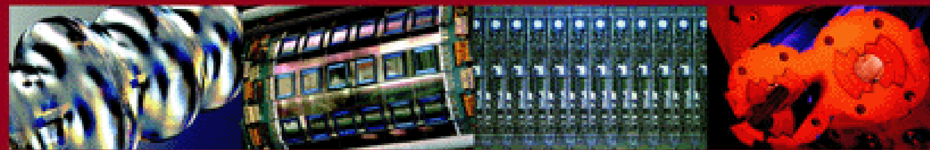
430. WILHELM UND ELSE HERAEUS-SEMINAR

Accelerators and Detectors at the Technology Frontier



26 - 29 April 2009
Physikzentrum Bad Honnef

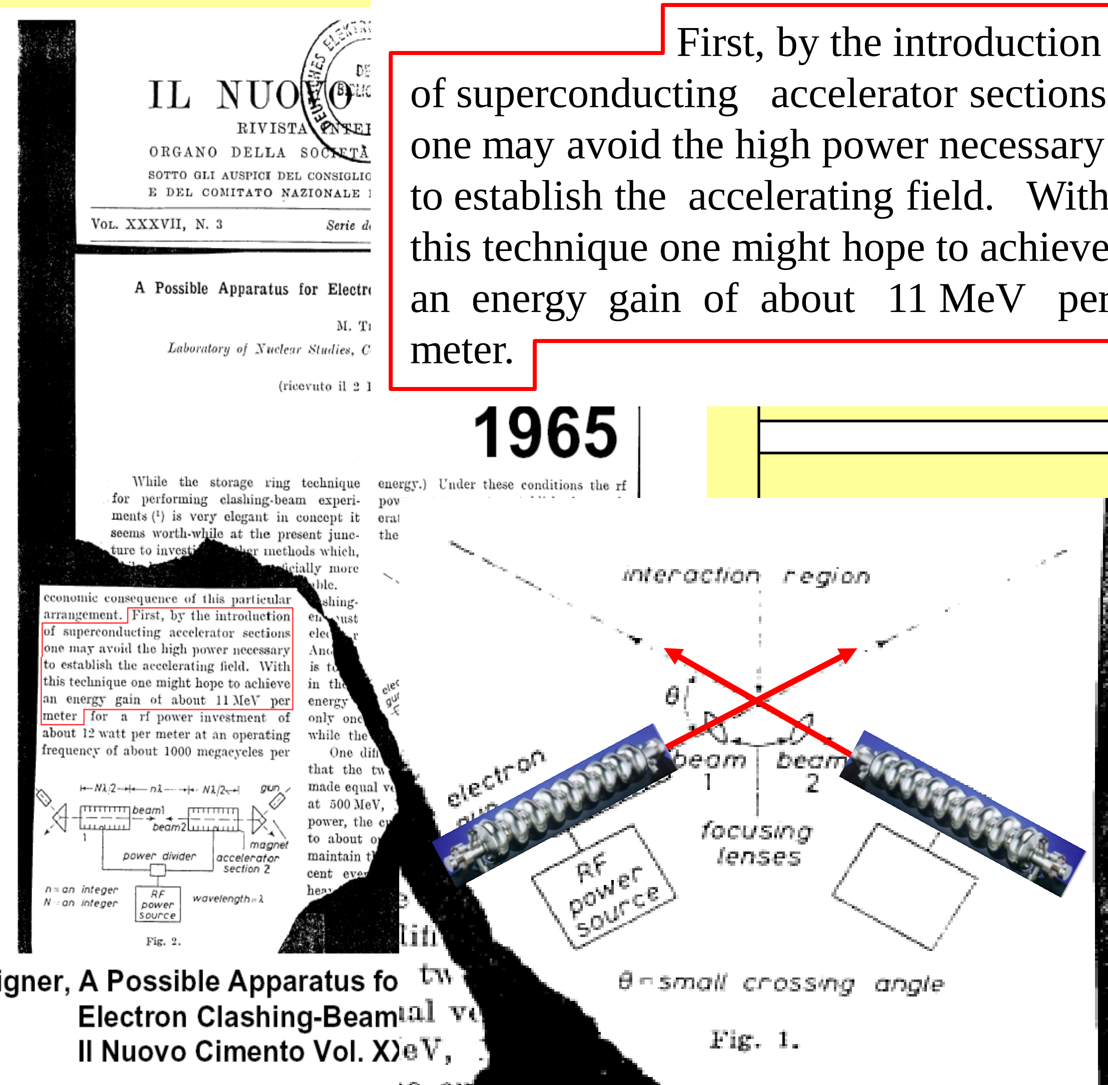
Electron Accelerators based on Superconducting RF Technology

Hans Weise

An old Idea – The Cold Linear Collider

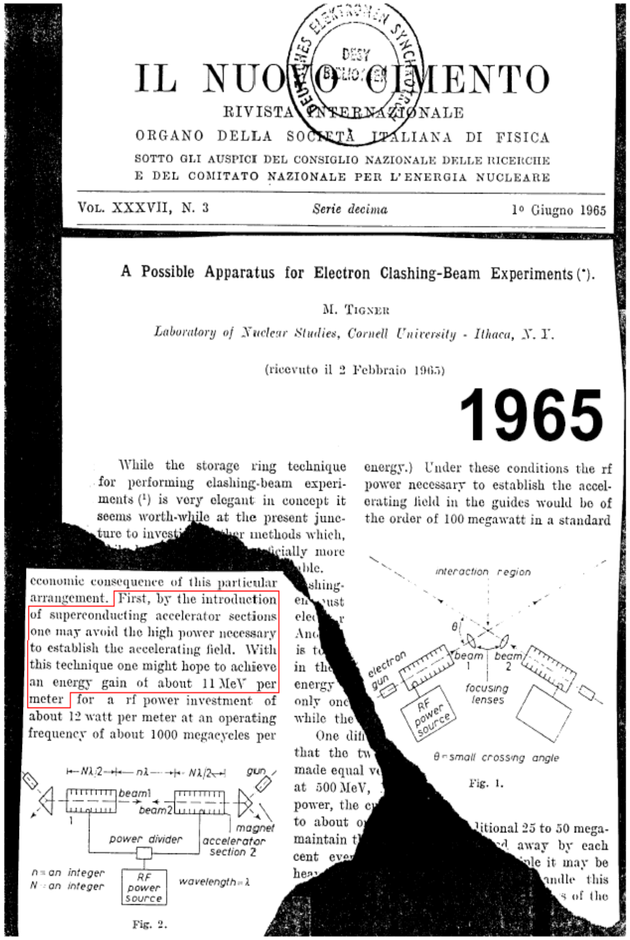
First, by the introduction of superconducting accelerator sections one may avoid the high power necessary to establish the accelerating field. With this technique one might hope to achieve an energy gain of about 11 MeV per meter.

1965



M. Tigner, A Possible Apparatus fo
Electron Clashing-Beam
Il Nuovo Cimento Vol. X

The TESLA Collaboration's TDR


IL NUOVO CIMENTO

RIVISTA INTERNAZIONALE

ORGANO DELLA SOCIETÀ ITALIANA DI FISICA

SOTTO GLI AUSPICI DEL CONSIGLIO NAZIONALE DELLE RICERCHE E DEL COMITATO NAZIONALE PER L'ENERGIA NUCLEARE

Vol. XXXVII, N. 3 — *Serie decima* — 1° Giugno 1965

A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. Tigner

Laboratory of Nuclear Studies, Cornell University - Ithaca, N. Y.

(ricevuto il 2 Febbraio 1965)

1965

While the storage ring technique for performing clashing-beam experiments (1) is very elegant in concept it seems worth-while at the present juncture to invest... methods which, ...cially more ...ble.

economic consequence of this particular arrangement. First, by the introduction of superconducting accelerator sections one may avoid the high power necessary to establish the accelerating field. With this technique one might hope to achieve an energy gain of about 11 MeV per meter for a rf power investment of about 12 watt per meter at an operating frequency of about 1000 megacycles per

energy.) Under these conditions the rf power necessary to establish the accelerating field in the guides would be of the order of 100 megawatt in a standard

Fig. 1.

Fig. 2.

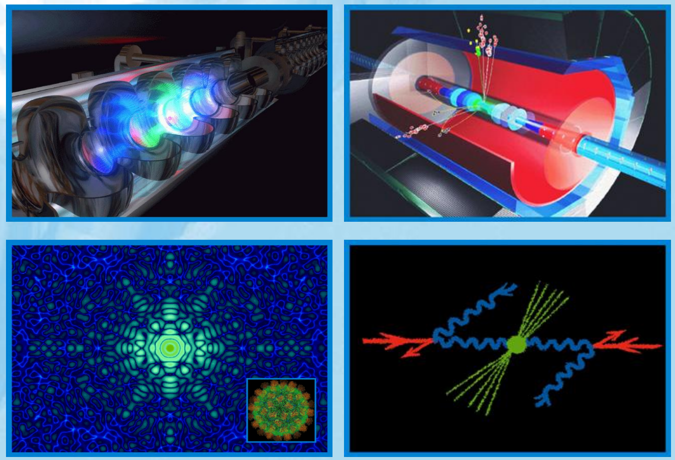
...litional 25 to 50 mega- ...d away by each ...le it may be ...andle this ...s of the

M. Tigner, A Possible Apparatus for Electron Clashing-Beam Experiments Il Nuovo Cimento Vol. XXXVII, No.3 (1965)

TESLA

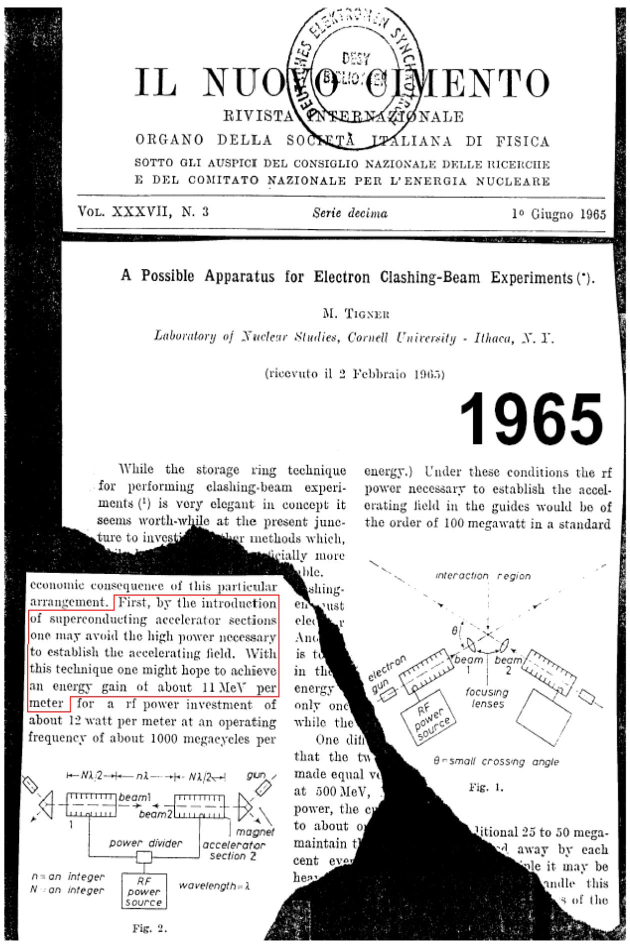
The Superconducting Electron-Positron Linear Collider with an Integrated X-Ray Laser Laboratory

Technical Design Report



March 2001

… was converted into the ILC TDR



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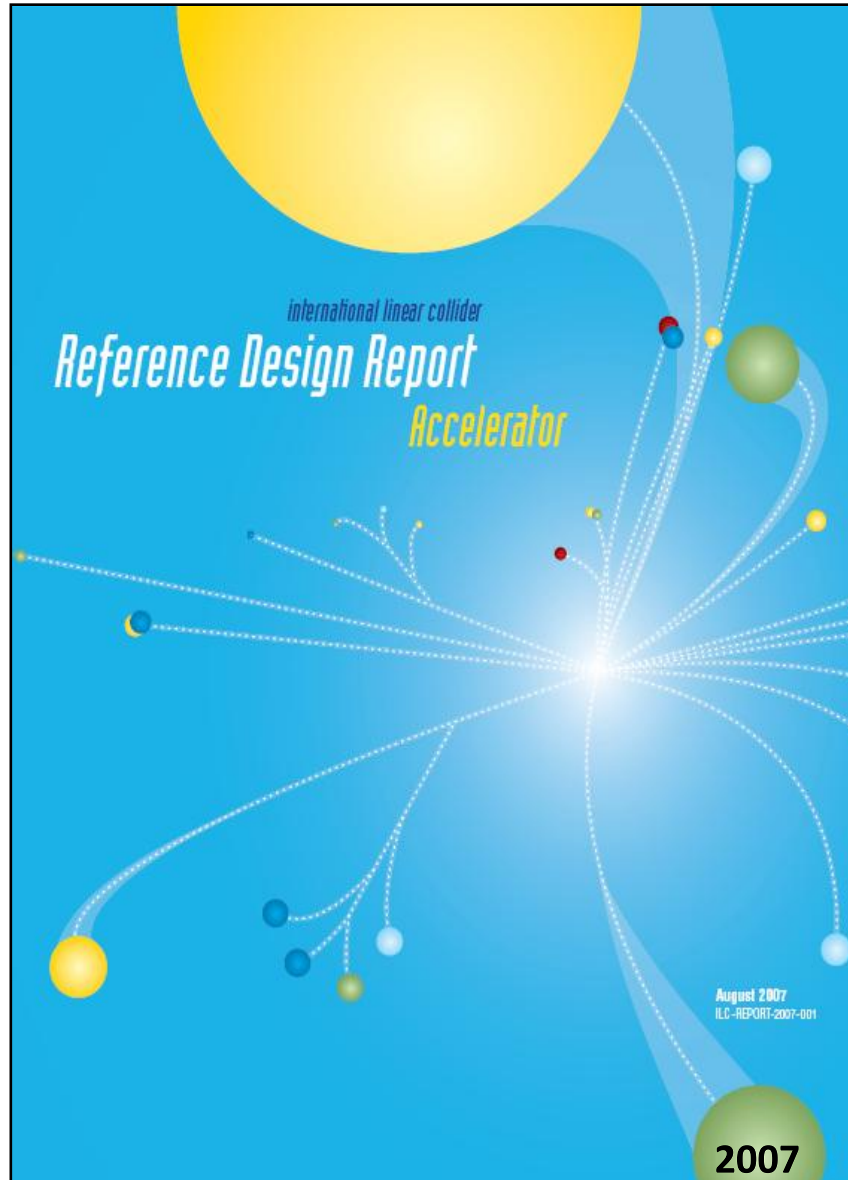
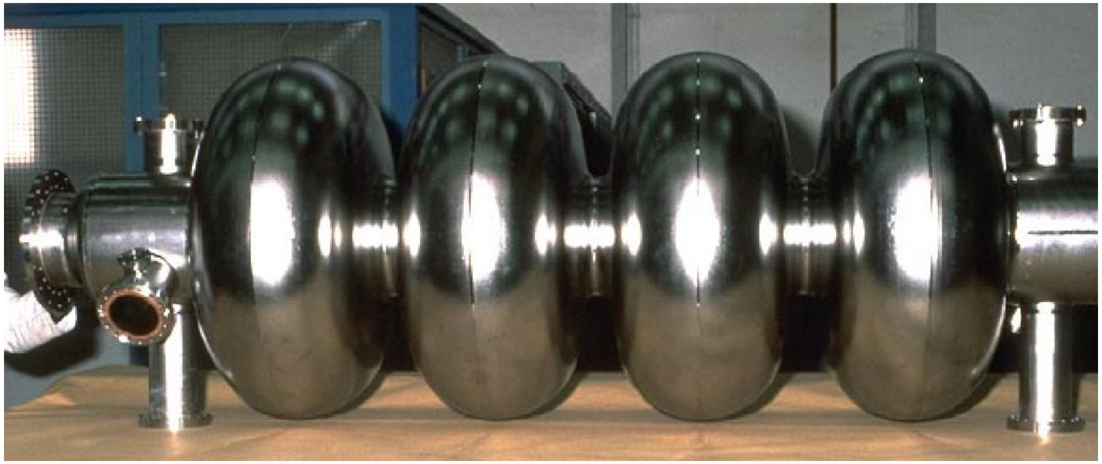


Hans Weise / DESY, WEH Seminar, Bad Honnef, 26-29 April 2009
Accelerators and Detectors at the Technology Frontier

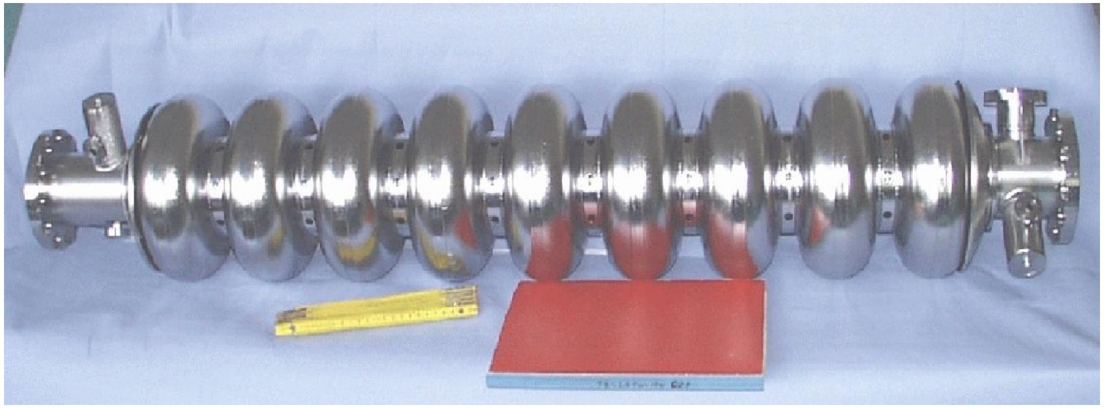
Modifications needed but cavities firm as a rock



