Simulations for the Gamma Factory Proof-of-Principle Experiment

A. Petrenko

Gamma Factory workshop at LAL, Orsay, June 3, 2019.

Overview of Simulations & Theory

Theory:

Evgeny Bessonov's Note: Latest MS Word version is available at our OneNote Page at CERN.
Latex version: https://www.overleaf.com/read/gpjksbkrxqcx

Another simplified version inserted into the Yellow Report:
https://www.overleaf.com/read/ztdwjrhqpyby

Simulations:

- My python-based code: https://anaconda.org/petrenko/psi_beam_vs_laser
- Camilla Curatolo's code.
- Wiesław Płaczek's modification of CAIN code.
- RH code by Siobhan Alden and Laurie Nevay.
- Semi-Analytical calculations by Aurelien Martens.

Mattermost channel on GF simulations:
https://mattermost.web.cern.ch/gammafactory/channels/simulation-tools

GF PoP parameter table: https://espace.cern.ch/PBC-acc-GammaFactory/default.aspx

Vittoria's GF FEL option studies.

Yellow Report

I've just started working on putting together different theory notes, notebooks and presentations into the Yellow Report.

In my opinion the key question in the theory/simulations at the moment is that we (at least me) don't know how accurate is the cross-section approximation for the case of short laser pulses:

where Γ is the resonance width SP: I think we should also prime the rest of the quantities as well as time since when transforming to laboratory frame, we will get spectral broadening of the radiation defined by the lifetime of the excited ion τ_0:

$$\Gamma = \frac{1}{\tau_0}. \tag{8.16}$$

Also

$$\Gamma = 2 r_e \omega_0'^2 f_{12} \frac{g_1}{c g_2}. \tag{8.17}$$

Therefore

$$\sigma(\omega' - \omega_0') = \frac{\sigma_0}{1 + 4\tau_0^2(\omega' - \omega_0')^2}, \tag{8.18}$$

where

$$\sigma_0 = \frac{\lambda_0'^2 g_2}{2\pi g_1}. \tag{8.19}$$

All our calculations are based on this approximation

The error in this approximation can have an impact on the whole theory and simulations section.

Unfortunately we could not finish comparison of our codes to Simon's density matrix code, but we certainly need to have an independent calculation of ion excitation rate with a short laser pulse which does not use cross-section approximation but more accurate quantum mechanical calculations.

New location

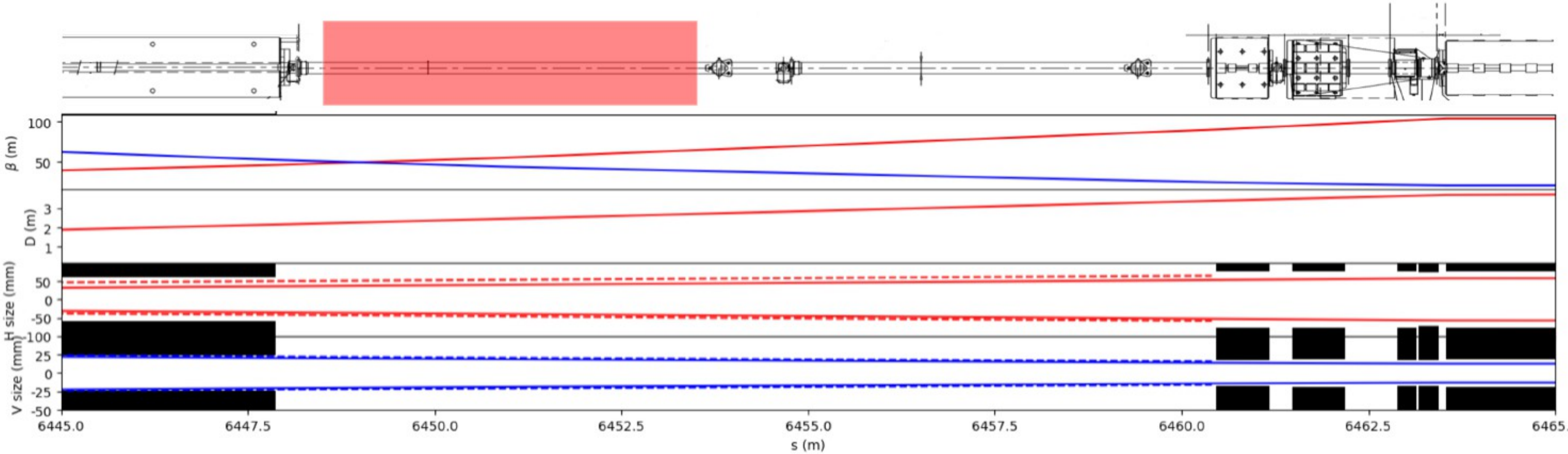
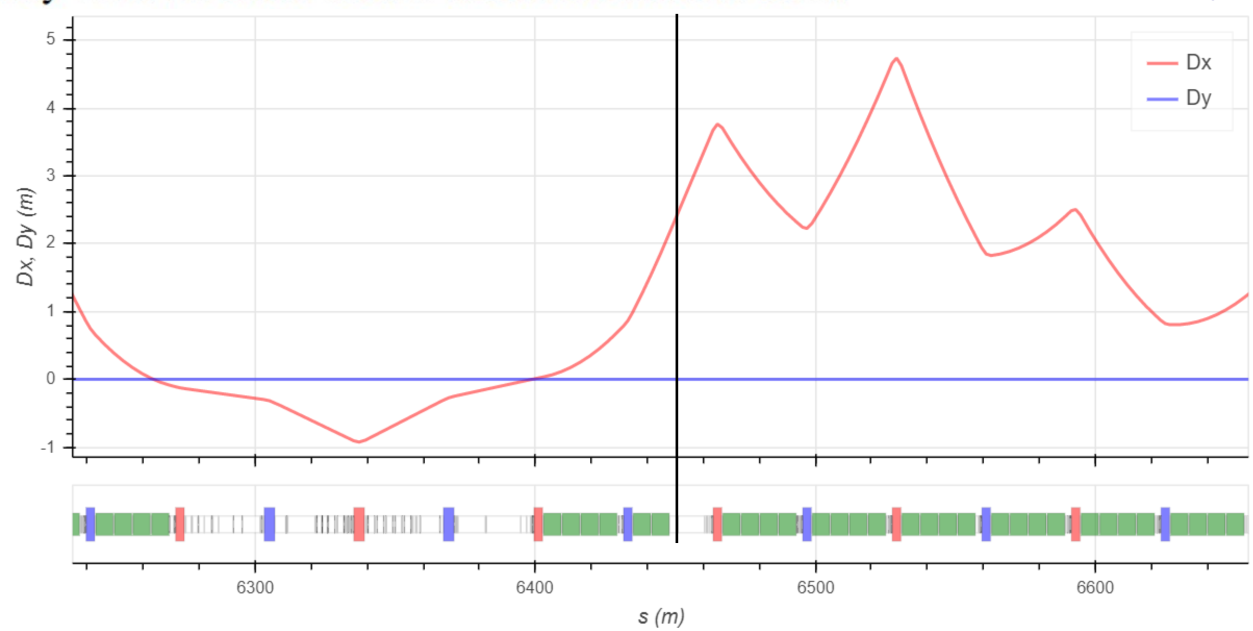


Figure 2: Layout of the SPS section 621 on top with the foreseen position of the laser cavity in red. Bellow, optical functions and beam sizes are shown in red for the horizontal plane and in blue for the vertical one. Dotted lines presents the minimum physical aperture required for compatibility with the other beams accelerated in the SPS. – [IPAC'2019 paper (moprb052)]

