Plasma Beam Dump and Possible Implementation in Future Colliders

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On behalf of A. Bonatto[1,2,3] , R.P. Nunes[4], S. Kumar[1,2], L. Liang[1,2], C. Davut[1,2]

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Outline

- Why plasma beam dump (PBD)?
- Plasma beam dump schemes
- PBD for EuPRAXIA beams
- PBD for collider beams
- Conclusion

Mini-Workshop on Plasma Beam Dumps and the Energy Recovery

chaired by Alex Chao (SLAC), Toshi Tajima (UCI), Guoxing Xia (The University of Manchester and the Cockcroft Institute)

from Thursday, 30 August 2018 at **09:00** to Friday, 31 August 2018 at **18:00** (Europe/London)
at **Schuster Building**
University of Manchester, Oxford Road, Manchester, United Kingdom, M13 9PL

Description This mini-workshop aims to discuss the current status and and key challenges for the plasma-based beam dumps and the energy recovery from the plasma. We will update the theoretical and numerical studies of various schemes of plasma beam dumps, discuss how to implement the plasma beam dumps to the current and future projects such as AWAKE, EuPRAXIA, ELI and the ILC, and investigate the solutions to achieve the energy recovery from the plasma. In addition, the experiment tests at the facilities such as CLARA, CLEAR, KEK ATF, etc. will also be discussed. Novel ideas to improve the plasma beam dump research such as employing the artificial intelligence in parameter optimization and new HEP physics exploration in plasma beam dumps will be discussed. The collaboration and the joint-funding opportunities will also be explored.

Participants Alexandre Bonatto; Lewis Boulton; Alexander Chao; Bernhard Hidding; Robin Kennedy-Reid; Agnese Lagzda; Yangmei Li; Aravinda Perera; Denis Perret-Gallix; Javier Resta Lopez; Philippa Rubin; Haibo Sang; Zhengming Sheng; Toshi Tajima; Guoxing Xia; Baisong Xie; Yuan Zhao

Go to day

Thursday, 30 August 2018

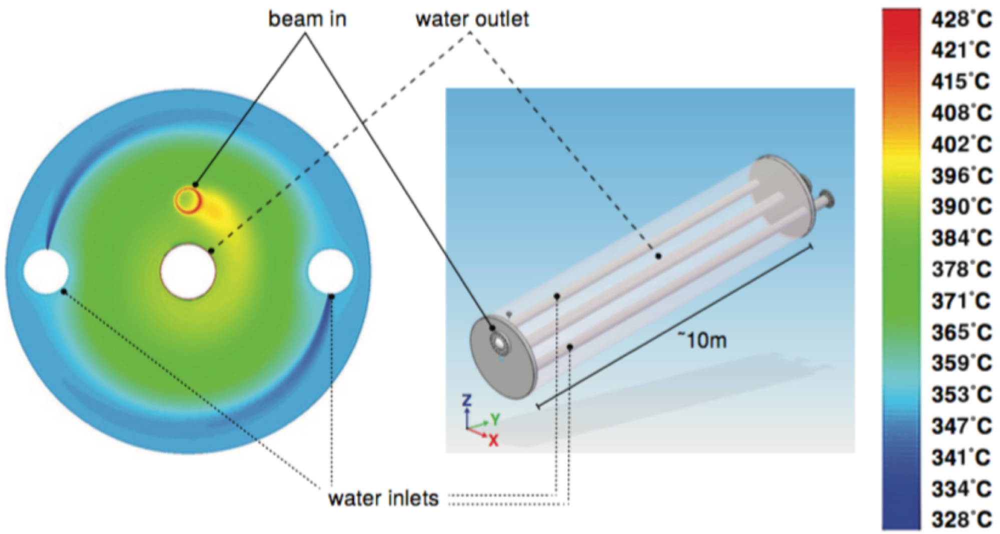
09:00 - 09:30	Registration/Welcome *30'* Material: **Slides**
09:30 - 12:30	Theoretical and Numerical Advances on Plasma Beam Dumps 1 Material: **slides**
12:30 - 14:00	Lunch Break
14:00 - 15:30	Theoretical and Numerical Advances on Plasma Beam Dumps 2 Material: **slides**
15:30 - 16:00	Coffee Break
16:00 - 18:00	Experiment Study of Plasma Beam Dumps at Research Facilities Material: **slides**
18:00 - 22:00	Dinner Location: Manchester City Centre

