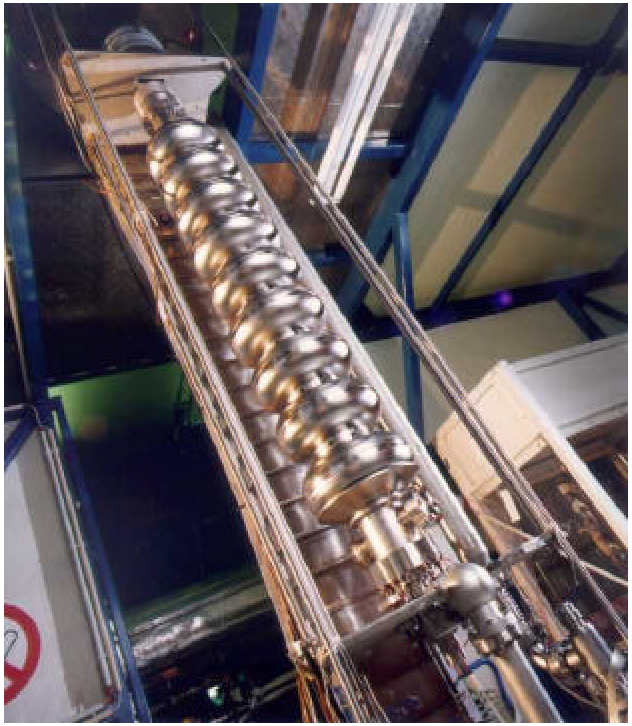
The TESLA
Linear Collider

Winfried Decking (DESY)
for the TESLA Collaboration

Outline

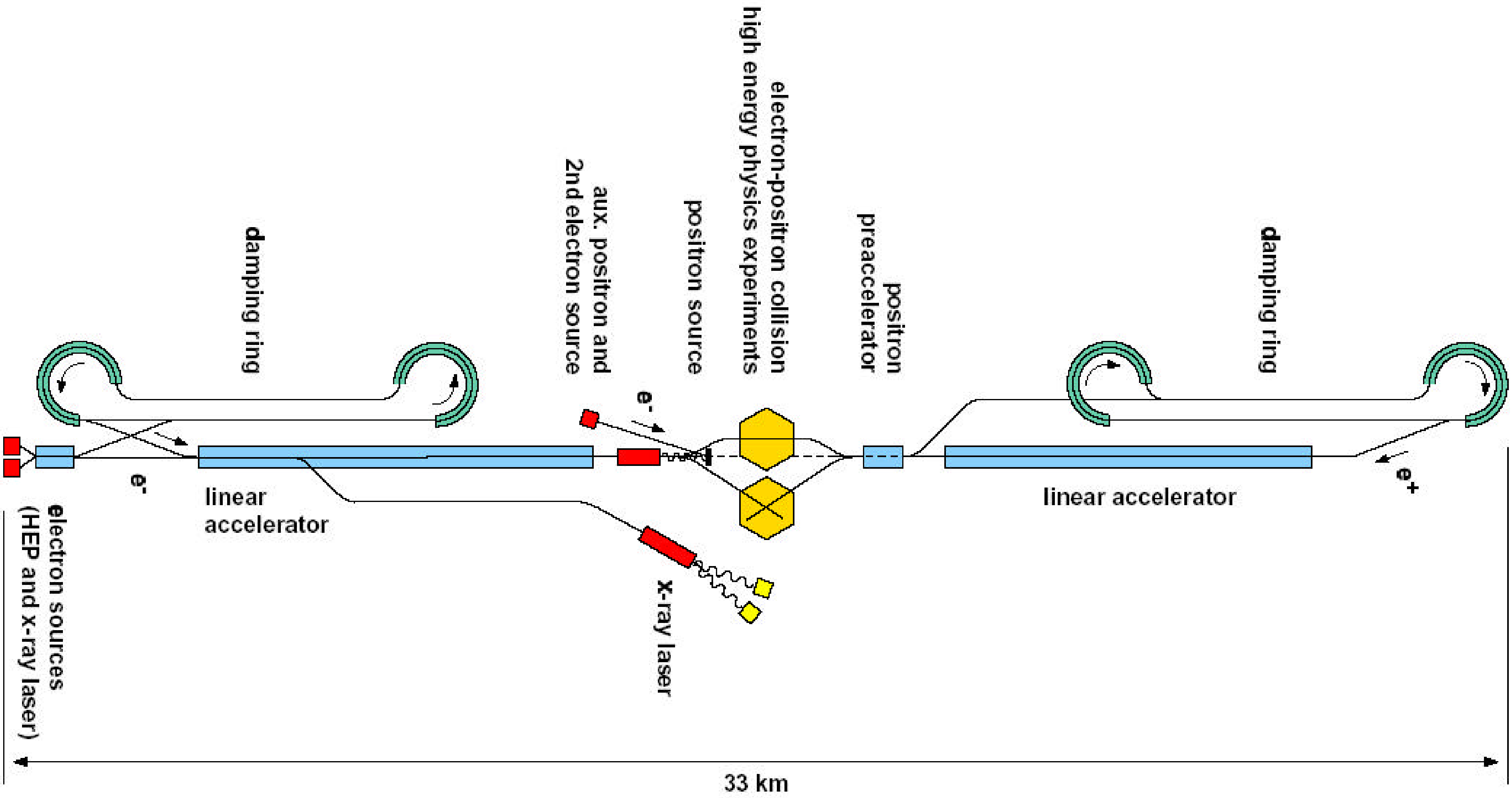
- Project Overview
- Highlights 2000/2001
  - Publication of the TDR
  - Cavity R&D
  - TTF Operation
- A0 and PITZ
- TESLA Beam Dynamics
- Site Investigation (PFV)
- Summary

TESLA – A Quick Overview



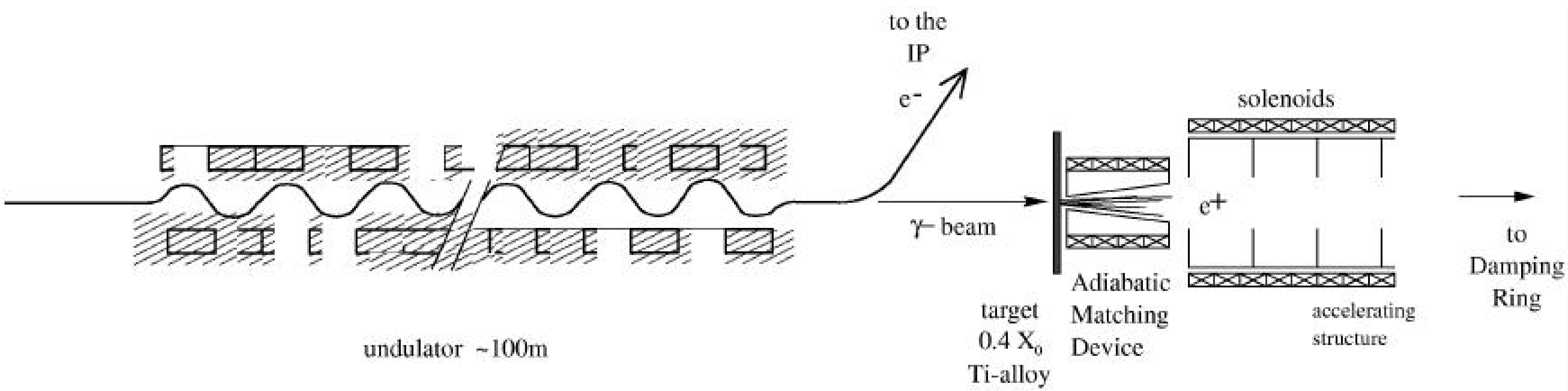
- Superconducting 1.3 GHz cavities
  - small wakefields
  - high wall-plug power to beam power efficiency
  - long beam pulse with large inter-bunch spacing
- 500-800 GeV c.m.
- Luminosity $3.4\text{-}5.8\times10^{34}\ \mathrm{cm^{-2}s^{-1}}$
- Proposed by an international collaboration (42 institutes, 10 countries) on a site at DESY in Hamburg/Germany

Layout



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

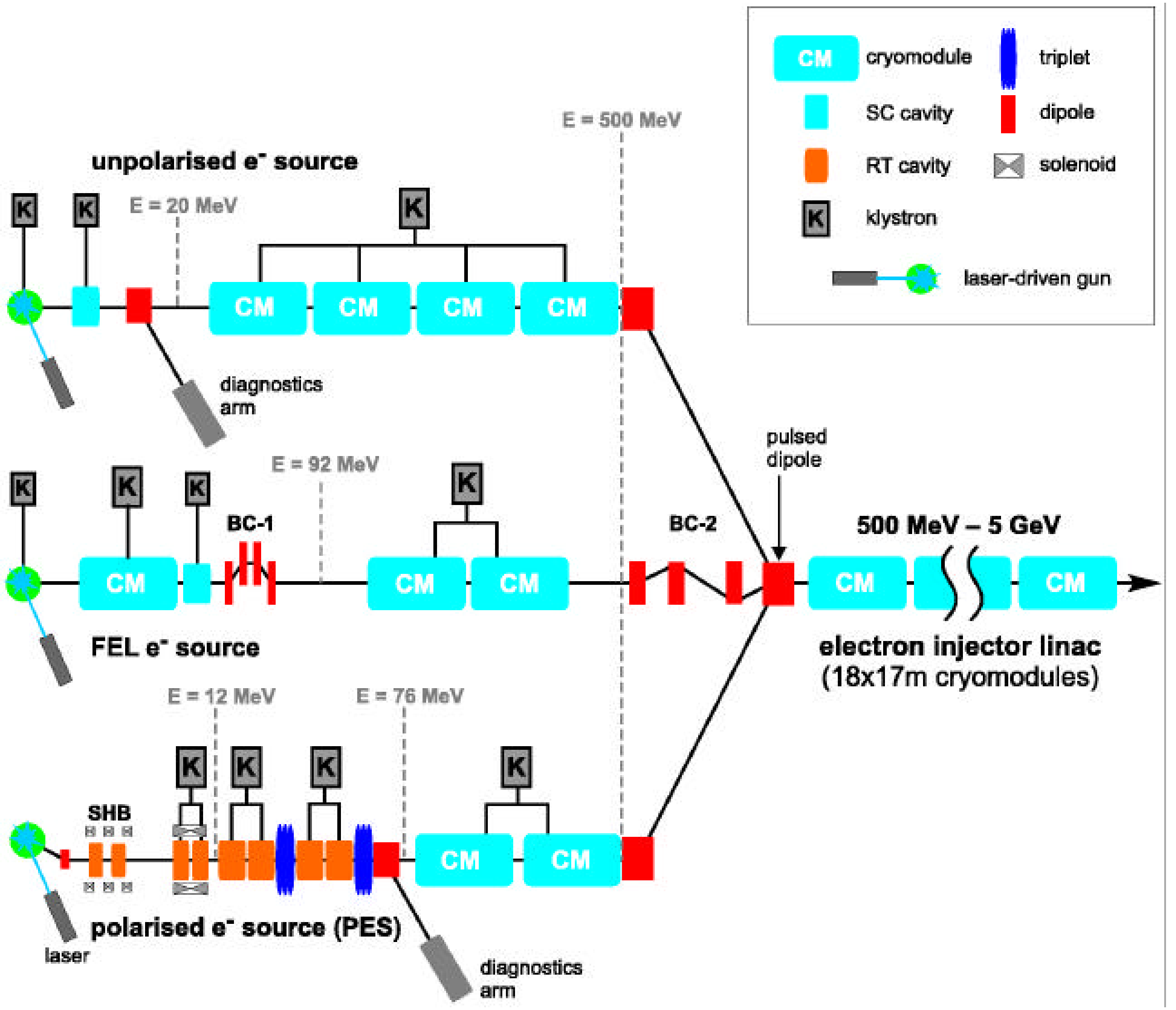
Positron Source



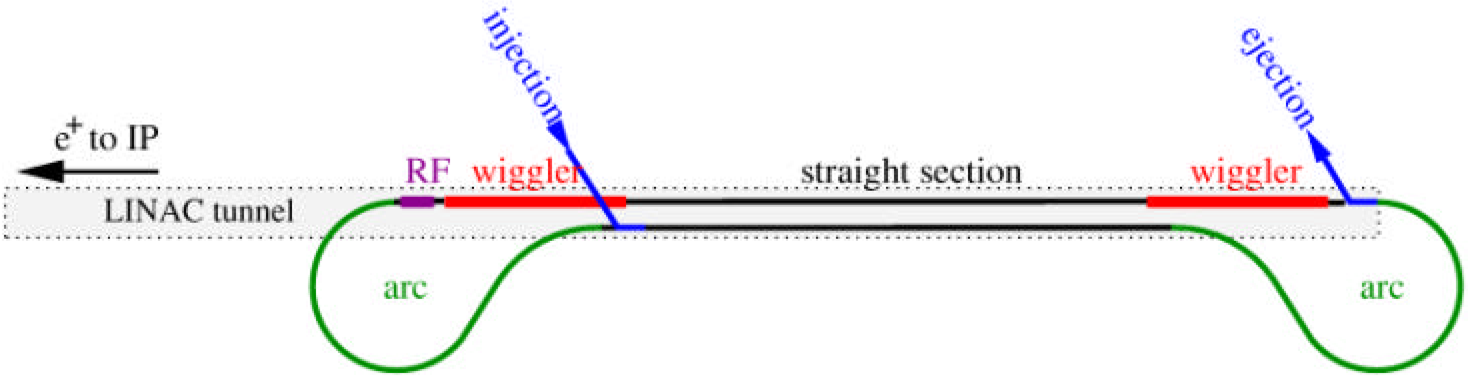
- γ produced by high energy electron beam in undulator placed before the IP

