The European
X-Ray Laser Project XFEL X-Ray Free-Electron Laser

Review of the European XFEL Linac System

Cold Magnets and Vibrations

H. Brueck

DESY MKS

March 26, 2007

Topics

- Prototype magnets
- Prototype Leads
- Plans for testing at DESY
- Vibration measurements

Involved people so far are:

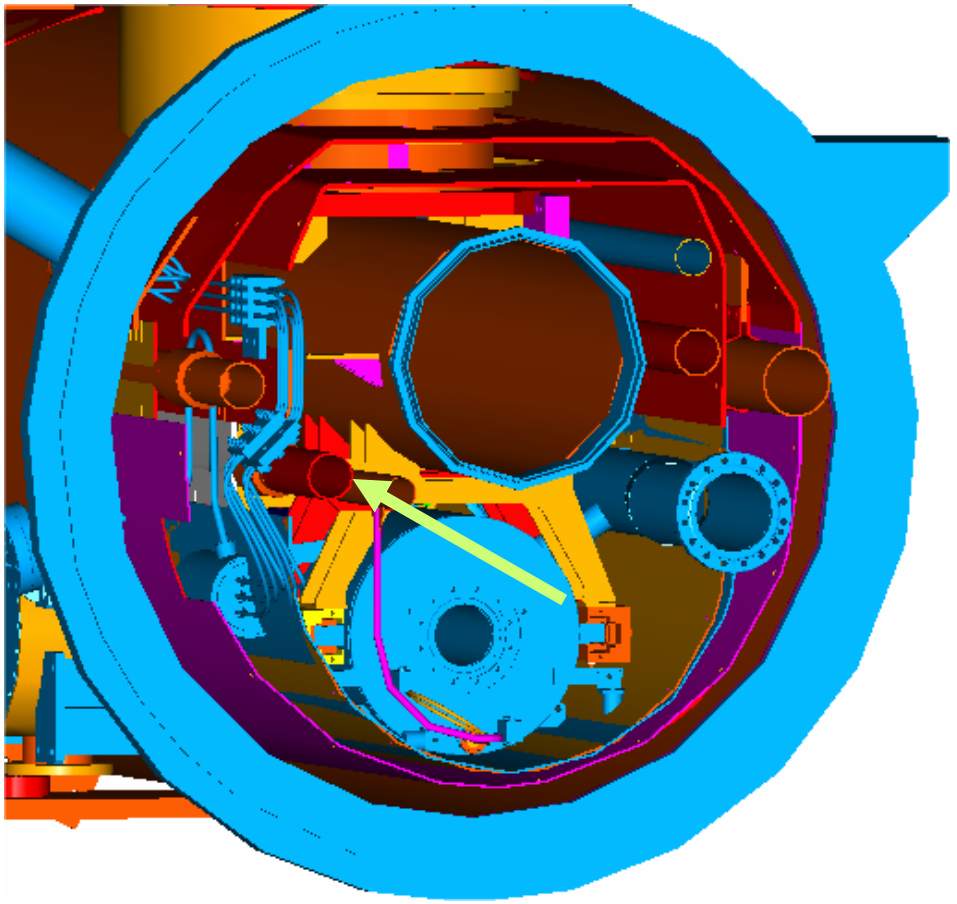
F. Toral, P. Abramian,J. Calero, L. García-Tabarés, J.L. Gutierrez,
E. Rodriguez, I. Rodríguez, S. Sanz, C. Vazquez, CIEMAT-CEDEX, Spain
J. Lucas, Elytt-Energy, Madrid, Spain

A. Ballarino, P. Denis, CERN

R. Bandelmann, Y. Bozhko, A. Zolotov, M. Stolper, J. Fischer, W. Shi, W. Maschmann,
H. Brueck, DESY MKS
N. Mildner, DESY MVP

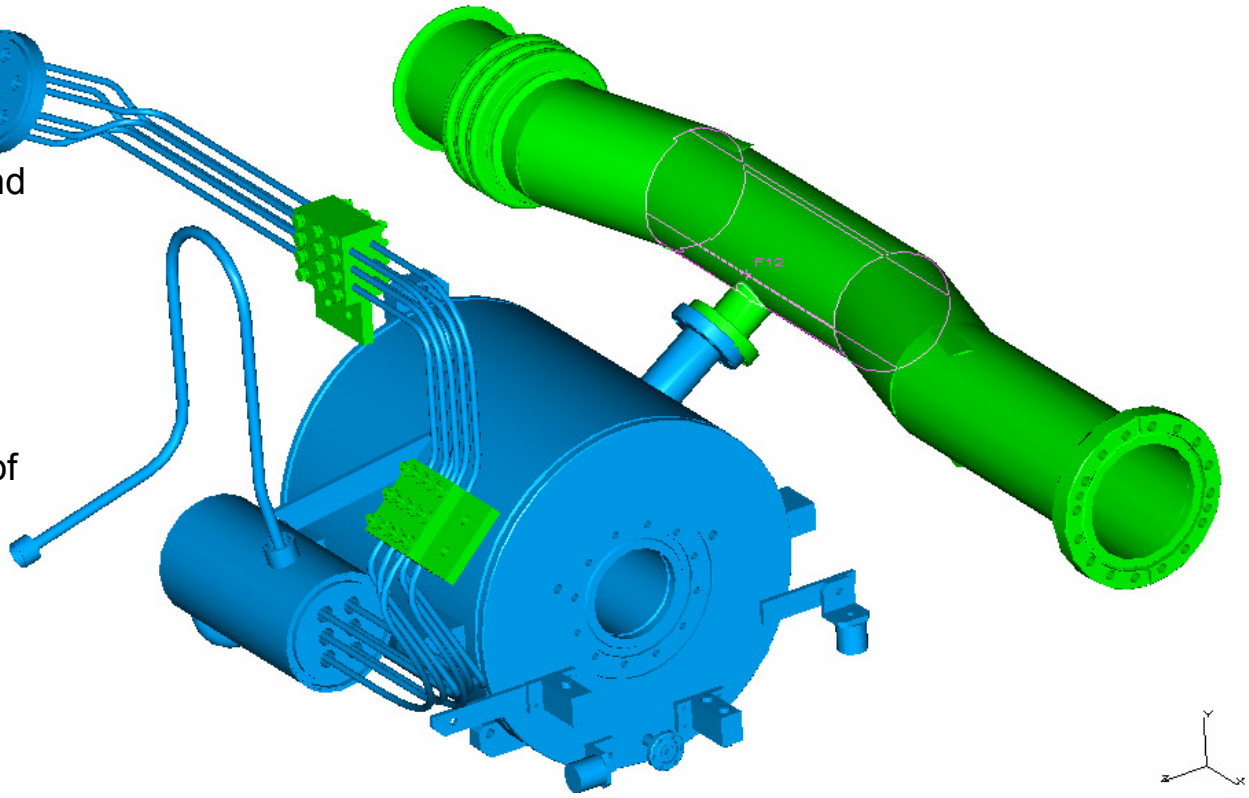
XFEL Magnet and Lead Design

- Magnet at beam exit side
- BPM (not shown) flanged to magnet
- Magnet supported like cavities, connected to invar rod
  - Moves by about 3 cm when cooled down



Present XFEL Design

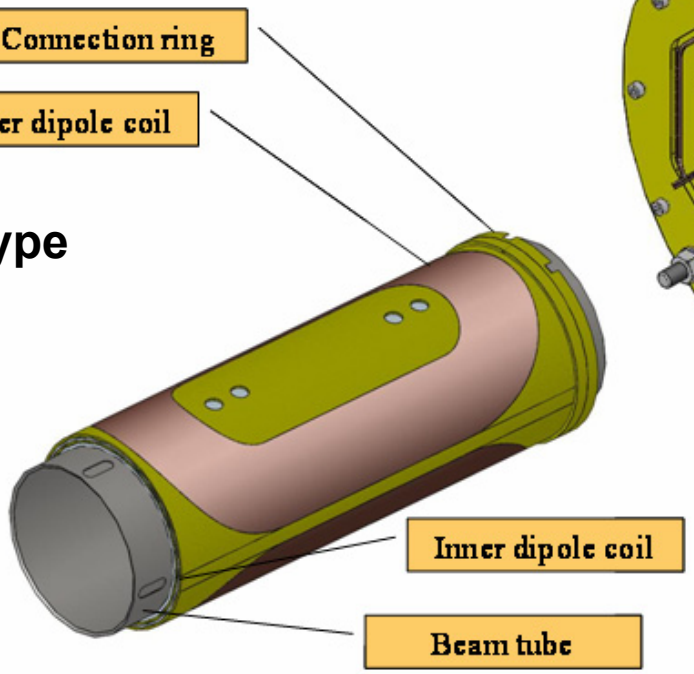
- Prototype Magnet and Lead assembly at DESY
- Stainless steel vessel
- Copper coated beam pipe
- Flange only to 2K He tube and to warm-up tube
- Conduction cooled current leads for 50A with two heat sinks at 4-8K and 40-80K
- CERN type
- No gas flow
- Heat loads at 50A (for each of the six leads)
  - 2.56 W/lead at 70 K,
  - 0.54 W/lead at 4.5 K,
  - 0.04 W/leads at 1.9 K
- At zero current load at 1.9 K will vary from 0.02 to 0.035 depending on the length



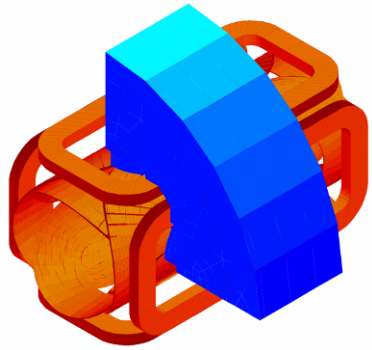
Magnet Package

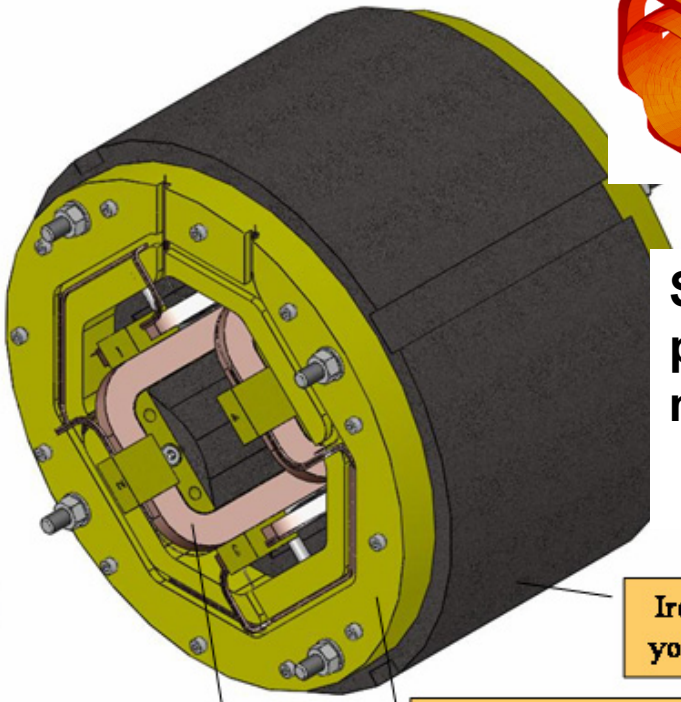
Three nested magnets

“cosΘ” type dipoles



“super ferric” quadrupole





Solid yoke for prototype magnets

MINISTERIO DE EDUCACIÓN Y CIENCIA
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Quadrupole Parameter

Iron yoke inner diameter	[mm]	94.4
Iron yoke outer diameter	[mm]	270
Nominal current	[A]	50
Nominal gradient	[T/m]	35
Magnetic length	[mm]	169.6
Number of turns		646 (34x19)
Wire diameter (bare/insulated)	[mm]	0.4/0.438
Copper to superconductor ratio		1.35
RRR		>70
Filament diameter	[micron]	35
Twist pitch	[mm]	50
Iron yoke length	[mm]	145
Coil length	[mm]	200.6
Stored magnetic energy at 50A	[J]	1462
Self inductance	[H]	1.17
Integrated gradient at 50A	[T]	5.976
Integrated b6 at 50A	10^{-4} × b2 at 30mm	-1.87
Integrated b10 at 50A	10^{-4} × b2 at 30mm	2.75
Coil peak field	[T]	2.48

