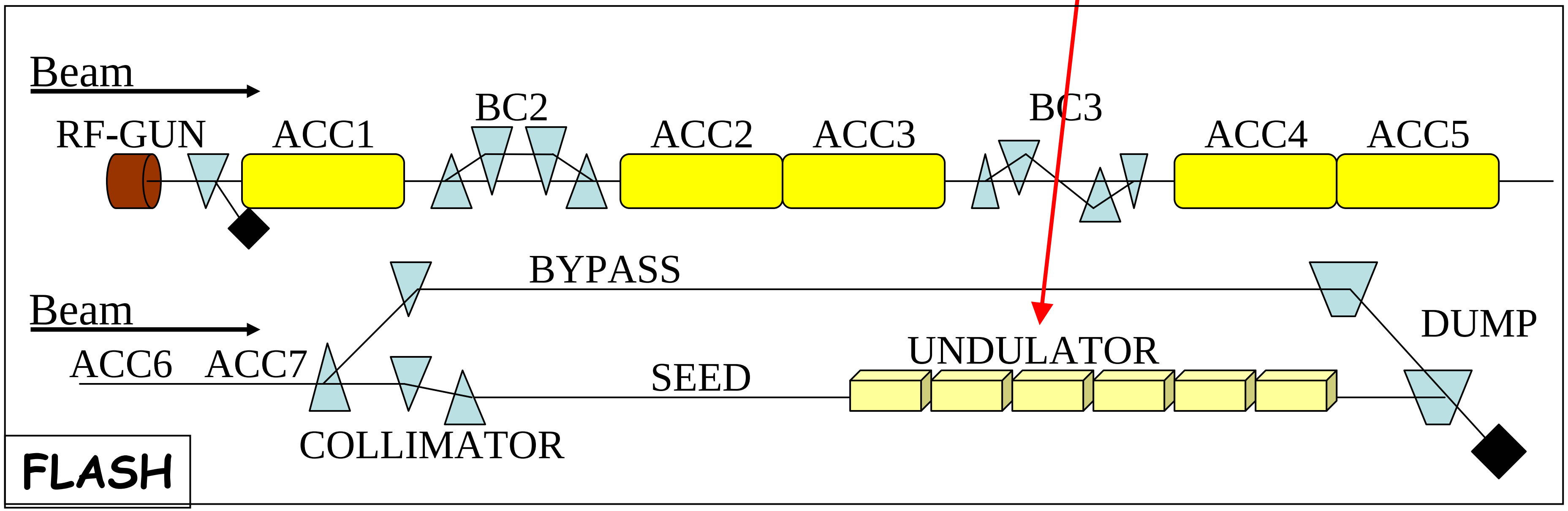
Progress status of beam-based alignment in the undulator section

P.Castro



Overview of the talk:

- motivation
- principles of BBA
- results of quad.-monitor offset
- remanent dipole field in quads
- undulator deflection

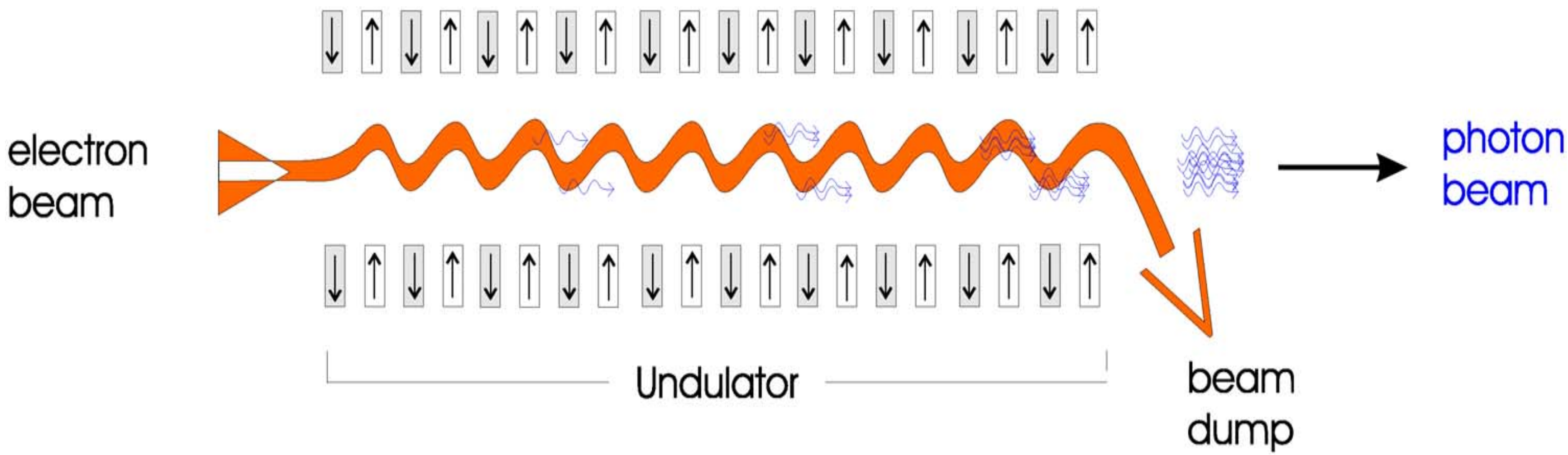
1) Motivation

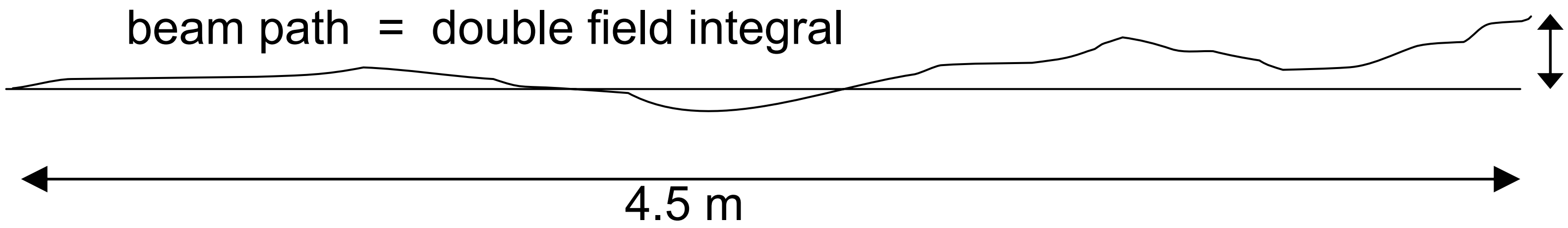
Goal:

- align all quadrupoles between undulator modules
- to get straight trajectory in undulator section

- to increase the overlap between electrons and photons
  so that the SASE process can take place
  in the whole undulator section

Undulator fabrication tolerances

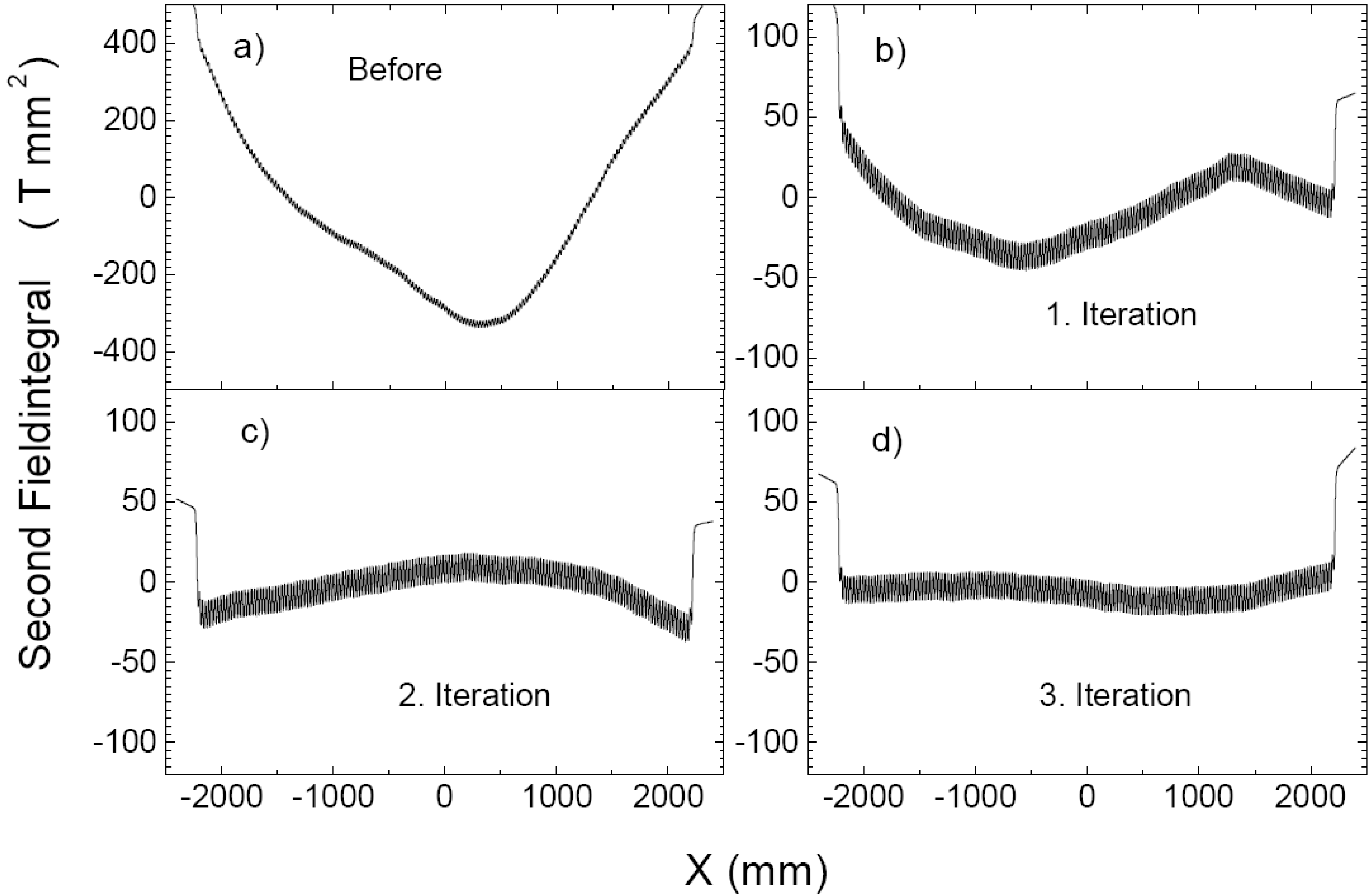




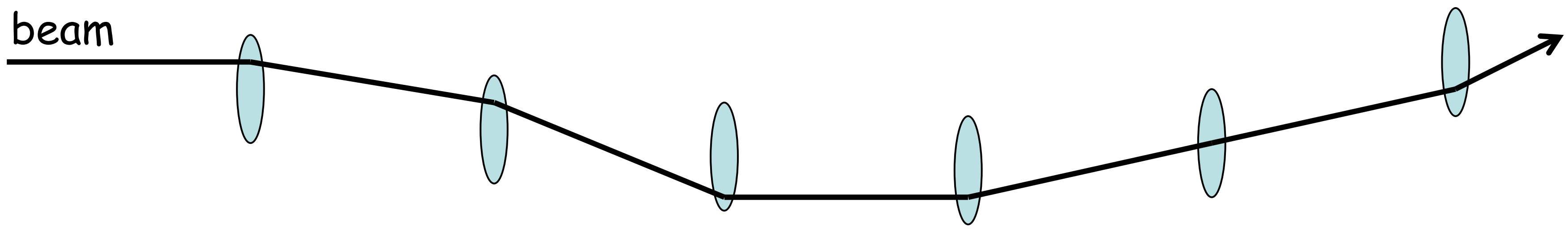
		required	SASE 400	SASE 500	SASE 600	SASE 700	SASE 800	SASE 900
$I_{2,Z,\,RMS}^{2}$	Tmm^2	< 30	4	1.2	4.2	1.7	7.9	9.8
$I_{2,Y,\,RMS}^{2}$	Tmm^2	< 30	7	8.2	6.9	7.0	3.2	2.2

30 Tmm^2 corresponds to 10µm at 1GeV

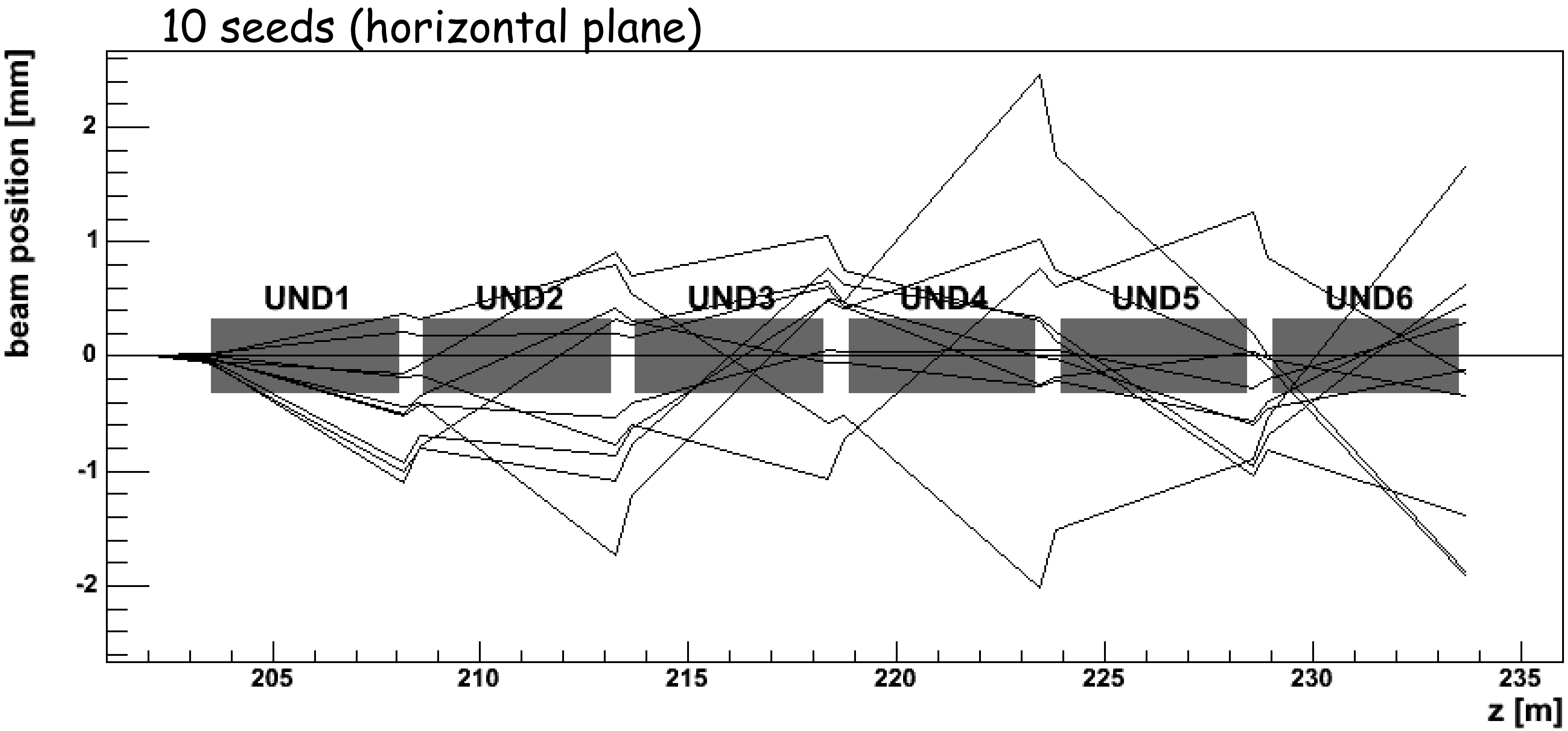
Measurement by J.Pflüger et al.



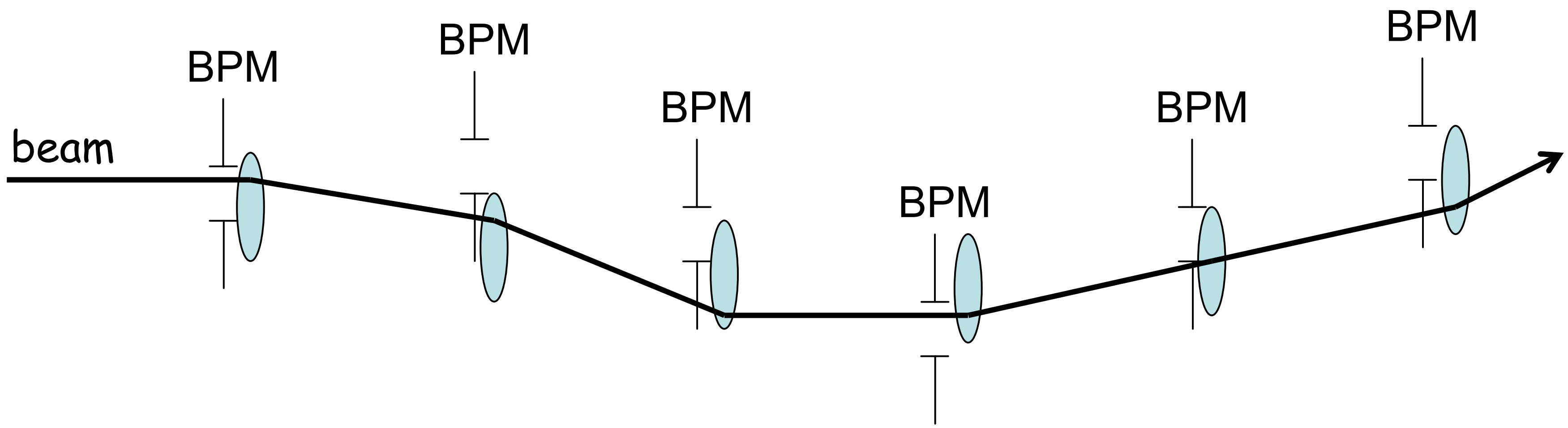
DESY Jahresbericht 1999 Measurement by J.Pflüger et al.


beam

orbit simulation for quadrupole misalignment of 0.1 mm RMS



for so-called optics v4 (with k1=7.14 m^{-1} and k2=-6.14 m^{-1})


beam
BPM
BPM
BPM
BPM
BPM
BPM

2) BBA in undulator: steps (overall plan)

1) "ballistic alignment", i.e., align quadrupoles to the beam

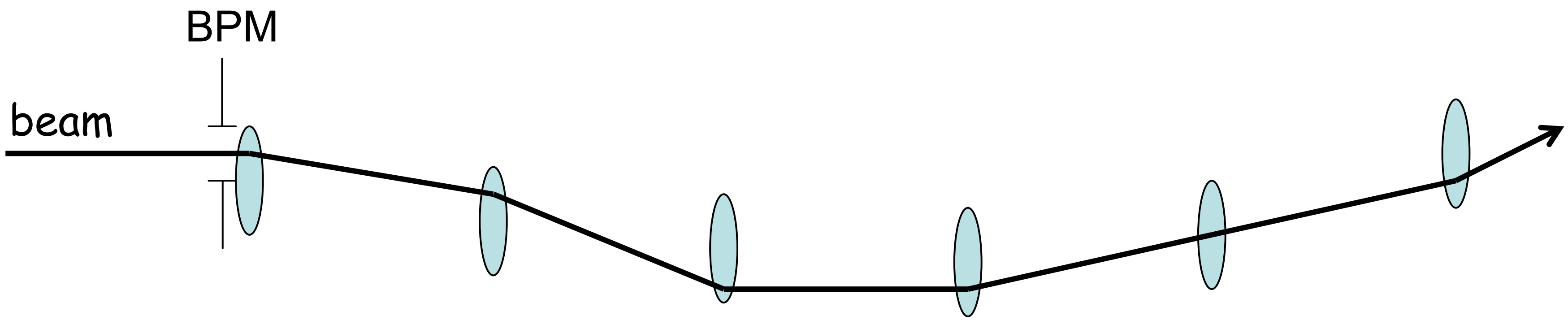
   it needs to measure relative offset
   between quadrupoles and BPM (or wire-scanners)

2) measure dispersion created ONLY in undulator section and correct it

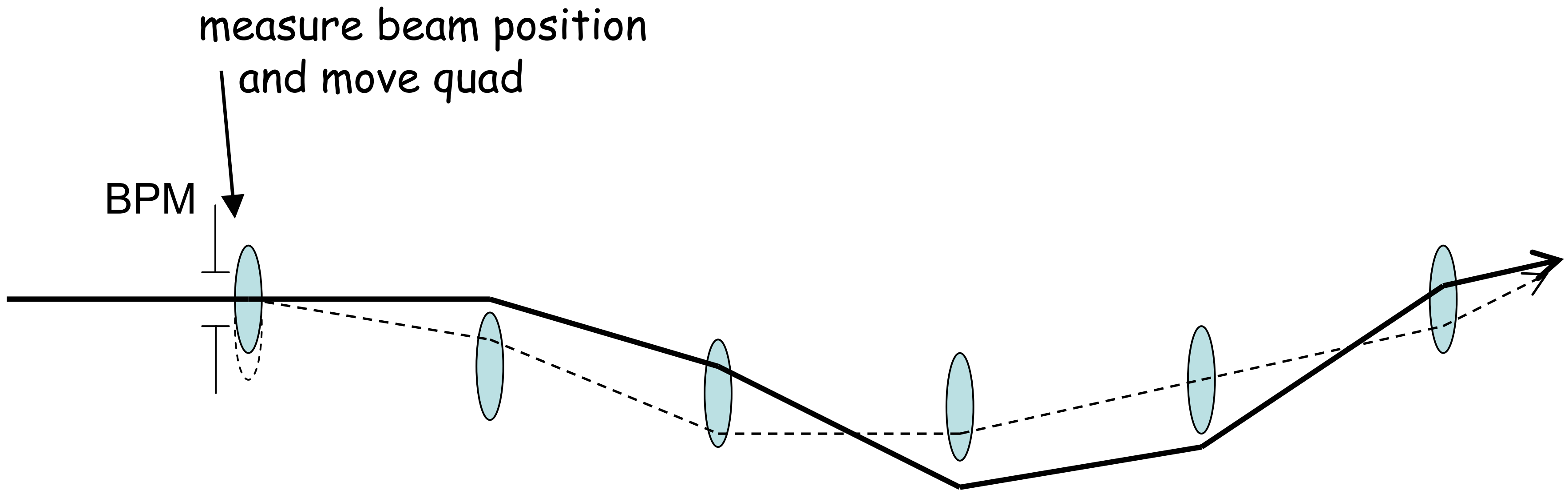
   it needs masking of incoming disperion
   and needs very precise BPMs

Principle of “ballistic alignment“

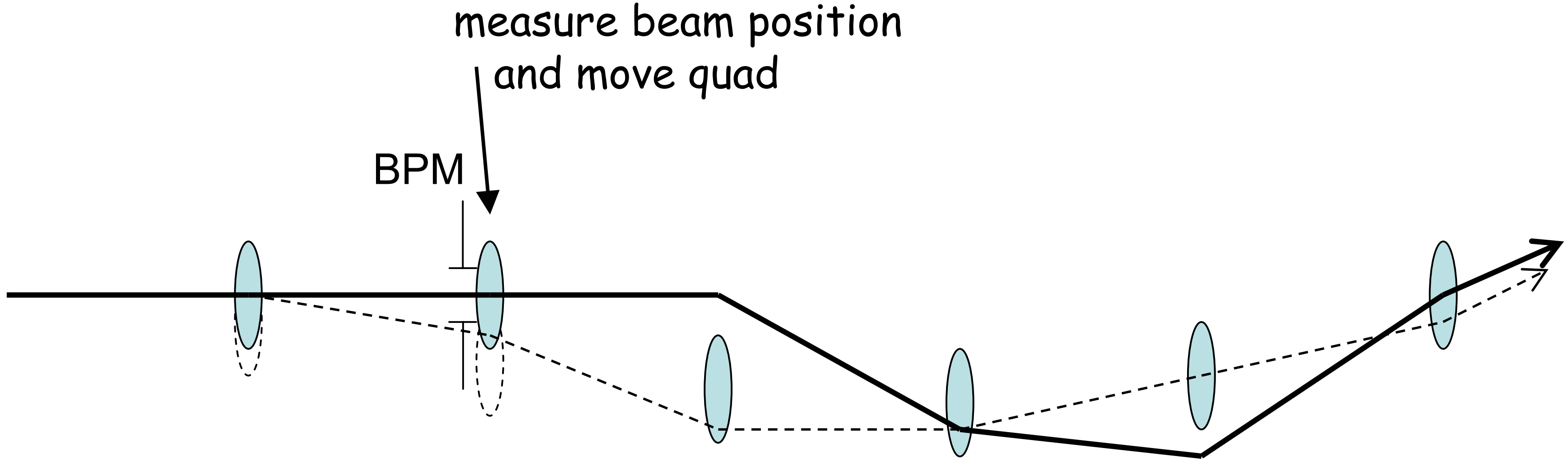
(Note: it works if there is ONLY pure quadrupole fields)



