ECFA Study

Physics and Detectors
for a Linear Collider

First Workshop
Montpellier, France, 13-16 November 2003

Report on the TESLA Project

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Talk Outline

- The e+ e- TeV Collider must be linear
- Competing Technologies
- The TESLA Challenge
- Status of the TESLA Project
- First and Second ILC-TRC
- Ongoing work for the best LC
- Concluding remarks

Linear vs Circular

- Historically: circular colliders are the machine of choice in HEP
- **But** not at ultra-high energy for electrons! SR scaling law for electrons:

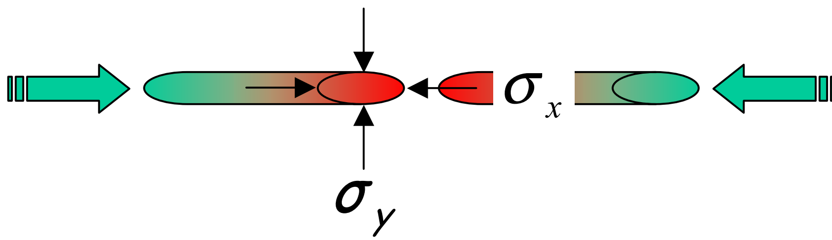
$$U_{SR}\ [\text{GeV/turn}] = 8.85 \times 10^{-5}\ E^4\ [\text{GeV}]\ /\ r\ [\text{m}]$$

- Ring RF system must replace this loss
- Balance length costs vs RF system costs
  - r scales approximately as E^2
  - LEP @ 100 GeV/beam: 27 km around, 2 GeV/turn lost
  - Possible scale to 250 GeV/beam i.e. **E_{cm} = 500 GeV**:
    - **170 km** around
    - **13 GeV/turn** lost
- Consider also the luminosity
  - For a luminosity of ~ 10^{34}/cm^2/second, rings use ~ amperes of beam current
  - 13 GeV/turn x 2 amperes = **26 GW RF power**
  - Because of conversion efficiency, this collider would consume more power than the state of **California in summer: ~ 45 GW**
- Both size and power seem excessive

U_{SR}	=	energy loss per turn
E	=	beam energy
r	=	machine radius

All you need is... Luminosity

$$L \propto \frac{N_e^2}{\sigma_x \sigma_y}$$



$$L \propto n_b \times f_{rep}$$

L = Luminosity

N_e = # of electron per bunch

$\sigma_{x,y}$ = beam sizes at IP

IP = interaction point

$$L \propto \frac{P_b}{E_{c.m.}} \times \frac{N_e}{\sigma_x \sigma_y}$$

N_b = # of bunches per pulse

F_{rep} = pulse repetition rate

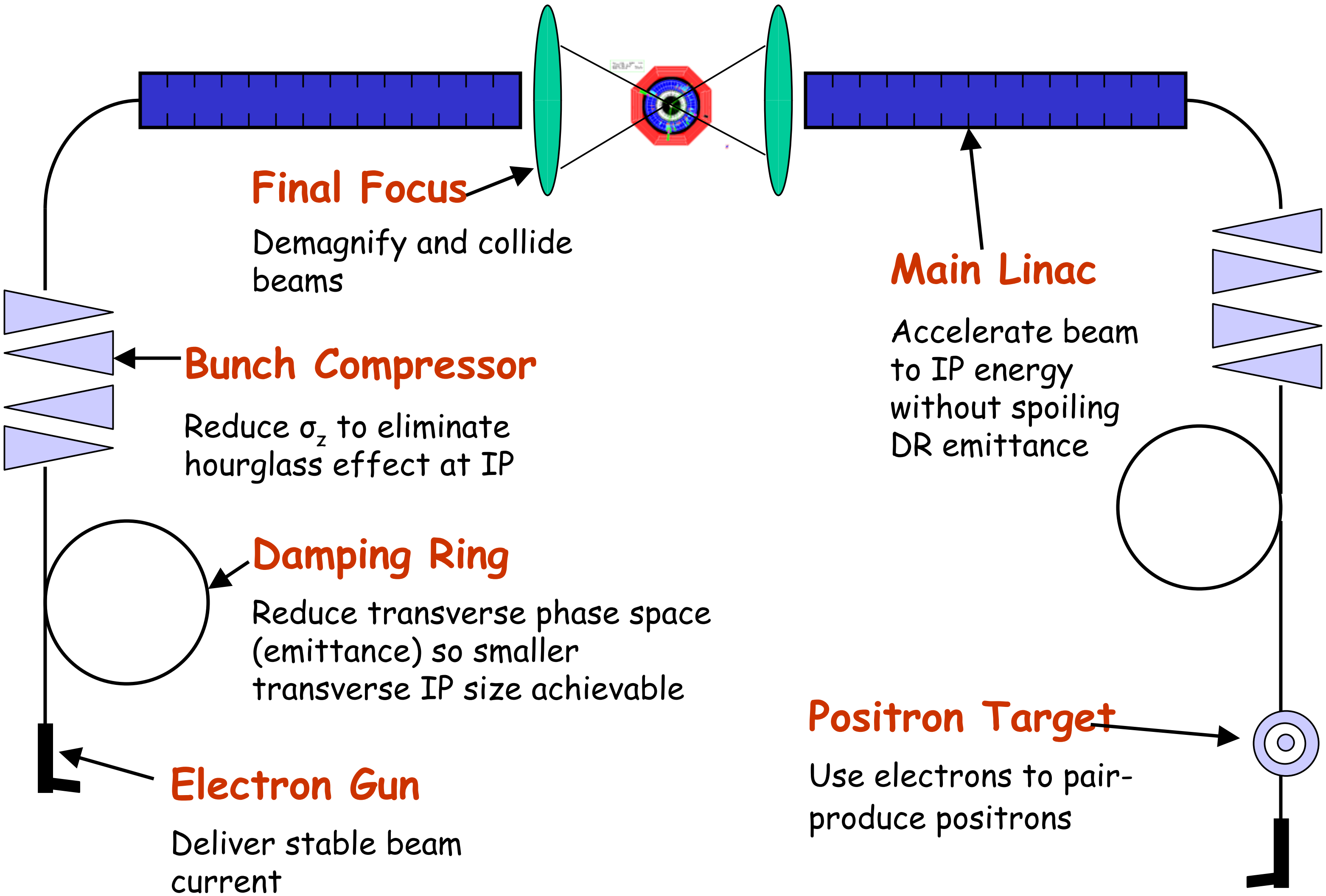
P_b = beam power

$E_{c.m.}$ = center of mass energy

Parameters to play with

- ↓ Reduce beam emittance ($\varepsilon_x \cdot \varepsilon_y$) for smaller beam size ($\sigma_x \cdot \sigma_y$)
- ↑ Increase bunch population (N_e)
- ↑ Increase beam power ($P_b = N_e \cdot n_b \cdot f_{rep}$)
- ↑ Increase beam to-plug power efficiency for cost

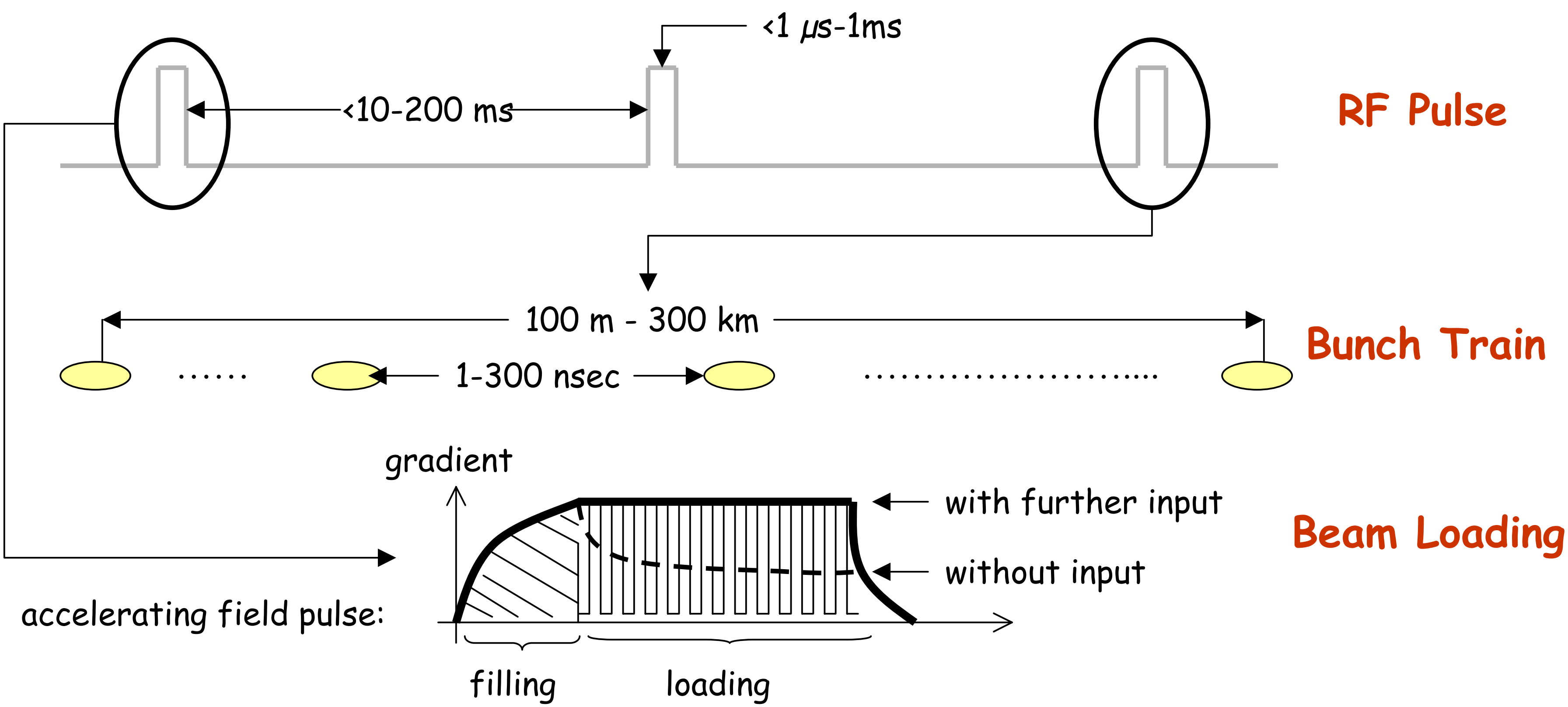
LC conceptual scheme



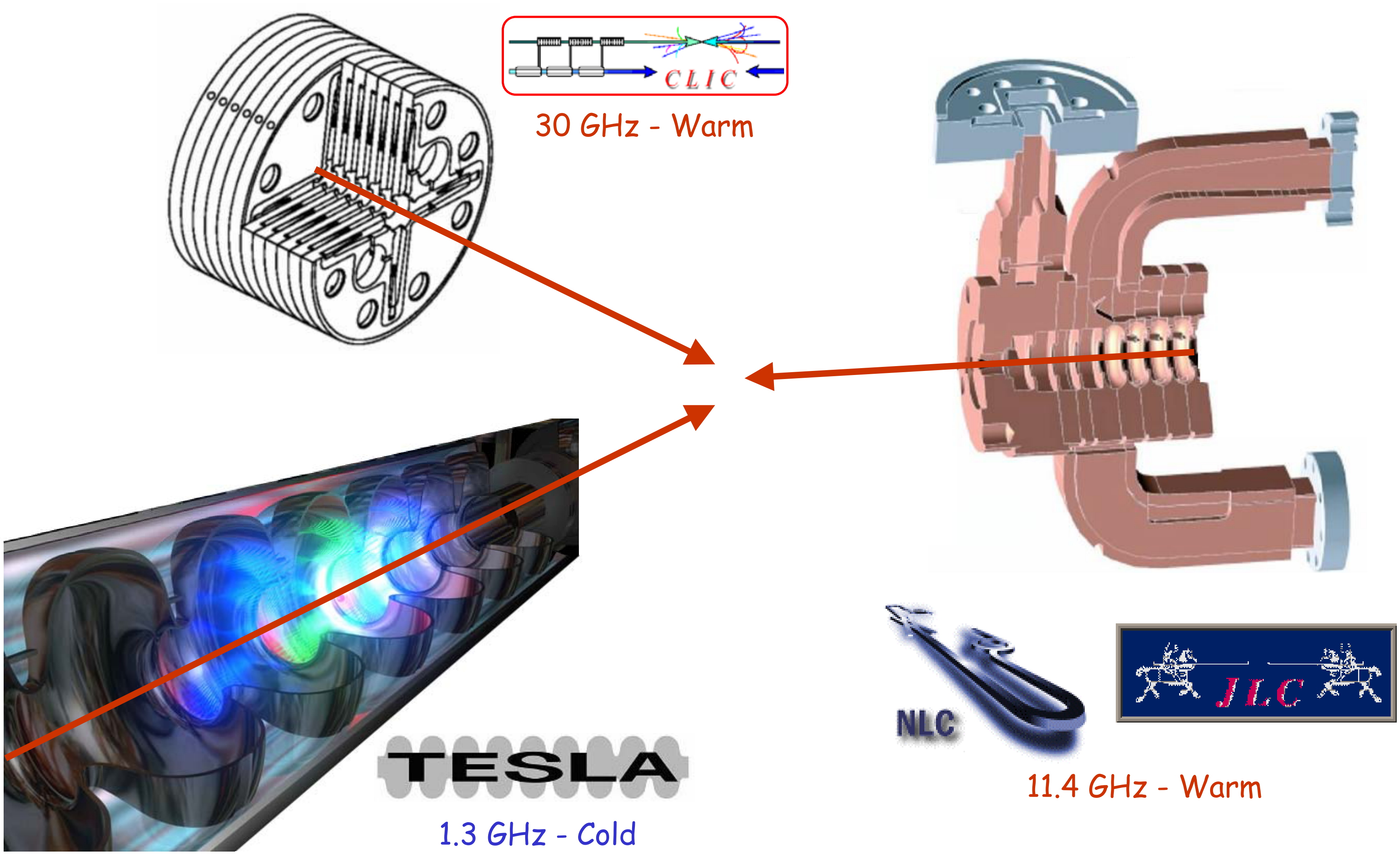
Linear Colliders are pulsed

LCs are pulsed machines to improve efficiency. As a result:

- duty factors are small
- pulse peak powers can be very large



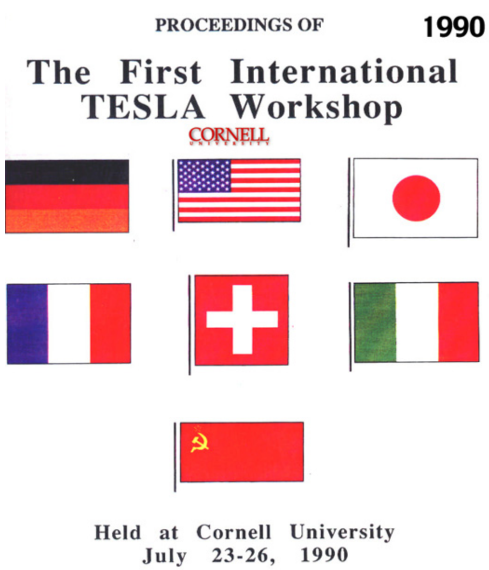
Competing technologies

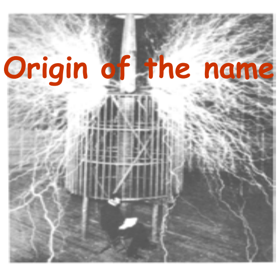


The TESLA challenge

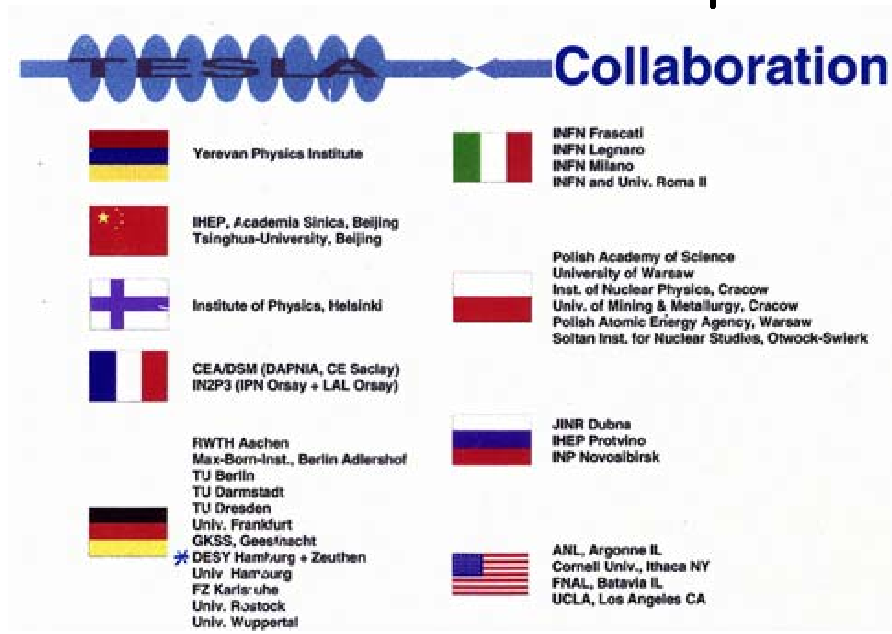
Use Superconducting RF: higher conversion efficiency
smaller emittance dilution

Physical limit at 50 MV/m → ≥25 MV/m should be possible
→ Common R&D effort for TESLA





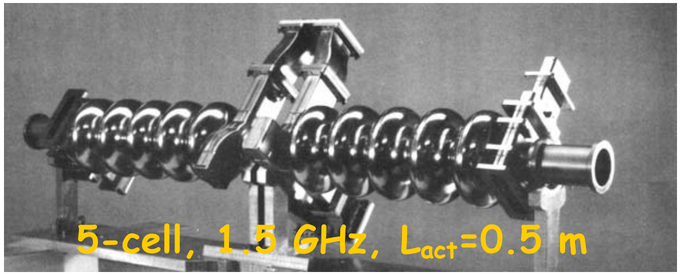
1992 - TESLA Collaboration set up at DESY



Examples: CEBAF, LEPII, HERA

1984/85: First great success

- A pair of 1.5 GHz cavities developed and tested (in CESR) at Cornell
- **> 300 cavities produced for CEBAF** at TJNAF for a nominal E_{acc} = 5 MV/m

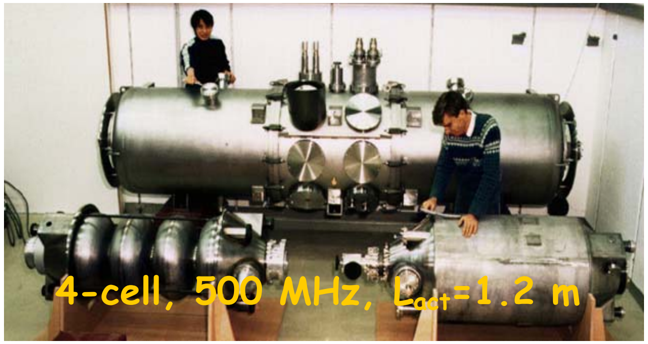


32 bulk niobium cavities

- Limited to 5 MV/m
- Poor material and inclusions

256 sputtered cavities

- Magnetron-sputtering of Nb on Cu
- Completely done by industry
- **Field improved with time** $\langle E_{acc} \rangle$ = 7.8 MV/m (Cryo-limited)



16 bulk niobium cavities

- Limited to 5 MV/m
- Poor material and inclusions
- Q-disease for slow cooldown

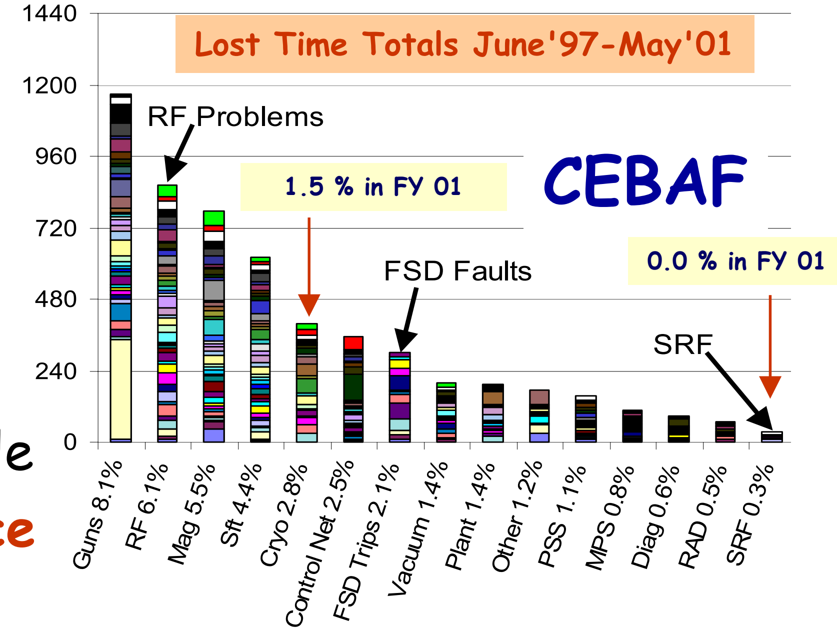
Important lessons learned

When not limited by a hard quench (material defect)

Accelerating field improves with time

Large cryo-plants are highly reliable

Negligible lost time for cryo and SRF



Once dark current is set to be negligible

No beam effect on cavity performance

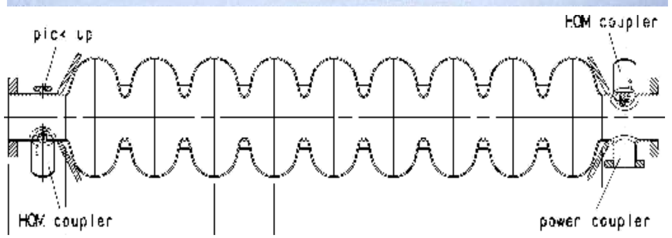
Once procedures are understood and well specified

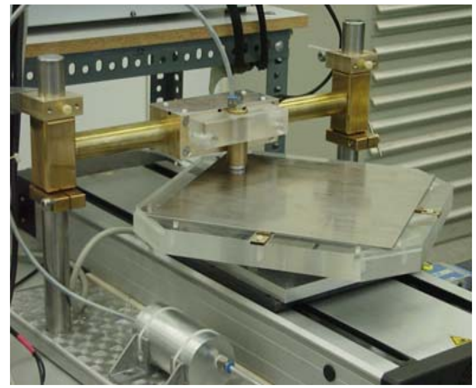
Industry can produce status of art cavities and cryo-plants

The 9-cell TESLA cavity

Major contributions from: CERN, Cornell, DESY, CEA-Saclay

- 9-cell, 1.3 GHz





Eddy-current scanning system for niobium sheets

Cleanroom handling of niobium cavities

Preparation Sequence

- Niobium sheets (RRR=300) are scanned by eddy-currents to detect avoid foreign material inclusions like tantalum and iron
- Industrial production of full nine-cell cavities:
  - Deep-drawing of subunits (half-cells, etc.) from niobium sheets
  - Chemical preparation for welding, cleanroom preparation
  - Electron-beam welding according to detailed specification
- 800 °C high temperature heat treatment to stress anneal the Nb and to remove hydrogen from the Nb
- 1400 °C high temperature heat treatment with titanium getter layer to increase the thermal conductivity (RRR=500)
- Cleanroom handling:
  - Chemical etching to remove damage layer and titanium getter layer
  - High pressure water rinsing as final treatment to avoid particle contamination

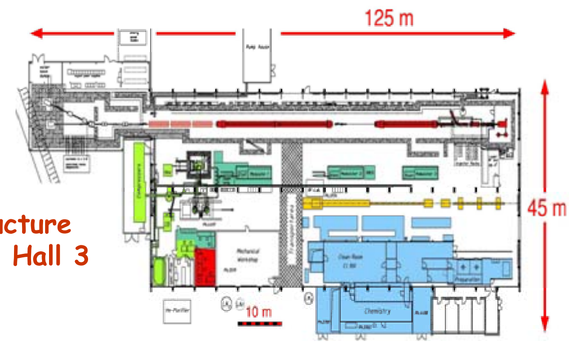
TESLA cavity parameters

R/Q	1036	Ω
E_{peak}/E_{acc}	2.0	
B_{peak}/E_{acc}	4.26	mT/(MV/m)
$\Delta f/\Delta l$	315	kHz/mm
$K_{Lorentz}$	≈ -1	$Hz/(MV/m)^2$

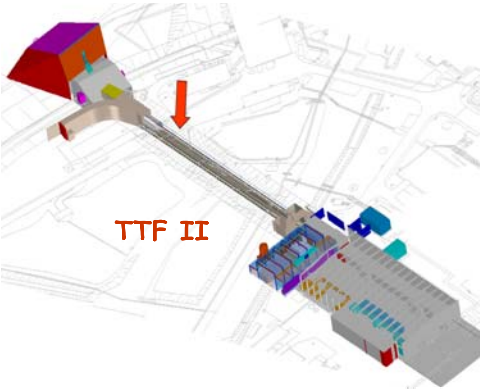
TESLA Milestones

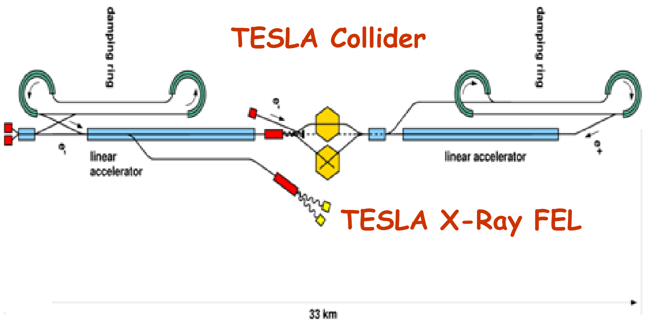
- 23-26 July 1990 – 1° International TESLA Workshop @ Cornell University
- 7-9 August 1991 – 1° Meeting on SC Cavities and TESLA @ DESY
- February 1992 – 1° TESLA Collaboration Board Meeting @ DESY
- March 1993 - "A Proposal to Construct and Test Prototype Superconducting RF Structures for Linear Colliders"
- March 1995 -TESLA Test Facility Linac Design Report-A VUV Free Electron Laser at the TESLA Test Facility at DESY
- May 1996 – First beam at TTF
- March 2001 – First SASE-FEL Saturation
- March 2001 – TESLA Technical Design Report
- February 2003 – Positive news from German Government

