



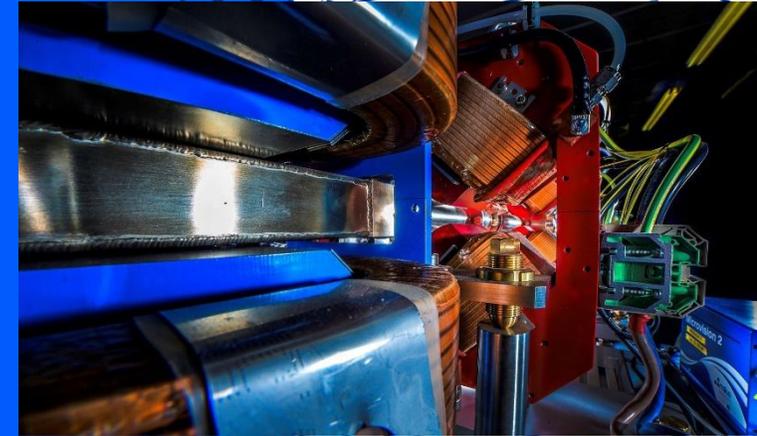
Science and
Technology
Facilities Council

ASTeC

*Making a brighter future through
advanced accelerators*

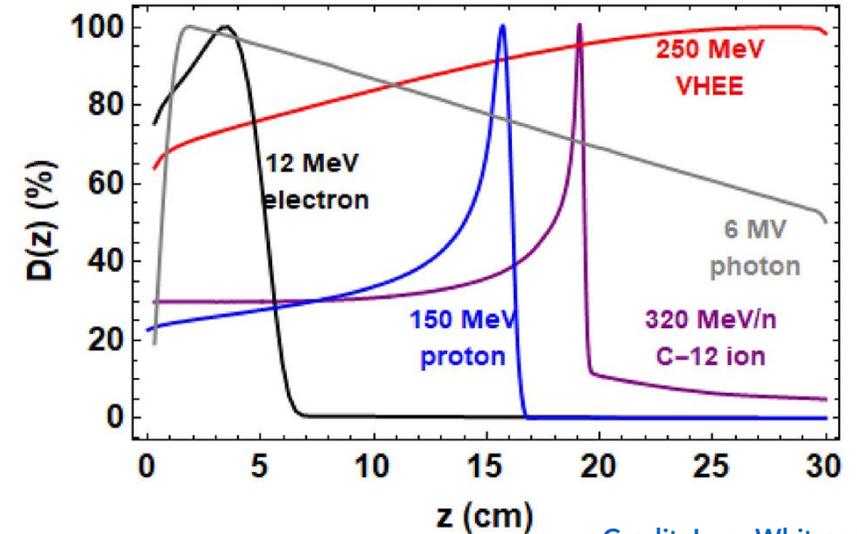
Medium Energy Electron Accelerator Facilities in Europe Supporting R&D for VHEE/FLASH Radiotherapy

Deepa Angal-Kalinin
ASTeC, STFC Daresbury Laboratory and
The Cockcroft Institute

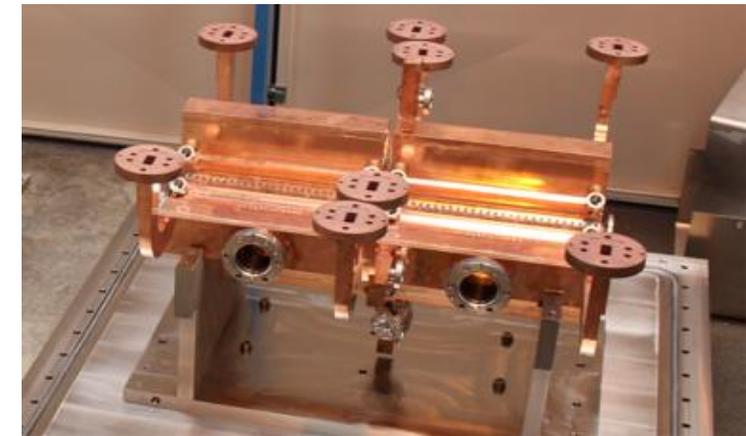


VHEE Context

- Very High Energy Electrons (VHEE) are gaining significant interest in combination with FLASH (dose rate >40 Gy/sec) radiotherapy (RT) as a cancer treatment modality with potential reduction in side effects.
- Promising RT approach but there are a lot of open questions to be solved to be applied in the clinical context; e.g. beam dosimetry and detectors, treatment planning, imaging and modelling, radiobiology & radiochemistry,....
- Recent advances in RF technologies, especially in high gradient RF (> 100 MV/m) are now achievable and are transforming the landscape for VHEE RT. Several Laser Plasma Accelerator technologies are also being used for R&D in VHEE+FLASH.



Credit: Lucy Whitmore



CLIC X-band (12GHz, 100MV/m)

Medium Energy Electron Beam Facilities in Europe

ARES: Accelerator Research Experiment at SINBAD, DESY, Hamburg, Germany,
Operational since 2020

CLARA: Compact Linear Accelerator for Research and Applications, STFC, Daresbury
Laboratory, U.K.
Phase 1 operational 2017, Phase 2 operational in 2025

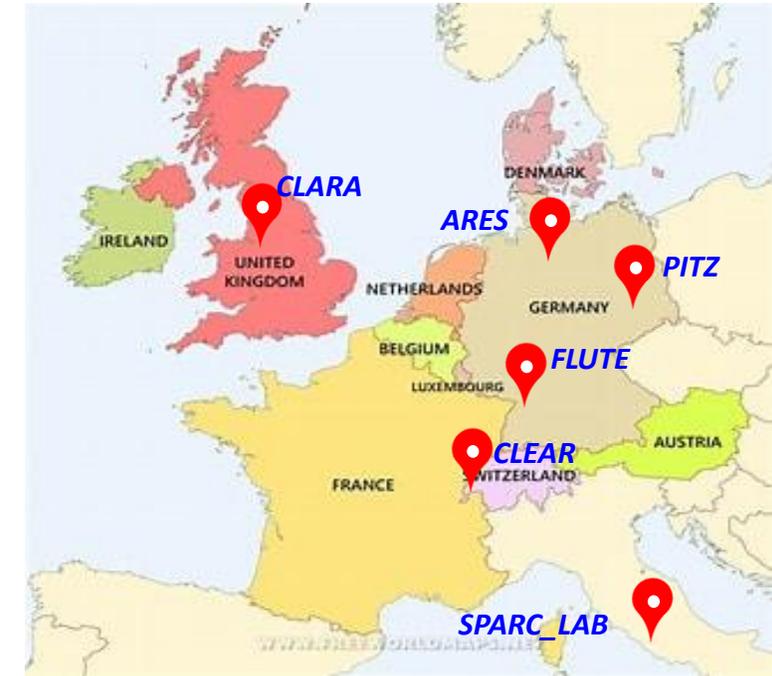
CLEAR: The CERN Linear Electron Accelerator for Research, CERN, Geneva,
Operational since 2017

