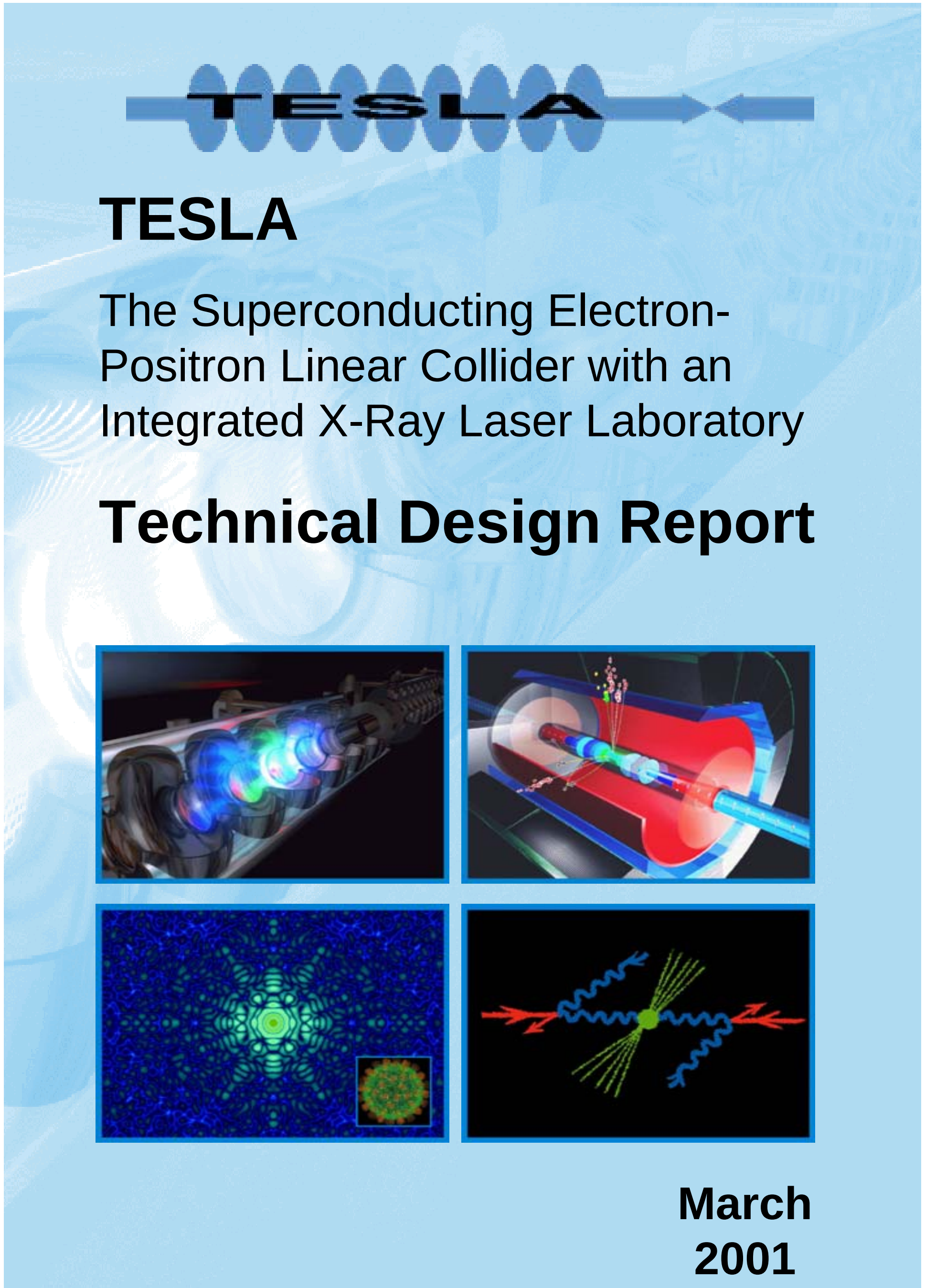
11th WORKSHOP ON RF-SUPERCONDUCTIVITY
SRF 2003
8. – 12. September 2003
LÜBECK/TRAVEMÜNDE MARITIM - STRANDHOTEL

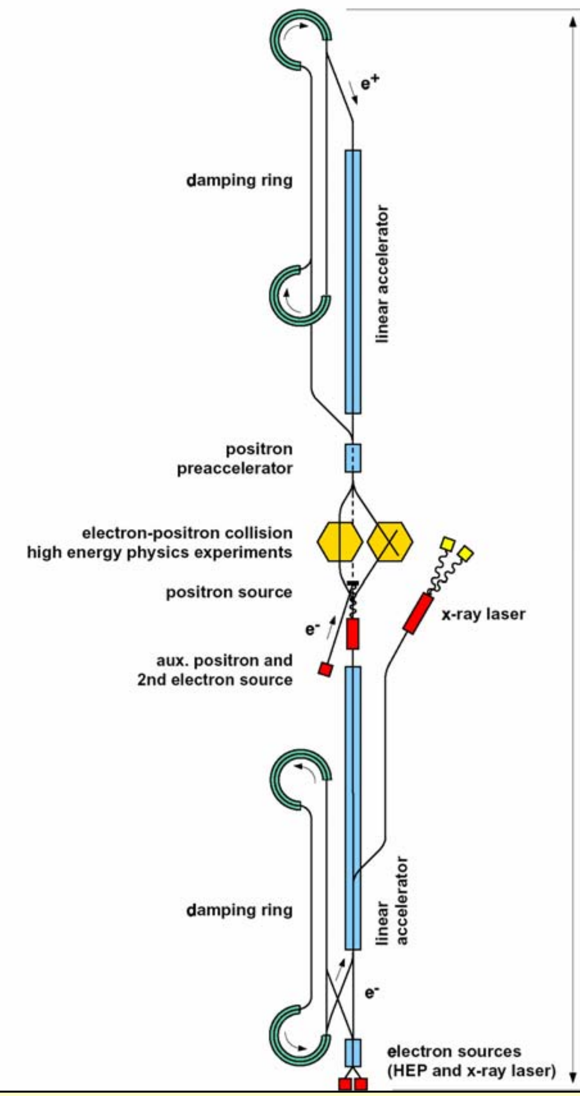
The four-masted barque PASSAT was one of the famous flying P-Liner and sailed Cape Horn not less than 39 times. Today the PASSAT is anchored as museum ship in Travemünde opposite of the MARITIM-Hotel.

The X-Ray FEL at DESY

Hans Weise / DESY

TESLA





integrated into TESLA LC:

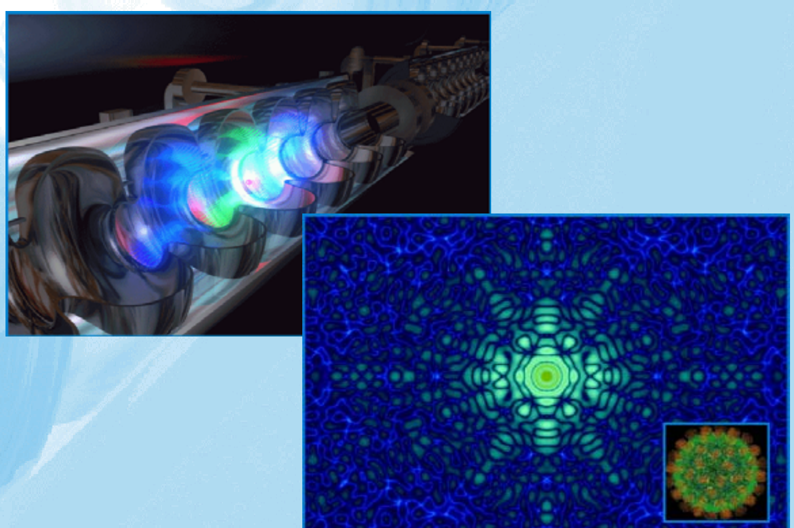
using part of e- linac, two extraction points, long beam transfer → cost effective but less flexible solution

TESLA XFEL

First Stage of the X-Ray Laser Laboratory

Technical Design Report

Supplement



October 2002

TDR update 2002:

