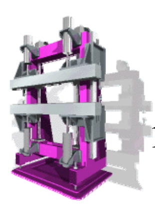
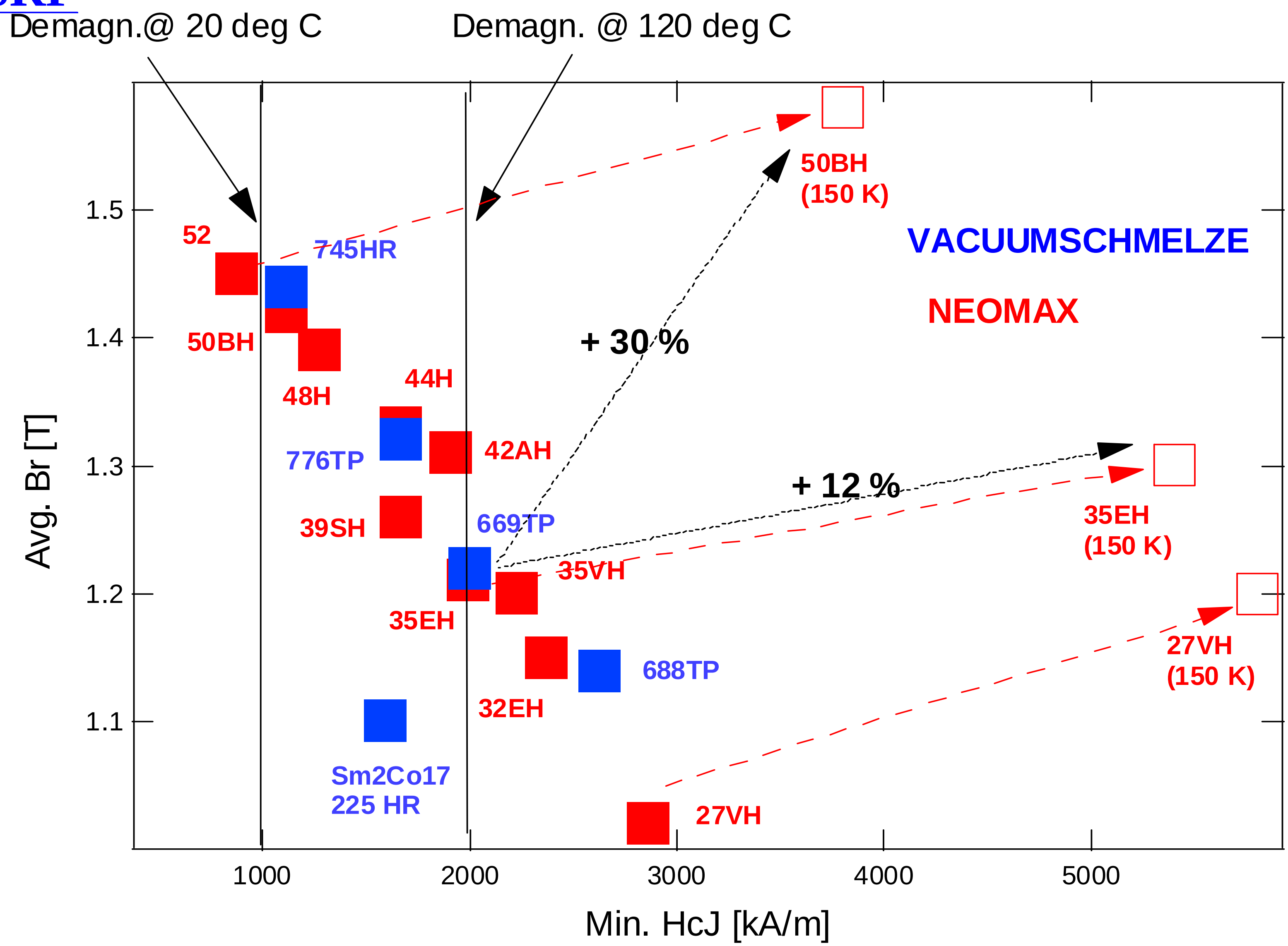
ESRF

Cryogenic Permanent Magnet Undulator Development at the ESRF

J. Chavanne, C. Kitegi, C. Penel, B. Plan,
F. Revol



Permanent magnet materials



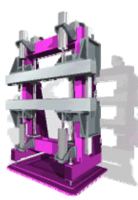
Strategy : Minimize risk of failure

Prototype #1

- Slight modification of the ESRF in-vacuum undulator design
- Hybrid structure Period 18 mm, L=2 m
- Relaxed phase error
- Can be baked at 120 deg C
- Can be operated at room or cryogenic temperature
- Develop the cooling strategy
- Develop the magnetic field measurement at cryo Temp..
- Test with electron beam
- Routine operation in a beamline
- Improve the design

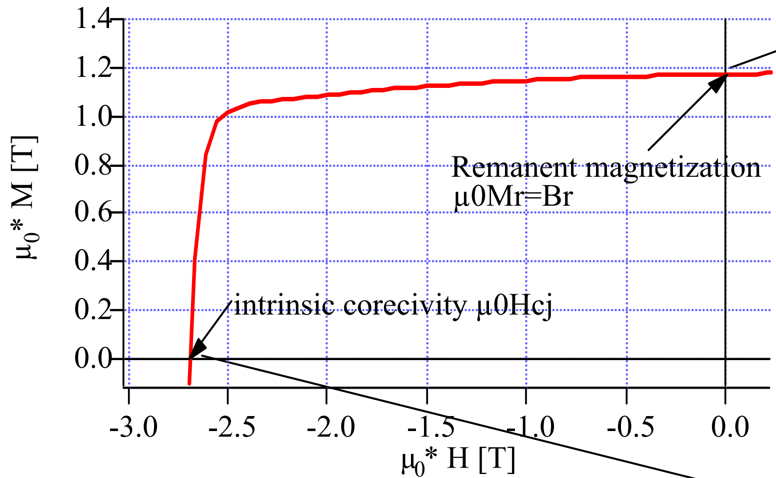
• Prototype # 2

• Highest magnetic field
• Low phase error
• Install on a beamline

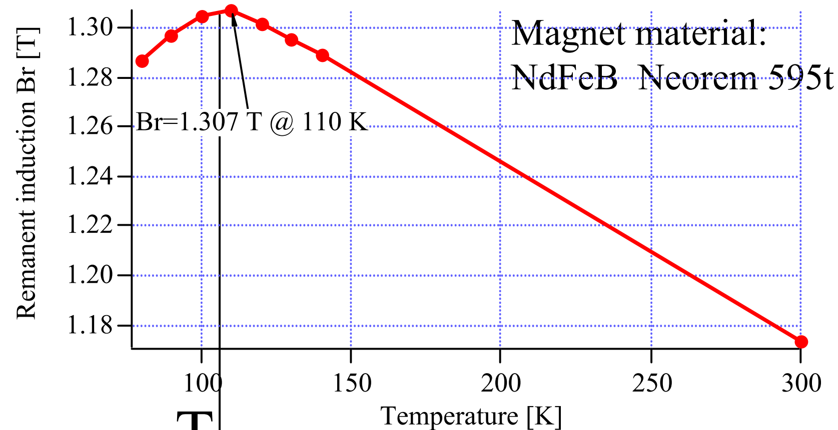


NdFeB material at low temperature

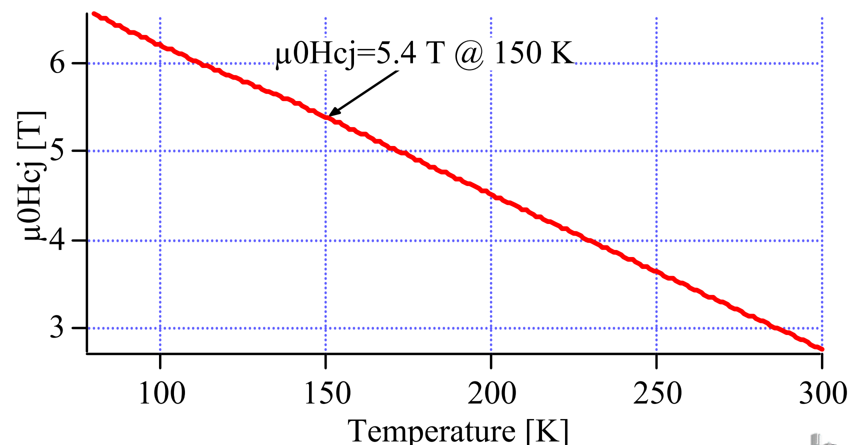
Measurements done at Laboratory Louis Néel
C.N.R.S Grenoble
C.Kitegi, D.Givord



