Micro-bunching Conventional Particle Beams To Drive Plasma Wakefield Acceleration

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Synchrotron Facilities Worldwide

Image Source: http://www.veqter.co.uk/residual-stress-measurement/synchrotron-diffraction

Synchrotron Facilities Europe

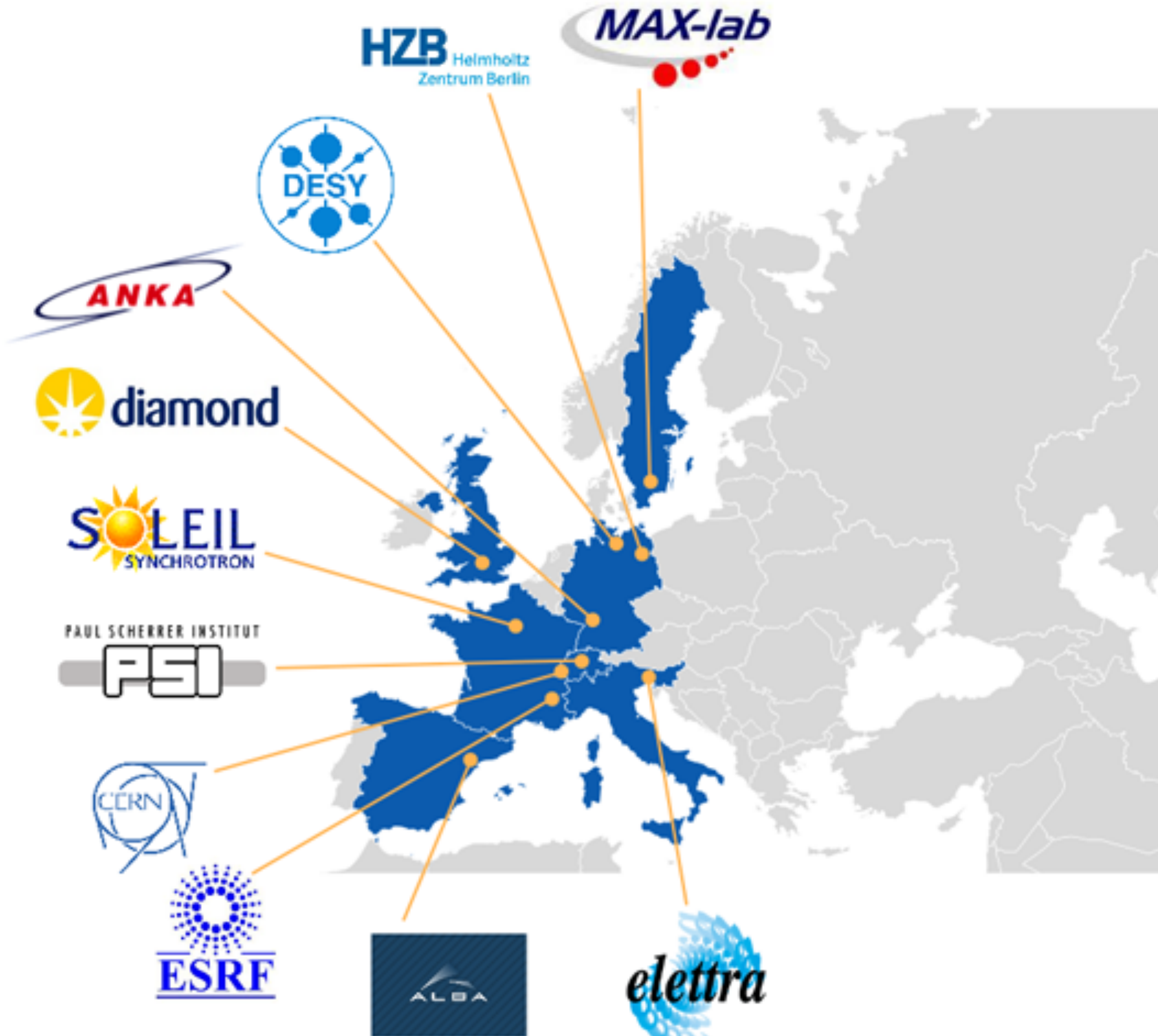


Image Source: http://www.veqter.co.uk/residual-stress-measurement/synchrotron-diffraction

