Driving Plasma Wakefields
With Particle beams and laser beams

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University of Oxford, Oxfordshire, UK
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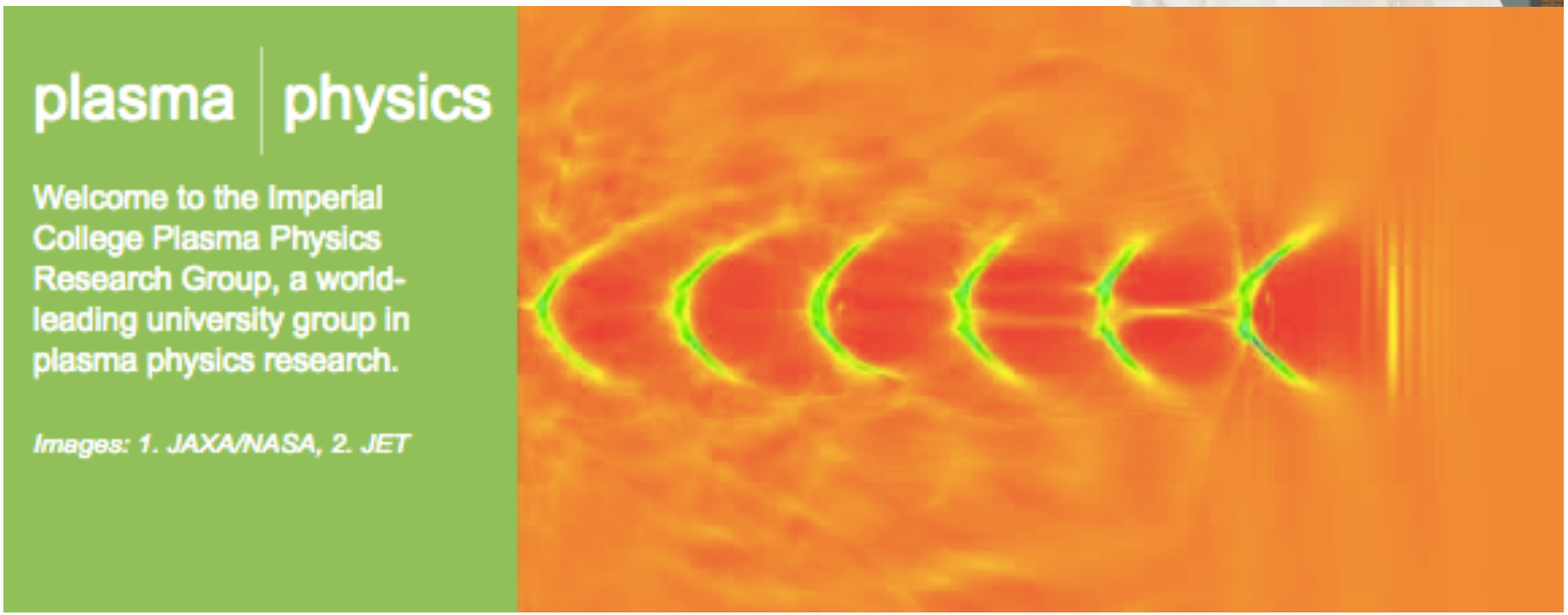
Physics around two thirds of England

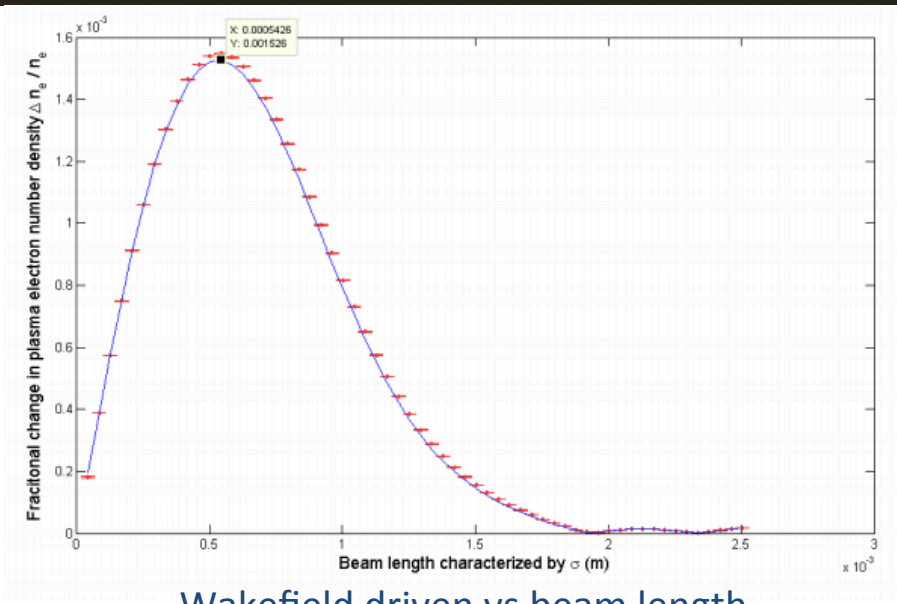
Imperial College: Plasma Wakefield Acceleration

- First encountered PWA at Imperial College
- Worked with Zulfikar Najmudin simulating laser driven PWA
- First heard about AWAKE collaboration (at the time called PDPWA)
- Started simulating using PIC codes

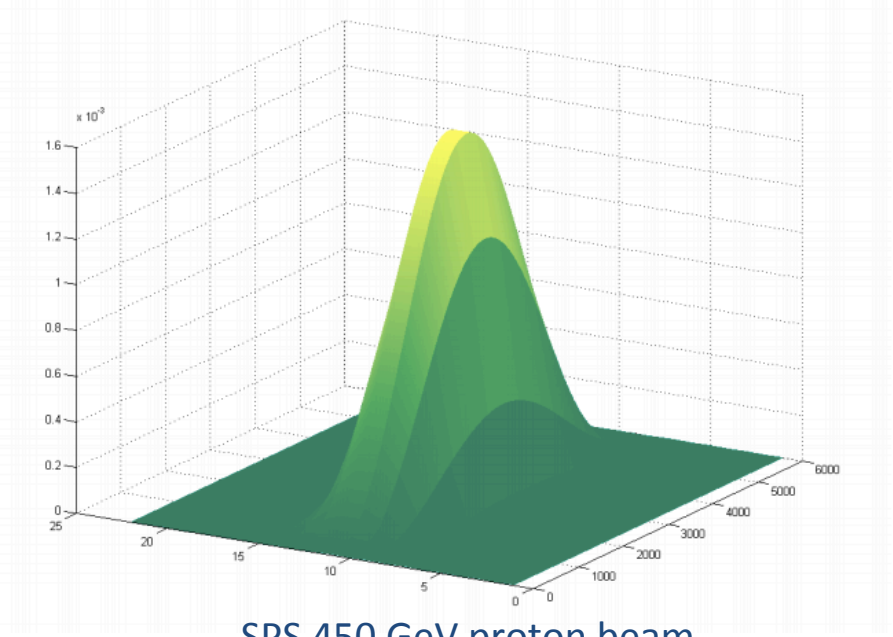


Imperial College: Plasma Wakefield Acceleration

- Investigated driver beam length on PWA
- Cross checked theoretical model against code
- Performed technical parameter scans (resolution, particle per cell etc.)
- Started simulating real particle beams propagating through plasma (the SPS beam)



Wakefield driven vs beam length



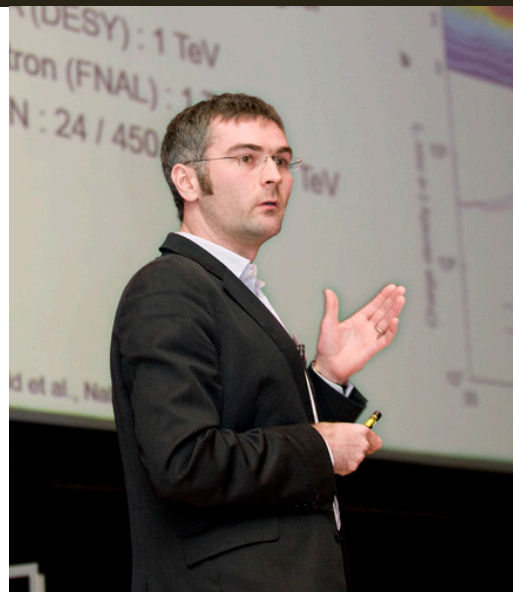
SPS 450 GeV proton beam

Physics around two thirds of England

University College London

- Started PhD at University College London
- Supervisors M. Wing and P. Norreys
- Joined the AWAKE collaboration (still called PDPWA)

- Started devising a way to use the Diamond beam to drive PWA
- Joined an Imperial College experiment using the Astra Gemini laser beam to drive PWA



Professor Matthew Wing


Professor Peter Norreys

Physics around two thirds of England

The Astra Gemini Experiment

- 8 week run
- Use the 14 Joule 40 fs laser to drive high amplitude wakefield
- Generate bright X-rays from wakefield and use for phase contrast imaging
- Learnt experimental skills as a few tricks of the trade from highly experienced Imperial team
- Got my name on first paper

Compact laser accelerators for X-ray phase-contrast imaging

Z. Najmudin, S. Kneip, M. S. Bloom, S. P. D. Mangles, O. Chekhlov, A. E. Dangor, A. Döpp, K. Ertel, S. J. Hawkes, J. Holloway, C. J. Hooker, J. Jiang, N. C. Lopes, H. Nakamura, P. A. Norreys, P. P. Rajeev, C. Russo, M. J. V. Streeter, D. R. Symes, M. Wing

Astra Gemini laser room

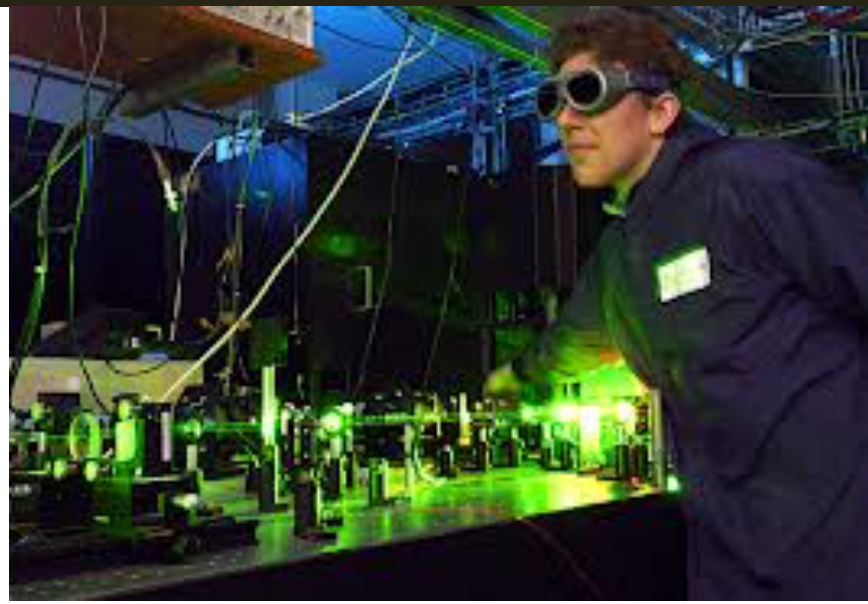
Astra Gemini target area

The Astra TA2 experiment

- 6+ month run (!)
- Use a laser pulse several plasma periods long to drive a wakefield – look for self-modulation of the laser pulse.
- Frequency of the modulation is the plasma frequency.

