A 7T Multipole Wiggler for BESSY II

First Commissioning Experience

Ernst Weihreter / BESSY

Collaboration between:

BESSY / Berlin
BINP / Novosibirsk
Hahn-Meitner Institut (HMI) / Berlin

- ♣ Basic ideas of wiggler concept
- ♣ Wiggler parameters
- ♣ First commissioning results:

    Beam induced LHe consumption

    Beam optical implementation in BESSY II

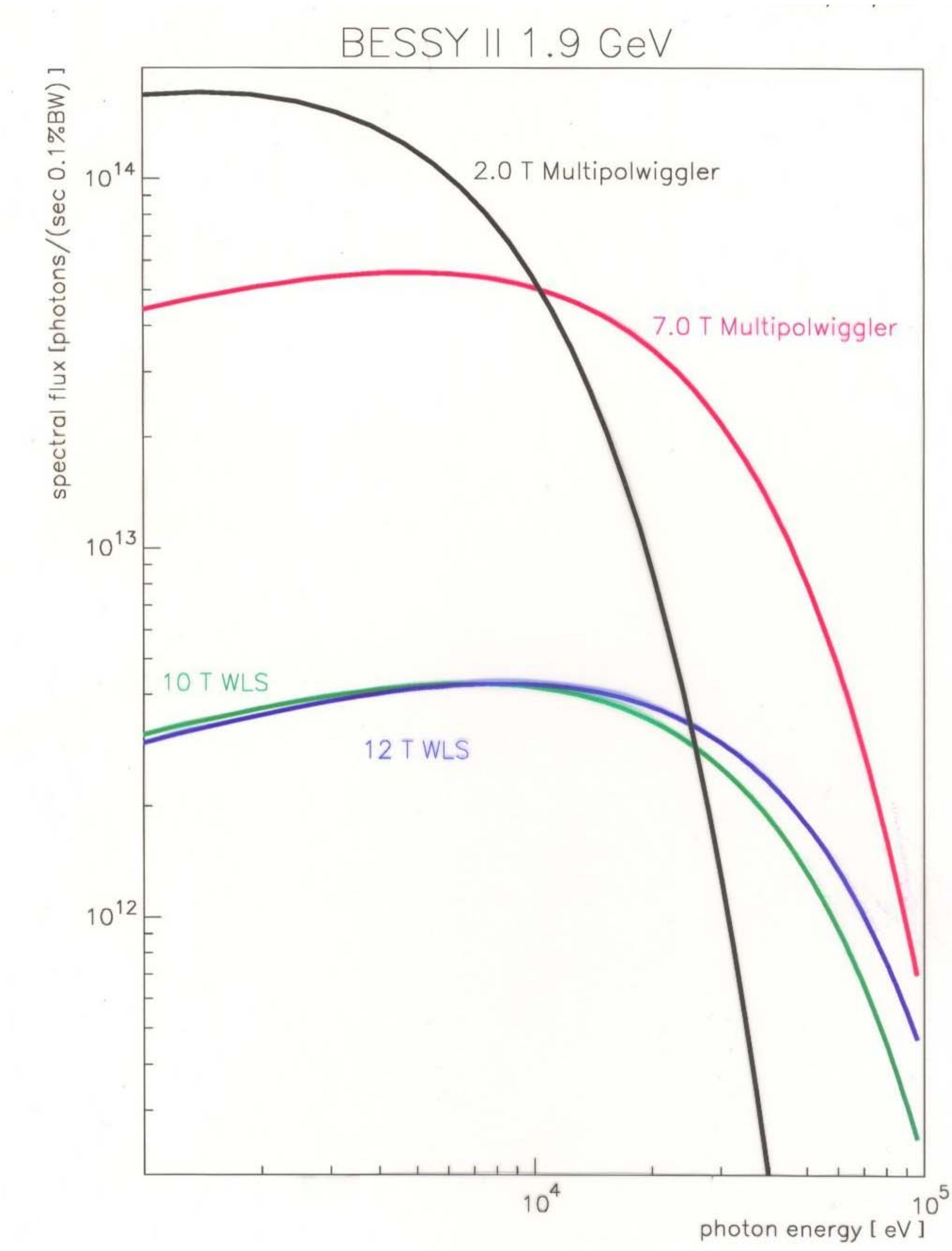
Motivation for the wiggler project:

Provide a high photon flux up to 60 keV for the HMI for

- ♣ X-ray residual stress analysis of technical samples
- ♣ X-ray magnetic scattering studies

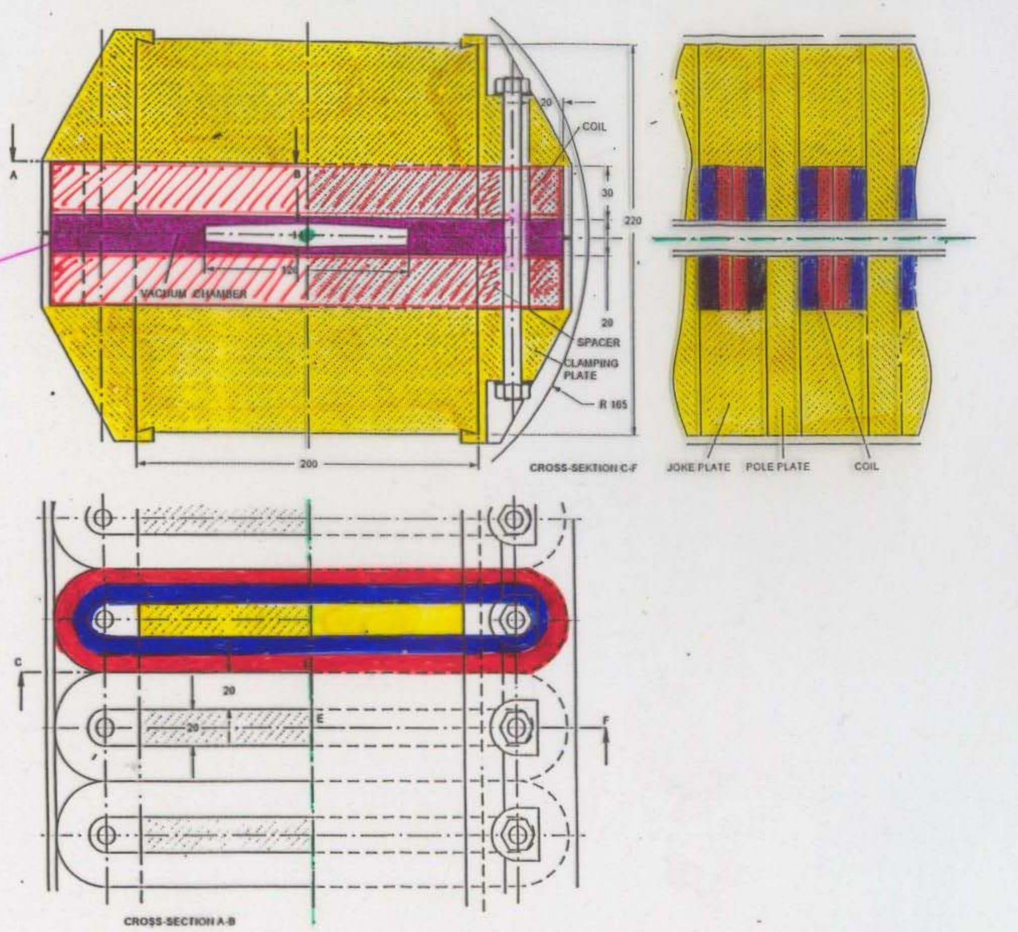
Specific design goal:

Provide 10^{10} photons / sec at 60 keV in an aperture of 0.5 x 0.5 mm in a 30 m distance from the source



Wiggler Concept:
(for SESAME)