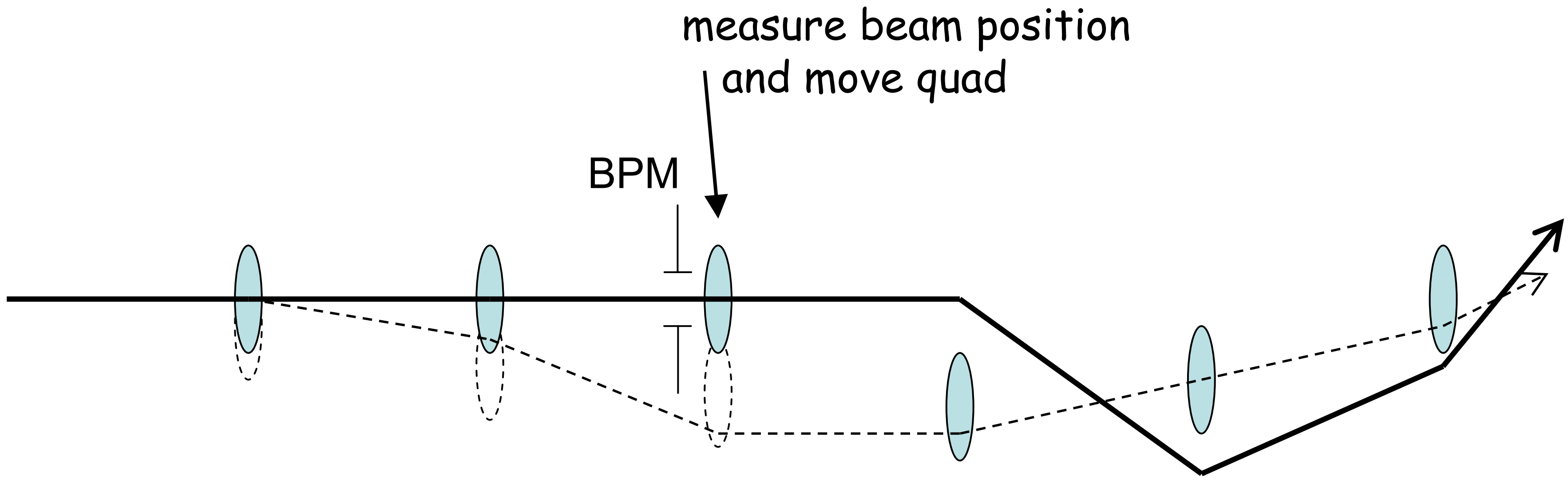
Principle of “ballistic alignment“



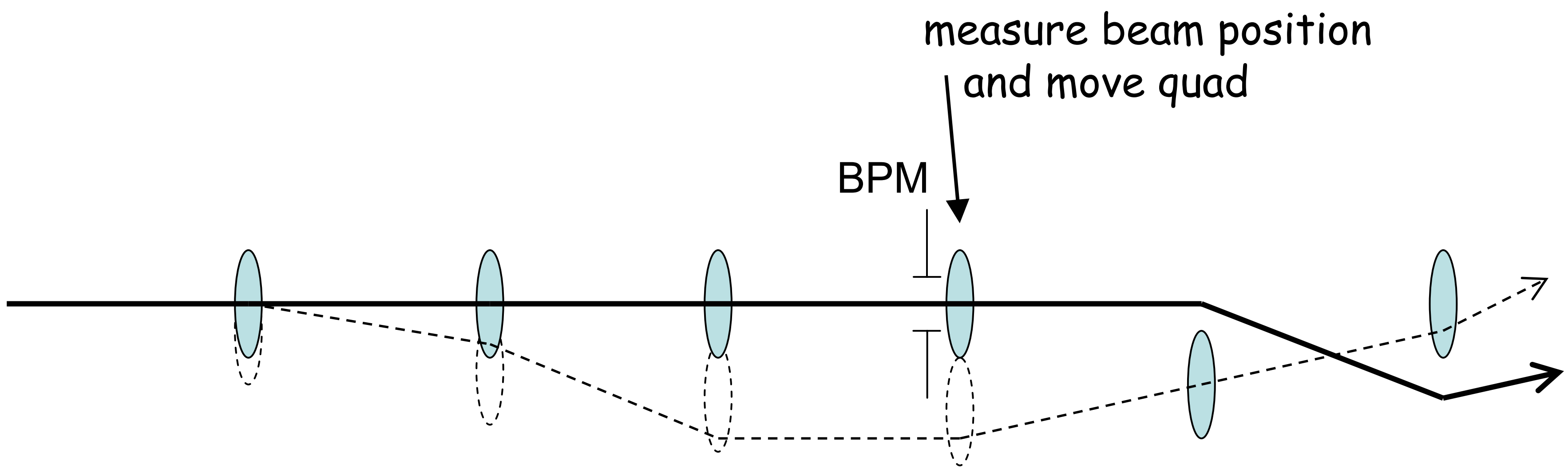
Principle of “ballistic alignment“



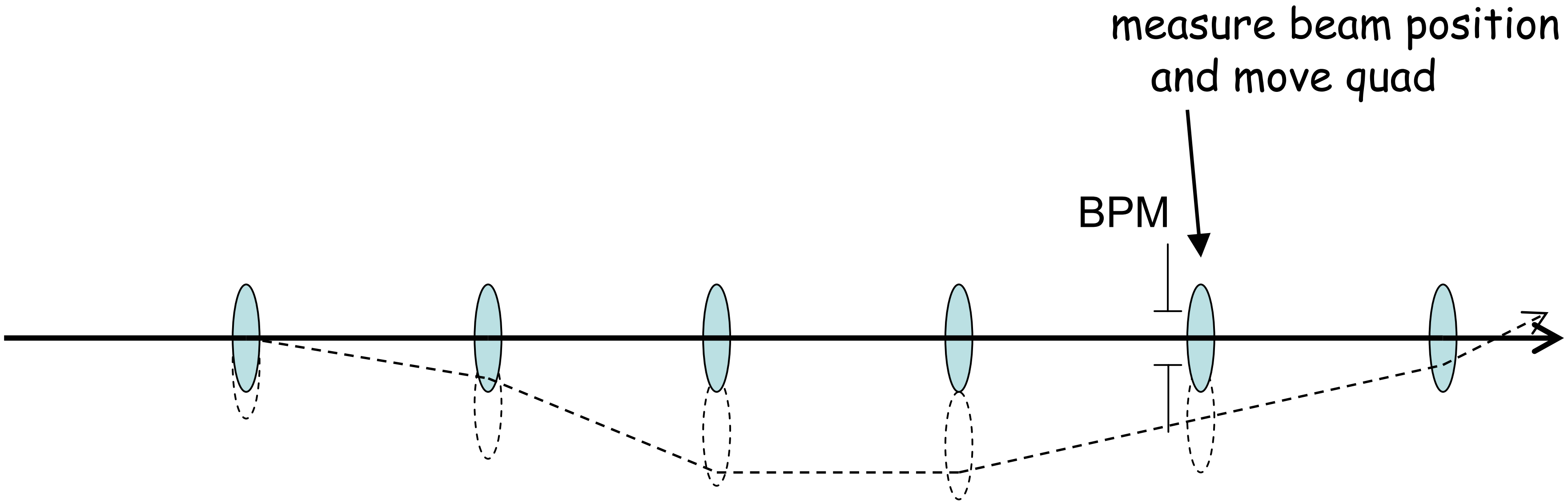
Principle of “ballistic alignment“



Principle of "ballistic alignment"



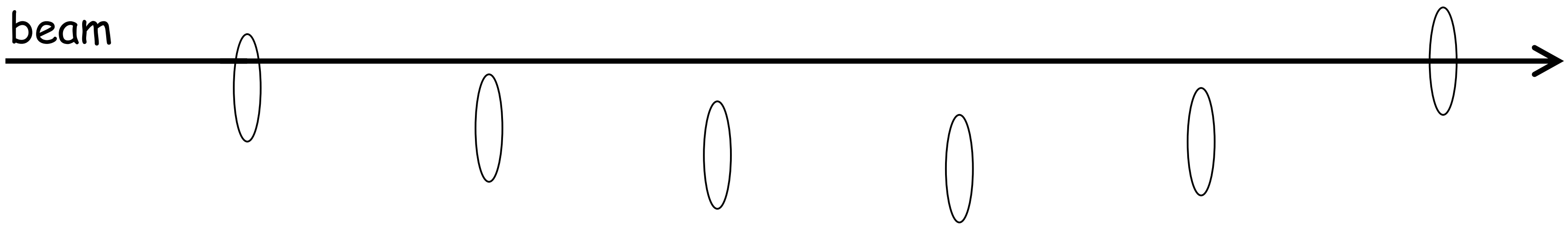
Principle of "ballistic alignment"



→ all quads are steering free

→ no dispersion generated by quads

An alternative procedure: with quads OFF



Principle of “ballistic alignment”

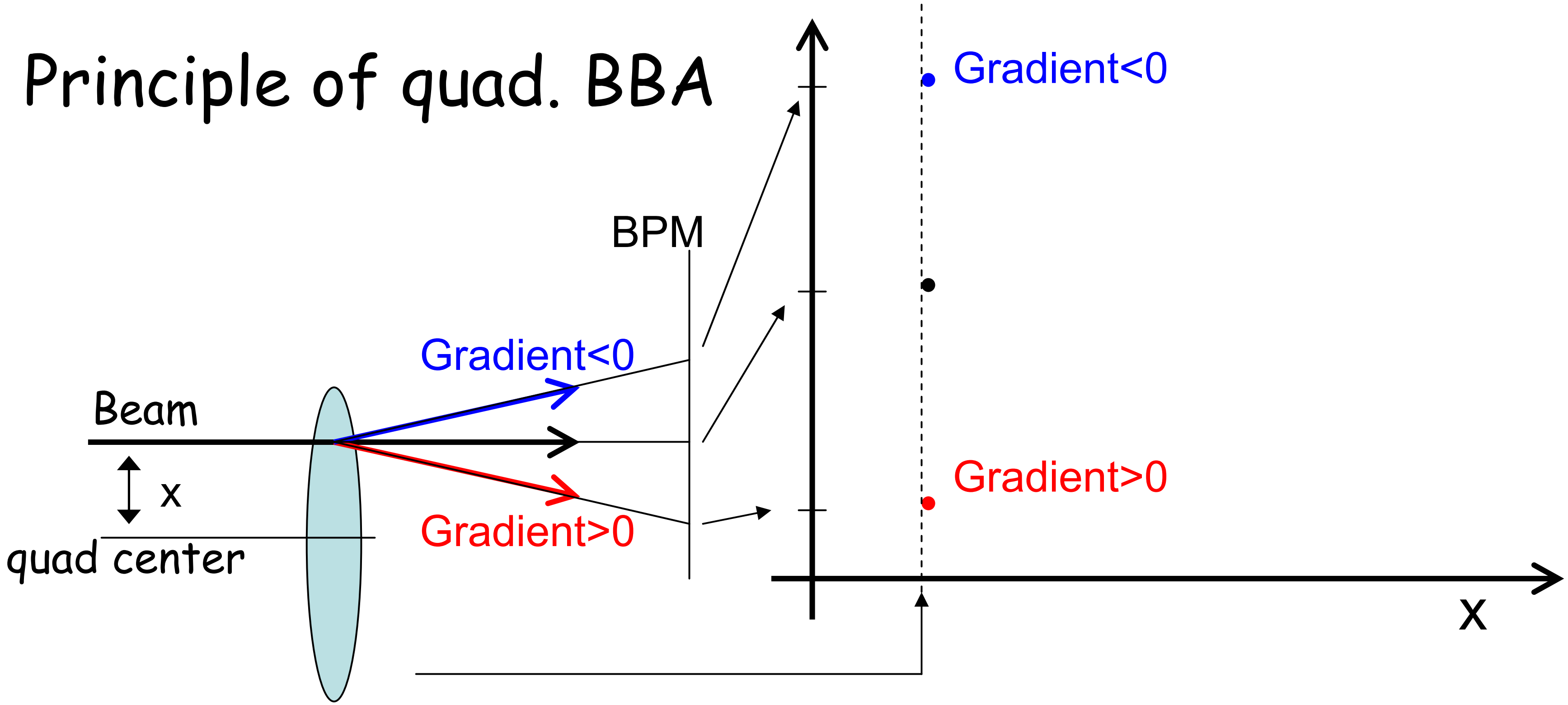
(Note: it works if there is ONLY pure quadrupole fields)

→ it needs to measure relative offset between quadrupoles and BPM (or wire-scanners)

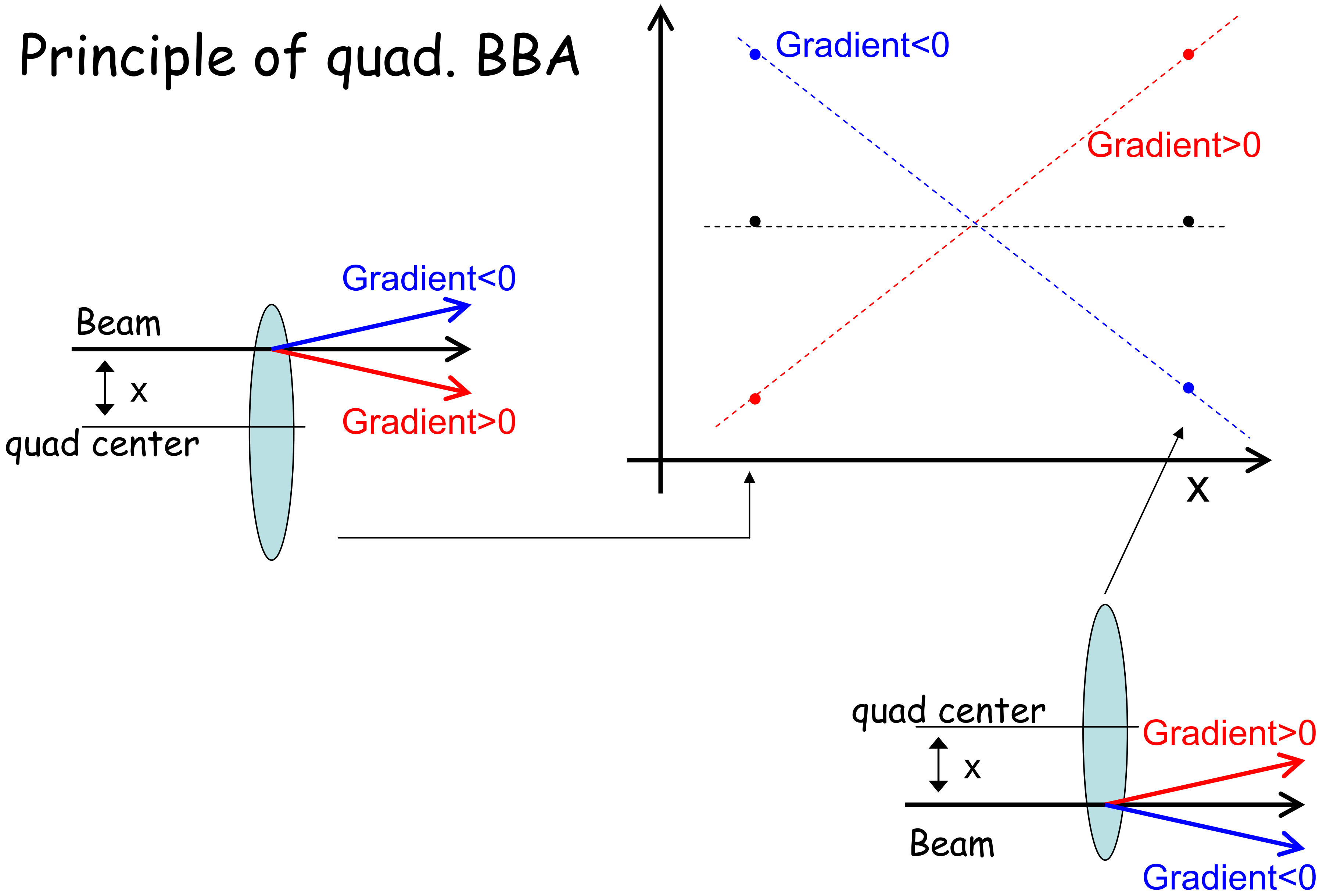
(with more precision than achieved with survey instruments)

we have done it using “quadrupole beam-based alignment” (BBA)