Reversible properties vs temperature

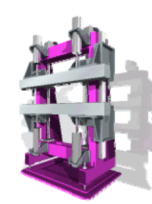


Spin Reorientation transition (SRT)



More details at EPAC2006

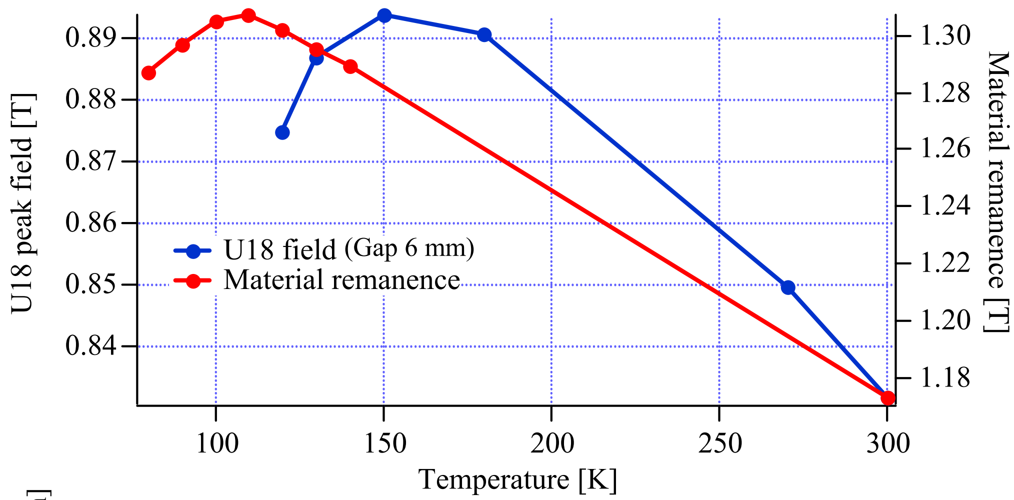
Development of cryogenic permanent magnet in-vacuum undulator at ESRF (C. Kitegi)



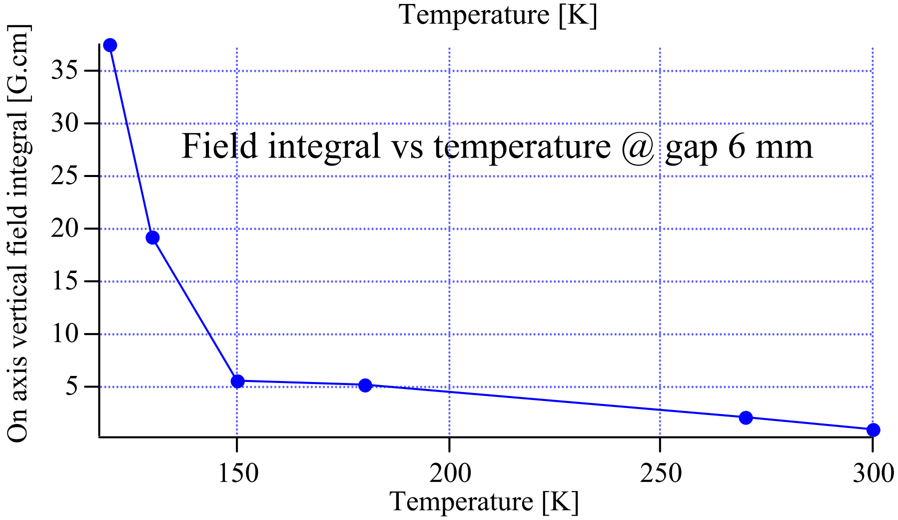
Numerical Magnetostatic Simulations

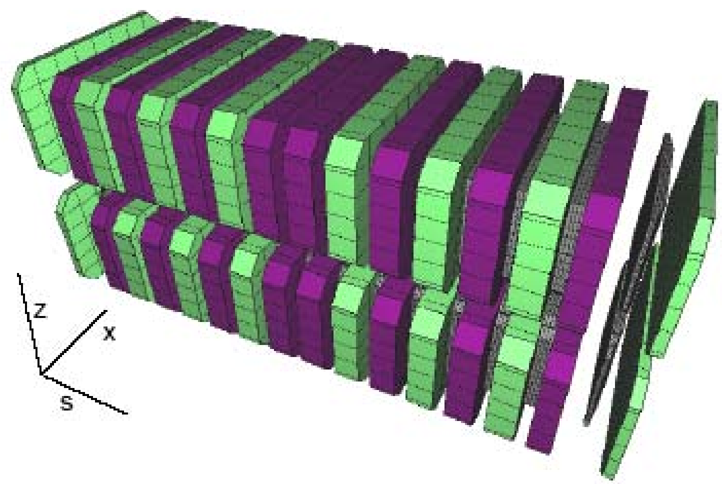
Radia model :

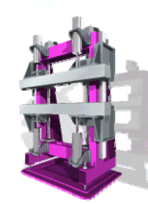
- Requires **non linear treatment of permeabilities** (transv. & long.)
- Model becomes inaccurate if $T < T_{SRT}$



Peak field maximum at 150 K







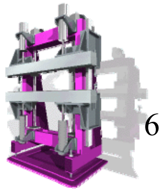
Liquid Nitrogen Closed Loop Cooling

Benefits:

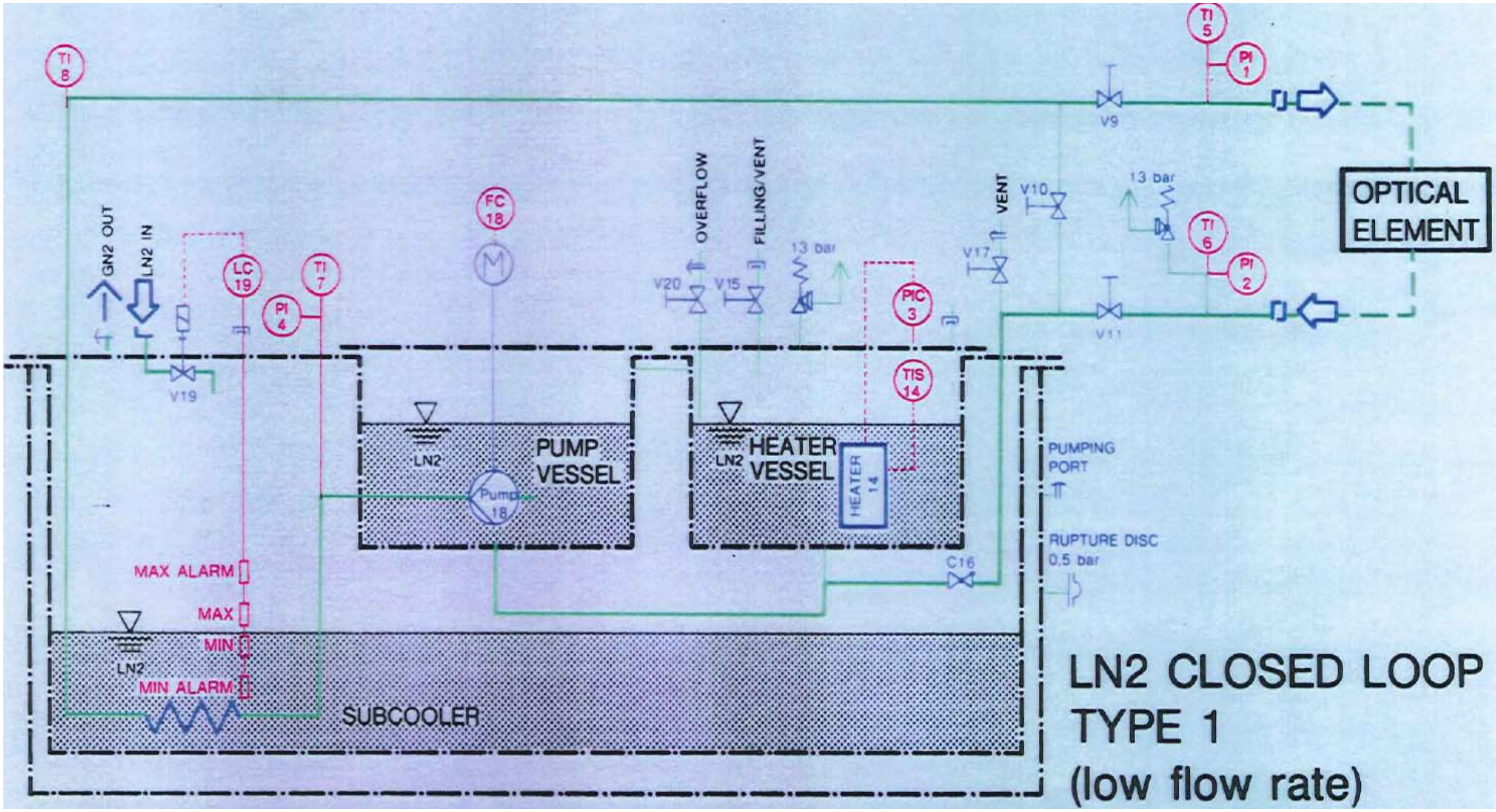
- Low thermal gradient in girder
- Cryogenic pumping @ 77 K
- Reliable
- Simple maintenance (2 years)
- Automatic LN2 filling
- 200 Watts electrical power
- Used on ESRF monochromators
- Large Power Margin

Drawback:

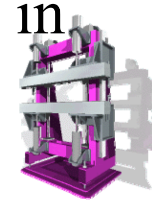
- Limited temperature variations. Need additional heaters for temperature tuning



