# Radiation pressure driven ion acceleration at BNL - Focus on Laser Channeling

Ginevra Casati, Nicholas Dover, Oliver Ettlinger, Mikhail Polyanskiy, Igor Pogorelsky, William Li, Charlotte Palmer and Zulfikar Najmudin

# Overview

- Laser driven ion sources – applications
- Notable Previous work and main results
- Experimental setup at BNL
- 2024 run overview and results
- 2022 run, focus on laser channeling
- Further work and Conclusions

# Why laser driven ion acceleration ?

**Laser driven ion sources:**

- **compact sources**
- **high energy ions –** above 100MeV
- **high peak currents**
- **Low emittance**
- **Short ion beams -** ps to ns
- **high divergence beams** $\sim 10^{\circ} - 20^{\circ}$

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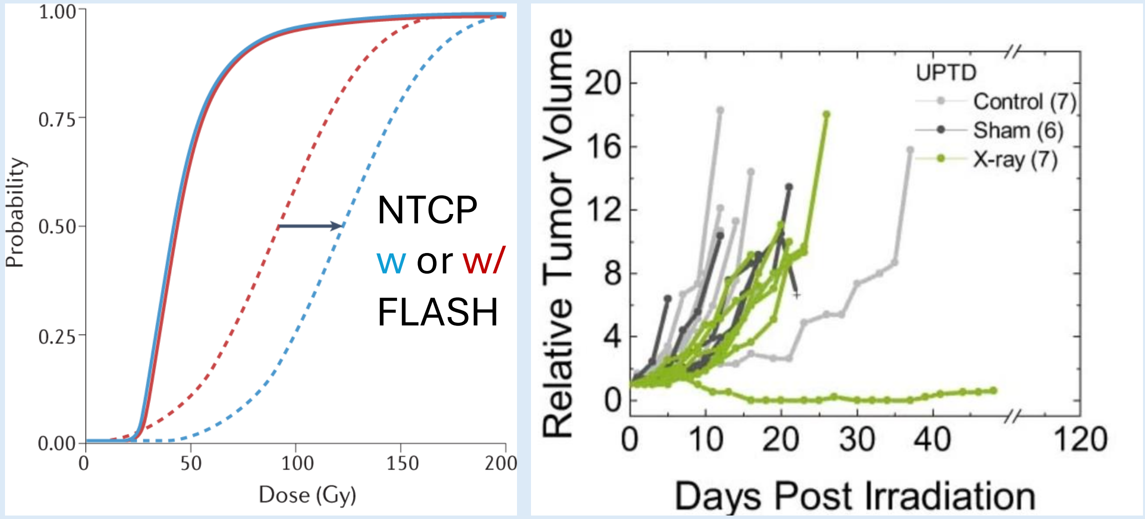
Flash Irradiation therapy [1]



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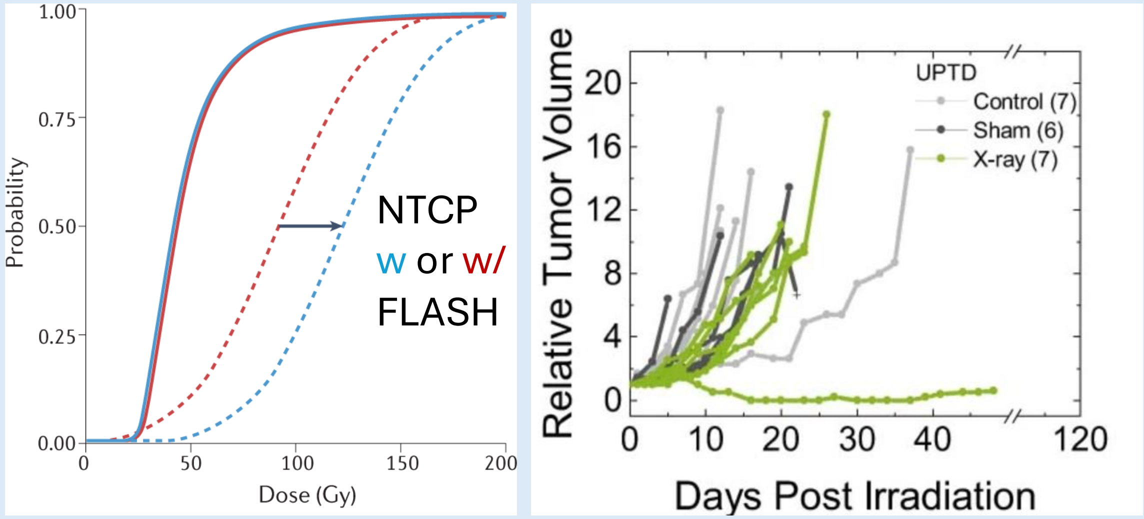
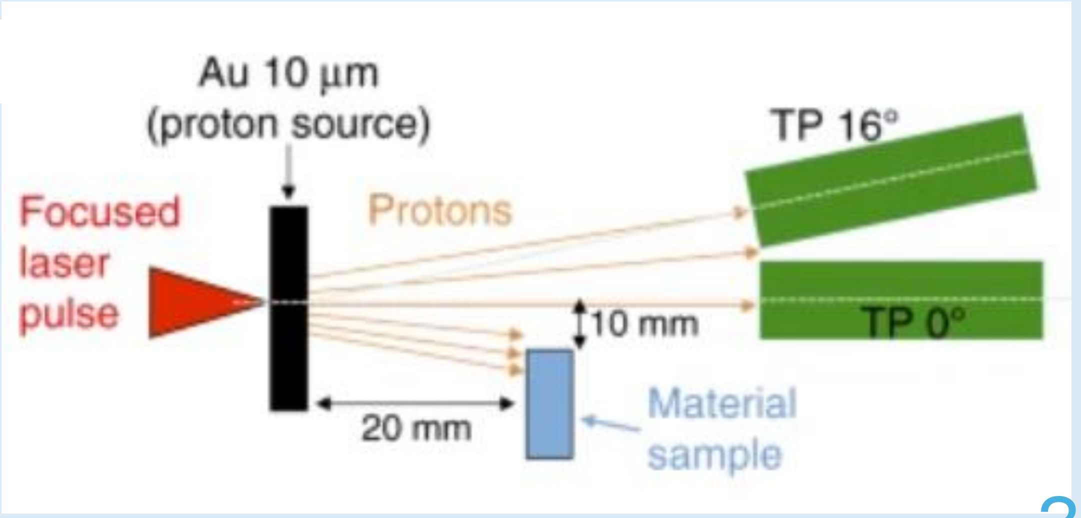


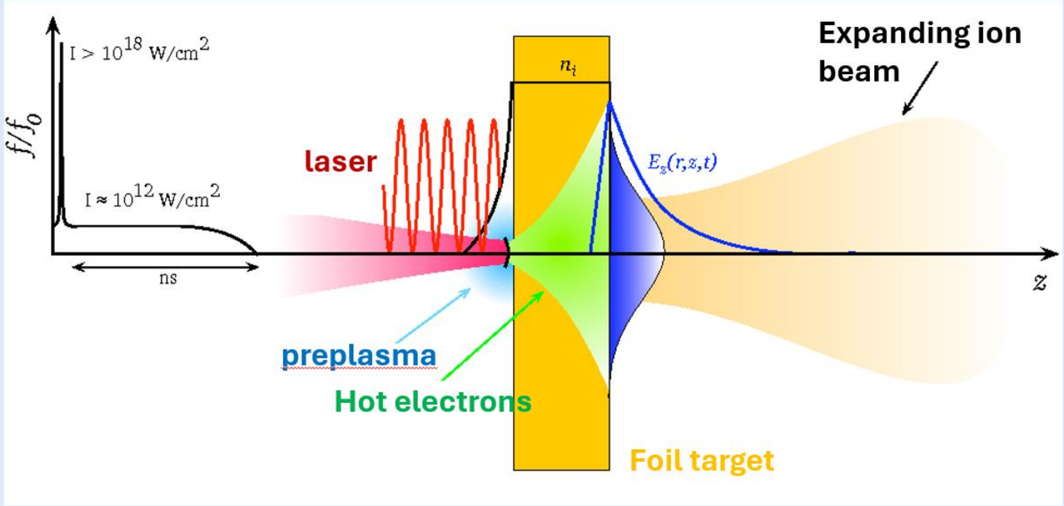

Stress testing of materials [2]



# Laser-Plasma ion acceleration

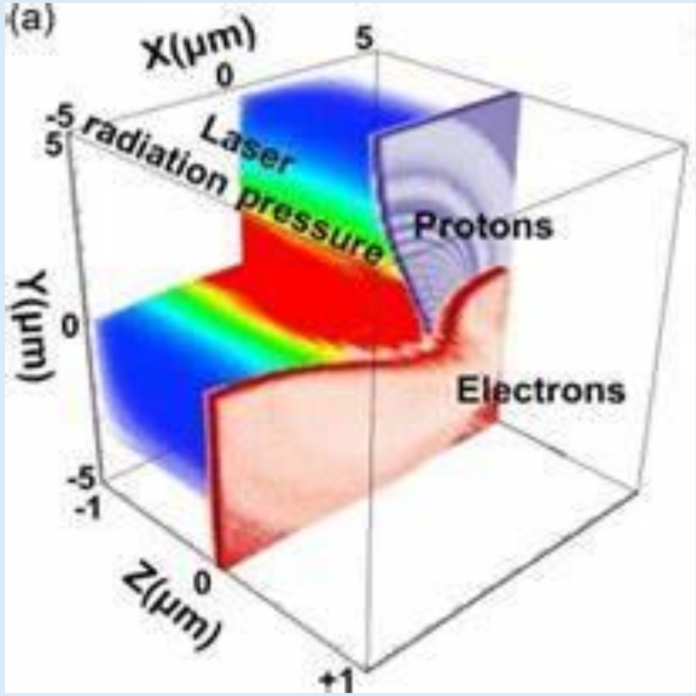
Several mechanisms exist, the two most common are:

### Sheath Acceleration



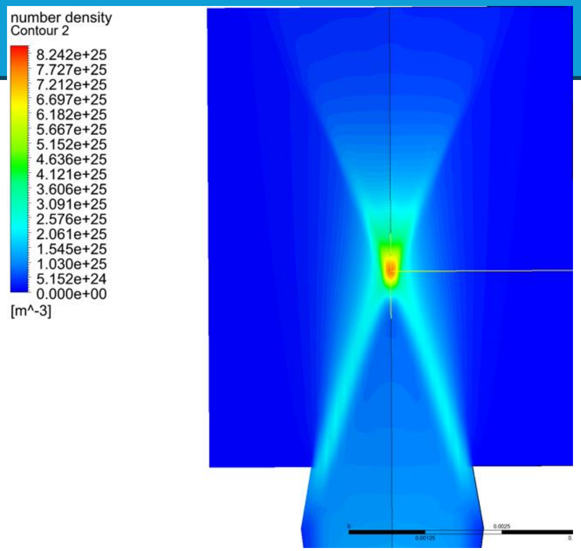

Implementing this method is challenging when using gas targets.

### Radiation Pressure Acc. (RPA)




Very high intensities and very thin targets are required. Gas targets are suitable for front surface acceleration configurations.

# Why we chose the BNL facility




The main reasons why we chose BNL:

- It is a $CO_2$ laser → **Very long wavelength ~ 9.2 μm**

  This has several implications:

  - the **a0** of the laser scales favorably as: $a_0 = \frac{E_0 e \lambda}{m_e c}$
  - the **critical density is 100 times lower** than for Ti-sapph lasers: $n_c = \frac{m_e \varepsilon_0}{e^2 \lambda^2}$

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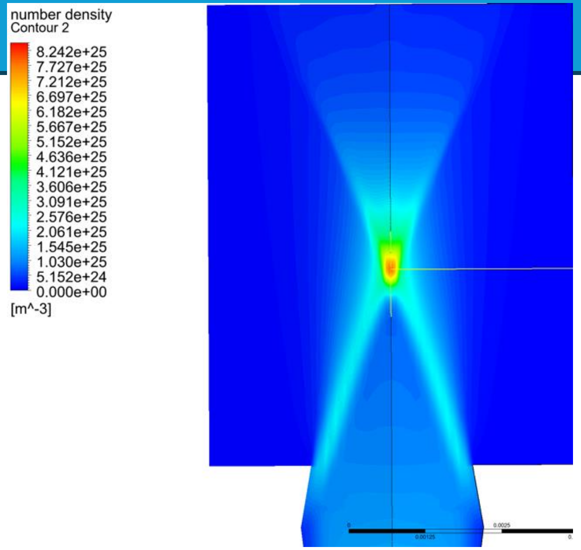


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Hence gas targets can be used and still be in the critical density regime !

