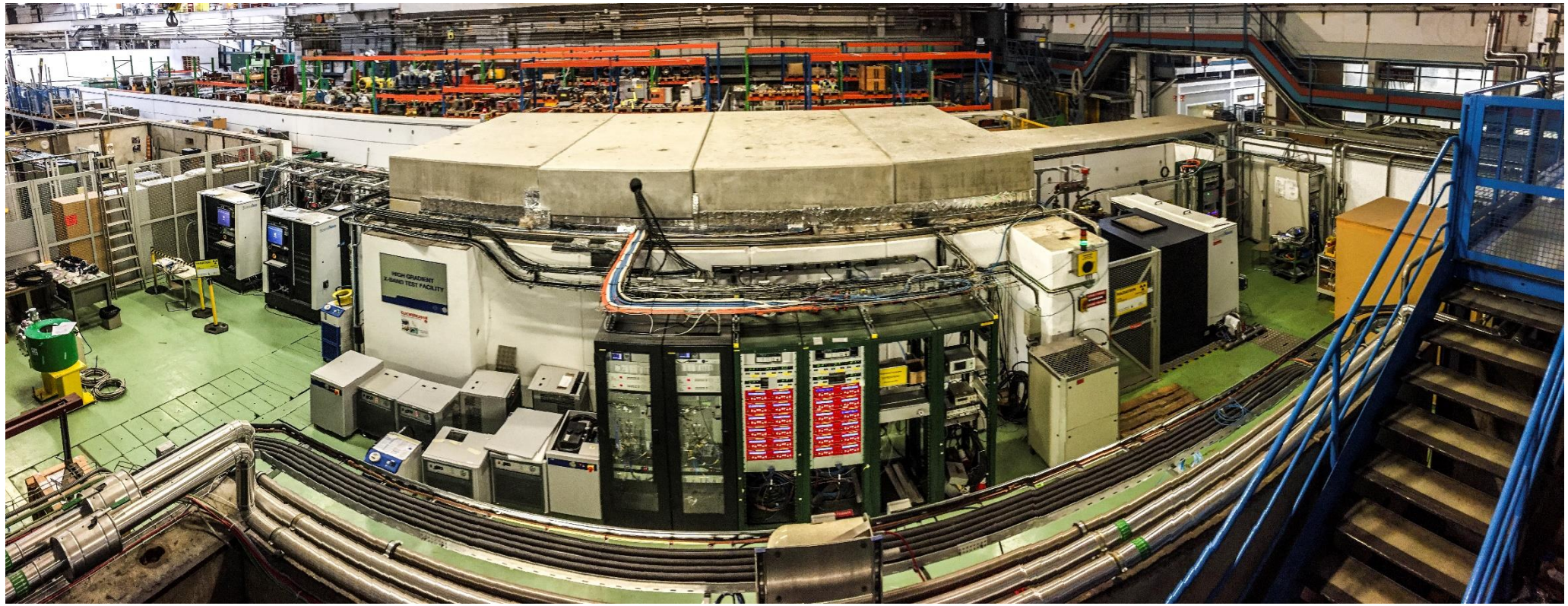
Applications of X-band and high-gradient technology

Introduction

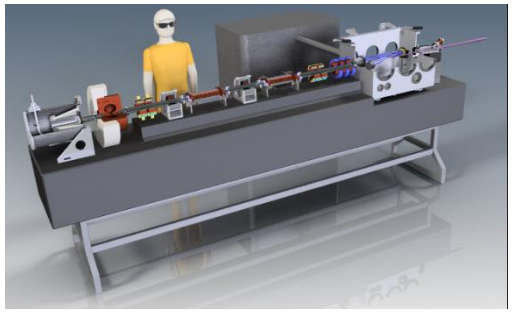
An important aspect of the CLIC R&D strategy is to assist and promote application of high-gradient, X-band and advanced normal conducting technology.

The objective is to add to direct resources with those in other projects and broaden the technical base.

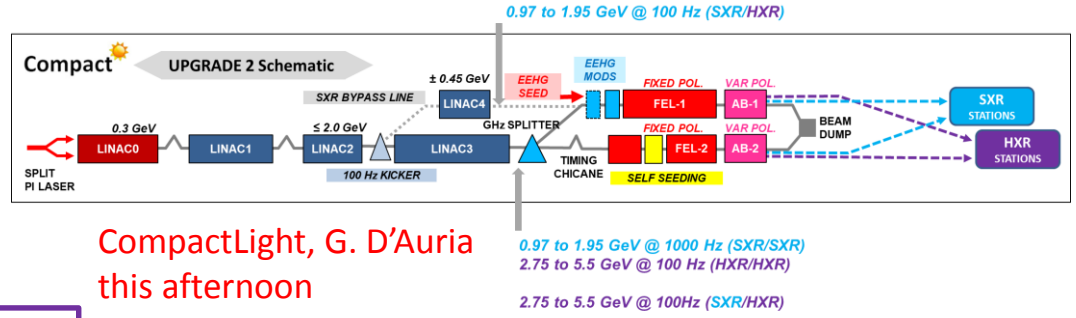
I will now present a selection of examples of projects CLIC actively collaborates with.



