Elettra Sincrotrone Trieste

Overview of high gradient X-band RF technology development

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Outline

- Overview and historical remarks
- The X-band technology
- X-band applications:
  - Linear collider
  - Photon sources
  - Beam diagnostics and manipulation
- Conclusions

Considering the vastness of the subject, only a selection of activities at laboratories that provided me with information and data about their projects/activities will be presented.
I apologize in advance for those who will not be mentioned.

Overview and Historical Remarks

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Already in the mid 60's,

the Slac "Blue book" reports

a clear interest in the accelerator community

for X-band technology.

Table 6-2 Design parameters of 20-GeV accelerator at three frequencies[a]

Parameter	Frequency (L-Band) 1000 MHz	(S-Band) 3000 MHz	(X-Band) 9000 MHz
Shunt impedance r (megohms/meter)	31	53	92
RF loss factor (Q)	2.25×10^4	1.3×10^4	0.75×10^4
Filling time t_F (μsec)	4.31	0.83	0.16
Total RF peak power (MW)	9216	5320	3072

Historical Remarks II

- The driving force behind the X-band technology development has been the scientific interest for the construction of a Multi TeV e^+e^- linear collider. From the late 1980's to 2004, groups from SLAC, KEK and Fermilab began a dedicated development of X-band technology for a TeV-scale Linear Collider. The frequency choice, 11.4 GHz, four times that of SLAC linac, was motivated by cost benefits:
  - high gradients ì shorter and cheaper linacs;
  - lower energy per pulse ì fewer RF sources.
- In 2004, the International Technology Review Panel (ITRP) selected L-band superconducting RF technology for the International Linear Collider (ILC) which led to a slowdown in X-band activities.
- In 2007 CERN decided to lower the Compact Linear Collider (CLIC) frequency to 12 GHz (previously at 30 GHz) producing a new interest in X-band and the CERN-SLAC-KEK collaboration on high gradient X-band development.

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X-band applications

In addition to the Linear Collider application, X-band technology is now rapidly expanding for the multiple uses that it can satisfy. In particular:

- **Very compact X-ray FELs and photon sources, based on few tens of MeV up to multi GeV linacs.**
- **Diagnostics for X-ray FELs, i.e.:**
  - **transverse deflecting cavities for bunch length measurements and beam phase space characterization with extremely high resolution.**
- **Beam manipulation, i.e.:**
  - **energy linearizer, already in use at LCLS, FERMI, SwissFEL, and SXFEL.**
  - **crab cavities for beam luminosity improvement at collider IP (i.e. CLIC).**
- **Medical and industrial applications, i.e.:**
  - **linacs for proton and carbon ion therapy, IORT…**
  - **low energy compact linacs for radiographies and non-destructive inspections.**

Not included in this presentation

Overall activities/projects

X-band high power test infrastructures

Laboratory	Name	Power	Status
CERN (CH)	XBox-1-2	50 MW	Operat.
	XBox-3	4 x 6 MW	Operat.
KEK (Japan)	NEXTEF	2 x 50 MW	Operat.
Tsinghua Un. (CINA)	TTX	50 MW	Commiss.
INFN-LNF (ITA)	EuSPARC-Lab	50 MW	Procurem.
SINAP (Cina)		50 MW	Procurem.
ALS (AU)		2 x 6 MW	Proposed
SLAC (USA)	ASTA	50 MW	Operat.

X-band linacs

Laboratory	Name	Power	Status
TU/e (NL)	ICS -50 MeV	6 MW	Des. & proc.
CERN (CH)	CLEAR–50 MeV	50 MW	Des. & prep.
INFN-LNF (ITA)	EuSPARC-1 GeV	50 MW	CDR
Internat. Collab.	CompactLight 5.5 GeV	Design Study	
CERN (CH)	LDMX–3.5 GeV	50 MW	Proposal
Gronin. Univ. (NL)	X-FEL-1.4 GeV	NL roadmap	
CERN (CH)	CLIC–380 GeV	50 MW	CDR
LLNL (USA)	ICS - 30 MeV	50 MW	Commiss.
SLAC (USA)	NLCTA – 350 MeV	50 MW	Operat.
STFC	XARA – 1.0 GeV	50 MW	Proposal

X-band linearizers and deflectors

Laboratory	Name	Power	Status
Elettra - ST	Fermi Lin.	50 MW	Operat.
PSI	SwissFEL Lin.	50 MW	Operat.
	SwissFEL TDC	50 MW	Des. & Proc.
DESY	FLASH FW TDC	6 MW	Des. & Proc.
	FLASH2 TDC	6 MW	Des. & Proc.
	Sinbad TDC	tbd	Planning
SINAP	SXFEL Lin.	6 MW	Operat.
	SXFEL TDC	2 x 50 MW	Proc.
STFC	CLARA Lin.	6 MW	Des. & Proc.
Tsinghua Univ.	TTX Lin.	6 MW	Planning
SLAC	LCLS Lin.	50 MW	Operat.
	LCLS TDC (3)	50 MW	Operat.
	NLCTA TDC (2)	50 MW	Operat.
	FACET TDC (1)	50 MW	Operat.

Pros/Cons of higher frequency linacs

Advantages:

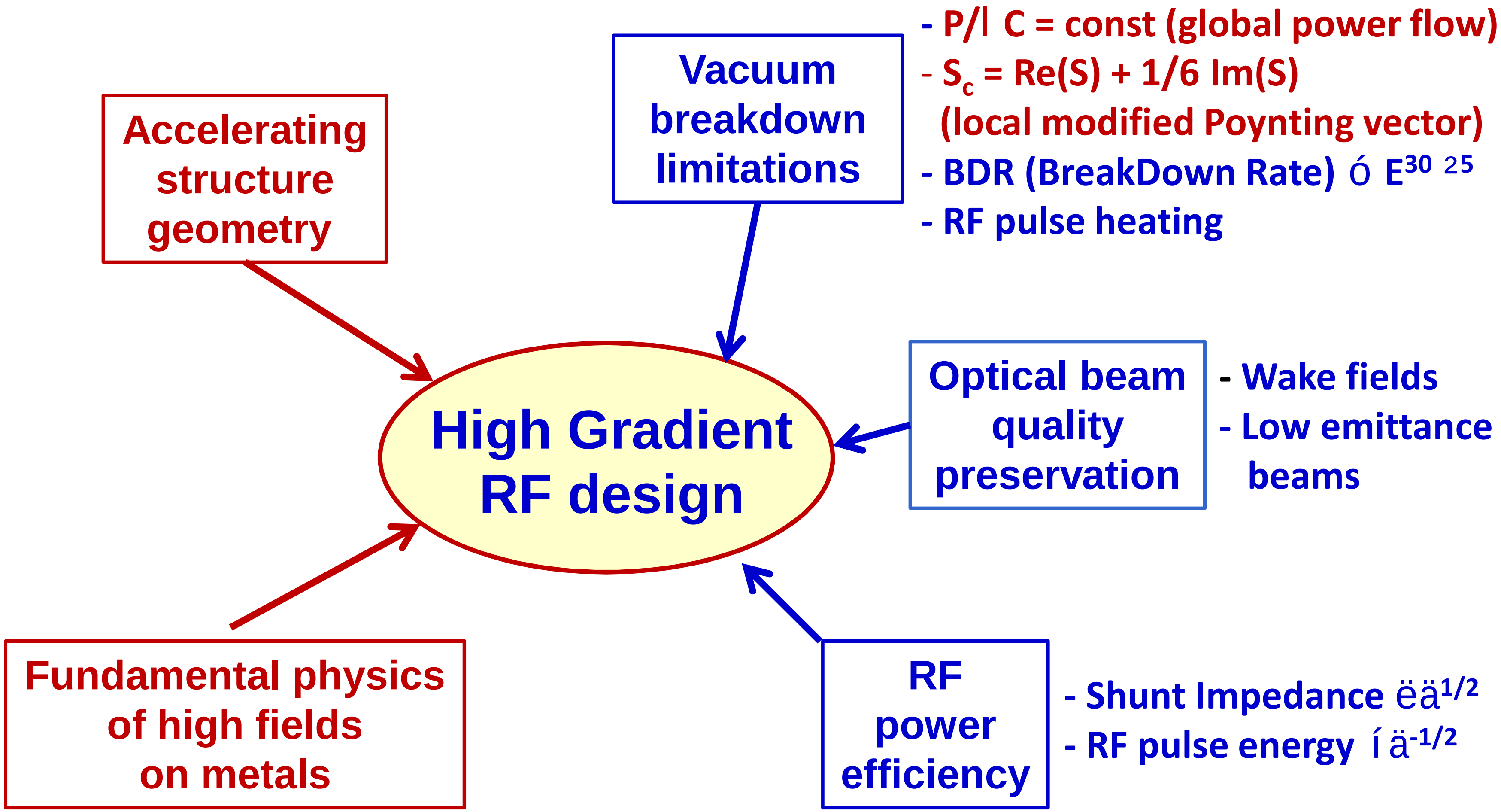
- Higher operating gradients
  - X-band is capable up to 80-100 MV/m
  - S-band is limited to about 20-24 MV/m
  - C-band is limited to about 32-35 MV/m
- Higher energy efficiency, especially for short pulse operation
  - Important for lightly loaded operation
  - Opens possibility of higher repetition rates , i.e. kHz X-ray FELs

Drawbacks:

- Larger wakefields*
  - Need larger iris radius to reduce the short-range wakes
  - Need HOM damping to reduce the long-range wakes
- Very tight alignment tolerances

*Generally small for X-FELs operating with short bunches (≤ 100 fs) and low bunch charge < 250 pC

High Gradient RF design: methodology & constraints



i.e. BDR specification for CLIC:

á $3x10^{-7}$/pulse/m

(at 50 Hz, 1 BD every 3 days/structure)

