The last 2 years of CLEAR Facility operation

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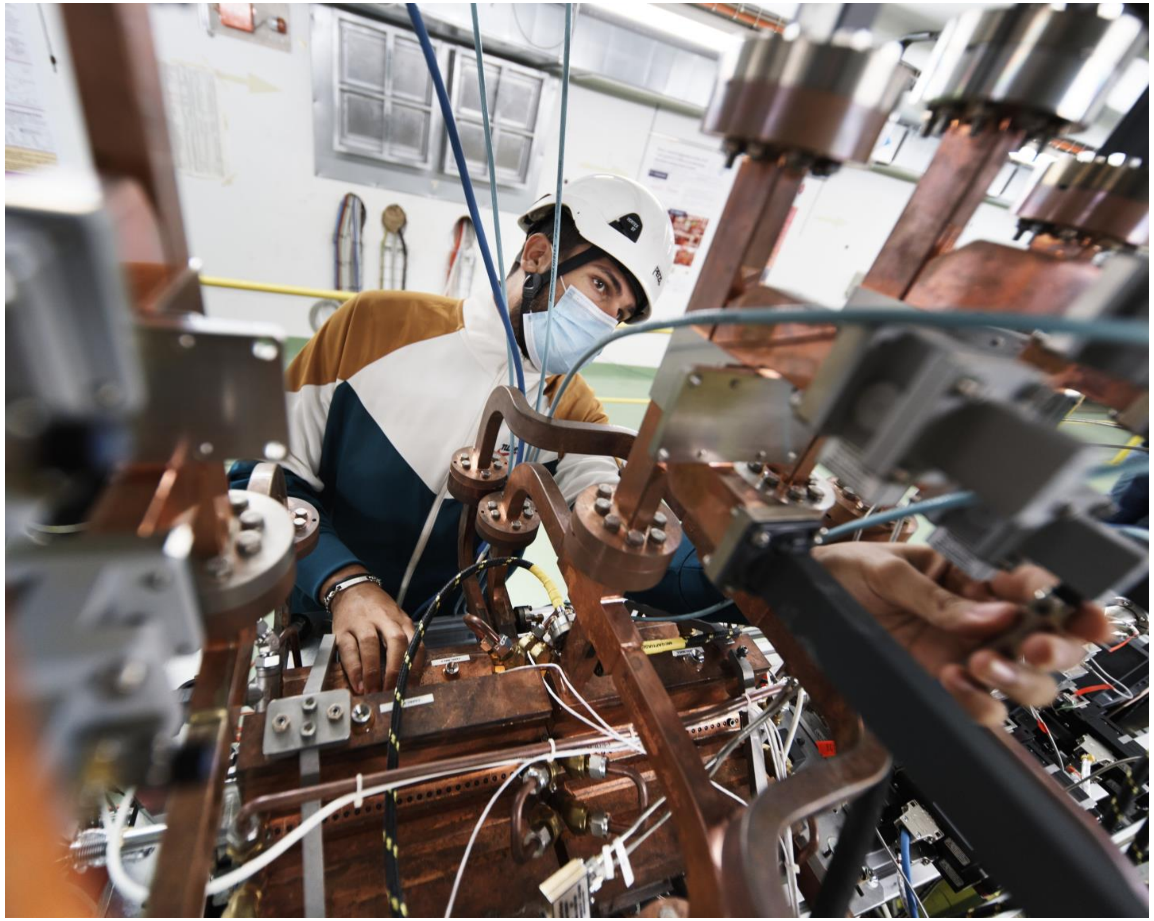
for the CLEAR Team

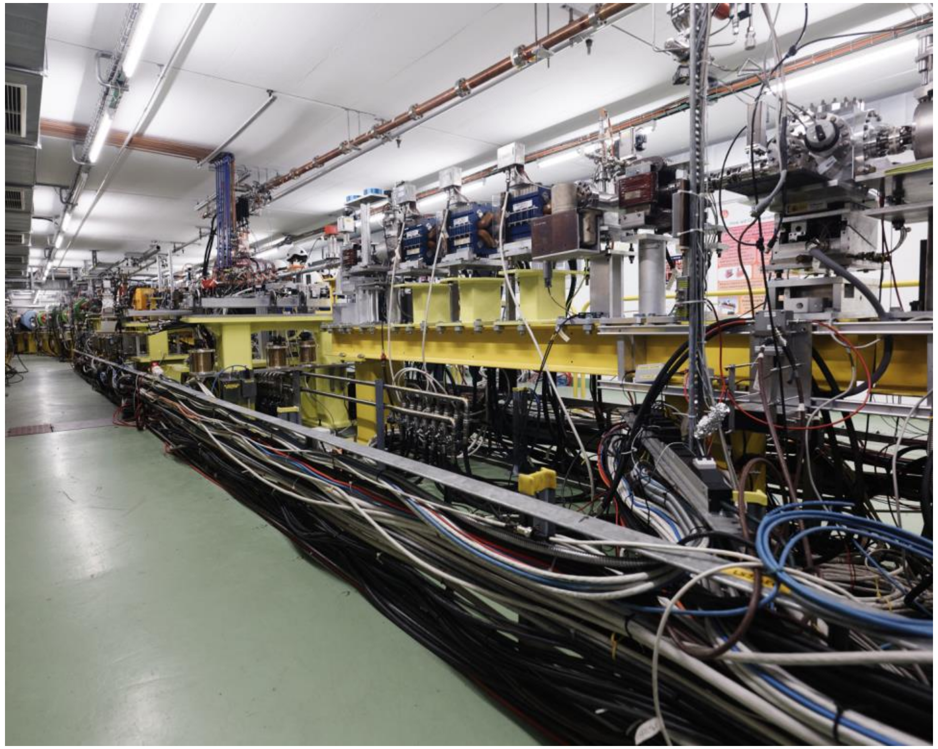
Outline

Update from last CLEAR review

- Introduction to CLEAR
- Operational mode
- Operation statistics (uptime, beam time for different activities…)
- Follow-up of 1st Review recommendations
- Main results, publications, PhD thesis, outreach…



The CERN Linear Electron Accelerator for Research (CLEAR)

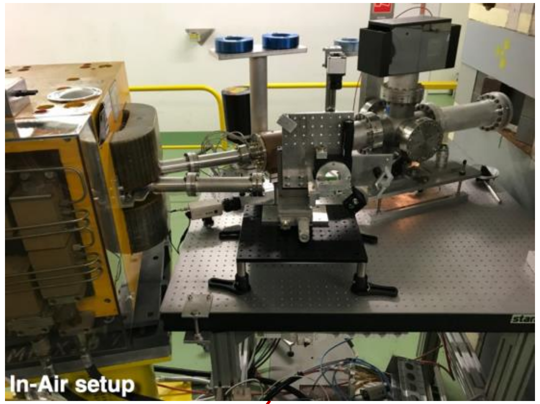


CLEAR is a versatile 200 MeV electron linac + a 20 m experimental beamline, operated at CERN as a multi-purpose user facility.

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.

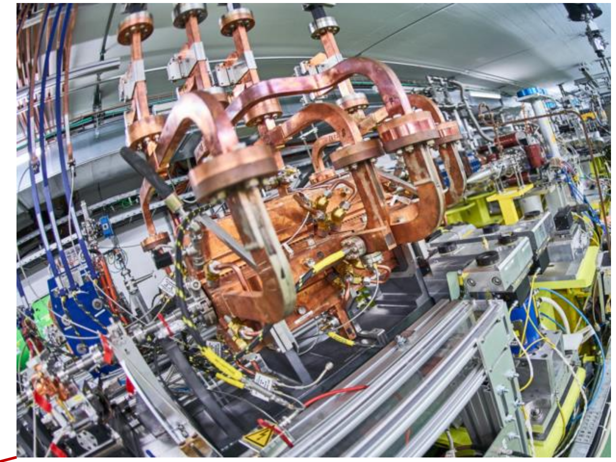
CLEAR Layout & main installations



In-air test stand

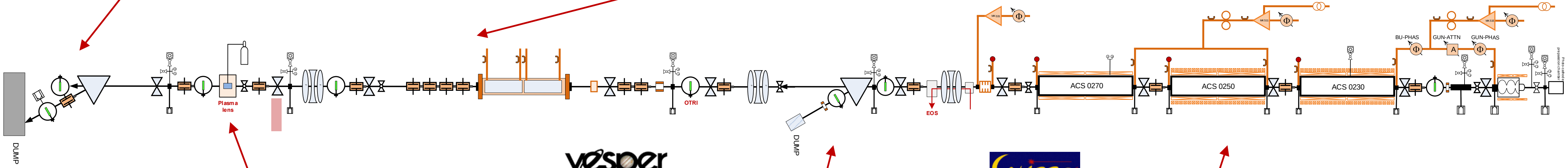
Testing ground for beam diagnostics R&D and THz radiation studies

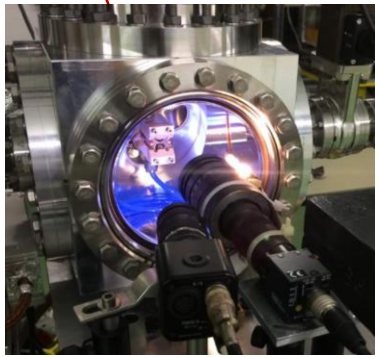
Irradiation for medical and other applications



CLIC Test-Stand

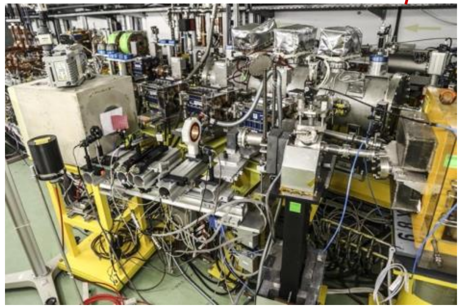
High-gradient and linear colliders R&D





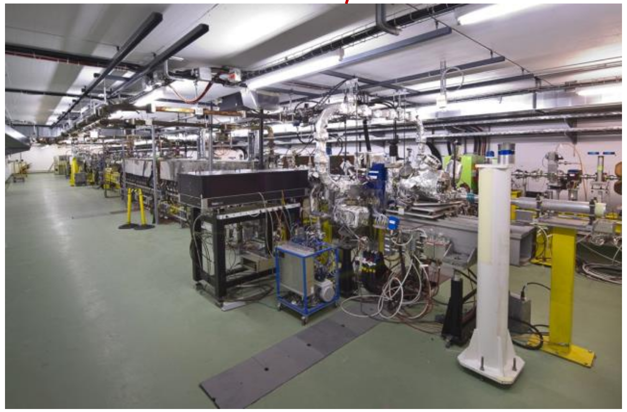
The Plasma Lens Experiment

Novel concepts of plasma-based focusing and acceleration



VESPER

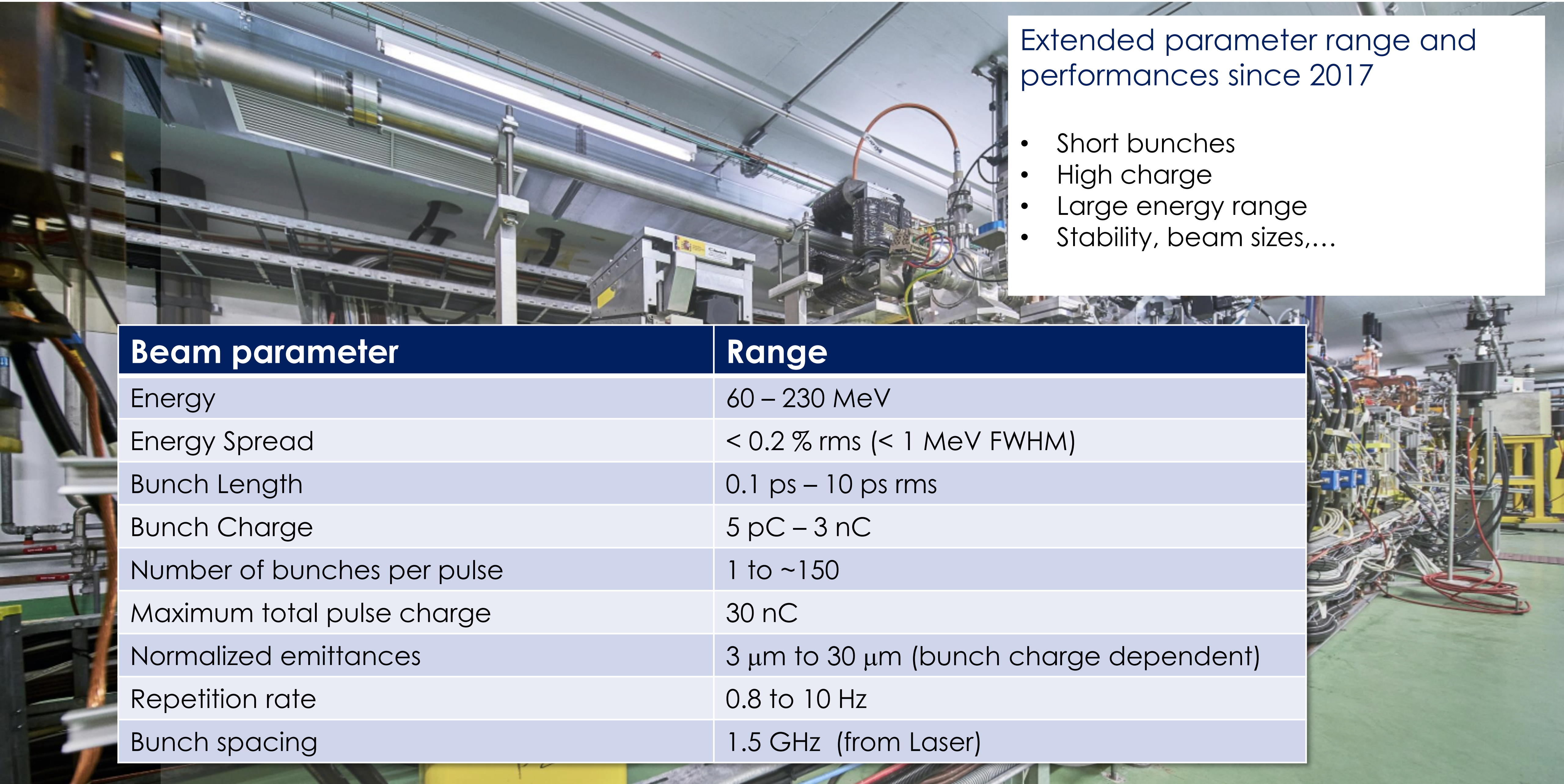
Beam irradiation facility for studies on radiation damage of electronics and medical applications



CALIFES electron linac

Flexible accelerator providing 200 MeV electron beams to all CLEAR users

CLEAR Beam Parameters



Extended parameter range and performances since 2017

- Short bunches
- High charge
- Large energy range
- Stability, beam sizes,…

Beam parameter	Range
Energy	60 – 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	30 nC
Normalized emittances	3 μm to 30 μm (bunch charge dependent)
Repetition rate	0.8 to 10 Hz
Bunch spacing	1.5 GHz (from Laser)

