Compact Electron Linacs for Research, Medical, and Industrial Applications

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Contents

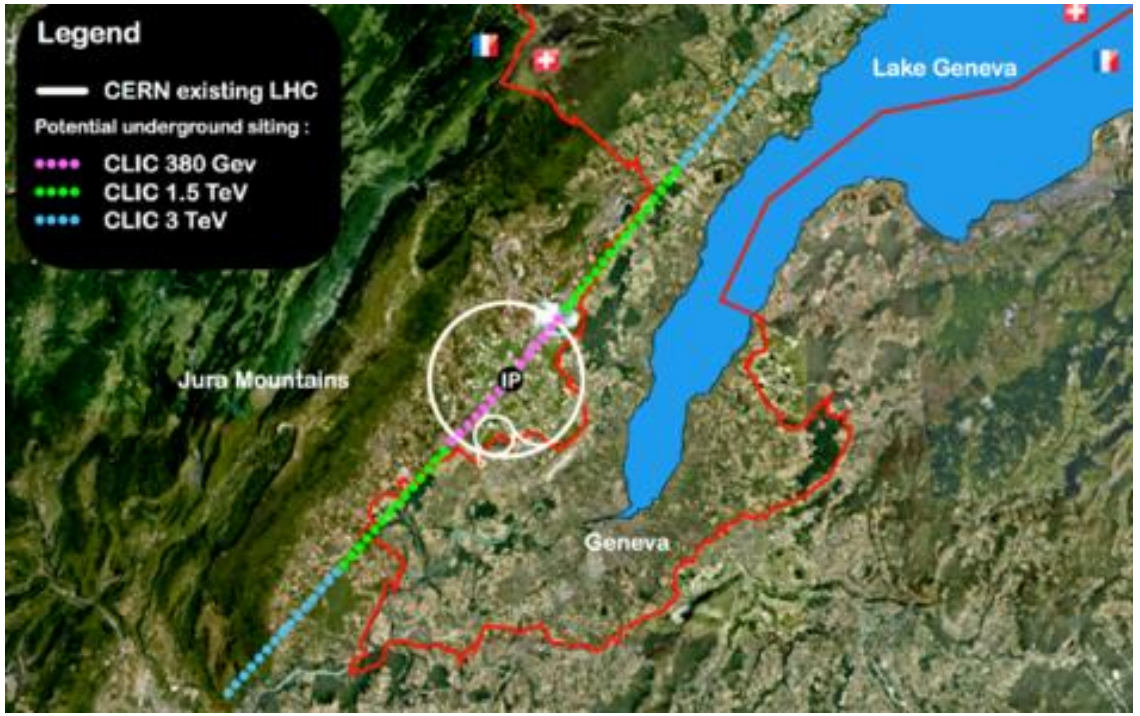
- **High-gradient technology**
  - CLIC
  - X-Band

- **Compact electron linac projects presented in this talk**

Medical	Industrial	Research
DEFT	VULCAN	CLEAR / AWAKE Injector
STELLA		PolariX
	EuPRAXIA@SPARC_Lab ⟷	EuPRAXIA@SPARC_Lab
	XLS ⟷	XLS
	VIGAS ⟷	VIGAS
	Smart*Light ⟷	Smart*Light

CLIC (Compact Linear Collider)

- **Concept, design, and technical R&D for next-gen, multi-TeV linear collider**
- **Required development of high-gradient accelerator technology**
  - More compact
  - More efficient
  - More affordable
- **Promote industrial base and application of CLIC technologies as part of R&D strategy**

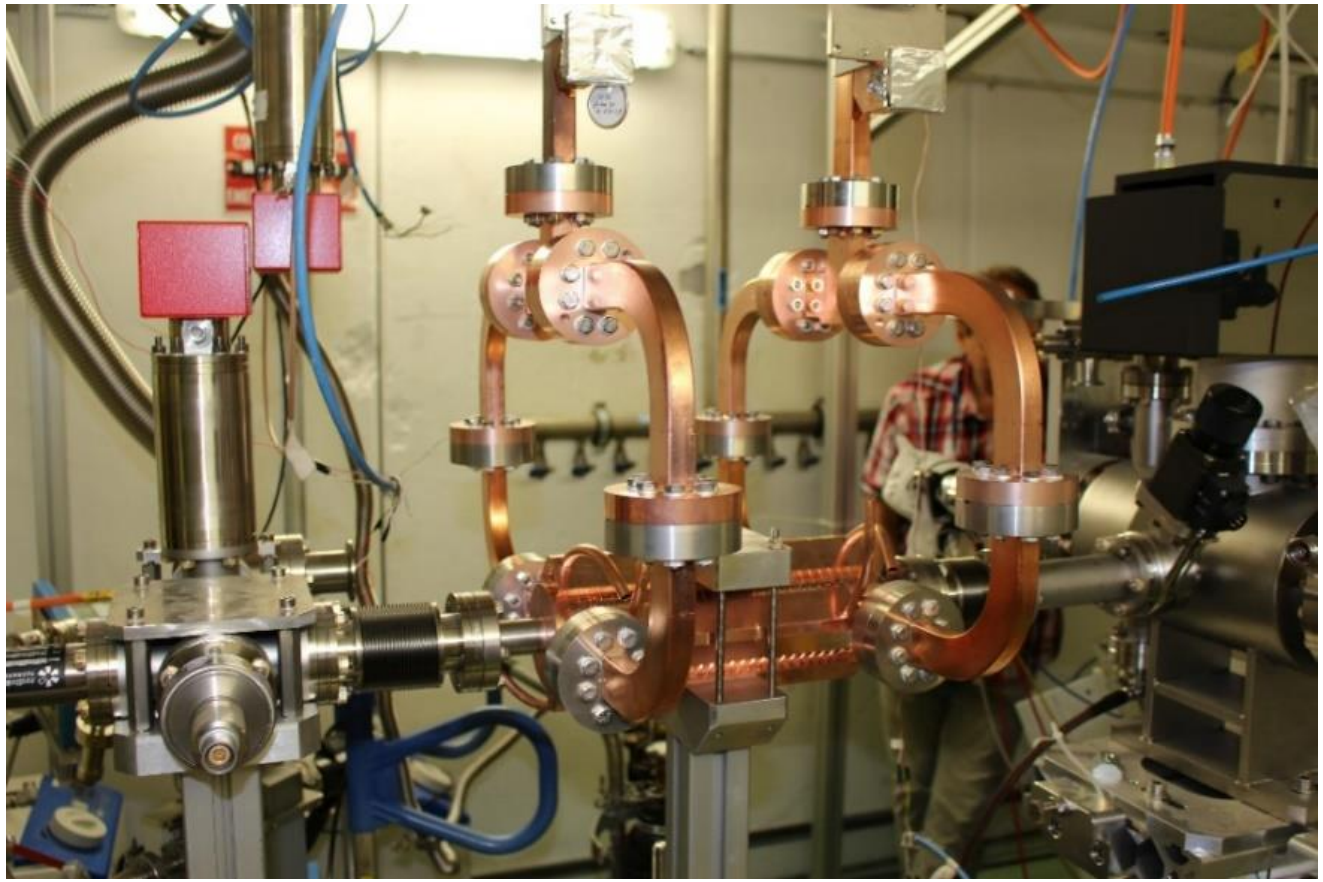


Accelerating structure prototype for CLIC:

