Beam Monitoring and Diagnostics Options for Future ERLs

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PERLE

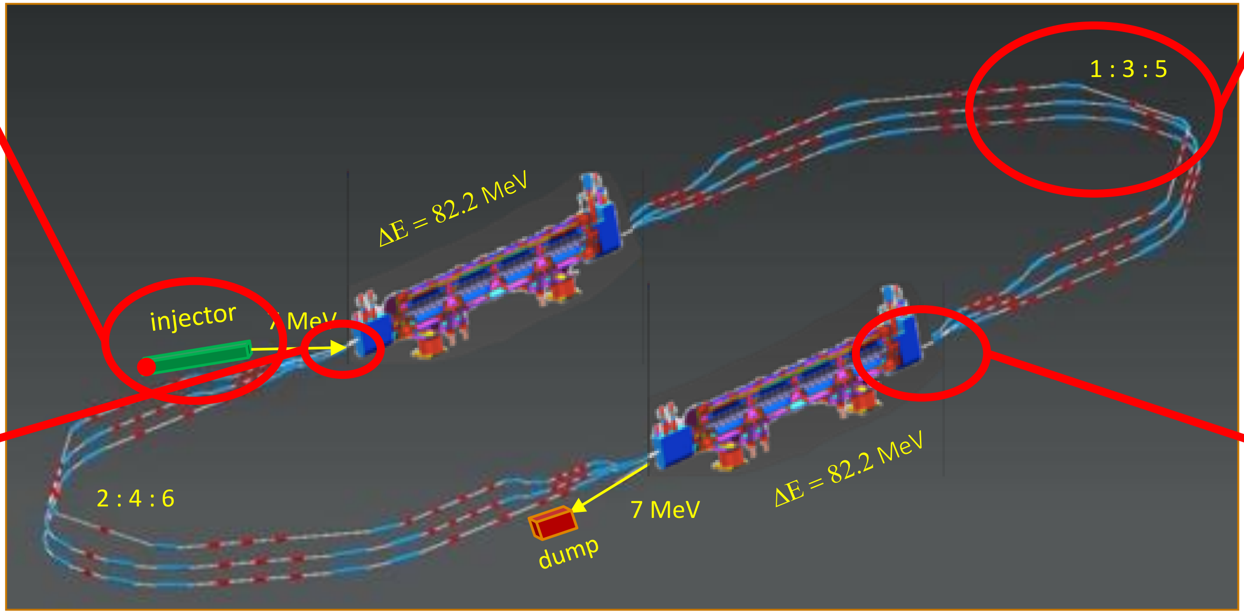
Overview

Injector beamline

- Space charge

Injection "point"

- Efficiency



Recirculation arcs

- Standardisation of diagnostics

Common beamlines

- Different energies

[1]

Overview

- **Single-shot emittance measurements**
- **Halo imaging with DMD-masking**
- **Optical-fibre beam loss monitor**
- **Virtual diagnostics**

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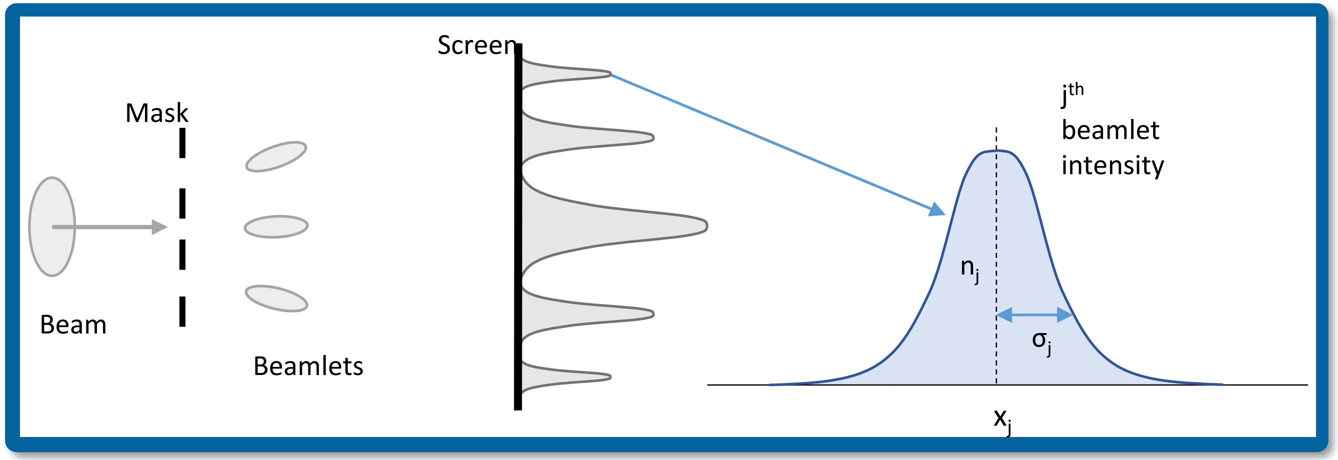
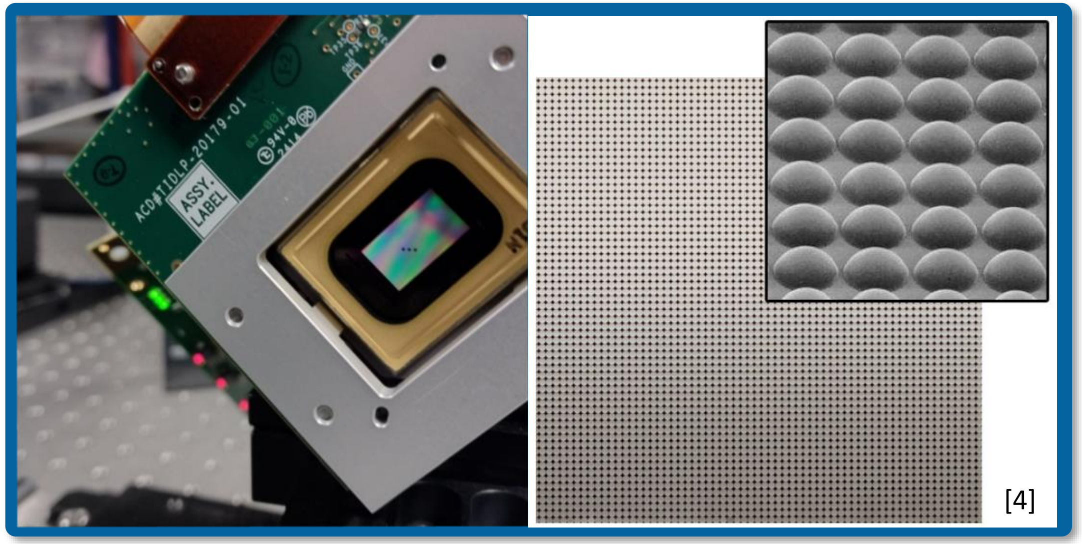
Single-shot emittance measurements

