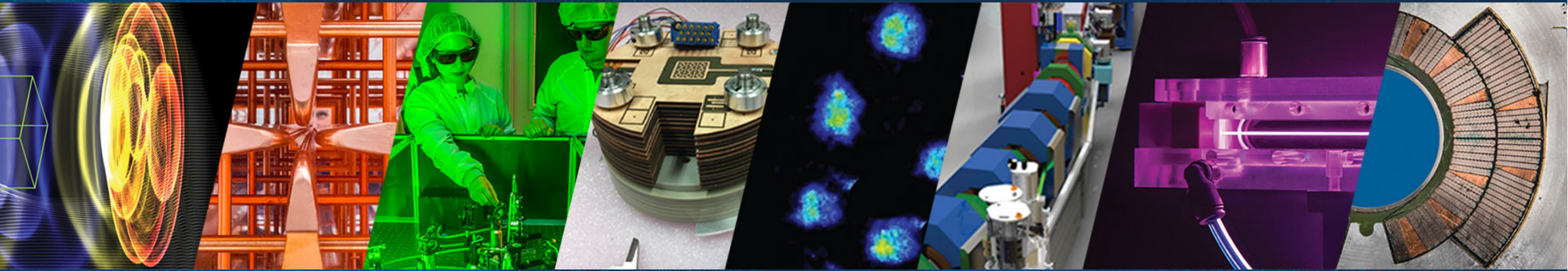
Controlled injection and acceleration of 10 GeV-class electron beams in a laser wakefield accelerator

Alex Picksley
Accelerator Technology & Applied Physics Division



International Particle Accelerator Conference 2026, France

May 20th 2026

BERKELEY LAB

ACCELERATOR TECHNOLOGY & APPLIED PHYSICS DIVISION ATAP

U.S. DEPARTMENT OF ENERGY | Office of Science

Contributors

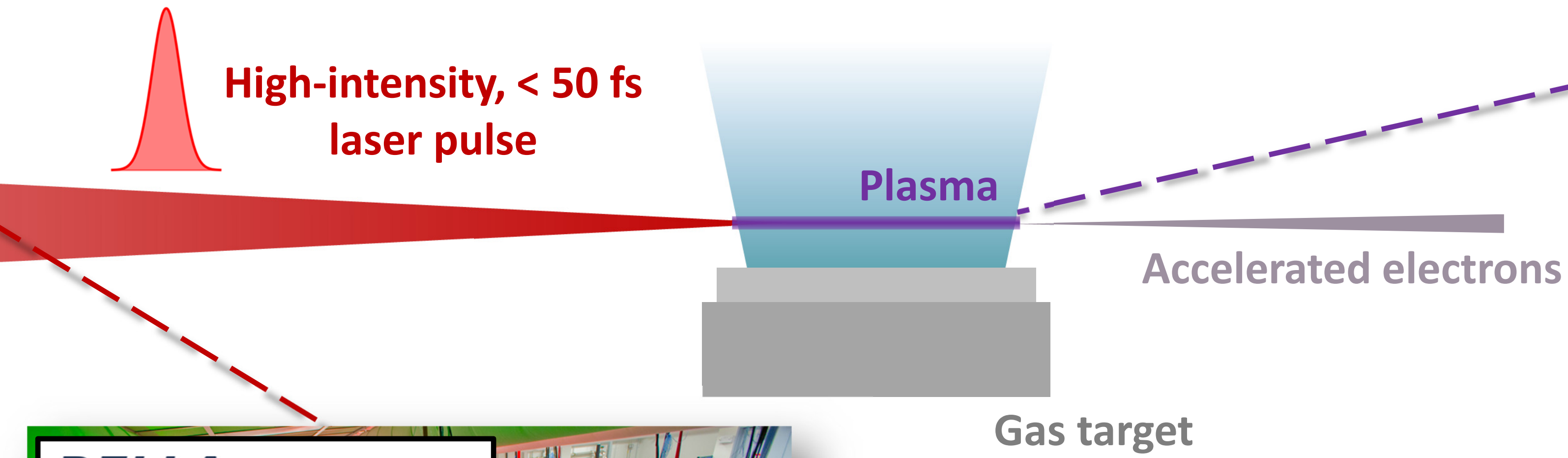
Alex Picksley
Tony Gonsalves
Joshua Stackhouse
Carlo Benedetti
Kei Nakamura
Davide Terzani
Stanimir Kisyov

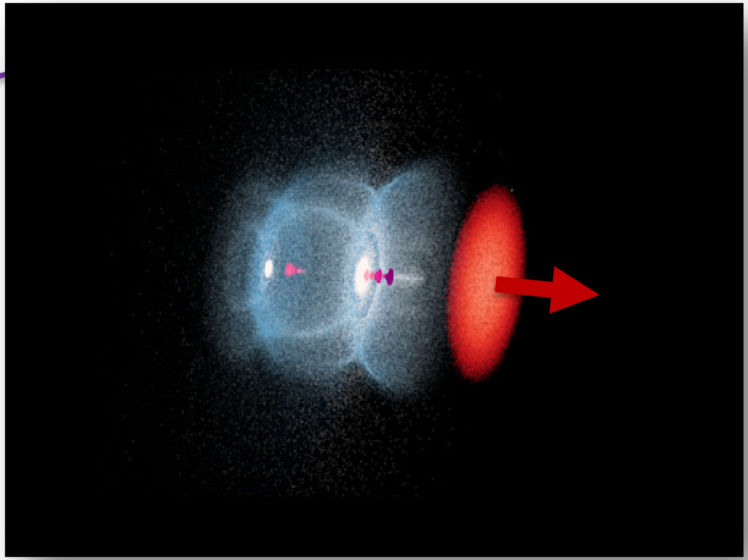
Hai-En Tsai
Raymond Li
Carl Schroeder
Jeroen van Tilborg
Eric Esarey
Cameron Geddes

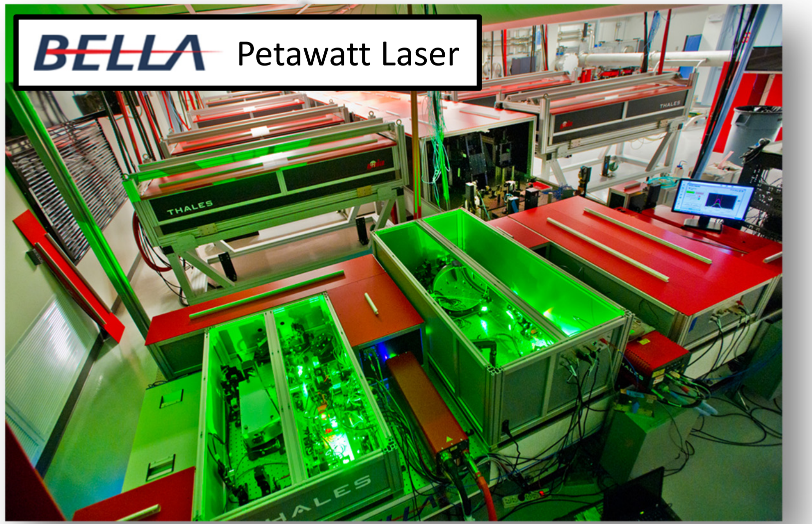
University of Maryland
Bo Miao
Jaron Shrock
Ela Rockafellow
Howard Milchberg

This work was supported by the Director, Office of Science, Office of High Energy Physics, of the U.S. Department of Energy under Contract No. DE-AC02- 05CH11231, the Defense Advanced Research Projects Agency, and used the computational facilities at the National Energy Research Scientific Computing Center (NERSC).

Laser-plasma accelerators: ultrahigh fields provide compact accelerator modules for future colliders and near-term applications







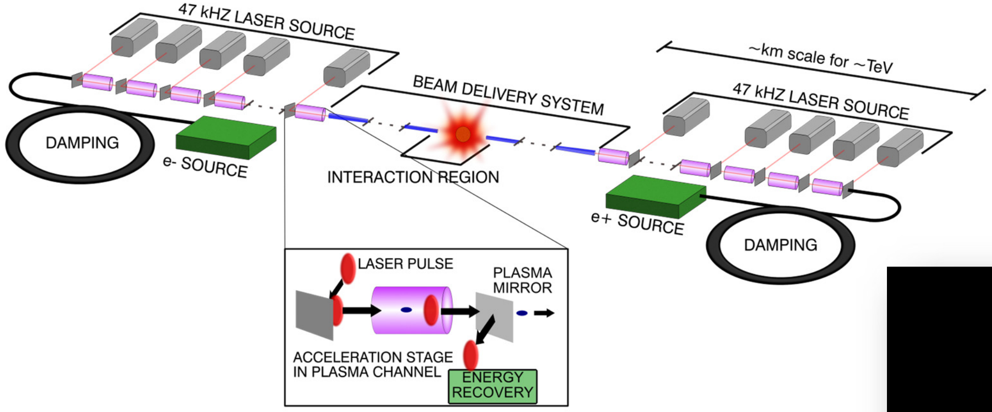
- Ultrahigh fields: 1-100 GV/m
- Potential to:
  - Reduce the size & cost,
  - Increase application space of accelerators

Tajima and Dawson, *Physical Review Letters* (1979)
E. Esarey et al. *Review of Modern Physics* (2009)

Dream Beam Papers:
J. Faure et al., *Nature* (2004)
S. P. D. Mangles et al., *Nature* (2004)
C. D. R. Geddes et al., *Nature* (2004)

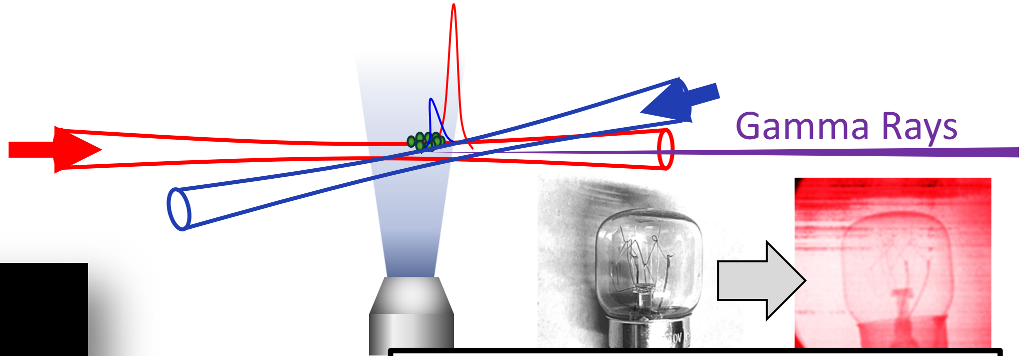
At the BELLA Center, we explore LPAs for compact drivers of linear colliders and secondary radiation sources

High energy physics colliders

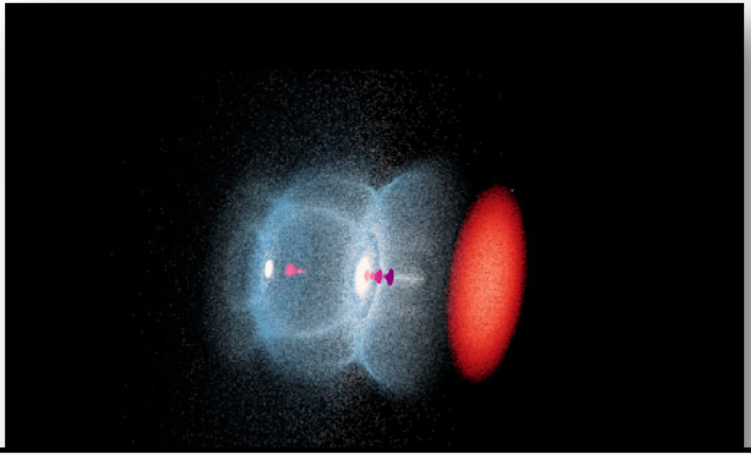


C. Schroeder, et al., *J. Instrum. 18*, T06001 (2023).

Thomson scatter γ-source

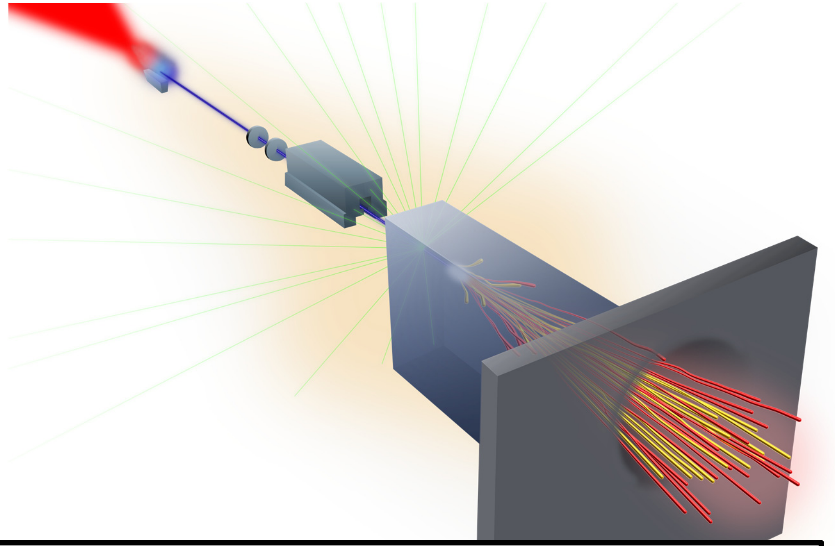


C. Thornton et al. *arXiv,* (2024) 2404.09270
H. E. Tsai et al., *Accepted to Sci Rep*



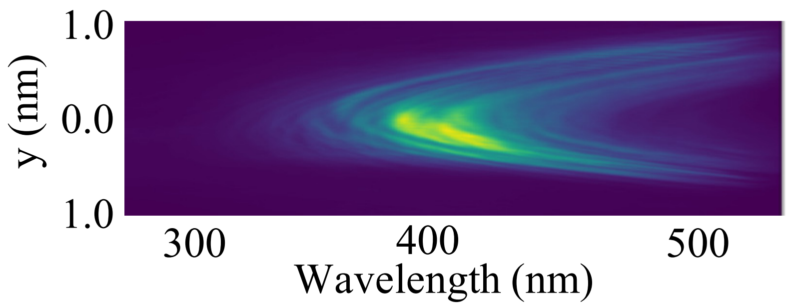
A. J. Gonsalves et al. *Physical Review Letters* 122.08 (2019)
A. Picksley et al. *Physical Review Letters* 133.25 (2024)

Compact muon sources for muography



D. Terzani et al. *Physical Review Accelerators and Beams* (2025) 28 (10)

Free Electron Lasers



S. Barber, et al., *Physical Review Letters* (2025) 135.5
F. Kohrell et al. *Physical Review Accelerators and Beams* (2026) 29.4

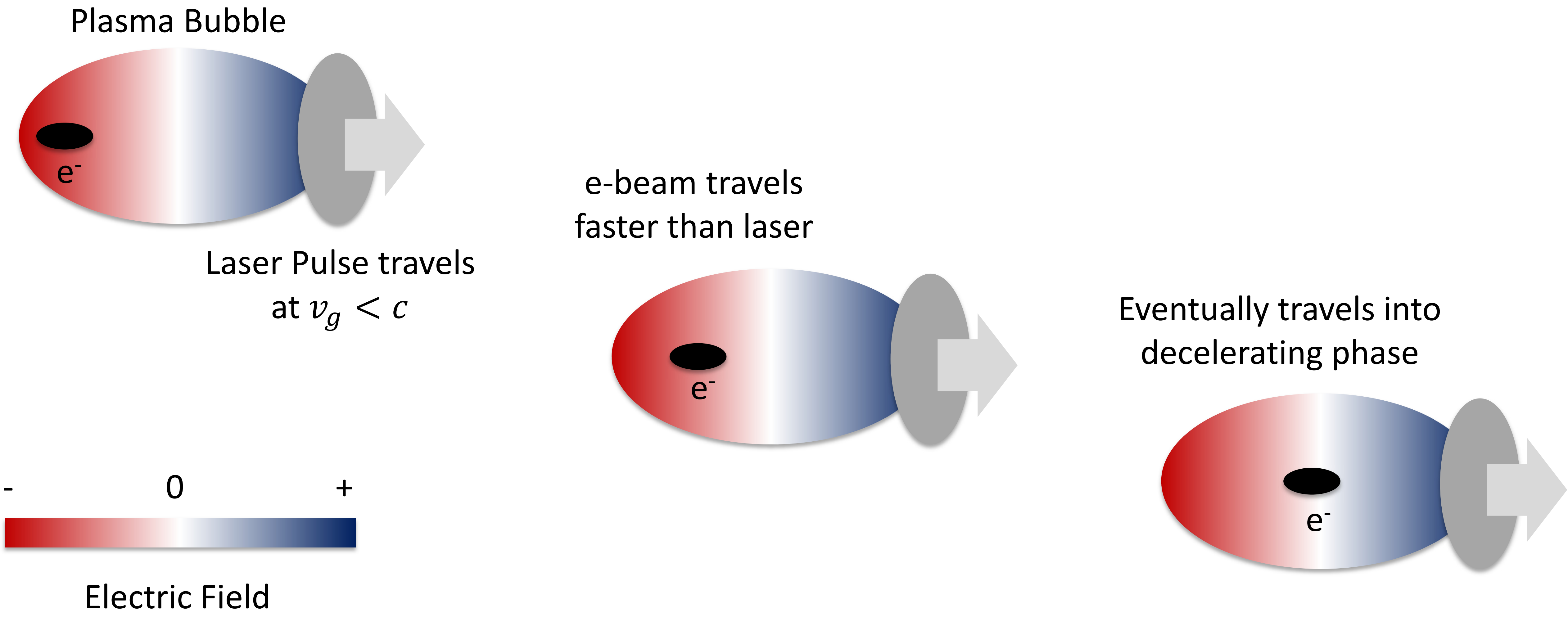
Talk Outline

1. Maximizing electron beam energy in a laser-plasma accelerator
2. Matched guiding and acceleration in a 10-GeV-class laser-plasma accelerator
3. Towards an LPA stage suitable for applications

Talk Outline

1. Maximizing electron beam energy in a laser-plasma accelerator
2. Matched guiding and acceleration in a 10-GeV-class laser-plasma accelerator
3. Towards an LPA stage suitable for applications

LPAs are fundamentally* limited by Dephasing



$$L_{\text{dephase}} \propto \frac{1}{n_e^{3/2}}$$

*see Liberman, A, et al. *Nature Communications* (2025)

Diffraction mitigation essential for achieving high energy gain

Scaling laws

$$\text{Energy gain} \propto \frac{1}{n_e}$$

$$\text{Accelerator length} \propto \frac{1}{n_e^{3/2}}$$

- Fundamental Limit **Dephasing**
- Scaling laws for LPAs indicate that 10-GeV-class stages
  - Several centimeters long
  - Density $n_{e0} \sim 10^{17}\ \mathrm{cm}^{-3}$

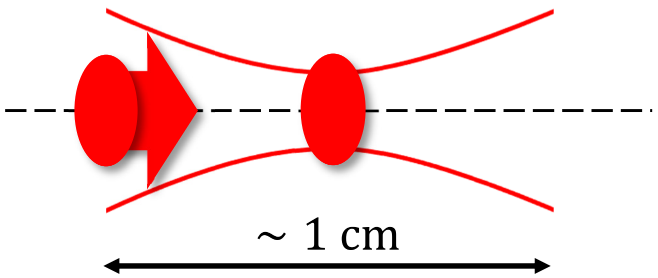
Diffraction mitigation essential for achieving high energy gain

Scaling laws

$$\text{Energy gain} \propto \frac{1}{n_e}$$

$$\text{Accelerator length} \propto \frac{1}{n_e^{3/2}}$$

Vacuum diffraction over Rayleigh length



- Fundamental Limit **Dephasing**

- Scaling laws for LPAs indicate that 10-GeV-class stages
  - Several centimeters long
  - Density $n_{e0} \sim 10^{17}\ \mathrm{cm}^{-3}$

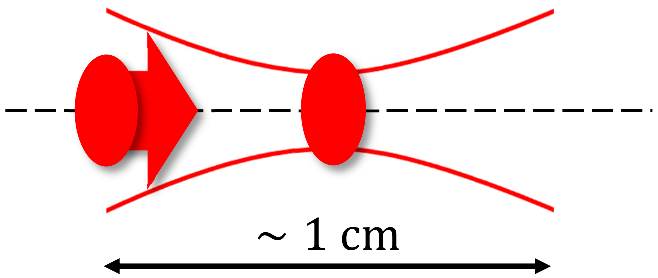
Diffraction mitigation essential for achieving high energy gain

Scaling laws

$$\text{Energy gain} \propto \frac{1}{n_e}$$

$$\text{Accelerator length} \propto \frac{1}{n_e^{3/2}}$$

Vacuum diffraction over Rayleigh length



- Fundamental Limit **Dephasing**
- Scaling laws for LPAs indicate that 10-GeV-class stages
  - Several centimeters long
  - Density $n_{e0} \sim 10^{17}\ \text{cm}^{-3}$
- Guiding either:
  - Self-focusing through relativistic and ponderomotive effects
  - Preformed plasma waveguide

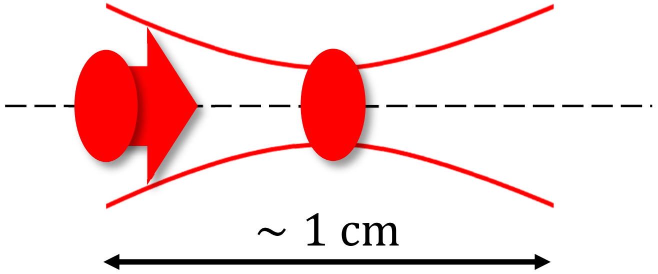
Diffraction mitigation essential for achieving high energy gain