The Plasma
• $n_e = 10^{17} - 10^{19}$ m^{-3}
• Ion = He
• $E_r = 1$ GVm^{-1}

Astra Laser
• E = 600 mJ
• σ_t = 200 fs
• σ_r = 20 um
• λ = 800 nm

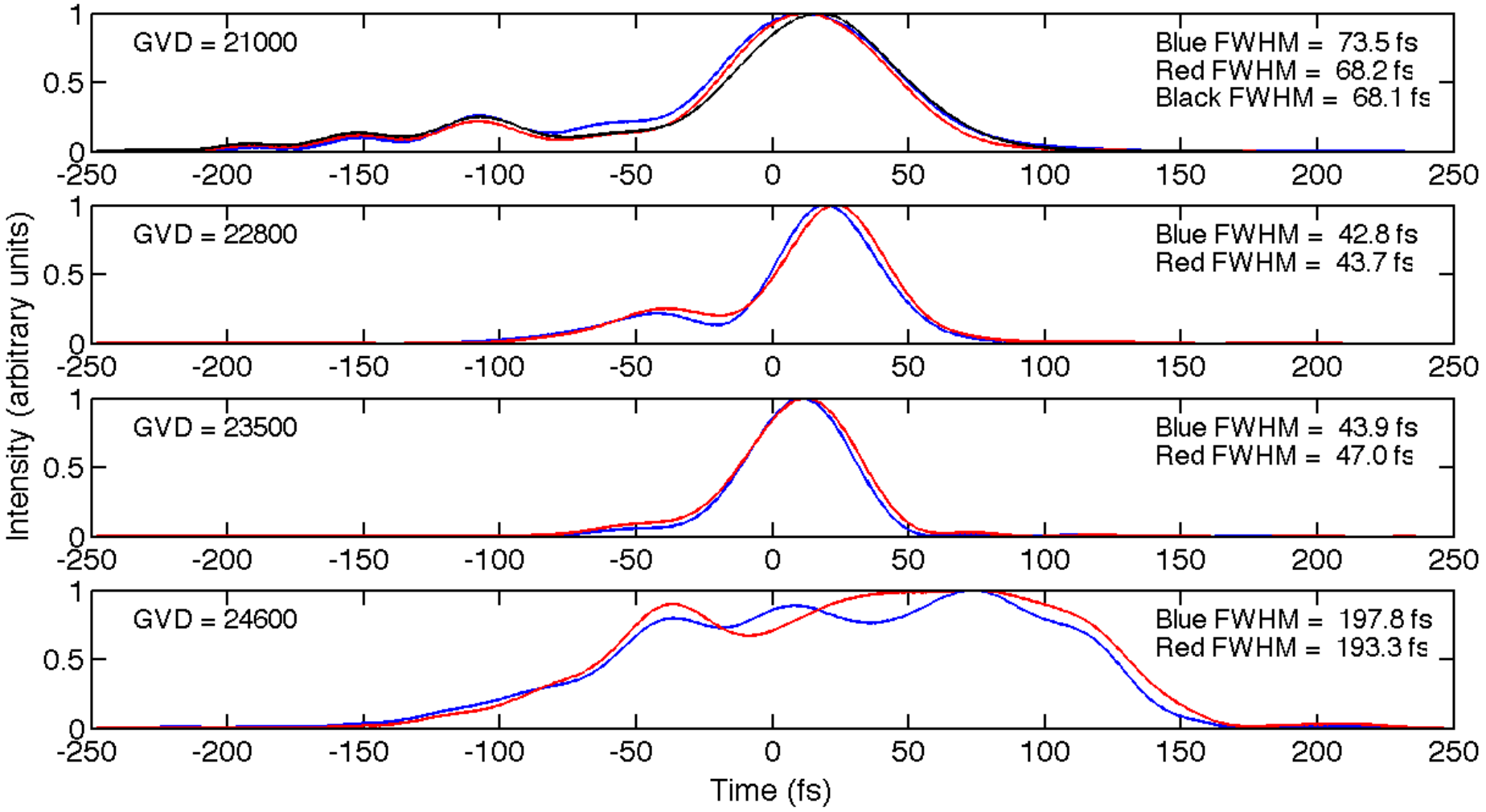


Astra Gemini laser room

Astra Gemini target area

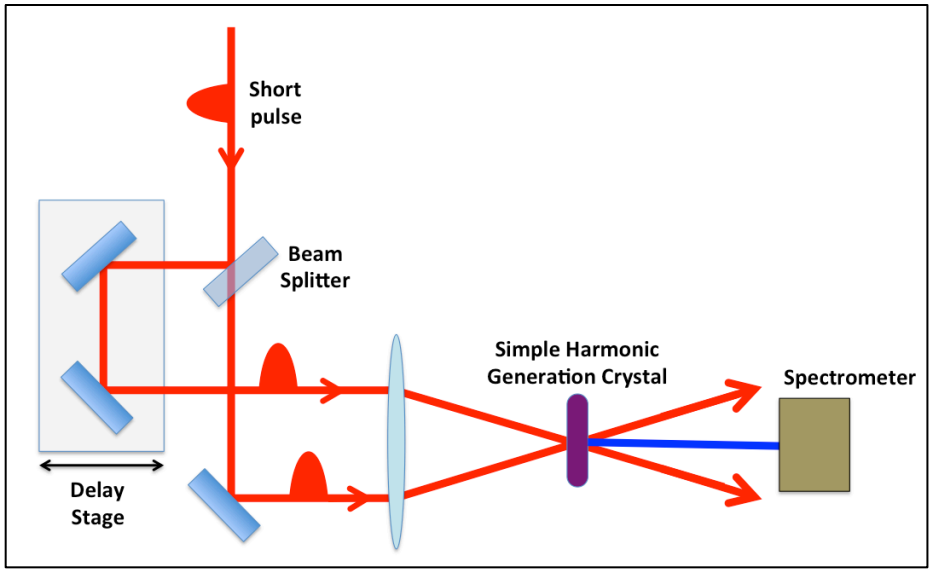
The lengthened Astra Laser

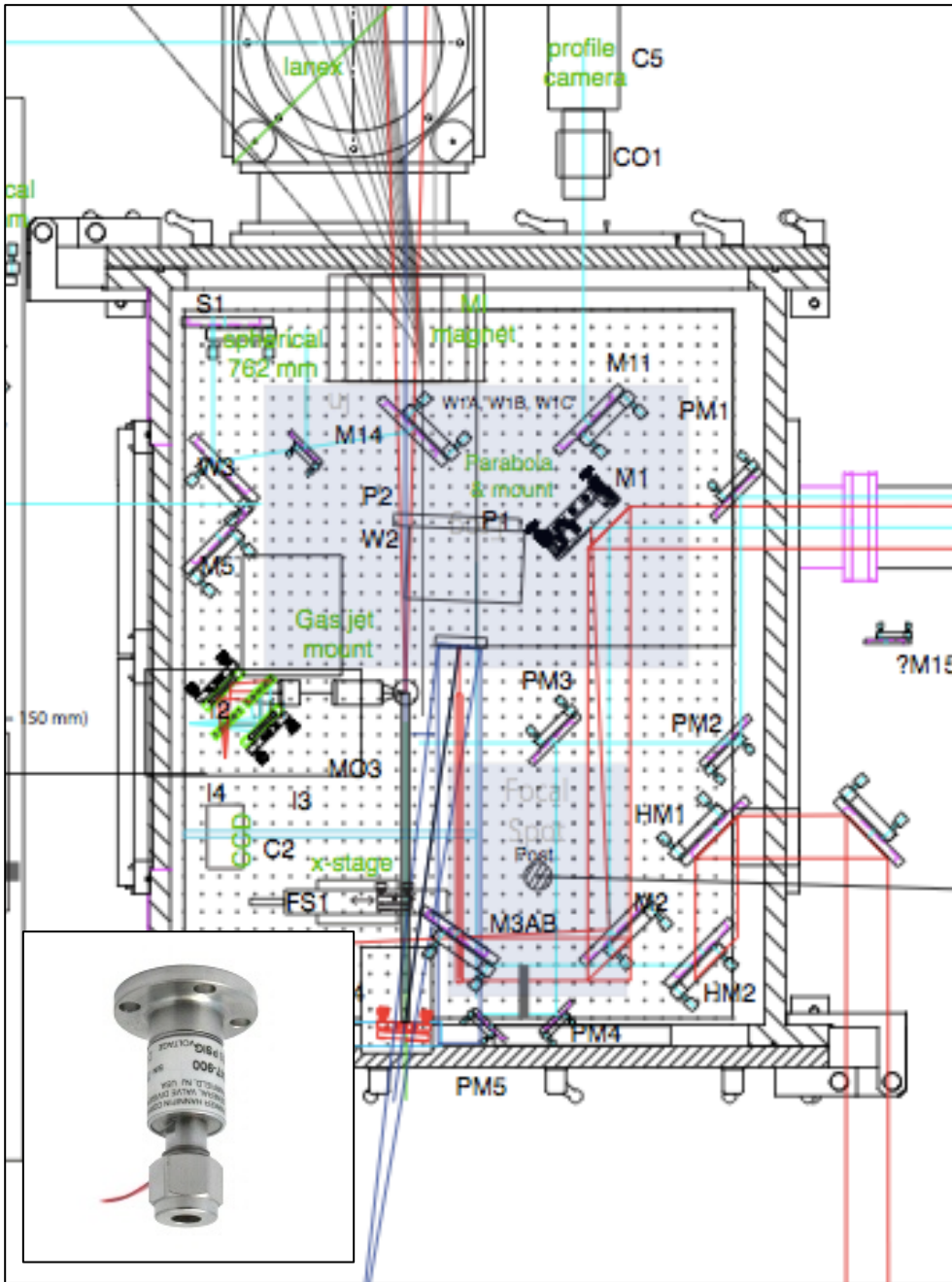
Introducing GVD at the start of the laser chain



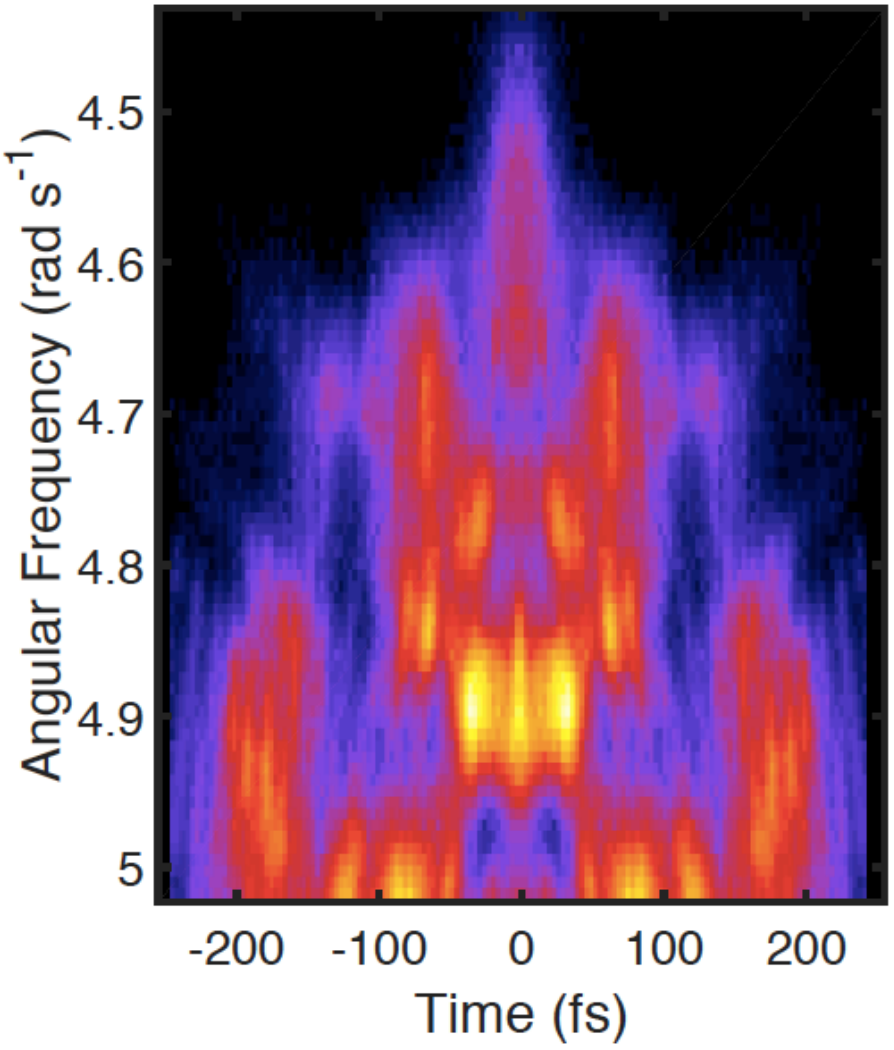
Astra TA2 experiment

- 200 fs laser pulse enters vacuum chamber
- Impinges He gas target
- Drives a wakefield
- Surviving laser light collected by FROG