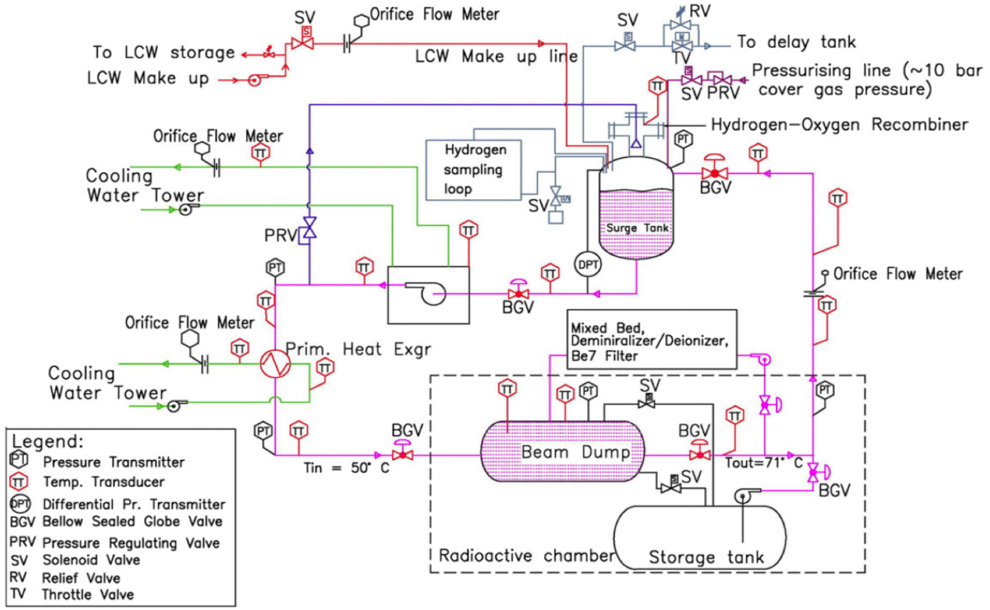
Friday, 31 August 2018

H.C. Wu, T. Tajima, et al., Collective deceleration: Toward a compact beam dump. PRST Accel. Beams 13, 101303 (2010)

Conventional beam dump

- Conventional beam dumps use high density materials – graphite, metal, water etc.
- They require high power density cooling, can produce radionuclides and (for water) explosive gasses through decomposition.
- Stopping a beam with a low density material could have advantages.

