Raman Amplification with a 1 x 10^{15} W/cm^2 Seed

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Collaborators

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Summary

The UR LLE Raman amplification platform explores a unique parameter space including a joule-class pump and a seed with intensities $\geq 1 \times 10^{15}$ W/cm^2

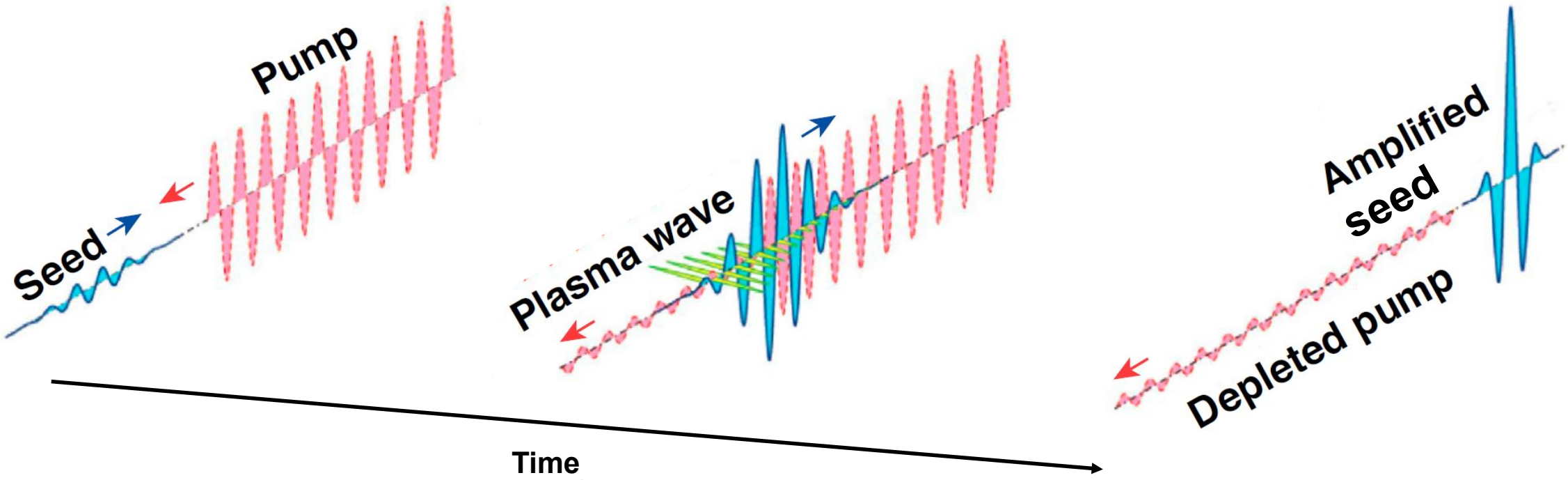
- **Initial experiments have demonstrated single-pass Raman amplification with amplification factors as high as 12.6x and efficiencies as high as 7.4%.**

- **Amplification and efficiency scale linearly with pump intensity for intensities up to 1.1×10^{16} W/cm^2 and 3.3×10^{15} W/cm^2, respectively, then roll off**

- **The amplification factor scales inversely with seed intensity, while the efficiency scales approximately linearly with seed intensity**

Physical Picture

Raman amplification uses a plasma wave to transfer energy from a longer, more-energetic pump pulse to a shorter seed pulse



Raman amplification is a potential route to achieve focused intensities > 10^{23} W/cm^2, which would open new fields of physics such as testing QED in the low-energy, strong-field regime

Motivation

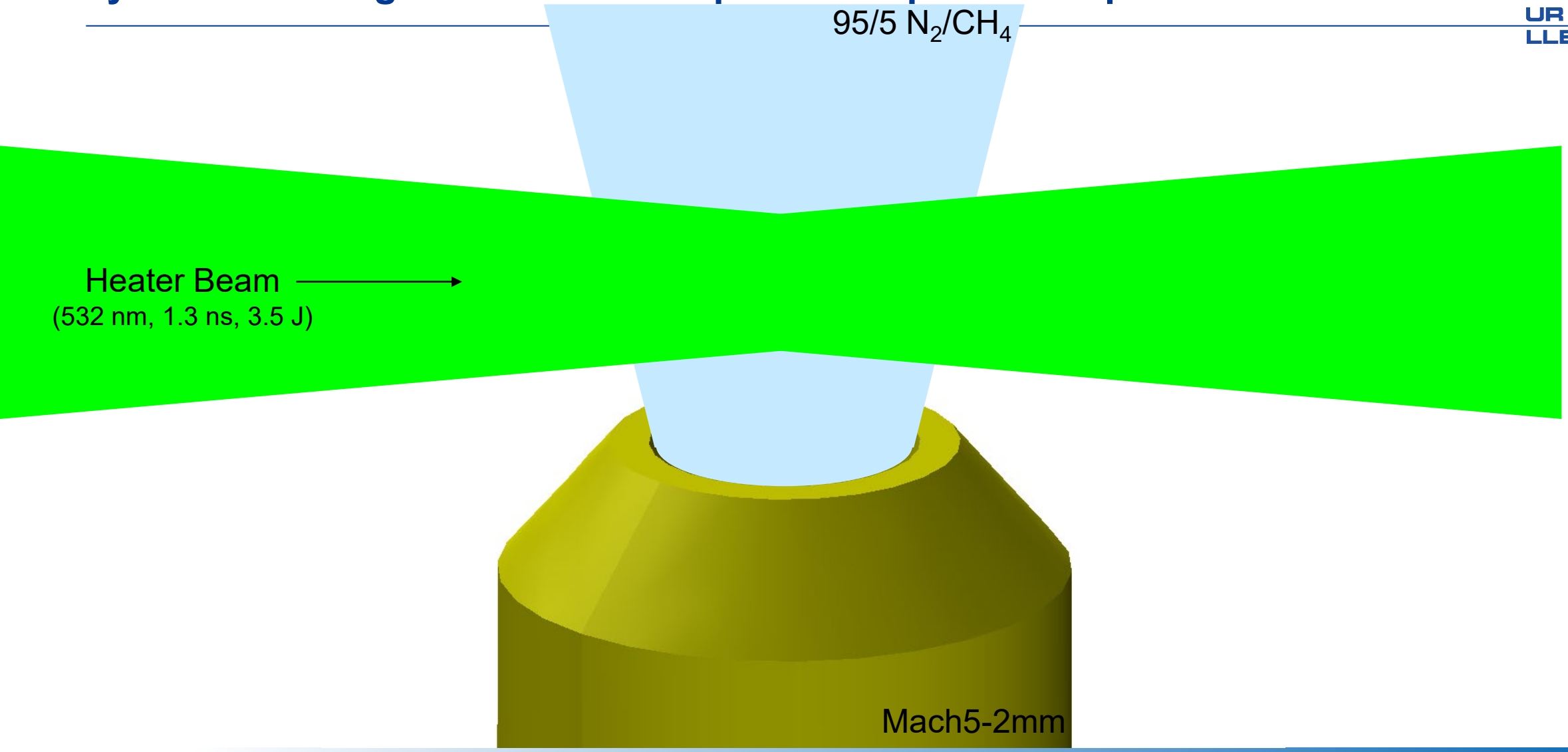
The LLE Raman amplification experiments explore the process in a previously unexplored regime in search of a practical, scalable amplifier

