Prospects for Plasma Wakefield Acceleration at the MAX IV Laboratory

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WALLENBERG ACADEMY FELLOWS

Lund Laser Centre

MAX IV

LUND UNIVERSITY

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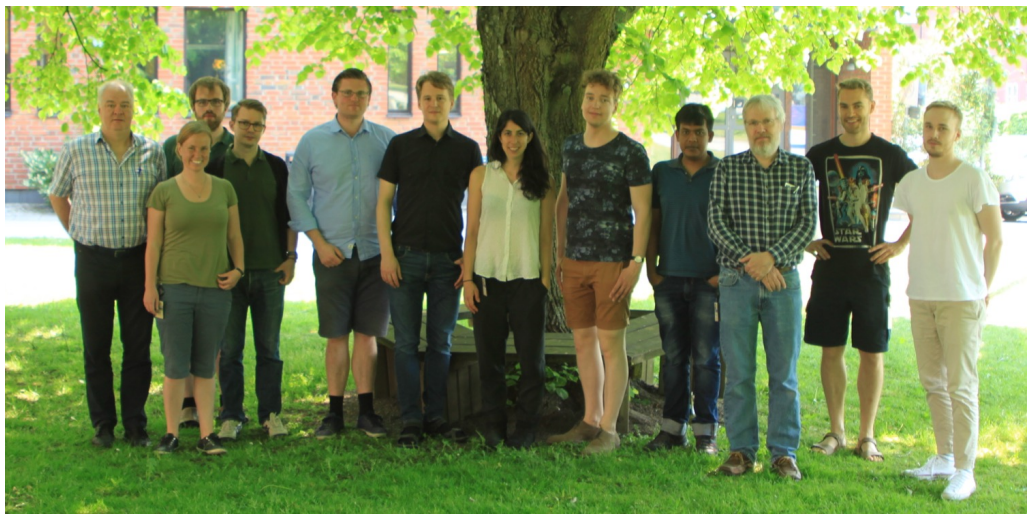

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Vetenskapsrådet

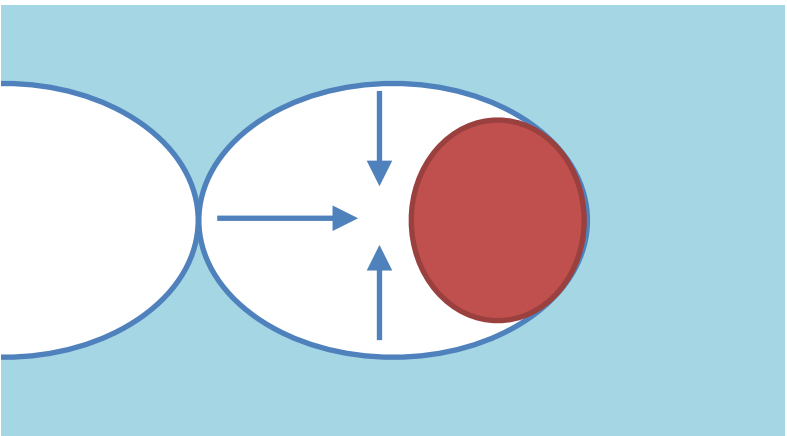
Swedish Foundation for Strategic Research

SNIC

ARIES

Laserlab Europe

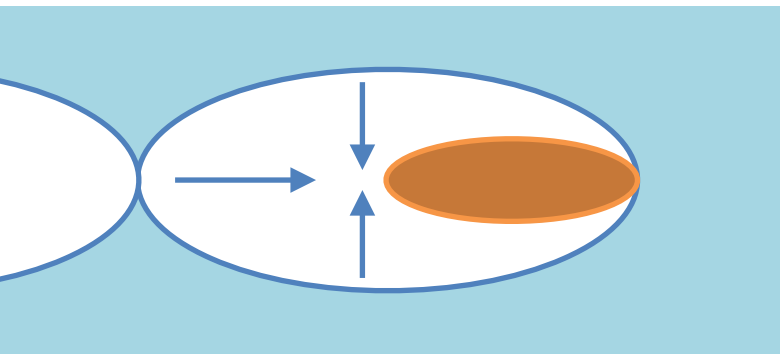
Particle acceleration in a plasma



LWFA

Wakefield driven by laser pulse

+ Lasers are compact and available
+ Internal injection schemes well developed
- External injection (synchronisation) difficult
- Dephasing limits energy in one stage



PWFA

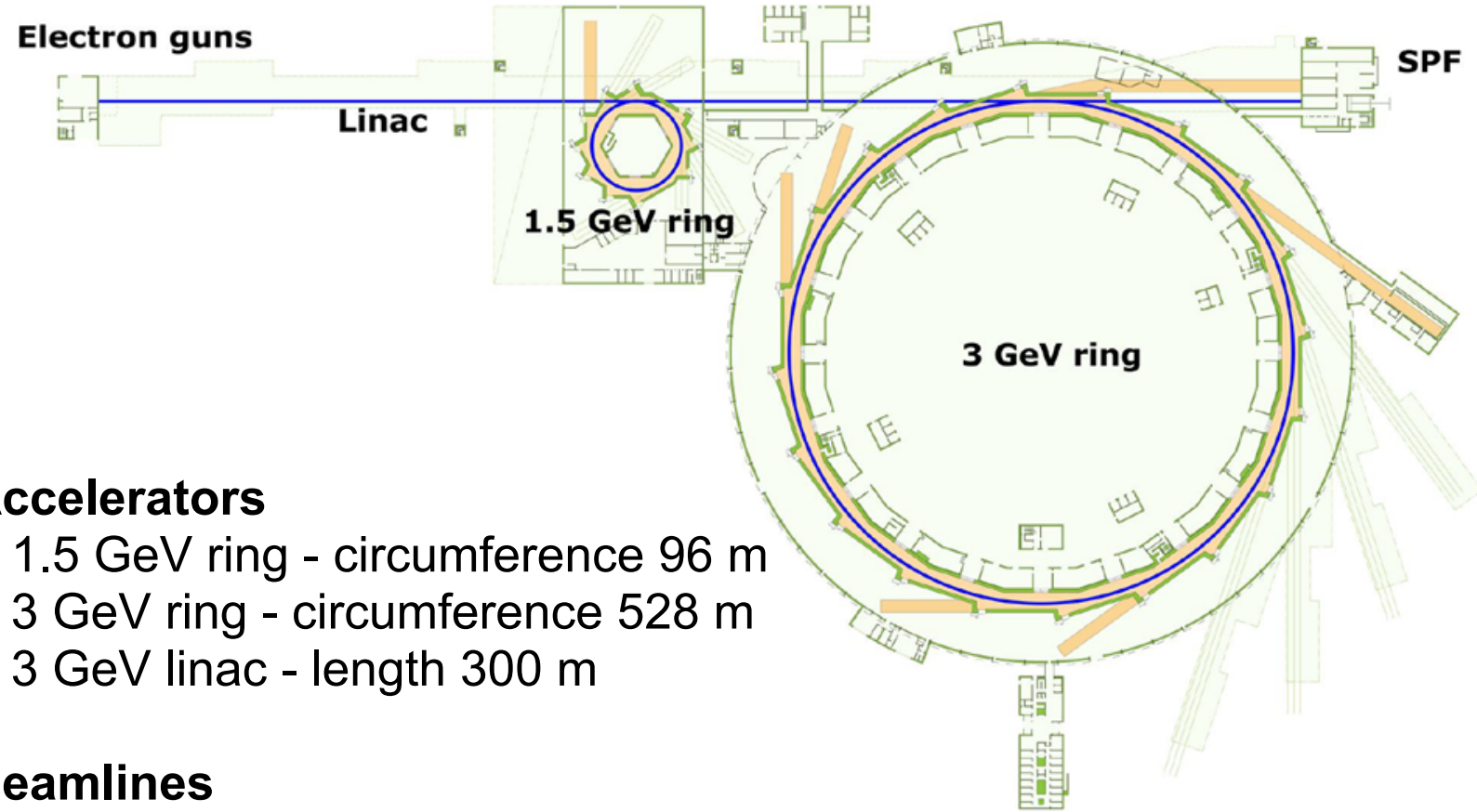
Wakefield driven by particle beam

+ No dephasing, energy gain limited by depletion
+ External injection (synchronisation) “easier”
- Needs large particle accelerator

Outline

- What is MAX IV Laboratory and its 3 GeV linac?
- Can it be used for acceleration of double-bunches?
- Can it be used for PWFA with external injection?

MAX IV Laboratory



Accelerators

- ✦ 1.5 GeV ring - circumference 96 m
- ✦ 3 GeV ring - circumference 528 m
- ✦ 3 GeV linac - length 300 m

Beamlines

- ✦ 14 (soon 17) BLs funded
- ✦ 5 BLs open to users
- ✦ 25 BLs in 2026
- ✦ Short Pulse Facility