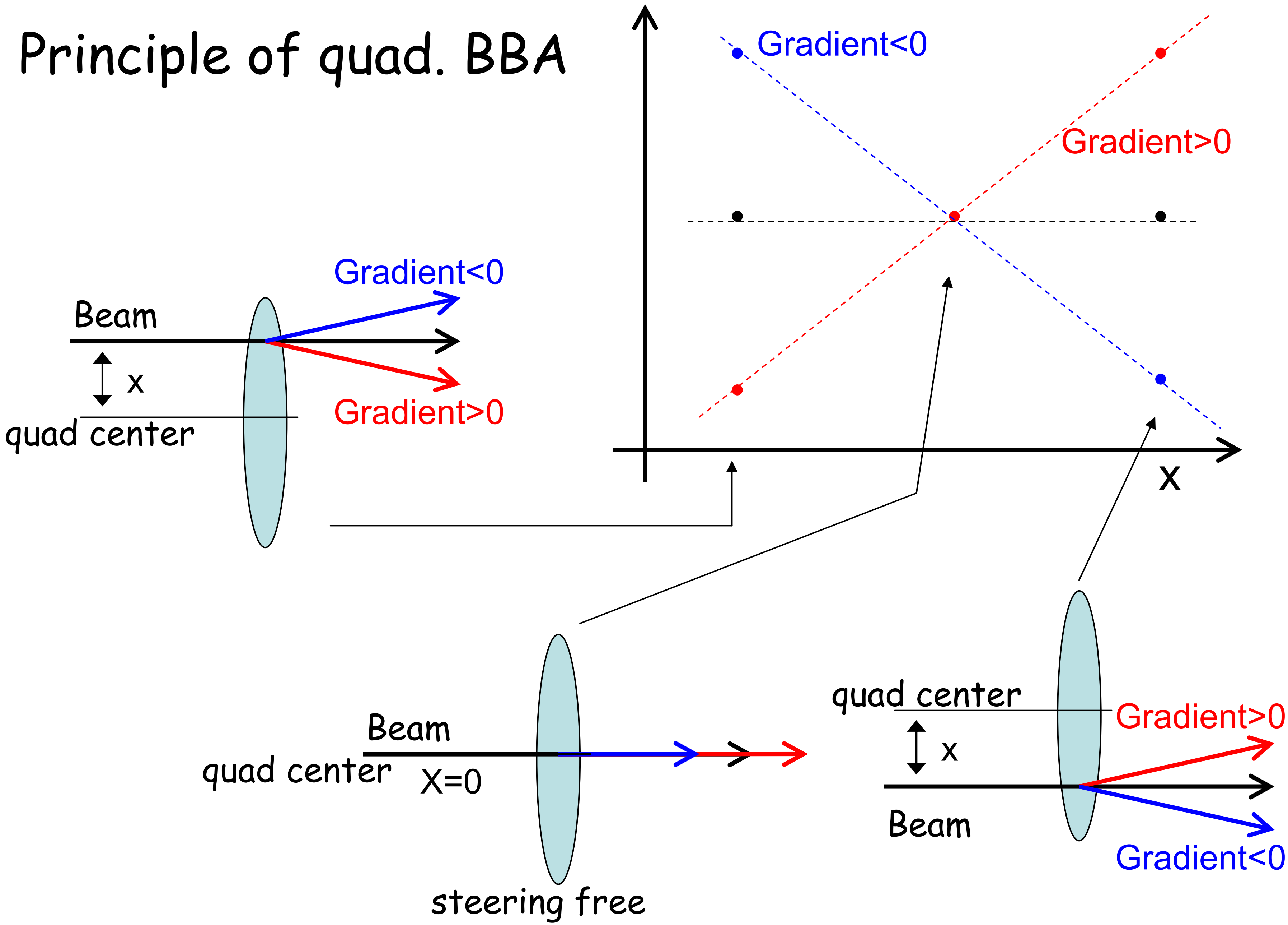
Principle of quad. BBA



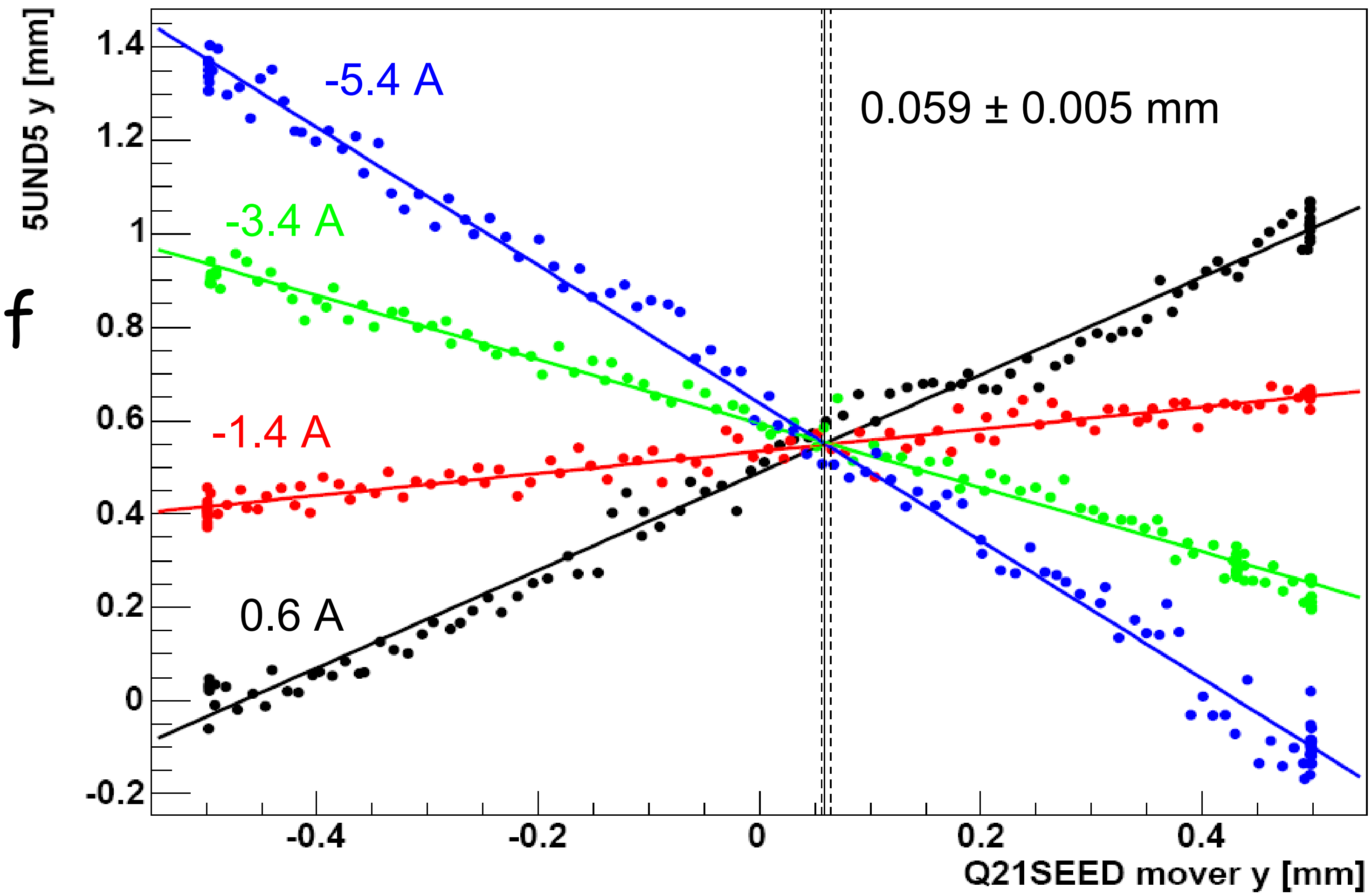
Principle of quad. BBA

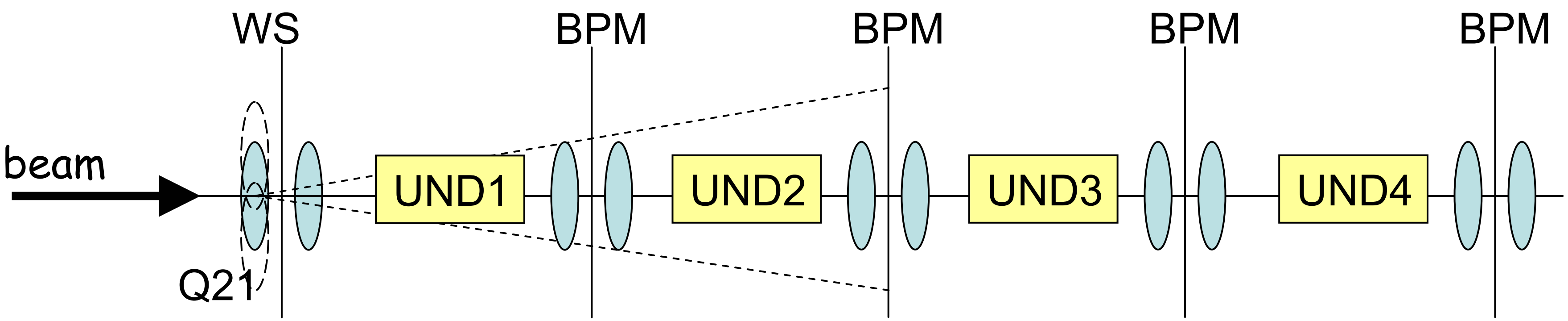


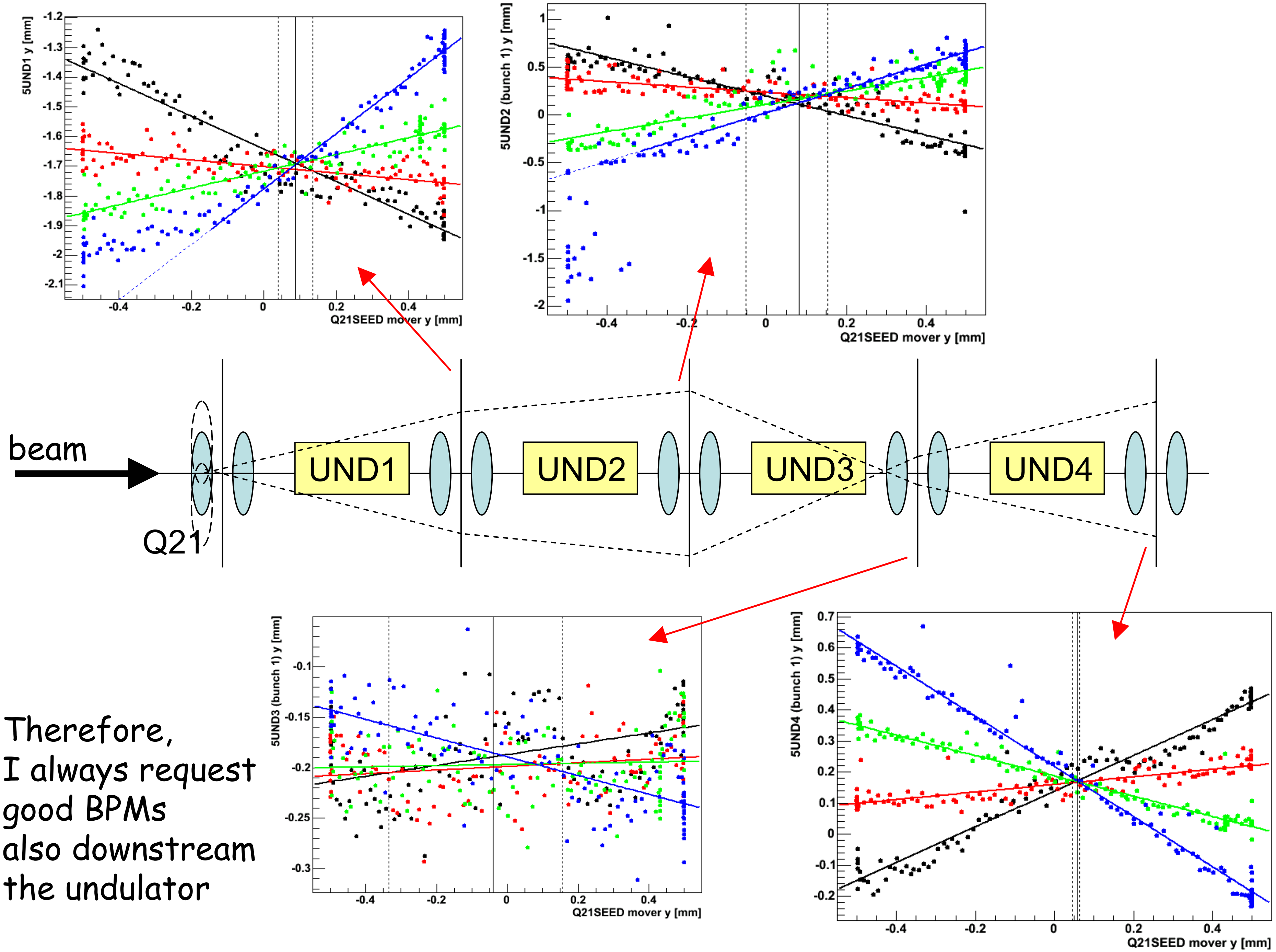
Principle of quad. BBA



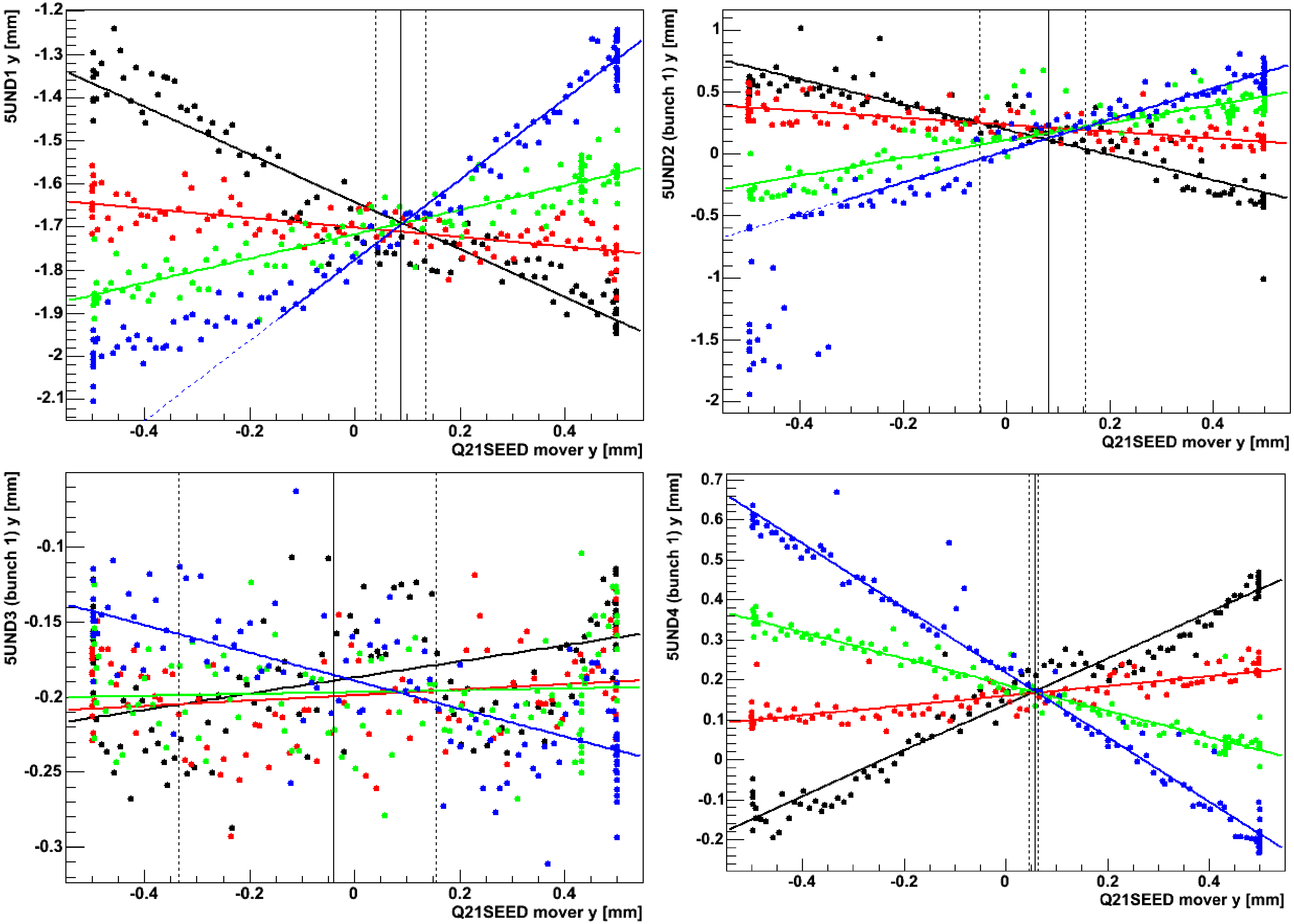
Example of quad BBA





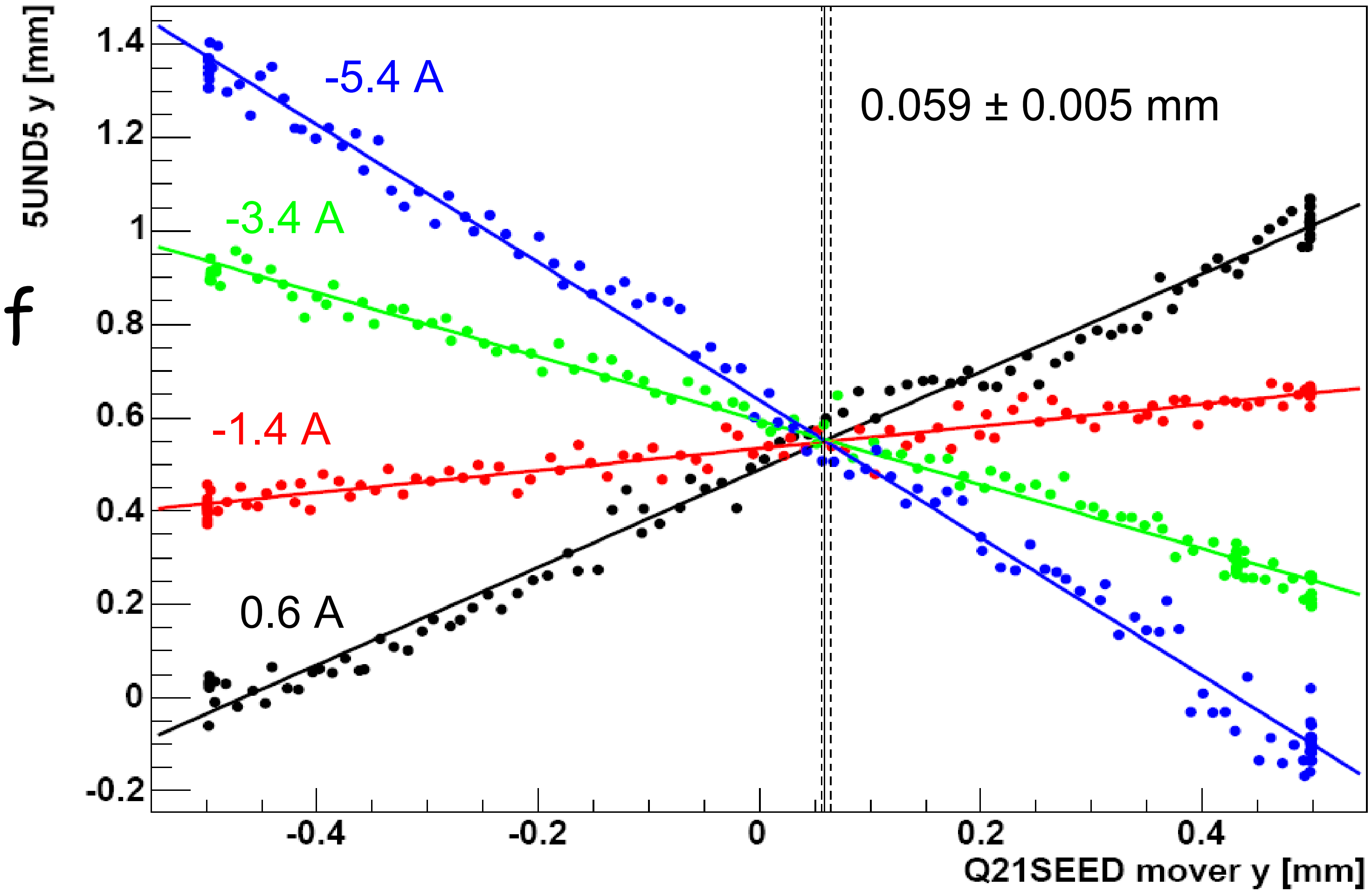


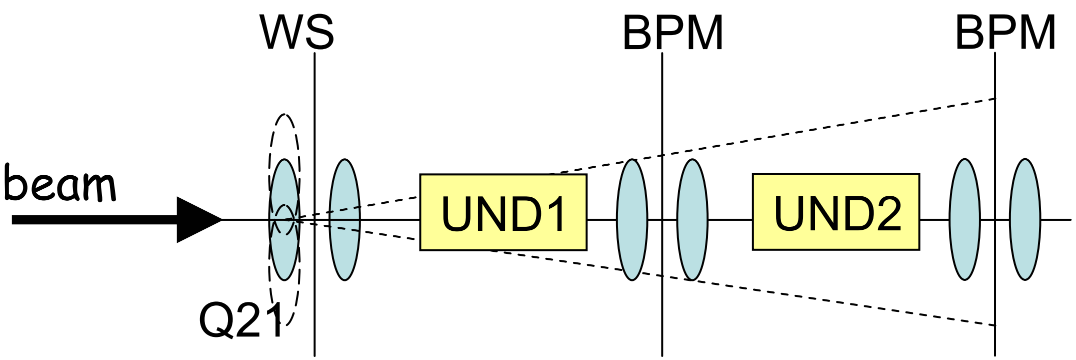
Therefore,
I always request
good BPMs
also downstream
the undulator



5UND1 y [mm]
Q21SEED mover y [mm]
5UND2 (bunch 1) y [mm]
Q21SEED mover y [mm]
5UND3 (bunch 1) y [mm]
Q21SEED mover y [mm]
5UND4 (bunch 1) y [mm]
Q21SEED mover y [mm]

Example of quad BBA

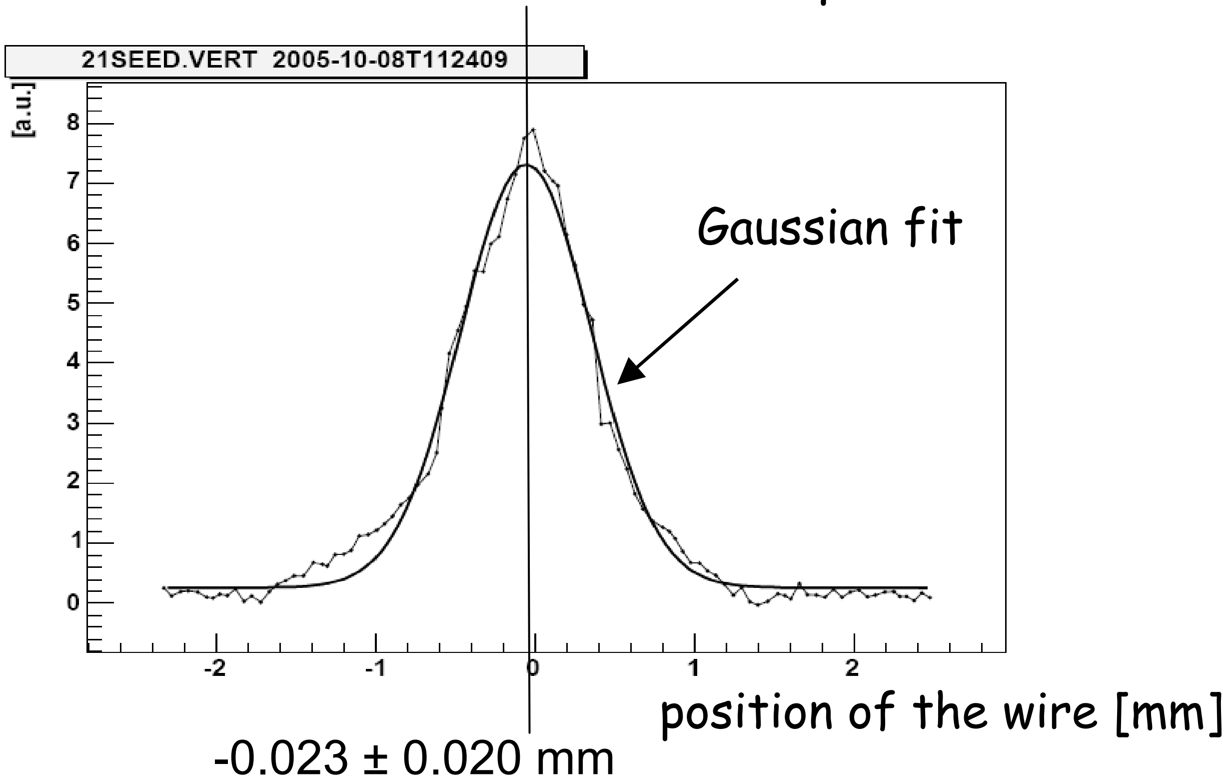




cross:

beam position **with respect to** quadrupole reference

Vertical beam profile measured with wirescanner near quad



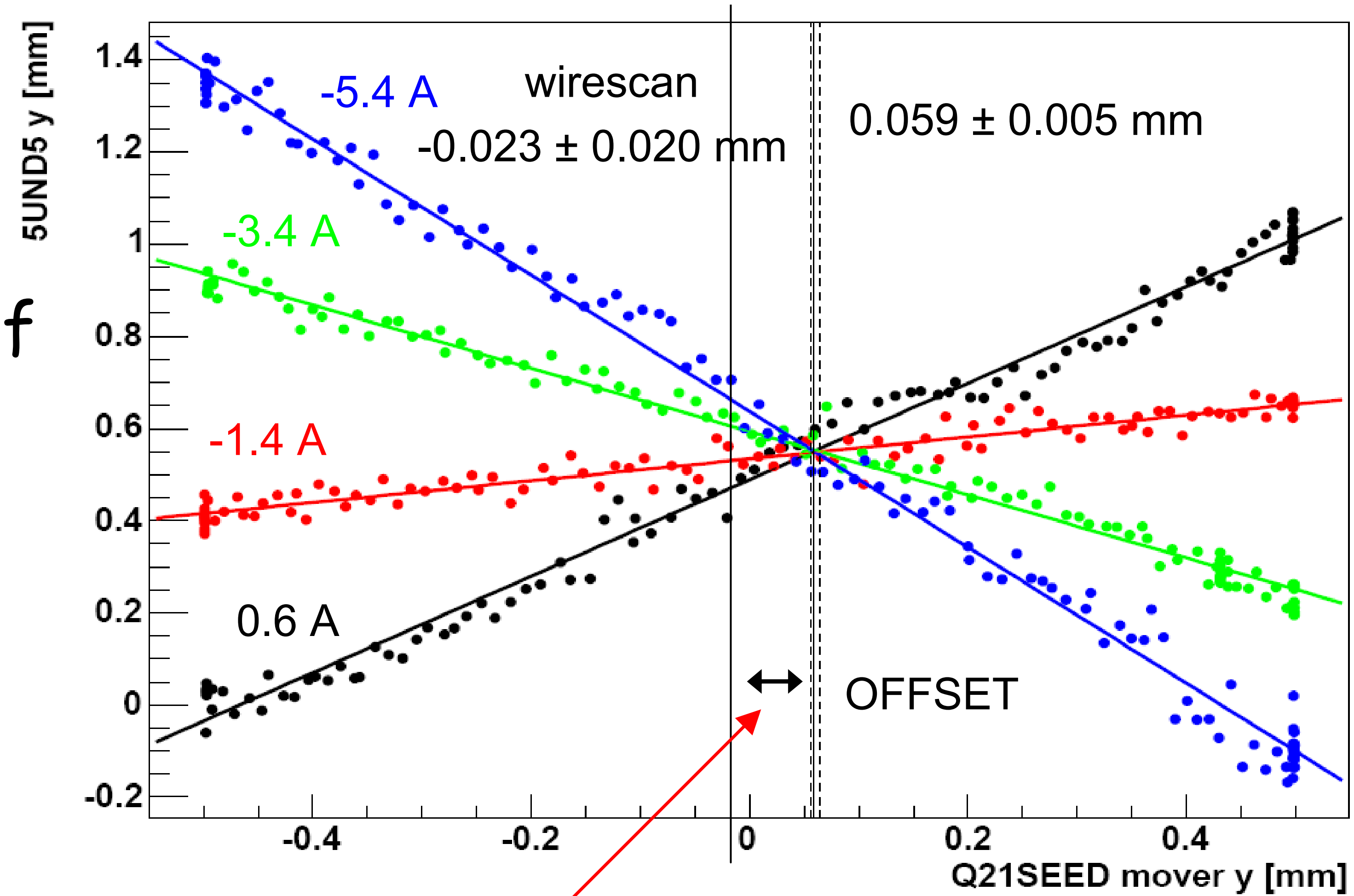
we measure the beam position **with respect to** wirescanner reference

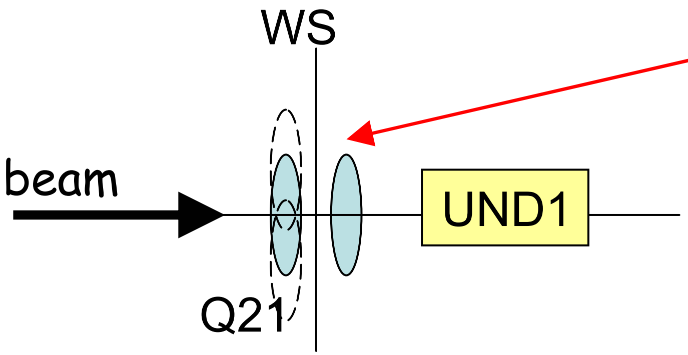
advantage of wirescanner:

- no scale error in the full range (±4.5 mm)

recommended: on-crest acceleration to have symmetric (Gaussian) profiles

Example of quad BBA





offset between:
- wirescanner reference and
- quad position reference

Δ = -0.167 ± 0.020 mm

Summary of the quad. BBA in undulator

horizontal plane:

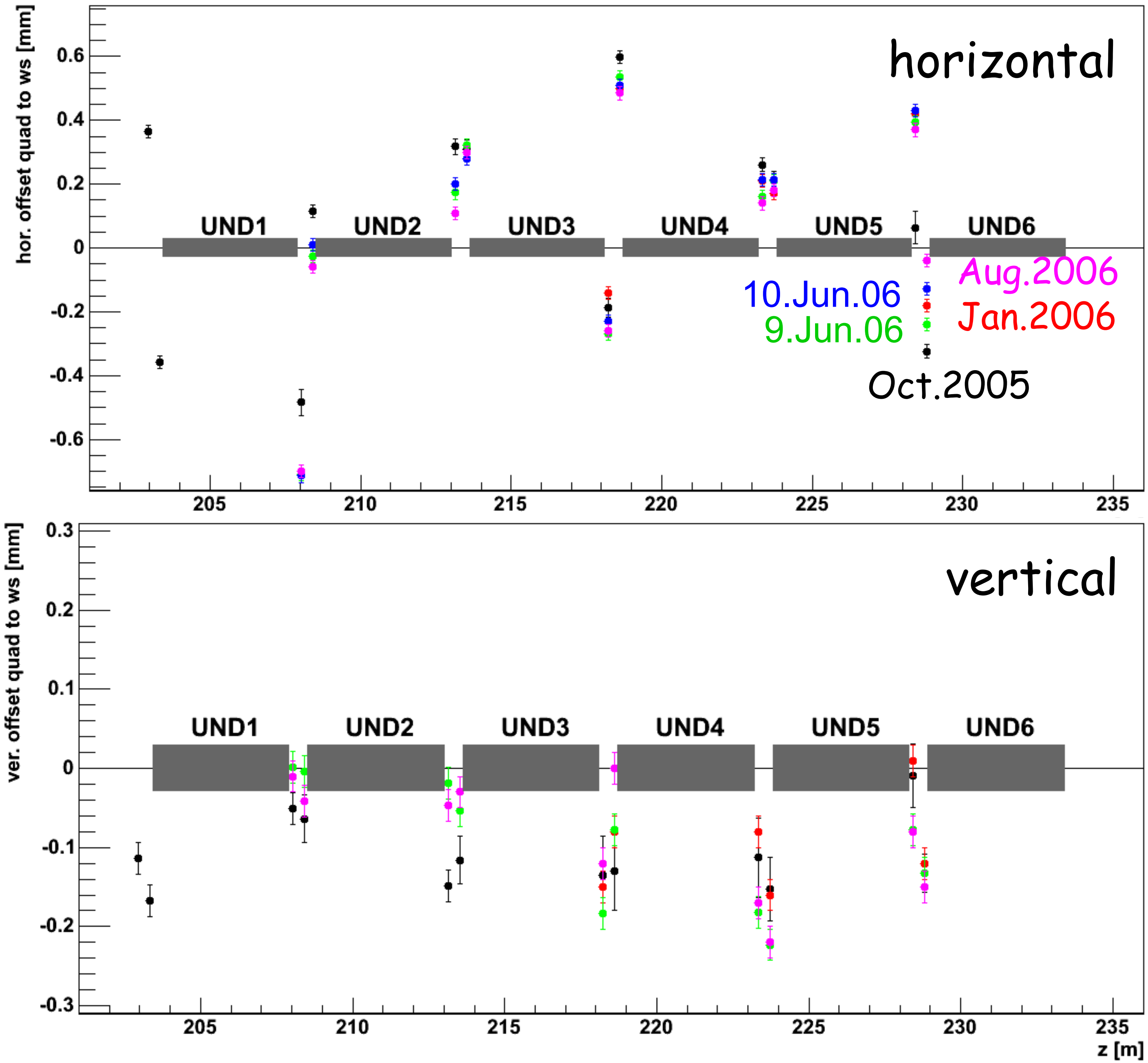
date\quad	Q21SEED	Q22SEED	Q5UND1	Q6UND1	Q5UND2	Q6UND2	Q5UND3	Q6UND3	Q5UND4	Q6UND4	Q5UND5	Q6UND5
24 Aug. 2006			-0.70	-0.06	0.11	0.30	-0.26	0.485	0.14	0.180	0.37	-0.05
10 June 2006			-0.714	0.011	0.200	0.281	-0.229	0.509	0.215	0.214	0.430	-0.127
9 June 2006			-0.710	-0.026	0.173	0.321	-0.269	0.536	0.162	0.210	0.410	-0.239
12 Jan. 2006							-0.14	0.50	0.21	0.17	0.42	-0.18
11 Oct. 2005	0.364	-0.359	-0.484	0.115	0.318	0.310	-0.186	0.598	0.261	0.210	0.06	-0.324

vertical plane:

date\quad	Q21SEED	Q22SEED	Q5UND1	Q6UND1	Q5UND2	Q6UND2	Q5UND3	Q6UND3	Q5UND4	Q6UND4	Q5UND5	Q6UND5
24 Aug. 2006			-0.01	-0.041	-0.047	-0.03	-0.12	0.00	-0.17	-0.22	-0.07	-0.16
10 June 2006												
9 June 2006			0.002	-0.004	-0.019	-0.054	-0.183	-0.078	-0.182	-0.223	-0.077	-0.133
12 Jan. 2006							-0.15	-0.08	-0.08	-0.16	0.01	-0.12
11 Oct. 2005	-0.114	-0.167	-0.051	-0.067	-0.148	-0.116	-0.135	-0.13	-0.113	-0.153	-0.01	-0.132