XFEL driver linac separate from LC

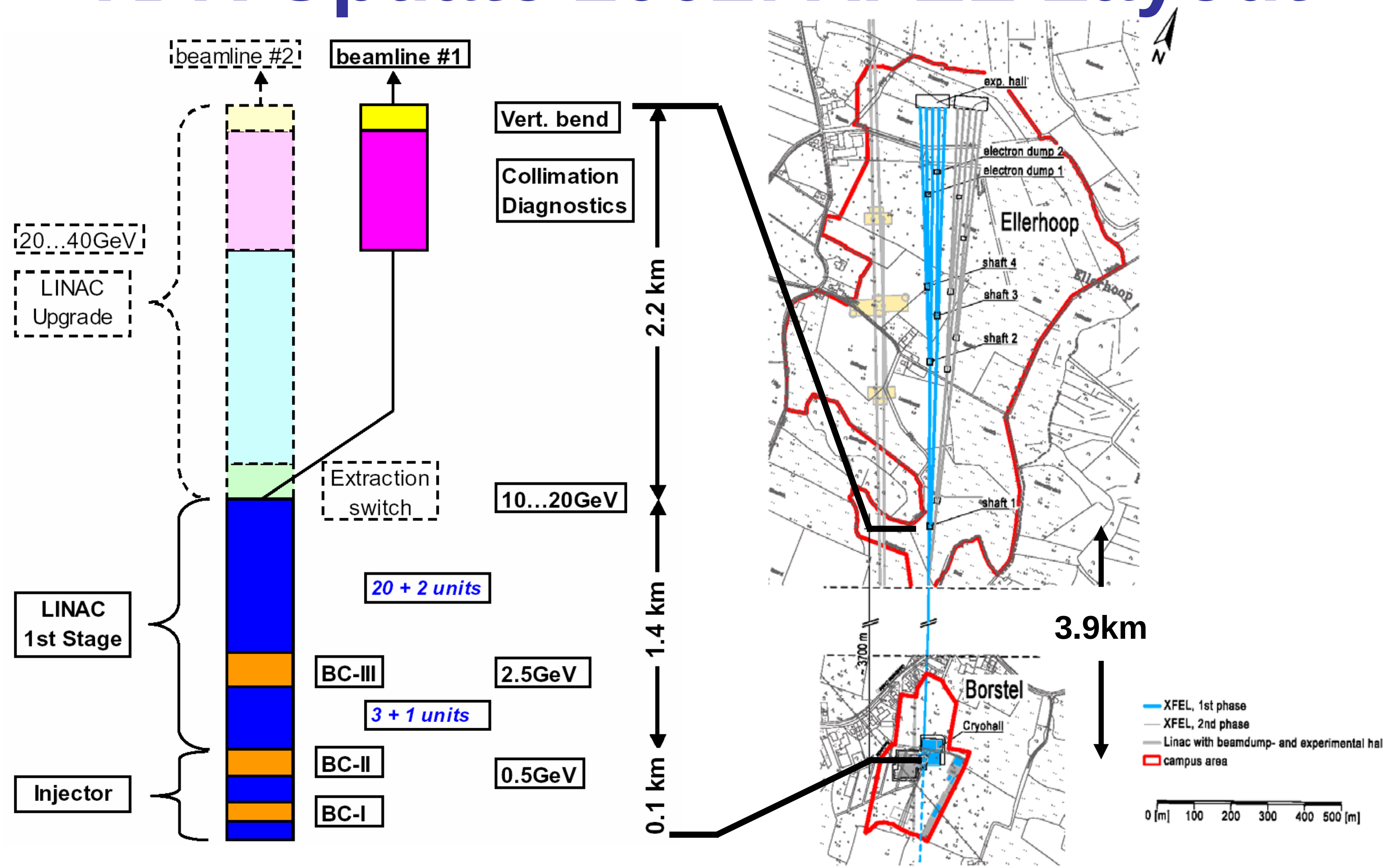
→ de-coupling of LC-XFEL regarding construction & operation (and: ***approval***)

- maintaining common site
- identical linac technology
- detailed analysis of potential gain in flexibility was not included in the update

Remark:

cost increase w.r.t. TDR2001 limited by reduction of energy to 20 GeV (*First Stage of ...*) and by a reduced number of photon beamlines 10 → 5

TDR Update 2002: XFEL Layout



XFEL Key Parameters

Lower beam energy can be compensated easily:

Slightly lower emittance and slightly modified undulator.

	E_b [GeV]	ε [10^{-6}m]	σ_E [MeV]	I_{pk} [kA]	λ_U [mm]	K_U	gap [mm]	L_{sat} [m]	L_{tot} [m]
TDR2001	25	1.6	2.5	5	45	4	12	210	311
Update02	20	**1.4**	2.5	5	**38**	**3.8**	**10**	**145**	**213**

Present work: starting from TDR-update, develop a guideline for detailed project definition to start construction in ~2 years.

Basic Assumptions for the Linac Specification

- Linac has to deliver a beam energy of 20 GeV at a gradient close to 23 M/m; the corresponding linac length represents the final stage, i.e. higher energy reach comes from better cavity performance

  The “trend”: arguments towards higher beam energy become weaker

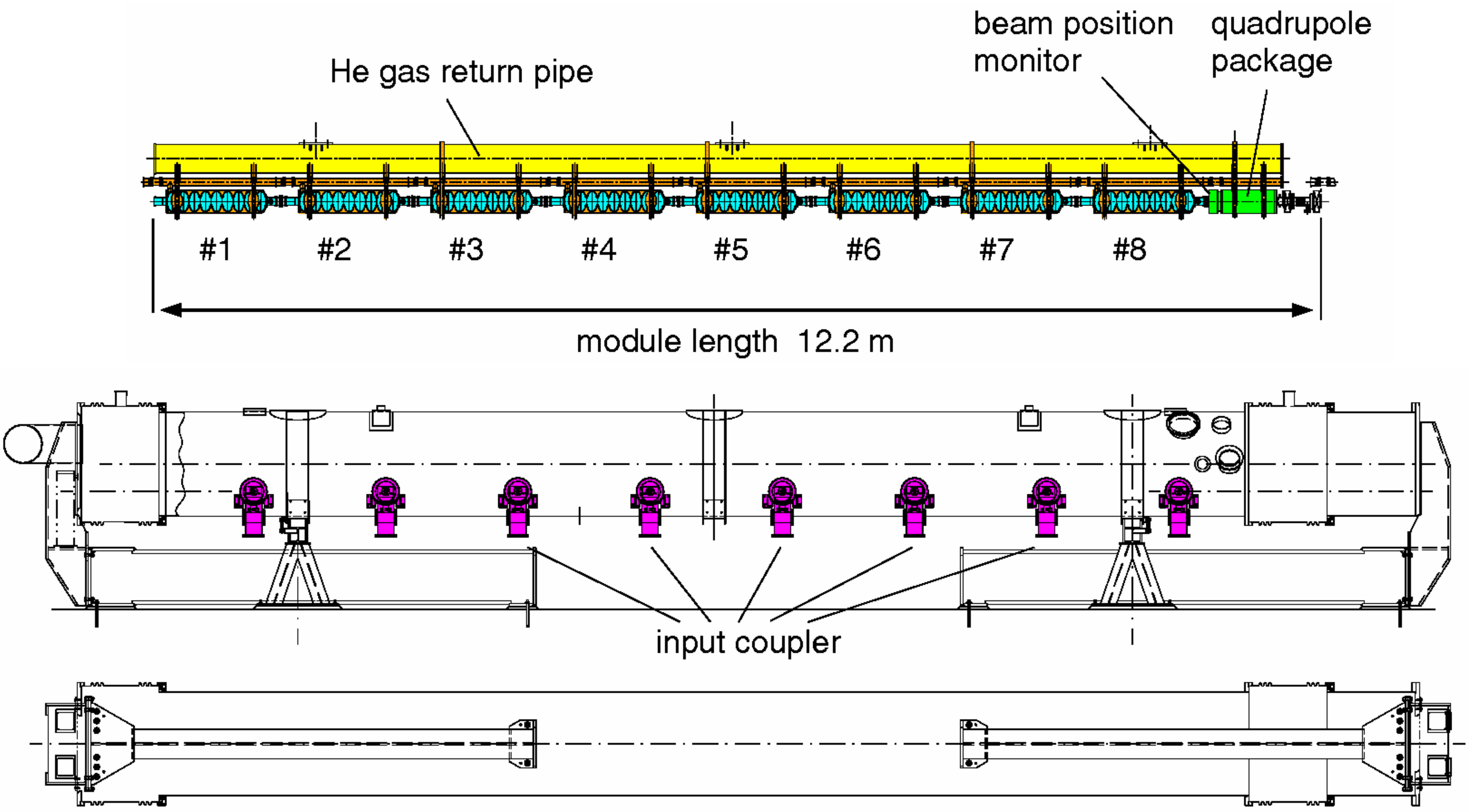
  - more aggressive undulators
  - better beam quality (careful: we haven’t seen the 1.4 mm mrad …)
  - higher harmonics generation

  This together with recent achievements in cavity performance makes the linac length extendibility hard to justify (cost!).
- Linac to be constructed in TTF-like technology:

  12m modules with 8 cavities + quad package (exact length, cavity spacing, magnet specifications to be reviewed)
- Limit average beam power to ~600 kW

