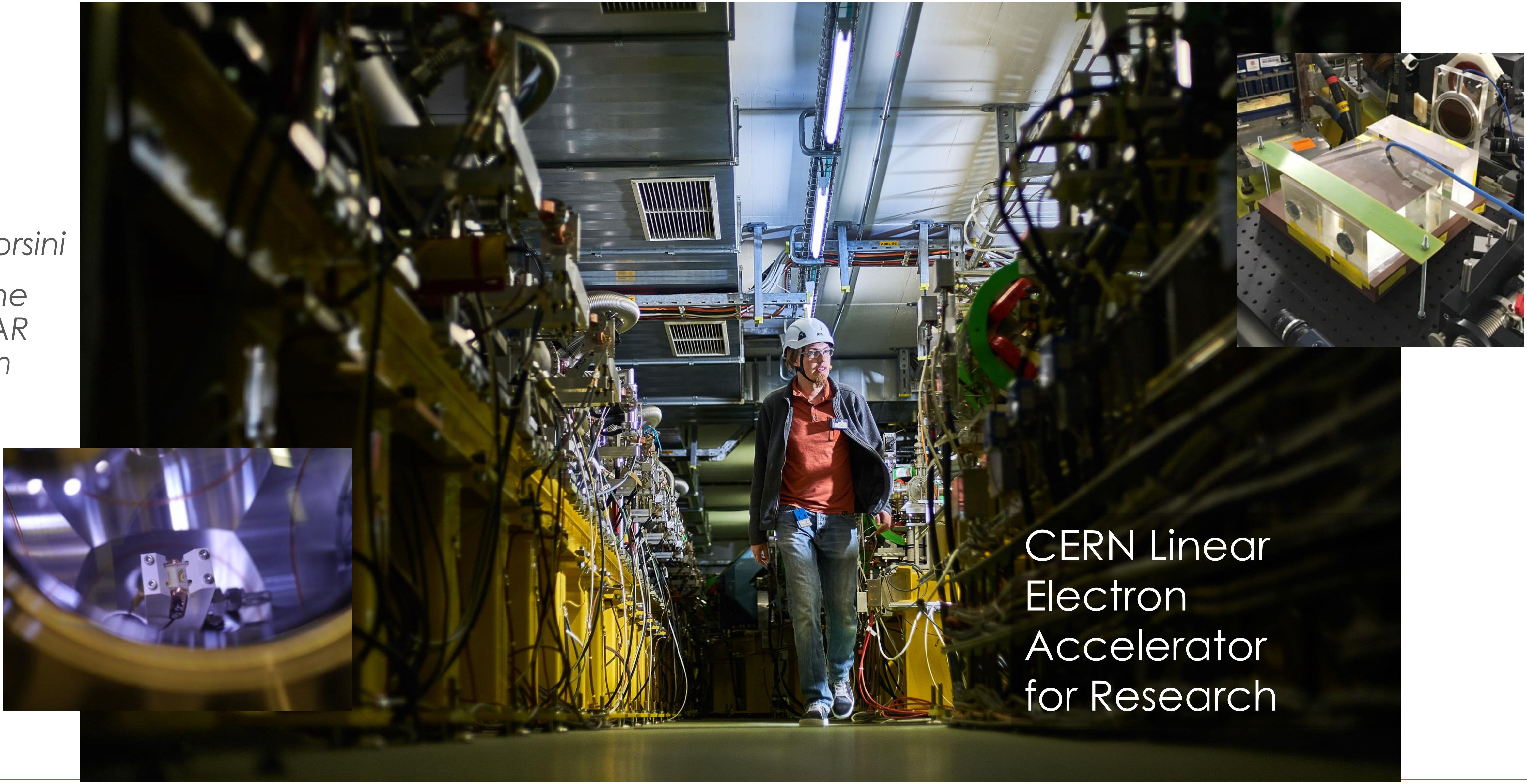
The CLEAR scientific program - past experience and outlook

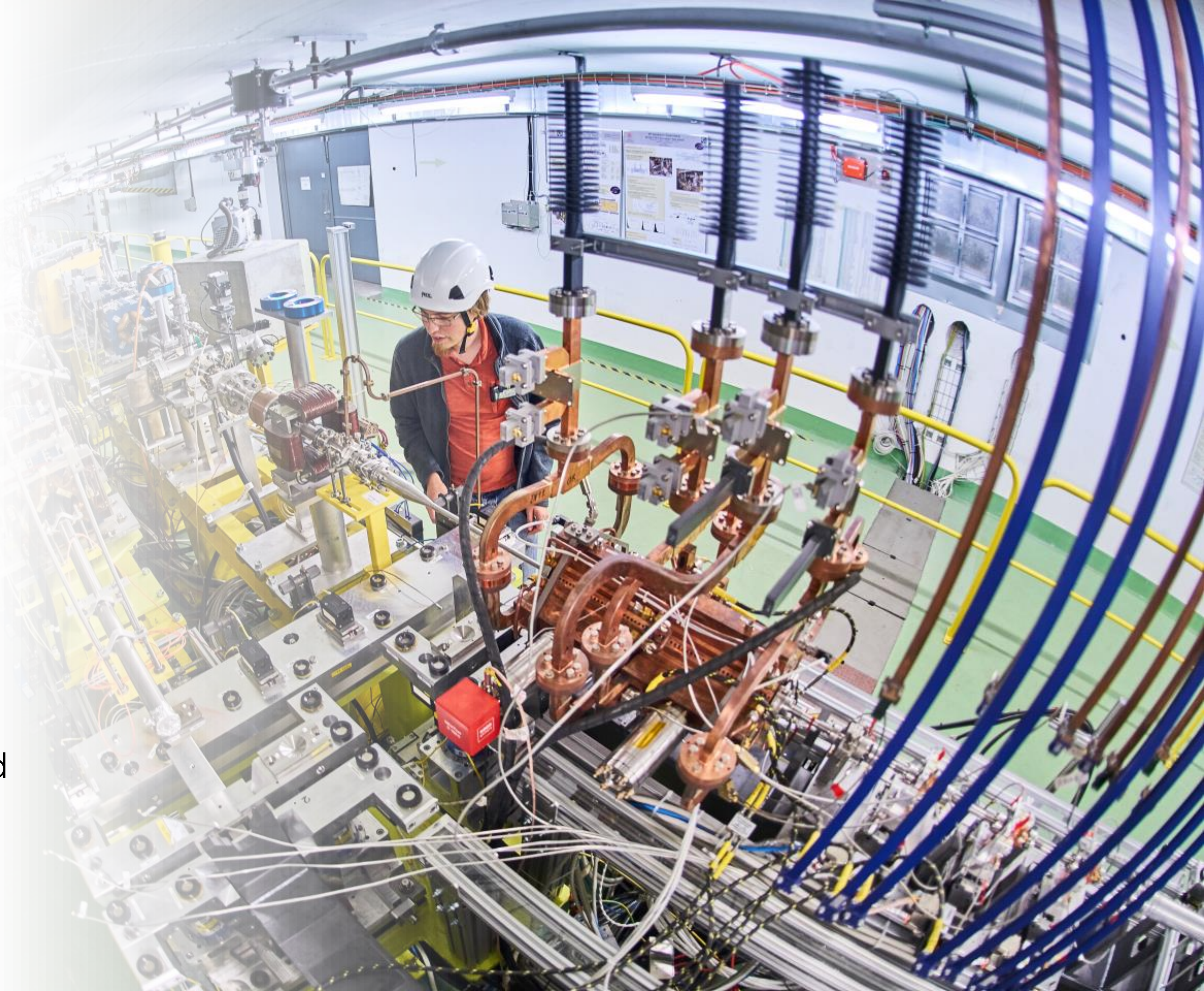
R. Corsini

for the CLEAR team

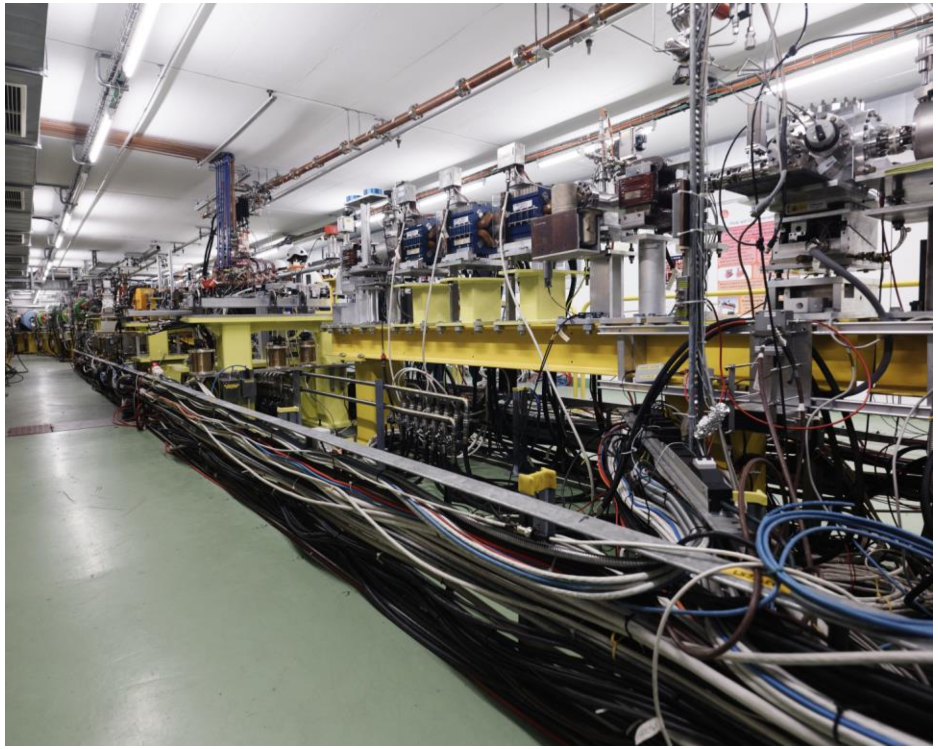


Talk outline

- Introduction
- Operation statistics (users, beam time for different activities…)
- Publications, PhD thesis, outreach…
- Some experimental highlights
- Recommendations from the CLEAR Scientific Board & Outlook



The CERN Linear Electron Accelerator for Research (CLEAR)



CLEAR is a versatile 200 MeV electron linac + a 20 m experimental beamline, operated at CERN as a multi-purpose user facility.

Scientific and strategic goals:

- Providing a test facility at CERN with high availability, easy access and high quality e- beams.
    - Performing R&D on accelerator components, including beam instrumentation prototyping and high gradient RF technology
    - Providing an irradiation facility with high-energy electrons, e.g. for testing electronic components in collaboration with ESA or for medical purposes(VHEE/FLASH)
    - Performing R&D on novel accelerating techniques – electron driven plasma and THz acceleration.
- Maintaining CERN and European expertise for electron linacs linked to future collider studies
- Using CLEAR as a training infrastructure for the next generation of accelerator scientists and engineers.

