

OVERVIEW OF BEAM DIAGNOSTICS FOR PERLE*

M. Ben Abdillah[†], S. Brault, A. Fomin, J. Michaud, R. Roux, Université Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France
on behalf of PERLE collaboration
J. Wolfenden, Cockcroft Institute, Daresbury, United Kingdom

Abstract

PERLE is an Energy Recovery Linac (ERL) that will be built at the IJCLab in Orsay. It will be the first multibunch ERL with the ambition to reach a beam power of 5 MW. Diagnostics are a key element for the functioning of PERLE, an overview of these diagnostics is discussed. The article focuses on the design and the operation of the diagnostics for PERLE injector. Finally, the article presents challenging diagnostics to monitor beam parameters in PERLE SRF LINAC and PERLE recirculation arcs.

INTRODUCTION

PERLE facility is a new generation energy recovery machine covering the 5 MW power regime with 20 mA beam current and 250 MeV beam energy [1]. It is a compact multiple pass ERL based on SRF technology, to serve as testbed for the validation of a broad range of accelerator phenomena and technical choices for future projects.

An overview of PERLE is sketched in Figure 1. The photocathode gun is on the far right with the injector section immediately following. In this configuration, the peak beam energy is 250 MeV. This is achieved by passing three times through a SRF LINAC.

Starting from a 7 MeV injector, the beam gains 82 MeV per turn, reaching successively 89 MeV, 171 MeV and a final energy of 250 MeV after 3 recirculation passes. After a path length shift of exactly half of RF period, it is then decelerated through the same linac structure to recover the beam energy up to the final dump at 7 MeV, thereby demonstrating full multi-pass energy recovery at high current.

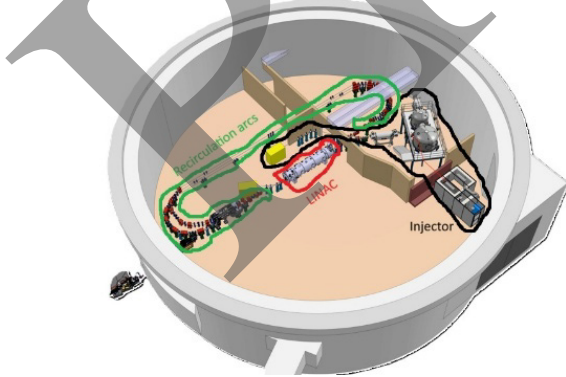


Figure 1: Overview of PERLE in Orsay.

PERLE diagnostics should monitor specific beam properties at different locations. The following list outlines the diagnostic requirements for PERLE:

- Comprehensive beam measurements at the output of the injector to obtain a precise characterization of the beam at the entrance of the SRF LINAC.
- Calibration of the LINAC cavity phases to optimize the operation of the LINAC.
- Beam path monitoring for each recirculation arc to precisely adjust the length of the path of each beam in the recirculation arcs.
- Monitoring of several beams: measurement of the position of each beam individually.
- Measurement of beams properties in the recirculation arcs for machine protection and optimization of its operation.

Some of these measurements are particularly challenging due the large dynamic ranges over which the beam might operate:

- Beam type: pulsed to cw
- Charge: 10 pC to 500 pC
- Energy: 350 keV to 250 MeV
- Current: 100 μ A to 20 mA
- Longitudinal length: 3mm or 10 ps

This article focuses on diagnostics for PERLE injector and details other diagnostics with challenging issues.

DIAGNOSTICS FOR THE INJECTOR

PERLE is currently under construction in the IGLOO building at the IJCLab in Orsay, France. The project is progressing in successive phases, each designed to validate a key step toward the full ERL operation. The first phase, scheduled for late 2028, focuses on realization and the commissioning of the injector sketched in Figure 2.

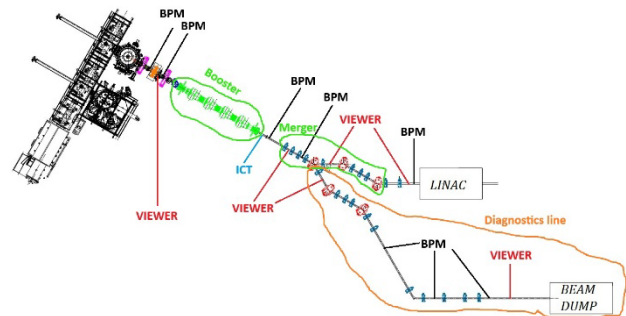


Figure 2: PERLE injector overview with diagnostics.

This includes testing the high current electron gun, aiming to deliver up to 20 mA and 350 keV electron bunches at a repetition rate of 40.079 MHz, as well as the

* This work received government funding managed by the Agence Nationale de la Recherche (ANR) in the France 2030 framework - reference ANR-24-RRII-0001

[†]sidi-mohammed.ben-abdillah@ijclab.in2p3.fr

superconducting RF booster that accelerates these bunches to 7 MeV.