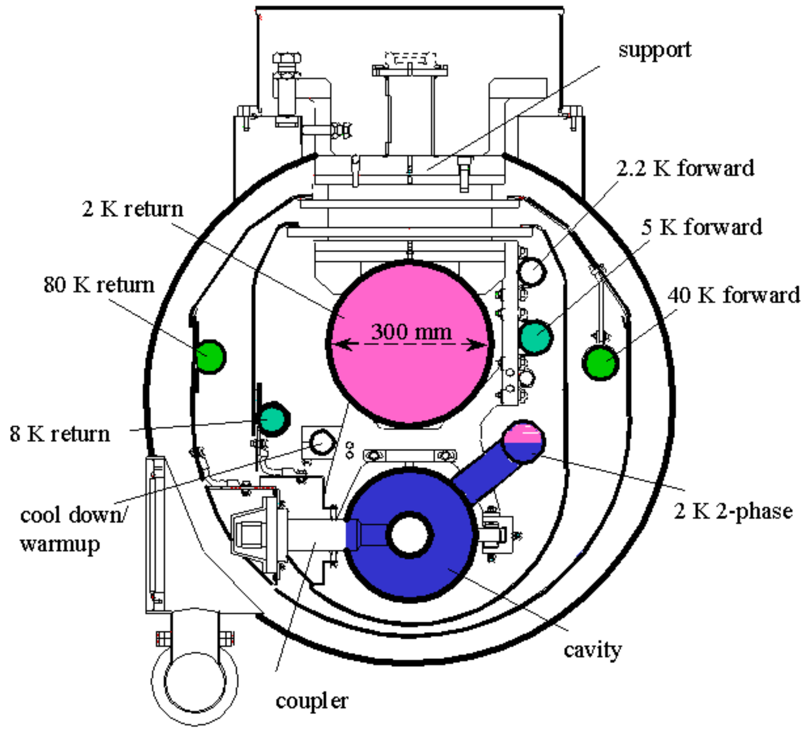
  (two solid state beam dumps in the 1^{st} stage, 300 kW each)

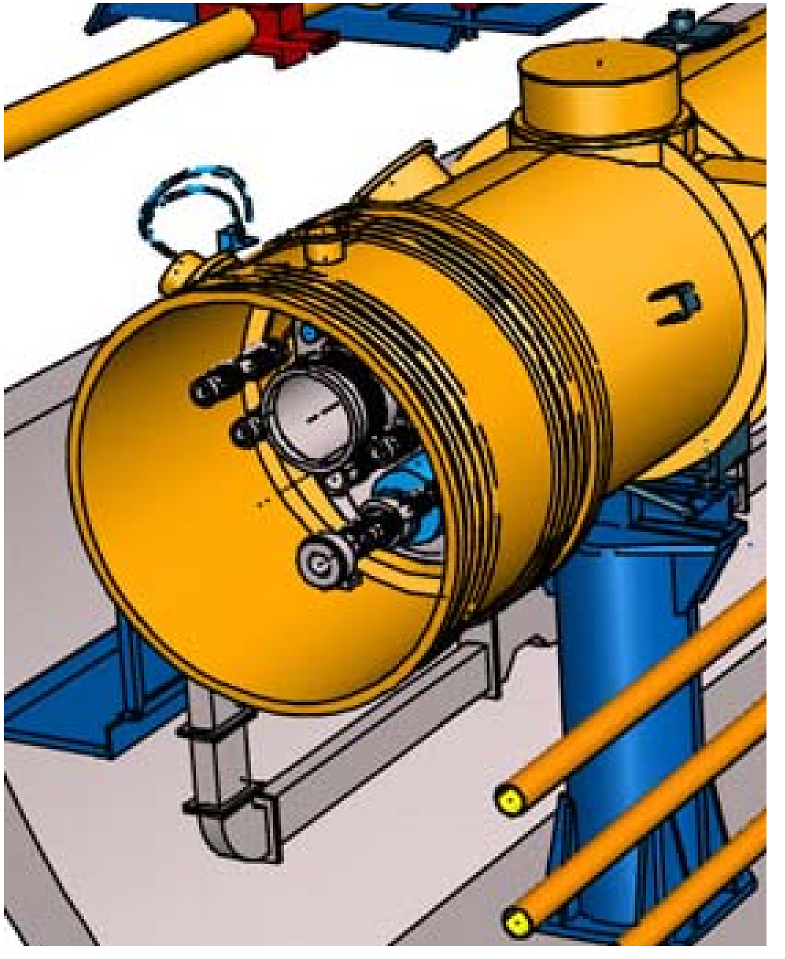
TTF Linac Accelerator Modules



TTF Linac Accelerator Modules

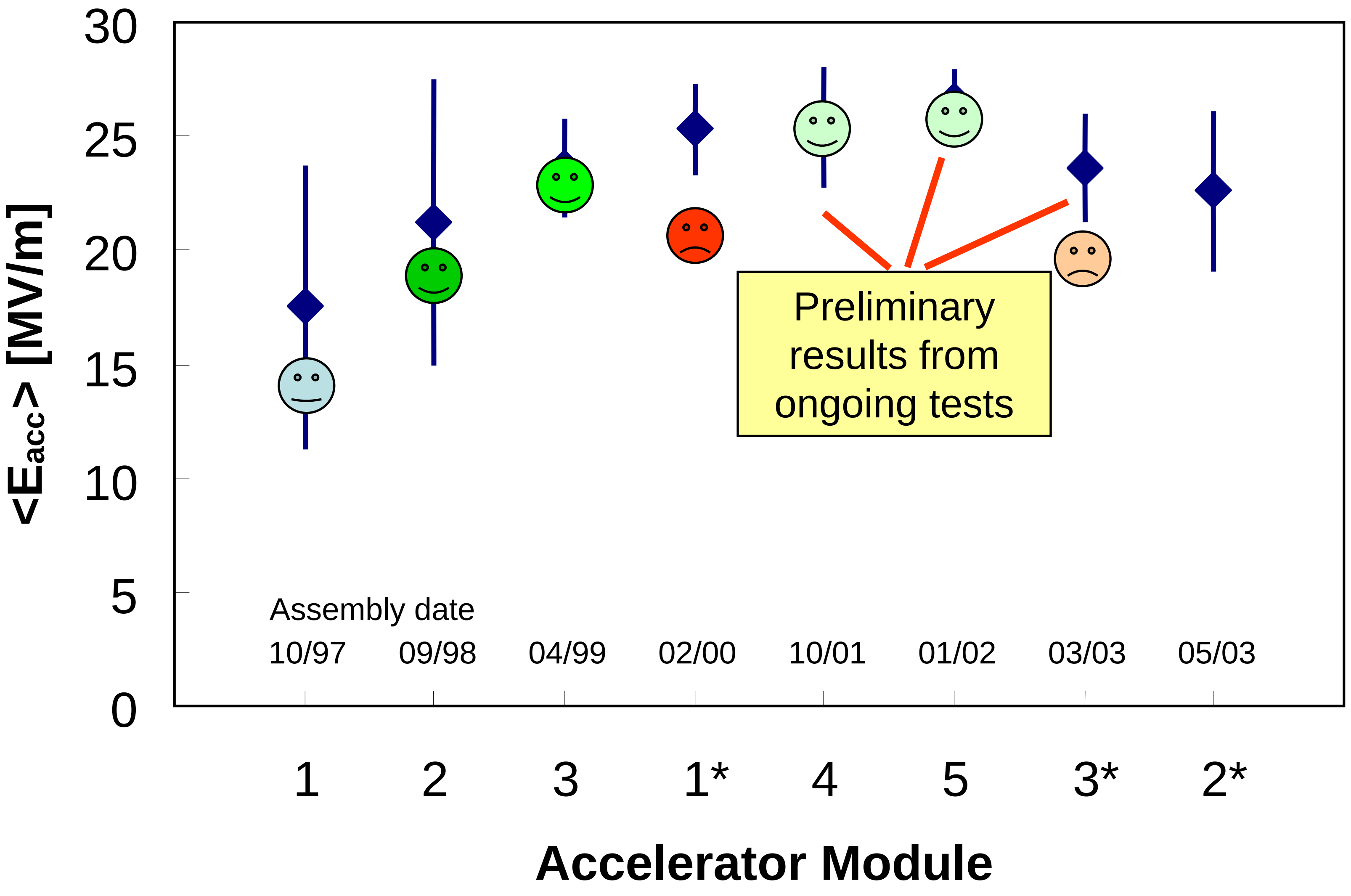
New Type as XFEL Prototype (modules #4 and #5)



