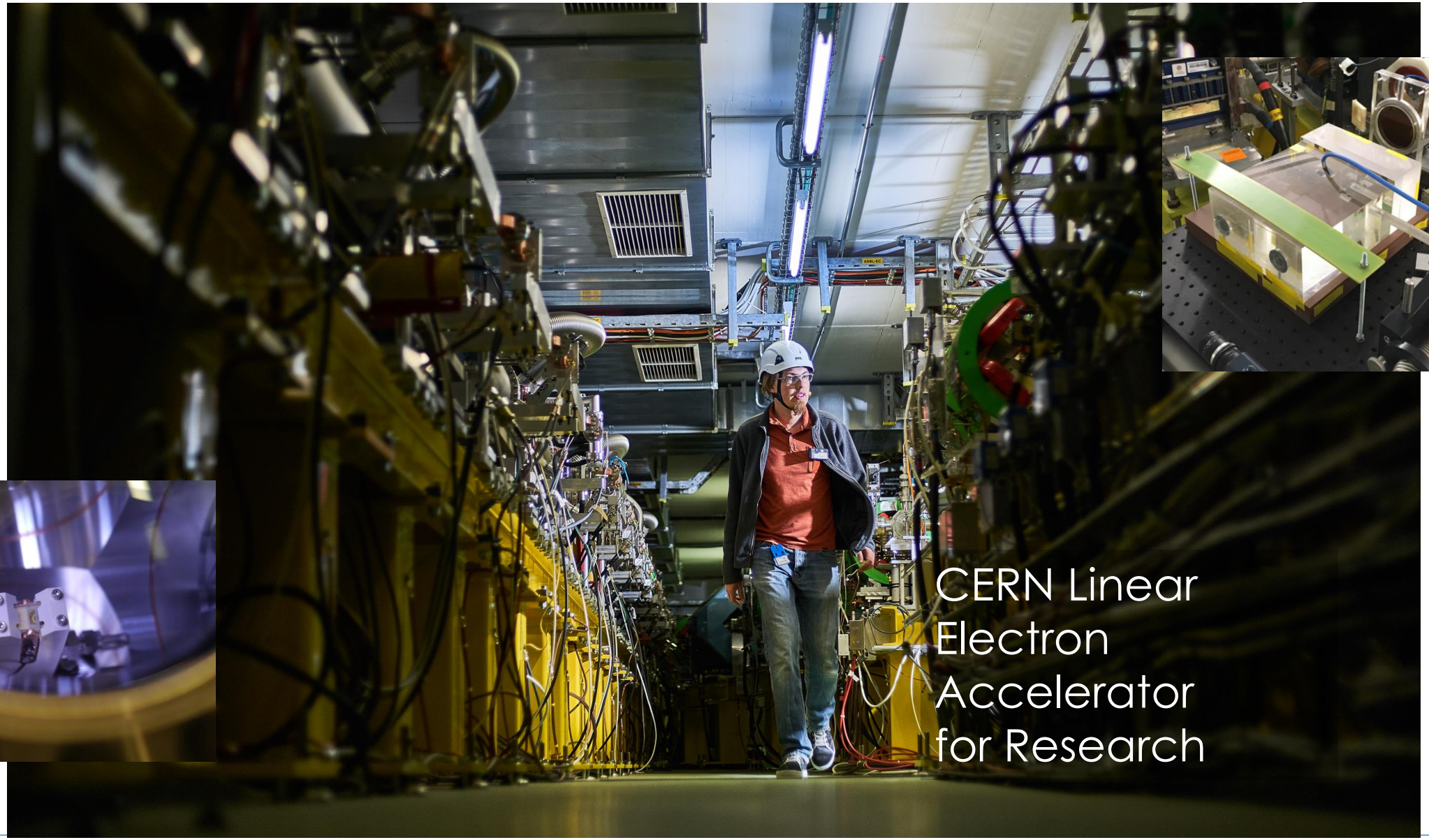
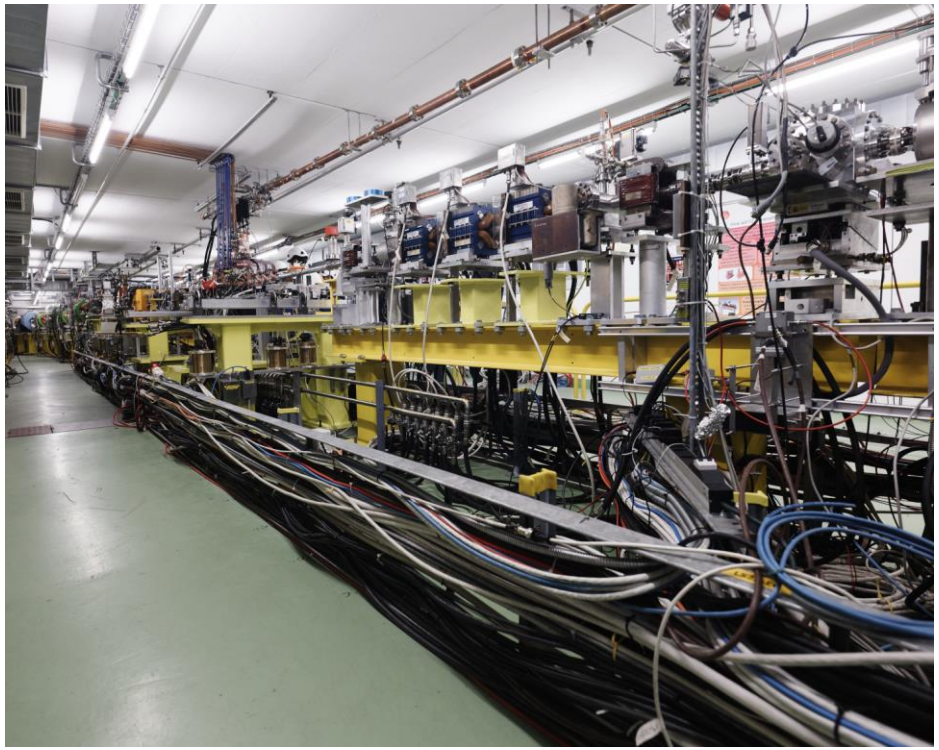
CLEAR beyond 2025 and Scenarios for e- Future Test Facilities at CERN

R. Corsini
for the CLEAR Team



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.

