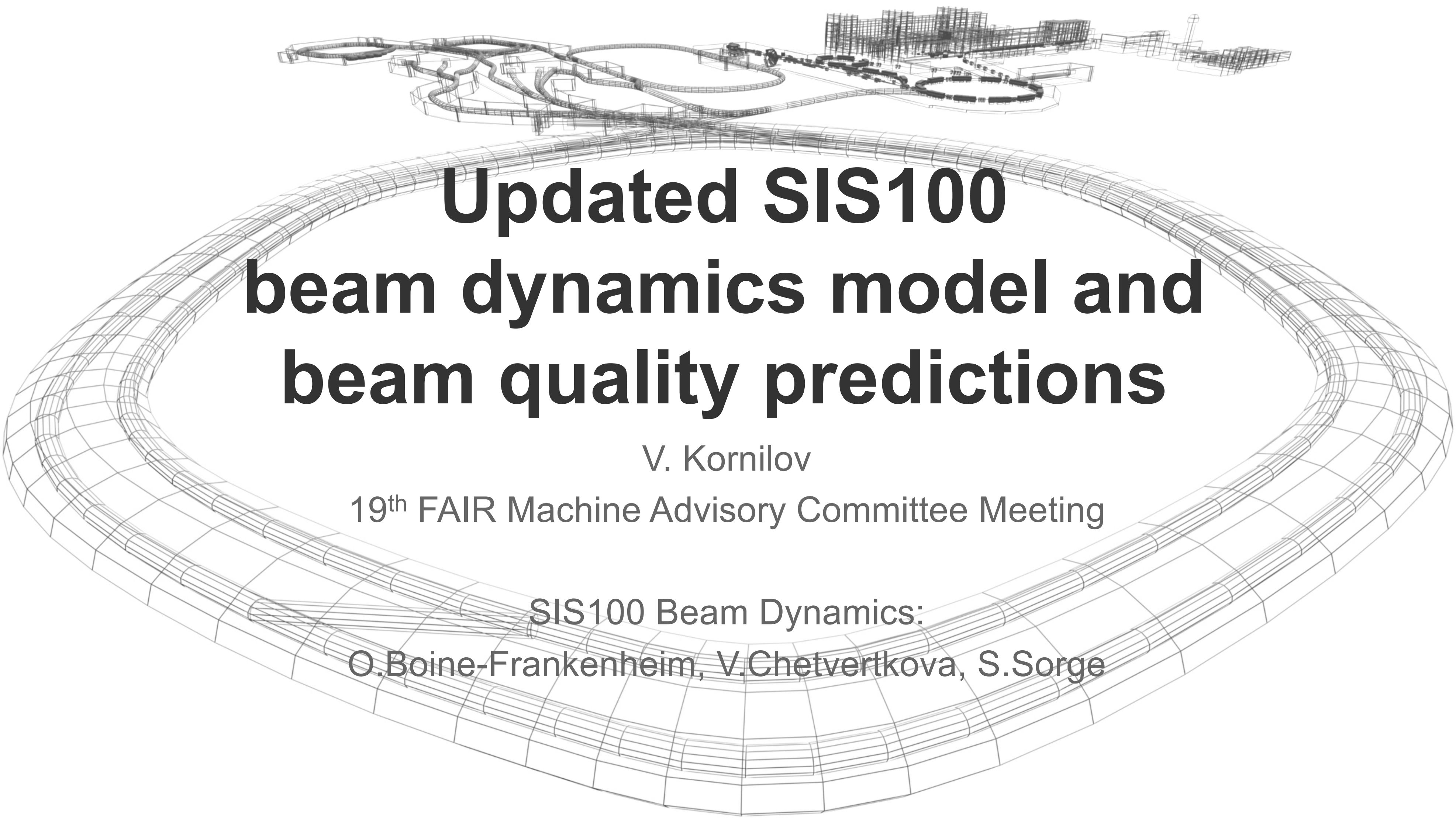

Updated SIS100 beam dynamics model and beam quality predictions

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19th FAIR Machine Advisory Committee Meeting

SIS100 Beam Dynamics:
O.Boine-Frankenheim, V.Chetvertkova, S.Sorge

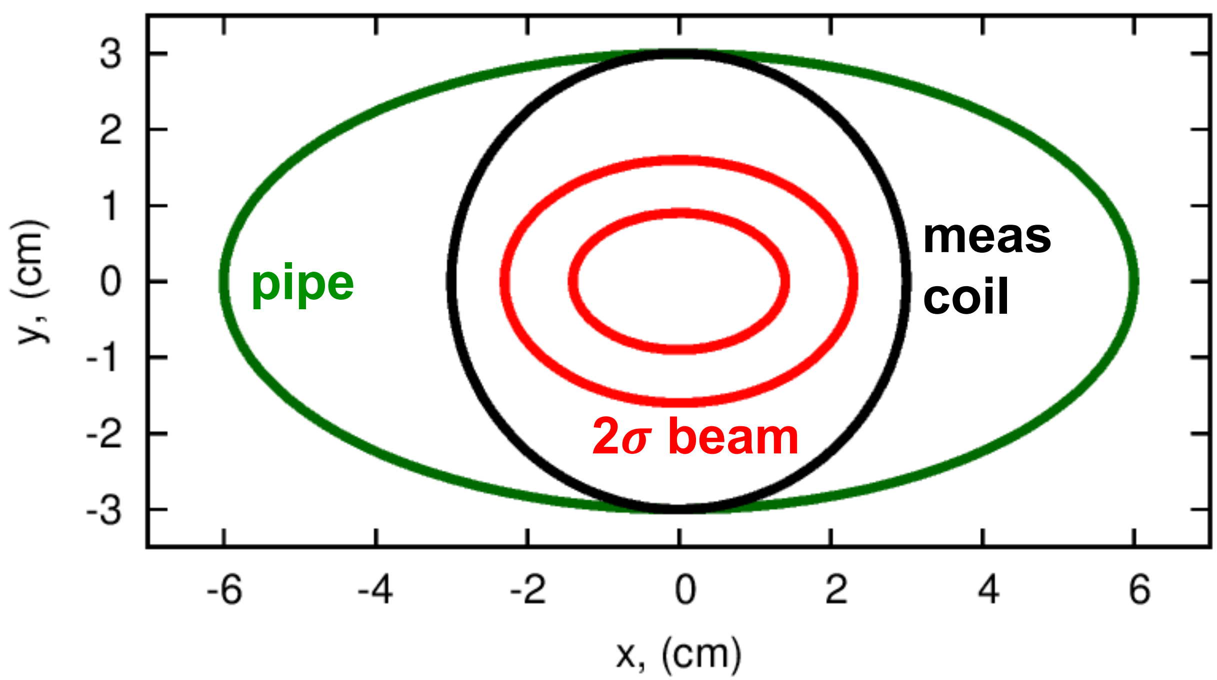
SIS100 BEAM DYNAMICS: STATUS

- Dynamic aperture studies (MAC2009) with the computational model for magnets: generally safe.
- First Beam Loss simulations (space-charge + comp model magnets, MAC2010): losses (up to one-third) during the cycle.
- Magnet field data from the First of Series (FoS) dipole magnet (MAC2014): large field errors, insufficient particle stability.
- Substantial improvements of the magnet design (FoS2), and of the measurement system. First series dipole magnet measurements. This MAC.