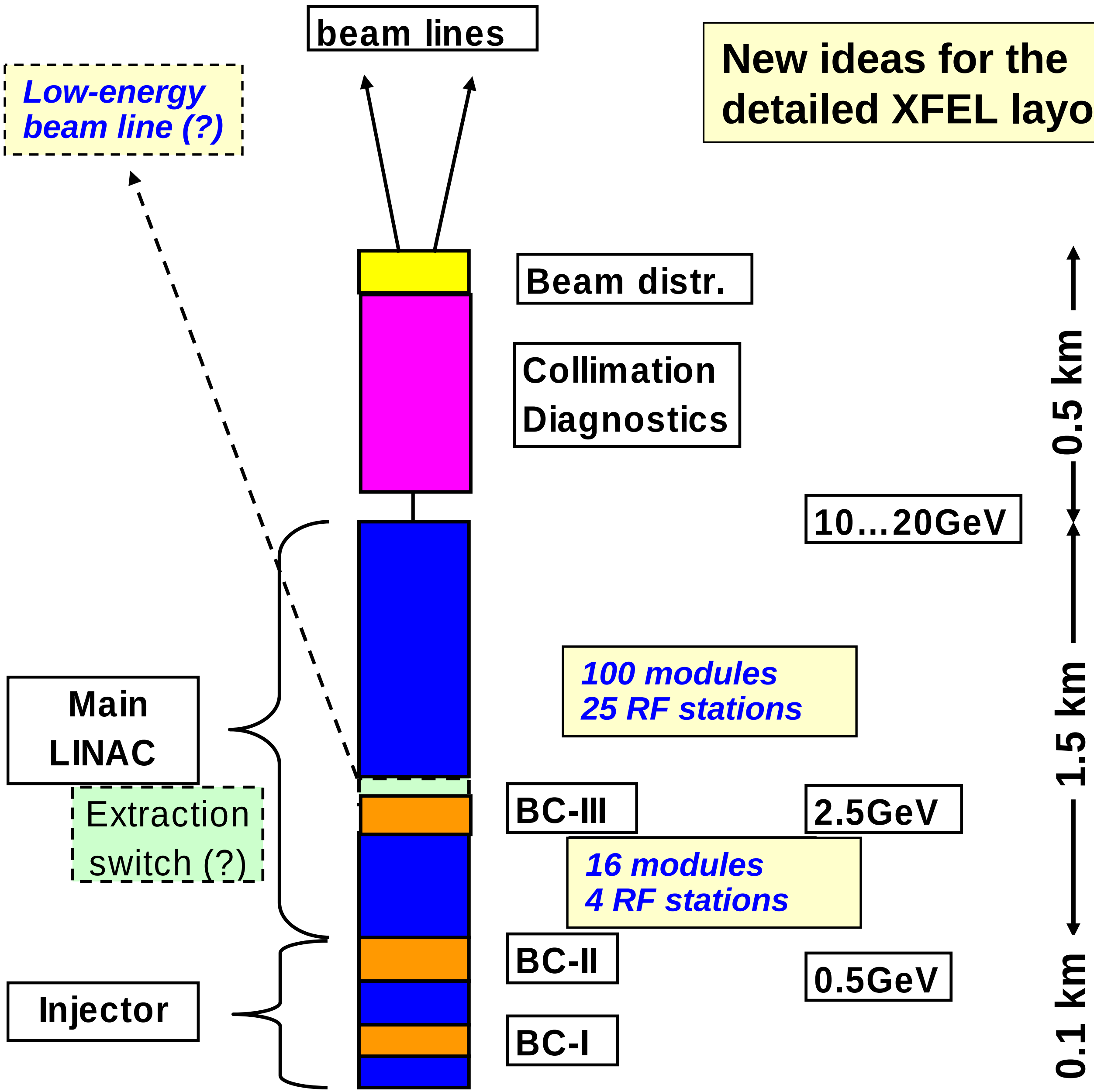


- **Reduced diameter**
- **New concepts accomodate for long. shrinkage during cooldown**

Gradient of Accelerator Modules



New ideas for the detailed XFEL layout



Reference Parameter Set

Main linac Section 2	
Energy gain	2.5 → 20 GeV
# installed modules	100
# active modules	92
acc gradient	22.9 MV/m
# installed klystrons	25
# active klystrons	23
beam current	5 mA
power→beam p. klystron	3.8 MW
incl. 10% + 15% overhead	4.8 MW
matched Q_{ext}	$4.6 \cdot 10^6$
RF pulse	1.37 ms
Beam pulse	0.65 ms
Rep. rate	10 Hz
Av. Beam power	650 kW

4 modules (32 cavities) per klystron.

two spare rf stations.

10% for phase / amplitude ctrl.

pulse structure to be defined.

Reference Parameter Set

Main linac Section 1	
Energy gain	0.5 → 2.5 GeV
# installed modules	16
# active modules	12
acc gradient	20.1 MV/m
# installed klystrons	4
# active klystrons	3

4 modules (32 cavities) per klystron.

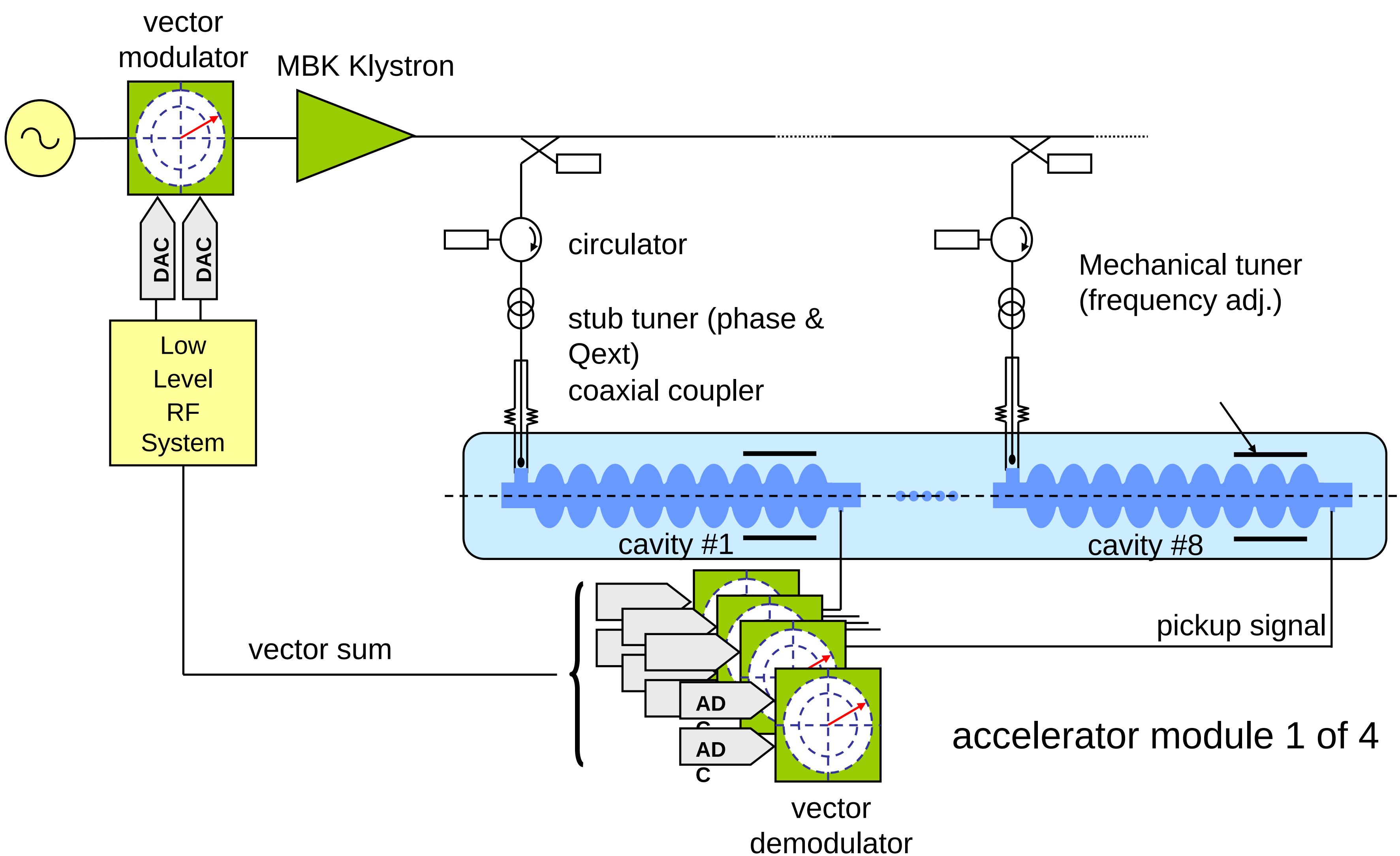
one spare rf station.

Comment 1: energy management in case of failure requires reserve RF unit in both section 1 and 2 of the main linac. The 2.5 GeV energy at BC-III is important for the bunch compression.

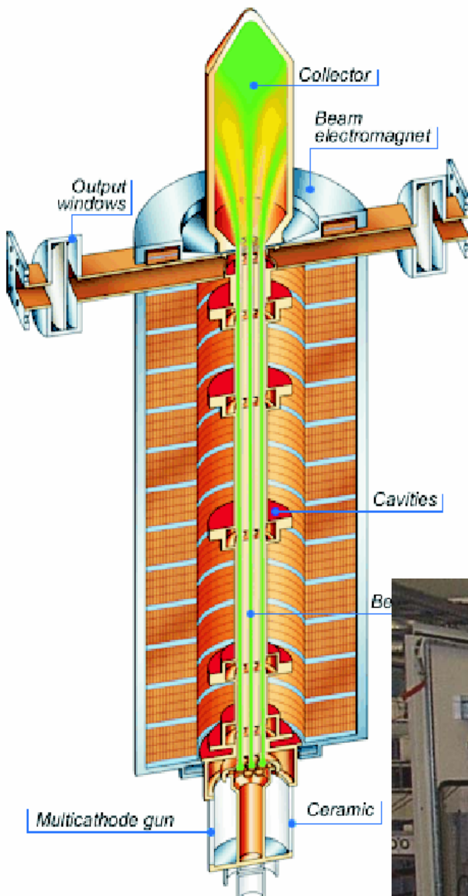
Comment 2: lower gradient in section 1 can be advantageous in view of desirable flexibility (see below) with respect to rep.rate.