X-band and high-gradient applications overview

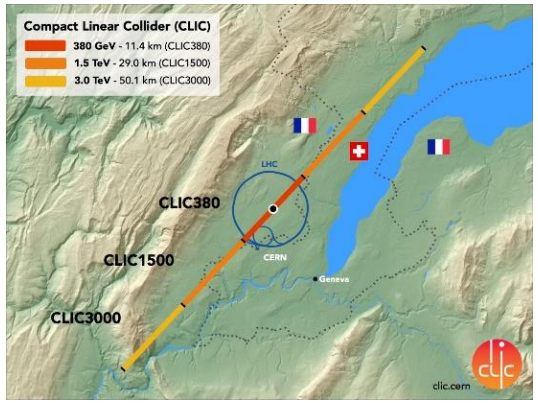


Inverse Compton Scattering Source

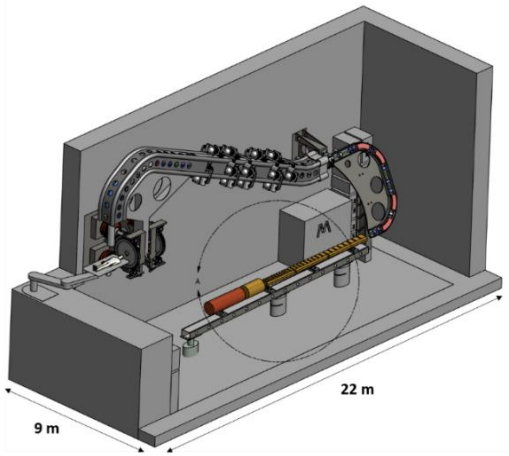


CompactLight, G. D'Auria this afternoon

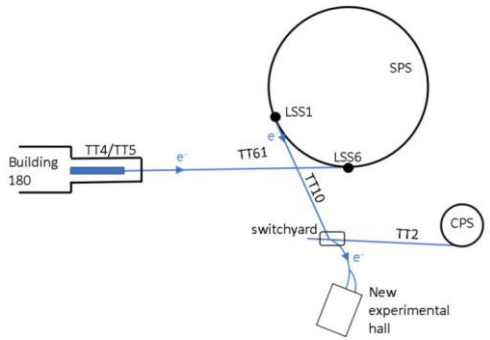
XFEL



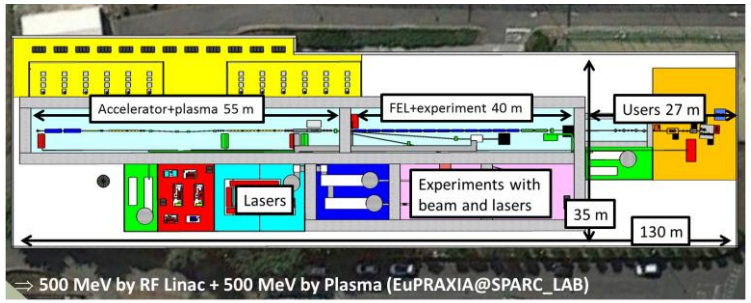
Linear collider



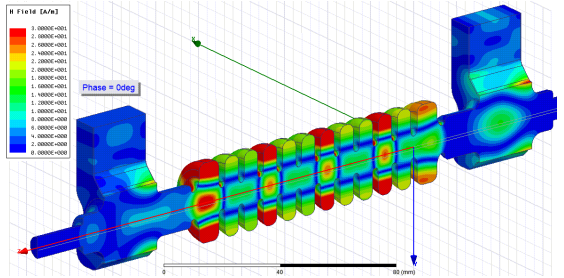
Medical applications

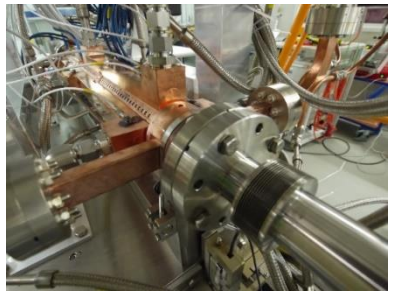


eSPS, S. Stapnes this afternoon



GeV-range research linacs





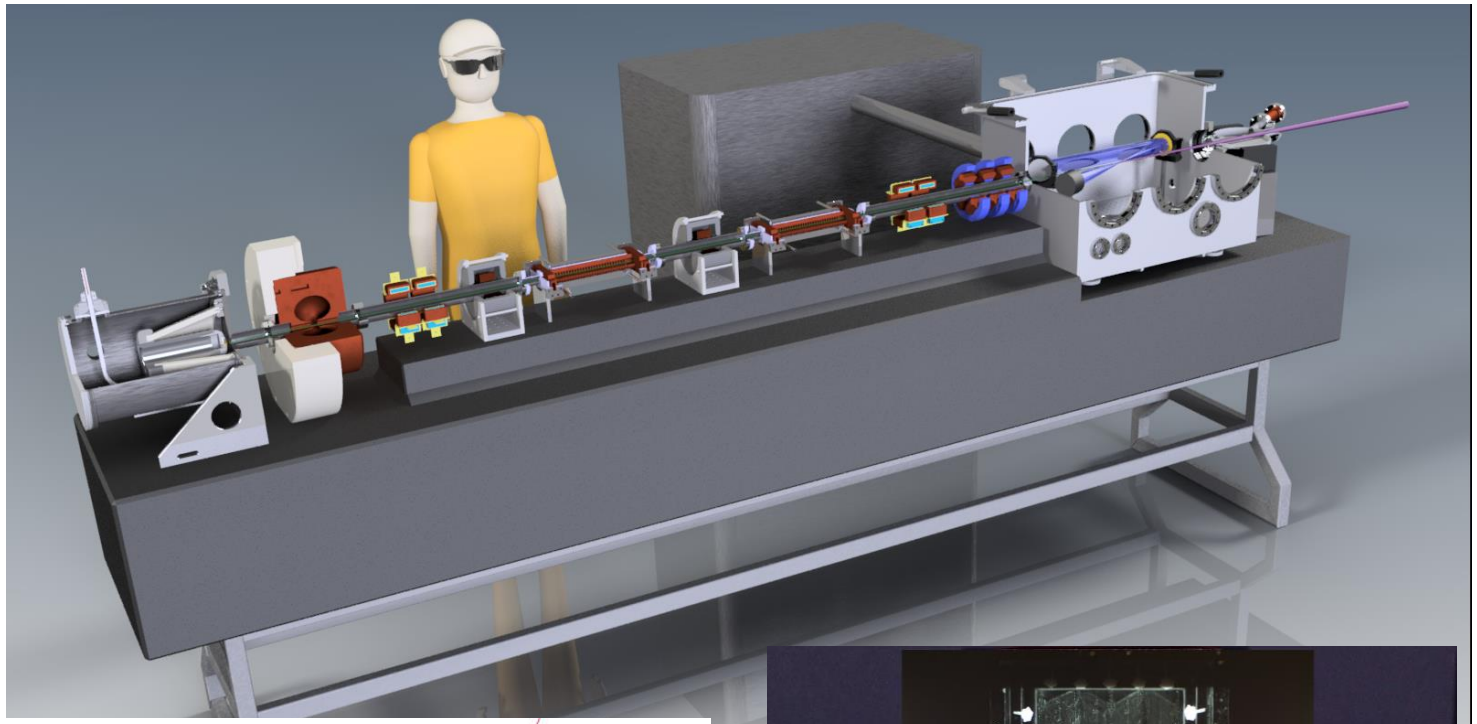
Beam manipulation

X-band and high-gradient applications *selection*

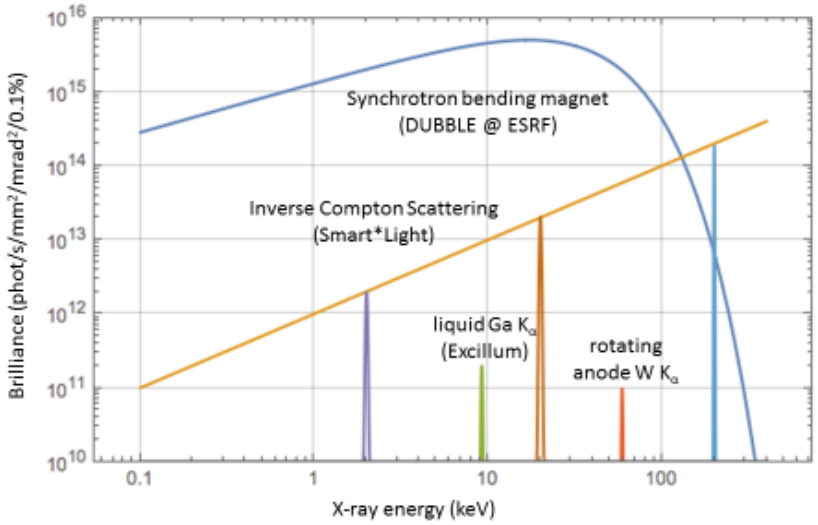
- Smart*Light – Compact Inverse Compton Source
- POLARIX – Variable polarization deflector
- SwissFEL – Operational C-band linac
- XARA – CLARA energy upgrade
- EuPRAXIA@SPARC_Lab – Advanced accelerator development
- FERMI – XFFEL Energy upgrade
- Tsinghua – Thompson source energy upgrade
- PSI, FERMI, SINAP – Energy spread linearizers
- CompactLight – XFEL Gerardo D'Auria
- eSPS – injector of SPS Steinar Stapnes

Inverse Compton Scattering Source – Smart*Light

Compact, highly monochromatic X-ray source.
Complementary to X-ray tube and synchrotron light source.
Applications in cultural heritage, material science, medical, etc.



Brilliance



Inverse Compton Scattering Source – Smart*Light

Smart Light collaboration funded by Interreg

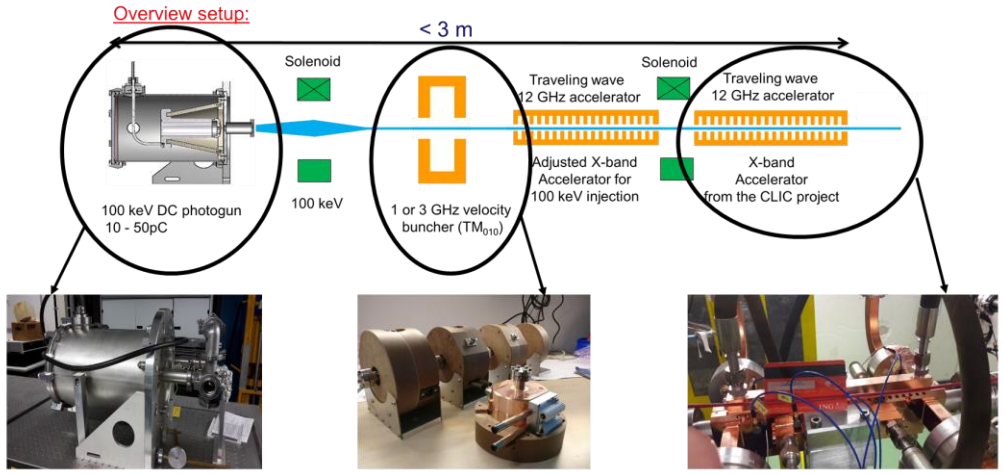
Interreg Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling

UGCT · Erasmus MC · museum boijmans van beuningen · AGFA HealthCare · VDL Enabling Technologies Group · UNIVERSITEIT GENT · M2i materials innovation institute · COAST Community of Innovation · TU/e · TU Delft · Universiteit Antwerpen · XRE

Will build the Compton source

5 October 2018 2

Already developed and available material for the electron beam line:



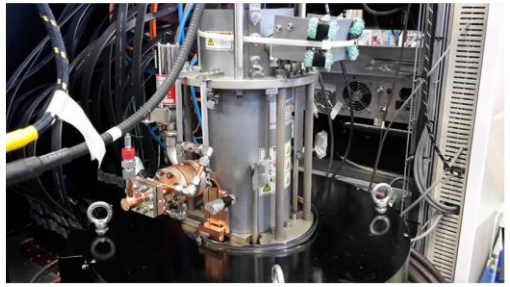
5 October 2018 TU/e Technische Universiteit Eindhoven University of Technology 7

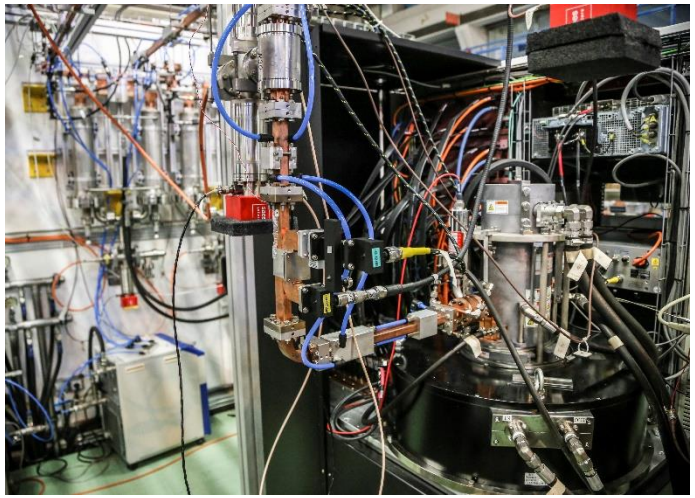
Inverse Compton Scattering Source – Smart*Light

Already developed and available material for the electron beam line:

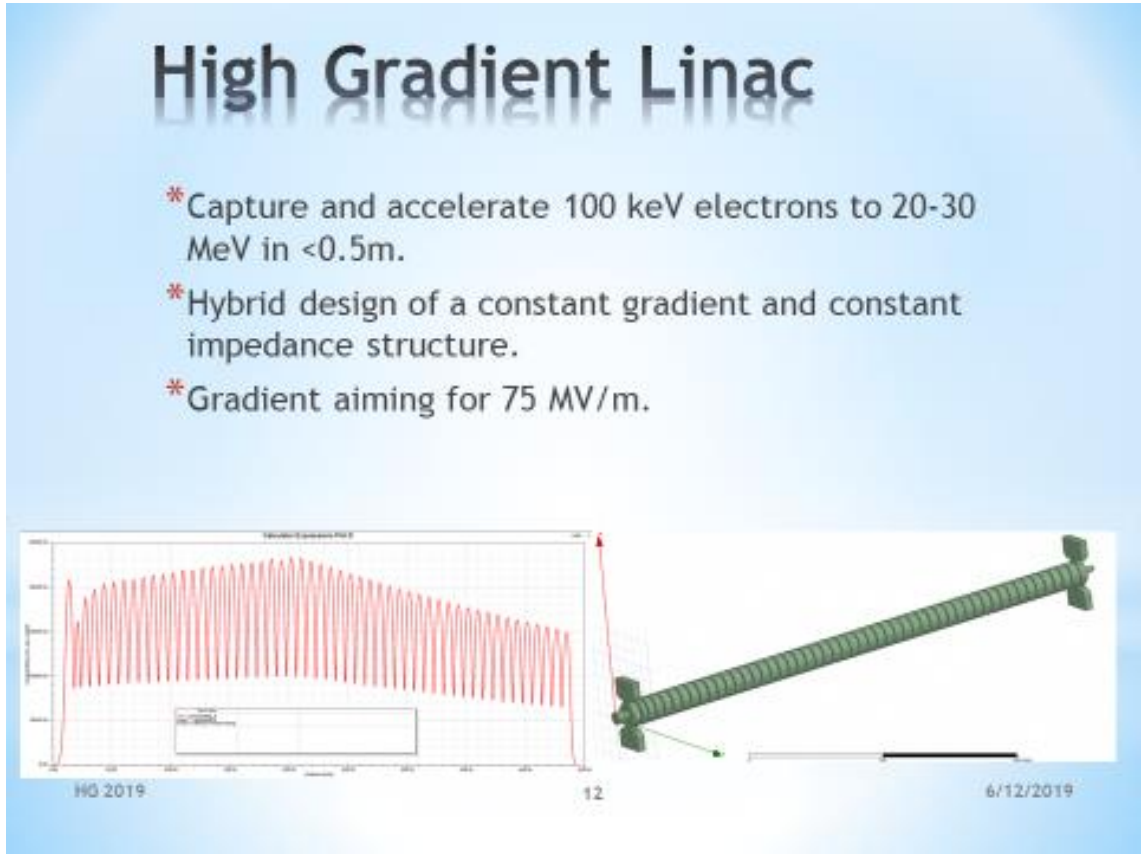
Bunker empty :