2011: Brunnshög outside Lund

2011-2015: Building construction

2013-2015: Linac installation and commissioning

2015: Buildings completed

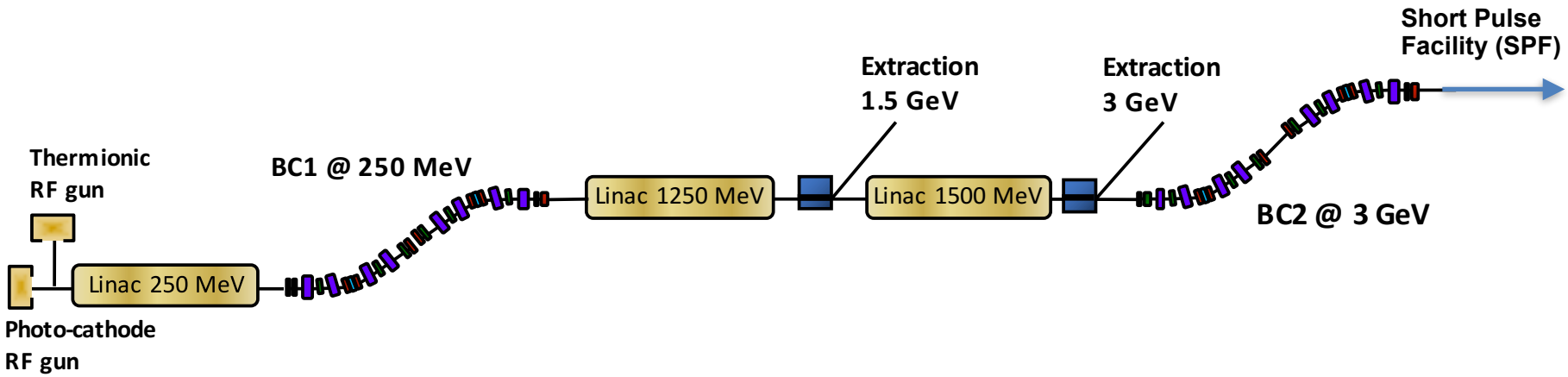
Feb 7 2015: 3 GeV achieved in the linac

Midsummer 2016: Inauguration

Sept 2017: ESS construction site

Planned: Science Village, between MAX IV and ESS

MAX IV Linear Accelerator

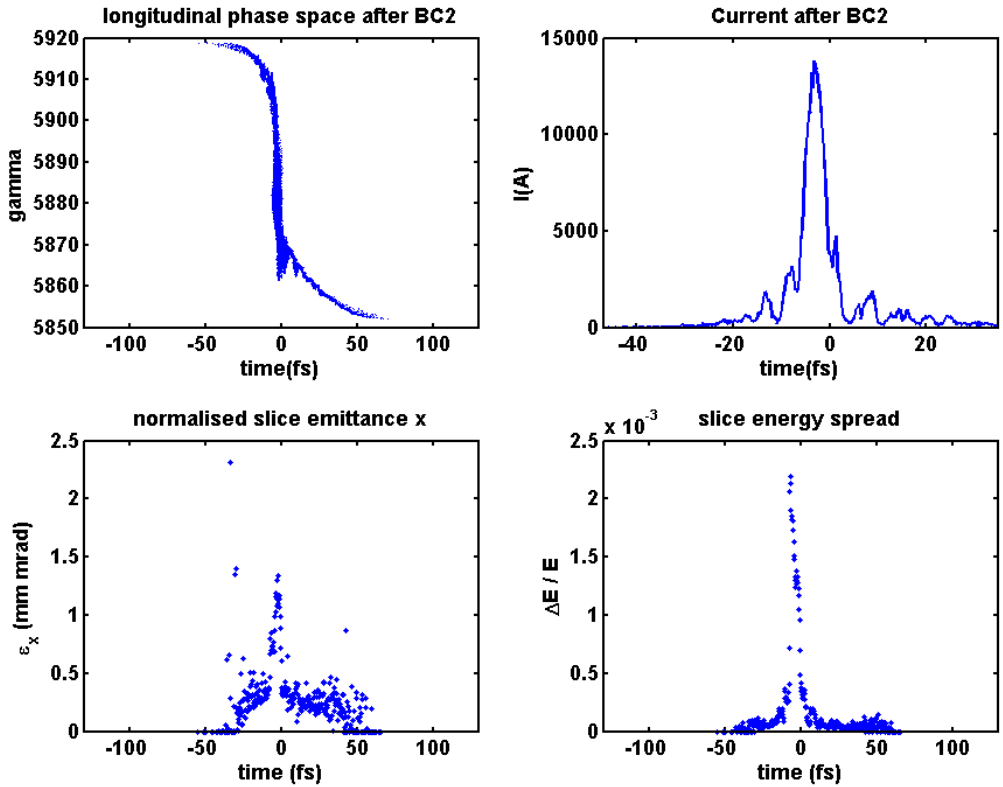


Operation modes

- Top-up injection for storage rings (~every 5-10 min)
- Driver for Short Pulse Facility (SPF, 100 Hz)

Contact: Sara Thorin

Simulation - full compression

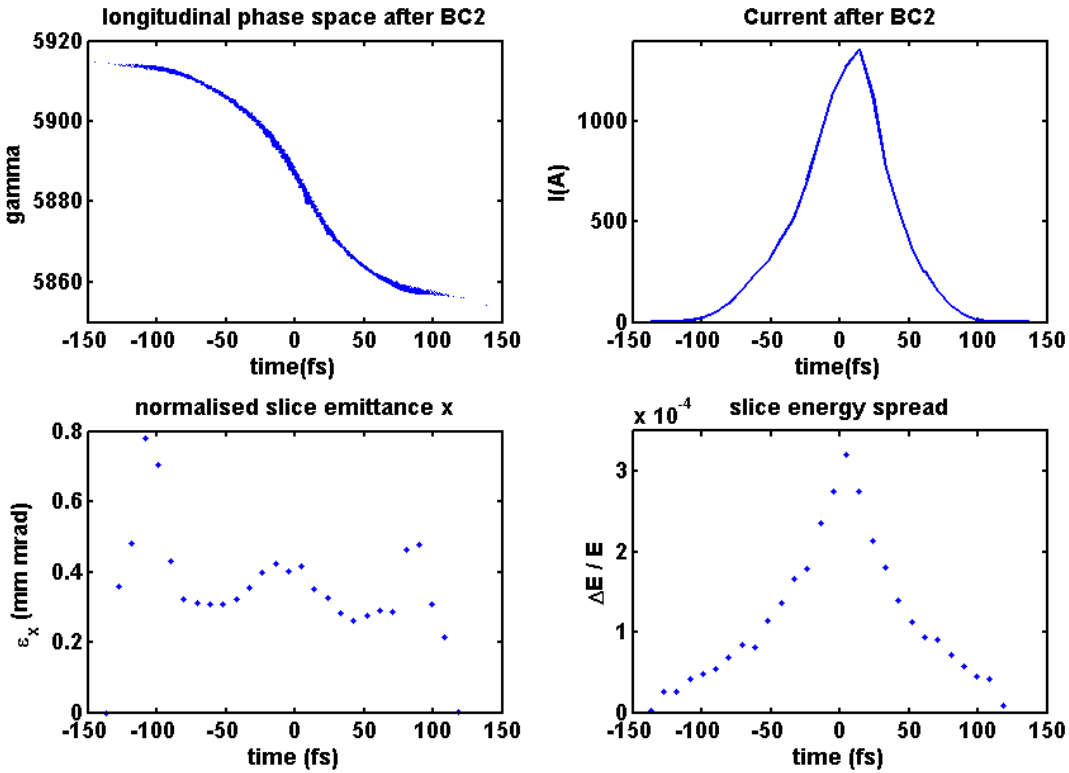


Gun – 1st linac: ASTRA
Linac + compressors: ELEGANT

Charge	100 pC
Δt fwhm	10 fs
Peak current	14 kA
Compression factor	500
Slice εN	1.5 mm mrad
Proj εN	2.4 mm mrad
Emittance increase (slice)	375 %
Slice ΔE/E	0.25 %

ELEGANT simulation: Sara Thorin

Simulation - small emittance

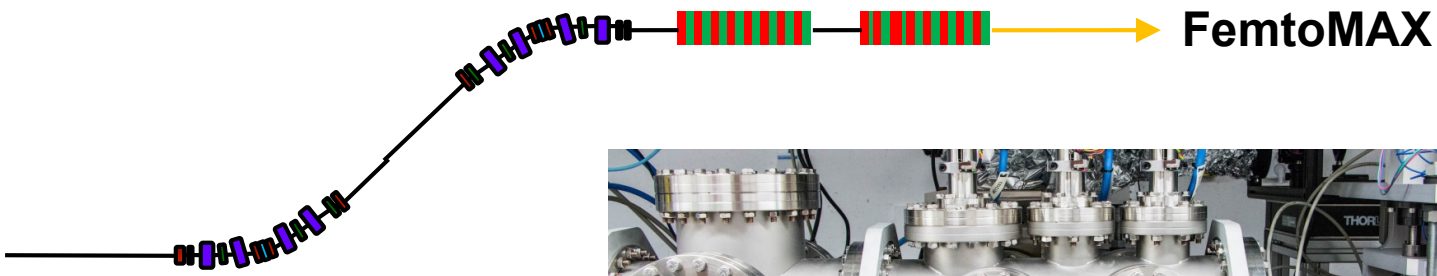


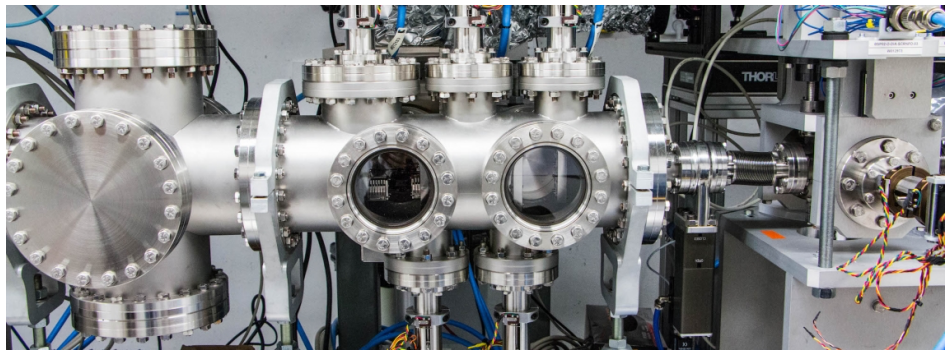
Gun – 1st linac: ASTRA
Linac + compressors: ELEGANT

Charge	100 pC
Δt fwhm	100 fs
Peak current	1.5 kA
Compression factor	50
Slice εN	0.42 mm mrad
Proj εN	0.55 mm mrad
Emittance increase	5 %
Slice ΔE/E	0.035 %

ELEGANT simulation: Sara Thorin

Short Pulse Facility - FemtoMAX





FemtoMAX

Ultrafast X-ray beam line for studies of the structure and dynamics of materials

2-20 keV, 10^7 photons @ 6 keV

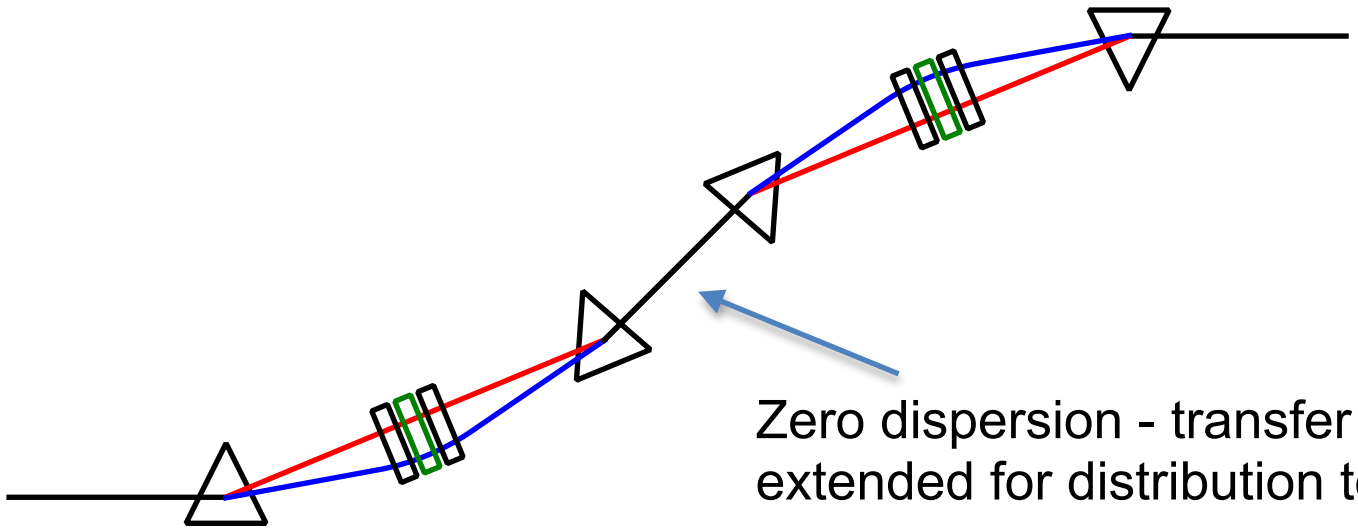
Ultrafast laser (10 mJ@800 nm)

Crystal monochromator, focusing mirror, Be-lenses, robot detector holder…

First users 2017, full operation 2018

Contact: Prof. Jörgen Larsson

Bunch compressors - double achromats



Zero dispersion - transfer section is easily extended for distribution to experiments

Short Pulse Facility - SXL

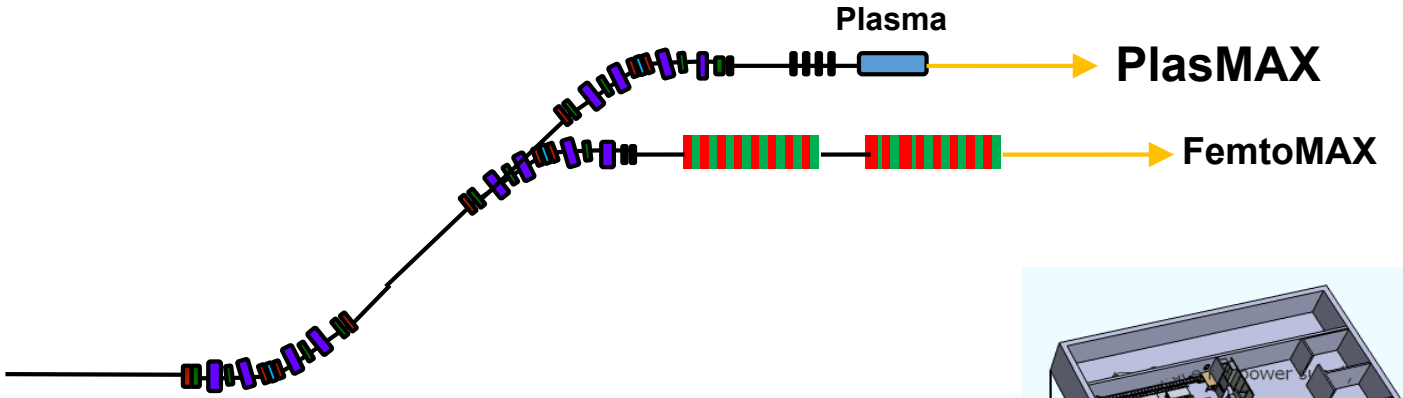
Conceptual Design Study

- Two year study of feasibility and detail planning for a **soft x-ray laser beamline**
- Will start 2018

