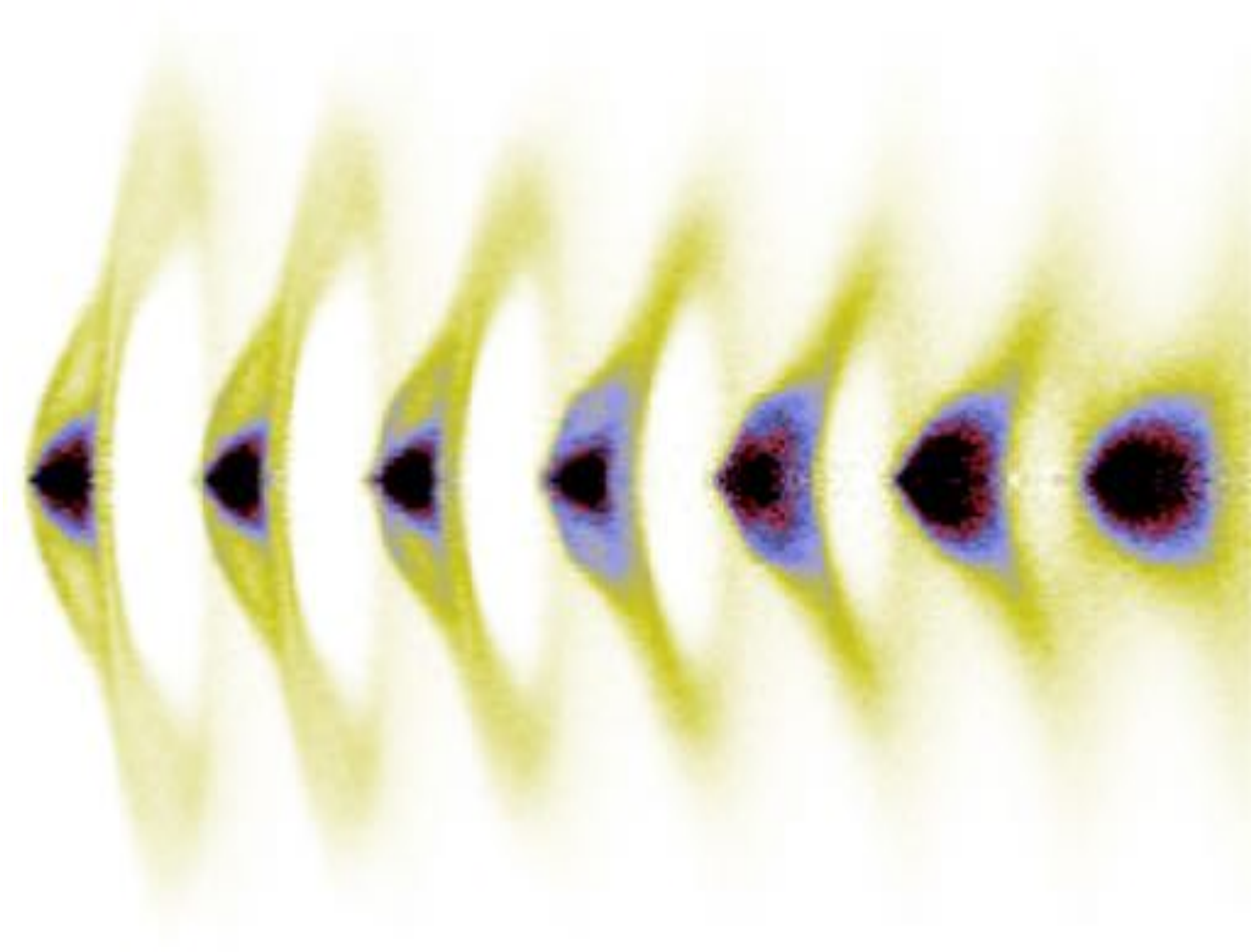
Influence of proton bunch and plasma parameters on the AWAKE experiment

Mariana Moreira

Advisor: Jorge Vieira

GoLP / Instituto de Plasmas e Fusão Nuclear
Instituto Superior Técnico, Lisbon, Portugal

epp.tecnico.ulisboa.pt || **golp**.tecnico.ulisboa.pt



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Antiprotons as wakefield drivers

Asymmetry between opposite charges

- most PWFA experiments have used electrons as drivers
- positrons seem to be less efficient as drivers*
- linear wakefield theory is perfectly symmetrical for opposite charges

Third question

How would the hypothetical substitution of the driver protons by antiprotons change the AWAKE experiment?