Infrastructure @ DESY in Hall 3



TTF I





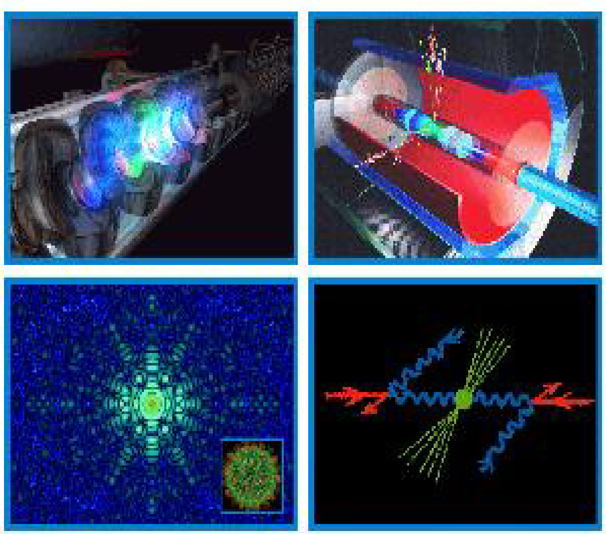
The TESLA TDR - March 2001

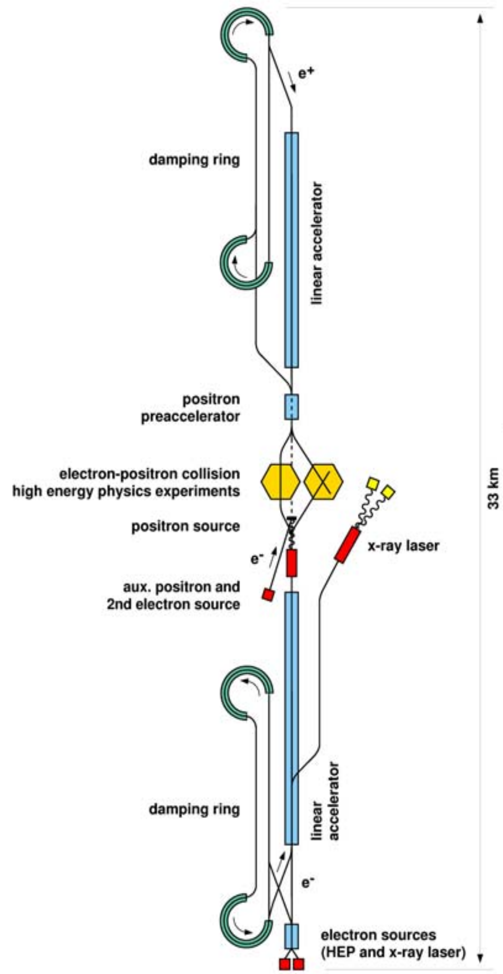
TESLA

The Superconducting Electron-Positron Linear Collider

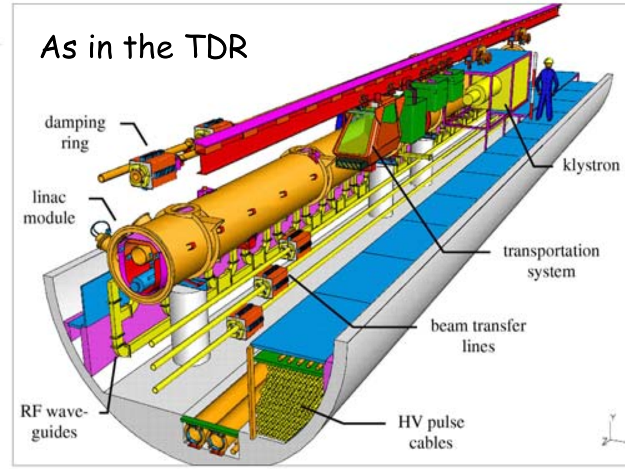
with an Integrated X-Ray Laser Laboratory

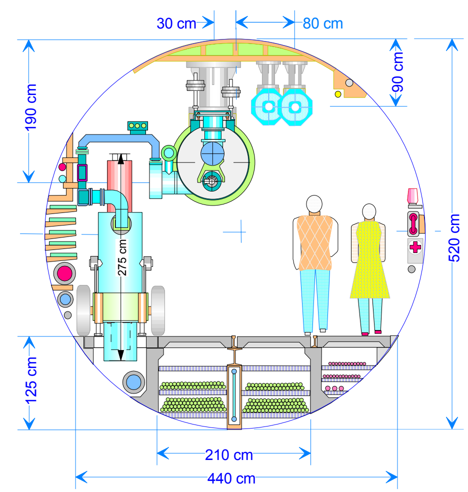
Technical Design Report





As in the TDR





Updated tunnel cross section

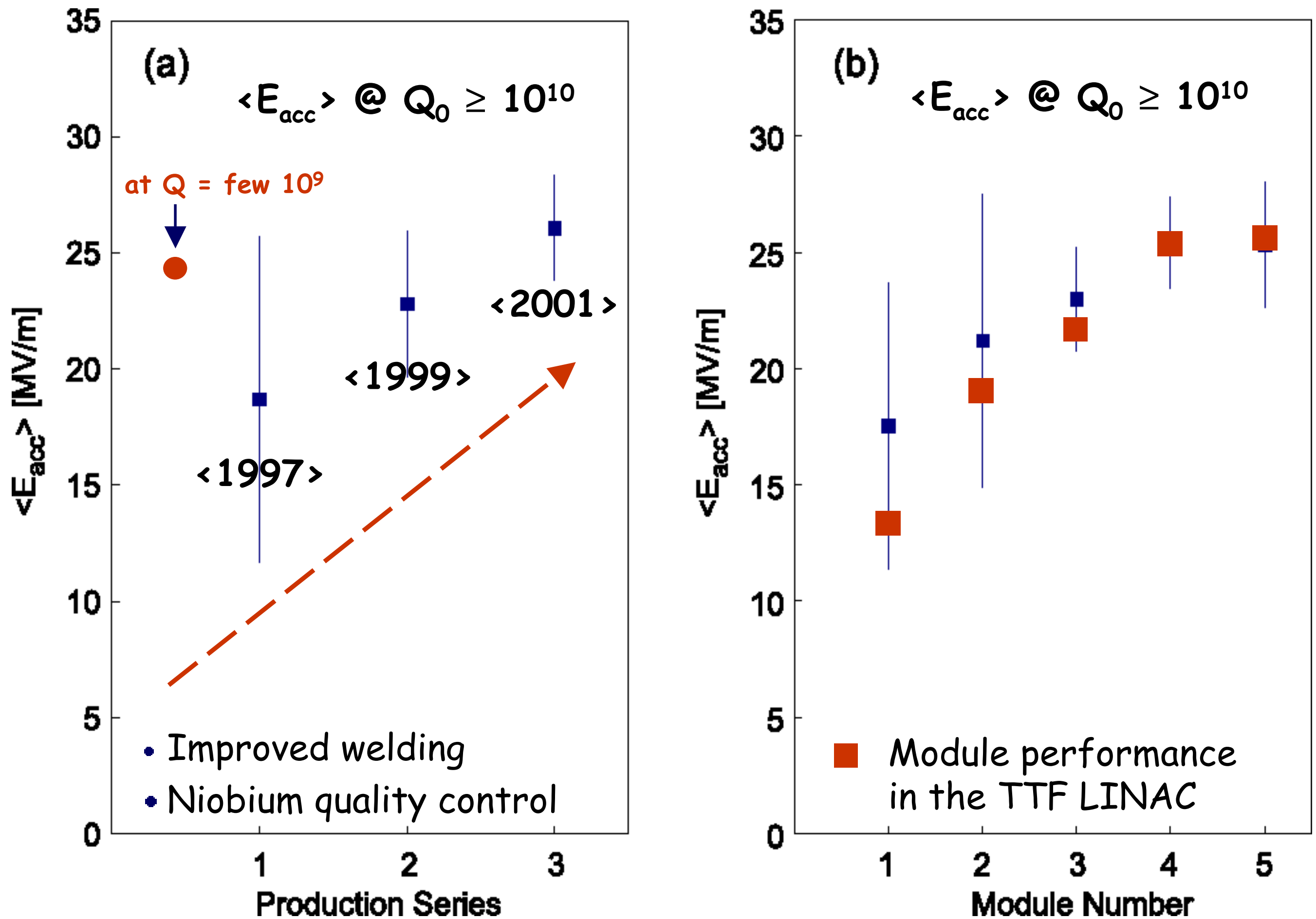
Learning curve with BCP

BCP = Buffered Chemical Polishing

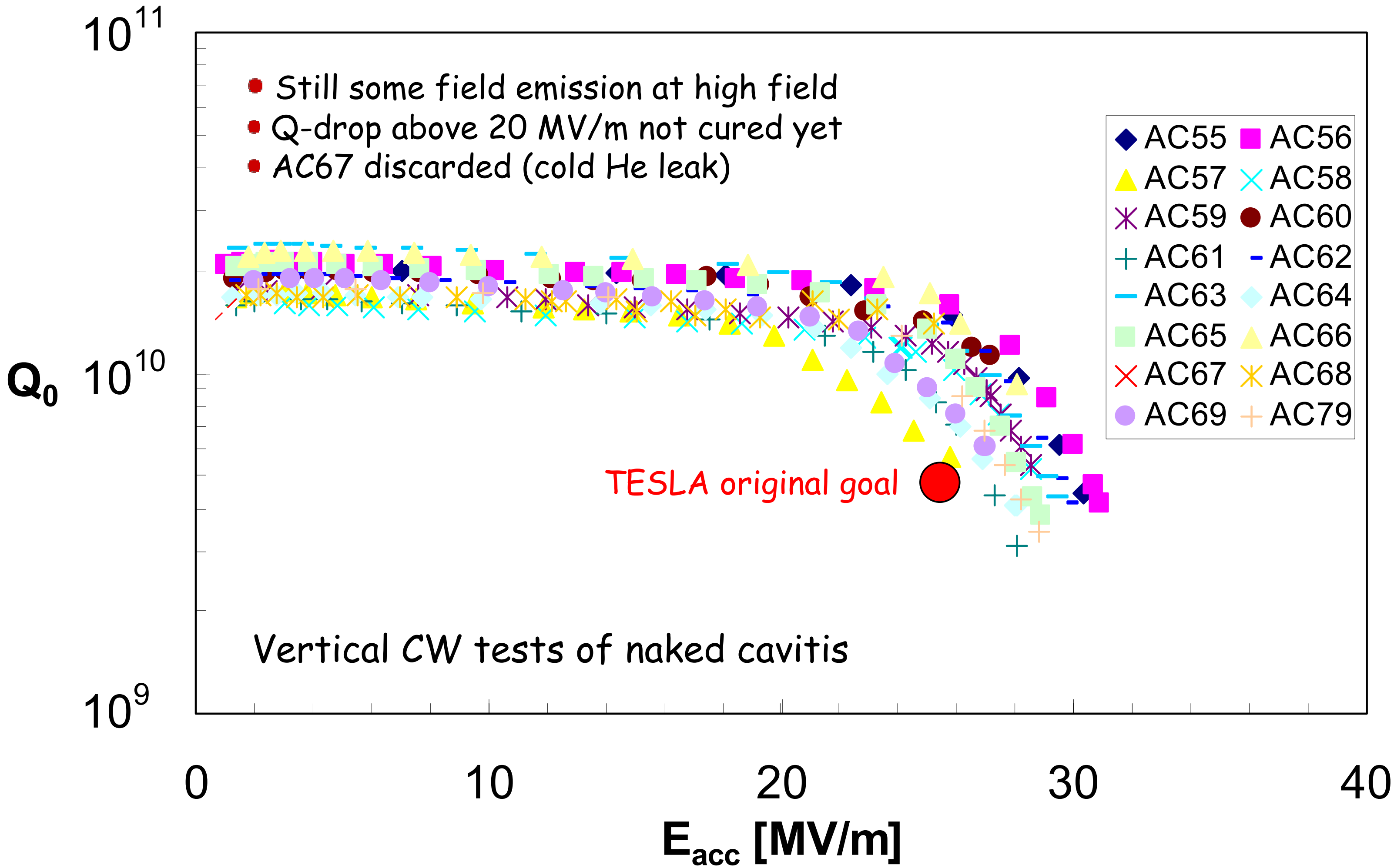
3 cavity productions from 4 European industries: Accel, Cerca, Dornier, Zanon

