Field quality of MBH 11-T dipoles for HL-LHC and impact on beam dynamic aperture

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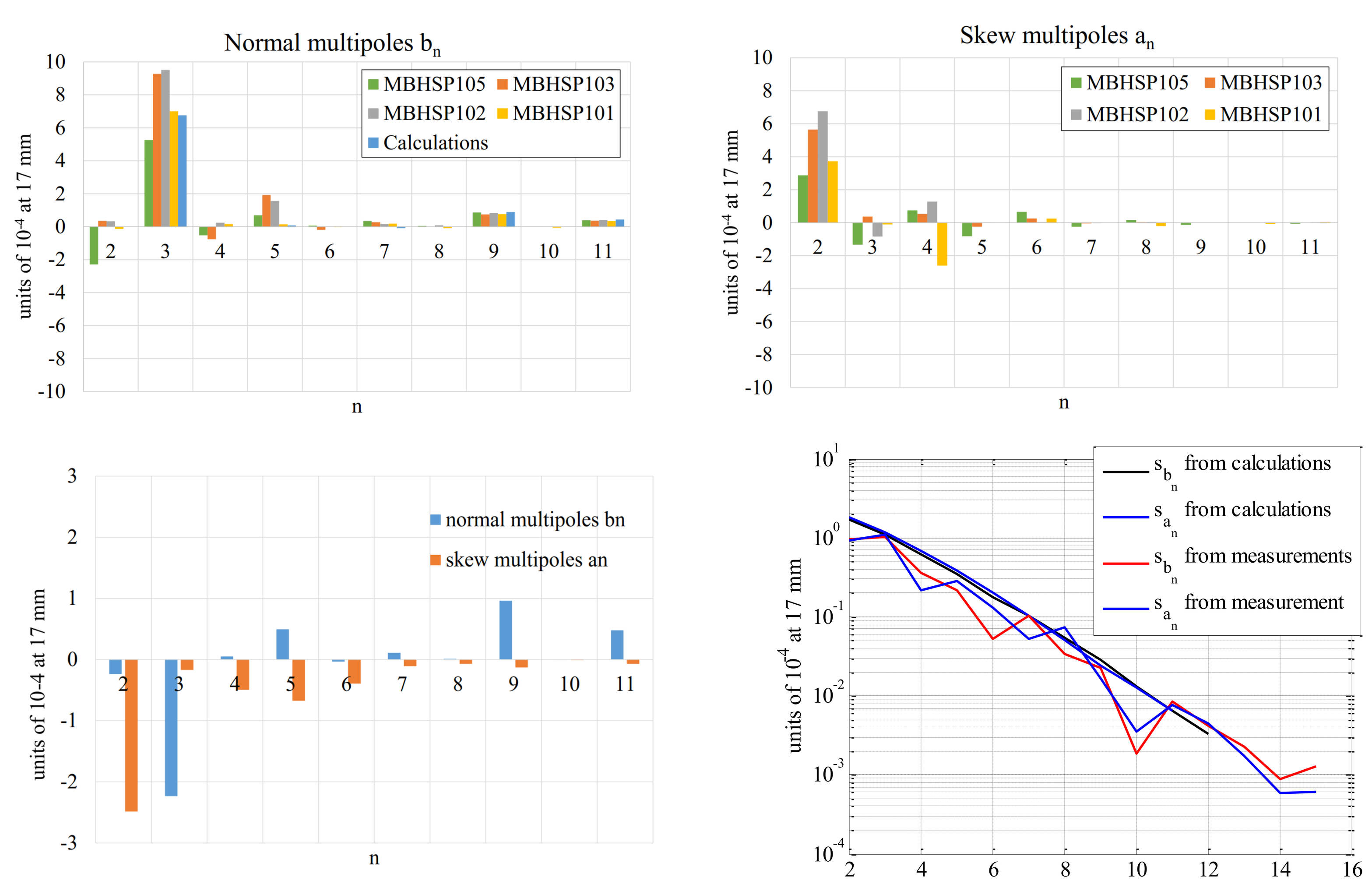
Abstract