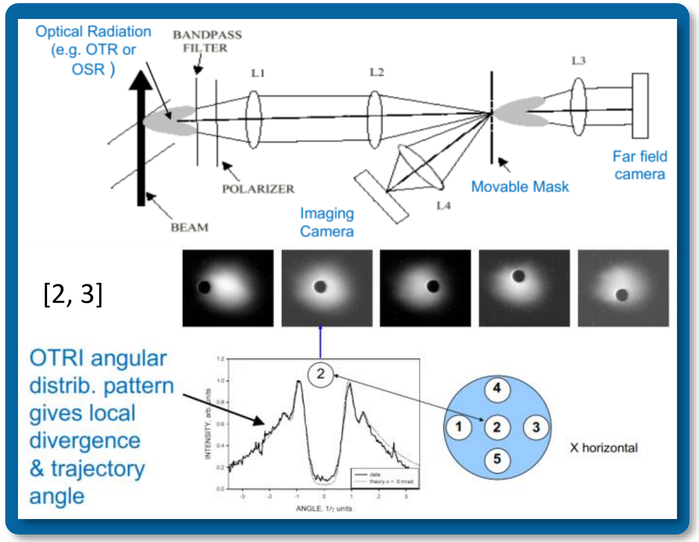
Single-shot emittance measurements

- Standard **<u>emittance</u>** diagnostics ***difficult*** due to **space charge** effects
- **Optical versions** of slit/pinhole scans and pepper-pot avoid this issue
- Focusing on **OTR** – Optical Transition Radiation
  - Could investigate other types of radiation, e.g. synchrotron or diffraction radiation
- Two methods under investigation:
  - **DMD** – Digital Micro-mirror Device
  - **MLA** – Micro Lens Array

Single-shot emittance measurements







- Analysis based on *existing* pinhole/slit beam-based methods [5]
- Optical version provides **two main benefits**:
  - Subset of measured particles is much larger
  - Space-charge contribution is completely avoided
- **Non-invasive** if radiation can be produced non-invasively (e.g. OSR)

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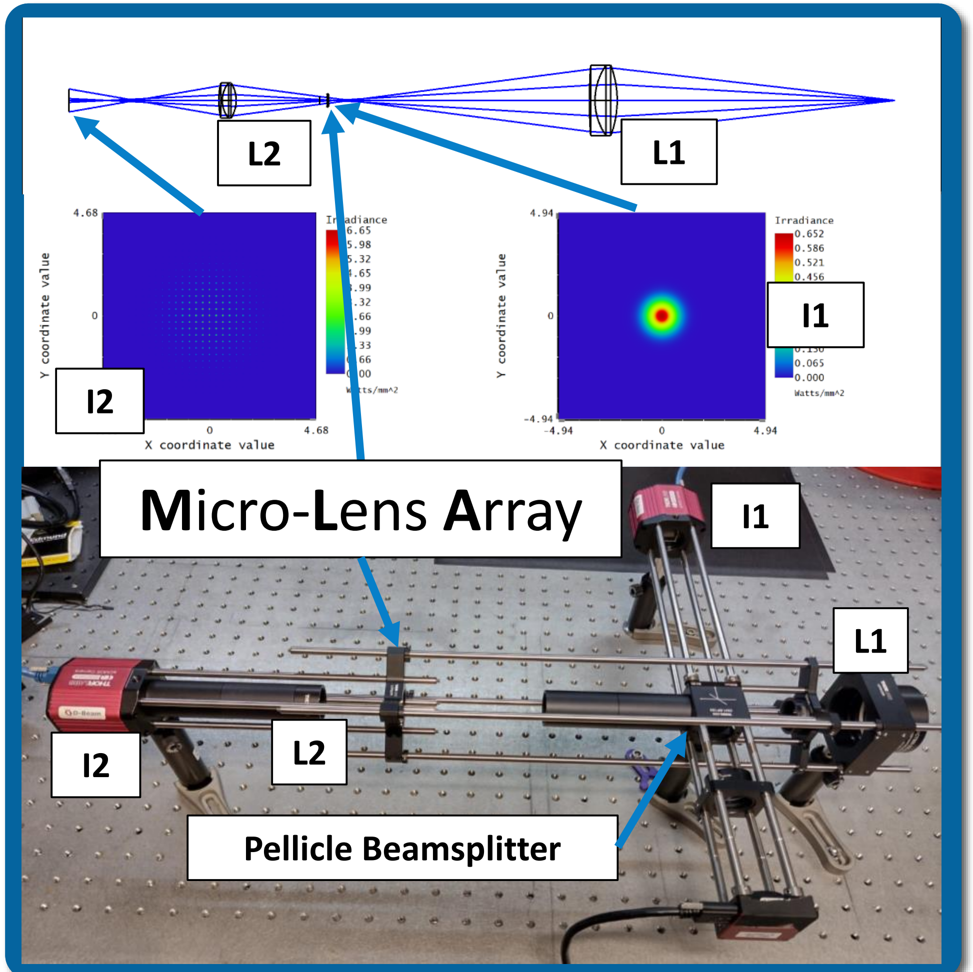
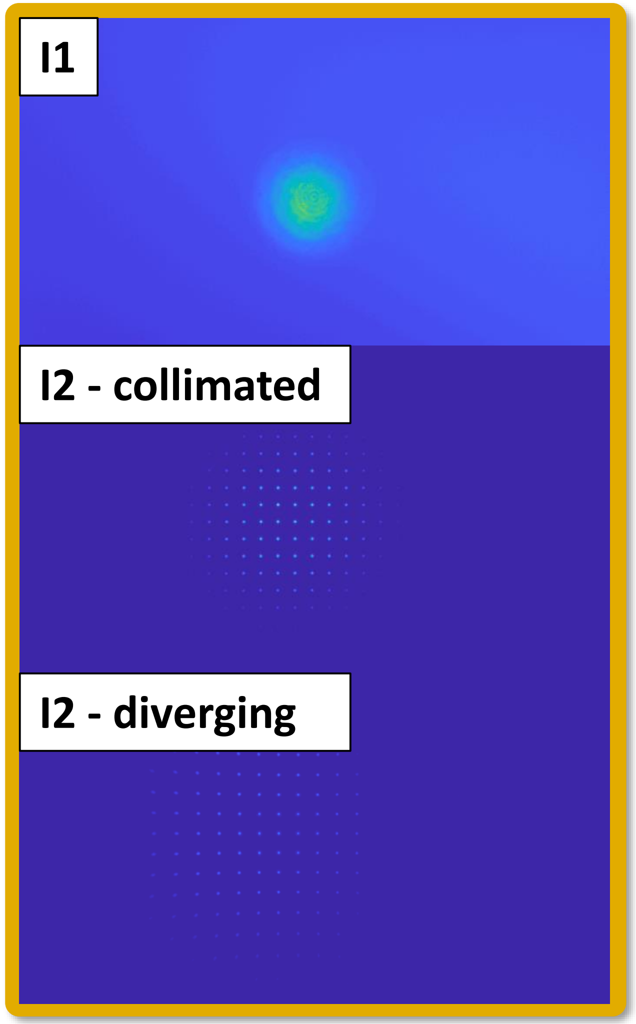
Single-shot emittance measurements