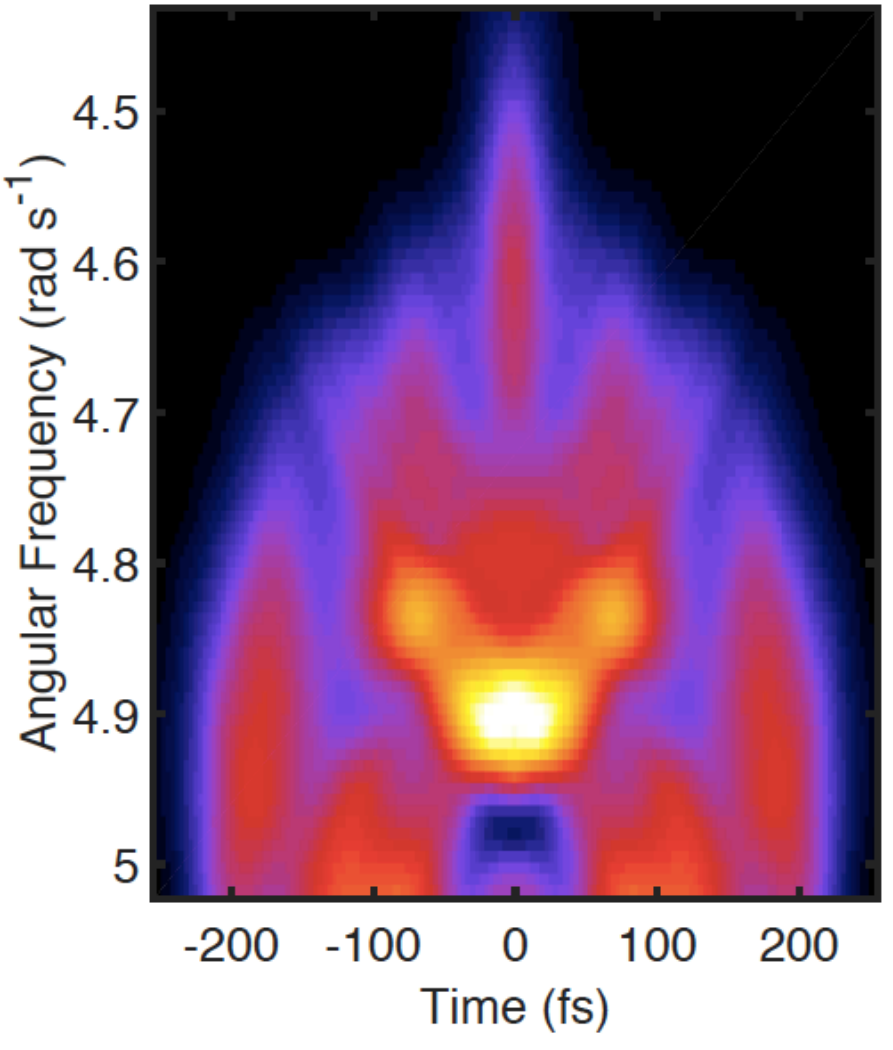




FROG – Full Intensity and Phase Measurement

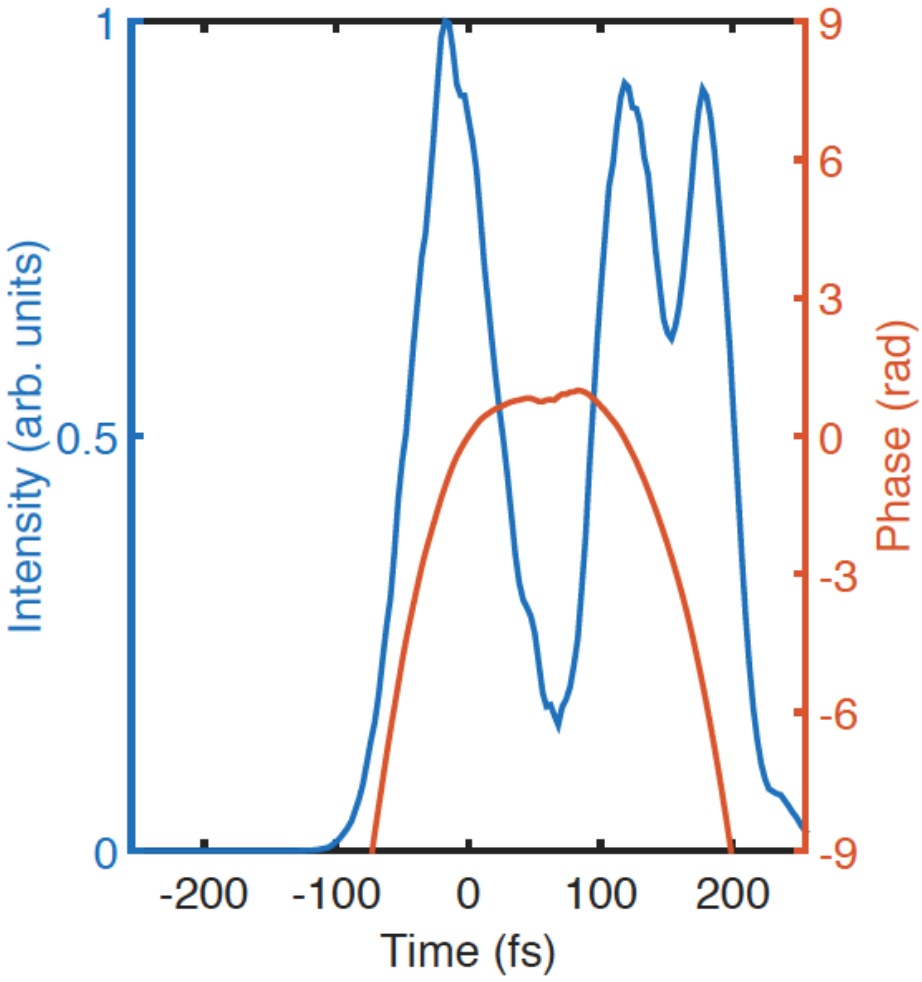


Raw FROG trace

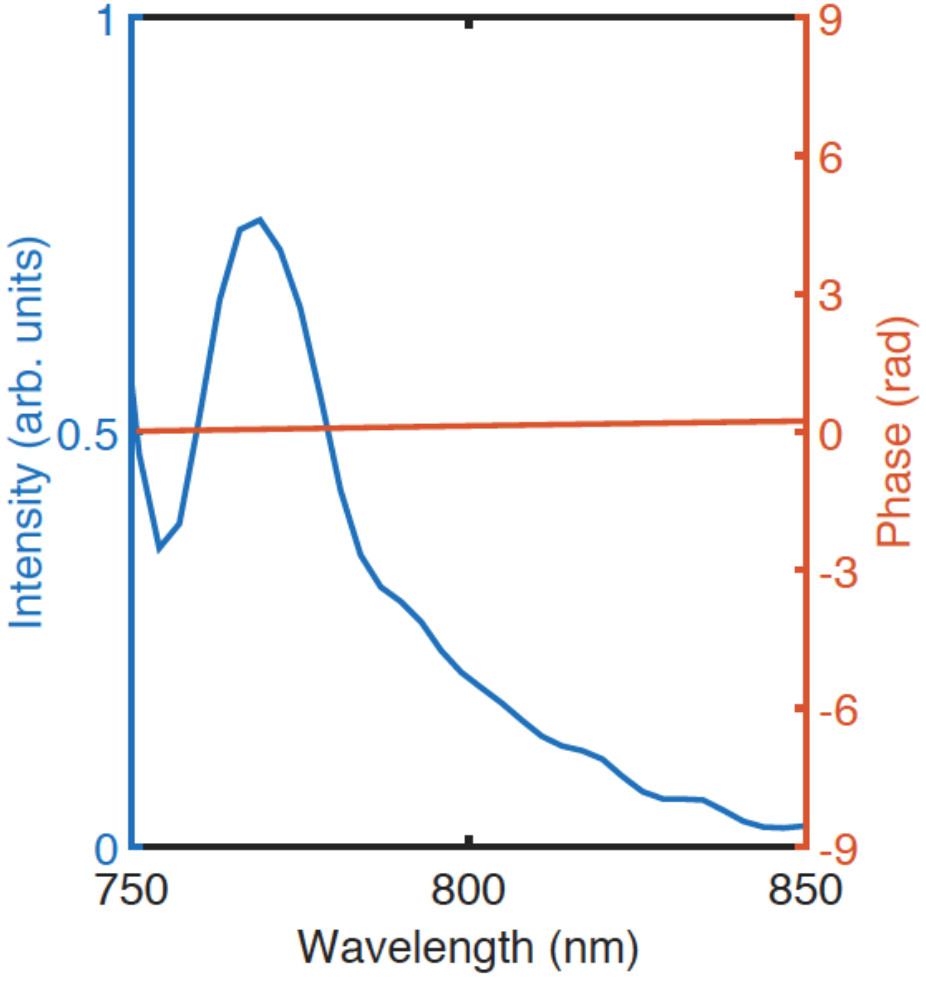


Retrieved FROG trace

FROG – Full Intensity and Phase Measurement

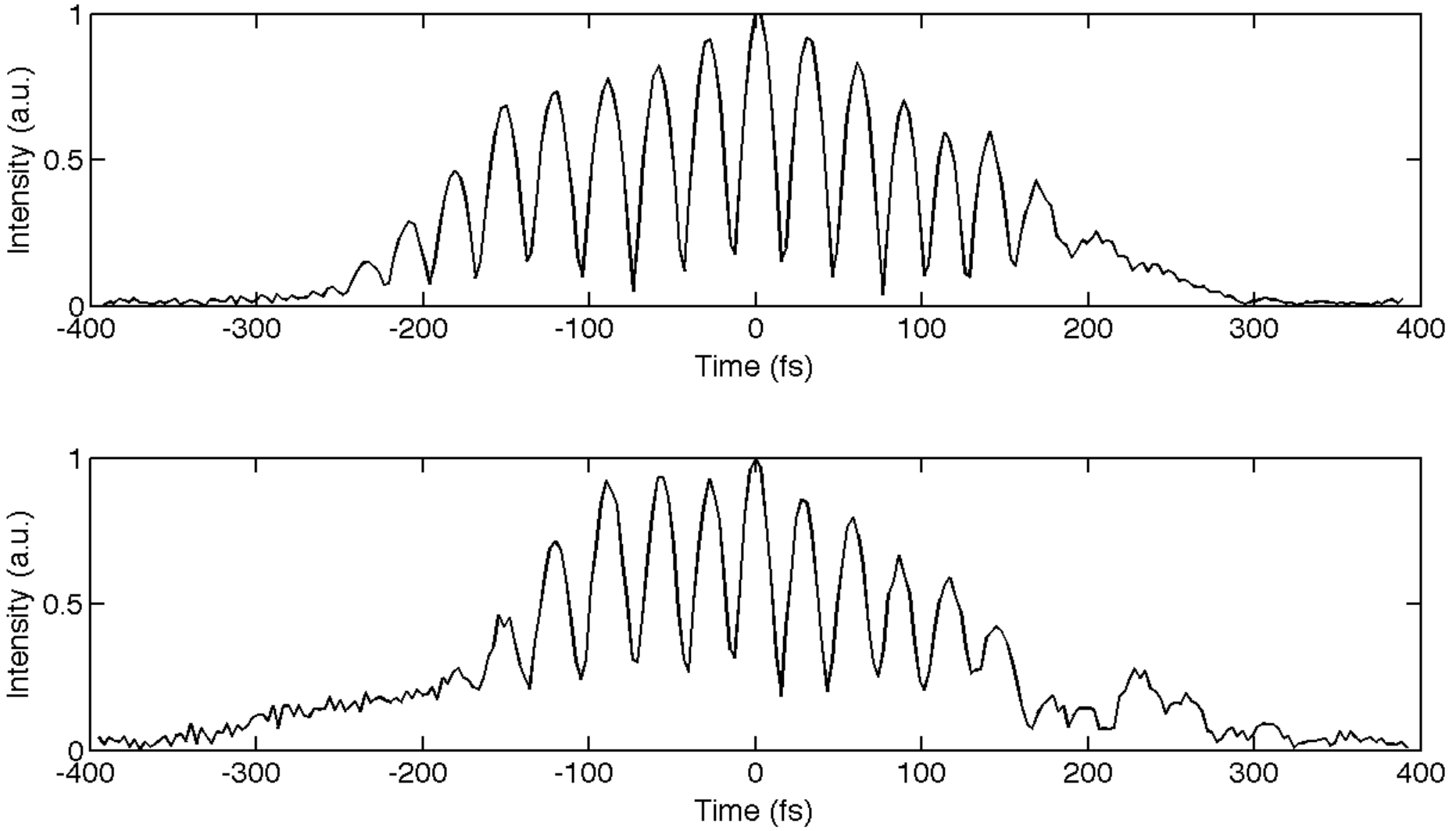


Retrieved laser intensity

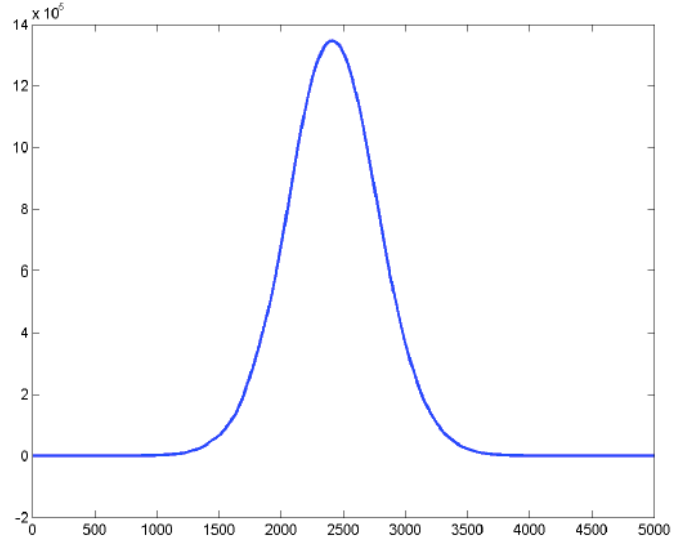


Retrieved laser spectrum

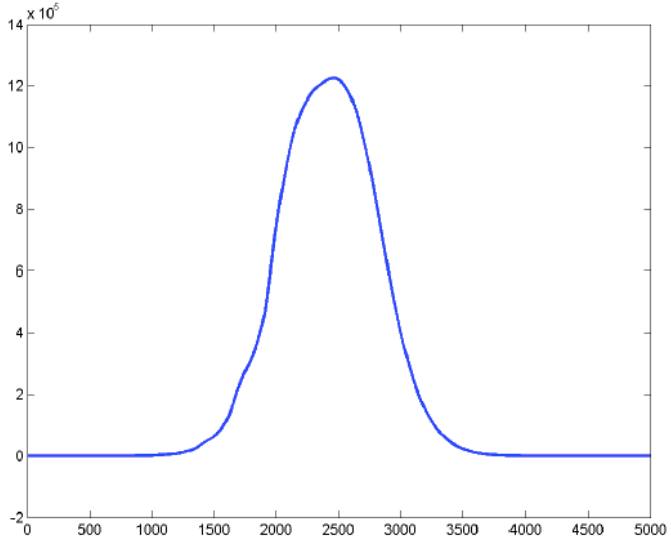
Laser Emerging from Plasma



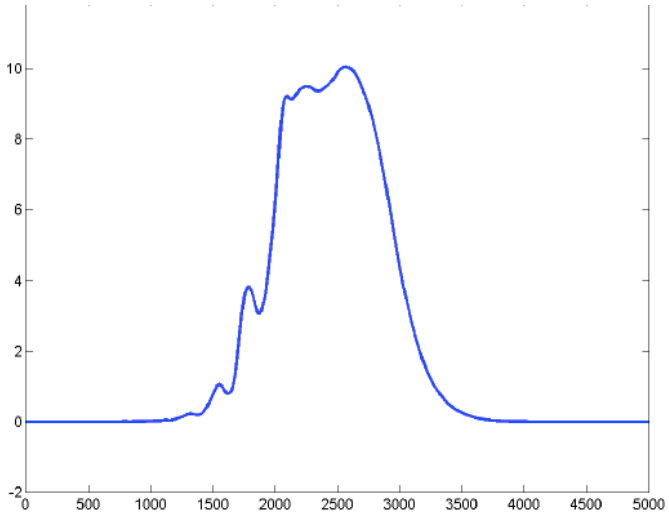
Laser Emerging from Plasma - Simulations



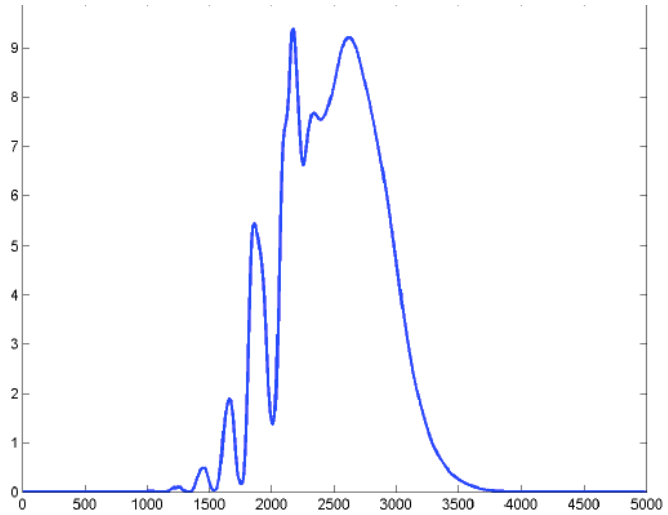
