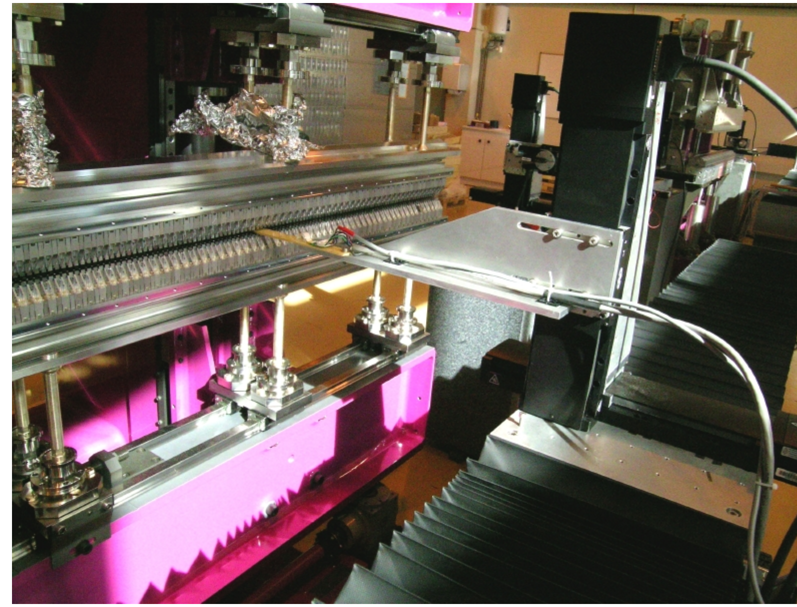
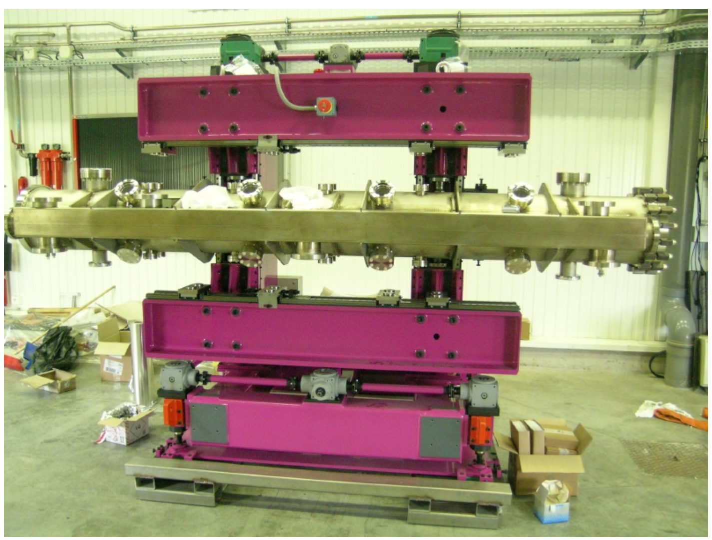
Development of Cryogenic Permanent Magnet Undulators at ESRF

In vacuum undulator

Cryogenic Permanent Magnet undulators





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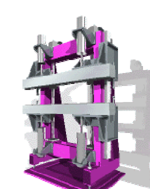
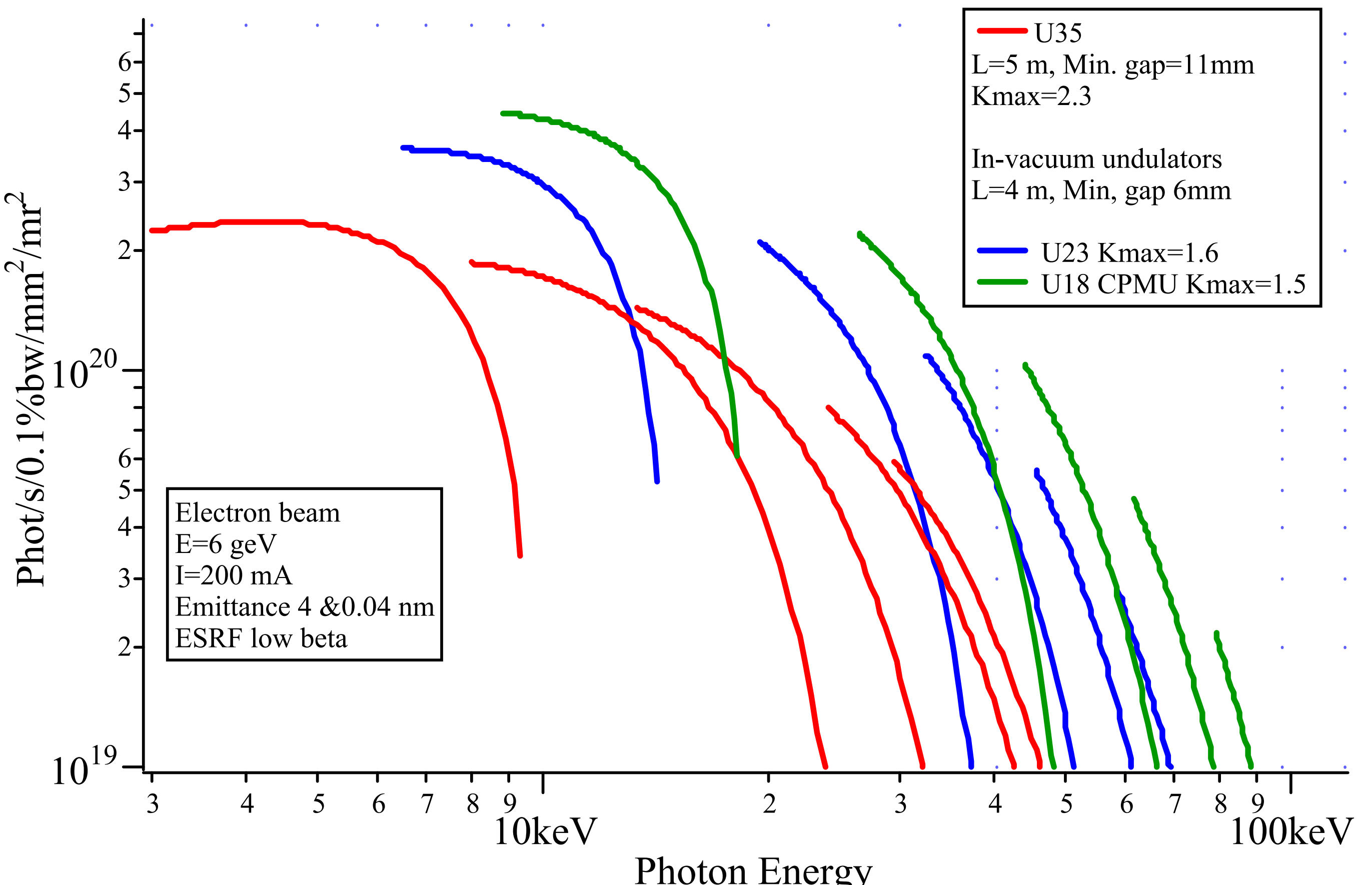
Support on cryogenic systems

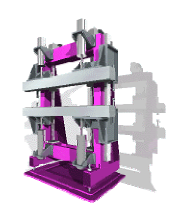


High energy undulators

Higher field shorter period



Fundamental in the 10-20 keV region



NdFeB vs. Sm2Co17

Demagnetization of p.m material by electron beam for IVUs at small gap

Many studies carried by Spring 8 (T.Bizen & al.)

- magnet blocks exposed to a 2 Gev electron beam
- NdFeB & Sm2Co17

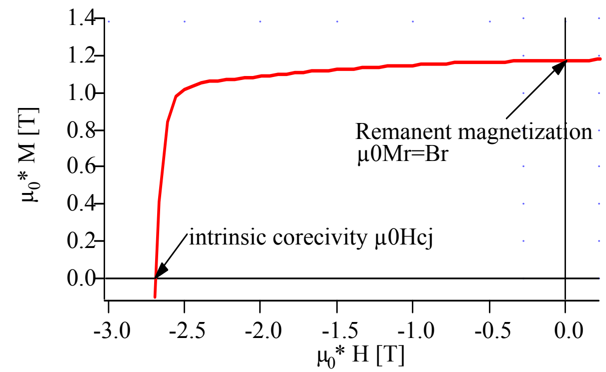
Very high coercivity NdFeB material is comparable to Sm2Co17

