Undulator an wiggler construction at the ESRF

- ID magnetic structures
- ID magnetic design
- Field measurements
- ID field corrections
- ESRF IDs status

ID group: J. Chavanne, B. Cottin, T. Deshaux,
C. Joan, C. Penel, F. Revol, A. Ribes, P. Van Vaerenbergh

Pure Permanent Magnet IDs (PPM)

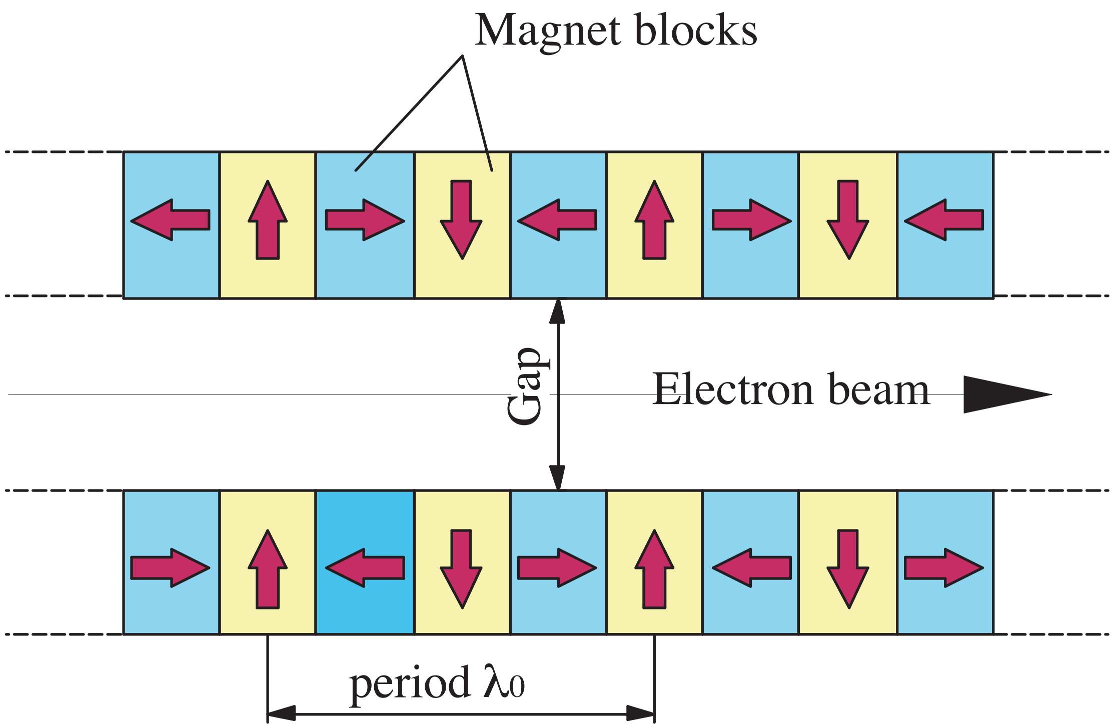
Simple structures

4 magnet blocks /period

Material

- NdFeB

- Sm2Co17



80 % of ESRF IDS

Hybrid IDs

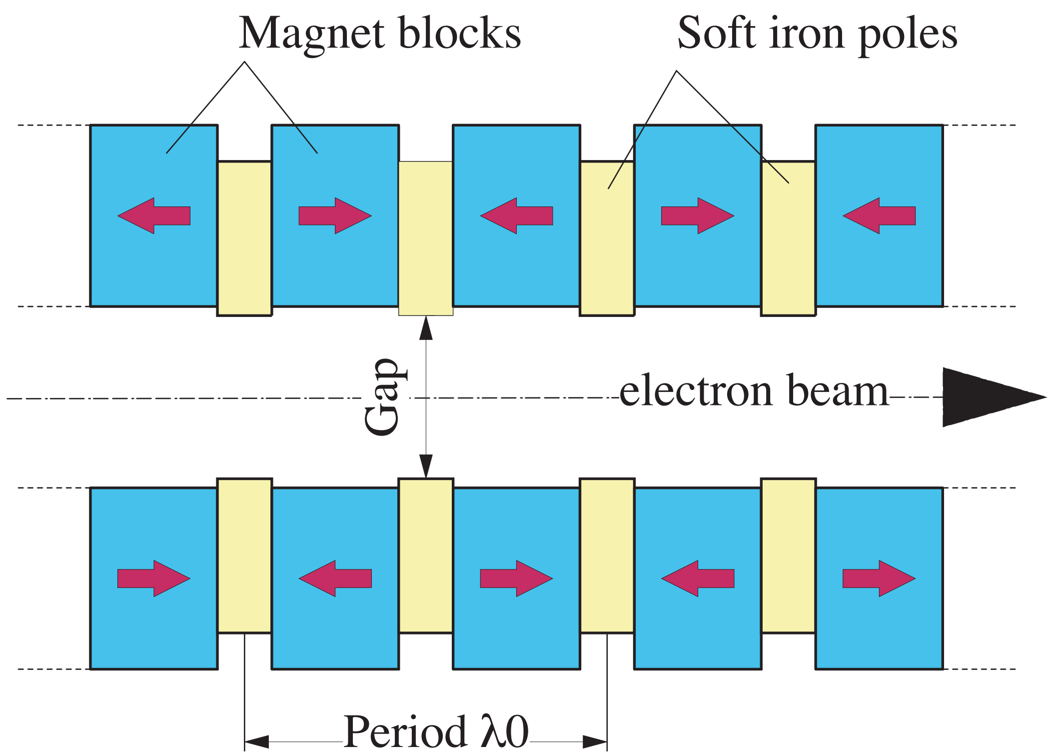
Magnet material

- -NdFeB
- -Sm2Co17

Pole material

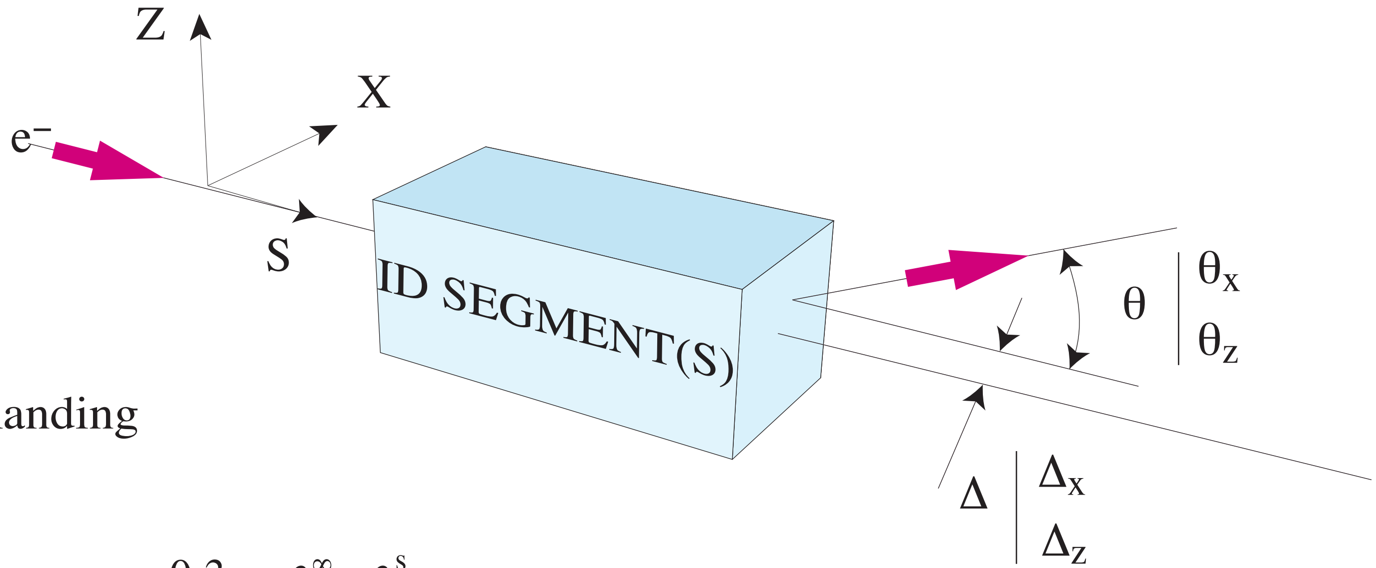
- -Fe-Co
- -low carbon steel

20 % of ESRF IDS



ID specifications

ID residual interaction with stored beam should be negligible.



In particular:

$$\theta_x = \frac{0.3}{E[GeV]}\int_{-\infty}^{\infty} B_z ds \approx 0$$

$$\theta_z = \frac{0.3}{E[GeV]}\int_{-\infty}^{\infty} B_x ds \approx 0$$

Most demanding

at any magnetic gap

$$\Delta_x = \frac{0.3}{E[GeV]}\int_{-\infty}^{\infty}\left(\int_{-\infty}^{s} B_z(x,z,s')ds'\right)ds \approx 0$$

$$\Delta_z = \frac{0.3}{E[GeV]}\int_{-\infty}^{\infty}\left(\int_{-\infty}^{s} B_x(x,z,s')ds'\right)ds \approx 0$$

Important for the machine

--> beam stability

Also important for the users

--> closed orbit modifications induced by an ID segment can be seen by all the users around the ring

ID magnetic design

Two main goals

1- User requirements (X -rays properties)

- Photon flux versus energy
- Photon energy range
- Heat load limitations
- polarization

involve essentially the nominal periodic part

2 - Minimize systematic interaction with the stored beam

- Field integral at field terminations (complicated)
- non linear effect (focusing) in some cases

Design of periodic part

Essentially maximum field & minimum period

Presently easy in 3D

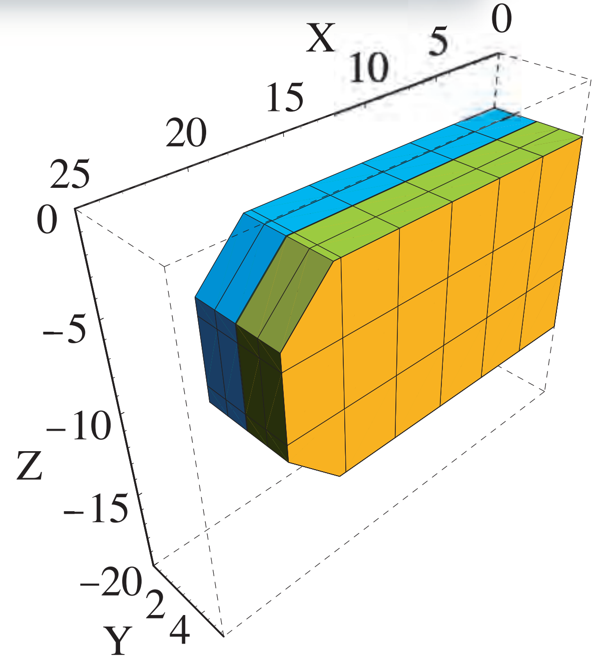
- symmetries reduce the size of problem
- 1/4 of period longitudinally

