Status of the Alice magnetic field analysis

R.Shahoyan, 05/10/06

Field reconstruction method

From $\vec{\nabla}\times\vec{B}=0$ and $\vec{\nabla}\cdot\vec{B}=0$ it follows that each field component must be solution of Laplace equation $\Delta B_i=\partial_i(\vec{\nabla}\cdot\vec{B})=0$

Classical method due to H.Wind [NIM 84, (1970), 172-124] is

- fit the dominant field component by function with zero Laplacian to the date measured on the surface of the volume where the field is needed
- obtain by its integration the scalar potential Ψ
- compute all components as $\vec{B}=\vec{\nabla}\Psi$

Advantage of the fitting the surface only is because the solution of Laplace equation has its extremum on the surface. Since both fitted and real field have 0 Laplacian, their difference (i.e. the error of the computed field because of the measurement errors) being also solution of Laplace equation, will have its maximum on the surface. Thus the fitted field inside the volume can be (in principle) more precise than the direct measurement.

In the cylindrical coordinates the general solution of Laplace equation may be written as:

$$\Psi(r,\varphi,z)=\sum_{m,k}C_{mk}\begin{Bmatrix}\sin(m\varphi)\\ \cos(m\varphi)\end{Bmatrix}\begin{Bmatrix}\cosh(kz)\\ \sinh(kz)\end{Bmatrix}J_m(kr)+\sum_{m,k}D_{mk}\begin{Bmatrix}\sin(m\varphi)\\ \cos(m\varphi)\end{Bmatrix}\begin{Bmatrix}\sin(kz)\\ \cos(kz)\end{Bmatrix}I_m(kr) \qquad (1)$$

Terms with J_n (Bessel function of the I kind) are for the boundary condition $B_z=0$ on the cylinder surface, while I_n (modified Bessel function of the I kind) are for $B_z=0$ on the endplates

For details: R,Ganci, IT-ASD W1029-W1030,
R.Ganci and A.Melissinos, CBX-80-53 (CLEO magnet mapping)

There is an obsolete CERN program MAGFIT (R.Ganci, H.Wind, W1029/W1030 and W1043) which was performing such a fit in cylindrical coordinates. However it had certain restrictions and limited precision.
Using it as a prototype a new fitting code was written in C++.

Since the data may be biased due to the probes alignment/inclinations, simple fit to data is not enough.

1) Fit the surface (cylinder + 2 endplates) to measured (adjusted) data according to (1)

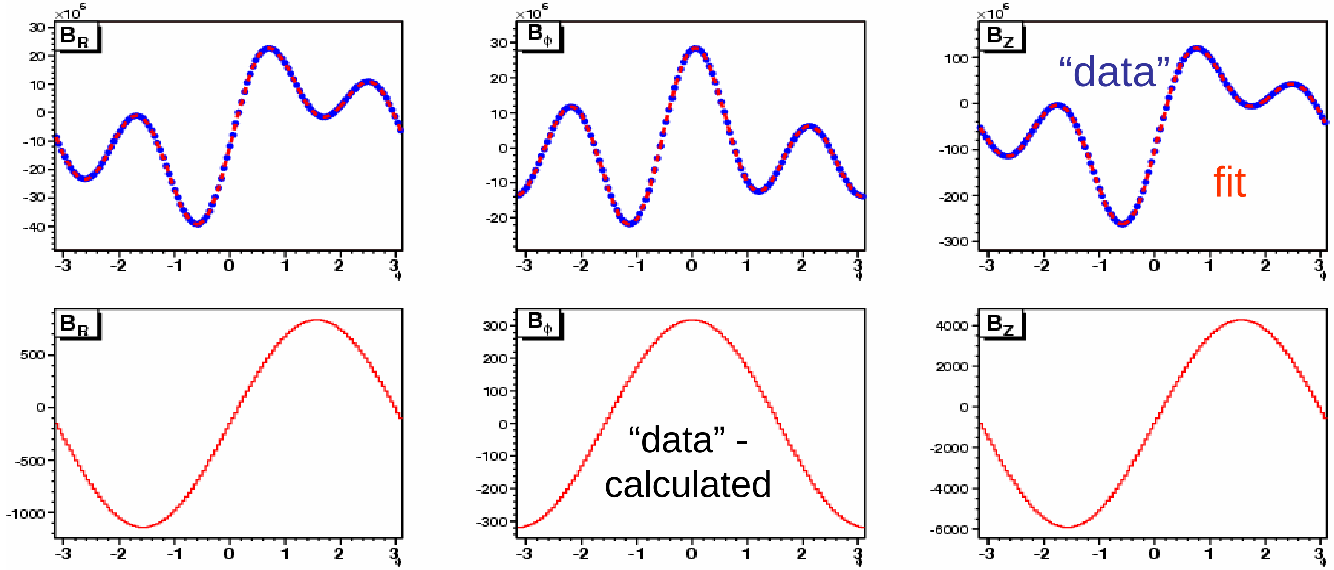
2) Compute all field components at all measured points (including those inside the volume):
the errors of the measured field (apart from the proper probes errors) are (say at φ=0):

$$\frac{\delta B_Z^M}{B_Z} \sim \frac{(\theta^2{}_X + \theta^2{}_Y)}{2} + \frac{B_R}{B_Z}\theta_X + \frac{B_\theta}{B_Z}\theta_Y; \quad \frac{\delta B_R^M}{B_R} \sim \frac{B_Z}{B_R}\theta_Y + \frac{B_\varphi}{B_R}\theta_X; \quad \frac{\delta B_\varphi^M}{B_\varphi} \sim \frac{B_Z}{B_\varphi}\theta_X + \frac{B_R}{B_\varphi}\theta_Y;$$

where $\theta_{X,Y}$ are the overall inclination angles of the probe wrt X and Y axes (~10^{-3} mrad), while for the computed field all relative errors are those of B_Z. Since $B_Z >> B_R$ and B_φ , the transverse components of the calculated field are much more precise than the measured ones.

3) Correct the measured data by matching its transverse components to computed ones by varying:
- angles of the rotation plane of the arm wrt the plane normal to the Z axis
- angles of the each probe wrt its ideal position on the arm at each Z step
- calibration of the probe (restricted to be within 1 Gauss)

Method works with the test field (~10^{-5} precision)



Only Bz on the surface is fitted, all components inside the volume are computed from the reconstructed ψ

Caveat: Ψ is obtained by integration of B_Z by Z $\Rightarrow$ $$\Psi(r,\varphi,z) = \int B_Z(r,\varphi,z)\,dz + \psi(r,\varphi)$$

$\Rightarrow$ if there are z-independent transverse components, they cannot be derived from the B_Z, but should be fitted separately to data.

Sources of Z independent components:

- currents along the Z axis (due to the helix-like winding of the solenoid, current return buses etc.)
- fit in the restricted region whose center does no coincide with the symmetry plane of the field: for the component like $B_R = C(Z - Z_0)$ only $B_R = CZ$ part can be reconstructed from the Ψ obtained from B_Z . Need to apply certain constraints to disentangle such components from probe misalignment effects.

Problem: Because of the probes tilt fake transverse components appear. Data alone cannot remove the ambiguity between the real Z-independent field and the effect of the tilts $\Rightarrow$ need to apply an ad-hoc contraints.

For the solenoid the transverse components should vanish close to the axis $\Rightarrow$ require that there is no (r,φ,z)-constant dipole component (i.e. any transverse field on the axis is due to the tilts)

Cleaned data: list of files containing at least 1 Z position with full scan in φ

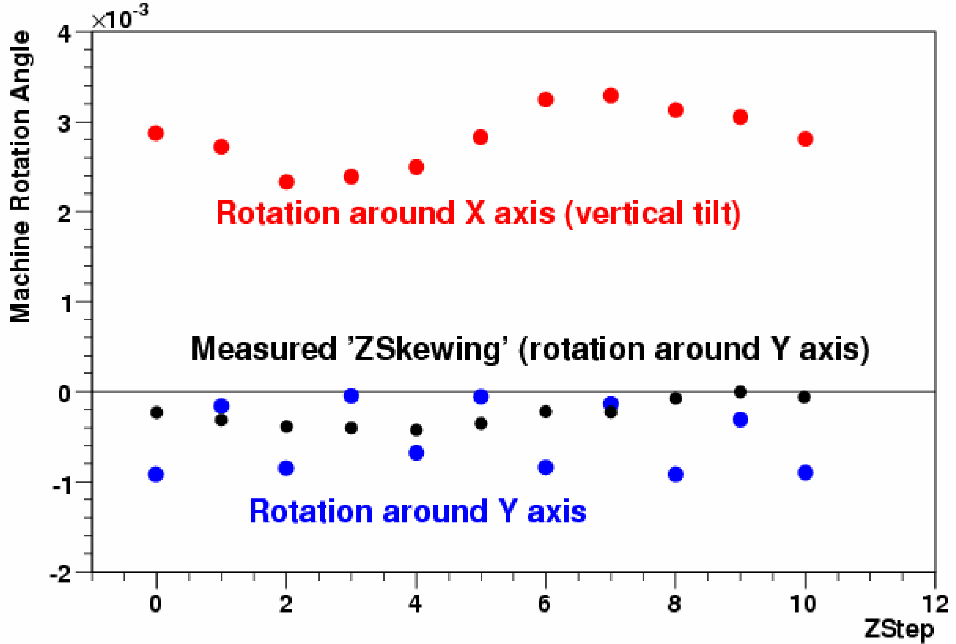
Total Z coverage: -343 < Z < 499 cm, R<423 cm

	Id	Original name	Current	Pos	Nprobes	Zmin	Zmax	Nphi	PhiMin	PhiMax Start	Time End	List of complete Z positions	TASK FILE
A	4	L312kAPOSRB26.dat	12000	1	30	-343.173	76.827	121	0	360	30/07/2005 04:38:27	0_20_40_60_80_100_120_140_160_180_200_220_240_260_280_300_320_340_360_380_400_	**p12_p1A**
B	6	l3--30ka.dat	30000	1	28	-343.173	-123.173	121	0	360	20/08/2005 02:09:10	0_20_40_60_80_100_120_140_160_180_200_	**m30_p1A**
B	7	l3---30ka.dat	30000	1	28	-343.173	-123.173	121	0	360	20/08/2005 08:22:41	0_20_40_60_80_100_120_140_160_180_200_	
B	9	L3-30kA0to1.dat	30000	1	28	-343.173	-243.173	121	0	360	22/08/2005 21:57:24	0_20_40_60_80_	
B	10	l3-30ka0-1.dat	30000	1	28	-343.173	-303.173	121	0	360	23/08/2005 01:00:06	0_20_	
B	11	l3-30ka0--1.dat	30000	1	28	-343.173	-243.173	121	0	360	23/08/2005 02:24:08	0_20_40_60_80_100_	
B	13	L3-30ka1--2.dat	30000	1	28	-243.173	-163.173	121	0	360	23/08/2005 08:40:58	100_120_140_160_	
B	12	L3-30kA1--2.dat	30000	1	28	-243.173	-143.173	121	0	360	23/08/2005 12:24:04	100_120_140_160_180_200_	
B	14	l3-30ka2-3.dat	30000	1	28	-143.173	-43.173	121	0	360	23/08/2005 15:48:46	200_220_240_260_280_300_	
B	16	L3-30kA2.8.dat	30000	1	28	-63.173	-63.173	121	0	360	24/08/2005 12:30:58	280_	
B	17	L3-30kA3.00.dat	30000	1	28	-43.173	-43.173	121	0	360	24/08/2005 13:02:10	300_	
B	18	L3-30kA3.2.dat	30000	1	28	-23.173	-23.173	121	0	360	24/08/2005 13:33:56	320_	
B	19	L3-30kA3.4.dat	30000	1	28	-3.173	-3.173	121	0	360	24/08/2005 14:05:41	340_	
C	21	L3+12kapos2_0.dat	12000	2	28	-46.173	-46.173	121	0	360	25/08/2005 19:15:22	0_	**p12_p2**
C	22	L3+12kapos2_0.2.dat	12000	2	28	-26.173	-26.173	121	0	360	25/08/2005 19:53:48	20_	
C	23	L3+12kapos2_0.4.dat	12000	2	28	-6.173	-6.173	121	0	360	25/08/2005 20:25:35	40_	
C	24	L3+12kapos2_0.6.dat	12000	2	28	13.827	13.827	121	0	360	25/08/2005 20:58:42	60_	
C	25	L3+12kAPOS2_08.dat	12000	2	28	33.827	33.827	121	0	360	25/08/2005 22:20:45	80_	
C	26	L3+12kApos2_1.dat	12000	2	28	53.827	53.827	121	0	360	25/08/2005 22:55:31	100_	
C	28	L312kapos2_1.2_next.dat	12000	2	28	73.827	73.827	121	0	360	25/08/2005 23:58:32	120_	
C	29	L3+12kApos2_1.4.dat	12000	2	28	93.827	93.827	121	0	360	26/08/2005 01:02:59	140_	
C	30	L3+12kApos2_1.6.dat	12000	2	28	113.827	113.827	121	0	360	26/08/2005 01:36:28	160_	
C	31	L3+12kApos2_1.8.dat	12000	2	28	133.827	133.827	121	0	360	26/08/2005 02:09:13	180_	
C	32	L3+12kApos2_2.dat	12000	2	28	153.827	153.827	121	0	360	26/08/2005 02:41:04	200_	
C	33	L3+12kApos2_2.2.dat	12000	2	28	173.827	173.827	121	0	360	26/08/2005 03:13:23	220_	
C	34	L3+12kApos2_2.4.dat	12000	2	28	193.827	193.827	121	0	360	26/08/2005 03:45:30	240_	
C	36	L3+30kApos2_0.dat	30000	2	28	-46.173	-46.173	121	0	360	26/08/2005 12:51:45	0_	**p30_p2**
C	37	L3+30kApos2_0.2.dat	30000	2	28	-26.173	-26.173	121	0	360	26/08/2005 13:22:37	20_	
C	38	L3+30kApos2_0.4.dat	30000	2	28	-6.173	-6.173	121	0	360	26/08/2005 13:57:01	40_	
C	39	L3+30kApos2_0.6.dat	30000	2	28	13.827	13.827	121	0	360	26/08/2005 14:28:43	60_	
C	40	L3+30kApos2_0.8.dat	30000	2	28	33.827	33.827	121	0	360	26/08/2005 15:00:40	80_	
C	41	L3+30kApos2_1.dat	30000	2	28	53.827	53.827	121	0	360	26/08/2005 15:32:32	100_	
C	42	L3+30kApos2_1.2.dat	30000	2	28	73.827	73.827	121	0	360	26/08/2005 16:07:37	120_	
C	43	L3+30kApos2_1.4.dat	30000	2	28	93.827	93.827	121	0	360	26/08/2005 18:24:39	140_	
C	44	L3+30kApos2_1.6.dat	30000	2	28	113.827	113.827	121	0	360	26/08/2005 18:57:20	160_	
C	45	L3+30kApos2_1.8.dat	30000	2	28	133.827	133.827	121	0	360	26/08/2005 19:30:00	180_	
C	46	L3+30kApos2_2.dat	30000	2	28	153.827	153.827	121	0	360	26/08/2005 20:02:56	200_	
C	48	L3+30kApos2_2.2next.dat	30000	2	28	173.827	173.827	121	0	360	26/08/2005 21:14:05	220_	
C	49	L3+30kApos2_2.4.dat	30000	2	28	193.827	193.827	121	0	360	26/08/2005 21:53:38	240_	
C	50	L3+30kApos2_2.6.dat	30000	2	28	213.827	213.827	121	0	360	26/08/2005 22:27:45	260_	
D	51	L3-12kapos2_0to2.6.dat	-12000	2	31	-46.173	13.827	121	0	360	04/09/2005 08:38:52	0_20_40_	**m12_p2A**
D	52	L3-30kapos2_0to2.4.dat	-30000	2	30	-46.173	193.827	61	0	360	07/09/2005 17:55:39	0_40_80_120_160_200_240_	
E	61	l3-12kapos3z0.8.dat	-12000	3	27	233.827	393.827	61	0	360	12/09/2005 21:11:51	80_120_160_200_240_	**m12_p3A**
J	93	l3+12kapos3v1.dat	12000	3	31	153.827	393.827	121	0	360	01/10/2005 20:08:28	0_20_40_60_80_100_120_140_160_180_200_220_240_	**p12_p3**
J	94	l3+30kapos3v1.dat	30000	3	31	273.827	393.827	121	0	360	02/10/2005 03:38:03	140_160_180_200_220_240_	**p30_p3**
J	96	l3+30kapos3v1-z1.0-0.dat	30000	3	31	153.827	253.827	121	0	360	02/10/2005 08:16:51	0_20_40_60_80_100_	
J	97	l3-30kapos3v1.dat	-30000	3	31	153.827	393.827	121	0	360	02/10/2005 14:04:08	0_20_40_60_80_100_120_140_160_180_200_220_240_	**m30_p3**
J	98	l3-12kapos3v1.dat	-12000	3	31	153.827	393.827	121	0	360	02/10/2005 22:31:38	0_20_40_60_80_100_120_140_160_180_200_220_240_	**m12_p3**
K	99	l3-12kapos2v1.dat	-12000	2	31	-46.173	-26.173	121	0	360	07/10/2005 23:38:48	0_	**m12_p2**
K	100	l3-12kapos2v1z0.2p306to0.dat	-12000	2	31	-26.173	-26.173	103	0	306	08/10/2005 01:00:05	20_	
K	101	l3-12kapos2v1z0.4to2.48.dat	-12000	2	31	-6.173	201.827	121	0	360	08/10/2005 01:14:44	40_60_80_100_120_140_160_180_200_220_240_248_	
K	102	l3-30kapos2v1.dat	-30000	2	31	53.827	201.827	121	0	360	09/10/2005 01:00:00	120_140_160_180_200_220_240_248_	**m30_p2**
K	103	l3-30kapos2z0-1v1.dat	-30000	2	31	-46.173	53.827	121	0	360	09/10/2005 09:16:02	0_20_40_60_80_100_	
K	104	l3+12kapos2v1.dat	12000	2	31	-46.173	133.827	121	0	360	09/10/2005 15:06:54	0_20_40_60_80_100_120_140_160_180_	**current unstable**
L	107	l3+12kapos4.dat	12000	4	31	359.327	499.327	121	0	360	12/10/2005 22:14:08	0_40_80_120_130_140_	**p12_p4**
L	108	l3+30kapos4.dat	30000	4	31	359.327	499.327	121	0	360	13/10/2005 01:40:00	0_20_40_60_80_100_110_120_130_140_	**p30_p4**
M	109	l3+12kapos1v1.dat	12000	1	31	-343.173	-83.173	121	0	360	14/10/2005 16:20:06	0_20_40_60_80_100_120_140_160_180_200_220_240_260_	**p12_p1**
M	110	l3+30kapos1v1.dat	30000	1	31	-343.173	-83.173	121	0	360	15/10/2005 01:00:01	0_20_40_60_80_100_120_140_160_180_200_220_240_260_	**p30_p1**
M	111	l3-12kapos1v1.dat	-12000	1	31	-343.173	-83.173	121	0	360	15/10/2005 18:38:22	0_20_40_60_80_100_120_140_160_180_200_220_240_260_	**m12_p1**
M	112	l3-30kapos1v1.dat	-30000	1	31	-343.173	-83.173	121	0	360	16/10/2005 12:55:42	0_20_40_60_80_100_120_140_160_180_200_220_240_260_	**m30_p1**

