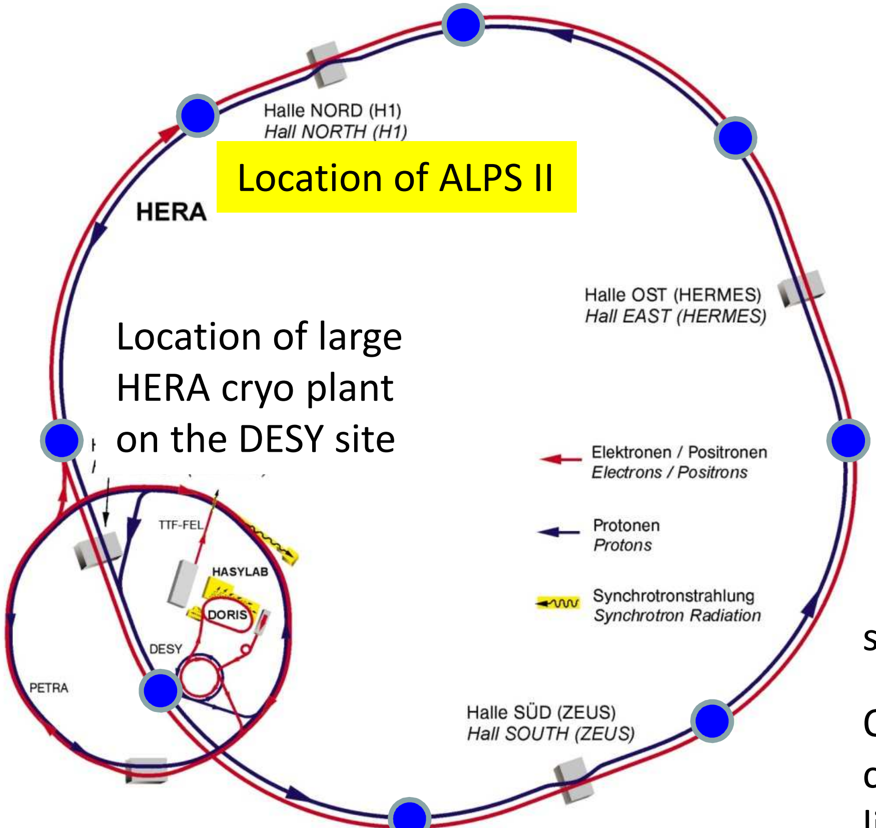
Some information on the HERA dipoles for a magnetic birefringence measurement with the ALPS II setup

- Short HERA overview
- Increasing the aperture of the dipoles for the laser beam
- The principal setup of the magnet string in the HERA tunnel
- Achievable modulation frequency of the magnetic field

HERA Overview

4 straight tunnel sections
~ 120/ 150 m long

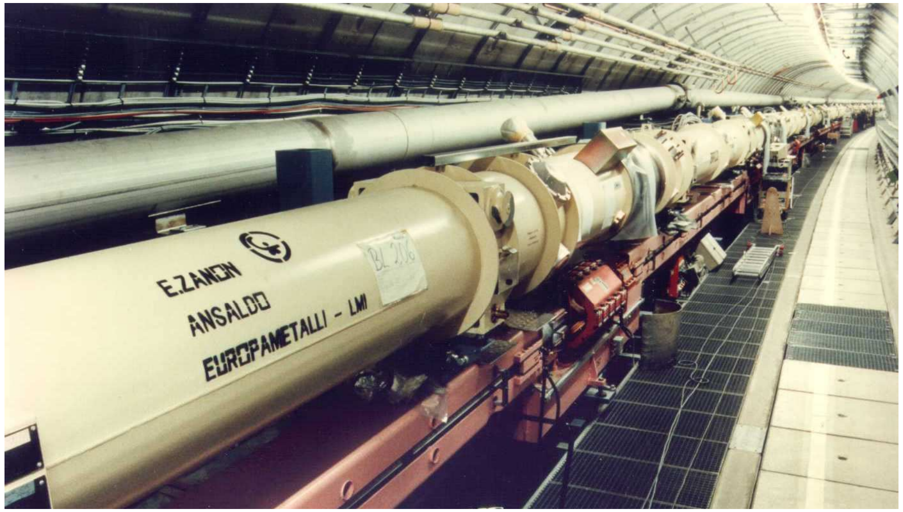
Circumference 6336 m



Location of ALPS II

Location of large HERA cryo plant on the DESY site

Cryogenic boxes at the ends of the arcs

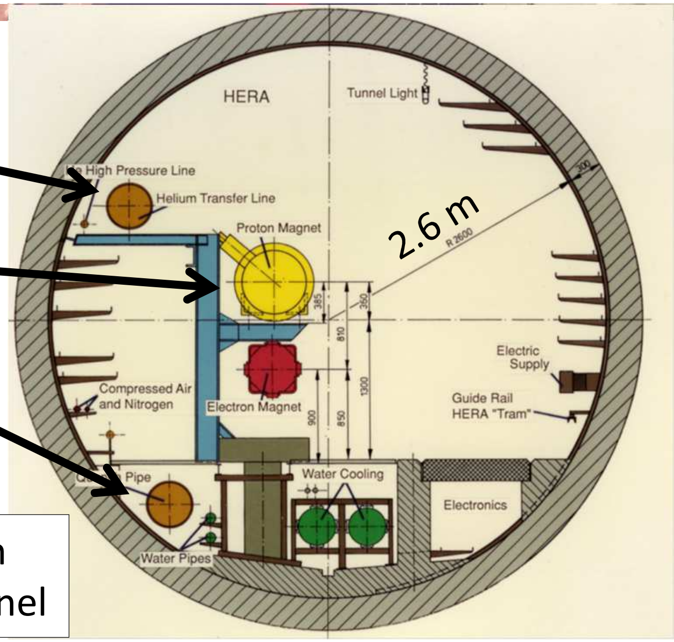


Accelerator components are still in place

Helium transfer line

sc Magnets

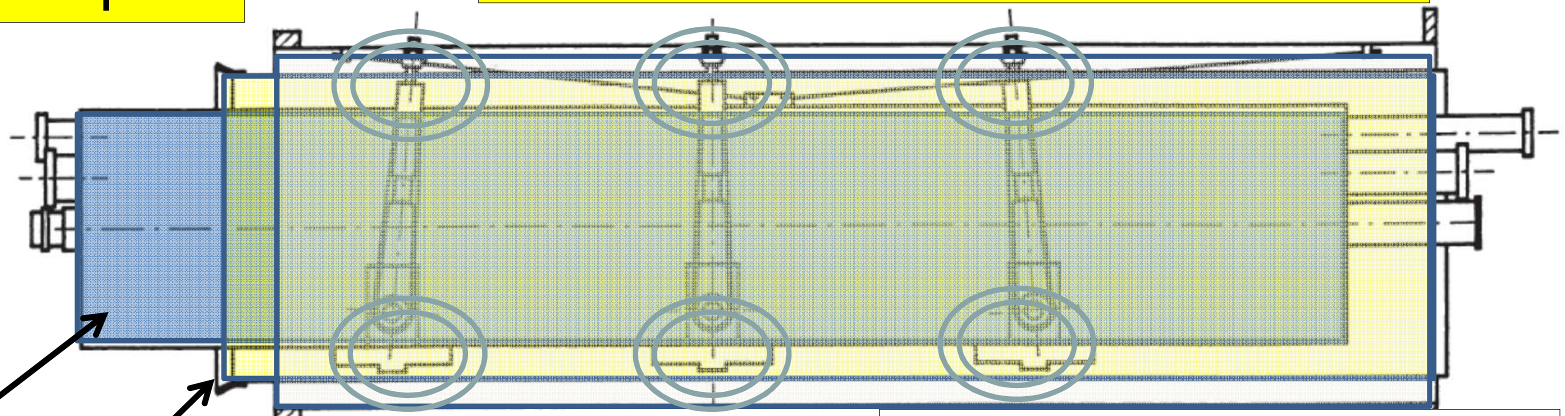
Quench gas collection line



cross section of HERA tunnel

HERA sc Dipole

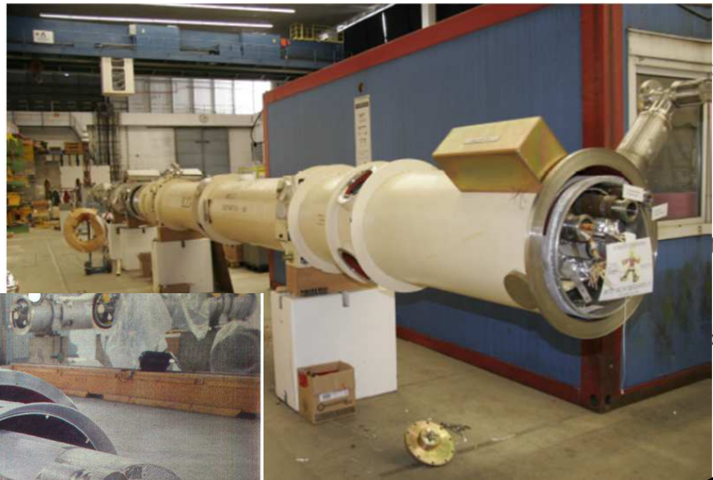
5.3 T @ 5700 A for ALPS II 4.2 K

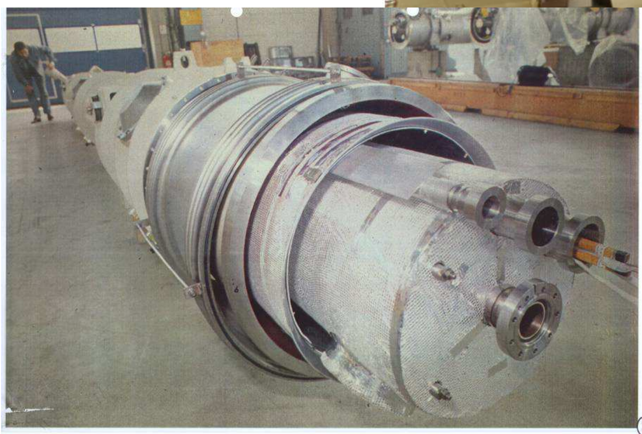


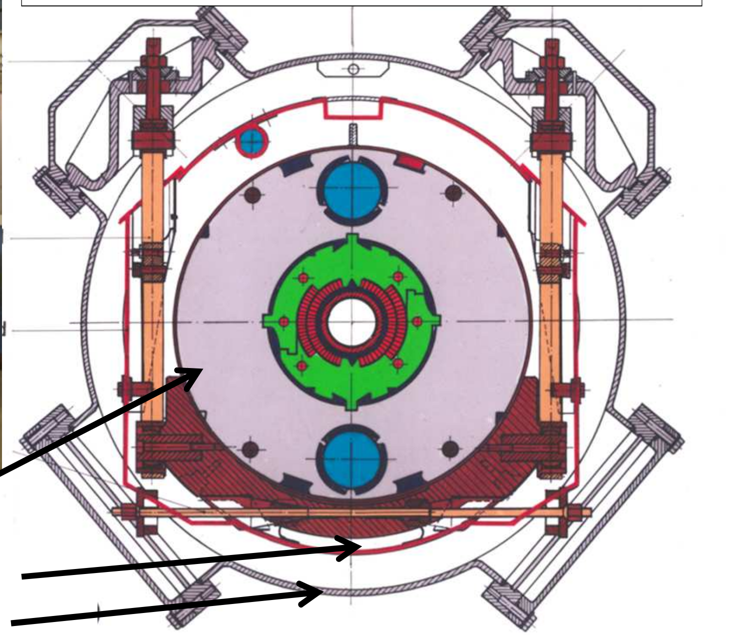
‘cold mass’
radiation shield
vacuum vessel

magnetic length	8829.6mm	
total length	9766	mm

diameter of cryostat	610	mm
diameter of cold mass	400	mm
diameter radiation shield	510	mm







‘cold mass’
radiation shield
vacuum vessel

- HERA overview

- Increasing the aperture of the dipoles for the laser beam

- The principal setup of the magnet string in the HERA tunnel

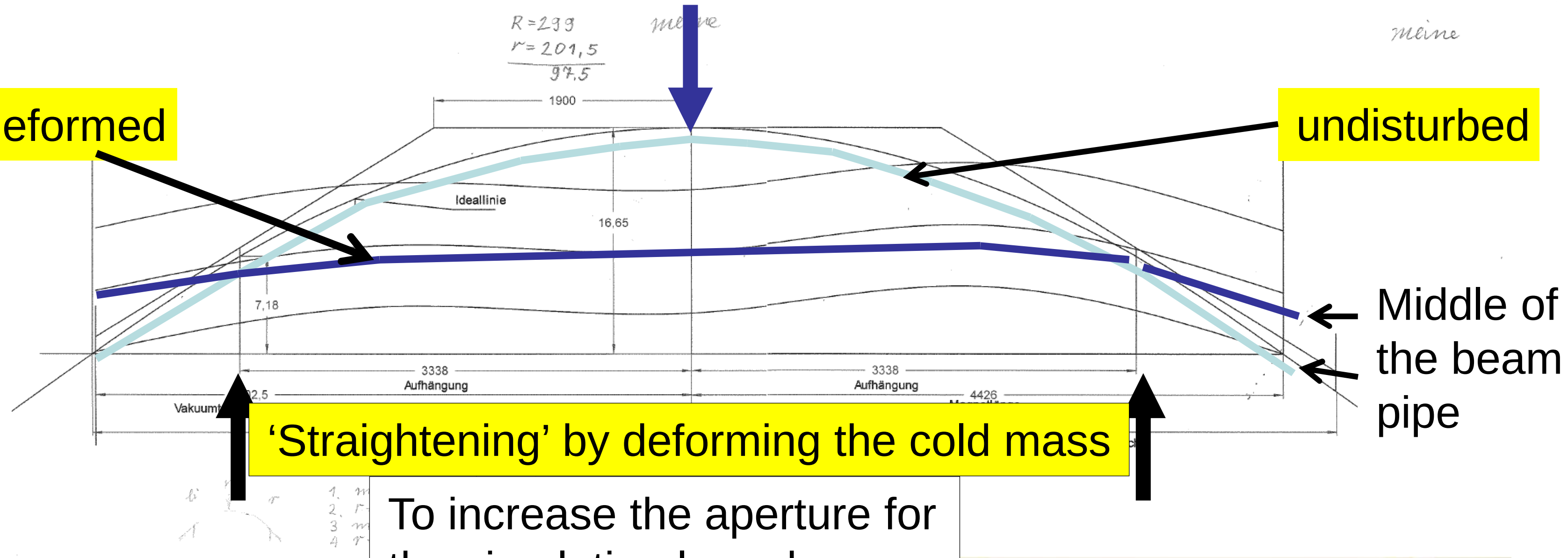
- Achievable modulation frequency of the magnetic field