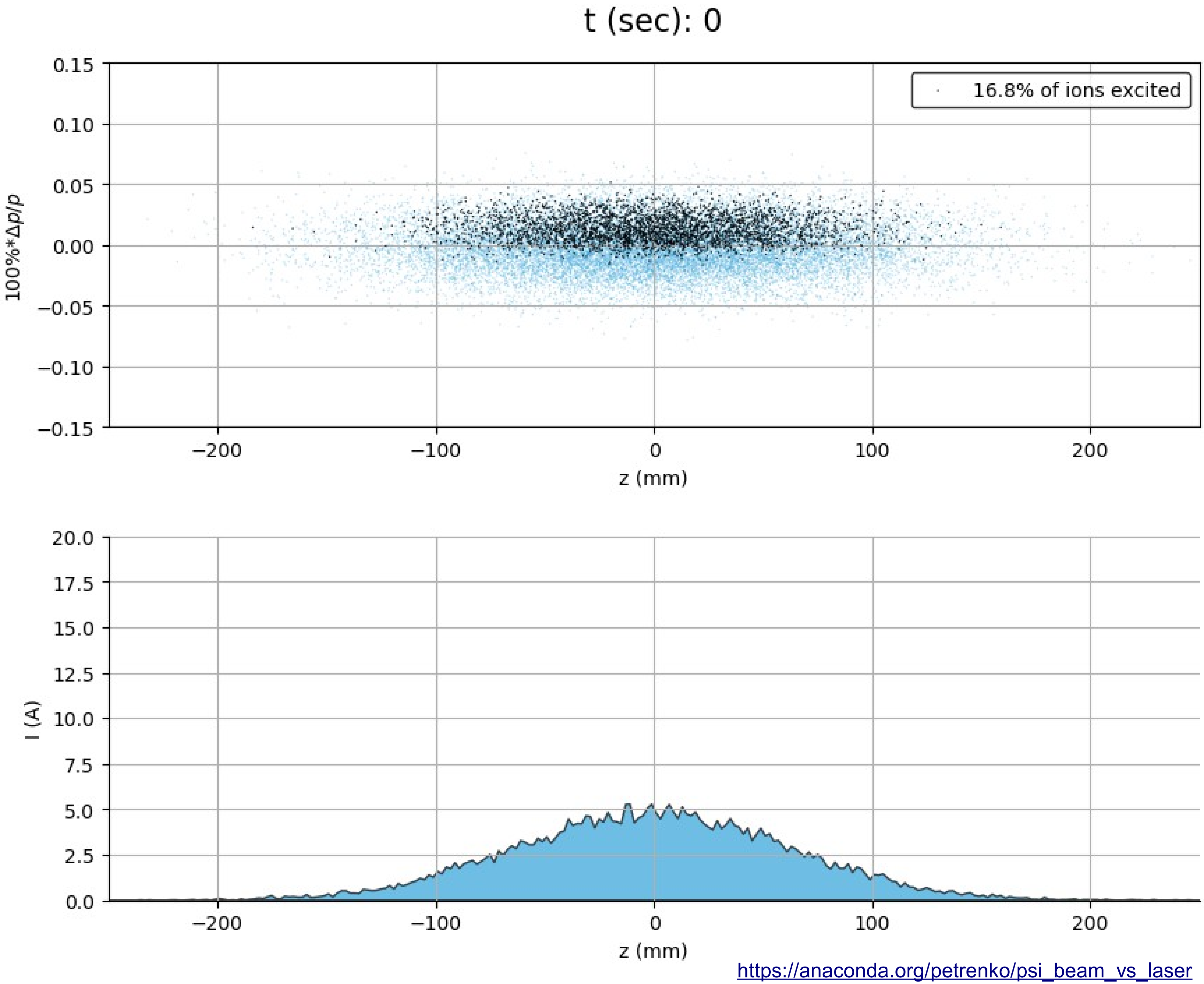
Beta-functions and the ion beam size is similar to the previous location but now there is a significant dispersion function:

This can lead to transverse effects (transverse heating or cooling).



https://apetrenko.blob.core.windows.net/sps/SPS_optics_Q26.html

Longitudinal Cooling



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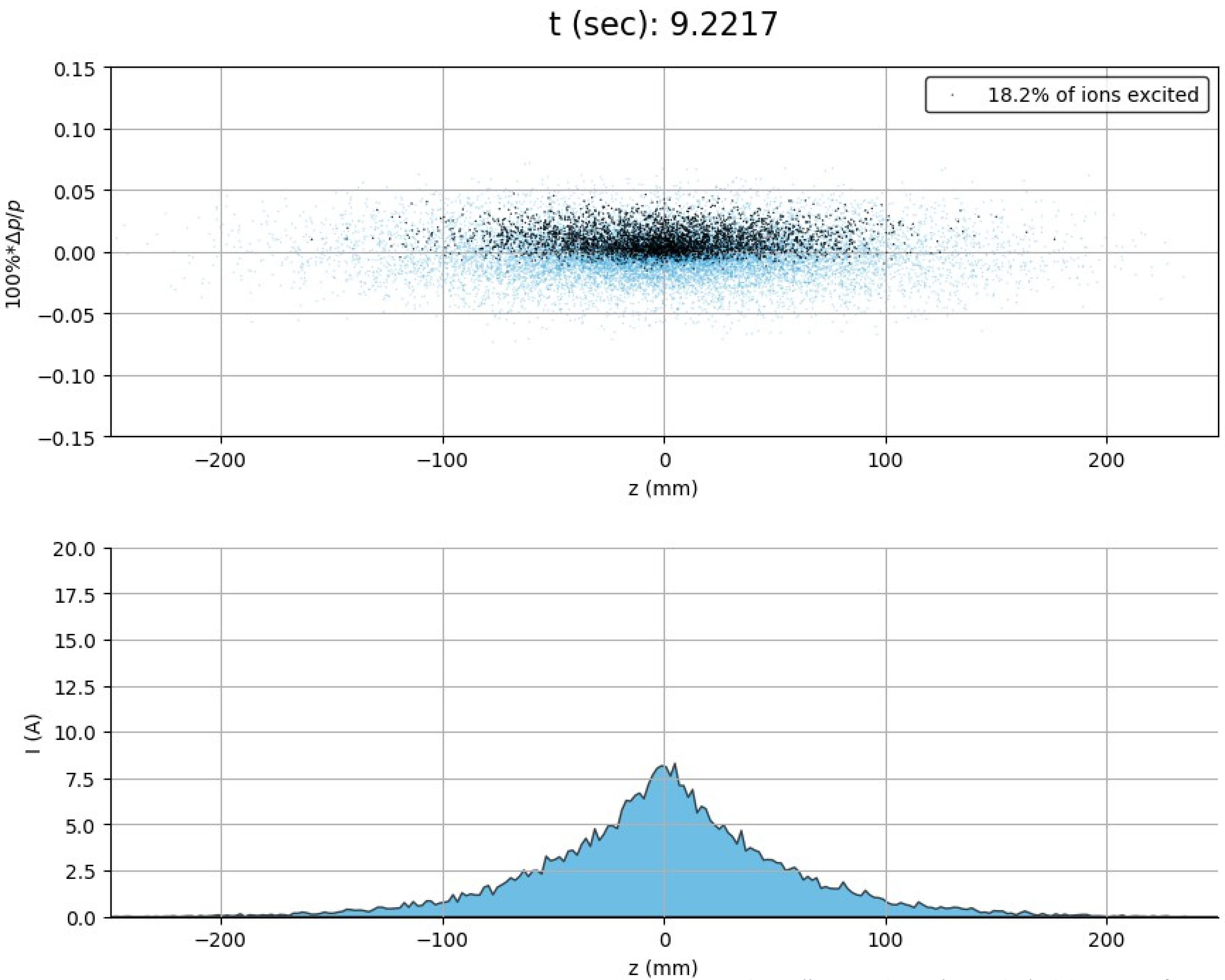