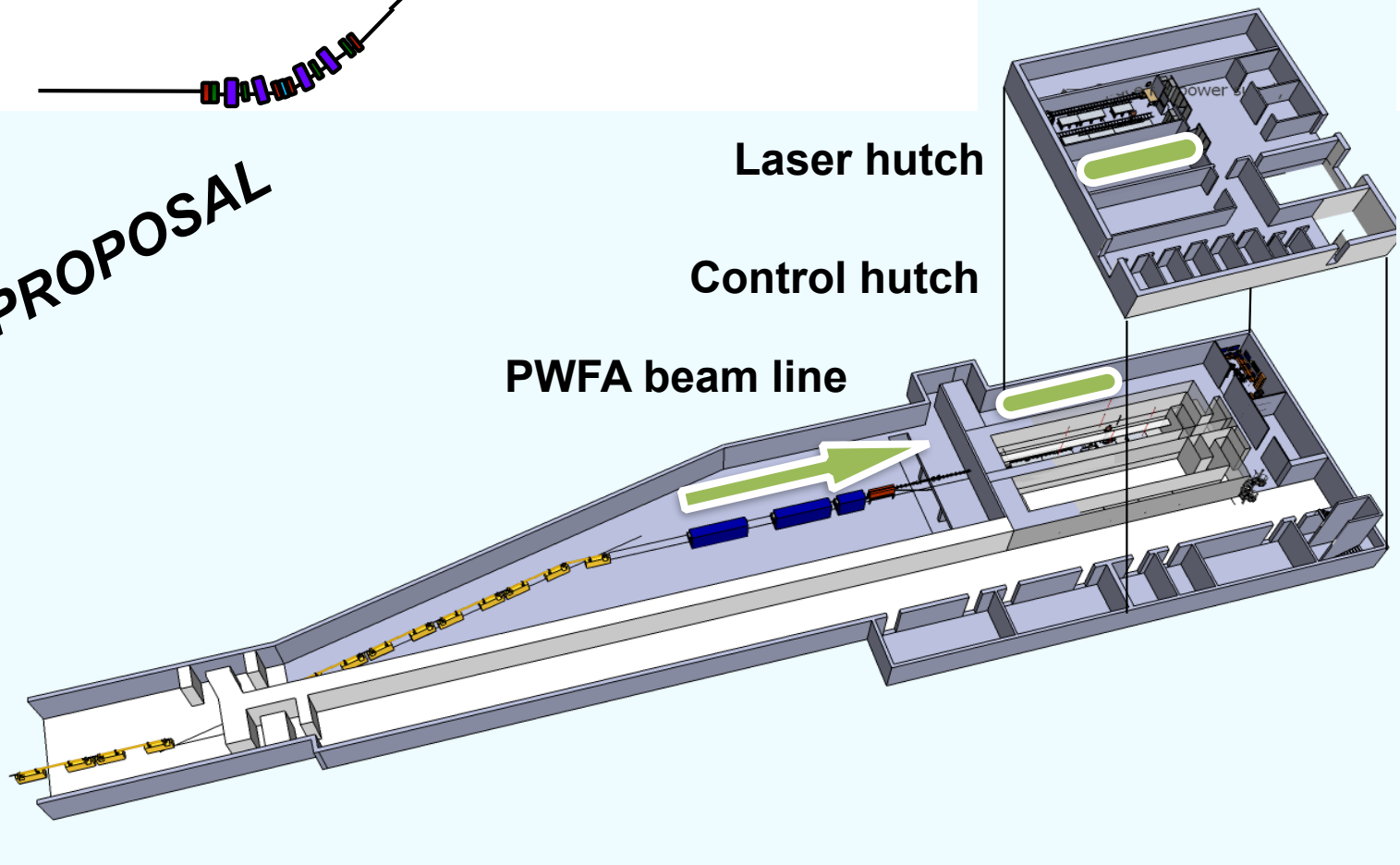
Wavelength	**1-5 nm**
Photon energy	**0.25-1 keV**
Pulse length	10-100 fs
Rep rate	100 Hz
Power (peak)	~1 GW
Ph/pulse	$10^{11\text{-}12}$

Contact: Pedro Fernandes Tavernes (MAX IV)