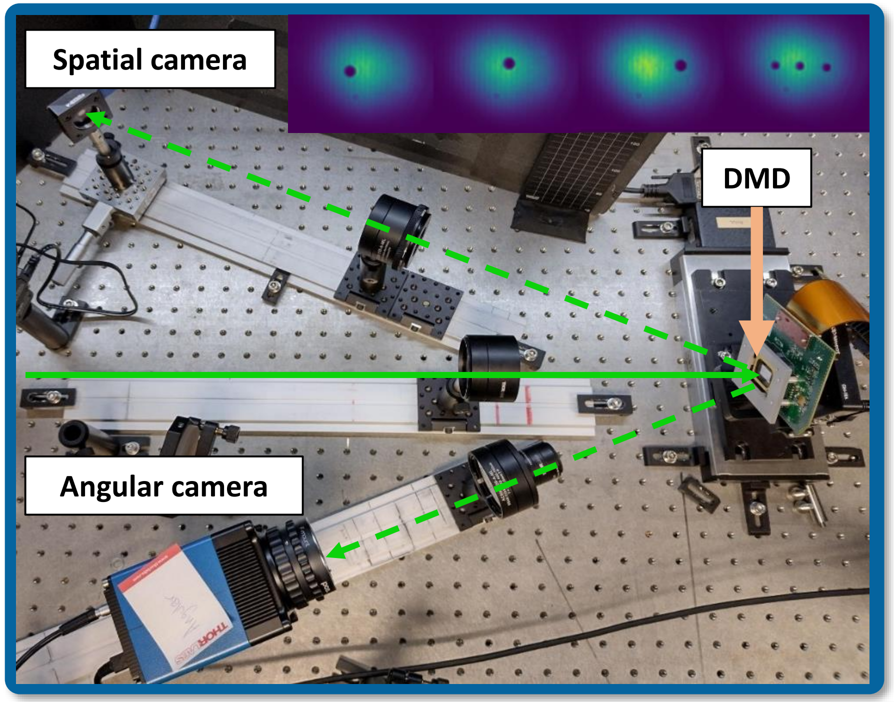


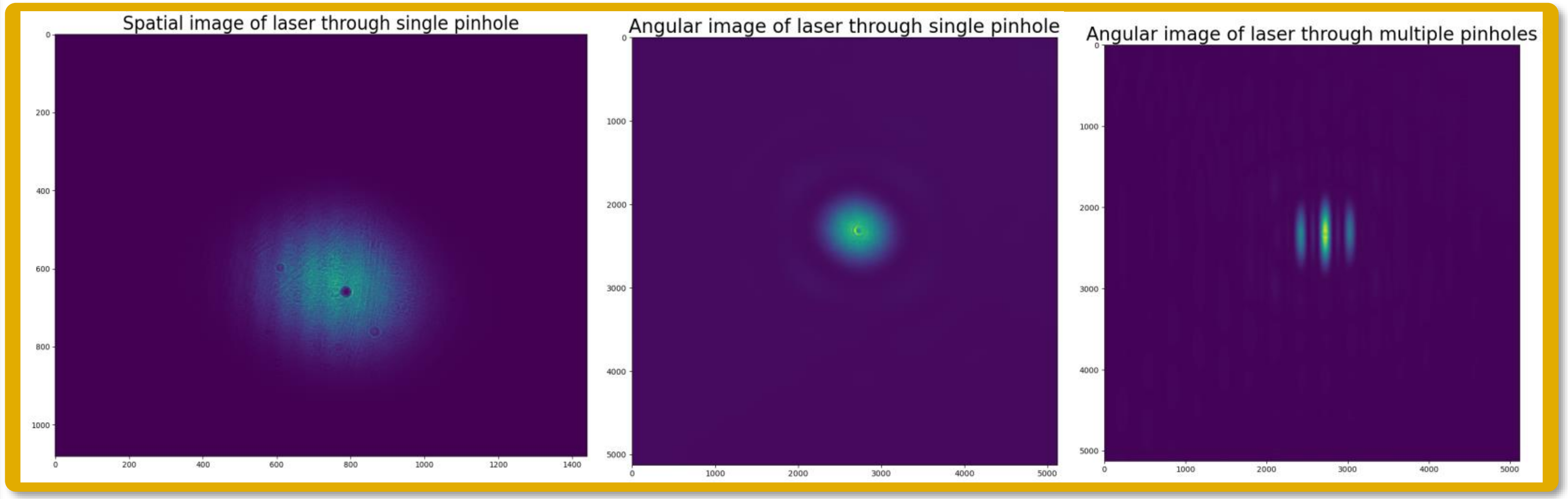
Next steps:

- Simulation of OTR source
- PoC measurements (CLEAR)
- ML-based image-to-phase space analysis

[6]

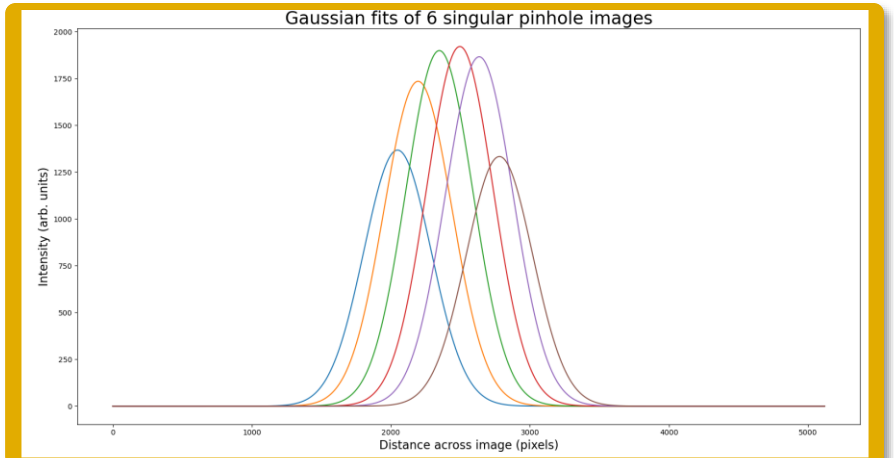
Single-shot emittance measurements





Next steps:

- Quantify resolution improvement
- Simulate OTR source
- PoC measurements (CLEAR)
- ML-based image-to-phase space analysis



Single-shot emittance measurements

Possible implementation options:

- **Recirculation/common beamlines**
  - Using OSR, could be applied on dipoles/spreader/recombiner magnets non-invasively
  - Would provide full 4D characterisation including coupling
  - Beamsplitter would enable streak camera (>5ps) to be placed at the same locations
  - Need to assess divergence resolution/requirements
- **Injection diagnostic station**
  - Divergence resolution from low energy beam would need to be studied
  - Technique resolution scales with beam energy
  - Options to improve resolution, e.g. OTRI?
  - High resolution multi-shot measurement?