CLIC Design

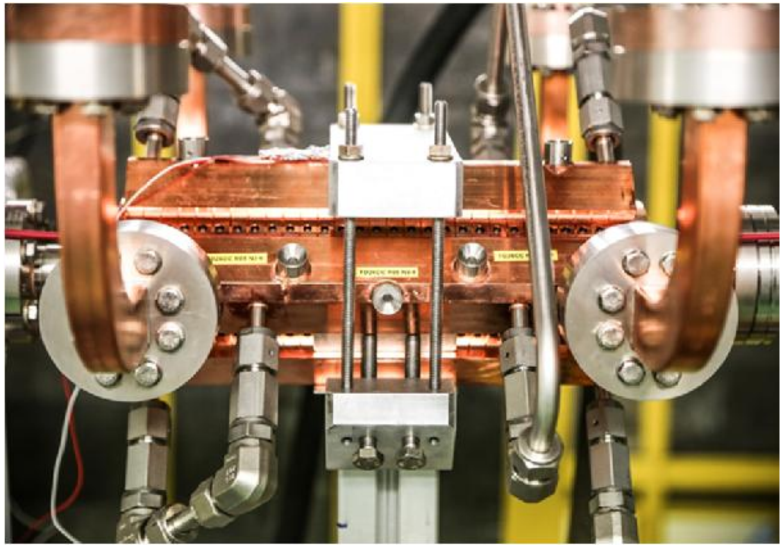
ä = 11.994 GHZ

E_{acc}. > 100MV/m

Input power ¼ 50 MW

Pulse length ¼ 200 nsec

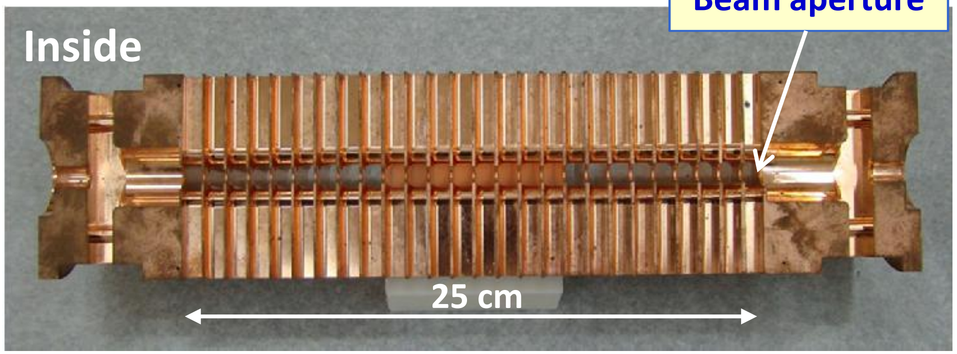
Repetition rate 50 Hz

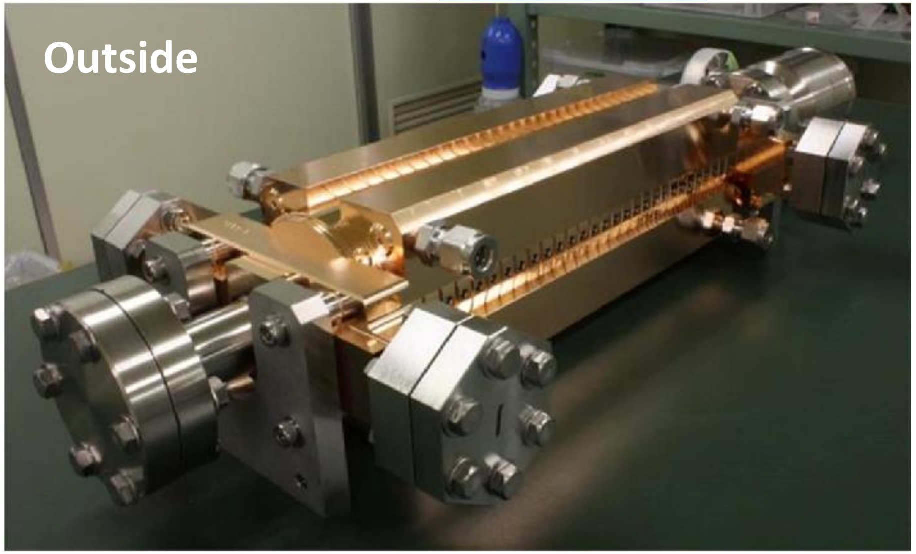


Micron–precision disk

HOM damping waveguide

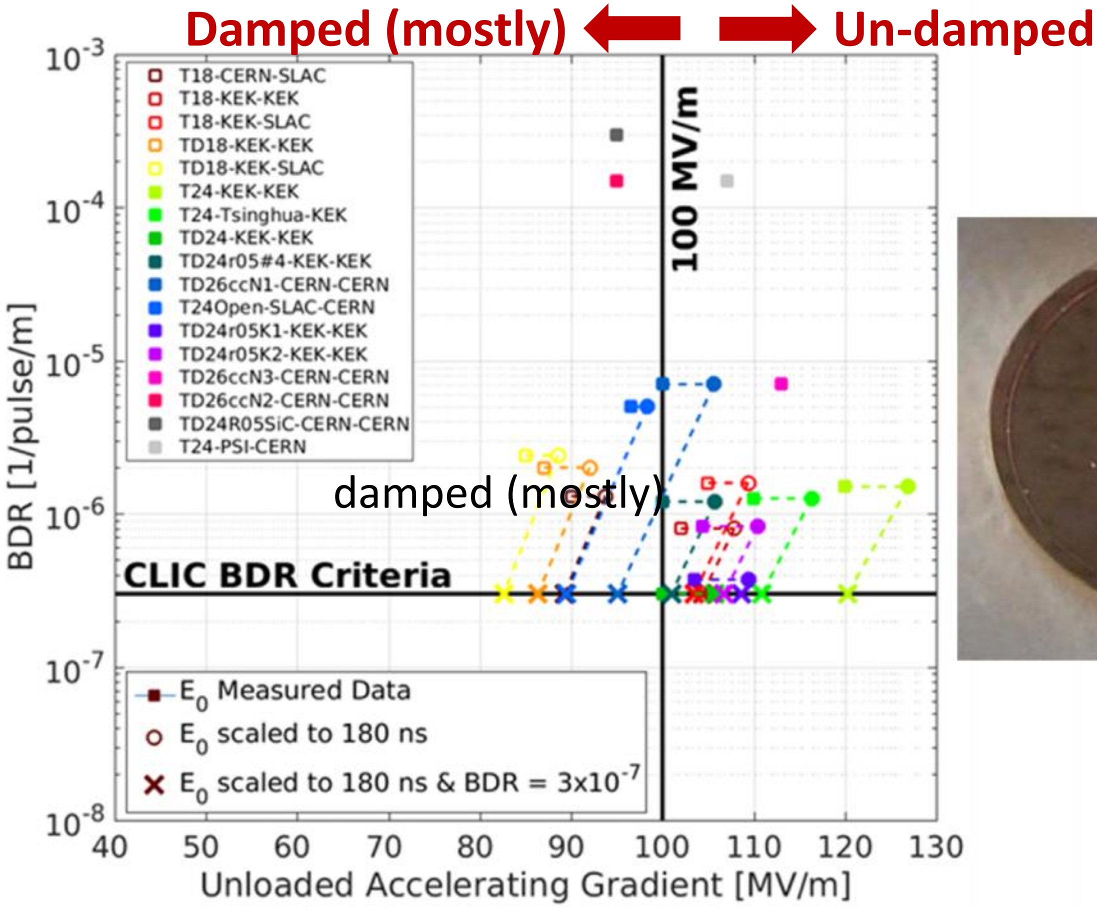
6 mm diameter Beam aperture

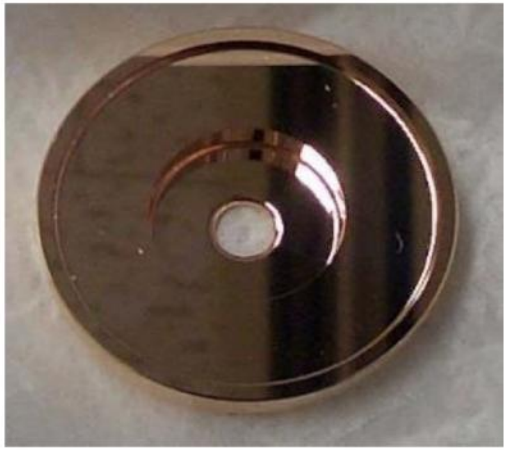




Courtesy W. Wuensch

Gradient perspectives





Courtesy
W. Wuensch

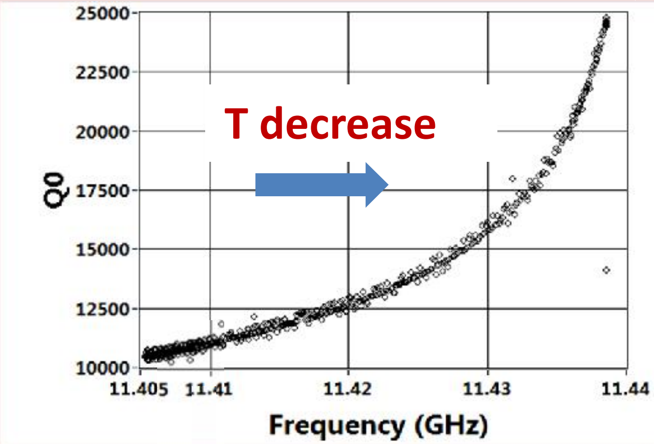
X-band activities at SLAC

- Since the late 80's SLAC has pioneered the X-band technology development with a major contribution from KEK for the high gradients accelerating structures.
- The important R&D effort brought the development of many high power RF components at 11.424 GHz, i.e. klystron, HG structures, WG components.
- From 2007 SLAC has been actively involved with CERN and KEK on high gradient X-band development (i.e. CLIC), as well as to support many X-ray laboratory programs (FELs and compact photon sources).
- In 2010, SLAC made an extremely important contribution for CLIC and for FEL applications with the manufacture of the first 50 MW at 12 GHz klystron.
- Recently SLAC has moved to new ambitious developments based on Cryogenic RF Technologies.

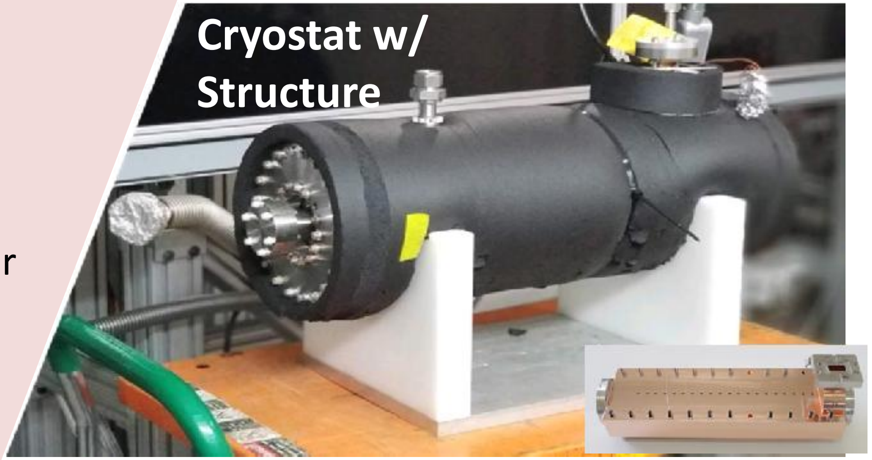
SLAC perspectives and new developments

Cryogenic-Copper Accelerating Structures: New Frontier for Beam Brightness, Efficiency and Cost-Capability

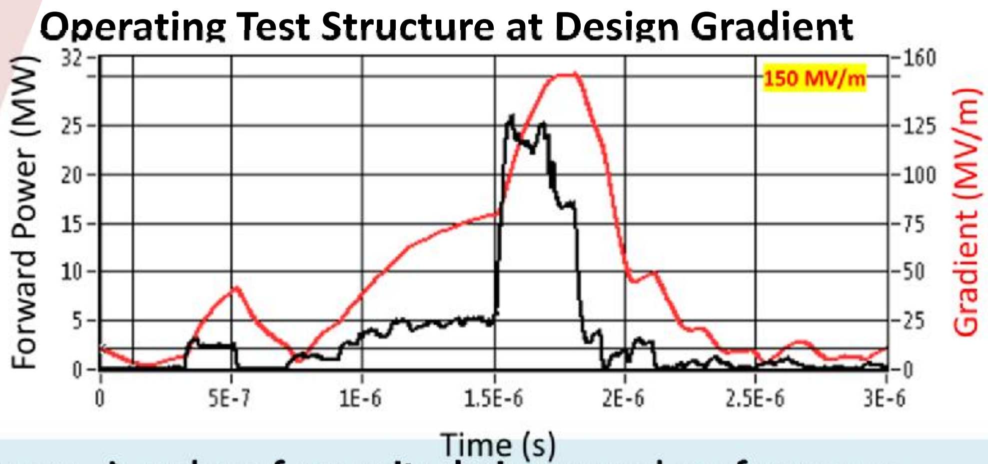
- Increased conductivity and hardness enables higher gradients
- Dramatic reduction in cost of system including cryogenics at 77K
- 2.5X less power establishing gradient allows for heavy beam loading even at high gradient – improving system efficiency



Increase in Q_0 by a factor of 2.5



M. Nasr, S. Tantawi, E. Nanni, et el.,



Impact of novel structures and temperatures → order of magnitude increased performance

Courtesy
E. Nanni

X-ray FELs and photon sources

Compact

- The CompactLight project (*http://CompactLight.eu*) is an EU funded design study aimed at promoting the construction of the next generation FEL based photon sources with innovative accelerator technologies.

- The objective is the design of a 5.5 GeV X-band linac to drive a FEL facility with soft and hard x-ray options that can be simultaneously operated.

The CompactLight Collaboration (24 members)

Preliminary CompactLight FEL parameters

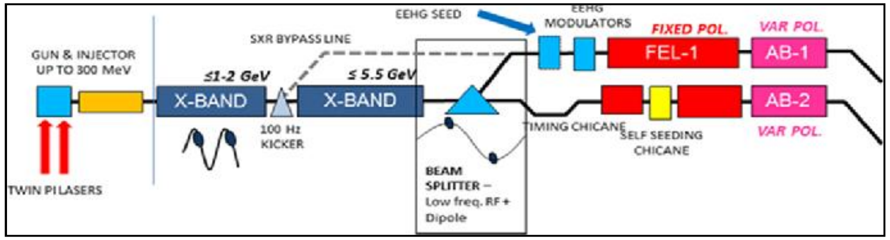
Parameter	Unit	Soft x-ray FEL	Hard x-ray FEL
Photon energy	keV	0.25 - 2.0	2.0 - 16.0
Wavelength	nm	5.0 - 0.6	0.6 - 0.08
Repetition rate	Hz	100 to 1000*	100
Pulse duration	fs	0.1 - 50	
Polarization		Variable - Selectable	
Two-pulse delay	fs	± 100	
Two-colours separation	%	20	10
Synchronization	fs	< 10	

*With a progressive approach

Linac beam parameters at full energy

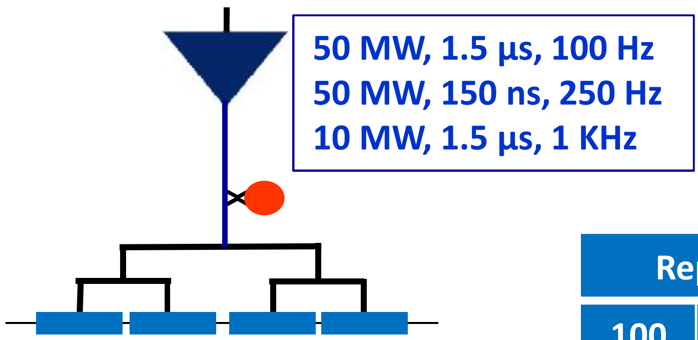
Parameter	Value
Max energy	5.5 GeV @100 Hz
Peak current	5 kA
Normalised emittance	0.2 mm.mrad
Bunch charge	< 100 pC
RMS slice energy spread	10^{-4}
Max photon energy	16 keV
FEL tuning range at fixed energy	×2
Peak spectral brightness @16 keV	10^{33} ph/s/mm^2/mrad^2/0.1%bw

FEL layout



RF system design

RF system parameter and layouts done for 100 Hz baseline, 100/250 Hz dual mode and 100/1000 Hz dual klystron



	Rep. rate [Hz]		
	100	250	1000
Average gradient <G> [MV/m]	65	32	30.4
Max klystron available out. power [MW]	50	50	10
Req. klystron power per module [MW]	39	42.5	8.5
RF pulse length [μs]	1.5	0.15	1.5
SLED	ON	OFF	ON
Av. diss. power per structure [kW]	1	0.31	2.2
Peak input power per structure [MW]	68	10.6	14.8
Av. Input power per structure [MW]	44	10.6	9.6
Module energy gain [MeV]	234	115	109

Parameter	Value
Frequency [GHz]	11.9942
Phase advance per cell [rad]	$2\pi/3$
Shunt impedance R [MΩ/m]	90-131
Effective shunt Imp. R_s [MΩ/m]	387
Group velocity v_g [%]	4.7-1.0
P_{out}/P_{in}	0.215
Filling time [ns]	144
Number of cells per structure	108
Unloaded SLED Q-factor Q_0	180000
External SLED Q-factor Q_E	23000
# structures per module N_m	4
Module active length L_{mod} [m]	3.6
Average iris radius <a>	3.5
Iris radius input-output [mm]	4.3-2.7
Structure length L_s [m]	0.9

Courtesy D. Alesini

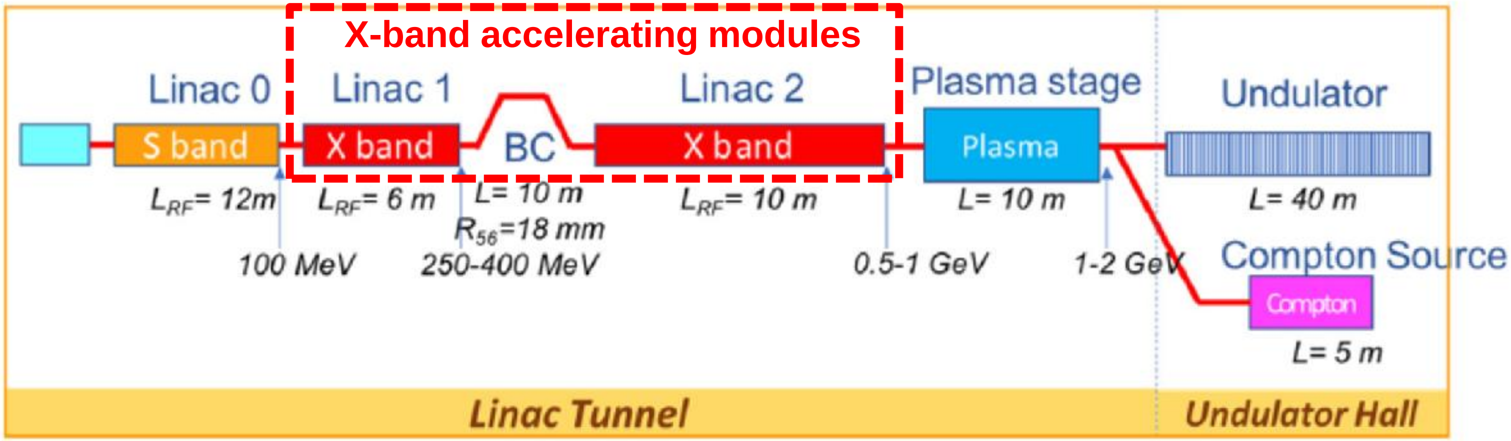
EuPRAXIA@SPARC_LAB

The EuPRAXIA@SPARC_LAB project (INFN-LNF), is a new multi-disciplinary user-facility, equipped with a soft X-ray FEL driven by a 1 GeV high brightness linac based on plasma accelerator modules.

