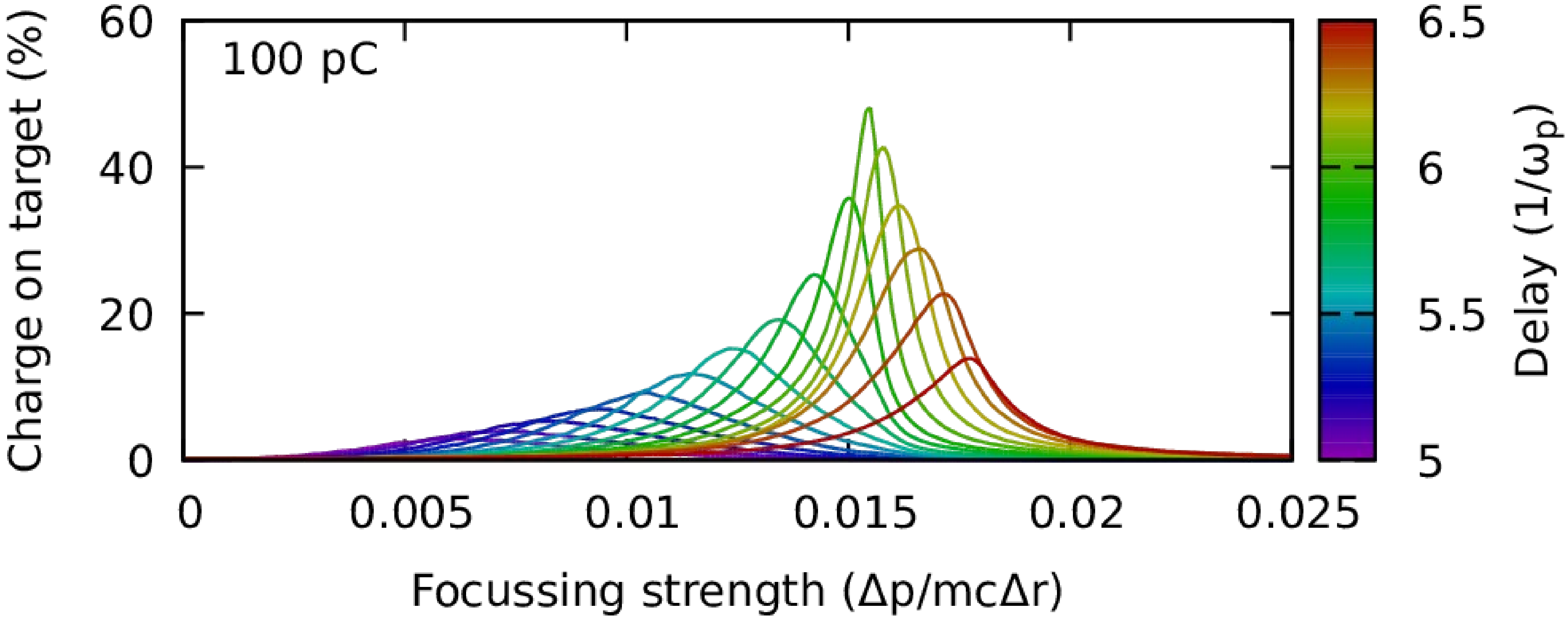
Injection tolerances for AWAKE Run 2c



John Farmer, Linbo, Rebecca, Francesco, Martin, Edda, Patric

Motivation

Can a LWFA be used as in injection scheme for AWAKE?

- What are the tolerances for the witness bunch parameters at the injection point?

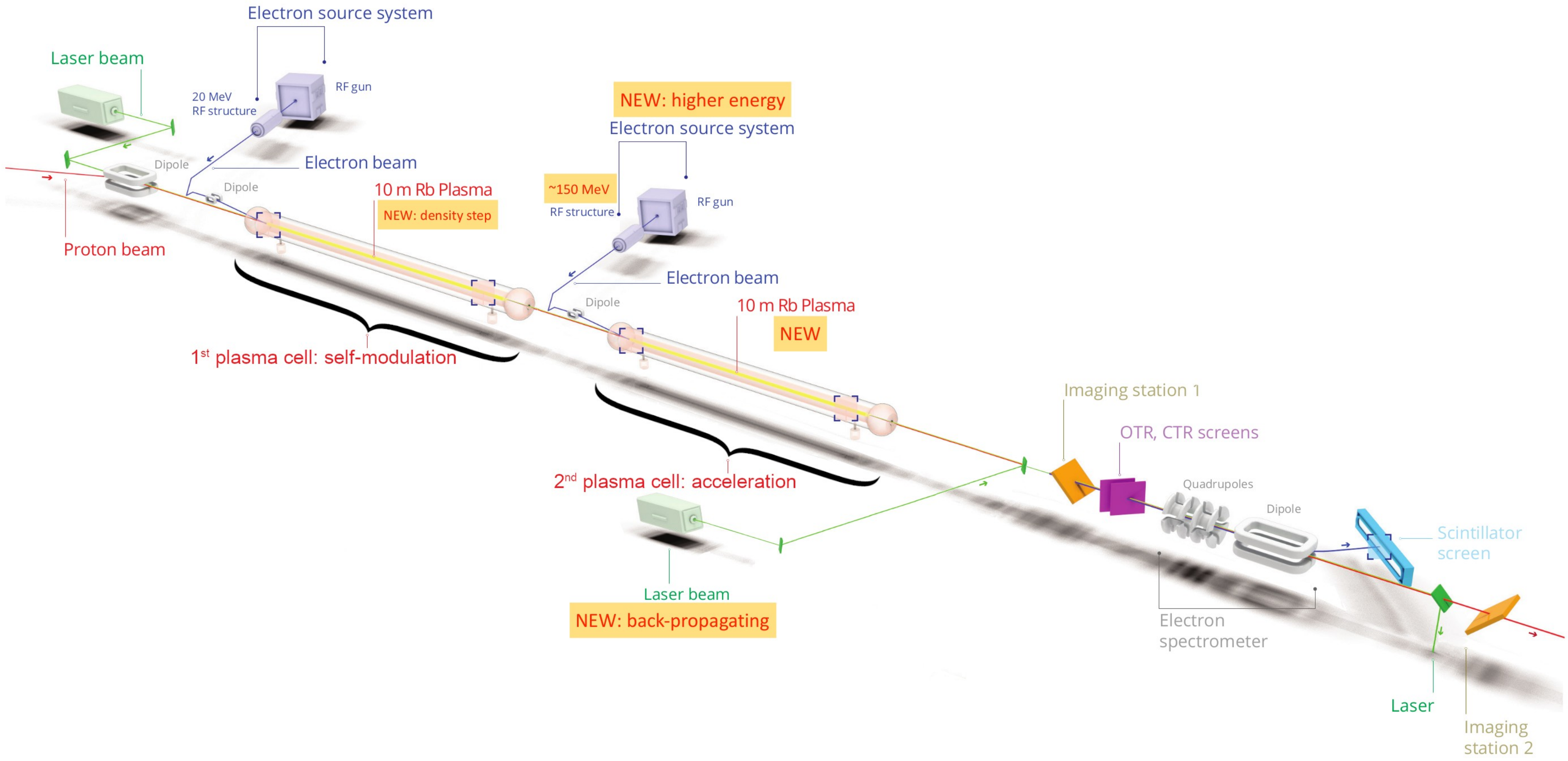
Answering in a meaningful way requires a *figure of merit*, a quantitative measure of the accelerated beam quality.

What is the figure of merit for AWAKE?

Outline

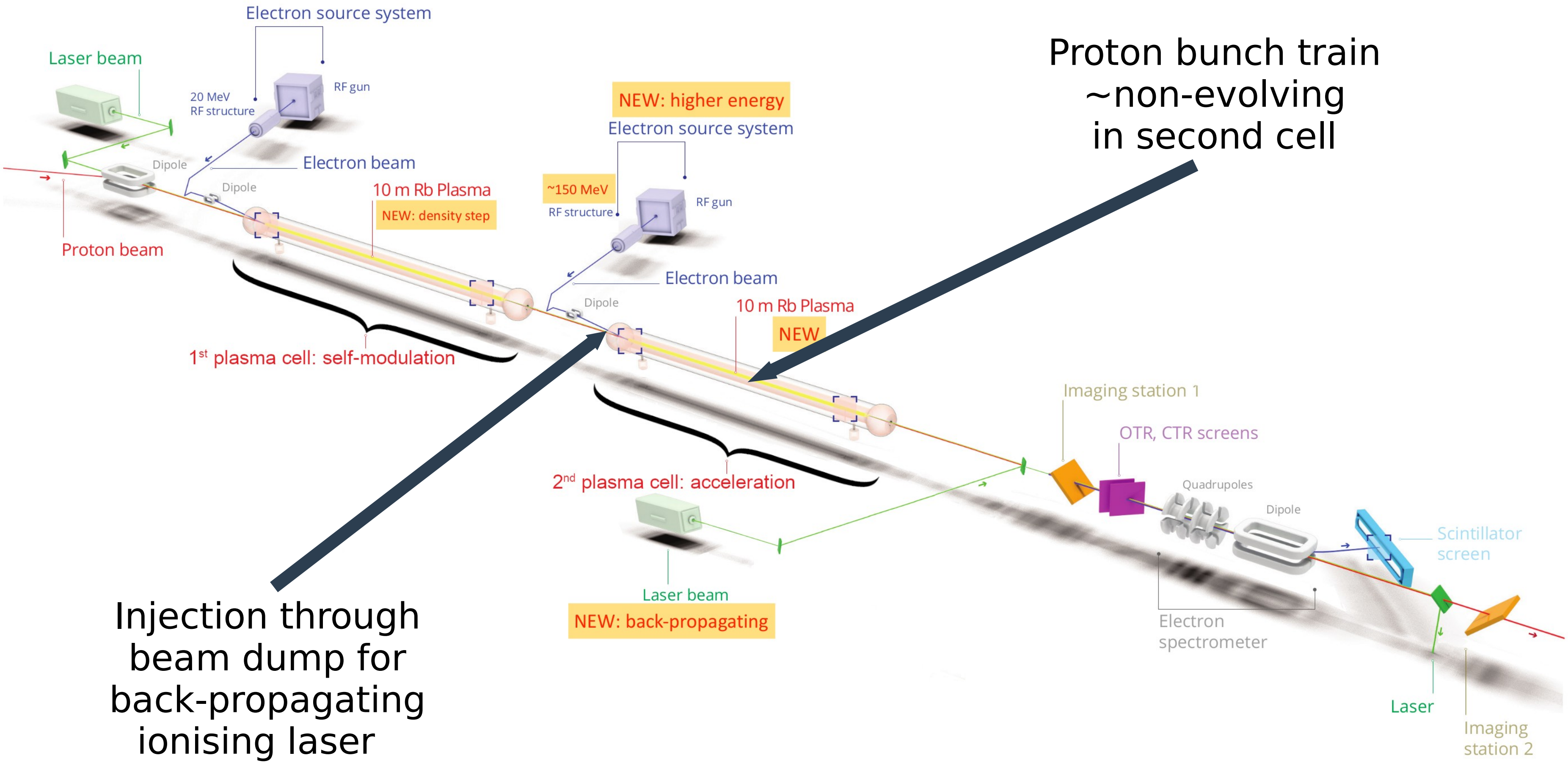
- Simulation configuration
- Simple example: delay scan
- Figure of merit
- Tolerances
- Influence of wakefield amplitude
- Conclusions

Run 2c



Goal for Run 2 – better control of the acceleration process

Run 2c



Proton bunch train
~non-evolving
in second cell

Injection through
beam dump for
back-propagating
ionising laser

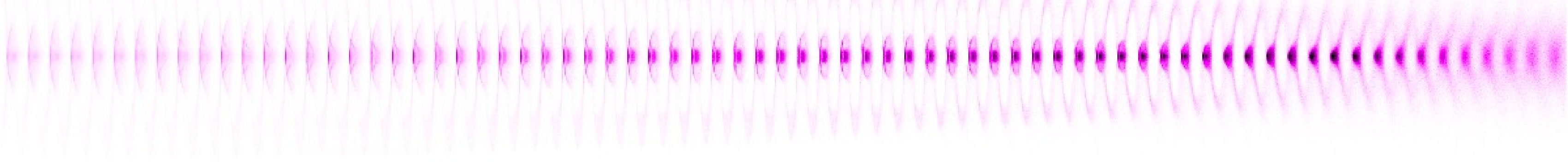
Goal for Run 2 – better control of the acceleration process

Simulation configuration

Long proton beam

Self modulation instability (first plasma cell)

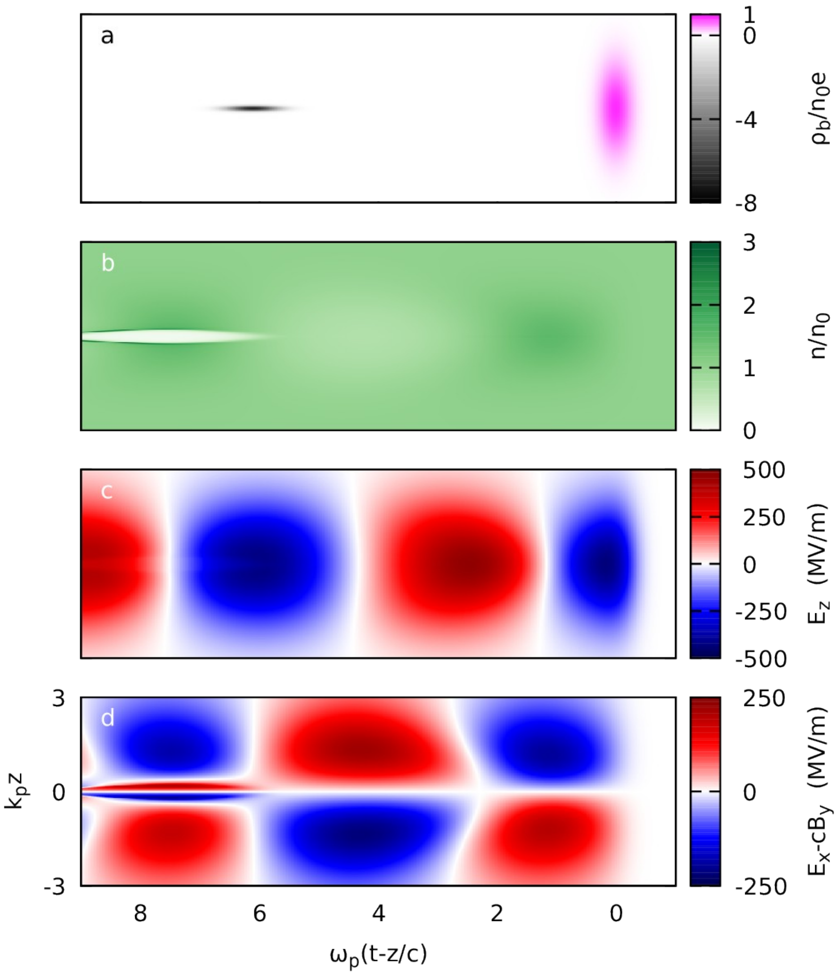
Train of short microbunches



- Plasma density step should give ~non-evolving bunch train
- Microbunch wakes add ~resonantly