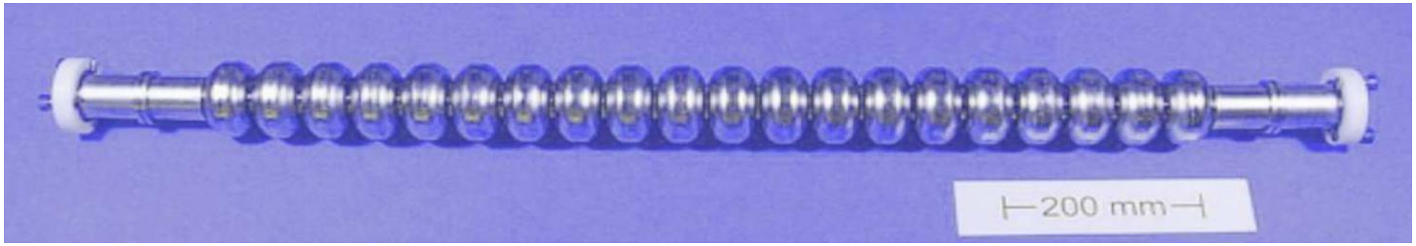

Superconducting Accelerating Cavities



352 MHz
LEP



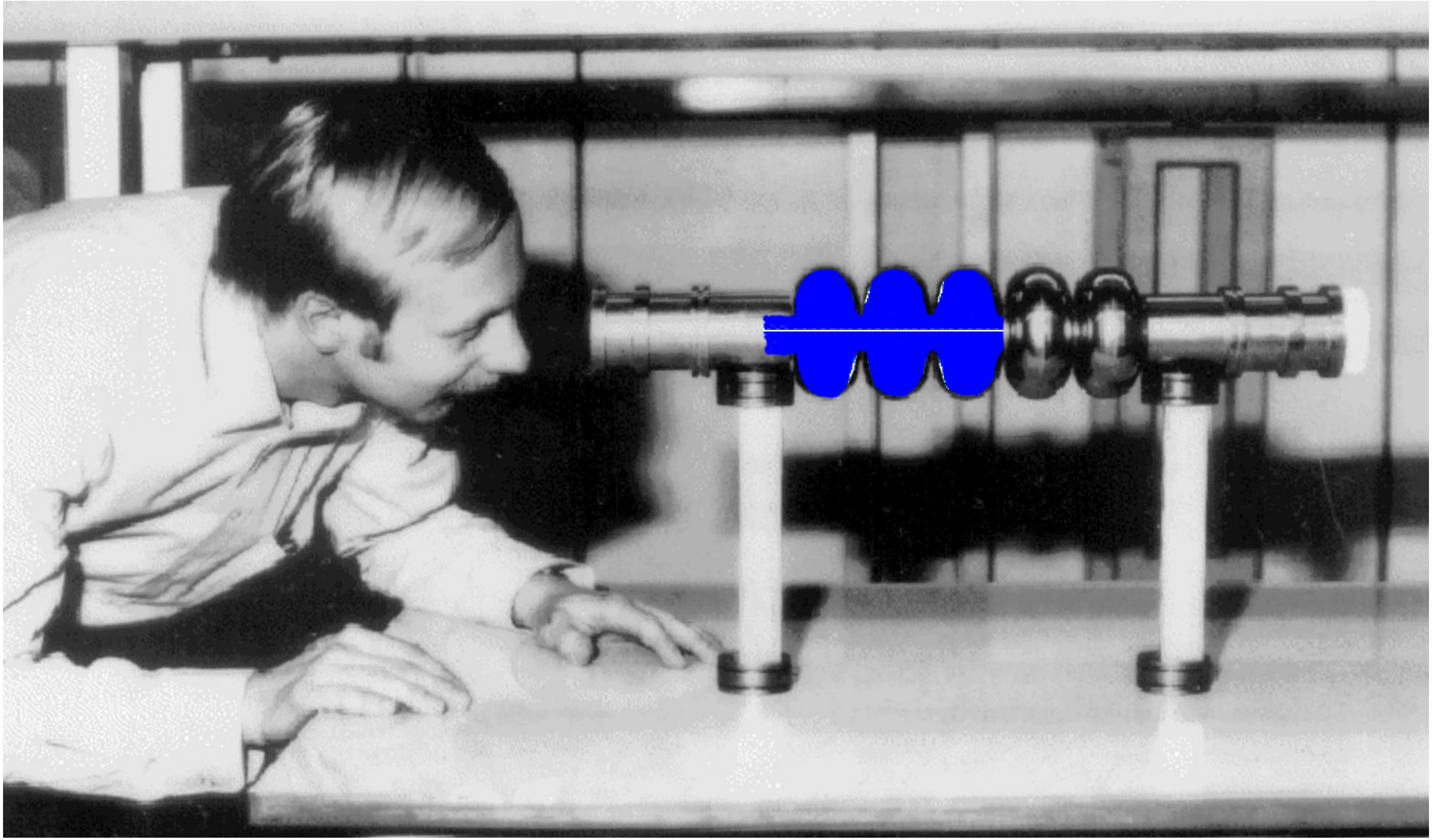
1300 MHz
TESLA



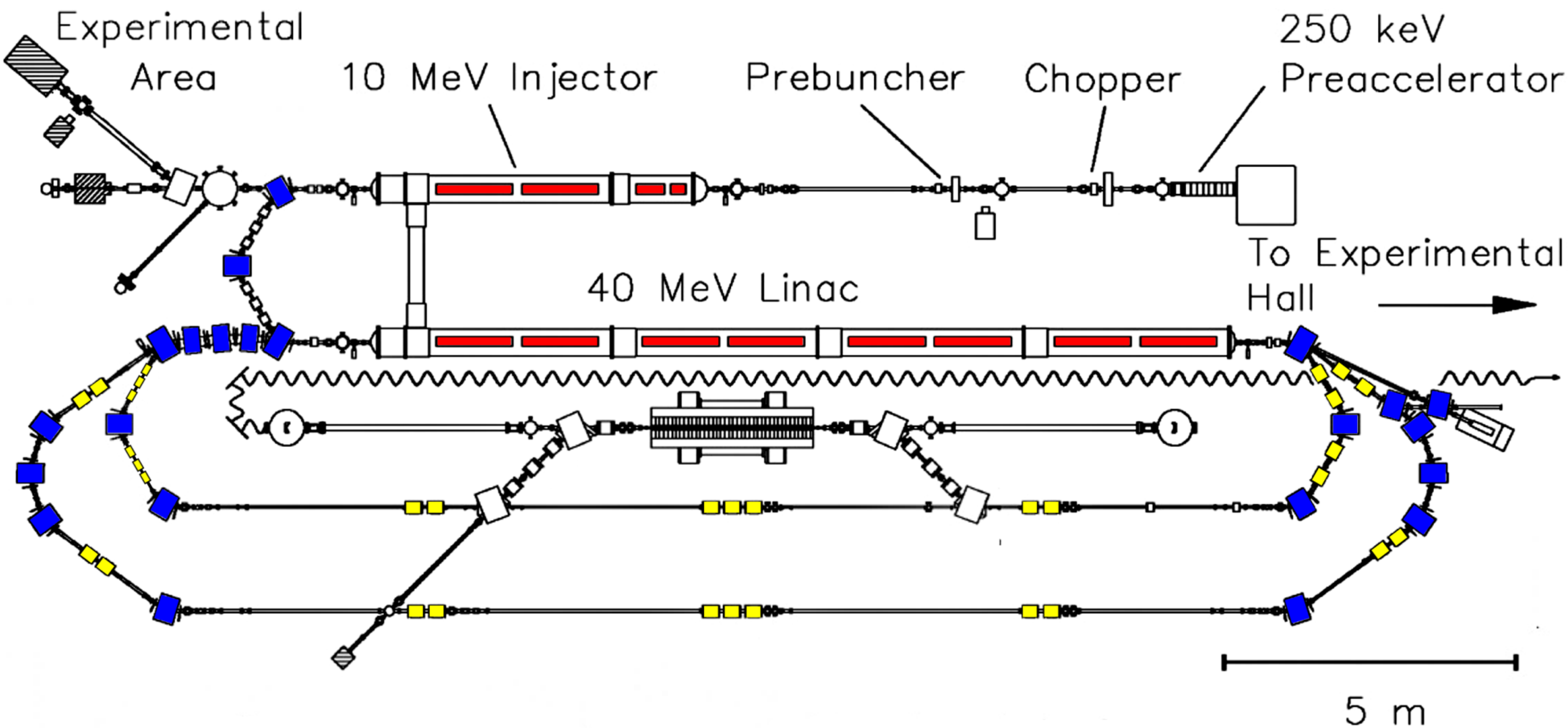
3000 MHz
S-DALINAC

Superconducting Accelerating Cavities

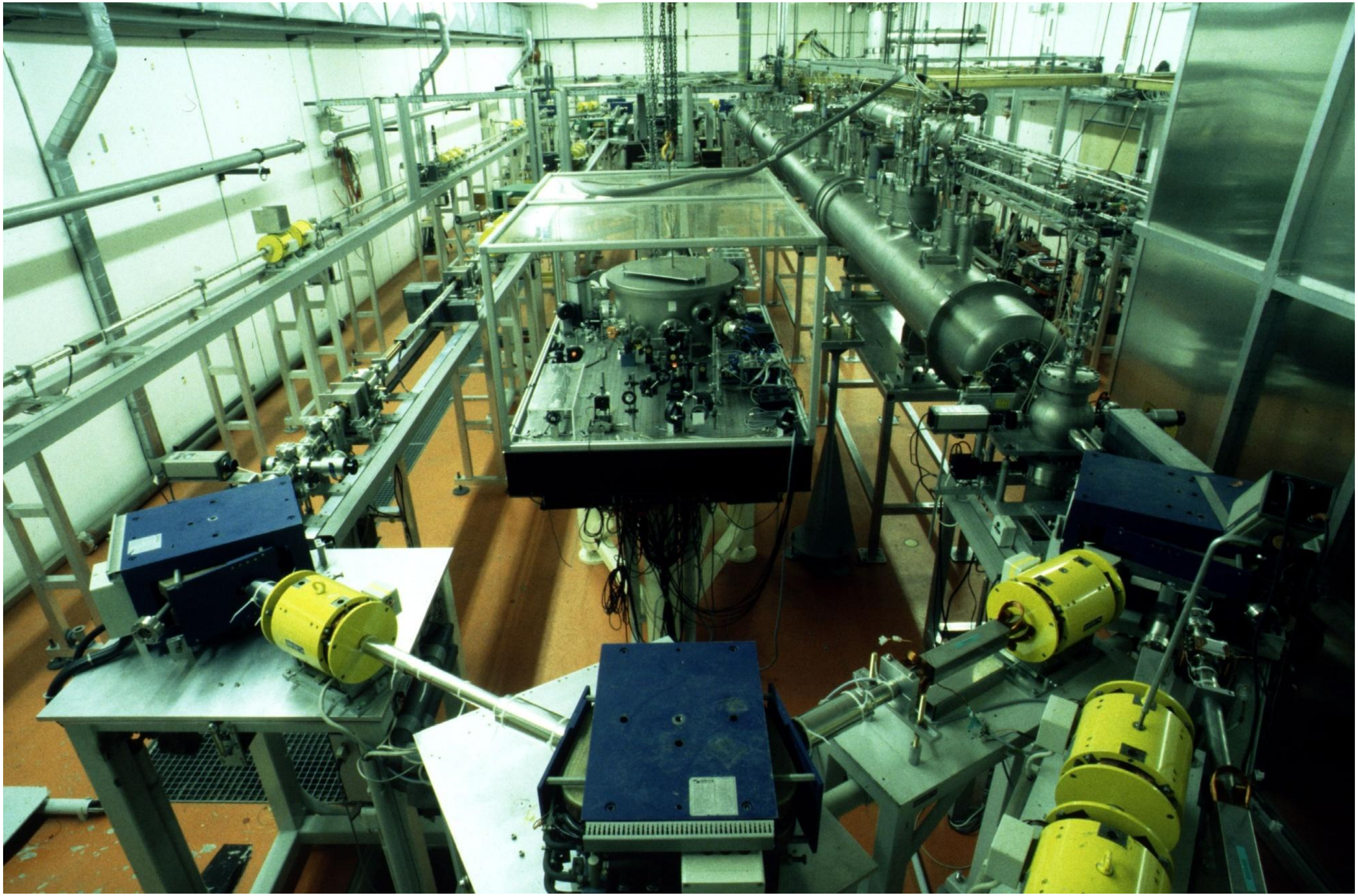
Superconducting Accelerating Cavities



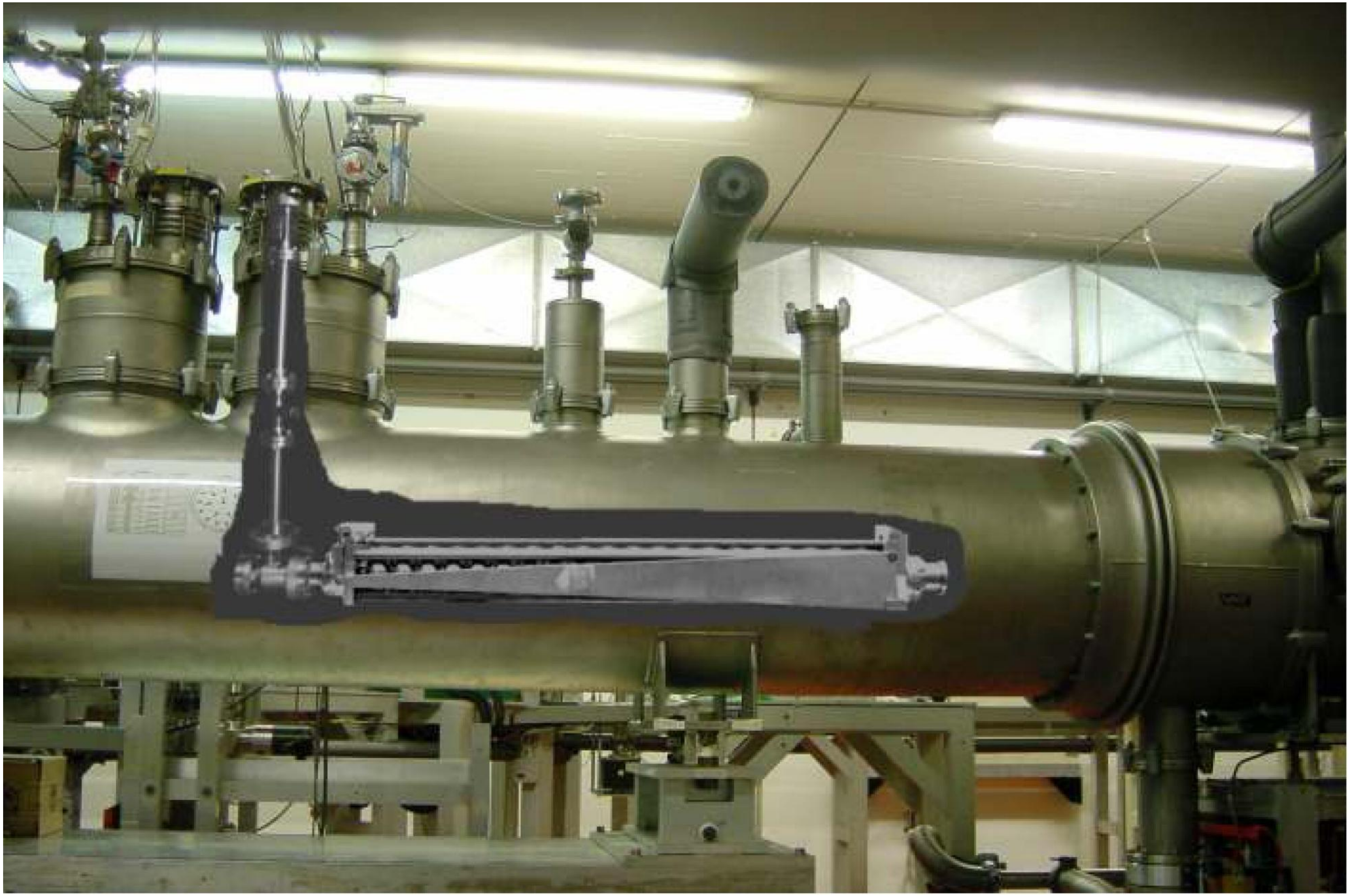
S-DALINAC – A Recirculating Linac



S-DALINAC



S-DALINAC with its 20-Cell Cavities



The Recirculating Linac Idea is quite old

FIRST WEEK – SUPERCONDUCTING RF CAVITIES AND LINACS

Chairman: H.A. SCHWETTMAN, Stanford University

The Summer Study began with a week on applications of superconducting surfaces at radio frequencies. Under the able leadership of Alan Schwettman, an easy and informal atmosphere was rapidly achieved and soon a free and vigorous interchange of information was in progress between exponents of various techniques and representatives of the manufacturers whose technology will be essential to progress in this field. The session was dominated by the energetic Stanford group who continually amazed the audience with the scope and daring of their plans.

Chairman H. Alan Schwettman with W.M. Fairbank and E. Jones, all of Stanford. G.A. Loew and R.B. Neal of SLAC. In the background is H.J. Halama of Brookhaven.

