transmission ≥ 65% (≥ 77 %)
- Ion wave damping rate < 1% (10%)

This reproduces the conditions well with much lower IAW damping.

Timing of Beams
(1ns square interaction pulses)



Time Integrated Energy Amplification Shows Similar Intensity Saturation with Both Weak (Al) and Strong (CH) Ion Wave Damping



(pump = 7 x 10^{14} W/cm^2)

The probe beam amplification is found to scale non-linearly and is consistent non-linear ion wave models (shown) and may also be consistent with localized Pump depletion.

This scaling is the first demonstration that *Energy Transfer can be non-linearly saturated* (PRL Nov. 2002 and submitted).

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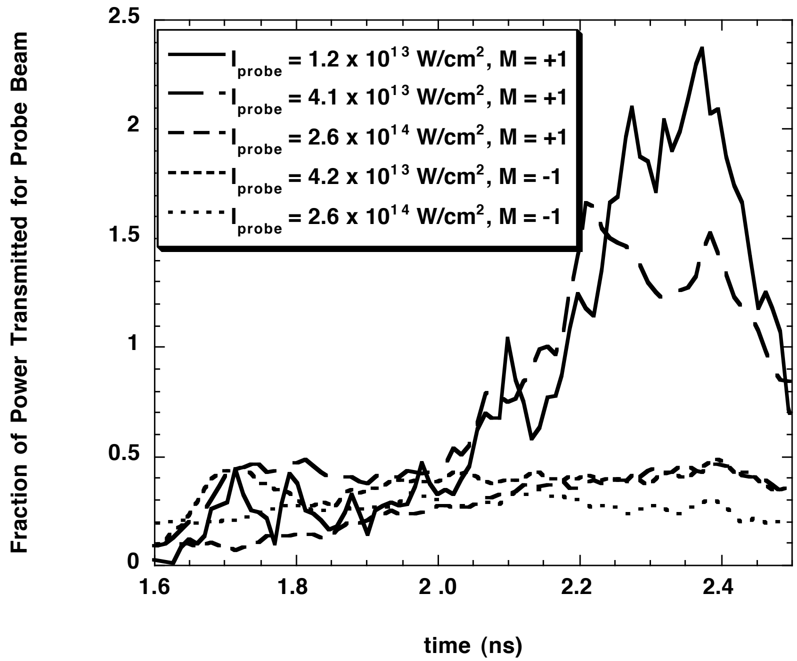
Power Transmission Wave Forms Show Enhancement at Mach +1, and Strong Time Dependence of Amplification



pump intensity = 7×10^{14} W/cm^2

The large enhancement at late time is consistent with the localized Resonance moving into the beam crossing volume.

Time variation of the incident pulse can confuse interpretation.

The Highest Intensity (Saturated) Case Shows Similar Time Dependent Amplification in Both CH and Al Plasmas

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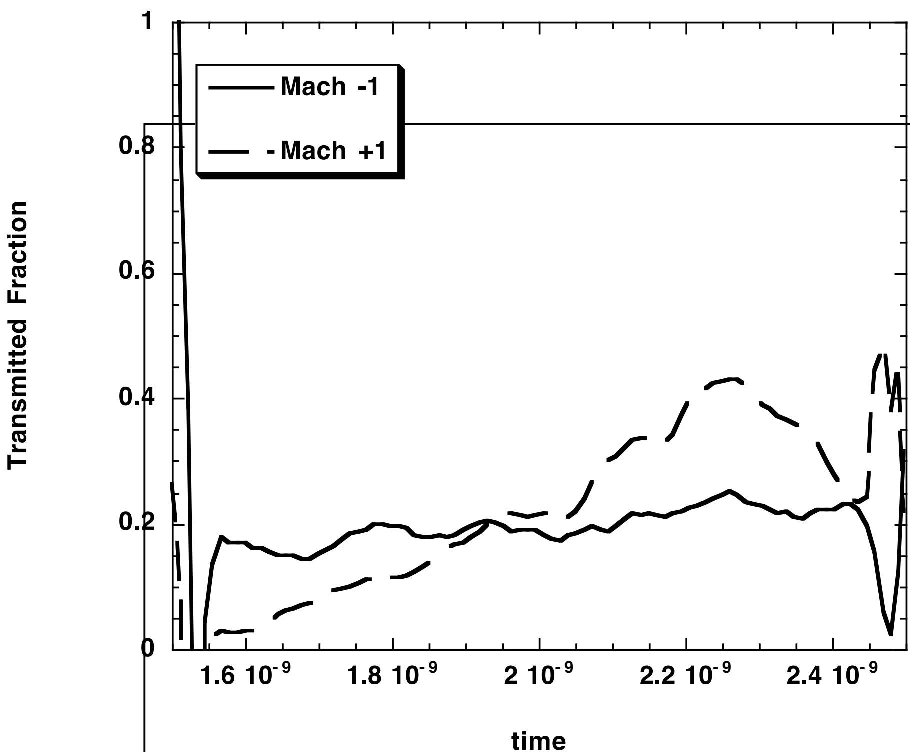

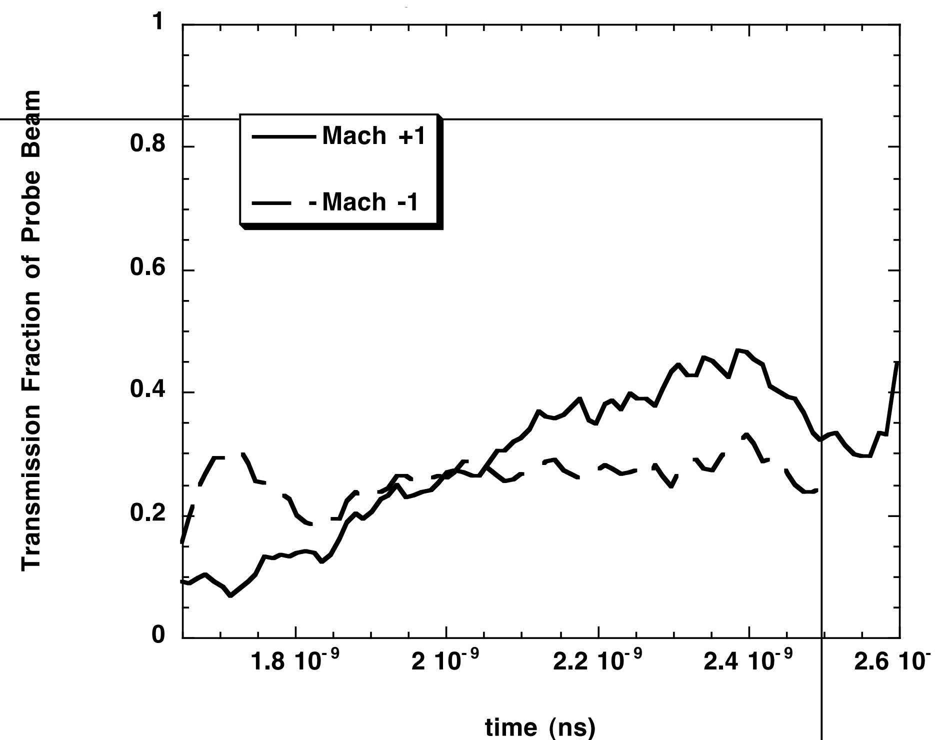

Transmitted power waveforms are divided by incident power measurements And similar amplification is seen at late time in Al and CH