Roxie and Ansys calculations

Quench model calculations show:

T_{max}~70K

U_{max}~70V

Working point on load line at 4.2K	[%]	40
Working point on load line at 2K	[%]	27
Saturation at 50 A (integrated)	[%]	~4

Dipole Parameter

Inner diameter	[mm]	83.6	88.5
Nominal current	[A]	50	50
Nominal field	[T]	0.04	0.04
Magnetic length	[mm]	203.7	205
Number of turns		36	37
Wire diameter (bare/insulated)	[mm]	0.7/1.03	0.7/1.03
Copper to superconductor ratio		1.8	1.8
RRR		>100	>100
Filament diameter	[micron]	<20	<20
Twist pitch	[mm]	25	25
Iron yoke length	[mm]	145	145
Coil length	[mm]	230	230
Self inductance	[mH]	0.96	1.07
Integrated field at 50A	[Tm]	0.00815	0.00820
Working point on load line at 4.2K	[%]	11.1	11.3
Working point on load line at 2K	[%]	7.9	7.9
Saturation at 50 A (integrated)	[%]	9	10

Roxie and Ansys calculations

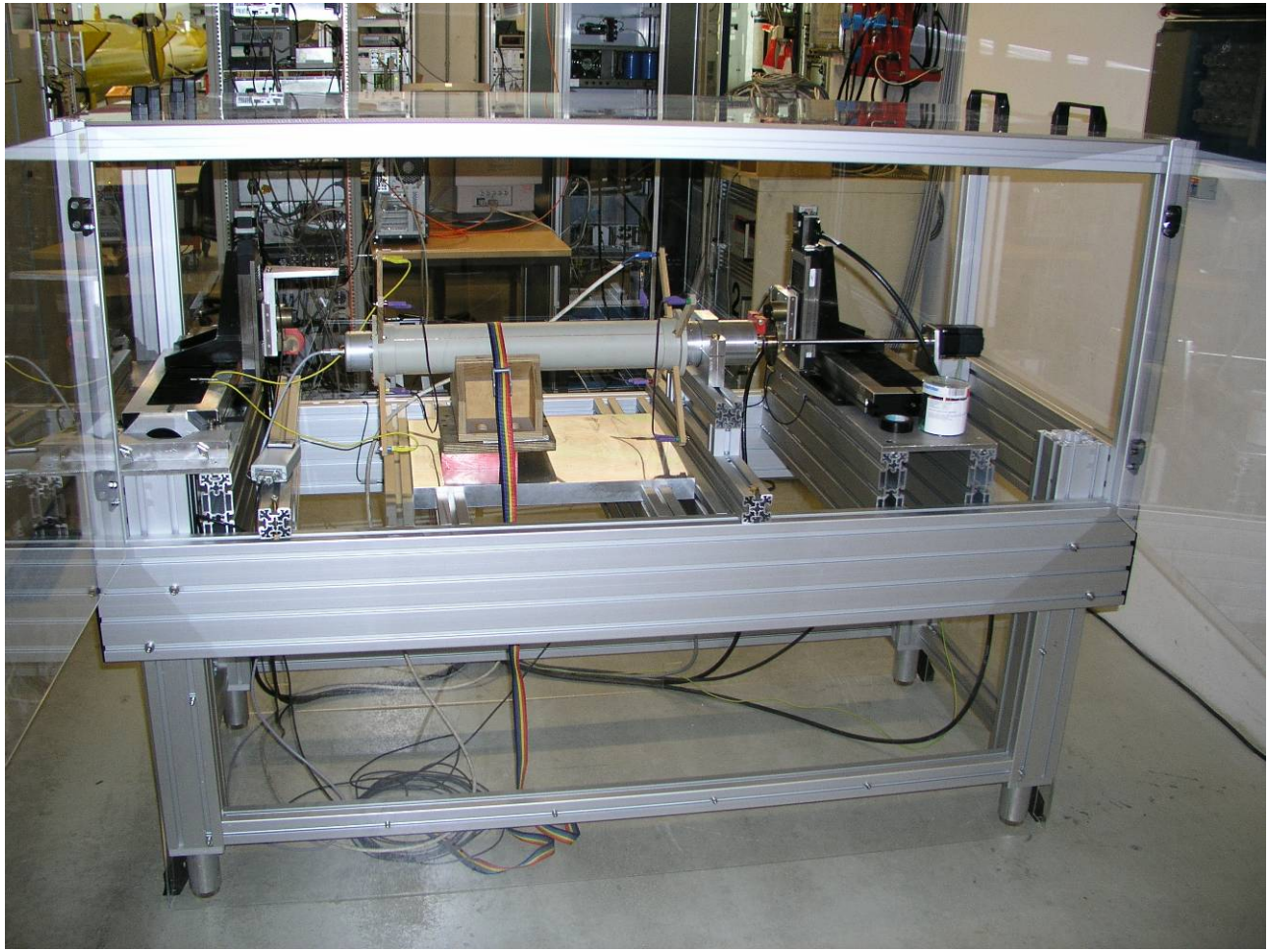
- The Working point is rather low! (left over HERA cable)
  - large persistent current effects may show up
  - Proposal is to increase copper to superconductor ratio for next magnets

With Quad at 50A

Prototype Magnets

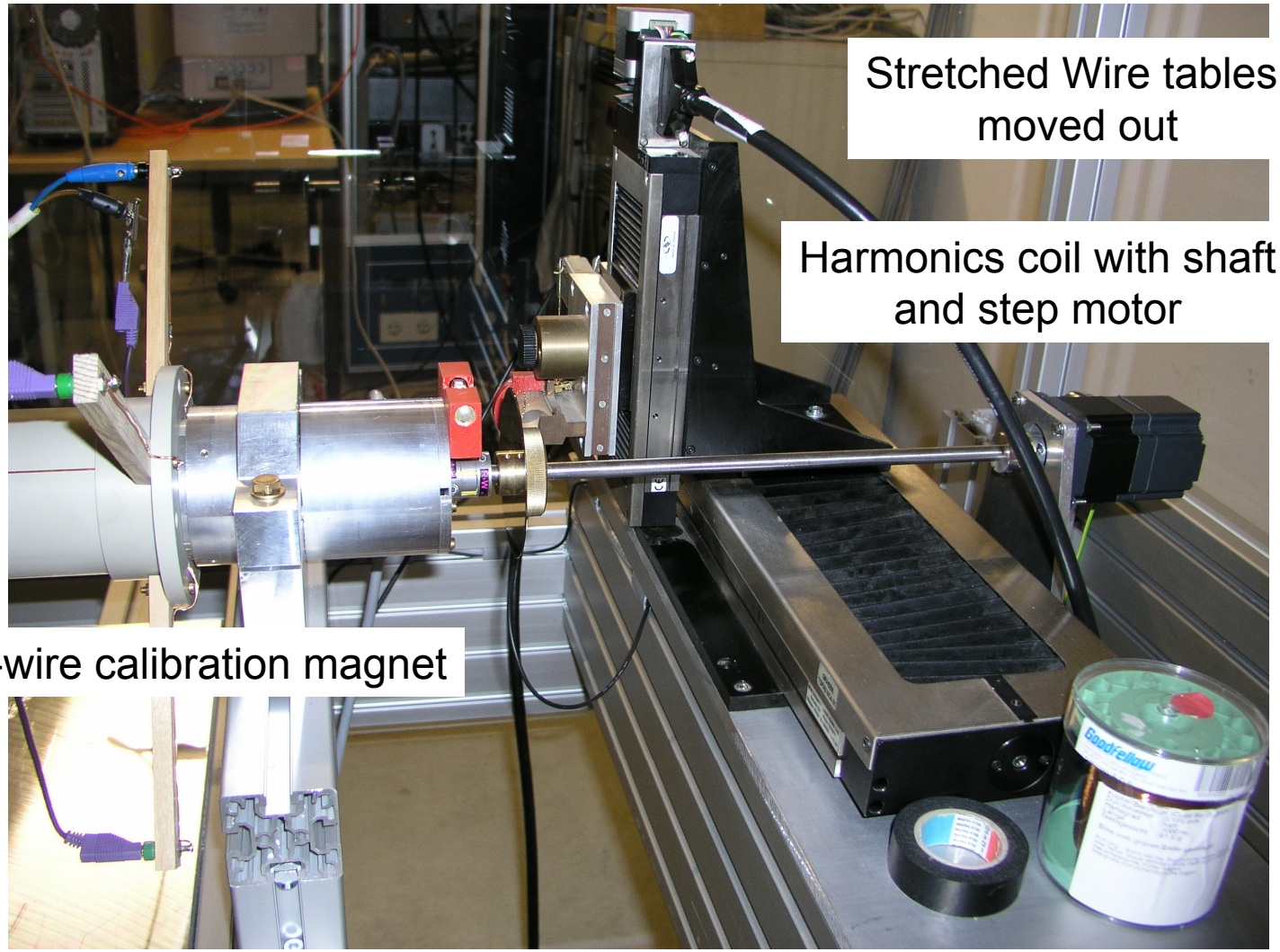
- Production of 4 magnets with He-vessels in collaboration with CIEMAT, Spain
- First magnet arrived end of December
  - Since then setup of measurement equipment and first warm measurements
  - Now waiting for a time slot in Hall 3 for cold tests in a vertical bath cryostat
  - Hope to finish early April

XFEL Warm Measurement Setup

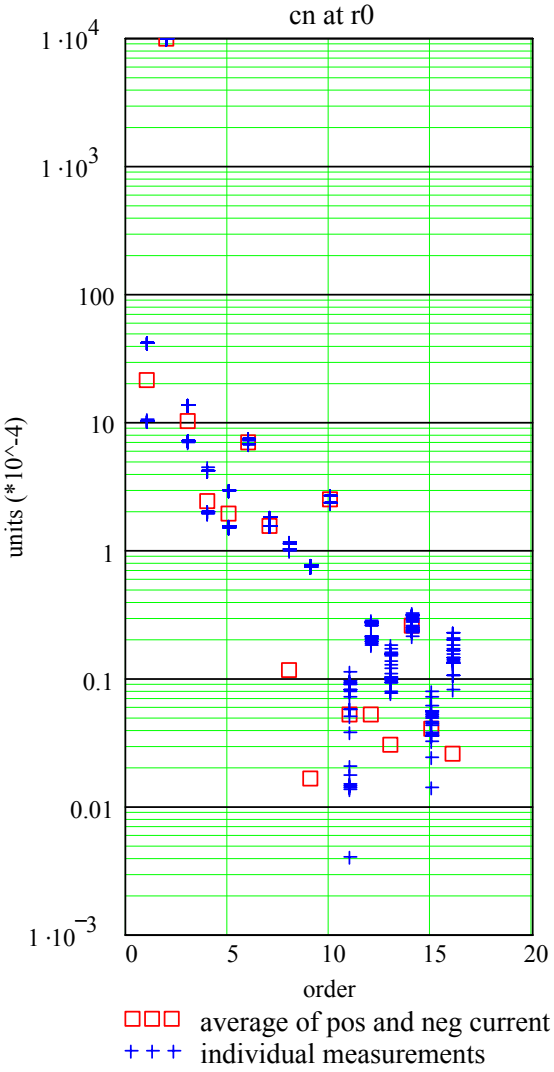


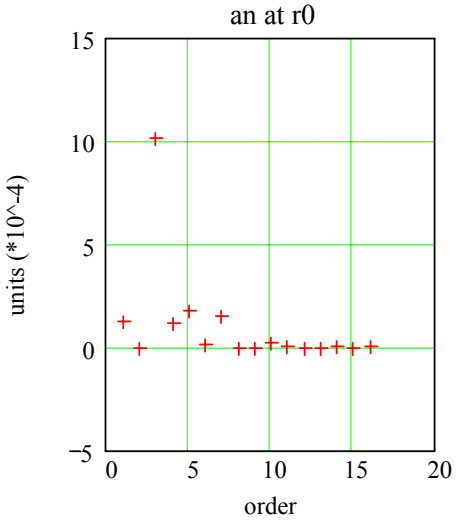
- Setup for
  - Rotating Coil
  - Stretched Wire
- Closed hermetically by windows
- “4-wire” calibration magnet mounted to check harmonics coil