X-band material is being bought and delevoped





Based on one unit of XBox-3

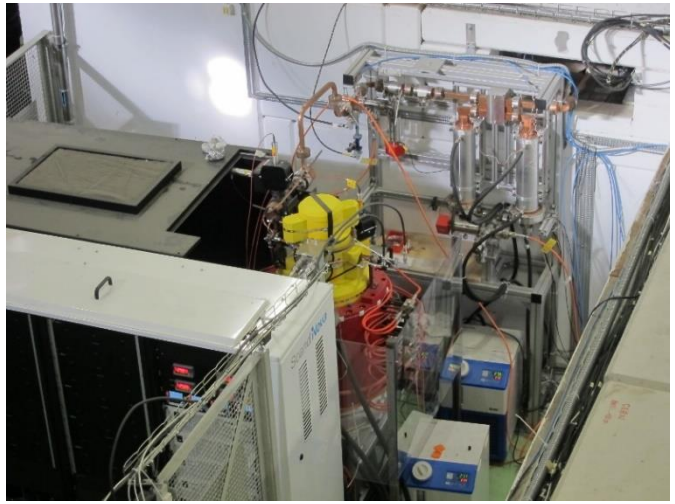


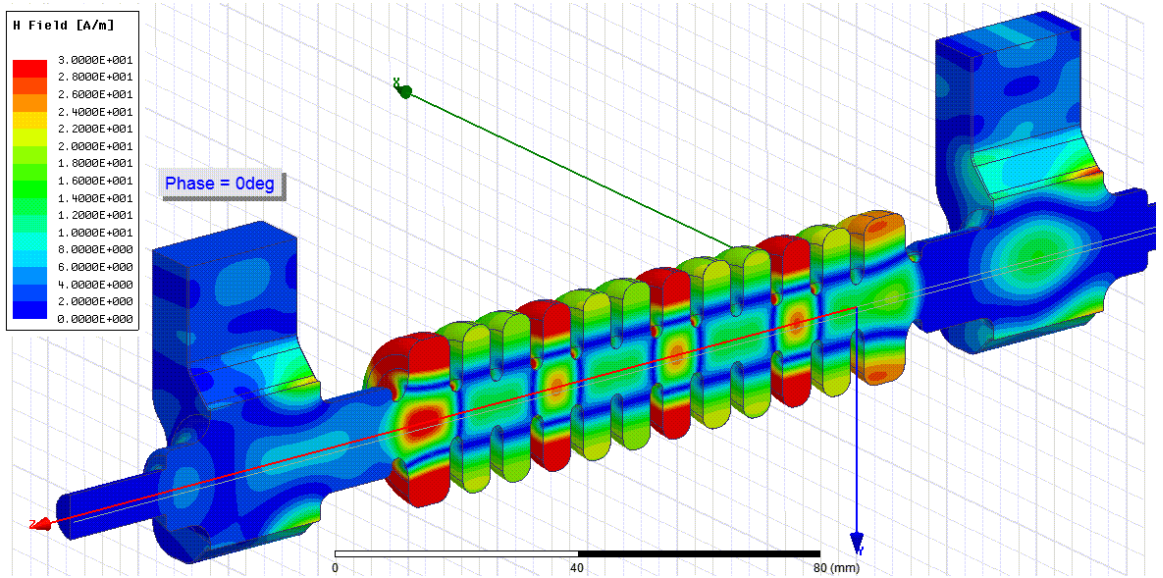
POLARIX transverse deflector

Variable polarization transverse deflector for measurement of phase space of short bunches.

Joint collaboration between CERN, DESY and PSI

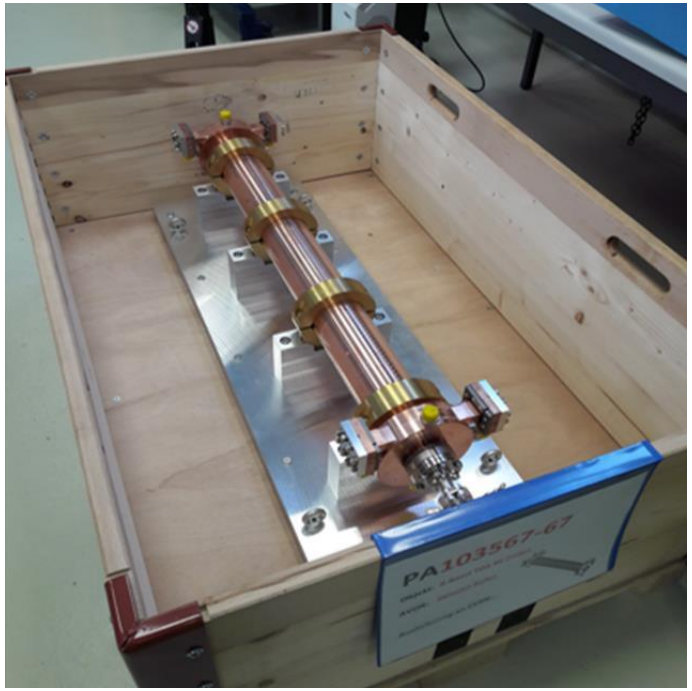
- CLIC structure concept and rf design
- High-power systems based on XBox-1 and 2 (PSI) and XBox-3 (DESY)
- PSI fabrication based on SwissFEL technology
- High-power structure validation at CERN
- Operational at DESY in FLASH2
- Preparation at PSI





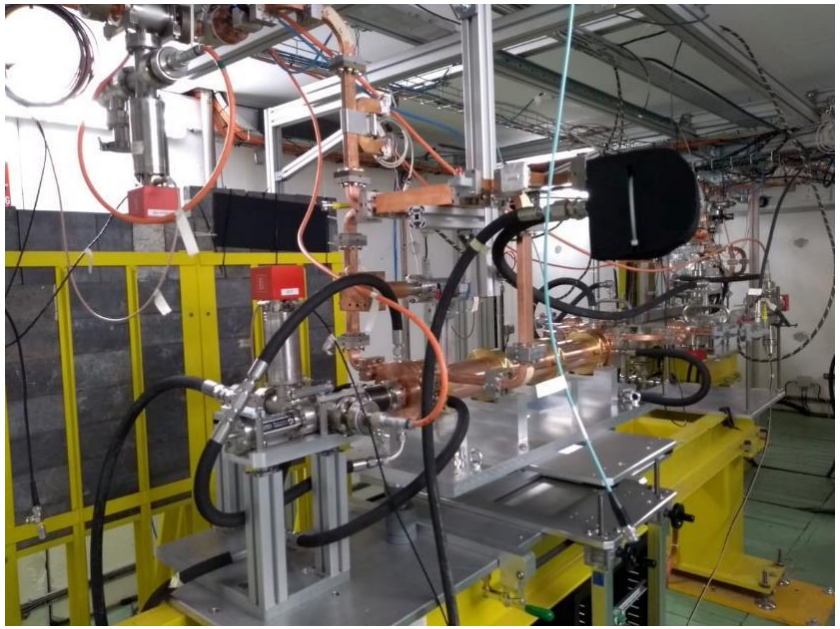
POLARIX transverse deflector

First POLARIX structure under fabrication at PSI



It arrives at CERN

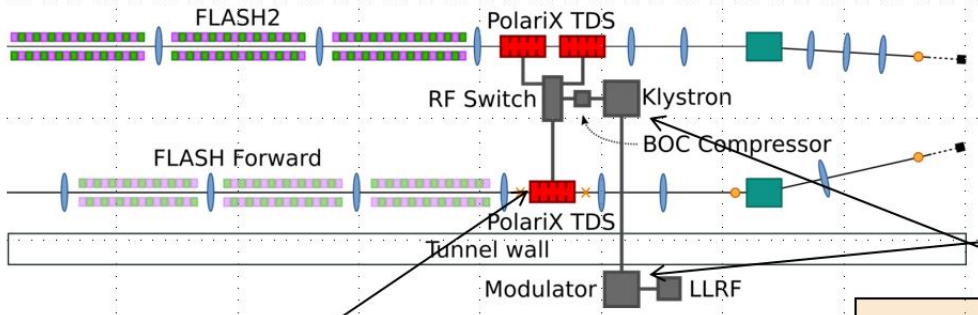
Installed in XBox-2 for high-power testing



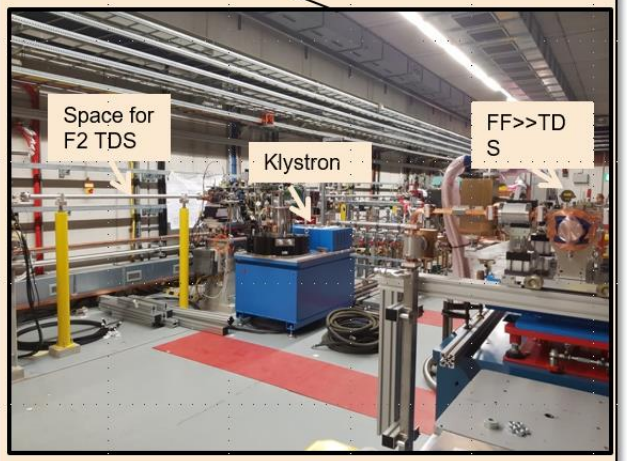
POLARIX transverse deflector

Description of the Installation of the Prototype at DESY

This is the final RF-Scheme for the Installation of the PolariX Structures at FLASH (2019 + 2020)



Prototype cavity installed in the **FLASHForward** beamline,



- 6MW Toshiba E37113A Klystron
- No XBOC nor RF switch installed in 2019
- The initially foreseen SLED has been replaced by an XBOC that will be installed in 2020 (together with the RF switch).

- Ampegon Type M-Class Modulator
- Located outside the tunnel
- Connected to the klystron via a ~12 m long high power cable

DESY. | PolariX TDS and ARES Linac | Barbara Marchetti, MAC Meeting October 2019

Page 1

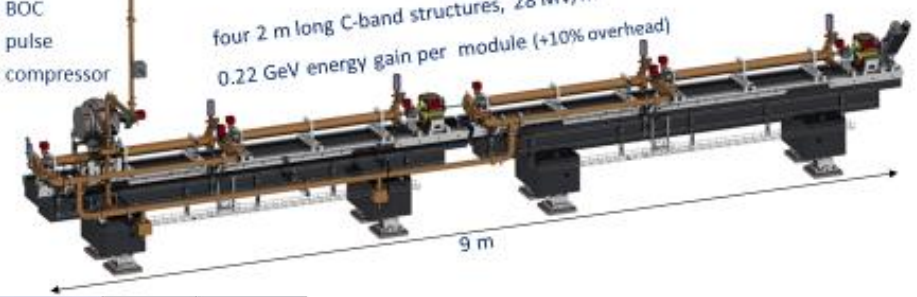
SwissFEL

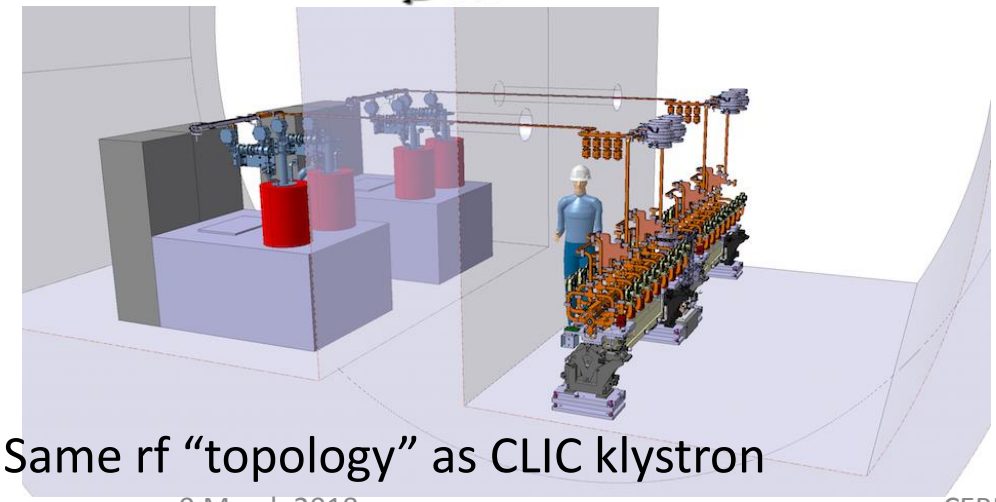
- Recent implementation of a large-scale normal-conducting linac – 5.8 GeV, over 100 accelerating structures.
- Strong linear collider technology heritage and with implementation many important lessons have been learned.