(a) $n_e = 3 \times 10^{24}\ m^{-3}$



(b) $n_e = 5 \times 10^{24}\ m^{-3}$

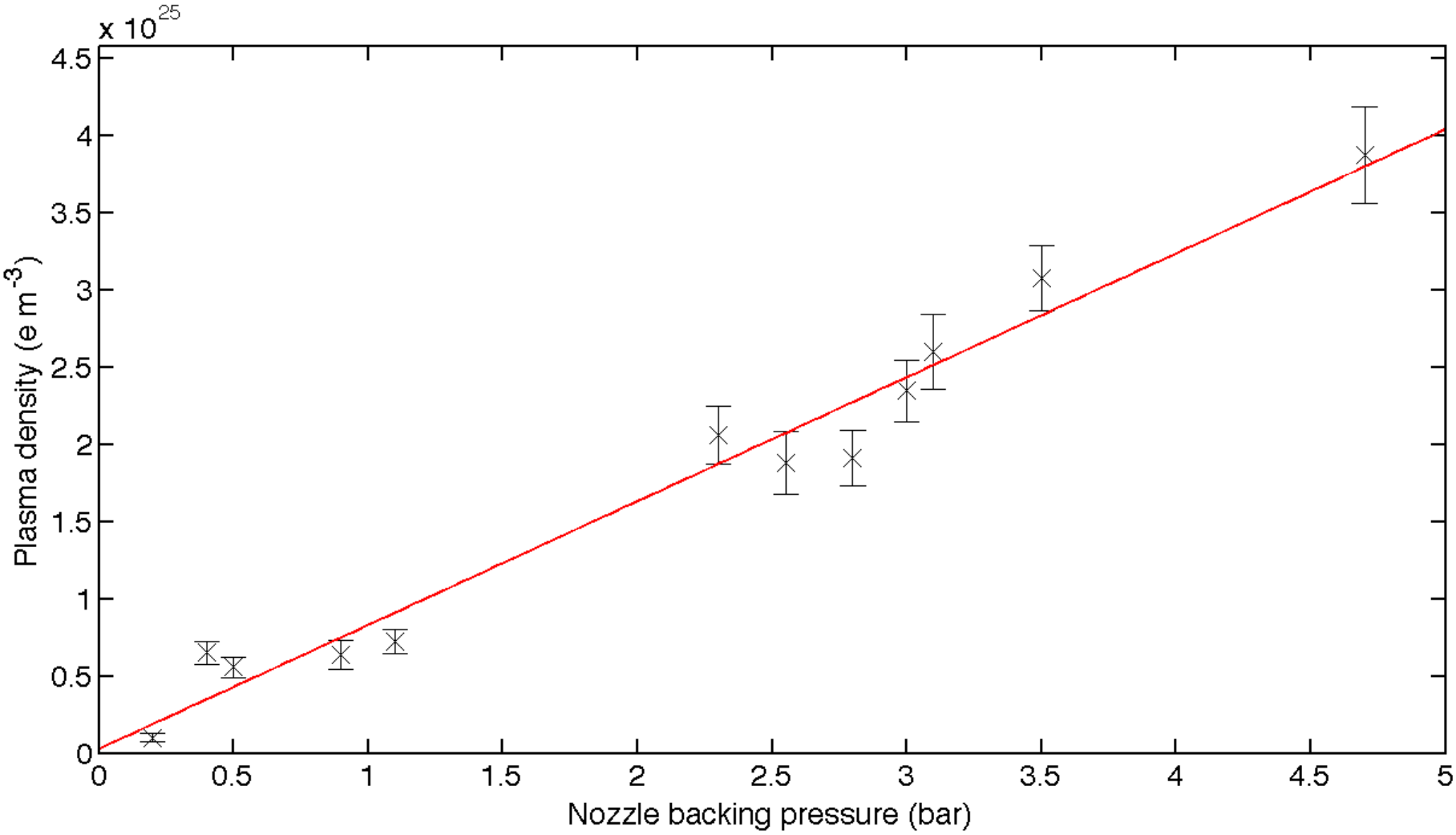


(c) $n_e = 7 \times 10^{24}\ m^{-3}$



(d) $n_e = 9 \times 10^{24}\ m^{-3}$

Measured Plasma Density

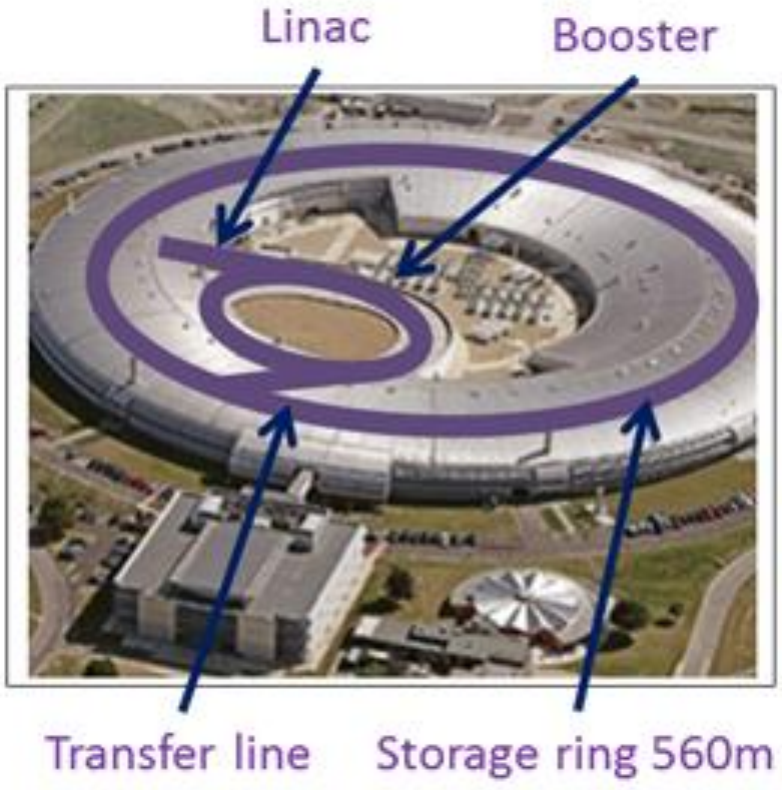


Physics around two thirds of England

The Diamond Light Source Proposal

1. Micro-bunch the Diamond beam using ‘Wakefield Lens’ design
2. Drive E = 2 GVm^{-1} wakefield in second plasma stage
3. Brilliant X-rays generated from radial oscillations of micro-bunches
4. Accelerate witness electron beam to greater than 3 GeV