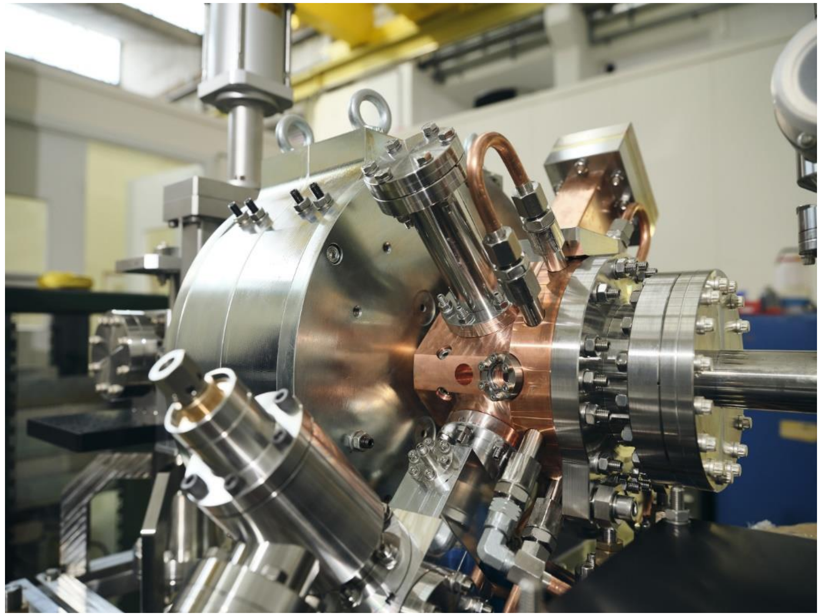
Introduction

Two reviews taking place in 2019 and 2021 confirmed and recommended the extension of CLEAR operation, currently approved until end 2025.

In view of the increased demand from experiments on CLEAR, its Scientific Board, held in February 2024, confirmed the scientific case to further extend CLEAR operation.

Future exploitation of CLEAR would profit from:

- a new beam line being built in CLEX to provide additional test areas for users
- a planned upgrade of the present laser system including a new front end
- the operation for users of the new electron source jointly developed by CLIC/AWAKE/CLEAR



Recommendation 3: CSB recommends that CERN support this approach towards upgrades, including CTF2. The committee encourages the CLEAR team to investigate the possibilities for utilisation of CTF2, define the necessary resources, and evaluate the user interest in CTF2 beyond the planned Incoherent Compton Scattering (ICS) studies.

From CLEAR Scientific Board Report 2024

CLEAR 2024 Review Mandate

The Review Panel is asked to assess whether:

1. The continued operation of the CLEAR facility beyond 2025 is scientifically justified based on the input provided by the CLEAR Scientific Board?

2. The current levels of resources, both in terms of workforce and material budget, are sufficient for ensuring the efficient operation of the facility?

3. The recommendations from the 2021 review have been effectively implemented.

4. The proposed consolidation and upgrade plans meet the following criteria:

   - Are they necessary for providing the required beams and reliability for researchers working in areas aligned with the global CERN strategy?
   - Are they adequately covered in terms of both workforce and budget?
   - Are they in alignment with CLEAR's potential strategic role in providing a testbed for the construction of a future e+e- collider at CERN?

5. Additionally, the committee is encouraged to provide recommendations for organisational and operational improvements should an operation extension be approved.

CLEAR Review Timetable

Morning

- **09:30** → 09:45 **Closed Session** — 15m
- **09:45** → 10:00 **Coffee break** — 15m
- **10:00** → 12:00 **Open Session**
  - 10:00 **Welcome** — 10m
    Speaker: Mike Lamont (CERN)
  - 10:15 **The CLEAR scientific program - past experience and outlook** — 20m
    - Experimental highlights - main results
    - Operation statistics (uptime, beam time for different activities…)
    - Publications, PhD thesis, outreach…
    - Recommendations from the CLEAR Scientific Board & Outlook

    Speaker: Roberto Corsini (CERN)
  - 10:40 **Medical applications in CLEAR** — 15m
    Speaker: TBD
  - 11:00 **Beam Diagnostics R&D in CLEAR** — 15m
    Speaker: Stefano Mazzoni (CERN)
  - 11:20 **CLEAR resources - material and manpower** — 15m
    Speaker: Roberto Corsini (CERN)
  - 11:40 **Recommendations from 2021 Review** — 15m
    Speaker: TDB
- **12:00** → 13:00 **Lunch** — 1h

Afternoon

- **13:00** → 14:20 **Open Session**
  - 13:00 **Short term upgrades - Laser** — 10m
    - Review of laser performance
    - Spares
    - Consolidation and Upgrades

    Speaker: Eduardo Granados (CERN)
  - 13:20 **Short term upgrades - 2nd beam line** — 10m
    Speaker: Wilfrid Farabolini (CERN)
  - 13:40 **RF Consolidation program and CTF2 e- source** — 15m
    Speaker: Steffen Doebert (CERN)
  - 14:05 **Long term outlook** — 15m
    Speaker: Davide Gamba (CERN)
- **14:20** → 15:00 **Closed Q & A session**
- **15:00** → 15:20 **Coffee break** — 20m
- **15:20** → 17:40 **Closed Session** — 2h 20m

CLEAR operation & resource level

- CLEAR is a standalone installation, running also during Long Shutdowns. In a typical year 30-40 weeks of beam operation are provided, between March and December.
- The operation team comprises on average 1 staff, 1- 2 fellows and 1 associate, plus contributions of some students and part-time associates. A total of about 4 staff FTE/year is allocated to the facility, including technical support.
- The CLEAR material budget is of the order of 800 kCHF/year (including M to P)
- CLEAR operation is currently approved until end 2025.

- A CLEAR budget line (M+P) is present in the current MTP beyond 2025.
- A decision in mid 2024 allows to better organize and possibly anticipate the long-term consolidation of the infrastructure(substitution of obsolete material, restock of spares), as well as to prepare the manpower plan.

Draft MTP2023

Accelerator technologies and R&D	Total 2023-2028 M+P [MCHF]
RF technologies R&D	55.2
High-field superconducting accelerator magnets R&D	136.3
Proton-driven plasma wakefield acceleration (AWAKE)	33.5
CERN Linear Electron Accelerator for Research (CLEAR)	9.2
Other accelerator R&D	18.9

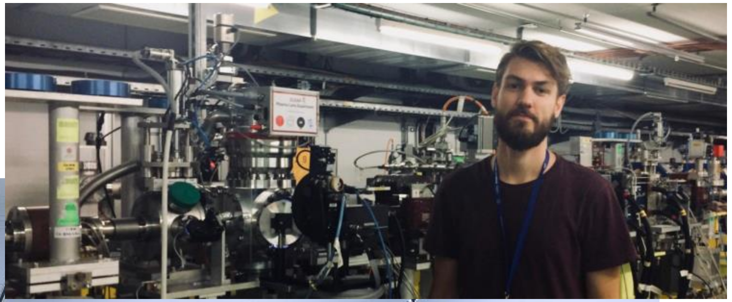
M. Lamont, 329th IEFC meeting

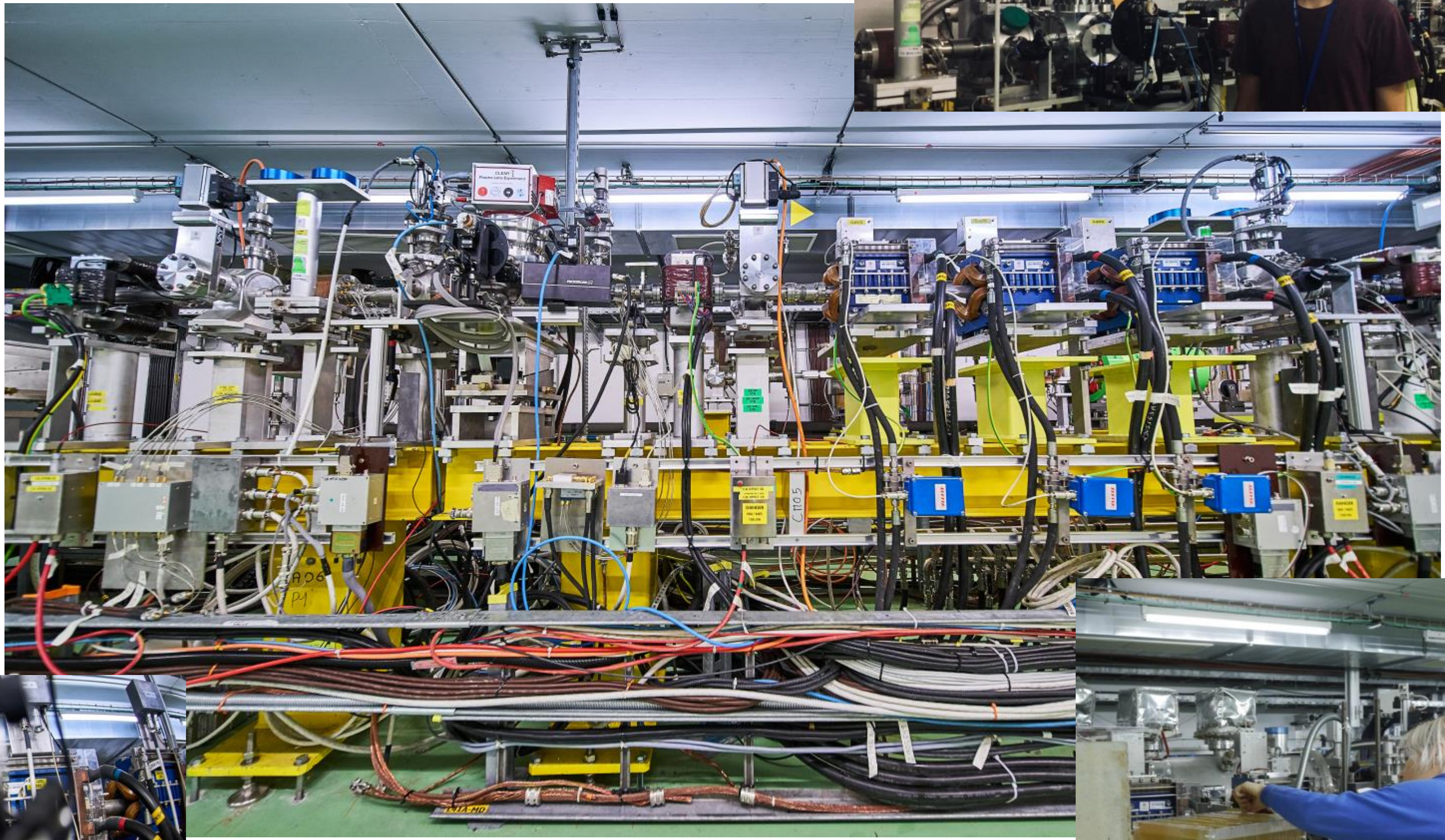
CLEAR Operation 2017 - 2023

Start with beam August 2017

- 19 weeks of operation in 2017
- 36 weeks in 2018
- 38 weeks in 2019
- 34 weeks in 2020
- 35 weeks in 2021
- 37 weeks in 2022
- 38 weeks in 2023

Due to Covid-19 related measures, 2020-2021 activities were impacted, and mainly limited to CERN users





