A programme with a low energy electron beam - CLEAR at CERN

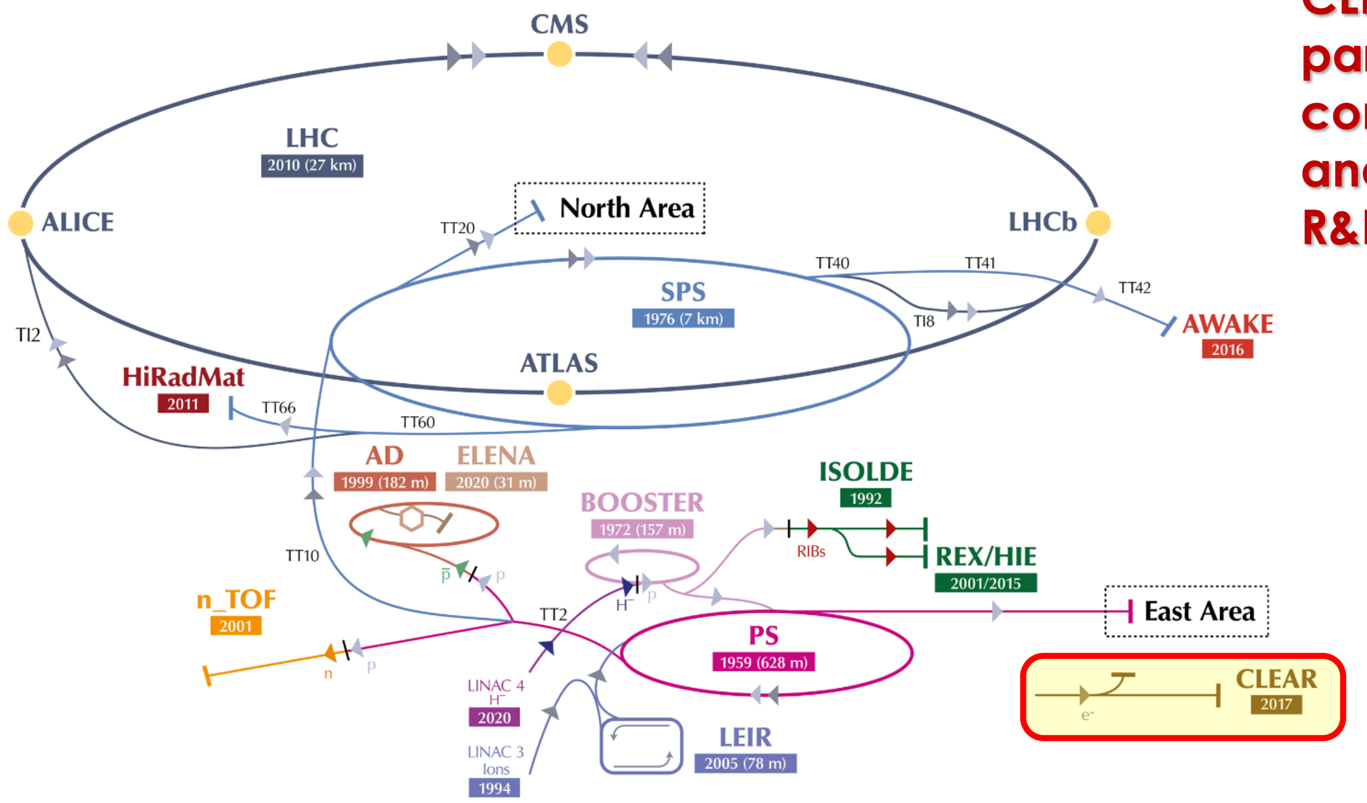
R. Corsini - W Farabolini – A. Gilardi - P. Korysko – L. Dyks – D. Gamba – K. Sjobaek- L. Garolfi - S. Doebert – G. Mc Monagle – E. Granados – H. Panuganti

clear

Summary

- Where is CLEAR and where it is coming from ?
- Why CLEAR at CERN ?
- Facility description
- Beam characteristics
- Some experiments :
  - Wakefield effects and high accuracy cavity BPMs
  - Plasma Lens
  - Electronics irradiations
  - Medical related researches (dosimetry, beam delivery, VHEE and Flash beam mode)
  - THz generation
  - Beam diagnostics (EOS, Cherenkov BPMs, Thin layer BPMs, Beam loss monitors…)
- Support provided to users
- How to request beam time ?
- Conclusion

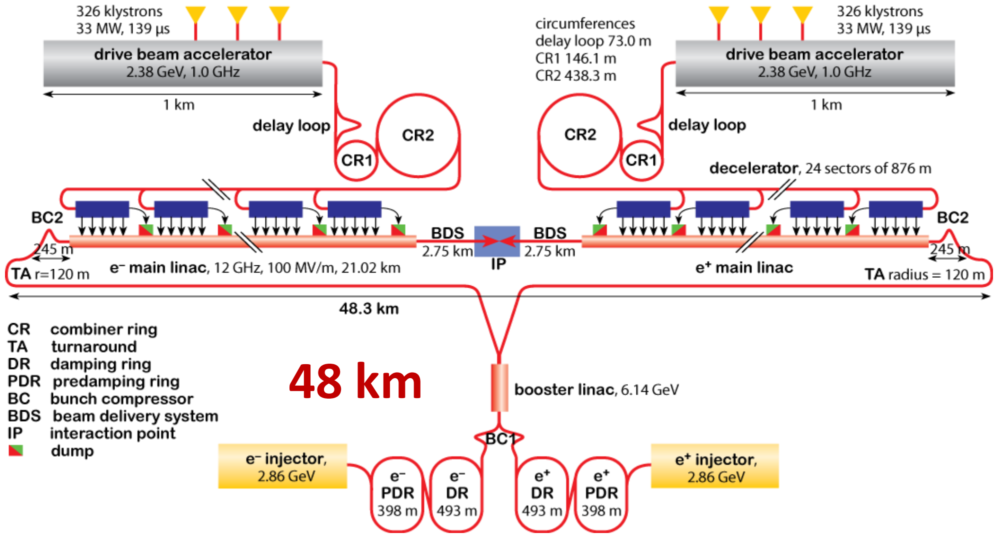
CERN – European Center for Nuclear Research

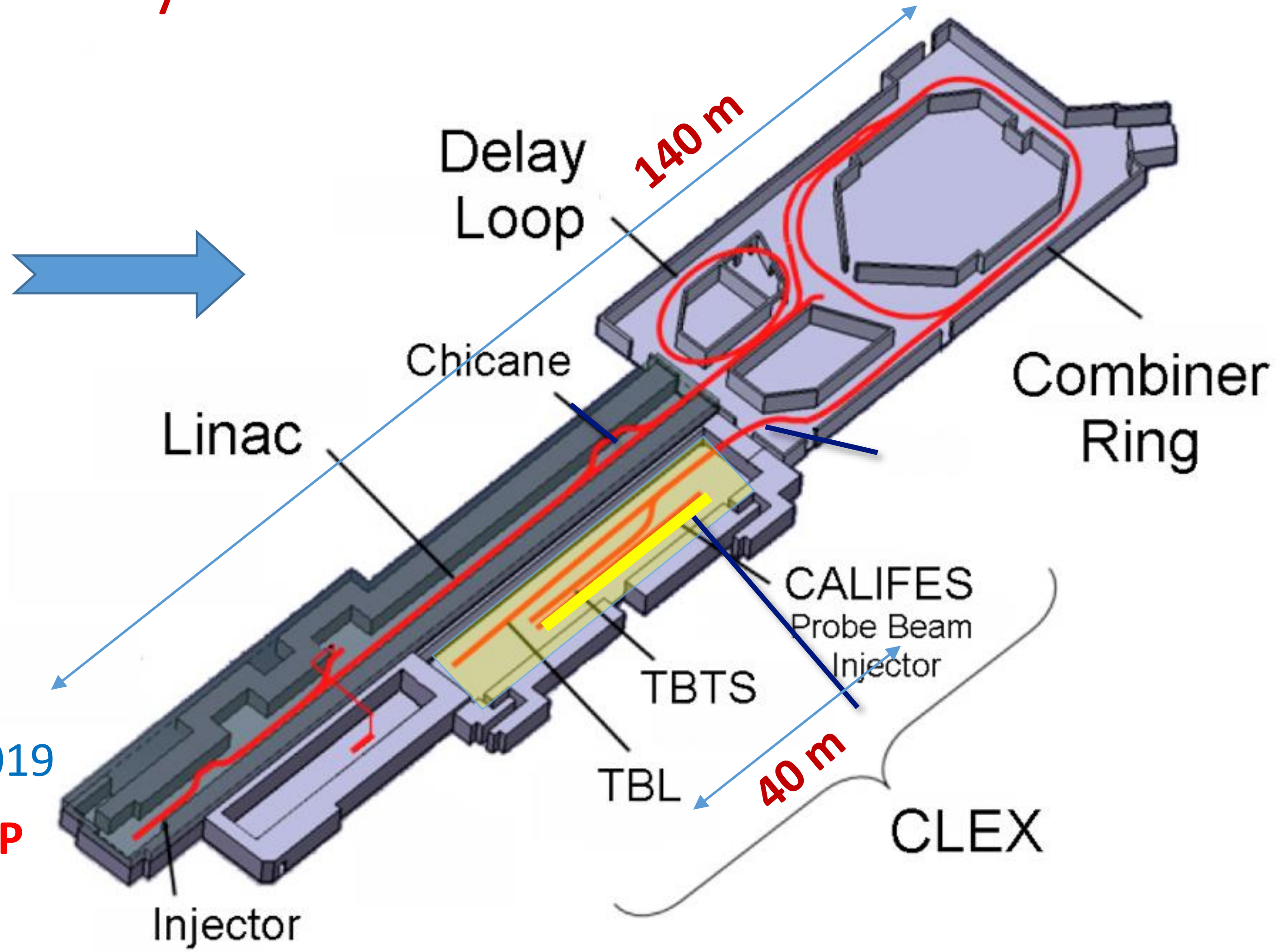


CLEAR is a user facility at CERN, running in parallel with the main CERN accelerator complex, with the primary goal of enhancing and complementing the existing accelerator R&D and testing capabilities at CERN.