SwissFEL rf unit

C-band linac modules

Main LINAC	#
LINAC module	26
Modulator	26
Klystron	26
Pulse compressor	26
Accelerating structure	104
Waveguide splitter	78
Waveguide load	104





Same rf "topology" as CLIC klystron

Installation of last Linac girder: Sept. 13, 2016

Solid-state modulators for C-band linac

Two prototypes were tested at PSI for evaluation of the series.

50 MW / 3µs RF, 370kV / 344A / <20 ppm voltage stability pulse to pulse @ 100 Hz

AMPEGON

Type-µ modulator prot. for PSI C-band

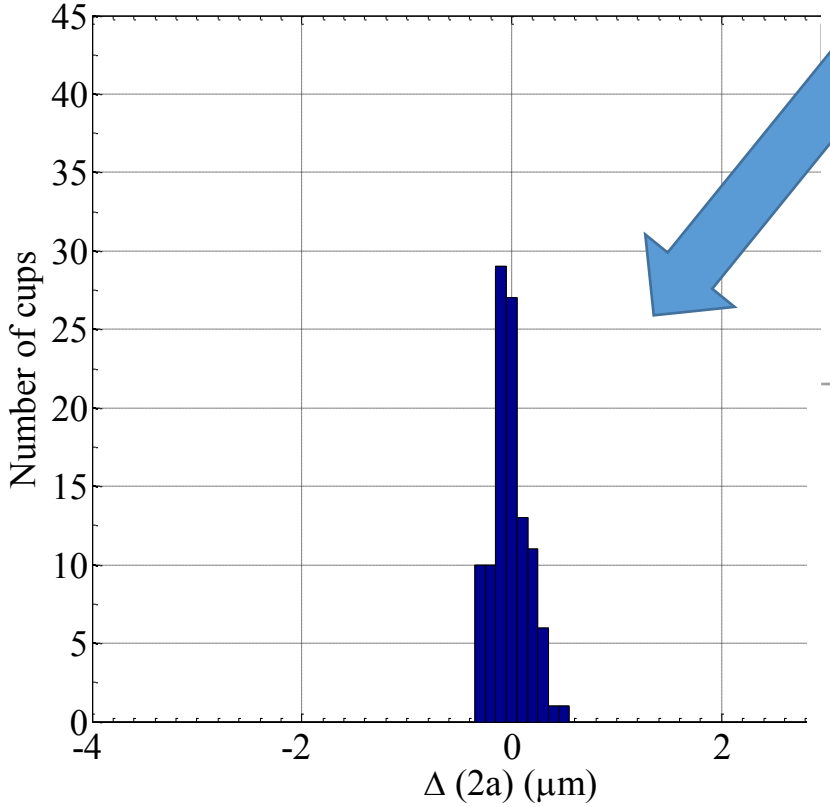
- 13 modulators (Linac 1, Linac 2)
- Installation planned from Nov. 2016 – June 2017

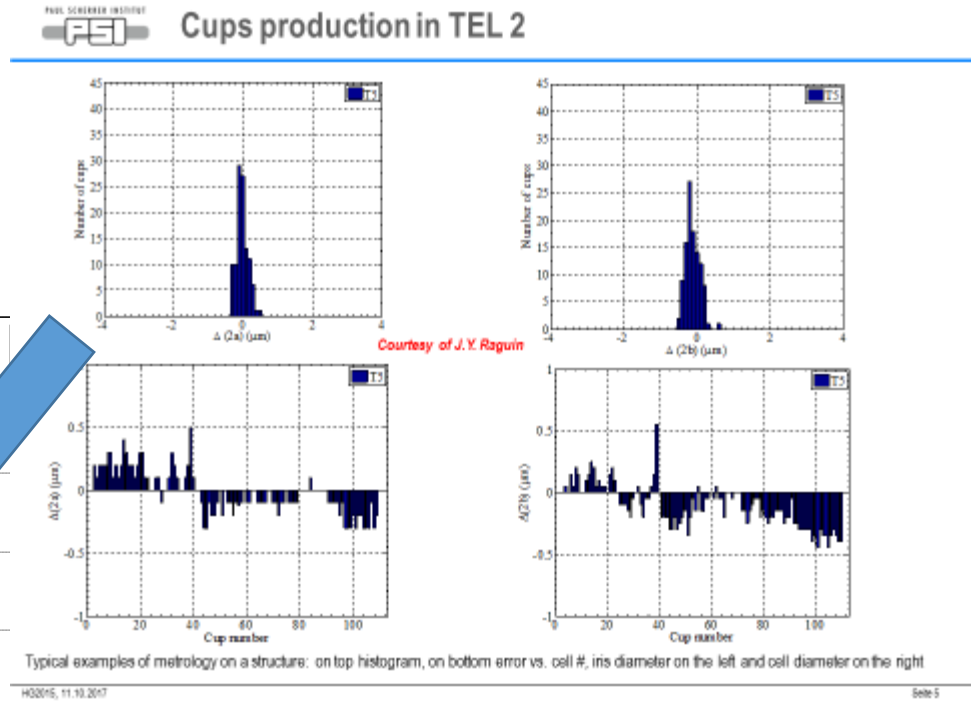
ScandiNova

K2-3 proto. for PSI C-band

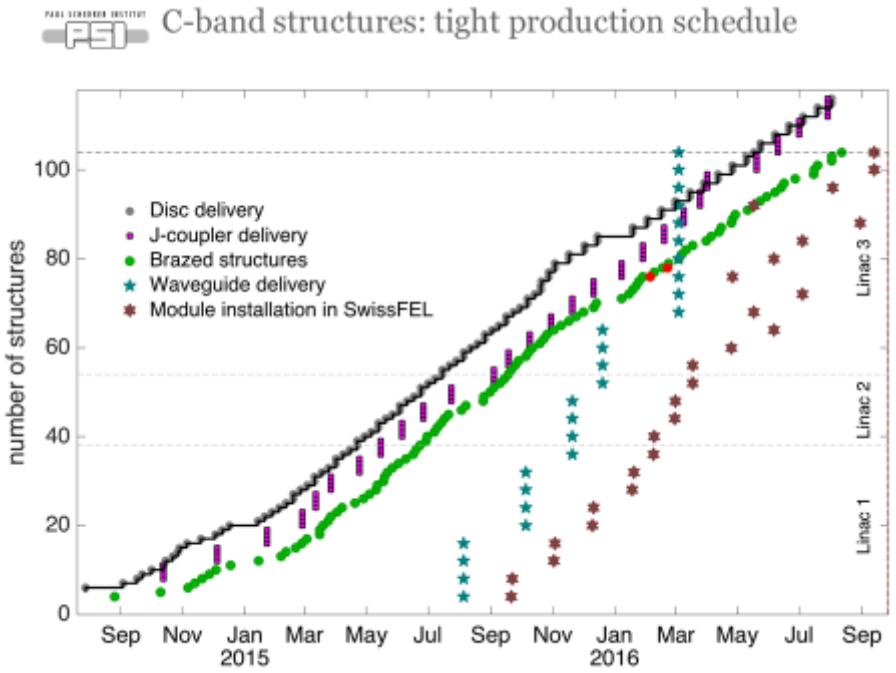
- 13 modulators (Linac 3)
- Installation planned from March 2016 – Sep. 2017

SwissFEL micron tolerances





Sub-micron precision achieved in production!

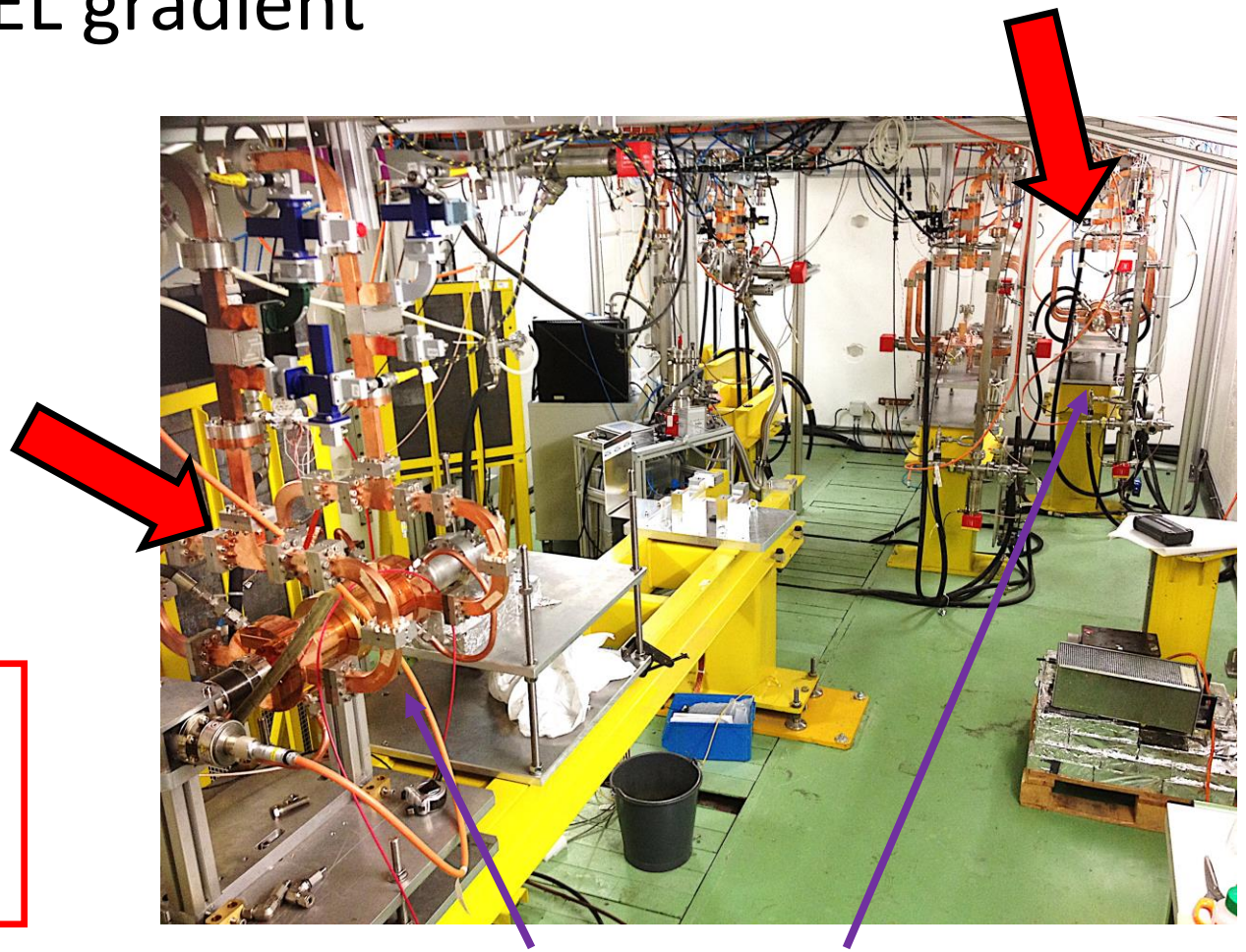


SwissFEL gradient

C-band structures

- Structures are machined "on tune", no provisions for dimple tuning!
- Cup manufacturing with micron precision at VDL ETG Switzerland
- Coupler manufacturing at VDL ETG
- Stacked by robot at PSI
- Vacuum-brazed at PSI
- Production rate: 1-2 / week
- Production finished August 2016
- **High power results for first structure:**
  - → Conditioned to 52 MV / m
  - → Break-down rate at 52 MV / m ≈ 2×10^{-6}
  - → At nominal 28MV/m, break-down rate negligible (well below the specified threshold of 10^{-8})

R. Zennaro et al.
"Measurement and High Power Test of the First C-Band Accelerating Structure for SwissFEL", Proceedings of LINAC2014, Geneva, Switzerland



Two PSI-built X-band structures have been tested in the Xboxes – both operated at over 115 MV/m.

