LHC upgrade plans

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Content

- Scope of Phase 1 of the LHC Lumi upgrade
- Status of the project
- New situation from spring 2010
- Present plan for the upgrade
  - Scope
  - Completion of Phase 1 R&D
  - Preparing LHC: MSs, Corrector new scheme…
  - New technologies for IR magnets
  - Crab cavities
  - Other technologies (Collimation, SC links, …
- Thanks are due to : R. Ostojic, S. Fartouk, S. Russenschuck, G. Kirby, M. Karppinen, A. Ballarino, S. Caspi and many others

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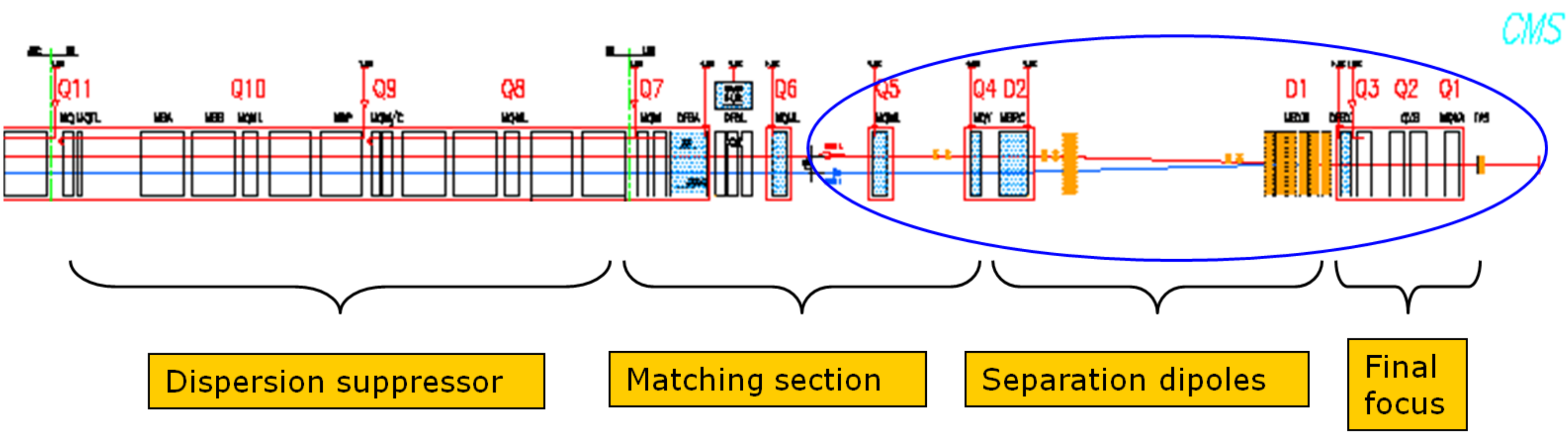
  - Crab cavities
  - New Cryogenics
  - Back up solutions…

The ATLAS and CMS interaction regions



LHC low-β triplet

• Position	$L^* = 23$ m
• Quad gradient	205 T/m
• Coil aperture	70 mm
• β^*, $\mathcal{L}$	55 cm, 10^{34} cm^{-2}s^{-1}
• Dissipated power	180 W @ 1.9 K

Nominal Luminosity $1 \cdot 10^{34}$ cm^{-2}s^{-1}

LHC IR Upgrade – Phase-1

Goal of the Project:

Provide more flexibility for focusing of the LHC beams in the ATLAS and CMS insertions, and enable reliable operation of the LHC at 2 10^{34} $cm^{-2}s^{-1}$.

Scope of the Project:

1. Upgrade of ATLAS and CMS interaction regions. The interfaces between the LHC and the experiments remain unchanged.
2. The cryogenic cooling capacity and other infrastructure in IR1 and IR5 remain unchanged and will be used to the full potential.
3. Replace the present triplets with wide aperture quadrupoles based on the LHC dipole (Nb-Ti) cables cooled at 1.9 K.
4. Upgrade the D1 separation dipoles, TAS, TAN and other beam-line equipment so as to be compatible with the inner triplets.
5. Upgrade the LHC optics, ensure optics flexibility and machine protection with appropriate layout and additional protection equipment.

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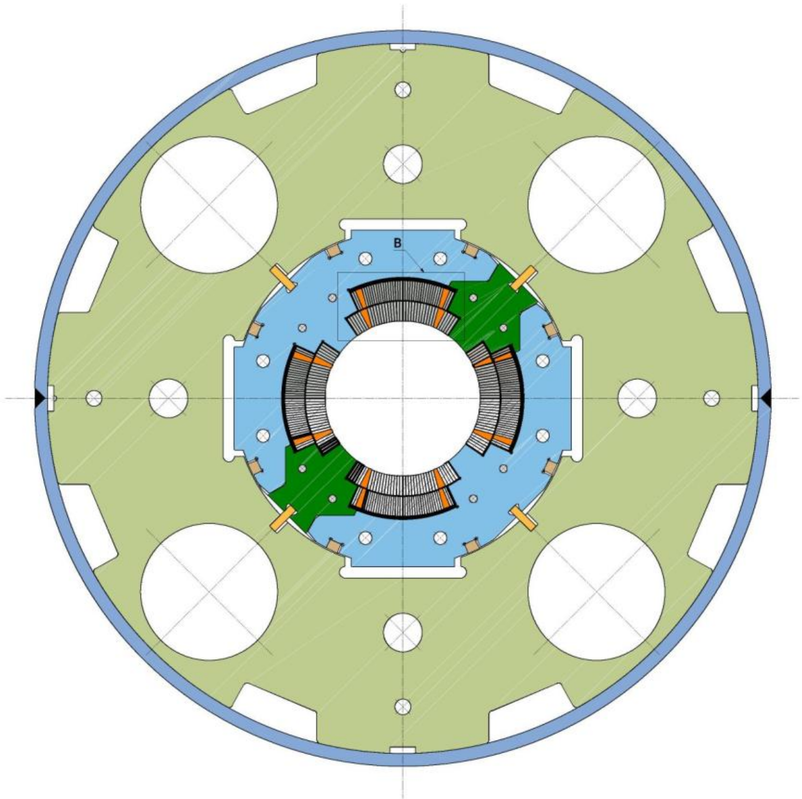
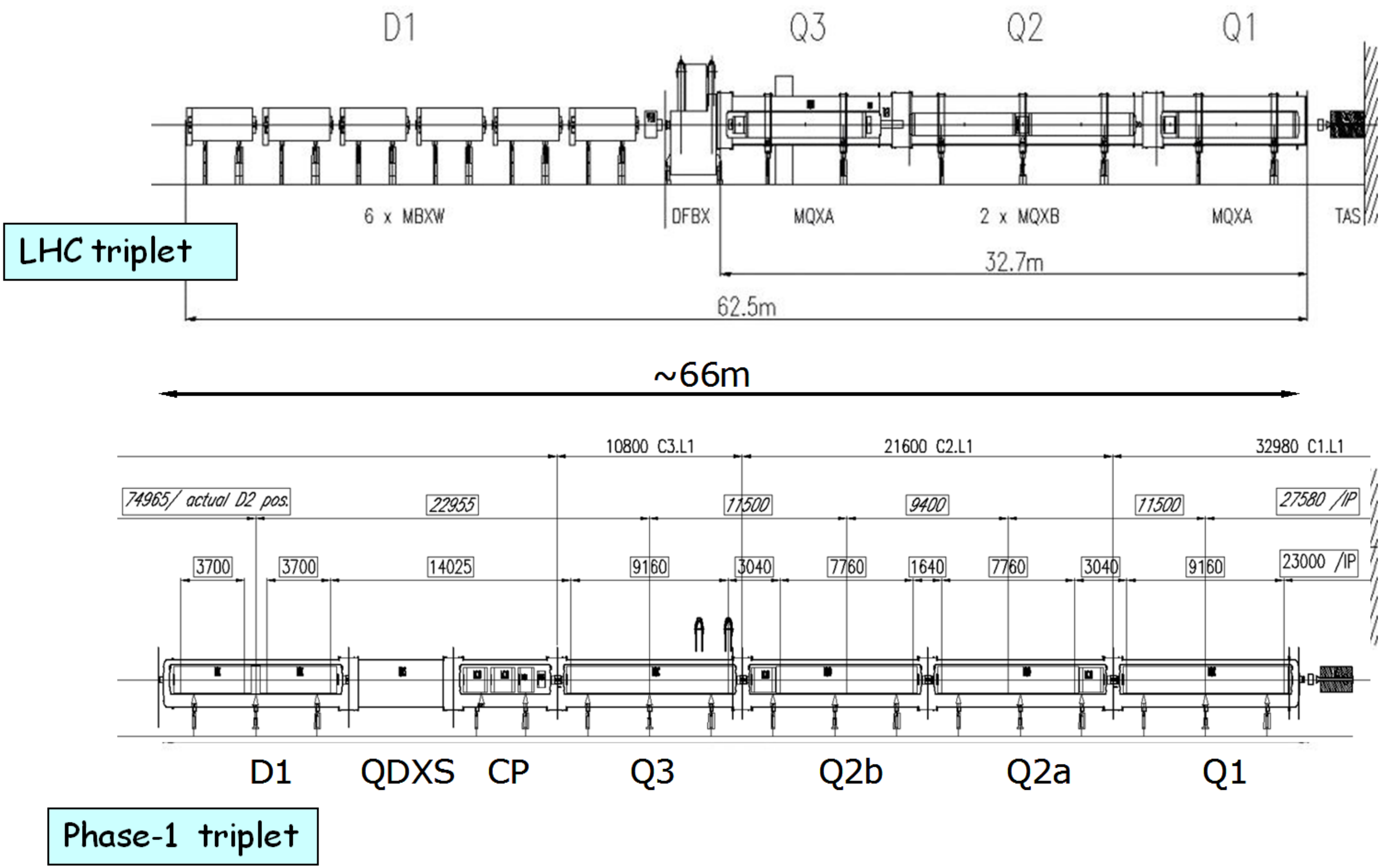
Main Magnets : MQXC