- The only pure electron machine at CERN.
- Independent from the rest of the CERN (no shut-down for LS2).
- Benefit from the CERN environment and expertise.

From CLIC Test Facility CTF3 to CLEAR





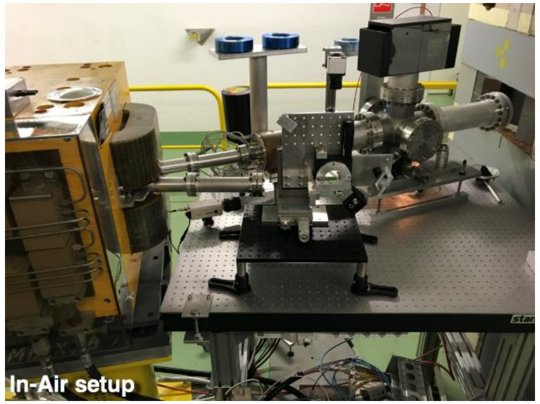
- CLEAR: Cern Linear Accelerator for Research
- Approved in December **2016**, as a 2 + 2 years program
- Reviewed and extended until 2020 in February 2019
- Included in the new CERN Medium Term Plan **MTP 2021-2025** approved by the CERN Council in September 2020
  - Operational budget, independent from CLIC, 800 kCHF/year (material)
- Clear review tomorrow the 16th of March

Motivation

CLEAR - 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 innovative beam instrumentation prototyping, high gradient RF technology realistic beam tests and beam-based impedance measurements.
  - Providing an irradiation facility with high-energy electrons, e.g. for testing electronic components in collaboration with ESA or for medical purposes(VHEE), possibly also for particle physic detectors.
  - Performing R&D on novel accelerating techniques – electron driven plasma and THz acceleration. In particular developing technology and solutions needed for future particle physics applications, e.g., beam emittance preservation for reaching high luminosities.
- Maintaining CERN and European expertise for electron linacs linked to future collider studies (e.g. CLIC and ILC, but also AWAKE and FCC-ee injectors), and providing a focus for strengthening collaboration in this area.
- Using CLEAR as a training infrastructure for the next generation of accelerator scientists and engineers.

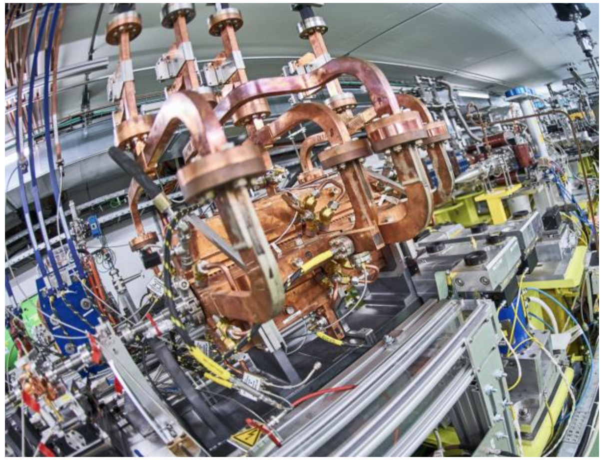
CLEAR Layout & main installations



In-air test stand

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

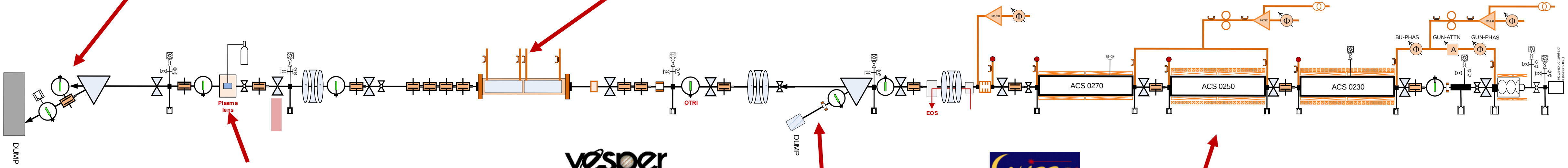
Irradiation for medical and other applications