At HERA the magnet and the beam tube are **curved**

Inner diameter of beam pipe 55 mm

deviation from straight line in the middle of magnet: ~ 17 mm

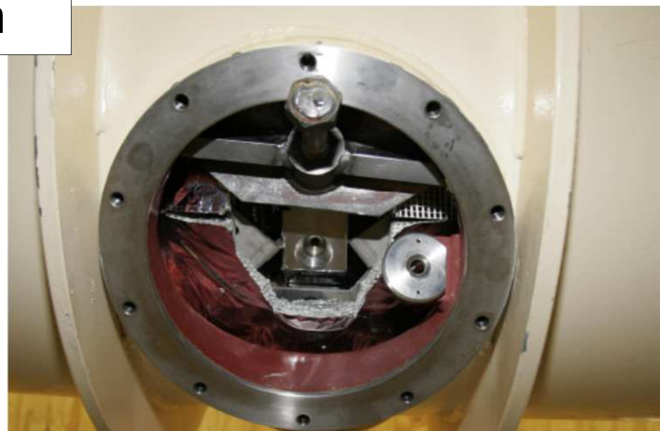
Width of free sight 35 mm



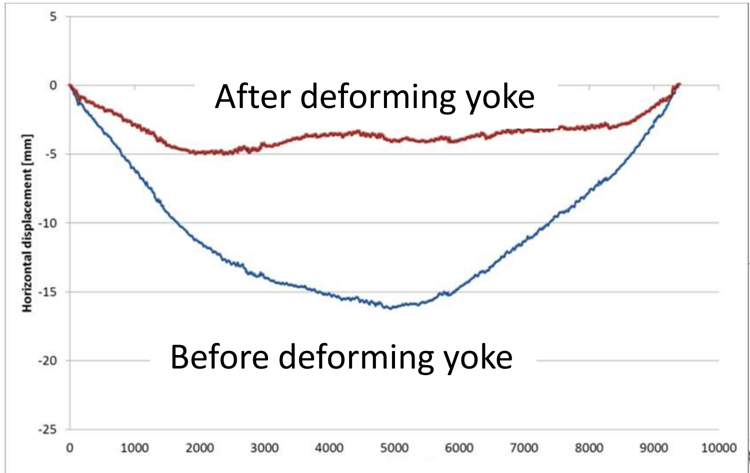
'Straightening' by deforming the cold mass

To increase the aperture for the circulating laser beam

pressure screws

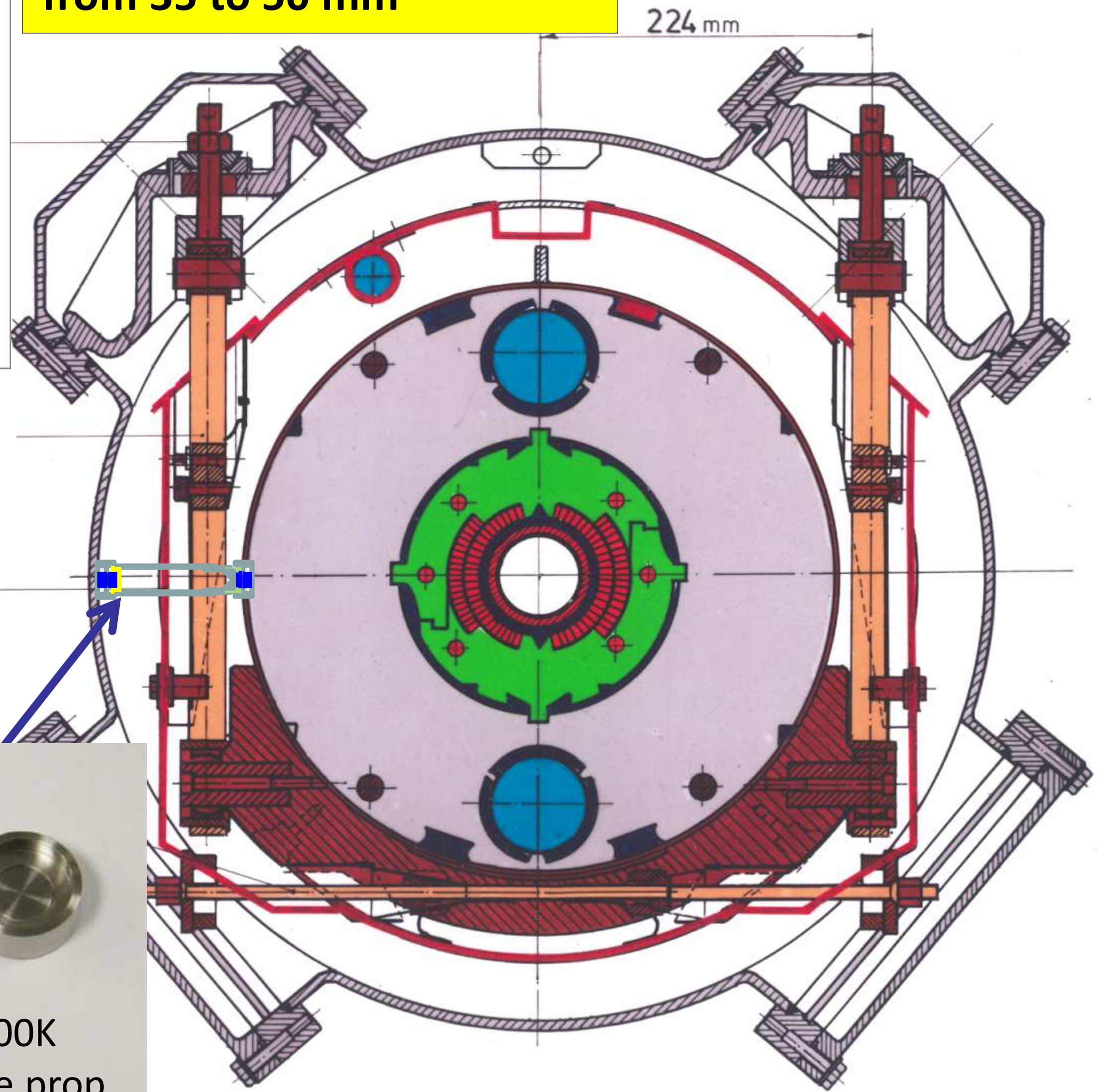


pressure screw inserted at lower flange in support plane



Center of beam pipe vs length

Increase width of free sight from 35 to 50 mm

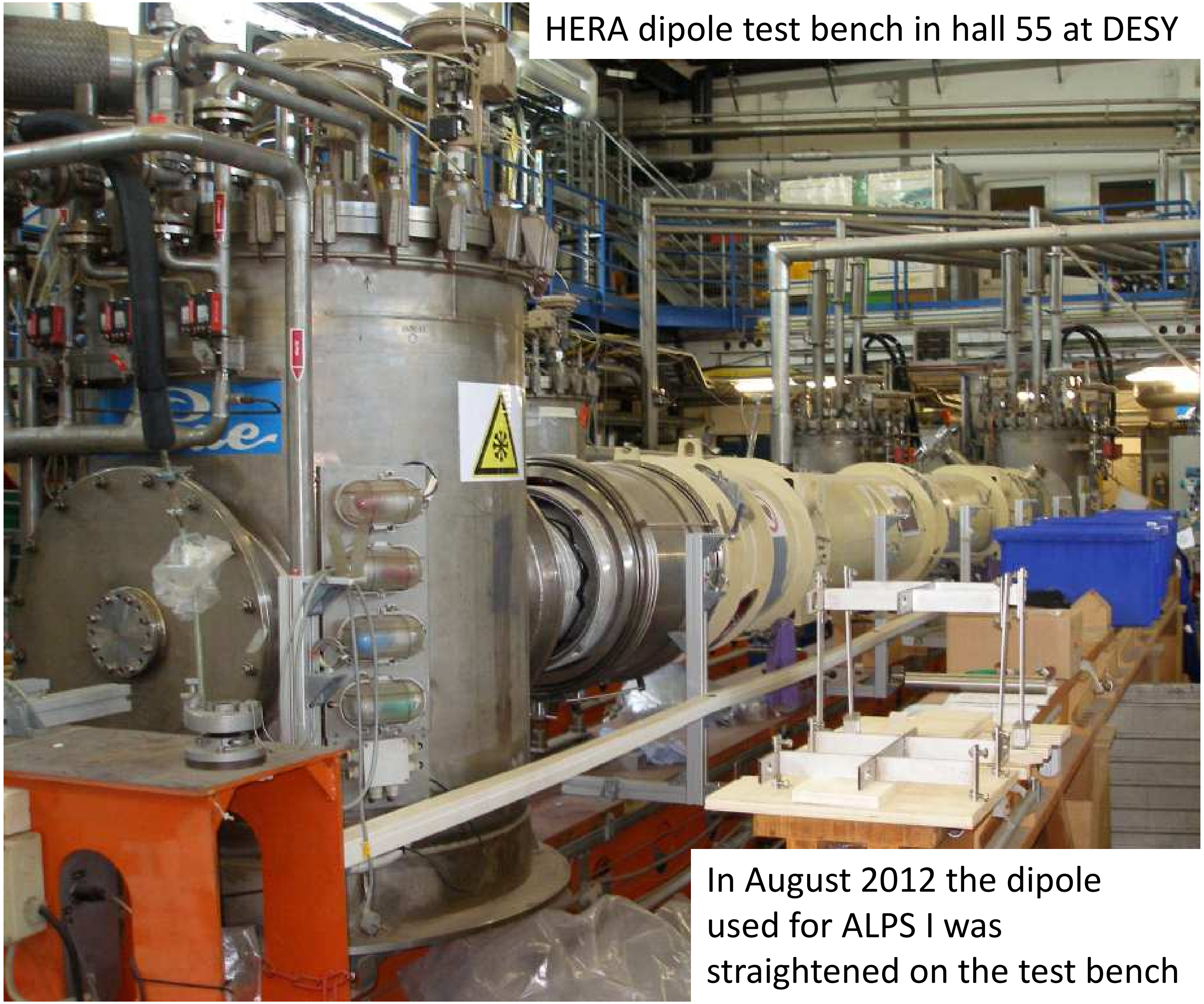


Allows for string of 2*10 dipoles with very small losses by clipping

After deformation the screws are replaced by pressure props

Static heat load grows from 4 to 7 Watt

HERA dipole test bench in hall 55 at DESY

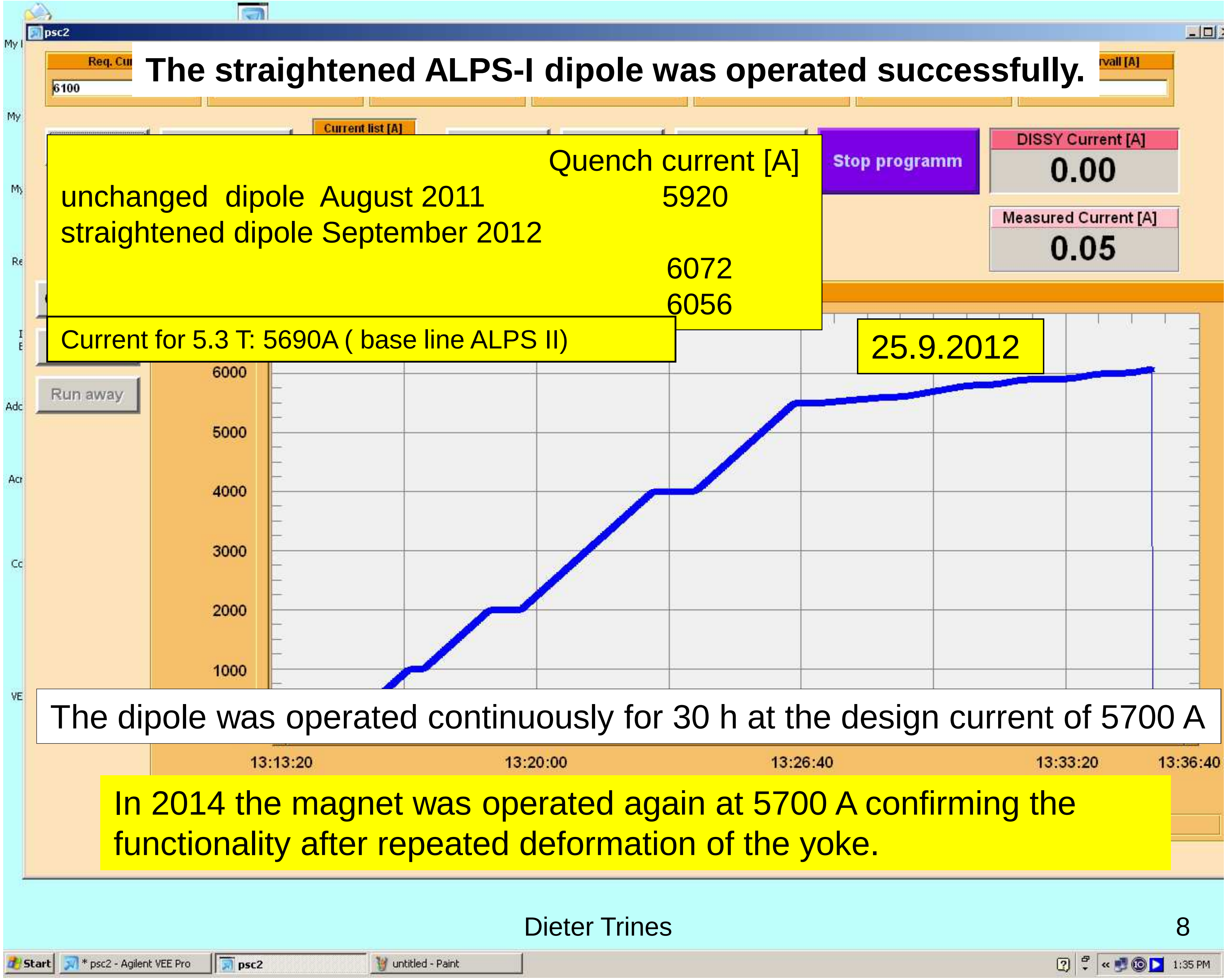


In August 2012 the dipole used for ALPS I was straightened on the test bench

The straightened ALPS-I dipole was operated successfully.