CLEAR Timeline

- Approved in December 2016, as a 2 + 2 years program
- Started operation in August 2017
- Reviewed and extended until 2020 in February 2019
- Operation extended in 2021 and possibly beyond, with independent budget included in the new CERN Medium Term Plan 2021-2025 (approved by the CERN Council in September 2020)

Main activities

- Beam Diagnostics R&D

  SY/BI is our main interface, collaboration with external institutes, or other CERN projects mainly through them

- Medical Activities

  Main collaborator is CHUV-Lausanne, but independent collaborations exist with several other institutes/firms

- Irradiation

  Similar to beam diag R&D, our main interface is the R2E team at CERN – collaboration with others (e.g., ESA) handled jointly

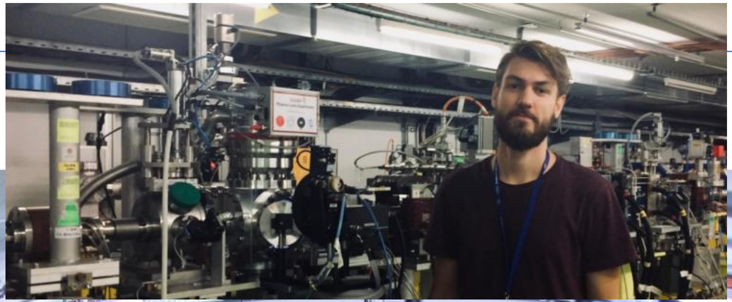
- Advanced acceleration

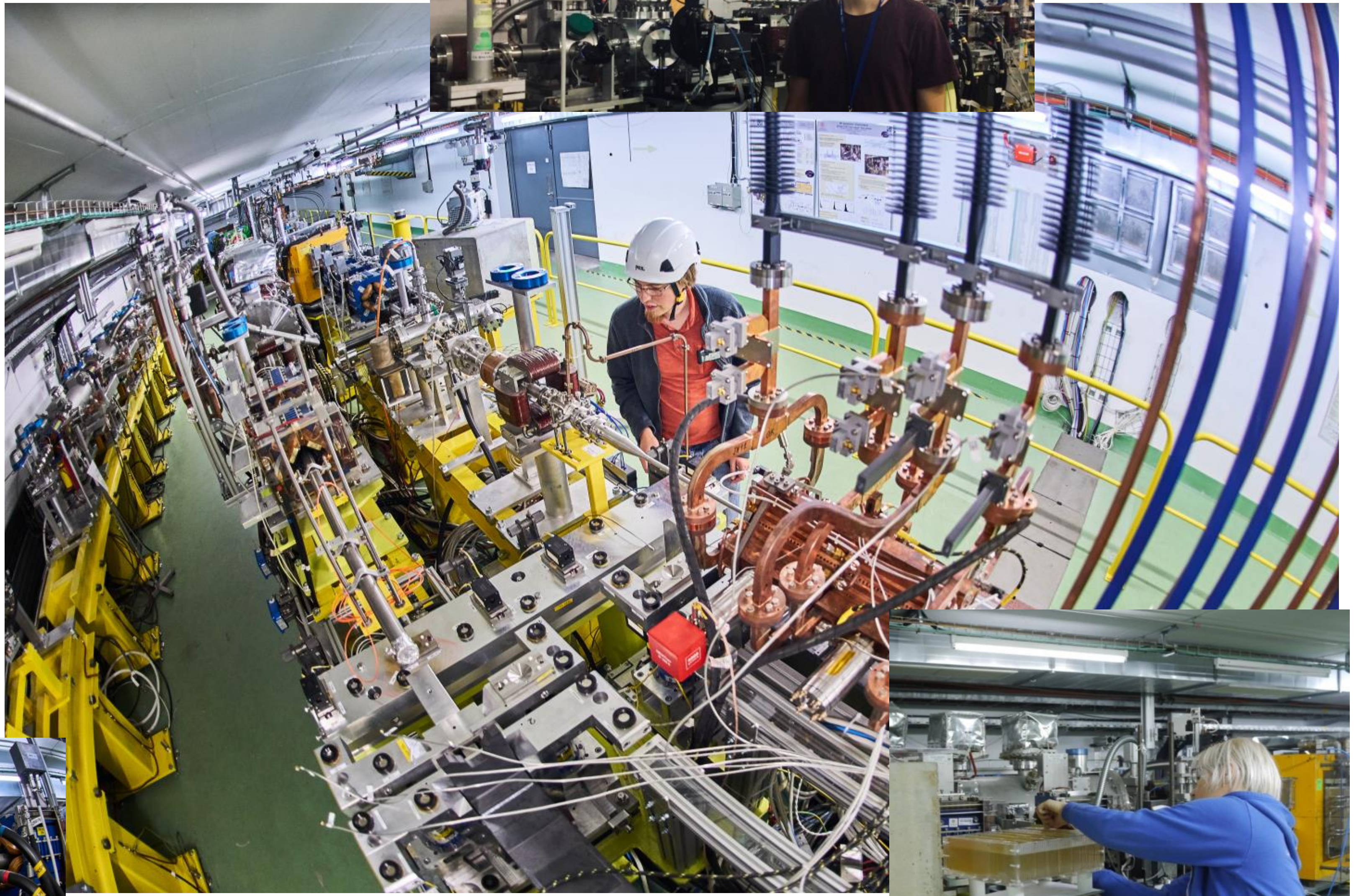
  Two main "clients" so far: CLIC and AWAKE, plus the Plasma Lens Collaboration lead by Oslo University

- Others

  We routinely receive (and follow) beam time requests in many different fields, different from the above. One example is the testing of micro-Beam Profile Monitors we do for the IRRAD facility at CERN - I'll give other examples later

CLEAR operation 2017-2020





Start with beam August 2017

- 19 weeks of operation in 2017
- 36 weeks in 2018
- 38 weeks in 2019
- 34 weeks in 2020 with about two months lockdown

Due to Covid-19 related measures, 2020 activities were limited to CERN users

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 in 2020)

- Current operating team:
  2 associates, 2 PhD students, 1 part-time associate (in remote) + myself

- Support from CERN services and groups on technical systems, in general on best effort basis and subject to priorities, no piquet service

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

Access to beam time

- Any user willing to access the facility has to fill-up a beam time request form (https://clear.cern/content/beam-time-request), specifying:
  - Experiment description, scientific aim and justification
  - Needed beam parameters
  - Experimental apparatus and logistics, safety aspects

- User teams often ask for beam time on a given activity a few times during an year, and often over 2 or more years. Following a recommendation from the last review, beam time request beyond 1 year requires to fill out a new form

- In general, some iterations between the operation team and the requester are needed (before of after receiving the form) in order to clarify requirements and understand goals

- The CLEAR Technical Board is responsible to check technical, safety and RP issues before giving the final authorization and allocate the beam time in the schedule

CLEAR operation 2020 – Beam Time Requests

- 25 formal beam time request received
- 19 fully or partly covered
- 6 not covered (external users)

2337478 v.1	18-Calibrate Gafchromic EBT3	1	In	2019-09-24	Karolina Kokurewicz
2337479 v.1	19-Response of secondary standard ionisation chambers to VHEE	1	In	2019-11-01	Anna Subiel
2337580 v.1	20*-CHUV	1	In	2020-01-20	DAVIDE GAMBA
2337586 v.1	21-light yield and spectrum of Chromox screens	1	In	2020-02-27	Havard Gjersdal
2337591 v.1	22-Optical Transition Radiation Interferometry (OTRI) and Digital Micro-mirror Device (DMD)	1	In	2020-01-30	Carsten P. Welsch
2337596 v.1	23-Dosimetry control and characterisation for R2E + ESA Monitors	1	In	2020-01-31	Vanessa Wyrwoll
2337890 v.1	24-IRRAD BPM test	1	In	2020-02-03	Giuseppe Pezzullo
2337894 v.1	25-Fiber optic dosimetry	1	In	2020-02-03	Francesco Fienga
2337898 v.1	26-R2E impact of neutrons	1	In	2020-02-03	Rubén García Alía
2337902 v.1	27-radiation damage and stuck bits in SDRAMs	1	In	2020-02-03	Daniel Söderstörm
2337905 v.1	28-Yield of the Cherenkov radiation within soft X-ray	1	In	2020-02-11	Aleksandr Kubankin
2337909 v.1	29-Coherent Cherenkov diffraction radiation by Surface Plasmon Polariton	1	In	2020-02-19	Thibaut Lefevre
2337910 v.1	30-Coherent Cherenkov diffraction radiation in dielectrics	1	In	2020-02-19	Thibaut Lefevre
2337913 v.1	31-CLIC wake field monitor studies	2	In	2020-02-24	Kyrre Sjobak
2337914 v.1	32-Plasma Lens Studies	2	In	2020-02-25	Erik Adli
2337918 v.1	33-CLIC Cavity BPMs	1	In	2020-03-05	Alexey Lyapin
2337920 v.1	xx-Test of new Rad-tolerant cameras from Microcameras		In	2020-02-27	Thibaut Lefevre
2337922 v.1	xx-EOS bunch length measurement for AWAKE		In	2020-02-27	Thibaut Lefevre
2337924 v.1	xx-Impedance studies on Coherent Cherenkov radiation		In	2020-02-27	Thibaut Lefevre
2337926 v.1	xx-JUAS		In	2020-02-27	Wilfrid Farabolini
2396415 v.1	38-Machine Learning for beam imaging system	1	In	2020-07-12	Georges Trad
2396850 v.1	39-Investigation on Degradation of Irradiated EPI (epitaxial) Silicon Pad Diodes	1	In	2020-07-13	Giuseppe Pezzullo
2440179 v.1	40-Irradiation of SmartFusion 2 FPGA	1	In	2020-11-16	Mattia Rizzi
2442530 v.1	41-Test of OTR and YAG screens exposed to Rubidium vapour	1	In	2020-11-19	Jan Pucek
2446497 v.1	42-LBLM Study	1	In	2020-11-28	Belén María Salvachua

Statistics – running time and faults 2020

- 34 Weeks
- 144 Days
- No running over week-ends in 2020

- Programmed interruptions
  - Cathode rejuvenation + RF conditioning 5 days
  - Power cut 3 days
  - Hardware recommissioning after lockdown 2 days
  - Other interventions 3 days

- Main faults:
  - Vacuum 4 days
  - Klystron issues 2 days
  - Exchange beam screens 2 days
  - Laser cooling leaks 2 half days (not counted in the chart)

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jan			1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
Feb	27	28	29	30	31	1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
Mar	24	25	26	27	28	29	1
	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
Apr	30	31	1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
May	27	28	29	30	1	2	3
	4	5	6	7	8	9	10
	11	12	13	14	15	16	17
	18	19	20	21	22	23	24
	25	26	27	28	29	30	31
Jun	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
Jul	29	30	1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
Aug	27	28	29	30	31	1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30
Sep	31	1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
	21	22	23	24	25	26	27
Oct	28	29	30	1	2	3	4
	5	6	7	8	9	10	11
	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
Nov	26	27	28	29	30	31	1
	2	3	4	5	6	7	8
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	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
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	14	15	16	17	18	19	20
	21	22	23	24	25	26	27
	28	29	30	31			

running

scheduled stops

lock-down

holidays

Major faults

Statistics – beam time per activity

- 34 Weeks
- 144 Days

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jan			1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
Feb	27	28	29	30	31	1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
Mar	24	25	26	27	28	29	1
	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
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	6	7	8	9	10	11	12
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	20	21	22	23	24	25	26
May	27	28	29	30	1	2	3
	4	5	6	7	8	9	10
	11	12	13	14	15	16	17
	18	19	20	21	22	23	24
	25	26	27	28	29	30	31
Jun	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
Jul	29	30	1	2	3	4	5
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	20	21	22	23	24	25	26
Aug	27	28	29	30	31	1	2
	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30
Sep	31	1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
	21	22	23	24	25	26	27
Oct	28	29	30	1	2	3	4
	5	6	7	8	9	10	11
	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
Nov	26	27	28	29	30	31	1
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	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
Dic	30	1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
	21	22	23	24	25	26	27
	28	29	30	31			

running

scheduled stops

lock-down

holidays

Major faults

Beam days per activity

Beam Commissioning and MDs	36
Bunch Length Compression studies	10
JUAS Practical Course	2
Wake Field Monitors / Wake kicks	14
BI THz piroeletric	4
BI Electro Optical Sampler	16
BI AWAKE Cherenkov BPMs	8
BI Cherenkov Plasmonics	8
BI Optical Fiber BLMs	7
BI CLIC BPMs	1
Dosimetry	11
IRRAD u-BPMs	12
mask irradiation tests	2
LHCb det irradiation	2
Optic fiber - machine learning	1
R2E (Diodes, PDD, FPGA)	7
AWAKE screen in rubidium	3
Total	**144**

Beam days per "user"

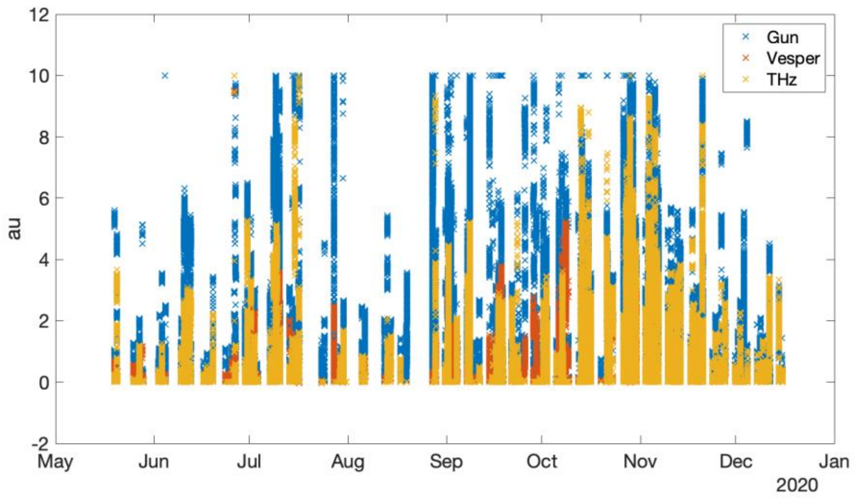
CLIC	15
AWAKE	11
Other BI	35
Medical	13
R2E and other irrad	10
IRRAD u-BPMs	12
Bunch Compression	10
JUAS	2
Total	**108**

Statistics from NXCALS recorded data

Assumptions

D. Gamba

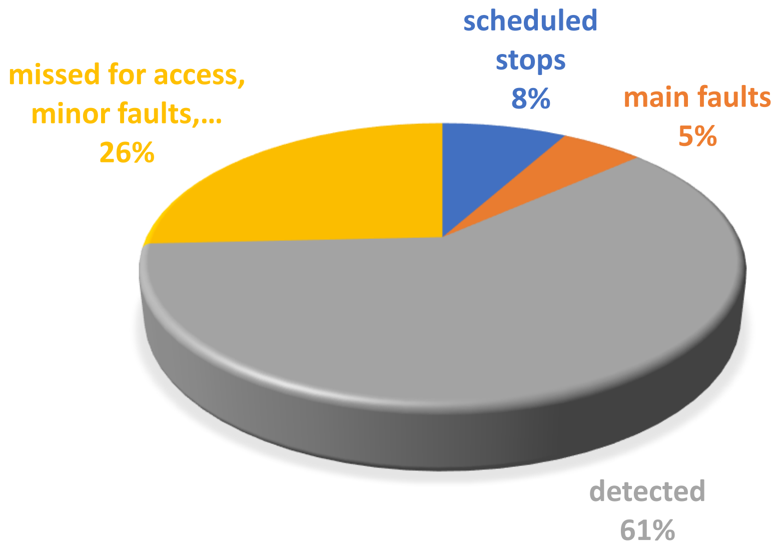
- Neglecting restart time in February (and therefore JUAS)
  - from f18 May 2020 (first day of people back on site after lockdown)
  - to 15 December 2020 (last day of operation)
- Assuming 8 hours operation and 1 “shot” (or burst in case of higher repetition rate) every 1.2 seconds, one obtains:
  - 24’000 shots/working day
  - 149 working days
    (212 total, 60 weekend days, 3 days vacation),
    i.e. 3’576’000 possible shots in 2020
- Looking at data of:
  - 3 BCTs (Gun, VESPER, THz);
  - 3 main RF signal (Gun, Buncher, Acc. Structures)
- Definitions:
  - Beam ON: some charge detected in Gun BCT and RF ON.
  - Beam on dump: some charge detected at VESPER or THz BCTs and Beam ON.