Input

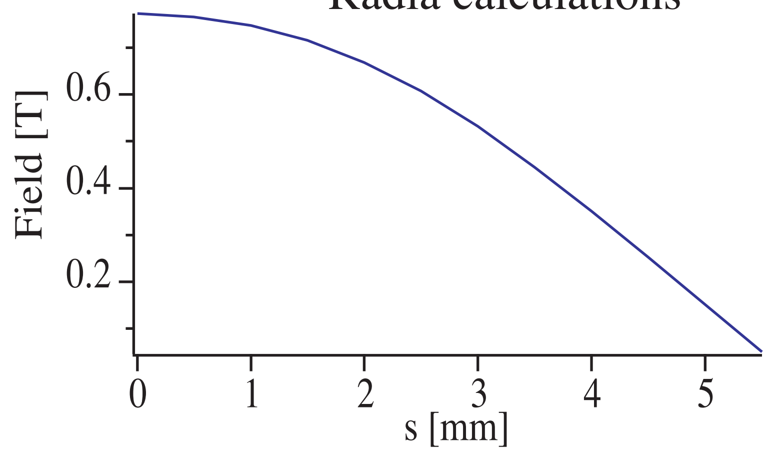
- geometry (parametrization is important)
- magnetic properties
  - Magnet blocks (mostly linear anisotropic)
  - Soft magnetic material (non linear)

Definition of:

- reasonable magnet block geometry
- available magnetic material properties
  - remanence
  - coercivity

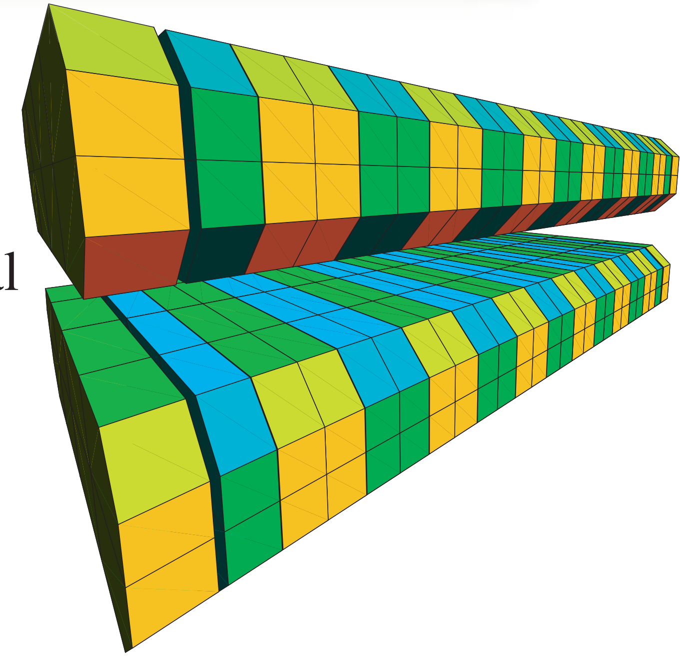


Radia calculations



Design of end field parts

Goal: control the entry/exit sequence to:

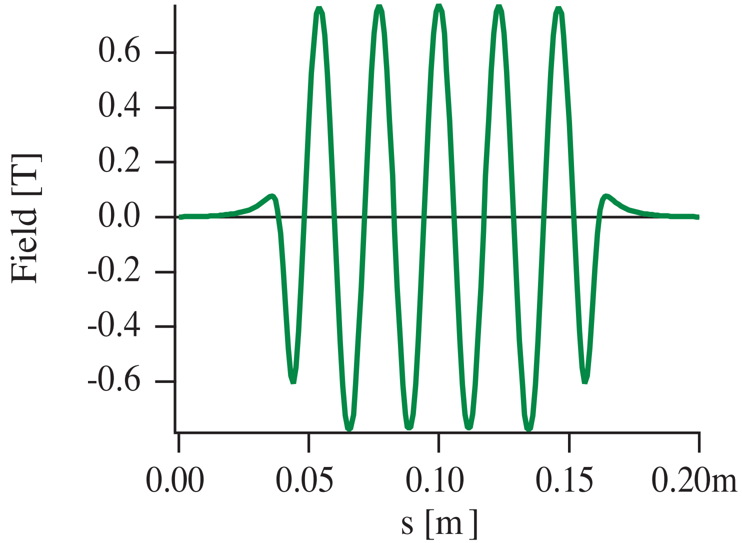


- Minimize field integral
    - Comes from non unit permeability of magnet material
    - More complicated for hybrid than for p.p.m.

- Minimize beam offset (2nd integral)

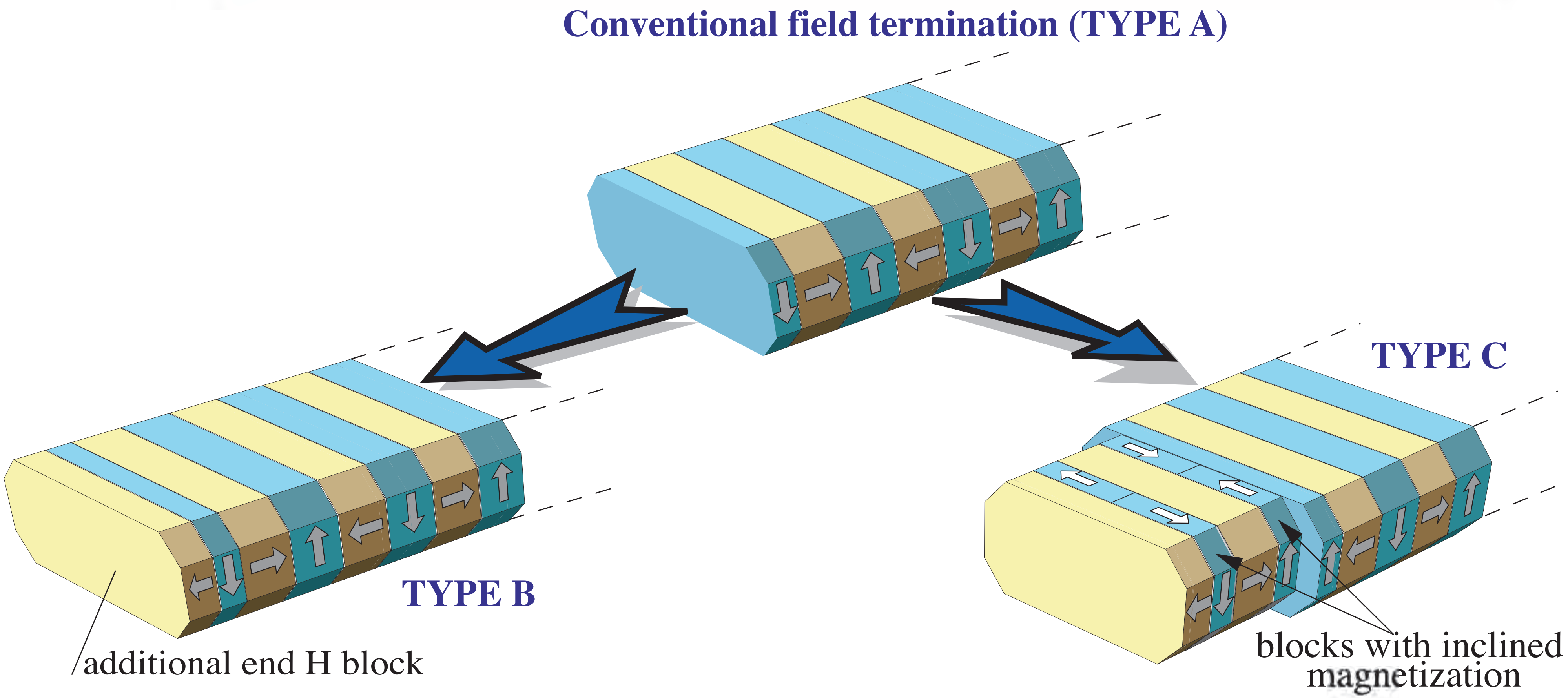
- Provide optical phasing between segmented undulators

At ANY magnetic gap



---> more complicated than periodic part
- involve a model with several periods
- the origin of RADIA

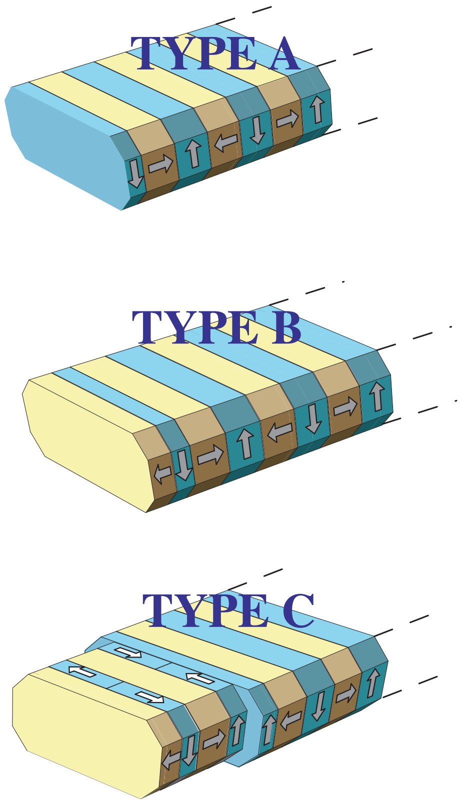
Passive field terminations for ppm IDs

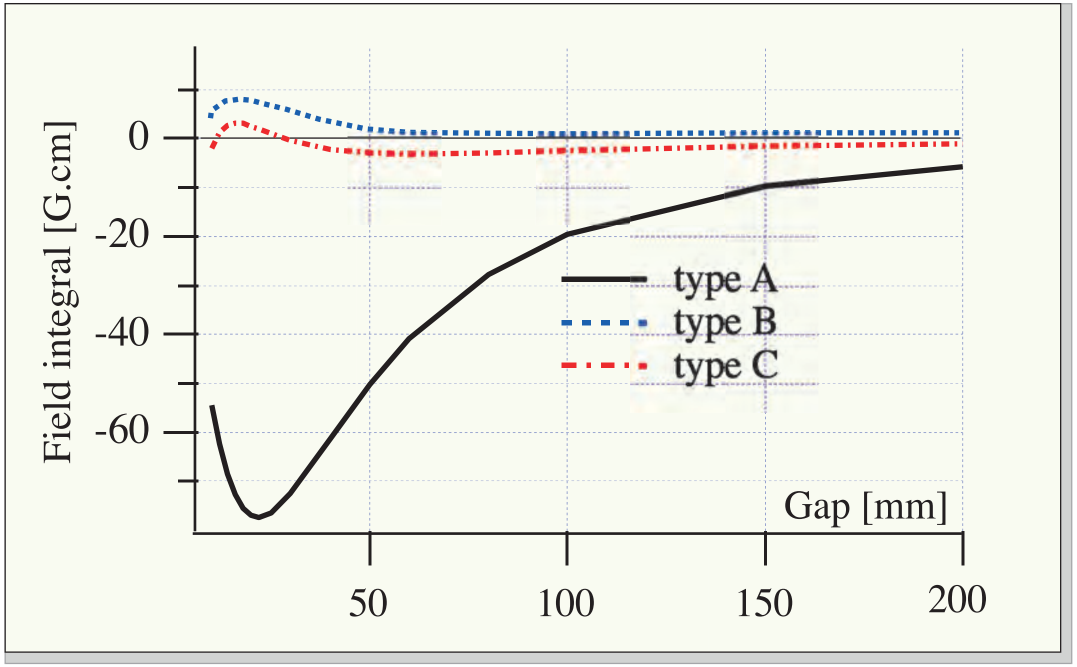


Minimize first & 2nd field
Integral vs. gap

Minimize first field integral
+phasing between segmented
undulators vs. gap

End field structrures for ppm IDs





UNDULATOR U40

period 40 mm
P.M material: NdFeB
Br=1.15 T
Parallel permeability =1.06
Transverse permeability =1.17