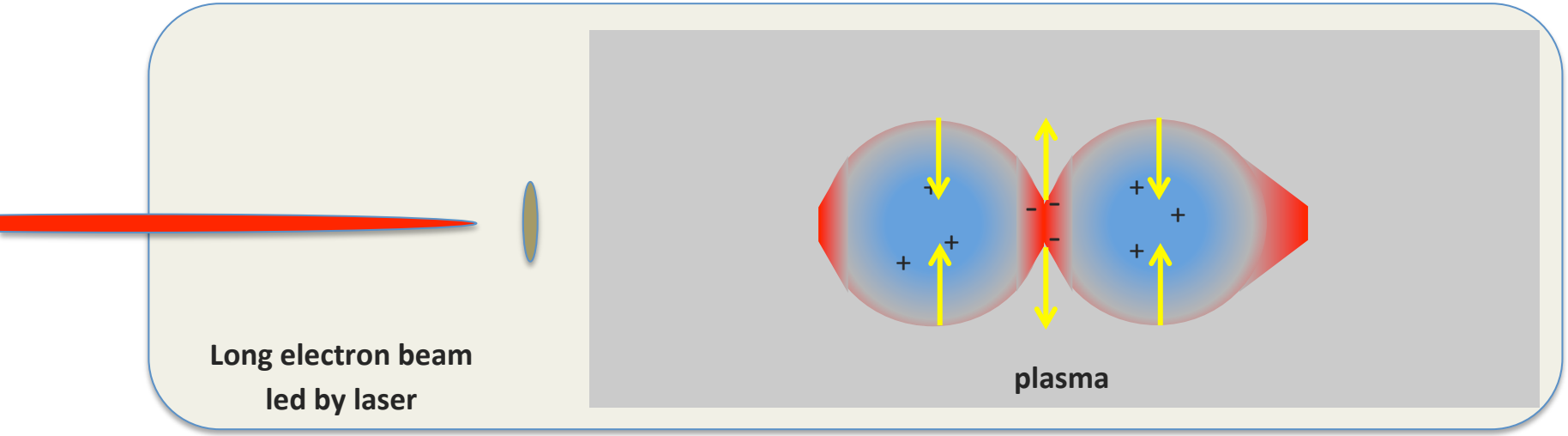
- Have been in talks with Diamond personnel
- Devised a way to perform experiment without intrusion



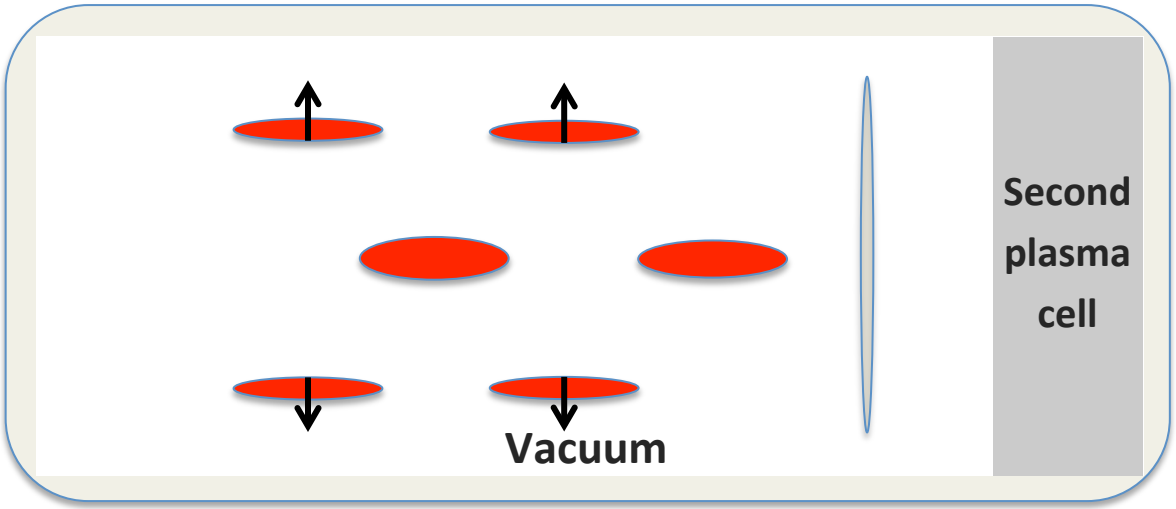
Diamond Booster Beam

- E = 3 GeV
- ε = 140 nm rad
- **σ_z = 26 mm**
- Q = 2 nC

Micro-Bunching Via 'Wakefield Lens and Drift Space'



- Strong transverse kick from laser wakefield
- **Propagate beam through vacuum**
- Pass micro-bunches into second plasma stage



Micro-bunched driver beam.

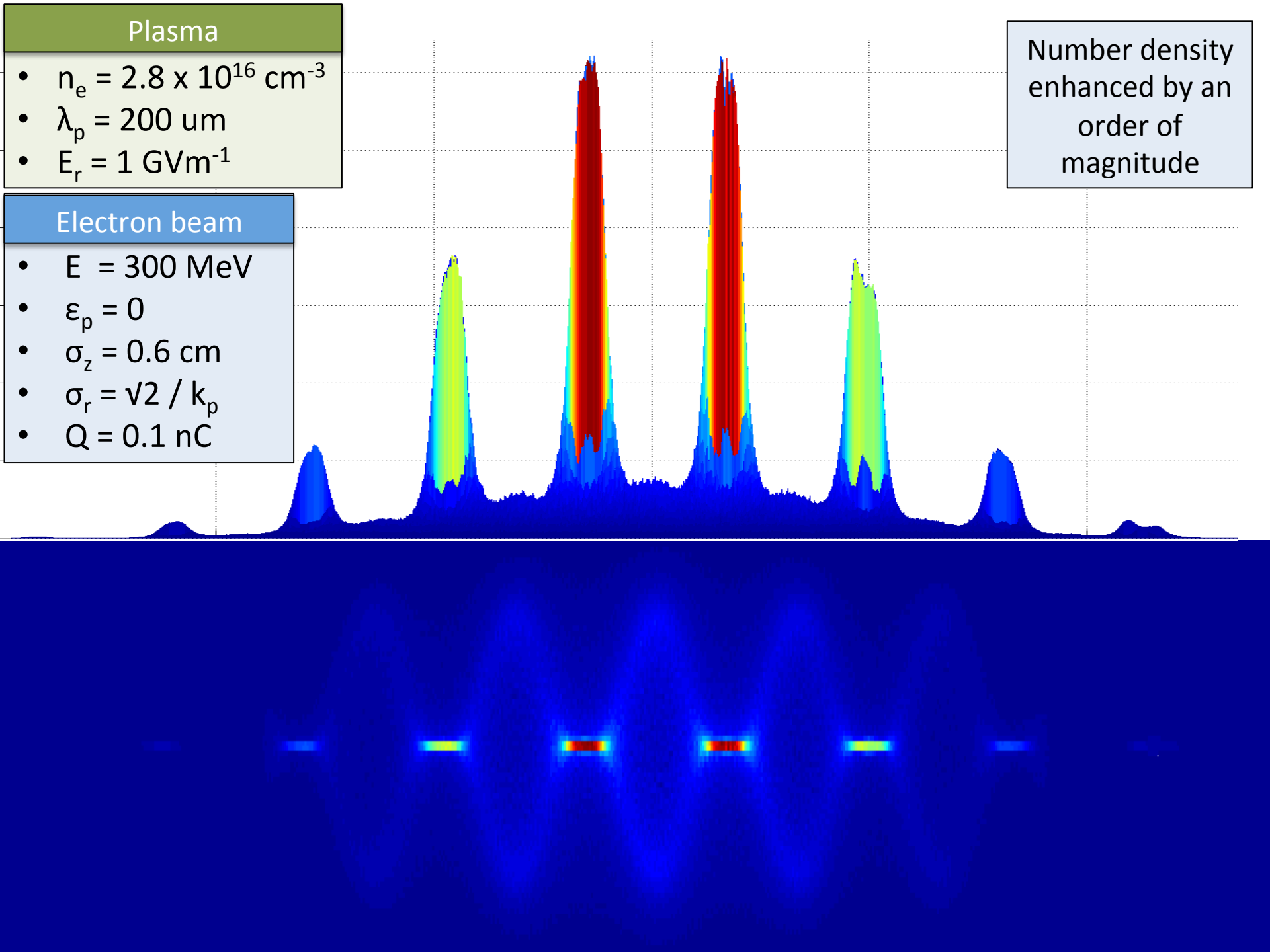
Plasma

- $n_e = 2.8 \times 10^{16}$ cm^{-3}
- $\lambda_p = 200$ um
- $E_r = 1$ GVm^{-1}

Electron beam

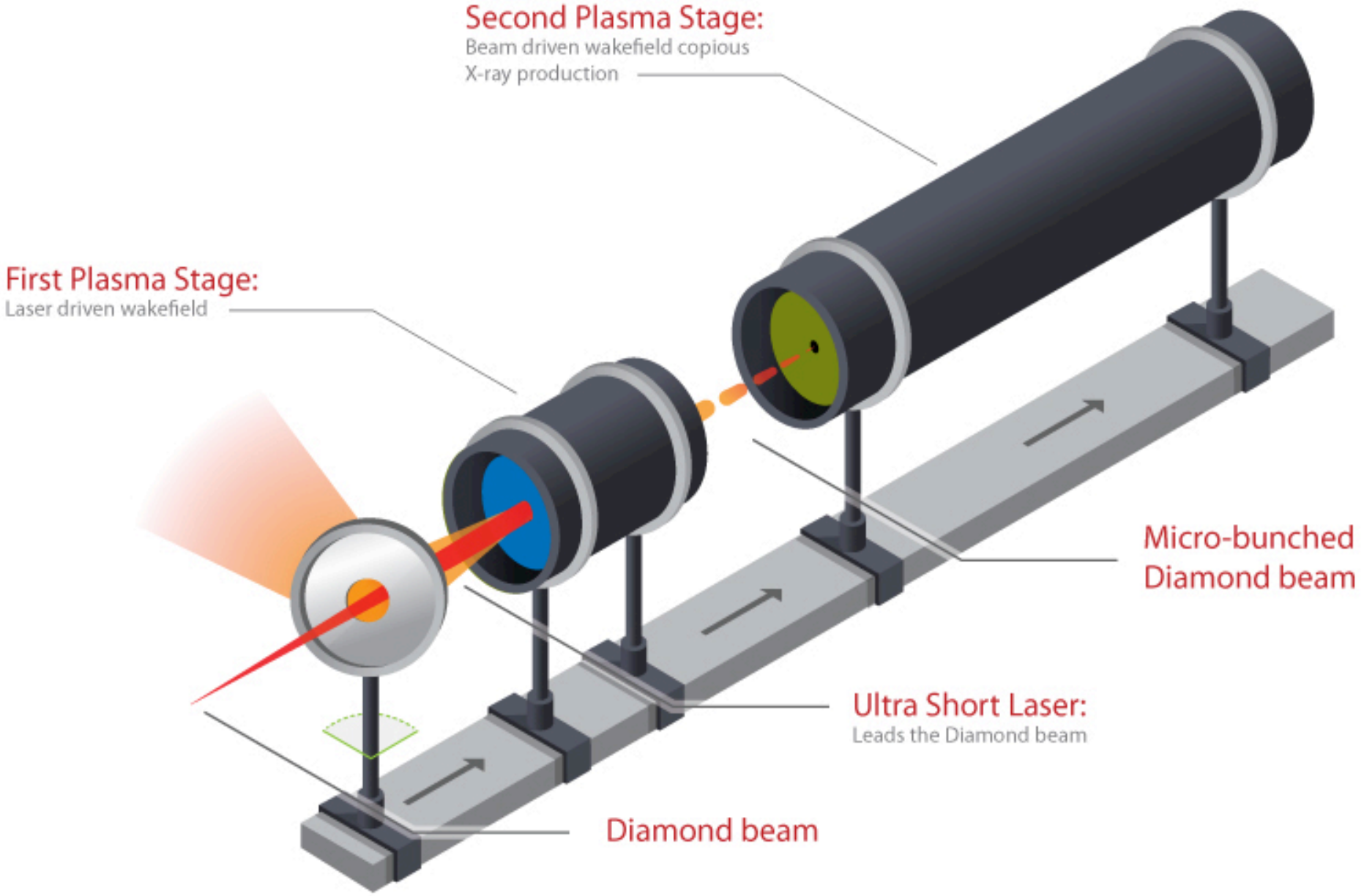
- E = 300 MeV
- $\varepsilon_p = 0$
- $\sigma_z = 0.6$ cm
- $\sigma_r = \sqrt{2} / k_p$
- Q = 0.1 nC

