OUTPUT OF THE CABLE REVIEW

E. Todesco and the QXF team
CERN, Geneva Switzerland

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- Report
- Actions on critical current
- Actions on margin
- Actions on cable size

Introduction

- Critical and important project; unique opportunity to make higher performance, space effective accelerator magnets using Nb_3Sn
- Enthusiastic transatlantic team, bringing a new generation
- Good communication between Hi-Lumi and LARP
- Great recent progress
- It has to move from an R&D effort to a construction project!

Overall/schedule - 1

- Design goals shall be conservative because Nb_3Sn accelerator magnet technology is still not sufficiently matured and impregnated Nb_3Sn coils operated at 1.9 K are prone to self-field instabilities

- Therefore: optimize margin by all means, such as: increasing length, revisiting Cu-to-non-Cu ratio, and so on.

- Make use of model/prototype phase for finalizing specifications essential for success, including of acceptance criteria

Overall/schedule - 2

- Keep 2 strand suppliers; if one supplier has less maturity, it will require more resources
- Schedule is challenging; there should be some clearly defined articulations and decision points between the phases
- Address plan B

Technical specs: Not complete at this time

- Relationship of superconductor properties to magnet performance has not been clearly defined
- Add requirement on strand cleanliness and surface conditions (especially for bare copper strands)
- Clarify billet/unit length approval
- Benefit from model/prototype program to confirm that the following specs are correct:

  - strand I_c: 361 A at 4.2 K and 15 T

  -RRR: 150 on virgin strand/100 on extracted strand
- Address R_a and R_c on cable

REPORT

- *RRP*

- Go ahead with 132/169 lower Sn content; final decision in one year concerning series production contract (back up being 108/127)
- Consider proposal to reduce keystone angle

- *PIT*

- Promote a substantive development program with BEAS to optimize strand properties and establish performance baseline for series production
- In the meantime, CERN should go ahead with RRP for model magnet production and should optimize phasing of strand/cable deliveries between RRP and PIT.
- Reduced keystone angle is a must

Conclusion

1. Are the Functional or Technical Specification for conductor strand and cable adequate to the scope of the MQXF ?

Incomplete

Are they sufficiently developed and reasonably finalized ?

Incomplete

2. Does the design of strand and cable meet the specifications in terms of minimum Ic, maximum allowed degradation, minimum RRR, maximum Deff, stability request, cable size, and unit length ?

I_C and minimum RRR have to be revisited

D_{eff} is not critical around 50 μm

REPORT

Assess the likelihood of meeting – with adequate margin – the chosen specifications and requirements based on the decade long experience acquired by LARP in cables and magnet construction and the most recent experience in Europe.