FLUTE: Ferninfrarot Linac- Und Test-Experiment, IBPT, KIT, Karlsruhe, Germany,
Operational since 2018

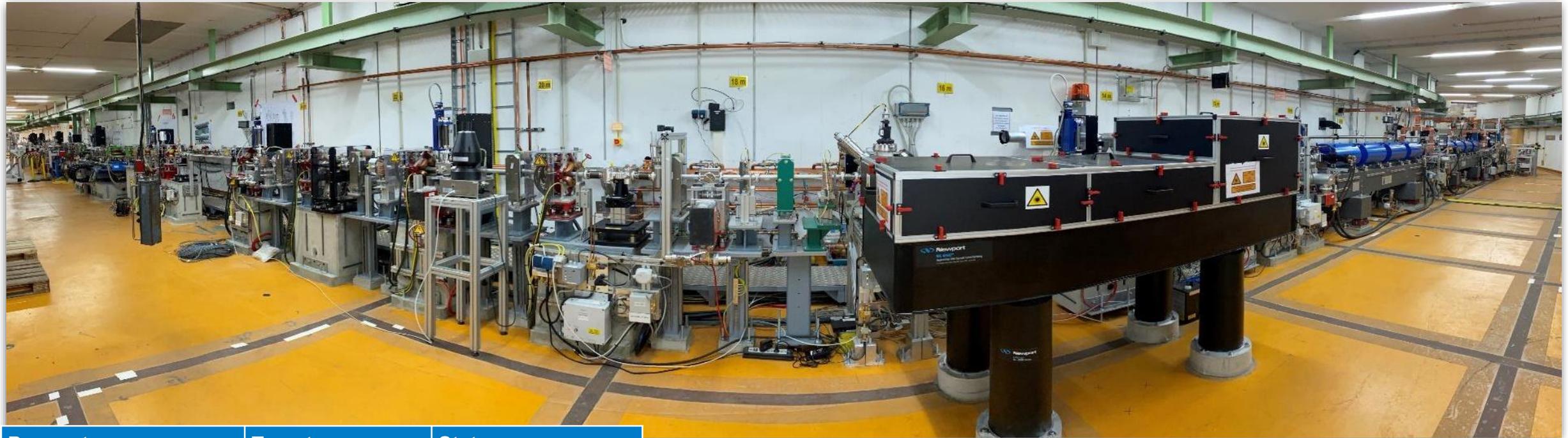
PITZ: Photo Injector Test facility at DESY in Zeuthen, Berlin, Germany
Operational since 2002

SPARC_LAB: Sources for Plasma Accelerators and Radiation Compton with Laser
And Beam, INFN, Frascati, Italy, Operational since 2004

SAFEST: Currently under development, Univ of Roma/INFN/SIT, Rome, Italy



Disclaimer: This presentation covers conventional (RF based) medium energy (<250 MeV) high brightness electron beam test facilities in Europe which provide user access for novel applications (not an exhaustive list)



Parameter	Target	Status
Charge	0.05 - 200 pC	0.003 - 200 pC
Momentum	50 - 150 MeV/c	20 - 160 MeV/c
Momentum Spread	10^{-4}	10^{-4} (res. limited)
Rep rate	10 Hz	1 - 50 Hz
Bunch Length (rms)	Sub-fs to ~10 fs	≈ 2.9 fs
Dose / pulse		2 - 5 Gy

ARES goals:

Generate and characterize **ultrashort e- bunches** (fs to sub-fs) with **high stability** for applications related to **accelerator R&D**.

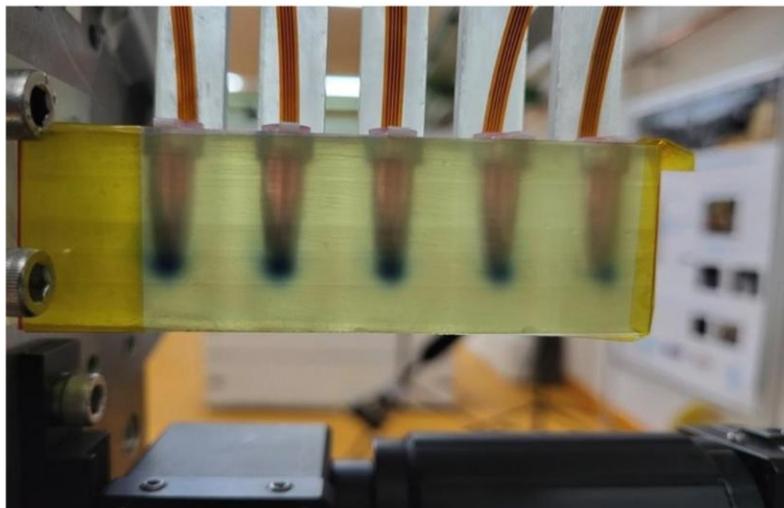
Now strong focus on **medical applications, VHEE & FLASH**, with dedicated experimental area.

