# Magnetic Measurements of APPLE II Type Undulators

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- brief overview of the equipment for magnetic measurements related to insertion devices at BESSY
- experience with the UE56 double undulators
- a new set up for the characterization of block inhomogeneities
- geometrical tolerances
- shimming techniques
- first results of the UE46 APPLE device

# Insertion Devices at BESSY II

## Permanent Magnet undulators

| device | design | operational | $\lambda(mm)$ | periods |
|---|---|---|---|---|
| U49-1 | hybrid | 1998 | 49.4 | 83 |
| U49-2 | hybrid | 2000 | 49.4 | 83 |
| U125-1 | hybrid | 1998 | 125 | 31 |
| U125-2 | hybrid QPU | 2000 | 125 | 31 |
| U41 | hybrid | 1999 | 41.2 | 79 |
| UE56-1 | APPLE II | 1999 | 56 | 2*30 |
| UE56-2 | APPLE II | 1999 | 56 | 2*30 |
| UE46 | APPLE II | 2001 | 46 | 71 |
| UE52 | APPLE II | 2001 | $\approx 52$ | $\approx 80$ |
| UEnn | APPLE II | 2002 | $\gg 100$ | |

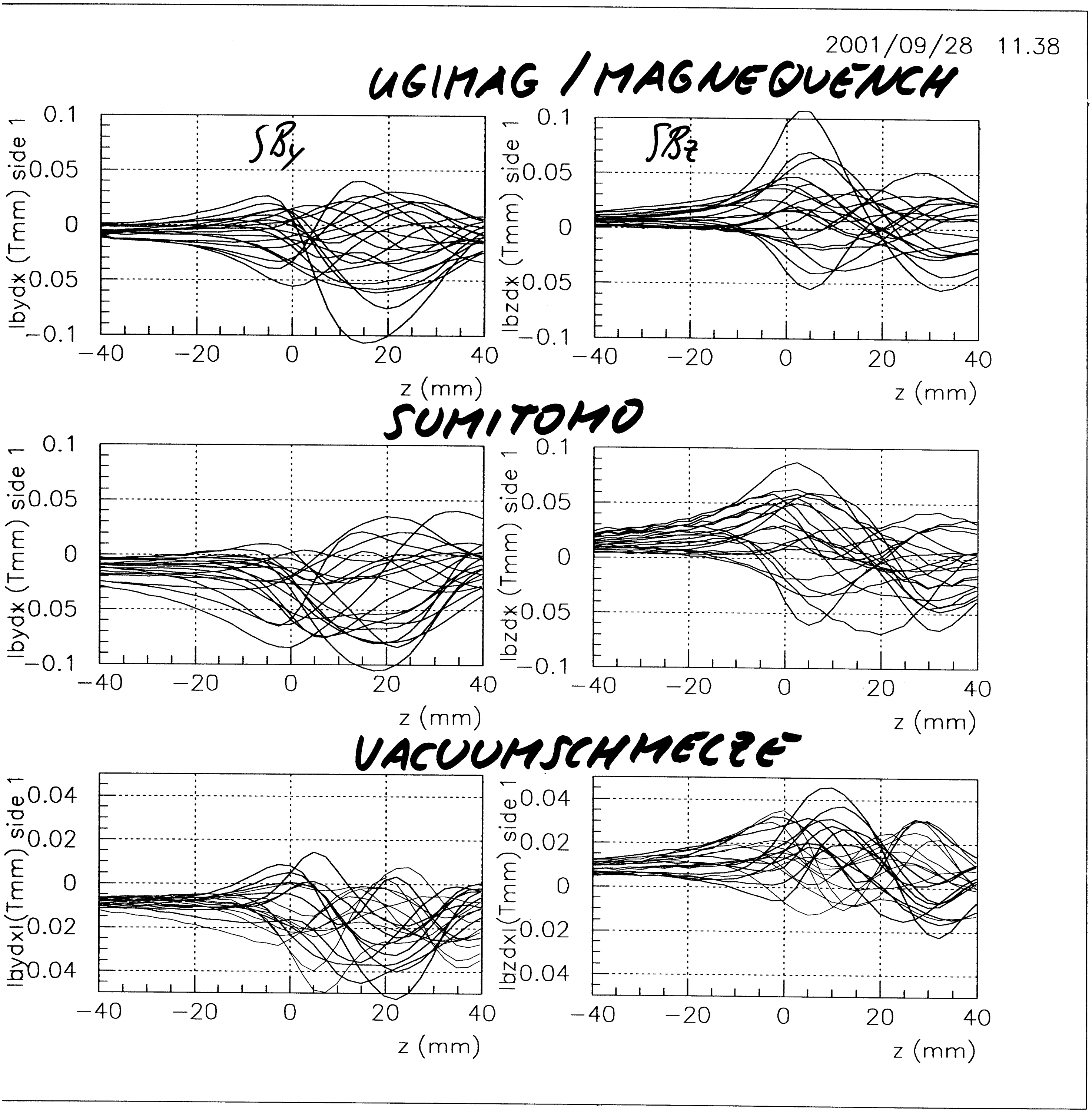
## Electromagnetic Undulator

| device | design | operational | $\lambda(mm)$ | periods |
|---|---|---|---|---|
| U180 | planar | 1998 | 180 | 23 |

## Superconducting WLS and MPW

| design | field | operational |
|---|---|---|
| WLS | 4(6) T | 1999(2000) |
| WLS | 7 T | 2000 |
| WLS | 7 T | 2002 |
| MPW | 7 T | 2002 |

