深圳综合粒子设施研究院
Institute of Advanced Science Facilities, Shenzhen

Cycle of Seminars by Carlo Pagani

Seminar # 3

The TESLA Cryomodule for high real-estate gradient

Shenzhen, 22 July 2022

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STUDIORUM UNIVERSITAS MEDIOLANENSIS

INFN LASA

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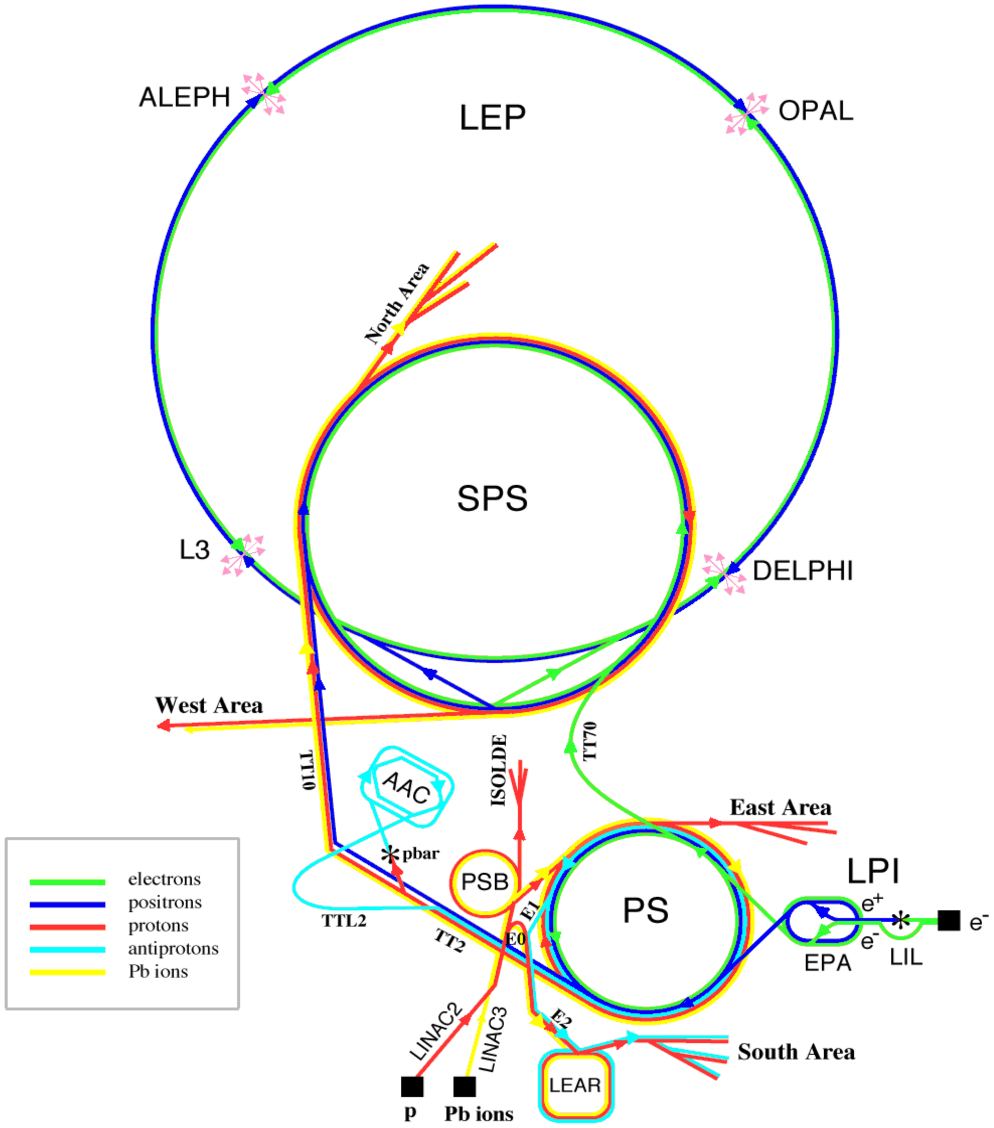
At the end of Eithies LEP-II was the King

Aerial view of the CERN site with an indication of the circular LEP tunnel

- Linacs and synchrotrons were used to inject in the 28 km synchrotron where both electron and positrons were accelerated up to 100 GeV to collide with a centre of mass energy of 200 GeV
- LHC was designed, prototyped, and ready to make use of the LEP 27 km tunnel and of most of its injection accelerator complex

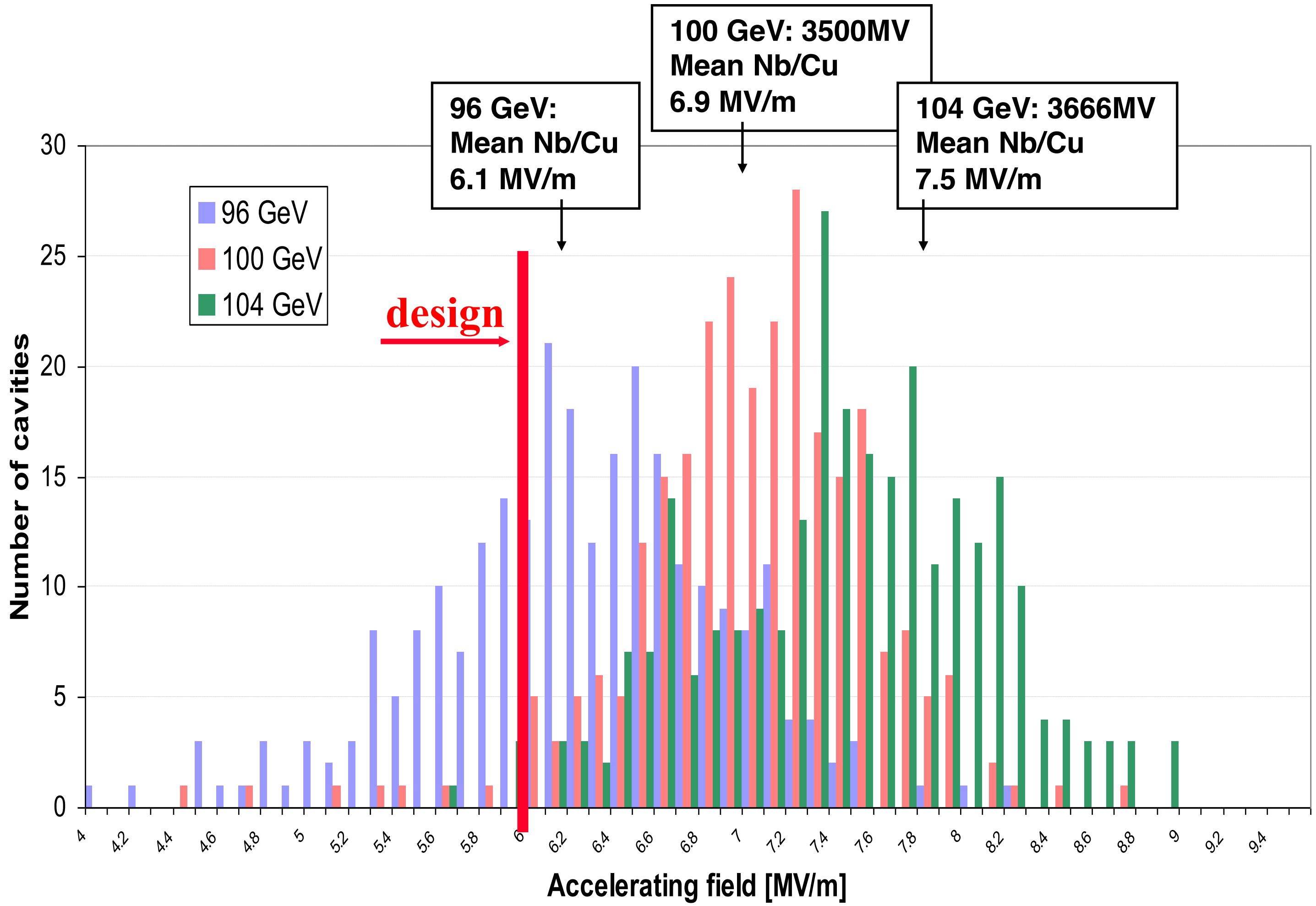


A Great success for LEP-II

Accelerating Field Evolution with time

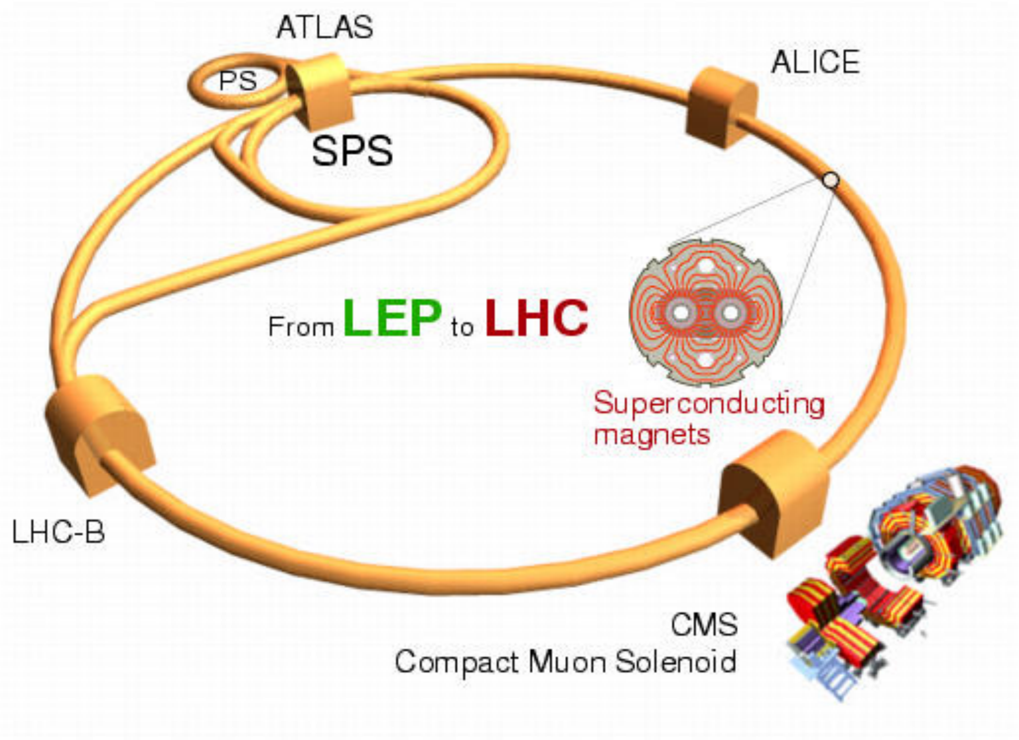
from G. Geschonke's Poster for the ITRP visit to DESY

Final energy reach limited by allowable cryogenic power



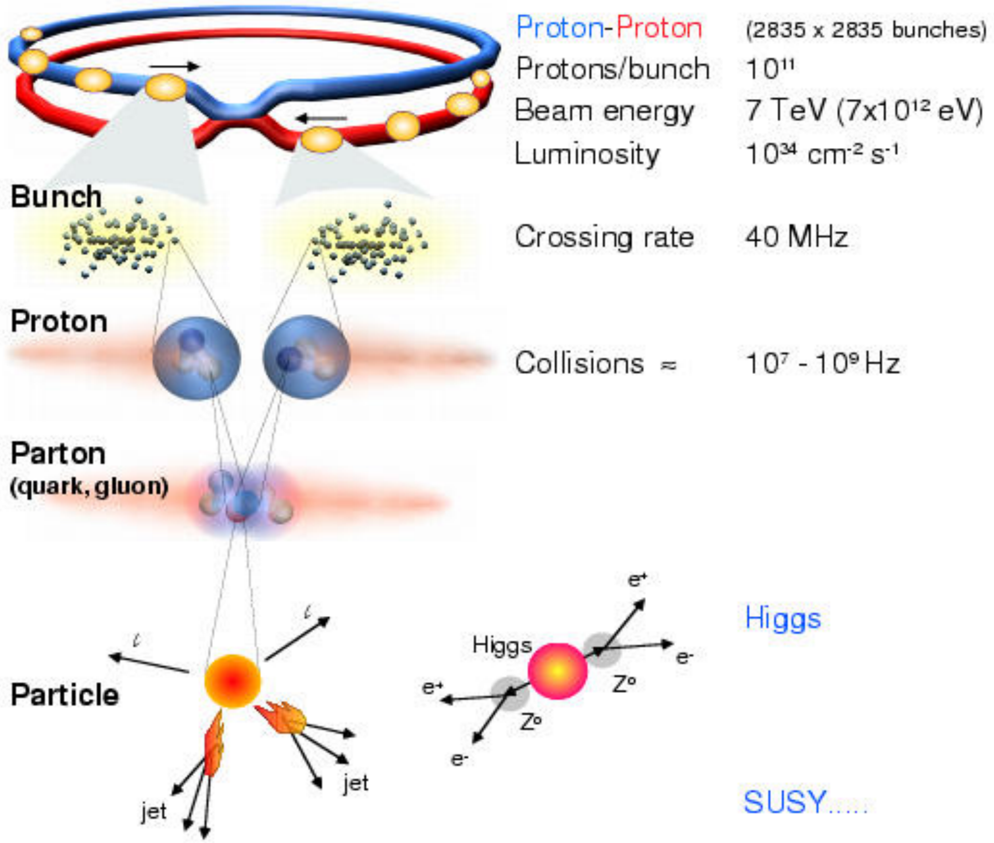
LEP-II success pushed for the LHC

The Large Hadron Collider (LHC)



	Beams	Energy		Luminosity
LEP	e+ e-	200	GeV	10^{32} cm^{-2}s^{-1}
LHC	p p	14	TeV	10^{34}
	Pb Pb	1312	TeV	10^{27}

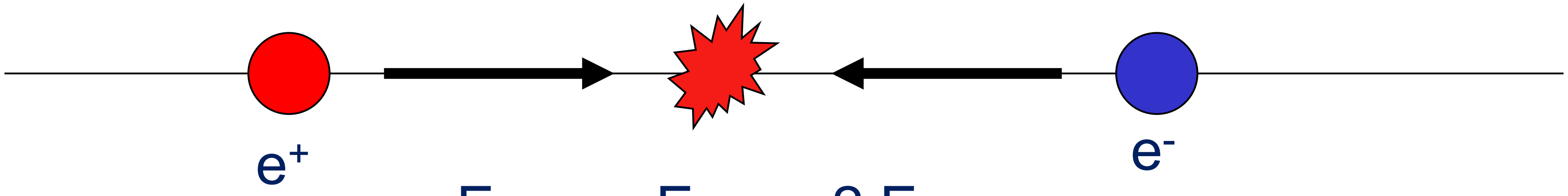
Collisions at LHC



Selection of 1 in 10,000,000,000,000

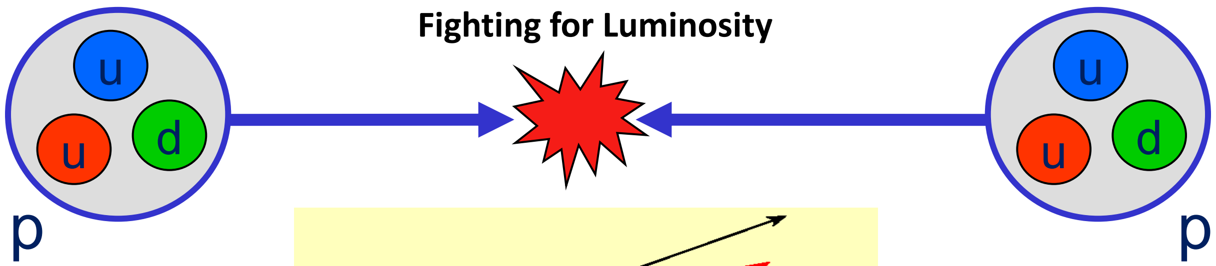
But Leptons needed to complement LHC

Leptons (e^-, e^+, μ^-, μ^+) are Fermions, i.e. matter constituents

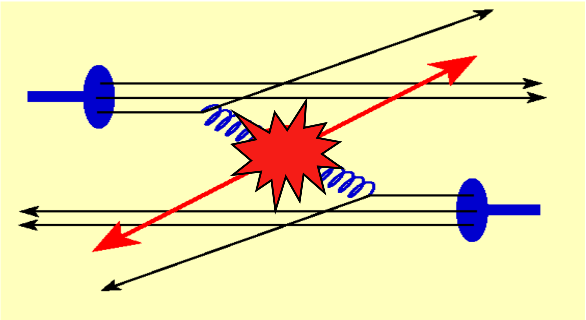


$E_{react.} = E_{c.m.} = 2\ E_{beam}$

Hadrons (p, $\overline{p}$, ions) are complex composite particles



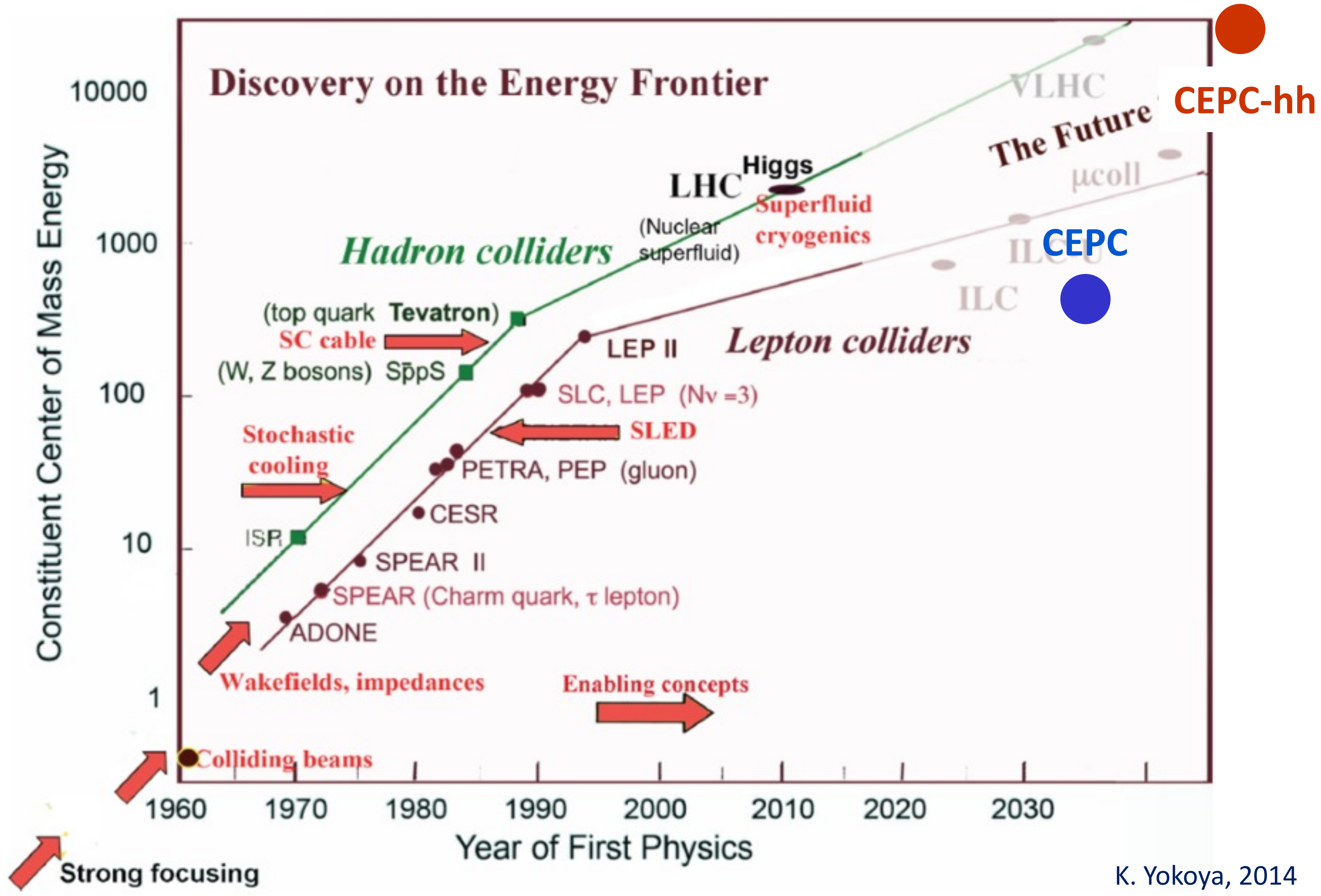
$E_{react.} << 2\ E_{beam}$



Gluon-Gluon Collision

$E_{react.}$ cannot be controlled and it is unknown

Livingston chart for Colliders

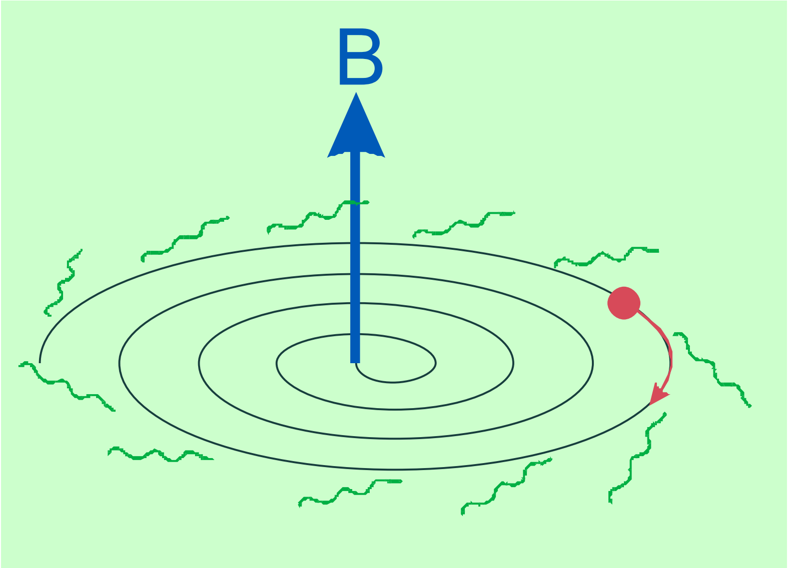


K. Yokoya, 2014

No Circular e^+e^- Collider after LEP !