	Quench current [A]
unchanged dipole August 2011	5920
straightened dipole September 2012	6072
	6056

Current for 5.3 T: 5690A (base line ALPS II)



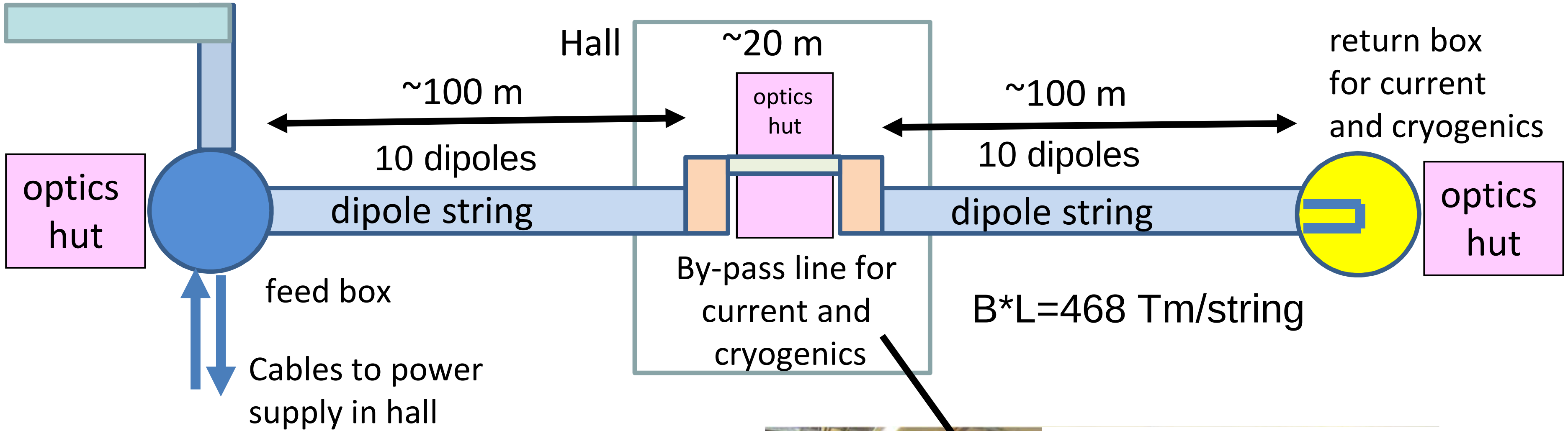
25.9.2012

The dipole was operated continuously for 30 h at the design current of 5700 A

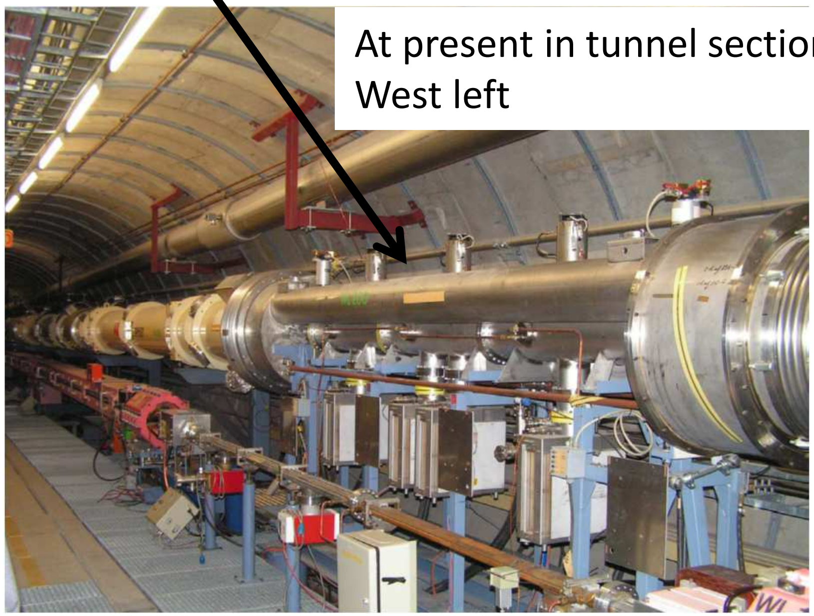
In 2014 the magnet was operated again at 5700 A confirming the functionality after repeated deformation of the yoke.

- HERA overview
- Increasing the aperture of the dipoles for the laser beam
- The principal setup of the magnet string in the HERA tunnel
- Achievable modulation frequency of the magnetic field

Schematic setup of ALPS II in the tunnel HERA North with spare dipoles

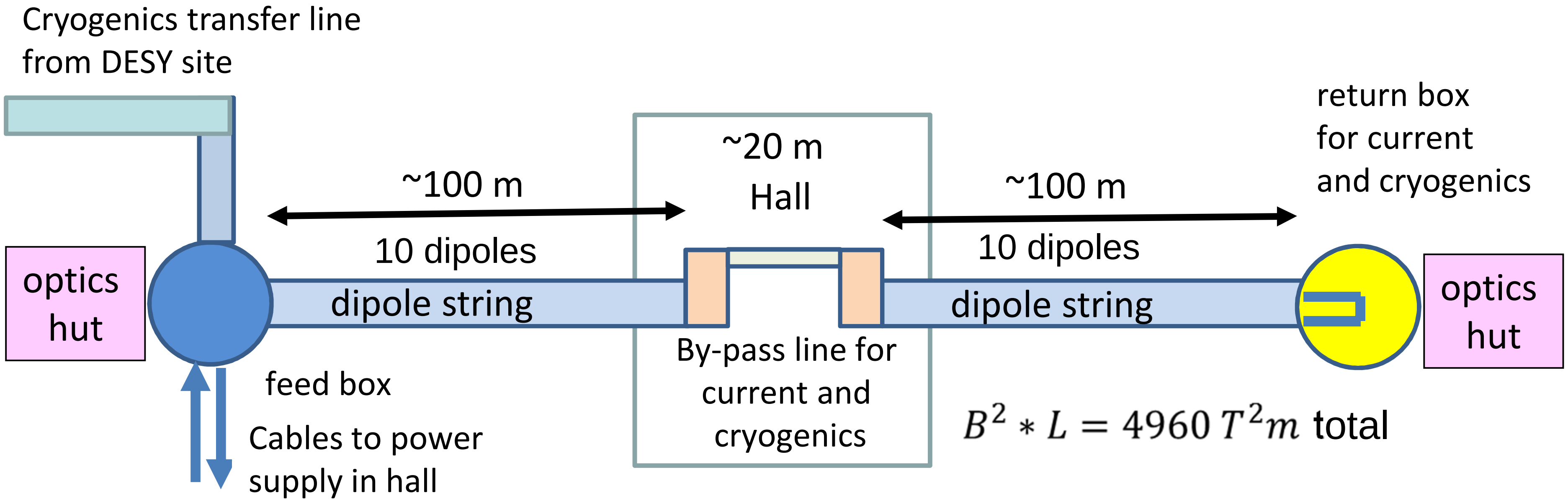


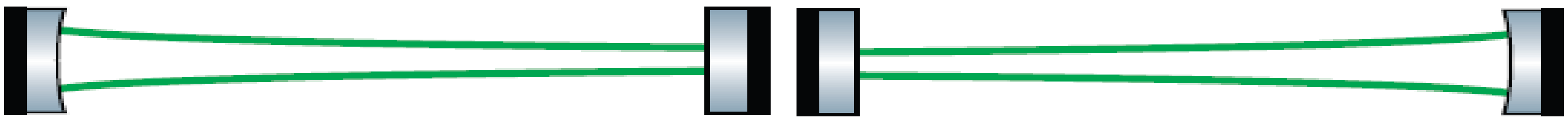
cryogenics boxes are taken from the neighbouring arcs of HERA



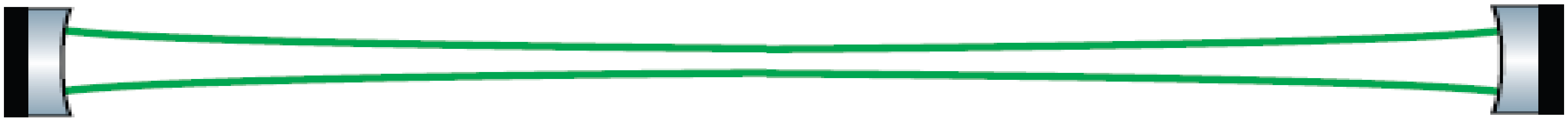
At present in tunnel section West left

Schematic setup of HERA-X in the tunnel HERA North





After the completion of ALPS II the mirrors
in the vacuum vessel in the middle are removed for HERA-X



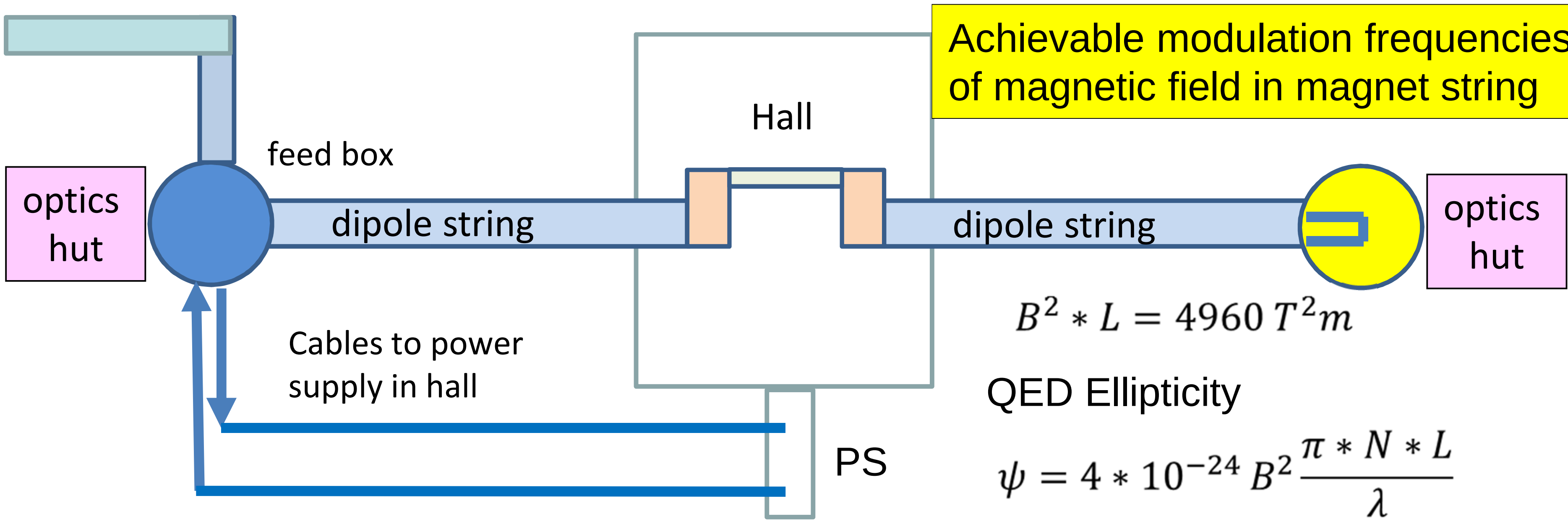
- The HERA dipole

- Increasing the aperture of the dipoles for the laser beam

- The principal setup of the magnet string in the HERA tunnel

- Achievable modulation frequency of the magnetic field

Achievable modulation frequencies of magnetic field in magnet string



$$B^2 * L = 4960\, T^2 m$$

QED Ellipticity

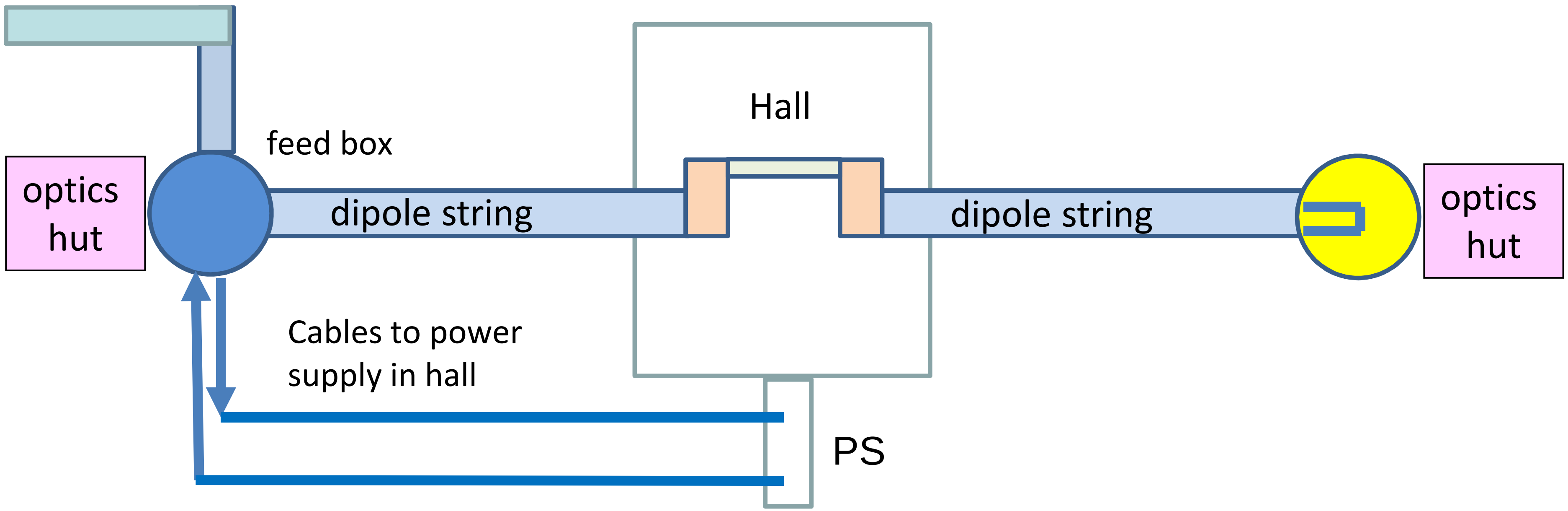
$$\psi = 4 * 10^{-24}\, B^2 \frac{\pi * N * L}{\lambda}$$

A modulation of the magnet current yielding $I^2\,(t) = Ak + Ck * \cos \omega i * t$ seems to be the best measure, to obtain clean peaks in the frequency spectrum for the ellipticity measurement.

$$Ak = \frac{1}{2}(Imax^2 + Imin^2) \qquad Ck = \frac{1}{2}(Imax^2 - Imin^2)$$

The modulation frequency ωi of the dipole string is determined by the available voltage at the power supply and the inductivity of the magnets.

