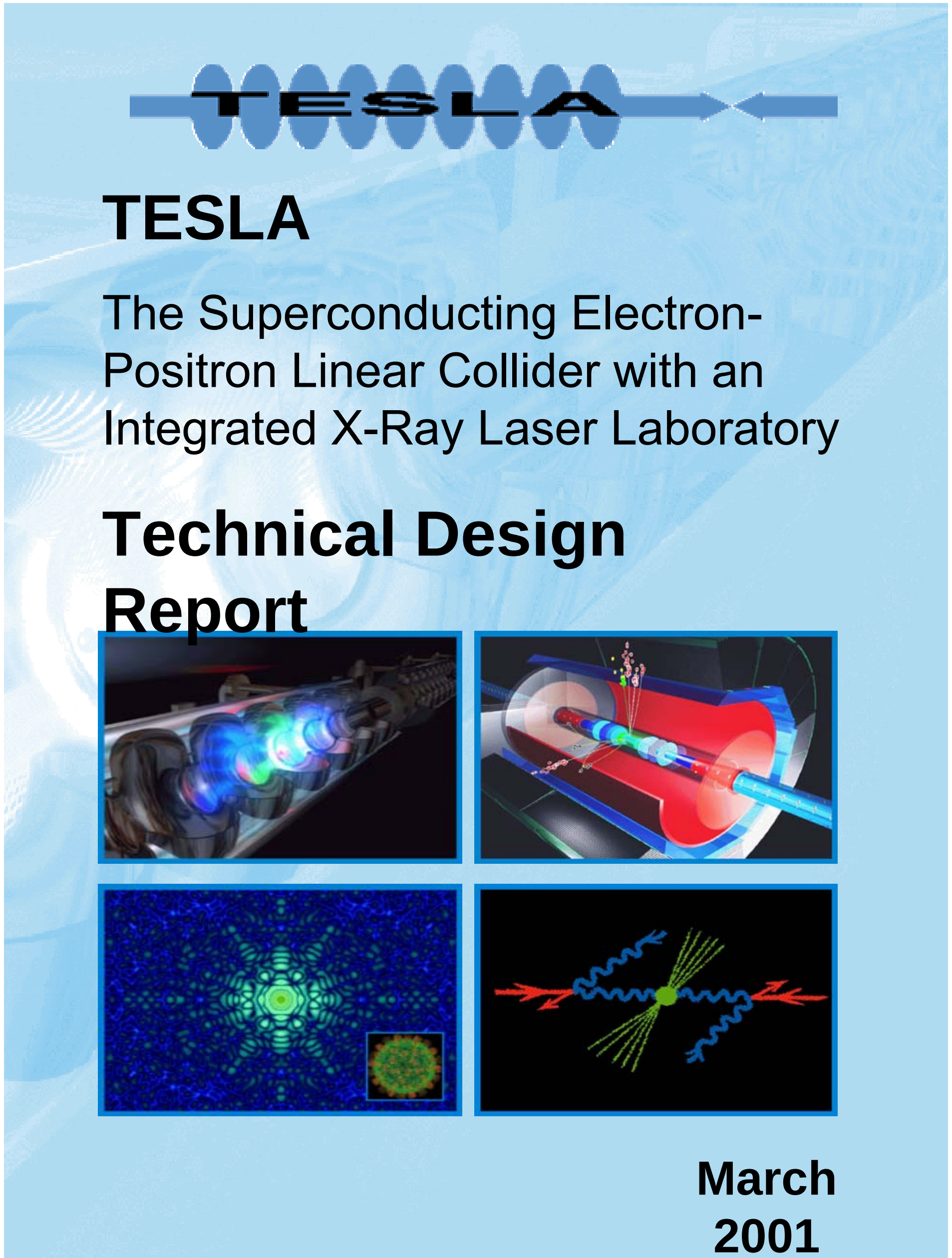
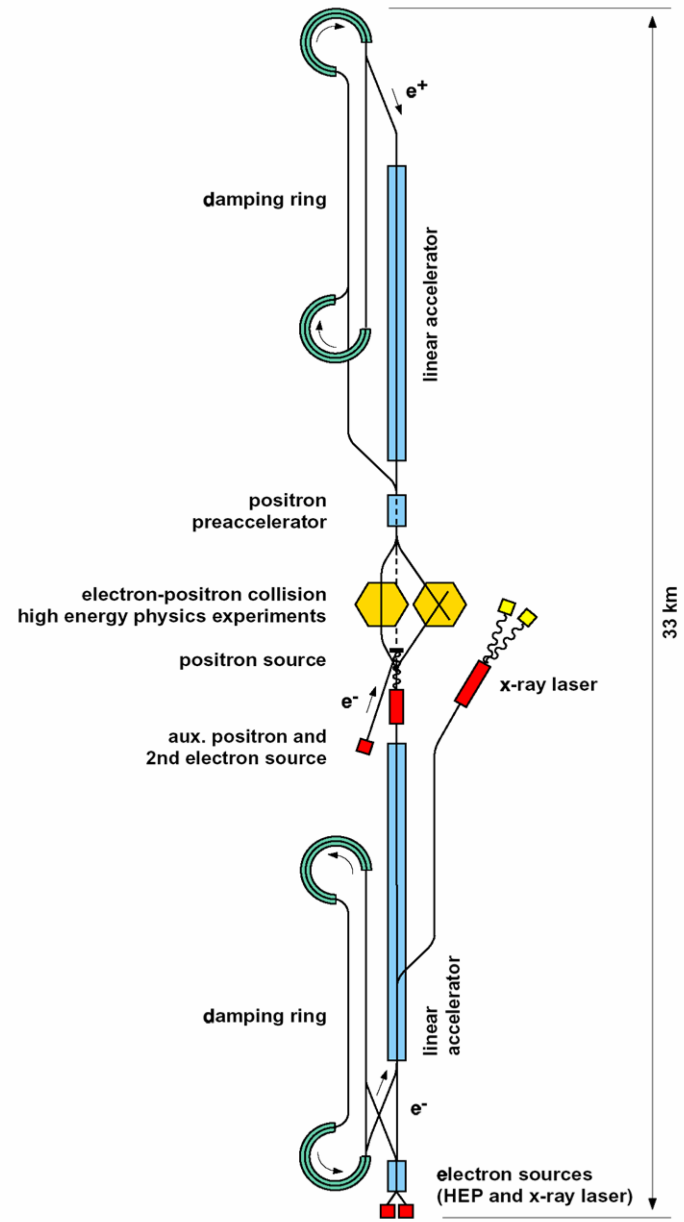
The European X-ray FEL

Accelerator Layout

Reinhard Brinkmann, DESY
for the XFEL Group


TESLA
TESLA
The Superconducting Electron-Positron Linear Collider with an Integrated X-Ray Laser Laboratory
Technical Design Report
March 2001

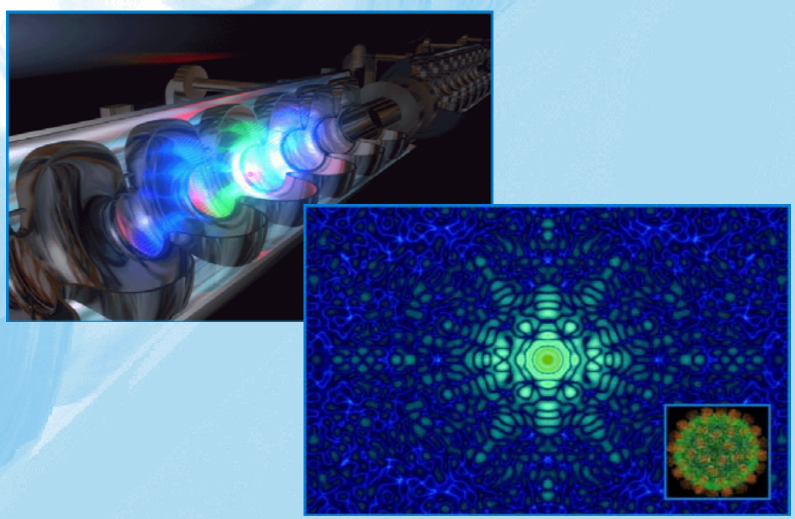

e+
damping ring
linear accelerator
positron preaccelerator
electron-positron collision
high energy physics experiments
positron source
e-
aux. positron and
2nd electron source
x-ray laser
33 km
damping ring
linear accelerator
e-
electron sources
(HEP and x-ray laser)

TESLA XFEL

First Stage of the X-Ray Laser Laboratory

Technical Design Report

Supplement



October
2002

TDR update 2002:

Separate **linac for XFEL**
(maintain common site & same s.c. linac technology)

→

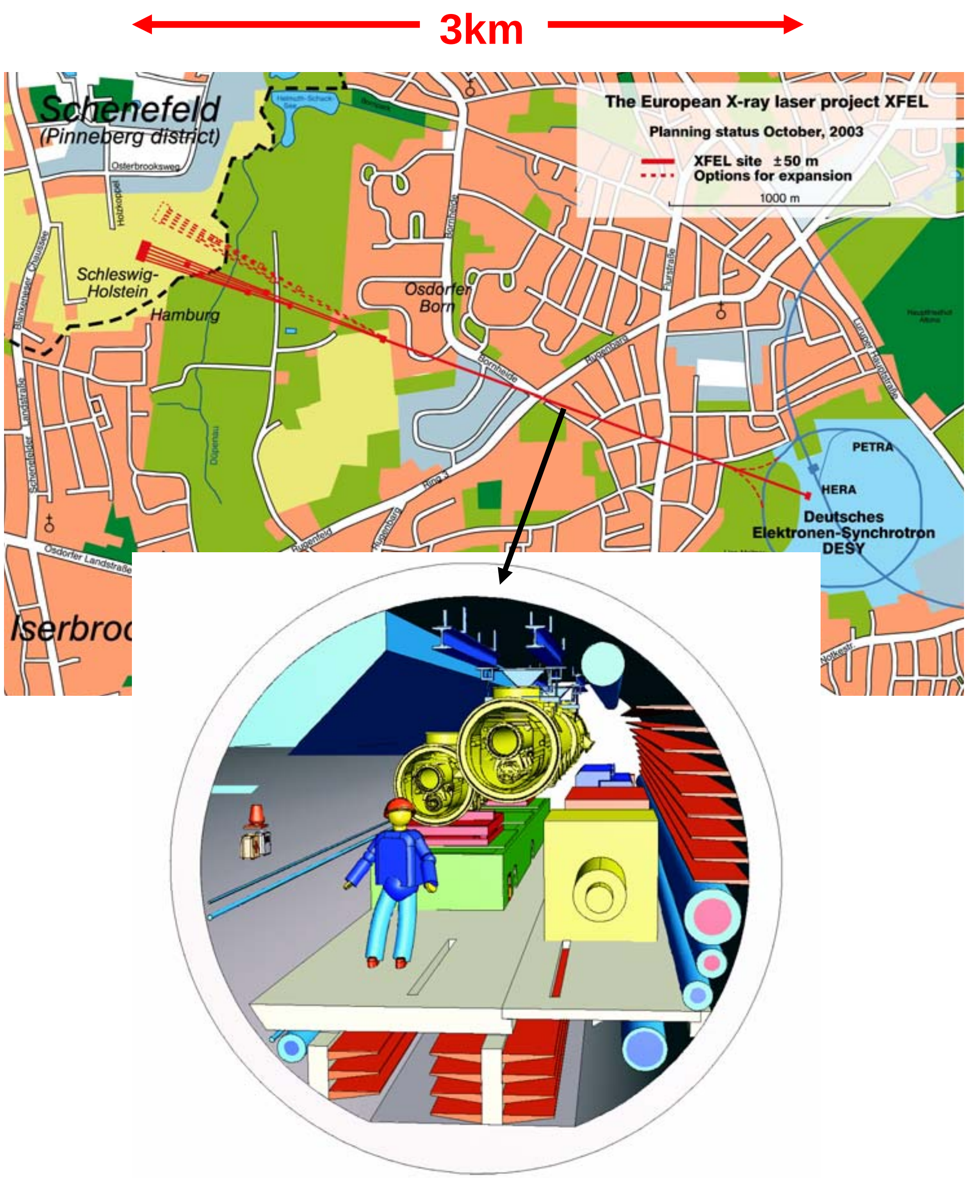
- **De-coupling from LC regarding construction & operation (and: *approval*)**
- **Gain in operational flexibility**