ARES: The 3 Pillars for Medical Research

Courtesy of F. Burkart

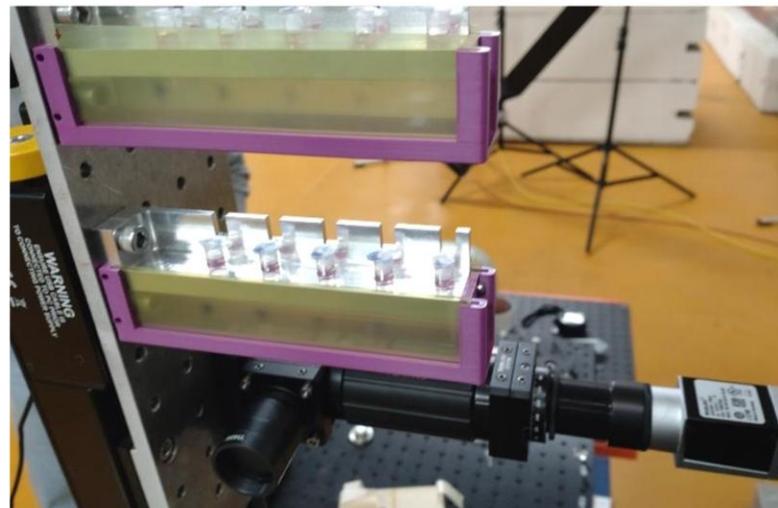


Dosimetry



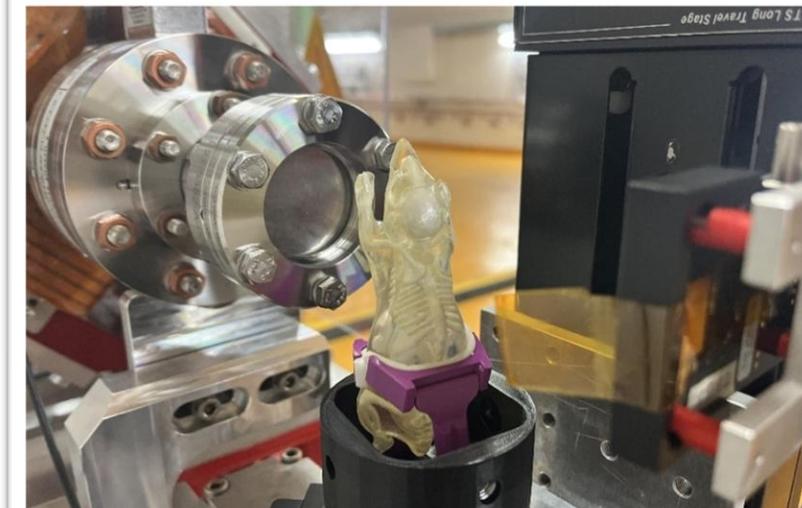
Strong collaboration to develop and test fast & precise dosimetry.

VHEE & FLASH cell irradiation



Starting with cell irradiations, VHEE / FLASH beam parameters with medical partners.

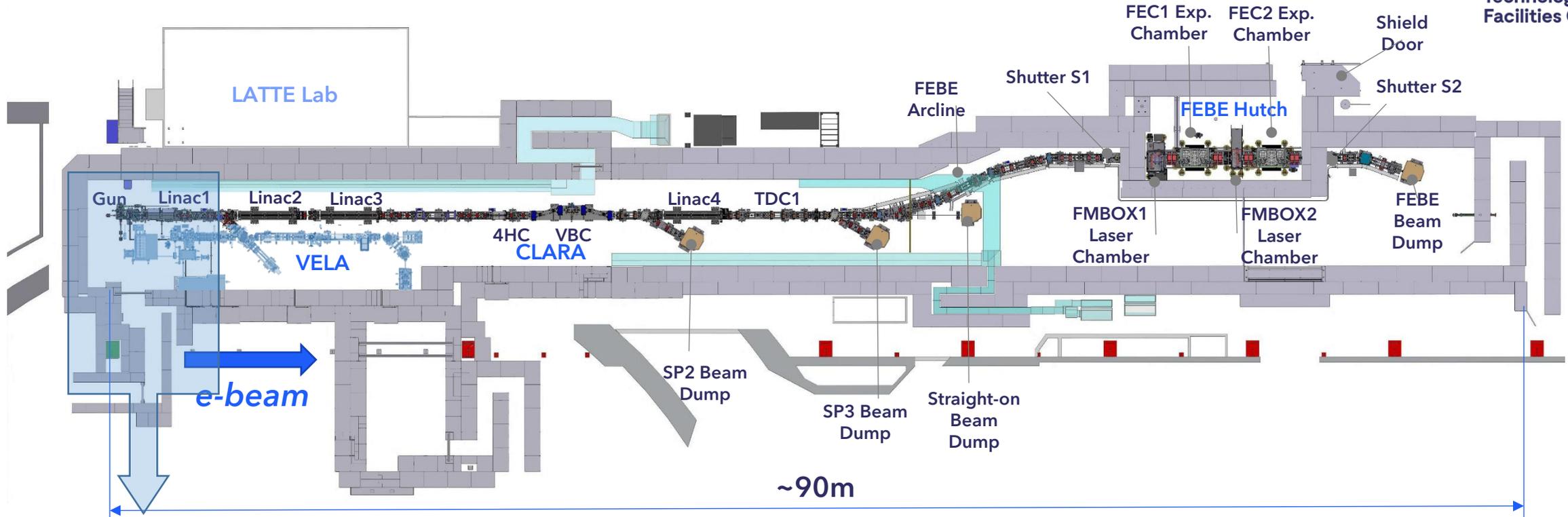
Medical Imaging



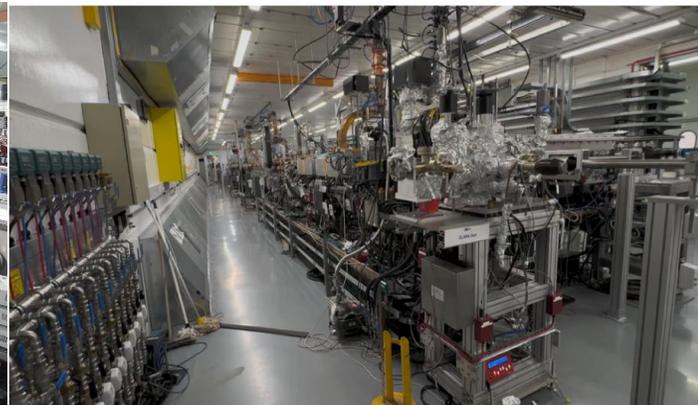
Medical imaging – the electron CT, DESY internal collaboration

Details of these pillars can be found at Status of ARES@DESY, Florian Burkart: [International Workshop on Very High Energy Electron Radiotherapy \(VHEE'25\) \(15-17 September 2025\): Facility Updates Session · STFC Indico](#)

