



DESIGN STUDY FOR THE LHC UPGRADE WP3: MAGNETS

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Thanks to O. Bruning, G. De Rijk, T. Nakamoto, J. M. Rifflet,
L. Rossi, P. Wanderer, R. V. Weelderen



TASK LIST

1. Communication and management
2. Nb₃Sn quadrupoles
3. Separation dipoles
4. Cooling
5. Miscellaneous



TASK 2 – Nb₃Sn QUADRUPOLES

● Task Objectives

- Finalize the requirements for the HL-LHC inner triplet Nb₃Sn quadrupole
- Analyze the **performance of existing Nb₃Sn models**, in particular LARP HQ quadrupoles
- Conceptual design of the **final aperture** option (135 mm ? 150 mm ?)

● Task description

This task is intended to give a final assessment of the possibility of using Nb₃Sn quadrupoles for the LHC inner triplet and the performance parameters that can be achieved. A tentative layout with a 120 mm aperture quadrupole is given from WP2, and the necessary full list of requirements (field quality, radiation resistance, integration in the machine) should be worked out. A comparison with the present performance of the 120 mm aperture short model (HQ) magnets of LARP should be done, and iterations on the design if needed should be carried out. In particular we plan to analyze the following issues: (i) **radiation resistance** of all components (ii) magnet **field quality** and the possibility to apply corrections using magnetic shims (iii) option of **splitting the magnet into two coils**, with a related estimate of the loss in performance, possibly complemented by a hardware test, (iv) design of a **helium containment vessel** compatible with a magnet structure based on aluminum shrinking cylinder (v) **magnet protection**).

This task will be mainly driven by LARP collaboration (BNL, FNAL and LBL). LASA will lead the quench protection study.



TASK 2 – Nb₃Sn QUADRUPOLES

- Deliverables

 - M48 Report on design study of the Nb₃Sn inner triplet

- Milestones

 - M12 Requirements for Nb₃Sn inner triplet and comparison with present status of the art (to be started asap)

 - M24 Study of magnetic shimming in HQ

 - M36 Study of minimal distance between two coils in a cold mass

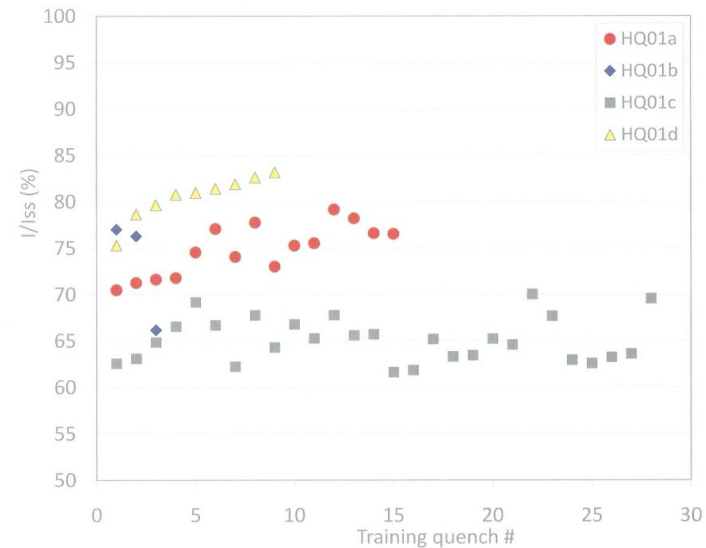
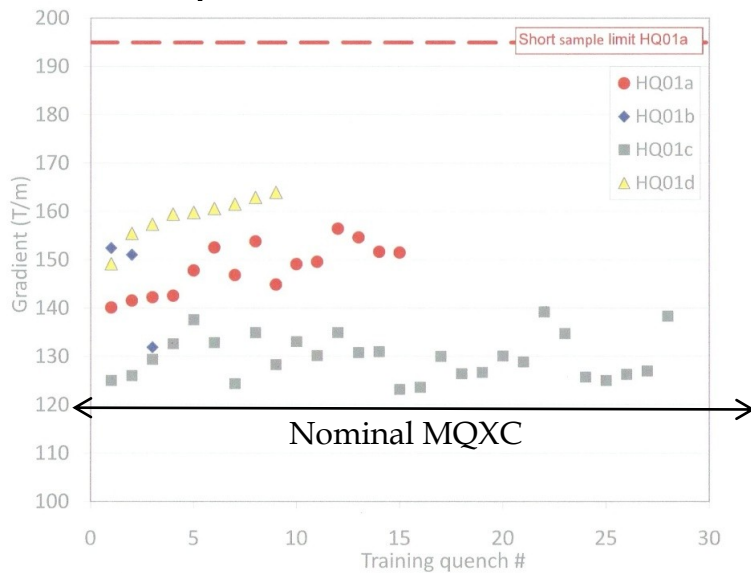
- Relation to other WP

 - Inputs from WP2. Moreover, this task feeds directly back to WP2 (e.g. required space for eventual absorber inserts at regions with higher losses etc which have an impact on the detailed IR layout).