Gas targets are important because:

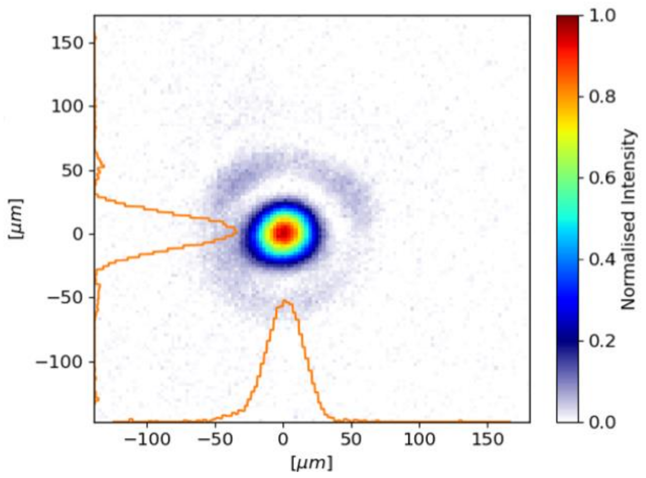
- they can produce pure beams, in particular the medical field wants pure He beams,
- they don't generate debris,
- And they can operate at high rep rates

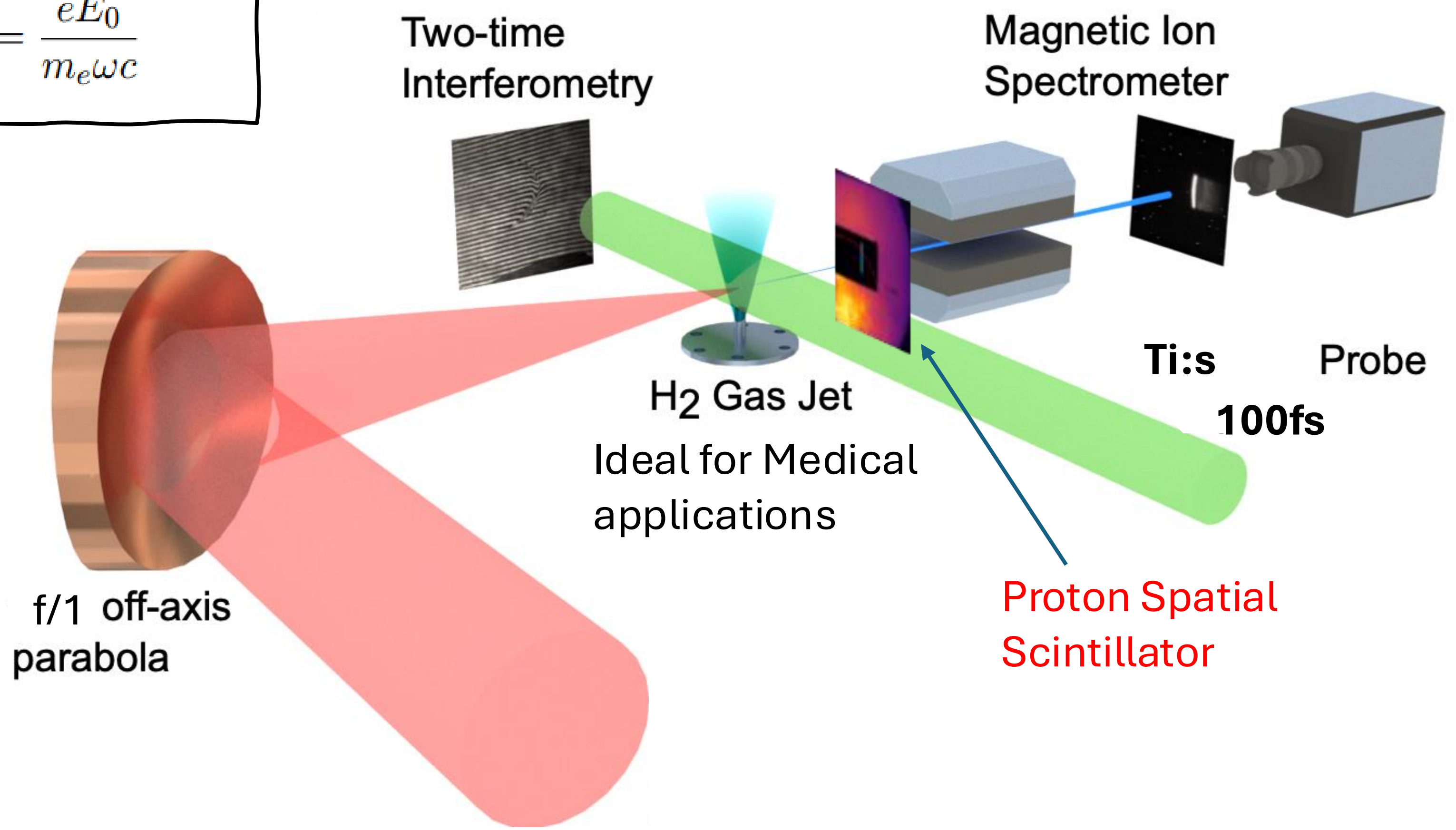
# BNL CO2 laser facility

**$CO_2$ laser:**
**~ 9.2 μm wavelength**
**~ 3 ps pulse length**
**~ 5J  Energy on target**
**~ 25 μm focal spot size**
**~ 9E+21 W/$m^2$**
**~ 5.4 $a_0$**

**Favorable scaling:**

$$a_0 = \frac{v}{c} = \frac{eE_0}{m_e \omega c}$$



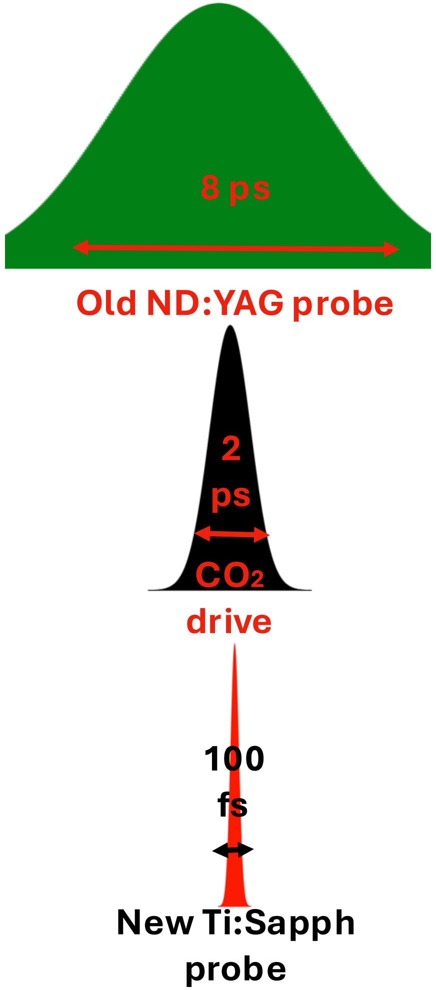




Credits to Nicholas Dover

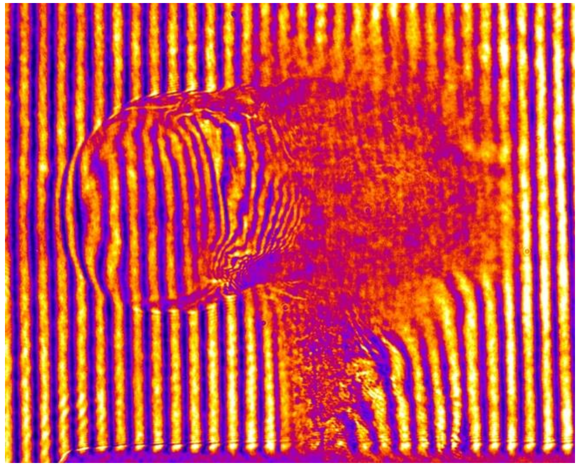
# Femtosecond probe - measuring intrapulse dynamics

- Previously: 8 ps ND:YAG, results in significant image blur

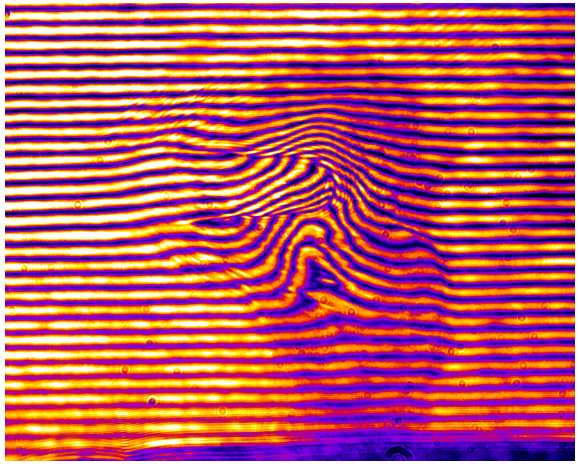
- Recently implemented <100 fs Ti:Sapphire probe, allowing measurement of intrapulse dynamics