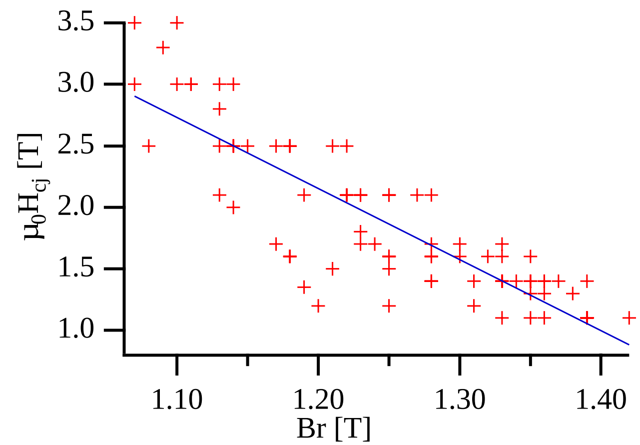
- needs a coercivity higher than 2800 kA/m
- thermal stabilization

But

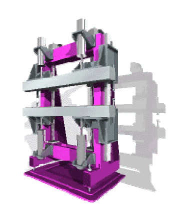
The remanence is low:

≈ 1.05 T at R.T. (similar to Sm2Co17)





Data taken from various suppliers
R.T values for NdFeB materials



Cryogenic Permanent Magnet Undulators

SPRING 8 proposal : Phys. Rev. Sp. Top. - Acc. & Beam,V0 **7**, 050702 (2004)

Target:
- high coercivity at low temperature (limited demagnetization risk)
- Increase the peak field with NdFeB p.m. material (≈ 25 %)

Detailed studies needed

1- Magnetic material

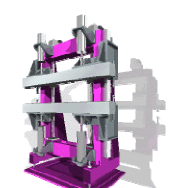
-full characterization of NdFeb at low temp

2- Mechanical deformation at low temperature

- gap parallelism

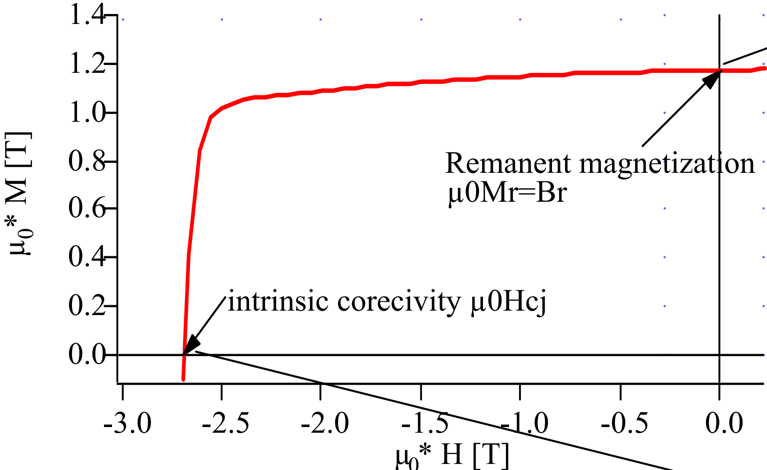
3- Magnetic Measurements

- reliable local measurements
- phase error vs temperature

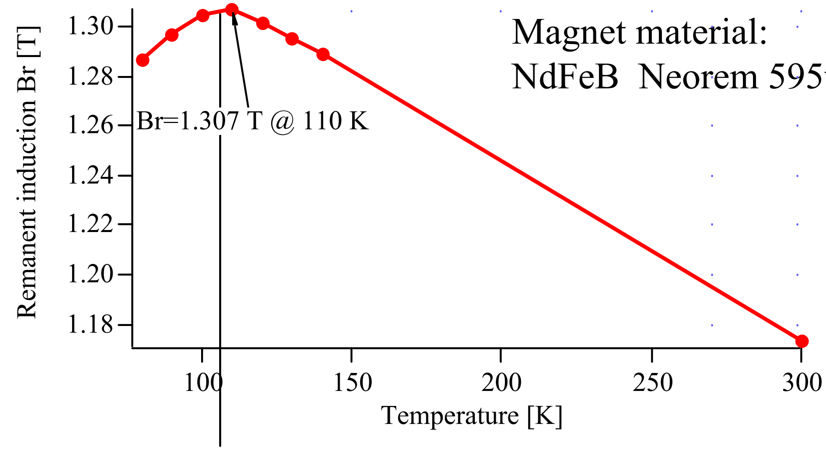


NdFeB material at low temperature

Measurements done at Laboratory Louis Néel
C.N.R.S Grenoble
C.Kitegi, D.Givord

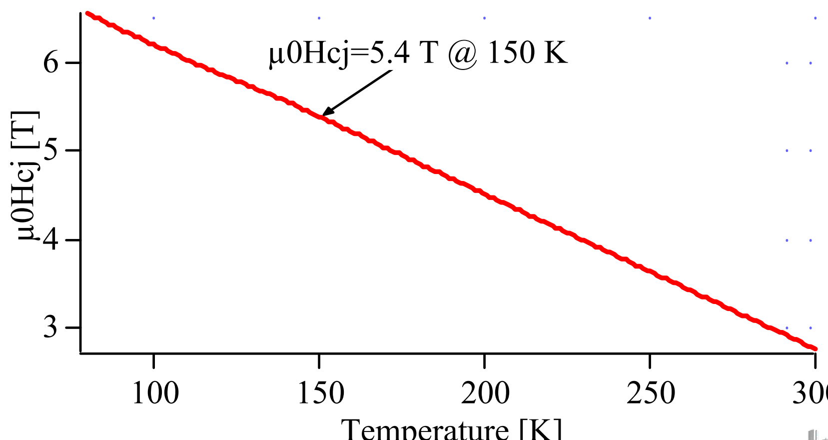


Reversible properties vs temperature



Magnet material:
NdFeB Neorem 595t

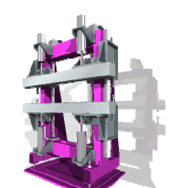
Spin Reorientation transition (SRT)



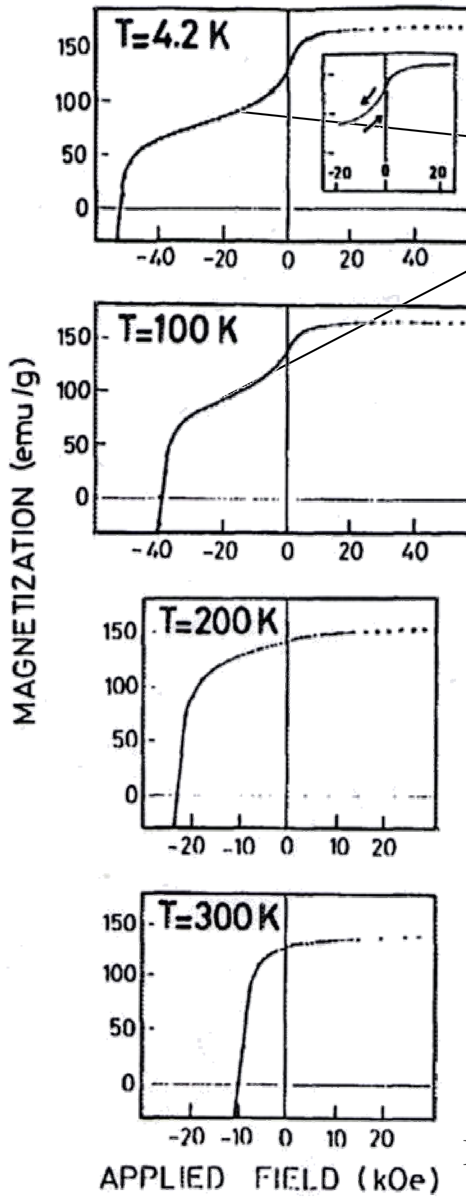
SRT-> extra difficulty for the construction of NdFeB CPMU

More details at EPAC2006

Development of cryogenic permanent magnet in-vacuum undulator at ESRF (C. Kitegi)