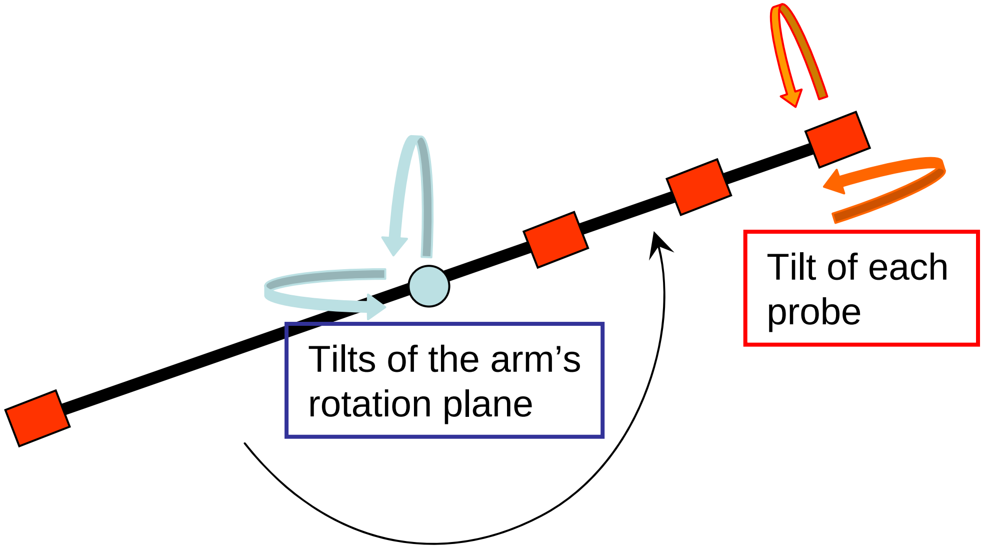
Each color is for the different setting of the measuring machine. 21 sets of data (some overlapping) were selected from 109 data files

Problems in the data

- ID's of some probes are corrupted: these probes are identified by their pedestals/gain pattern.
- Some probes from time to time are changing their calibration values or produce random data: these probes were ignored in all data files
- The probes are fixed on the arm with some tilt (up to 30 mrad!), leading to fluctuations of thr measured values as a function of R: accounted in the fit by rotational degrees of freedom unique for each probe.
- The movement of the measuring machine on the rails was not uniform: each step in Z has certain tilt θ_Y wrt Y axis. This leads to fake horizontal dipole component: this tilt was measured during the scan (ZSkewing) but strongly differs from the fitted one. Accounted as extra degrees of freedom for each Z step.
- There was also tilt θ_X wrt X axis, leading to fake vertical dipole component. There is a contradiction between the survey data from EDMS616573 (18/07/05), which seen no tilt and EDMS679908 (10/11/05) with θ_X ~5.5 mrad: accounted in the fit in a same way as for Y axis.
- Data shows a small (~1Gauss) maximum in Bz close to the L3 axis, where the minimum is expected: not solved
- Uncertainty in the initial Z position of the machine (data from different Z scans don't match each other) fit Z position + input from H.Taureg?

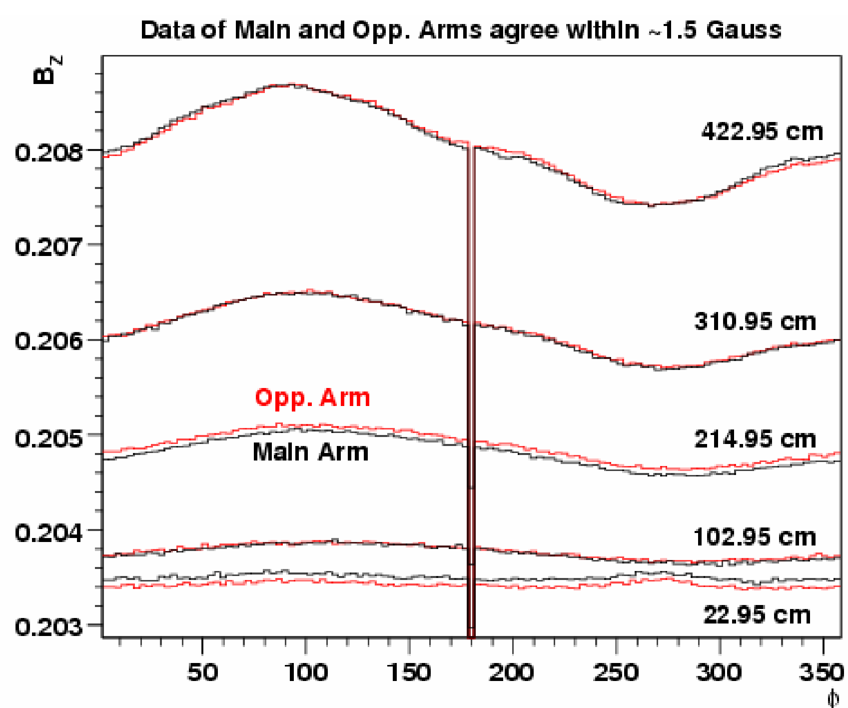


Tilts: degrees of freedom for correcting the data

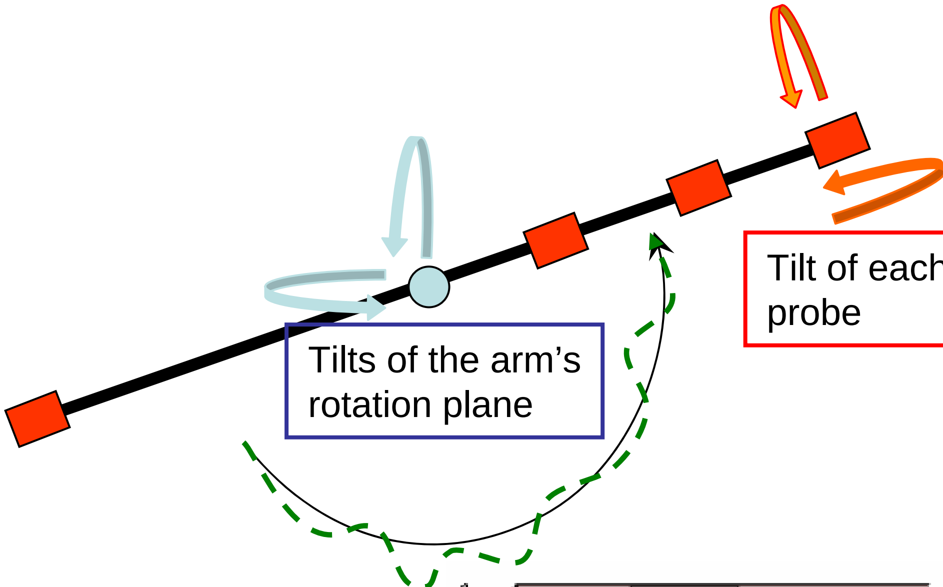


Is there a single rotation plane or the axis of the arm was precessing?

The probes of the “opposite arm” at arm position φ should measure the same field as the probes of the “main arm” at φ+π (the difference due to the probes own tilts and calibration should not depend on φ)



Tilts: degrees of freedom for correcting the data

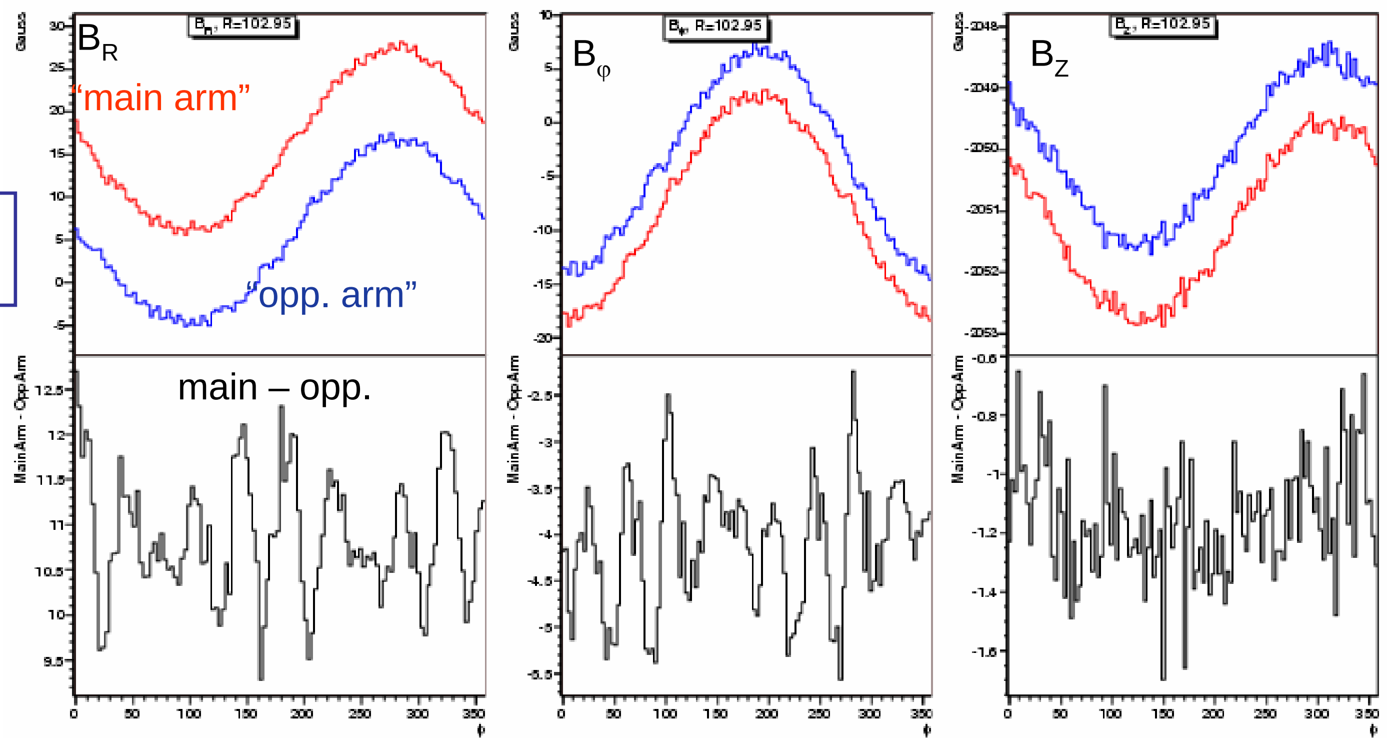


Tilt of each probe

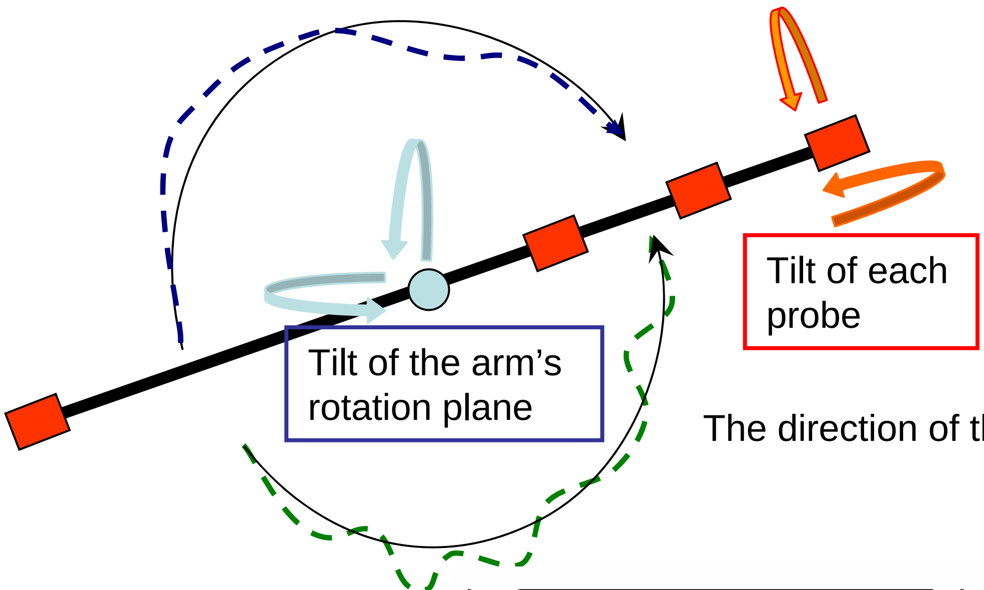
Tilts of the arm's rotation plane

odd Z steps

The tilt angle depends on the position of the arm!