- Thin target converts the γ to positrons

Electron Sources

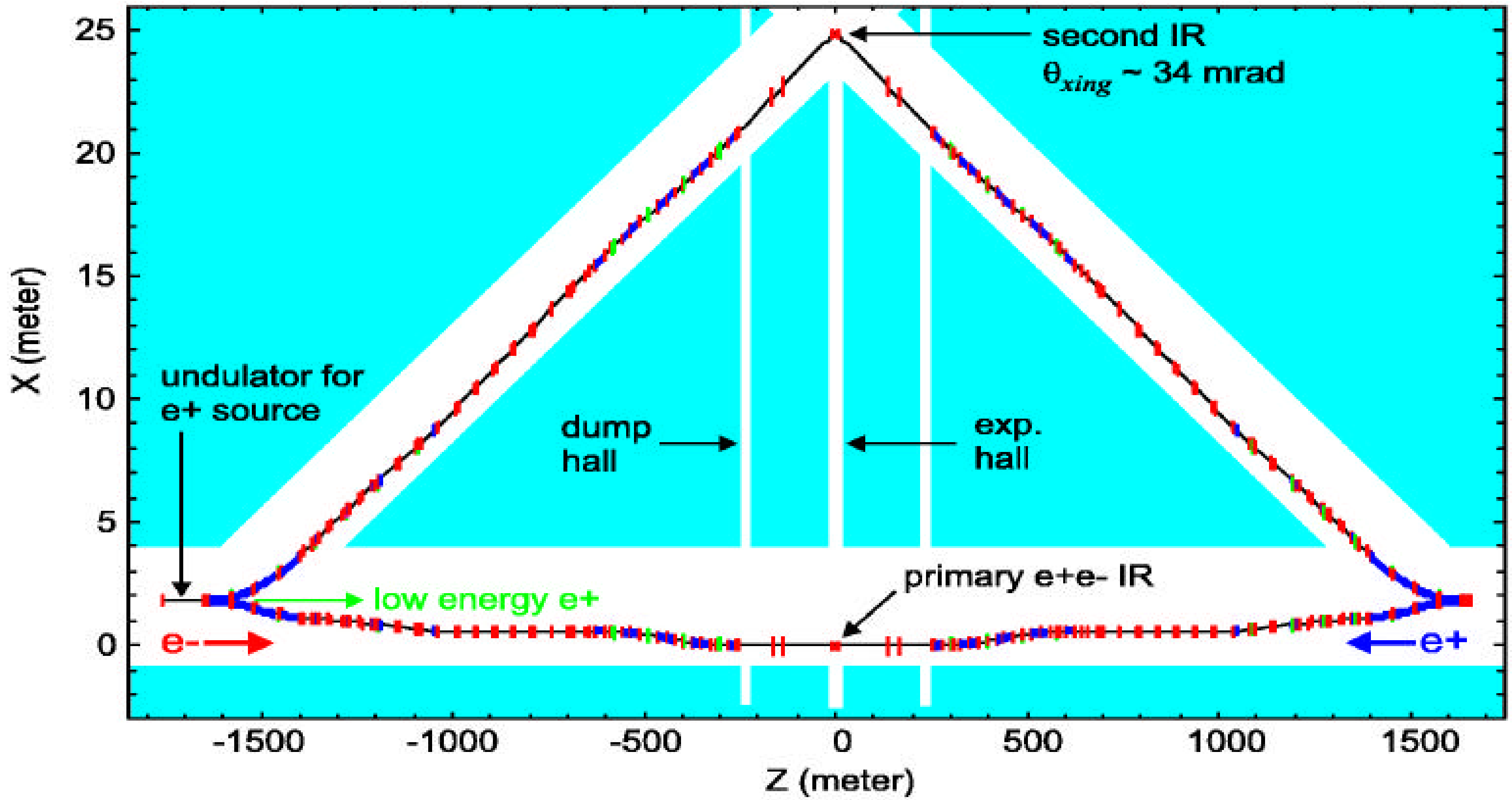


Damping Ring



- 17 km long to accommodate TESLA bunch train
- Looks unconventional, but major ‘new’ issue is space charge, cured by local coupling
- Needs a 20 ns rise/fall-time injection kicker system

Beam Delivery and Interaction Region

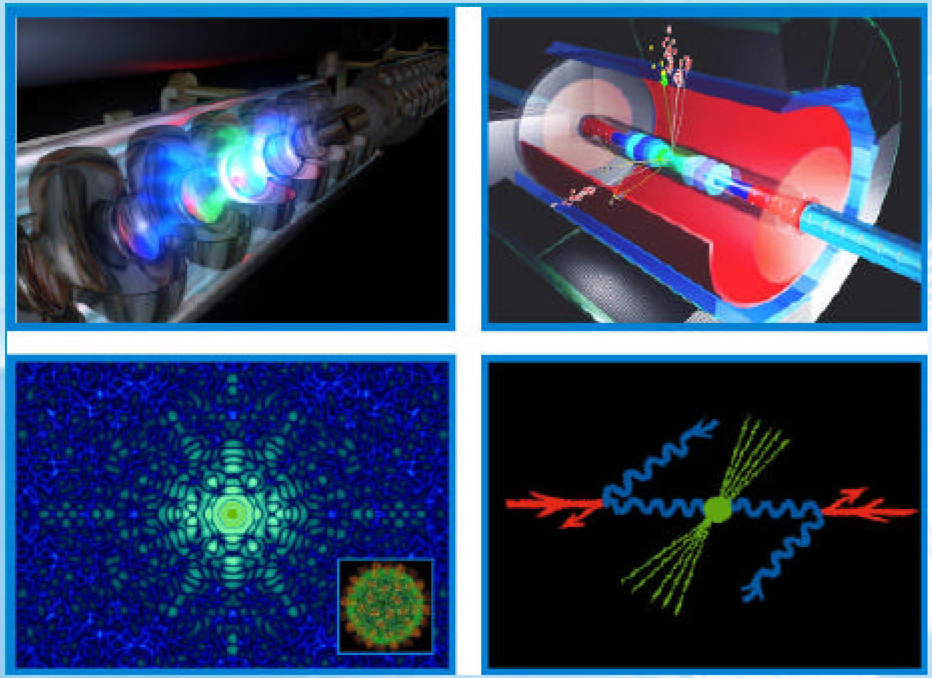


- 1st IP has no crossing angle
- FFTB style layout

TESLA Parameters

Site length	km	33			
# of cavities		21024			
Energy (c.m.)	GeV	500			800
		$e^+ e^-$	$e^- e^-$	$\gamma\gamma$	$e^+ e^-$
Repetition Rate	Hz	5			4
Beam pulse length	μs	950			860
# of bunches		2820			4886
Bunch spacing	ns	337			176
Charge per bunch		2e10			1.4e10
Beam size at IP	nm	553 / 5		157 / 5	391 /2.8
Bunch length at IP	mm	0.3			
Beamstrahlung	%	3.2	2.0	--	4.3
Luminosity	10^{34} $cm^{-2}s^{-1}$	3.4	0.47	0.6	5.8
Total beam power	MW	22.6			34
Linac electric power	MW	97			150
Accelerating gradient	MV/m	23.4			35
# of klystrons	MW	584			1240

The TDR



1: Executive Summary

2: The Accelerator

3: Physics at an e+e-Linear Collider

4: A Detector for TESLA

5: The X-Ray Free Electron Laser

6: Appendices

- Colloquium March 2001
- 1134 authors from 36 countries
- Part 2: The Accelerator
  - 380 authors
  - 54 institutes
  - major activity in 2000
  - Includes:
    - System description
    - Technical description
    - Project costs and schedule

tesla.desy.de/new_pages/TDR_CD/start.html

Highlights Cavity R&D

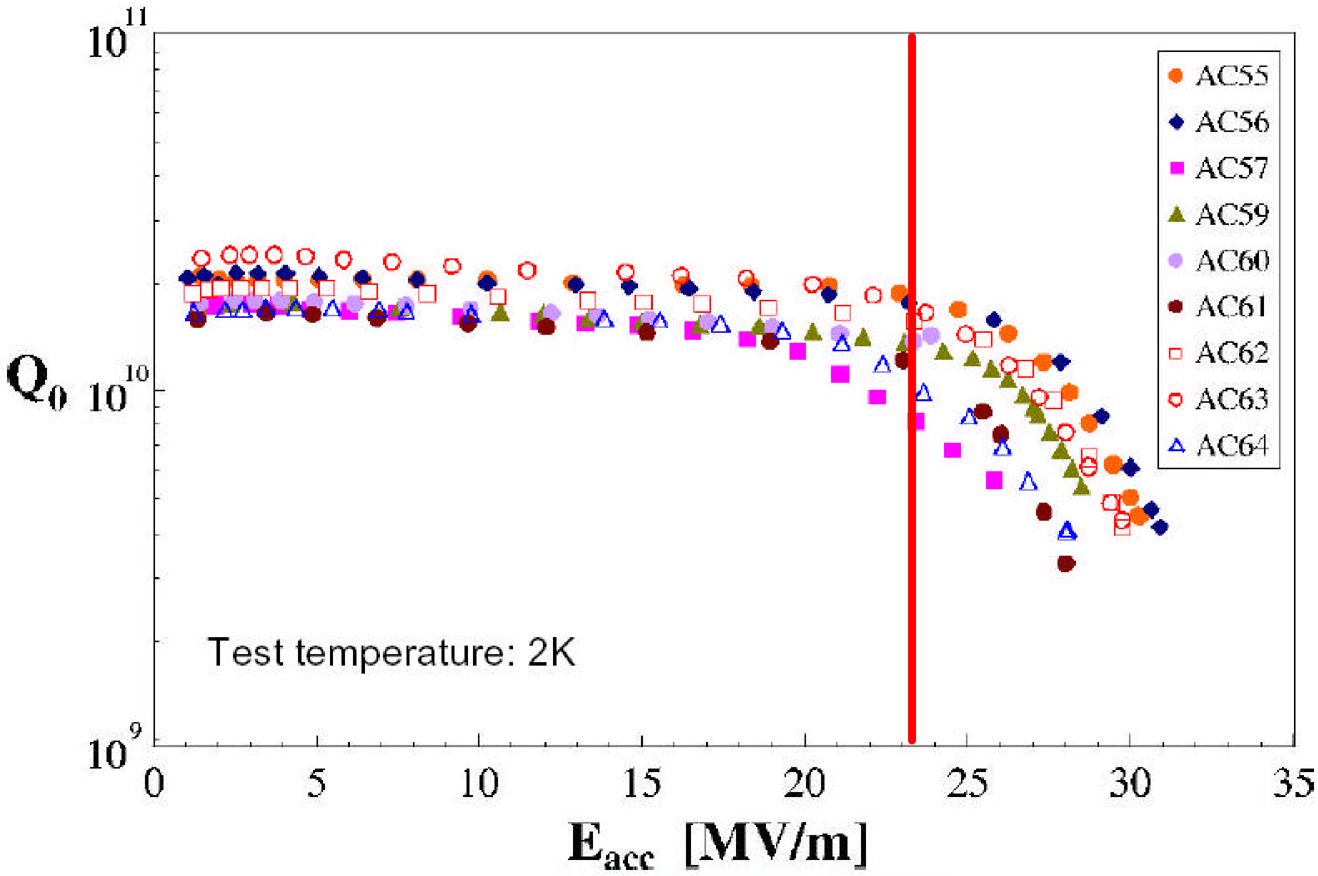
- Standard 9-cell cavities >25 MV/m
- Gradient record >42 MV/m in electro polished seamless single-cell NB cavity
- Gradient > 40 MV/m in seamless single-cell NBCu cavity and in electro polished single-cell NB cavity
- Gradient 32 MV/m in electro polished 9-cell NB cavity

Standard Cavity Preparation

- Niobium sheets (RRR=300) are eddy-current scaned to avoid foreign material inclusions
- Industrial production of full nine-cell cavities:
  - Deep-drawing of subunits (half-cells, etc.) from niobium sheets
  - Electron-beam welding according to detailed specification
- 800 °C high temperature treatment stress anneals the Nb and removes hydrogen
- 1400 °C high temperature treatment with titanium getter layer to increase the thermal conductivity (RRR=500)
- Chemical etching to remove damage layer and titanium getter layer
- High pressure water rinsing as final treatment to avoid particle contamination

What do we get?