Very optimistic, needs more optimization

4. Is the plan for two types of strand architecture (RRP and PIT) correctly managed inside the program?

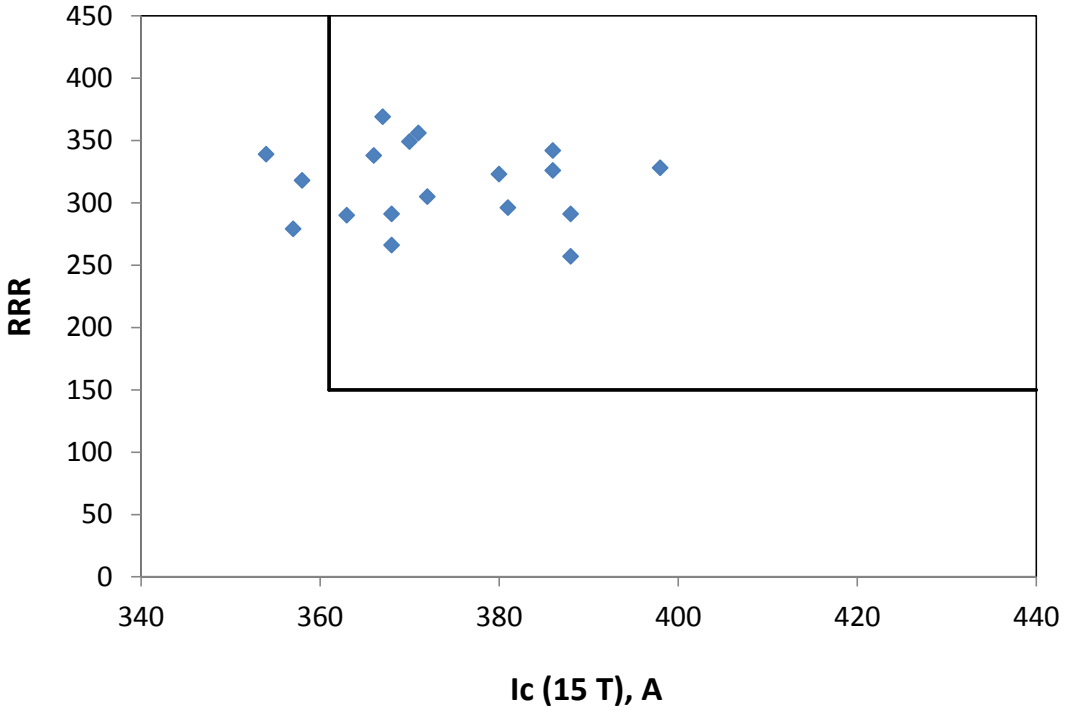
PIT needs more support

5. Is the procurement schedule, with associated QA and test plan, credible and adequate for the prototyping phase (where applicable) and for the construction phase?

No yet, need to better articulate the different project phases and the decision points

CRITICAL CURRENT

- First major point: the critical current is not there
  - Specifications are not met – further optimization should be done
  - We are >5% lower, I guess (340 A looks confortable)



Ic vs RRR for 132/169 RRP strand [A. Ghosh]

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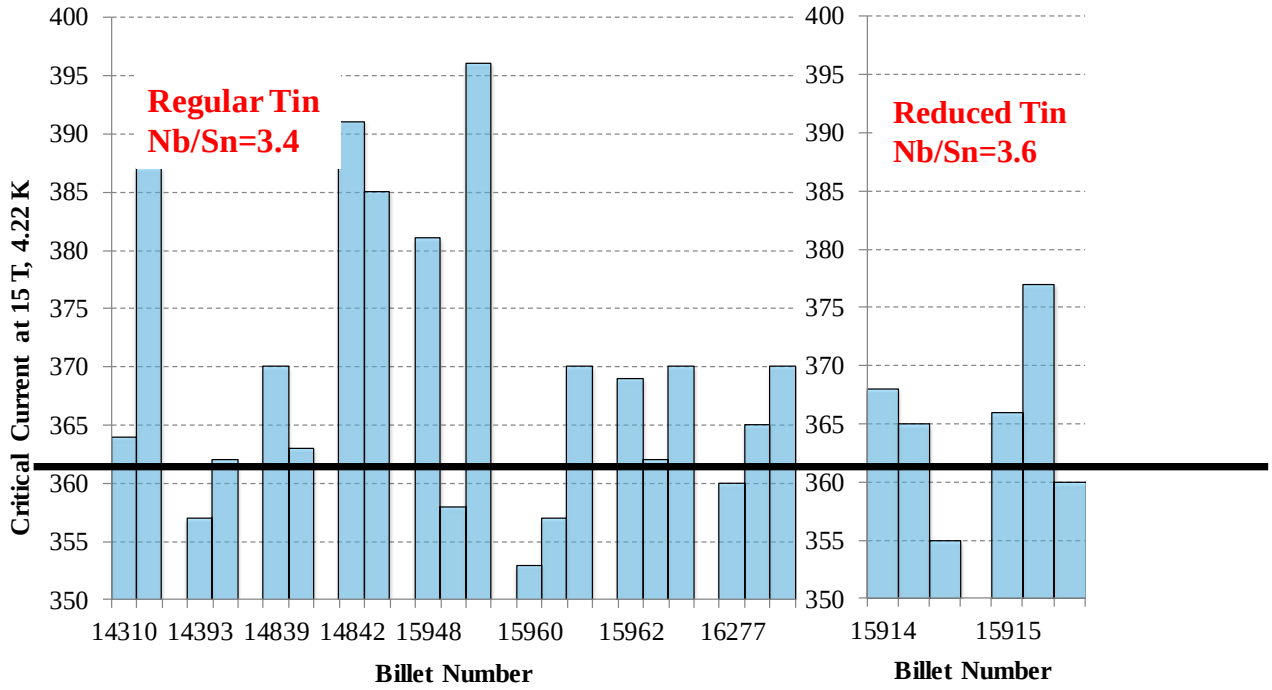
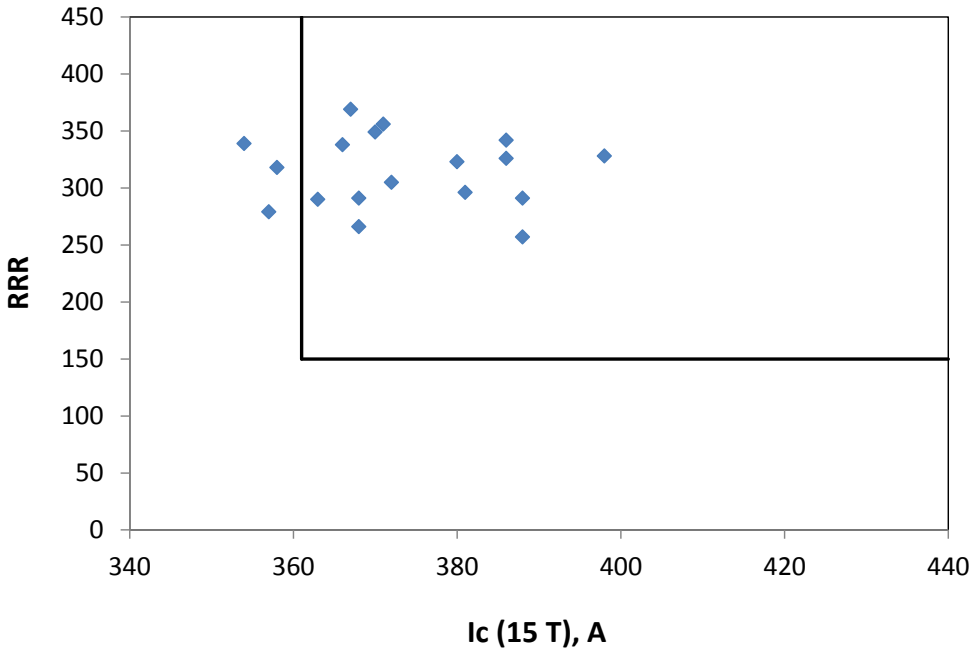