	Units	1 GeV Plasma driven	1 GeV X-band only
Bunch charge	pC	30	200
Bunch length rms	fs	10	60
Peak current rms	kA	3	2
Rms energy spread	%	1.	0.1
Slice energy spread	%	0.1	0.05
Rms norm. emittance	µm	1.	1.
Slice nor. emittance	µm	$< 1.$	$< 1.$
Slice length	µm	0.75	1.
Radiation wavelength	nm	3	3
ρ	$\times 10^{-3}$	< 1	< 1
Undulator period	cm	1.5	1.5
K		0.987	0.987

Courtesy
M. Diomede

EuPRAXIA@SPARC_LAB



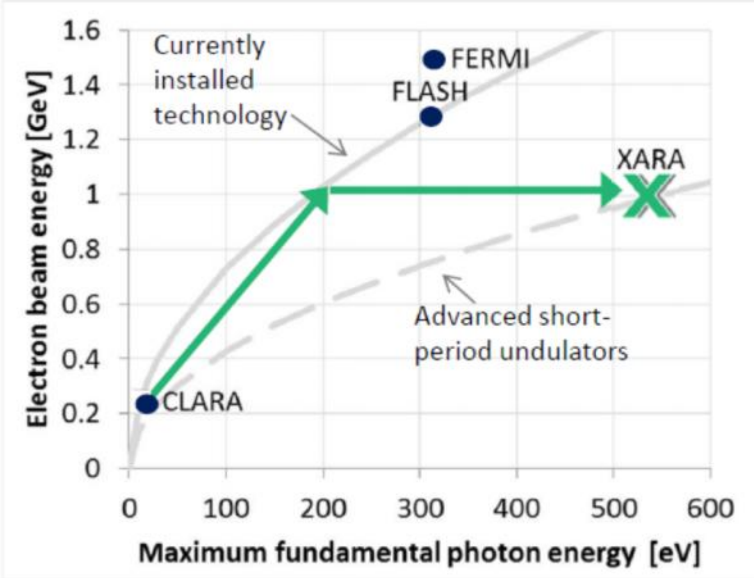
X-Band LINAC parameters			
total active length L_t	16 m		
Number of sections N_s	32 (4 modules x 8 sections)		
available RF power	50 MW (@klystron output coupler) 40 MW (@ section input couplers)		
	Injection in the plasma	Injection in the undulator	Ultimate
linac energy gain ΔW_{linac}	480 MeV	910 MeV	1280 MeV
average acc gradient $<E_{acc}>$	30 MV/m	57 MV/m	80 MV/m
total required RF power P_{RF}	44 MW	158 MW	310 MW

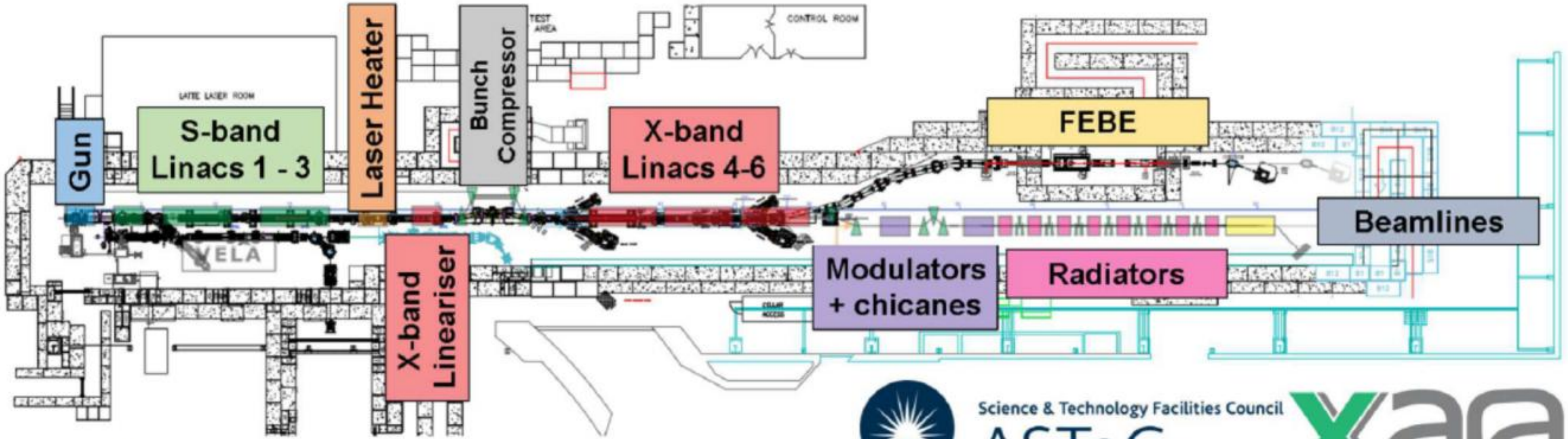
Courtesy
M. Diomede

XARA: X-band Accelerator for Research and Applications

Proposed X-band upgrade to the CLARA facility at Daresbury (250 MeV →1 GeV)

- **X-band technology** — 9 m of X-band structures at **80 MV/m**
- **Advanced FEL technology** — Reach higher photon energies and the **water window**
- **Electron beam exploitation** — **Full Energy Beam Exploitation** (FEBE) line for novel acceleration etc.





(Potential layout)

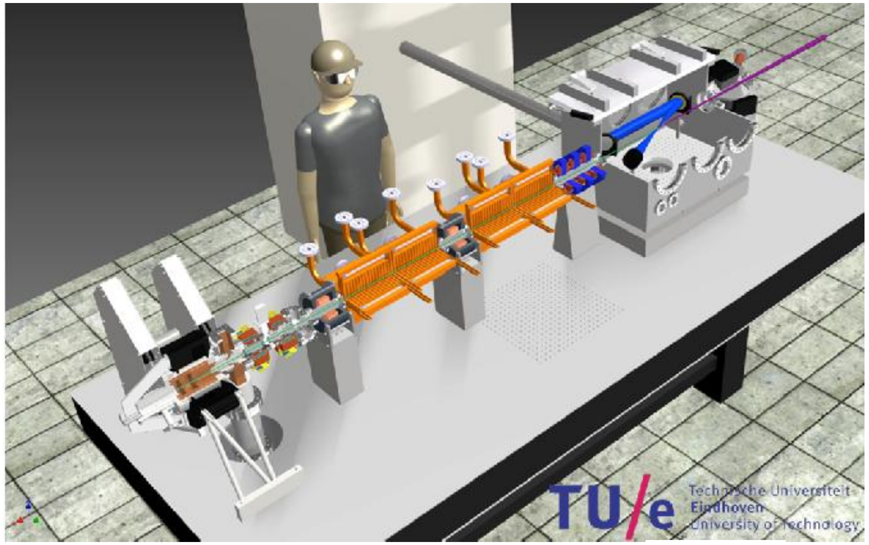
Science & Technology Facilities Council ASTeC

xara

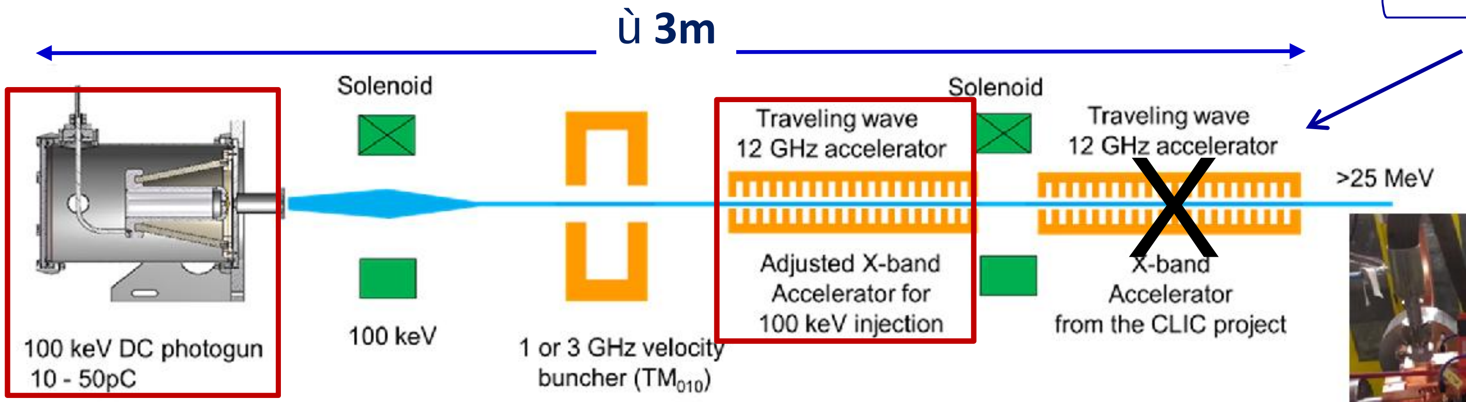
Courtesy L. Cowie

Smart*Light ICS X-ray source

Inverse Compton Scattering (ICS) source for tunable, monochromatic and highly coherent hard X-ray beams in a compact setup.



	Phase 1	Phase 2 > Brill.	Phase 2 > X-ray En.
Electron energy (MeV)	20	20	50
Charge per electron pulse (pC)	25	50	50
Electron beam waist (μm)	10	5	5
Laser wavelength (nm)	400	512	512
Energy per laser pulse (mJ)	5	100	100
# Electron bunches / train	1	10	10
Repetition rate klystron (Hz)	400	400	400
X-ray en. (keV)/Wavelength (Å)	19.9/0.6	15.5/0.5	97.1/0.13
Emission angle 0.1% bw (mrad)	0.79	0.79	0.32
# photons/s	$6.6E10^{7}$	$1.4E10^{11}$	$1.4E10^{11}$
# photons/s/0.1% bandwidth	$2.5E10^{5}$	$5.2E10^{8}$	$5.2E10^{8}$
Brill. (ph/s/mrad^2/mm^2/0.1% bw)	$4.0E10^{9}$	$3.3E10^{13}$	$2.1E10^{14}$



CLIC Acc. structure

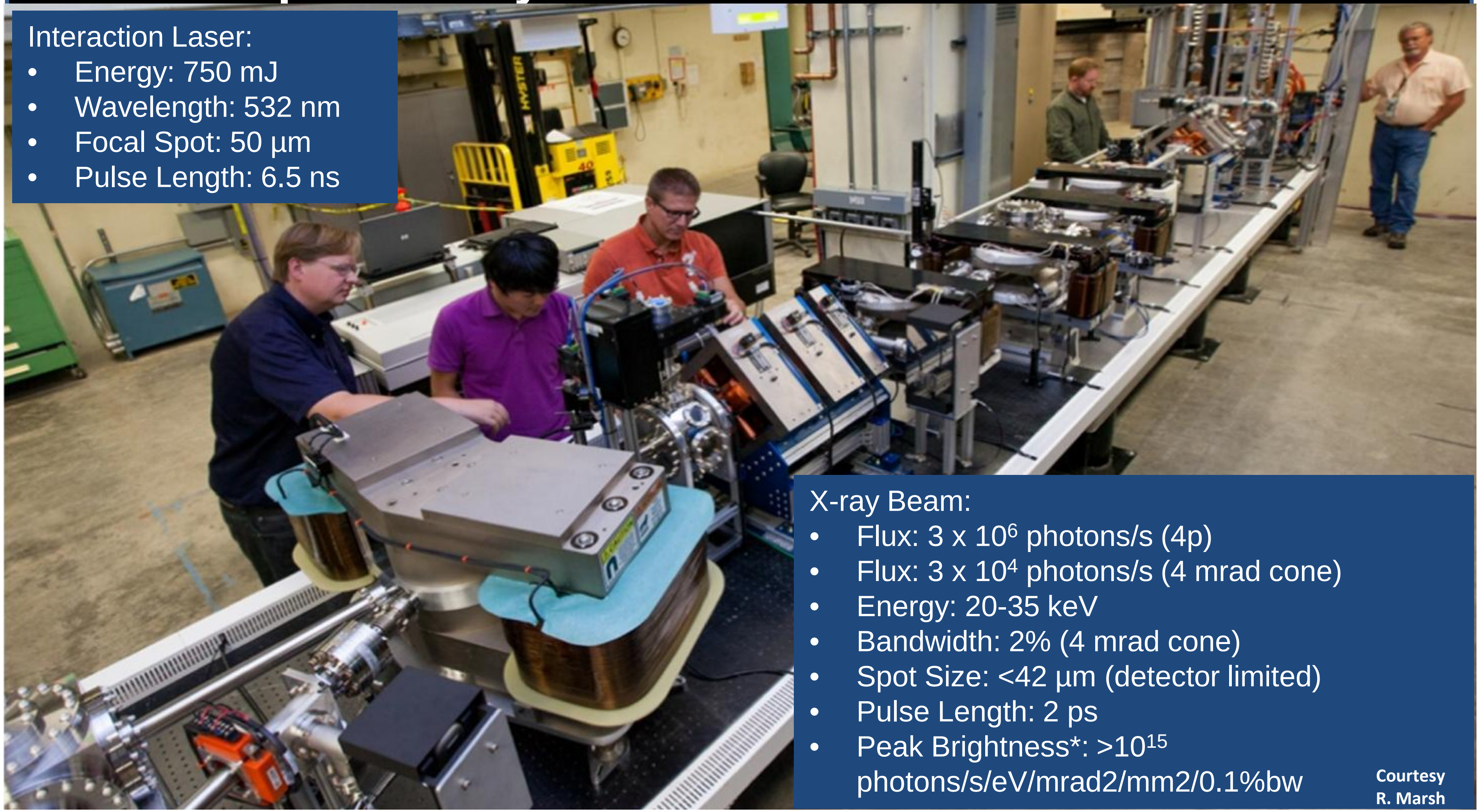
Courtesy
J. Luiten

LLNL ICS x-ray source

Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory

Laser-Compton X-Ray Source



Interaction Laser:

- Energy: 750 mJ
- Wavelength: 532 nm
- Focal Spot: 50 µm
- Pulse Length: 6.5 ns

X-ray Beam:

- Flux: 3 x 10^6 photons/s (4p)
- Flux: 3 x 10^4 photons/s (4 mrad cone)
- Energy: 20-35 keV
- Bandwidth: 2% (4 mrad cone)
- Spot Size: <42 µm (detector limited)
- Pulse Length: 2 ps
- Peak Brightness*: >10^{15} photons/s/eV/mrad2/mm2/0.1%bw