CLARA@Daresbury

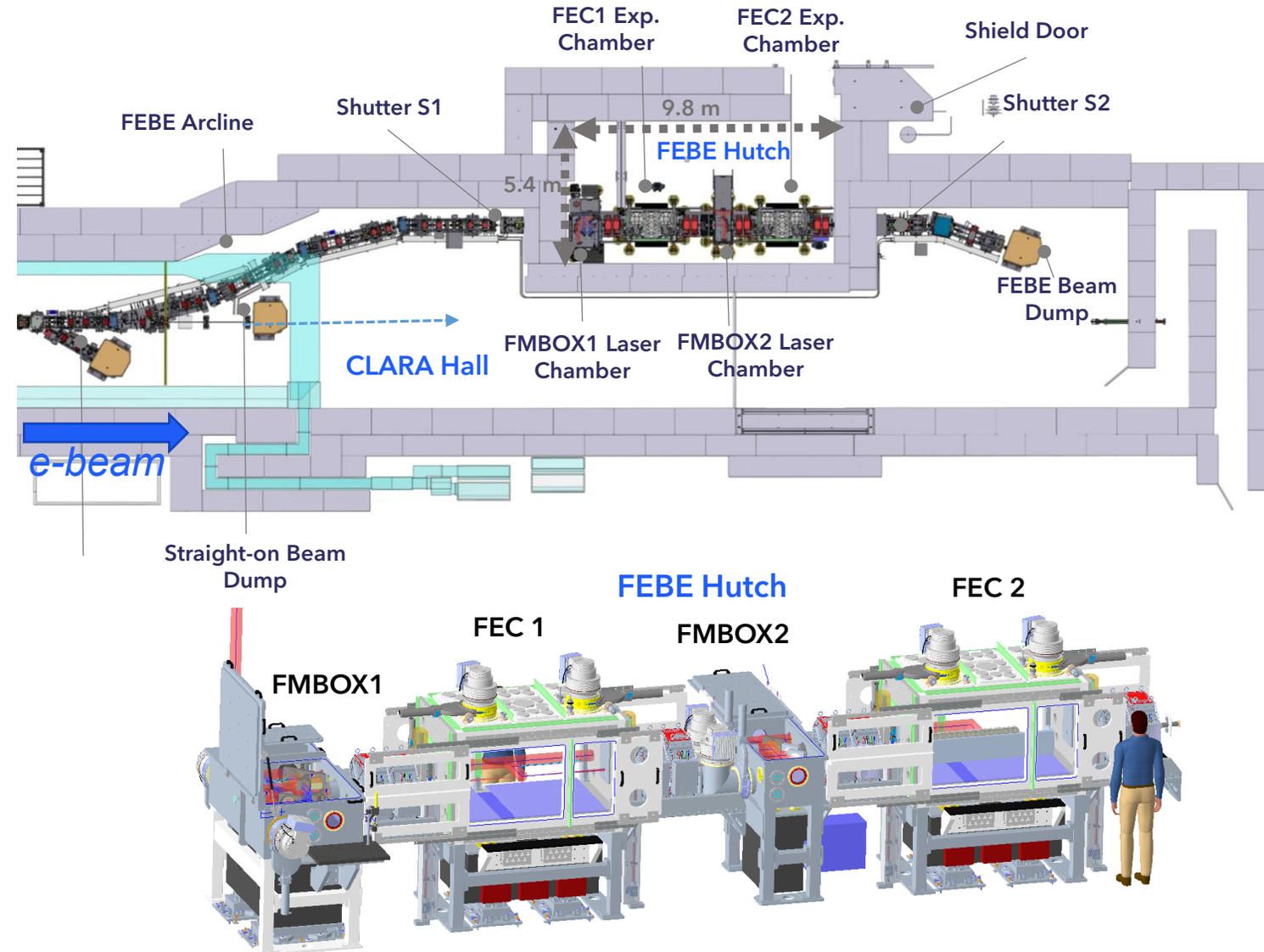


PHASE 1
 50 MeV, 250 pC at 10 Hz
 ACHIEVED (2017).
 Beam delivered to first VHEE
 experiments from 2018-
 2022.



PHASE 2
 250 MeV, 250 pC at 100 Hz.
 First friendly user programme
 currently ongoing.

CLARA Phase 2 – Experimental Hutch



Offered parameters to evolve
'Day 1' → *Nominal* → *R&D*

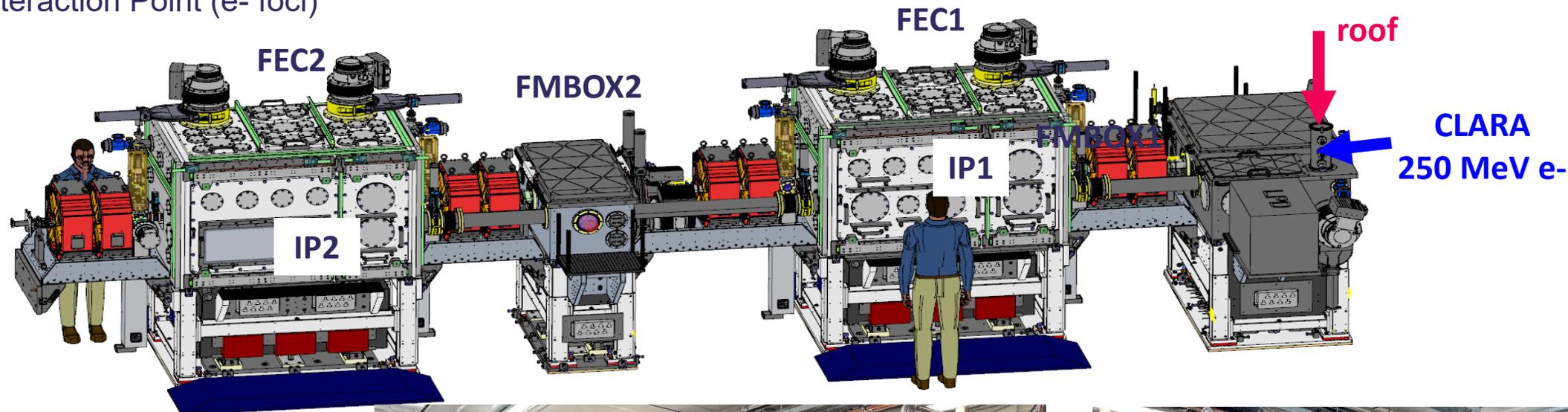
Parameter	High charge	Low charge
Energy [MeV]	250	250
Charge [pC]	250	5
RMS t [fs]	100 (50)	50 (≤ 50)
σ_E/E [%]	<5 (1)	<1 (<1)
RMS x [μm]	100 (50)	20 (1)
RMS y [μm]	100 (50)	20 (1)
$\epsilon_N x$ @ 250 MeV [μm]	5 (<5)	2 (1)
$\epsilon_N y$ @ 250 MeV [μm]	5 (<1)	2 (<1)

These parameters are for short bunches.
As longitudinally compressed bunches will not be required for VHEE/FLASH, emittance will be reduced.