- ***12 GHz (L~25 cm)***
- ***100 MV/m***

High-Gradient Acceleration

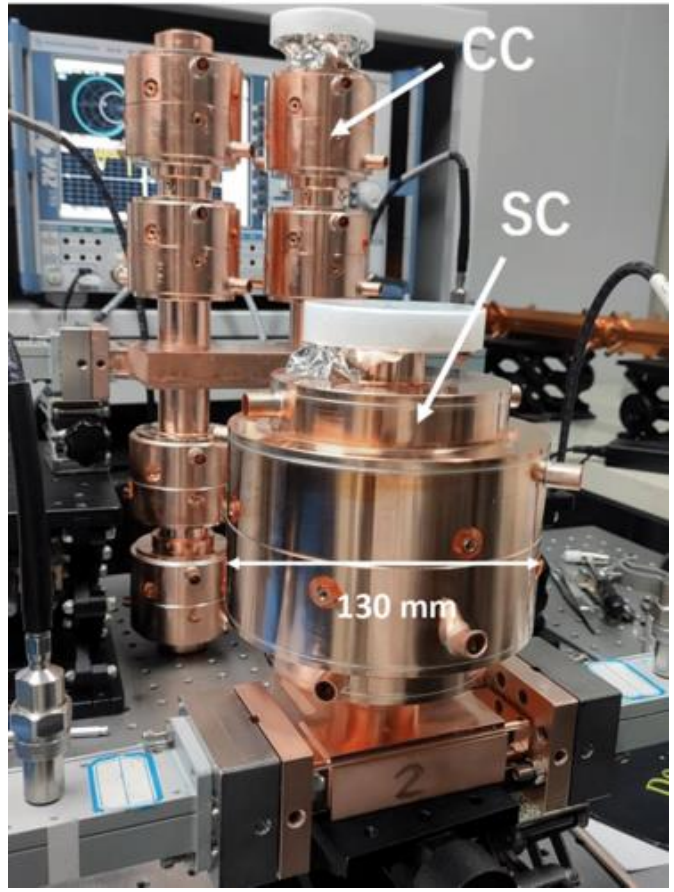
- **12 GHz X-band accelerating structures**
  - Micron precision machining
  - 100 MV/m gradients



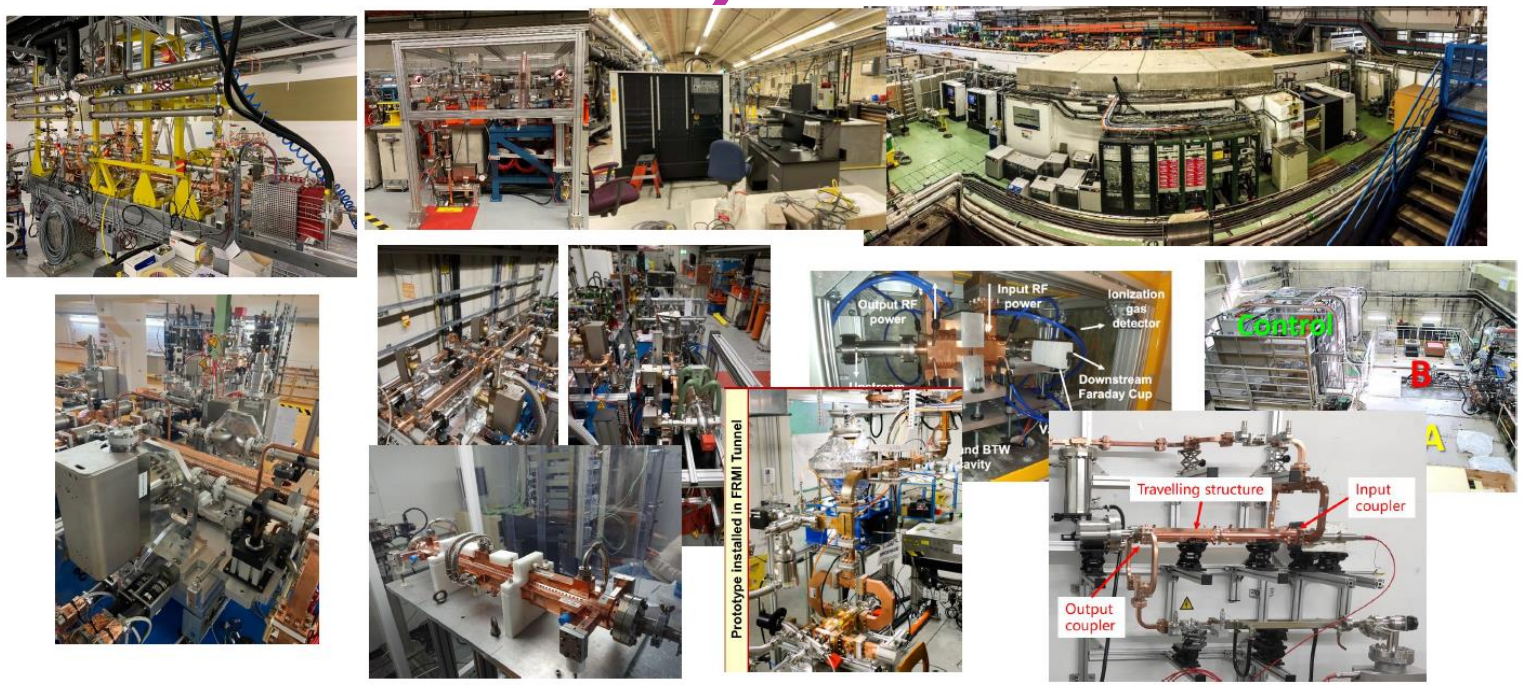
High-Gradient Acceleration

- **X-band RF power sources**
  - 5-50 MW klystrons
  - High efficiency (~60 %)

- **X-band pulse compressors**
  - Increase peak power output from klystrons by up to ~ 4x



Global X-band and High-Gradient Deployment (Non-Exhaustive List!!!)