Gradient only limited by C-band power source

XARA

Science & Technology Facilities Council | UK Research and Innovation

XARA

A medium-scale national light-source facility and a centre for particle accelerator R&D – using existing infrastructure to significantly reduce cost

Louise Cowie

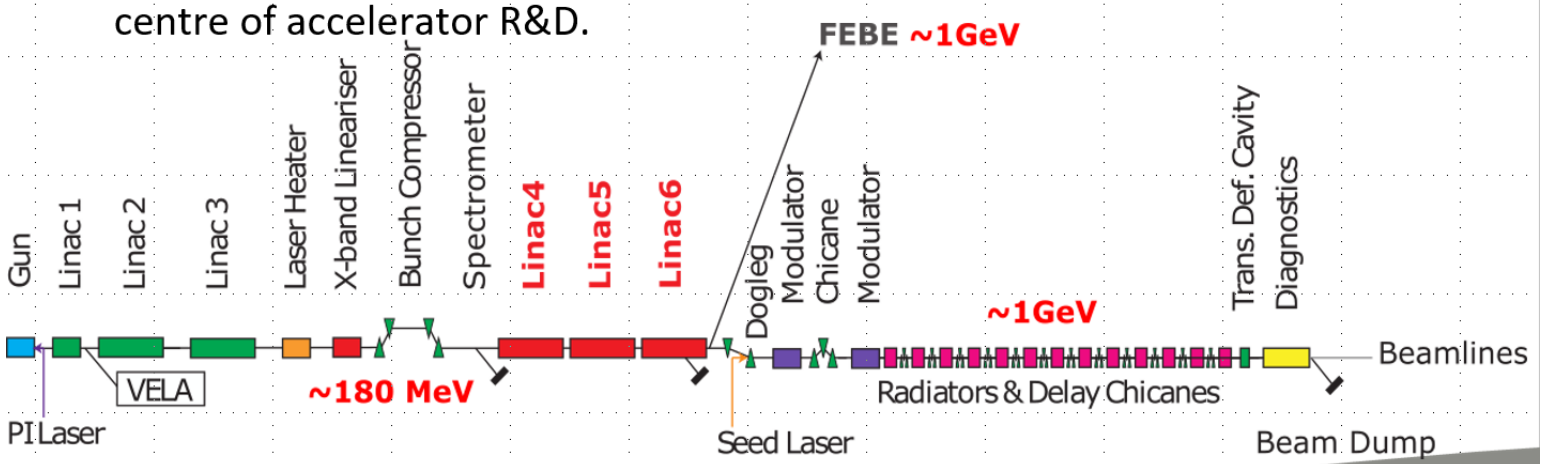
on behalf of the XARA team at Daresbury Lab

High Gradient Workshop 2019

Upgrade to the CLARA facility at Daresbury

Upgrade proposal: XARA

- X-band Accelerator for Research and Applications
- The 4th CLARA linac is replaced by an X-band accelerating section to reach 1 GeV
- Novel FEL technology
- An EUV/soft x-ray FEL facility for ultra fast chemistry and biology, and a centre of accelerator R&D.



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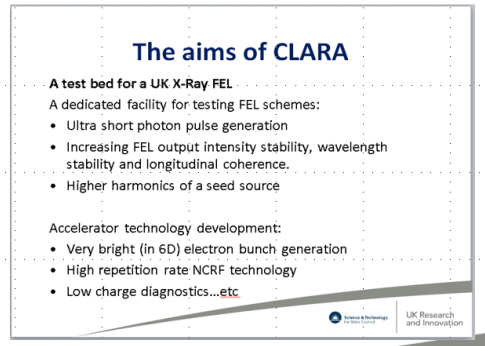
XARA

Accelerator Science on XARA

- Compact accelerator development:
  - X-band technology
  - Compact FEL section
  - Single cycle FEL pulses
- Up to 1 GeV/c electron beam exploitation line
- Even more relevant for developing UK XFEL technologies
- Plus..



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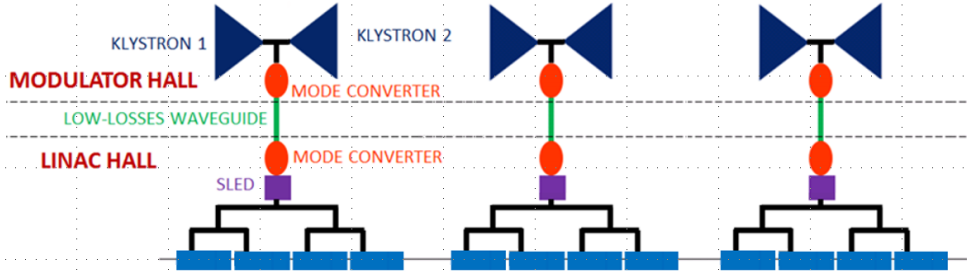
X-band linac

- Based on EuPRAXIA@SPARC_LAB/CompactLight/eSPS RF module
- 4 x 0.9 m 80 MV/m x-band cavities per module
- 3 modules



M. Diomede et al 2014, NIMA Vol. 909

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EuPRAXIA@SPARC_LAB

- Electron linac facility for XFEL and plasma acceleration research at INFN Frascati, CDR submitted.
- Central element is 1 GeV linac using X-band technology.
- Strong collaboration on linac between Frascati and CERN, including X-band test stand at Frascati.

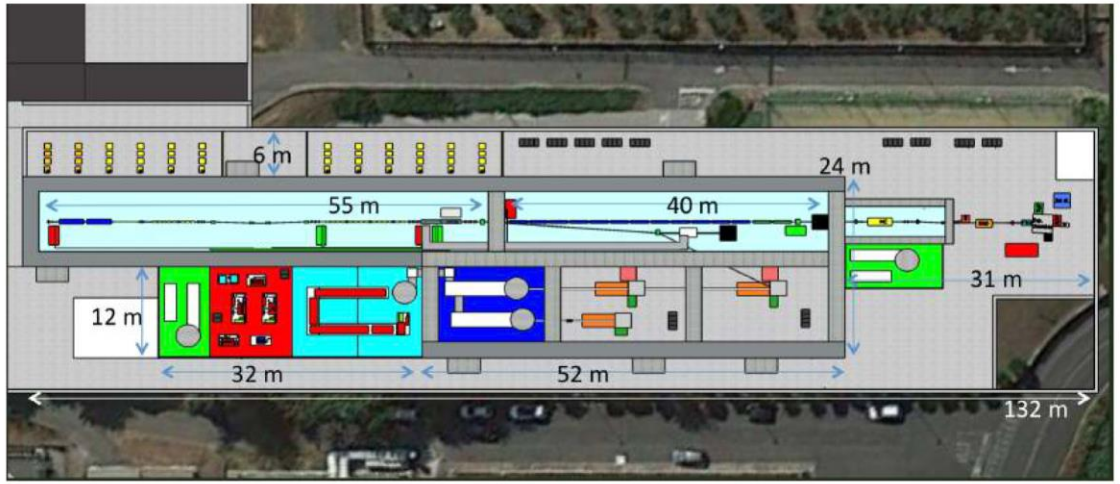


Figure 6: The layout of the EuPRAXIA@SPARC_LAB infrastructure.

The EuPRAXIA@SPARC_LAB project

Executive Summary

Abstract:

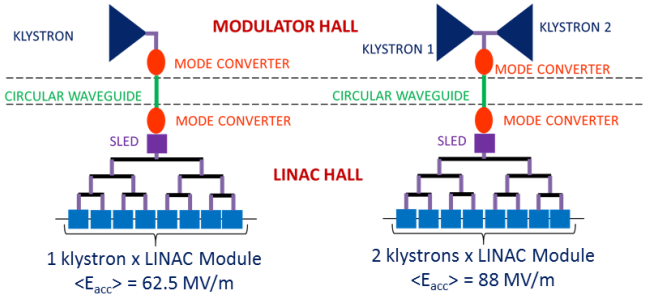
It is widely accepted by the international scientific community that a fundamental milestone towards the realization of a plasma driven future Linear Collider (LC) will be the integration of a high gradient accelerating plasma modules in a short wavelength Free Electron Laser (FEL) user facility. In this context the Horizon2020 Design Study EuPRAXIA (European Plasma Research Accelerator with eXcellence In Applications) will in October 2019 propose a first European Research Infrastructure that is dedicated to demonstrate usability of plasma accelerators delivering high brightness beams up to 1-5 GeV for users. In this report we discuss the EuPRAXIA@SPARC_LAB project, intended to put forward LNF as host of the EuPRAXIA European Facility. The EuPRAXIA@SPARC_LAB facility will equip LNF with a unique combination of a high brightness GeV-range electron beam generated in a state-of-the-art advanced compact linac, a 0.5 PW-class laser system and the first 5th generation light source. These unique features will enable at LNF new promising synergies between fundamental physics oriented research and high social impact applications, especially in the domain of key enabling technologies (KET) and Smart Specialisation Strategies (S3).