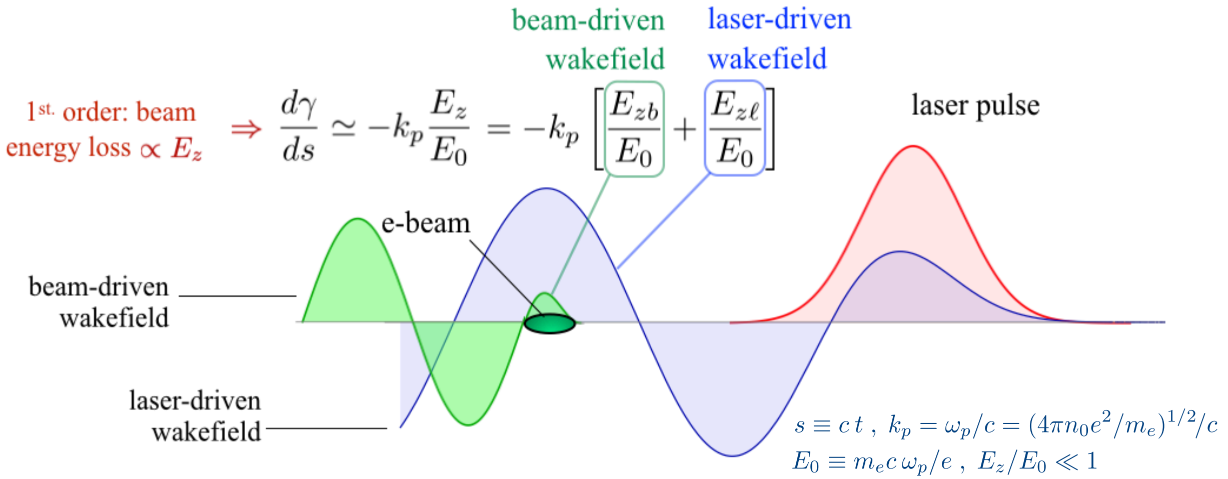




P. Satyamurthy et al., NIMA 679, 67 (2005)

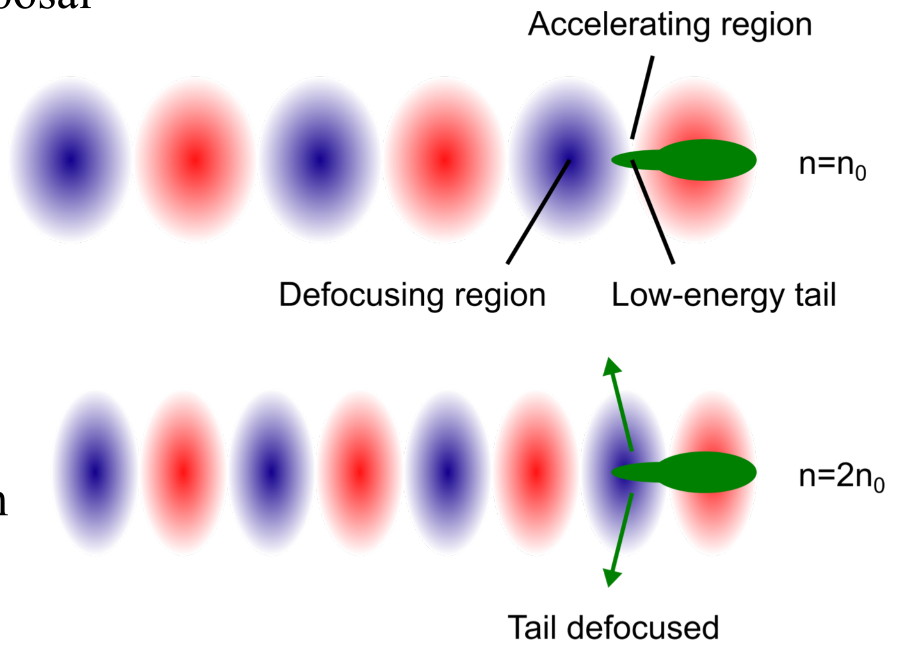
Schemes of plasma beam dump

- **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.

A. Bonatto et al., *Phys. Plasmas 22*, 083106 (2015)

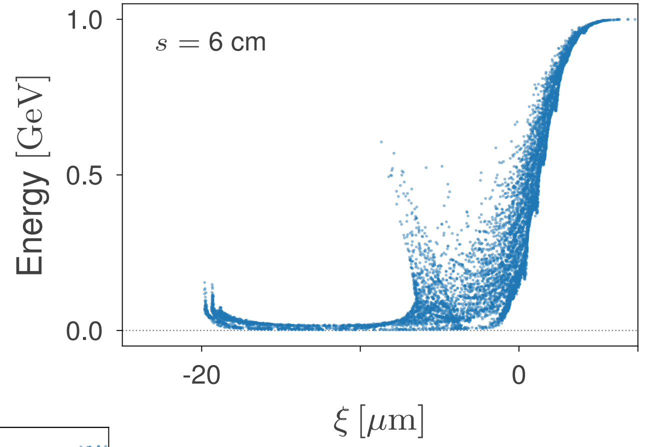


K. Hanahoe et al., *Phys. Plasmas 24*, 023120 (2017)

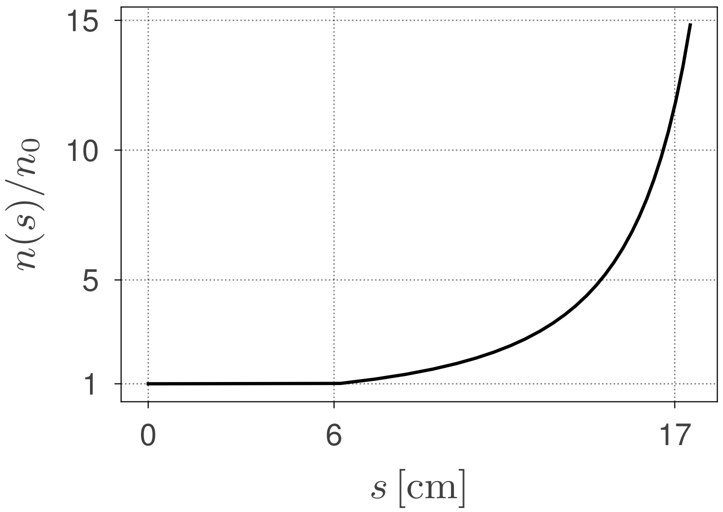
Passive beam dump-for EuPRAXIA beam*

Beam energy	1 GeV	5 GeV
Bunch charge	30 pC	30 pC
Transverse bunch size	1.4 µm	1.4 µm
Longitudinal bunch length	2.0 µm	2.0 µm
Energy spread	1.0%	1.0%
Angular divergence	1.0×10^{-5}	1.0×10^{-5}

