A novel scheme in the plasma beam dump

Guoxing Xia*, Oscar Jakobsson, Alexandre Bonatto, Yangmei Li,
Roger Pizzato Nunes, Yuan Zhao, Toshiki Tajima

The University of Manchester

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*guoxing.xia@manchester.ac.uk

Introduction

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- LPAs already provide high-energy, high-quality electron beams
  (new energy record of 8 GeV in 20 cm achieved at LBNL)

PHYSICAL REVIEW LETTERS 122, 084801 (2019)

Editors' Suggestion | Featured in Physics

Petawatt Laser Guiding and Electron Beam Acceleration to 8 GeV in a Laser-Heated Capillary Discharge Waveguide

A. J. Gonsalves,[1,*] K. Nakamura,[1] J. Daniels,[1] C. Benedetti,[1] C. Pieronek,[1,2] T. C. H. de Raadt,[1] S. Steinke,[1] J. H. Bin,[1] S. S. Bulanov,[1] J. van Tilborg,[1] C. G. R. Geddes,[1] C. B. Schroeder,[1,2] Cs. Tóth,[1] E. Esarey,[1] K. Swanson,[1,2] L. Fan-Chiang,[1,2] G. Bagdasarov,[3,4] N. Bobrova,[3,5] V. Gasilov,[3,4] G. Korn,[6] P. Sasorov,[3,6] and W. P. Leemans[1,2,†]

- EuPRAXIA: next-generation 5 GeV LPA accel. module

Nuclear Inst. and Methods in Physics Research, A

Design of a 5 GeV laser–plasma accelerating module in the quasi-linear regime

Xiangkun Li *, Alban Mosnier, Phu Anh Phi Nghiem

- Future technology: LPA colliders?

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 13, 101301 (2010)

Physics considerations for laser-plasma linear colliders

C. B. Schroeder, E. Esarey, C. G. R. Geddes, C. Benedetti, and W. P. Leemans
Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
(Received 11 June 2010; published 4 October 2010)

Nakajima *Light: Science & Applications* (2018)7:21 Official journal of the CIOMP 2047-7538

NEWS AND VIEWS Open Access

Seamless multistage laser-plasma acceleration toward future high-energy colliders

Kazuhisa Nakajima[1]

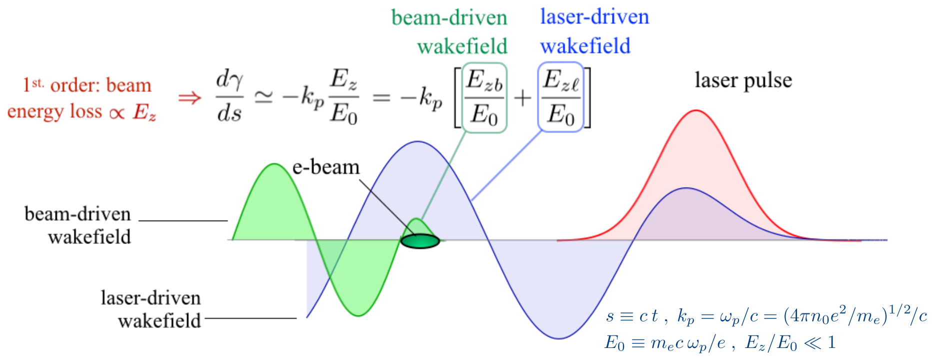
- High-energy beams / high-rep-rate accelerators → larger, heavier "conventional" beam dumps…

advances in accelerator technology → higher quality, higher energy beams; higher repetition rates → conventional beam dumps with more demanding specs → higher cost; larger volume and mass; higher radioactive hazards

Alternative approach: **plasma beam dumps**

Plasma beam dumps - background

- **Plasma beam dump:**
  - Passive → beam self-driven wakefield
  - Active → beam + laser wakefield



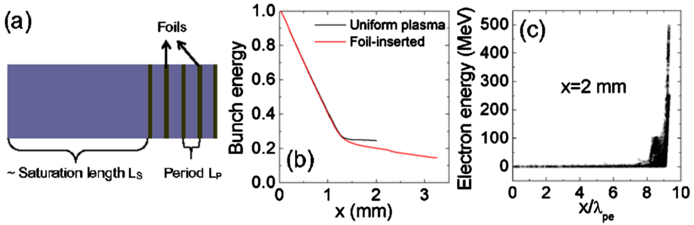
- Plasma beam dumps could extract most of the beam total energy before its disposal in a conventional beam dump.
- This could greatly mitigate conventional beam dump specs.
- Active beam dump provides a more homogeneous energy extraction along the beam (laser wakefield removes energy from beam's "head")
- However, it's more complex and expensive (due to laser energy required).
- Since the passive scheme is less complex to implement (than active), it's worth exploring its potential.

Plasma beam dumps - literature background

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **13**, 101303 (2010)

Collective deceleration: Toward a compact beam dump

H.-C. Wu,[1] T. Tajima,[1,2] D. Habs,[1,2] A. W. Chao,[3] and J. Meyer-ter-Vehn[1]
[1]*Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany*
[2]*Fakultät für Physik, Ludwig-Maximilians-Universität München, D-85748 Garching, Germany*
[3]*SLAC National Accelerator Center, Stanford University, Stanford, California 94309, USA*
(Received 10 December 2009; published 5 October 2010)



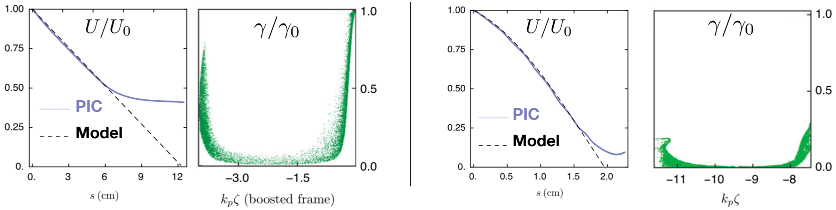
Compact, plasma-based beam dump

PHYSICS OF PLASMAS **22**, 083106 (2015)

Passive and active plasma deceleration for the compact disposal of electron beams

A. Bonatto,[1,2,a)] C. B. Schroeder,[1] J.-L. Vay,[1] C. G. R. Geddes,[1] C. Benedetti,[1] E. Esarey,[1] and W. P. Leemans[1]
[1]*Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[2]*CAPES Foundation, Ministry of Education of Brazil, Brasília, DF 700040-020, Brazil*

