DAFNE wiggler modification

M. Preger

Mini-Workshop on Wiggler Optimization for Emittance Control
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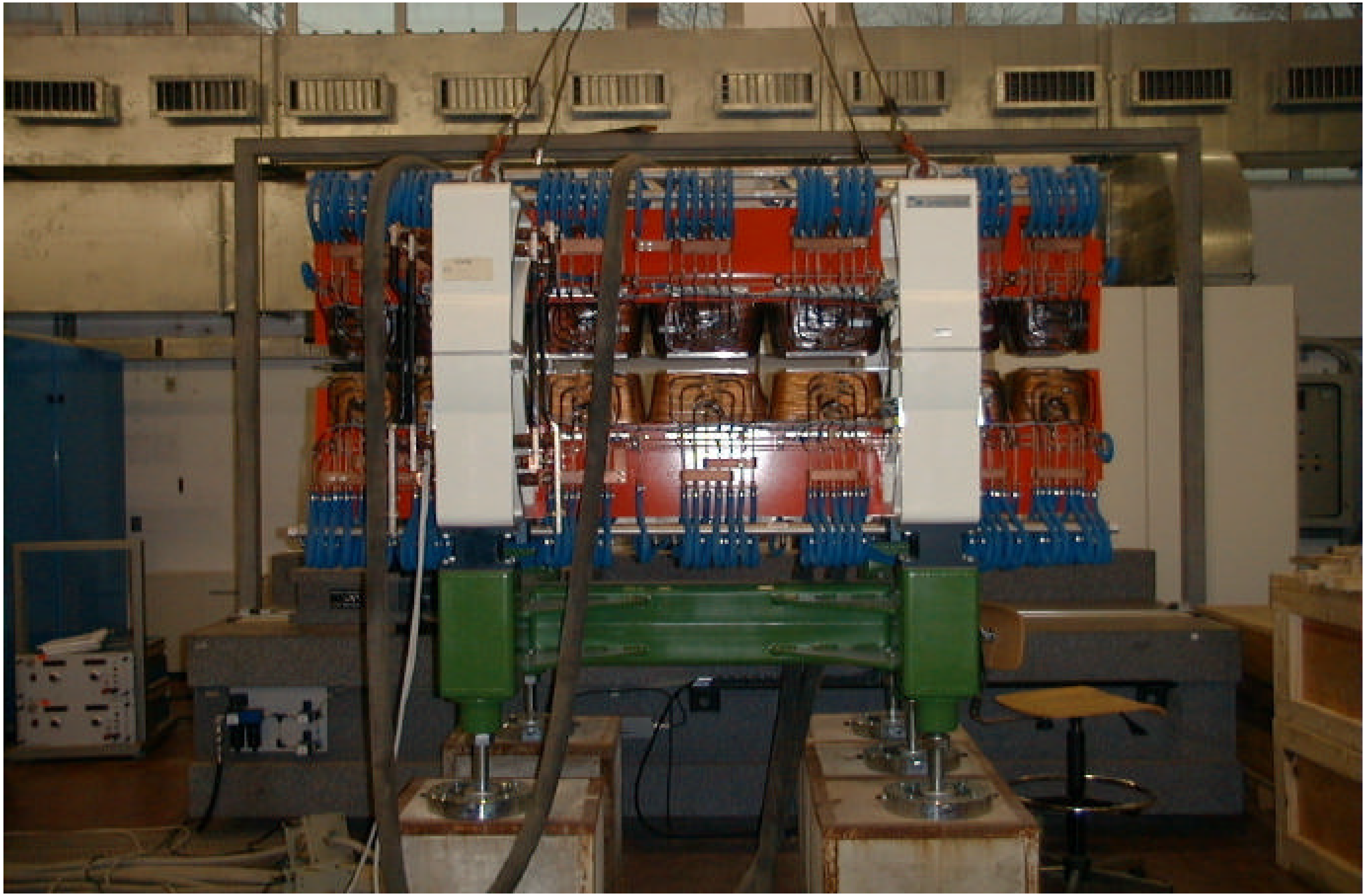
Contributors

A. Battisti, S. Bertolucci, B. Bolli, S. Ceravolo,
M. Incurvati, F. Iungo, M. Paris, M. Preger,
P. Raimondi, C. Sanelli, F. Sardone, F. Sgamma
M. Troiani

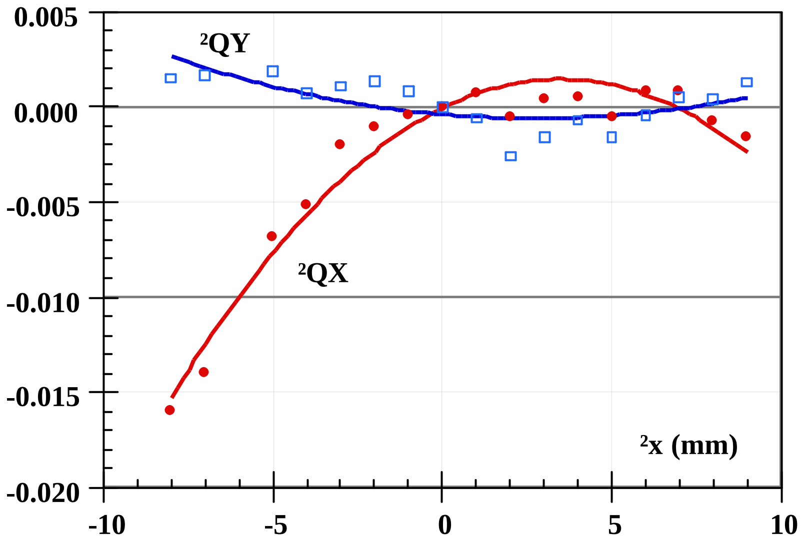
Ref: "The modified wiggler of the DAFNE Main Rings"
DAFNE Technical Note MM-34
http://www.lnf.infn.it/acceleratori/dafne/technotes.html