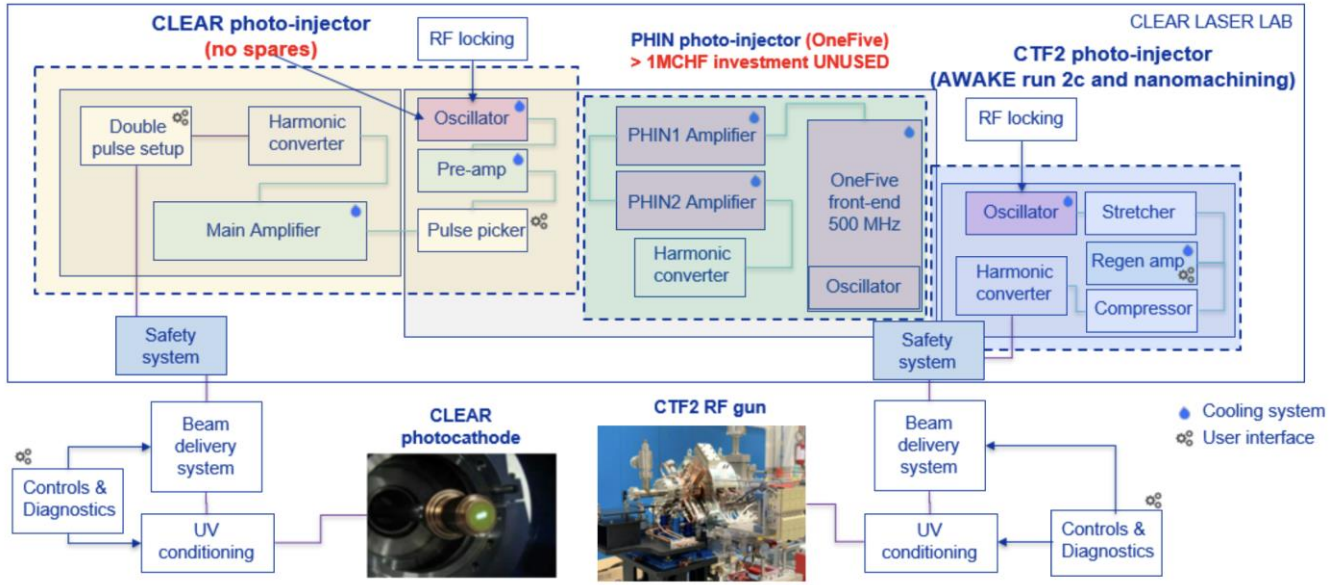
Scientific and strategic goals:

- 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.

Short-term improvements - laser

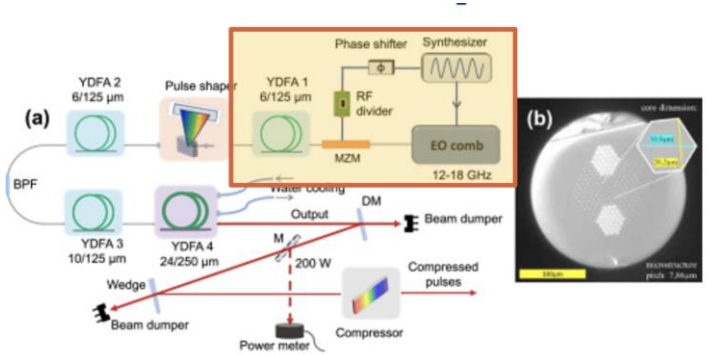
Laser systems at CLEAR – current status

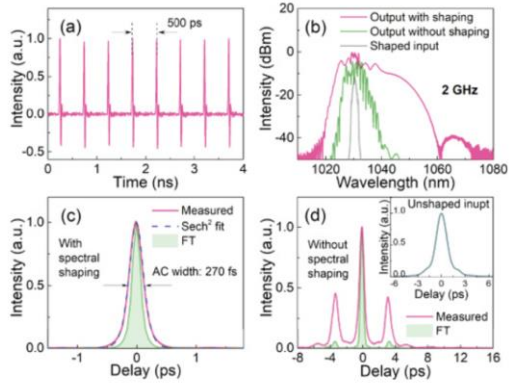


E. Granados, B. Marsh

CLEAR laser points of failure:

- Ageing oscillator – could be replaced by OneFive system but operating at 500 MHz
- Laser sub-systems often fail and require replacements and spares (chillers, pulse-picker power supplies, laser diodes, laser power supplies, optical elements and motors)





New EO comb front-end

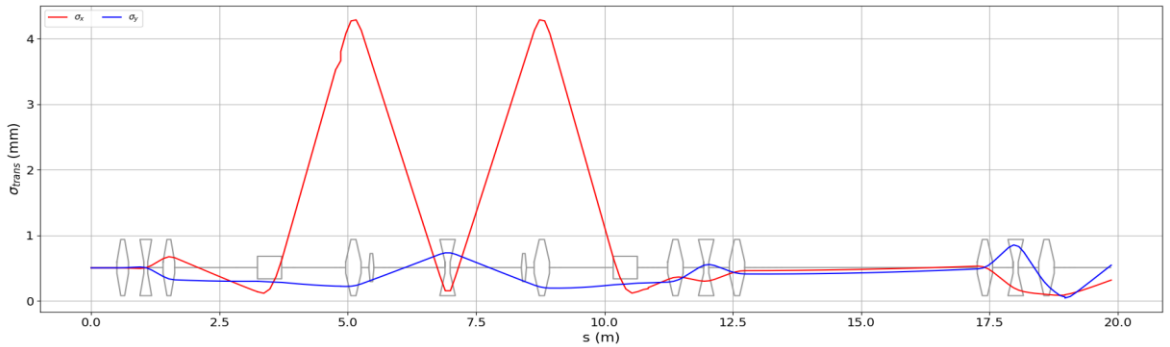
- Enhance significantly CLEAR performances (stability, time structure flexibility, high rep-rate)