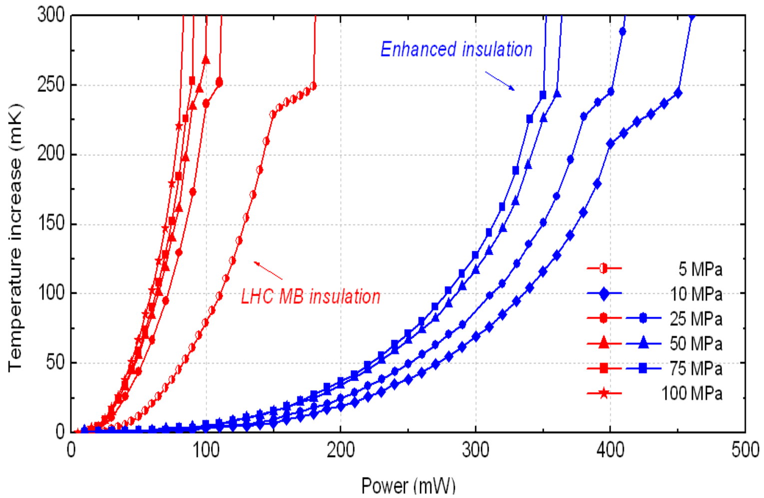
• Coil aperture	120 mm
• Gradient	127 T/m
• Operating temp	1.9 K
• Current	13.8 kA
• WP on load-line	85%
• Inductance	5.2 mH/m
• Yoke ID	260 mm
• Yoke OD	550 mm
• Magnetic length	9160 mm (Q1,Q3) 7760 mm (Q2)

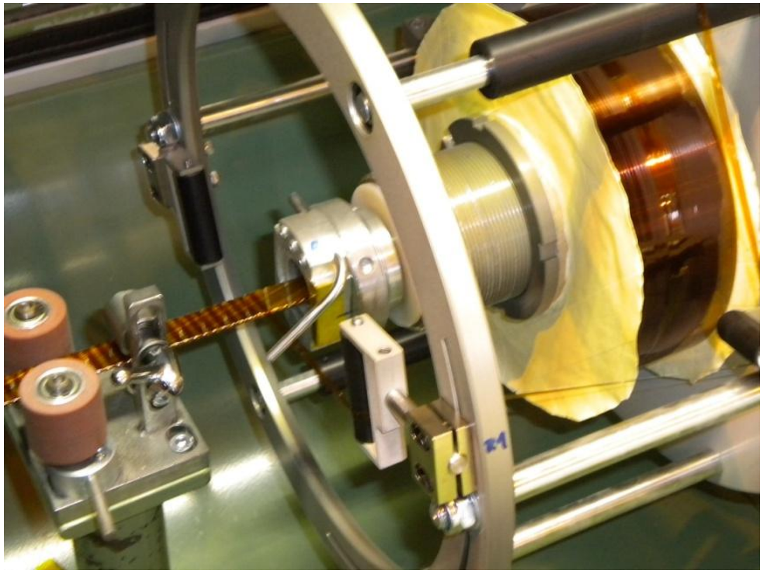
- LHC cables 01 and 02
- Porous cable polyimide insulation
- Yoke OD identical to MB
- Self-supporting collars
- Single piece yoke
- Welded-shell cold mass