G.A. Voss / DESY
H. Kaiser / DESY
E. Weihreter / BESSY



Vacuum chamber 4k

B_o = 7.5 T, N_p = 15

g_M = 20 mm
λ_W = 14 cm
free aperture = 14 mm

cold chamber

Senkrechte Schnitte durch den Wiggler-
magneten und die Vakuumkammer

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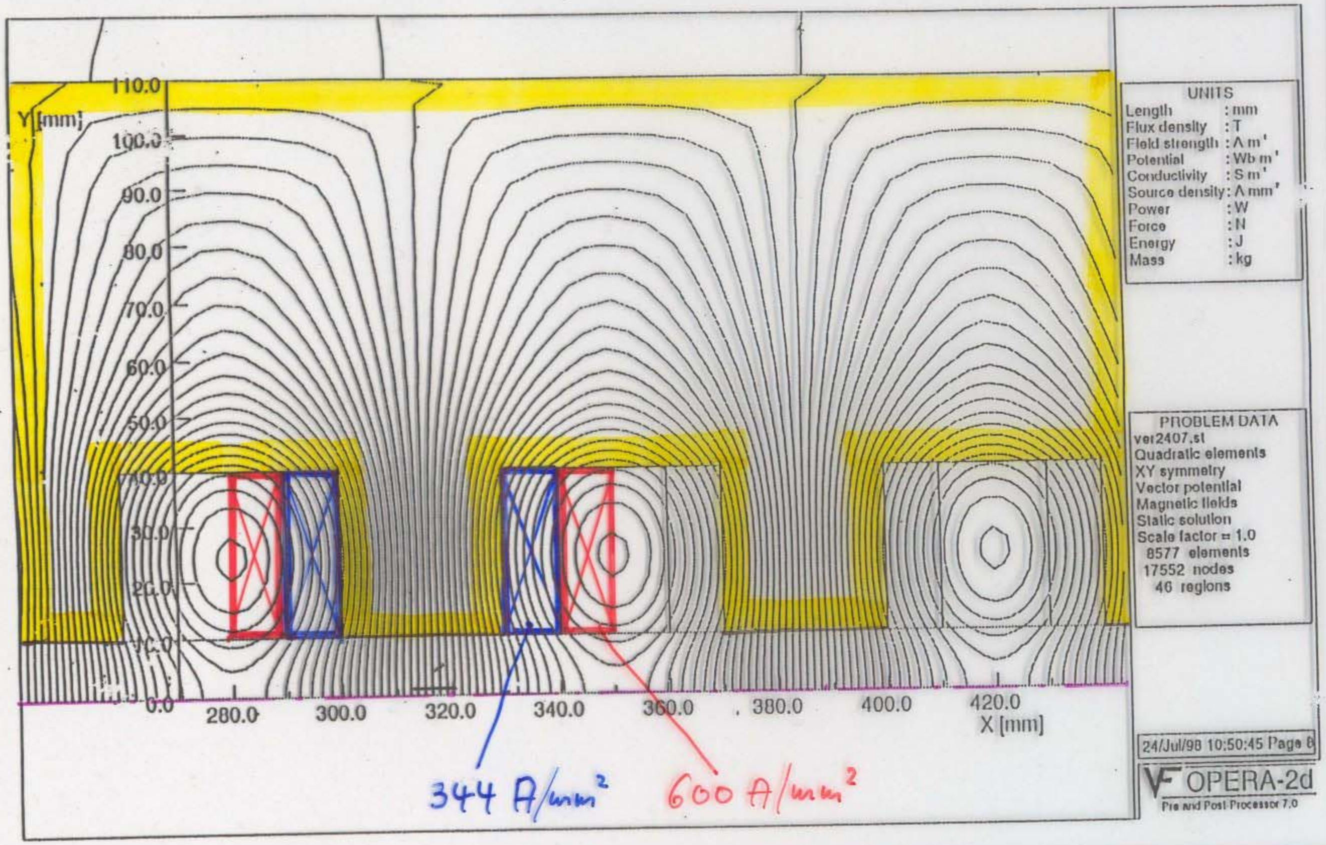

hmi

Verlauf der magnetischen Feldlinien (Detailansicht)

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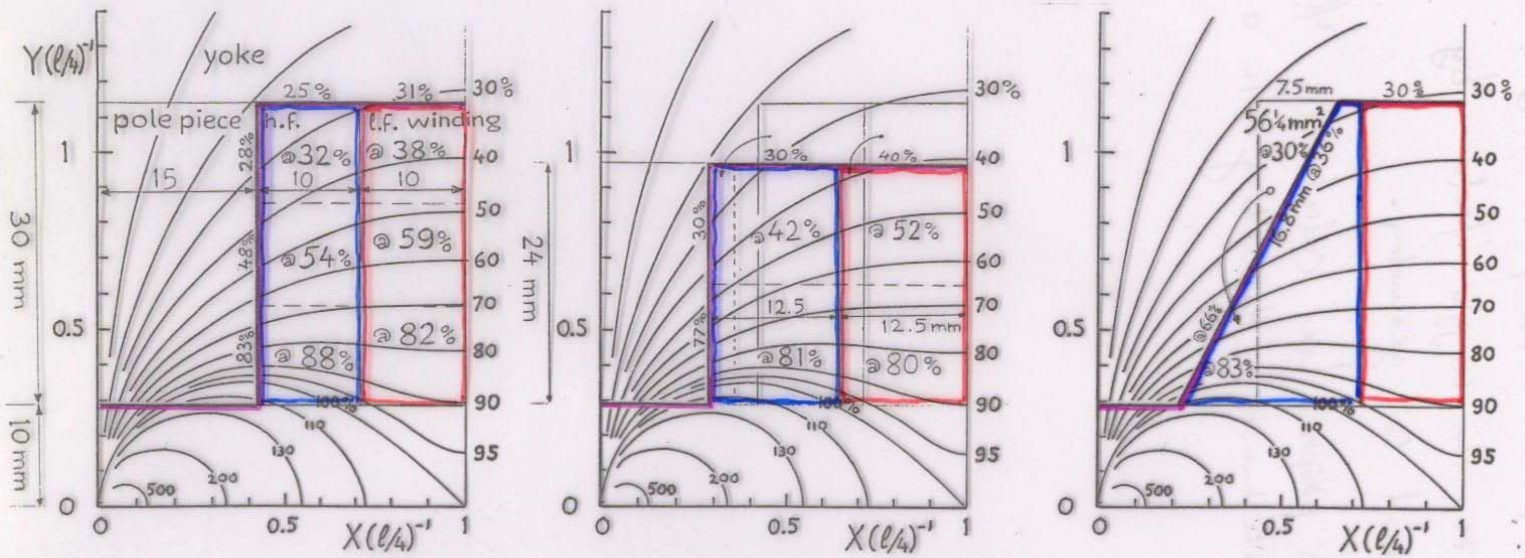
S.L. Wipf / DESY : "Efficiency" curves for the placement of windings

Fig. 12 "SESAME" geometry ($\ell = 140$ mm) and modifications thereof
@ 60 kA/cm² low field wdg / 34.4 kA/cm² high field wdg

a) original b) narrow pole c) slanting pole side



Fe poles: B = 7.31 T 7.86 T 7.65 T

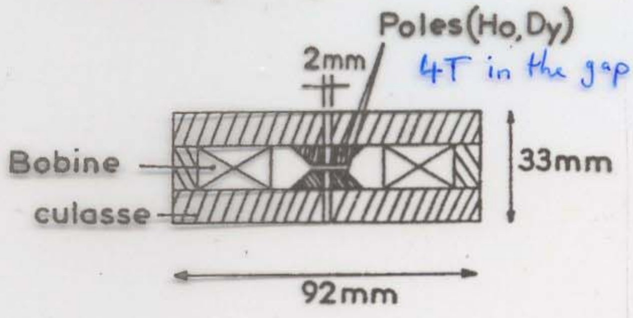
Ho/Dy poles: 8.17 T 8.37 T 8.33 T

Pole pieces from Lanthanides ?

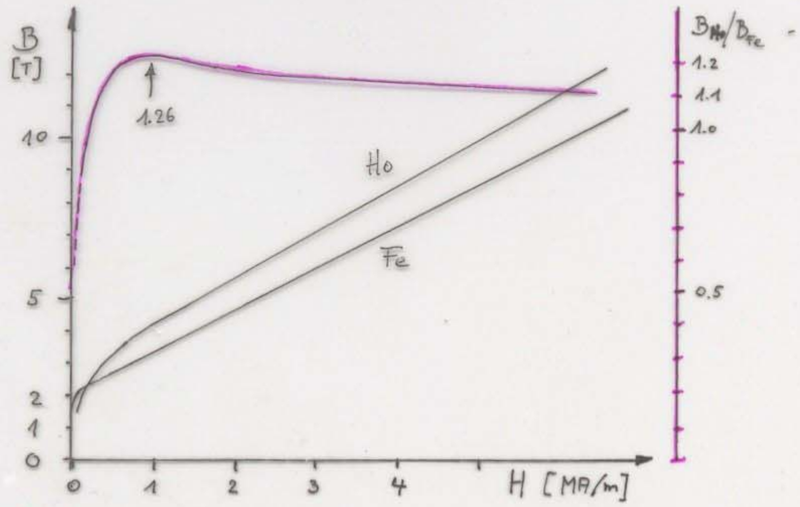
suggested by S.L. Wipf / DESY

	B_{sat} T	T_{Neel} K	T_{Curie} K
Gd^{64}	2.69		293
Tb^{65}	3.41	230	220
Dy^{66}	3.84	179	89
Ho^{67}	3.87	132	20
Er^{68}	3.45	85	20
Tm^{69}	2.76	58	32

Bonjour, Septier (1967):
Electron focusing lens



Meissner / HMI (1999): 2.5T field enhancement with Dy pole pieces in a 14.5T split pair magnet