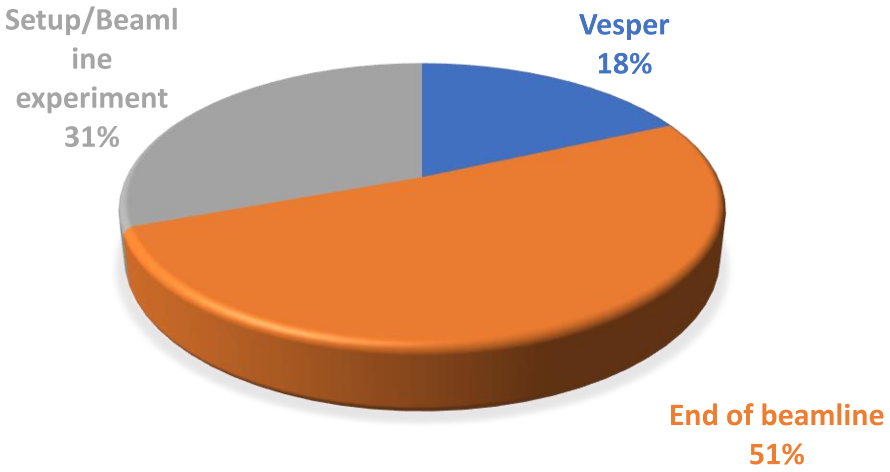


General statistics of usage

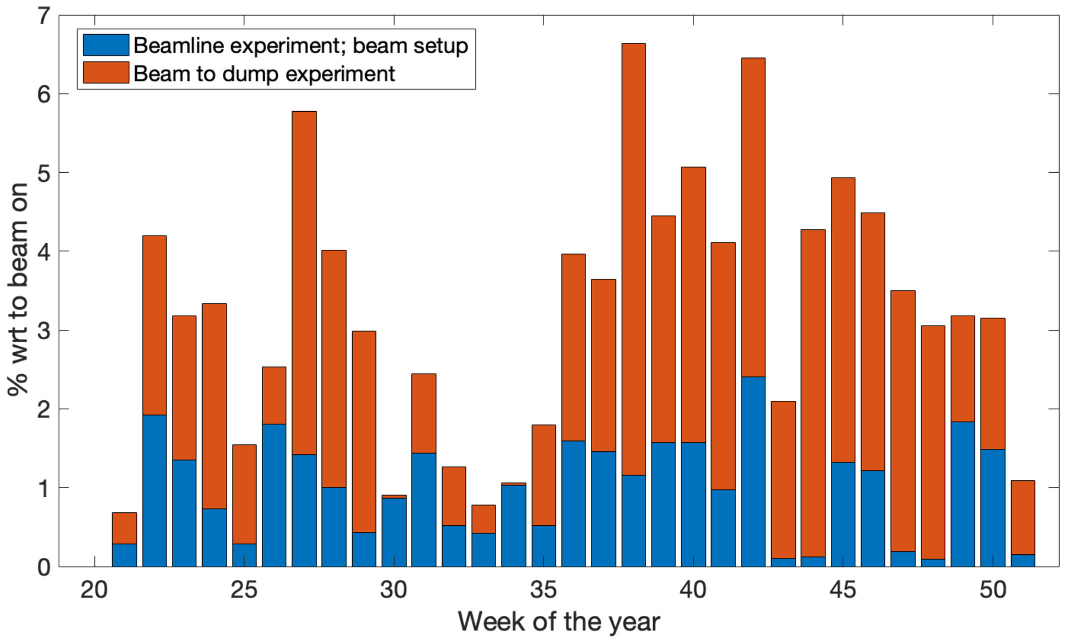
D. Gamba

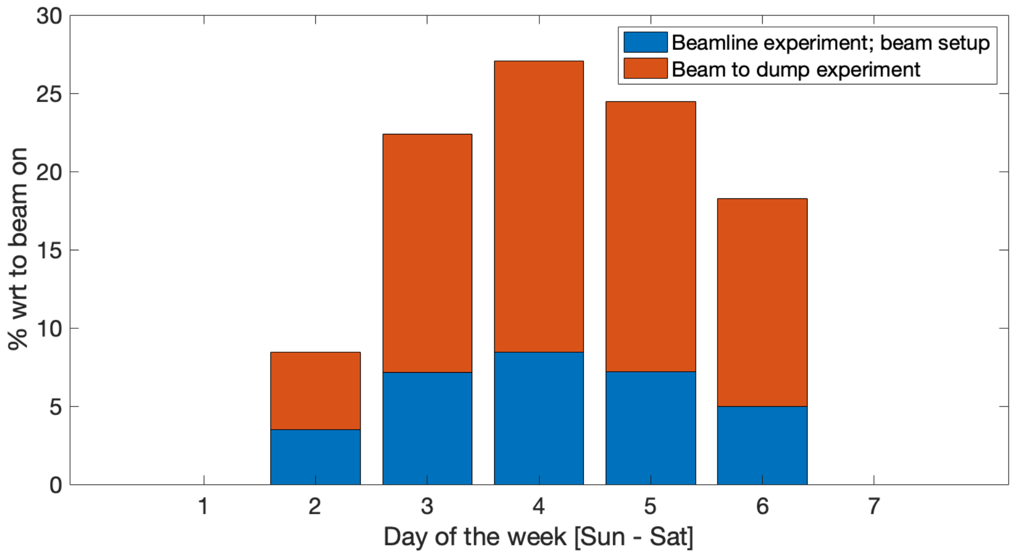
- 2’175’372 detected shots (61% facility beam availability wrt to ~3.6M possible shots)
- 69% beam availability if scheduled stops are subtracted
- 1’508’652 shots on dump:
  - 396’812 shots on VESPER
  - 1’111’840 shots on THz
- The other shots have been used for machine setup, destructive beam measurements or to perform experiments in the beamline (e.g. CLIC cavity BPMs, EOS, …)

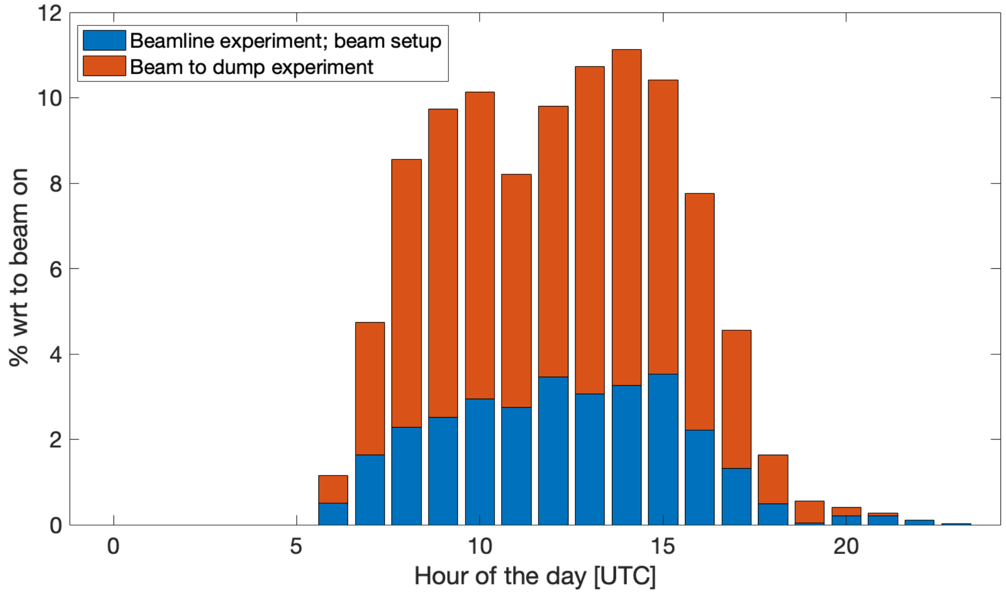




Use of the facility over the year, weekly, daily







D. Gamba

1st Review Follow-up

See previous slides on beam time allocation and beam statistics

1. *Track beam usage, beam availability, and fault rate with the operational log-book and follow strictly the procedure for experiment registration and beam time allocation, with the goal of producing statistics of machine availability and of beam time usage by the different experiments.*

   The recommendation was followed up exploring the possibility to implement a system for fault logging. Since end of 2019 CLEAR uses the Accelerator Fault System to track faults, and had integrated it with the logbook, but it's not fully used - not for minor faults - due to the overhead to operation. A more rigorous documentation of faults in the operational e-logbook than previously done was however implemented; main faults are documented in the logbook, and since a system to record accelerator signals has been implemented as well, this enables us to get more precise data on beam availability and correlate these data to main fault statistics. Most beam parameters are in fact logged on NXCALS, and we can extract the information of how much time we were running over the last couple of years or so, and where the beam was going along the beamline. We can get also data on beam time usage per user, since all performed experiments are now documented by 1) The corresponding beam time request, 2) The online schedule on the web site and the corresponding logging in the e-logbook, 3) Weekly reports on operation (from mid 2019), and 4) for most of them post-experiment internal reports and eventually publications.

1st Review Follow-up

See following talks from Steinar and Edda, and my last presentation on future running

2. *Produce a technical report on the proposed upgrade options including motivation, design, resource-loaded schedules, commissioning plans and operation staffing and submit it for approval to the ATS management. The budget should clearly identify the contributions from CLEAR operation, from CLIC, and from external sources. This should be completed before any significant additional work is carried out for any particular option.*

The proposed upgrade options were postponed for further consideration due to lack of resources and considering that – as pointed out during the review – "most of the benefits will be exploited only if the operation of the facility is extended beyond 2020". In the meantime the AWAKE project included the joint development of an advanced source as part of the baseline for its 2nd run, as presented in AWAKE Collaboration Meetings:
https://indico.cern.ch/event/841011/contributions/3529426/attachments/1894890/3125846/AWAKE-08-2019.pdf
and
https://indico.cern.ch/event/954169/contributions/4011621/attachments/2104595/3539083/AwakeCollabMeetSept2020electronsource.pdf
Such development is now jointly pursued and funded by the AWAKE and CLIC project. The possibility of using the source prototype in CLEAR for a few years is still open – and it's now fully compatible with its final move to AWAKE in 2026 according to the new AWAKE Run2 schedule. In such a case, only the resources needed for the relocation (to be evaluated) will have to be covered within the CLEAR budget. The installation of a second (passive) beam line in 2022, re-using existing CTF3 equipment, is also under consideration and will be further pursued if the extended run of CLEAR is confirmed. Some preliminary study will be presented at the review.

1st Review Follow-up

See last part of this talk, and documentation on the CLEAR web site

3. *Increase the visibility of the facility and its experiments with a wider use of the CERN communication channels, and continue keeping track of publications making sure that CERN and CLEAR are properly recognized.*

   A number of initiatives were taken along these lines, including articles on the CERN Courier, Accelerating News and other CERN or accelerator community related media, presentations at Seminars/Workshops and, e.g., the organization of a remote workshop on one of the main areas of application, VHEE/FLASH radiation therapy, in autumn 2020. Several press releases, from CERN or collaborating institutes, dealing with results obtained in CLEAR has been released. International visibility and recognition of CLEAR as a CERN based facility has clearly grown by a large amount, as also demonstrated by the many beam time requests received from communities not initially directly linked to the facility. A full list of CLEAR-related publications is maintained, including newsletter articles like the ones on CERN Courier and press releases, and can be found on the CLEAR website: (https://clear.cern/content/publications)

1st Review Follow-up

4. Not fully explored, linked to possible upgrades and future directions

One of the main reasons – impedance studies with beam – not currently pursued mainly due to resources

5. See also following talks

4. *Study the possibility of adapting the CLEAR electron beam parameters to be closer to their high energy, proton equivalents, in particular in terms of bunch length (~100ps), bunch charge (~30pC) and bunch structure (25ns).*

An initial exploration was done. Bunch charges around 30 pC (or lower) has been experimentally achieved (diagnostics is limited to about 10 pC/bunch by intrinsic resolution of the measurement system – 10 pC bunches have been produced and used in experiments routinely). However, a bunch length of 100 ps is beyond the present performances of the beam line, due to the corresponding phase extension in the 3 GHz accelerating bucket and subsequent energy spread. In principle, a secondary beam line with a high momentum compaction dog-leg can achieve similar bunch lengths, but the present hypothesis for an additional beam line is for a low momentum compaction one (simpler, better footprint, lower cost). The maximum bunch length obtainable will be quantified within the current study. The 25 ns bunch spacing is also not feasible with the present installation. It will be possible (for only two bunches) with a second source.

5. *For future experiments, evaluate the impact on performance and resources of carrying out the measurements at other suitable facilities outside of CERN.*

The possibility of performing an experiment elsewhere is routinely considered during the preliminary discussions with the users, before or after receiving a beam time requests. In general other (known) facilities don't present advantages in terms of performance and/or do not grant access to the experimenters. A particular case is the one of CERN groups, for whom the closeness and availability of CLEAR represents a decisive advantage.

VHEE at CERN – Background & Motivation

- The idea of investigating the use of very high-energy electron (VHEE) beams (50-250 MeV) for RT recently gained interest, since electrons at these energies can travel deep into the patient.
- Potential advantages:
  - Depth – dose profile for electrons better than the quasi-exponential decay given by X-rays
  - Charged particles like electrons may be focused and steered in ways that are not possible with X-rays
  - Electron beams rather unsensitive to tissue inhomogeneities
  - Electron accelerators comparatively more compact, simpler and cheaper than proton/ion machines
- This last advantage is now especially true given the recent advancements on high-gradient acceleration, e.g. X-band CLIC technology.
- Ultra-high dose rate (above 100 Gy/s) radiation delivery, termed FLASH radiotherapy, showed normal tissue sparing capabilities, without compromising tumor control. Electron linacs can relatively easily reach the high beam currents needed for FLASH treatment of large fields.