Decision by German Government Feb. 2003:

Go ahead with XFEL as European Project, commitment for funding 50% of estimated 684 M€ (year 2000 price basis)

New site: XFEL – LC synergy argument no longer valid

- Use existing infrastructure on DESY site
- Acc subsystems (injector, cryogenics, modulators,…) on DESY site
- Linac tunnel 15 – 30m underground in urban area
- User facility in rural area, place for possible extension
- Legal procedure for construction *(Planfeststellung)* in preparation → permission by end of 2005



New site: XFEL – LC synergy argument no longer valid

- Use exi
  DESY s
- Acc su
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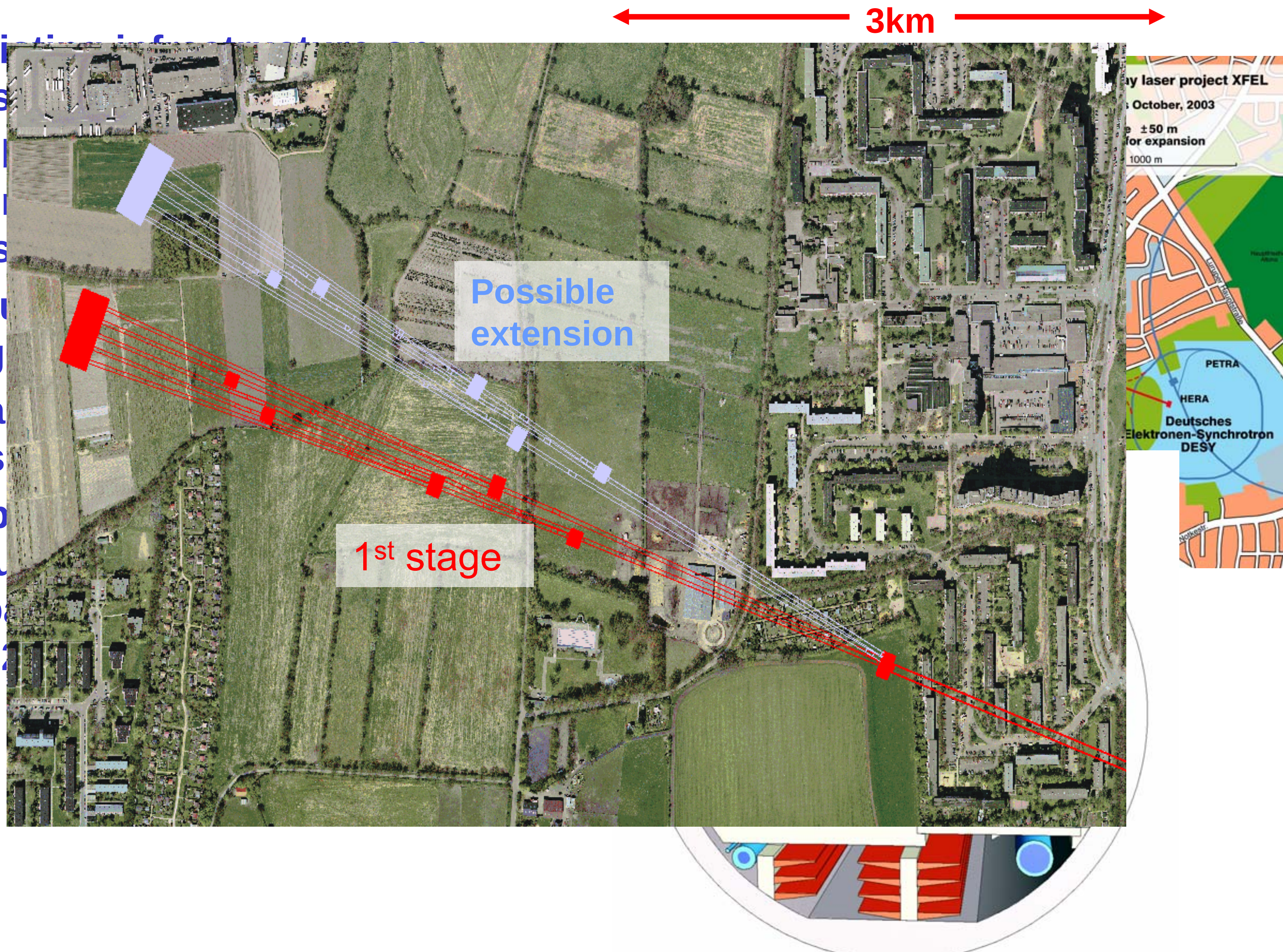
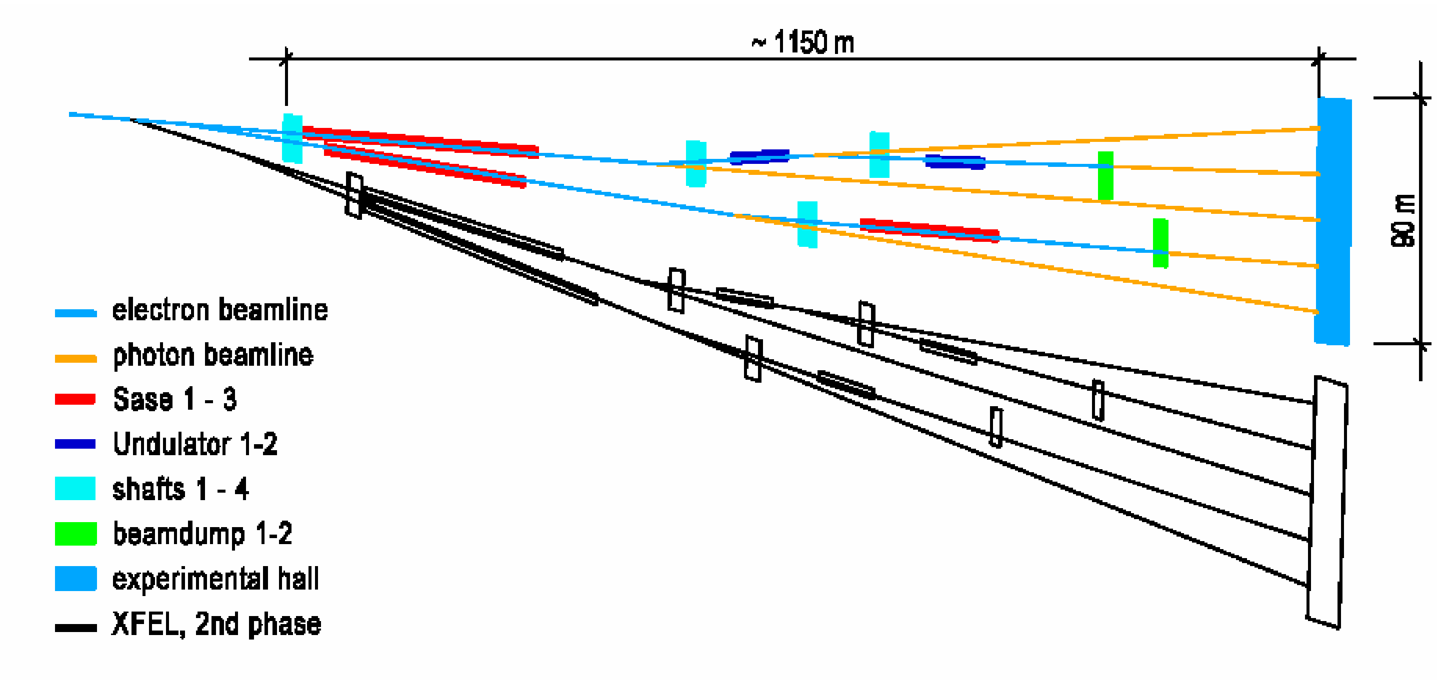


User facility - Beam lines

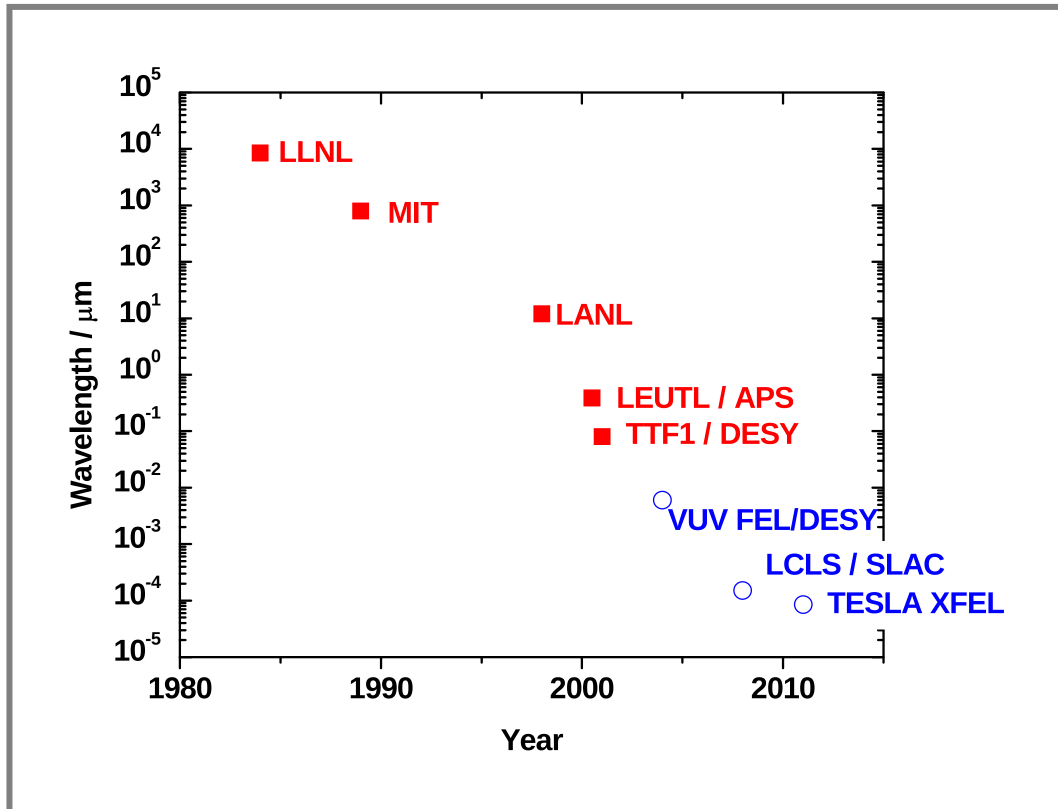


SASE undulators 0.1 – 6nm, magn. Length 150 – 80m

- Variable gap (min 10mm) → independent λ-tuning, electron/photon beam alignment
- Options: fast independent switch of FEL process for sequence of U's, sub-fs pulses by modulation with ultra-short laser, seeding, …