However:
- Ho, Dy difficult to handle, very reactive
- rather expensive in bulk (technical) form ~ 2'000 €/kg

HMI Multipole Wiggler Field Parameters
(Specs)

Field direction	vertical	
Nominal peak on-axis field, B_o	7.0 T	
Maximum peak on-axis field	7.2 T	
Period length λ_w (target value)	140 mm	148 mm
Number of poles	17	
strength distribution	¼, ¾, 1 (13 poles), ¾, ¼	
Vacuum chamber aperture:		
elliptical shape		
horizontal (for λ_w = 140 mm)	110 ± 0.1 mm	
vertical	14 ± 0.1 mm	13 mm
Good field region Δx:	$\pm$ 6 mm horizontal from the central axis	
$\lvert \Delta B/B_o \rvert$ at $\Delta x = \pm 6$ mm in midplane	$\leq 5 \times 10^{-4}$	
horizontal field B_x on the nominal axis	$\leq 3 \times 10^{-3}\, B_y$	
max. stray field on axis at a distance of 1 m from either end of the iron yoke	$2 * 10^{-4}$ T	
time to ramp up or down between 0 T and 7 T	≤ 5 min	
field stability $\Delta B_y/B_y$ over two weeks	$1 \cdot 10^{-4}$	
Total Radiated Power		
for BESSY II (1.9 GeV, 500 mA)	56 kW	

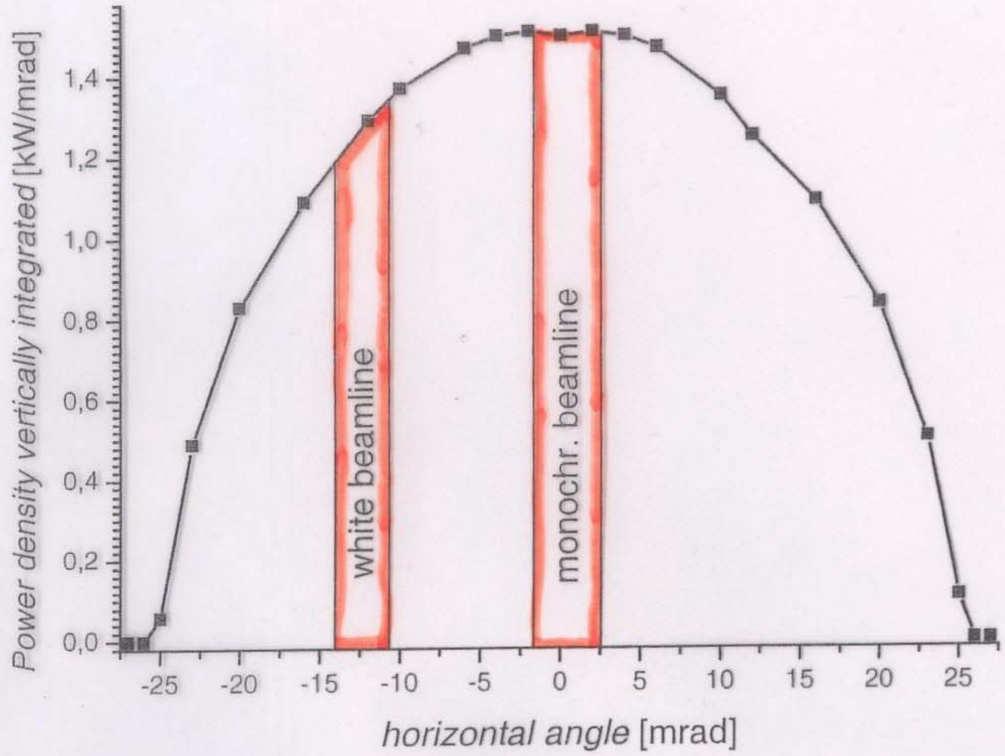


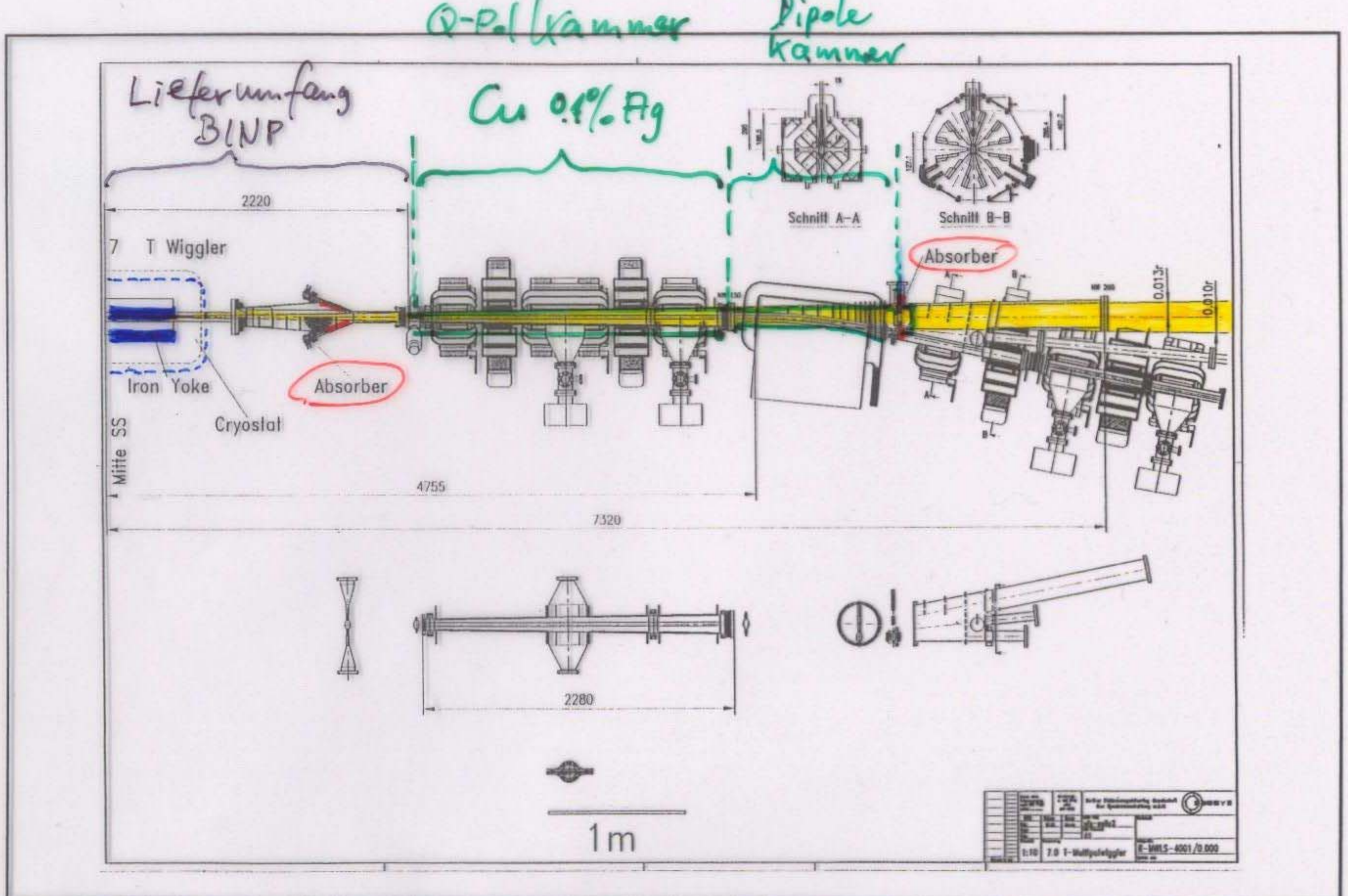
Figure 4: Horizontal power distribution of the 7 T multipole wiggler at 1.9 GeV / 500 mA, total power 56 kW

Power incident on cold chamber

i)	**Backscattering of SR from the first absorber**	**0.25 W**
ii)	**Low energy radiation (0.1 – 3 eV) due to vertical radiation distribution**	**0.6 W**
	1mm orbit offset, 1mrad angle error	**4.3 W**
iii)	**Wake fields due to surface roughness**	**0.01 W**
iii)	**Ohmic losse due to mirror currents $\propto I^2$:**	
	stainless steel	**2.8 W**
	copper	**0.04 W**