During this phase, the merger section and a diagnostic mirror line will also be constructed to ensure that the beam properties meet the design specifications.

Injector diagnostics should give detailed parameters of the beam at the input of the LINAC. The measurements include beam position, charge, transverse and longitudinal profiles, energy profile and emittance.

Therefore, four beam positions monitors (BPM), one Integrated current monitor (ICT) and three Beam viewers are needed along the gun and the merger. Longitudinal profile, energy profile and emittance will be monitored on the diagnostic line mirroring the merger.

2 BPMs and 1 Beamviewer were already purchased with PERLE Gun: the BPMs internal diameter is 68.6mm and it is integrated with steerers as sketched in Figure 3.

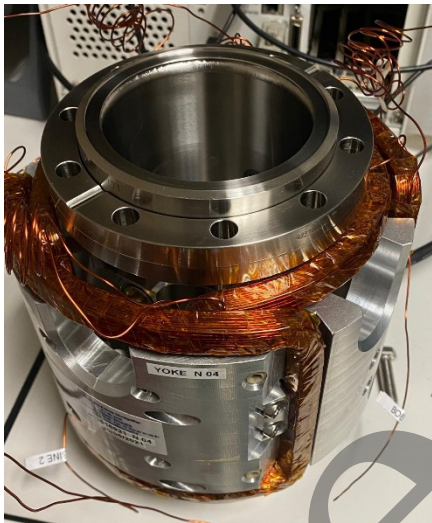


Figure 3: PERLE Gun BPM with steerers.

The following sub sections detail the design and the operation of each diagnostic in the injector.

Beam Position Monitors

Both commissioning and routine operation of PERLE will necessitate orbit measurement and correction capabilities with a precision of approximately 100 μm . Although this requirement is stringent, it remains achievable based on the performance levels demonstrated in recent accelerators. Button BPMs are adequate regarding the bunch properties (current, longitudinal length, repetition rate, ...). Button BPMs are also a suitable solution regarding housing issues in some locations in the injector.

For the injector, the BPM internal diameter is 60 mm and it stands within a CF63 flange with an overall thickness of 17.5mm. Each 25ns, a single bunch is injected through the injector. Position measurement for these bunches is typically performed at a predefined frequency F as for LIBERA Spark modules [2]. The choice of F takes into account affordable acquisition electronics with “Off the shelf” RF components are available at F : particularly band pass filters with less than 10MHz bandwidth.

Current Transformers

For PERLE injector the goal is to measure transmission coefficient of the booster. Since injector bunches are very short and operate in various configuration in terms of repetition rate and bunch charge, fast ICT with a pulse response below 5ns allows the discrimination of each bunch.

In-flange ICT from BERGOZ [3] eases mechanical integration and is compatible with ultrahigh vacuum conditions. As ICTs are sensitive to transverse magnetic fields particularly those generated by dipoles, the ICT is located at the booster exit far away from the merger first dipole.

Faraday Cup

Regarding PERLE project, a Faraday Cup (FC) was purchased from NTG [4] to measure the beam current at the gun exit and subsequently at the exit of the diagnostics line (energy 7MeV, current up to 1mA). The FC is presently mounted with its shielding at the gun exit as sketched in Figure 4. It operates for a beam transverse size as small as 3 mm RMS. The cup is moved in and out of the beam line using a pneumatic actuator. Its default position is inserted since the Faraday Cup also serves as beam dump. In order to block the secondary emissions, an electron suppressor is integrated. A bias voltage of 500V is included for a proper operation of the suppressor.



Figure 4: Faraday cup at PERLE Gun exit.

Beam Viewers

As the bunch energy in the injector is low, YAG screens are employed. A YAG screen was purchased from RI for PERLE Gun. Its design is based on a single vacuum port dedicated to the translation of the screen holder, as well as to the transmission of the emitted radiation toward the light collection system. As a result, only part of the active element lies within the camera focal plane, leading to a degradation of the optical resolution along one axis. For this

reason, a conventional design is applied for the screens located downstream of the booster.

Beam viewers are versatile instruments, they allow the measurement of a wide range of beam parameters:

- **Transverse beam profile:** it's the main use for the screens in PERLE injector aside diagnostics line. It provides beam size and position.
- **Transverse emittance:** it is measured in the diagnostic line by performing a quadrupole scan that allows reconstruction of the normalized emittance.
- **Energy:** it is measured both in merger and diagnostic line with the help of a dipole magnet. The beam position on the screen can be used to infer the beam energy. Placing the screen in a high-dispersion area allows the measurement of the distribution of the beam energy.
- **Longitudinal profile:** it is measured in the diagnostic line with the help of a RF deflecting cavity that maps the temporal structure into a spatial dimension.