- For Raman amplification to be a viable technology to produce high focused intensities, need to demonstrate that it can be scaled to the PW level
  - State-of-the-art OPCPA systems in ~10 PW
- Goal is to demonstrate a proof-of-principle system that would be scalable to the PW level, based on three minimum criteria*
  - Intensity gains ≥ 10
  - Output intensities $\geq$ 100x pump intensity
  - Efficiency $\geq 30\%$
- Our platform can access some of the major factors limiting the efficiency, which is the criterion most challenging to satisfy and underlying the other two criteria
  - Careful study of pump propagation
  - High seed intensity so no growth/evolution time required
- Other capabilities include
  - Large amounts of pump energy available (up to 5.5 J on target), allowing potential for large energy transfer to the Seed
  - Ability to study Seed-ionized regime owing to high seed intensity

* D. Haberberger *et al*, "Hot Raman Amplification," Phys. Plasma 28, 062311 (2021)

Experimental Setup

Raman amplification experiments utilized three separate single-shot laser systems to bring an intense seed pulse to a preheated plasma



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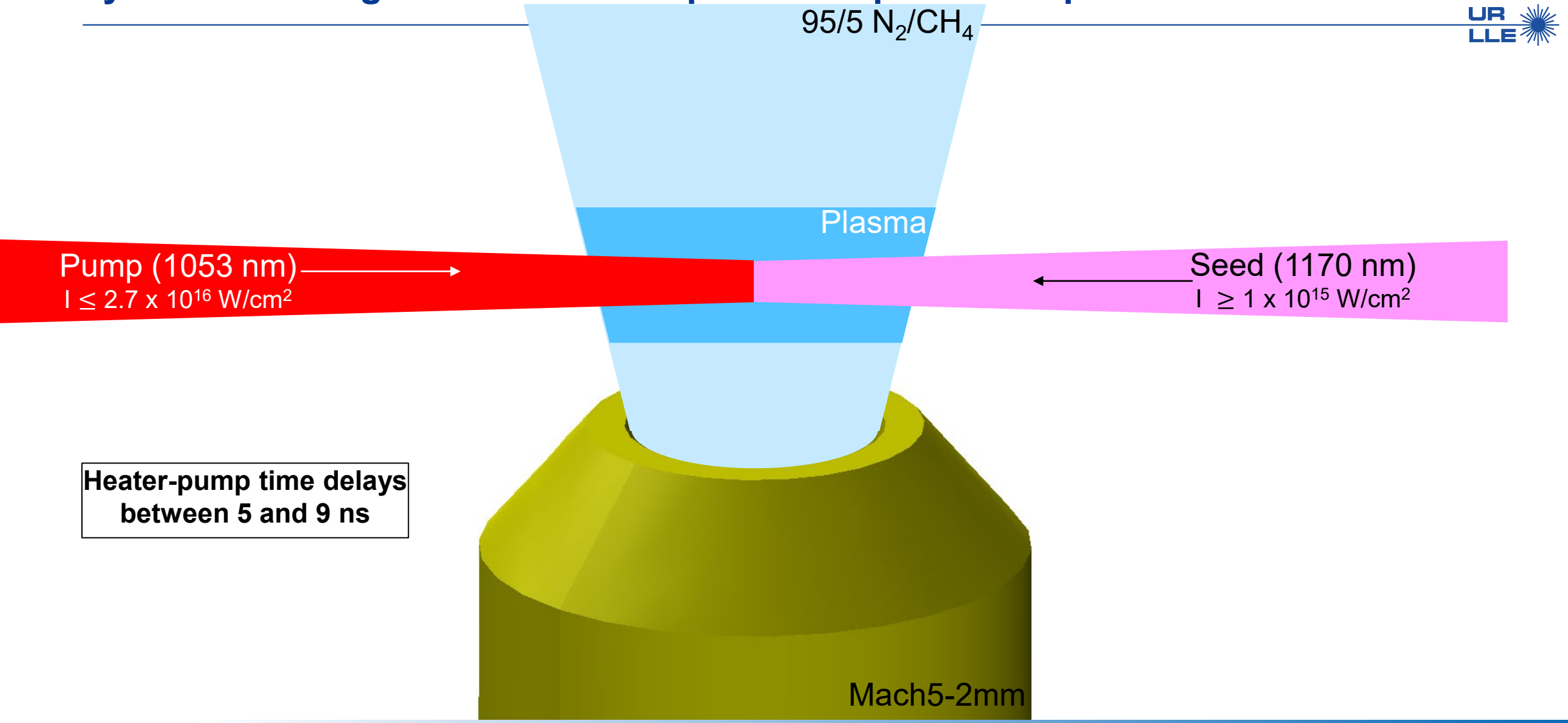
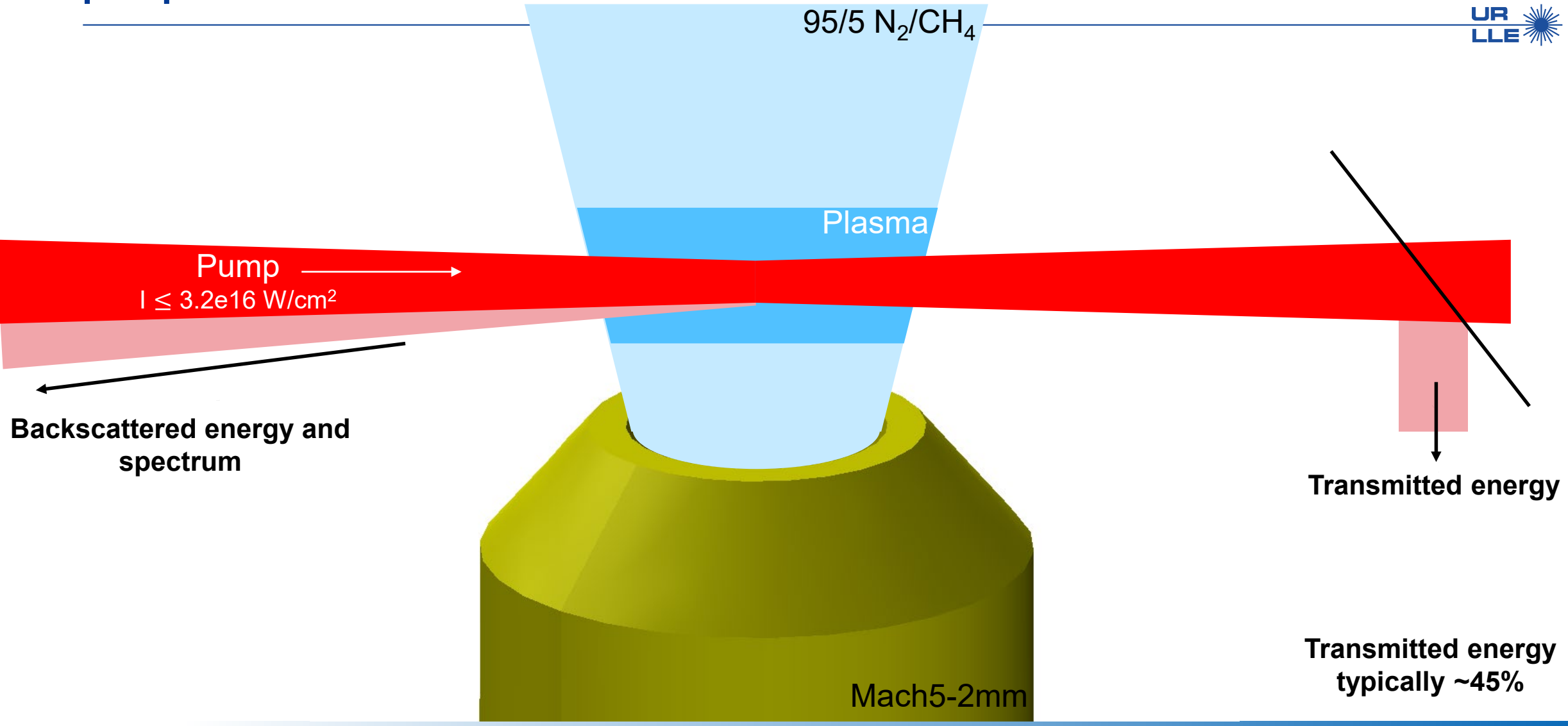