Halo imaging with DMD-masking

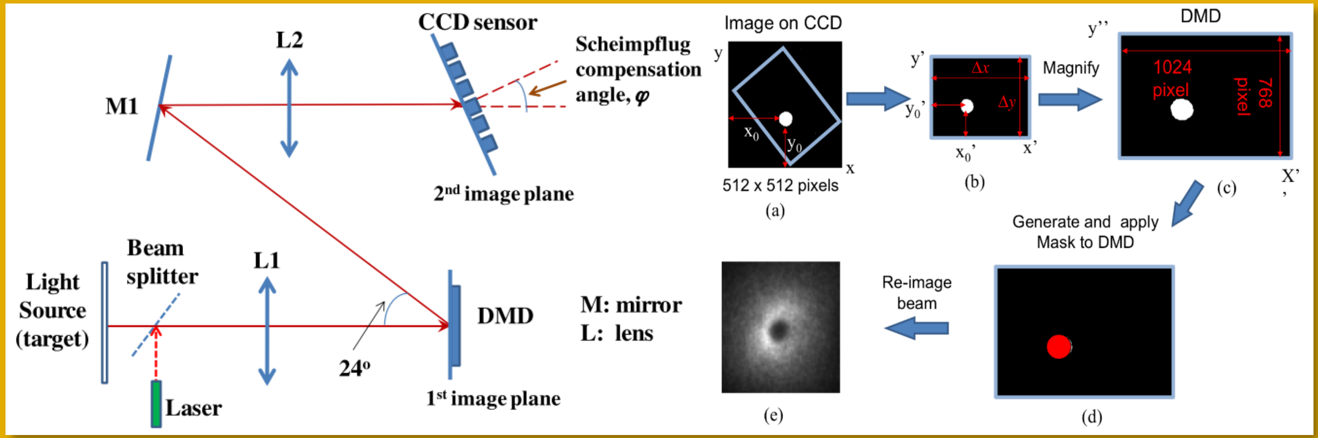
Halo imaging with DMD-masking

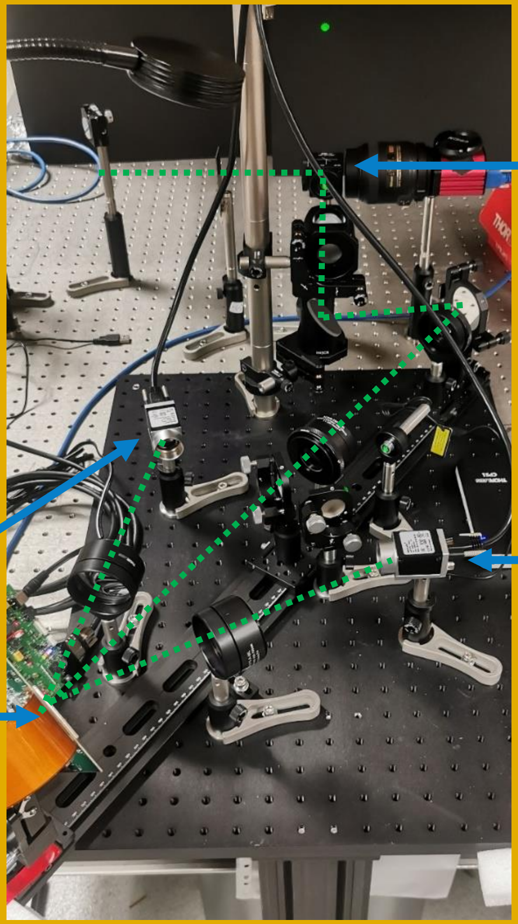
- **Beam halo** will be an important factor to monitor at PERLE
- **DMD masking** has been used many times to ***separate light from core and halo***

Example:

- Existing halo monitor at AWAKE used *fixed masks*, proposed **DMD as a flexible alternative**