Synchrotron Radiation

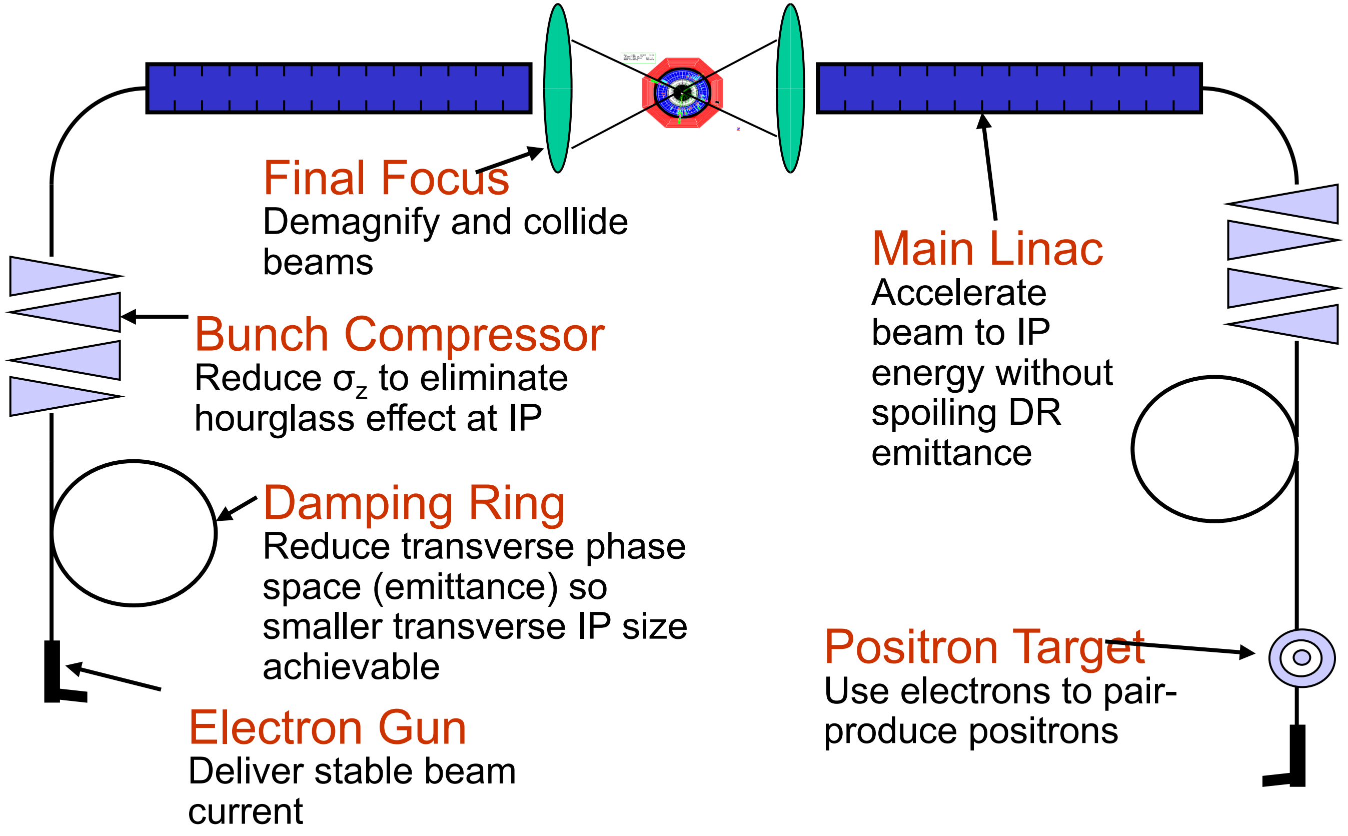
From an electron in a magnetic field:



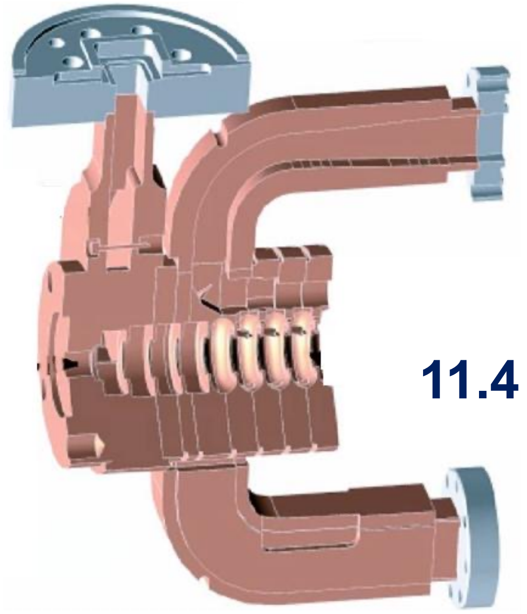
Energy loss must be replaced by RF system

$$U_{SR}[\text{GeV}] = 6 \cdot 10^{-21} \cdot \gamma^4 \cdot {}^{1}\!/_{r[km]}$$

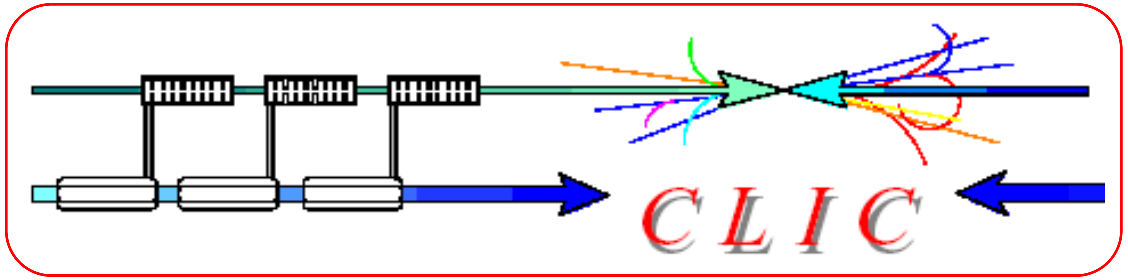
$$\$ \propto E_{cm}^2$$



All competitors were Normal Conducting



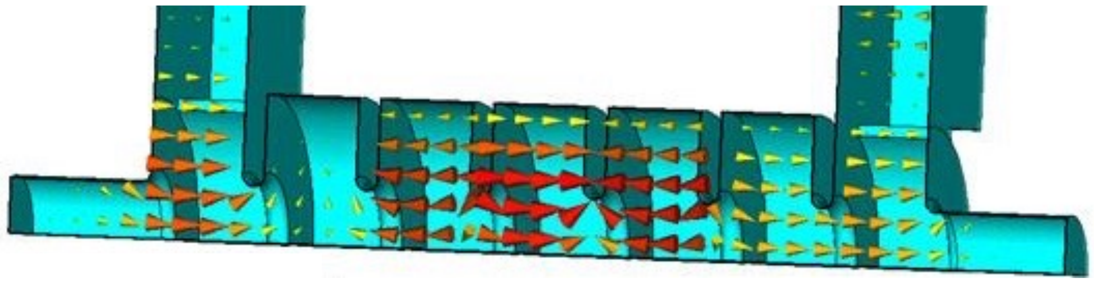
11.4 GHz



30 GHz

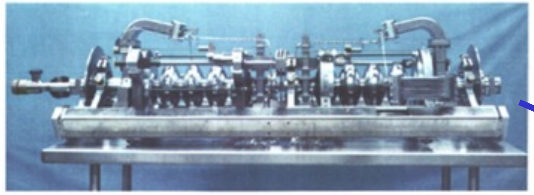
NC Traveling wave

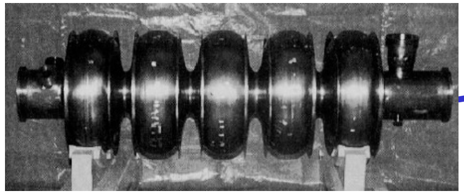
$v_{ph} \approx c$ and $v_g < c$ Nornal Conducting

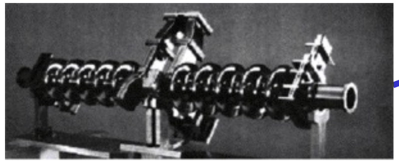


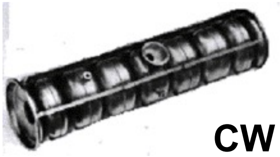
SRF in 1990, when TESLA was born

All SRF cavities operated in CW

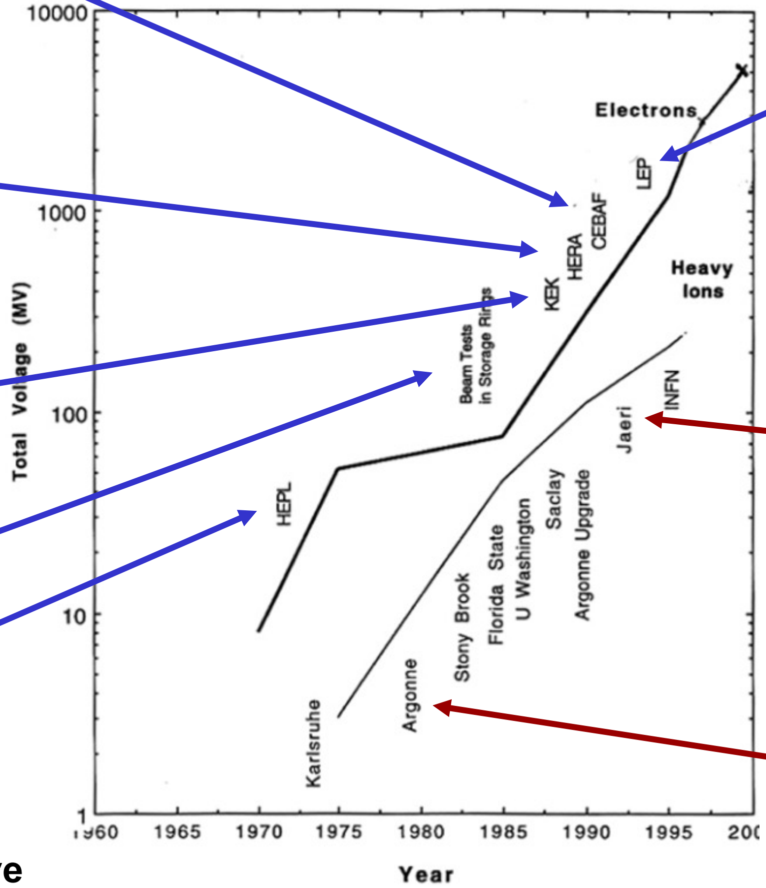








"Livingston Plot" from H. Padamsee



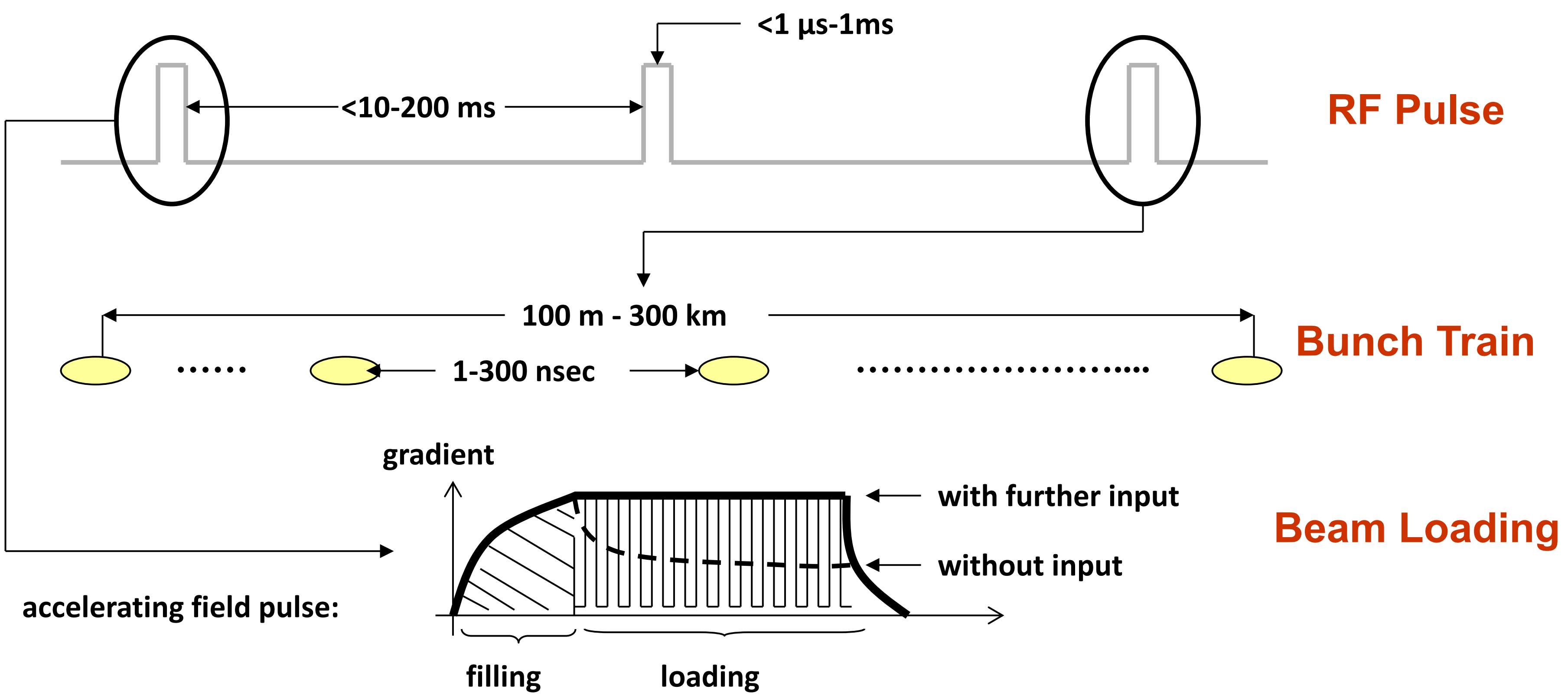
CW = Continuous Wave

But… all Linear Colliders must be pulsed

C. Pagani - ISLC08 - Lecture 1
Oak Brook, October 20, 2008

All the LCs must be pulsed machines to improve efficiency. As a result:

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

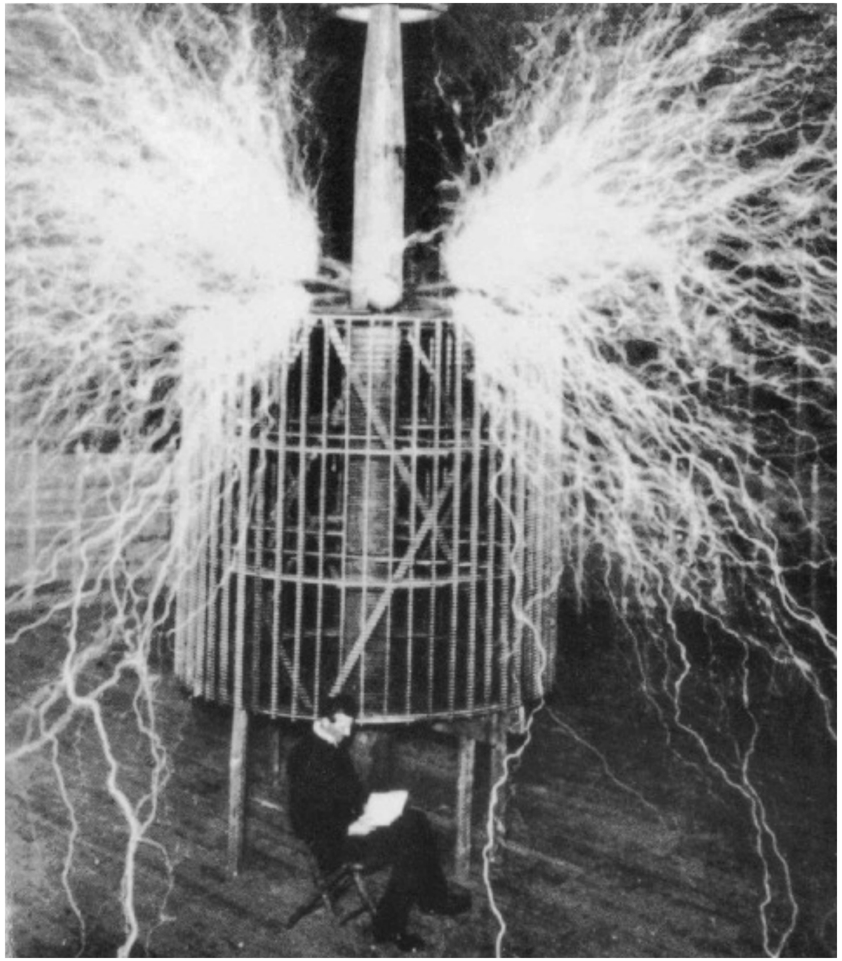


The Origin of TESLA *(The SRF Linear Collider)*

PROCEEDINGS OF

The First International TESLA Workshop

Held at Cornell University
July 23-26, 1990



Ws Summary by Hasan Padamsee

1. OVERALL SUMMARY

TESLA Workshop on Superconducting Linear Colliders

Hasan Padamsee

A 4-day Workshop on a TeV Energy Superconducting Linear Accelerator (TESLA) was held at Cornell University on July 23 - 26, 1990. The purpose of the meeting was to work on a parameter list for TESLA and to explore ideas on improving gradients and lowering cost.

About 70 scientists participated from the laboratories at Argonne, BNL, CEBAF, CERN, Cornell, Darmstadt, DESY, Fermilab, IHEP Protvino, INFN (Frascatti, Genova, Milano), KEK, Lawrence Livermore, Los Alamos, Saclay, SLAC, Stony-Brook, and Wuppertal. The TESLA collaboration was created in August '89 at the end of the KEK workshop on rf superconductivity. During the ensuing year, working groups were formed and bilateral collaborations started.

The first day of the workshop was devoted to plenary talks. M. Yoshioka from KEK reviewed the KEK Linear Collider Workshop (March 1990) covering JLC, NLC, TLC, CLIC, VLEPP and TESLA. U. Amaldi from CERN promoted new parameter strategies for TESLA, which helped guide the working group sessions. The final talk on Electron-Proton Colliders Beyond HERA (B. Wiik and M. Tigner) could not be given to due the unfortunate illness of M. Tigner. A copy of his talk is included in the proceedings.

The plenary talks were followed by progress reports from chairs of various working groups. The remaining three days were devoted to working groups and final summaries. Group 1 and 6 decided to combine their activities, and so did groups 4a and 4b.

A staged approach to TESLA was considered reasonable. The starting energy is a function of high energy physics interest and of progress in higher gradients in SRF cavities. Linear colliders have the advantage that, if a suitable site is selected, the length can be extended periodically.

If there is interest in a high-luminosity Z_0-factory, an initial TESLA energy of 0.1 TeV would be sensible. An accelerating gradient of 15 MeV/m was considered. Using the estimate of 135 ± 30 GeV for the energy of the Top quark, the next energy could be 0.3 TeV (CM), with the corresponding gradient of 20 MeV/m, total length 15 Km. Gradients of 25, 30 and 40 MeV/m were considered for the final three energies (0.5, 1 and 1.5 TeV) which are relevant to investigating the Standard Model, and allow comparision with NLC, JLC and TLCs.

Parameter sets for these machines were generated. In contrast to on-going applications such as for high energy storage rings, rf for TESLA must necessarily be pulsed to keep the refrigerator costs affordable. A high duty cycle (few %), however, retains the many attractive features of the SRF approach.

The guiding parameter philosophy was to make the most of high beam powers allowed by the high efficiency of SRF cavities. Thus it was possible to reach high luminosities, e.g. 5×10^{33} $cm^{-2}sec^{-2}$ @ 1 TeV CM, but to relieve the final focus spot size to $\sigma_y \sim 100$ nano-meters from the miniscule 2 nanometers size beam for room temperature machines. A larger beam size makes it easier to bring the beams into collision, and relaxes the demand for minute source emittances.

The TESLA parameters provide more than a factor of 10 smaller beamstrahlung induced energy spread, improving the physics potential, especially in cases such as a Toponium factory. Reduced backgrounds are also expected from the e^+e^- pairs generated by beamstrahlung photons.

Adding to the favorable physics parameters, there are many attractive features to an SRF linac, which stem from the factor of 10^5 lower losses than a copper linac. SRF cavities can be filled slowly, greatly reducing the peak rf power demand, for e.g., from many hundreds of Mwatts/meter to a few tens of Kwatts/meter. Existing klystron technology can be used. Development of high power rf sources remains one of the many challenging aspects of room temperature linear colliders.

The push towards higher rf frequencies (11.4 - 17 GHz) in normal conducting linacs makes wakefield effects very serious. Because SRF cavities can store energy efficiently, they allow a low rf frequency (1.5 - 3 GHz). With the curtailed wakefields, tolerances on alignment and injection jitter are enormously relaxed. The energy spread is smaller, so that final focus system can be greatly simplified with larger apertures, and no need for a crossing angle.

With SRF cavities, the rf pulse length can be many thousand times longer than for copper cavities, so many hundreds of bunches can be accelerated. Conversion efficiencies as high as 20% from ac power to beam power can be reached, in contrast to normal conducting machine efficiencies of ~ 1%. Bunches are then spaced very far apart (km), eliminating the possibility of wrong bunches colliding at the intersection region. With such a large bunch spacing and lower wakefields, the damping of higher modes can be considerably relaxed. To avoid multibunch instabilities in normal conducting colliders, dangerous modes must be damped to Q's< 20. For TESLA, very little transverse blow-up is expected even if the Q's of higher modes are 10^6.

The major challenges for TESLA are to increase the gradients and lower the costs. The present state of the art of gradients achieved with structures for electrons is Eacc = 5 MeV/m in operating SRF systems of TRISTAN and LEP. Acceptance tests on more than 70 meters of industrially produced structures average close to 9 MeV/m.

Progress in gradients continues. Recently, at 1.5 - 3 GHz, the best 5 and 6-cell structures from four different labs (CEBAF, Cornell, Saclay and Wuppertal) reached surface electric fields (Esp) between 33 and 40 MV/m with the standard chemical surface treatment. In structures with reduced Esp/Eacc = 2.1, these results correspond to accelerating fields, Eacc = 16 - 19 MeV/m. Thus several labs have now provided existence proofs for Eacc > 15 MeV/m in full scale structures.

Field emission is recognized to be the dominant obstacle to reaching higher fields. Basic studies continue to improve understanding of this pernicious phenomenon which plagues both normal and superconducting cavities. Cures are being developed. With specially developed heat treatment techniques at 1400 - 1500 C, 1.5 GHz, 1-cell Nb cavities at Cornell now reach much higher fields. The average is Esp = 50 MV/m at Q values above 10^9, with 60 MV/m as the record best value. When the new heat treatment was applied to a 5-cell, 3 GHz structure at Wuppertal, it reached Esp = 67 MV/m. These values correspond to Eacc = 24 - 32 MeV/m.

A Nb cavity operating near the theoretical limit of Eacc = 50 MeV/m, needs to support an rf surface electric field ~ 100 MV/m. A basic question is whether a Nb surface under any condition will tolerate this value. In a specially designed "mushroom" shaped cavity at Cornell and in an "RFQ-type" cavity at Argonne, cw surface rf electric fields of 145 MV/m were demonstrated without breakdown, while a pulsed (1 msec) field of 210 MV/m was reached in the RFQ.

Many ideas were advanced for lowering structure costs. Since a Qext of 10^6 appears sufficient for damping higher modes, the number of cells can be increased from the customary 4-5 cells/structure to 10 cells. By polarizing individual cells, deflecting modes can be oriented so that one coupler can do the job of two. Economical cryostat designs were worked out that improve the filling factor from 0.5 to 0.75, and reduce static heat losses from 5 watts/m to below 1 watt/m.

The parameter sets worked out for TESLA need to be optimized from the point of view of the overall costs, which is the domain of future workshops. To continue progress on gradient and cost issues, needs for increased funding and manpower were stressed. There were many discussion on strengthening existing collaborations. The next TESLA workshop will be held in DESY, in conjunction with the 5th International Workshop on RF Superconductivity.

The importance of SRF for particle accelerators is growing rapidly, with large scale application of SRF cavities to electron and ion accelerators around the world. If gradients continue to improve, and costs can be lowered from today values, there are many attractive reasons to consider the use of SRF cavities for a fully superconducting, high luminosity TeV linear collider.