The DAFNE wiggler (side view)



The DAFNE wiggler (front view)

Measurement of tune shift as a function of beam displacement inside DAFNE wigglers exhibits a strong third order non linearity



Expand the wiggler field in the horizontal direction as a polynomial around the wiggler axis

$$B(z,x) = B(z,0) + \sum_{1}^{\infty} \frac{1}{n!} \left(\frac{\partial^n B(z,0)}{\partial x^n} \right) x^n$$

The derivative of order k around the wiggler trajectory x_t is given by

$$\frac{\partial^k B(z,x_t)}{\partial x^k} = \left(\frac{\partial^k B(x,0)}{\partial x^k} \right) + \sum_{k+1}^{\infty} \frac{1}{(n-k)!} \left(\frac{\partial^n B(x,0)}{\partial x^n} \right) x_t^{(n-k)}$$

The effect of a (2k+2)-pole term on the beam dynamics is represented by a constant

$$K_k = \frac{1}{B\rho} \int \frac{\partial^k B(z,x)}{\partial x^k} dz$$

In particular, the quadratic behaviour of the tune is due to a third order component of the field around the wiggling trajectory

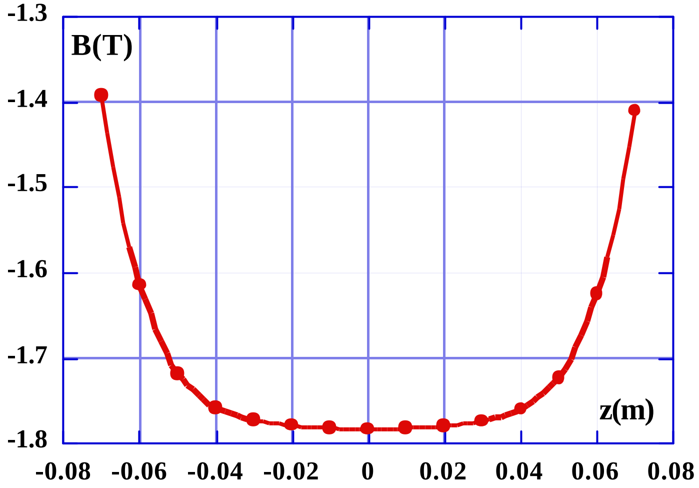
$$K_3 = \frac{1}{B\rho} \int \frac{\partial^3 B(z,x_t)}{\partial x^3} dz = \frac{1}{B\rho} \left[\int \left(\frac{\partial^3 B(x,0)}{\partial x^3}\right) dz + \int \left(\frac{\partial^4 B(x,0)}{\partial x^4}\right) x_t(z) dz + \cdots \right]$$

- **The wiggler is essentially symmetric in the horizontal plane with respect to its longitudinal axis, so that only even derivatives are expected to be significant**
- **Small asymmetries are due to the fact that all coils are connected to the power supplies on the same side of the magnet**
- **The field changes sign from pole to pole, and, to a first approximation, the contributions of adjacent poles to the derivatives cancel each other**
- **However, all terms containing a derivative multiplied by an odd power of the beam displacement from the wiggler axis add coherently**
- **The main contribution to the quadratic behaviour of the tune versus beam displacement in the wiggler is therefore due to a third order on linearity due to a decapole term in the field combined with the wiggling trajectory. Its intensity, derived from the beam tune measurement, is:**

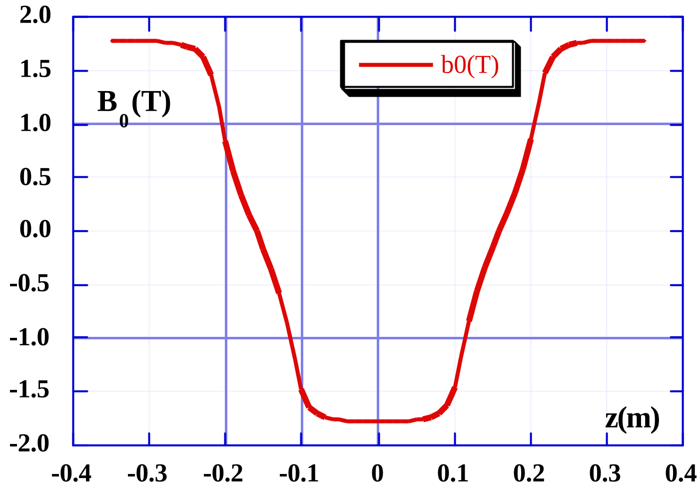
$$\frac{\partial Q_x}{\partial x^2} = \frac{\beta_x K_3}{8\pi} \approx -1\times 10^2 m^{-2} \Leftrightarrow K_3 \approx -8\times 10^2 m^{-3}$$