Earlier studies on SRT



SRT: change in easy axis direction

Non linear property

Mostly investigated in fundamental magnetism

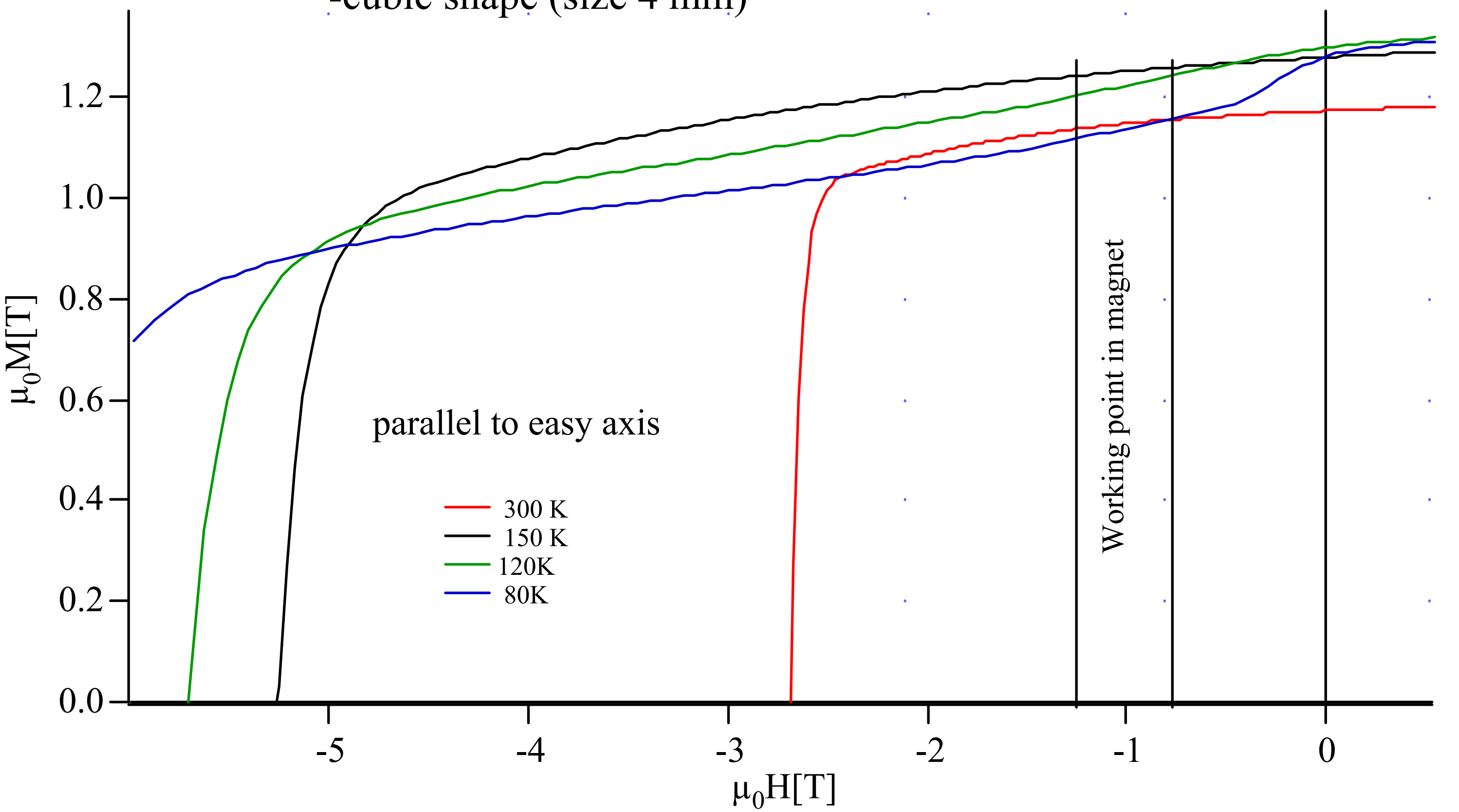
but

Need for macroscopic material models for (sintered) NdFeB materials as used in undulators

D. Givord and Al. , Sol. St. Com. 51, 857, (1984).

NdFeB material at low temperature in 2nd quadrant

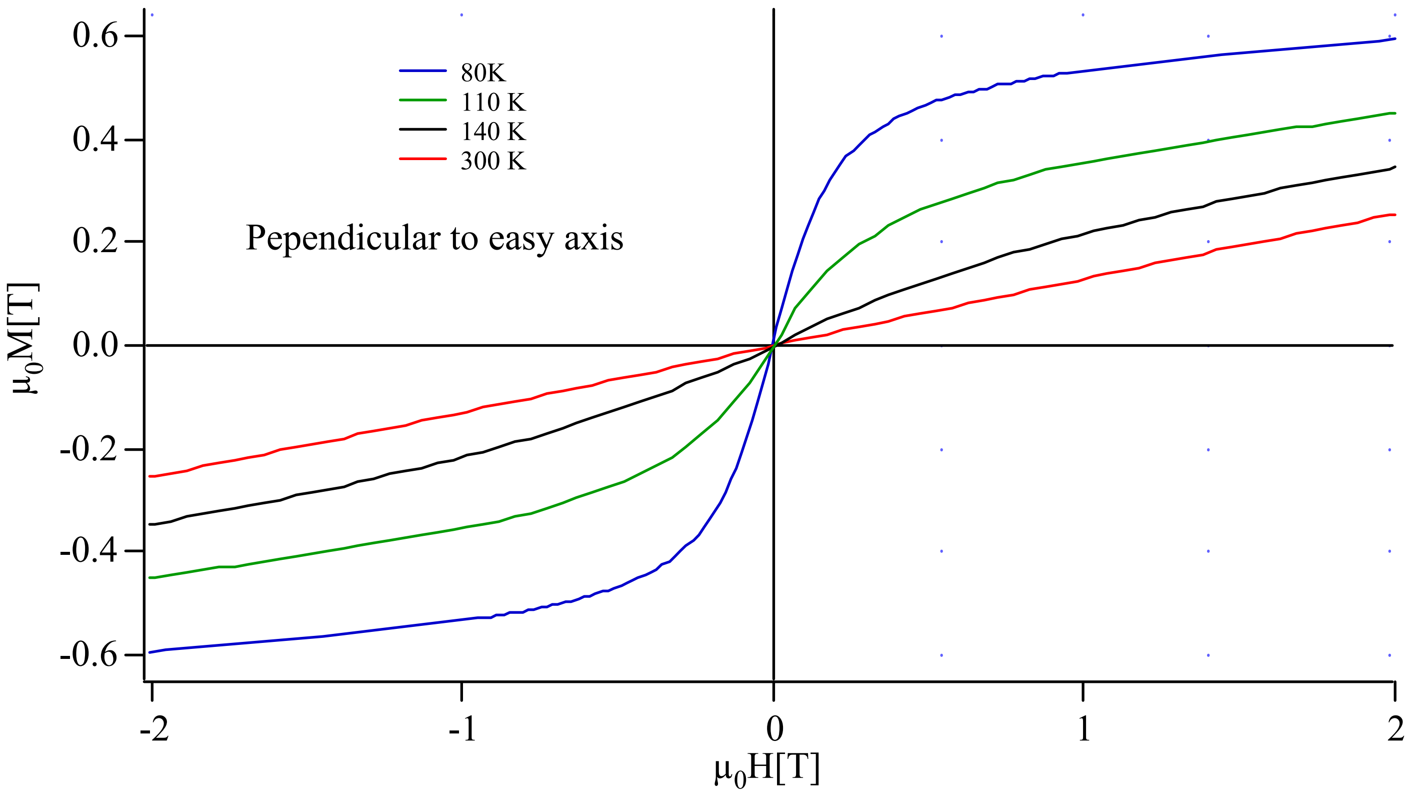
Magnet samples: Neorem 595t , Br=1.18 T at room temperature
-cubic shape (size 4 mm)



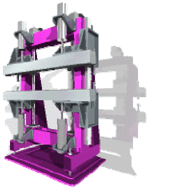
Temperatures for maximum undulator field and maximum Br are different

NdFeB material at low temperature (perpendicular to easy axis)

Perpendicular to the easy axis (needed for complete material model)



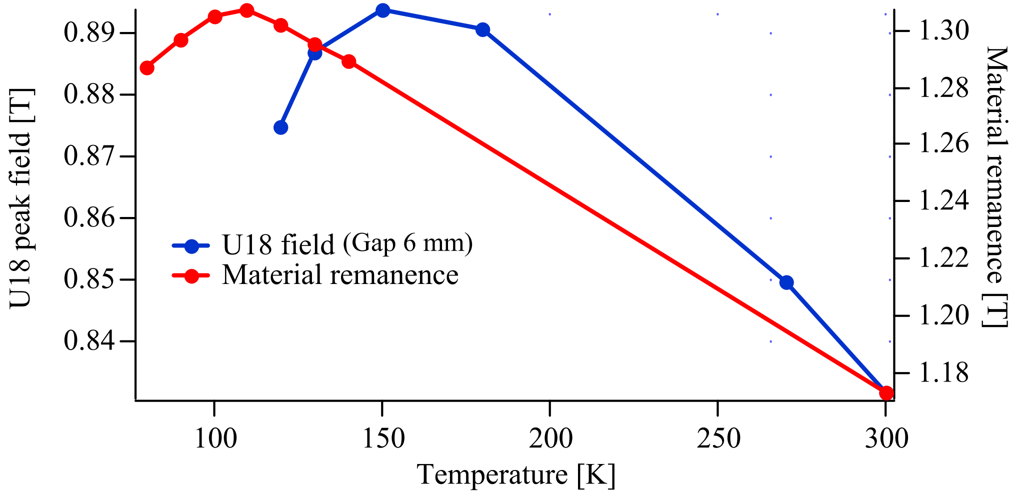
- The transverse permeability increases while decreasing temperature
- non linear when close to SRT