Cornell 1995

5-cell

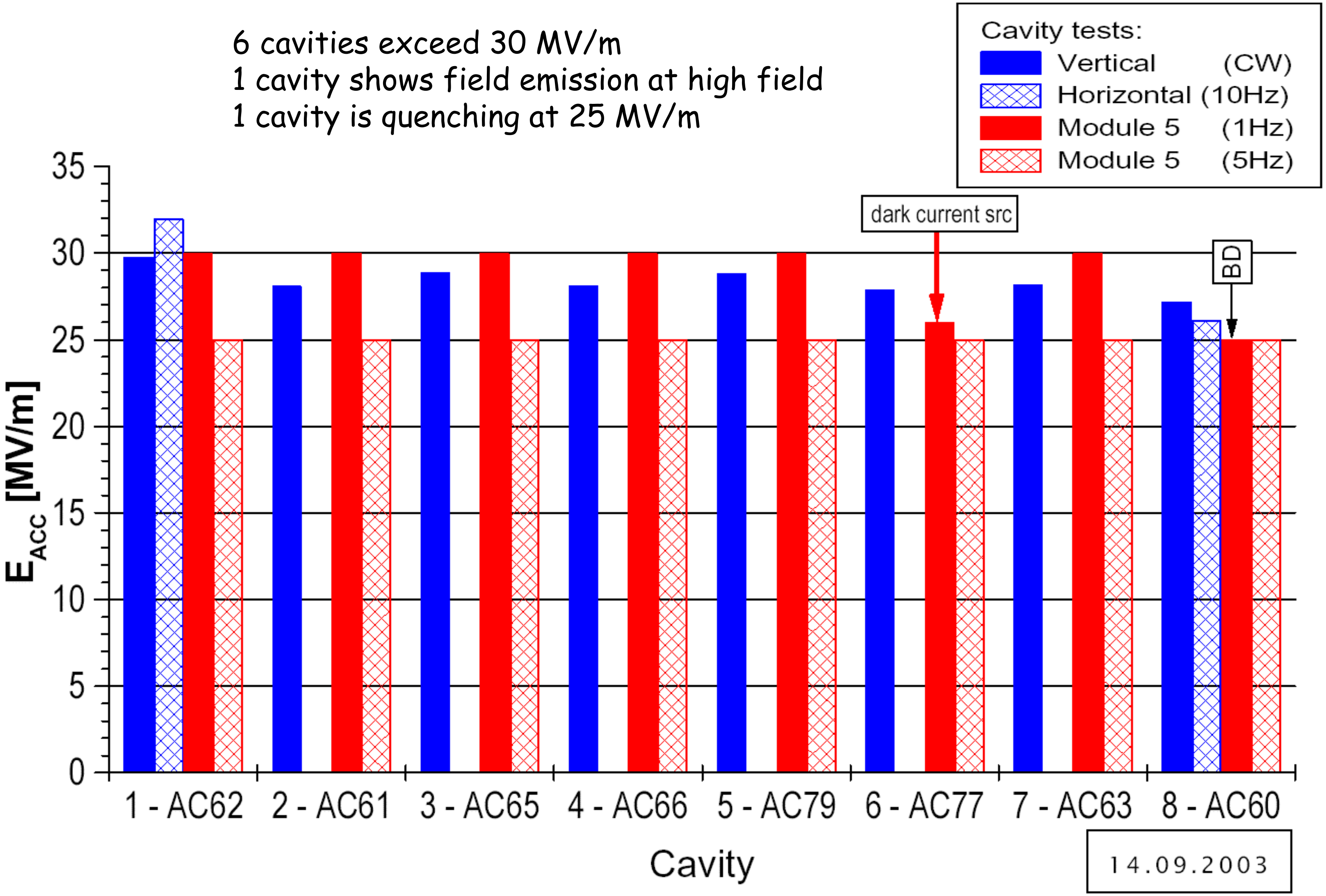


3rd cavity production with BCP



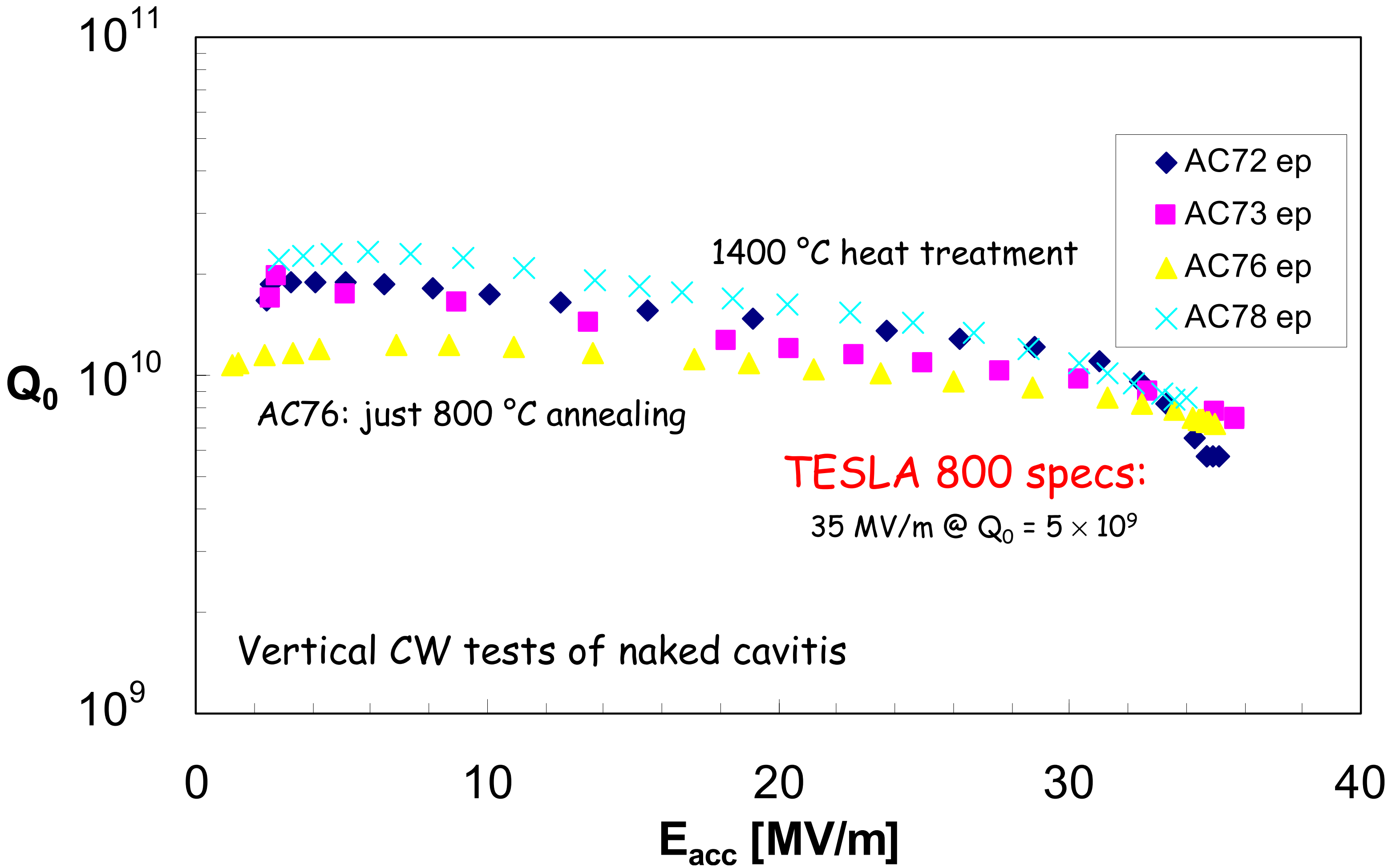
Recent results in module # 5

6 cavities exceed 30 MV/m
1 cavity shows field emission at high field
1 cavity is quenching at 25 MV/m



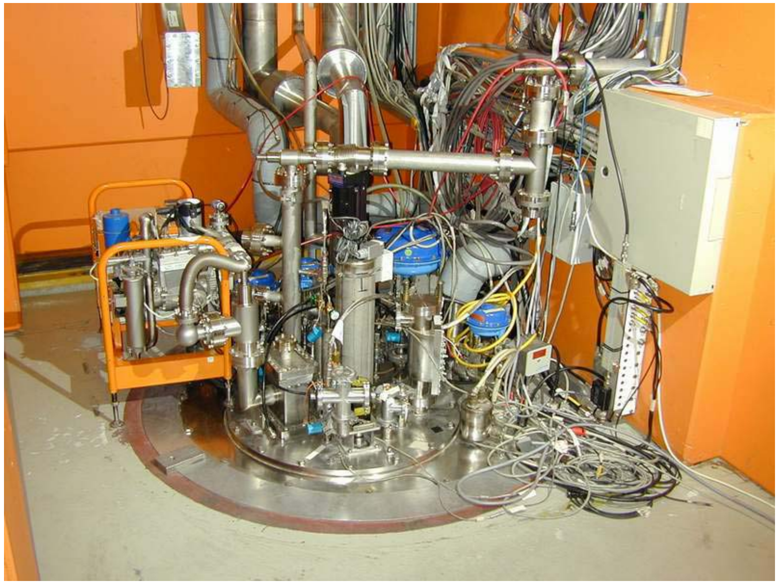
TESLA 800 Performances with EP

EP (Electro-Polishing) developed at KEK by Kenji Saito (originally by Siemens)
Coordinated R&D effort: DESY, KEK, CERN and Saclay



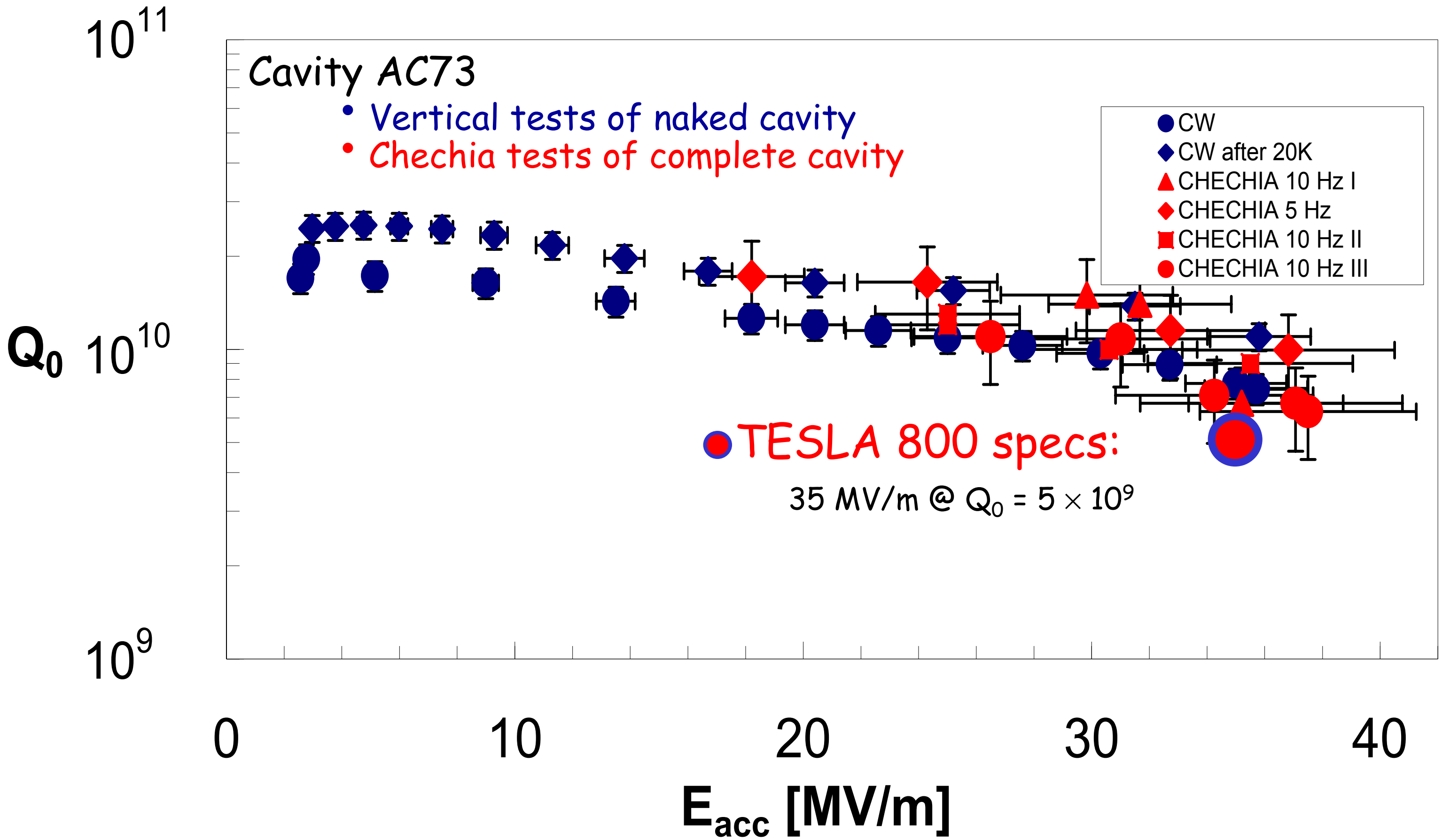
Cavity Vertical Test

- The naked cavity is immersed in a super-fluid He bath.
- High power coupler, He vessel and tuner are not installed
- RF test are performed in CW with a moderate power(< 300W)



TESLA 800 in "Chechia"

- Long Term (> 1000 h) Horizontal Test
- In Chechia the cavity has all its ancillaries
- Chechia behaves as 1/8th (1/12th) of a TESLA cryomodule

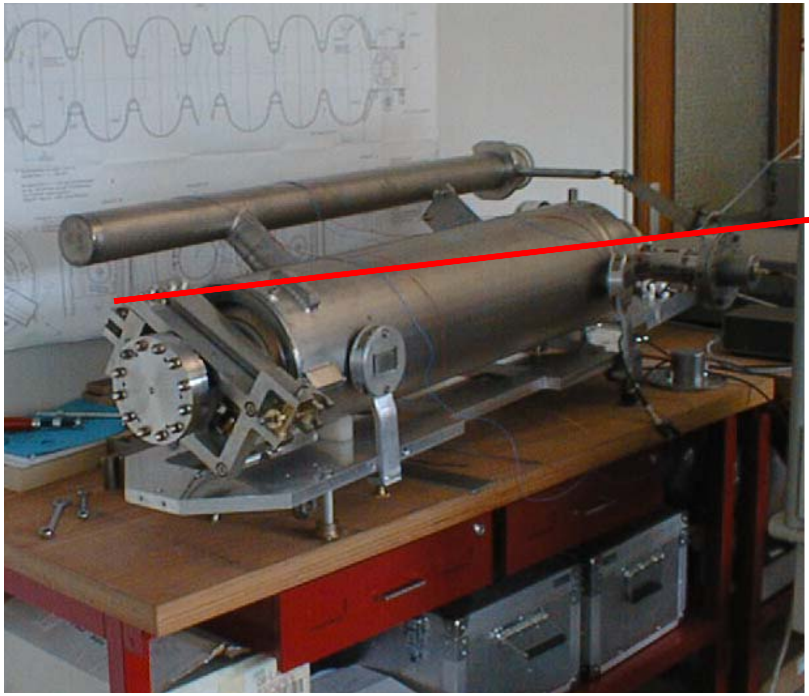


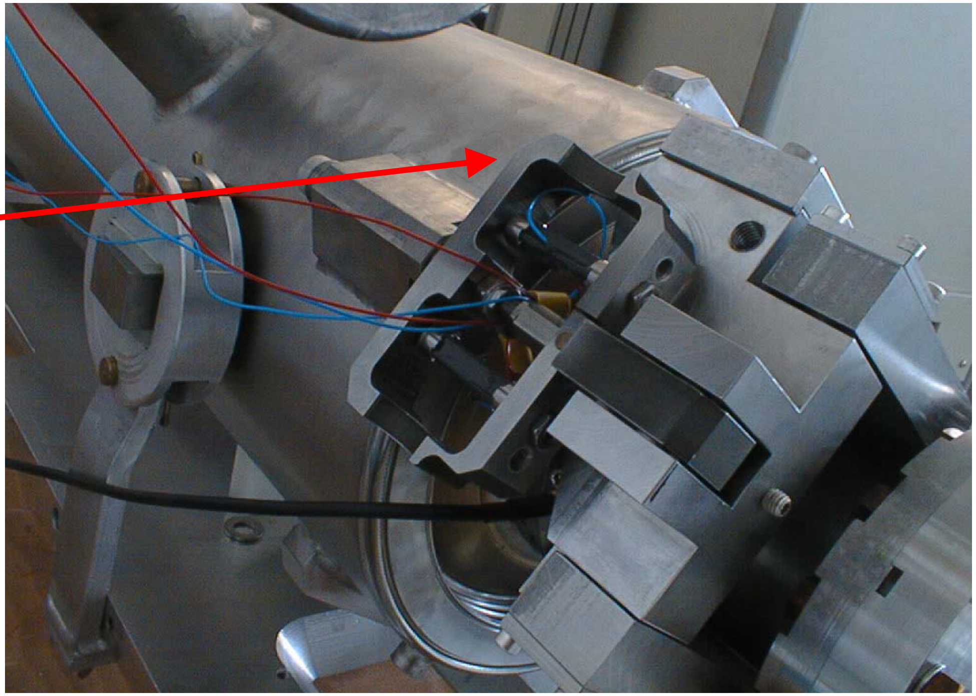
Horizontal tests in “Chechia”