XFEL schedule:

- TTF / VUVFEL
  - Pilot facility for the XFEL (s.c. linac, beam dynamics/diagnostics, FEL process, user operation…)
- LCLS
  - first to reach SASE in Å regime
  - Common interests & fruitful cooperation
- EUROFEL
  - Coordinated FEL R&D in Europe, co-funding by EU recently approved



Ongoing Project Organisation at European Level

XFEL Steering Committee (Chair: H. Schunck, BMBF)

- Representatives of all countries intending to contribute to the XFEL facility
- 1st meeting Feb. 2004
- Work out MoU for construction and operation of the European XFEL by 2005

WG on Scientific and Technical issues STI (chair: F. Sette, ESRF)

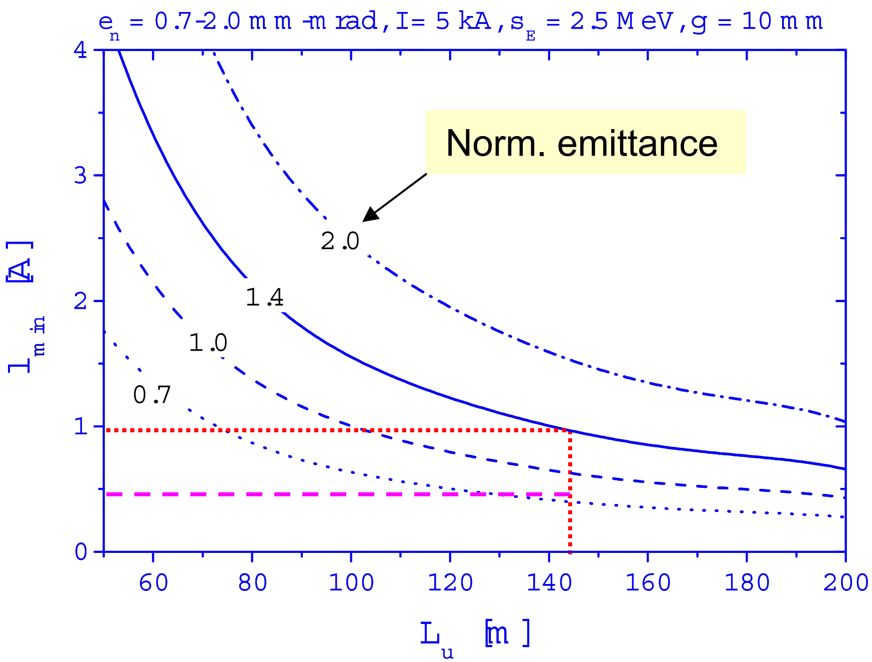
- 1st meeting Apr. 1-2, 2004
- Reach consensus on the scientific goals and the overall layout of the facility
- Prepare technical report as part of the MoU

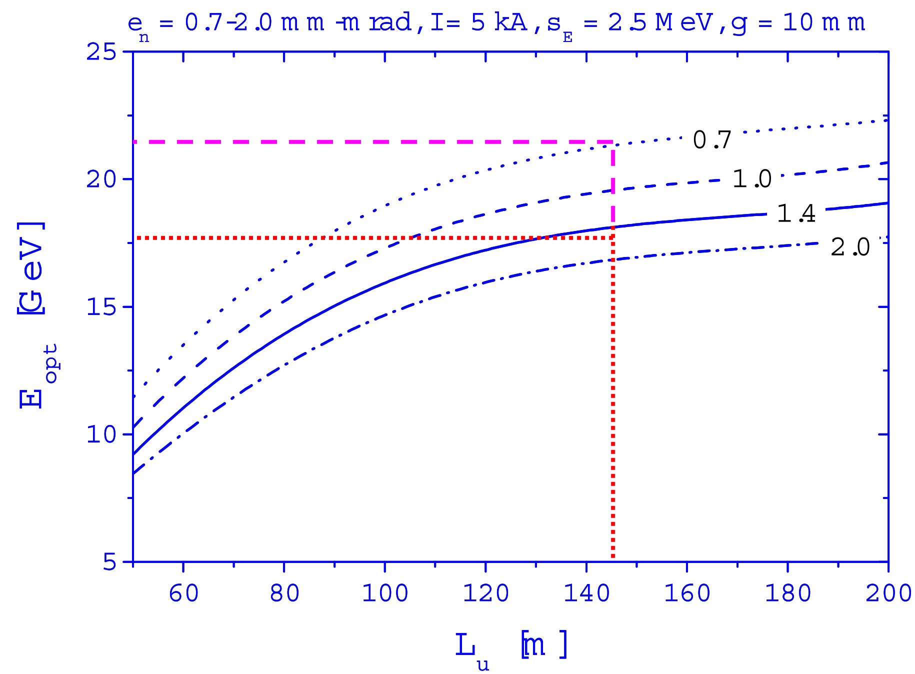
WG on Administrative and Funding issues AFI (chair: H.F. Wagner, BMBF)

- 1st meeting March 19, 2004
- Work out legal framework and organisational scheme for construction & operation
- Explore and reach consensus on the cost breakdown and spending profile

Parameter considerations - Choice of beam energy

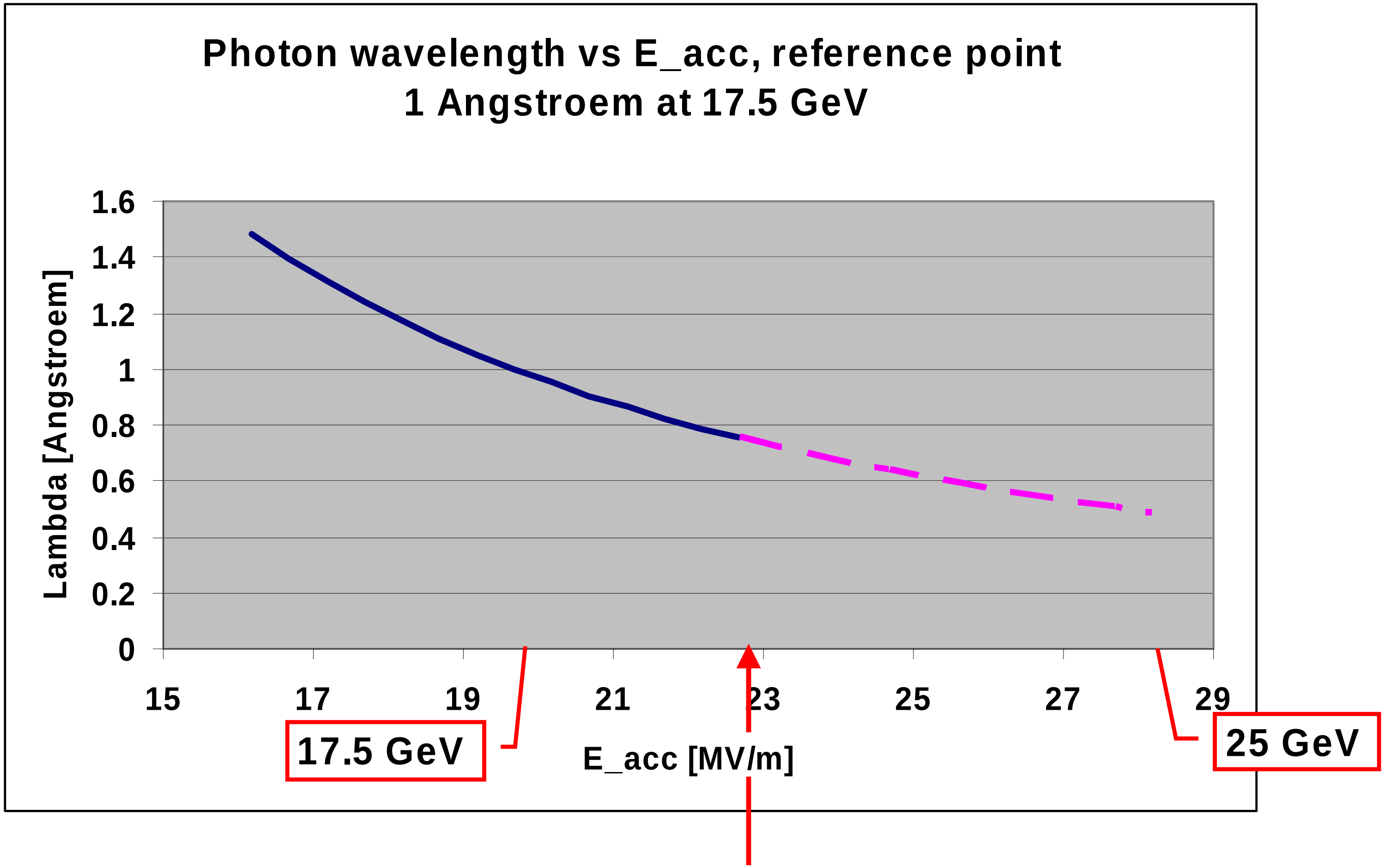
Conservative assumption on slice energy spread: 2.5 MeV *(expect ~1MeV including incoherent SR)*