Synchrotron Facilities Europe

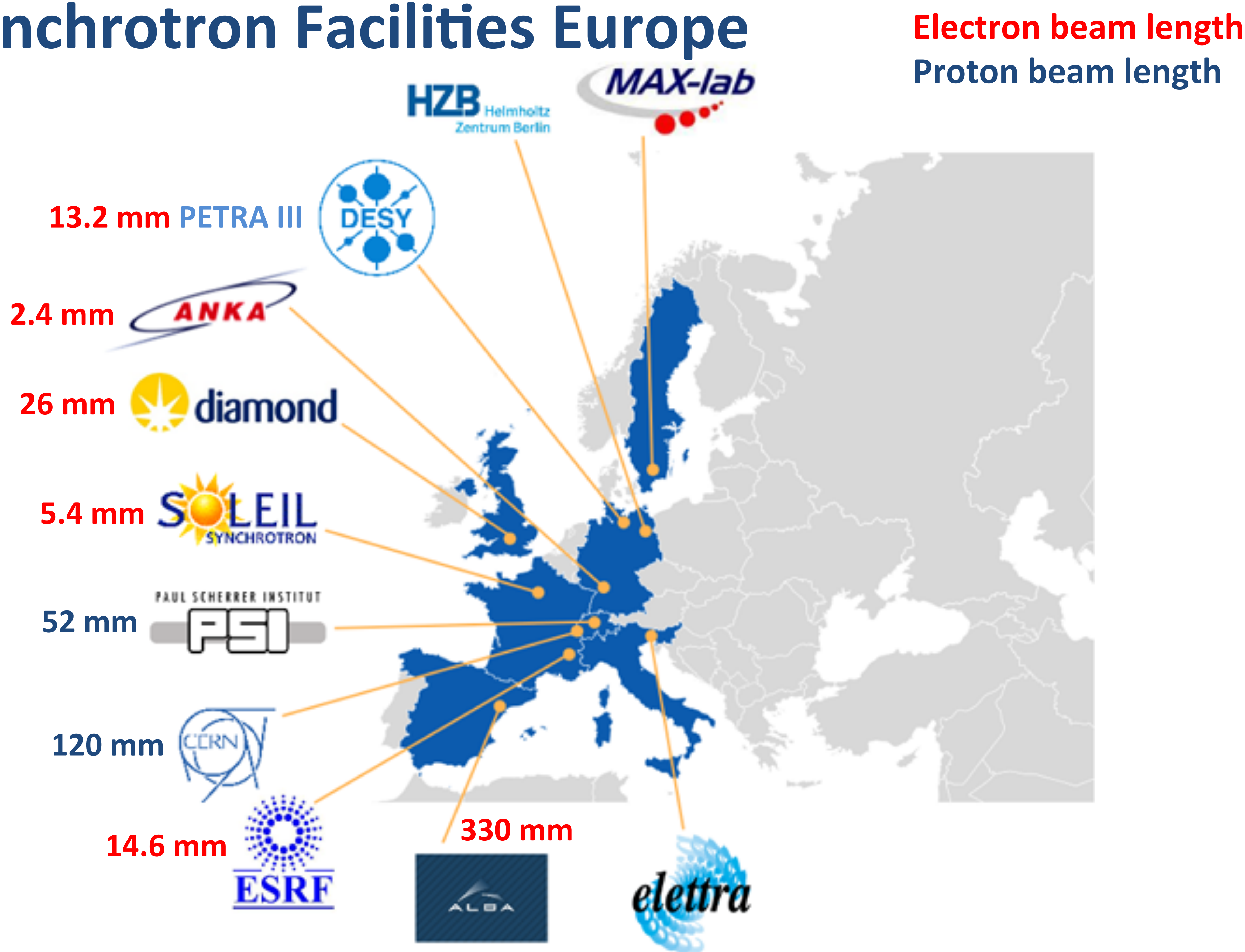


Image Source: http://www.veqter.co.uk/residual-stress-measurement/synchrotron-diffraction

The Goal

- Use existing facilities' beams to drive PWA
- Accelerate higher energy beams from PWA
- Generate harder X-rays from 3rd generation light sources

The Problem

- These beams are too long to drive effective wakefields
- Existing beam lines have limited space
- Longitudinal compression via magnetic chicanes takes considerable space and expense

$\sigma_{ideal} = \lambda_p / (\pi\sqrt{2})$

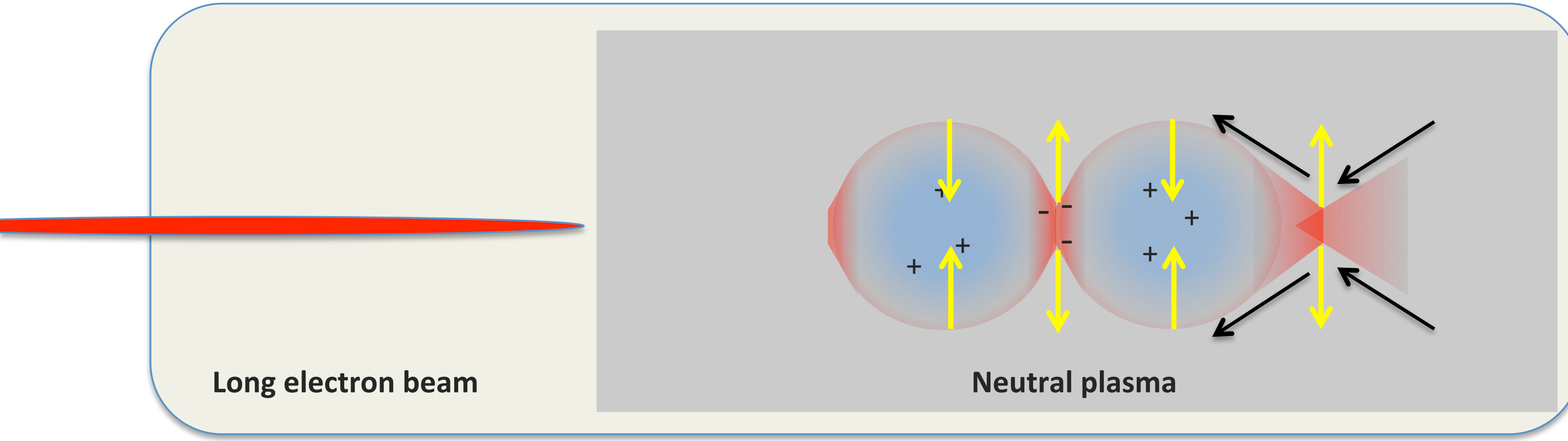
Need beam lengths of:

$\sigma_z < 1$ mm

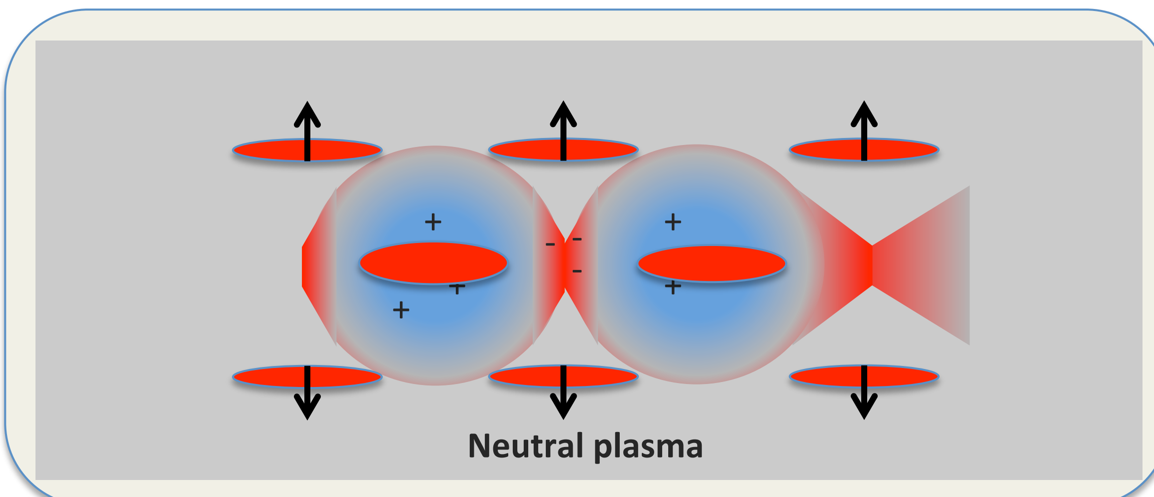
The Solution

- Micro-bunch beams to make them an effective wakefield driver

Micro-Bunching Via Self Modulation



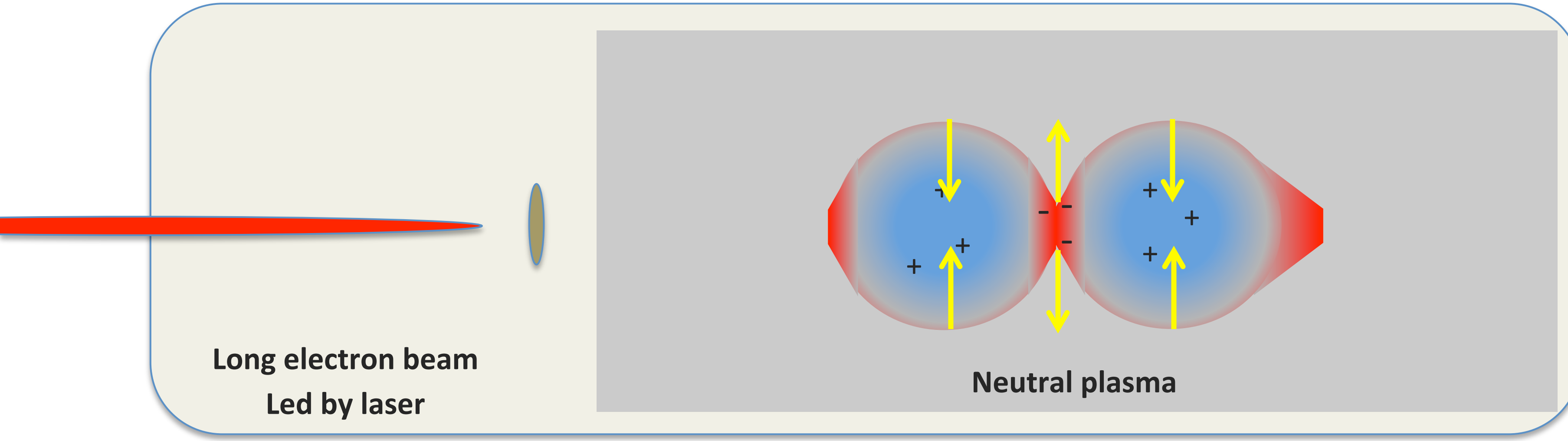
- Seed instability
- Wakefield modulates beam
- Beam drives harder wakefield
- Feedback mechanism
- Takes time for instability to saturate



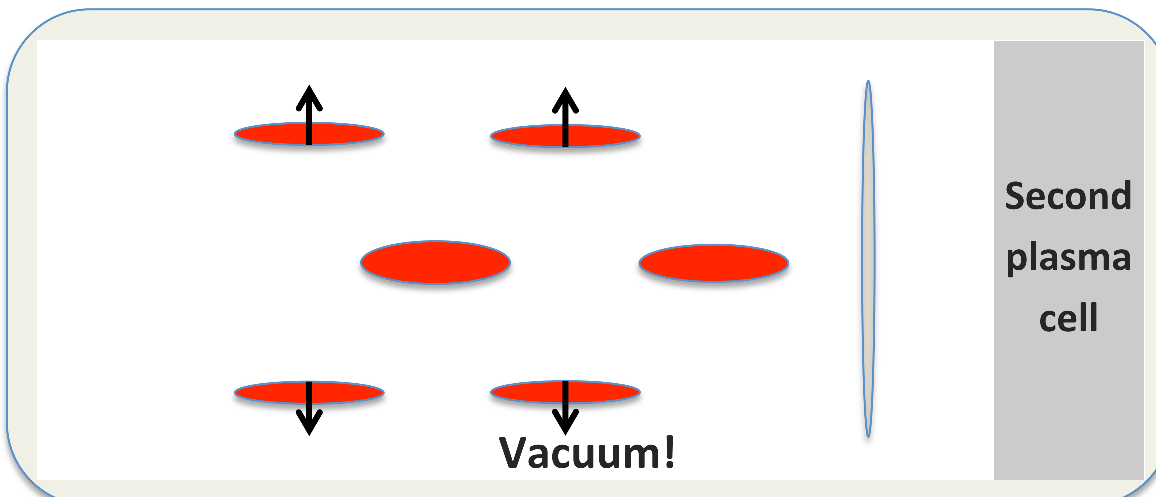
Micro-bunched beam.

This is not the scheme I use

Micro-Bunching Via Wakefield Kick and Drift Space

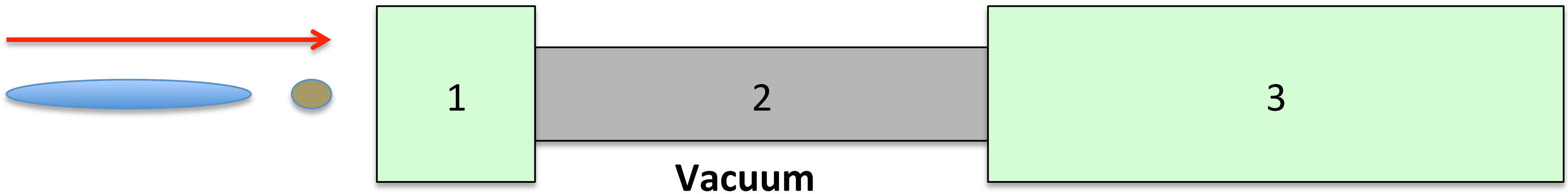


- Strong transverse kick from laser wakefield
- **Propagate beam through vacuum**
- Pass micro-bunches into second plasma stage when on-axis number density maximised



Micro-bunched driver beam.

The 'Drift Space' Design



Vacuum (48.5 mm)

First Plasma Cell (3.5 mm)

Second Plasma Cell (> 100 mm)

1) The long beam given transverse momentum by strong wakefield.

2) Micro-bunches form as half e- defocused, other half focused

3) At the moment the beam has achieved best micro-bunching*, pass into the second plasma cell.