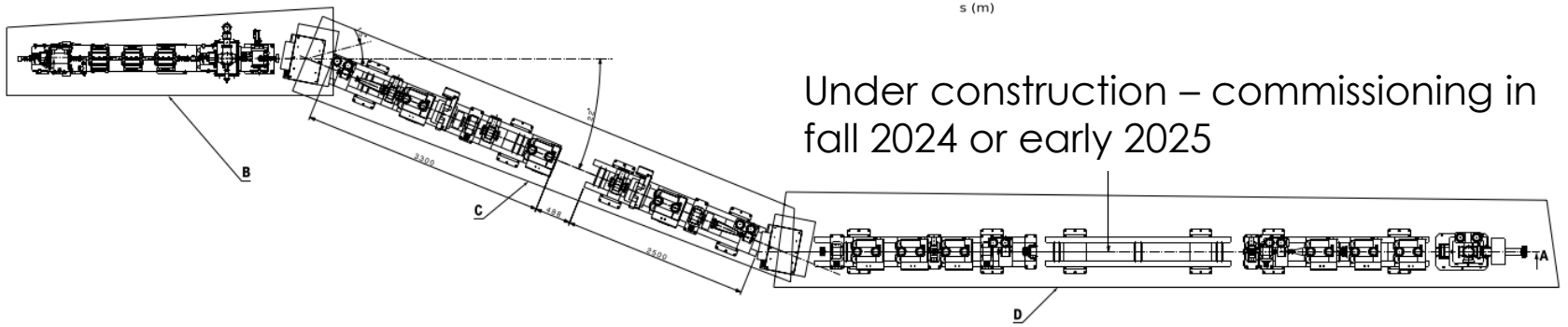
- ~ 100 kCHF program over 2 years
- System may be ready at end 2024

Short-term improvements – new beam line

Motivations

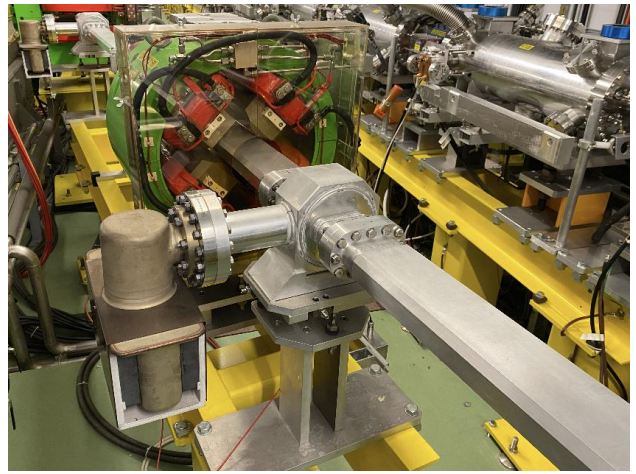
- Create more in-air and in-vacuum test areas for experiments – avoid repeated mounting/dismounting of experiments and diagnostics equipment, hence more beam time
- Added operational flexibility – allow for "non compatible" experiments to be performed in the same week or day, with fast turnaround time
- Expand beam parameter space, e.g., large beam sizes and strong focusing





Under construction – commissioning in fall 2024 or early 2025

Magnets, power supplies and most components and vacuum chambers from former drive beam chicane and TBL in CLEX, including pumping ports, bellows, pumps, vacuum valves, …



Longer-term improvement – new electron source

- A new electron source (photoinjector + X-band accelerating structure) is presently being commissioned in stages in the former CTF2 area, adjacent to the CLEAR hall.
- Joint effort between CLIC, AWAKE and CLEAR.
  - The initial aim was to develop a front-end for AWAKE Run 2, and to use it before final installation in AWAKE as an additional source in the CLEAR hall.
  - Present plans favors its use after commissioning and before installation in AWAKE as an independent beam line in the present location (CTF2), and as a part of the CLEAR user facility.
  - This solution will have the advantage of being less costly and time consuming, and will better fit present user demand for more beam time and for low-energy beams, rather than two-beam experiments
- This option depends on the actual timeline for AWAKE, the eventual CLEAR extended operation, and on the potential user interest. Main user operation beyond 2025, but some limited use is possible before.
- It will also require some additional resources, particularly in manpower.

Common development of novel electron source

CLIC-AWAKE-CLEAR

Expectations and outlook on activities 2025+

So far, demand for experiments on CLEAR steadily increased (bar the pandemic period). As shown previously, we are now saturating our capacity to provide beam time to all users. We expect requests will not decrease for the next few years. Improvements and consolidation should enable us to cope with a slightly higher load.

- Beam diagnostics R&D is an important area, with about 30% of total tests, and now shared equally between CERN and external users – easy to anticipate that requests will increase/stay constant for several years beyond 2025.
- Novel acceleration techniques (plasma, THz, x-band high gradient) are not growing, but there are a few rather long-term programs which will continue (including Plasma Lens, continued support to AWAKE, and potentially a full-fledged ICS experiment).
- Medical activities are surely a highlight – the next 4-5 years will be critical to fully establish VHEE/FLASH (fundamental studies, including time structure dependence, and optimization of parameters) and its enabling technologies (beam delivery, dosimetry and control). If extended, CLEAR will be for several years a unique facility for VHEE/FLASH, with a key role in the field – including knowledge transfer to other labs with capability for animal testing.
- Activity in other areas (irradiation, neutron production, beam test of particle detectors and detector components…) is also increasing overall, and it will provide further opportunities.

Finally, from a strategic viewpoint, CLEAR is well placed to play a role on the roadmap towards a Higgs factory at CERN > *more on the next slides*

Strategic role of CLEAR for future Higgs factories

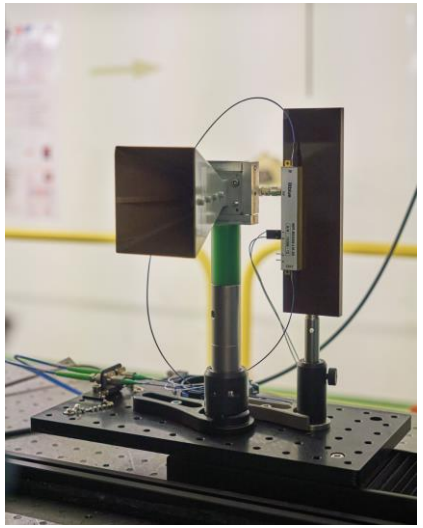
Main relevant areas:

1. Beam diagnostics R&D for FCC-ee
2. Other FCC-ee dedicated experiments in CLEAR
3. Keeping at CERN hands-on experience (both on hardware and beam operation) on electron accelerators – a role partly shared with AWAKE
4. Training of young scientists
5. Both the CLEAR machine and its experimental team might be the seed for a future larger facility paving the way to FCC-ee