HEPL

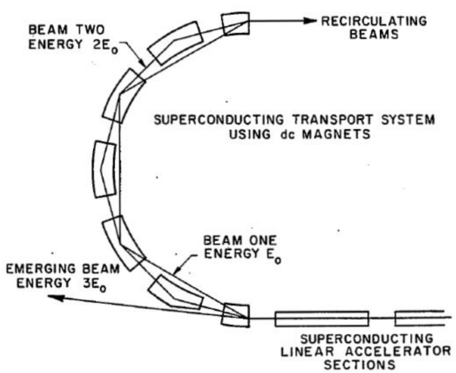
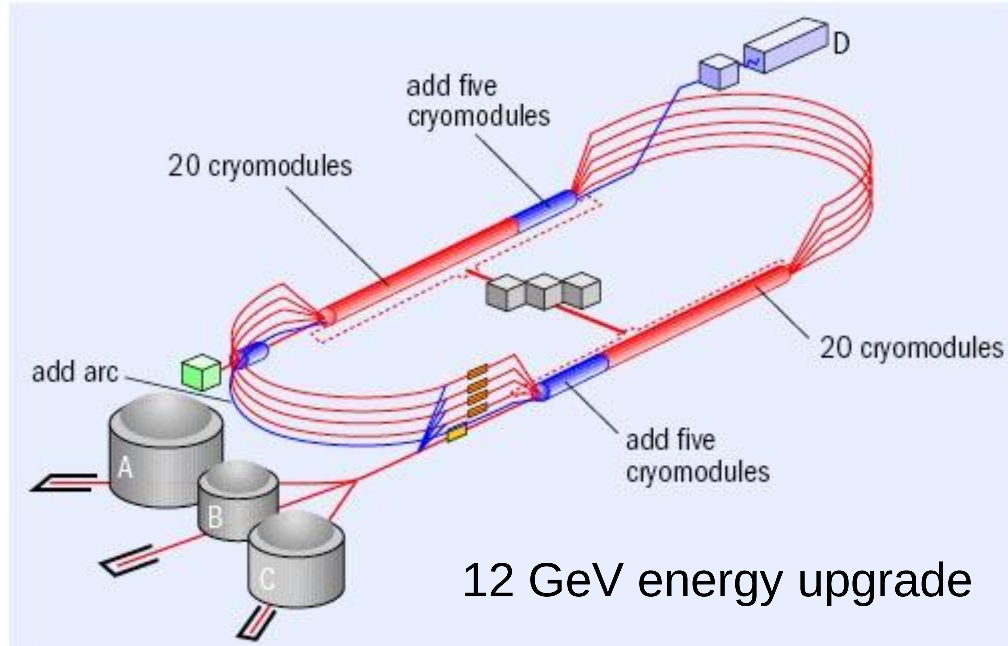
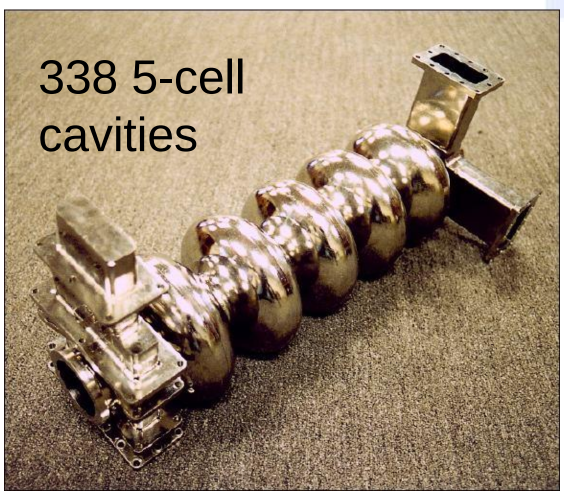
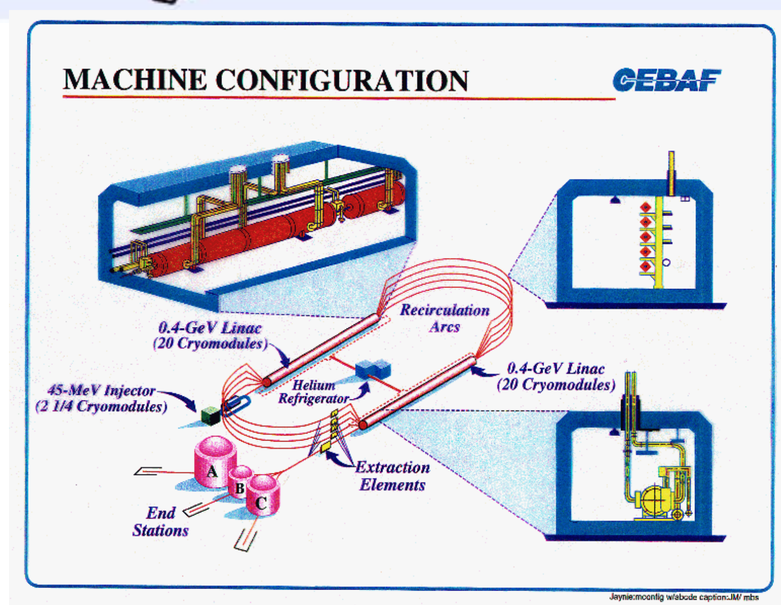


Fig. 6. Schematic drawing of a simple recirculating linac.

The Recirculating Linac – CEBAF (TJNL)







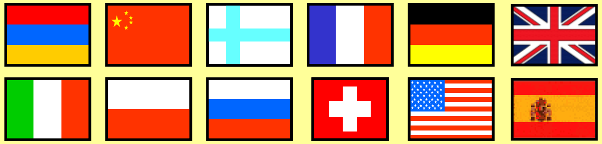
One Decade of TESLA R&D

Goal of the TESLA collaboration

- Increase cavity gradient from 5 to 25 MV/m
- Reduce costs by a comparable factor

Common effort of almost all laboratories using s.c. accelerating cavities, e.g.

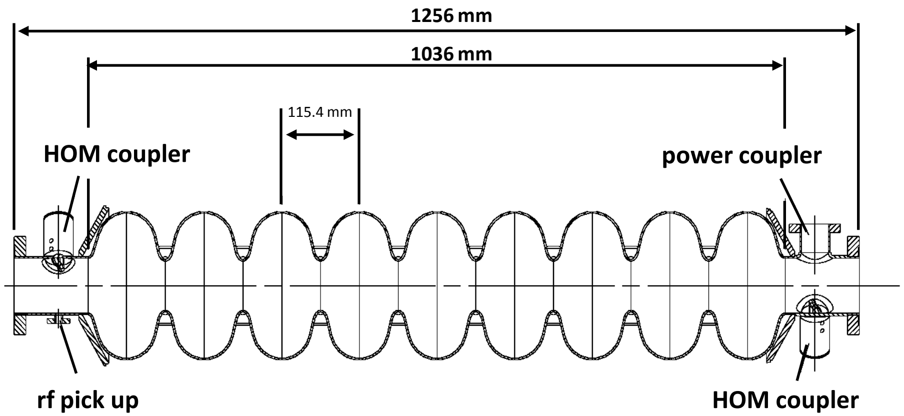
- (CERN), Cornell, DESY, INFN, (KEK), Saclay, TJNL
- 53 partners from 12 countries

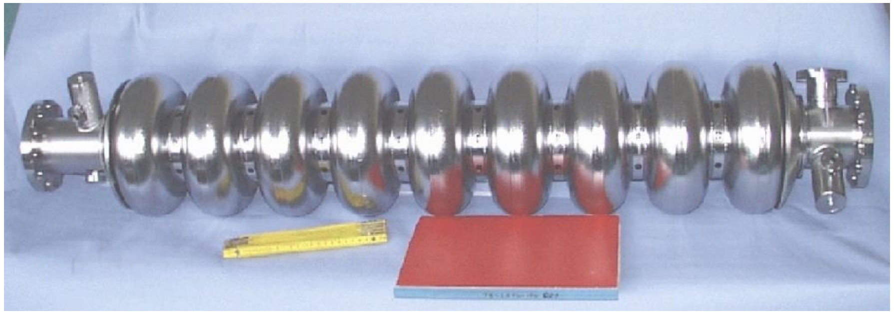


Improved material quality check

New cavity preparation procedures

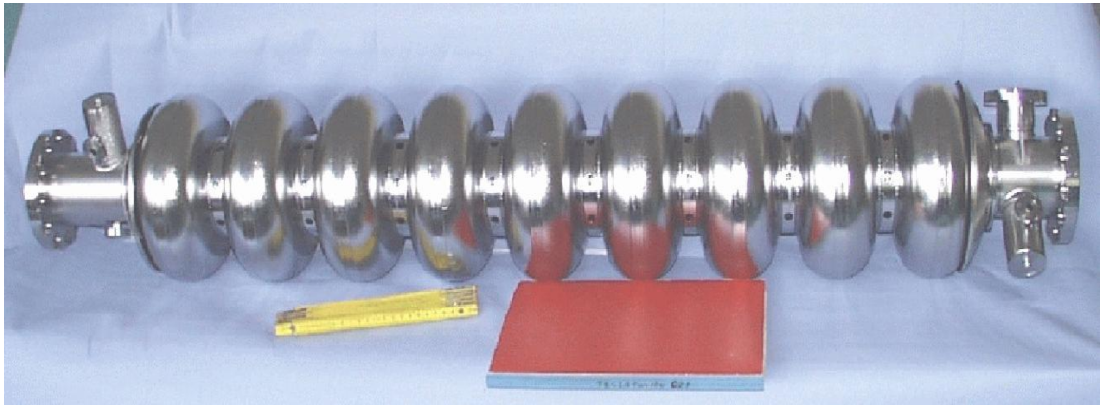
- 1400 ºC annealing with a titanium getter
- ultra-pure, high pressure water rinsing
- high peak power processing





One standard 9-cell TESLA accelerating structure operated as a π-mode standing-wave cavity. One 230 kW rf input coupler, an rf pick up antenna and two Higher Order Mode antennas are assembled to each cavity.

TESLA Cavities



Made out of solid, pure (RRR >300, high thermal cond.) Niobium

Nb sheets are deep-drawn to make cups (≈**100 µm tolerances**), which are electron beam welded to form structures.

Fill time 420 µs, i.e. $Q_{ext} = Q_{beam} \approx 3 \times 10^6$, $\Delta f \approx 400$ Hz

RF pulse length (400 µs filling + 920 µs flat top) = 1320 µs.

Operated at 2 K in superfluid Helium bath.

RF losses approx. 1 W/m.

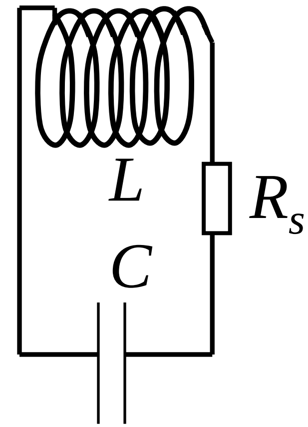
RF amplitude and phase adjusted during filling and flat top to compensate beam loading. In steady state **essentially 100% rf input power goes into the beam.**

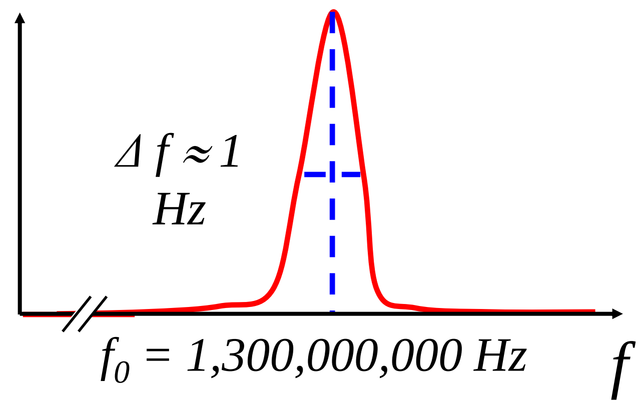
$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

frequency

$$Q_o = \frac{f}{\Delta f} = \frac{G}{R_s}$$

quality factor

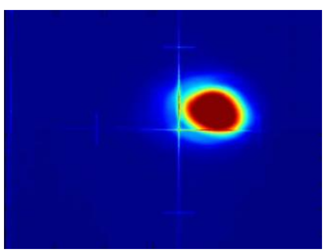




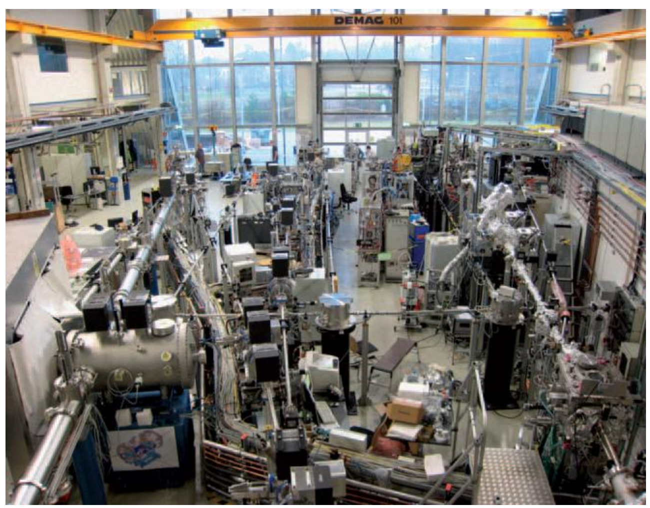
$Q_0 \approx 10^9 - 10^{10}$

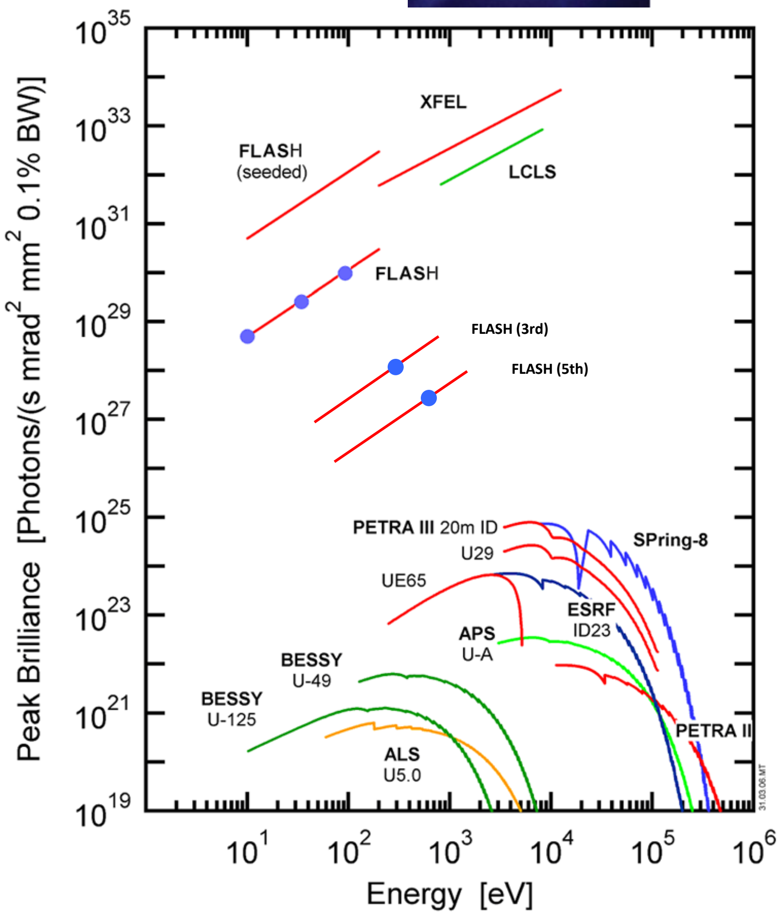
FLASH – based on TESLA Technology

Wavelength **(fundamental)**	**47 – 6.5**	**nm**	**(tunable!!!)**
FEL range **(harmonics)**	**→ 2.7**	**nm**	
Average energy per pulse	up to 100	µJ	
Maximum energy per pulse	200	µJ	
Radiation pulse duration	10 – 50	fs	
Peak power (calc. from average)	~ 3 – 4	GW	
Spectral width (FWHM)	**0.5 – 1**	**%**	
Angular divergence (FWHM)	160	µrad	
Peak brilliance (calc. from max)	**5-10 10^{29}**	ph/s/mrad²/mm²/ (0.1% bw)	

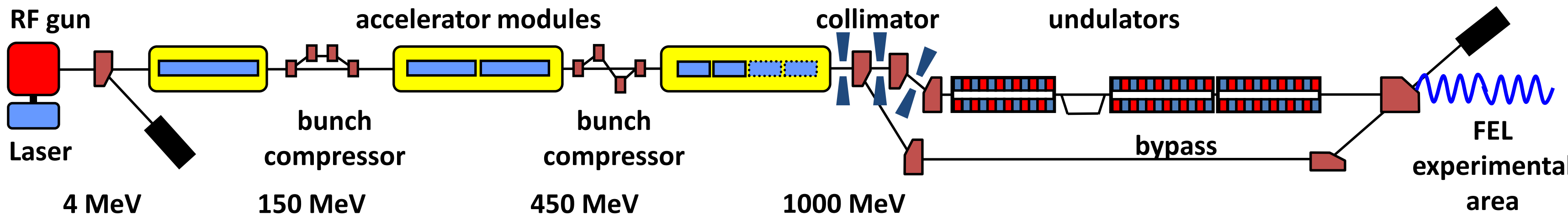


<E> = 70 µJ





The FLASH VUV-FEL Facility at DESY



→ **6 accelerator modules** routinely in operation; design beam energy & photon wavelength (6.5 nm) since Oct. 2007

→ **pilot facility** regarding practically all aspects (accelerator technology, beam physics, FEL process, user operation) of the XFEL

Why FLASH and XFEL?

Time to explore the femtosecond dynamics of nature

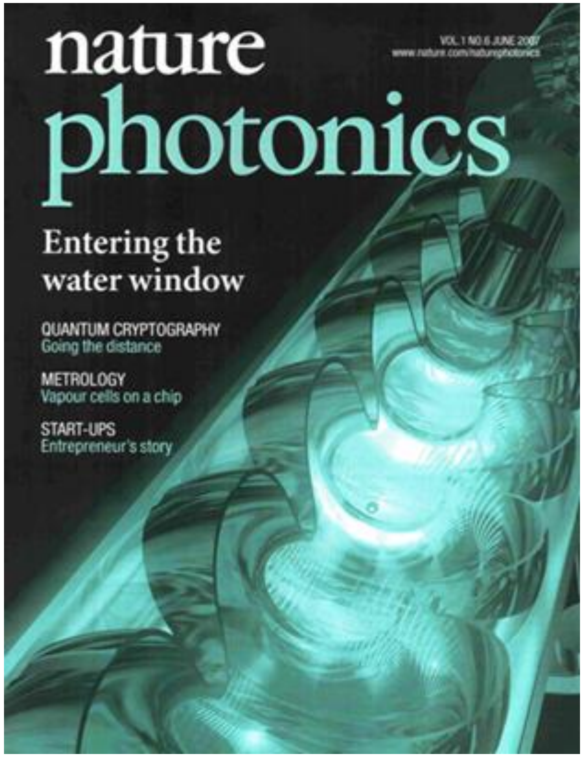
Ever seen the machinery of a living cell at work at atomic resolution?