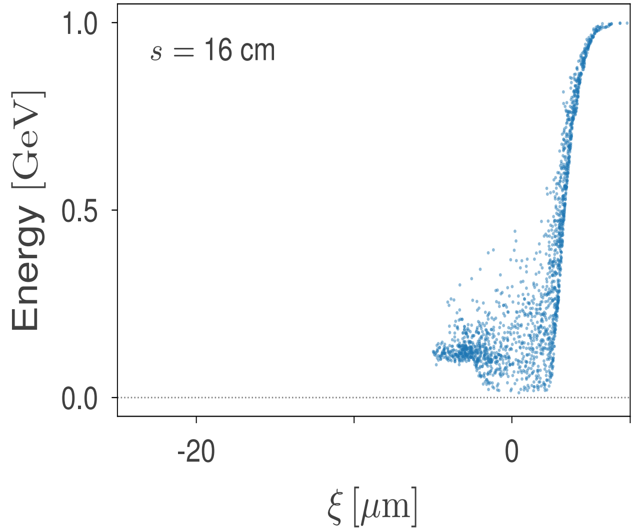
Beam density ~ 3e18 cm^{-3}, plasma density n_0 = 9.9e17 cm^{-3}



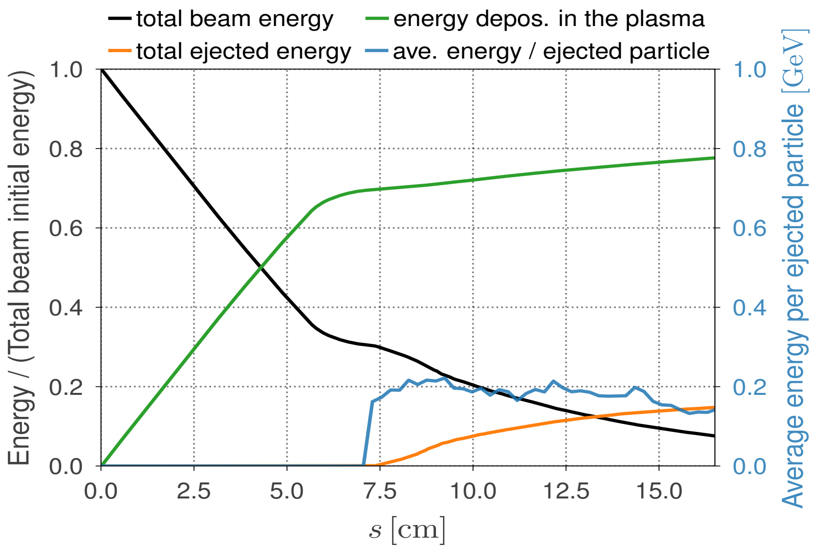
EuPRAXIA 1 GeV beam longitudinal phase space after 6 cm propagation in plasma.



Tailored plasma-density profile designed to eliminate the re-acceleration of particles in the bunch tail for EuPRAXIA 1 GeV beam.



EuPRAXIA 1 GeV beam longitudinal phase space after 16 cm propagation in plasma.