XFEL RF Unit

1 klystron for 4 accelerating modules, 8 nine-cell cavities each

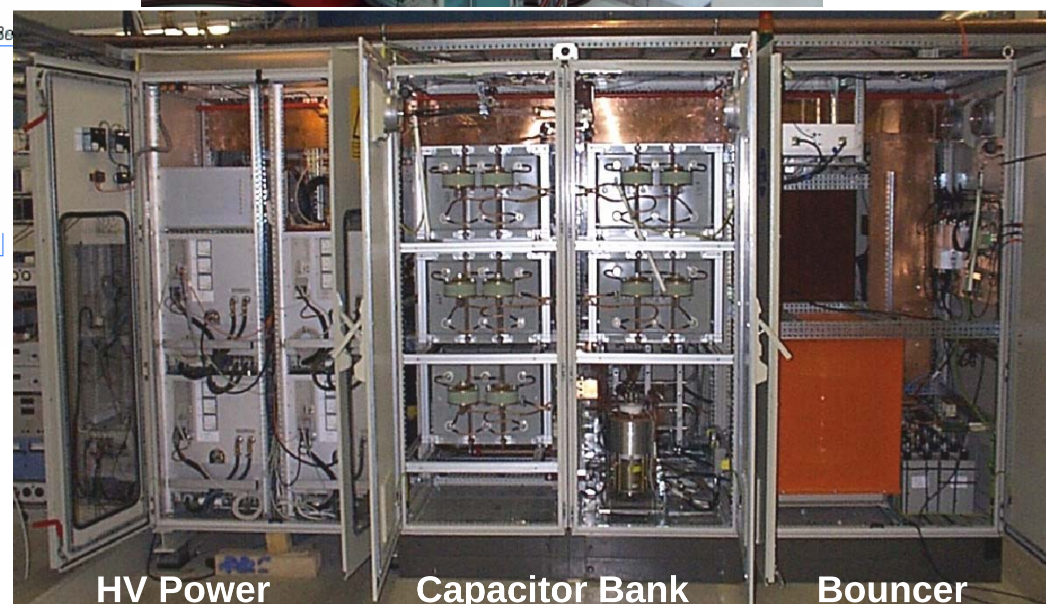


TTF High Power RF

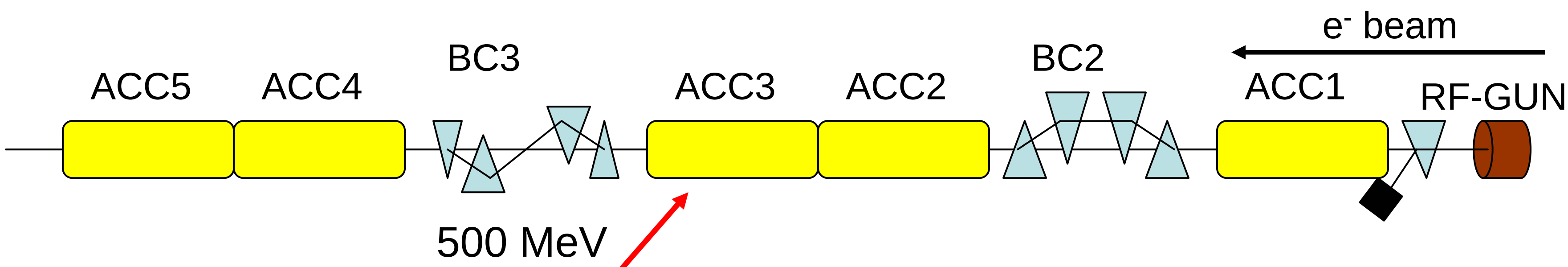


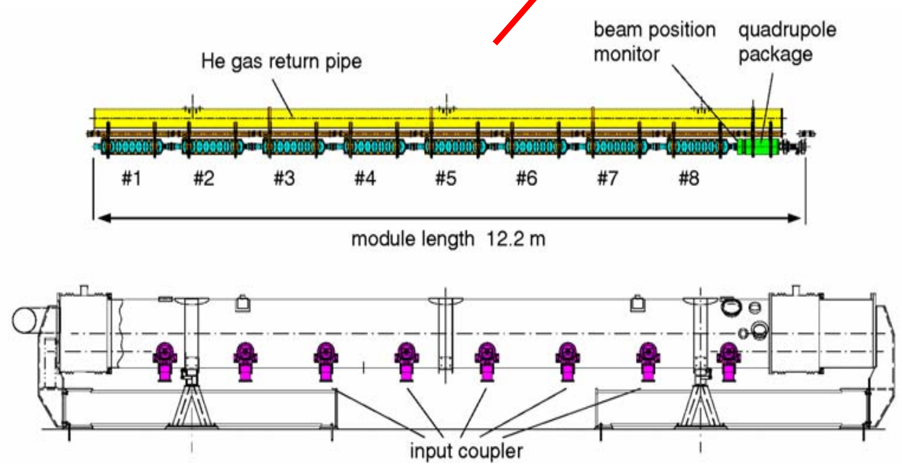
TH1801
Multi-Beam
Klystron

IGCT Stack



TESLA Test Facility Linac as Prototype for the XFEL Injector





Party Line Towards Full Project Specification: what we will *not* do

- **Go from pulsed linac to *CW operation* as baseline design**
  - 20 GeV linac would require cryogenic plant ~3 times the capacity of entire 500 GeV LC
  - He distribution would have to be drastically modified
  - Concepts exist, but to date CW beam source is not available
- **Develop 17m module with *superstructures***
  - Relation between R&D effort and gain in fill factor is not reasonable for a ~1.5 km long linac
  - Cost saving on RF couplers must be balanced against investment in cavity treatment infrastructure and time delay for acc. module specification
- **Maintain the common *LC and FEL site***
  - No green light from government for an LC site near Hamburg at this point in time; process in international community towards LC technology decision, international funding and site decision likely to take several years
  - Synergy / cost saving arguments for Ellerhoop site can't be used anymore to push the plan approval procedure through

Party Line Towards Full Project Specification:
what we ***should*** do: cost analysis

Example: Klystrons / RF stations

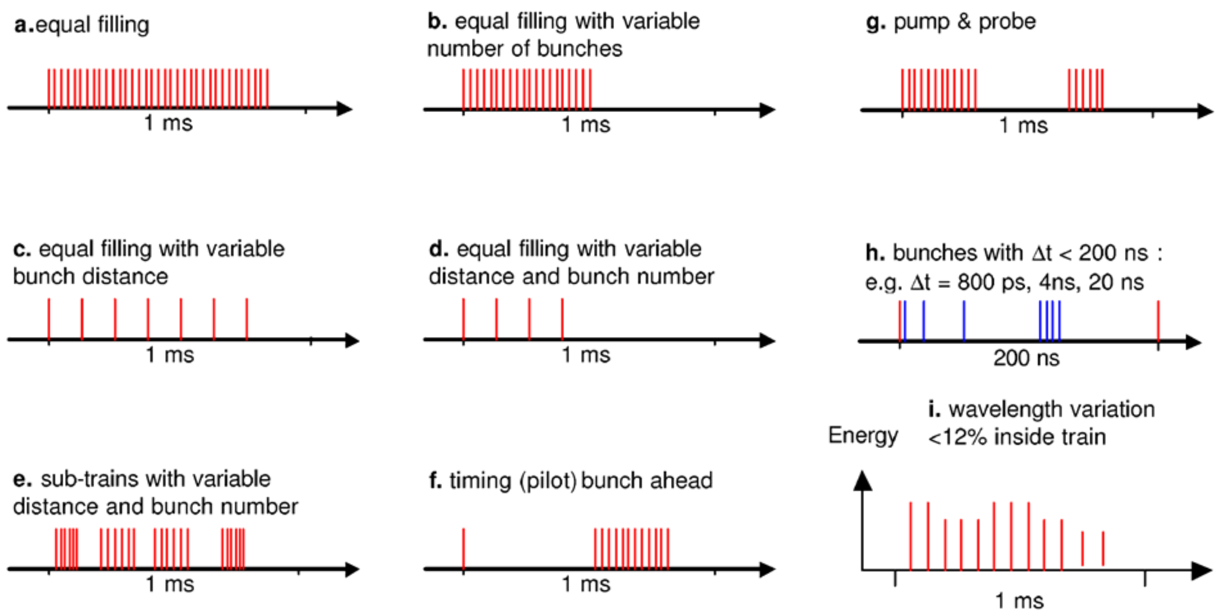
- To meet reference parameters, in principle 5MW klystrons are sufficient → potential cost saving on R&D and final investment
- Alternative: Keep the 10MW MBK, but reduce # of RF stations
  - Model for (crude) estimate scaled from TDR-update cost figures:
  - **0.9 M€** per 12m accelerator module
  - **1.8 M€** per 10MW RF station driving 36 cavities
  - Assume ***75%*** of RF cost ∝ ***# of klystrons***, ***25%*** ∝ ***# of cavities***

Compare two options: (1) 6 modules/klystron and
(2) 8 modules per klystron
(3) with reference 4 modules per klystron

somewhat surprising result, reason being inevitable need for reserve stations… (1) and (2) are cheaper than (3)
but also (1) is cheaper than (2)

Parameter Flexibility

User requirements still need to be reviewed / discussed,
but one trend seems to go towards flexibility in beam timing Structure.