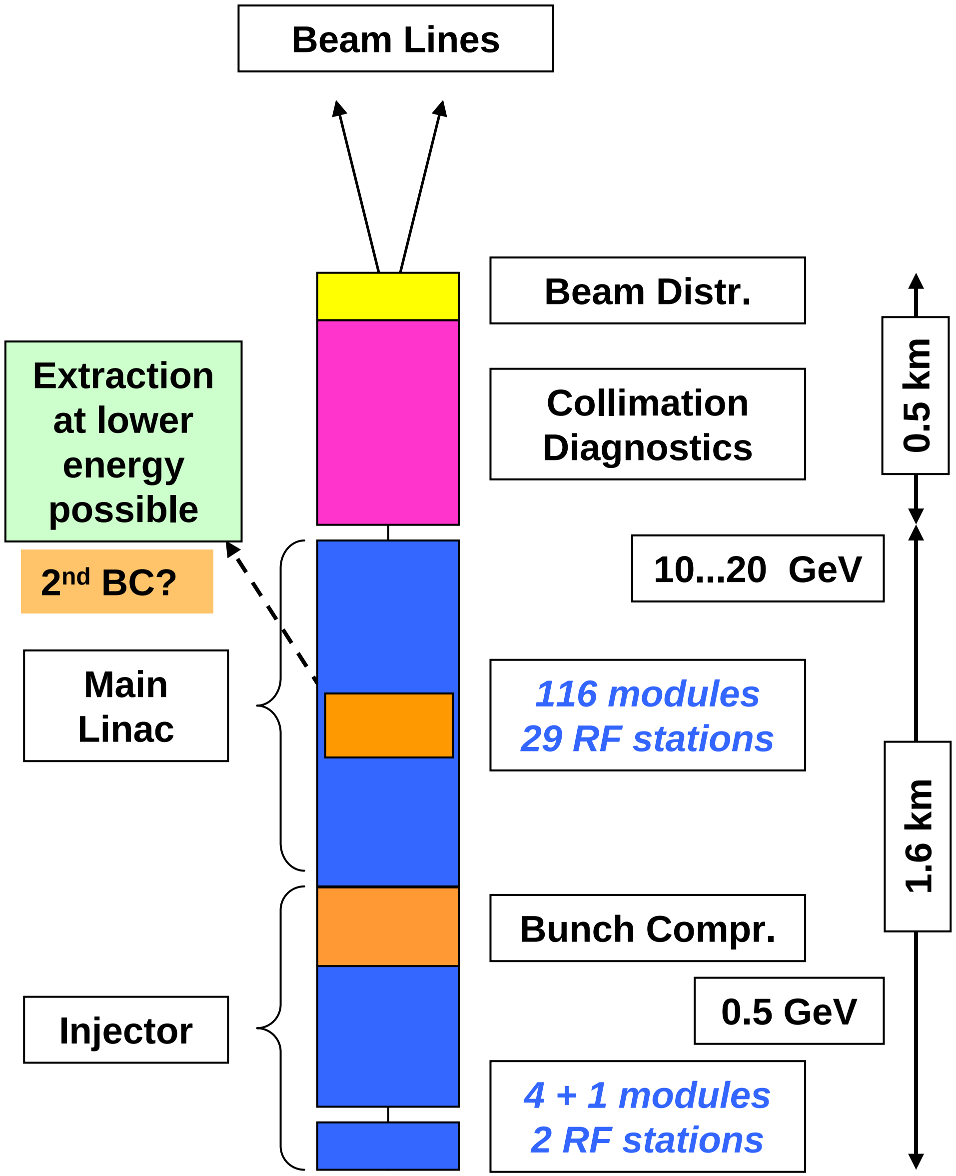
→ 17.5 GeV for 1Å

Wavelength vs. acc gradient



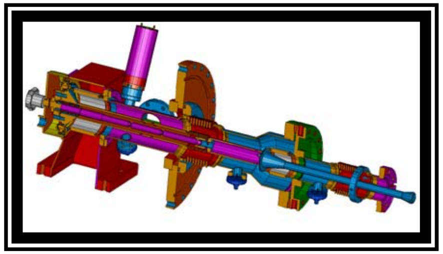
Nominal linac energy 20 GeV, includes ^{57}Fe line @ 0.8Å

Basic Accelerator Layout



Main linac	
Beam energy	20 GeV
acc gradient	22.9 MV/m
Bunch spacing	200 ns
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
# bunches p. pulse	3250
Rep. rate	10 Hz
Av. Beam power	650 kW

3 kl. built by French company, operated @ design spec TTF



THP52

var. Q_ext with adjustable coupler and/or waveguide tuner

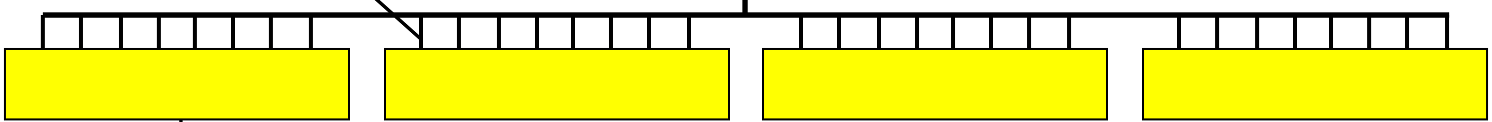
Prototypes from US & J industry *THP39, THP45*

5 MW RF source

TUP80, THP49

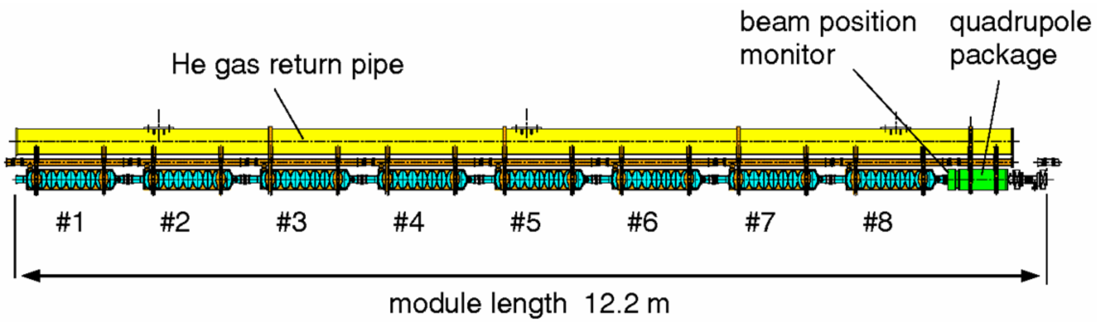
De-rated 10MW MBK

Bouncer-type modulator

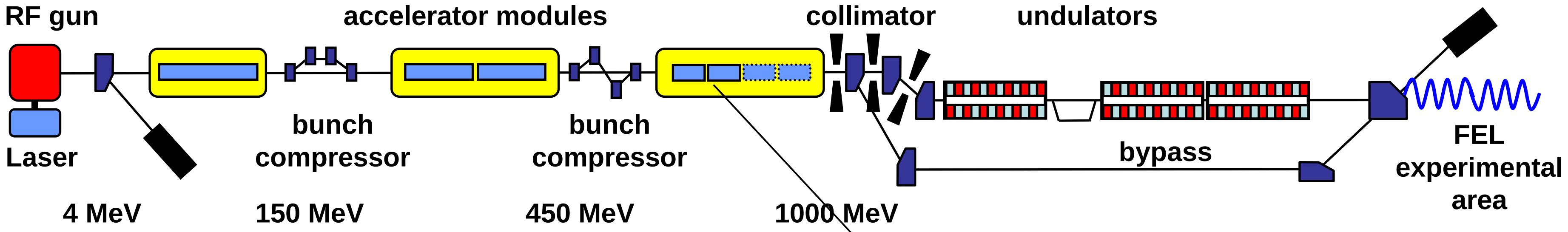


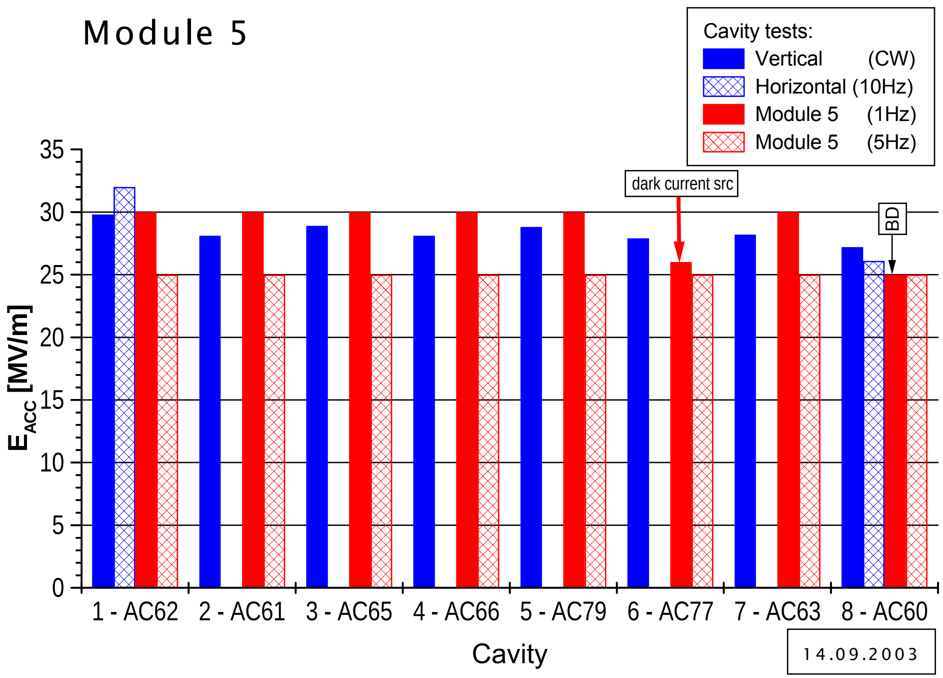
eight 9-cell Nb cavities at 2K, $Q_0=10^{10}$