→ Can approximate the plasma response with
a single short, non-evolving, extra-dense microbunch

Simulation configuration



Short drive bunch (violet) trailed by witness (black)

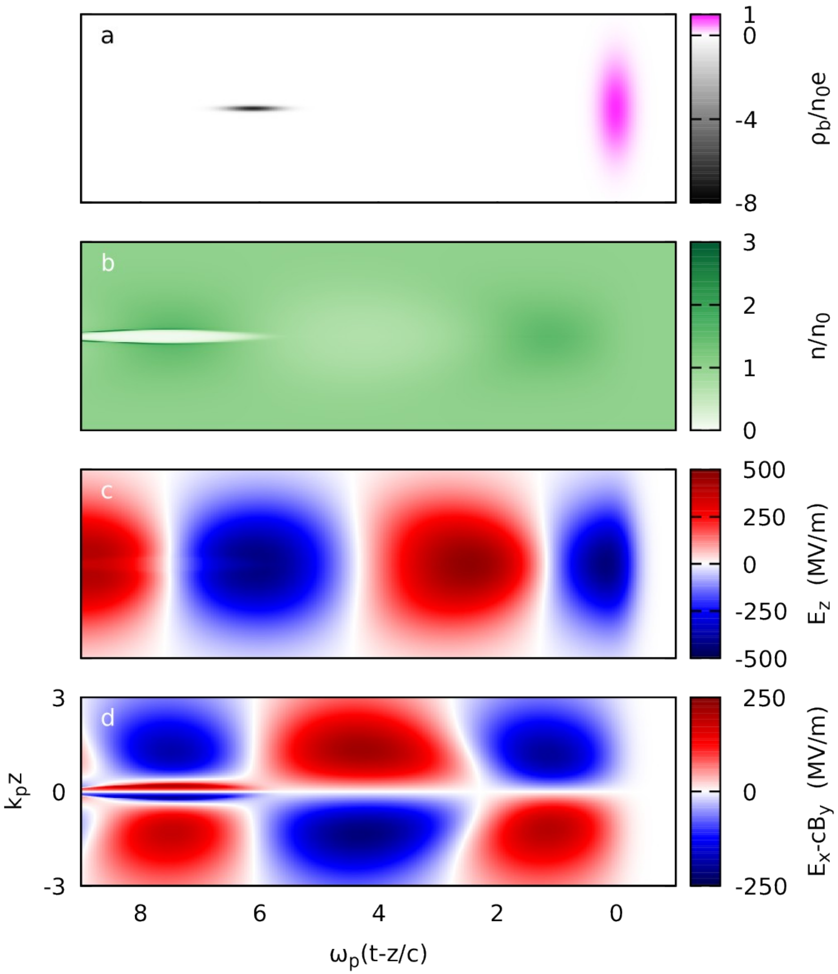
Plasma responds to both bunches. Sufficiently dense witness drive a blowout

Driver generates accelerating wake, witness charge results in “beamloading”

Blowout provides uniform focussing field, allows emittance conservation

Run simulation with LCODE

Simulation configuration



Driver γ=426, σ_y=200 µm

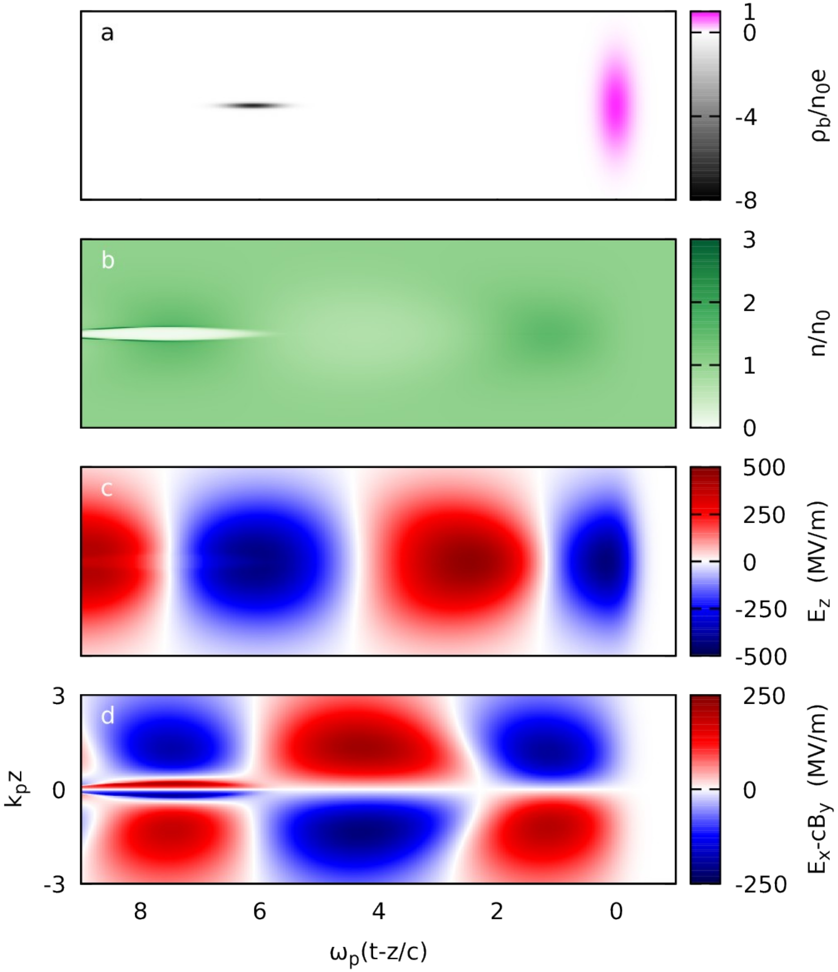
n_0=7x10^{14} cm^{-3}

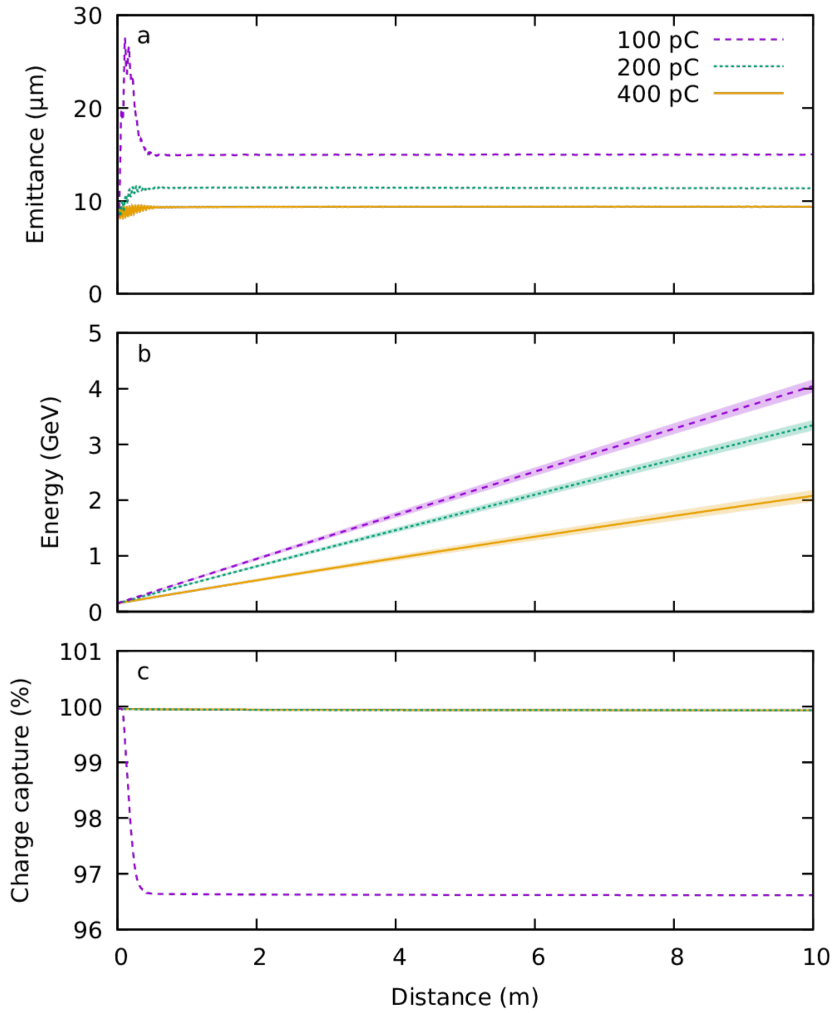
Driver charge chosen for E_z=470 MV/m (density step + 1-m gap, Vlada)

Exactly the model used by Veronica Olsen *et al.* (PRAB,2018)