Single bunches.
Few bunches.
Long trains.

Sub-trains with **variable distance / bunch number**.

The s.c. linac will take care of it.

<u>But</u>: **Duty cycle, i.e. Repetition Rate ???**

<u>Impact on</u> ***RF Gun laser***
RF & LLRF
cryogenics

Duty cycle limitations: Cryogenics

- LC TDR layout for module / He distribution allows for an upgrade to 800 GeV (∅ He Gas Return Pipe, pressure drop)

  At ~23 MV/m, the 1.5km linac (2.5 GeV → 20 GeV) could be operated up to about 20 Hz rep rate (~2% duty cycle)

- Required cryogenic plant would have approximately the size of ***one*** of the six TESLA-500 LC plants
- From cryogenics point of view, one could use the scaling law

duty cycle $\propto$ 1/energy^2

Duty cycle limitations: RF system

- present design of modulator / klystron station can operate at max. 10 Hz, 10MW, 1.4ms pulse length, 65% max. efficiency (average power ***into*** klystron ~220kW)
- Higher duty cycle at lower peak power possible
  average power into klystron gun is kept ≤ 220 kW
  (careful: DC→RF efficiency drops at lower power!)
  concerns: IGCTs at high rep rate, RF drive power
- Scale

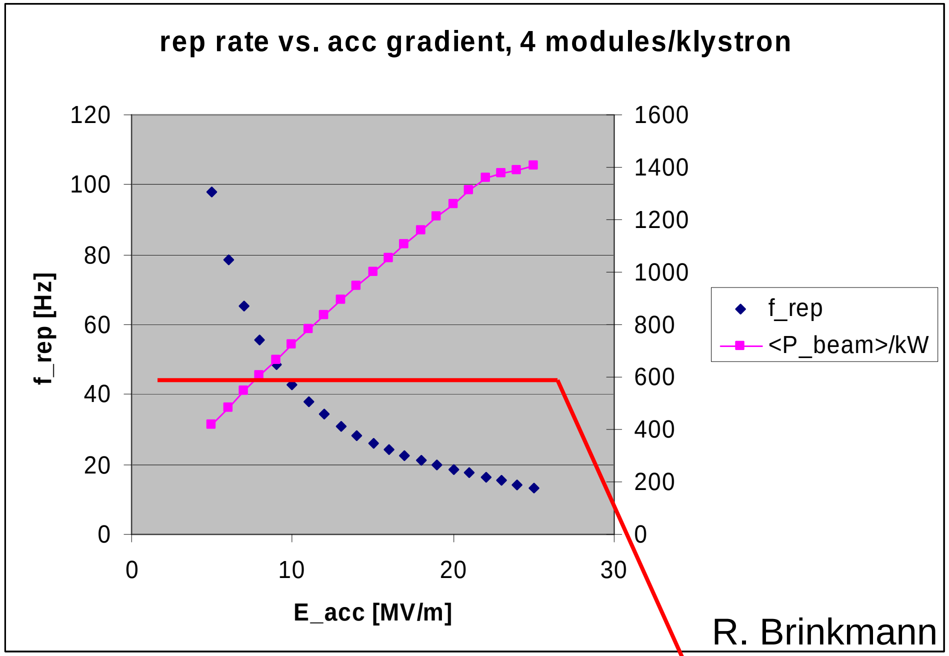
  beam pulse current with acc. gradient (i.e. energy)
  the loaded Q_{ext} remains constant

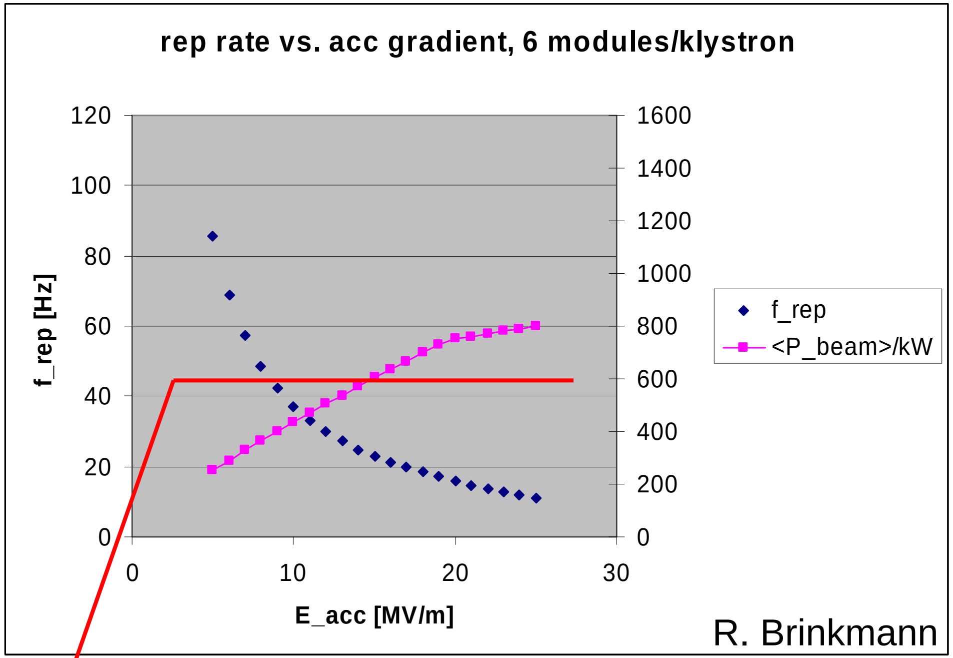
- or optimize

  for constant beam current which requires
  a variable Q_{ext}

Max rep. rate and beam power, 4 vs. 6 modules / klystron

Calculation includes klystron efficiency, scale beam current during macro pulse with gradient, and aims for maximum possible beam power.



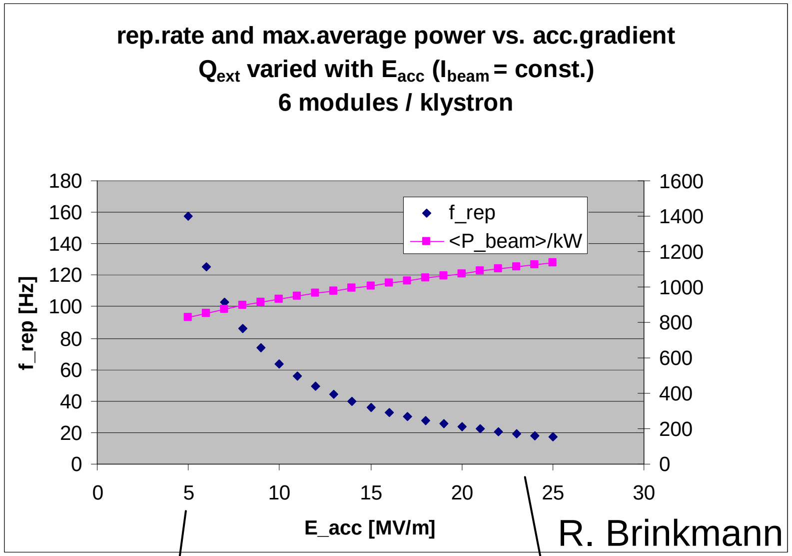


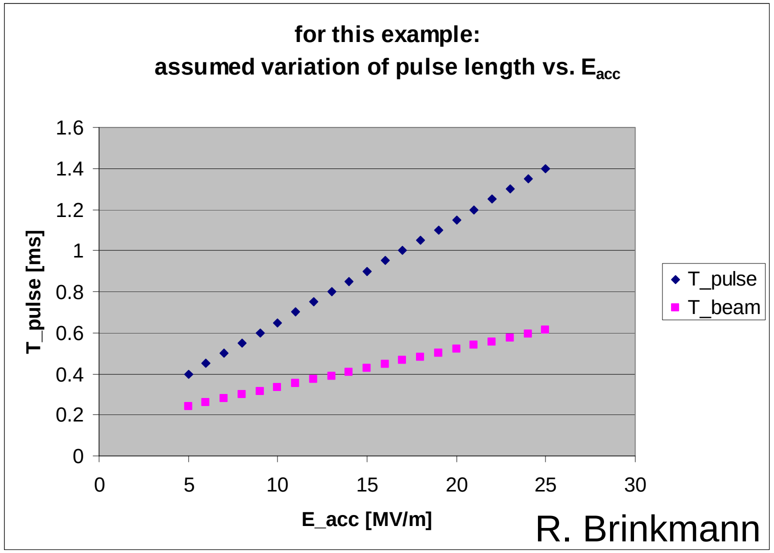
because of beam dump (solid absorber) we wanted to limit $P_{av} \leq 600$kW

Variable Q_{ext} (I_{beam} = const.) 6 modules / klystron

Keep I_{beam} = 5 mA constant, scale $Q_{ext} \propto E_{acc}$

Attractive option: shorter pulses / higher f_{rep} (RF gun!)