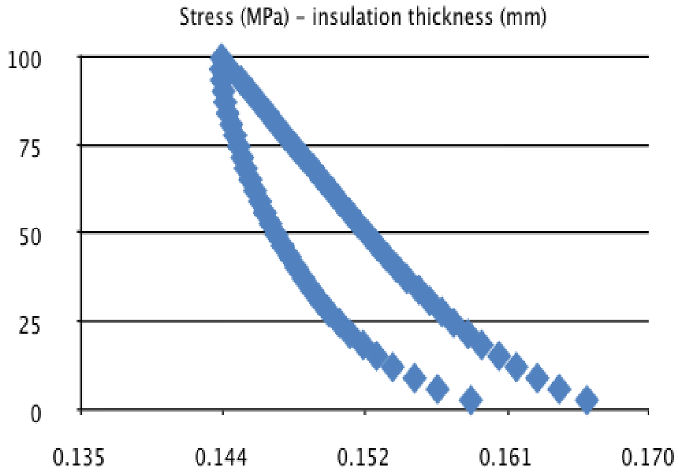
Triplet layout

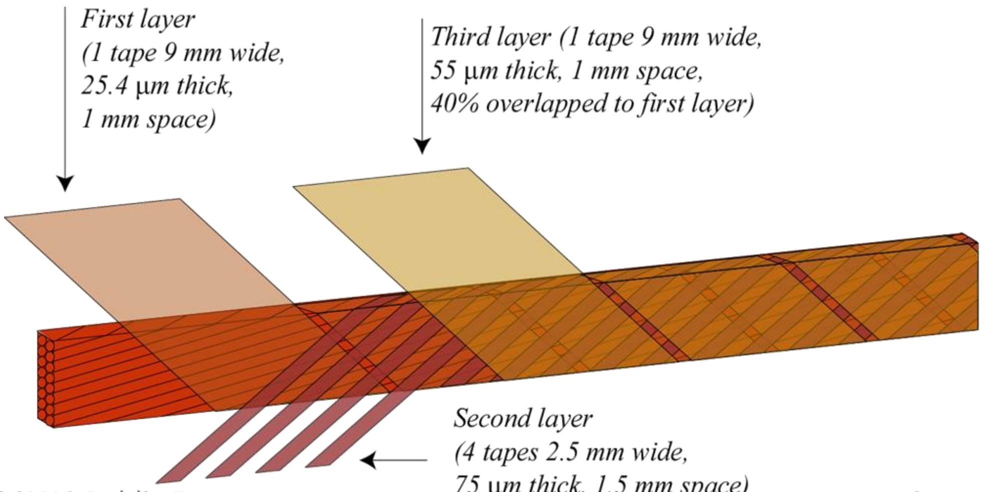


New features : porous cable insulation

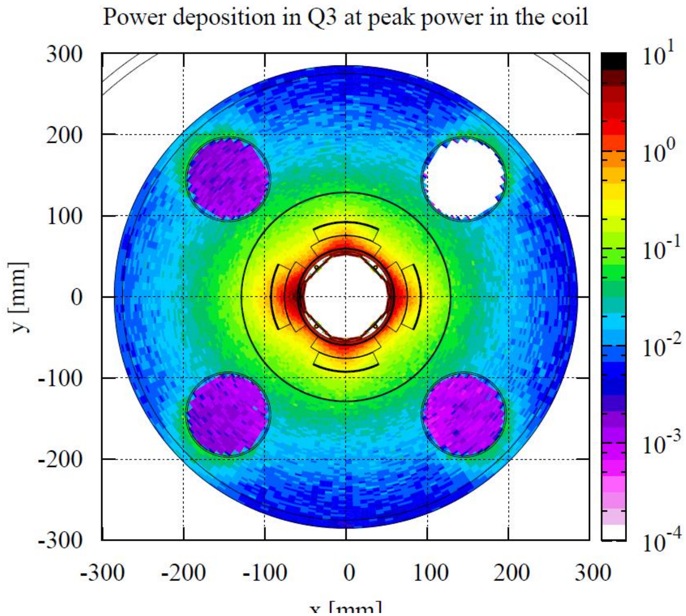


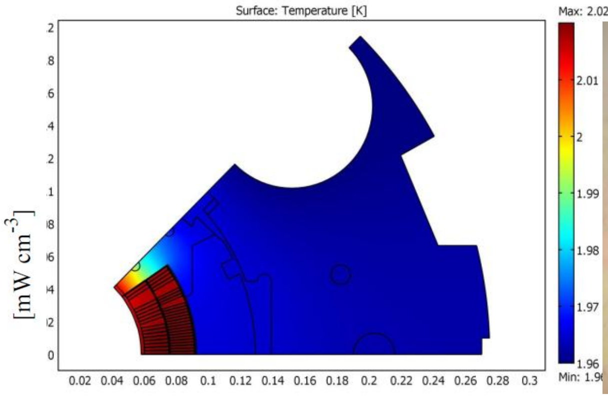


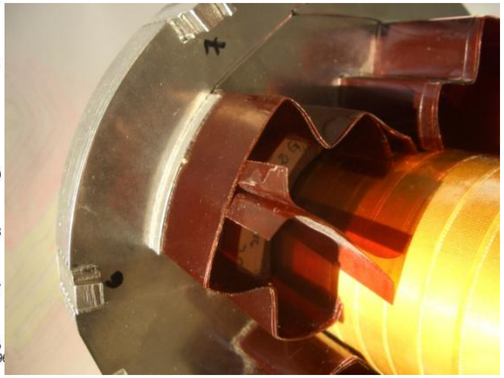




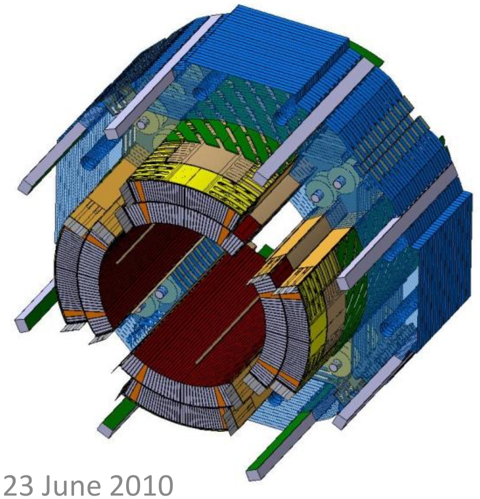
Porous inter-layer insulation

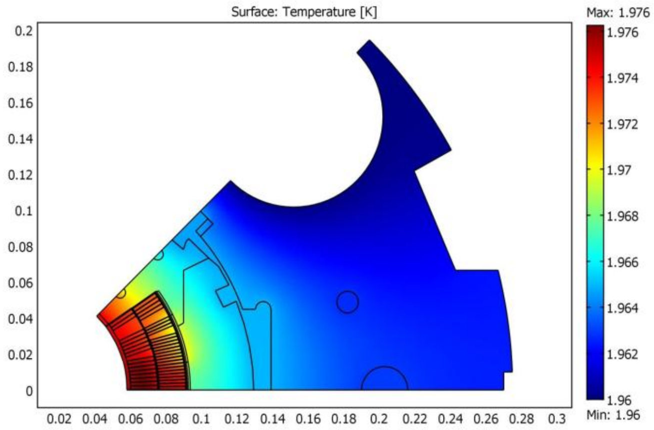


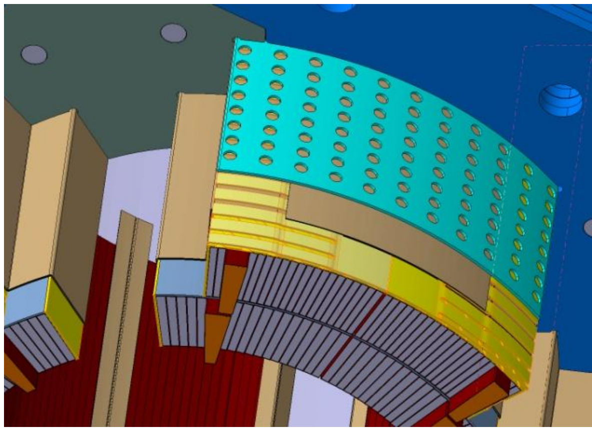




Conventional ground insulation



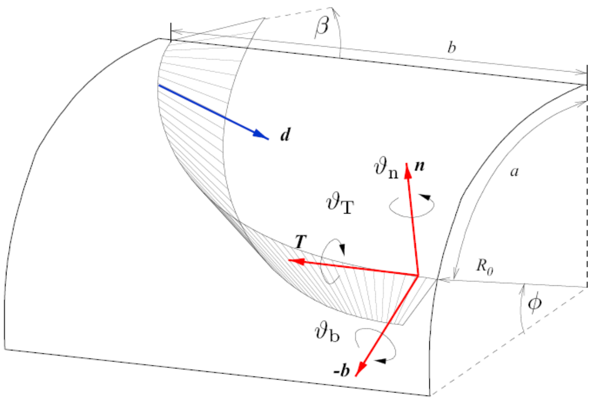


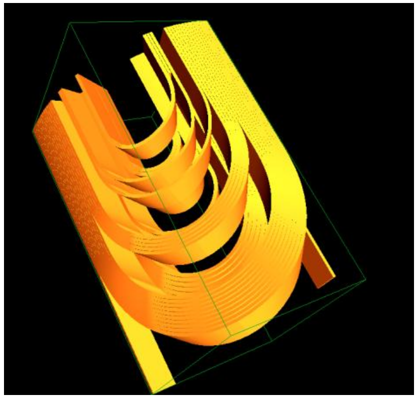


Open KCS ground insulation

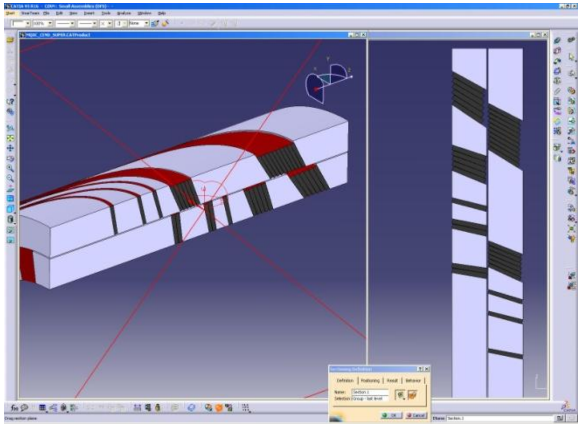
Advanced Engineering

Differential Geometry Model

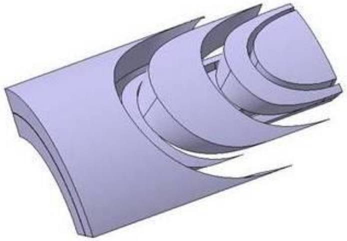


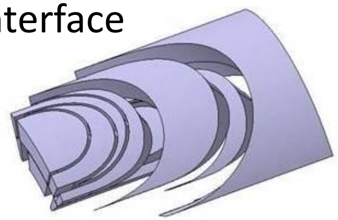


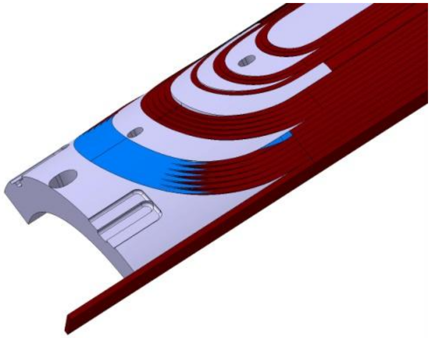
Virtual Reality Preview



Roxie-Catia Interface



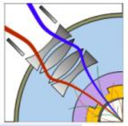


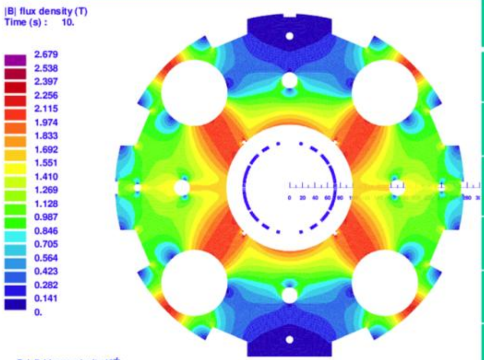


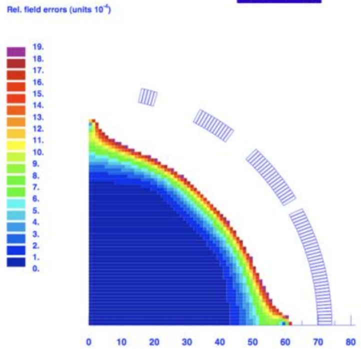
Rapid Prototyping

Main corrector magnets

MCXB Single-Layer Design



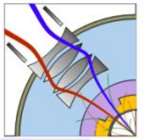


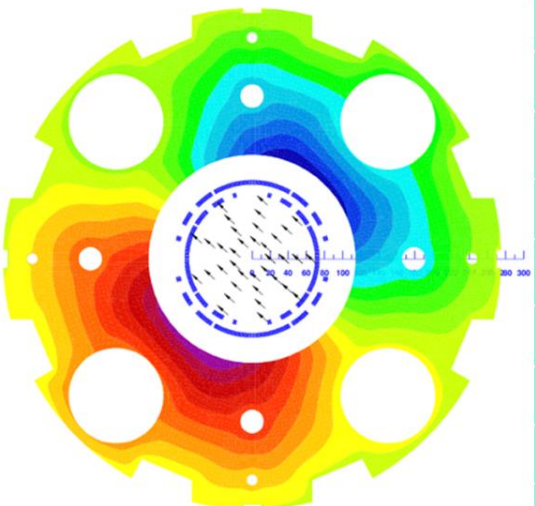


	Unit	
Integrat		
Nomina		
Mag. len		
Nomina		
Stored e		
Self indu		
Working		
Cable w		
Total len		
Apertur		
Total ma		

M. Karppinen TE-

MCXB Nested Design Concept





	Unit	
Integrated field H & V	Tm	1.5
Nominal field H &V	T	2.3
Mag. length	m	0.65
Nominal current	A	2400
Working point		<70%
Cable width/mid-height	mm	4.37 / 0.845
Total length	m	~1
Aperture	mm	Ø140
Total mass	kg	~2000

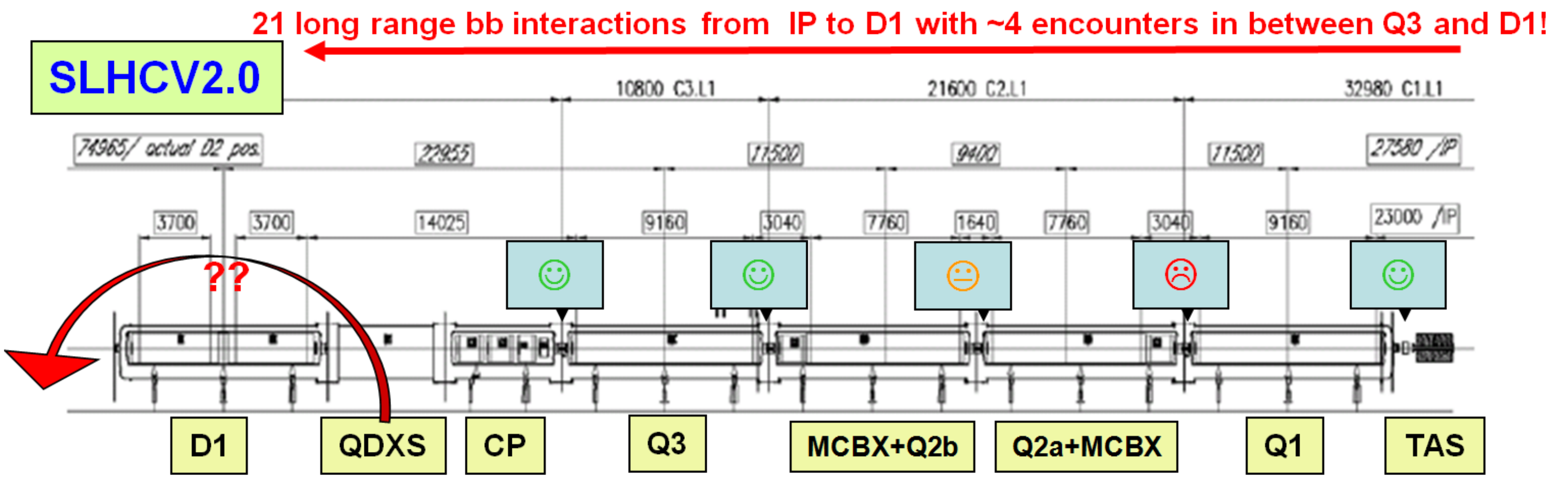
Very robust fixing between layers
5-10 time more rad hard than present

03/02/10 M. Karppinen TE-MSC-ML 12

A complete solution for β* ≥ 30 cm (1/4)

- **Layout**

→ **Two different versions developed in 2009 with similar β_{max}**



Triplet → **2 types of different length** Q1/Q3 & Q2a/b: 120 mm coil ID, 123T/m(Q1,Q2) & 122T/m(Q3)

Orbit corrector → **MCBX in the Q2a & Q2b cold masses: Double plane highly desirable (sLHC-PR30)**

BPM → BPMSW in front of Q1, 4 cold BPM's in the IT: **all except 1 BPM very close to optimal positions.**

Corrector package (CP) → MCBXH/V, MQSX(a2), MCSX(b3), **(a3, a4, b4, b6) not yet implemented.**

Separation dipole → **New D1** using 2 RHIC DX magnets per D1: 180 mm aperture, ~30Tm ITF.