- Cleared to install mid-2021 alongside existing system
  - New system couldn't prevent existing system operating!

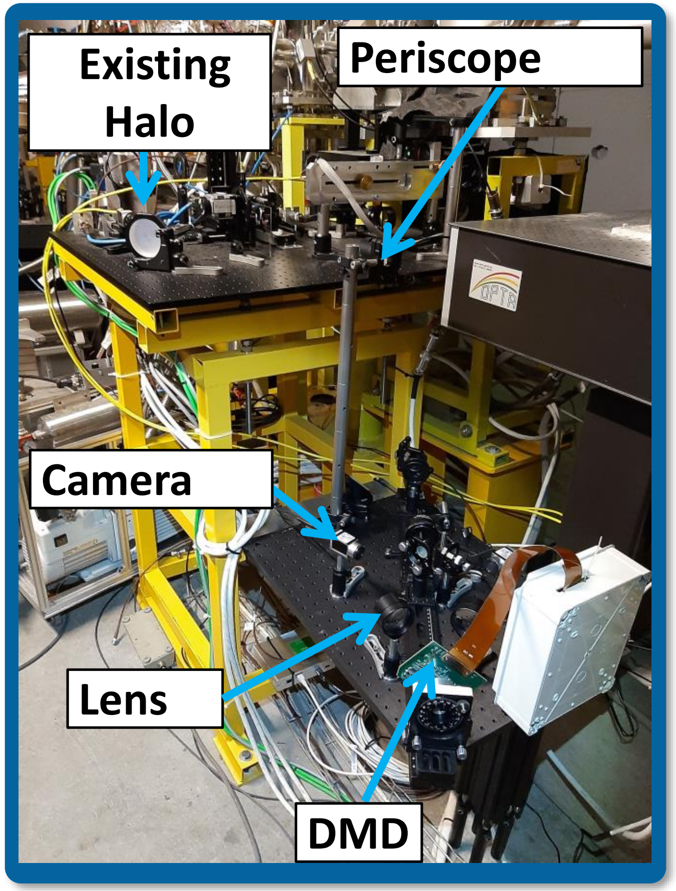
Halo imaging with DMD-masking

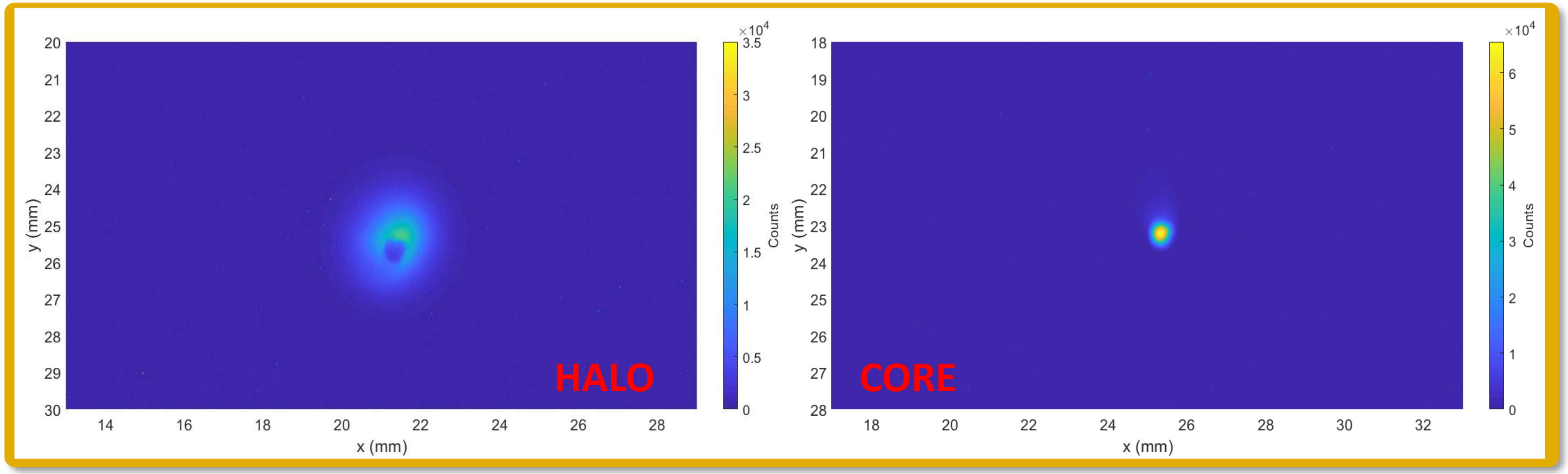




- Core of beam selected and binary mask is defined
- Mask is displayed on DMD
- Two cameras can be used to image two paths
- **Simultaneous imaging of core and halo**