12m TTF-like acc. modules



TTF / VUVFEL: pilot facility for the XFEL



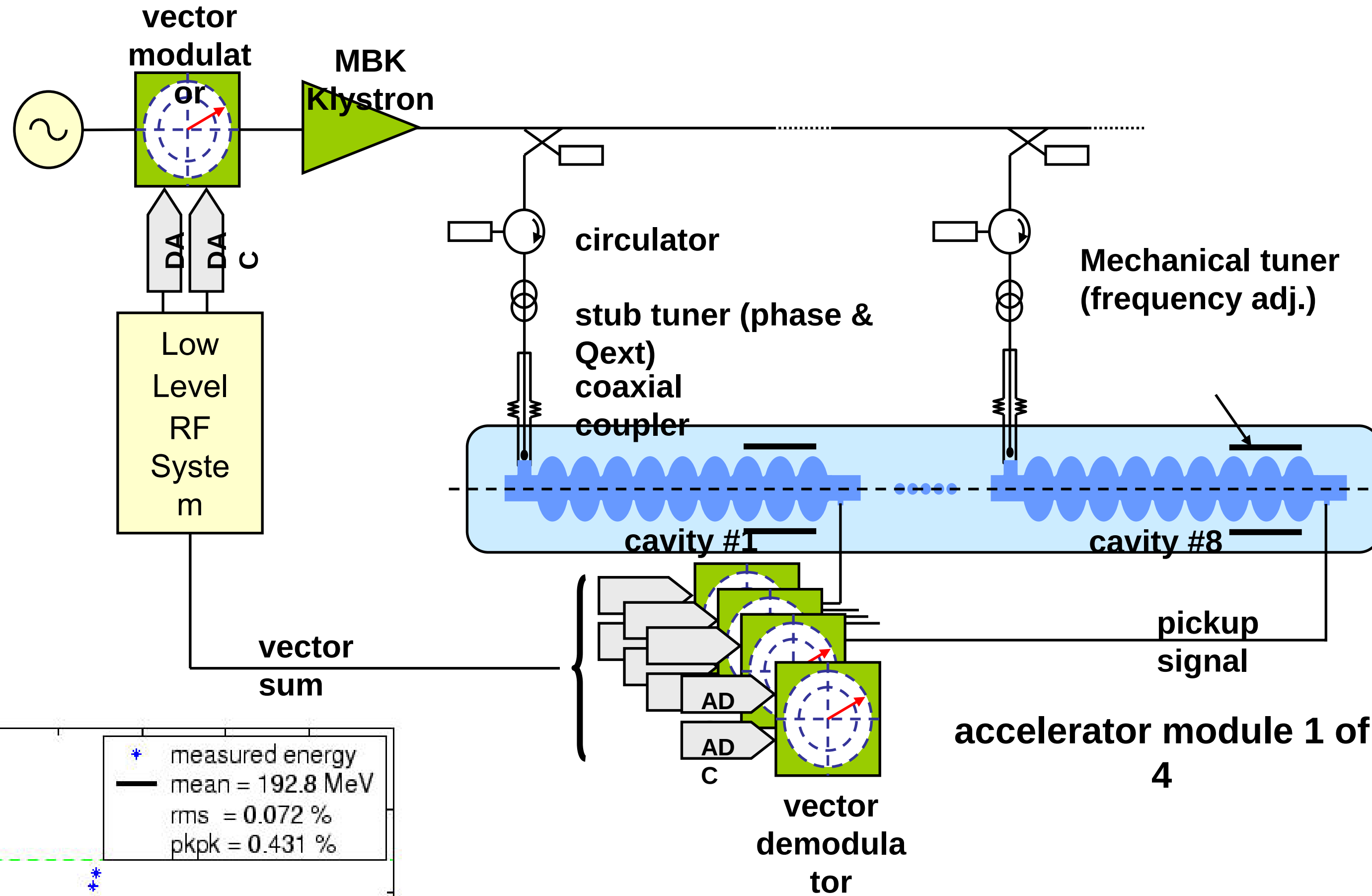


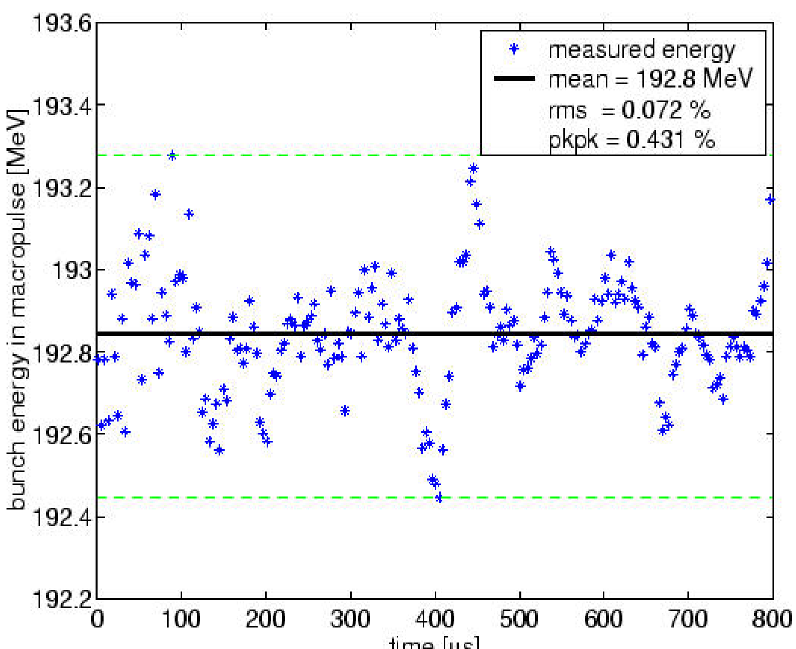
M5 Test with RF, Q_0 = $8{\cdot}10^9$ at 25 MV/m

→ D. Kostin, THP32

LLRF

control & field stabilisation





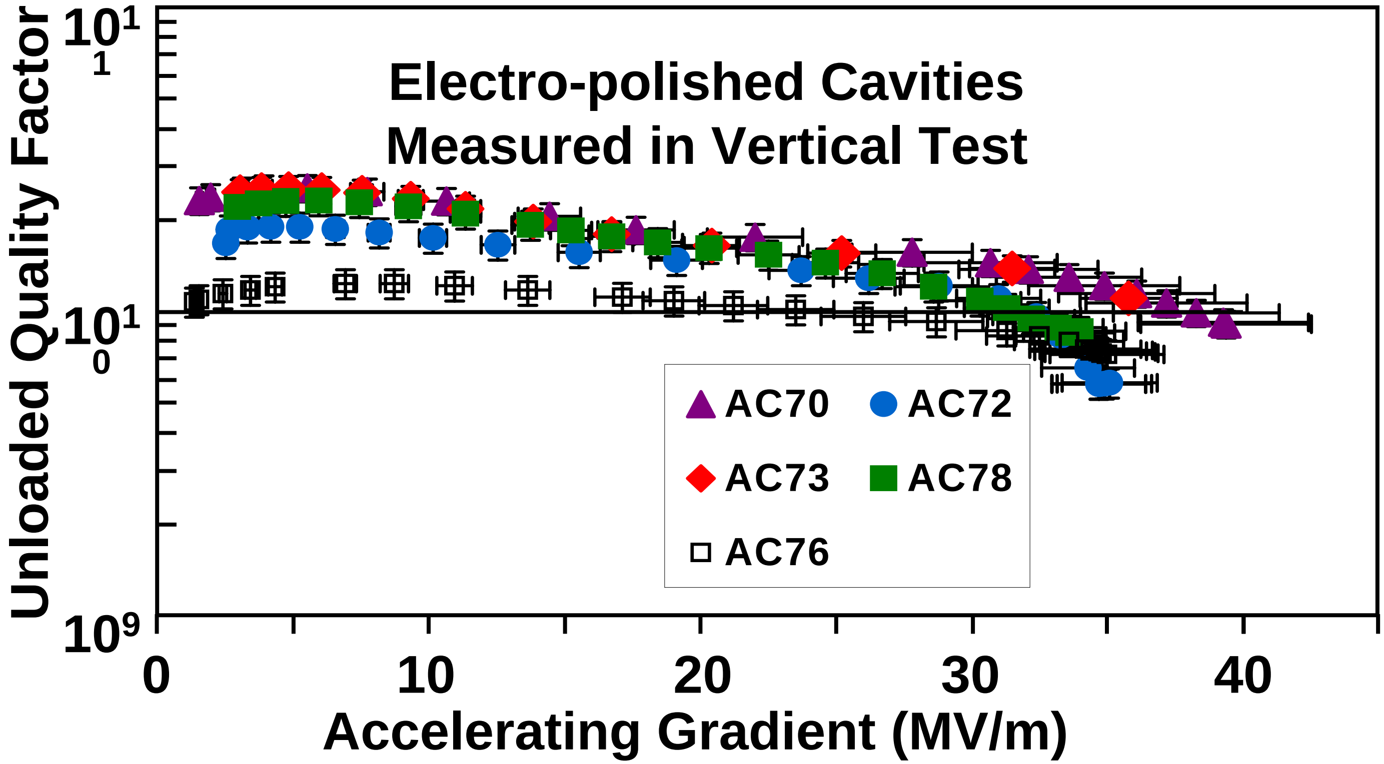
S. Simrock, WE103

T. Jezynski et al., TUP78

W. Cichalewski et al., TUP98

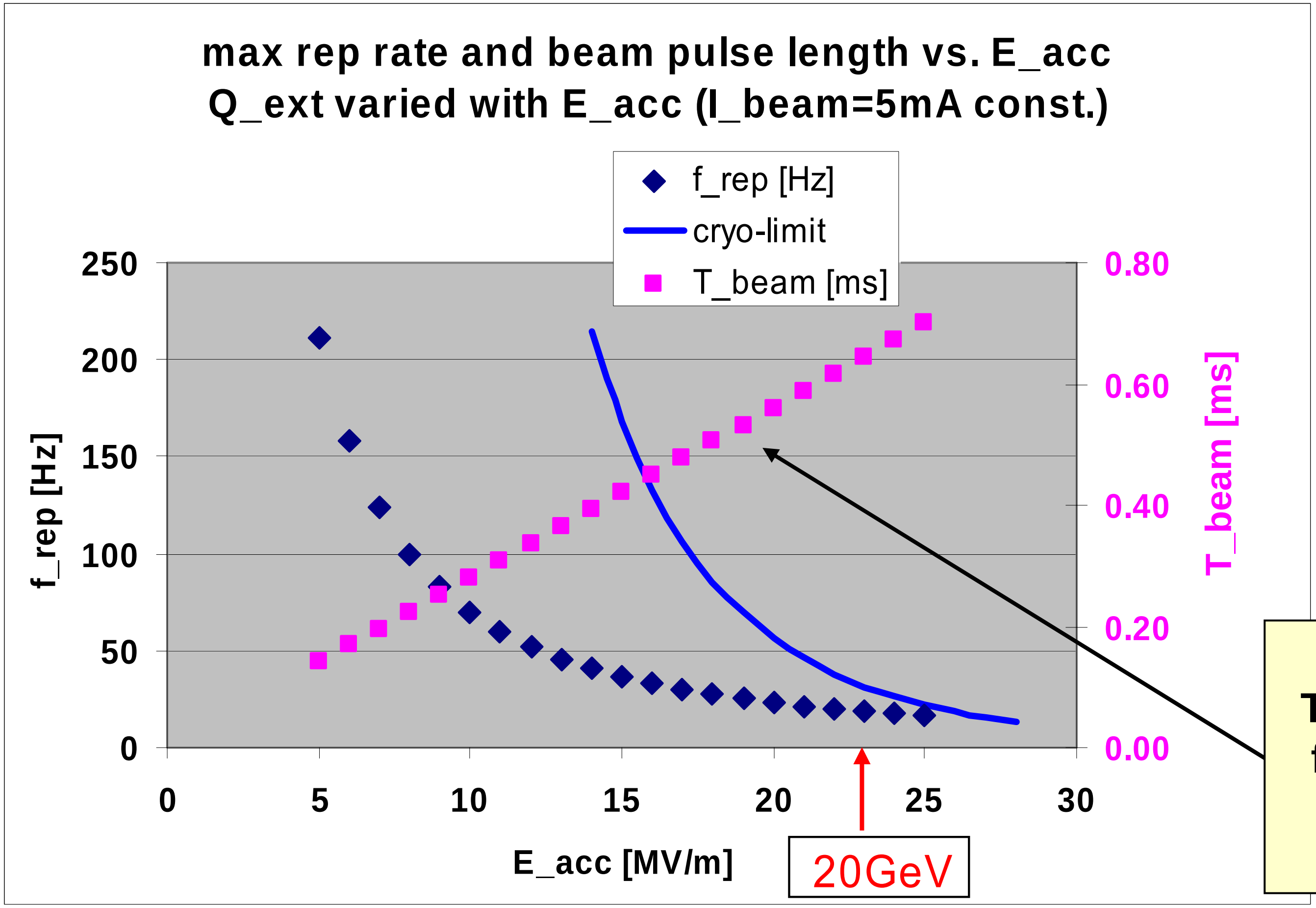
State-of-the-art electropolished cavities

*→ **L.Lilje, WE102   A. Matheisen et al., THP95***



- 40 MV/m achieved ***without*** 1400C baking/Titanisation
- One cavity installed in module and tested with beam at 35MV/m