*Previously: blur due to ionisation and plasma dynamics*

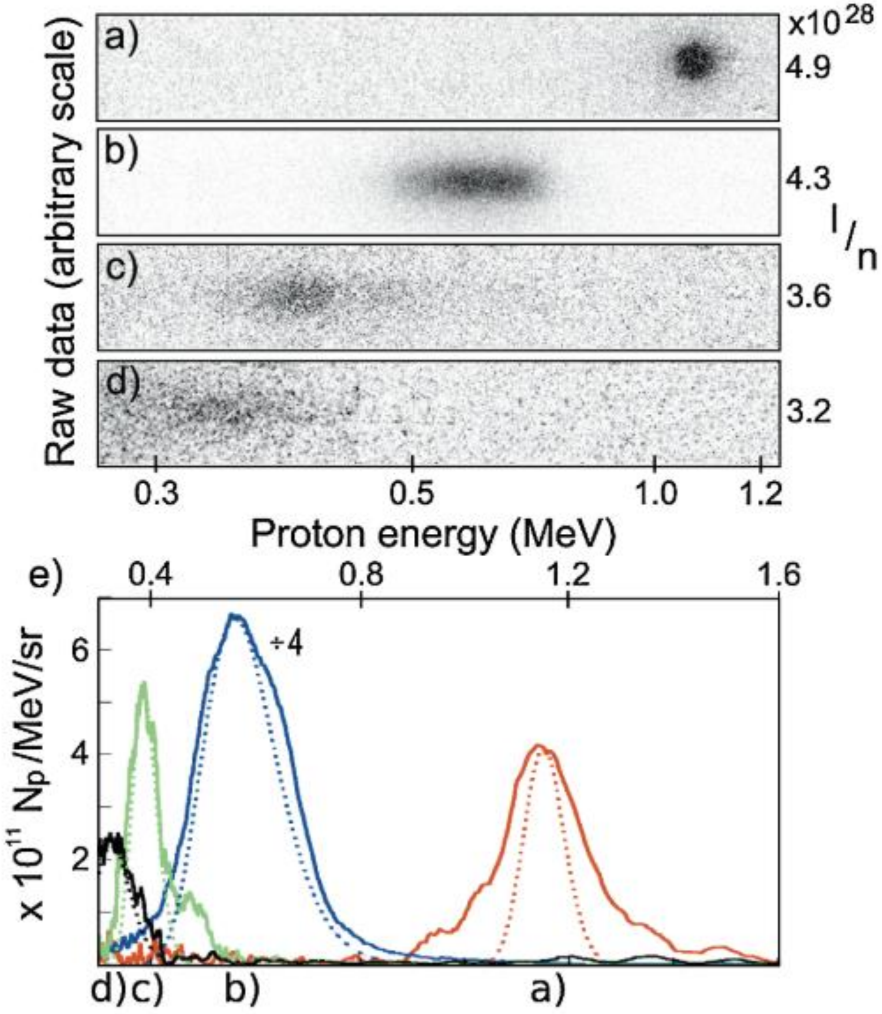


*Now: clean images when overlapping drive and probe*



# Work on radiation pressure driven acceleration

*Palmer+, Phys. Rev. Lett. 106, 014801 (2011)*



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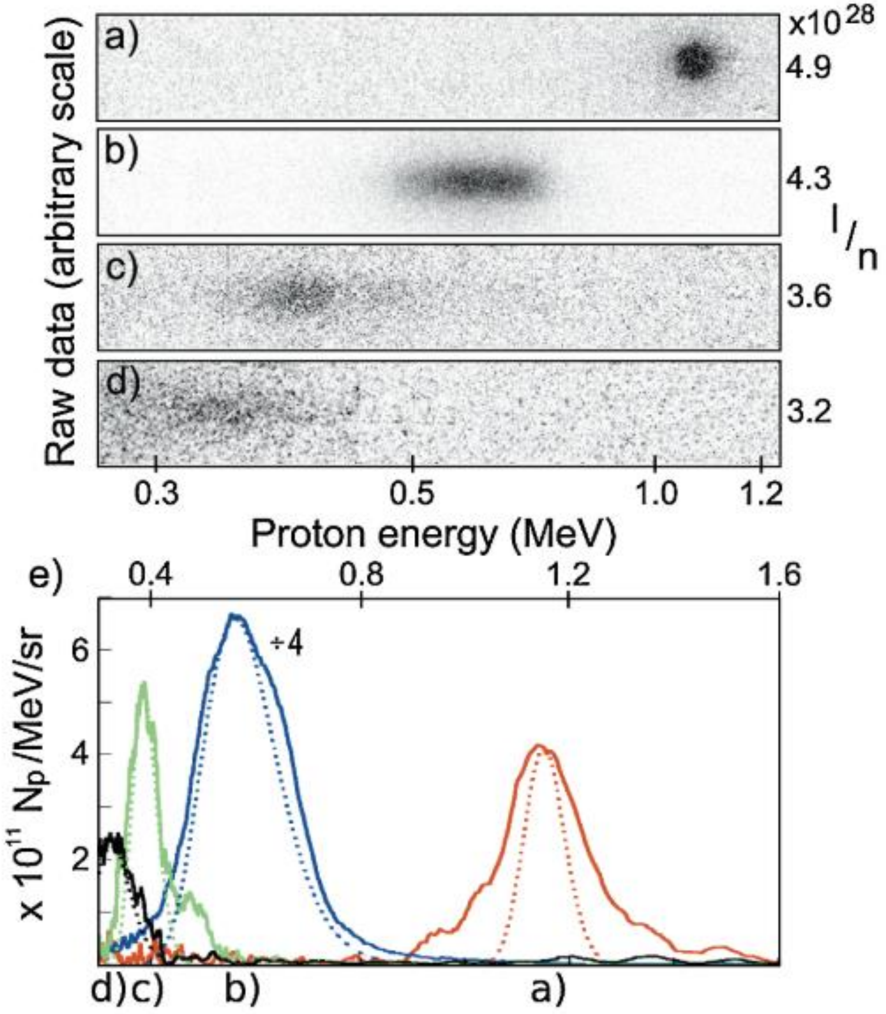
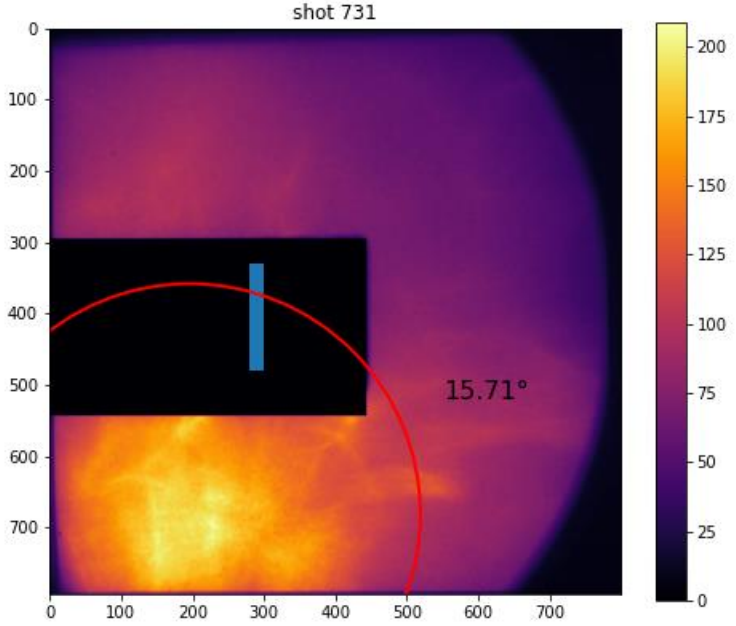
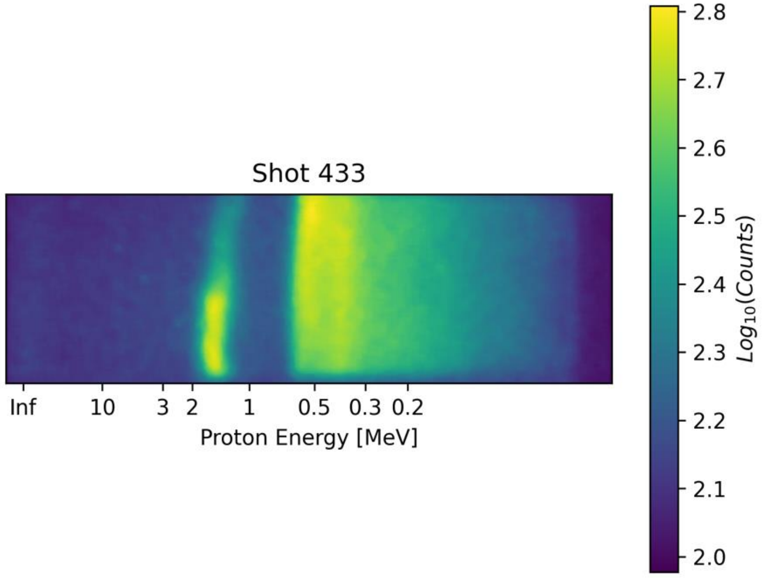



Recent experimental run exemplary shot:



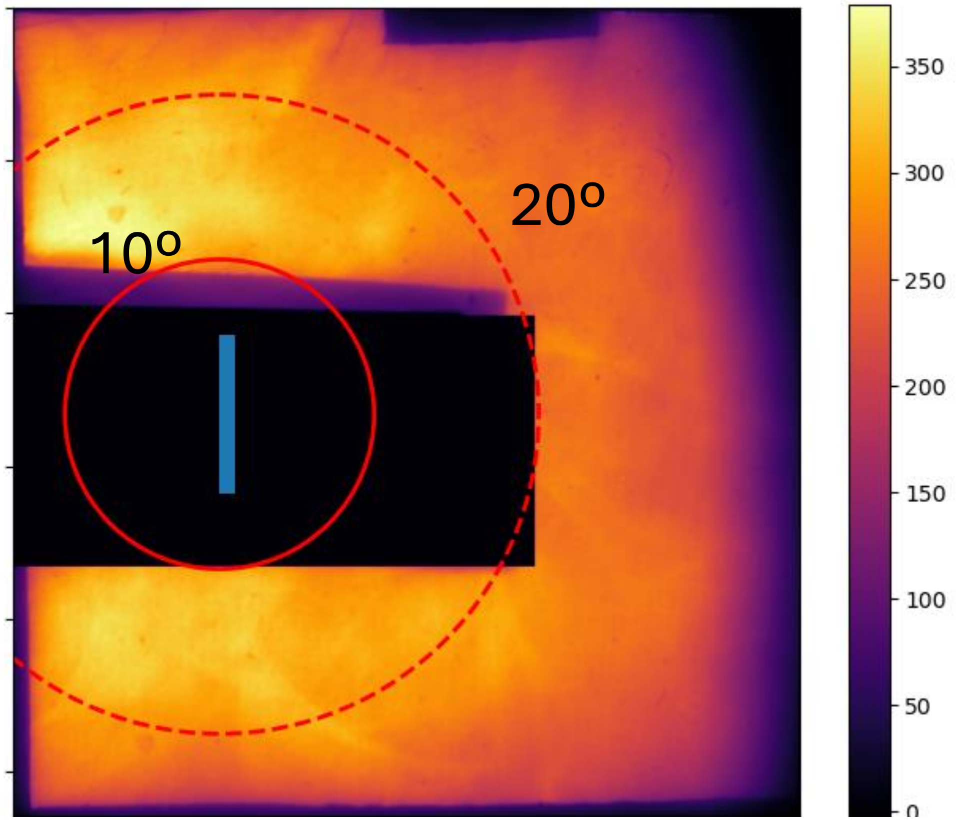

Proton spatial screen



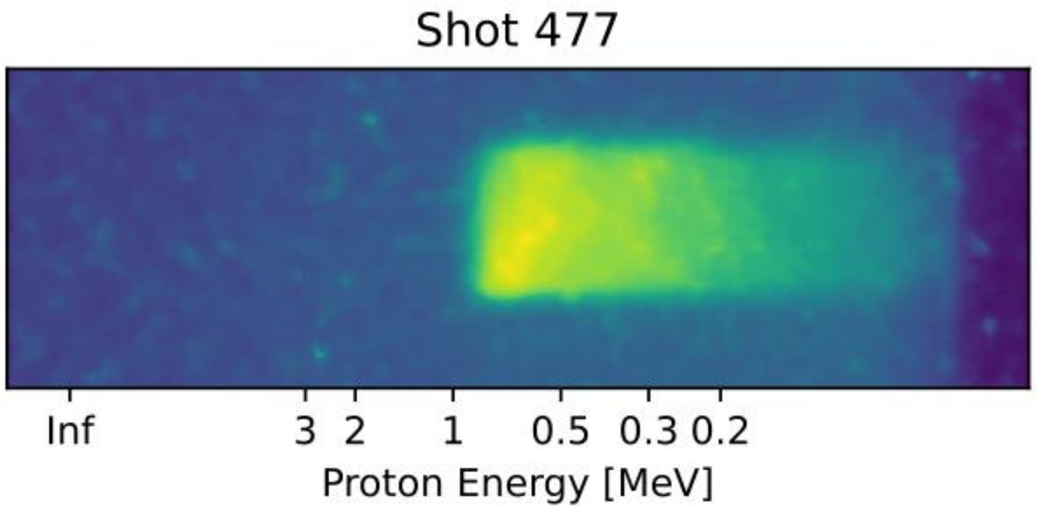

Thompson Spectrometer

# Scenario where shock acceleration failed

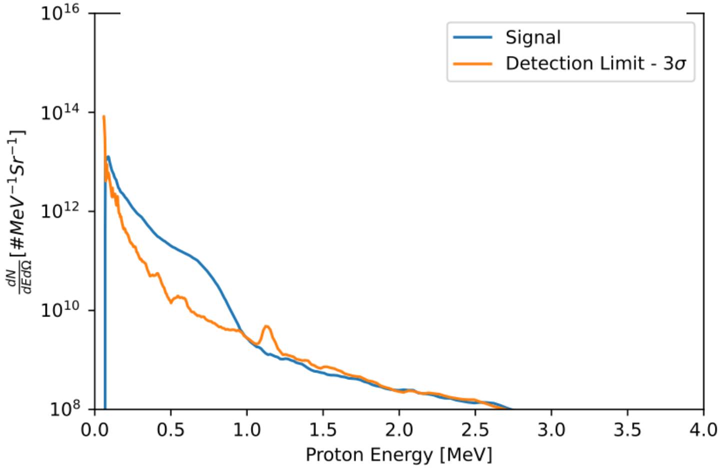
Divergence higher than 20º




Thermal ion beams

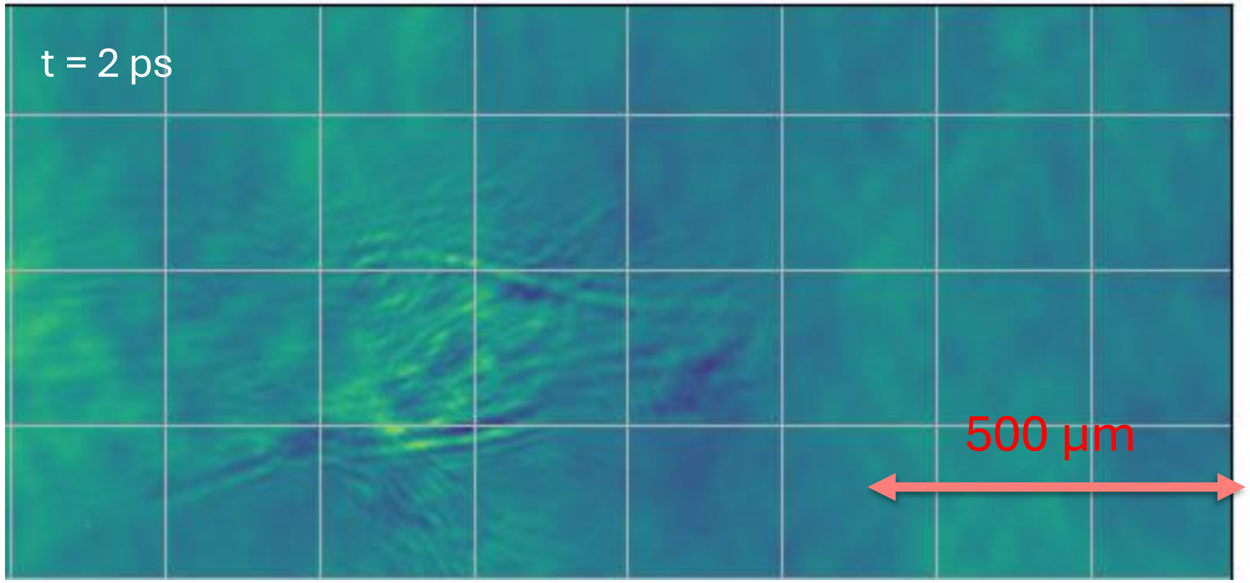


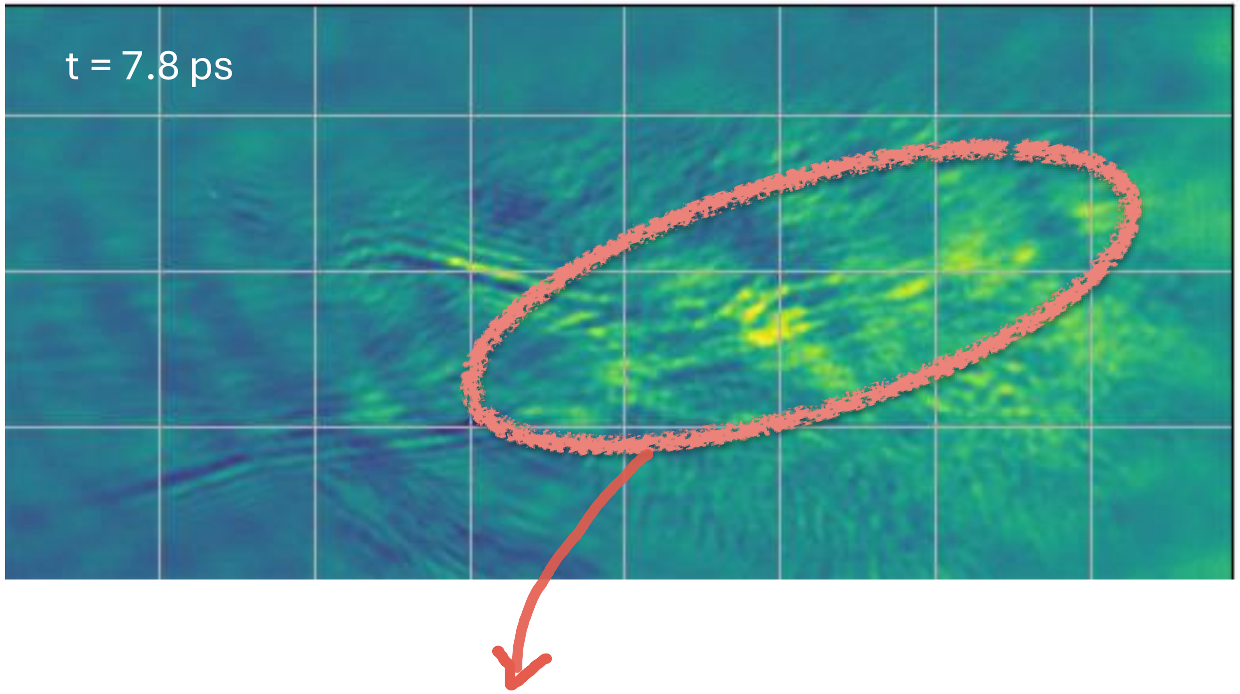

Deconvolved spectrum



# Channeling in near critical density plasma

Shadowgraphy at two times from the same shot:

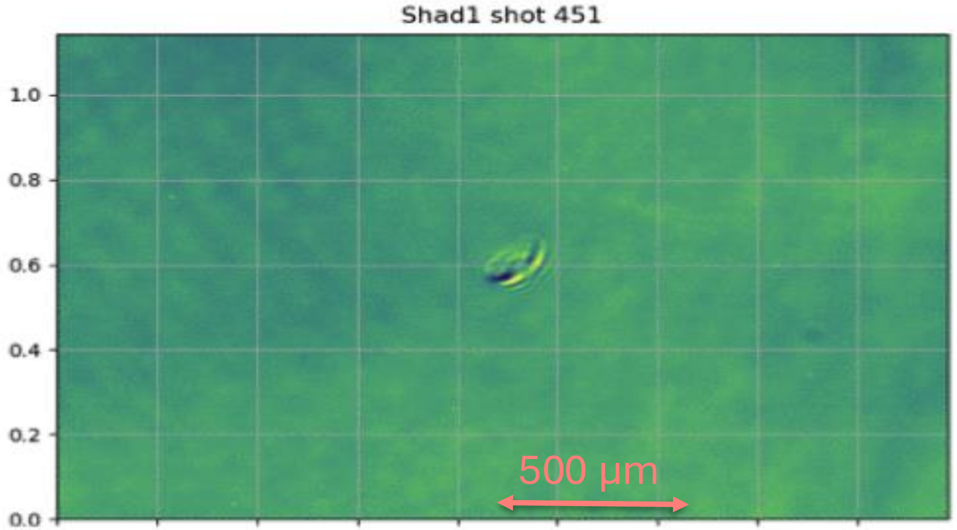


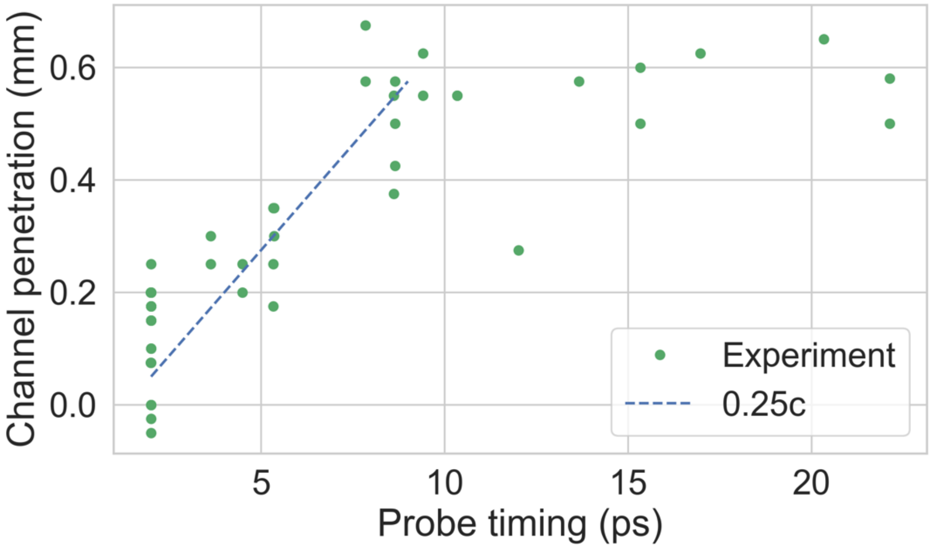




~1 $n_c$ hydrogen plasma

Generation of a clear laser-driven channel

# Laser channeling and thermal ions



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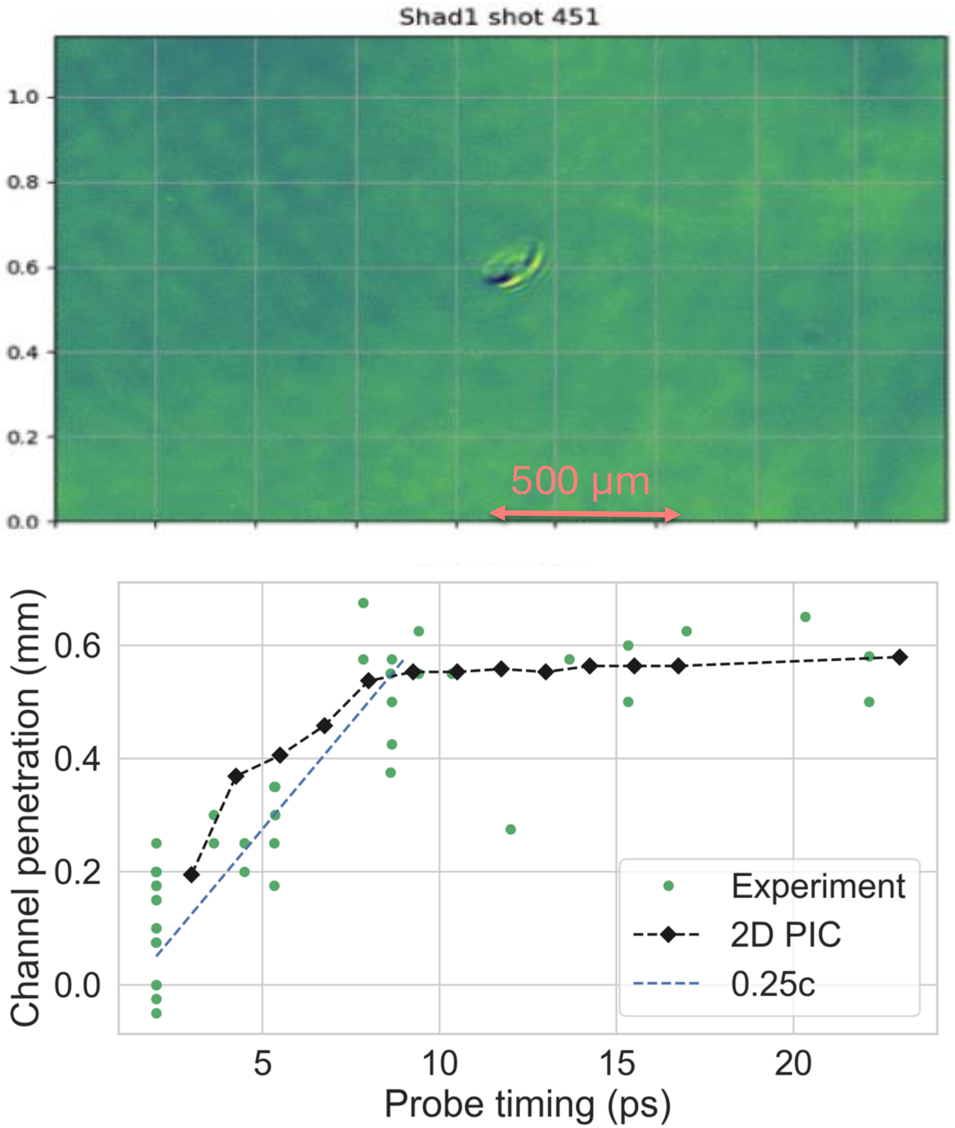


