Effects of pulsed hollow electron lens operation on the beam core in HL-LHC: First experimental studies and simulations.*

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In the HL-LHC a considerable amount of energy is stored in the beam tails due to the high beam intensity and an overpopulation of the tails compared to a Gaussian distribution. To control and clean the tail population, the installation of two hollow electron lenses, one per beam, is considered. Beside the DC operation, also a pulsed operation of the hollow electron lens is considered, which would considerably increase the diffusion speed by putting noise on the halo particles. In the ideal case, that is in case of no field at the beam core, only the halo particles are excited while leaving the core unperturbed. The picture though changes, if a residual field is present also at the location of the beam core putting noise also on the beam core. In this paper we present for estimates of the residual field at the beam core expected from the HL-LHC hollow electron lens and first experimental results of the effect of this excitation on the beam core together with the supporting simulations.

I. INTRODUCTION

Considering past, current and future high energy and intensity colliders, each new machine has represented a considerable leap in stored beam energy with rising values for future accelerators and colliders (see Table I). Recent measurements at the LHC furthermore show that the tails of the transverse beam distribution are overpopulated compared to a Gaussian distribution resulting in a considerable amount of energy being stored in the beam tails alone. In case of the LHC explicitly around 5% of the beam population is stored in the tails above 3.5 σ compared to 0.22% in case of a Gaussian distribution leading to 19 MJ of stored energy in the tails in case of nominal LHC parameters and 34 MJ in case of HL-LHC [4].

All of the above reasons lead to the conclusion that a mechanism is needed to deplete the beam tails in a controlled manner (see for example [5] in case of HL-LHC). The most obvious idea is to decrease the collimator gaps or scrape the tails with a collimator type device Why is that not possible?. This is however not possible due to impedance issues. Other mechanisms must therefore be found to actively deplete the tails. Most promising are methods, which considerably increase the diffusion speed in the region of the tail particles while leaving the beam core unperturbed. The diffusing tail particles are then intercepted by the collimation system and removed (see FIG. 1 for illustration). In view of the need for LHC and HL-LHC in particular and in general for future high power accelerators, different methods have been studied in the last recent years [6], of which the HEL is considered the superior device at least in case of the HL-LHC [5] and is also considered for other future high energy colliders like HE-LHC and FCC-hh [].

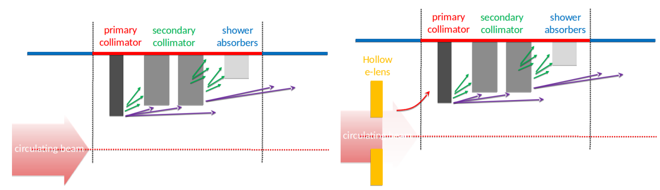

FIG. 1. Sketch of passive halo control as with the collimation system (top) and active halo control using in addition for example a hollow electron lens (HEL) to control the diffusion speed in the region tail region without affected the beam core (bottom). **Any acknowledgement needed for the plots?**.

The concept of active halo control however breaks down if also the beam core is affected, which would ultimately lead to a degradation of the performance. In this paper, we will concentrate on this aspect for the HEL foreseen to be installed in the HL-LHC. We will summarize possible sources of perturbations of the beam core concentrating in particular on the case of pulsed operation and with the focus on the beam experiments at the LHC performed in the context of these studies.

This paper is structured as follows: Section II gives an introduction to the concept of HELs and summarizes the design parameters of the HL-LHC HEL. Section III is dedicated to describing the sources of a residual field from the HEL in the core region. Section IV presents the results of the LHC experiment to study the effects on the beam core in case of a pulsed operation of the HEL, explicitly a resonant excitation. This includes the detailed

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TABLE I. Stored beam energy for different past, present and future colliders. Each new machine represents a leap in stored beam energy.

Collider	Tevatron (protons) [1]	LHC 2016 [] [a]	LHC nominal [2]	HL-LHC [] [b]	FCC [3] [c]
Beam energy [TeV]	0.98	6.5	7.0	7.0	50.0
Number of bunches	36	2076	2808	2748	?
Number of particles per bunch	2.90×10^{11}	1.18×10^{11}	1.15×10^{11}	2.2×10^{11}	1.0×10^{11}
Stored beam energy [MJ]	1.6	255.1	362.2	678.0	8400

[a] values from `https://lhc-commissioning.web.cern.ch/lhc-commissioning/performance/2016-performance.htm`
[b] values from parameter and layout committee website `https://espace.cern.ch/HiLumi/PLC/default.aspx`
[c] get right reference and values

analysis of the observed losses, emittance and transverse beam distribution changes. To the knowledge of the authors, the observed distribution changes presented in this paper have never been measured before in the context of a resonant excitation. A resonant excitation has been previously studied at the Tevatron in the context of the HEL experiments [7] and the abort gap cleaning used in operation [8]. Both studies however only concentrated on the losses and emittance changes without measuring the detailed changes of the distribution. In addition the presented experiment also provides scaling of the losses and emittance growth with the excitation amplitude allowing for a comparison with simulations and ultimately an extrapolation to HL-LHC.

II. HOLLOW ELECTRON LENS FOR HL-LHC

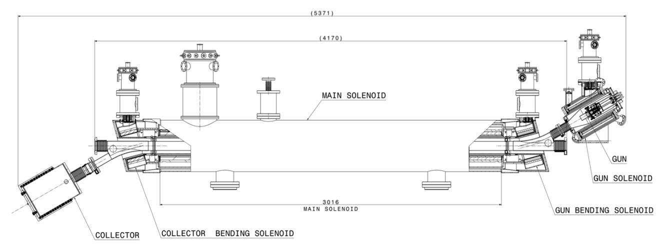

FIG. 2. Layout of HL-LHC HEL **Ask Diego how to acknowledge correctly**.

III. SOURCES OF RESIDUAL FIELD IN THE PROTON BEAM CORE REGION

IV. LHC EXPERIMENT

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Appendix A: Appendixes

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