Electron beam

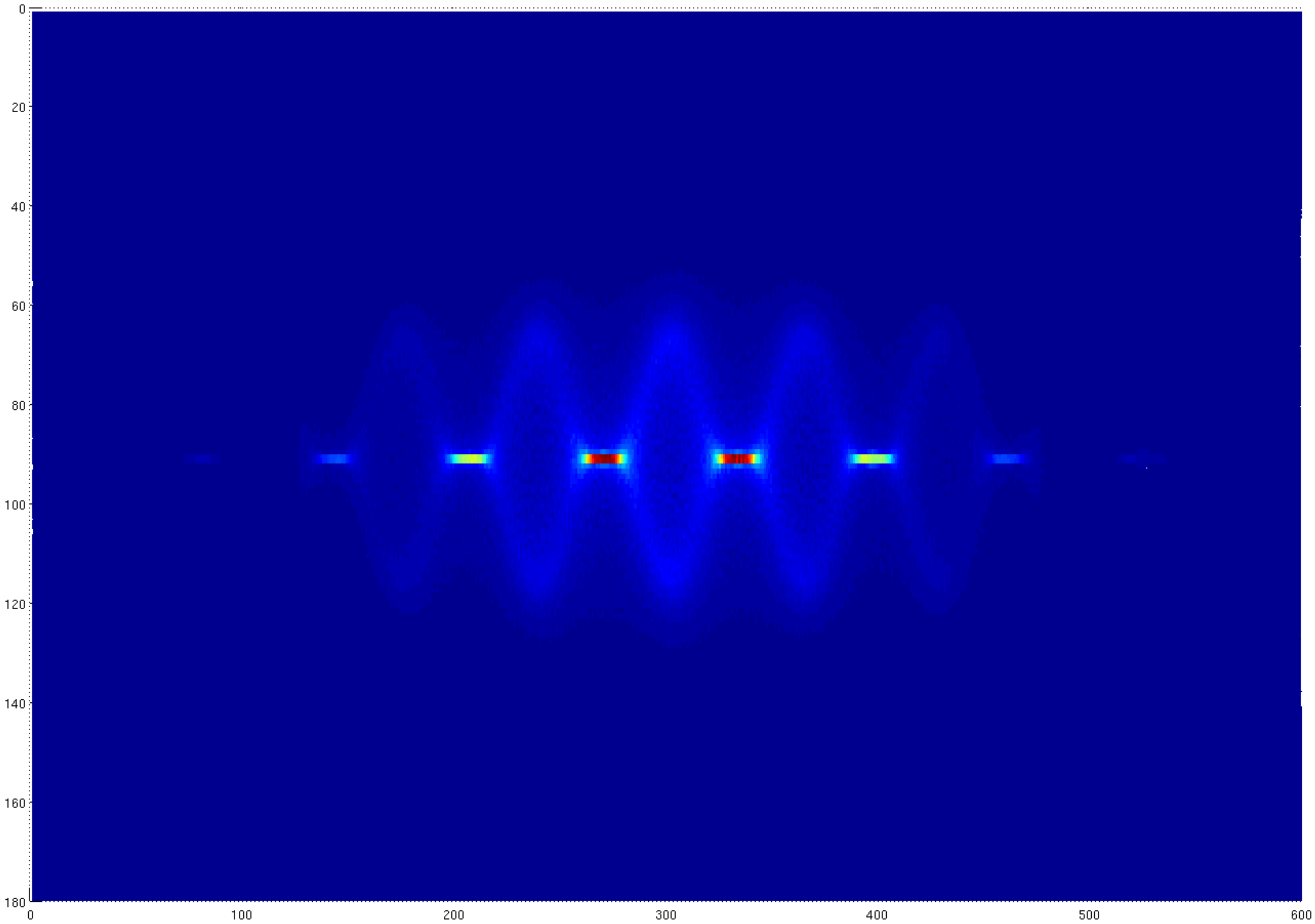
- $E = 300$ MeV
- $\varepsilon_p = 0$
- $\sigma_z = 0.6$ cm
- $\sigma_r = \sqrt{2} / k_p$
- $Q = 0.1$ nC
- $E_r = 1\ \mathrm{GVm}^{-1}$

The Plasma

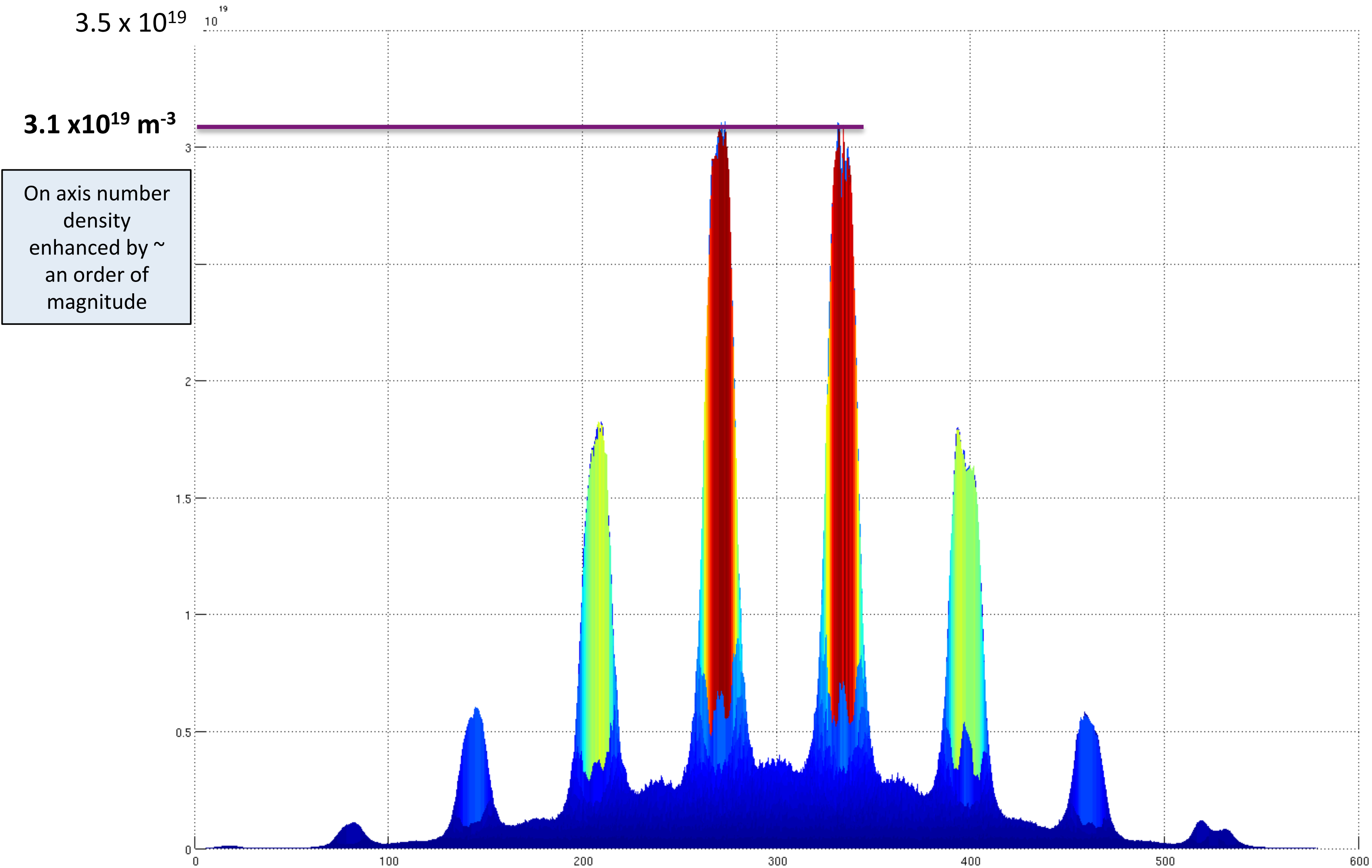
- $n_e = 1.11\mathrm{e}22\ \mathrm{m}^{-3}$
- $\lambda_p = 300$ um

- First plasma cell analogous to lens
- Longer first cell results in a stronger focus and shorter vacuum needed
- However strong focus results in higher emittance micro-bunches