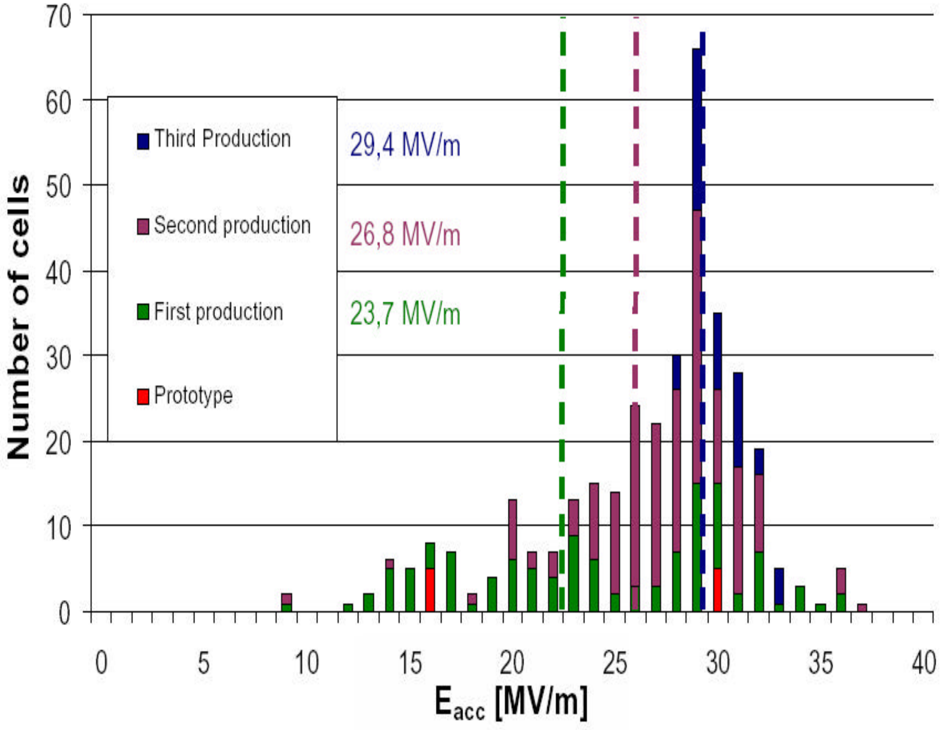
Excitation Curve Cavities Latest Production



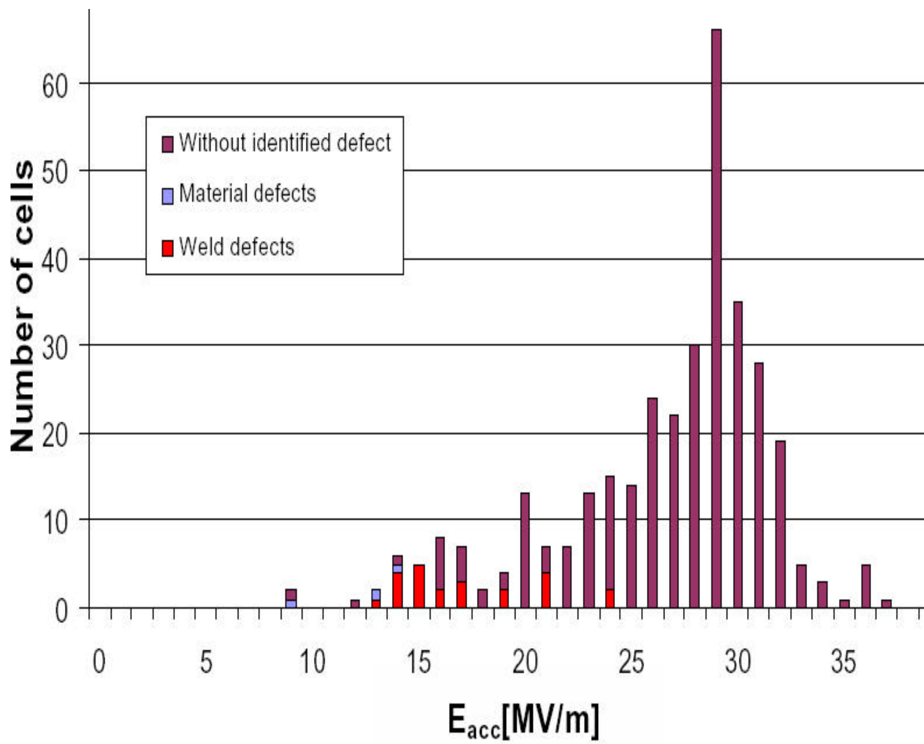
Some Statistics

Mode analysis (single cell gradient of 9-cell cavity)

Improvements 1st 2nd and 3rd production

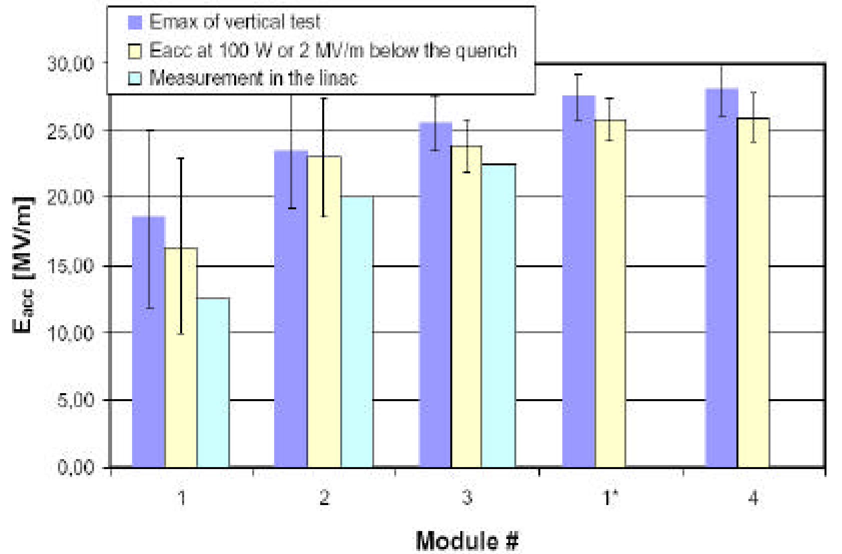


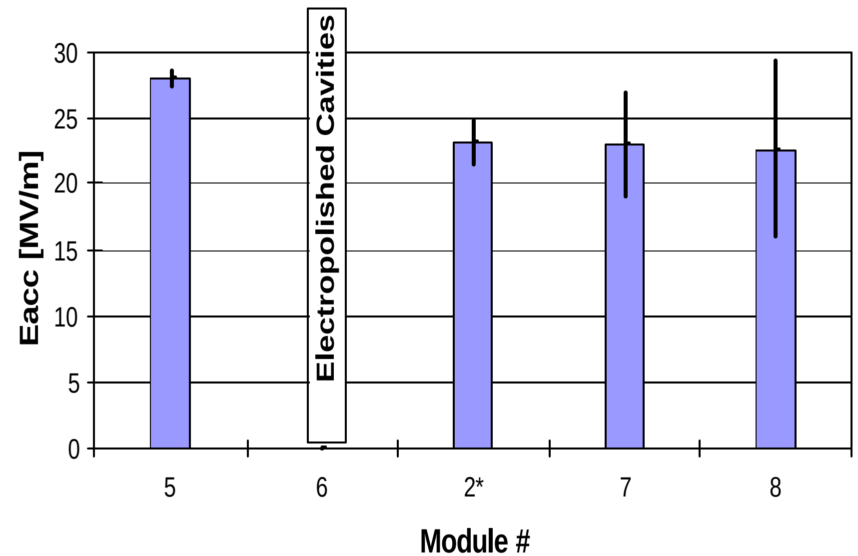
Knwon defects can explain tails



So – Where are we?

- 3 production series of 9-cell cavities with ≈ 30 cavities each
- Improvements for series 2 and 3:
  - welding technique
  - eddy current scans of every Nb-sheet to detect imperfections
- 5 modules built so far, 3 tested with beam
- 4 (+1) more modules to be built
  - one with electropolished cavities



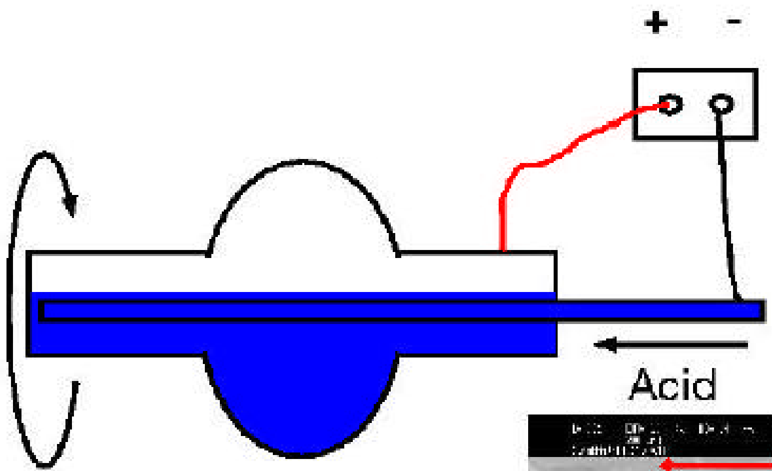


The Road to 35 MV/m

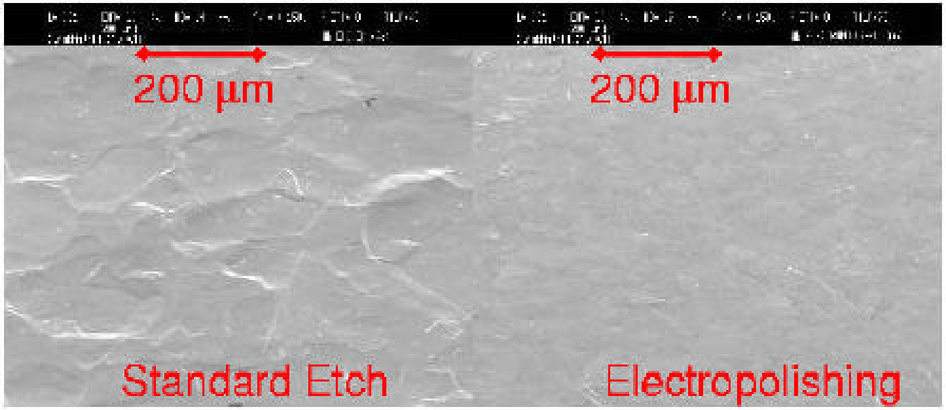
Quench limit	Improve surface quality of cavities through electropolishing
Lorentz forces / detuning	•Cavity stiffening •Active tuning with piezoelectric tuner
Field emission	Cleaning, high power conditioning

Electropolishing (KEK, CERN/CEA/DESY)

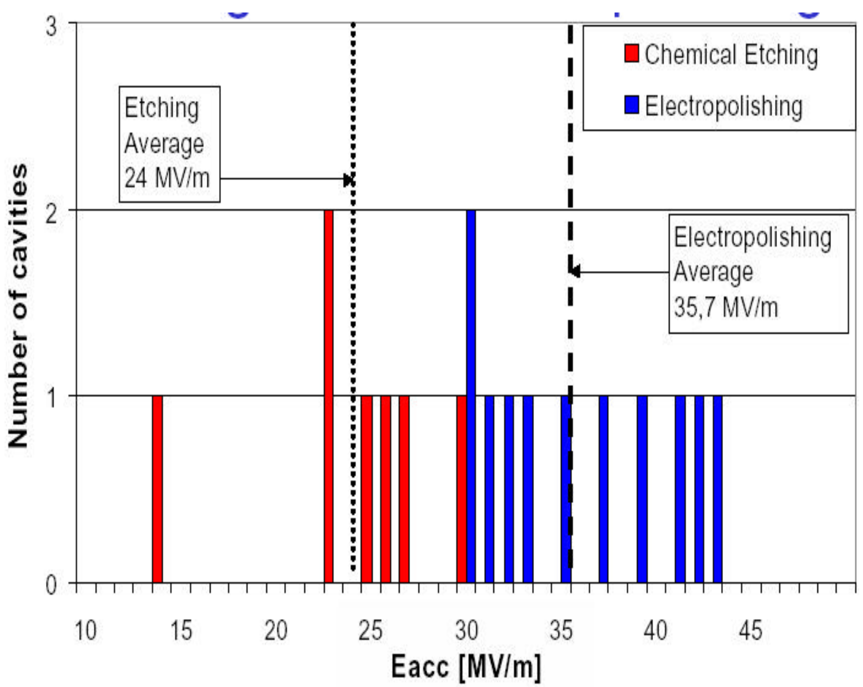
Electropolishing of 1-cell cavities (Scheme)