* S. Lee et al. Phys. Rev. E 64 045501 (2001)

An antiproton driver brings several benefits

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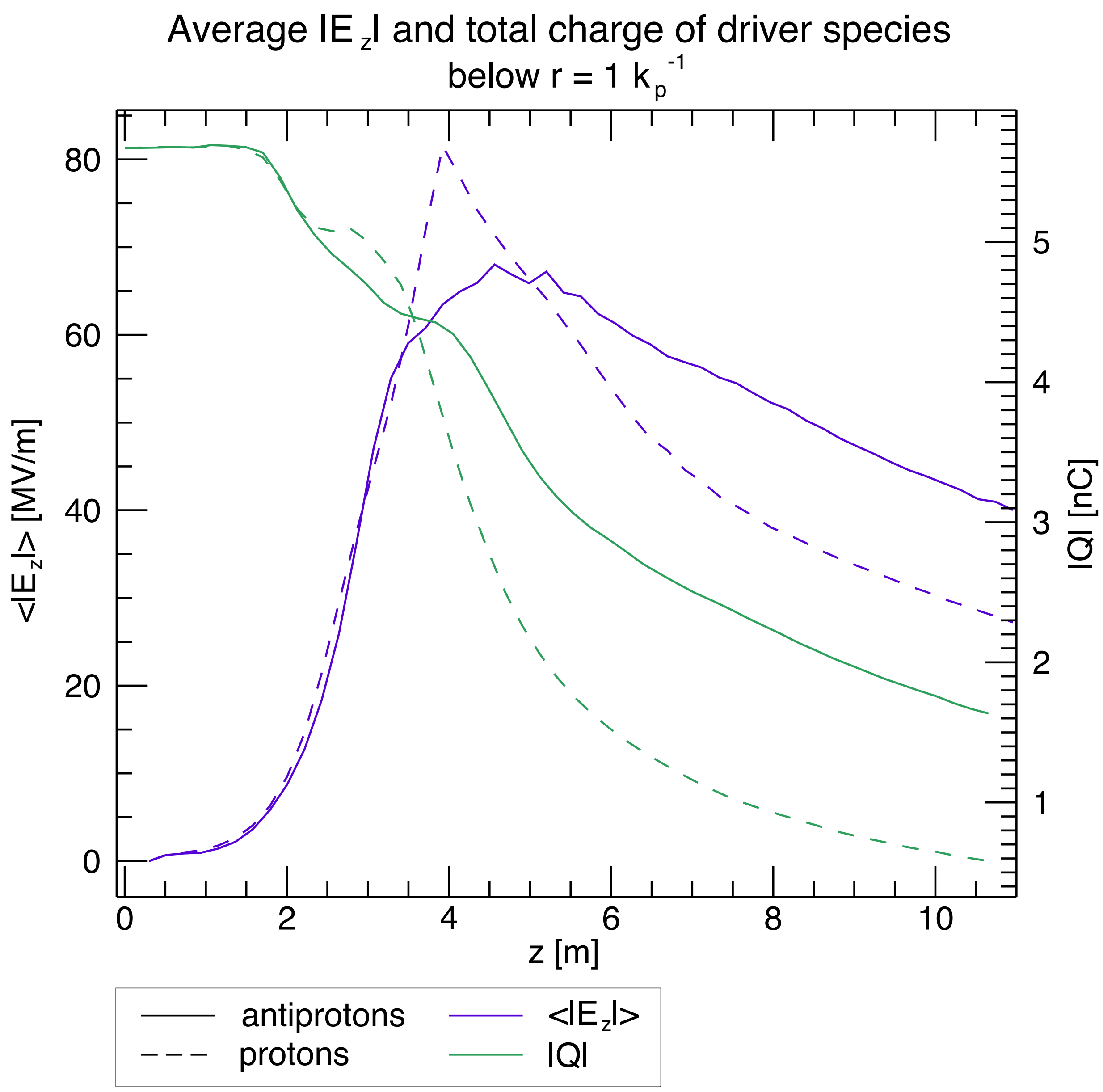
More driver charge available