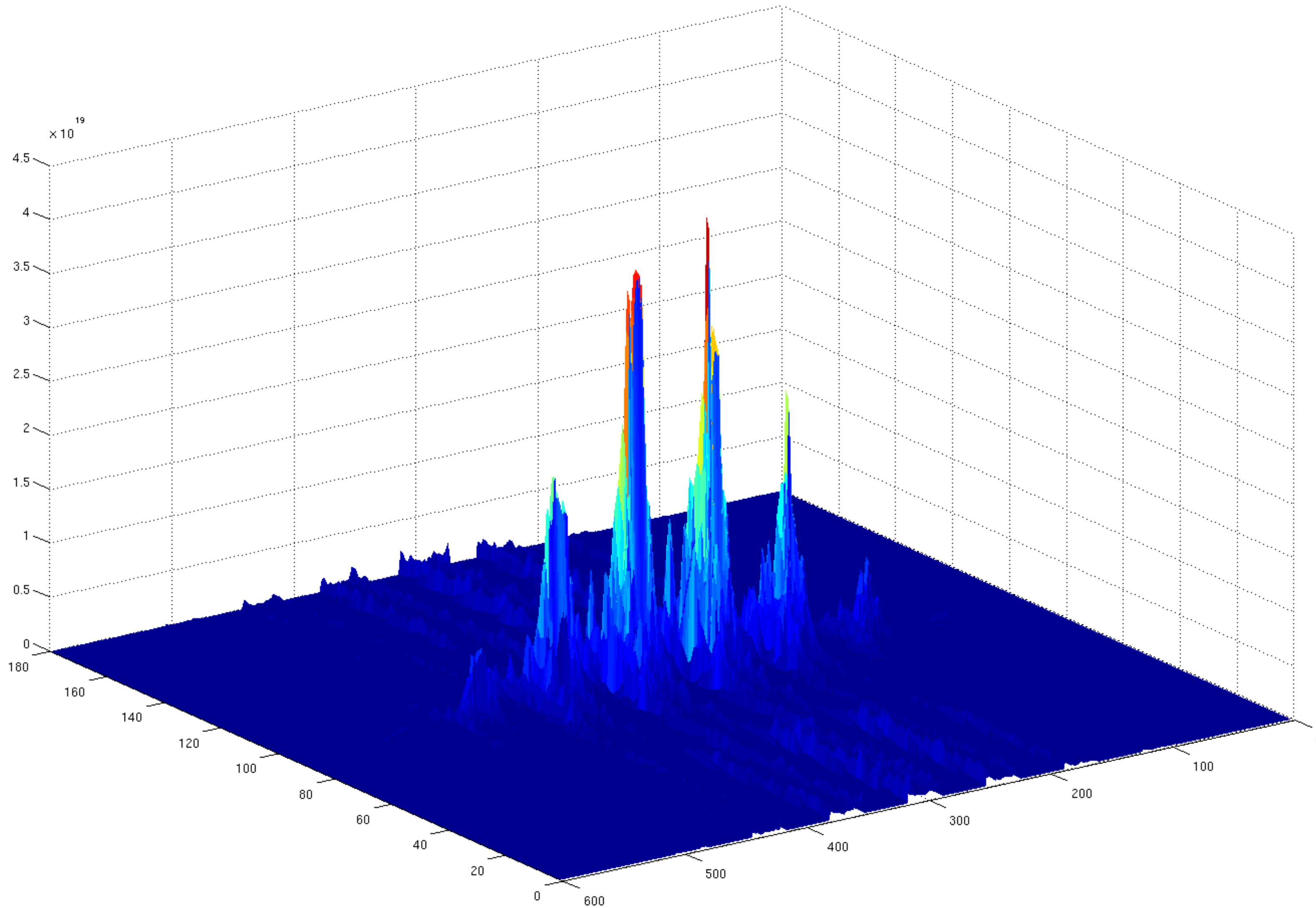
Beam number density. 51 mm of propagation



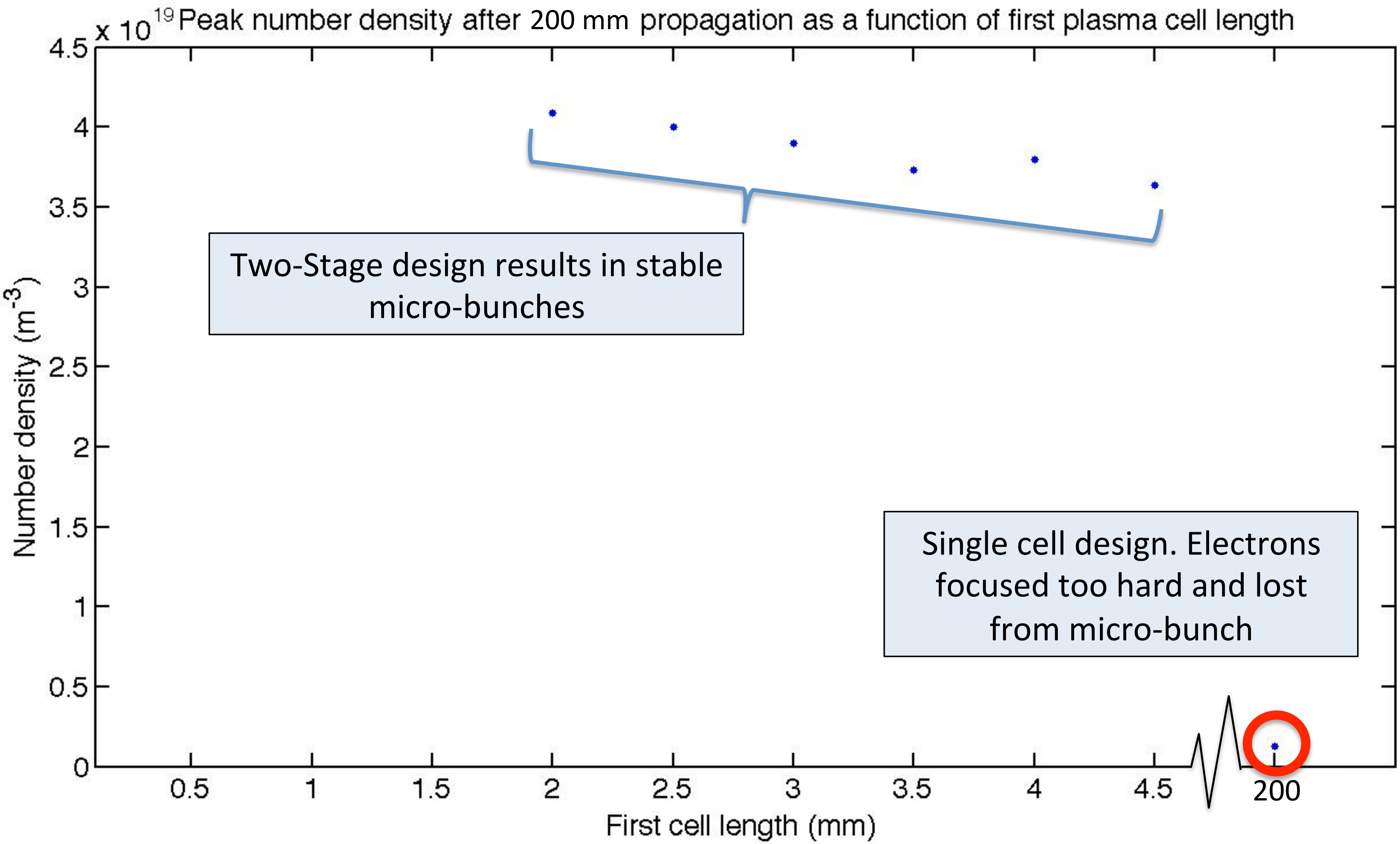
Beam number density. 51 mm of propagation



Beam number density. 200 mm of propagation



Effects of First Cell length



The Diamond Light Source

The Diamond light source at RAL uses a 3 GeV electron beam to generate soft x-rays.