Radiation shield inside the beam chamber on a temperature T > 4K is recommended

$P_{rad} = 56\ kW$ @ 500 mA



Gerader Abschnitt mit Vakuumkammer

BESSY

Wiggler Concept Budker Institute of Nuclear Physics

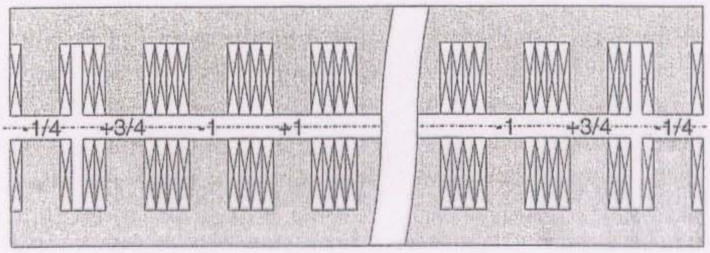


Fig. 2: Schematic configuration of the wiggler with 13 full poles (+/- 1) and 2 endpoles (- ¼ and ¾) on each side

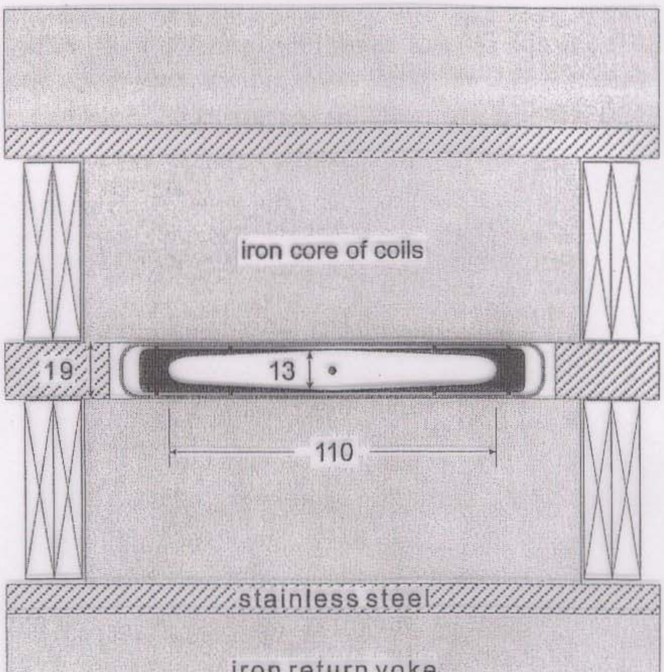


Fig. 3: Vertical cross-section of the wiggler with the vacuum chamber (@ 4.2K) and the inner radiation shield (@ 20K)

7T Multipole Wiggler Tests

- Maximum field 7.4 T after 11 quenches

- Continuous operation over 80 hours at 7 T
  15 hours at 7.2 T

- Field measurements:

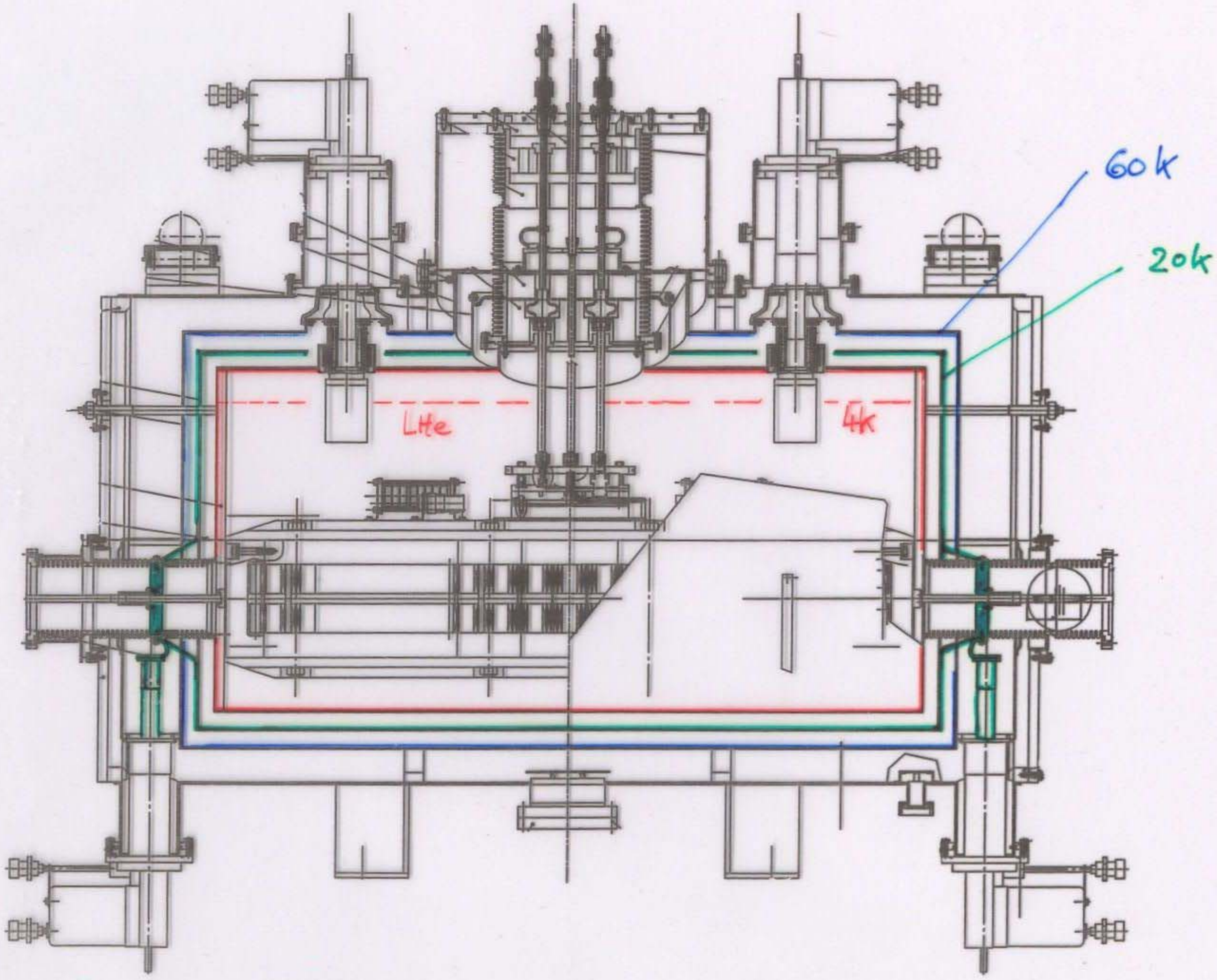
  Hallprobe: i) field on axis
  ii) horizontal field distribution for several poles

  "Stretched wire" measurements: integrated multipoles

Integral field at 7T	measured	specified
Second integral	2.6 10^{-4} Tm^2	2. 10^{-4} Tm^2
integr. Q-pole	> 1. 10^{-2} T	1. 10^{-2} T
integr. sextupole	0.63 T/m	0.5 T/m

→ ***Within error bars field is according to specs***

- LHe consumption: ~ 0.6 liter / hour at 7T in steady state operation


60k
20k
LHe
4k

Beam induced LHe consumption

I=0, B=0 : Q= 0.5 l/h (0.36 W)

I=100 mA, B=0 : Q= 1.6 l/h (1.15 W)

Beam induced consumption: Q_b = 1.1 l/h (0.8 W) @100mA

Current dependence: $Q_b \approx I^2$

20K-shield temperature: T = 10 K @ I = 0.
T = 28 K @ I = 300 mA

Potential causes:

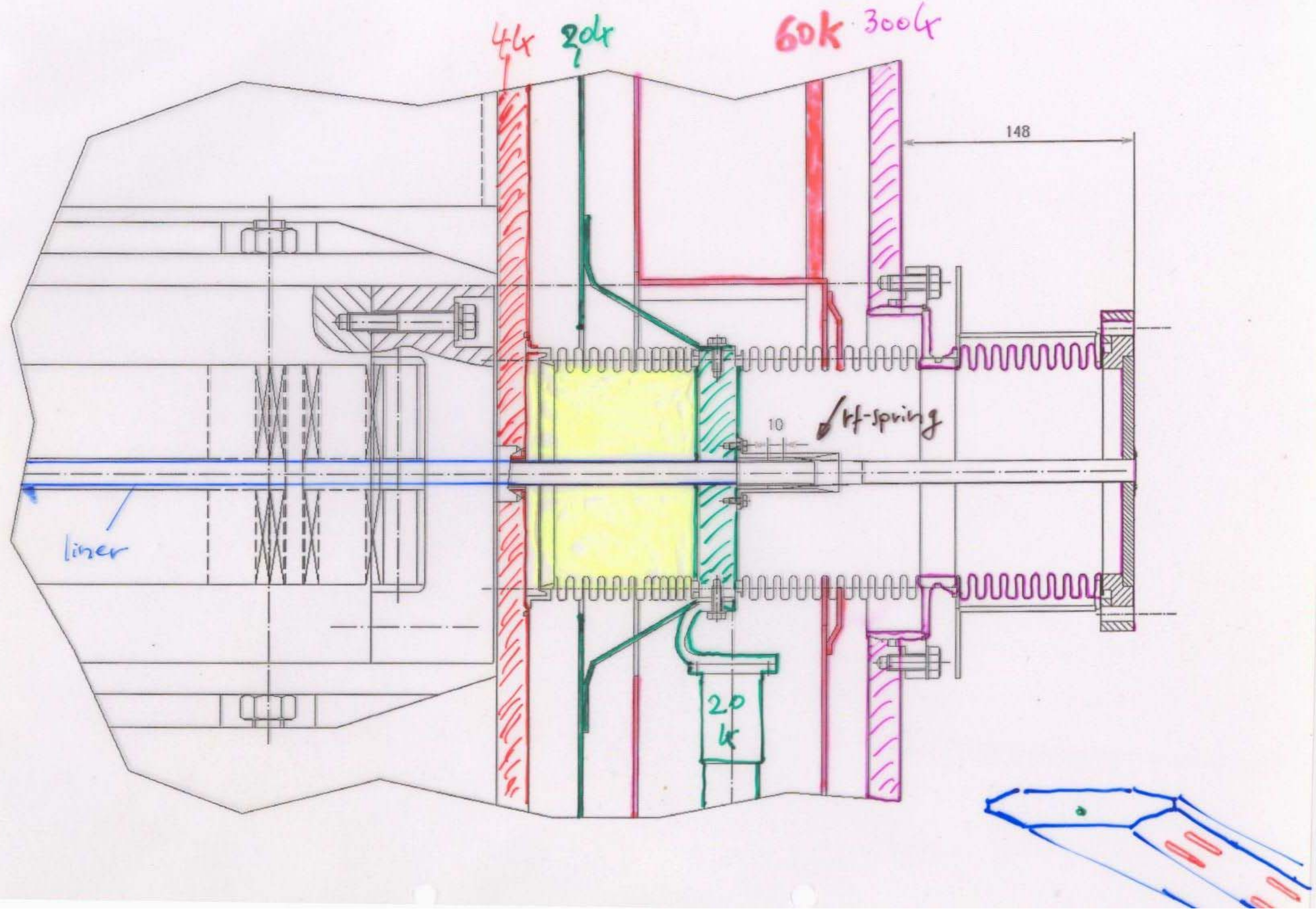
♣ resistive wall effect in the liner
analytical estimate: P = 0.13 W @ 100 mA

♣ wake fields induced by

i) cross section steps in the liner and rf-spring

ii) pumping slits in the liner

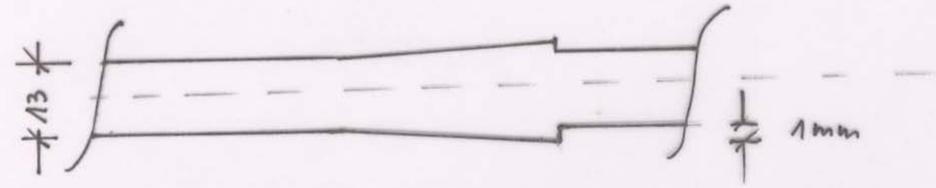
iii) resonance inside the bellows


4k
20k
60k
300k
148
10
rf-spring
20 k
liner

Step at rf-spring / MAFIA simulation

S. Khan / BESSY

vertical cut:



mesh size 0.5 mm / 3D
σ_{rms} = 5 mm

$\curvearrowright$ $k_{\parallel} = 0.18 \cdot 10^{11} \left[\frac{V}{C}\right]$
loss factor

$$P_{loss} = N_b \, q_b^2 \, k_{\parallel} \, \frac{1}{T_0}$$

T_0 = 800 nsec
N_b = 360
$q_b = 6.7 \cdot 10^{-10}$ C @ I = 300 mA

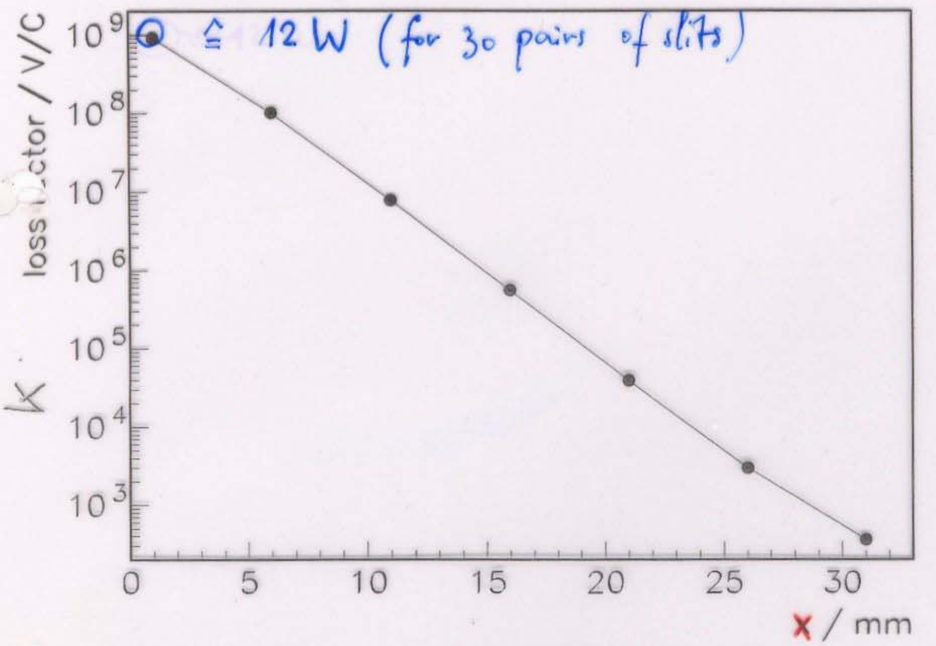
$\curvearrowright$ $P_{loss} \approx 3.6$ W

2 rf-spring + step in the liner $\rightarrow$ $P_{loss} \approx 11$ W

Weih / 26.11.02

Loss-factor of 2 pairs of slits in the liner (bunch length σ = 5 mm)