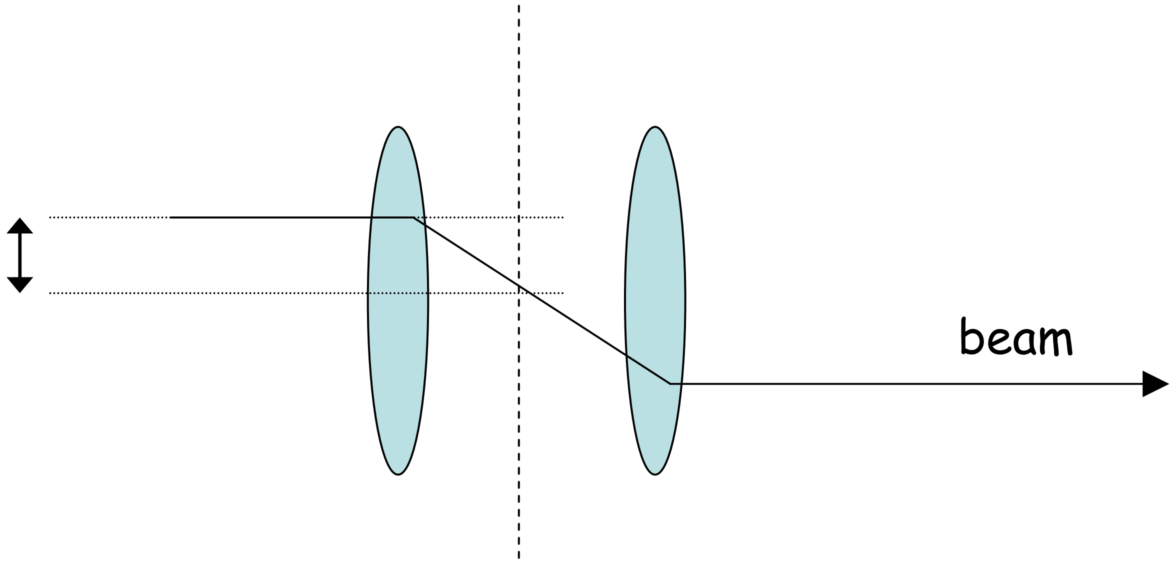
are the measurements reproducible?
are the offsets quad-to-wirescanner stable?

Measured offset between quad. and wirescanner



Possible sources of errors:

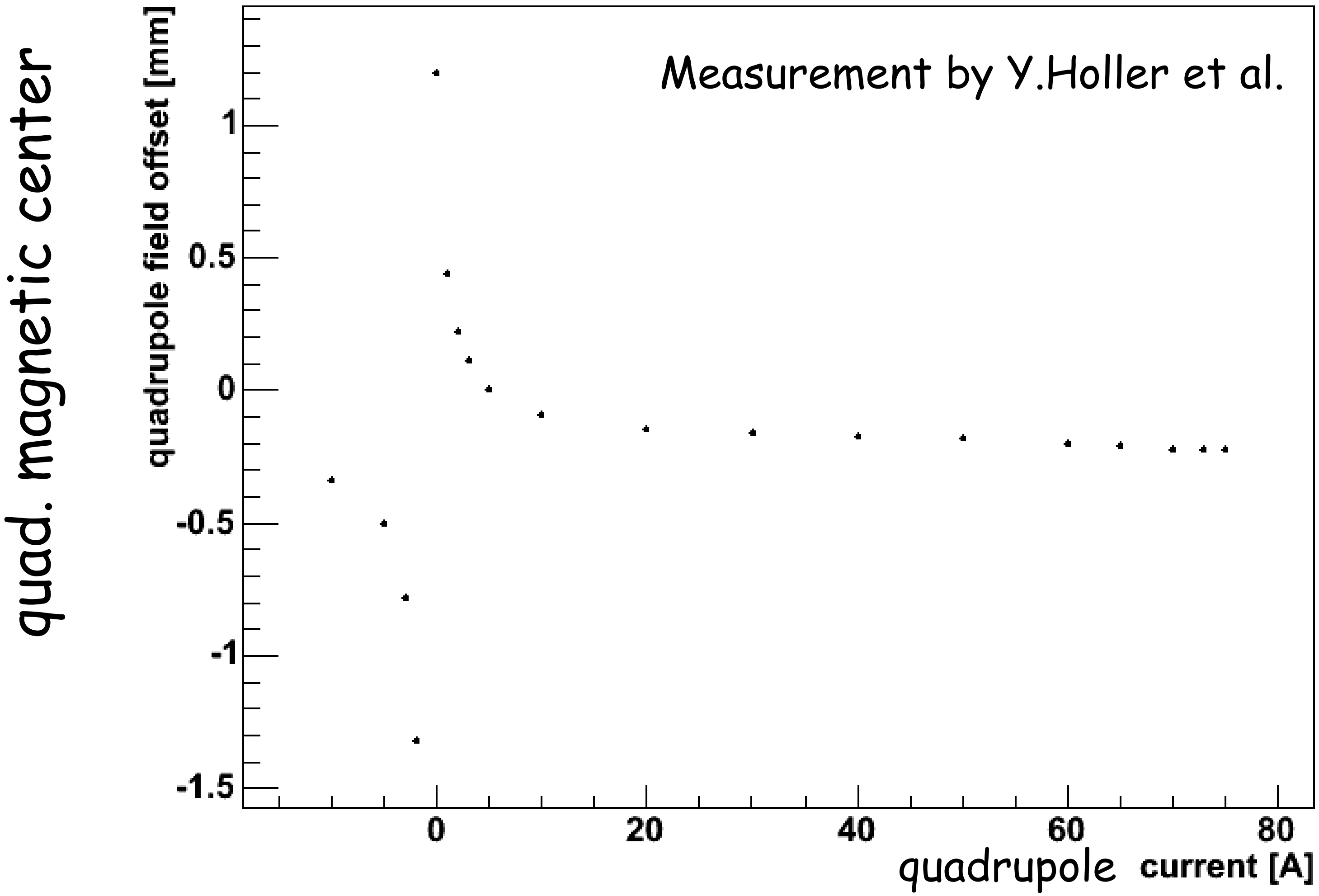
- beam angle at wirescanner



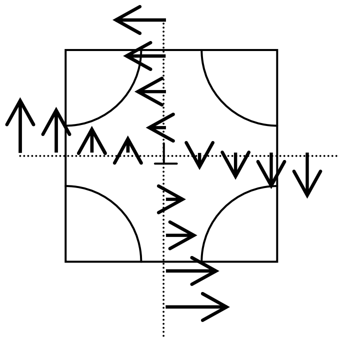
with quads off → the systematic error is smaller

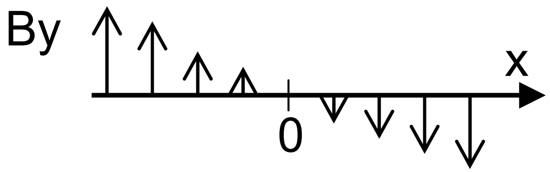
Possible sources of errors:

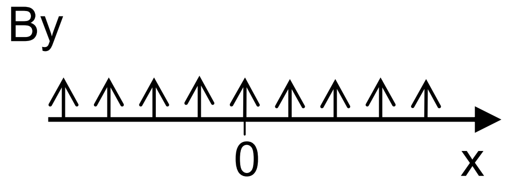
- quad. magnetic center "moves" as function of its current

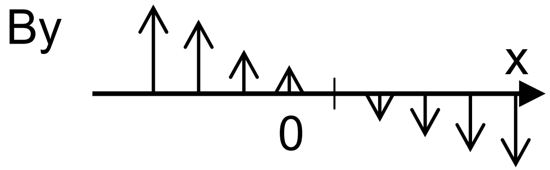


quadrupole field (transversally)





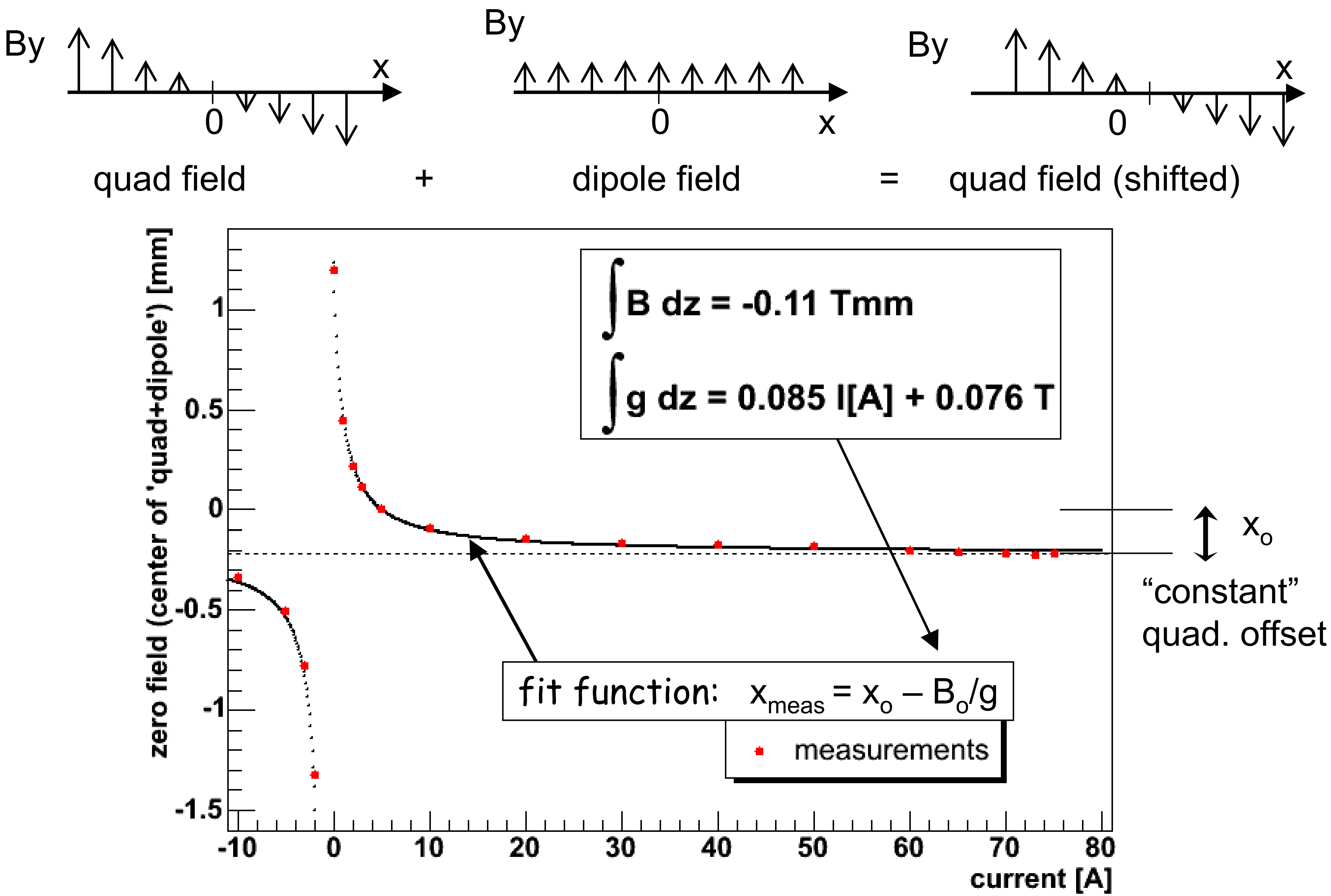




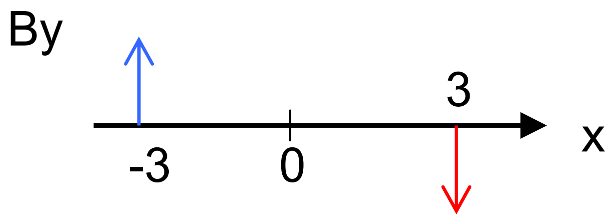
quad field	+	dipole field	=	quad field (shifted)
$By(x) = g\,x$		B_o		$By(x) = g\,x + B_o$
center: 0		?		$-B_o/g$

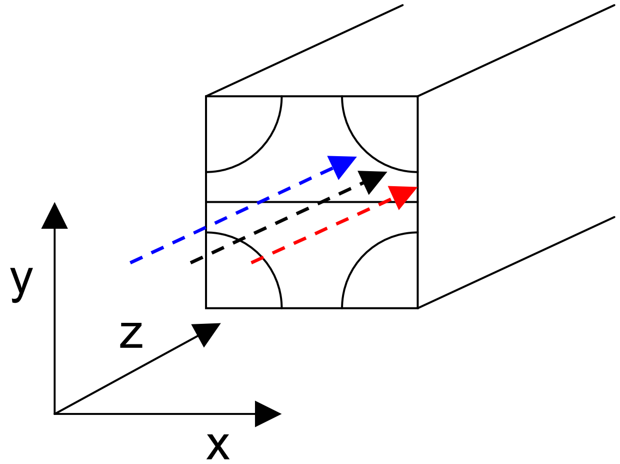
g is function of current

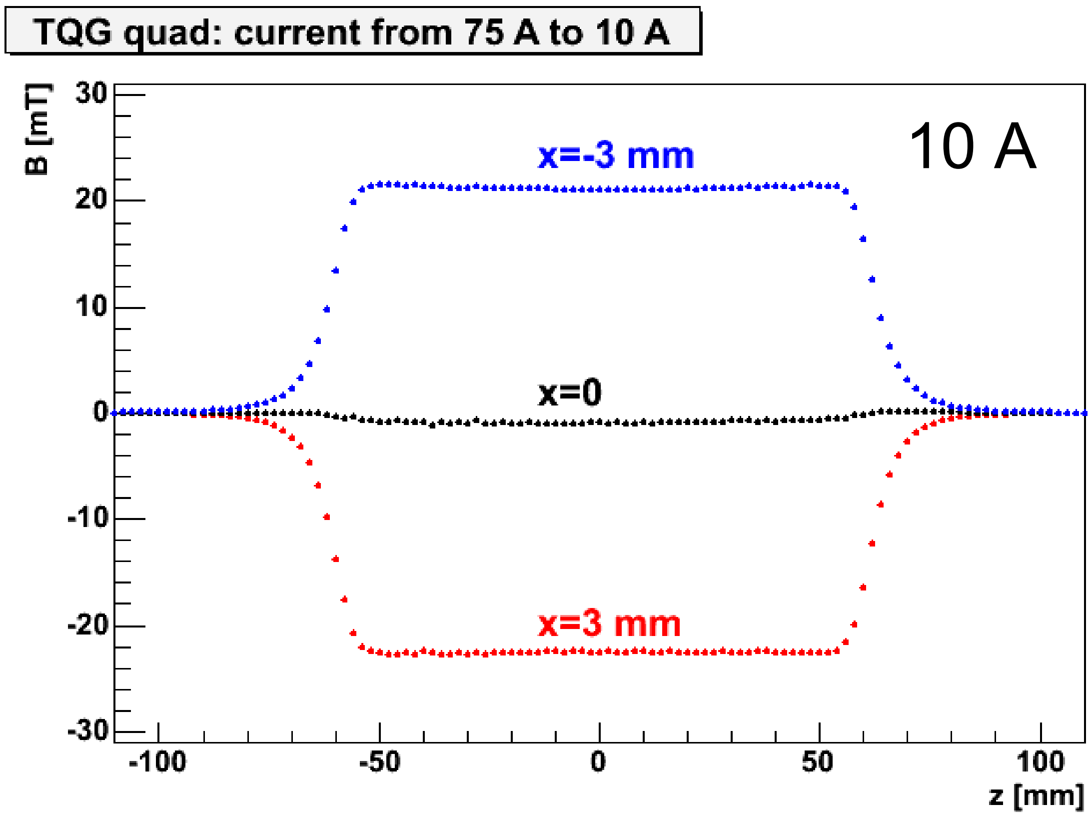
Measurements of the quad center vs current (on spare quad)