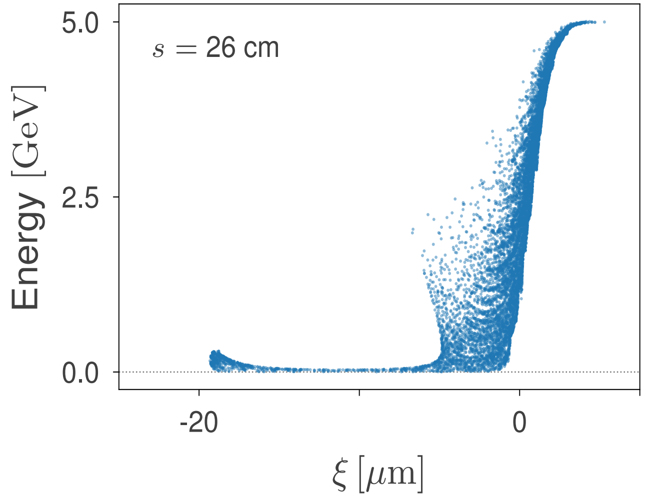


Beam energy plots as a function of propagation distance in plasma

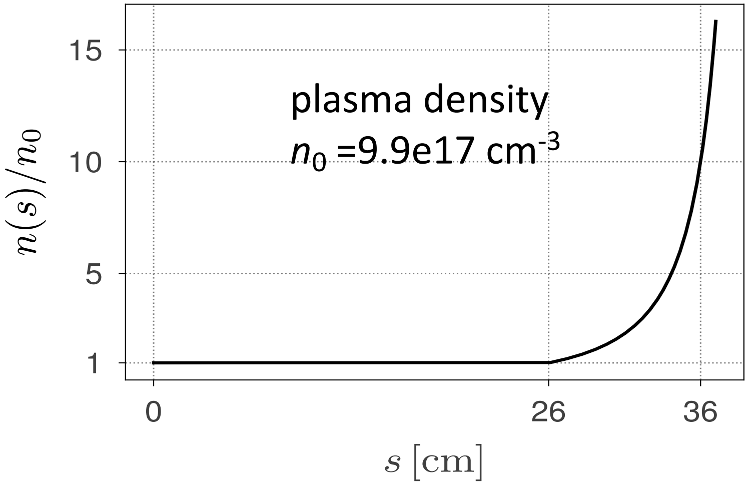
*R. W. Assmann, et al., *The European Physical Journal Special Topics* 229, 3675–4284 (2020)

G. Xia, A. Bonatto et al., *Instruments* 4(2):10 (2020)

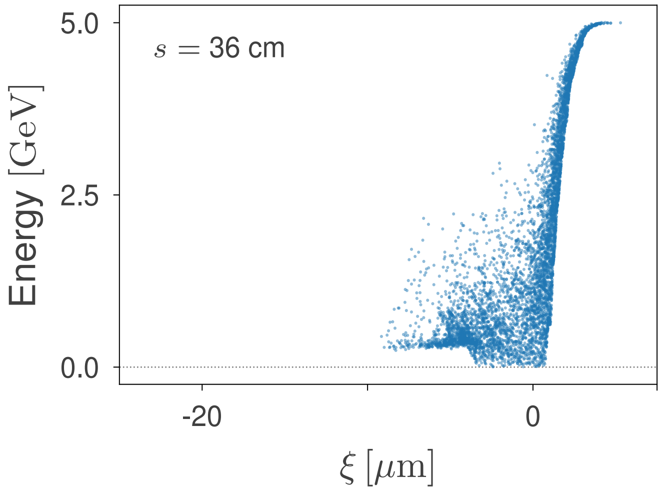
Passive beam dump-EuPRAXIA 5 GeV beam*



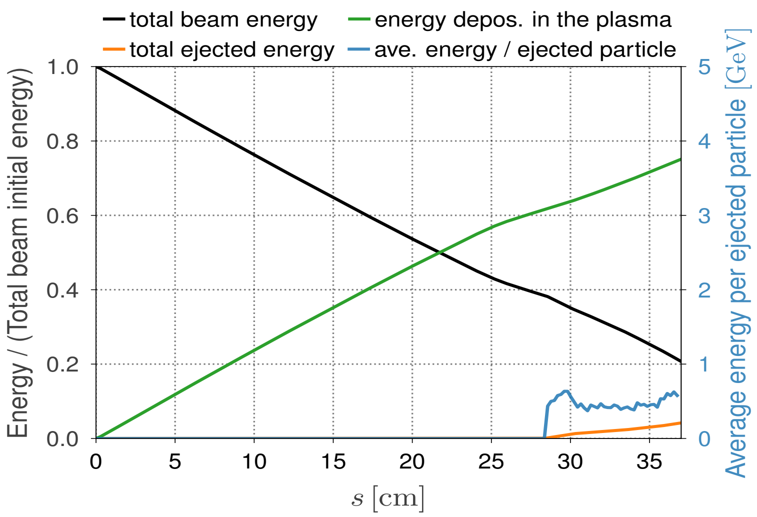
Beam longitudinal phase space after 26 cm propagation in plasma



Tailored plasma-density profile designed to eliminate the re-acceleration of particles in the bunch tail



Beam longitudinal phase space after 36 cm propagation in plasma



Energy plots as a function of propagation distance in plasma

*R. W. Assmann, et al., *The European Physical Journal Special Topics,* 229, 3675–4284 (2020)