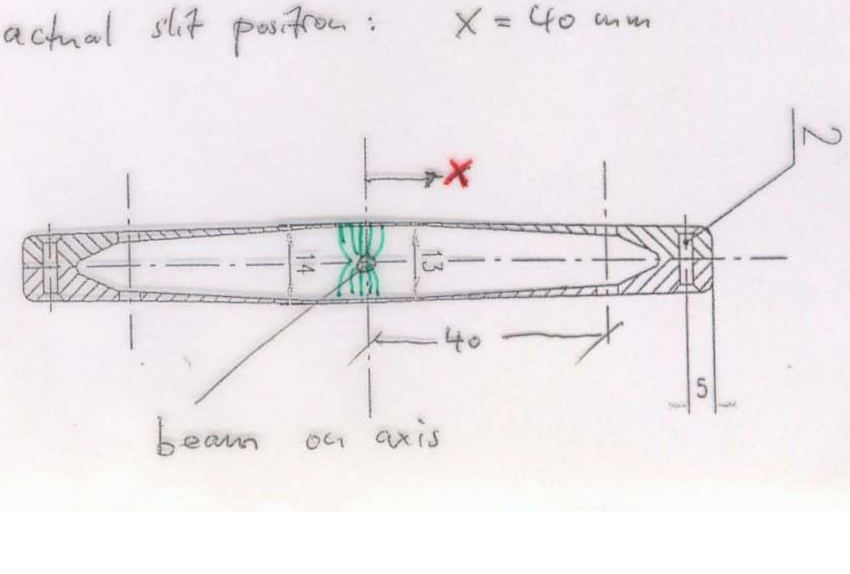
length of slits : 15 mm
width : 2 mm

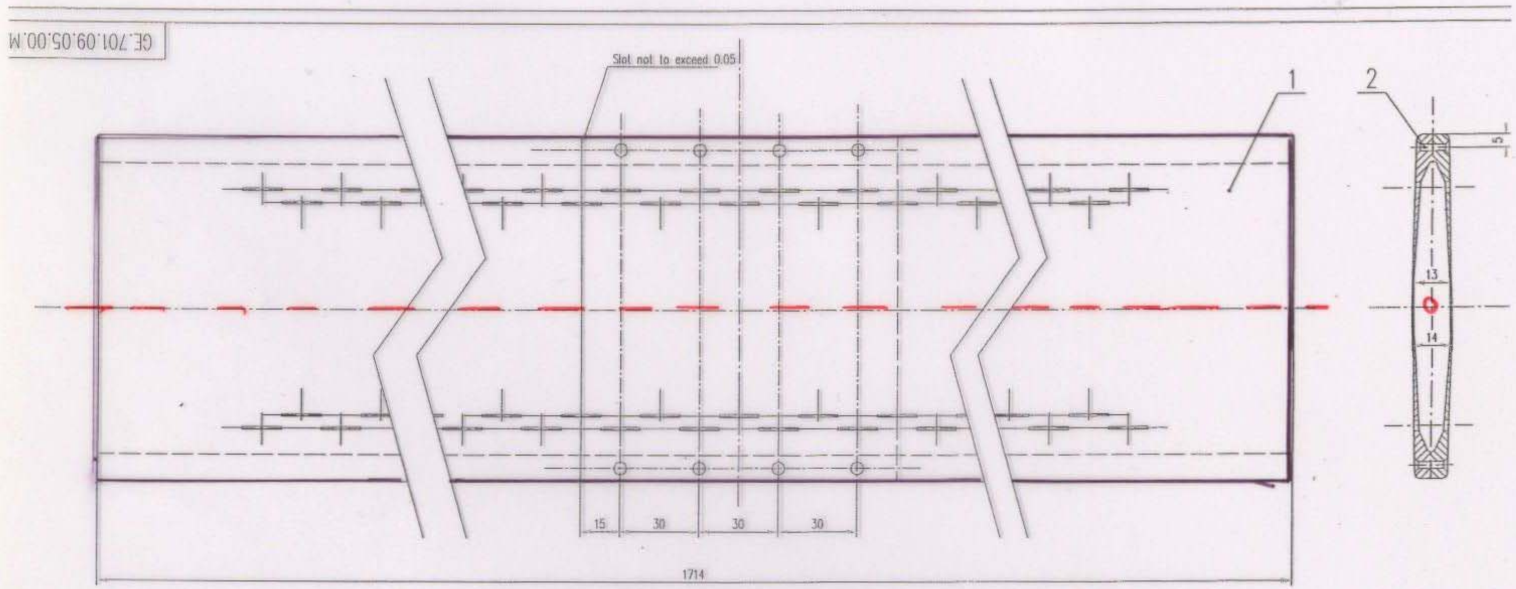


S. Lehan
MAFIA calc.

x : position of slit in horizontal direction from vertical mid-axis

actual slit position : x = 40 mm





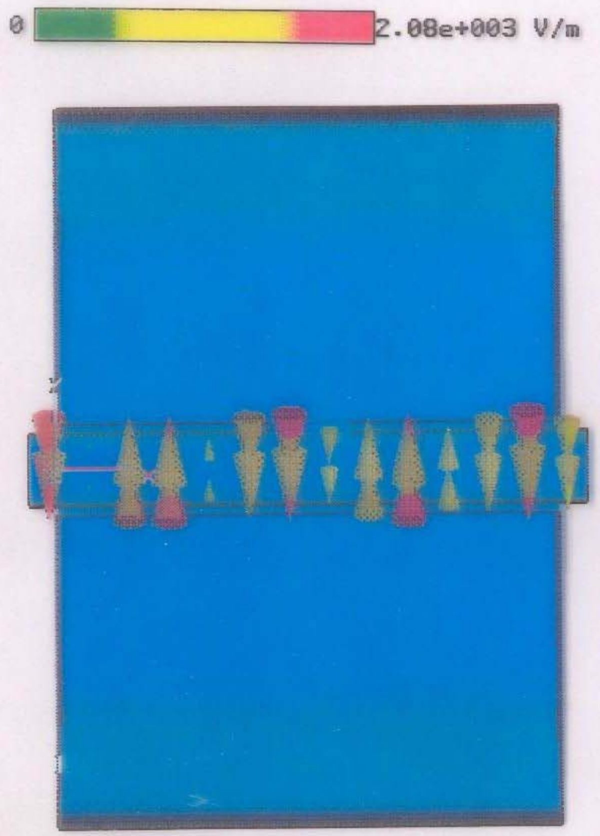
Size	Zone	Item	Part Number	Name	Qty	Notes
				Assembly units		
		1	GE.701.09.05.01.M	Semi-liner	2	
				Standard articles		
		2		Rivet 2.5x12	8	
				Brass (Nickel-plate 12 μm)		

Rev. Sheet Docum. No Signat. Date
Designed Zhurba
Checked
Approved

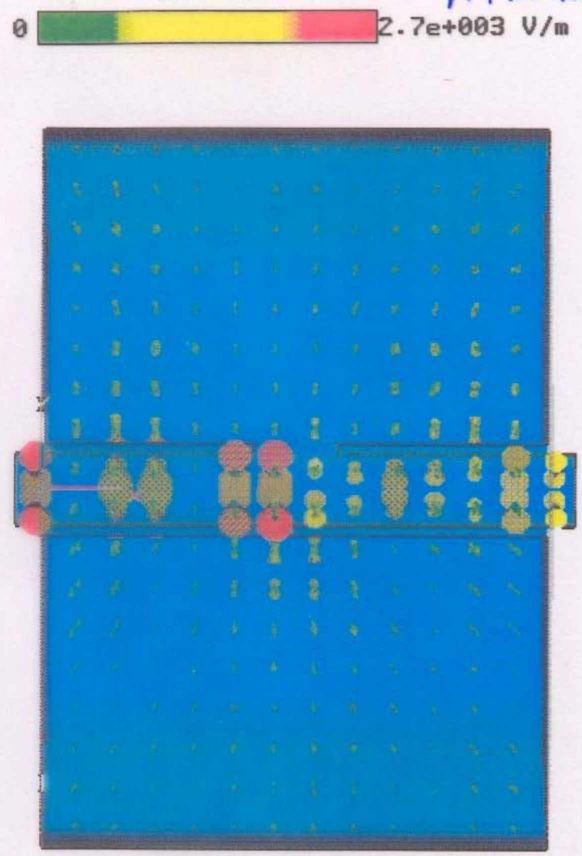
GE.701.09.05.00.M.A
Liner
Letter No
Sheet of
Institute

Figure 4-29 Liner

Microwave Studio Calculation
F. Marhauser



Type = E-Field
Monitor = 15 GHz [1,1
Maximum = 3610.09 V/m
Max. Arrow = 2079.52 V/m
Frequency = 15
Phase = 202.5 degrees



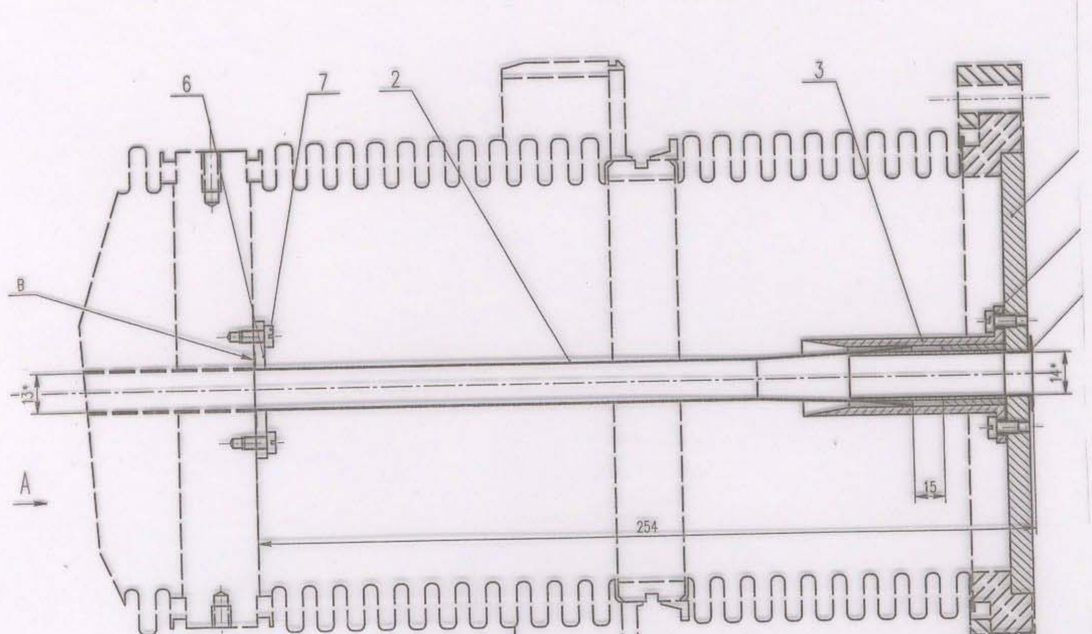
Type = E-Field
Monitor = 15 GHz [1,2
Maximum = 9755.07 V/m
Max. Arrow = 2696.22 V/m
Frequency = 15
Phase = 202.5 degrees