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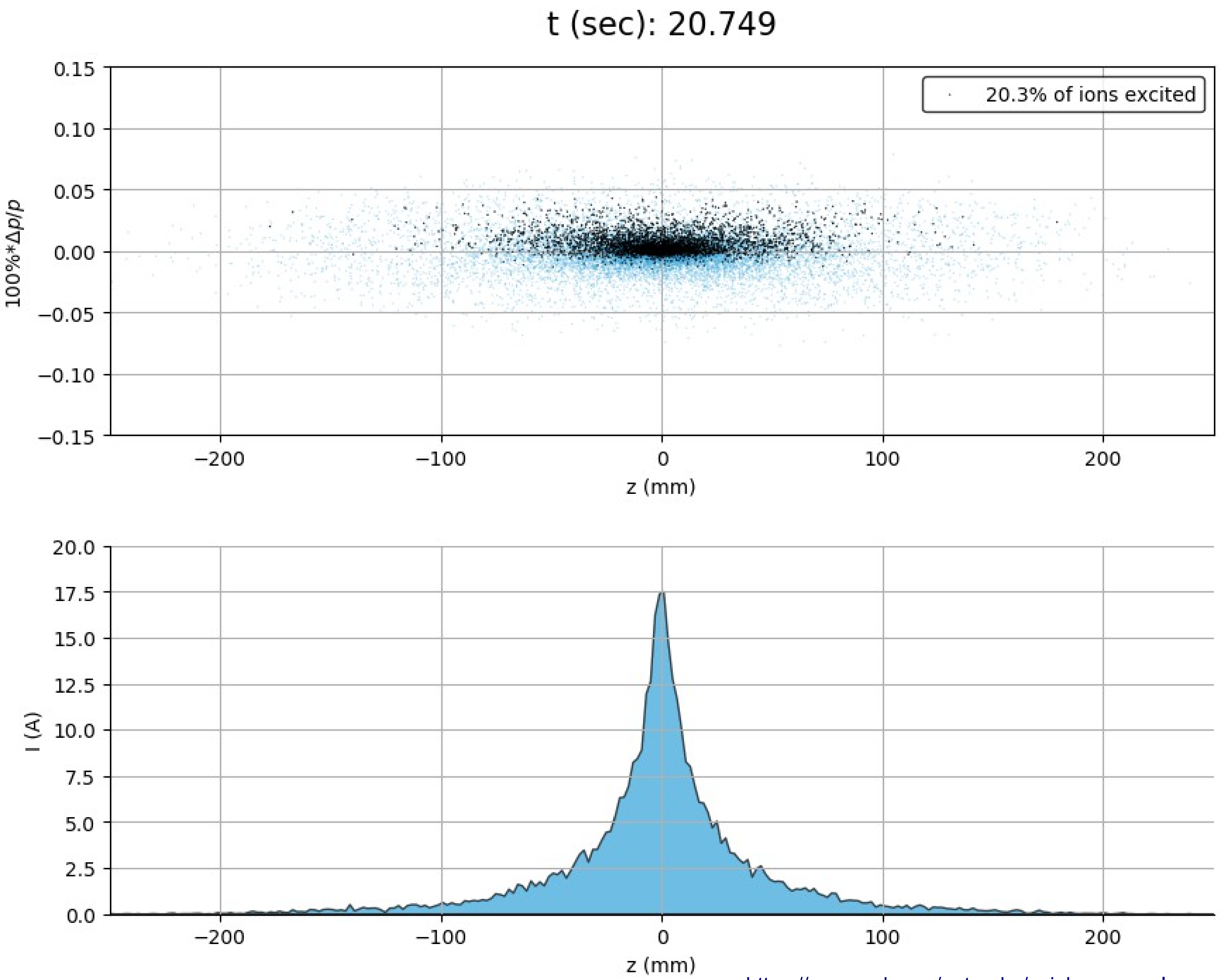

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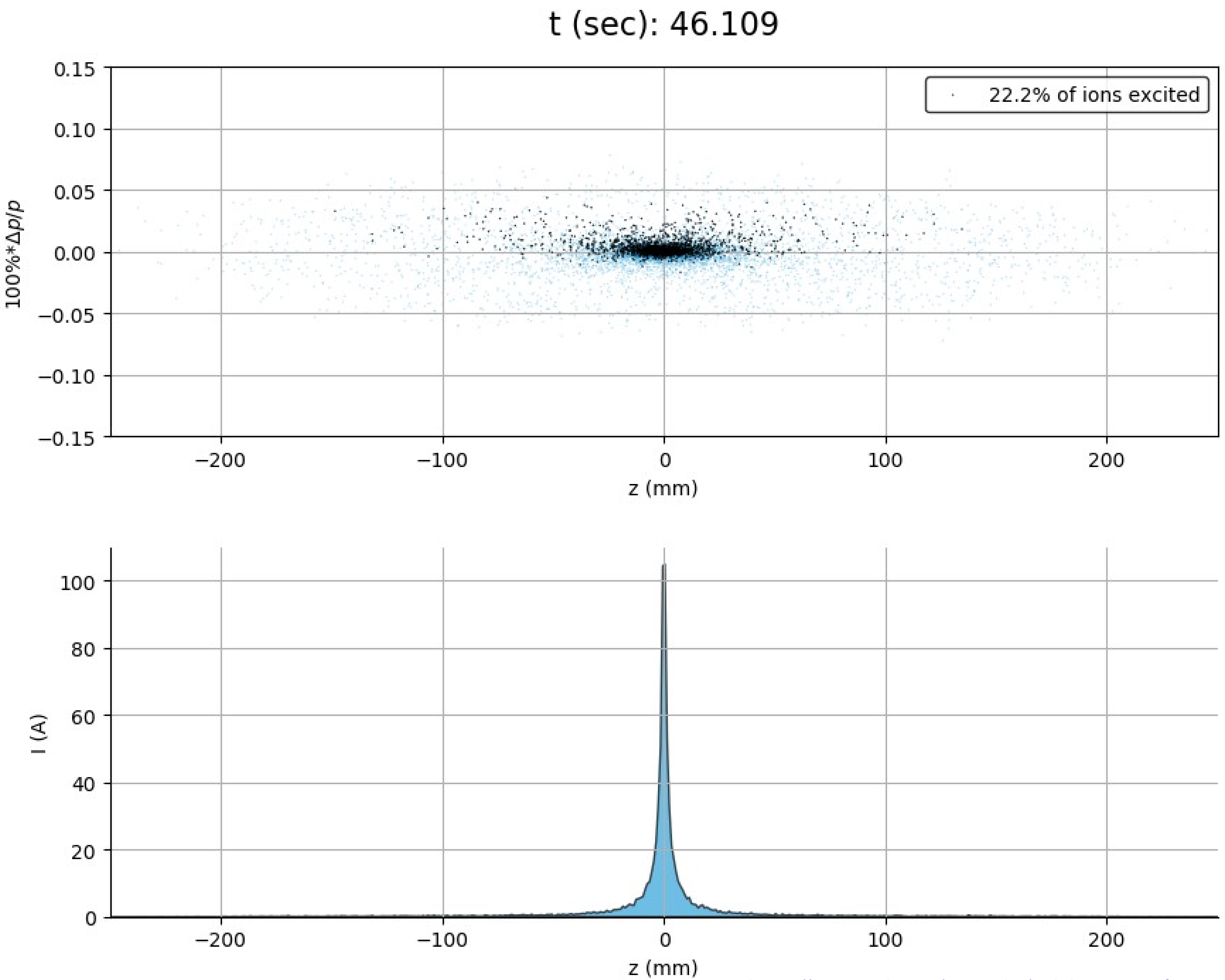