1) available 20 Volt power supply in HERA North

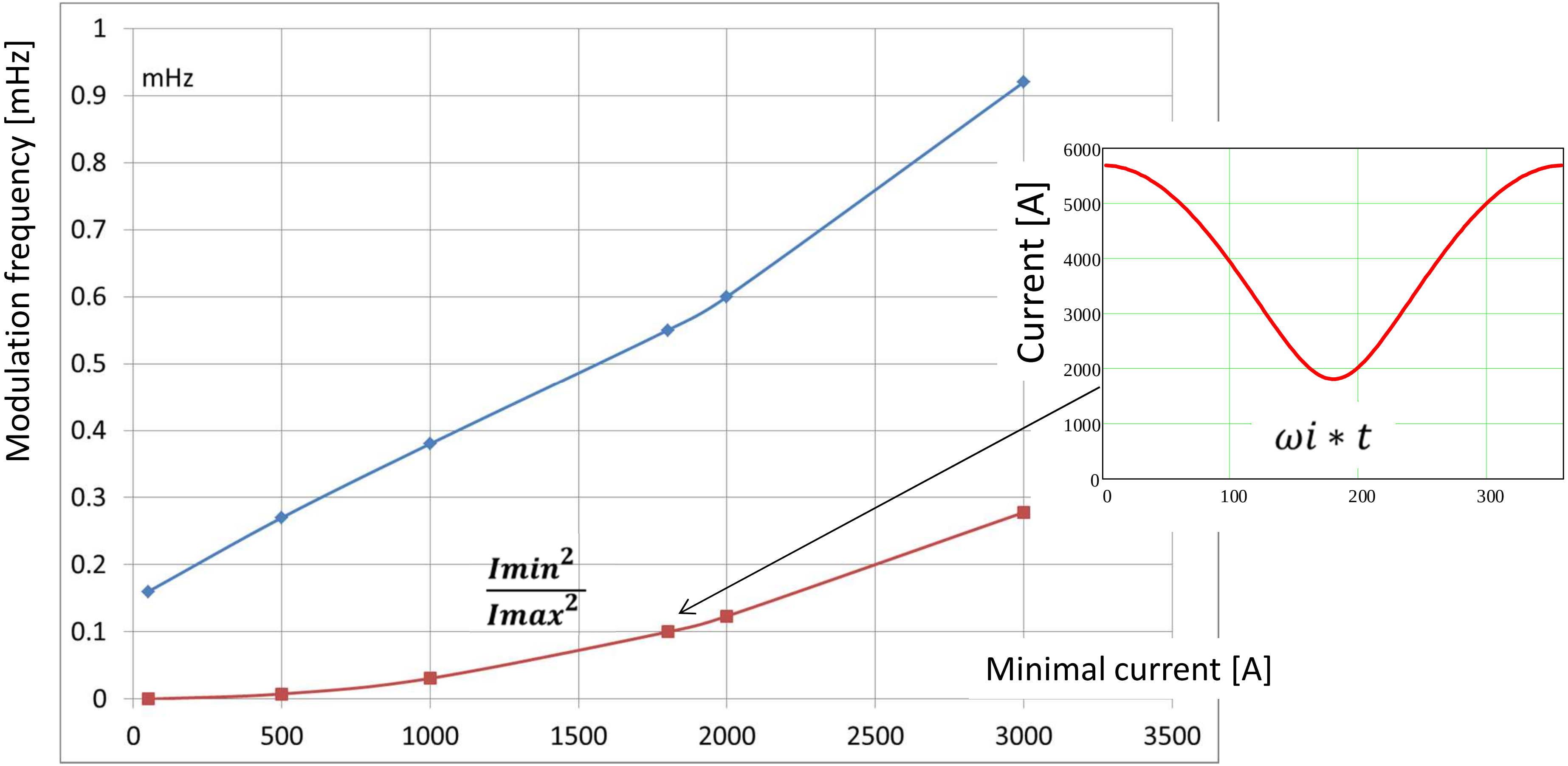


Nominal current for ALPS II string	5690	A
resistance of cable connection between magnet string and PS	$3*10^{-3}$	Ohm
Resistive voltage at nominal current	17	Volt
Voltage of power supply hall North	20	Volt
Inductance of single magnet	$58*10^{-3}$	Henry
Inductance of ALPS II string	1.16	Henry
Time constant	387	sec

When the magnet current is modulated according to $I^2(t) = Ak + Ck * \cos \omega i * t$ between nominal current and zero the maximum frequency possible is ~ 0.2 mHz.

Increasing $Imin$ raises the possible frequency.

Staying within 20 Volt for the maximum voltage at the power supply



2) The HERA power supply presently located in HERA hall West.

Voltage of HERA power supply	-300 to 500	Volt
forward voltage threshold of cold diodes	~ 2.5	Volt

In the case of the HERA power supply (when transferred to hall North) the limitation of the modulation frequency does not come from a limitation in the available voltage, but is due to the **threshold voltage** of the **cold diodes** in the HERA dipoles.

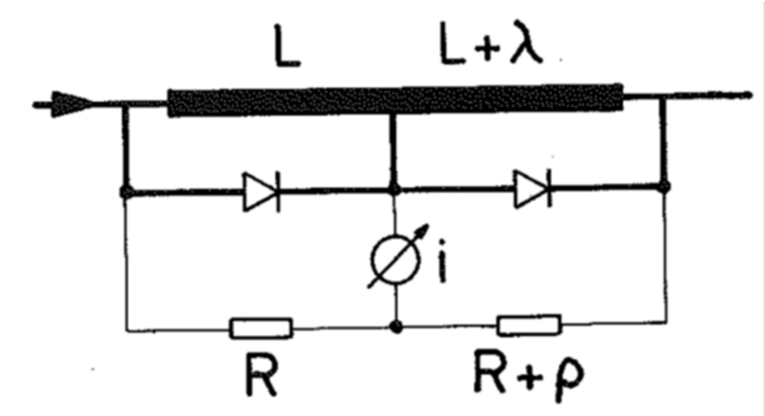
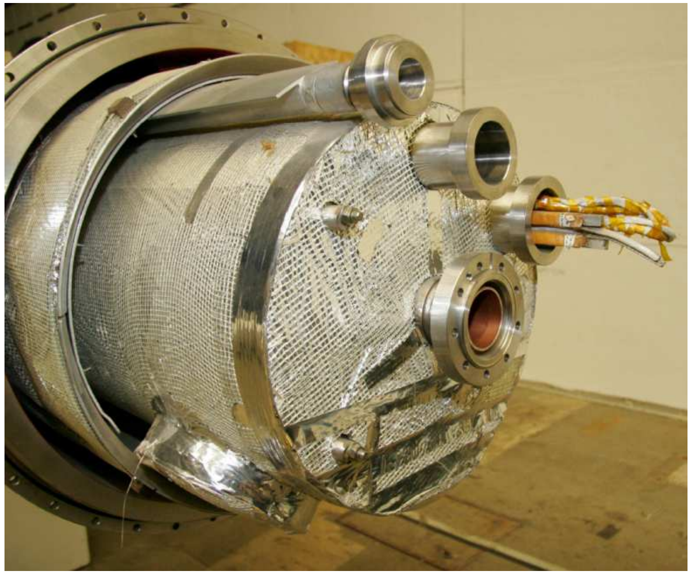


Fig. 2 Electrical connections of a dipole

The diodes protect the coils in case of a quench



Location of cold diode package

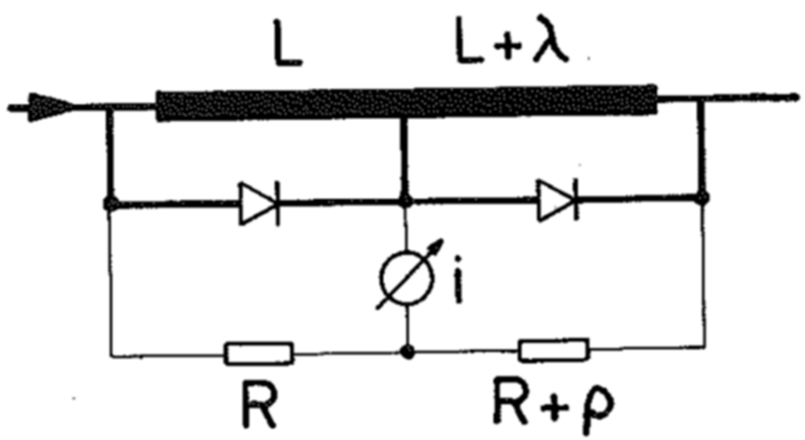


Fig. 2 Electrical connections of a dipole

The diodes will get conductive for forward current at a threshold voltage of ~ 2.5 Volt.

When approaching this threshold, one diode will get conductive before the other
-due to the scatter in threshold values-
which will lead to an imbalance in the bridge.

The quench protection system will react as for a quench:

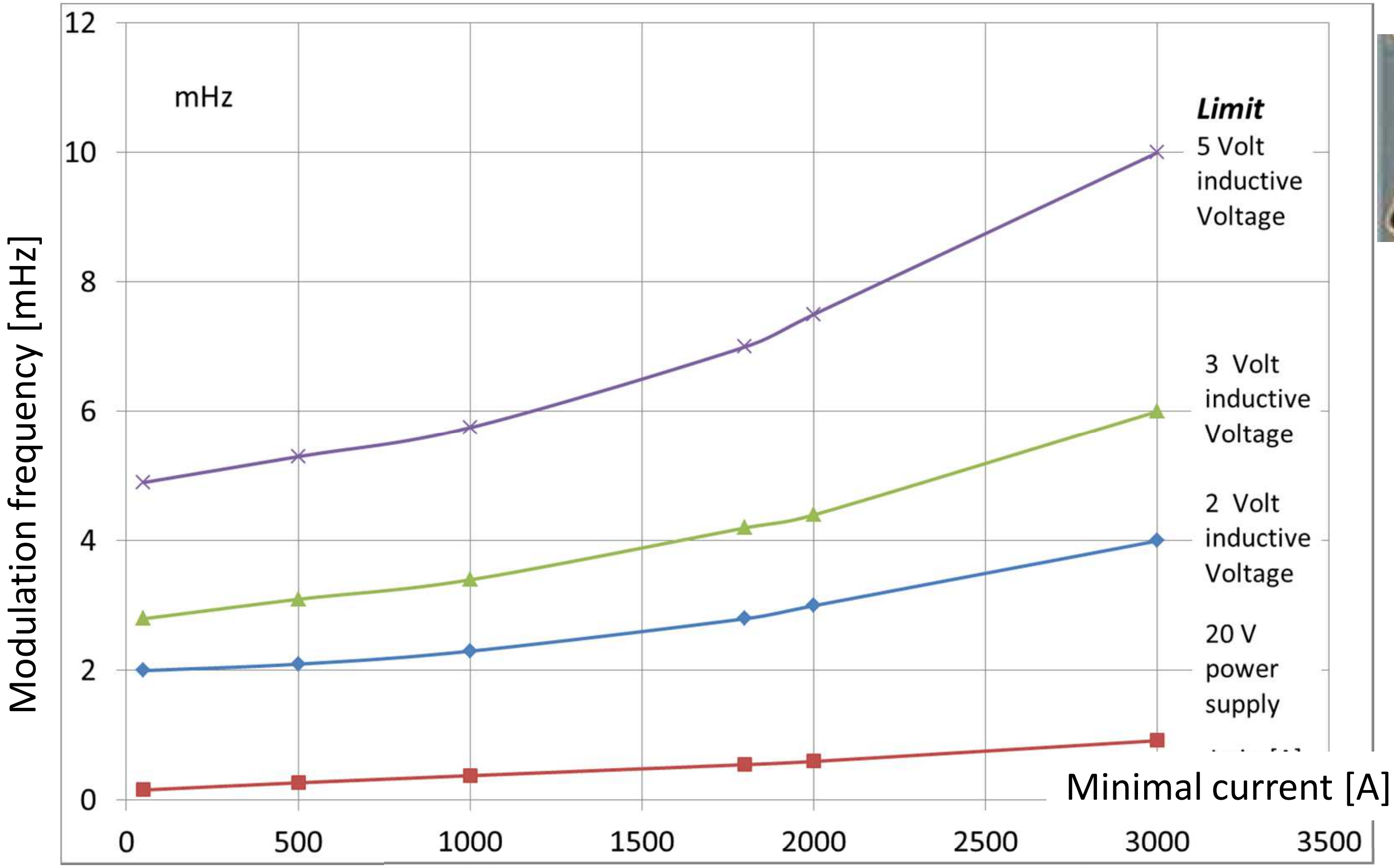
The heaters on the coils are fired, to make the coil normal conducting and dissipate the heat

The power supply is switched off and dump resistors are switched into the current loop

Obviously this must be avoided.