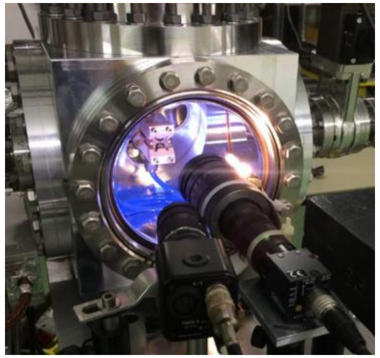


CLIC Test-Stand and high resolution cavity BPMs

High-gradient and linear colliders R&D

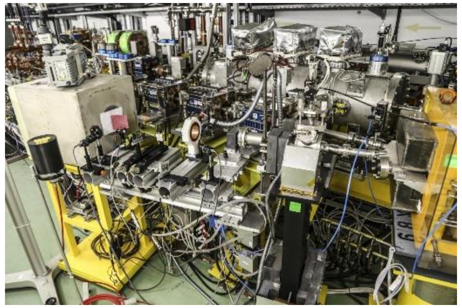
Beam direction





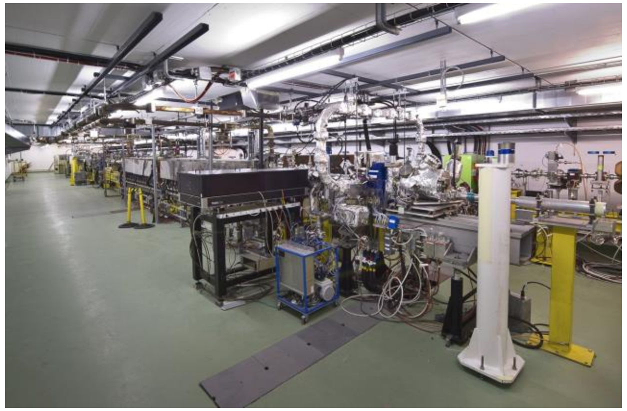
The Plasma Lens Experiment

Novel concepts of plasma-based focusing and acceleration



VESPER

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

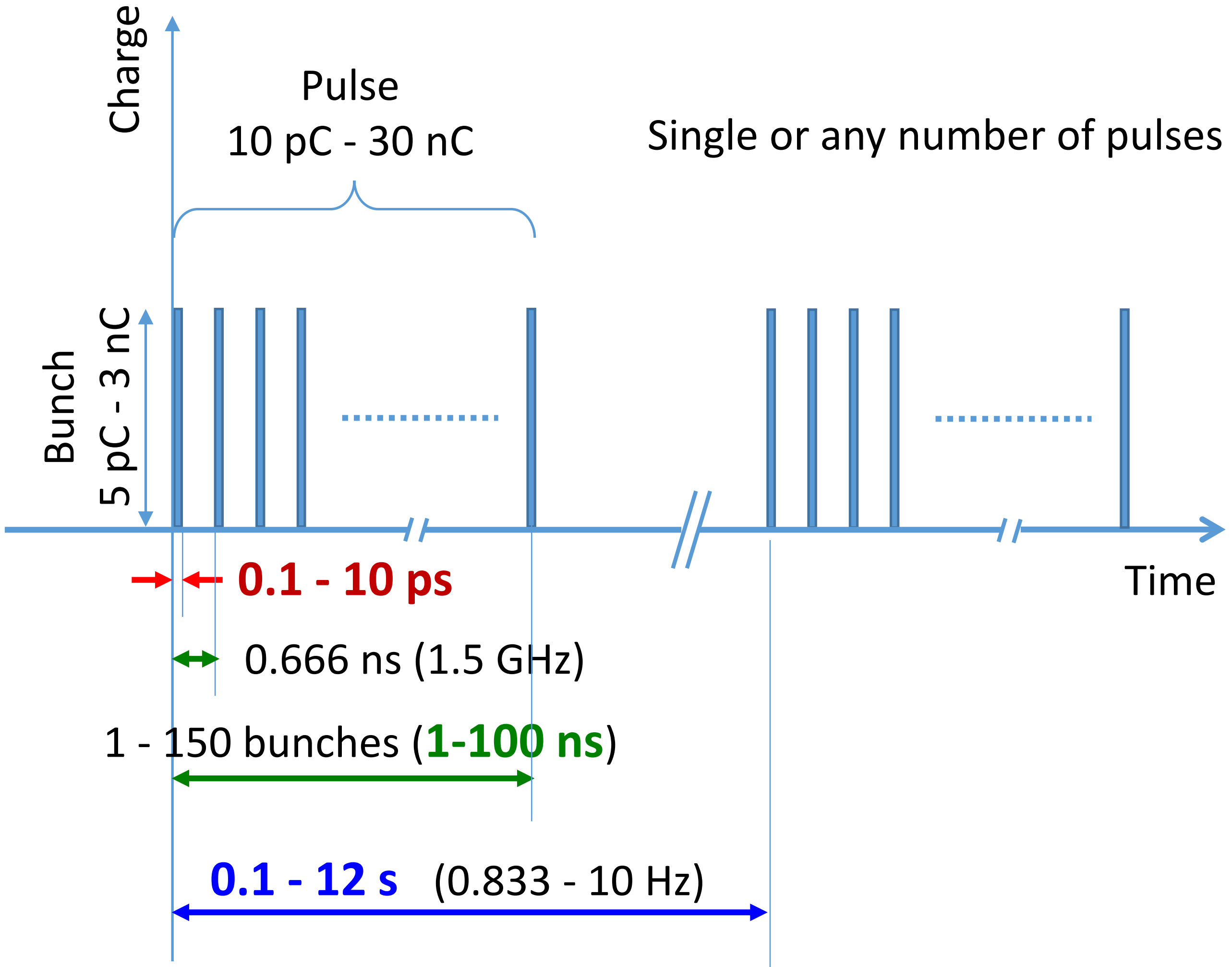


CALIFES electron linac

Flexible accelerator providing up to 220 MeV electron beams to all CLEAR users

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)



Experiments/Activities in 2019 > 2020

In 2020: 25 formal beam time request received, 19 fully or partly covered,
34 Weeks - 145 Days of beam operations

- JUAS Practical Work Days
- NPL – Irradiation/dosimetry
- CHUV – FLASH dosimetry
- AWAKE Cherenkov BPM
- CLIC Wake-Field Monitors
- EOS bunch length monitor
- Inductive BPMs
- Test of OTR and YAG screens exposed to Rubidium vapor

- CLIC Structure wake-field kicks
- THz Smith-Purcell radiation
- THz high power generation/bunch length monitoring
- Ionization chambers dosimetry (Oldenburg U. /PTW)
- R2E Irradiation studies SEU-SEE
- R2E – ESA monitor flash
- Machine learning for beam imaging system
- Investigation on Degradation of Irradiated epitaxial Silicon Pad Diodes

- R2E – displacement damage
- Plasma Lens (Oslo, DESY, Oxford U.)
- VHEE radiobiology/plasmid irradiation (Manchester U.)
- AWAKE spectrometer calibration
- Cryogel radiation length evaluation (FCC detectors R&D)
- Cherenkov X-ray pre-tests (Belgorod)
- RP measurements/neutrons
- Double-bunch generation
- High Charge bunch compression

- Irradiation of DCDC converters for detectors (EP/ESE group)
- IRRAD Beam Profile Monitors prototype tests
- WSM-BPR diagnostics tests
- Cherenkov Plasmonic waves
- Fiber optic beam loss monitor

CLIC related activities

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

Experiments:

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

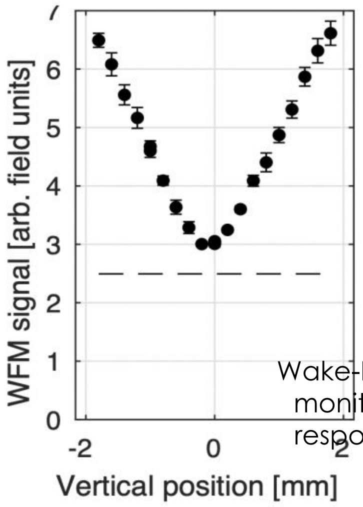
Main collaborators

- University of Oslo
- CEA - Saclay
- Università di Napoli Federico ..
- RHUL

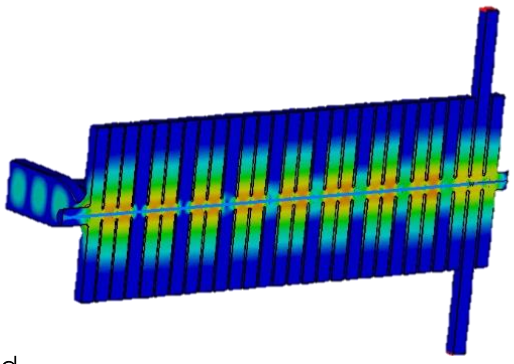
Future step, connecting the cavity to X-Box1

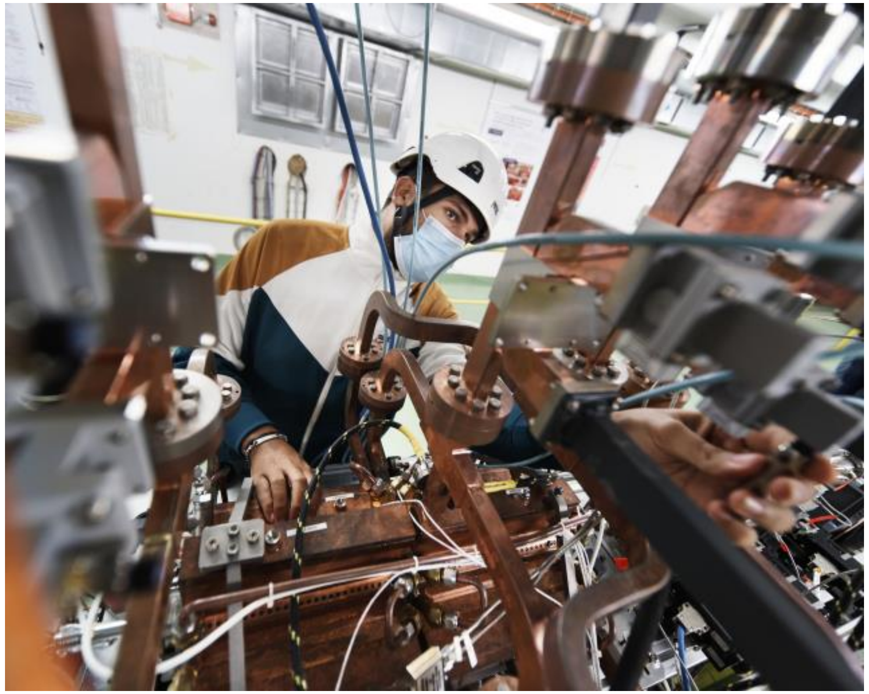
possible tests:

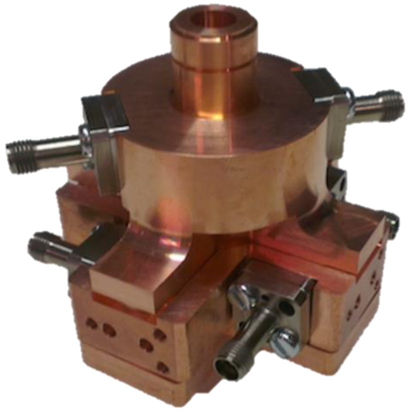
- RF kicks
- Breakdown kicks
- RF effect on WFMs
- Stability & reliability runs

