Tunable Beam-dump using Collective Fields in Plasma: Controlling Radiation Background and Stopping Power

Proposed Research: Highly efficient yet controlled beam energy absorption is a critical need for many generic accelerator applications including high energy physics.

Application-driven demand for *ever-increasing beam energy-densities* has led to challenges in conventional collisional stopping mechanisms.

We propose to investigate a tunable beam dump based on beam energy coupling to collective fields in a plasma.

Unlike conventional individual particle collisional stopping, beam-driven collective fields in plasmas exploit beam-plasma resonances of different plasma modes that not only reduce hard radiation and secondary particle flux (muons, neutrons – that have even longer stopping range) by many orders of magnitude, but also enable compact size given their many GV/m gradients.

The proposed effort is theoretical, computational, and experimental.

It will enable on-demand access to a tunable lower beam energy to applications downstream from the main target area without disrupting the main beam, a feature that conventional design does not allow.

Success of the proposed work will also minimize radio-activation and make compact beam-dumps for generic accelerator systems including light-sources and colliders.

This effort is scalable because of the trend in reduction of beam volumes yet increase in the beam charge which favors driving of higher amplitude collective plasma fields.

It is timely because of the recent demonstration of strong coupling of a mismatched proton beam of high rigidity to plasma at CERN.

A high signal-to-noise ratio (SNR) is a critical parameter for any accelerator application and is achieved by minimizing the radiation background. A major accomplishment of this work will be to ease up the demands on detectors by lowering the radiation noise from the beam-dump and thus improve the quality of data.

Moreover, novel compact accelerators like cm-scale laser wakefield accelerators have little advantage if the radio-activation and hazardous material handling dominate the size and cost. Apart from being beneficial to size and radiation related challenges our approach is also amenable to energy recovery.

Our approach is to use simulation-driven (Particle-In-Cell) proof-of-principle beam deceleration experiments at the Accelerator Test Facility (ATF) in Brookhaven National Lab (BNL). We will also utilize experience gained from our parallel FlashForward facility at DESY, Germany in collaboration with the Univ. of Manchester, UK.

Experiments in unison with simulations will specifically characterize different approaches to control and optimize collective field and stopping power for beams that may be mismatched to plasma while minimizing radio-activation.
Scope / Statement of Work (preliminary proof-of-principle stage):

This work is targeted towards a step-wise buildup of a prototype at BNL-ATF over the period of performance. The main tasks to be accomplished are computational & experimental:

[1] demonstration of control and maximization of the deceleration gradient and loss of a major fraction of beam energy by coupling to plasma modes under the variation of beam and plasma (Yr.1/2/3).

[2] demonstration of tunability of beam energy loss as well as other beam properties using its coupling to plasma by varying the plasma parameters over a wide-range of beam properties (Yr.1/2/3).

[3] characterization of competing mechanisms such as self-modulation, hosing, current filamentation instability, beam scalloping etc. of the stopping bunch in order to optimize the collective deceleration gradient over a wide-range of parameters (Yr.2/3).

[4] evaluation of the effect of long-term evolution of beam energy coupled plasma electron and ion modes and thus the effect of average beam power on plasma beam-dumps and accelerators (Yr.2/3).

[5] evaluation of the effect of externally applied magnetic fields on the plasma (entrance/exit and bulk) on the excited plasma modes as well as on competing instability mechanisms in order to optimize the collective deceleration gradient over a wide-range of parameters (Yr.2/3).

[6] demonstration of advanced beam-dump strategies such as an active plasma beam-dump using laser-driven collective fields to extract the beam energy by phasing the stopping bunch in the deceleration phase of the laser-driven wave

[7] demonstration of advanced beam strategies such as an active plasma beam-dump using two-bunch driven collective fields where the drive or pre-processing bunch energy loss is like in a passive dump whereas the second or the stopping bunch rides the deceleration phase of the plasma wave to lose its energy. (Yr.2/3)

[8] demonstration of other advanced strategies such as staging of plasmas, plasma in an undulator etc. (Yr.3)

[9] build a scalable and tunable model for controlled beam energy loss and other beam properties over the interaction parameter set of beam, plasma and laser properties. (Yr.3)

[10] quantification of the strategies and limits associated with beam energy recovery from various plasma modes (Yr.3).

Preliminary requested setup and parameters

plasma density - $[10^{14} – 10^{18} \text{cm}^{-3}]$
beam waist – short-term: 50 – 100um, long-term: 5-50um
bunch-length – 90fs (100pC) to 5ps (1nC)

requested diagnostics:
interferometric probe (Nd:YAG or YAG – plasma density limits ?)
TCAV bunch profile measurements