- Task leader: G. Luca Sabbi

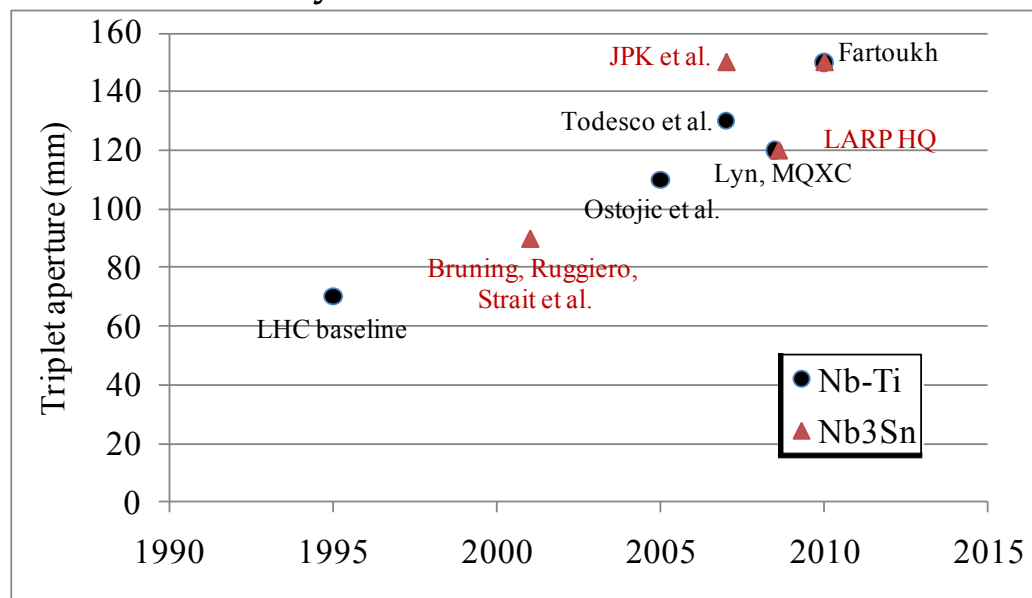
● Latest news about HQ

- This is the LARP Nb₃Sn 120 mm aperture quadrupole – testbench for checking all the requirements for going in the machine
- First assemblies had electrical problems (shorts) et al.
- Fourth assembly tested a few days ago: started at 80% of short sample, and reached 86% after 10 quenches



Latest news on HQ training [S. Caspi, April 2011]

- The aperture is the crucial parameter for us
 - 120 mm aperture models are being built (Nb-Ti and Nb₃Sn)
 - 150 mm proposed
 - We **should take a decision before the end of this year**
 - Even if not all information from beam dynamics is available
 - Otherwise we will stay with 120 mm



Optimal aperture for the LHC triplet versus time



TASK 3 – SEPARATION DIPOLES

● Task Objectives

- Conceptual design of **separation dipoles** according to the specifications given by WP2 using either **Nb₃Al** or **Nb-Ti**. If a model is built, specify and follow-up the tests needed for assessing the design.
- Explore the possibility of using **separation dipoles to create doglegs** to increase the beam separation, thus allowing the installation of non-compact crab cavities.

● Task description

For the D1 we propose considering Nb₃Al or Nb-Ti conductor. For the D2 the Nb-Ti option only is considered. Main issues as (i) **field quality**, (ii) **peak stresses** at operational field, (iii) **integration** in the machine, (iv) **radiation resistance** (v) **magnet protection** will be analysed. 2nd step: short model to assess the Nb₃Al technology. 3rd step: follow-up the construction of the model, contributing to the test definition and to the analysis of the test results.

A similar type of technology would allow to further separate the LHC beams from the nominal distance of 194 mm to a wider one (400 to 500 mm).

