Overview of an optical fibre beam loss monitoring system for energy recovery LINACs

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Innovations for a Sustainable Tomorrow—Symposium

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Benefits of optical fibre detectors

- Continuous coverage of accelerator
- < 1 m beam loss location precision
- Low cost

Optical fibre detectors and energy recovery LINACs (ERLs)

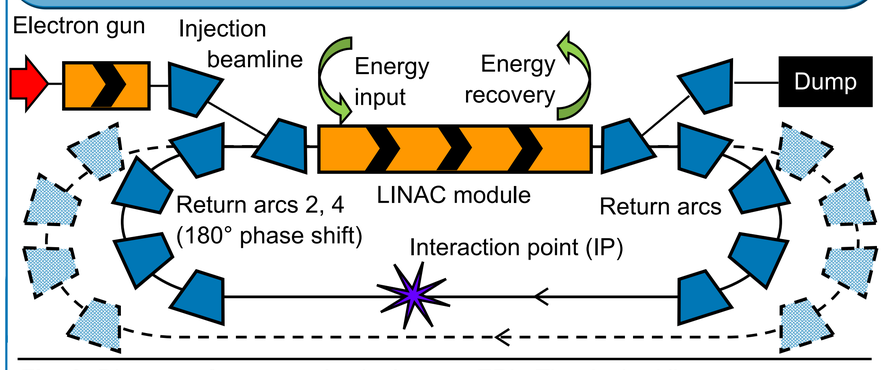
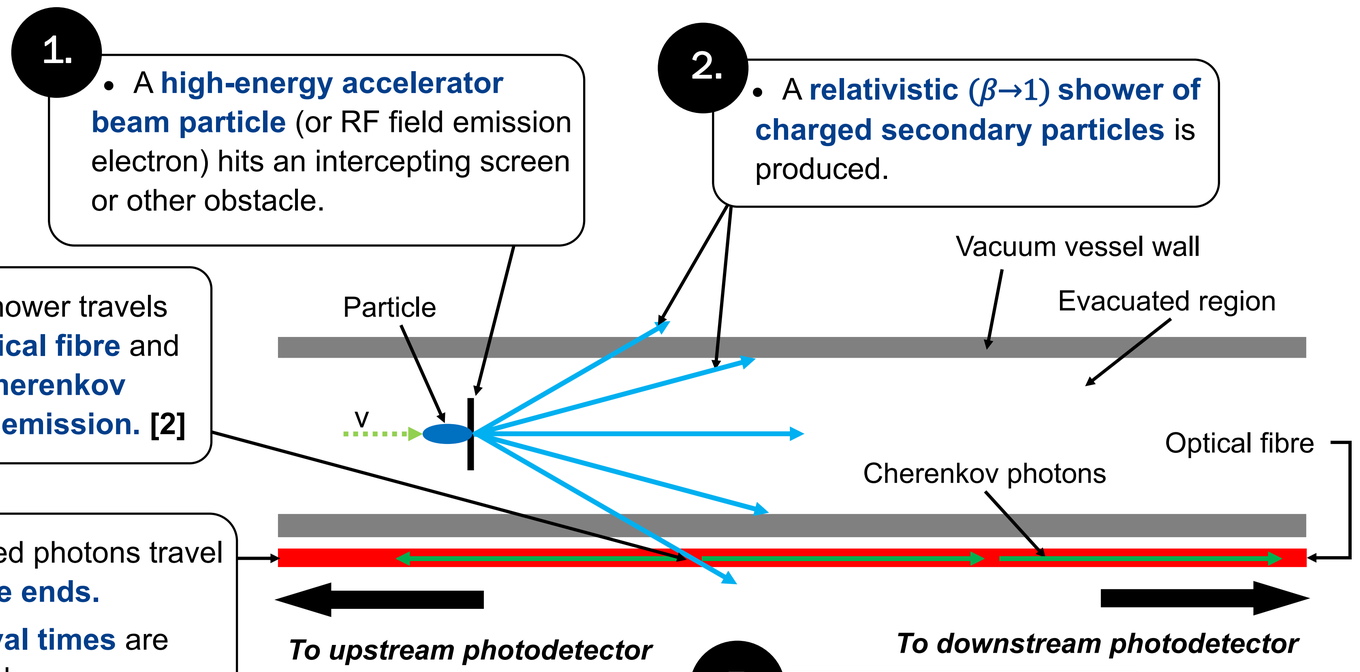


Fig. 2: Diagram of an example single-pass ERL. The dashed lines represent a

- ERLs are a promising option for sustainable accelerators.
- Energy is recovered into the RF field from used beams and transferred to new beams.
- ERLs are approximately 10x more energy efficient than a conventional LINAC **[3]**.
- They aim to provide both the low beam emittance of a LINAC and the high energy efficiency and beam currents of a storage ring synchrotron **[4]**.

Detector operation

Fig. 1 (right) [1] Beam loss detection mechanism.