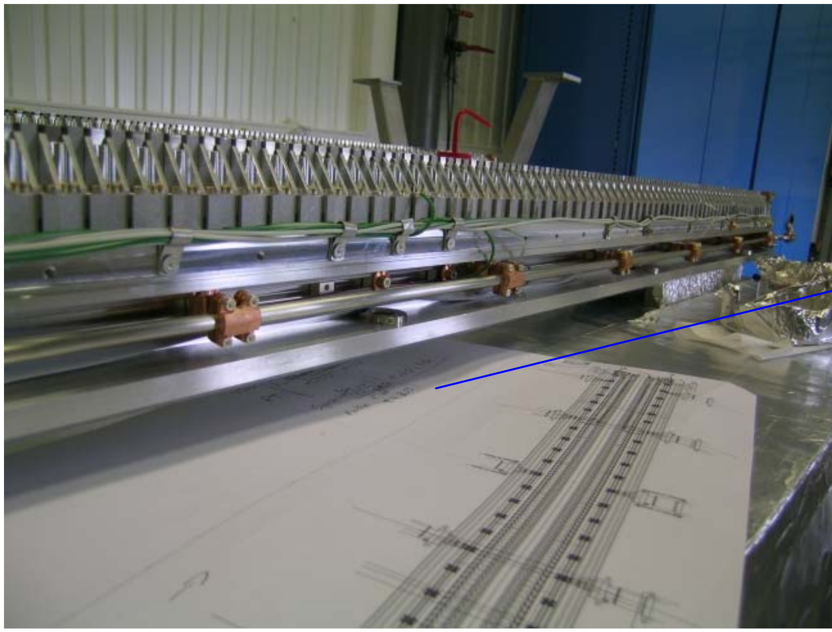
N2 Close Loop

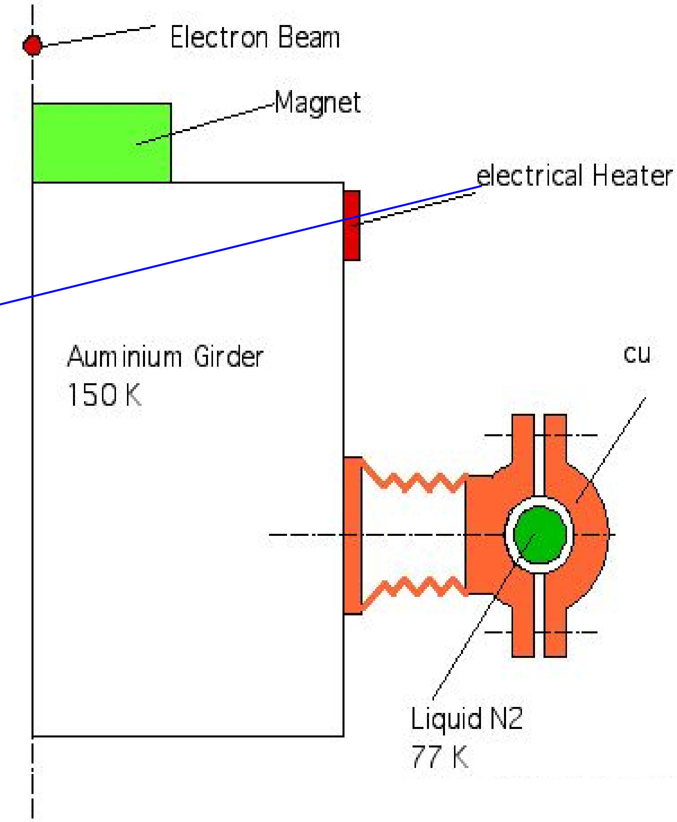


Return Pressure by heater ~ 1.5 Bars to avoid boiling helium in



Girder assembly





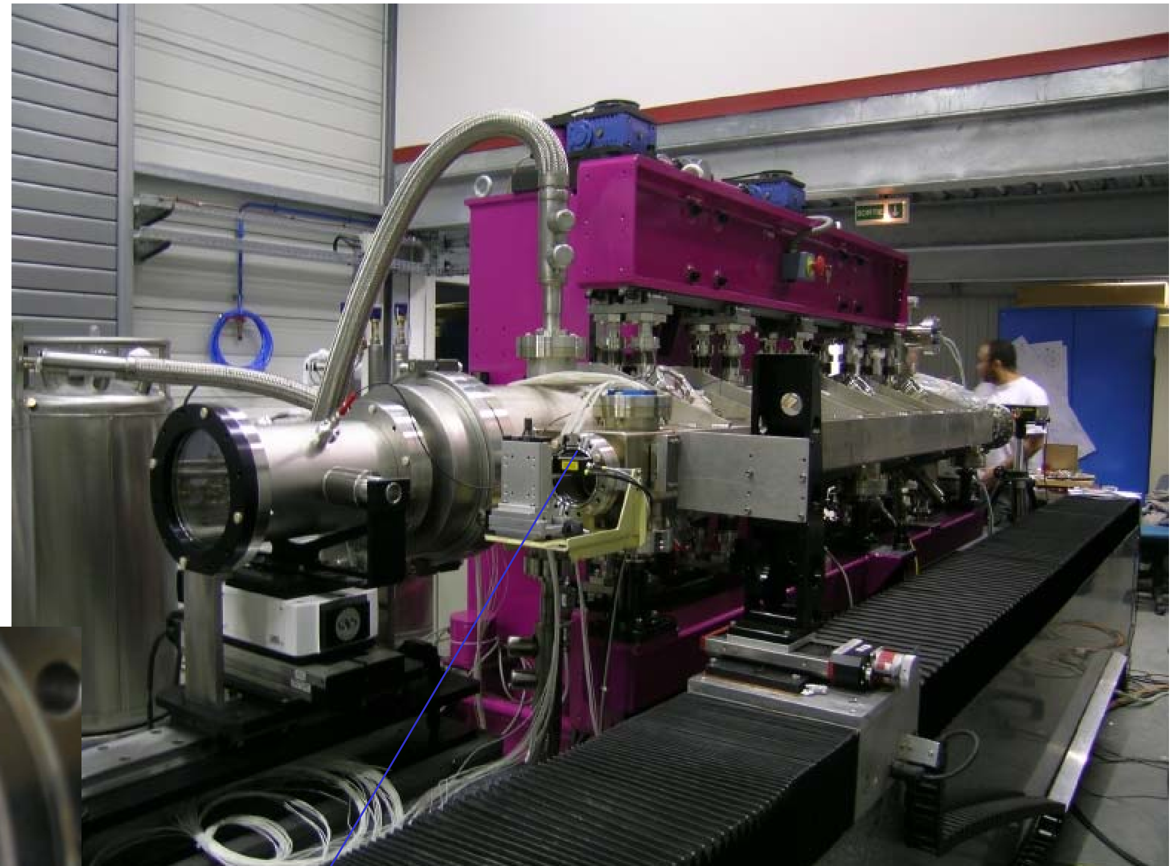
Heat Load budget without beam @ 130 K : 150 W (measured)

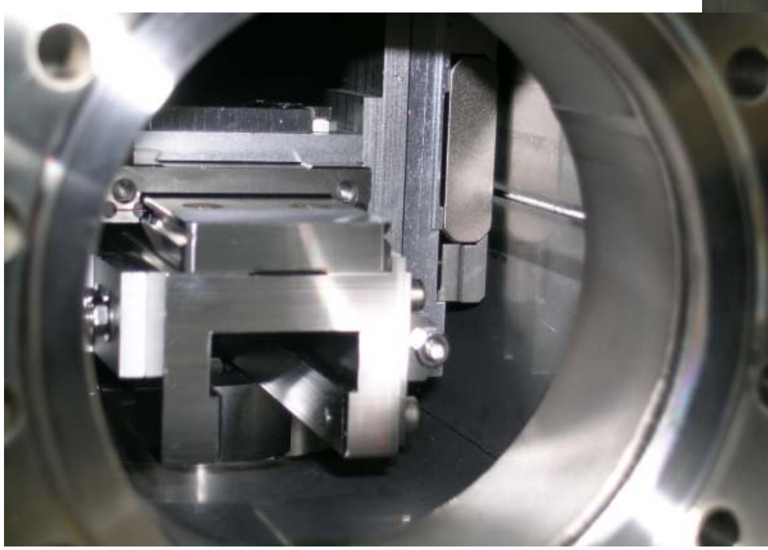
- Conduction 60 W (computation)
- Radiation 90 W

Magnetic Measurements at Cryogenic Temperature

Built :

- A dedicated vacuum chamber for field measurement only
- A stretched wire bench
  - -Field Integrals
  - -Gap Measurement
- A fast scanning Hall probe





Hall Probe Scanning Bench

Difficulties

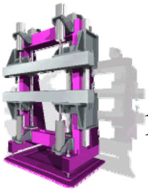
- Drive system lacked rigidity and needed to implement two laser interferometers in order to correctly determine the longitudinal position of the Probe.
- Hall probe calibration solved by keeping Hall Probe at 20 deg C by internal heating

Performances

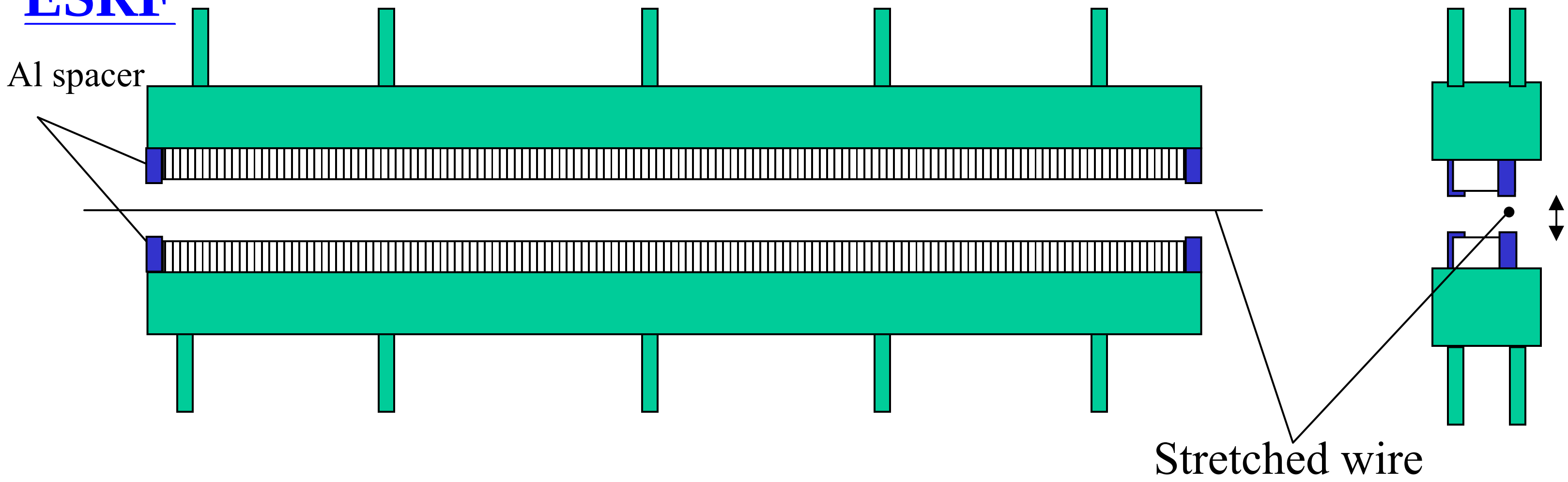
- Measure Bx,By,Bz
- Sample : 0.1mm over 2.5 m (25000 pts) in 90 sec
- Measured repeatability at cryogenic temperature