Passive beam dump | Active (laser-driven) beam dump

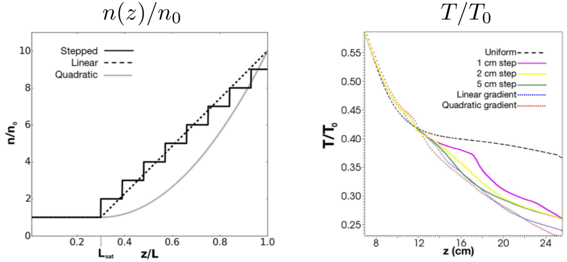


Analytical model for the beam energy loss in passive and active beam dumps

PHYSICS OF PLASMAS **24**, 023120 (2017)

Simulation study of a passive plasma beam dump using varying plasma density

Kieran Hanahoe,[1,2,a)] Guoxing Xia,[1,2] Mohammad Islam,[1,2] Yangmei Li,[1,2] Öznur Mete-Apsimon,[3,2] Bernhard Hidding,[4,2] and Jonathan Smith[5]
[1]*School of Physics and Astronomy, University of Manchester, Oxford Road, Manchester M13 9PL, United Kingdom*
[2]*Cockcroft Institute, Sci-Tech Daresbury, Keckwick Lane, Daresbury, Cheshire WA4 4AD, United Kingdom*
[3]*Department of Engineering, Lancaster University, Bailrigg, Lancaster LA1 4YW, United Kingdom*
[4]*Department of Physics, University of Strathclyde, Richmond Street, Glasgow G1 1XQ, United Kingdom*
[5]*Tech-X UK Ltd., Sci-Tech Daresbury, Keckwick Lane, Daresbury, Cheshire WA4 4FS, United Kingdom*



Passive beam dump improvement achieved by tailoring the plasma profile

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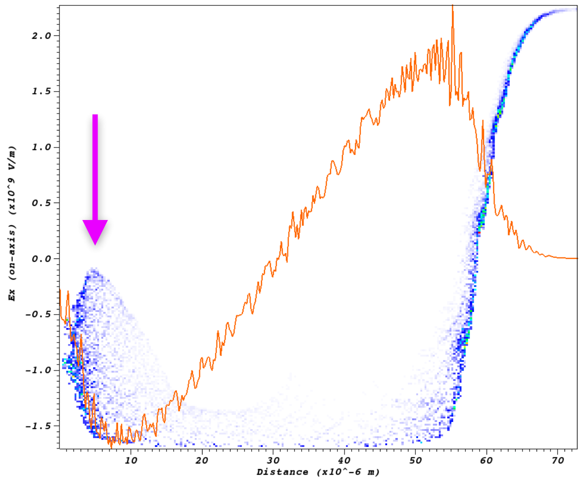
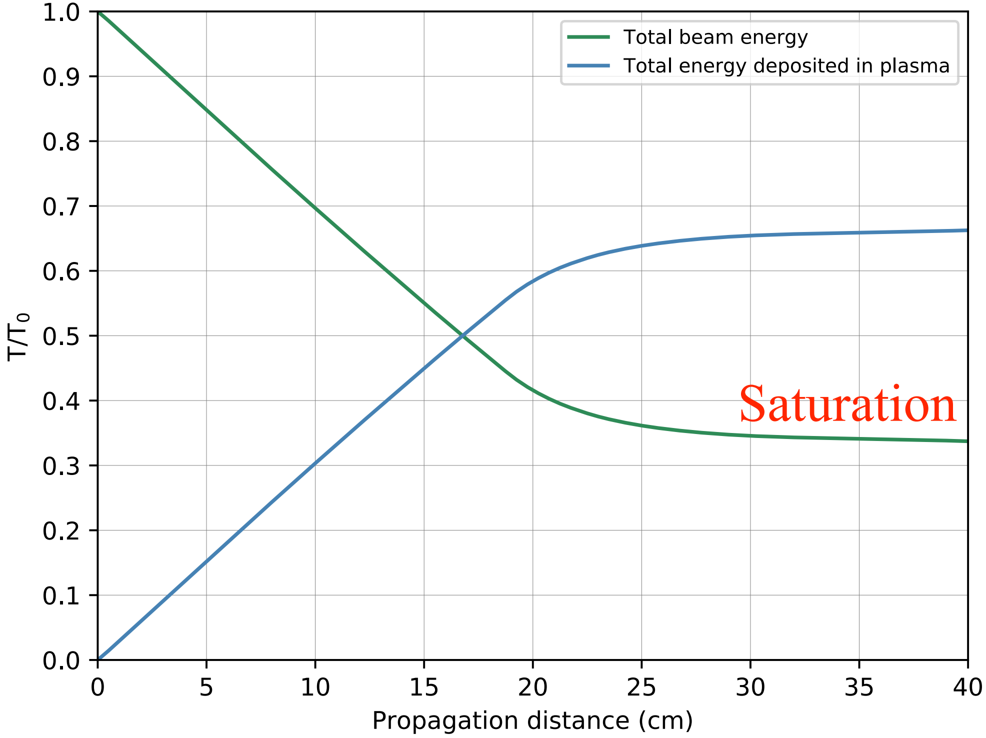
- In a plasma, the beam energy decreases linearly until a saturation point where:
  - Decelerated particles in the beam start falling behind and get re-accelerated by the wakefield.
  - Energy loss saturates as plasma starts giving energy back to the beam.