CPMU18 Numerical Simulations

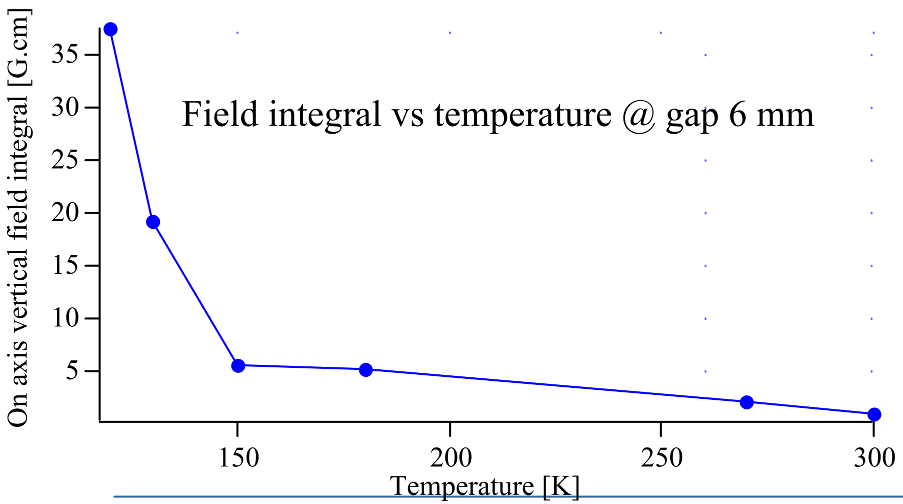
Radia model

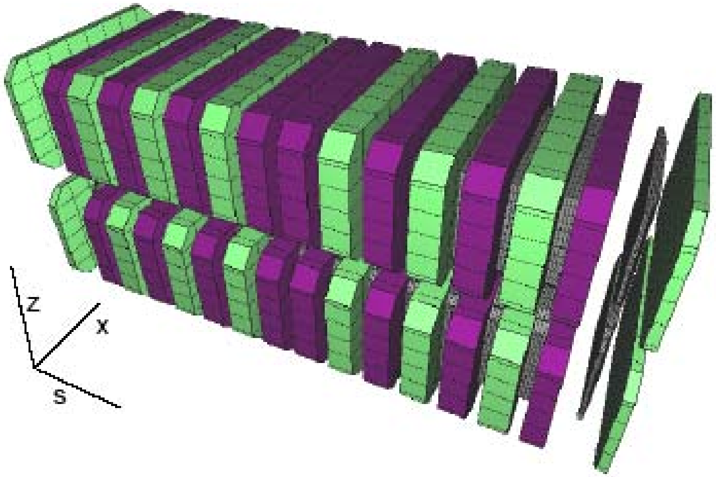
- U18 hybrid structure (geometry)
- non linear material model M(H) → $M(H)=\sum_{i=1}^{3} M_{si} Tanh\left(\frac{\chi_i}{M_{si}}(H+H_c)\right)$

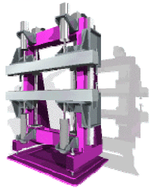


Model acceptable for T≥ TSRT
but inaccurate below
(magnetization components are not independent)

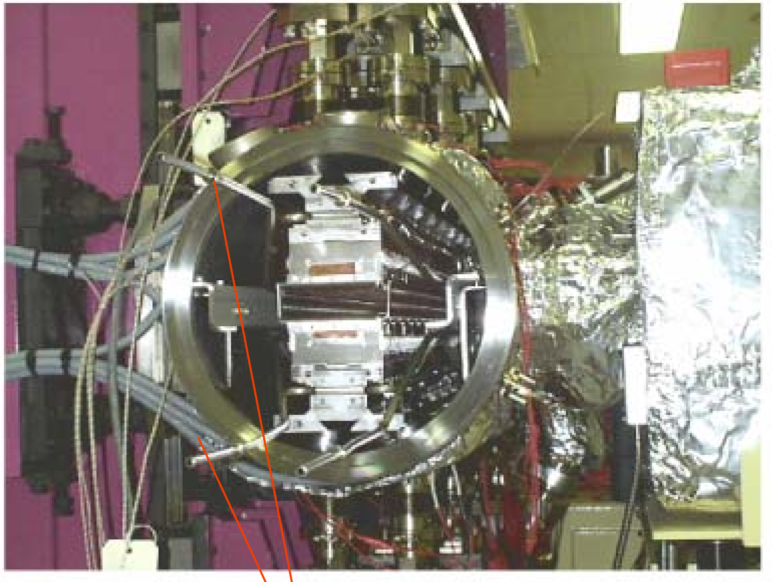
Peak field maximum at 150 K

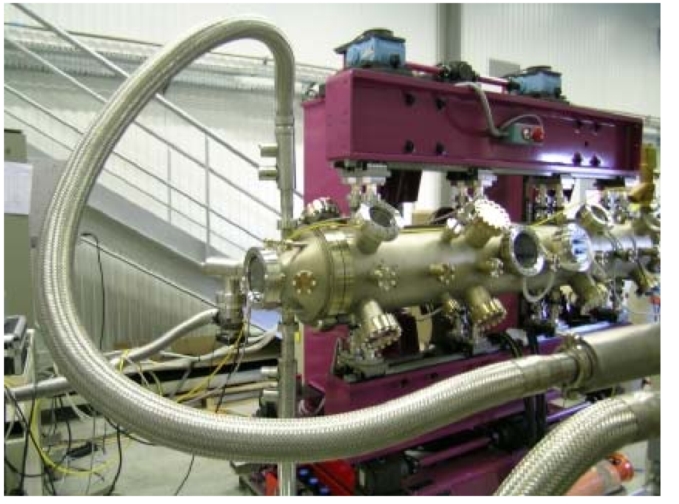






ESRF C.P.M.U



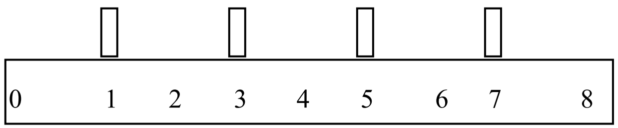


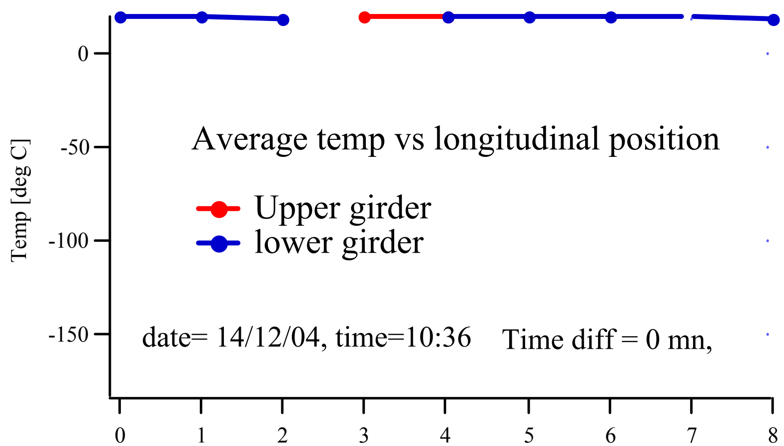
Liquid nitrogen loop for CPMU

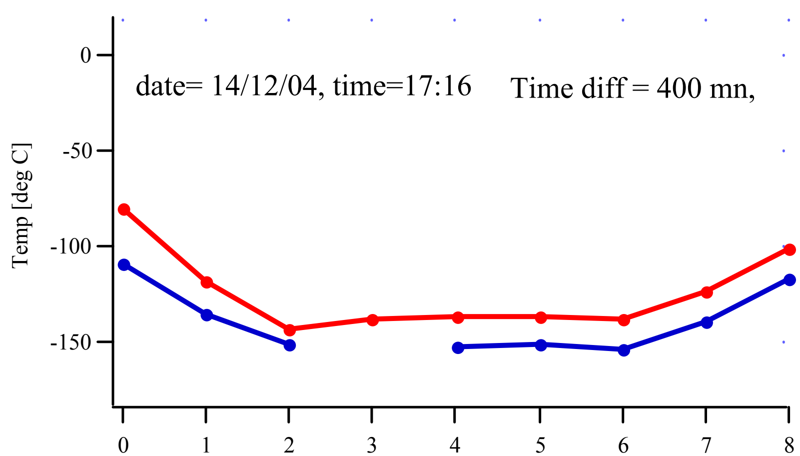
Cooling pipes
(water in standard IVUs)