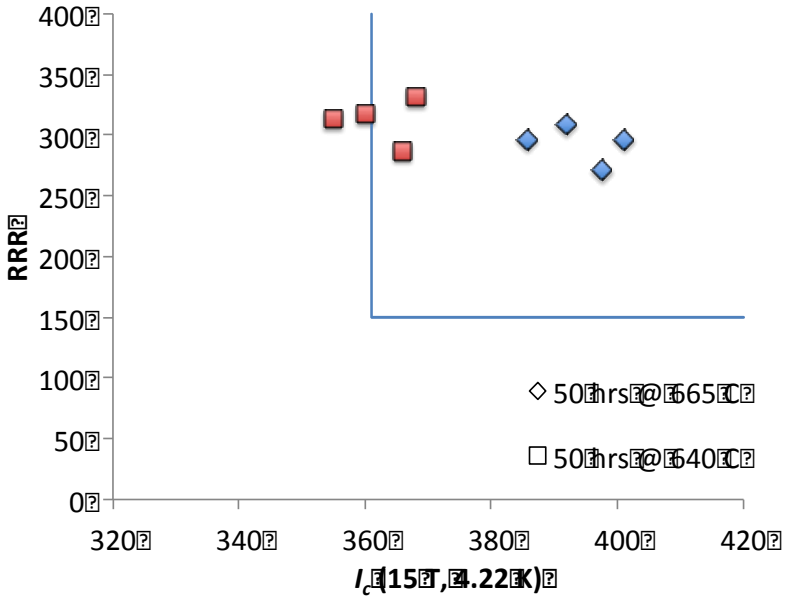
Ic for 132/169 RRP strand [B. Bordini]

CRITICAL CURRENT

- Possible actions: change heat treatment
  - Best solution, no change of strand layout, no impact on protection ☺