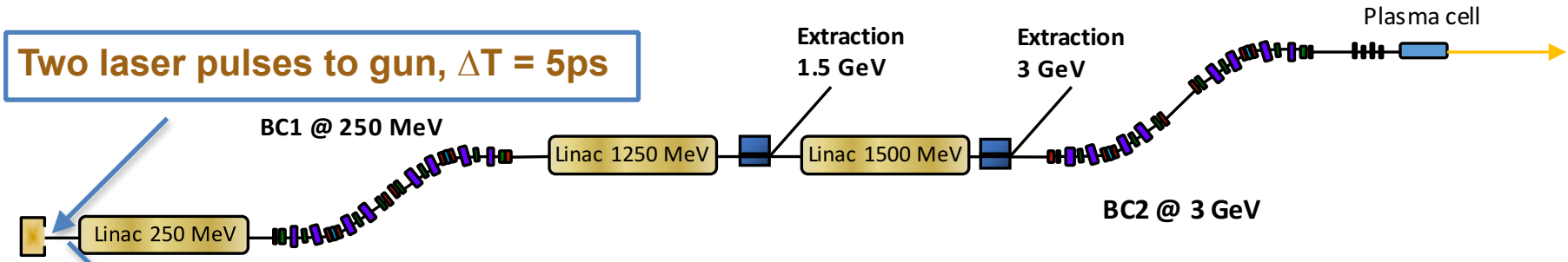
Short Pulse Facility - PlasMAX proposal

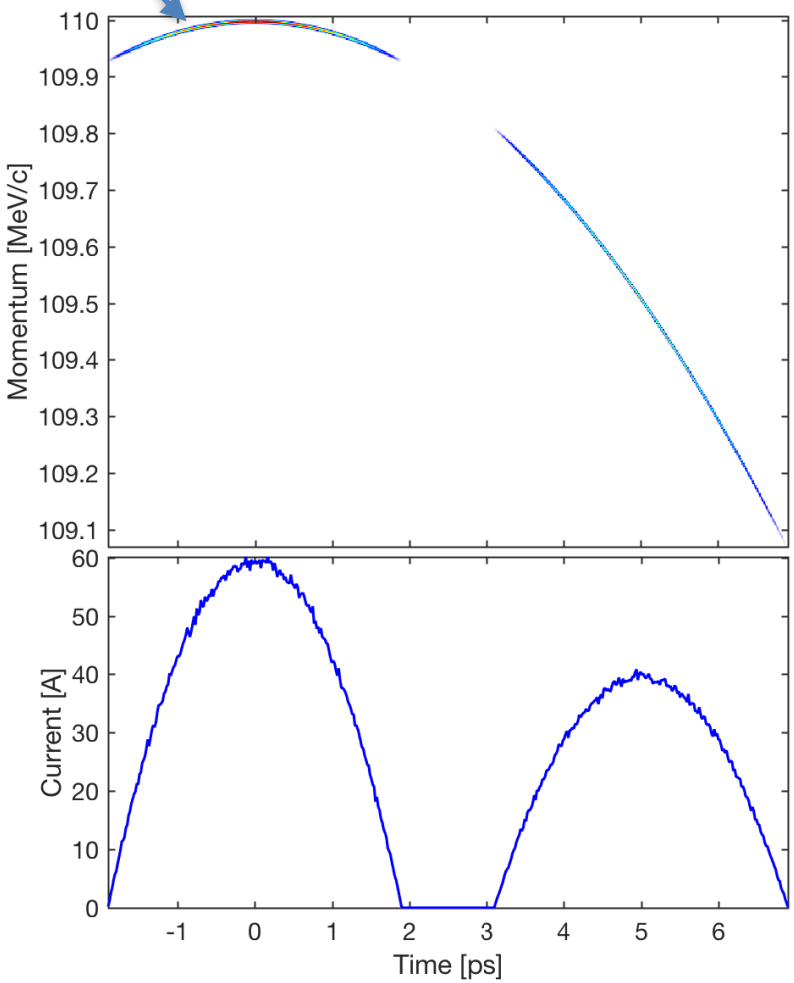


PROPOSAL



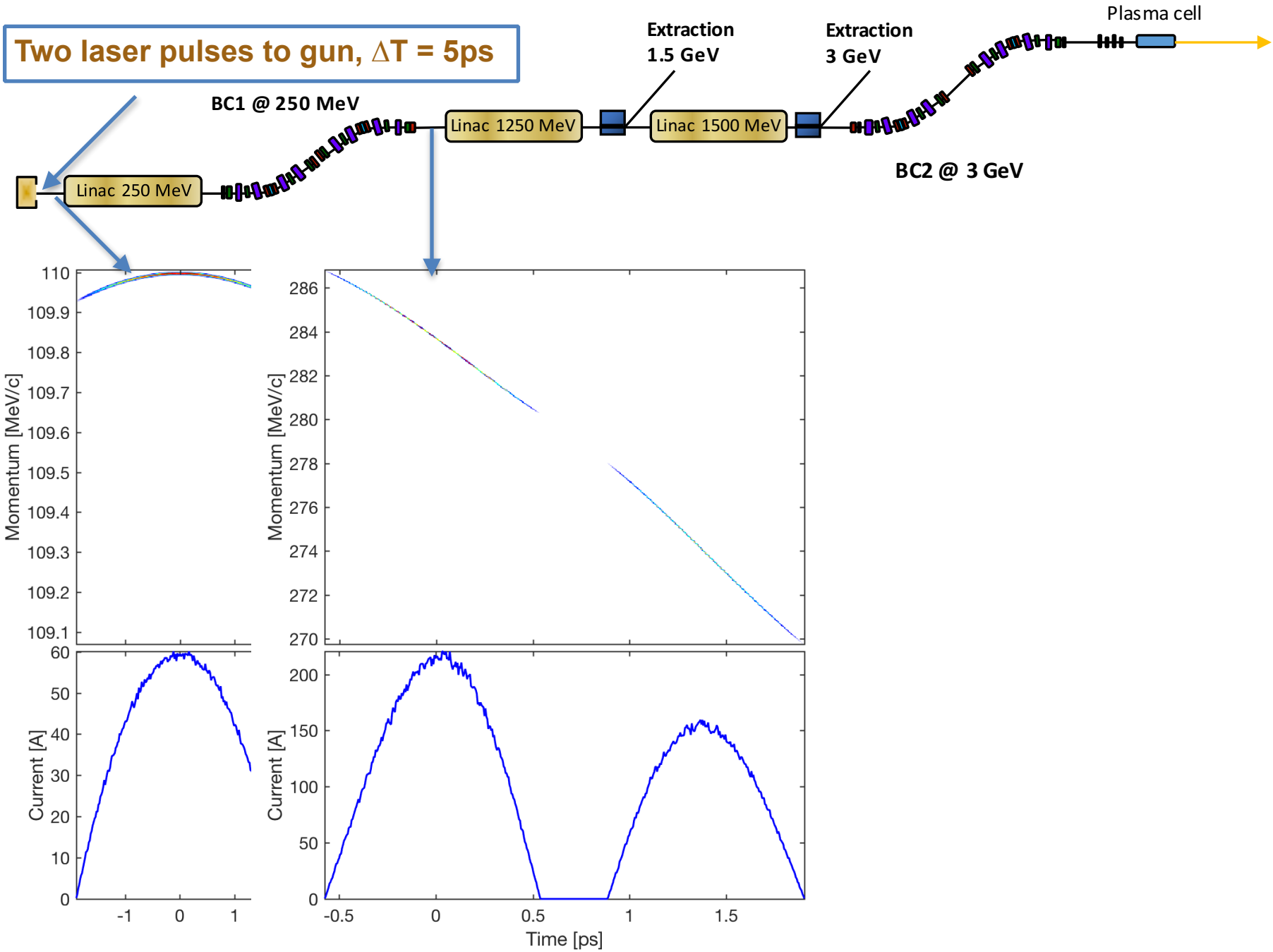
Two laser pulses to gun, ΔT = 5ps





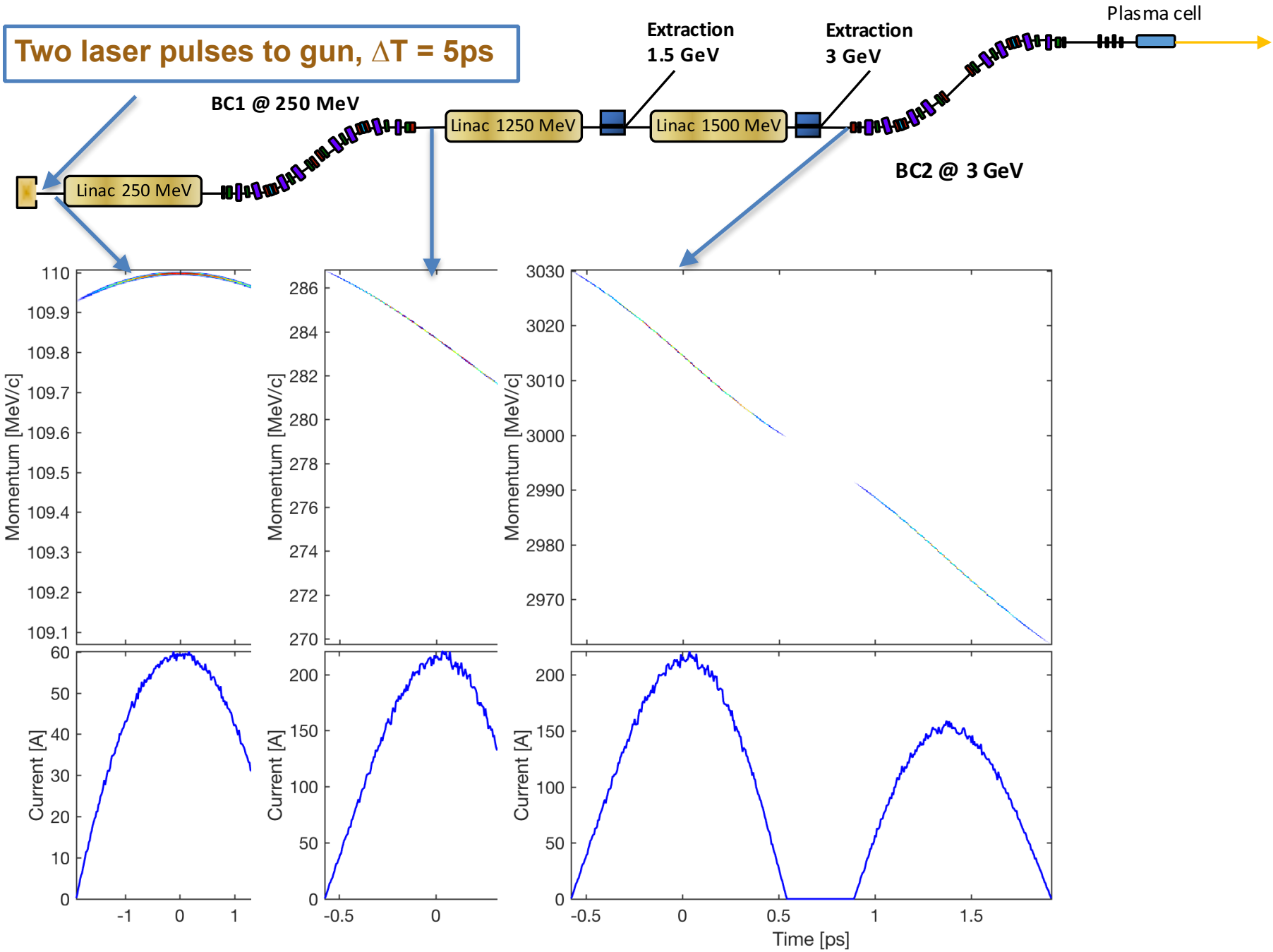
ELEGANT simulation

Two laser pulses to gun, ΔT = 5ps



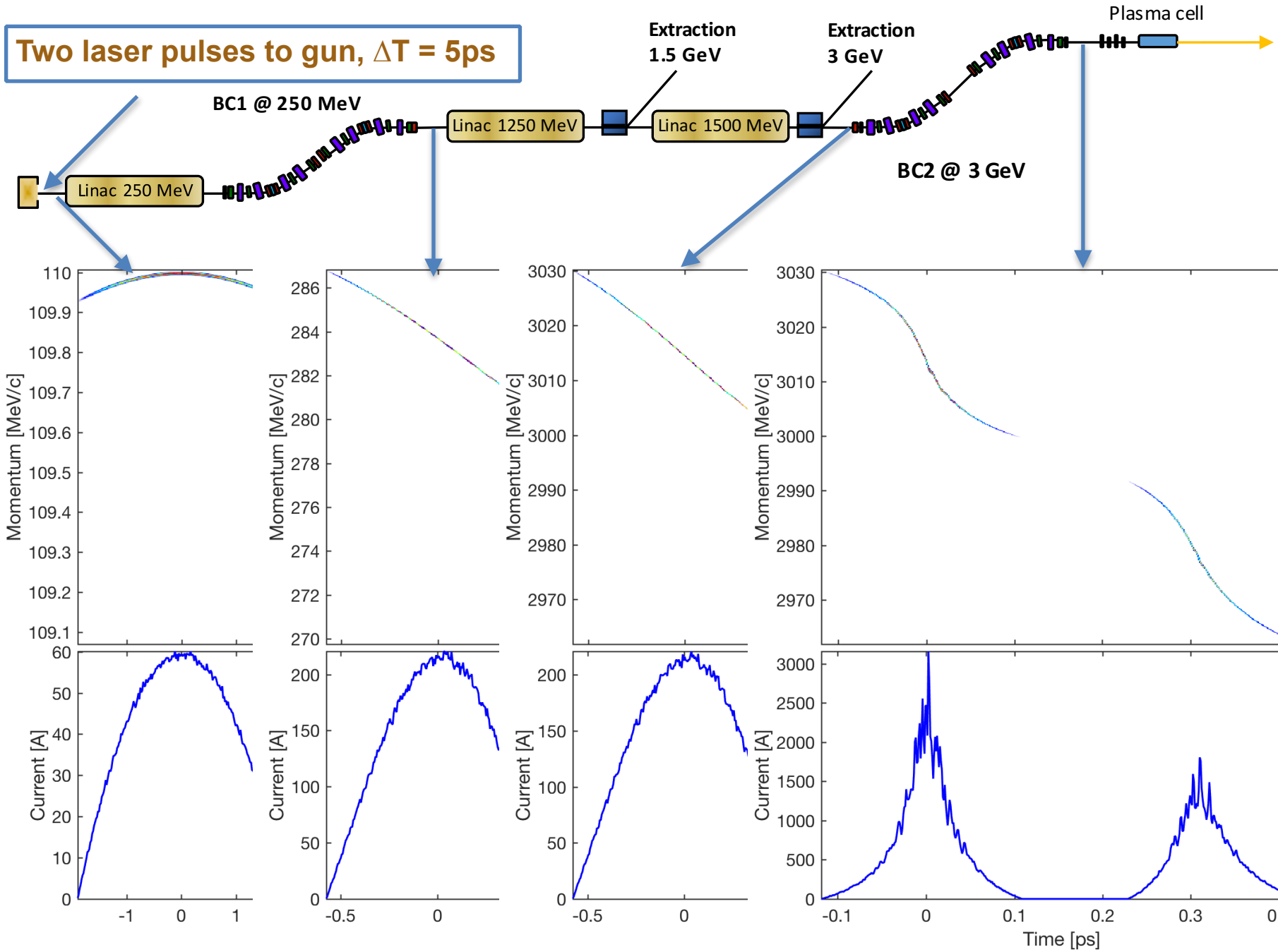
ELEGANT simulation

Two laser pulses to gun, ΔT = 5ps



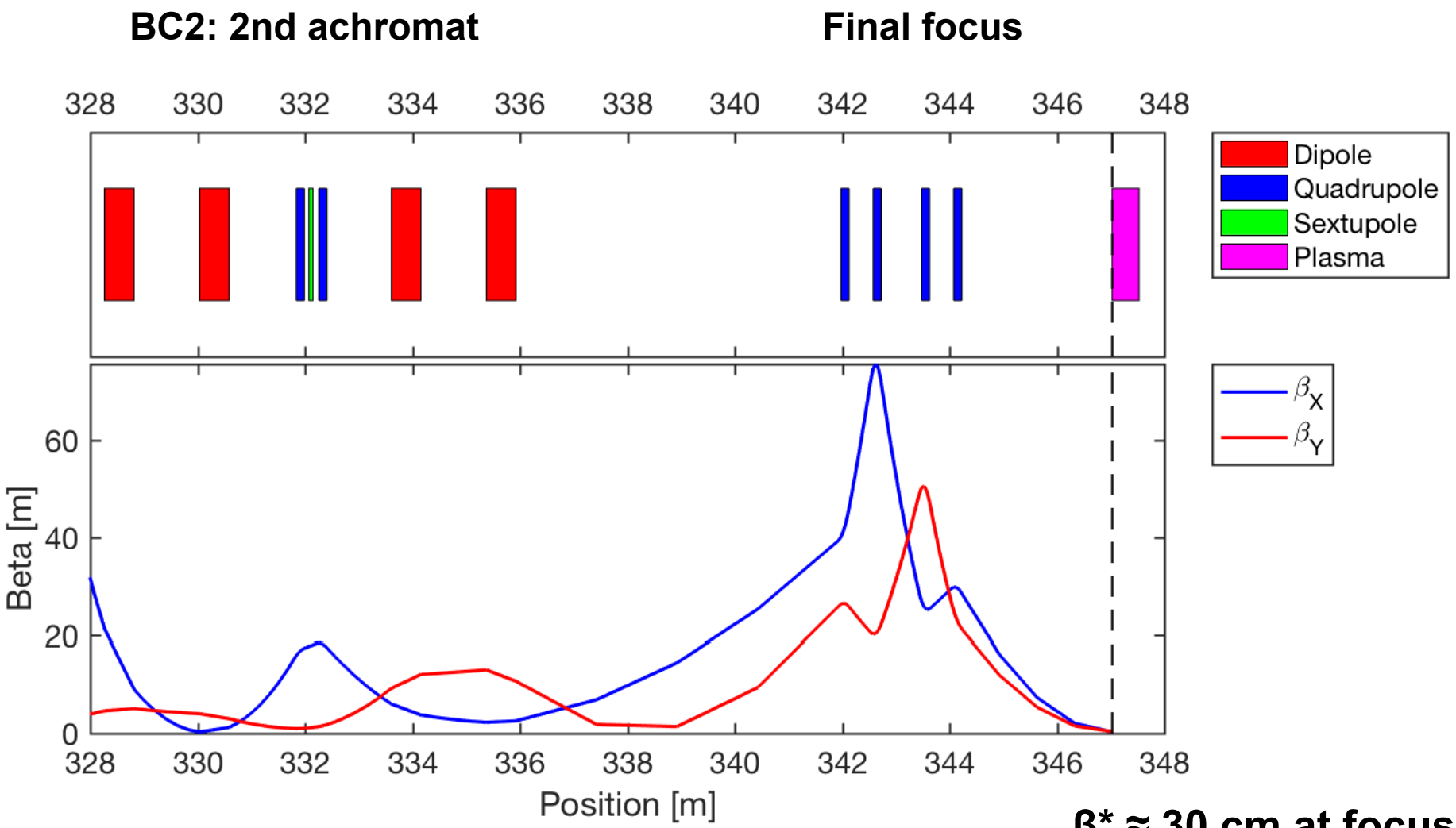
ELEGANT simulation

Two laser pulses to gun, ΔT = 5ps



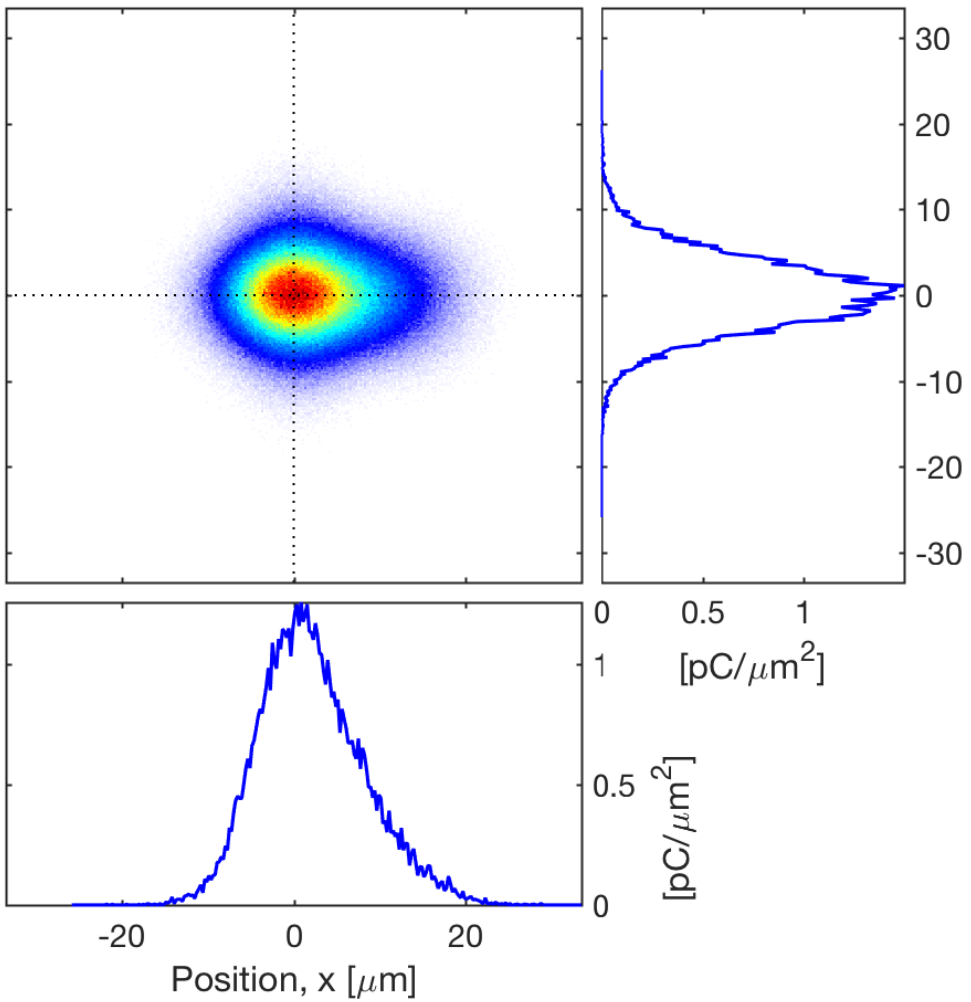