As in the case of the 20 Volt power supply the modulation frequency can be increased by raising the minimal current for the HERA power supply.

The plot shows the dependence of the modulation frequency on the minimum current with the inductive voltage across a dipole as a parameter.



Field errors due to persistent and eddy currents are $<10^{-3}$ above 1600 A up to ramp rates of 50 A/sec

*It should be mentioned , that according to an estimate of Hans-Joerg Eckoldt from the MKK group responsible for the power supplies in the DESY accelerator division the transfer of the HERA power supply to hall North would constitute quite an effort and require **~200000 Euro** due to the electrical infrastructure needed like transformers and cables.*

Summary for $\frac{Imin^2}{Imax^2}$ of 10%

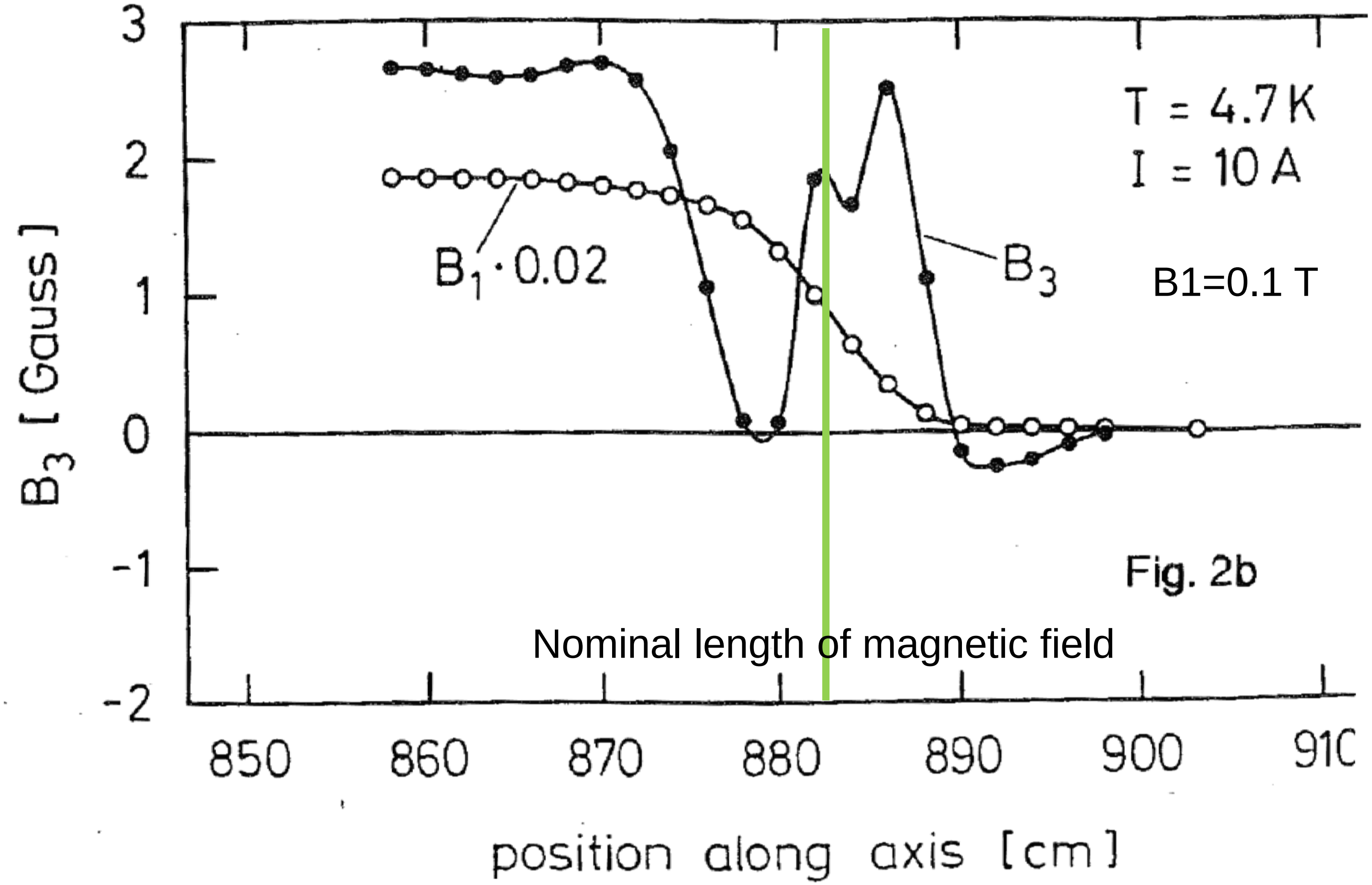
Heat generated in the magnet coils due to eddy currents

frequency [mHz]	Uind dipole [Volt]	dI/dt max [A/sec]	Δheat dipole [Watt]	Total Δheat string [Watt]	Power supply
0.6	0.4	7	0.02	0.4	20 Volt
2.8	2	34	0.5	10	HERA
4.2	3	50	1	20	HERA
7.0	5	84	3	60	***Limit***

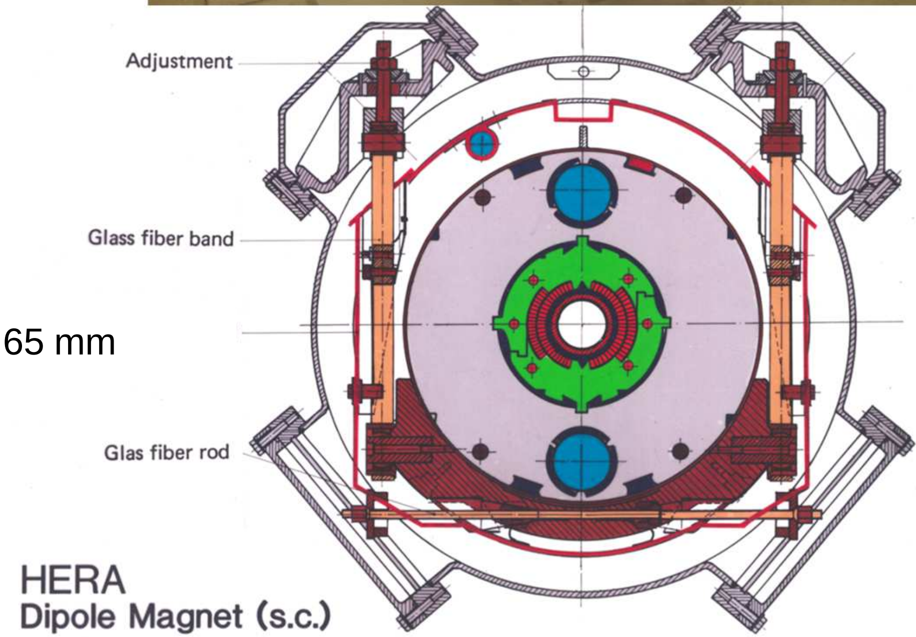
End

Backup slides

From Heiner Brueck et al



HERA cryogenic plant: 3 cold boxes with 6.3 kW at 4.3 K
20 kW at 40 kW



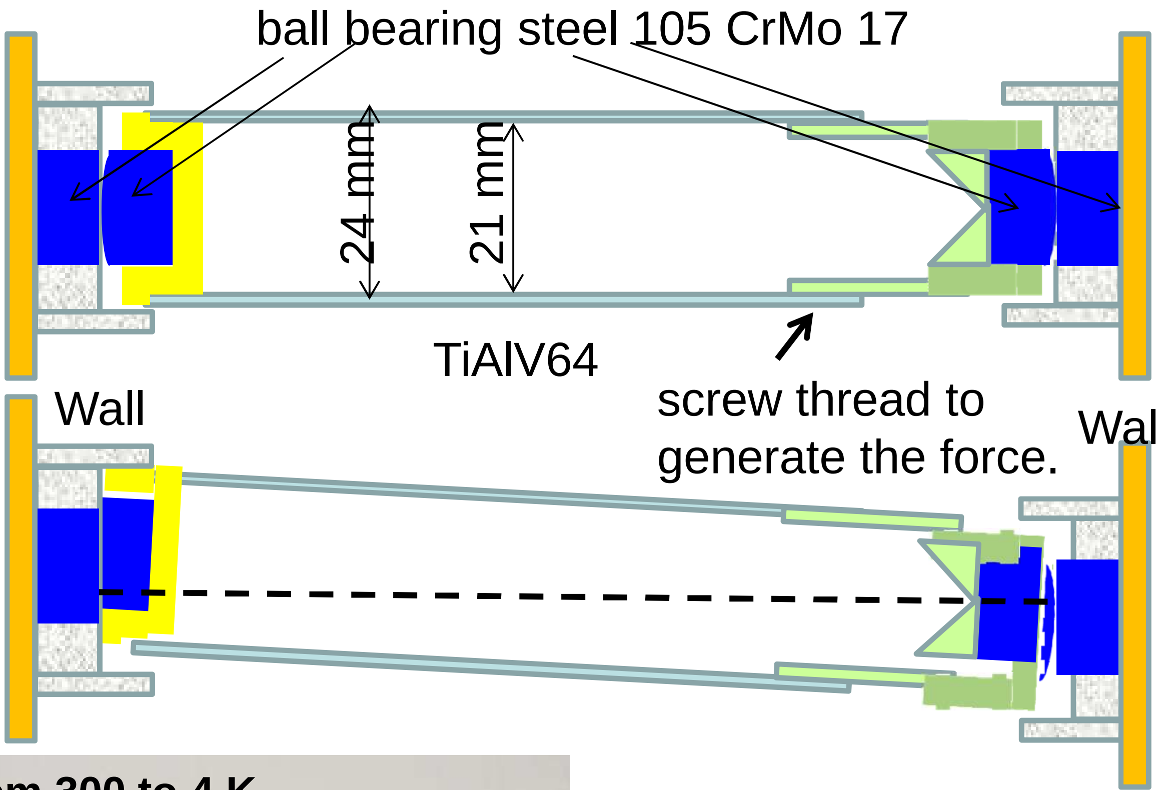
radius of curvature of coil and beam pipe: 585 m

deviation from straight in the middle of magnet: 16.65 mm

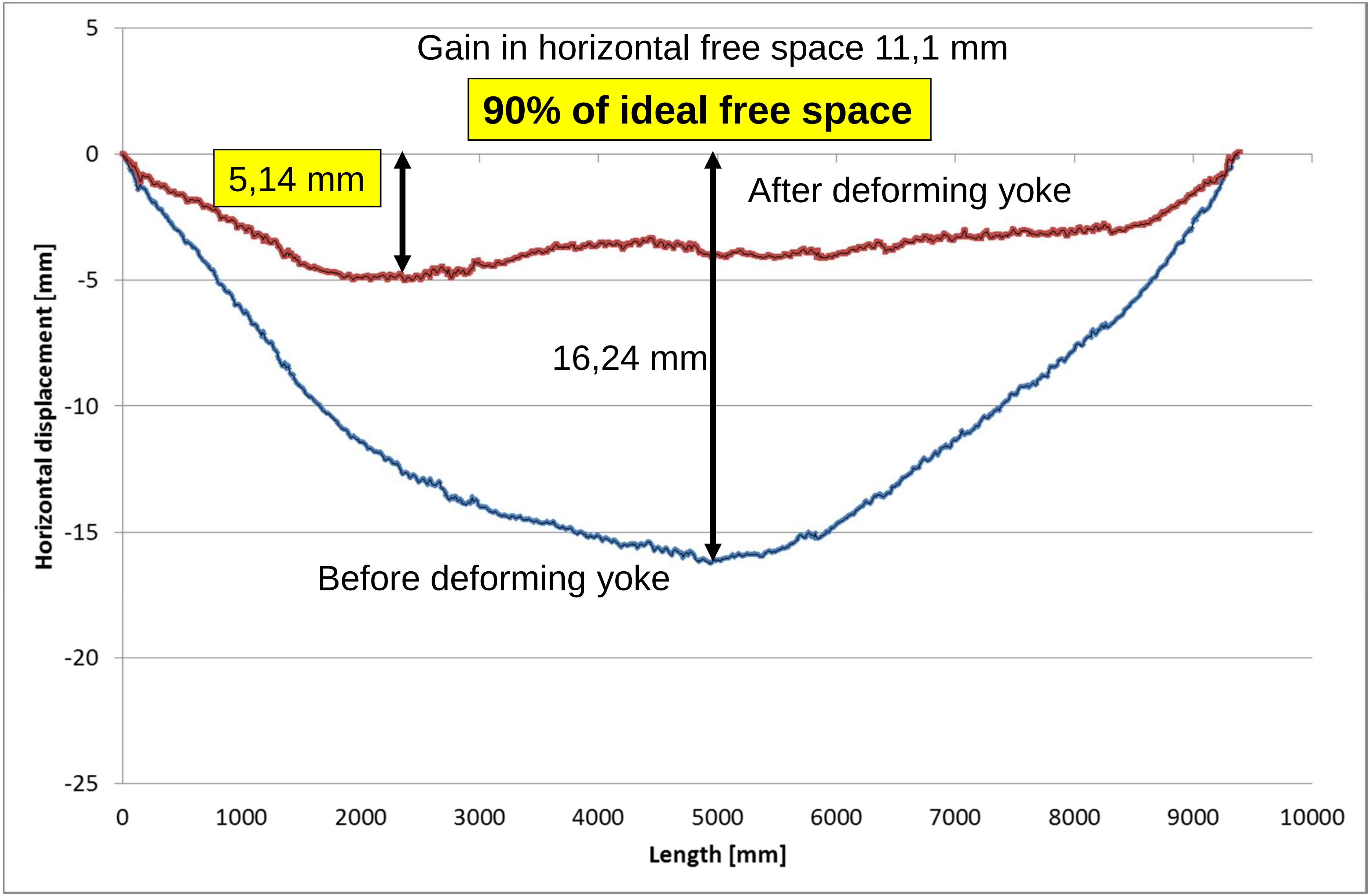
The problem to compensate the shrinkage of the cold mass was solved by G. Meyer by using the section of a sphere, which rolls with the motion of the cold mass.