Scaling laws

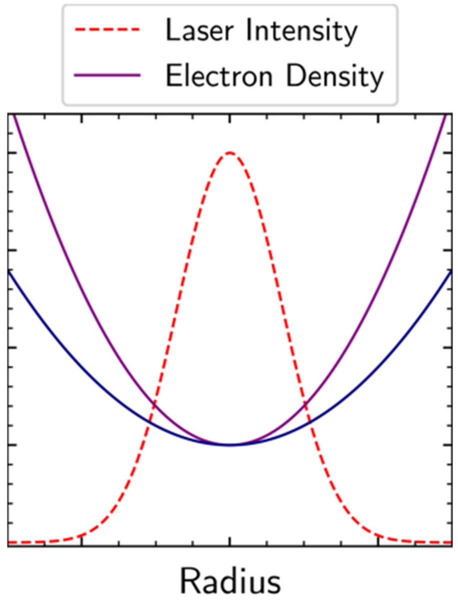
Energy gain $\propto \frac{1}{n_e}$

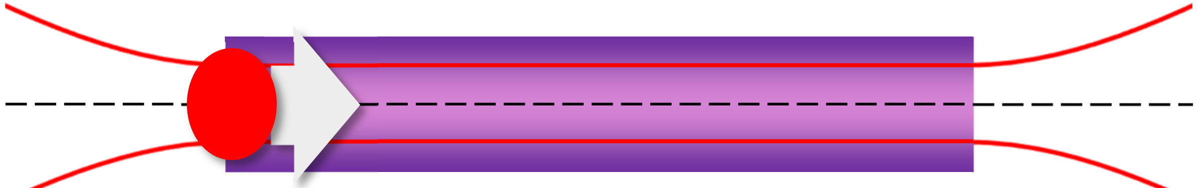
Accelerator length $\propto \frac{1}{n_e^{3/2}}$

Vacuum diffraction over Rayleigh length



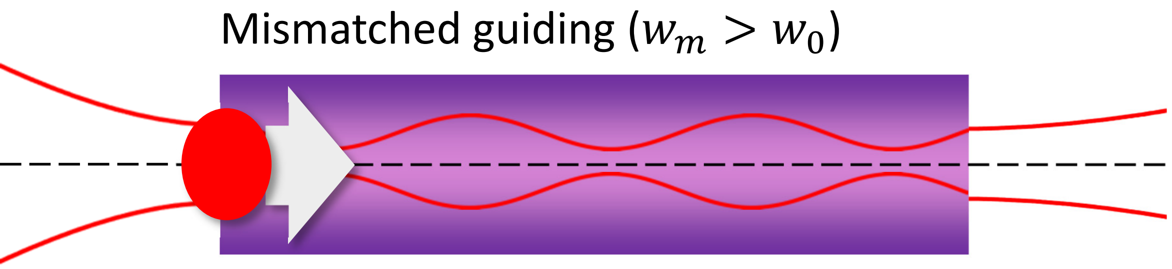
- Fundamental Limit **Dephasing**
- Scaling laws for LPAs indicate that 10-GeV-class stages
  - Several centimeters long
  - Density $n_{e0} \sim 10^{17}\ \mathrm{cm}^{-3}$
- Guiding either:
  - Self-focusing through relativistic and ponderomotive effects
  - Preformed plasma waveguide

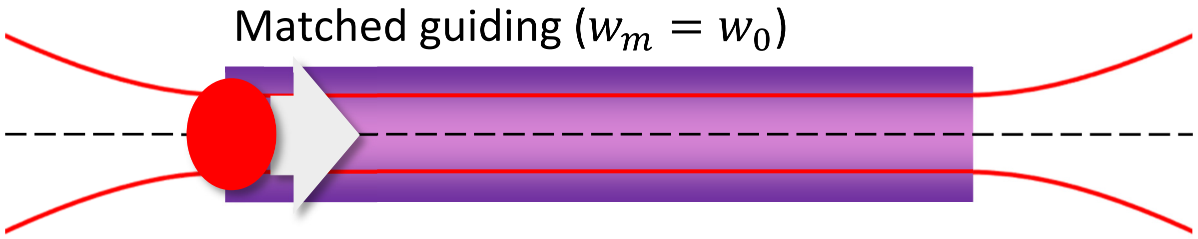




Accelerator length >> 1 cm

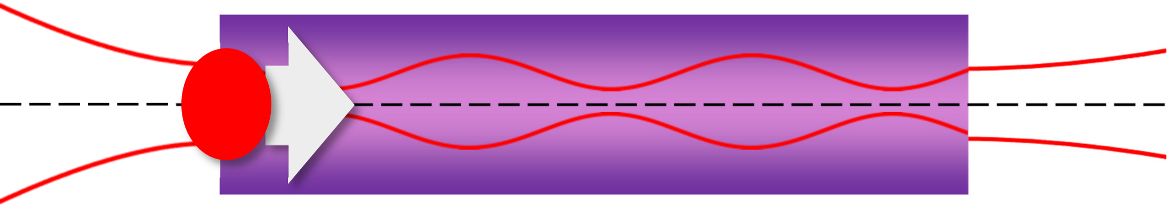
Control over the plasma channel provides control over the accelerator



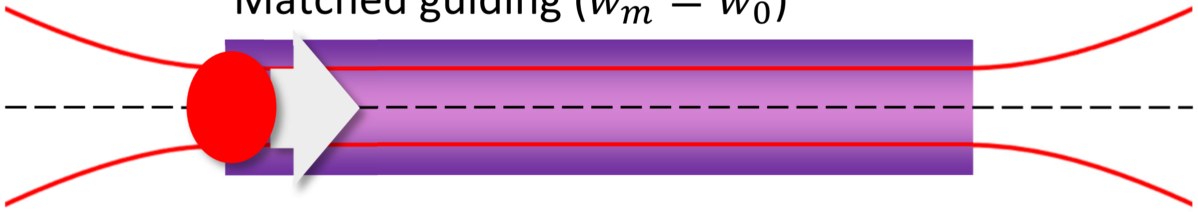


Control over the plasma channel provides control over the accelerator

Mismatched guiding ($w_m > w_0$)



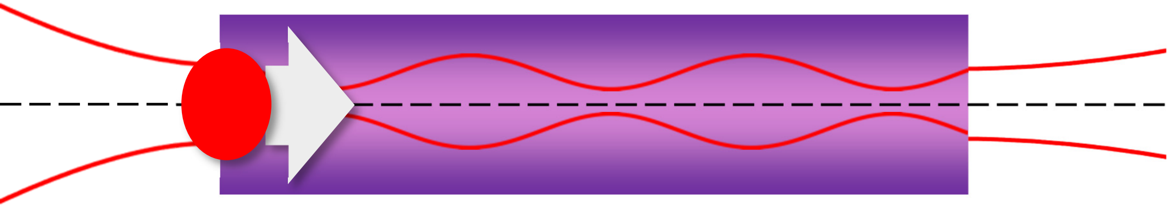
Matched guiding ($w_m = w_0$)



- **Channel depth** too shallow for the laser radial size
- Laser oscillates, high-order modes of the plasma channel excited
- Reduced control over accelerator properties

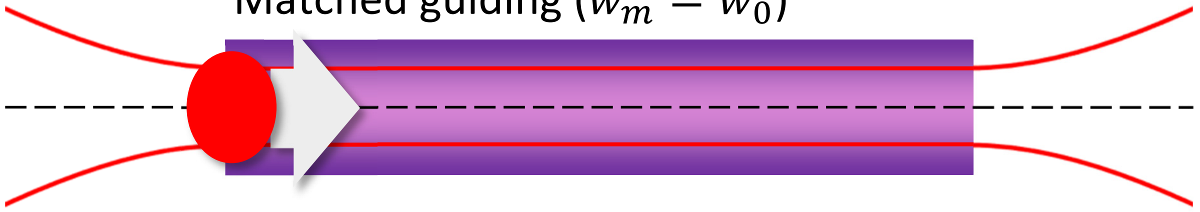
Control over the plasma channel provides control over the accelerator

Mismatched guiding ($w_m > w_0$)



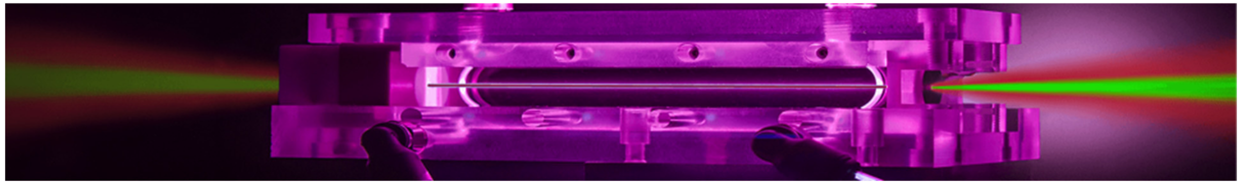
- **Channel depth** too shallow for the laser radial size
- Laser oscillates, high-order modes of the plasma channel excited
- Reduced control over accelerator properties

Matched guiding ($w_m = w_0$)



- **Channel depth matched to laser**
- Maximum control over accelerator
- Maximum laser-to-plasma transfer efficiency

2019: Capillary discharge enhanced with ns-pulse enabled acceleration to 7.8 GeV

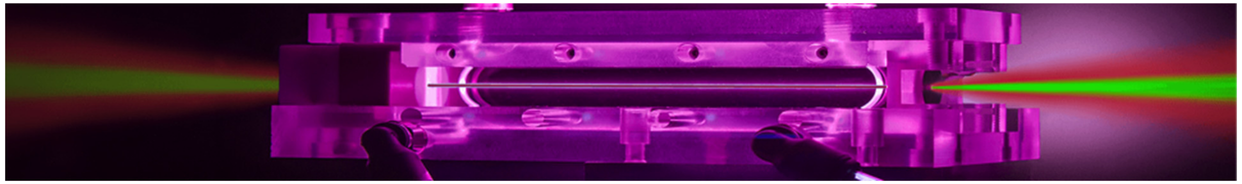


- Discharge creates plasma
- Weak guiding structure formed
- ns-pulse reheats plasma and deepens waveguide

Capillary Discharge Waveguides
DJ Spence and SM Hooker. *PRE* 63.1 (2000)
A. Butler et al, *PRL* 89.18 (2002)

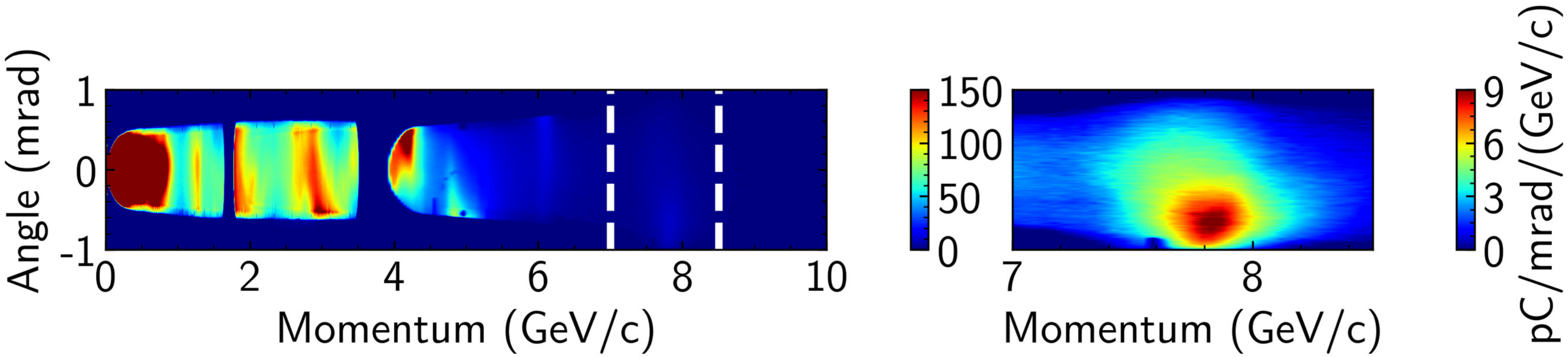
A. J. Gonsalves et al. *PRL* 122.08 (2019)
C. Pieronek et al., *PoP* 27.9 (2020)
A. J. Gonsalves et al. *PoP* 27.5 (2020)

2019: Capillary discharge enhanced with ns-pulse enabled acceleration to 7.8 GeV



- Discharge creates plasma
- Weak guiding structure formed
- ns-pulse reheats plasma and deepens waveguide

- 7.8 GeV achieved:
  - 31 J laser energy required
  - $n_{e0} \approx 2.7 \times 10^{17}$ cm^{-3}
  - $w_m \approx 61$ µm

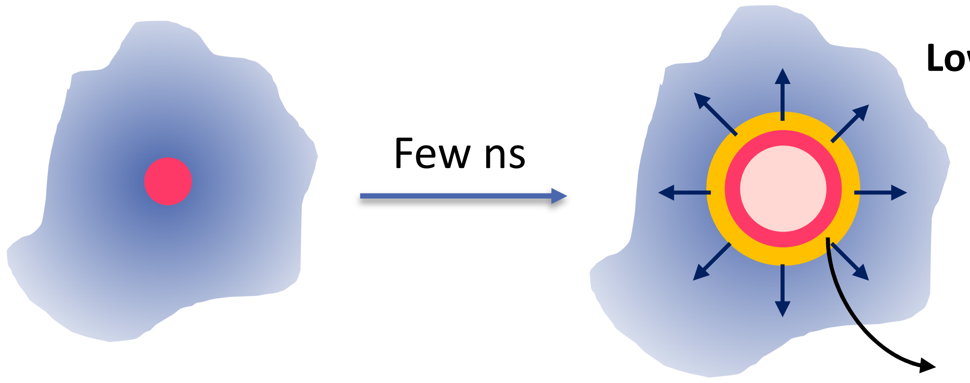


- Matched spot size limited by:
  - Capillary diameter (to avoid damage)
  - Inverse Bremsstrahlung heating (which relies on collisions)
- Lifetime limited by damage and heating
- Matched guiding **not possible**

Capillary Discharge Waveguides
DJ Spence and SM Hooker. *PRE* 63.1 (2000)
A. Butler et al, *PRL* 89.18 (2002)

A. J. Gonsalves et al. *PRL* 122.08 (2019)
C. Pieronek et al., *PoP* 27.9 (2020)
A. J. Gonsalves et al. *PoP* 27.5 (2020)

Hydrodynamic expansion of optical field ionised plasmas (HOFI) provides route to steep, low density plasma channels

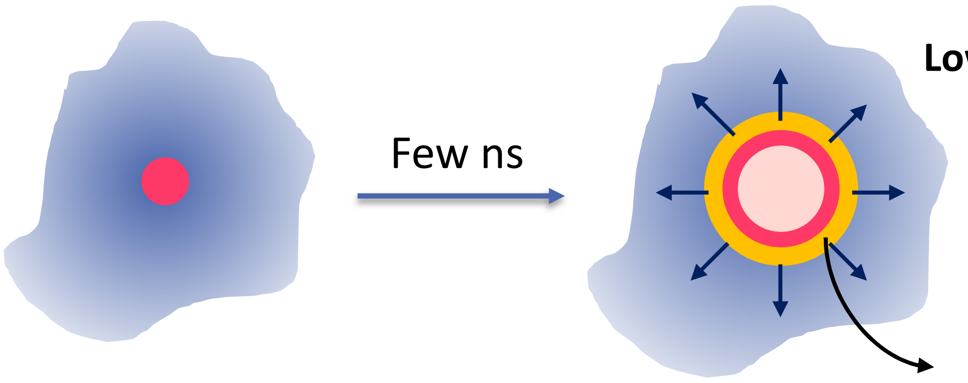


- Optical field ionisation by femtosecond pulse of permits **low densities**

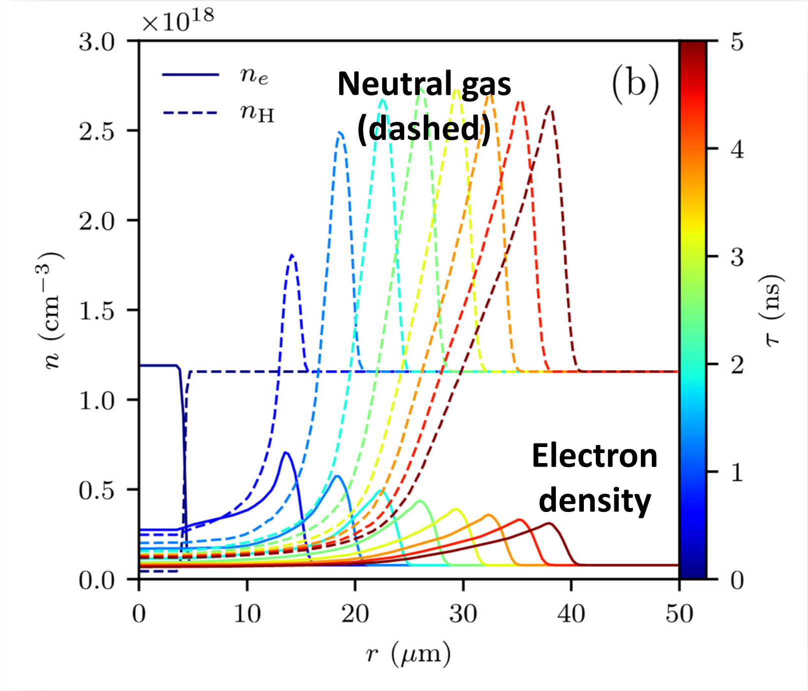
Hydro plasma channels at $n_0 > 1 \times 10^{18}\ \mathrm{cm}^{-3}$
C Durfee et al, *PRL*, 71(15) (1993).
P Volfbeyn et al. *PoP* 6.5 (1999).
N Lemos et al. *PoP* 20.6 (2013).

Low density Plasma Channels
Hooker, S. M. *AAC Workshop* (2016)
Shalloo, R. J.,*et al.*, (2018), *PRE, 97*(5)
Shalloo, R. J.,*et al.* (2019), *PRAB*, *22*(4)

Hydrodynamic expansion of optical field ionised plasmas (HOFI) provides route to steep, low density plasma channels



- Optical field ionisation by femtosecond pulse of permits **low densities**



- HOFI plasma channels were originally too "leaky" due to low wall depth, limiting useful length
- The expanding cylindrical shock is ionized by the head of a guided laser pulse to create a deep, thick plasma channel with extremely low losses

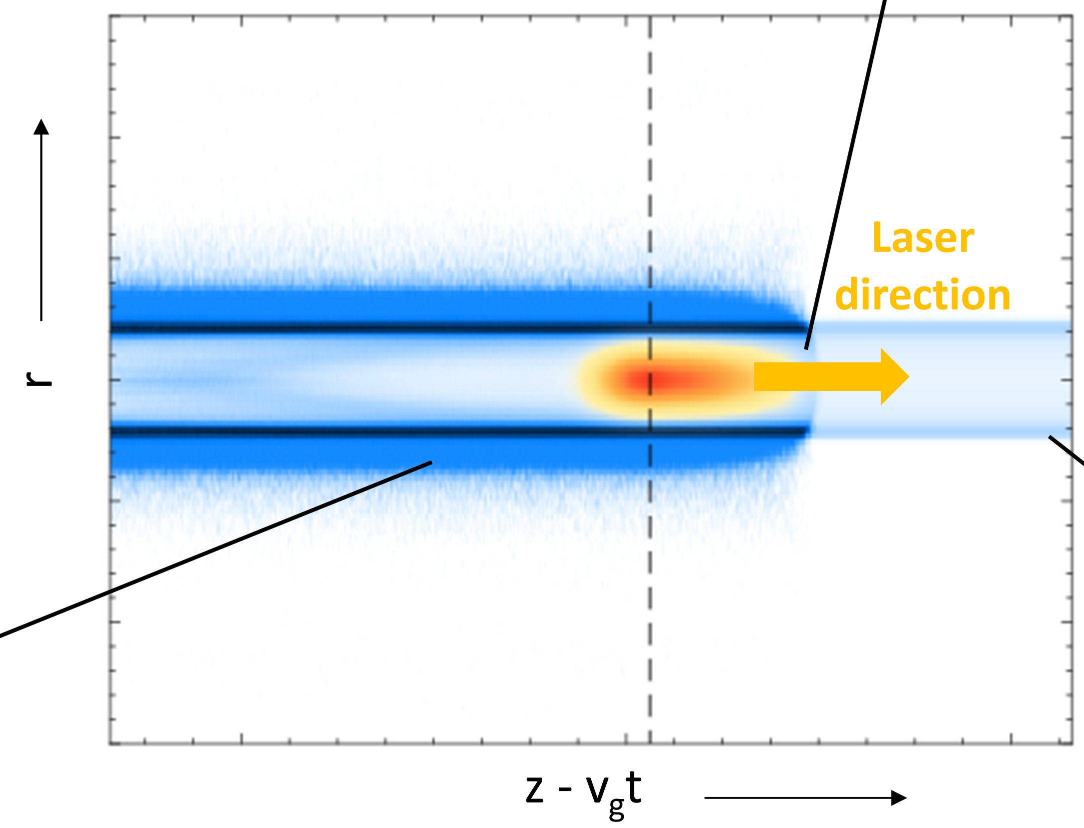
Hydro plasma channels at $n_0 > 1 \times 10^{18}$ cm^{-3}
C Durfee et al, *PRL*, 71(15) (1993).
P Volfbeyn et al. *PoP* 6.5 (1999).
N Lemos et al. *PoP* 20.6 (2013).