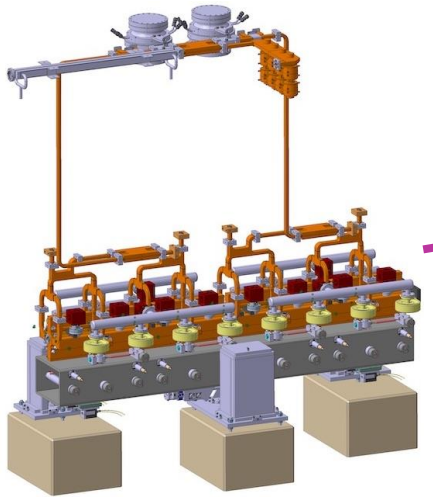
- Trieste, Fermi: Linearizer
- SwissFEL: Linearizer and Polarix deflector
- SARI: Linearizer, deflectors
- CERN: Xbox-1 with CLEAR, accelerator
- DESY: FLASHForward and FLASH2, PolariX deflectors
- SLAC: NLCTA, XTA
- Argonne: AWA
- Arizone: CXLS, ICS

- KEK: NEXTEF
- CERN: XBox-2,3 and SBox
- Tsinghua: TPot
- Valencia: IFIC VBox
- Trieste: FERMI S-Band
- SLAC: Cryo-systems
- LANL: CERF-NM
- INFN Frascati: TEX
- Melbourne: AusBox

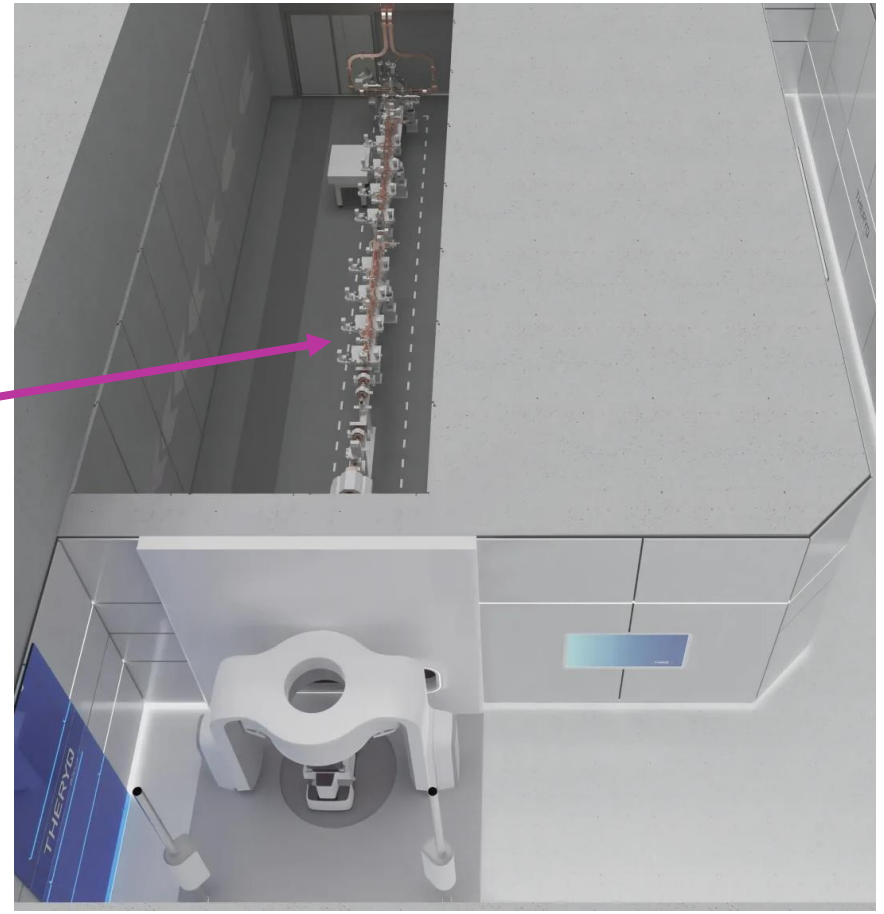
- TU Eindhoven: Smart*Light, ICS
- Tsinghua: VIGAS, ICS
- CERN: AWAKE electron injector
- INFN Frascati: EuPRAXIA@SPARC LAB, accelerator
- DESY: SINBAD/ARES, deflector
- CHUV/CERN: DEFT, medical accelerator
- Daresbury: CLARA, linearizer
- Trieste: FERMI energy upgrade
- + MANY MORE!!!!

Medical - DEFT (Deep Electron Flash Therapy)

- **CERN-CHUV-THERYQ collaboration**
  - VHEE (100 – 250 MeV)
  - FLASH (>40 Gy/s, < 100 ms)
  - Clinical trials planned for 2025