G. Xia, A, Bonatto et al., *Instruments* 4 (2):10 (2020)

Active beam dump-EuPRAXIA 1 GeV beam

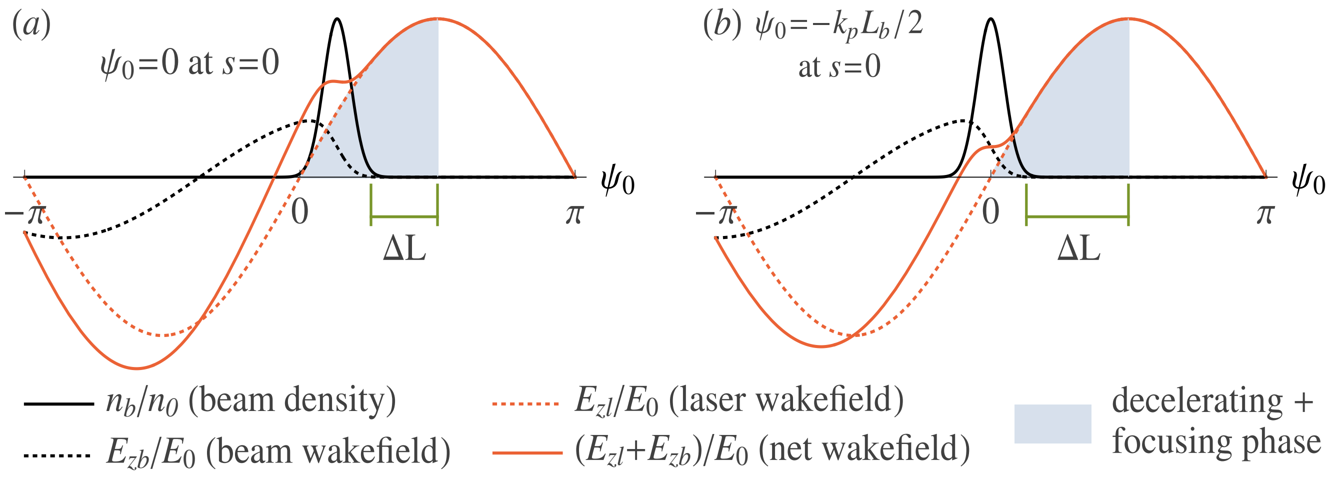
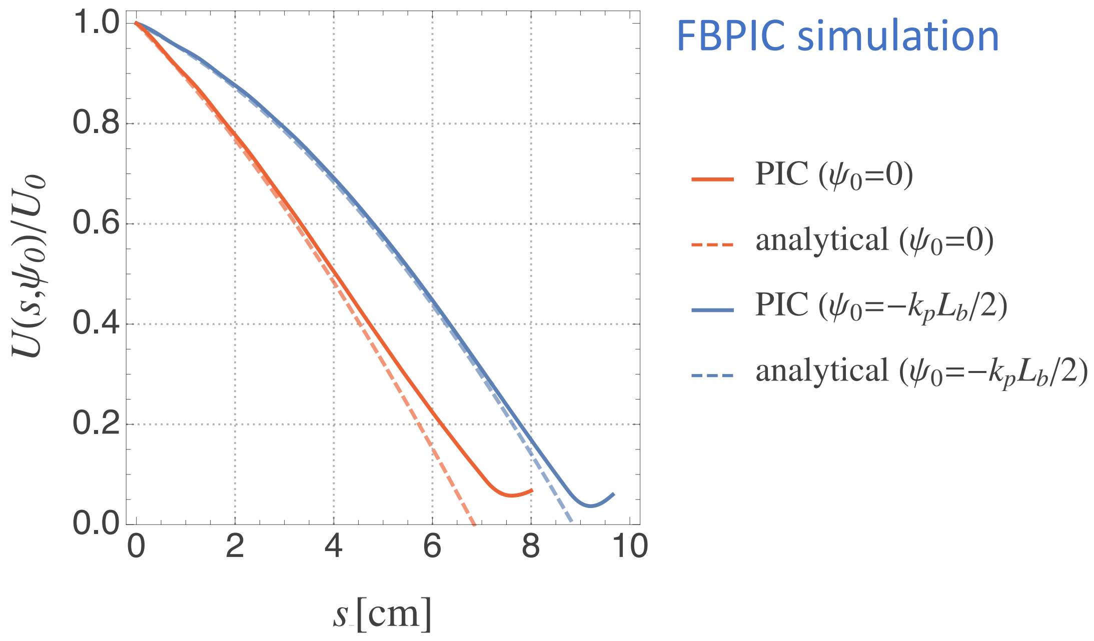


Figure 1. Beam density (*solid black line*), beam wakefield (*dashed black line*), laser wakefield (*dashed red line*), and net wakefield (*solid red line*) for (**a**) ψ_0, and (**b**) $\psi_0 = -k_pL_b/2$. In this figure, the beam propagates in the plasma from left to right, and ΔL is the distance between the beam head and the end of the simultaneously decelerating and focusing phase (*light-blue-filled region*).