ELEGANT simulation

Preliminary focusing system

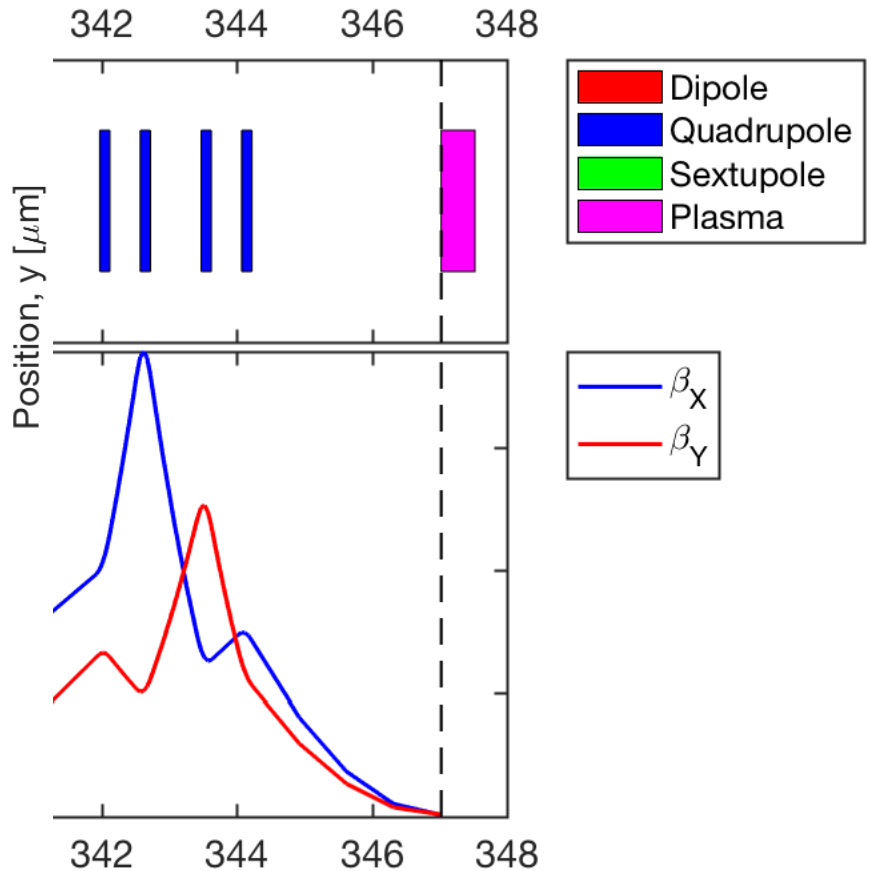


β* ≈ 30 cm at focus

Preliminary focusing system

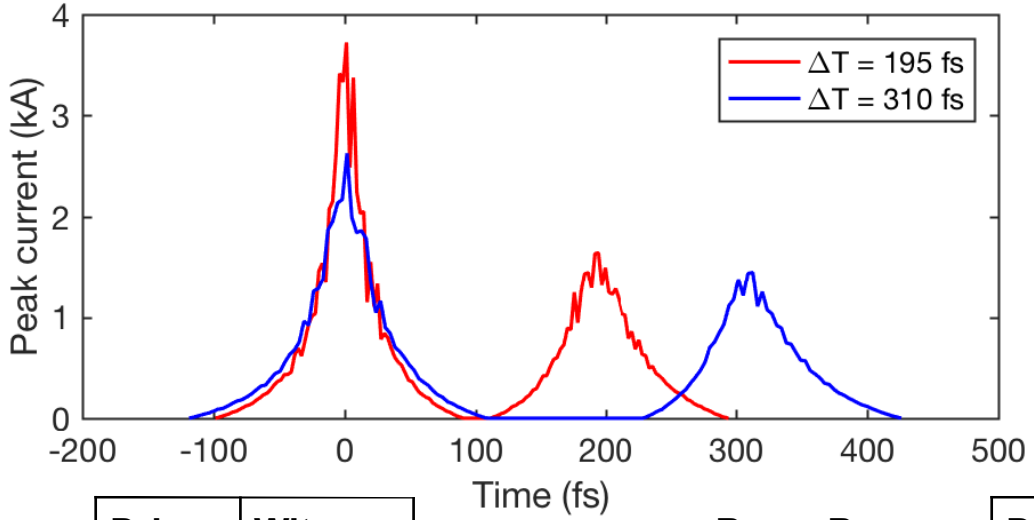


Final focus



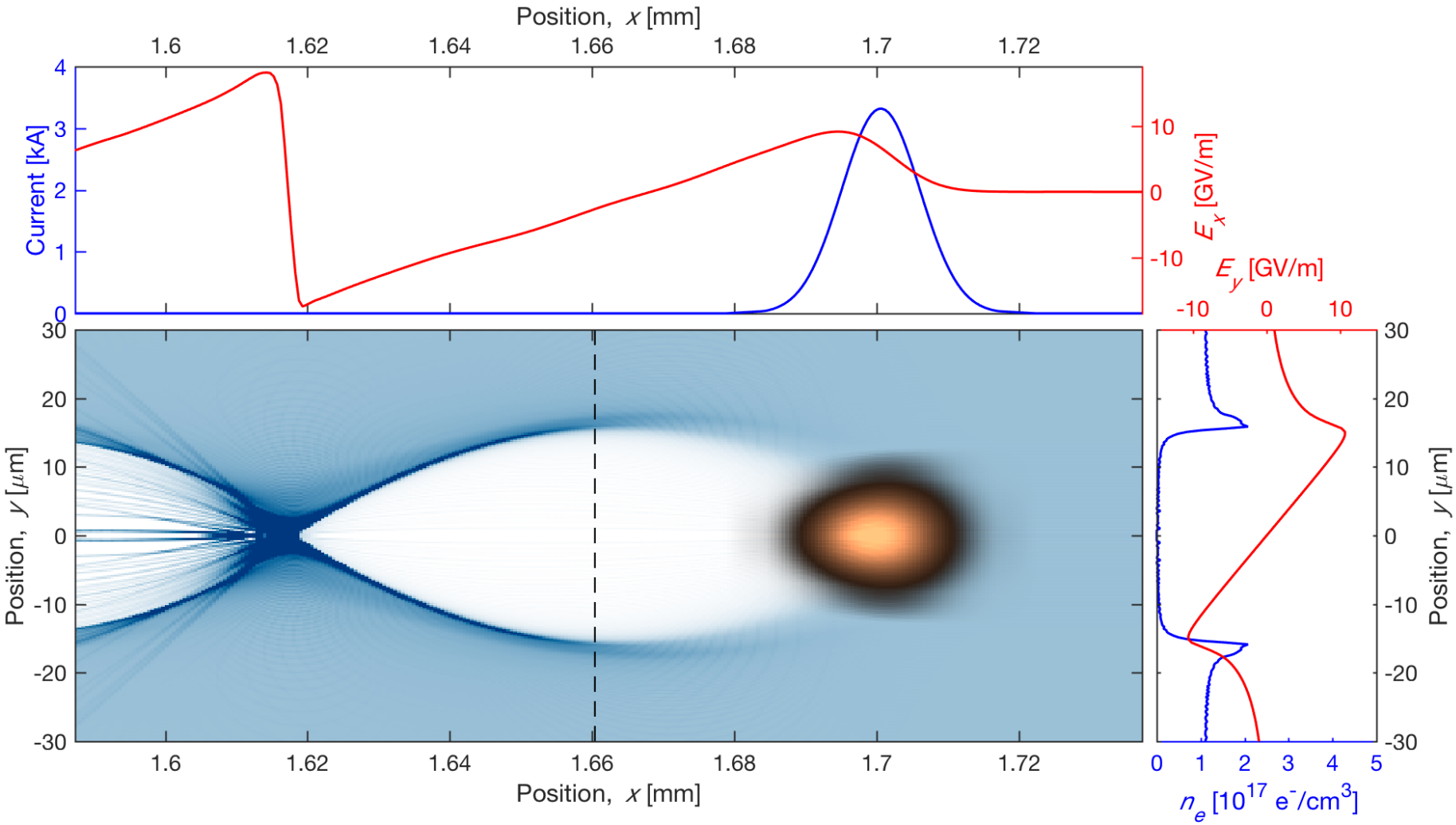
β* ≈ 30 cm at focus

Adjustable beams



Beam A	Drive	Witness	
Delay		310	fs
Duration	50	62	fs
Peak current	2.2	1.4	kA
Peak density	4.0	2.1	10^{17} cm^{-3}
Charge (pC)	150	100	pC
Emittance hor.	0.47	0.40	mm mrad
Emittance, vert.	0.35	0.38	mm mrad
Width, hor.	15	11	μm
Width, vert.	8.5	9.8	μm
Energy spread	0.8	0.8	%

