Public Comment: Possibilities in Raman Amplification and Compression of High Power Light in Plasma

Nathaniel Fisch
Princeton University

High Energy Density Physics Workshop
May 24-26, 2004
Gaithersburg, Maryland

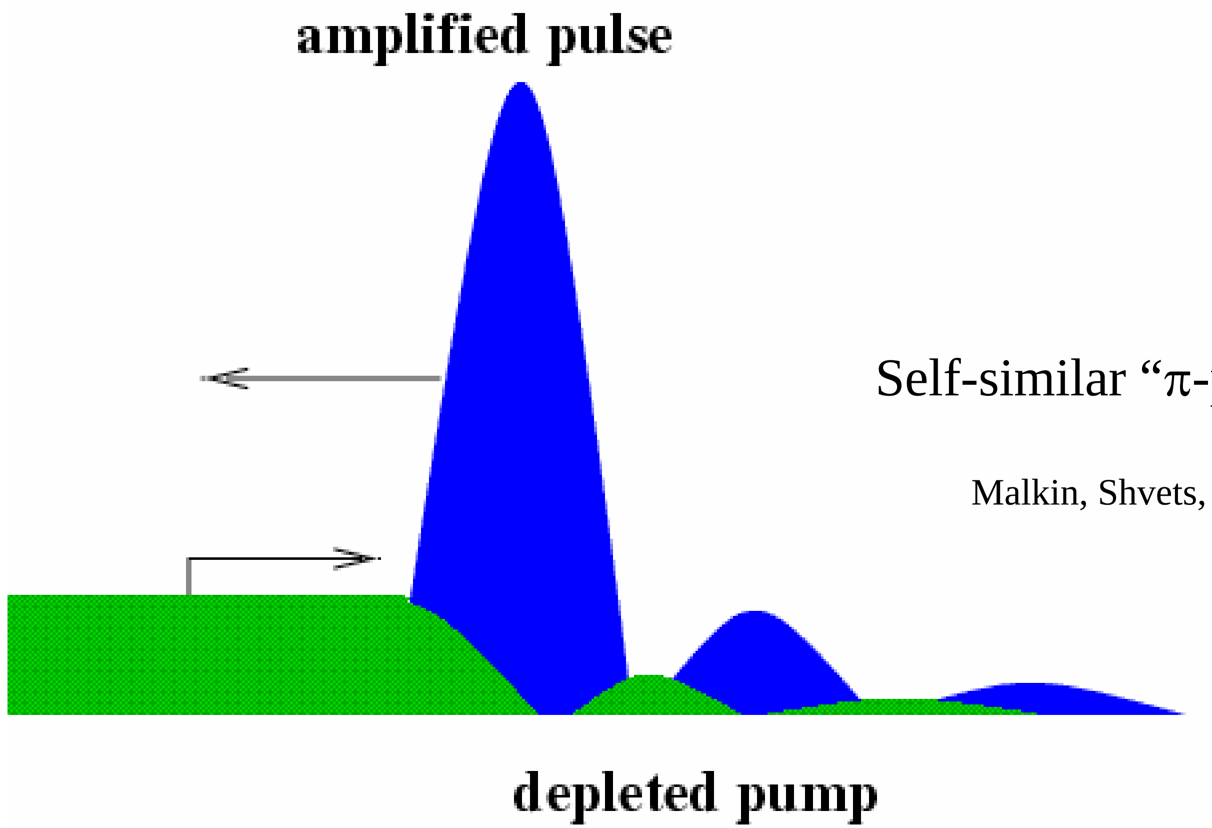
1. What are some ideas for getting to the next generation of laser power densities?

2. What are the recent results?

7th compelling intellectual question: Note: First 6 given by Todd

How can we access the next generation of laser intensities at different frequencies?