Run simulation with LCODE

Simulation configuration

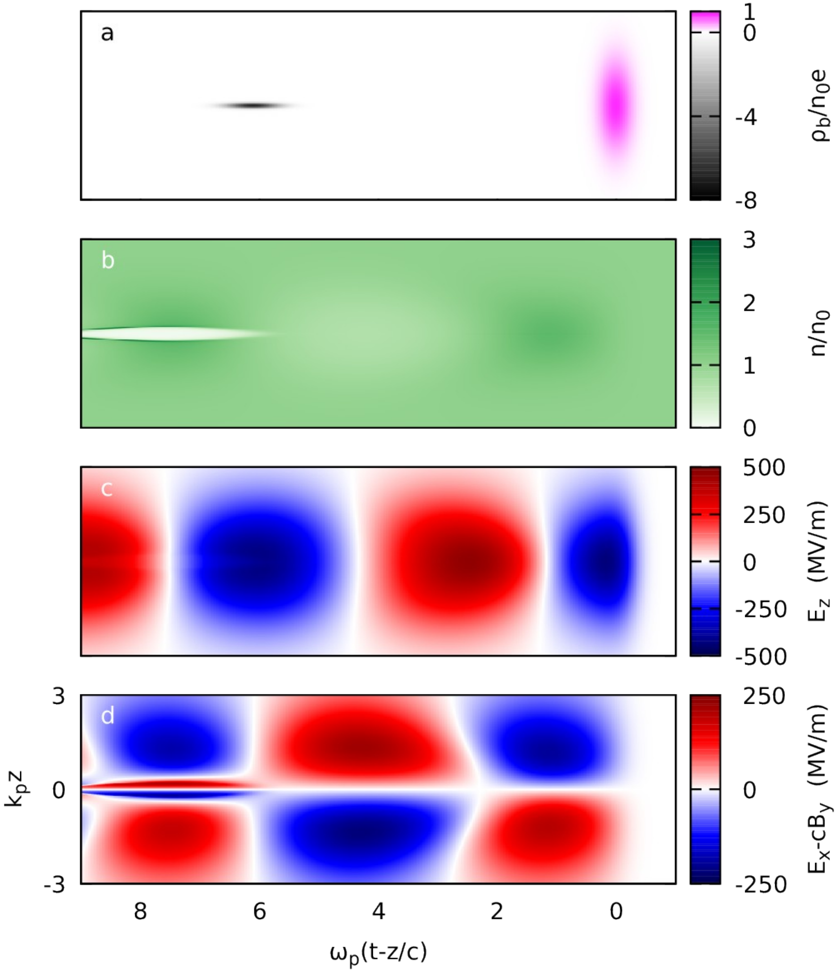




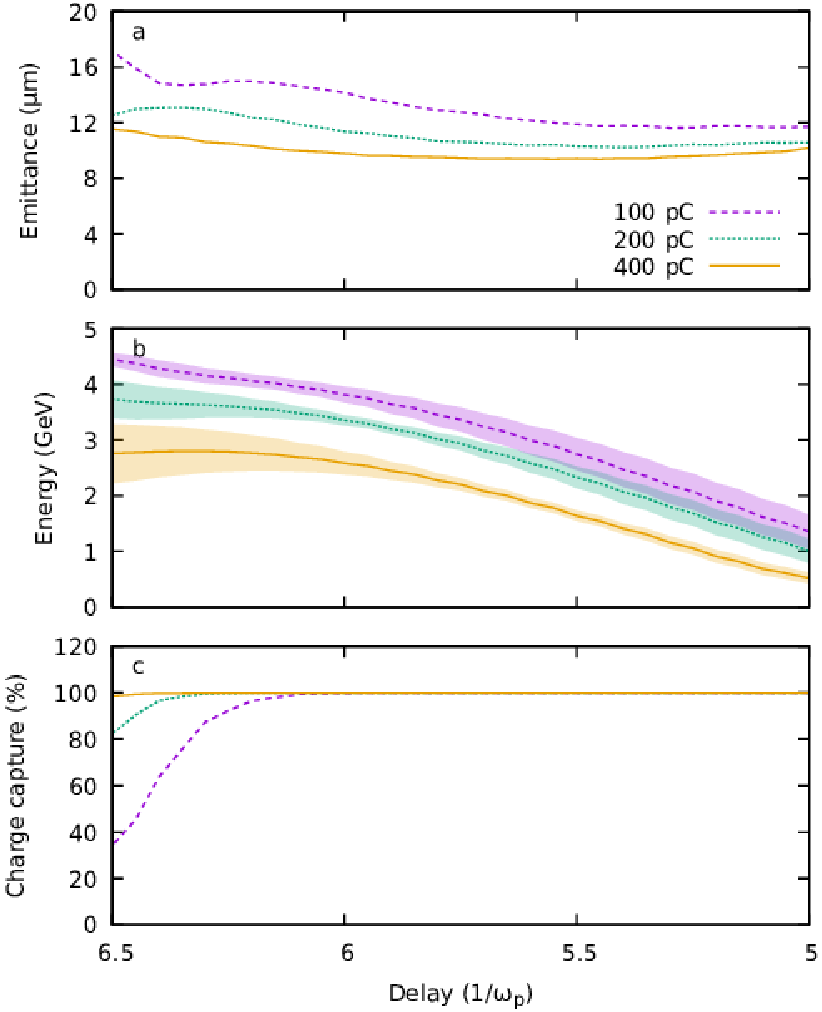
Run simulation with LCODE

Initial witness: 150 MeV, 8 µm emittance

Simple example: delay scan



Run simulation with LCODE



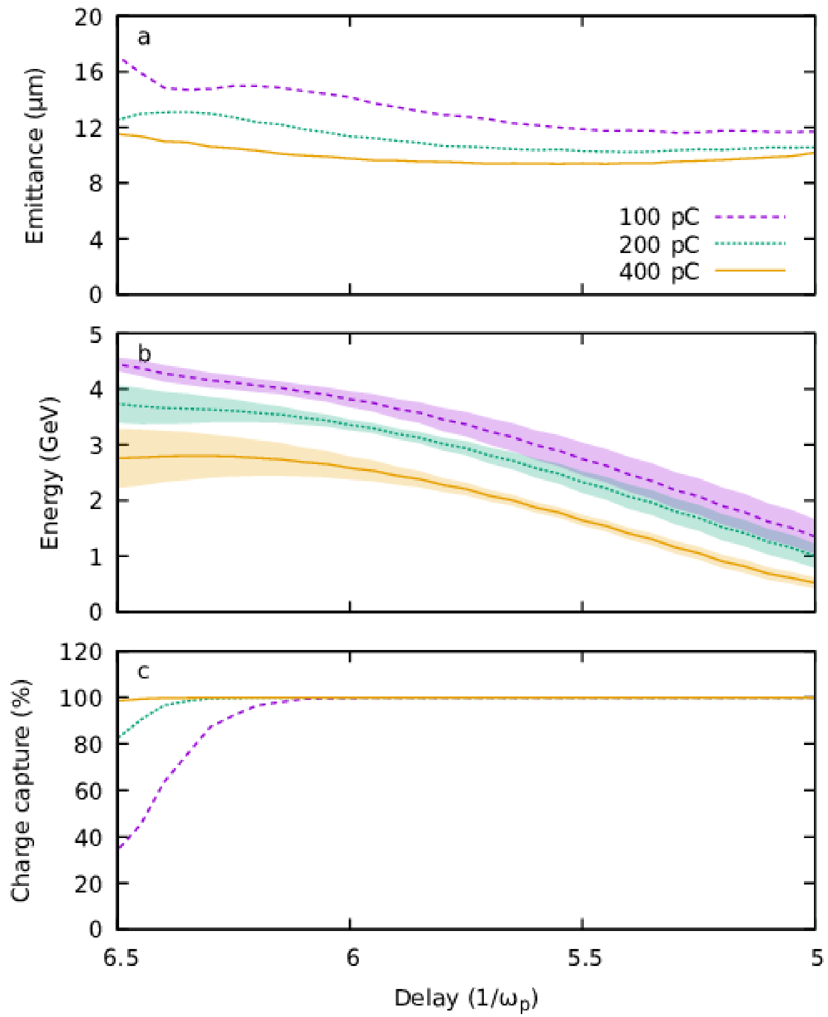
Witness parameters after 10m acceleration

Simple example: delay scan

Lots of physics

- Higher charge gives lower emittance
- Too much charge gives larger energy spread
- Charge loss for larger delays

What is the relative importance of these quantities?



Witness parameters after 10m acceleration

Figure of Merit

The relative importance of emittance, energy spread and charge capture will depend on the desired application.

We simply this by introducing a single metric for beam quality, based on a potential application.

→ Figure of merit

Figure of Merit

Several possible applications for AWAKE
(see recent Symmetry paper)

For this work, we consider the **electron–proton collider**

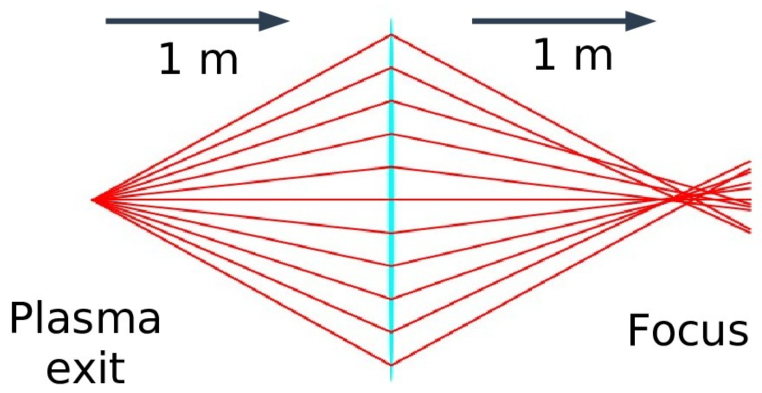
- Exploits AWAKE’s unique position at CERN
- Challenging but achievable requirements on beam quality

Figure of Merit

Relevant quantity is the charge that can be focussed into cross-section of counter-propagating proton beam

Calculation (by Allen) suggests a proton beam radius ~10 μm

Can again use a toy model, this time for beam transport



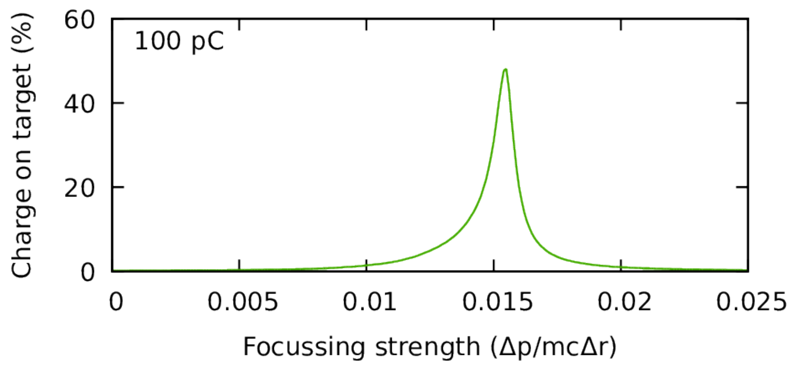
Perfect focussing element, 1m from plasma exit

Measure charge on a 10-μm-radius target, a further 1 m downstream

Figure of merit

- Take simulation output after 10 m of acceleration
- Scan focussing strength
- Measure charge on target

Single simulation



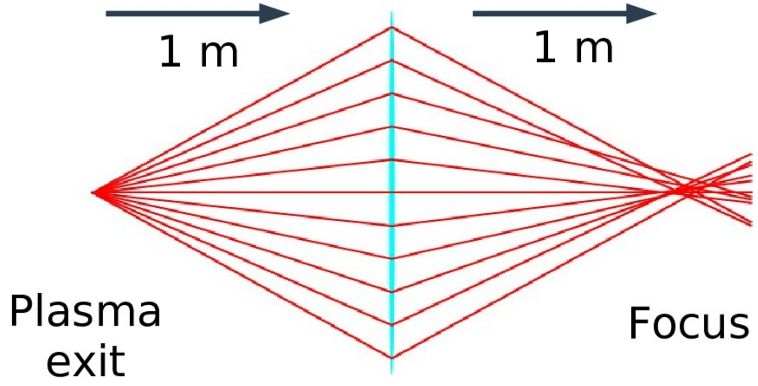
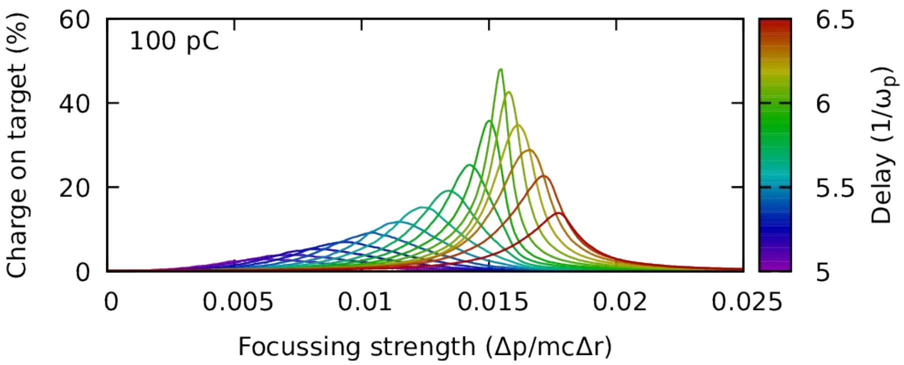


Figure of merit

- Take simulation output after 10 m of acceleration
- Scan focussing strength
- Measure charge on target

Delay scan



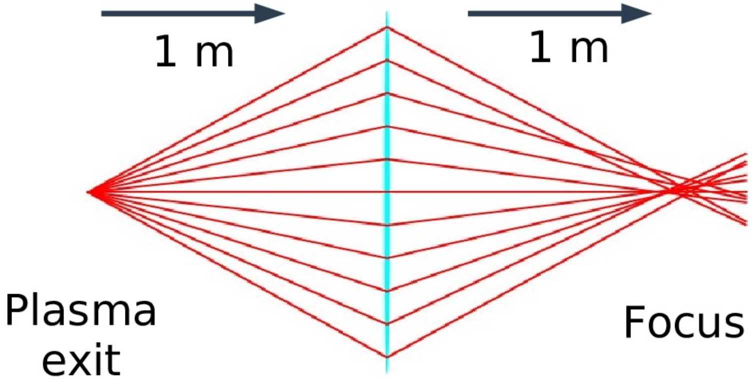


Figure of merit

- Take simulation output after 10 m of acceleration
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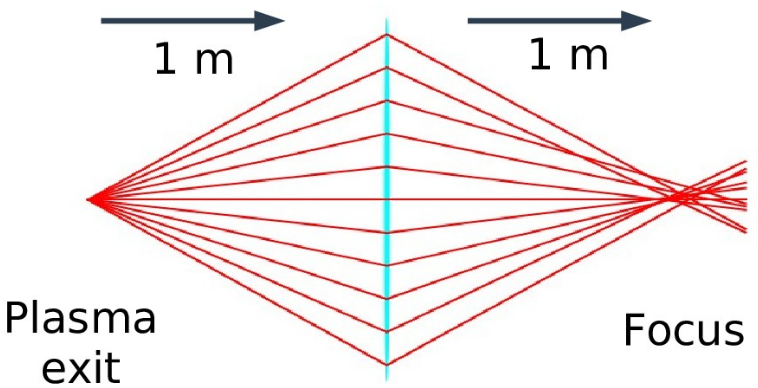
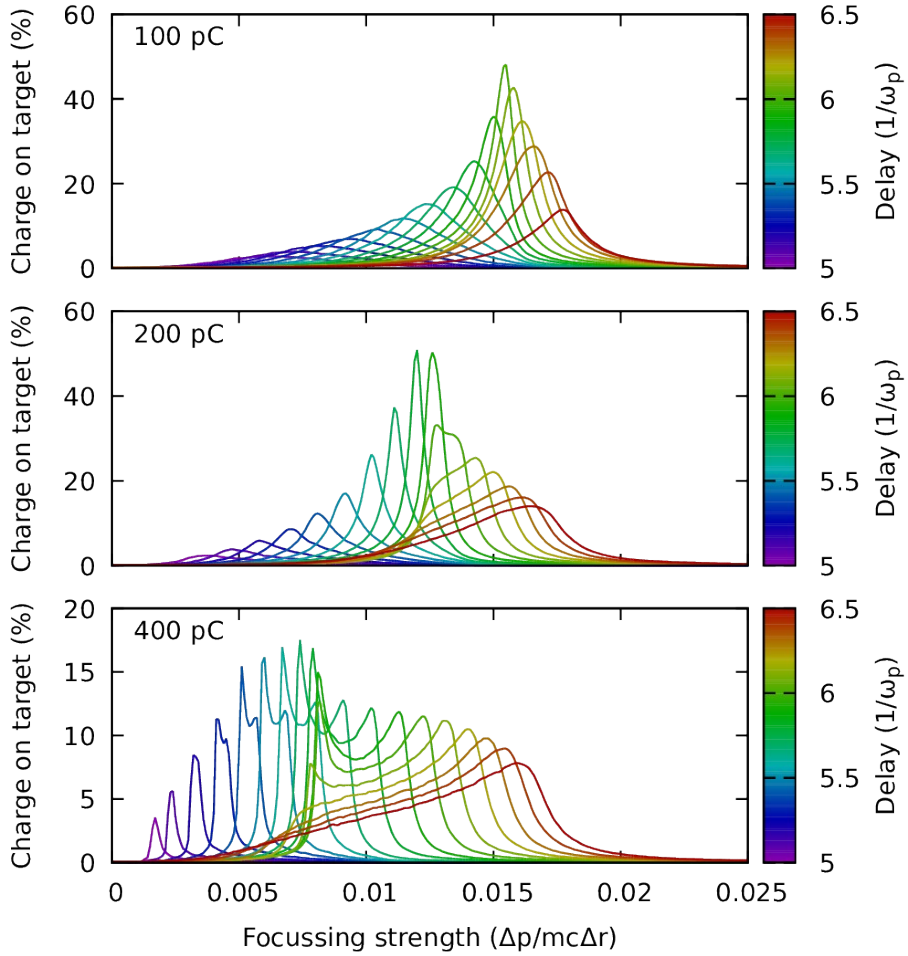
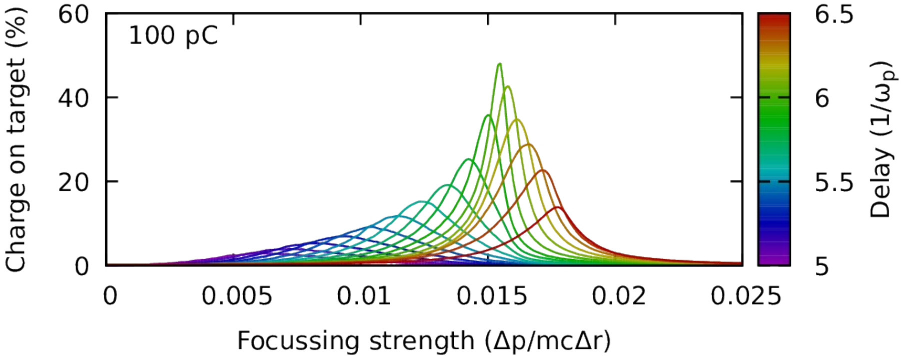