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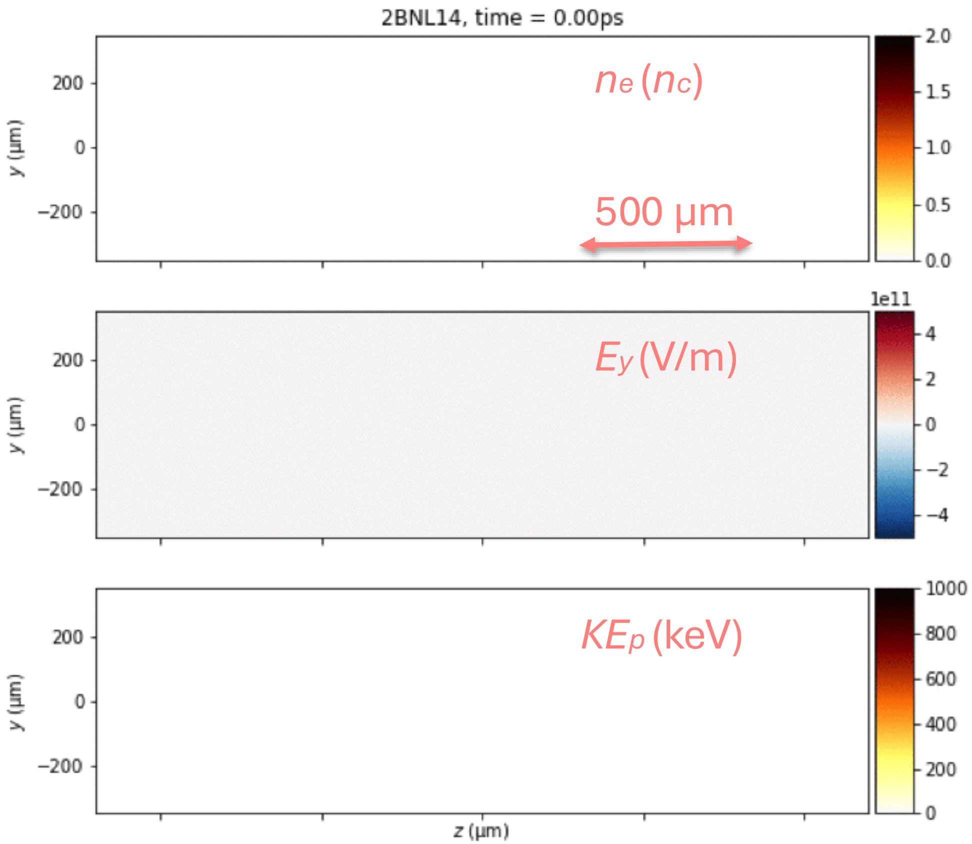

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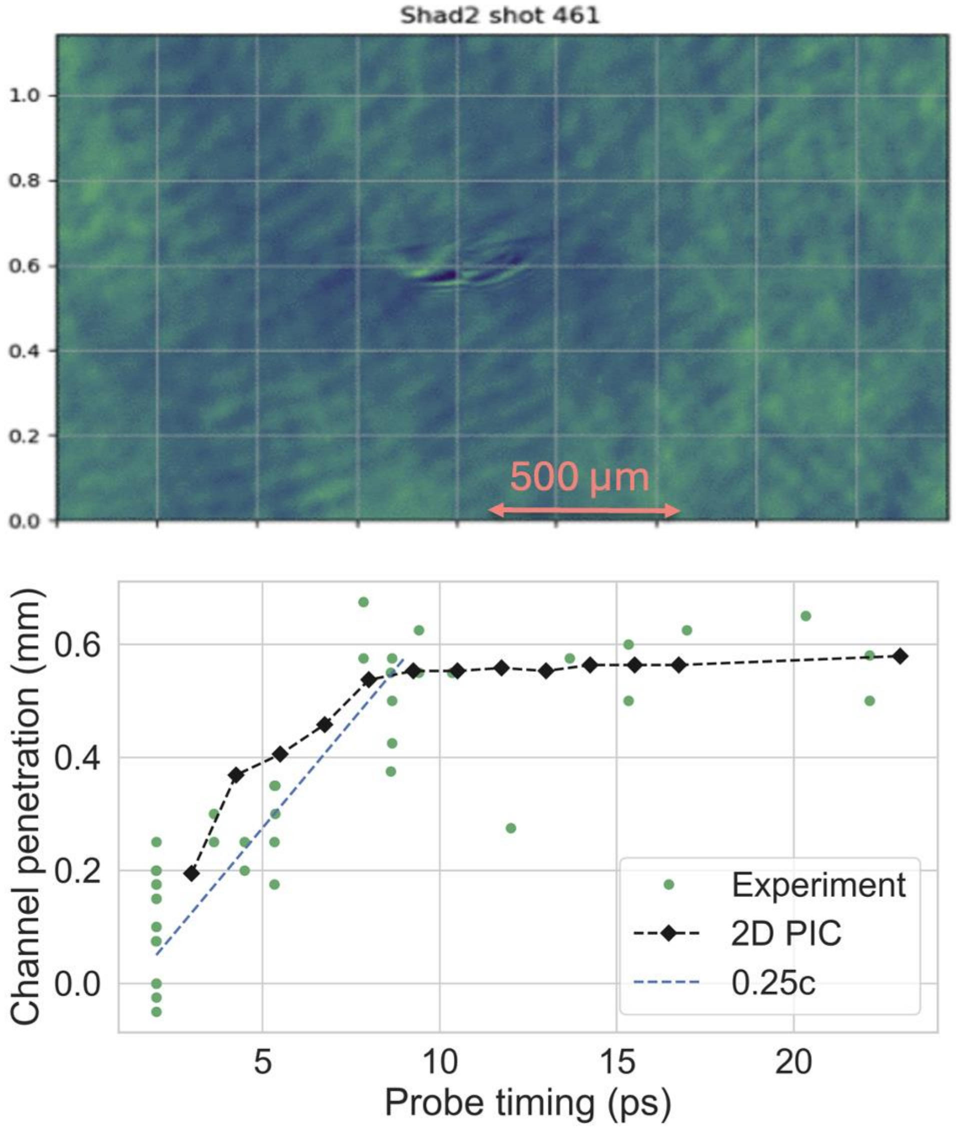


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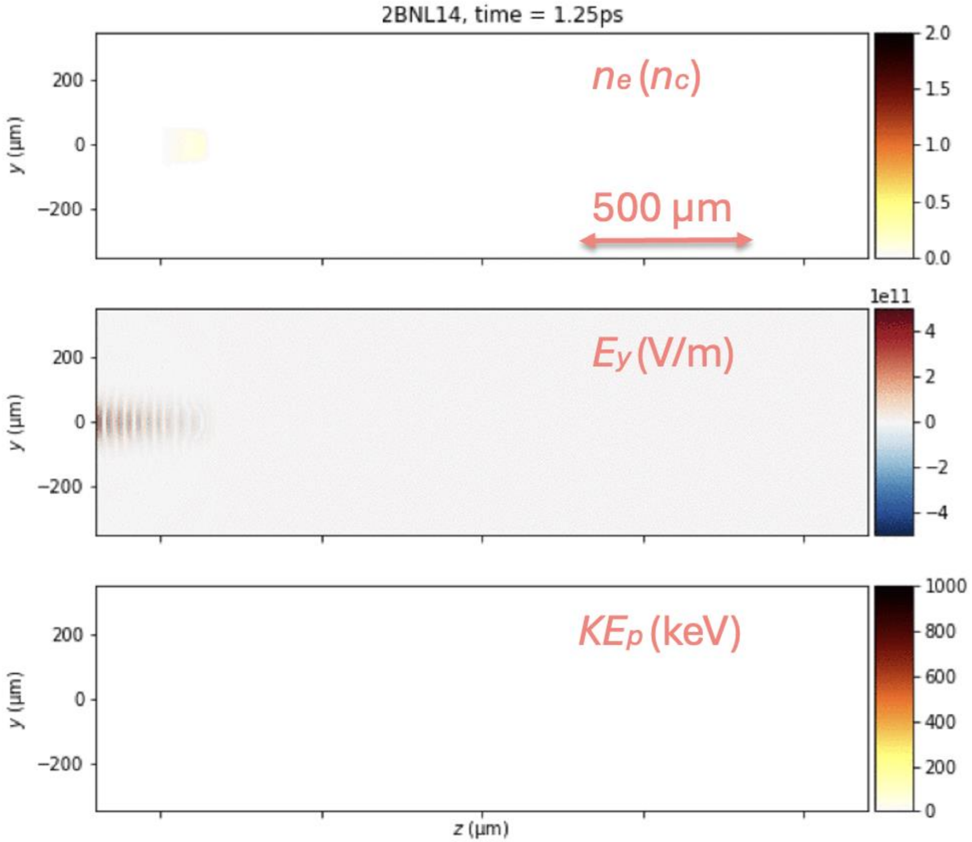

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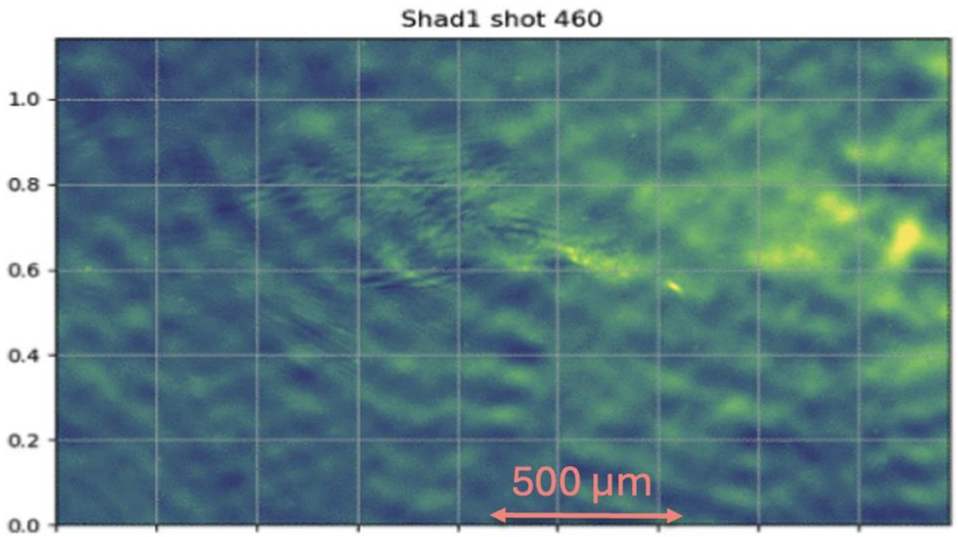


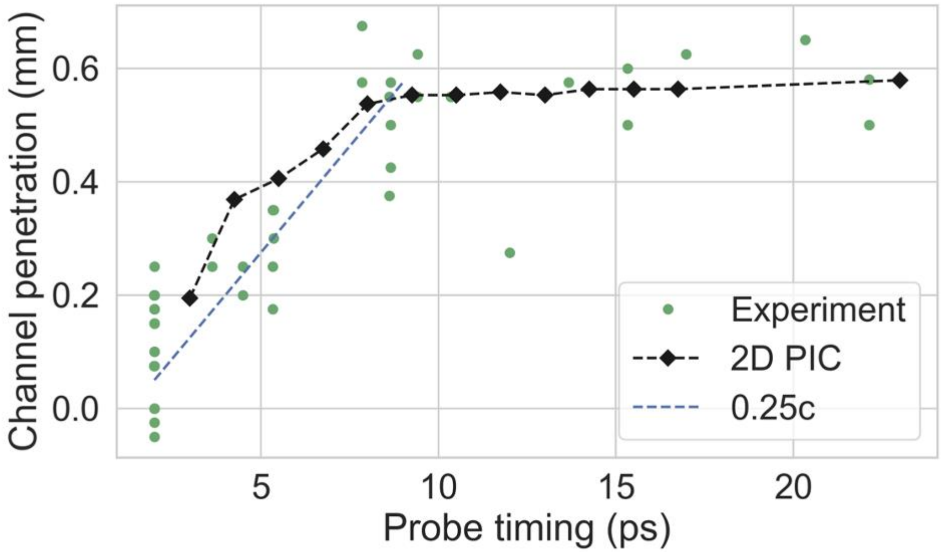


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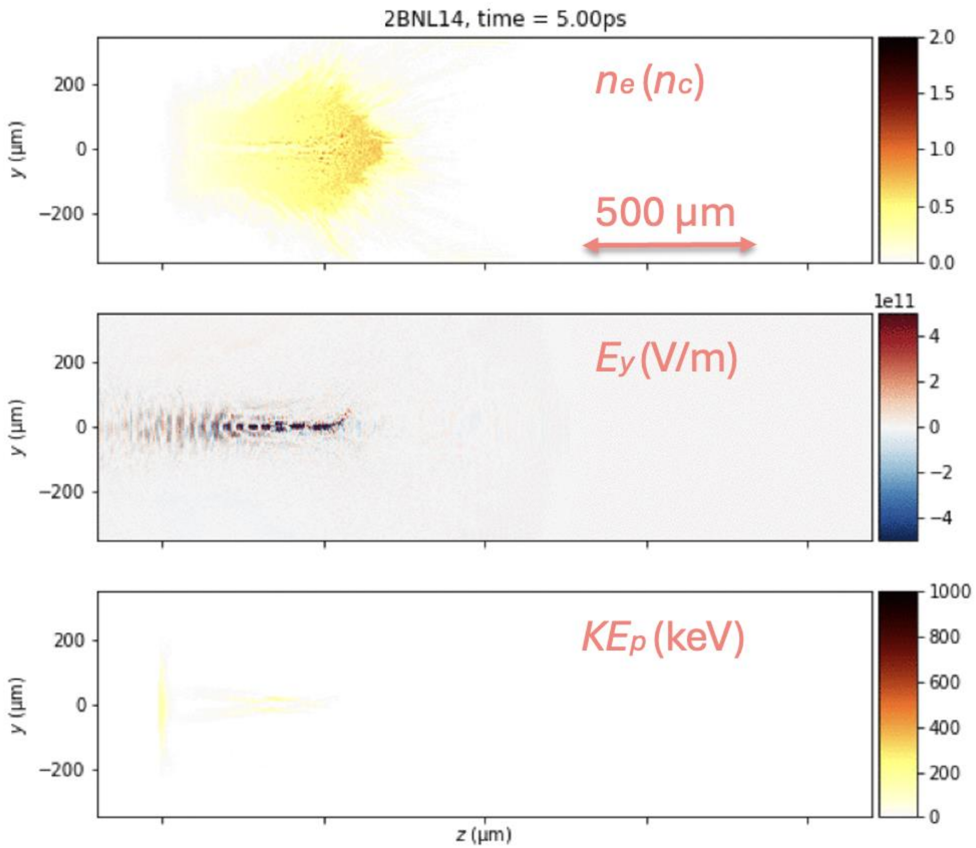