Operational flexibility – duty cycle



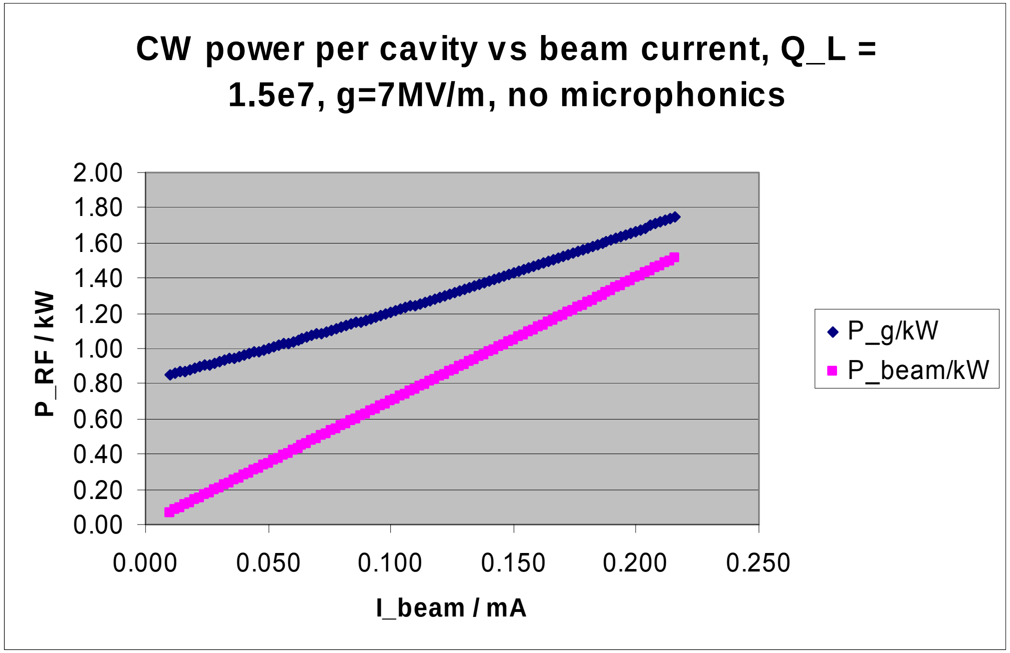
Decreasing T_{beam} at higher f_{rep} helps, but injector is an issue!

Sketch of possible future CW operation mode

If Å FEL radiation at lower beam energy comes in reach (better injector/beam quality, advanced FEL concepts, …) → high duty cycle, up to CW, can become an attractive option

Linac layout & cryogenics consistent with this option (at E_{acc} = 7…8 MV/m), different RF system has to be added

Maintain good RF → beam efficiency with moderate over-coupling (87 Hz bandwidth, expect <10 Hz rms microphonics)



Sketch of future CW operation mode cont'd

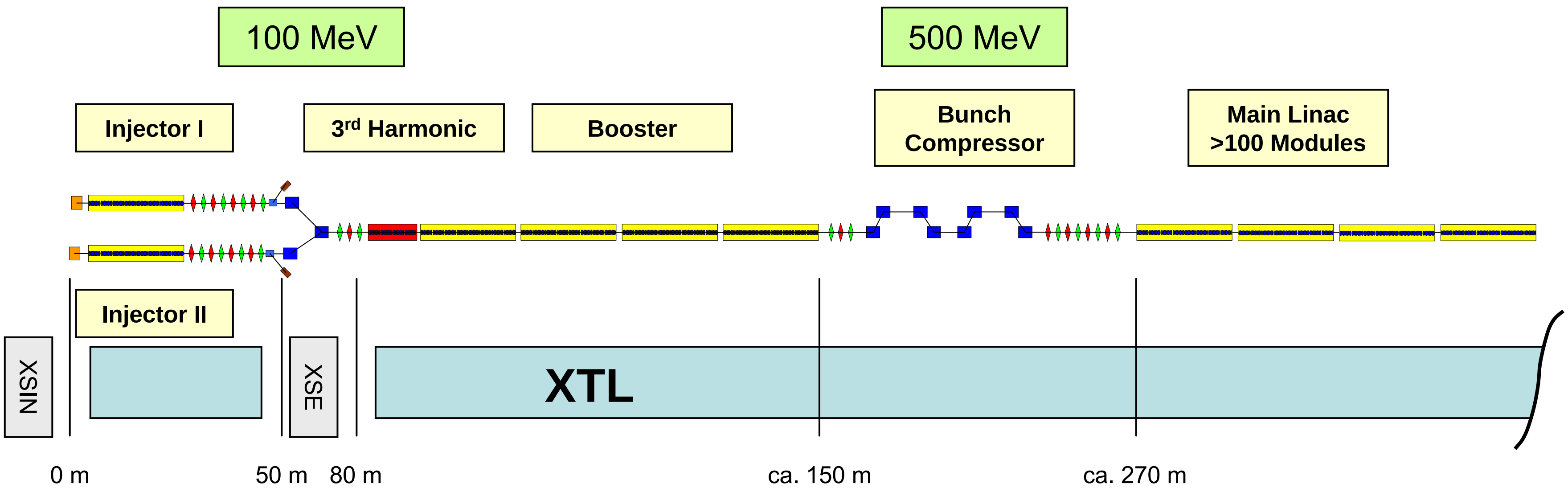
Beam energy [GeV]	6.5
Acc gradient [MV/m]	7
Beam current$^{\$}$ [mA]	0.18
Bunch spacing [μs]	5.5
RF power / module [kW] (incl. overhead)	~20
Dynamic cryo load 2K [kW]	~2.4

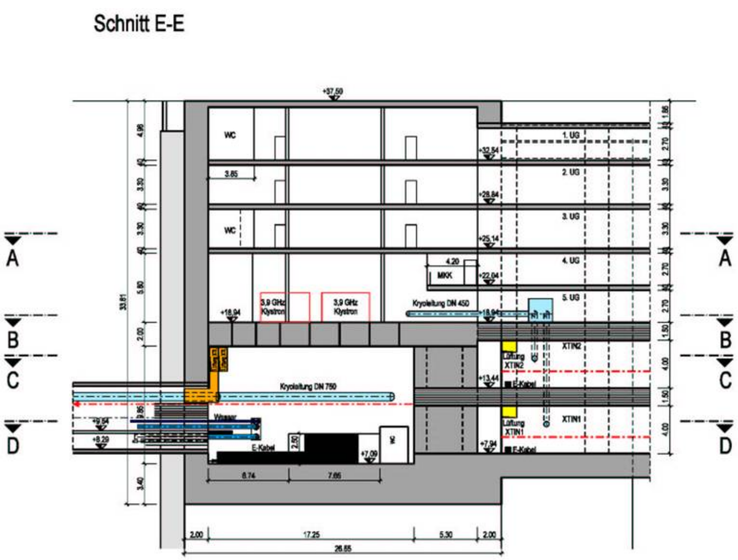
B. Petersen, MOP87

$: total beam power of 1.2 MW sufficient to operate simultaneously 4 undulator beam lines at beam dump limit of 300kW

If user demand for very high average power, ERL option is conceivable

Injector & bunch compressor

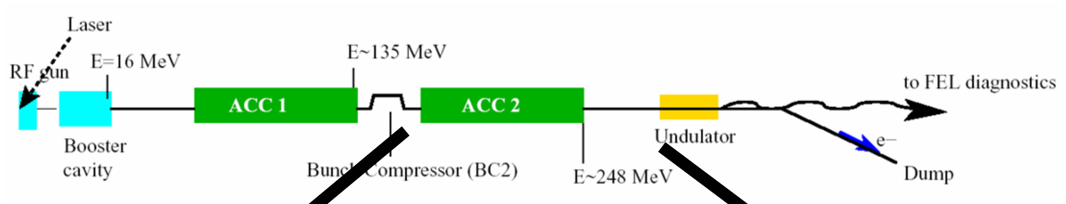




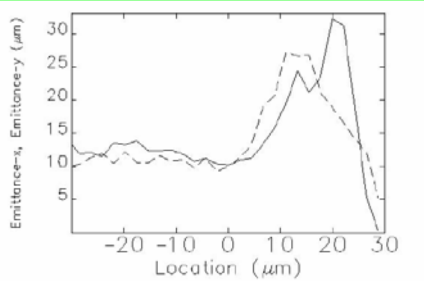
Start-to-end beam simulations:

ASTRA (DESY) - space charge dominated e-beams
TraFiC4/CSRtrack(DESY) - self-consistent CSR effects
MAFIA (TUD/CST) - general e.m. field solver for wakefields etc.
***elegant* (Argonne Natl. Lab.) - e-beam tracking with wakefields**
GENESIS1.3 (DESY) - 3D SASE FEL code
FAST (DESY/JINR) - fast SASE FEL code for parameter optimization

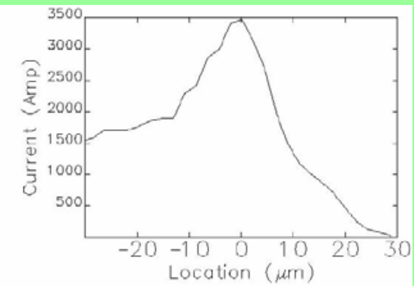
Example of start-to-end analysis: TTF1 FEL



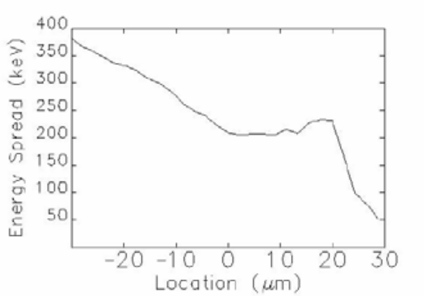
after bunch compressor



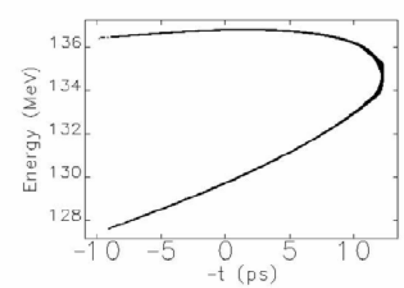
Emittance (x-solid, y-dashed)



Peak current

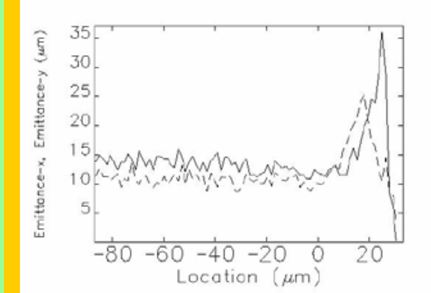


Slice energy spread

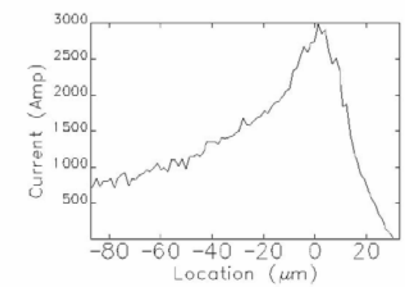


Longitudinal phase space

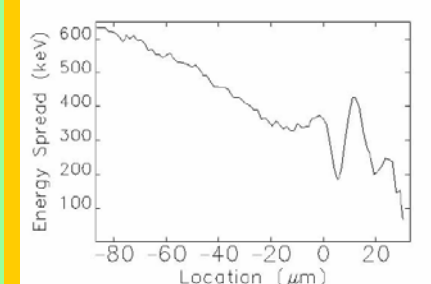
at entrance of undulator



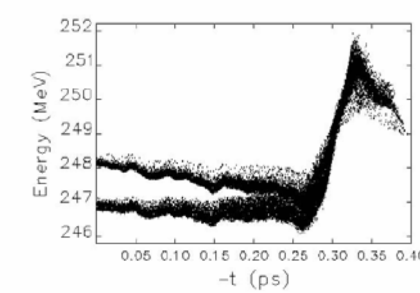
Emittance (x-solid, y-dashed)