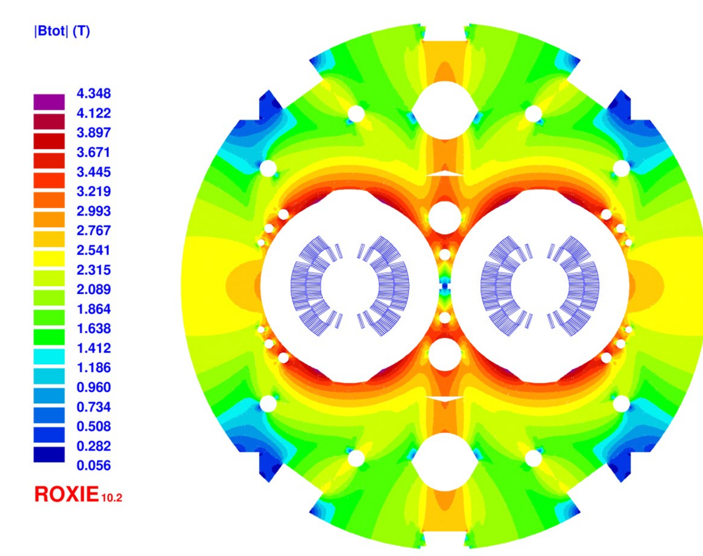
For the High-Luminosity upgrade of the Large Hadron Collider (HL-LHC), the development of the 11-T Nb3Sn dipole (MBH) is progressing. At present, one double-aperture and five single-aperture short-model magnets have been built and tested. Magnetic measurements have been performed both at ambient and cryogenic temperature. Besides, and additional double-aperture short model and the first full-length collared-coil assemblies have been produced and measured at ambient temperature. In this paper, the measurement results collected up to the present moment are reported and discussed. The geometrical field multipoles, the iron saturation effects as well as the effects of persistent currents are summarized. Experimental data are compared with the magnetic calculations using the CERN field computation program ROXIE, and discussed in view of the construction of the final magnets. In addition, based on the measured field errors, beam dynamics simulations have been carried out by taking into consideration different scenarios with and without MBH magnets installed.

Geometric multipoles



Geometric components of multipoles can be measured at ambient temperature and then can be confirmed by measurements at cryogenic temperature. In the figures, the magnetic multipoles measured on some **1-in-1 short models** are depicted and compared to the expected values from calculations. The results show some deviations among magnets and with respect to the calculations. The shim thickness on the mid-plane explains the difference visible on the allowed multipoles while the insulation layers have an effect on $\mathbf{a_2}$ and $\mathbf{a_4}$.

The first measurements obtained on the **full-scale collared-coil assembly**, to be used in the prototype, show that the field quality is well controlled.



MBH SHORT MODELS TESTED UP TO THE PRERSENT MOMENT.

Name	Configuration	Coils	Strand layout [7]
SP101	1-in-1	106-107	108/127
SP102	1-in-1	106-108	108/127, 132/169
SP103	1-in-1	109-111	132/169
SP104	1-in-1	112-113	132/169
SP105	1-in-1	114-115	150/169
DP101	2-in-1	106-108, 109-111	132/169
DP102	2-in-1	109-112, 114-115	132/169, 150/169