Courtesy R. Marsh

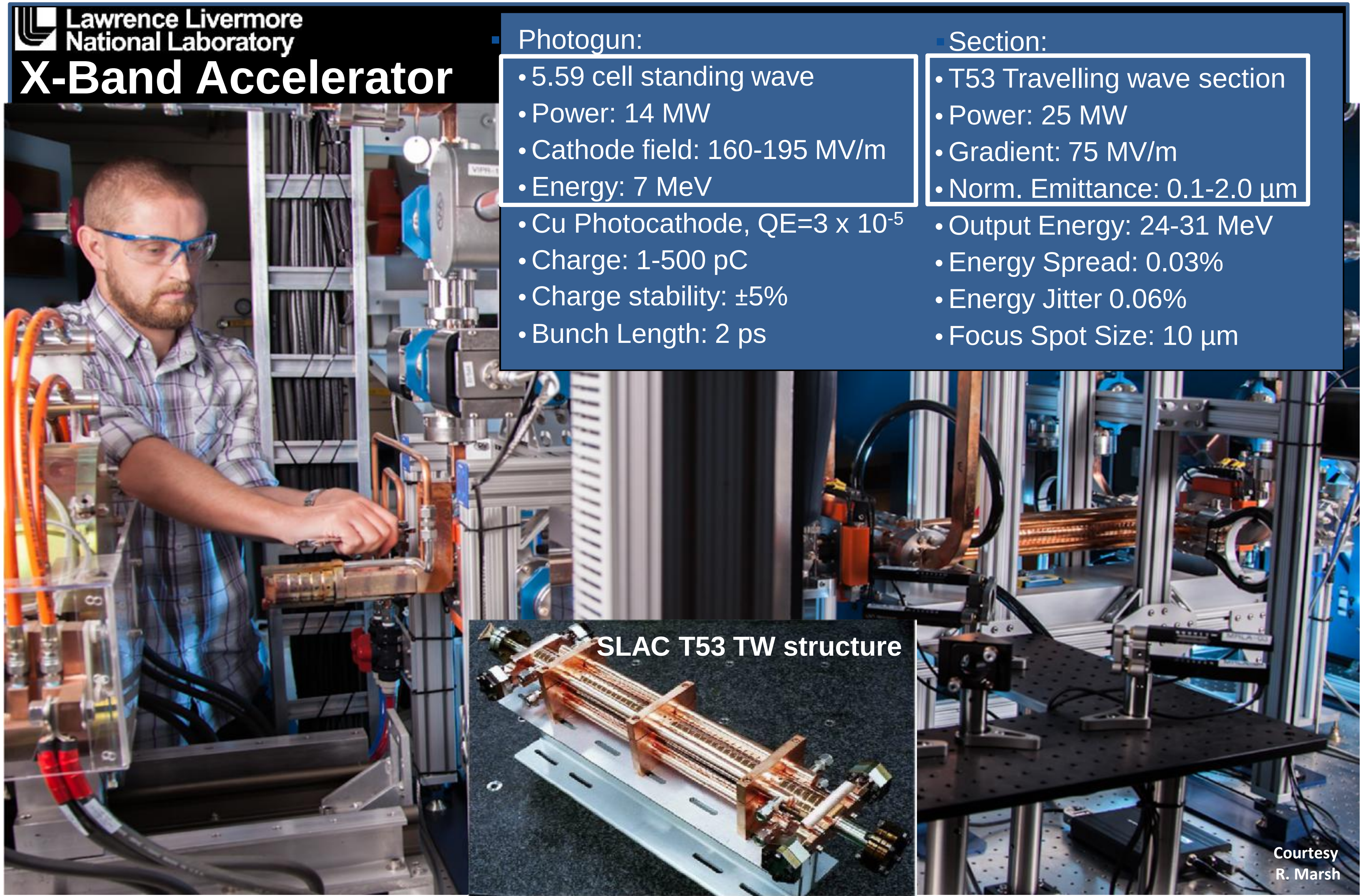
LLNL ICS x-ray source

Photogun:

- 5.59 cell standing wave
- Power: 14 MW
- Cathode field: 160-195 MV/m
- Energy: 7 MeV
- Cu Photocathode, QE=3 x 10^{-5}
- Charge: 1-500 pC
- Charge stability: ±5%
- Bunch Length: 2 ps

Section:

- T53 Travelling wave section
- Power: 25 MW
- Gradient: 75 MV/m
- Norm. Emittance: 0.1-2.0 µm
- Output Energy: 24-31 MeV
- Energy Spread: 0.03%
- Energy Jitter 0.06%
- Focus Spot Size: 10 µm

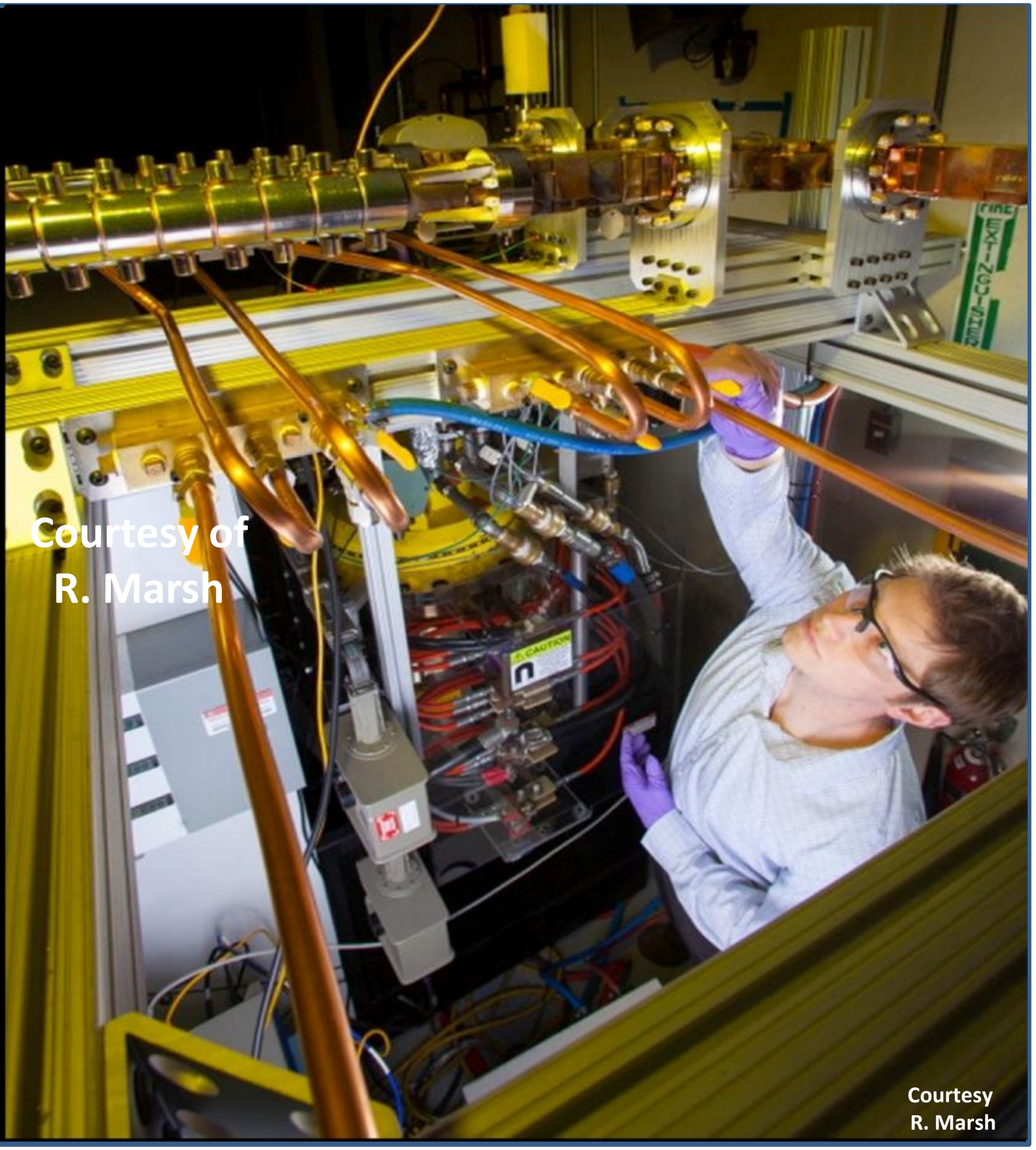


LLNL ICS x-ray source

Lawrence Livermore National Laboratory

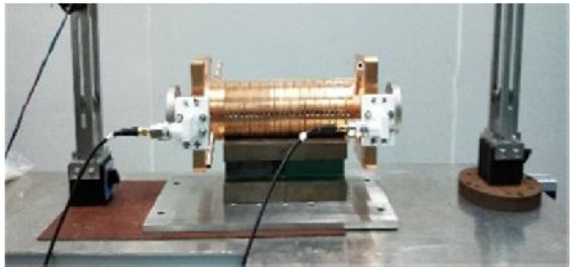
X-Band Power Supply

- RF Source:
  - SLAC XL-4 Klystron & Scandinova Modulator
  - Rep Rate: 120 Hz max
  - Flatness: 0.1%
  - Shot-to-Shot: 0.01%
  - Phase: <0.5°



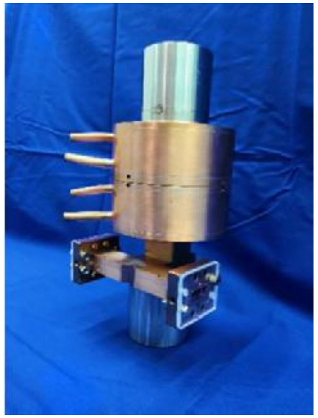
Courtesy
R. Marsh

High gradient X-band in China: SSRF/SINAP



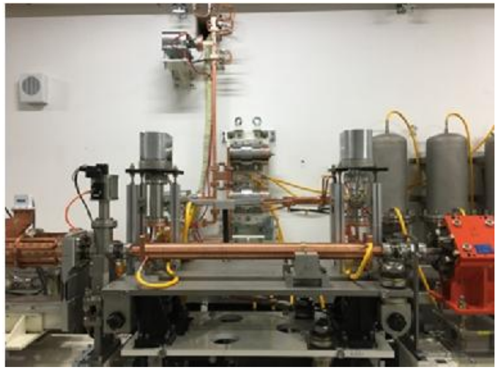
T24 CERN prot. Struct.

- Re-design based on CLIC T24
- ä = 11.424 GHz
- Brazed (not diffusion bond.)
- Tuned and ready for high power RF tests



Spherical X-band PC

- ä = 11.424 GHz
- Mode TE_{114}
- Q_0 = 95000
- = 4.6
- Peak power fact. = 6.4



X-band linearizer for SXFEL (operational)

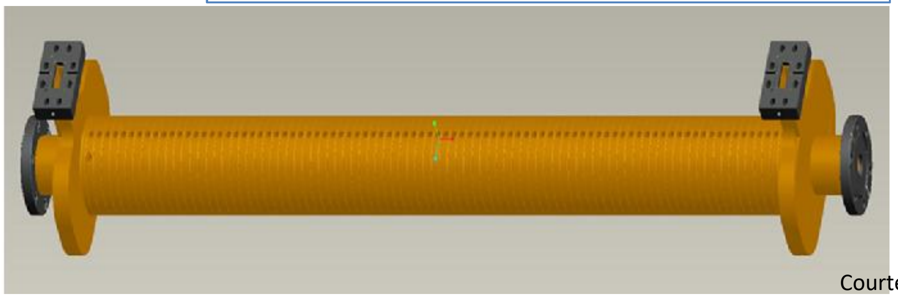
- 1m structure (20 MV/m)
- Max gap voltage reached 15 MV
- 6 MW klys. with pulse comp.
- Mov. support (1mm accuracy)

1m accelerating unit (80 MV/m)

- ä = 11.424 GHz
- Effective Length = 944.73 mm
- Phase advance = 4π/5
- Aperture radius = 4.3-3.05
- Filling time = 150 ns
- Input power P_{in} = 80MW@80MV/m

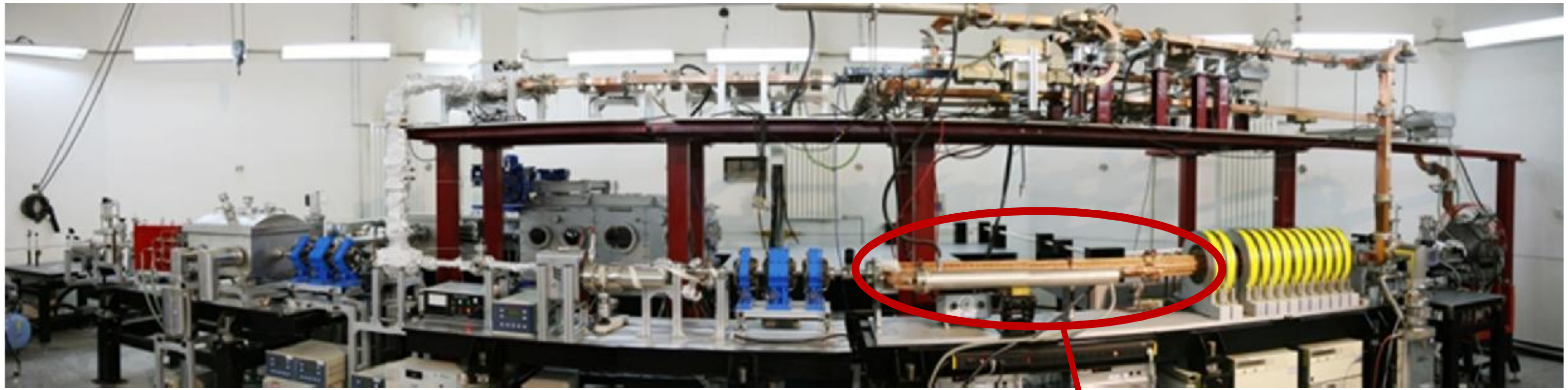
20-cells TDC

- Freq.	11.994 GHz
- Length	230 mm
- Iris apert.	8 mm
- Q_0	6222
- Tf	21 ns
- Epks	152 MV/m