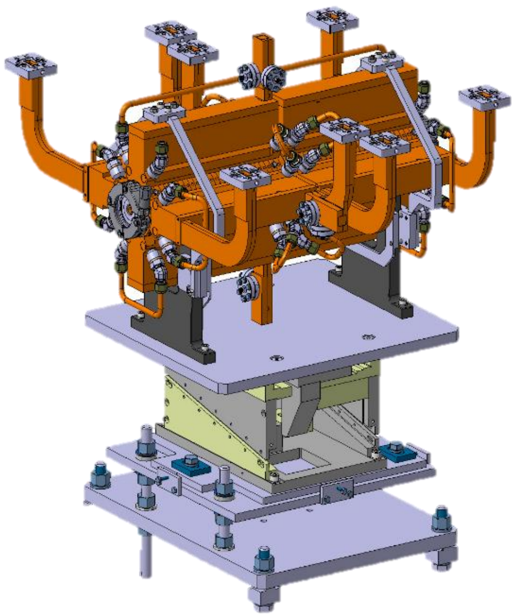


Wake-Field monitors response









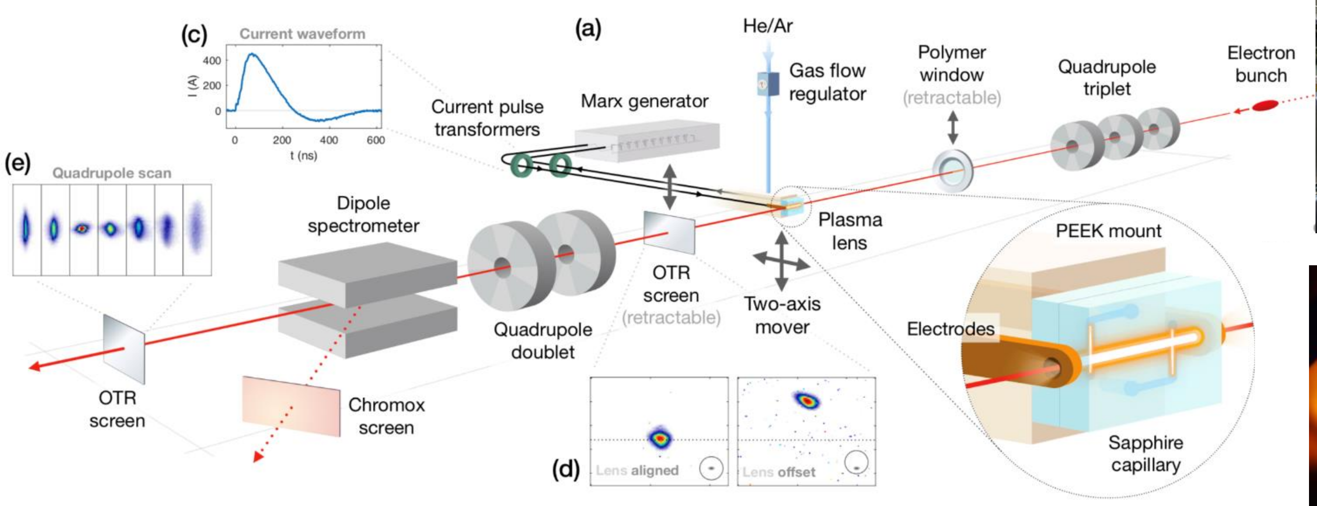
Cavity BPM and X-band structure on movers

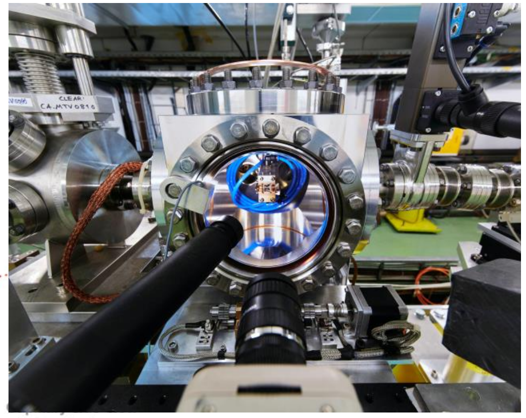
Past highlights – Plasma lens

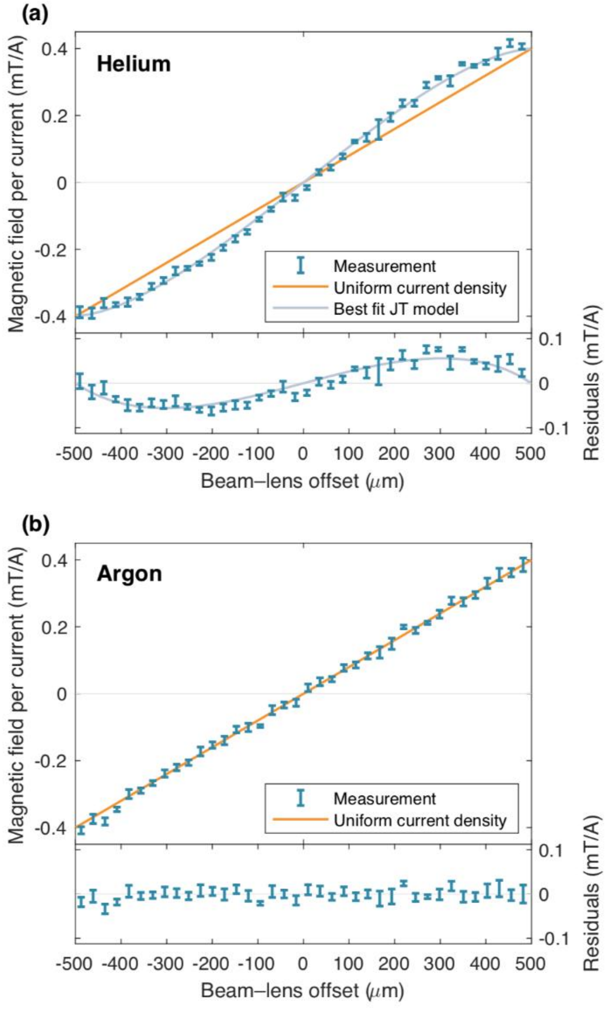
Emittance Preservation in an Aberration-Free Active Plasma Lens

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 and fully linear focusing in an active plasma lens demonstrated with the use of an argon-based discharge capillary.
- Direc… d nonlin…

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.

C. Lindstrom, E. Adli, K. Sjobaek et al.

Beam Instrumentation R&D

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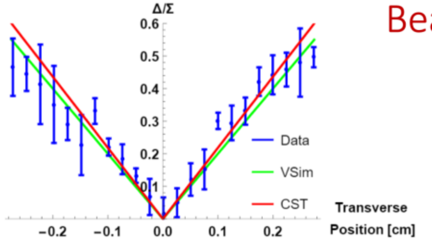
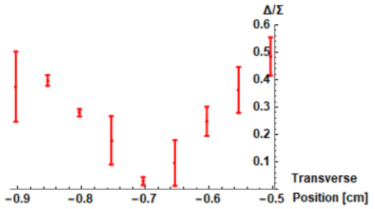
A Coherent Cherenkov-Diffraction-based Beam Position Monitor



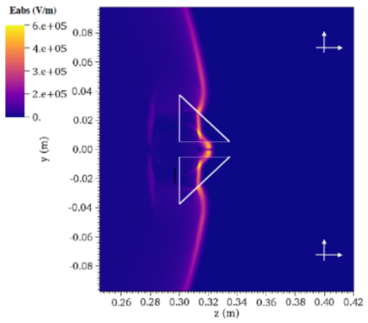
Beam centered

BPM formula

$$\left|\frac{\Delta}{\Sigma}\right| = \left|\frac{S_{left} - S_{right}}{S_{left} + S_{right}}\right|$$