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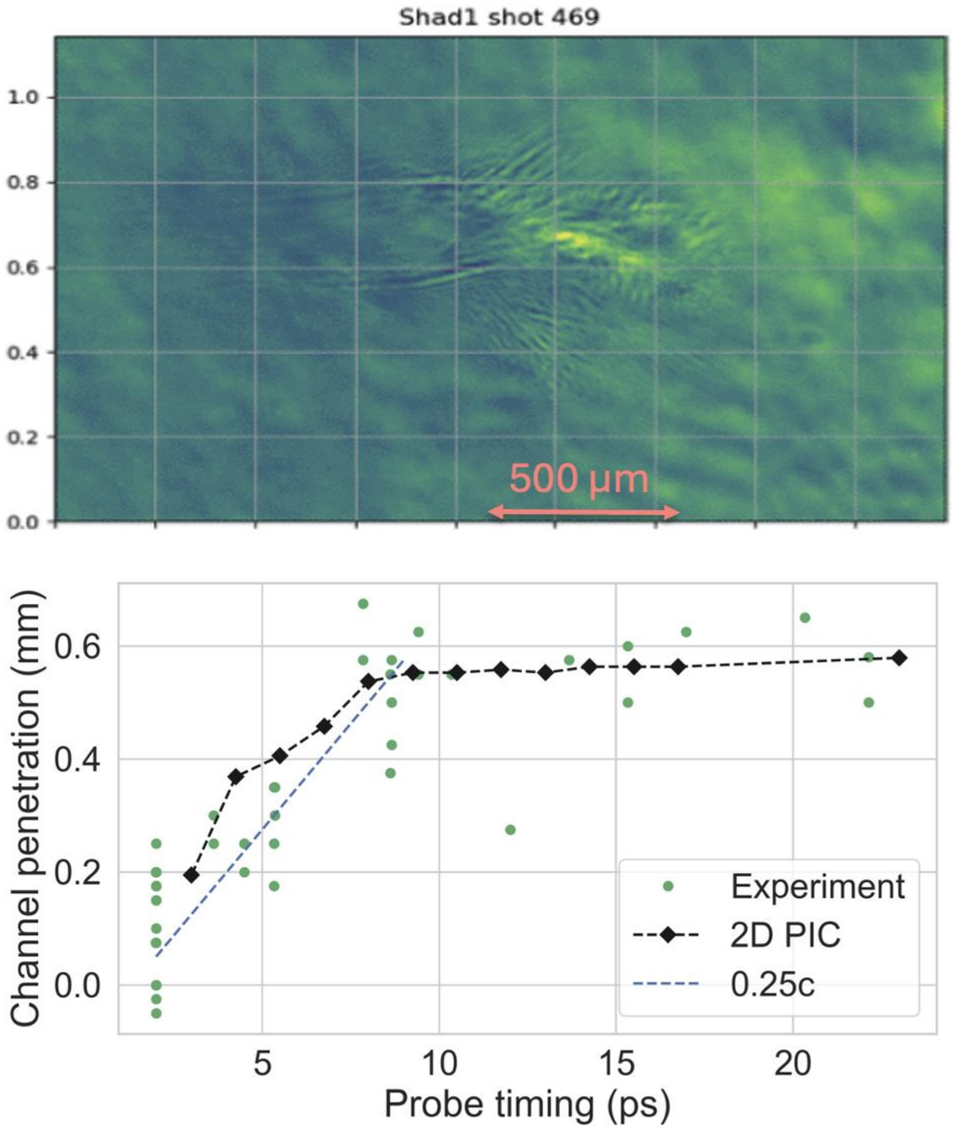


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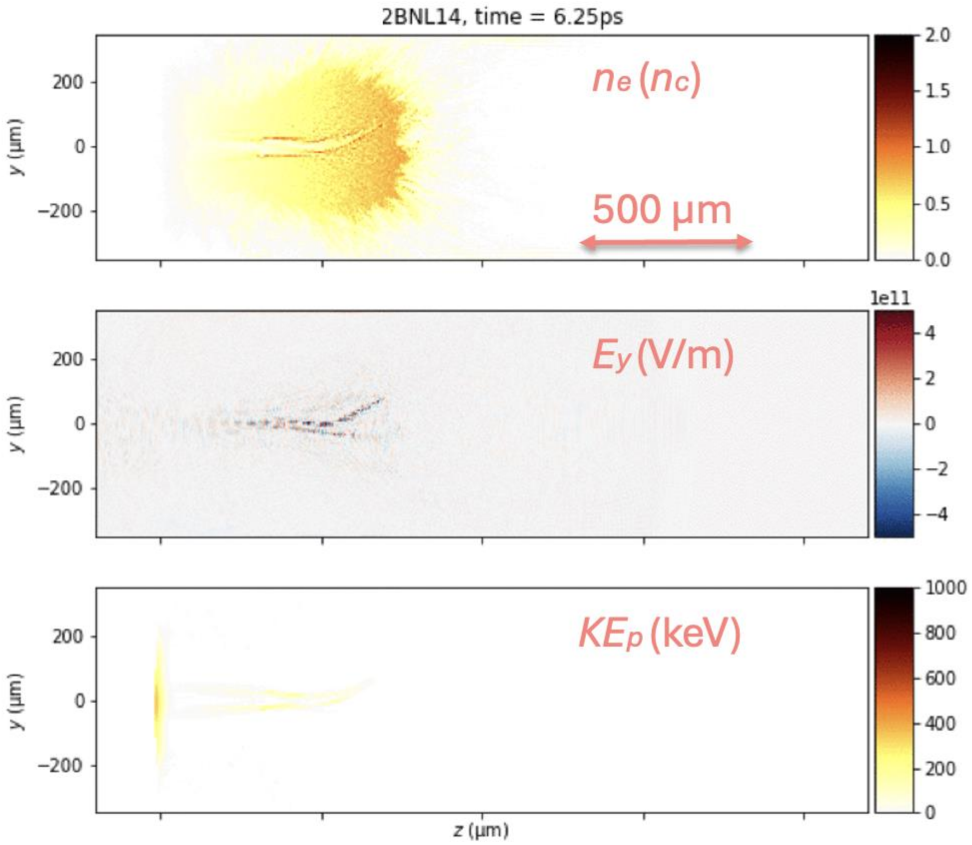

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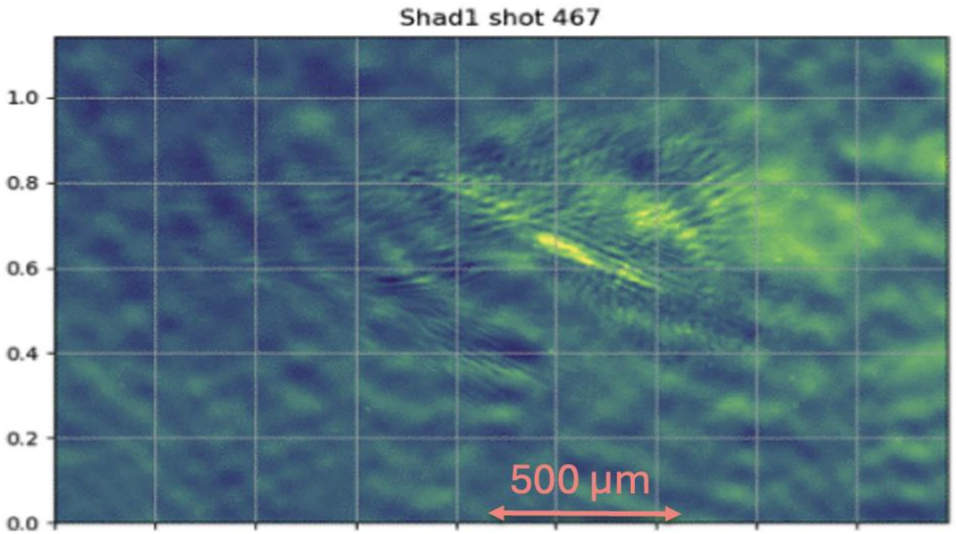


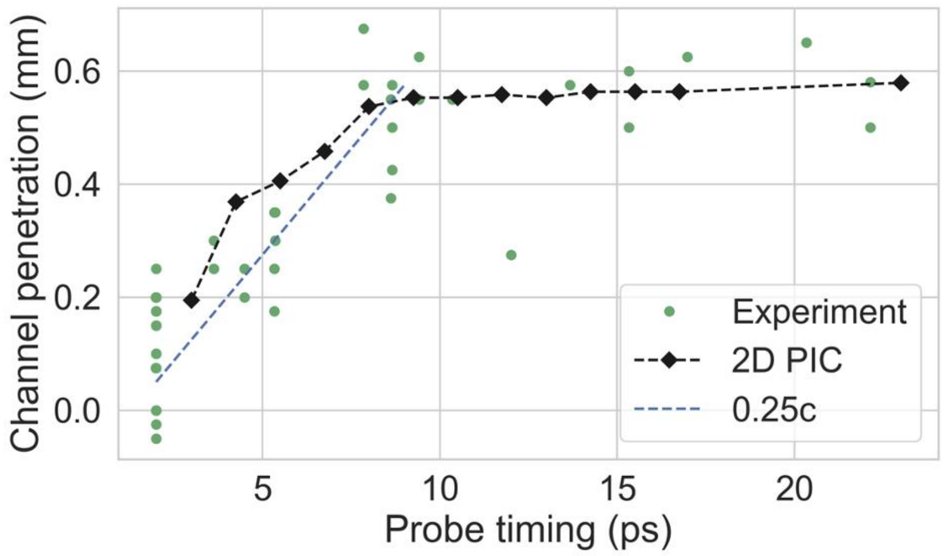


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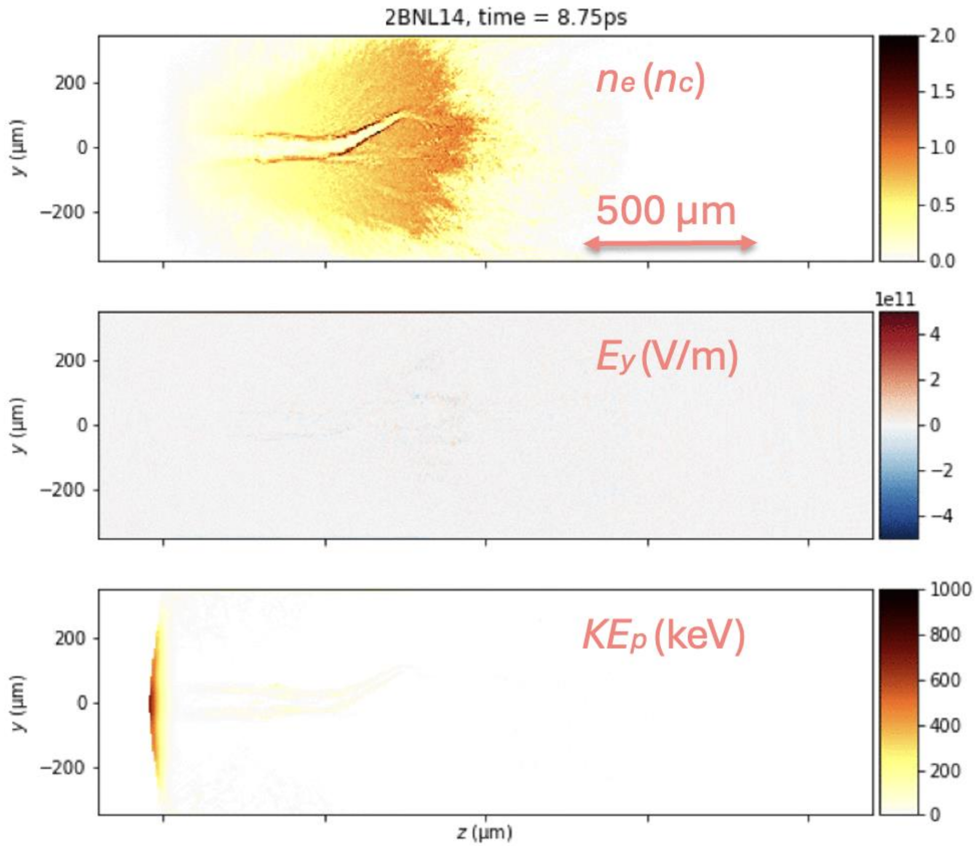