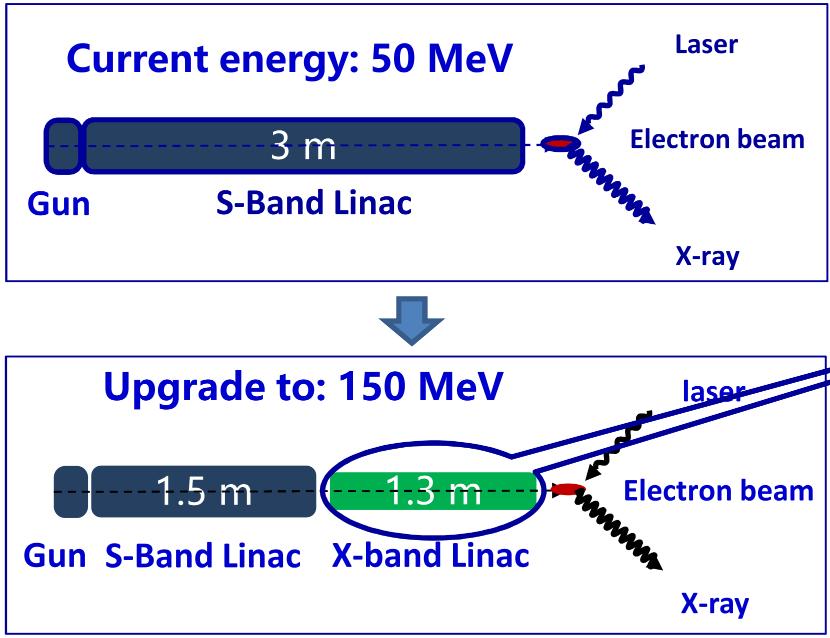


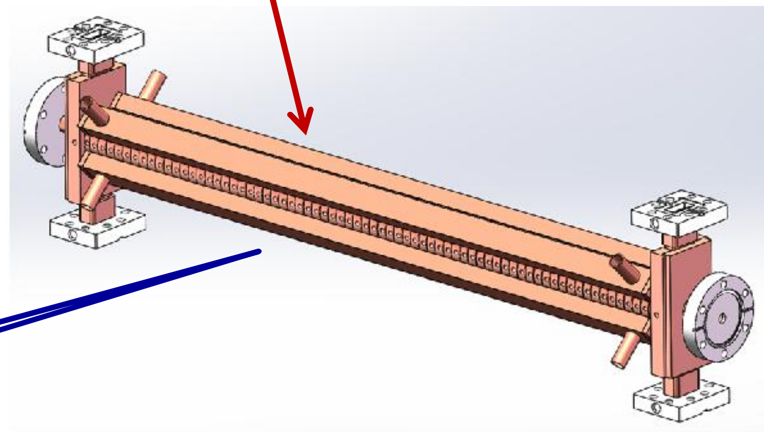
Courtesy W. Fang

TTX (Tsinghua Thomson X-ray source)



- Use X-band structures (80 MV/m) to upgrade the beam energy from 50 MeV to 150 MeV
- One 50 MW-1.5ms klystron + RF pulse compressor for single bunch operation mode

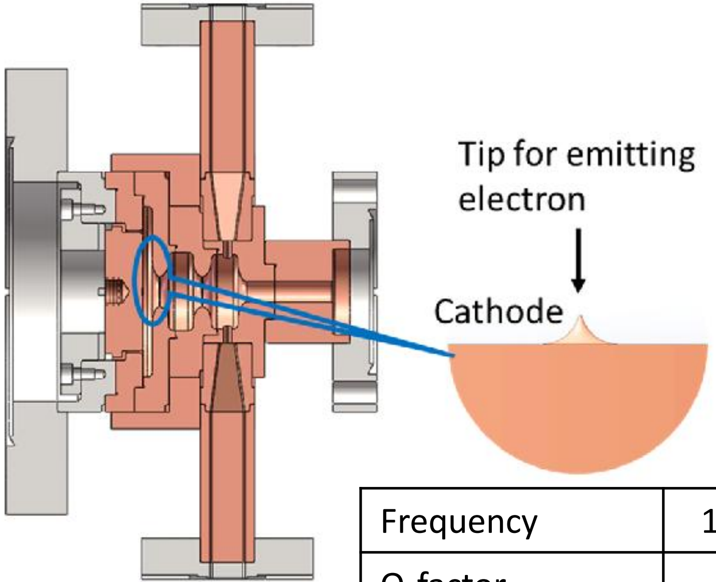




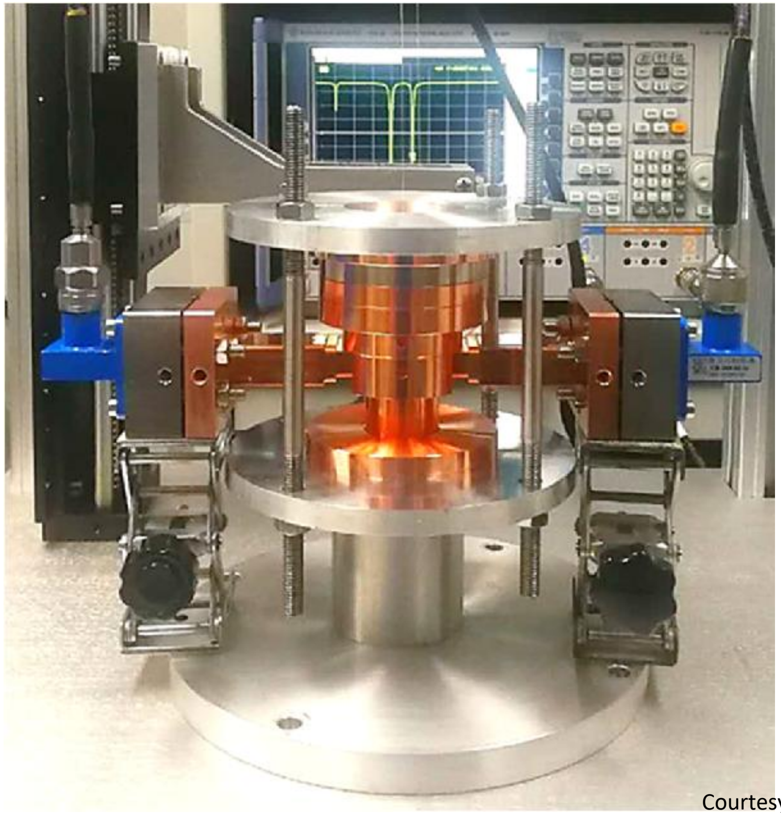
2 x 72 cells, constant impedance 80 MV/m

X-band field emission electron rf gun

- 2.5 cell standing wave design, operated at π mode.
- The goal of cathode gradient: 200 MV/m
- Max E-field at the tip ≈ 1.2 GV/m



Frequency	11.424 MHz
Q-factor	5775
Coupling β	1.17
Input power	24.5 MW
Eacc at cathode	200 MV/m
Emax surface	258 MV/m

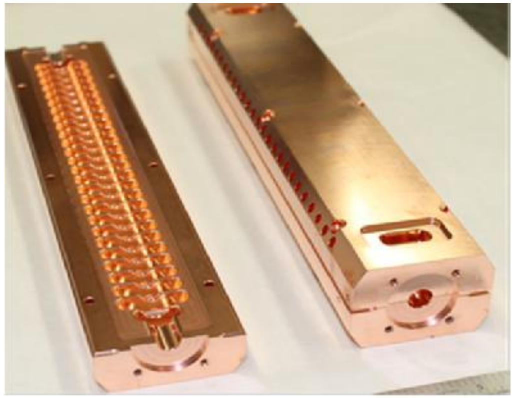


Courtesy J. Shi

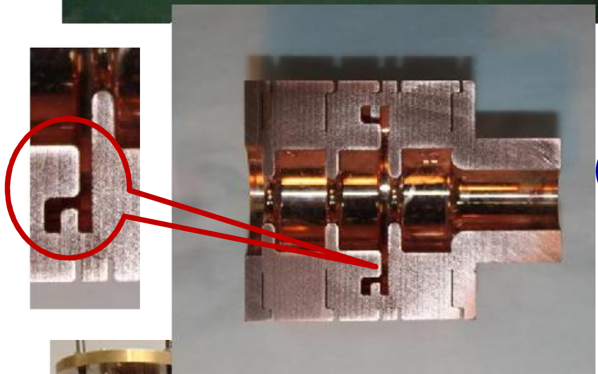
Accel. Struct. prodution & test

Total rf-on time about 3,600 h
(6.47×10^8 rf pulses)
Good high-gradient performance
(reached 110.2 MV/m)

Validate the fabrication capability of Tsinghua Univ. for X-band high-gradient structures



CLIC-T24-Open: 100 MV/m
C12-Open (at Tsinghua): 87 MV/m

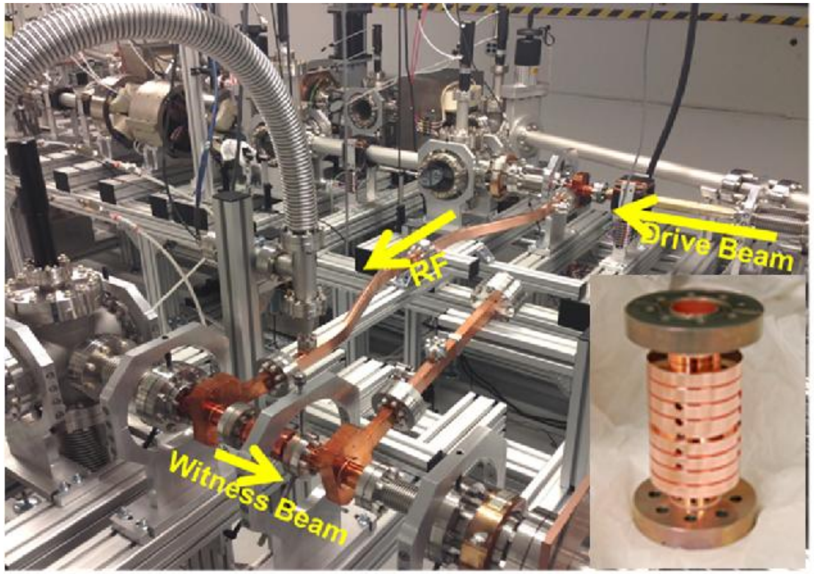


H.G. choke-mode damped X-band structure (collab. with KEK and CERN)

RF test at Nextef (KEK) reached 123 MV/m

11.7GHz RF power extractor for Argonne Wakefield Accelerator

parameters		value
frequency	f_0 (GHz)	11.7
phase advance	φ (DEG)	120
aperture diameter	$2a$ (mm)	17.6
group velocity	v_g/c	0.22
shunt impedance	R/Q (kΩ/m)	3.92
length	L (cm)	30
quality vactor	Q	6500