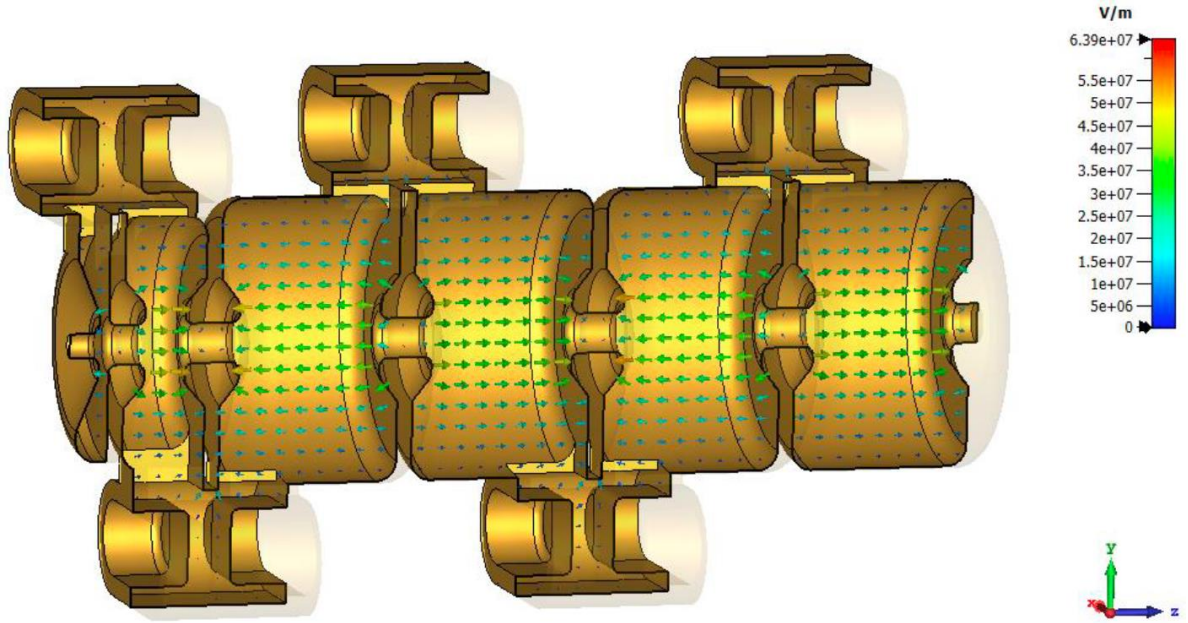


- **Accelerator technology**
  - S-band photoinjector
  - X-band accelerating structures mounted on girders
  - X-band klystrons with pulse compressor



Medical - STELLA (Smart Technologies to Extend Lives with Linear Accelerators)

- **CERN-ICEC-STFC-Lancaster University-Oxford University-Cambridge University collaboration**
  - 6 MeV electron linac for x-ray radiotherapy
  - Optimised for LMICs
  - Prototype construction by late 2020s

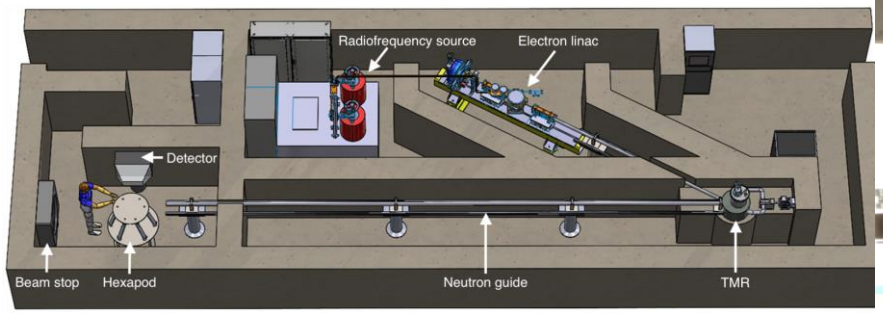


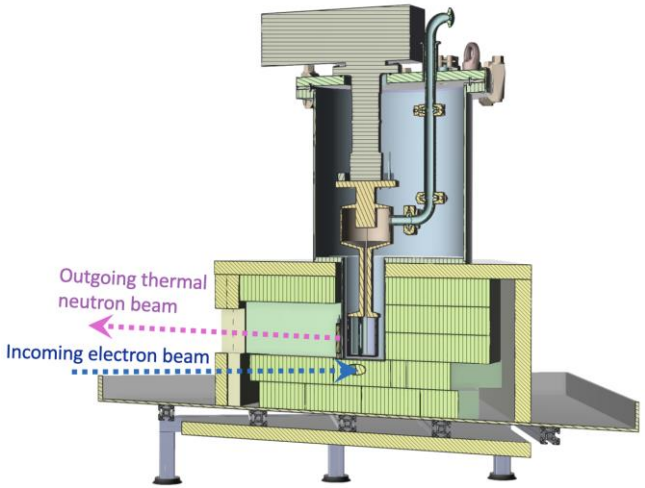
- **Accelerator technology**
  - Single high-capture, high-gradient accelerating structure
  - Long lifetime RF power source
  - Modular, upgradable (hardware and software), maintainable design ethos.

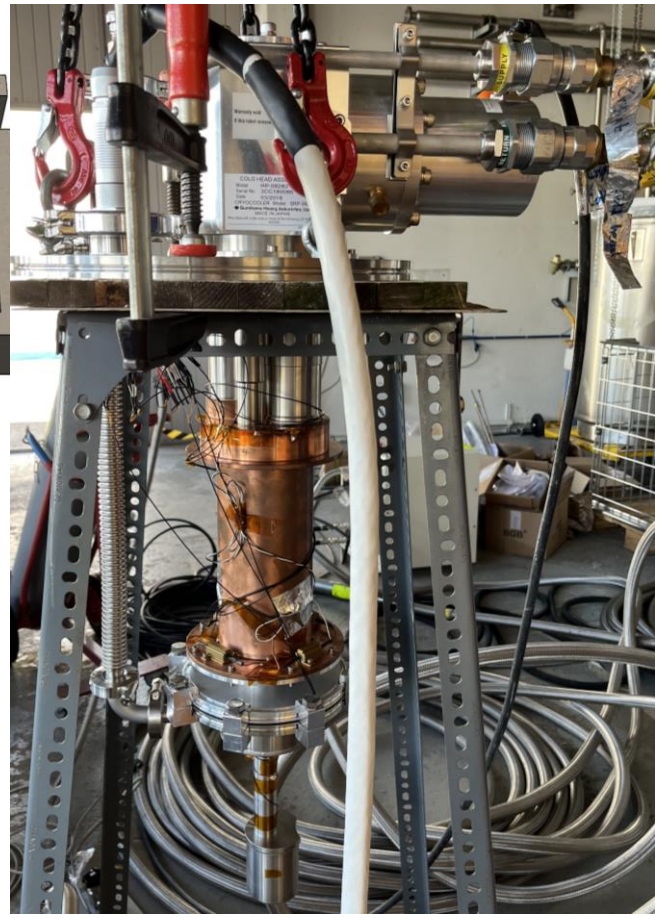
Industrial - VULCAN (Versatile ULtra-Compact Advanced Neutron Generator)

- **CERN-DAES-DTI-Xnovotech collaboration**
  - 35 MeV, kW-scale electron linac
  - Target-moderator-reflector for converting electrons to thermal neutrons
  - Stress-strain measurements, battery & fuel-cell investigations
  - Proof of concept testing in CLEAR this year, complete prototype construction by mid-late 2020s

- **Accelerator technology**
  - High-gradient accelerating structures and pulse compressor optimized for compactness, cost, beam power and efficiency
  - High-power, high-efficiency klystrons