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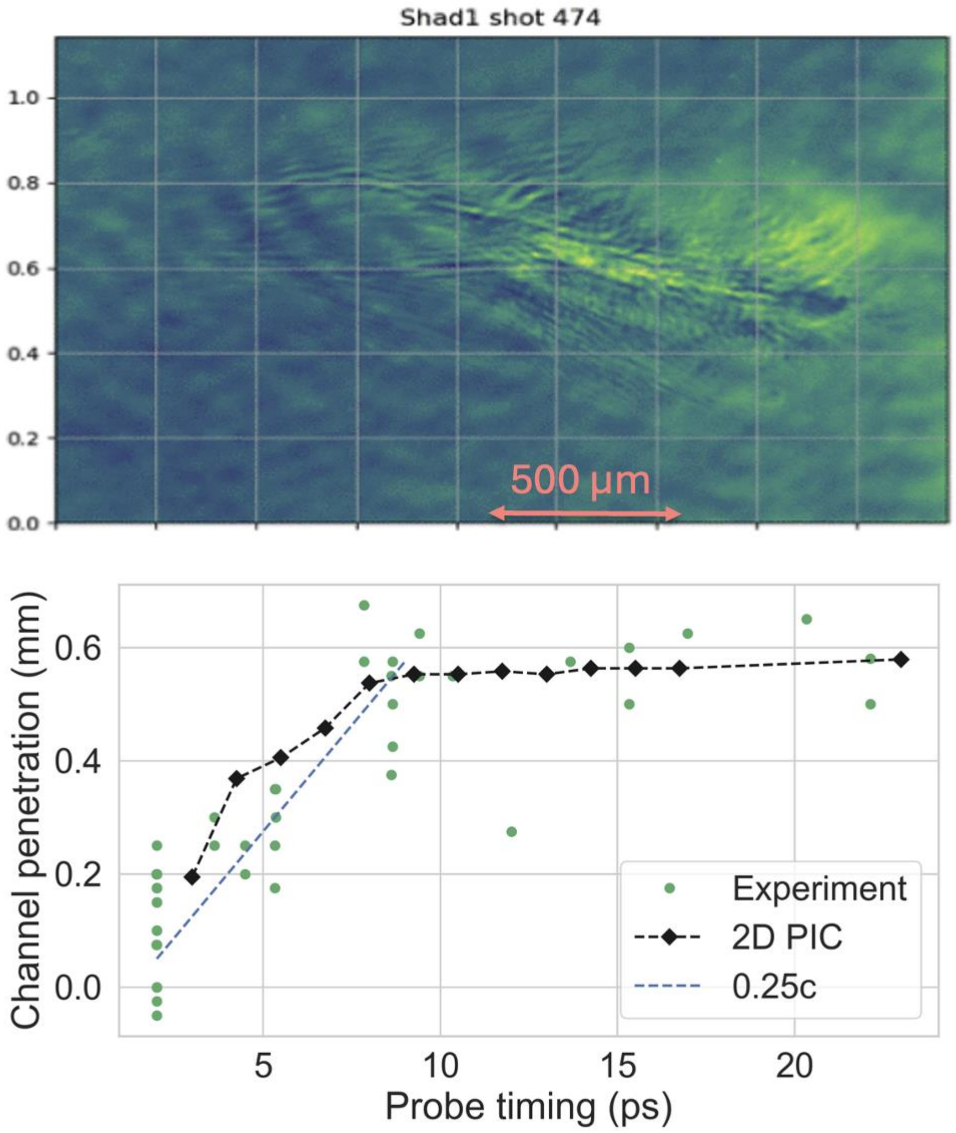


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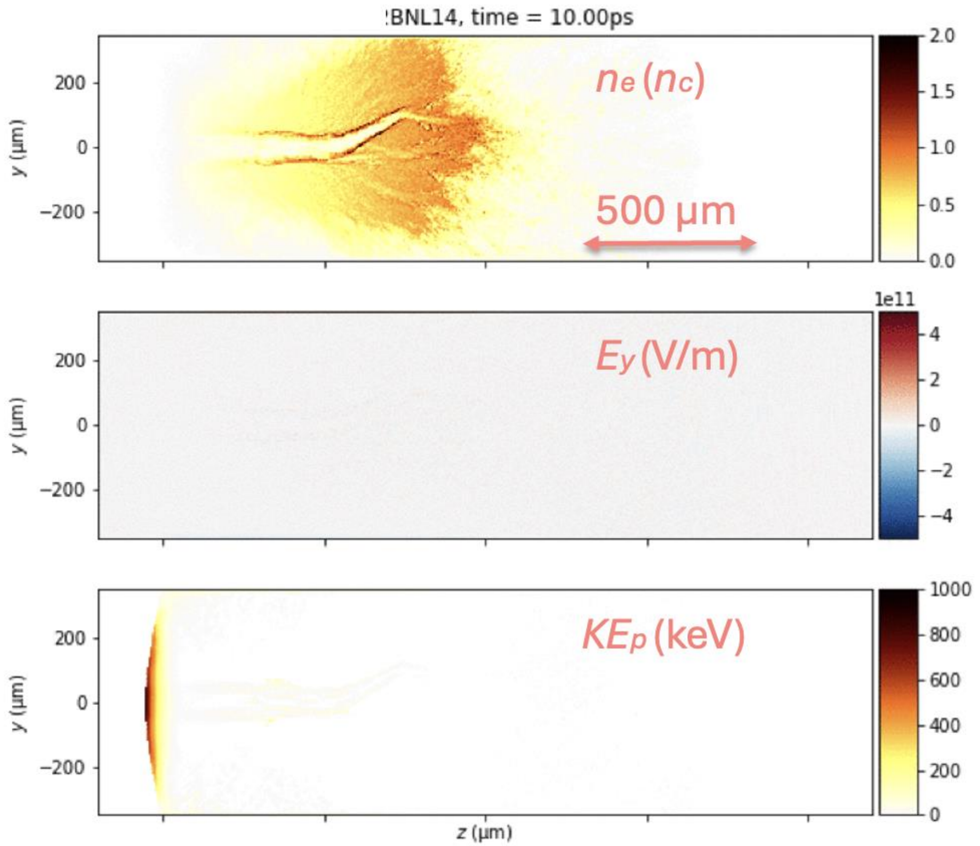

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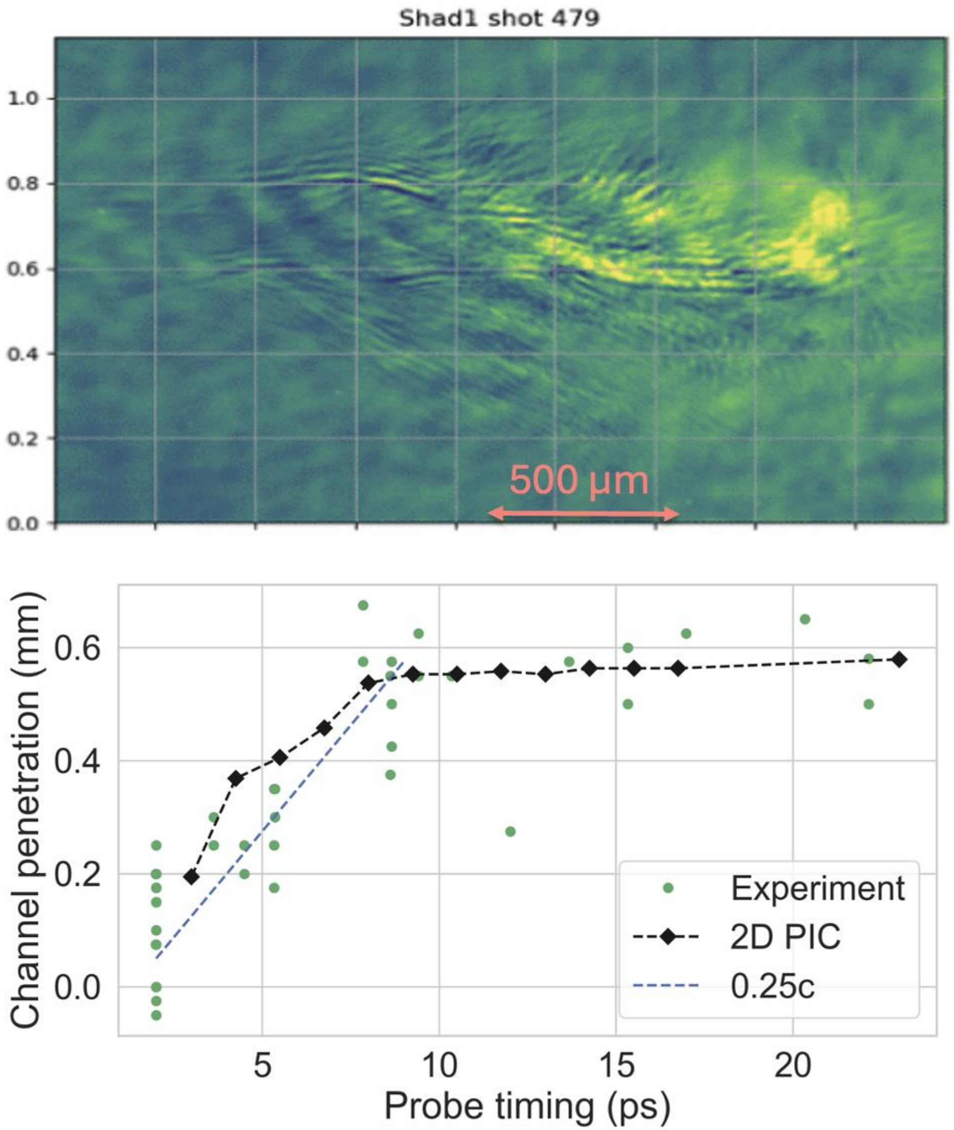