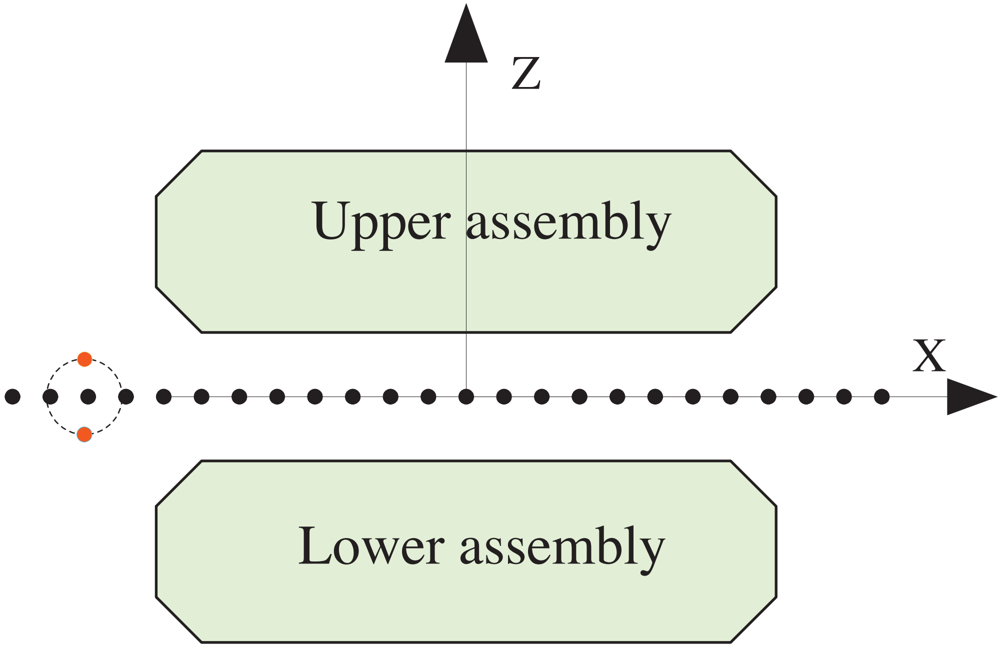
Blocks size (Hor.*Vert.*long.):
55 mm*20 mm *10 mm

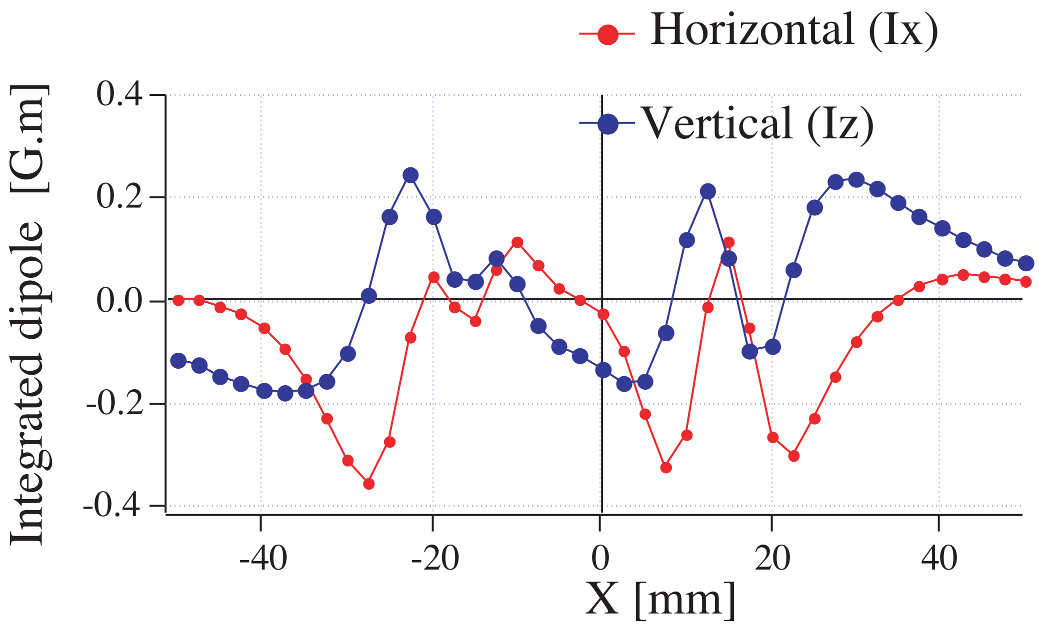
End field structures of type B or C are systematically used on ppm ESRF undulators

-simplify field integral correction during magnetic measurements
-no need of active (coil) correction vs.gap

Field integral measurements

- Measurement of integrated dipole versus transverse position:





Higher order integrated multipoles --> $$\frac{\partial^n}{\partial x^n}\left(I_{x,z}\left(x,z\right)\right)$$

based on flip coil or streched wire

Local integral measurements

- Integrate voltage /90 degree : 8 values V_i

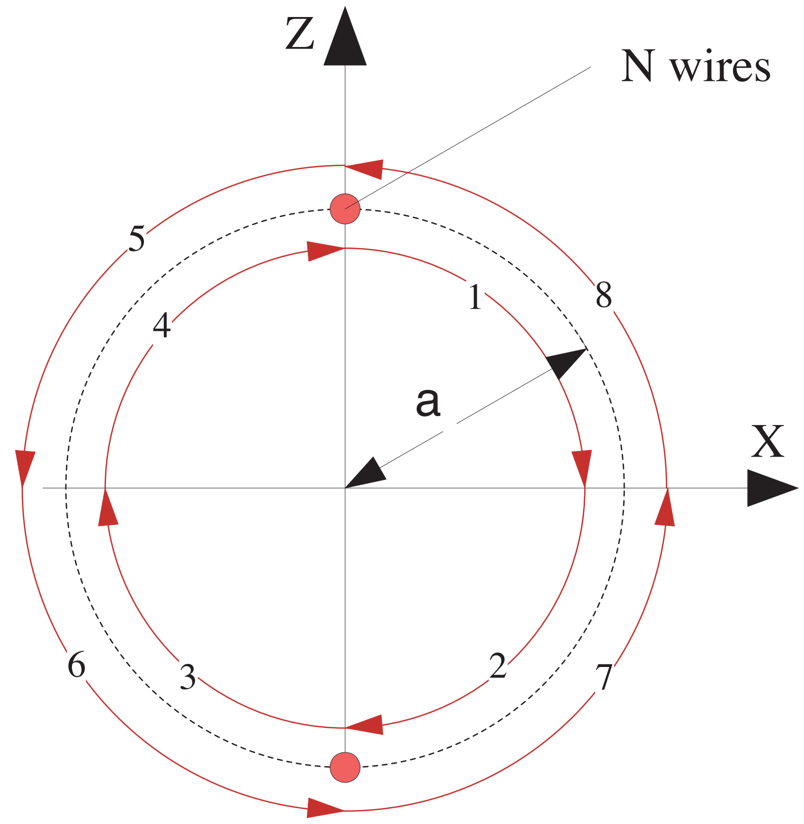
Integrated dipole

Horizontal

$$I_x(x,z) = \frac{\sum_{i=1,2,5,6} V_i - \sum_{j=3,4,7,8} V_j}{16Na}$$

Vertical

$$I_z(x,z) = \frac{\sum_{i=1,4,6,7} V_i - \sum_{j=2,3,5,8} V_j}{16Na}$$



Takes ≈ 20 sec/point

Field integral scans

Two methods

1 Local measurement at each grid point (point by point)

-Time consuming ≈15 minutes (100 mm, 2.5 mm steps, 41 pts)