$Q_{ext} = 1\times10^6$

$Q_{ext} = 4.6\times10^6$

Too high rep.frequencies might cause problems with the RF gun!

Injector and low-energy linac section

- Possibility of RF gun operation at 50Hz or more has to be studied. Pulse shortening likely to help!
- 500 MeV injector can't be scaled in E_{acc} for higher f_{rep} (bunch compression, beam dynamics)

  ↷ special solution for RF system desirable (lower power/higher duty cycle klystrons?)
- 0.5 → 2.5 GeV linac section (before BC-III):

  To which extend can we change the energy in BC-III?

  If constant energy at BC-III is necessary then the 2 GeV pre-linac needs a modified layout (rf system, reduced gradient?).

Prepare for Start of Project Construction

The XFEL Project Group structures the **work necessary to prepare for start of project construction** in ~ two years. A total of **38 work packages** was created. WPs cover different categories for complete project definition:

Overall design & parameters, beam physics

Major technical components

Sub-systems

Other issues

WPs are not orthogonal – good communication / interaction necessary. All WPs have one **DESY representative**.

This does not mean to imply that DESY wants to take over all tasks! Leadership and / or participation from other labs is already present, especially for s.c.linac technology, e.g.

C. Pagani / INFN & TESLA Coll.Leader (acc. module development)

T. Garvey / Orsay et al. (RF couplers)

C. Magne / Saclay et al. (linac BPMs)

Participation from outside will grow in the future.

Partners will be integrated in the XFEL Project Group as early as possible.

XFEL Project Group: 38 work packages

Work packages
1. RF System
2. Low Level RF (LLRF)
3. Accelerator Modules
4. S.C. Cavities
5. Power Coupler
6. HOM Coupler / Pick-Up
7. Frequency Tuner
8. Cavity Flanges / Cold Vacuum (incl.warm injector section)
9. Cavity String Assembly / Clean Room Quality Assurance

Work packages
10. Module Test Facility
11. Cold Magnets
12. Warm Magnets
13. Cryogenics

Work packages
14. Injector
15. Bunch Compression and Start-to-End Simulation
16. Lattice Design and Beam Optics/Dynamics
17. Standard Beam Diagnostics
18. Special Beam Diagnostics
19. Vacuum system (warm)
20. Beam Dumps
21. Undulators

Groups
accelerator modules
module test / magnets / cryogenics
linac components (injector, bunch compressors, diagnostics, dumps)
Photons
FEL concepts
Controls / Operability
Infrastructure (site, civil construction, survey, tunnel layout, utilities)
Safety
Organisation

Work packages
22. Generic Hard Photon Beam Line
23. Generic Medium Energy Photon
24. Photon Diagnostics
25. Experimental Areas
26. Detector Development

Work packages
27. FEL Concepts

Work packages
28. Control Systems
29. Operability/Failure Handling

Work packages
30. Ground Motion and Mechanical Stability
31. Site and Civil Construction
32. Survey and Alignment
33. Tunnel installation
34. Utilities

Work packages
35. Radiation Safety
36. General Safety

Work packages
37. Construction Plan Approval Procedure
38. Overall Project Progress Tracking

XFEL Project Group: 38 work packages

Work package	Area
1. RF System	accelerator modules
2. Low Level RF (LLRF)	
3. Accelerator Modules	
4. S.C. Cavities	
5. Power Coupler	
6. HOM Coupler / Pick-Up	
7. Frequency Tuner	
8. Cavity Flanges / Cold Vacuum (incl.warm injector section)	
9. Cavity String Assembly / Clean Room Quality Assurance	
10. Module Test Facility	module test / magnets / cryogenics
11. Cold Magnets	
12. Warm Magnets	
13. Cryogenics	

linac components (injector, bunch compressors, diagnostics, dumps)

Photons

FEL concepts

Controls / Operability

Infrastructure (site, civil construction, survey, tunnel layout, utilities)

Safety

Organisation

XFEL Project Group: 38 work packages

14. Injector	accelerator modules
15. Bunch Compression and Start-to-End Simulation	module test / magnets / cryogenics
16. Lattice Design and Beam Optics/Dynamics	linac components (injector, bunch compressors, diagnostics, dumps)
17. Standard Beam Diagnostics	Photons
18. Special Beam Diagnostics	FEL concepts
19. Vacuum system (warm)	Controls / Operability
20. Beam Dumps	Infrastructure (site, civil construction, survey, tunnel layout, utilities)
21. Undulators	Safety
22. Generic Hard Photon Beam Line	Organisation
23. Generic Medium Energy Photon	
24. Photon Diagnostics	
25. Experimental Areas	
26. Detector Development	

XFEL Project Group: 38 work packages

27. FEL Concepts
28. Control Systems
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accelerator modules

module test / magnets / cryogenics

linac components (injector, bunch compressors, diagnostics, dumps)

Photons

FEL concepts

Controls / Operability

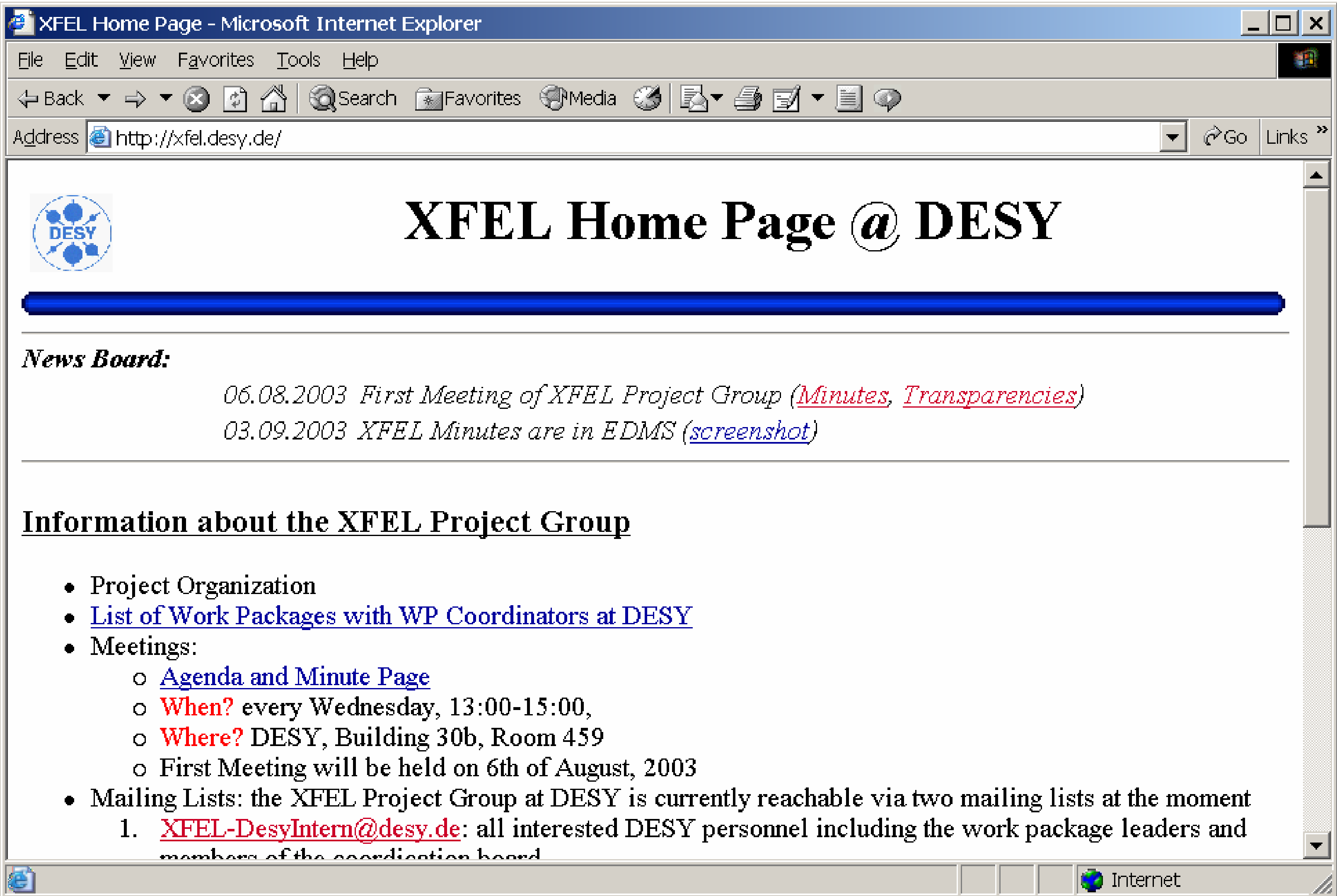
Infrastructure (site, civil construction, survey, tunnel layout, utilities)

Safety

Organisation

If you are ~~curious~~ please check http://xfel.desy.de

want to participate



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XFEL Project Group

1. RF System

- Cost-optimized and still flexible (rep. rate) system: 10MW MBK final decision or alternatives?
- Design + tests necessary for modulator at high repetition frequency?
- Concept for fast Klystron Exchange?