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Dispersive Coupling

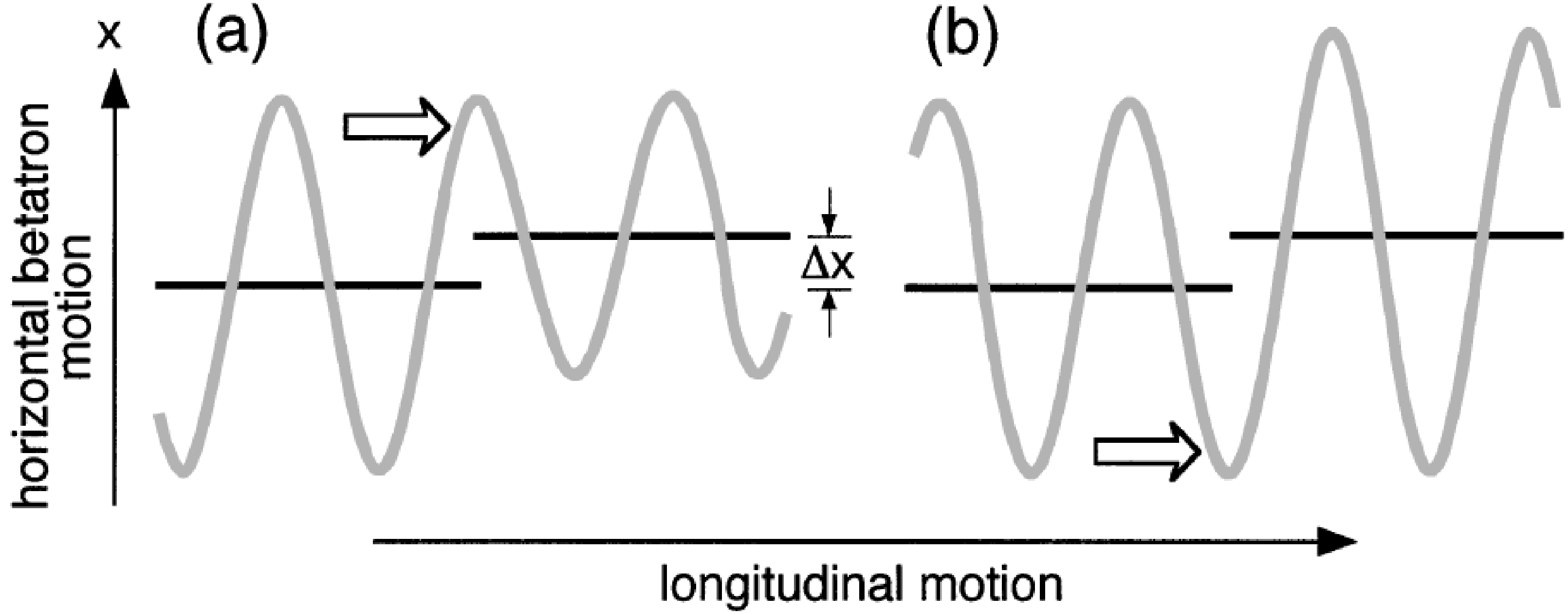
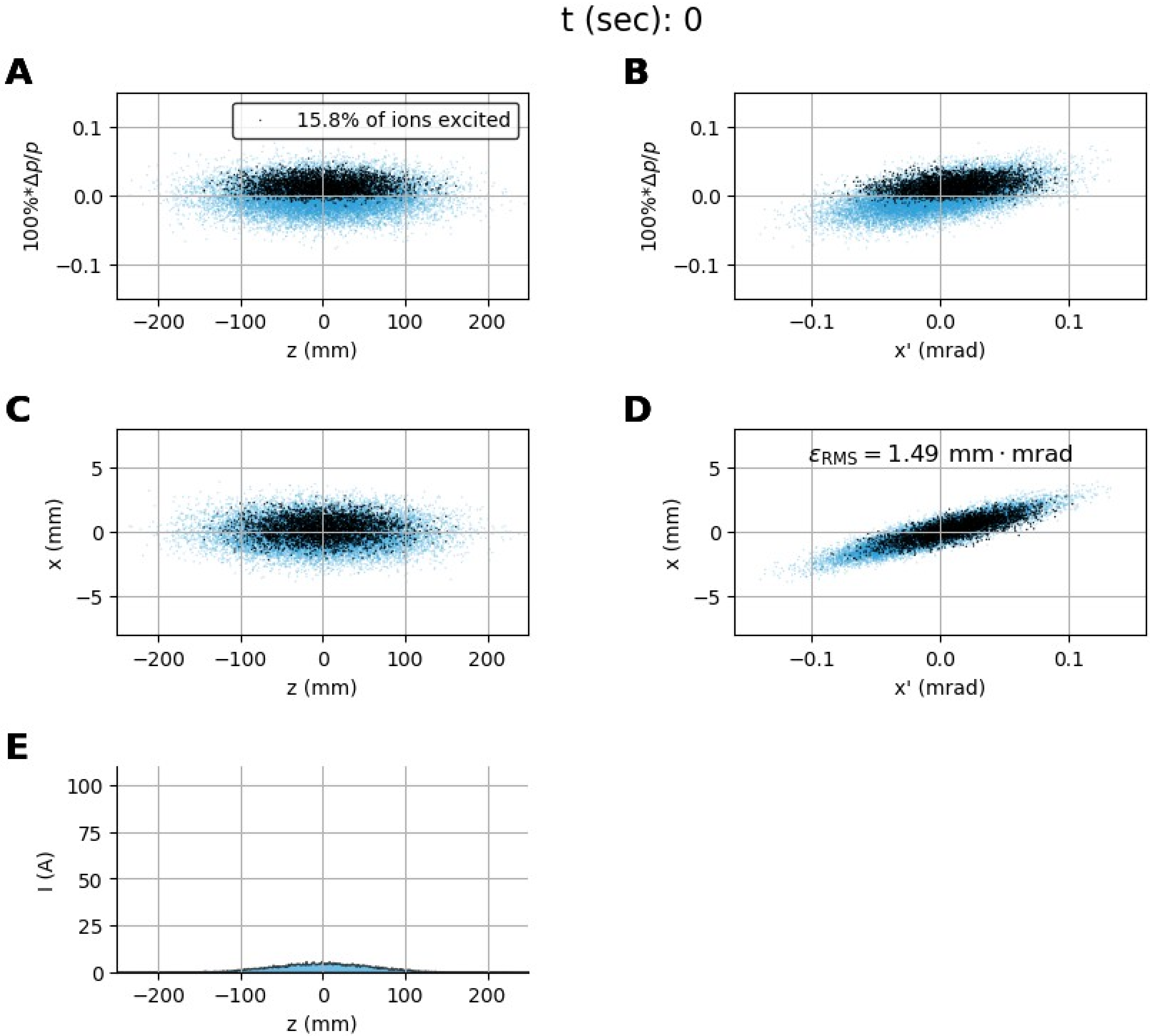