Low heat flow pressure prop

The distance between warm and cold wall does not change during roll except for a thermal shrinkage of the sphere

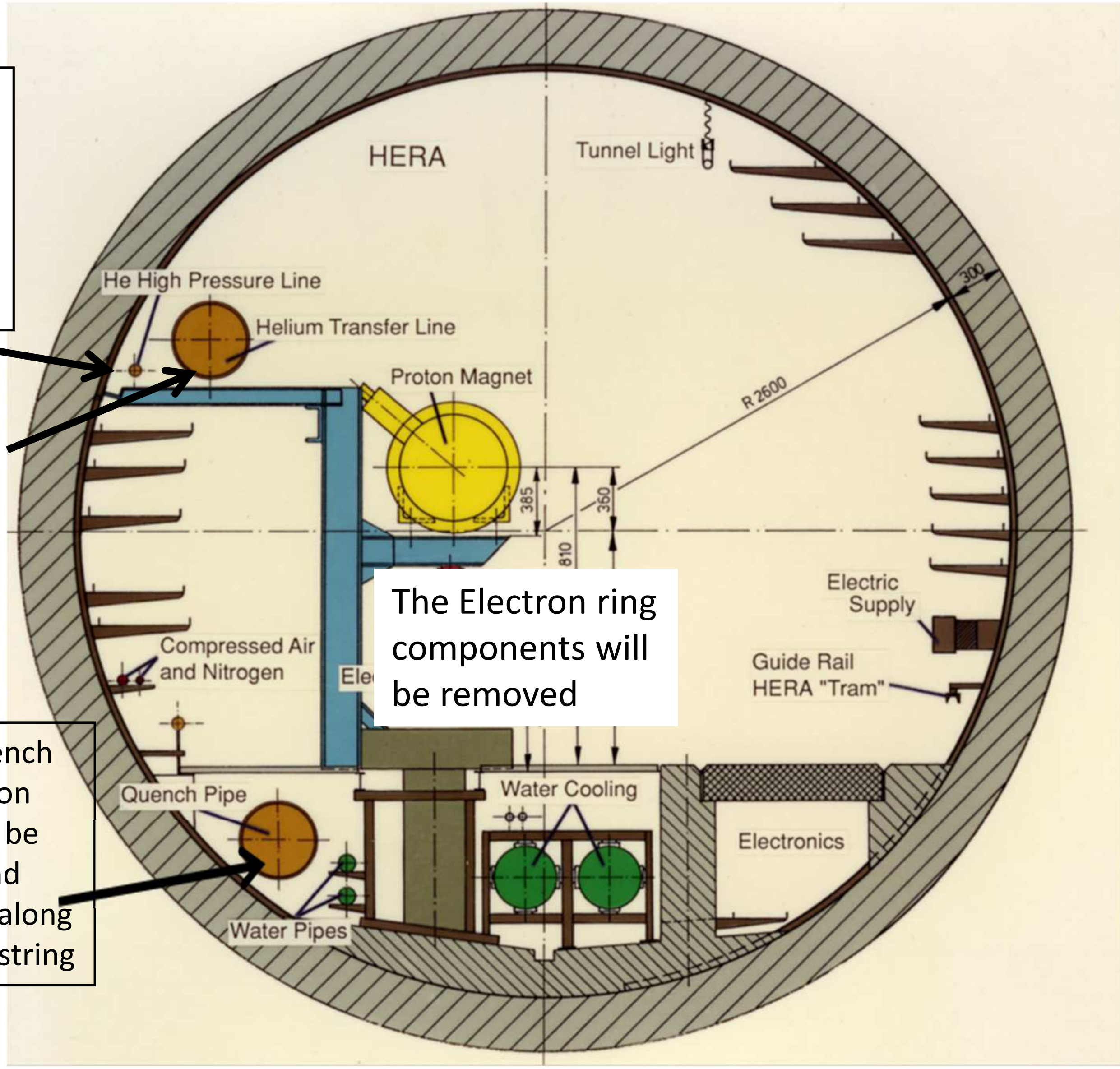


calculated thermal flow from 300 to 4 K
~1 Watts per prop

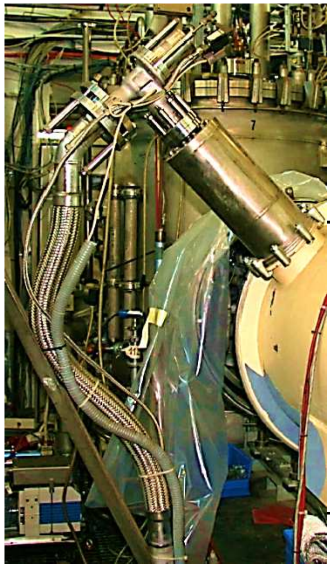

Gain in horizontal free space 11,1 mm
90% of ideal free space
5,14 mm
After deforming yoke
16,24 mm
Before deforming yoke
Horizontal displacement [mm]
Length [mm]
5
0
-5
-10
-15
-20
-25
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

A new high pressure line will have to be installed along the ALPS II string to operate the Kautzky valves

The helium transfer line stops at the cryo boxes

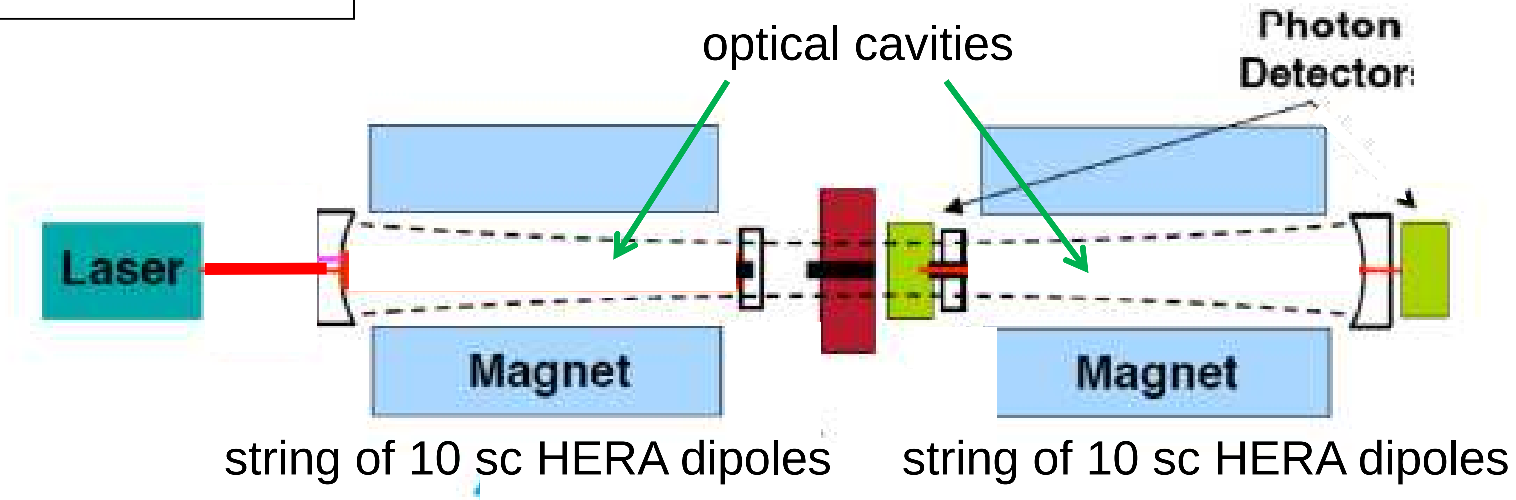


The Electron ring components will be removed

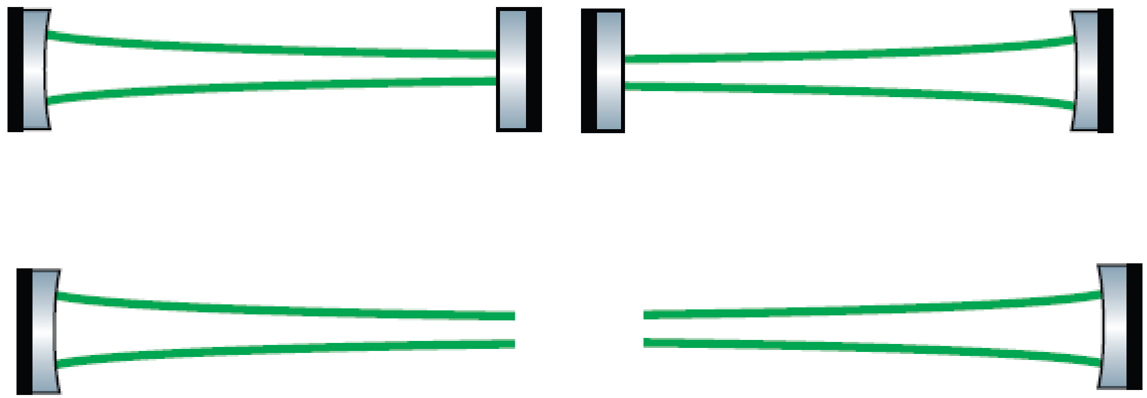


A new Quench gas collection pipe has to be installed and connected along the ALPS II string