From the H. Padamsee' Summary - 1

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What we need to use SRF

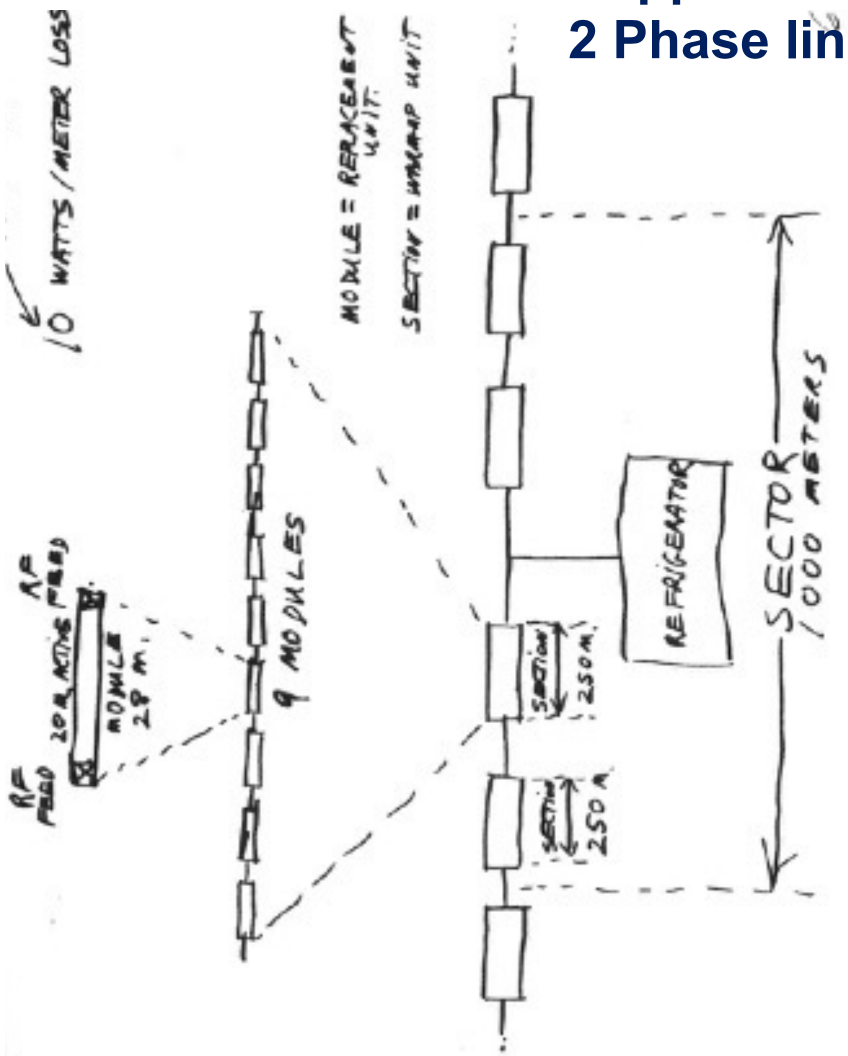
- The power is deposited at the operating temperature of few K
- We need to guarantee and preserve the 2 K environment
- Cavity is sensitive to pressure variations; only viable environment is sub-atmospheric vapor saturated He II bath
- We need a thermal “machine” that performs work at room temperature to extract the heat deposited at cold
- The Thermal machine efficiency is just a fraction of the Carnot efficiency
- Less favorable Geometrical Factor G

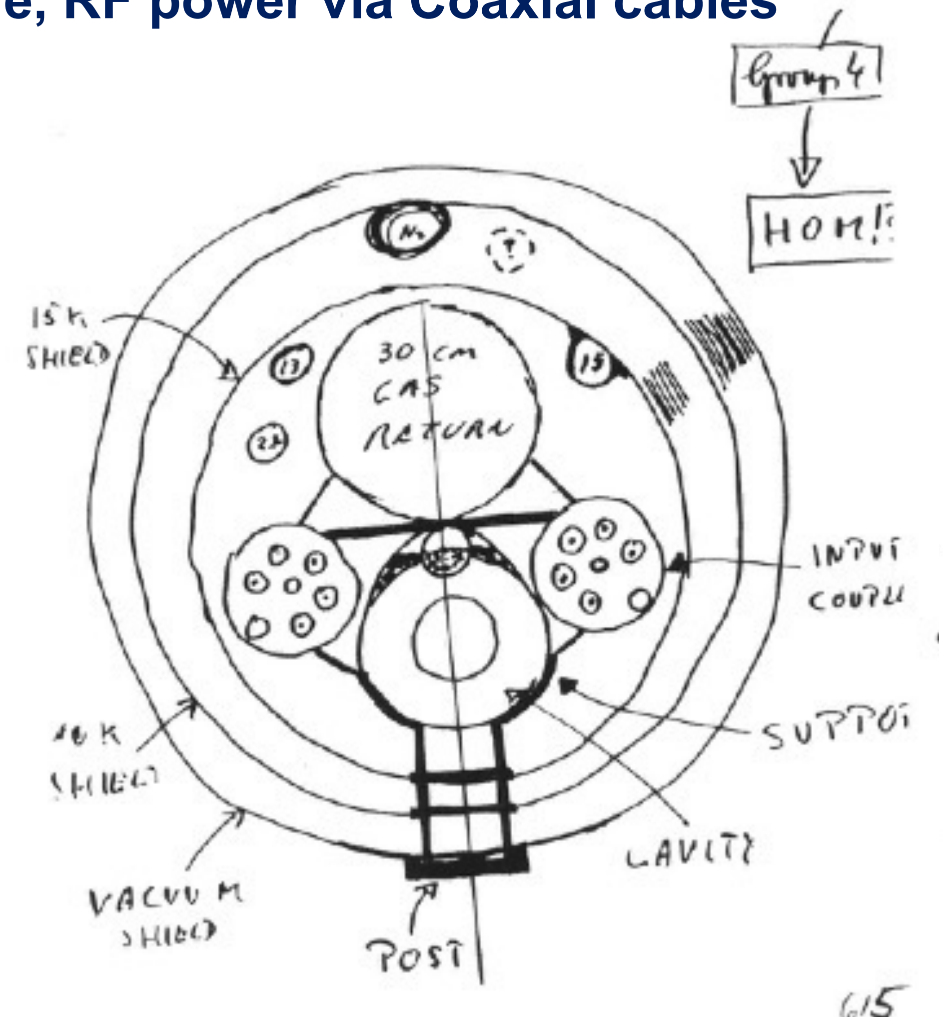
Contents

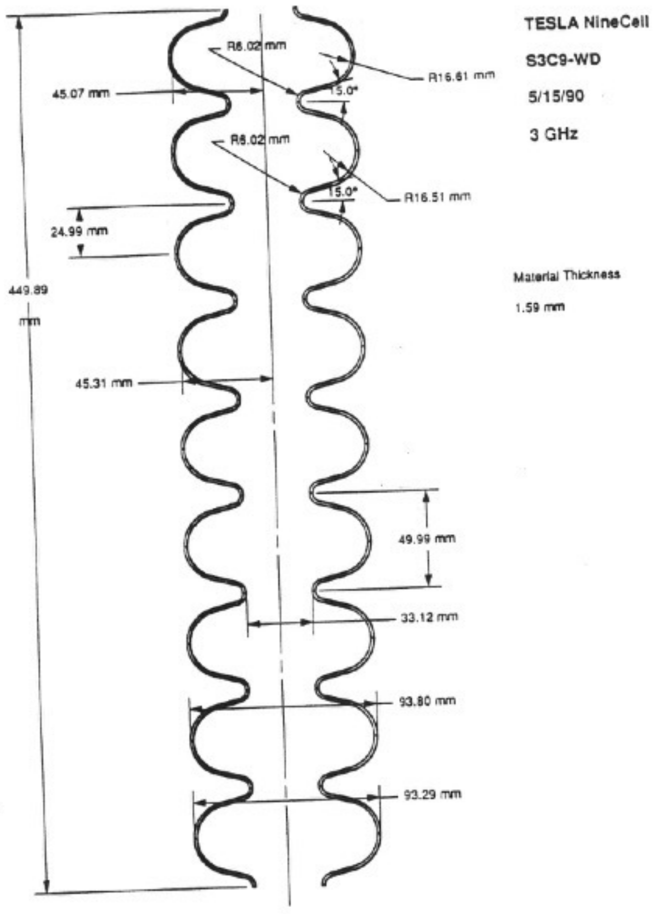
Cryomodule & Cavity Concept from Cornell

Support Posts, Gas Return Pipe, 2 Shields
2 Phase line, RF power via Coaxial cables

9-cell, 3 GHz







Memories from the Cornell Workshop

Kako

L-Band Superconducting Cavity

at KEK

<u>Frequency</u> 1.3 GHz

<u>Fabrication of Single-cell Cavity</u>

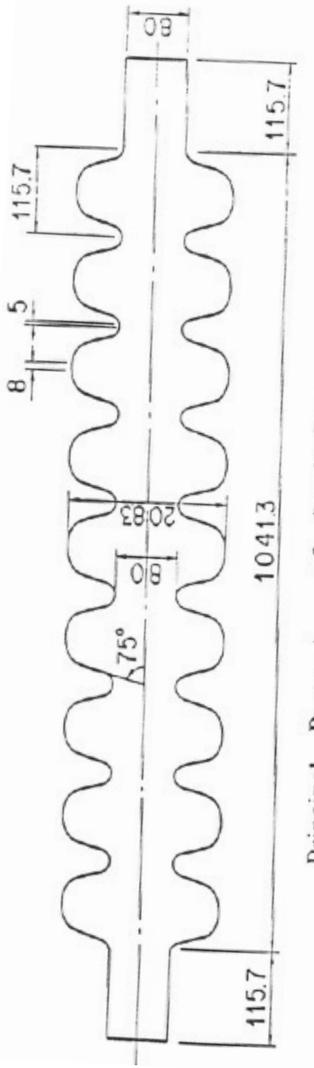
. Nb Cavity

. Nb Coated Cu Cavity

<u>Calculation of 9-cell Cavity</u>

. Higher Order Modes

. Loss Parameters



<u>Principal Parameters of 9-cell Cavity</u>

Frequency	1296	MHz
Effective Length	1.04	m
R / Q	913	ohm
Geometrical Factor	261	ohm
Esp / Eacc	2.04	
Hsp / Eacc	43.5	Oe/MV/m
Cell to Cell Coupling Coefficient	2.5	%
Radius of Beam Pipe	40	mm

1992: DESY hosts the TESLA Collaboration

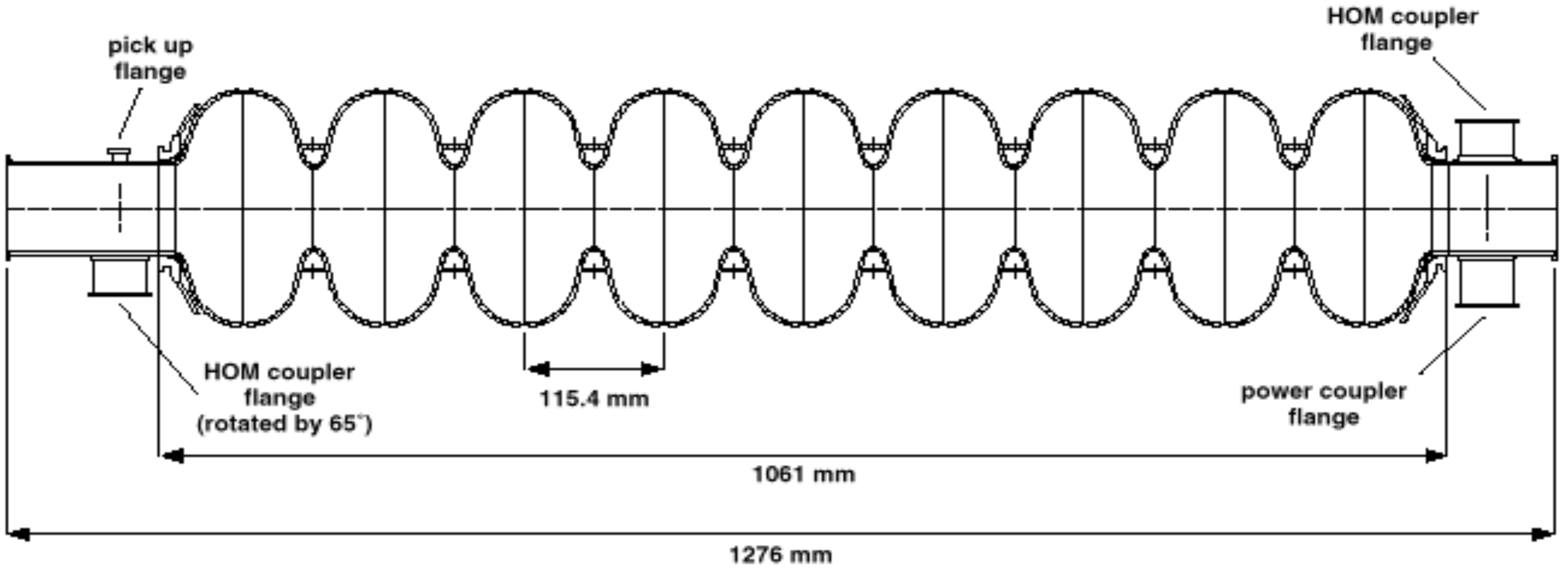
Develop SRF for a TeV Linear Collider

- **Increase gradient by a factor of 5** (Physical limit for Nb at ~ 50 MV/m)
- **Reduce cost per MV by a factor 20** (New cryomodule concept and Industrialization)
- **Make possible pulsed operation** (Combine SRF and mechanical engineering)

Major advantages vs NC Technology

- **Higher conversion efficiency**: more beam power for less plug power consumption
- **Lower RF frequency**: relaxed tolerances and smaller emittance dilution

The TESLA SRF Cavity, 1.3 GHz, 9-cell



type of accelerating structure	standing wave
accelerating mode	TM0 π mode
fundamental frequency	1300 MHz
design gradient E_{acc} (TTF)	15 MV/m
design gradient E_{acc} (TESLA)	25 MV/m
unloaded quality factor Q_0 (TTF)	$> 3 \times 10^9$
unloaded quality factor Q_0 (TESLA)	$> 5 \times 10^9$
shunt impedance R / Q	1036 Ω
E_{peak} / E_{acc}	2.0
B_{peak} / E_{acc}	4.26 mT / (MV/m)
cavity bandwidth at $Q_0 = 3 \times 10^6$	430 Hz

TESLA Cryomodule Design Rationales

High Performance Cryomodule was central for the TESLA Mission

- More then one order of magnitude was to be gained in term of capital and operational cost

High filling factor: to maximize real estate gradient

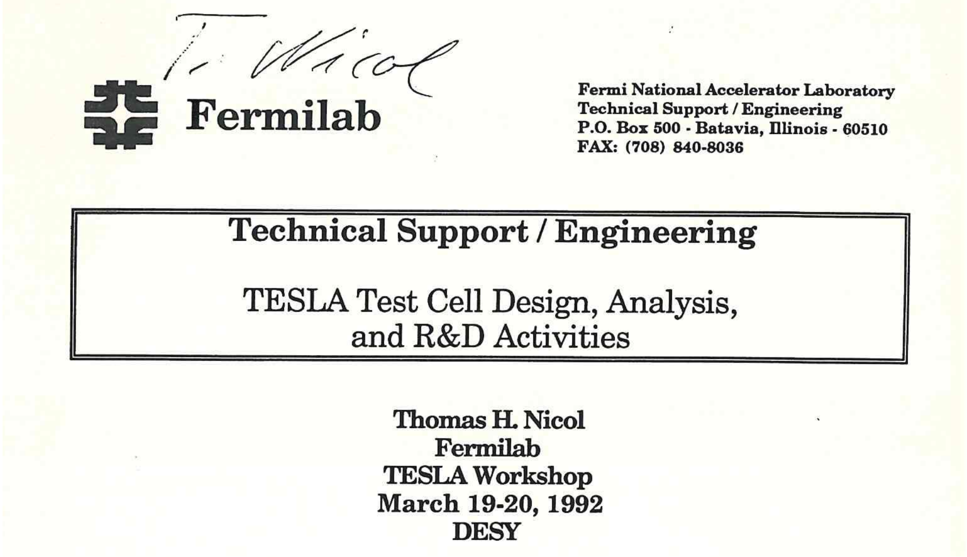
- Long sub-units with many cavities (and quad): cryomodules
- Sub-units connected in longer strings
- Cooling and return pipes integrated into the main cryomodule

Low cost per meter: to be compatible with a long TeV Collider

- Cryomodule used also for feeding and return pipes
- Minimize the number of cold to warm connections for static losses
- Minimize the use of special components and materials
- Modular design using the simplest possible solution

Easy to be alligned and stable: strict beam requirements: +/- 0.3 mm (rms)

Cryomodule Evolution at Fermilab


T. Nicol

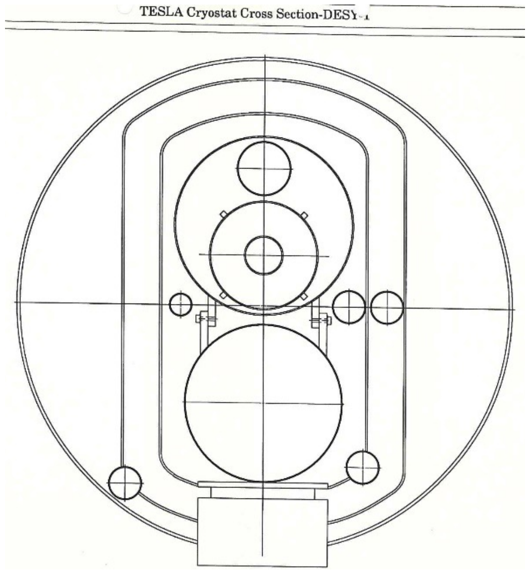
Fermilab

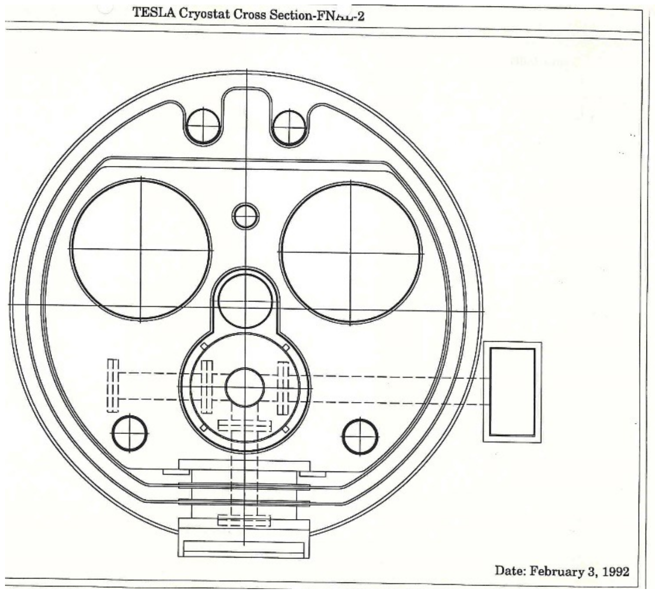
Fermi National Accelerator Laboratory
Technical Support / Engineering
P.O. Box 500 - Batavia, Illinois - 60510
FAX: (708) 840-8036

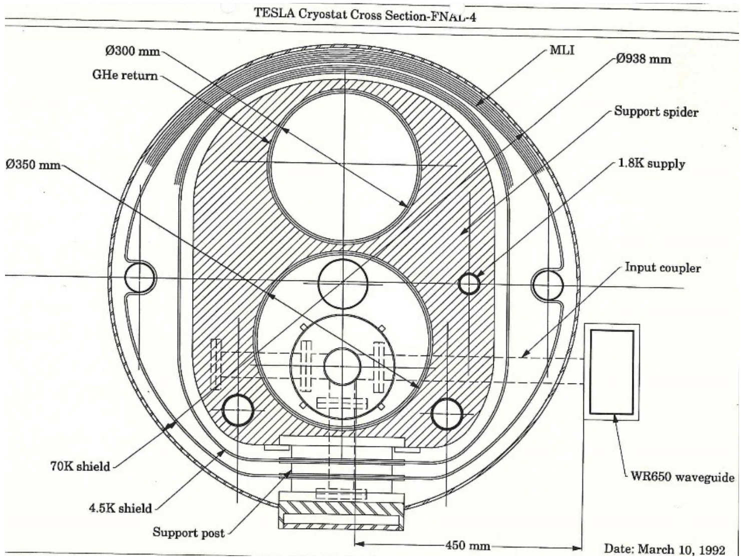
Technical Support / Engineering

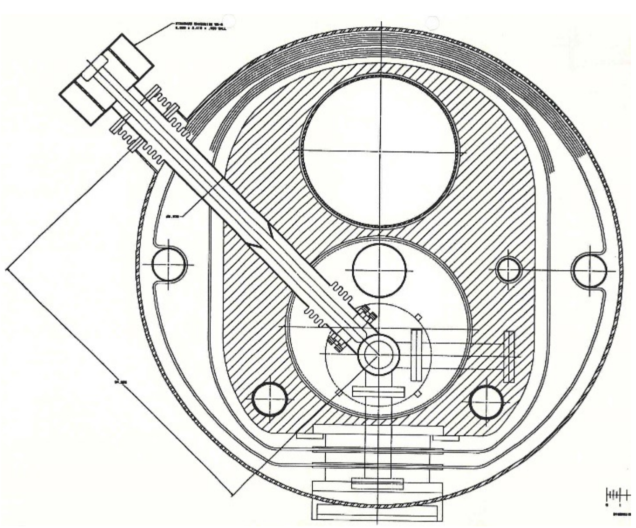
TESLA Test Cell Design, Analysis, and R&D Activities

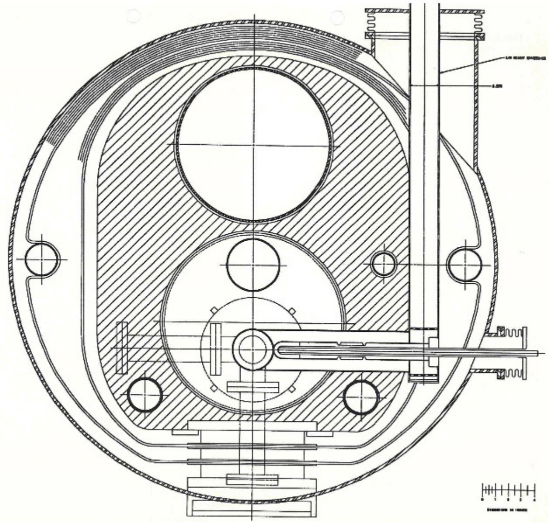
Thomas H. Nicol
Fermilab
TESLA Workshop
March 19-20, 1992
DESY