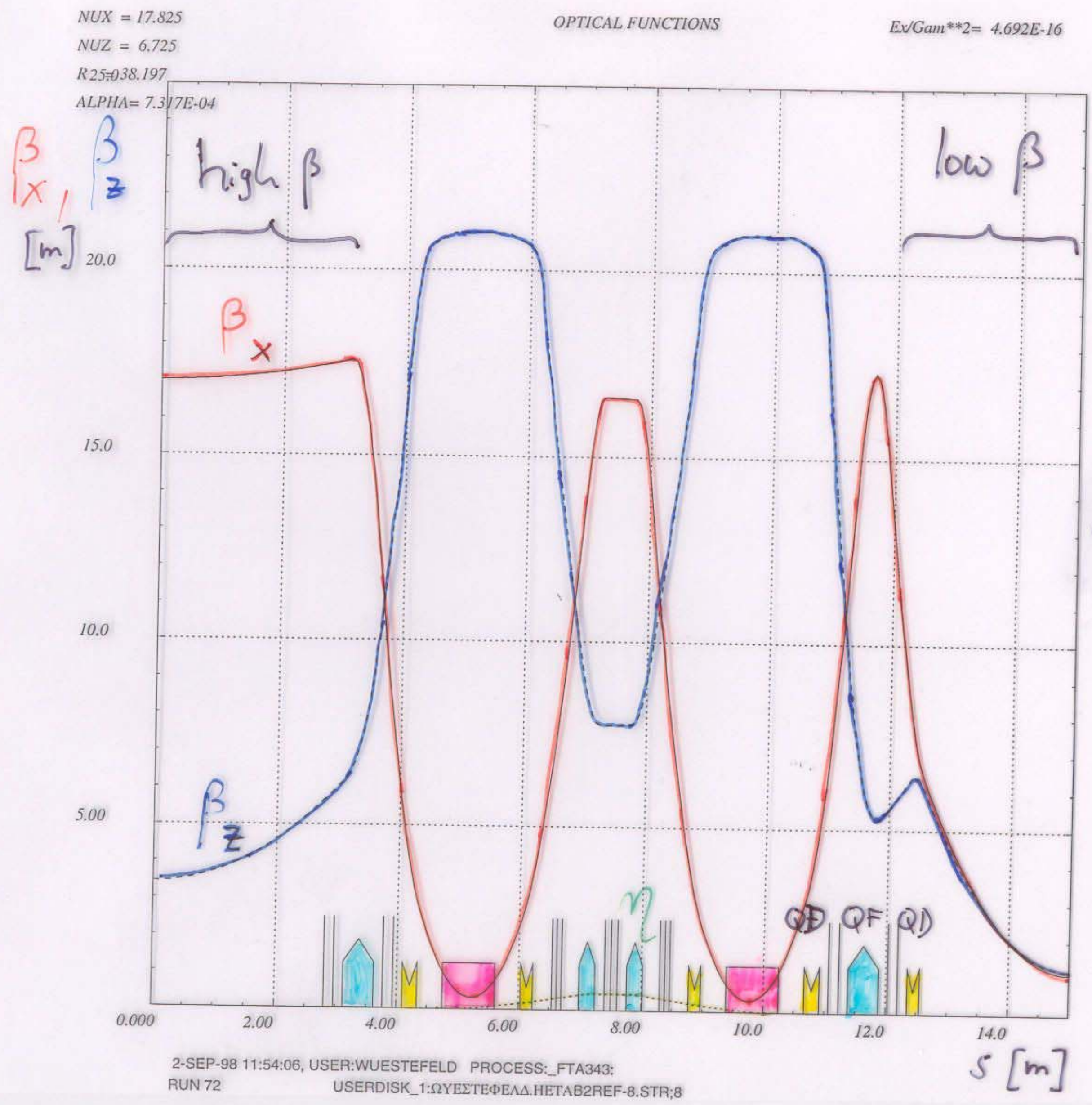
Beam chamber modifications

no holes in the liner

smooth transition at 20 K flange

rf-spring holder at 300 K side





Linear effects:

tune shift

$$\Delta Q \simeq \frac{KL\beta}{4\pi}\left(1+\frac{L^2}{12\beta^2}\right)$$

$$\simeq 0.081$$

stop band width

$$\delta Q \simeq \frac{KL\beta}{2\pi}\left(1-\frac{L^2}{12\beta^2}\right)$$

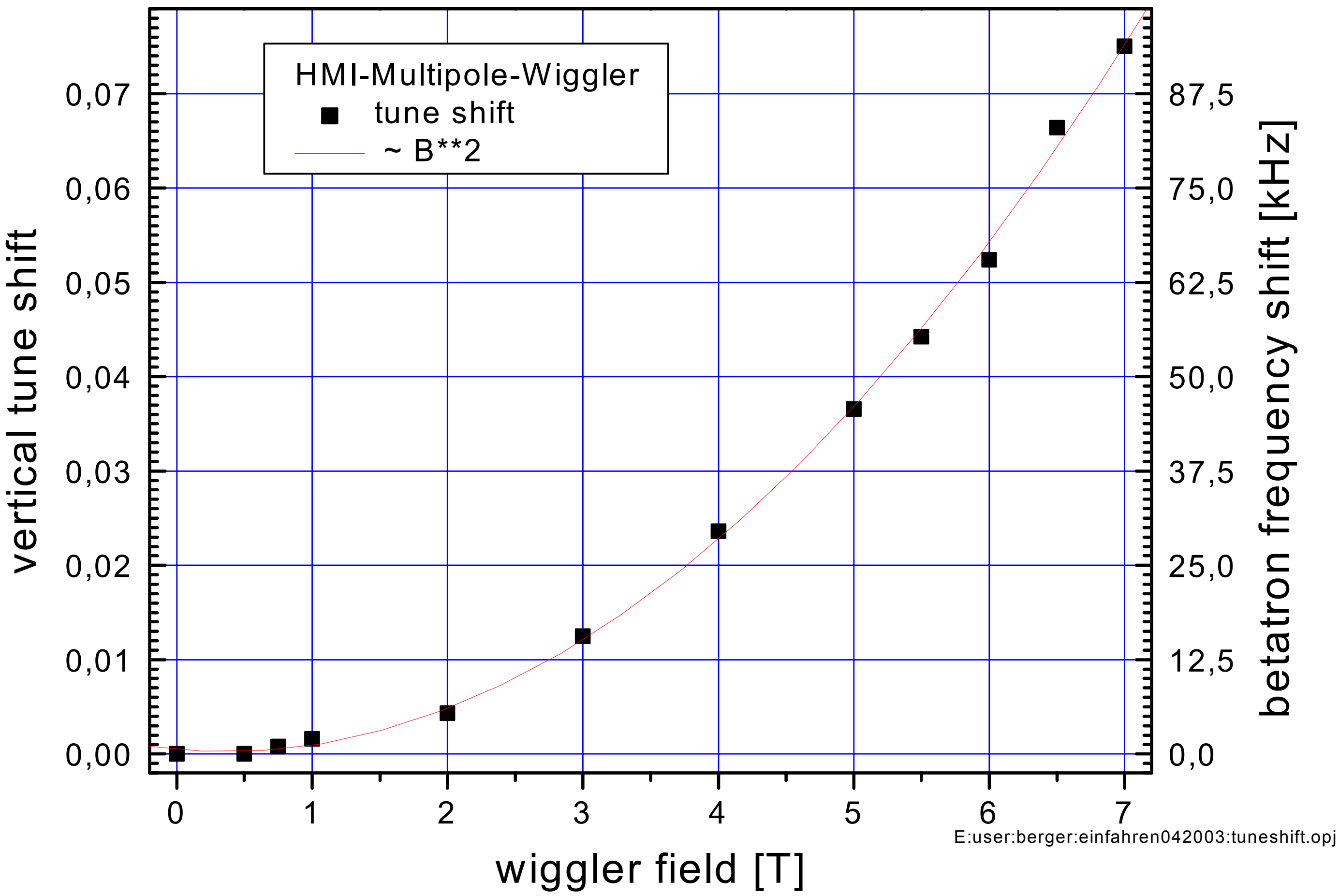
$$\simeq 0.13$$

β - beat

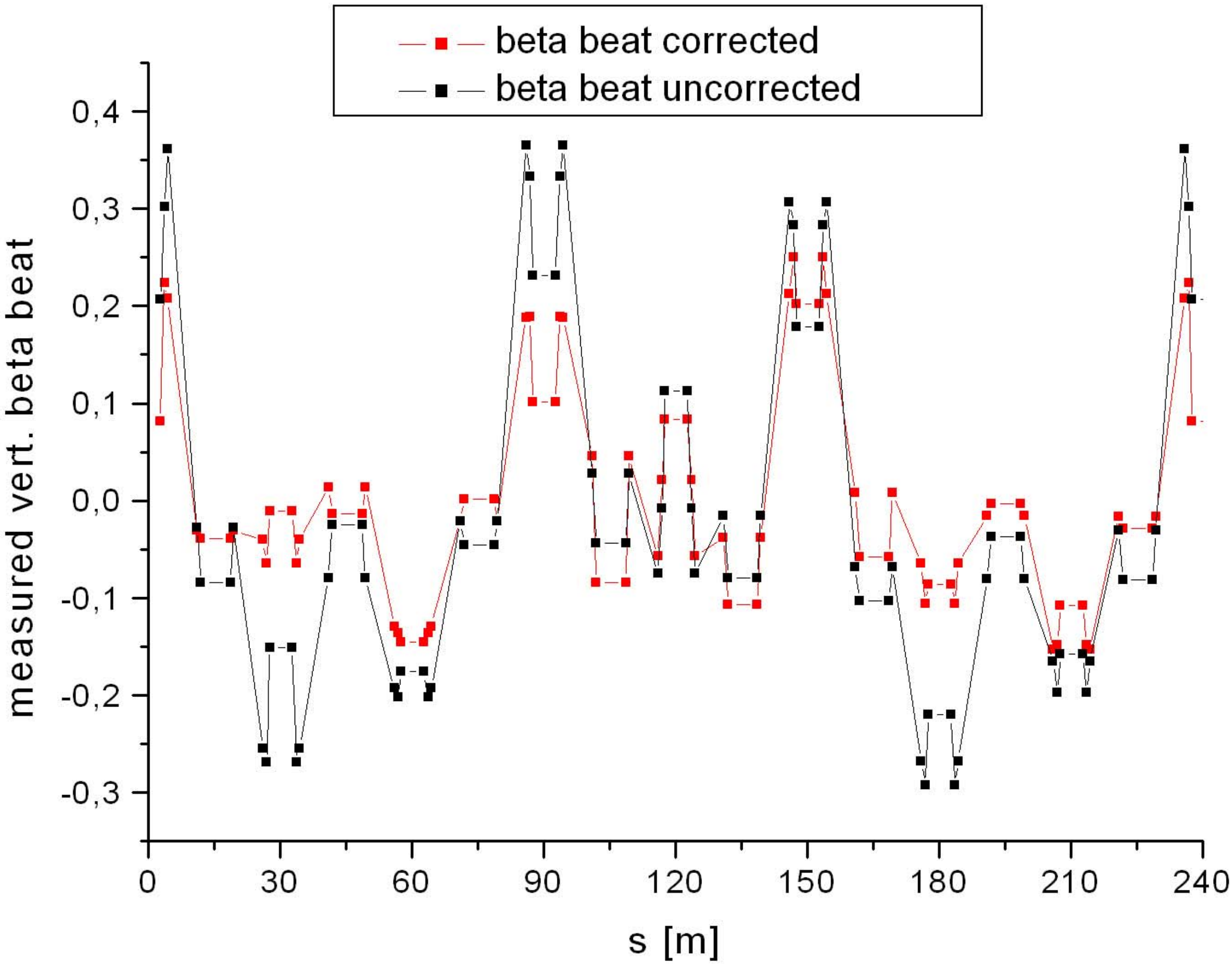
$$\frac{\Delta\beta}{\beta} \simeq \frac{KL\beta}{2\sin\mu}\left(1-\frac{L^2}{12\beta^2}\right)$$

$$\simeq 0.82$$

Vertical tune shift vs wiggler field



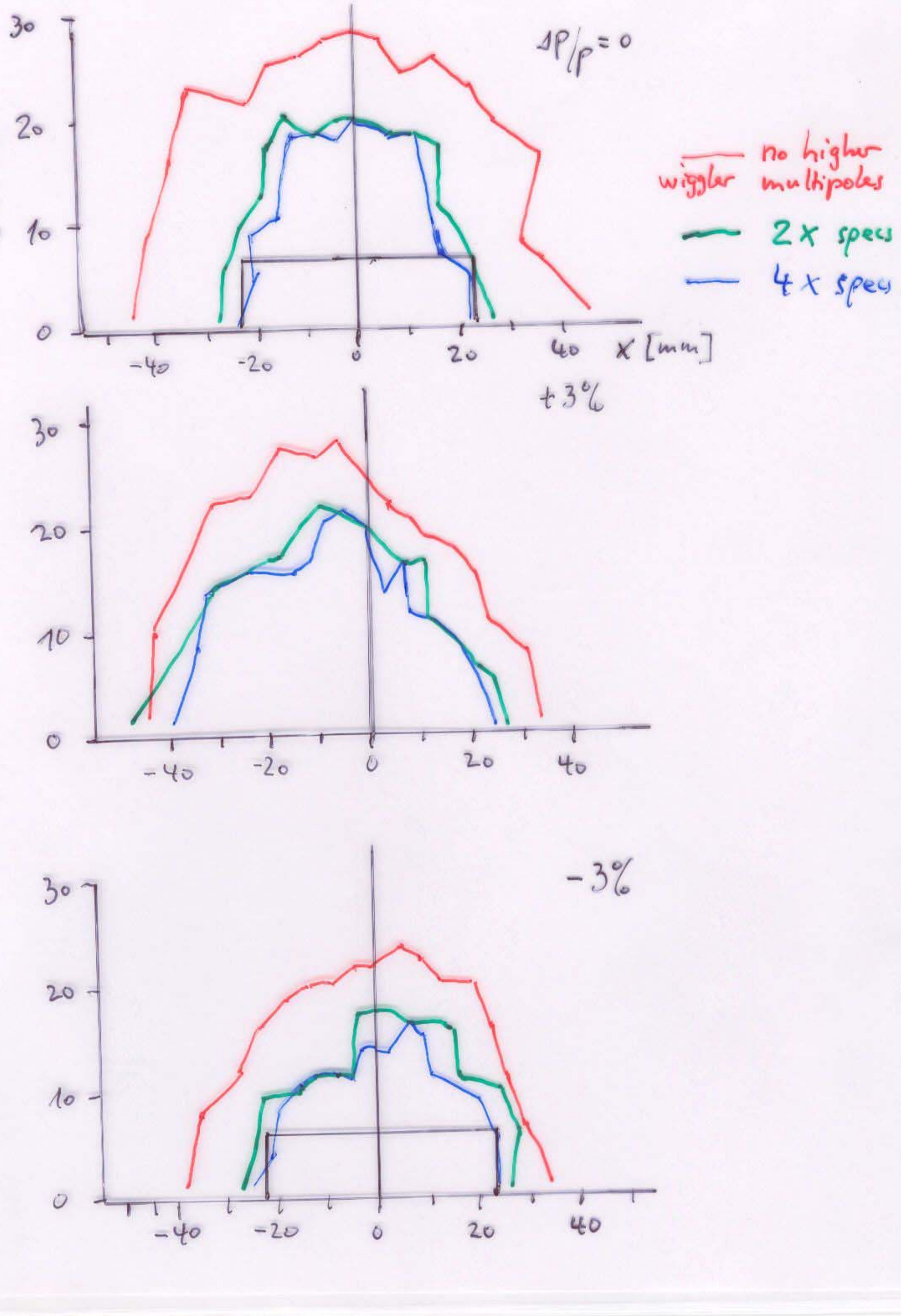
HMI Wiggler at 7T:
Measured vertical beta beat



Dynamic Aperture

(beta beat compensated)

(G. Wüstefeld)



Field specification

Table 2.1.2: Maximum Integrated Magnetic Field

Errors in good field region

Dipole ($\int B_y dz$)	$1*10^{-4}$ T*m
Skew Dipole ($\int B_x dz$)	$1*10^{-4}$ T*m
Quadrupole $(\int \frac{dB_y}{d_x} d_z)$	$1*10^{-2}$ T
Skew Quadrupole	$1.0*10^{-2}$ T
Sextupole $(\int \frac{d^2B_y}{d_x^2} d_z)$	0.5 T/m
Skew Sextupole	0.2 T/m
Octupole $(\int \frac{d^3B_y}{d_x^3} d_z)$	90 T/m^2
Scew Octupole	90 T/m^2
Second integral of Dipole ($\iint B_y d^2z$)	$2*10^{-4}$ T*m^2

Resumé:

- ♣ Wiggler magnet meets field specifications, max. field 7.4 T
- ♣ Unexpected beam induced LHe consumption has been analysed and cured
- ♣ Optical implementation of the wiggler in BESSY II is feasible
  - Injection is possible with the wiggler at 7T
  - First attempts to minimise the beta beat are promising

However: All studies have been made so far at low beam currents, I < 20 mA

Next steps:

- ♣ Commissioning of the wigger interlock and safety system at full beam current, I = 250 mA
- ♣ Further beam optical studies to optimise beam lifetime at full current

7T Multipole Wiggler at BESSY II

Collaborators

BESSY: K. Bürkmann, V.Dürr, J. Feikes, B. Franksen, B. Kuner, P. Kuske, R. Müller, J. Rahn, E. Weihreter, G. Wüstefeld

BINP: A. Boulygine, S. Demine, N. Mezentsev, E. Miguinskaia, V. Repkov, V. Shkaruba, and many others

HMI: D.Berger, R. Daum, H. Krauser, M. Rose