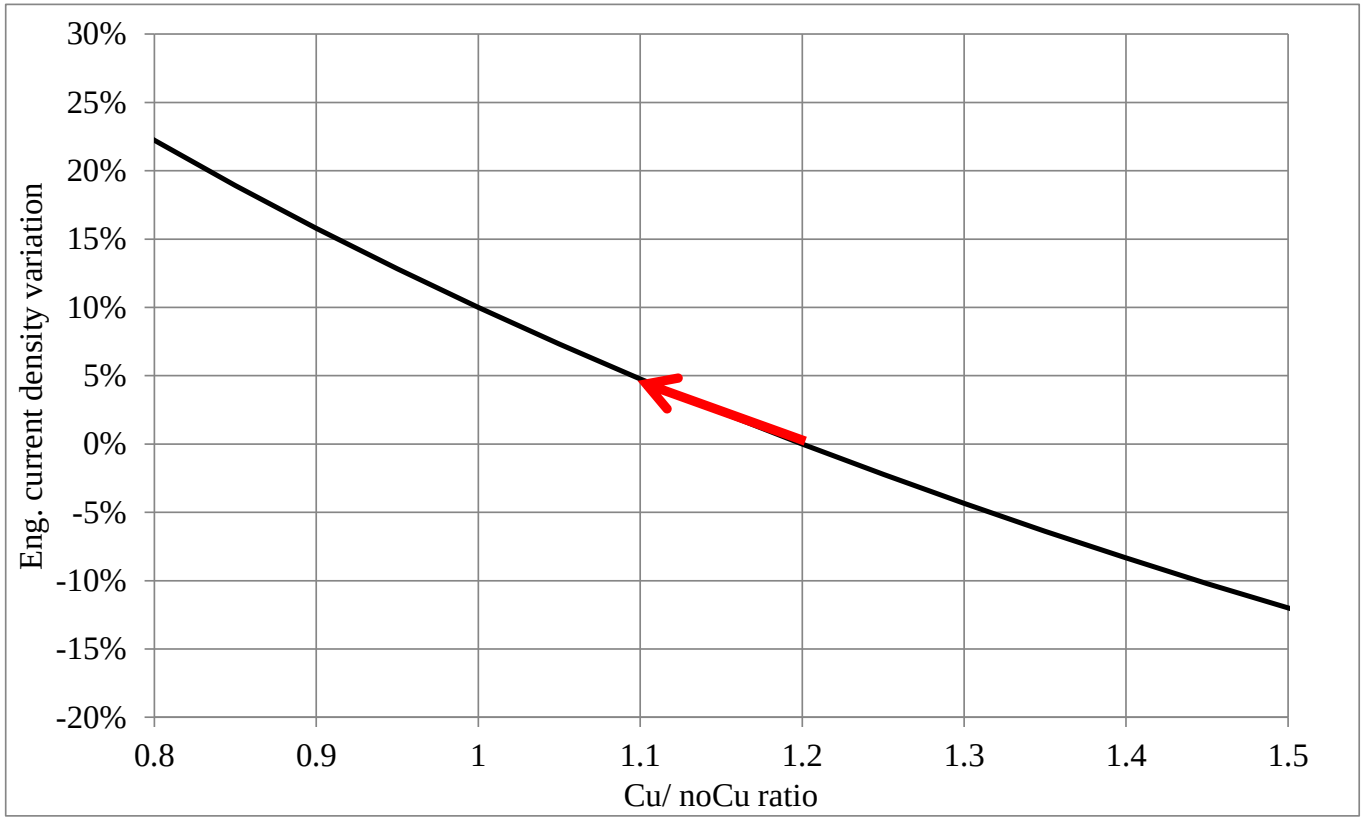
Ic vs RRR for 132/169 RRP strand [A. Ghosh]



Change of heat treatment for RRP to increase critical current [B. Bordini]

CRITICAL CURRENT

- Possible actions: decrease the copper ratio to 1.1
  - To recover 5% one has to reduce from 1.2 to 1.1 – impact on protection small (6-7 K in hotspot), small change of layout :-/