Example of a "typical" year - 2023

Week	Type of experiment	Institute	Install (h)	Acces nb.	Beam time (h)
11	MD	ABP	6	1	6
	Neutron monitors	CERN- RP	2	7	22
12	Optic fiber dosimetry	Oxford U.	5	8	20
	Film dosimetry	Oslo U.	5	2	19
13	LUXE BPM	INFN Bol./Pad.	16	5	46
14	Scatterers	Oxford U.	8	5	24
	Real time dosimetry	Oxford U.	2	0	6
	Uniform beam generation	Cern-ABP	0	0	6
15	Wall current transformer				
	MD Cavity BPMs				
16	MD Dispersion free steering				
	Optic fiber dosimetry				
	Film dosimetry				
	MD Flat Beam space charge				
17	Plasmid irradiations				
	Film dosimetry				
18	Medical irradiation Ch. ZFE Cells				
	Optic fiber dosimetry				
19	Ch DR				
20	VHEE UHDR				
	ZFE irrad. And phantom dosimetry				
	MD				
21	Scintillator dosimetry				
	VHEE UHDR larve irrad.				
	Spatially fractionated irrad.				
	MD	ABP	0	0	6
22	Ch DR BPMs for Awake	Oxford U.	2	2	20
23	EOS	CERN-BI	4	9	25
	LUXE BPM	INFN Bol./Pad.	0	0	4
24	MD	ABP	1	0	50
25	Quarz fiber Cherenkov	Bologna U.	10	5	32
	LUXE BPM	INFN Bol./Pad.	1	0	3
26	MD	ABP	8	7	36
27	Ch DR EOS	CERN_B	4	4	35
28	MD BBA	ABP	0	0	8
	CHUV preparation	CHUV	3	3	12

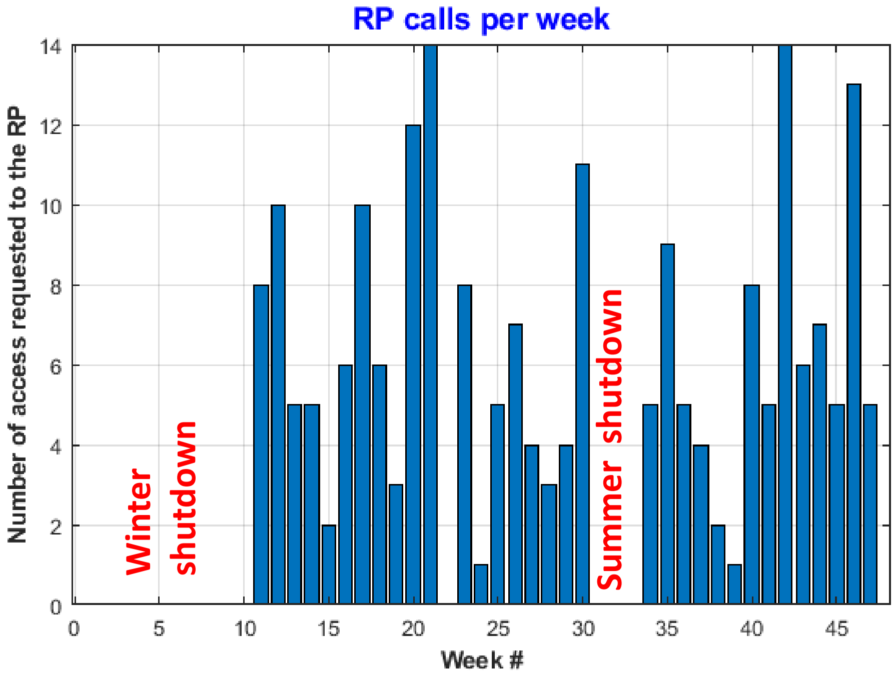
29	Bunch Length Monitor EOS for FCC	KIT	8	3	25
	LUXE BPM	INFN Bol./Pad.	2	1	5
30	Real time dosimetry	Oxford U.	6	7	25
	ZFE irrad	CHUV	1	4	6
	MD uniform beam	ABP	0	0	12
31-33	Summer shut-down PL installation		30	1	
34	Plasma Lens	Oslo U.	6	5	25
35	Dual Scatterers for flat beam	Oxford U.	6	9	30
			4	6	15
			0.5	2	6
			1	6	17
			0.5	1	4
			1	1	18
			16	1	0
			16	1	25
		croft	2	8	36
			0	0	3
			5	5	50
			0	0	5
			12	7	18
			8	7	15
			3	2	4
			0	4	32
			5	5	50
			0	2	5
45	P-cubed BBP	PSI	4	3	30
46	microBPMs	CERN-EP-DT	3	7	12
	Detectors	Kansas U.	3	6	20
47	VHEE irradiation of cells	CHUV	2	5	20
48	optic fiber BPM	Oxford U.	8	2	15
	Dual Scatterers for flat beam	Oxford U.	2	1	15
	YAG/film comparison	Oslo U.	1	1	2
	MD dosimetry prediction code	ABP	0	0	5
49	MD BBA	ABP	0	0	50
	Flat beam generation	ABP	0	0	10
total			**279**	**230**	**1209**

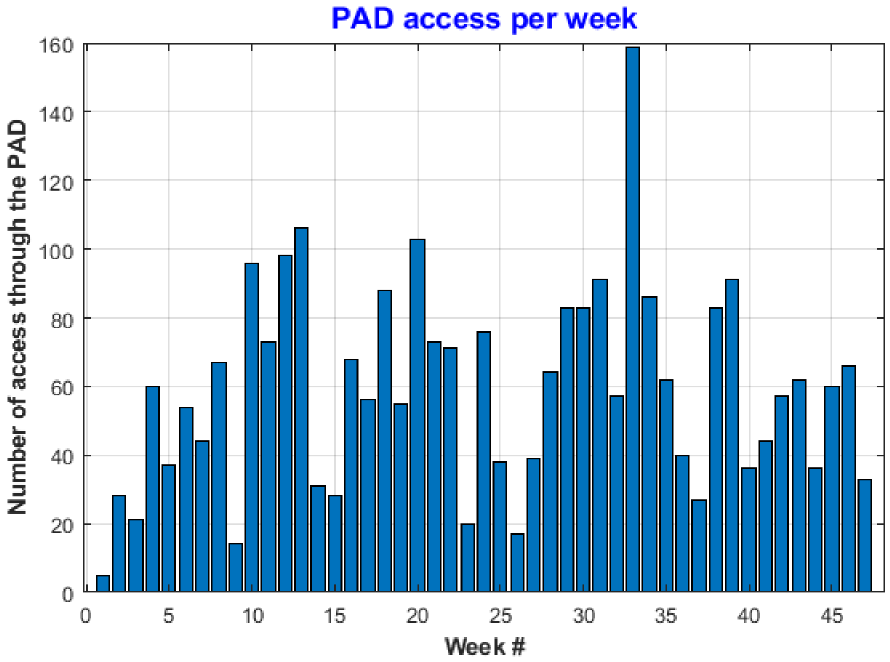
- 38 weeks of beam
- 279 hours of set-up installation
- 230 accesses with radioprotection
- 1209 hours of beam
- 40 hours of fatal failure
- 1.9 experiments per week in average

Operation flexibility - accesses

A very large number of accesses for experiment installation and user interventions.

- RP calls: > **213** (until 30/11/23) - minimum delay 30 min, require klystron stop, limited to working hours
- PAD accesses: **2802** (*D. Chapuis*)





In average:

- 9 per day
- 59 per week
- 253 per month

Mutualizing accesses with two experimental beam lines will increase the overall running time and allow more experiments per week. Complex set-up could stay installed for longer time.

Operation

- CLEAR is a stand-alone installation, thus operation during general stops of the global CERN accelerator complex, including long shut-downs, is possible.

- CLEAR is operated for 30 to 40 weeks/year – typically from March to December, often 2-3 weeks stop in summer.
  - Operation organized over 2 shifts, roughly during working hours, 5 days/week
  - No night shifts or week-end running (apart few exceptions)
  - Sometimes remotely supervised operation in nights/week-ends (low-charge irradiation – none recently)

- Current operating team:
  1 Staff, 1 ½ associates, 2 fellows, 1 PhD student, plus 1 part-time associate (in remote)

- Support from CERN services and groups on technical systems, in general on best effort basis and subject to priorities

- Detailed weekly activities organized at the Monday operation meeting (often followed by access in the hall) and coordinated by a weekly supervisor (member of the operation team)

CLEAR operation peculiarities

- Flexibility:
  - flexibility of access (see previous slide),
  - flexibility in acceptance and scheduling of experiments,
  - flexibility in beam conditions (from low charge single-bunch to trains of high charge bunches, beam sizes from a few tens of microns to cm size, different energies and bunch lengths…),
  - flexibility in adapting hardware and experimental set-ups to evolving user requirements,
  - flexibility in experiment locations (in-air and in vacuum),
  - flexibility (not to be abused) in working after hours and week-ends
- Availability: long experimental run (March-December), run during long shut-downs.
- Support: the CLEAR team provides to the users specialized equipment, support for machining of small parts, assembly of experimental set-ups, small vacuum interventions, data acquisition, data analysis…
- Collaboration: CLEAR is a user facility but in most cases, we don't just provide a beam following user specs, but we help - if needed - to better define the experiment, optimize methods and adapt the measurement program, analyze and interpret the results. Many of the CLEAR experiments evolve in a full two (or more) sided collaboration.
- Flexibility. Did I mention flexibility?

Origin of experiments

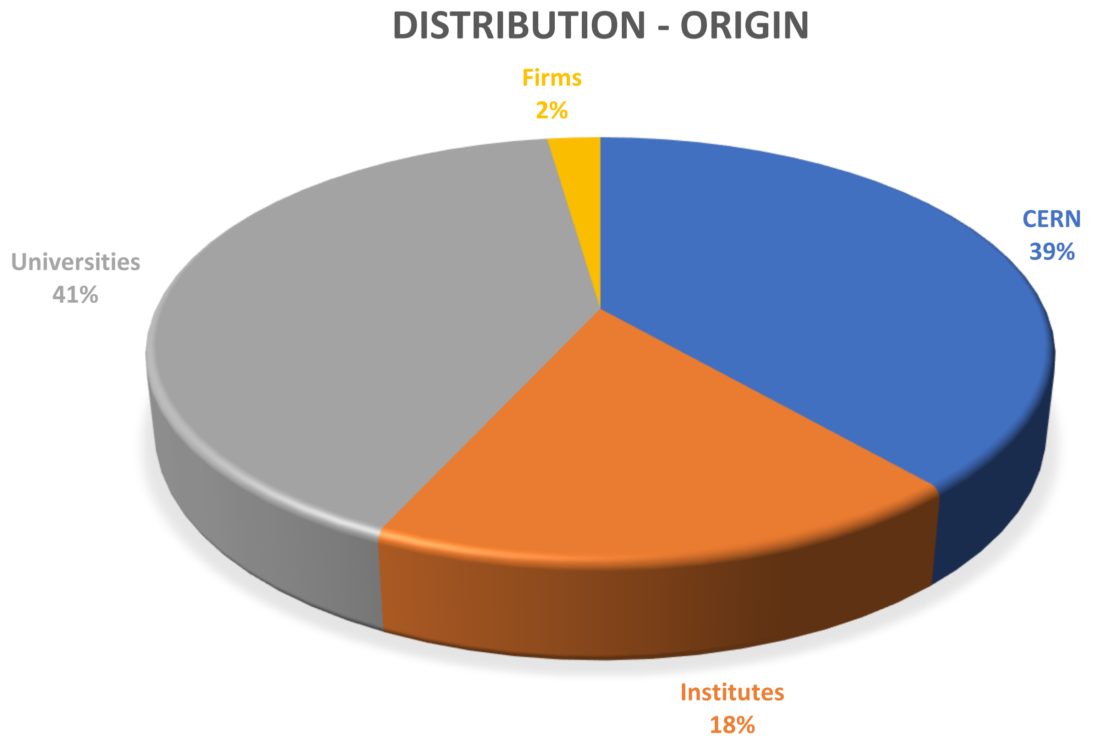
- 27 independent experiments (~ 35 including repetitions, plus MDs)
- About 21 User Groups internal/external
- More than 18 external collaborating institutes