TAS/TAN → **New TAS** (50 mm aperture), **new TAN** with wider aperture not yet defined.

Matching section → **Nominal**

S. Fartoukh LHC Performance Workshop 2010 7

A complete solution for $\beta^* \geq 30$ cm (4/4)

- **Squeeze … A very complex gymnastic!**

→ The LHC IR's were designed to be squeezable at **constant overall phase.**

→ **Not enough tunability in the dispersion suppressors to make a full squeeze at constant Left and Right phase individually.**

→ Playing with the triplet settings during the squeeze (at the 2-3% level) is found the only way to **keep constant the Left/Right IR phase advance at least over a certain range of β^*: 30 cm < β^* <1.5m.**

→ The squeeze is then done in **3 steps:**

1) **More or less "standard" up to β^*=1.5 m** **at cst overall phase advance**
2) **Stop at β^*= 1.5 m** to prepare the correction of the off-momentum β-beat (full use of the 32 sextupole families per beam).
3) **Continue up to β^*_{min} =30 cm** **at cst Left/Right IR phase advance** (to preserve the chromatic correction efficiency).

Summary and discussion

- **An new overall optics** is needed for the chromatic correction of the new IT. **This means an almost new machine to be re-commissioned.**

- **A palette of solutions is possible in collision, between two extreme configurations, each of them hitting at least one hard limit given by the LHC ring @ 7 TeV:**

→ **β* = 30 cm → 40 cm:** lower β* hardly limited by **gradient limits** (lattice sextupole, IR quads) and then **MS aperture**.
→ **Full crossing-angle = 410 → 560μrad:** higher X-angle hardly limited by **MCBY/MCBC strength**
→ Giving a peak luminosity between **2 × 10^{34} cm^{-2}s^{-1} and 3 × 10^{34} cm^{-2}s^{-1} @ ultimate intensity.**

- **While the aperture of the new IT is clearly not questioned, the IT layout shall still be optimized keeping in mind these two extreme configurations:**

→ **Double plane MCBX** highly desirable for the quality of the orbit correction in the new IT, but also to decouple it from the generation of the X-scheme, otherwise a X-angle of 560 μrad is out of reach (sLHC-PR30).
→ **Minimize the number of parasitic b-b encounters:** QDXS moved on the non-IP side of D1, solution with N-lines?
→ Further optimize the **Field Quality of the new IT** (targets still to be finalized and a good compromise to be found) with a **particular concern for D1** (e.g. a factor of 5 missing for a2/b3 comparing the requirements and the first offer).

- The next step is to decide **what is the most likely configuration to "guaranty a reliable operation of the machine with a peak lumi ≥ 2 × 10^{34} cm^{-2}s^{-1} @ ultimate intensity".**

→ Why did we push for a wide aperture for the new IT?.. Certainly for beam-beam, collimation, but not necessarily β* !
→ **β* ~ 40 cm (→ 35 cm ?)** seems then to be the most promising option, **with a X-angle of ~13 → 16σ still to be fine tuned** for beam-beam, collimation efficiency and impedance (n1/n2), but also debris coming from the IP.

- **Further steps in this direction** shall not be forgotten **to restore operational margins on the "non-IT side"**, also because possibly easy (??) or already needed for the nominal machine:

→ Re-commission **the lattice sextupoles and Q7/Q9's (MQM @1.9K) at higher than nominal current.**
→ Install **warm orbit corrector at Q4** (~1 Tm) to reinforce the MCBY's for IP steering and Vernier scans @ 7 TeV.

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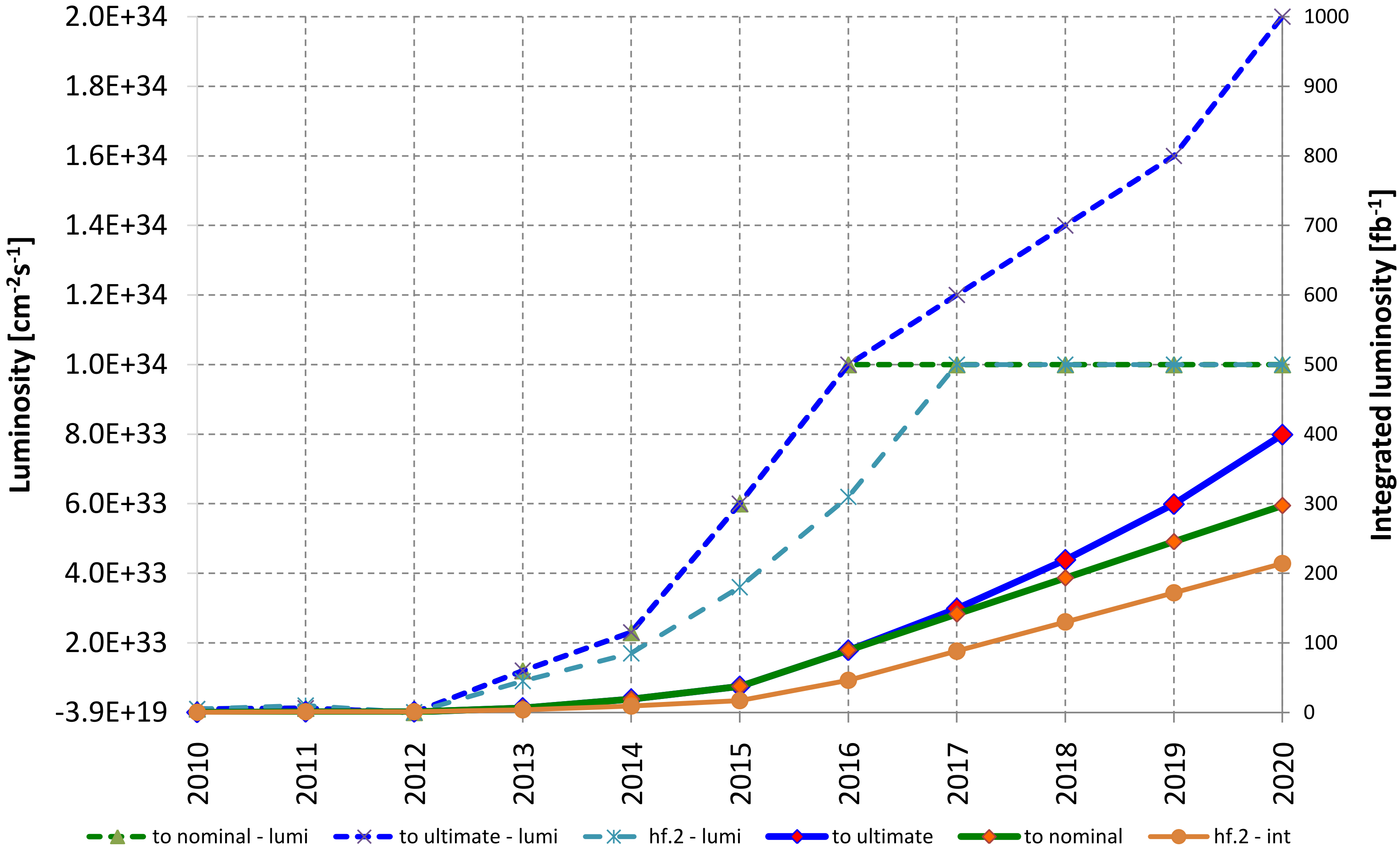
Luminosity increase : plan Spring 2010



Reconsideration on Phase 1

- 1.2 to 1.35 better luminosity with present limitation
- Because of new plan the radiation damage not an issue till 2020
- In any case because of new plan the Triplet cannot be built before 2016 at best.
- Optics much more rigid;
  - requires special scheme. **Aberration sat the limit of LHC correction capability. Longer magnets (same technology) does not help.**
  - 30 cm β^* is more difficult than 55 cm of the present LHC. Better solution found with $\beta^* = 40$ cm offering a 3 sigma margin per beam (which was part of the initial goal) but only 1.2 gain in lumi over nominal. Today we are limited by a single element. IR upgrade will use all the margins in the whole ring.
- To change this:
  - modification in MS positions and replacement of a few magnets,
  - additional IR collimators to catch higher losses in IR matching section (lower aperture due to higher beta* in the not-changed magnets
  - Use ultimate strength in the sextupoles, NEW powering scheme of MQT corrector families. Other possible schemes under study.
- Logistics is hard: The logistic for ancillary equipment is hard.
  - A solution NOT fully satisfactory has been found for IP1; more difficult for IP5.
  - A real long term solution devised, based on long vertical Sc links integrated in a more global study for radiation protection of electronics

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GOAL $5 \cdot 10^{34}$ cm^{-2} s^{-1}