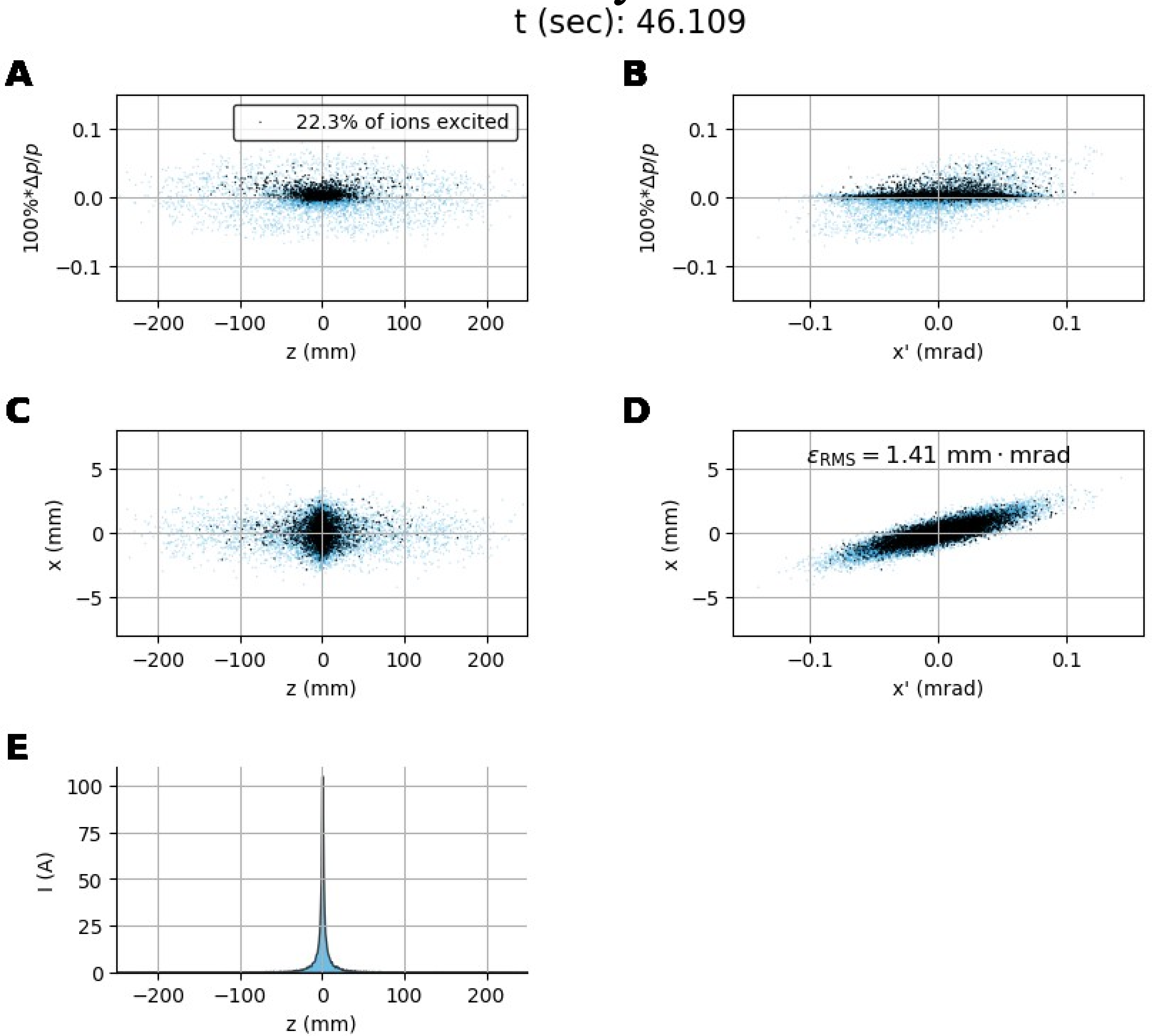
FIG. 1. Longitudinal-horizontal coupling through dispersion. Depicted is the horizontal betatron motion of a stored ion experiencing a longitudinal momentum change Δp indicated by the arrow. Through dispersion the closed orbit is shifted by Δx. (a) The longitudinal momentum transfer happens at $x > 0$ leading to a decrease of the betatron amplitude. (b) Momentum is transferred at $x < 0$ yielding an increase of the betatron amplitude.

I. Lauer et. al. Transverse Laser Cooling of a Fast Stored Ion Beam through Dispersive Coupling. PRL 81, 2052 (1998). – laser cooling of non-relativistic (4% of c) $^9Be^+$ at TSR ring in Heidelberg.

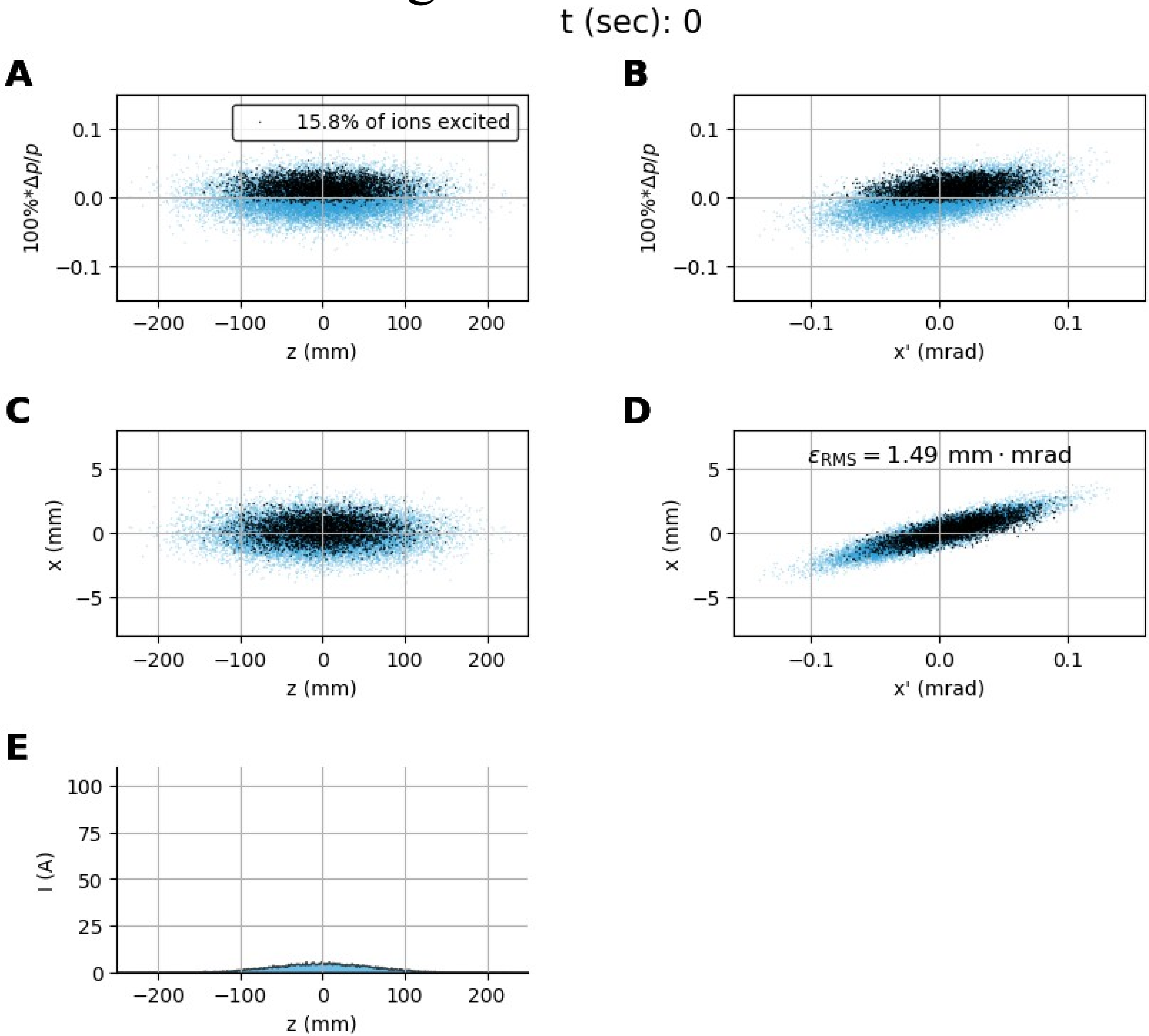
Transverse dvnamics



Transverse dynamics



Transverse cooling is faster if we shift the laser:



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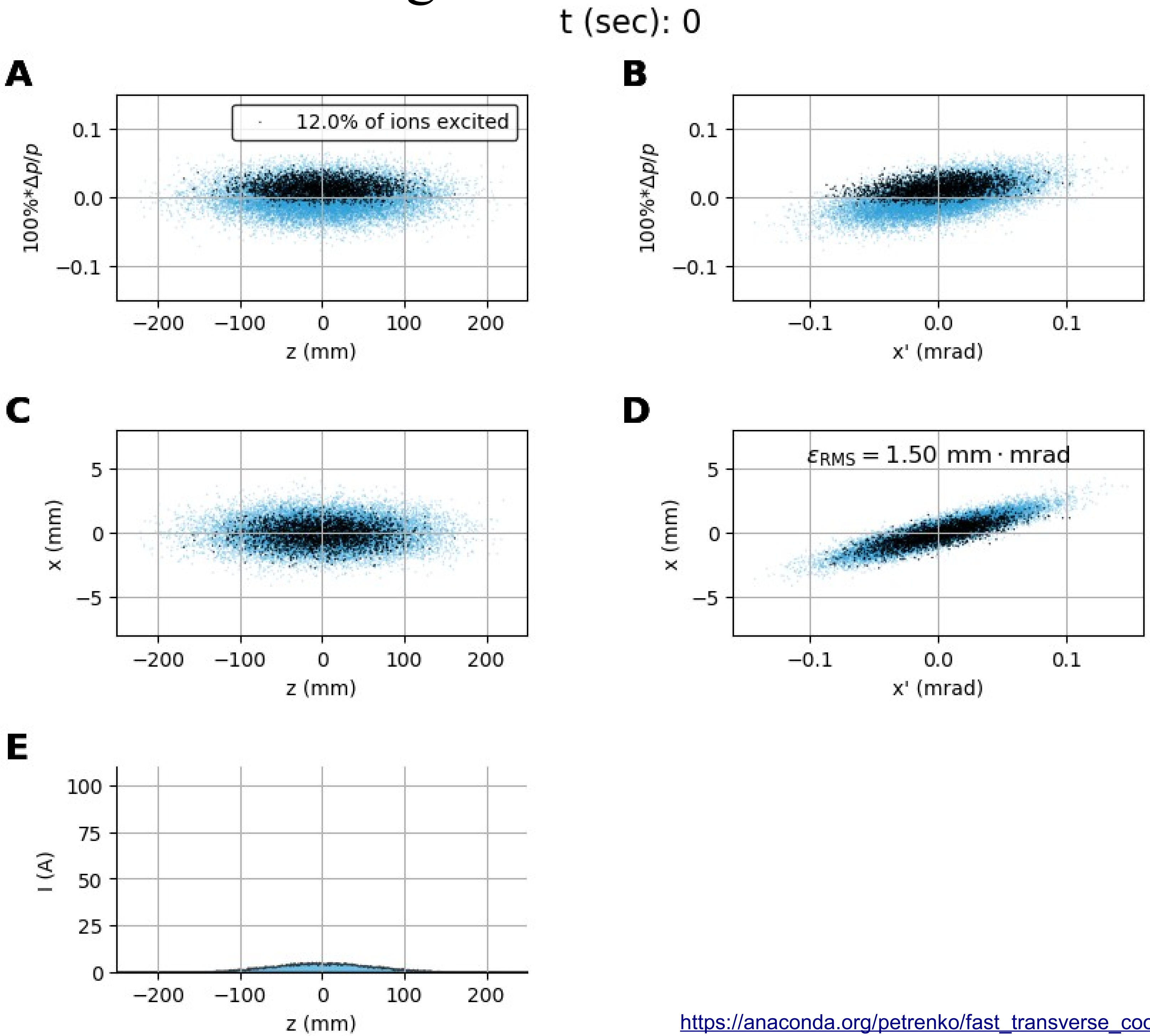

1 mm shift
of the laser

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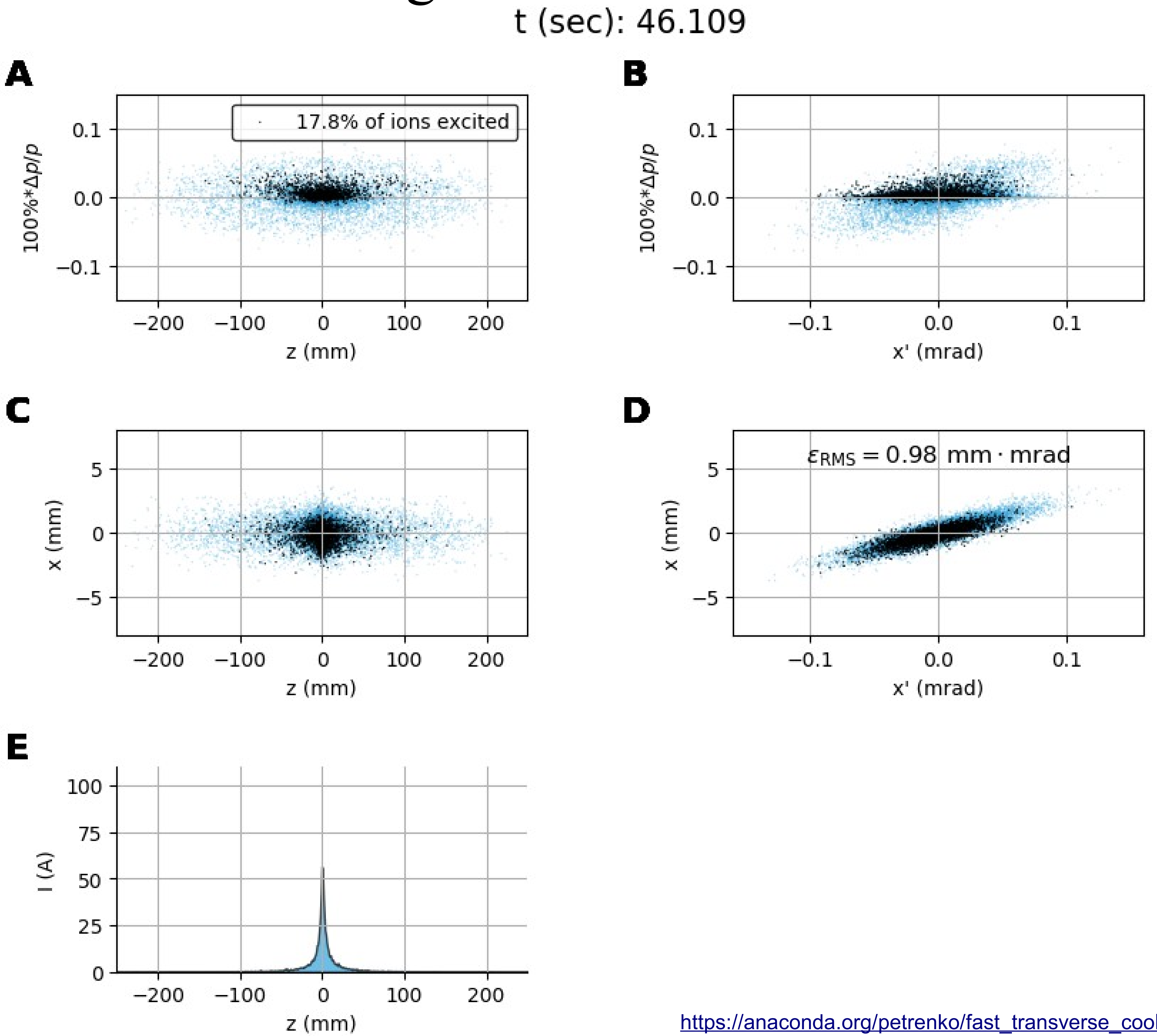