Amplification of Pulse by Resonant Raman Backscatter



Self-similar "π-pulse" regime

Malkin, Shvets, and Fisch (PRL, 1999)

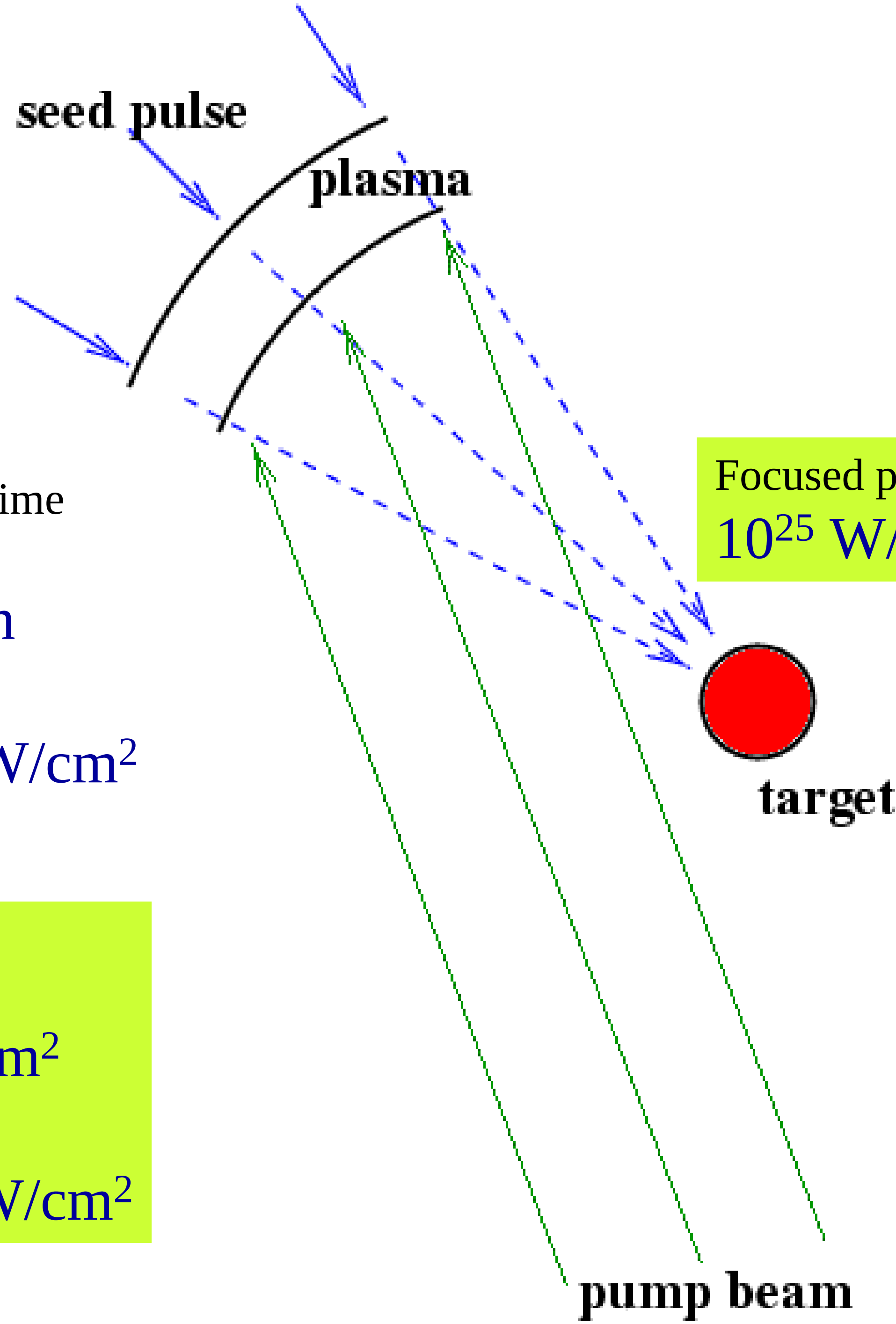
Plasma as an Amplifier

Representative parameters
For Resonant Raman Backscatter Regime

Plasma width	0.7 cm
Pump duration	50 ps
Pump intensity	10^{14} W/cm^2

Output parameters (unfocused)