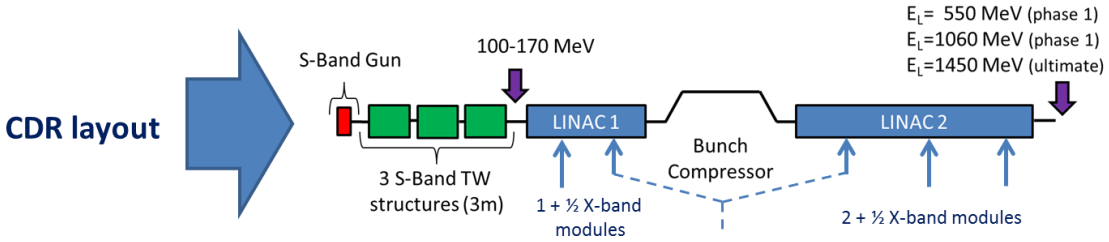
EuPRAXIA@SPARC_LAB

X-BAND LINAC DESIGN

WP1: particle driven plasma acceleration
WP2: laser driven plasma acceleration
WP3: no plasma acceleration, only RF

X-Band LINAC parameters				
L_t [m]	16			
	WP1	WP2	**WP3**	Ultimate
E_0 [MeV]	100	170	**170**	170
E_{gain} [MeV]	450	380	**890**	1280
<G> [MV/m]	20(L1)-36(L2)	20(L1)-27(L2)	**57**	80
E_L [MeV]	550	550	**1060**	1450

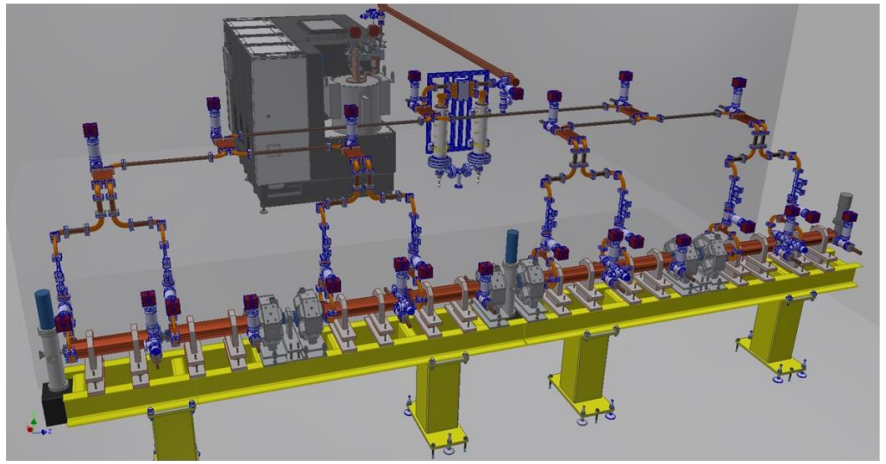




Design under revision (2 RF modules in both linac #1 and #2). Work is well advanced.

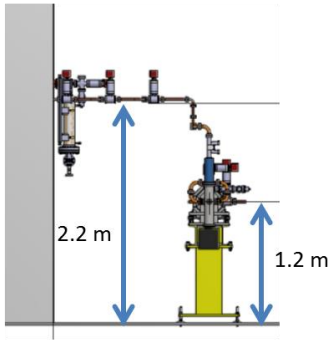
EuPRAXIA@SPARC_LAB CDR Review Committee Meeting
27-28 November 2018 INFN Frascati
A. Gallo: X-band RF Linac technology

RF MODULE LAYOUT



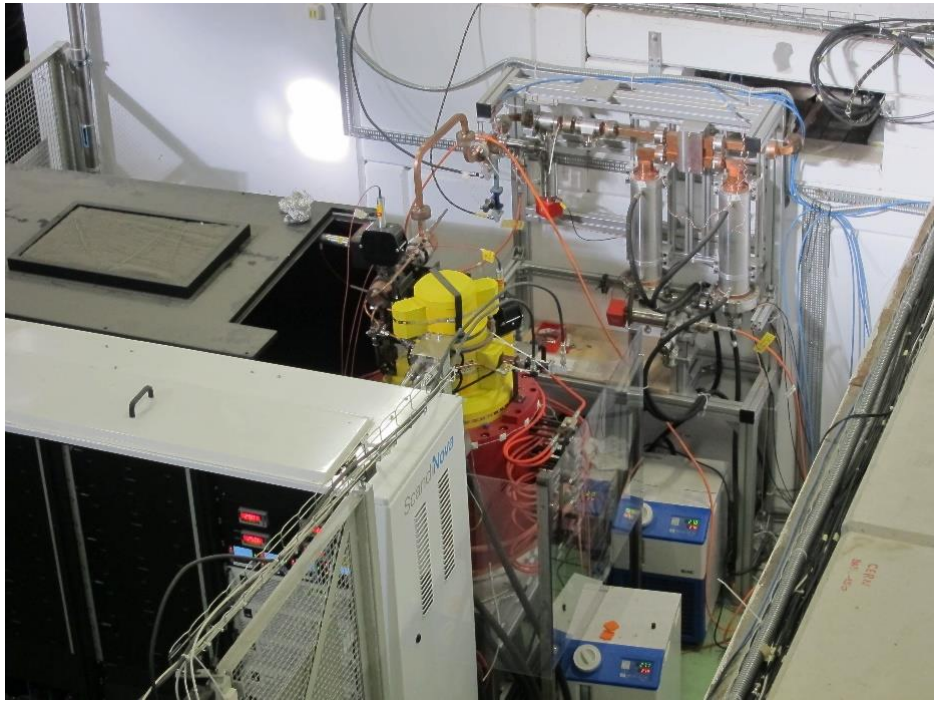
Preliminary layout of the **RF module** (collaboration with CERN): **8 structures, 1 SLED, 1 or 2 Klystrons** per module.

Estimated **waveguide attenuation** (including circular waveguide): **10%**



WR-90 total length [mm]	3758
WC-50 circular wg length [mm]	3674
WR-90 loss [dB]	-0.368
WC-50 loss [dB]	-0.0456
total loss [dB]	-0.414
total loss [%]	-9.09

EuPRAXIA@SPARC_LAB



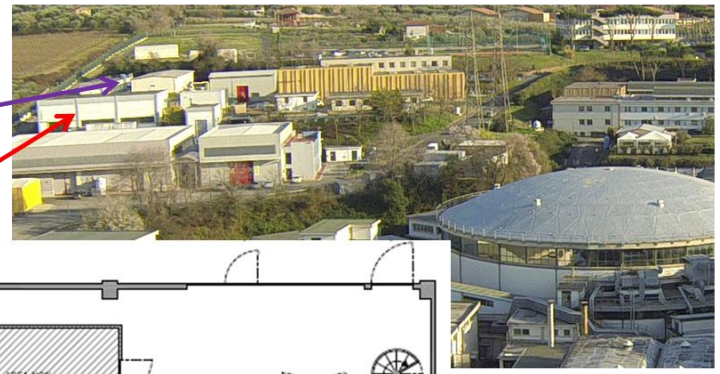
Based on XBox-2

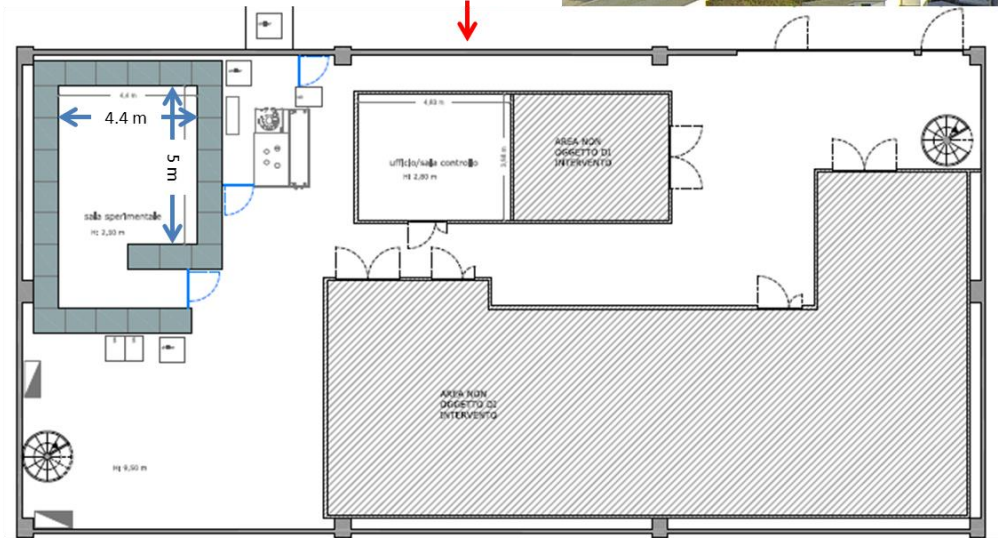
EuPRAXIA@SPARC_LAB CDR Review Committee Meeting
27-28 November 2018 INFN Frascati

A. Gallo: X-band RF Linac technology

As part of the CERN-INFN collaboration agreement, CERN will support the construction of a X-band high power test stand (the Frascati X-box, duplication of the CERN X-box #2)

INFN Frascati will get one klystron, one pulse compressor, plus some other components, on loan.





it will be located in LNF building #7, very close to the SPARC_LAB area, formerly used for testing and conditioning of the DAFNE RF power plants and cavities

5

EuPRAXIA@SPARC_LAB

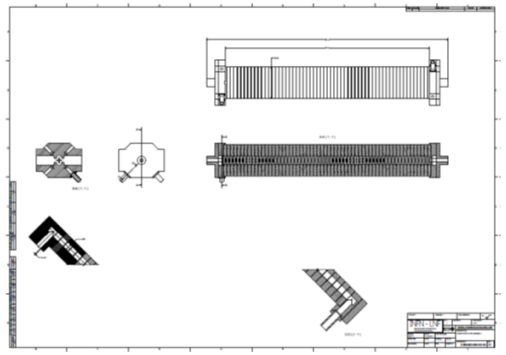
Technology return:

- Based on ELI-NP linac production experience, INFN is pursuing fabrication of brazed accelerating structures.
- Will provide important experience for medium series production and possibly lower cost alternative to CLIC baseline.

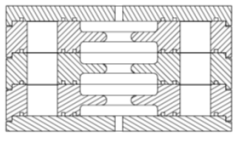
X-BAND PROTOTYPE ACTIVITY

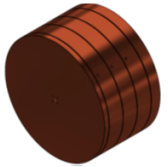
We would like to fabricate two prototypes before the production of a first «real» prototype to be tested at high power:

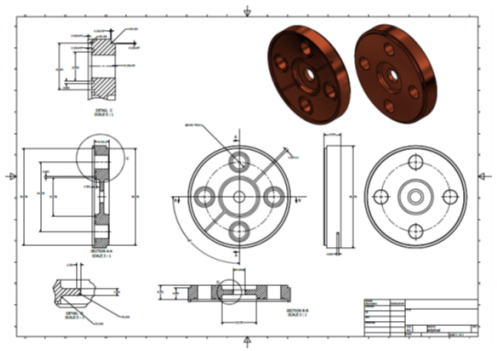
1) Full scale mechanical prototype: to test the brazing process of the full structure and the cell-to-cell alignment we are able to achieve using the LNF vertical vacuum furnace.



2) 3 cell RF prototype: to test the precise machining capabilities of the «local» companies that we would like to qualify for the production of the cavities and the effect of the brazing process. We would like to avoid tuning and/or limit the tuning process to few cells (input/output couplers).







D. Alesini

FERMI energy upgrade

Upgrade FERMI linac by keeping existing S-band klystron/modulator power stations and rebuild rest of rf system based on latest high-gradient ideas.