# Magnet Blocks from 3 Suppliers



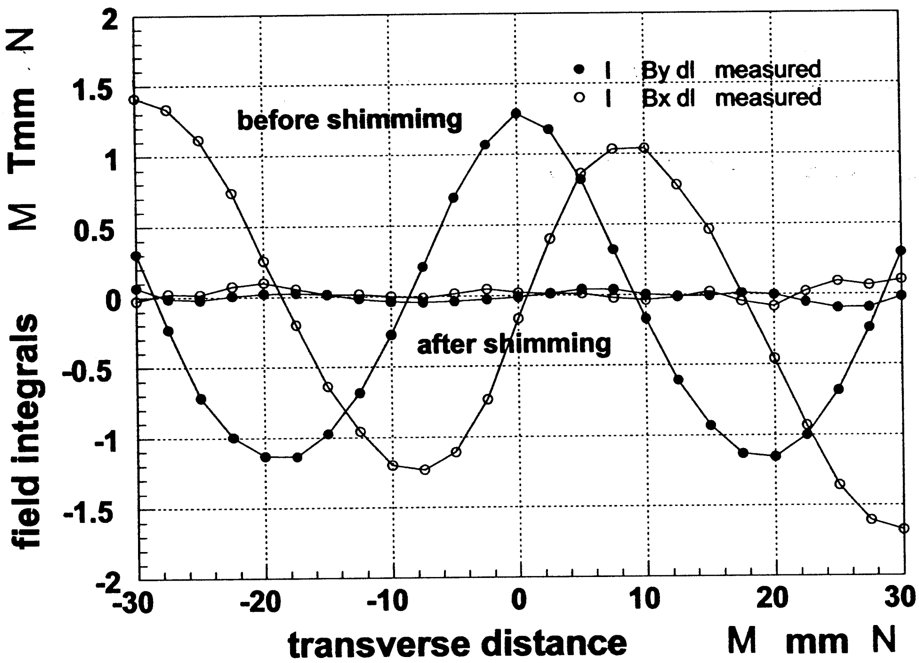

Signal = Σ (Dipole and Inhomogeneities)

Conclusion: i) Inhomogeneities of all suppliers are comparable

ii) Inhomogeneities can not be neglected

# Consequences of Systematic Inhomogeneities

## UE56 double undulators at BESSY



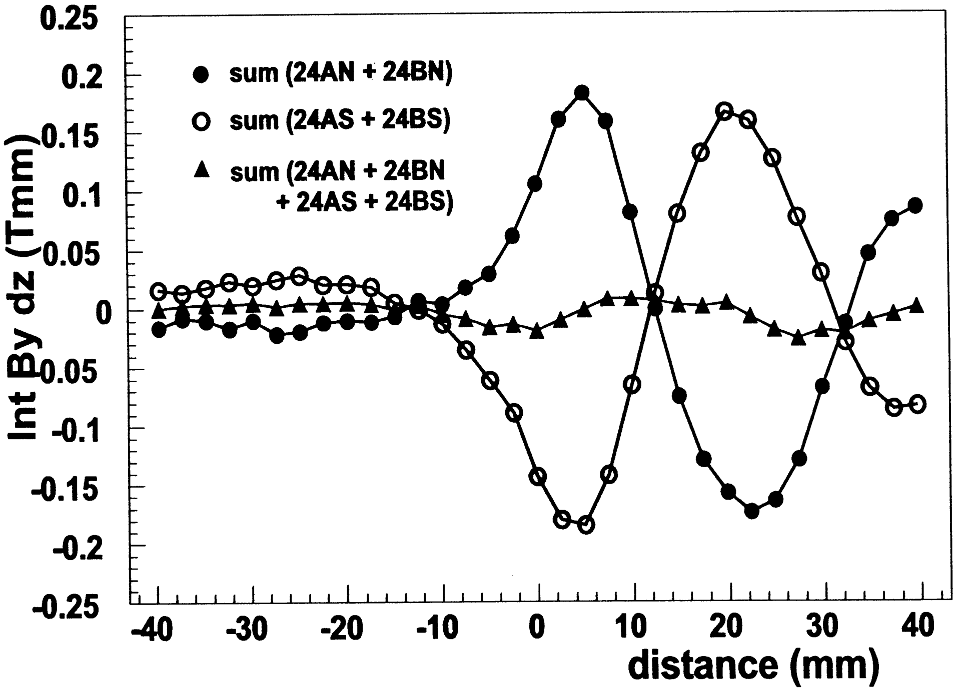

## Strategy to solve the problem:

**magnetize some magnets parallel and some antiparallel with respect to pressing direction**

## Concept has been successfully applied to

**BESSY UE52**

**PSI UE56 (in collaboration with BESSY)**



# Field Optimization Strategy for BESSY Undulators

## ➢ Block characterization and sorting

dipole data from Helmholtz coil (not sufficient for APPLE devices)
inhomogeneity data from mini stretched wire

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simulated annealing code ← COST function:
- field integrals at 11 transverse location
- phase errors

⇓

magnet glueing and assembling ← tight geometrical tolerances

⇓

## ➢ Shimming

**planar devices:**

metal sheets on poles for trajectory shimming
phase errors 2-3° without phase shimming

**helical devices (APPLE type):**

UE56 double undulators:

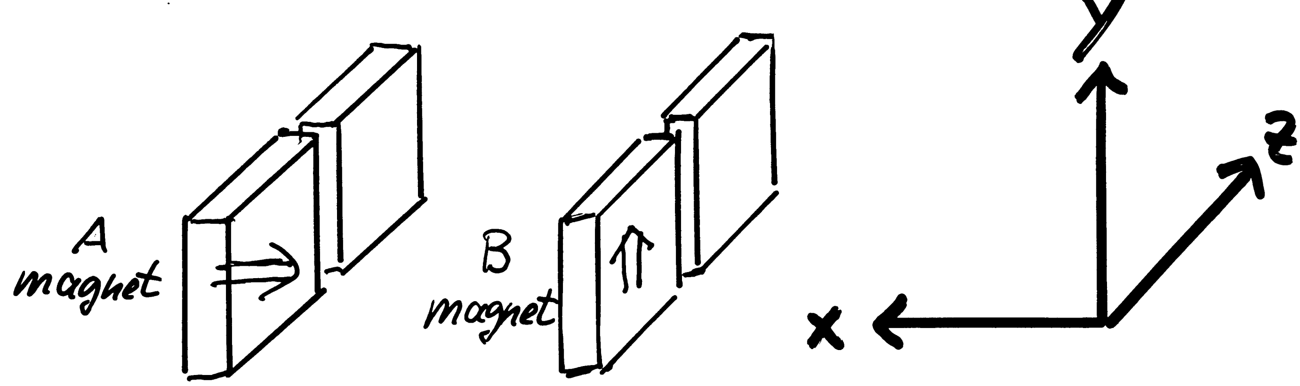
permanent magnet shims (0.5x7x14)
to compensate for large systematic inhomogeneites