Tilts: degrees of freedom for correcting the data

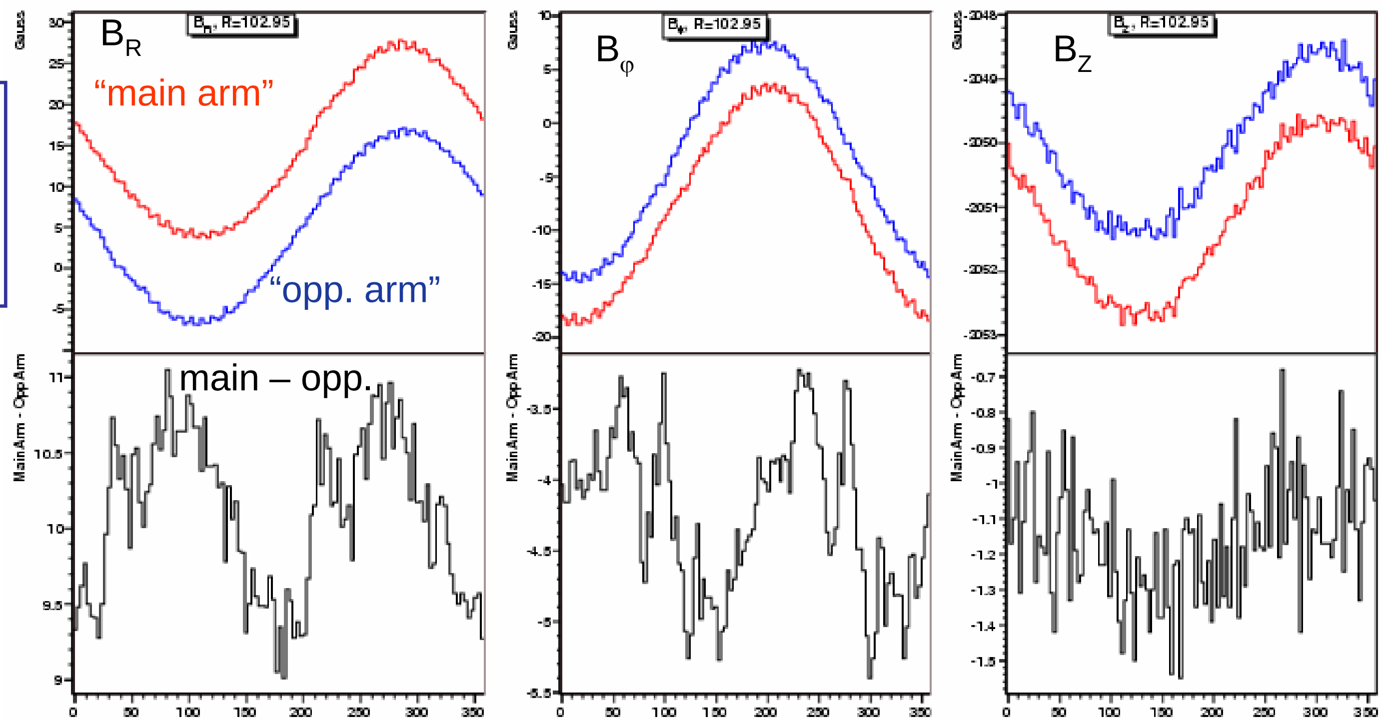


The direction of the arm rotation was changed at each Z step

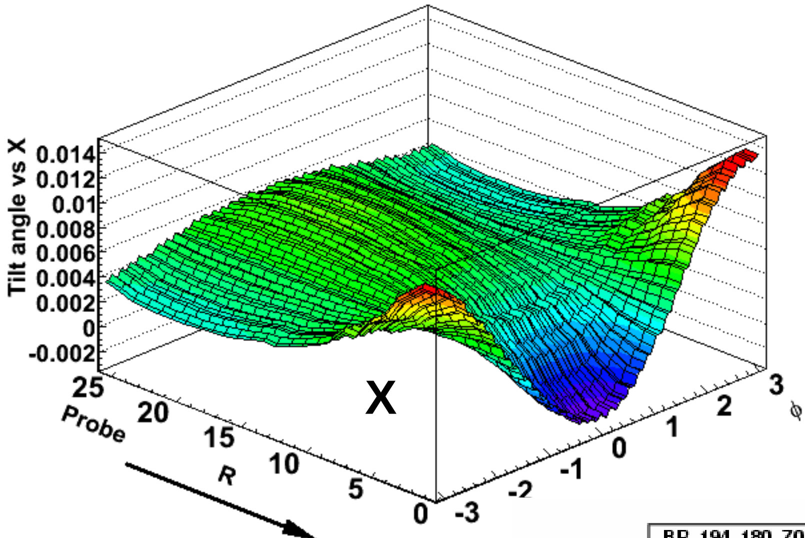
even Z steps

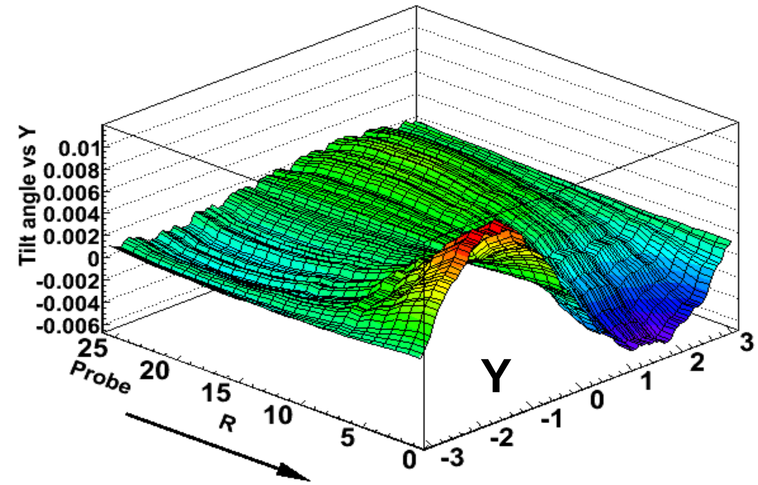
The tilt angle depends on the position of the arm!

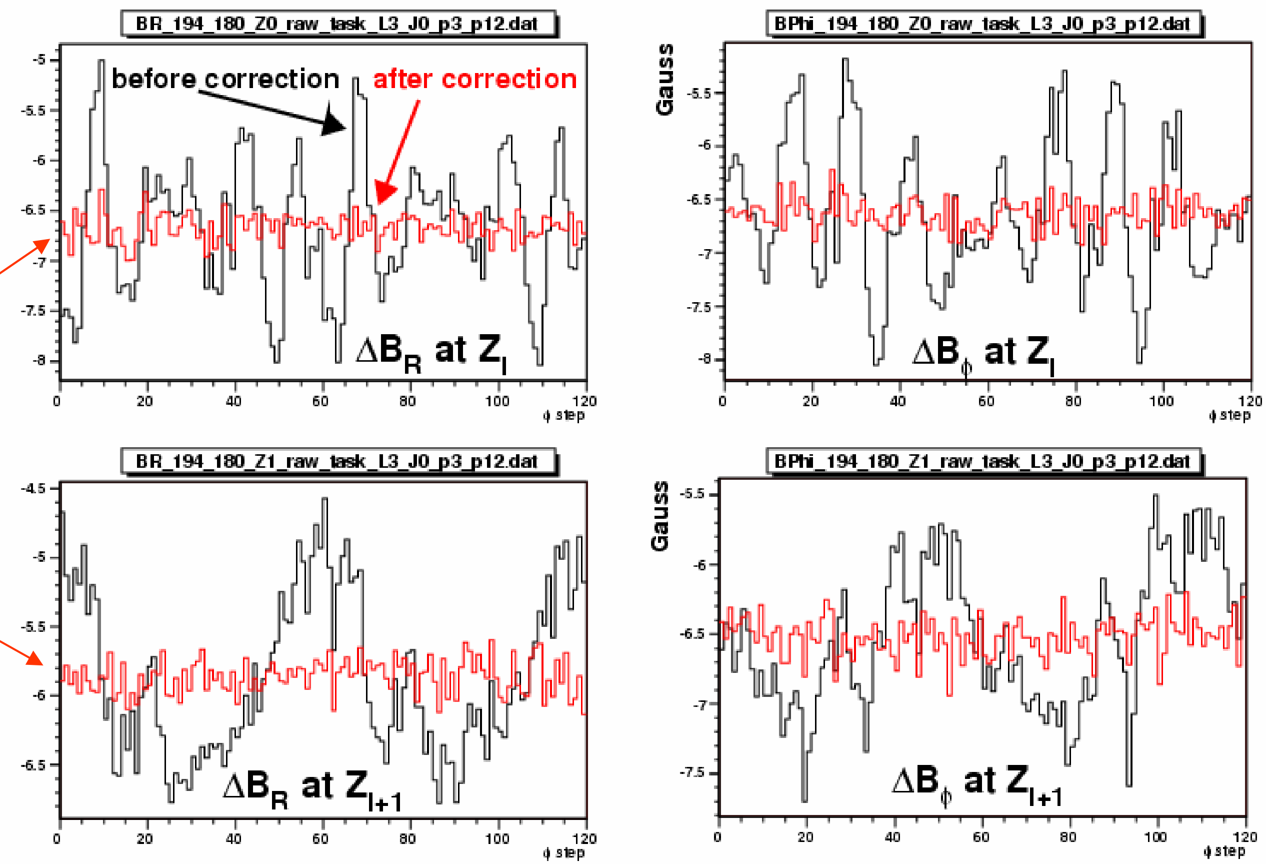
Even worse: it depends on R
⇒ the arms were bent!