→ Exploit CERN expertise in accelerators, especially the one on high-gradient electron machines developed by the CLIC study. The CLEAR user facility offers as well a unique opportunity for experimental VHEE and FLASH studies with a high-current 200 MeV e- beam.

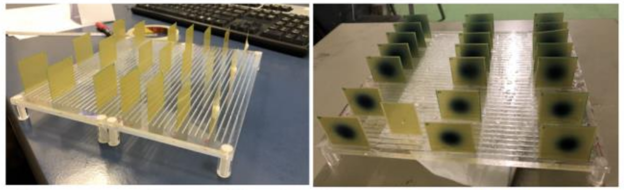
VHEE/FLASH activities in CLEAR

Calibration of operational medical dosimeters – nonlinear effects with high-dose short pulses

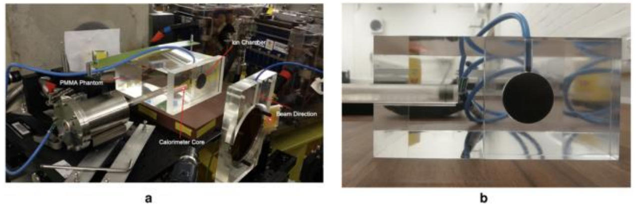
Verification of FLASH effect using biological dosimeters

Experimental verification of dose deposition profiles in water phantoms

Demonstration of "Bragg-like peak" deposition with focused beams



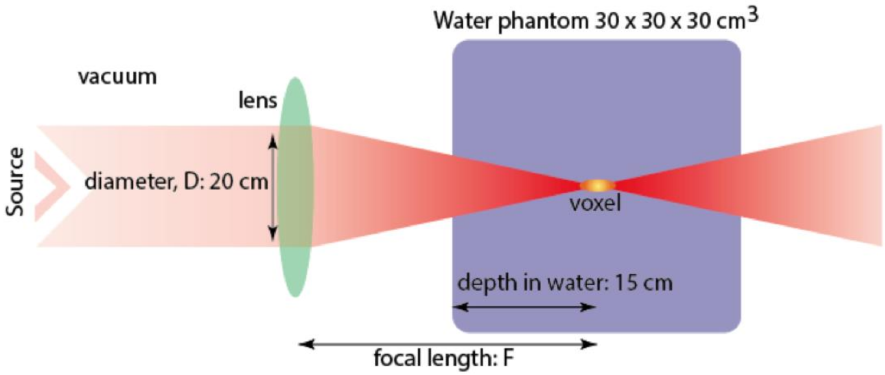
Films set-up for profile depth dose, CHUV Lausanne
(M.C. Vozenin, C. Bailat, R. Moeckli et al.)



Calorimeter and ROOS chamber, Nat. Phys. Lab. UK
(A. Subiel et al.)

High dose rate dosimetry

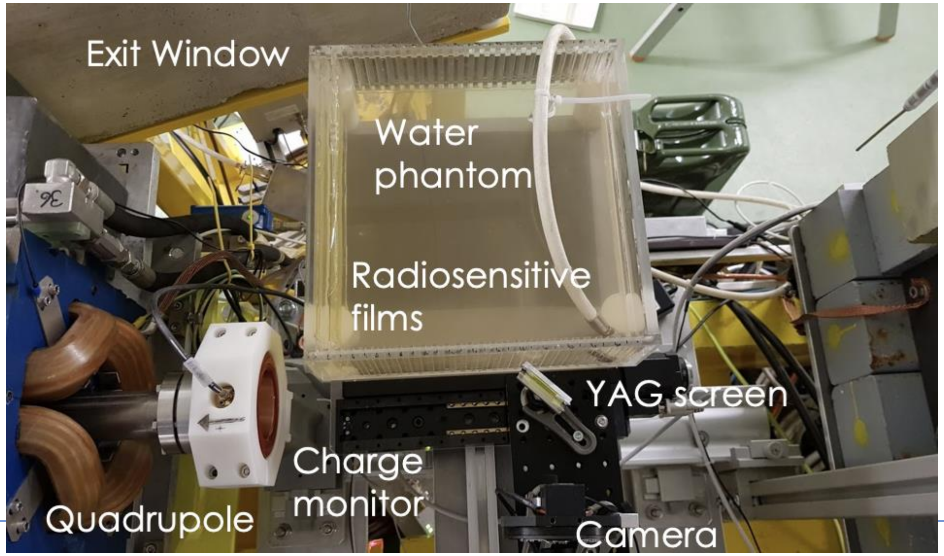
Advance Markus chambers and SRS Array, Oldenburg University and PTW
(B. Poppe, D. Poppinga et al.)



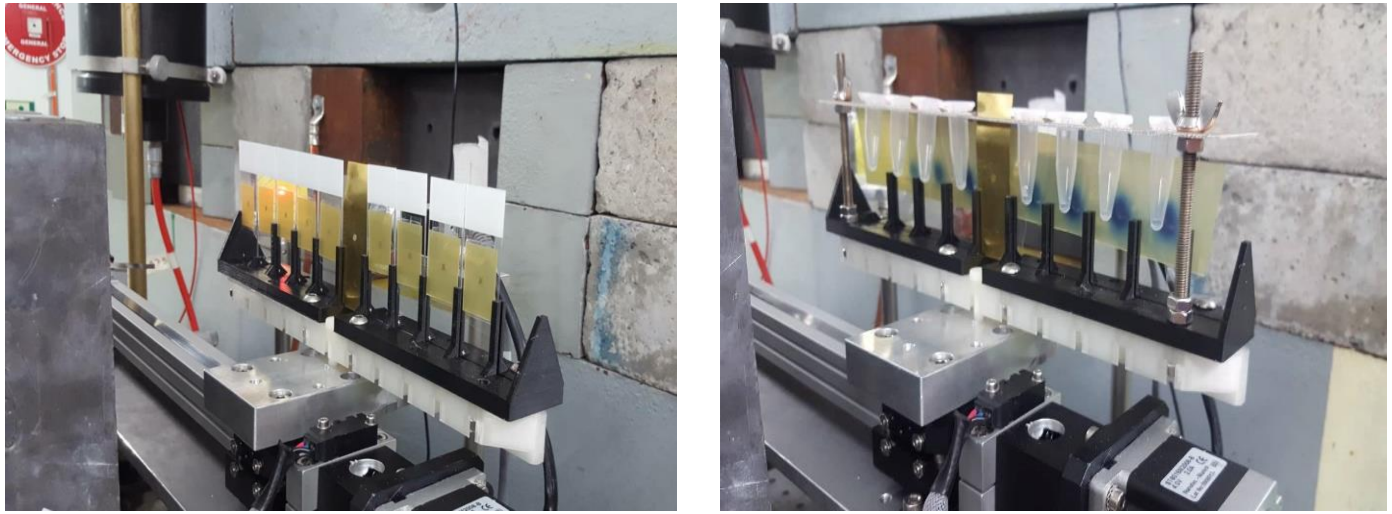
Aim:

Focus the beam on the tumour to minimize the dose on the nearby healthy tissues

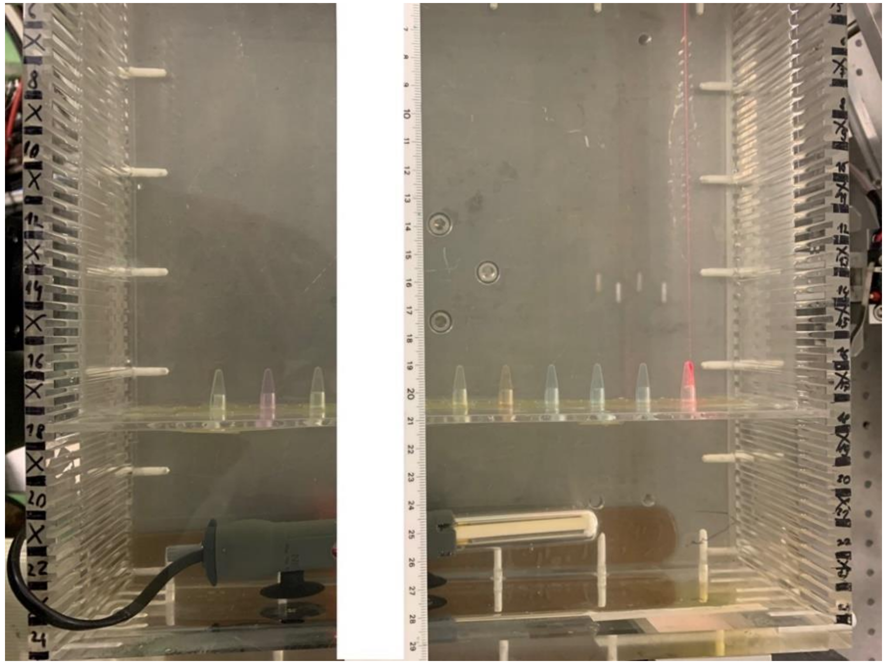
Strathclyde and Manchester



Biological effects of high dose rates



Left: dry plasmid samples on glass microscope slides.
Right: wet plasmid samples in Eppendorf tubes.
EBT-XD film placed behind samples, Manchester University
(K. Small, R. Jones et al.)



Set-up in the water tank. Zebra fish eggs, alanine pellets, gafchromic films,
CHUV Lausanne
(M.C. Vozenin, C. Bailat, R. Moeckli et al.)

VHEE in CLEAR – References

Some recent radiotherapy-related publications based on CLEAR experiments

- **A. Lagdza**, R. Jones et al., Influence of heterogeneous media on Very High Energy Electron (VHEE) dose penetration and a Monte Carlo-based comparison with existing radiotherapy modalities, Nuclear Inst. and Methods in Physics Research, B, 482 (2020) 70-81.
- **K. Small**, R. Jones et al., Evaluating Very High Energy Electron RBE from nanodosimetric pBR322 plasmid DNA damage, Nature Scientific Reports, Nature Sci. Rep. 11, 3341 (2021).
- **M. McManus**, A. Subiel, The challenge of ionisation chamber dosimetry in ultra-short pulsed high dose-rate Very High Energy Electron beams, Nature Scientific Reports (2020) 10-9089.
- **D. Poppinga** et al., VHEE beam dosimetry at CERN Linear Electron Accelerator for Research under ultra-high dose rate conditions, 2021 Biomed. Phys. Eng. Express 7 015012.
- **K. Kokurewicz**, E. Brunetti, A. Curcio et al., An experimental study of the dose distribution of focused very high energy electron (VHEE) beams for radiotherapy, Nature Commun. Phys. 4, 33 (2021).

CLEAR scientific output

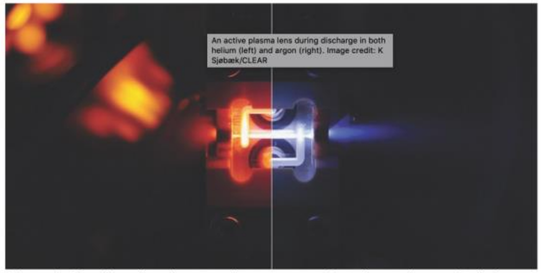
- 24 scientific papers published
  - 14 on peer-reviewed Journals, 10 in Conference Proceedings

- Many oral presentations/posters in Conferences and Workshops
- Full documentation in: https://clear.cern/content/publications

NEWS

Plasma lenses promise smaller accelerators

30 November 2018



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

ELSEVIER

Physics Letters A

Volume 391, 5 March 2021, 127135

Diffractive shadowing of coherent polarization radiation

A. Curcio [a], M. Bergamaschi [a], R. Corsini [a], D. Gamba [a], W. Farabolini [a], R. Kieffer [a], T. Lefevre [a], S. Mazzoni [a], V. Dolci [b], M. Petrarca [b], P. Karataev [c], K. Lekomtsev [d, c], S. Lupi [e], A. Potylitsyn [f]

Noninvasive bunch length measurements exploiting Cherenkov diffraction radiation

A. Curcio, M. Bergamaschi, R. Corsini, W. Farabolini, D. Gamba, L. Garolfi, R. Kieffer, T. Lefevre, S. Mazzoni, K. Fedorov, J. Gardelle, A. Gilardi, P. Karataev, K. Lekomtsev, T. Pacey, Y. Saveliev, A. Potylitsyn, and E. Senes

Phys. Rev. Accel. Beams **23**, 022802 – Published 10 February 2020

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

Education and Training

- PhD Thesis

  with experimental work in CLEAR

Agnese Lagzda
University of Manchester
2015-2019
Radiotherapy studies with very high energy electrons (VHEE) (50-250 MeV)
Supervisor: R.M. Jones
✓

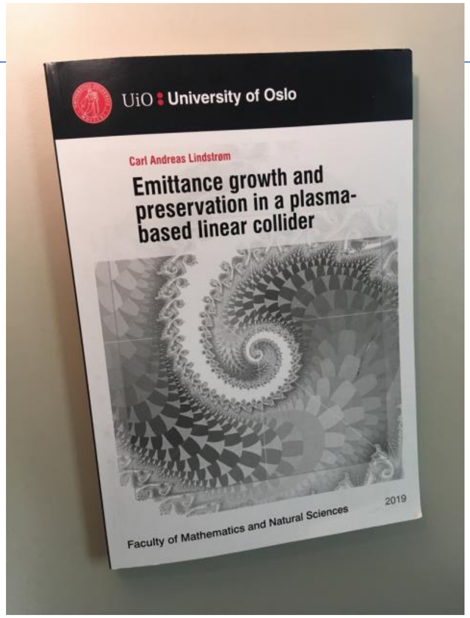
Carl A. Lindstroem
University of Oslo (Norway)
2015-2018
Emittance Growth and Preservation in a plasma-based linear collider
Supervisor: E. Adli
✓

Maris Tali
University of Jyväskylä (Finland)
2015-2019
Single Event Radiation Effects in hardened and state-of-the-art components for space and high-energy accelerator applications
Supervisor: A. Virtanen
✓

Antonio Gilardi
Università Federico II Napoli (Italy)
2018-2020
Measurements of impedance and wake-field with beam in linear electron accelerators: a case study at the CLEAR user facility
Supervisor: P. Arpaia
✓

Eugenio Senes
Oxford University (UK)
2018-2020
Measuring the beam position of a low intensity picosecond long electron bunch in the presence of a high intensity nanosecond long Proton bunch
Supervisor: P. Burrows
✓

Luke Aidan Dyks
University of Oxford
Novel acceleration technique studies in the CLEAR user Facility and its potential future upgrades
Supervisor: P. Burrows



Previous Ph.D. Thesis with experimental measurements on the CALIFES beam:

Rui Pan
University of Dundee
Bunch length monitoring using electro-optical spectral decoding
Supervisor: A. Gillespie

Michele Bergamaschi
RHUL
Emittance measurements for linear colliders using a combined OTR/ODR monitors
Supervisor: P. Karataev

Joint Universities Accelerator School juas

JUAS Practical Work, and also…

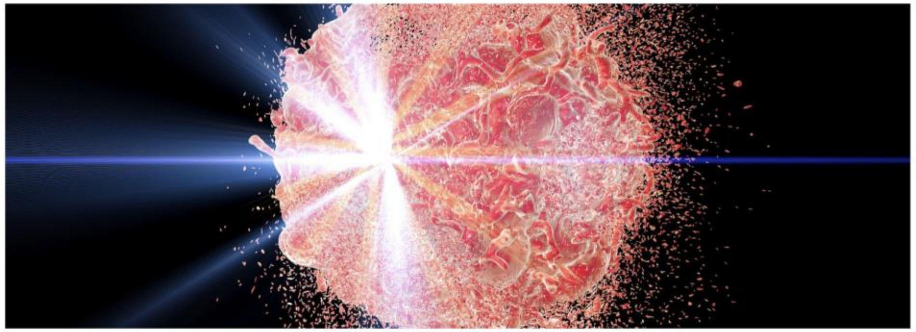
- Several Master Thesis
- Trainees and summer students

Recent Press Statements

University of Strathclyde Glasgow

News

High energy radiotherapy could 'paint' tumours to avoid harming healthy tissue



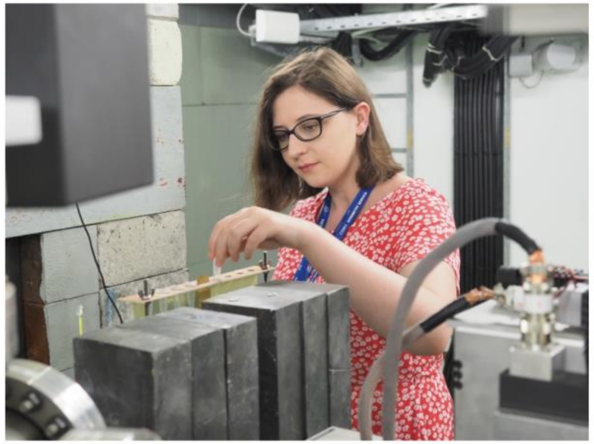
23 February 2021

A radiotherapy technique which 'paints' tumours by targeting them precisely, and avoiding healthy tissue, has been devised in research led by the University of Strathclyde.