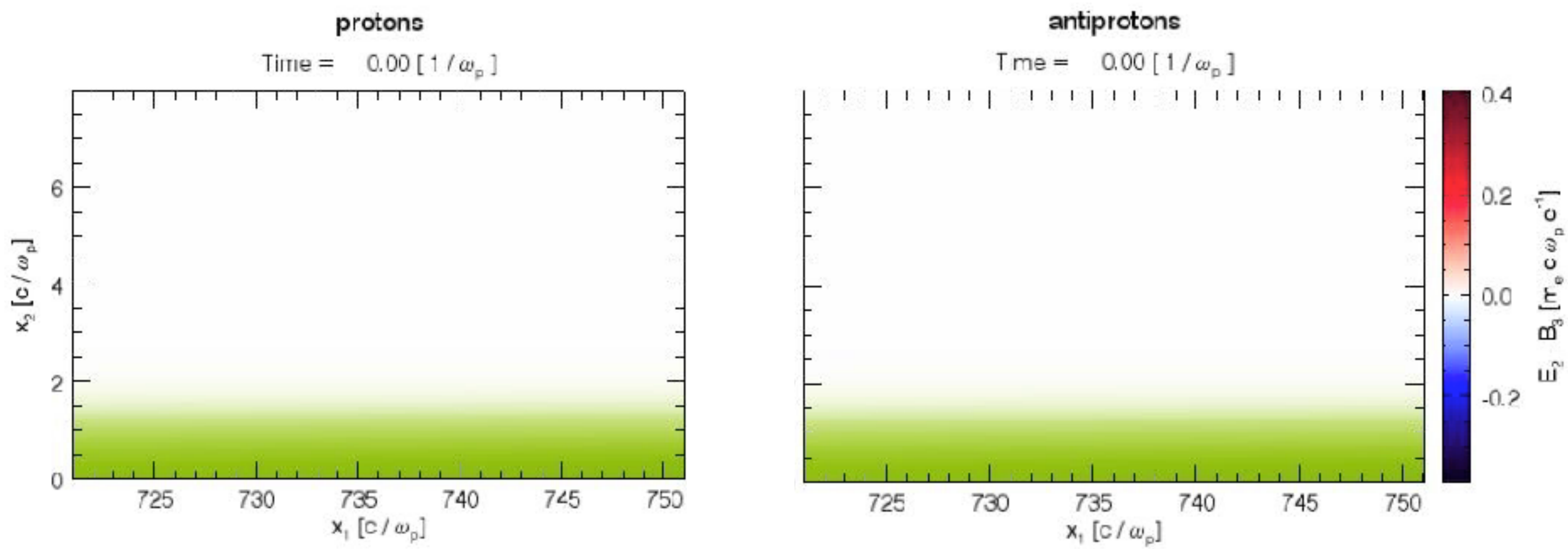


2.8x more driver charge at 10.33 m

1.5x higher average $|E_z|$ at 10.33 m

Field configuration recaptures off-axis charge

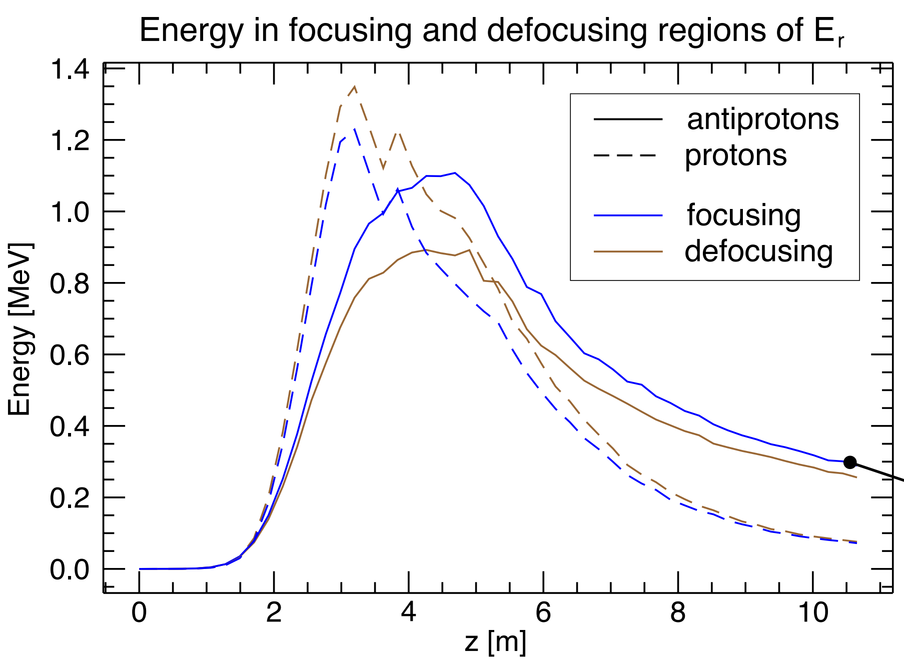