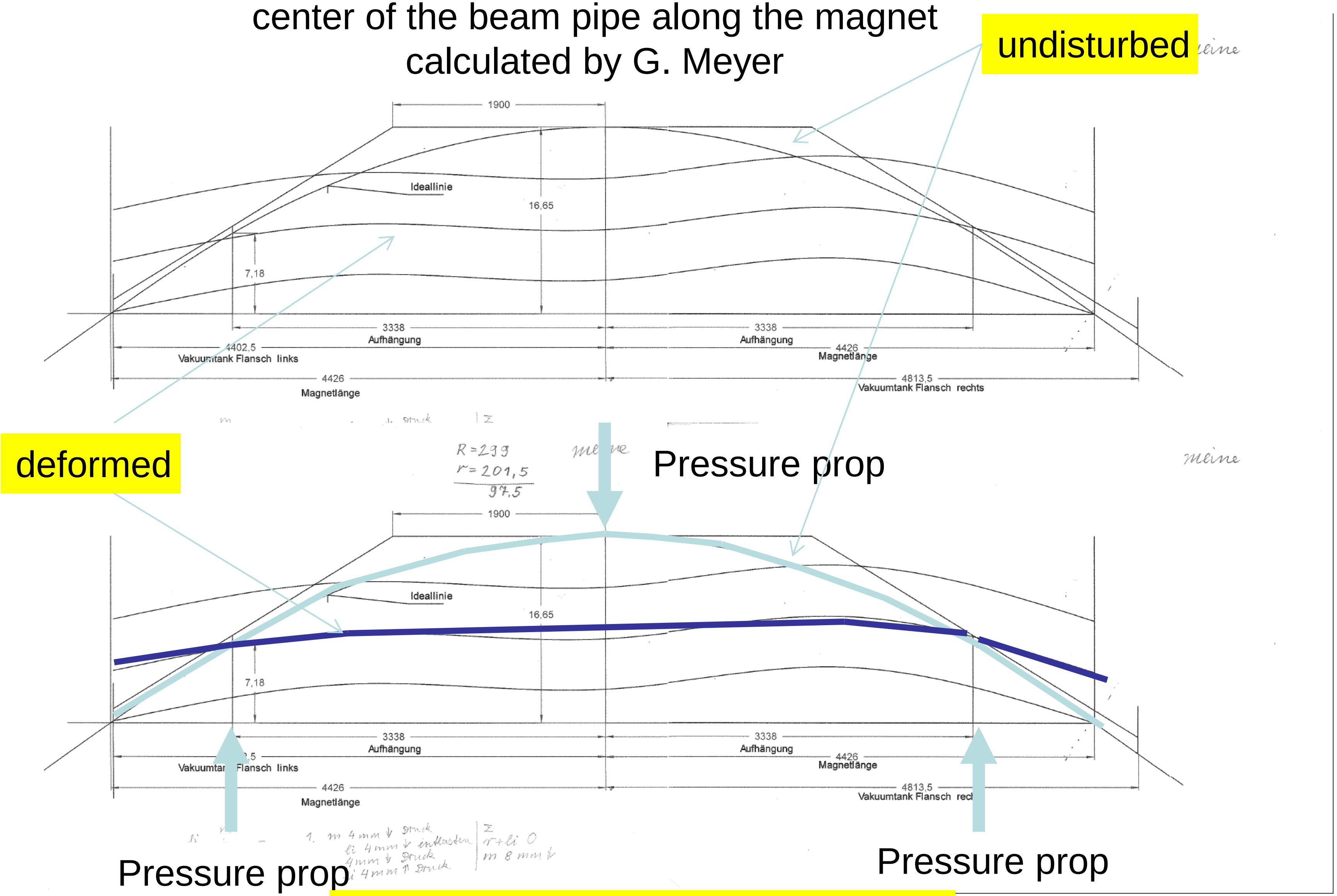
Principal concept of ALPS II



Picture from P.Sikivie, D.B.Tanner, and Karl van Bibber arXiv:hep-ph/0702298v1



center of the beam pipe along the magnet
calculated by G. Meyer

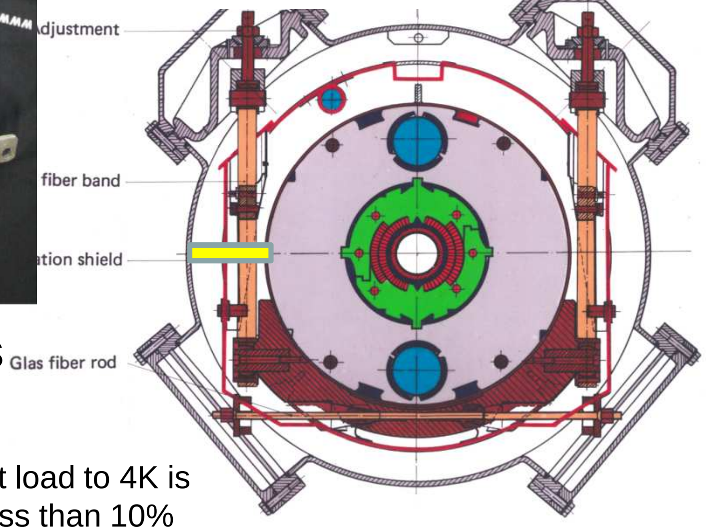


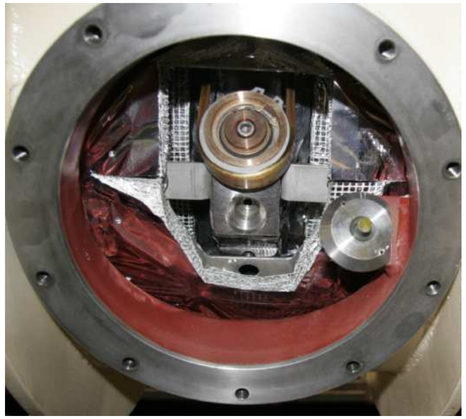
Total reduction of horizontal free space
after cool down to 4 K: ~0.7 mm

The new suspensions

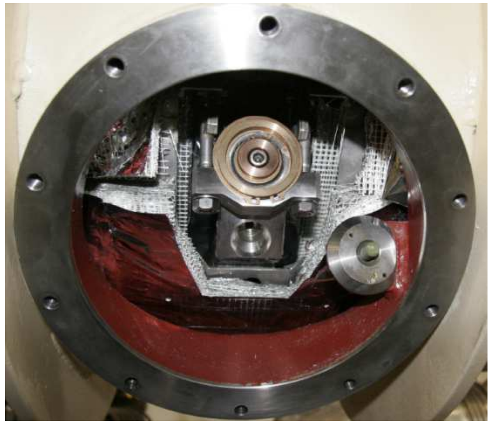
The original suspensions

New suspensions



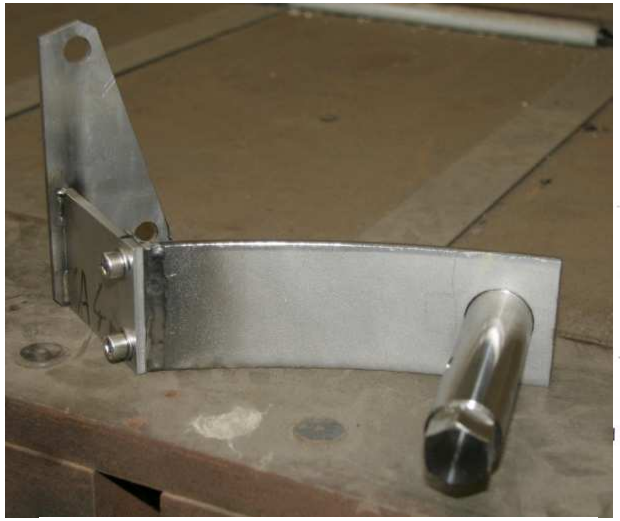


The G10 support loop is replaced by 1mm titanium strips

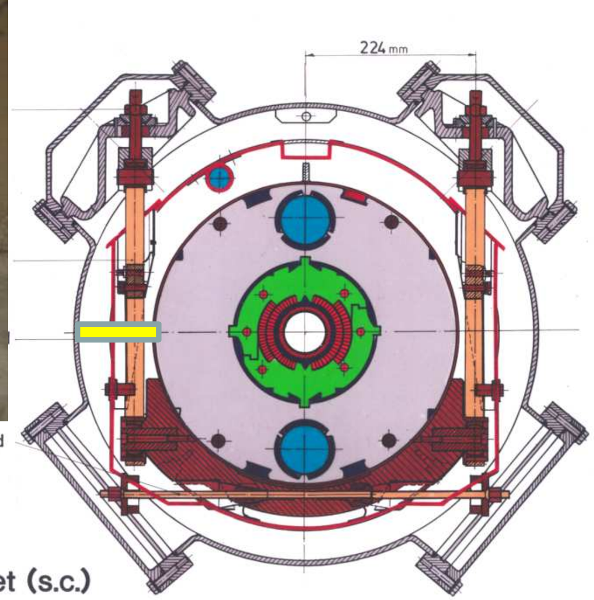


Increase of heat load to 4K is 0.25 Watt i.e. less than 10% of the pressure props

New tools were developed allowing to insert the pressure props properly with respect to position and angle



for the middle of the dipole

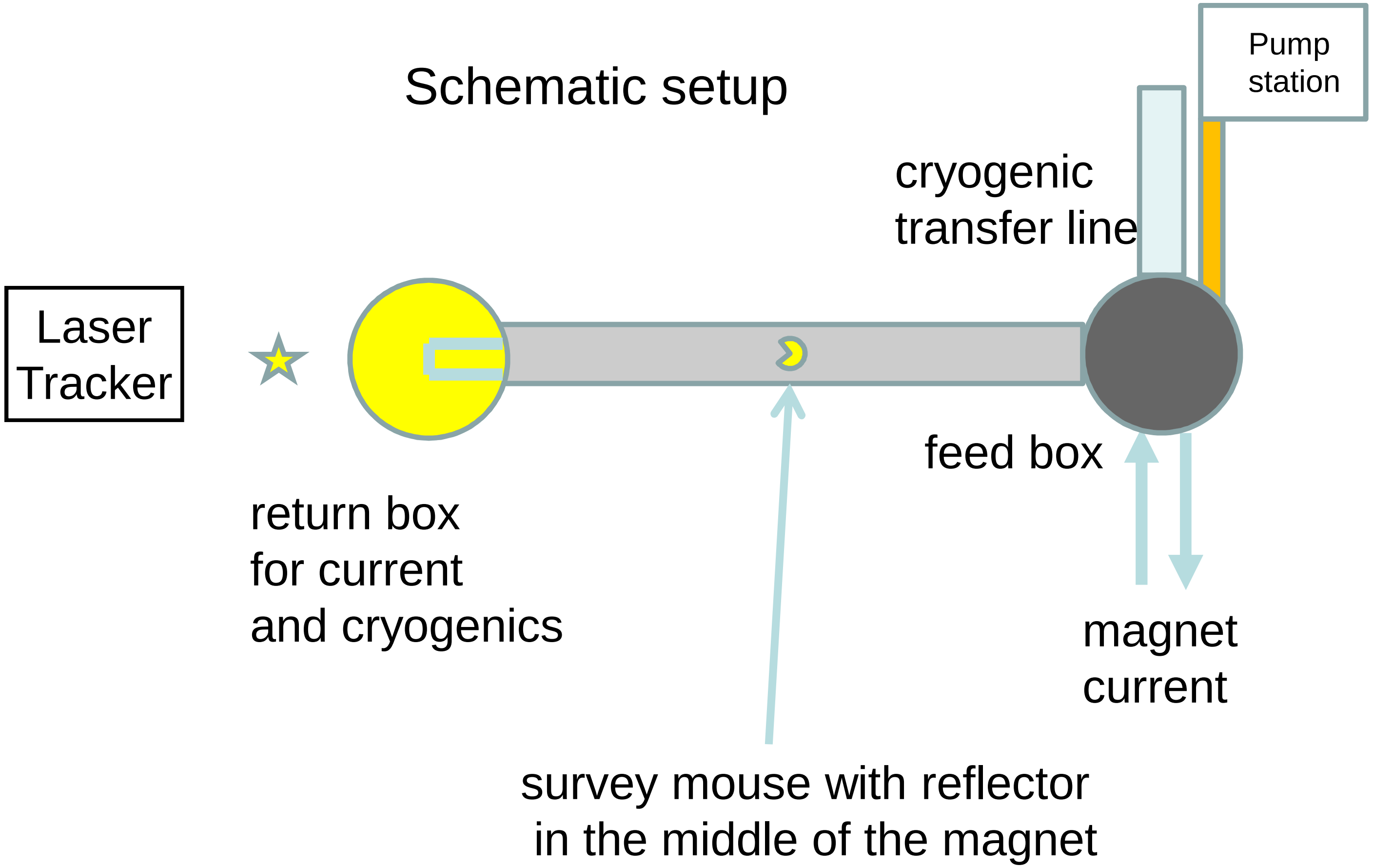


for the ends of the dipole

HERA
Dipole Magnet (s.c.)

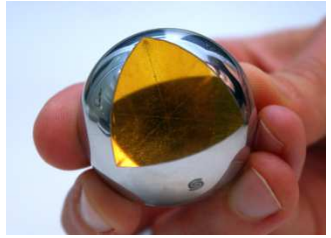
Before the operation of the dipole at the design current
a measurement of the **movement of the beam pipe**
from room temperature to 4 K was performed, inserting
a survey ‘mouse’ into the beam pipe in the middle of the magnet.