Researchers used a magnetic lens to focus a Very High Electron Energy (VHEE) beam to a zone of a few millimetres. Concentrating the radiation into a small volume of high dose will enable it to be rapidly scanned across a tumour, while controlling its intensity.

The study was undertaken at the CERN Linear Electron Accelerator for Research (CLEAR) facility, and involved researchers at CERN, the University of Oxford, the National Physical Laboratory, the John Adams Institute for Accelerator Science, the University of Napoli Federico II, the University of Oslo and Saclay Nuclear Research Centre in France. It has been published in Nature Communications Physics.

MANCHESTER 1824 The University of Manchester



24 February 2021

Critical step forward for radiotherapy with a new method to treat cancer

Following experiments carried out by The University of Manchester, at CERN's CLEAR 250 MeV facility and at Daresbury Laboratory, the findings show Very High Energy Electron (VHEE) beams are effective at causing DNA damage, important for killing cancer cells, for radiation given over the course of several minutes and for the rapidly evolving field of sub-second FLASH radiation.

The collaborative research team have published their findings in Nature's journal, *Scientific Reports*,

Thanks for your attention!

A table…

Weeks of operation	55	19 in 2017, 36 in 2018
Days with beam (estimated)	300	
Hours of operation (estimated)	2500-3500	
Number of experiments	19	completed (including 9 extensions)
Experiment requests received	14	including 3 planned and 1 pending
External institutes participating	26	from 9 countries
Number of external users (estimated)	30 - 40	
Scientific papers published	14	6 peer-reviewed, 8 conf. proceedings
PhD Thesis	6	

CLEAR Review
Thursday 7 February 2019

Report from the Review Committee

Weeks of operation 127 > 38 in 2019, 34 in 2020

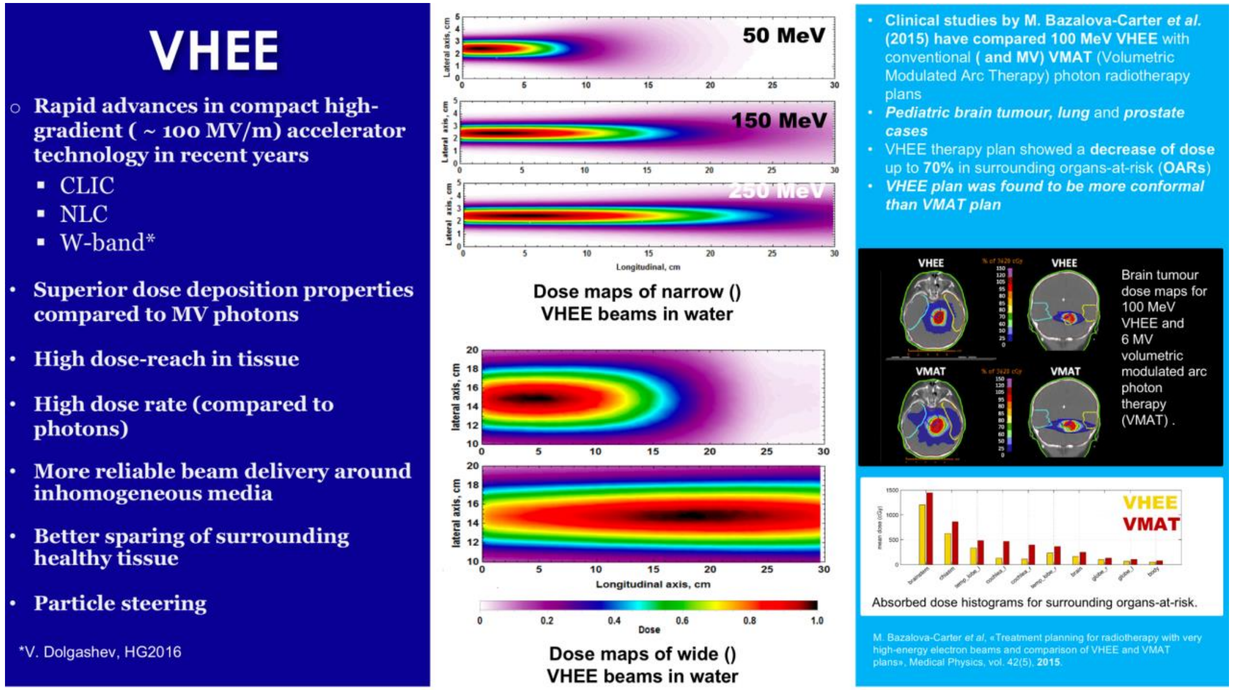
Days with beam New estimation (based on 2020 recorded data): about 540

In 2020 about 800 hours of beam time, around 1000 hours of operation including access, etc.
Hours of operation New estimation 3000 hours of beam time, 3700 hours of operation

Experiments completed 58 = 19 + 20 + 19 (incl. extensions)
Requests until 2020 42 (plus 22 extensions) = 64 (6 requests not covered in 2020)

Scientific papers published 24 (14 peer-reviewed, 10 conf. proceedings)
PhD thesis 5 out of 6 completed (the last one due for April), one more ongoing, one to start in September…

VHEE in CLEAR, an outline



Manchester University: A. Lagzda, R. Jones and other
- Project to characterize VHEE irradiation on radiosensitive films

Initial interest: Manchester Univ. *(A. Langzda, R. Jones)*

- Three measurements campaigns (2017-2018)

Further requests from:

Nat. Phys. Lab. UK *(A. Subiel et al.)*

- Two measurement campaigns (end 2018, spring 2019)

Strathclyde University *(K. Kokurewicz et al.)*

- One campaign completed (end 2018)

Oldenburg University and PTW *(B. Poppe, D. Poppinga et al.)*

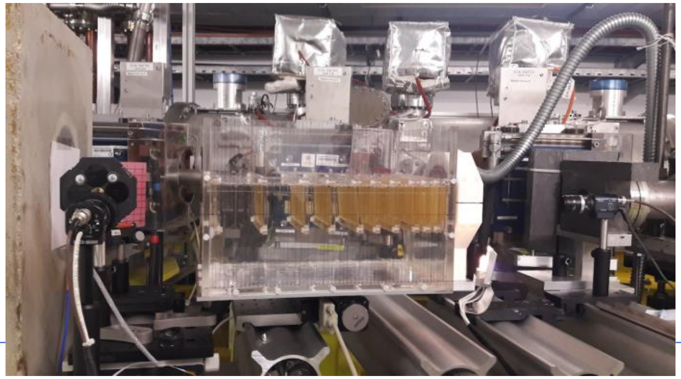
- Two campaigns completed (end 2018, September 2019)

CHUV Lausanne *(M.C. Vozenin, C. Bailat, R. Moeckli et al.)*

- Preliminary tests (end 2018, spring 2019)

Activities:

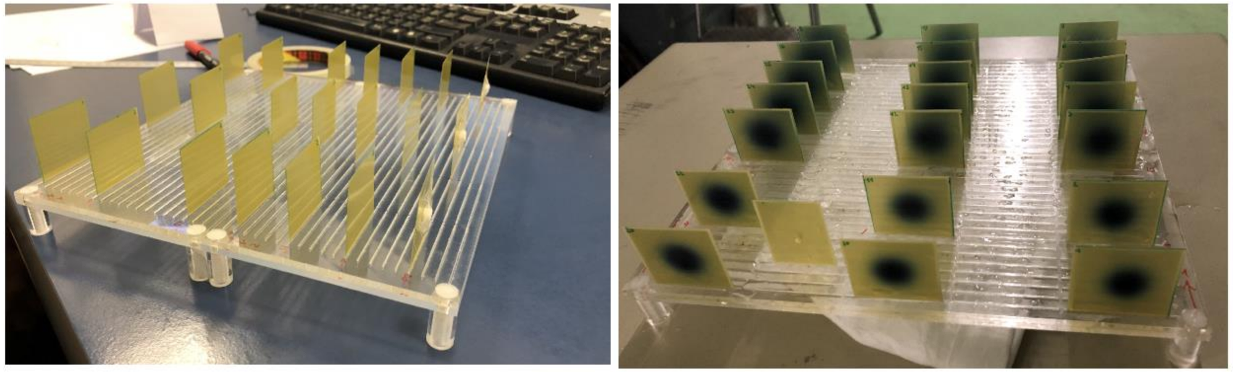
- Experimental verification of dose deposition profiles in water phantoms
- Calibration of operational medical dosimeters – nonlinear effects with short pulses
- Demonstration of "Bragg-like peak" deposition with focused beams



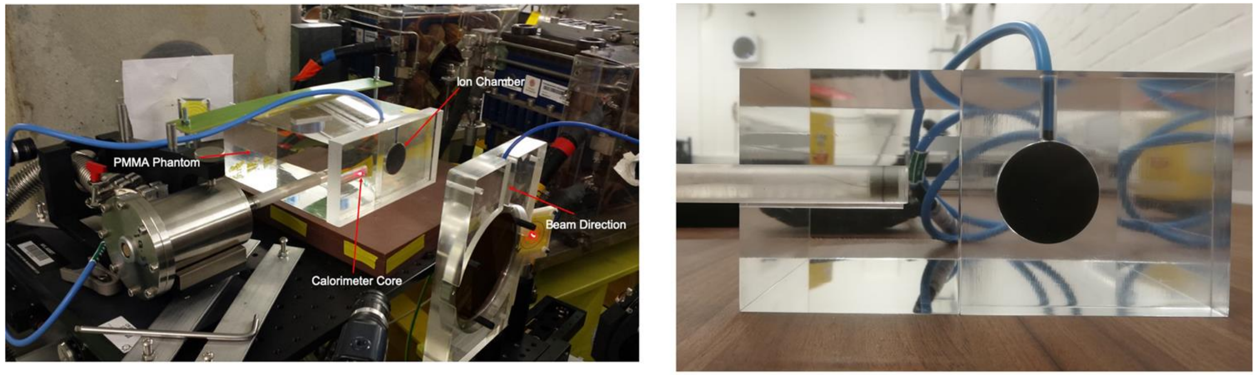
Relative Insensitivity to Inhomogeneities on Very High Energy Electron Dose Distributions
IPAC 2017 Proceedings • May 19, 2017
Agnese Lagzda, R.M. Jones, D. Angal-Kalinin, J. Jones, A. Aitkenhead, K. Kirkby, R. MacKay, M. van Herk, W. Farabolini, S. Zeeshan

Very-High Energy Electron (VHEE) Studies at CERN's CLEAR User Facility
IPAC 2018 Proceedings • 2018
Agnese Lagzda, R.M. Jones, A. Aitkenhead, K. Kirkby, R. MacKay, M. van Herk, R. Corsini, W. Farabolini

High dose rate dosimetry



Films set-up for profile depth dose, CHUV Lausanne
(M.C. Vozenin, C. Bailat, R. Moeckli et al.)

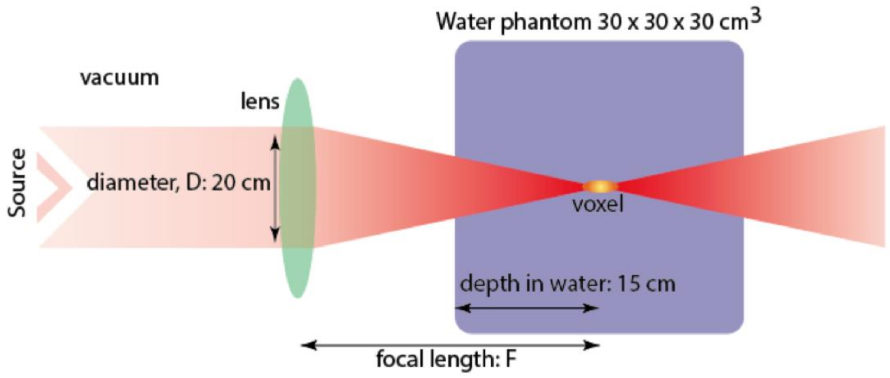


a b

Calorimeter and ROOS chamber, Nat. Phys. Lab. UK
(A. Subiel et al.)

Advance Markus chambers and SRS Array, Oldenburg University and PTW
(B. Poppe, D. Poppinga et al.)