UE46, UE52, UE56-PSI:

virtual shimming for trajectory and phase optimization
use of lamellated spacers for hor. and vert. adjustment (25μm)

magic fingers at ID-ends for multipole shimming
4mm grid for shim magnets

# Geometrical Tolerances

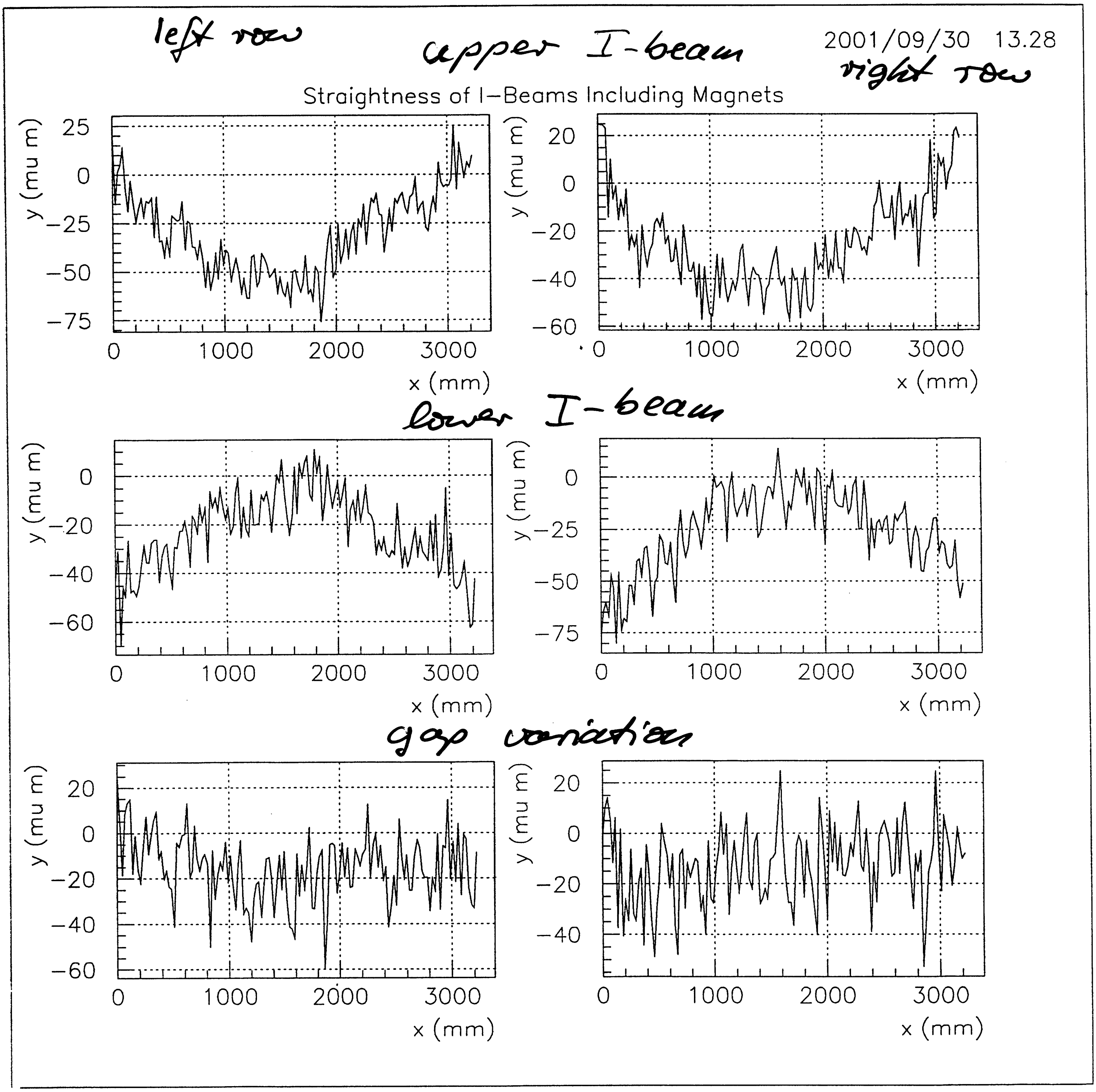



| magnet type | operation | max. field integral variation (RADIA) | rms-error achieved (UE46) 4) | field error scaled to 70 periods 3) |
|---|---|---|---|---|
| | ↻ x | 0 | 0.073° | 0 |
| | ↻ y | 0.012 Tmm / 0.2° | 0.073° | 0.10 Tmm |
| A-magnet | ↻ z | 0.015 Tmm / 0.2° | 0.073° | 0.13 Tmm |
| | → z | 0 | 30 µm 1) | 0 |
| | → y | 0 | 20 µm 2) | 0 |
| | ↻ x | 0.015 Tmm / 0.02° | 0.073° | 0.13 Tmm |
| | ↻ y | ≈ 0 | 0.073° | 0 |
| B-magnet | ↻ z | ≈ 0 | 0.073° | 0 |
| | → z | 0.022 Tmm / 0.1 mm | 30 µm 1) | 0.16 Tmm |
| | → y | 0.022 Tmm / 0.1 mm | 20 µm 2) | 0.10 Tmm |

1) slit error
2) gap error
3) field error of single block scaled with $\sqrt{560}$
4) including magnet block tolerances : □ 30 µm
⊥ 50 µm
∥ 50 µm