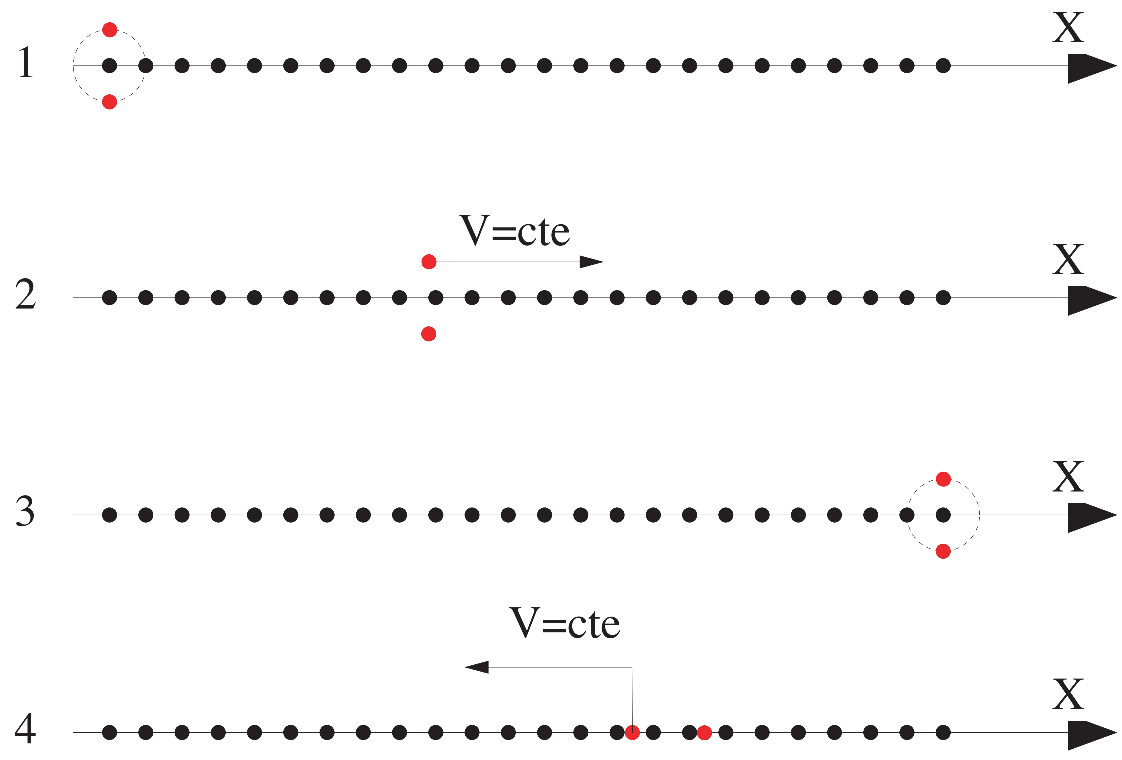
2- Fast scans

--> Speed up measurements

-55 sec for 41 pts

-needs timing control

Mostly used



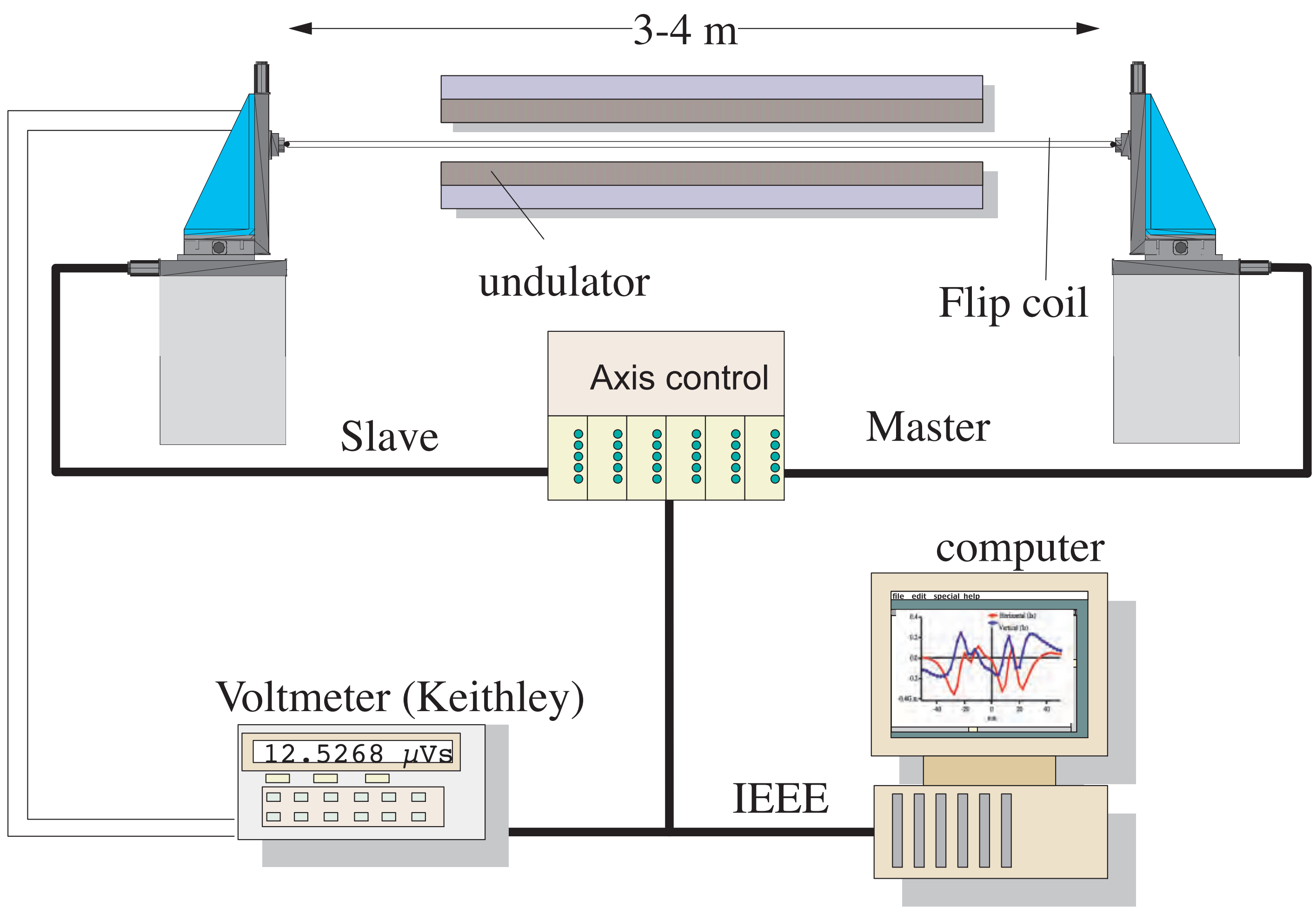
Field integral bench

Positioning accuracy not critical :

± 0.2 mm in X & Z
± 0.1 degree in θ

are sufficient

3 identical units in the ESRF ID magnetic measurment lab.



Field integral bench performances

In the range ± 150 G.cm

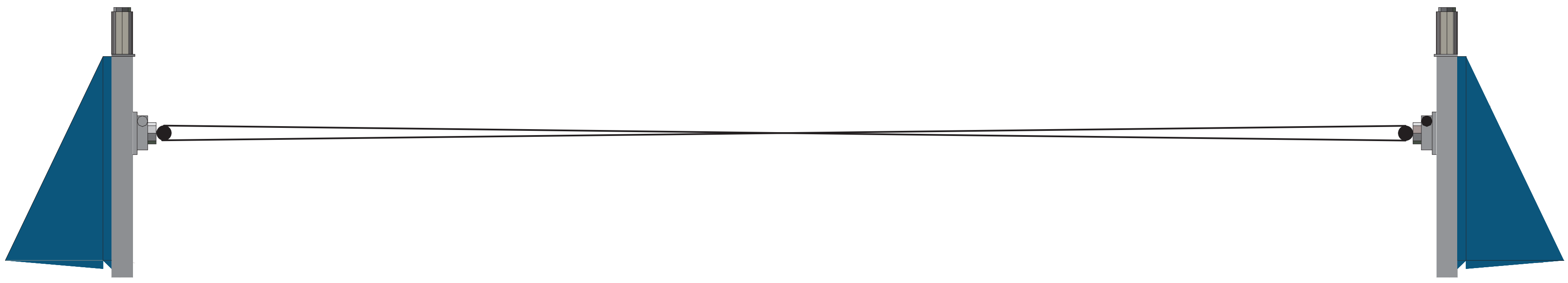
Both scanning methods agree well (± 4 Gcm)

Repeatability

± 2 Gcm for local measurement

± 4 G.cm for fast scans

Remark: Second field integral can be measured using twisted coil (easy)



Local measurements

➔ Presently based on Hall sensors (KSY 14)

3 components of magnetic field needed

- Enable correction of sensors angular errors
- Enable non linear corrections (planar hall effect)

Accuracy on longitudinal position is important

- ≈100-200 T/m field gradient
- Needs linear encoder (optical ruler or interferometer)

Accuracy on transverse position is not critical

- ± 0.1mm is enough

Fast field mapping is essential

Hall probe bench

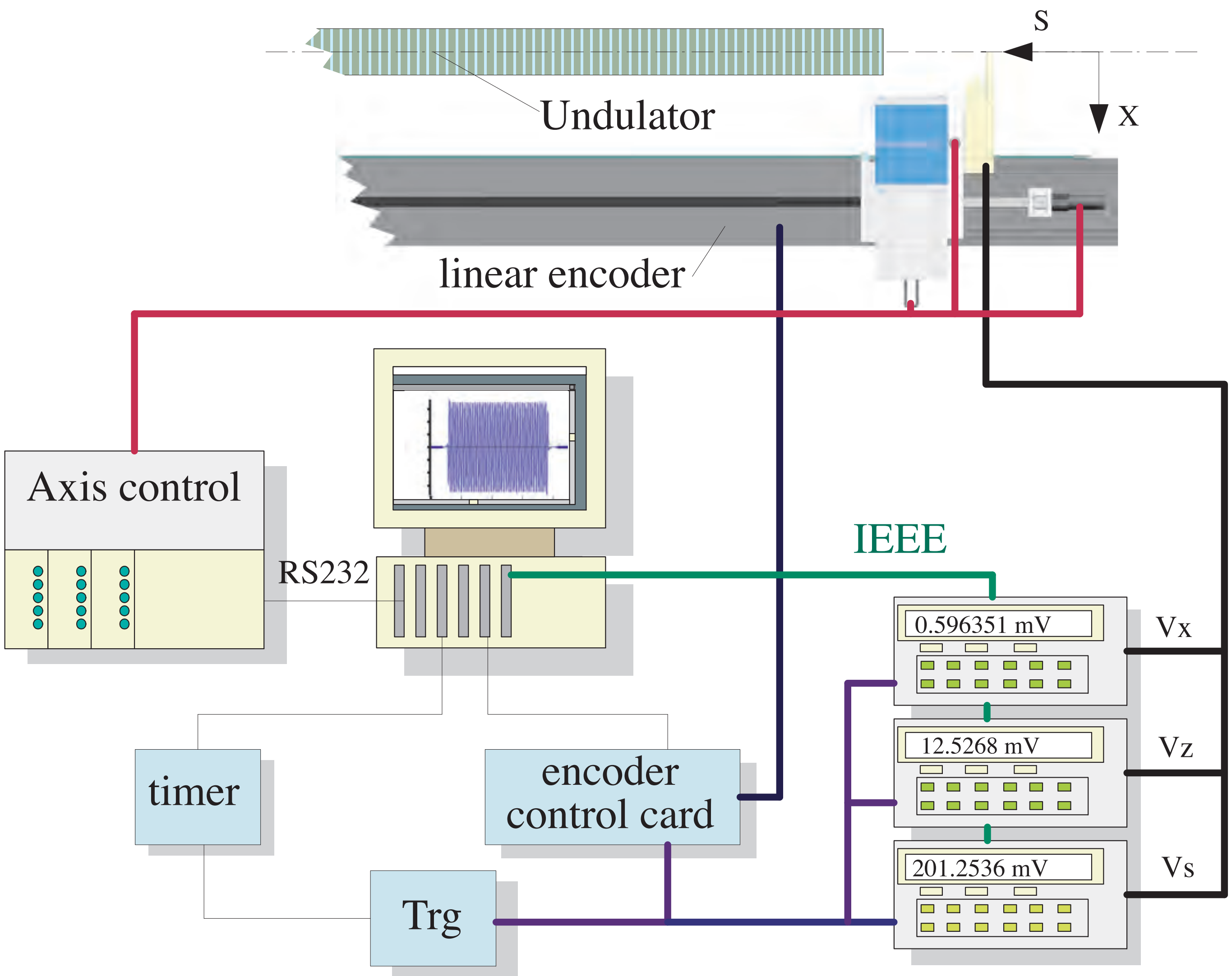
"on the fly" measurement

-Speed up to 30 mm/sec
-2500-5000 pts
per field component

Typical scan

-L= 2500 mm
-1 pt/mm/comp.
-V=20 mm/sec
-≈ 2 mn

3 similar units in the ESRF ID laboratory



Hall data acquisition

Fourier transform of the magnetic field gives many informations on non linearity of hall sensors (even harmonics for ex.)