Delay scan: different charges

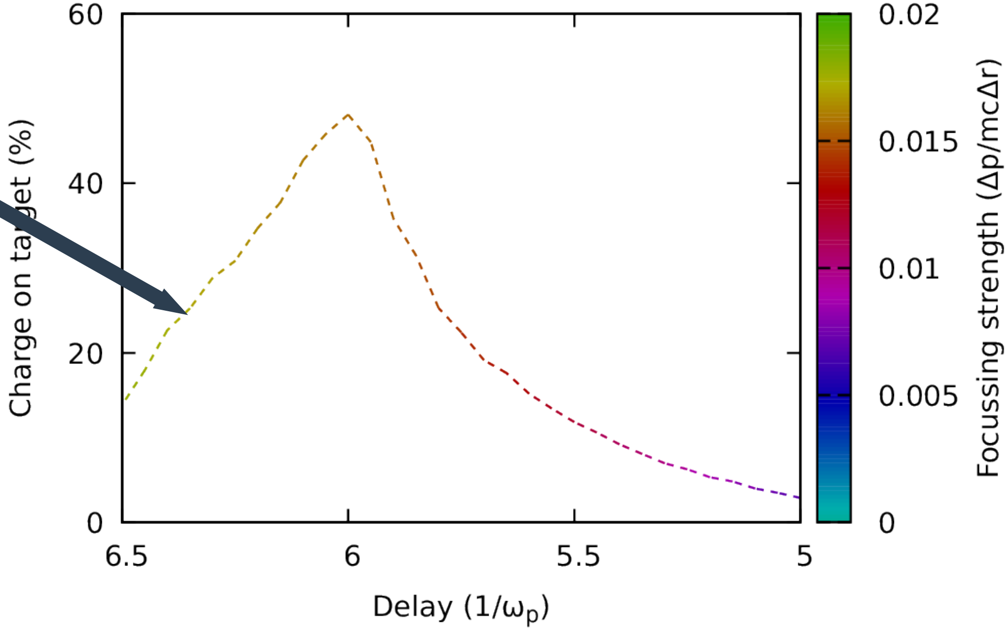


Tunability vs stability

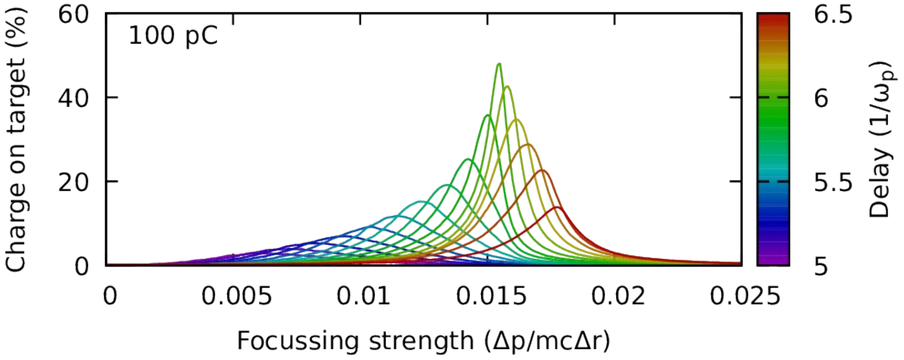


Looks pretty.
Is it useful?

Scan delay while optimising focussing: **tunability** constraint



Tunability vs stability



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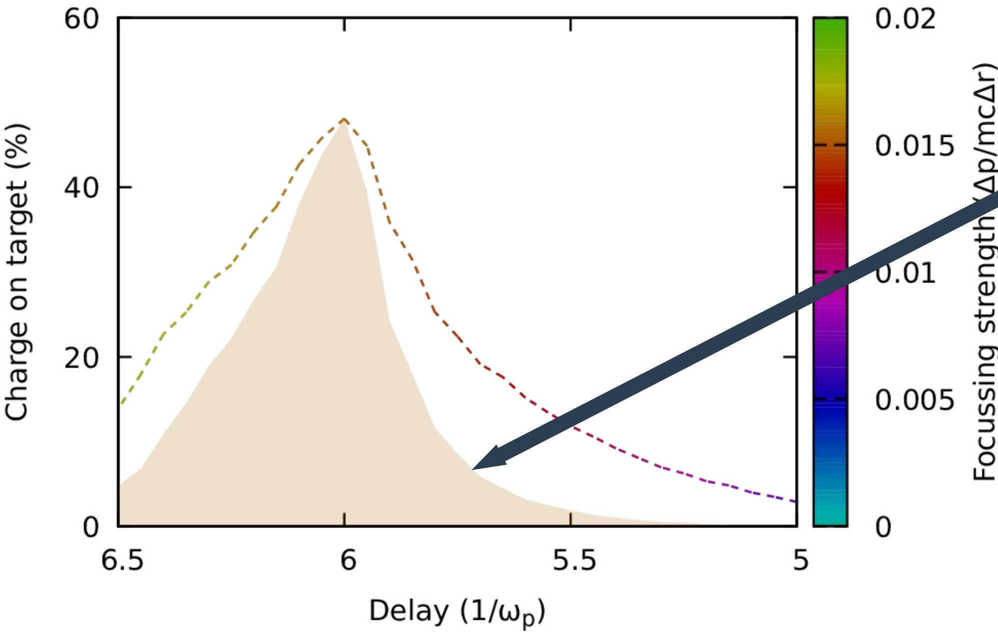
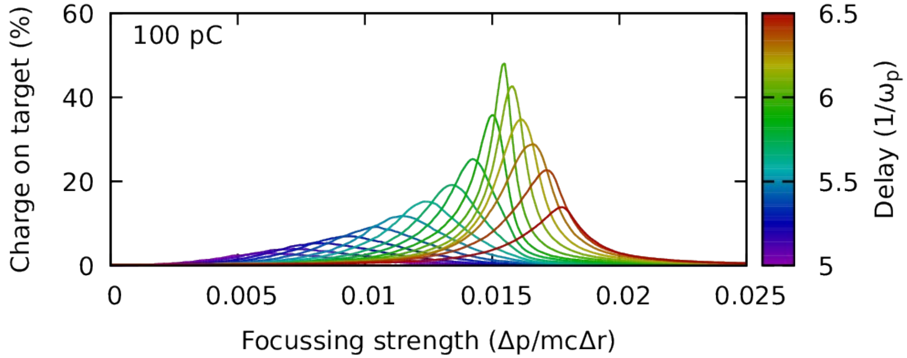
Scan delay while optimising focussing: **tunability** constraint



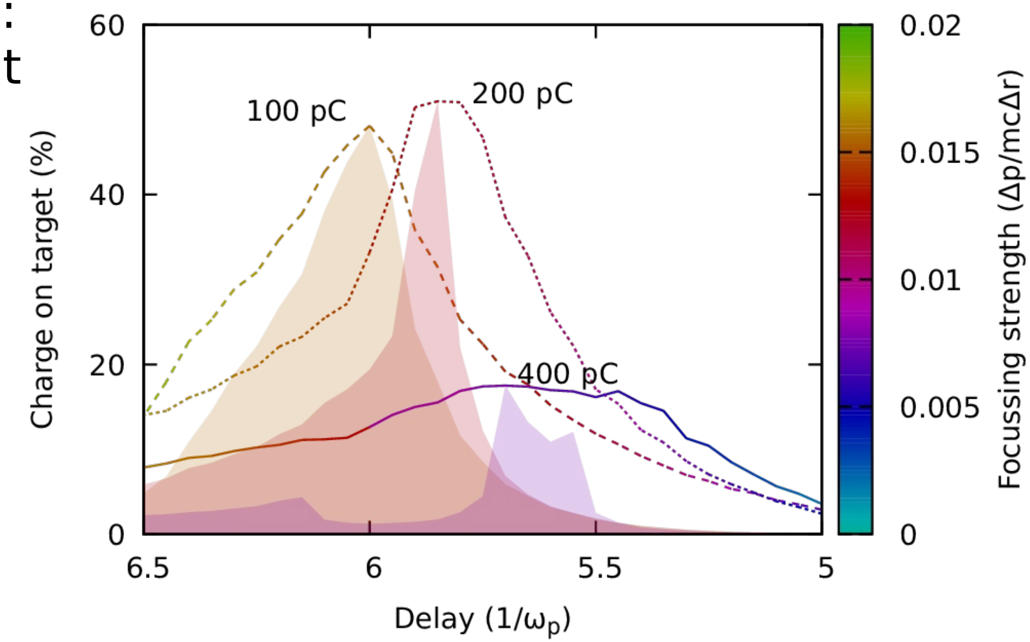
Scan delay with fixed focussing: **stability** constraint

Tunability vs stability



Looks pretty.
Is it useful?

Scan delay while optimising focussing: **tunability** constraint



Scan delay with fixed focussing: **stability** constraint

Interlude

Figure of merit

We develop a figure of merit to characterise the beam quality.

It is application-based, and uses the whole distribution.

This naturally gives rise to constraints on tunability (scan with adaptive focussing) and stability (scan with fixed focussing).

Any questions?

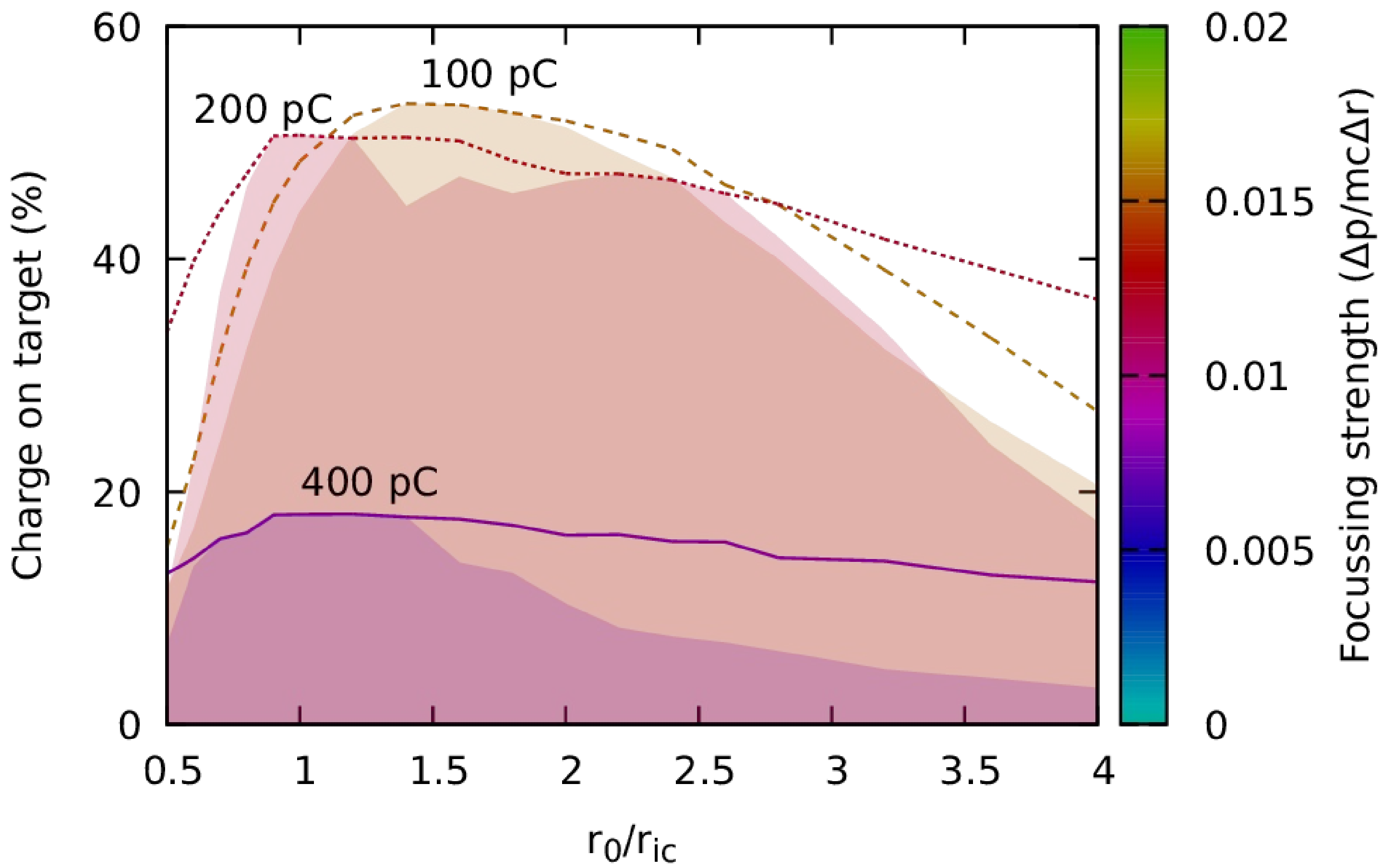
The rest of the presentation is based on these ideas, so ask now.

Tolerances: radius

Acceleration quality depends only weakly on radius at the injection point. Good news!

Lots of physics here, ”self-matching” of the wakefields to the witness bunch.