Pulse fluence	4 kJ/cm^2
Pulse duration	40 fs
Pulse power	10^{17} W/cm^2

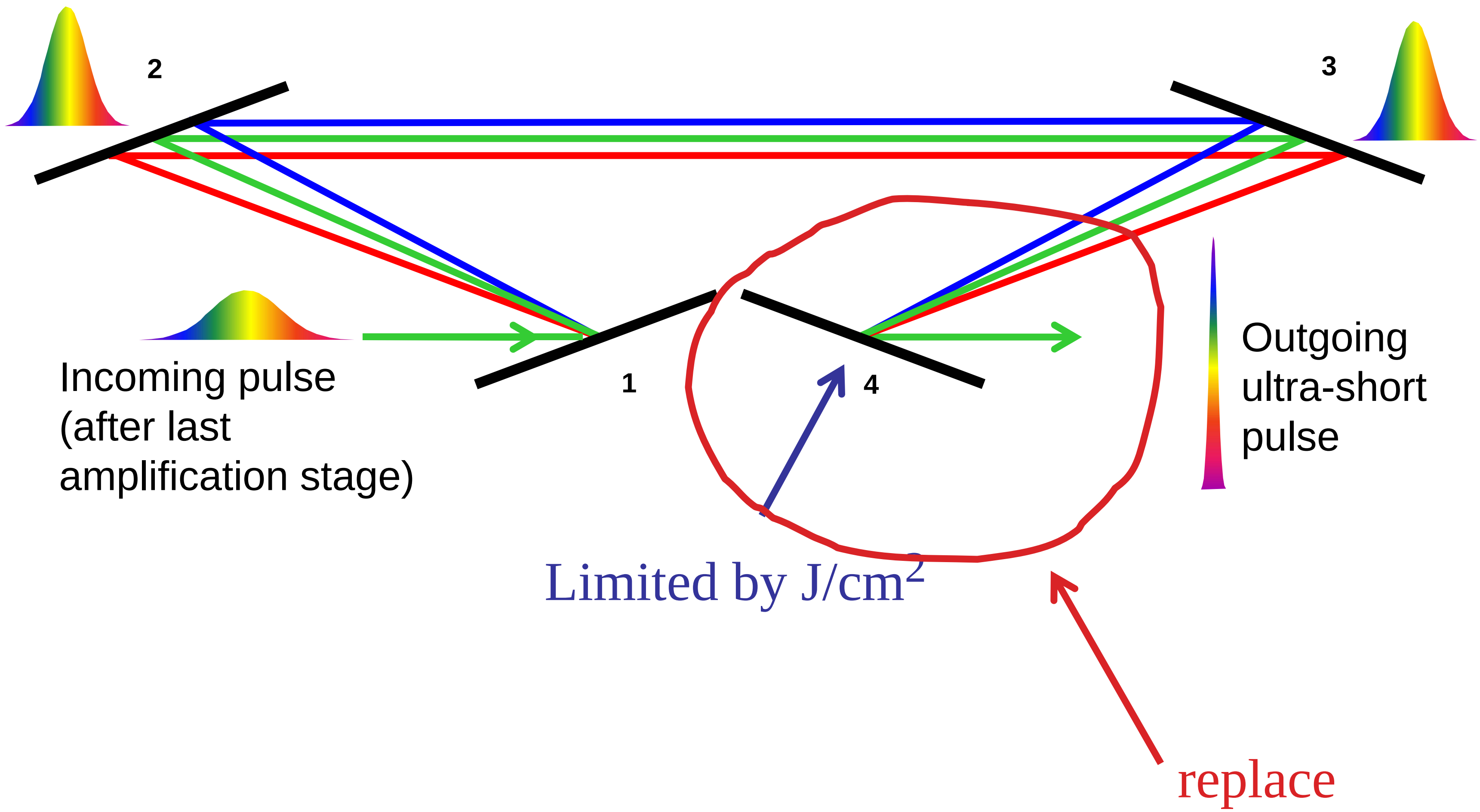


Focused power:
10^{25} W/cm^2

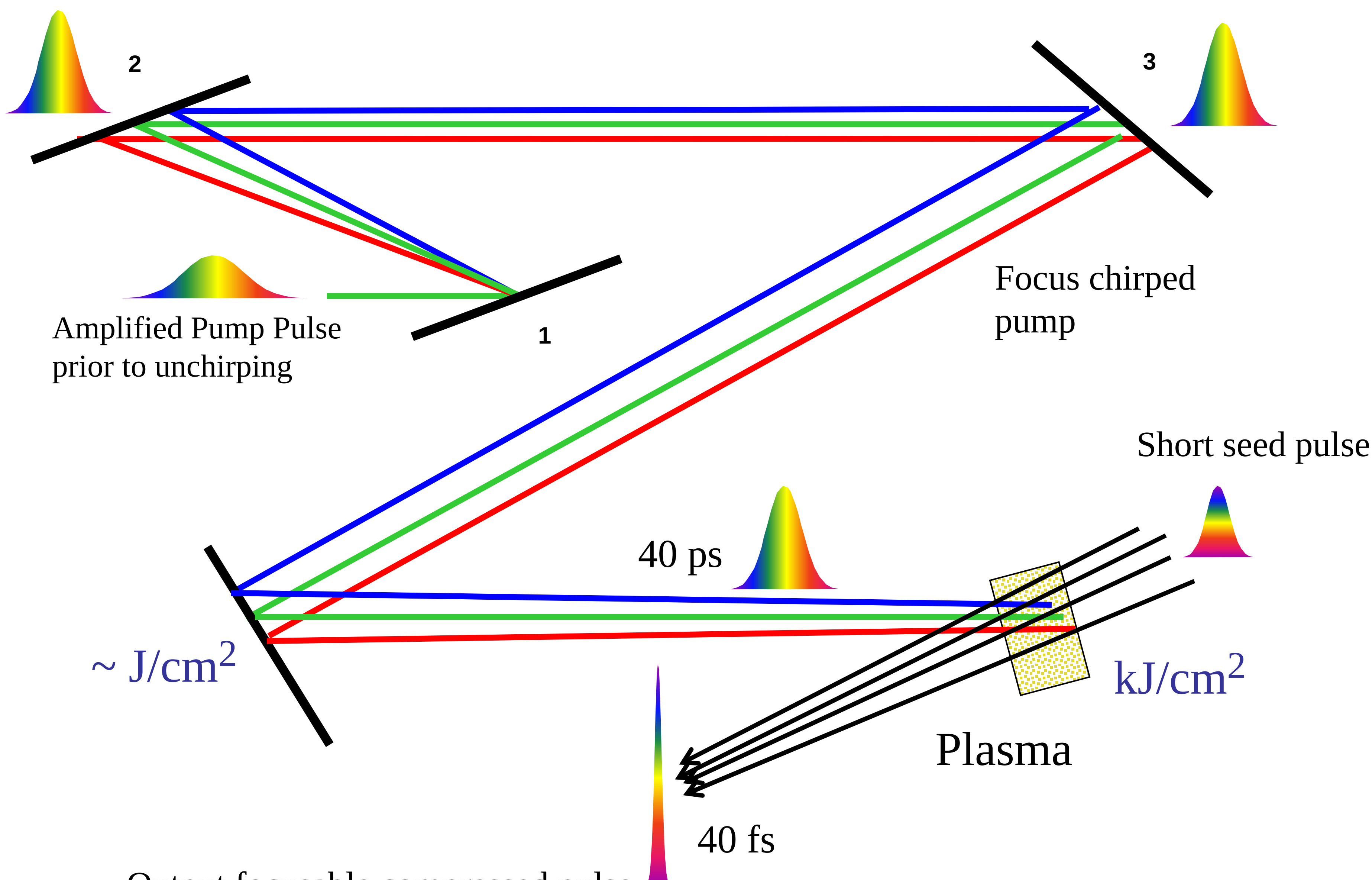
Examples

Wavelength of laser μm	1/40	1/4	1	10
Duration of pump ps	1.25	12.5	50	500
Intensity of pump W/cm^2	1.6×10^{17}	1.6×10^{15}	10^{14}	10^{12}
Pump vector-potential a_0	0.006	0.006	0.006	0.006
Laser-to-plasma frequency ratio	12	12	12	12
Concentration of plasma cm^{-3}	1.1×10^{22}	1.1×10^{20}	7×10^{18}	7×10^{16}
Linear e-times growth length cm	.00043	.0043	.013	.13
Total length of amplification cm	.018	.18	.7	7
Output pulse duration fs	1	10	40	400
Output pulse fluence kJ/cm^2	160	16	4	0.4
Output pulse intensity W/cm^2	1.6×10^{20}	1.6×10^{18}	10^{17}	10^{15}