Measurements on the original wiggler
Central pole

Vertical field component at Pole center versus horizontal coordinate

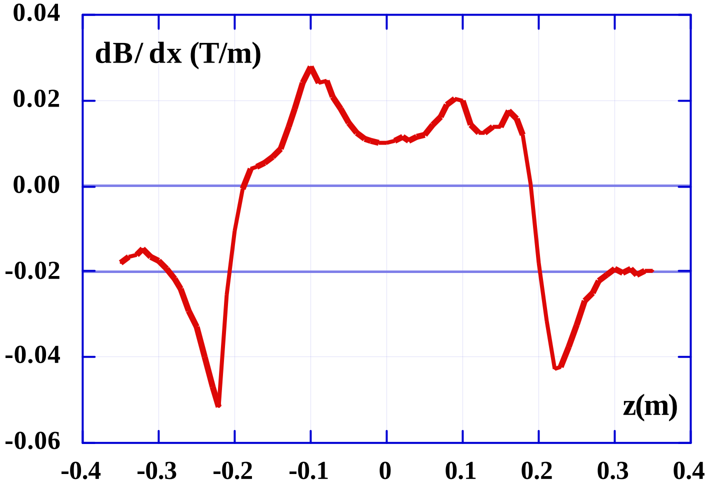


0-th order component of 4-th order polynomial fit at pole center versus longitudinal coordinate

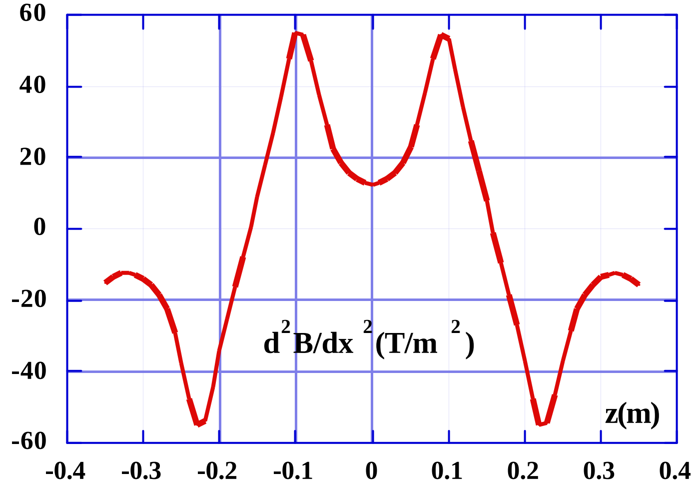


Measurements on the original wiggler
Central pole

First order component of 4-th order polynomial fit at pole center versus longitudinal coordinate

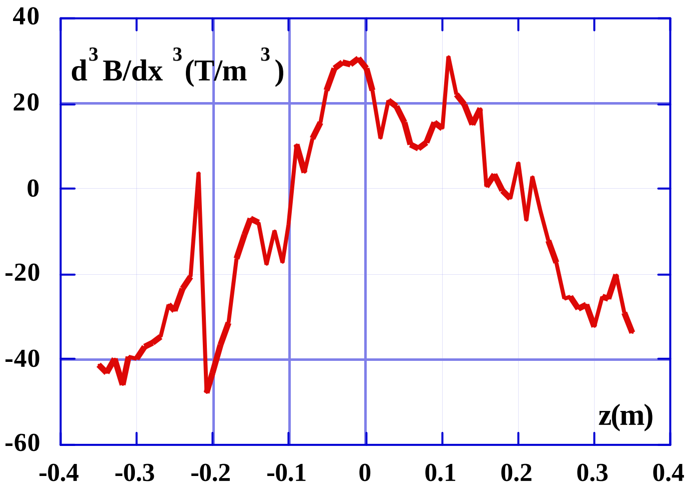


Second order component of 4-th order polynomial fit at pole center versus longitudinal coordinate

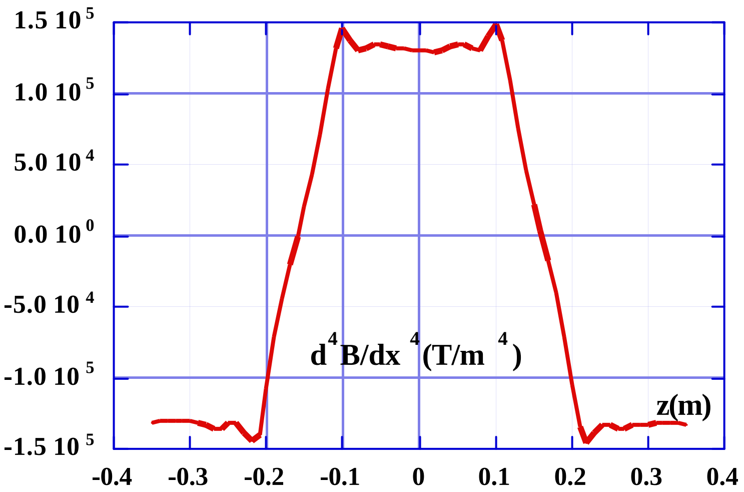


Measurements on the original wiggler
Central pole

Third order component of 4-th order polynomial fit at pole center versus longitudinal coordinate



Fourth order component of 4-th order polynomial fit at pole center versus longitudinal coordinate