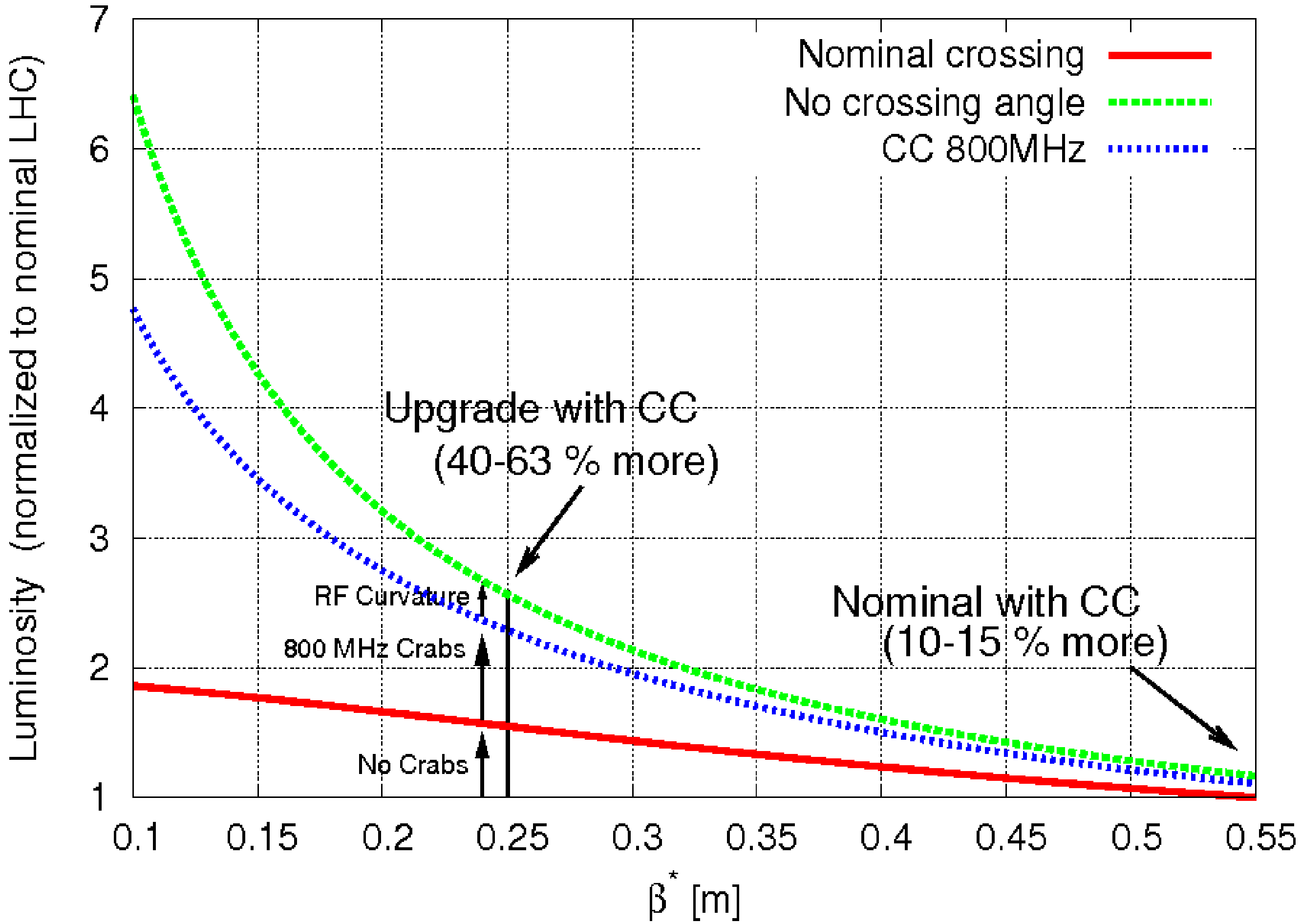
based on ultimate beam intensity - 0.86

- PREPARATION ACTIONS
- Improve some correctors
  - Commissioning @ 600-650 A the lattice sextupoles
  - New MQT corrector scheme using existing spare 600 A bus bars
- Re-commissioning DS quads at higher gradient
- Review MSs
  - Change of New Q5/Q4 (larger aperture), with new stronger corrector orbit, displacements of few magnets
  - Larger aperture D2
- (may be other actions, more quads in points 6 and 7)
- Displacement of Power Converters & DFBs at least of Inner Triplets but also of OTHER equipment on **surface** by means of SC links.
- Cryo-plant for RF in point 4 : 5-7 kW @ 4.5 K

Main technology for the upgrade

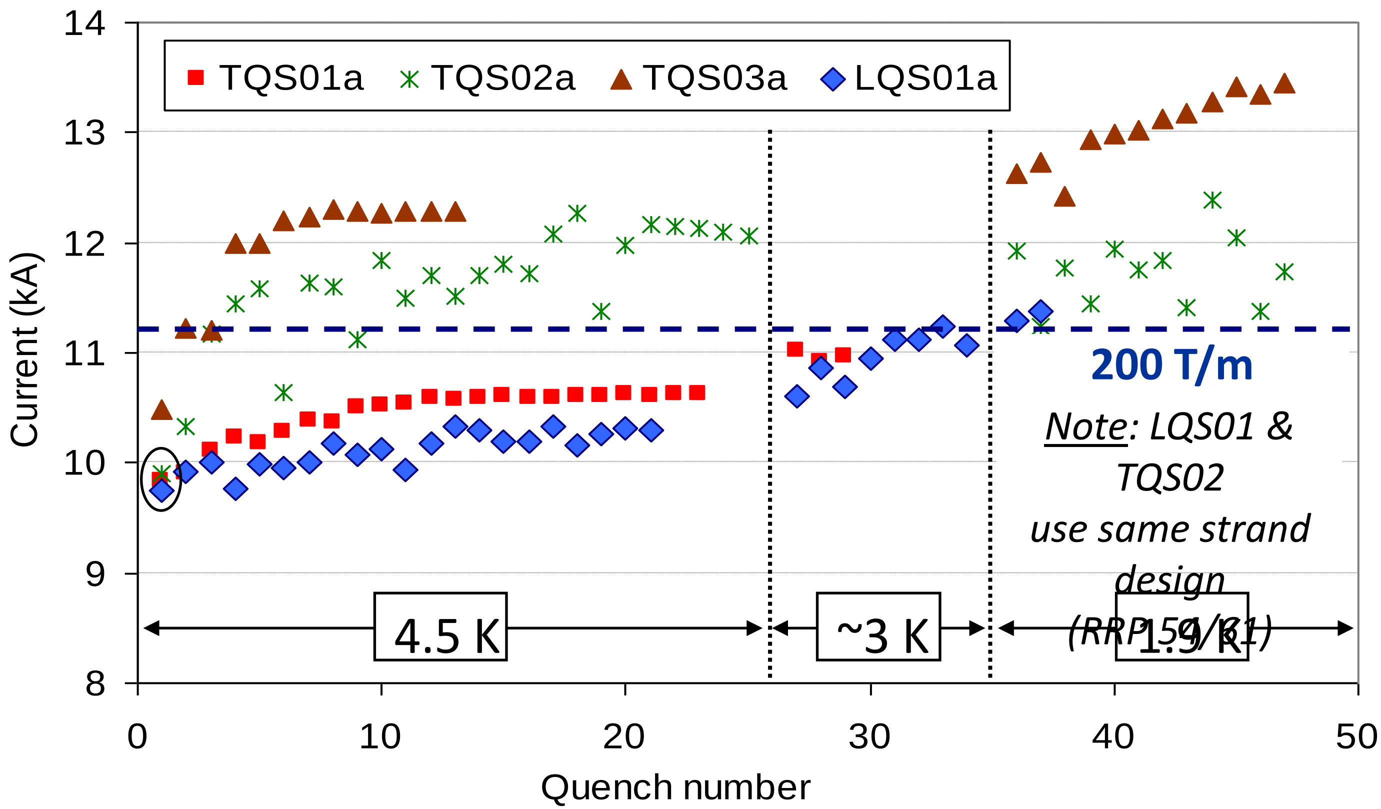
- **High Gradient/Large Aperture Quads, with B_{peak} 13-15 T.** Higher field quadrupoles translate in **higher gradient/shorter length** or larger aperture/same length or a mix . **US-LARP engaged to produce proof by 2013. Construction is 1 year more than Nb-Ti : by 2018** is a reasonable assumption. β^* as small as 22 cm are possible with a **factor ~2.5** in luminosity by itself, **if coupled with a mechanism to compensate the geometrical reduction.**
  - If a new way of correcting chromatic aberration could be found**, β^* as small as 10-15 cm can be eventually envisaged (S. Fartouk).**
- **Crab Cavities**: this is the best candidate for exploiting small β^* (for β^* around nominal only +15%). However it should be underlined that today Crab Cavities are not validated for LHC , not even conceptually: **the issue of machine protection should be addressed with priority.**
    - Global Scheme. 1 cavity in IP4, Proof on LHC, good for 1 X-ing.
    - Semi-global; it may work!(JP Koutchouck)
    - Local scheme; 1 cavity per IP side. **Maybe local doglegs needed.**
  - **Early Separation Scheme** could be an alternative (or a complement)
- **SC links** to replace at the surface elecronic equipment today in the tunnel and exposed to high radiation
- **New Cryoplants** in IP1 & IP5: for power AND to make independent Arc- IR: 2.8 kW @ 1.8 K scales as 5.2 kW @ 2 K (for 1 set of cold compressor)

« Coupling » between HG Quad magnets and Crab Cavities



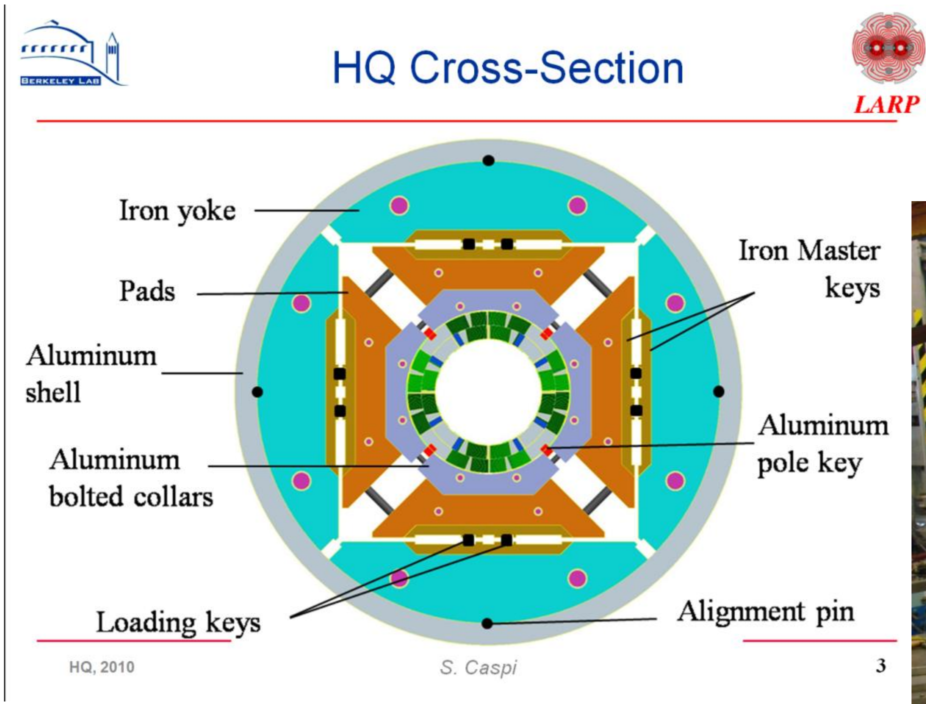
HF Nb_3Sn Quad

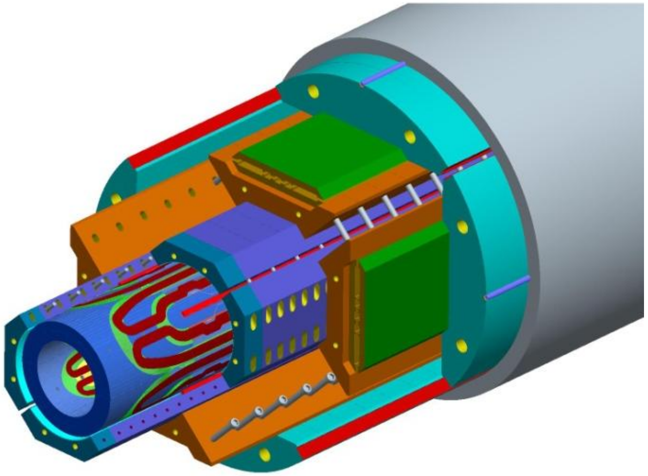
- Nb_3Sn is becoming a reality (first LQ long -3.6 m – quad 90 mm)
- This year we expect a second test of LQ-1 and test of LQ-2