Beam length: σ_z = 26 mm

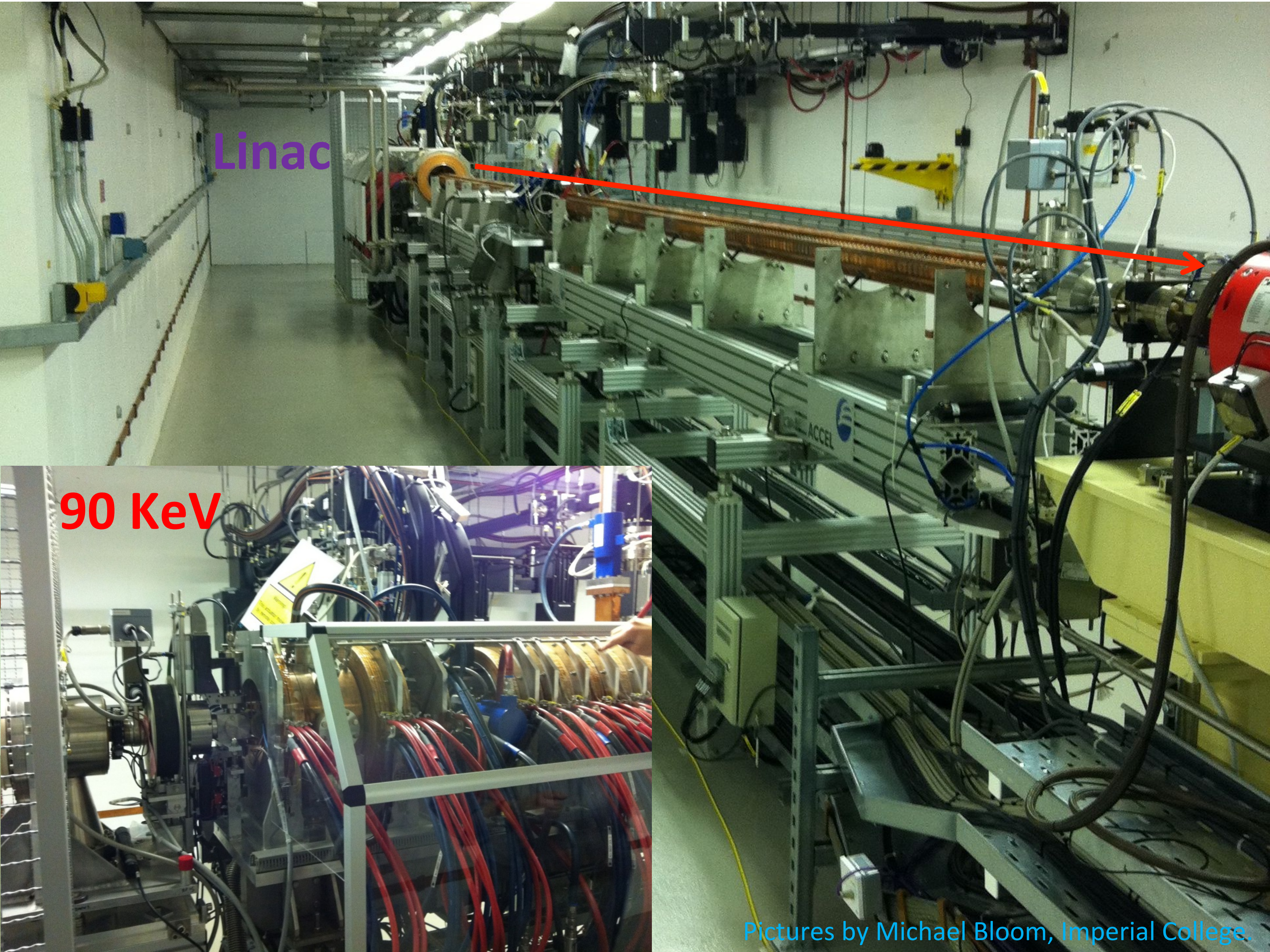
Too long to effectively drive a wakefield!
(λ_p ~ O(100um)).

A proof of principle experiment has been proposed
to micro-bunch the beam using a laser-driven wakefield. The beam can then drive a PWA to:

- Create a higher energy electron beam
- Create a poor mans FEL using betatron oscillations within the wake

Diamond Booster Beam

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

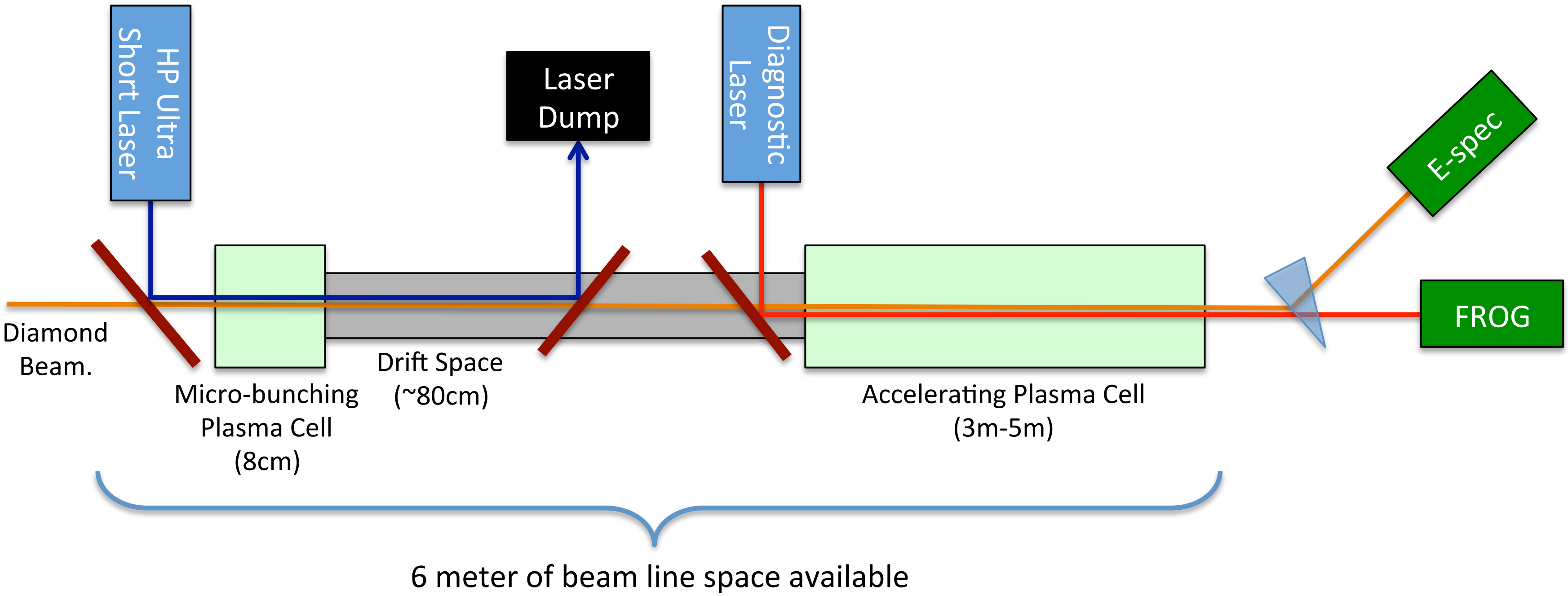

Linac
ACCEL
90 KeV
Pictures by Michael Bloom, Imperial College.