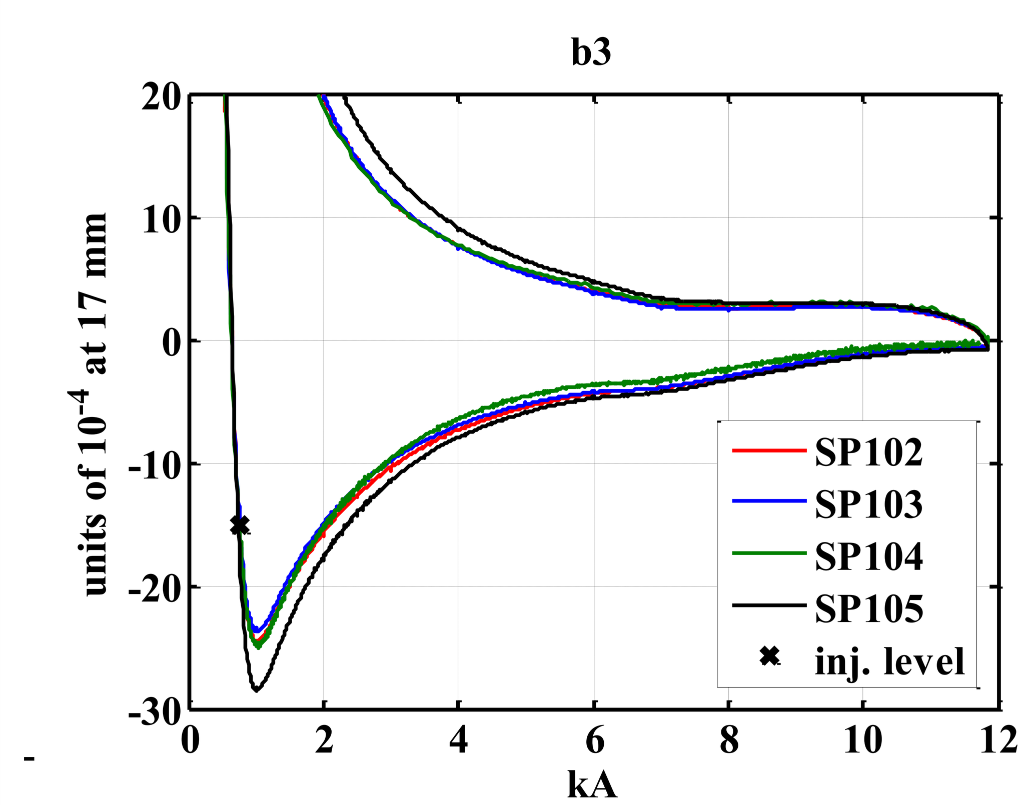
Field quality

The field quality of MBH magnets is evaluated on both collared-coil assemblies and cold masses at **ambient temperature**. In these conditions, the magnet is powered with limited current, 20 A in both positive and negative polarities, and the geometric field components measured.

At **1.9 K**, three main powering cycles are performed and the magnetic field measured: i) stair-step cycle, ii) ramp-rate study, and iii) machine simulation cycle with injection plateau and parabolic acceleration profile. In these conditions, the effects of **persistent currents** and iron saturation can be evaluated.

Measurements in several longitudinal positions and on different magnets give information about the **precision of cable positioning** in the magnet cross-section.

Persistent currents



The effects of persistent current are mainly visible on the allowed multipoles. The figure shows the measured b_3 on the single-aperture models. Persistent current effects are larger in SP105 since its coils are made of a different cable with strand layout 150/169. The average net effect on b_3 at injection level is **16 units** when the strand 132/169 is used. The total change, from injection to nominal field level, is quantified to about **22 units**.