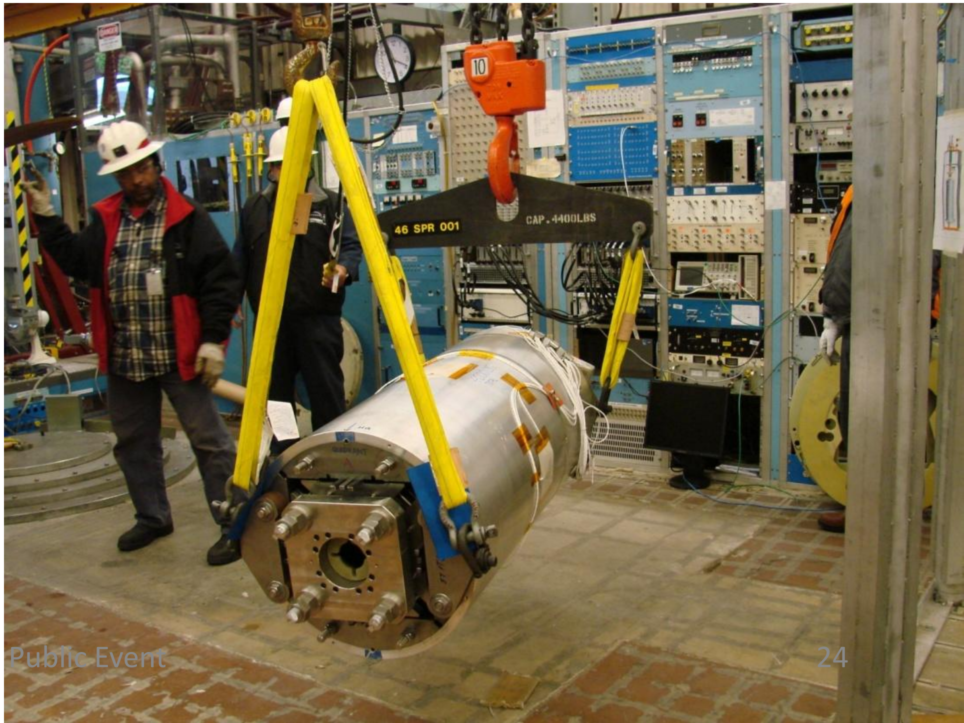


NB_3Sn : HQ

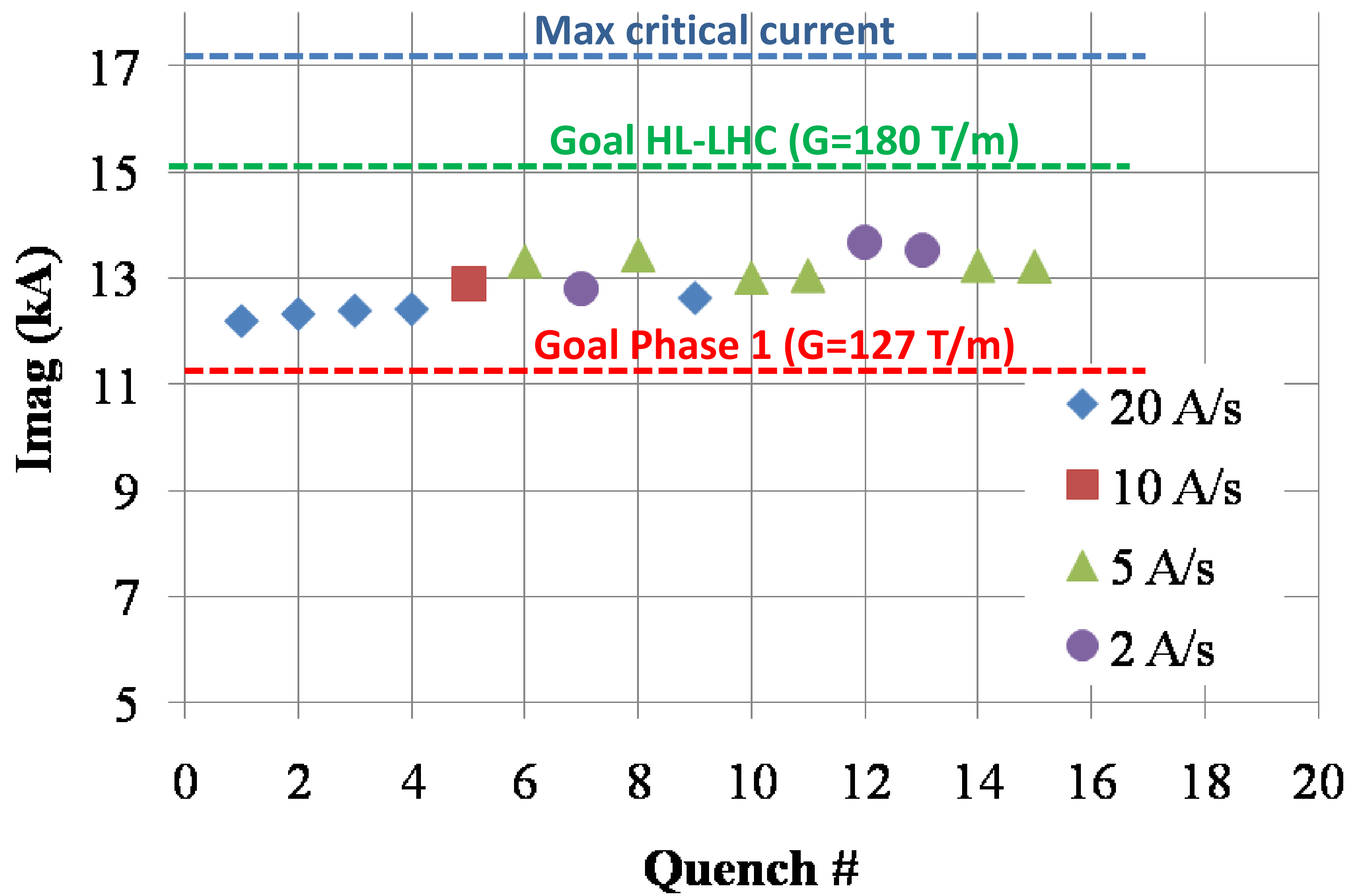
- **HQ: a 1 m long - 120 mm** aperture model
- whose second test is under way



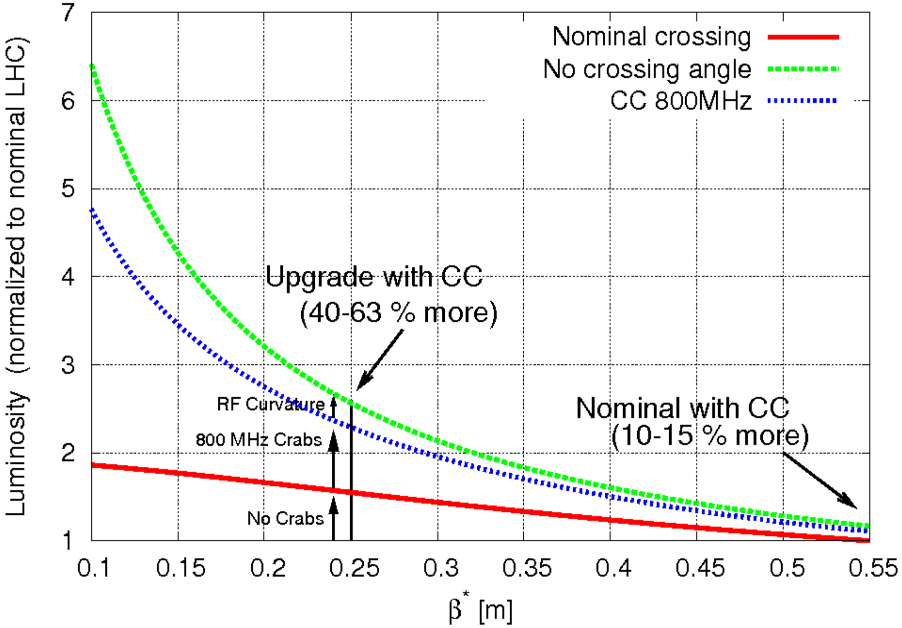


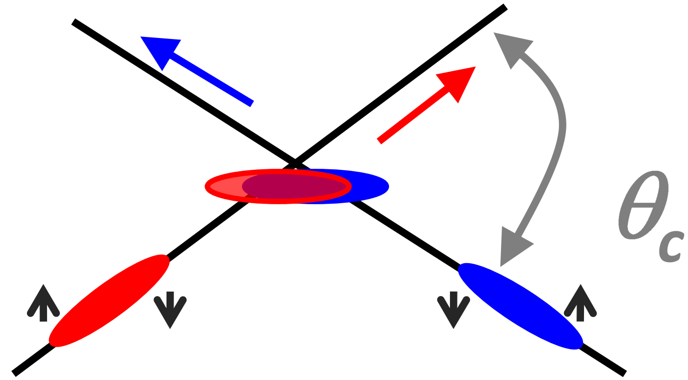


First test : already above the minimum goal (Phase-1 SLHC)