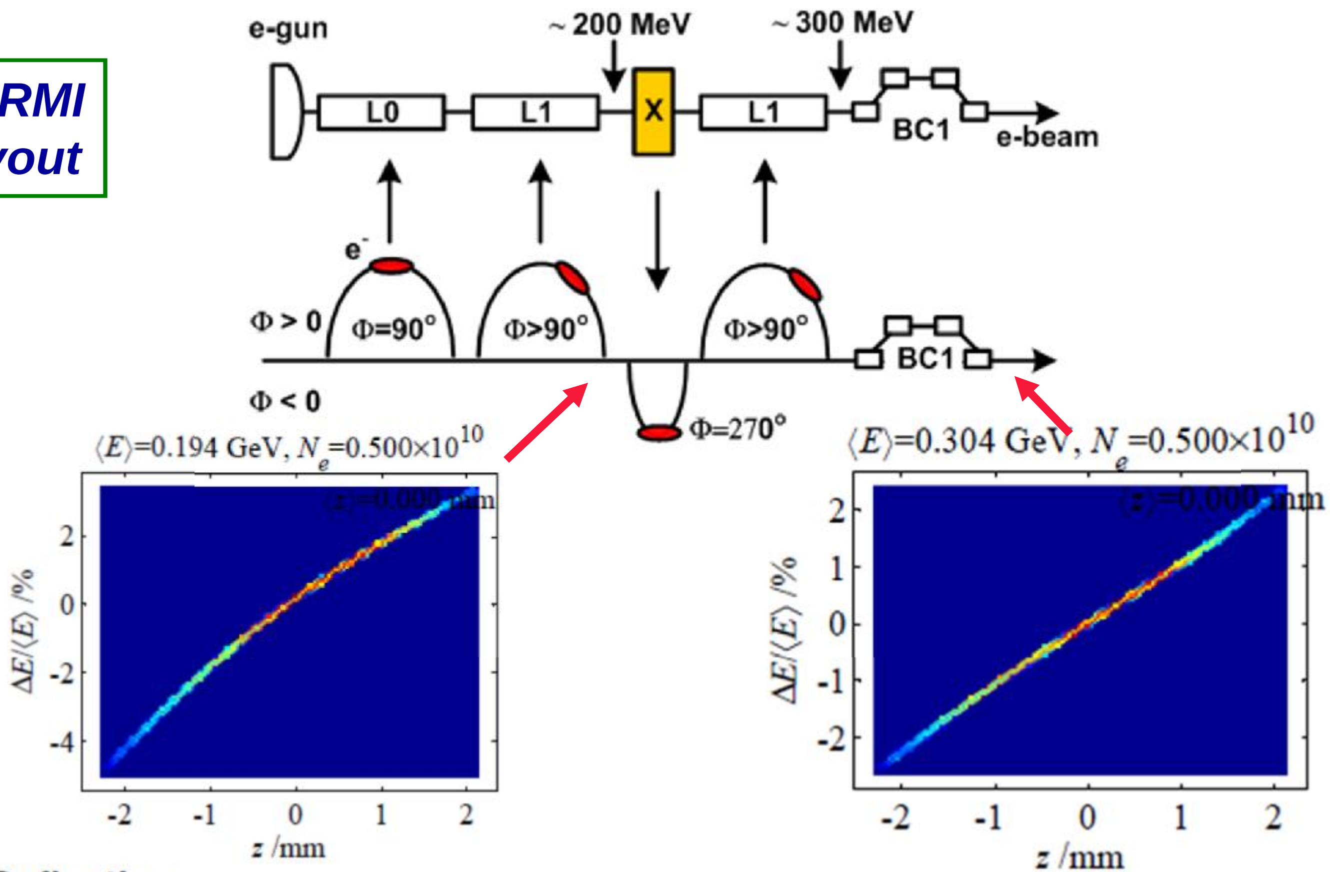
Accelerating structure for TBA at ANL

Courtesy
J. Shi

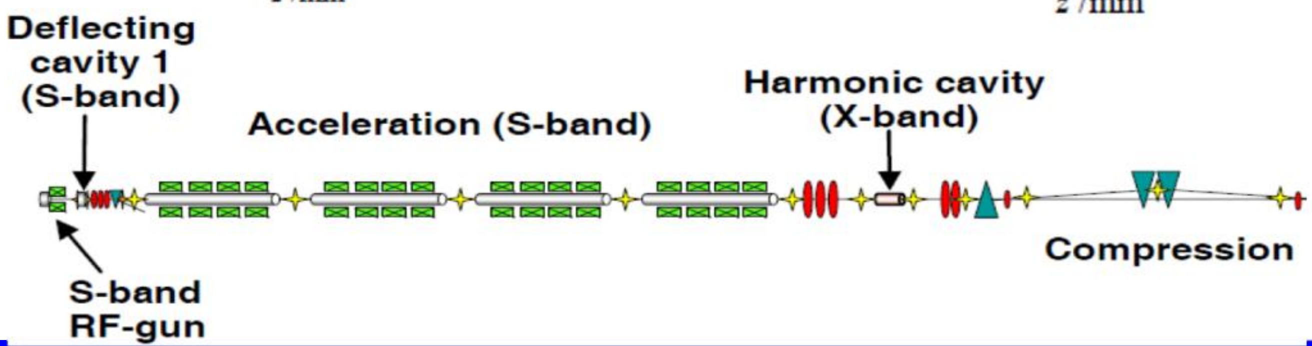
Diagnostics & beam manipulation

Phase space linearizers_FERMI & SwissFEL

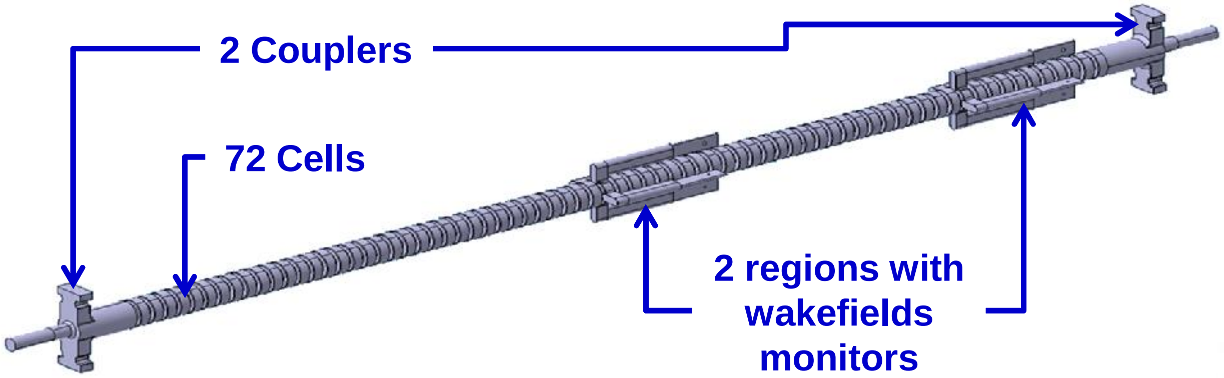
FERMI layout

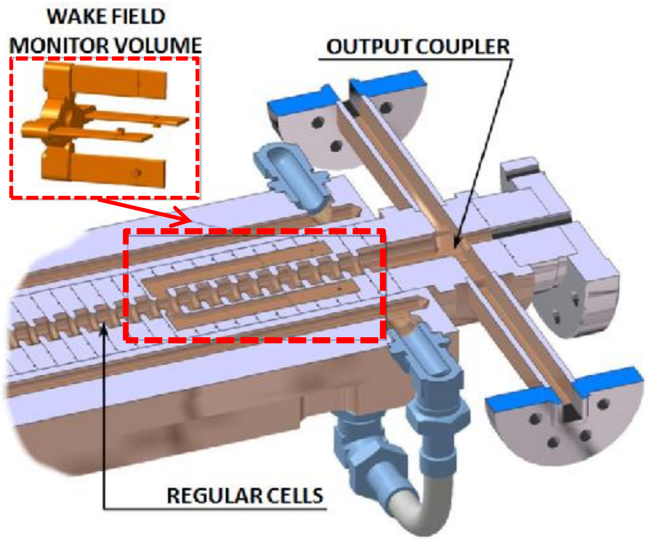


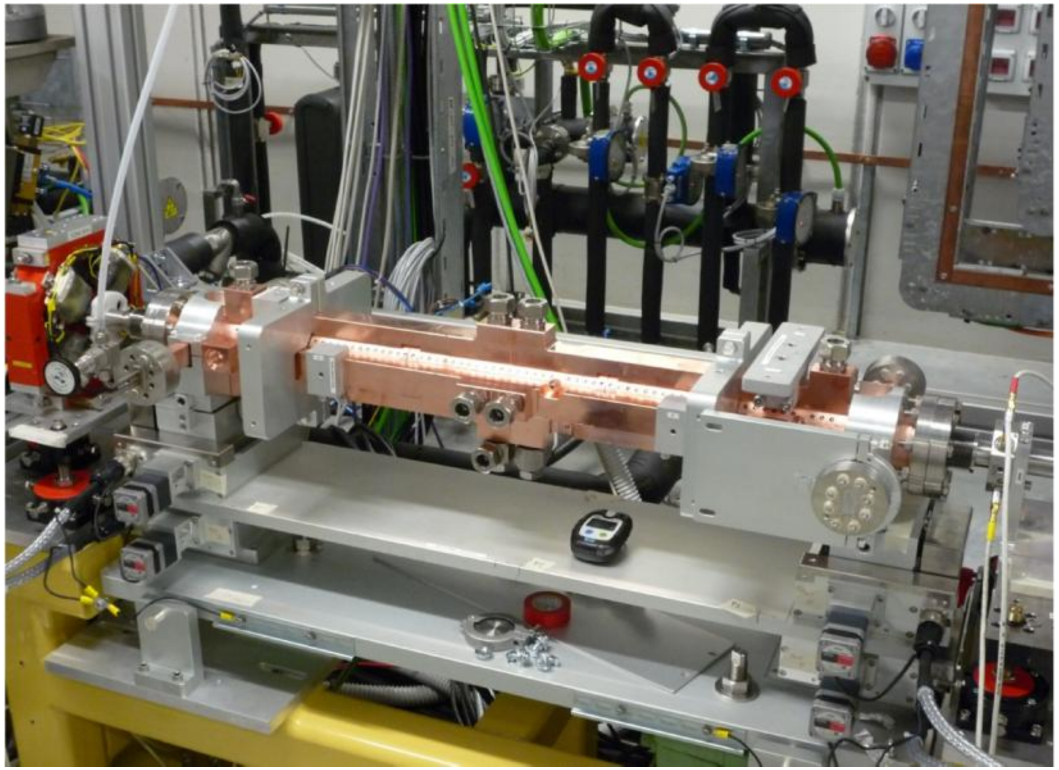
SwissFEL layout



FERMI & SwissFEL linearizers

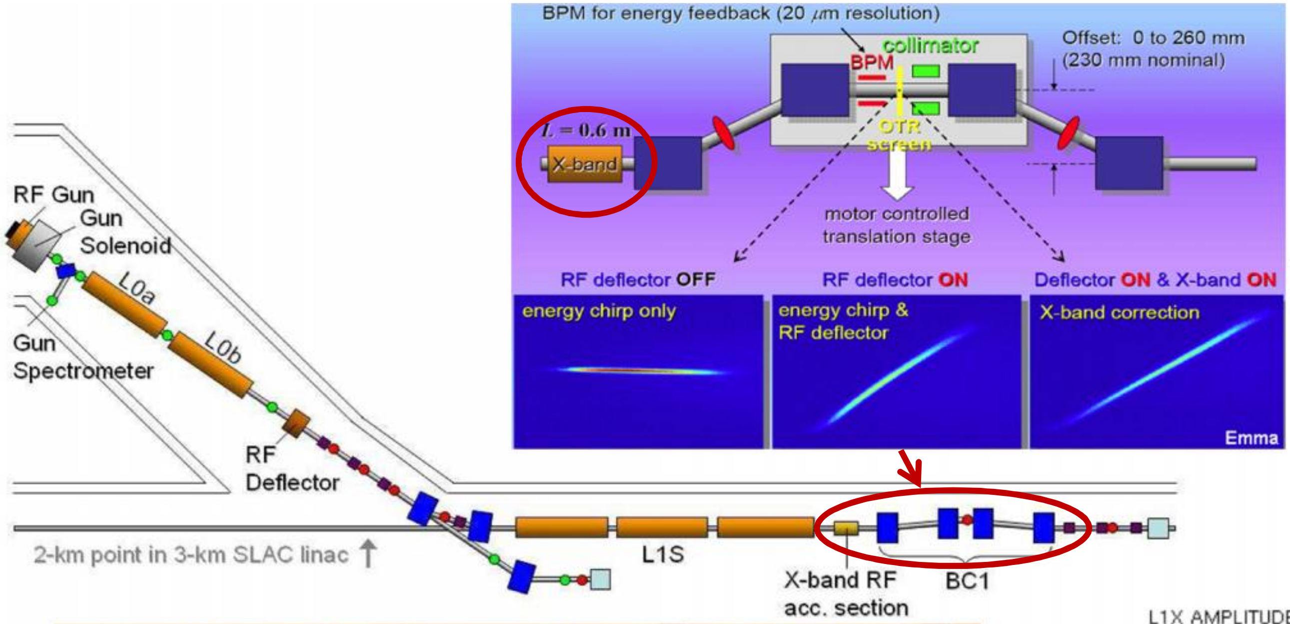


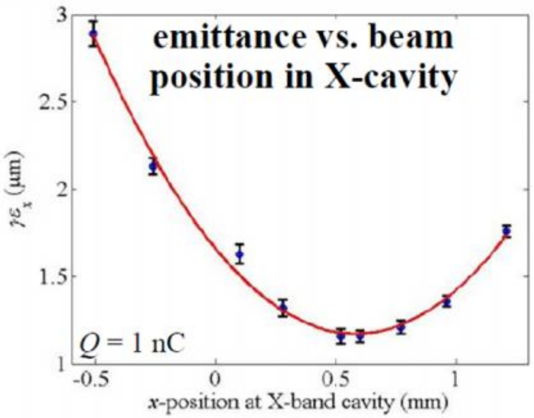


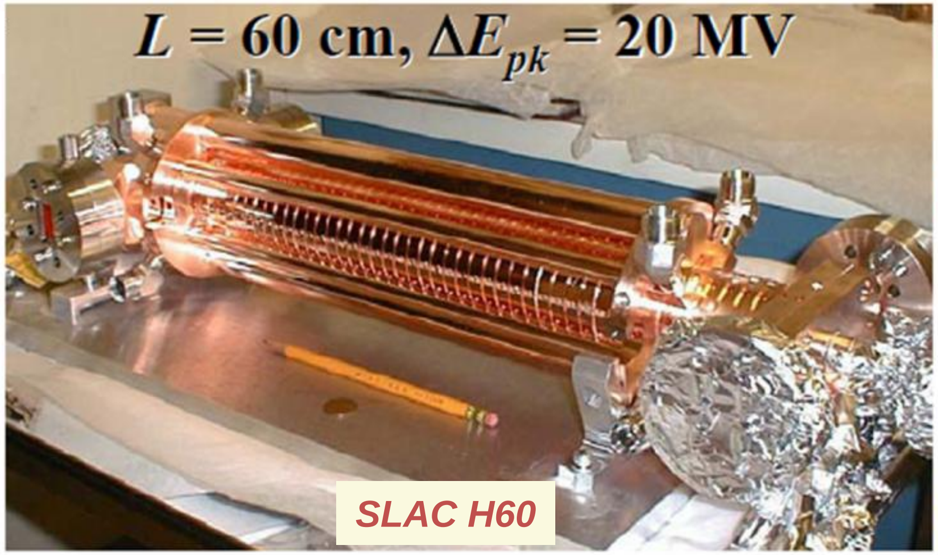


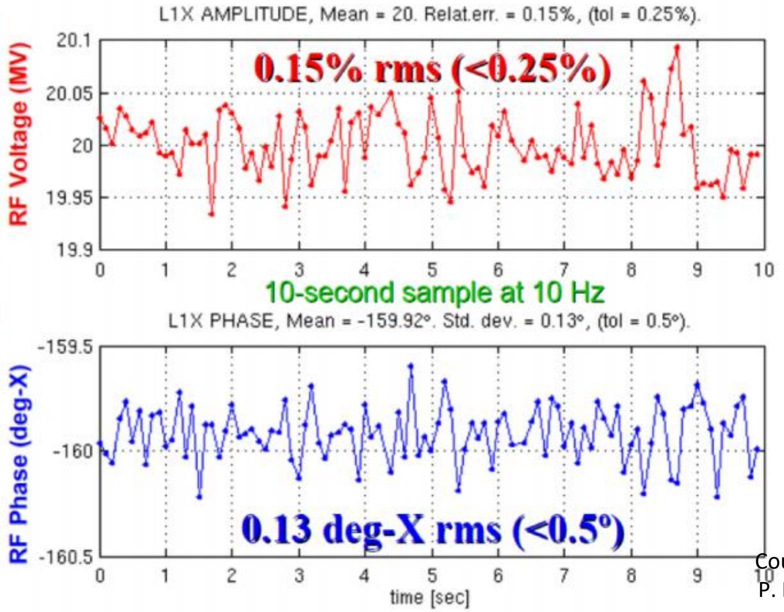
Parameter	*Value*	*Units*
Structure type	72 cells, CG, 5/6 ®, no HOM damping	
Working frequency	11,992	GHz
Overall length	0,965	m
Active length	0,75	m
Iris diameter (average)	9,1	mm
Group velocity variation	1.6 - 3.7	%
Filling time	100	ns
Pulse repetition rate	50	Hz