  < 2 G in the peak field

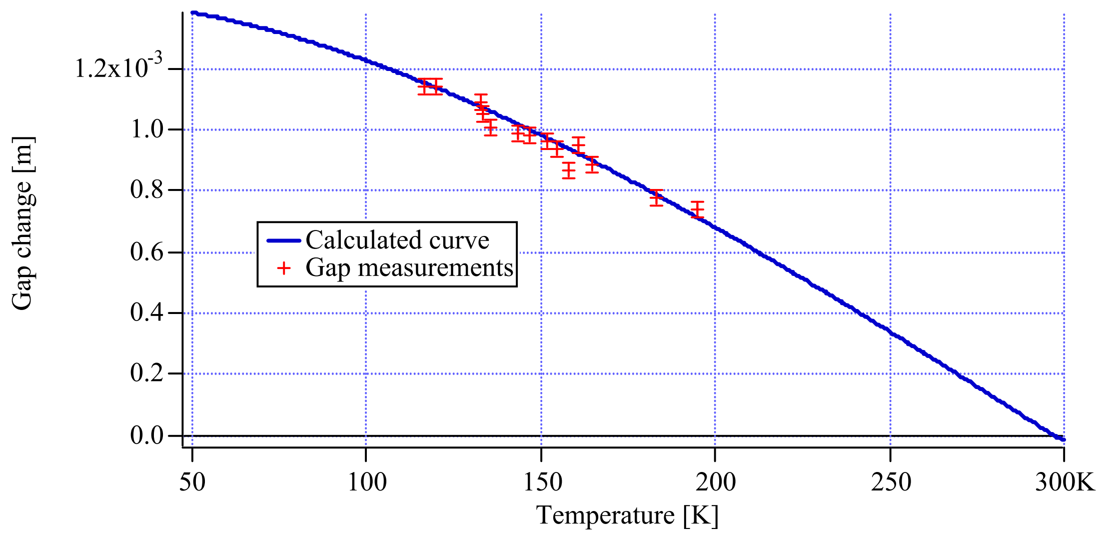
  ~ 0.1 deg rms of phase deviation



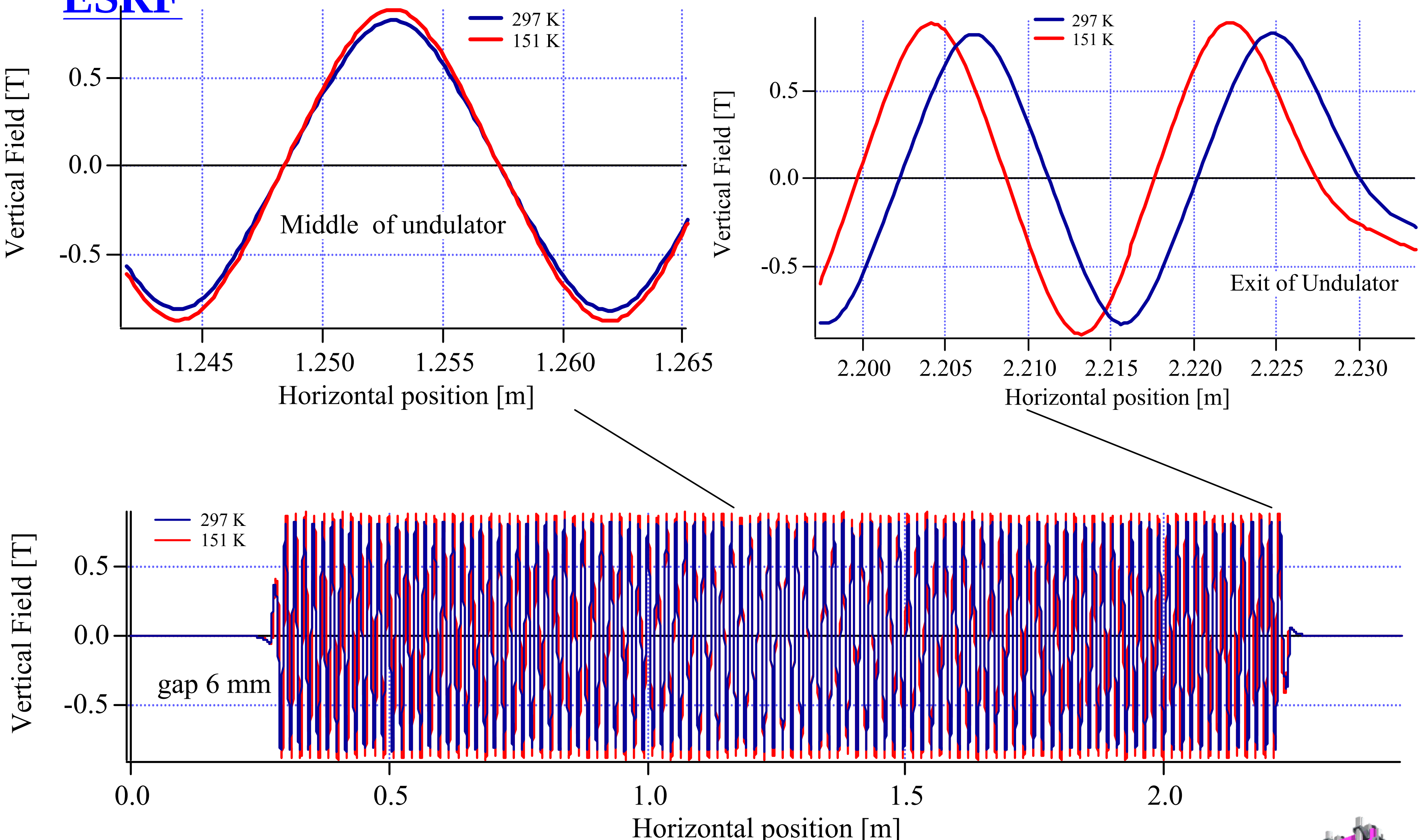
Gap determination is an issue



Gap change vs temperature is measured with the stretched wire

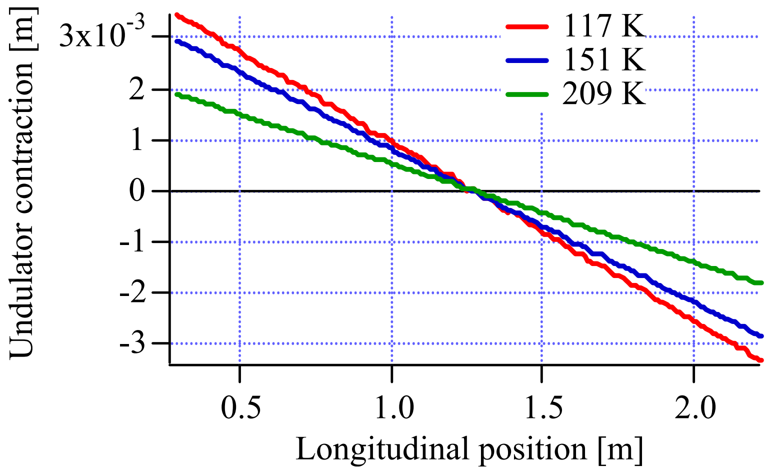


Longitudinal Thermal Expansion

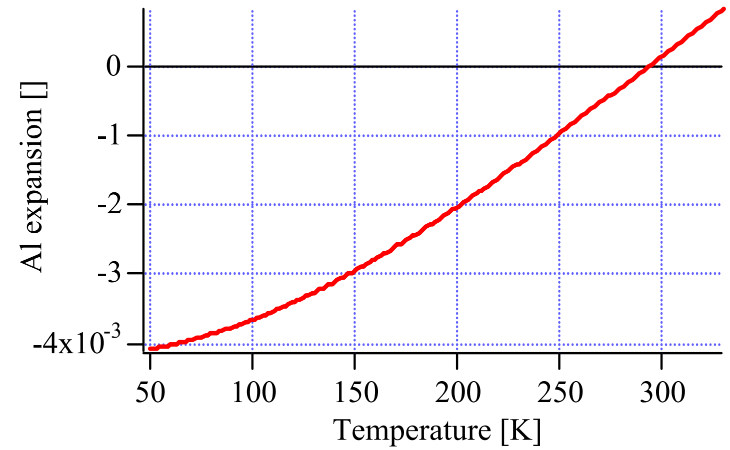


Accurate determination of temperature gradients

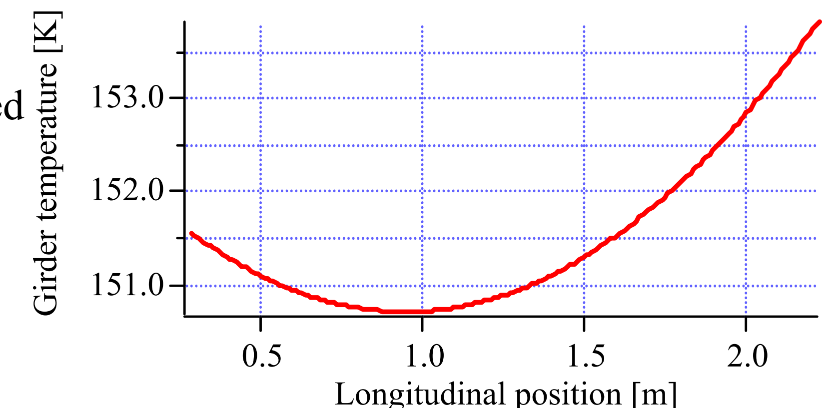
Longitudinal position of peak field



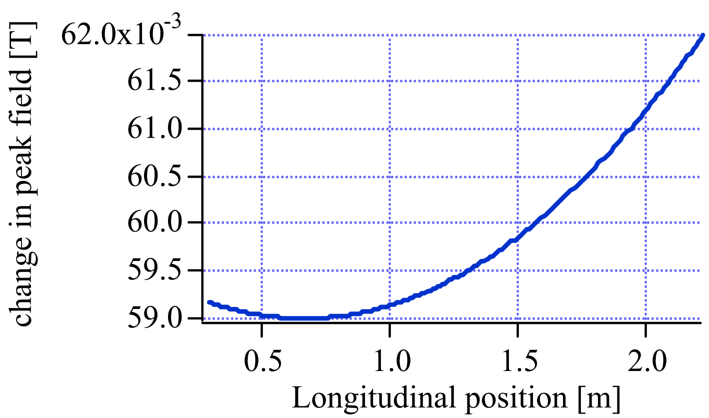
+