Number density enhanced by an order of magnitude

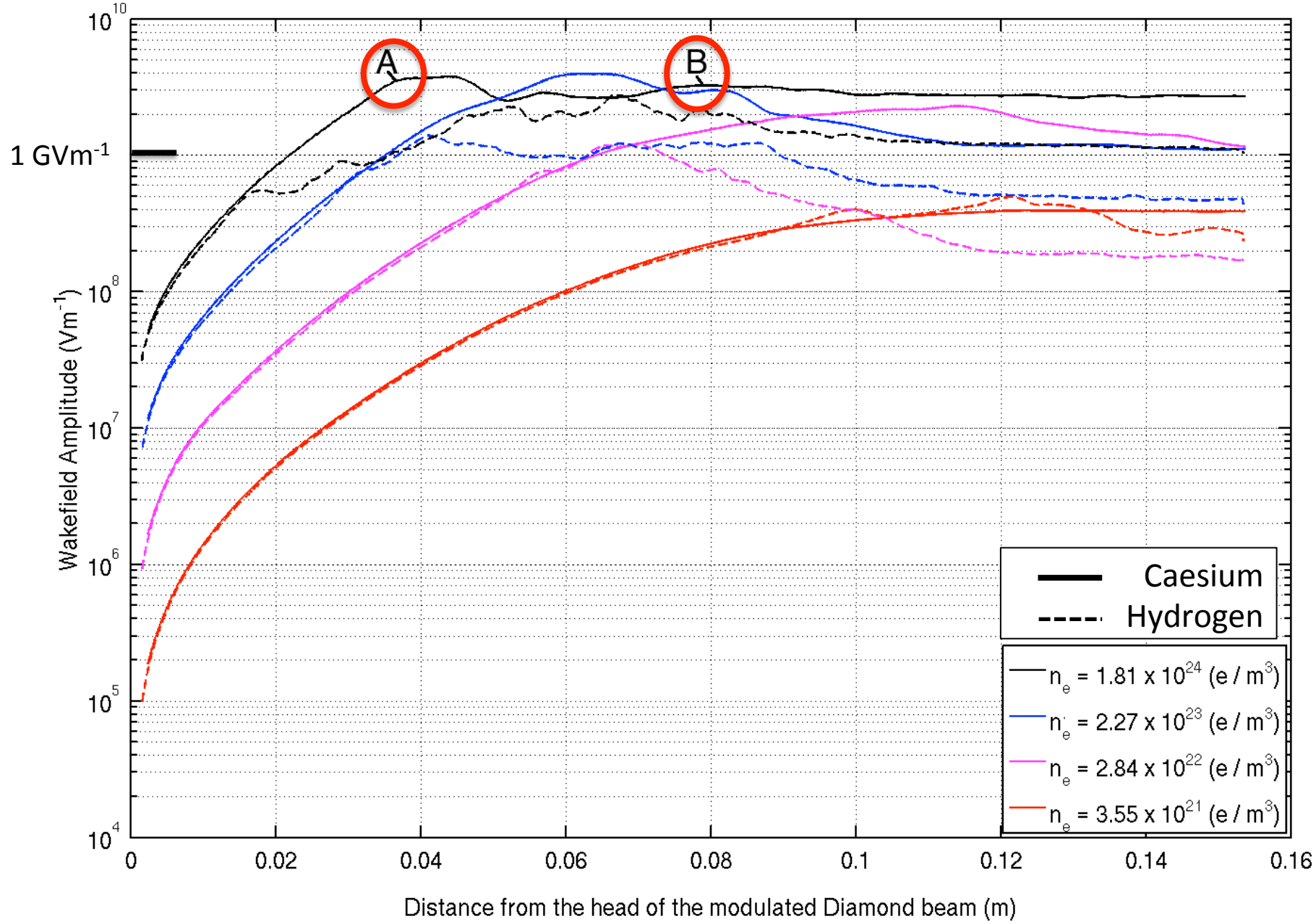


Pictures by Michael Bloom, Imperial College.

The ‘Drift Space’ Design

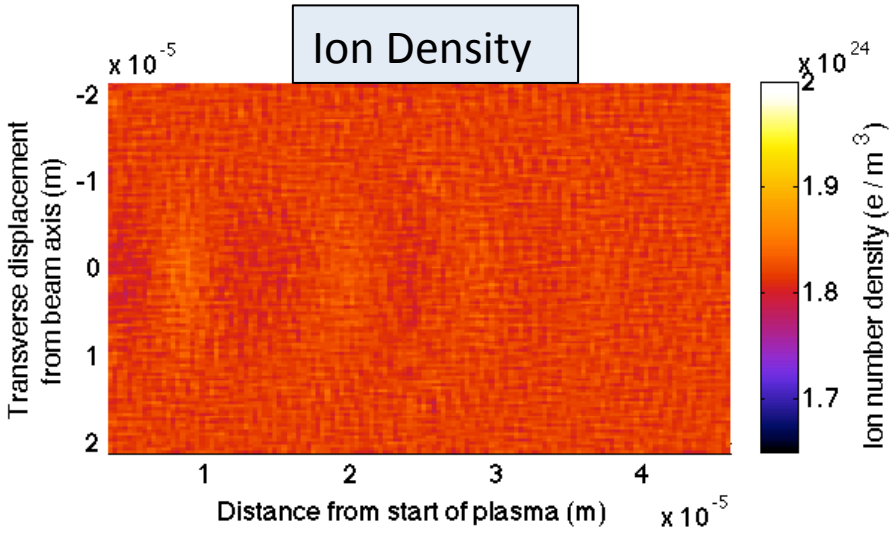


Wakefield Driven by Micro-bunched Beam

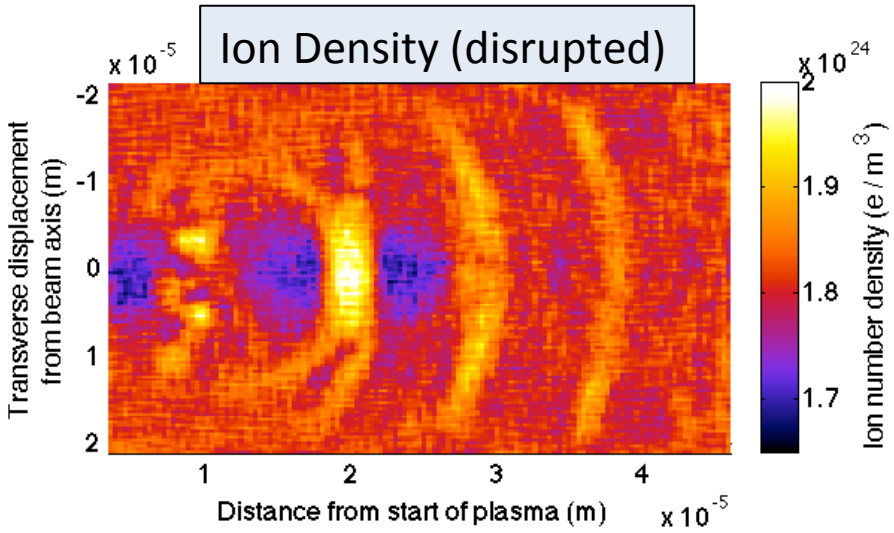


Ion Motion

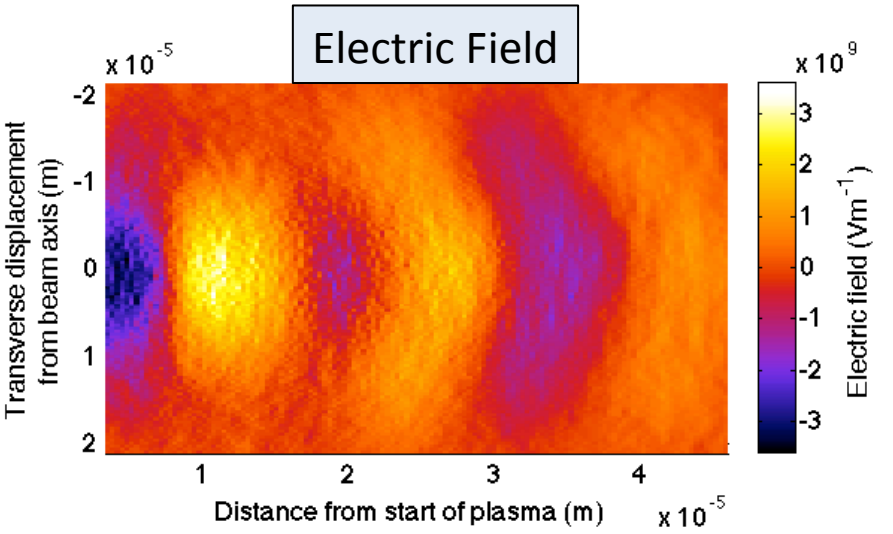
A



B



A



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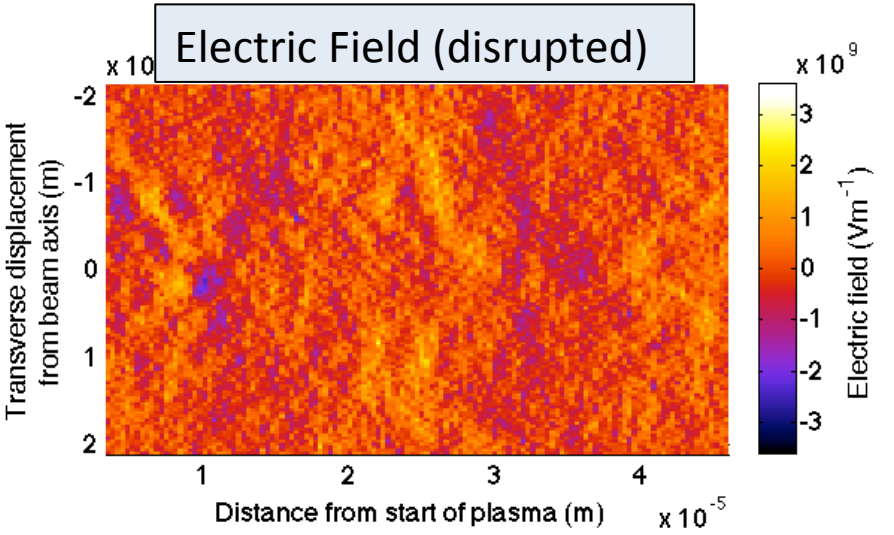
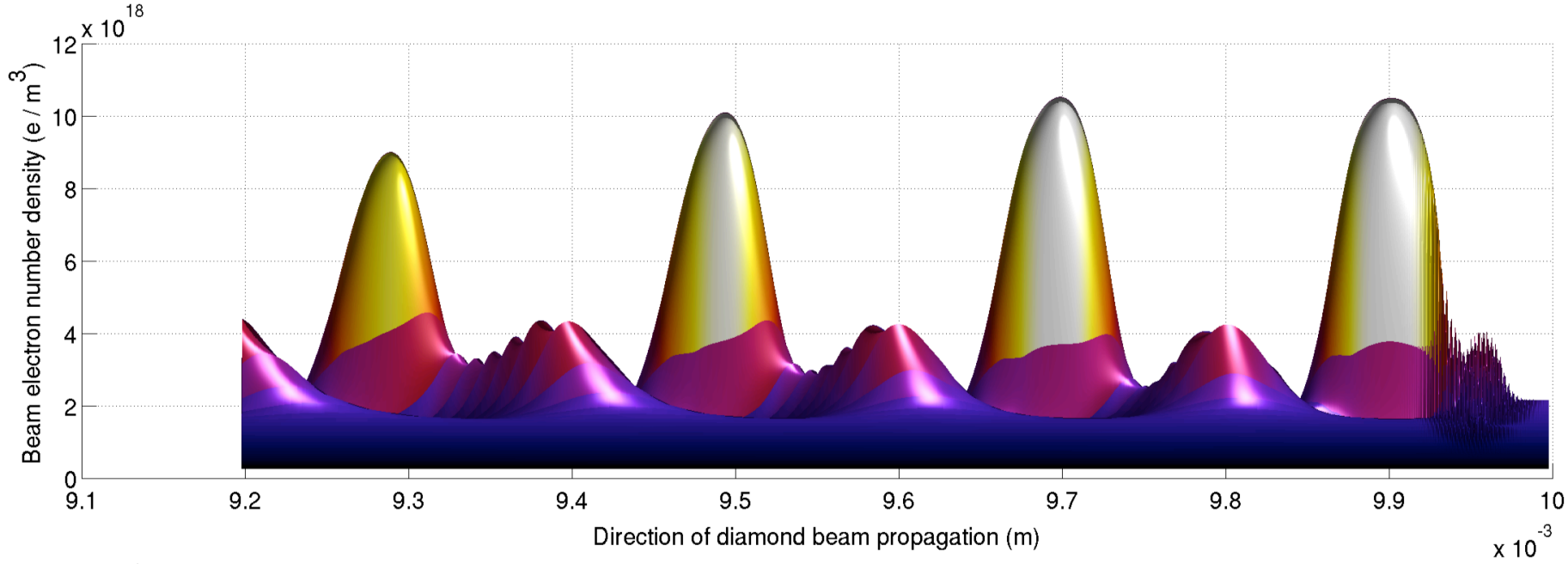
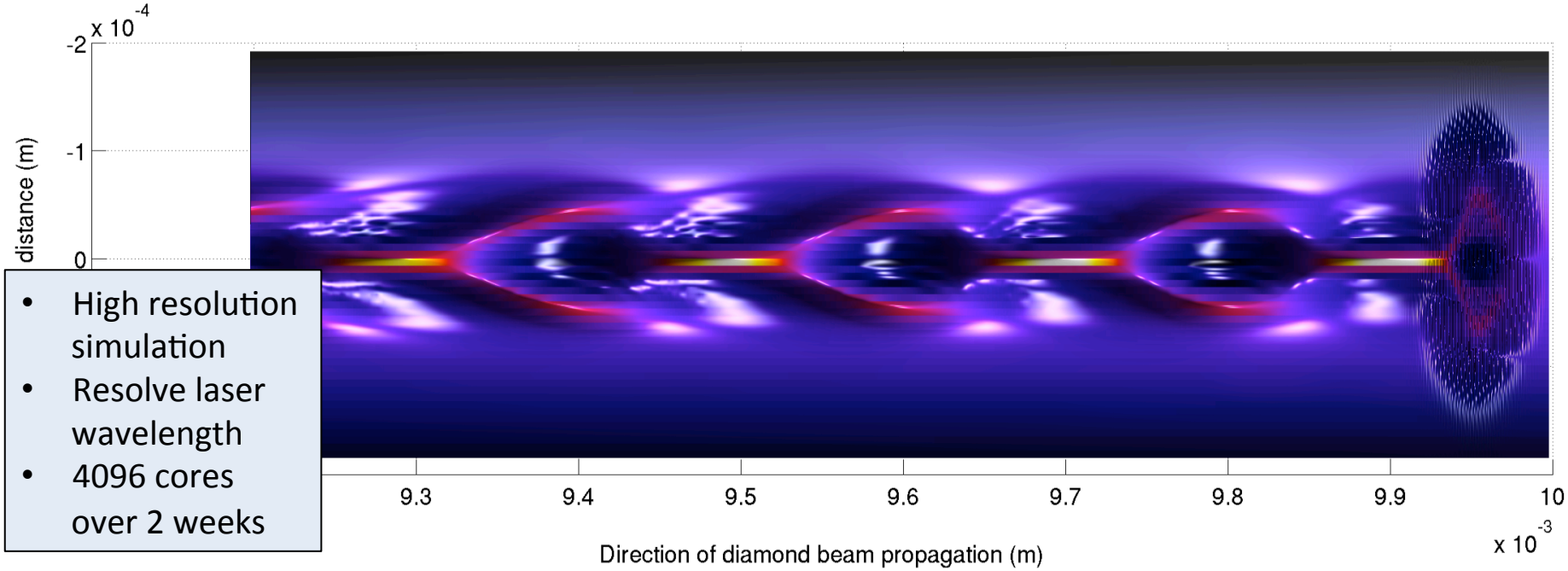