Peak current

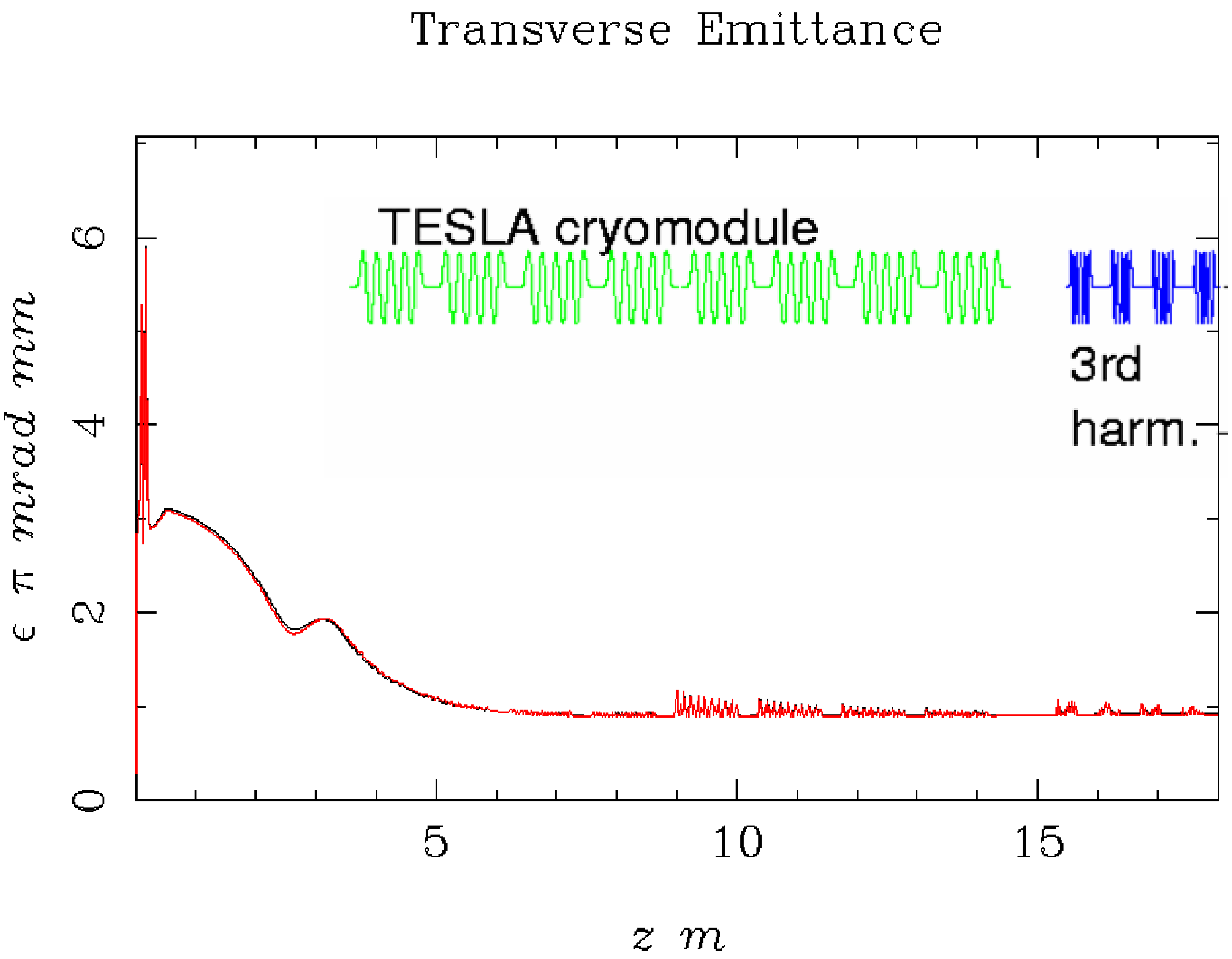


Slice energy spread



Longitudinal phase space

Emittance from photocathode RF gun injector

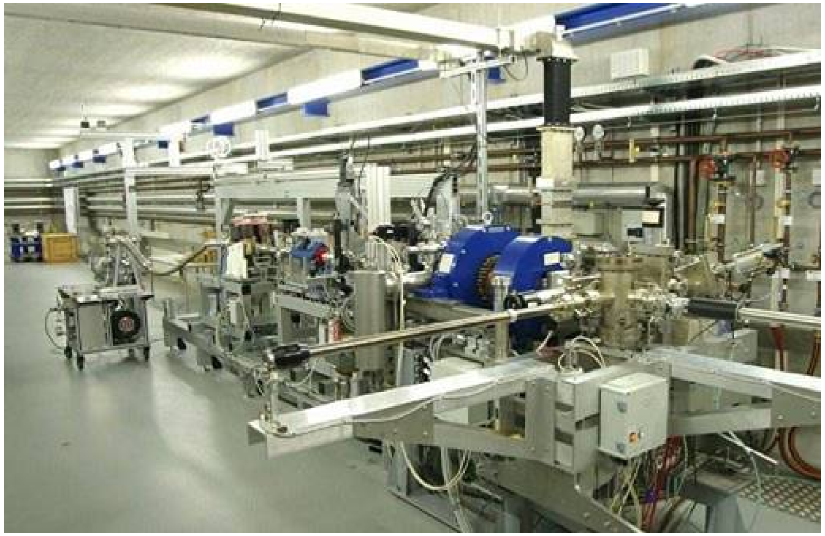


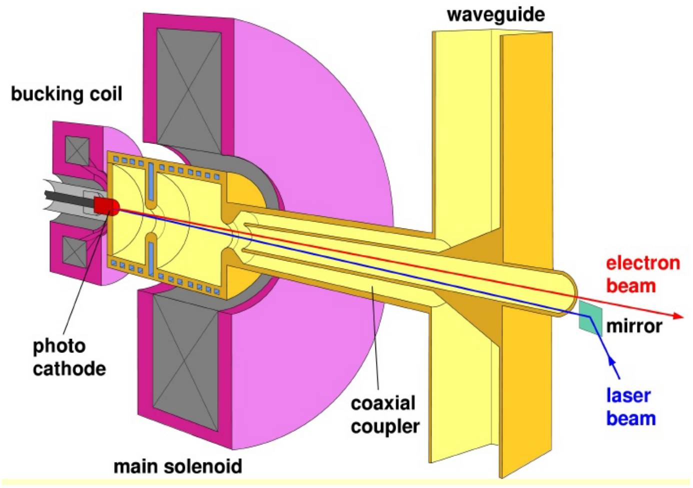
- 1nC charge
- uniform transverse distribution
- longitudinal flat-top with 2 ps rise time
- incl. thermal emittance

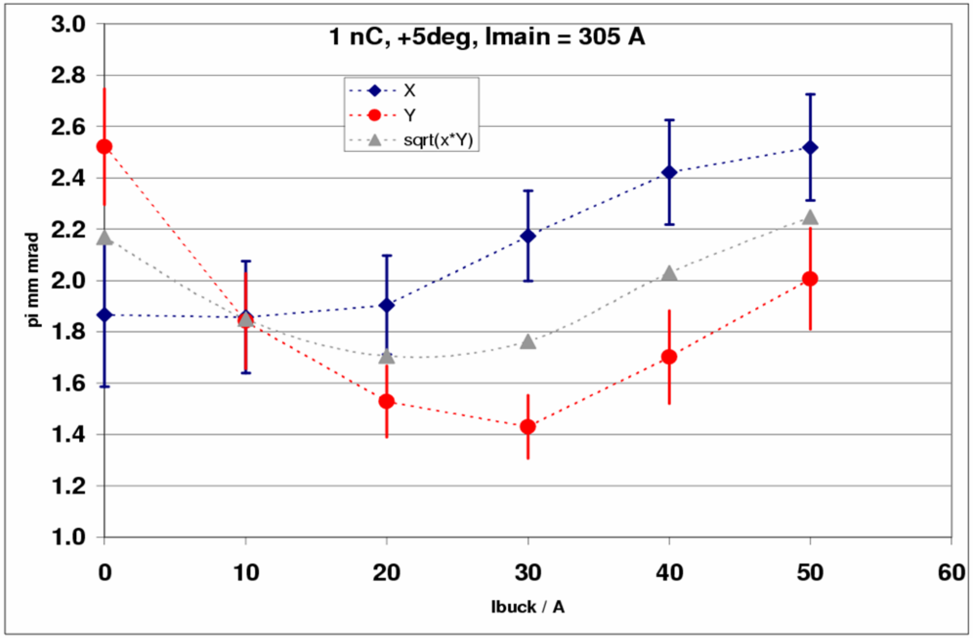
$\varepsilon_n = 0.9\ \mu m$

Y. Kim et al., TUP57

RF gun development at PITZ, DESY-Zeuthen





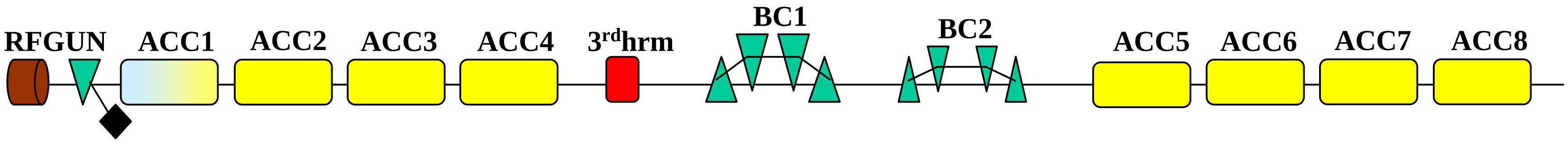


On-going programme:

- increase the gradient on the cathode from 40 MV/m to 60 MV/m
- further improve the transverse and longitudinal laser profile (collab. Max-Born Institute, Berlin)
- PITZ gun now part of TTF-II/VUVFEL injector (commissioning started, not yet flat long. laser profile)

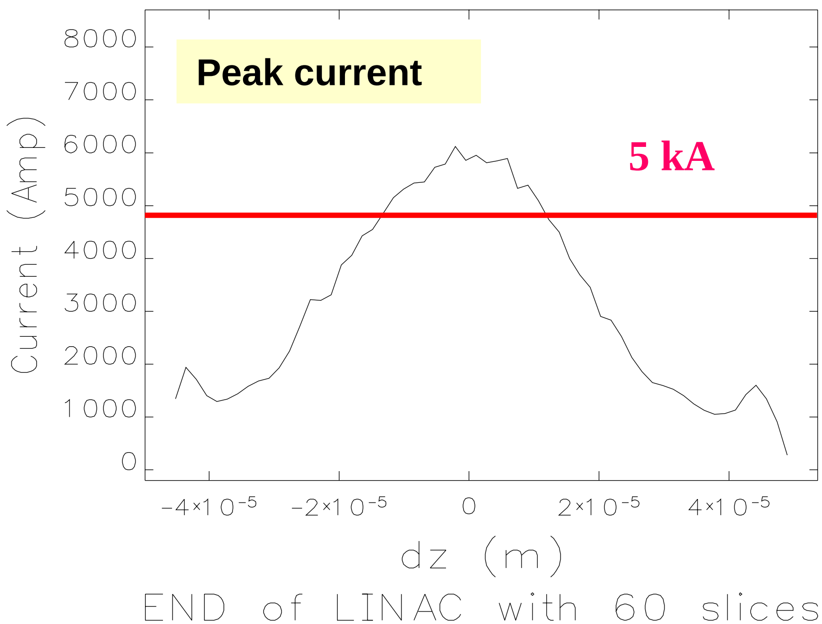
Bunch compressor – single stage/double chicane