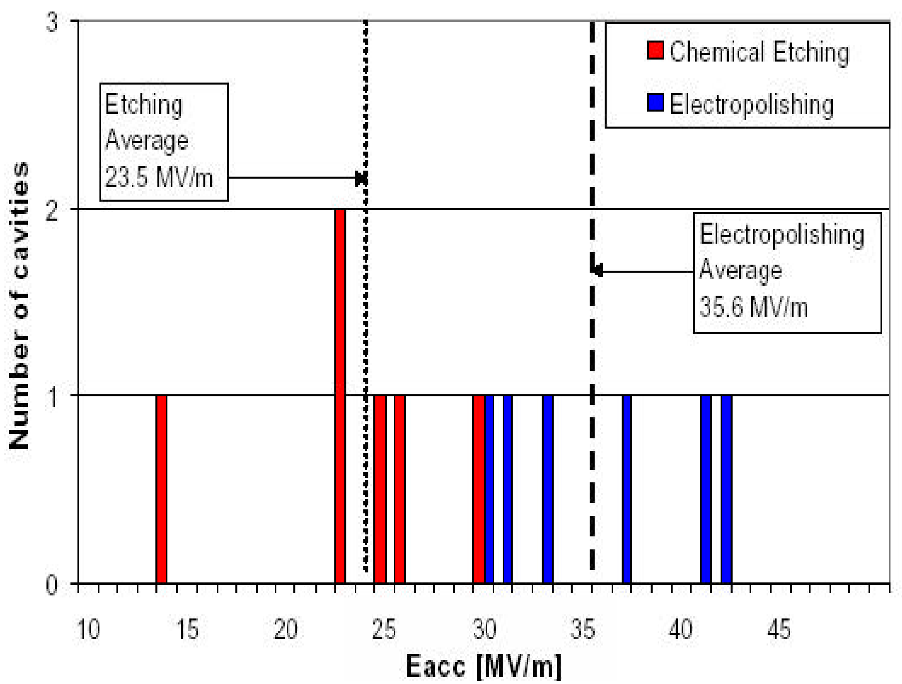


- EP electrolyte
- 90 % H_2SO_4
- 10 % HF
- 30 °C
- 0,5 µm/min removal of material



Electropolishing Results – Single Cell

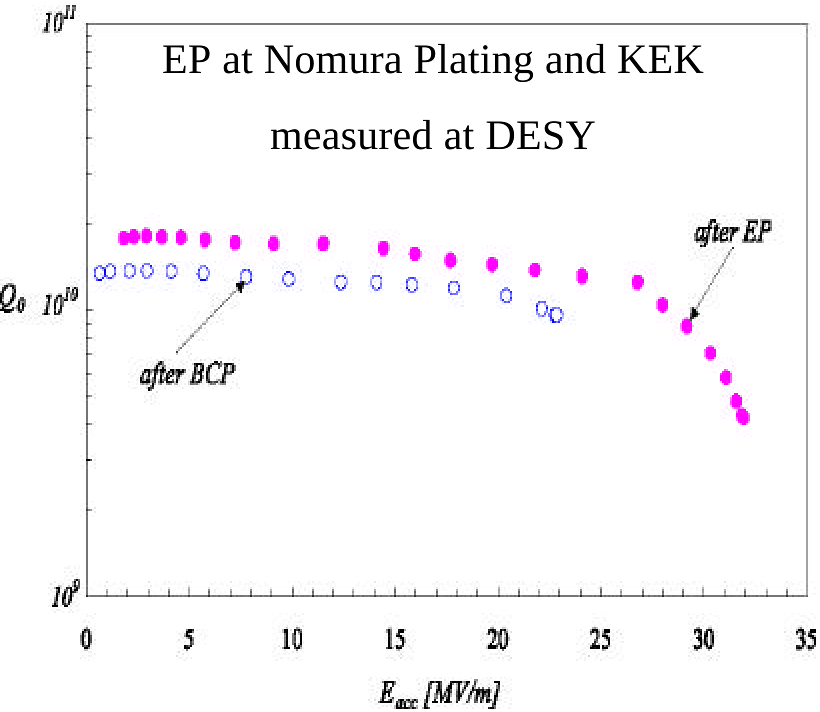




Sample of single cell NB cavities   Same 6 cavities after BCP resp. EP

12 cavities > 40 MV/m worldwide, 10 EP, 2BCP

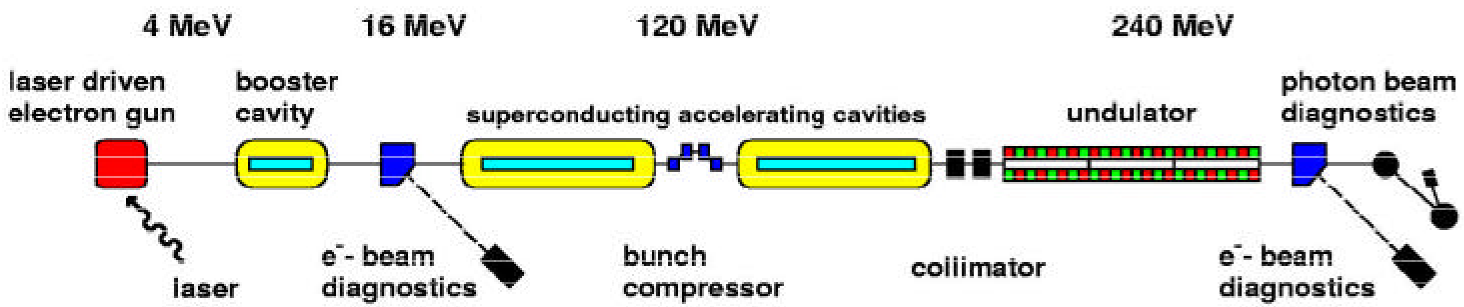
Electropolishing Results - 9-cell Cavities



9 cell NB cavity

- Very promising result on 1st EP 9-cell cavity
- Goal:
  - Improve EP procedure
  - Built a module out of EP cavities only by 2003
- Infrastructure for 9-cell EP built at DESY, commissioning starts March
- Module 6 will be made of EP cavities only, test in 2003

TESLA Test Facility

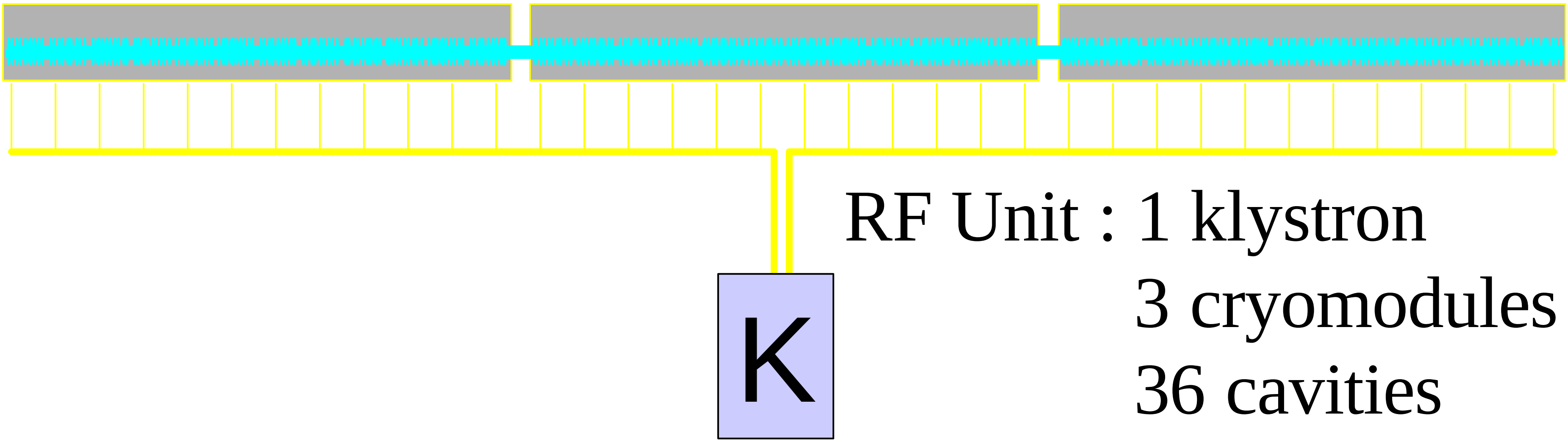


- First SASE at 109 nm February 2000
- Saturation at 100 nm September 2001

Future Module Tests at TTF1 and 2

• Full beam-loading with high gradient	March/April 02
• Superstructure without/with beam	July-September 02
• Reconstruction TTF1 to TTF2	May 02 – June 03
• Module 1* (25 MV/m)	July-October 02
• Module 3, 4, 5 (all around 25 MV/m)	
– RF tests	Feb.-April 03
– Beam operation	start July 03
• Module 6 (electro-polished)	
– On module test stand	End of 2003
– In TTF2	2004

TESLA RF Distribution System



RF Unit : 1 klystron

3 cryomodules

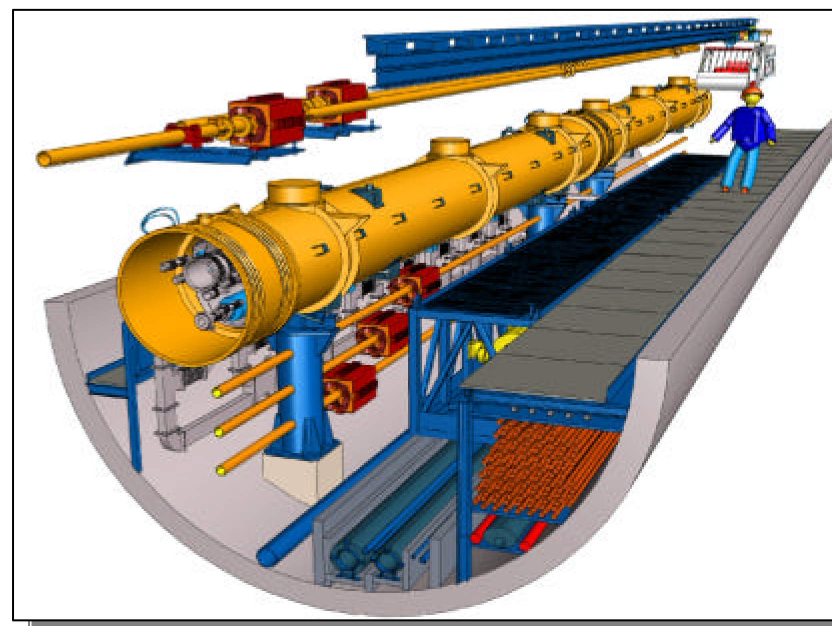
36 cavities

286 RF Units per LINAC :

10,296 Cavities

858 Cryomodules

286 Klystrons



Multibeam Klystron

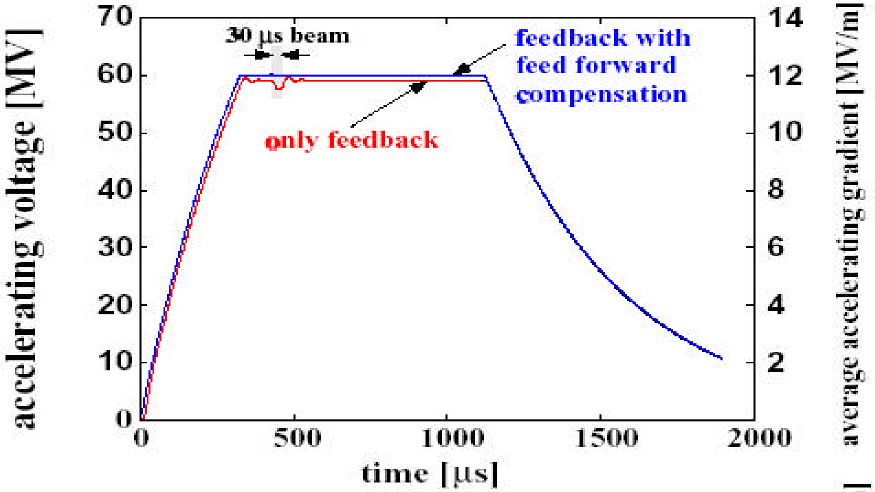
Acceptance test:

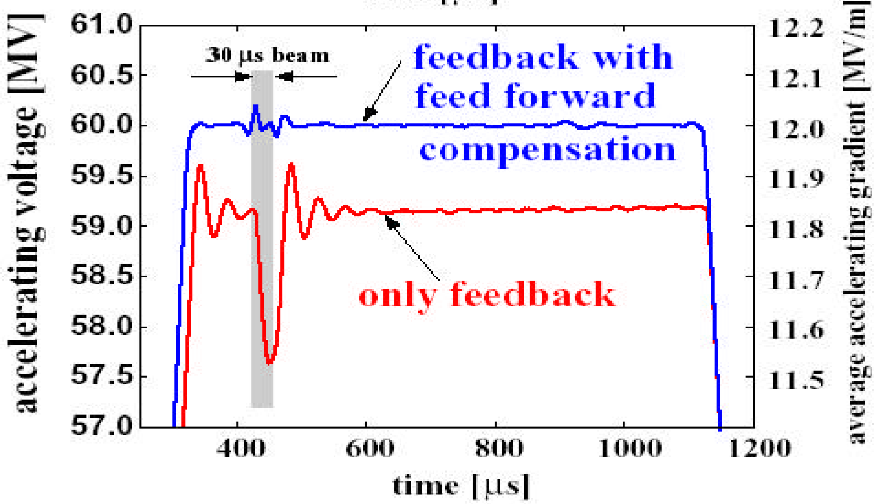
116 kV, 10 MW, 1.5 ms, 5 Hz, η=65%

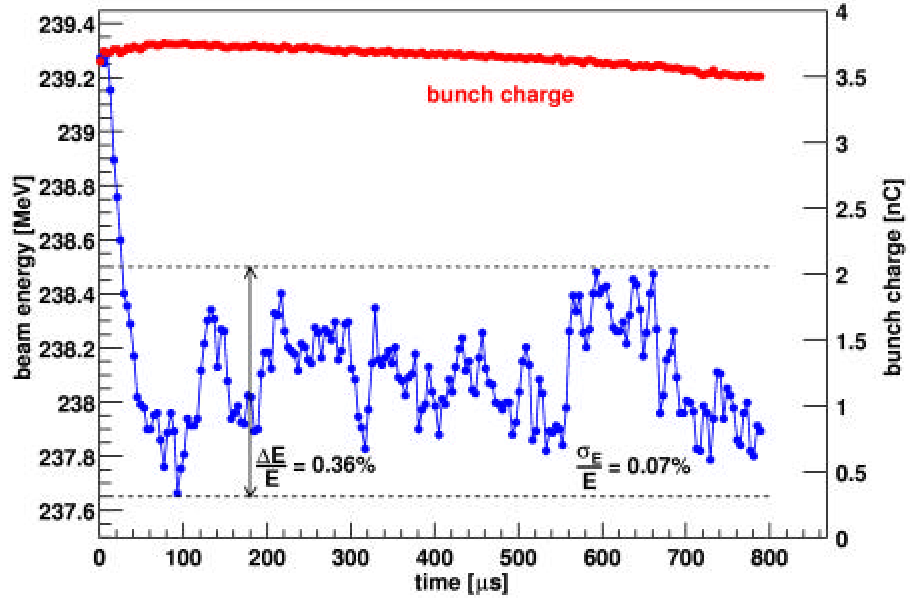
Typical operation at TTF in 2001:

95-100 kV, 3-4 MW, 1.5 ms, 1 Hz

Beam Loading Compensation



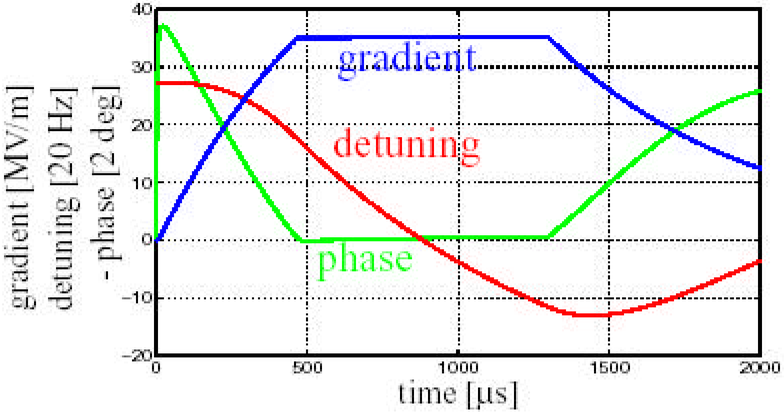


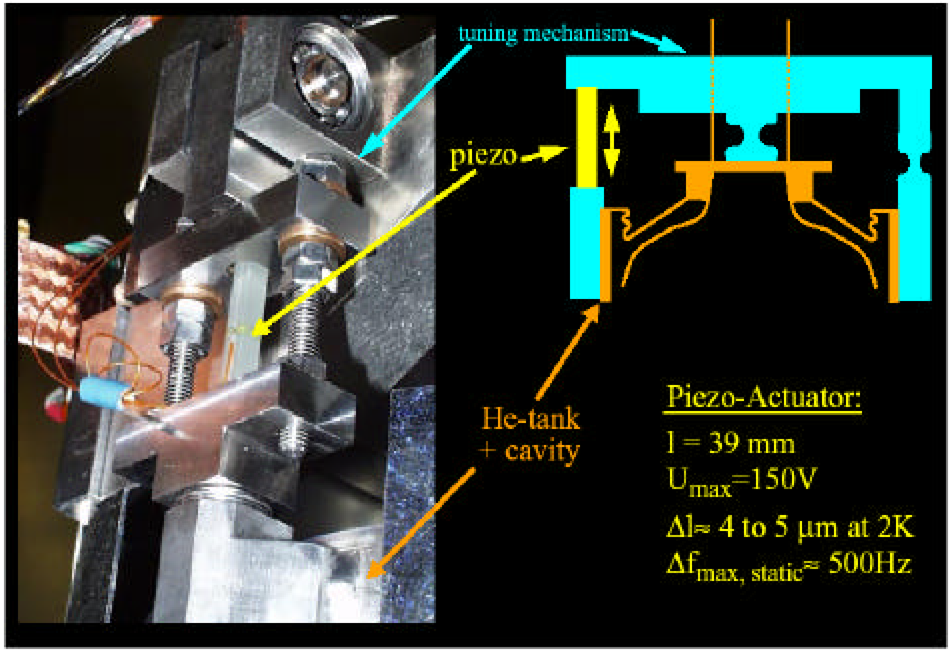


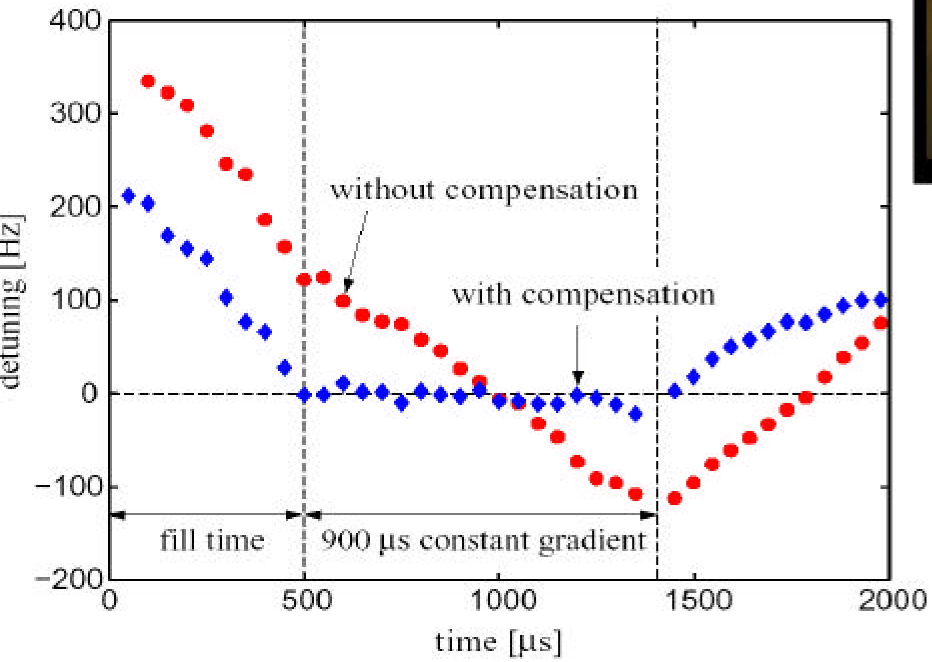
Full TESLA current

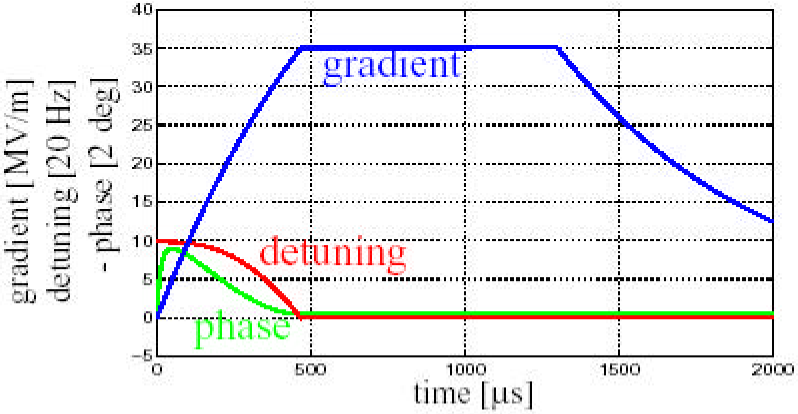
Performance of low level RF control

Lorentz Force Detuning

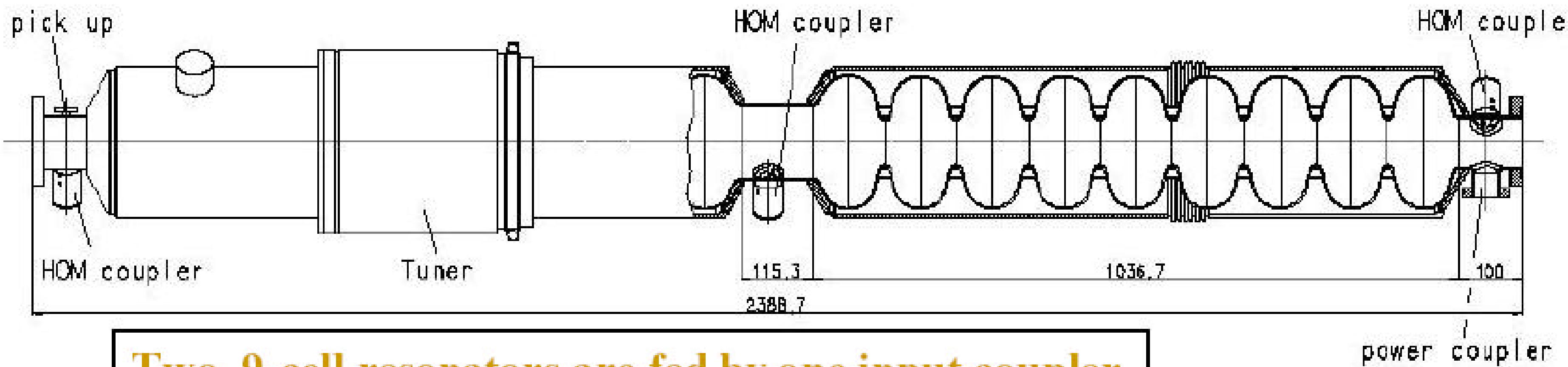








Superstructure



Two 9-cell resonators are fed by one input coupler

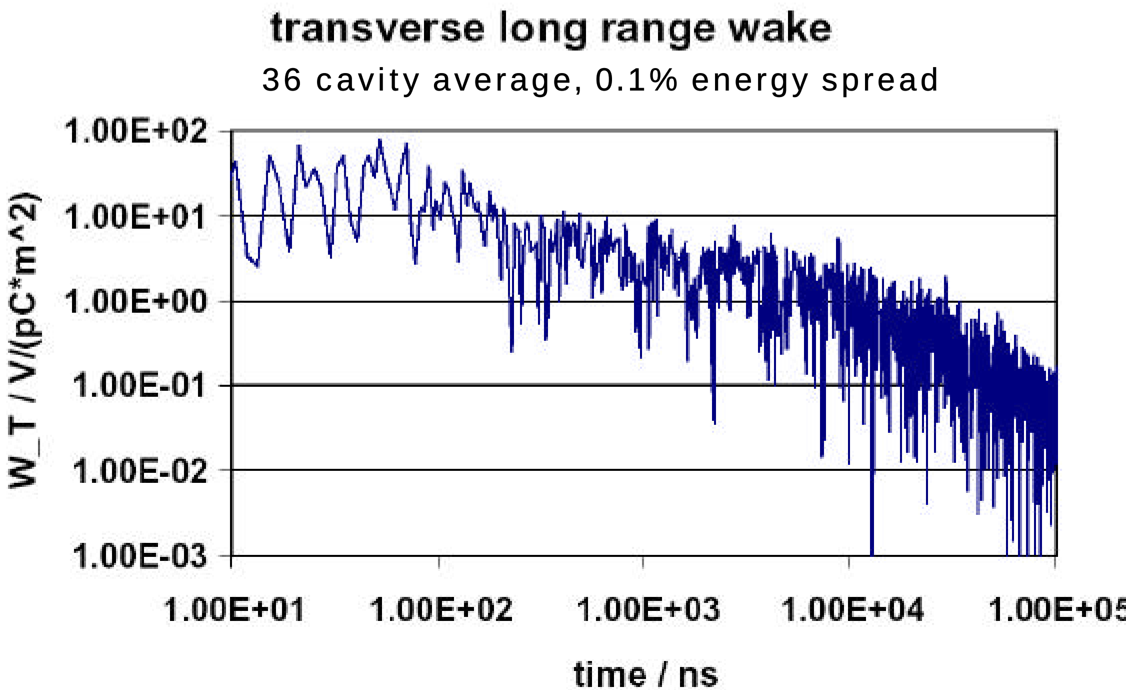
Higher filling factor 78.9% -- 84.8%
ie gradient for 500 GeV
23.4 -- 22 MV/m