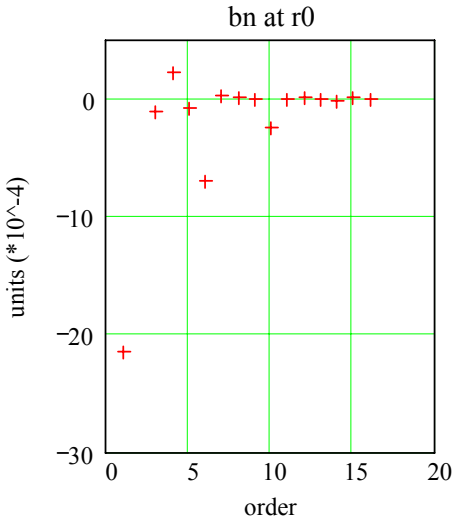
XFEL Warm Measurement Setup



DC, Final Quad ±0.17A, earth file elimination







k =	a_{f_k} =	b_{f_k} =	c_{f_k} =
1	1.21	-21.46	21.49
2	0	10000	10000
3	10.12	-1.06	10.18
4	1.16	2.15	2.44
5	1.73	-0.82	1.91
6	0.15	-6.99	6.99
7	1.53	0.2	1.54
8	-0.02	0.11	0.11
9	-0.01	-0.01	0.02
10	0.24	-2.49	2.5
11	0.05	0.02	0.05
12	-0.04	0.03	0.05
13	-0.02	0.02	0.03
14	0.02	-0.26	0.26
15	-0.01	0.04	0.04
16	0.01	0.02	0.03

[A]

$curr_{m_i}$ =

0.17
0.17

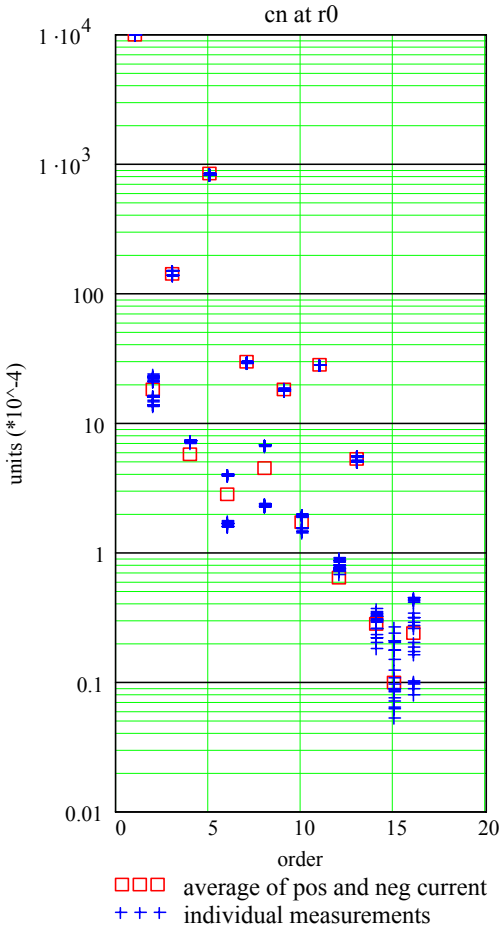
$$\frac{cmm_{IR}}{10} = 3.612 \quad \text{mTm/A}$$

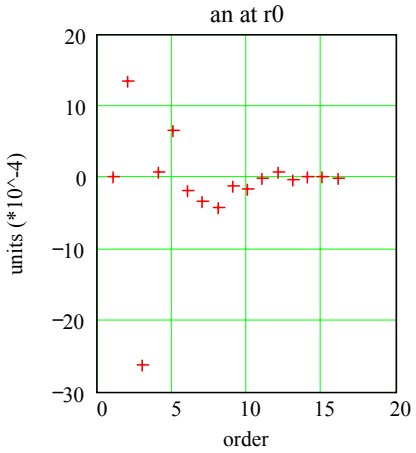
$$\frac{cmm_{IR}}{r0 \cdot 10} = 120.392 \quad \text{mT/A}$$

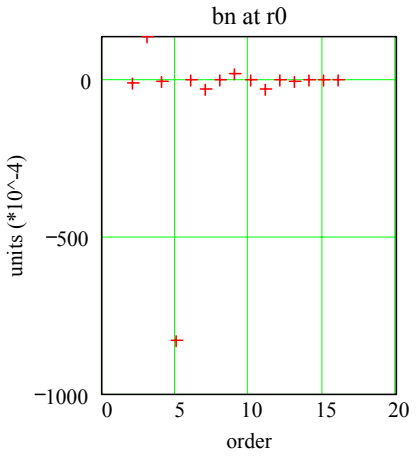
fn1 = "HA0_07032007_0948.res"

fn2 = "HA0_07032007_0954.res"

DC Final, Inner Dipole ±2A , earth file elimination







k	a_{f_k}	b_{f_k}	c_{f_k}
1	0	10000	10000
2	13.51	-11.85	17.97
3	-26.32	139.99	142.45
4	0.82	-5.65	5.71
5	6.63	-828.2	828.23
6	-1.82	2.12	2.79
7	-3.35	-28.97	29.16
8	-4.19	1.5	4.45
9	-1.22	17.76	17.8
10	-1.64	0.38	1.69
11	-0.1	-27.82	27.82
12	0.64	-0	0.64
13	-0.42	-5.25	5.27
14	0.06	0.27	0.28
15	0.08	0.06	0.1
16	-0.08	0.22	0.24

[A]

$curr_{m_i}$ =

1.998
1.998

$$\frac{cmm_{IR}}{10} = 0.156 \quad \text{mTm/A}$$

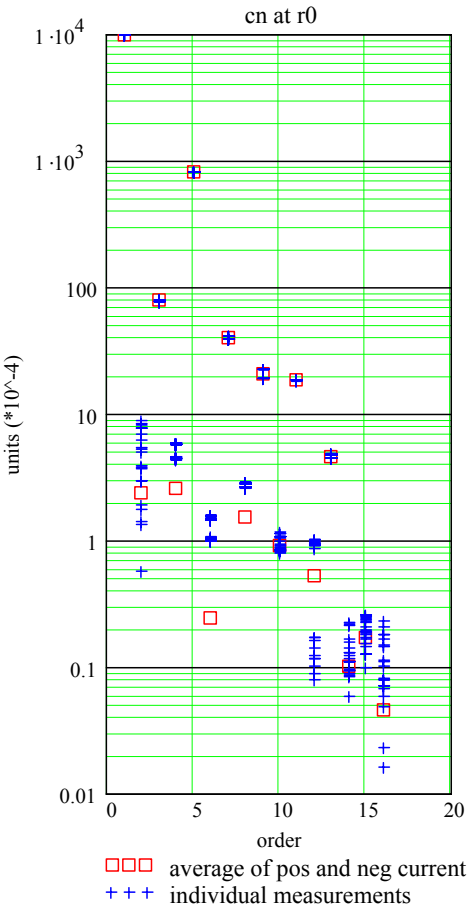
$$\frac{cmm_{IR}}{r0 \cdot 10} = 5.2 \quad \text{mT/A}$$

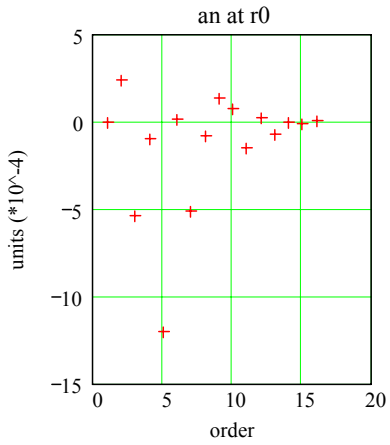
fn1 = "HA0_07032007_0915.res"

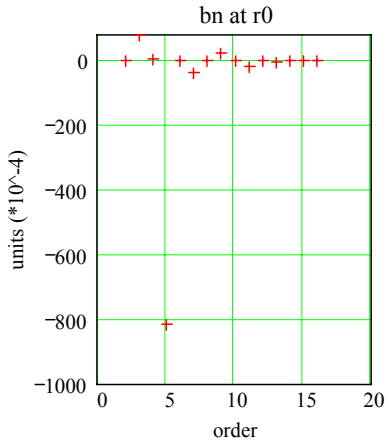
fn2 = "HA0_07032007_0923.res"

About 1/769 of quad at 30mm, ilf both at same current

DC Final, Outer Dipole ±2A , earth file elimination







k	a_{f_k}	b_{f_k}	c_{f_k}
1	0	10000	10000
2	2.35	-0.22	2.36
3	-5.37	78.17	78.35
4	-0.96	2.38	2.57
5	-12.05	-813.86	813.94
6	0.15	-0.19	0.24
7	-5.15	-39.53	39.87
8	-0.79	-1.29	1.51
9	1.31	20.68	20.72
10	0.75	0.49	0.9
11	-1.49	-18.28	18.34
12	0.21	0.48	0.52
13	-0.72	-4.56	4.61
14	-0.06	-0.08	0.1
15	-0.16	-0.05	0.17
16	0.03	0.04	0.05

[A]

$curr_{m_i}$ =

1.998
1.998

$$\frac{c_{mm_{IR}}}{10} = 0.157 \quad \text{mTm/A}$$

$$\frac{c_{mm_{IR}}}{r0 \cdot 10} = 5.232 \quad \text{mT/A}$$

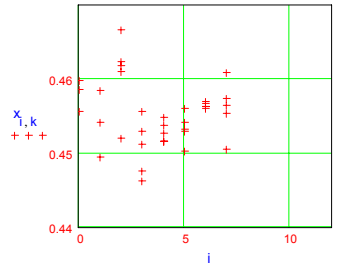
fn1 = "HA0_07032007_0858.res"

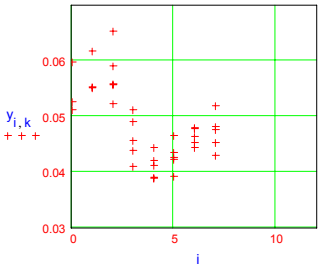
fn2 = "HA0_07032007_0905.res"

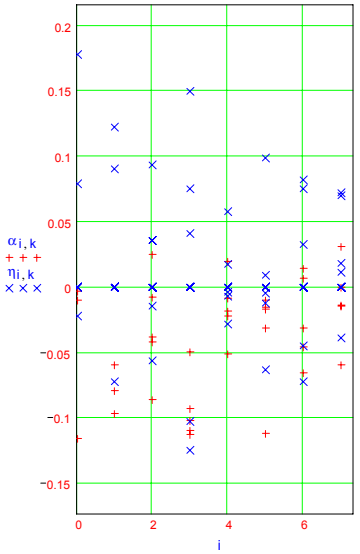
Alignment and Mounting of BPM

- Axis and angle measurement with “stretched wire system” (info) at room temperature with small current
- DC signals not big enough, switched to AC, about 5Hz
- Required accuracy
  - 0.3 mm for axis offset
  - 3 mrad for roll angle
- Reference of magnetic centre and angle w. r. t. mechanical centre (left/right) using reference plates fixed by dowel pins
- Connection to the BPM
  - Using same reference plate for referencing on a milling machine
  - Drilling of dowel pin holes for exact mounting of the BPM
  - This allows arbitrary pairs of Quads and BPMs