Schematic setup



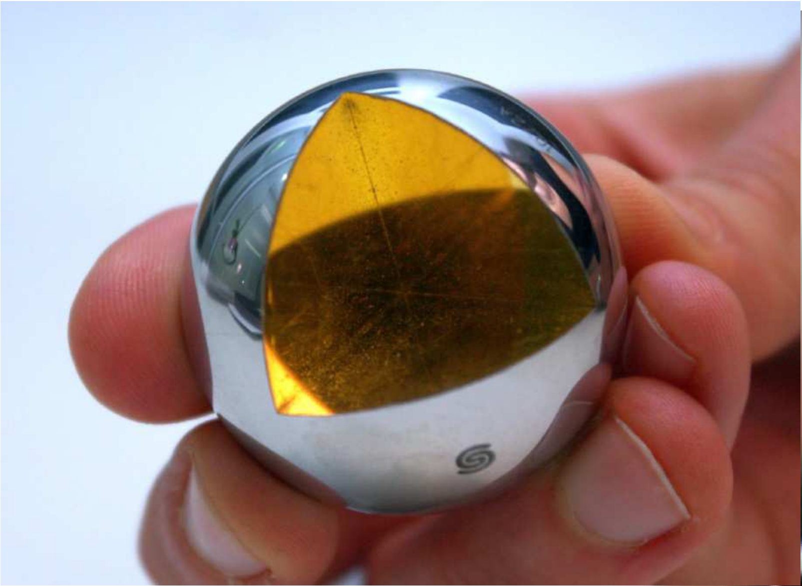
The survey mouse

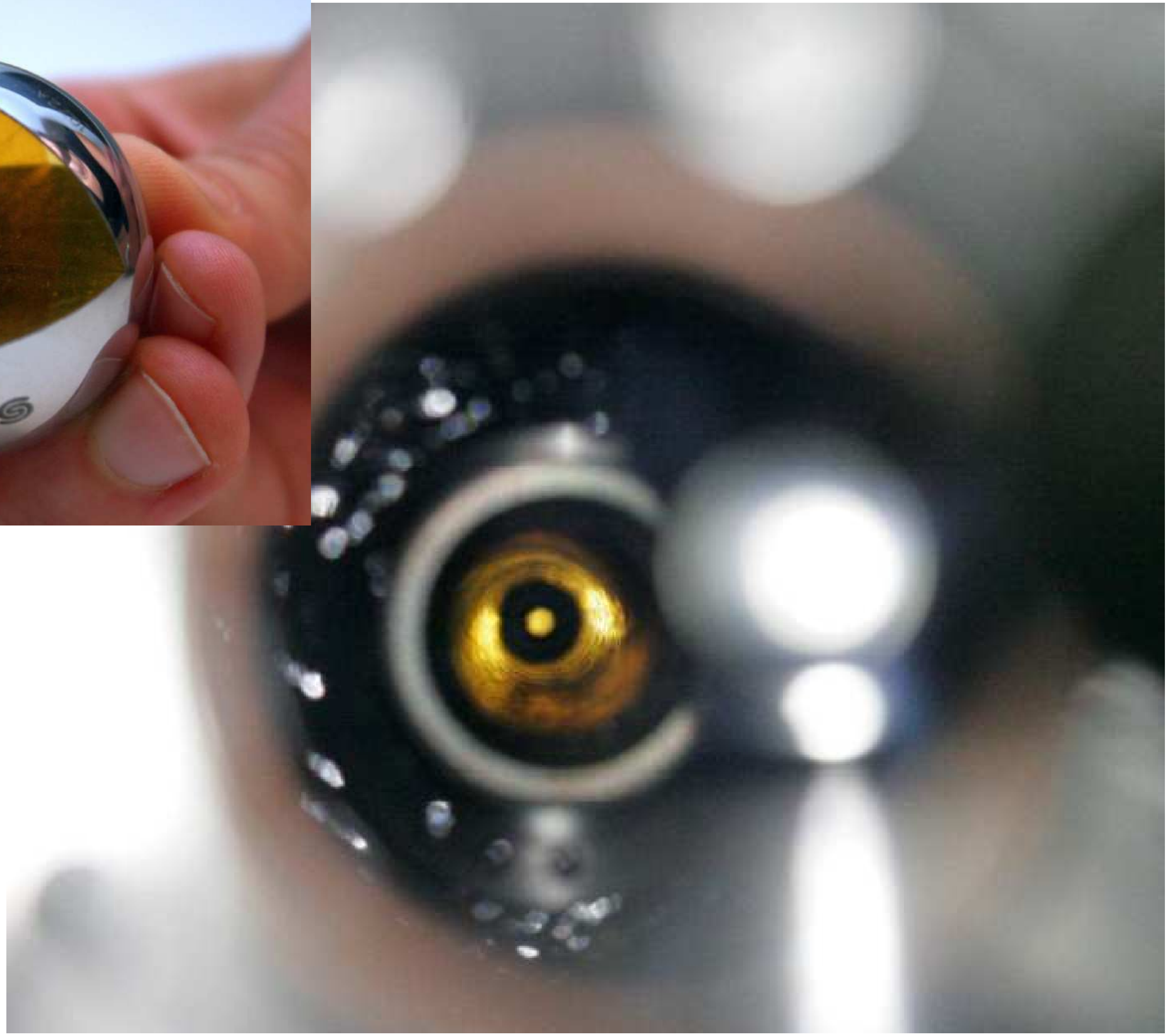
Older picture in the Reemstma hall



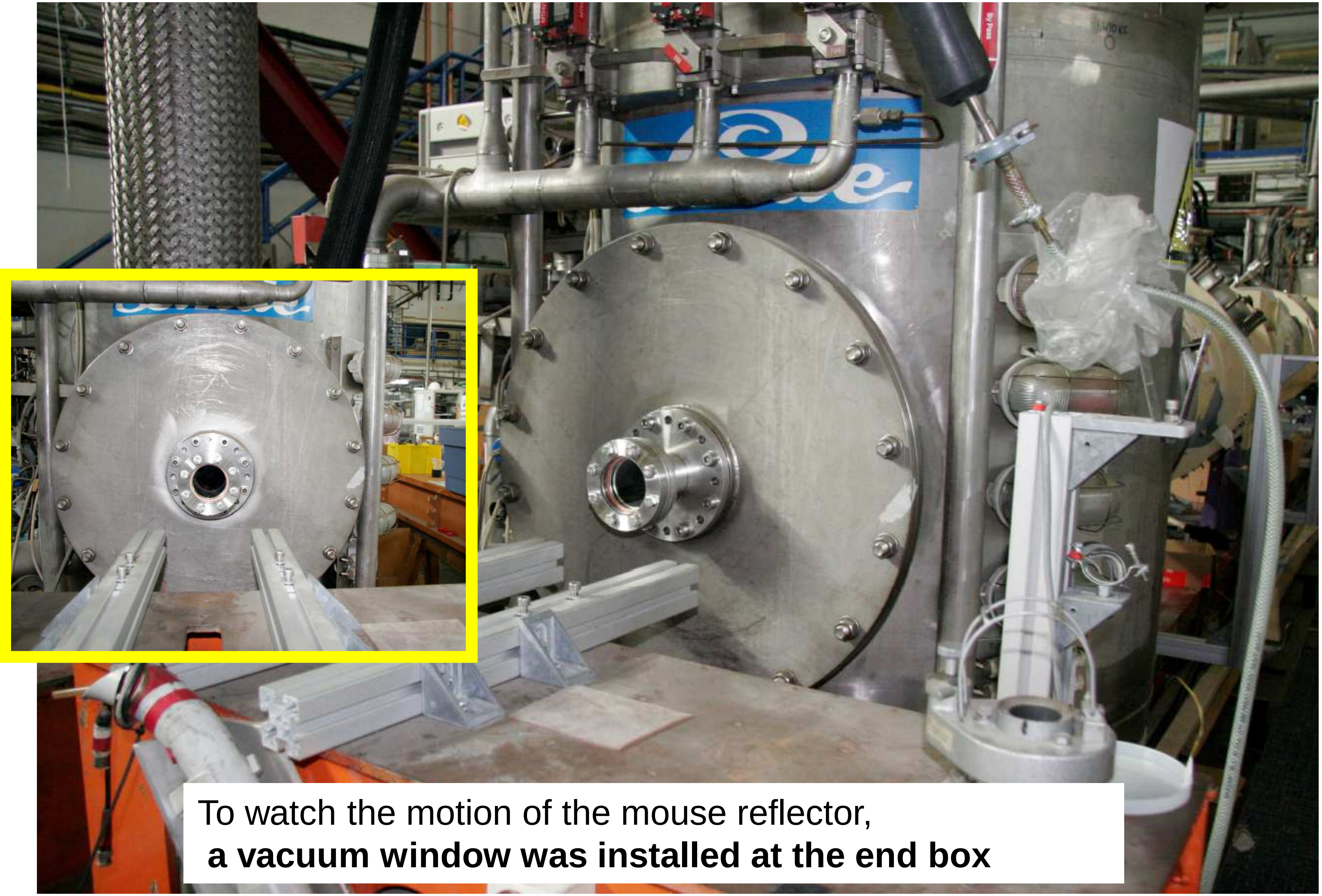
reflector

The reflector is missing in the picture. It is attached to the mouse later



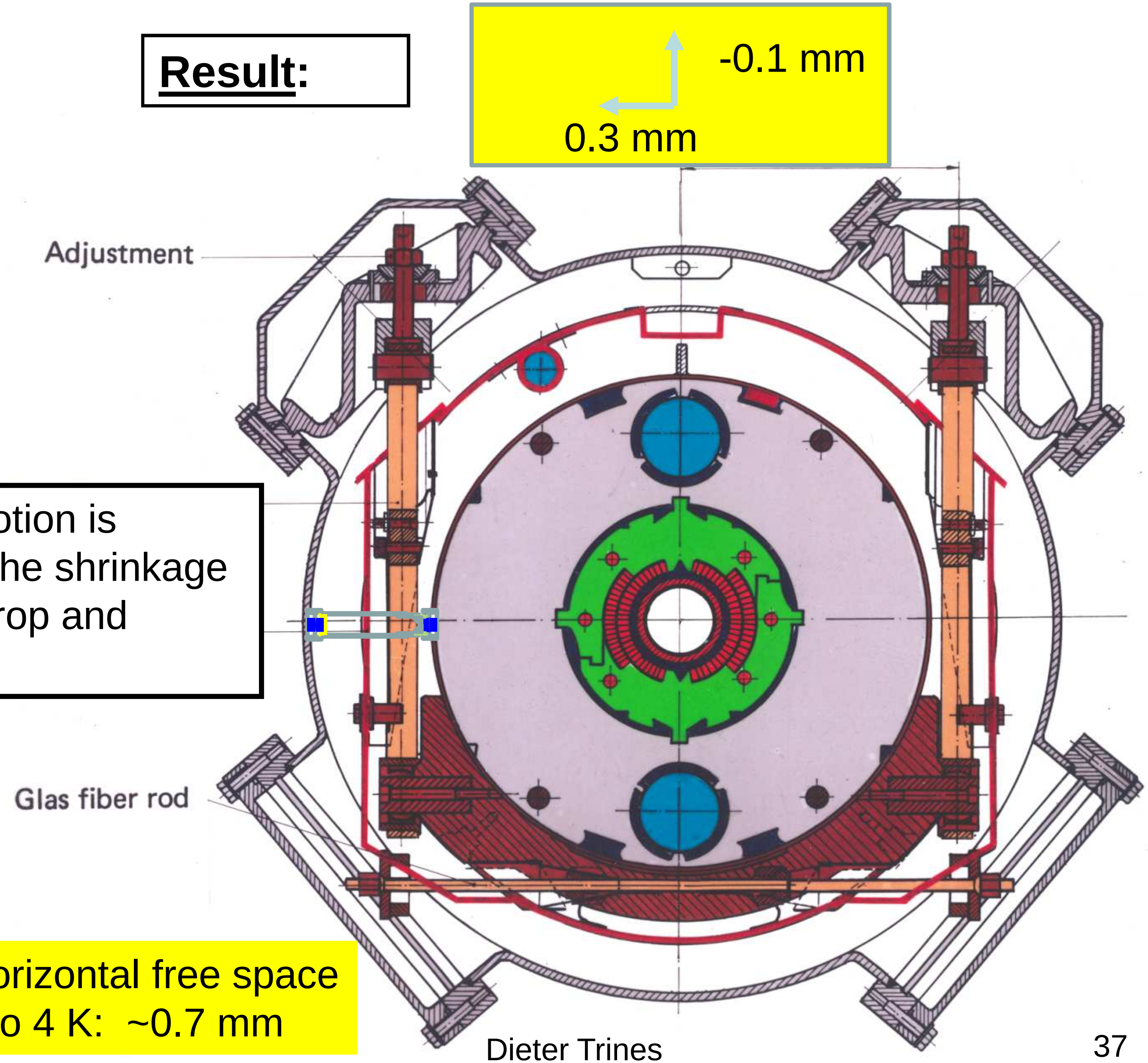


A view into the beam pipe showing the reflection from the mouse
in the middle of the magnet when shining with a flash lamp into the pipe.



To watch the motion of the mouse reflector,
a vacuum window was installed at the end box

Result:



The horizontal motion is expected due to the shrinkage of the pressure prop and the magnet iron

Total reduction of horizontal free space after cool down to 4 K: ~0.7 mm

The additional heat flow via the supports to the shield and the yoke has to be kept within acceptable limits!!

From HERA 1986-08 we have the values for the HERA ring

Heat load at 4K [Watt]		Heat load at 40-80 K[Watt]	
Dipole	Quadrupole	Dipole	Quadrupole
3.7	8.0	21.4	38

The heat load on the **shield** of **100 m HERA** was ~**320 Watt**

For ten dipoles (i.e. 100m) without modification it would be 214 Watt

This allows for additional 10 Watts per dipole on the shield to stay within the HERA heat load budget

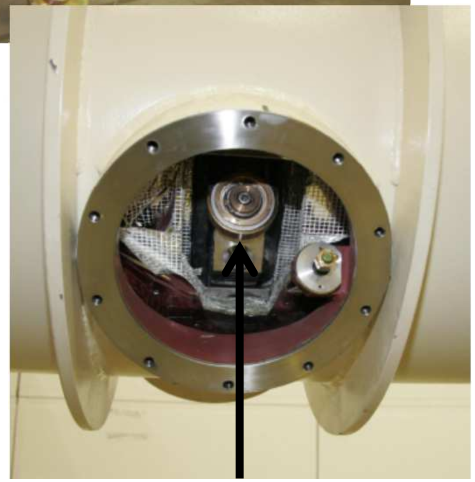
The heat load on **4K** for **100m HERA** was ~ **60 Watt**

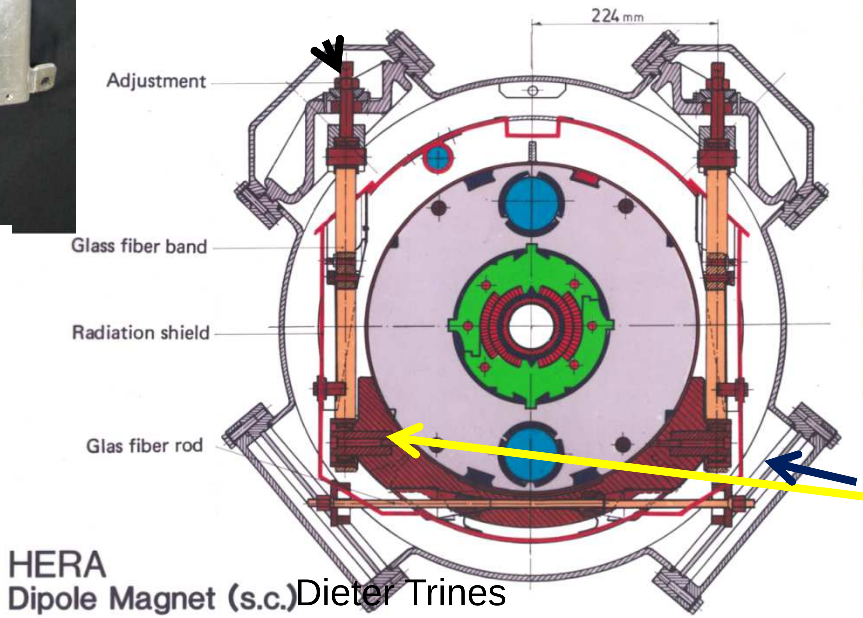
For 10 dipoles (i.e. 100m) without modification it would be 37 Watt

This allows for additional 2.3 Watts per dipole on 4K to stay within the HERA heat load budget or **~0.8 Watts per support**

The original suspensions

Suspension for cold mass and shield





support pivots at the cold mass

$$I^2\ (t) = Ak + Ck * \cos \omega i * t \quad \text{where } Ak = \frac{1}{2}(Imax^2 + Imin^2) \text{ and } Ck = \frac{1}{2}(Imax^2 - Imin^2)$$

resistance of cable connection between magnet string and PS	$3*10^{-3}$	Ohm
Inductance of single magnet	$58*10^{-3}$	Henry
Inductance of ALPS II string	1.16	Henry
Voltage of power supply hall North	20	Volt
Nominal current for ALPS II string	5690	A
Ramp rate of string with 20 Volt power supply	2.6	A/sec
Time constant	387	sec
Inductive voltage per dipole in ramp	0.15	Volt

Inductance of HERA ring	25.85	Henry
nominal current of HERA	5600	A
Resistance of HERA ring	0.039	Ohm
Voltage of HERA in stationary state at 5600 A	218	Volt
Voltage of HERA power supply	-300 to 500	Volt
Time constant	663	sec
operational dI/dt for HERA ramp	15/ -5.6	A/sec
total inductive voltage for HERA ramp	-388/ 145	Volt
Inductive voltage per dipole in ramp	-0.9/ 0.3	Volt
forward voltage threshold of cold diodes	~ 2.5	Volt