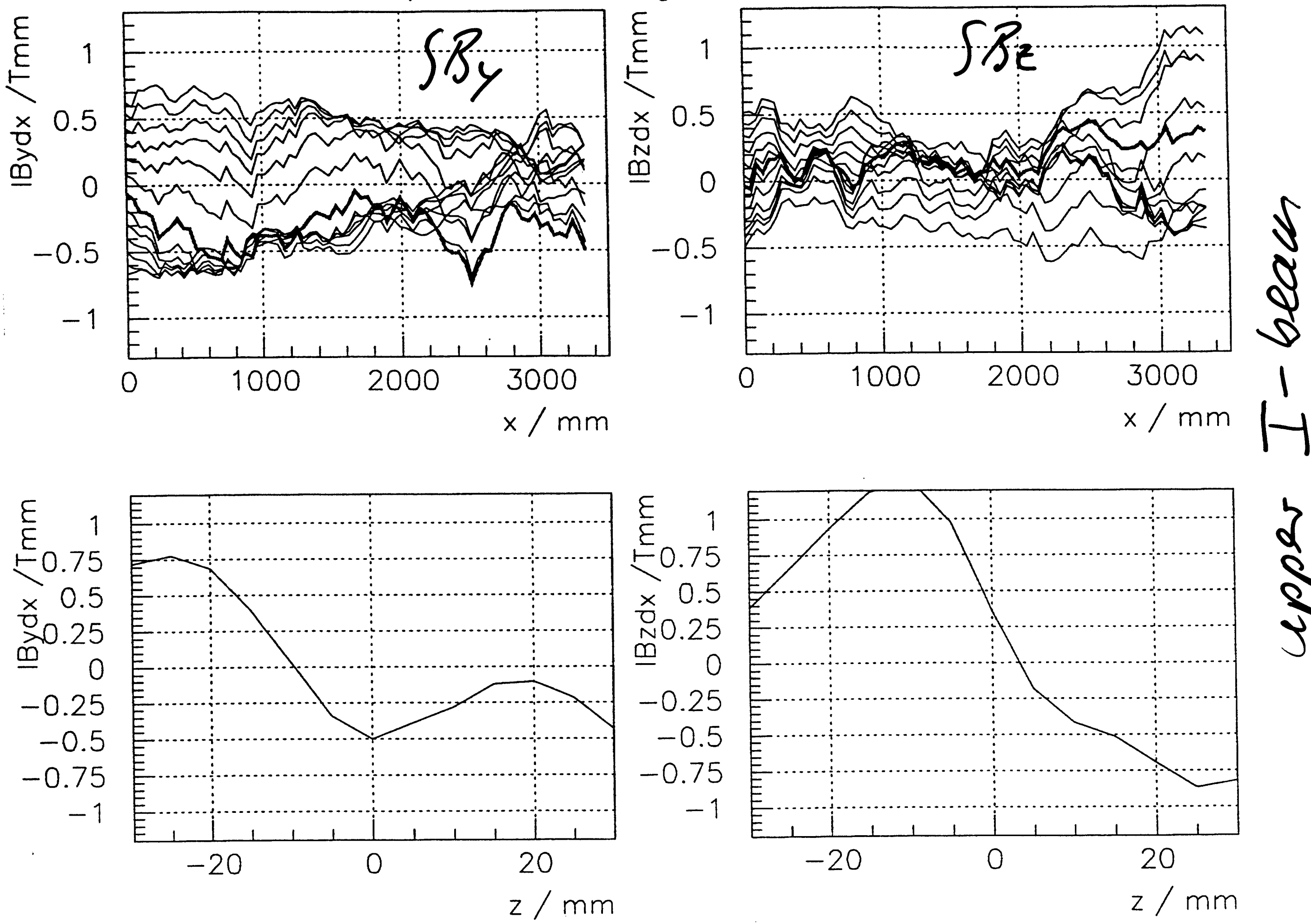
- field integral errors based on geometrical tolerances are expected to be not larger than 0.25 Tmm