The main goal in data treatment:

- investigate "random" angular quicks along ID field (trajectory)
- calculation of optical phase error

What is observed ? (B < 1T)

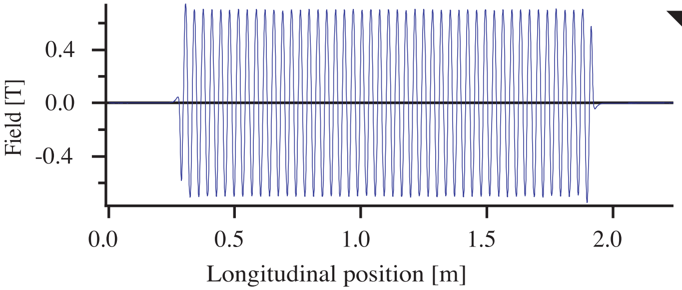
- reproducible field integral calculated from hall data (stable within 10 G.cm)
- but always different (≈ 0.5 G.m) from coil measurements (non linearity of hall sensors)

Correction of hall data :

- Hall data are systematically corrected so that the calculated field integrals are equal to coil measurements (quadratic correction)

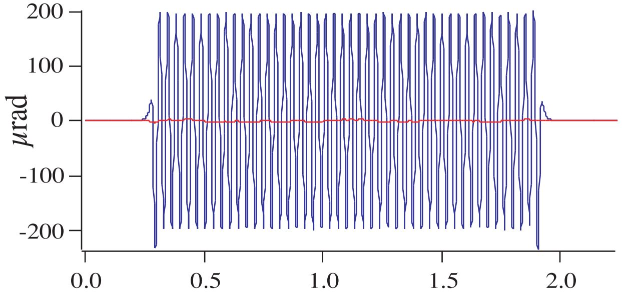
Hall data processing

Hall Voltages -> B

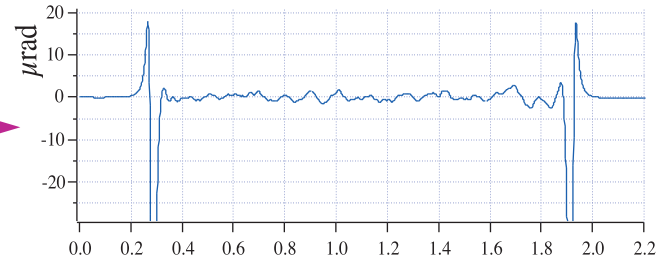


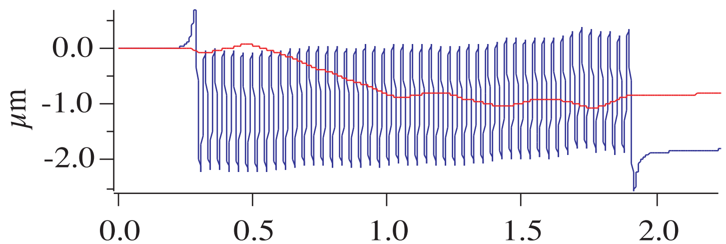
field integral correction

First integral (angle)



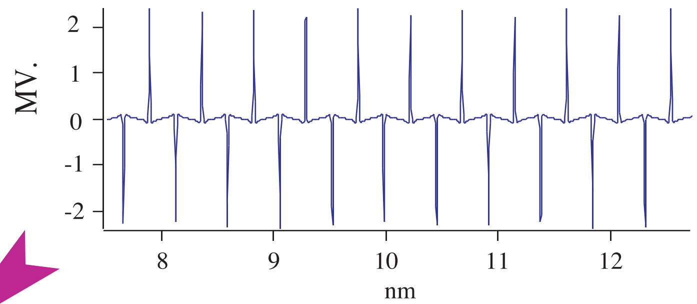
smoothed angle



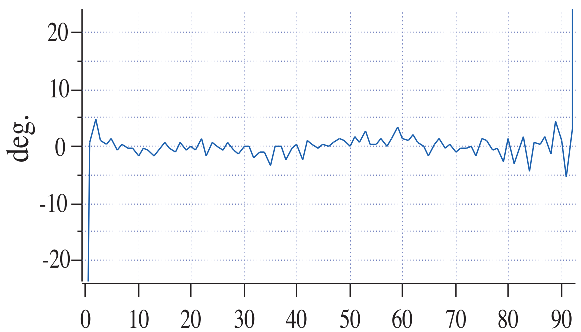


Trajectory

Electric field



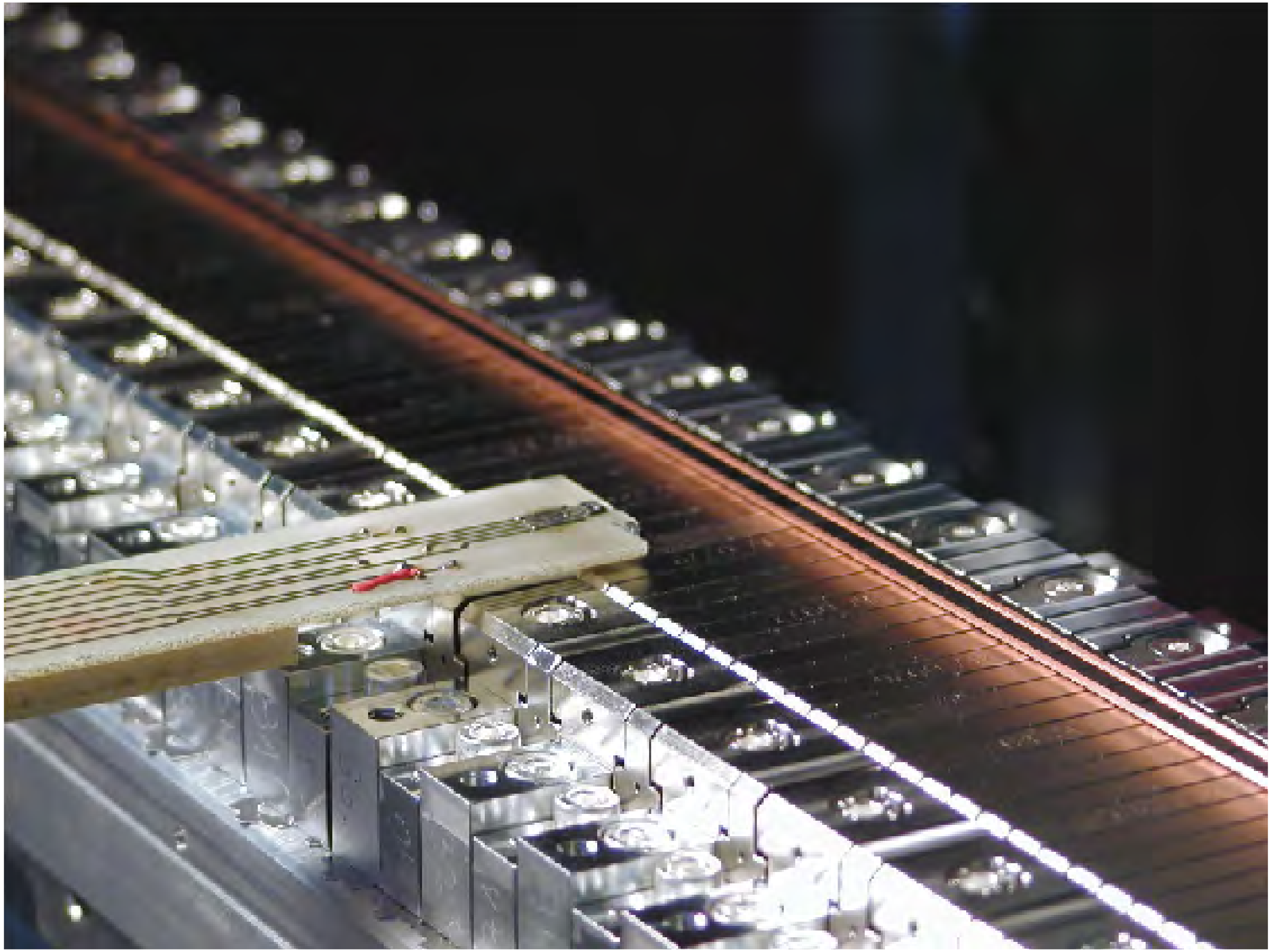
Phase error repeatability 0.1 deg



Bench control & data processing (B2E) made with IGOR pro

Coil and Hall probe benches

Hall probe keeper



ID field correction

The main source of errors

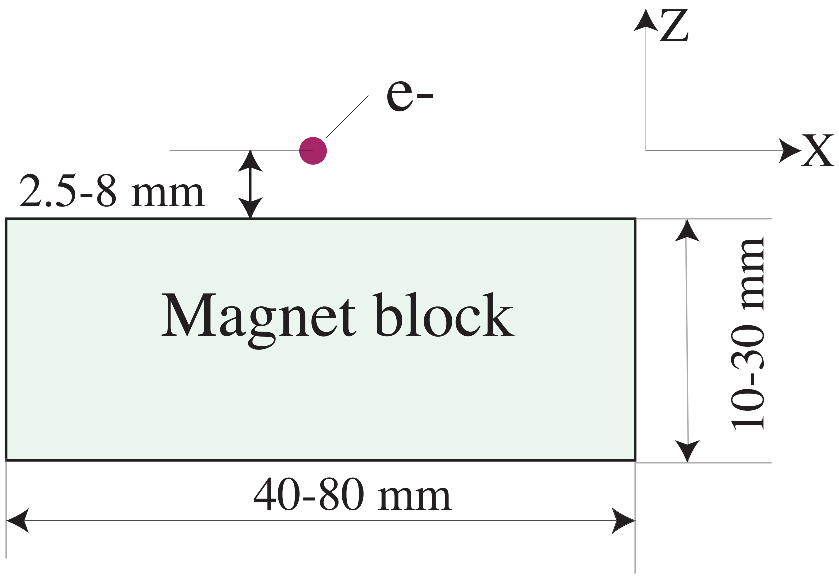
-Magnet block properties (homogeneity of magnetization) are inconsistent with required ID field quality