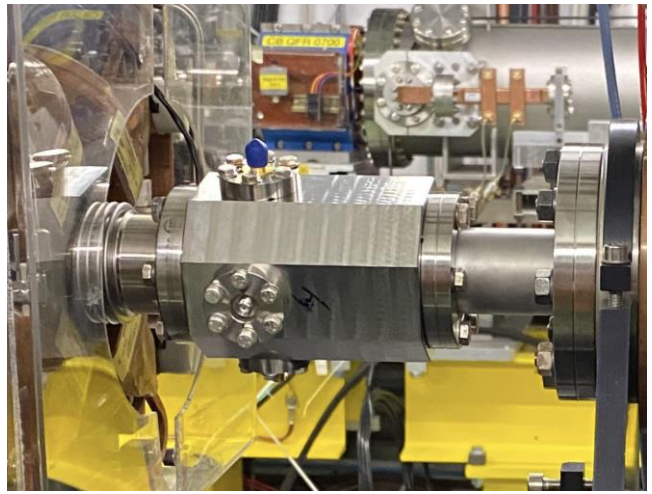
Present contributions to FCC-ee

Beam diagnostics Experiments in 2023

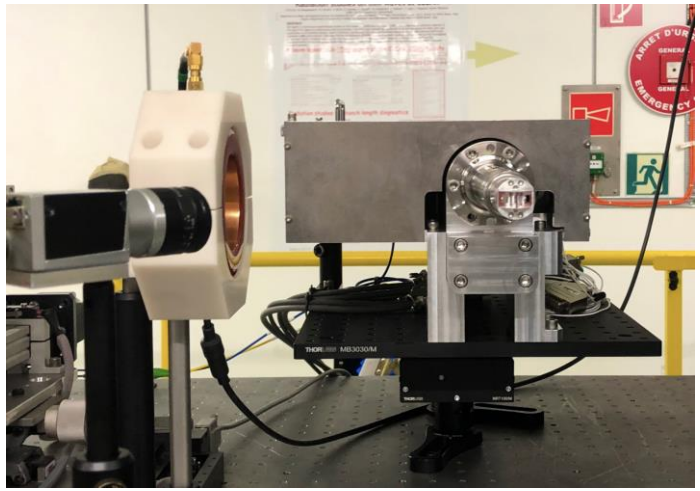
CERN & external institutes, usually in collaboration



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



Broadband Pick-up for the PSI Positron Production Project (P^3 - FCC-ee collaboration)



Bunch Profile Monitor for FCC-ee (KIT - Karlsruhe)

Planned Experiments in 2024

- Electro-Optical Longitudinal Bunch Profile Monitor for FCC-ee (KIT)
- Coherent Cherenkov diffraction radiation dielectric buttons (CERN, BI)

NEW: Damage test of positron target materials (CERN, STI – M. Calviani, A. Perillo Marcone)
⇨ discussion ongoing on future program, including positron detection, etc…

Training

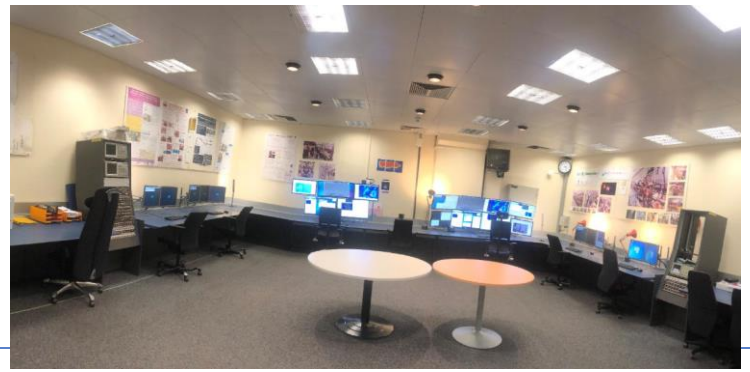
juas
Joint Universities Accelerator School



Hands-on training (JUAS, EURO-LABS), hosting Trainees, Summer/Technical and PhD students, Fellows, Associates…

PhD Thesis:

- **University of Manchester (2023)**: Design and Experimental Verification Study of Non-invasive Short Electron Bunch Length Monitor for AWAKE Run 2 (link).
- **University of Jagiellonian (2022):** Non-Invasive Beam Diagnostics With Schottky Signals and Cherenkov Diffraction Radiation (link).
- **University of Huddersfield (2022)**: Design and Development of an Optical Beam Loss Monitor Based on Cherenkov Light Detection for the CERN Super Proton Synchrotron Accelerator (link).
- **University of Oxford (2022):** Studies for upgrading and optimising the CLEAR beamline, and generating uniform electron-beam profiles for irradiation experiments (link).
- **University of Cambridge (2021)**: Convolutional neural networks and photonic crystals for particle identification at high energy collider experiments (link).
- **University of Naples (2021)** : Measurements of wakefields and bunch length with beam in linear electron accelerators: a case study at CLEAR (link).
- **University of Oxford (2020):** Development of a beam position monitor for co-propagating electron and proton beams (link).
- **University of Strathclyde (2020):** Investigation of focused Very High Energy Electrons (VHEEs) as a new radiotherapy method (link).
- **University of Manchester (2019):** VHEE Radiotherapy Studies at CLARA and CLEAR facilities (link).
- **University of Jyväskylä (2019):** Single-Event Radiation Effects in Hardened and State-of-the-art Components for Space and High- Energy Accelerator Applications (link).
- **University of Oslo (2019):** Emittance growth and preservation in a plasma-based linear collider (link).