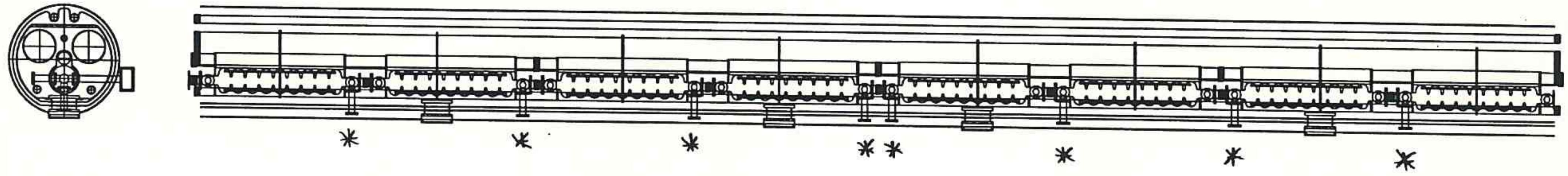






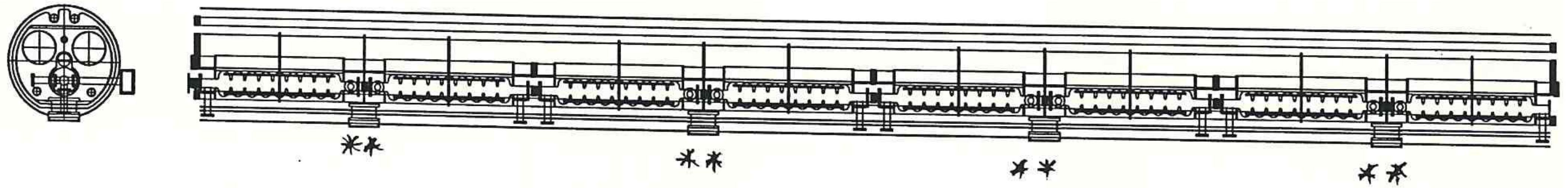


Schematic Longitudinal Layout



(*) INPUT COUPLERS

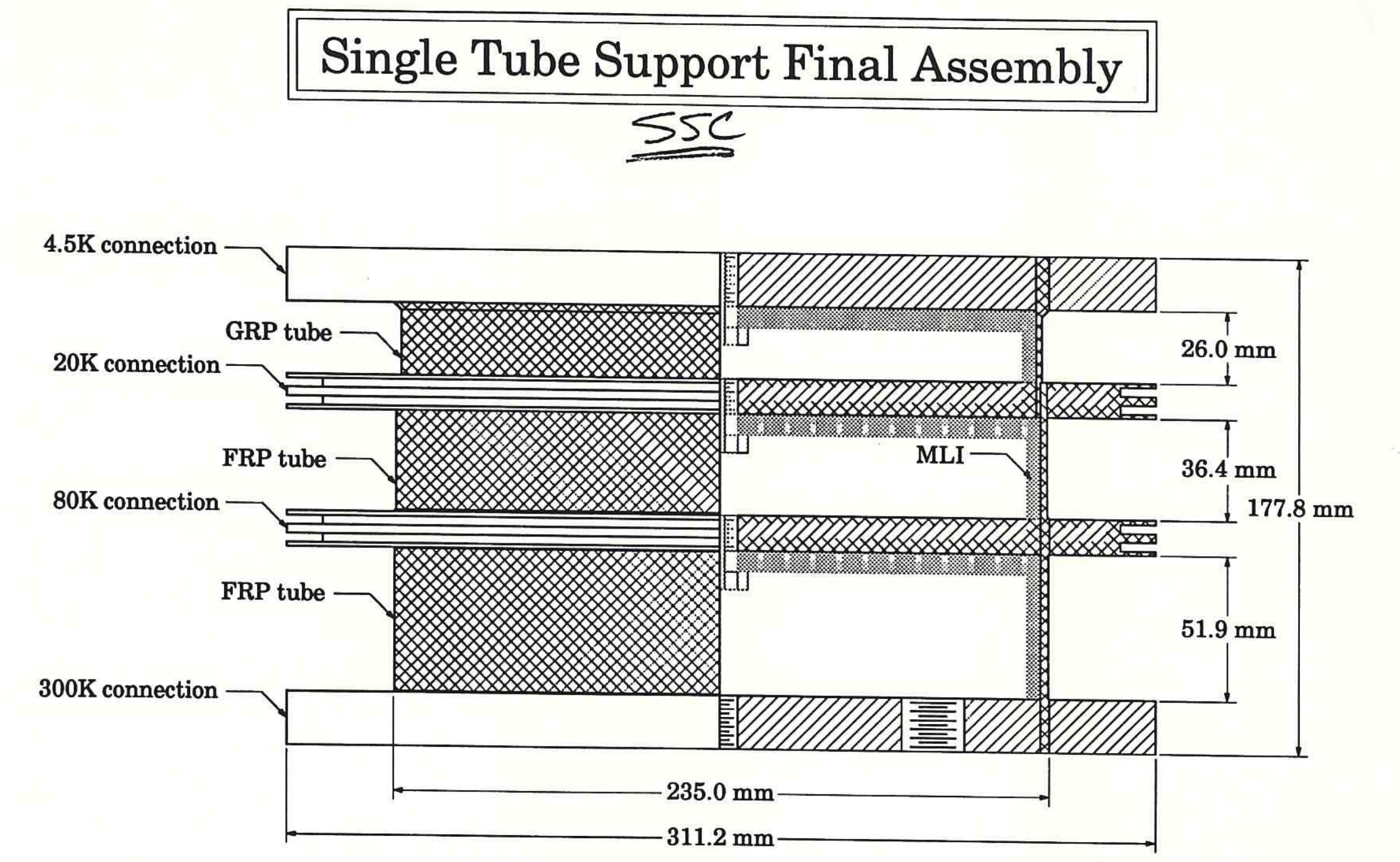
COUPLER MOVEMENT $\simeq$ 3mm



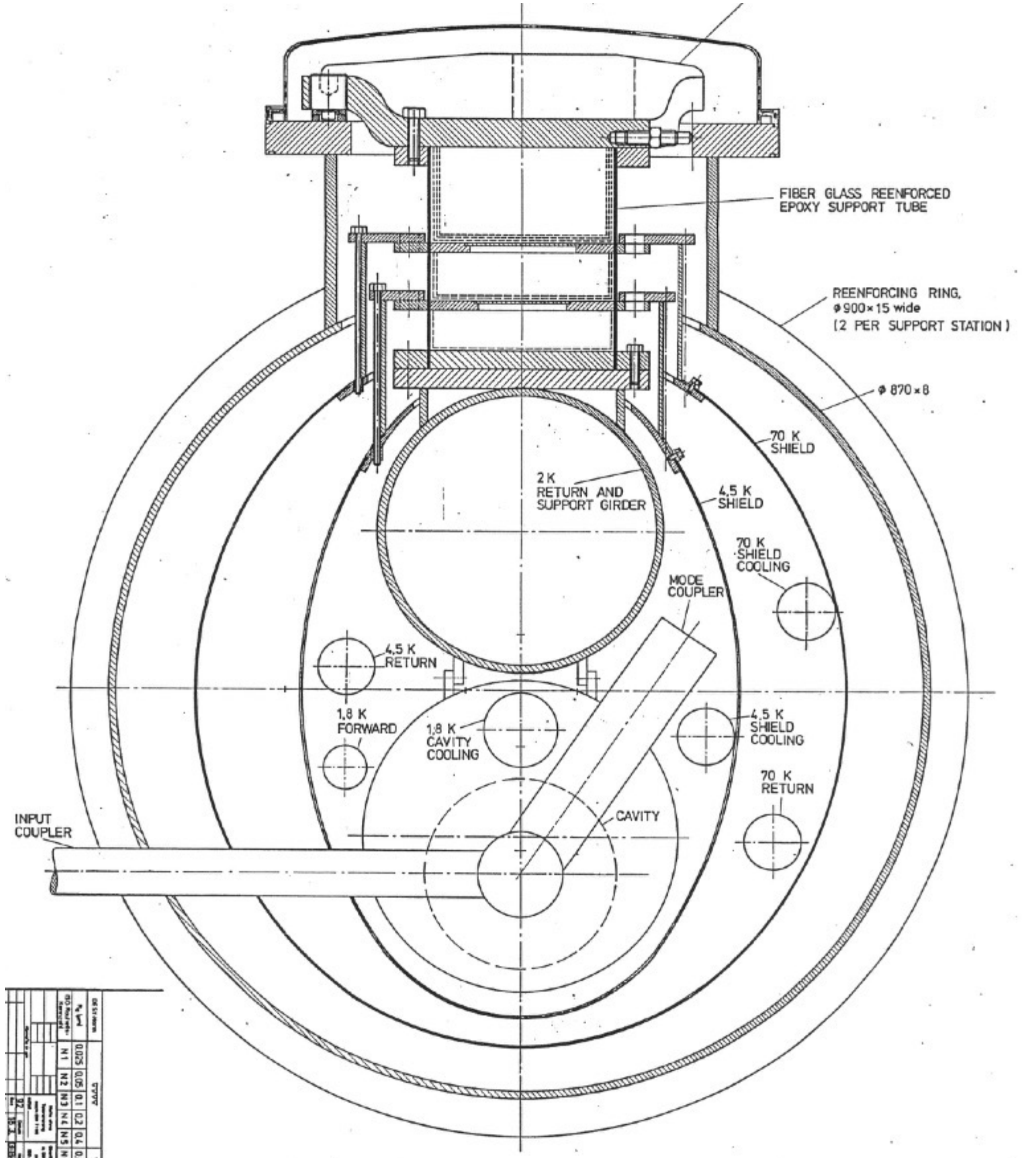
INPUT COUPLERS

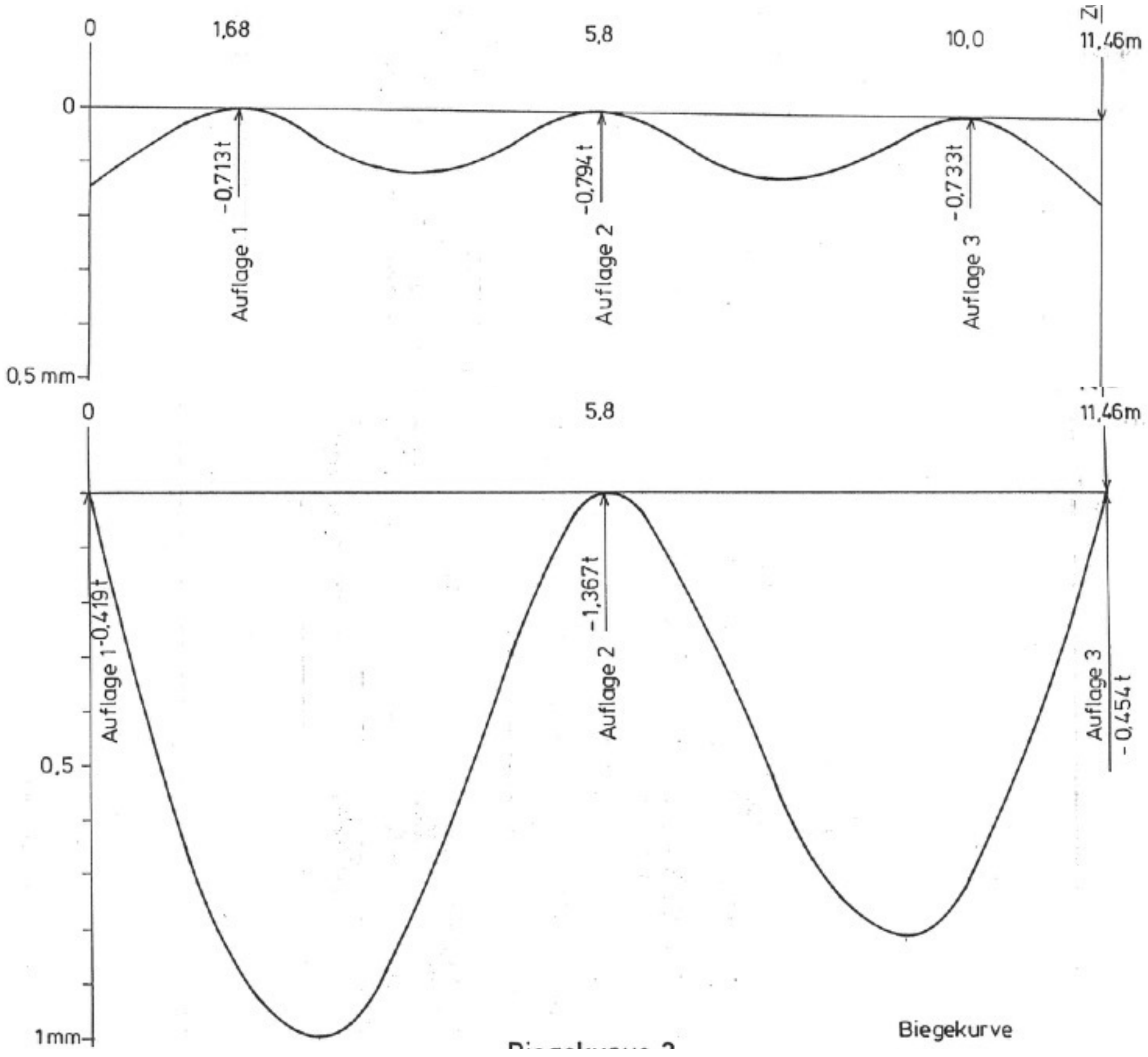
COUPLER MOVEMENT < 1mm

The Fermilab Support Post



Design Review by DESY (and INFN)





CRY 1 – Some new Hints from Fermilab

TESLA-Report 1994-12

Fermilab

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TESLA Test Facility Cryostat
Gas Helium Return Tube Thermal Gradient Analysis

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P.O. Box 500
Batavia, IL 60510 USA

March 23, 1994

Introduction

Concern has been expressed over the course of the TESLA test facility (TTF) cryostat development about thermally induced distortions of the gas helium return tube. Specifically, the issue involves thermal gradients which can occur in this tube from flow stratification during cooldown. These thermal gradients induce mechanical distortions and thermal stresses in the tube and impose structural loads on the support system. The following report summarizes the results of a structural analysis on this tube. The analysis does not attempt to predict the details of cooldown, but rather to assess the behavior of the tube given a set of discrete assumptions.

Tube Geometry

The gas helium return tube is continuous through the entire TTF cryostat. It is supported at three points along its length by support posts attached to the vacuum vessel and serves as the main structural support for all eight cavity helium vessels and the quadrupole. Figure 1 illustrates a cross section through the cryostat assembly at a typical cavity location. For the sake of this analysis the tube is assumed to be symmetric about the center of the cryostat assembly. This is not exactly correct due to the presence of the quadrupole at one end, however, the errors resulting from this assumption are small. Figure 2 illustrates the model of the tube used in this analysis. It is modeled using the left half of INFN drawing number 02.01.00. All of the pertinent tube parameters are summarized in Table 1.

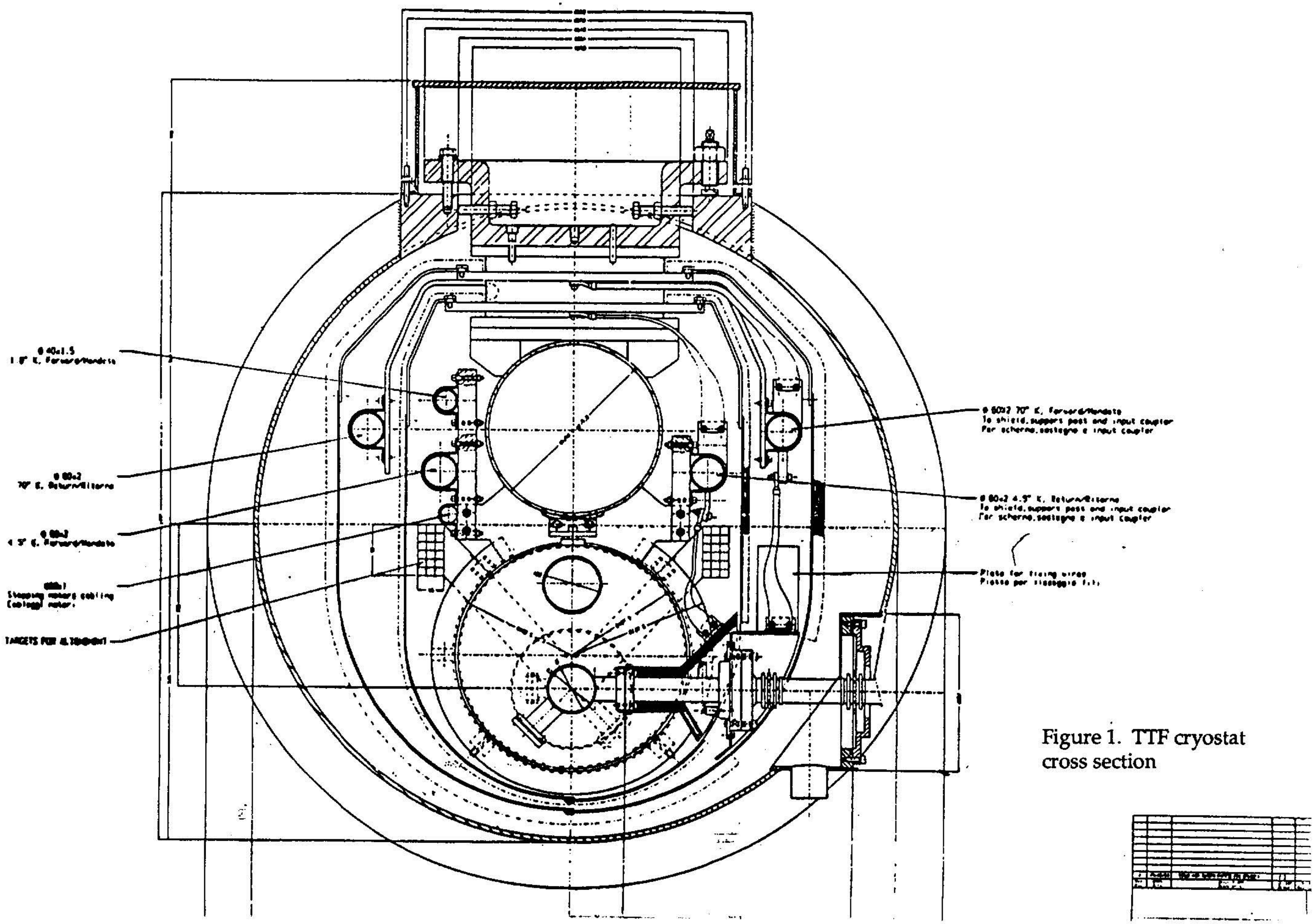

Figure 1. TTF cryostat cross section

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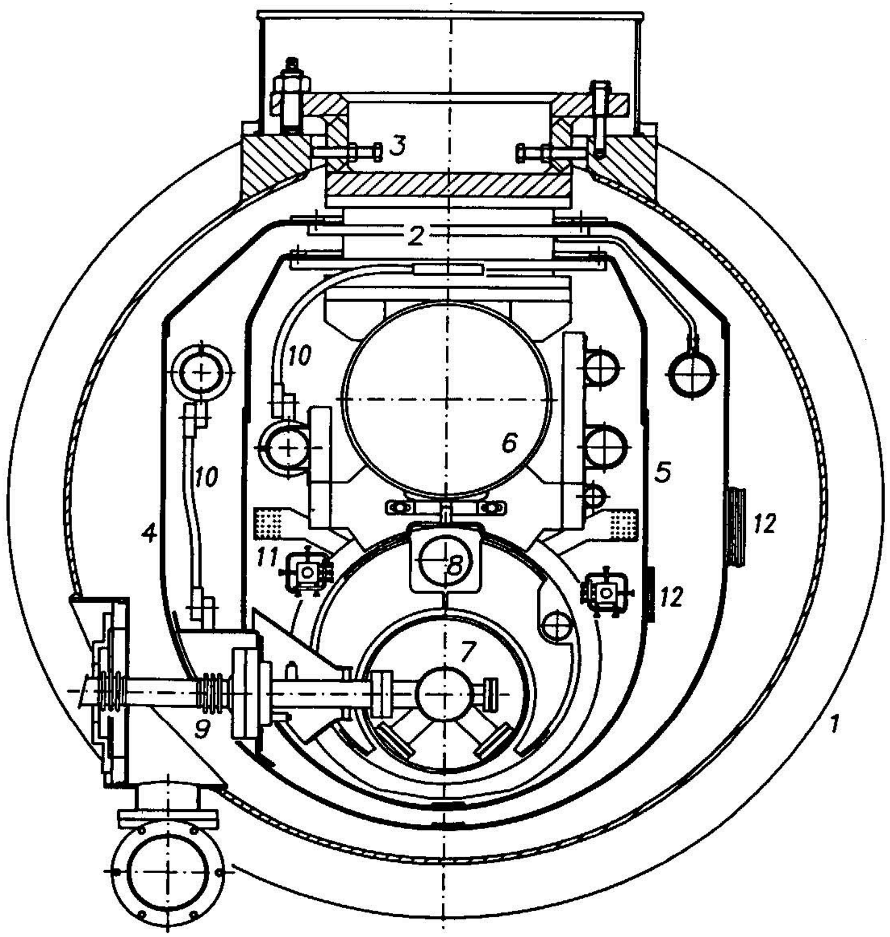
Contents

CFY-1: the FNAL-DASY-INFN Compromize

DESIGN MANUFACTURE AND TEST OF THE TESLA-TTF CAVITY CRYOSTAT

F. Alessandria[1], G. Cavallari[2], M.Minestrini[3], T.H.Nicol[4], C. Pagani[1], R.Palmieri[5], S. Tazzari[6], G. Varisco[1]

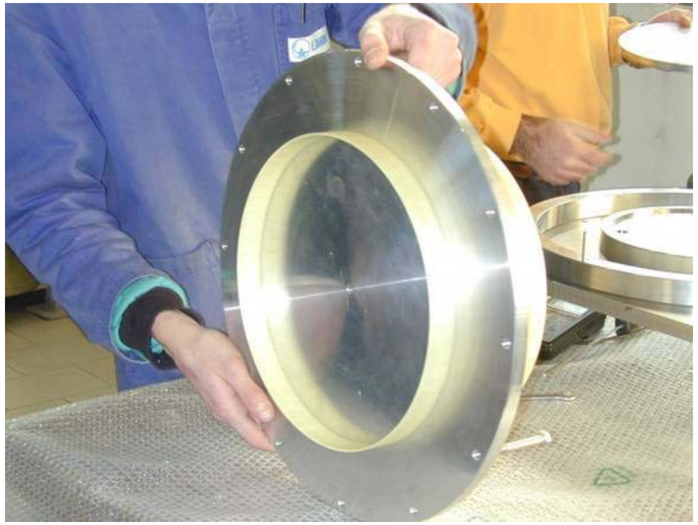


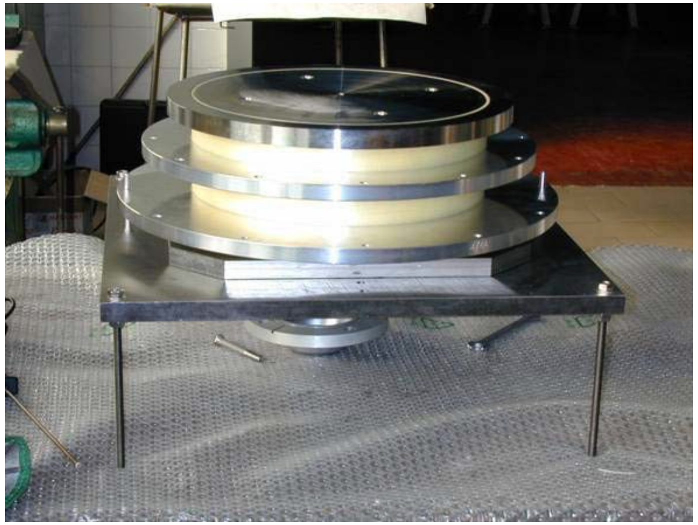
1 VACUUM VESSEL
2 COMPOSITE POST
3 SUPPORT BRACKET
4 70 K SHIELD
5 4.5 K SHIELD
6 1.8 K He GAS RETURN PIPE
7 CAVITY
8 1.8 K LHe SUPPLY
9 MAIN COUPLER
10 Cu BRAIDS
11 ALIGNEMENT TARGETS
12 ML INSULATION

Support Posts (FNAL Design) - 1

- Support Posts are the mechanical cryogenic connections of the HeGRP (He Gas Return Pipe) that supports all the active elements. FNAL Design
- The insulating element is a fiberglass pipe dimensioned in order to keep the eigenfrequencies high
- Stainless Steel and aluminum flanges are shrink-fitted for mechanical connection to GRP, thermal shields and room temperature support
- Each support post has been tested by compression-tension cycles to verify the stiffness of the interference junction
- A break test shown that the post break point is about 100 kN

Support Posts (FNAL Design) - 2


CRY 2, new shields and fabrication strategy

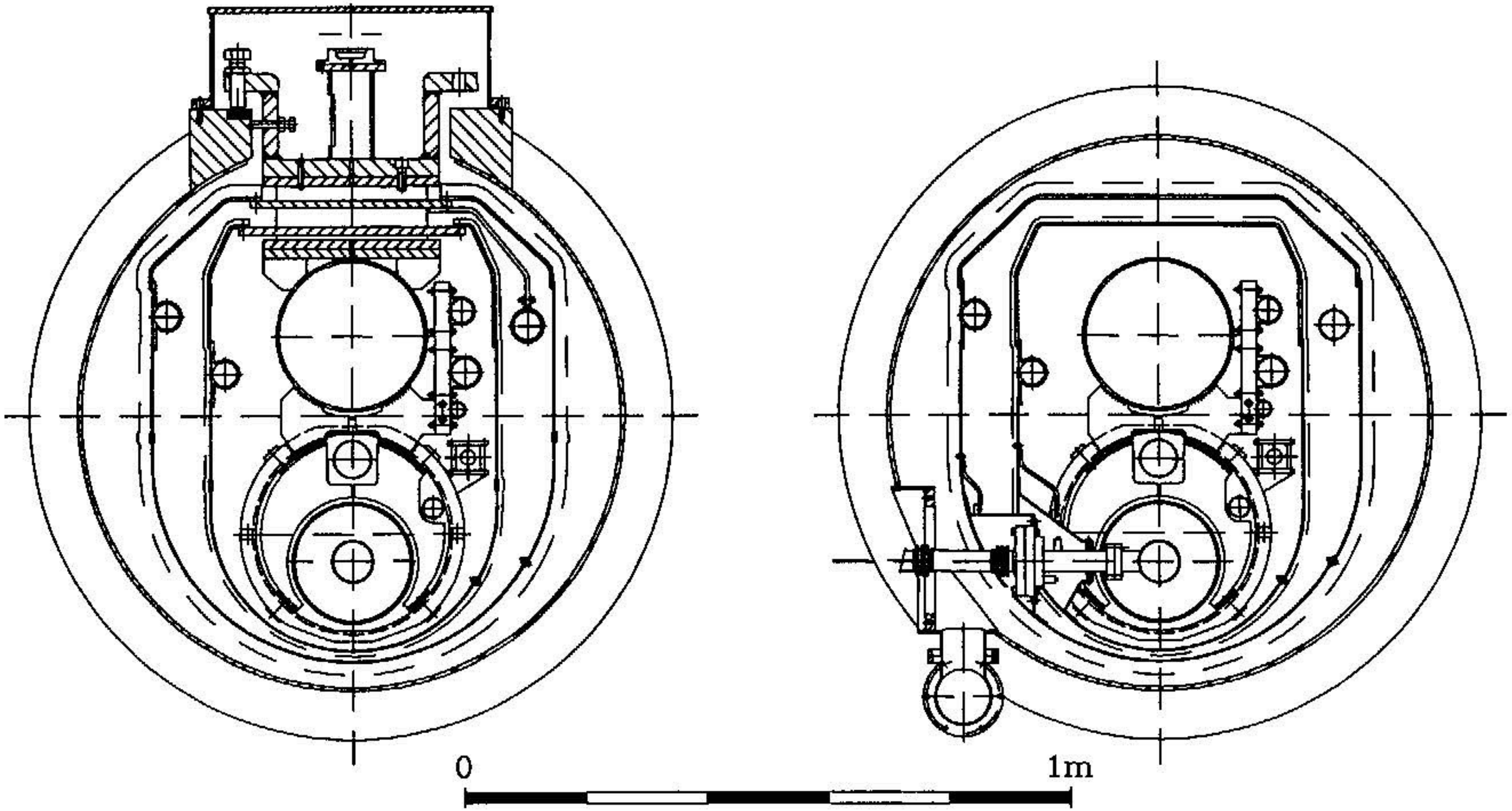


Fig. 2 - Second cryomodule generation (Cryomodule 2 –3). Shields are welded to Helium cooling pipe by small fingers that prevent deformation and high stresses

CRY 3, the reference for most projects

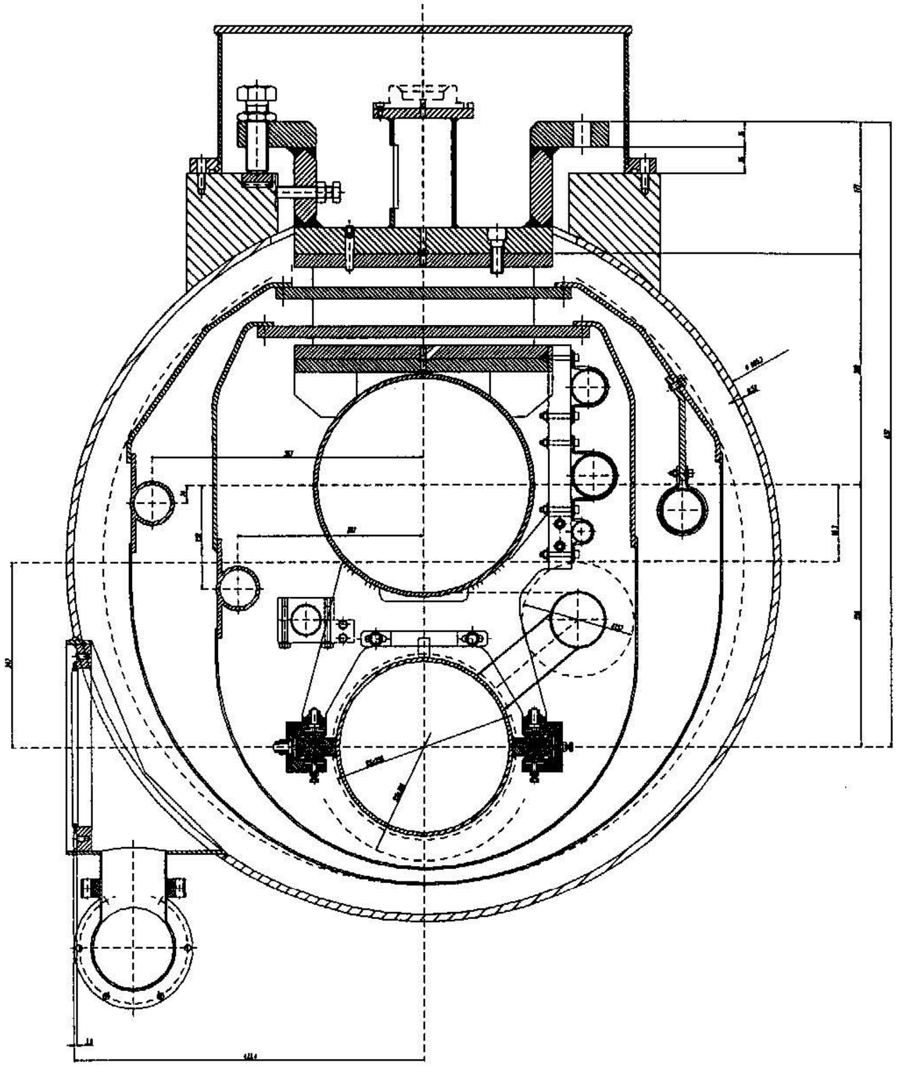


Fig. 5 - Third generation cryomodule cross-section. The vacuum vessel diameter has been reduced and components have been redistributed.