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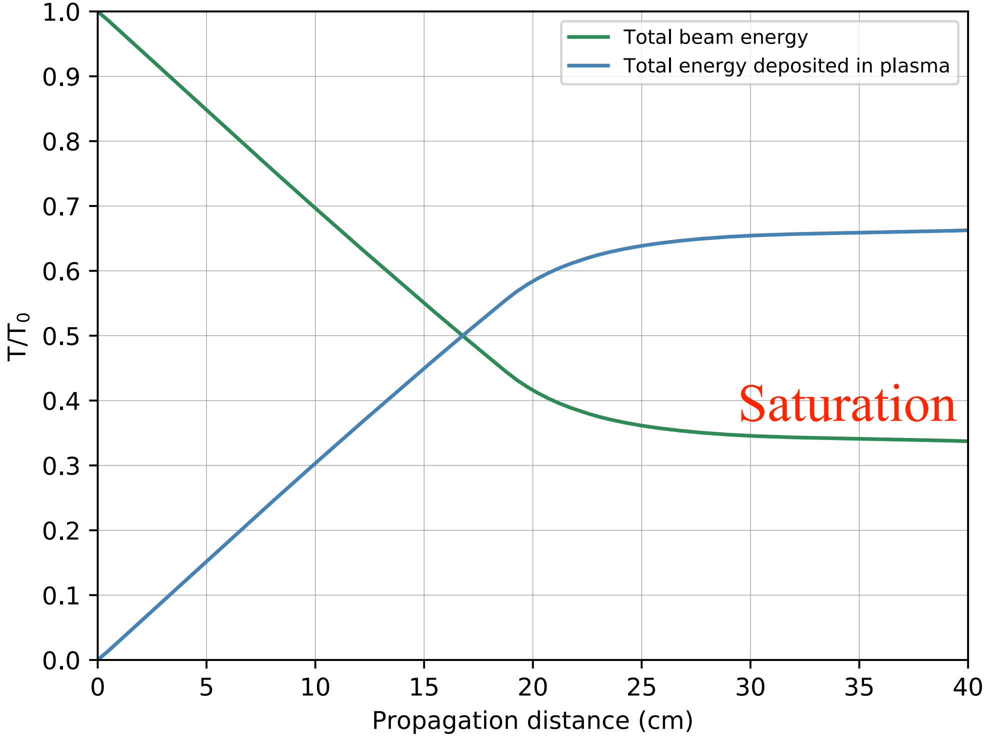
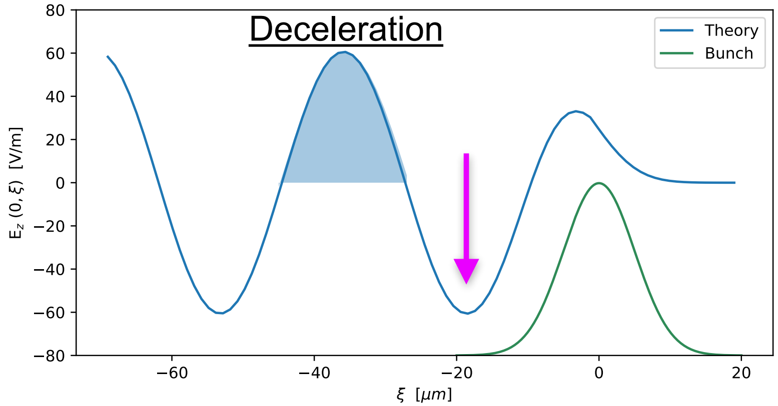
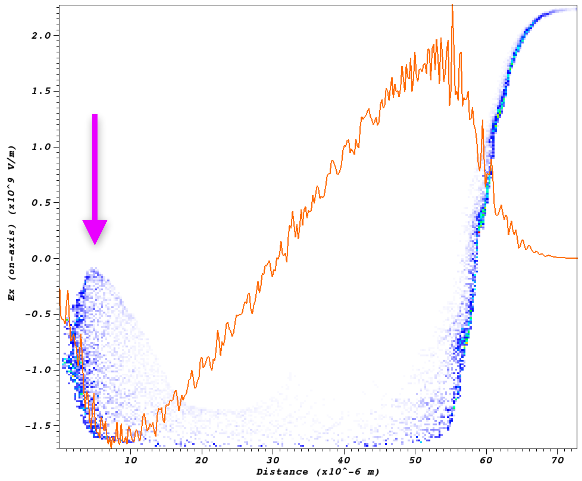
  - Decelerated particles in the beam start falling behind and get re-accelerated by the wakefield.
  - Energy loss saturates as plasma starts giving energy back to the beam.
  - EuPRAXIA beam parameters:
    - $\sigma_\xi = \sigma_r = 5\ \mu\text{m}$
    - Charge: 30 pC
    - Energy: 1 GeV
    - RMS energy spread: $\sigma_E/E = 1\,\%$
    - Angular divergence: 10^{-5}
  - Plasma density: $n_0 = n_{beam} = 10^{17}\ \text{cm}^{-3}$

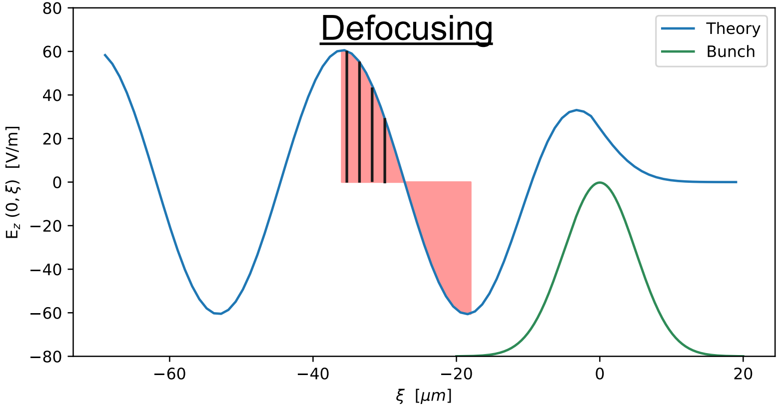


Plasma beam dump - Avoiding saturation

- Change plasma density: $n_0 \to n_1 \to n_2$
- Re-acceleration peak is
  - decelerated if $(3/2)^2 \le n_1/n_0 \le (5/2)^2$
  - defocused if $1 \le n_1/n_0 \le 4$
- Choose $n_0 \to n_1$ such that re-acceleration peak gets decelerated and defocused