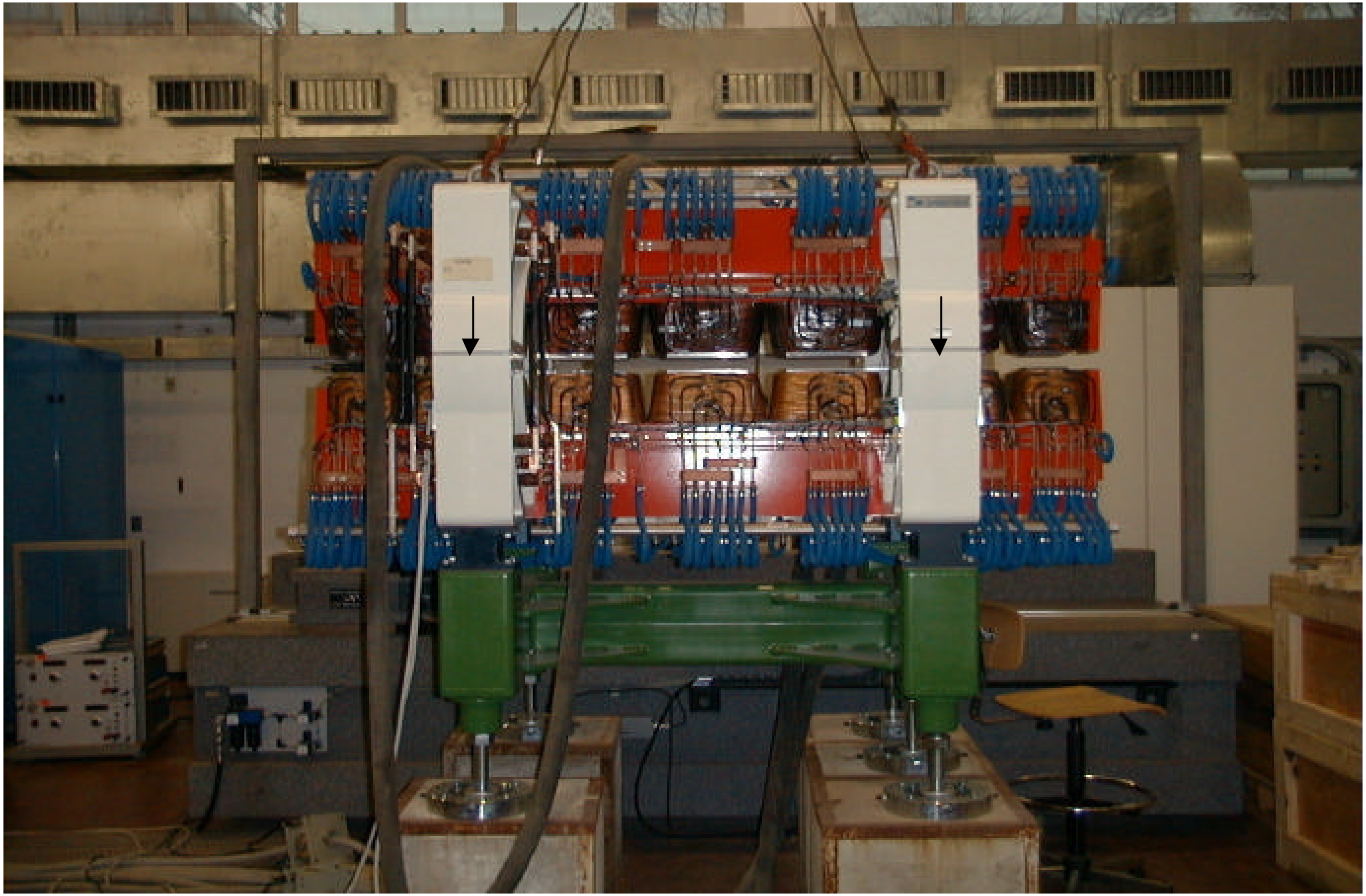


Strategy

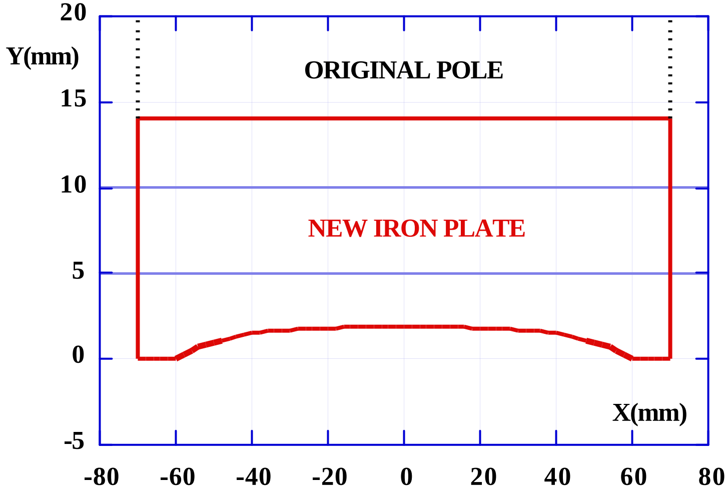
- Buy a spare wiggler built on the same design and with the same material as those operating in DAFNE (4 per ring)
- Insert 28 mm thick spacers between the two halves of the “C” supports to increase the wiggler gap
- Glue additional 14 mm thick flat iron plates on the pole faces to restore the original wiggler gap and measure the field reduction caused by the magnetic circuit lengthening
- Machine the iron plates to compensate the field fall off at large distance from the wiggler axis according to:

$$gap(x) / B_{meas}(x) = const$$

Wiggler with spacers and additional flat poles

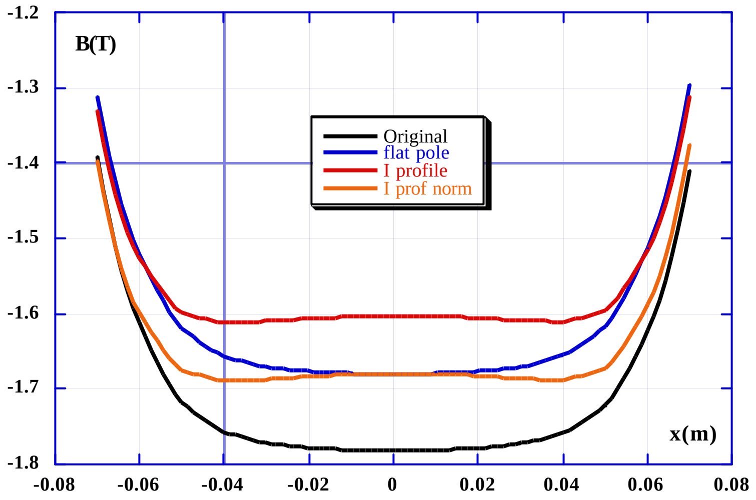


New pole profile - Front view



Additional machined plates glued on poles

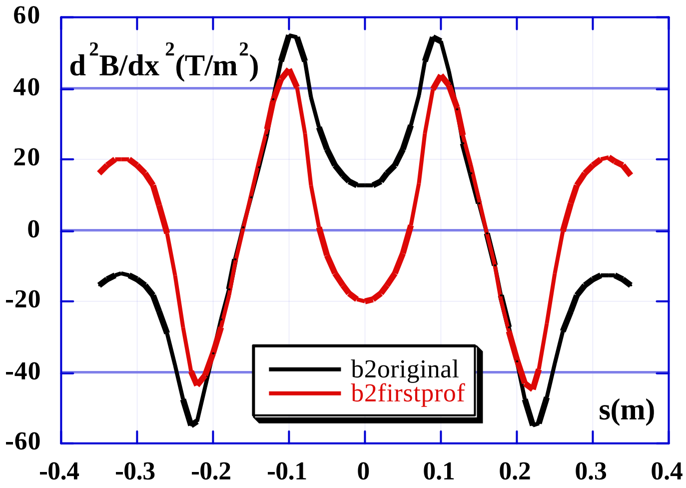
Results

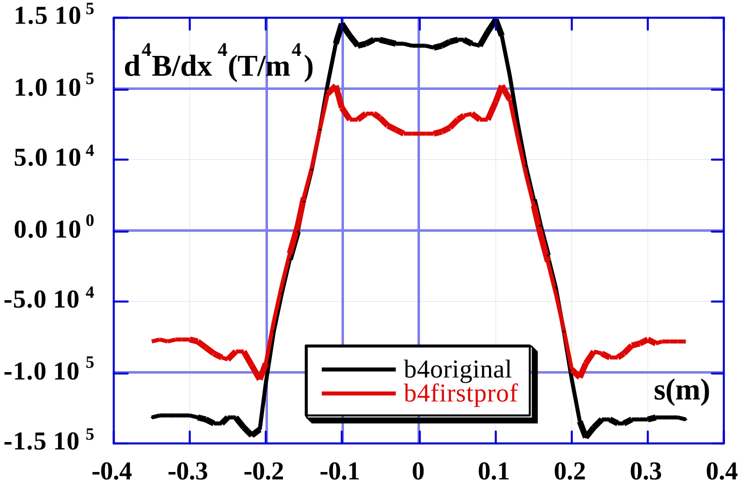


The good field region is larger by ~ 2 cm

The center field is reduced by ~ 11%

Results (cont.)





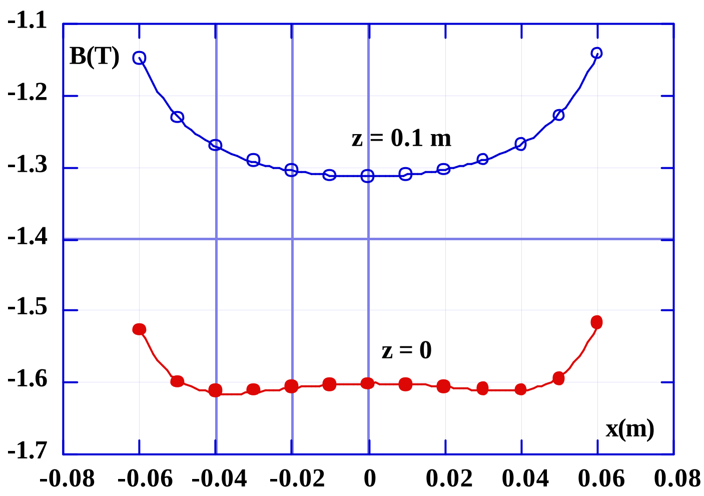
The second derivative is smaller and negative at pole center
K2 drops from 5.2 to 2.1 m^{-2}

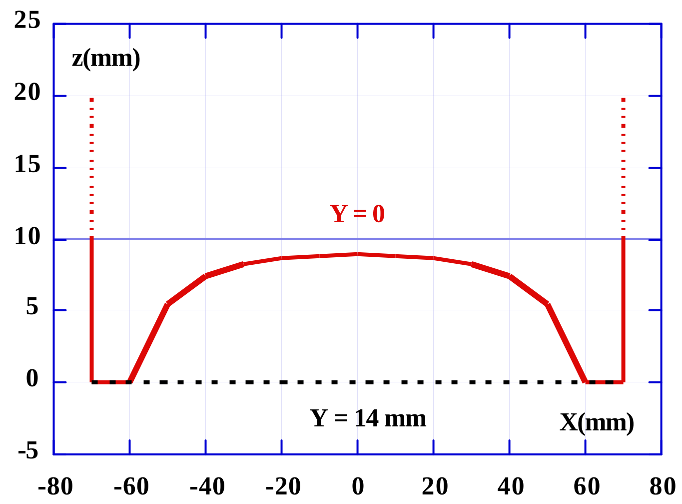
The fourth derivative is reduced by almost a factor 2