SIS100 Dipole Magnets

Series dipole magnet measurements:

- A large coil R=30 mm (FoS: 17 mm)
- Coil on the axis (FoS: straight shaft → Δx)
- In this talk: the seven series magnets



SIS100 Dipole Magnets

An example for the field measurements for one of the series magnets (data by F. Kaether, et al)

Multipole coefficients of the field errors

$$B_y + iB_x = (B_n + iA_n)\left(\frac{x + iy}{r_0}\right)^{n-1}$$

B_n normal ; A_n skew

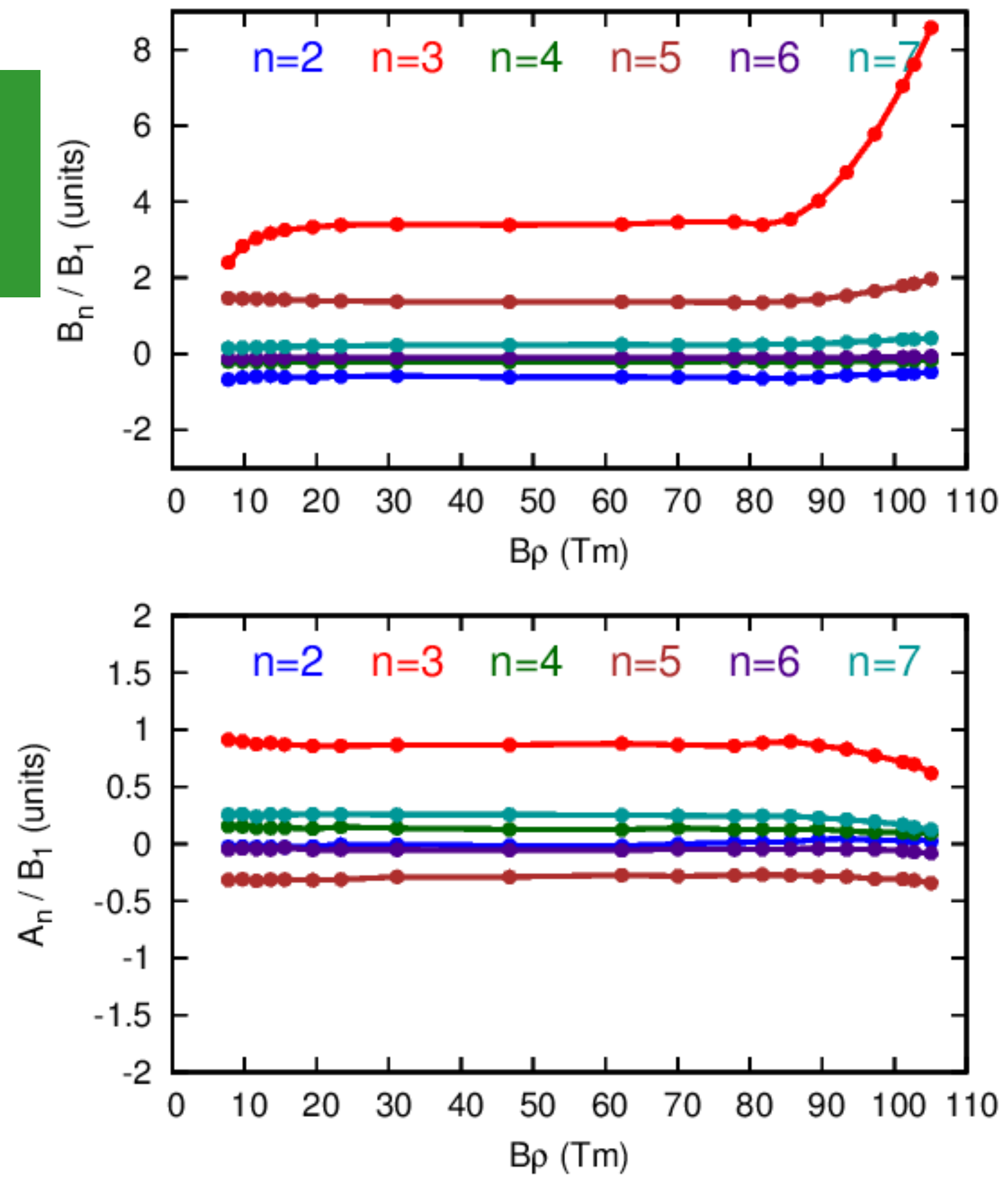
B_1 , A_1 dipole