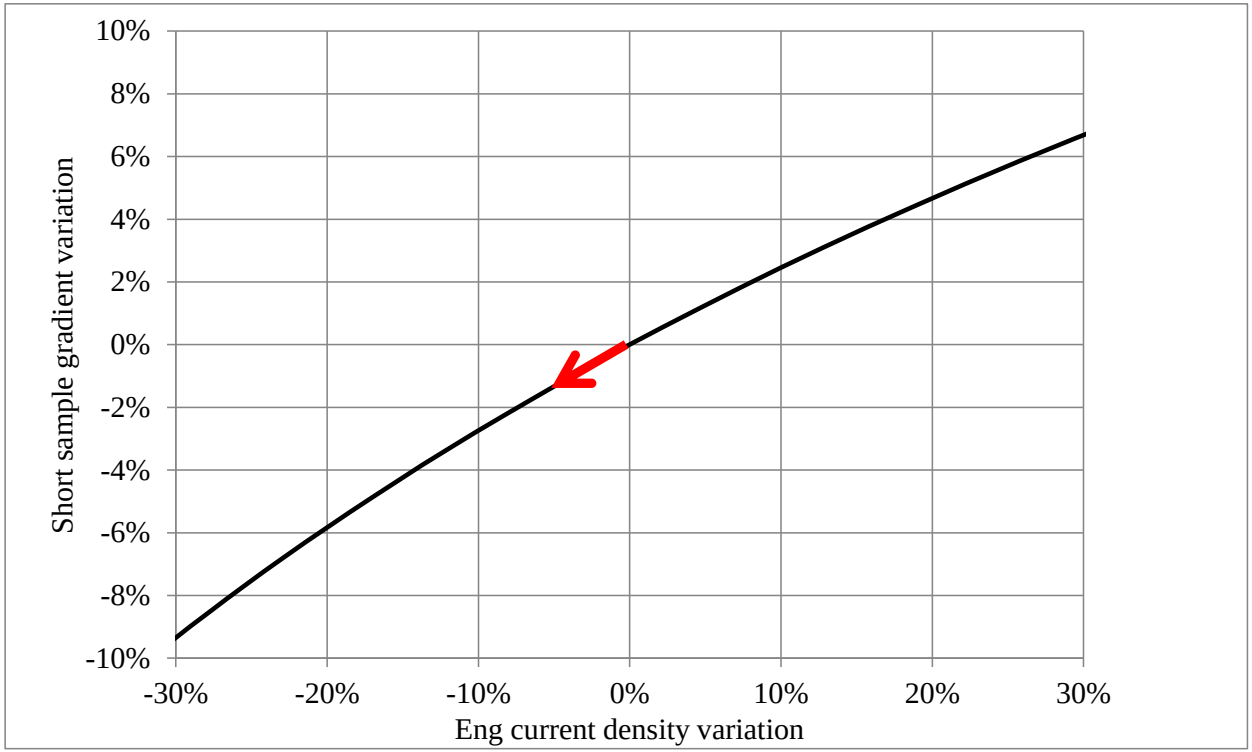


Engineering current density vs Cu/ no Cu ratio

CRITICAL CURRENT

- Possible actions: increase filament size
  - i.e. go to 108/127 – this is possible from the point of view of field quality, but
    - Change of layout is not favourite option ☹
    - No guarantee of getting more current

- Possible actions: accept the reduction of spec
  - Decrease from 361 to 340 A
    - Surrender … ☹ ☹
    - Loss of 1.5% precious margin (from 80% to 81.5% on the loadline)



Short sample gradient vs Cu/ no Cu ratio

MARGIN

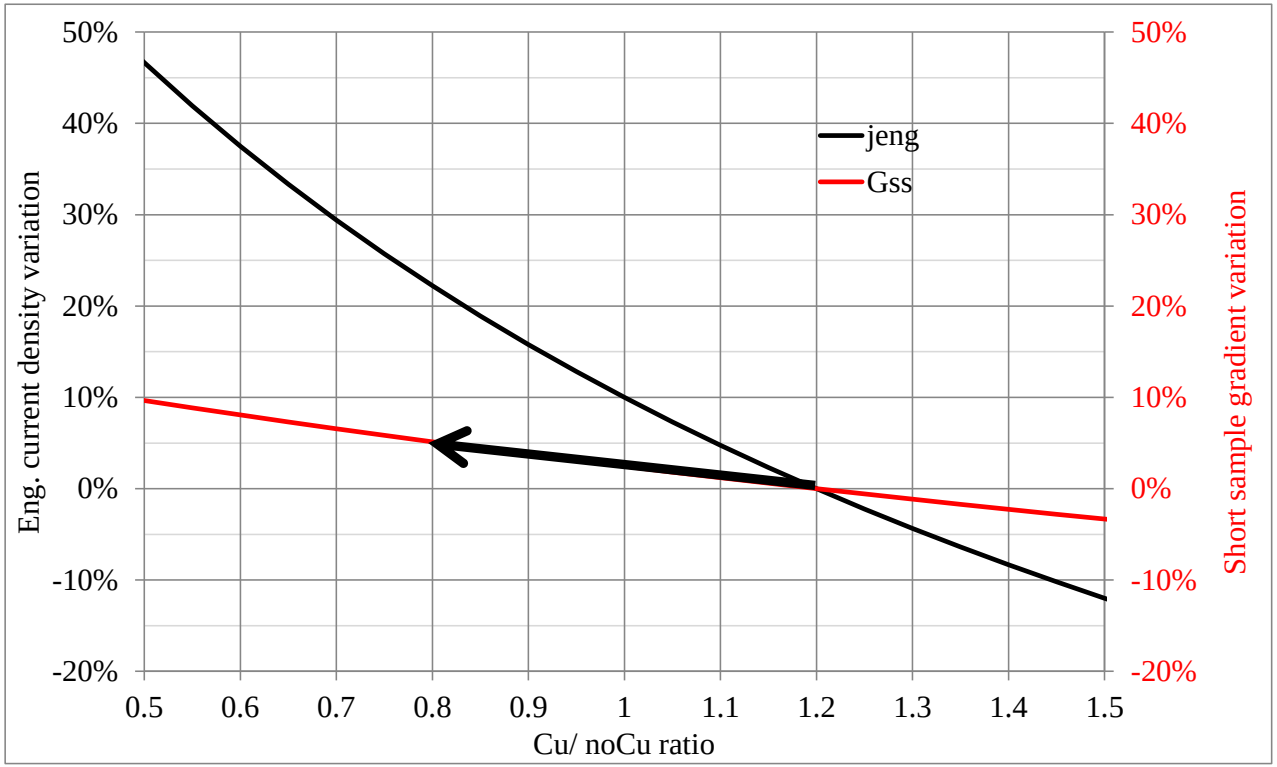
- Second major point: margin
  - Review of LARP results gives some optimism that this margin can be met [G. L. Sabbi talk]
- But (my point of view)
  - Working at 80% on the loadline we take unnecessary risks for the first or second massive (more than 100 m of magnets) application of Nb_3Sn to accelerator
    - In the triplet we can increase the length, and the risk reduction is strong
  - Replacement of a magnet requires at least 6 months
- Possible solution: increase 5% the length: from 4 to 4.2 m for the Q1/Q3 magnets and from 6.8 to 7.15 m for Q2a/Q2b
    - This brings the operational point from 80% to ~75%, with limited performance loss
    - Impact on cost, and limits from the test station