Why is so much antiproton charge retained?



Energy contained in E_r offers important clues

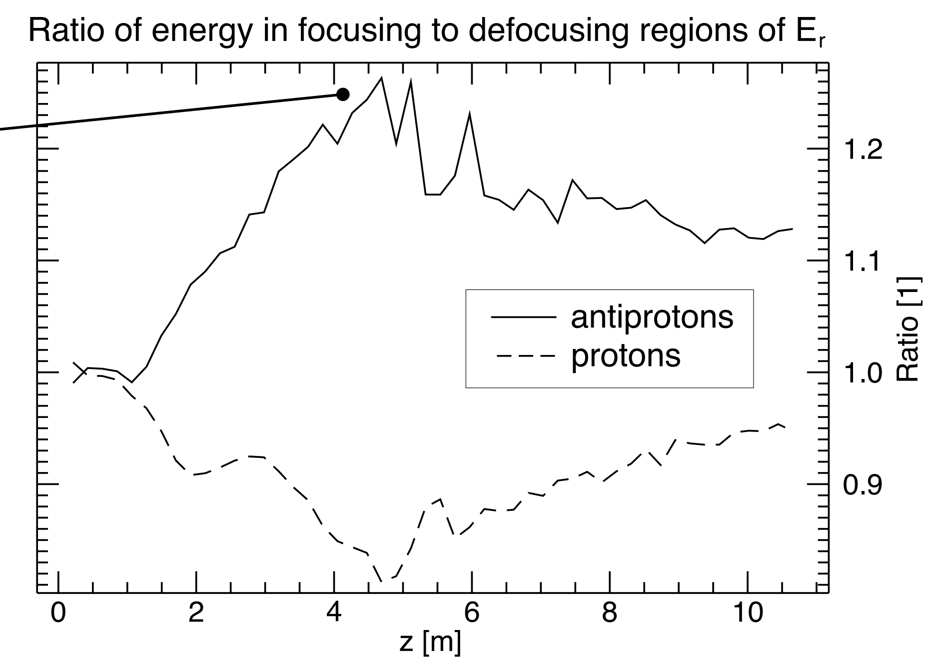
Why is so much antiproton charge retained?