Tilts precession is corrected at each φ,Z step



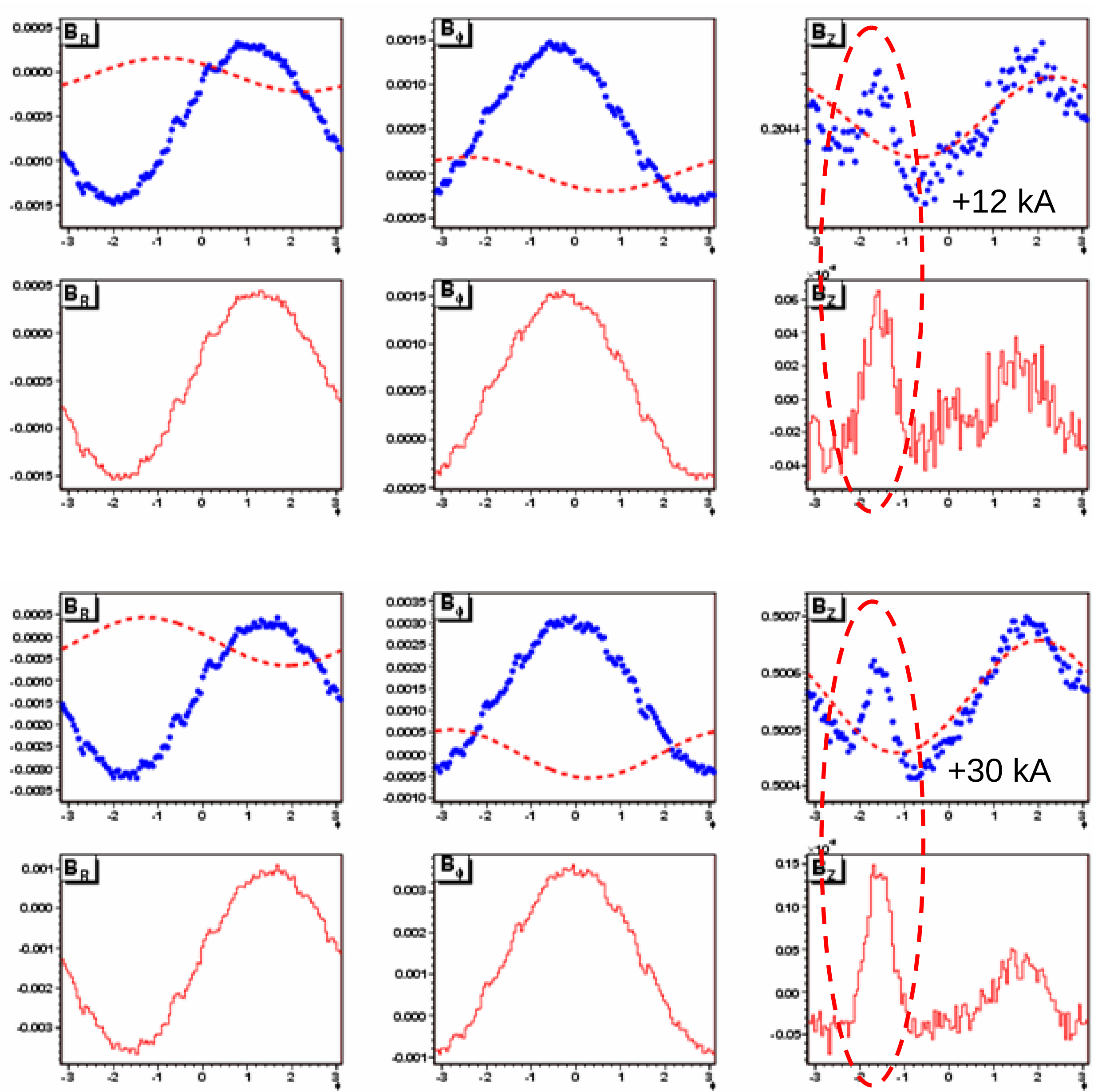




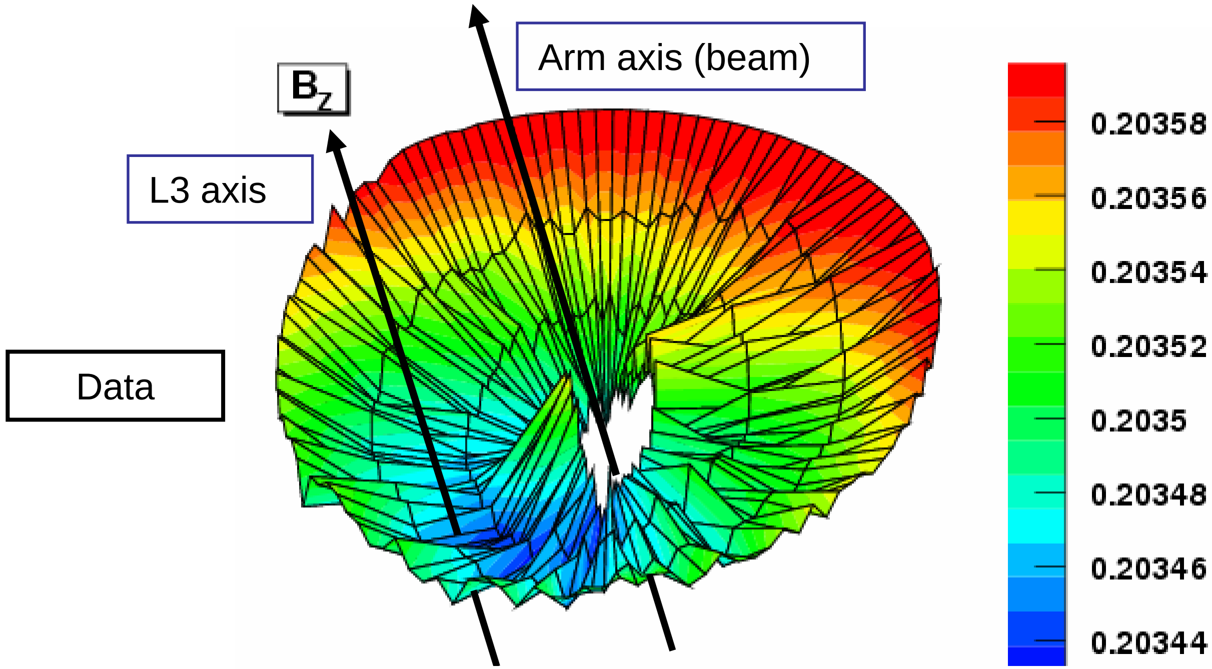
The remaining constant difference between the “Main” and “Opp” arms measurements is because of the probes own tilt and is corrected separately

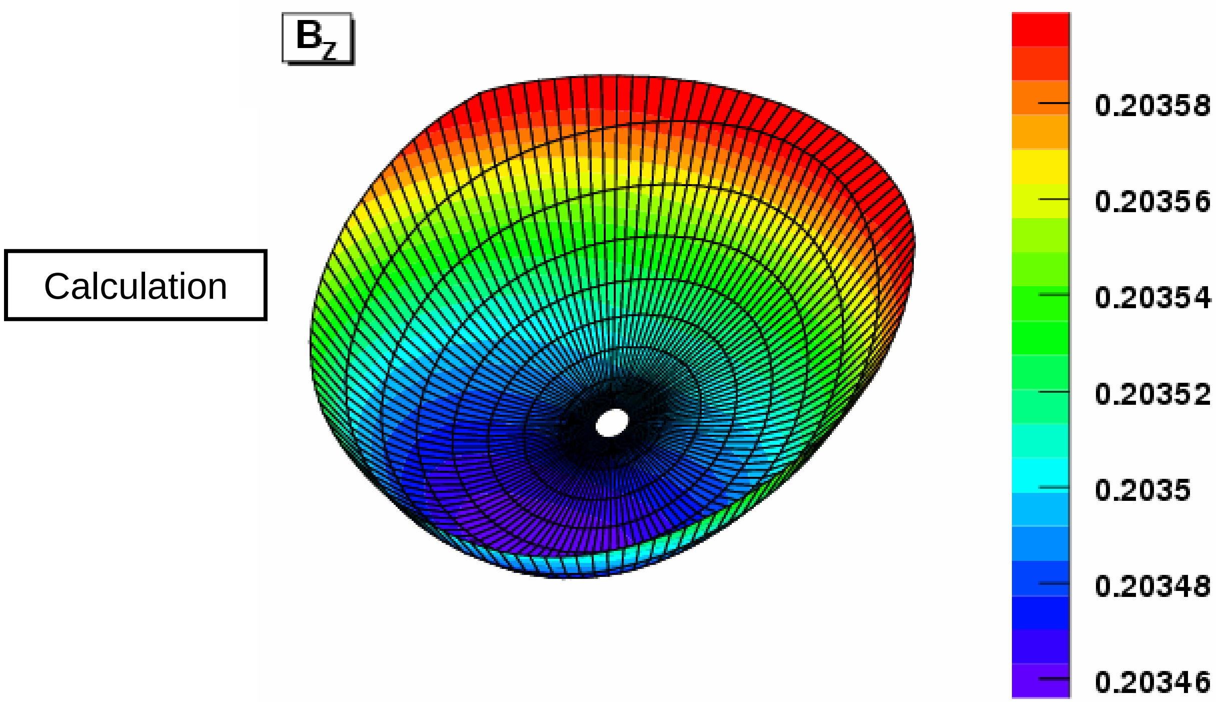
Spike in Bz close to arm rotation axis: the fit in Bz is very good for all probes except the ones at R=23cm

Appears at ~3/2π where the probe is at the shortest distance from the L3 axis ⇒ the minimum of Bz.



- Instead of the minimum a small bump of ~1 Gauss is observed.
- The spike is independent in Z but scales with the L3 current.
- Impossible to fit with $\Delta\Psi$=0 model (Tosca also does not see any maximum)

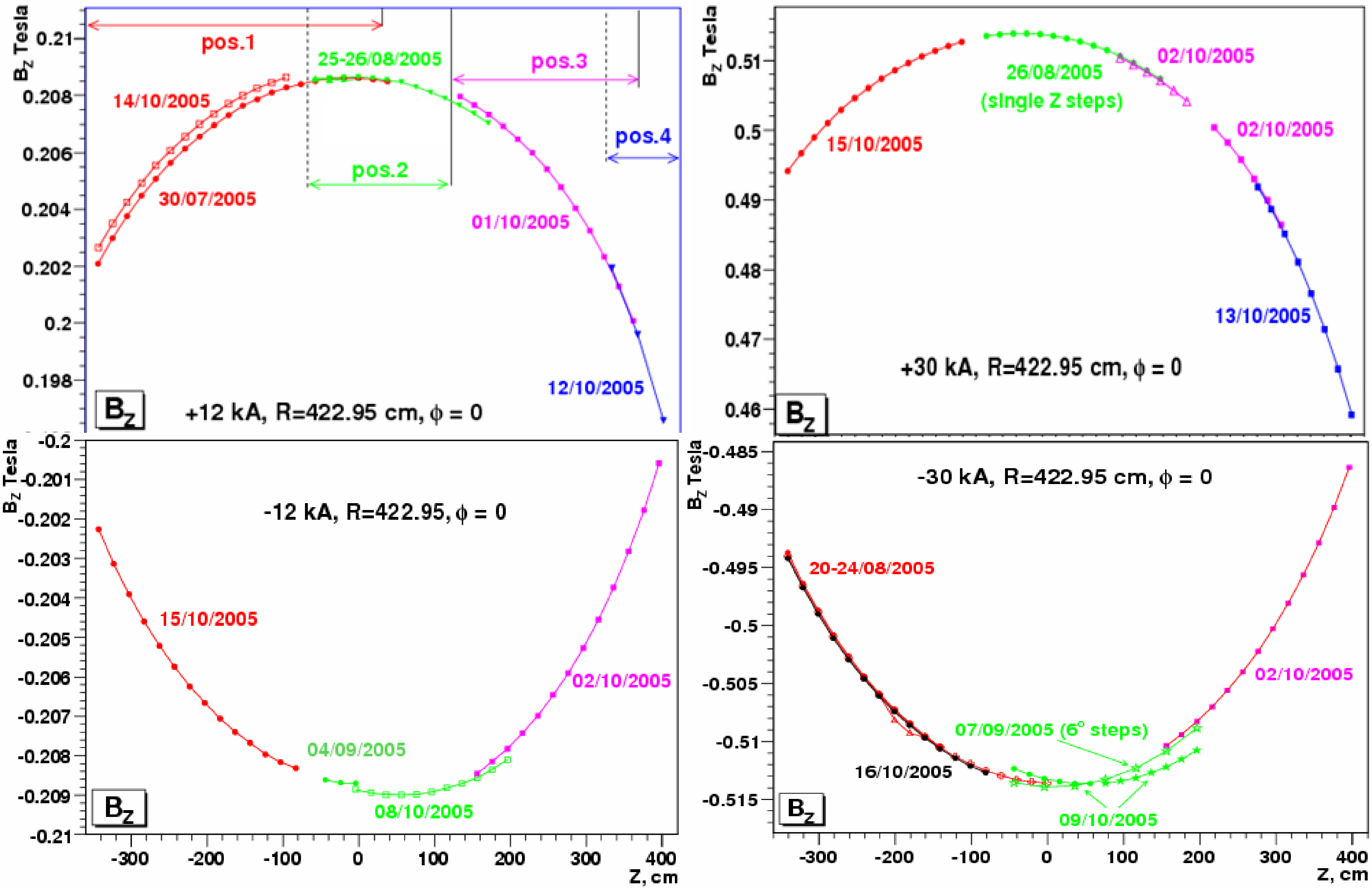




Influence of the machine?

This spike is neglected in the fits

Mismatch between the measurements in different Z windows
(note: Bz is very stable (<1Gauss variations) against all tilts and calibration problems)



To do:

L3 map

- Spike at small R's : disregard?
- Global fit of the data in different Z ranges (1st version works but may need some improvements).
  Hopefully this will solve the question of the magnitude of Z-independent transverse terms.
  The real solution would be just a few precise measured points with well aligned probe!
- Putting together the fits from different Z ranges:
  1. filling the gaps where the field was not measured
  2. rescaling different data sets to have the field continuous
     (eliminate the changes in the current, residual magnetization of the iron …)
  3. Need precise positions of end-switches for each of 4 Z ranges
     (H.Taureg will check in his records)
- Fitted field calculation by model (1) is very slow: ~ 1000 terms with Bessel, hyperbolic or trigonometric functions ⇒ a few msec./point on 2GHz CentrinoII CPU.
  Once the functions are defined interpolate them Chebyshev polynomials (standard technique)
  ⇒ orders of magnitude faster.

<u>L3 map should be ready in a few weeks</u>

Dipole

For the moment only the "lost probes address" recovery is done.

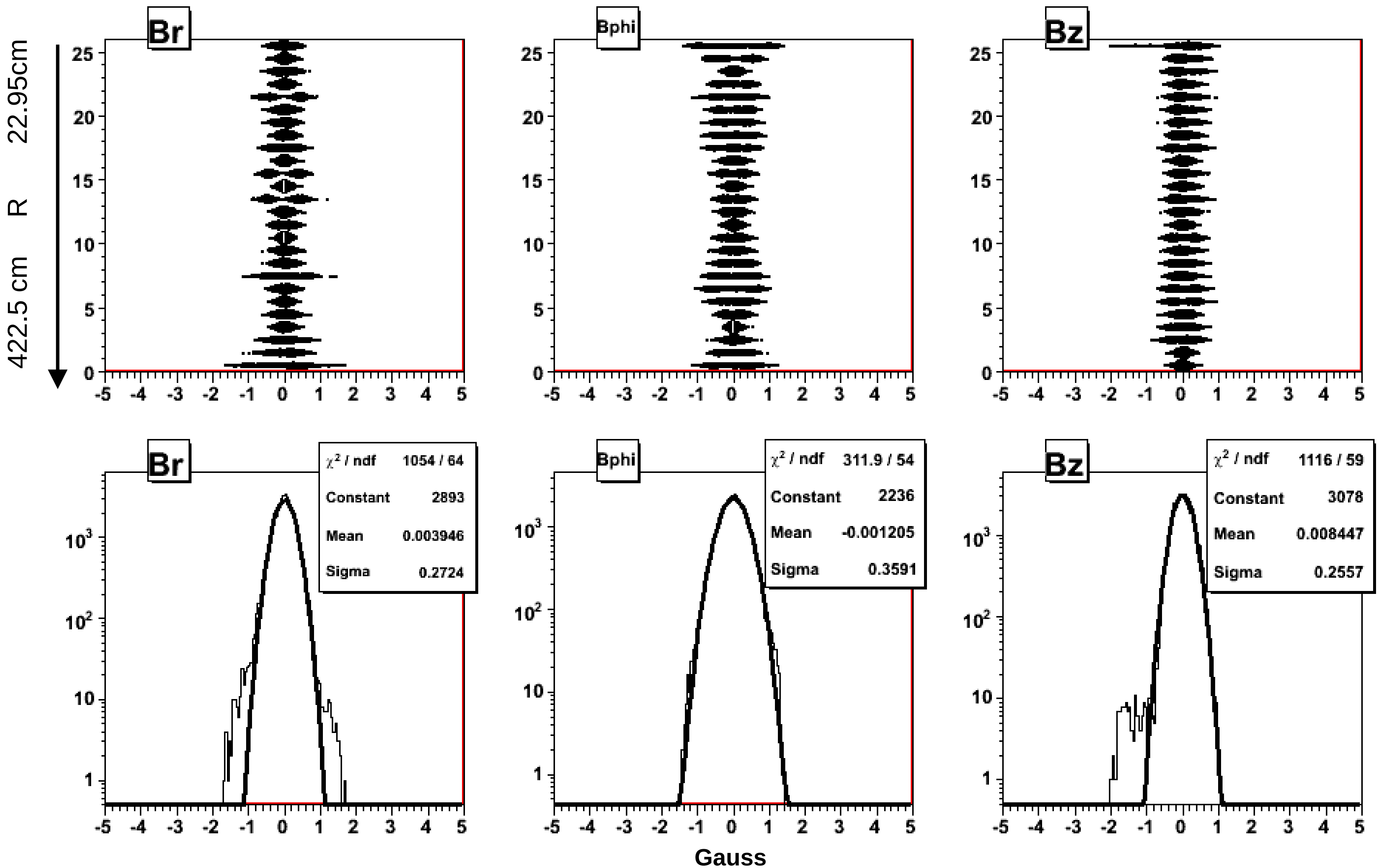
Implement a field fitting model for Cartesian coordinates.