Observed how molecules change shape in femtoseconds during chemical or biochemical reactions?

Watched a drug molecule enter a protein receptor in real time?

Soon X-ray free-electron lasers will enable us to probe ultra fast physical, chemical and biochemical processes at atomic resolution, opening new frontiers for science and technology. At long last we may see, and not just model, how molecular machines really work.

FLASH References



Operation of a free-electron laser from the extreme ultraviolet to the water window

nature photonics | VOL 1 | JUNE 2007 | www.nature.com/naturephotonics

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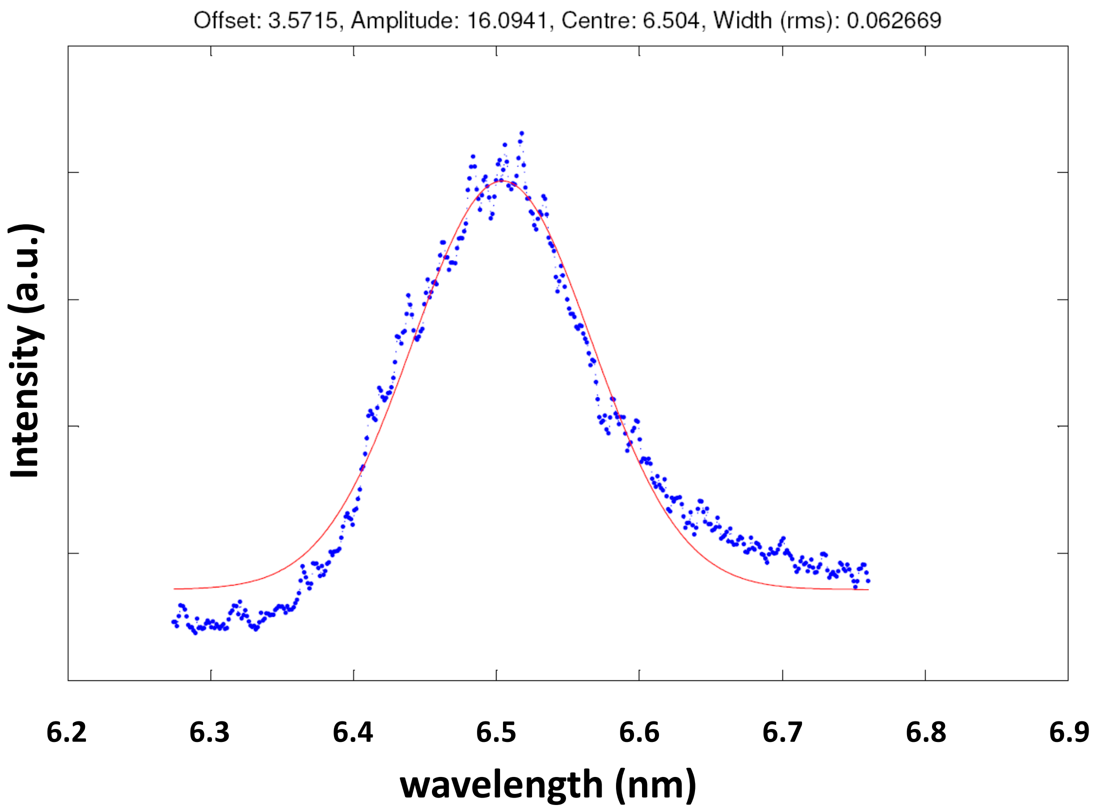
http://flash.desy.de/

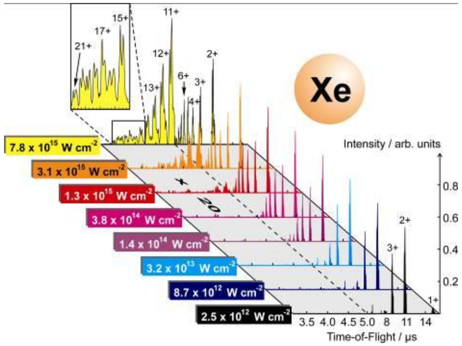
Lasing at 6.5 nm wavelength

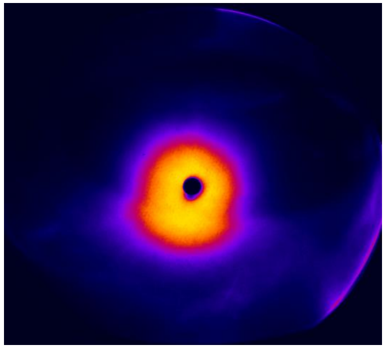


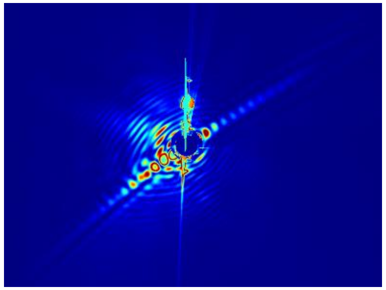
- first lasing at 80 nm (TTF1) took months
- first lasing at 6.9 nm instead of the previously reached 13 nm took hours

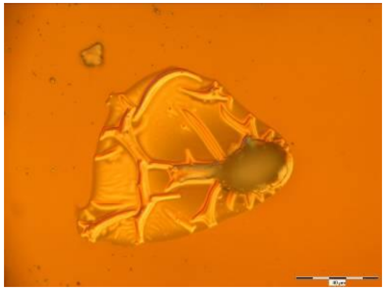
This demonstrates the scalability of the concept towards the XFEL.

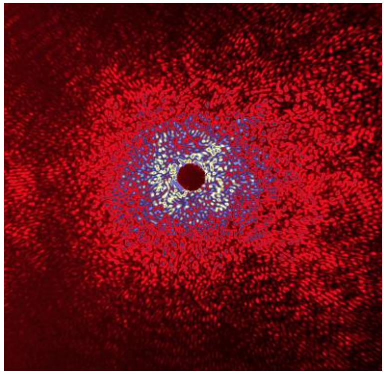
Experiments with the FEL Beam







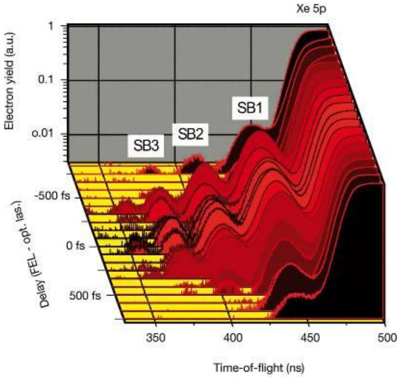




about 30 publications already,
many more to come

11 PRL
6 APL
1 Nature,
1 Nature Physics
4 Nature Photonics
…

See, e.g.,
http://hasylab.desy.de/facilities/flash/publications



XFEL Introduction / History

Oct 2002: XFEL supplement to TESLA TDR → Feb 2003 approval by German government to realize the XFEL as European project with at least 40% funding contributions from partners → ***intense preparation work on technical design, industrialization of components, evaluation of cost/schedule, international project organization***

July 2006: completion of XFEL TDR, submitted to and approved by International Steering Committee → ***986M€/y2005 construction cost (+preparation & commissioning cost), negotiations of funding contributions continuing***

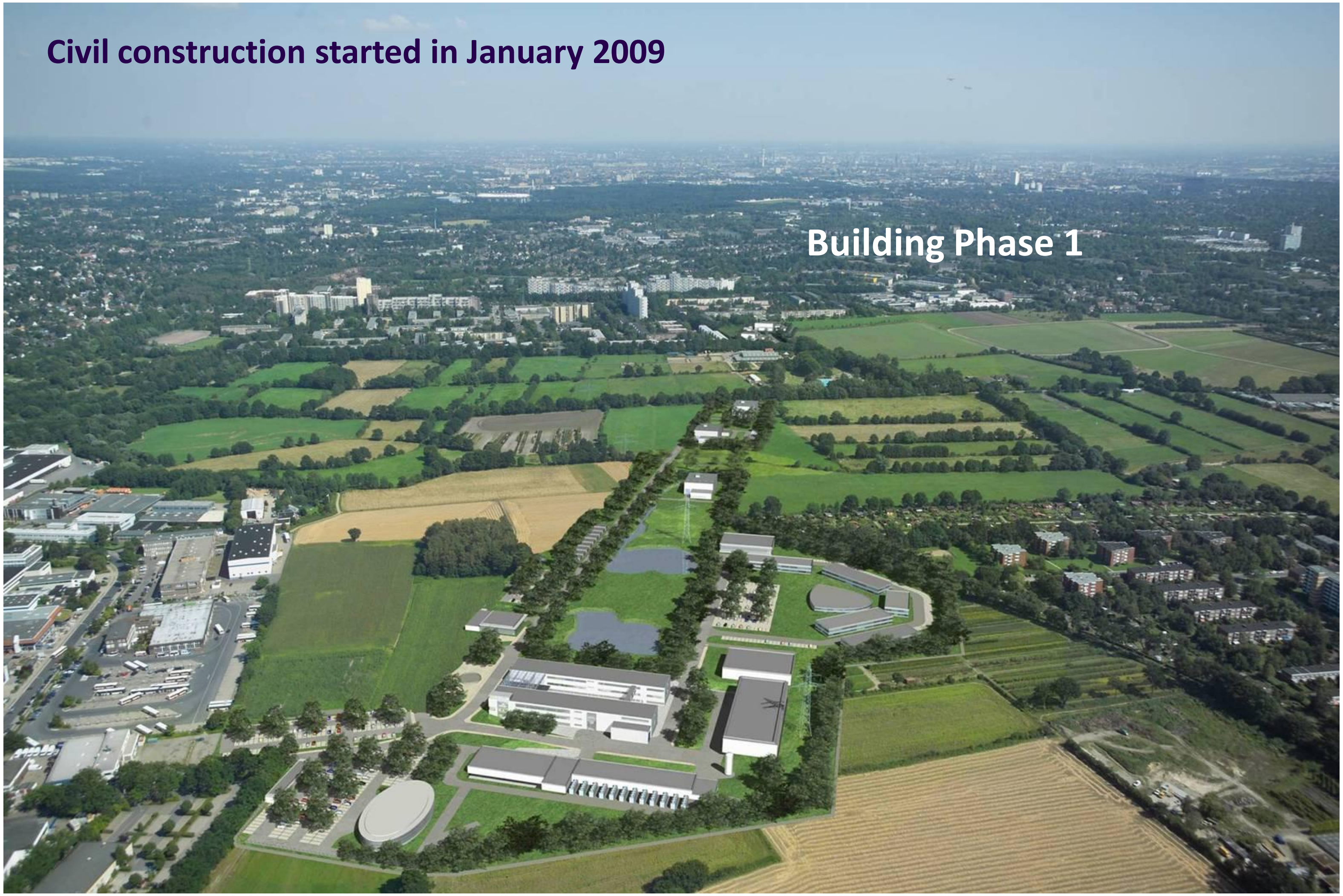
June 5, 2007: Official project start announced on basis of initially de-scoped start version at 850M€/y2005 construction cost → ***launch tender process for civil construction, finalization of legal documents & prep of XFEL GmbH foundation, negotiations of in-kind contributions***

Overall layout of the European XFEL

Hans Weise / DESY, WEH Seminar, Bad Honnef, 26-29 April 2009
Accelerators and Detectors at the Technology Frontier

XFEL Site in Hamburg/Schenefeld

… after construction (computer simulation)



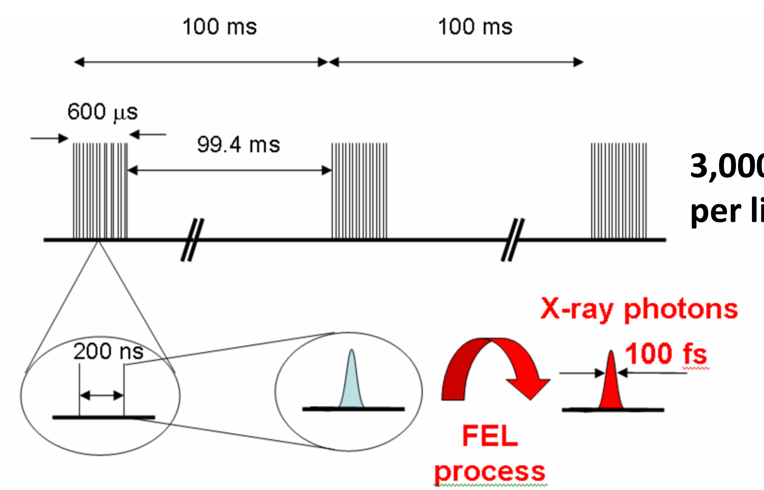
Properties of XFEL Radiation

X-ray FEL radiation (0.2 - 12.4 keV)

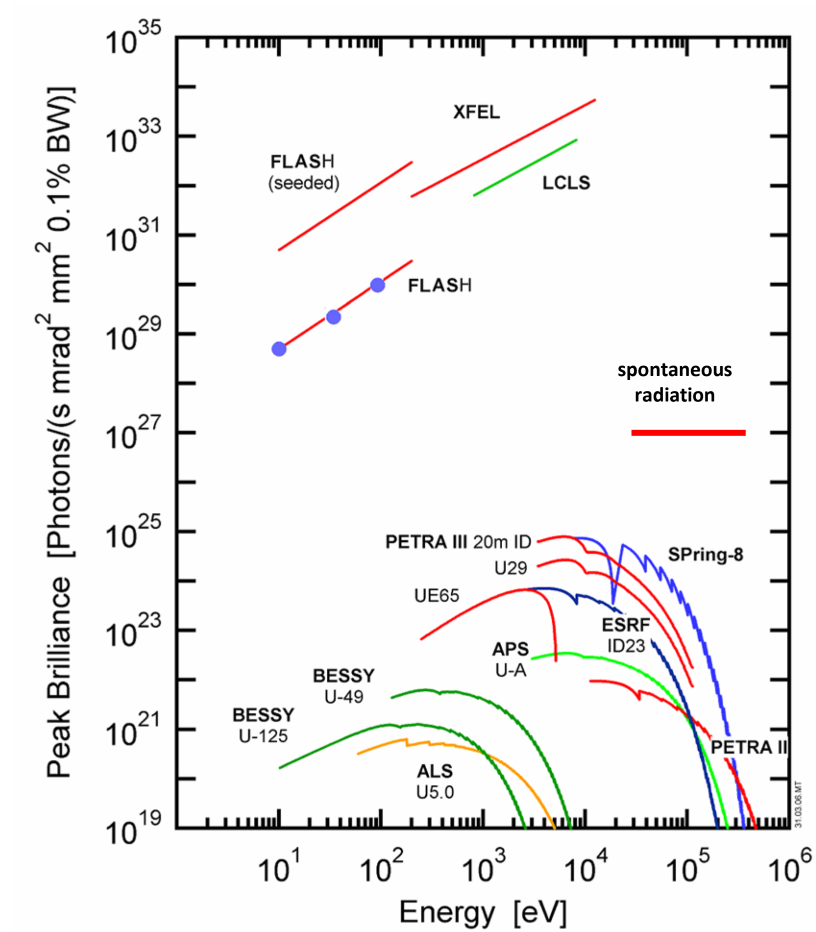
- ultrashort pulse duration <100 fs (rms)
- extreme pulse intensities 10^{12}-10^{14} ph
- coherent radiation x10^9
- average brilliance x10^4

Spontaneous radiation (20-100 keV)

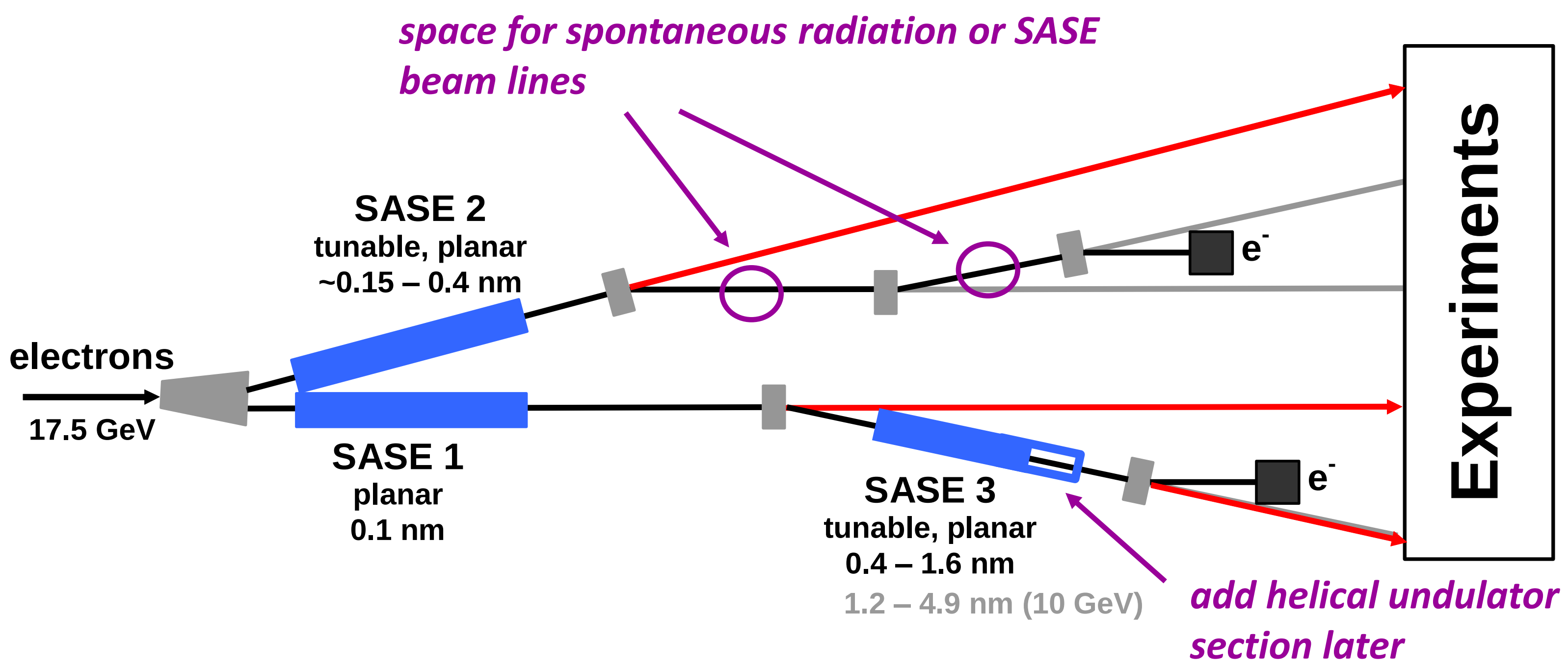
- ultrashort pulse duration <100 fs (rms)
- high brilliance



3,000 bunches per linac pulse



Beam lines in start version



three photon beamlines

superconducting linac: 17.5 GeV

→ Photon wavelengths below 0.1 nm design value require a linac gradient above 23.6 MV/m (design value)

Selection of first instruments was made

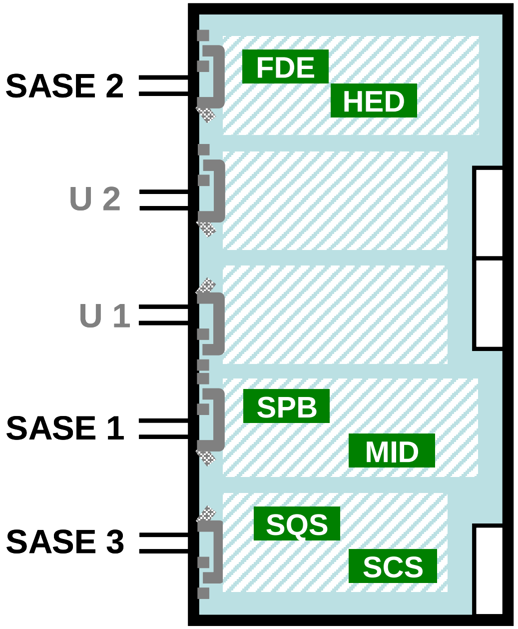
Hard X-rays

Soft X-rays

Instrument	Brief description of the instrument
SPB	Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules – Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.
MID	Materials Imaging & Dynamics –Structure determination of nano- devices and dynamics at the nanoscale.
FDE	Femtosecond Diffraction Experiments – Time-resolved investigations of the dynamics of solids, liquids, gases
HED	High Energy Density Matter – Investigation of matter under extreme conditions using hard x-ray FEL radiation, e.g. probing dense plasmas.
SQS	Small Quantum Systems – Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena.
SCS	Soft x-ray Coherent Scattering –Structure and dynamics of nano-systems and of non-reproducible biological objects using soft X-rays.