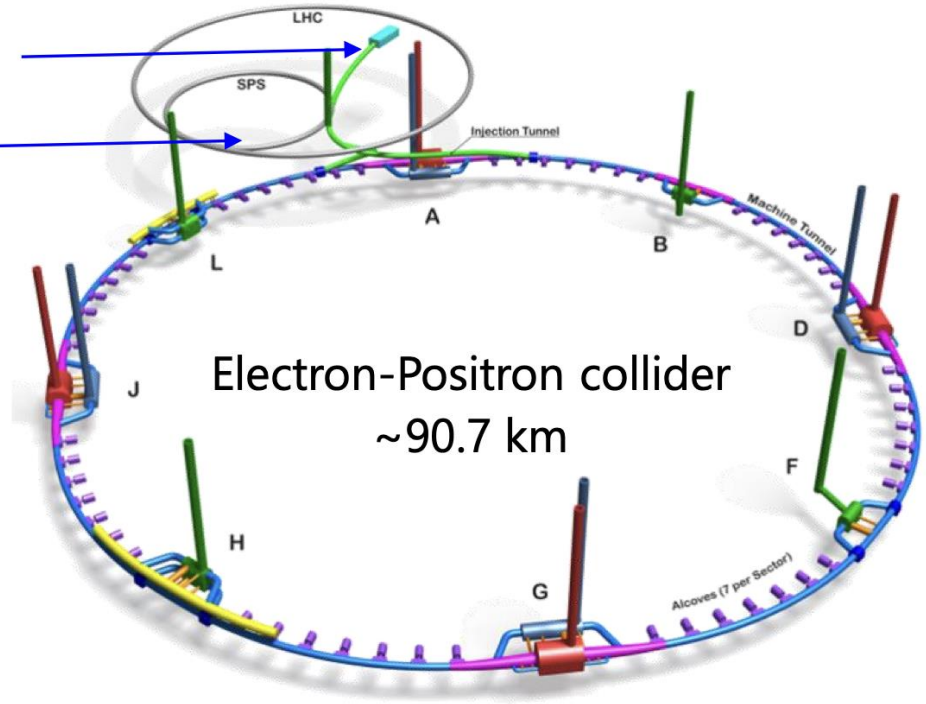


A few thoughts on future facilities I

Paolo Craievich

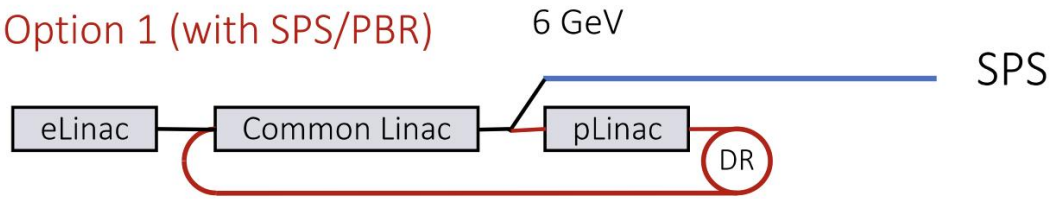
Injector complex, total length ~1.1 km

SPS to be used as a Pre-booster

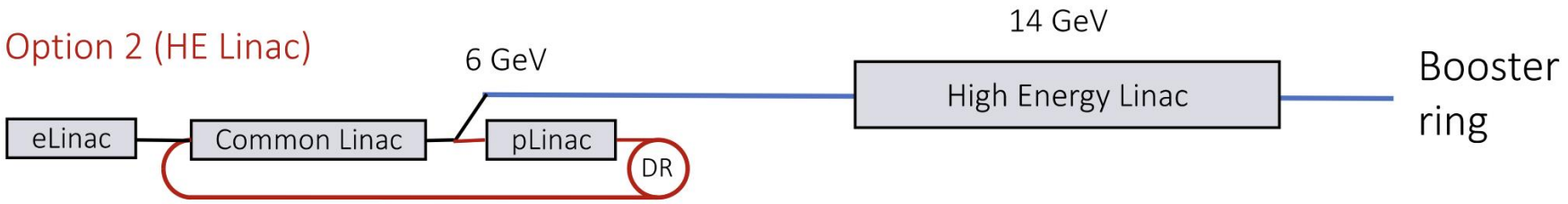


FCC Injector Complex

Option 1 (with SPS/PBR)



Option 2 (HE Linac)



S band (2 GHz, 2.8 GHz)

C band (2 GHz, 5.6 GHz)

	SPS	HE Linac	Unit
Injection energy	6	20	GeV
Bunch charge both species	4.0*	4.0*	nC
Repetition rate	200	200	Hz
Number of bunches	2	2	
Bunch spacing	25	25	ns
Norm. emittance (x, y) (rms)	10,10	10,10	mm mrad
Bunch length (rms)	~1	~1	mm
Energy spread (rms)	0.3	~0.1	%