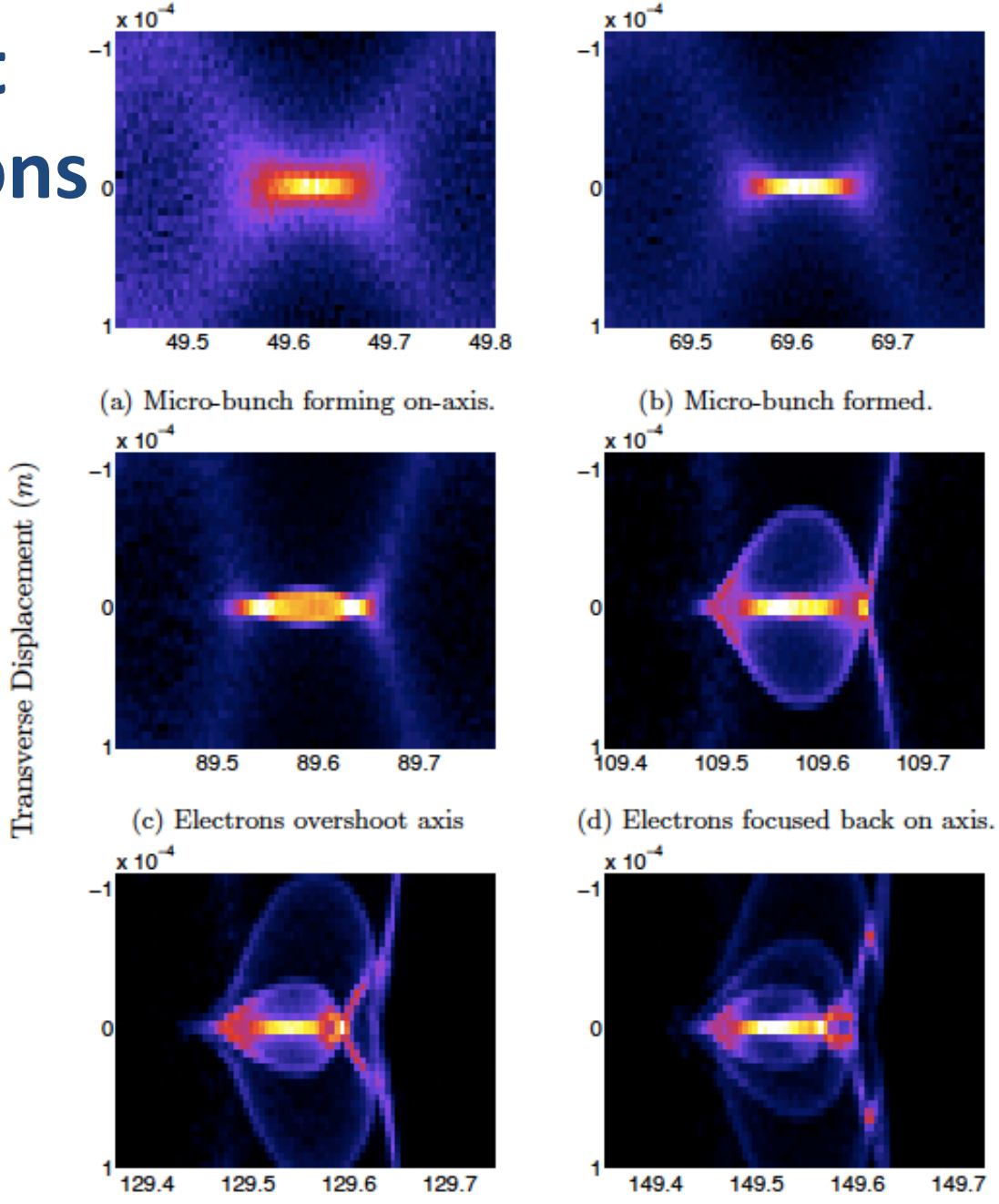
The Micro-Bunched Diamond Beam





- High resolution simulation
- Resolve laser wavelength
- 4096 cores over 2 weeks

Coherent Oscillations



(a) Micro-bunch forming on-axis.

(b) Micro-bunch formed.

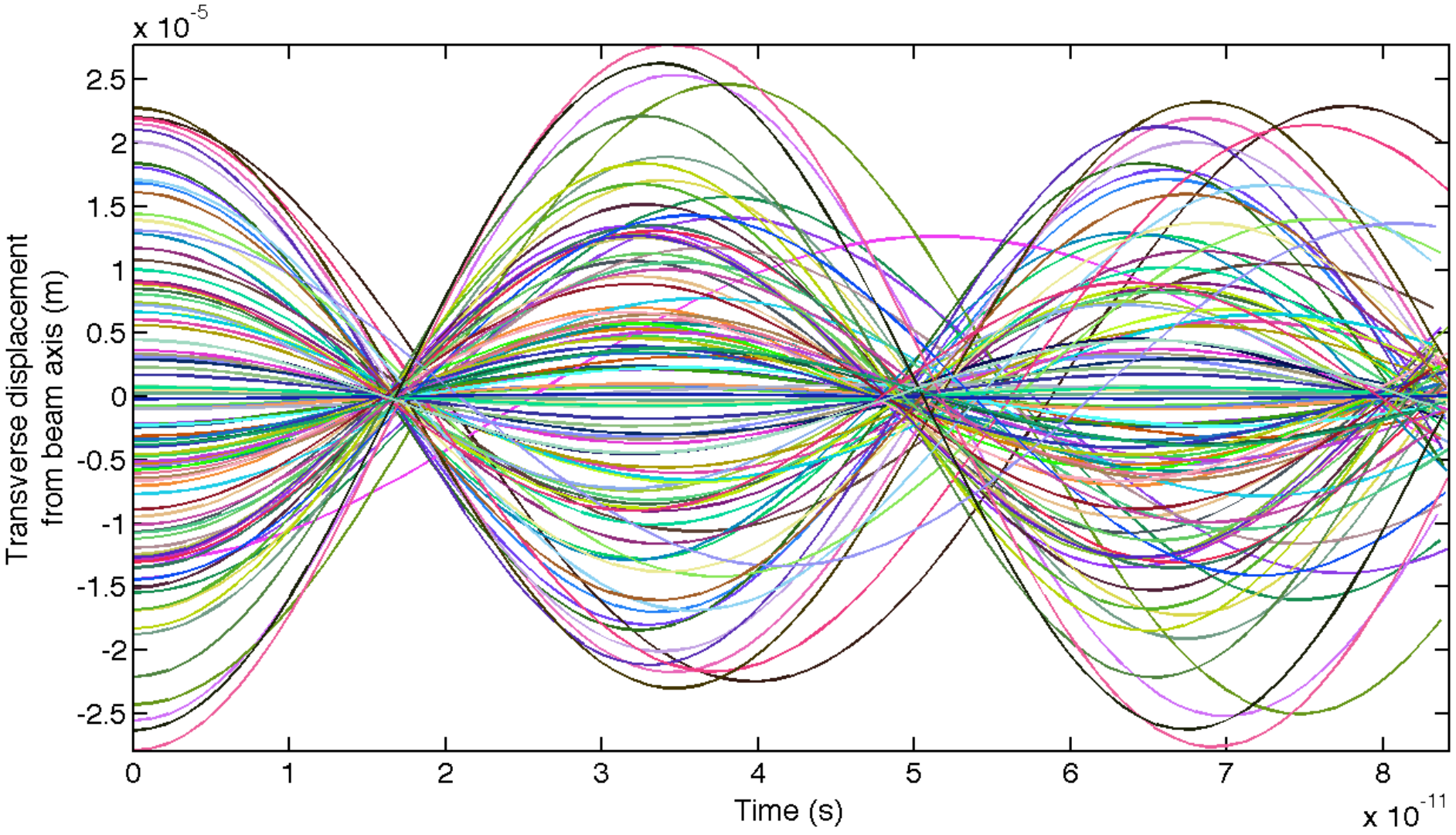
(c) Electrons overshoot axis

(d) Electrons focused back on axis.

(e) Second undulation.