- Cavity is fully assembled
- It includes all the ancillaries:
  - Power Coupler
  - Helium vessel
  - Tuner (…and piezo)
- RF Power is fed by a Klystron through the main coupler
- Pulsed RF operation using the same pulse shape foreseen for TESLA

Piezo-assisted Tuner on AC73

- To compensate for Lorentz force detuning during the 1 ms RF pulse
  Feed-Forward
- To counteract mechanical noise, "microphonics"
  Feed-Back

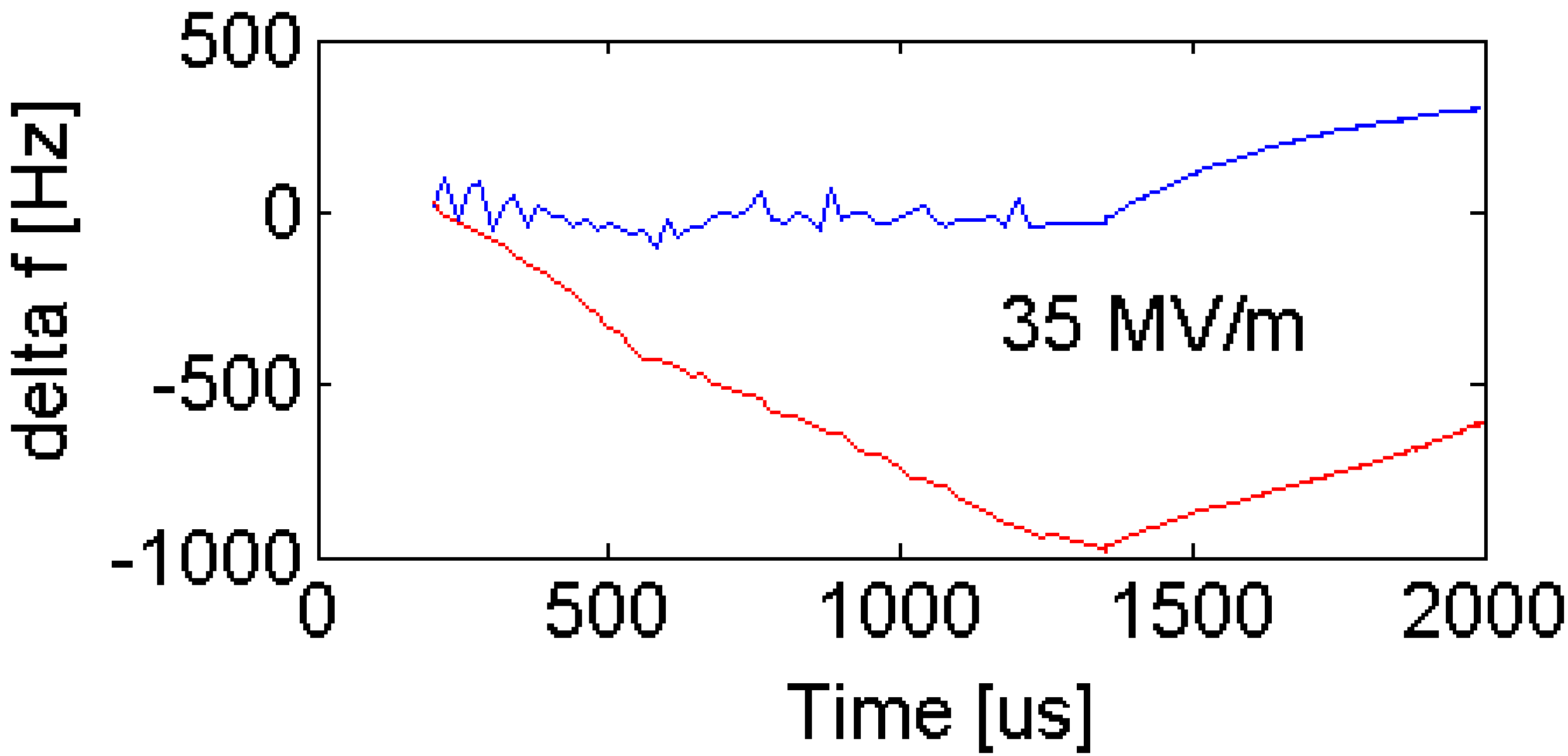




Successful Compensation @ 35 MV/m

Cavity detuning induced by Lorentz force during the tests performed in Chechia at **TESLA-800 specs**

- Piezo-compensation on: just feed-forward resonant compensation
- Piezo-compensation off



Important results for TESLA LC

EP & 120°C backing are the key steps of the recipe

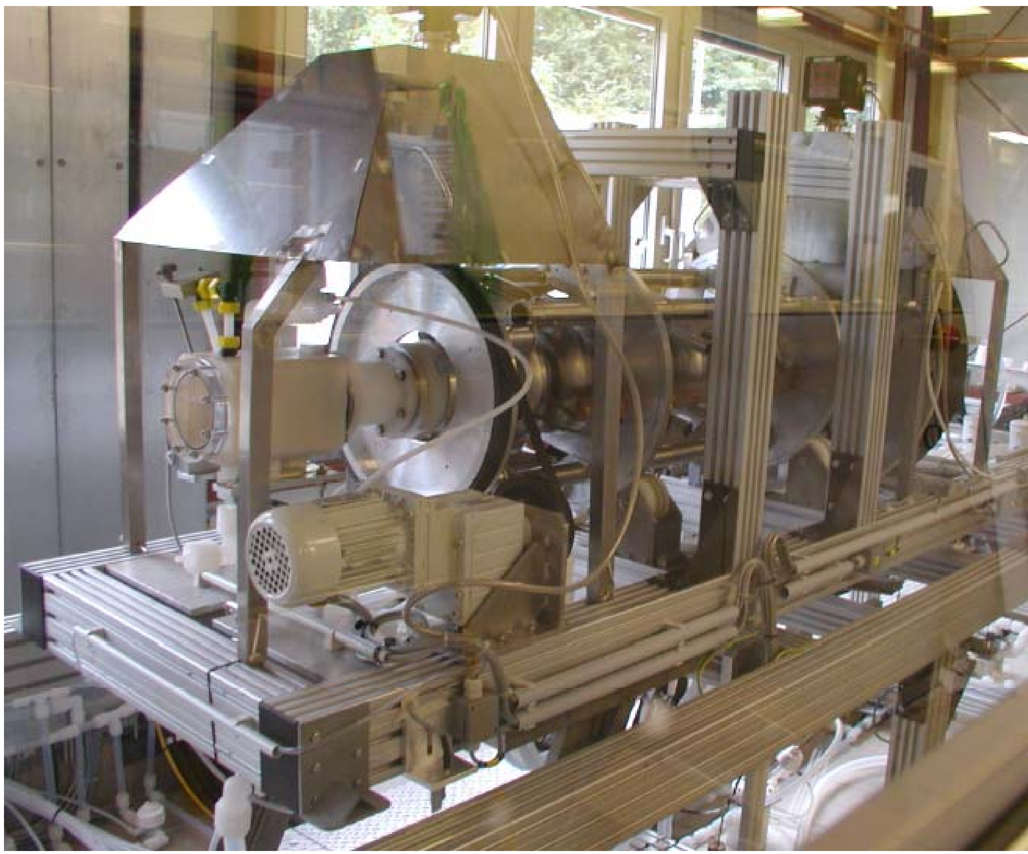
Field Emission and Q-drop cured

- Maximum **field is still slowly improving**
- Negligible Field Emission detected, that is
- **Negligible dark current expected** at this field level
- Cavity can be **operated close to its quench limit**
- Induced **quenches are not affecting cavity** performances

EP at DESY fully commissioned

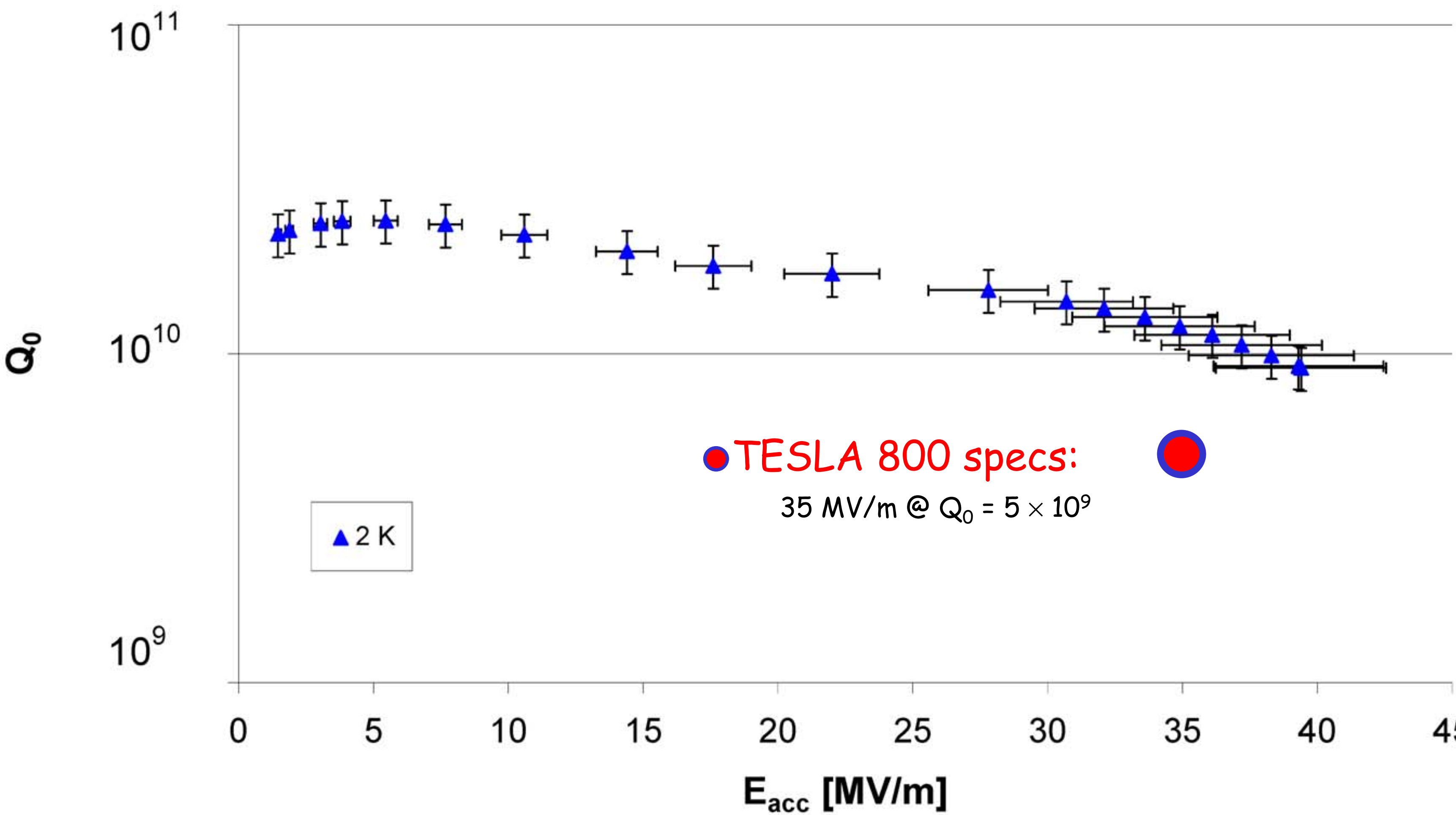
DESY EP Infrastructure fully operational