Halo imaging with DMD-masking





- Light generated using scintillation screen
- Halo image captured at longer exposure, taking into account scintillation decay
- Halo imaging demonstrated at AWAKE late 2021
- **Showed dynamic range ~10^6**

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Halo imaging with DMD-masking

Possible implementation options:

- **Arcs/common beamlines**
  - Using OSR, could be applied on dipoles/spreader/recombiner magnets non-invasively
  - Operation with beamsplitter with other diagnostics demonstrated
- **Injection diagnostic station**
  - Simple to implement with OTR

Optical fibre beam loss monitor

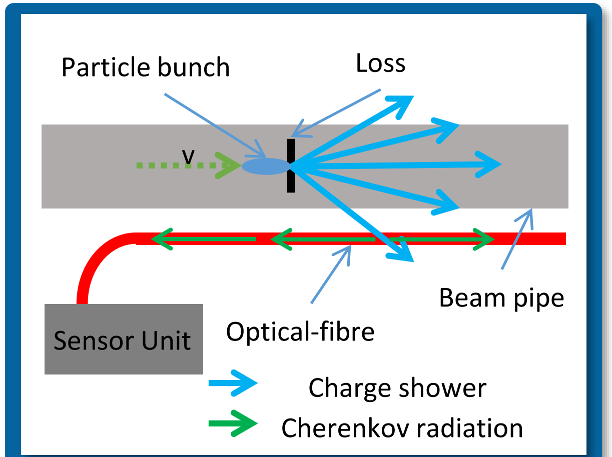
Optical fibre beam loss monitor

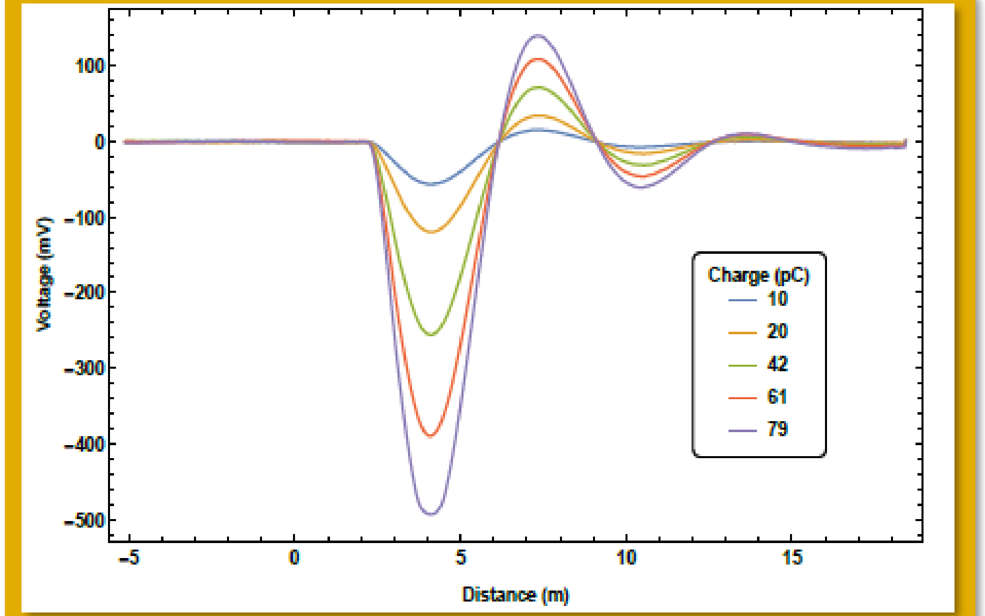
- **Beam loss monitoring** will be critical at PERLE
- Typical systems give absolute values of loss at discrete locations
- BLM based on optical fibre provides continuous coverage at ~10cm loss location resolution

Example:

- Optical fibre BLM (OBLM) installed at **CLARA**
- Demonstrated beam loss measurements and RF breakdown detection

Optical fibre beam loss monitor





[7, 8, 9, 10]

* J. Wolfenden et al. *Sensors* 23(4), 2248 (2023); https://doi.org/10.3390/s23042248

- Improved loss location resolution, <10cm, and applications of RF breakdown detection – New paper*
- Two new PhD students working in this area – one dedicated to applications to ERLs
- Beginning simulation studies to study novel applications

Optical fibre beam loss monitor

Possible implementation options:

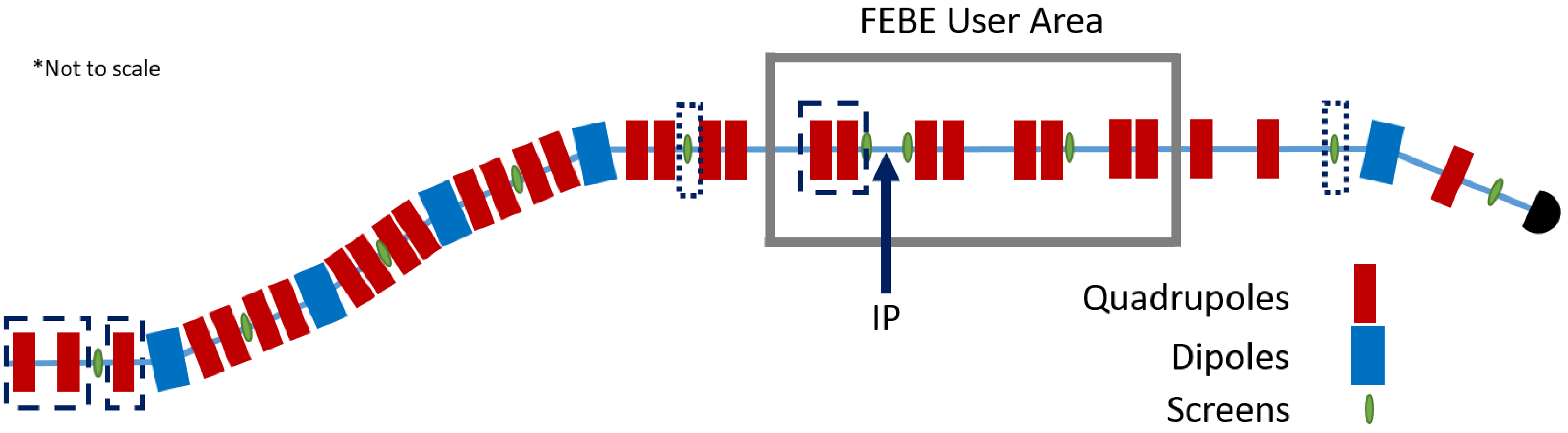
- **Everywhere**
  - Completely non-invasive
  - Layout of fibres would need some thought, but could be easily adapted
  - Coverage of up to ~100m per fibre
  - Would need to consider “cross-talk” of signals on arcs

Virtual diagnostics

Virtual diagnostics

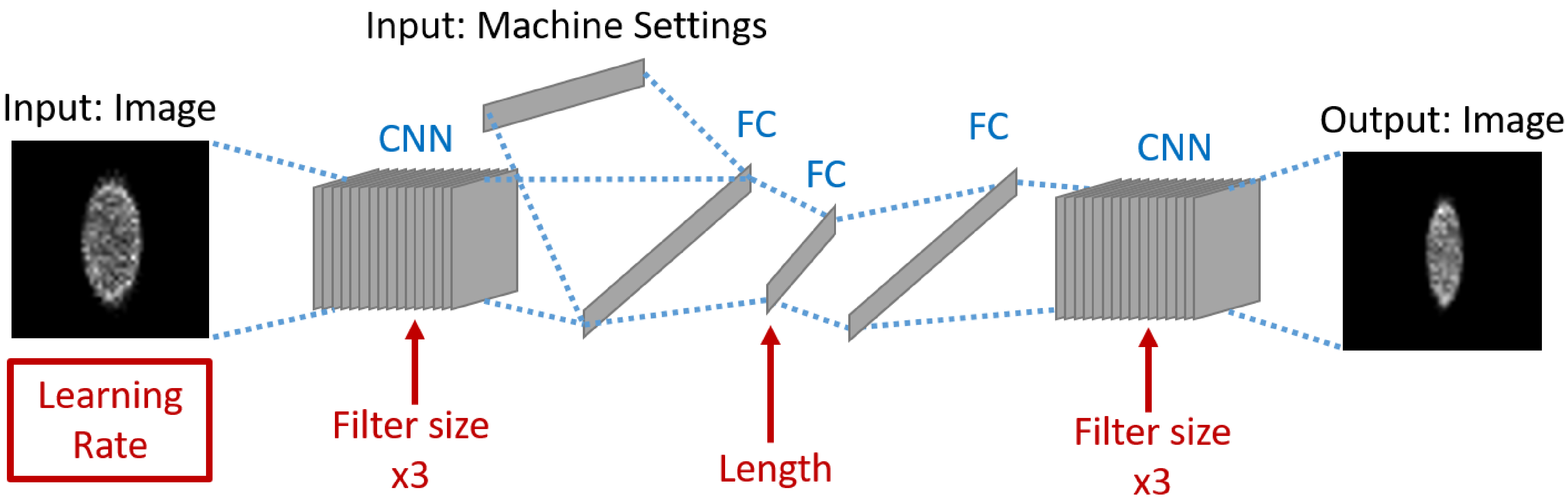
- Ideally beam characteristics at key locations (IP, injection, etc.) would be **monitored online**
- Can be difficult to integrate non-invasive diagnostics in these locations
- **Virtual diagnostics** (VD) can take data away from an IP and infer properties at an IP
- **Example**:
  - Simulation study on profile measurements at the FEBE on CLARA user IP
  - Upstream and downstream X-Y measurements to infer IP measurements

Virtual diagnostics



- Initial **simple demonstration** – existing planned profile measurement points
- Quadrupoles were varied and profiles at screens were simulated