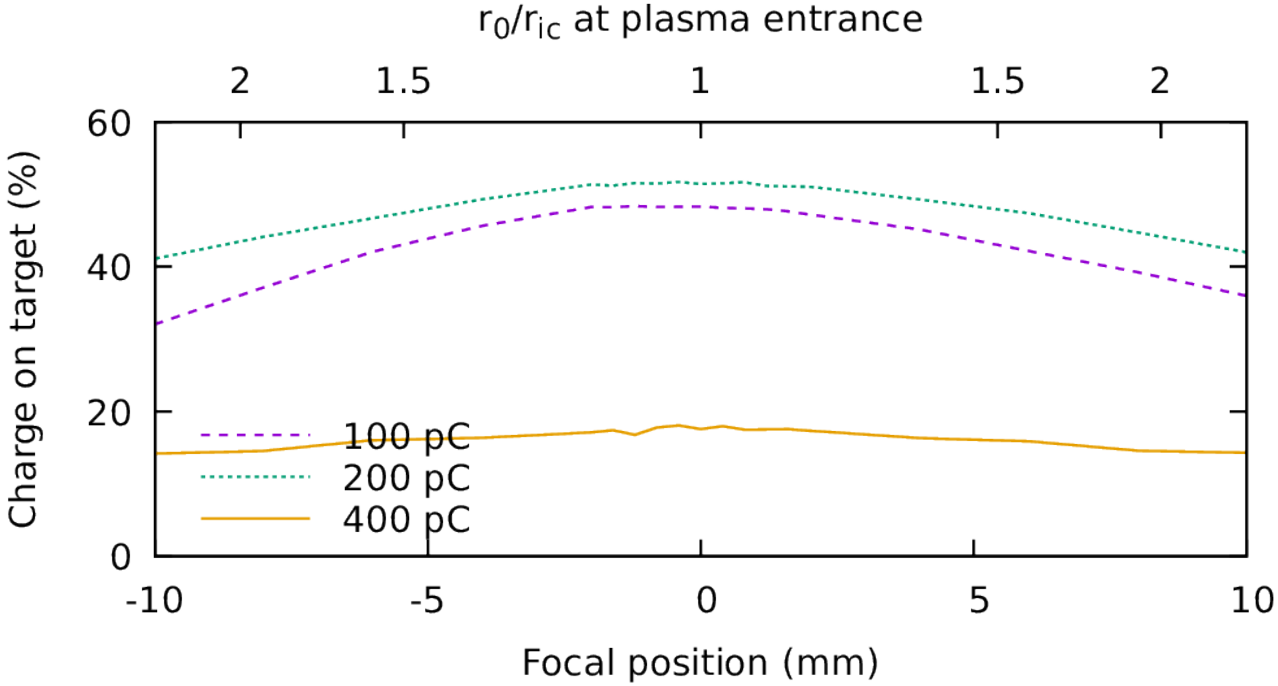
Doesn’t mean radius doesn’t matter - scattering plays a role (see Rebecca’s forthcoming paper)



Tolerances: focal position

Again, weak dependence on focal position, and again, there will be design constraints due to scattering.

Likely some interesting physics here, effect stronger than equivalent change in radius only.



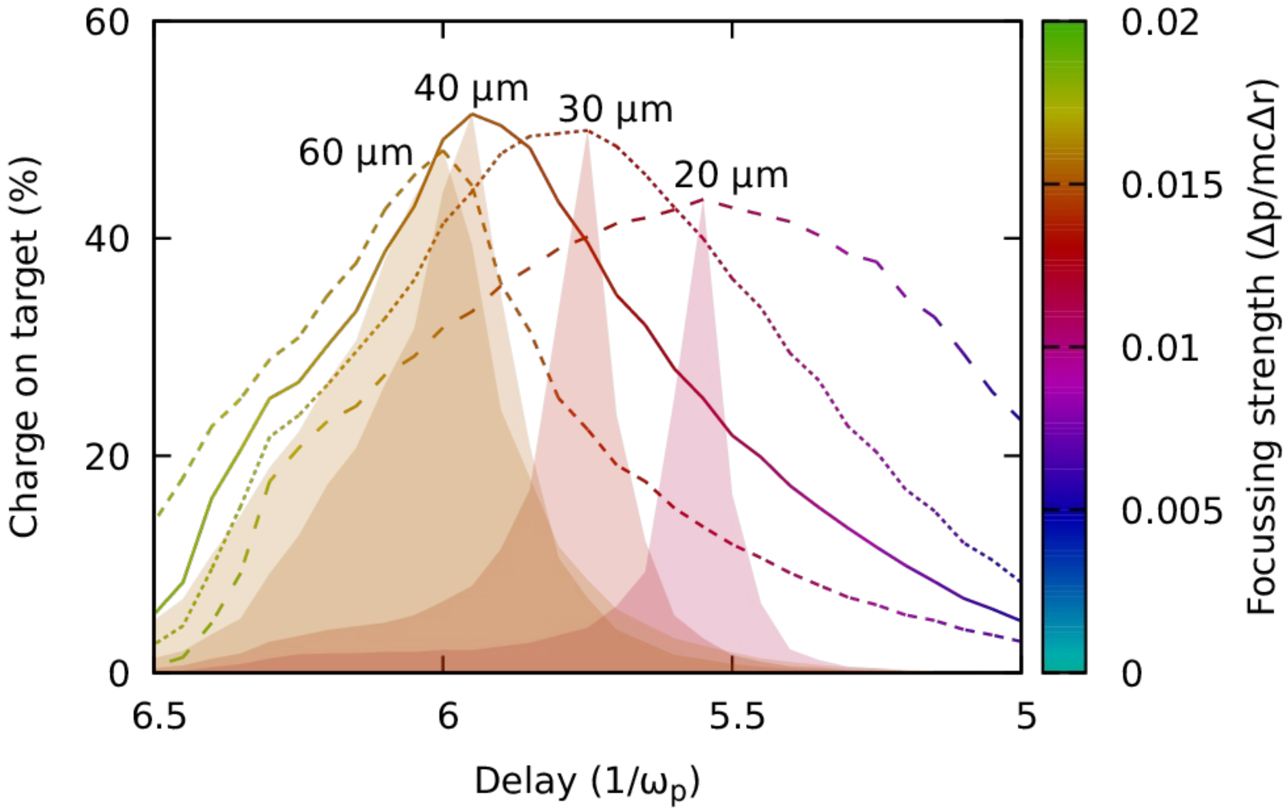
Waist size chosen as matched radius r_{ic}.
Negative values is waist before plasma.

Tolerances: witness duration

Achievable beam quality depends only weakly on witness length.

However, length changes the relative constraints on tunability and stability.

Arises due to energy spread – shorter witness gives smaller spread over larger range of delays, so moves out of focus more rapidly.



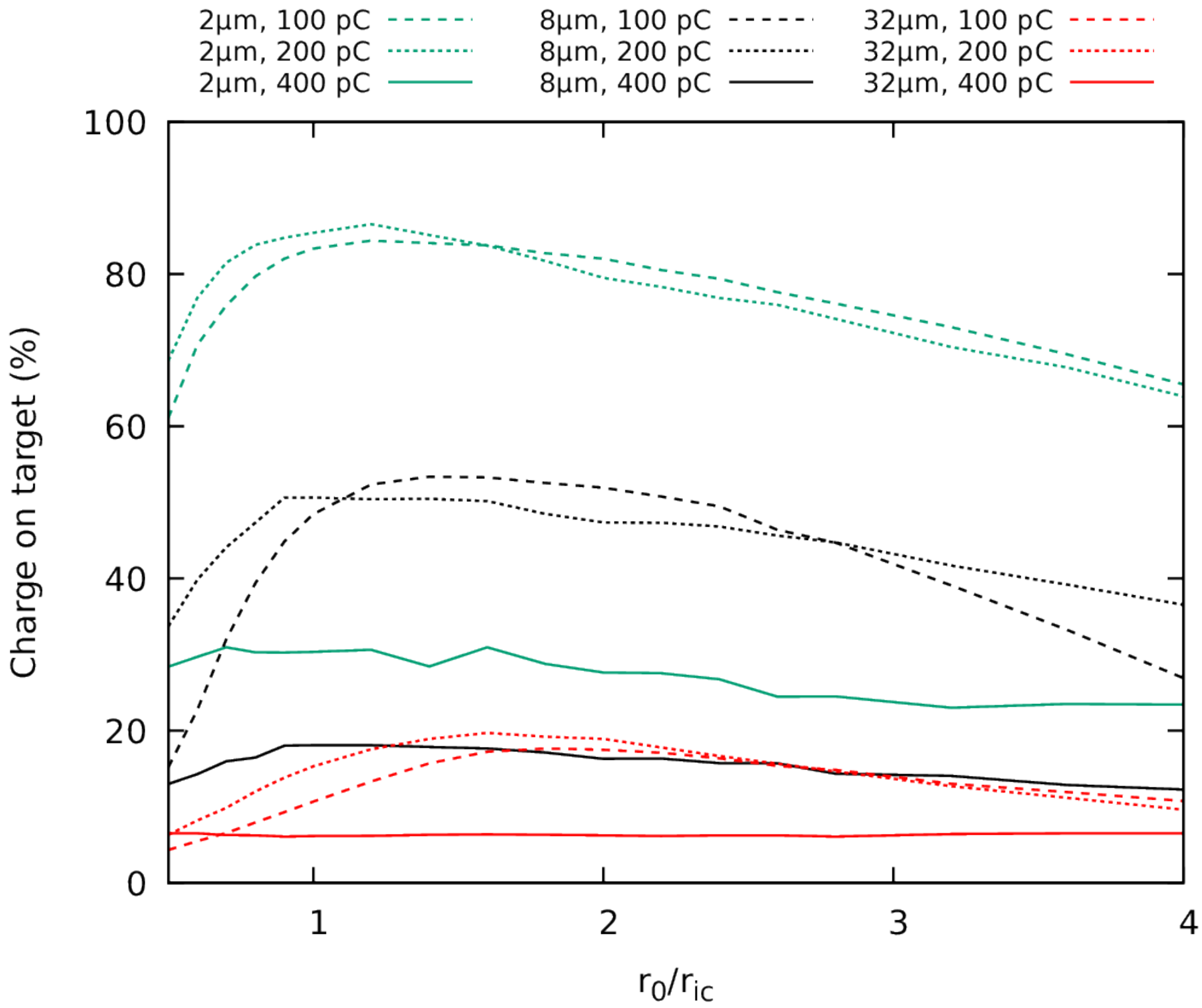
Waist size chosen as matched radius r_{ic}.
Negative values is waist before plasma.

Tolerances: influence of emittance

Nothing too surprising here – lower emittance gives better quality accelerated beam.

Shift of optimal radius to larger values for higher emittance confirms role of blowout formation.

Trends for charge are similar for different emittances.

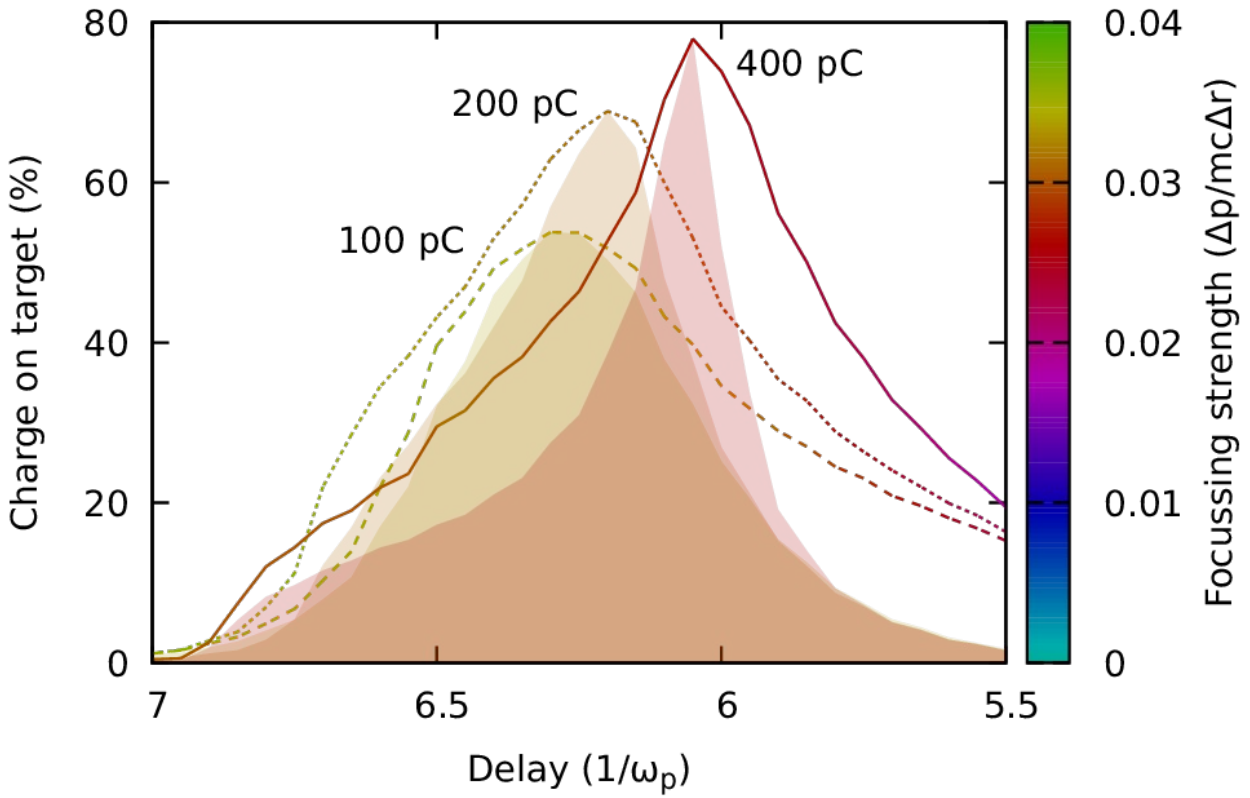


Influence of wakefield amplitude

Double wakefield amplitude to 950 MV/m (equivalent to no gap between plasmas - see simulation in symmetry, Giovanni's talk today)

Changes charge dependence – larger wake supports/requires larger charge

Higher achievable charge on target – influence of lower emittance finally plays a role.