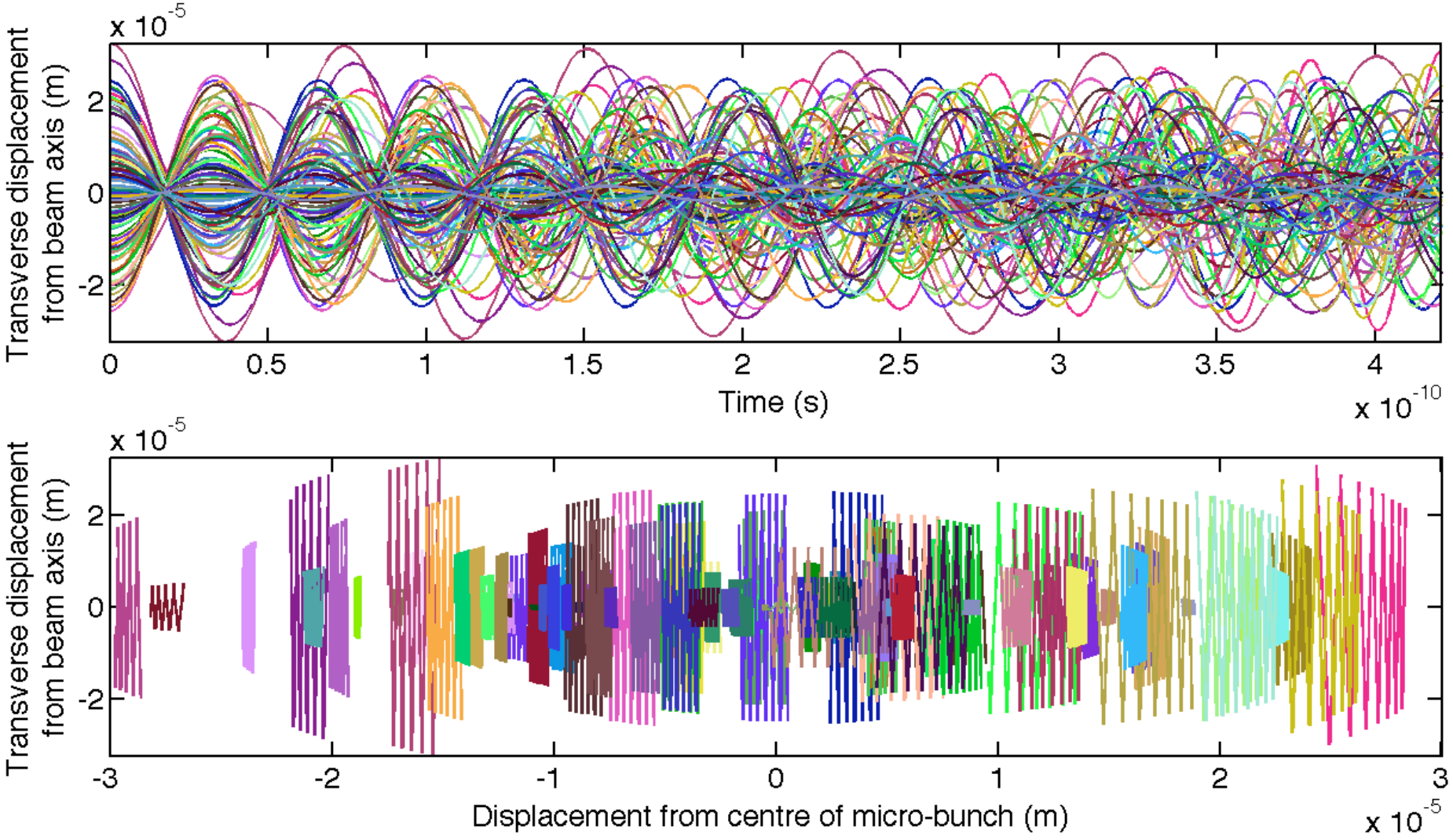
(f) Third undulation.

Coherent Oscillations



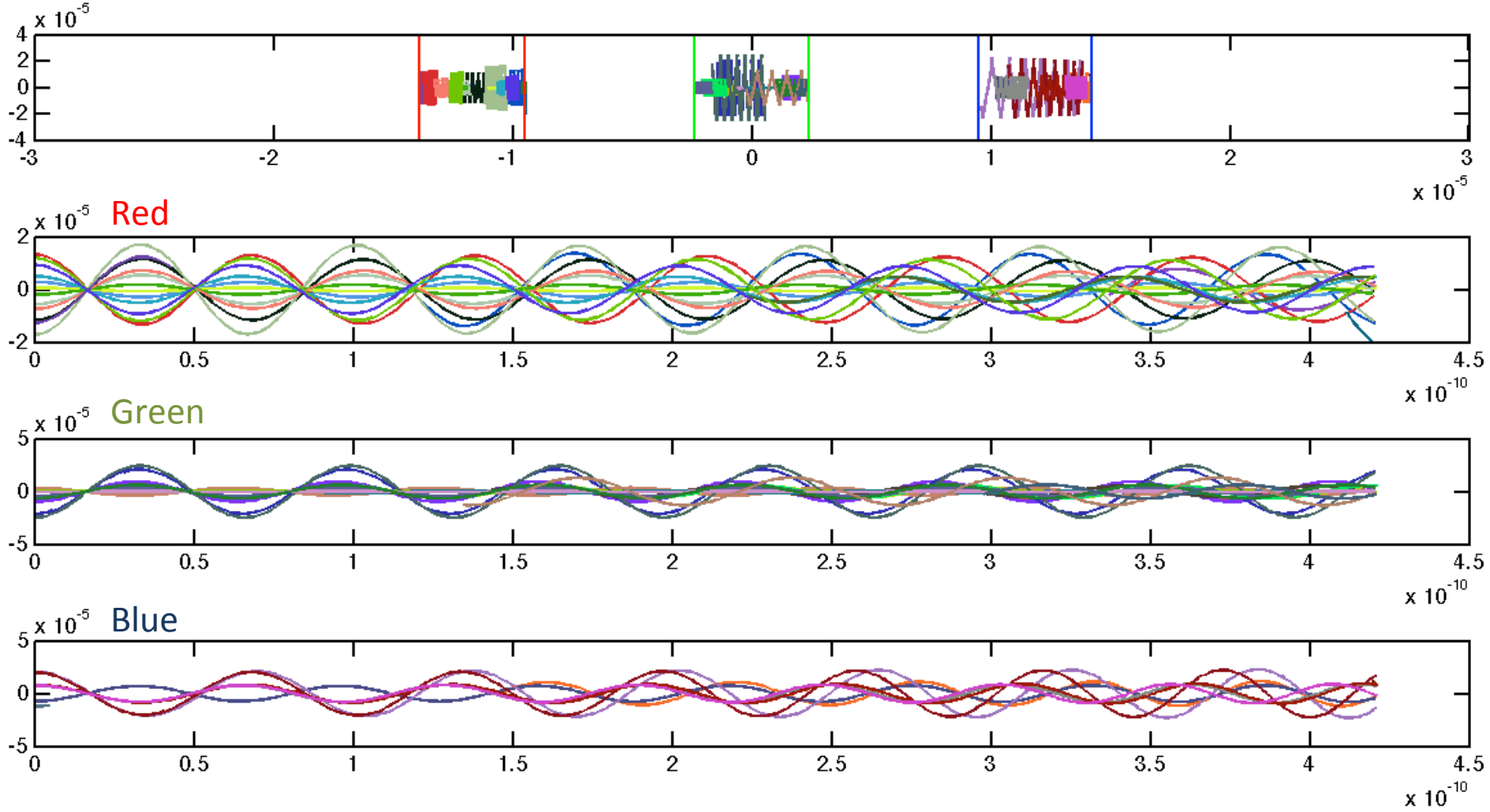
2.5 cm plasma stage

Incoherent Oscillations

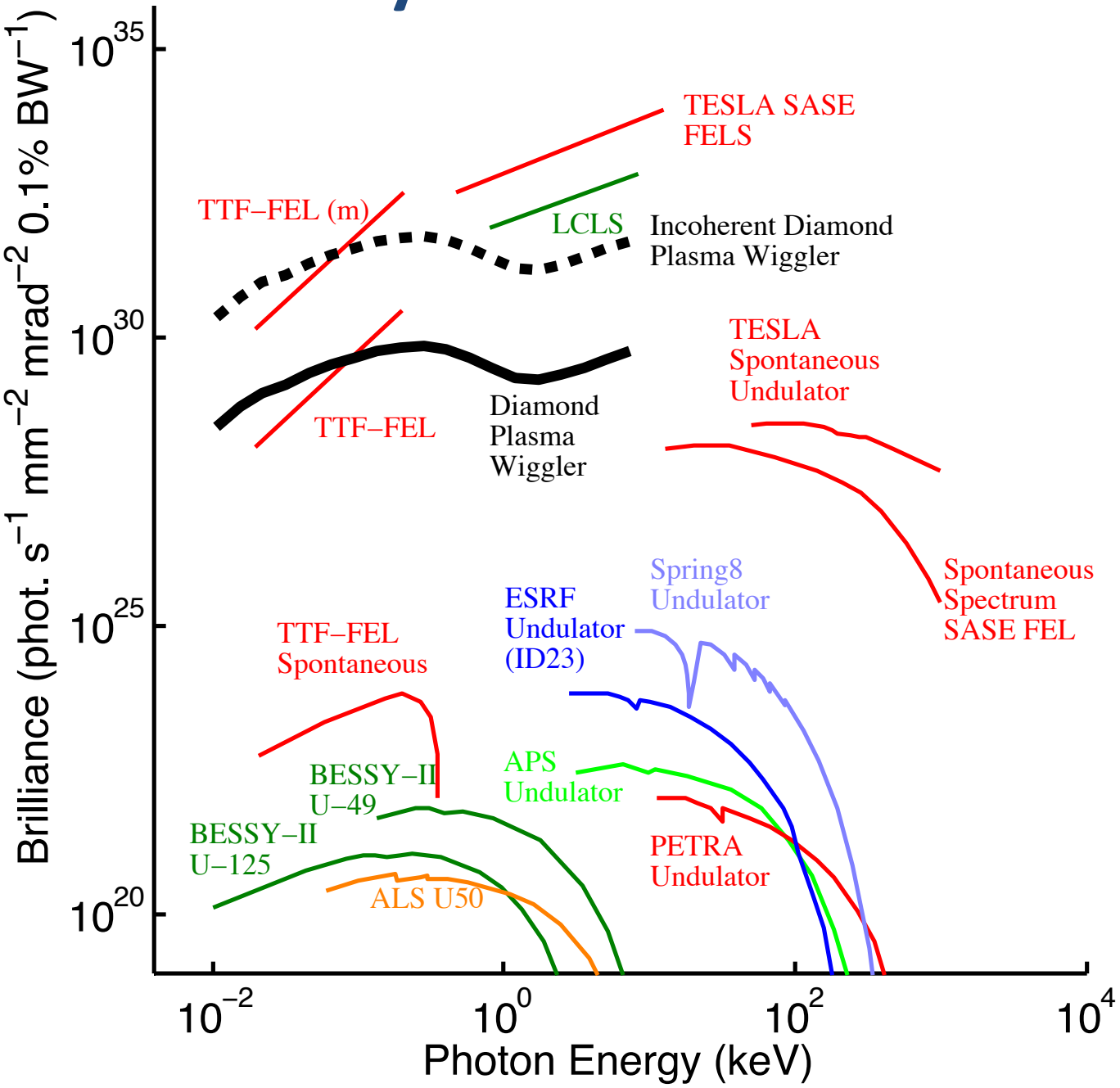


12.75 cm plasma stage

Oscillations in a Narrow Region



Plasma as an X-ray Source



Physics around two thirds of England

Work at Oxford

Current

- Submitted ERC funding application to fund the Diamond experiment
- Further developing photon acceleration as a plasma diagnostic
- Upcoming 12 week experimental slot at Astra
- Co-ordinating PIC and HPC knowledge across JAI (via pooling knowledge into online wiki)

Future

- Machine learning as a tool for parameter optimisation for PWA experiments
- Co-ordinate with EPOCH developers to develop physics packages relevant to PWA
- Study in ion motion and mitigating it's disruptive effects on PWA

Outreach: I'm a Scientist Get me Out of Here

- Event takes place over a couple of weeks
- Students submit questions for 5 scientists via a website
- Students have live chat sessions with 5 scientists via internet
- Students vote off one scientist at a time until one remains
- Last scientist gets £500 to spend on further outreach programs
- I spent it on mini-experiments for hands on teaching

I'm a Scientist Get me out of here

"Wow well that was really good fun! I'm back to my normal work and feel somehow that I'm m
paced chat rooms and quirky questions. I really enjoyed taking part, getting to know the studer
bit along the way." – Jimmy Holloway, scientist

"goodbye fellow beings, I will miss you greatly, please have a wondrful life" – connorhiggins, st

"THANKS JAMES YOUVE INSPIRED ME AND OPENED MY EYES TO THE WORLD AROUND ME, TH
chloloz123, student

"I'm a scientist is brilliant - when we did it last year the children loved it and TWO of the scientis

Outreach

- Led to visiting Westfields Primary school on two occasions
- Took part in Diamond open day
- Taking part in upcoming Laser Road Show event for the international ‘year of light’
- Upcoming visit to primary school in Clapham

INTERNATIONAL YEAR OF LIGHT 2015

Tom Holloway (fantastic teacher!)

Diamond Light Source open day

Extra Curricular Activities

- When the PDPWA collaboration wanted to develop a brand they invited suggestions for the logo
- Mine was accepted
- My acronym ‘Propel’ however lost out to the one ‘Awake’
- Having identified me as having a design eye I was then charged with building and maintaining the website (!)
- www.cern.ch/awake

AWAKE

Designed the logo and built the webpage