Less input couplers and simpler waveguide-system
Reduced cost

Resonators have independent tuners

TESLA HOM Model

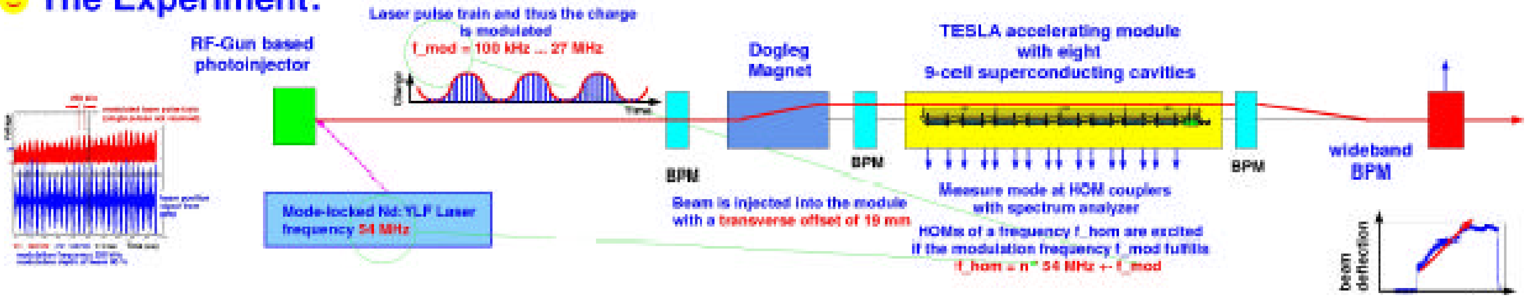
Frequency (ave. meas.) [GHz]	Loss factor (simulation) $[V/pC/m^2]$	R/Q (simulation) $[\Omega/cm^2]$	Q (meas.)
	TE_{111}-like		
1.6506	19.98	0.76	$7.0 \cdot 10^4$
1.6991	301.86	11.21	$5.0 \cdot 10^4$
1.7252	423.41	15.51	$2.0 \cdot 10^4$
1.7545	59.86	2.16	$2.0 \cdot 10^4$
1.7831	49.20	1.75	$7.5 \cdot 10^3$
	TM_{110}-like		
1.7949	21.70	0.77	$1.0 \cdot 10^4$
1.8342	13.28	0.46	$5.0 \cdot 10^4$
1.8509	11.26	0.39	$2.5 \cdot 10^4$
1.8643	191.56	6.54	$5.0 \cdot 10^4$
1.8731	255.71	8.69	$7.0 \cdot 10^4$
1.8795	50.80	1.72	$1.0 \cdot 10^5$
	TE-like		
2.5630	42.41	1.05	$1.0 \cdot 10^5$
2.5704	20.05	0.50	$1.0 \cdot 10^5$
2.5751	961.28	23.80	$5.0 \cdot 10^4$

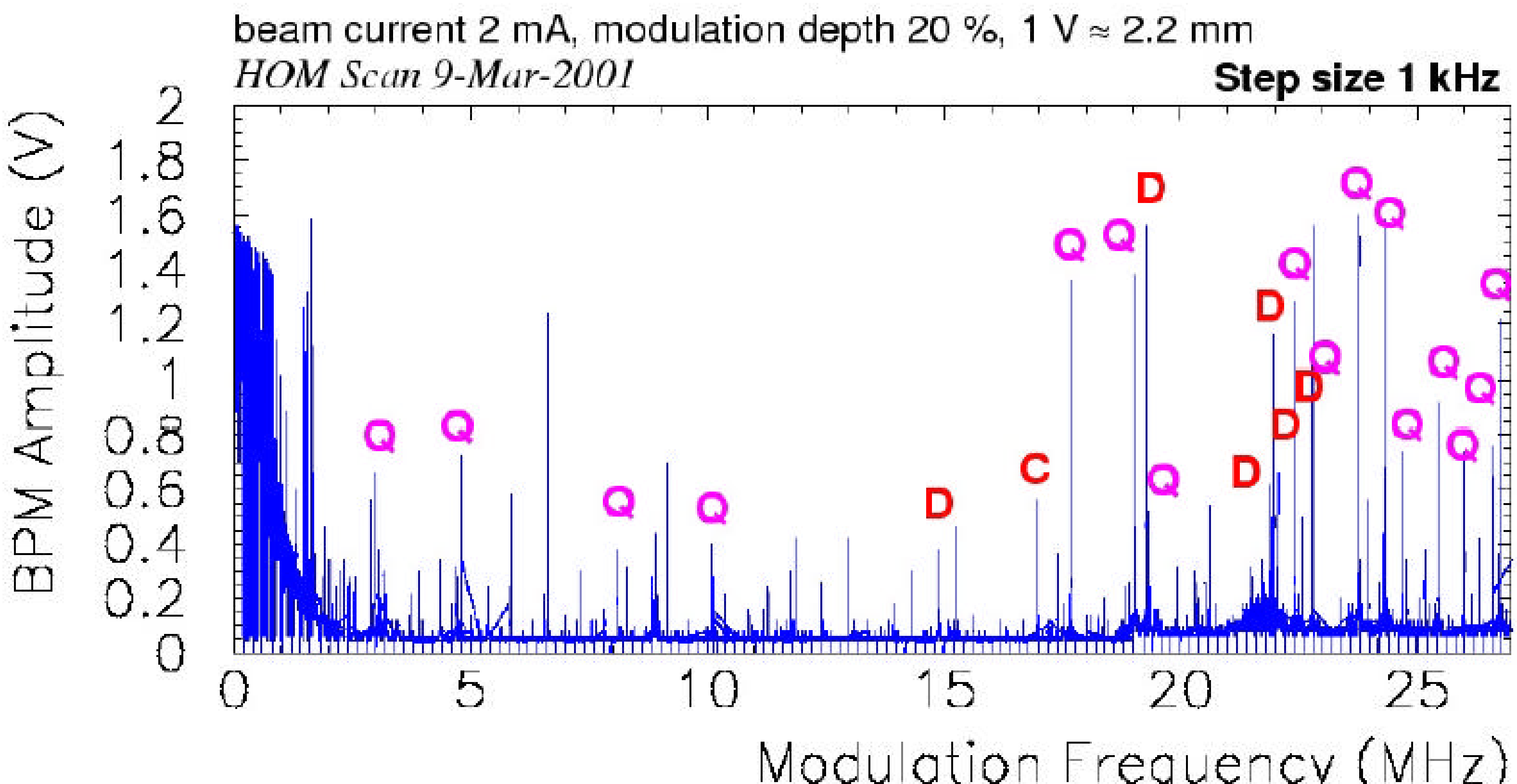


all modes damped below 1×10^5, but …

Higher Order Mode Measurements with Beam

The Experiment:





High-Q HOM in the 3rd Passband

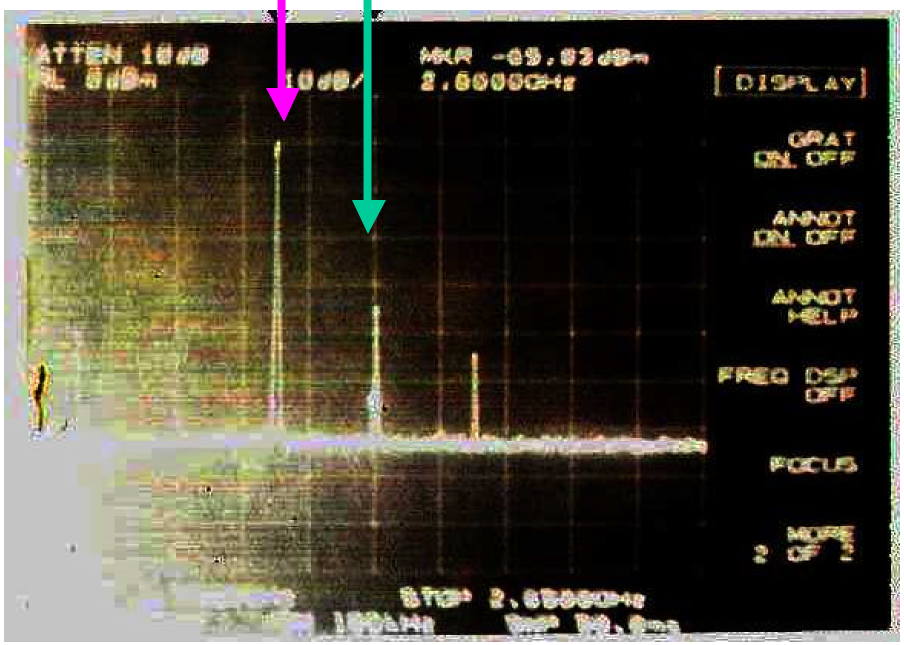
- Measured with intensity modulated beam with position offset
- Detected in HOM coupler and broadband BPM

HOM Pickup Signal

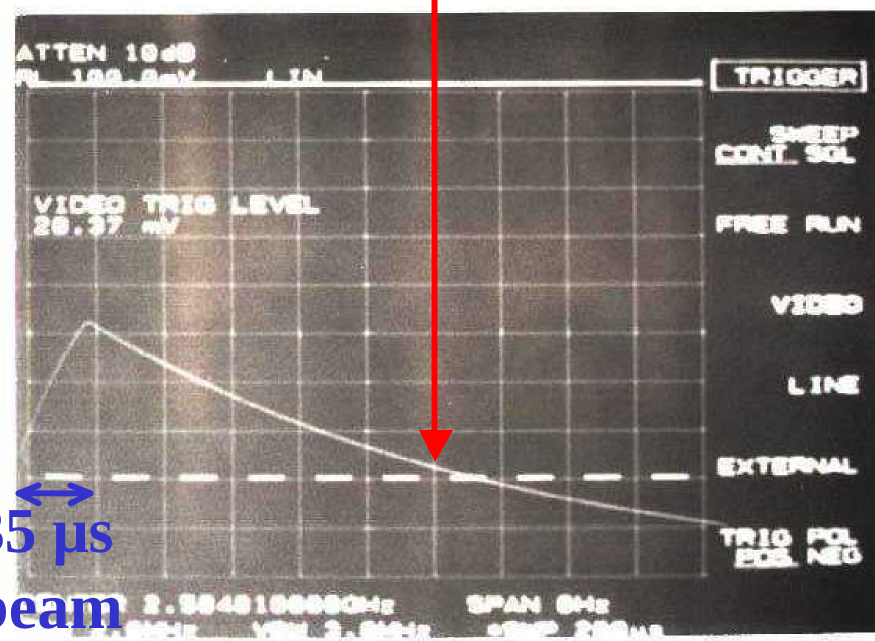
HOM at 2.585 GHz

Beam at 2.6 GHz

Decay time ⇒ $Q = 10^6$



frequency domain



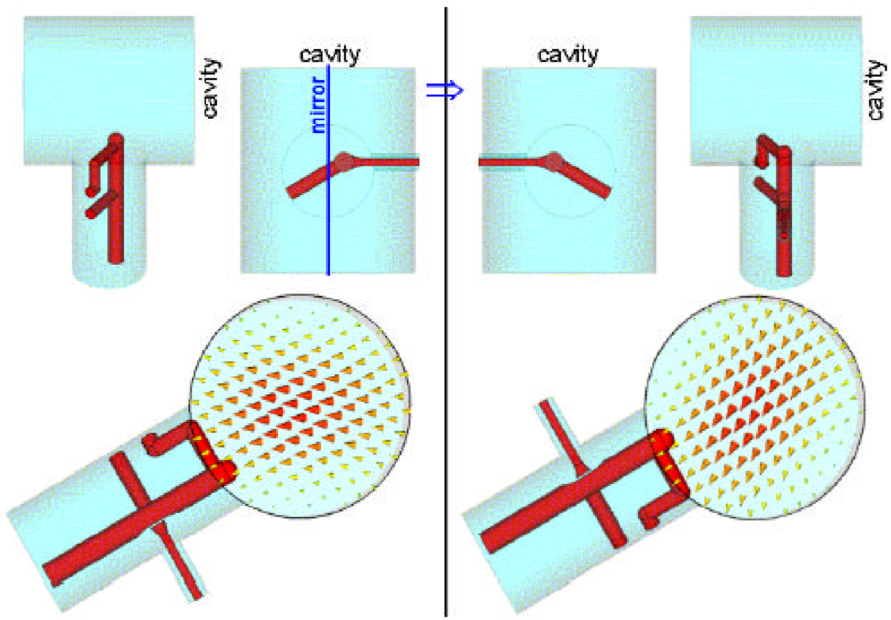
35 µs beam

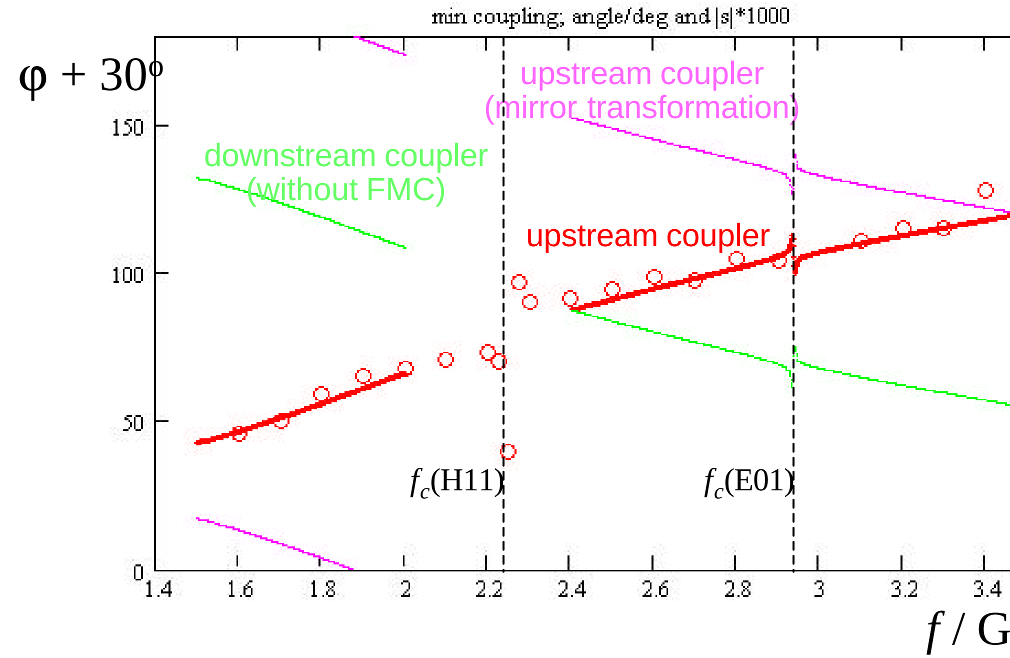
time domain

Damping the 2.585 GHz mode

DESY type
HOM coupler

One coupler is
"mirrored"