Axis and Angle (x, y, α, η) Measurements using AC SW







xa_i	xs_i	ya_i	ys_i	αa_i	αs_i	ηa_i	ηs_i
0.458	0.002	0.055	0.004	-0.043	0.051	0.078	0.082
0.454	0.004	0.057	0.003	-0.078	0.015	0.047	0.085
0.461	0.005	0.058	0.004	-0.030	0.037	0.019	0.051
0.451	0.003	0.046	0.004	-0.093	0.023	0.008	0.105
0.453	0.001	0.041	0.002	-0.016	0.023	0.007	0.029
0.453	0.002	0.043	0.002	-0.037	0.038	0.005	0.053
0.456	0.000	0.046	0.001	-0.024	0.030	0.014	0.063
0.456	0.003	0.047	0.003	-0.011	0.029	0.026	0.041

$\text{mean}(xa) = 0.455$ $\text{mean}(ya) = 0.049$ $\text{mean}(\alpha a) = -0.042$ $\text{mean}(\eta a) = 0.026$

$\text{stdev}(xa) = 0.003$ $\text{stdev}(ya) = 0.006$ $\text{stdev}(\alpha a) = 0.028$ $\text{stdev}(\eta a) = 0.024$

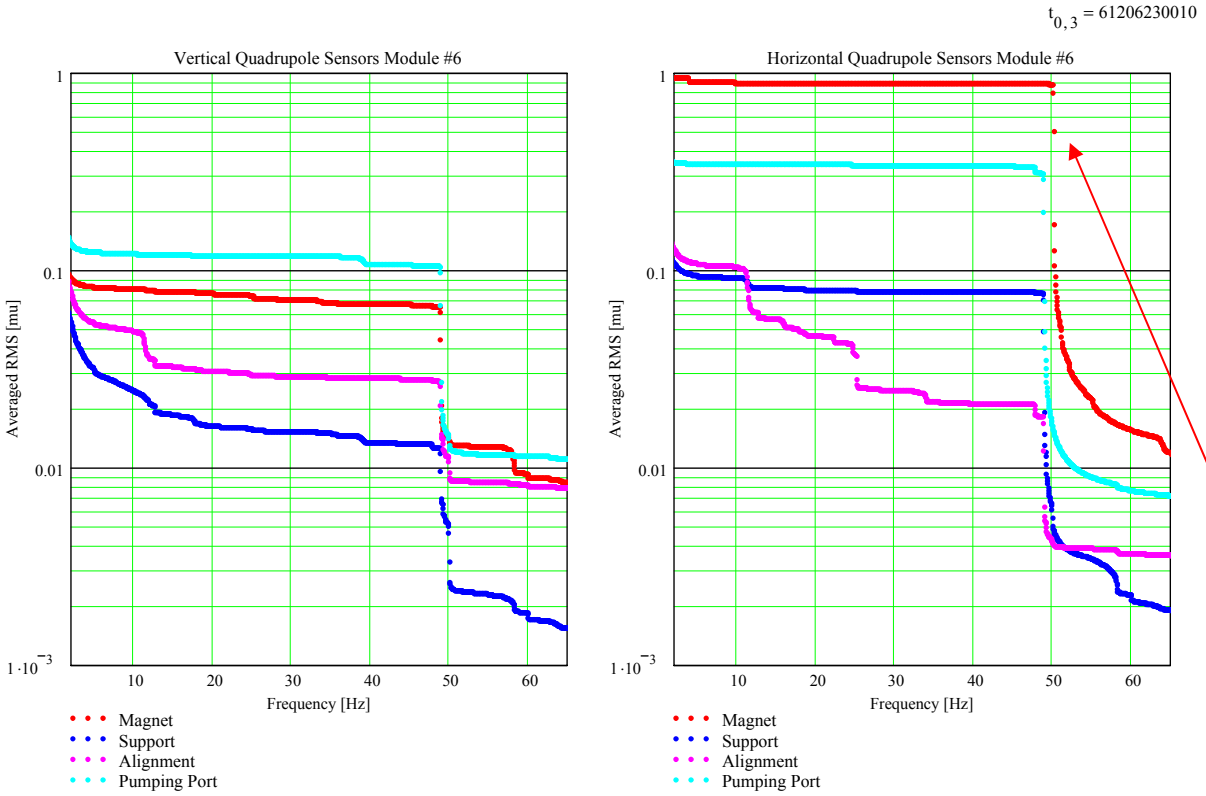
- Stretched Wire system
- 0.1A AC current in Magnet
- Reproducibility good
  - x ~ .003 mm
  - y ~ .006 mm
  - α ~ .03 mrad
  - η ~ .03 mrad
- Averages themselves not useful, tables were not finally aligned

Cold Magnet Tests in H55

- Tests at 2K in horizontal cryostat of each magnet together with the lead assembly in H55, ready early next year
- Operation test
  - Quench safety
  - Measure transfer functions, saturation, cold harmonics…
- Special tests with a subset only (~10% of magnets)
  - Persistent current effects
  - Axis and angle stability tests, during excitation, effect of nested coils
- Using
  - Harmonic coil (to be ordered)
  - Stretched Wire
- Cold leak rates

Vibration Measurements Module 6 CMTB

cold 06.12.06 23:00-01:00

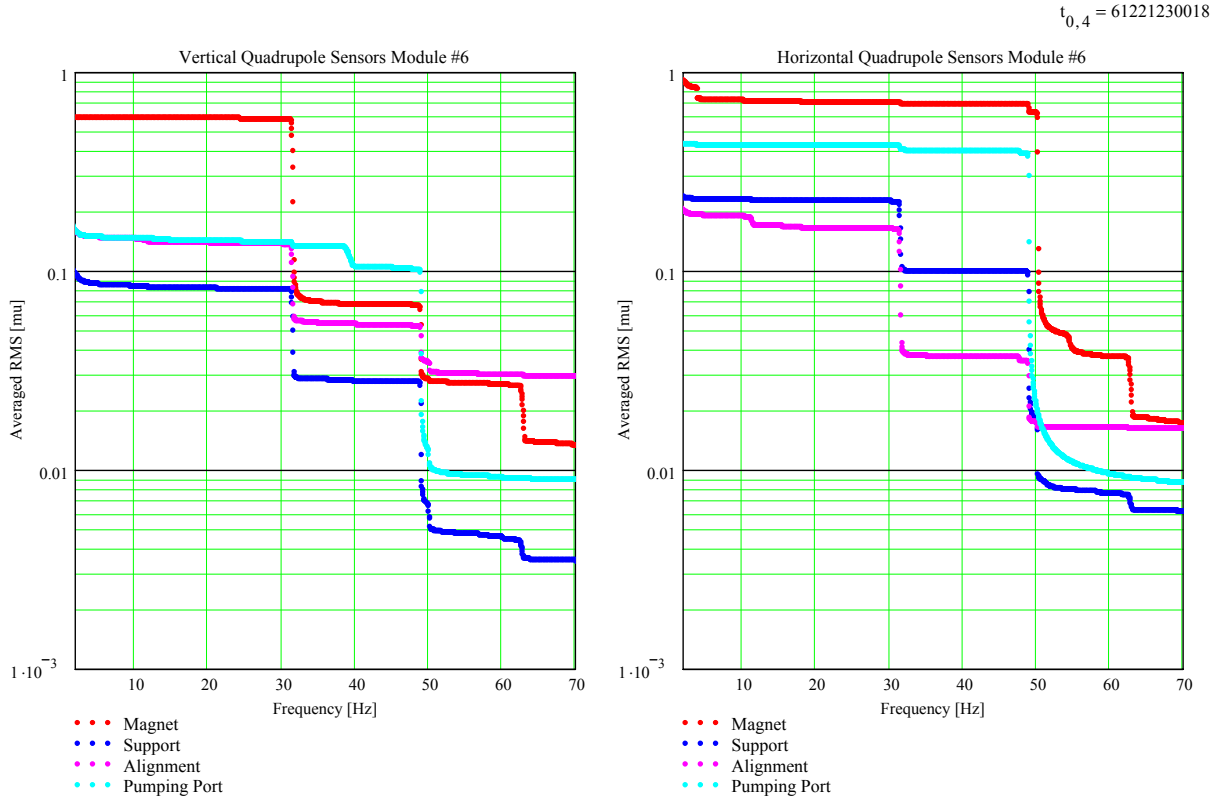


- Sensor at support shows lowest RMS_{2Hz} of 52 nm and 107 nm
- Sensors at pumping port show very large horizontal values (RMS_{2Hz}=352 nm)
- Magnet
  - Multiplied by 3 because of cold sensitivity loss
  - horizontal sensor shows probably wrong signal, step at 50Hz indicates noise
- Vertical, no significant steps during this time interval, step only at about 48 Hz
- RMS_{2Hz}=95 nm

Need re-measurement at next module

Vibration Measurements Module 6 CMTB

cold 21.12.06 23:00-01:00

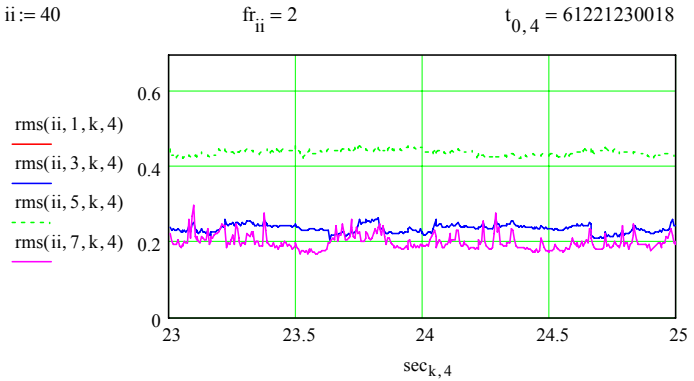


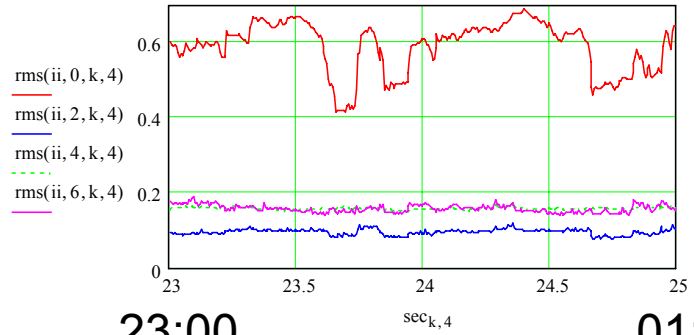
- Large steps at 31.7 Hz in all signals
- Not seen on 6.12.06!