Conclusion (1/2)

Introduction of a figure of merit

- Based on a “toy model” transport system for an electron–proton collider
- Gives the quality of the accelerated beam in a single metric, allowing different configurations to be easily compared
- Naturally leads to constraints on tunability and stability

Conclusion (2/2)

Results for the tolerances are very positive.

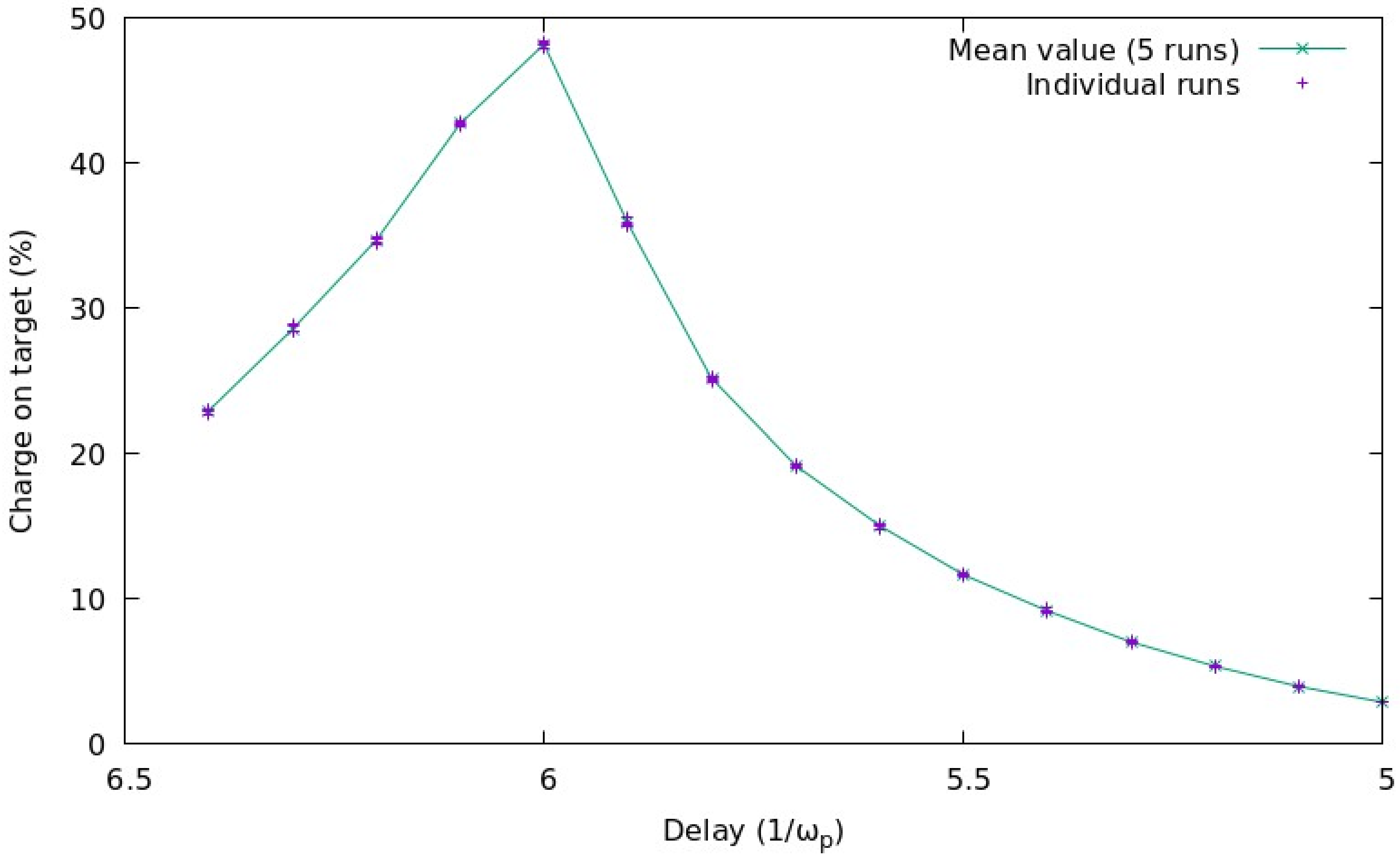
- 100 – 400 pC charge (optimal depends on wake amplitude)
- Few μm emittance before laser beam dump
- Broad tolerances for bunch length and radius at injection

Main questions for LWFA are likely technical
(beam transport/integration)

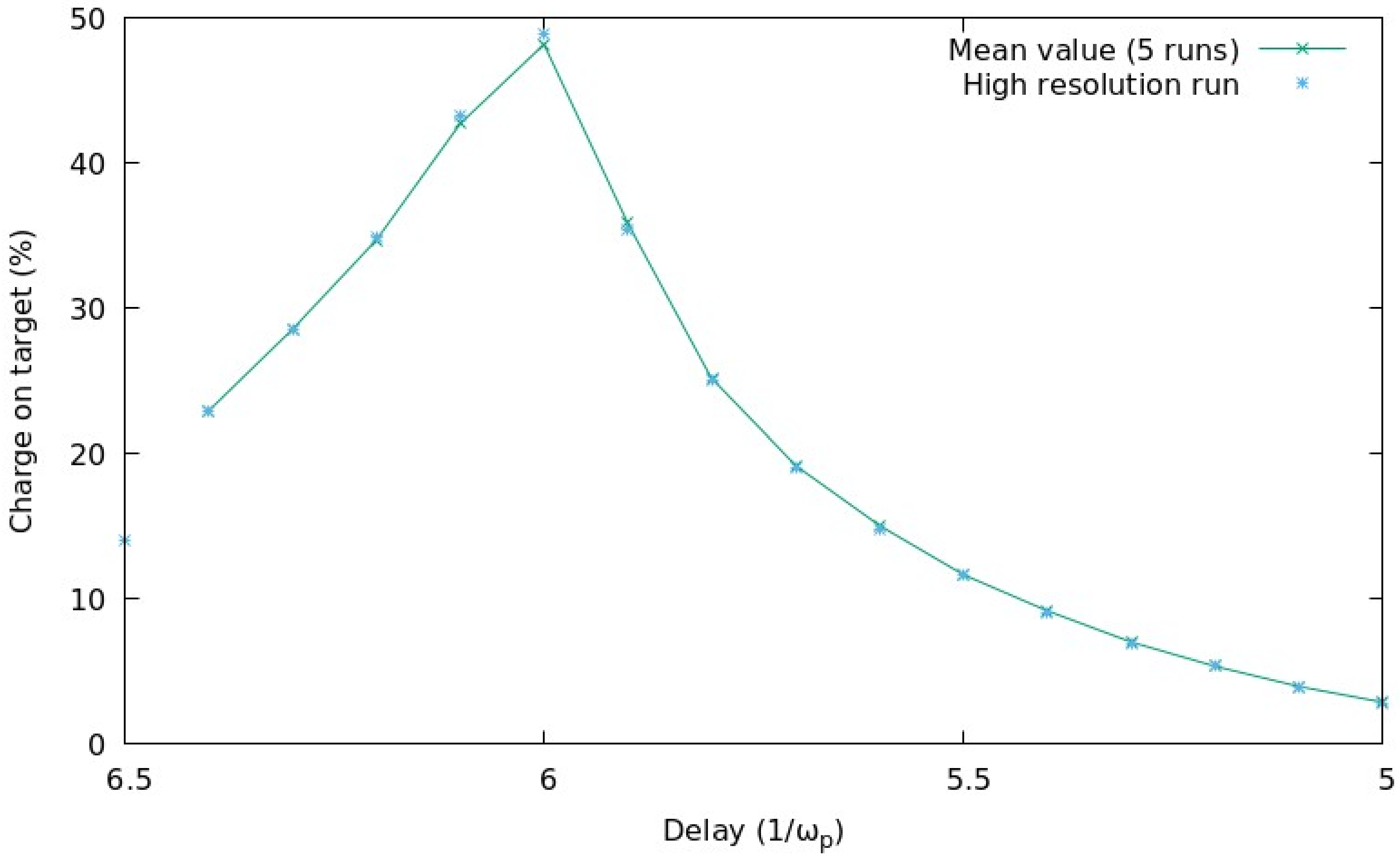
Draft paper available now:
http://arxiv.org/abs/2203.11622

~FIN~

Extras – RNG noise

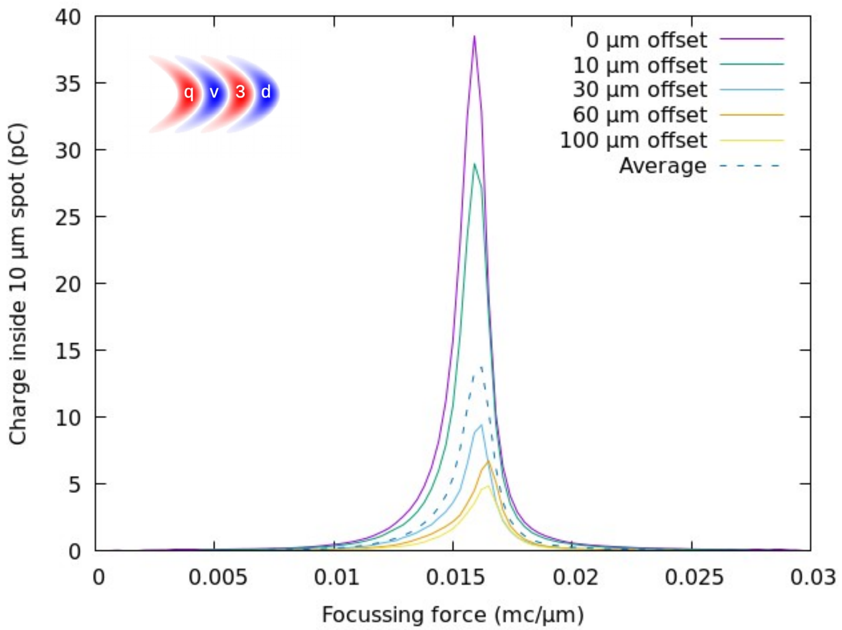


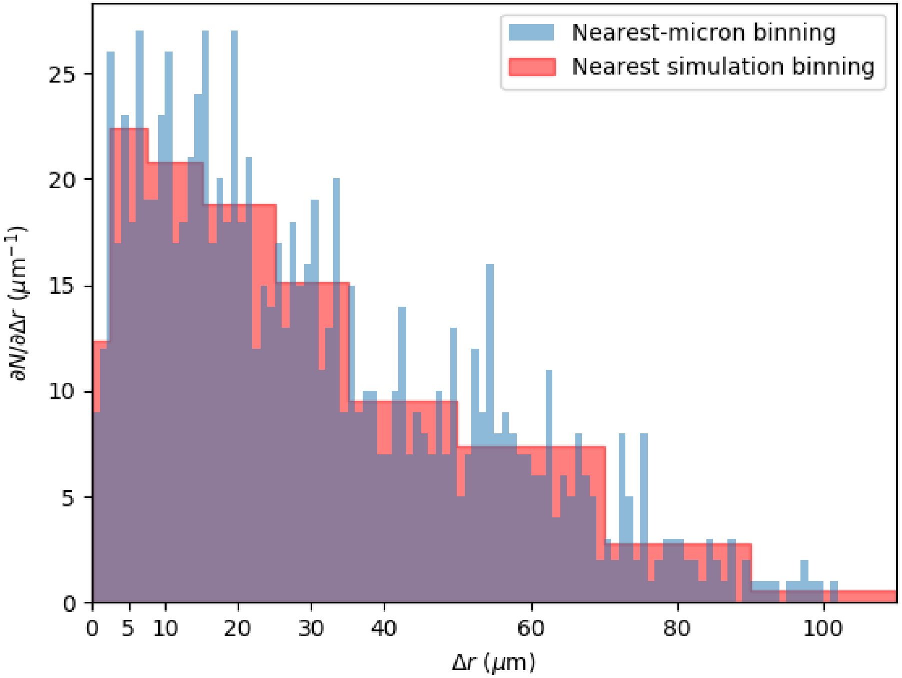
Extras – resolution convergence



Extras – transverse jitter

Using simulated extractions from MAD-X, the average values for beam quality can be extrapolated