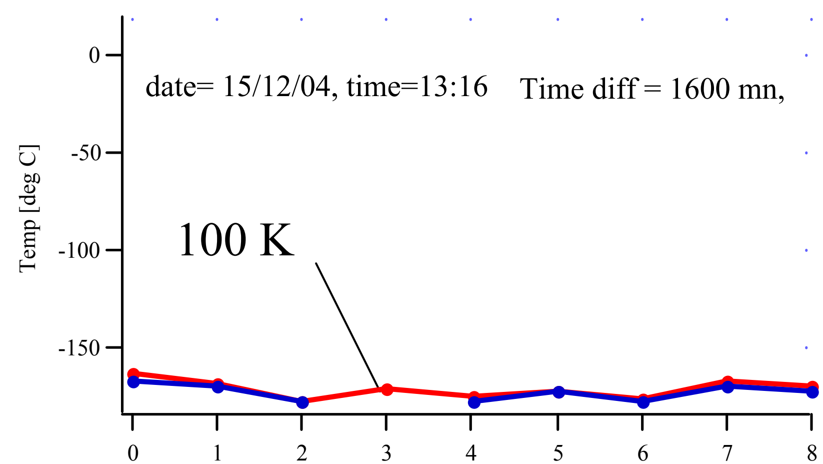
Stainless steel girders
Equipped with thermal sensors

Temperature measurements

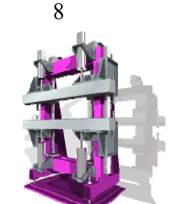




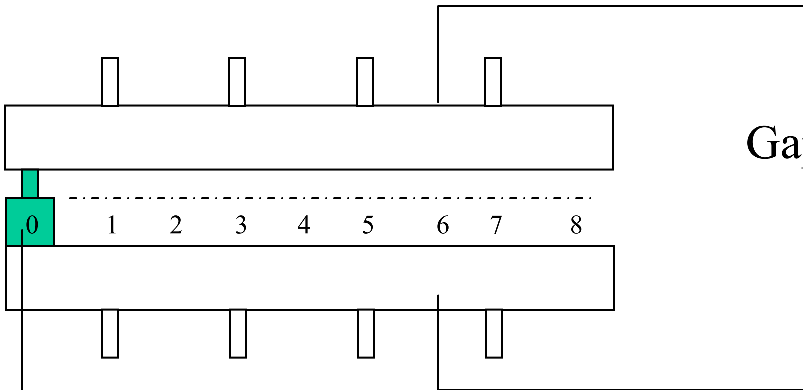




Heat budget ≈ 150 W



Impact of cooling on Gap



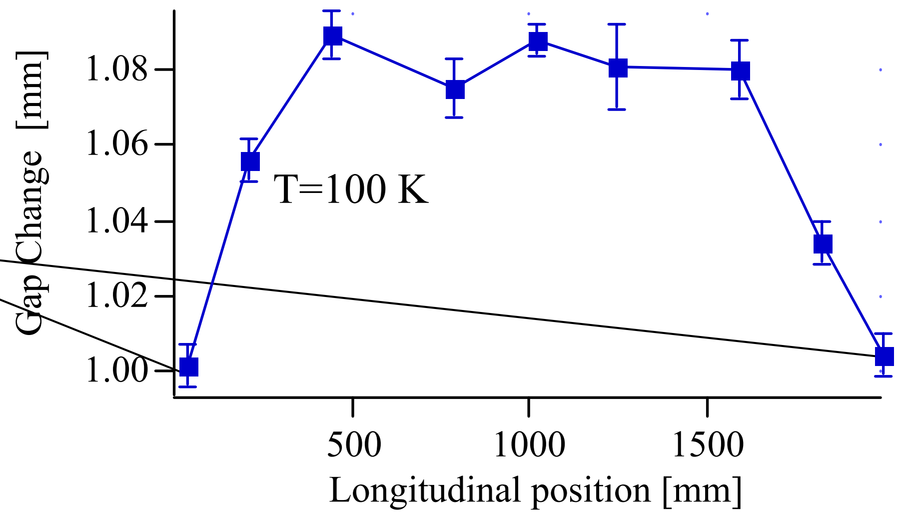
Gap measurements:

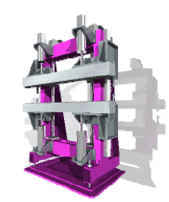
- provided by gap encoder (absolute)

Electrical contact (9 units)

Change in parallelism between lower and upper girders (phase error)

Limited thermal connection between girders and cooling pipes





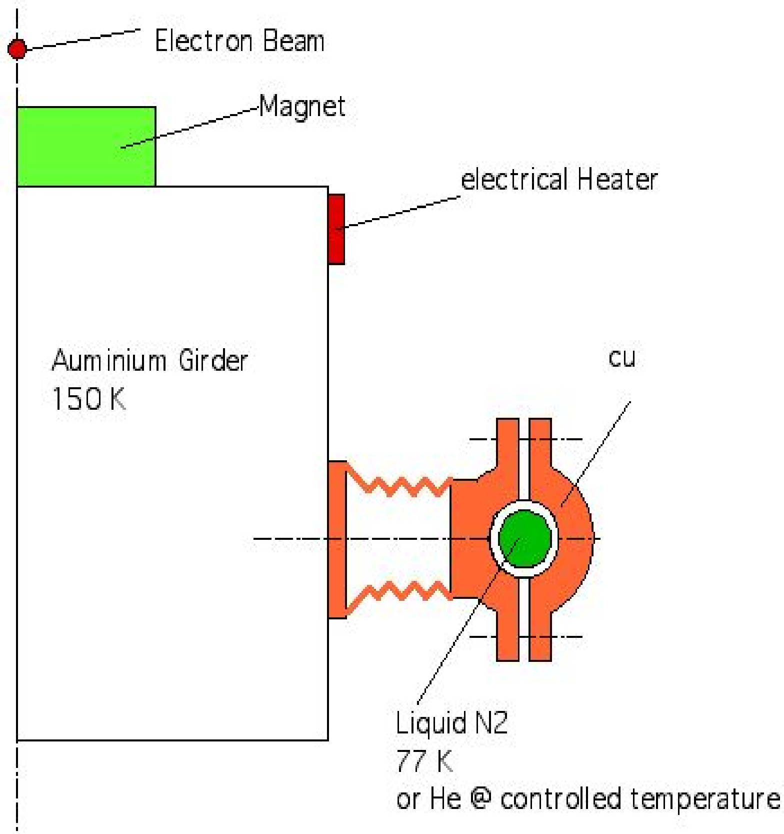
CPMU design considerations

Mechanics & thermal transfer

Stainless steel girder -> Aluminium girder

Thermal connection to cooling pipes with calibrated spacers (≈ 80 units)

Modified tension mechanism of Cu-Ni sheet



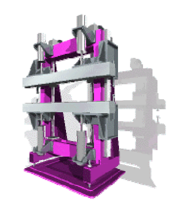
NdFeB material

Coercivity ≥ 2000 kA/m, Br ≈ 1.2 -1.25 T

- baking at 120 deg. C maintained
- no significant cryo_pumping expected at 150 K