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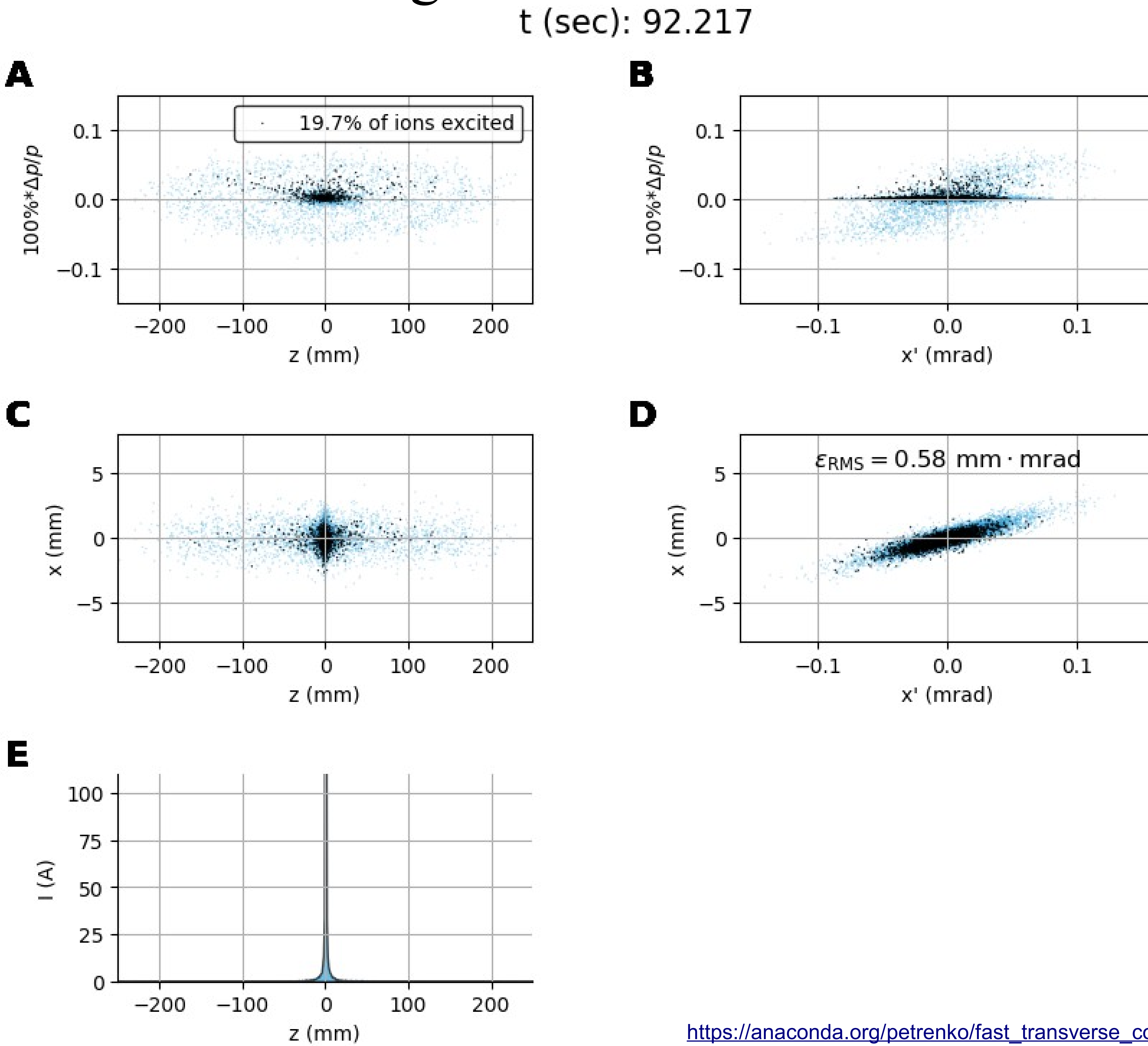

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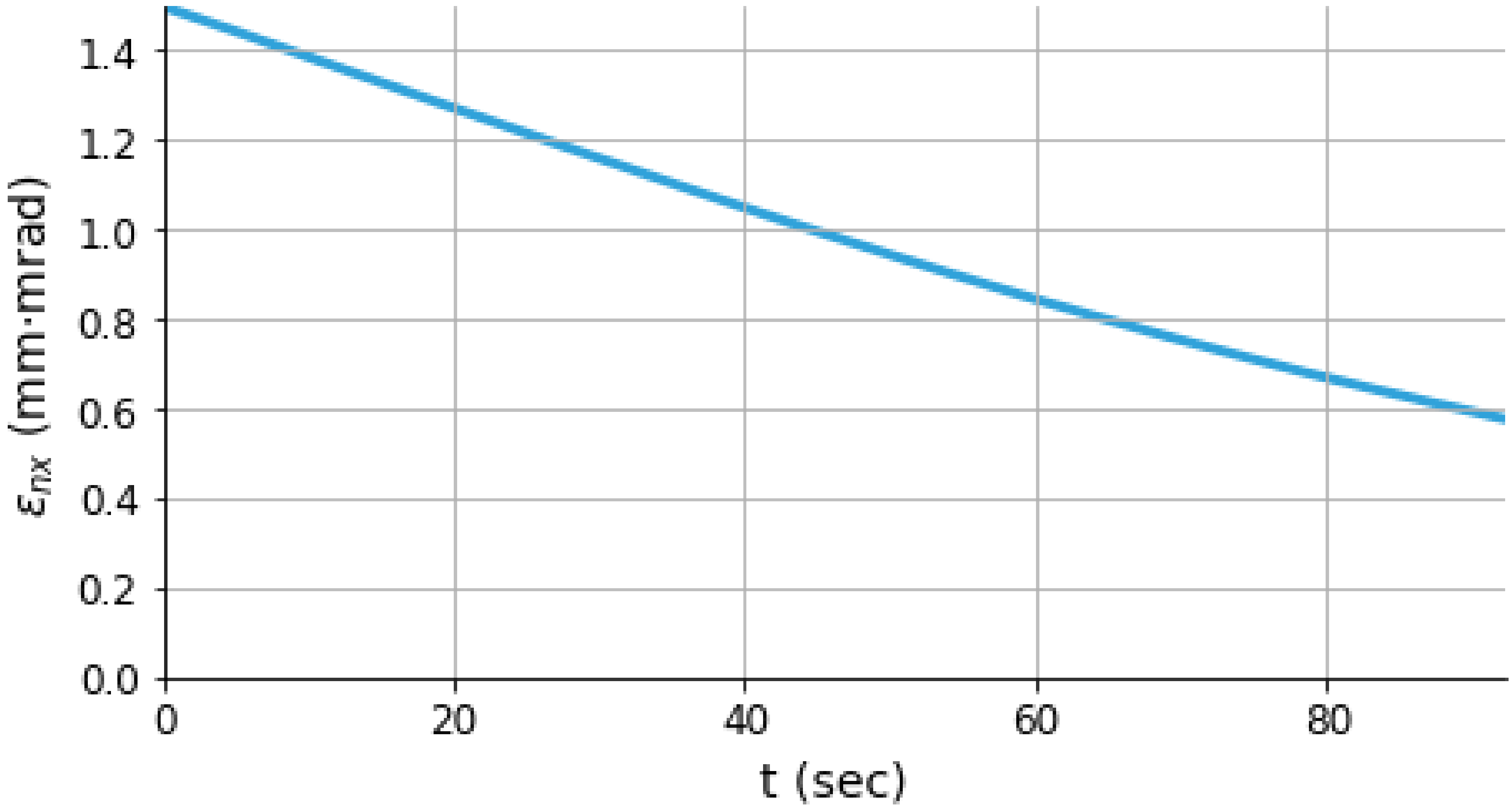
Emittance evolution