-The usual block measurements by Helmotz coil give averaged magnetic data

-Necessary

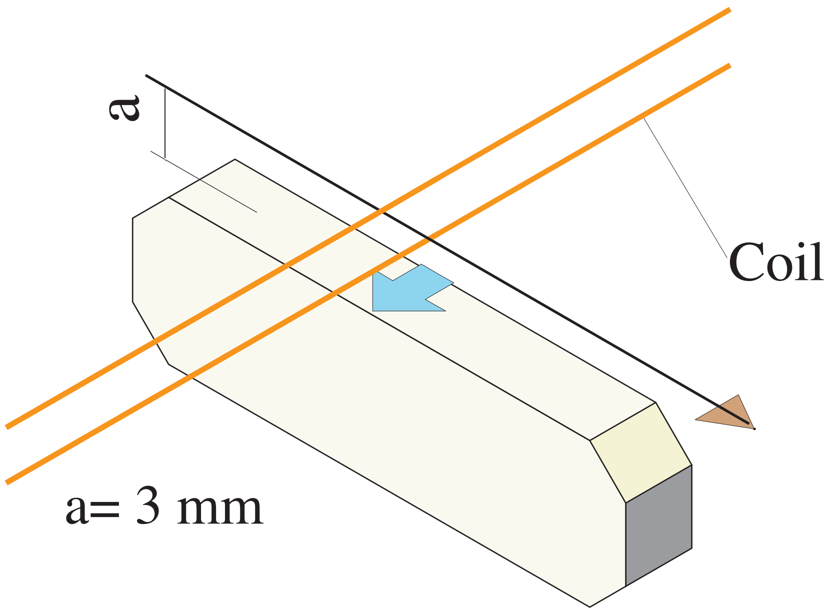
-But far from being sufficient

The electron beam "sees" locally the magnet blocks.

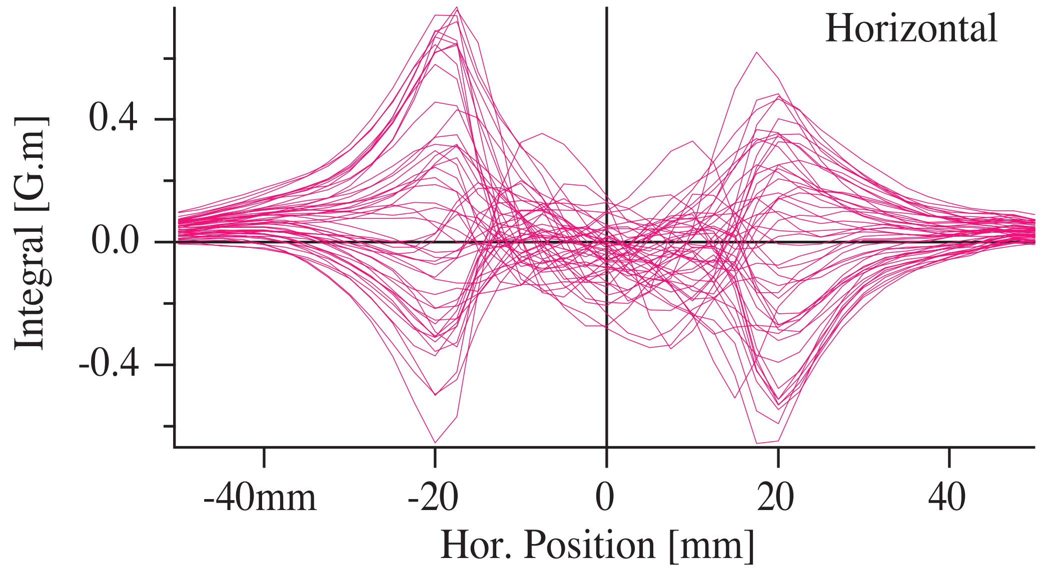


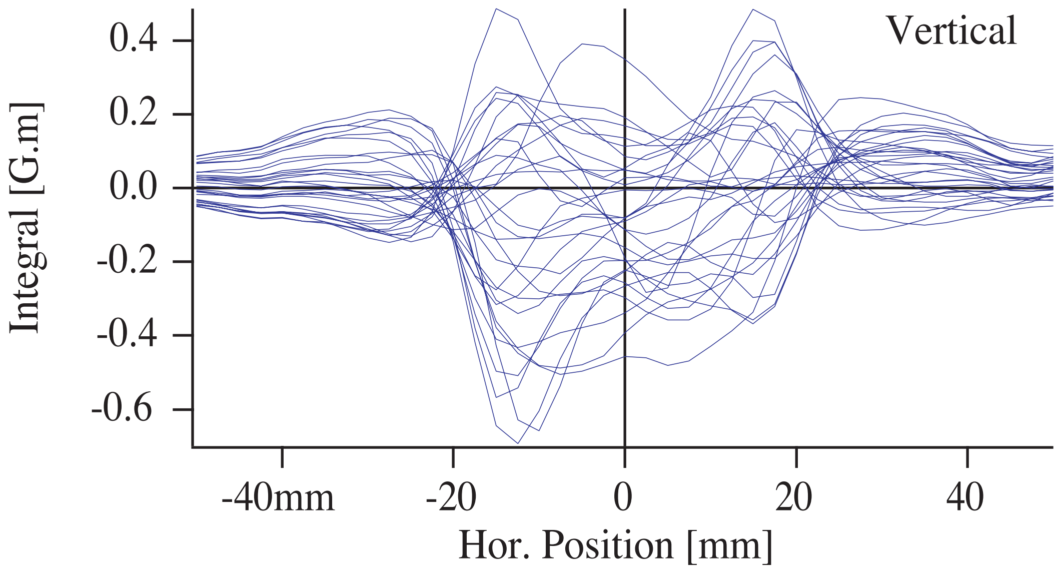
Magnet blocks

Looking locally magnet blocks



Magnet blocks:
Lx*Lz*Ls= 41*12*5.75 mm^3
30/200 units





ID field correction

Field integral

- ---> Cancel integrated dipole versus horizontal position

    - Cancel also higher order multipoles

Method

1 -Using field integral scans on single blocks and/or sub assemblies (modules)

- Time consuming for magnet blocks measurements but reduce considerably the following method
- Presently under development for the production of in vacuum undulators
- Seems to be a promising method

2- Using "multipole shimming"

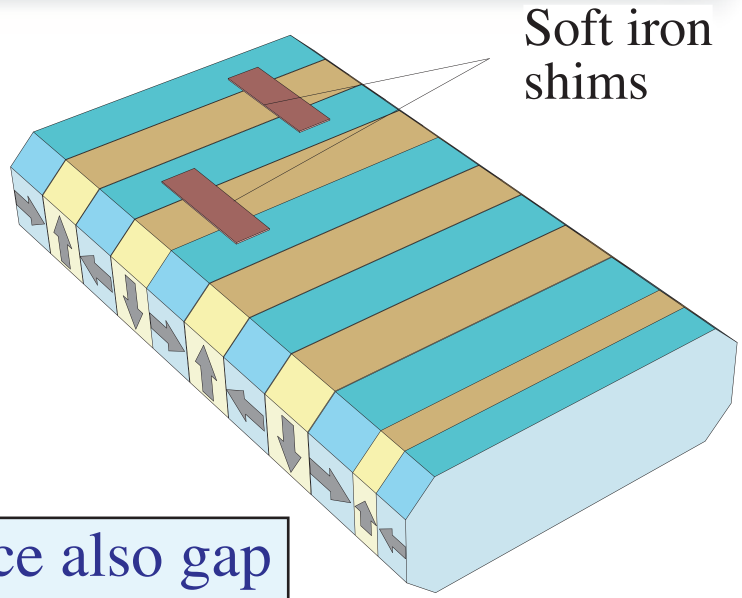
- with magnet block displacements
- but mostly with soft iron shims

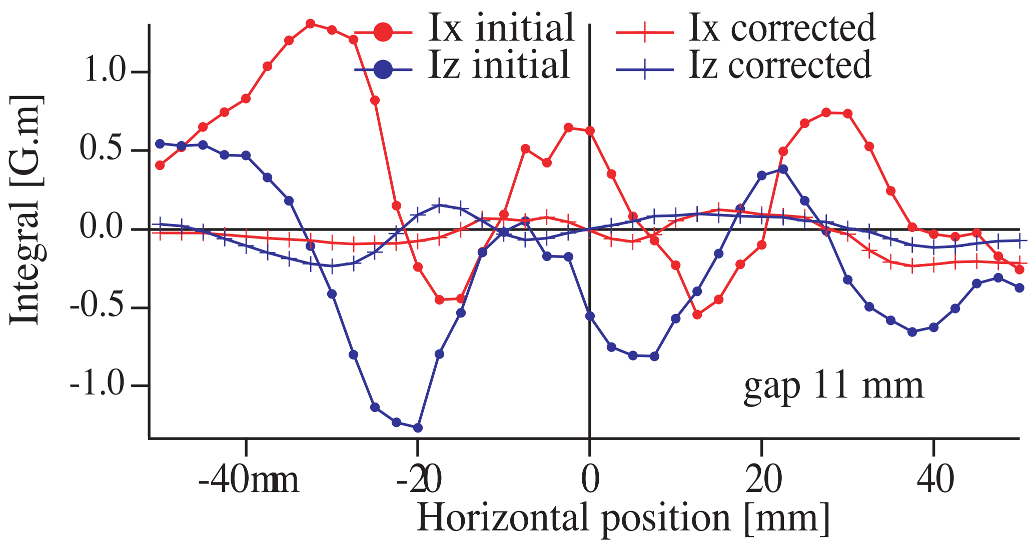
Routinely applied on all ESRF IDs

ID field integral correction

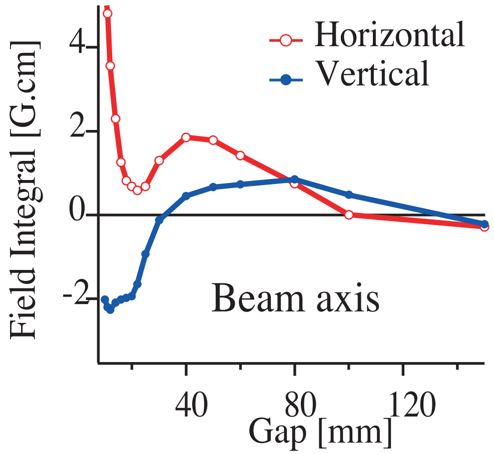
Multipole shimming

-Linearity with thickness (0.2 mm max)
-needs a few iterations
-Shims “signatures” can be calculated using RADIA