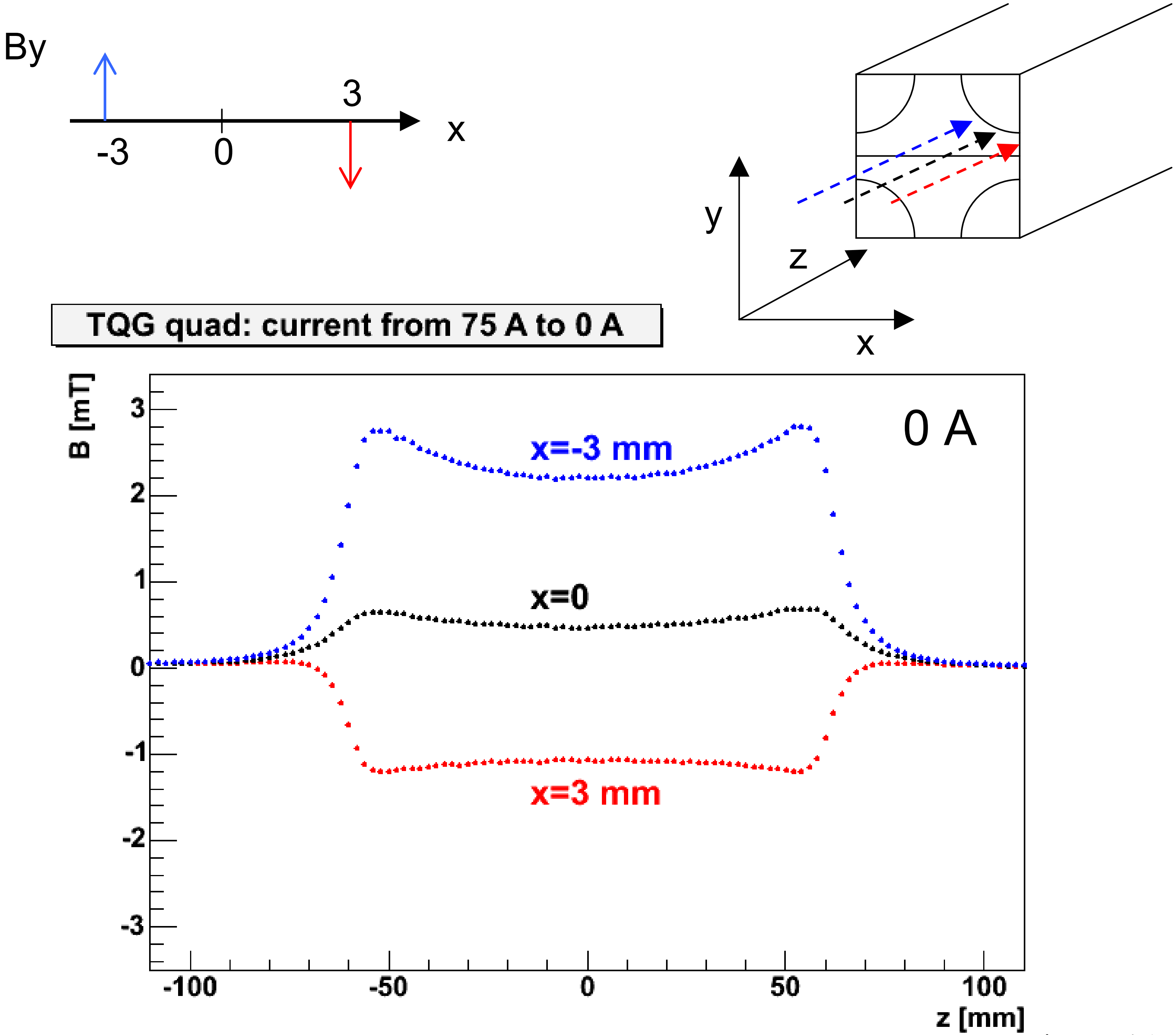
Typical quad field



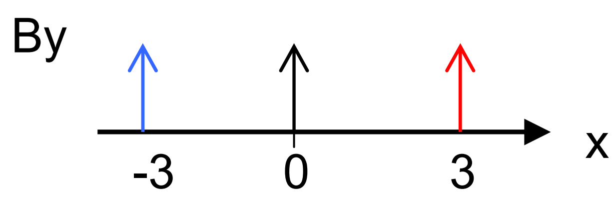




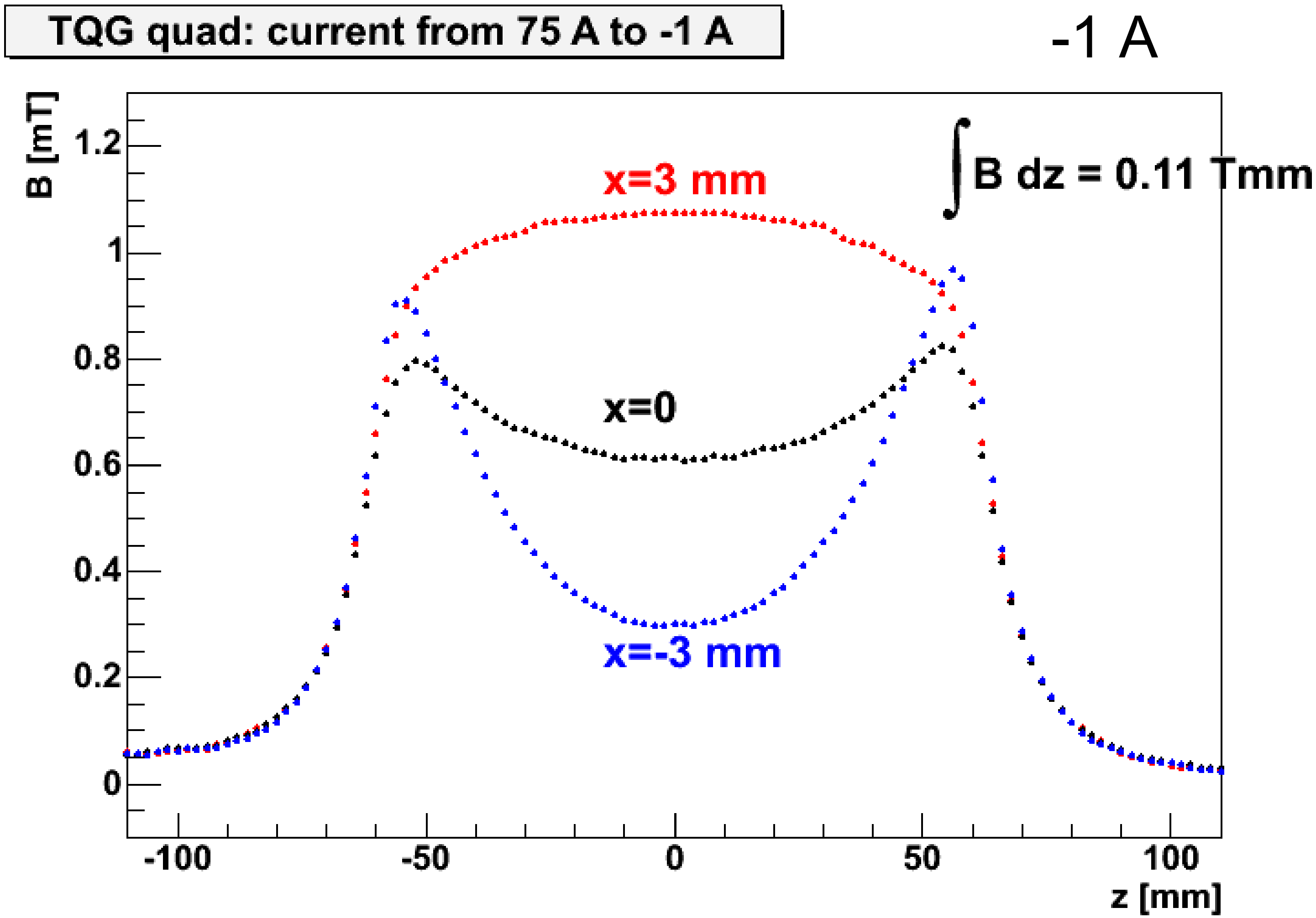
Measurement by Y.Holler et al



Measurement by Y.Holler et al

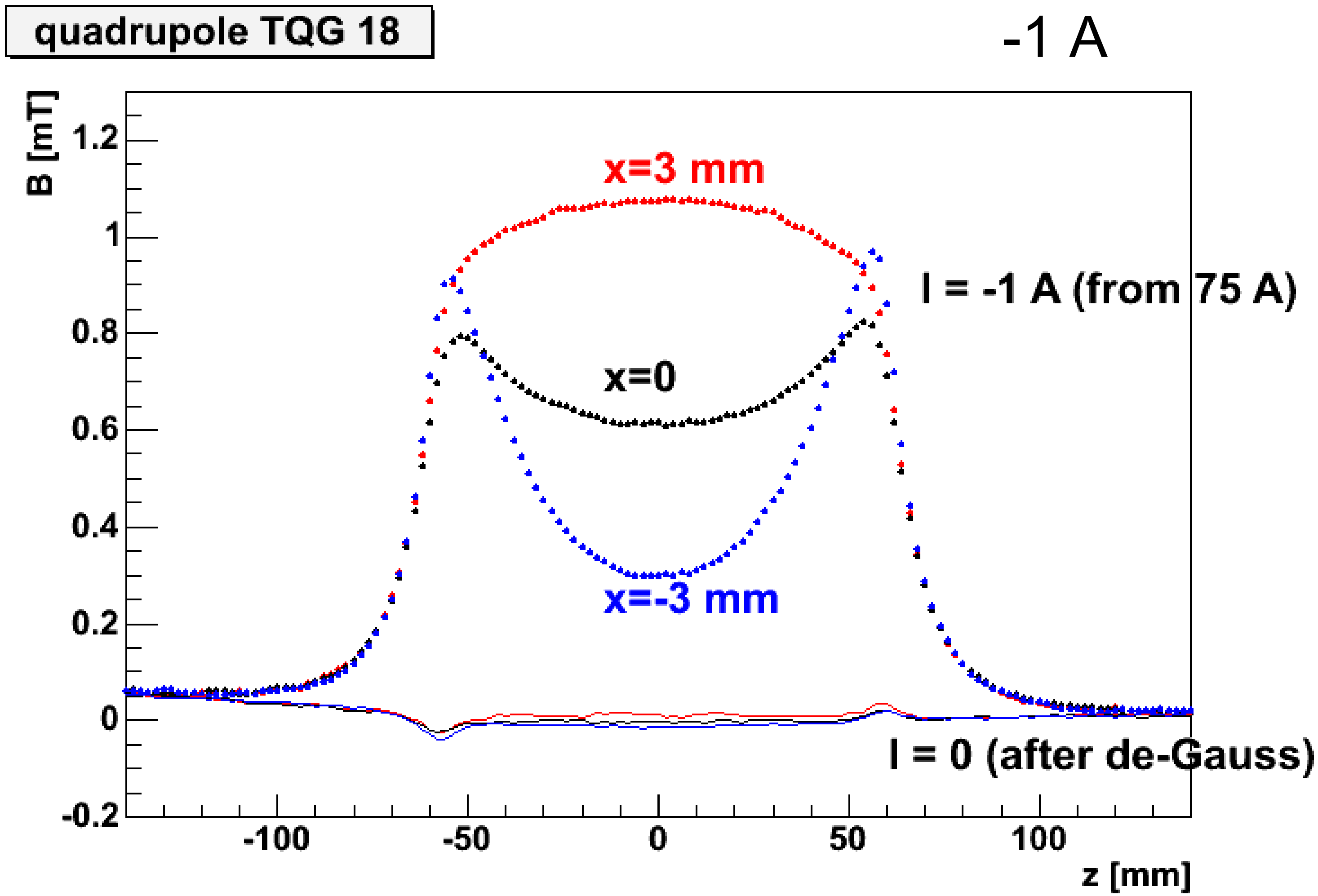


dipole field



Measurement by Y.Holler et al

-1 A



Measurement by Y.Holler et al

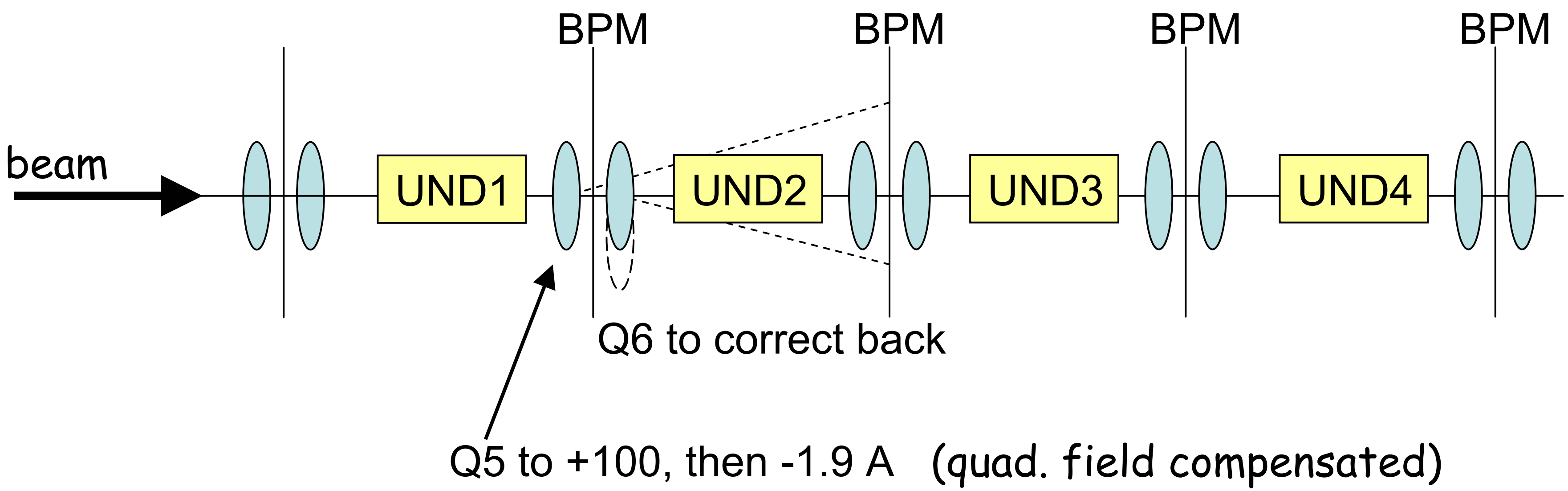
~~"moving" quad. center~~

remanent dipole field when large current is applied

after degauss → B = 0

Is this remanent field the same for all quadrupoles ? NO

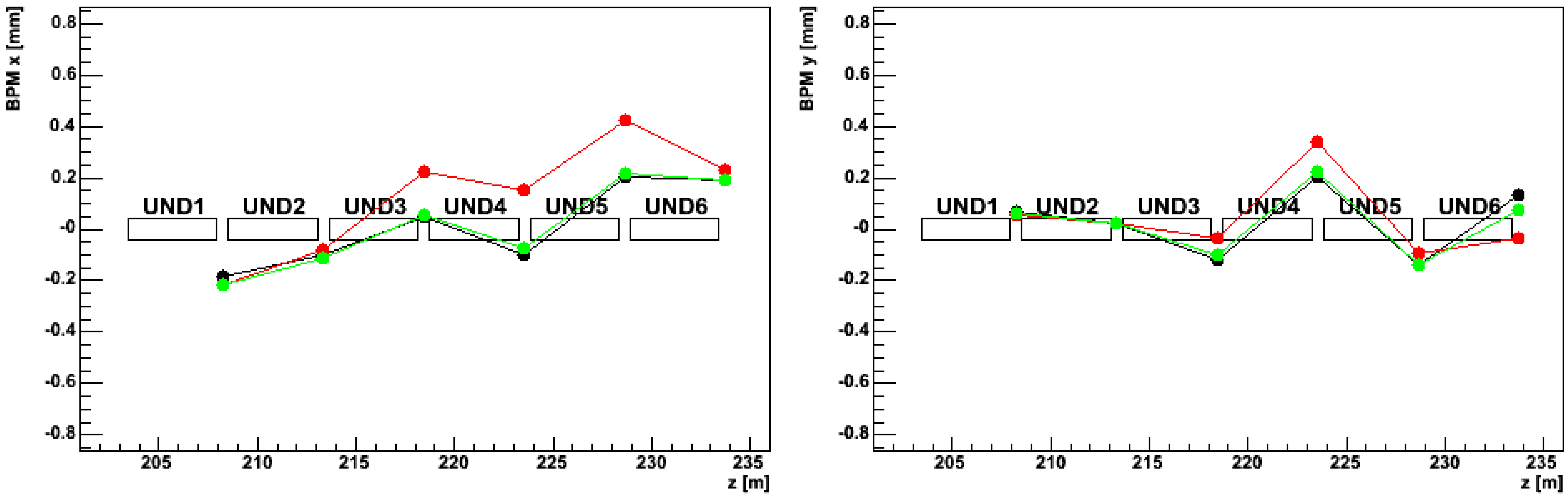
How large is the remanent dipole field in the quadrupoles INSTALLED ?

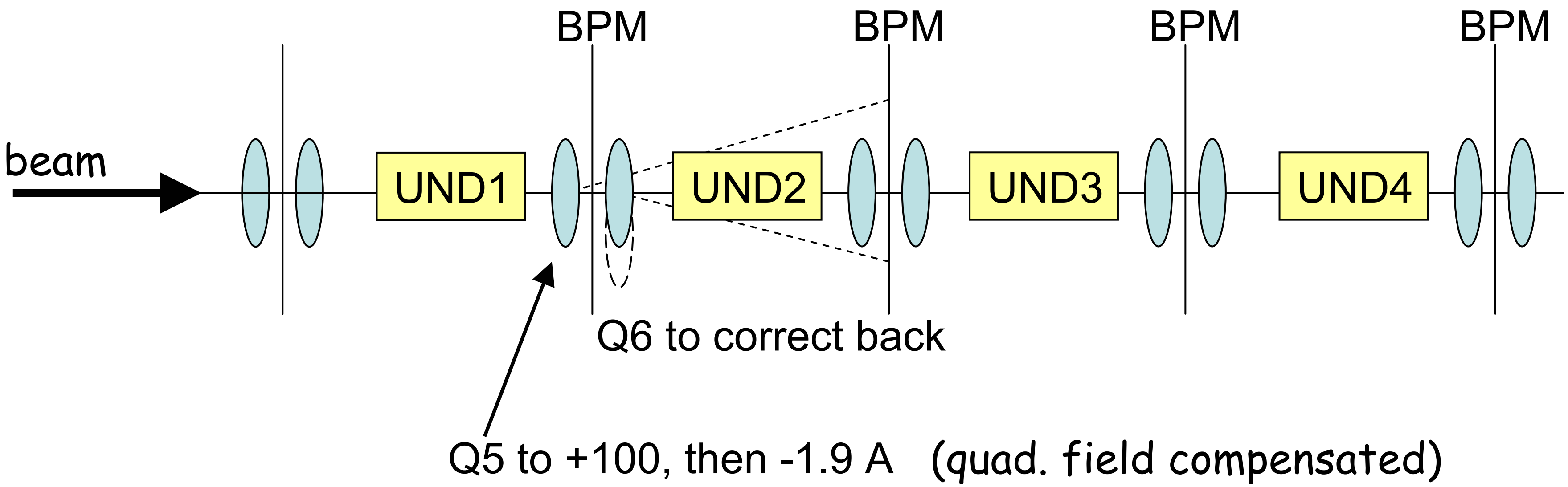


black orbit: Q5 quads are degaussed ← reference orbit

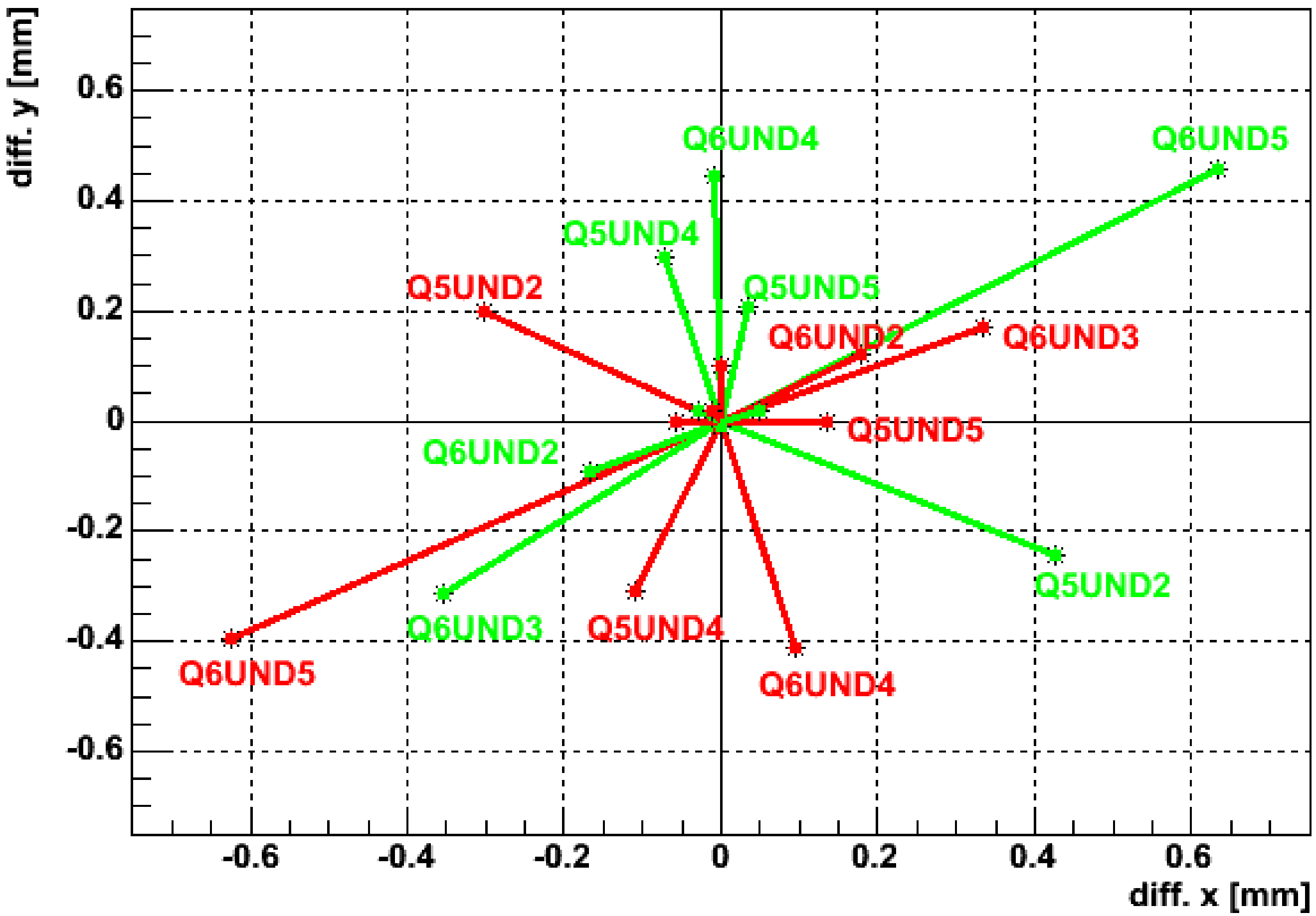
red orbit: Q5 quads set to +100 A then to -1.9 A

green orbit: Q6 moved to correct orbit to reference





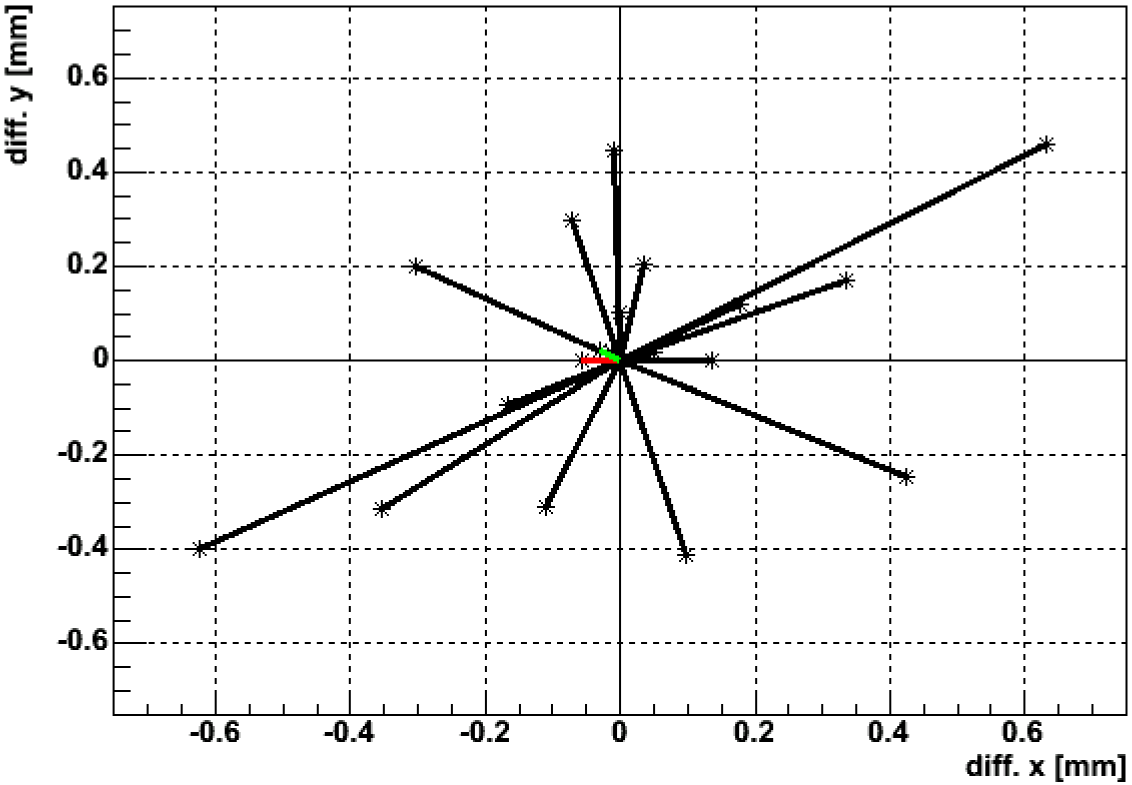
Quadrupole shift applied to compensate remanent dipole field



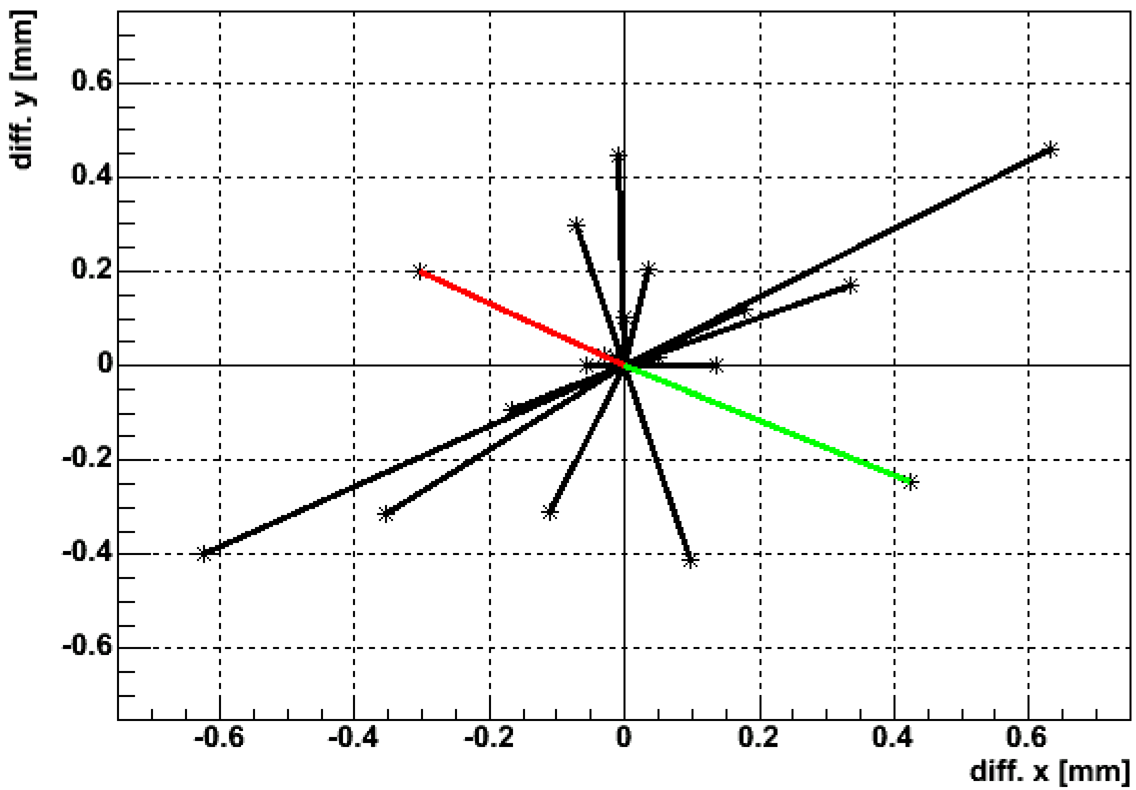
two measurements:

red: after cycling to 100 A then to -1.9 A
green: after cycling to -100 A then to +1.9 A