Need re-measurement at next module

Effects vs Time (23:00-01:00, no average)

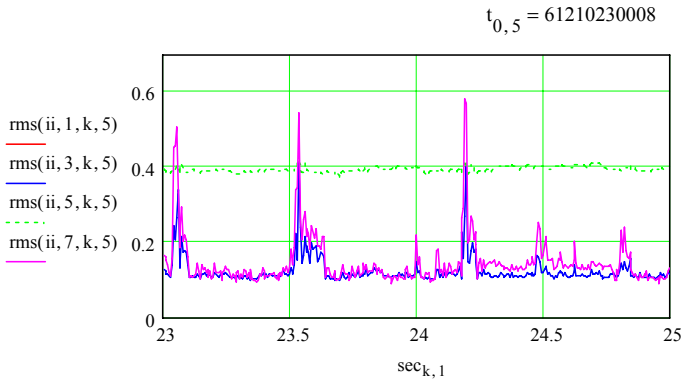
21.12.06 23:00-01:00

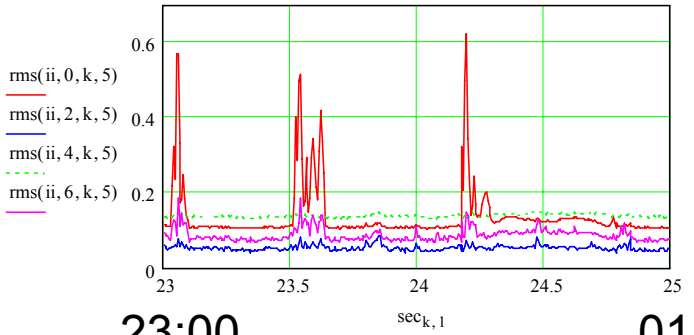




23:00 01:00

10.12.06 23:00-01:00





23:00 01:00

horizontal

vertical

- **Sometime large effects occur, peaks of RMS_{2Hz} of about 600 nm**
- **Due to peak at**
  - **31.5Hz on 10.12**
  - **26Hz on 21.12**

Quad
Lower support
Pumping port
Survey platform

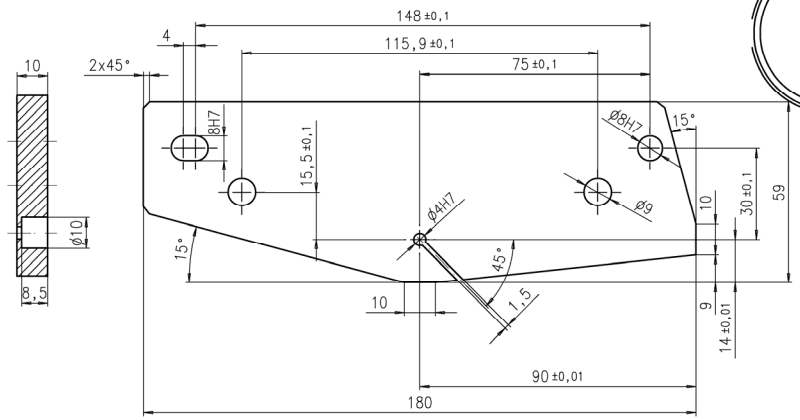
Vibration Measurements M6 CMTB Summary

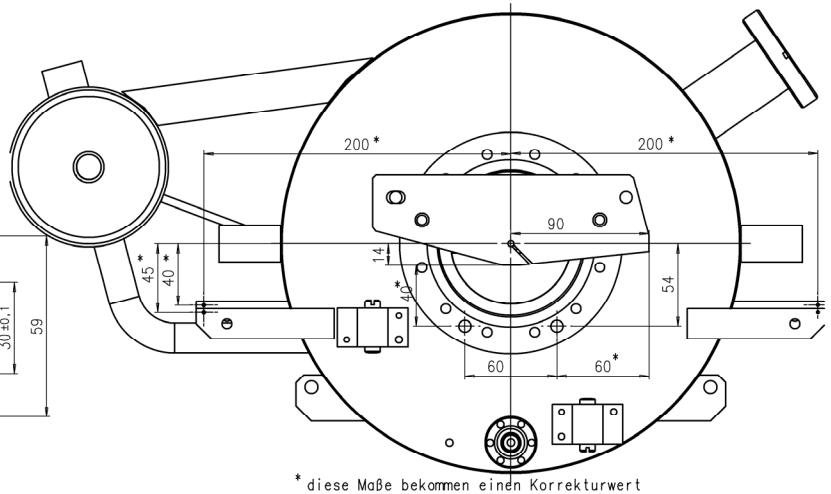
- Floor motion larger as at FLASH
- Signals at pumping port rather large especially the horizontal signal (RMS_{2Hz} up to 350nm)
- Warm Quad motion larger as at TTF
- Horizontal quad sensor probably gives wrong results when module cold
- Cold vertical quad motion depends strongly on conditions in the CMTB
  - RMS_{2Hz} often only about 95nm
  - Under certain conditions sometimes large motions (RMS_{2Hz} factor 6 larger up to 600nm)
- Need more measurements on module 7
- Need more investigations to find correlation to environment conditions

End

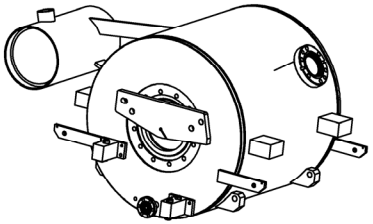
Reference Plates

Referenzplatte 1
(Strahlaustrittseite)

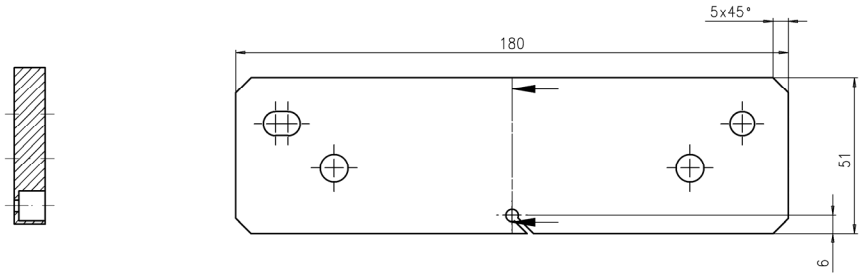




* diese Maße bekommen einen Korrekturwert

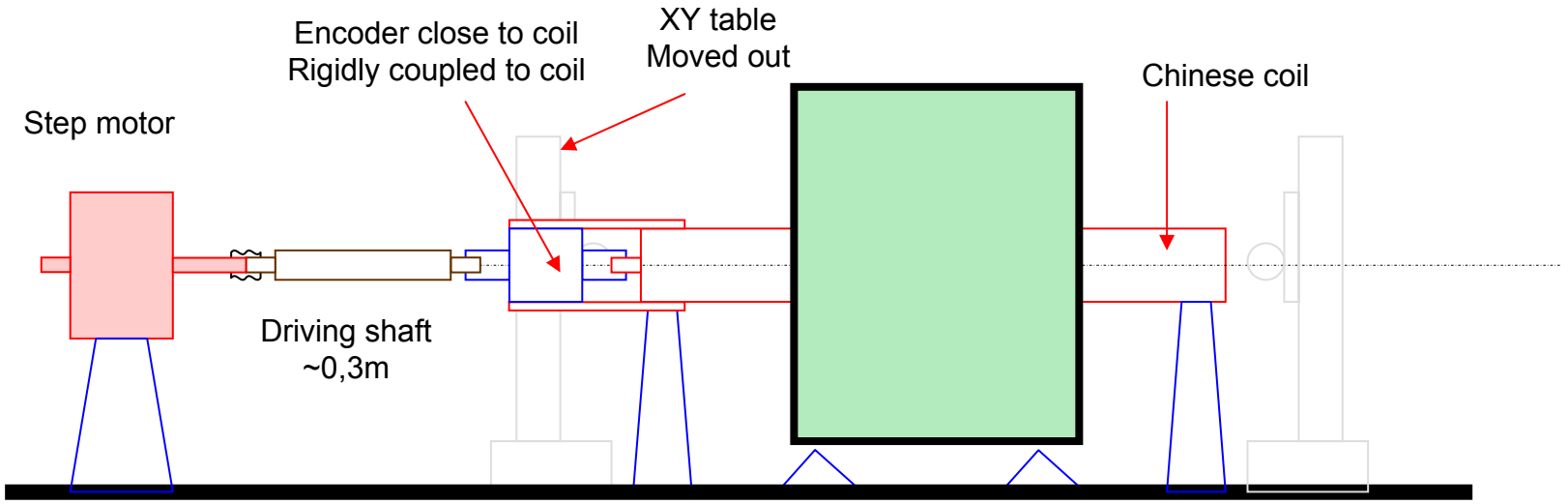


Referenzplatte 1
(Strahleintrittseite)



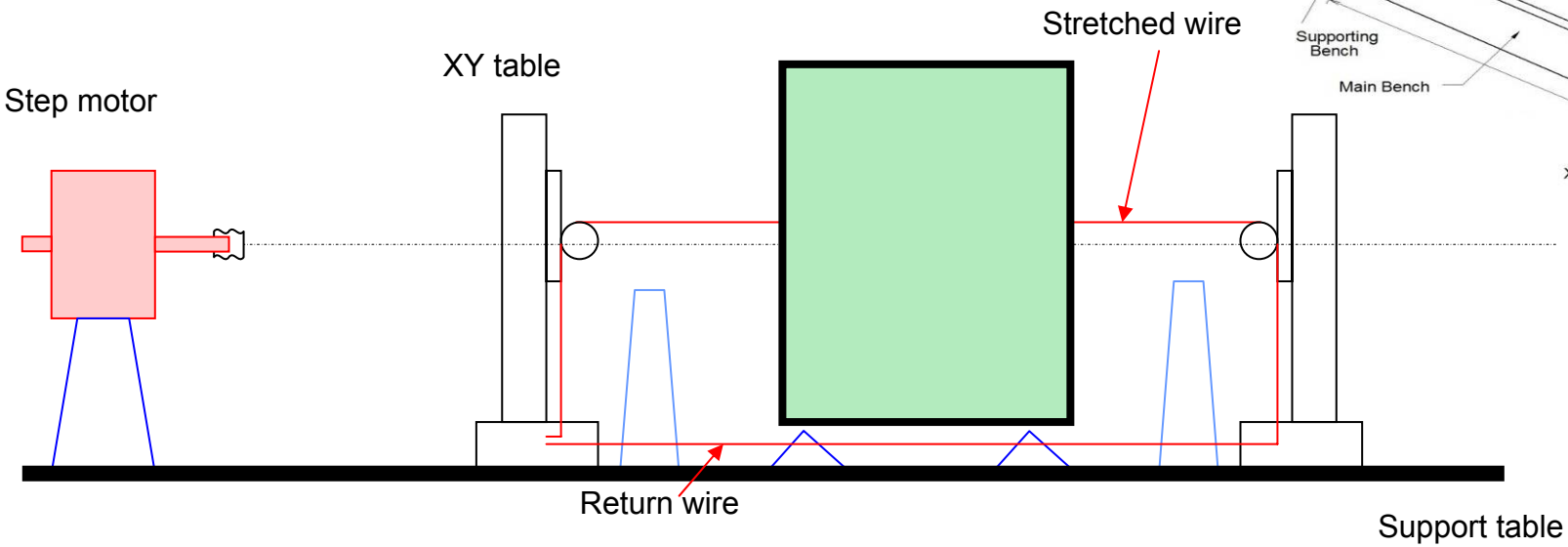
fehlende Maße und Toleranzen
wie Referenzplatte 1