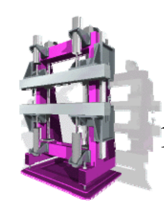
Polynomial fit



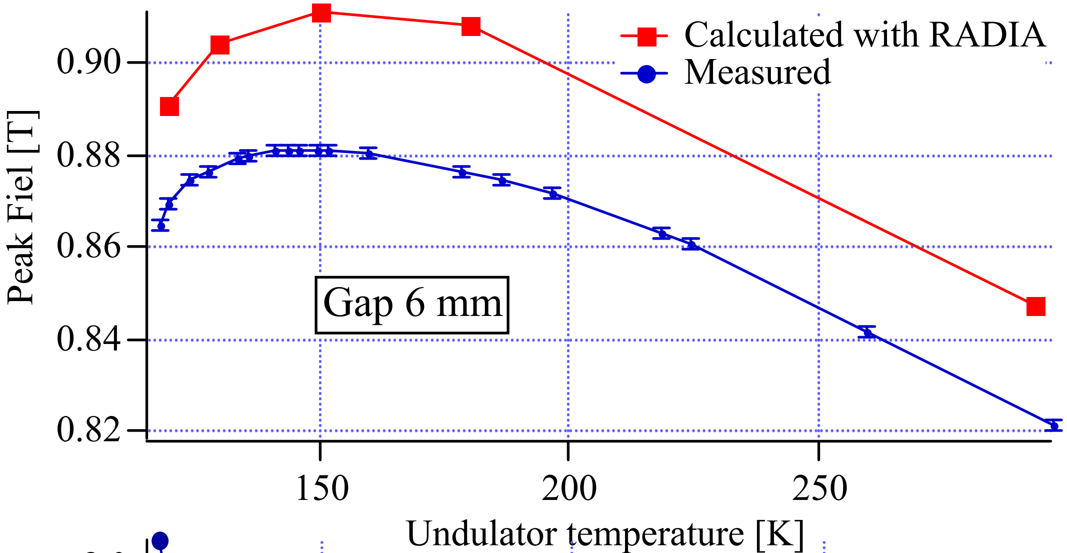
Well correlated with



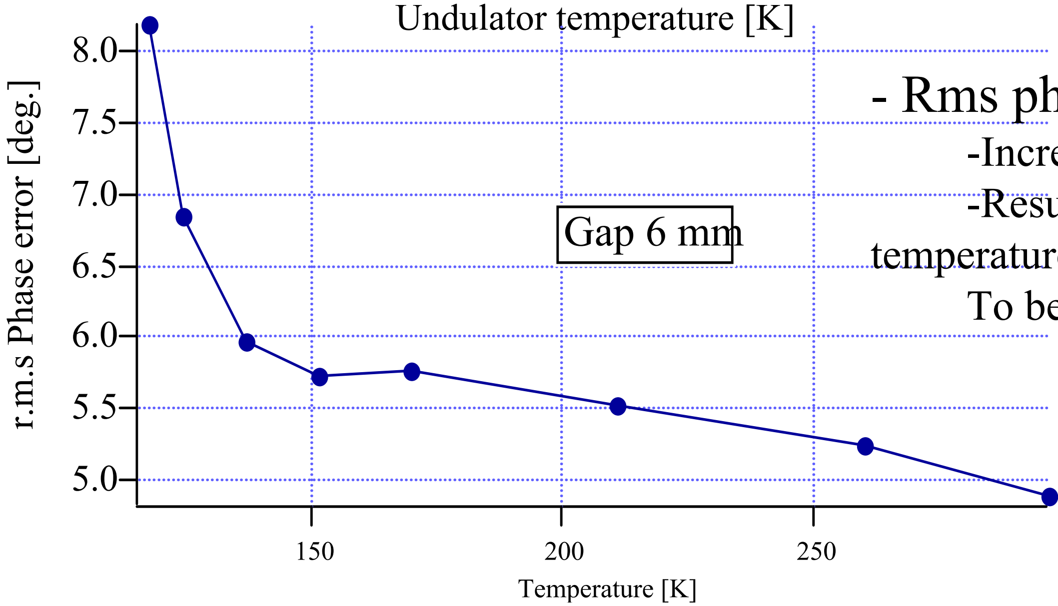
Longitudinal temperature gradient can be determined with field measurements



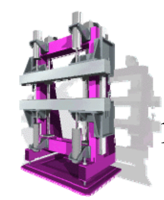
Field measurements



Agreement of peak field vs Temp between Measurement and Radia prediction



- Rms phase error :
  - -Increase by ~ 1 degree from 300 to 150 K
  - -Results from residual longitudinal temperature gradient
  - To be improved for future devices.