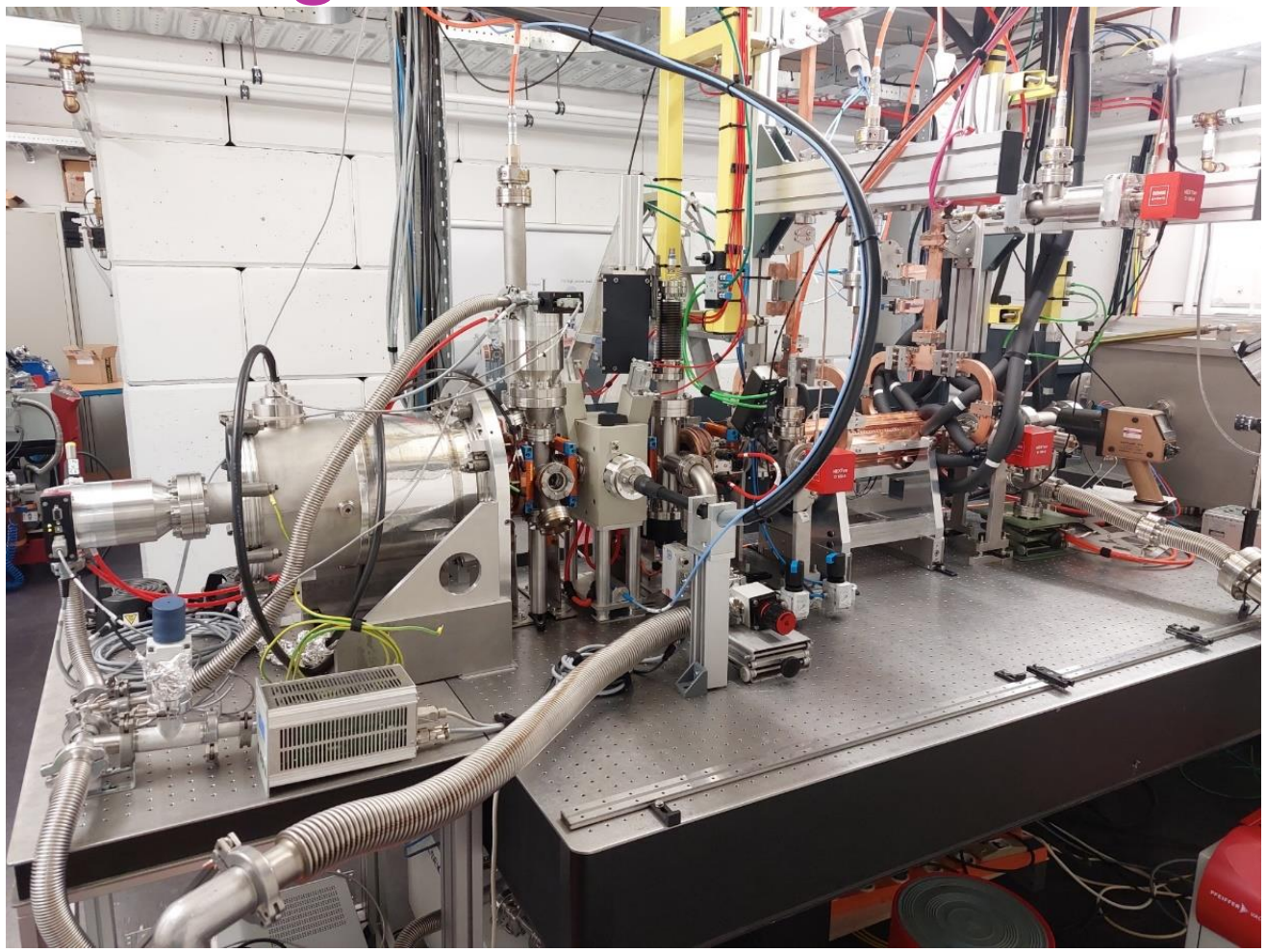




Research / Industrial - Smart*Light

- **Dutch-Flemish collaboration, at Eindhoven University of Technology**
  - 30 MeV electrons producing 40 keV X-rays through laser interaction
  - Upgrading to Smart*Light 2.0 with 60 MeV and 100x higher repetition rate
  - Table-top device in operation

- **Accelerator technology**
  - Single X-band accelerating structure
  - 6 MW X-band klystron with pulse compressor