Heater-pump time delays between 5 and 9 ns

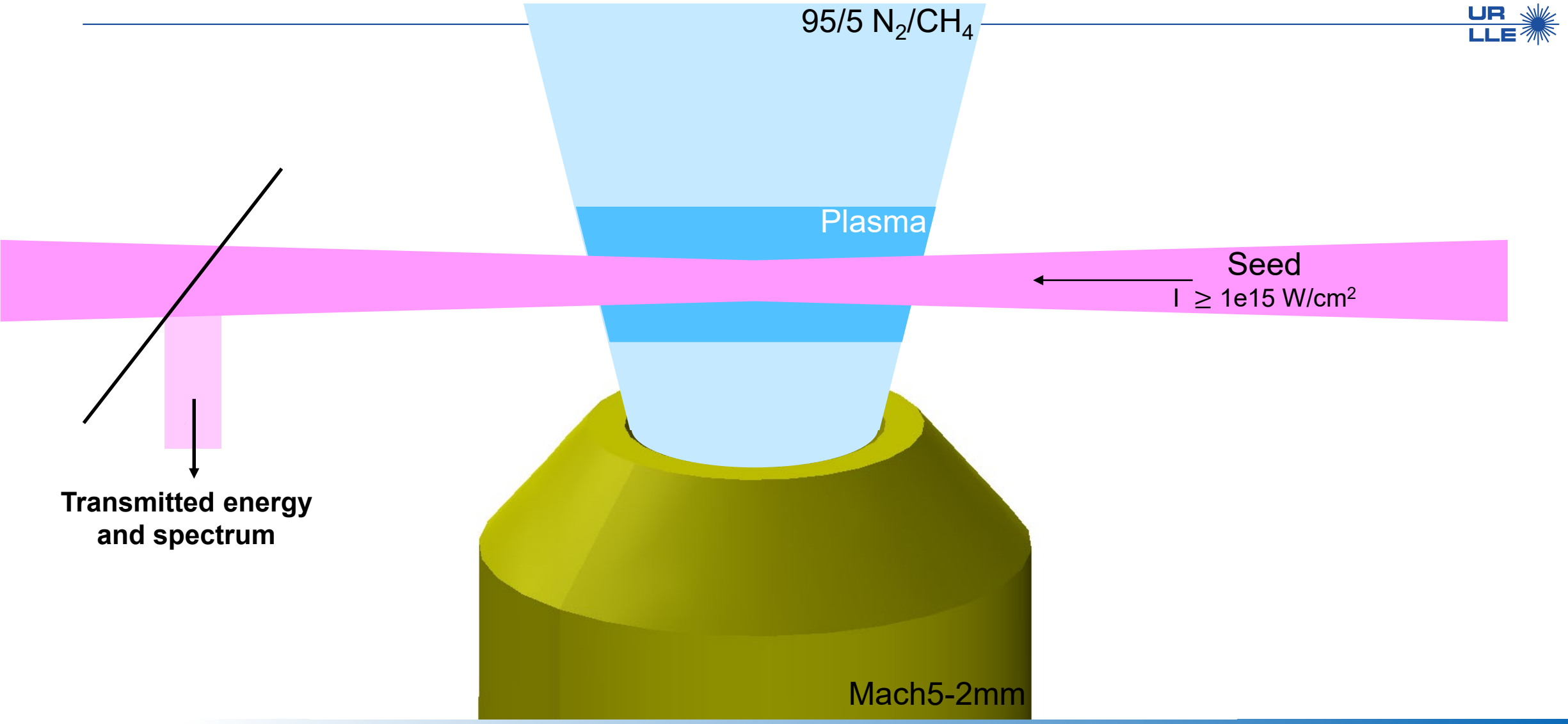
Experimental Setup

Transmitted energy and backscattered energy and spectrum are measured for the pump



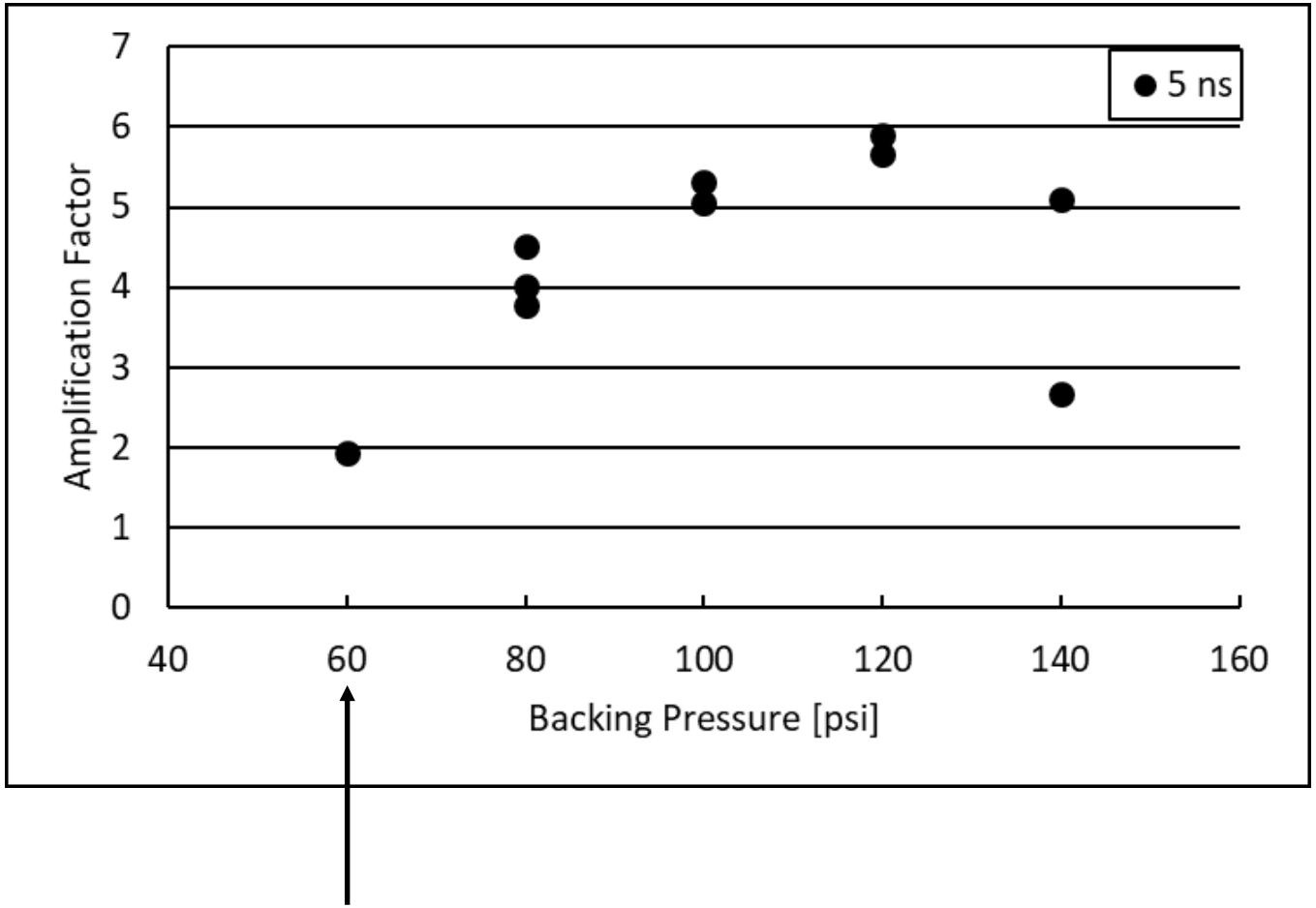
Transmitted energy typically ~45%

Seed transmitted energy and spectrum are measured



Backing pressure was tuned to optimize resonant density for amplification

- Based on wavelengths of seed and pump, resonant density should be at 1 x 10^{19} cm^{-3}
- Amplification Factor: $\frac{E_{out,seed}}{E_{in,seed}}$
  - $E_{out,seed} = E_{out,total} - E_{backscatter,average}$



1 x 10^{19} cm^{-3} based on backscattered spectrum

Scaling with Pump Intensity

The amplification factor scales ~ linearly with pump intensity for intensities up to 1.2×10^{16} W/cm^2