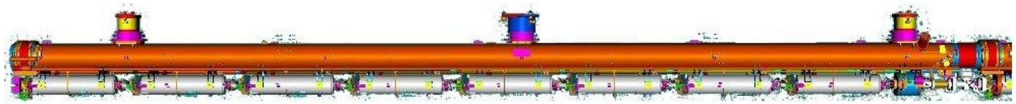
Distribution of first instruments

Source	Photon beam line characteristics
SASE 1	FEL radiation ~12 keV High coherence Spontaneous radiation (3^{rd}, 5^{th} harmonics)
SASE 2	FEL radiation 3-12 keV High time-resolution Spontaneous radiation (3^{rd}, 5^{th} harmonics)
SASE 3	FEL radiation 0.25 – 3 keV; High flux
	FEL radiation 0.25 – 3 keV; High resolution



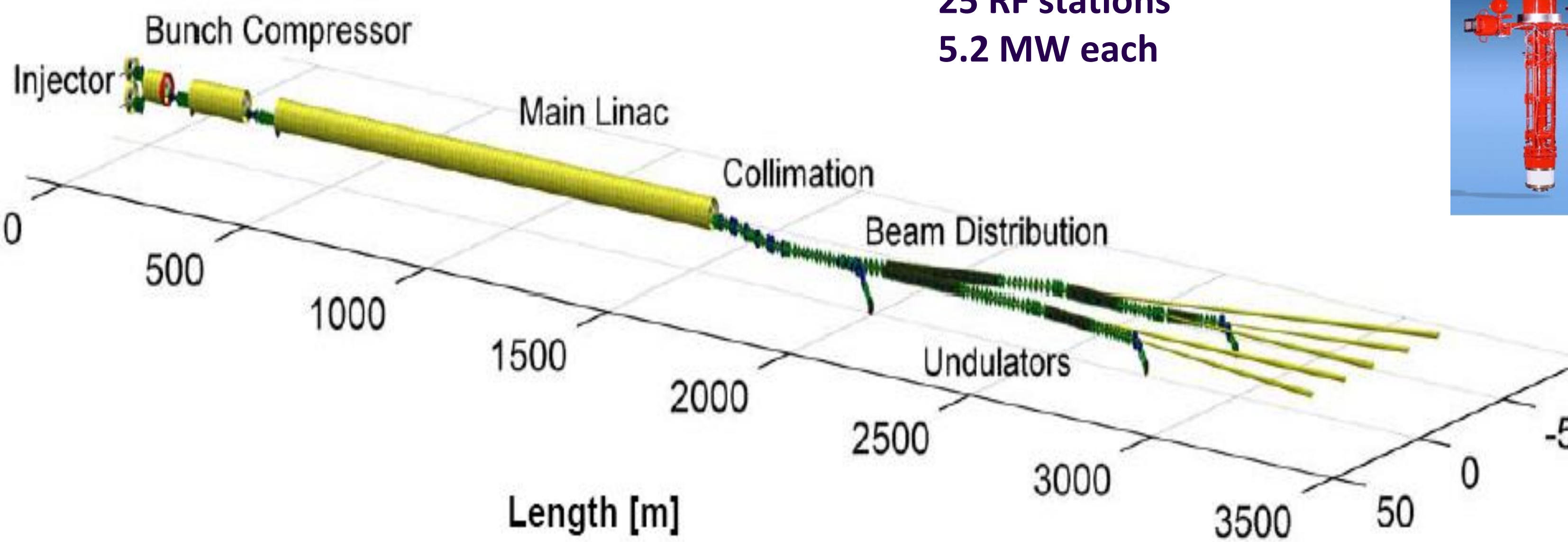
Accelerator complex

100 accelerator modules

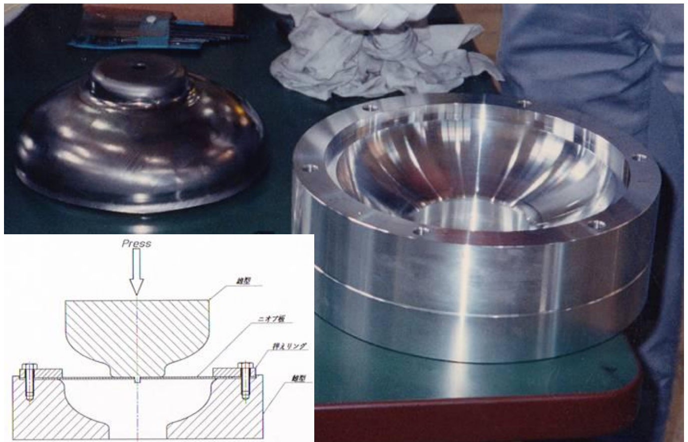


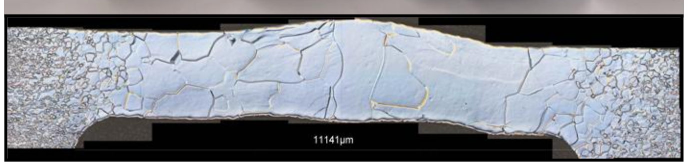
800 accelerating cavities
1.3 GHz / 23.6 MV/m

25 RF stations
5.2 MW each



Cavity fabrication



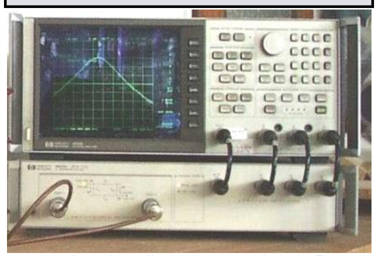


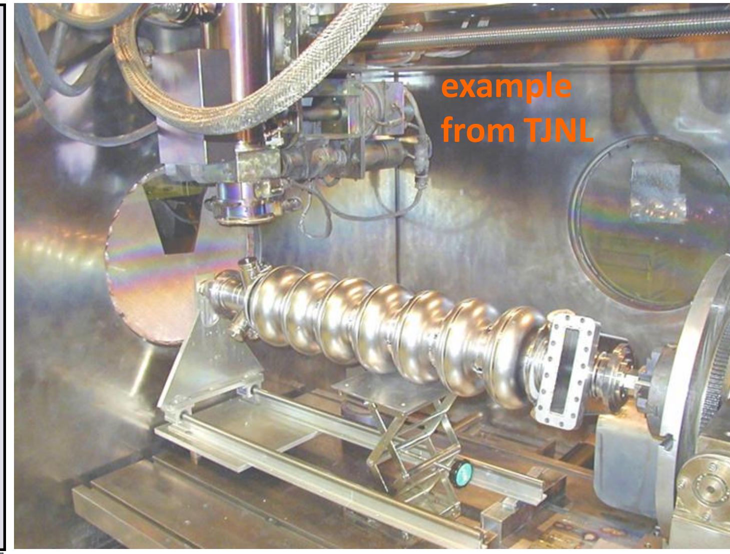
Half cells are produced by deep drawing.

Annealing is next to achieve complete re-crystalisation.

Dumb bells are formed by electron beam welding.

RF measurements support visual inspection.



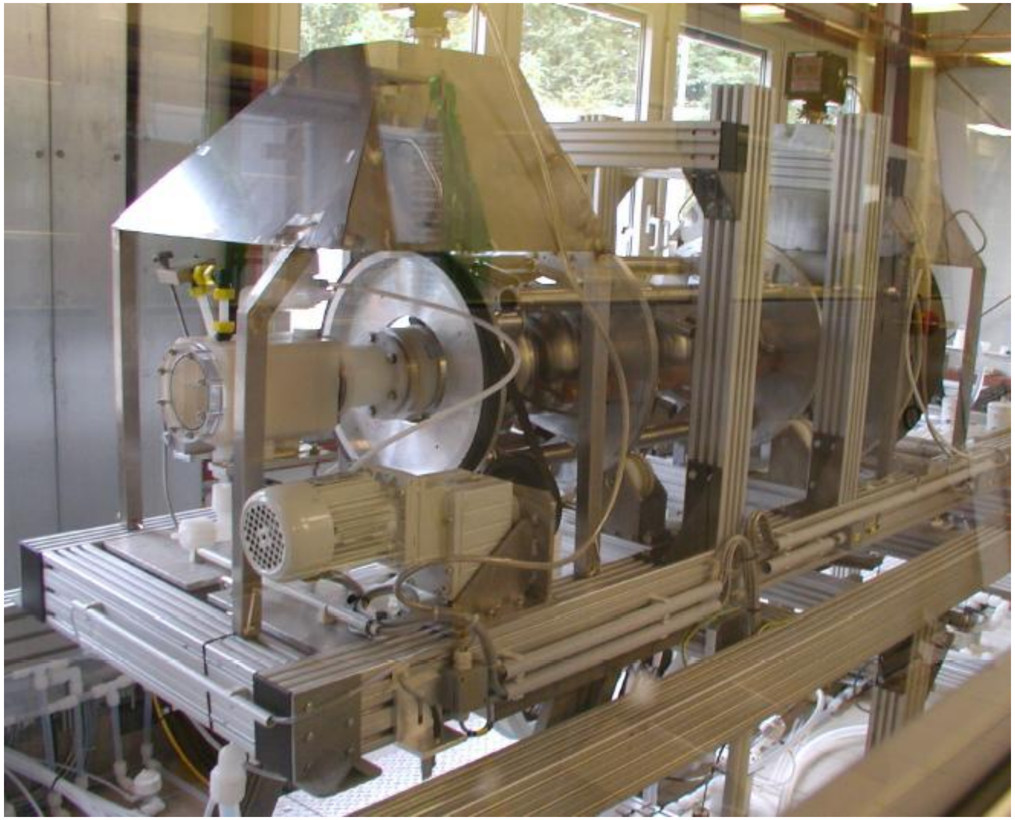


After proper cleaning eight dumb bells and two end group sections are assembled in a precise fixture.

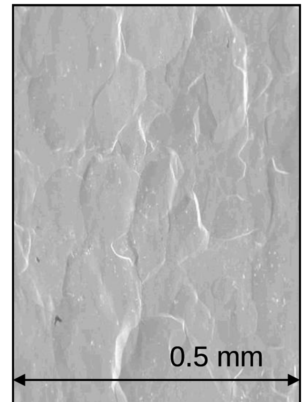
All equator welds can be done in one production step.

Engineering Data Management Systems (EDMS) is used for the documentation of the cavity fabrication process.

Cavity preparation (Electrolytical Polishing)



Electro-polishing (EP) instead of the standard chemical polishing (BCP) eliminates grain boundary steps.
Gradients above 40 MV/m at
Q values above 10^{10} have been achieved.



BCP Surface
(1µm roughness)

EP Surface
(0.1µm roughness)

EP 150 µm (inside)

→

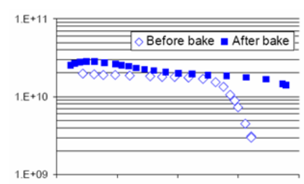
UHV 800 C annealing

→

"flash" BCP ~10 µm

***Or:* final EP ~40 µm**

→



UHV 120 C baking

→

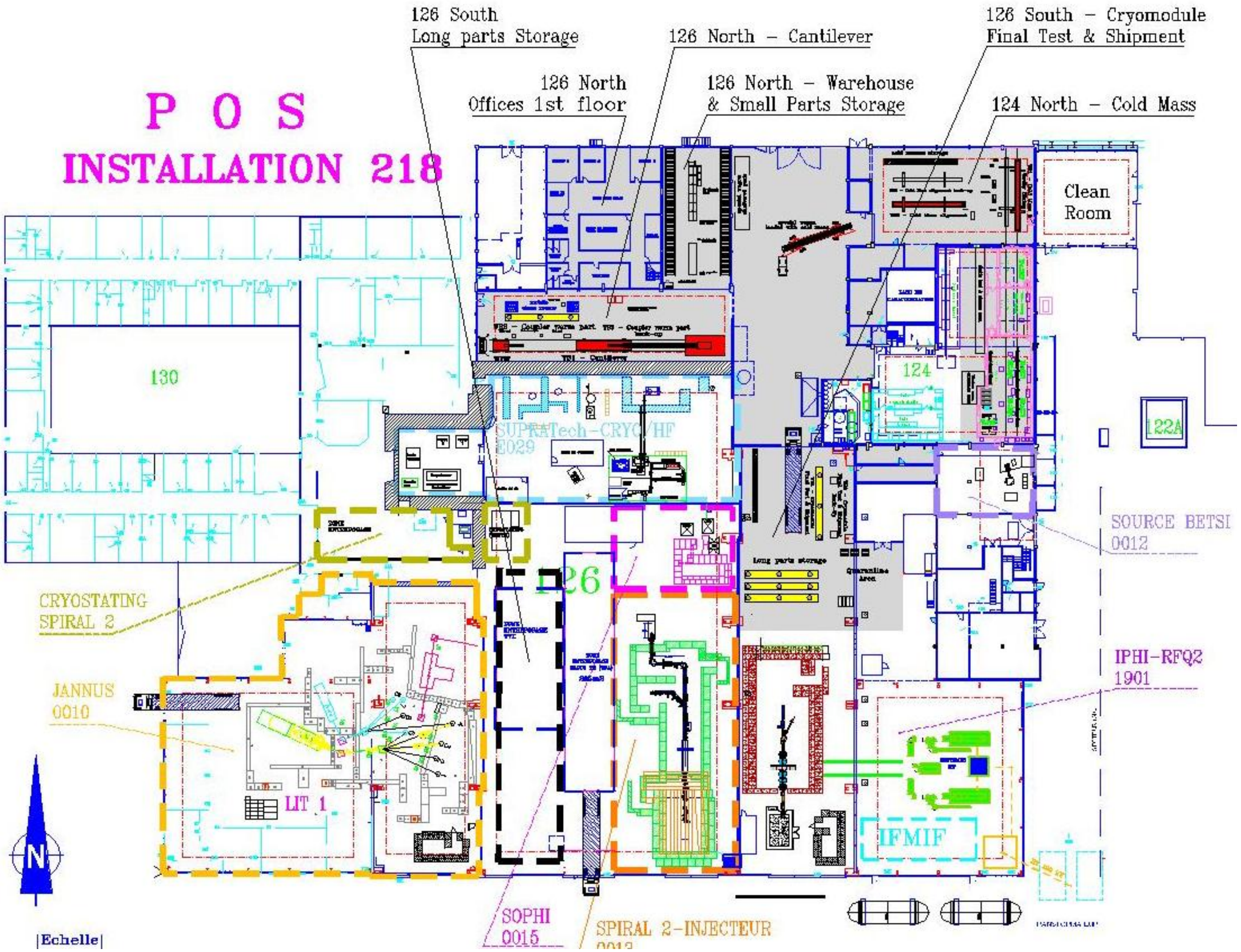
100 bar HPR (6)

Cavity string & module assembly

Using experience gained at DESY and results of industrial studies, the assembly facility for all 100 XFEL modules will be set up at the CEA-Saclay site.