Reduce also gap dependence



ID: U35 L=1.6m Bmax=0.7 T @ 11 mm

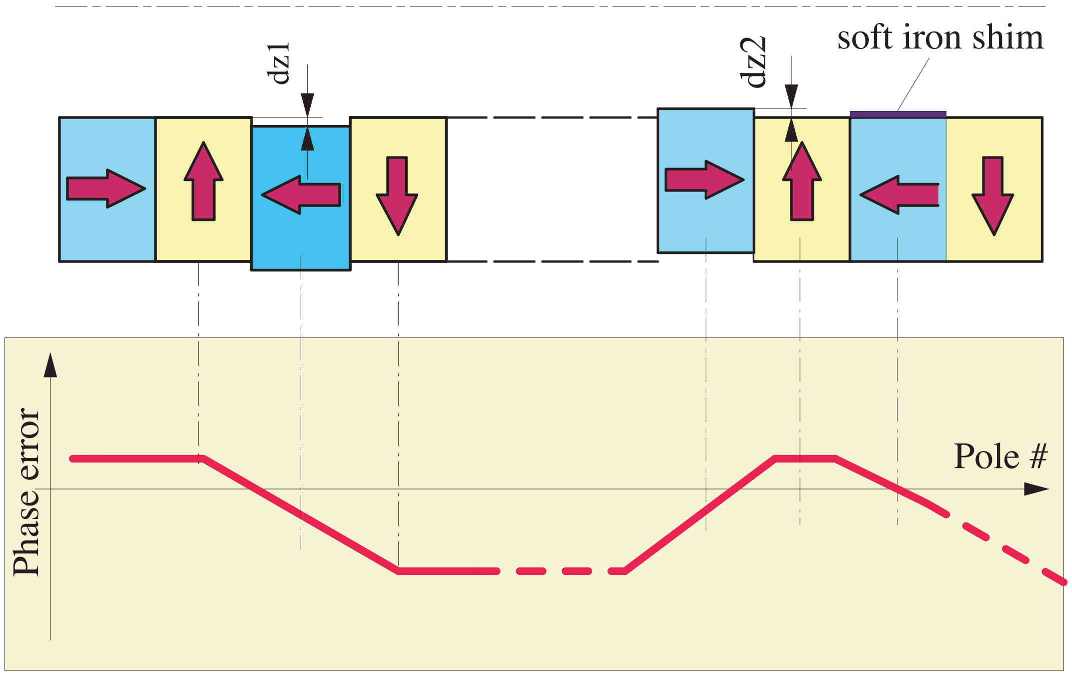
ID field correction

Local field correction

- ---> Cancel optical phase error at each pole
  - Using mostly small (±0.1 mm) vertical block displacements
  - Or soft iron shims optionally

Method is easy:

-Linearity with displacement or
- shim thickness
-need a few iterations
-correct also trajectory

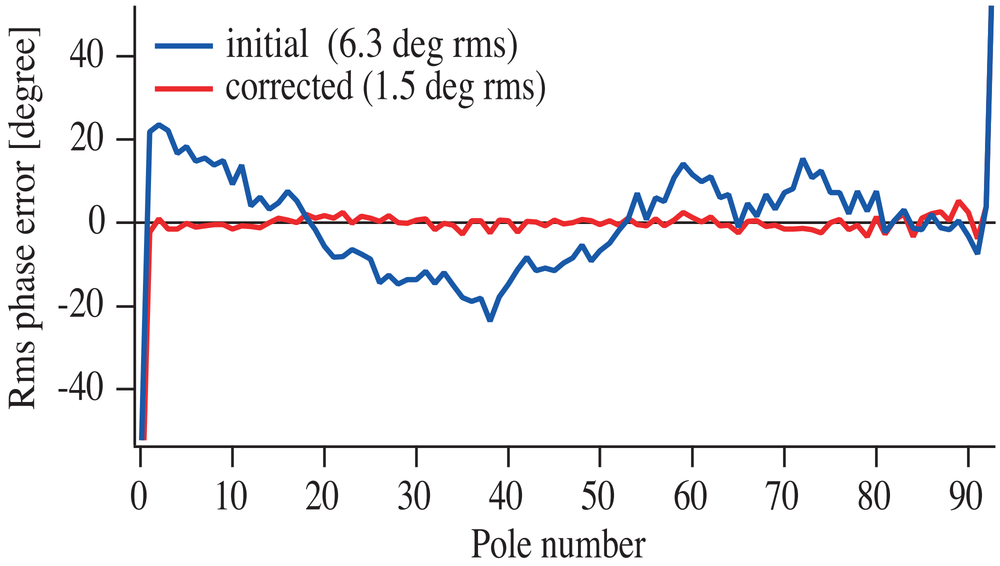


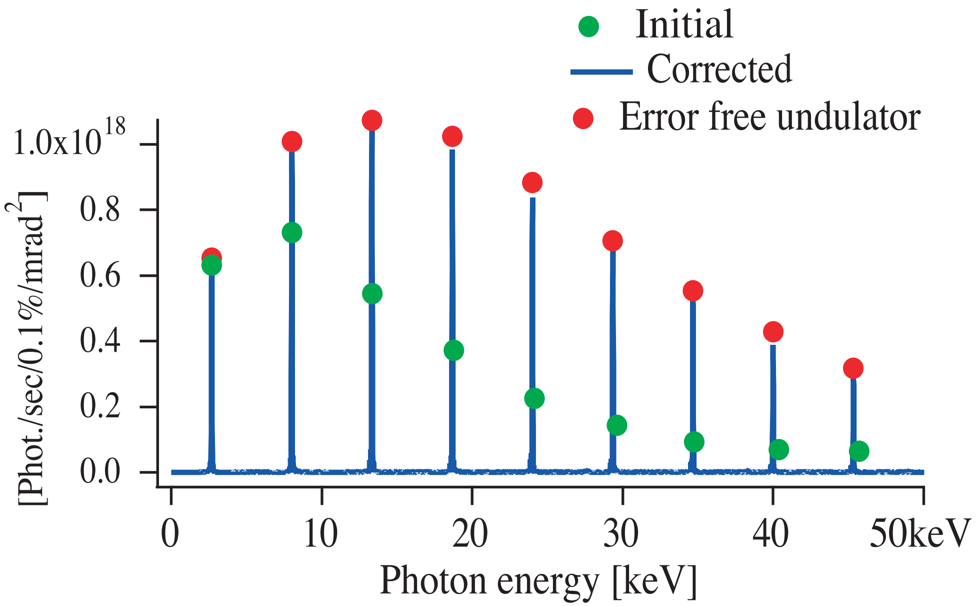
Routinely applied on ESRF undulators

ID local field correction

Spectrum/phase shimming

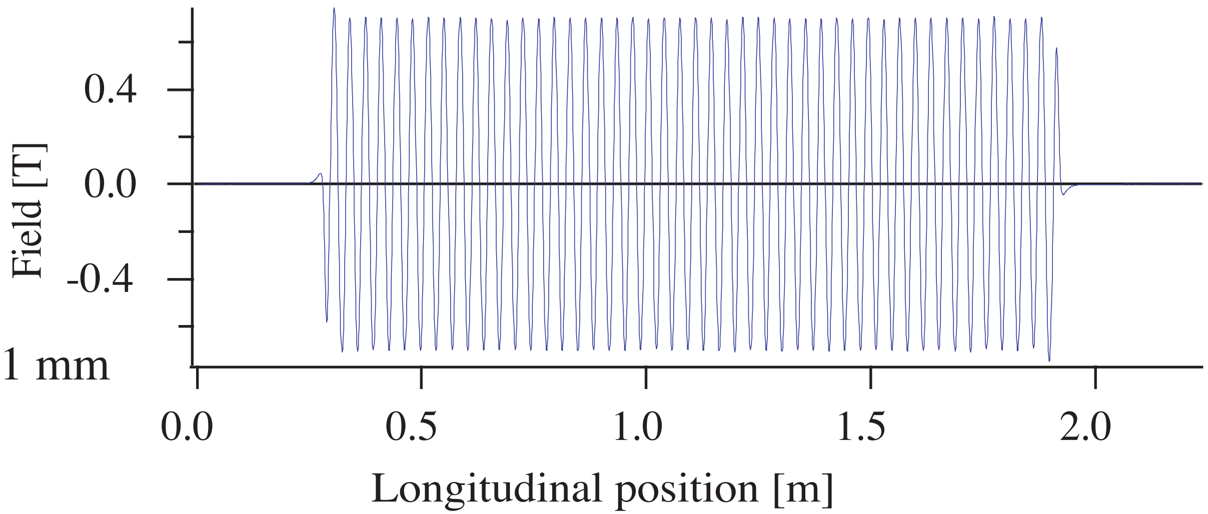
- ---> blocks displacements and shim effects can be computed (RADIA)
  - takes a few iterations
  - R.m.s phase error easily reduced < 2 degree





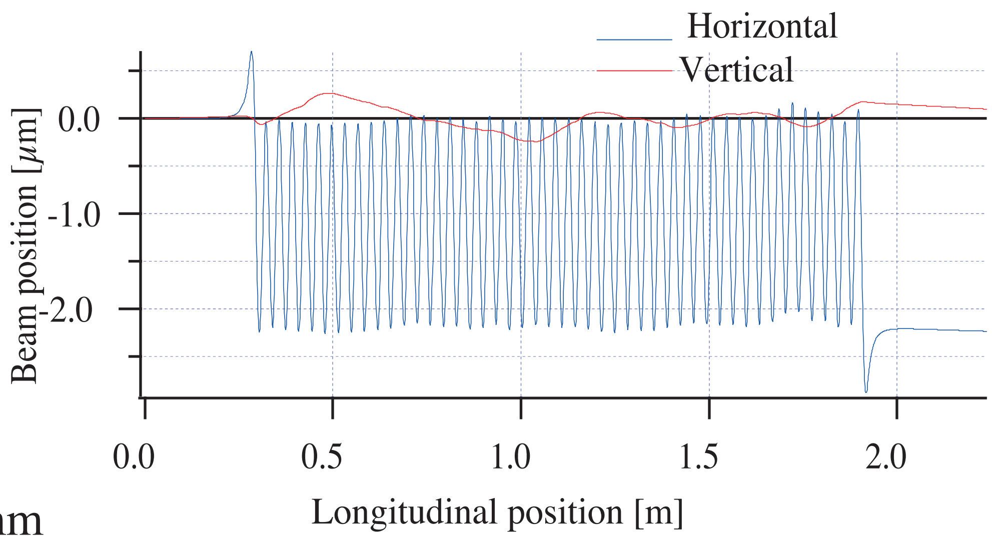
Undulator: period 35 mm, L=1.6 m, gap 11 mm