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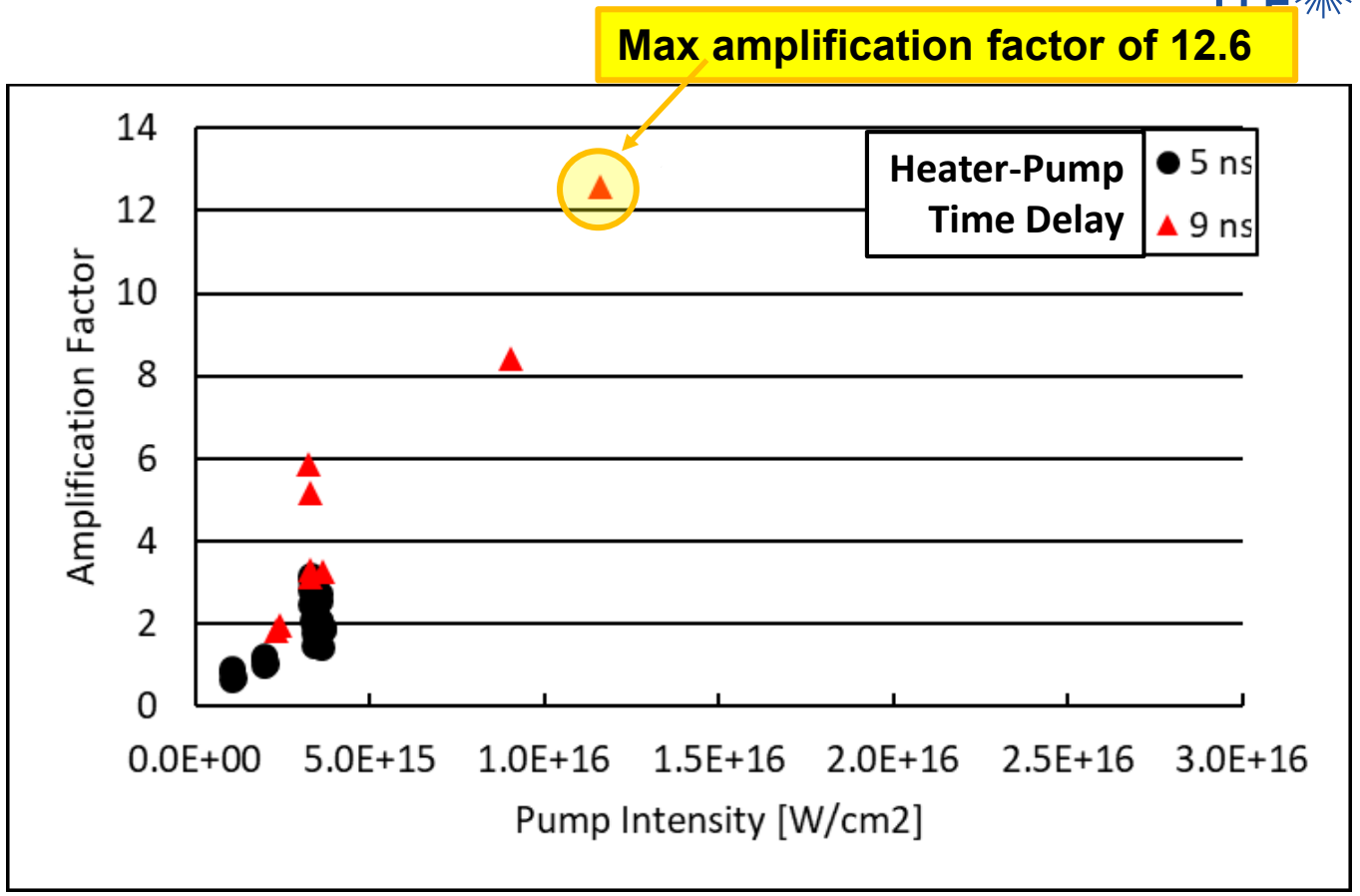

The amplification factor scales ~ linearly with pump intensity for intensities up to 1.2 x 10^{16} W/cm^2 before rolling over and becoming highly irreproducible