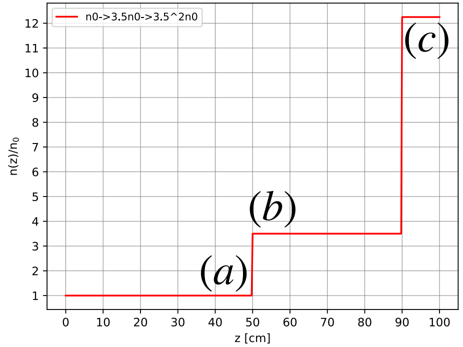




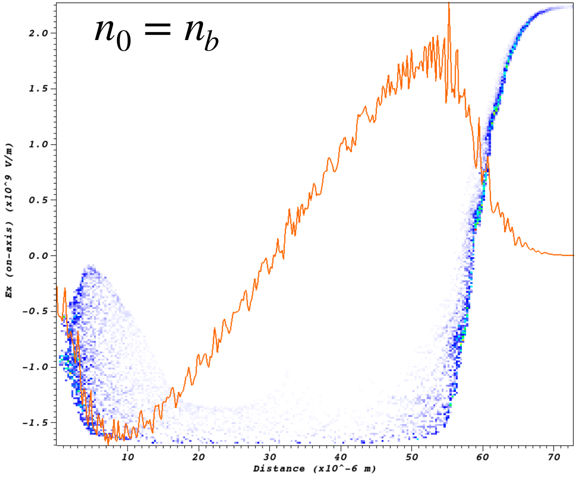


Sharp density increase

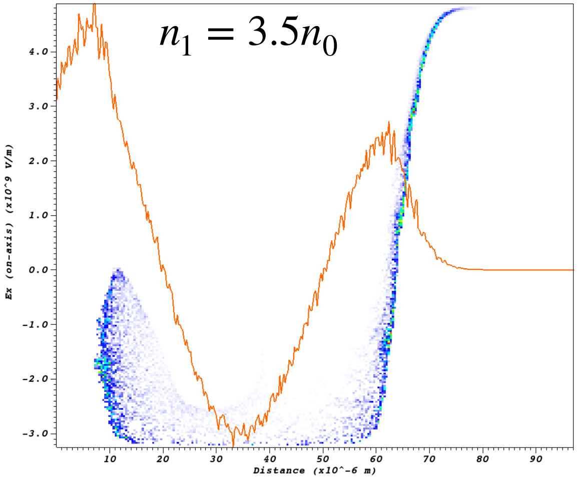
- Make density transitions $n_0 \rightarrow n_1 = 3.5n_0 \rightarrow n_2 = 3.5^2 n_0$ after each re-acceleration peak has formed
  - Re-acceleration peaks are defocused and decelerated.
- Final beam energy: **6%**



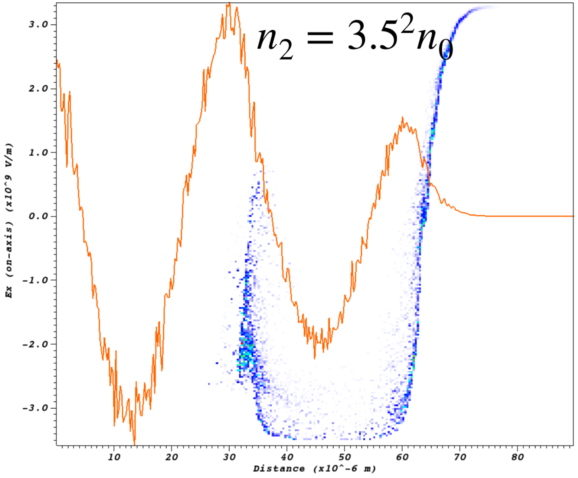
(a) Saturation at 50cm



(b) Decelerate and defocus re-acceleration peak



(c) Let new re-acceleration peak grow before defocusing again



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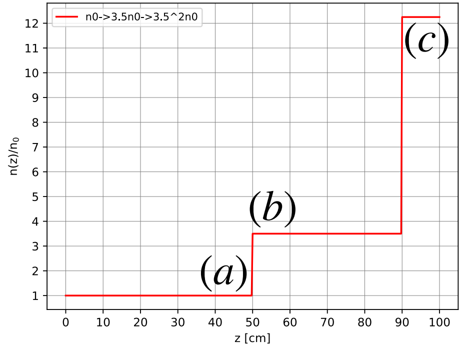
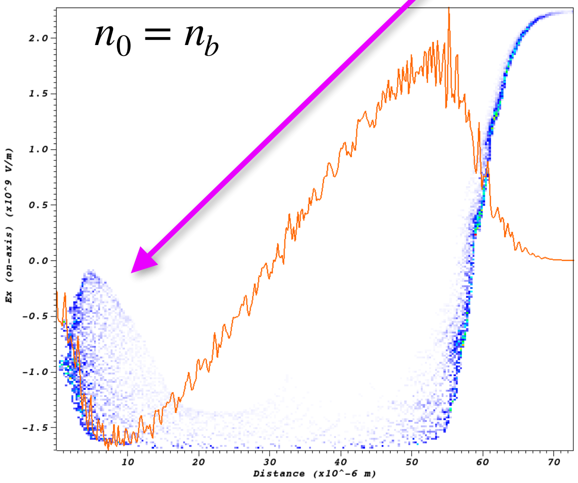
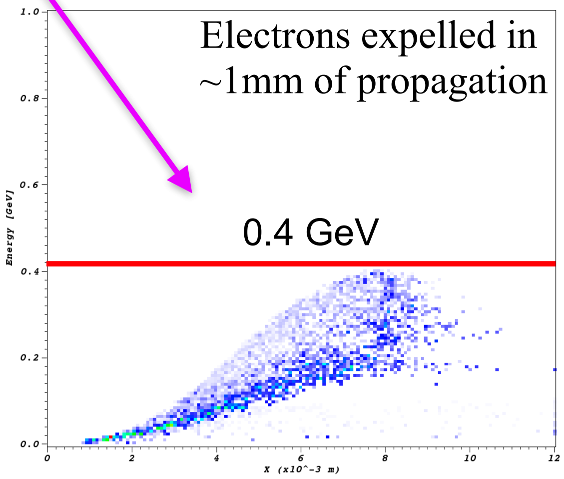
- Final beam energy: **6%**
- But high energy electrons are expelled at density transitions



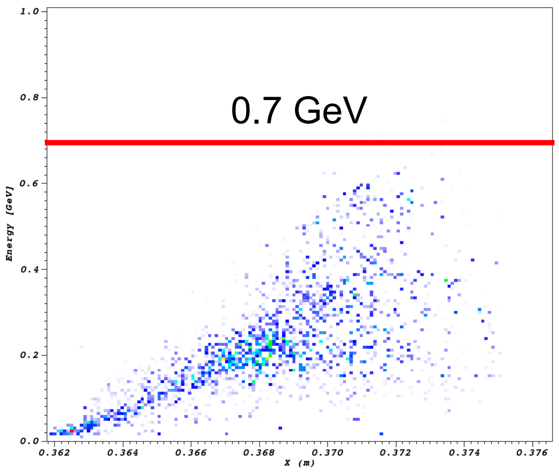
(a)



(b)



(c)