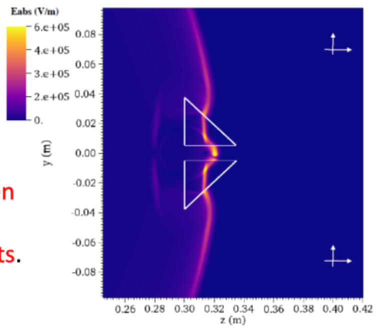


Beam not centered

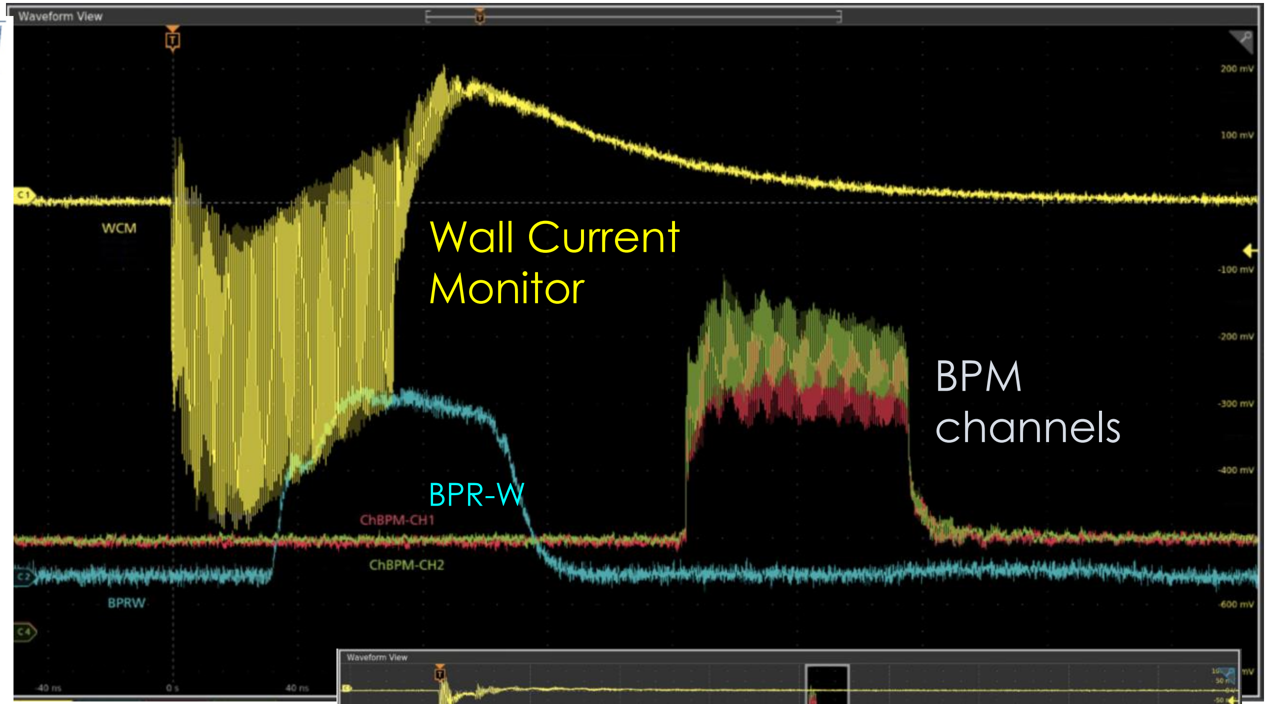


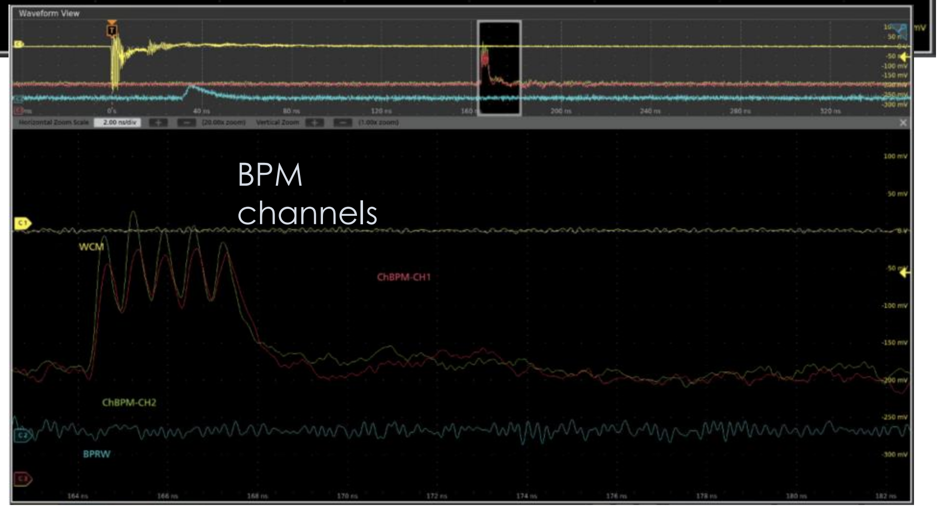
(courtesy of **K. Lekomtsev**)

Important note: This BPM, based on coherent radiation, is sensitive only to bunches shorter than a certain threshold bunch length. This means that it can be used to distinguish between bunches of different length, or even to make bunch length measurements.

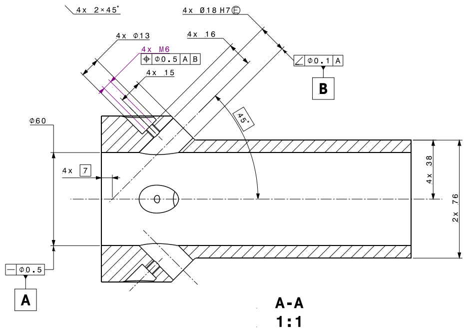


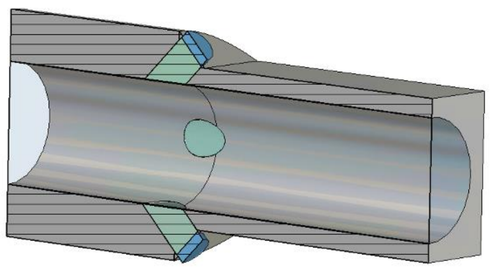
(courtesy of **K. Lekomtsev**)





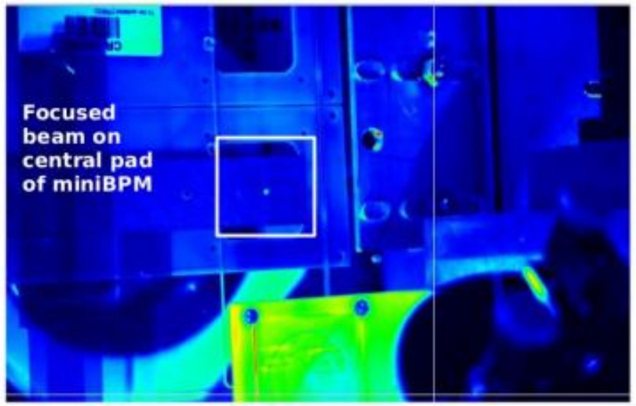
AWAKE Cherenkov BPMs

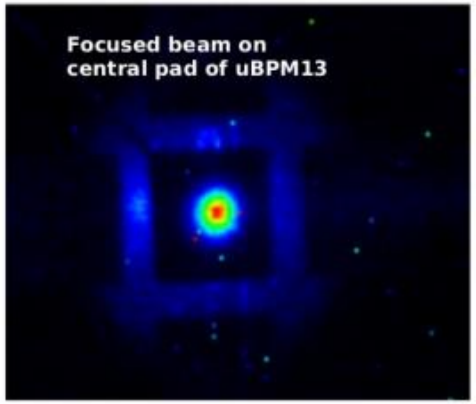


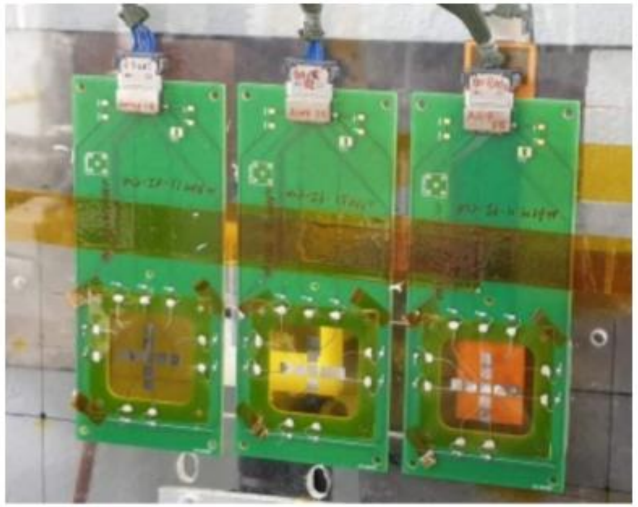


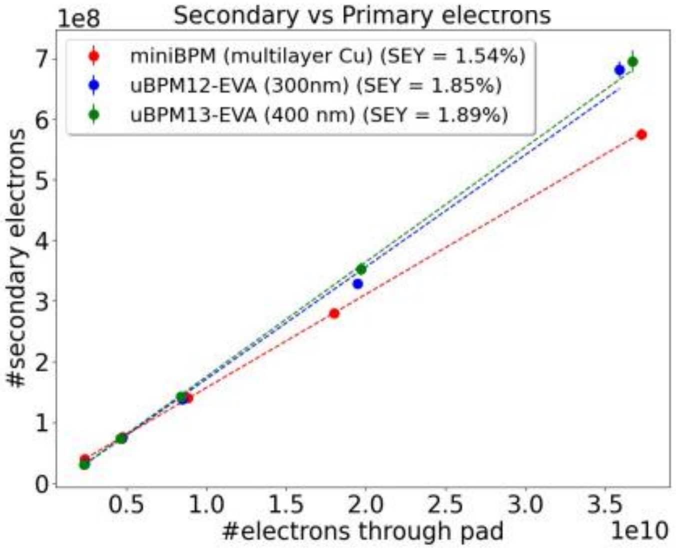
A. Curcio, E. Senes, S. Mazzoni, T. Lefevre…