Data cleaning/selection

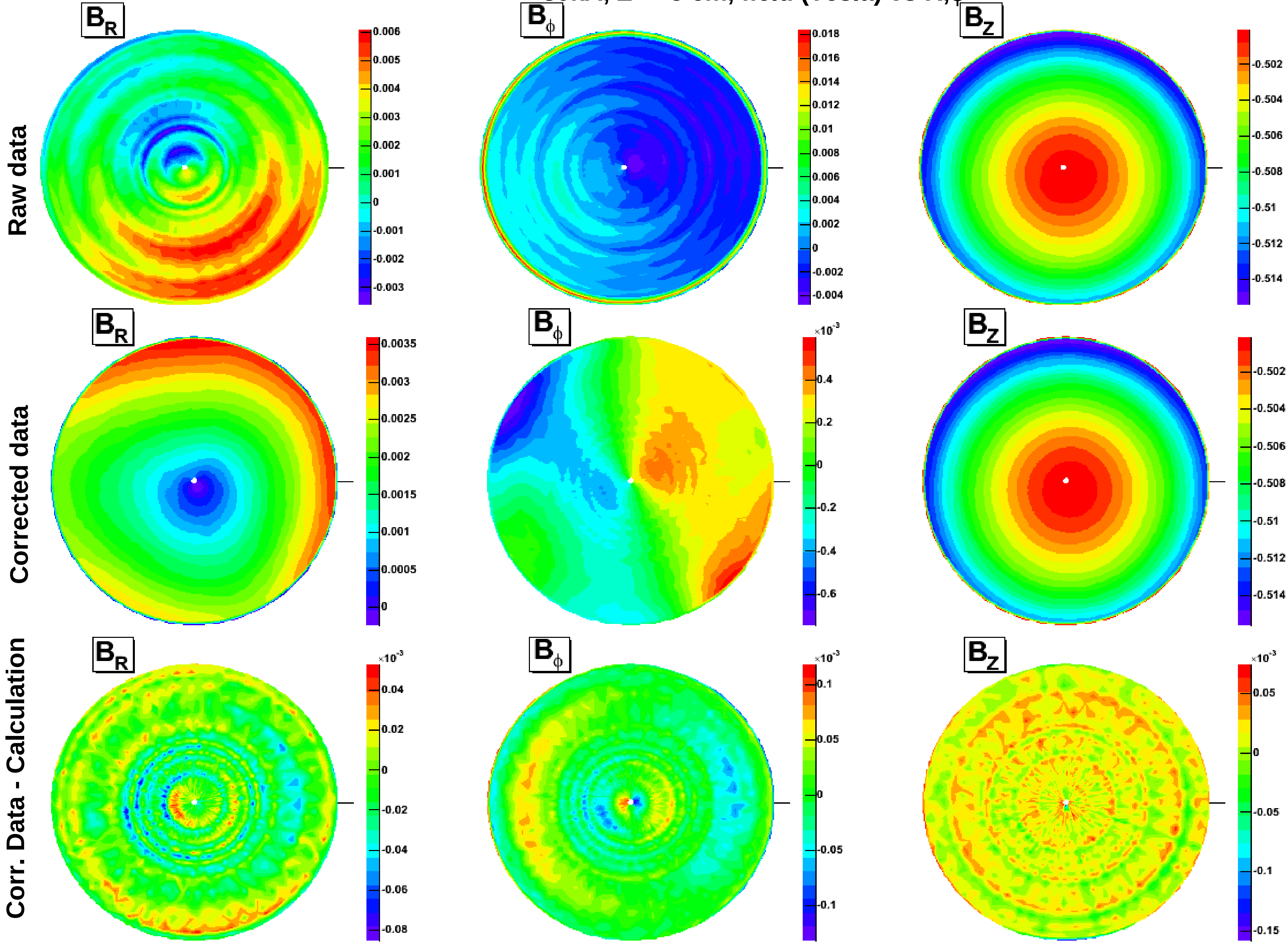
<u>to be done in September-October</u>

Results

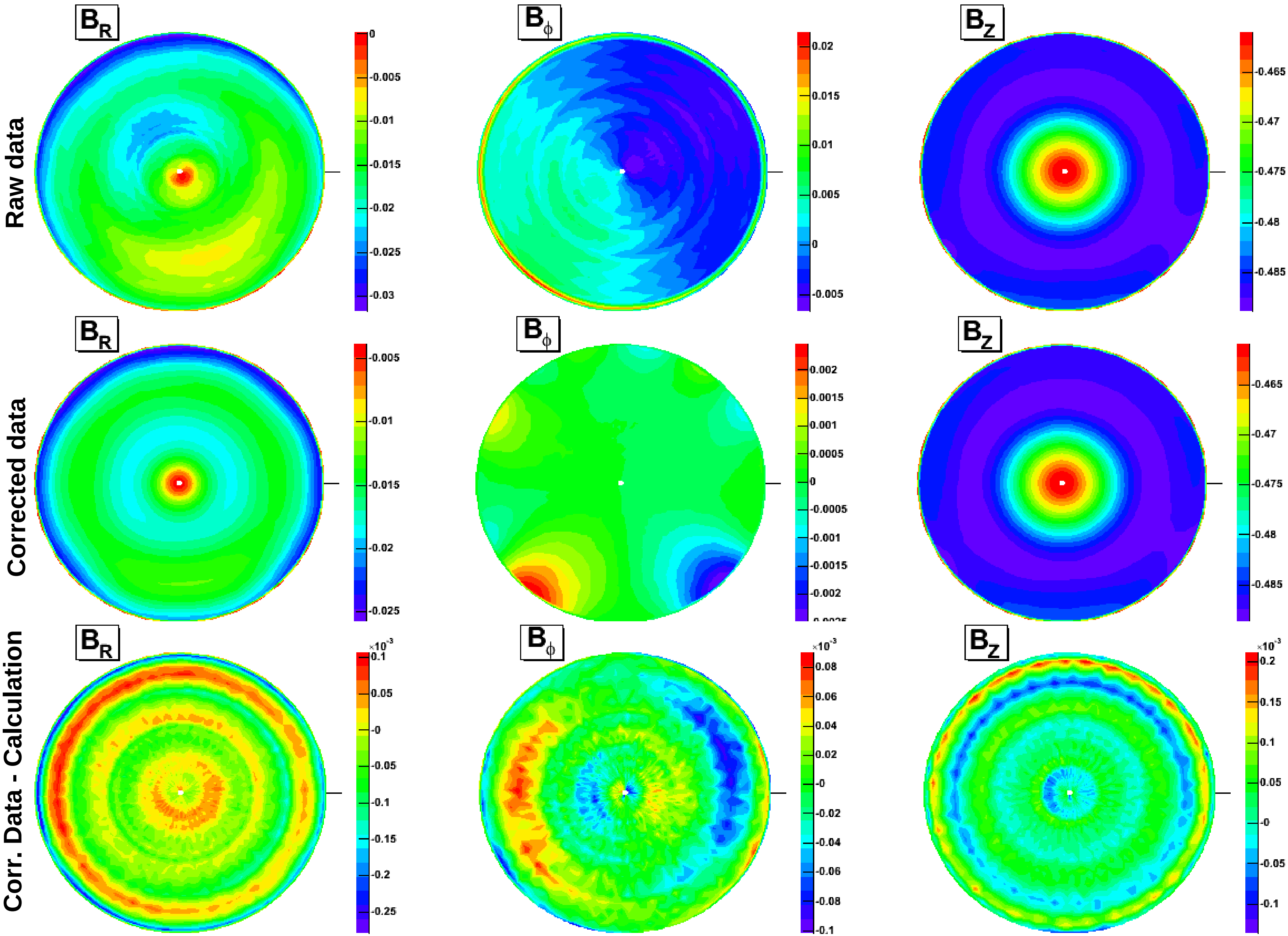
Corrected data – Calculation (Gauss), -30kA, - 46 < Z < 202 cm



-30kA, Z ~ -5 cm, field (Tesla) vs R,φ



-30kA, Z ~ 400 cm, field (Tesla) vs R,φ



What to put in Aliroot?

Field reconstruction from potential fit is very CPU demanding (sum of >1000 terms..): ~ 10 ms/point with good processor ⇒ not appropriate for use in the software.

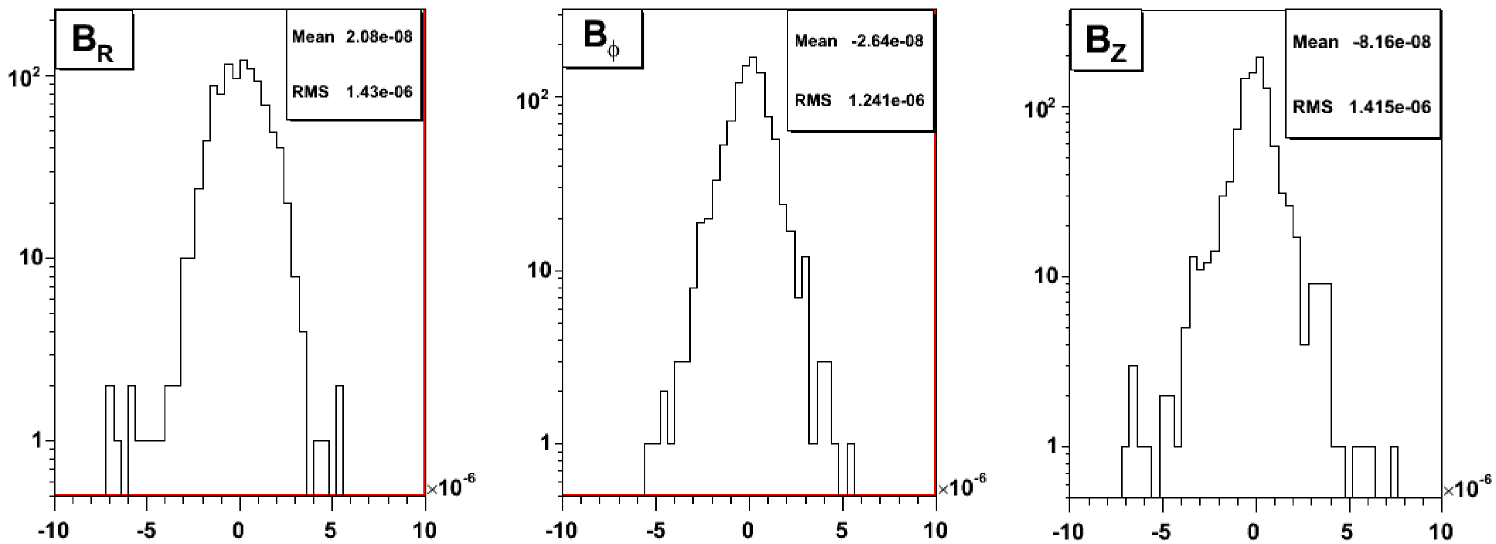
Alternatives:

1) Generate field on the grid and use (linear) interpolation:

- ✓ already implemented in Aliroot
- ✓ very fast: **~3 μs/point**
- ✗ memory consuming: field gradients of ~0.1 Gauss/cm ⇒ 10 cm steps to have 1 Gauss prec.
  ⇒ >0.6 M points to cover central part of L3 (R<4.5, -5<Z<5 m) ⇒ >**7 MB just for L3**.

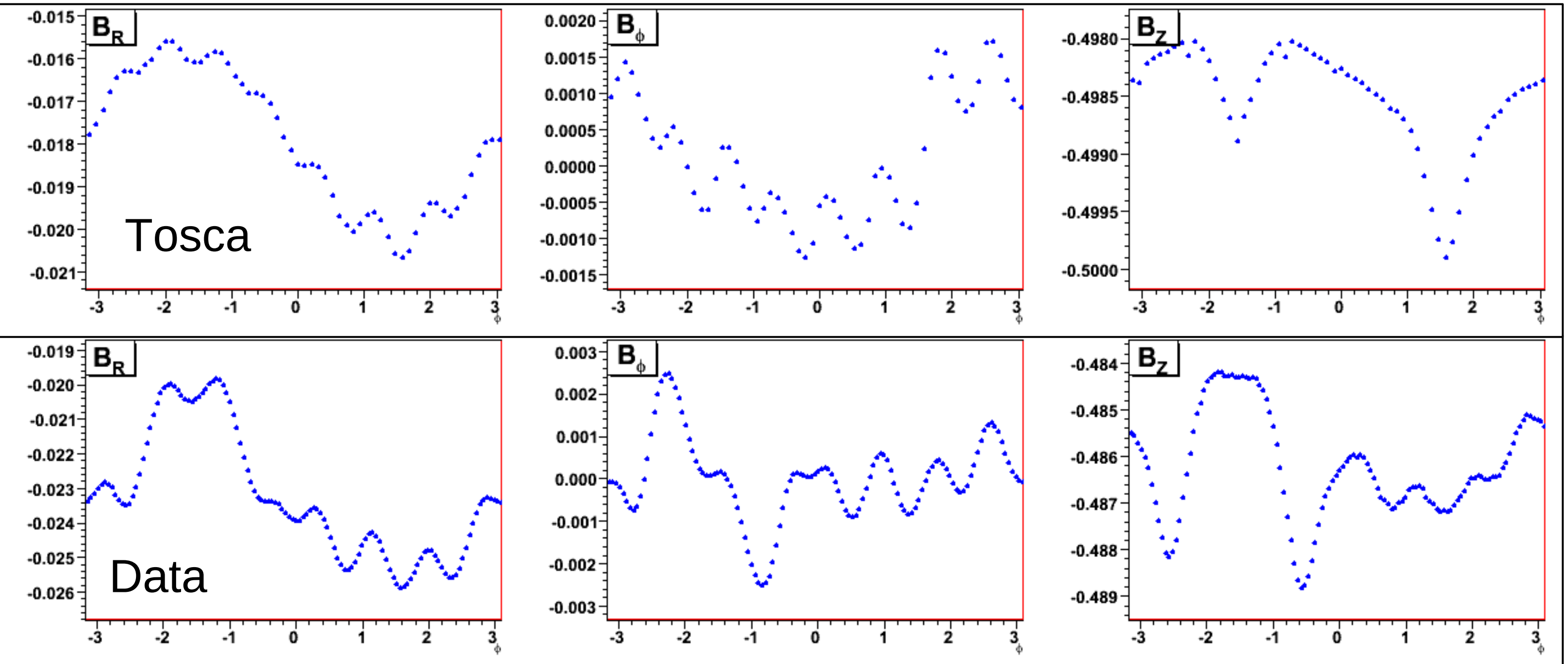
2) Use fast Chebyshev parameterization, which can guarantee any requested precision:

- ✓ already implemented as separate class, trivial to insert to Aliroot
- ✓ very compact: just few 10 kB.
- ✗ slower: **~30 μs/point** if 0.1 Gauss precision is requested, **~14 μs/point** for 1 Gauss .
  May be reduced by factor 2-3 by splitting the volume in few pieces.