Sharp density increase - Results

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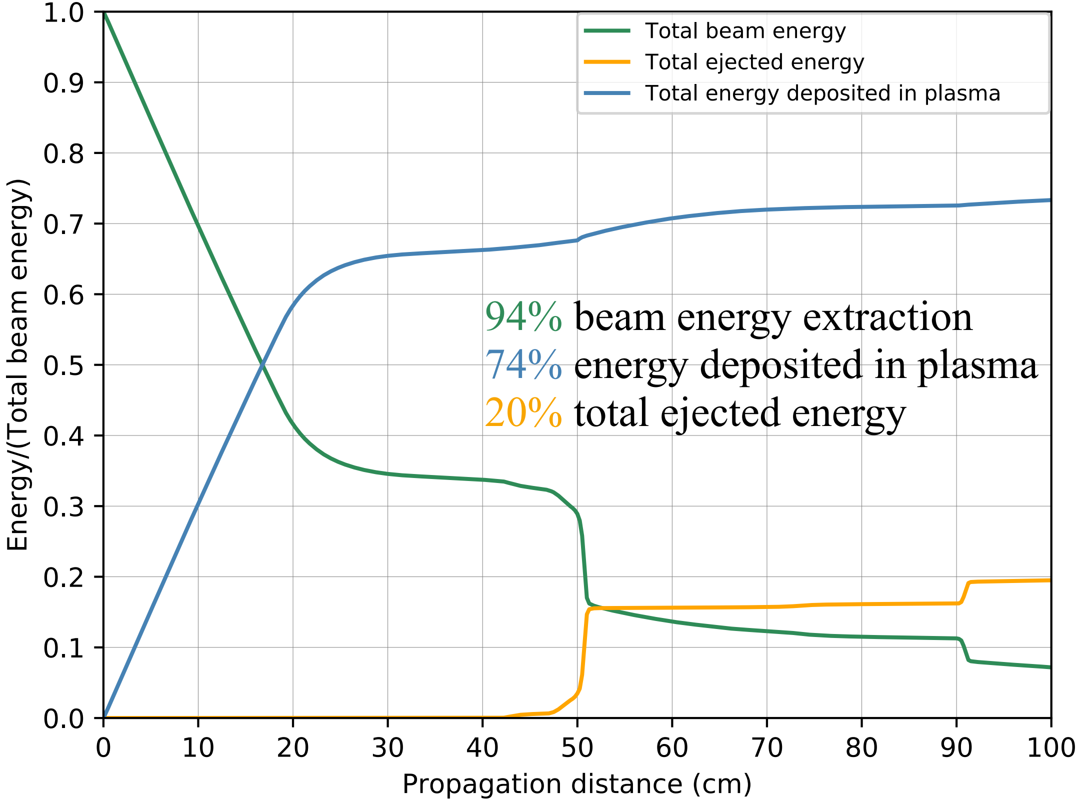
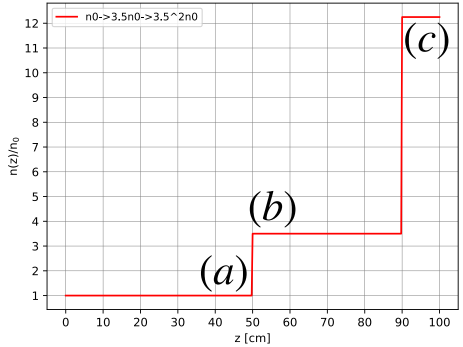
- Final beam energy: **6%** after 100cm.

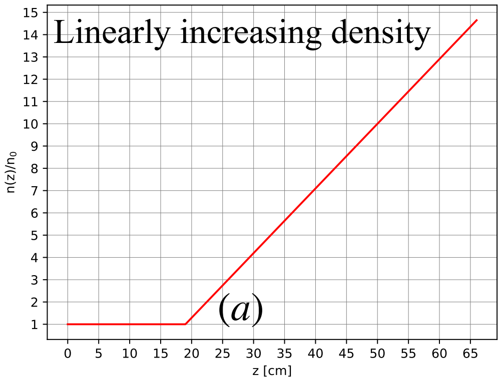


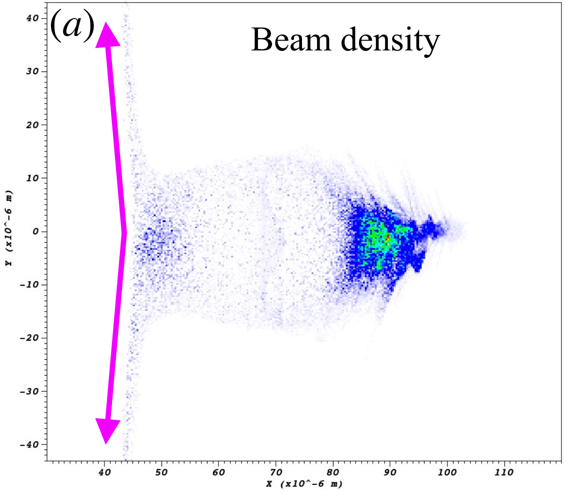


- But effect of energetic electrons ejected into plasma vessel must be investigated.
  - Damage, radio-activation and longevity of beam dump

Linearly increasing density

- Start increasing density once particles start to fall behind
- Plasma wavelength decreases as density increases
  - Defocusing region moves closer to beam, ejecting decelerated electrons