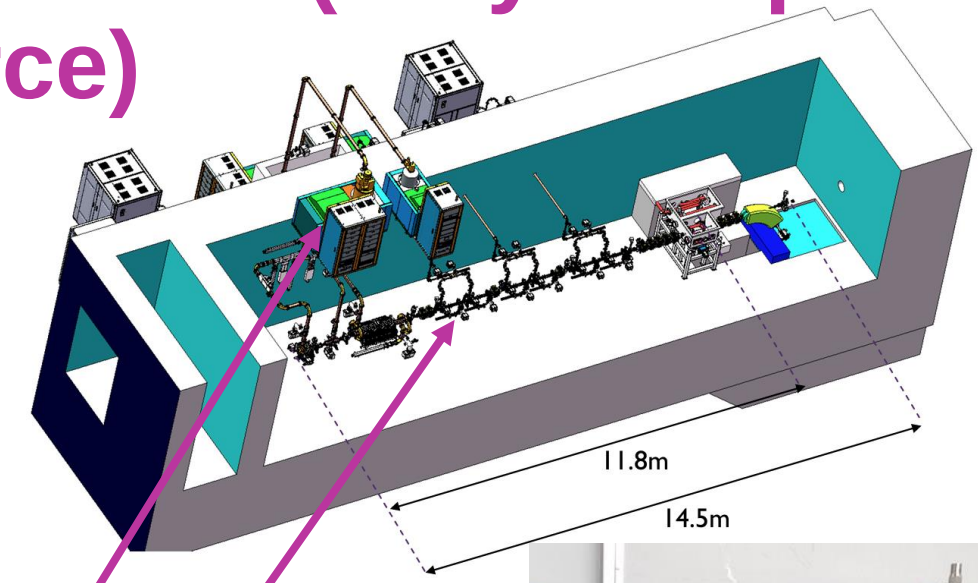


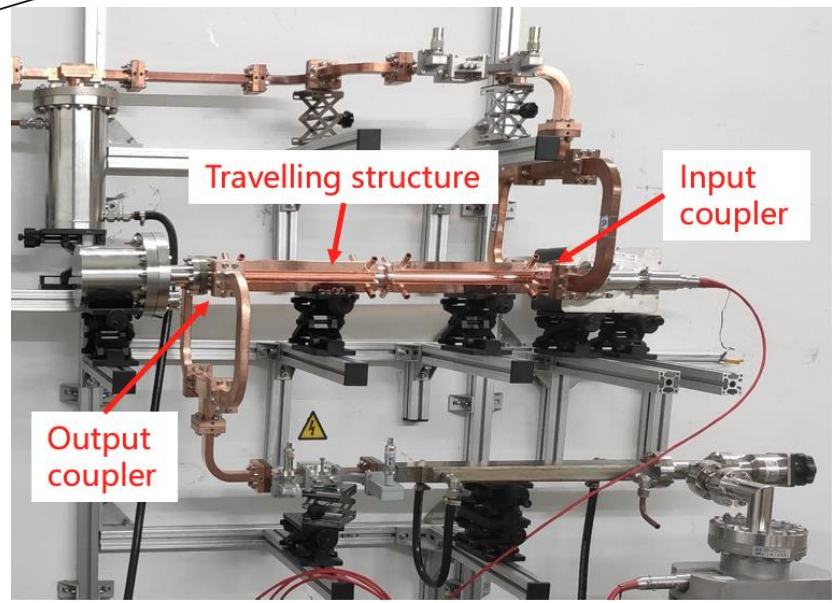
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Research / Industrial - VIGAS (Very compact Inverse compton GAmma-Source)

- **Hosted at Tsinghua University**
  - 350 MeV electrons producing 0.2–4.8 MeV gamma-rays through laser interaction
  - Accelerating structures fabricated, tuned and tested
  - Operate at full energy by late 2025

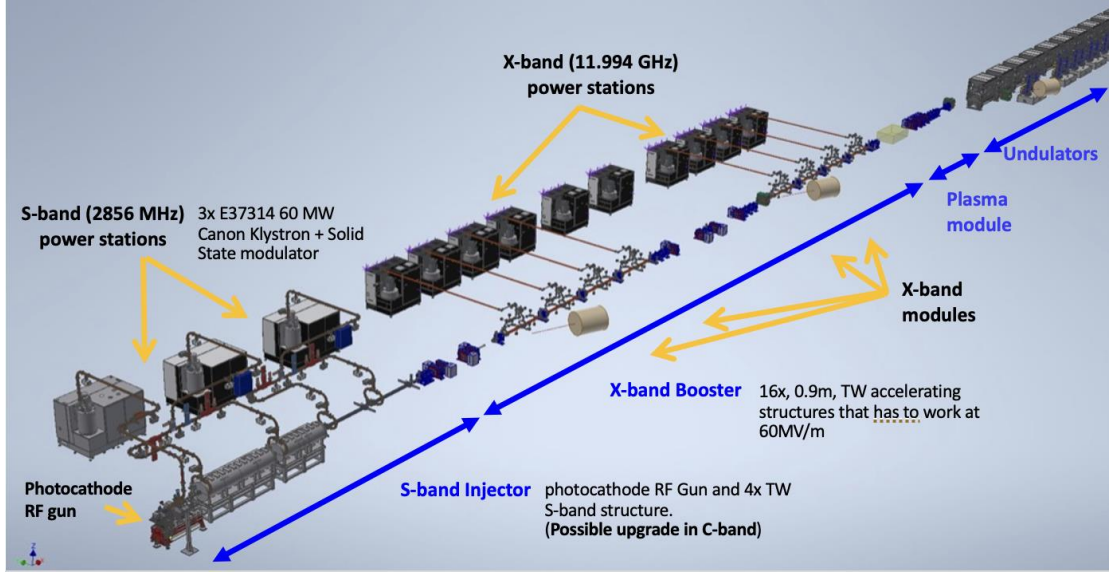
- **Accelerator technology**
  - S-band injector
  - Three 50 MW X-band klystron with pulse compressor
  - Six 72-cell X-band accelerating structures



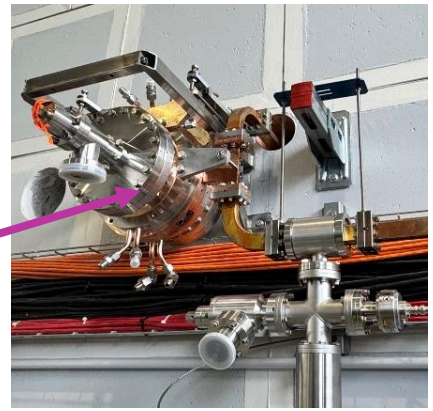


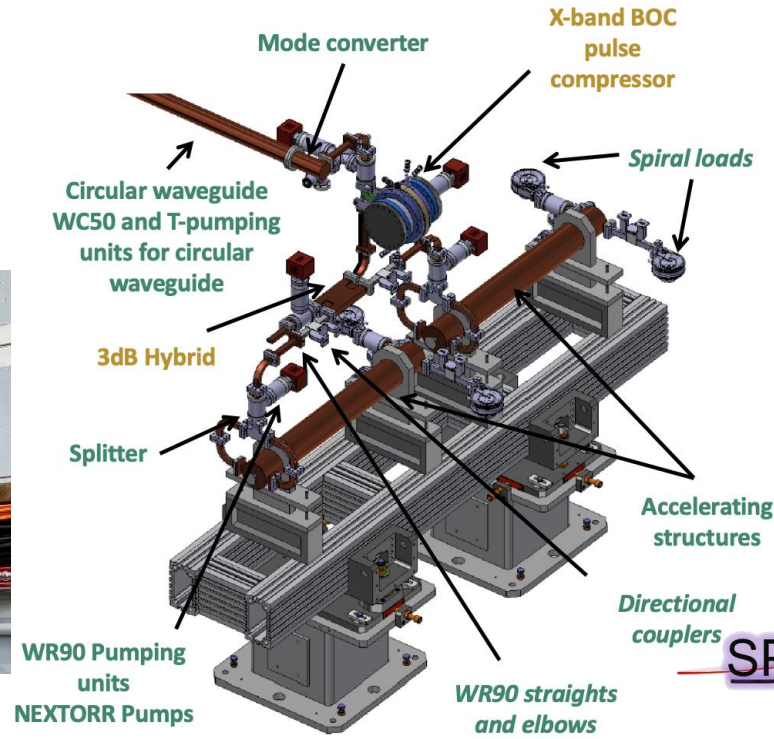
Research - EuPRAXIA@SPARC_LAB

- **41 laboratory collaboration, hosted at INFN Frascati**
  - FEL facility driven by plasma acceleration
  - 1 GeV X-band electron linac driver of a plasma wakefield accerator
  - Expected ready for operation in 2028