Low interception Micro Beam Profile Monitors





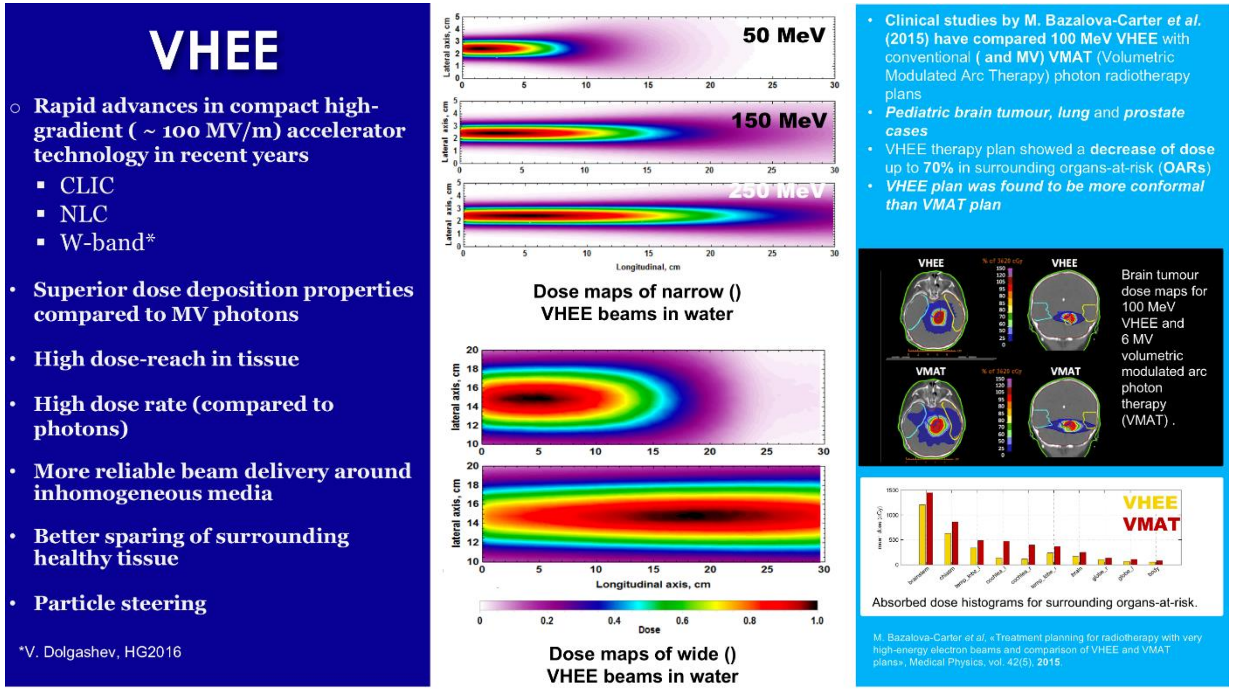




O. Sidiropoulou, G. Pezzulo, I. Mateu, F. Ravotti

Kapton layer with Al coating BPMs

Medical irradiation tests - VHEE



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

11

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.)*

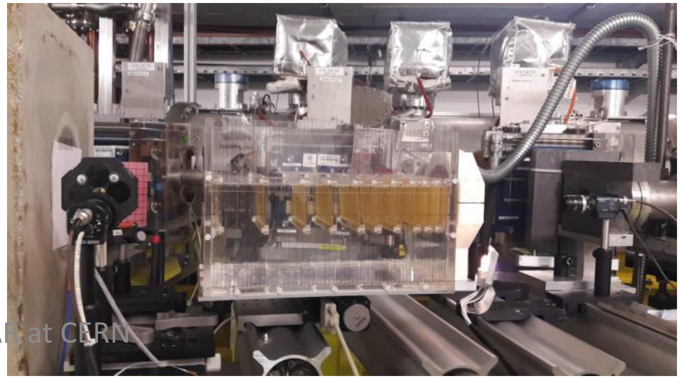
- Two campaigns completed (end 2018, September 2019)

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

- Preliminary tests (end 2018, spring 2019)

Activities:

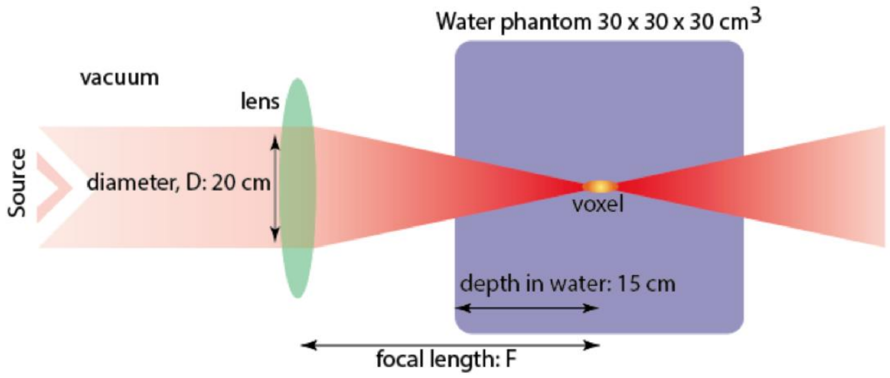
- Experimental verification of dose deposition profiles in water phantoms
- Calibration of operational medical dosimeters – nonlinear effects with short pulses
- Demonstration of "Bragg-like peak" deposition with focused beams



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

VHEE strong focusing

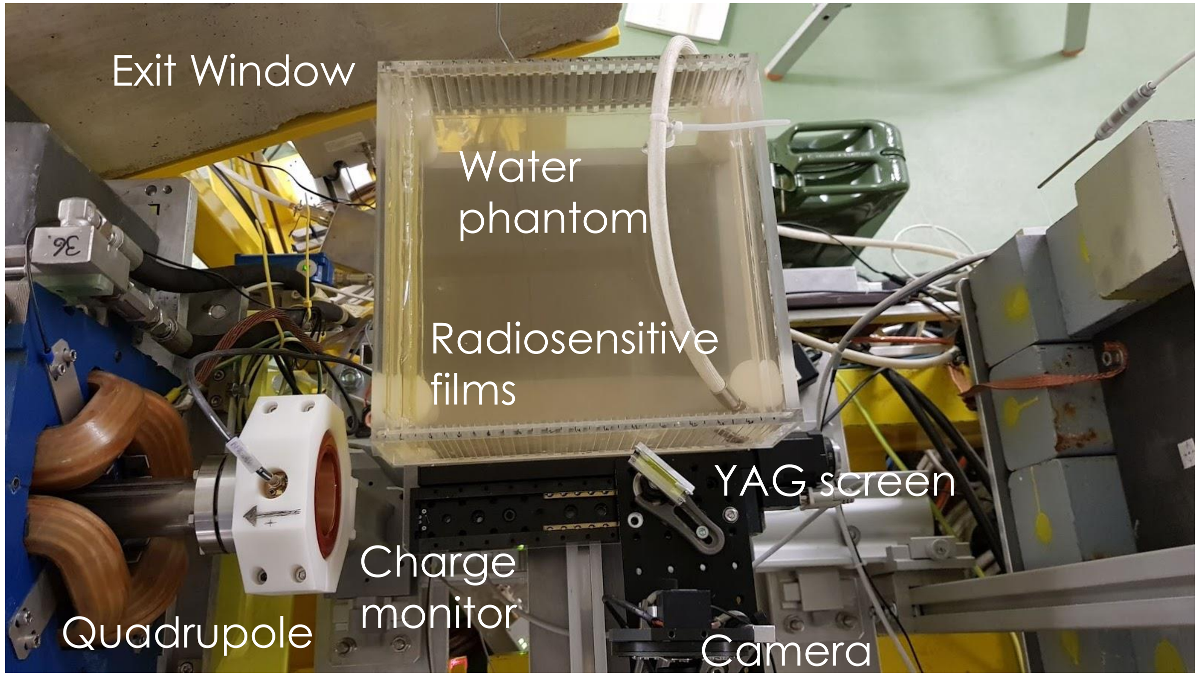


Aim:

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

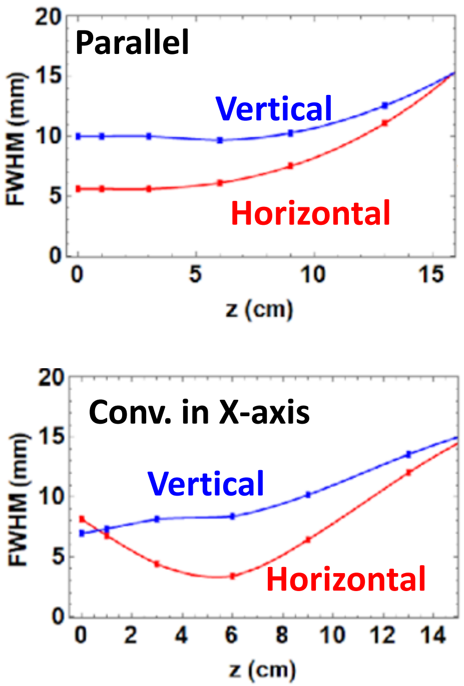
- Main activity in October 2019

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

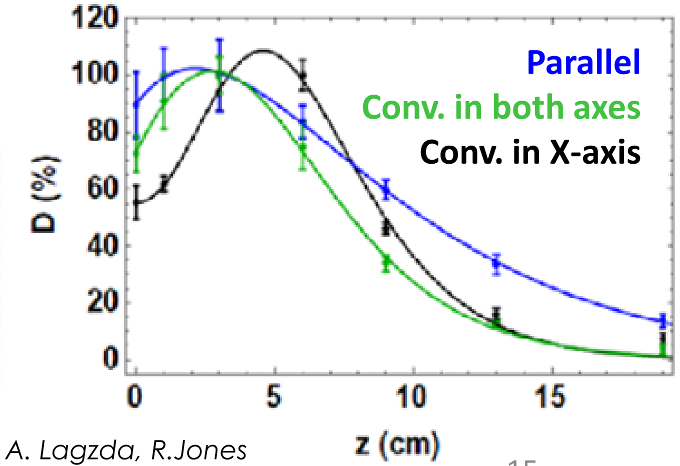


W. Farabolini, E. Senes, K. Kokurevicz

Beam size

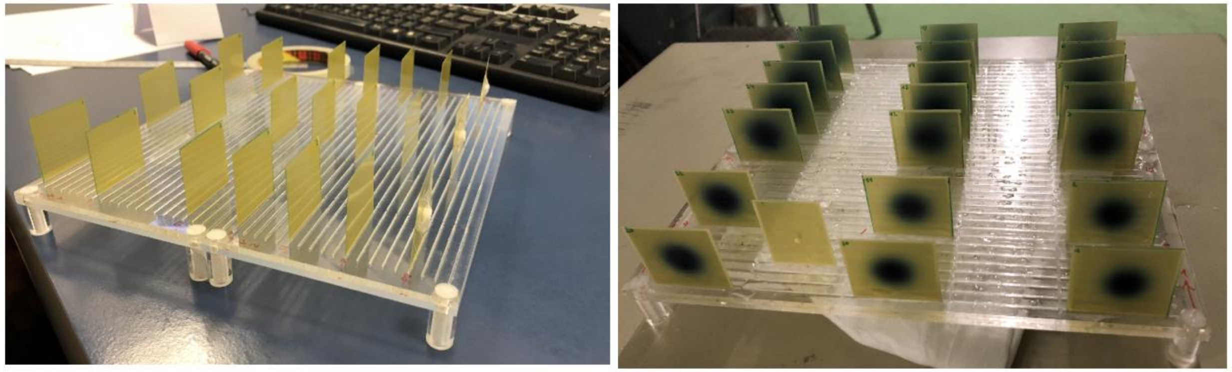


Dose deposition

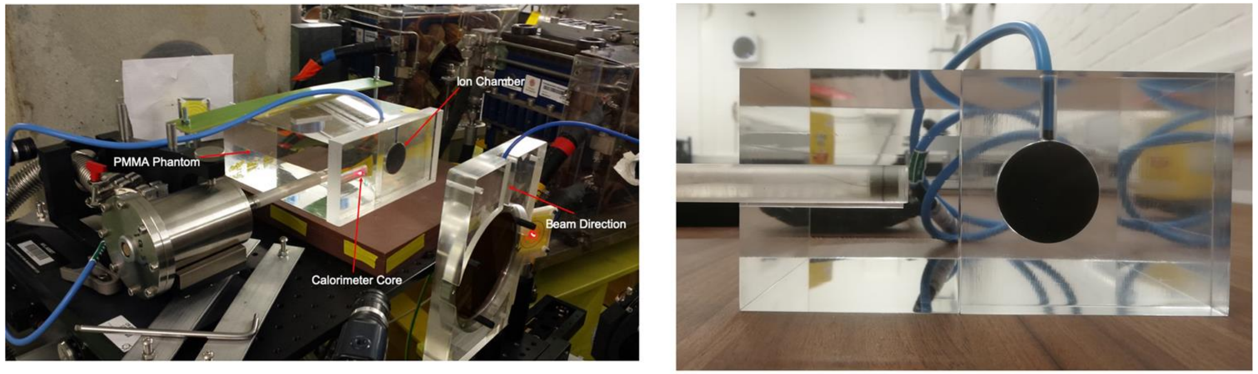


A. Lagzda, R.Jones

High dose rate dosimetry



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

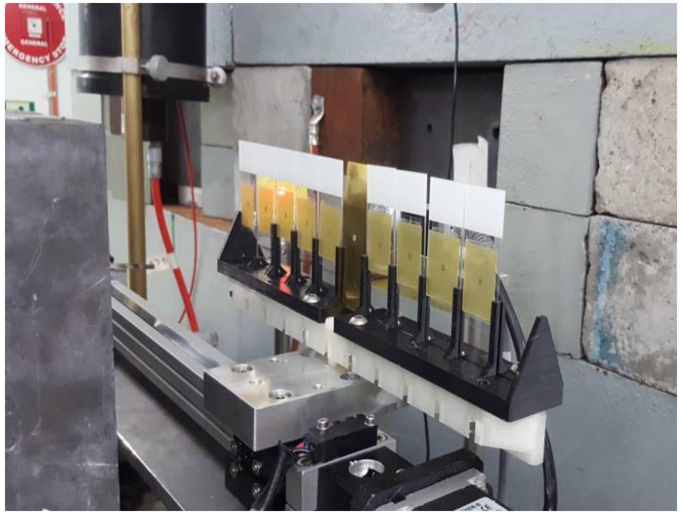


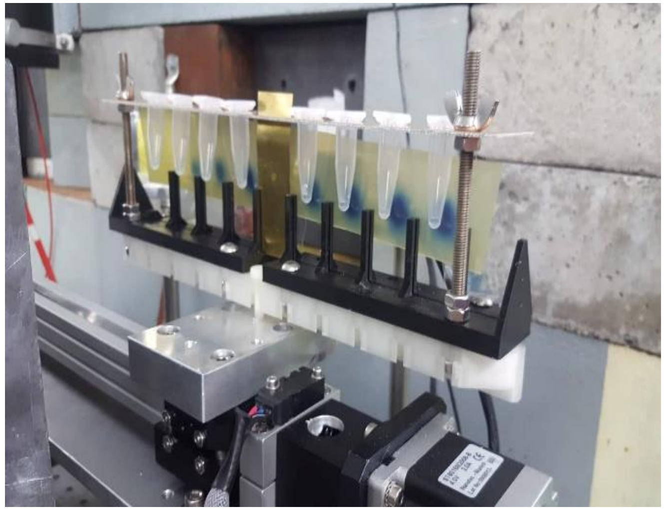
a **b**

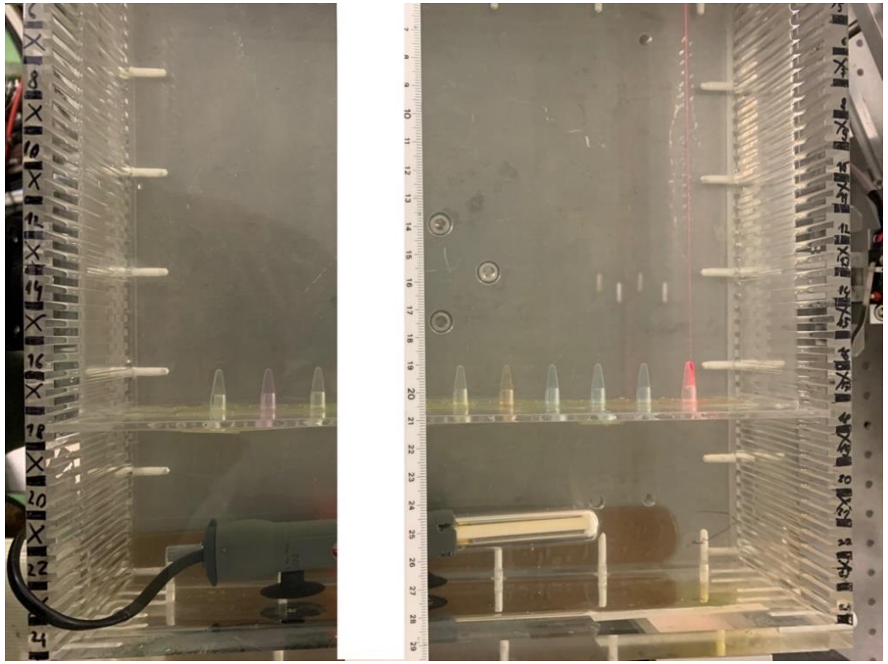
Calorimeter and ROOS chamber Nat. Phys. Lab. UK
(A. Subiel et al.)

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

Biological effects of high dose rate vs. “classical” dose rates







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

Set-up in the water tank. Eggs @ 19.5cm [19-20.5]. Alanine @ 21.1 cm. Film @ 21.3 cm, CHUV Lausanne *(M.C. Vozenin, C. Bailat, R. Moeckli et al.)*

Some radiotherapy related publications based on CLEAR experiments

- **K. Kokurewicz**, D. Jaroszynski et al., "An experimental study of the dose distribution of focused very high energy electron (VHEE) beams for radiotherapy". **Nature Communication Physics 4, no. 33** (February, 2021). doi:10.1038/s42005-021-00536-0.

- **K. Small**, R. Jones et al., . "Evaluating Very High Energy Electron RBE from nanodosimetric pBR322 plasmid DNA damage". **Nature Scientific Reports 11, no. 3341** (February, 2021). doi:10.1038/s41598-021-82772-6.