Virtual diagnostics

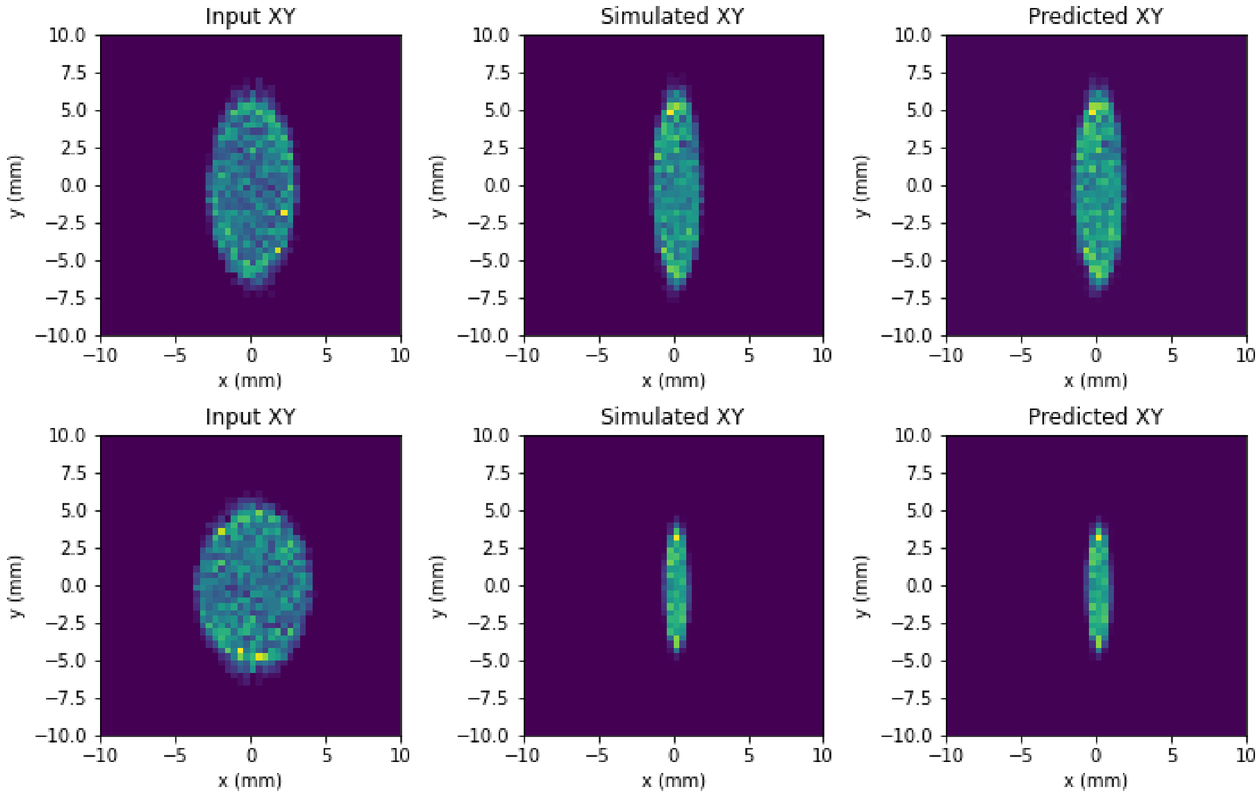


- **Convolutional Neural Network (CNN)** used with tuneable **hyperparameters**
- **Upstream and downstream** versions of the diagnostic were tested

Virtual diagnostics

Upstream

Downstream

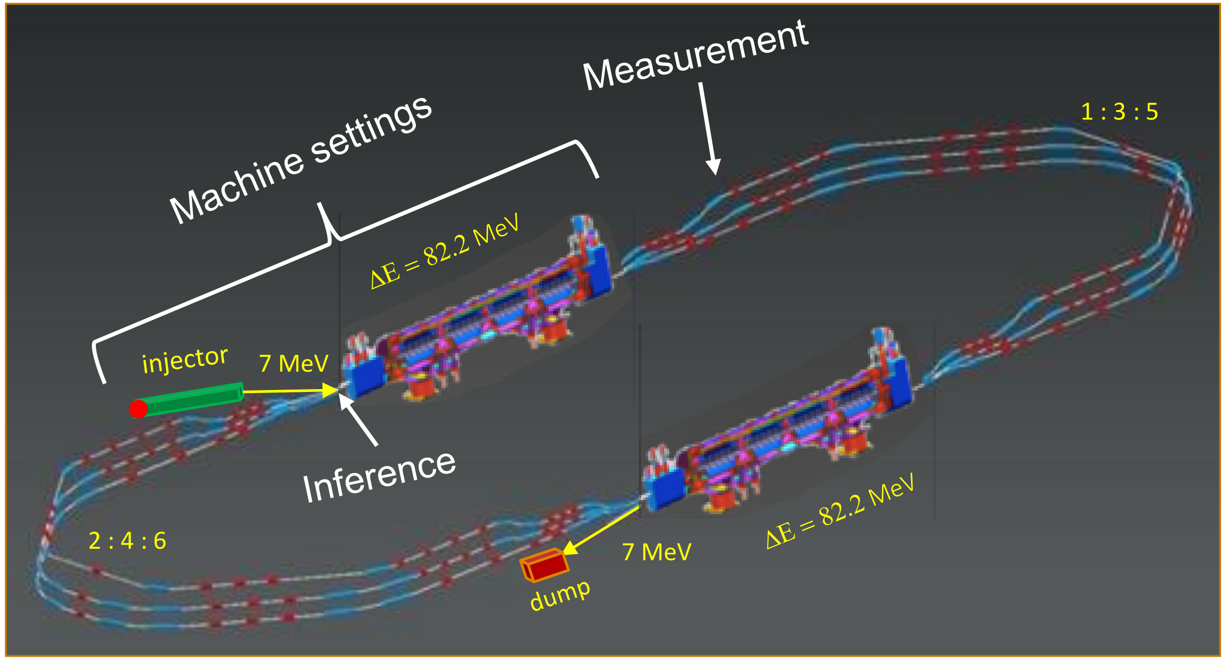


- **Can infer X-Y beam profile away from the IP – no other beam parameters needed**
- **Either via non-invasive pre-IP measurements or invasive post-IP measurements**

Virtual diagnostics

Possible implementation options:

- **Everywhere**
  - Main limitation is the accumulation of training data – case-by-case basis
  - In principle, any existing diagnostic could be used
  - Example: injection



Summary

Summary

- **Single-shot emittance measurements**
  - Both MLA and DMD systems currently being tested and benchmarked at CI
  - Plans in place to test both systems at CLEAR (Oct 23) and FEBE on CLARA
- **Halo imaging with DMD-masking**
  - Core/halo imaging demonstrated many times in the past
  - Straightforward to apply to PERLE
- **Optical fibre beam loss monitor**
  - Two new PhD students started recently focused solely on OBLM (ERL and SPS/LHC)
  - Test new prototype in research and industrial setting, concentrating on novel applications
- **Virtual diagnostics**
  - Simple case demonstrated for transverse profile measurements
  - Going to extend to more complex models and diagnostics

Thank you for your attention!
Questions?

References:
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