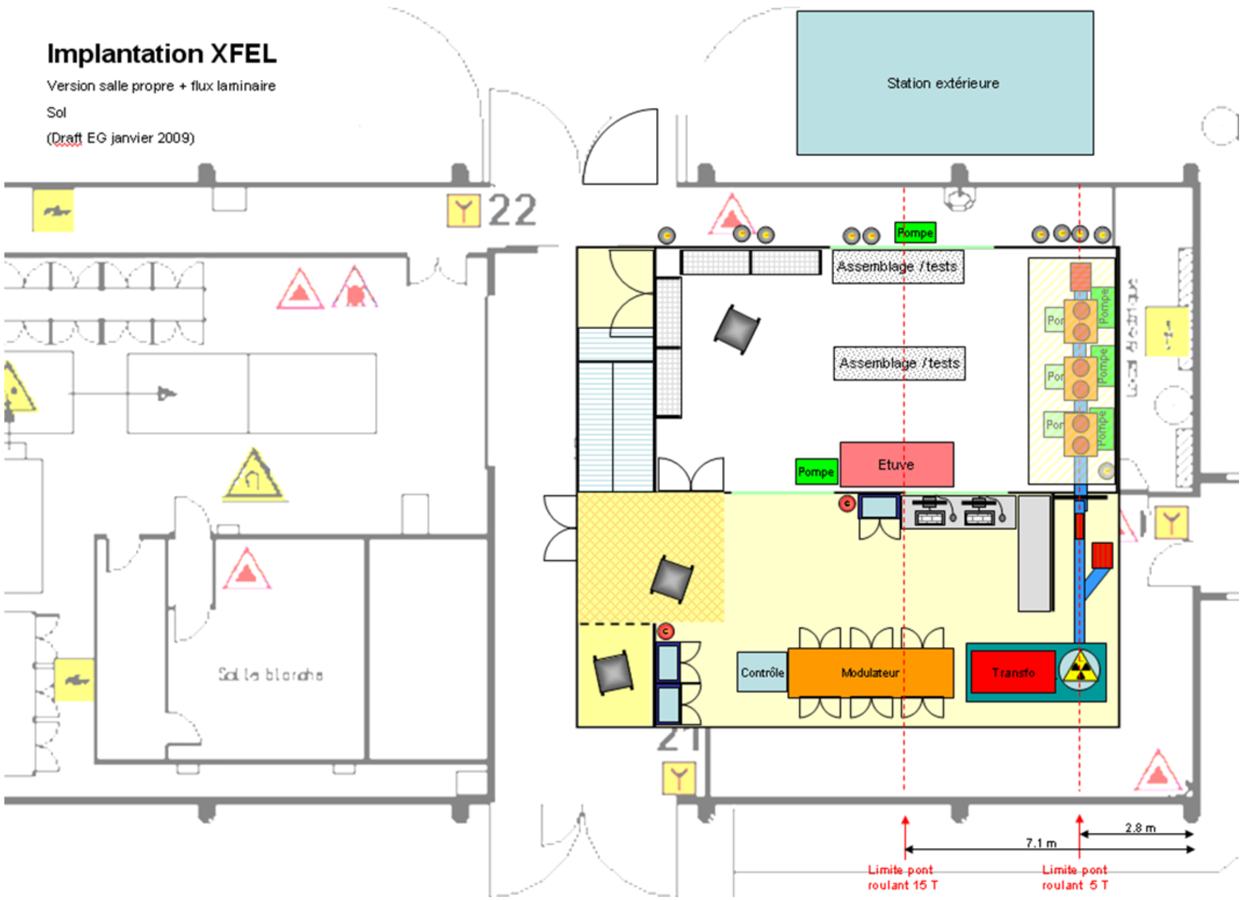
CEA (IRFU), CIEMAT, DESY, INFN-Milano, LAL Orsay, Swierk take the responsibility for the cold linac.

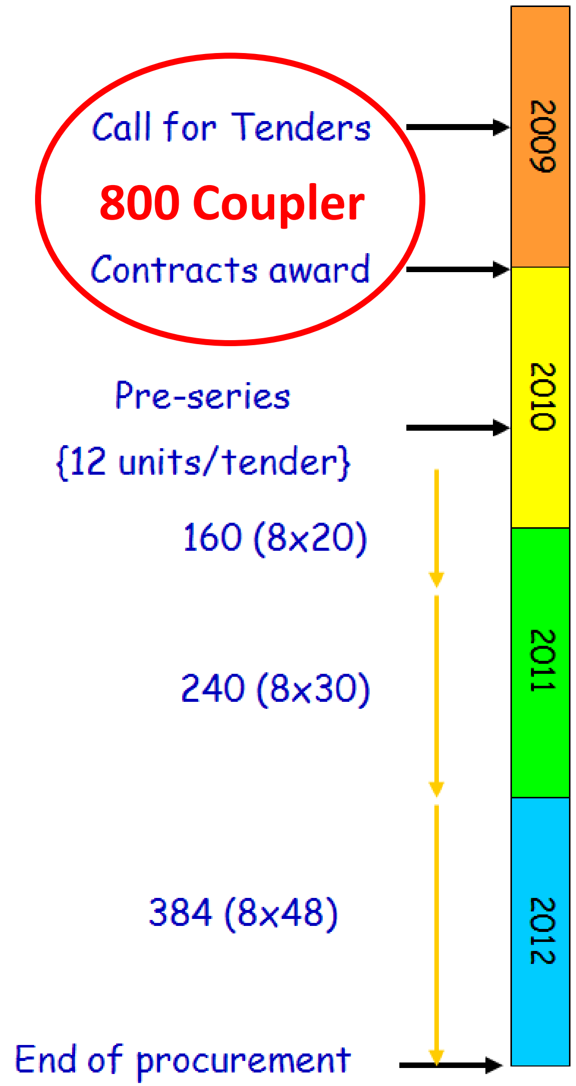
Saclay Infrastructure for Module Assembly



Construction work at Saclay is ongoing;
clean room commissioning will start in 2009

XFEL Coupler Conditioning at LAL Orsay





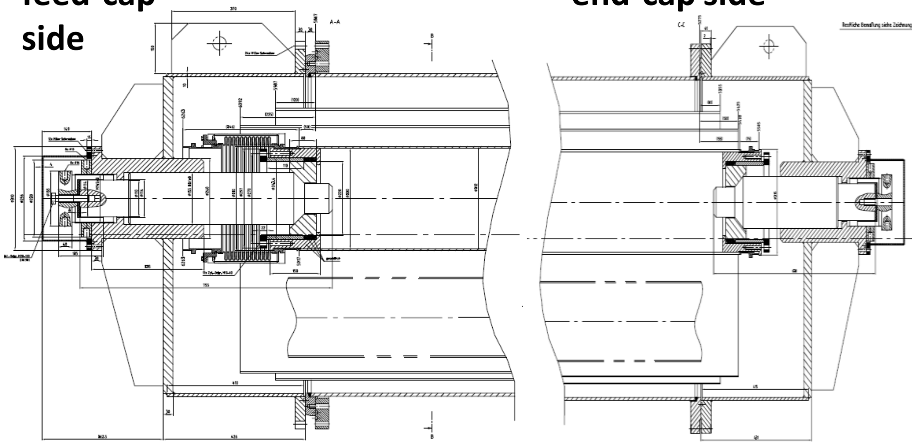
RF station ready for commissioning beginning of 2010.

Accelerator Modules - Transport Tools

irfu
cea
saclay
INFN
DESY
HELMHOLTZ ASSOCIATION

feed-cap side

end-cap side



some **minor modifications** after the first transportation

Module 8 Transport

A First Cryostat Being Produced in France

Status 28.11.2008

Vacuum vessel final welds and machining

Cold mass final welds and machining, welds done by a additional subcontractor

A First Cryostat Being Produced in Spain

irfu cea saclay

INFN

DESY

HELMHOLTZ ASSOCIATION

Status 27.11.2008

A First Cryostat Being Produced in China

irfu cea saclay

INFN

DESY

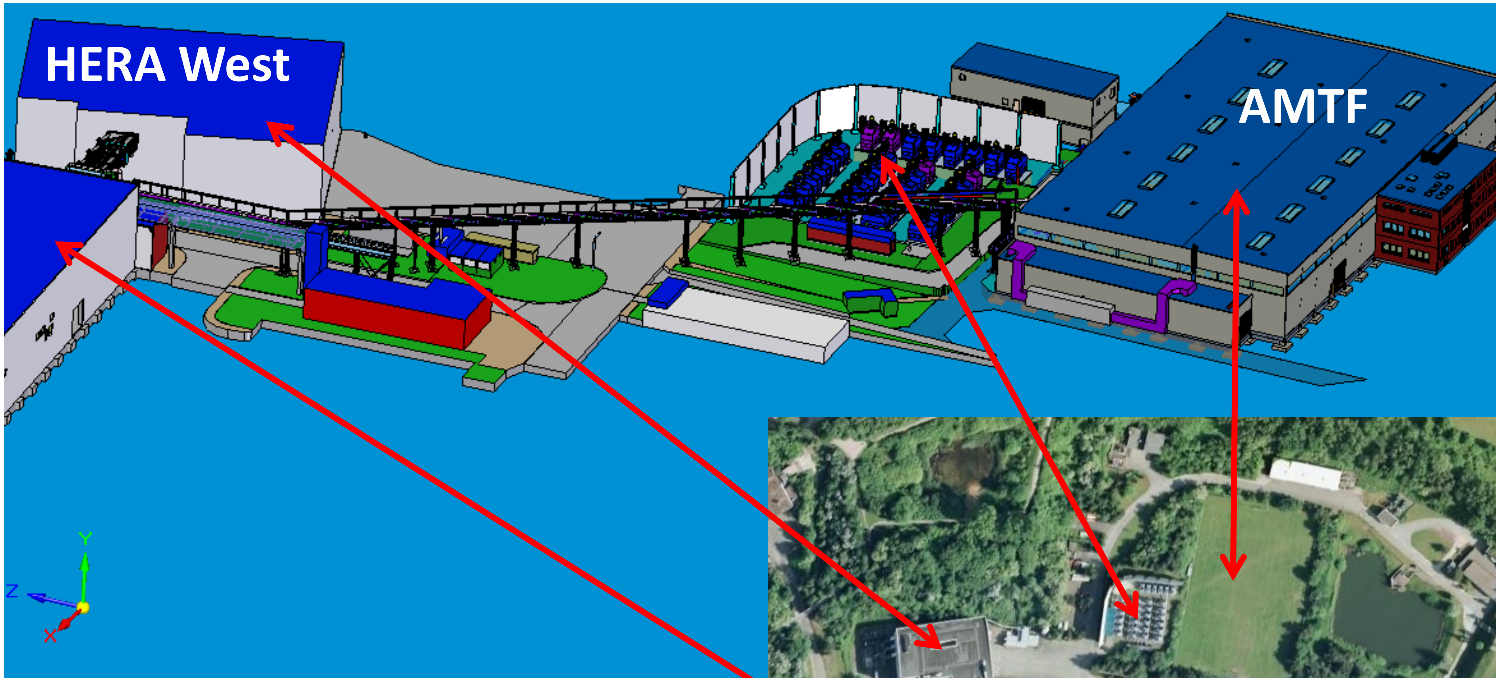
HELMHOLTZ ASSOCIATION

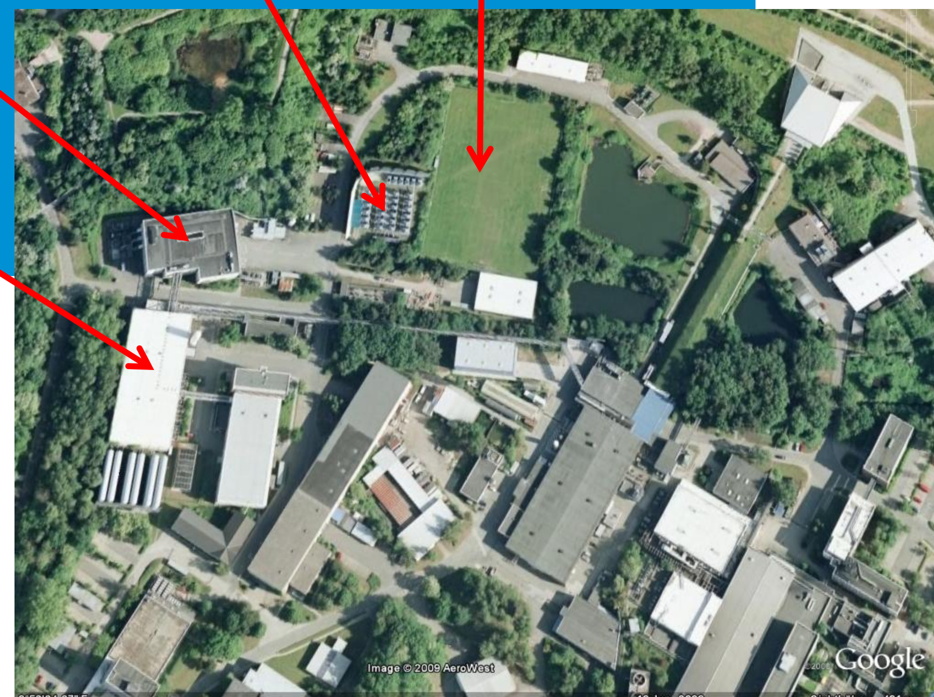
Status 28.11.2008

The First Cryostat Before Shipping

The First Cryostat After Shipping

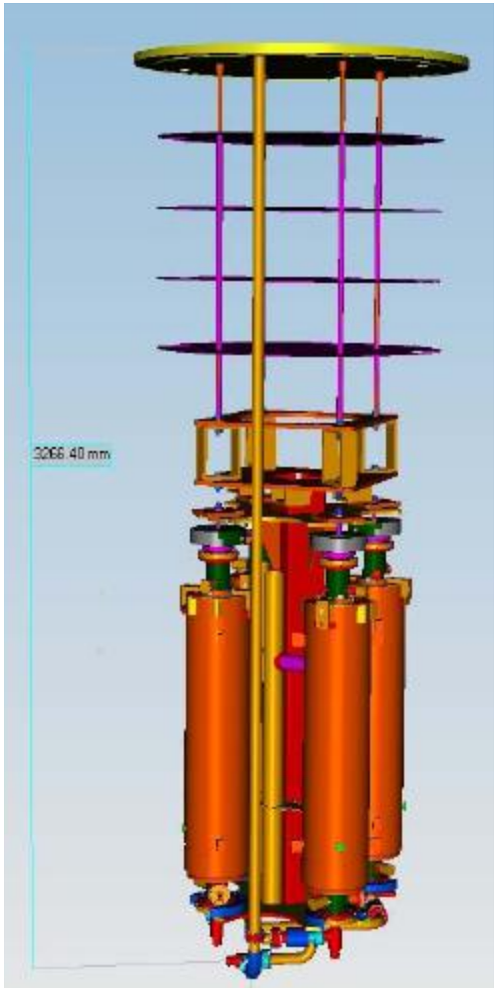
Accelerator Module Test Facility (AMTF)

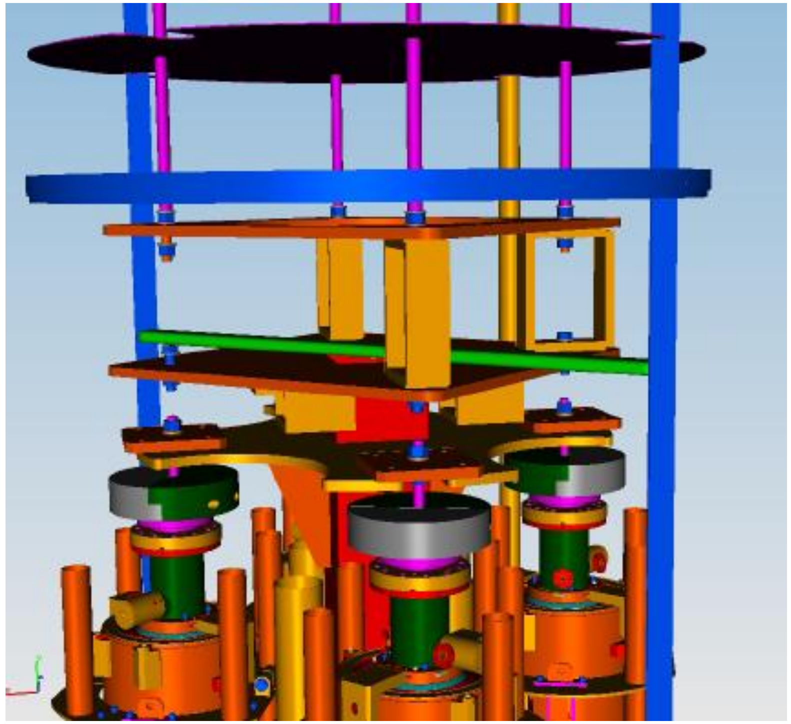




- Commissioning of **module test** facility 4/2011
- First **cavity tests** required for beginning of 2011
- AMTF ready for **infrastructure installation** 3/2010
- AMTF **Civil Construction** starts in June 2009

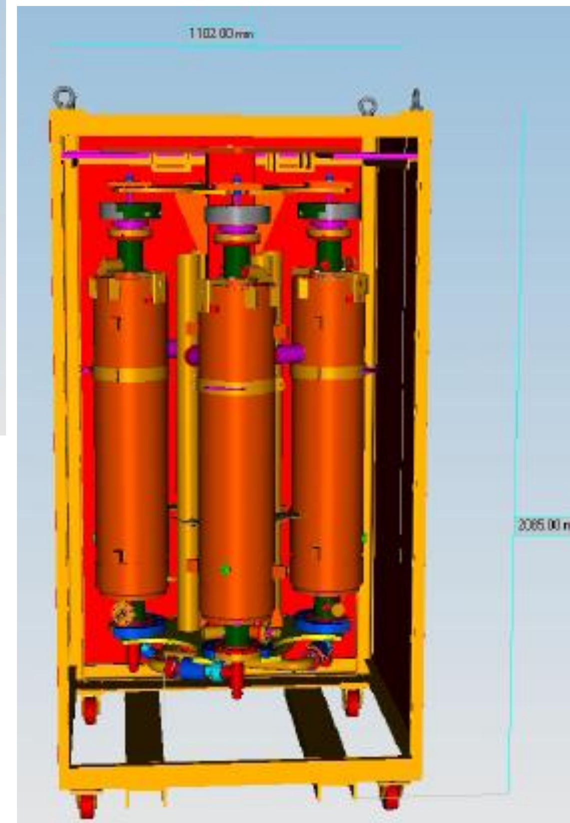
Cavity Tests at AMTF Starting in 2011





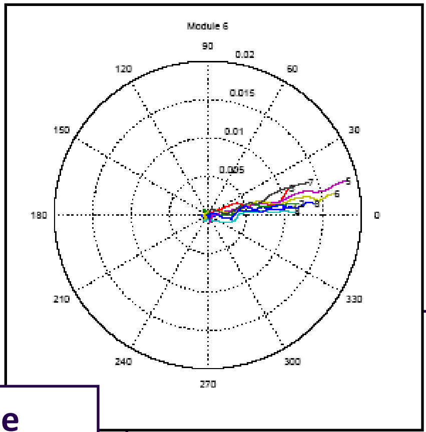
4-cavity insert for AMTF test cryostats; design ready, **construction needs to be started NOW** since the cavity CFT is scheduled for 5/2009