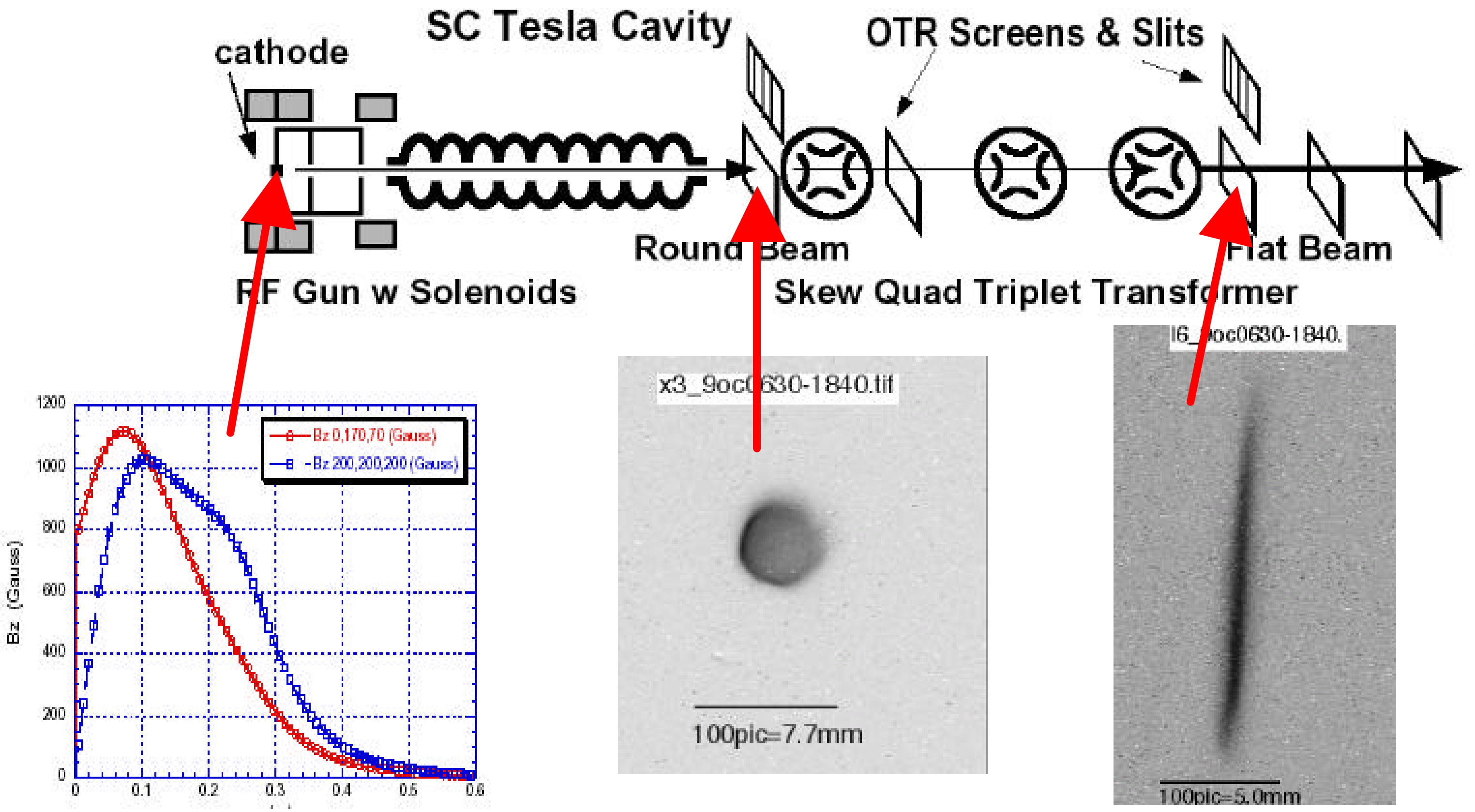




Coupling depends on frequency
and polarization

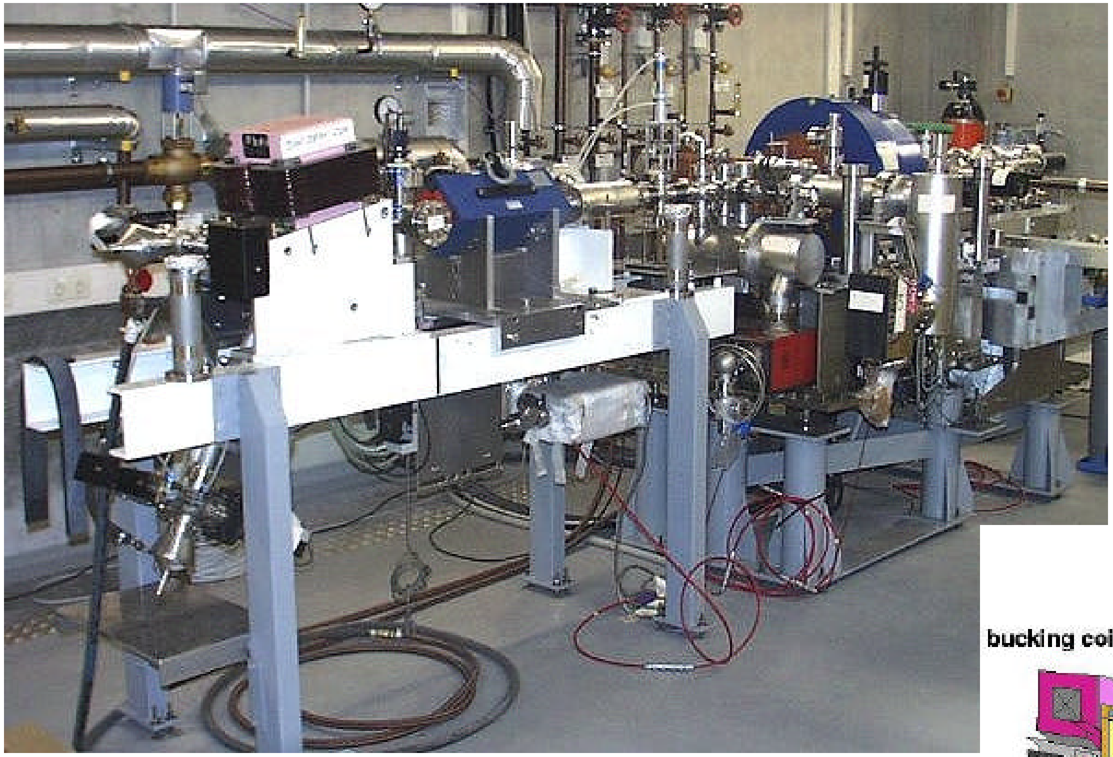
Flat Beam Experiment at A0/FERMILAB

Extract flat beam from RF-gun through combination of non-zero solenoid field on cathode surface and skew quad beam transformer

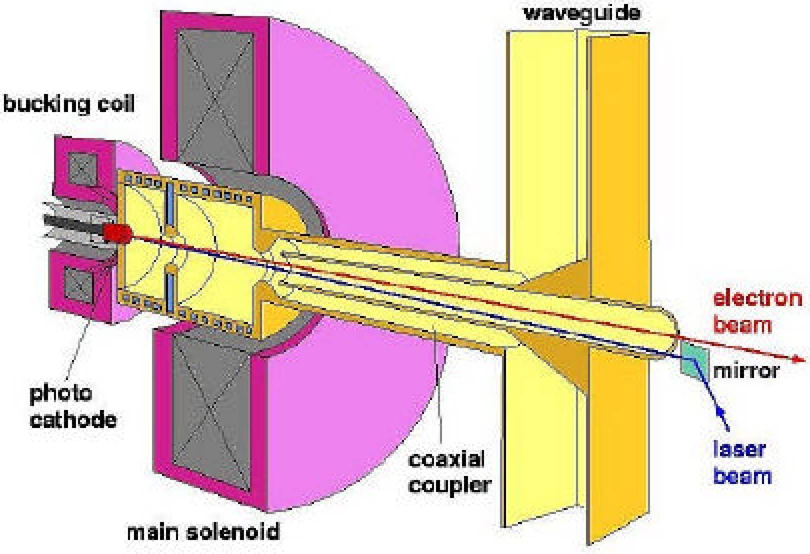


Maximum measured emittance ratio: 50/1

Photo Injector Test Stand in Zeuthen



First photo electrons January 2002



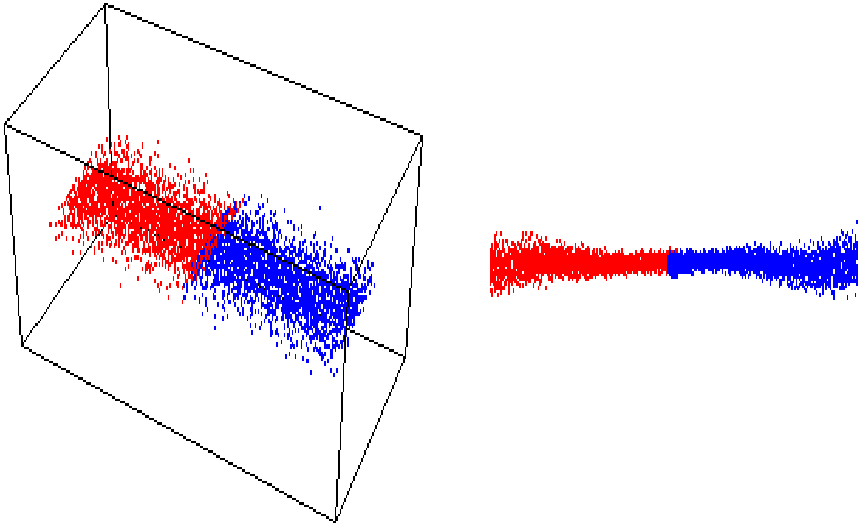
‘Banana’ Effect – Beam-Beam Simulation

•Instability driven by vertical beam profile distortion

•Strong for high disruption

•Distortion caused by transverse wakefields and quad offset – only a few percent emittance growth

•Tuning can remove static part

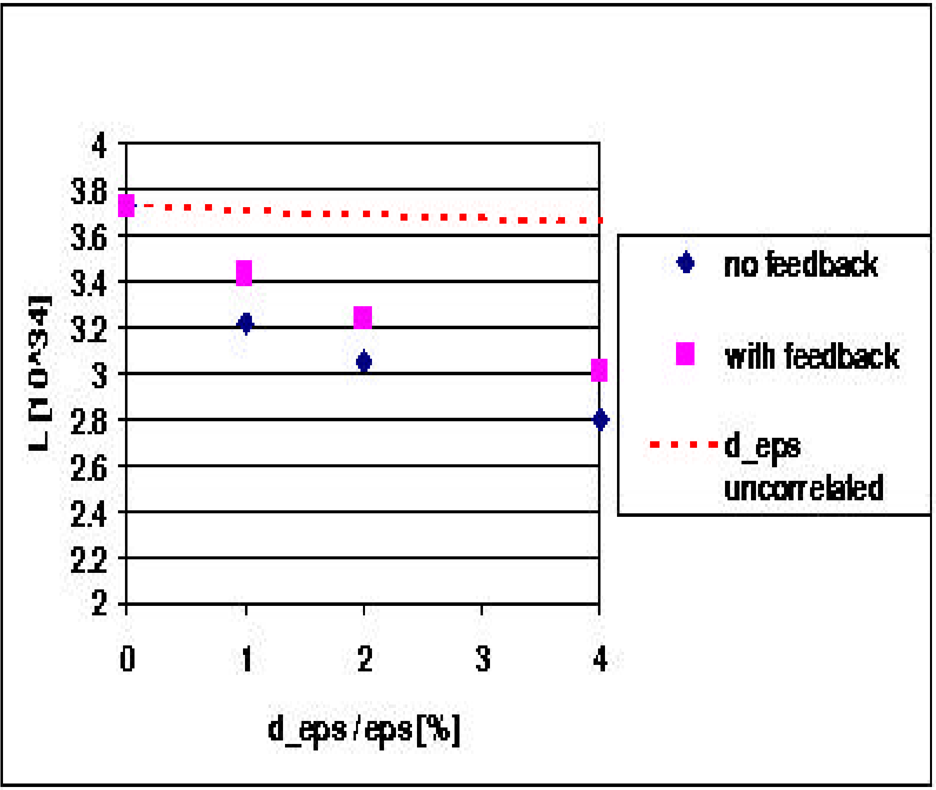


Nominal TESLA Beam Parameters +

y-z correlation (equivalent to few % projected emittance growth)