Magnetic structure

Hybrid



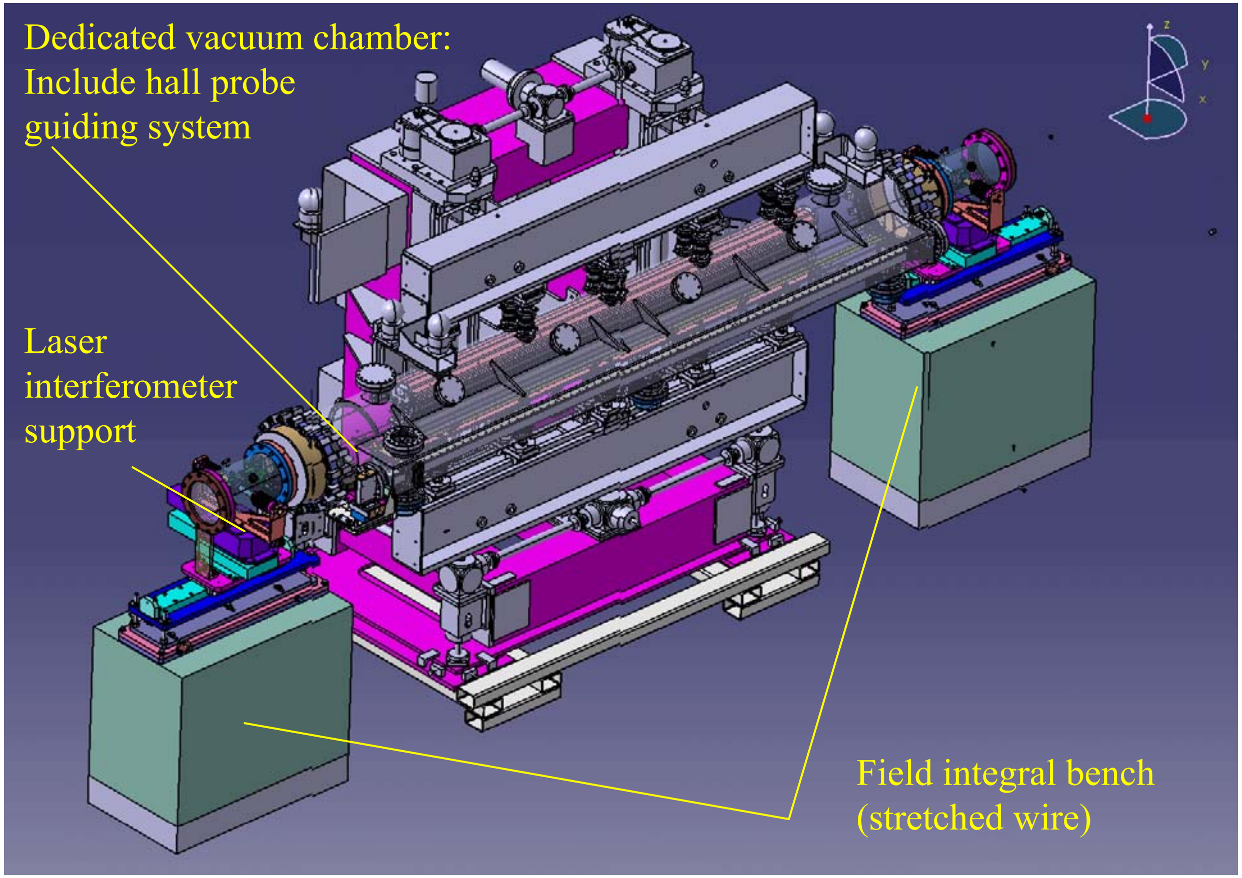
CPMU magnetic measurements

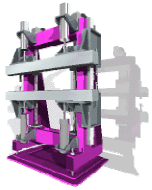
Undulator field quality
vs.
temperature

Local measurements
(phase error)

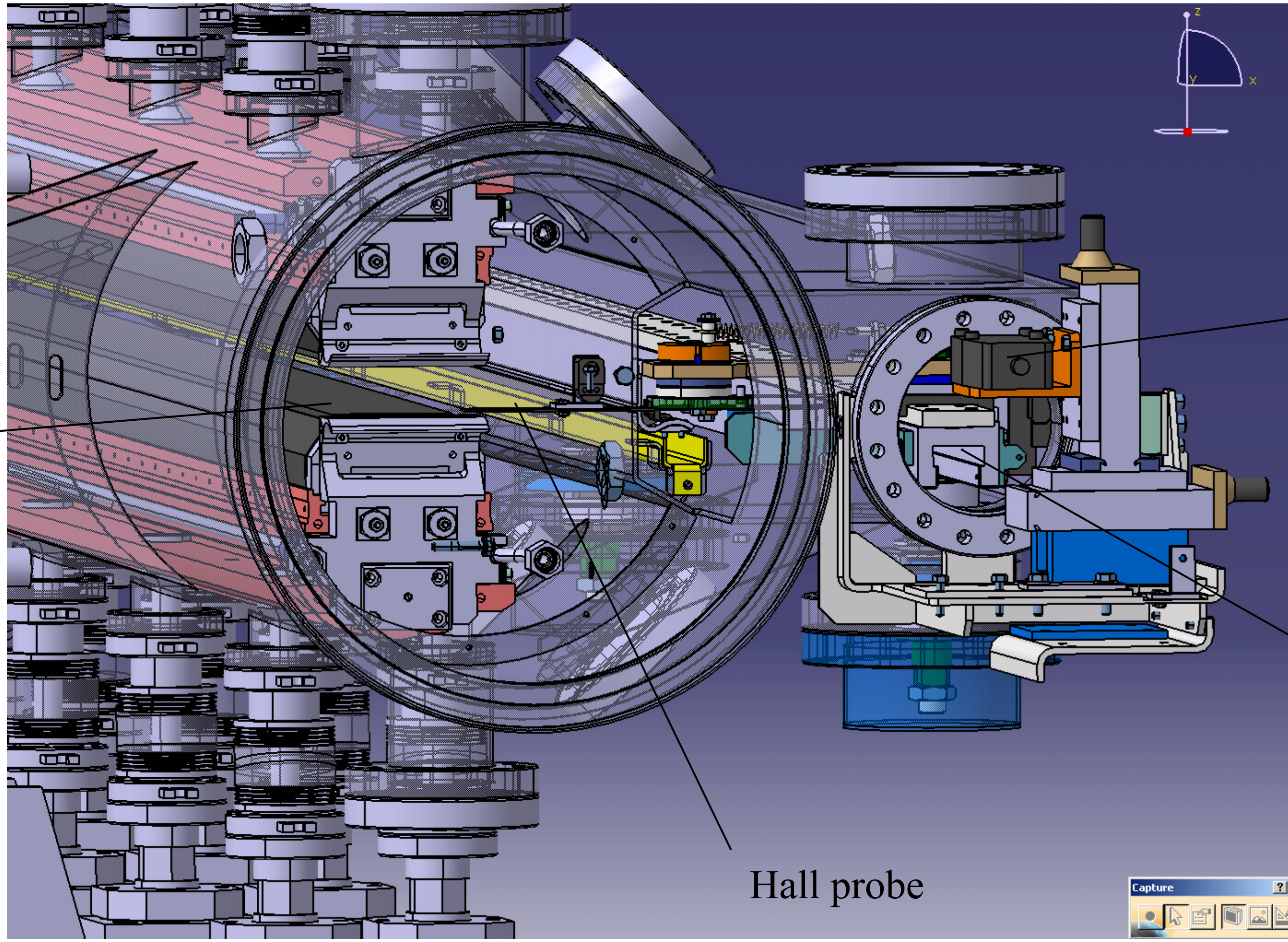
+
Integral measurements

In vacuum measurements
- 10^-6 mbar



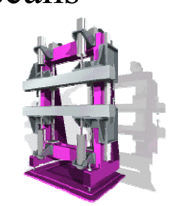


CPMU local field measurements

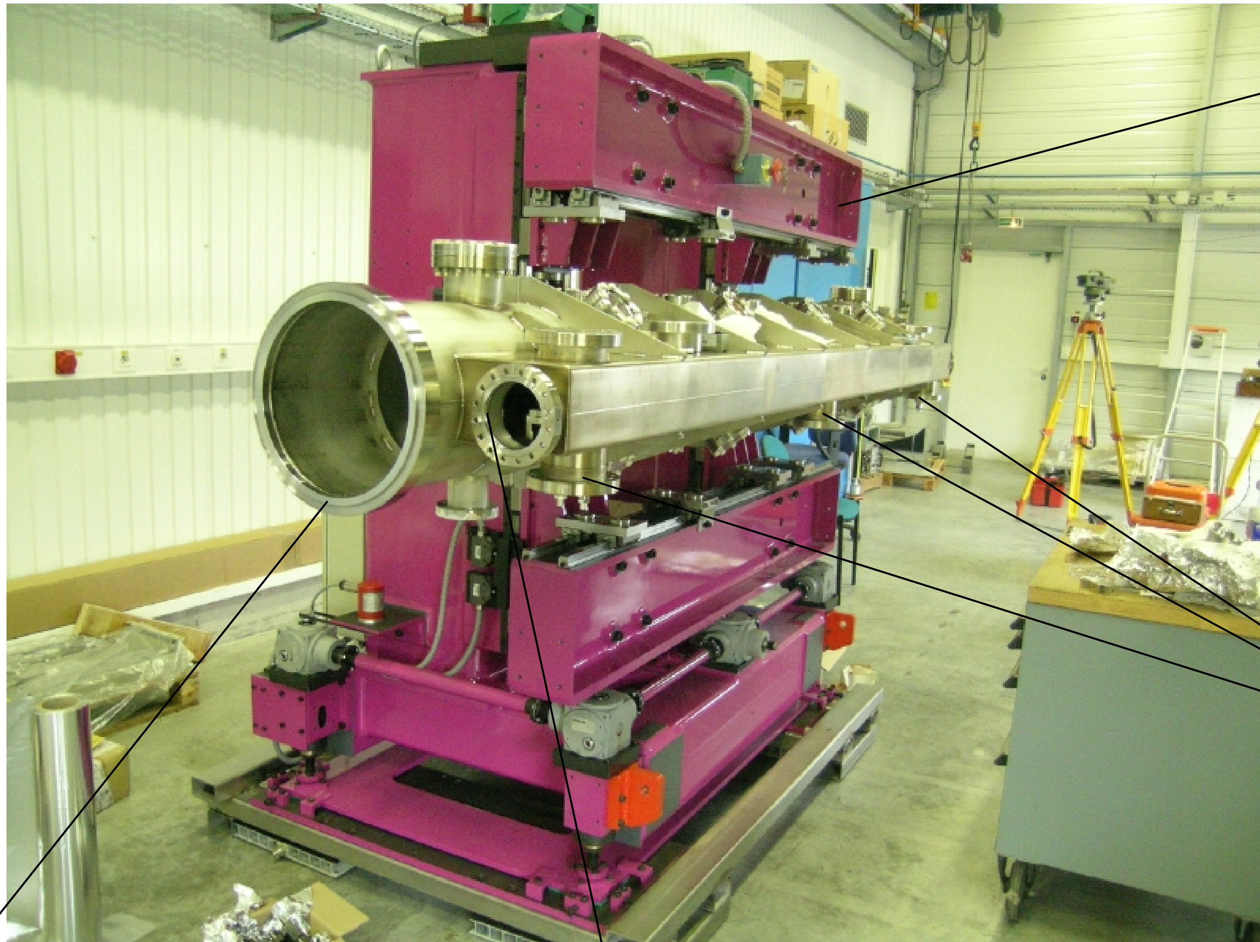


Longitudinal motion: magnetically coupled with an external axe (old hall probe bench) -> fast scans