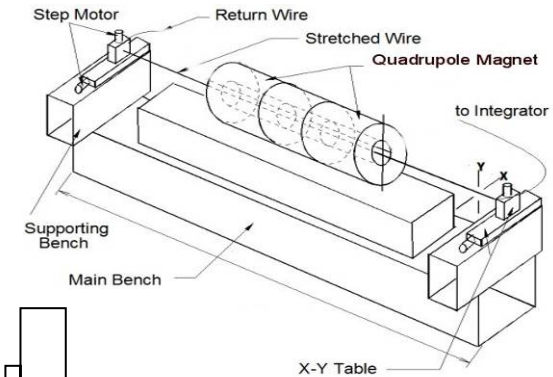
Warm AC Harmonics



- Coil and motor support fine tunable
- No magnetic material in SW tables

Warm AC Stretched Wire

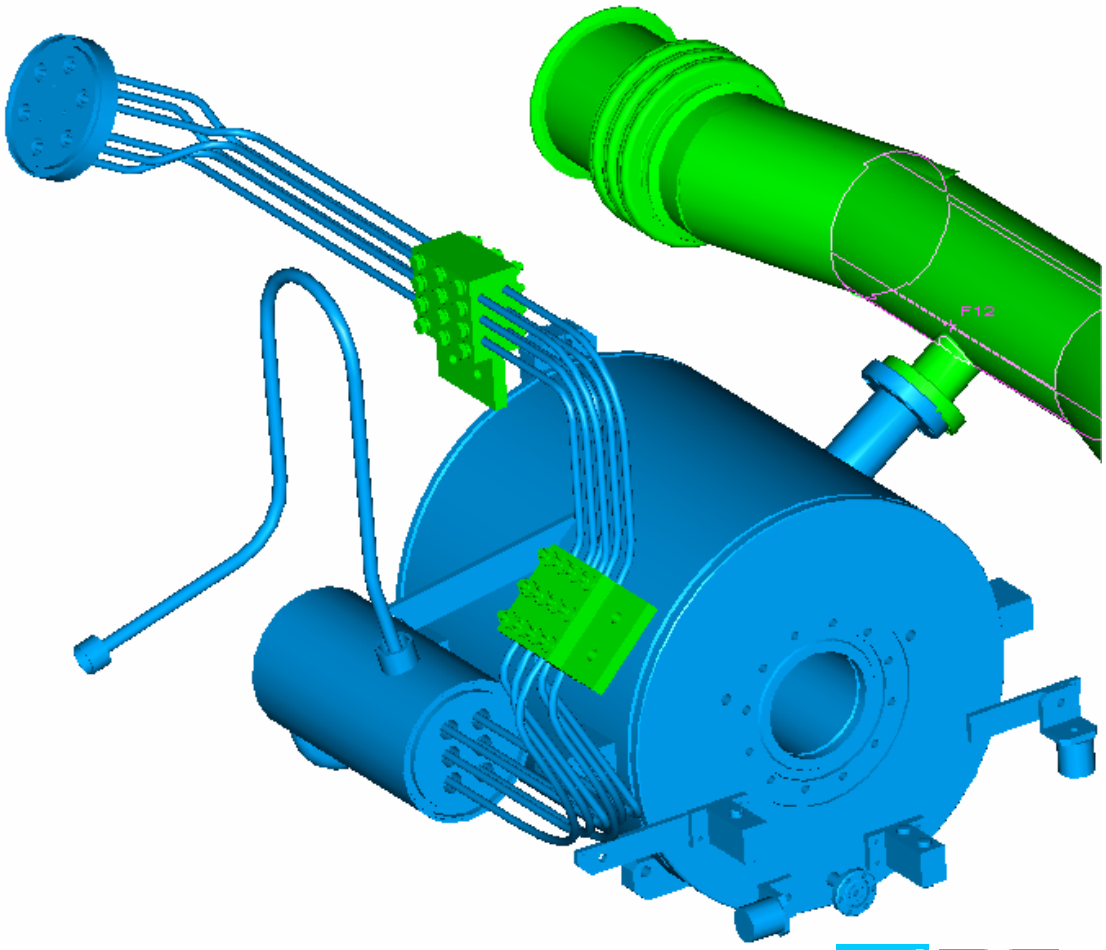




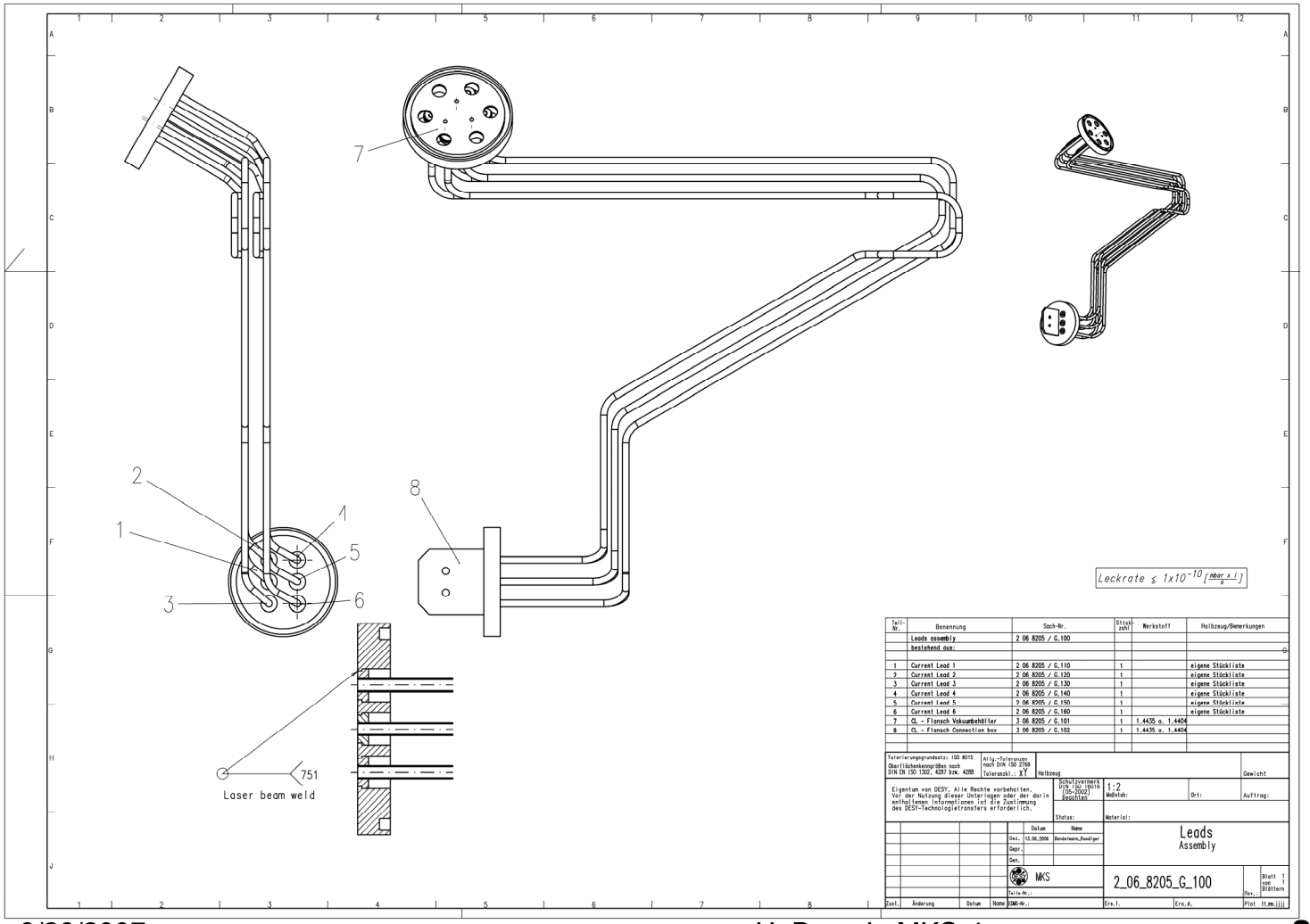
- Rigid support table
- Moving table accuracy:
  - ~5µm for 100mm move from reference point
  - x: ~1.5 µm, y: ~3.5 µm hysteresis
  - ~50-100 µrad angle stability during move
- Reproducibility for stretched wire measurements about 10 µm for x and y and about 10 µrad for the angle

Current Leads

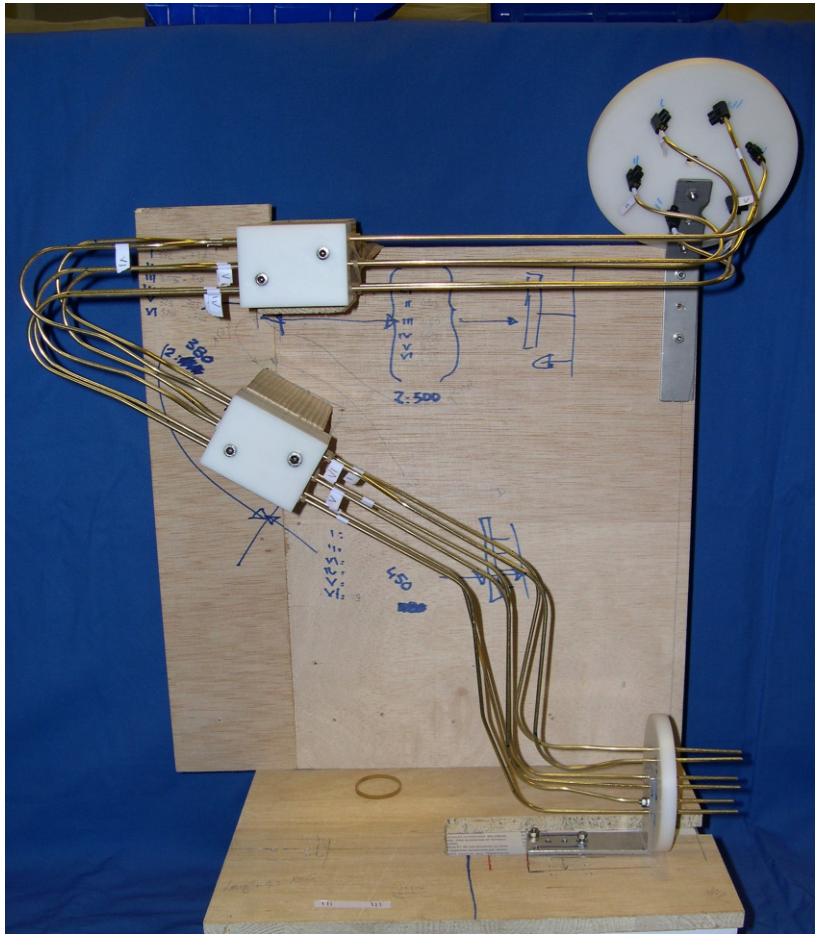
- Conduction cooled current leads for 50A with two heat sinks at 4-8K and 40-80K
- No gas flow
- Designed and fabrication of one prototype (for module 8) at CERN
- Heat loads at 50A (for each of the six leads)
  - 2.56 W/lead at 70 K,
  - 0.54 W/lead at 4.5 K,
  - 0.04 W/leads at 1.9 K
- At zero current load at 1.9 K will vary from 0.02 to 0.035 depending on the length



