CLEAR, operational status and machine learning opportunities

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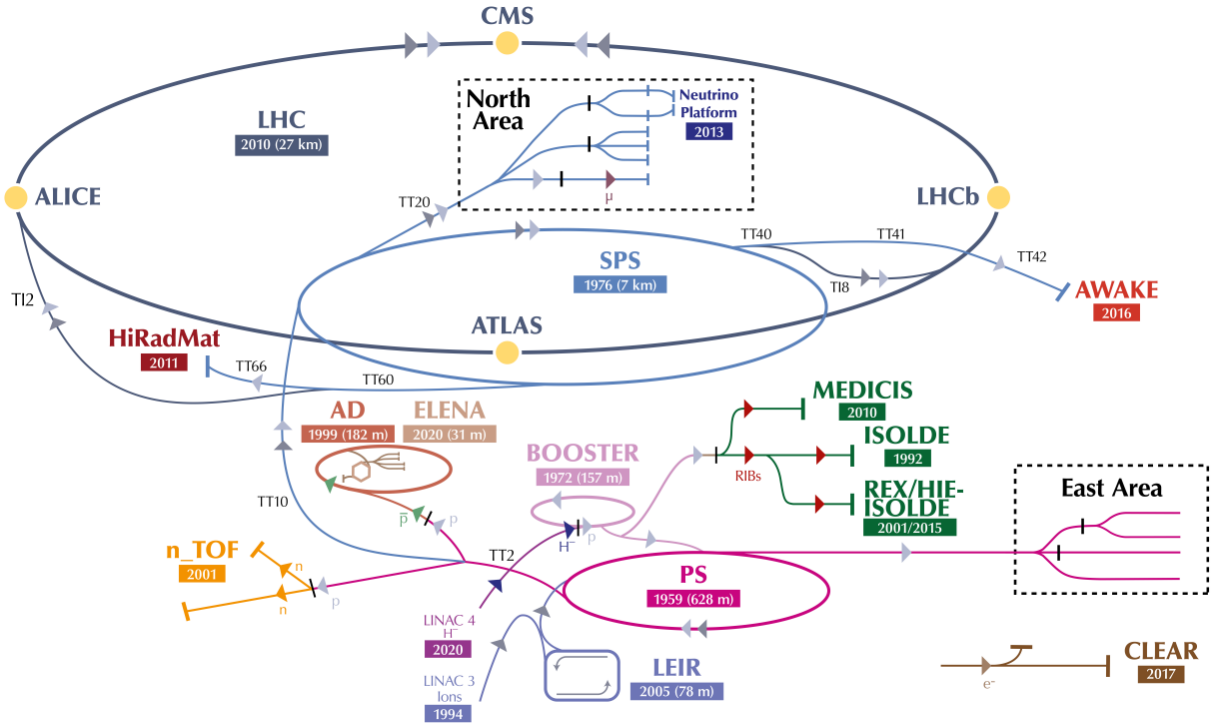
What is CLEAR?

- **C**ERN **L**inear **E**lectron **A**ccelerator for **R**esearch
- Versatile linear accelerator facility, supports R&D in accelerator technologies and applications.
- Provides electron bunches with energies up to ~**200 MeV**, flexible bunch structure and timing.
- **Key applications**:
  - Accelerator component testing (e.g., diagnostics, kickers, RF systems)
  - High-gradient structure experiments
  - Medical and industrial beam applications
  - Plasma wakefield acceleration studies
  - **Machine Learning**