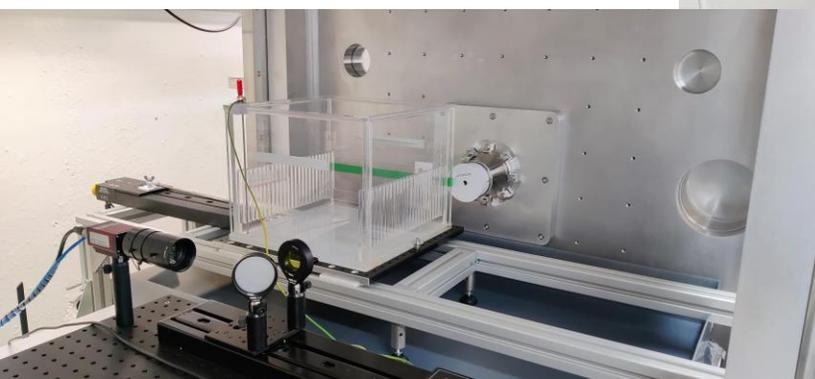
FEBE Hutch Beamline

FEC = FEBE Experiment Chamber
IP = Interaction Point (e- foci)

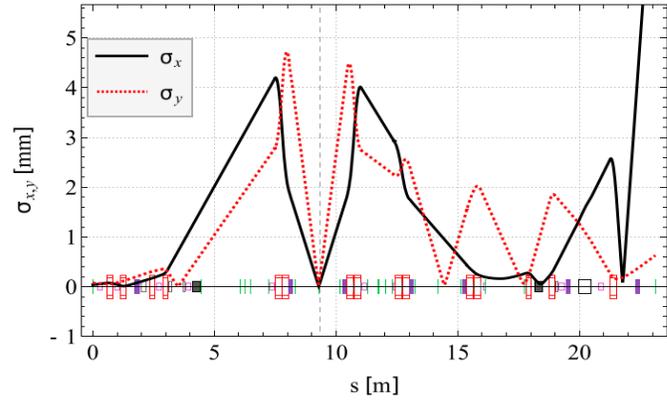
FMBOX = FEBE Mirror Box for high power laser
Laser from



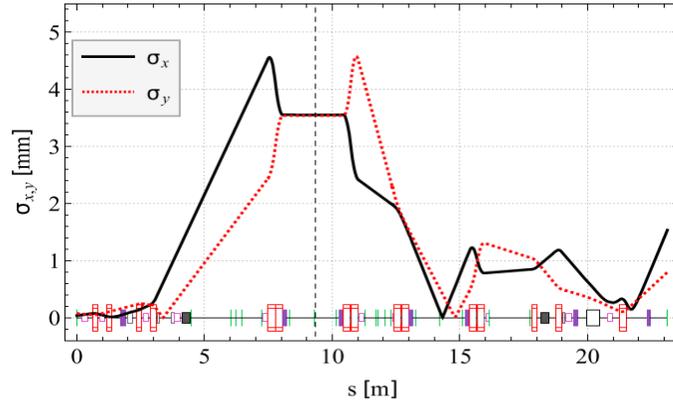
In-air VHEE water phantom in FEC2



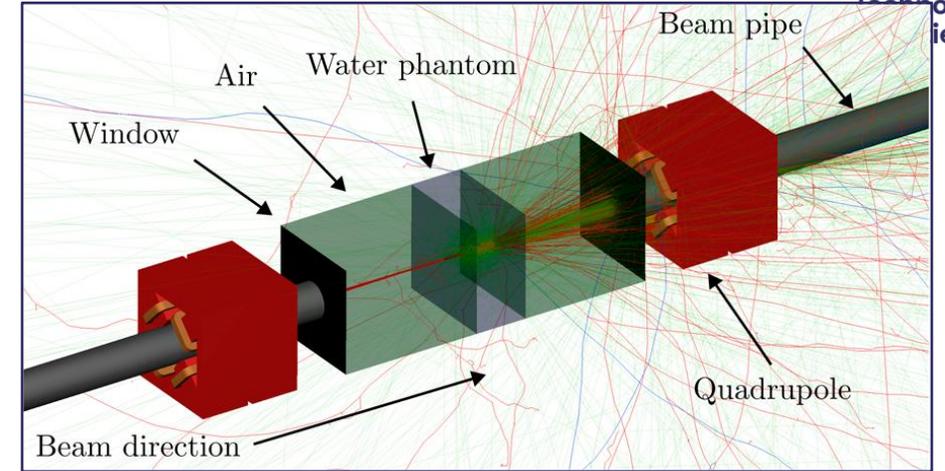
FLASH doses at CLARA



Transverse beam sizes for a focused beam at IP1 in FEC1 *in vacuo*.



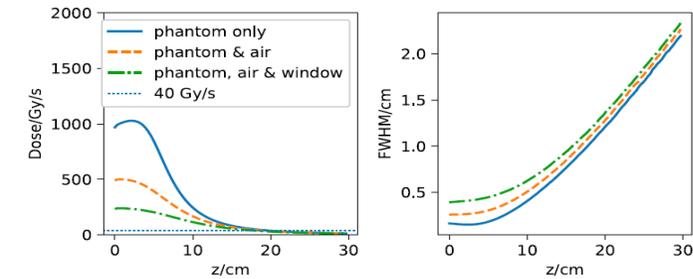
Transverse beam sizes for a pencil beam at IP1 in FEC1 *in vacuo*.



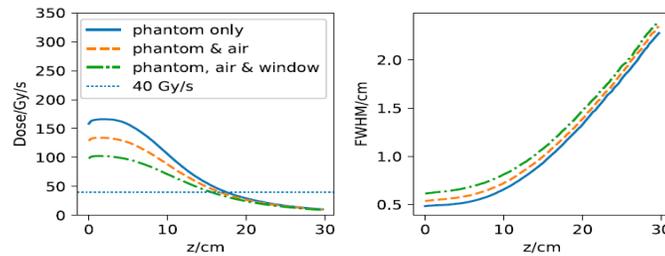
BDSIM/Geant4 visualisation region around the water phantom, including the quadrupoles before and after the experimental chamber.

Possible to deliver FLASH doses on CLARA.