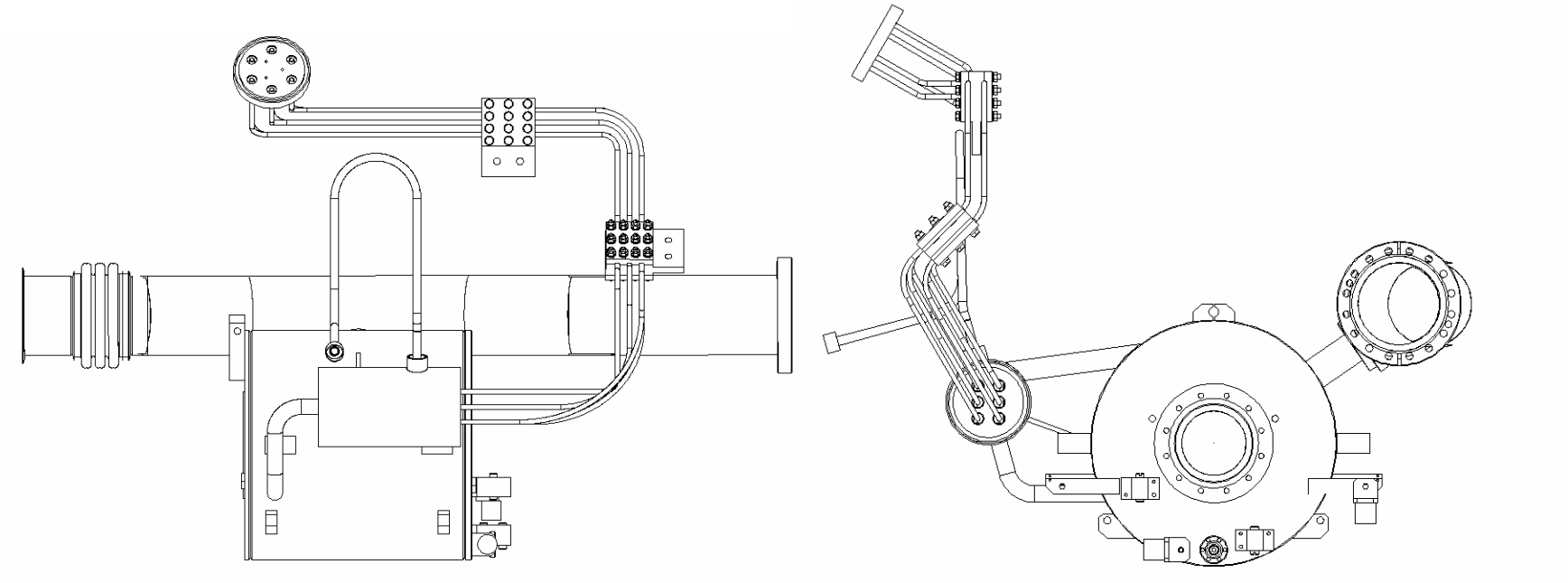
Lead Design for Module 8



Mock-up at an earlier stage



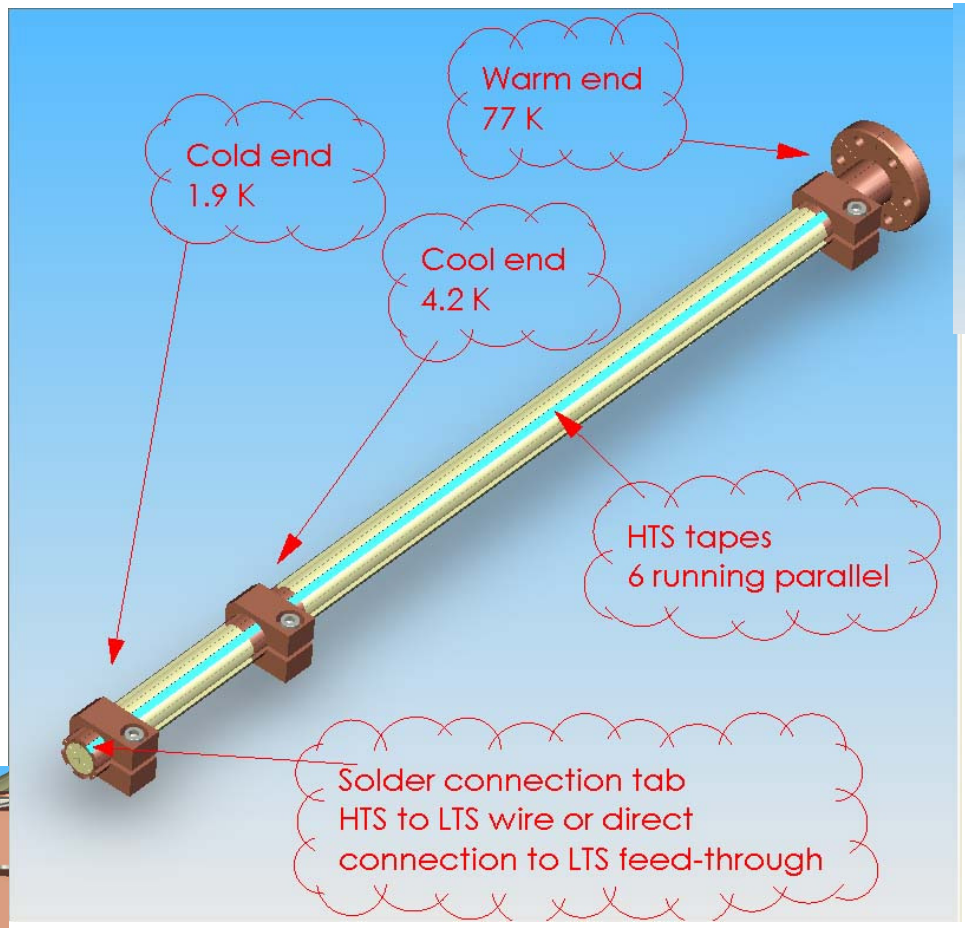
XFEL Lead Design (proposal)

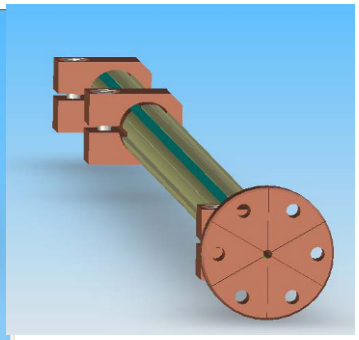


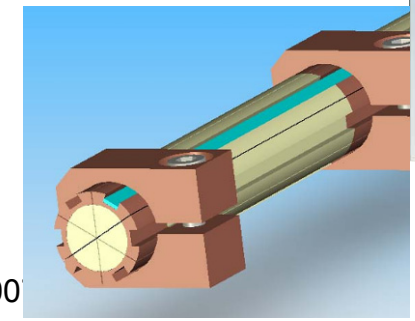
- Details need to be discussed with CERN

Alternative HTS leads

- Alternative design
- Present problems are:
  - The temperature at warm end
    - Connect to 40-80K by copper braid
    - 77K cannot be realized by a reasonable copper section
  - Supporting
    - Forces due to movement during cool down







Status of the Current Lead Assemblies

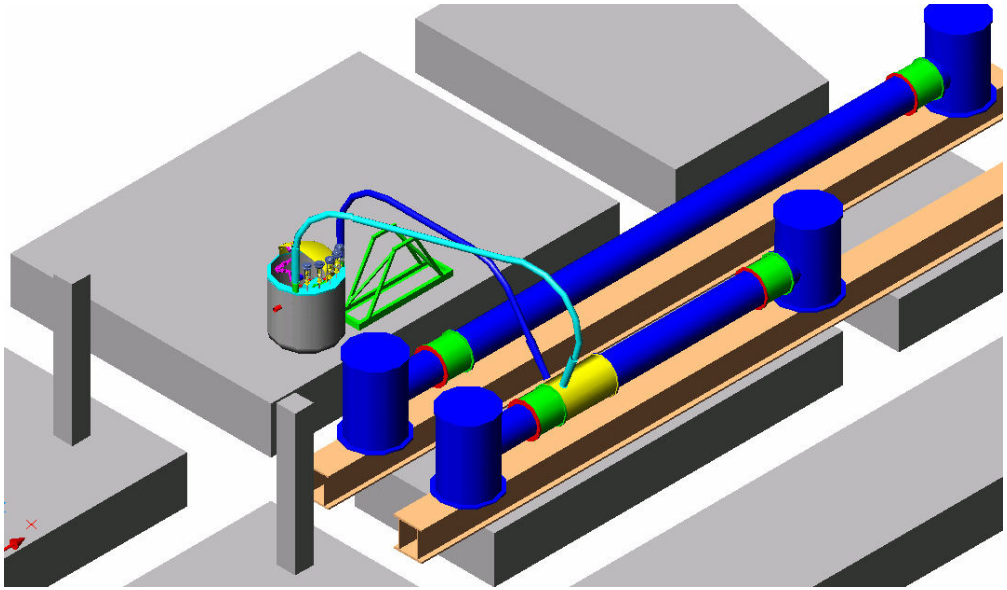
- Prototype ready by the end of this month (details)
- Some parts to connect the lead assembly to the vacuum tank have to be manufactured here at DESY
- We plan a meeting end of September at CERN to discuss
  - the implications due to the design changes for the “final” XFEL module version
  - Who will update the design drawings for series production
  - Where we can produce more prototype assemblies
- The ordering of the HTS lead assembly is delayed
  - Best is to order a “preliminary” assembly to test it at DESY

Plans for Testing

- Tests of each magnet and each lead assembly warm and cold
  - Prototype phase
  - Series production phase (at rate of 1 magnet and 1 lead per week)
- Need a special cryostat only for these tests
  - Equipped with an anti-cryostat to allow for a warm measurement systems inside of the cold magnet
- Decision taken to build a cryostat in H55 (cold HERA magnet test area) using existing installations and cryo connections to the HERA cryo plant
- Need new test benches and equipment for warm and cold tests

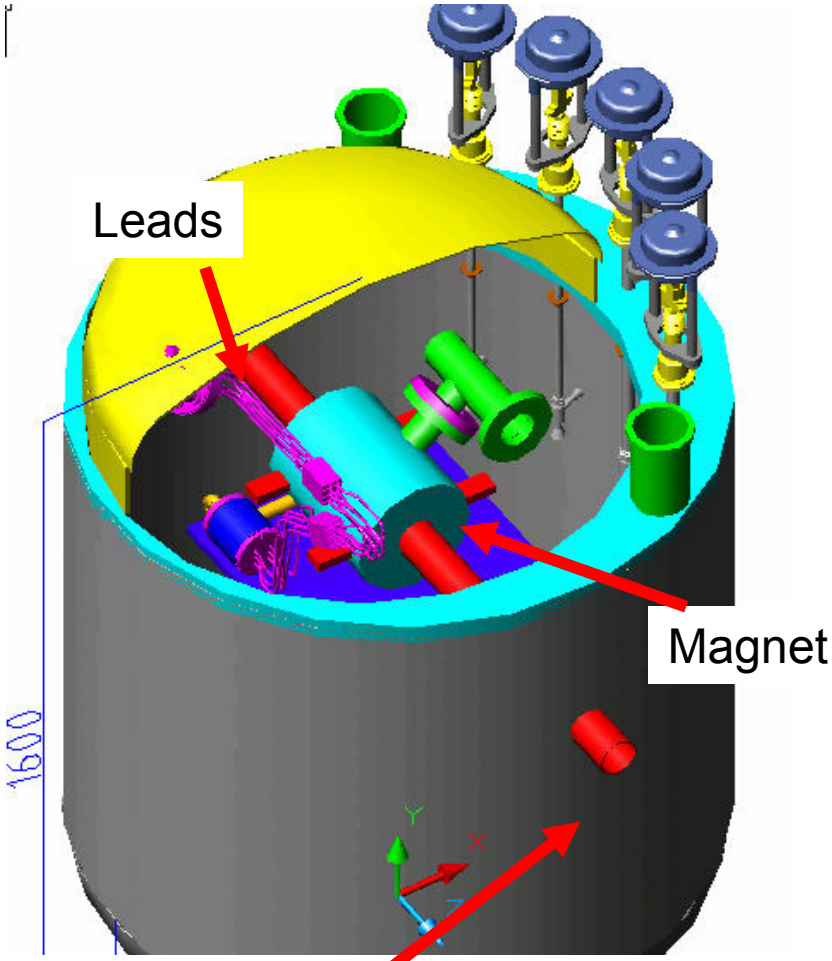
Test Area in H55

- Cryostat close to HERA test stand
- HERA measurements still possible
- Special adapter with flexible connection to cryostat
- Pump for 2K, 30mbar operation
- Timescale:
  - Specifications are in preparation
  - Place order by end of 2006
  - Installation in autumn 2007



Cryostat Proposal

- Vertical cylinder with access from top
- Magnet preinstalled and aligned on support outside
- Support with magnet mounted in cryostat always in the same position
  - Then no precise alignment necessary
  - Only for some magnets precise alignment with respect to stretched wire system
- Connections leads-tank, lead magnet are not welded but sealed by Aluminum rings instead
- Tests of magnet and current lead assembly at the same time



Anti-cryostat,
access for “warm measurement equipment

Magnet Tests in H55 “warm”

- Tests at room temperature on special test bench
- Harmonic measurement with coil to check field quality (info)
  - collaboration with IHEP Beijing, building pickup coil
- Axis and angle with “stretched wire” (info)
  - Reference magnetic centre w. r. t. mechanical centre (left/right)
    - Details need to be discussed with alignment people
  - Preparation of the connection to the BPM
    - Required accuracy 0.3mm for axis offset and 3mrad for roll angle difference for arbitrary pairs
    - Measure offset of mag. Axis w. r. t. to alignment plates (sketch)
    - Drill precise holes for dowel pins on milling machine using the alignment plates