Low density Plasma Channels
Hooker, S. M. *AAC Workshop* (2016)
Shalloo, R. J.,*et al.*, (2018), *PRE, 97*(5)
Shalloo, R. J.,*et al.* (2019), *PRAB*, *22*(4)

Overcome leakage by ionizing neutrals:
Morozov, A et al. (2018). *PoP*, *25*(5)
Shalloo, R. J. *Thesis 2018*
Picksley, A., et al. (2020). *PRE*, *102*(5)
Feder, L., et al. (2020). *PRR*, *2*(4)

Hydrodynamic expansion of optical field ionised plasmas (HOFI) provides route to steep, low density plasma channels

Leading edge of the pulse ionises neutrals



Leaky HOFI structure

Deep plasma channel with large radial extent

PIC simulations of low loss channel generation:
Picksley, A., et al. (2020). *PRE*, *102*(5)
Picksley *Thesis* 2021

Talk Outline

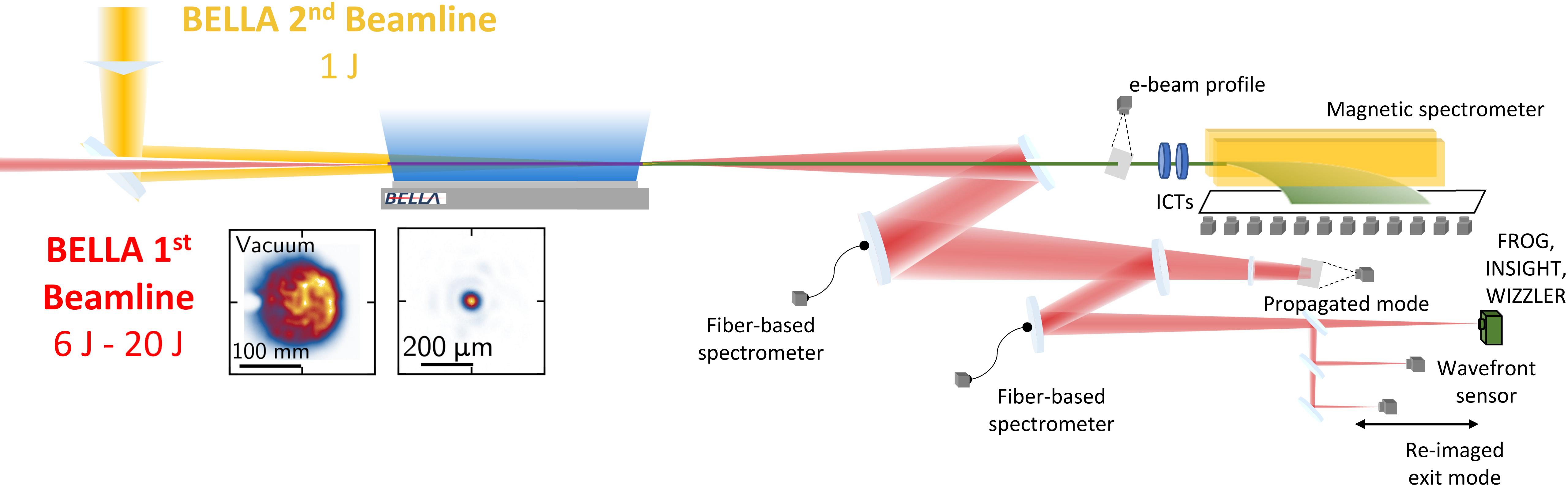
1. Maximizing electron beam energy in a laser-plasma accelerator

2. Matched guiding and acceleration in a 10-GeV-class laser-plasma accelerator

3. Towards an LPA stage suitable for applications

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

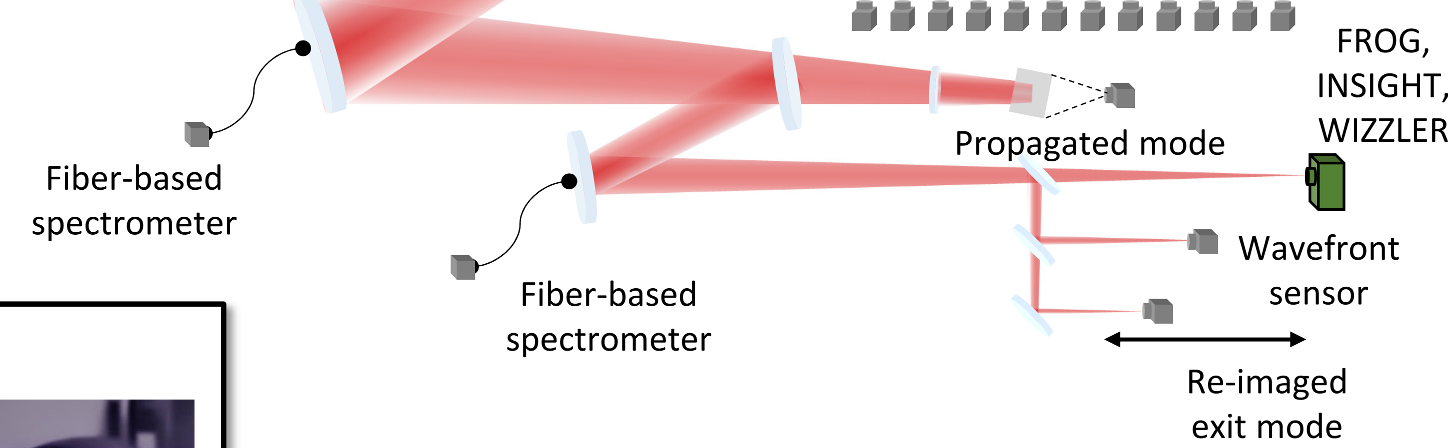
BELLA PW provides unmatched opportunity to study physics of guiding in HOFI plasma channels



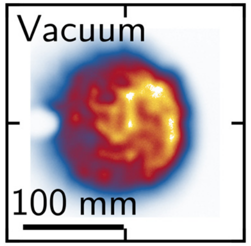
Advanced diagnostic suite for both guided laser and electron beams developed since 2012

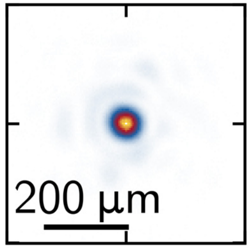
Collaboration with University of Maryland

BELLA PW provides unmatched opportunity to study physics of guiding in HOFI plasma channels

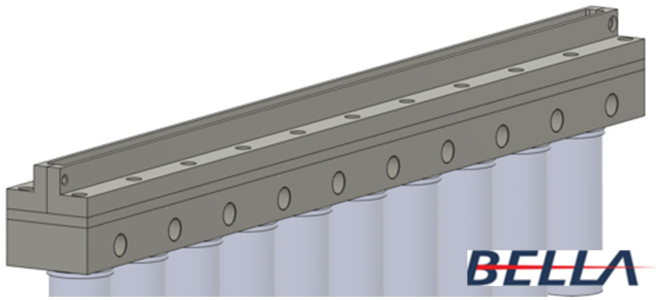


BELLA 1st Beamline
6 J - 20 J





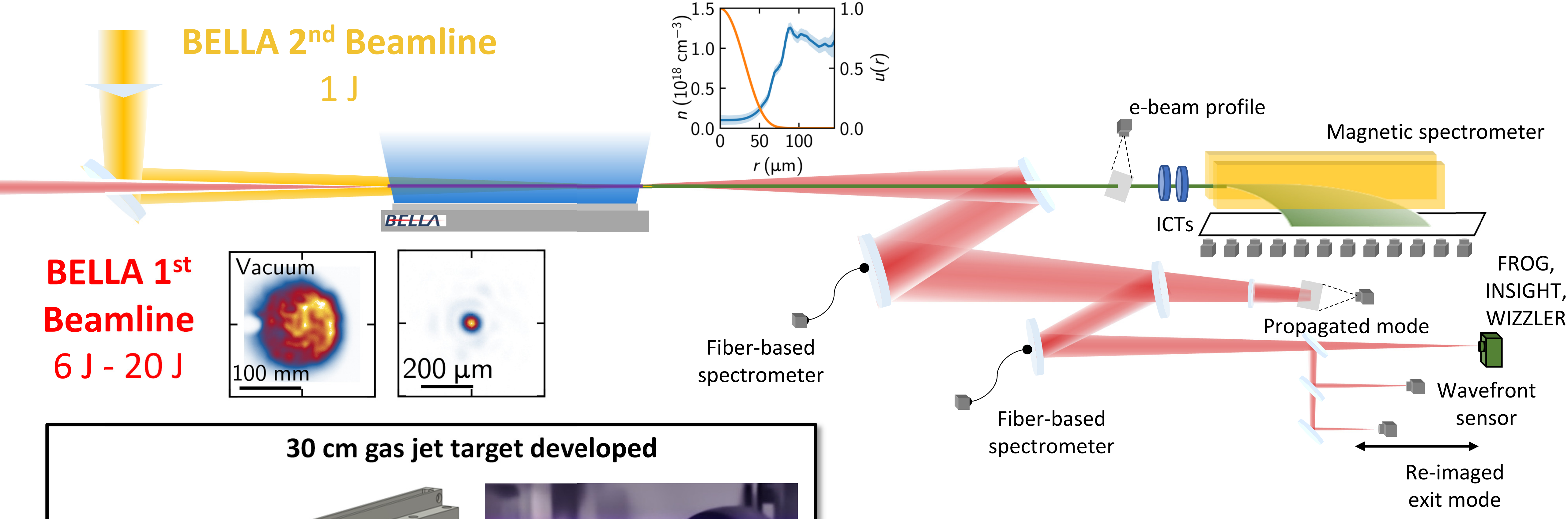
30 cm gas jet target developed



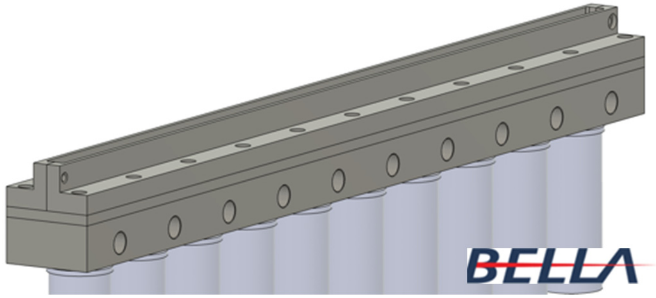
Collaboration with University of Maryland

Advanced diagnostic suite for both guided laser and electron beams developed since 2012

BELLA PW provides unmatched opportunity to study physics of guiding in HOFI plasma channels



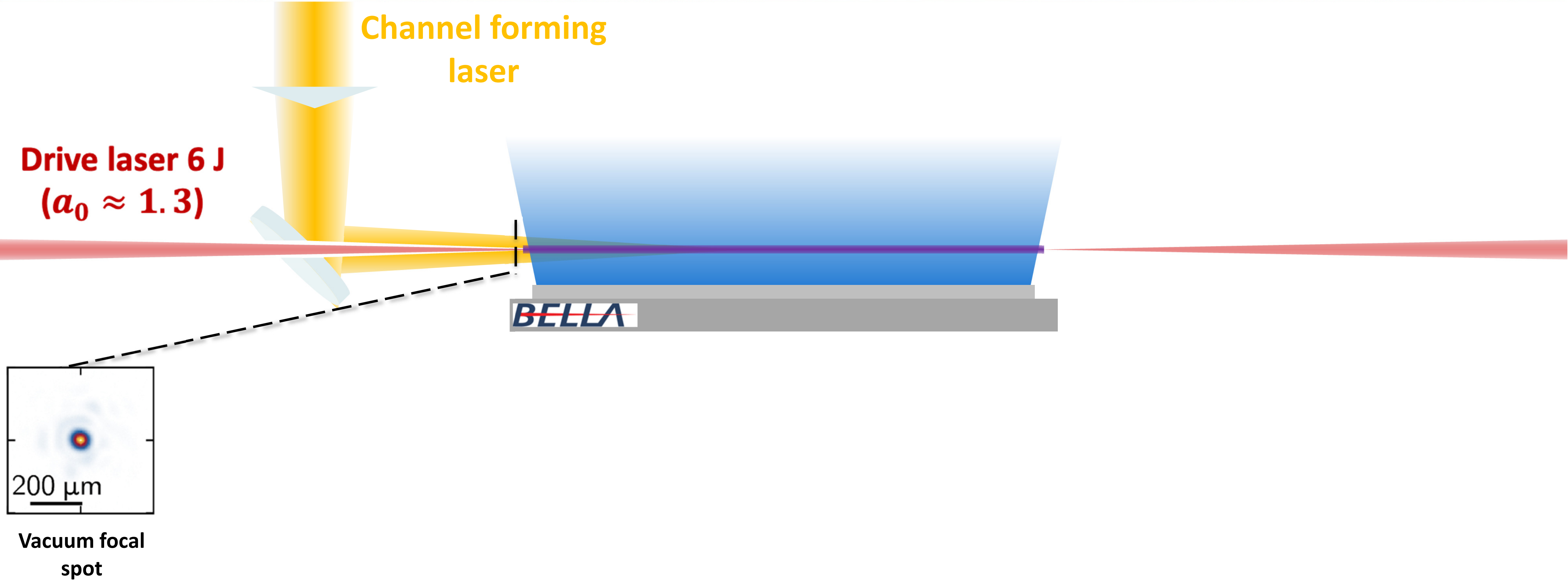
30 cm gas jet target developed



Advanced diagnostic suite for both guided laser and electron beams developed since 2012

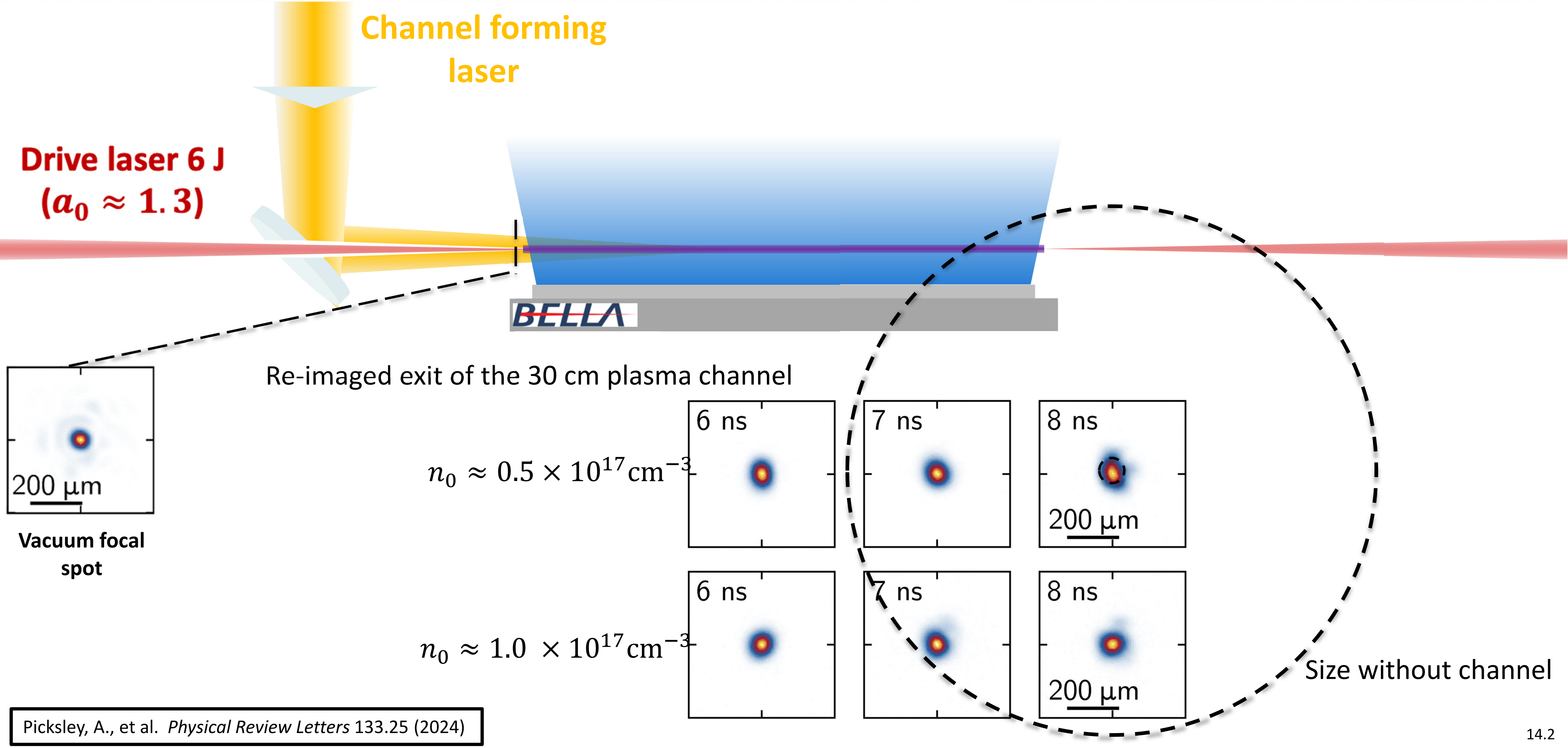
Collaboration with University of Maryland

High quality guiding of the BELLA PW laser pulse was observed over the 30 cm gas jet



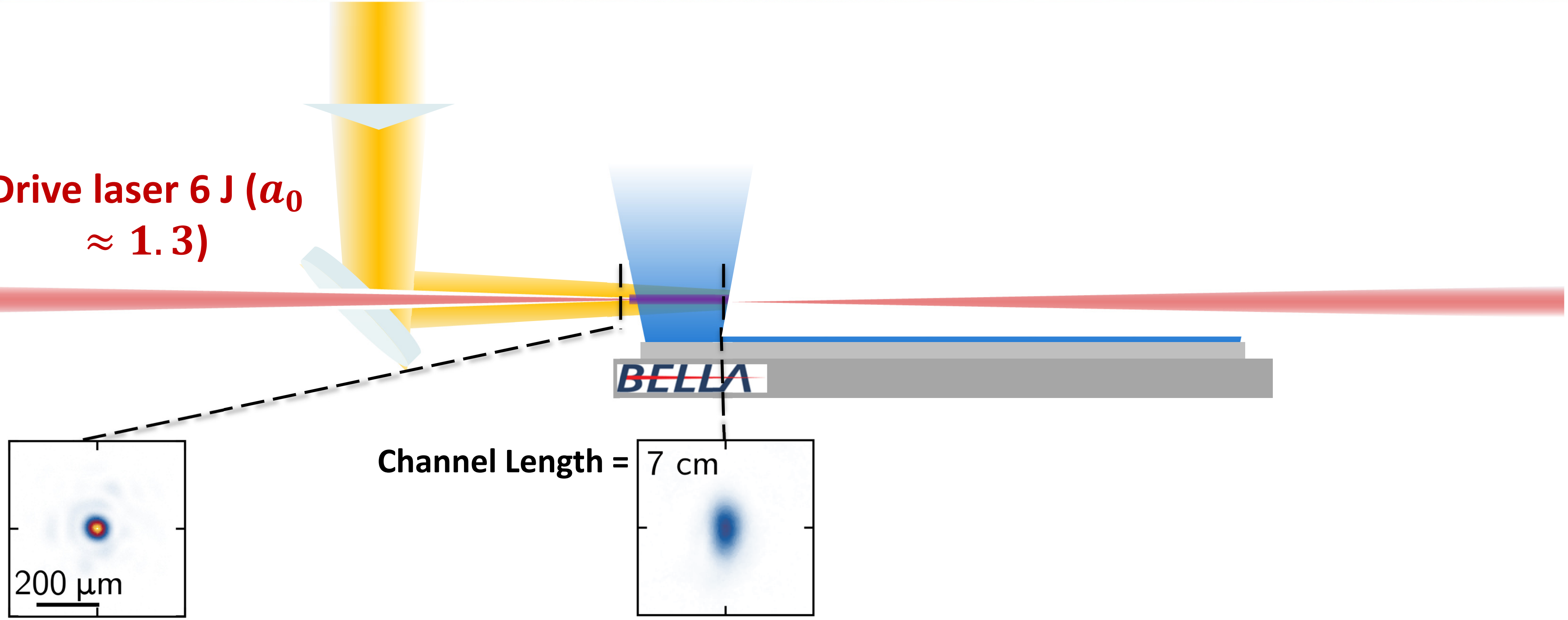
Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

High quality guiding of the BELLA PW laser pulse was observed over the 30 cm gas jet



Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

By varying the gas jet length, we gain insight into mechanisms of laser propagation in HOFI plasma channels