MARGIN

- Second major point: margim - reviewers asked to consider plan B in case of major problems

- Mechanical structure allows easy replacement of limiting coils [G. Ambrosio talk]
  - Already done in LARP, requires more coils
  - Plan is already assuming 25% limiting coils (5 coils to make one quadrupole)
  - Risk reduction factor: early test to intercept problems before final assembly
- Mixed magnets option not wise
  - Solution with Nb-Ti and Nb_3Sn entails large loss of performance …
  - … and a huge overhaed of fully developing another very long Nb-Ti magnet

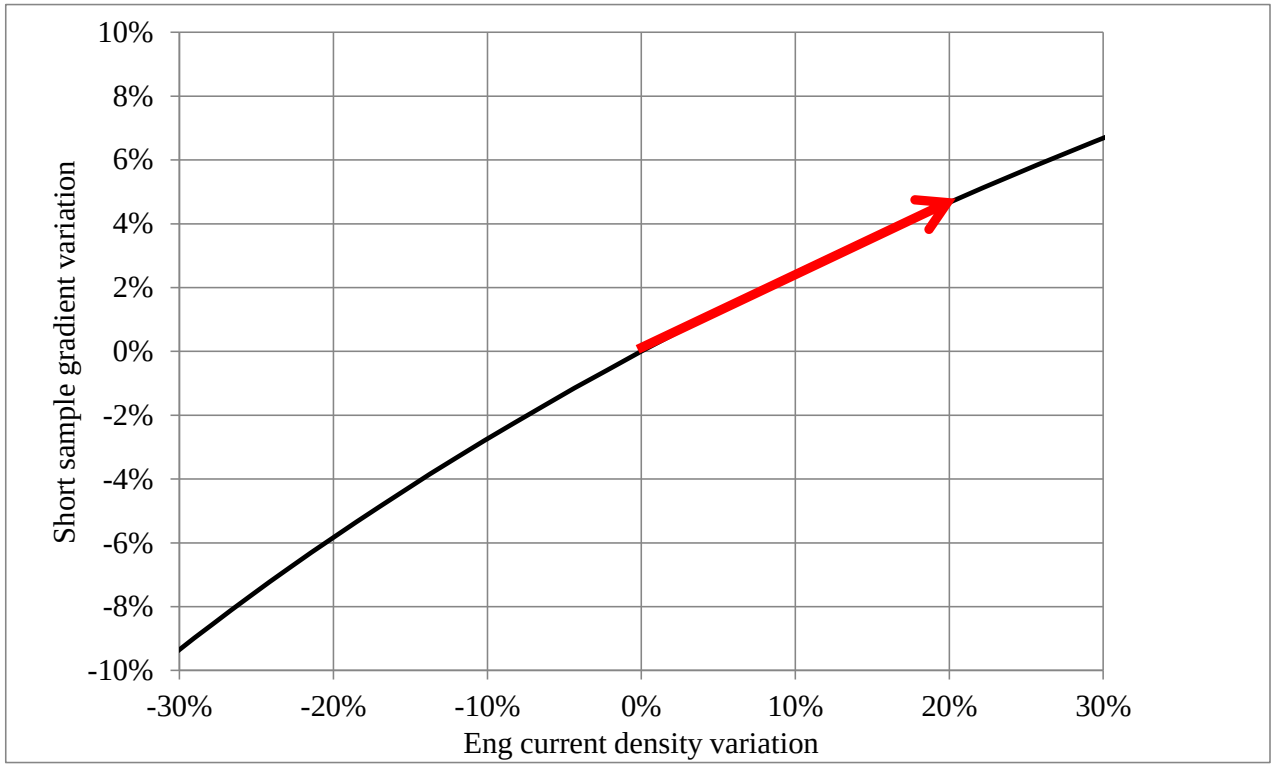
- Others solutions look less viable
  - Example 1: decrease copper – to get 5% more margin you need to lower from 1.2 to 0.8 – non negligible impact on quench protection, which is already tigth