CERN – ABP
CERN – BI
CERN – RP
CERN – EP
CERN – TE
CERN – SY

BERGOZ

Manchester U.
Oxford U.
RHUL
London U.
Liverpool U.
Strathclyde U.
Oslo U.
Victoria U.
Kansas U.
Politecnico Milano

PSI
CHUV
EPFL
INFN Bologna
INFN Padova
KIT
Cockcroft Inst.
JAI



Activities

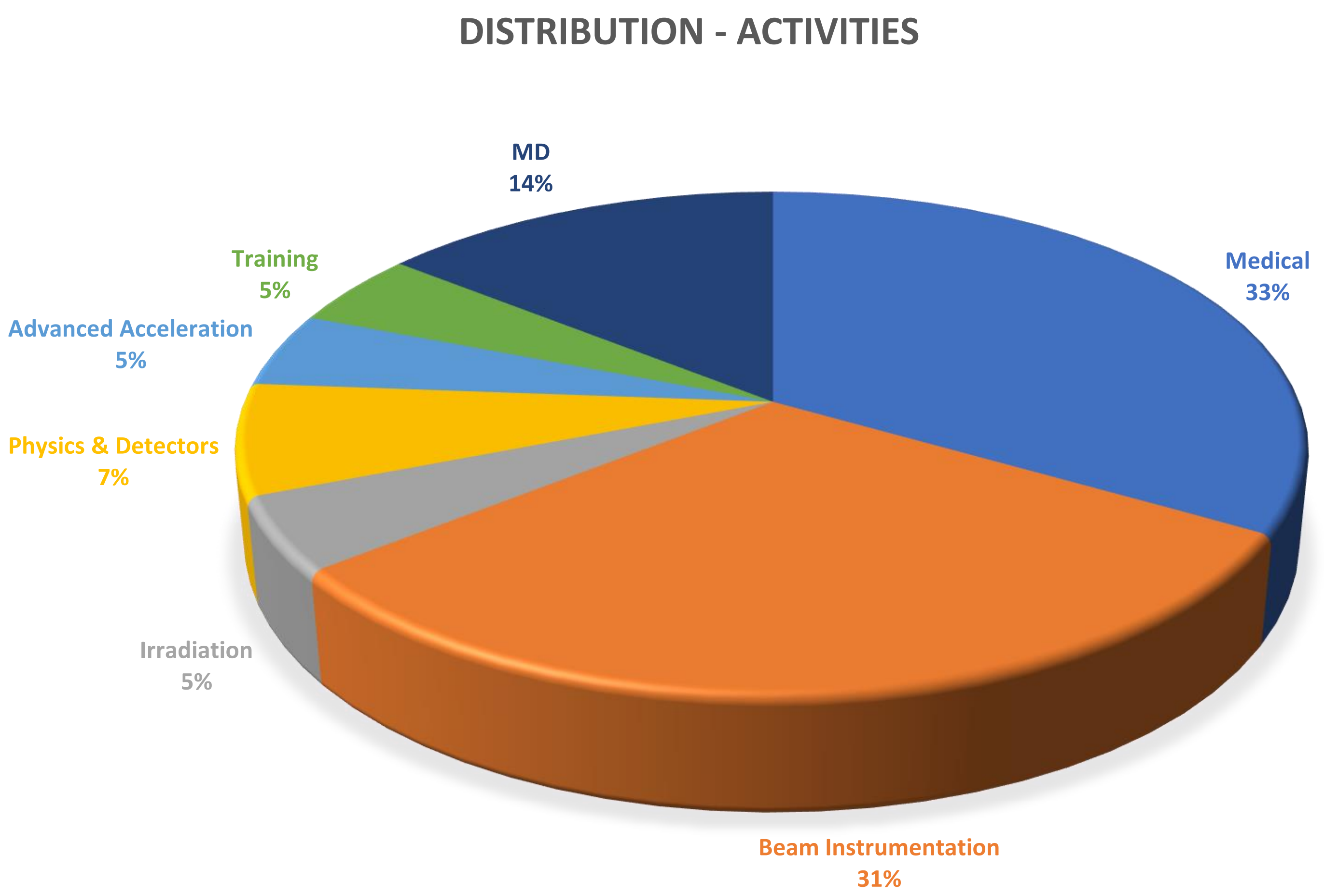
Not always straightforward to classify (and quantify), however:

- Two main activities:
  - medical
  - beam instrumentation R&D

- Together they constitute about 2/3 of the total requests/beam time

In the following, I'll give some highlights mainly concentrating on the other activities

see following talks for medical and beam instrumentation activities



Publications – scientific output

In 6 ½ years of operation, the experimental activities carried out in the CLEAR user facility have generated:

- 23 Journal papers
- 36 Conference papers
- More than 12 completed PhD thesis, plus several ongoing.
- More than 17 outreach publications in specialized journals, press releases, …

https://clear.cern/content/publications

Journal papers:

- **Nature Scientific Reports - May. 2024**: CERN-based experiments and Monte-Carlo studies on focused dose delivery with very high energy electron (VHEE) beams for radiotherapy applications (doi).
- **Physics in Medicine & Biology - Apr. 2024**: Development of a novel fibre optic beam profile and dose monitor for very high energy electron radiotherapy at ultrahigh dose rates (doi).
- **Physics Medicine & Biology - Feb. 2024**: Mini-GRID radiotherapy on the CLEAR very-high-energy electron beamline: collimator optimization, film dosimetry, and Monte Carlo simulations. (doi).
- **IEEE Sensors Journal - Jan. 2024:** Plastic scintillator dosimetry of ultrahigh dose-rate 200 MeV electrons at CLEAR (doi).
- **IEEE Transactions on Nuclear Science - Mar. 2022:** Analysis of the Photoneutron Field Near the THz Dump of the CLEAR Accelerator at CERN With SEU Measurements and Simulations (doi).
- **Physical Review Accelerators and Beams - Dec. 2021:** Strong focusing gradient in a linear active plasma lens (doi).
- **Biomed. Phys. Eng. Express - Dec. 2021**: VHEE beam dosimetry at CERN Linear Electron Accelerator for Research under ultra-high dose rate conditions (doi).
- **IEEE Transactions on Nuclear Science - Mar. 2021:** Electron-Induced Upsets and Stuck Bits in SDRAMs in the Jovian Environment (doi).
- **Physics Letters A - Mar. 2021**: Diffractive shadowing of coherent polarization radiation (doi).
- **Nature Communications Physics - Feb. 2021:** An experimental study of focused very high energy electron beams for radiotherapy (doi).
- **Nature Scientific Reports - Feb. 2021**: Evaluating very high energy electron RBE from nanodosimetric pBR322 plasmid DNA damage (doi).
- **Nuclear Instruments and Methods in Physics Research Section B - Nov. 2020:** Influence of heterogeneous media on Very High Energy Electron (VHEE) dose penetration and a Monte Carlo-based comparison with existing radiotherapy modalities (doi).
- **IEEE Transactions on Instrumentation and Measurement**: A Measurement Method based on RF Deflector for Particle Bunch Longitudinal Parameters in Linear Accelerators (doi).
- **Nature Scientific Reports - Jun. 2020**: The challenge of ionisation chamber dosimetry in ultra-short pulsed high dose-rate Very High Energy Electron beams (doi).
- **Nature Scientific Reports - May 2020**: Enhancing particle bunch-length measurements based on Radio Frequency Deflector by the use of focusing elements (doi).
- **Physical Review Accelerators and Beams - Feb. 2020**: Noninvasive bunch length measurements exploiting Cherenkov diffraction radiation (doi).
- **Nucl. Instr. and Meth. in Physics Research Sect. B - Oct. 2019:** A magnetic spectrometer to measure electron bunches accelerated at AWAKE (doi).
- **Physical Review Accelerators and Beams - Feb. 2019:** A beam-based (sub-)THz source at the CERN Linear Electron Accelerator for Research facility (doi).
- **IEEE Transactions on Nuclear Science - Jan. 2019:** Mechanisms of Electron-Induced Single-Event Latchup (doi).
- **Physical Review Letter - Nov. 2018**: Emittance Preservation in an Aberration-Free Active Plasma Lens (doi).
- **Nuclear Instruments and Methods in Physics Research Section A - Nov. 2018**: Overview of the CLEAR plasma lens experiment (doi).
- **IEEE - Jun. 2017:** High-Energy Electron-Induced SEUs and Jovian Environment Impact (doi).

Experimental program 2017-2024

- 138 beam time requests received from 2017

- 116 experiments carried out and documented in the experiment list:
  (https://pkorysko.web.cern.ch/CLEAR/Table/CLEAR_experiments.html)

- A few selected highlights

  (medical applications and beam diagnostics covered in next two talks)

- 2018
- 2019
- 2020
- 2021
- 2022
- 2023
- 2024
  - 3019115 (v.1) 108-Hollow Core Fibres Studies
  - 3020002 (v.1) 109-Electro-Optical Longitudinal Bunch Profile Monitor Studies
  - 3022962 (v.1) 110-Gold Nanoparticles Plasmid Studies
  - 3022963 (v.1) 111-Plan Delivery to an Anatomical Phantom
  - 3023200 (v.1) 112-VHEE at UHDR Studies with Liposomes
  - 3023212 (v.1) 113-VHEE at UHDR Studies with Short Peptides and LCMS
  - 3023218 (v.1) 114-VHEE at UHDR Studies with Cells
  - 3023221 (v.1) 115-VHEE at UHDR Studies with Biodosimeters
  - 3023518 (v.1) 116-Fibre Beam Loss Monitor Studies
  - 3023873 (v.1) 117-Bergoz Beam Current Transformer Studies
  - 3024188 (v.1) 118-Plasma Lens Studies
  - 3025110 (v.1) 119-AWAKE Spetrometer Scintillator Screen Studies
  - 3026329 (v.1) 120-Digital Micro-mirror Device OTR Studies
  - 3026331 (v.1) 121-Micro-Lens Array OTR Studies
  - 3026997 (v.1) 122-VHEE at UHDR Studies with Drosphila
  - 3026998 (v.1) 123-Beam Scanning Spatially Fractionated RT Studies
  - 3027000 (v.1) 124-VHEE Material Irradiation Studies
  - 3030195 (v.1) 125-Radio-Enhancement Effect Studies of Nanoparticles
  - 3031780 (v.1) 126-ChDR EOSD Studies
  - 3031785 (v.1) 127-EOSD In-Air Studies
  - 3035076 (v.1) 128-ChDR Bunch Length Monitor
  - 3036197 (v.1) 129-Passive Streaking for Temporal Diagnostics
  - 3044873 (v.1) 130-Sapphire Detector Studies for LUXE
  - 3044875 (v.1) 131-Detector Irradiation Studies for LUXE
  - 3054102 (v.1) 132-Real-Time Dosimetry Studies with Cuvettes
  - 3054717 (v.1) 133-Resonance of the Internal Clock the Electron Studies
  - 3063880 (v.1) 134-Real-Time Dosimetry for UHDR VHEE
  - 3063916 (v.1) 135-RPL dose-rate studies
  - 3087447 (v.1) 136-Chromox Screen Studies
  - 3087448 (v.1) 137-FCCee BPM Studies
  - 3092772 (v.1) 138-flashDiamond Detector Studies

Irradiation on electronics

CLEAR has been important to R2E activities over the last years

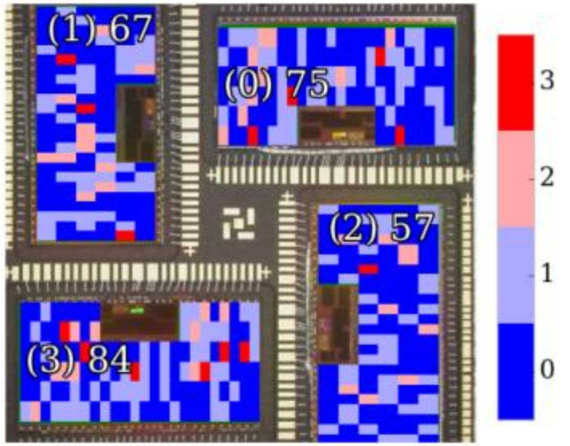
- Initial interest for Jovian environment space missions (JUICE from ESA)

Electron-induced effects in electronics are **not as well explored** as those from ions, protons or neutrons. CLEAR is central to the investigation of these effects.