Pole length modification (top view)

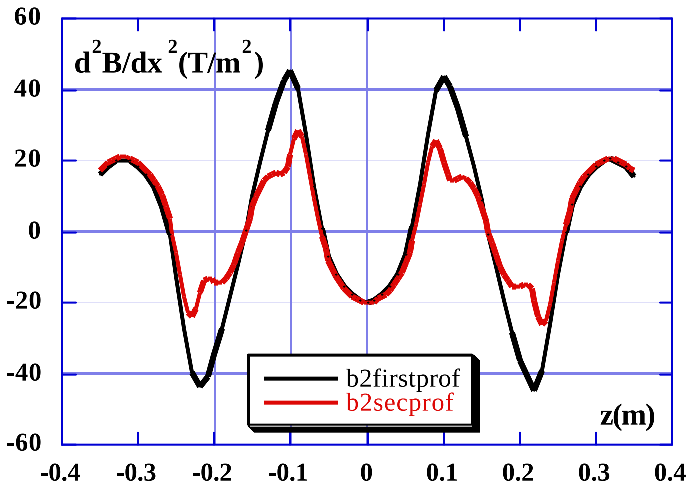
In order to smoothen the behaviour of the second derivative the pole length has been machined according to

$$L(x) * ?_{meas} B(x,z)dz = const$$





Result

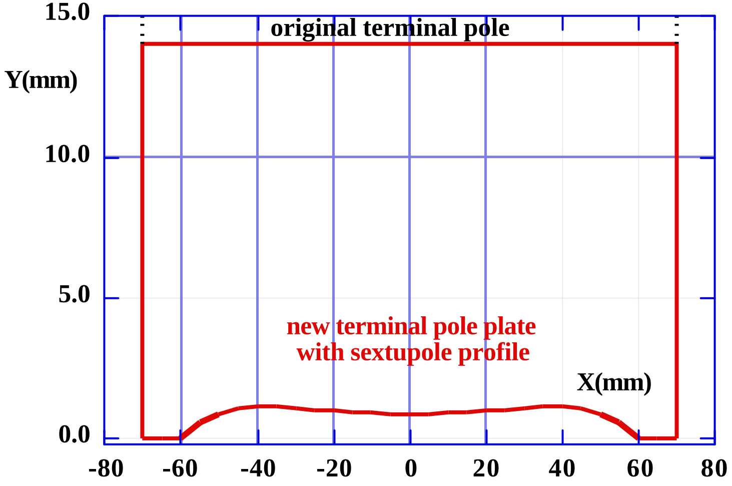


The peaks at pole ends are reduced by a factor ~ 2

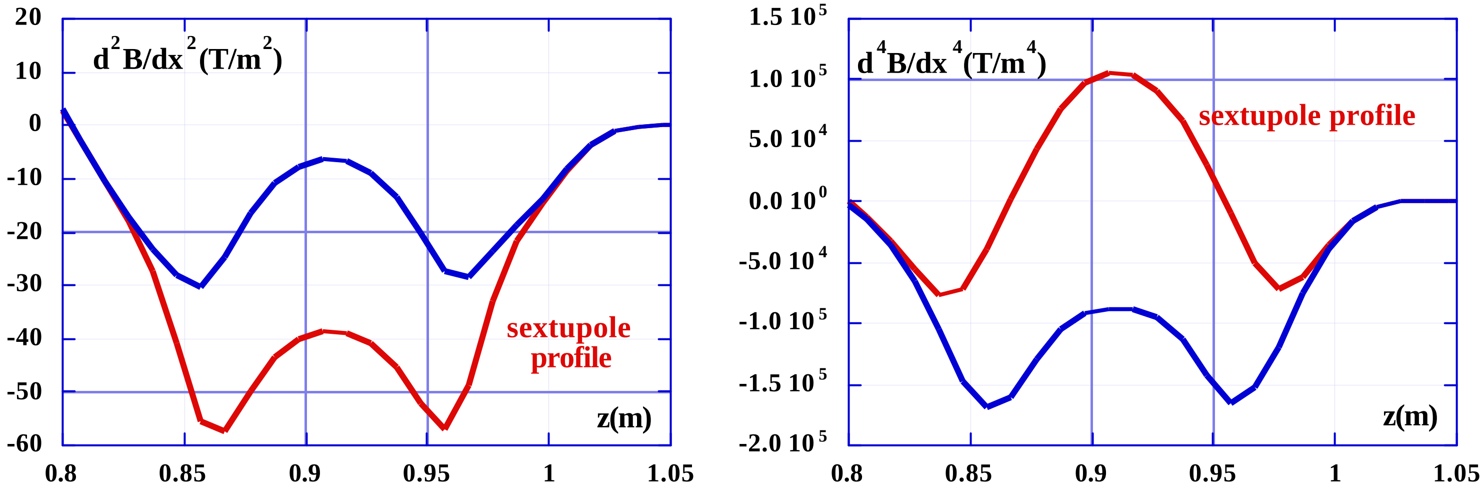
K2 over the central pole drops from 2.1 to 0.7 m^{-2}