Beam B	Drive	Witness	
Delay		195	fs
Duration	31	55	fs
Peak current	3.3	1.5	kA
Peak density	6.0	2.6	10^{17} cm^{-3}
Charge (pC)	150	100	pC
Emittance hor.	0.51	0.40	mm mrad
Emittance, vert.	0.34	0.37	mm mrad
Width, hor.	15	9.3	μm
Width, vert.	8.6	9.4	μm
Energy spread	0.9	0.9	%



Bunch parameters

3.3 kA

31 fs (FWHM)

10 μm (FWHM)

150 pC

$n_b = 6 \cdot 10^{17}$ cm^{-3}

Plasma parameters

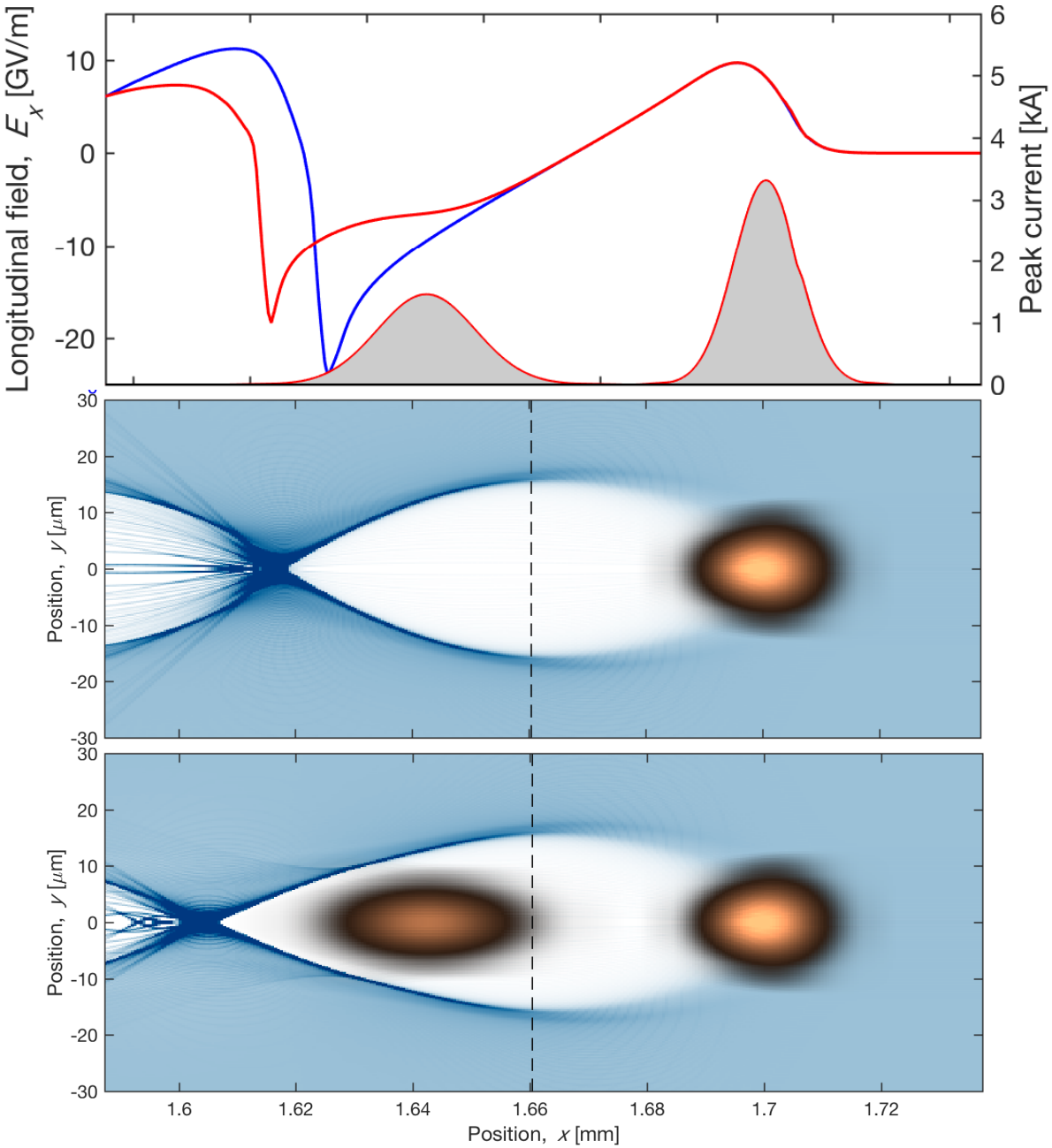
L_{ramp} = 500 μm

$L_{plateau}$ = 500 mm

$n_e = 1.1 \cdot 10^{17}$ cm^{-3}

Simulation using CALDER-CIRC

CALDER-CIRC: Lifshitz et al, J Computat Phys 228 (2009) 1803–1814



Plasma density chosen so both bunches are in the bubble

Driver bunch

3.3 kA

31 fs (FWHM)

10 μm (FWHM)

150 pC

$n_b = 6 \cdot 10^{17}$ cm^{-3}

Driver bunch

1.5 kA

55 fs (FWHM)

10 μm (FWHM)