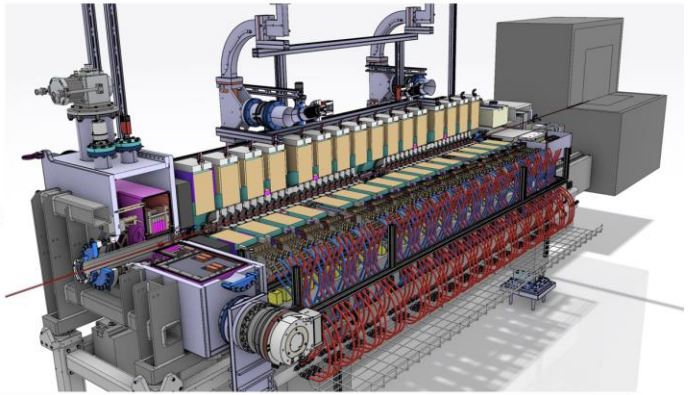
A few thoughts on future facilities II

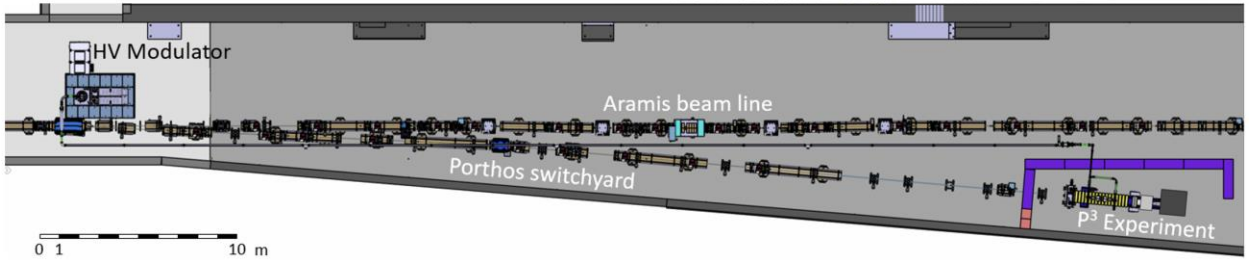
Paolo Craievich

PSI Positron Production (p-cubed) experiment

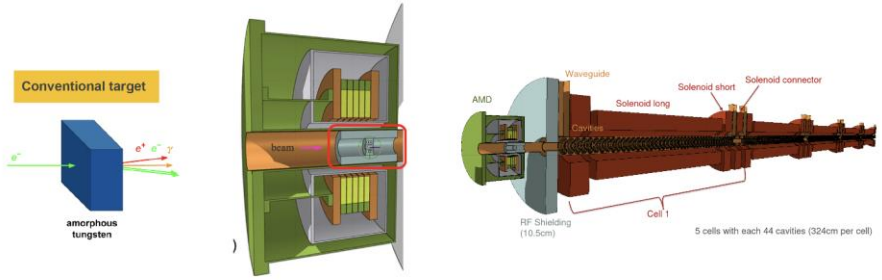
FCC Page 22

- Design phase well advanced, several components are ordered
- Installation on the Porthos extraction line ongoing
- Ongoing collaboration with CERN STI for the target
- Experiments in 2025/2026





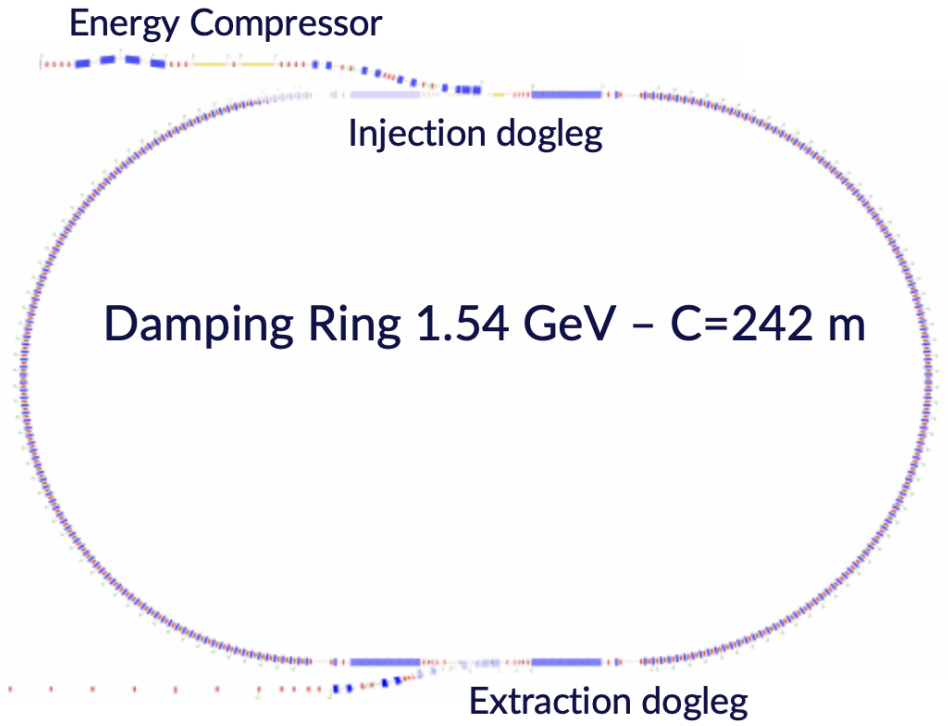
N. Vallis et al., Proof-of-principle e + source for future colliders, accepted PR AB.



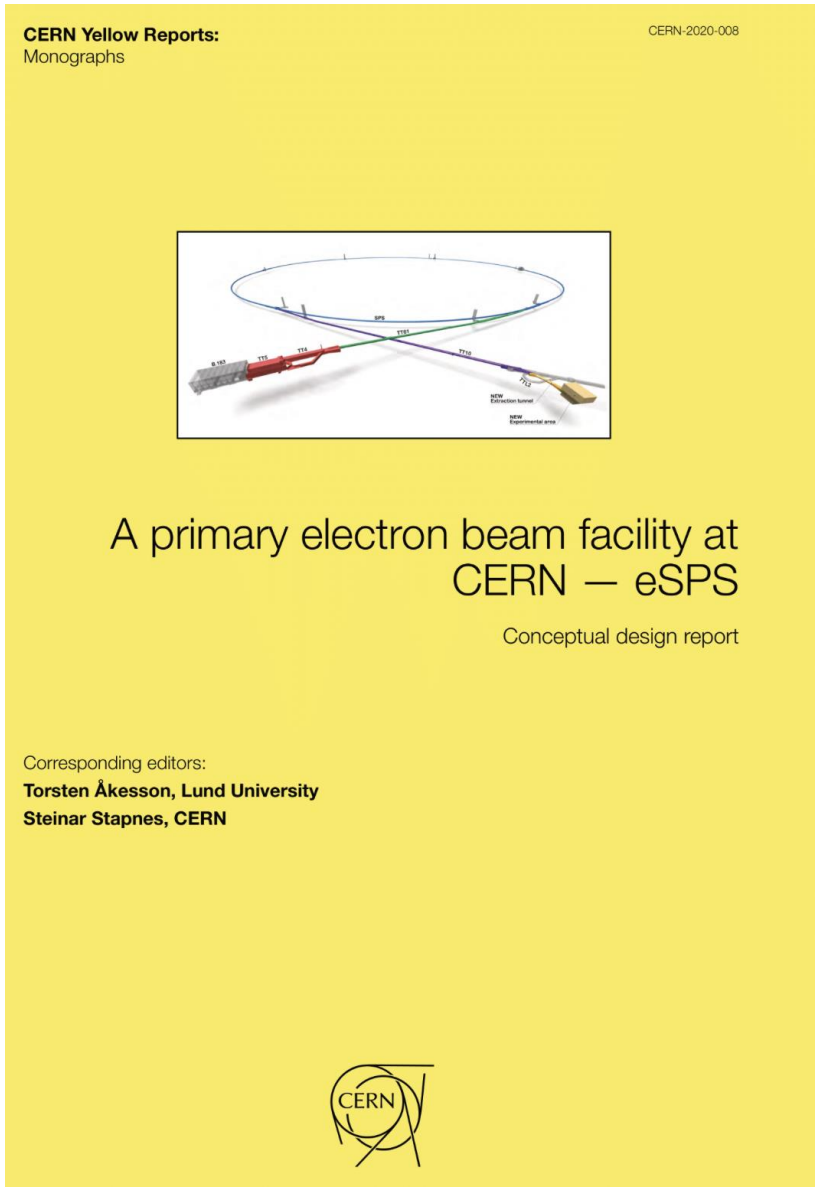
Conventional target

Matching device (MD)