# Straightness of Magnetic Structure

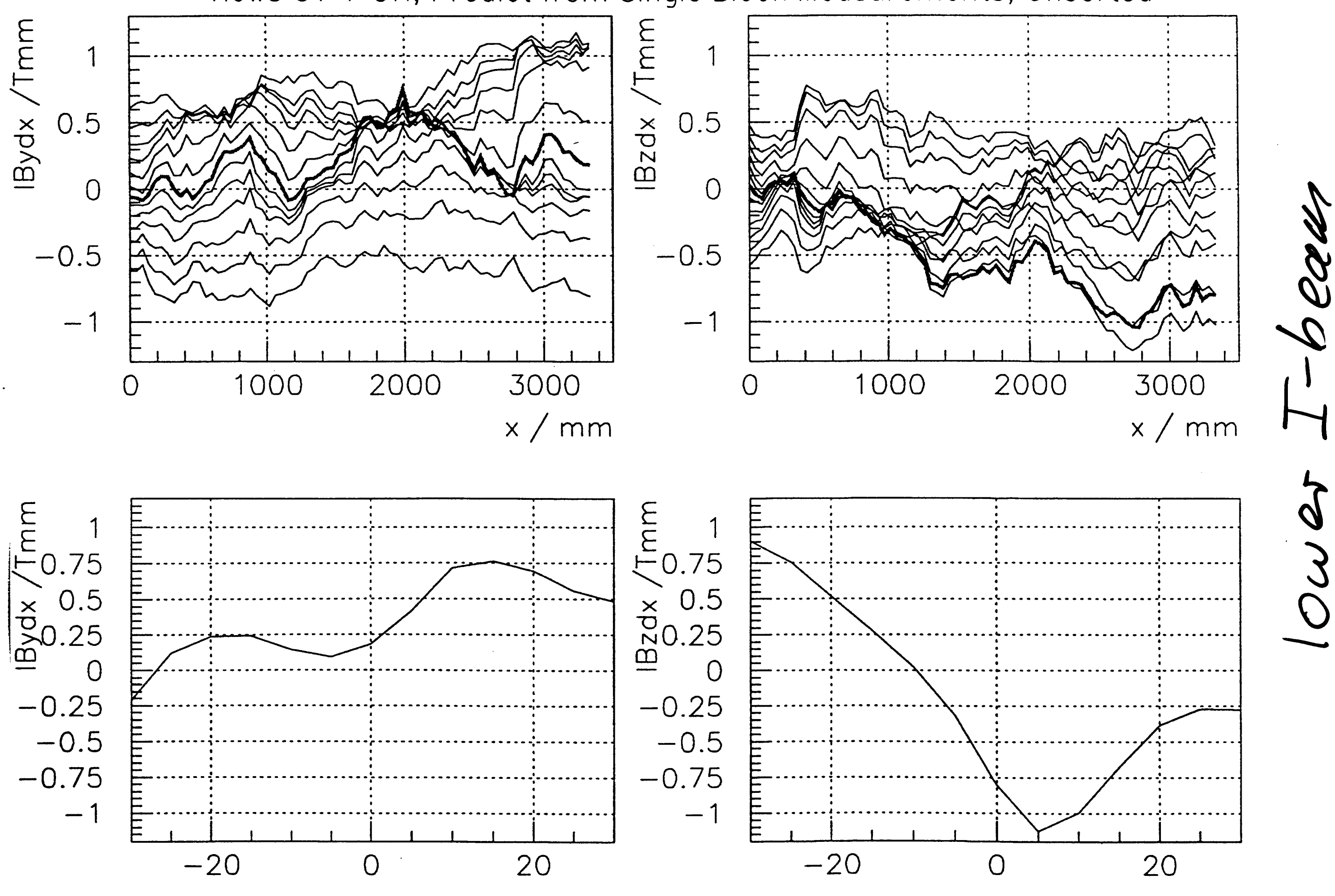


# 1st Field Integrals, Unsorted

Rows OV + UH, Predict from Single Block Measurements, Unsorted

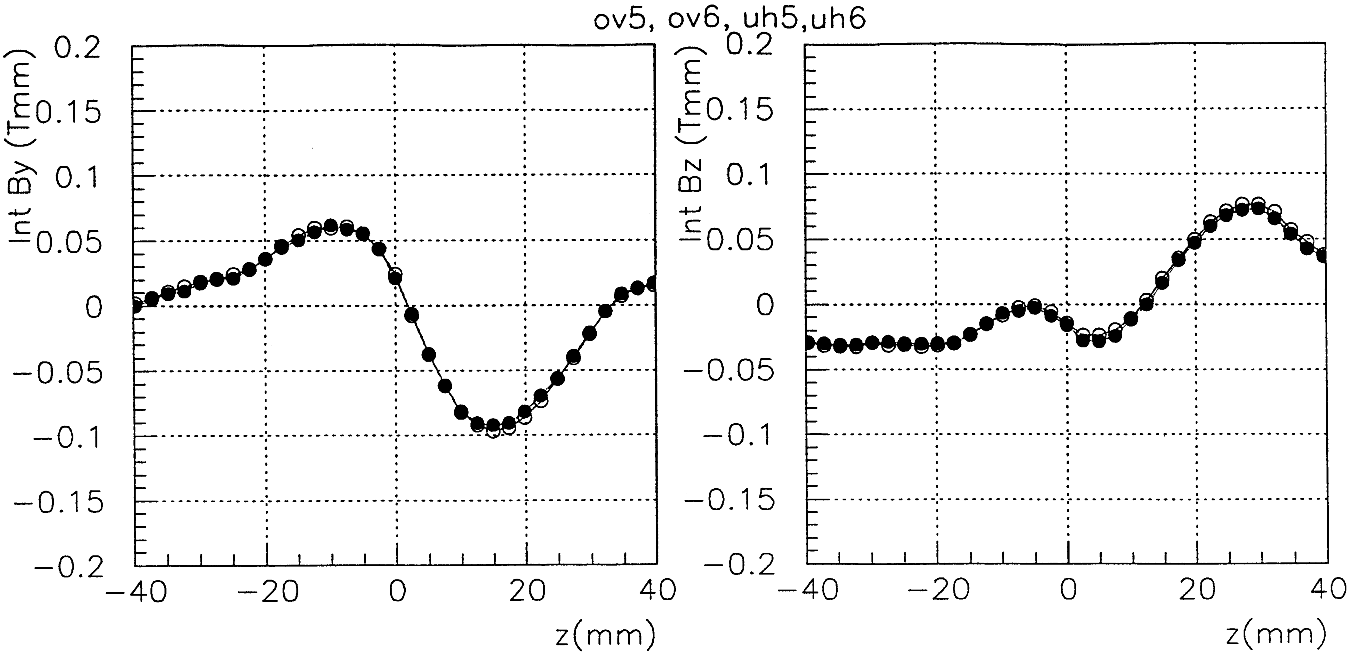


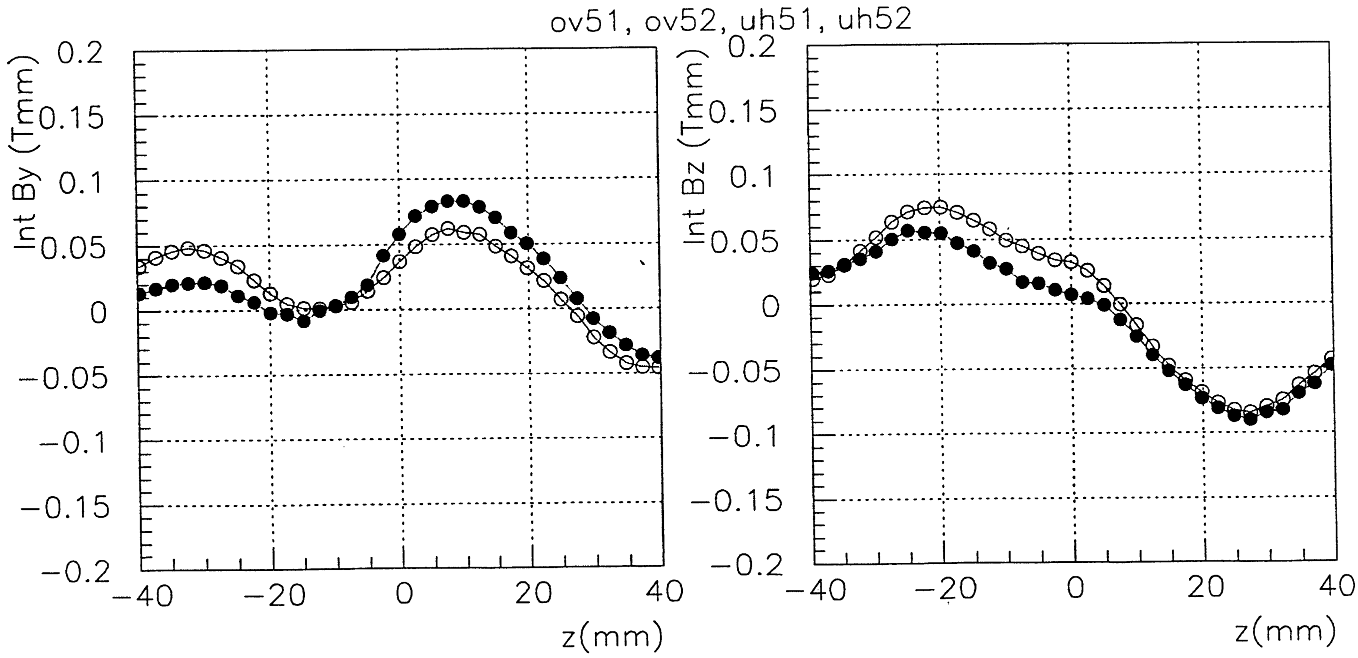

Rows UV + OH, Predict from Single Block Measurements, Unsorted



# Comparison of Single Block and Magnet Pair Measurements

black circles: sum of field integrals of 8 single magnet blocks
open circles: sum of field integrals of 4 magnet pairs (glued units)