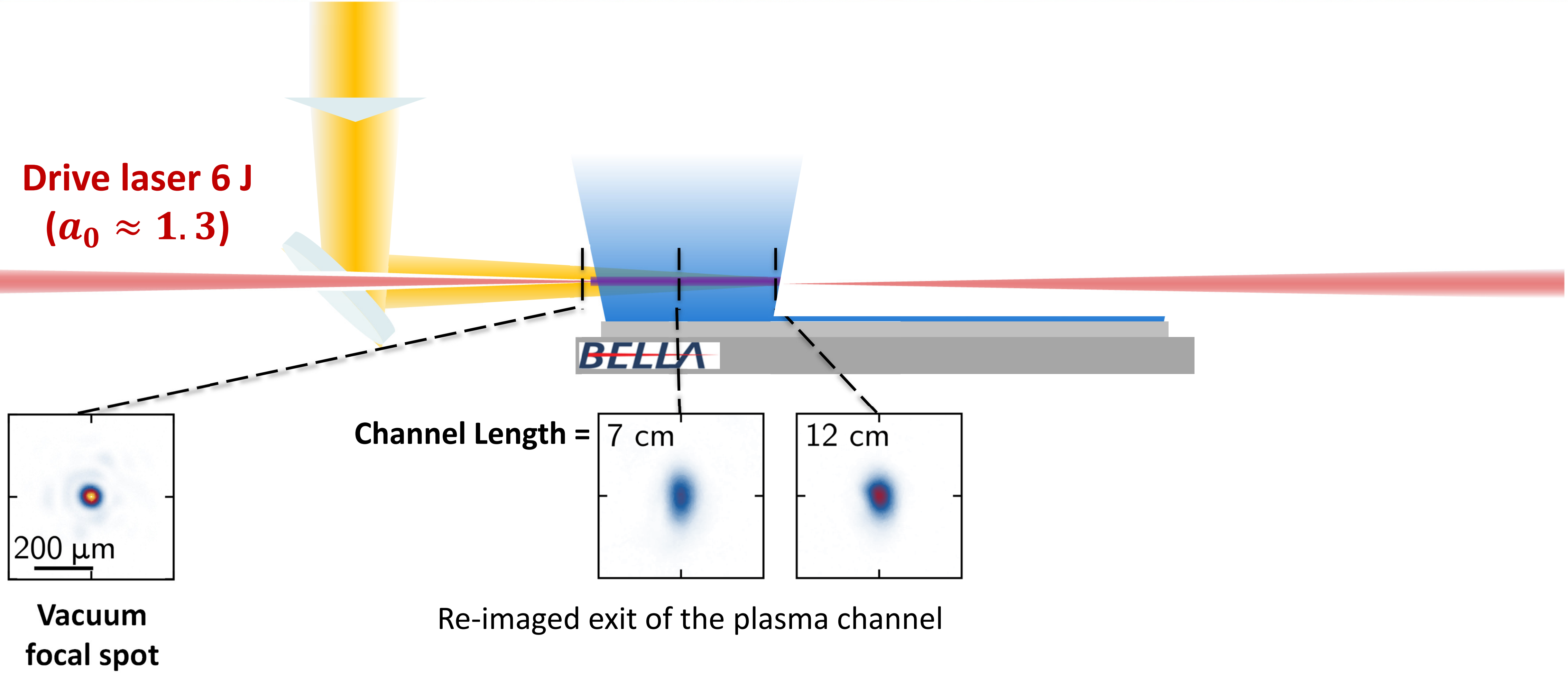
Vacuum focal spot

Re-imaged exit of the plasma channel

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

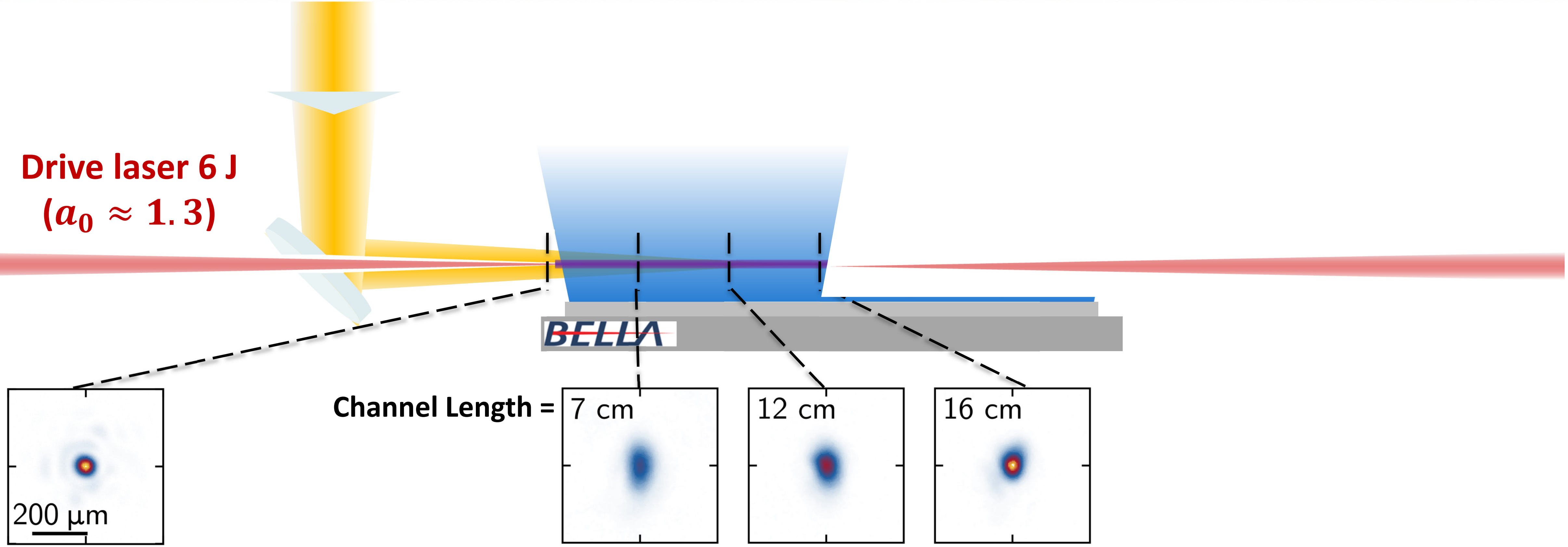
By varying the gas jet length, we gain insight into mechanisms of laser propagation in HOFI plasma channels

Drive laser 6 J
($a_0 \approx 1.3$)



Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

By varying the gas jet length, we gain insight into mechanisms of laser propagation in HOFI plasma channels

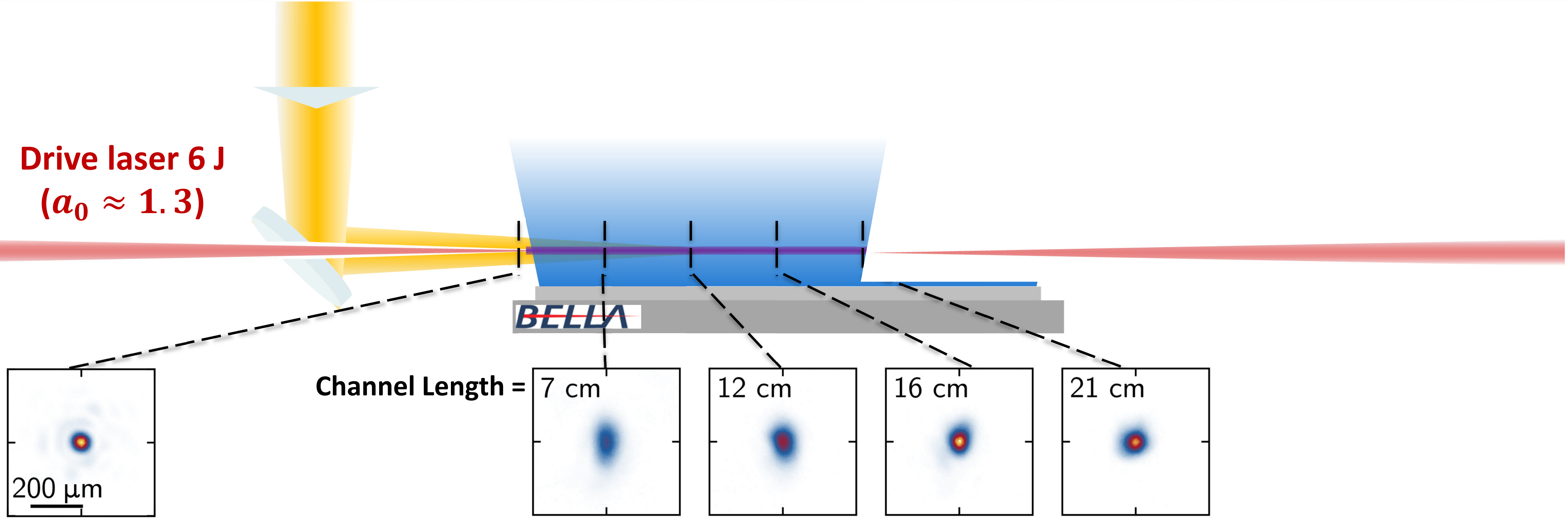


Vacuum focal spot

Re-imaged exit of the plasma channel

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

By varying the gas jet length, we gain insight into mechanisms of laser propagation in HOFI plasma channels

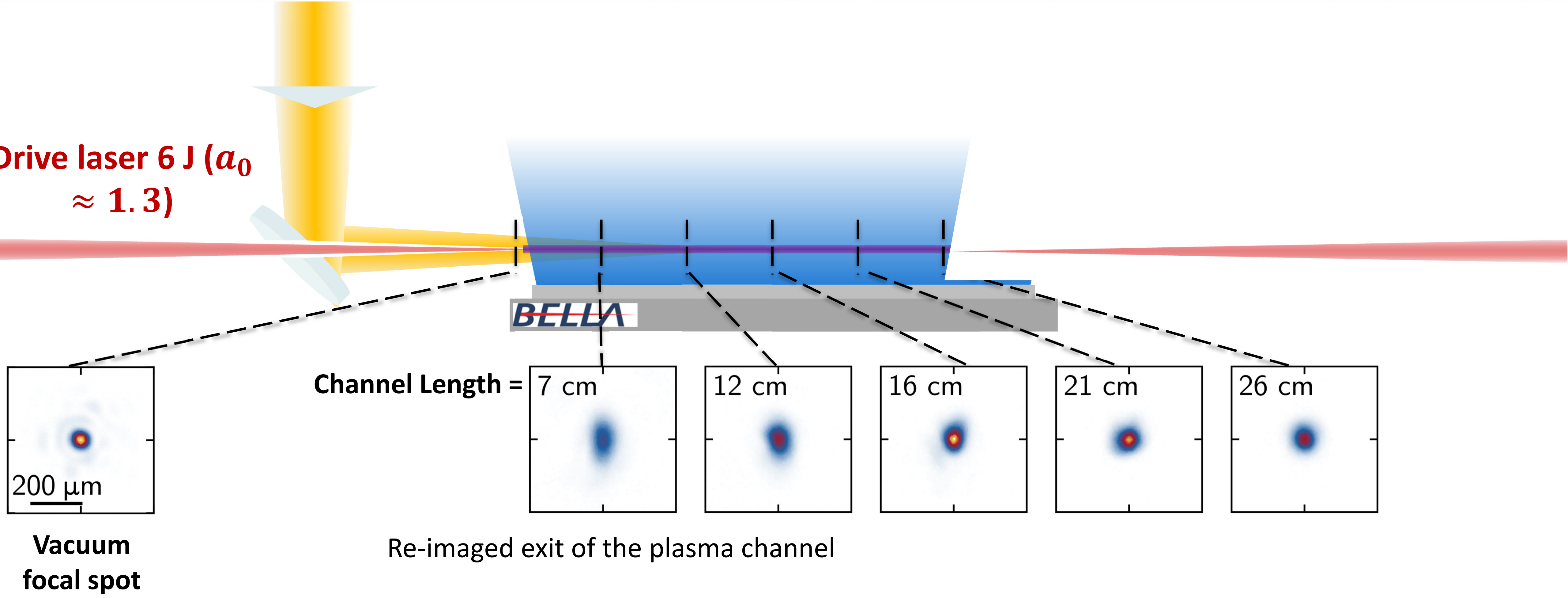


Vacuum focal spot

Re-imaged exit of the plasma channel

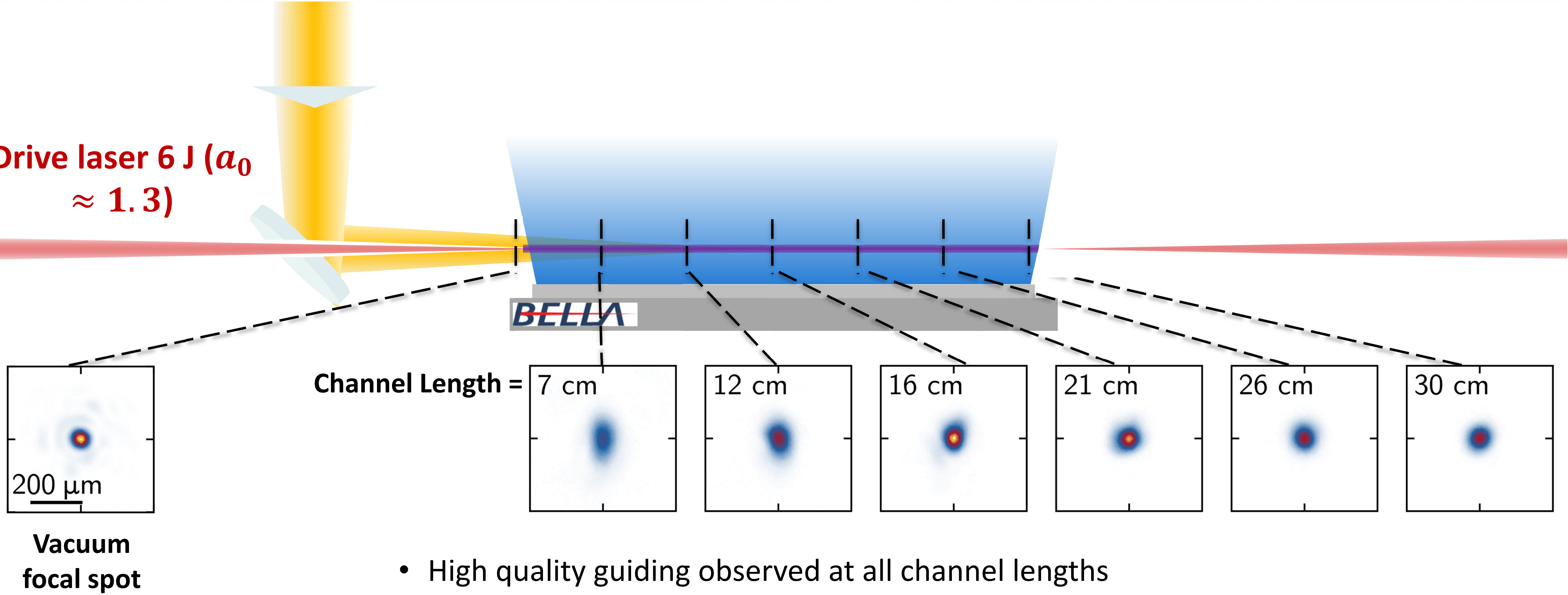
Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

By varying the gas jet length, we gain insight into mechanisms of laser propagation in HOFI plasma channels



Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

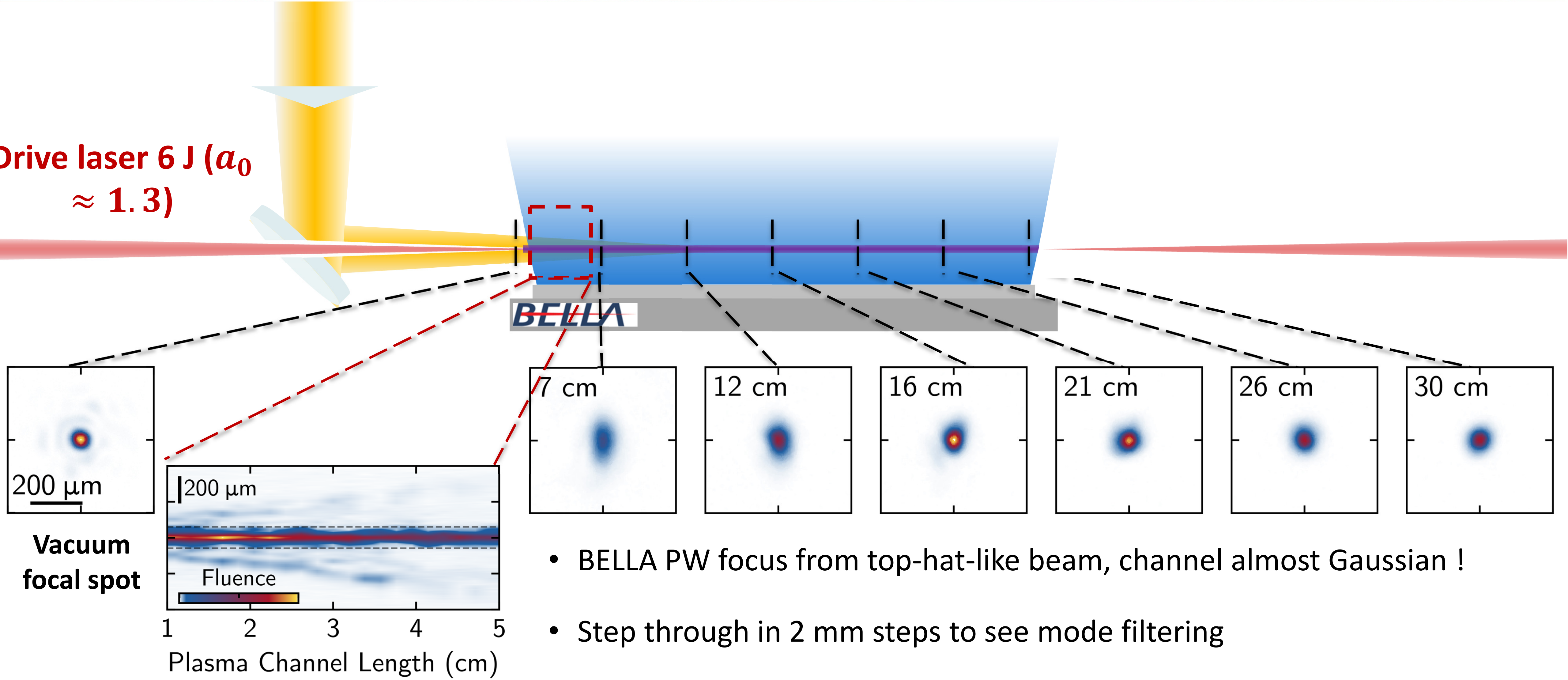
By varying the gas jet length, we gain insight into mechanisms of laser propagation in HOFI plasma channels



- High quality guiding observed at all channel lengths
- Enables examination of key features of a LPA stage

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

By varying the gas jet length, we gain insight into mechanisms of laser propagation in HOFI plasma channels

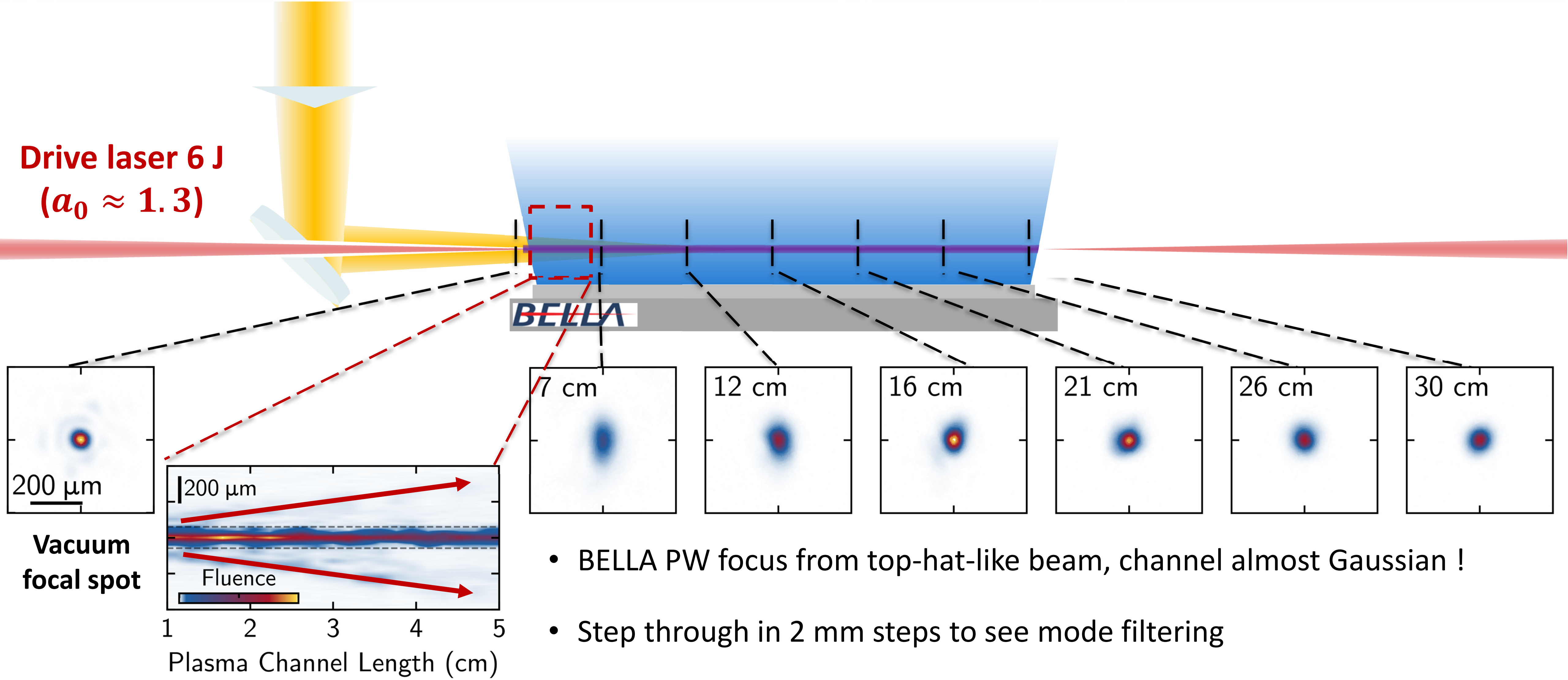


- BELLA PW focus from top-hat-like beam, channel almost Gaussian !
- Step through in 2 mm steps to see mode filtering
- Spot-size does not change for $z \gtrsim 12$ cm indicating matched guiding !