- **Accelerator technology**
  - S-band injector
  - 50 MW X-band klystrons
  - X-band pulse compressor
  - X-band accelerating structures





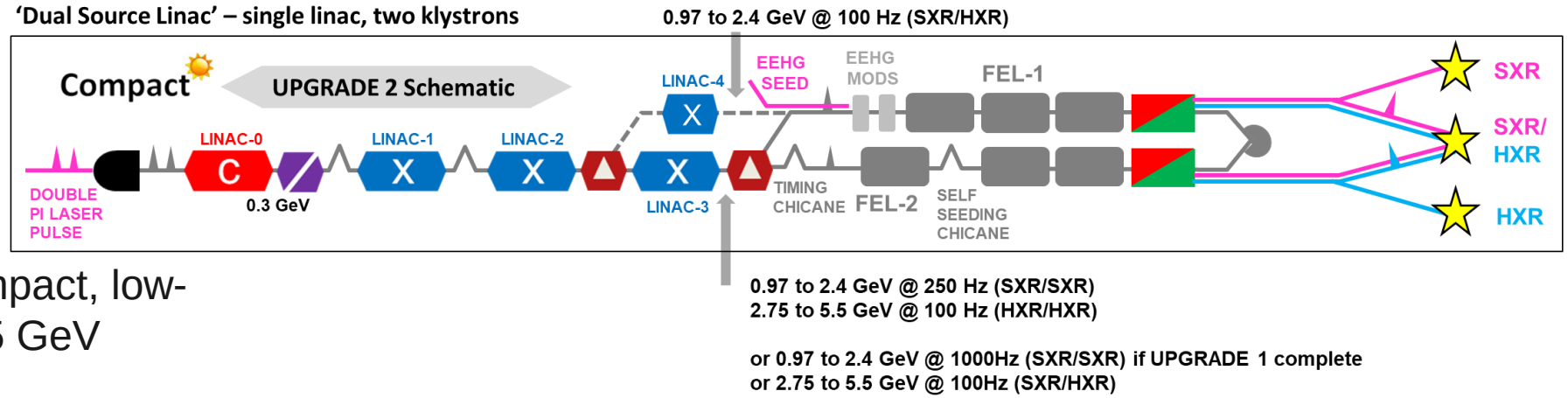
INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

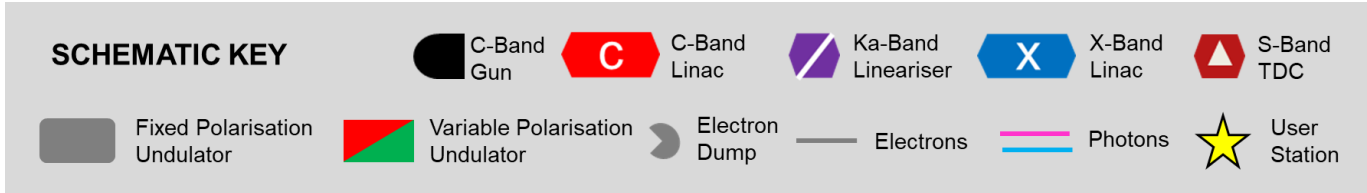
EuPRAXIA

SPARC LAB

Research / Industrial – CompactLight

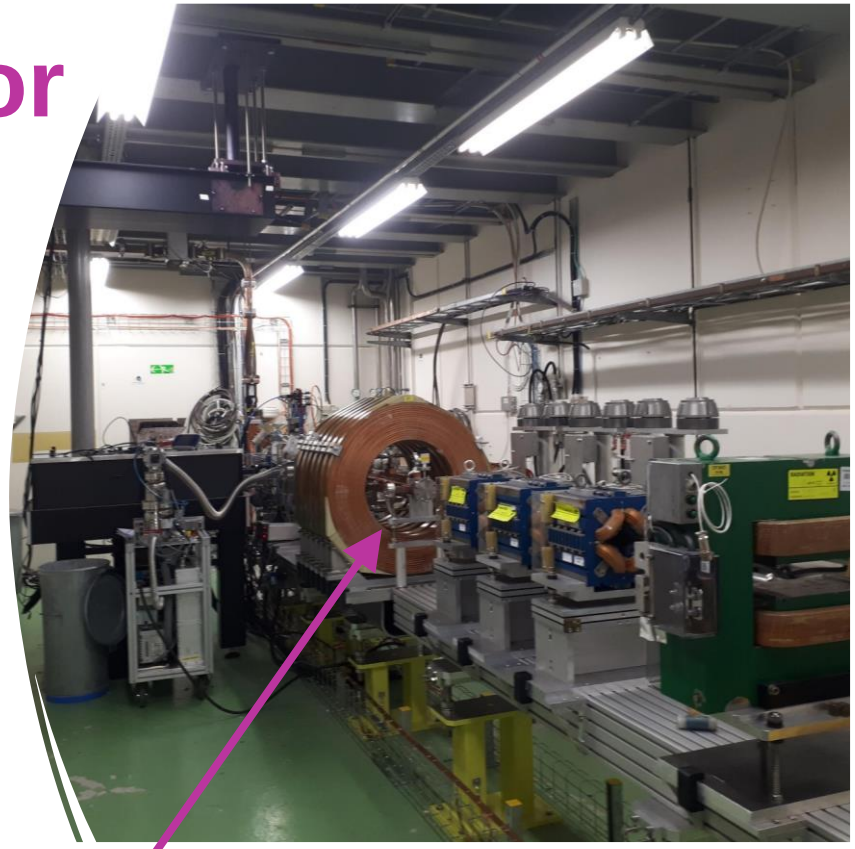
- **26 laboratory collaboration**
  - CDR developed for a compact, low-cost XFEL driven by a 5.5 GeV electron beam
  - Hard (2-16 keV) X-rays at 1 kHz
  - Soft (0.25-2 keV) X-rays at 100 Hz
- **Accelerator technology**
  - C-band injector
  - X-band accelerating structures