ID local field correction

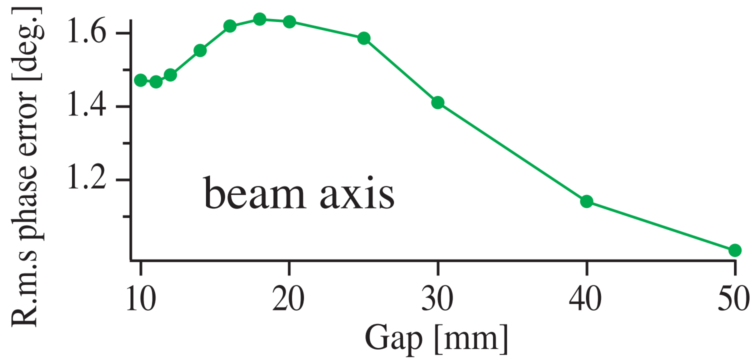


gap 11 mm

Undulator
period 35 mm, L=1.6 m
Peak field fluctuation 0.4 %
Period fluctuation 0.2 %
(2 poles removed at either ends)

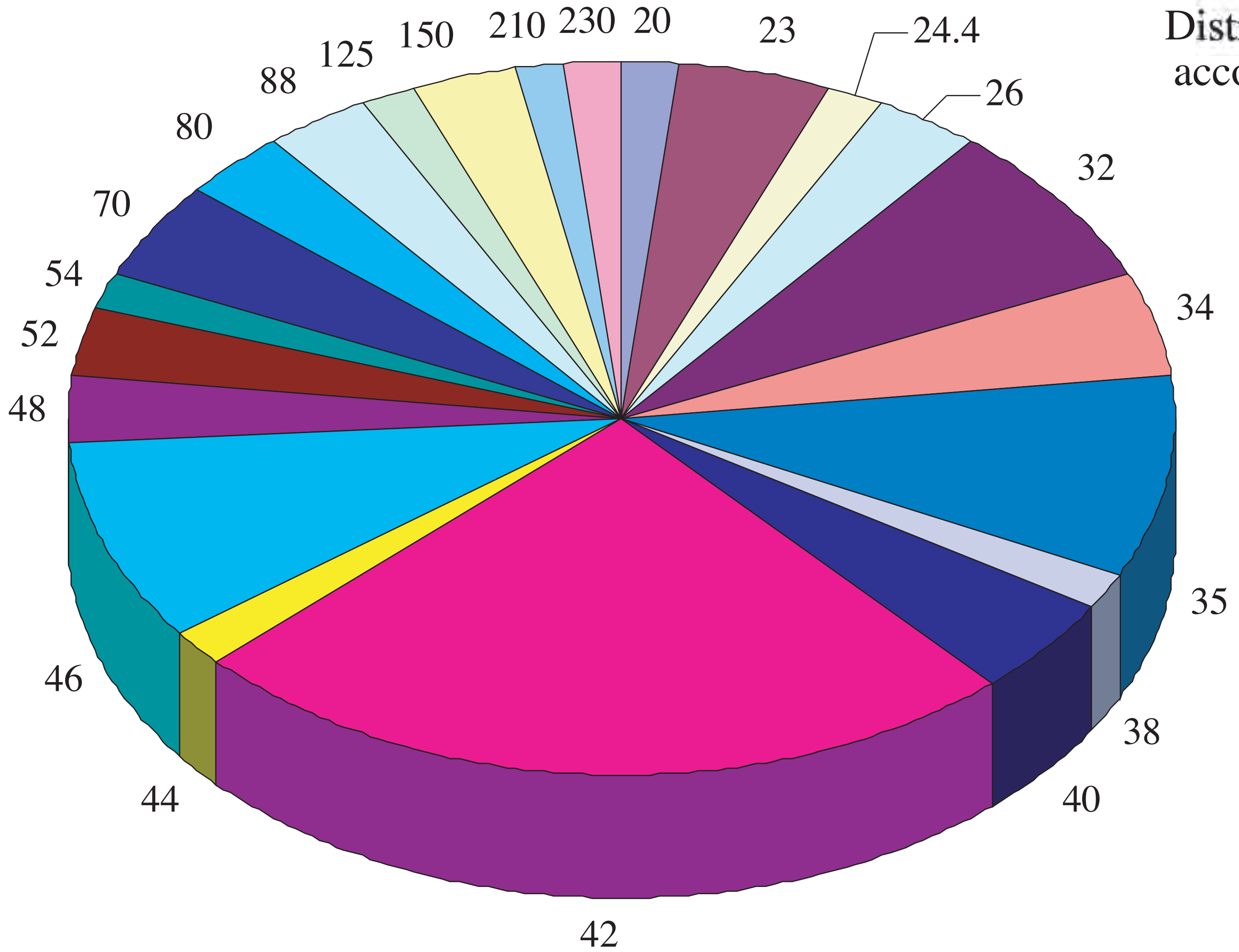


gap 11 mm



Dependence on gap

Installed IDs on the ESRF ring



Distribution of ESRF IDs according to their period [mm]

1 Oct 2001

Total number = 65

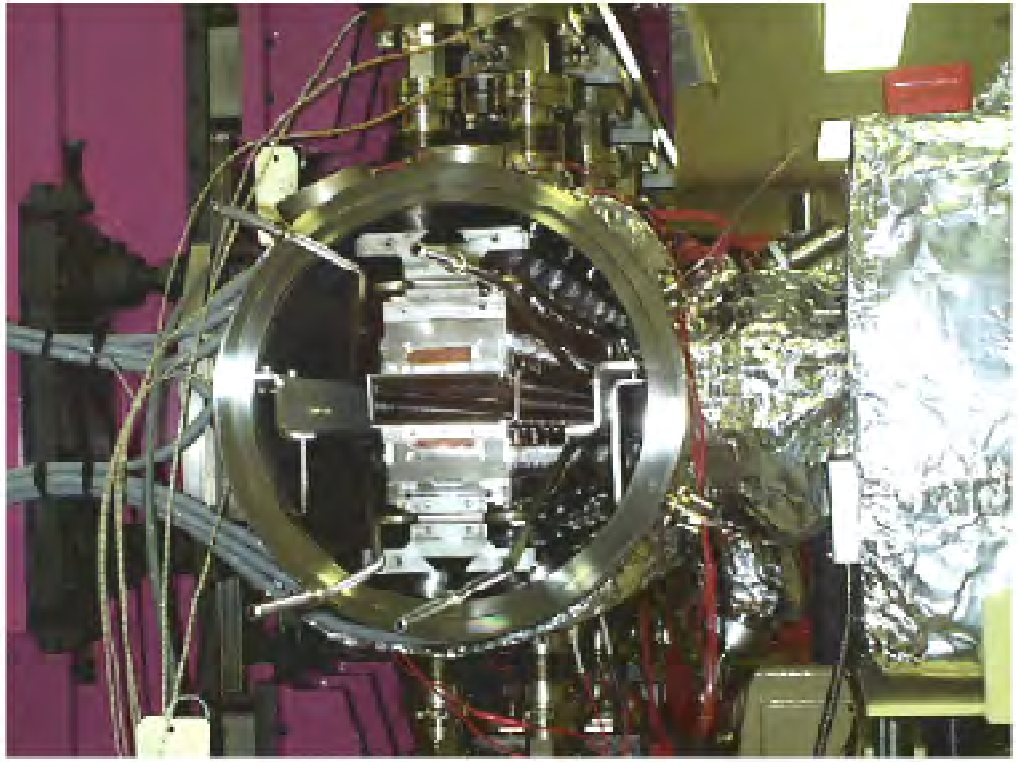
- 86 % undulators
- 14 % wigglers

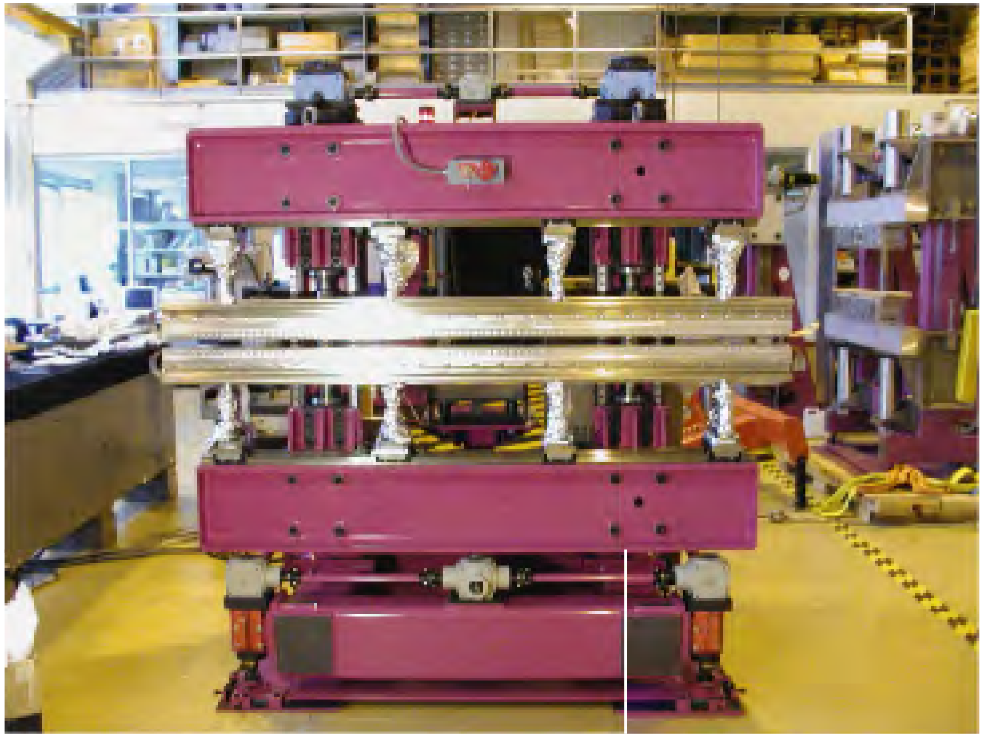
-15 % dedicated to circular polarization

Photon energy range:

0.3 to 200 keV

In Vacuum undulators





Length: 2 m,   min gap: 6 mm

- 2 devices installed (period 23 mm)

- 3 devices under construction: period 17,18 & 21 mm

Summary/conclusion

1-Numerical simulations are essential in IDs construction

- at design stage for the elimination of undesirable systematic effects
- during the field correction using various shimming methods

2-Magnetic measurement equipment

- Simple and reliable tools in "production' context
- measurement speed is important

3- Field correction

- Mostly dominated by magnet blocks properties
- probable need for specific magnet block characterization