- outstanding results recently obtained
- 1400°C treatment not required



Last week results on AC70 - 1

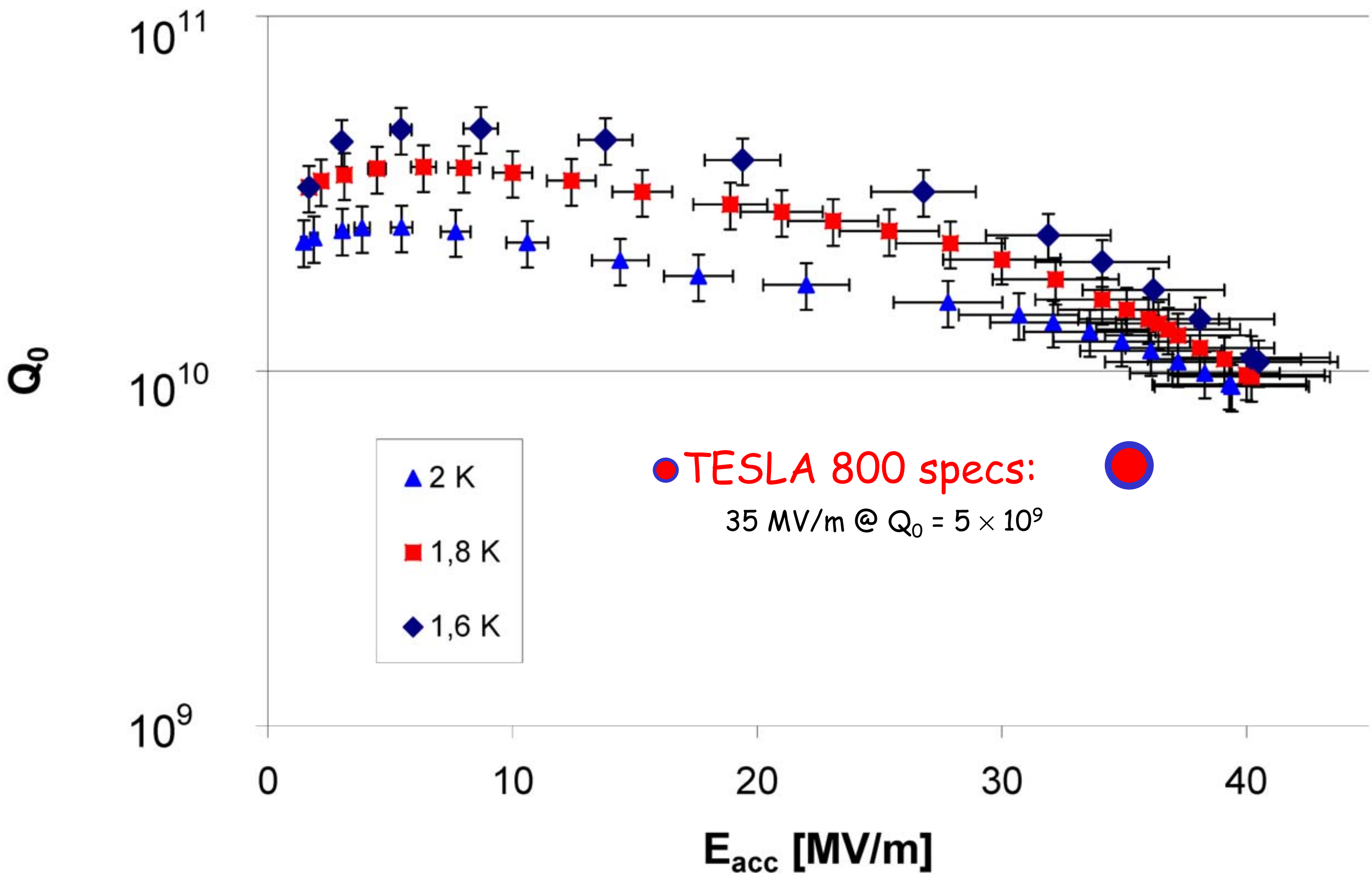
EP at the new DESY plan 800°C annealing 120°C Backing



Last week results on AC70 - 2

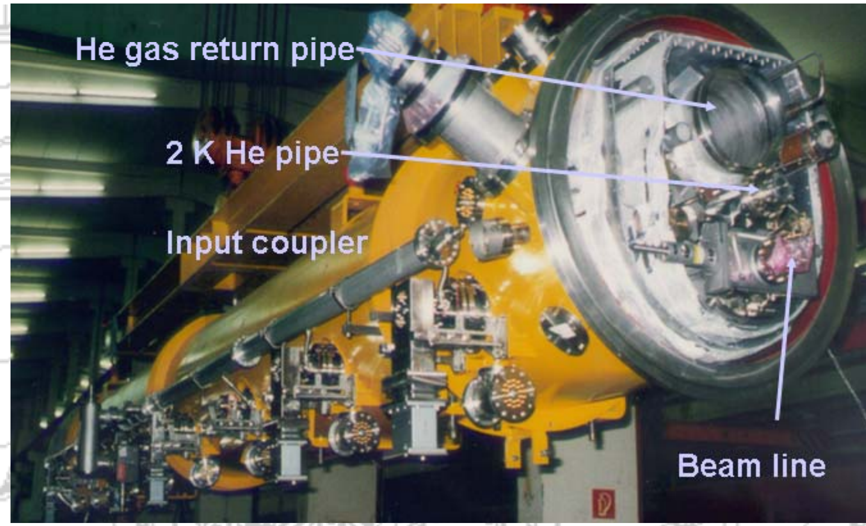
Very low residual resistance

Negligible Field Emission



Performing Cryomodules

Three generations of the cryomodule design, with improving simplicity and performances, while decreasing costs

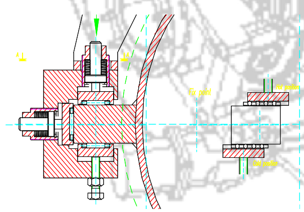


Cryomodule Characteristics

Length		12	m
# cavities		8	
# doublets		1	
Static Losses	@ 2 K	1.5	W
	@ 5 K	8	W
	@ 50 K	70	W

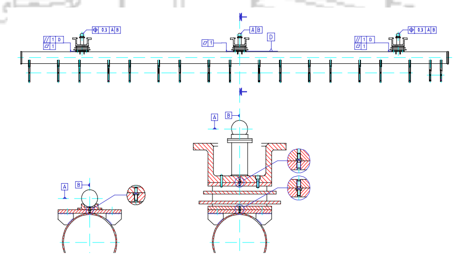
Required plug power < 6 kW

Sliding Fixtures @ 2 K



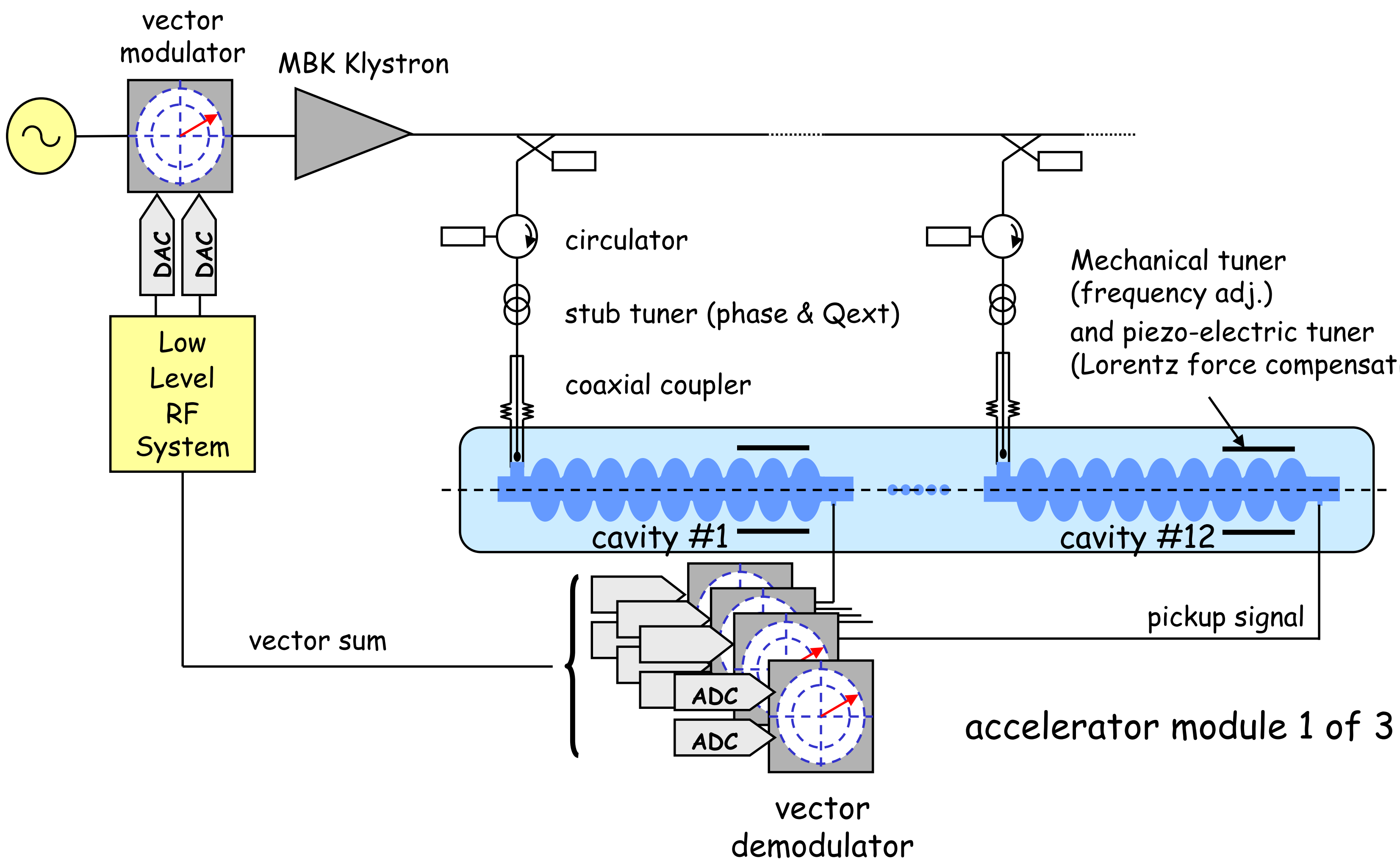
"Finger Welded" Shields

Reliable Alignment Strategy



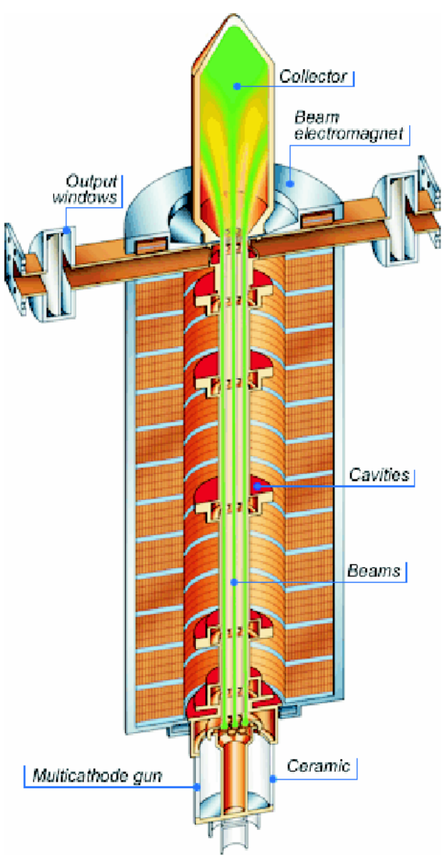
TESLA RF Unit

1 klystron for 3 accelerating modules, 12 nine-cell cavities each



TESLA Multi Beam Klystrons

Three Thales TH1801 Multi Beam Klystrons have been produced and tested



MBKs reduce HV and improve the efficiency: lower space charge.

Seven beams, 18.6 A, 110 kV, produce 10 MW with 70% eff.

Cathodes are still the weak point

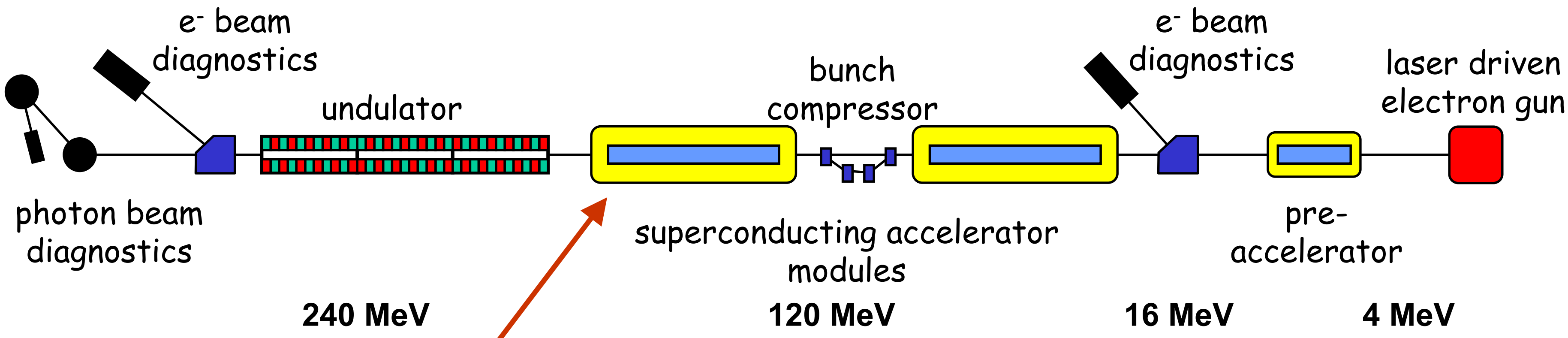
Operational experience

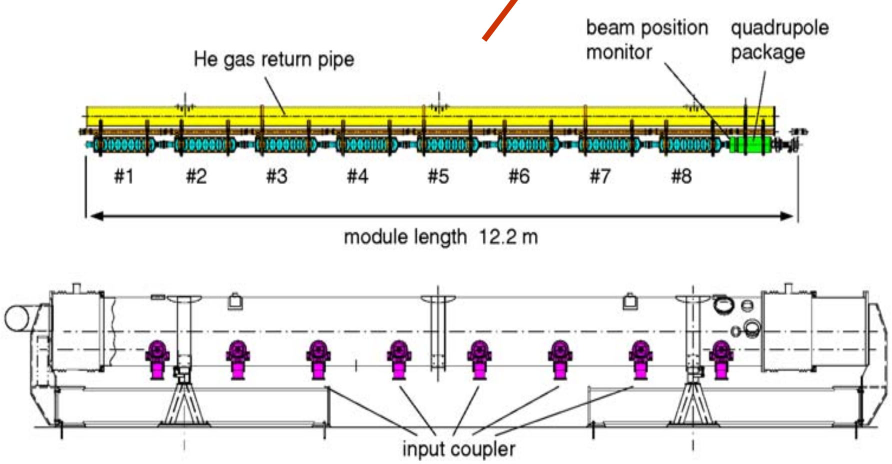
Achieved efficiency	65%
RF pulse width	1.5 ms
Repetition rate	5 Hz
Operation experience	> 5000 h