100 pC

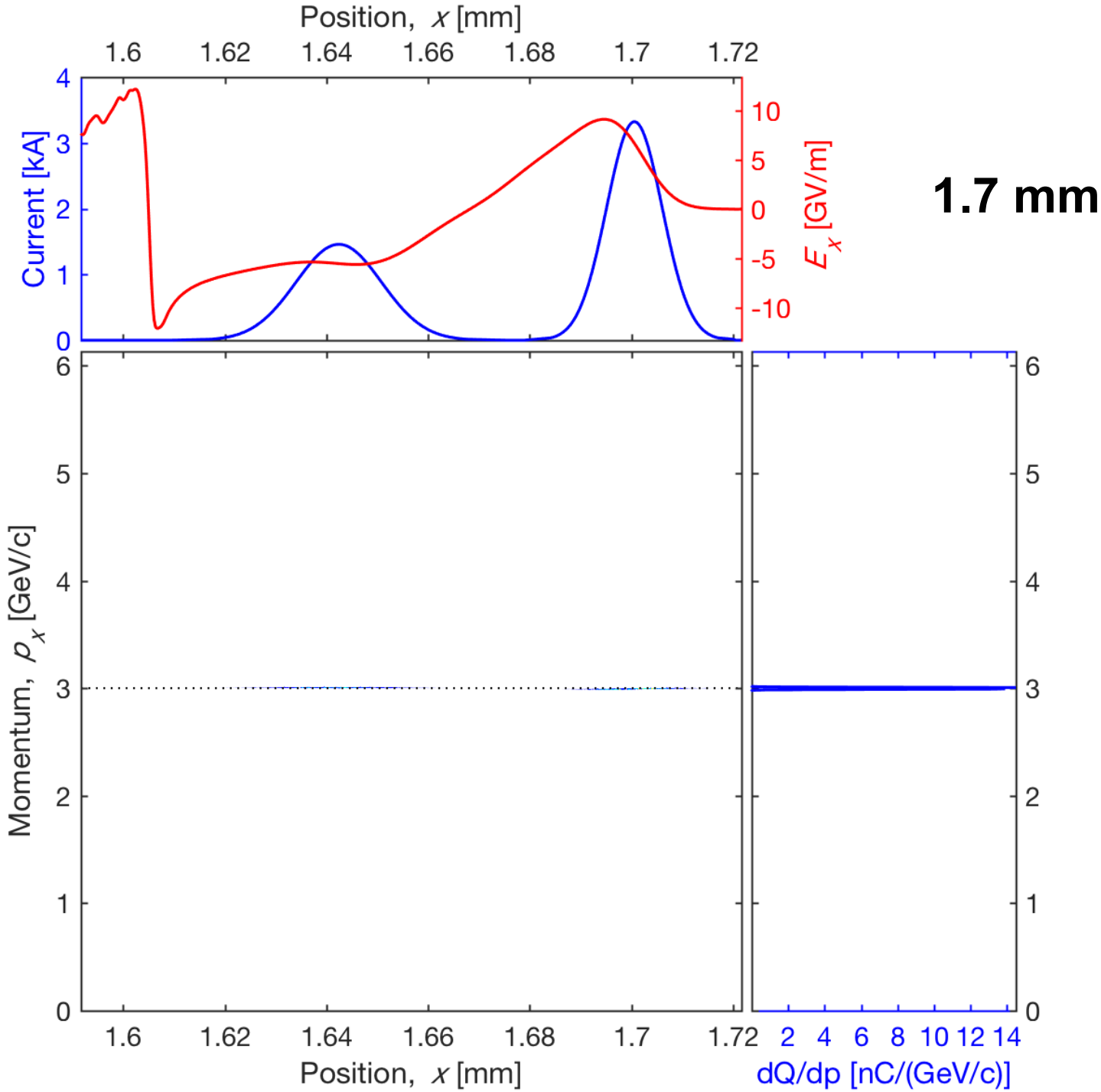
$n_b = 2.6 \cdot 10^{17}$ cm^{-3}

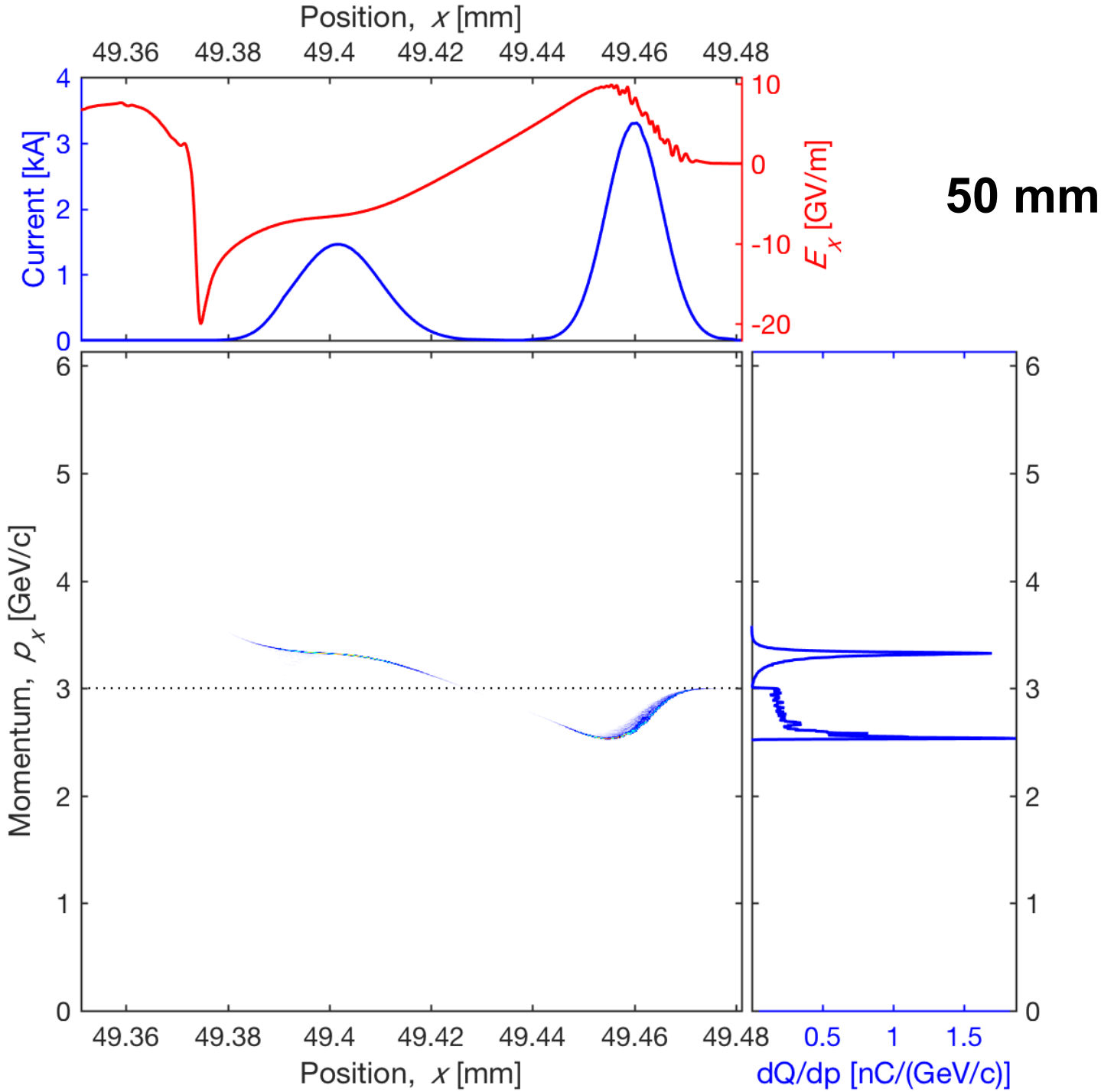
Plasma parameters

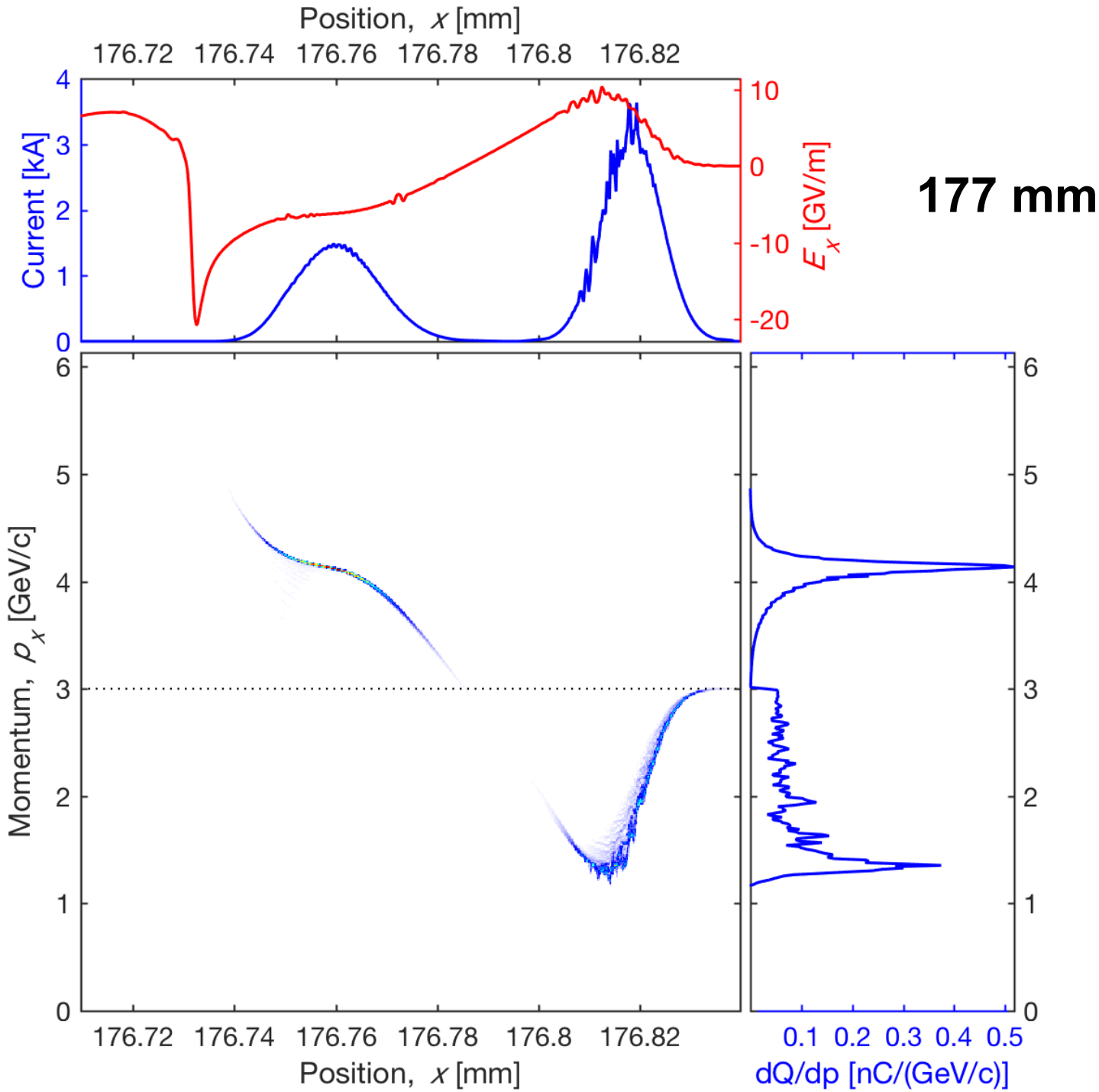
$L_{ramp} = 0.5$ mm

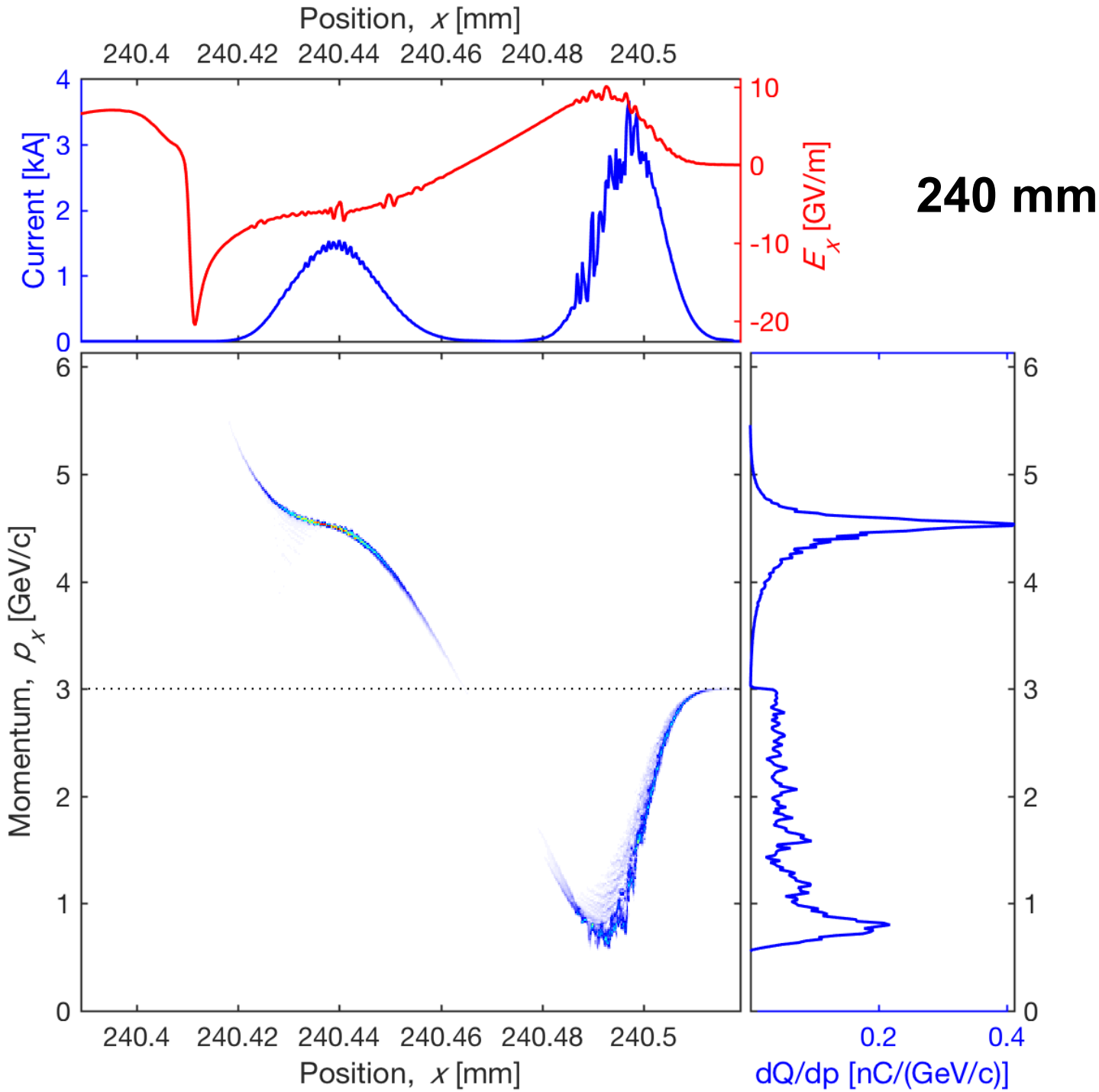
$n_e = 1.1 \cdot 10^{17}$ cm^{-3}

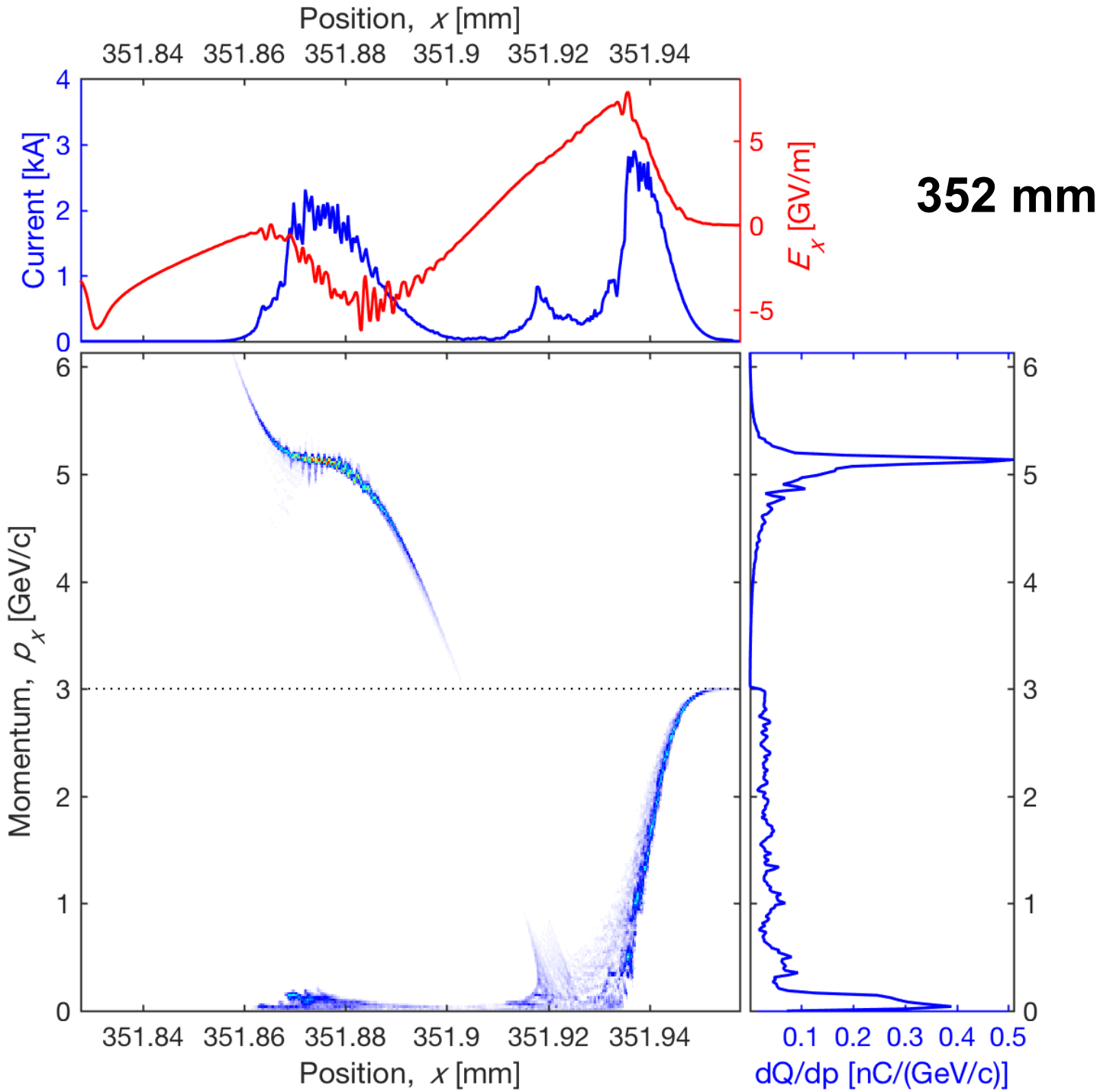
Simulation using CALDER-CIRC


Position, x [mm]
1.6
1.62
1.64
1.66
1.68
1.7
1.72
Current [kA]
E_x [GV/m]
1.7 mm
Momentum, p_x [GeV/c]
dQ/dp [nC/(GeV/c)]