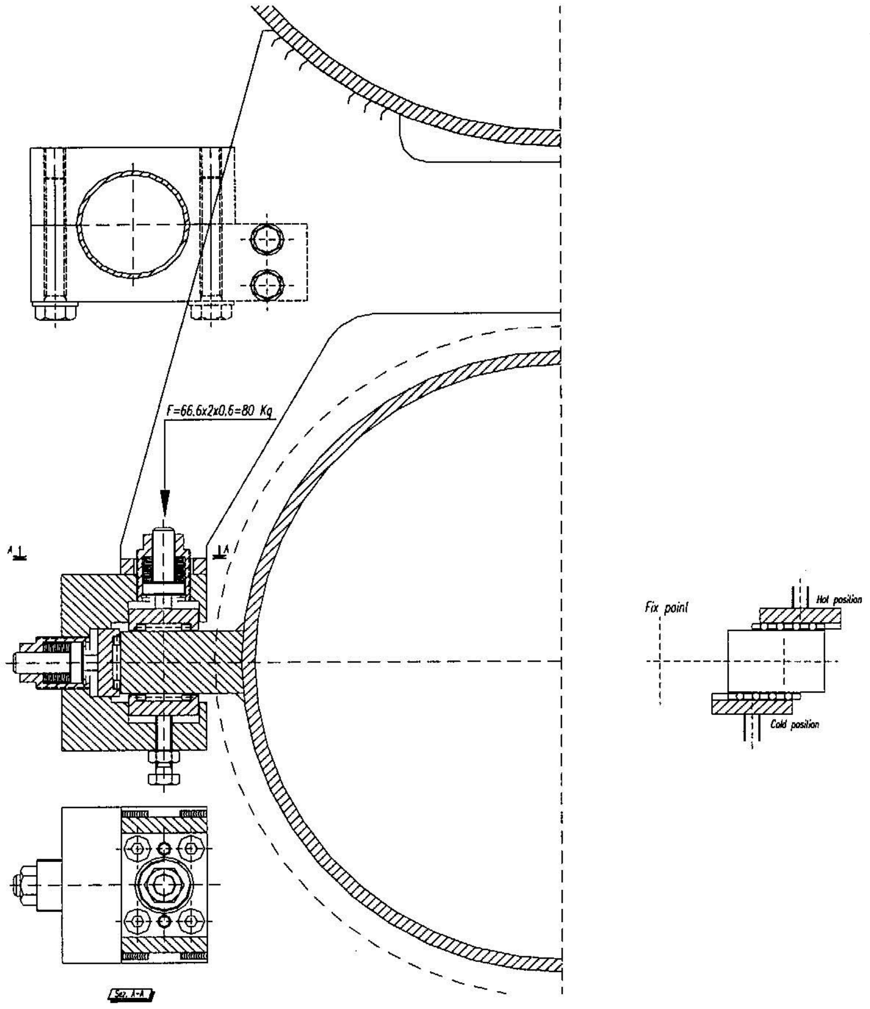


Fig. 7 - The new joint keeps cavity longitudinally free. It lets cavity support run over on auto leveling rolls. This solution doesn't require too high precision in the fabrication of the blocks supporting the cavity

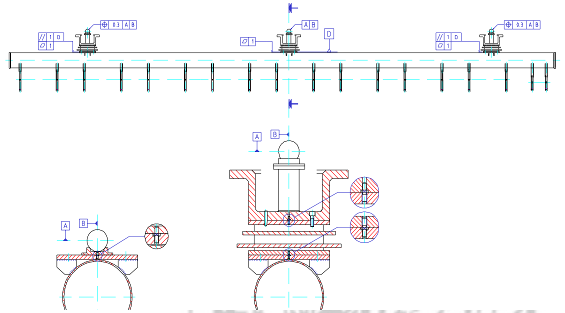
Cryomodule & Assembly as Crucial as Cavity

Three cryomodule generations to:

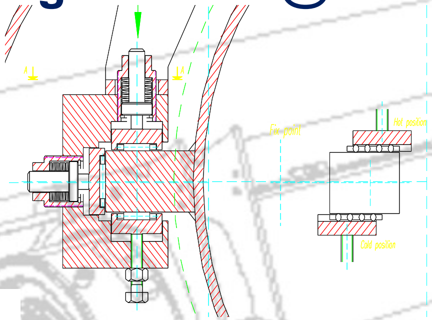
- improve simplicity and performances
- ensure precise alignment
- minimize the cost

"Finger Welded" Shields

Reliable Alignment Strategy

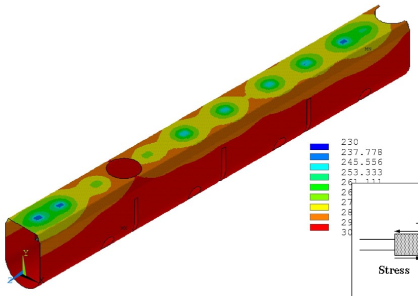


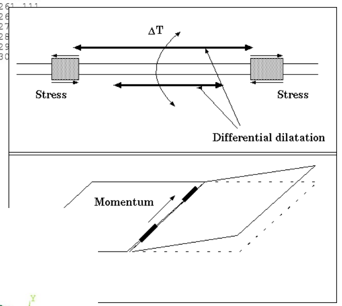
Sliding Fixtures @ 2 K

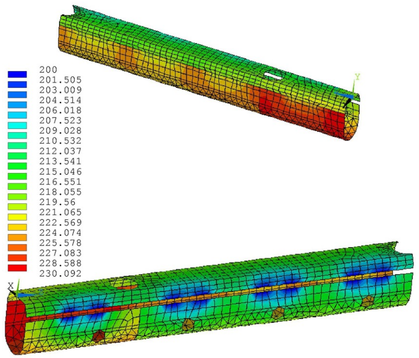


Required plug power for static losses < 5 kW / (12 m module)

From Cry 1 Prototype to Cry 3

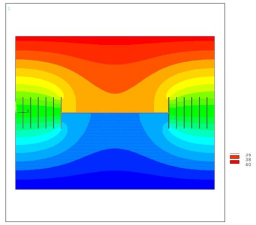


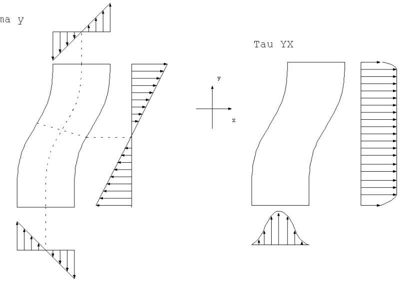


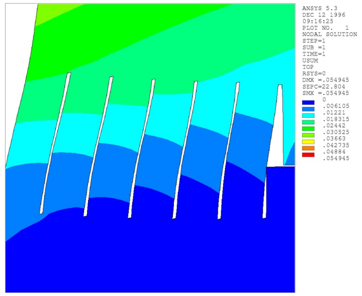


Extensive FEA modeling (ANSYS™) of the entire cryomodule

- Transient thermal analysis during cooldown/warmup cycles,
- Coupled structural/thermal simulations
- Full nonlinear material properties



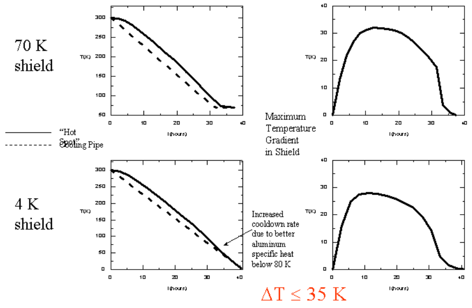


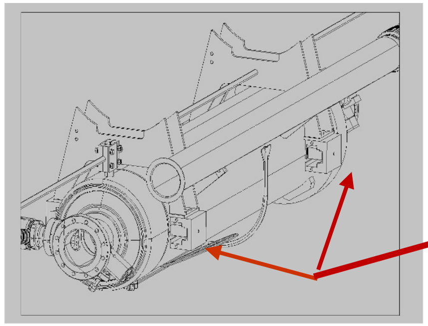


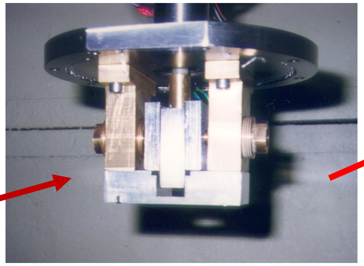
Detailed sub-modeling of new components and Laboratory tests

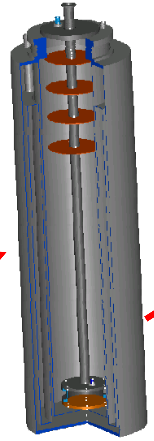
- Finger-welding tests at ZANON
- Cryogenic tests of the sliding supports at INFN-LASA

Welded Shields

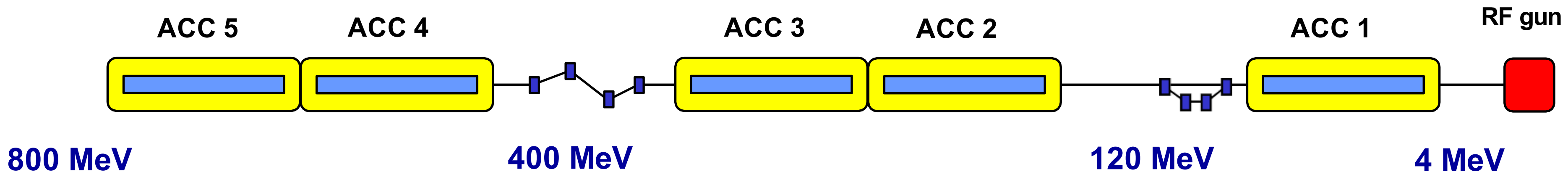


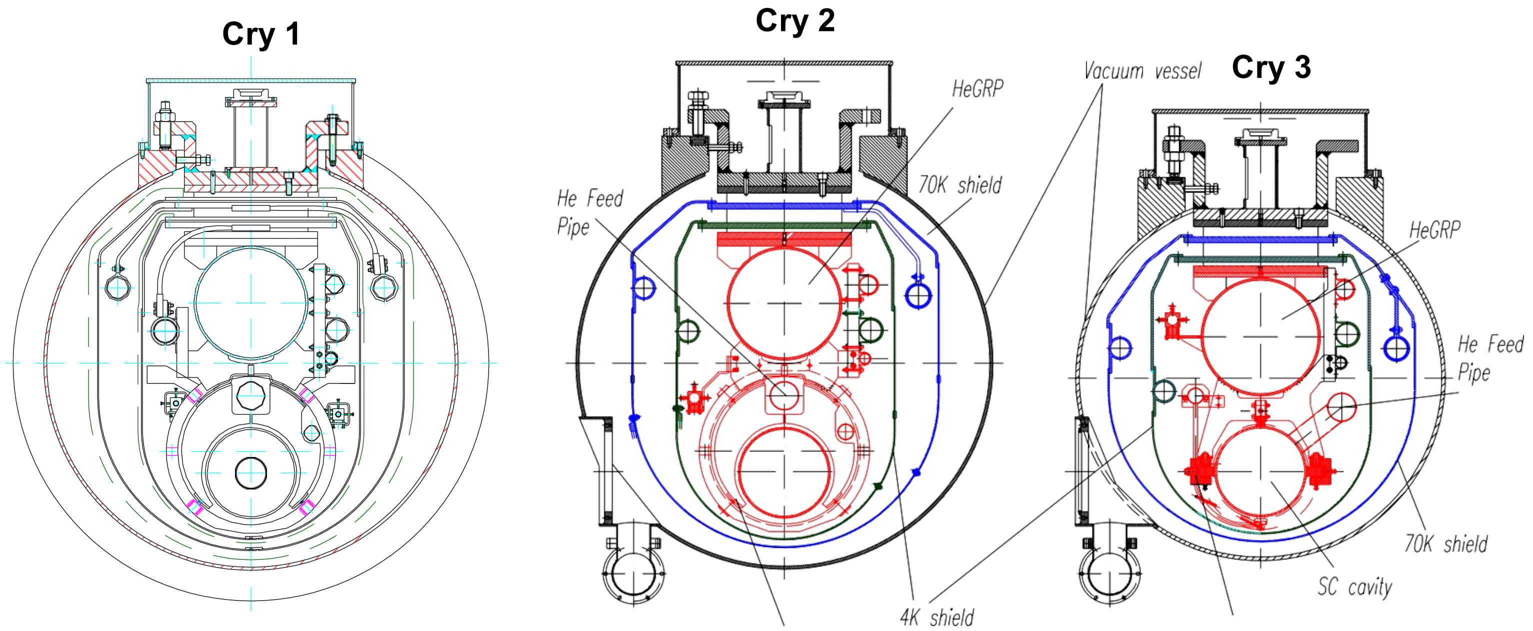






The Three Generations in TTF



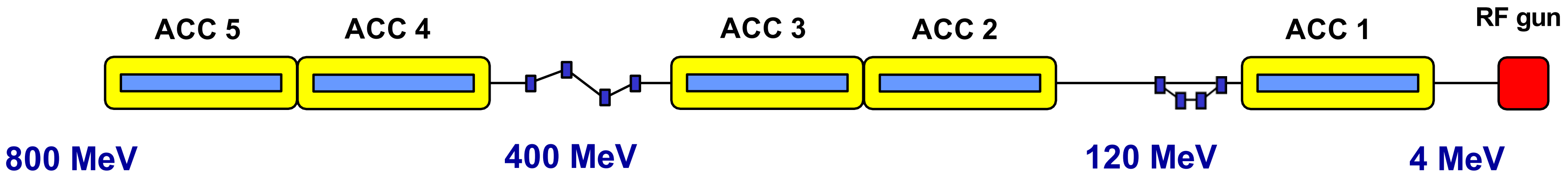


1st Module in TTF I

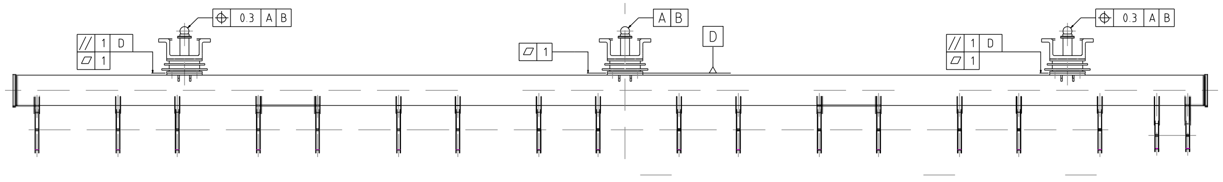
Module 1 & 2 in TTF I
Module 1, 2 & 3 in TTF II

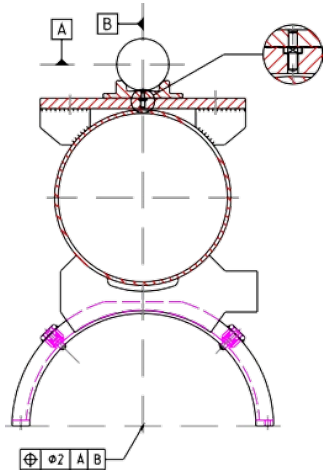
Module 4 & 5 in TTF II

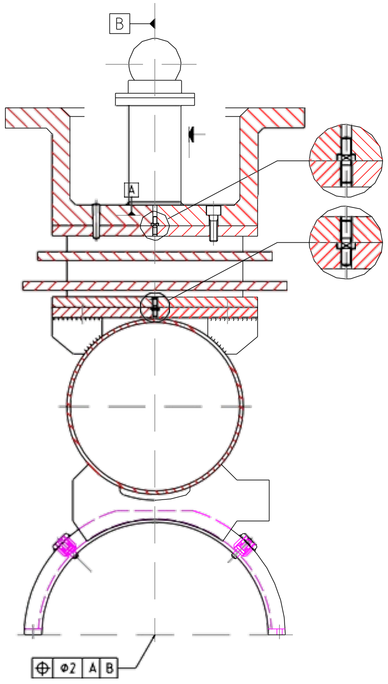
Cryoodules installed in TTF II

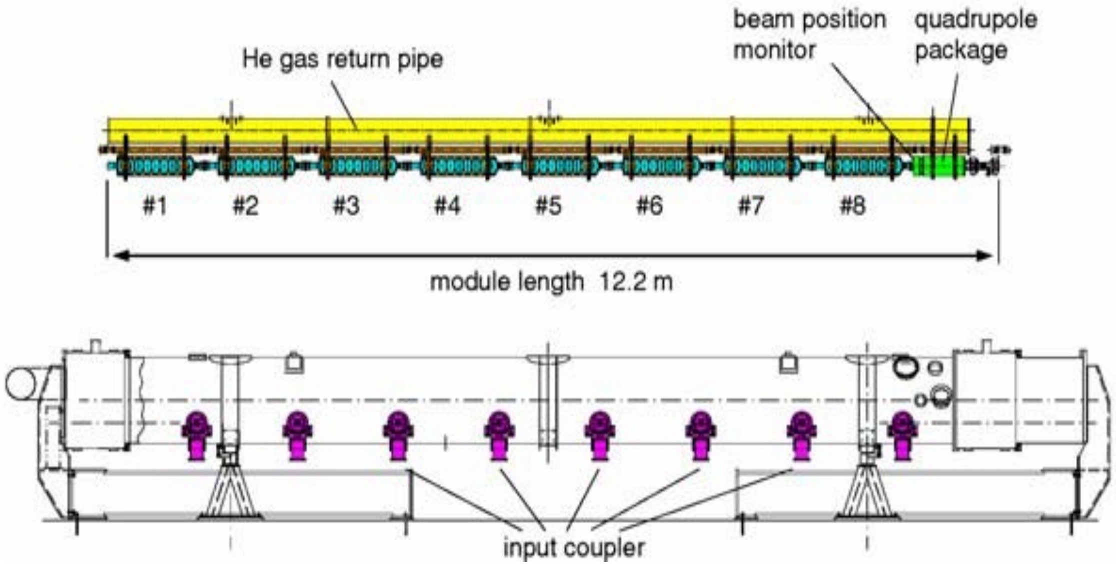


New strategy for tolerances and allignment



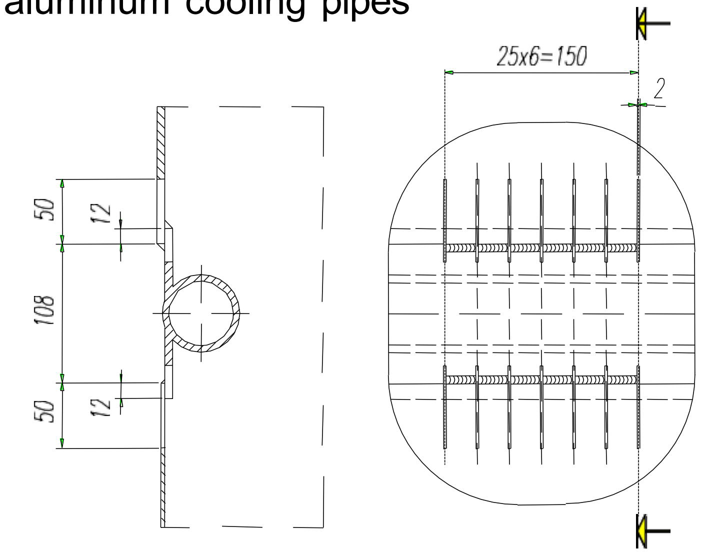






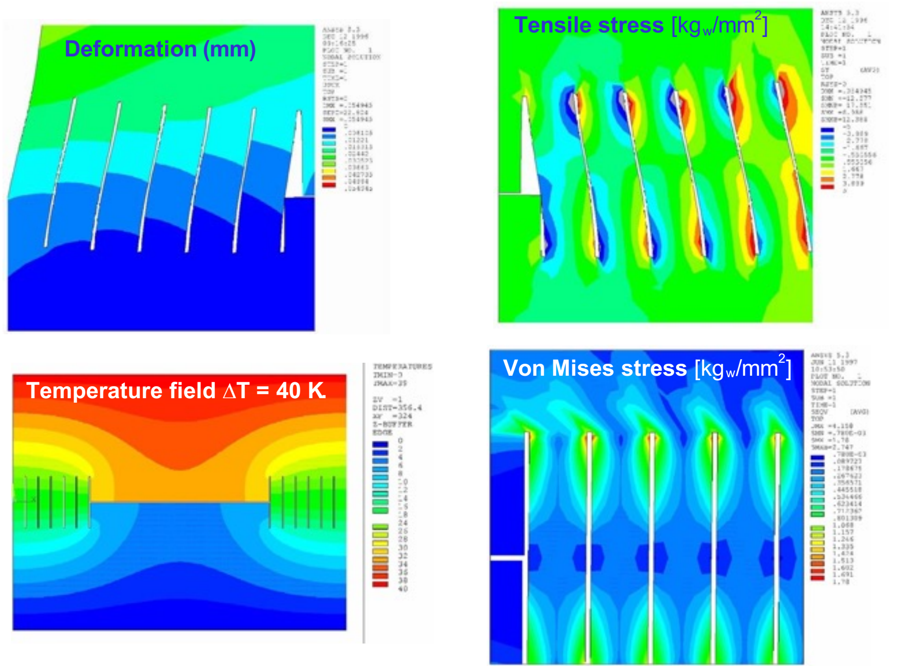
New Shield Connection by “Finger Welding”

- The thermal heat loads have been computed both in static and dynamic operation
- Dynamic operation supposed: E_{acc} = 23.4 MVm $Q_0 = 10^{10}$ @ 5 Hz.
- The thermal shields are identical to the 3rd generation TTF modules. The new **“finger welding”** technique is used to connect the shield aluminum panels to the aluminum cooling pipes



- The efficiency of welded shields has been demonstrated with FEM calculation and then verified during TTF operation.
- Cool-down of finger welded shields was performed in 10 hours, while limiting the shield deformations inside safe limits

Finger welding FEM check in real temperature field.