Transport frame; design finished, tests with single cavities is on-going

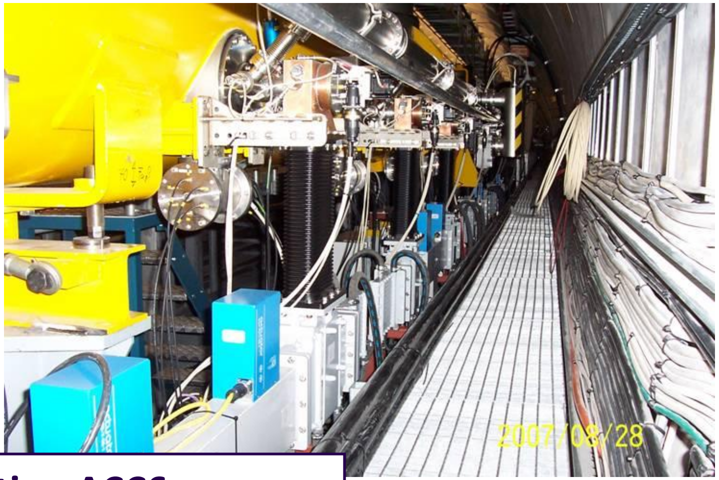


Pre-adjusted Waveguide Distribution

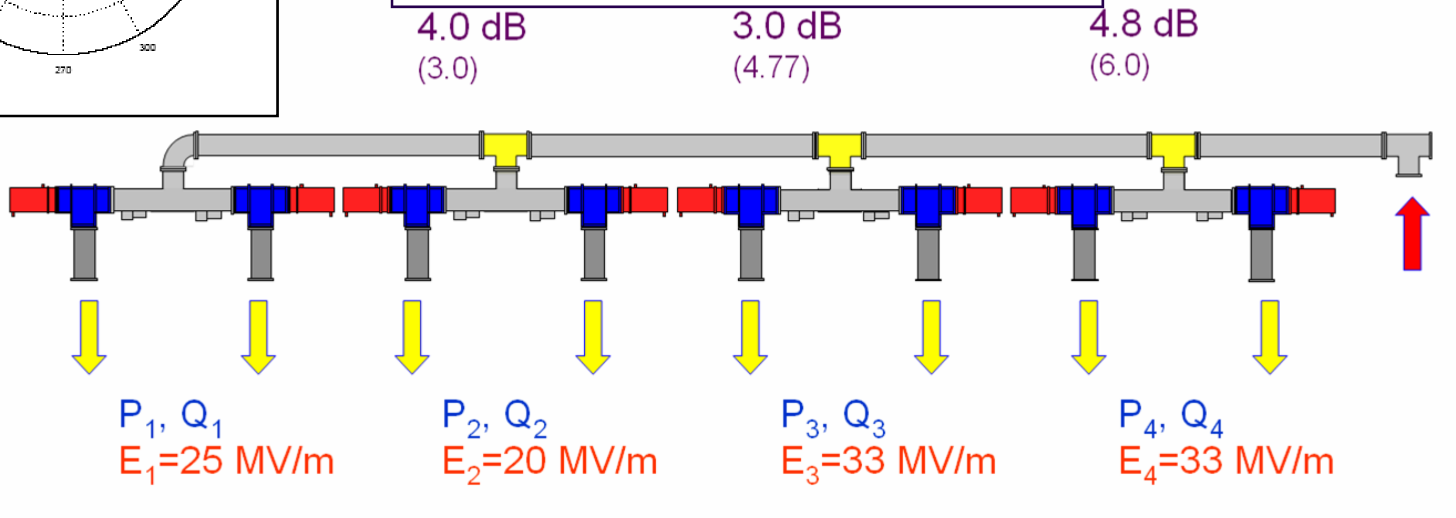
Power distribution and phase distribution for the individual cavities almost perfect



Initial phase distribution



Waveguide distribution ACC6



Klystron and Modulator Prototyping

Toshiba E3736H at Toshiba, Japan

- Factory Acceptance Test in Nasu successfull on August 22/23, 2007
- Klystron arrived at DESY on 18th Sept.
- **Site Acceptance Test at DESY successfull!**

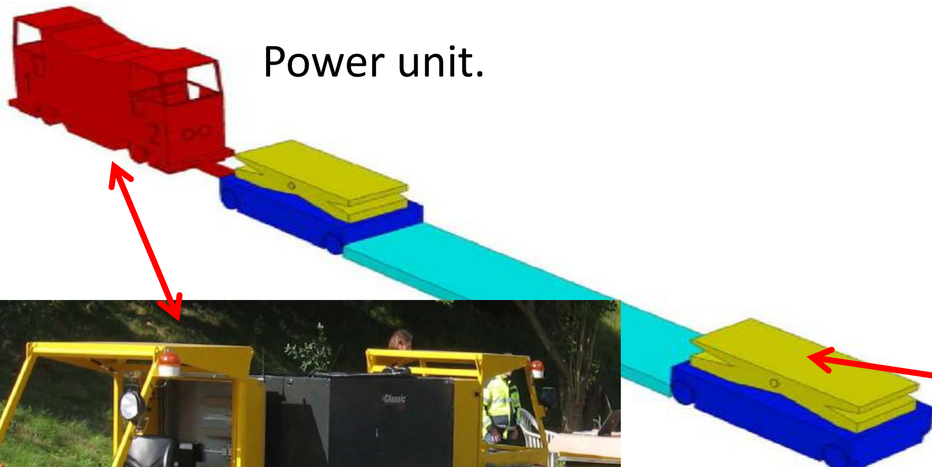
Prototypes from two more manufacturers in near future

Test stand @ DESY, Zeuthen

Prototype from 1st of two companies recently arrived – test program started

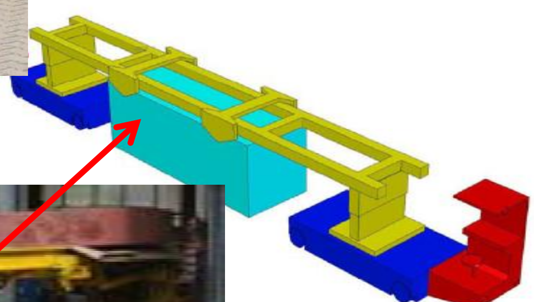
Tunnel Mock-up for Installation Checks

Transportation in the Tunnel

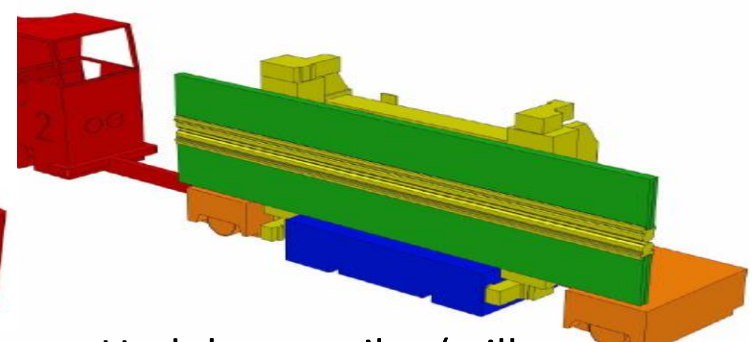


Power unit.

Platform trailer with scissor lifts for accelerator modules.



Load train for e.g. pulse transformers.



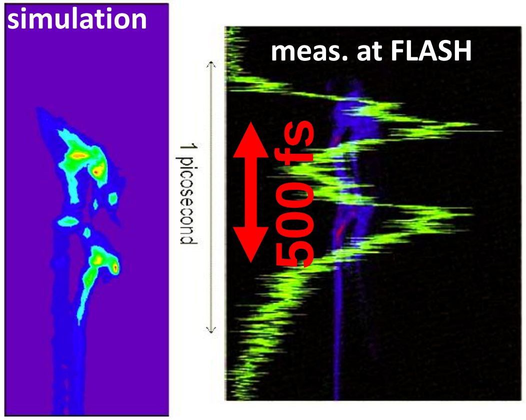
Undulator trailer (still under design).

Other Important XFEL R&D at DESY

- **Injector R&D at PITZ**
  → small emittance, dark current reduction
- **Extensive S2E simulations**
  → Slice emittance at undulators < 1 mm*mrad
- **FEL simulations**
  → SASE1: 0.1nm with wakefields
- **Slice emittance diagnostics**
  → different methods tested at FLASH
- **Timing / synchronisation**
  → diagnostics in fs-regime
- **Beam distribution**
  → Fast intra-train feedback system
  (DESY & PSI cooperation)

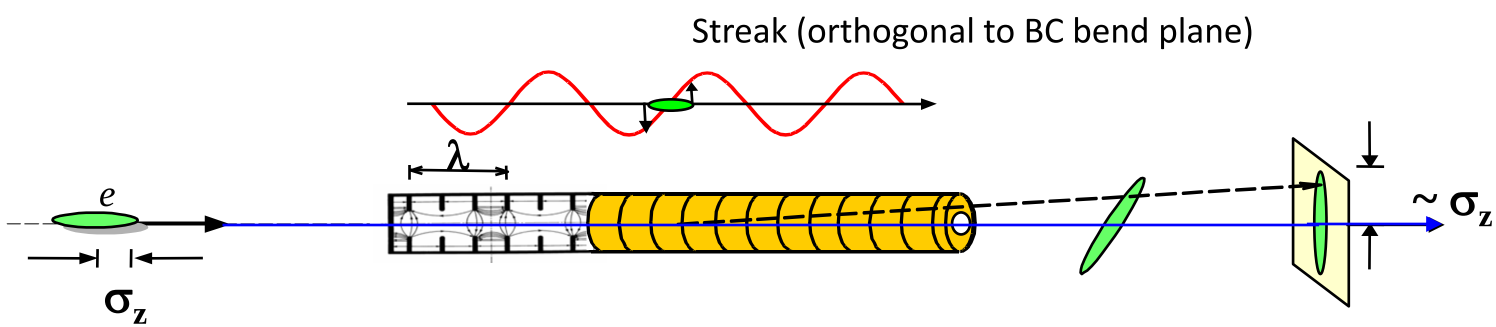
Most of the R&D is done in collaboration between DESY & PhD students from different universities

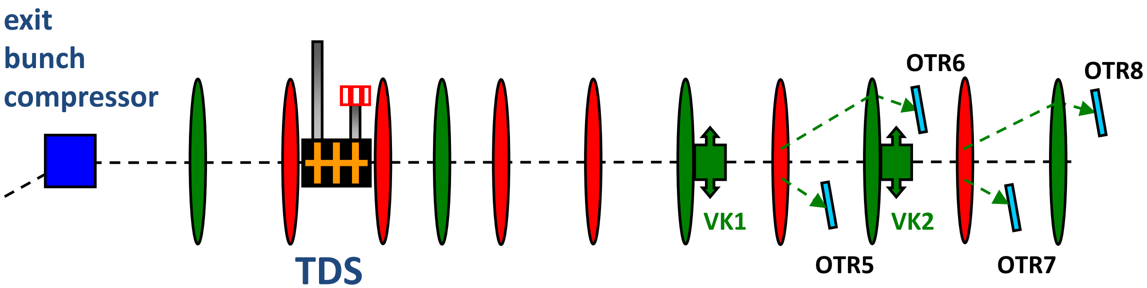
Injector R&D at PITZ



Slice emittance diagnostics

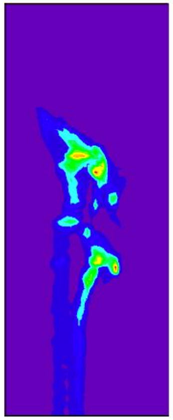
Slice emittance diagnostics



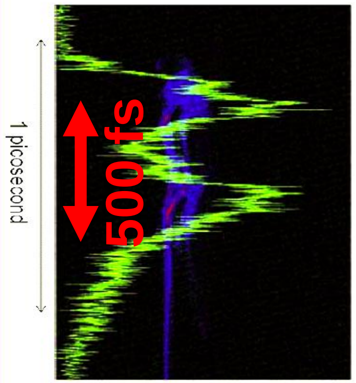


XFEL layout: Single bunches can be extracted from bunch train

→ continuous monitoring of bunch slice parameters



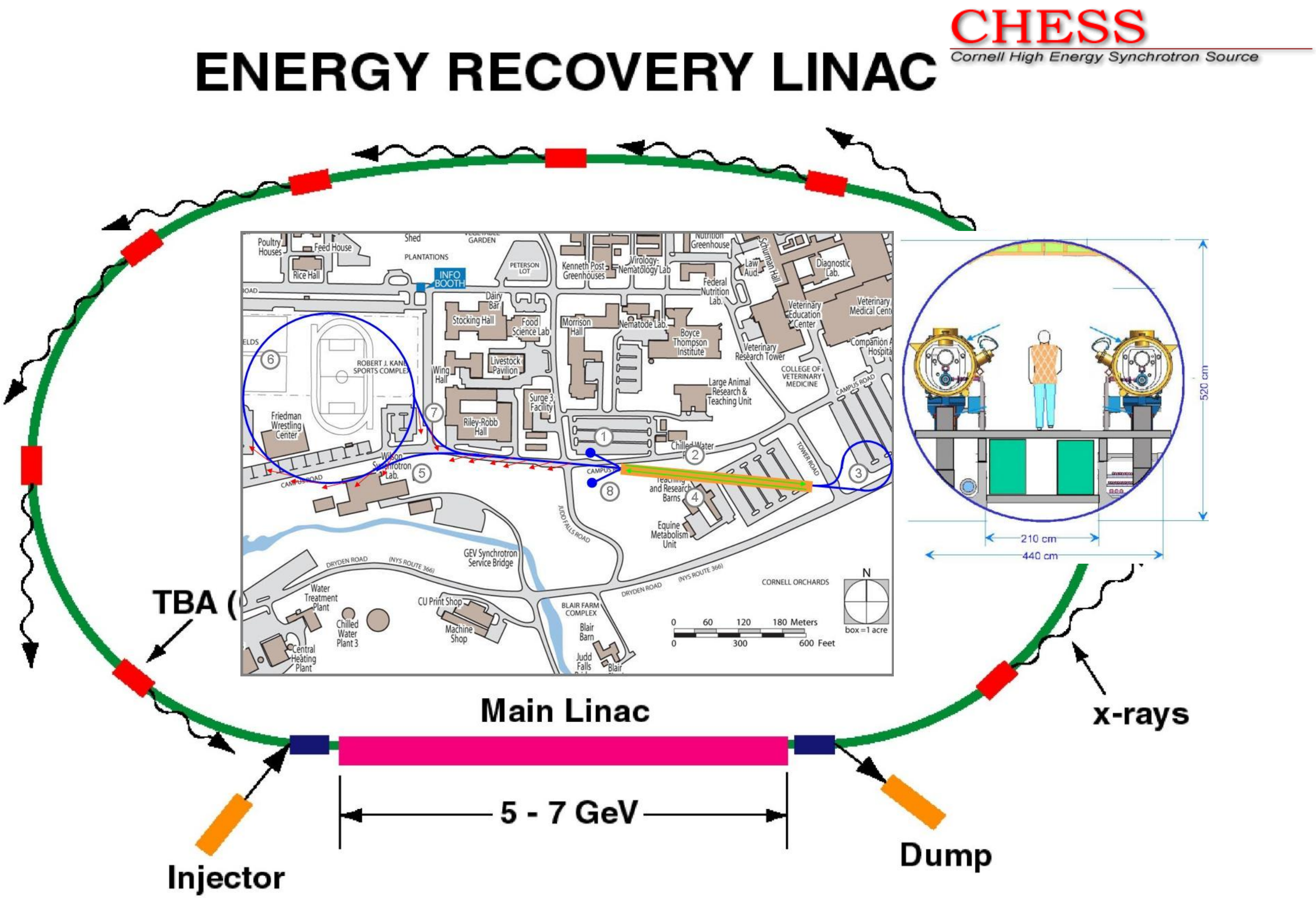
simulation



Example of measurement at FLASH ("LOLA")