Engineering current density and short sample gradient vs Cu/ no Cu ratio

MARGIN

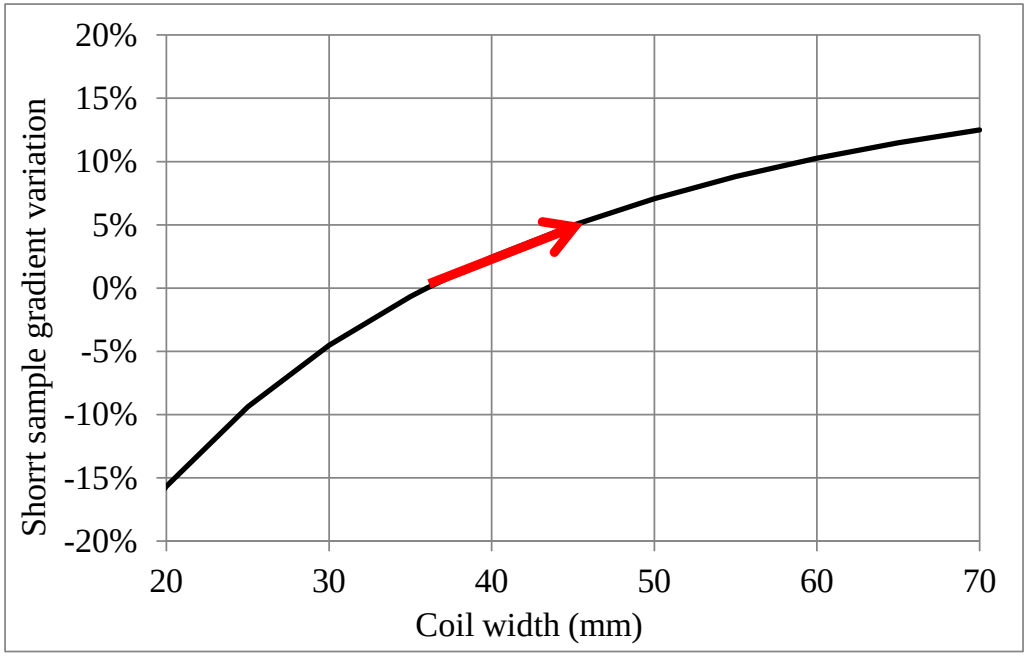
- Others solutions look less viable
  - Example 2: increase current density (already not there) – ~20% more needed to get 5% more margin



short sample gradient vs engineering current density

MARGIN

- Others solutions look less viable
  - Example 3: increase cable width
    - We are at 40 strands, limit for CERN cabling machine, so this would imply go to larger strands (0.9 to 1 mm diameter) – major change
    - Moreover, to get 5% more we would need 46 mm width (,three layers +30% cable cost)