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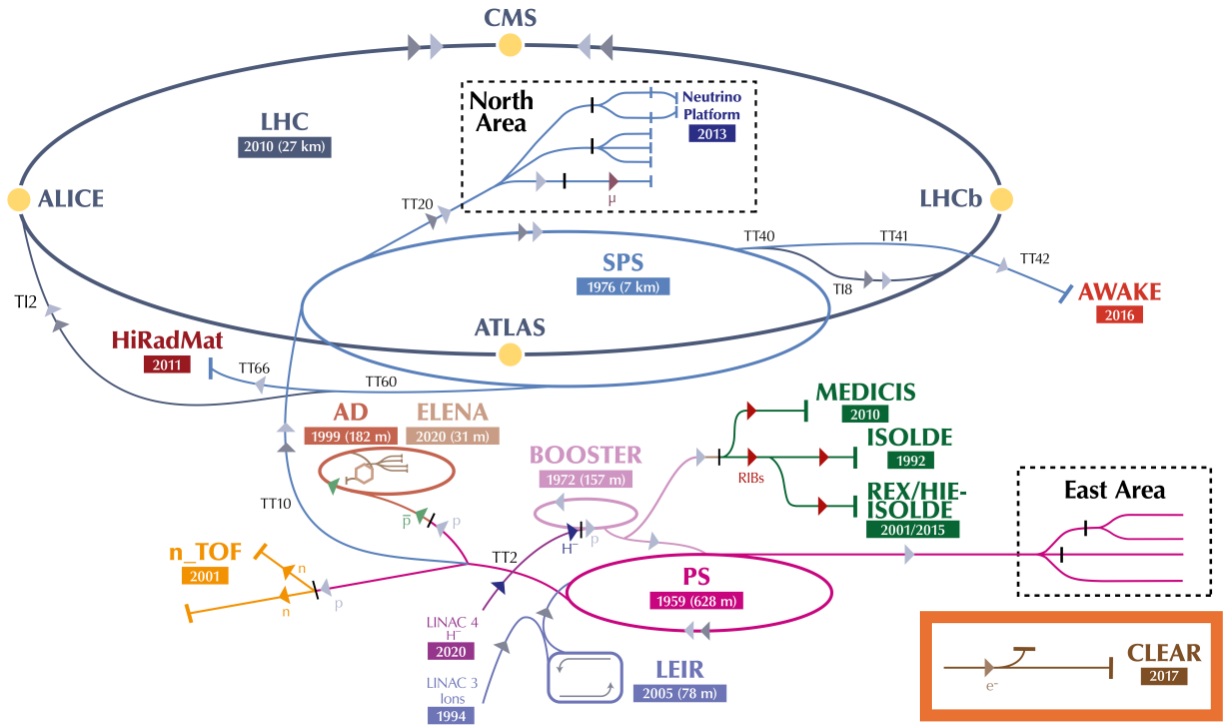
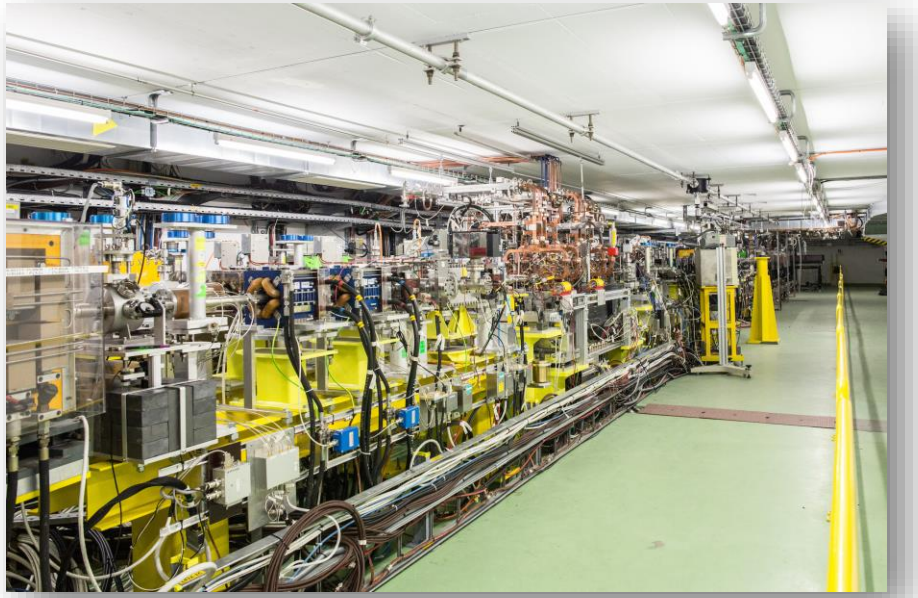
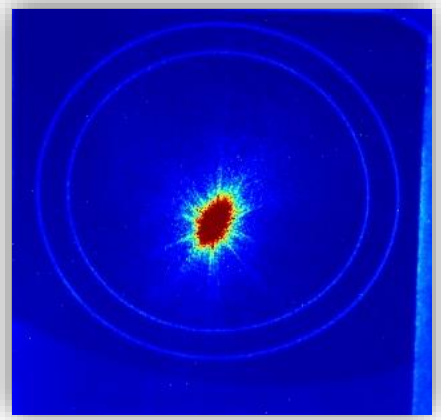


Operational Tools

- **CLEAR DAQ**
  - Data acquisition system for automated, synchronized collection of beamline measurements.
  - **CLEAR Data Handling** - Structured data storage and access.
  - **CLEAR Image Handling** – Management of beam images from screen monitors.
- **CLEAR Online Dosimetry**
  - Real-time dose measurement and feedback for radiation-sensitive applications.
- **Scan Worker**
  - Framework to automate multi-parameter scans (e.g., laser, RF settings) and coordinate data acquisition.
- **Quadrupole Scans**
  - Tool to perform emittance measurements and optics studies via quadrupole strength variation.
- **CLEAR Simulations**
  - Accompanying simulation framework to compare with experimental results.





Machine Learning opportunities

- Two paths:
  - **Simplifying Accelerator Operation**:
    - Moving towards autonomous control
      - Autonomous beam trajectories optimization
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  - **Enhancing Accelerator Performance**:
    - Beam energy evolution forecasting
    - Charge evolution forecasting

Simplifying Accelerator Operation

- **Automatic Beam – based alignment studies**
  - For now, a **steady-hand** and **time-consuming work for the operator**
  - Tried one-to-one and Dispersion Free Steering techniques, promising first results but need for 3-5 iterations to work

- **Reinforcement Learning for autonomous control**
  - Agent training to have it ready to go, as **operational help**
  - For now, still following **invasive procedures** (mirrors and screens)

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Enhancing Accelerator Performance

- **Energy and charge forecasting studies**
  - **Non-invasive measurements** → virtual diagnostics
  - Model trained with **1-step-ahead forecasting**
  - Linear regression model comparable to more complex ones
  - Will to **extend to multi-step prediction** and insert into real-time feedback loops for beam stabilization

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- **Implementation of Supervised and Reinforcement Learning on simulation model of CLEAR**
  - Mid-to-Long term plan
  - First step on experimental beamline only, to have operative simulation of the tools
  - Second step to increase action region to the whole LINAC (photocathode)

References and Publications

- Papers, used as a reference in this presentation, regarding CLEAR can be found at clear.cern/content/publications.
- Some of the presented work has not been published yet.
- Many thanks to the whole CLEAR team.

Questions?
Ideas?

Thank You!

clear.cern.ch

Backup Slides

CLEAR Parameters

Beam parameter	Range
Energy	30 – 230 MeV
Energy Spread	< 0.2 % rms (< 1 MeV FWHM)
Bunch Length	0.1 ps – 10 ps rms
Bunch Charge	5 pC – 3 nC
Number of bunches per pulse	1 to ~150
Maximum total pulse charge	80 nC
Normalized emittances	3 μm to 30 μm (bunch charge dependent)
Repetition rate	0.8 to 10 Hz
Bunch spacing	1.5 GHz or 3 GHz