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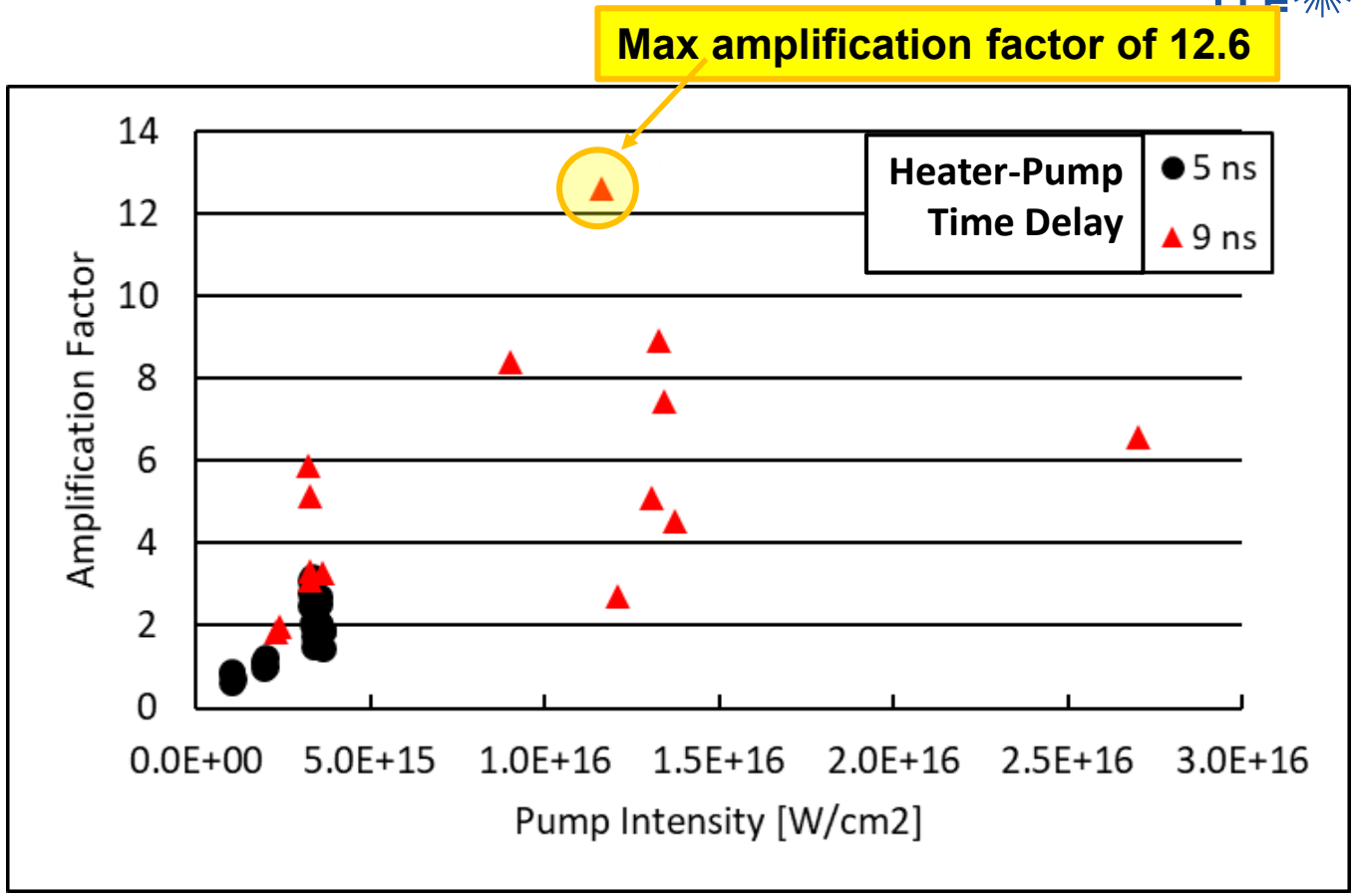
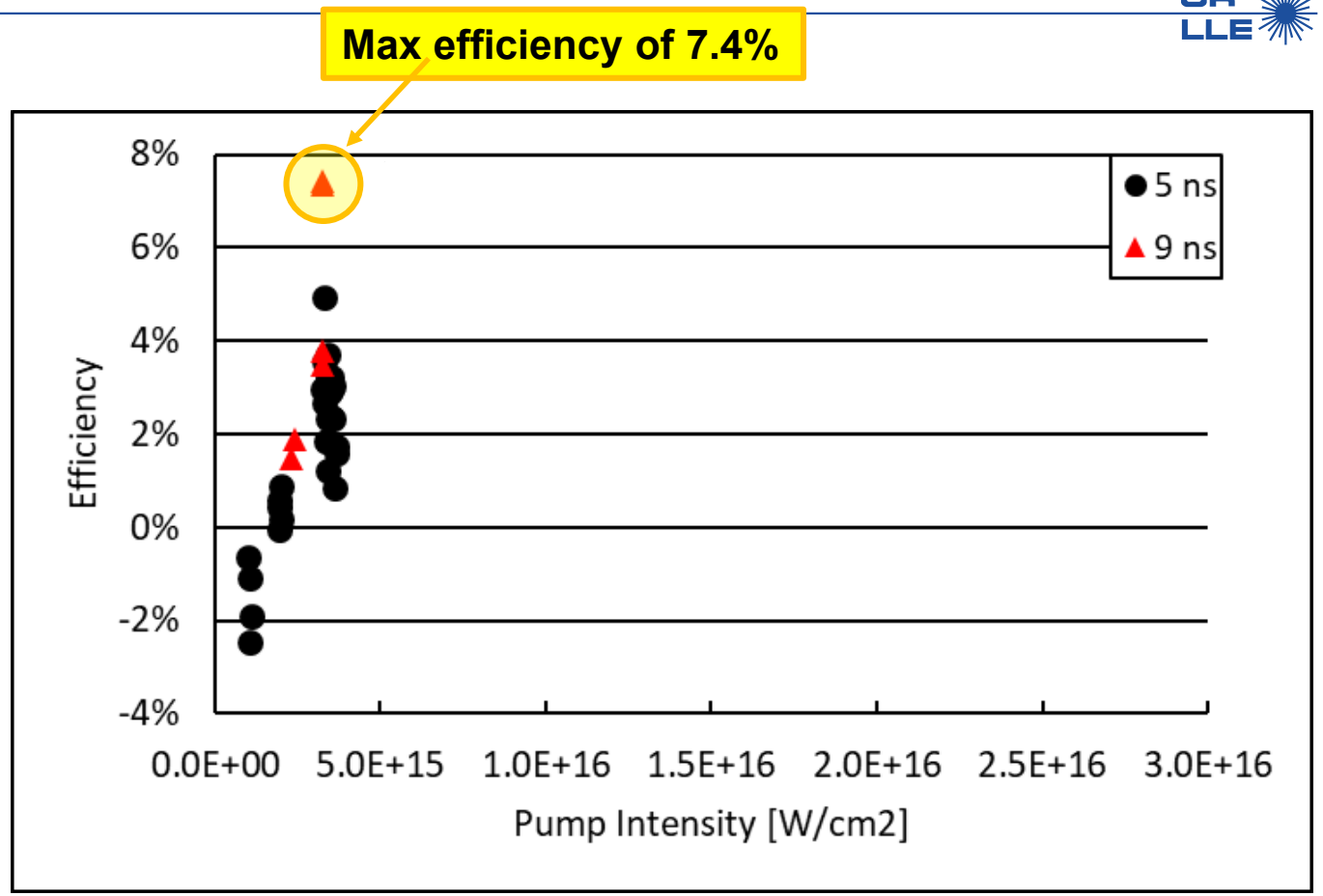