Linear collider developed high-gradient methodology is broadly applicable!

Elettra Sincrotrone Trieste

HIGH POWER TESTING OF HIGH GRADIENT S-BAND STRUCTURES FOR THE FERMI FEL

Nuaman Shafqat

on behalf of

FERMI RF Team

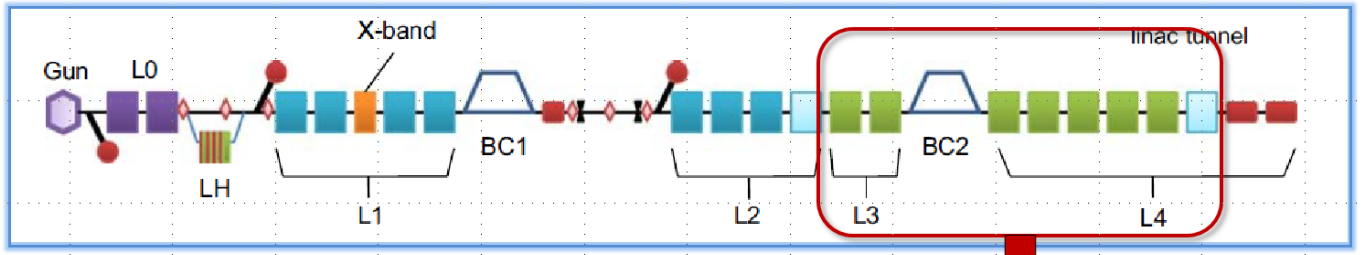
HG2019, Chamonix, 10-14 June 2019 — Nuaman Shafqat, 11/06/2019 — 2

Elettra Sincrotrone Trieste

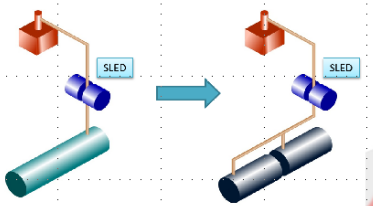
THE FERMI UPGRADE PROPOSAL

TO EXTEND THE RANGE TO SHORTHER WAVELENGTH UP TO 2 nm

Actual Linac Energy **1.5 GeV @ 10Hz** → Target Linac Energy **1.8 GeV @ 50Hz** → Solution **High Gradient 30MV/m**



Replace 7 BTW with high gradient accelerating modules

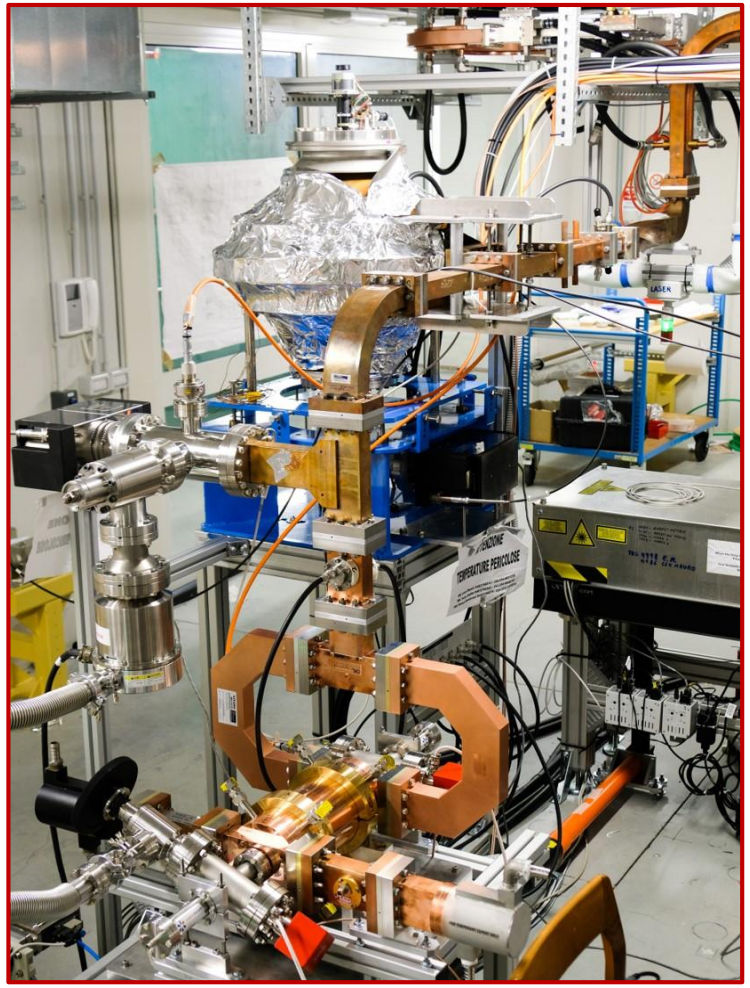


$$BDR \propto E_a^{30}.t^5$$

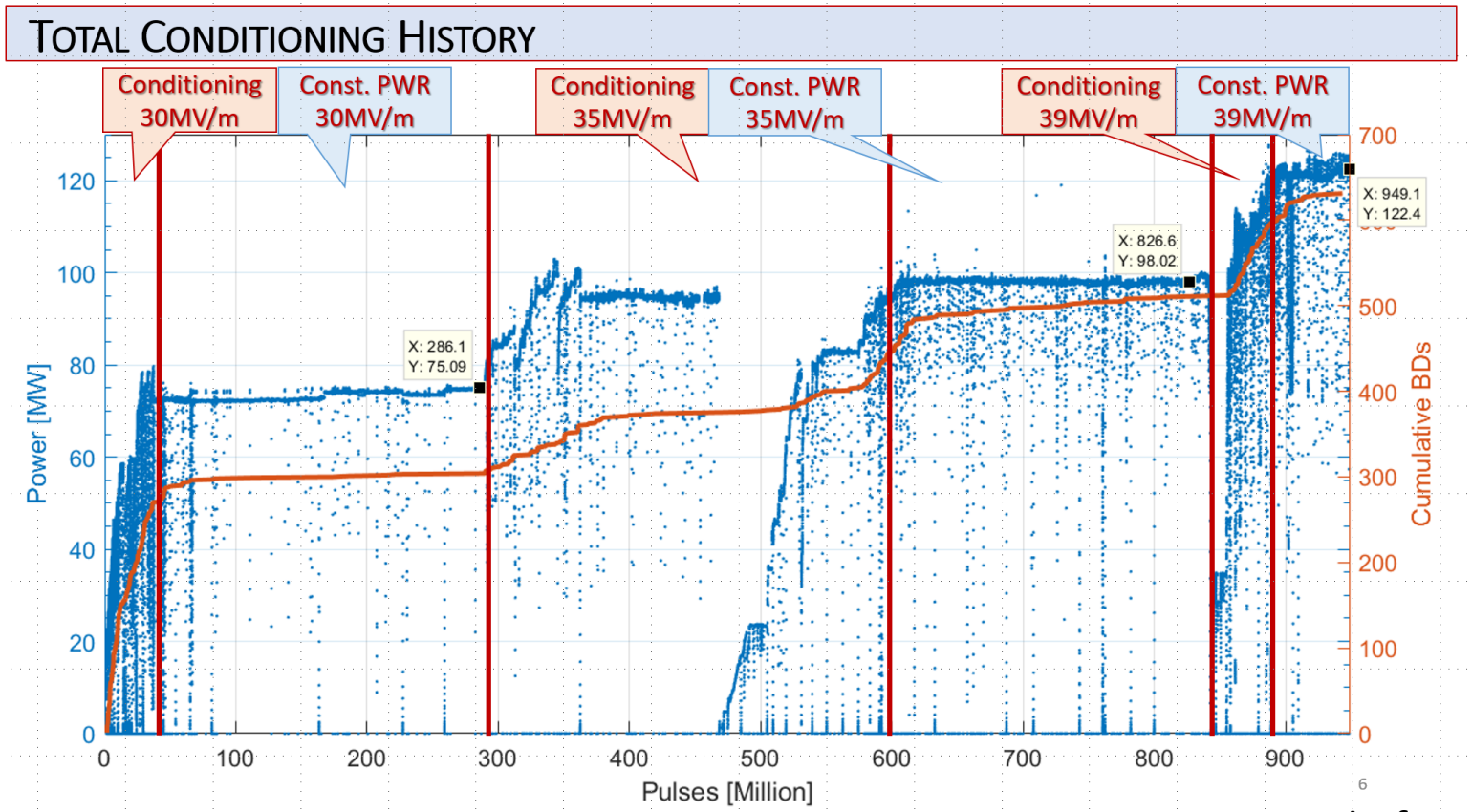
From 24MV/m to 30MV/m, the **BDR will increase by a factor of 800!!!**

HG2019, Chamonix, 10-14 June 2019 — Nuaman Shafqat, 11/06/2019 — 7

FERMI energy upgrade



Structure built by PSI and installed in Trieste.



N. Shafqat

Conditioning history – test continues!

Tsinghua Thompson source energy upgrade

ACCELERATOR LABORATORY OF TSINGHUA UNIVERSITY

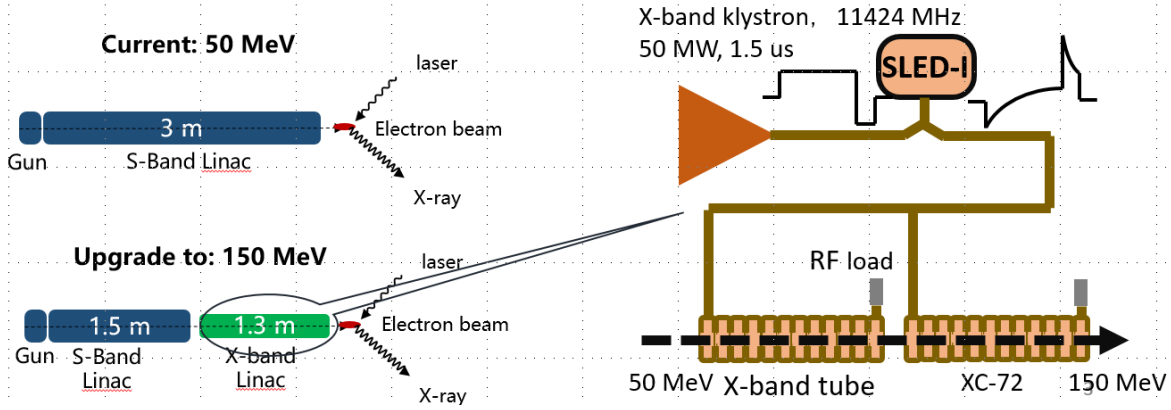
Developments of high gradient structures at Tsinghua University

Hao Zha, Jiaru Shi, Jiayang Liu, Liuyuan Zhou, Xiaowei Wu

The 12th International Workshop on Breakdown Science and High Gradient Technology, Chamonix, France

Tsinghua Thomson scattering X-ray source facility

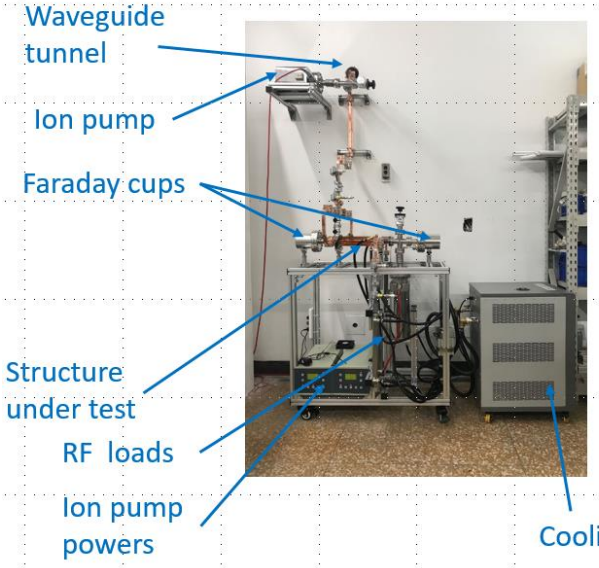
- Use X-band structures (80 MV/m) to upgrade the beam energy from 50 MeV to 150 MeV.
- Single bunch mode: RF compressor is used to reduce the power from klystron (Only one klystron is demanded).