B_2 , A_2 quadrupole

B_3 , A_3 sextupole

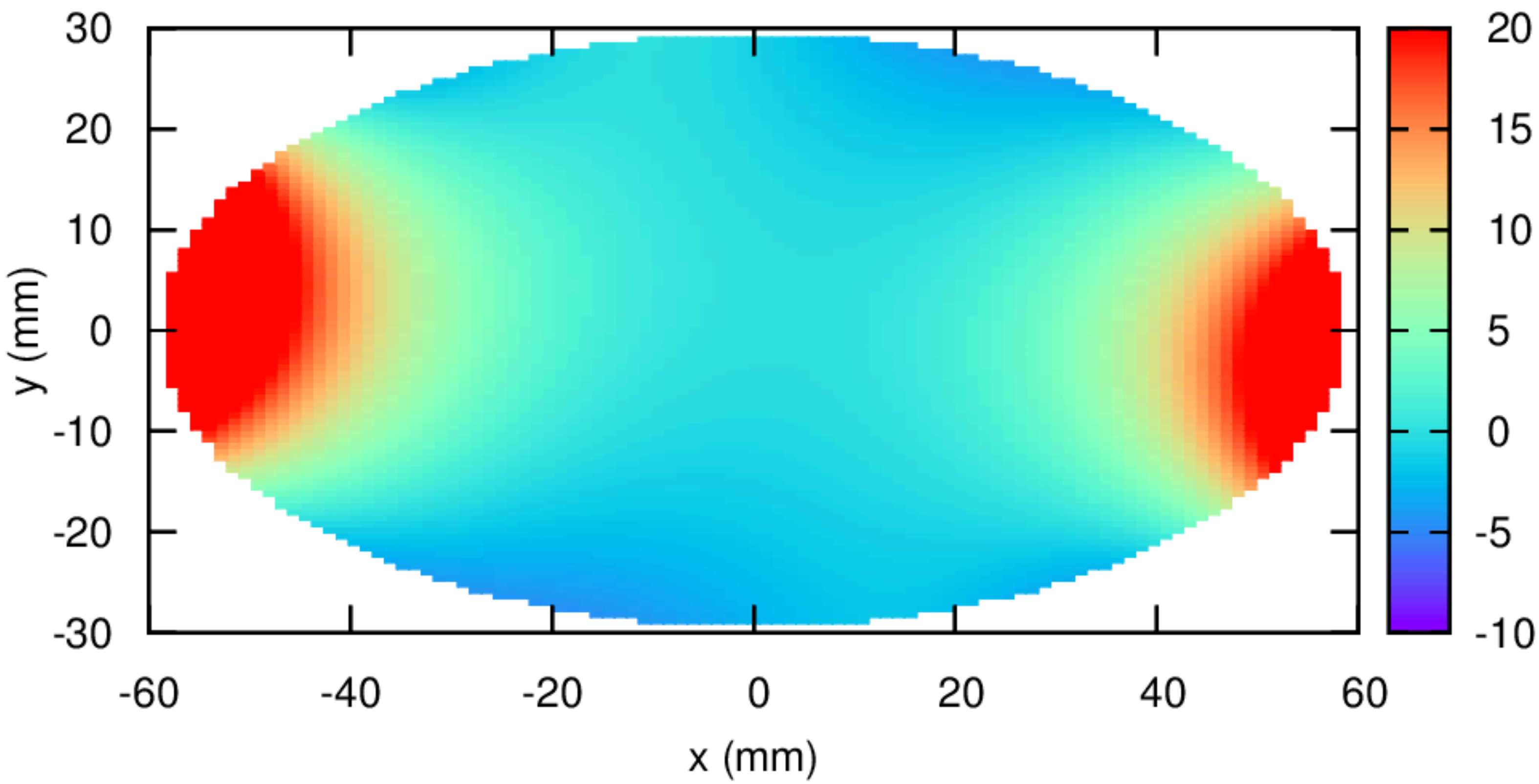
B_4 , A_4 octupole

r_0=30mm, 1 unit = 10^{-4}



SIS100 Dipole Magnets

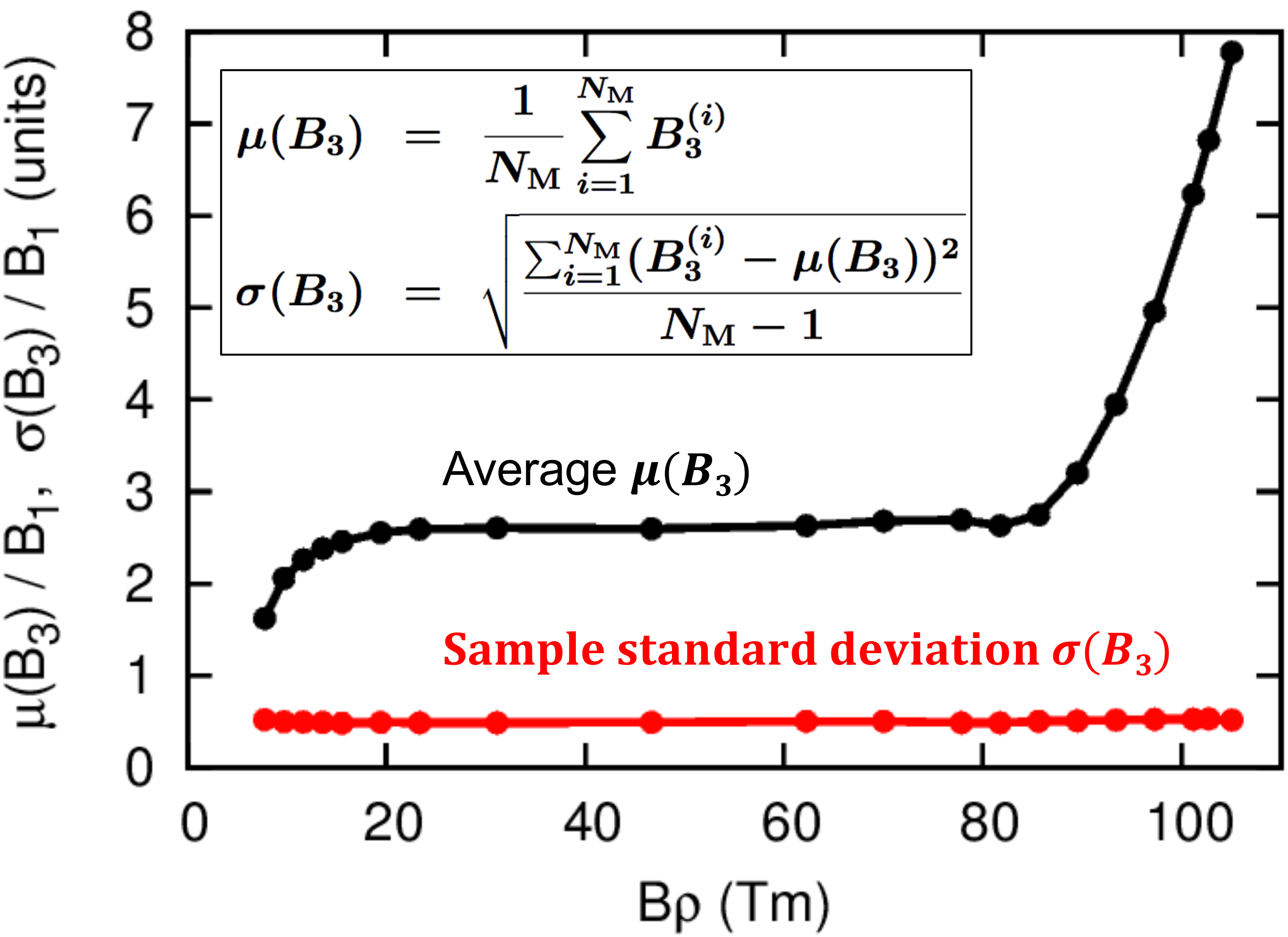
The resulting field distortion inside the vacuum pipe.
Δb_y in units: 10^{-4}



$$\Delta b_y(x, y) = \frac{B_y(x, y) - B_y(0, 0)}{B_y(0, 0)}$$

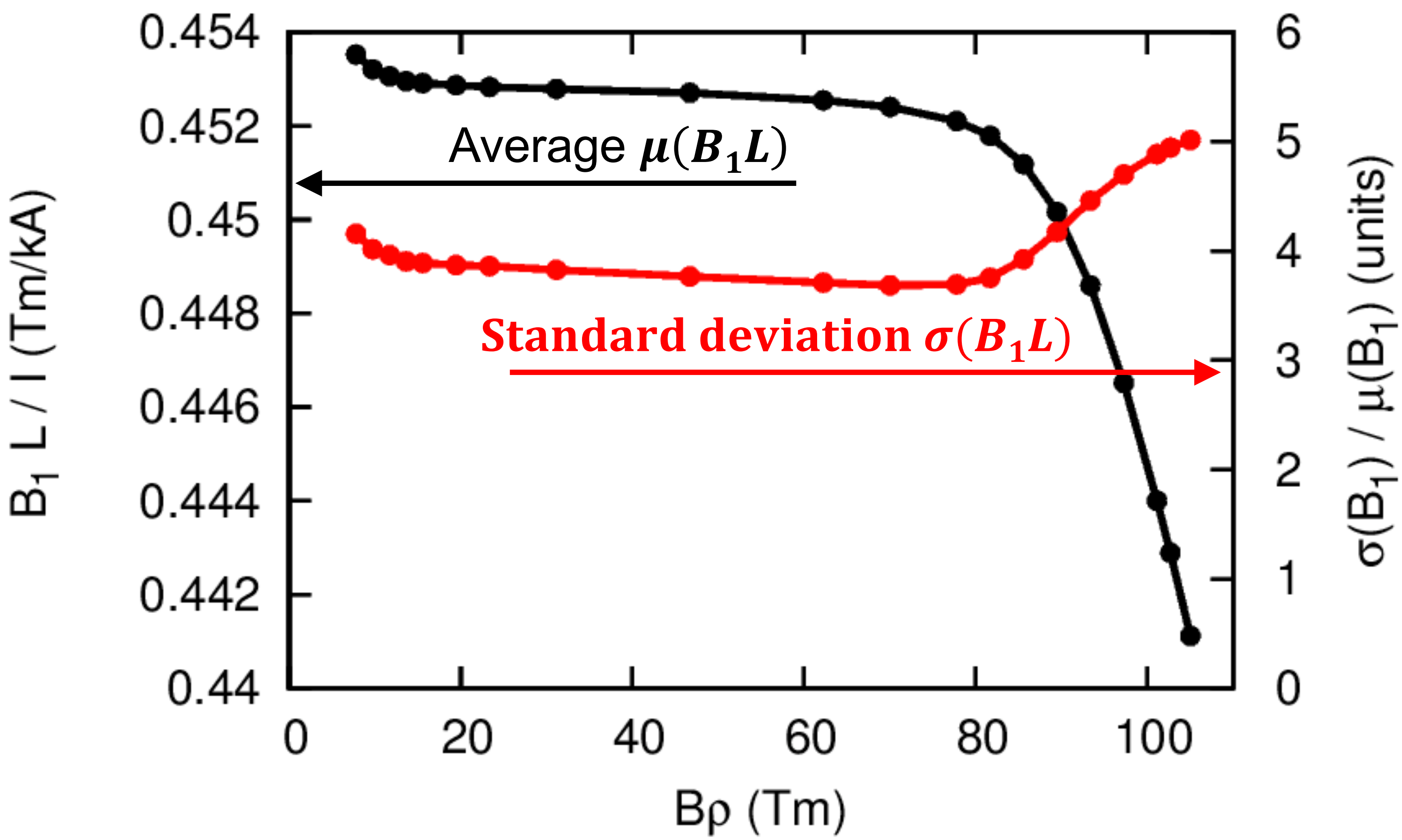
SIS100 Dipole Magnets

The strongest error component: sextupole.
Very systematic (from N_M=7 series magnets)