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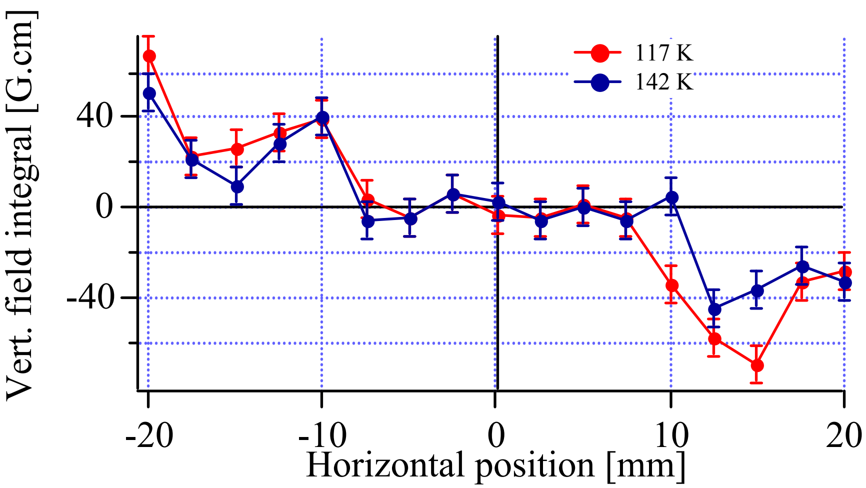
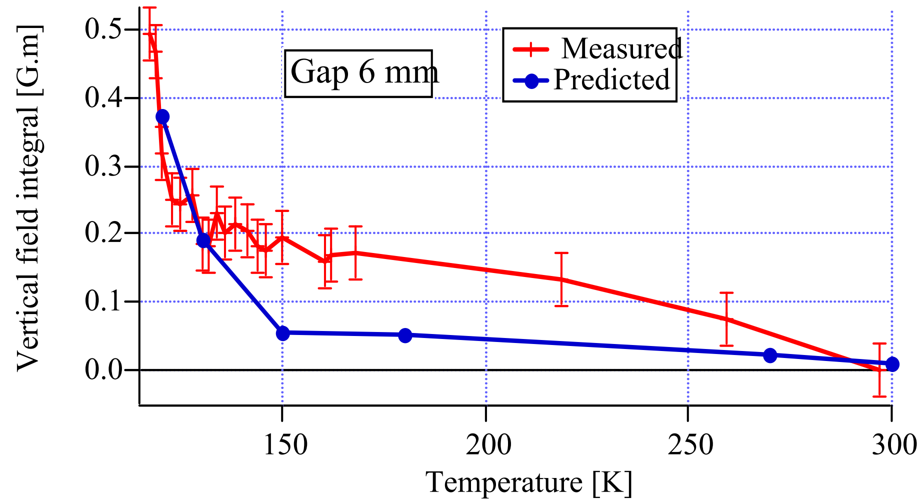
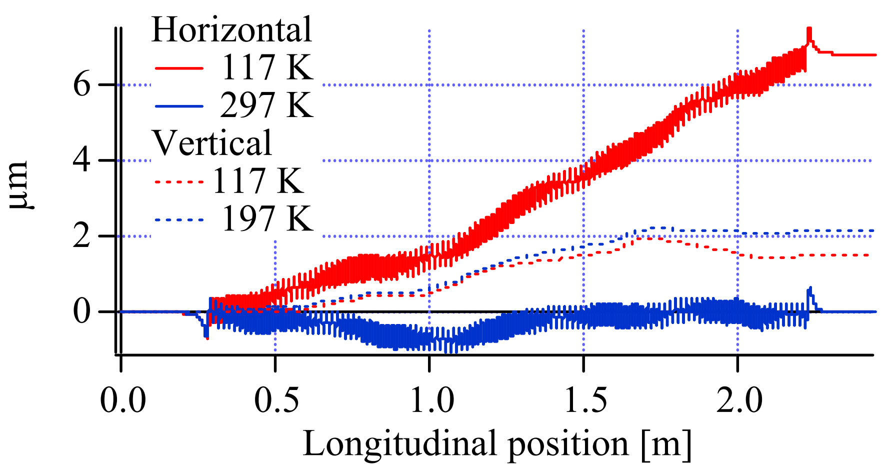
Field Integrals







Vertical field integral induced et each extremity which is generated by the variation of magnetic properties vs temperature.

Cu-Ni Foil & End blocks

Spring loaded tension mechanism of Cupper-Nickel foil :

- Compatible with differential thermal expansion between Copper and Aluminium
- Copper ends block thermally decoupled from Aluminium girder