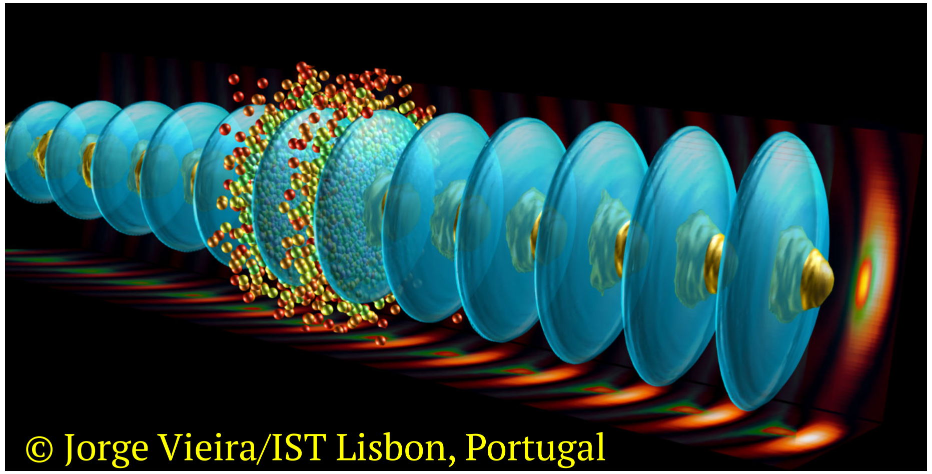
Beam total energy loss *vs.* distance in plasma

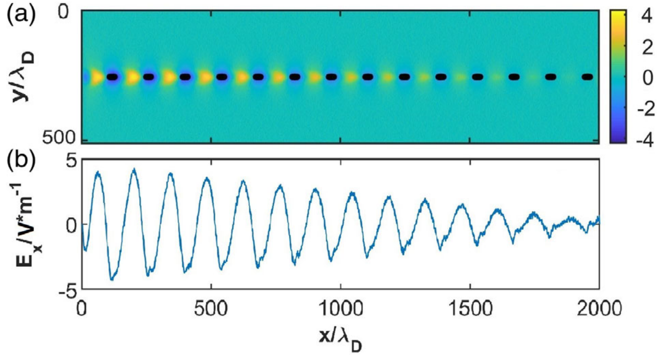
R. Lehe et al., Comp. Phys. Commun. 203, 66-82 (2016)

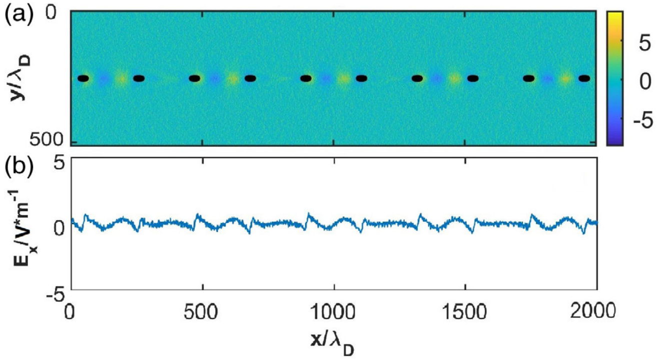
A. Bonatto, G. Xia et al., submitted (2021)