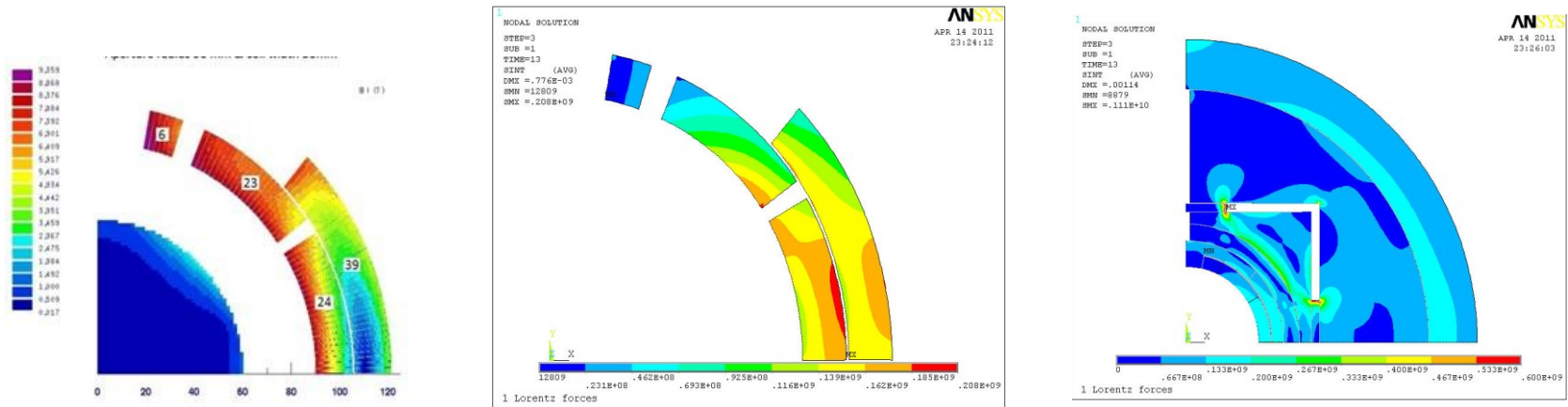
This task is lead by KEK for the Nb₃Al part and by BNL for the Nb-Ti option. LASA will steer the studies on protection



TASK 3 – SEPARATION DIPOLES

- Deliverables
 - M48 Report on design study of the separation dipoles
- Milestones
 - M12 Requirements for separation dipoles
 - M24 Conceptual design of Nb₃Al and Nb-Ti separation dipoles
 - M36 Conceptual design of a crab cavity dogleg
- Relation to other WP
 - Inputs from WP2 and WP4. The task results feed also back to WP: the final length for the dipole magnets will impact the space available for local Crab Cavity installations and potential installations for the compensation of long-range beam-beam interactions.
- Task leader: T. Nakamoto & P. Wanderer

- KEK already sent Proj. Ass. (Q. Xu)
 - At CERN since 1 March, preliminary work on separation dipole
 - Analysing apertures from 120 to 180 mm with parametric approach
 - Coil width from 10 to 30 mm
 - Two cases studied in detail
 - Margin: I would propose to stay at 67% of loadline



Preliminary study on 180 mm aperture D1 [Q. Xu]



TASK 4 – COOLING

● Task Objectives

- **Choose the operational temperature** of the inner triplet quadrupoles and of the separation dipoles. Consider and compare both the superfluid and supercritical He options.

● Task description

The cooling system of the Nb₃Sn inner triplet can operate either in superfluid (i.e., below 2.17 K) or in supercritical helium (i.e., above 2.17 K). Contrary to Nb-Ti magnets, Nb₃Sn can operate in supercritical helium at around 4.5 K with a limited loss in field gradient w.r.t. the superfluid option (about 10%). This would also solve the Nb₃Sn conductor instability issues that have been found by the US colleagues during the last decade.

As the heat loads envisaged today are more than one and a half order of magnitude above what is prevalent in the previous accelerators magnets designed for operation at supercritical helium (RHIC, HERA, Tevatron), it is mandatory to address the problem of cooling from the very beginning of the design of future quadrupoles.

Both the **supercritical and the superfluid options should be analysed and compared**. The program can be divided into different phases: (i) analysis of **heat loads** and status of the different cooling scenarios (ii) principle of **heat removal system**, thermohydraulic simulations and first experiments (iii) **validation of the system**.

A similar study should be carried out for the separation dipoles.

This task is steered by CERN for the superfluid part and by CEA-Grenoble for the supercritical part.



TASK 4 – COOLING

- Deliverables
 - M48 Report on design study of the cooling
- Milestones
 - M18 Study of the supercritical He cooling
 - M36 Study of the superfluid He cooling
- Relation to other tasks and WP
 - Relation to tasks 3.2 and 3.3, and inputs from WP2.
- Task leader: R. Van Weelderen



TASK 5 – MISCELLANEOUS

● Task Objectives

- Design a **two-in-one quadrupole for the outer triplet (Q4-Q6)** with nominal beam separation (192 mm) and aperture as large as possible (80-100 mm), satisfying the electromagnetic and mechanical requirements. Design of a **two-in-one quadrupole for the inner triplet in the case of a dipole first option.**
- Review the **Nb-Ti option for the inner triplet** considering the new targets in luminosity, and follow-up the tests of the short model built within the SLHC-PP program.
- Analysis of the expected **lifetime of resistive quadrupoles in IR3 and IR7**. Study of possible solutions for the time scale of 2030 with in integrated radiation of 3000 fb^{-1} , both resistive and superconductive.