Position, x [mm]
49.36
49.38
49.4
49.42
49.44
49.46
49.48
Current [kA]
E_x [GV/m]
50 mm
Momentum, p_x [GeV/c]
dQ/dp [nC/(GeV/c)]


Position, x [mm]
176.72
176.74
176.76
176.78
176.8
176.82
Current [kA]
E_x [GV/m]
177 mm
Momentum, p_x [GeV/c]
dQ/dp [nC/(GeV/c)]


Position, x [mm]
240.4
240.42
240.44
240.46
240.48
240.5
Current [kA]
E_x [GV/m]
240 mm
Momentum, p_x [GeV/c]
dQ/dp [nC/(GeV/c)]
0.2
0.4

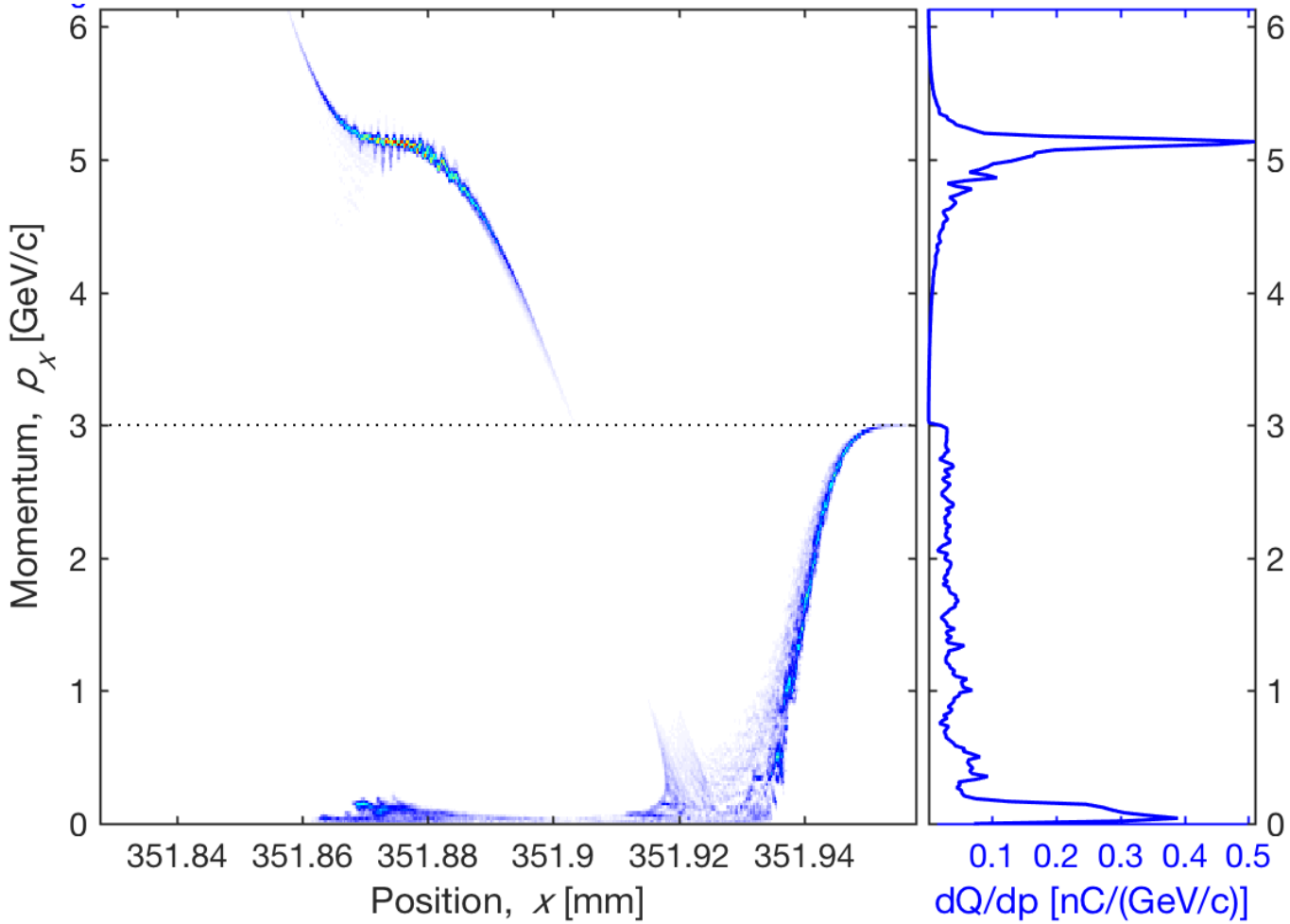

Position, x [mm]
351.84 351.86 351.88 351.9 351.92 351.94
Current [kA]
E_x [GV/m]
352 mm
Momentum, p_x [GeV/c]
Position, x [mm]
dQ/dp [nC/(GeV/c)]

Depletion of the driver after 35 cm

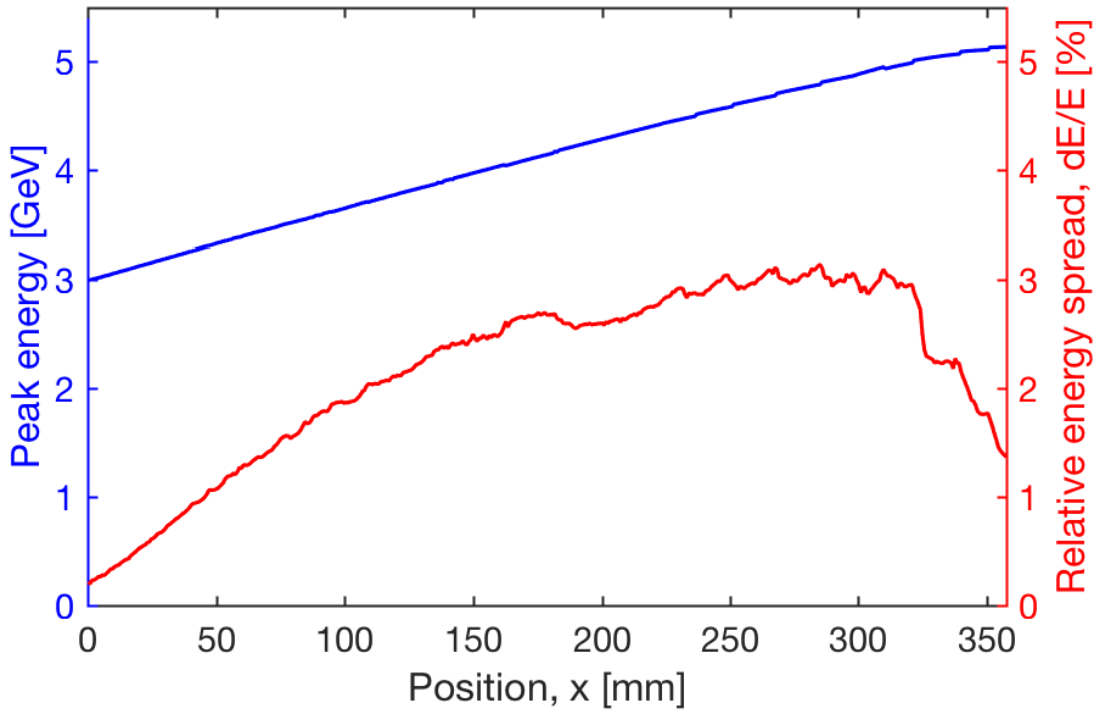
Witness energy = 5.1 GeV (2.1 GeV gain)

Effective accelerating gradient 6 GV/m

Energy spread 1.5 %



Energy gain and spread

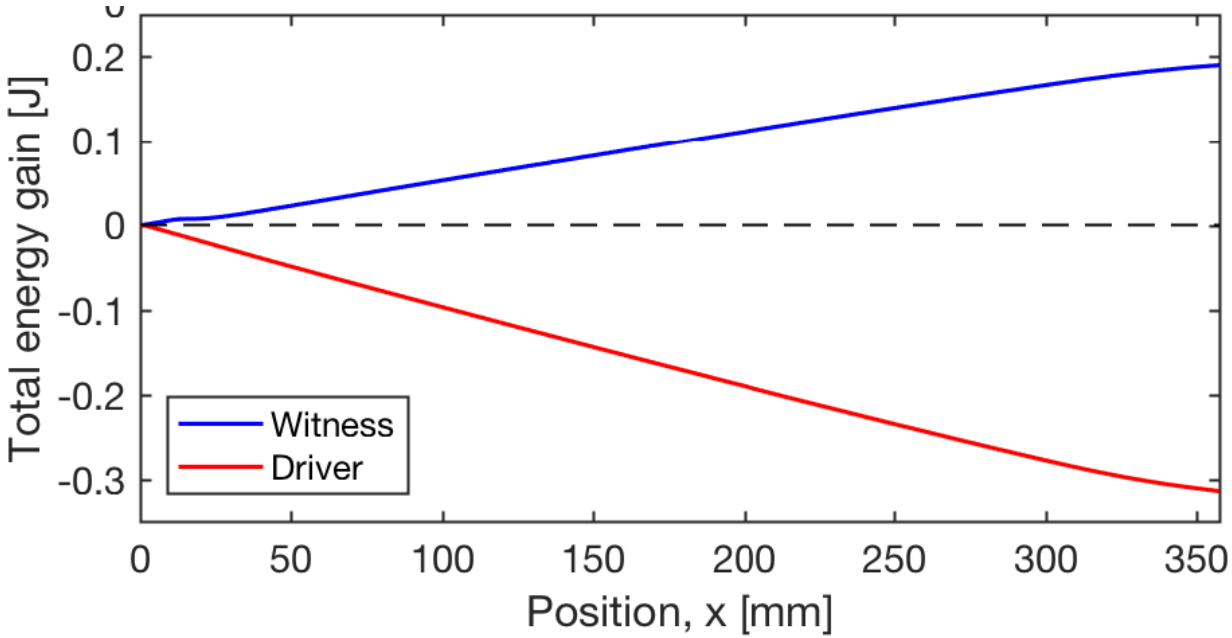


Energy spread grows during acceleration to ~3%

Momentum compression during driver depletion

$\Delta E/E$ = 1,5% at 5.1 GeV

Efficient energy transfer



~60 % of the energy lost by driver is gained by witness

Prospects for PWFA at MAX IV

Conclusions

Yes, the MAX IV Linac is ***excellent*** for PWFA

Witness energy gain of 6 GeV/m

There is space (~25 m) in the switchyard

Synergies with existing and planned BLs at the SPF

What's next?

Produce and measure kA-double-bunches

Endorsement by the MAX IV laboratory (enter strategic plan)

- Make a strong science case
- Identify a large user pool