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)
Mode Leakage: Clark, T. R., et al. *PRE* 61.2 (2000).

By varying the gas jet length, we gain insight into mechanisms of laser propagation in HOFI plasma channels

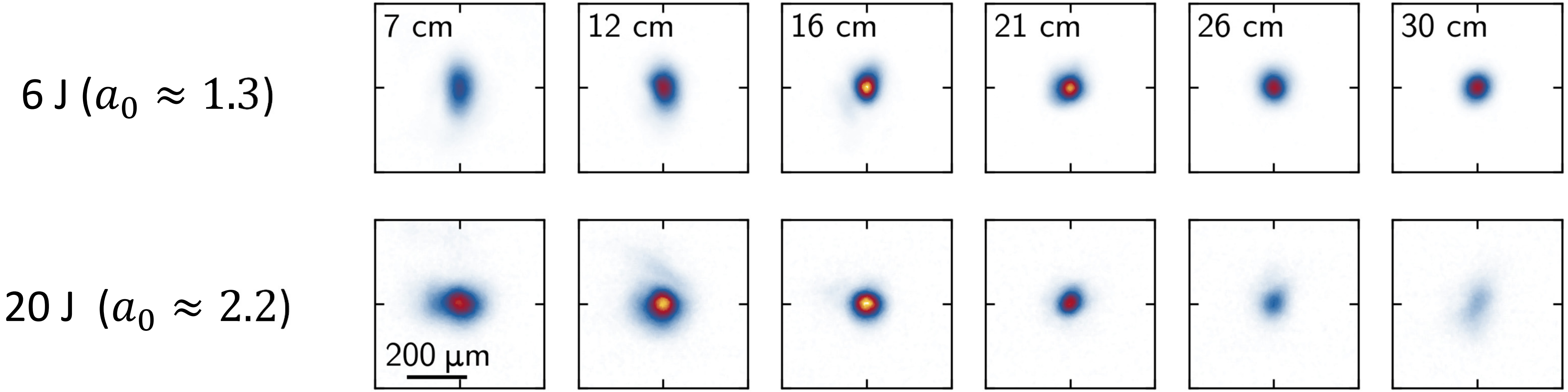
Drive laser 6 J
$(a_0 \approx 1.3)$



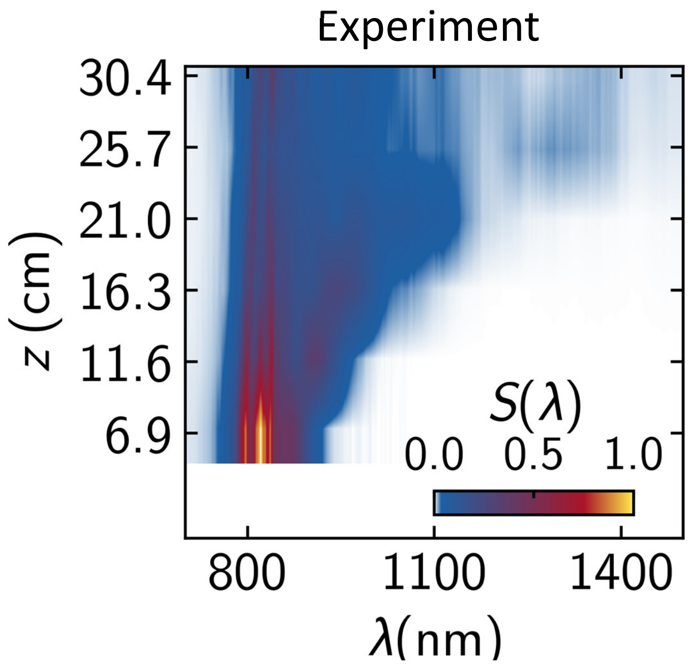
- BELLA PW focus from top-hat-like beam, channel almost Gaussian !
- Step through in 2 mm steps to see mode filtering
- Spot-size does not change for $z \gtrsim 12$ cm indicating matched guiding !

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)
Mode Leakage: Clark, T. R., et al. *PRE* 61.2 (2000).

With increased drive energy, we explicitly observed gradual depletion of laser energy to the plasma wave

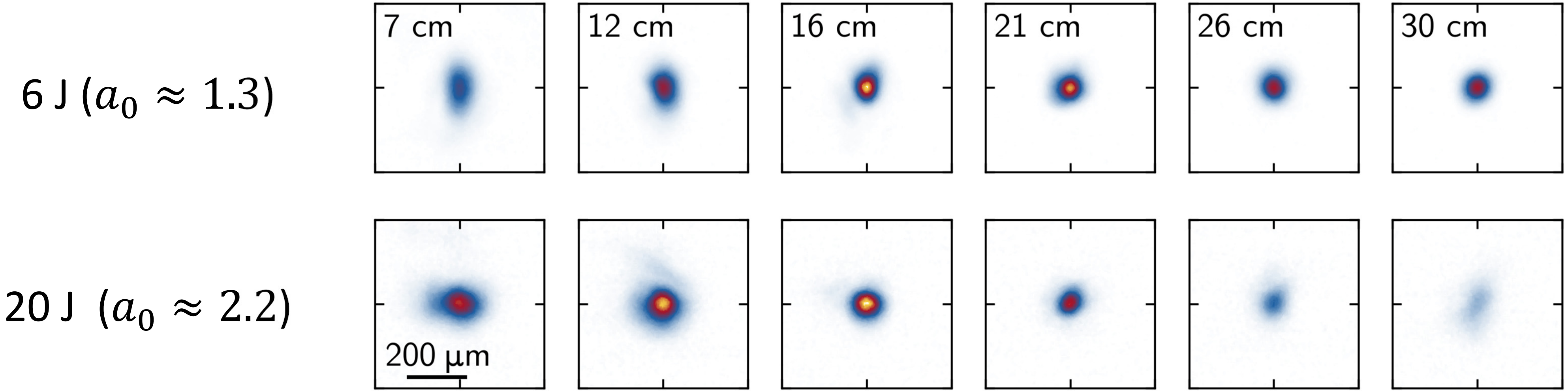


- Similar guiding behavior, but decreased energy transmission
- Redshift diagnostic indicated gradual, depletion of laser energy to the wake over the length of the plasma
- Verified by PIC simulations using INF&RNO

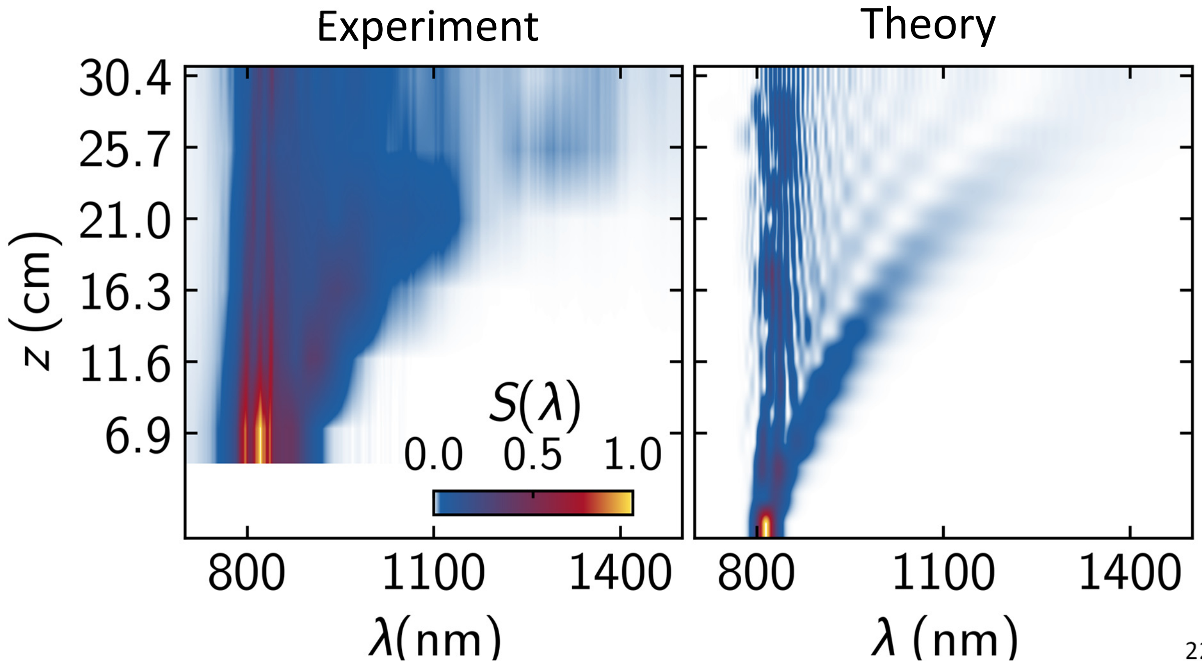


λ (nm)

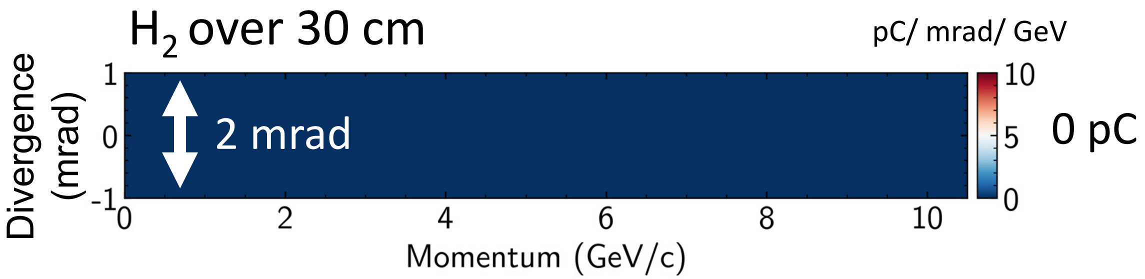
With increased drive energy, we explicitly observed gradual depletion of laser energy to the plasma wave

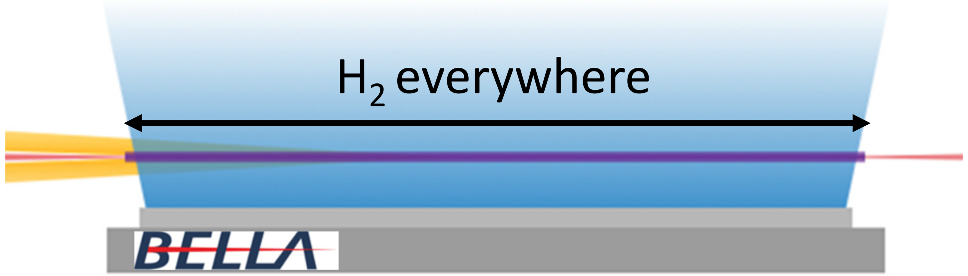


- Similar guiding behavior, but decreased energy transmission
- Redshift diagnostic indicated gradual, depletion of laser energy to the wake over the length of the plasma
- Verified by PIC simulations using INF&RNO



Demonstrated that we could power the accelerator without generating unwanted electron beams

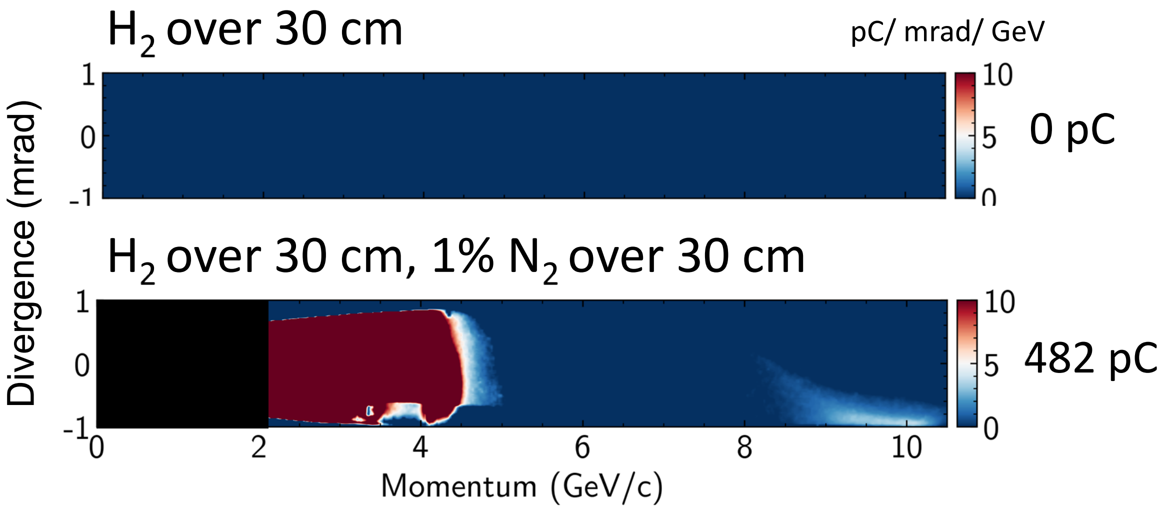


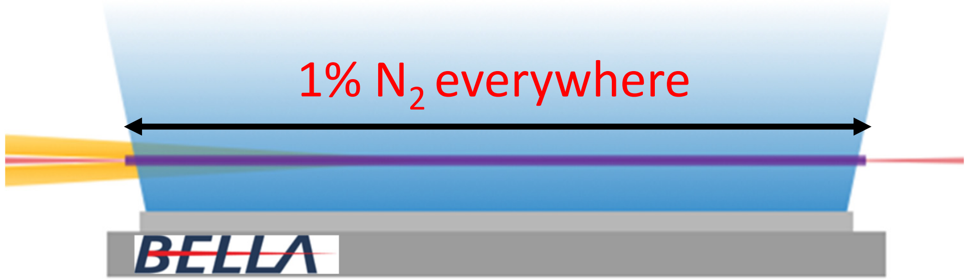


- No electrons observed in pure Hydrogen => suppression of the accelerator dark current

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

To trap electrons in the plasma wave, added a nitrogen dopant throughout the channel



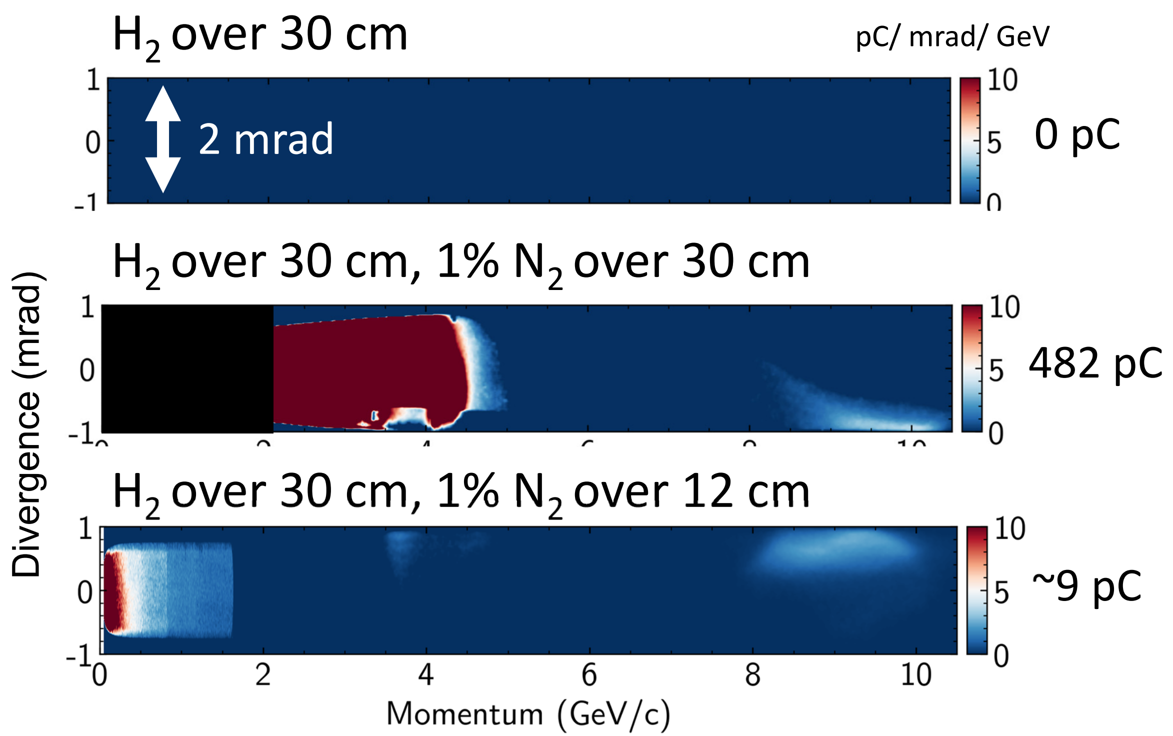


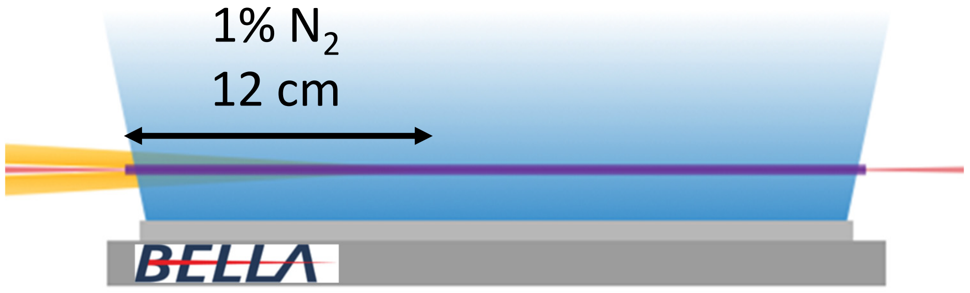
- Large energy spread as dopant gas extends throughout our gas target

Ionization Injection - Pak, A, et al. *PRL* 104.2 (2010).
McGuffey, C., et al. *PRL* 104.2 (2010).
Chen, M., et al. *PoP* 19.3 (2012).

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

Controlling dopant region demonstrated first high quality beams at the 10 GeV level

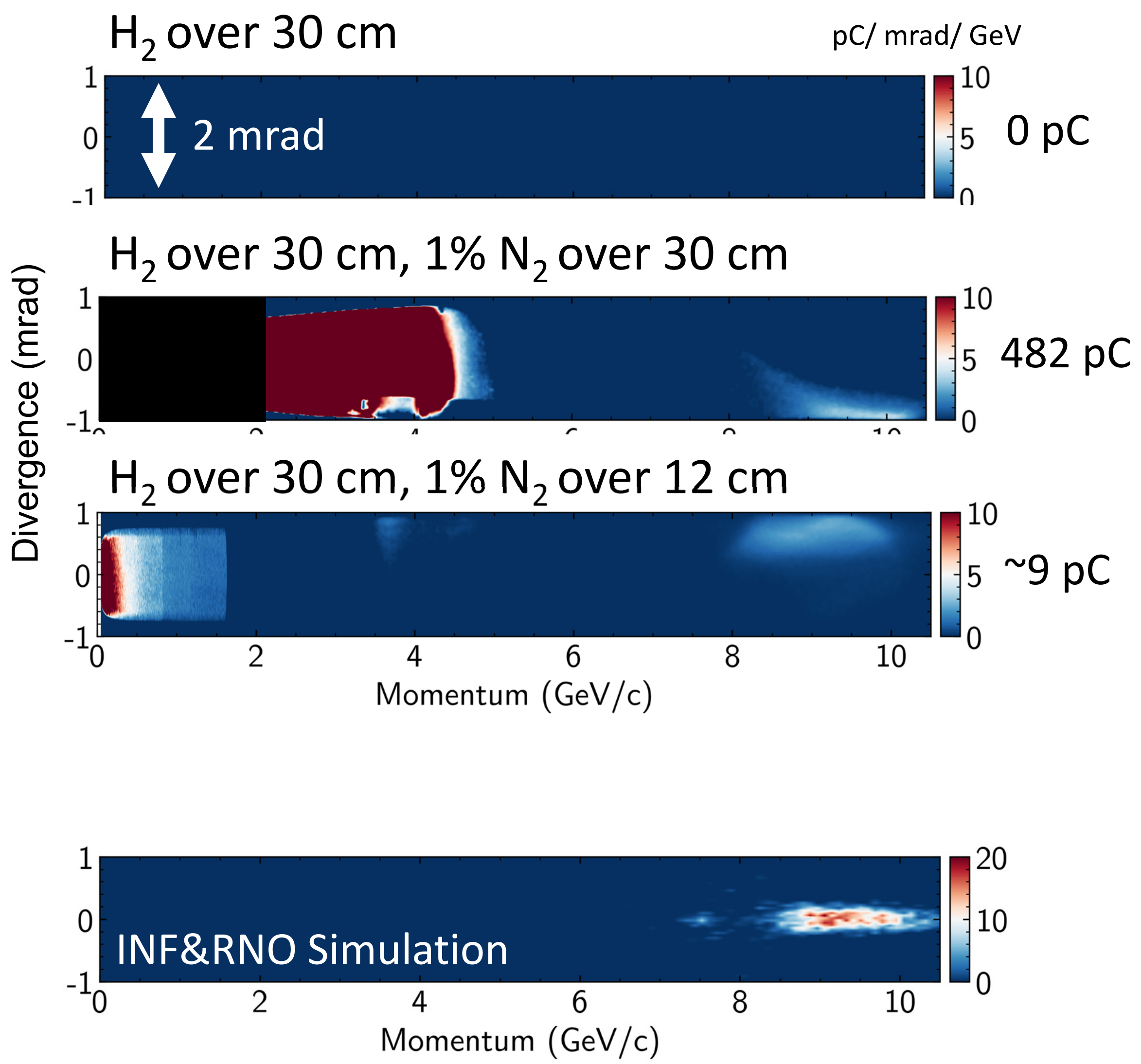


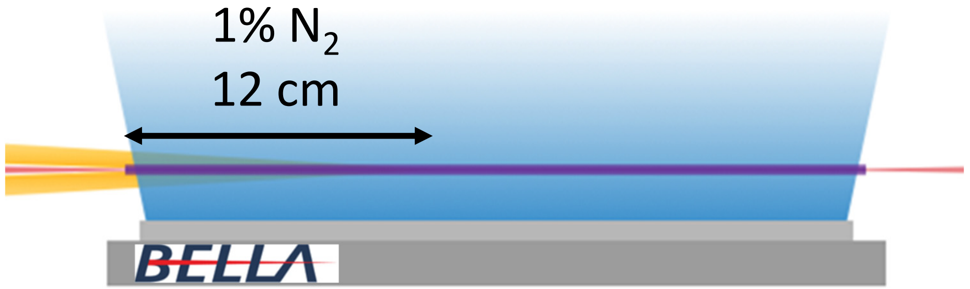


- Novel gas jet allowed localized region for gas with dopant

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

Controlling dopant region demonstrated first high quality beams at the 10 GeV level