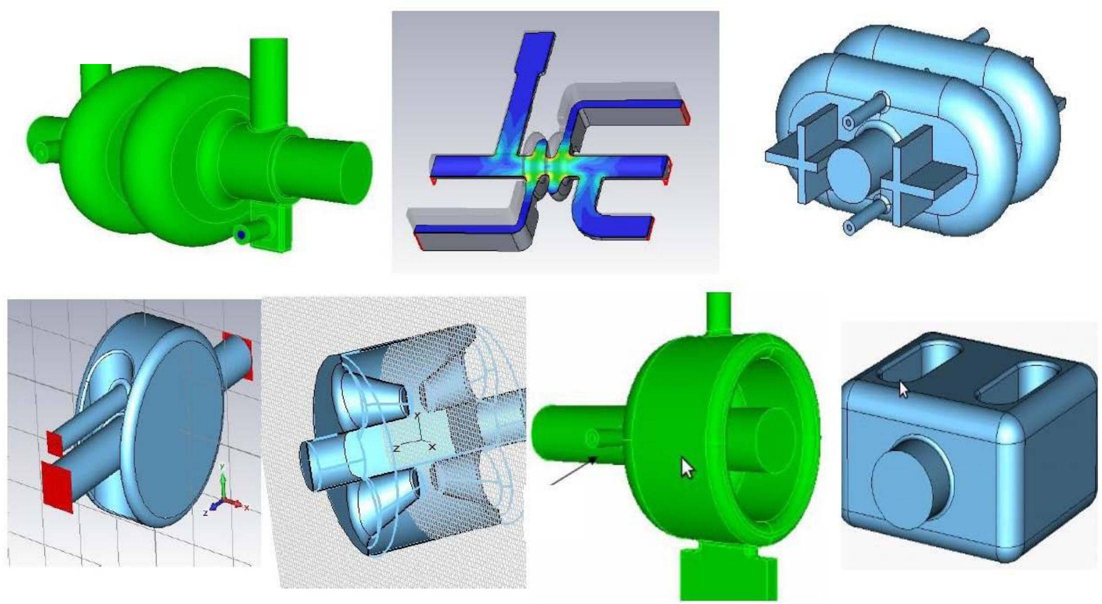


Crab Cavities





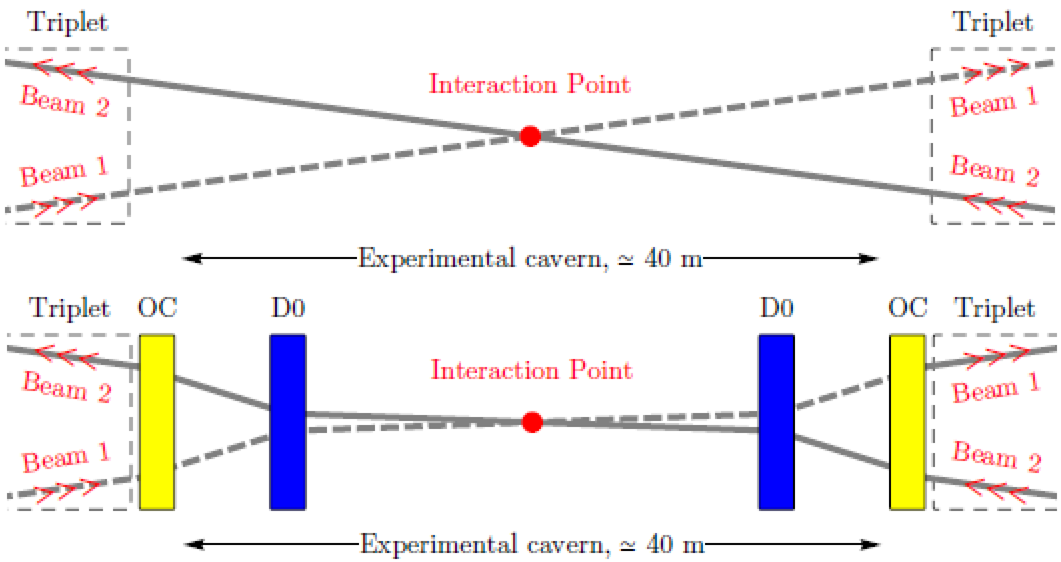
Elliptical 800 MHz not far from being designed. Require 400 mm beam-beam



400 MHz small cavity under conceptual study, they can (?) fit in 194 mm beam-beam. Required for final solution

Ref. : F. Zimmermann, Ed Ciapala

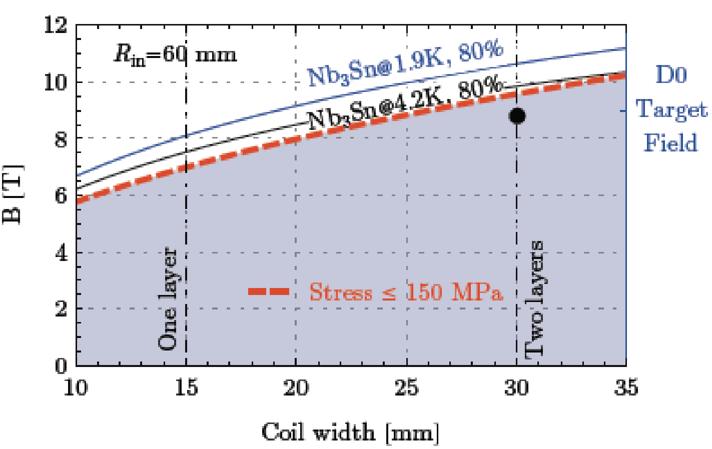
Early separation scheme possible alternative/complement

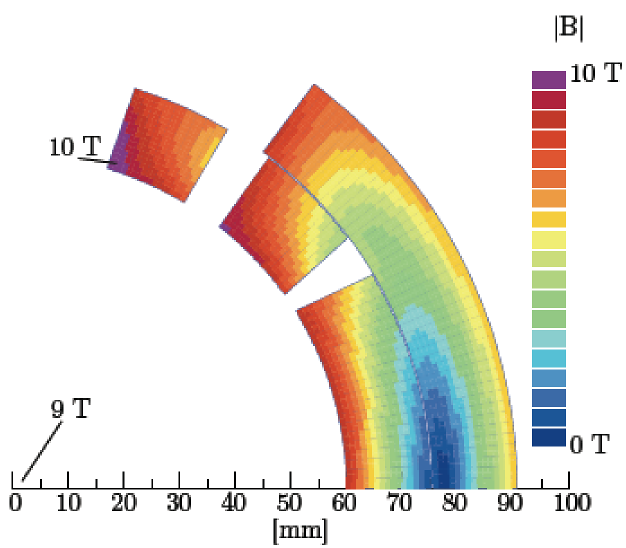


Nb3Sn at 8.5 T to have margin for heat deposition
13 m from IP

Integration difficult but not impossible
Leveling very easy…

Ref. :
JP Koutchouk and G. Sterbini



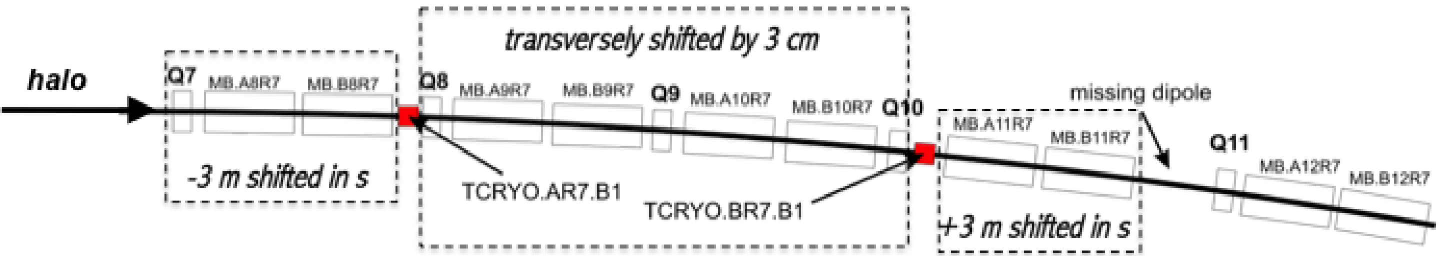


120 mm aperture Nb3Sn dipole required + W shield.

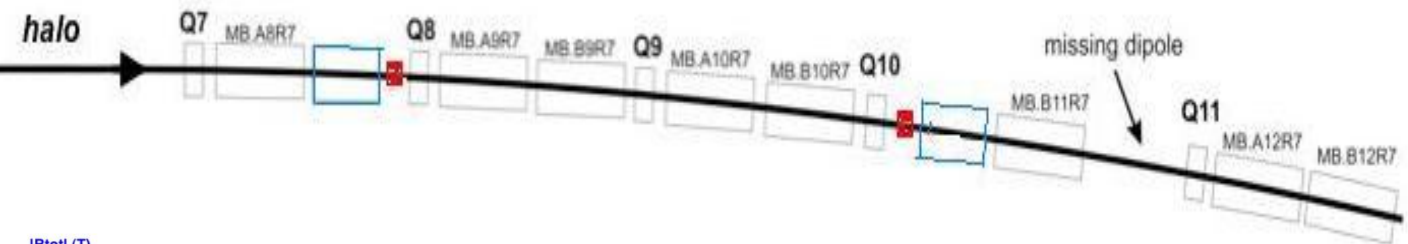
Lumi Plan : projects aiming at 2018-2020

1. New Triplet and IR region. In **2013/14 decision on technology** and of lay-out with all possible equipments. In the plan we assume that a strong US-LARP continue (and even reinforced).
   - **Either** Nb3Sn, if LHC quality magnets will can be manufactured by 2018-2020). New cryo-plant s **at 2K** or, possibly, at **4.5 K**.
   - **Or** Nb-Ti as fall-back solution (cryo-plant at 1.8 K)
2. Crab Cavity (**yes** or **not** in 2014, too) ready on the same time scale of 2018. However, they could be installed later if infrastructure is prepared with the triplets.
   - Early Separation scheme (today in shadow of crab, but…)
3. New DS dipole (twin, 11 T – 11 m) to make room for the cryo-collimators. Available from 2015 (for points 2,7, 1, 5: we assume that for point 3 we are late and we need to displace magnets).
4. New cryo-plants for IP1 – IP5, decision among: 1.8 K, 2.0 K, 4.5 K see above.