Contents

3rd Generation TESLA Cryomodule

Reduce the Cross Section and use a standard “pipeline” tube

- Redistribute the internal components
- Reduce the distances to the minimum

Improve the connection of the active elements to the HeGRP

- Sliding fixtures to allow “Semi Rigid Coupler” and Superstructures

Reduce alignment sensitivity to the forces on the HeGRP edges

- Move the external posts closer to the edges
- Include the 300 mm bellow in the in the backbone referencing

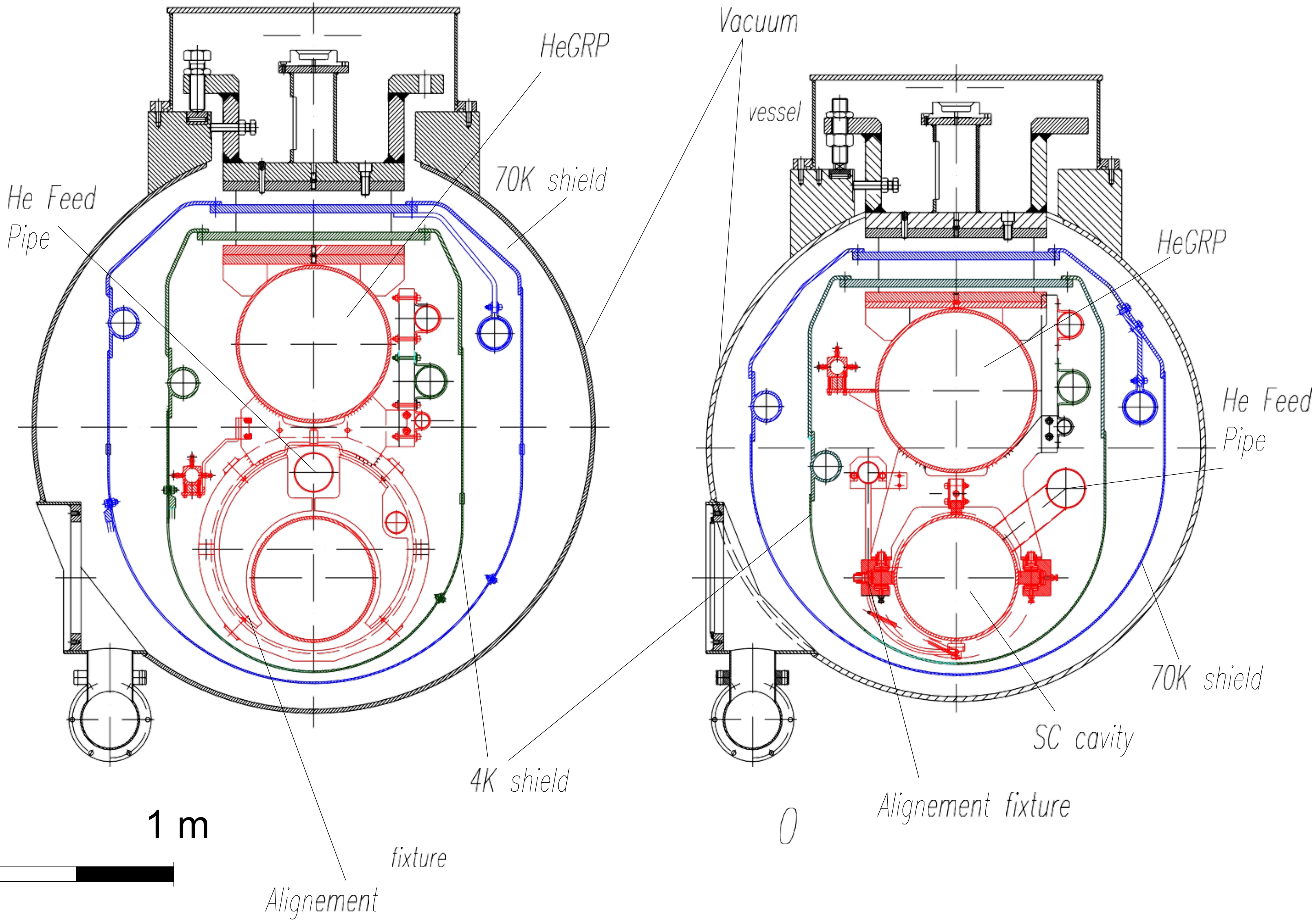
Further simplify the assembling procedure

- Simplify coupler cones and braids
- Reduce by a factor two the shield components

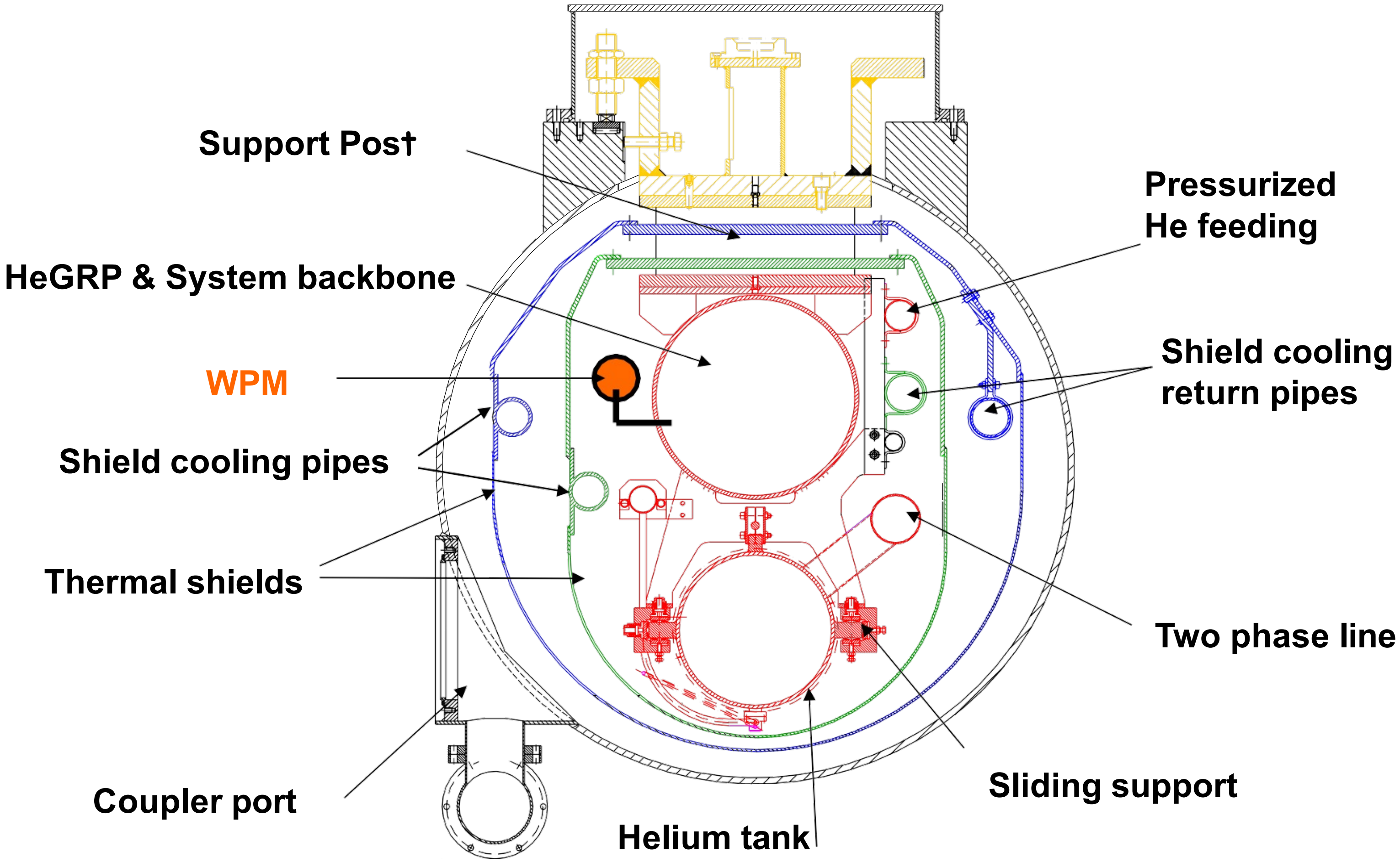
System thought for mass production cost cutting

- Tolerances reduced to the strictly required ones
- Simpler components and standard tubes wherever possible

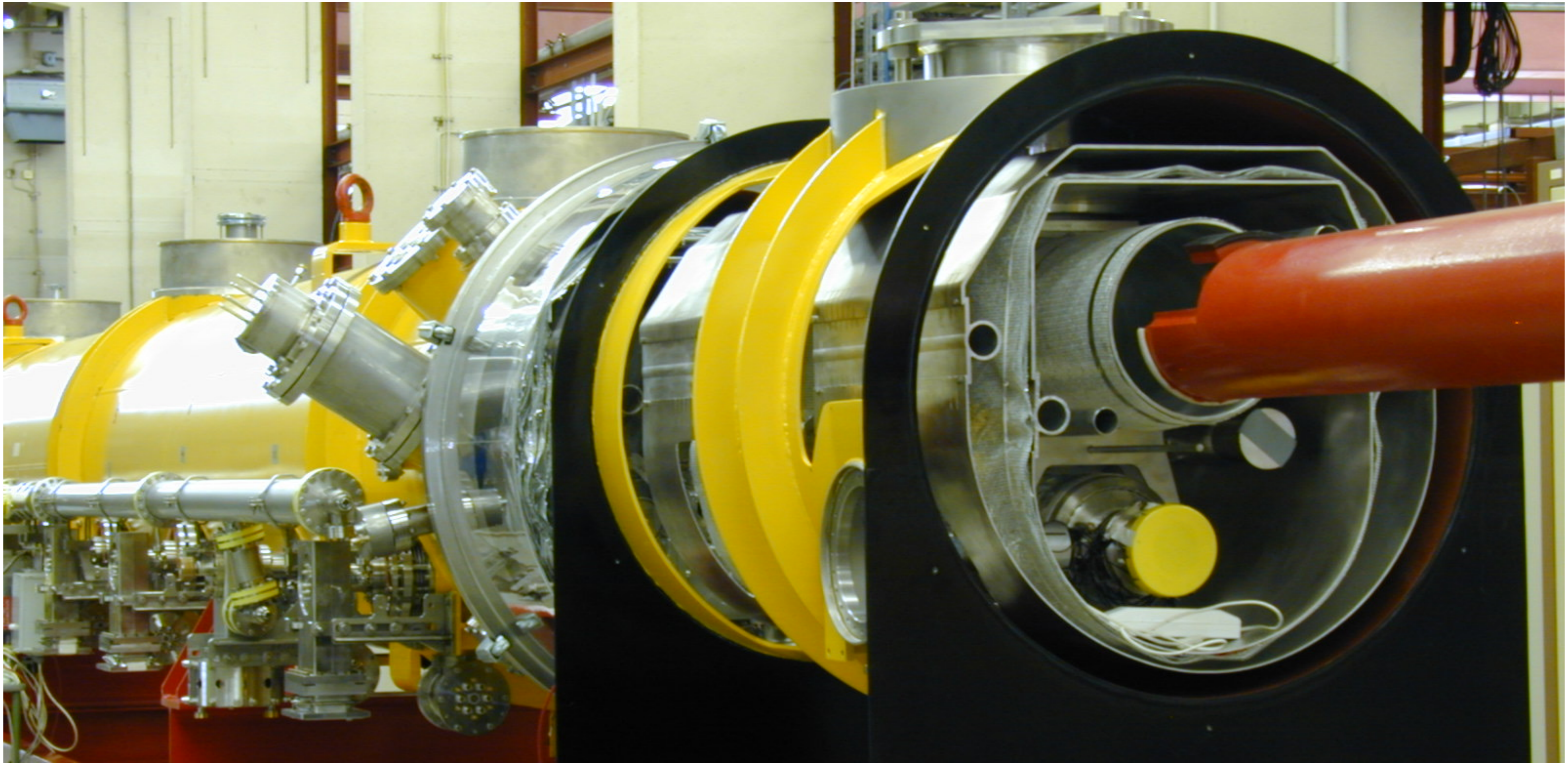
Cry2 & Cry3: Cross Sections



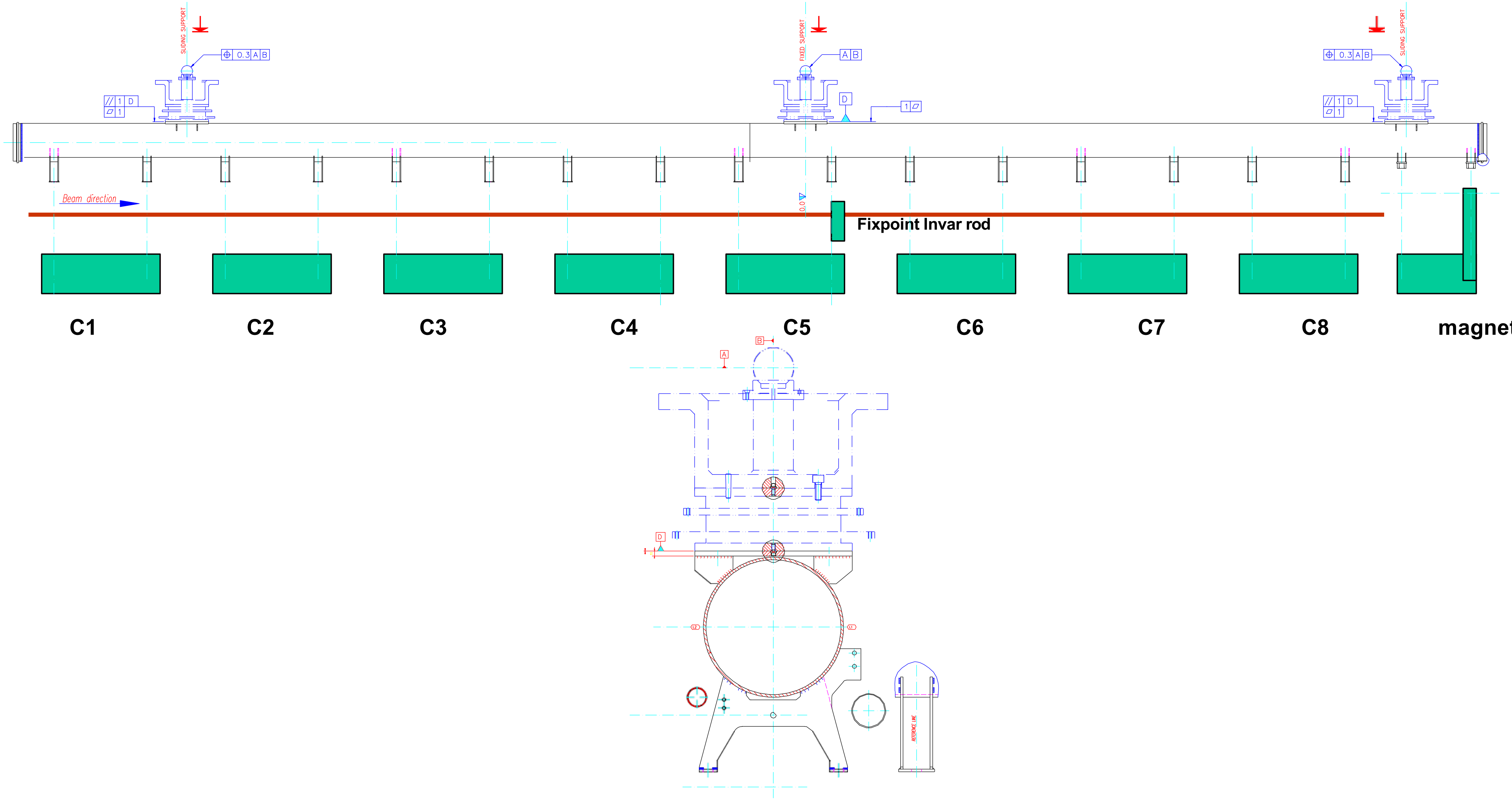
Cry3 Cross Section



Cry2 to Cry3: Diameter Comparison

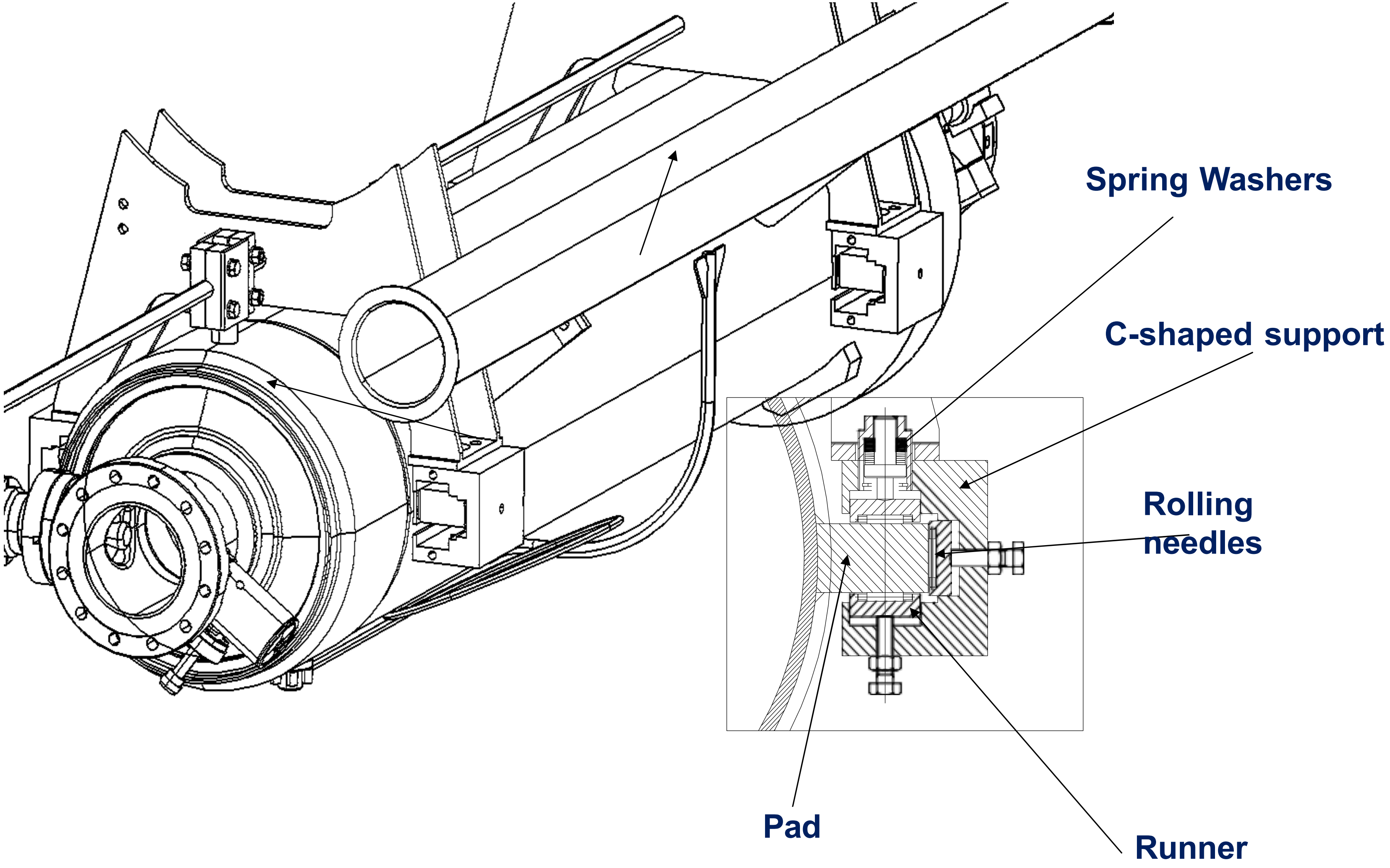


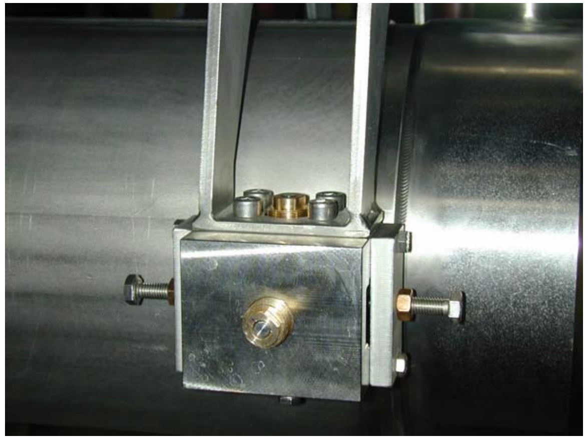
Helium GRP, Posts & Invar Rod

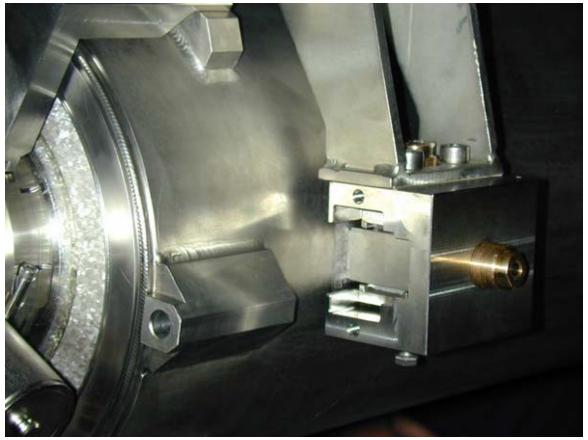


C-Shaped Fixtures and Rolling Needles

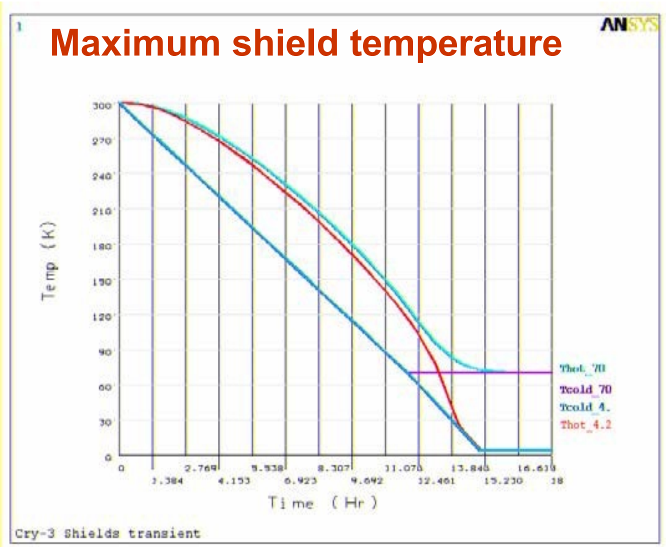
- Four **C-Shaped stainless steel fixtures** are used to define the position of each one of the thirteen active elements:
- 8 cavities and 1 quadrupole package. Each active element has **four titanium pads** welded to the helium tank
- Each active element is independently referred to the module axis through **screws and "belleville" pushers** on both **x** and **y** directions of each of the four pads
- **Rolling needles** reduce drastically the longitudinal friction
- The longitudinal position of each active element is defined through a fixture to the reference **Invar Rod**. This makes its position independent from the elongation and contraction of the supporting HeGRP

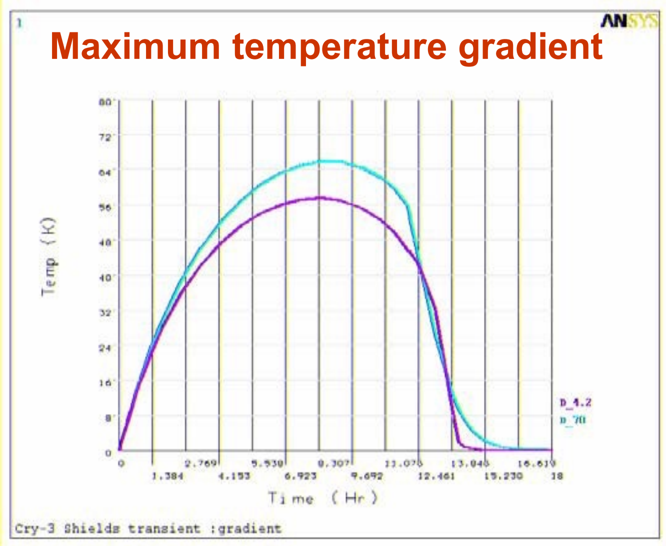

Spring Washers
C-shaped support
Rolling needles
Pad
Runner



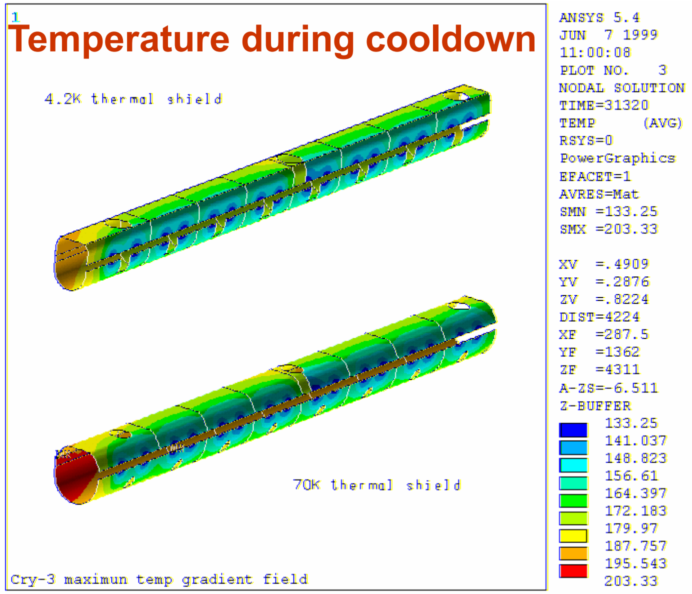


Finger-Welded Shield Behavior





- Cooldown simulation of the 4.2 K and 70 K aluminum thermal shields.
- We used a simultaneous 12 hour linear cooldown.
- The maximal thermal gradient on the shields (upper left graph) is below 60 K, a safe value.
- The temperature fields show that the gradient is concentrated in the welding region, where the fingers unload the structure