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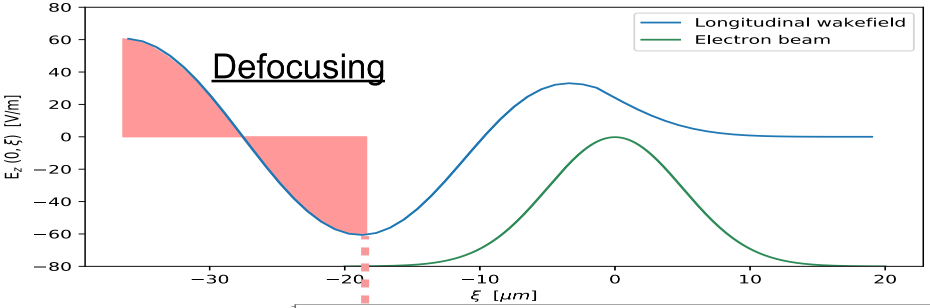
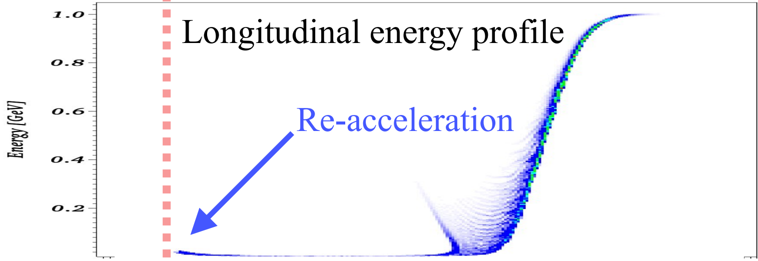
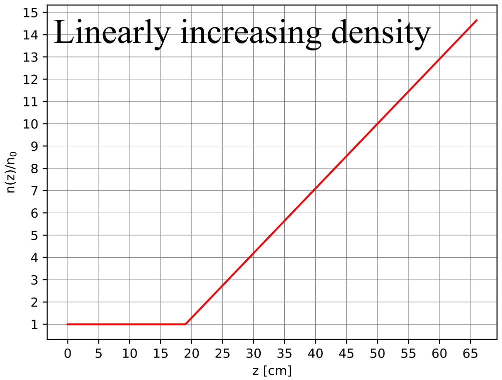
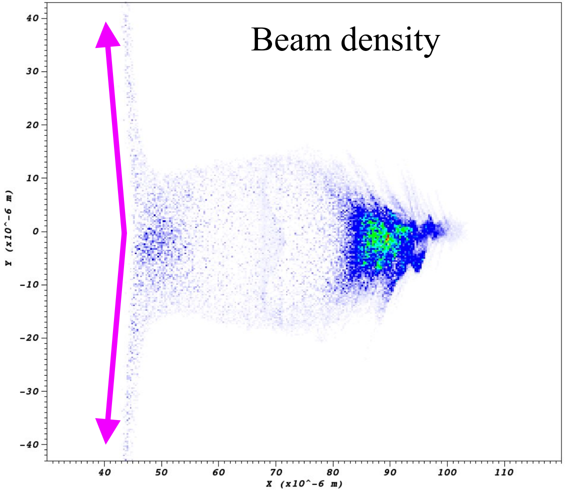
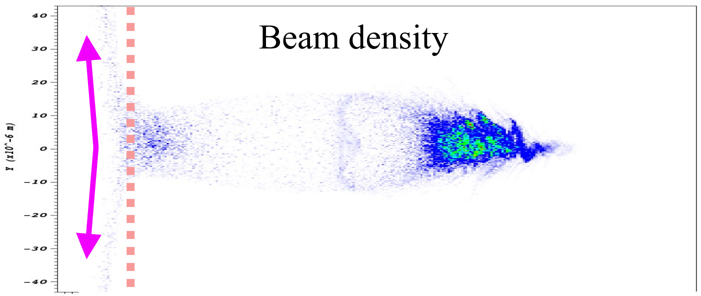