Antiprotons have more energy available for focusing



larger energy imbalance for antiprotons

3.8x more energy in focusing fields



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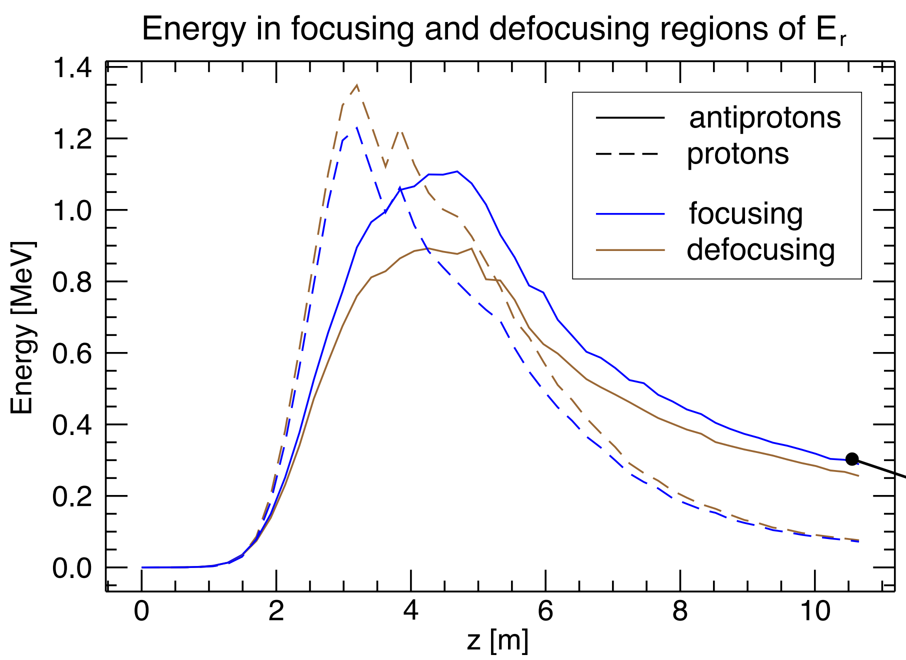

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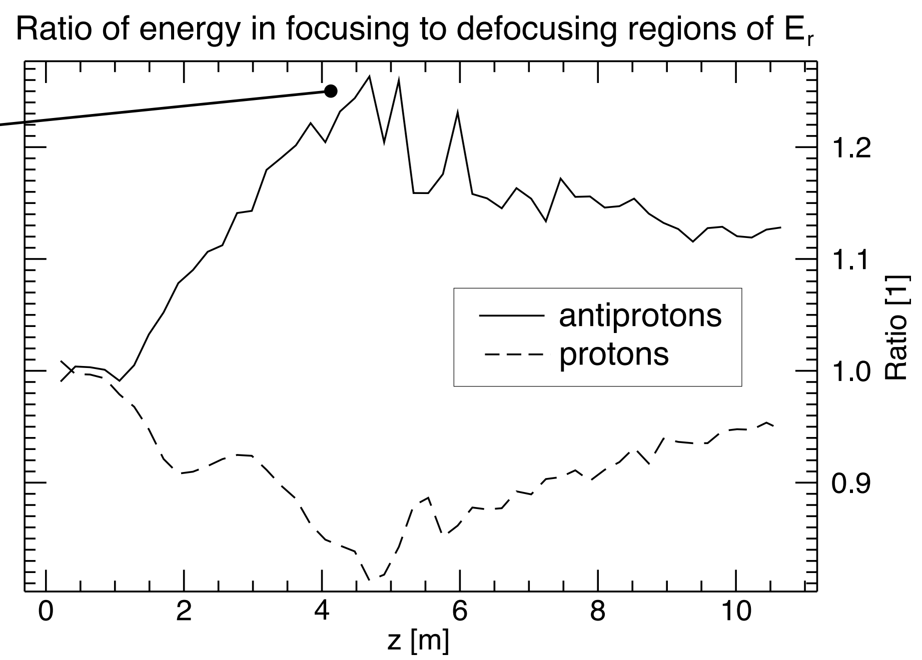
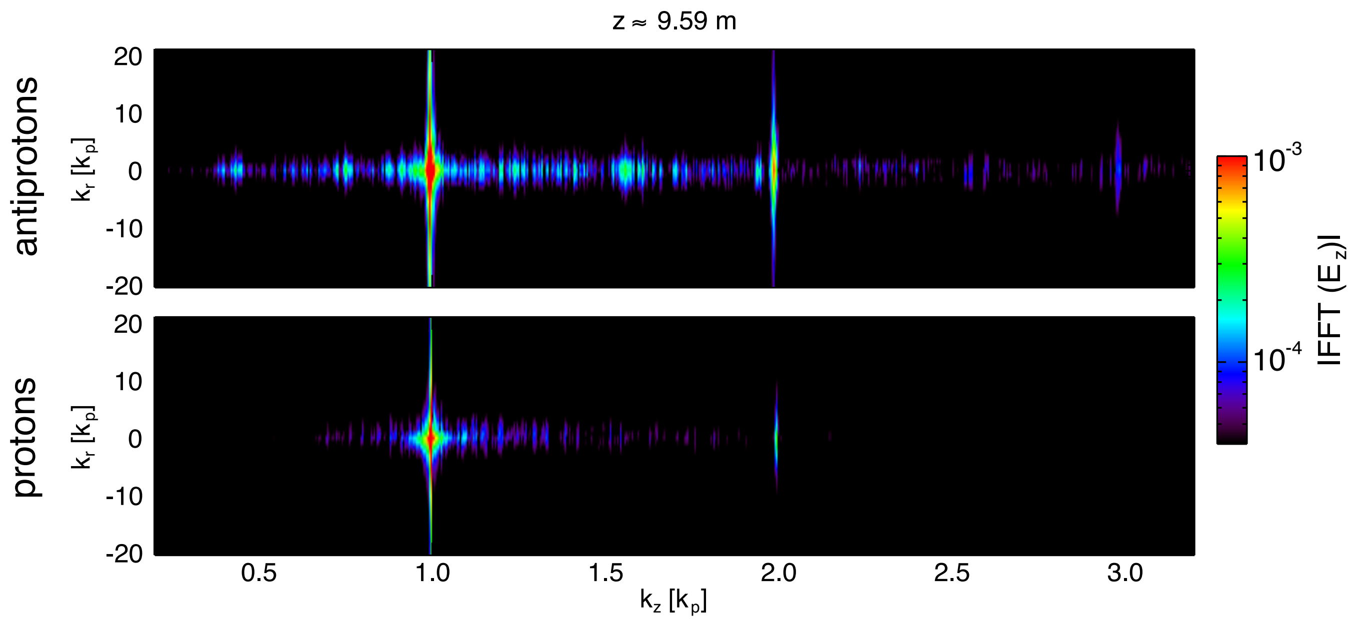