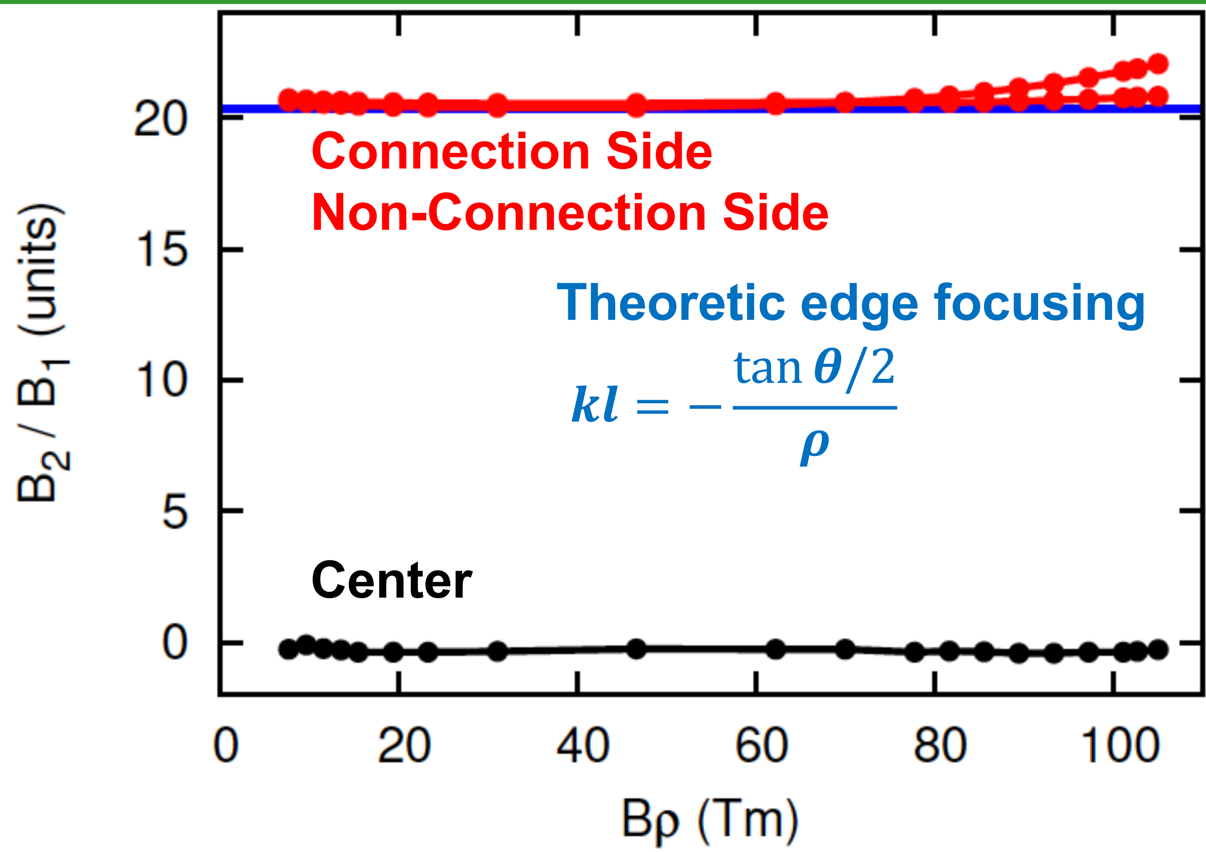
SIS100 Dipole Magnets

The total bending field B_1L from the 7 series magnets. Very systematic.
SIS100 Closed Orbit correction system covers at least 40 units.



SIS100 Dipole Magnets

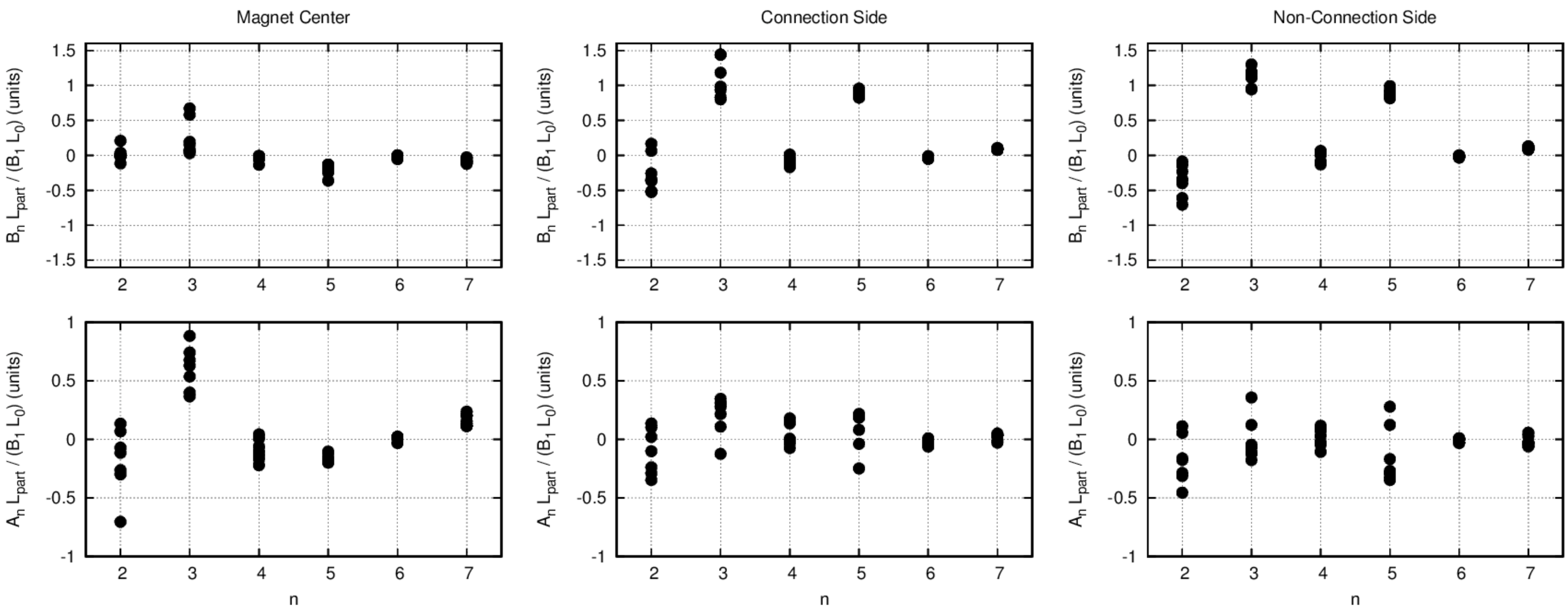
Measurement coil is parallel to the magnetic axis
→ non-perpendicular to the yoke → an edge quadrupole.
We must take it into account and modify the data.



We subtract the theoretical quadrupole, the rest is the B_2-error

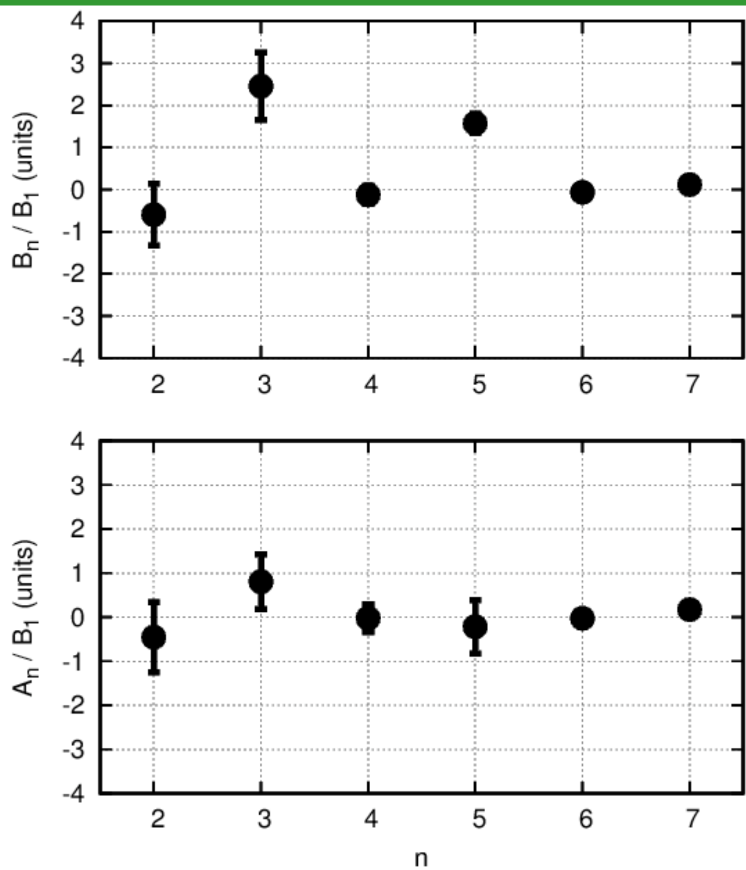
SIS100 Dipole Magnets

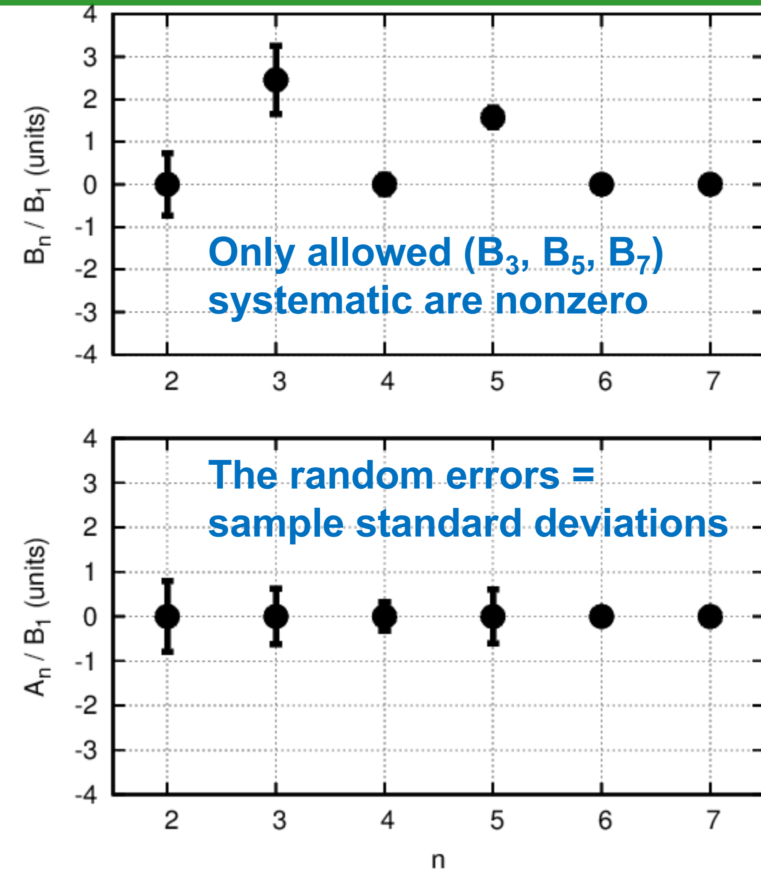
Outcome of the field measurements from the 7 series magnets:
in simulations can be replaced by the total-magnet values (checked)