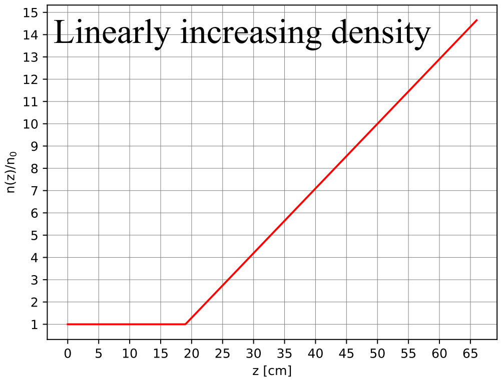


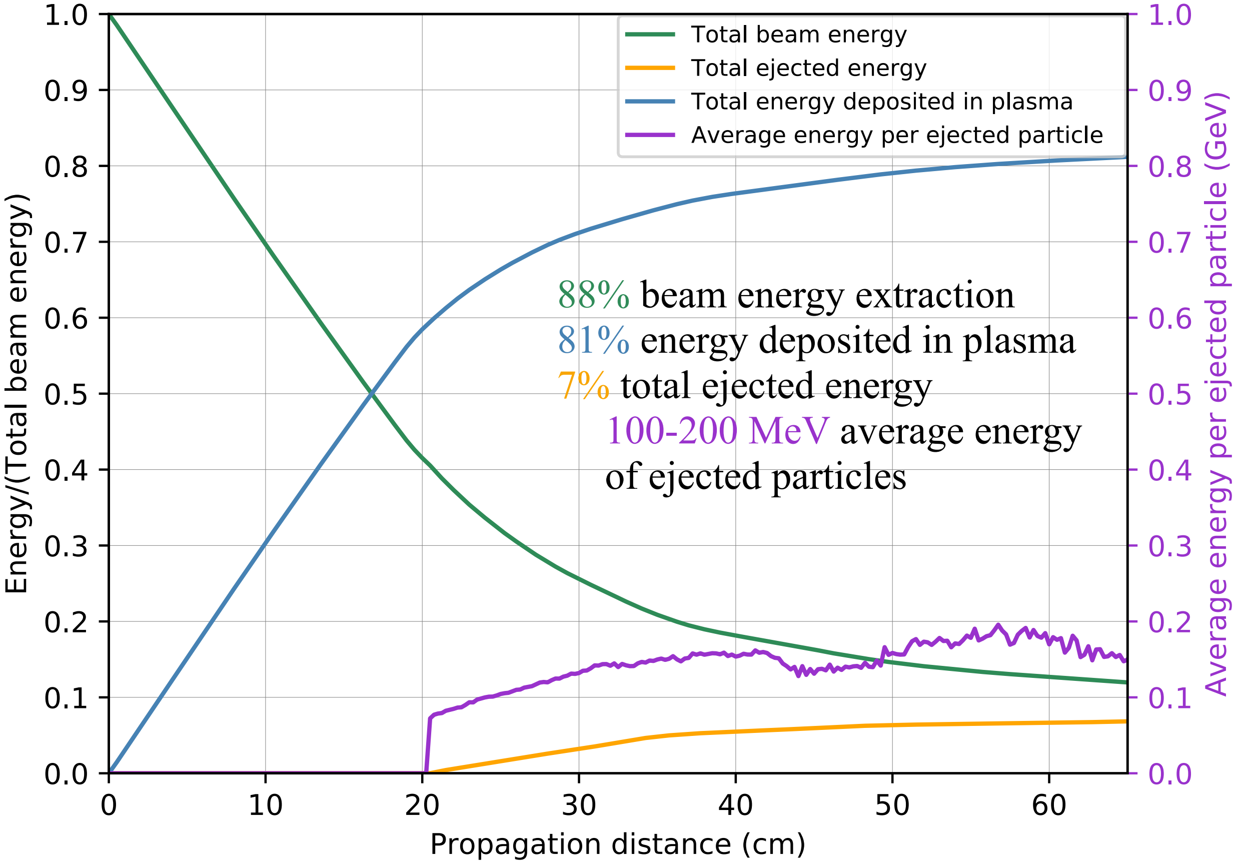




Linearly increasing density - Results

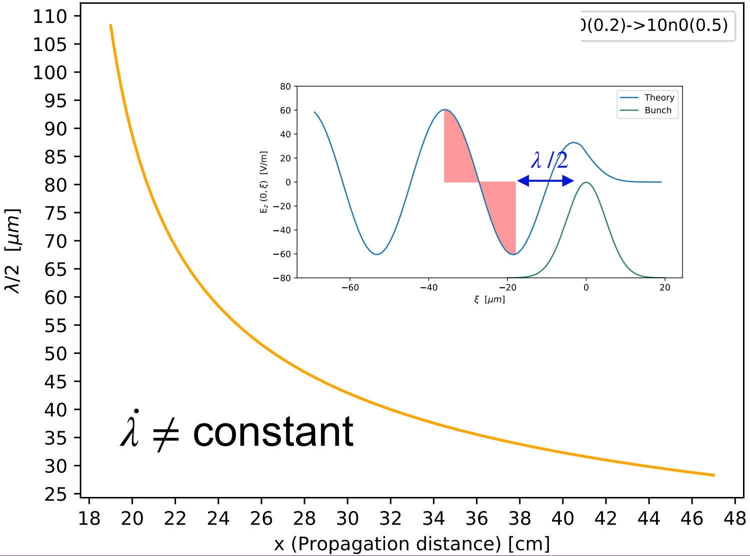
- We should aim to:
  - Maximise beam-to-plasma energy transfer
  - Maximise energy deposited in plasma
  - Minimise energy of ejected electrons

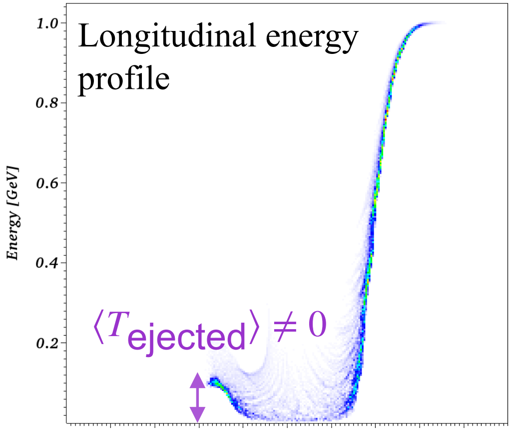


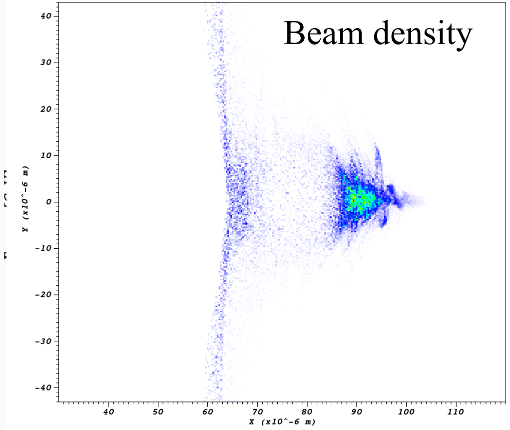


What determines energy of ejected particles?

- Energy of ejected particles is determined by the time it takes them to get defocused in the defocusing region.
  - For a linearly increasing density the wavelength changes quickly then levels off: $\dot{\lambda} \neq \text{constant}$
    - Speed of defocusing region decreases
      - More time for re-acceleration.