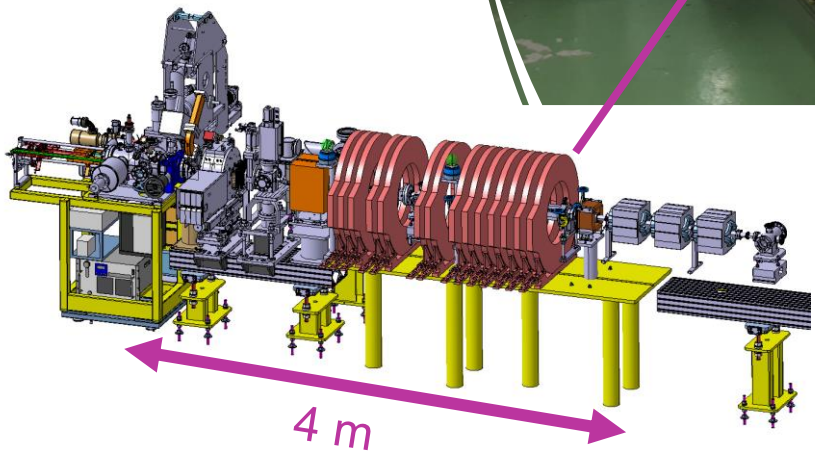




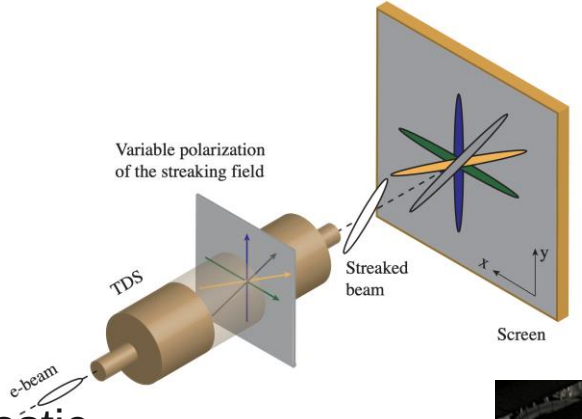
Research – CLEAR / AWAKE Injector

- **Hosted at CERN**
  - Demonstrate velocity bunching and emittance preservation with X-band
  - Standardise as injector for many applications
  - Currently undergoing experimentation in CERN's CLEAR facility to utilise as an ICS
- **Accelerator technology**
  - S-band injector system with RF-gun
  - X-band bunching and accelerating structures

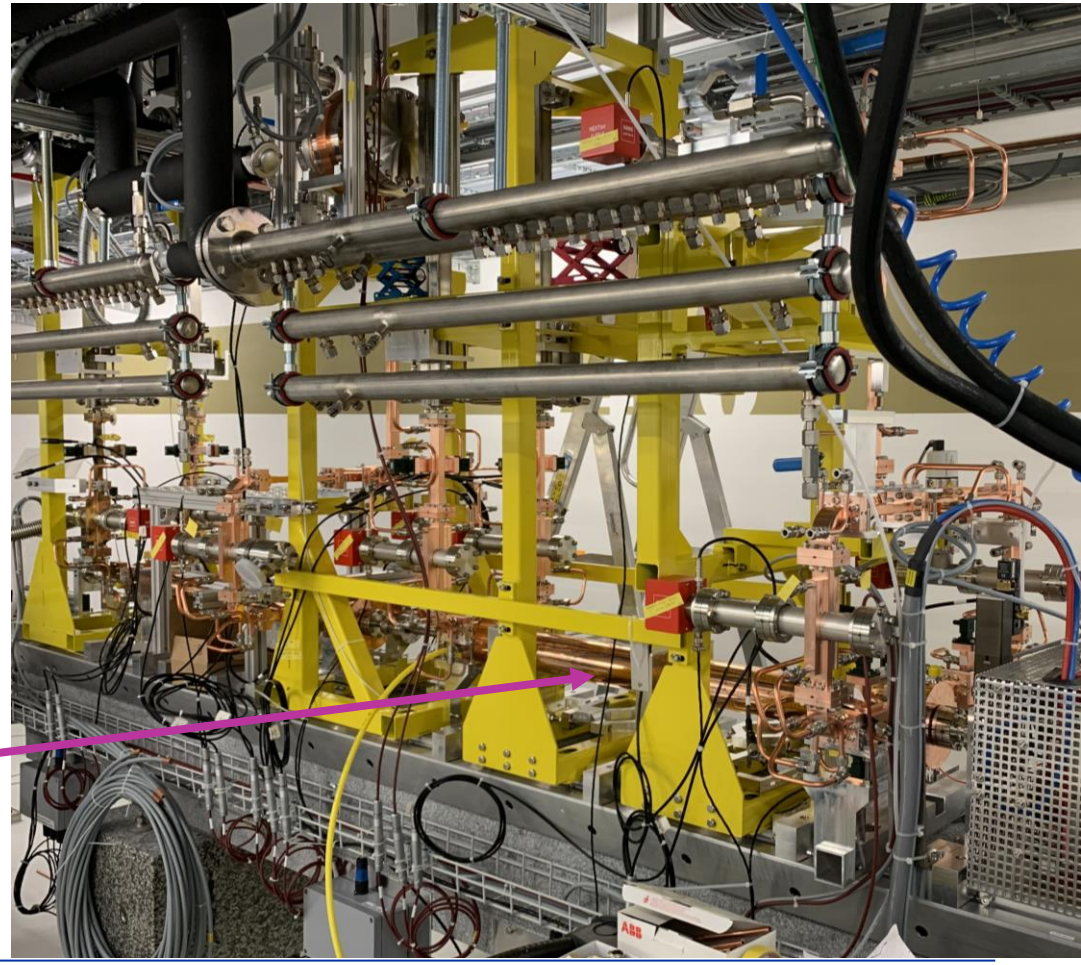




Research - PolariX



- **CERN-DESY-PSI collaboration**
  - High-resolution, time-resolved diagnostic tool
  - Transverse and longitudinal slice properties
  - fs and sub-fs resolution
  - Diagnose multidimensional phase space to study complex beam dynamics
  - 3D charge distribution reconstruction
  - Deployed in SwissFEL
- **Accelerator technology**
  - X-band pulse compressor
  - Polarizable X-band transverse deflecting structure



Conclusions

- **High-gradient, high-efficiency accelerator technologies developed for CLIC useful in a wide-range compact electron linacs for research, medical, and industrial applications**
  - Numerous projects highlighted
- **Wide-spread adoption benefits the original CLIC research and society at large!**

Conclusions

- **Thank you**

- **X-band and high-gradient facilities are documented by Walter Wuensch.**

  Please send any update please send to my colleague *walter.wuensch@cern.ch*