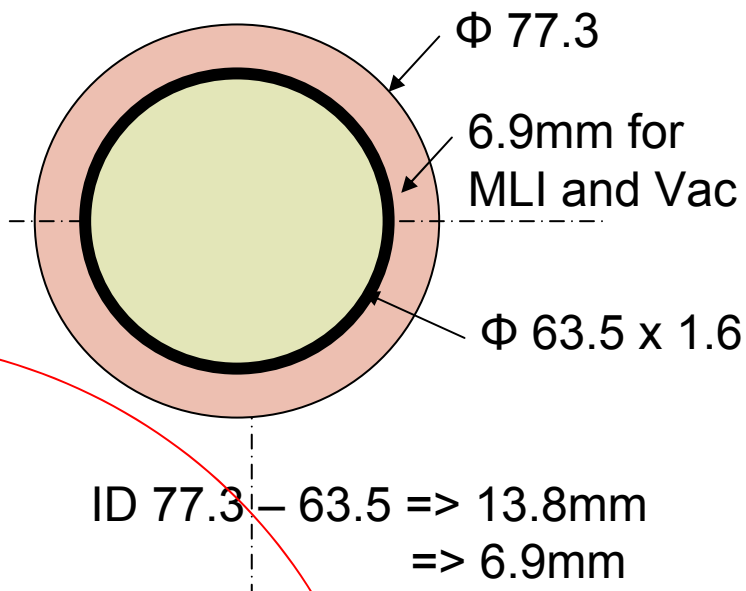
Status of the Preparation for Tests

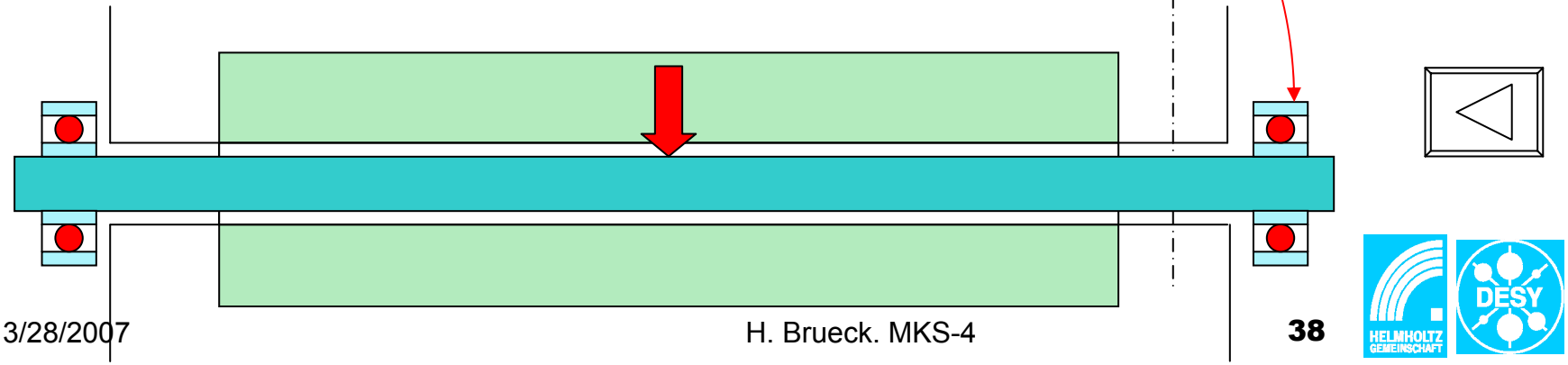
- Setting up for warm measurements
  - A new harmonic coils measurement system especially for short magnets with a large bore
  - Based on the “Chinese coil”
  - A new measurement table to hold the magnet, the harmonic coils system and the stretched wire system
- Preparing for cold measurements in H55 for winter 2007
  - Need to design and order new components

End

Measurement Coil

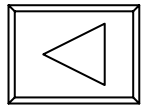
- Warm bore inner diameter 63.5-2*1.6=60.3mm
  - 6.9mm radial for MLI and iso-vacuum
- Coil OD up to about 59mm:
  - Either long coil with bearings outside
    - Bending problem
  - Or short coil with bearings inside
    - Support and drive
- Magnet length 300mm (TTF quad doublet 570mm)
- Cryostat diameter at measurement pipe 1200 or less
  - At least magnet length + ~200mm



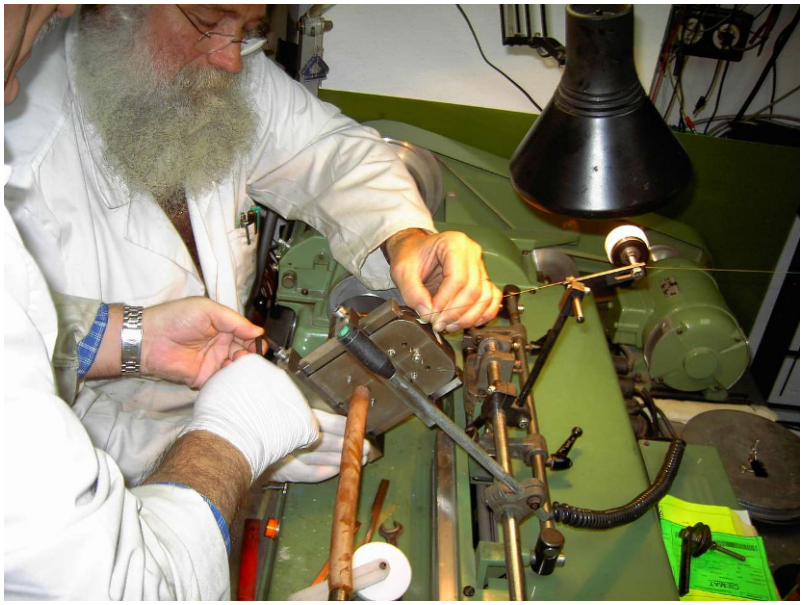


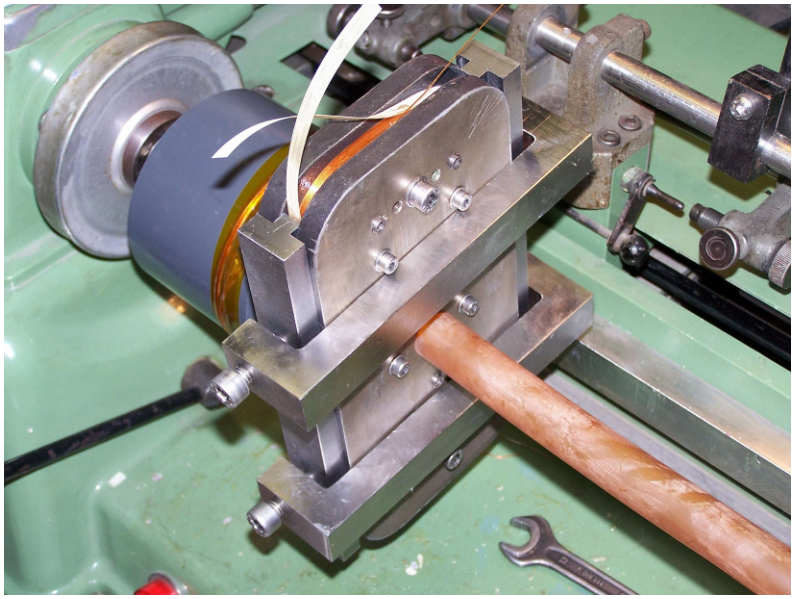
Status at CERN

- available at CERN
  - Brass rods, and are copper plated at CERN
  - Stainless steel pipes
  - Inserts were manufactured and are ready to be welded to the tubes
  - The two stainless steel flanges needed for one assembly are available
- Kapton tubes were ordered and they will be at CERN by end of September
- The PEEK flanges are going to be machined in September
- The optimization of the process for the EBW of the braid at the warm end of the lead was made: it was performed on some samples, where very good results were obtained
- One assembly could be completed by end of September- beginning of October
- A nice mock-up of the assembly that proves the feasibility of the shaping of the conductors was made
- Meeting sometime in October
  - By then, we should be able to have a look at the first assembly
  - There are also some few points that we would like to be discuss
    - thermalization blocks, fixation of warm terminals, tests to be made on the prototypes

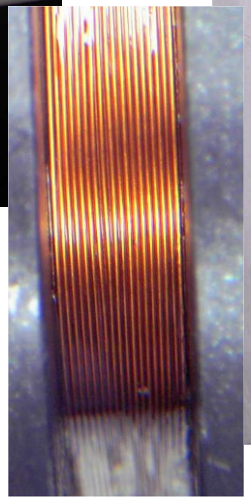


Quadrupole Production 1

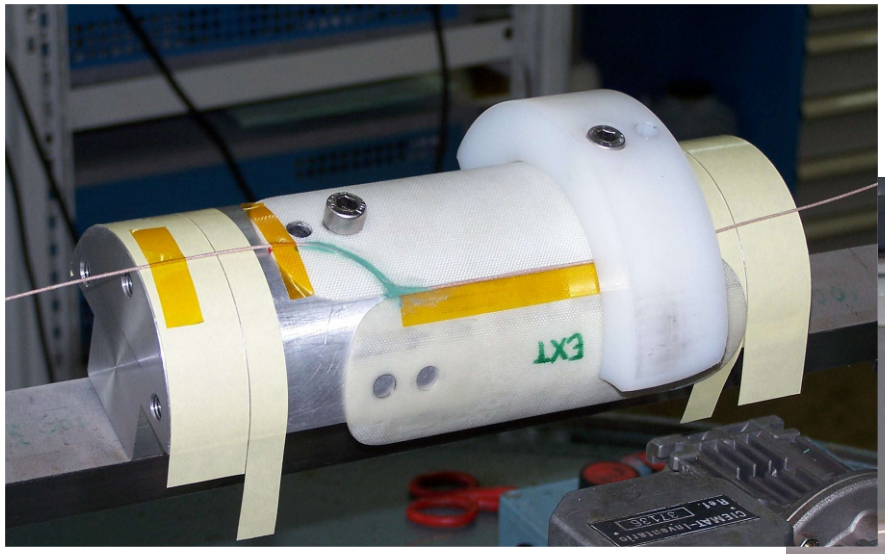


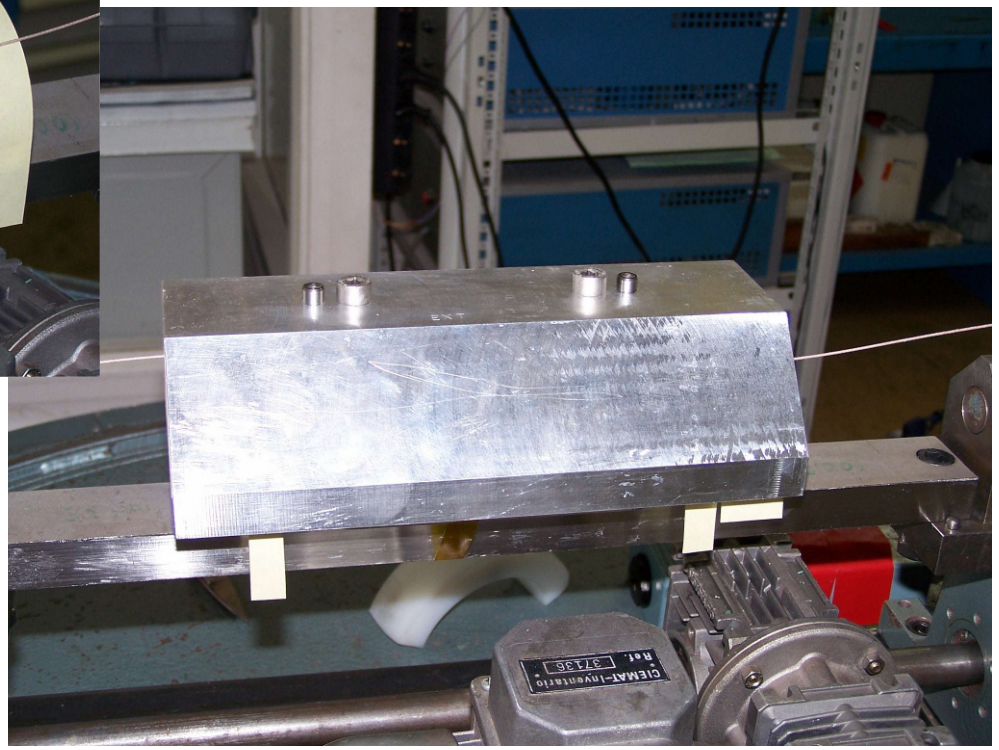


Quadrupole Production 2



Dipole Production 1





Dipole Production 2