- It enabled studying **key radiation effects** that it was not possible to study elsewhere

- Explored electron-induced **single-event effects** over a wider range of energy than what can be achieved in medical LINACs.
- Enabled **first ever observation** and demonstration that HEE can trigger SEL in SRAM.
- It enabled studying **displacement damage** effects in a short time and with low level of activation
- Allowed studies on HEE SEU, SEL, stuck bits…

S. Coronetti



ESA Monitor
(reference chip, 250 nm)

Publications

- M. Tali et al., "High-Energy Electron-Induced SEUs and Jovian Environment Impact," in IEEE Transactions on Nuclear Science, vol. 64, no. 8, pp. 2016-2022, Aug. 2017.
- M. Tali et al., "Mechanisms of Electron-Induced Single-Event Upsets in Medical and Experimental Linacs," in IEEE Transactions on Nuclear Science, vol. 65, no. 8, pp. 1715-1723, Aug. 2018.
- M. Tali et al., "Mechanisms of Electron-Induced Single-Event Latchup," in IEEE Transactions on Nuclear Science, vol. 66, no. 1, pp. 437-443, Jan. 2019.
- M. Tali, " Single-Event Radiation Effects in Hardened and State-of-the-art Components for Space
- and High-Energy Accelerator Applications", PhD Thesis, University of Jyväskylä, Finland, 2019.
- A. Coronetti et al., "SEU Characterization of Commercial and Custom-designed SRAMs manufactured in 90 nm technology and below", in IEEE Radiation Effects Data Workshop, Santa Fe, NM, USA, 2020.
- D. Söderström et al., "Electron-induced Single Event Upsets and Stuck Bits in SDRAMs in the Jovian Environment", accepted for publication in IEEE Transactions on Nuclear Science, 2021.
- D. Poppinga et al., "VHEE beam dosimetry at CERN Linear Electron Accelerator for Research under ultra-high dose rate conditions", Biomedical Physics Express, vol. 7, no. 1, 2021.

And more are coming...

CLIC

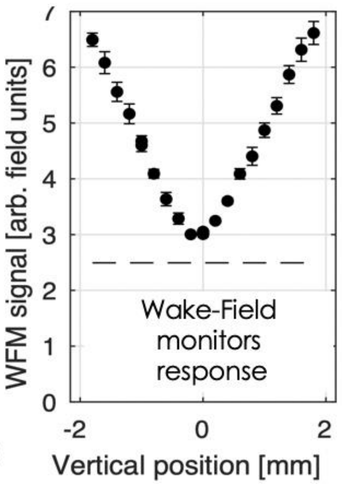
Key CLIC related activities

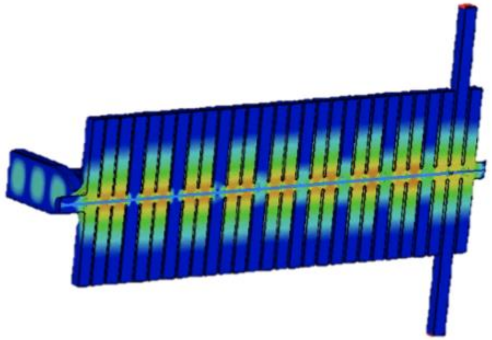
Experiments:
- Wake-Field monitors
- Wake-field kicks
- CLIC cavity BPMs

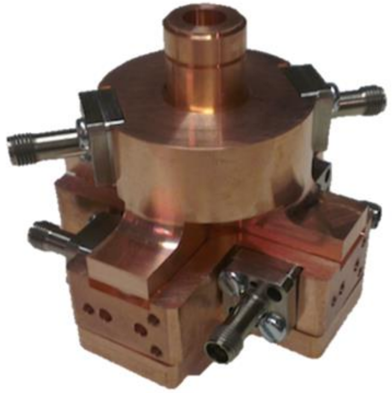
Main collaborators
- University of Oslo
- CEA - Saclay
- Università di Napoli Federico
- RHUL

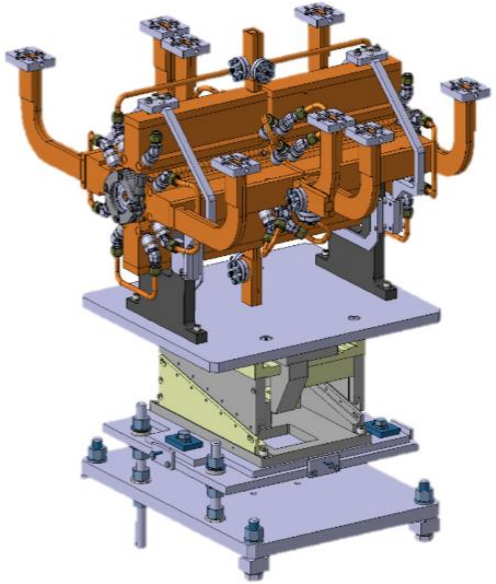
Future step, connecting the cavity to X-Box1

possible tests:
- RF kicks
- Breakdown kicks
- RF effect on WFMs
- Stability & reliability runs

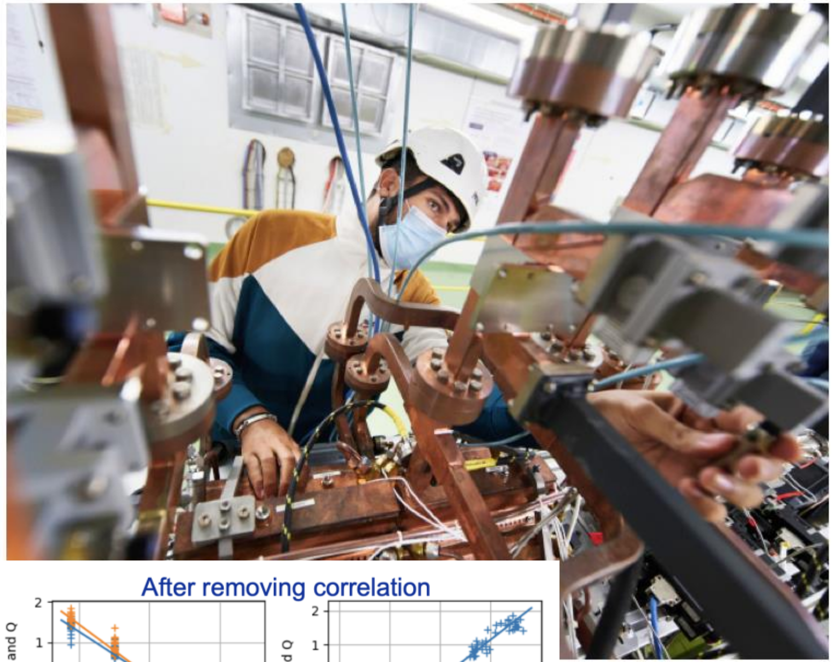


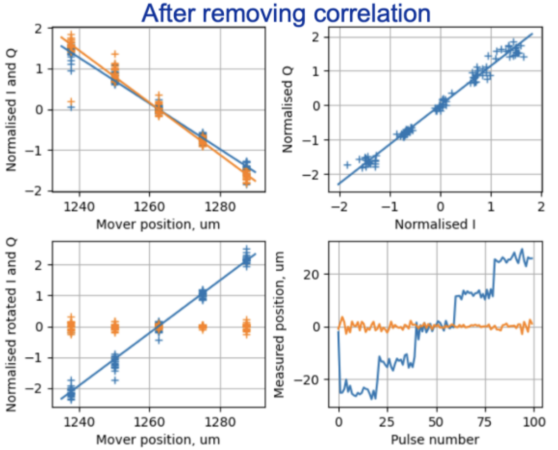






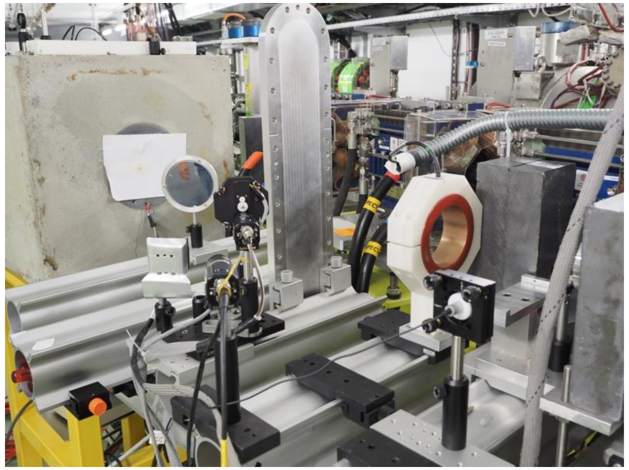
A. Gilardi, K. Sjobaek, M. Wendt, A. Lyapin