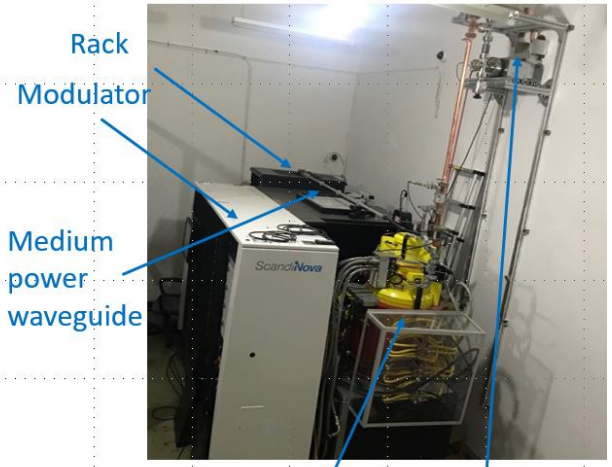
Tsinghua X-band test stand

TPoT-X pictures

TPoT-X bunker

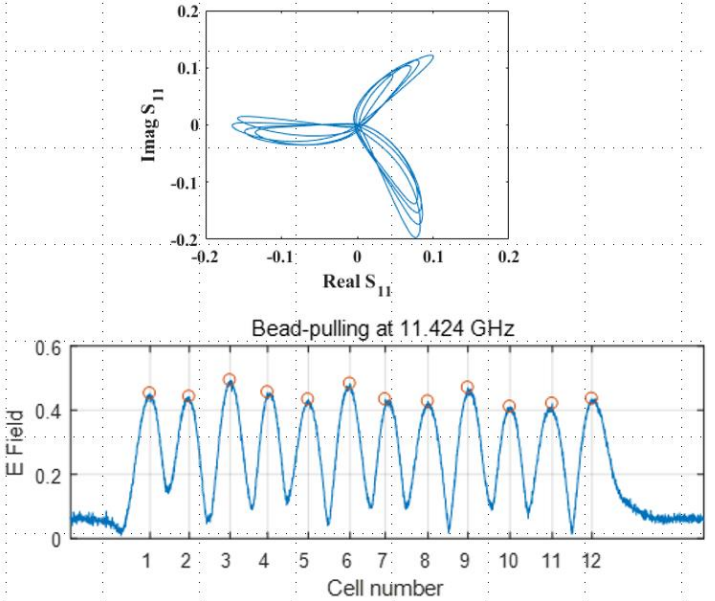


Outside of the bunker

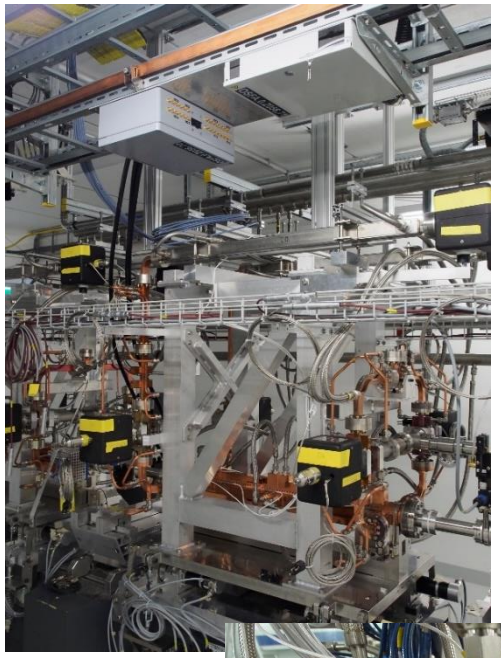


C12-Open structure

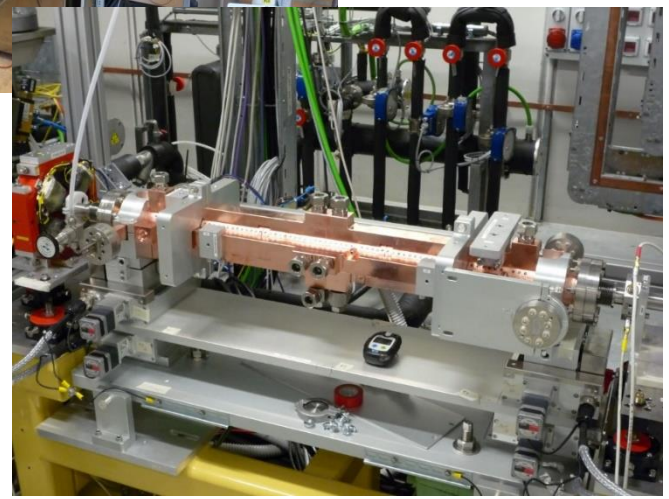
- Tuning wasn't performed and the field looks good.
- Structure was brazed by using Silver-Copper based alloy.



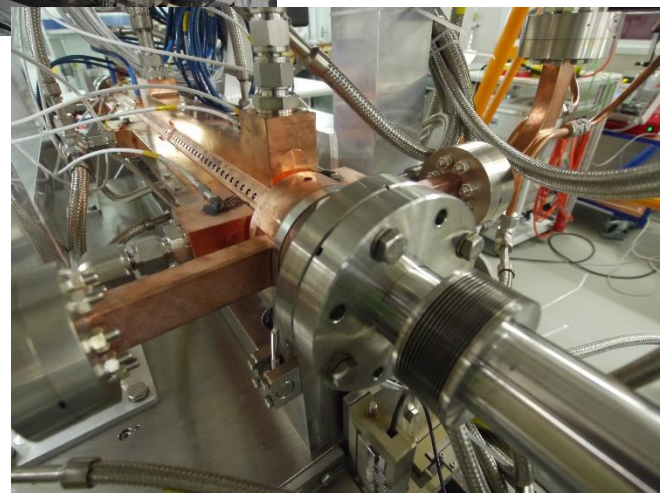
X-band energy spread linearizers at XFELs



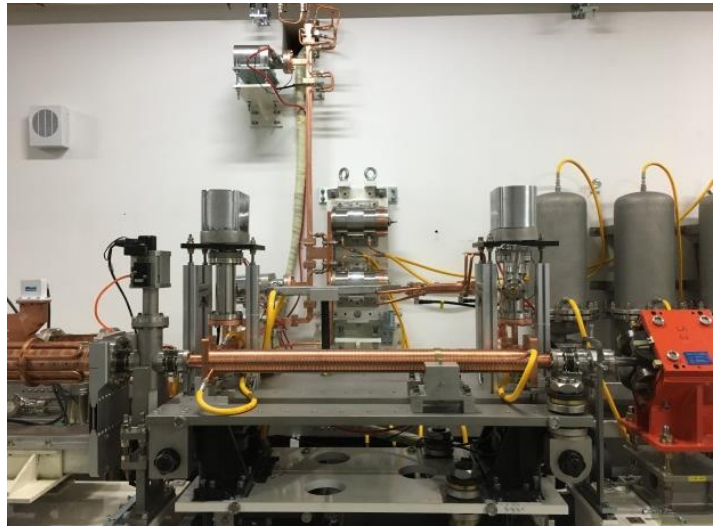
SINAP



PSI



FERMI



High-gradient test infrastructure

CERN	XBox-1	50 MW, 12 GHz	Operational (later to CLEAR)
	Xbox-2	50 MW, 12 GHz	Operational
	XBox-3	4x6 MW, 12 GHz	Operational
KEK	NEXTEF	2x50 MW	Reorganizing following fire
Tsinghua	TPOT-X	50 MW, 11 GHz	Operational
Trieste	CTF	45 MW, 3 GHz	Operational
Valencia		2x10 MW, 3 GHz	Commissioning
Frascati		50 MW, 12 GHz	Procurement
Shanghai		50 MW, 12 GHz	Installation
Melbourne, ALS		2x6 MW, 12 GHz	Planning
SLAC	NLCTA+XTA	2x50 MW, 11 GHz	Operational
	Klystron Test Lab	2x50 MW, 11 GHz	Operational
Los Alamos	CERF-NM	50 MW, 5.7 GHz	Commissioning

X-band linearizers and deflectors

Trieste	Linearizer for Fermi	50 MW	Operational
PSI	Linearizer for SwissFEL	50 MW	Operational
	Deflector for SwissFEL	50 MW	Procurement
DESY	Deflector for FLASHforward	6 MW	Operational
	Deflector for FLASH2	“	Installation
	Deflector for Sinbad	10 MW	Procurement
SINAP	Linearizer for soft X-ray FEL	6 MW	Operational
	Deflectors for soft X-ray FEL	2x50 MW	Procurement
Daresbury	Linearizer	6 MW	Procurement
SLAC	LCWS linearizer	50 MW	Operational
	LCWS deflector	50 MW	Operational
Dalian	Linearizer for DCLS	50 MW	Design

X-band linacs

SLAC	NLCTA+XTA	2x50 MW, 11 GHz	Operational
Eindhoven	Compact Compton source - 25 MeV	6 MW	Procurement
CERN	CLEAR – 50 MeV (from Xbox-1)	50 MW	Installation
Tsinghua	Thompson source upgrade + 50 MeV	50 MW	Procurement
	200 MeV Thompson source	2x50 MW	Proposal
Frascati	XFEL, injector to plasma - 1 GeV	8x50 MW	CDR submitted
Daresbury	Xara – 1 GeV	6x50 MW	Design study
Collaboration	CompactLight – 5.5 GeV	30x50 MW	Design study
CERN	eSPS – 3.5 GeV	24x50 MW	Letter of intent submitted
Groningen	1.4 GEV XFEL Accelerator - 1.4 GeV		NL roadmap
CERN	CLIC – 380 GeV	5800x50 MW	European Strategy Update

Further information on these applications can be found at HG2019 held this past June https://indico.cern.ch/event/766929/.

Conclusions

- The high-gradient linac technology developed for CLIC is turning out to be of importance for many small to medium scale applications.
- Excellent examples of “spin out” of developments in fundamental science.
- Strong return for the CLIC project.
- Applications growing!

Thank you for your attention!