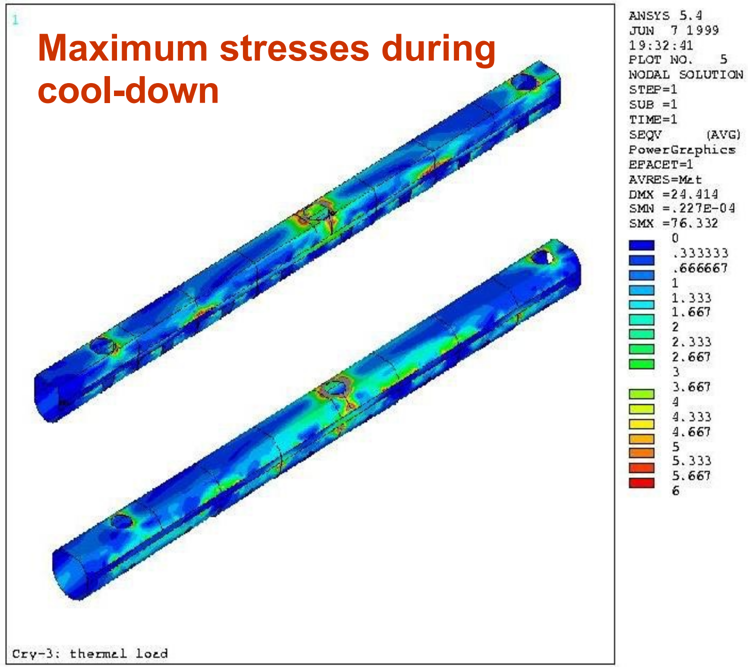


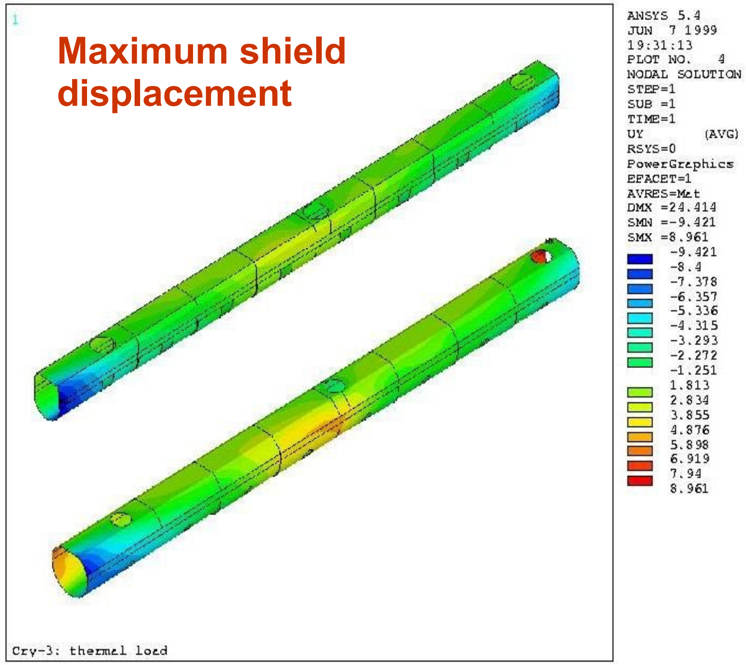
Thermo-mechanical analysis of Shields

Applying the computed temperature field, deformations and stress distribution can be easily computed.

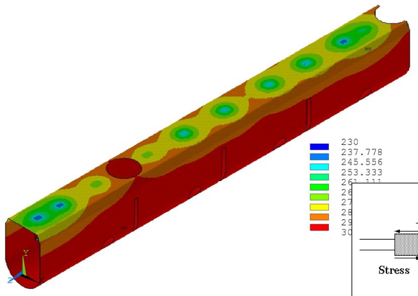
Maximum stresses are within acceptable limits

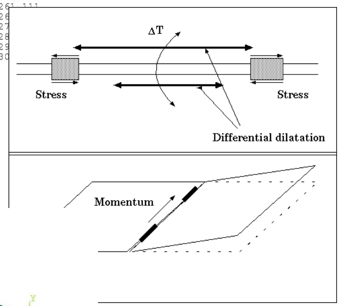
Maximum deformations due to asymmetric cooling are below 10 mm.

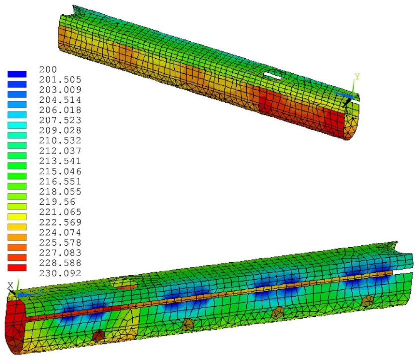




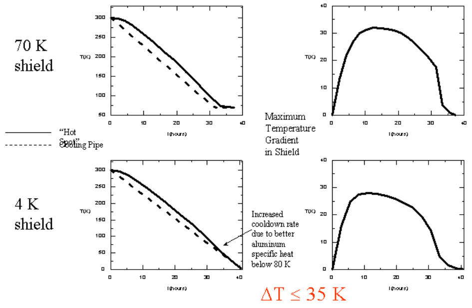
From Prototype to Cry 3







Welded Shields

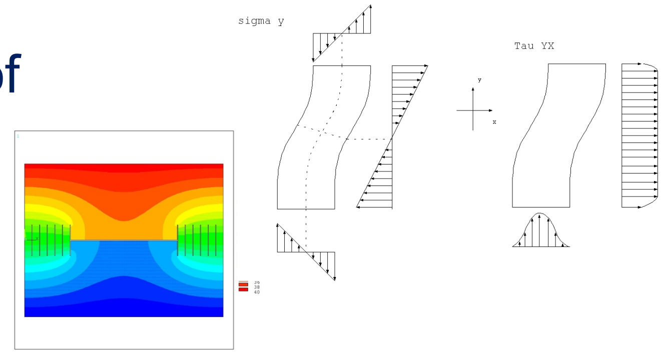


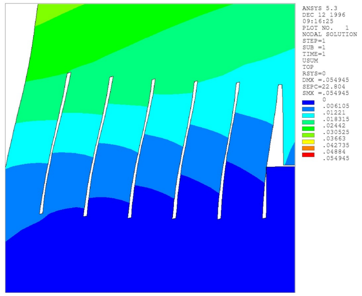
Extensive FEA modeling (ANSYS™) of the entire cryomodule

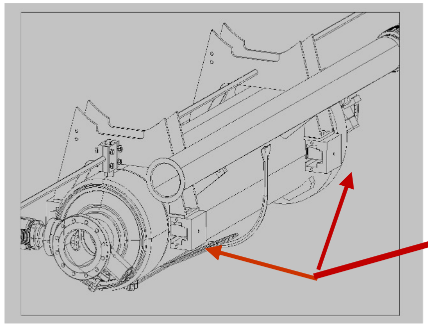
- Transient thermal analysis during cooldown/warmup cycles,
- Coupled structural/thermal simulations
- Full nonlinear material properties

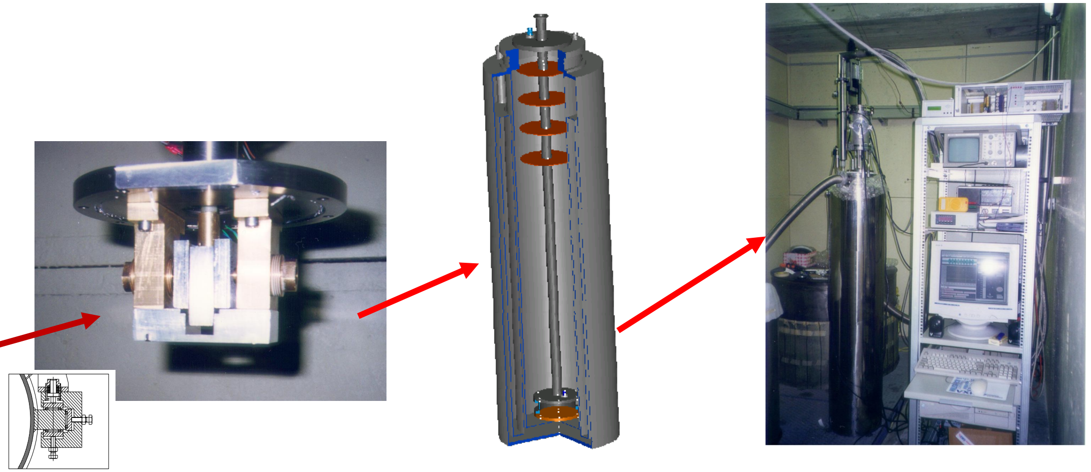
Detailed sub-modeling of new components and Laboratory tests

- Finger-welding tests at ZANON
- Cryogenic tests of the sliding supports at INFN-LASA









Contents

WPMs to qualify alignment strategy

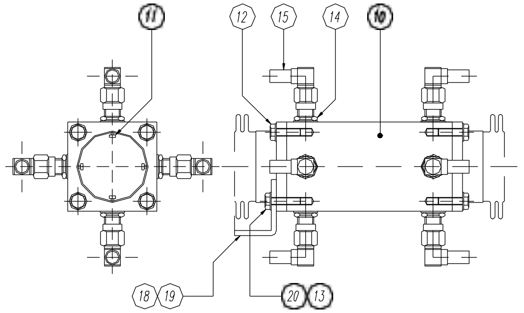
WPM = Wire Position Monitor

On line monitoring of cold mass movements during cool-down, warm-up and operation

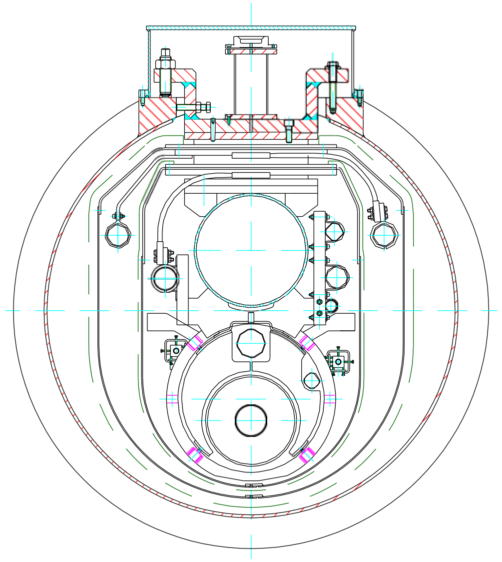
2 WPM lines with 2 x 18 sensors
4 sensors per active element
8 mm bore radius

1 WPM lines
1 sensors per active element 25 mm bore radius

1 WPM line
7 sensors/module
25 mm bore radius

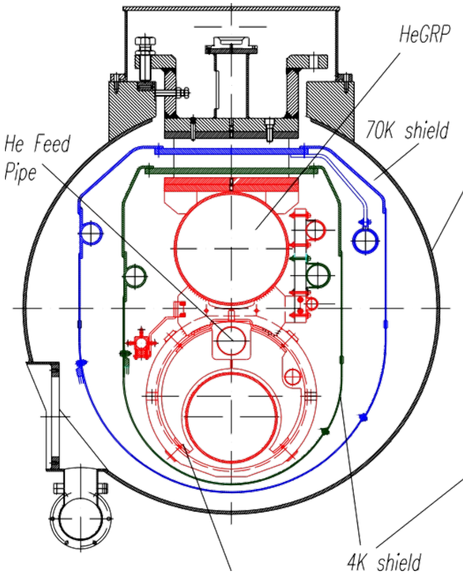


Cry 1



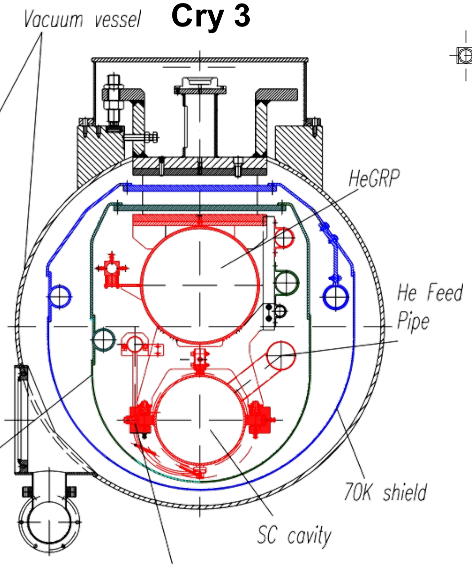
1st Module in TTF I

Cry 2



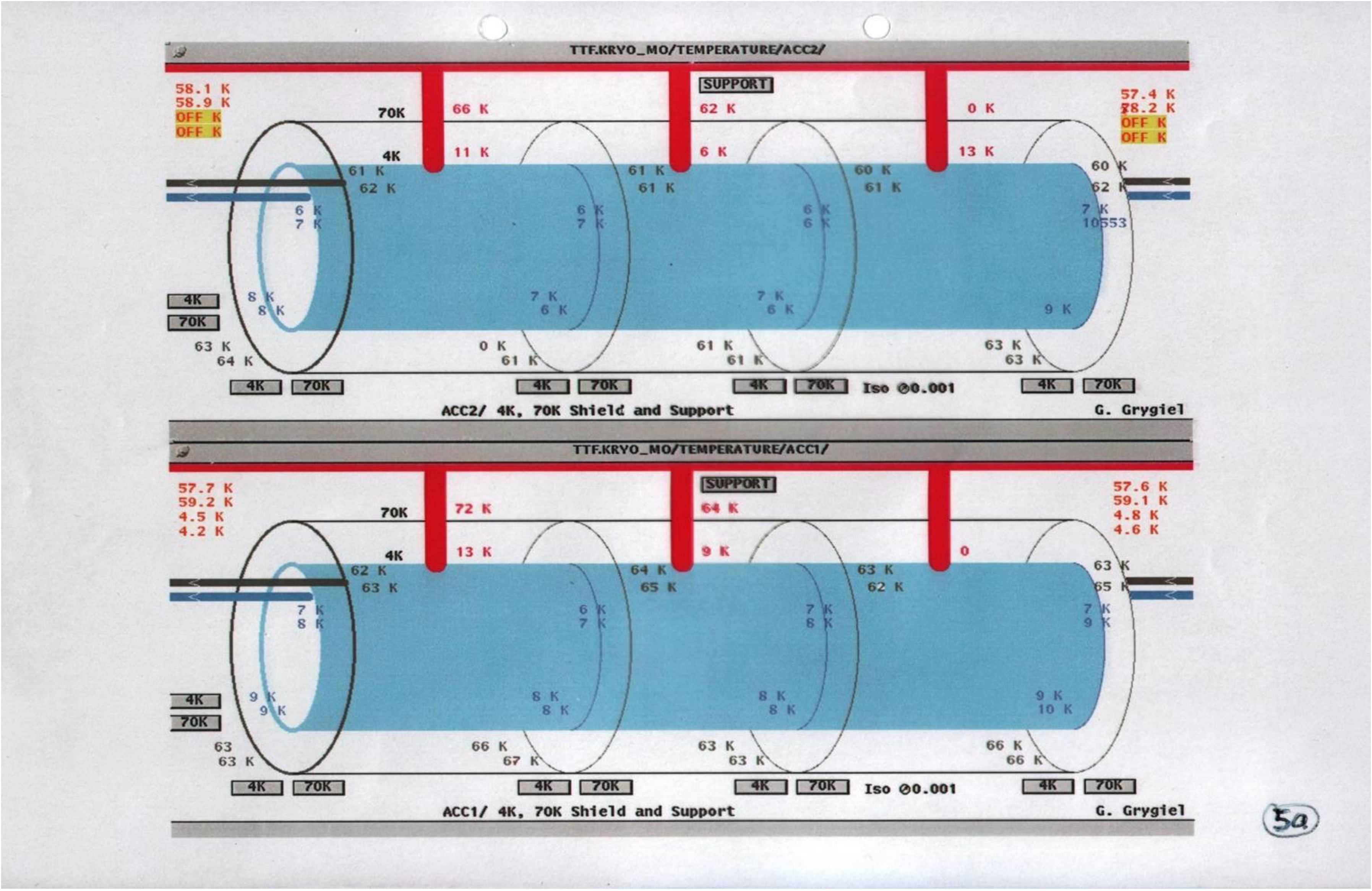
Module 1 & 2 in TTF I
Module 1, 2 & 3 in TTF II

Cry 3



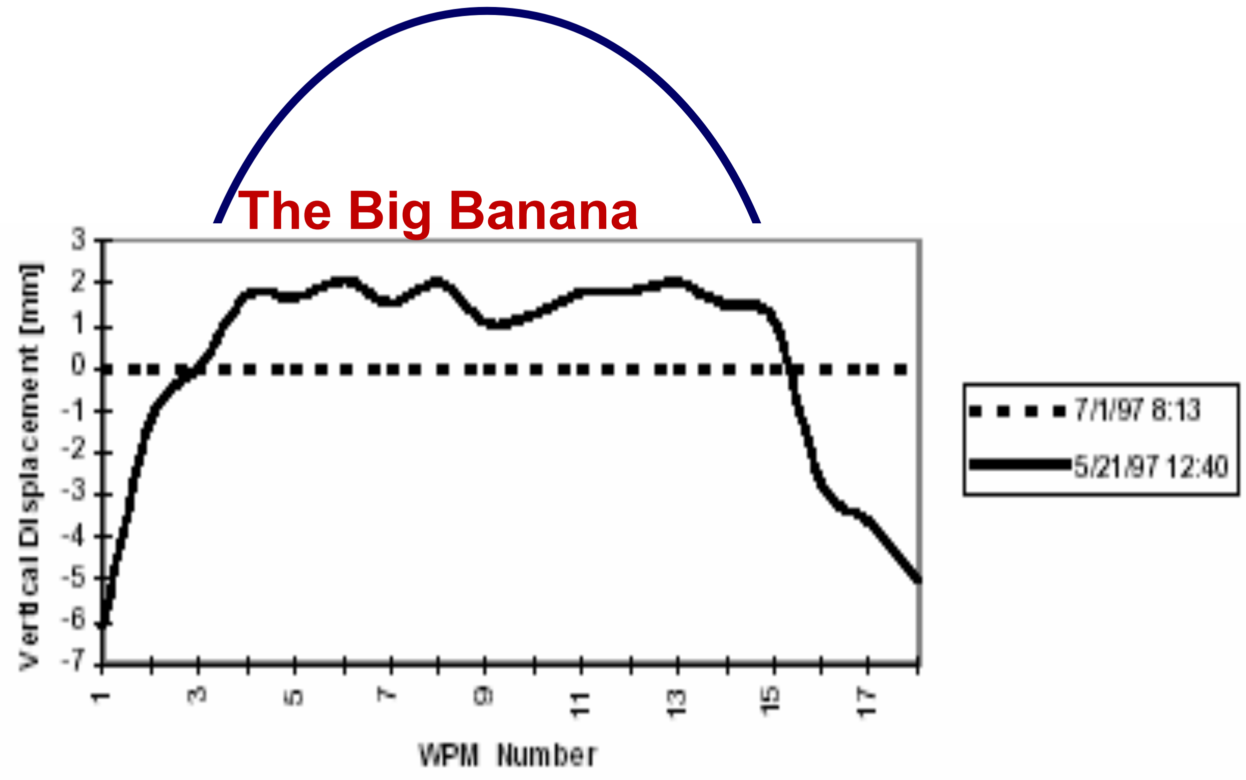
Module 4 & 5 in TTF II

Large ammount of thermal sensors

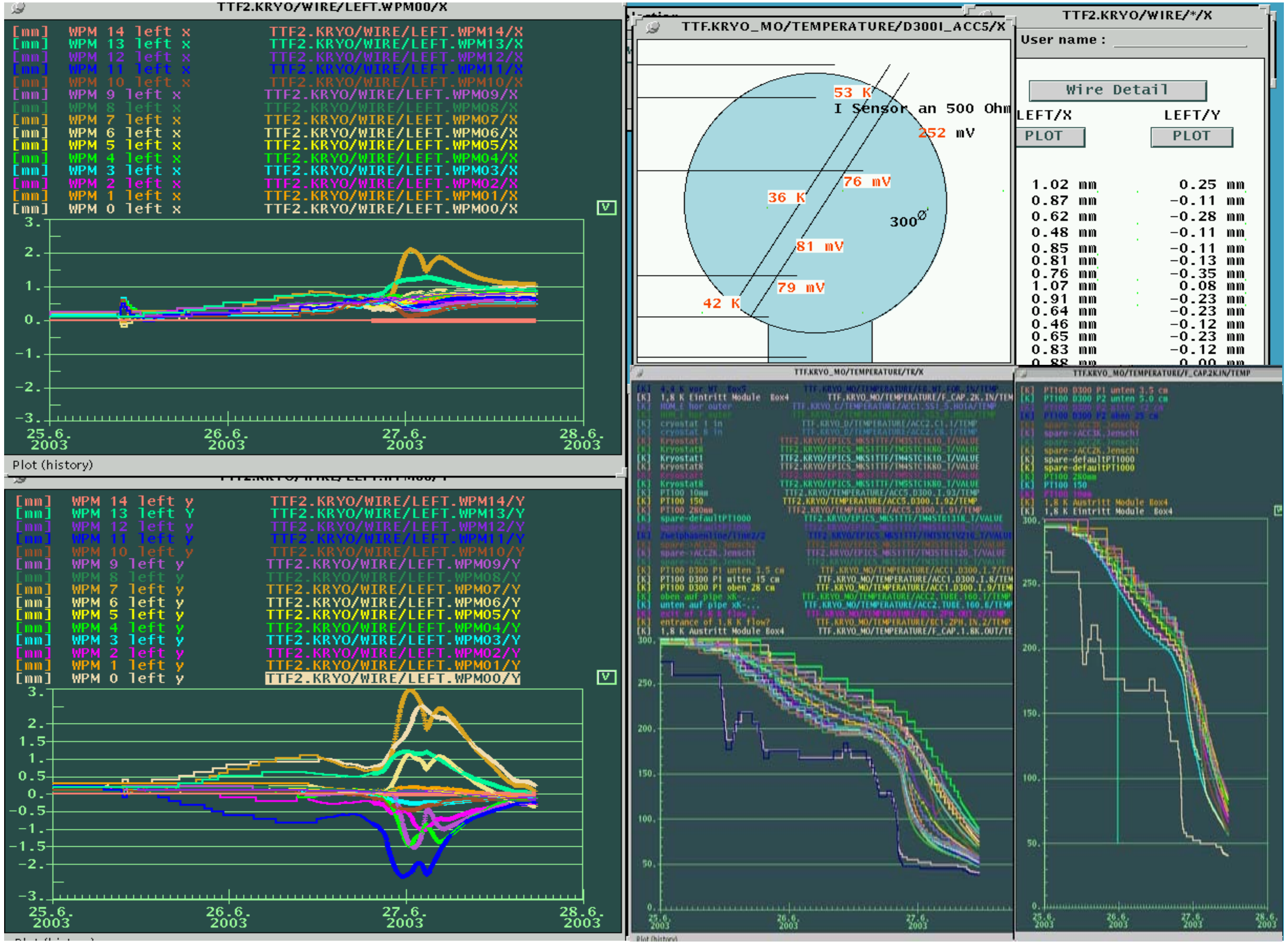


Large Bending in First Cooldown (CRY 1)