VHEE strong focusing

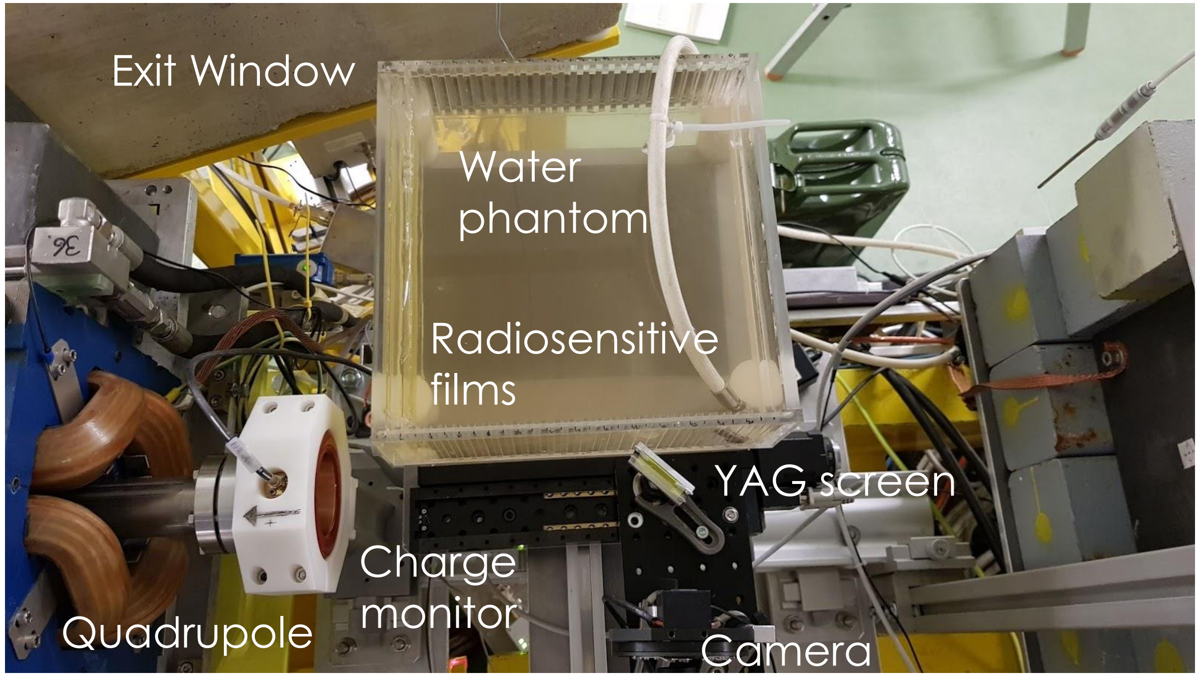


Aim:

Focus the beam on the tumour to minimize the dose on the nearby healthy tissues

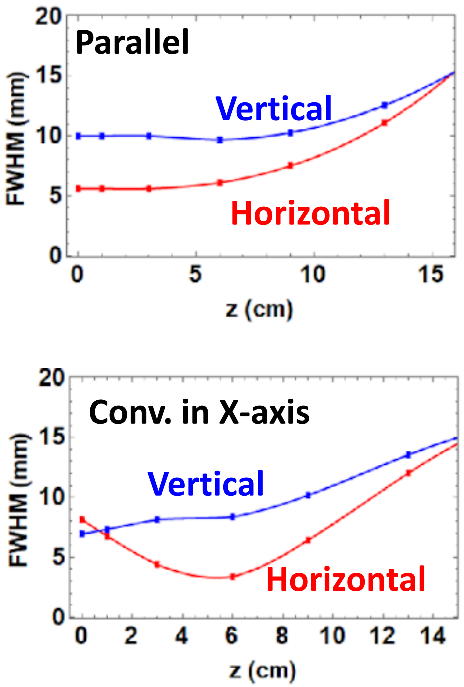
- Main activity in October 2019

- Two groups (Strathclyde and Manchester) Two full week of testing (plus installation and dismounting)
- Required rearrangement of beamline, with a temporary dump.

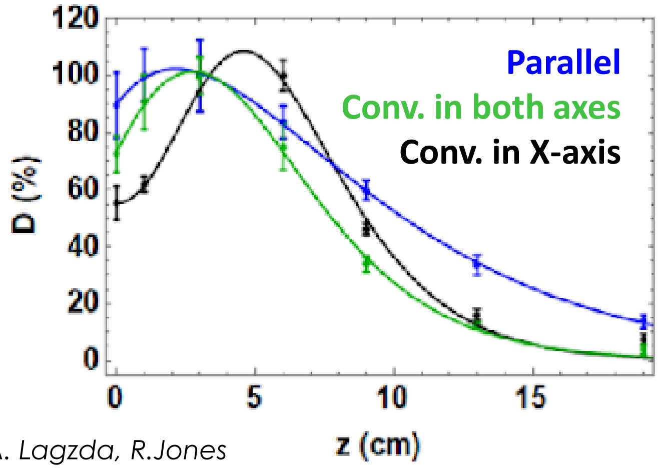


W. Farabolini, E. Senes, K. Kokurevicz

Beam size



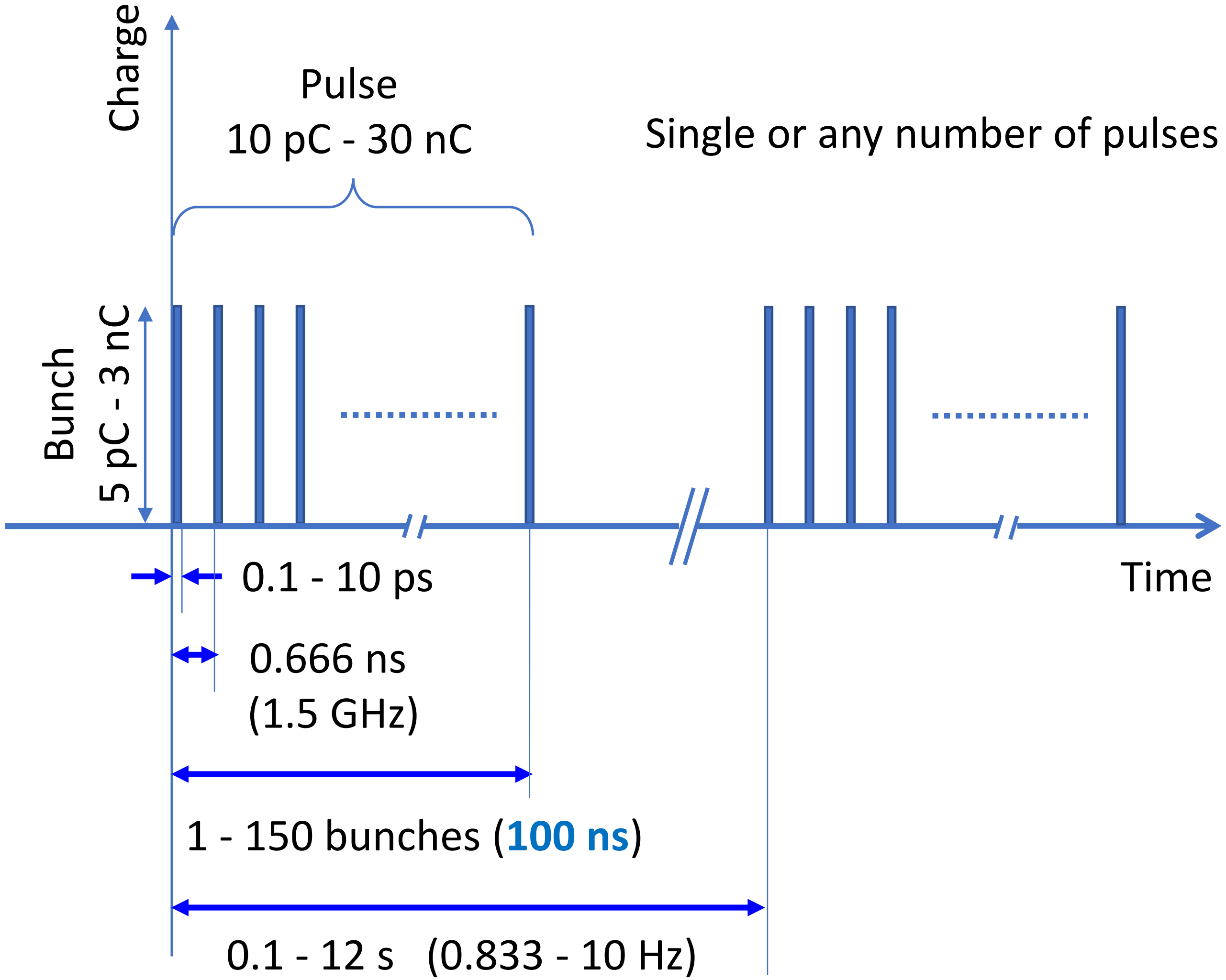
Dose deposition



A. Lagzda, R.Jones

CLEAR Beam Parameters and time structure

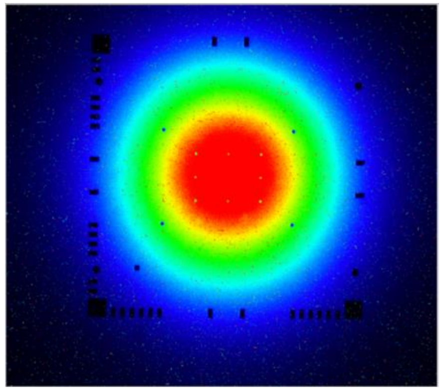
Beam parameter	Range
Energy	**60 – 220 MeV**
Energy Spread	< 0.2 % rms (< 1 MeV FWHM)
Bunch Length	0.1 ps – 10 ps rms
Bunch Charge	5 pC – 3 nC
Number of bunches per pulse	1 to ~150
Maximum total pulse charge	**30 nC**
Normalized emittances	3 μm to 30 μm (bunch charge dependent)
Repetition rate	0.8 to 10 Hz
Bunch spacing	1.5 GHz (from Laser)

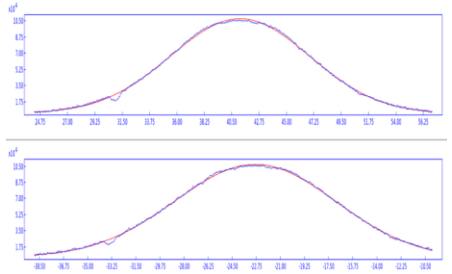


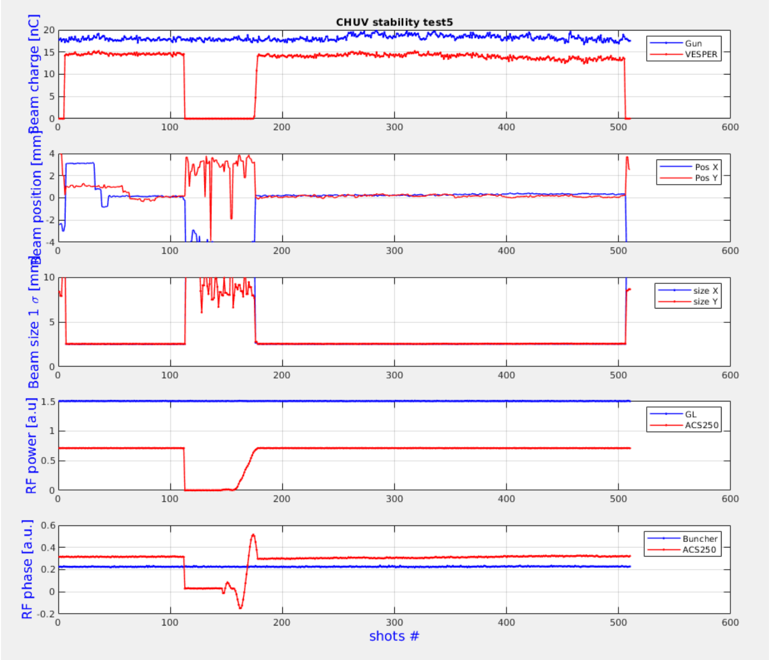
CLEAR team provided services

- Support users equipment installation (set-up, pulling cables, electronic shelter, radio-protection)
- Prepare and ensure the beam delivery (at least one operator is always present)
- Monitor the beam characteristics (charge, position, dimension, energy, bunch length) and provide data-log files
- Participate to the data processing, analysis and papers writing
- All of this free of charge for academic research activities

Large beam field size ($12 \times 12\ mm^2$ FWHM) at the end of the in-air test stand







Beam monitoring panel

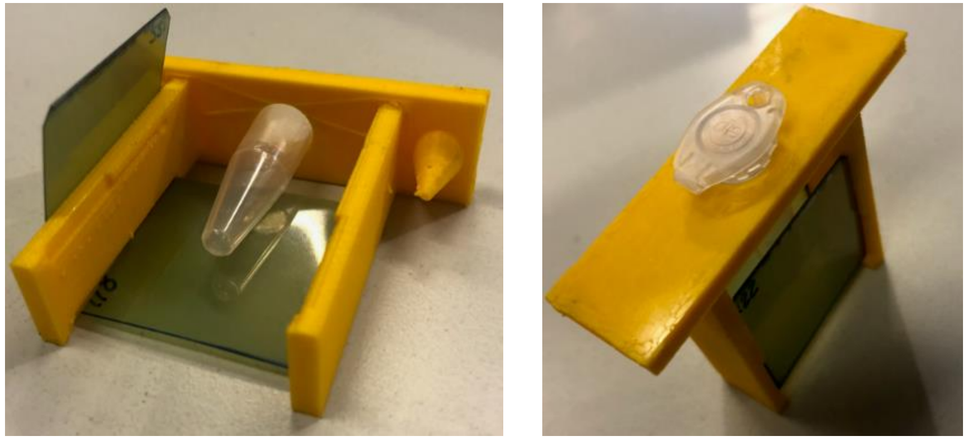
Development of equipment on users requirement

Eppendorf and films holder for multiple irradiations in a water tank

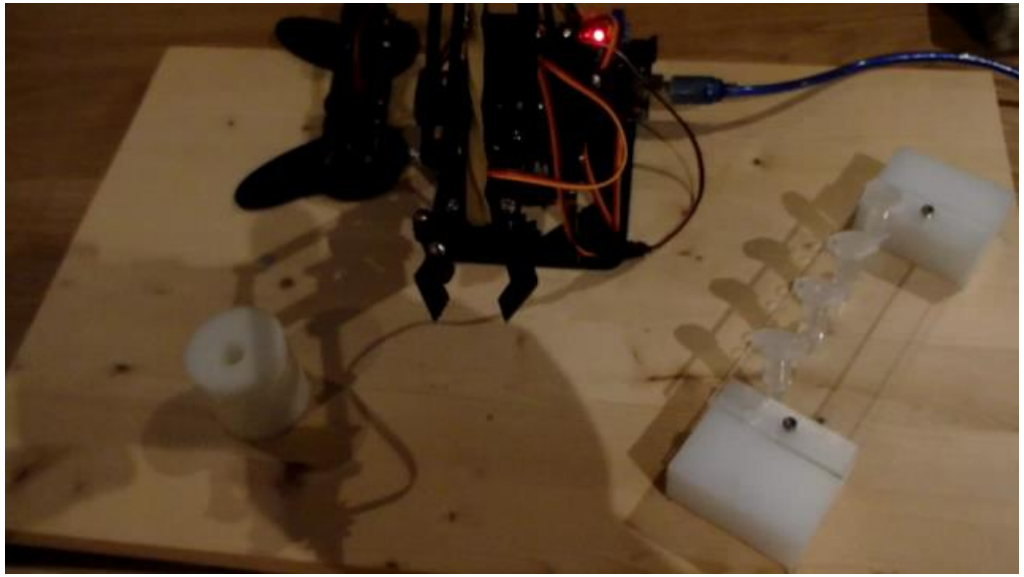
Motorized table for water phantom displacement