2. Low Level RF (LLRF)

- # cavities per Klystron?
- Electronics in tunnel (radiation)?
- Handling of non-uniform bunch trains?
- Intra-train energy scan?
- ‘Conventional‘ timing issues

XFEL Project Group

Improvements/changings for X-FEL module (necessary?) View of WP 3

-Tuners (standard/blad) saclay standard modified with piezo	WP 7
- New quad/dip doublet (pos. Field, 2K-cooling, HTc curr lead)	WP11
- Alignment/survey (more comfortable)	WP32
- HOM-Absorber, BPMs (position, cooling)	WP 6
- Module/module connections (300mm, 70mm, kind of weldings...)	WP 3
- Magn. Shielding	WP 3
- More safety for transportation/shipping	WP 3
- TÜV/AfA	WP 3
- Main Couplers (New design, heating in modules?)	WP 5
- Material specifications	WP 3
- ...	
- Module Test Facility	WP10

R. Lange

4. S.C. Cavities

- Cavity baking in-situ
- EP on cavities with tank
- Determination of electrical axis of cavity
- Check mechanical properties of niobium after 800C
- Define processes of cavity preparation and assembly
- Optimum EP parameters
- First 10 nine cell-preparations after EP + 800C + bake
- Material
- EP on half cells, dumb-bells
- Inter-cavity spacing
- Optimum stress annealing + hydrogen degassing temperature (600 – 1000C)
- Other cleaning techniques: Oxipolishing, BCP 1:1:10, etc.
- Development of CO2 cleaning
- Cavity Production

5. Power Coupler

- Alignment of coupler bellows
- Define processes for integration/assembly
- Define detailed specification for coupler
- Processing procedure
- Fixed or tuning of the coupler
- Define sensors needed
- Interlock electronics

6. HOM Coupler / Pick-Up

- TW absorber
- Define detailed specification for HOMs
- Define processes for assembly
- Improved existing HOM coupler
- Define detailed specification for pick-ups
- Define processes for integration/assembly
- Cavity HOM loads at 70K?
- Integrate antenna in feedthrough

7. Frequency Tuner

- Define detailed specification for tuner
- Define processes for integration/assembly
- Piezo mechanical design

XFEL Project Group

8. Cavity Flanges / Cold Vacuum (incl.warm injector section)

- Define detailed specification for flanges
- Define processes for integration/assembly
- Investigate/ Improve existing design for TTF2
- Type of bellows
- Number of bellows
- Number and design of gate valves
- development of new flange design
- Welded or flanged design? Where?

3 Accelerator Modules	R. Lange	Alignment inside module ▪Define processes for integration/assembly ▪Pre-Alignment of cavities and coupler position
4 S.C. Cavities	W. Singer	▪EP on cavities with tank ▪Define processes of cavity preparation and assembly ▪EP on half cells, dumb -bells ▪Cavity Production
5 Power Coupler	W.D. Möller	▪Alignment of coupler bellows ▪Define processes for integration/assembly ▪Processing procedure ▪60 mm ID coupler
6 HOM Coupler / Pick-Up	*N.N..*	▪Define detailed specification for HOMs ▪Define processes for assembly ▪Improved existing HOM coupler ▪Define processes for integration/assembly ▪Integrate antenna in feedthrough
8 Cavity Flanges / Cold Vacuum	K. Zapfe.	▪Define detailed specification for flanges ▪Define processes for integration/assembly ▪Investigate/ Improve existing design for TTF2 ▪Type of bellows ▪Number and design of gate valves ▪development of new flange design
10 *Cold* Magnets	H. Brück */Ciemat*	▪2K Quadrupole
17 *Standard* Beam Diagnostics	D. Nölle	▪BPMs

MKS3

MKS3

Influence on Cavity design ?

Influence on process of Cavity assembly

Influence on assembly / sequence of investigations

Influence on Infrastructure / assembly process

10. Module Test Facility

- Module test stand

XFEL Project Group

11. Cold Magnets

- 2K Quadrupole
- Measurement of mechanical vibrations

XFEL Project Group

12. Warm Magnets

- Design of all warm magnets for the entire machine
- Production or contact to production sites

13. Cryogenics

- Use of HERA plant?
- Separate injector/main linac systems?
- Cost aspect: start small, upgrade later?

14. Injector

- Long. internal bunch structure?
- Cavity tilts/coupler kicks?
- Bunch parameter space: low eps w. low charge/higher compression (or vice versa)?
- Rep. rate and duty cycle?

15. Bunch Compression and Start-to-End Simulation

- Compressors: parameter space: lower charge/higher compression (or vice versa)?
- Sensitivity of bunch shape/structure vs. charge, phase, etc. fluctuations?
- Energy at BC-III variable (at BC-II??)Å impact on energy vs. rep rate issue?
- FODO-type stage desirable (possible)?
- Switch yard
- Collimators
- Incorporation of FEL/SASE processes (undulators)

XFEL Project Group

16. Lattice Design and Beam Optics/Dynamics

- Main linac and BC matching
- Orbit correction & beam-based methods
- Collimation and diagnostic section
- Beam transport and distribution to user beam lines
- Orbit stability/stabilisation (slow and fast feedback)
- Lattice in undulator systems, phase shifters, correctors, matching sections
- Transfer to dump

17. Standard Beam Diagnostics

- BPMs
- Screen monitors
- Beam intensity and loss monitors

XFEL Project Group

18. Special Beam Diagnostics

- Slice Parameters and longitudinal phase space diagnostics
- Sub-picosecond timing and synchronization
- Other specialized devices

19. Vacuum system (warm)

- Warm beam pipe distribution starting from switch yard
- Bunch compressors
- Undulator vacuum
- Exit chambers to beam dumps
- Exit windows

20. Beam Dumps

- Modifications to adapt to new site?
- Else?

21. Undulators

- SASE, spontaneous, helical
- Design
- Mass production preparation

22. Generic Hard Photon Beam Line

- High resolution monochromators
- Mirrors and gratings
- Slits and absorbers
- Photon diagnostics
- Beam splitters
- Extreme focussing devices
- Vacuum system
- Control systems

XFEL Project Group

23. Generic Medium Energy Photon Beam Line

- High resolution monochromators
- Mirrors and gratings
- Slits and absorbers
- Photon diagnostics
- Beam splitters
- Extreme focussing devices
- Vacuum system
- Control systems

24. Photon Diagnostics

- Diagnostics for the photon beam quality
- Feedback to electron beam preparation and steering
- Undulator tuning

25. Experimental Areas

- Details according to ‘coherence’, ‘ultra short’, ‘diffraction’ etc.
- Lasers
- DAQ other than Control; Systems?
- Control systems

26. Detector Development

- Development of instrumentation and analysis tools for the XFEL physics
- experiments

XFEL Project Group

27. FEL Concepts

- Transportation of general theoretical developments in the area of FEL physics into the XFEL project
- Coordination of review of present FEL concepts
- Seeding options (coherent seeding, time slicing,?)

28. Control Systems

- Conventional timing issues
- Overall ‘slow control’ for the entire machine
- Automatic procedures (e.g. beam based corrections, failure recovery)
- Data analysis software
- Files systems and databases
- User interfaces

29. Operability/Failure Handling

- Assess technical risks from component failures
- Mean time to restart of user operation after failure of various components
- Single/two tunnel argumentation
- Maximize reliability aspects

30. Ground Motion and Mechanical Stability

- Monitoring of ground motion and vibrations
- Damping measures

31. Site and Civil Construction

- Evaluation of the two (?) DESY-near sites
- Civil construction
- Tunnels
- Switch yard
- Experimental hall and other buildings
- Access shafts

32. Survey and Alignment

- Survey and alignment issues, implementations, implications

33. Tunnel installation

- Layout
- Placement of components
- Support structures
- Transport system

34. Utilities

- Power distribution
- power supplies
- Water cooling, compressed air
- Integration of existing utilities
- Ventilation and air conditioning
- Temperature stabilisation
- Industry-type controls for utilities

35. Radiation Safety

- Analysis of radiation safety issues
- Implementation of radiation safety procedures and techniques
- Interlocks
- Construction plan approval issues

36. General Safety

- Analysis of general safety issues
- Implementation of general safety procedures and techniques
- Electrical safety
- Procedures

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37. Construction Plan Approval Procedure

- Preparation of all material for construction Plan approval procedure
- Organization of plan approval issues
- Discussion with the public
- Legal procedures
- Etc.

38. Overall Project Progress Tracking

- Organization and implementation of common tools for progress tracking
- Time schedule follow-up
- Cost to completion follow-up
- Configuration control
- Documentation
- Expenditure planning
- Work breakdown structure at higher levels