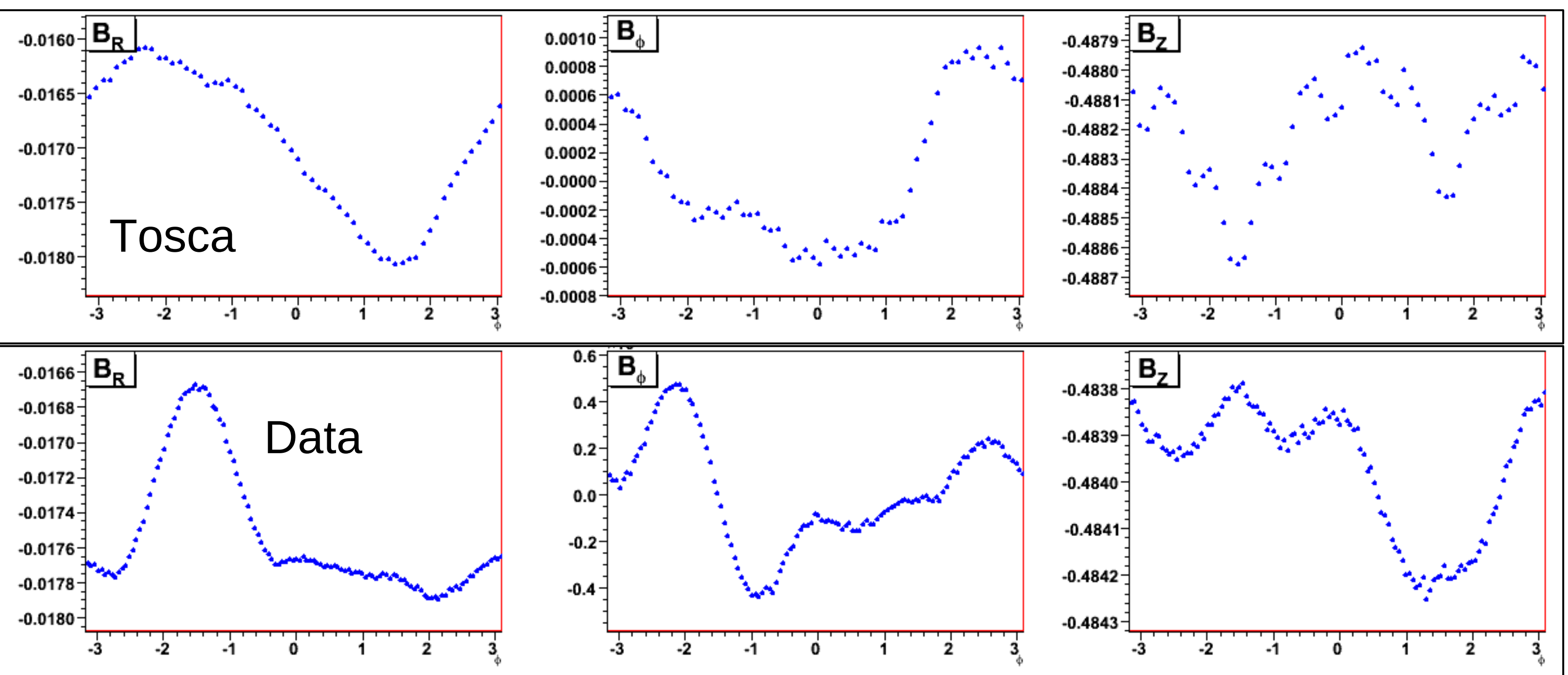
Difference between input "potential reconstruction" and Chebyshev parameterizations (Gauss) with 0.1 Gauss precision requested.