Capture linac and solenoid focusing



A few thoughts on future facilities III

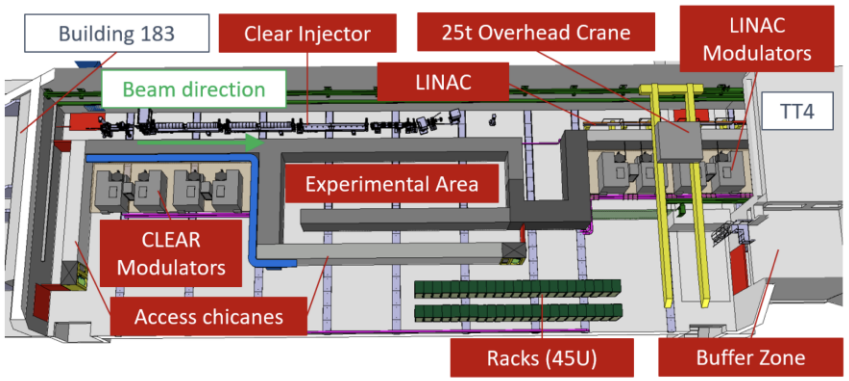


Physics motivations: Light dark matter searches, neutrino physics

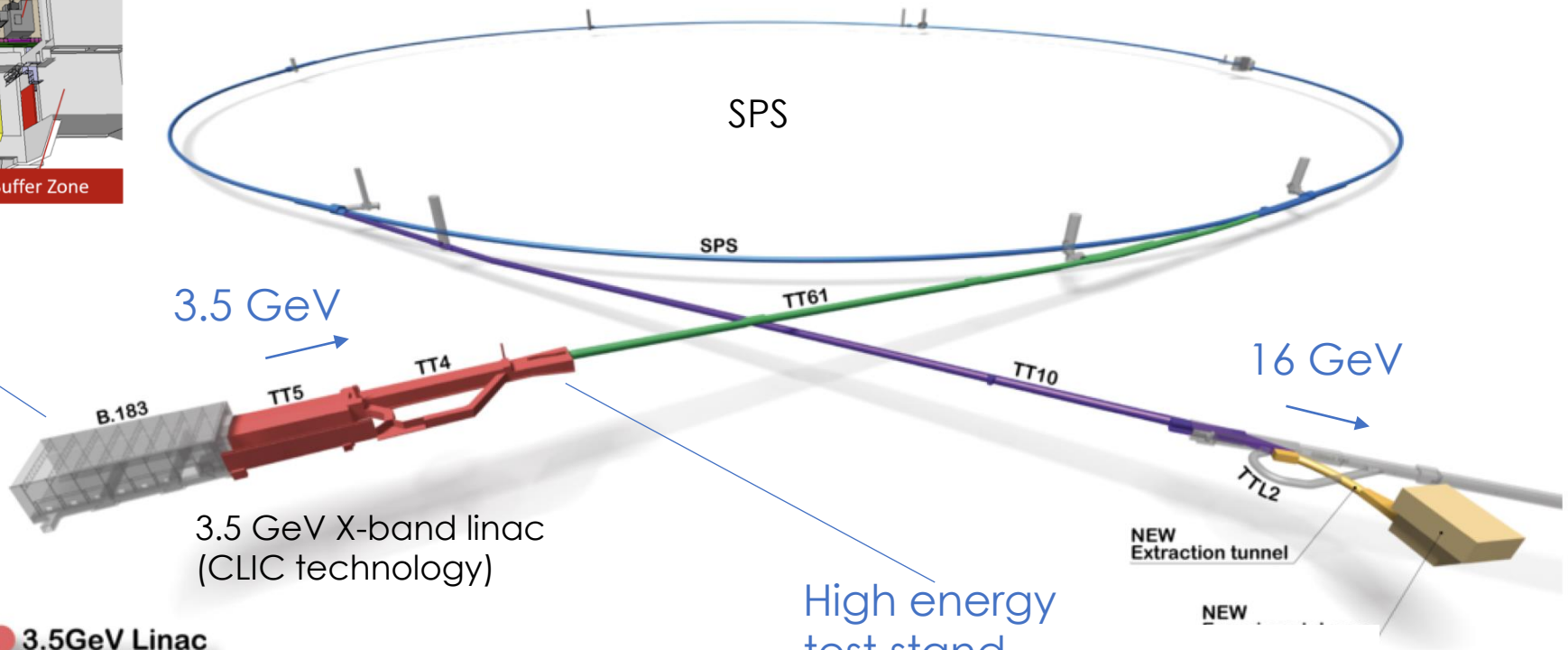
Abstract

The design of a primary electron beam facility at CERN is described. The study has been carried out within the framework of the wider Physics Beyond Colliders study. It re-enables the Super Proton Synchrotron (SPS) as an electron accelerator, and leverages the development invested in Compact Linear Collider (CLIC) technology for its injector and as an accelerator research and development infrastructure. The facility would be relevant for several of the key priorities in the 2020 update of the European Strategy for Particle Physics, such as an electron-positron Higgs factory, accelerator R&D, dark sector physics, and neutrino physics. In addition, it could serve experiments in nuclear physics. The electron beam delivered by this facility would provide access to light dark matter production significantly beyond the targets predicted by a thermal dark matter origin, and for natures of dark matter particles that are not accessible by direct detection experiments. It would also enable electro-nuclear measurements crucial for precise modelling the energy dependence of neutrino-nucleus interactions, which is needed to precisely measure neutrino oscillations as a function of energy. The implementation of the facility is the natural next step in the development of X-band high-gradient acceleration technology, a key technology for compact and cost-effective electron/positron linacs. It would also become the only facility with multi-GeV drive bunches and truly independent electron witness bunches for plasma wakefield acceleration. A second phase capable to deliver positron witness bunches would make it a complete facility for plasma wakefield collider studies. The facility would be used for the development and studies of a large number of components and phenomena for a future electron-positron Higgs and electroweak factory as the first stage of a next circular collider at CERN, and its cavities in the SPS would be the same type as foreseen for such a future collider. The operation of the SPS with electrons would train a new generation of CERN staff on circular electron accelerators. The facility could start operation in about five years, and would operate in parallel and without interference with Run 4 of the LHC.