SIS100 DIPOLE MAGNET MODEL

The field measurements of the dipole series provide the model of the dipole magnets for particle tracking simulations





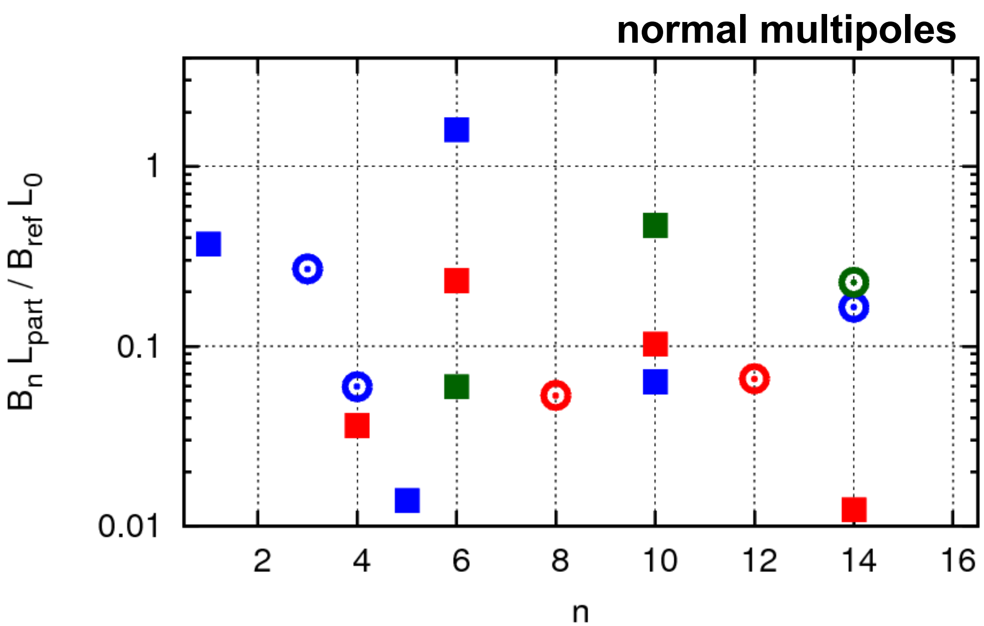
The 7 series magnets

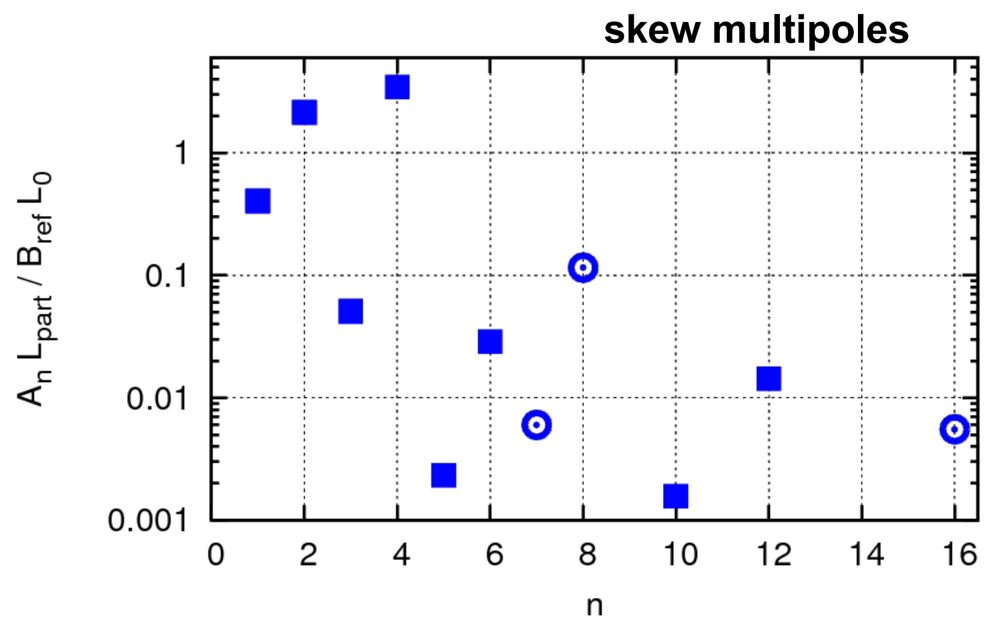
The resulting model

This magnet model is very different from the previous (comp model, $\sigma(B_n) = 0.3\ B_n$)

QUADRUPOLE MAGNETS

Quadrupole Magnet (166 in SIS100 + 2 warm)
Computational Model Akishin et.al. 2010, Sugita 2013
Center (red), Conn-End (blue), Nonconn-End (green)
O: positive; ■: negative





- r_0=40mm, 1 unit = 10^{-4}
- In simulations: random $\sigma(B_n)$= 0.3 B_n
- averaged over L_{center}=0.96m, L_{end}=0.35m
- The new data from FoS measurements are presently under consideration (large B_3 , B_4 , B_6 , A_3)