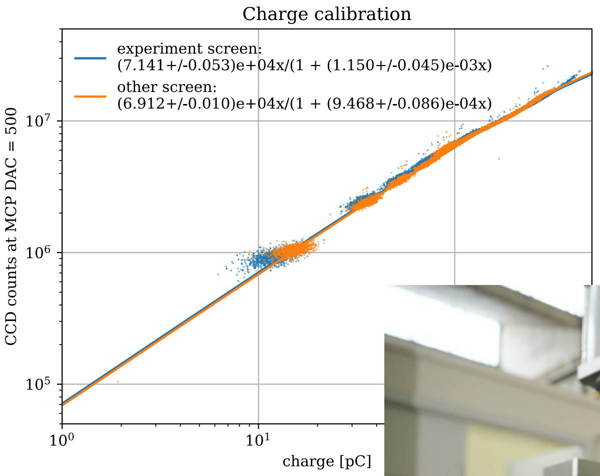




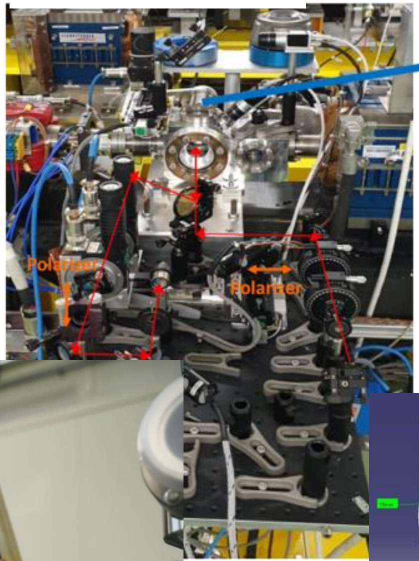
AWAKE

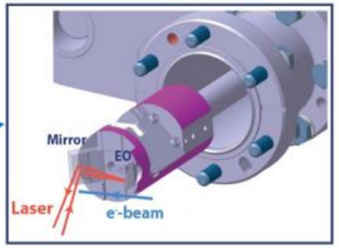
Charge calibration measurements of the AWAKE spectrometer scintillating screen/camera combination performed in 2017, 2018, 2019





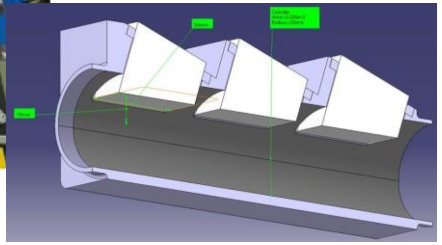
E. Gschwendtner

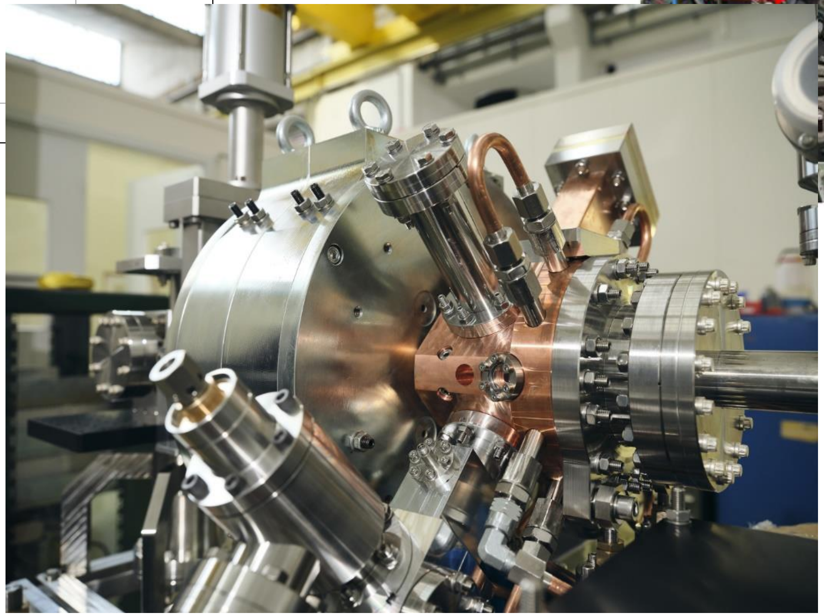




Bunch length monitors:

EOS and ChhDR





Cherenkov BPMs

Common development of novel electron source

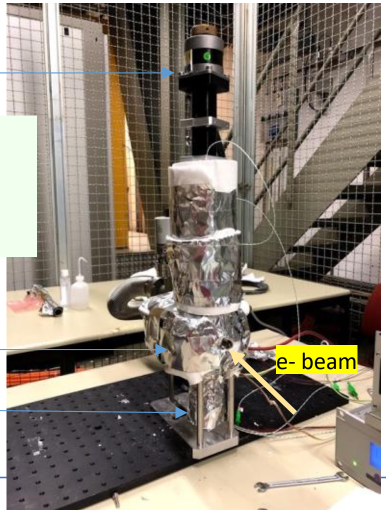
CLIC-AWAKE-CLEAR

Screen actuator

Beam Screen Survival Tests in Rubidium

Sapphire viewports

Rb reservoir (empty)

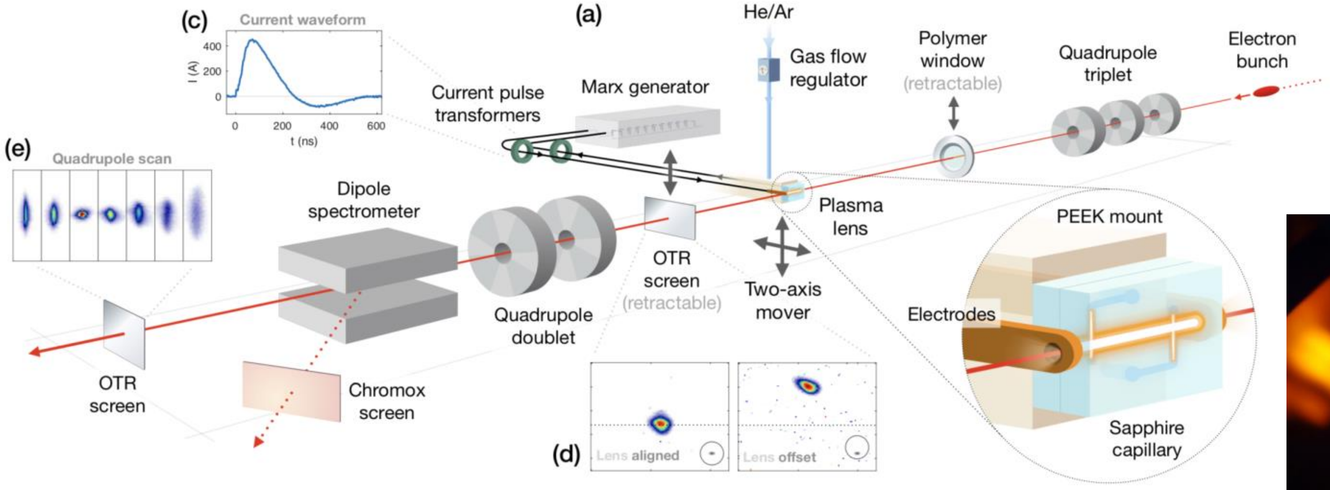


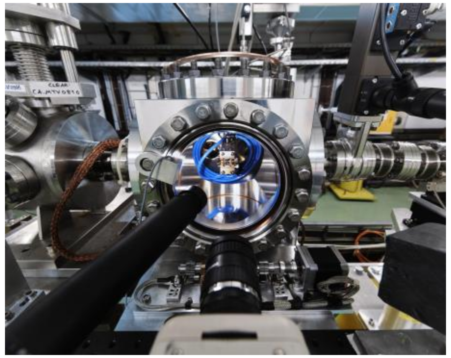
The Plasma lens experiment

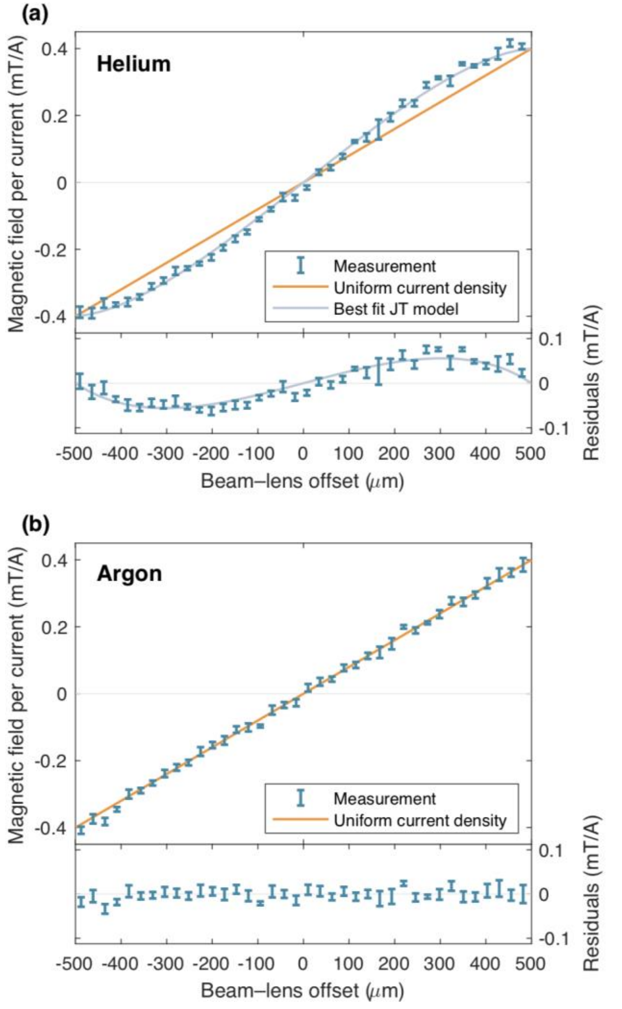
Lead by Univ. of Oslo, in collaboration with CERN, DESY and Oxford Univ.

Emittance Preservation in an Aberration-Free Active Plasma Lens

C. A. Lindstrøm, E. Adli, G. Boyle, R. Corsini, A. E. Dyson, W. Farabolini, S. M. Hooker, M. Meisel, J. Osterhoff, J.-H. Röckemann, L. Schaper, and K. N. Sjobak
Phys. Rev. Lett. **121**, 194801 – Published 7 November 2018







- Emittance preservation in an active plasma lens demonstrated for the first time with the use of an argon-based discharge capillary.
- Direc … d nonlir… in …

October 2019 – record magnetic field gradient of 5.2 kT/m !

- Quadrupole scans demonstrated expected emittance preservation and growth (respectively) consistent with the measured field profiles.

MDs, accelerator physics, beam dynamics

Apart from user experiments, some beam time is dedicated to Machine Development(MD) sessions, aimed at improving beam quality and expanding the beam parameter space.

In some cases, MD activities in CLEAR constitutes also a relevant contribution to the field of accelerator physics and beam dynamics.

Enhancing particle bunch-length measurements based on Radio Frequency Deflector by the use of focusing elements

Pasquale Arpaia, Roberto Corsini, Antonio Gilardi, Andrea Mostacci, Luca Sabato & Kyrre N. Sjobak

Scientific Reports **10**, Article number: 11457 (2020) | Cite this article

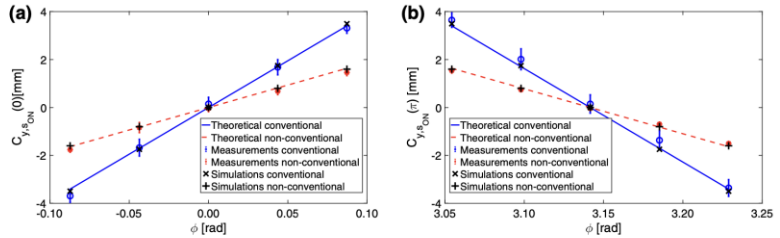
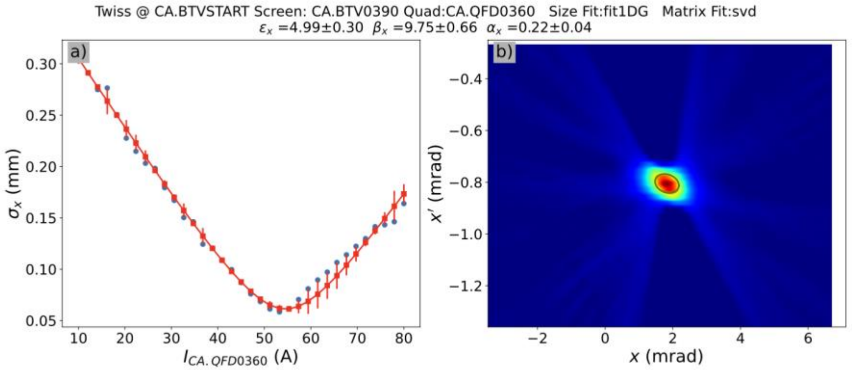


Figure 9. Vertical ($C_{y,ON}$) versus RFD phase in conventional and non-conventional layout around 0rad (**a**) and π rad (**b**): measurements (circle and star for conventional and non-conventional layout, respectively), theoretical values (solid and dashed lines for conventional and non-conventional layout), and simulation points (cross and plus sign for conventional and non-conventional, layout respectively).