Additional sextupole term in terminal pole

For an easier chromaticity correction, it was required to create an additional sextupole term in one of the two terminal poles



Result



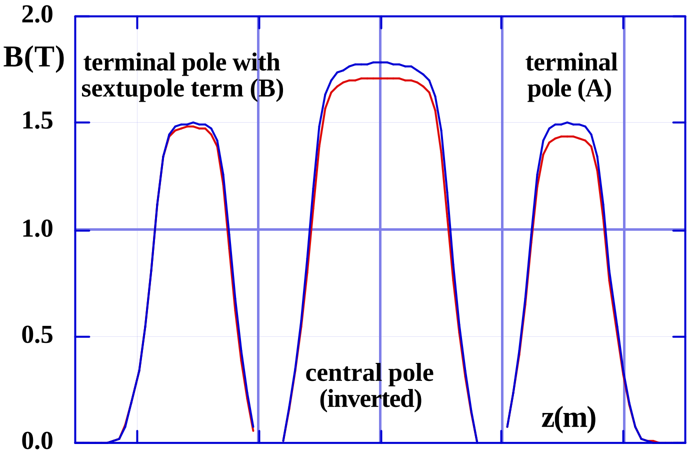
The sextupole constant is increased from 2.0 m^{-3} to 4.4 m^{-3}

Minimization of the peak field loss

The magnet gap has been reduced from 40 mm to 37 mm, still compatible with the vacuum chamber

The additional poles have been machined to bring the thickness from 14 m to 7 mm

The new spacers are 11 mm thick instead of 28 mm



The peak field reduction with respect to the original wiggler is now 4% instead of 11%

Field integral compensation

The wiggler field is compensated when:

a) The field integral on the beam trajectory vanishes

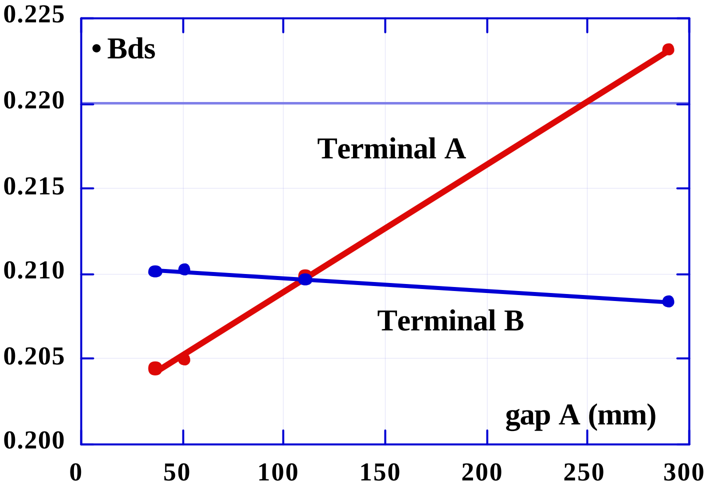
b) The field is symmetric in the longitudinal direction with respect to the magnet center

The first condition can be easily satisfied since each wiggler has an independent power supply for the terminal poles, which are connected in series

The second condition cannot be satisfied, in principle, due to the presence of the additional sextupole term in one of the two terminals

Terminal poles asymmetry compensation

The effect of the asymmetry between the two terminal poles has been minimized by changing the gap in the field clamp adjacent to the terminal without the additional sextupole term (terminal A), under the requirement of equal field integrals in the two terminals



Measurement of the full field map

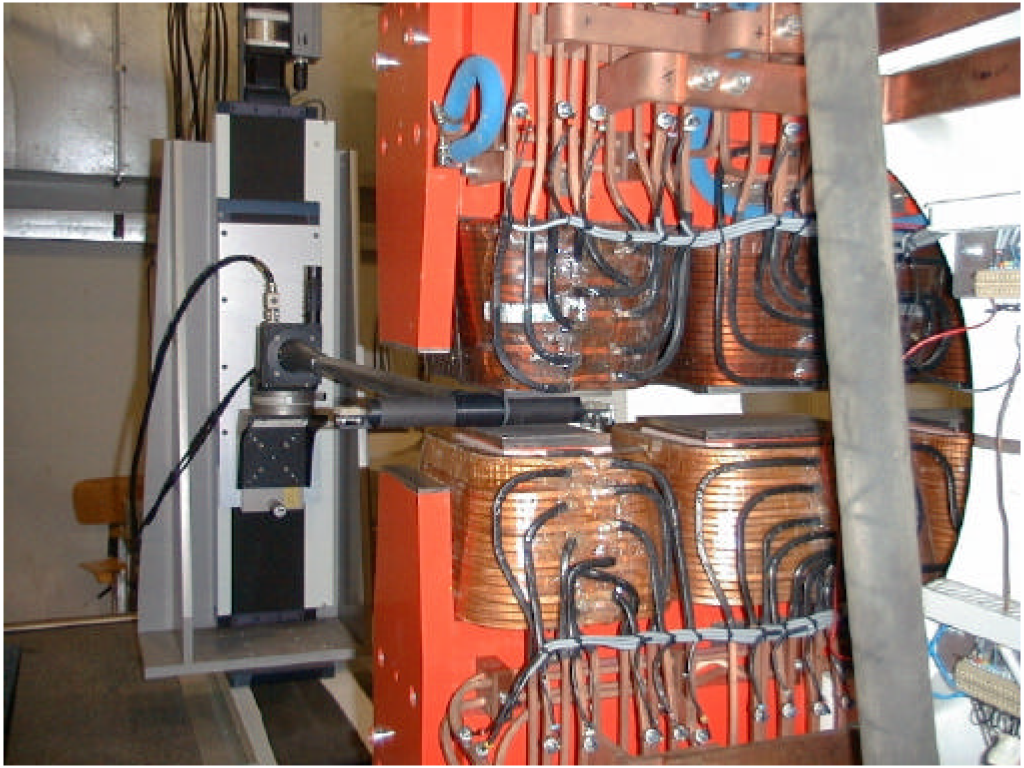
All measurements described until now have been performed with a single Hall probe mounted on a remote controlled positioning system with 4 degrees of freedom (x,y,z,φ) with <10μ accuracy and 1μ resolution.