Gafchromic films and alanine pellets dispenser using a plastic tape conveyor

Some equipment projects



Holder for Eppendorf and 2 films



Cheap robotic arm test

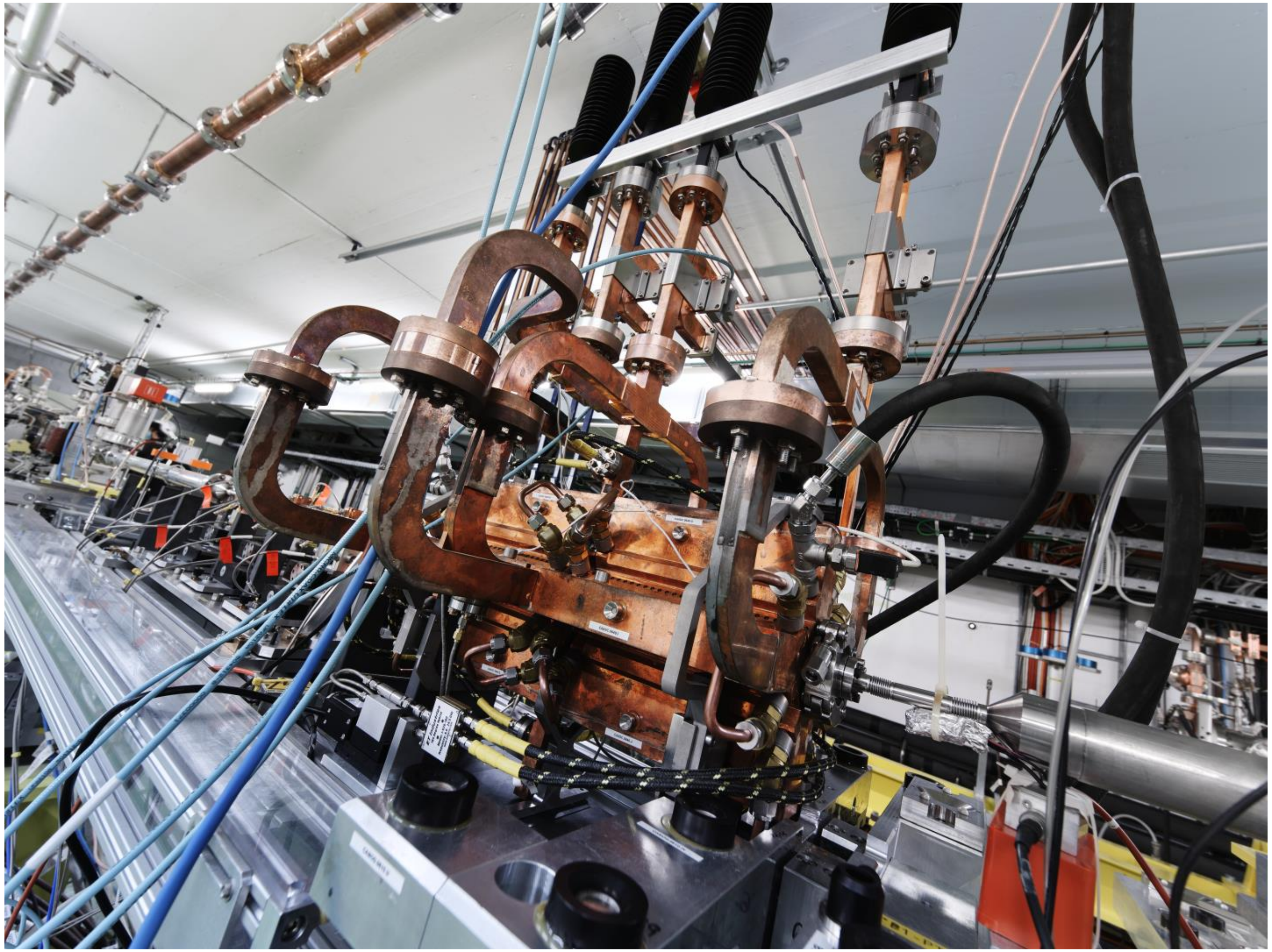
CLEAR has just been granted 10 keuros to develop a robotic arm for samples handling (grant to A. Gilardi).

CLIC X-band high-gradient technology

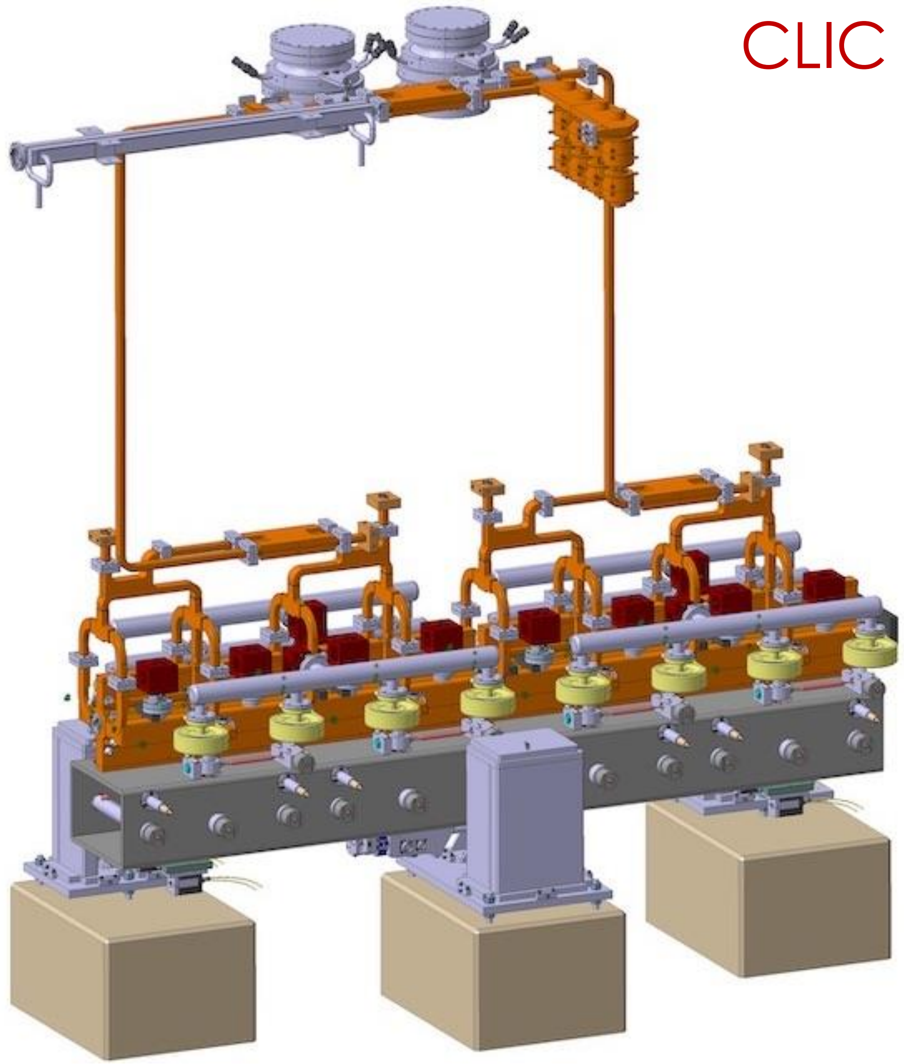
- RF systems for high-gradient, high-current electron linacs have been developed in the context of CLIC, a possible future TeV-range linear collider for the post-LHC era.

- To carry out the technology development for CLIC, we have nurtured a broad collaboration, including groups working on many different applications.

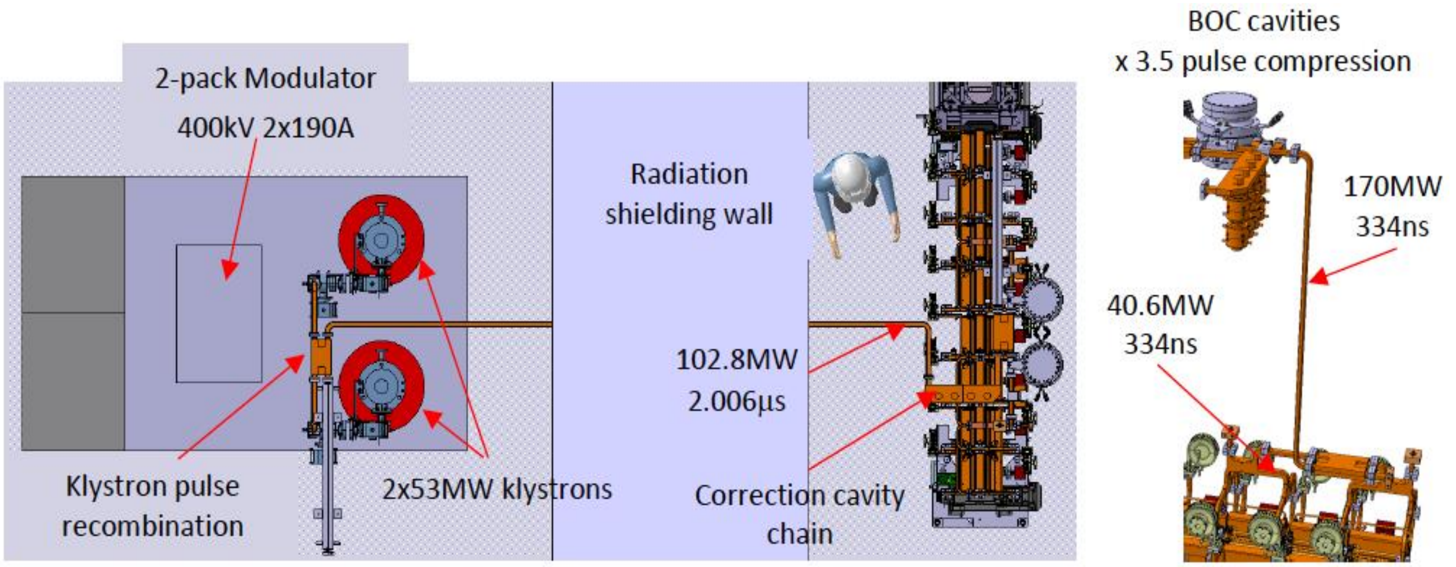
- This electron linac technology can make an important contribution to VHEE and FLASH facilities.



CLIC X-band high-gradient technology - Module



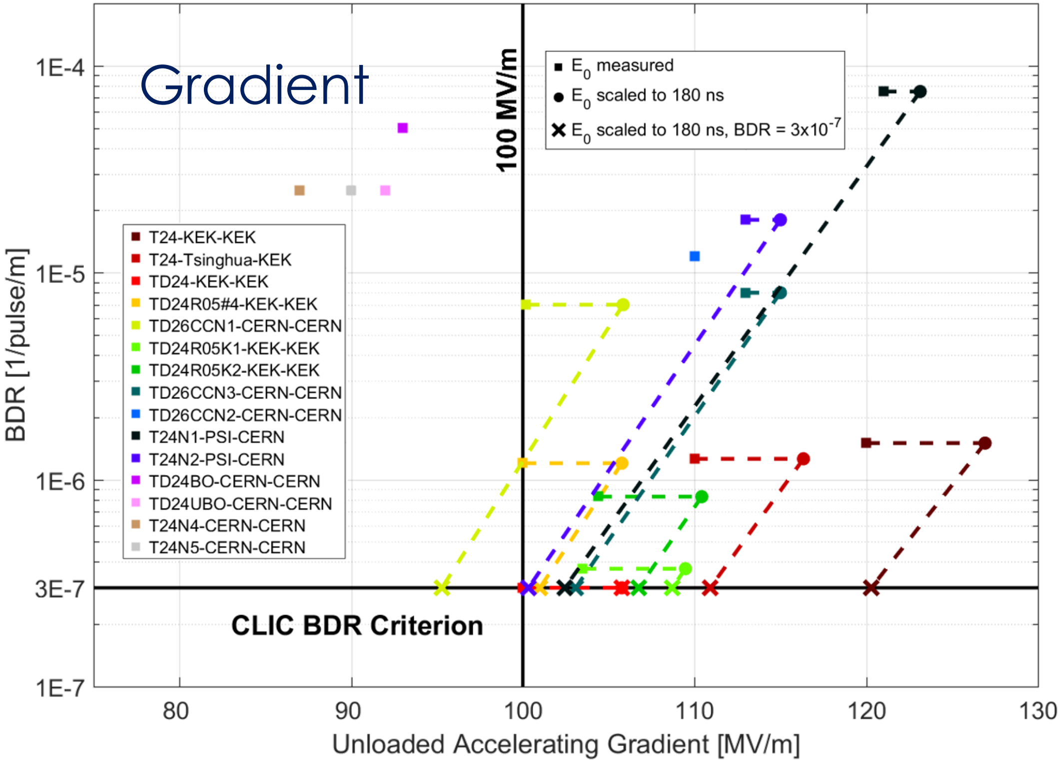
CLIC klystron-based module

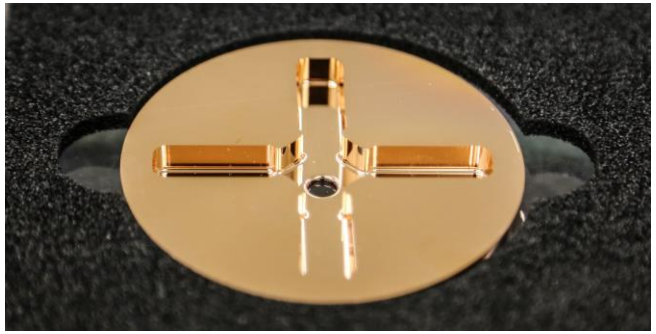


- 160 MeV energy gain
- 2 m long
- 1 A beam current

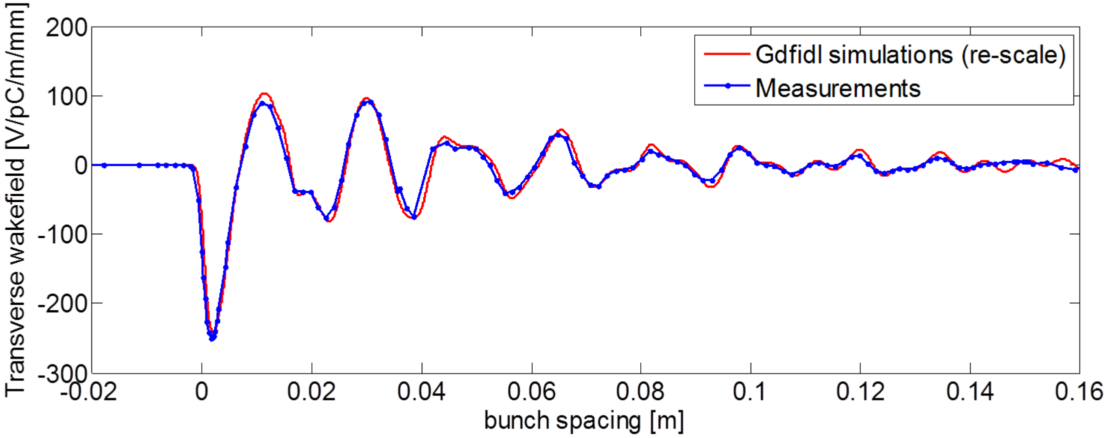
(round numbers)