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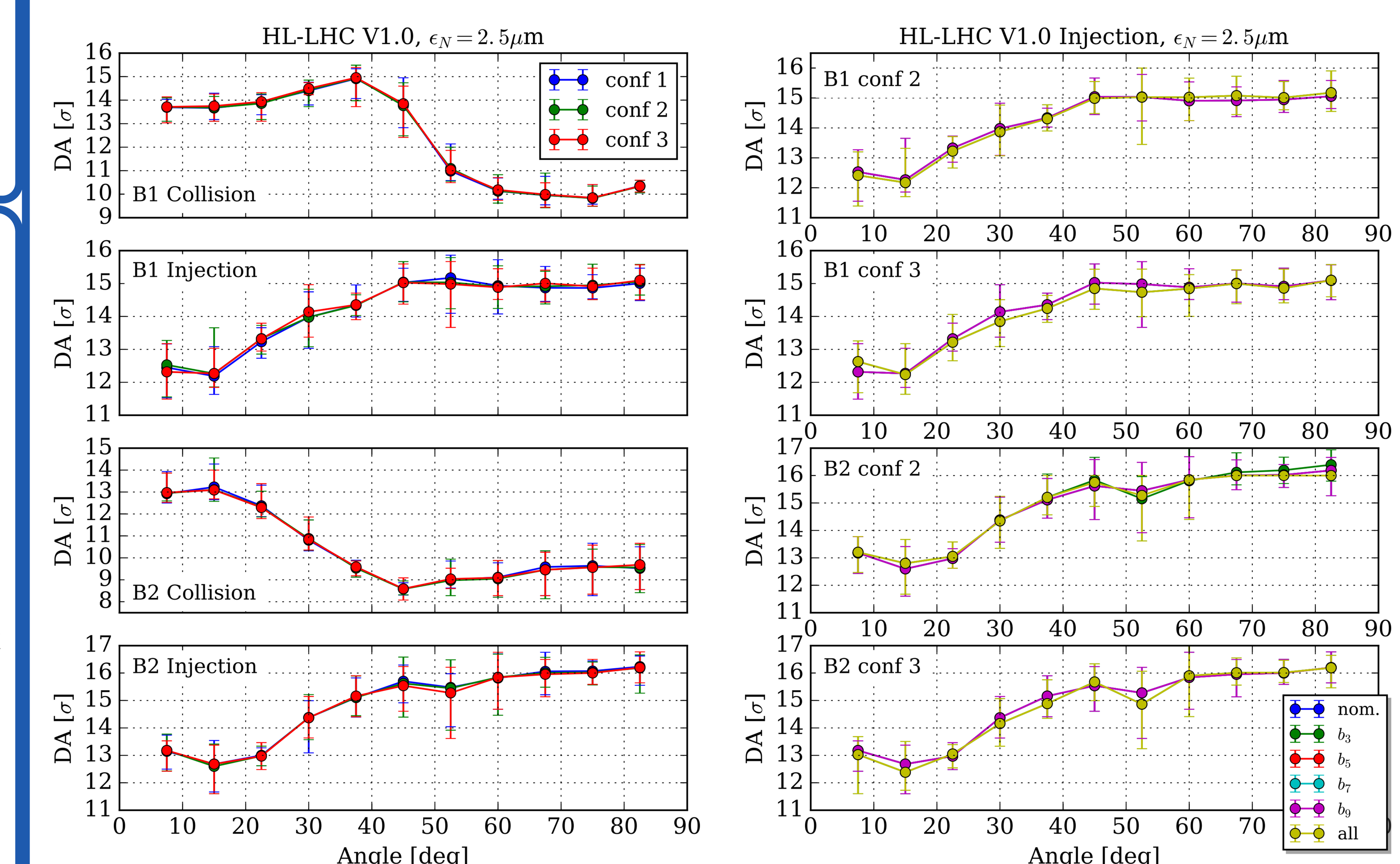
Beam dynamics considerations

Magnetic field errors from the MBH magnets installed in the HL-LHC lattice may have an impact on the dynamic aperture. The scenarios studied include simulations for both beams, lattices without (conf 1), with four (conf 2) and with eight (conf 3) MBH magnets per beam for both injection and collision energies.



It is clearly visible how the installation of either four or eight MBH magnets does not have a significant impact on the DA for any of the studied scenarios. The minimum DA for certain angles is slightly reduced if eight MBHs are installed per beam. However, the minimum DA in these simulations is still beyond the design specification of 11 σ and is considered acceptable. The impact of the MBH b2 component was studied in collision (conf 2). For this study all other field errors have been set to zero. The comparison of the β-beating distribution along the ring shows that the standard deviation is slightly increased. A compensation of the b2 from MBHs using the neighbouring quadrupoles is under consideration.

Conclusions

The field quality of the MBH 11 T dipole for HL-LHC has been assessed by combining experimental data and numerical calculations. Magnetic measurements have been performed on five single-aperture and two 2-in-1 short-model magnets, and one full-scale collared-coil assembly. The field errors have been analysed and reported in terms of systematic and random contributions and used as input for a set of simulations of the beam dynamic aperture for a variety of configurations. The dynamic aperture and β-beating including field errors of the MBH magnets is comparable to that without MBH magnets. Hence, the installation of MBH magnets does not negatively affect the expected dynamic aperture or β-beating.