In order to have a full map of the vertical field component on the horizontal symmetry plane of the wiggler it is necessary to overcome the problem of the suppprting “C” structures which are an obstacle for the Hall probe support.

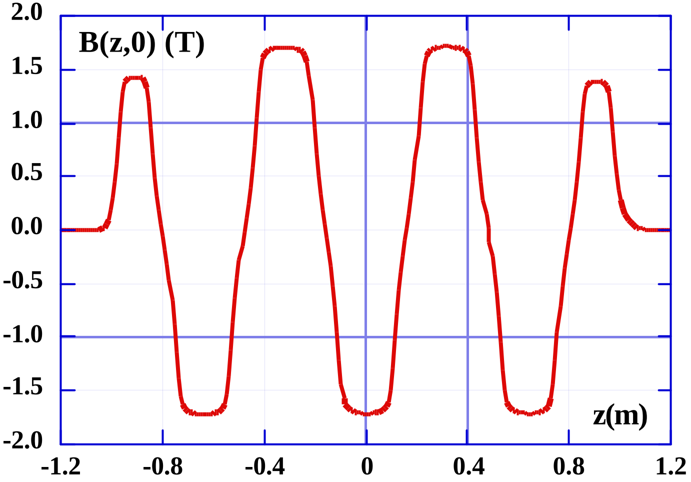
A new support with two probes has therefore been realized and unfortunately became operational only at the end of the wiggler optimization work.

The two probes have been intercalibrated in a constant field and their effective distance measured by finding the positions where the probes yield the same value near a zero crossing of the field

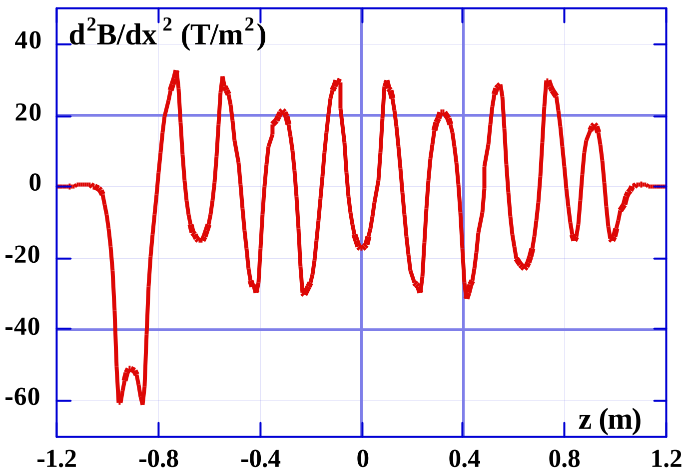
The double Hall probe system

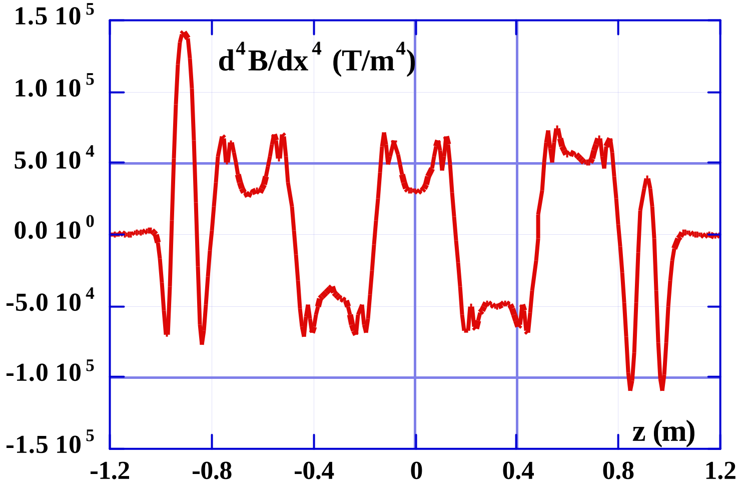


Measurement of the full field map



Measurement of the full field map





Summary

- A spare wiggler has been used to modify the field shape by means of additional iron plates glued on the pole faces
- The good field region haas been enlarged by almost 2 cm out of 14
- The decapole term in the field, responsible for the cubic term in the beam dynamics, has been almost halved
- The effect of the sextupole term, responsible for the linear tune shift in the beam, has been significantly reduced
- An additional sextupole, beneficial to the chromaticity correction has been created in one of the two terminals
- The full map of the vertical field component on the horizontal symmetry plane of the wiggler has been measured, in order to calculate the beam trajectory, find the current in the terminal poles for a correct field compensation and evaluate the contributions of the high order terms to the beam dynamics (presentation this afternoon by Catia Milardi)