LCLS linearizer



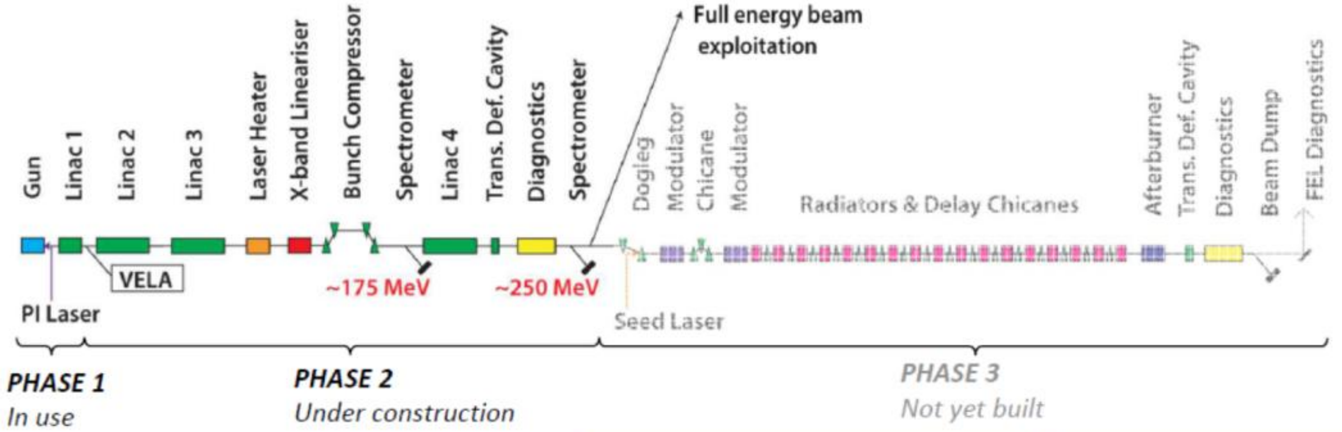


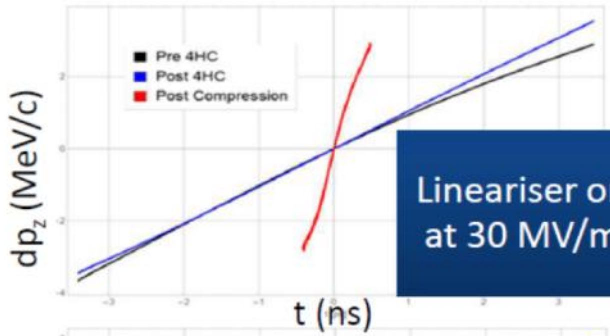




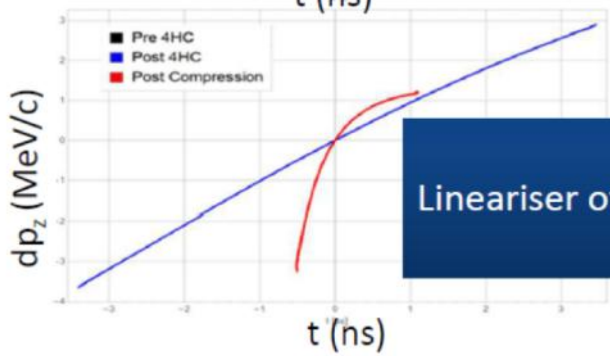
Courtesy
P. Emma

CLARA linearizer





Lineariser on at 30 MV/m



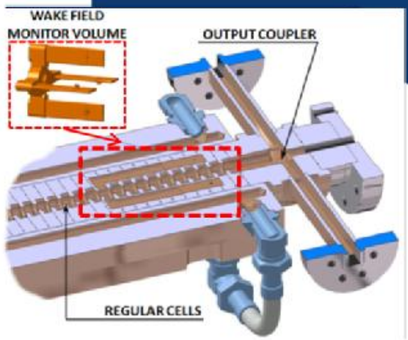
Lineariser off

Cavity with integrated beam alignment monitors (Dehler et al. PhysRevSTAB.12.062001)

Linearises the CLARA 250 pc beam before the bunch compressor

Currently under construction at CERN

Fed by a 6 MW klystron and SLED I type pulse compressor



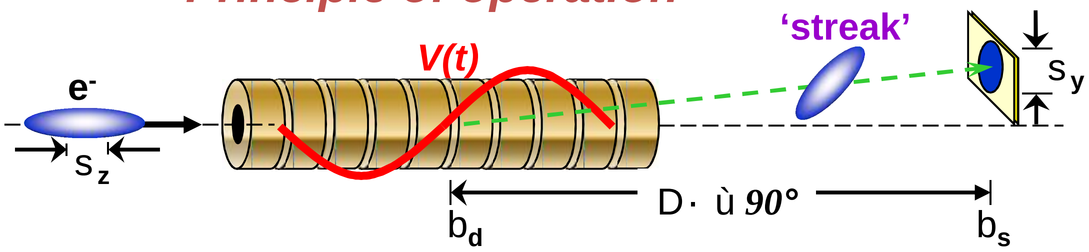
Science & Technology Facilities Council
ASTeC

Courtesy
L. Cowie

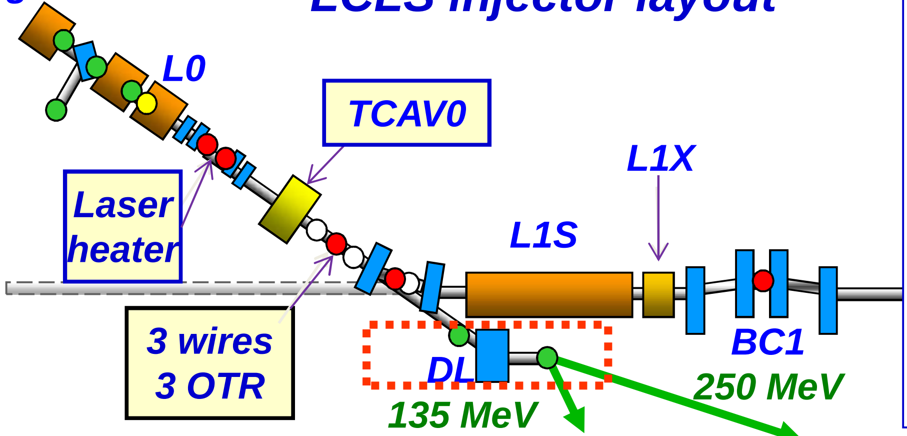
Transverse Cavity Diagnostics at LCLS

The Transverse Cavity (TDC) technique is now a well established diagnostic tool at the X-ray FELs to measure sub-ps temporal bunch profiles.

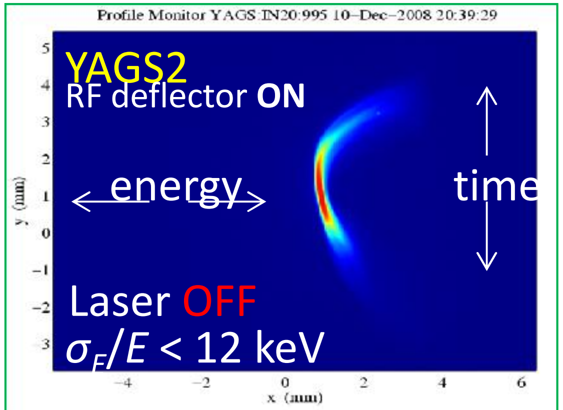
Principle of operation

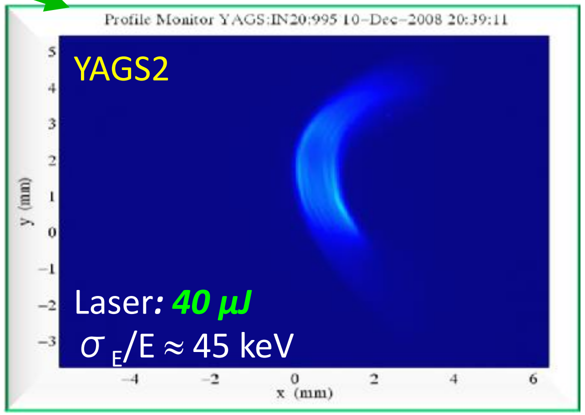


LCLS injector layout



The diagnostics is further enhanced if the deflected beam is observed on an energy spectrometer screen, where the energy dispersion is in the plane perpendicular to the RF deflection. The dispersion properties of the dipole allow for the complete characterization of the energy distribution of each bunch slice reconstructing the longitudinal phase space.





Energy profile and slice energy spread measurements with TCAV at LCLS

Courtesy P. Krejcik

TDC downstream LCLS undulator

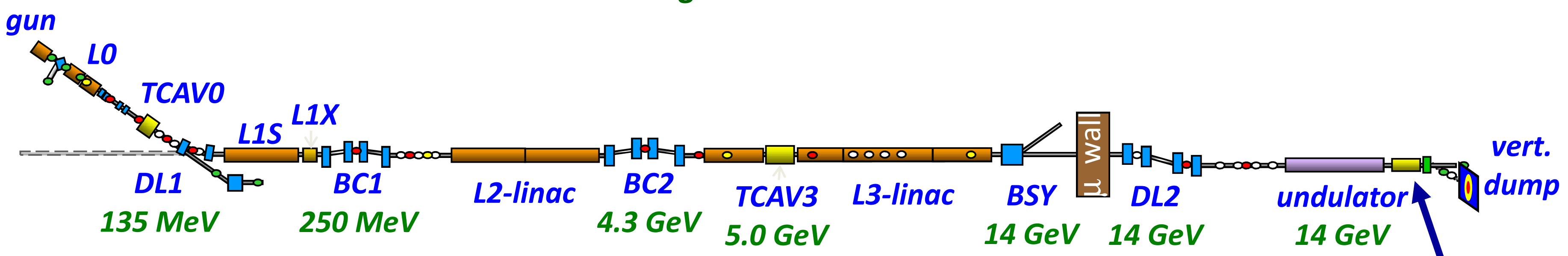
Ratio of beam size on the screen σ_y to bunch length σ_z:

$$S = \frac{\sigma_y}{\sigma_z} = \frac{eV_0}{E_e}\frac{2\pi}{\lambda_{RF}}\sqrt{\beta_d \beta_s}\left|\sin\alpha\right|$$

Measurement resolution

$$\sigma_{t,R} = \frac{\sigma_{y0}}{S} = \sqrt{\frac{\varepsilon_{n,y}}{\gamma\beta_d}}\frac{\lambda_{RF} E_e}{eV_0\left|\sin\alpha\right|}$$

The dependence on wavelength and gradient suggest that going from S to X band the resolution can be improved by a factor of 4 from the wavelength (10 cm → 2.5 cm) and at least another factor of 2 from the gradient!!!



Two 1 meter long X-band deflecting structures, located downstream the undulator (just before the electrons are bent down to the dump) for an ultra-short e-bunch and X-ray temporal diagnostics.

Operation of the TDC is non invasive to photon user operation.

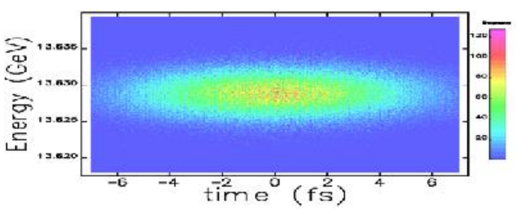
→ **XTCAV**

Courtesy P. Krejcik

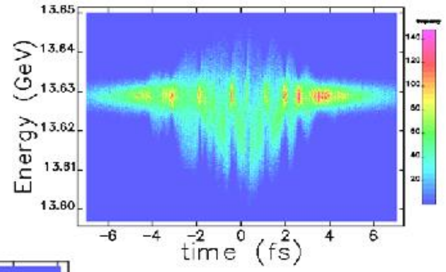
TDC downstream LCLS undulator

Only those parts of the bunch that do lase lose energy and increase their energy spread

FEL Off, E-beam only

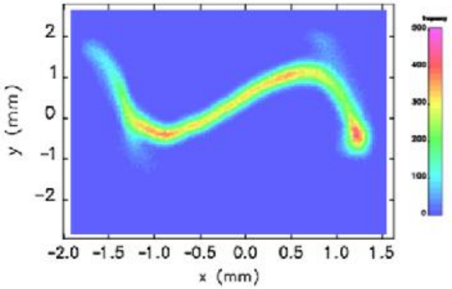


FEL On, Electron+Photon beam

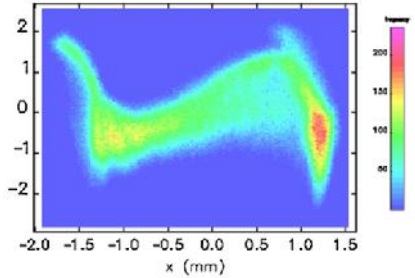


@13.6 GeV
250 pC
3 kA

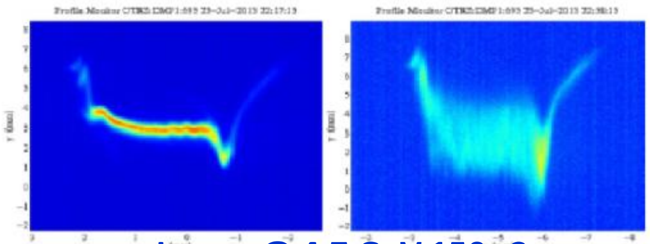
FEL Off



FEL On



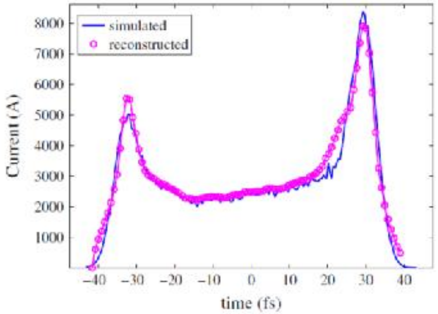
XTACV is ON, FEL is OFF

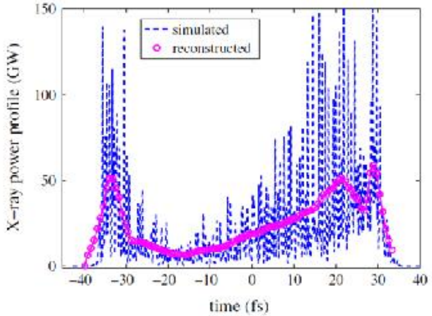


XTCAV is ON and FEL is ON

Image @ 4.7 GeV 150pC

Reconstructed electron beam profile



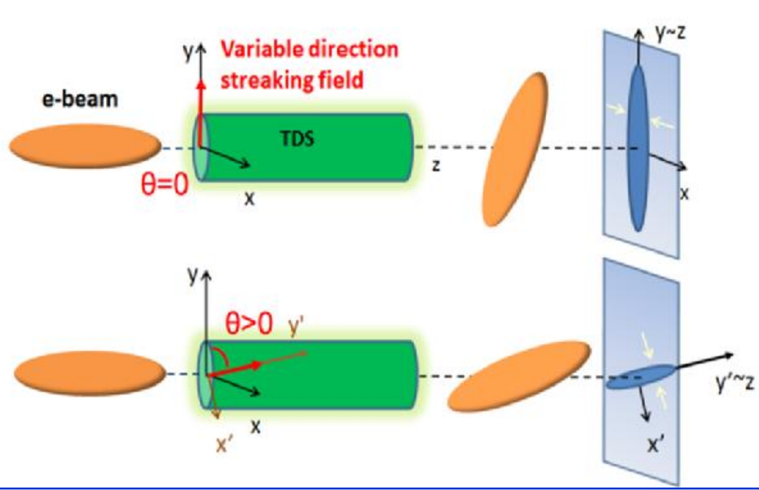


Reconstructed photon beam profile

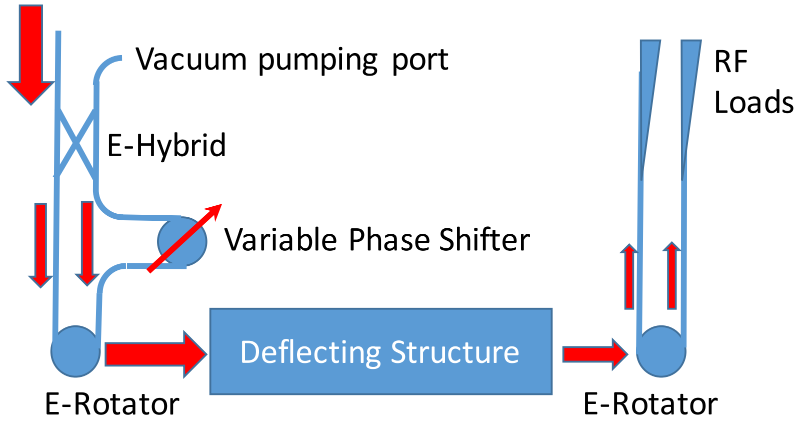
Courtesy
P. Krejcik

New developments

PolariX: a CERN-DESY-PSI collaboration for the development of a TDS with variable polarization



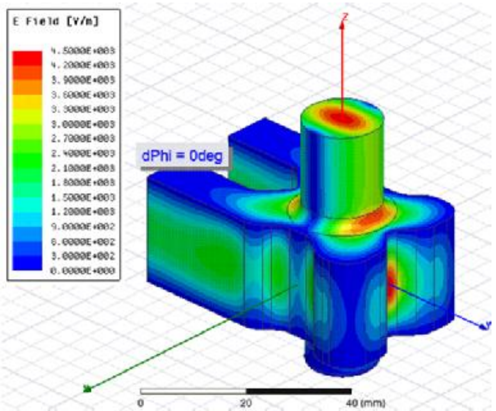
Single-shot characterization of the beam longitudinal phase space, i.e. slice emittance and 3D charge density distribution.