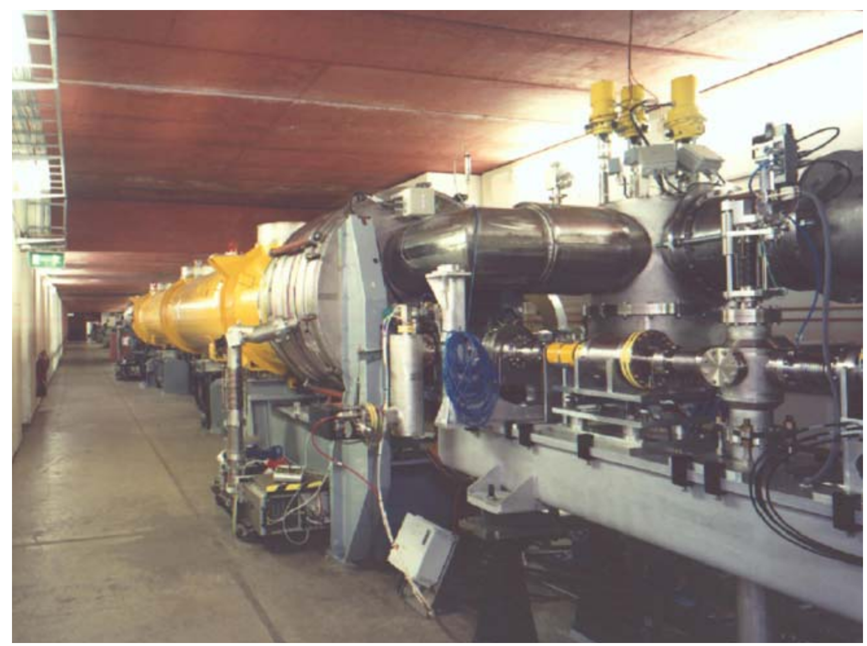
10% of operation time at full spec's

A new design proposed by Toshiba looks more robust and should reach 75% efficiency

Great experience from TTF I





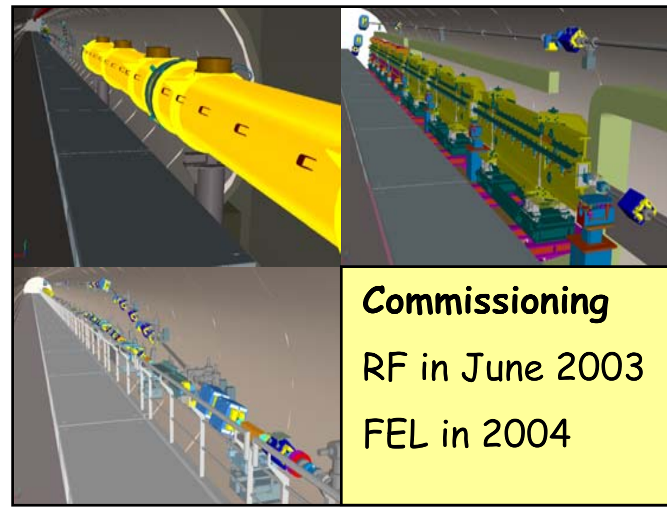


More experience from TTF II

FEL User Facility in the nm Wavelength Range

Unique Test Facility to develop X-FEL and LC

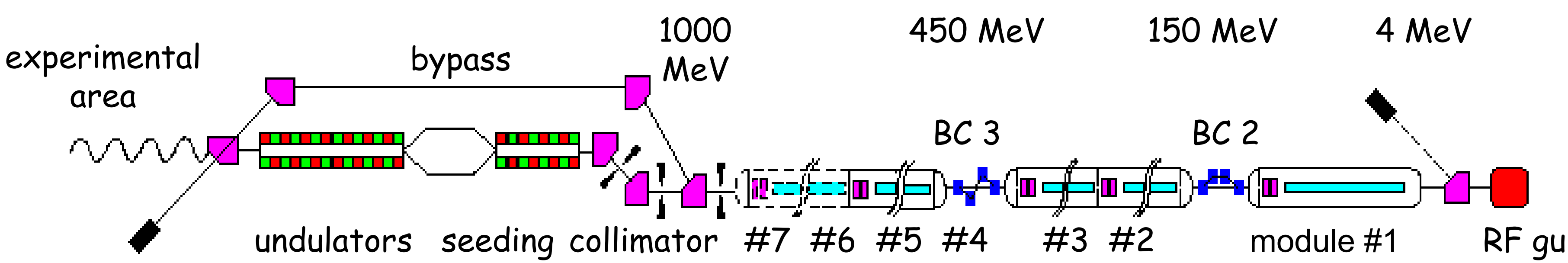
- Six accelerator modules to reach 1 GeV beam energy.
- Module #6 will be installed later and will contain 8 electro-polished cavities.
- Engineering with respect to TESLA needs.
- Klystrons and modulators build in industry.
- High gradient operation of accelerator modules.
- Space for module #7 (12 cavity TESLA module).



Commissioning

RF in June 2003

FEL in 2004



ILC-TRC (Greg Loew Panel)
International LC Technical Review Committee

- International Collaboration for R&D toward TeV-Scale e^+e^- LC asked for first ILC-TRC in June 1994
- ILC-TRC produced first report end of 1995
- 2001: ICFA requests that ILC-TRC reconvene to produce a second report with the following charge:
  - To assess the present technology status of the four LC designs at hand, and their potential for meeting the advertised parameters at 500 GeV c.m.
  - Use common criteria, definitions, computer codes, etc., for the assessments
  - To assess the potential of each design for reaching higher energies above 500 GeV c.m.
  - To establish, for each design, the R&D work that remains to be done in the next few years
  - To suggest future areas of collaboration
- ILC-TRC produced second report January 2003

  http://www.slac.stanford.edu/xorg/ilc-trc/2002/2002/report/03rep.htm

LC status at first ILC-TRC

End 1995

E_{cm} = 500 GeV

	TESLA	SBLC	JLC-S	JLC-C	JLC-X	NLC	VLEPP	CLIC
f [GHz]	1.3	3.0	2.8	5.7	11.4	11.4	14.0	30.0
$L \times 10^{33}$ [$cm^{-2}s^{-1}$]	6	4	4	9	5	7	9	1-5
P_{beam} [MW]	16.5	7.3	1.3	4.3	3.2	4.2	2.4	1-4
P_{AC} [MW]	164	139	118	209	114	103	57	100
$\gamma\varepsilon_y$ [$\times 10^{-8}$m]	100	50	4.8	4.8	4.8	5	7.5	15
σ_y^* [nm]	64	28	3	3	3	3.2	4	7.4

TESLA

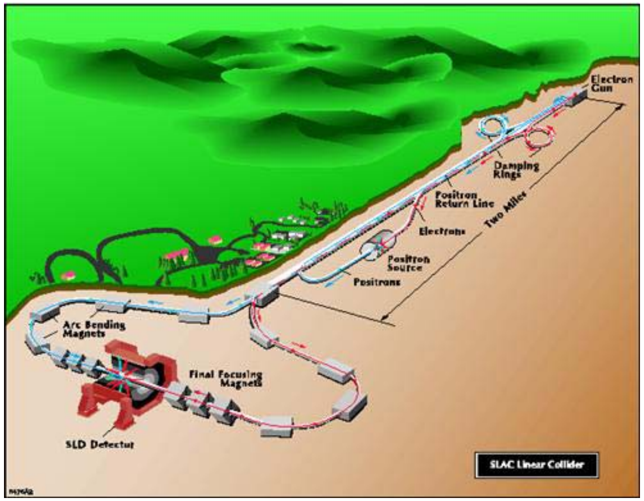
Tasks to be addressed

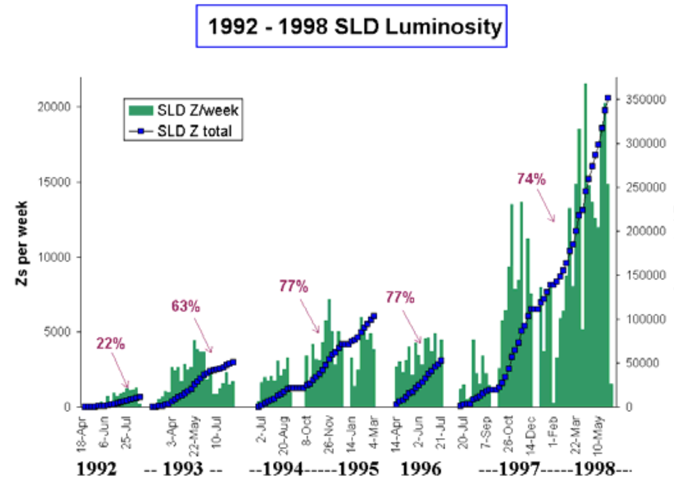
Baseline c.m. Energy stays at 500 GeV

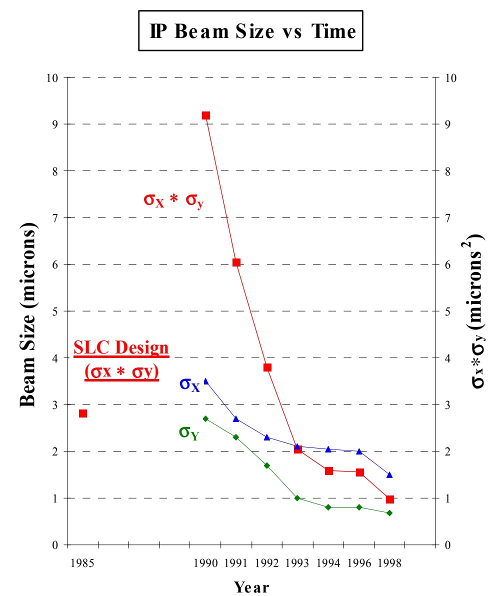
- **Push Luminosity to the maximum value**
- **Technology:**
  - Demonstrate that the proposed technology can be pushed to the limits required for a Linear Collider
  - Demonstrate that the proposed technology can be produced in large scale by industry with high reliability and reasonable cost
  - Find solution for all critical items
- **Design issues:**
  - Demonstrate that very small spot sizes ($\sigma_x \cdot \sigma_y < 1\ \mu m^2$) are possible
  - Investigate all beam physics critical issues
  - Support all design features with cross-checked simulations
  - Address reliability and availability issues
- **Roadmap for energy upgrade**
- **Test Facilities**

Lessons from the SLC

SLC = SLAC Linear Collider







New Territory in Accelerator Design and Operation

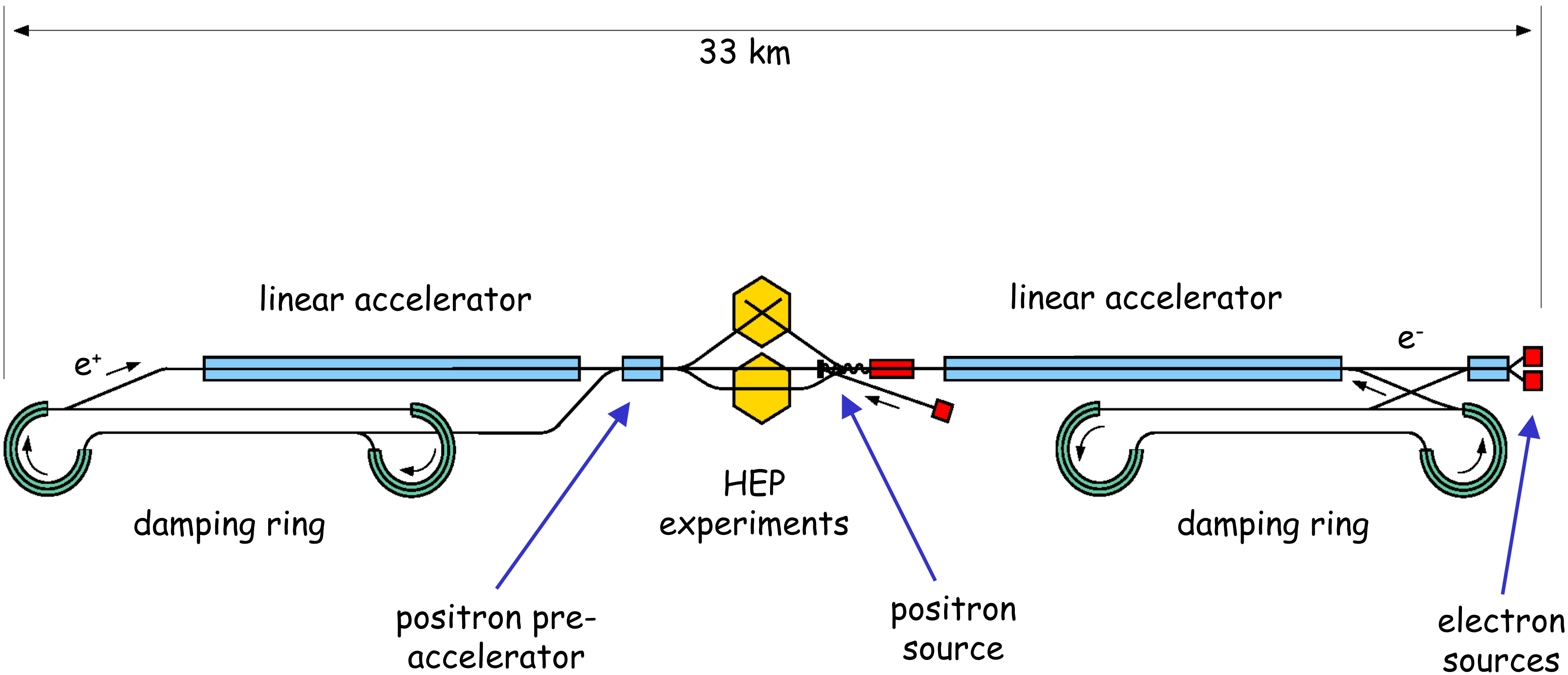
- Sophisticated on-line modeling of non-linear beam physics.
- Correction techniques (trajectory and emittance), from hands-on by operators to fully automated control.
- Slow/fast feedback theory and practice.