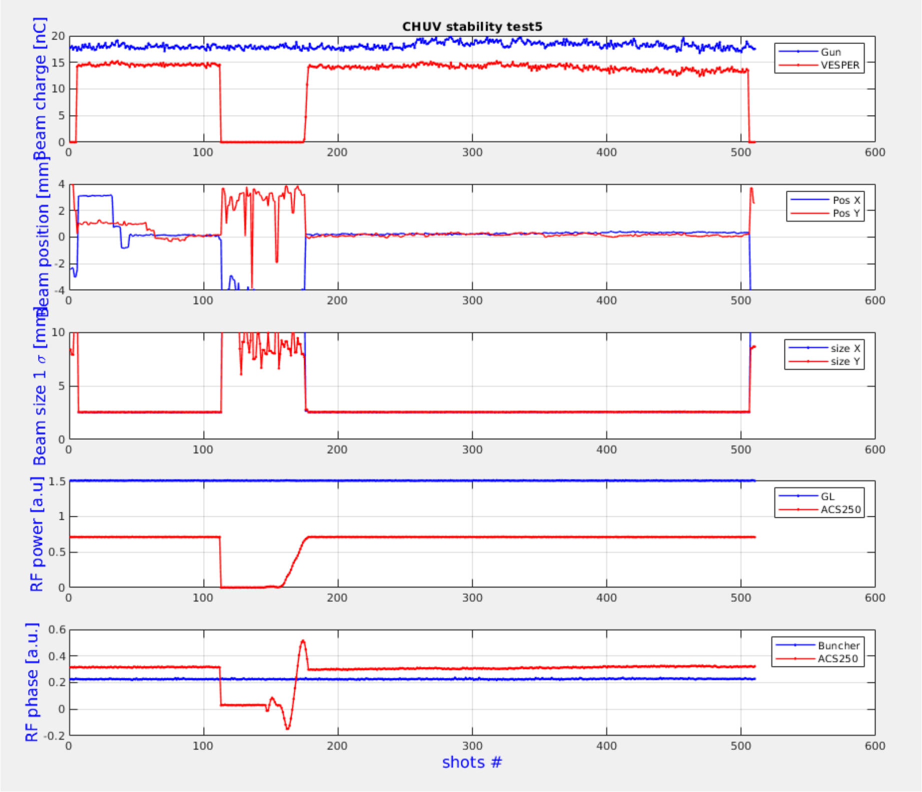
- **A. Lagdza**, R. Jones et al., Influence of heterogeneous media on Very High Energy Electron (VHEE) dose penetration and a Monte Carlo-based comparison with existing radiotherapy modalities, Nuclear Inst. and Methods in Physics Research, B, 482 (2020) 70-81

- **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, Biomedical Physics & Engineering Express 7, no. 1 (December, 2020). doi:10.1088/2057-1976/abcae5.

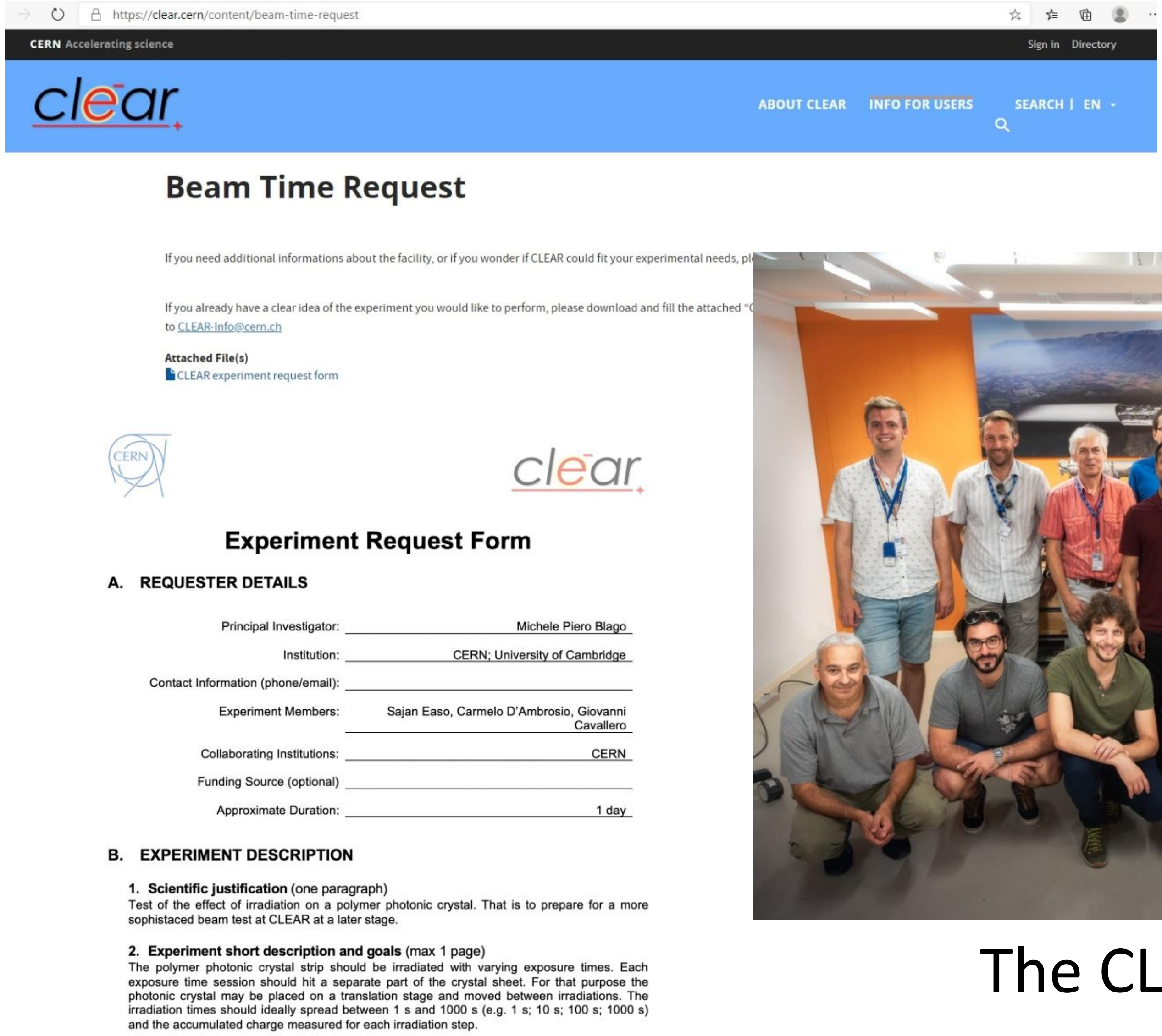
CLEAR team provided services

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



Beam monitoring panel

How to experiment in CLEAR



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

CERN Accelerating science — Sign in — Directory

clear — ABOUT CLEAR — INFO FOR USERS — SEARCH | EN

Beam Time Request

If you need additional informations about the facility, or if you wonder if CLEAR could fit your experimental needs, pl

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

Attached File(s)
CLEAR experiment request form

CERN — clear

Experiment Request Form

A. REQUESTER DETAILS

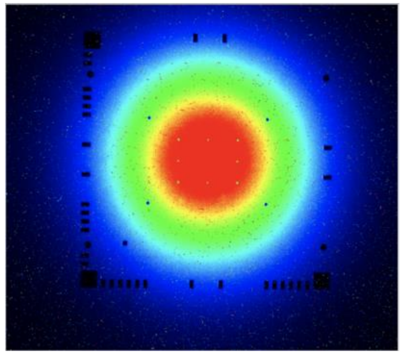
Principal Investigator: Michele Piero Blago
Institution: CERN; University of Cambridge
Contact Information (phone/email):
Experiment Members: Sajan Easo, Carmelo D'Ambrosio, Giovanni Cavallero
Collaborating Institutions: CERN
Funding Source (optional)
Approximate Duration: 1 day

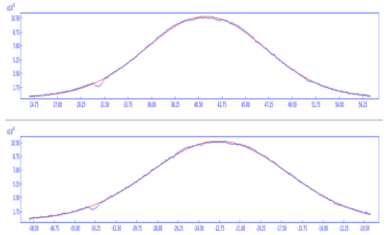
B. EXPERIMENT DESCRIPTION

1. **Scientific justification** (one paragraph)
Test of the effect of irradiation on a polymer photonic crystal. That is to prepare for a more sophistaced 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.

The CLEAR team





Large beam size (12 x 12 mm^2 FWHM on the final in-air test stand

Conclusions

- The CLEAR facility provides access to high quality e- beams to a wide community of users, with high availability and easy access
- The 2020 experimental run has been completed, with only relatively partial disruption by the Covid crisis
- Beam parameters and experimental infrastructure have been improved, and keep improving, since the facility start-up in 2017
- CLIC related activities are still playing a large role in CLEAR, and can be further extended with the connection to the X-band klystron.
- Beam time requests are increasing, further extending the scope of the facility
- CLEAR running has been de-facto extended at least to 2025, the longer time span implies a consolidation of the facility hardware, and gives the opportunity for a proper planning of upgrades