YAG pad with a diameter of 40mm is needed to cover transverse beam profile.

DIAGNOSTICS FOR LINAC AND RECIRCULATION ARCS

Beam Position Monitors

The salient feature about BPMs at the entrance and exit of the LINAC is the need to independently measure 6 different energy bunches. The response of a button BPM shows a periodic signal with 6 peaks asynchronously distributed over a period about 25ns. The response of the same BPMs in the recirculation arcs where beam of 89MeV and 171MeV circulate, show 2 peaks over the same period corresponding to an accelerated bunch and a decelerated bunch with the same energy in these two recirculation arcs.

BPMs are also used to calibrate LINAC cavities: bunch phase relative to the reference signal is measured at LINAC entrance and exit with a specific bunch scheme. The measurements results are used as mentioned in [5].

Moreover, BPM are used to tune the beam path length in order to ensure a maximum energy recovery efficiency: BPMs acquisition system should ensure that the bunch exiting the LINAC attains its entrance:

- With opposite phase for the bunches to be decelerated
- In phase for the bunches to be accelerated

A previous study on PERLE BPMs was conducted [6].

Beam Viewers

As bunches energies are way higher at LINAC terminals and in the recirculation arcs, OTR screens are more suitable; Although it's a bit interceptive, it allows a precise measurement of beam profile in the recirculation arcs for low intensity bunches.

Mechanical design will integrate both YAG and OTR pads on an arm sliding through the beam pipe with an actuator. Calibration techniques would allow a precise positioning of the pads.

Using OTR viewers remains appropriate in commissioning due to the high beam current and the need to recycle accelerated beam in ERLs. Non-invasive diagnostics in the recirculation arcs are suitable for beam operation.

The recirculation arcs of the PERLE lattice provide a readily available non-invasive radiation source in the form of synchrotron radiation, particularly optical synchrotron radiation (OSR). Studies have shown that a single bunch of 100 pC produces sufficient OSR for profile measurements the first-turn energy of 89 MeV. Among these measurements, the ability to quantify halo and diagnose its sources as well as implement effective mitigation strategies, is crucial. To this end, an OSR imaging system will be used in conjunction with a digital micro-mirror device (DMD) to directly image the transverse profile of the beam halo within the recirculation arcs. A DMD is an array of millions of μm scale, individually controllable mirrors that can rotate along a diagonal axis to two fixed positions. This allows the DMD to split an optical signal into two separate optical paths. The DMD mask can be dynamically adjusted to separate high intensity beam core from low intensity halo, sending the two signals to separate referred to as the core and halo cameras (see Figure 5).

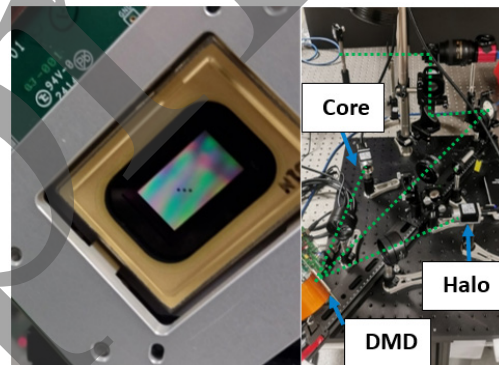


Figure 5: DMD setup for transverse profile and halo measurements at the arcs of PERLE recirculation arcs.

STATUS AND OUTLOOK

This document reports an overview of PERLE diagnostics. Gun diagnostics are already integrated and ready for the commissioning phase. The design of some injector diagnostics is well advanced and some prototypes might be delivered within this year. Some diagnostics are on a premature design stage like acquisition electronics of LINAC and recirculation arcs BPMs. Some diagnostics are even in a study stage like beam loss monitors. We outlook to scope within PERLE realization phases.

REFERENCES

- [1] D. Angal-Kalinin *et al.*, "PERLE. Powerful Energy Recovery Linac for Experiments: Conceptual design report", *J. Phys. G: Nucl. Part. Phys.*, vol. 45, no. 6, p. 065003, 2018. doi:10.1088/1361-6471/aaa171
- [2] LIBERA Spark, <https://www.i-tech.si/products/libera-spark-el/>
- [3] Bergoz, <https://www.bergoz.com>

- [4] NTG, <https://www.ntg.de>
- [5] J.S. Berg, “Phasing and calibration of the main linac cryomodule cavities for the CBETA energy recovery linac”, presented at *Proc. ERL'24*, Tsukuba, Japan, Sep. 2024, paper WEO05, unpublished.
- [6] S. M. Ben Abdillah, “Study of beam position monitors for PERLE”, in *Proc. IBIC'25*, Liverpool, UK, Sep. 2025, pp. 700-704. [doi:10.18429/JACoW-IBIC2025-WEPC037](https://doi.org/10.18429/JACoW-IBIC2025-WEPC037)

Preprint