Scaling with Pump Intensity

The efficiency peaks at a lower pump intensity of 3.3 x 10^{15} W/cm^2 before also rolling off

Efficiency:

$$\frac{\text{Energy}_{\text{seed,gained}}}{\text{Energy}_{\text{pump,temporal overlap}}}$$



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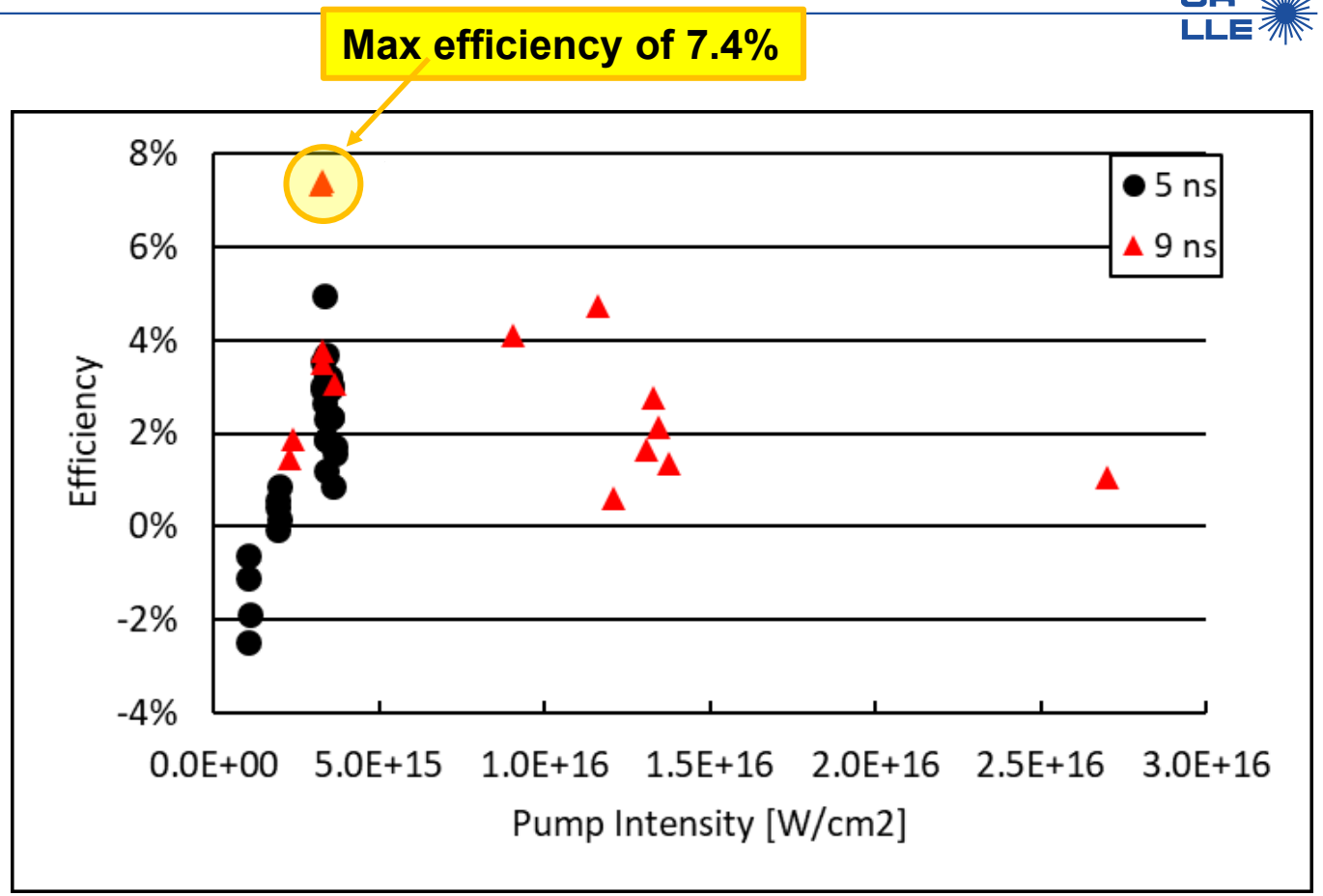
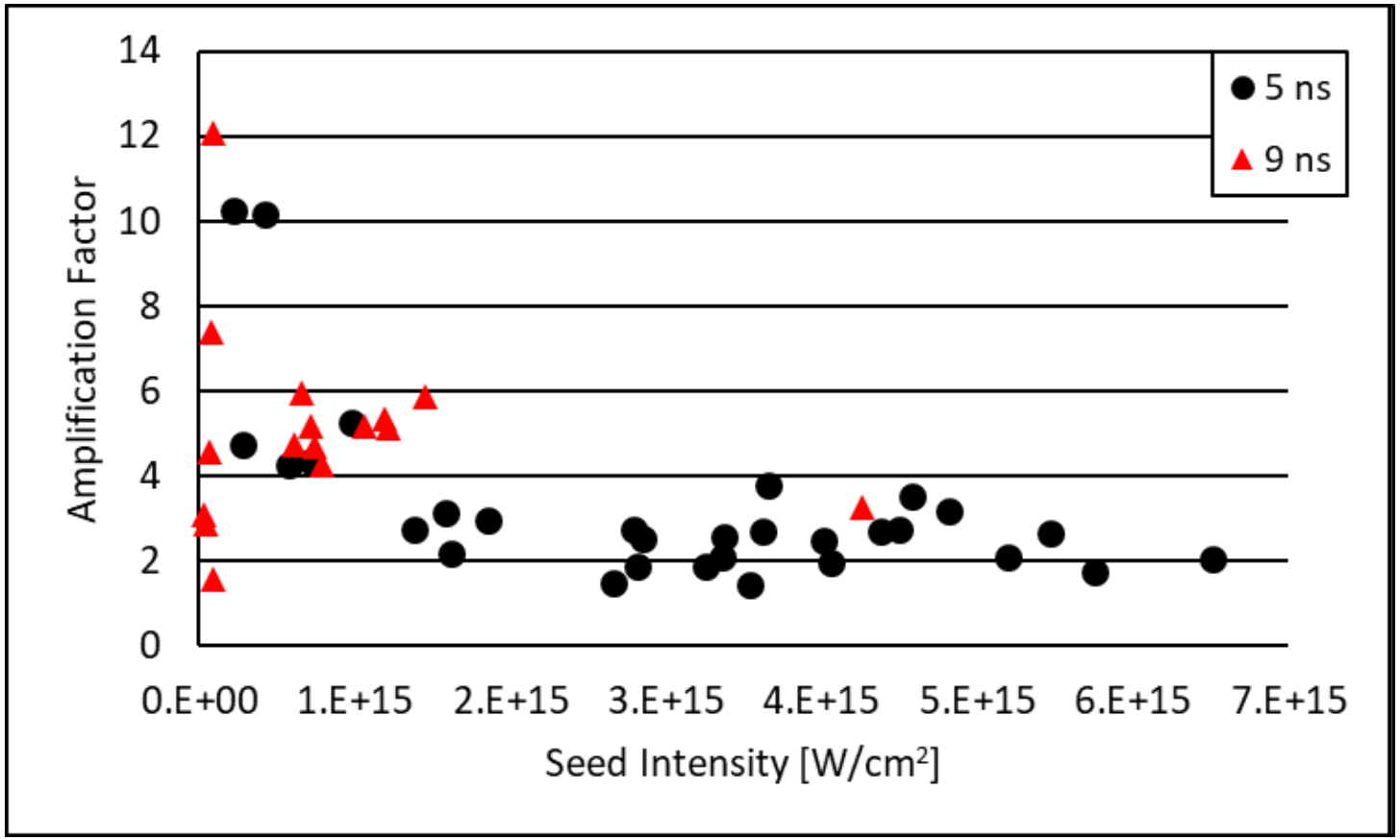