TASK 5 – MISCELLANEOUS

● Task description

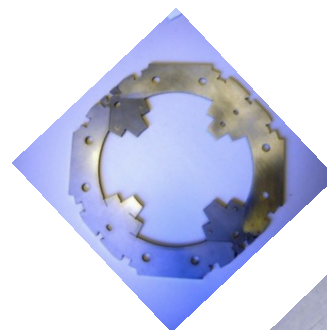
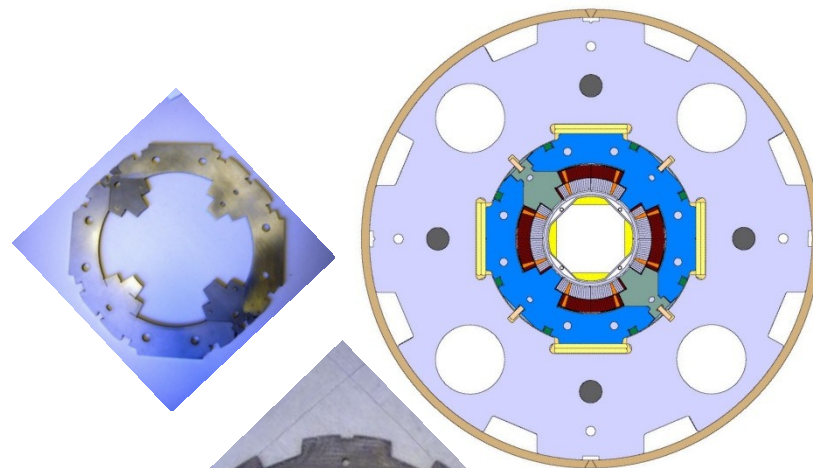
This task includes three different studies:

The conceptual design of a **large aperture two-in-one quadrupole** for the outer triplet. The present baseline of the LHC involves 70 mm aperture magnets (MQY) whose aperture could be a bottleneck. One should explore the possibility of having two-in-one quadrupoles with apertures in the range 80-100 mm, with the same constraint of the 194 mm beam separation. Electromagnetic and mechanical aspects should be analysed. This design also applies to the **option of a two-in-one inner triplet in the option of a dipole first option**. This subtask is steered by CEA-Saclay.

The analysis of the expected lifetime of the resistive quadrupoles used in the cleaning insertion (MQWA and MQWB). The first step is to have an estimate of the radiation load, together with the lifetime of the present hardware. Then solutions to extend the lifetime of present hardware up to 2030 or options to replace them will be analysed. This subtask is steered by CERN (TBC).

The Nb-Ti option for the inner triplet is the plan B in case that experience shows that the Nb₃Sn technology is not suitable. A considerable work has been done in the SLHC-PP framework, i.e. the so-called phase I, which aimed at a peak luminosity of $2.3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. A short model is being built. One has to check that the Phase I scenario and lay-out is compatible with the new targets of the HL-LHC. This subtask is steered by CERN (TBC).

- First coils wound
 - Press under commissioning
 - Collaring test coming one month
 - Assembly in summer 2011
 - Test end of the year
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- Warning
 - Aperture decided July 2008
 - First test end 2011
 - 3.5 years for a well-known technology!!
 - Follow-up of construction
 - Field quality!
 - Check design vs new requirements





TASK 5 – MISCELLANEOUS

- Deliverables
 - M48 Miscellaneous issues in magnet design
- Milestones
 - M18 Review of the Nb-Ti option for inner triplet for new peak and integrated luminosity targets
 - M36 Analysis of options for quadrupoles in cleaning insertions
 - M36 Study of two-in-one quadrupoles for outer triplet
- Task leader: J. M. Rifflet



OTHER REQUIREMENTS FROM WP2

- What is missing
 - Nested orbit corrector
 - Project in progress: imagined for Phase-I, to be checked for new scenario
 - Option of a magnetic TAS (either with dipole or quadrupole magnets)
 - Options of a D0 design integrated in the detectors
 - SC corrector magnet packages in the triplet assembly



PARTNERS

- EU:
 - CEA Saclay (Fr) – Magnet design
 - CEA Grenoble (Fr) – Supercritical cooling system
 - LASA INFN Milano (It) – Magnet protection
- World
 - LARP: FNAL, BNL, LBL (Us) – Nb₃Sn quadrupoles
 - BNL (Us) – Separation dipoles in Nb-Ti
 - KEK (Jp) – Separation dipoles in Nb₃Al