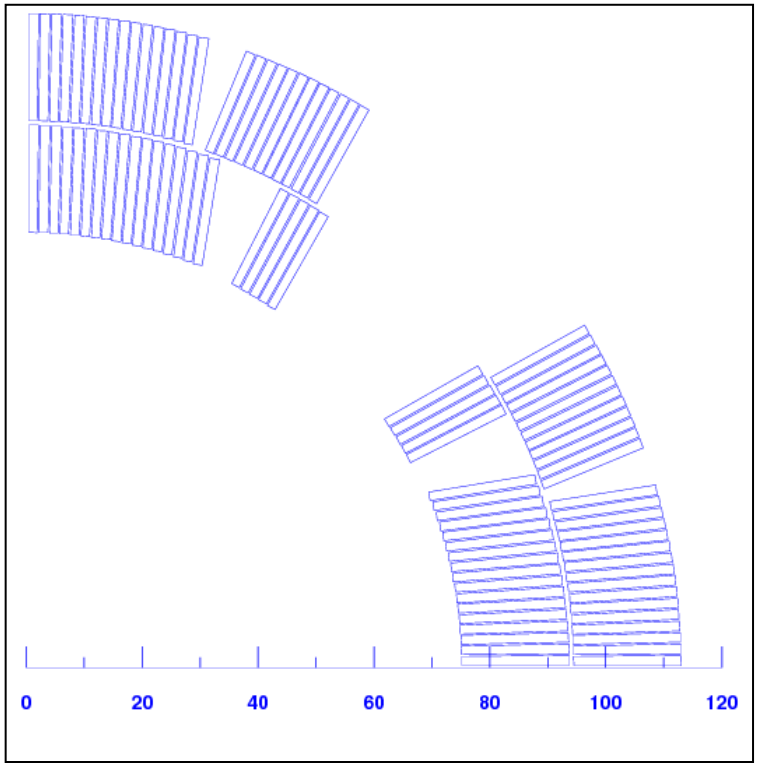
short sample gradient vs coil width

CABLE SIZE

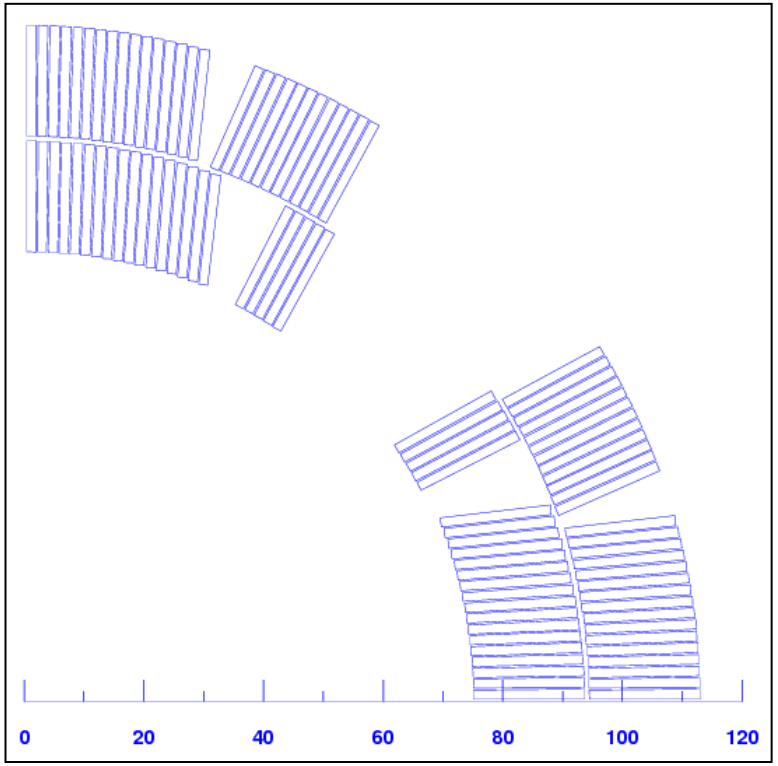
- There is some evidence that a fine tuning of the cable dimension provides less degradation (jc and RRR)
  - Mainly for PIT, could beneficial for RRP
  - Proposal to reduce keystone angle from 0.65° to 0.4°
  - Minimal impact on cross-section, but a new cross-section
  - Reduction of the risk associated to degradation due to cabling
- Overhead
  - Coils are already being fabricated, but no test done yet
  - If we go now with the fine tuning, we lose one/two model for statistics of reproducibility
    - Or better, we lose the statistic on b_6, but not on a_3, b_3, a_4, b_4, which are the most worrying
  - Otherwise we wait for the end of the model, get statistic, and make fine tuning for the production

CABLE SIZE

- I would call this a fine tuning, not a change of cross-section



Baseline cross-section (0.65° keystone angle cable)



Possibl fine tuning (0.4° keystone angle cable)

CONCLUSIONS

- Critical issues seen by the review
  - Current density not there
  - Margin too optimist
- Actions to improve current density
  - Guideline: keep the spec and try to get there
  - Actions (heat treatment and/or increase copper) in 2015
- Actions to improve margin
  - To be discussed in this review (longer magnet?)
  - Decision to be taken in January 2015
- Advice to minimize risk on RRR
  - Fine tuning on cable dimension
  - Decision to be taken in January 2015 (after more data and feedback of US colleagues on impact of change for the RRP)