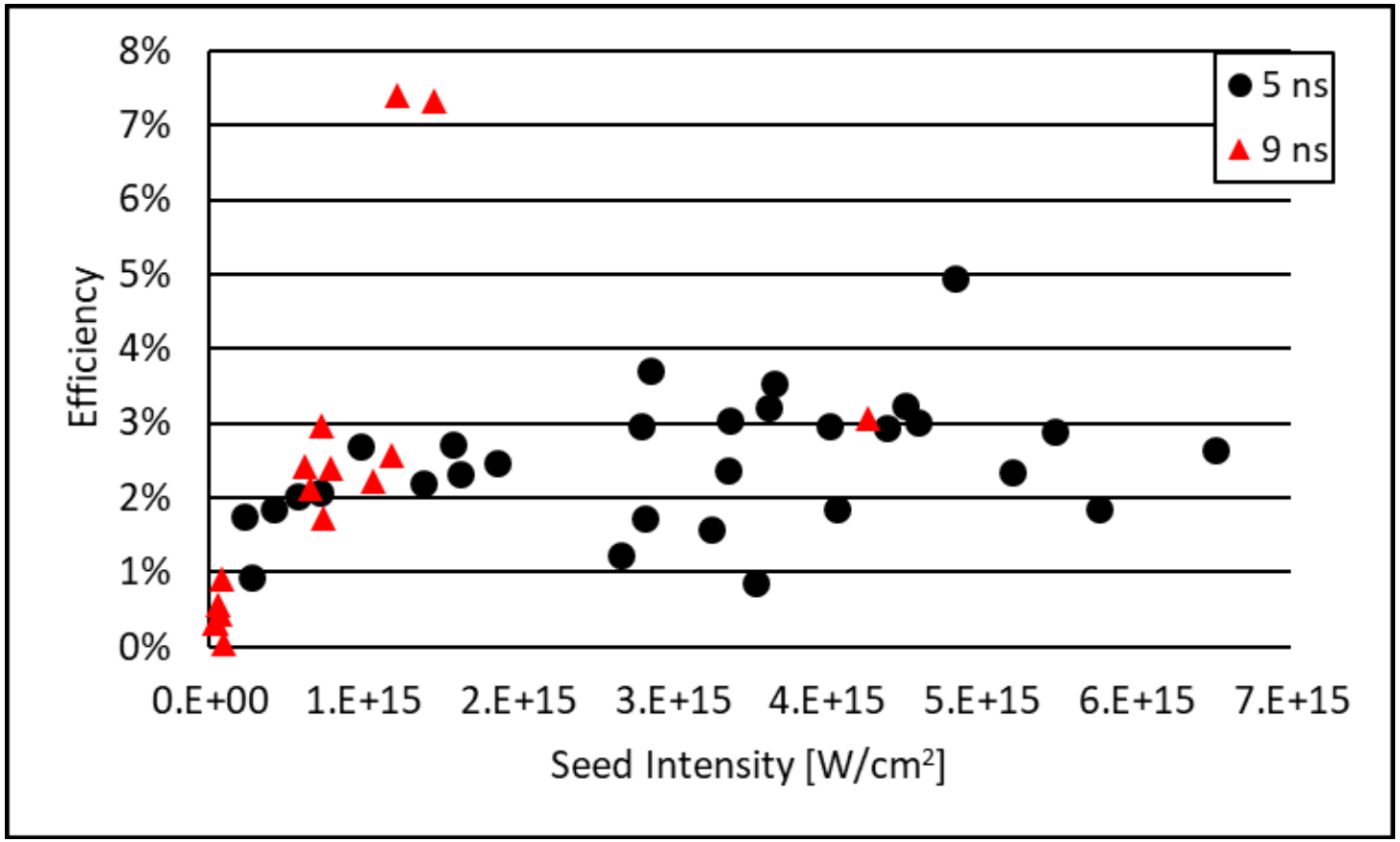


The maximum amplification factor scales inversely with seed intensity and shows high shot-to-shot variation at the lowest seed intensities



Scaling with Seed Intensity

The efficiency scales ~ linearly with seed intensity and shows a much stronger scaling with less fluctuation for the 9 ns heater timing



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