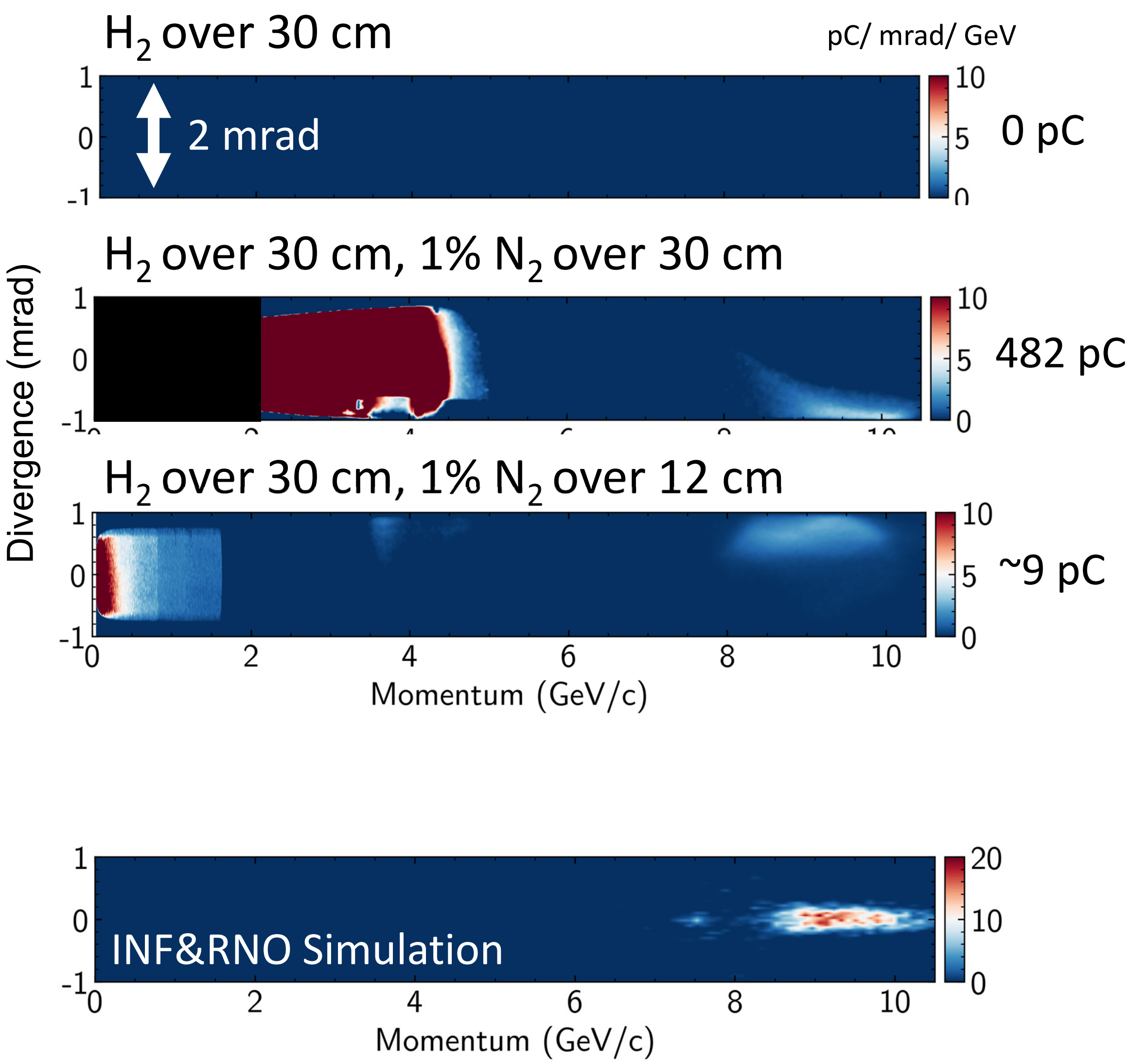


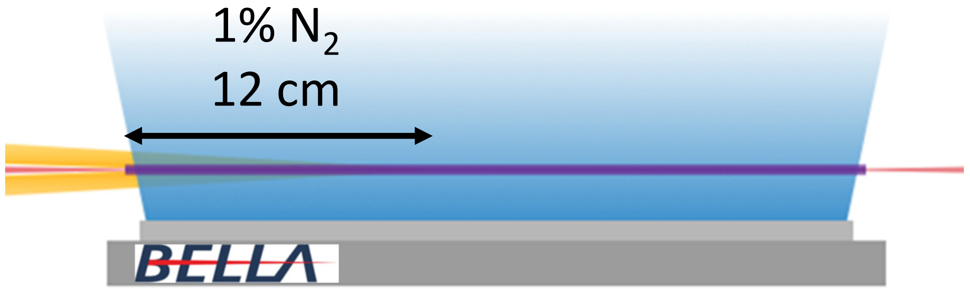


- Novel gas jet allowed localized region for gas with dopant

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

Controlling dopant region demonstrated first high quality beams at the 10 GeV level

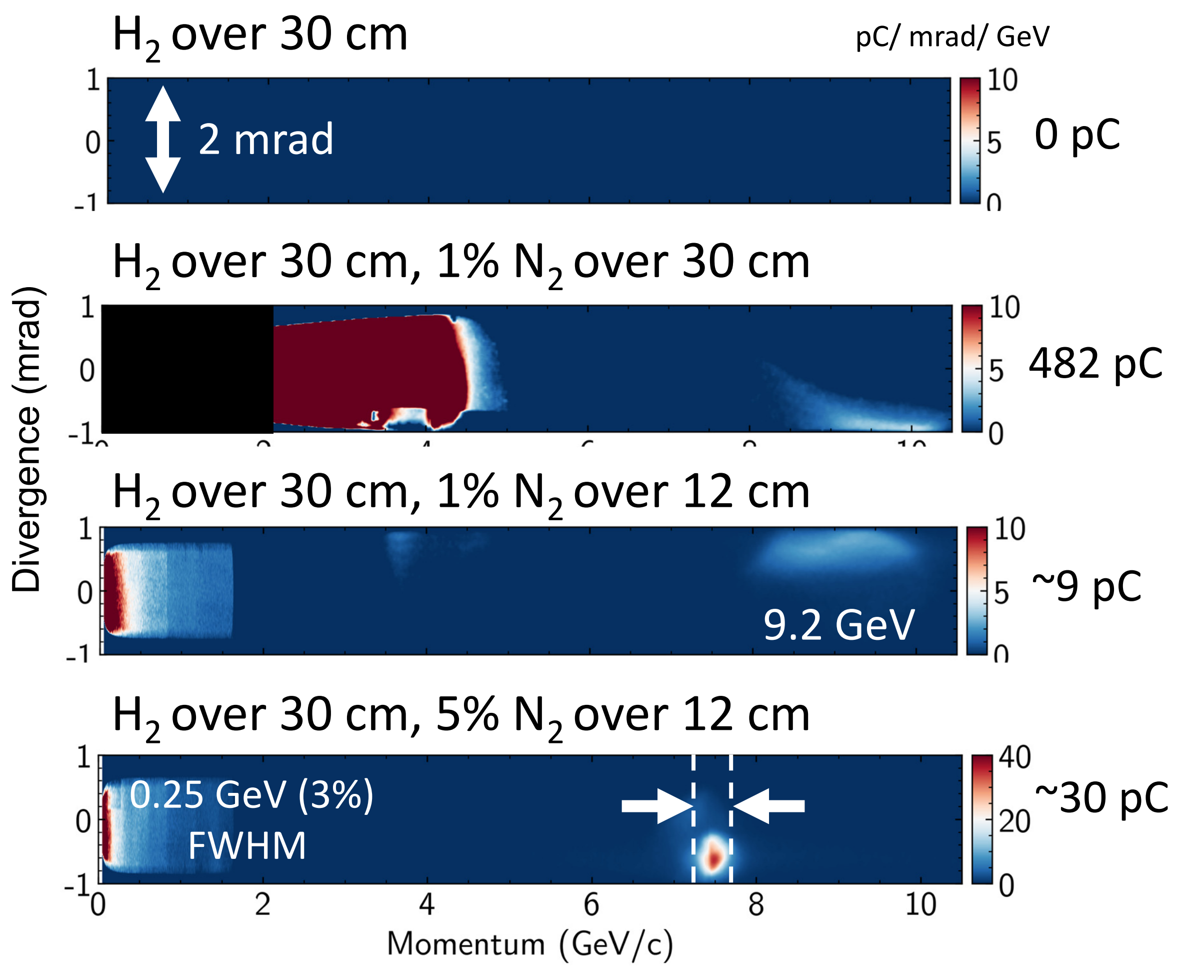




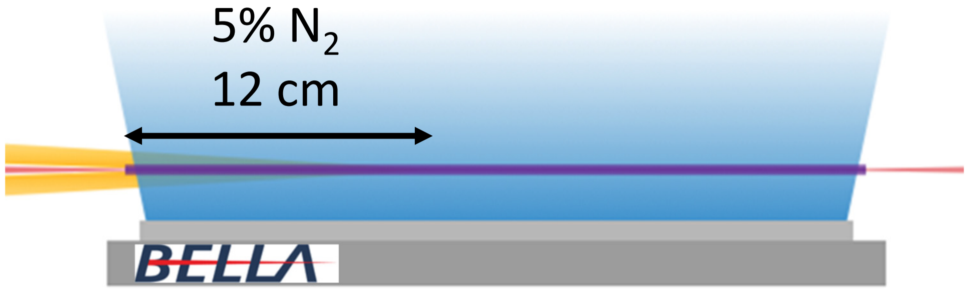
- Novel gas jet allowed localized region for gas with dopant

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

Controlling dopant region demonstrated first high quality beams at the 10 GeV level



5



- Novel gas jet allowed localized region for gas with dopant
- Tuning dopant level gives (some) control over e-beam properties

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)

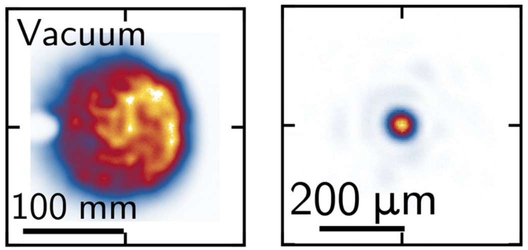
Slide 41

5 this is really what will address P5 demand for high quality and high efficiency stages

Cameron Geddes, 9/25/2024

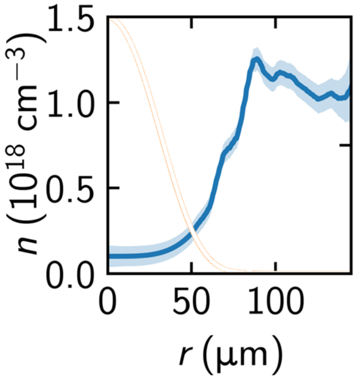
INF&RNO modelling gave clear insight into the guiding process, and how to maximize laser-to-bunch efficiency

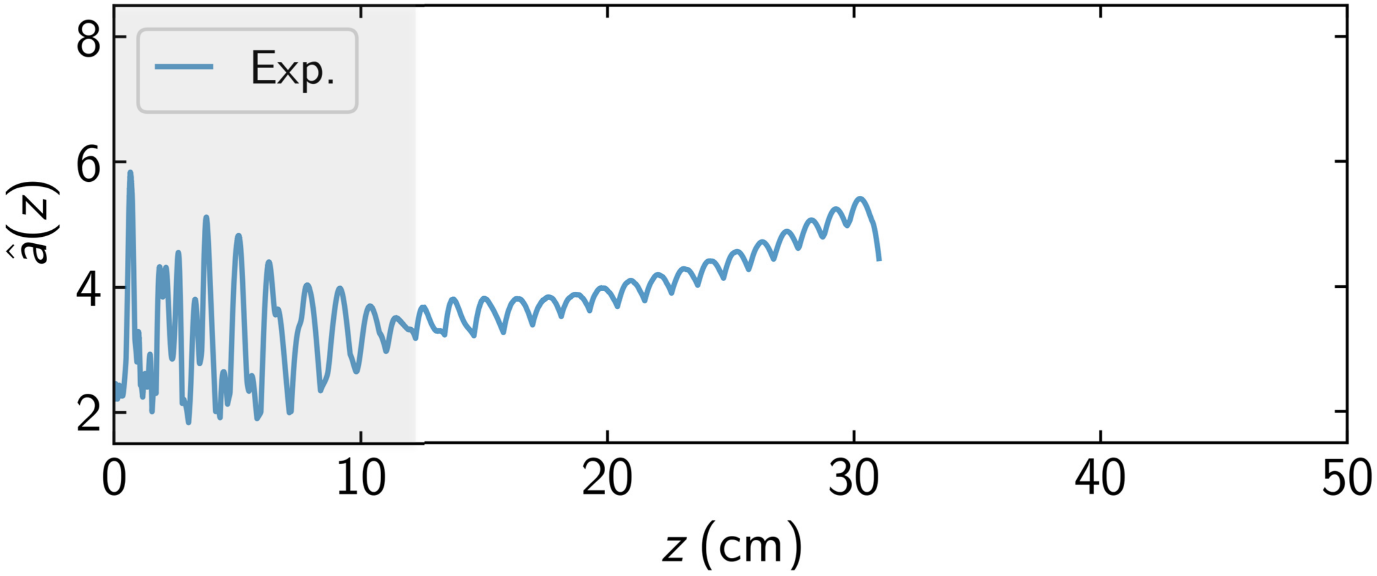
Experimental Mode



- Mode beating causes prevents high charge for $L_{\rm dop} \lesssim 6$ cm – as shown in experiments !
- Matching to the channel maintains charge injected at $z \sim 0$

Measured Plasma Channel





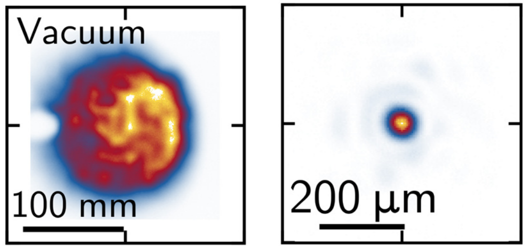
9.2 GeV, 9 pC

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)
Mode beating Esarey et al 1999, 2000
Mode beating in optical channels: Shrock, J. E., et al. *PRL (2024)*

Benedetti, C., et al. *PRE* 92.2 (2015),
Benedetti, C., et al. PoP (2012)

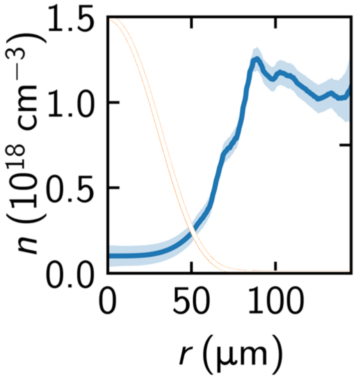
INF&RNO modelling gave clear insight into the guiding process, and how to maximize laser-to-bunch efficiency

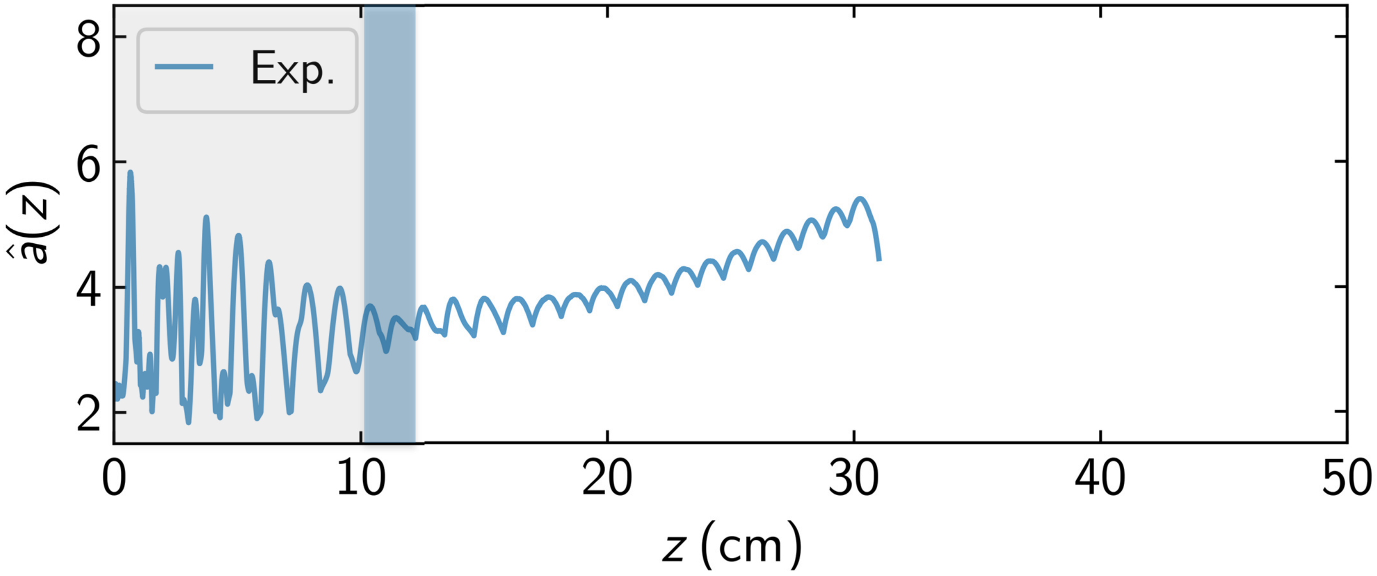
Experimental Mode



- Mode beating causes prevents high charge for $L_{\mathrm{dop}} \lesssim 6\ \mathrm{cm}$ – as shown in experiments !
- Matching to the channel maintains charge injected at $z \sim 0$

Measured Plasma Channel





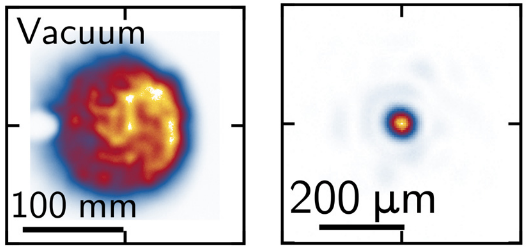
9.2 GeV, 9 pC

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)
Mode beating Esarey et al 1999, 2000
Mode beating in optical channels: Shrock, J. E., et al. *PRL (2024)*

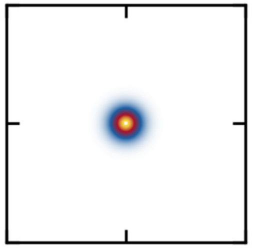
Benedetti, C., et al. *PRE* 92.2 (2015),
Benedetti, C., et al. PoP (2012)

INF&RNO modelling gave clear insight into the guiding process, and how to maximize laser-to-bunch efficiency