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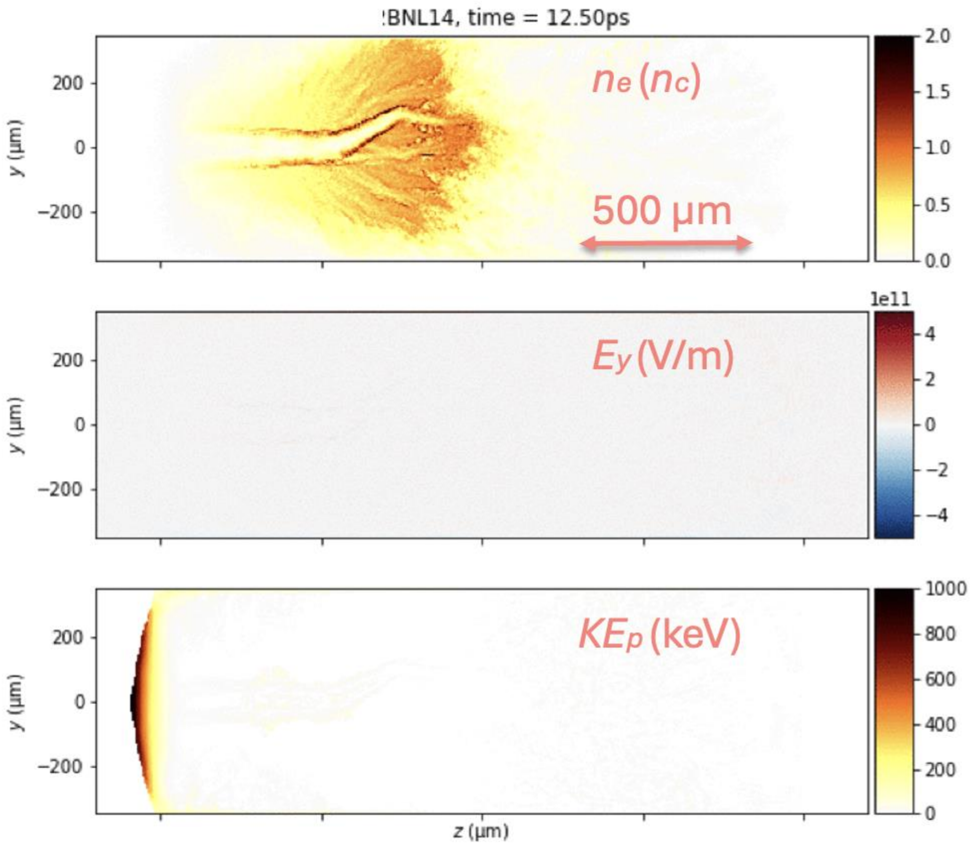

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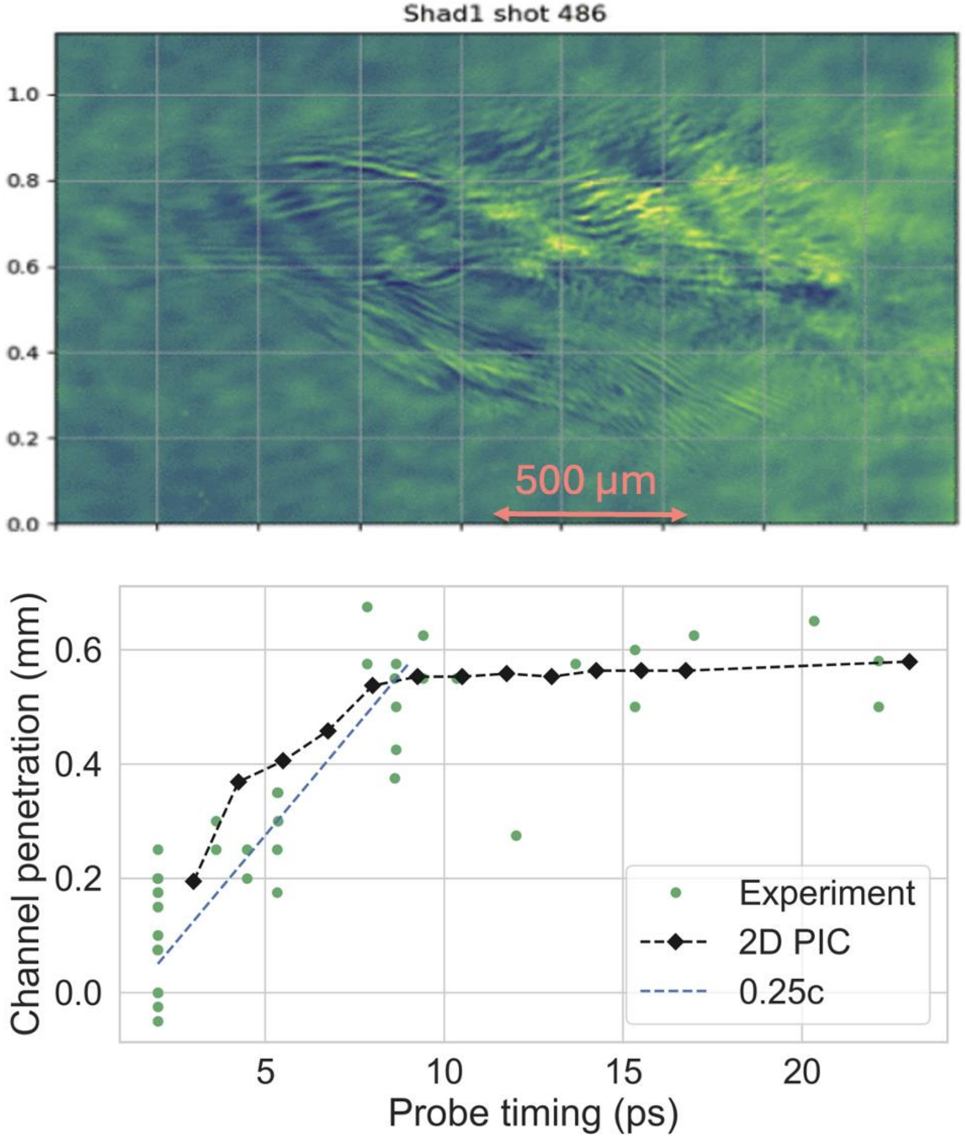


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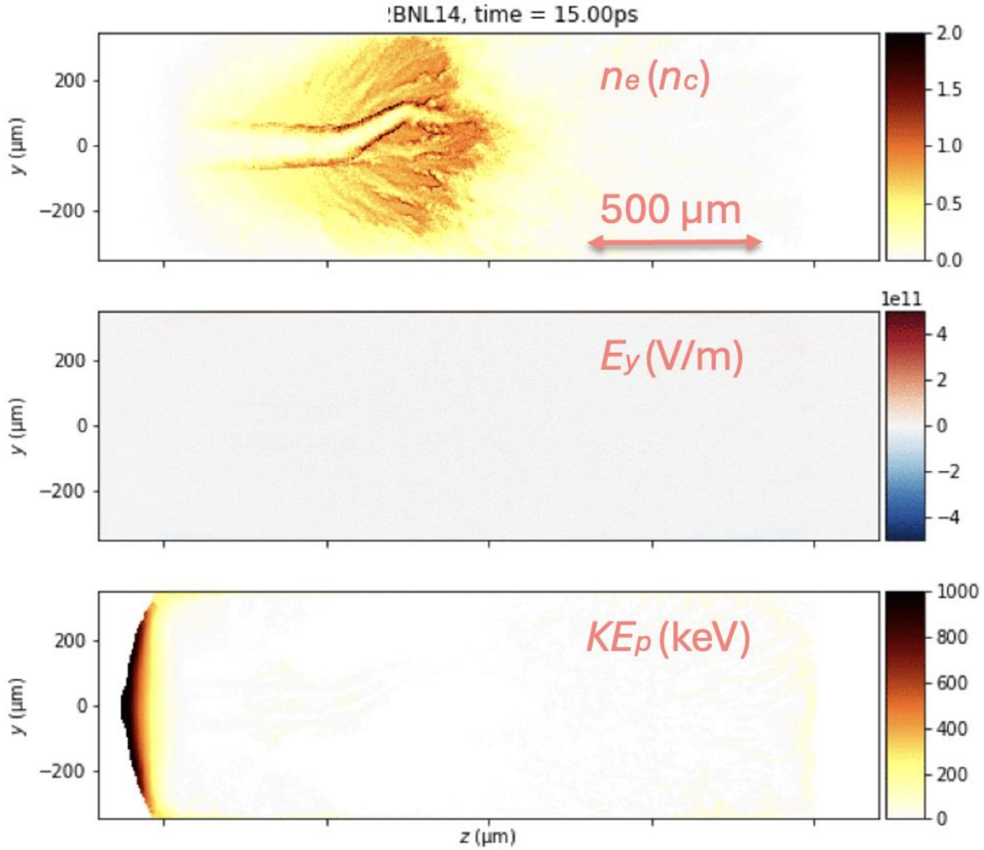
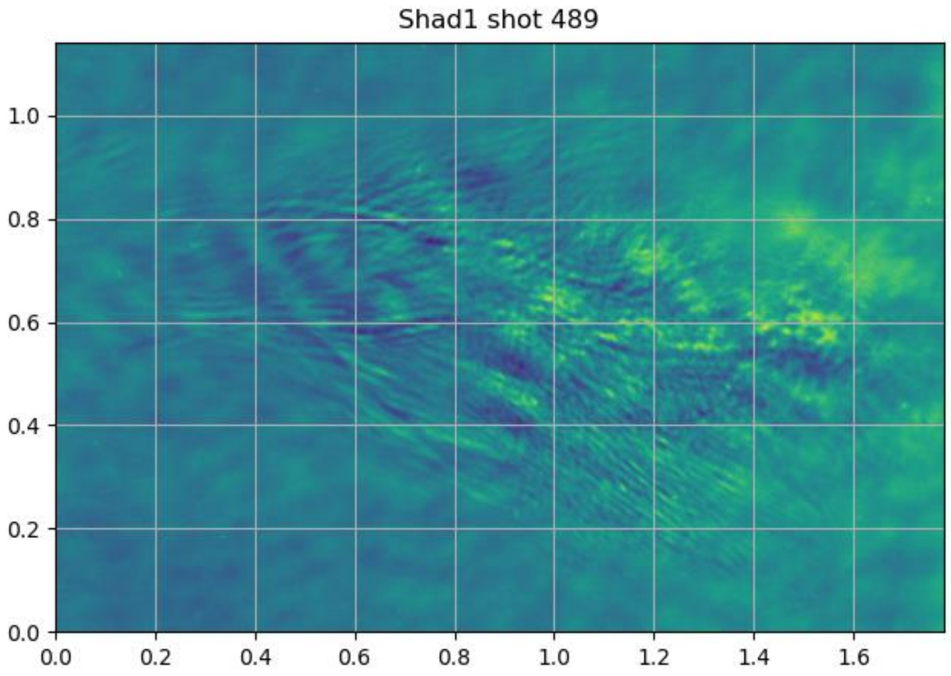
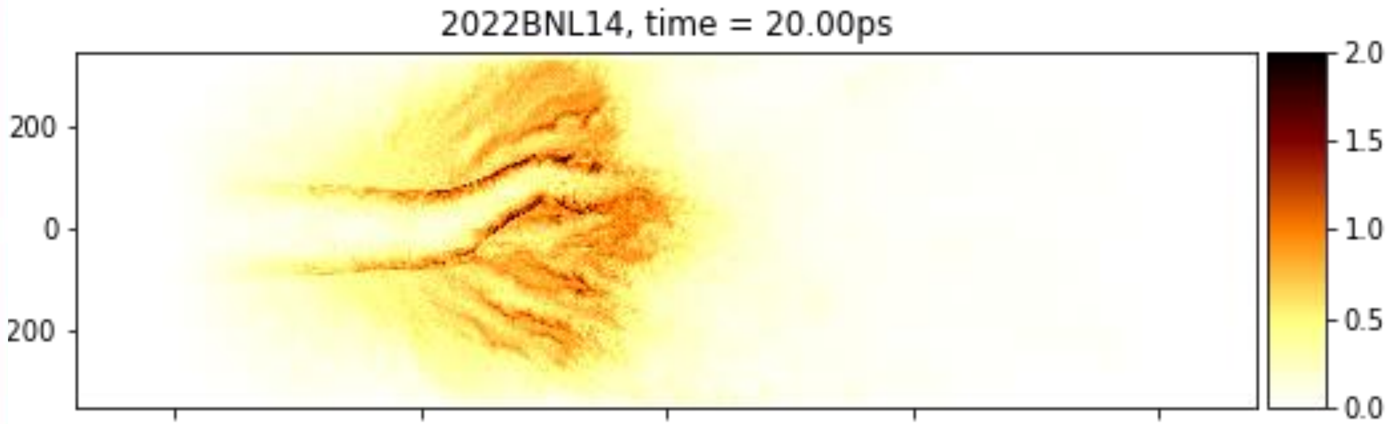


# Experimental shadowgraphy and 2D PIC



# Summary & Outlook

- Developing a testbed for laser driven ion source and fundamental LPI driven by longwave-IR laser
- Recent results include:
  - Investigation of shock ion acceleration with production of up to 5MeV monoenergetic ion beams
  - Channeling near critical-density plasma with production of ~1MeV thermal ions
- Exciting possibilities to exploit setup to look at many facets of critical density LPI