Presently under assembly



Assembly of CPMU measuring bench

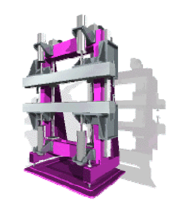


IVU
support structure

Vertical& horizontal
 tuning
of inner guide rail

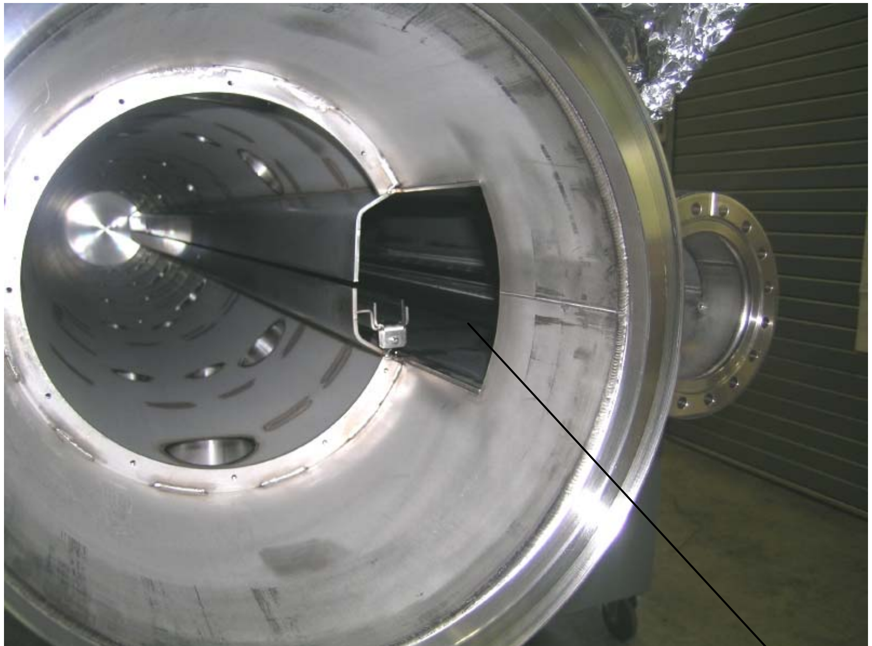
Interface with stretched wire parts

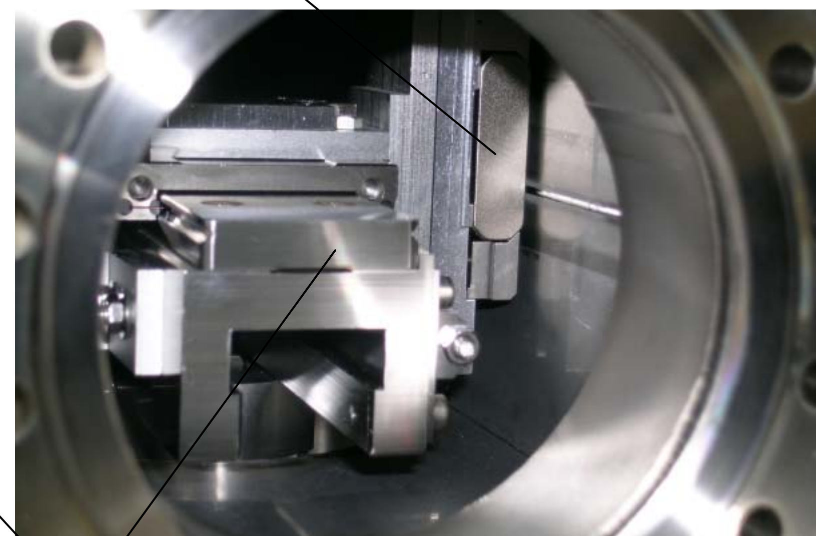
Window for laser interferometer



ESRF

Hall probe guiding assembly

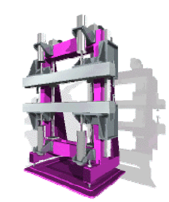




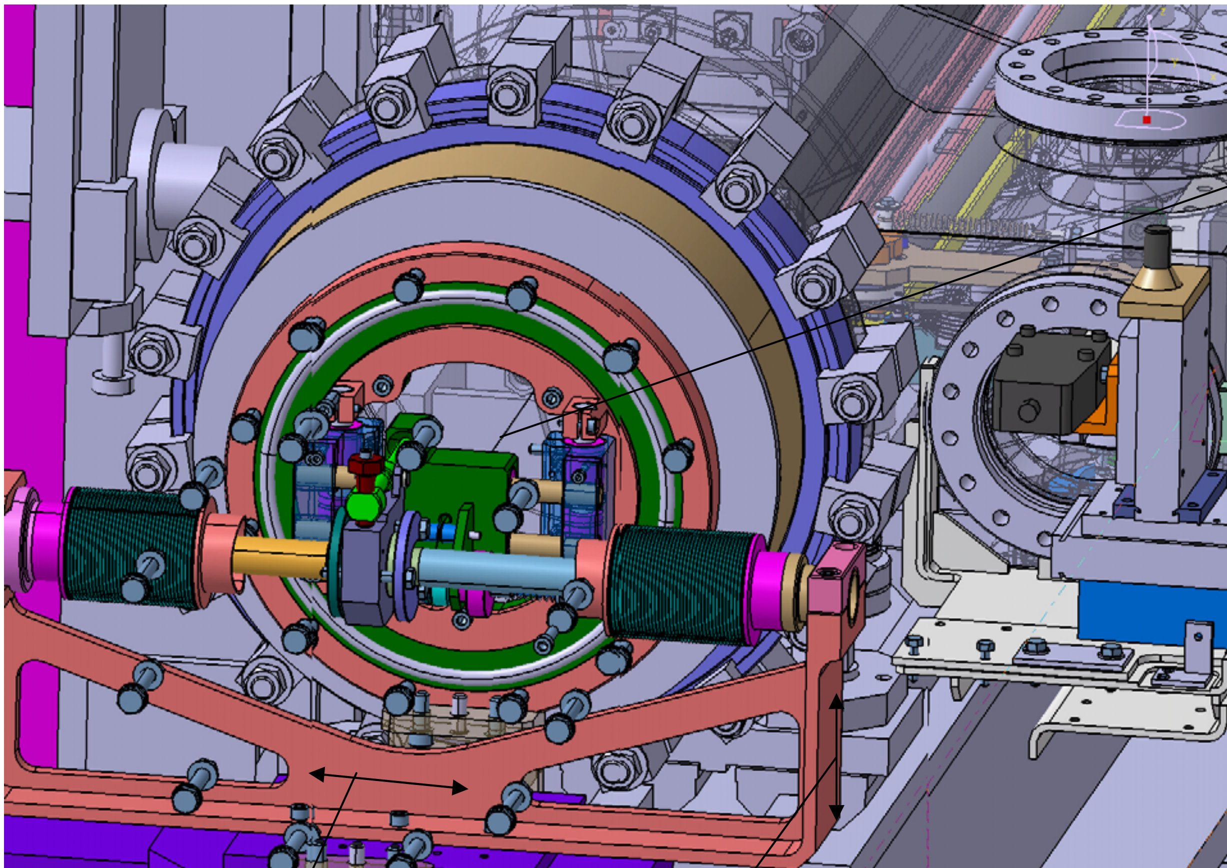
Permanent magnet module (3 magnets)
Magnetic coupling with external motion
(actuation force > 40 N@ magnetic gap 8 mm)