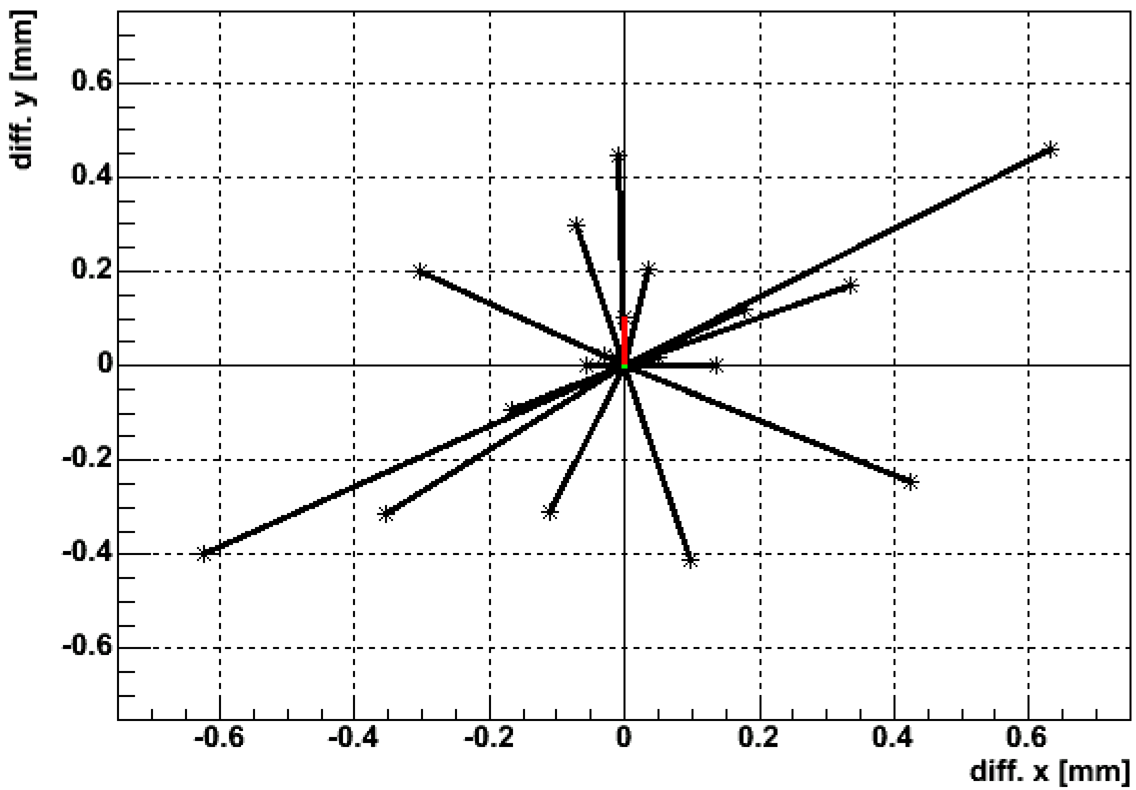
Q5UND1



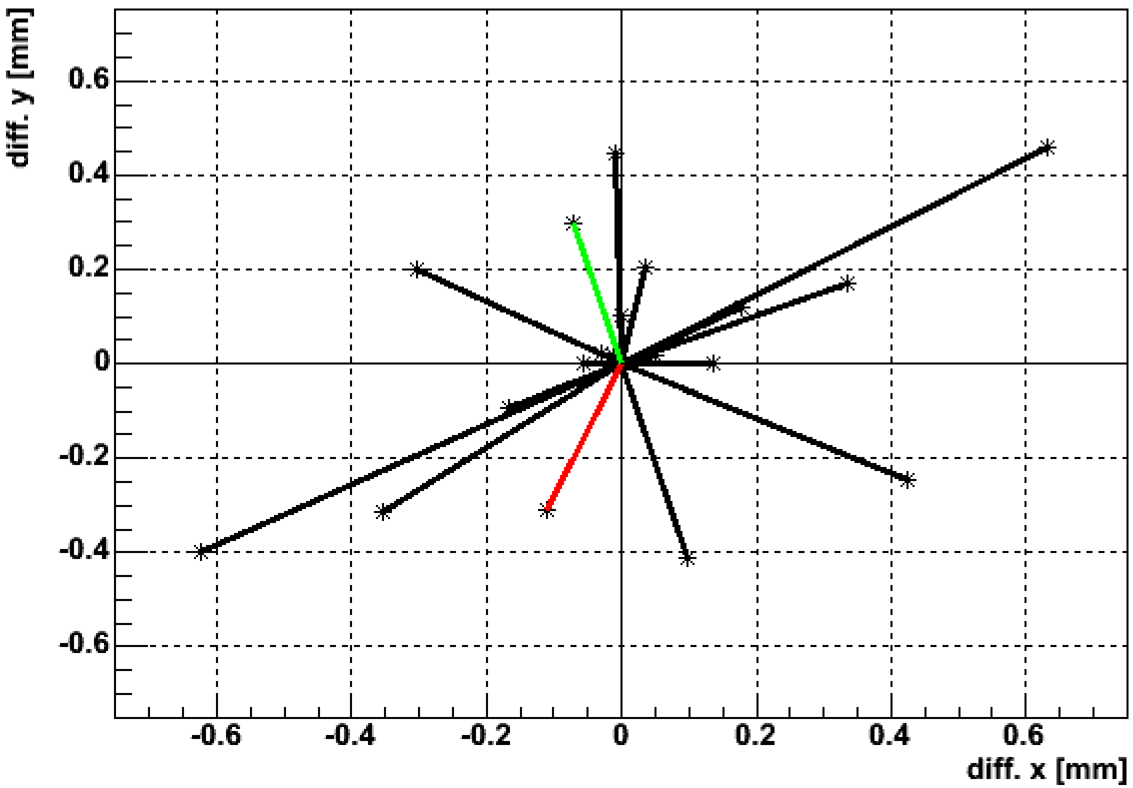
Q5UND2



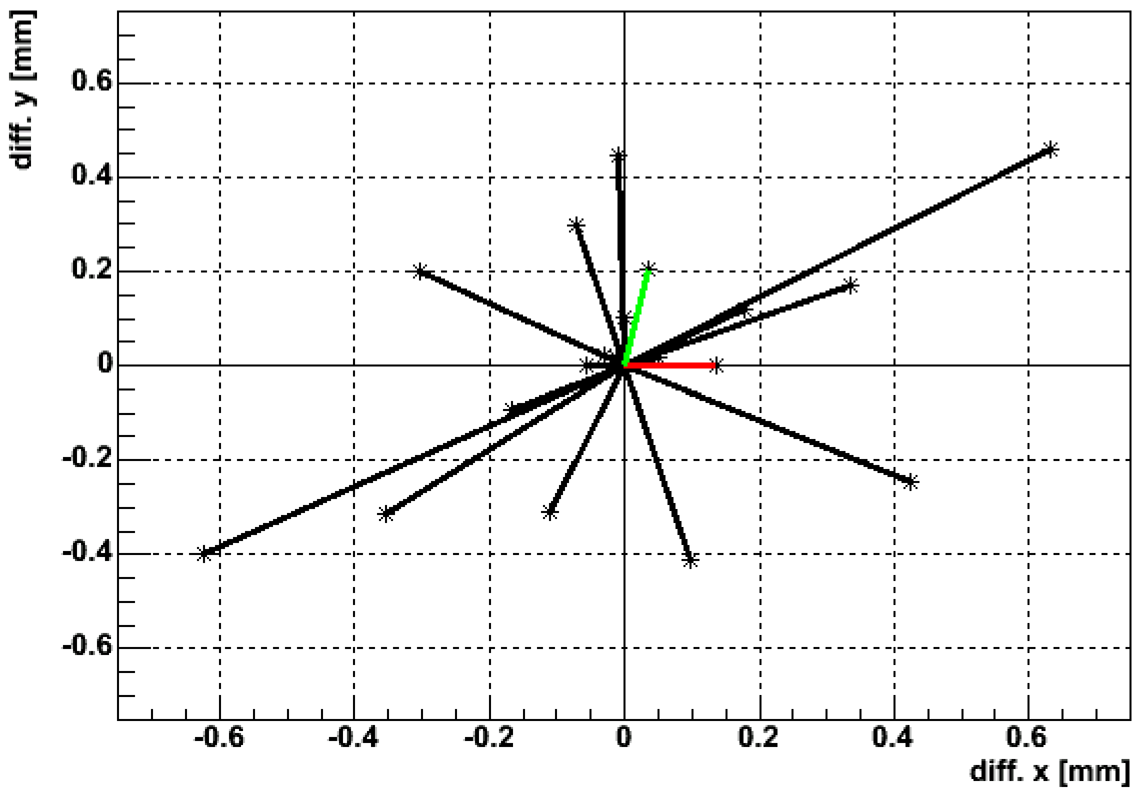
Q5UND3



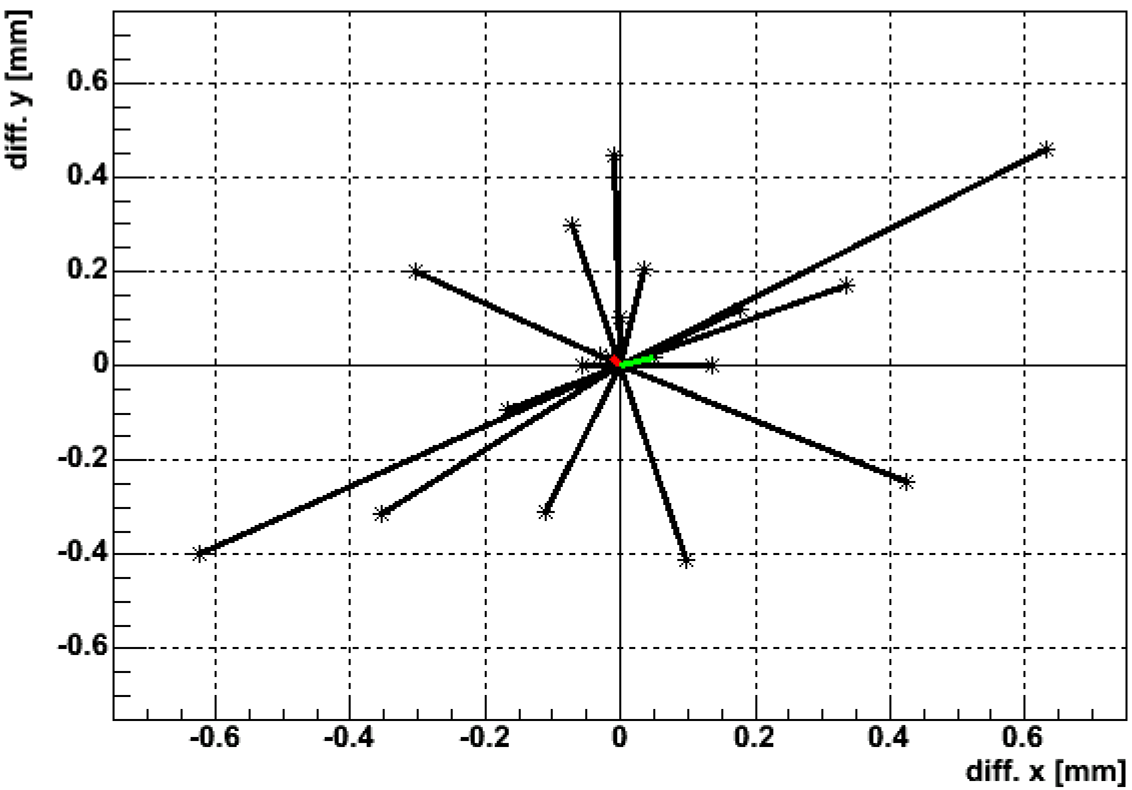
Q5UND4



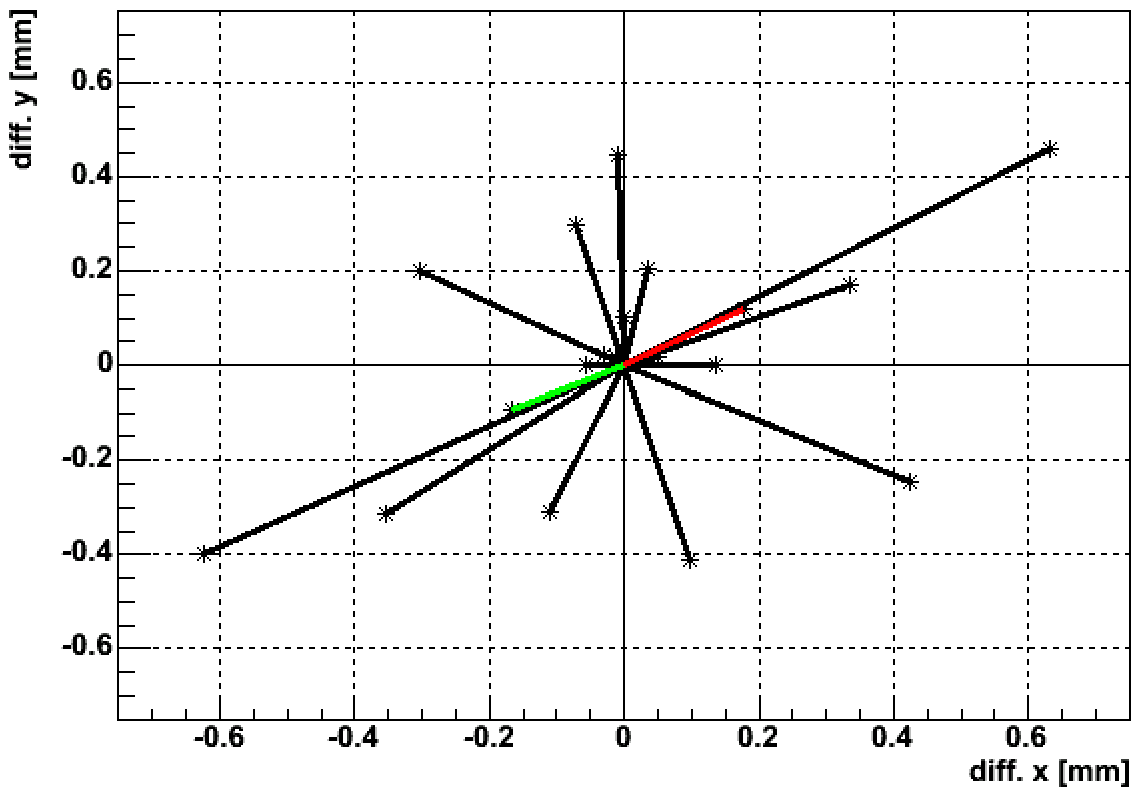
Q5UND5



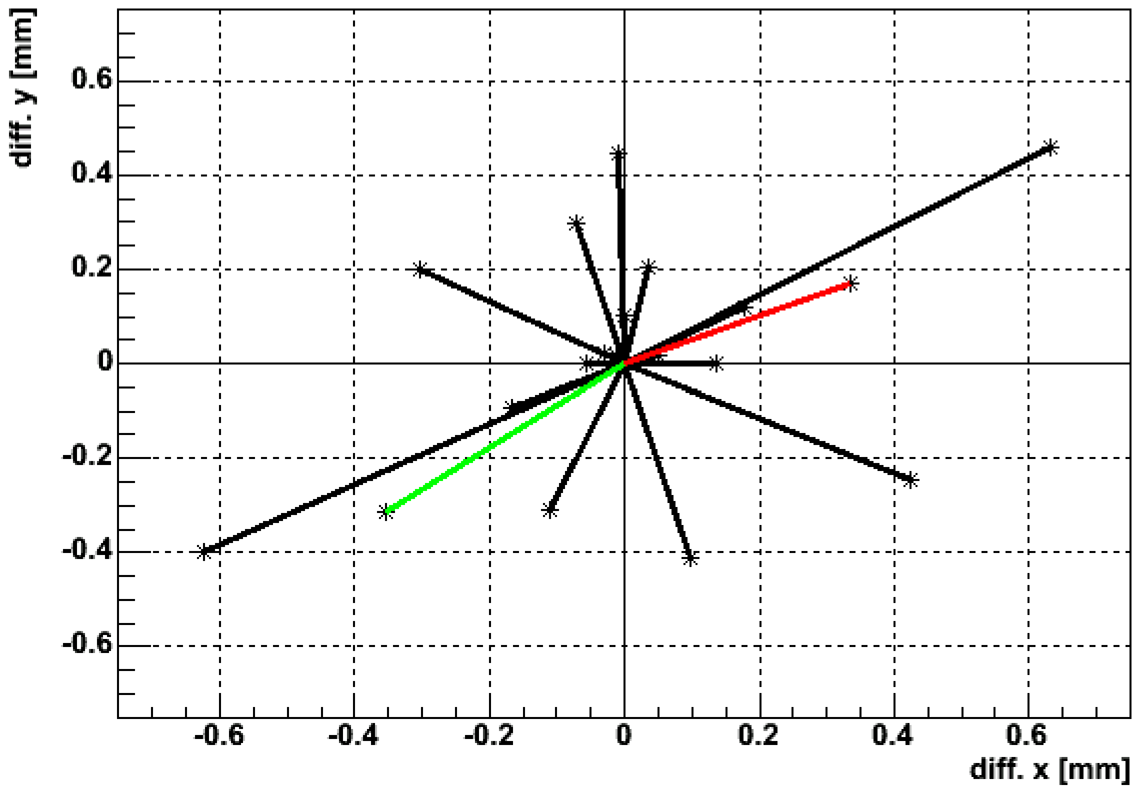
Q6UND1



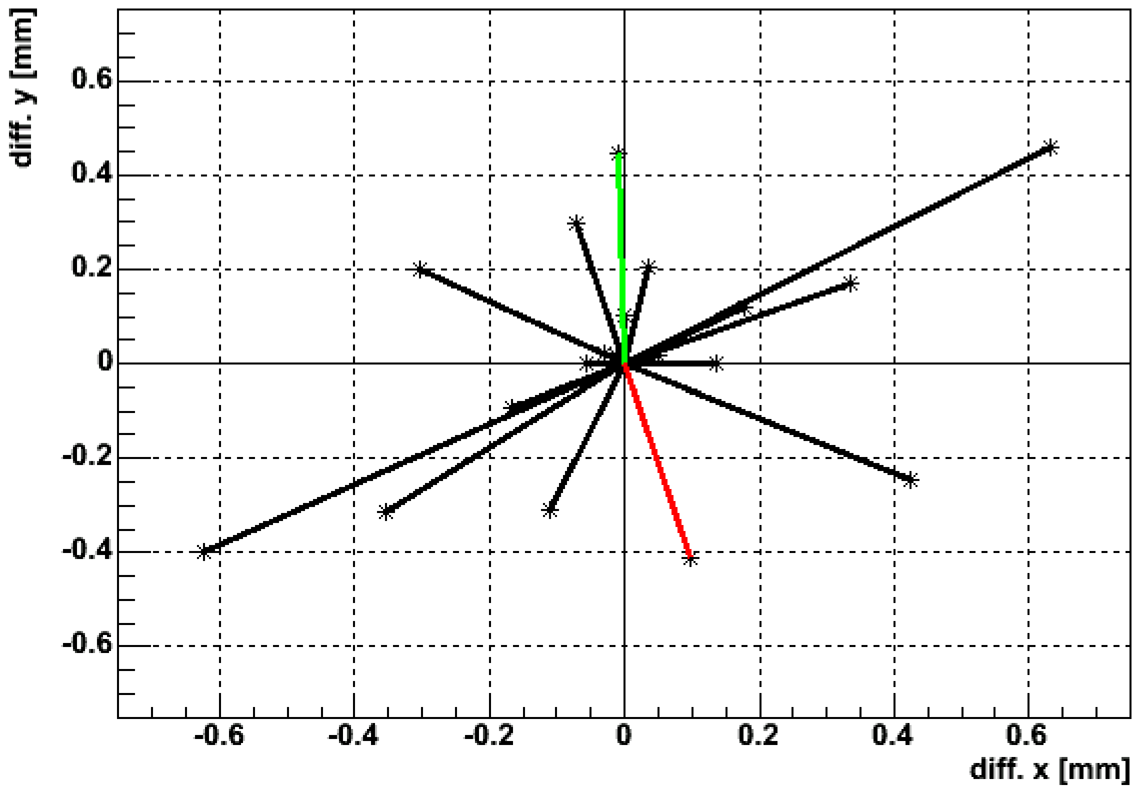
Q6UND2



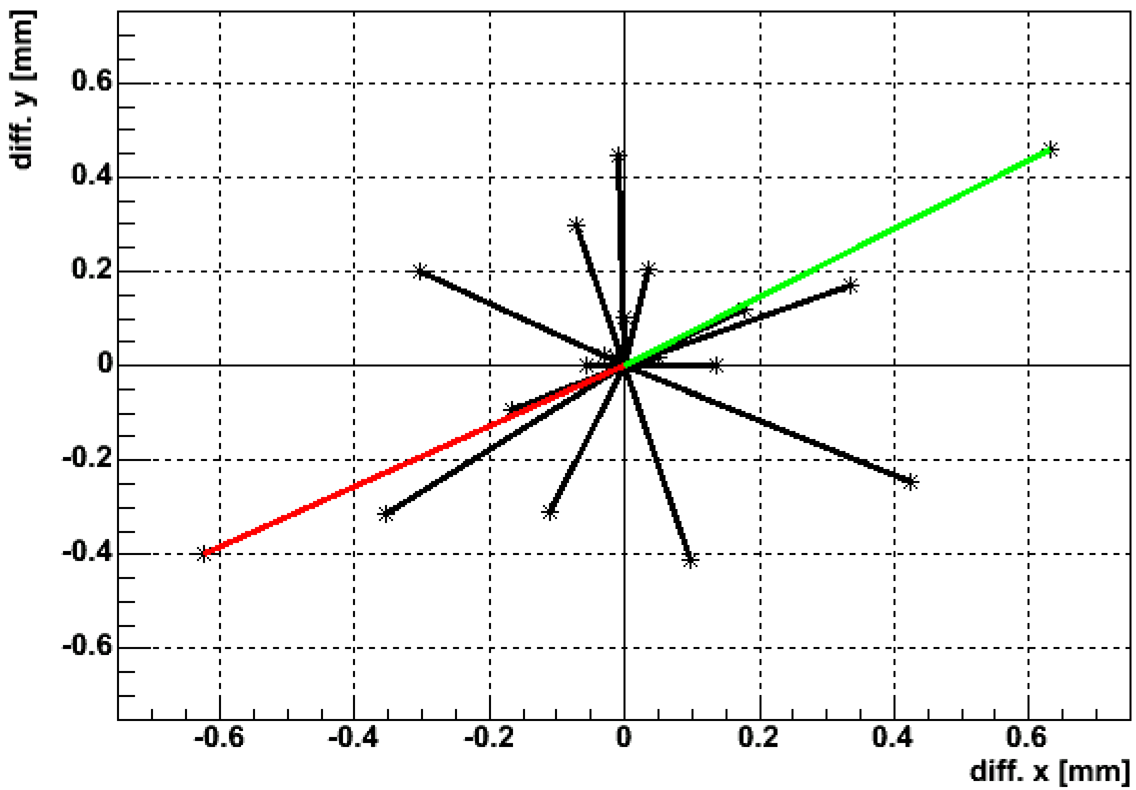
Q6UND3



Q6UND4



Q6UND5



The integrated remanent dipole field in the quadrupole

$$\int \vec{B} dz = \left(\int B_x dz, \int B_y dz \right)$$

from the position shifts of the quadrupole:

$$\Delta x_Q \quad \Delta y_Q$$ (shown in previous slide)

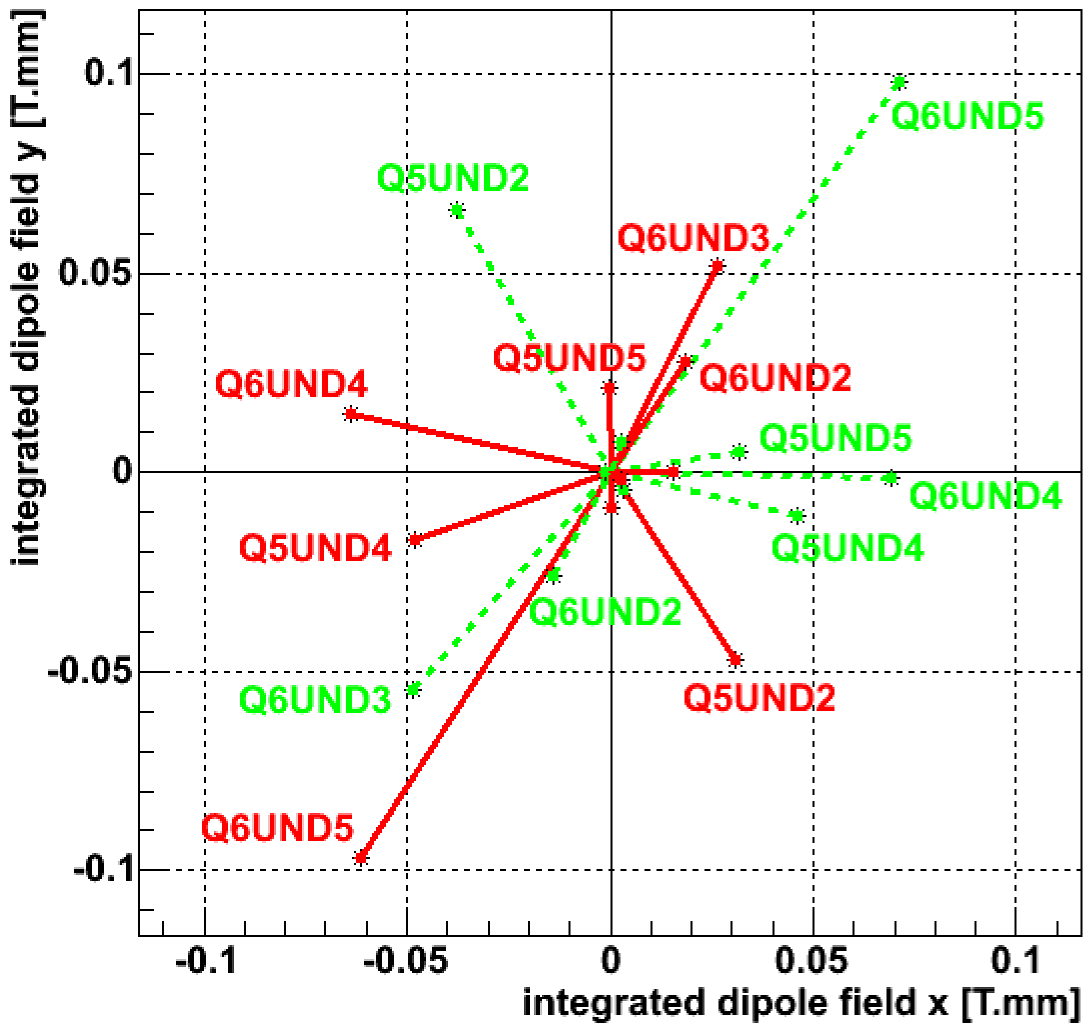
relationship:

$$\int B_y dz \simeq G_0 \cdot \Delta x_Q \quad , \quad \int B_x dz \simeq G_0 \cdot \Delta y_Q$$