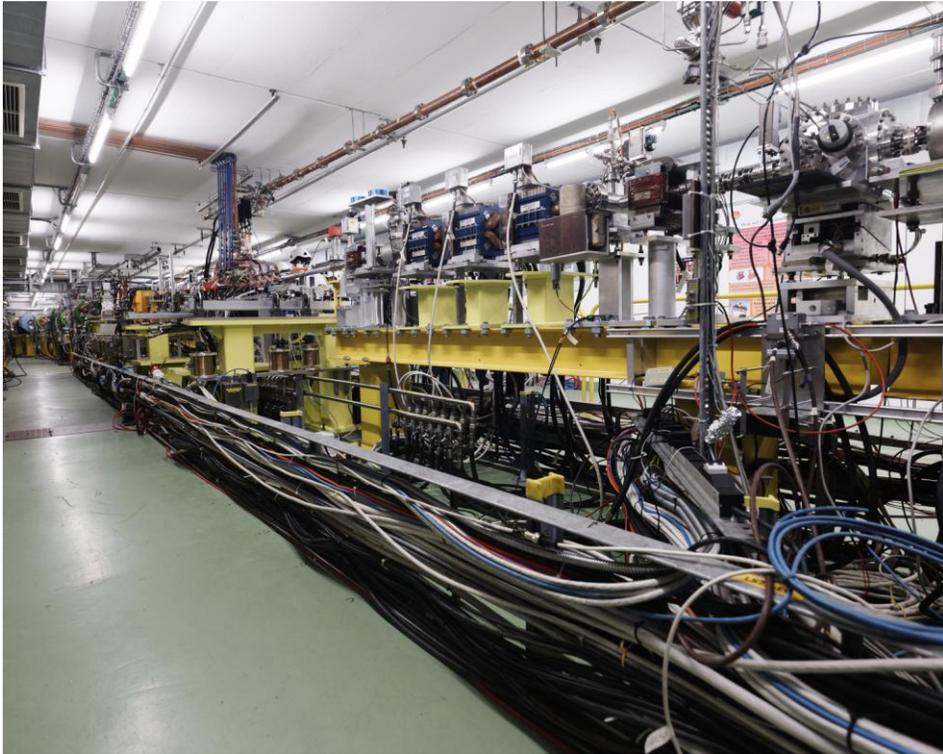
Achieving a large dose uniformly over a large volume will either require a focus spot scanning system or a scattering system.



Axial dose distribution for focused beam. FWHM at half maximum dose of the focused beam distribution as a function of depth in the water phantom.



Axial dose distribution for pencil beam. FWHM at half maximum dose of the pencil beam distribution as a function of depth in the water phantom.



CLEAR is a versatile 200 MeV electron linac followed by a 20 m experimental beamline, operated at CERN from 2017 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. to test electronic components or to investigate **medical applications (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.



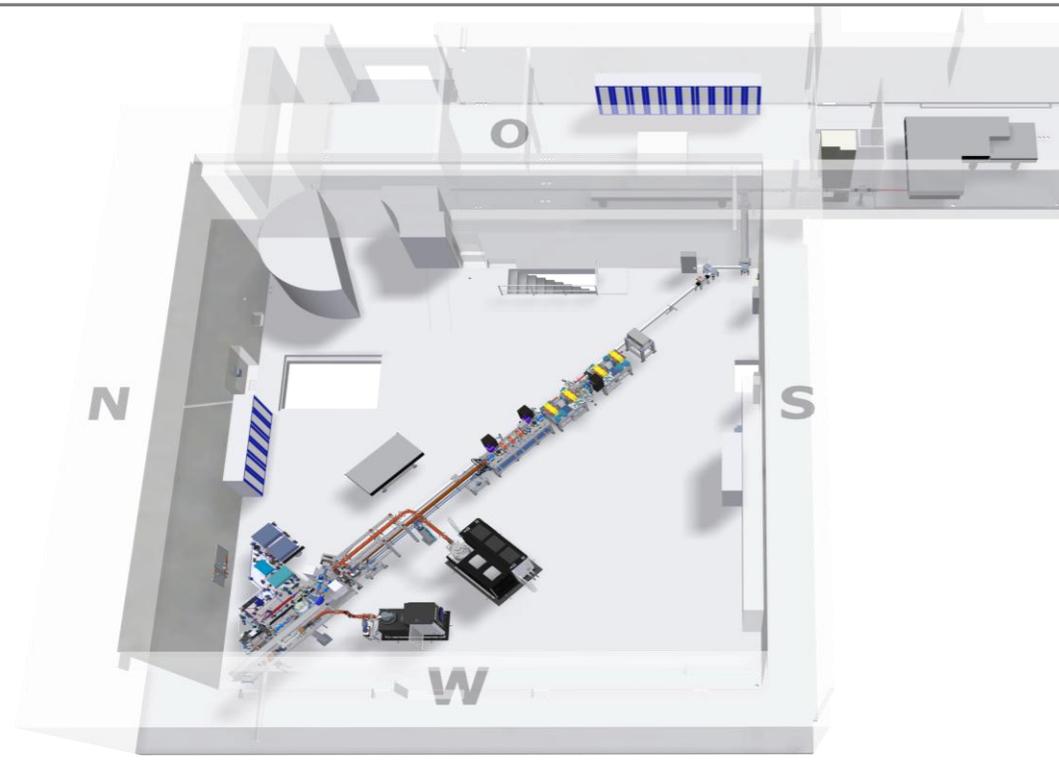
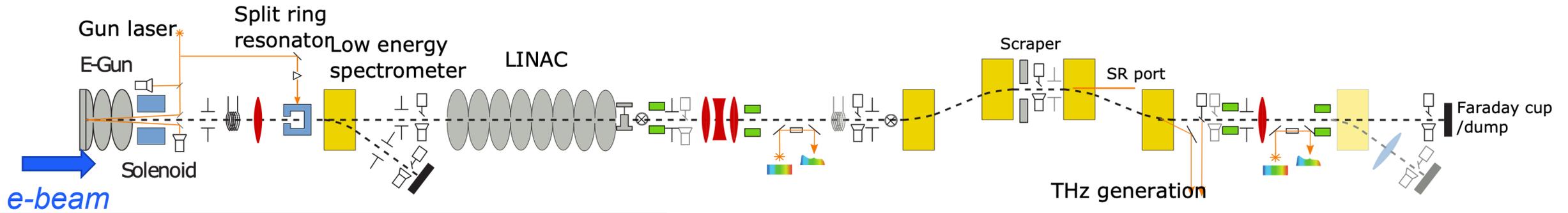
Extended parameter range and performances since 2017