A. Gilardi

Beam Tomography



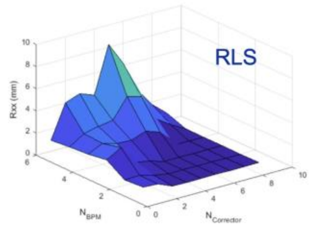
A. Aksoy

Beam Based Alignment

$X = X_0 + R\Theta, \quad R_{i,j} = \frac{\Delta x_i}{\Delta \theta_j},$

$\Theta = (R^T R)^{-1} R^T \Delta X$

DFS: $\begin{pmatrix} X \\ \omega(X - X') \\ 0 \end{pmatrix} = \begin{pmatrix} R \\ \omega(R - R') \\ \kappa I \end{pmatrix} \times \Theta,$



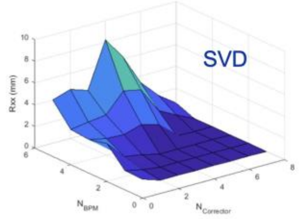
Operational BPMs allowed us to do high level beam physics.

We have developed an automated response matrix generation tool.

- Random or excitation in sequence of correctors for given machine setting
- R: for nominal energy, R' : for reduced energy

Based on chose one can create response matrix based on different algorithms (RLS, SVD) apply one-to one steering or DFS

Full process takes about 30 min



A. Aksoy

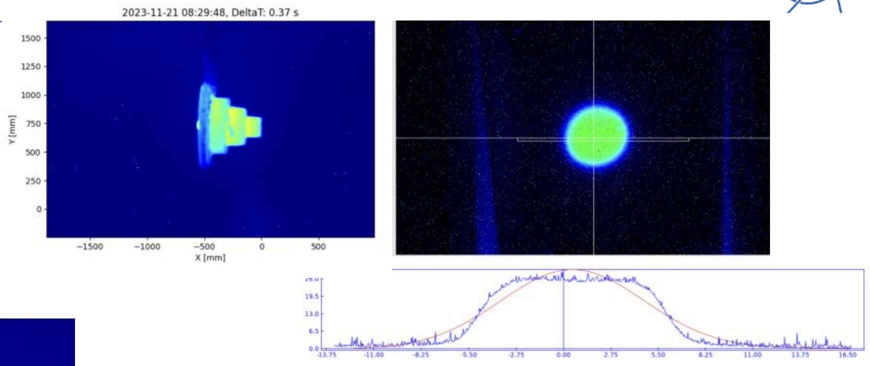
Important to preserve dedicated beam time for MDs – user pressure doesn't always allow us to do that…

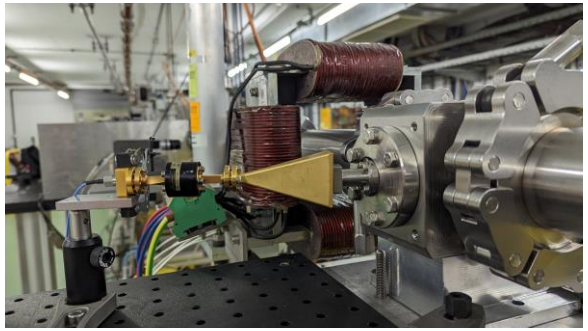
Operation 2023

- 27 Experiments
- About 21 User Groups internal/external
- More than 18 external collaborating institutes
- Beam from February 27th to December 15th (with 3 weeks summer stop)
- 38 weeks of operation in total

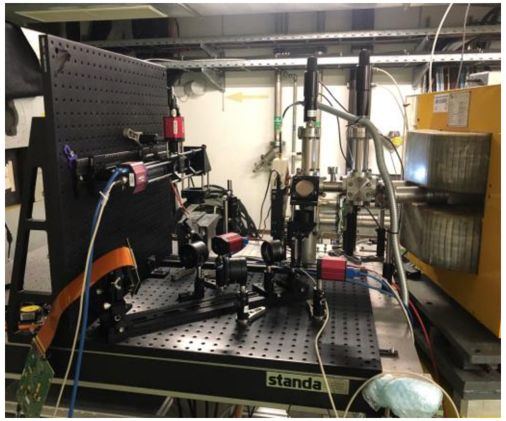
A few Highlights

Double-scattering system for uniform beam delivery for VHEE radiotherapy (CERN/Oxford U.)

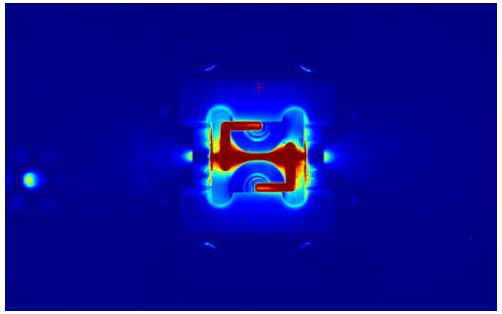




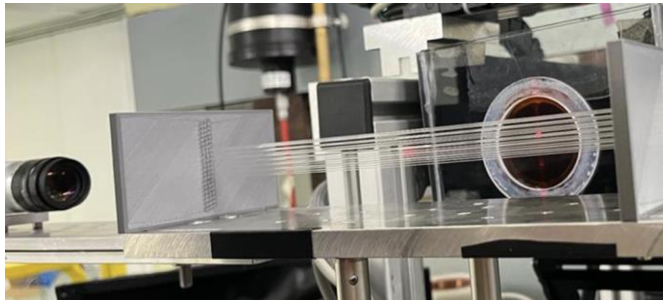
AWAKE Cherenkov Diffraction Radiation BPM



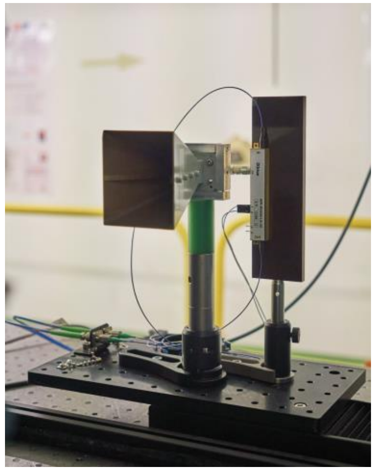
Novel OTR-based emittance meas. system for AWAKE (Liverpool U.)



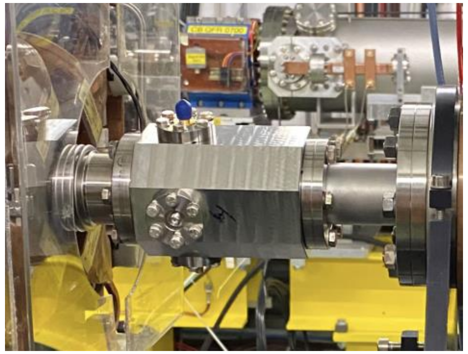
Plasma lens defocusing tests (Oslo U./CERN/Oxford U./DESY)



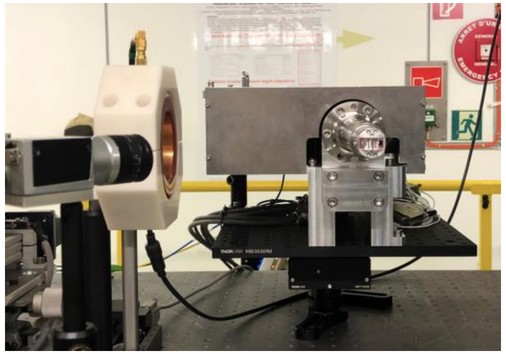
Fibre-optic beam profile and dose monitor for VHEE radiotherapy at ultra-high dose dates(CERN/Oxford U.)



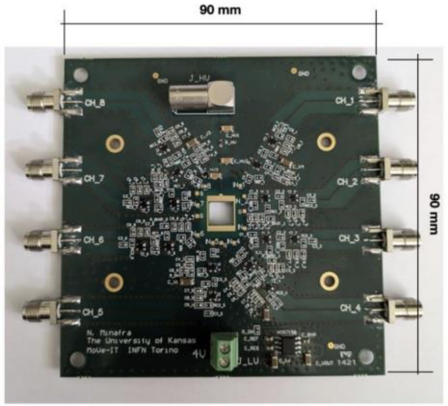
Coherent Cherenkov diffraction radiation dielectric buttons (FCC-ee bunch length monitors)



Broadband Pick-up for the PSI Positron Production Project (FCC-ee collaboration)

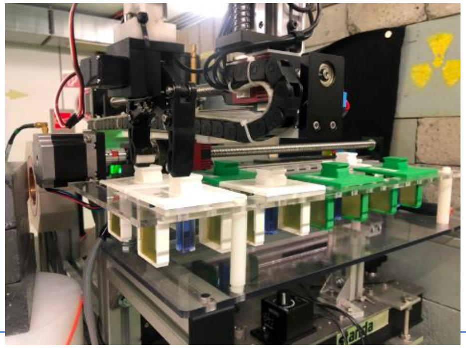


Bunch Profile Monitor for FCC-ee (Karlsruhe)



Beam testing of PCB + detectors using different technologies (Kansas U.)

Real-time dosimetry for VHEE radiotherapy using cuvettes (Strathclyde U.)