the remanent integrated quadrupole field: $G_0 = \int g_{rem} dz$

$$G_0 = 155 \text{ mT}$$

Measured remanent dipole field in undulator dipoles



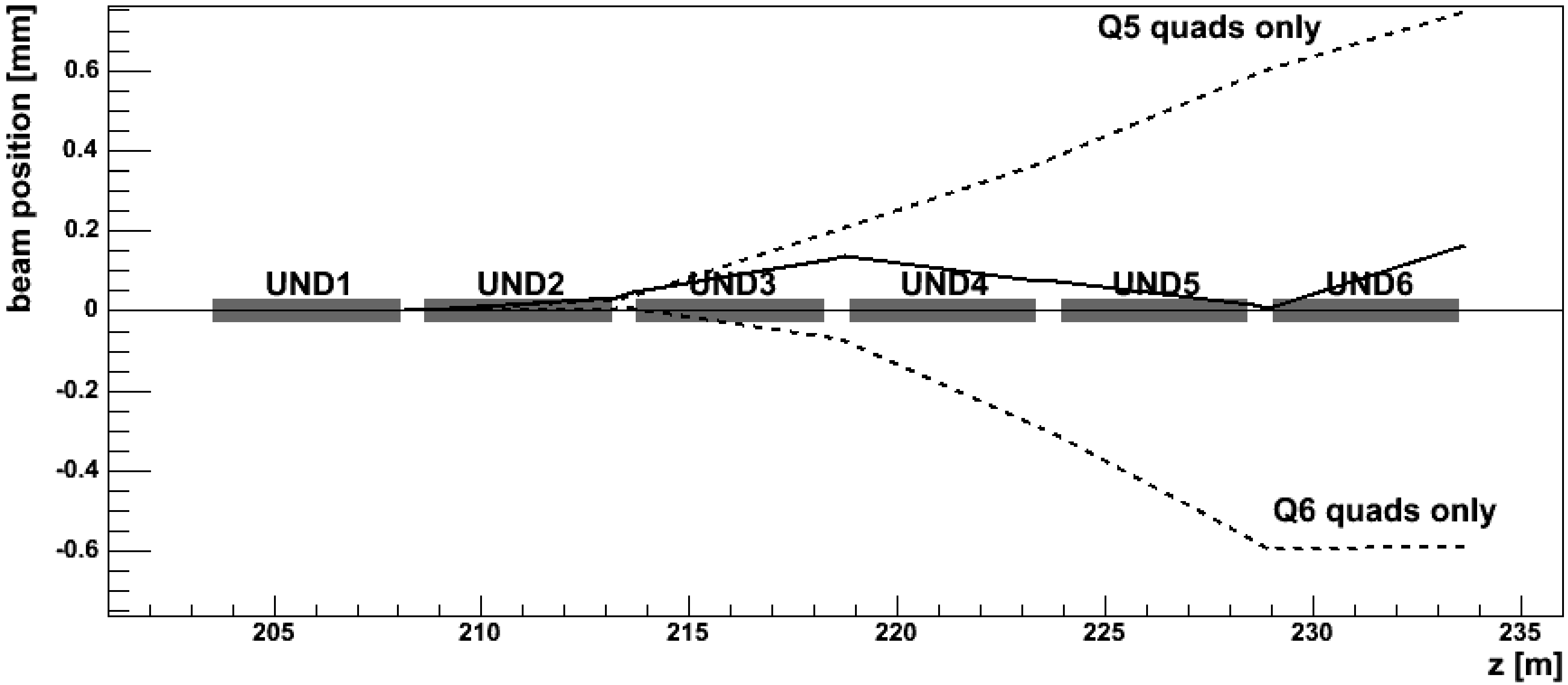
field amplitude:

max B = 0.11 T.mm

RMS = 0.08 T.mm

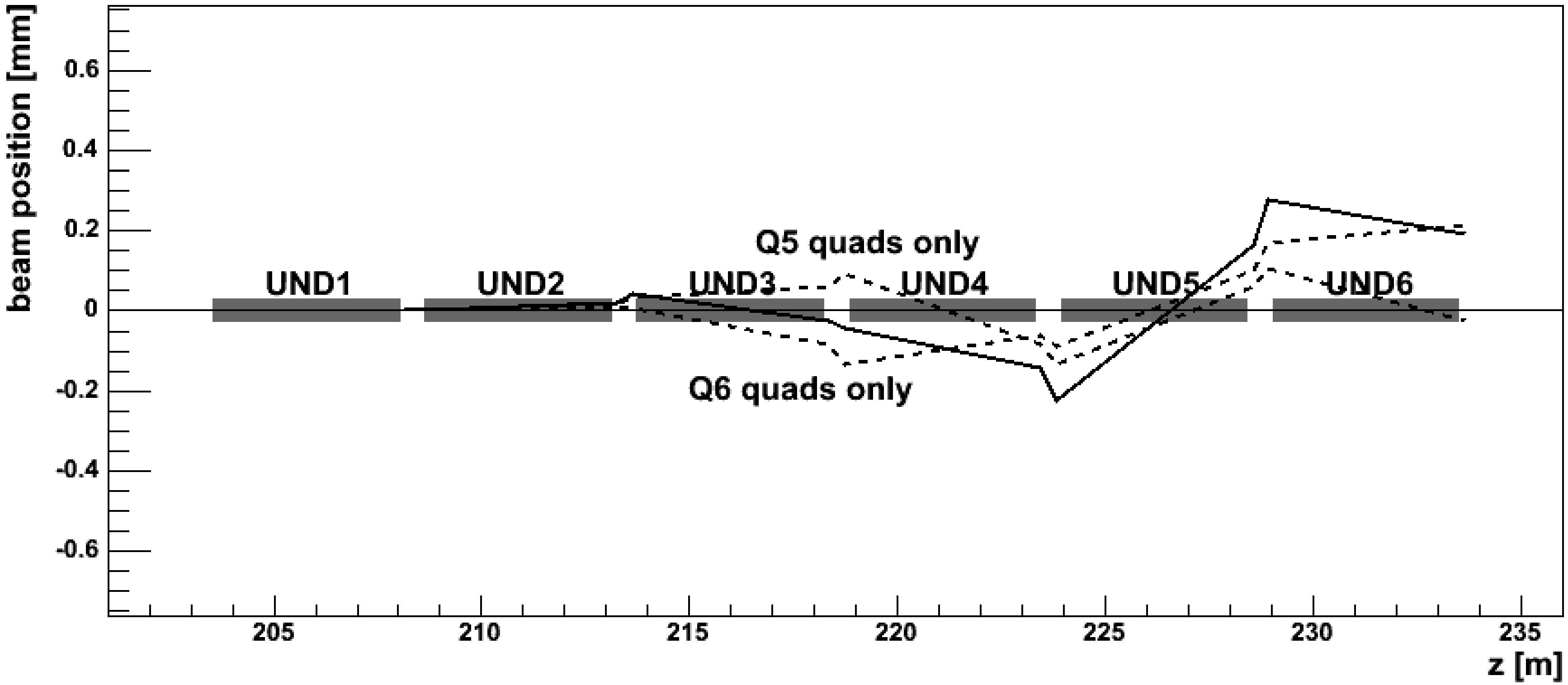
statistically, there is no difference between x and y plane

SIMULATION: effect of remanent dipole fields in quads



for k=0 (quadrupole gradient = 0)

SIMULATION: effect of remanent dipole fields in quads



for optics “variant 1” (k1 = 10.9 m^{-1} ,k2 = -10.6 m-1)

Recommendation:

degauss the quadrupoles in the undulator

5) Beam deflection in the undulator section

In the past we tried several times to get beam through undulator:

- with quadrupoles off
- with quadrupoles off + degaussed

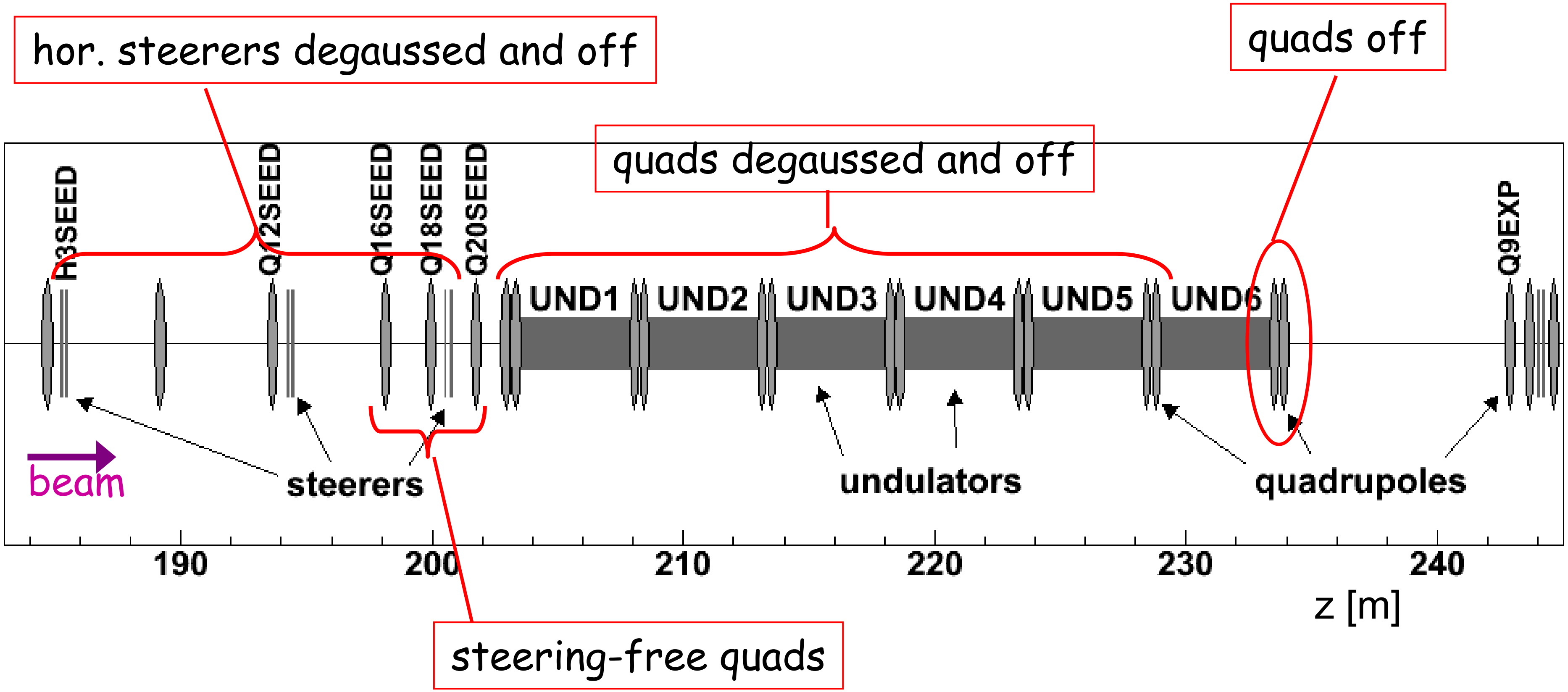
…unsuccessfully.

to get beam through the undulator with quads off and degaussed:

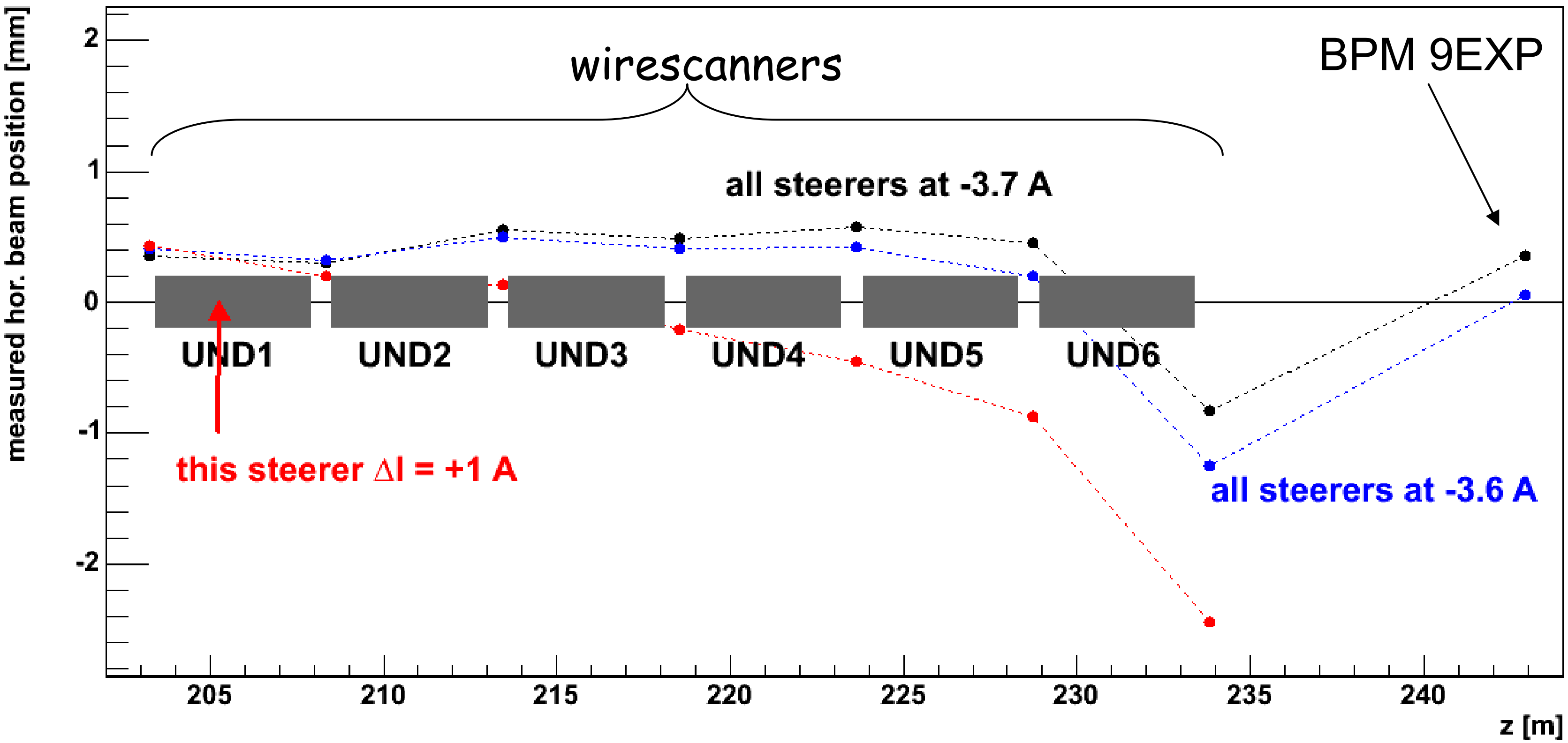
only when horizontal undulator steerers are used

August 2006

➢ minimize beam angle at undulator entrance



smallest beam angle at undulator exit: for I = -3.6 A



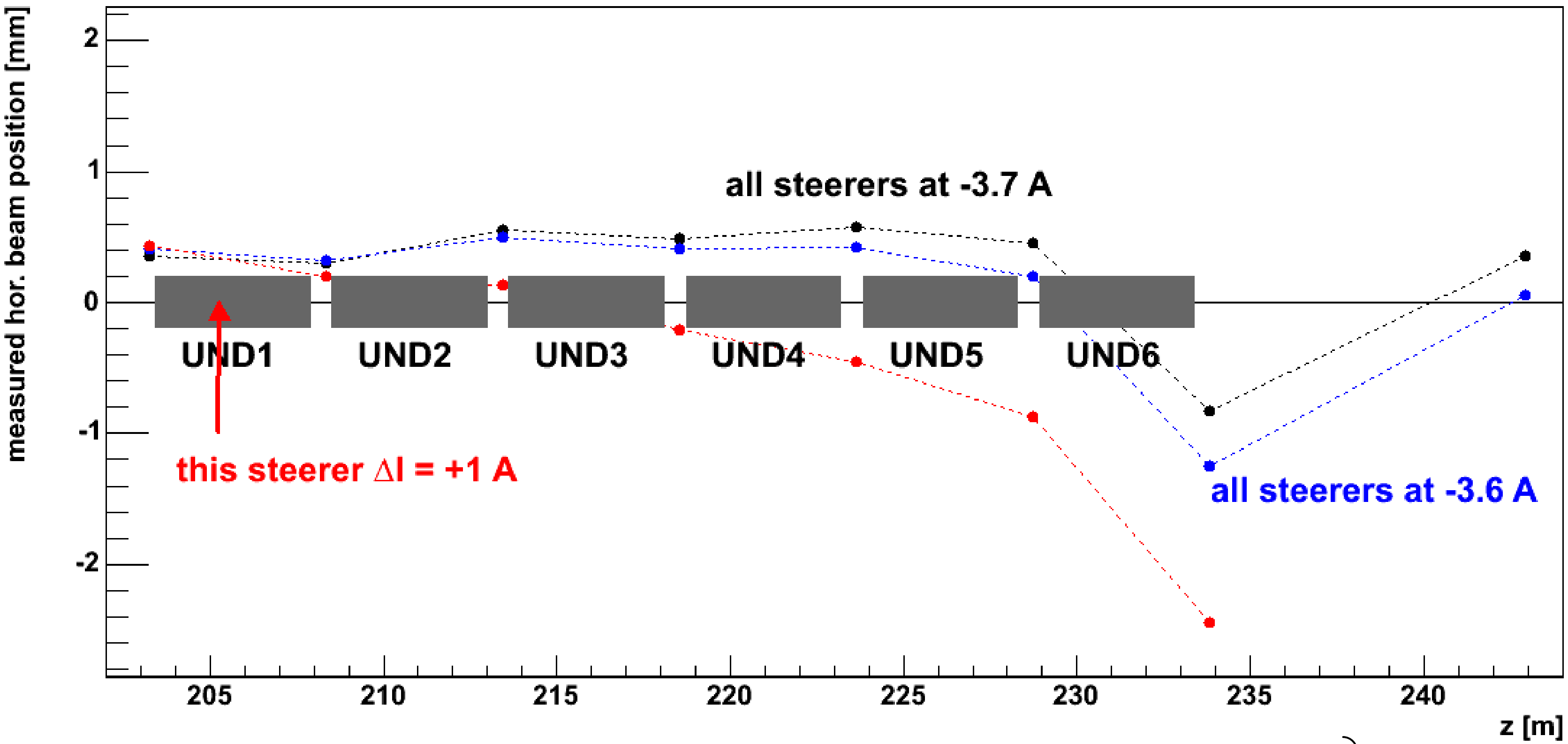
wirescanner results:

- beam parallel to undulator axis → very small incoming beam angle
- same deflection in each undulator segment

it looks like that:

- wires have systematic offset 0.4 mm (with a std.dev. 0.1 mm)
- wire 5UND6 has an offset -1.6 mm w.r.t. the other wires

smallest beam angle at undulator exit: for I = -3.6 A



steerer effect: 50 μrad / 1 A (at beam energy of 680 MeV)

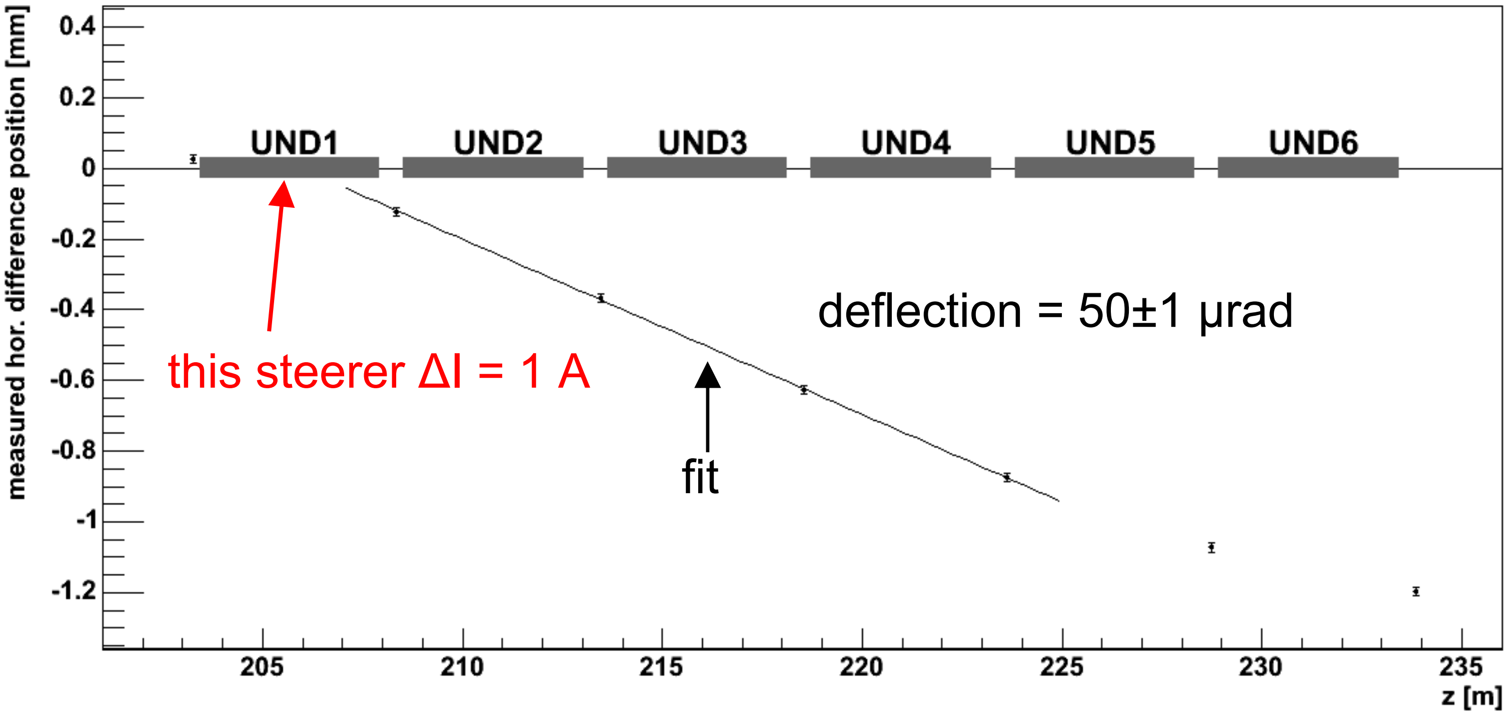
→ integrated dipole field = 0.113 T.mm/A = 1.13 G.m/A

(next slide)

for -3.6 A → integrated dipole field = 0.41 T.mm = 4.1 G.m

average field = 0.41 T.mm / 5 m = 82 μT (or 0.82 G)

Measurement of undulator steerer strength (with wirescanners)



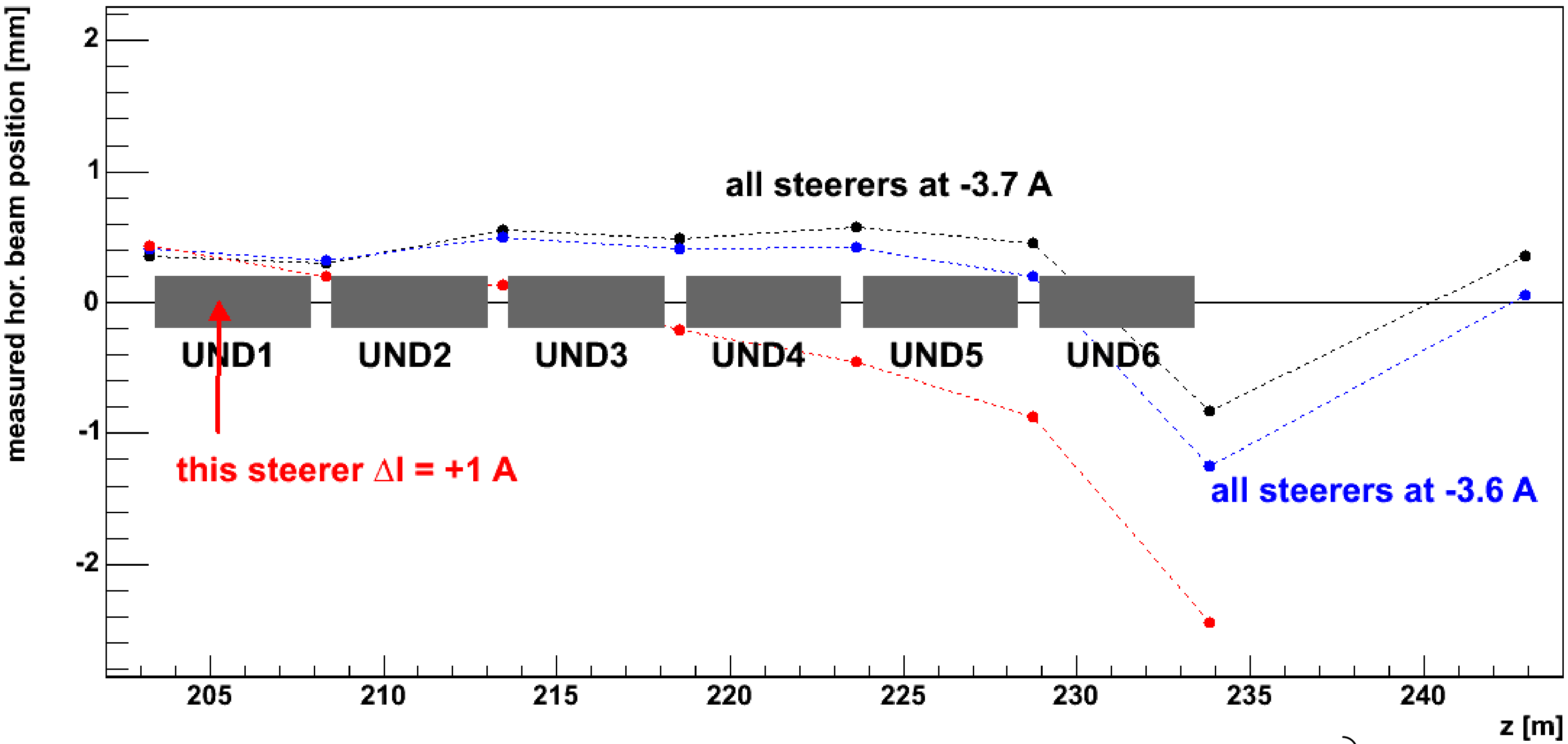
steerer effect: 50 μrad / 1 A (at beam energy of 680 MeV)