Experimental Mode

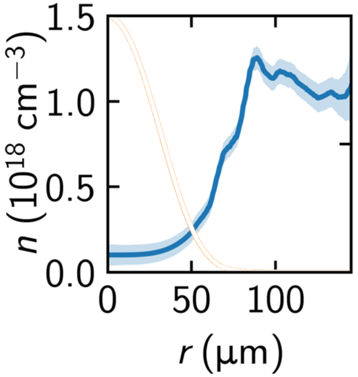


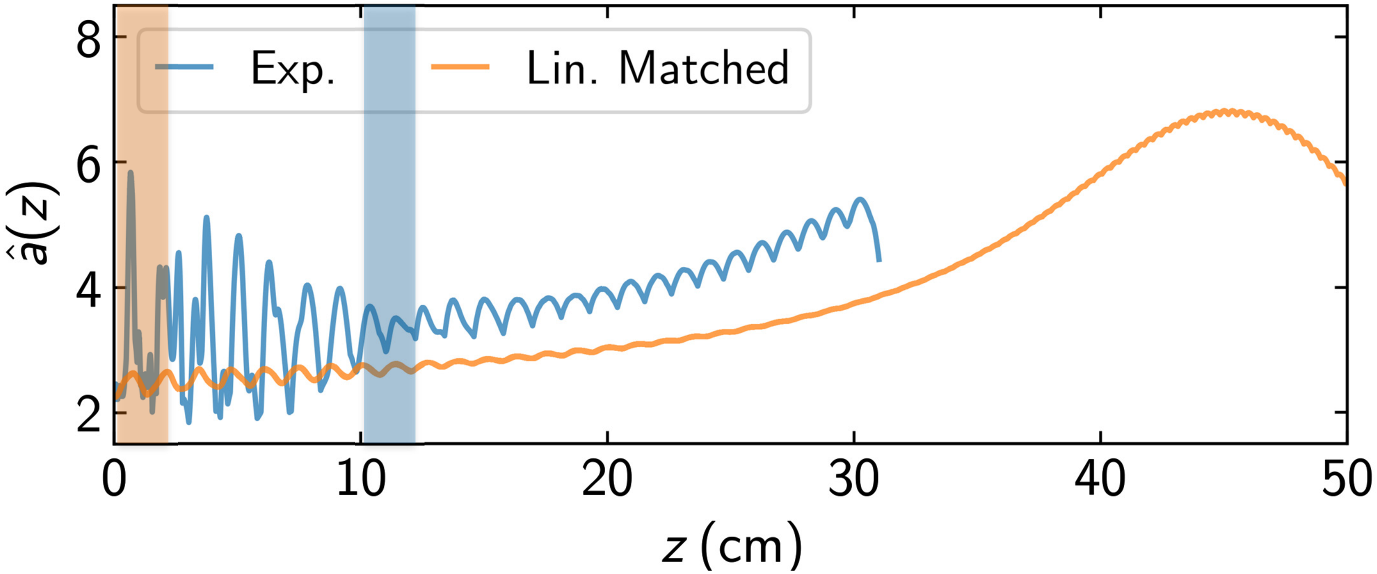
Linearly Matched



- Injected promoted from $z \approx 0$

Measured Plasma Channel





9.2 GeV, 9 pC

13.0 GeV, 65 pC

Picksley, A., et al. *Physical Review Letters* 133.25 (2024)
Mode beating Esarey et al 1999, 2000
Mode beating in optical channels: Shrock, J. E., et al. *PRL (2024)*

Benedetti, C., et al. *PRE* 92.2 (2015),
Benedetti, C., et al. PoP (2012)

Talk Outline

1. Maximizing electron beam energy in a laser-plasma accelerator

2. Matched guiding and acceleration in a 10-GeV-class laser-plasma accelerator

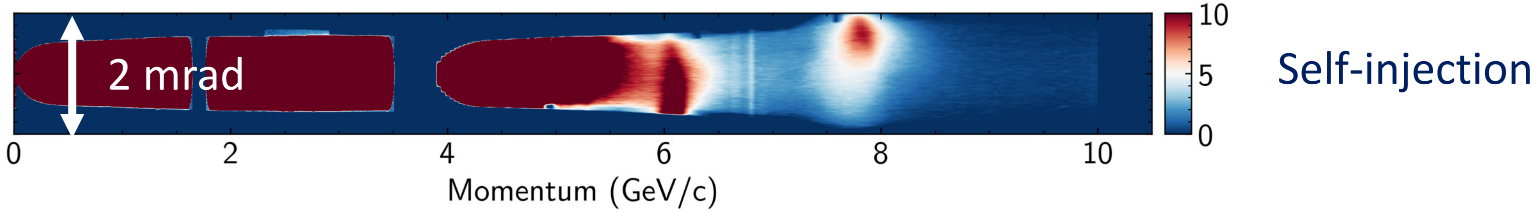
3. Towards an LPA stage suitable for applications

HOFI plasma channels allowed operation at a density where the accelerator could be powered without injecting unwanted charge

2019 – Laser heated capillary discharge

$n_{e0} \approx 2.7 \times 10^{17}\ \mathrm{cm}^{-3}$

$w_m \approx 61\ \mu\mathrm{m}$

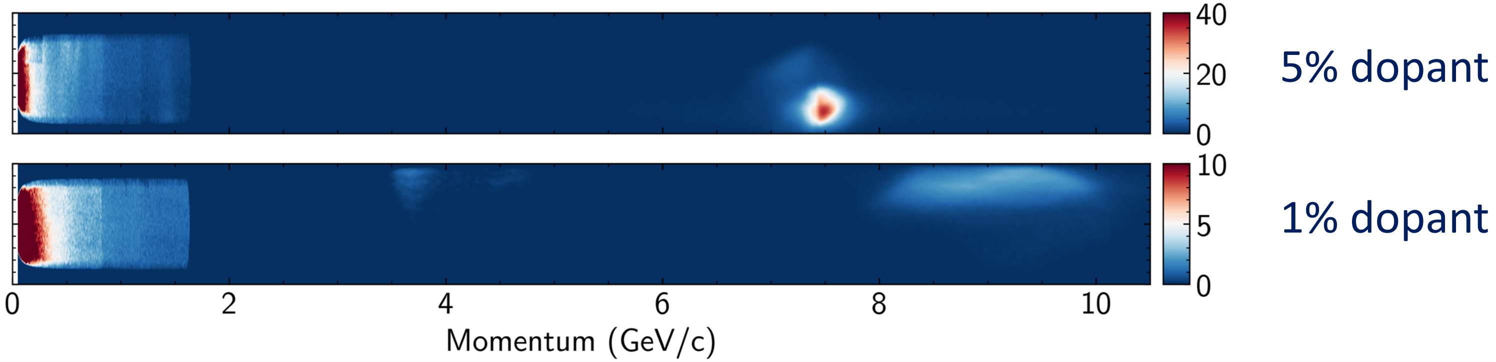


2024 – HOFI Plasma Channel

+ Localised Dopant

$n_{e0} \approx 1.0 \times 10^{17}\ \mathrm{cm}^{-3}$

$w_m \approx 40\ \mu\mathrm{m}$



- Dark current free operation vital for future applications, and for studies of staged LPAs
- Previously 0.5 – 1 J in electron beam across 0-8 GeV range
- Now up to 0.5 J in singly peaked beam
- In both cases, e-beam pointing stability similar **and** much worse than laser pointing

2025 : extended length scan method to study electron beam evolution

2024 :

30 cm Jet

$n_{e0} \approx 1 \times 10^{17}\ \mathrm{cm}^{-3}$

$r_{ch} \approx 40\ \mu\mathrm{m}$

2025 :

40 cm Jet

$n_{e0} \approx 0.6 \times 10^{17}\ \mathrm{cm}^{-3}$

$r_{ch} \approx 30\ \mu\mathrm{m}$ (**Controllable**)

Tang, H., et al. *arXiv :2604.25823 (Submitted)*

2025 : extended length scan method to study electron beam evolution

2024 :

30 cm Jet

$n_{e0} \approx 1 \times 10^{17}\ \mathrm{cm}^{-3}$

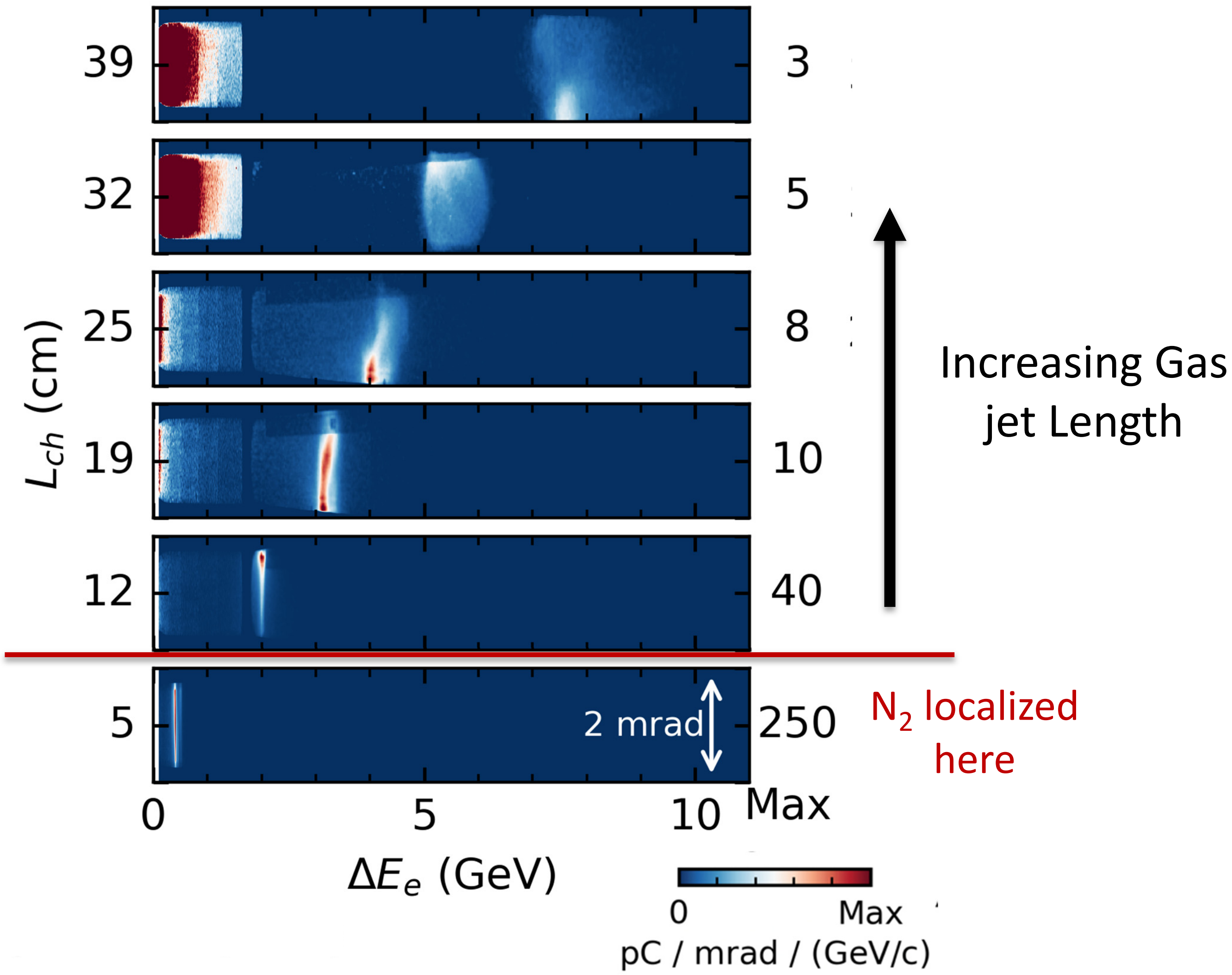
$r_{ch} \approx 40\ \mu\mathrm{m}$

2025 :

40 cm Jet

$n_{e0} \approx 0.6 \times 10^{17}\ \mathrm{cm}^{-3}$

$r_{ch} \approx 30\ \mu\mathrm{m}$ (**Controllable**)



Tang, H., et al. *arXiv :2604.25823 (Submitted)*

2025 : extended length scan method to study electron beam evolution

2024 :

30 cm Jet

$n_{e0} \approx 1 \times 10^{17}\ \mathrm{cm}^{-3}$

$r_{ch} \approx 40\ \mu\mathrm{m}$

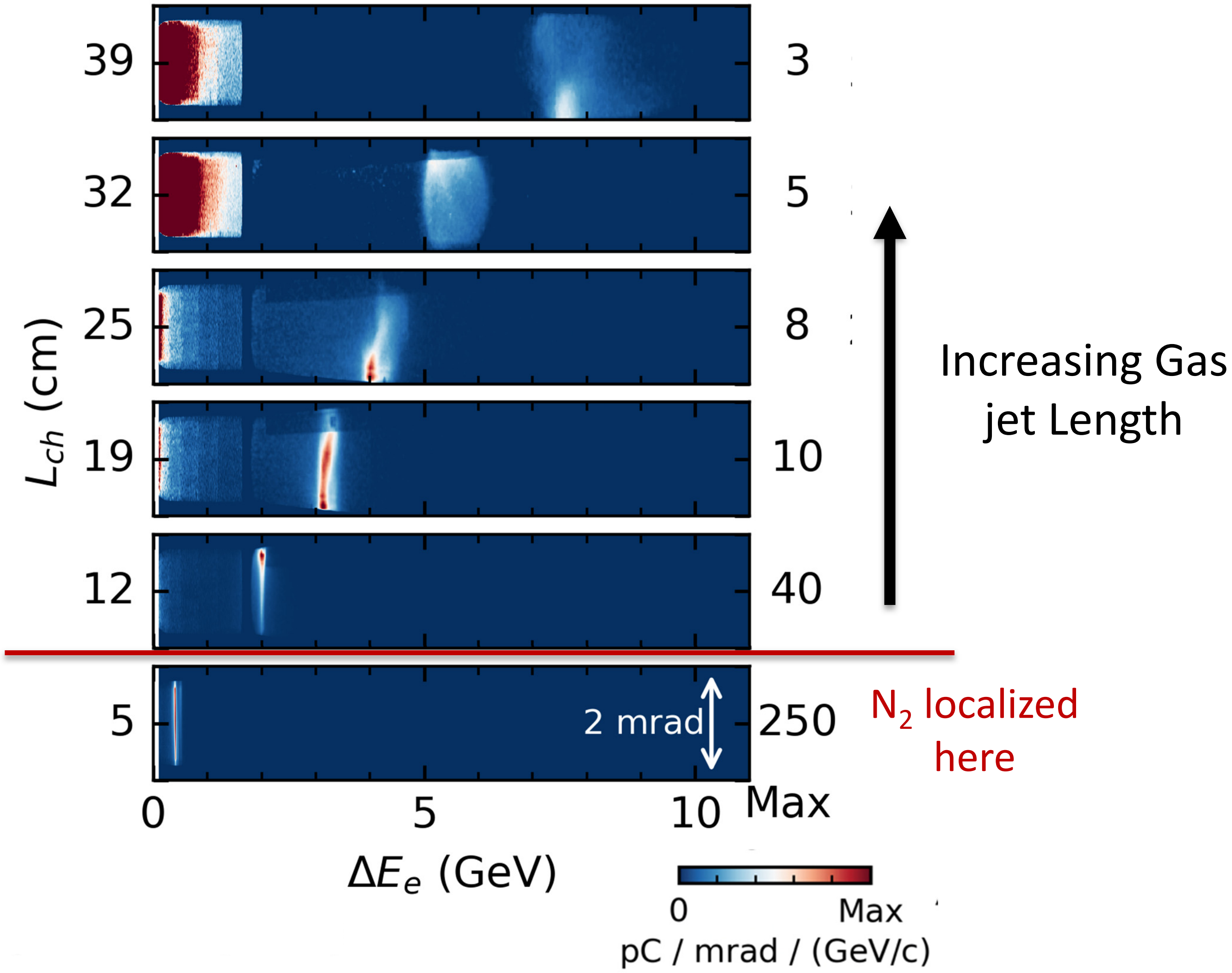
2025 :

40 cm Jet

$n_{e0} \approx 0.6 \times 10^{17}\ \mathrm{cm}^{-3}$

$r_{ch} \approx 30\ \mu\mathrm{m}$ (**Controllable**)

- Reduced channel size and density allowed for injection earlier



Tang, H., et al. *arXiv :2604.25823 (Submitted)*

2025 : extended length scan method to study electron beam evolution

2024 :

30 cm Jet

$n_{e0} \approx 1 \times 10^{17}\ \mathrm{cm}^{-3}$

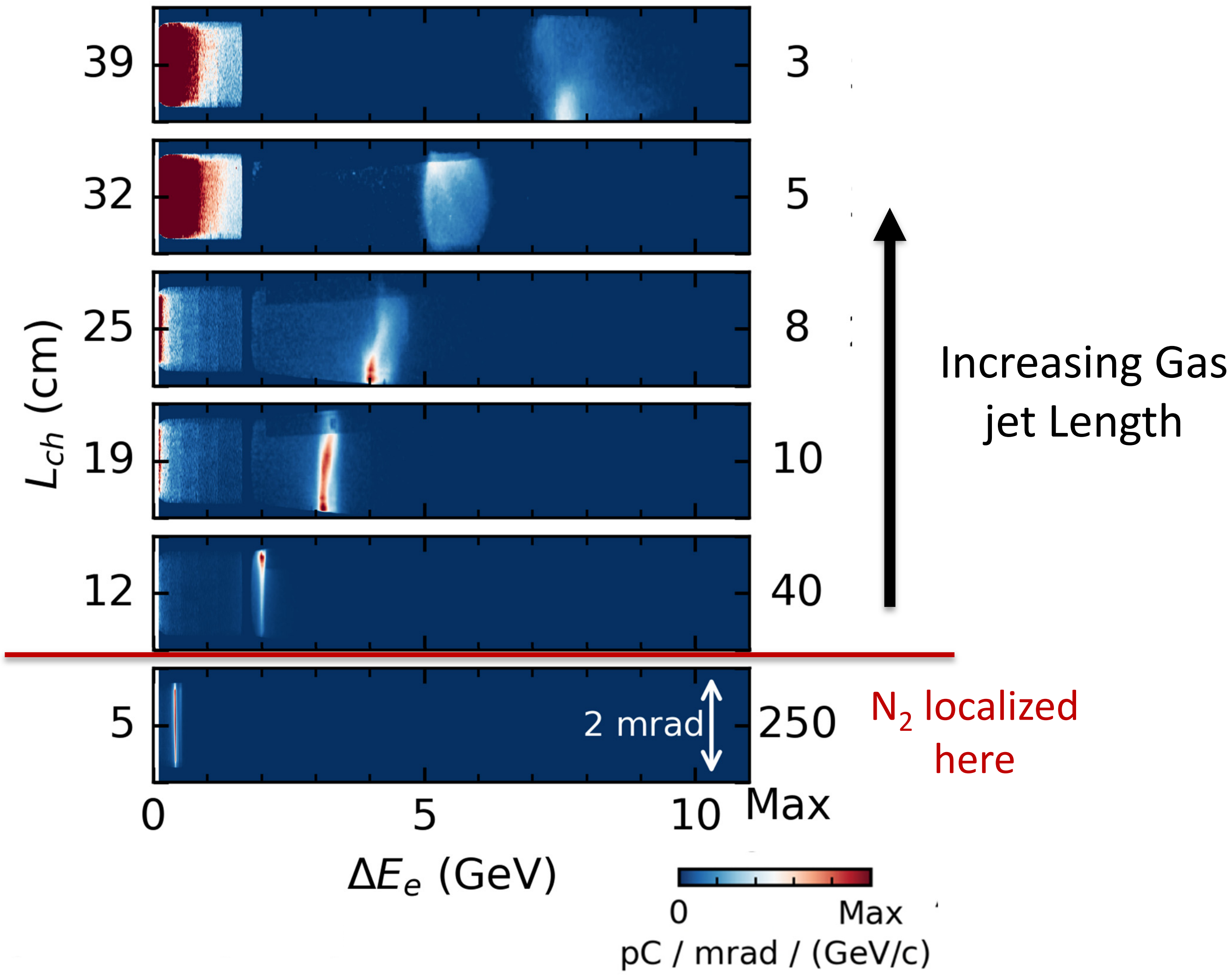
$r_{ch} \approx 40\ \mu\mathrm{m}$

2025 :

40 cm Jet

$n_{e0} \approx 0.6 \times 10^{17}\ \mathrm{cm}^{-3}$

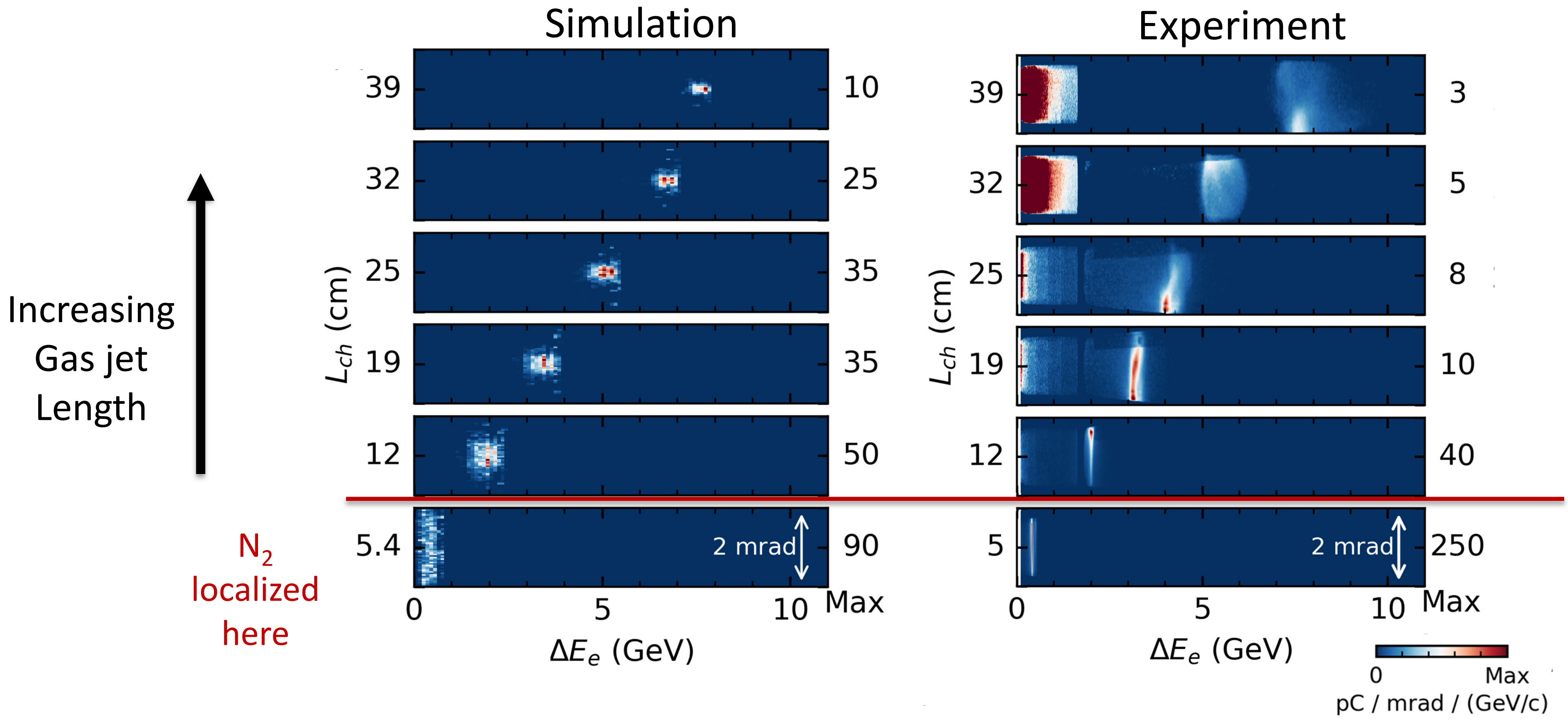
$r_{ch} \approx 30\ \mu\mathrm{m}$ (**Controllable**)