Modify Chirped Pulse Amplifier

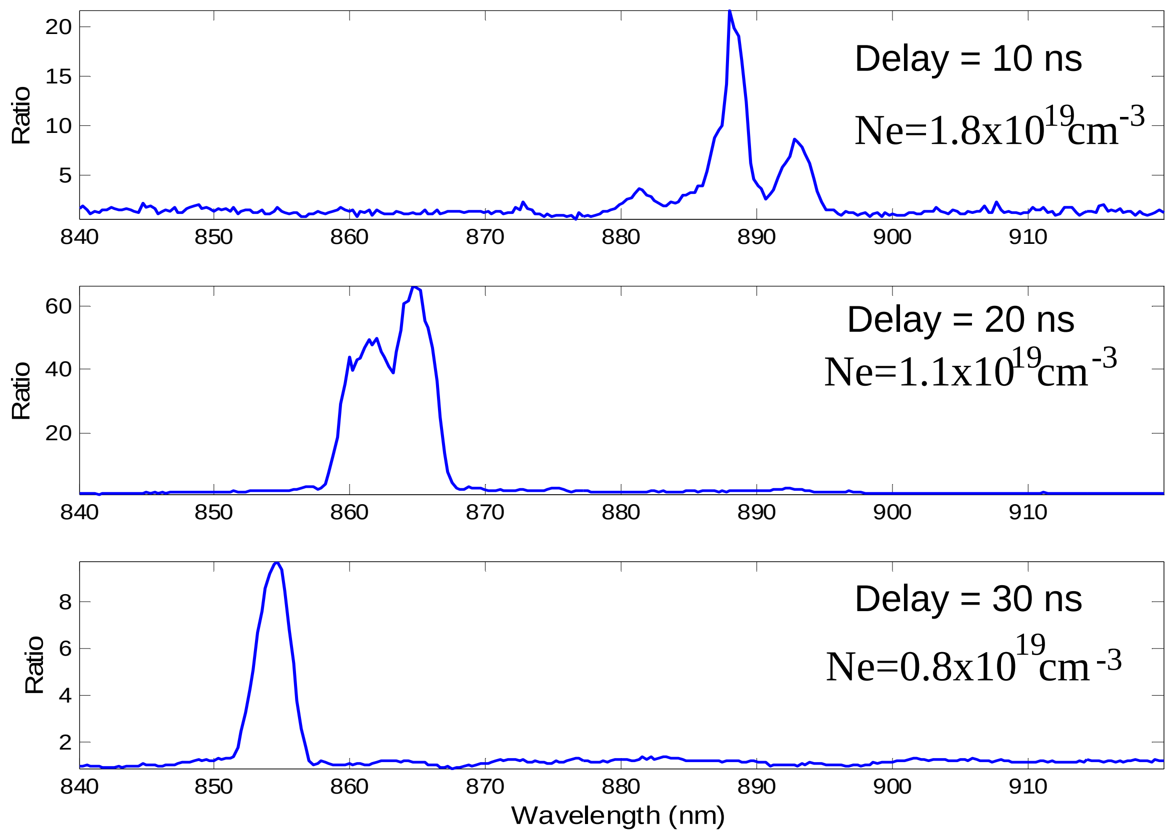


Pulse Compression using Raman Backscattering in Plasma



Fisch and Malkin (Phys. Plasma, 2003)

Raman Amplification in **2mm** Gas Jet Plasma at Three Densities (showing resonant effect)



Ping et al., PRL (March 2004)

Recent Results in Princeton Raman Amplification Experiment

Suckewer et al. (2004)