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

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



Antonio Gilardi's talk for details

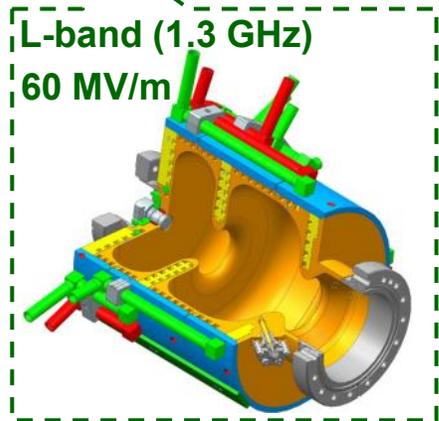
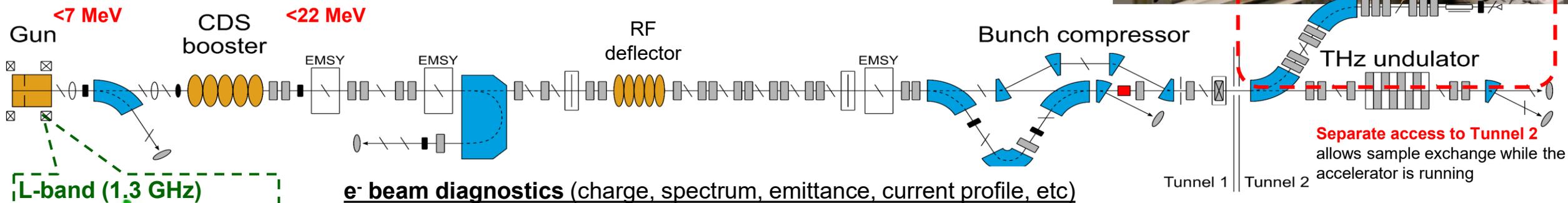
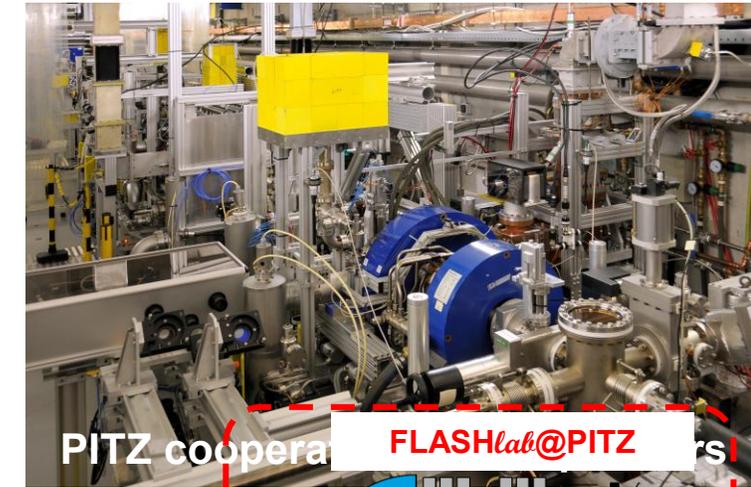


- Ultra-short electron bunches and diagnostics development
- Experiments with THz
- Plans to install SCU

Beam parameter	Range
Energy [MeV]	~41
Bunch Length [fs]	1 - 300
Bunch Charge [nC]	0.001 - 1
Repetition rate [Hz]	10
THz E-Field strength [GV/m]	up to 1.2

www.ibpt.kit.edu/flute

- PITZ develops optimized electron sources (minimized emittance) for short-wavelength Free Electron Laser (FEL) user facilities like the **European X-ray Free Electron Lasers** in Hamburg
- General accelerator R&D and applications of high brightness beam → R&D on electron FLASH radiation therapy (**FLASHlab@PITZ**)