The antiproton-driven wakefield is more nonlinear

- 2D Fourier transform of E_z
- purely linear wake:

$$k_z = \pm k_p$$



Bunch-plasma energy transfer provides no answer

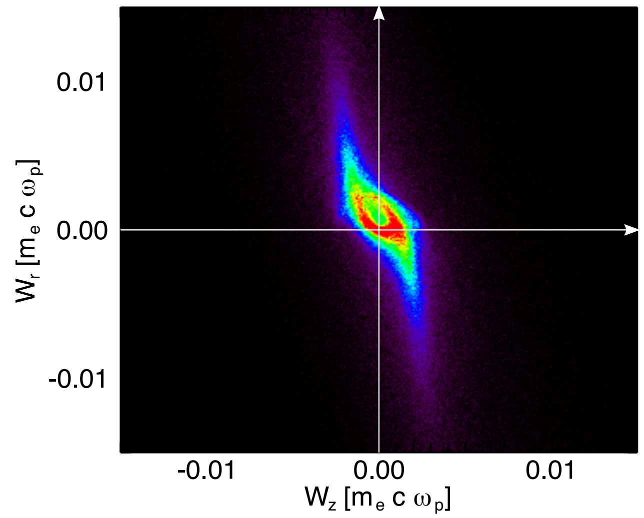
Why is the amplitude of the antiproton wakefield lower than expected?

Charge density in longitudinal and transverse force plane

- normalized, unsigned forces:

  $W_z = E_z \qquad W_r = E_r - B_\varphi$

- each increment of charge is deposited in W_r/W_z plane according to the fields acting on it