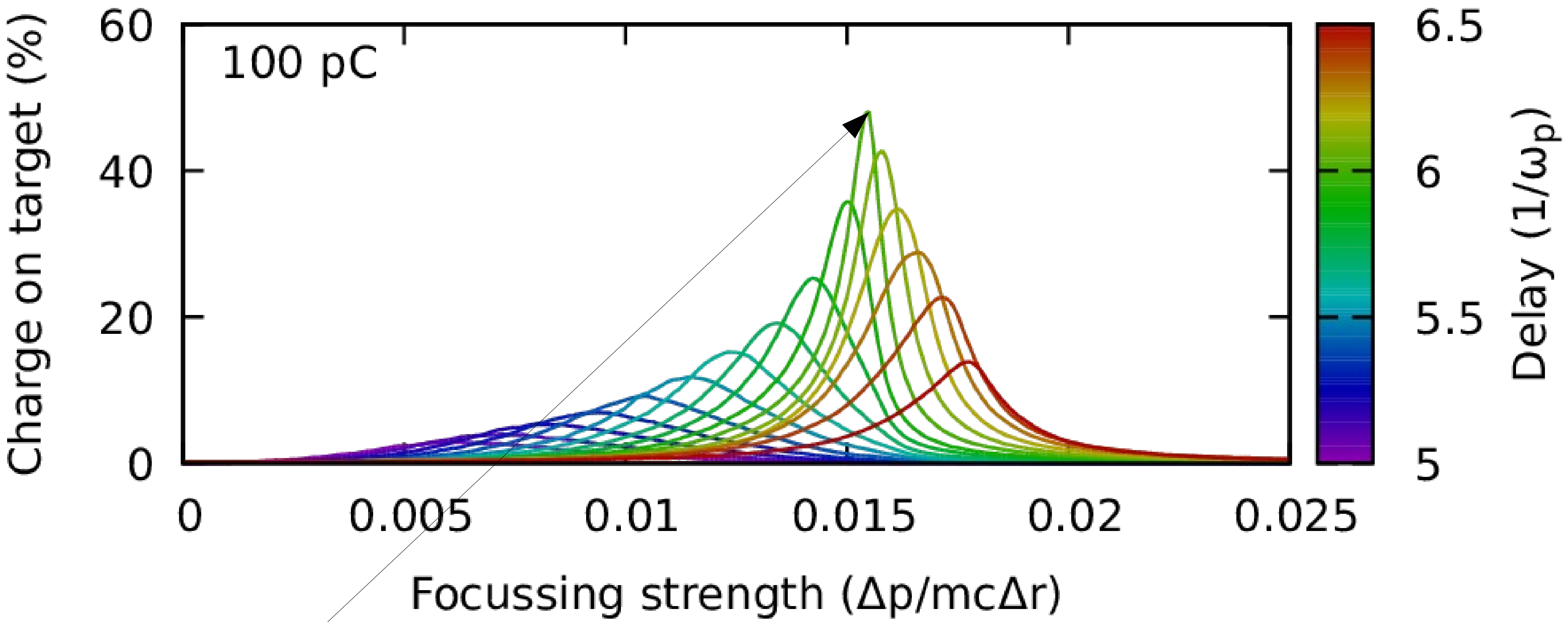




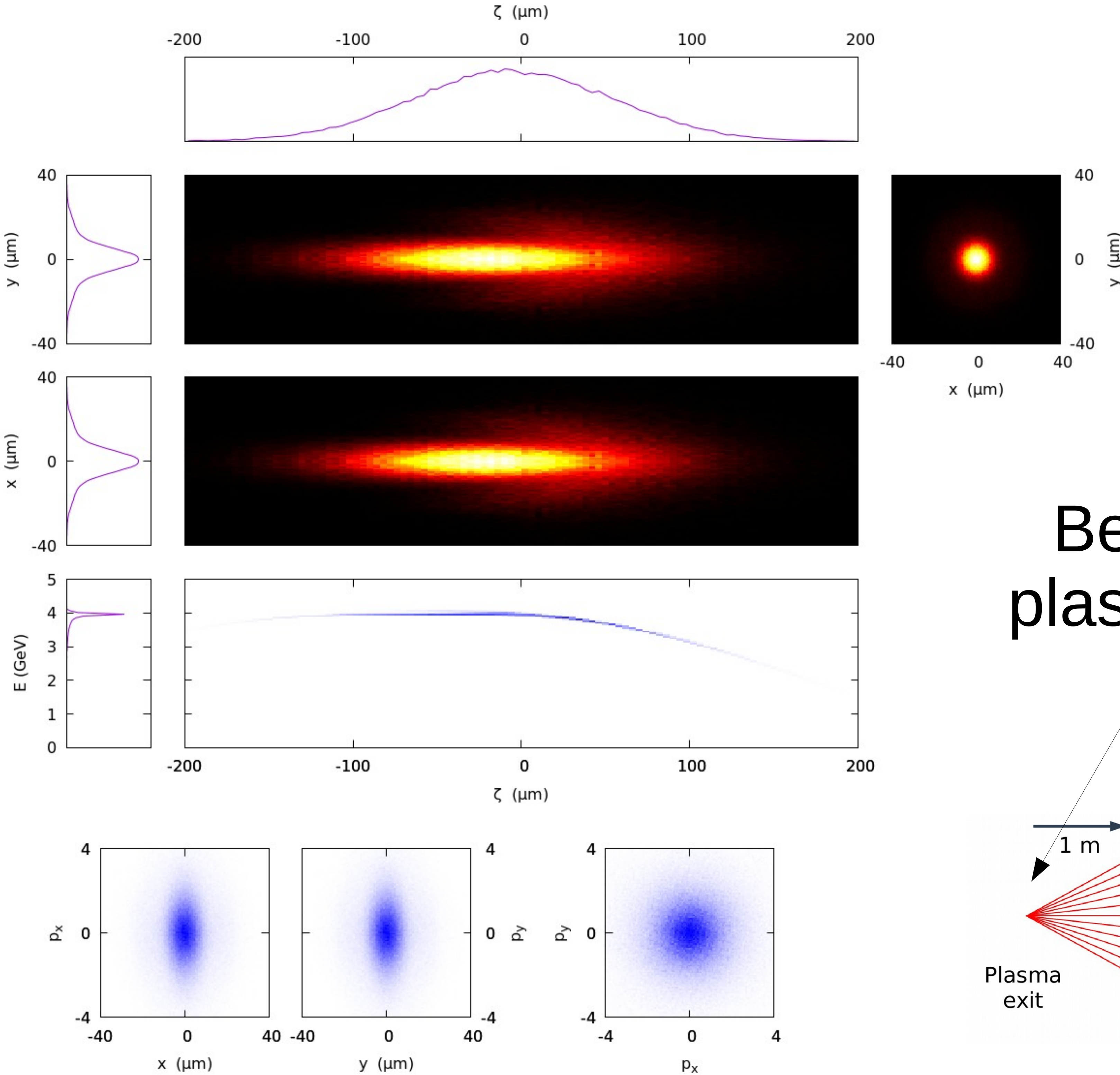
1000 simulated shots, Velotti *et al.*

Preliminary results (CSR),
Martin currently working towards a paper.

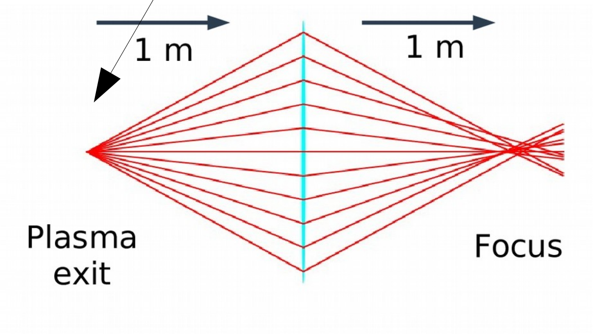
Extras – which particles get “lost”?