The e-SPS proposal



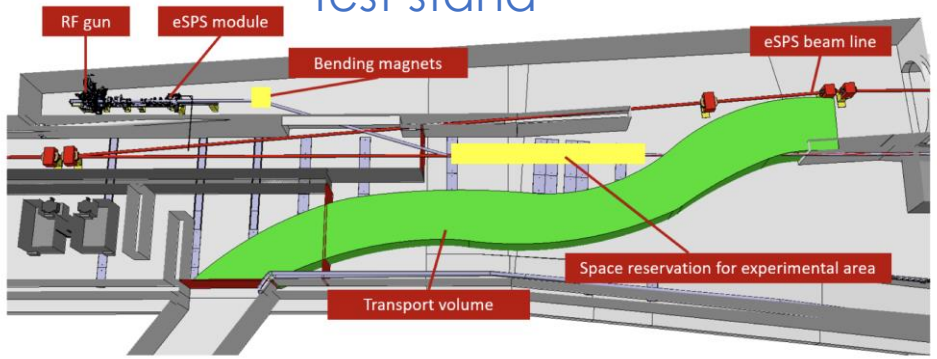
Low energy user facility
~ 200 MeV



3.5 GeV X-band linac
(CLIC technology)

- 3.5GeV Linac
- Transfer to SPS
- Acceleration in SPS
- Extraction
- NEW Extraction tunnel
- NEW Experimental area

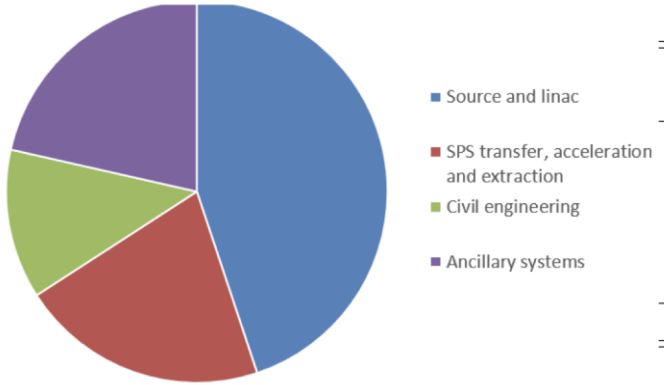
High energy test stand



Relevance of e-SPS for CLIC, cost

Table 6.1: Main CLIC related activities and their relation to the 3.5 GeV linac for eSPS.

Details	Purpose	eSPS Equivalent	Comment
Main linac modules			
Build ten prototype modules in qualified industries, two beam and klystron versions	Final technical design, qualify industry partners, verify performance	12 X-band klystron modules	Covered by eSPS but adaptations to two beam modules need to be considered
Accelerating structures			
Around 50 structures incl. for modules above	Industrialisation, manufacturing and cost optimisation	Same number needed	Programmes overlapping
Operating X-band test-stands, high efficiency RF			
X-band test-stands at CERN and collaborating institutes, cost optimised X-band RF	X-band component test, validation and optimisation, cost reduction and industrially available RF units	Similar test capacity needed for eSPS, 24 X-band RF units needed for eSPS	Programmes overlapping
Technical components			
Magnets, instrumentation, alignment, stability, vacuum	Luminosity performance, costs and power, industrialisation	These components are also needed for eSPS	eSPS specifications less stringent, however significant advantage to implement in smaller complete system
Design & Parameters			
Beam dynamics studies, parameter optimisation, costs, power	Luminosity performance, risk, costs and power reduction	Needed for eSPS linac	Specific studies for CLIC needed but good reality check



Item	cost [MCHF]
Source and linac	49.8
SPS transfer, acceleration and extraction	23.4
Civil engineering	14.0
Ancillary systems	23.8
Sum	111.0

- May a similar project be developed based on requirements for FCC-ee ?
- Is it the size/cost/time scale relevant/affordable?
- Possibly, such facility should aim at being compatible with (parts of) the final FCC-ee injector complex

Can't resist…

Proceedings of IPAC2013, Shanghai, China TUPME042

THE SPS AS AN ULTRA-LOW EMITTANCE DAMPING RING TEST FACILITY FOR CLIC

Y. Papaphilippou, R. Corsini and L. Evans, CERN, Geneva, Switzerland

Some additional considerations

- Presently, CLEAR (and the AWAKE e-linacs) are the only electron accelerators at CERN. If CERN is serious about a e^+e^- Higgs factory as its next flagship project, experimental activities based on electron accelerators should be at least maintained.
- Expertise and training achieved and maintained in CLEAR (and AWAKE) are strategically important for a future Higgs factory at CERN.
- In itself, CLEAR (and the AWAKE e-linacs) are not large enough to be a sufficiently large stepping stone towards FCC-ee (or a linear collider).
- A "large" facility would be needed to ramp-up expertise and industrial basis at the right level for the next flagship project. Such facility should have one or more physics goals and cover several critical aspects of the final project.
- If such a "large" facility could accommodate as well multi-purpose user-dedicated areas and R&D for future activities, it will be more attractive (and justified).
- An exercise on designing such a facility partly aimed at the CLIC project was done (e-SPS). This could be a good model to try and adapt.
- However, e-SPS was thought more a multi-purpose facility, covering needs of a pre-approval phase of a big project. If, e.g., the facility comes after approval of FCC-ee, it should possibly target (a part of) the final injector complex.
- One or more smaller facilities – or experiments, targeting specific technological or beam physics issues of the final project are also a possibility.

Conclusions

- Short-term improvements and consolidation of CLEAR equipment are under way and should provide the facility with more effective beam time and added flexibility already in 2025.
- The improvements may prove to be critical for some important experiments, mainly in the medical area, but also possibly for FCC-ee.
- User requests are growing, and the facility is very close to saturate all possible beam time. Some "real" selection will likely have to be put in place in 2024.
- We expect this load will continue in the future, at least for several years. We are planning for an extension to end 2030, and we believe a full, meaningful experimental program covering this period is granted.
- The CLEAR facility is fundamental for maintaining e-beam expertise at CERN, for training, and can be a potential stepping stone towards the next flagship accelerator at CERN, FCC-ee (or its potential alternatives).

Thanks for your attention!