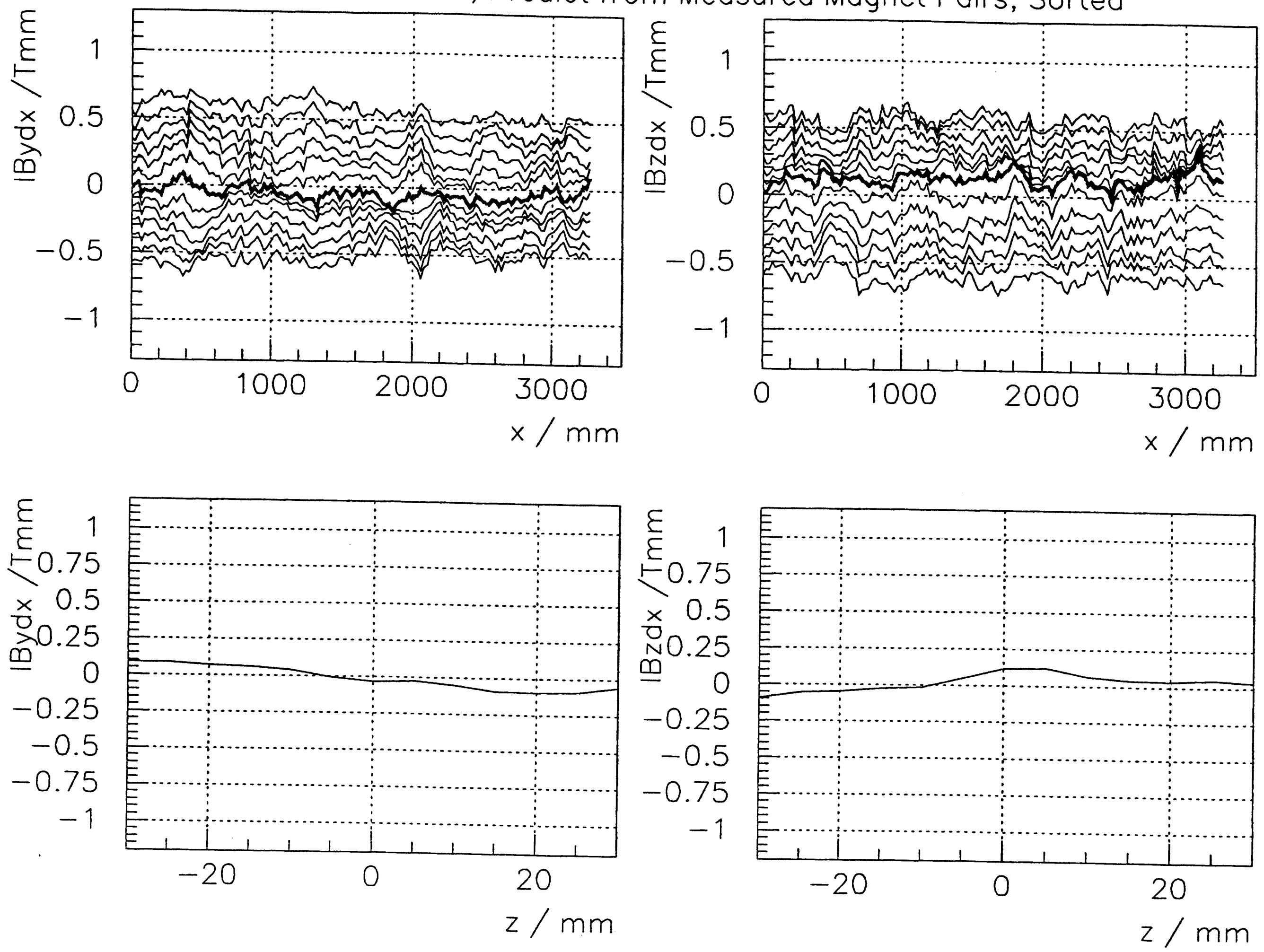


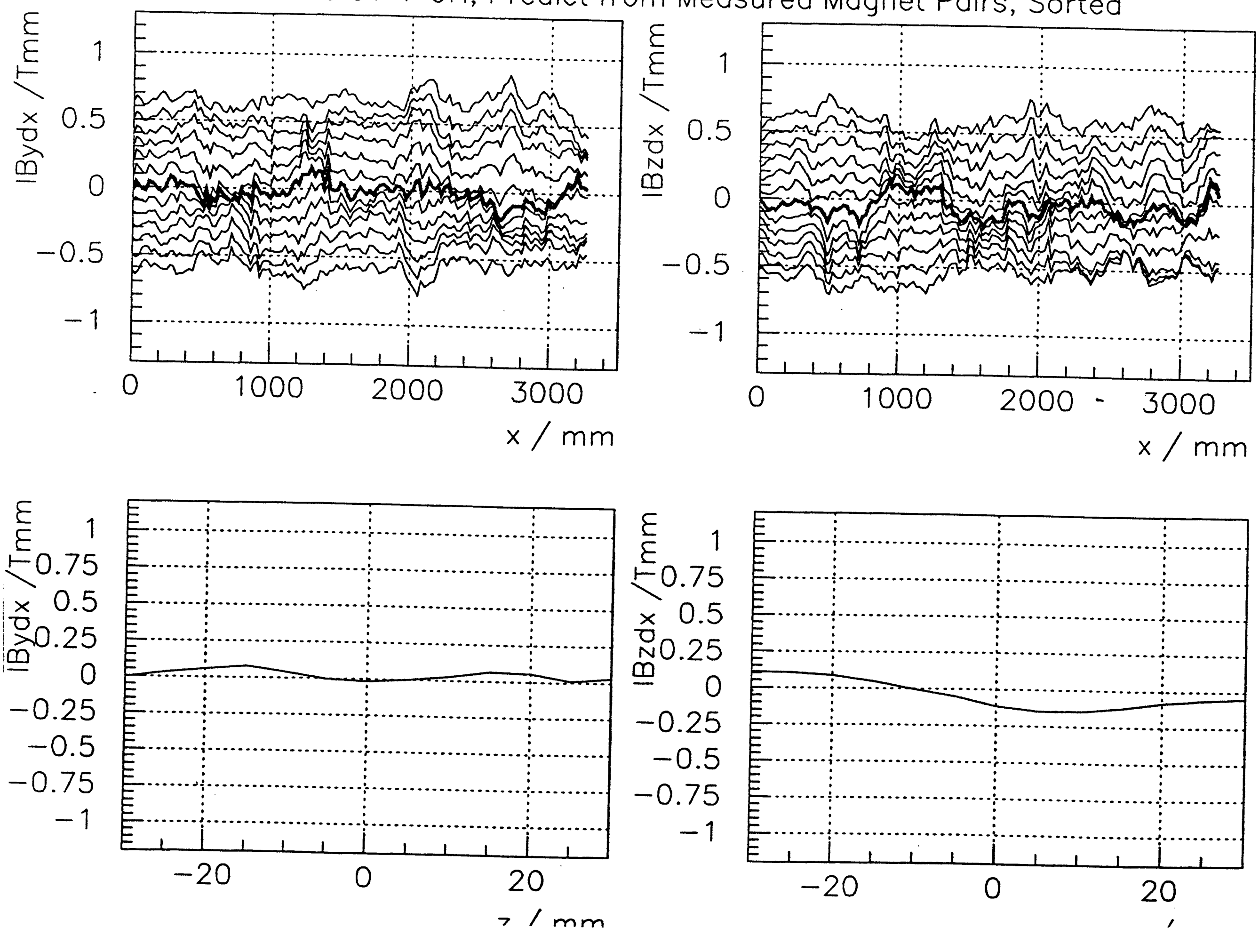

The comparison is a test for:

- bookkeeping of magnet blocks
- measurement accuracy (positioning accuracy)
- glueing errors, glueing tolerances
- sorting algorithm

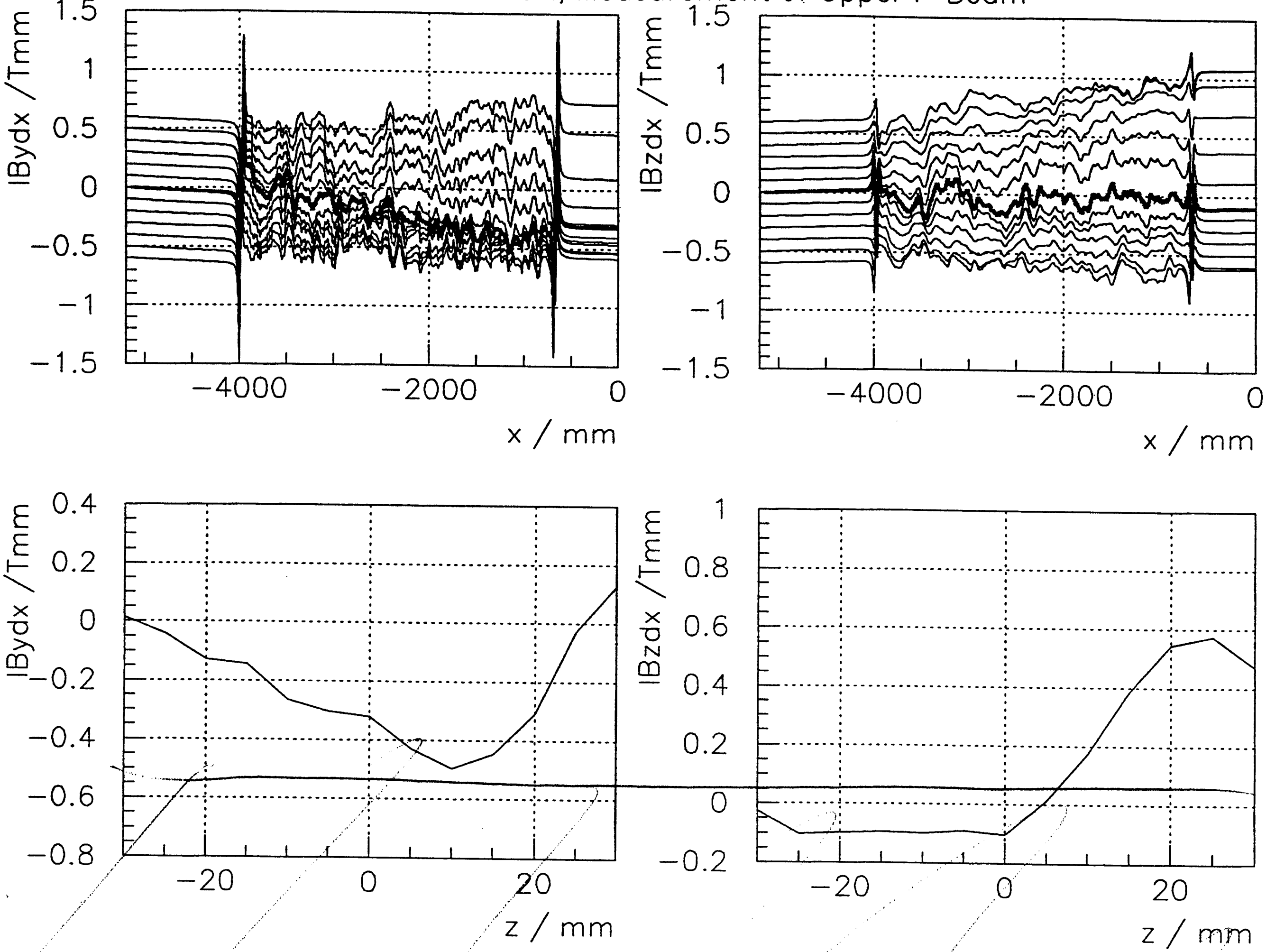
Rows OV + UH, Predict from Measured Magnet Pairs, Sorted