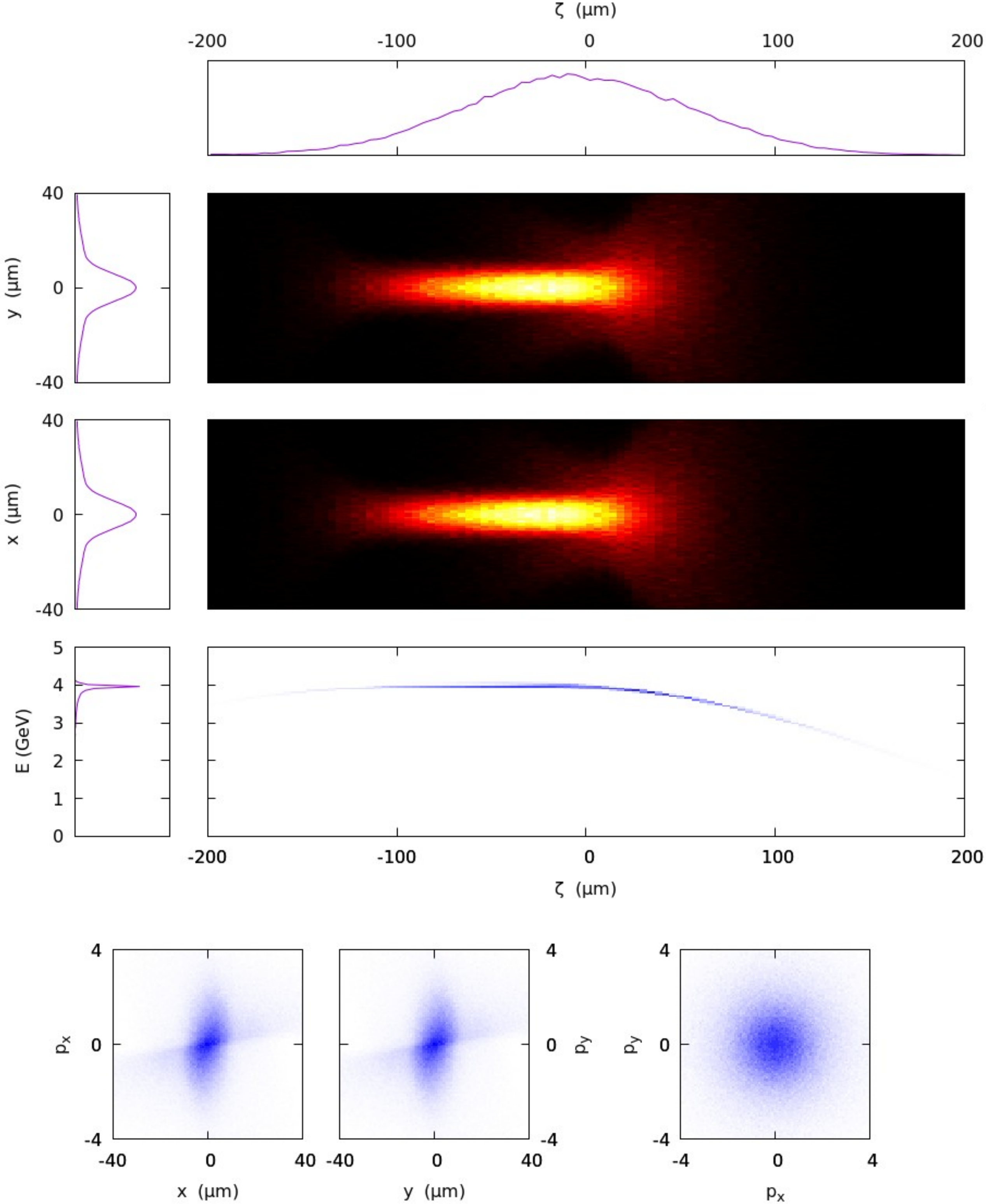


Consider optimal focussing for optimal delay for 8-µm, 100-pC bunch

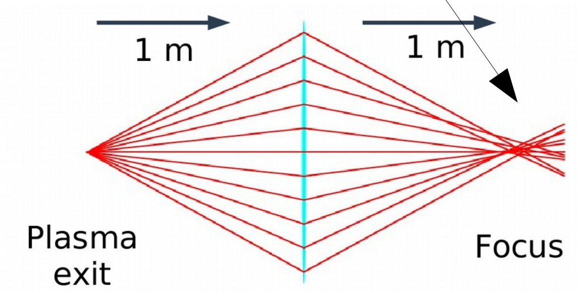


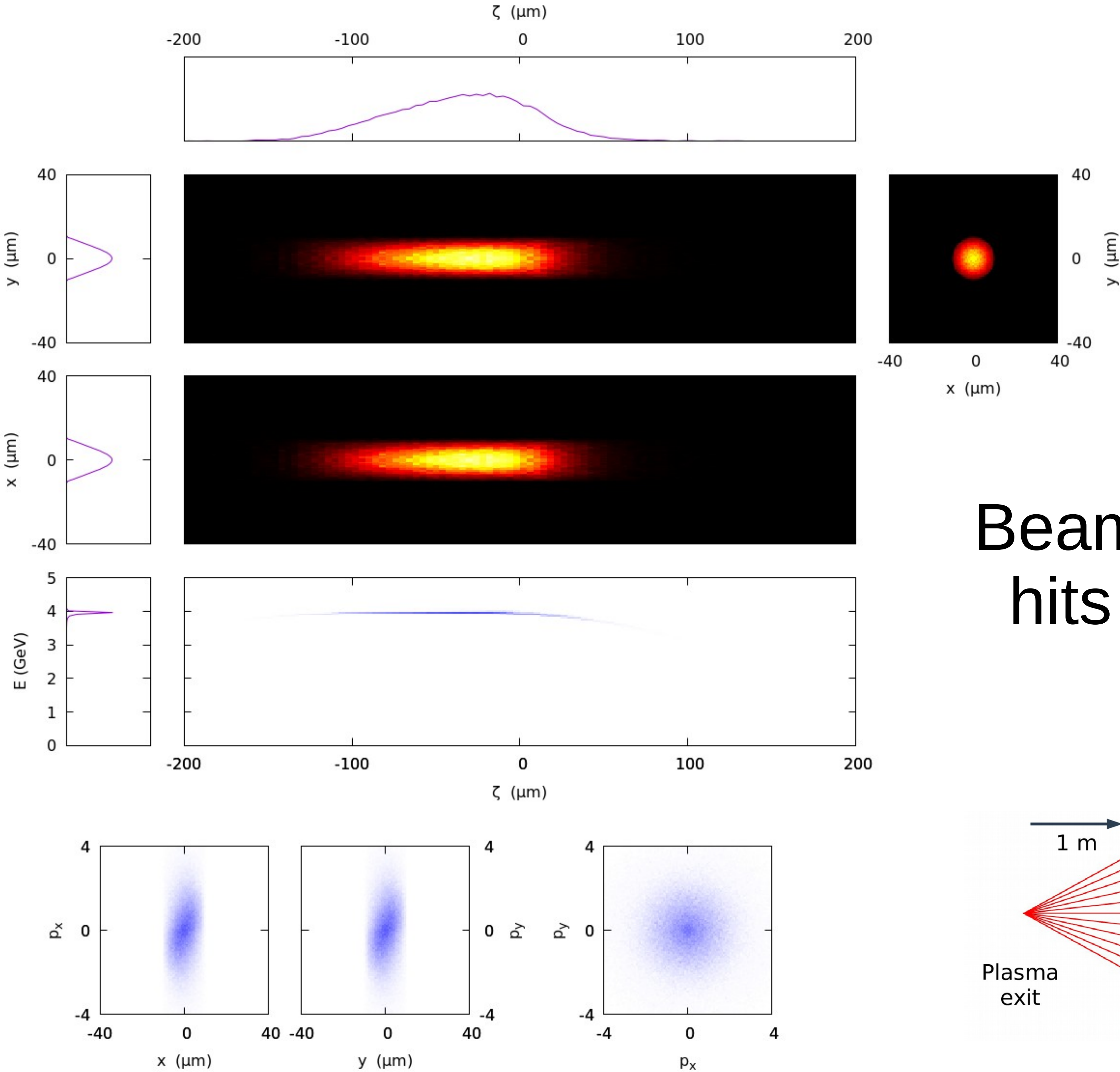
Beam at plasma exit



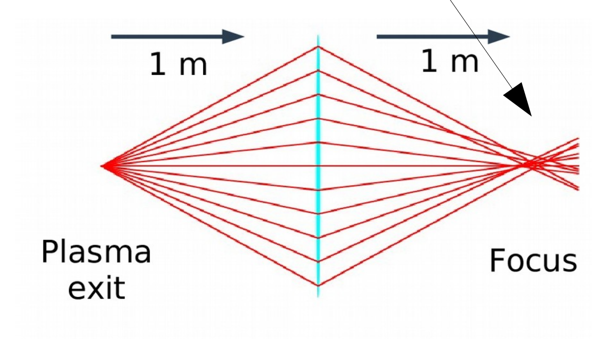


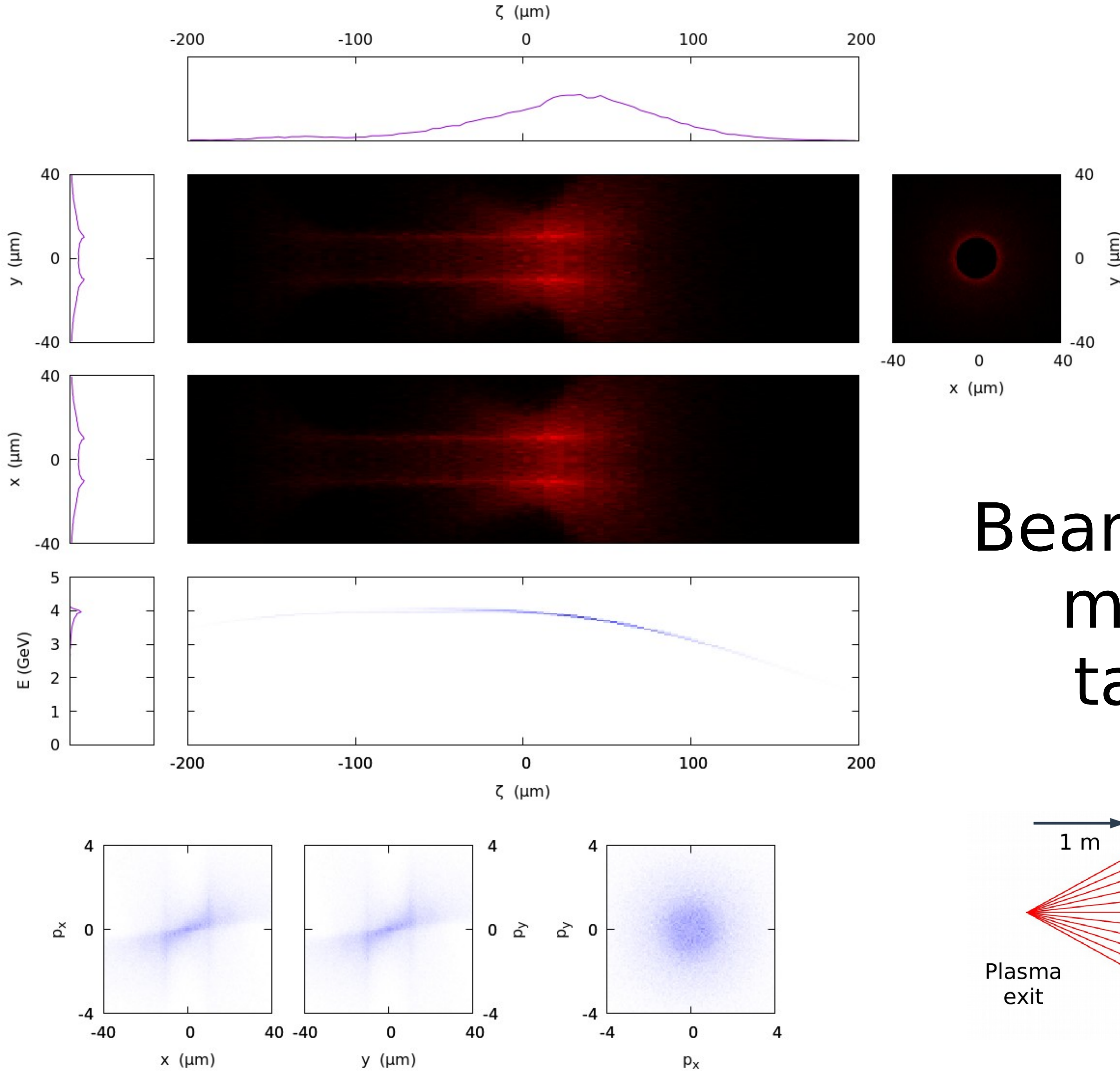
Beam at target



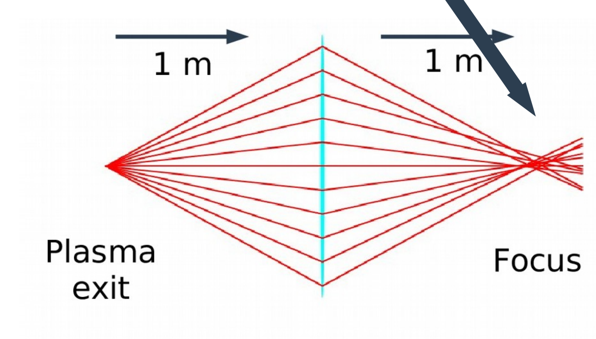


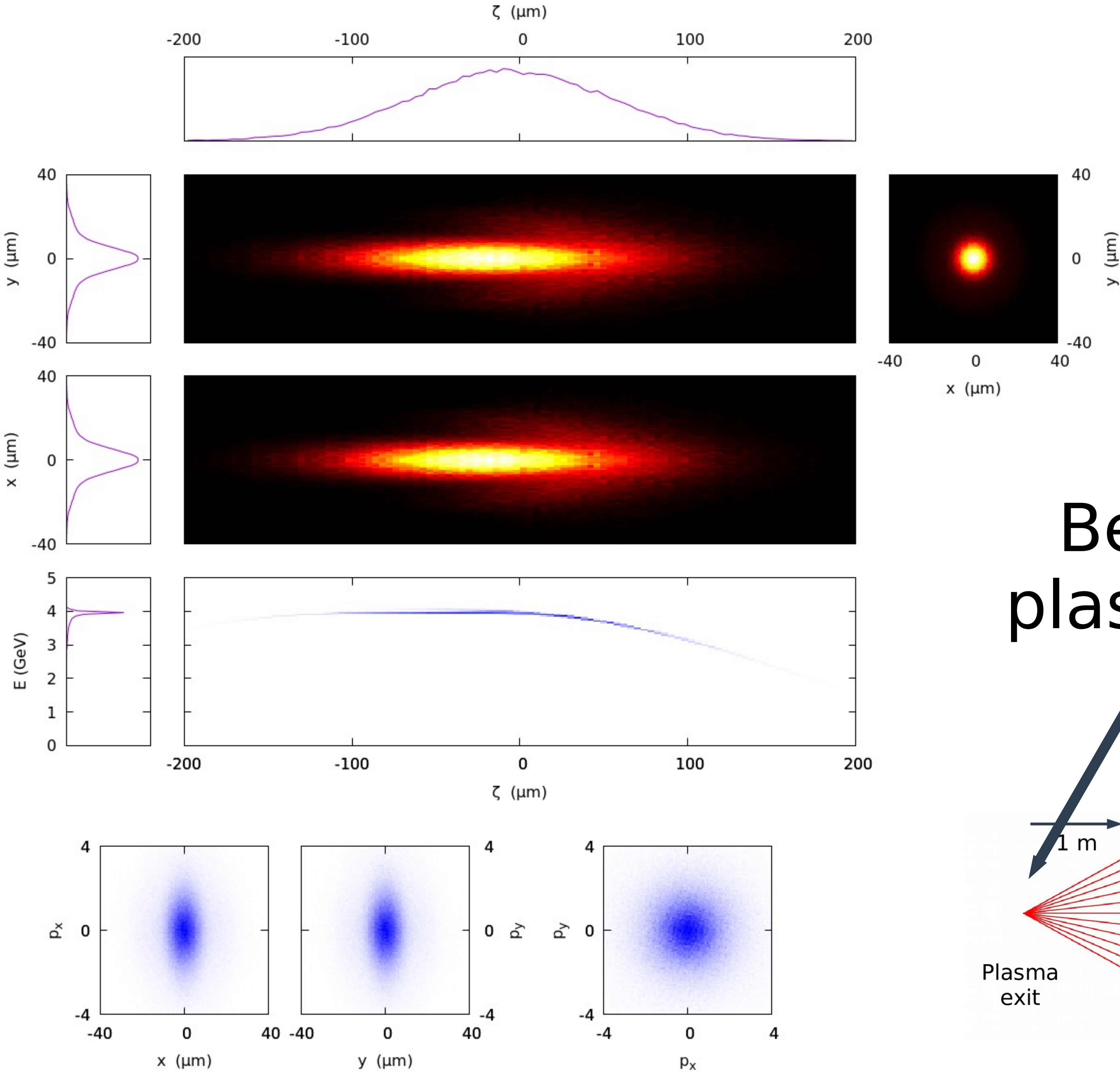
Beam which hits target



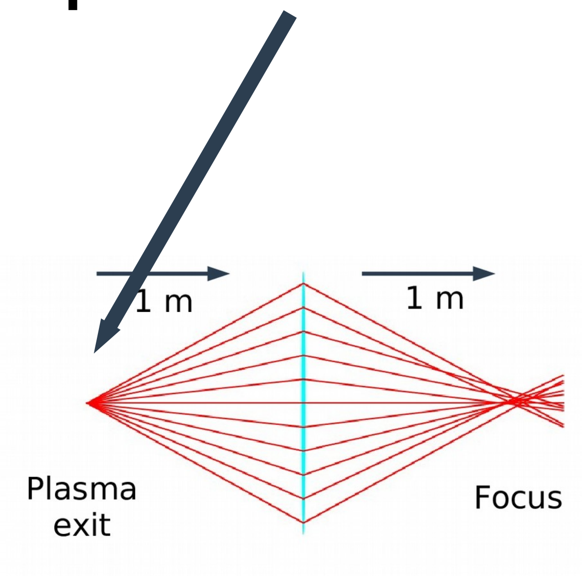


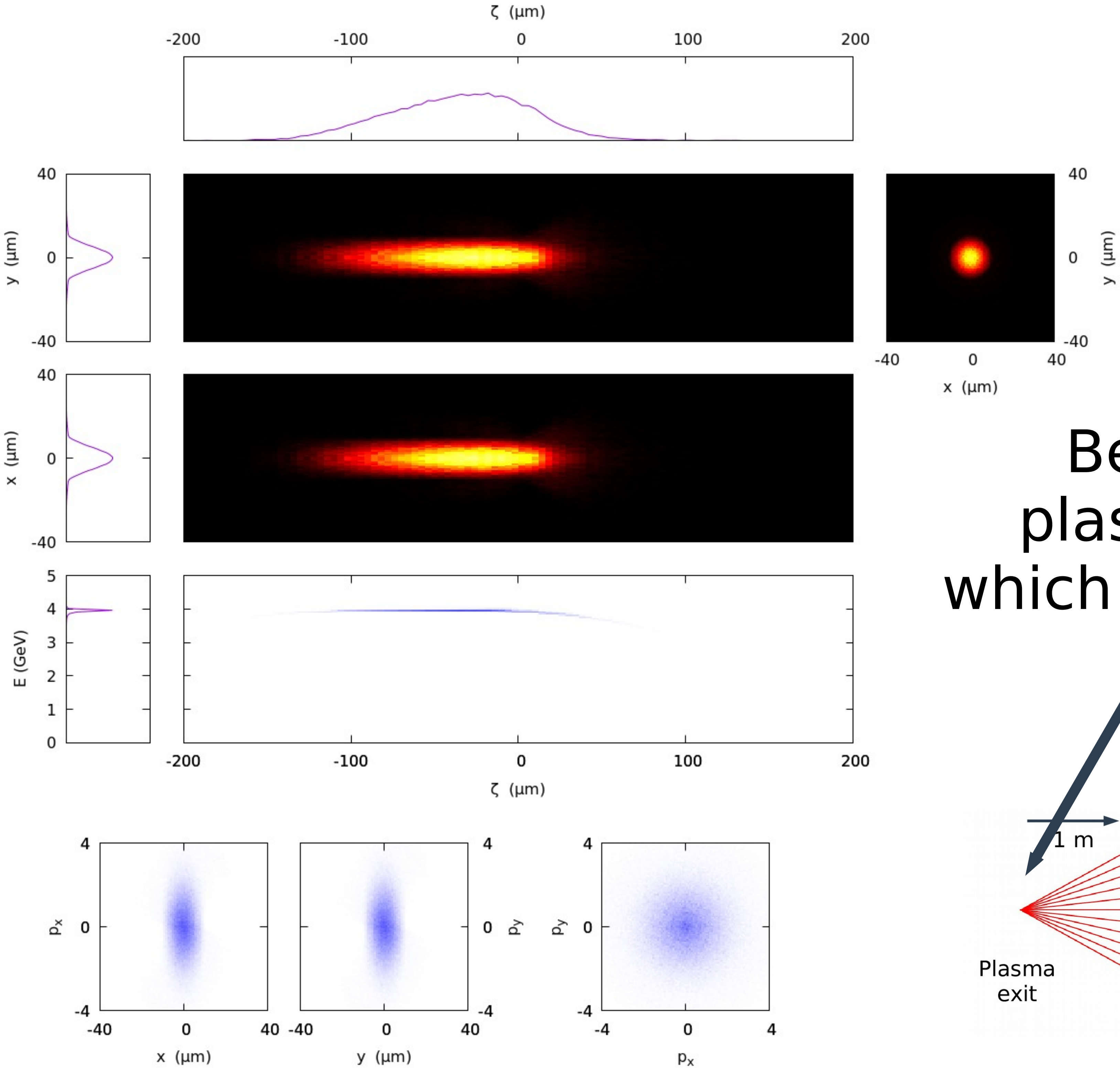
Beam which misses target





Beam at plasma exit





Beam at plasma exit which hits target