Challenges

- ERLs have increased susceptibility to beam loss from sources such as the beam break-up (BBU) and microbunching (μBI) instabilities **[5, 6]**.
- Optical fibre detectors can be used to monitor and diagnose these beam losses
- This could help manage instabilities such as BBU and μBI across the whole length of an ERL.
- However, the interleaved beams of ERLs increase the difficulty of tracking losses across a bunch's full journey through the machine.
- Beam loss energy estimation can aid in tracking losses, since ERL bunches have specific energies.
- Number of detected photons (oBLM signal intensity), measurable from the integrated photomultiplier signal **[2]**, is expected to be **proportional** to the beam loss energy **[7]**.
- Energy must be disentangled from other factors, such as the number of lost particles (loss intensity)

Investigating beam loss energy estimation

Electron beam loss experiments at CLEAR, CERN

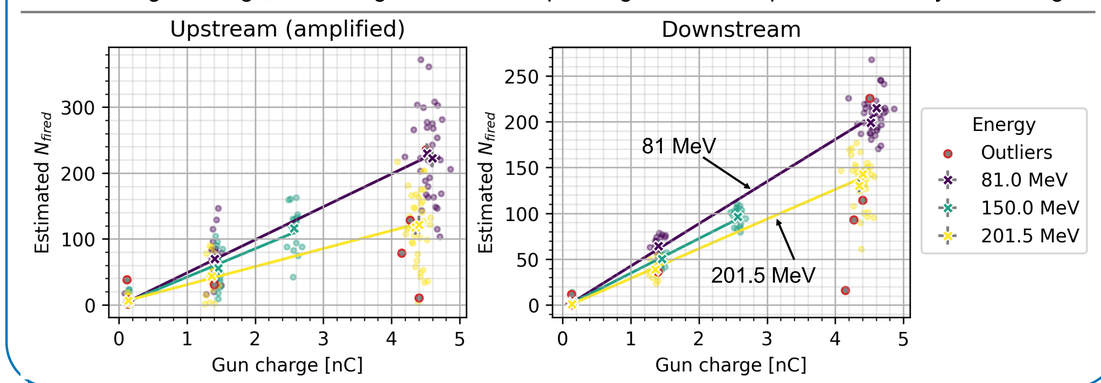
Experiment

- CLEAR (CERN Linear Electron Accelerator for Experiments) is a 30-220 MeV electron LINAC with an oBLM installed.
- A 200 μm YAG screen was inserted into the beam, and the change in oBLM signal intensity with beam energy and lost charge was investigated.
- Beam energy range: 80-200 MeV.
- Beam charge range: 0.13-6.72 nC.

Results (Fig. 3)

- oBLM signal intensity **increased** with charge, **in agreement** with expectation from the literature.
- oBLM signal intensity **decreased** with energy, **different** to expectation from literature.
- Attributed to low YAG screen thickness, and position close to the point where the fibre left the beamline.
- Since higher beam energies produce narrower particle showers, a smaller fraction of the shower intercepts the fibre at higher energies.
- This was investigated further using Geant4 simulations:

Fig. 3: Estimated number of photomultiplier signals N_{fired} (a measure of oBLM signal intensity) against accelerator gun charge, with straight-line fits incorporating the effect of photodetector dynamic range.



Simulations with Geant4

- Performed to investigate differences between literature and the experiment at CLEAR.
- A simplified model similar to Fig. 2 was used — beam pipe, a fibre, and obstacle (YAG screen).
- Scanned energies from 60-220 MeV, while varying obstacle thickness (0.1-4mm) and length of fibre downstream of the obstacle (2.5-10m).
- Expected number of detected photons was recorded for each data point (calculated from photodetector quantum efficiencies)

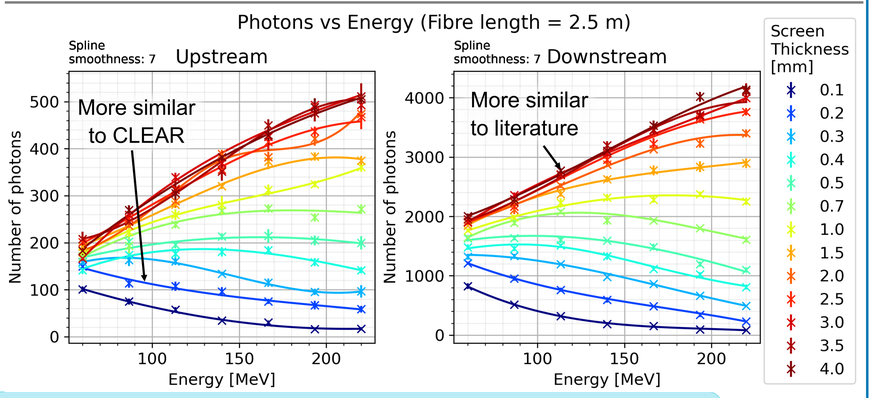
Results

- oBLM signal intensity decreased with energy for shorter downstream fibre lengths or thinner obstacles.
- For the longest downstream fibre lengths or the thickest obstacles, the oBLM signal intensity increased with energy
- Suggests the result from literature occurs under specific conditions.
- Variations in oBLM signal energy dependence are driven by changes in downstream fibre length, obstacle thickness and local shielding — all vary with beam loss position.

Results (continued)

- Detailed simulations are required to predict the oBLM signal energy dependence at different beam loss positions. These will be a focus of future work.
- High repetition rates of ERLs greatly increase difficulty of oBLM signal intensity estimation.
- Mitigation methods for this will also be investigated: faster photodetectors, segmented fibres, gated acquisition methods, and improved signal deconvolution algorithms.

Fig. 4: Variation in oBLM signal intensity with obstacle thickness.



Conclusions

- The data shows oBLM signal contains useful energy-dependent information
- This is strongly conditioned by loss geometry, local shielding, fibre placement, and lost charge.
- When combined with detailed radiation simulations, oBLMs have potential to form part of robust, non-invasive, and cost-effective diagnostics for ERLs.

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