- Reduced channel size and density allowed for injection earlier
- **BUT** – lower overall energy

Tang, H., et al. *arXiv :2604.25823 (Submitted)*

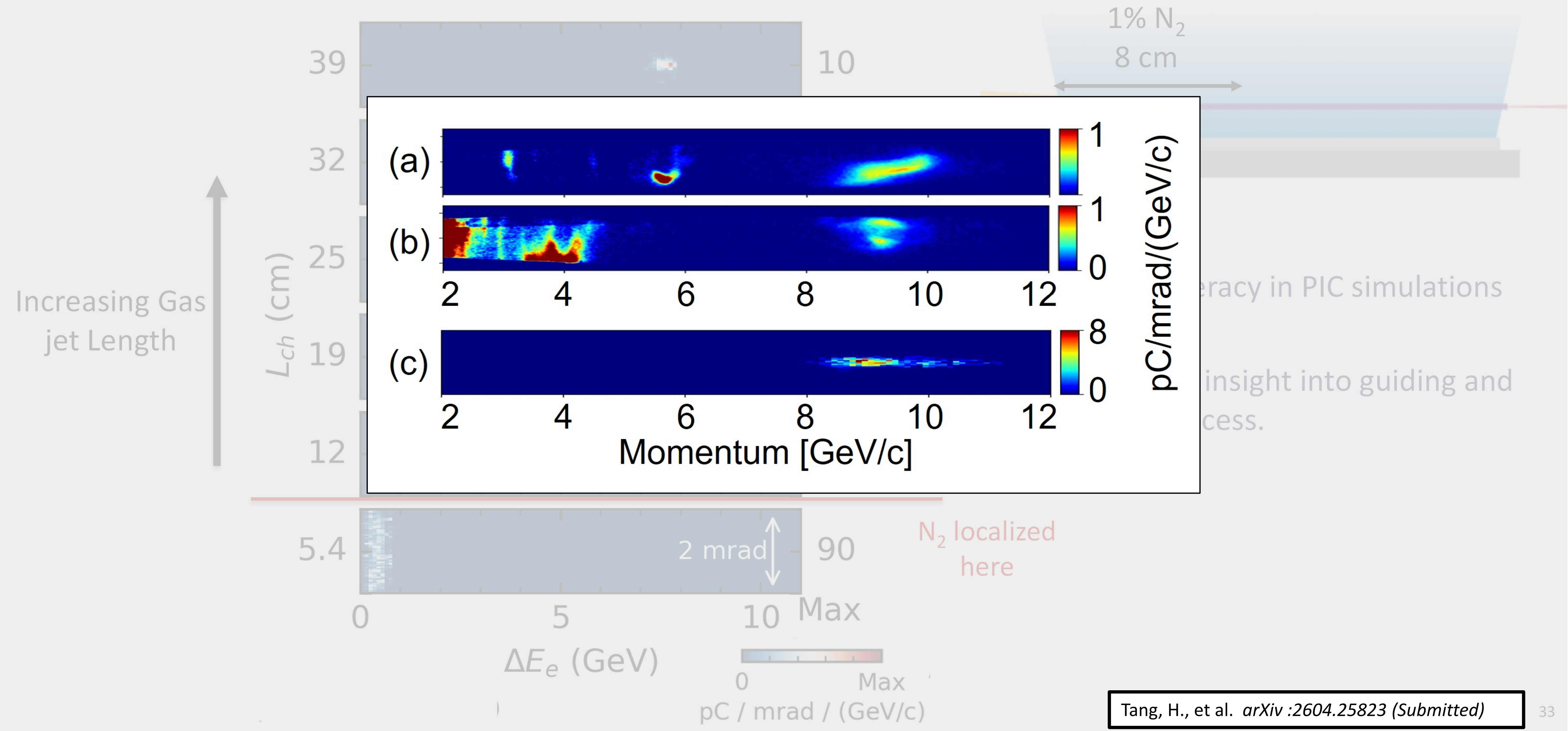
2025 : measured electron beam evolution and gave even further insight into LPA physics



- Length scan also reduced degeneracy in simulation inputs – gave us even further insight into best control over the channel

Tang, H., et al. *arXiv :2604.25823 (Submitted)*

Improved understanding led way to recover 10 GeV beams

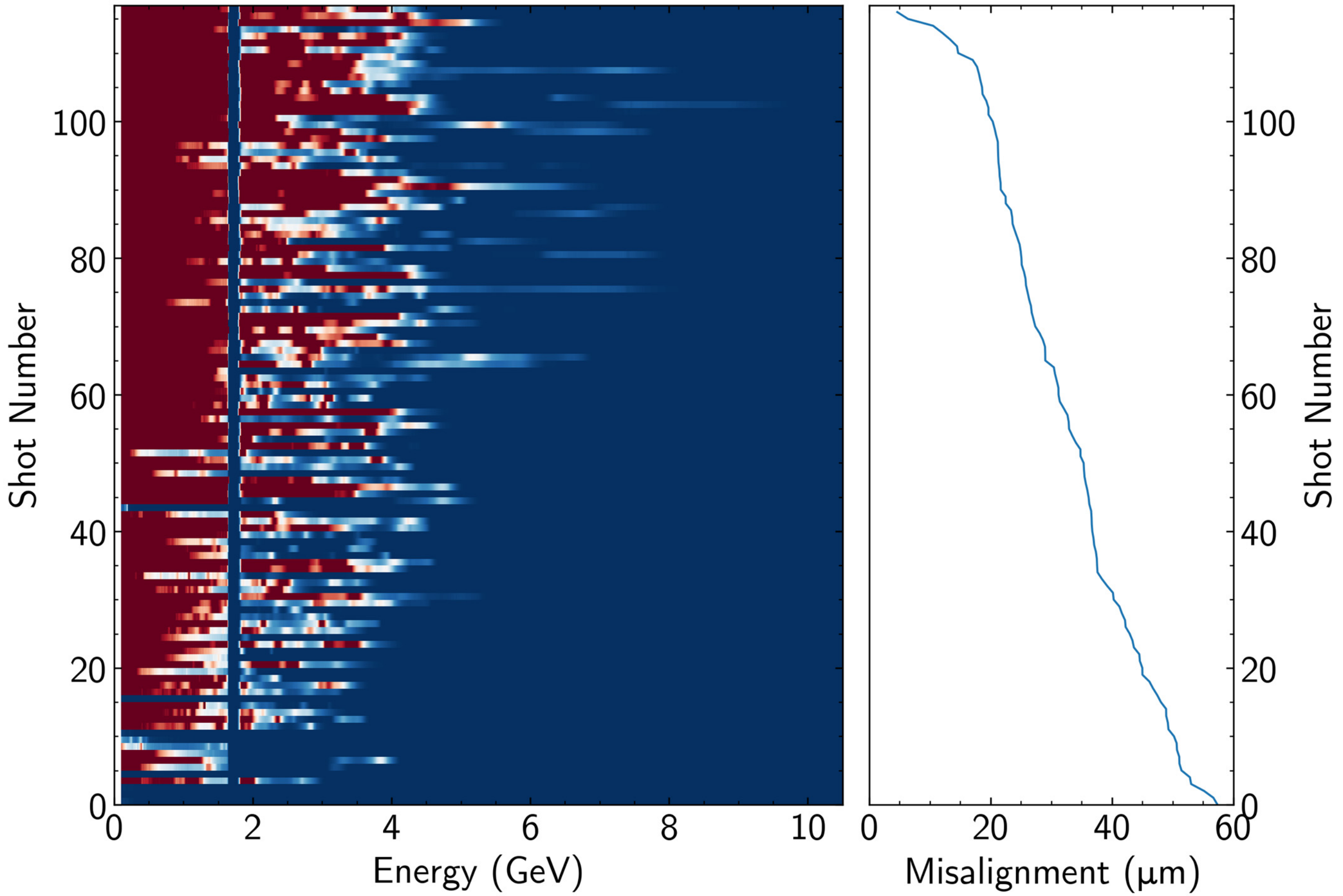


…racy in PIC simulations

…insight into guiding and …cess.

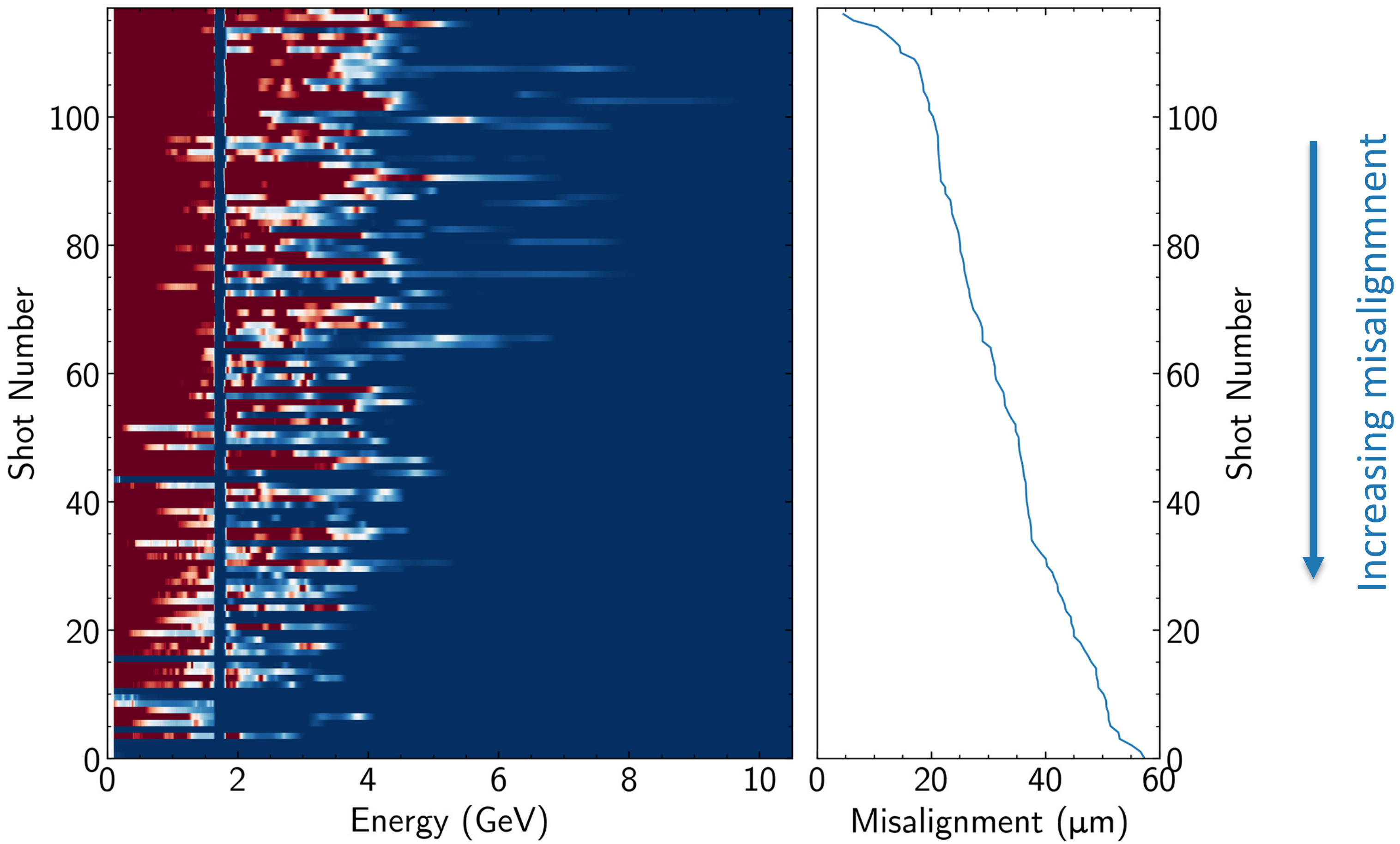
Tang, H., et al. *arXiv :2604.25823 (Submitted)*

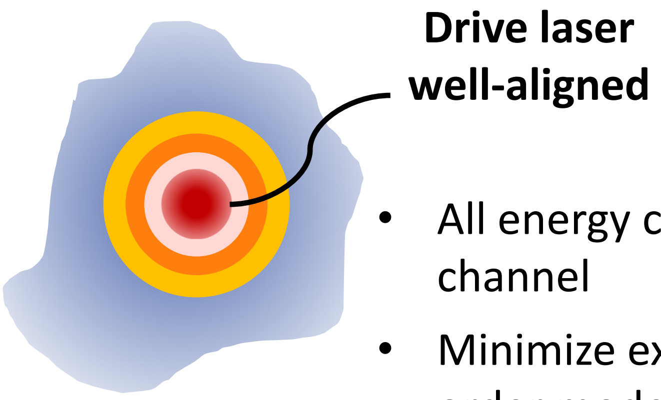
Electron beam stability requires stabilizing the laser.
HOFI LPAs fluctuations dominated by transverse pointing offset



Li, R., et al. *In preparation*
Similar effects noted in GeV HOFI LPAs:
A. Picksley, et al. *Physical Review Letters* 131.24 (2023)
K. Oubrerie, et al. *Light: Science & Applications* 11.1 (2022): 180.

Electron beam stability requires stabilizing the laser.
HOFI LPAs fluctuations dominated by transverse pointing offset

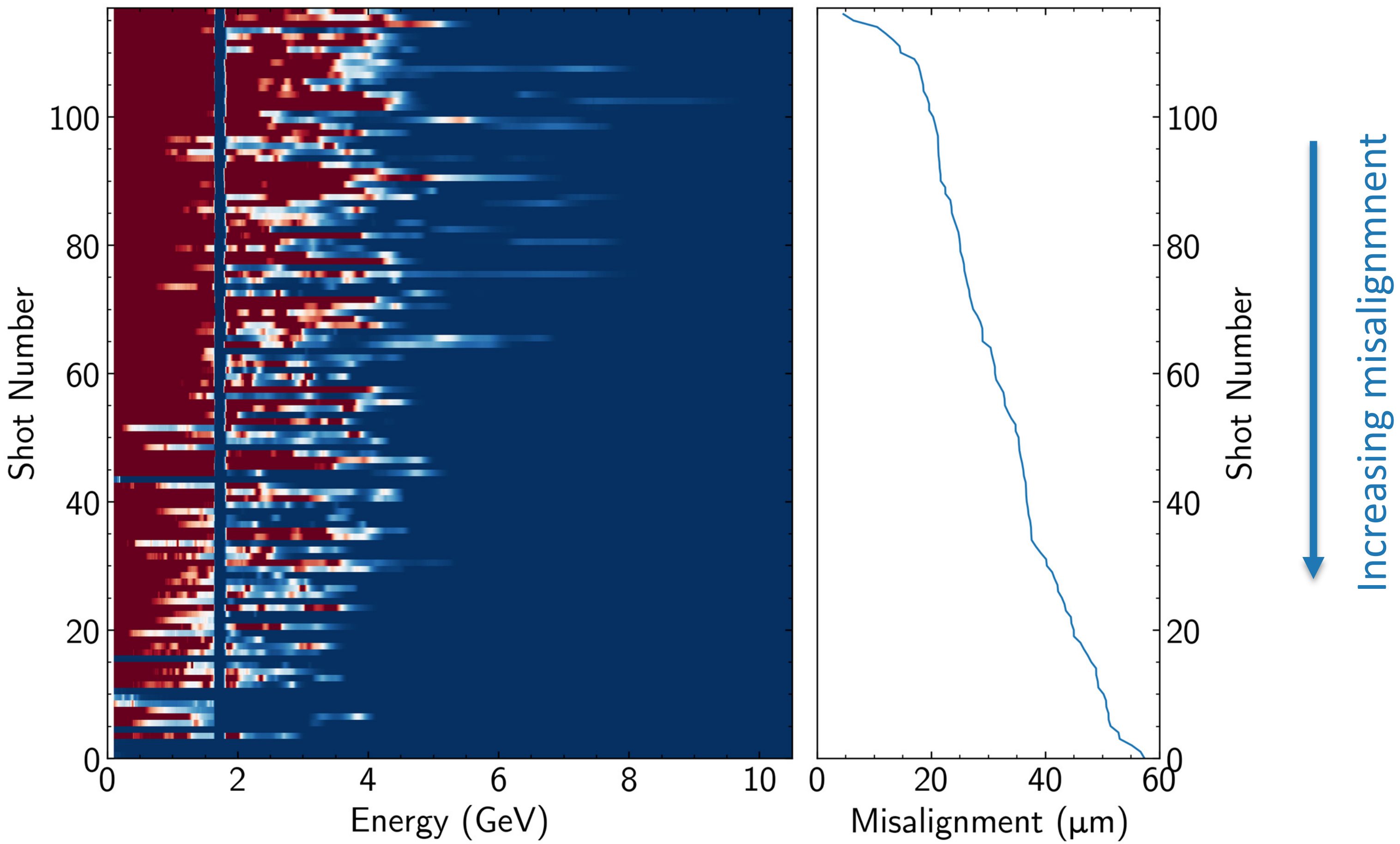


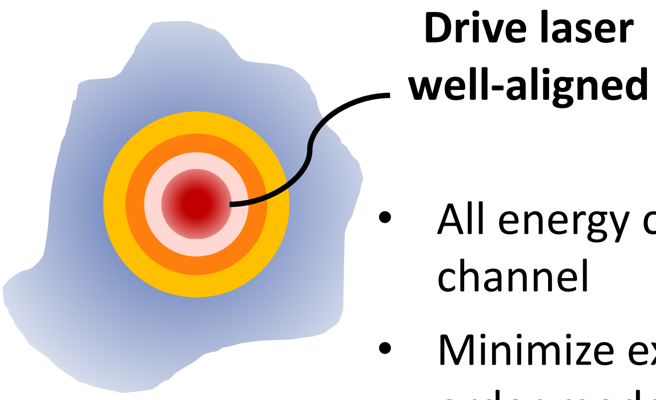


- All energy coupled into the channel
- Minimize excitation of higher order modes
- High energy beams

Li, R., et al. *In preparation*
Similar effects noted in GeV HOFI LPAs:
A. Picksley, et al. *Physical Review Letters* 131.24 (2023)
K. Oubrerie, et al. *Light: Science & Applications* 11.1 (2022): 180.

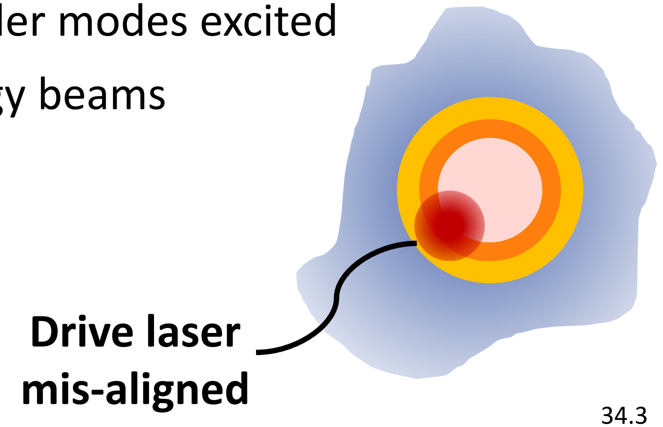
Electron beam stability requires stabilizing the laser.
HOFI LPAs fluctuations dominated by transverse pointing offset





- All energy coupled into the channel
- Minimize excitation of higher order modes
- High energy beams

- Higher order modes excited
- Low-energy beams



Li, R., et al. *In preparation*

Similar effects noted in GeV HOFI LPAs:

A. Picksley, et al. *Physical Review Letters* 131.24 (2023)

K. Oubrerie, et al. *Light: Science & Applications* 11.1 (2022): 180.

Conclusions

- Plasma channels formed by the hydrodynamic expansion of optical-field-ionised plasmas offer a route to steep, low-density, freestanding plasma channels suitable for 10-GeV-class laser plasma accelerators
- By varying the plasma channel length, we demonstrated mode filtering followed by matched guiding in 30-cm-long HOFI plasma channels
- Controlled injection into the dark current free structure led to singly peaked electron beams with peak energy of 9.2 GeV and charge extending beyond 10 GeV
- This could pave the way to stable, high repetition rate stages required for future applications