→ integrated dipole field = 0.113 T.mm/A = 1.13 G.m/A

calculated using magnetic model (undulator+steerer) : 0.114 T.mm/A

by M. Tischer

smallest beam angle at undulator exit: for I = -3.6 A



steerer effect: 50 μrad / 1 A (at beam energy of 680 MeV)

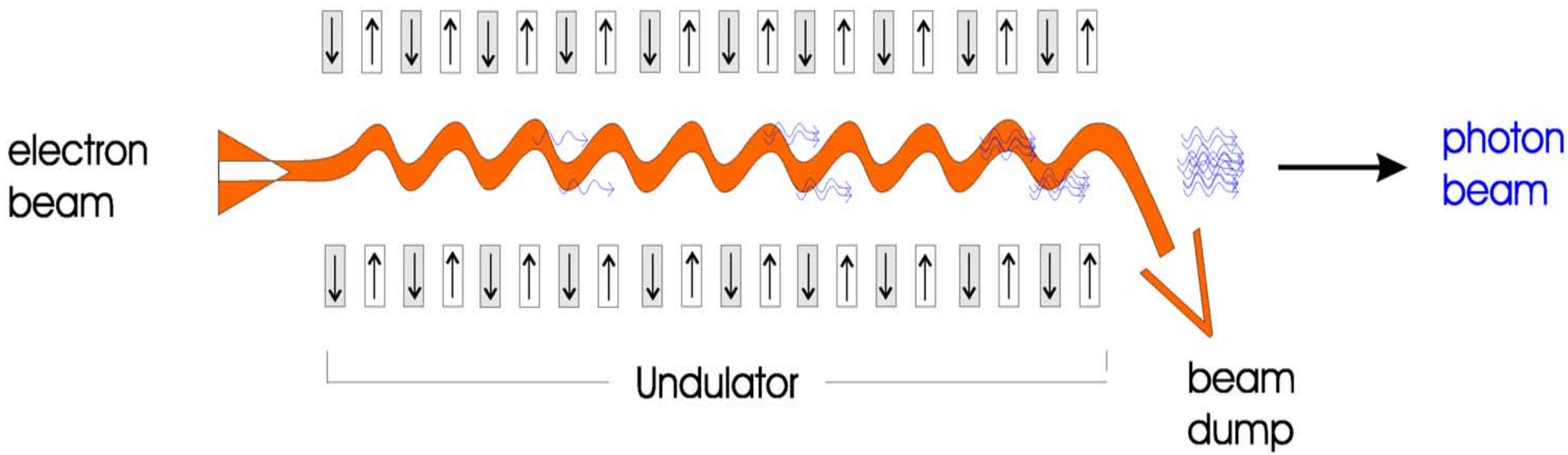
→ integrated dipole field = 0.113 T.mm/A = 1.13 G.m/A

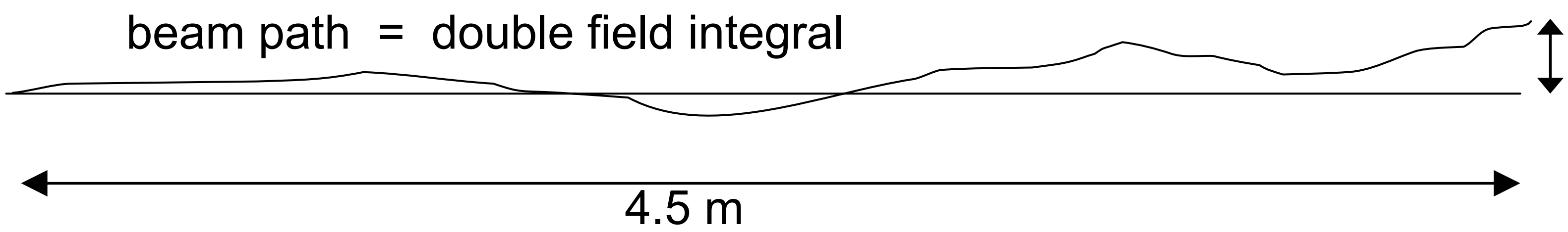
(next slide)

for -3.6 A → integrated dipole field = 0.41 T.mm = 4.1 G.m

average field = 0.41 T.mm / 5 m = 82 μT (or 0.82 G)

Undulator fabrication tolerances



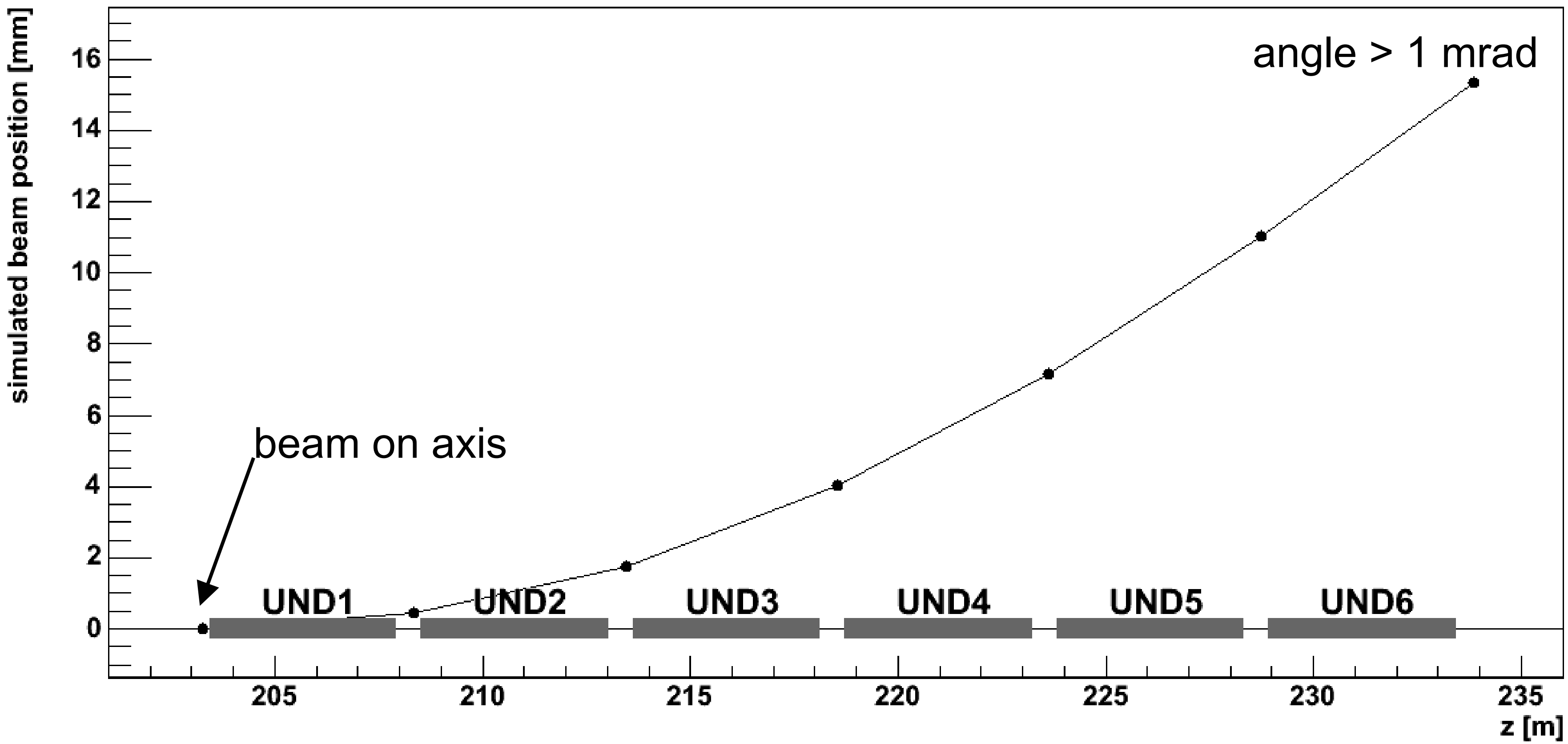


		required	SASE 400	SASE 500	SASE 600	SASE 700	SASE 800	SASE 900
$I_{2,Z,RMS}^2$	Tmm^2	< 30	4	1.2	4.2	1.7	7.9	9.8
$I_{2,Y,RMS}^2$	Tmm^2	< 30	7	8.2	6.9	7.0	3.2	2.2

30 Tmm^2 corresponds to 10µm at 1GeV

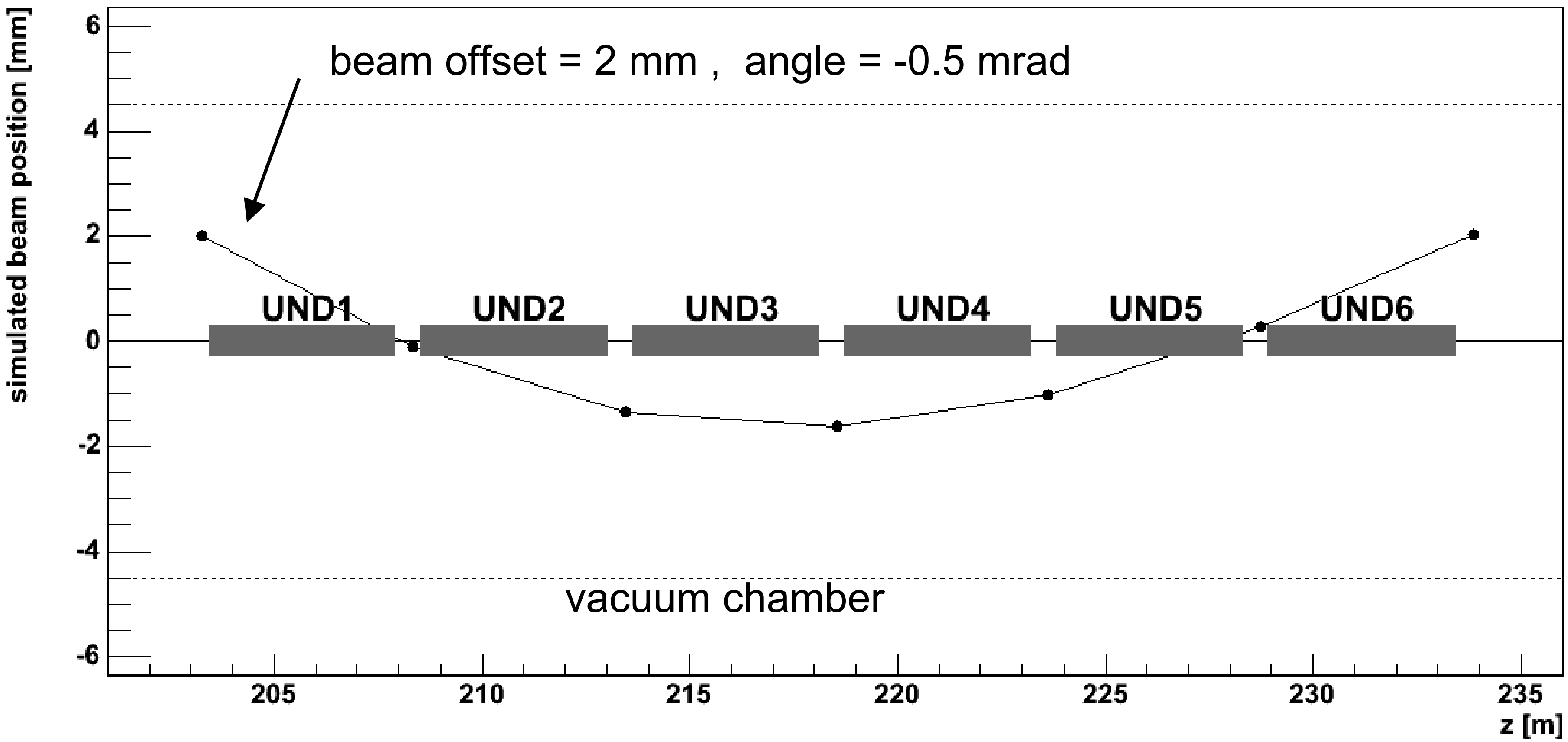
Measurement by J.Pflüger et al.

SIMULATION: effect of -3.6 A on ALL undulator steerers (in a drift space)

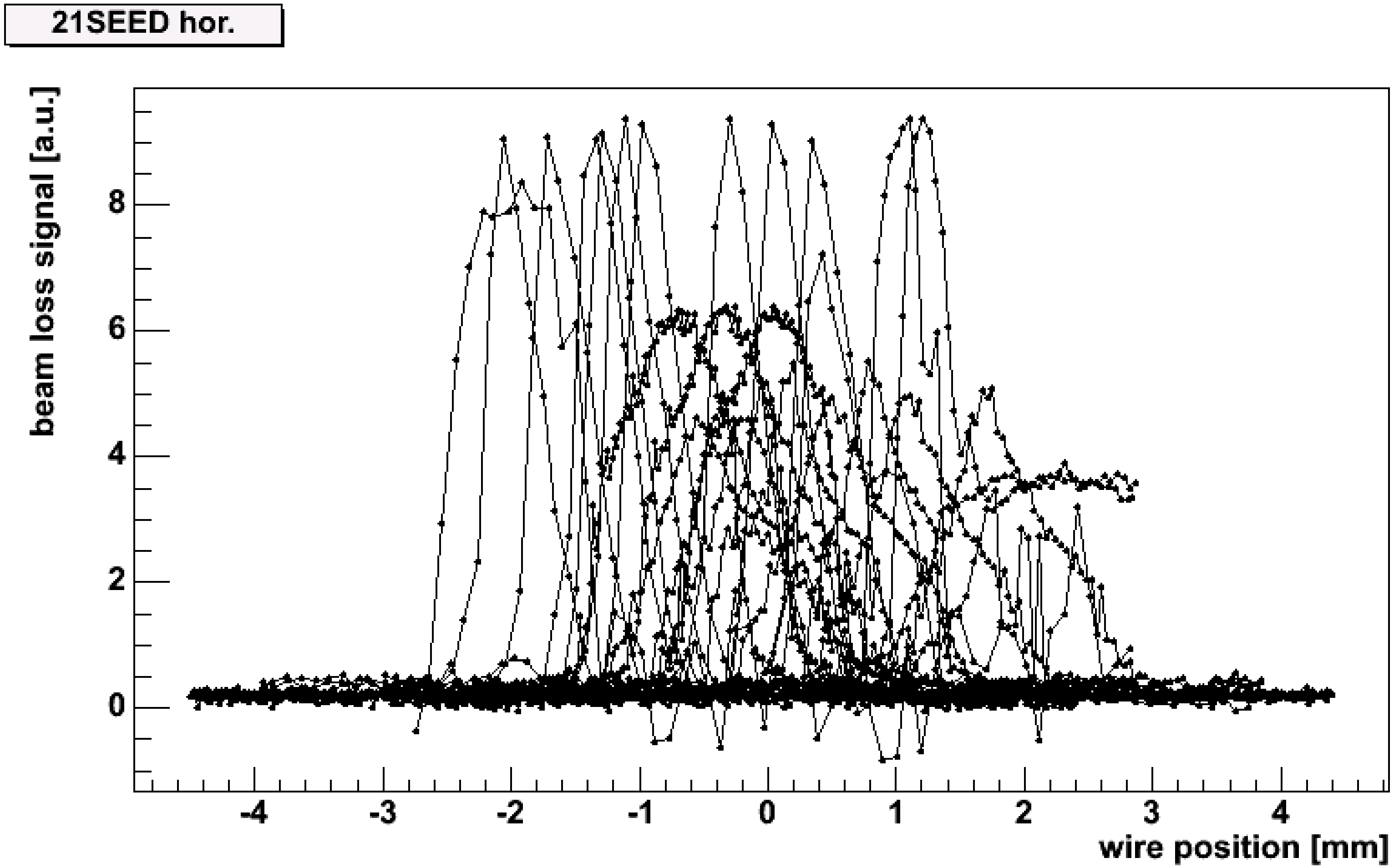


for k=0 (quadrupole gradient = 0)

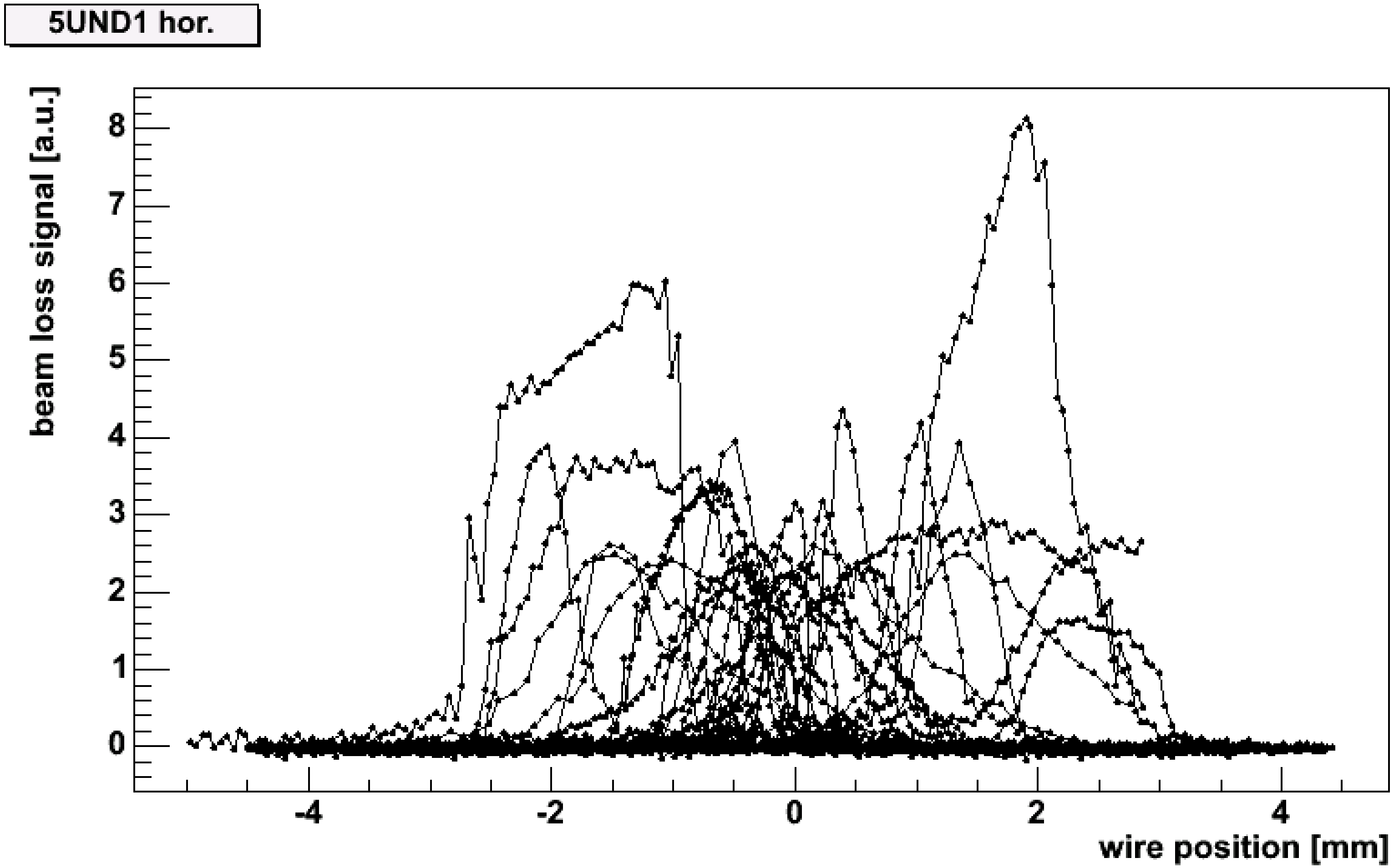
SIMULATION: effect of -3.6 A on ALL undulator steerers (in a drift space)



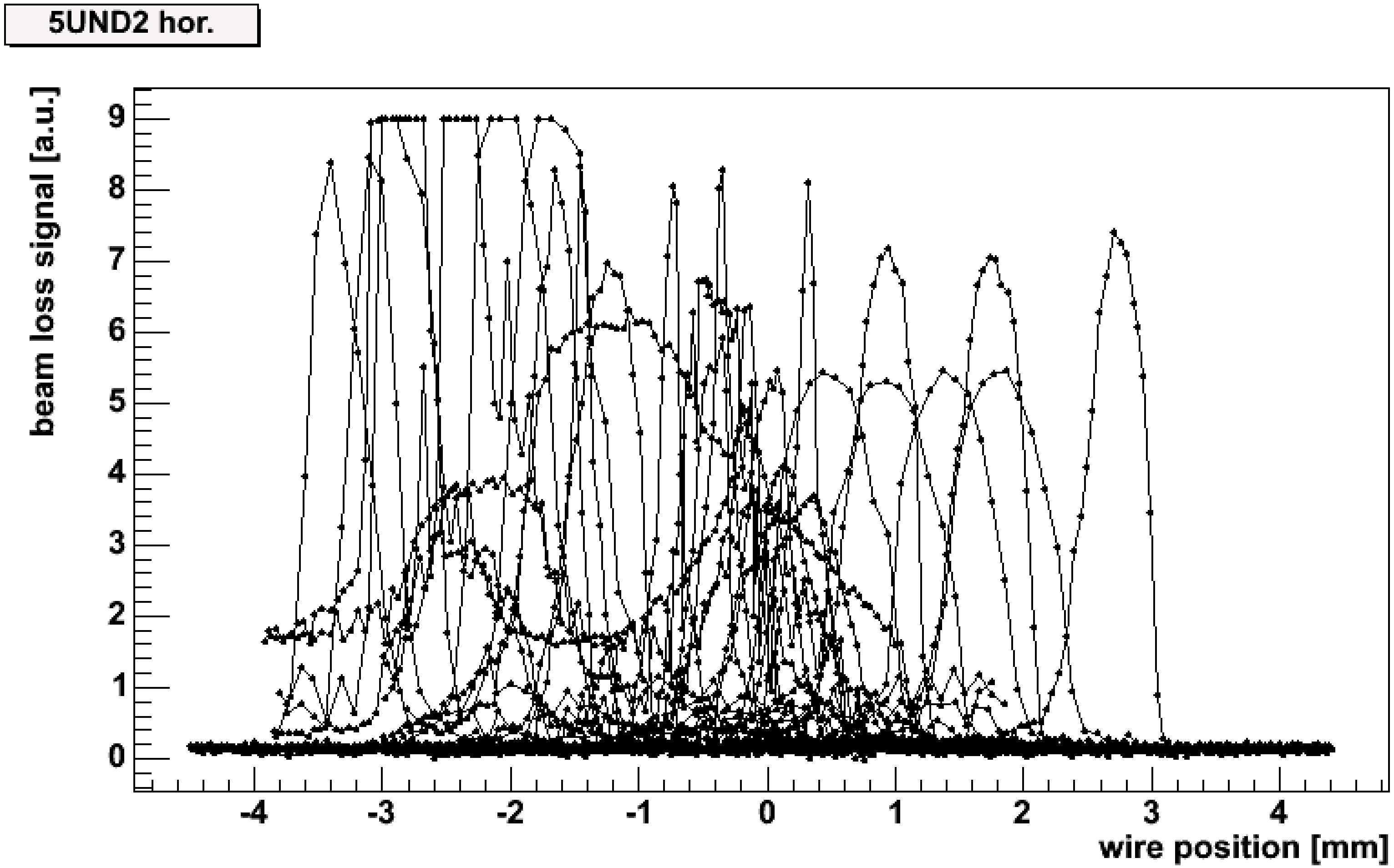
for k=0 (quadrupole gradient = 0)



21SEED hor.
beam loss signal [a.u.]
8
6
4
2
0
-4
-3
-2
-1
0
1
2
3
4
wire position [mm]



5UND1 hor.
beam loss signal [a.u.]
8
7
6
5
4
3
2
1
0
-4
-2
0
2
4
wire position [mm]


5UND2 hor.
beam loss signal [a.u.]
wire position [mm]
0
1
2
3
4
5
6
7
8
9
-4
-3
-2
-1
0
1
2
3
4

Wire position range with part of the beam seen:

21SEED	-2.6	2.8
5UND1	-2.7	3.2
5UND2	-3.8	3.1
5UND3	-4.2	3.4
5UND4	-2.7	2.8
5UND5	-3.0	3.0
5UND6	-3.6	3.4

recommendation: apply -3.6 A to all undulator steerers

Outlook:

next step of BBA: measure dispersion created in undulator

magnetic measurement of undulator segment in tunnel (by J. Pflüger et al)

improve BPM resolution (by N. Baboi et al)

This work would not have been possible without the help of:

B. Faatz
M. Sachwitz
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N. Baboi
D. Nölle
J. Thomas
U. Hahn
M. Tischer
Y. Holler
L. Gumprecht
M. Blöcher

and many more…

THANK YOU !