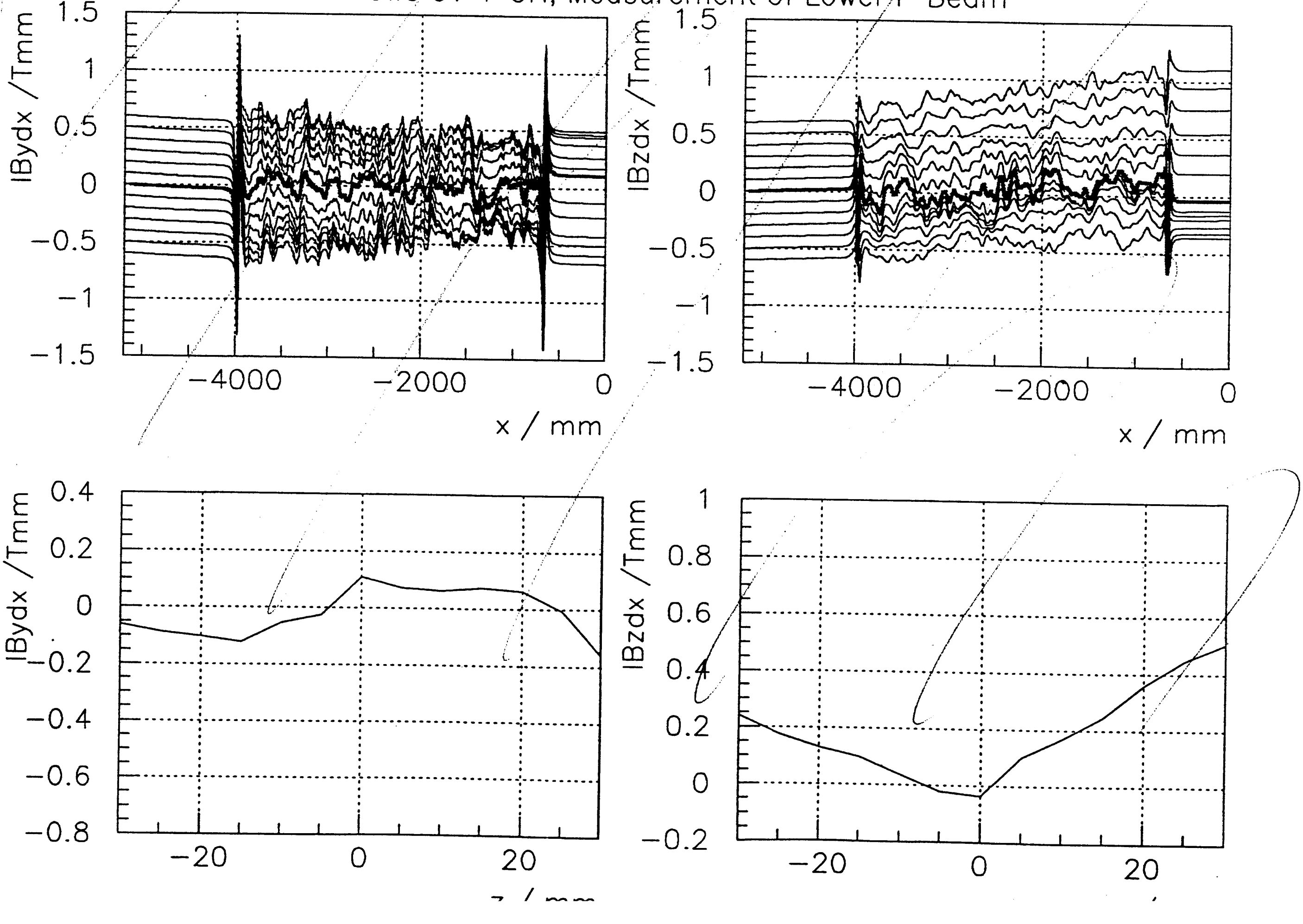

Rows UV + OH, Predict from Measured Magnet Pairs, Sorted



Rows OV + OH, Measurement of Upper I-Beam



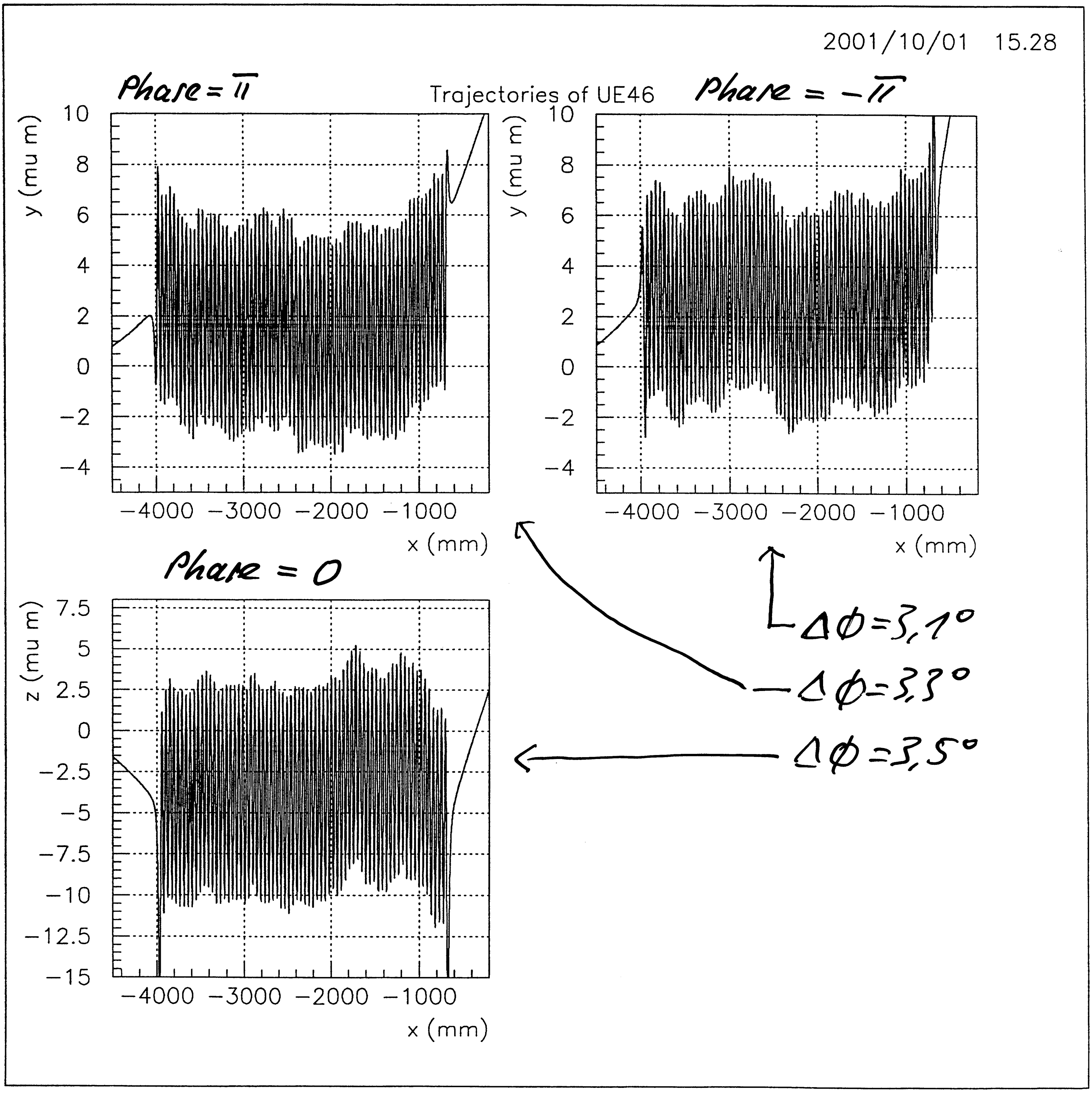

Rows UV + UH, Measurement of Lower I-Beam



UE46 APPLE Undulator (preliminary results, ends not yet compensated)

$\lambda = 46$ mm, 70 periods

Gap = 16 mm



## Future Developments
**(essential for large scale undulator production)**

Improvement of magnet block quality is desirable

In the meantime:

- complete characterization of the magnets including inhomogeneities
  - improvement of positioning accuracy for measurements
  - reduction of measurement time per unit
  - measurement of subassemblies instead of single blocks
- development of technologies for magnet assembly which are fast and precise to allow for a good prediction of field quality
- reduction of time for final shimming at granite bench by careful block characterization, sorting and precise assembly of magnetic structure