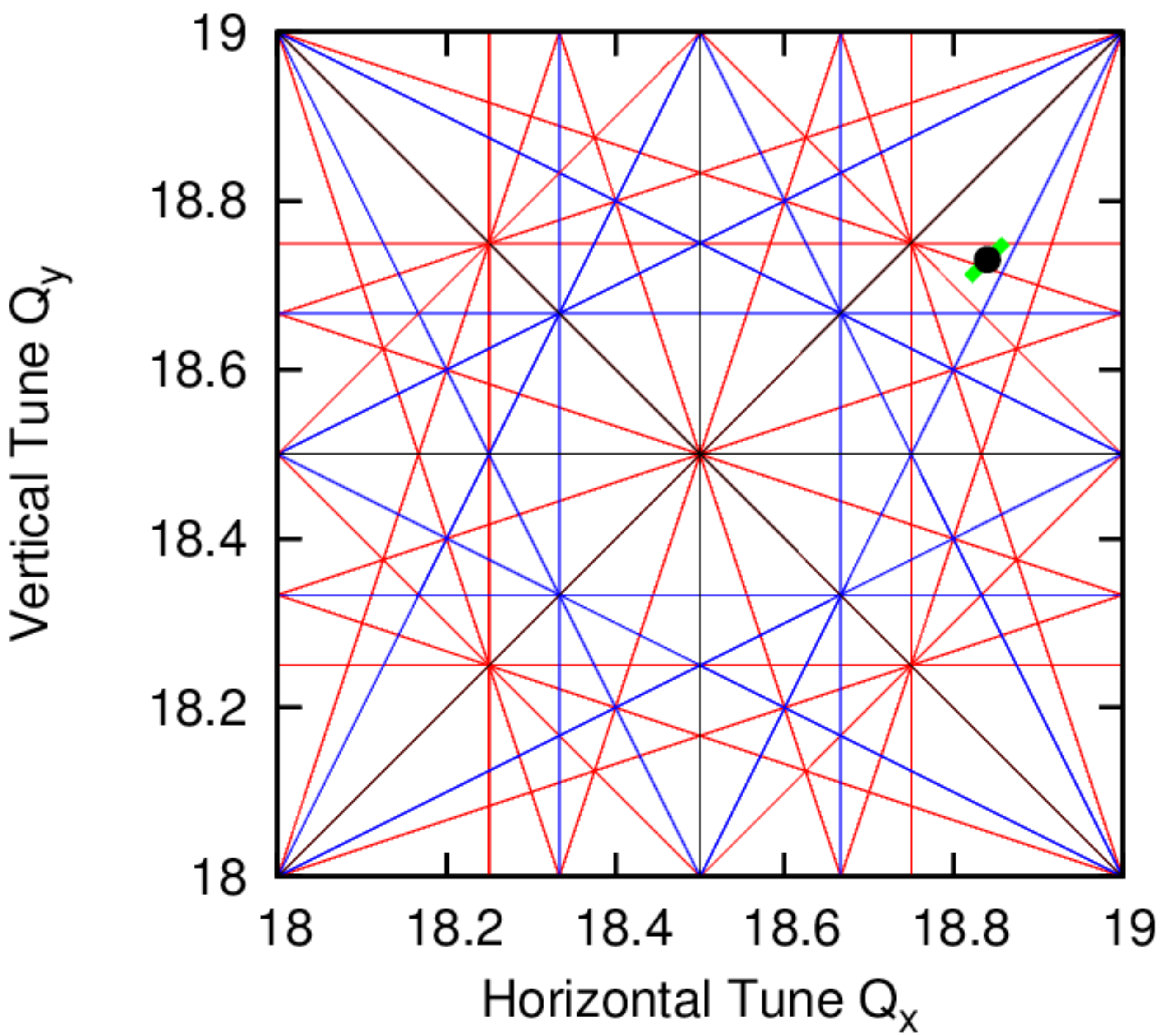
SIS100 RESONANCE DIAGRAM

Resonances in transverse oscillations:
$kQ_x + mQ_y = n$

2^{nd} order (quadrupole)
3^{rd} order (sextupole)
4^{th} order (octupole)

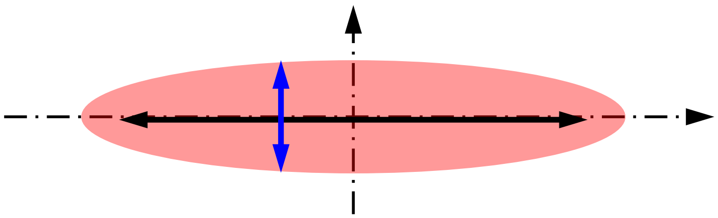
Set tune (heavy ions, fast extraction):
$Q_{x0} = 18.84$
$Q_{y0} = 18.73$

Green area: tune spread, here due to the chromaticity ξ

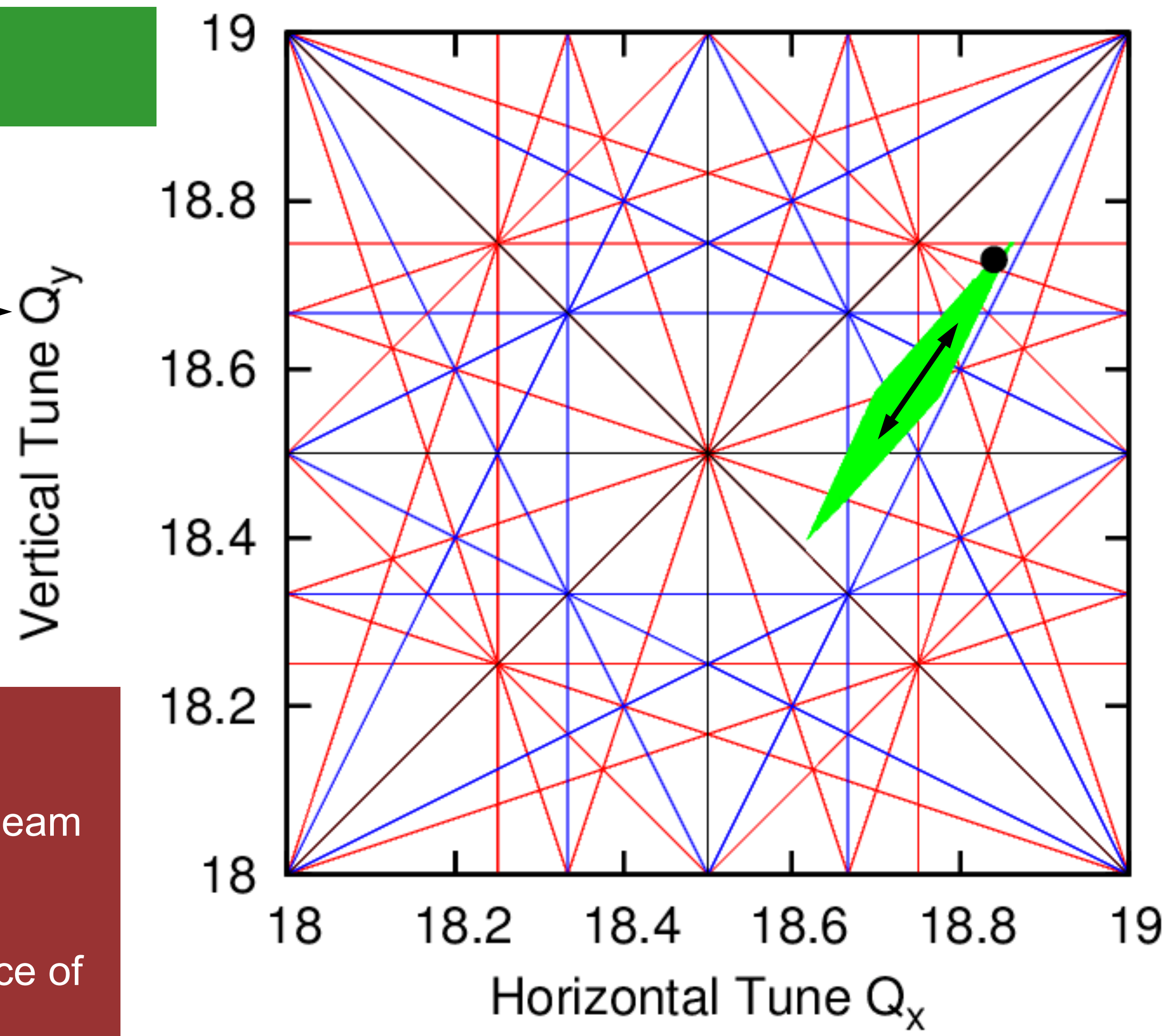


SIS100 RESONANCE DIAGRAM

Special situation for SIS100:
Tune spread due to space-charge



$f_{longitudinal} \approx 1.5$ kHz
(T ≈ 600 us)
$f_{transverse} \approx 5$ MHz
(T ≈ 0.2 us)