B vs φ



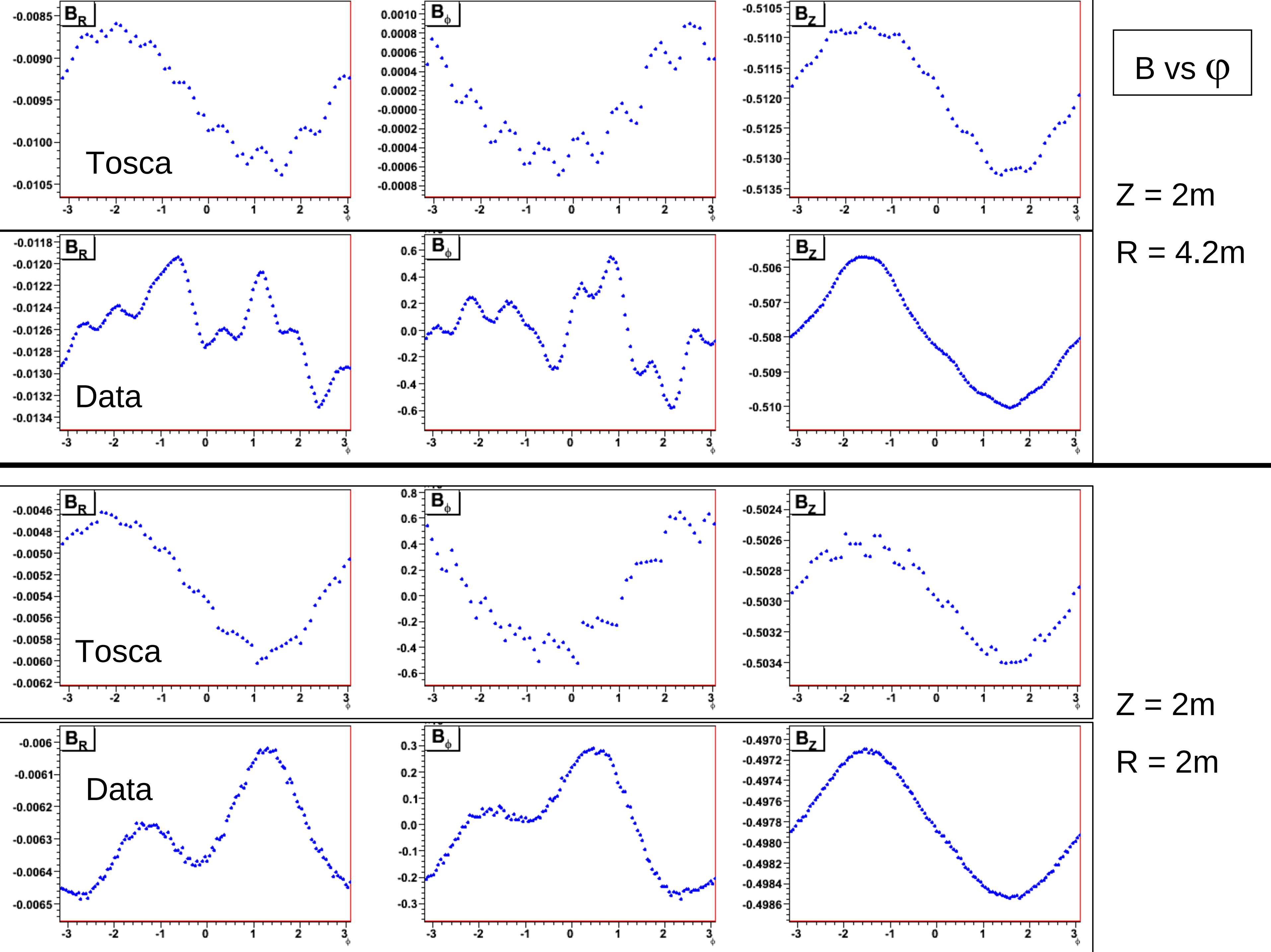
Z = 4m

R = 4.2m

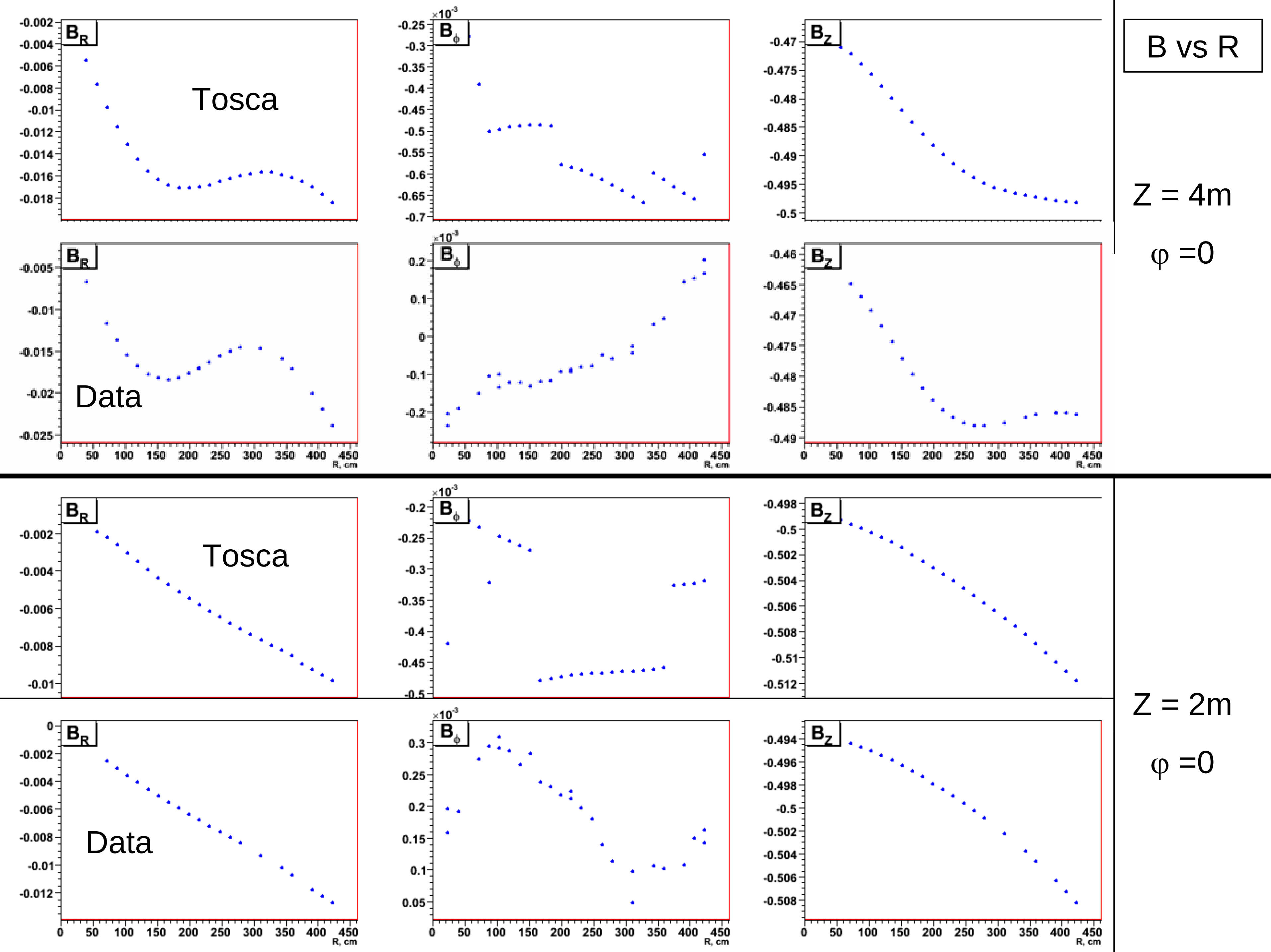


Z = 4m

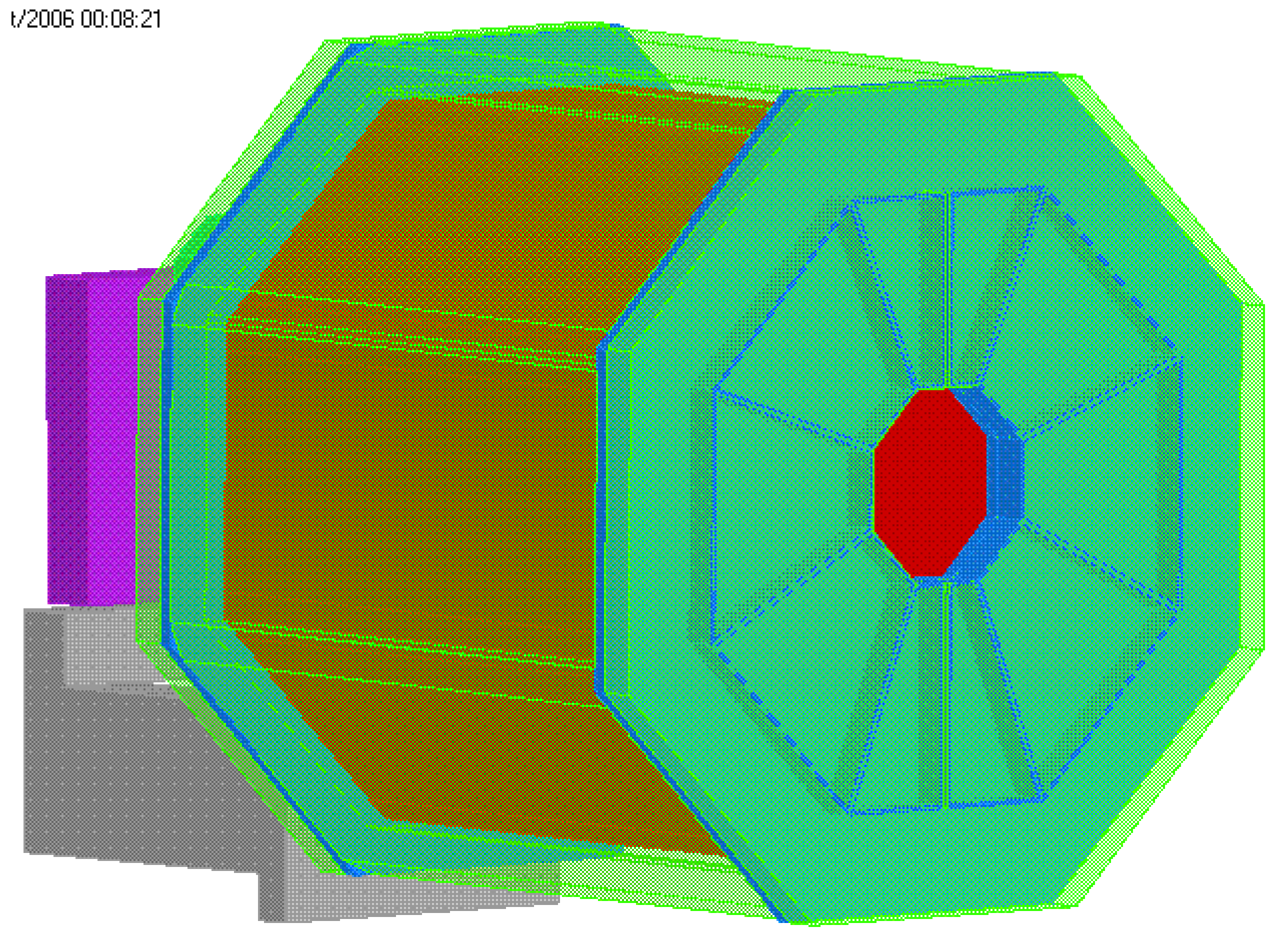
R = 2m



B vs φ
Z = 2m
R = 4.2m
Z = 2m
R = 2m
Tosca
Data
Tosca
Data
B_R
B_φ
B_Z
φ

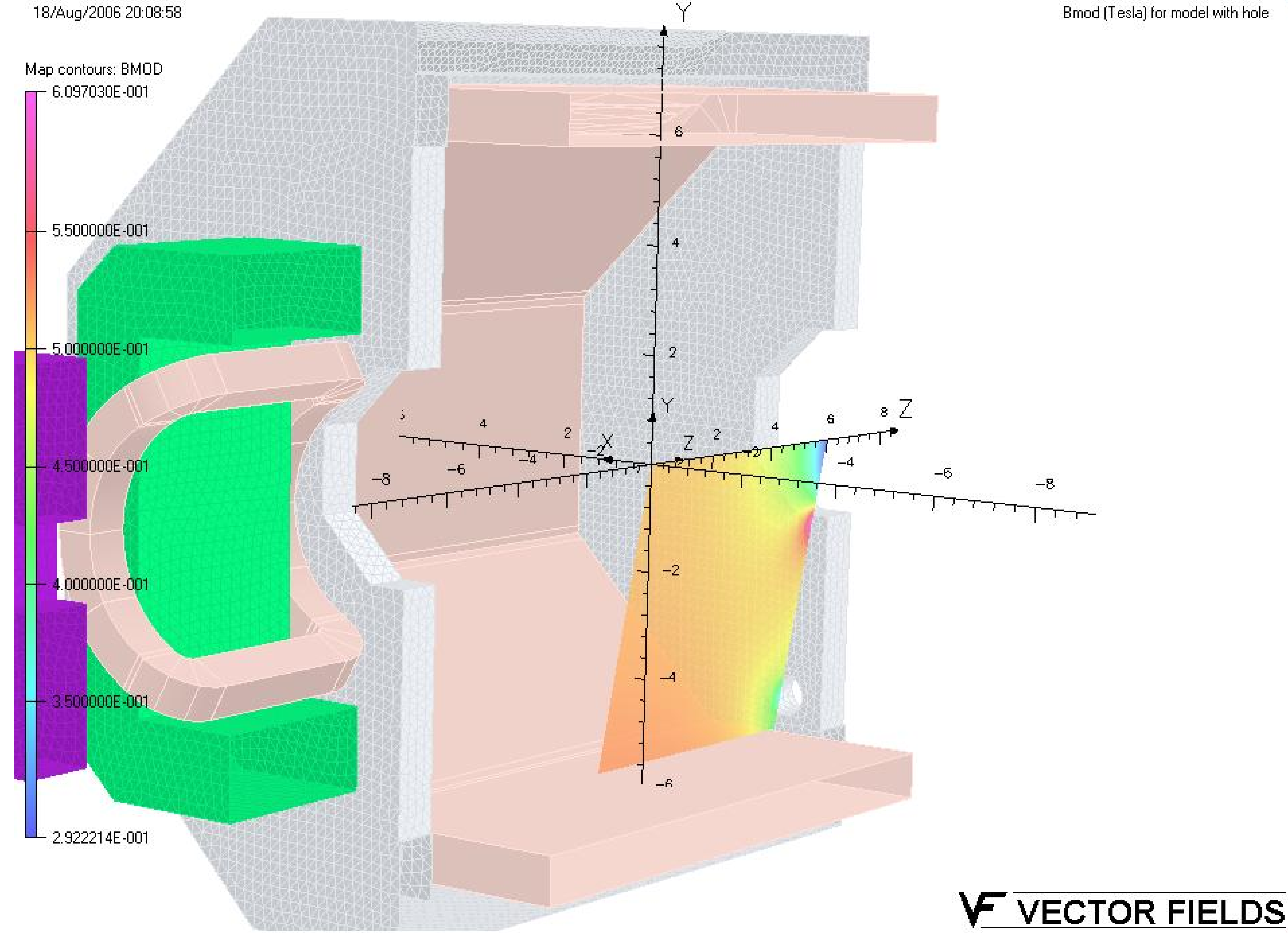


B vs R
Z = 4m
φ =0
Z = 2m
φ =0
Tosca
Data
Tosca
Data
B_R
B_φ
B_Z
×10^-3
R, cm

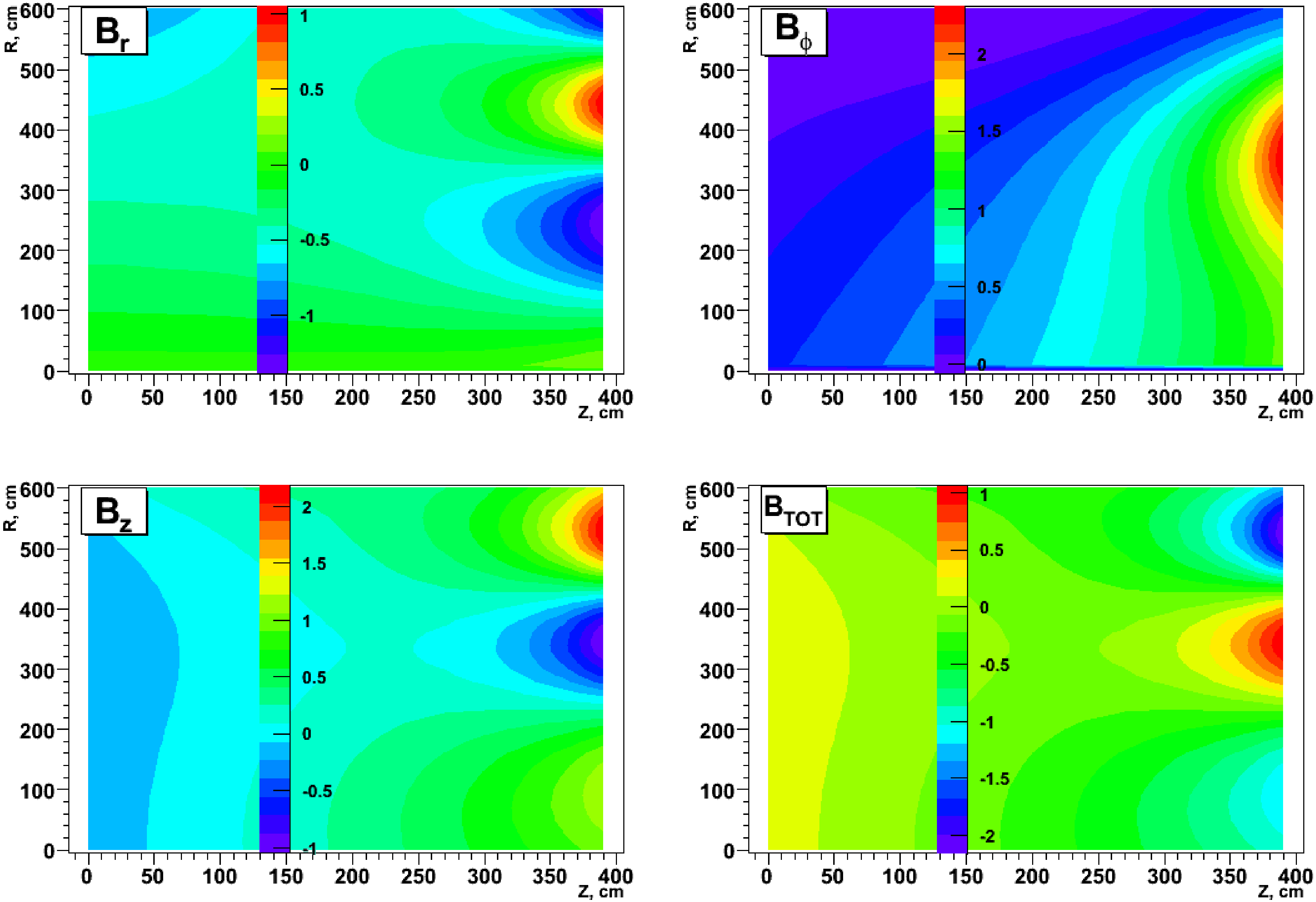


Modifications in the Alice Tosca model:

- Tilt of the dipole part
- Added the support frames of L3 doors and the air gaps between them
  (still there are some problems to solve with meshing of fine details)
- Reassigned BH curves of the dipole, frames and L3 filling iron to measured ones
- Separate calculation will be done with new access hole on L3 door


18/Aug/2006 20:08:58
Bmod (Tesla) for model with hole
Map contours: BMOD
6.097030E-001
5.500000E-001
5.000000E-001
4.500000E-001
4.000000E-001
3.500000E-001
2.922214E-001
Y
X
Z
VECTOR FIELDS

“Model_with_Hole” – “Model_with_Plug (no hole)”, Gauss fields difference in the plane passing through the hole and L3 axis



Summary

- ✓ L3 field analysis is finished in each of 4 measured regions:
  - ✓ precision ~1 Gauss.
  - ✓ fast and compact (Chebyshev) parameterization is ready.
  - ✓ missing the information about exact Z position of each region to put together different pieces.

- ✓ Tosca calculations with measured material properties and details of the setup are in progress.
  Still, the precision is not supposed to be better than 1%.

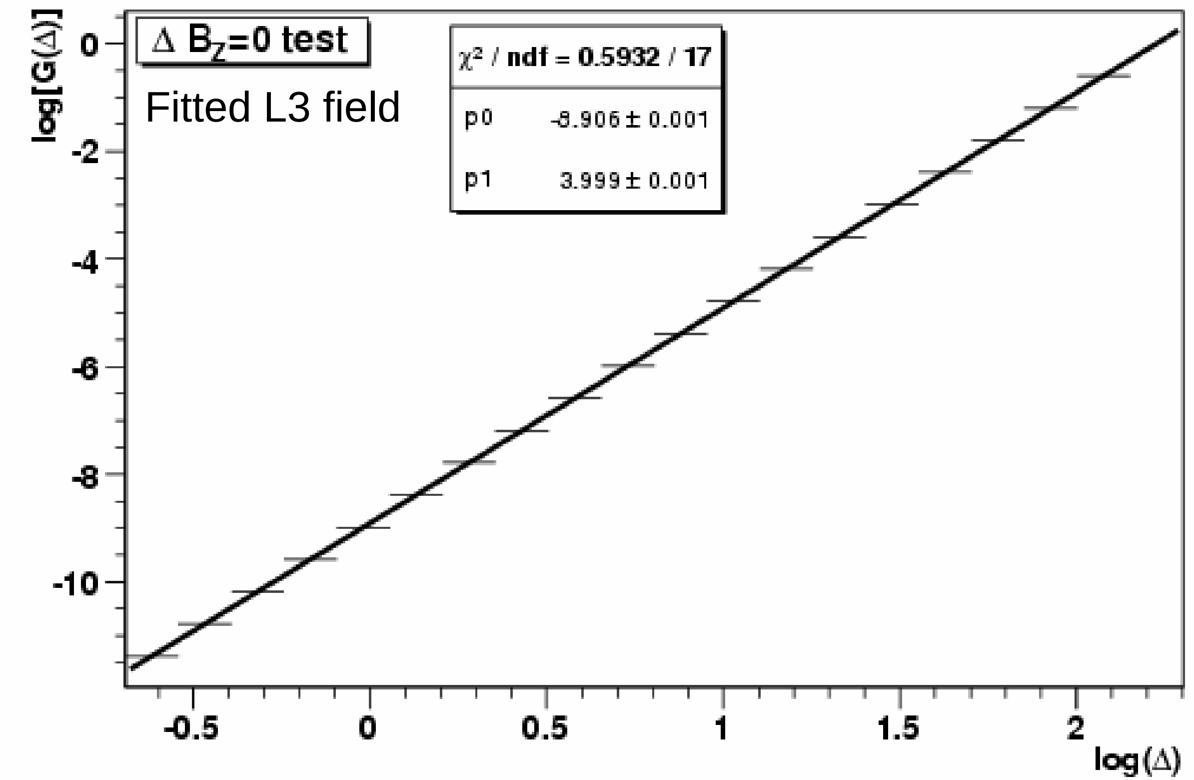
- ✓ Dipole field analysis:
  - ✓ preliminary data cleaning was done by A.Morsch.
  - ✓ recovery of lost probes is done.
  - ✓ correction of alignment and parameterization: still to be done.
  - ✓ missing the measurement geometry information for some part of data.

Test of zero Laplacian for computed field:

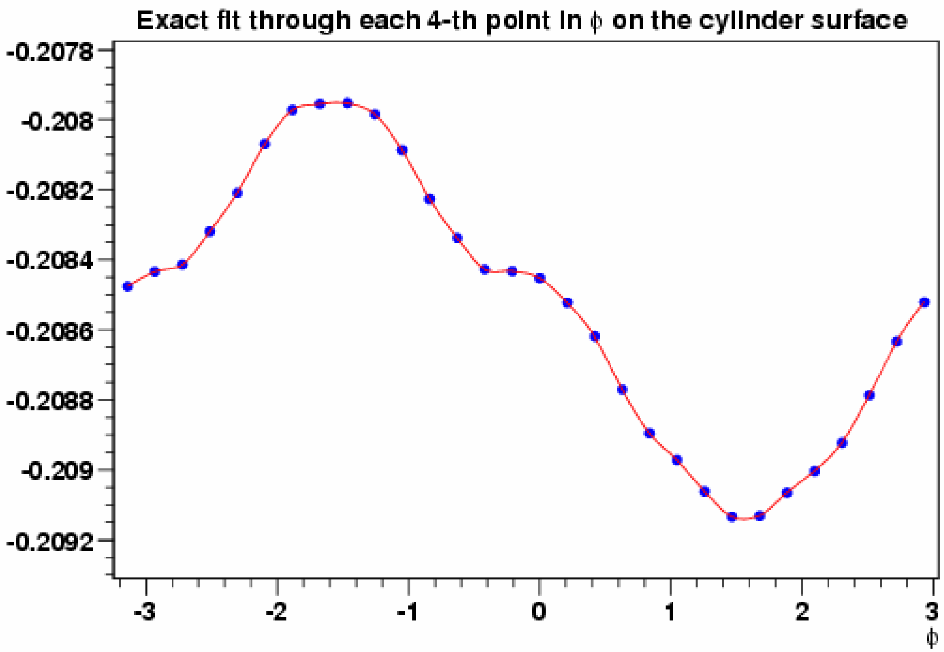
Compute for each component: $G(\delta) = B - \left[B(x+\delta) + B(x-\delta) + B(y+\delta) + B(y-\delta) + B(z+\delta) + B(z-\delta)\right]/6$

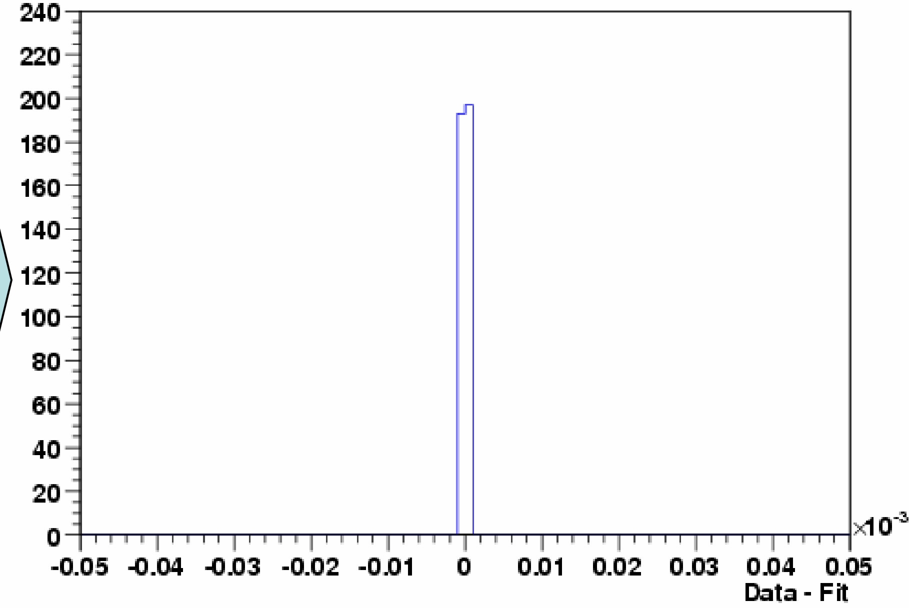
In the expansion vs. δ all odd terms disappear: $G(\delta) = \frac{\delta^2}{2!}\nabla^2 B + \frac{\delta^4}{4!}\nabla^4 B + O(\delta^6)$