Beam centroids head on

‘Banana’ Effect

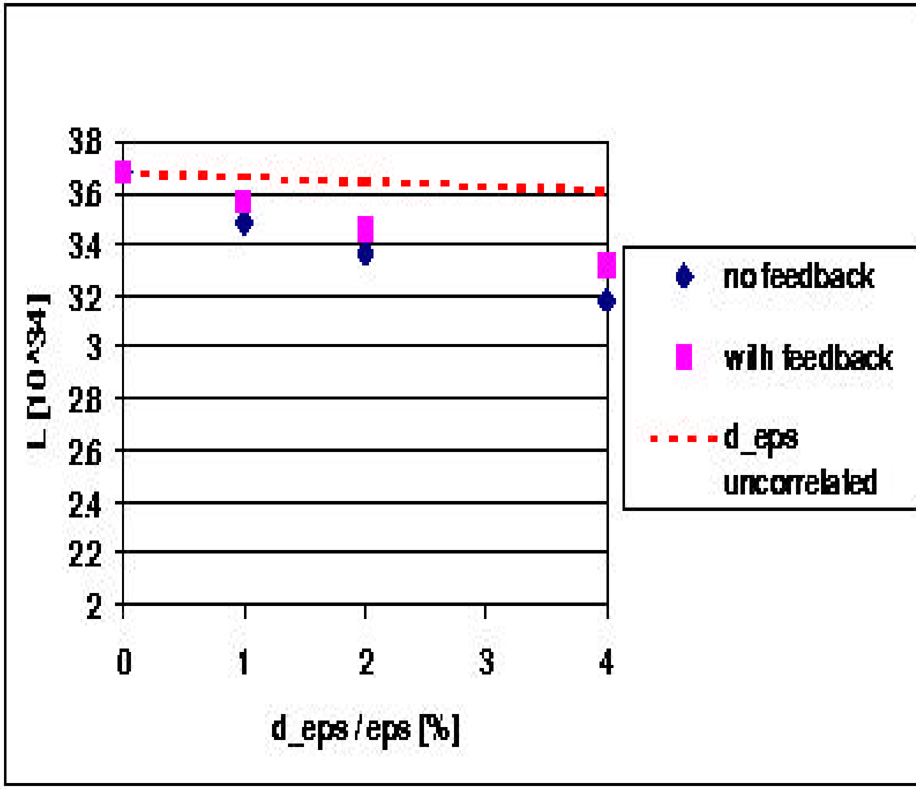


TDR Parameters

σ_s= 300 μm

β_x= 15 mm

β_y= 0.4 mm



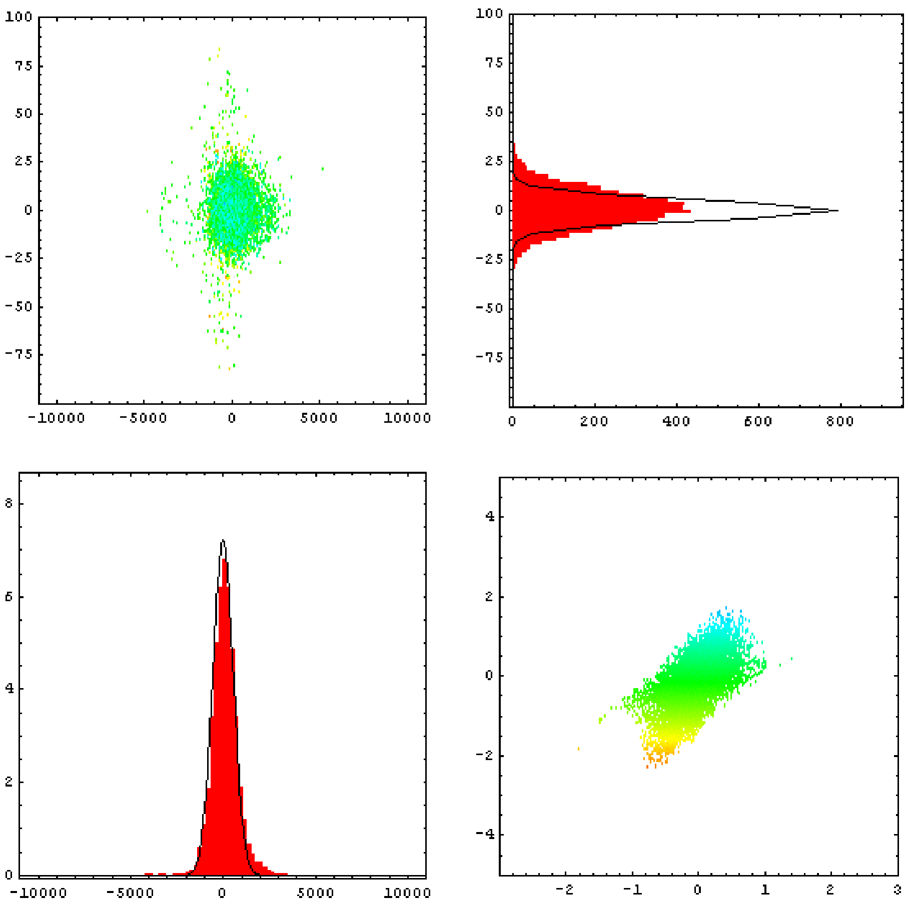
Bunch length shortened

σ_s= 150 μm

β_x= 20 mm

β_y= 0.3 mm

DR to IP Simulations



Gaussian bunch from DR

Ideal machine

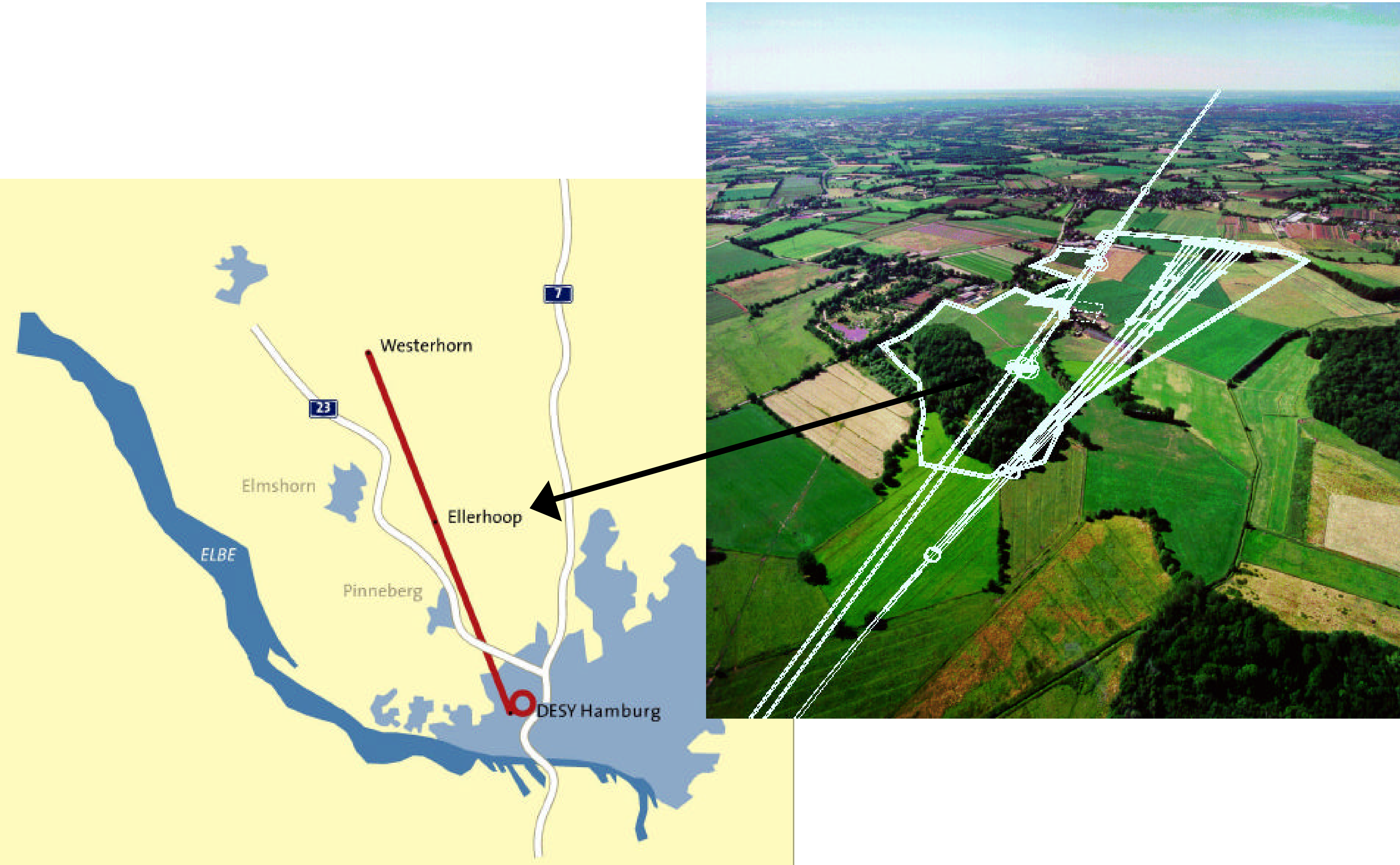
Change of bunch compressor phase by ± 2.5 deg (powerfull knob at the SLC)

This is just an example what one can (and will) do now

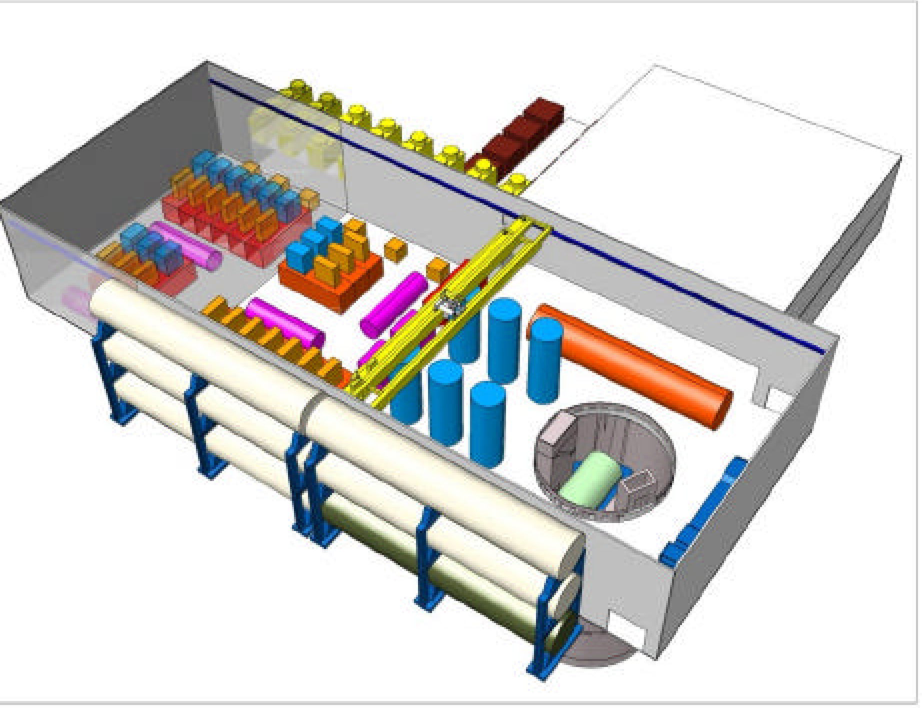
Planfeststellungsverfahren (PFV)

- Procedure to obtain legal approval to built TESLA on the specific site (not the political approval)
- Investigate:
  - Impact on Environment
  - Impact on Humans
  - Impact on Ecology
  - Safety issues
  - ...

Experimental Area



DESY Site and Cryo-Hall



Church of Rellingen

PFV

- Group of approximately 30 people (DESY and external contractors) works on:
  - Compiling the relevant informtion
  - Provide information to the public
- 3-D CAD heavely used for planing and communicating the concept
- Information publically available on the WWW

  http://www.desy.de/tesla-planung/
- This is almost like pooring the concrete

Summary

- 9 years of R&D on TESLA culminated in the publication of the TDR March 2001
- The technology for a 500 GeV collider is at hand
- Cavity R&D program continues with the goal to reach the ultimate performance limit of SC cavities
- TESLA collaboration has initiated the formal approval procedure to built a linear collider in Hamburg
- Since Snowmass 2001 a very intense international discussion has started on how, who, where, what, when

  … and will continue during LC02

Thanks to all colleagues for providing me with information.