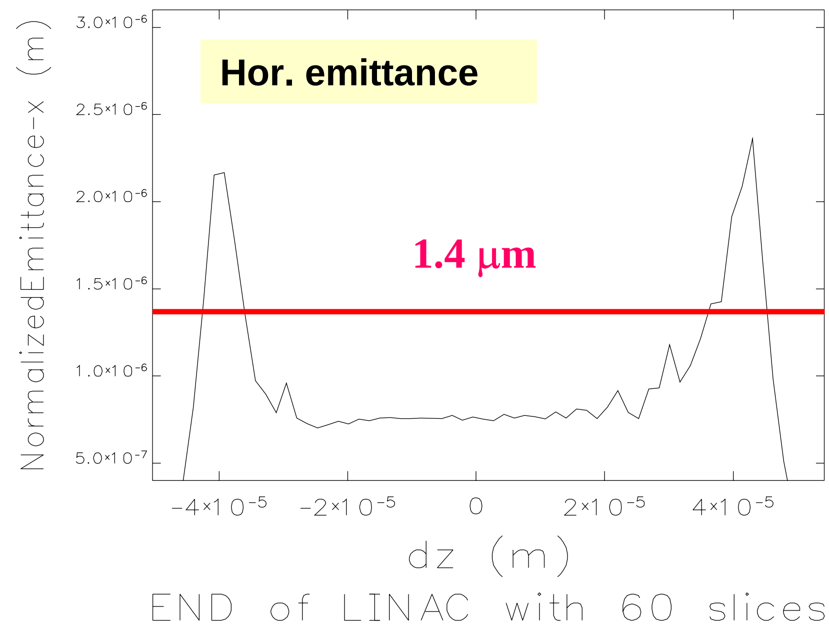
σ_z=1.8mm → σ_z=113μm → σ_z=21μm



BC1	BC2
E = 510 MeV	E = 510 MeV
$\sigma_\delta \sim$ 1.89%	$\sigma_\delta \sim$ 1.88%
R_{56} = 87 mm	R_{56} = 4.8 mm
θ = 3.95 deg	θ = 0.93 deg

Y. Kim et al., EPAC2004

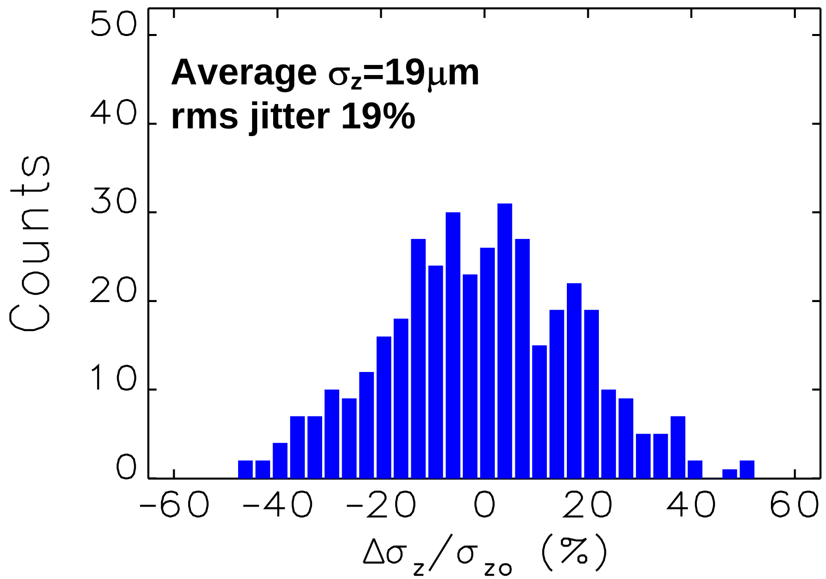




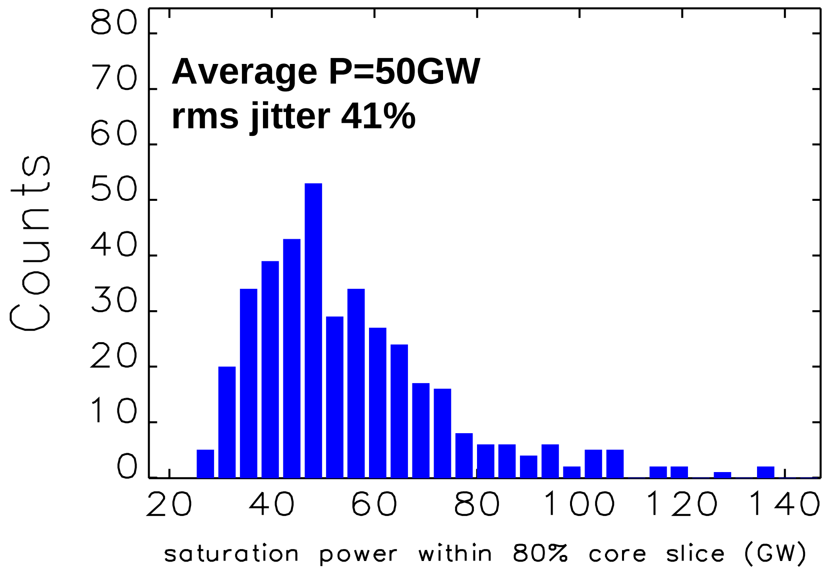
Estimate of beam jitter at undulator – challenging stabilisation issues

Model calculation: RF phase/amplitude jitter 0.05°/0.02%, laser timing 0.1ps,…

Bunch length



Photon saturation power



Possibility of intra-pulse RF feedback with SRF helpful

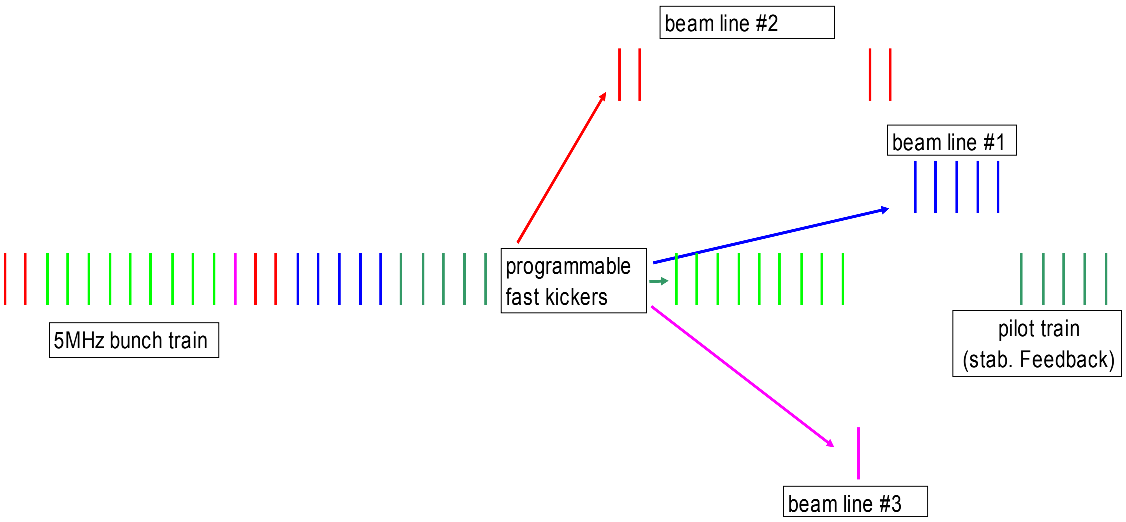
Potential advantage of 2nd stage compressor under study

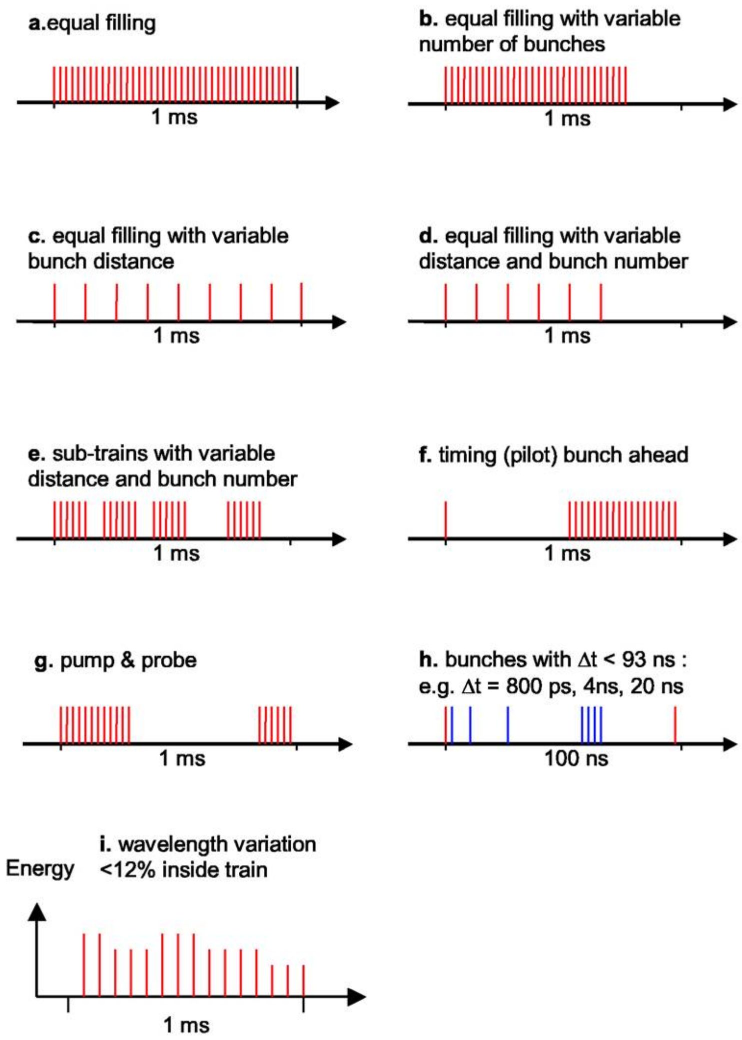
Y. Kim et al., TUP58

Bunch patterns / beam distribution

Generation of bunch train patterns:

- At the source
  varying transient effects in the entire accelerator (handled e.g. by the LLRF system)
- At the beam delivery / distribution system
  more challenging kicker devices





Conclusions

- The 20 GeV s.c. linac based on the technology developed by the TESLA collaboration and successfully demonstrated at TTF is an ideal driver for the Free Electron Laser facility, offering a broad range of operating parameters in its baseline design and with future upgrade options.

- With the R&D work towards industrial production of major components, the preparations for the site at DESY and the European project organisation under way, we should be ready to go into construction phase in ~2 years from now.