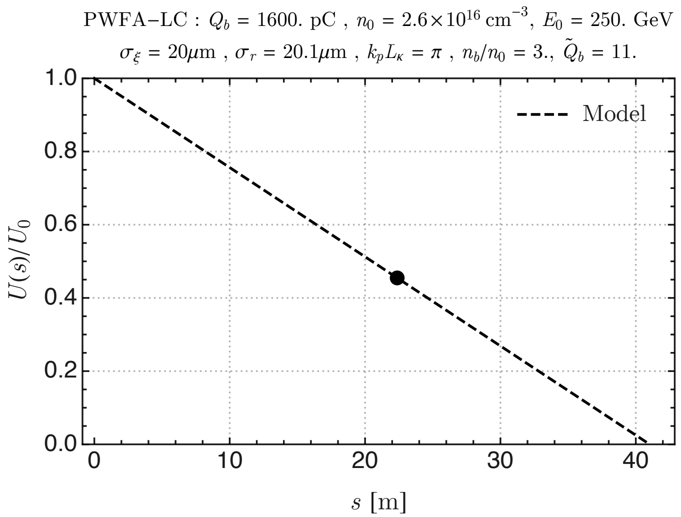
Plasma beam dumps for collider beams

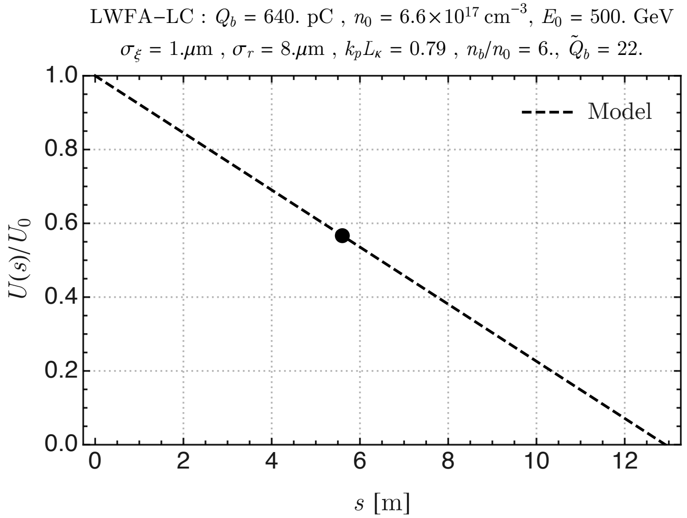
Beam parameters	ILC[1]	CLIC[1]	PWFA-LC[2]	PWFA-LC[2]	LWFA-LC[3]
CoM energy [GeV]	500	3000	500	3000	1000
Transverse rms beam sizes, $\sigma_{x,y}$ [nm]	475/6	40/1	470/2.7	190/1.1	10/10
Longitudinal rms beam size σ_z [μm]	300	44	20	20	1
Particles per bunch [x10^9]	20	3.72	10	10	4
Energy spread [%]	0.1	0.35	~1	~1	0.4
Normalized emittance $\varepsilon_{x,y}$[nm]	10^4/35	660/20	-	-	-











[1] D. Schulte, ICFA Beam Dynamics Newsletter 69, 237-245 (2016)
[2] E. Adli et al., IPAC2013, TUPME020 (2013)
[3] C. B. Schroeder et al., Phys. Rev. ST Accel. Beams 13, 101301 (2010)

K.X. Sun et al., Contrib. Plasma Phys. 2021;e202000187

Conclusion

- Plasma beam dump (PBD) utilizes the high-amplitude plasma wakefields to decelerate and absorb the energy of spent beams.
- For passive plasma beam dump (P-PBD) , ~60% of the beam energy can be extracted in a flat-density plasma before saturation due to re-acceleration.
- Tailored plasma-density profiles mitigate re-acceleration, allowing for ~90% of beam-energy extraction.
- The active plasma beam dump (A-PBD) allows for homogeneous energy extraction along the beam. In addition, the required plasma length is shorter compared to passive case. The final beam energy after plasma beam dump is also lower (~96% of beam-energy extraction).
- Plasma beam dump holds promise for compact LWFA-based facilities, allowing for the design of transportable applications based on such technology.
- Plasma beam dumps offer the possibility of energy recovery[1] .This is critical for future high-repetition-rate plasma-based accelerators and energy frontier colliders.

[1] J. Cowley et al., Phys. Rev. Lett. 119, 044802 (2017)

Questions from the community-Part 1

1) Where do you see HEP applications of advanced accelerators in 30 years?

ALIC; ILC afterburner; advanced accelerator based injectors for CEPC and FCC-ee; green colliders (with energy recovery)

2) What intermediate physics applications/steps do you see until a HEP linear collider?

LWFA-based FELs; fix target experiment based on AWAKE scheme…

3) What is the synergy with related fields?

Achieving high beam quality; advanced simulations; novel diagnostics; positrons…

4) What is the role of your work here?

Explore new schemes for plasma acceleration (to achieve collider quality beams) and deceleration (for plasma beam dumps); conduct experiment at test facilities

Questions from the community-Part 2

1) What are the important milestones for the next 10 years to get there from today?

   Fully understand the plasma beam dumps to achieve high efficiency; demonstrate energy recovery from plasma wakefield

2) What additional support is needed to achieve these?

   Funding, beam times from test facilities

3) What should be proposed as deliverables until 2026? Please list in order of priority.

   Experiment study of passive plasma beam dump via tailored plasma density;

   Test of active plasma beam dumps; test of energy recovery in plasmas

4) Is the R&D work for each of those deliverables already funded and, if not, what additional resources / support would be needed?

   Funding $$$, access to test facilities such as FLASHForward, ATF (BNL), CLARA, CLEAR, AWAKE…

Questions from the community-Part 3

1) What key R&D needs can be achieved in existing R&D facilities?

   The deliverables listed in Part 2

2) What is the role of the already planned future facilities in Europe and world-wide?

   Future facilities (such as EuPRAXIA, CLARA…) can provide beam times to test new ideas

3) What can be done with the existing and planned funding base?

   Some theoretical and experimental work on plasma acceleration and deceleration

4) Is a completely new facility needed?

   Yes, a new facility like EuPRAXIA would be perfect

5) Are additional structures needed beyond existing networks and projects, e.g. a design study for a collider or an advanced accelerator stage?

   Yes, existing network such as ALEGRO has paved the way. The improved structure will be needed to tackle each specific issues aiming to achieve FEL or collider-quality beams with high efficiency.

Thanks for your attention!