Second to first ILC-TRC Comparison

2003 vs. 1995 E_{cm} = 500 GeV

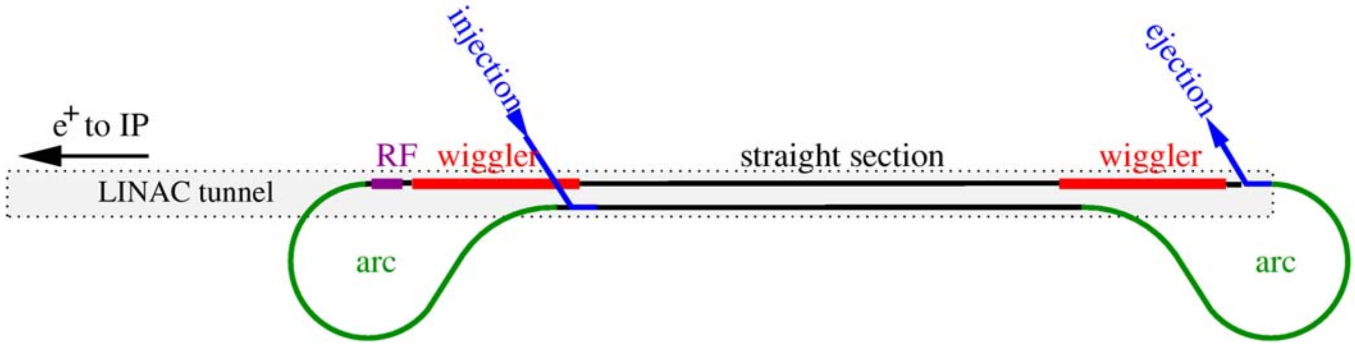
	TESLA 2003	TESLA 1994	JLC/NLC 2003	<JLC/NLC> 1994	CLIC 2003	CLIC 1994
f [GHz]	1.3	1.3	11.4	11.4	30.0	30.0
$\mathcal{L} \times 10^{33}$ [$cm^{-2}s^{-1}$]	34	6	20	6	21	1-5
P_{beam} [MW]	11.3	16.5	6.9	3.7	4.9	1-4
P_{AC} [MW]	140	164	195	110	175	100
$\gamma\varepsilon_y$ [$\times 10^{-8}$m]	3	100	4	5	1	15
σ_y^* [nm]	5	64	3	3	1.2	7.5

TESLA 0.5 - 0.8 TeV c.m.



One TESLA design problem

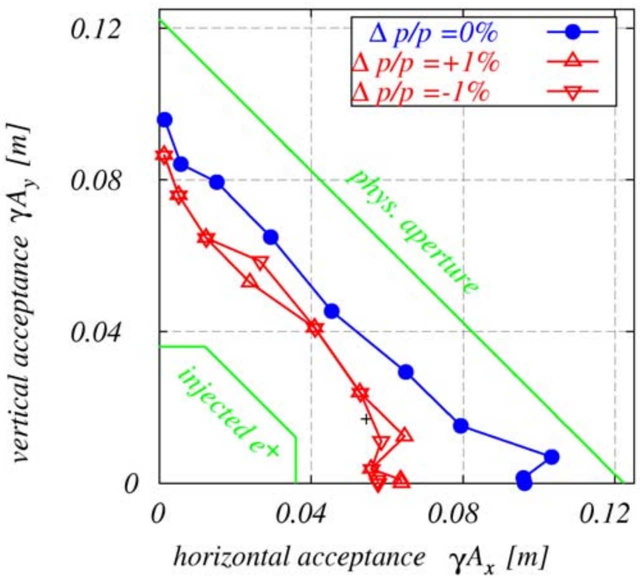
Very long damping rings: at present 17 km



Electron cloud and beam-ion instability effects:

- more simulation effort required,
- impact on vac. sys. layout?
- Problem with coupling bump?

Dynamic aperture with sextupoles OK, but not yet sufficient with present wiggler model



Superconducting Linac for LC

Advantages

- Low frequency – wakes weak, klystrons easy
- Low power loss in structures and high conversion efficiency
- Low input power (230 kW per structure)
- Low beam current (8 mA)
- Long bunch spacing (337 ns) so bunch-by-bunch control easy
- Standing-wave cavities have gradient uniform along length

Disadvantages

- Tight frequency tolerances, mechanical, piezo-assisted, tuners needed on all cavities
- Beam instrumentation more difficult (large apertures)
- Long bunch train requires long DR (17 km around)
- Low repetition rate (5 Hz) makes train-by-train control hard
- Lower gradients

ILC-TRC Methodology and Rankings

Methodology

- Review current designs and status (achievements) of R&D, particularly the test facilities
- Identify the positive aspects of the designs
- Identify those areas of 'concern' and
- identify R&D that needs to be done to address these issues
- Categorise (rank) the R&D items

Ranking Criteria

- **R1**: **R&D needed for feasibility demonstration of the machine.**
- **R2**: R&D needed to finalize design choices and ensure reliability of the machine.
- **R3**: R&D needed before starting production of systems and components.
- **R4**: R&D desirable for technical or cost optimization.

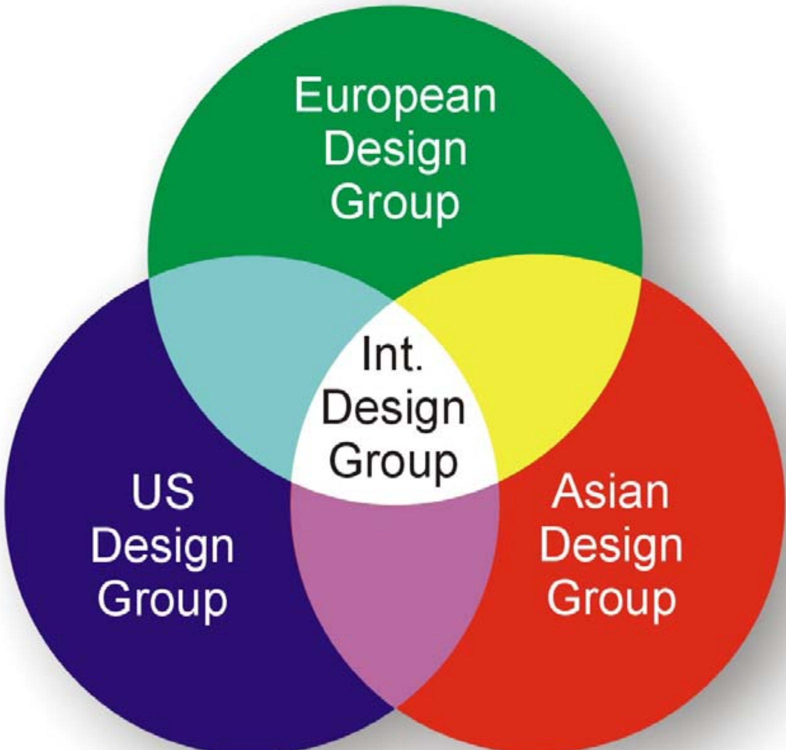
Rankings Score Sheet

	TESLA		JLC-C	JLC-X/NLC		CLIC		Common
E_{cm} [GeV]	500	800	500	500	1000	500	3000	
R1	0	1	2	2	0	5	2	0
R2	7	4	2	3	0	6	2	8
R3	10	3	3	11	0	5	0	19
R4	1	0	1	2	2	0	0	8

A few comments on ILC-TRC

- Rankings reflect the concerns of the working groups, but ILC-TRC overall findings were extremely positive
- "did not find any insurmountable obstacle to building TESLA, JLC-C, JLC-X/NLC within the next few years…"
- "also noted that the TESLA linac RF technology for 500 GeV c.m. is the most mature."
- Assuming the R1s are demonstrated, the RF systems of the two machines will be on an equal footing…
- The ILC-TRC is a excellent example of what we can achieve when the LC accelerator communities work together
- Attempts to maintain the 'momentum' post ILC-TRC are dwindling

LC design study groups

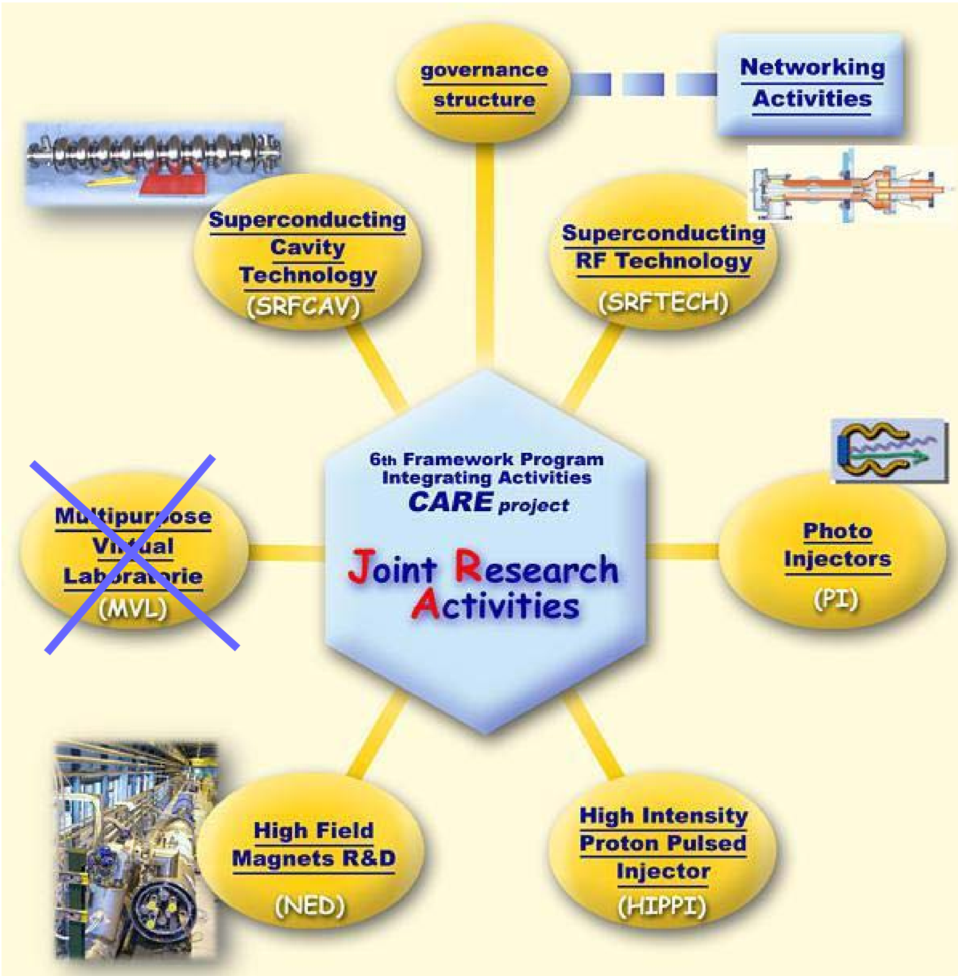


- The structuring of the Design Groups is independent of the Technology Choice, to be taken in 2004
- The European discussions should converge within a few months due to several constraints:
  - EU FP6 submission of Design Study proposals (March 2004)
  - Role of CERN and CERN Council
- Setting up of an GLC Design Group under ILCSC in 2004

CARE

Coordinated Accelerator Research in Europe

ECFA has given CARE a very high priority



- The program was considered essential to:
  - particle physics, synchrotron light sources, high intensity protons and ion beam facilities and operation of accelerators
- Network activities approved on:
  - Electron linacs, neutrino beams and proton machines
- *4 Joint Research Activities approved on:*
  - Superconducting RF cavities, controls and ancillaries
  - Photo Injectors for high charge and high brightness electrons
  - High Intensity Proton Pulsed Injectors
  - Next European Dipoles

Concluding remarks

- **We have a convincing scientific case and a world consensus** on the importance of a LC and on its timing with respect to the LHC
- **A performing and reliable LC can be built as a global project**
  - Valuable experience from numerous test facilities and SLC
  - Unprecedented simulation studies of tuning and operation have been performed and are ongoing
- **Two prospective RF technologies are available**
  - different (complementary?) strengths and weaknesses
  - by the mid of 2004 we will have a reliable idea of their capabilities
- **Technology decision by "wise persons" expected by end 2004**

The future of the LC is largely in our hands
Let's make it happen