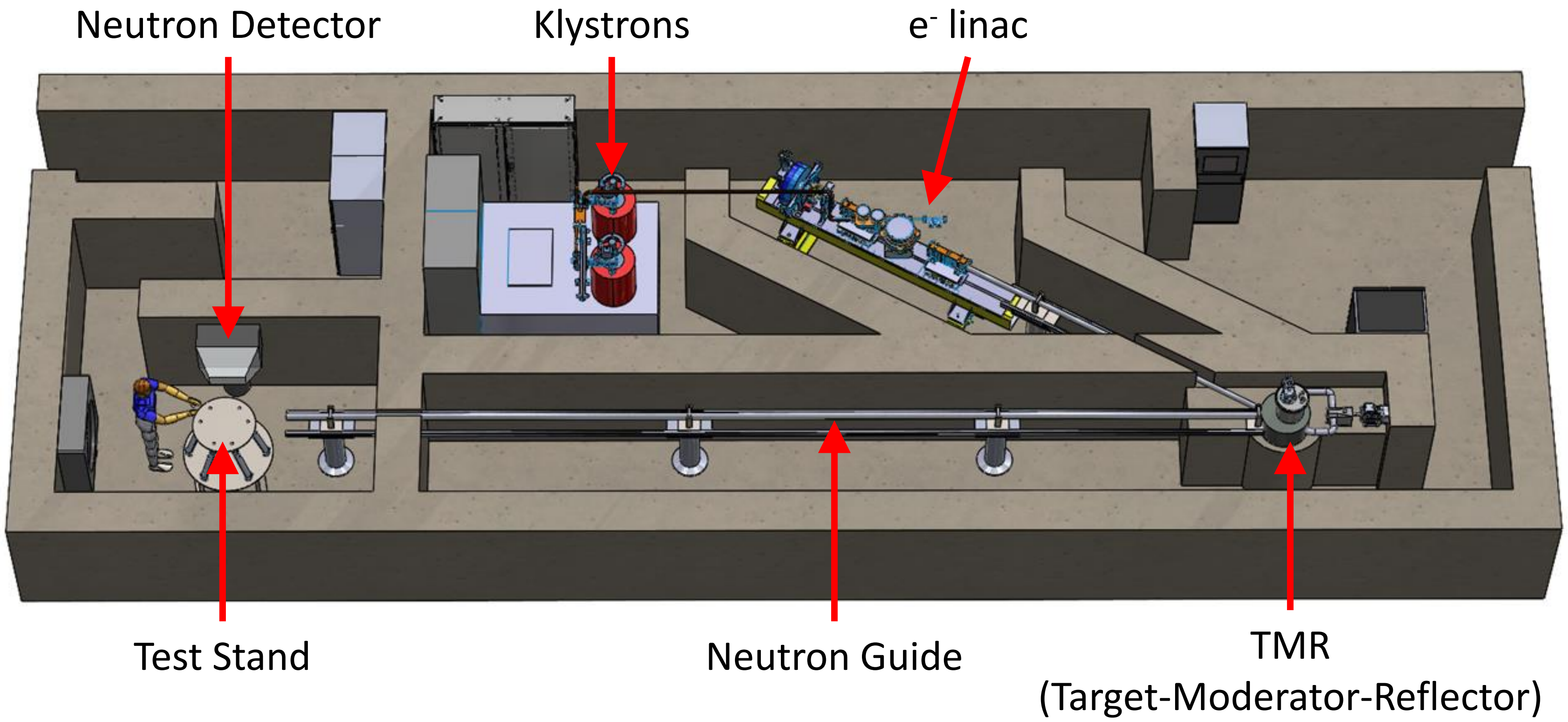
VULCAN - Overview

Versatile Ultra-Compact Advanced Neutron generator

VULCAN is a turn-key solution for generating thermal neutrons for:

- Stress-strain analysis of bulk materials
- Operational analysis of Li batteries and fuel cells electrodes

Optimised for industry – compact, affordable



- design + experimental study in CLEAR
- initially presented to the CERN KT initiative CIPEA in June 2022, approved and funded in 2023

The Target-Moderator-Reflector (TMR)

Novel TMR design is key for VULCAN

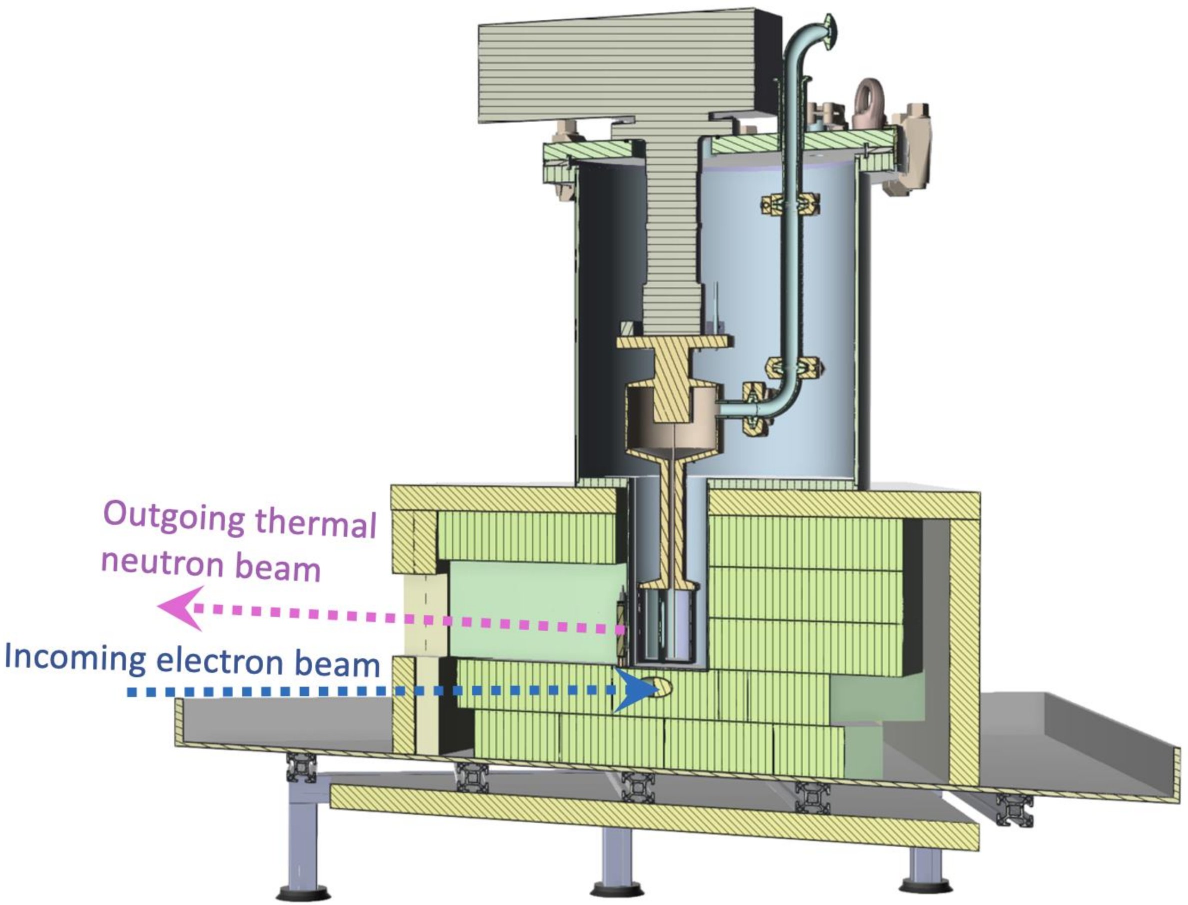
- Converts an incoming 35 MeV electron beam into ~ MeV neutron beam

Proof-of-concept of its performance to be undertaken in CLEAR

Flux and time-of-flight measurements

Complex experiment – issues with cryogenic – gas – safety…

Two weeks earmarked in July for installation and test



Outlook to end 2025

From CLEAR Scientific Board Report 2024

4. Future operations

Near-term through 2025

Near-term improvements to the CLEAR facility include the introduction of a second beamline. This addition enables the creation of more areas for in-air and in-vacuum testing, reducing the need for frequent mounting and dismounting of experiments and diagnostics equipment. Consequently, it increases the available beam time and operational flexibility, allowing for the parallel execution of 'non-compatible' experiments within the same week or day, with a quick turnaround. This modification also broadens the beam parameter space, for example allowing for larger beam sizes and stronger focusing. Commissioning is scheduled for late 2024 or early 2025.
The CLEAR laser systems have been identified as a potential source of failure and downtime. A new EO comb front-end is foreseen to increase the time structure flexibility, increase the repetition rate, and generally improve the reliability.

Finding 8: The second beamline and laser-system improvements will enhance reliability and flexibility for operations in 2024/25, and can be executed within the existing planned resource envelope.

A new electron source (comprising a photoinjector and an X-band accelerating structure) is currently being commissioned in stages in the former CTF2 area, adjacent to the CLEAR hall. This initiative is a collaborative effort involving CLIC, AWAKE, and CLEAR. Current plans favour its use after commissioning and before its installation in AWAKE as an independent beamline in the existing location (CTF2), and as an integral part of the CLEAR user facility.

Finding 9: While the timeline for AWAKE and any potential conflicts requires clarification, it is feasible to duplicate parts of the source with limited investment to avoid such conflicts.

Recommendation 3: CSB recommends that CERN support this approach towards upgrades, including CTF2. The committee encourages the CLEAR team to investigate the possibilities for utilisation of CTF2, define the necessary resources, and evaluate the user interest in CTF2 beyond the planned Incoherent Compton Scattering (ICS) studies.

Finding 10: The CLEAR programme has yielded important scientific results, has a growing user community, and an exciting future programme in various key areas. The aforementioned improvements and consolidations will enable CLEAR to accommodate a modest increase in user experiments, aligning with the growth of its user community demand.

Outlook beyond 2025

From CLEAR Scientific Board Report 2024

Beyond 2025

Finding 11: Considering a programme of user experiments beyond 2025, future priorities would likely include:

- Beam diagnostics R&D, which currently accounts for about 30% of total experiments and is roughly evenly divided between CERN and external users. It is reasonable to expect that demand for this will remain at least stable, or more likely increase due to demand from FCCee (see below).
- Priority for novel acceleration techniques (including plasma, THz, and X-band high-gradient technologies) will be maintained through long-term programmes supported as part of the LDG roadmap. This includes support for the plasma lens, ongoing assistance to AWAKE, and potentially a comprehensive ICS experiment.
- Medical applications are notably important and prominent. The next four to five years are crucial for fully establishing VHEE/FLASH therapy techniques, covering fundamental studies, time structure dependence, and optimization of parameters, as well as its supporting technologies, including beam delivery, dosimetry, and beam control. If extended, CLEAR will uniquely serve the VHEE/FLASH community for a number of years, playing a pivotal role in the field, including facilitating knowledge transfer to other laboratories equipped for animal testing.
- There is likely to be an overall increase in activities in other areas, such as irradiation, neutron production, beam testing of particle detectors and detector components, which will provide further demand.
- The role of training and EU projects, with CLEAR being recognized as a valuable infrastructure in projects such as EURO-LABS.

Completion of the construction and commissioning of the new beamline will be crucial to support an extended programme beyond 2025. This will provide more flexibility to cope with the increasing beamtime demands and will enlarge the technical portfolio of the CLEAR facility. Moreover, as preparations progress towards a future Higgs factory at CERN, there is growing consensus on the need for relevant electron-beam test facilities including, for example, prototypes of key system elements of the FCCee injector complex. If such future electron facilities are designed for versatile use, they could continue and expand the CLEAR programme, attracting a broad user community, in addition to serving as a foundational step towards a Higgs factory.

Finding 12: A CLEAR programme beyond 2025 could serve as a crucial step and bridge towards an electron-beam test facility based around developing key components required for a Higgs factory.

Recommendation 4: CSB recommends that the CLEAR team be centrally involved in discussion of electron test facilities for a future Higgs factory at CERN.

Thanks for your attention!

Acknowledgements to the CLEAR dream team:

S. Doebert, W. Farabolini, A. Ghilardi, P. Korysko, A. Malyzhenkov, A. Aksoy, K. Sjobaek, L. Dyks, V. Rieker, J. Bateman, C. Robertson, L. Wroe, E. Granados, M. Martinez, S. Curt, D. Gamba, …