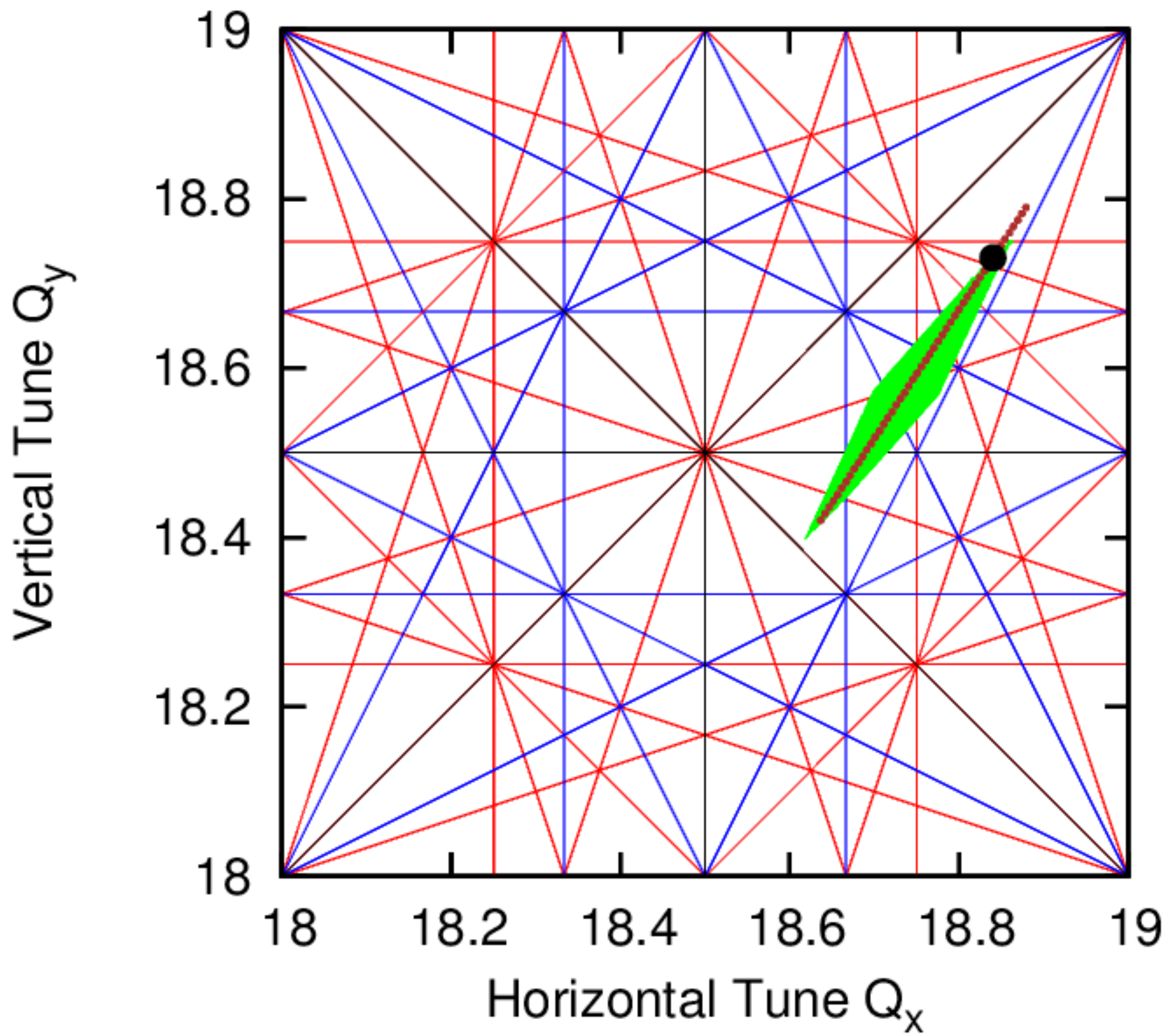


Resonance crossing due to space charge:

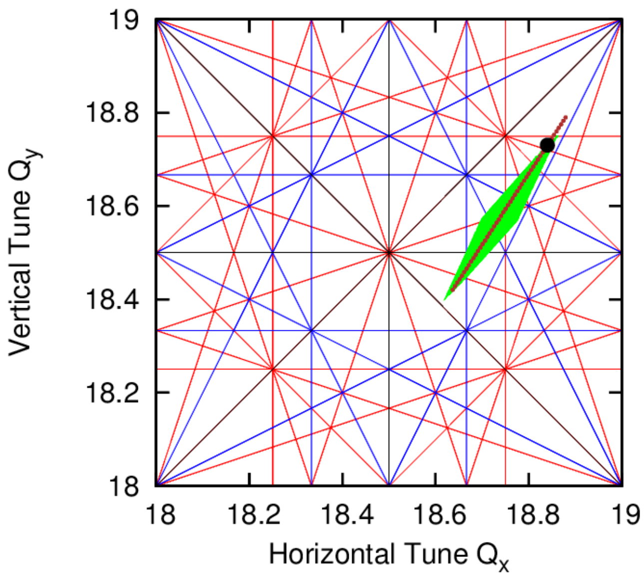
- a major challenge for SIS100 beam dynamics
- simulations and SIS18 studies
- countermeasures: dual-rf, choice of (Q_x,Q_y), correction magnets.

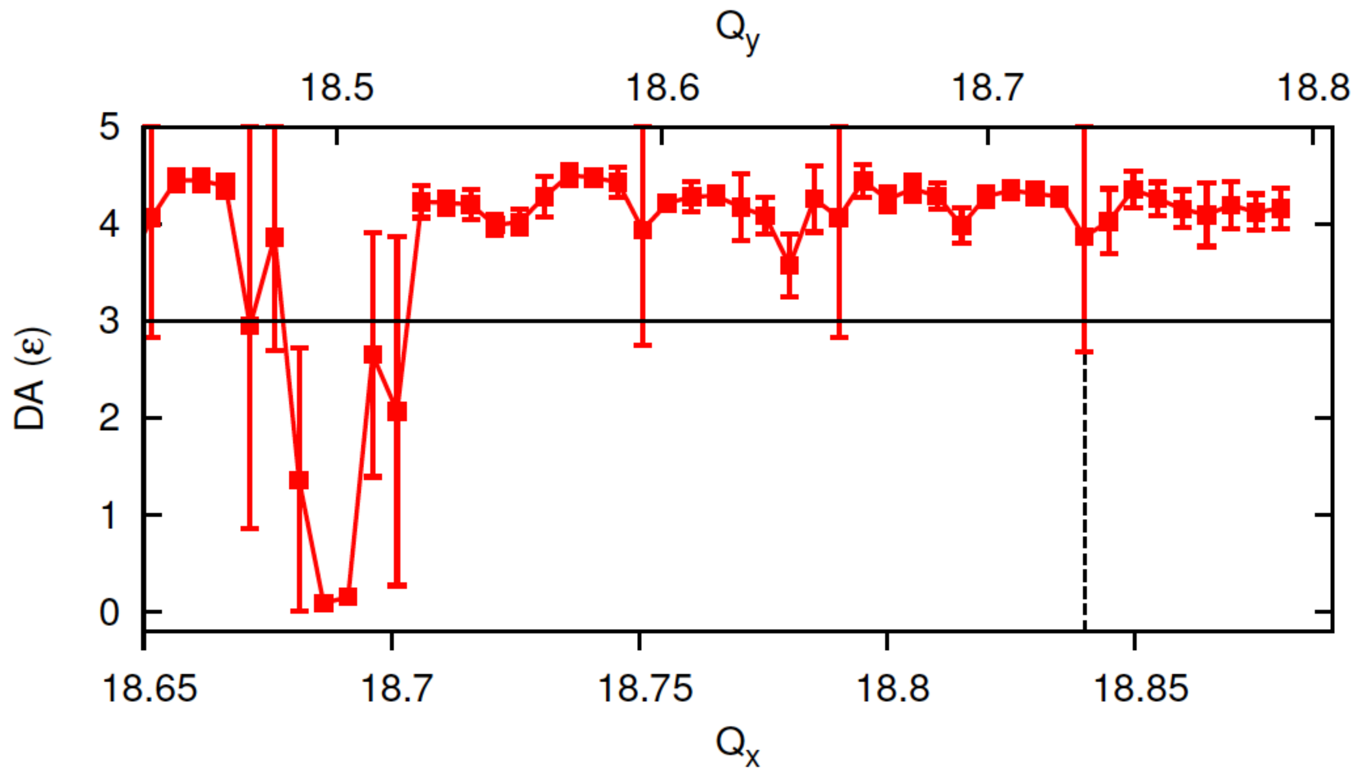
SIS100 PARTICLE STABILITY

As a limited assessment of the magnetic field quality: Dynamic Aperture simulations along the dot line.



DYNAMIC APERTURE SCANS





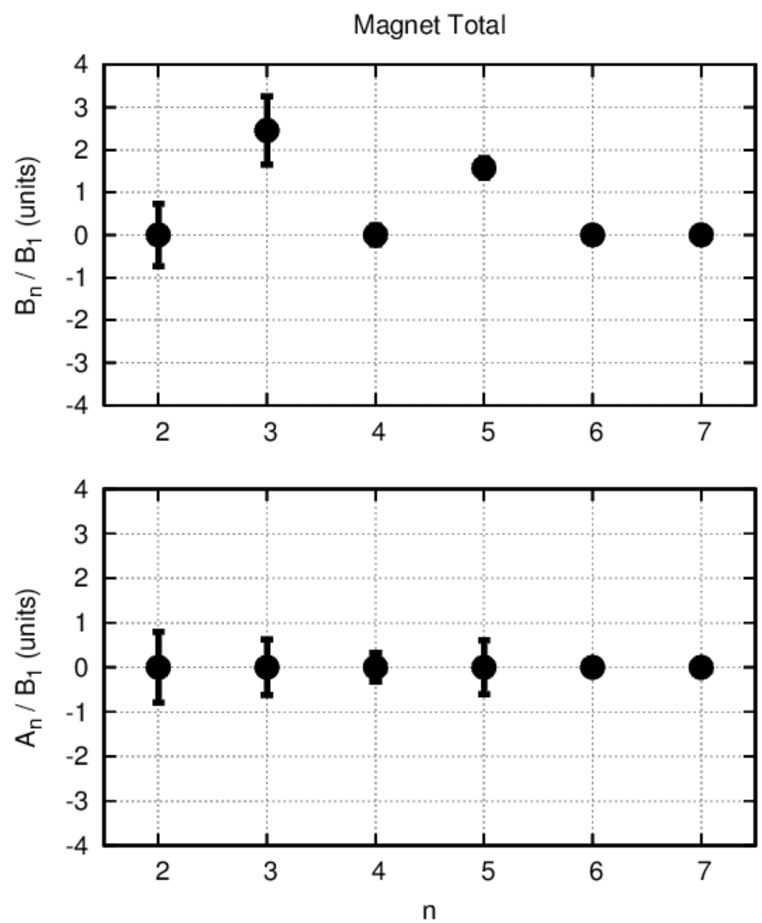
- Dynamic Aperture in tr. emittance units, 3ε is the safety margin
- Dipole Magnets: the model based on the series measurements
- Quadrupoles: The computer model
- Closed-Orbit: Δx_{rms}=1.5mm, Δy_{rms}=1.0mm
- 10^3−turn scans with MADX, ε=35 mm mrad→2σ beam
- Other working points: similar results