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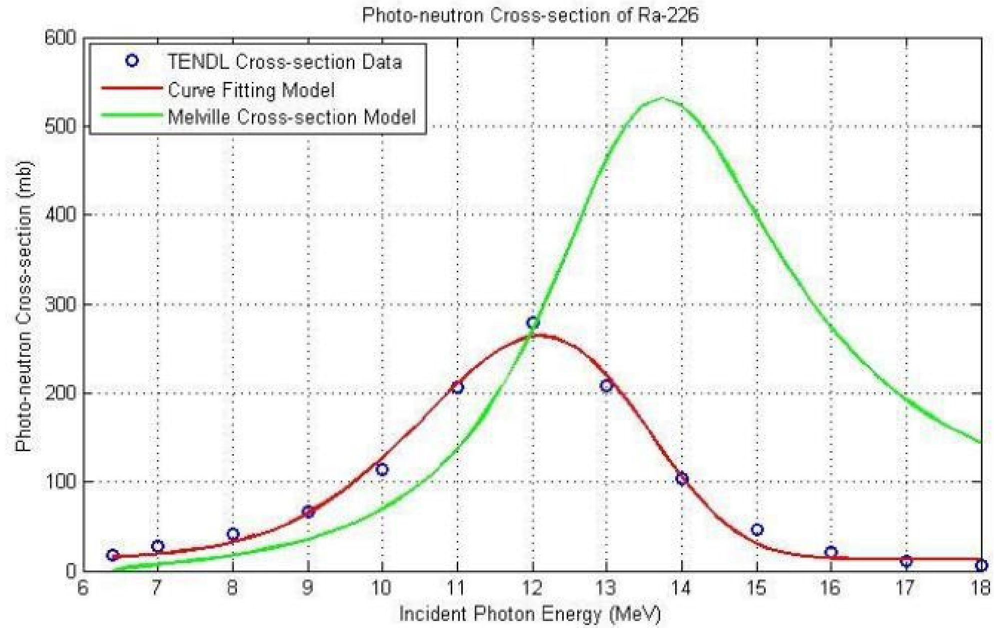
Off-topic slide on the photo-production of ^{225}Ac

From the recent talk of V. A. Khryachkov at Budker INP

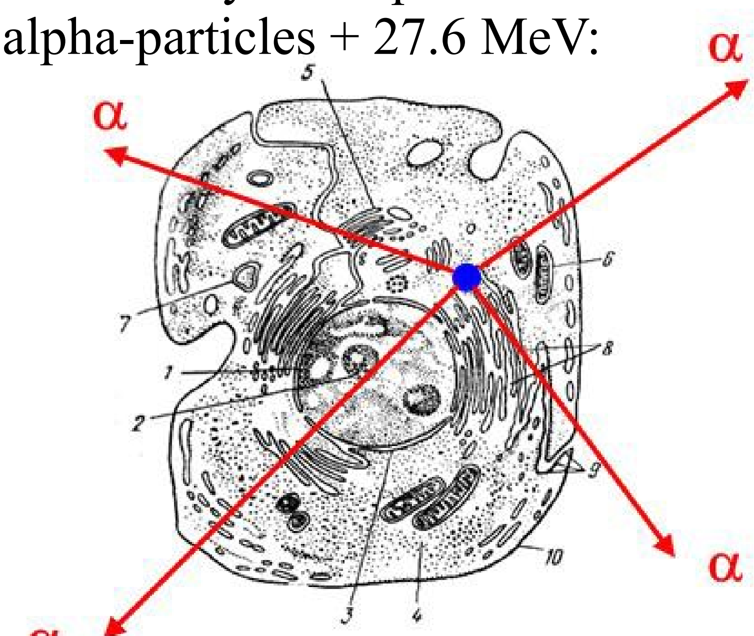
^{225}Ac is a promising isotope for a targeted alpha-therapy of metastatic cancer.

There is currently no efficient way to produce significant amount of ^{225}Ac.

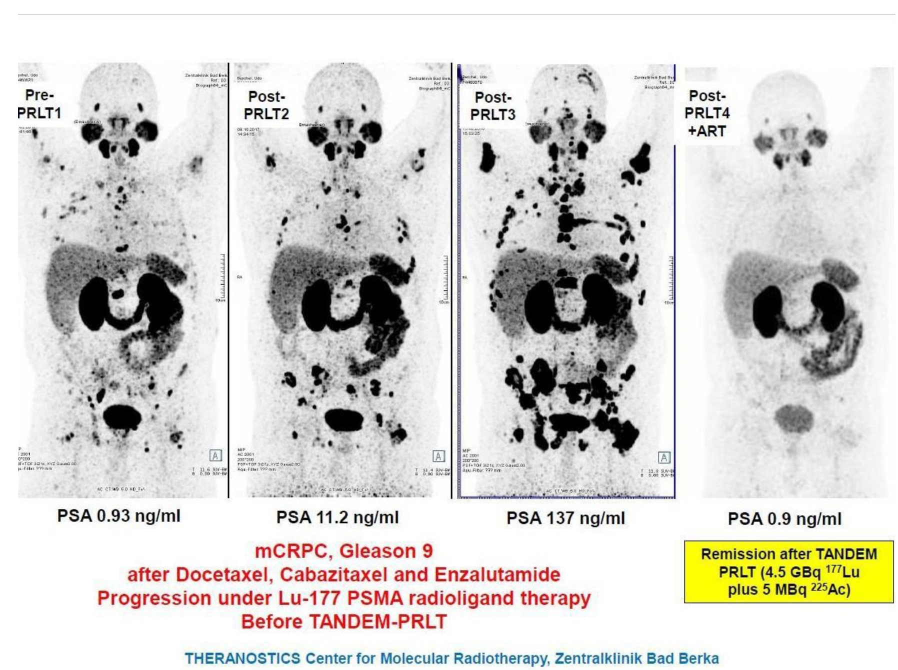
Photo-production of clean ^{225}Ac:
^{226}Ra + **10-15 MeV gammas** → ^{225}Ra
^{225}Ra decays into ^{225}Ac in 15 days.



^{225}Ac decay chain produces four alpha-particles + 27.6 MeV:



^{225}Ac was used for metastatic cancer treatment:



Several companies are working on this technology:
https://actiniumpharma.com, https://morphopharma.com/

Conclusions

- The new location seems to be just as good as the old one for the longitudinal cooling: 50% increase in the bunch peak current should be visible already over the first 9 sec of cooling.
- But now there is an interesting option of using dispersive coupling to demonstrate the fast transverse cooling! The first simulations show 1.5x reduction of horizontal emittance over 46 sec – this could be possible to detect. It is probably possible to reduce the cooling time further but we need to understand the mechanism of cooling better (or maybe simply run large parameters scans).