Booster
158m circumference
Pictures by Michael Bloom, Imperial College.

Pictures by Michael Bloom, Imperial College.


Storage Ring
Pictures by Michael Bloom, Imperial College.

Diamond Conceptual Layout



Diamond Beam Parameters

- E = 3 GeV
- ε_p = 140 nm mrad
- σ_E / E = 0.0007
- σ_z = 2.6 cm
- Q = 2 nC

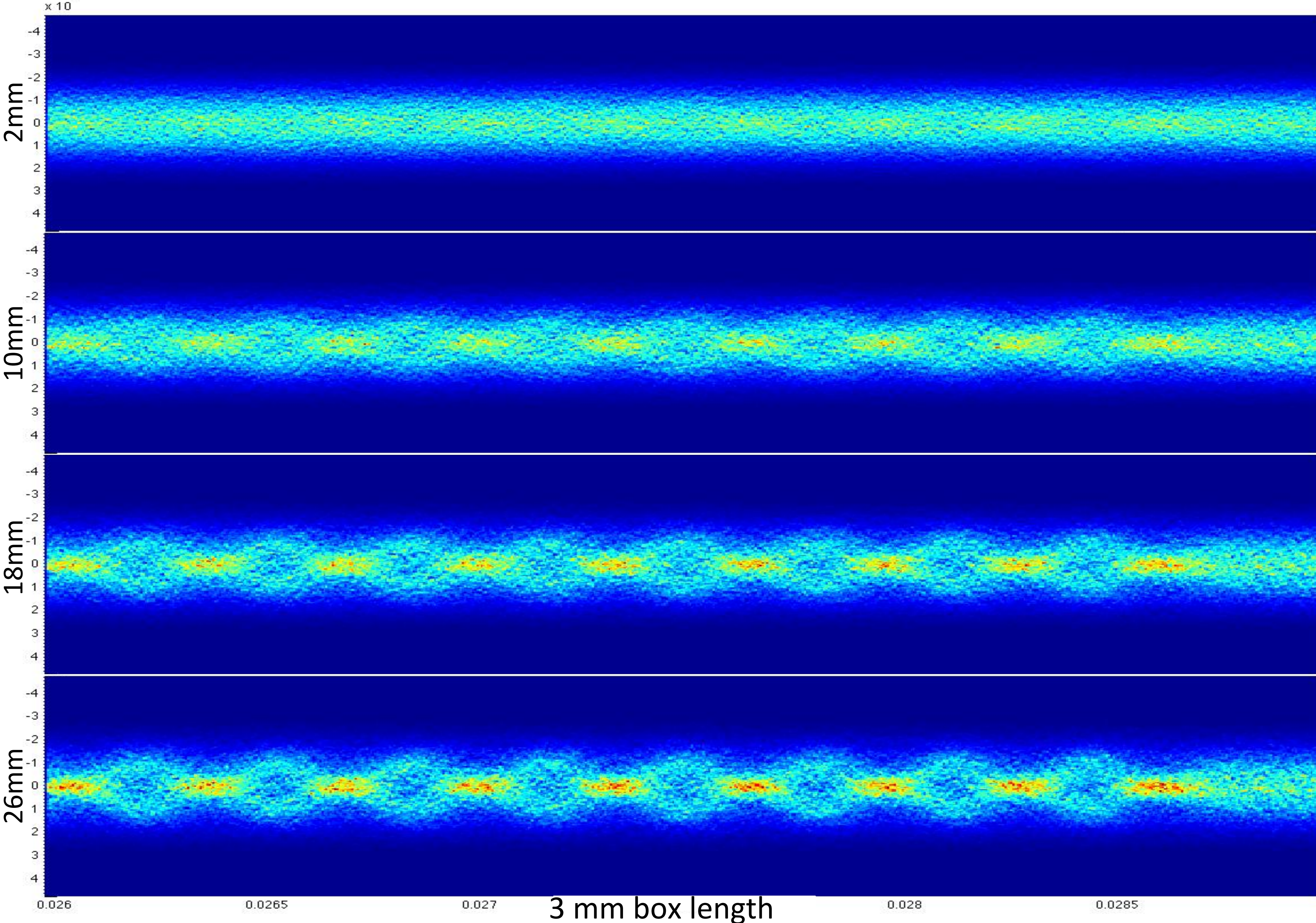
HP Ultra Short Laser

- λ = 1.06 um
- σ_r = 20 um
- E = 1 J
- I = 1e16 Wcm^{-2}
- τ = 50 fs

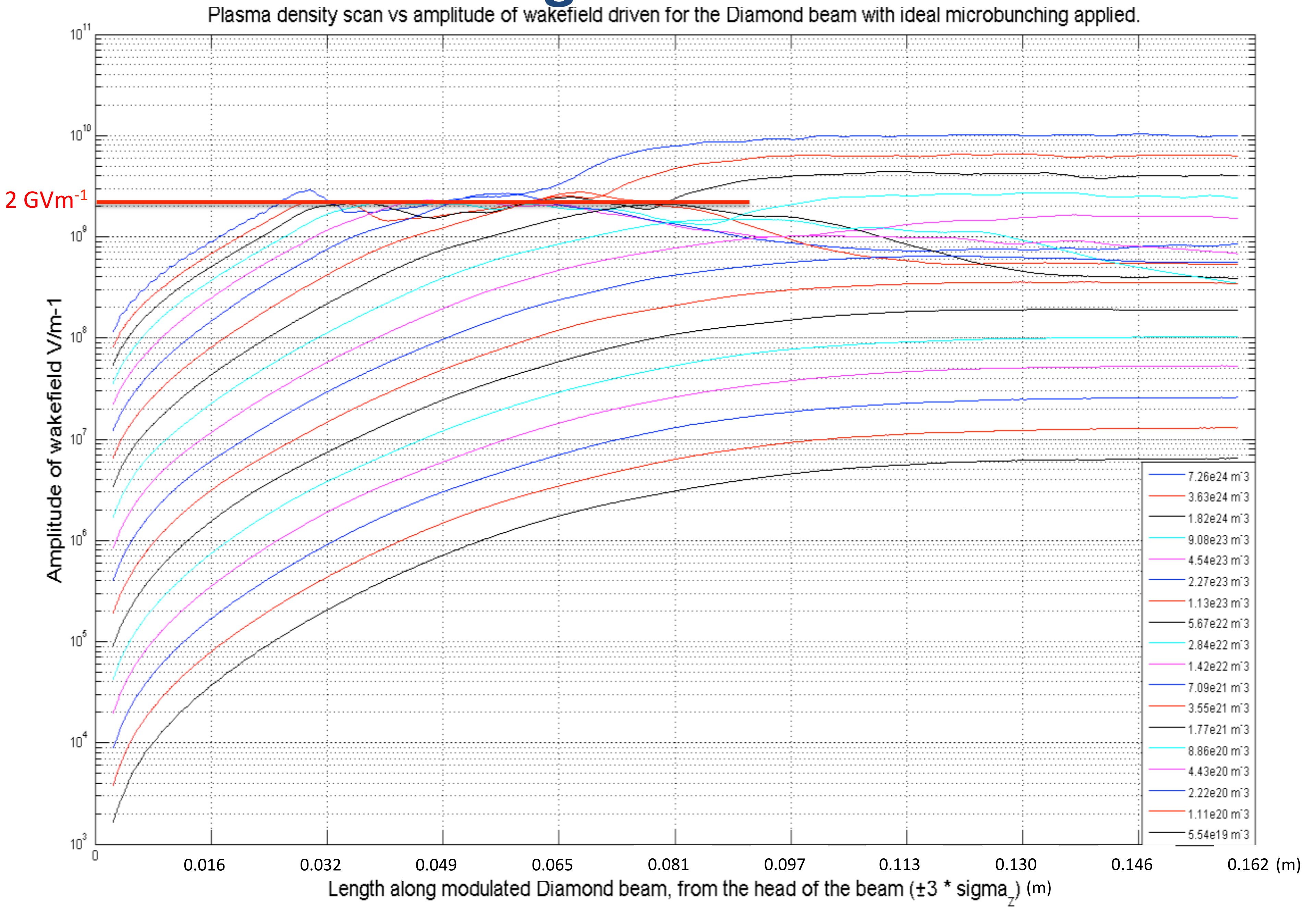
Plasma Parameters

- Ne = 1.11e23 cm^{-3}
- λ_p = 100 um
- Element = Xenon
- Cell = ~Discharge

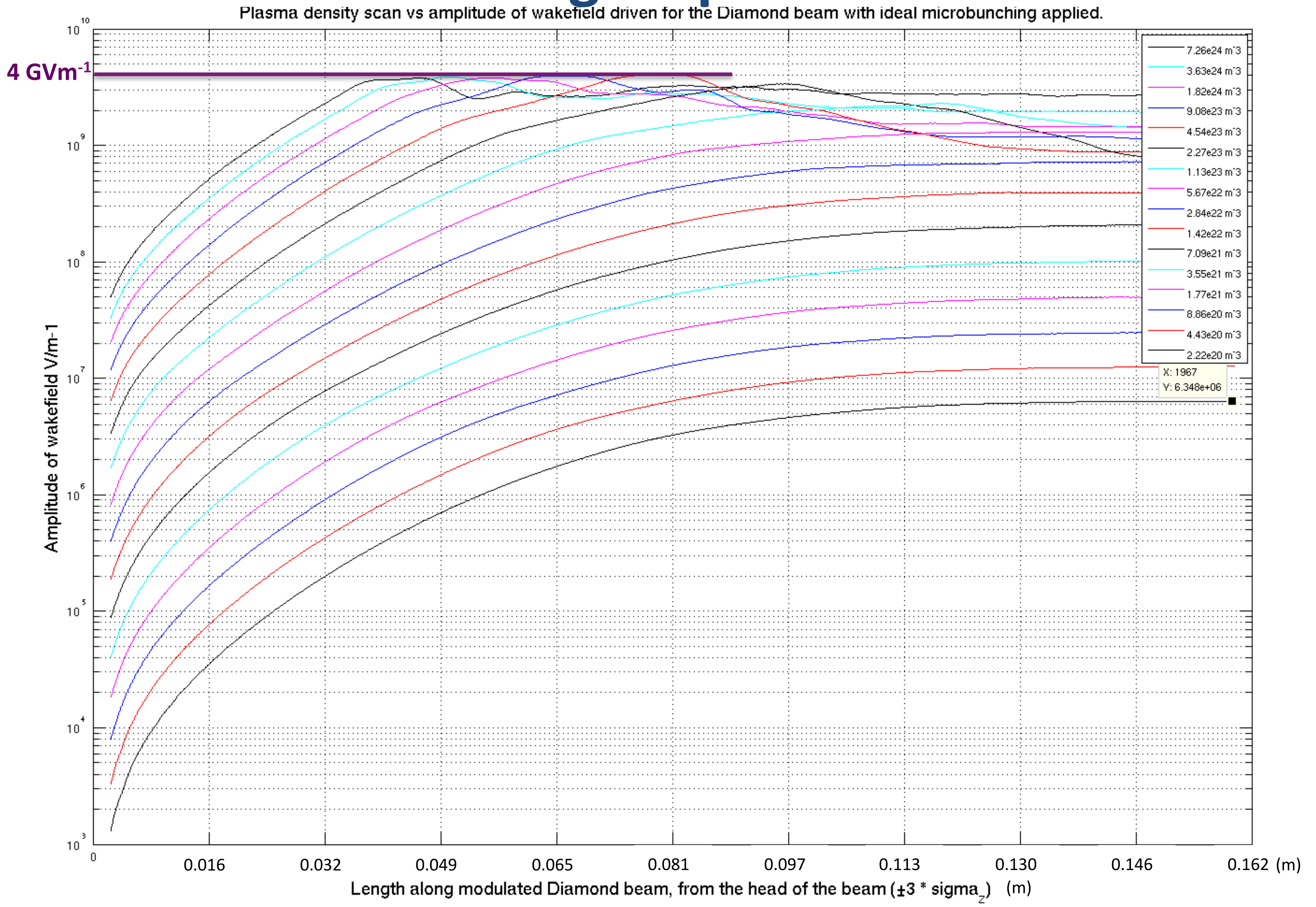
Diamond beam micro-bunched by 1 GVm^{-1} WF



The Catch With Long Beams: Ion Motion



Can alleviate with high Z plasmas



Acknowledgements

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Central Laser Facility, Rutherford Appleton Laboratory, UK

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Concluding

- Many existing particle beams out there
- Can treat these beams and make them suitable to drive PWA
- Two-stage Drift-space design achieves this over short distances
- PWA can generate higher energy electrons and in turn generate harder X-rays form existing infrastructure
- PWA can generate X-rays directly from betatron oscillations
- Ion motion is a problem!

Thank you for listening