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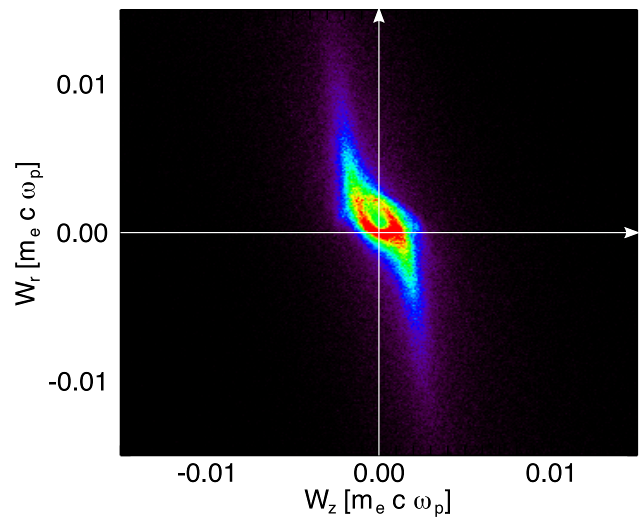
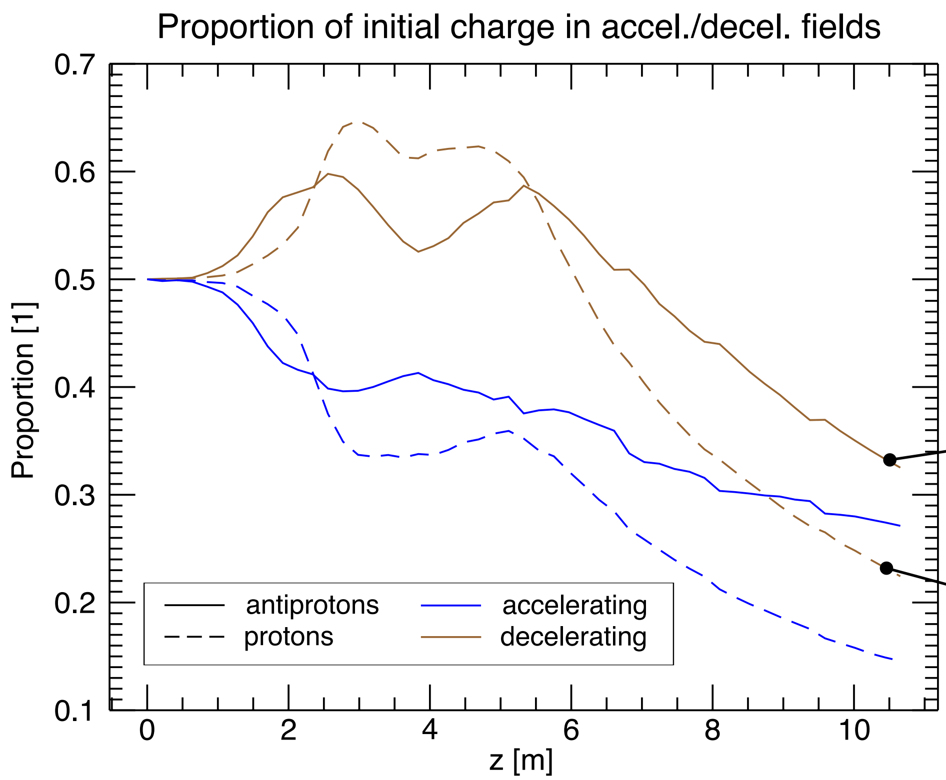