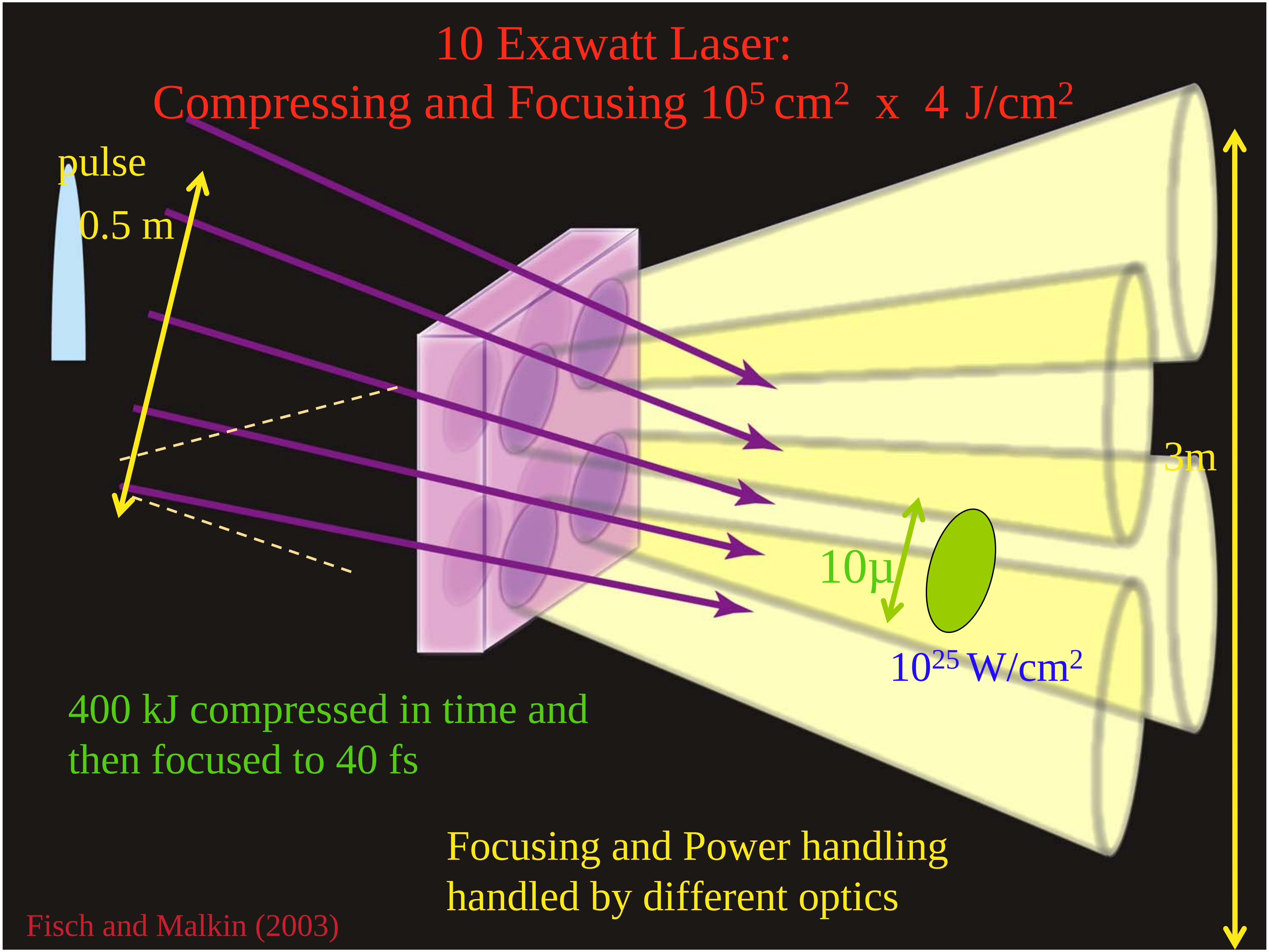
- Resonance at various densities demonstrated with a broadband seed.
- Larger amplification accompanied by broader bandwidth and shorter duration.
- Amplification of ~ 400 for 1μJ seed and ~100 for 5 μJ seed obtained.
- Nonlinear regime (seed pulse intensity exceeding pump pulse intensity) entered.

Where do we stand today?