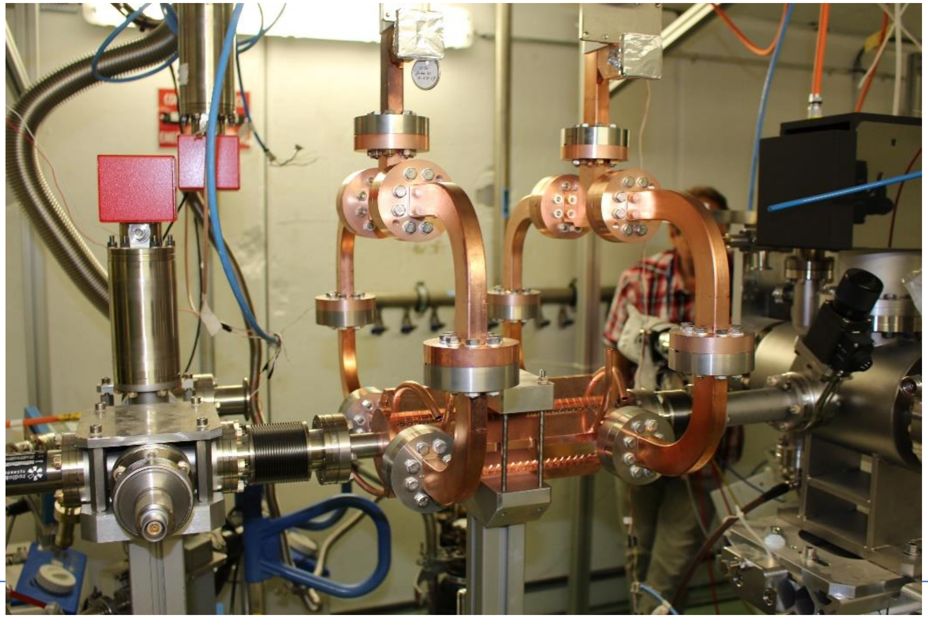
CLIC X-band high-gradient technology – Performances





Long – range wake-field damping (high-current)



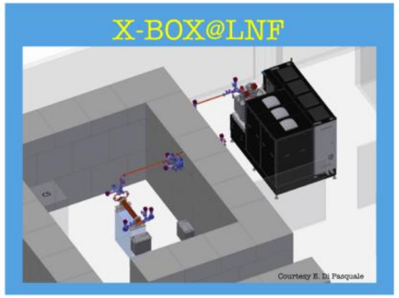


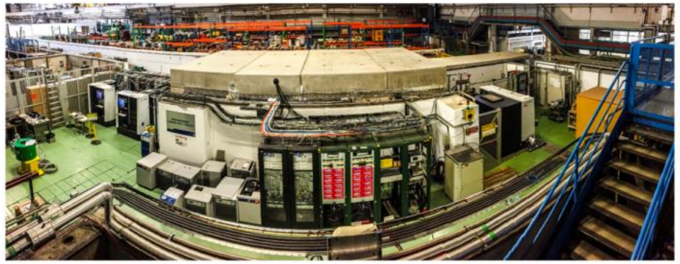
X-band accelerator technology

Based on extensive operation, high-performance X-band linac technology is well developed and well adapted to address the needs of VHEE and FLASH facilities.

CLIC collaboration-related high-power test stands

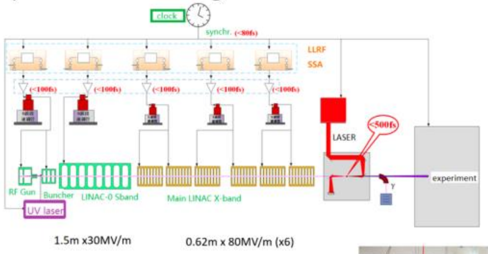
- XBox-1: CERN, 50 MW (CLEAR)
- XBox-2: CERN, 50 MW
- XBox-3: CERN, 2x6 MW
- SBox: CERN, 45 MW (3GHz)
- XBox-OZ: Melbourne, 2x6 MW
- TPOT-X: Tsinghua, 50 MW
- XBox@LNF: Frascati, 50 MW
- Valencia, 2x10 MW (3 GHz)
- Trieste, 45 MW (3 GHz)
- NEXTEF, KEK





Inverse Compton Source, Tsinghua

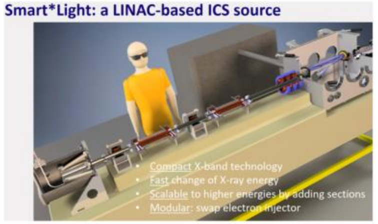
Layout for ICS at Tsinghua



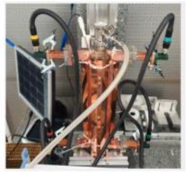
Beam energy: 50-350 MeV

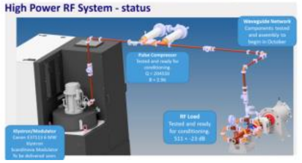
First generation facility operational, second approved

Inverse Compton Source, Eindhoven

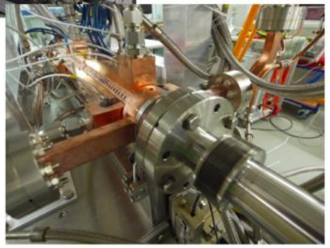


Initial layout 45 MeV, scalable

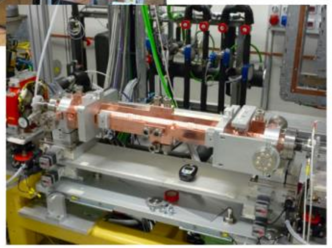




X-band energy spread linearizers at XFELs



PSI

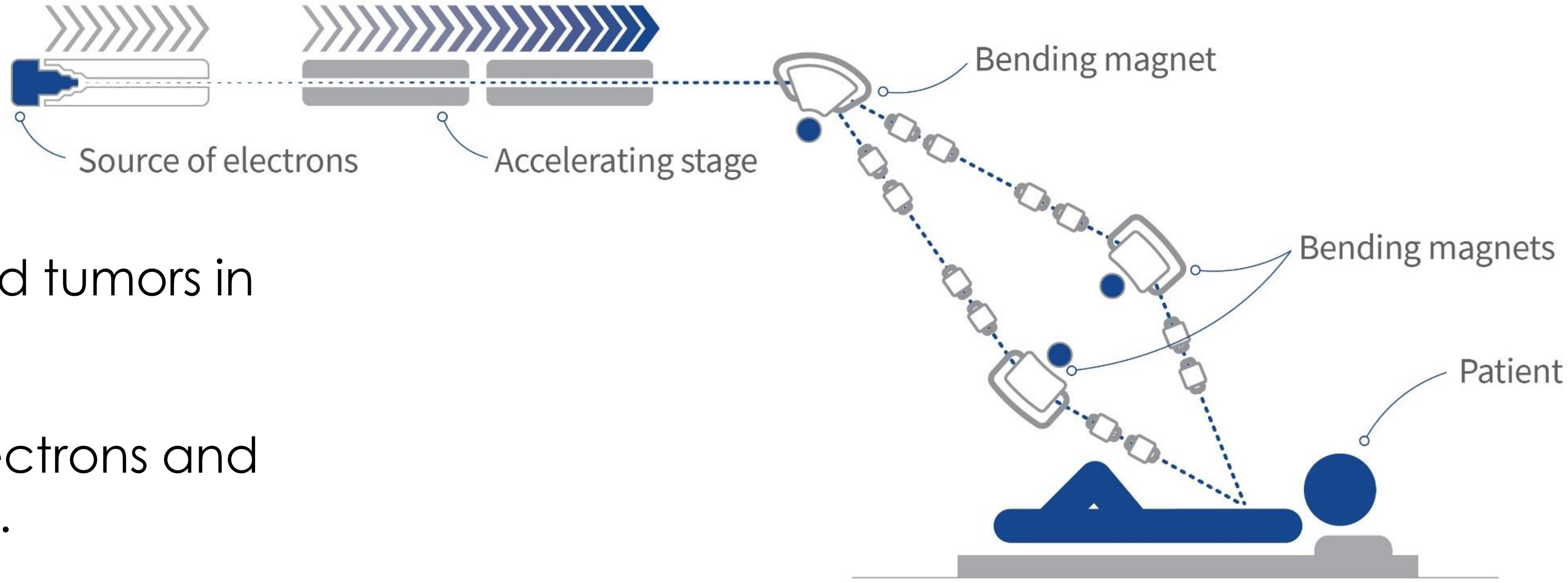


FERMI

SINAP

CERN – CHUV collaboration on FLASH

CLIC technology for a FLASH facility being designed in collaboration with CHUV



Treat large, deep-seated tumors in FLASH conditions.

Uses 100 MeV-range electrons and optimized dose delivery.

Compact to fit on a typical hospital campus.

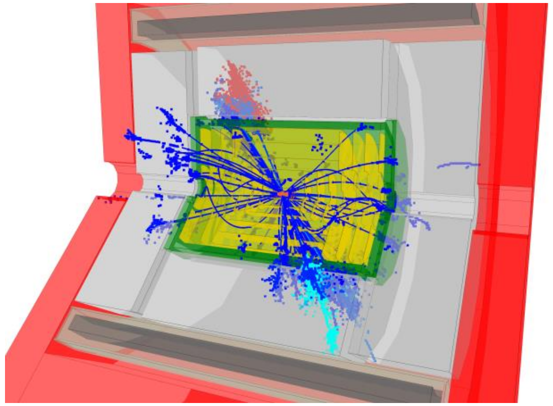
The remarkable connection between CLIC and FLASH

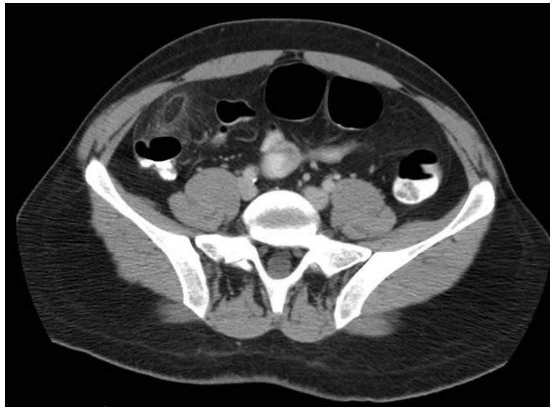
Both need:

- Very intense electron beams
- CLIC – to provide luminosity for experiments
- FLASH – to provide high dose rate for FLASH effect

- Very precisely controlled electron beams
- CLIC – to keep very small beams in collision
- FLASH – to provide reliable treatment in a clinical setting

- High accelerating gradient
- CLIC – to fit facility in the Geneva area and limit cost
- FLASH – to fit facility on a typical hospital campus and limit cost of treatment



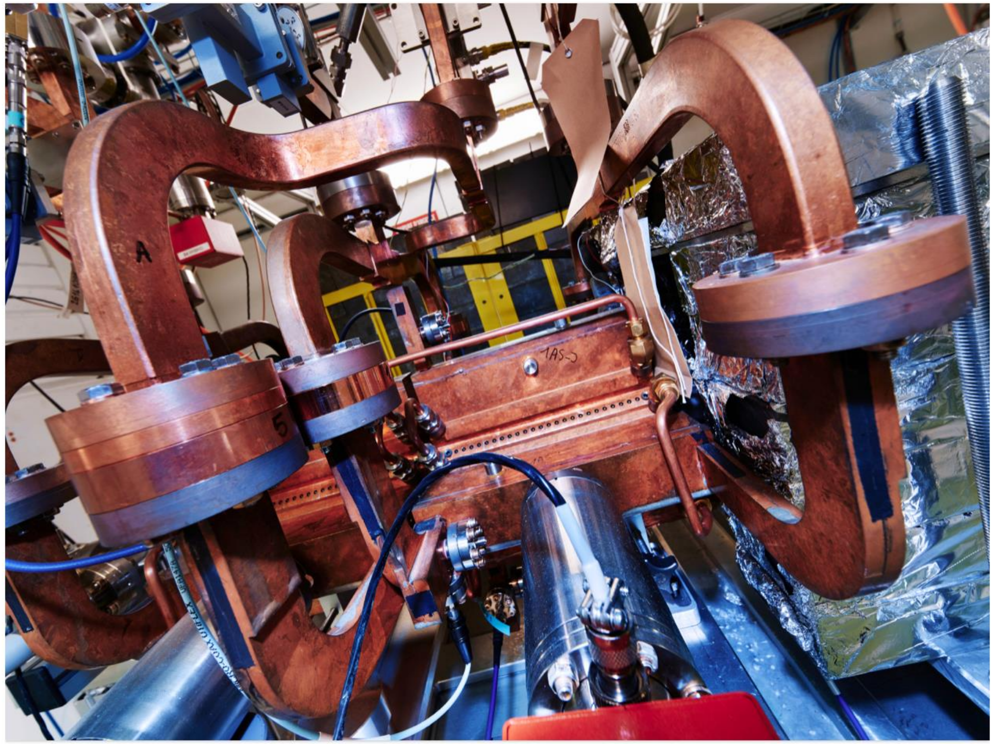


Press release

CERN and Lausanne University Hospital collaborate on a pioneering new cancer radiotherapy facility

CERN and the Lausanne University Hospital (CHUV) are collaborating to develop the conceptual design of an innovative radiotherapy facility, used for cancer treatment

15 SEPTEMBER, 2020



Close-up of the Compact Linear Collider prototype, on which the electron FLASH design is based (Image: CERN)

- CHUV and CERN are actively collaborating on the realization of a clinical FLASH facility for large, deep-seated tumors.
- We have worked intensively and are now confident that the facility is feasible and are establishing the design.
- We are now working towards the next steps of the project, with the target of a clinical facility.

https://home.cern/news/news/knowledge-sharing/cern-and-lausanne-university-hospital-collaborate-pioneering-new-cancer

How to experiment in CLEAR

https://clear.cern/content/beam-time-request

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Beam Time Request

If you need additional informations about the facility, or if you wonder if CLEAR could fit your experimental needs, please contact us at CLEAR-Info@cern.ch.

If you already have a clear idea of the experiment you would like to perform, please download and fill the attached "CLEAR experiment request form" and send it to CLEAR-Info@cern.ch

Attached File(s)
CLEAR experiment request form

CERN clear

Experiment Request Form

A. REQUESTER DETAILS

Principal Investigator:	Michele Piero Blago
Institution:	CERN; University of Cambridge
Contact Information (phone/email):	
Experiment Members:	Sajan Easo, Carmelo D'Ambrosio, Giovanni Cavallero
Collaborating Institutions:	CERN
Funding Source (optional)	
Approximate Duration:	1 day

B. EXPERIMENT DESCRIPTION

1. **Scientific justification** (one paragraph)
Test of the effect of irradiation on a polymer photonic crystal. That is to prepare for a more sophisticated beam test at CLEAR at a later stage.

2. **Experiment short description and goals** (max 1 page)
The polymer photonic crystal strip should be irradiated with varying exposure times. Each exposure time session should hit a separate part of the crystal sheet. For that purpose the photonic crystal may be placed on a translation stage and moved between irradiations. The irradiation times should ideally spread between 1 s and 1000 s (e.g. 1 s; 10 s; 100 s; 1000 s) and the accumulated charge measured for each irradiation step.

You're welcome!

https://clear.cern