A lower portion of the remaining antiprotons gives up energy



- integrate charge density on W_r/W_z plane for $W_z > 0$ and $W_z < 0$

55% of antiprotons left

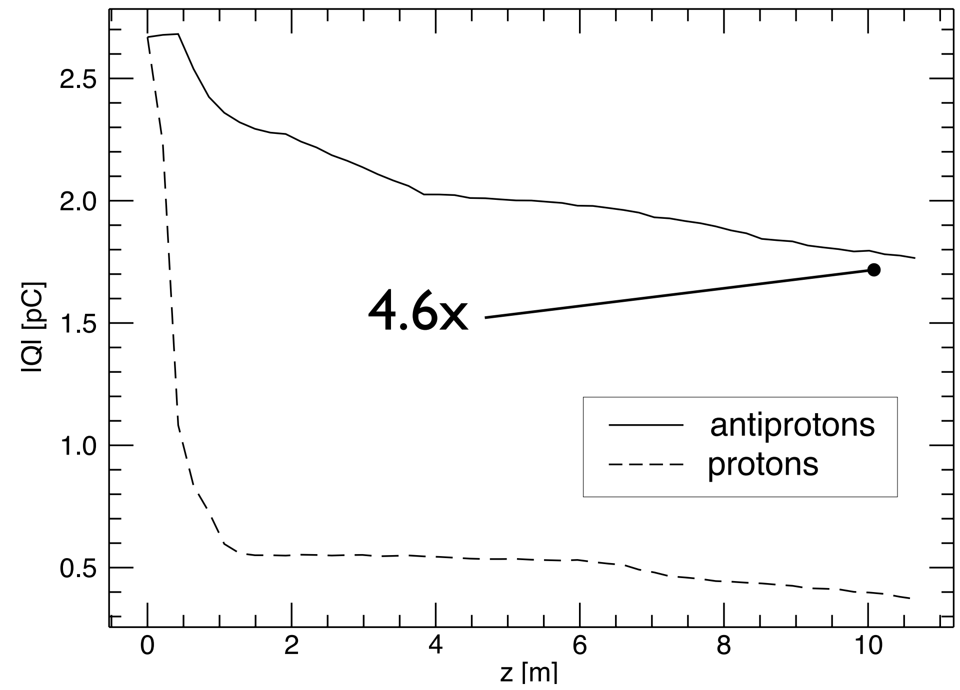
61% of protons left

difference is not large enough to explain the underwhelming amplitude of E_z

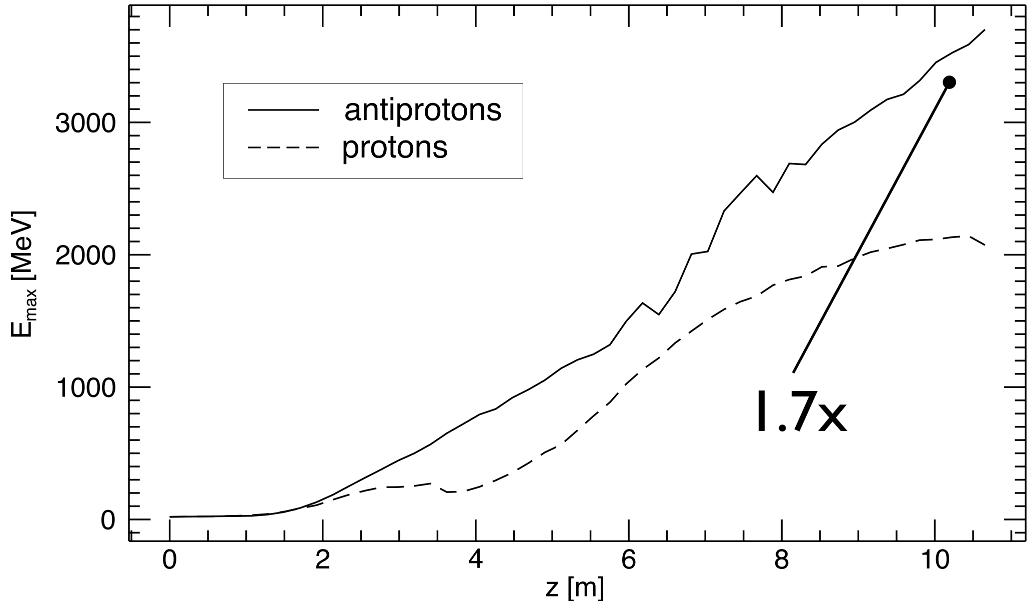
Benefits are also reflected on witness electrons

A witness electron bunch is introduced in the simulation

Witness charge



Max. electron energy



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Conclusions

Deterministic injection of electrons is possible for AWAKE

The outputs from the experiment are robust against shot-to-shot fluctuations

The temporal decline of the wakefield amplitude is due to charge loss

The spatial decline is due to incoherent interference between individual wake contributions

A parallel program was developed to study the nonlinear phase of the SMI

Antiprotons are more efficient as wakefield drivers

The wakefield driven by antiprotons is more nonlinear than the one driven by protons

More antiproton charge is preserved due to stronger fields