M. Roehrs / DESY & Hamburg Univ.

Recirculating Linac at CORNELL



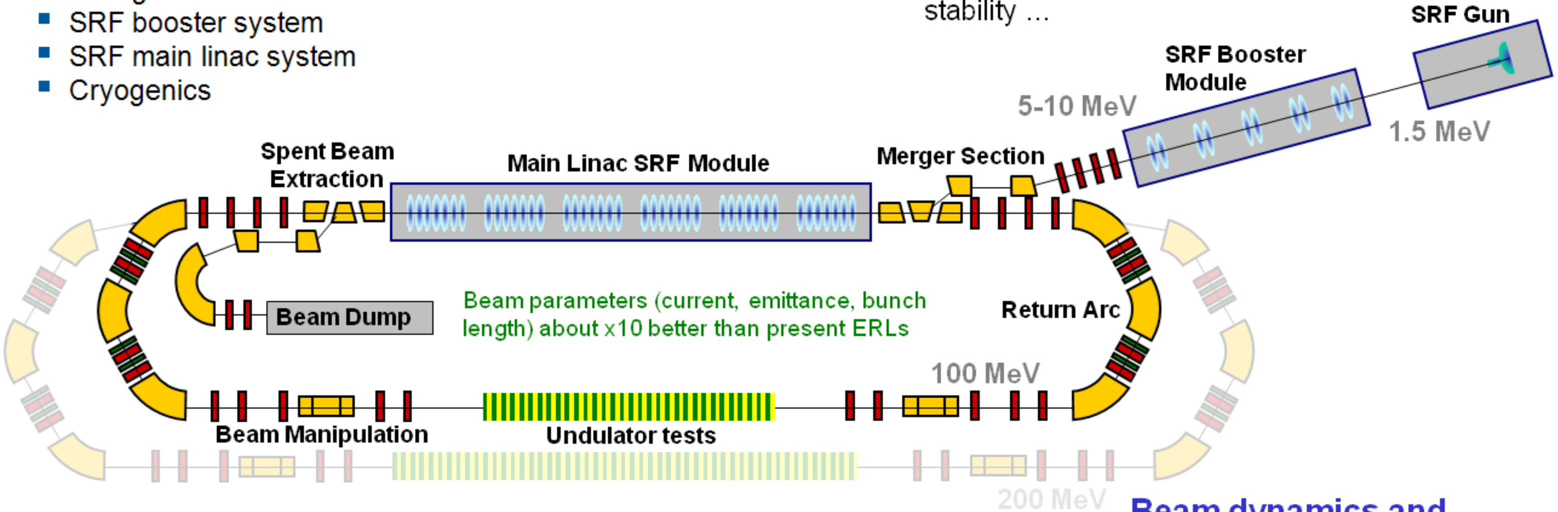
ERL Development in Germany

BERLinPro: Developing and Benchmarking ERL Technology

HELMHOLTZ ZENTRUM BERLIN für Materialien und Energie

Electron source
- Cathode issues, load-lock design …
- Drive laser: pulse shaping, stability, power …
- RF technology: SRF cavity design, HOMs, beam loading, stability …

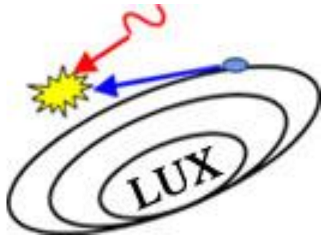
Superconducting accelerating RF structures
- SRF gun
- SRF booster system
- SRF main linac system
- Cryogenics

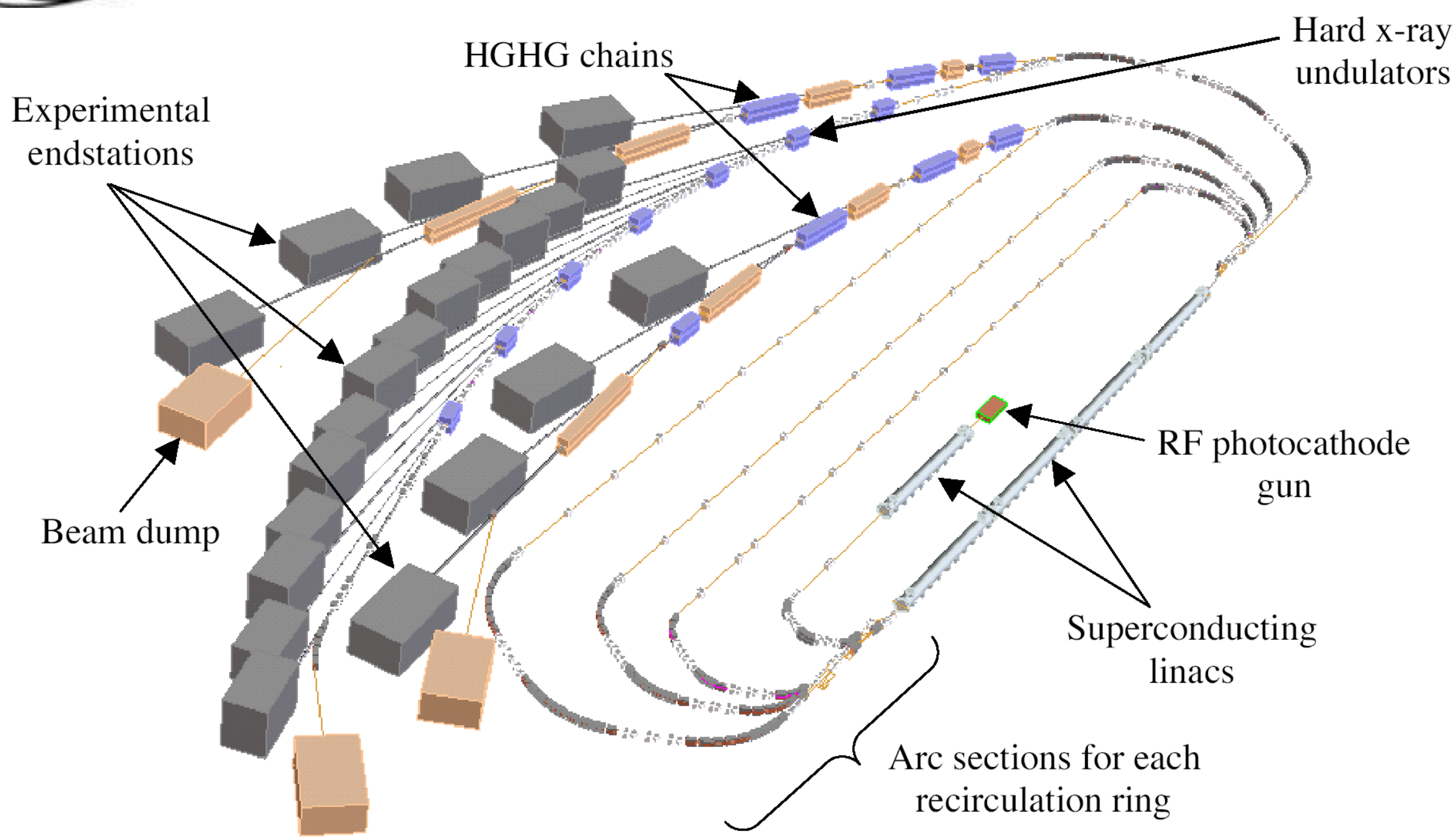


Beam diagnostics
- Small bunch dimensions
- Short pulses
- Slice diagnostics
- …

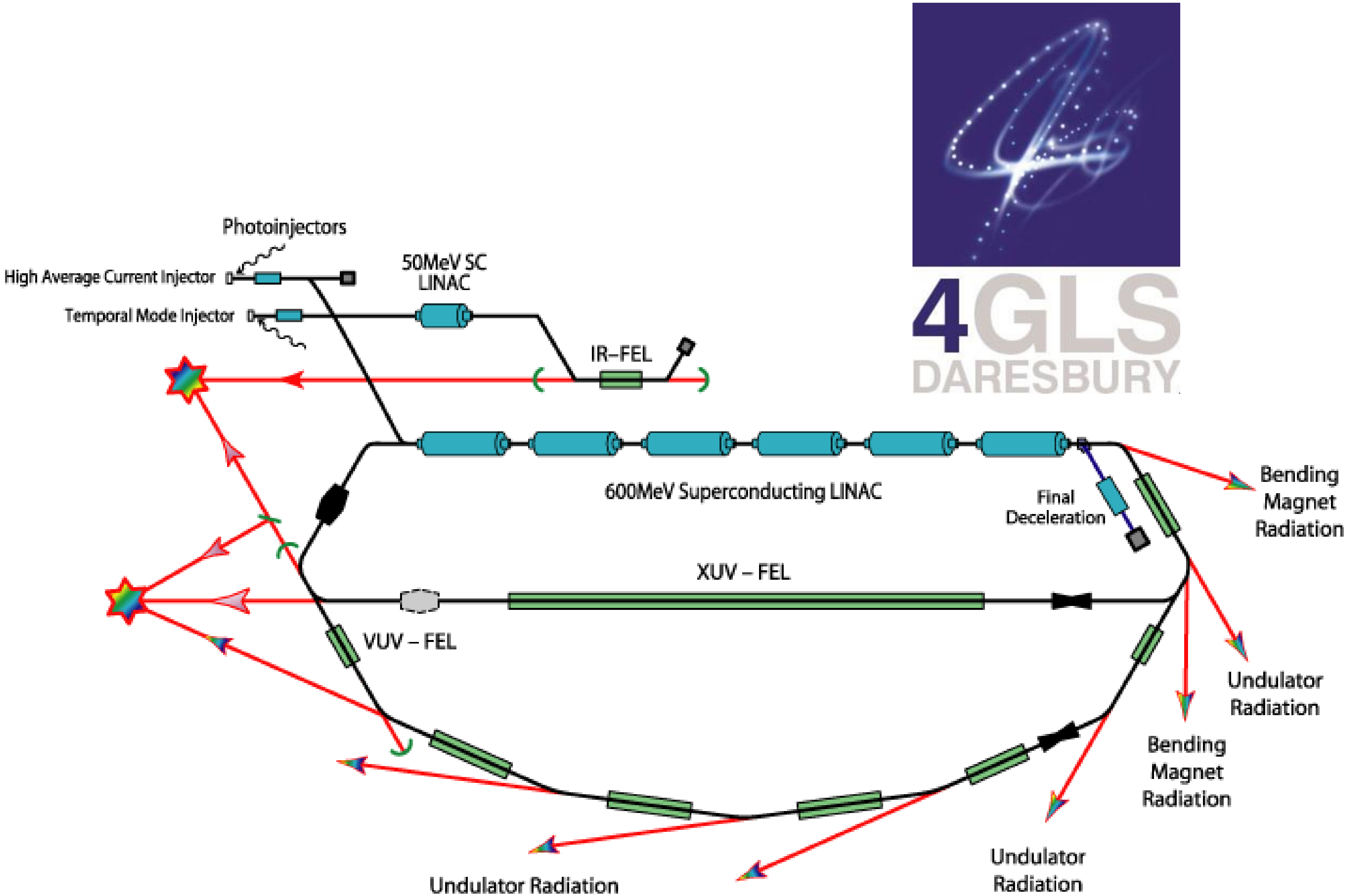
Beam dynamics and recirculation
- Space-charge dominated beam transport: beam brightness preservation
- Beam mainipulation: bunch compression, emittance exchange …
- Muliturn ERL: energy boost, BBU, beam manipulation …

Recirculating Linac at LBL

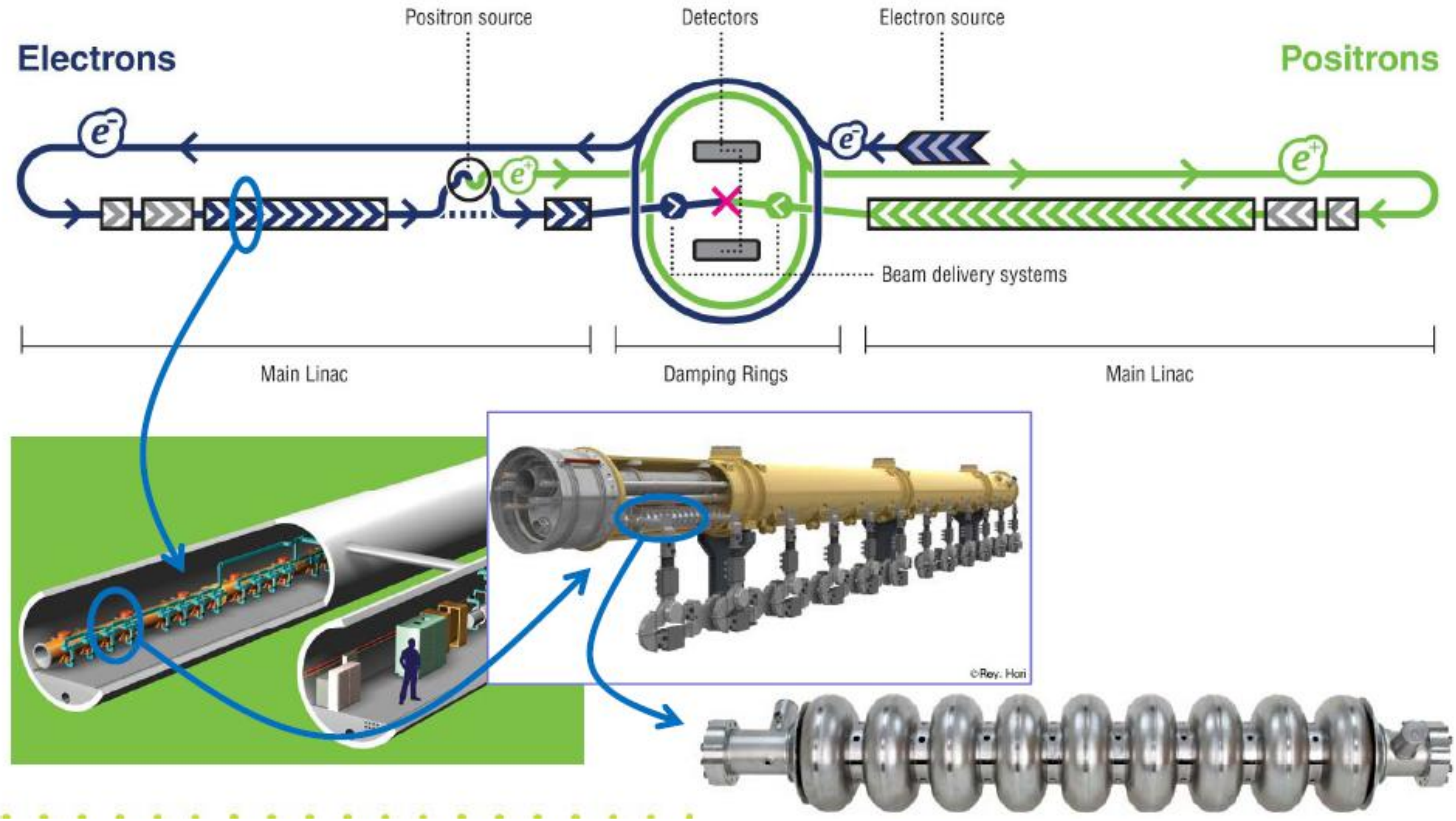




Recirculating Linac at Daresbury

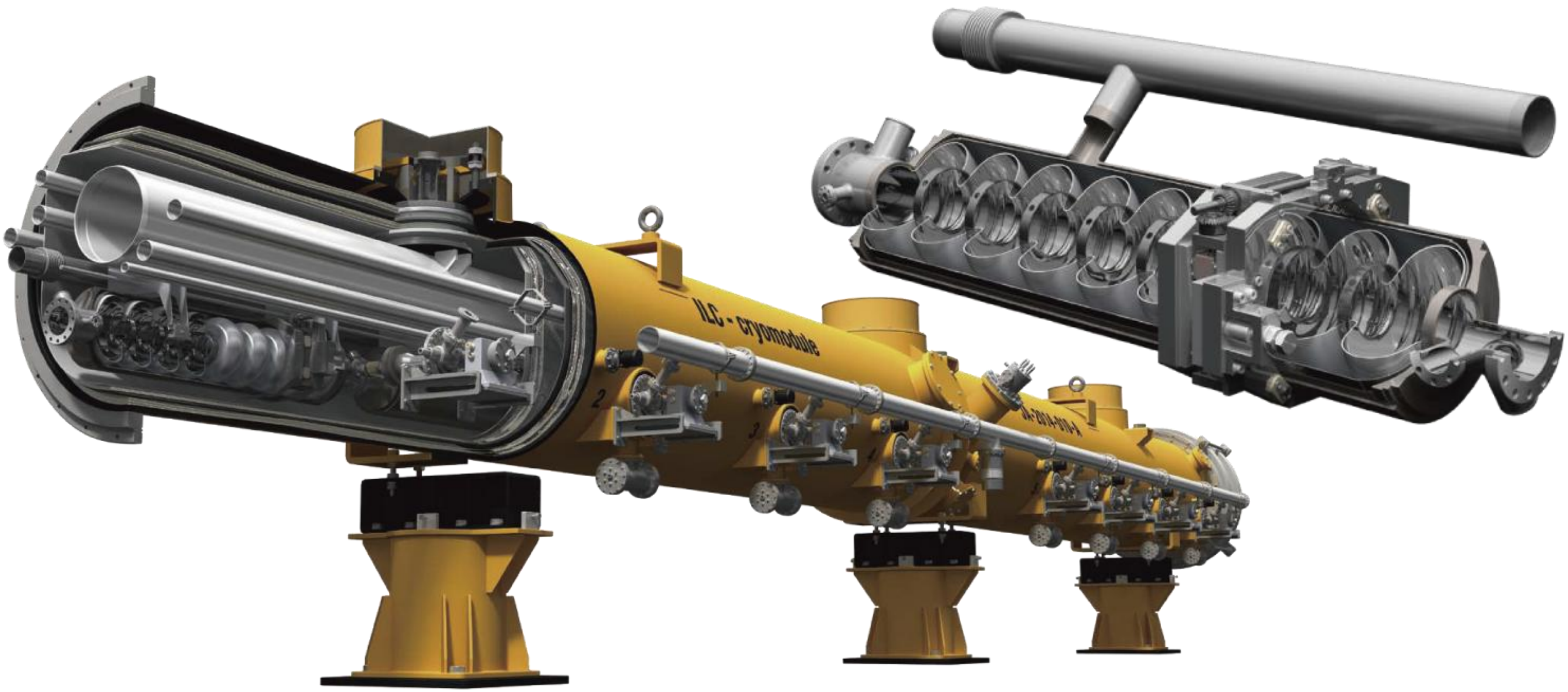


ILC Reference Design



ILC Cryostats and Cavities for Main Linacs

- 1 cryomodule contains 8 cavities + 1 magnet or 9 cavities (Eacc = 31.5MV/m on average, each having a length ~ 1m)



- Total ~1700 cryostats, ~16000 cavities.
- 3 cryostats to be driven by one 10MW L-band klystron
- Total 560 RF units in e+/e- main linacs

srf2009.helmholtz-berlin.de

SRF Conference: Sept 20-25, 2009 in Berlin

SRF Tutorials: Sept 17-19 in Dresden

- Fundamentals of Superconductivity
- Basic Principles of SRF
- High-beta cavity design
- Low-beta cavity design
- SC cavity materials and fabrication
- Cavity preparation and performance limits
- LLRF control systems
- High power and HOM couplers
- RF power sources
- Simulation tools
- Operational aspects of SRF with beam
- Cryomodule design
- He liquefiers