A. Key experimental results
   1. Factor of 400 in energy amplification
   2. Entering nonlinear regime: pulse intensity greater than pump intensity
   3. Approaching shorter output pulse than linear broadening
   4. Validation of mechanisms and technology of RBS
      a. Resonant interaction
      b. control over density, frequencies and timing
      c. Reasonable plasma target

B. Theoretical Understanding
   1. Understanding Present Experiments
   2. Consideration of potential Showstoppers
      a. Precursor or other instabilities of pulse
      b. focusability of pulse in noisy plasma
      c. Instabilities of pump, including sidescatter

C. Multiplicity of Methods
   1. Detuning methods
   2. Multiple pumps and pump frequencies
   3. Amplification at ionization front
   4. Utilization of Compton scattering effect


10 Exawatt Laser:
Compressing and Focusing 10^5 cm^2 x 4 J/cm^2
pulse
0.5 m
3m
10μ
10^25 W/cm^2
400 kJ compressed in time and
then focused to 40 fs
Focusing and Power handling
handled by different optics
Fisch and Malkin (2003)

References

G. Shvets, N. J. Fisch, A. Pukhov and J. Meyer-ter-Vehn, *Superradiant Amplification of an Ultrashort Laser Pulse in a Plasma by a Counterpropagating Pump*, PRL **81**, 4879 (November 1998).

V. Malkin, G. Shvets, N. J. Fisch, *Fast Compression of Laser Beams to Highly Overcritical Powers*, PRL **82**, 4448 (May 1999).

V. Malkin, G. Shvets, N. J. Fisch, *Detuned Raman Amplification of Short Laser Pulses in Plasma*, PRL **84**, 108 (February, 2000).

V. Malkin, Yu. A. Tsidulko, N. J. Fisch, *Stimulated Raman Scattering of Rapidly Amplified Short Laser Pulses*, PRL 85, 4068 (November, 2000).

V. Malkin and N. J. Fisch, *Backward Raman amplification of ionizing laser pulses*, Physics Plasma (October, 2001).

P. Mardahl, H. J. Lee, G. Penn, J. S. Wurtele and N. J. Fisch, *Intense Laser Pulse Amplification using Raman Backscatter in Plasma Channels*, Physics Letters A **296**, 109--116 (April, 2002).

Y. Tsidulko, V. M. Malkin, and N. J. Fisch, *Suppression of Superluminous Precursors in High Power Backward Raman Amplifiers*, Physical Review Letters 88, 235004 (June, 2002).

G. M. Fraiman, N. A. Yampolsky, V. M. Malkin, and N. J. Fisch, *Robustness of Phase Fronts in Backward Raman Amplifiers*, Physics of Plasma 9, 3617--3624 (August, 2002).

I. Y. Dodin, G. M. Fraiman, V. M. Malkin, and N. J. Fisch, *Raman Backscattering of Short Laser Pulses: Amplification in Capillary Plasmas*, Journal of Experimental and Theoretical Physics **95** (4), 625--638 (October, 2002).

References

N. J. Fisch and V. M. Malkin, *Generation of Ultra-high Intensity Laser Pulses*, Physics of Plasmas 10, 2056-2063 (May, 2003).

A. Solodov, V. M. Malkin, and N. J. Fisch, *Random density inhomogeneities and focusability of the output pulses for plasma-based powerful backward Raman amplifiers*, Phys. Plasmas 10, 2540-2544 (June, 2003).

D. S. Clark and N. J. Fisch, Particle-*in-cell simulations of Raman laser amplification in ionizing plasmas*, Physics of Plasmas 10, 4837--4847 (December, 2003).

D. S. Clark and N. J. Fisch, *Particle-in-cell simulations of Raman laser amplification in preformed plasmas*, Physics of Plasmas 10, 4848--4855 (December, 2003).

A. A. Balakin, G. M. Fraiman, N. J. Fisch, and V. M. Malkin, *Multi-frequency pumping for more robust backward Raman amplification of short laser pulses in plasmas*, Physics of Plasmas 10, 4856--4864 (December, 2003).

N. A. Yampolsky, V. M. Malkin, and N. J. Fisch, *Finite-Duration Seeding Effects in Powerful Backward Raman Amplifiers*, Physical Review E 69, 036401 (March, 2004).

Y. Ping, W. Cheng, S. Suckewer, D. S. Clark, and N. J. Fisch, *Amplification of Short Laser Pulses by Resonant Raman Scheme in a Gas Jet Plasma*, PRL 92, 175007 (April, 2004).

R. L. Berger, D. S. Clark, A. A. Solodov, E. J. Valeo, and N. J. Fisch, Inverse *bremsstrahlung stabilization of noise in generation of ultra-short intense pulses with backward Raman amplification*, Phys. Plasmas 11, 1931 (May, 2004).