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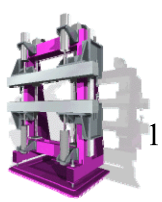
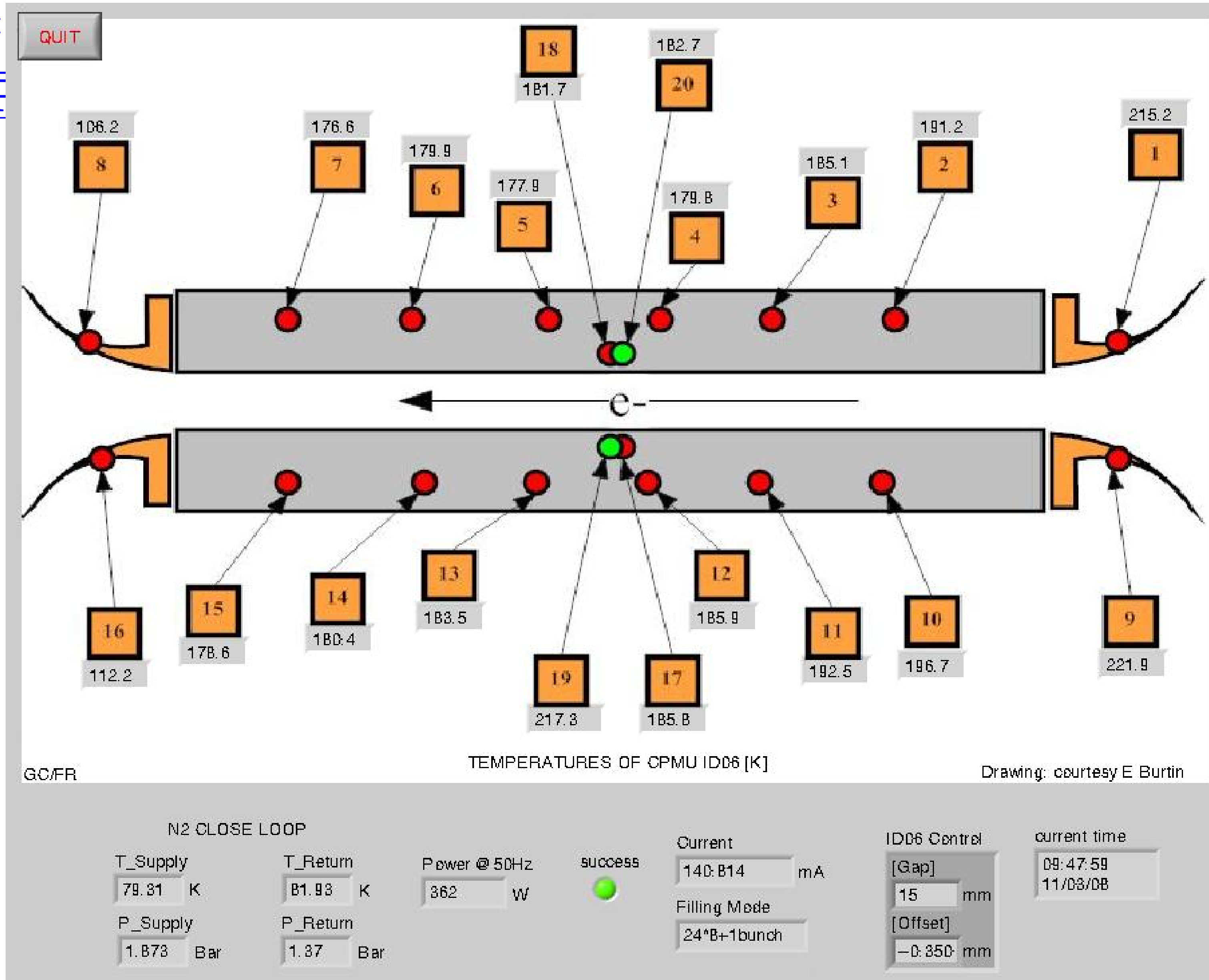
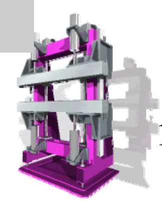
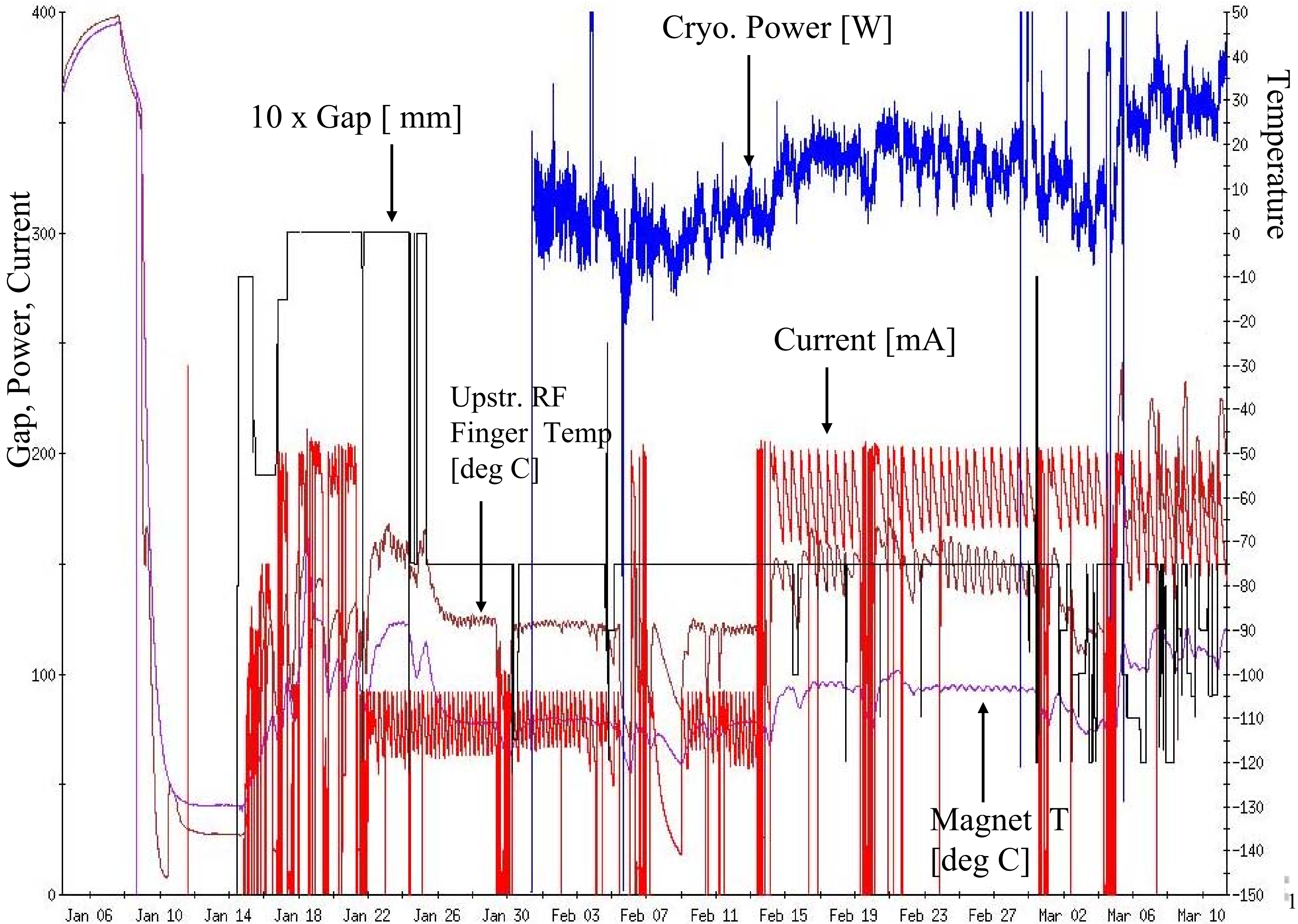
Experience with Beam

- Operated at Cryogenic Temperature since 8 January 2008. Beamline taking beam since 2 March 2008.
- Warm-up test scheduled during the March shutdown. Pressure Rise ?
- Closed Orbit error < 10 % of size in both plane uncorrected




QUIT
18
181.7
182.7
20
106.2
8
176.6
7
179.9
6
177.9
5
179.8
4
185.1
3
191.2
2
215.2
1
e-
16
112.2
15
178.6
14
180.4
13
183.5
19
217.3
17
185.8
12
185.9
11
192.5
10
196.7
9
221.9
GC/FR
TEMPERATURES OF CPMU ID06 [K]
Drawing: courtesy E Burtin
N2 CLOSE LOOP
T_Supply
79.31 K
T_Return
81.93 K
P_Supply
1.873 Bar
P_Return
1.37 Bar
Power @ 50Hz
362 W
success
Current
140.814 mA
Filling Mode
24*8+1bunch
ID06 Control
[Gap]
15 mm
[Offset]
-0.350 mm
current time
09:47:59
11/03/08





Cryo. Power [W]
10 x Gap [mm]
Current [mA]
Upstr. RF
Finger Temp
[deg C]
Magnet T
[deg C]
Gap, Power, Current
Temperature
400
300
200
100
0
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
Jan 06
Jan 10
Jan 14
Jan 18
Jan 22
Jan 26
Jan 30
Feb 03
Feb 07
Feb 11
Feb 15
Feb 19
Feb 23
Feb 27
Mar 02
Mar 06
Mar 10

Cryogenic Powers

Without Electron Beam

Radiation from Chamber Wall	90 W
Conduction in Supports	60 W
Power in N_2 Pipe (50 x 1 W/m)	50 W
Power in Circulation Pump	50 W

From Electron Beam

Beam WakeField in RF Finger	0-30 W	Extremities	predicted gap=30 mm I=16 x 6 mA
Return Current in Copper Sheet	10 W	Uniform	predicted gap= 5 mm I=16 x 6 mA
Unexplained yet	0-90 W	~uniform	measured fct(gap, Time struct)

Total Cryogenic Power	250-350 W	measured
N_2 Consumption	250 – 350 litre/day	measured

Remaining Issues

Observe 0-90 Watt with beam !!

- Depends on gap and filling pattern
- Is it HOM in undulator tank ?
- It changes the temperature ~ uniformly by 30 deg
- Small change of peak Field (< 1 %)
- No additional phase error

Lack of cooling in the upstream RF finger

- generate a gradient along the magnet array of about 10-15 deg corresponding to a flux input of 6-10 Watts
- Generate phase errors => must be reduced
- Remedies :
  - improved thermal connection to RF finger
  - Mechanical taper
  - Improve thermal conductivity in the magnet girder

Conclusion

ood progress

ome Issues still need to be understood

o operational problem with ring

ase variations follows the longitudinal temperature gradient

-Needs to reduce longitudinal temperature gradient for low phase error !

merous design improvements have been identified

Magnetic measurements systems

Choice of materials

Heat transfers

….

xt cryogenic undulator under design

High remanence (Br > 1.45 T @ 150 K)

Low phase error required (≤ 2.5 deg, operation above 60 keV)

Period 17-18 mm

No bake out of magnets