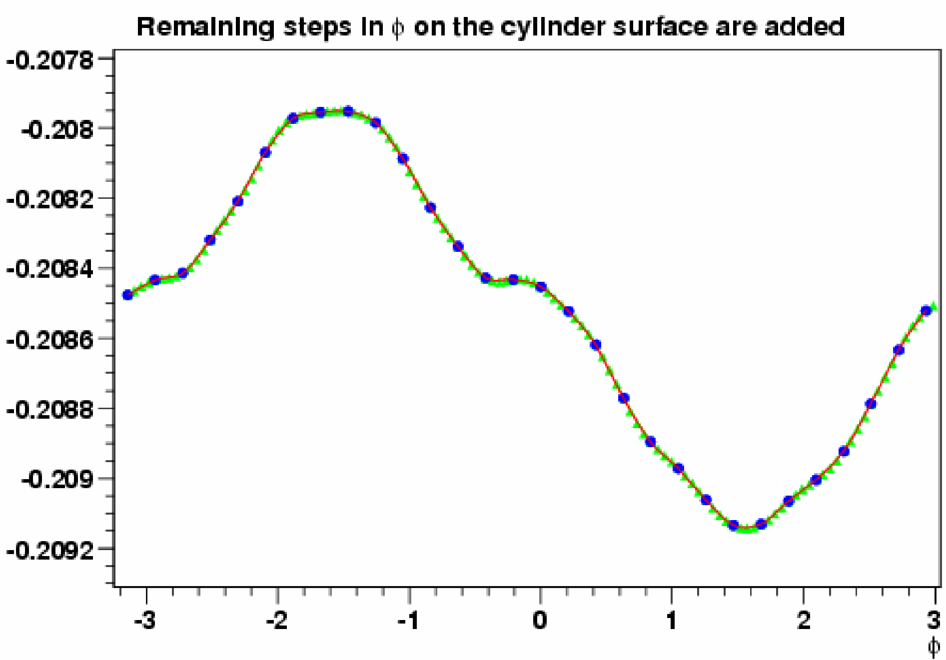
Thus, if $\Delta B = 0$, the logarithmic slope $\frac{d \ln |G(\delta)|}{d \ln \delta} \approx 4$

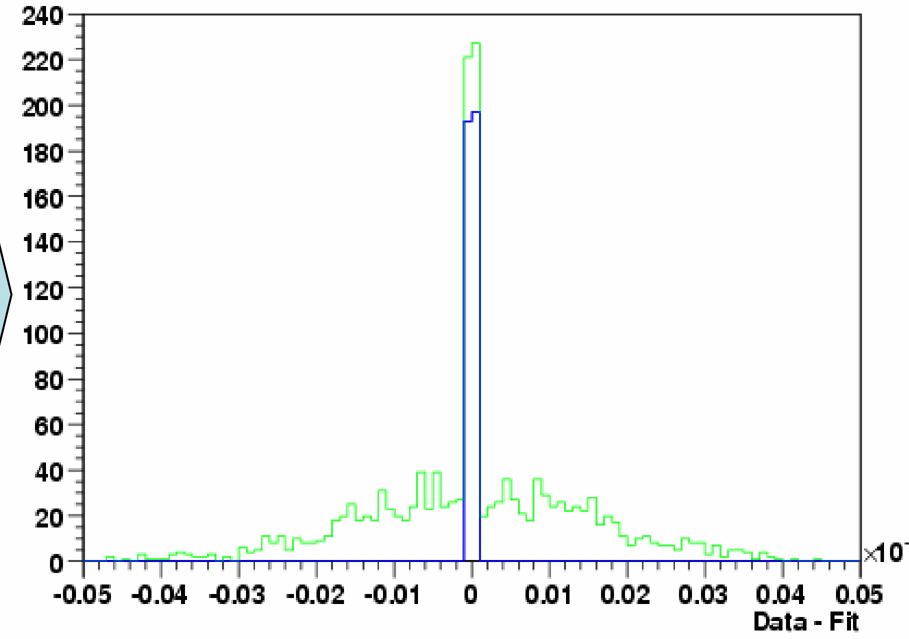


Single probe stability check

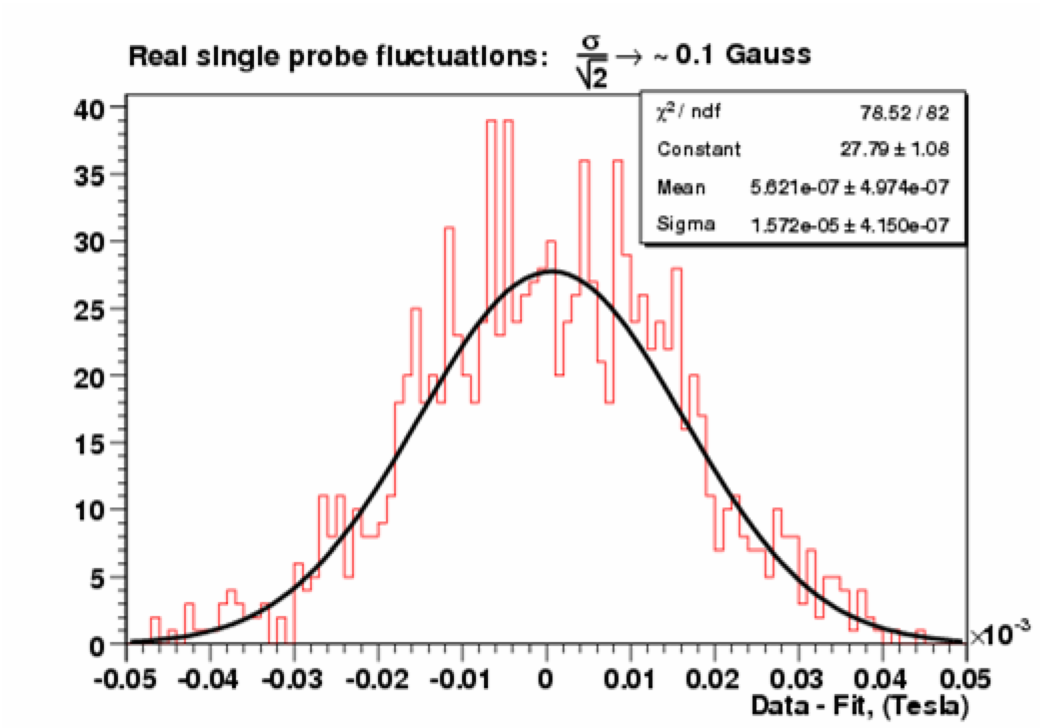




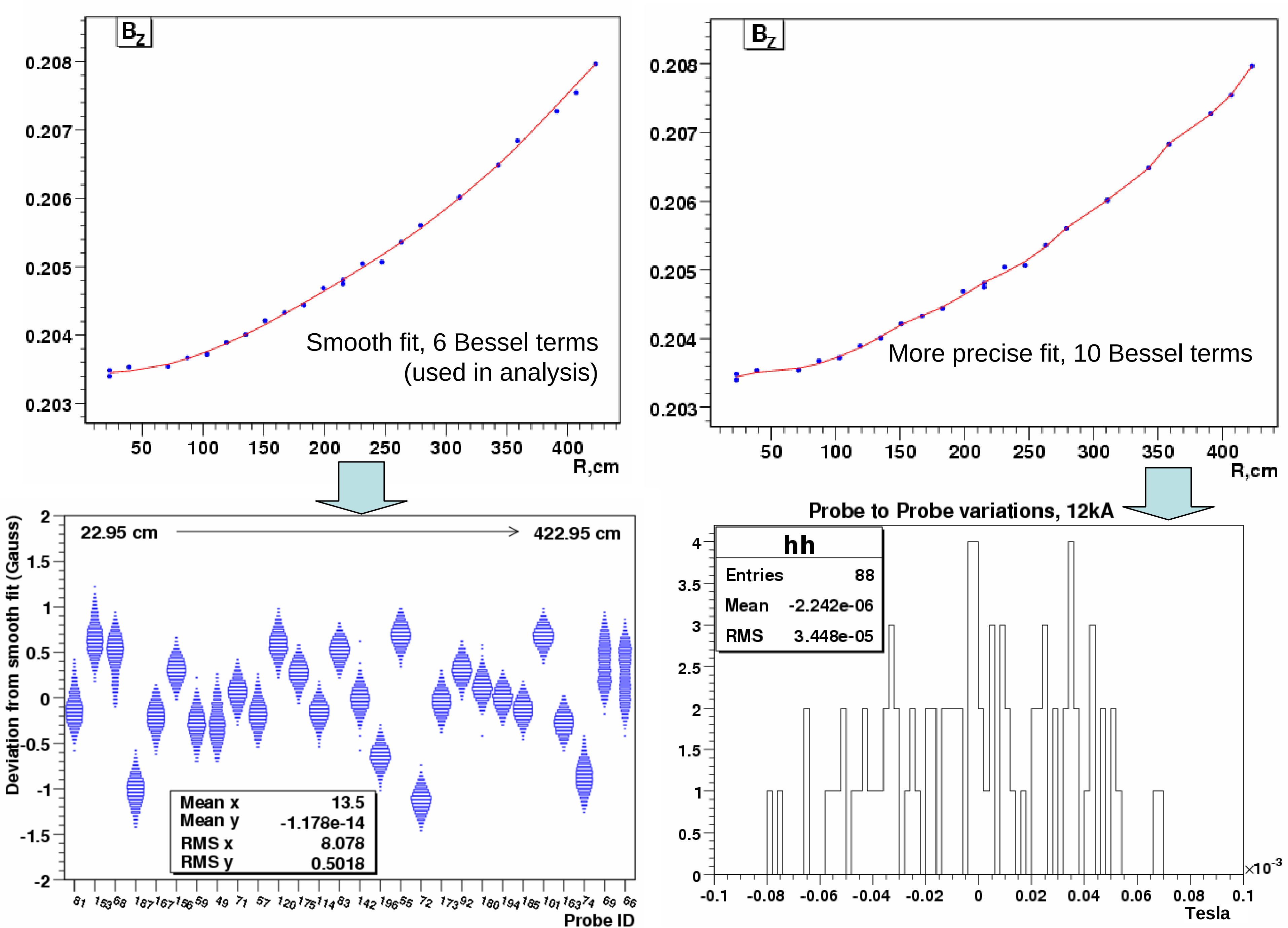




Single probe stability check

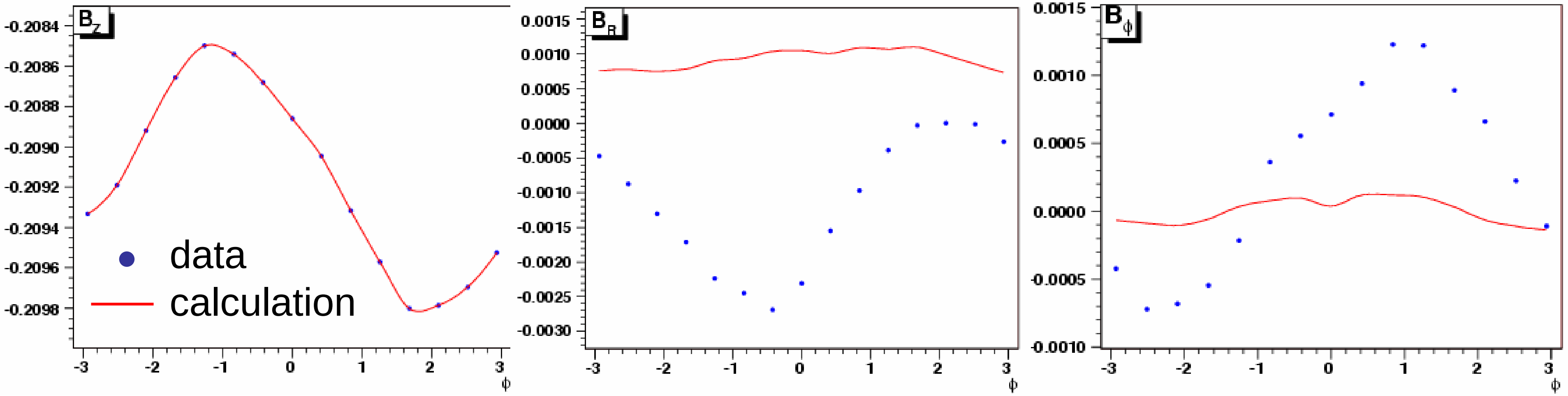


Probe to probe fluctuations

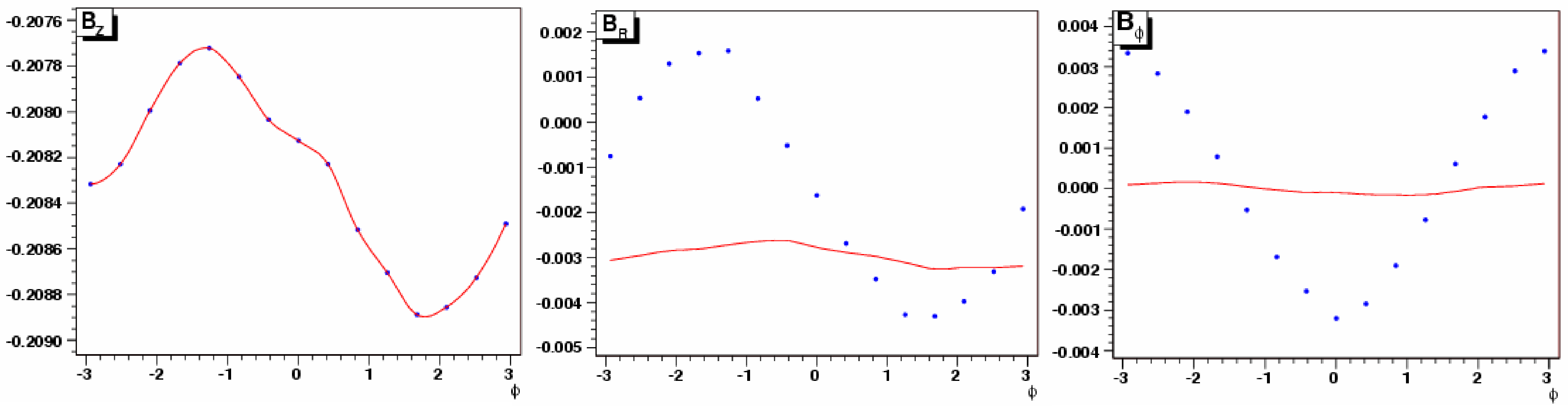


Example of fit w/o tilts correction, A=-12kA

φ-dependence, at R = 423 cm, Z ~ 0 cm (in Alice frame)



φ-dependence, at R = 423 cm, Z ~ 200cm.



Note that only B_Z is fitted to data, other components are deduced from the reconstructed potential.
The oscillations in the B_R and B_φ components are due to the measurements tilt?