Hall probe guide rail

Hall probe keeper



CPMU field integral measurements

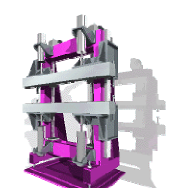


Stretched wire

Mechanical parts
Delivered in 2005

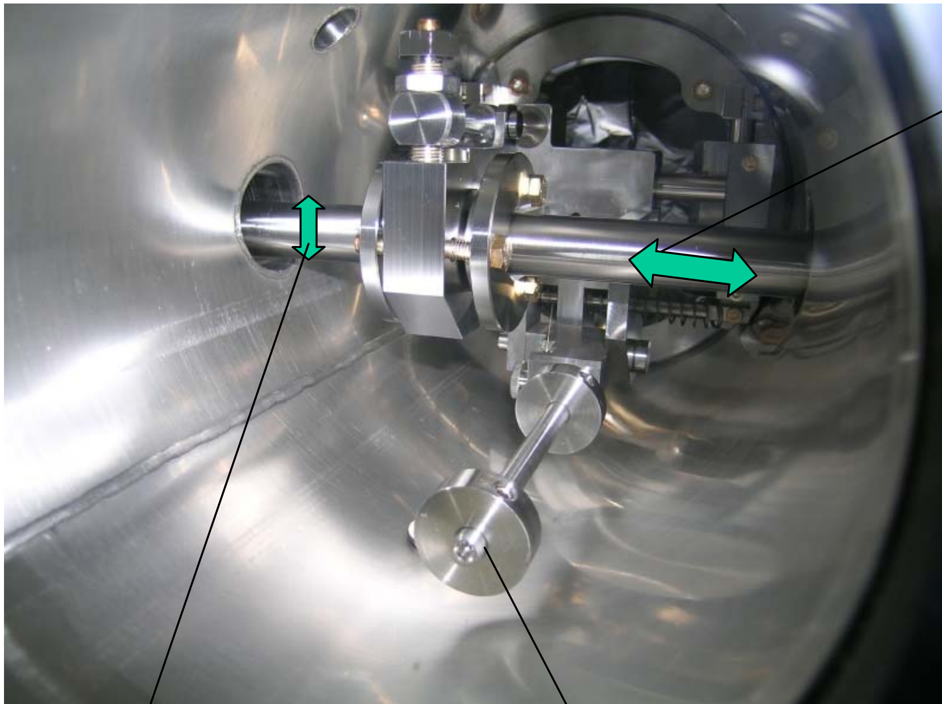
Horizontal motion ± 25 mm

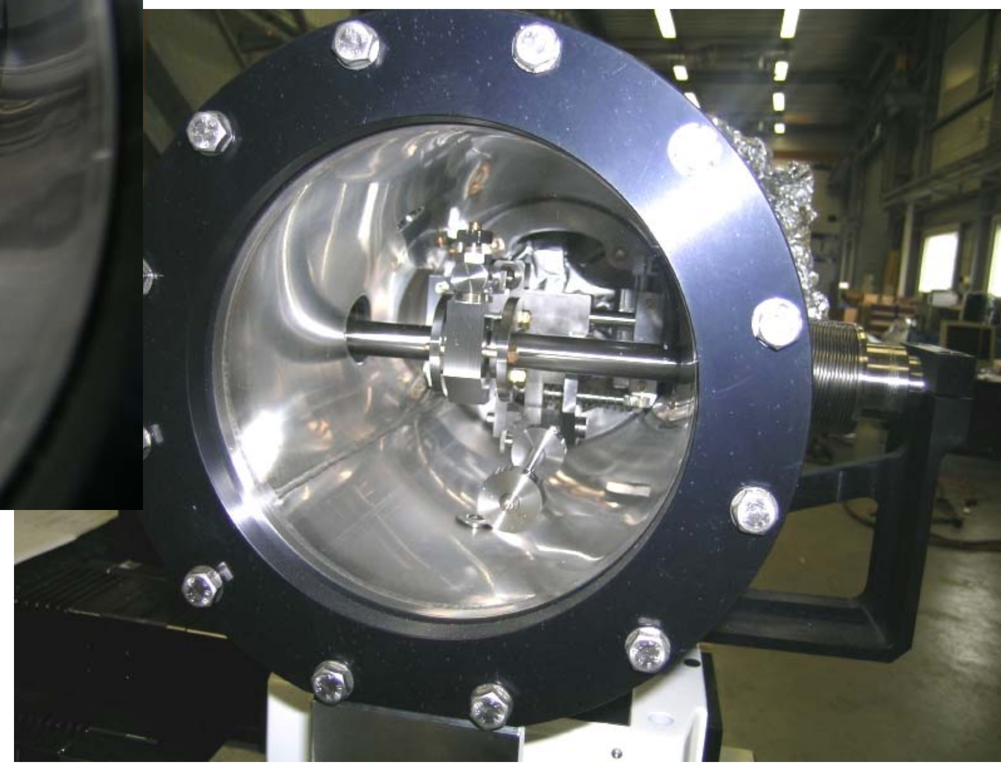
vertical motion ± 5 mm



Stretched wire assembly

Horizontal motion ± 25 mm





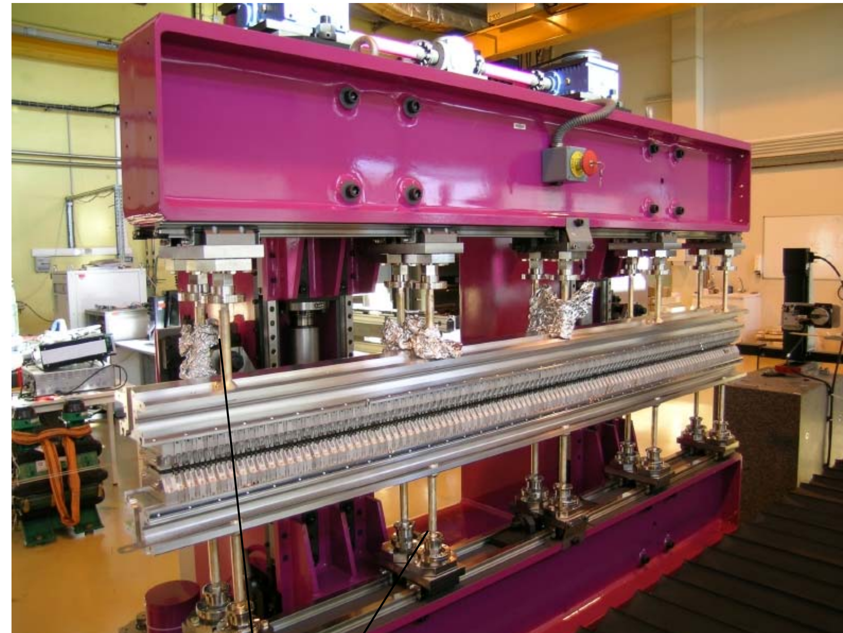
Verticall motion ±2 mm

Wire stretching mechanism

Status of ESRF CPMU

Undulator (U18):

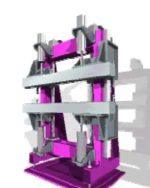
- period 18 mm
- hybrid structure
- L= 2m
- K=1.5 @ gap 6 mm (150 K)
-presently under magnetic measurements at room temperature



Stainless steel rods with reduced cross section

Magnetic measurements

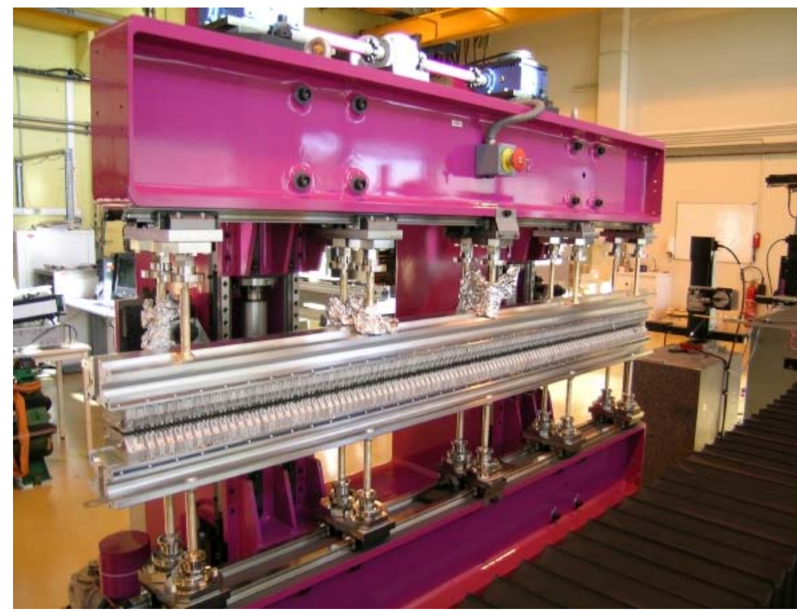
-final assembly
- control and test of motion
- measurement at room temperature
- measurements at cryogenic temperature



Concluding remarks

The development Cryogenic permanent magnet IVUs is mostly a technological effort.

- magnetic field performance vs cost is an issue



Field measurements

- field correction applied at room temperature should (must) remains valid at cryogenic temperature