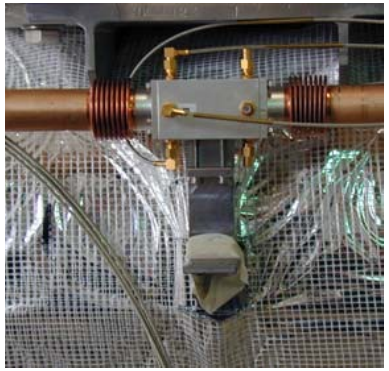
New Cooldown procedure thanks to the WPM's measurements during the first "fast" cooldown

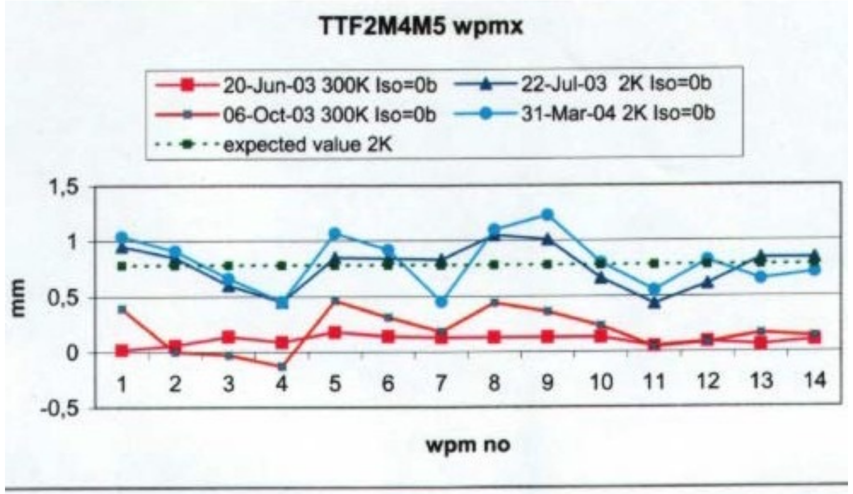


Safe Cooldown of ACC4 and ACC5



ACC4 & ACC5 Met Specs





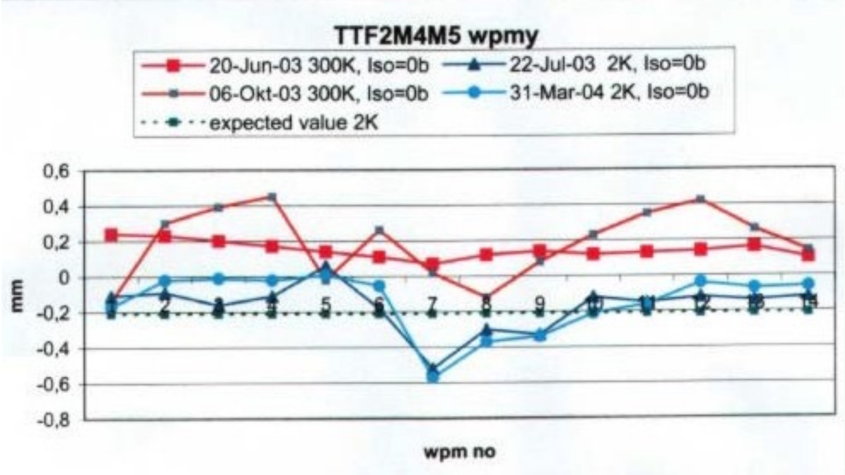


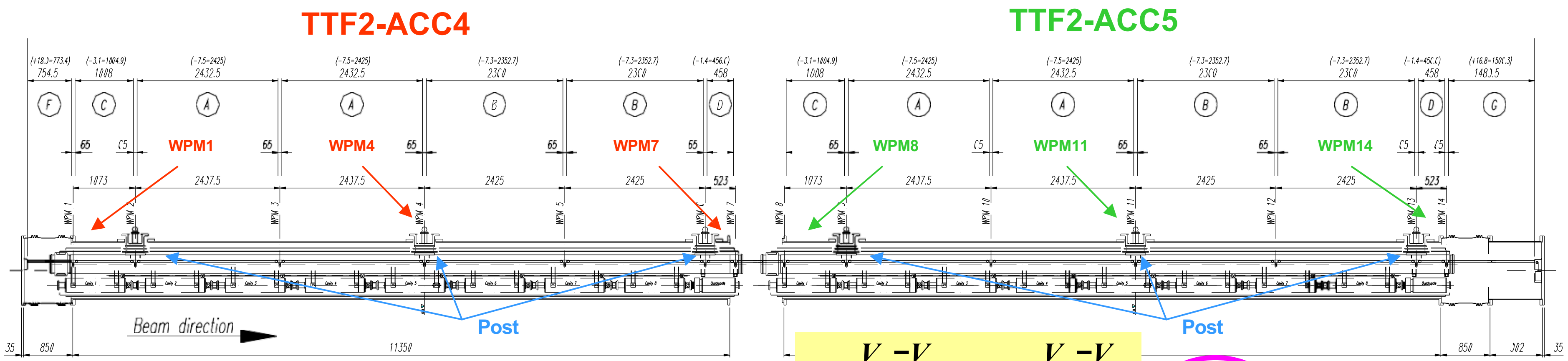
Table 1: Result Summary.

TDR Specifications (rms)		
Cavities	x/y	± 0.5 mm
Quadrupoles	x/y	± 0.3 mm
WPM results (peak)		
Cavities	x	+0.35/-0.27 mm
	y	+0.18/-0.35 mm
Quadrupoles	x	+0.2/-0.1 mm
	y	+0.35/-0.1 mm

Still some work at the module interconnection

Cavity axis to be properly defined

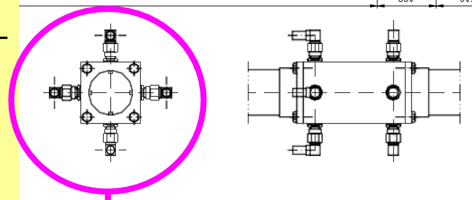
WPM as Vibration Sensors

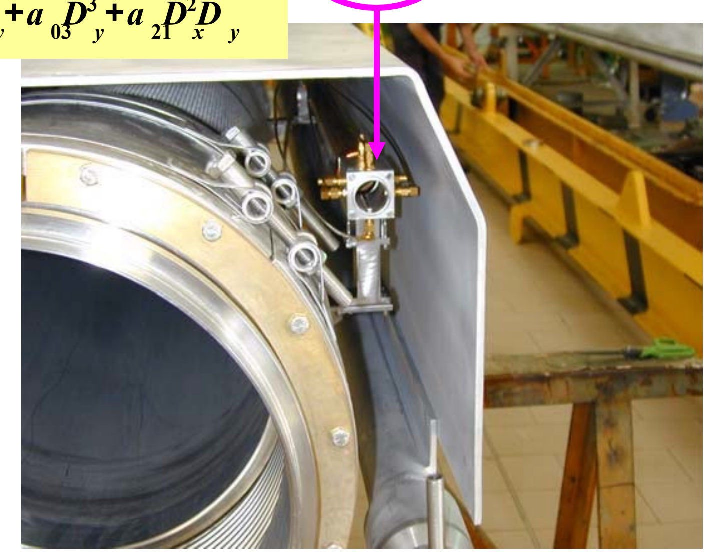


$$D_x = \frac{V_B - V_D}{V_B + V_D} \qquad D_y = \frac{V_A - V_C}{V_A + V_C}$$

$$x = a_{10} D_x + a_{30} D_x^3 + a_{12} D_x D_y^2$$

$$y = a_{01} D_y + a_{03} D_y^3 + a_{21} D_x^2 D_y$$





A WPM is a sort of microstrip four channel directional coupler. **A 140 MHz RF signal is applied on a stretched wire placed in the center of the monitor bore.**

A Wire Position Monitor (WPM) system has been developed for **on-line monitoring of the cold mass during cooldown and operation.**

The **low frequency vibrations** of the cold mass, amplitude modulate the RF signals picked up by the microstrips.

The **microphonics** (and the sub-microphonics) can be **recovered de-modulating the microstrip RF signal**.

TESLA Cryomodule Concept Peculiarities

Positive

- Very low static losses
- Very good filling factor: Best real estate gradient
- Low cost per meter in term both of fabrication and assembly

Project Dependent

- Long cavity strings, few warm to cold transitions Large gas return pipe inside the cryomodule
- Cavities and Quads position settable at ± 300 μm (rms) Reliability and redundancy for long MTTR (Mean Time To Repair)
- Lateral access and cold window natural for the coupler

Constraints

- Long MTTR in case of non scheduled repair
- Moderate (± 1 mm) coupler flexibility required

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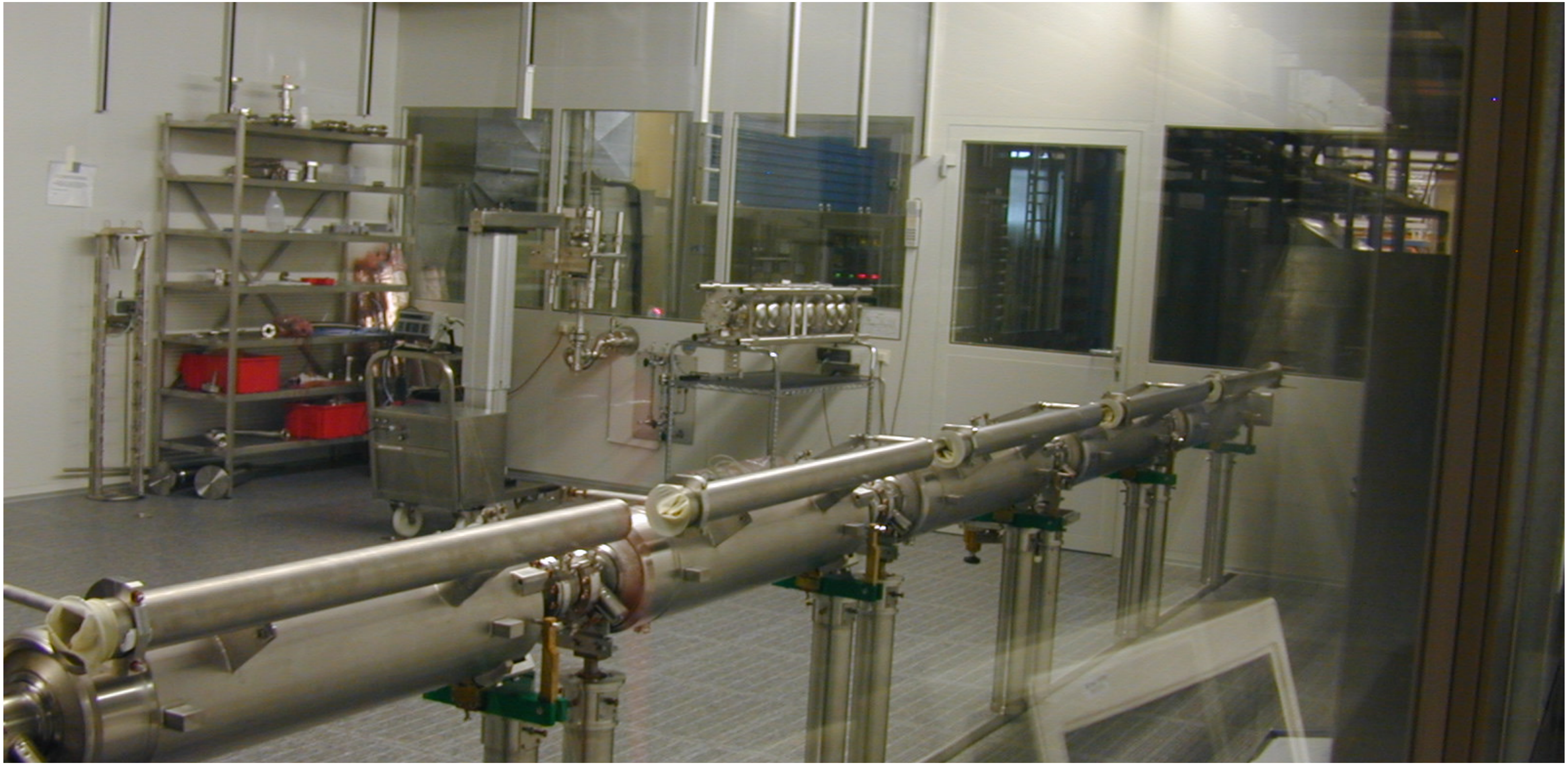
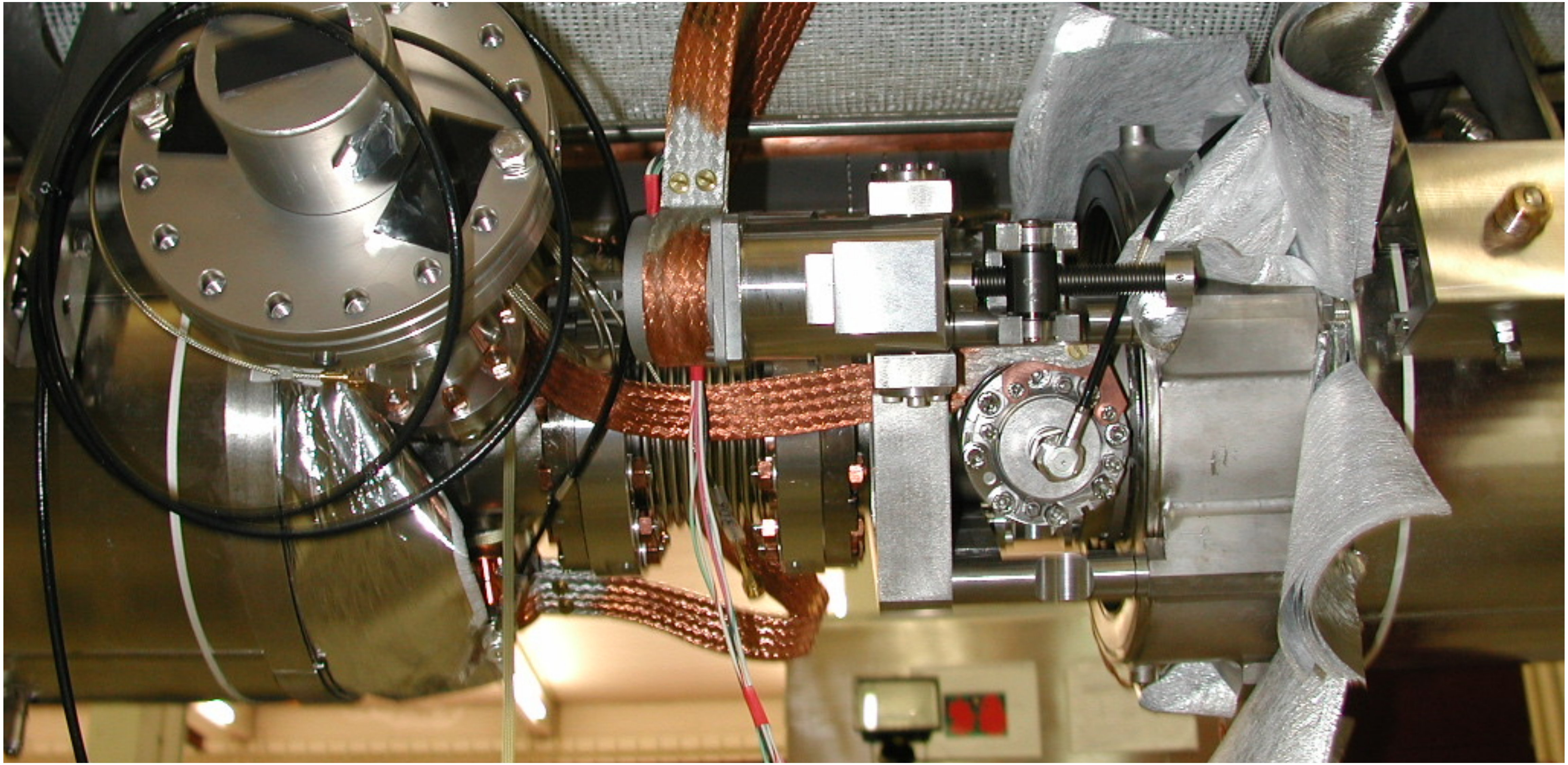
Module assembly picture gallery - 1



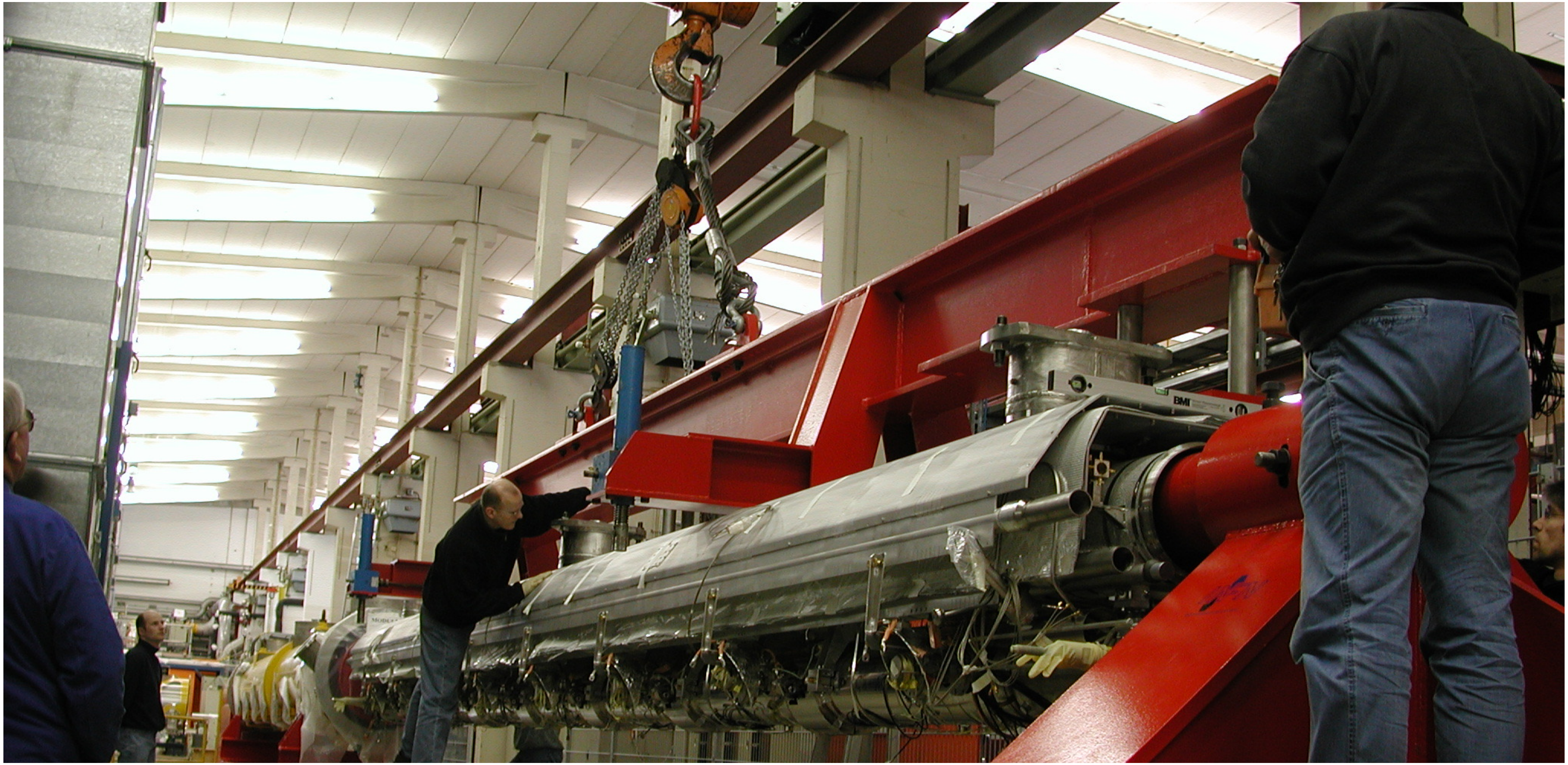
Module assembly picture gallery - 2

Module assembly picture gallery - 3

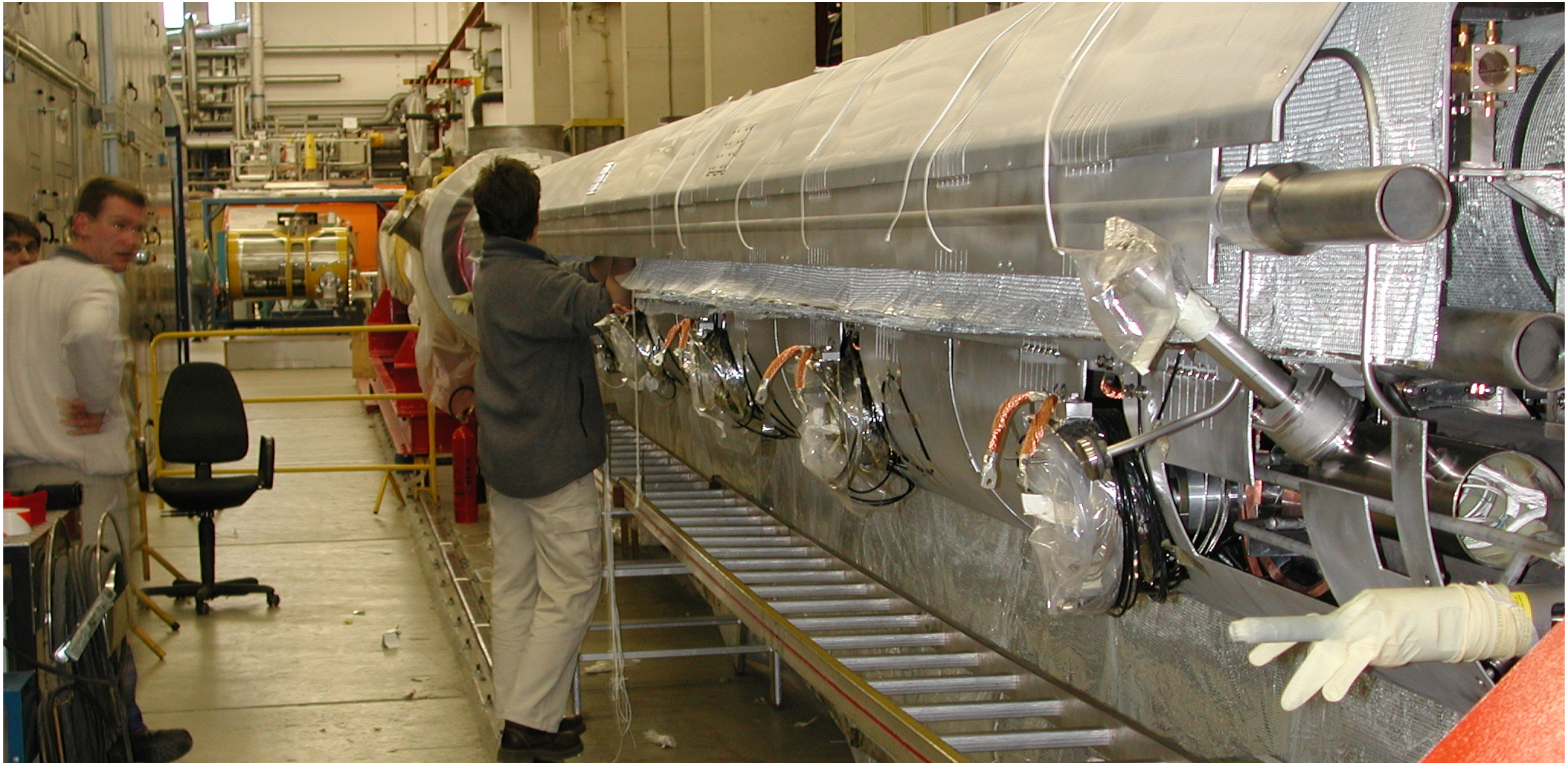


Module assembly picture gallery - 4

Module assembly picture gallery - 5



Module assembly picture gallery - 6



Module assembly picture gallery - 7

Module assembly picture gallery - 8

Module assembly picture gallery - 9

Module assembly picture gallery - 10

Design changes important for ILC

Move quadrupole to the center

Quad/BPM Fiducialization

High pressure rinsing and clean room assembly issues

Movers for beam based alignment? Why not if really beneficial

Short cavity design

Cutoff tubes length by e.m. not ancillaries (coaxial tuner)

Cavity inter-connection: Flanges and bellows (coating?)

Fast locking system for space and reliability (CARE activity)

Bellow waves according to demonstrated tolerances

Coaxial Tuner with integrated piezo-actuators

Parametric “Blade Tuner” or equivalent for real estate gradient

Integration of fast tuner (piezo actuated) underway

Longer module design: 10-12 cavities

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The INFN Cryomodule for XFEL & ILC