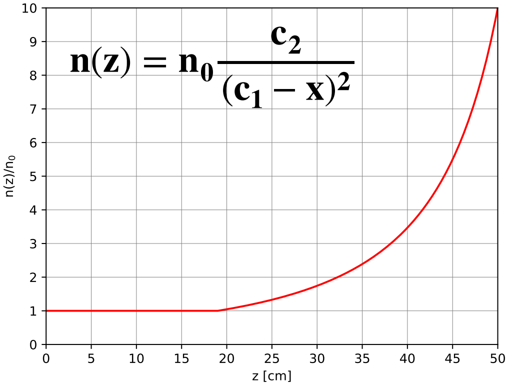


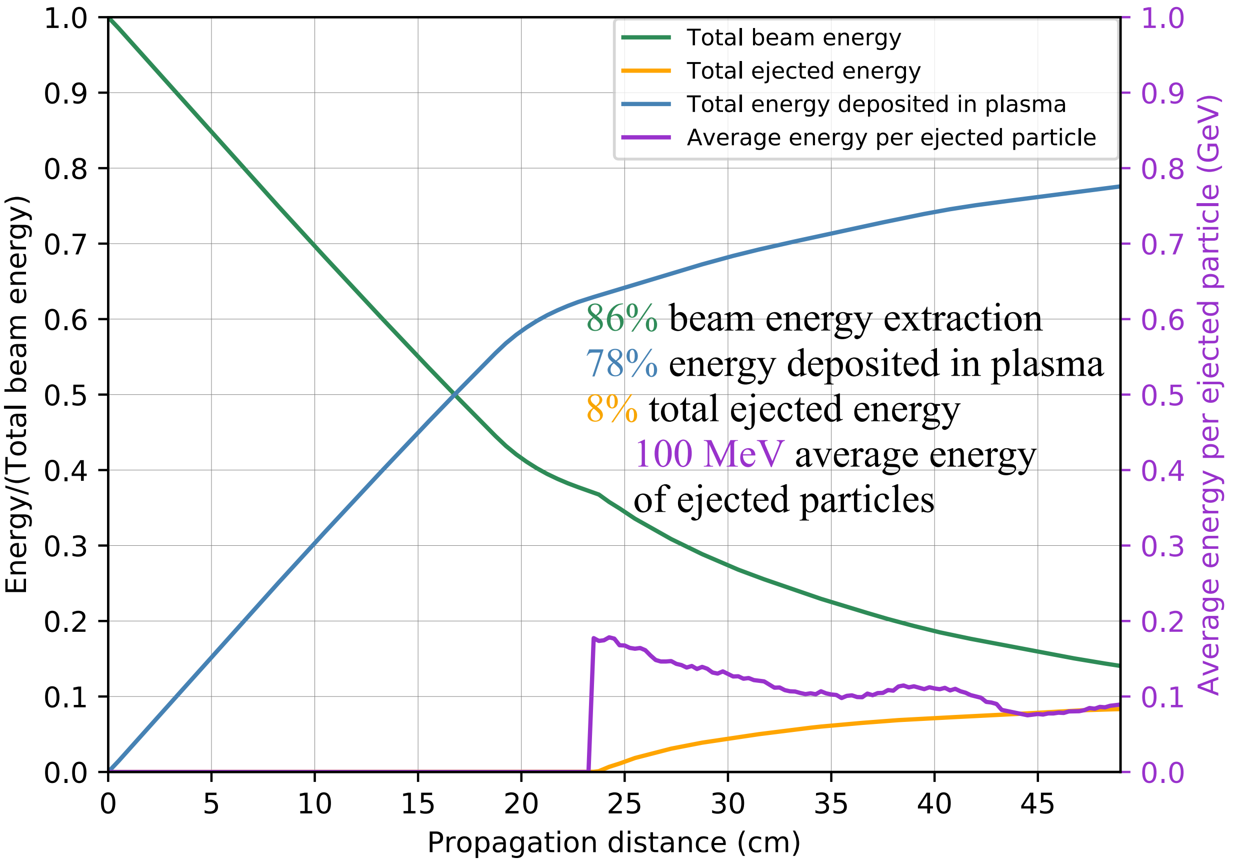


Constant speed of defocusing region: $\dot{\lambda}$ = constant

- Density profile: $\mathbf{n(x) = n_0 \frac{c_2}{(c_1 - x)^2}}$

  gives constant rate of change of plasma wavelength.
  - Defocusing region does not slow down.
    - Energy of ejected electrons is lowered compared to linear increase.





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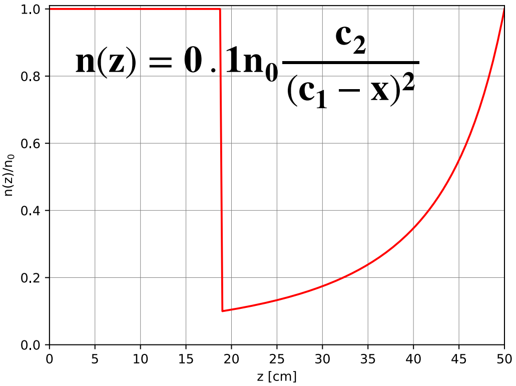
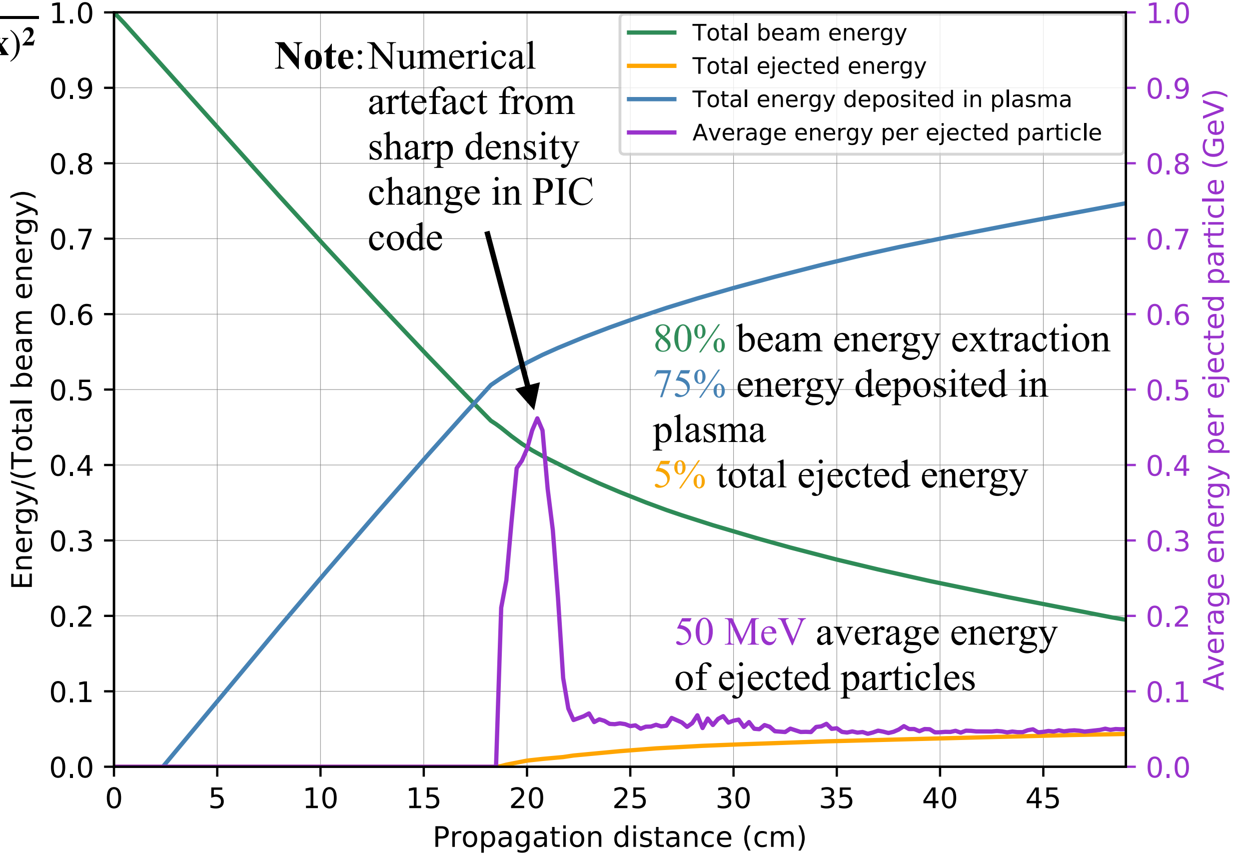
- Density profile: $\mathbf{n(x) = 0.1n_0 \frac{c_2}{(c_1 - x)^2}}$

  uses same density increase over same distance but starts from a lower density.
  - $\dot{\lambda}$ is larger, defocusing region moves faster.
    - Energy of ejected electrons is lowered to ~50 MeV





Conclusion

- Plasma beam dumps have the potential to absorb large amounts of beam energy with reduced radio-activation.
- Control over the plasma density profile allows for further increase in energy absorption.
  - The energy of the ejected particles depends on the rate of density change
- Ideal for dumping short LWFA bunches as technology is already at hand.
- Energy recovery from plasma may be a possibility.