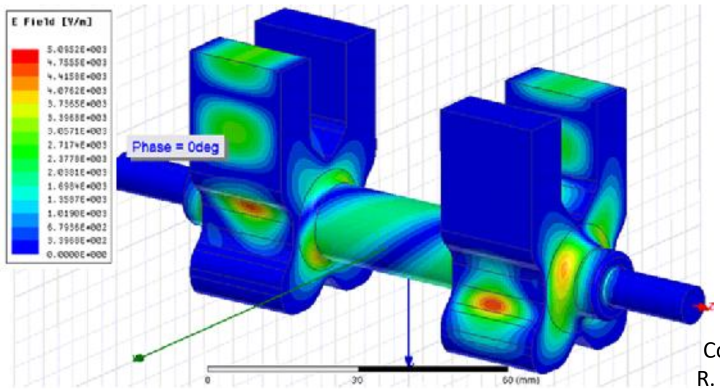


Phase difference between port 1 and port 2:

- **0 degree -> vertical polarization**
- **180 degree -> horizontal polarization**

Variable polarization circular TE11 mode launcher: E-rotator

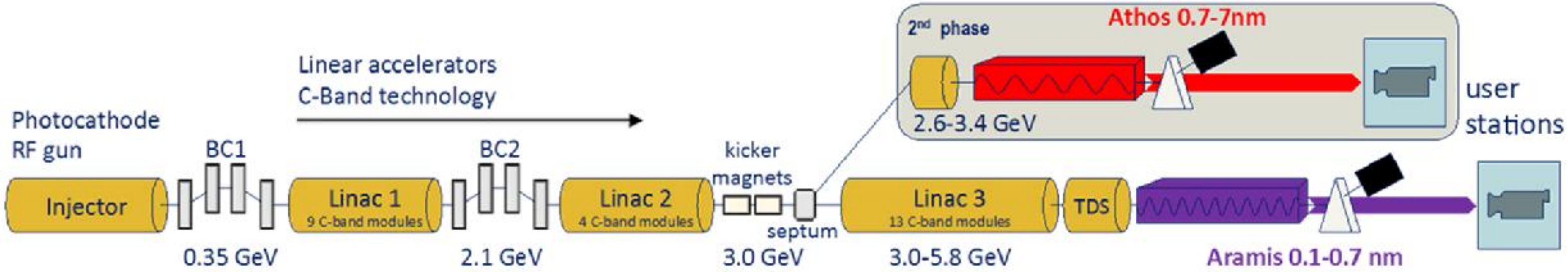


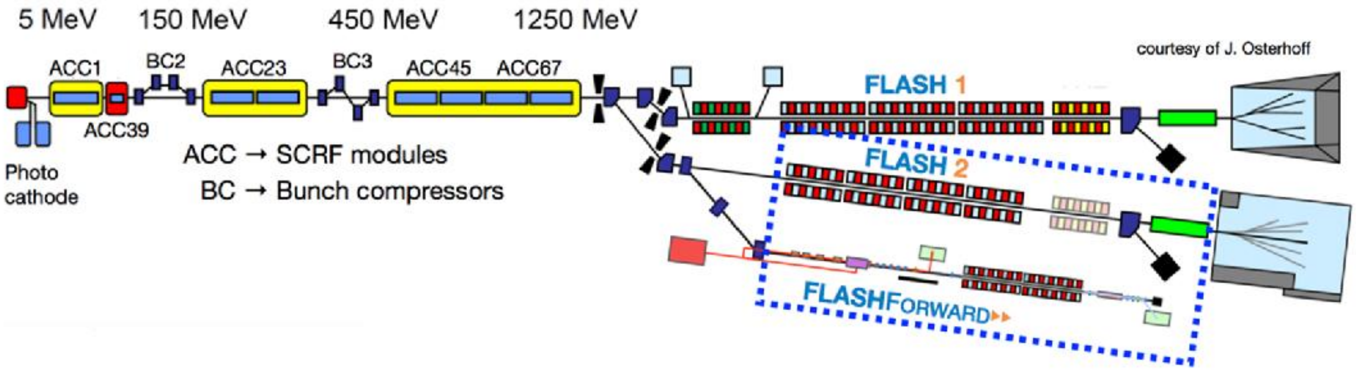


Courtesy
R. Zennaro

PolariX installations

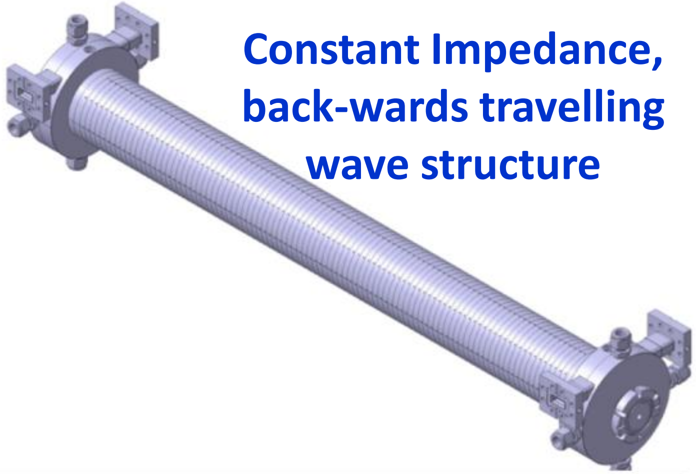
- RF cavity design done at CERN (A. Grudiev).
- Prototype assembled at PSI (using the tuning free assembly procedure).
- Beam tests will be done at DESY.
- Installations:
  - ✓ ATHOS beamline at SwissFEL
  - ✓ FLASHForward, FLASH2, SINBAD at DESY





Courtesy
R. Zennaro

PolariX accelerating structure

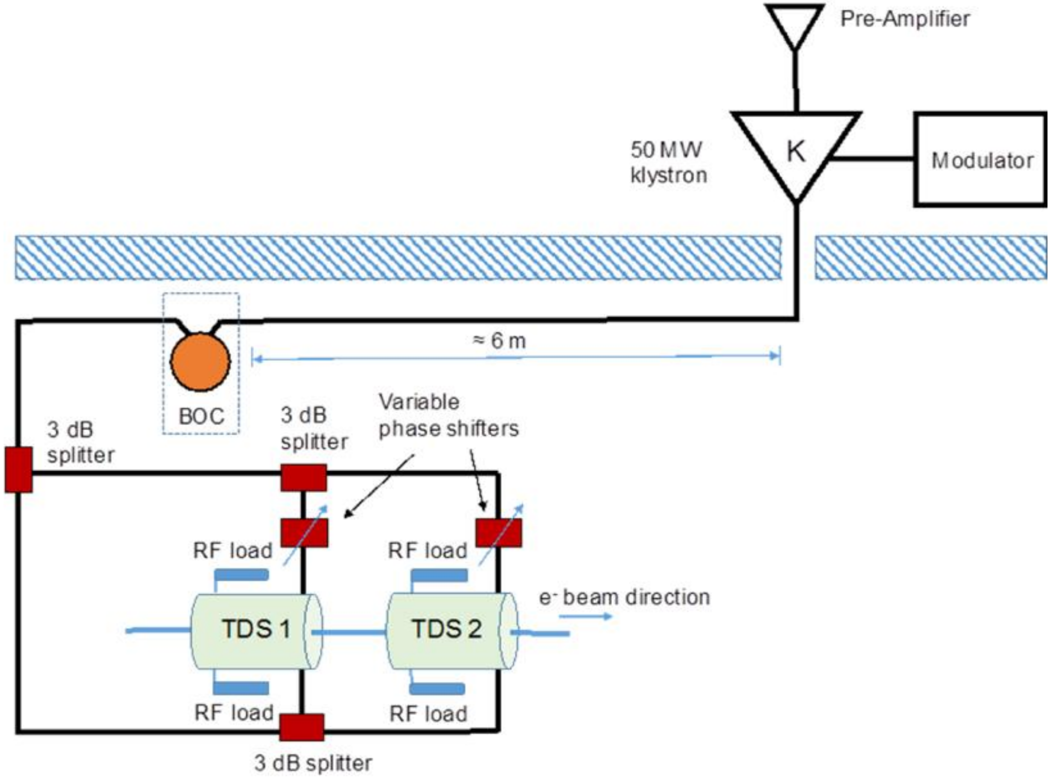


Constant Impedance, back-wards travelling wave structure

Cell parameter		Unit	
Frequency	11995.2	MHz	
Phase advance/cell	120	$^\circ$	
Iris radius	4	mm	
Iris thickness	2.6	mm	
Group velocity	-2.666	$\%c$	
Quality factor	6490		
Shunt impedance	50	$M\Omega/m$	
TDS parameter	**Short**	**Long**	**Unit**
n. cells	96	120	
Filling time	104.5	129.5	ns
Active length	800	1000	mm
Total length	960	1160	mm
Power-to-voltage	5.225	6.124	$MV/MW^{0.5}$
TDS + BOC	**Short**	**Long**	**Unit**
BOC Q_0	145000	145000	
BOC $\beta@t_k=1.5\mu s$	7	7	
Power-to-voltage	12.010	13.626	$MV/MW^{0.5}$

Klystron output power and defl. voltage (including the waveguide losses):

- **25 MW → Vt > 55 MV (one TDS, resolution ù 0.78 fs)**
- **25 MW → Vt > 79 MV (2 TDS resolution ù 0.54 fs)**

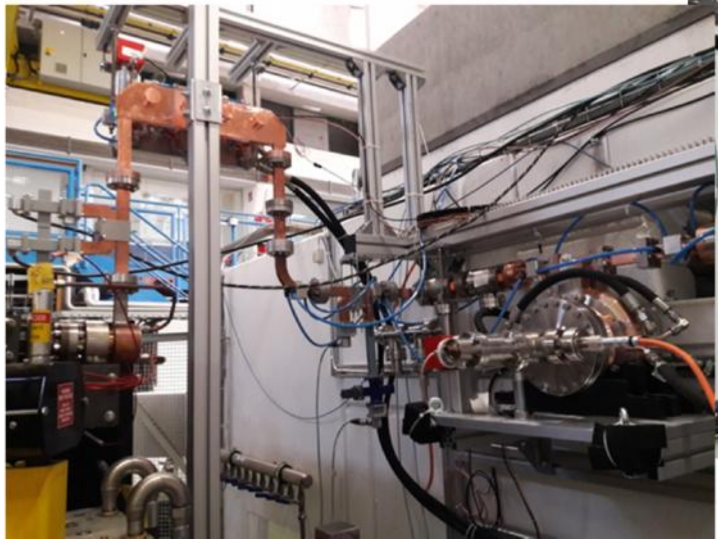


Courtesy
R. Zennaro

PolariX hardware

XBOC (no tuning required)

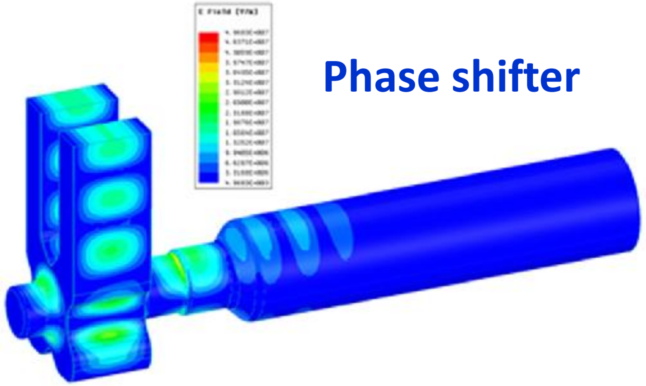
PolariX and XBOC in X-BOX



Measured parameters

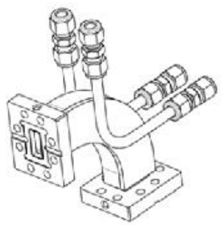
ä	1995.2 at 41.2 °C
Q_0	157800
Beta	7.88
Max. refl.	-31 dB

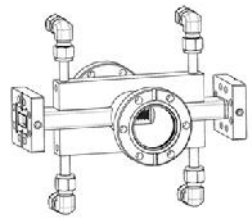
Phase shifter

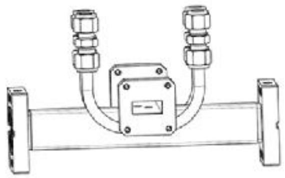


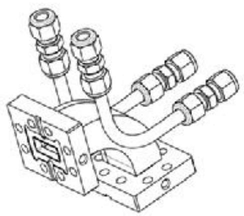
X-band waveguide comp. Under production:

- H-E Bends
- Splitters
- Vacuum ports
- Directional couplers
- Phase shifter
- BOC (XBOC)









Courtesy
R. Zennaro

Conclusions

- ✓ After an initial period of growth driven by linear collider, in the last years the X-band band technology has received renewed interest.
- ✓ With the proliferation of smaller-scale applications, the community of high gradient X-band users is nowadays continuously growing.
- ✓ For the X-ray community, the X-band technology represents a great opportunity for many labs to implement very compact and cost effective photon facilities.

Aknowledgements

My sincere thanks to the many colleagues who provided me information and data about their projects/activities.

In particular the members of the CompactLight Collaboration and colleagues from SLAC, KEK, LLNL and Tsinghua University.

Thank you for your attention!