SIS100 SERIES DIPOLE MAGNETS

Each of the 108 delivered magnet:

- contributes to the SIS100 Magnet Database
- updates the SIS100 Magnet Model
- gets evaluated (Dynamic Aperture, Beam Loss)

After a large number of magnets, decision about sorting (so far, seems to be not needed)



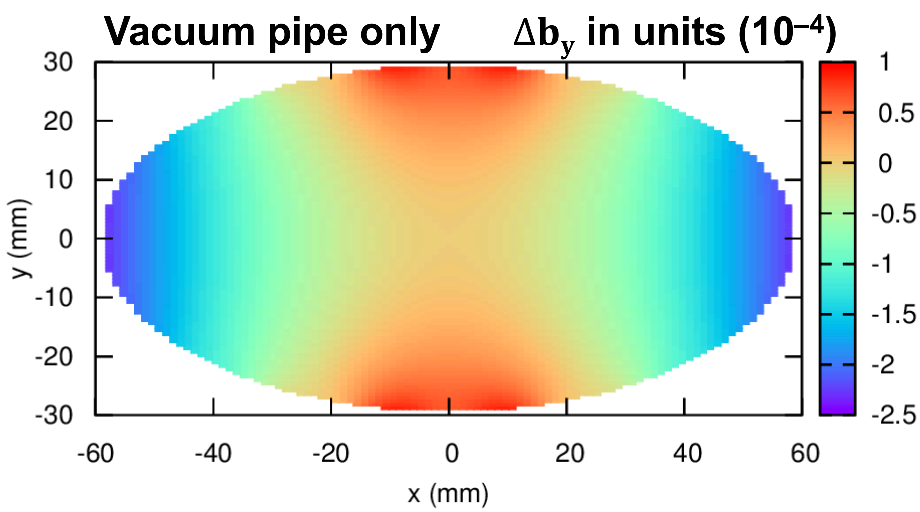
The resulting model

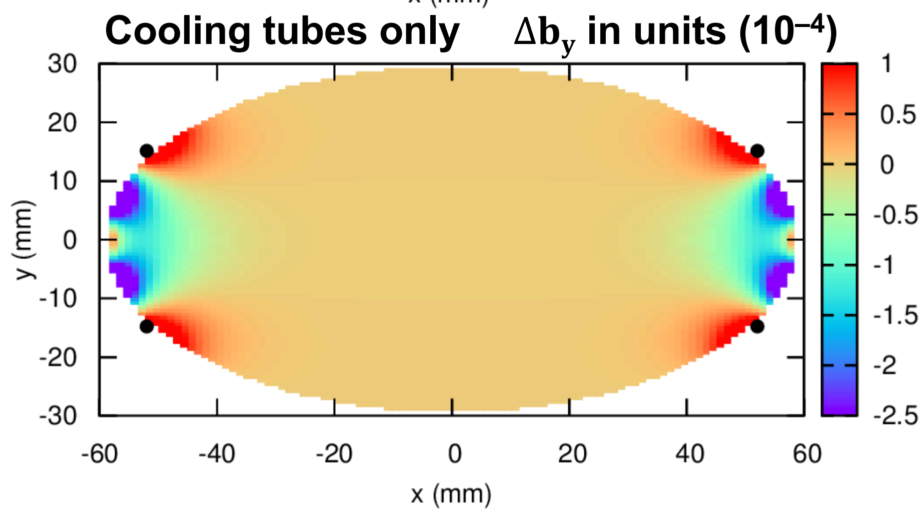
PARTICLE TRACKING SIMULATIONS

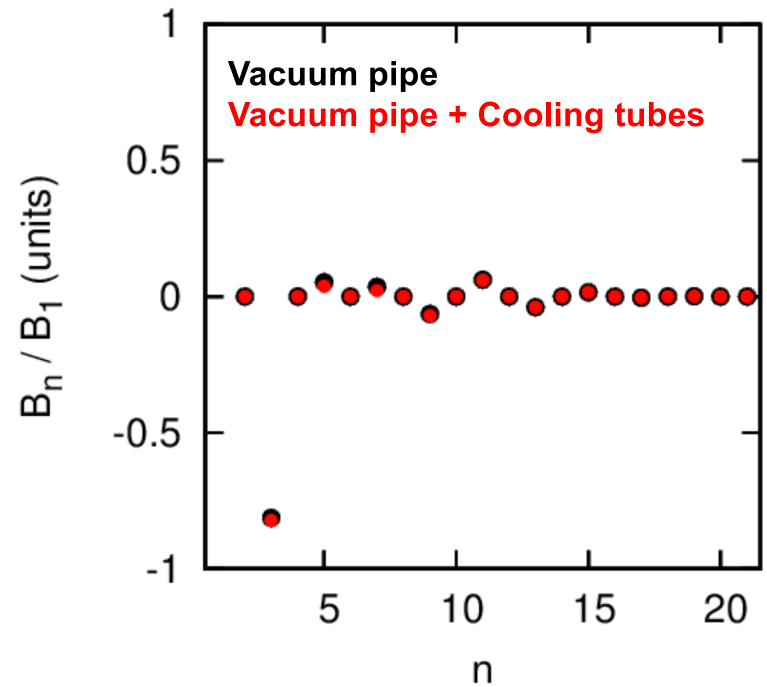
- The complete SIS100 machine model, 3D Gaussian bunches.
- Field errors and closed orbit: the same as for DA.
- Objective: beam-loss and emittance preservation study during the 1s accumulation after injection.
- Challenge: long (200000 turns) simulations with space charge.
- The tool: new version of MADX with “frozen” space charge (sufficient for slow-changing distributions).
- Investigations of the countermeasures: 1. beam parameters and the choice of (Q_x,Q_y); 2. dual-rf bucket; 3. correction magnets.
- Development and simulations are presently under progress.

DIPOLE MAGNET VACUUM PIPE

SIS100 dipole magnets: field distortions due to eddy currents in the vacuum pipe, and in the chamber-brazed cooling tubes







Coefficients provided by: K.Sugita, V.Marusov, S.Wilfert, June 2018

$$\Delta b_y(x,y) = \frac{B_y(x,y) - B_y(0,0)}{B_y(0,0)}$$

DIPOLE MAGNET VACUUM PIPE

- SC Magnets (K.Sugita, V.Marusov) and Vacuum Systems (S.Wilfert) provided B_n–coefficients for the field distortions due to eddy current in the vacuum pipe and in the chamber-brazed cooling tubes.
- All the components are purely systematic.
- For the max ramp rate 4T/s: b_1=8.5units (will be compensated), b_3=-0.8units (will be compensated).
- Additional contributions of the cooling tubes for nonlinear field distortions are below 0.02 units.
- Simulations for the dynamic aperture and for the emittance preservation showed no effect of the cooling tubes.

CONCLUSIONS

- The field data from the four series dipole magnets demonstrate a sufficiently good field quality.
- The total bending power (B_1), the largest component (sextupole B_3), have small random errors, easily correctable.
- The Dynamic Aperture simulations, and the preliminary long-time bunch simulations, fulfill the safety criterions.
- Further development of the particle simulations with space charge and with the complete beam/machine model is under progress.
- The field distortions due to the eddy currents in the chamber-brazed cooling tubes have a negligible effect.