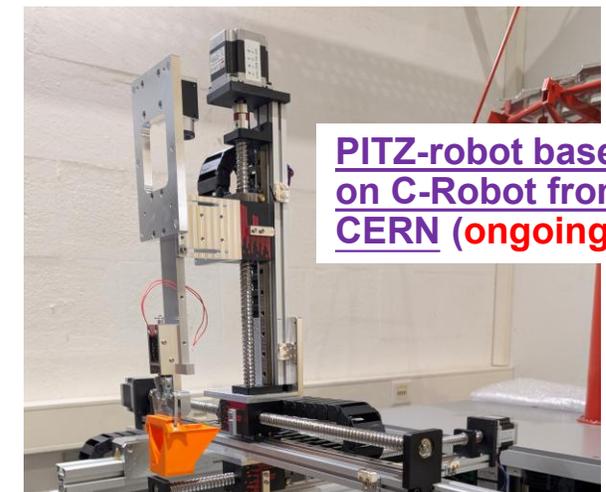
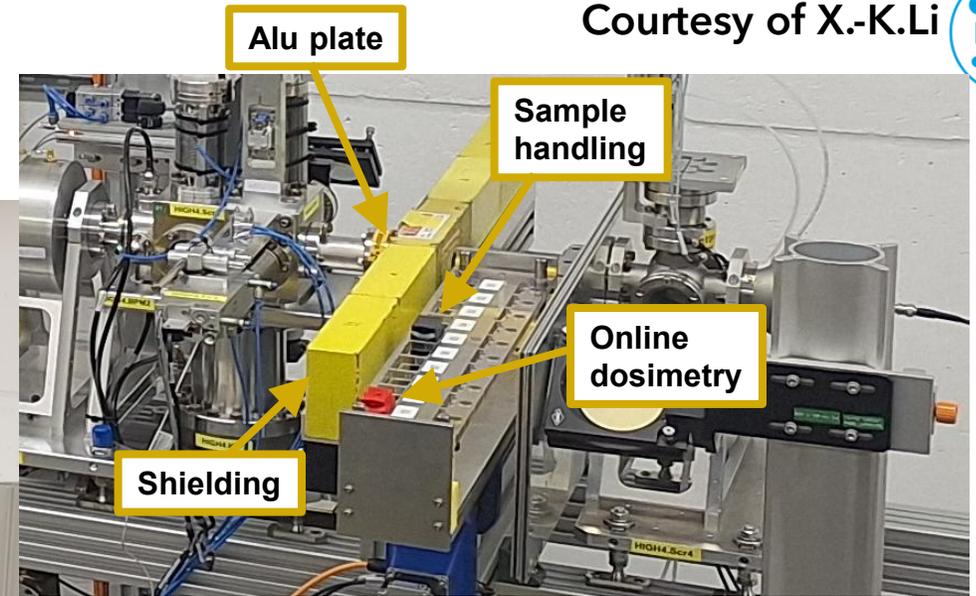
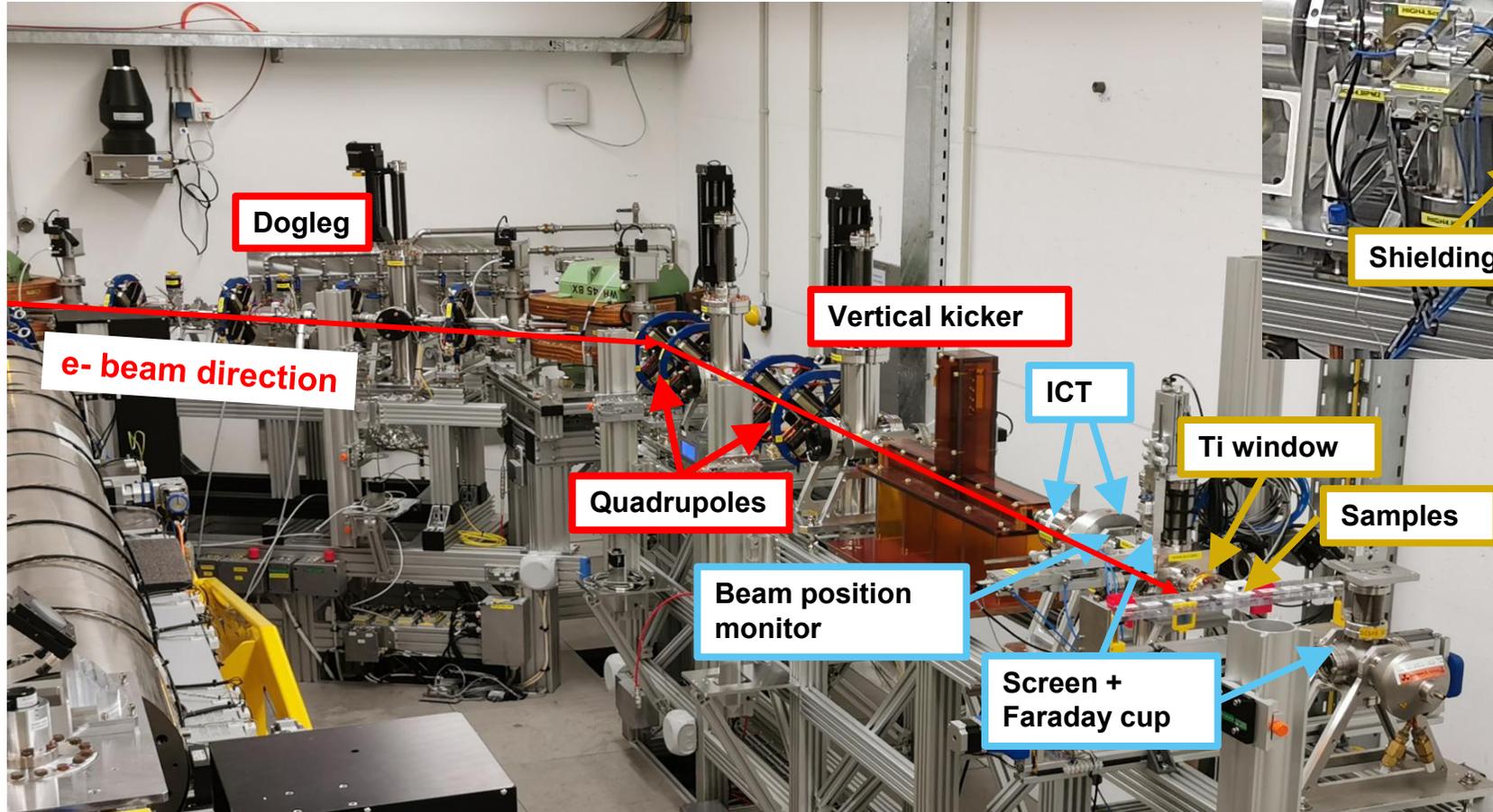
Property	Value
Energy	< 22 MeV
Bunch charge	fC to 5 nC
Duration (FWHM)	0.1 – 30 ps
Beam size (RMS)	μm – mm

- Unique beam properties at PITZ (high bunch charge and long bunch trains) allow extremely flexible treatment parameters and dose distribution (in space + time)
- Depending upon bunch charge (fC~5 nC), average dose rate of 0.02 Gy/s to 1.10⁹ Gy/s can be delivered.
- Beam can be scanned over treatment areas in 1ms.

FLASH lab@PITZ

Overview of beamline, in operation in August 2025

Courtesy of X.-K.Li



See details in X.Li's talk at:
[International Workshop on Very High Energy Electron Radiotherapy \(VHEE'25\) \(15-17 September 2025\): Facility Updates Session · STFC Indico](#)

Overview of Applications at European Facilities

	ARES	CLARA	CLEAR	FLUTE	PITZ	SPARC_LAB
Accelerator Components R&D	√	√	√	√	√	√
Diagnostics R&D	√	√	√	√	√	√
Novel Acceleration (DWA, DLA)	√	√				
Novel Acceleration using high power laser (PWFA, LWFA*, THz)		√				√
Radiation sources				√	√	√
Plasma Lens R&D			√			
VHEE Radiotherapy	√	√	√			
FLASH Radiotherapy		√	√	√	√	
Other medical applications	√			√		
Irradiation experiments (excl RT)			√			

*External injection into LWFA

Summary

- R&D in VHEE, FLASH, VHEE+FLASH is being carried out at several conventional medium energy range facilities in Europe.
- There are several LWFA facilities where this is a hot topic of R&D, which I have not covered here.
- In 2017, we started VHEE workshop at Daresbury, followed by 2020(CERN), 2023 (DESY) and 4th one in Daresbury in 2025. The next one will be in Rome in 2027.

- Significant growth in the research community as well as engagement with industry.
- Many challenges (e.g. radiobiology, dosimetry, treatment therapy,...etc) remain to be addressed to establish VHEE+FLASH radiotherapy modality clinically.



[The 4th International Workshop on Very High Energy Electron Radiotherapy \(VHEE'25\) \(15-17 September 2025\): Overview · STFC Indico](#)

**Thank you for
listening**

**Any
Questions?**