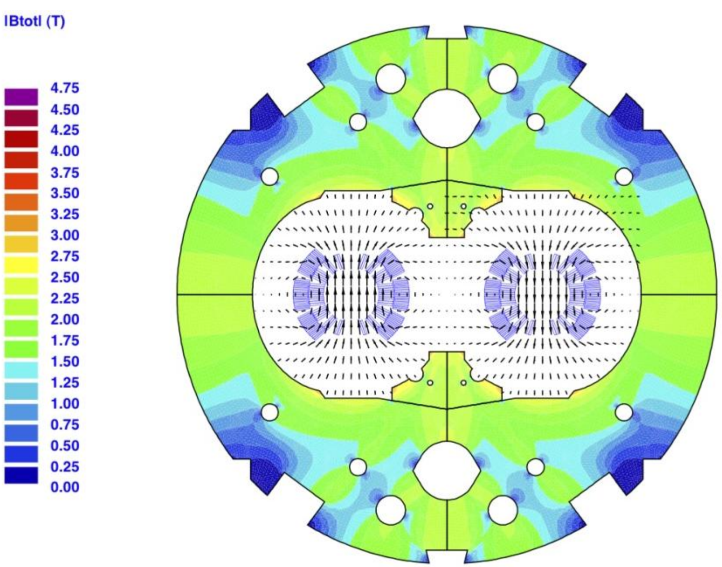
11 T – 11 m Twin Dipole for DS

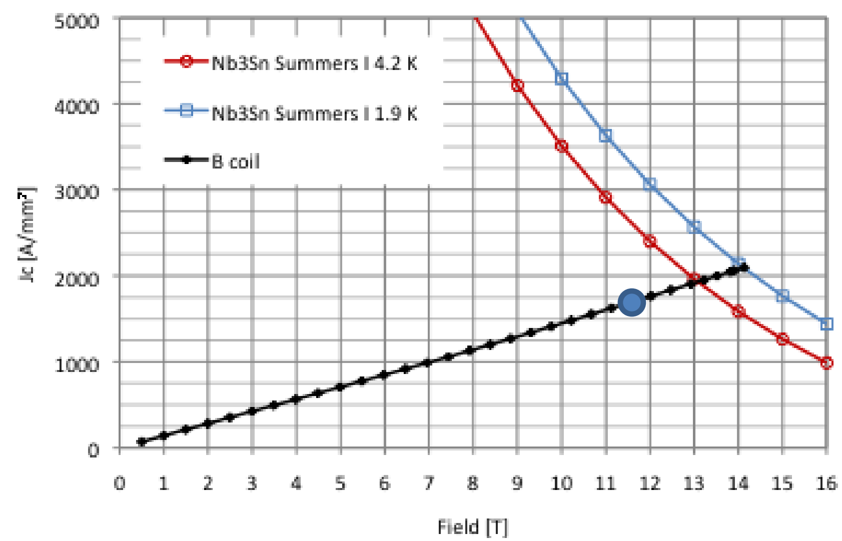


Shift in the magnet position requires to make room for collimators (red squares).

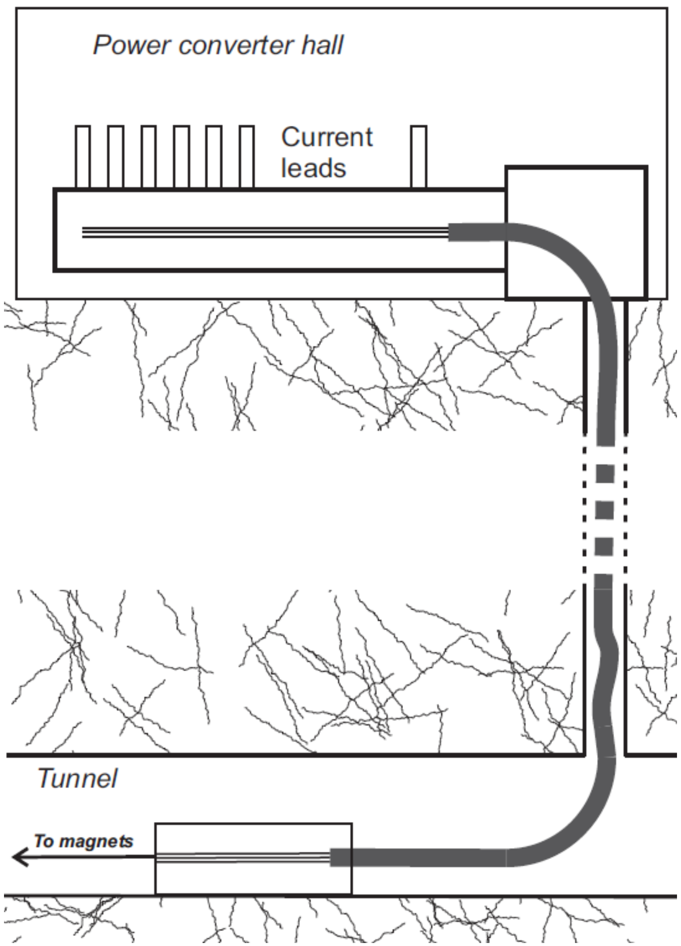


Alternative option based on stronger and shorter magnets (blue rectangles).

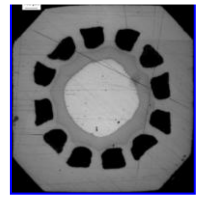




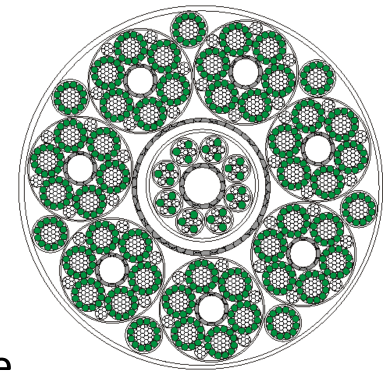
SC link to remove Po.Conv. from H.Rad.



Vertical link
H = 100 m

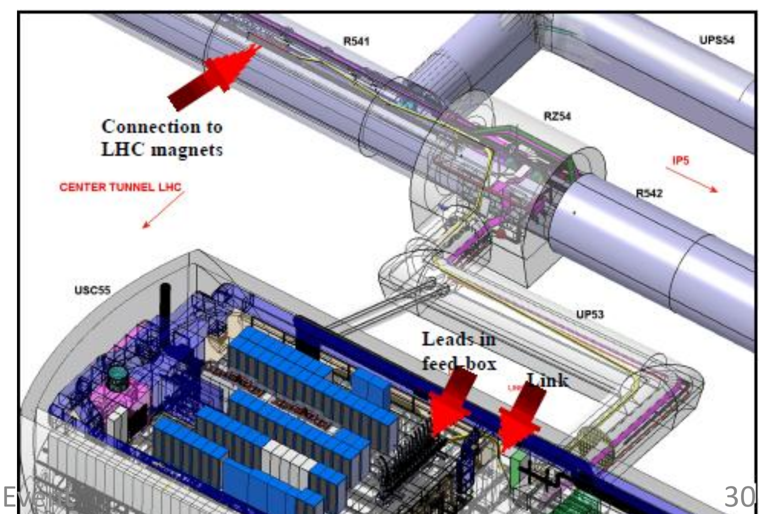


1.1 mm
MgB_2 wire

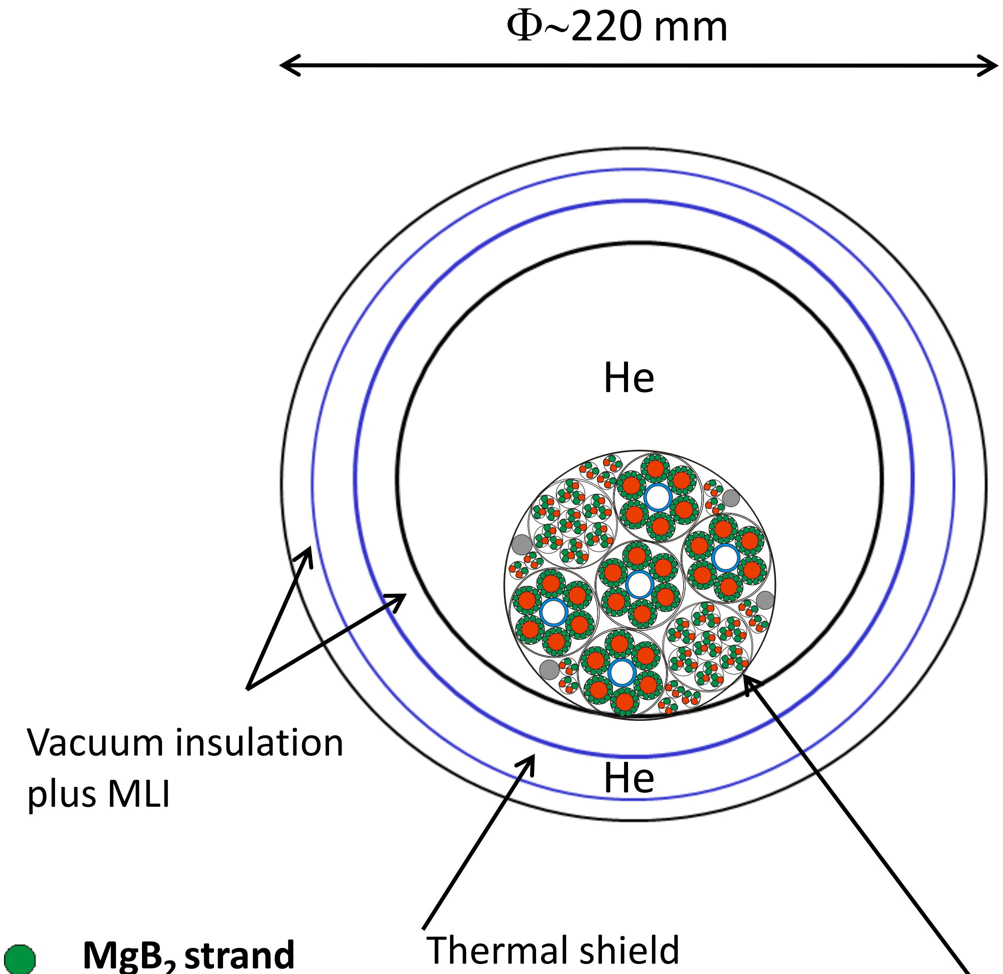


Φ = 62 mm

Semi-horizontal link (100-700 m)



SC link scheme



- **MgB_2 strand**
- **Cu stabilizer**

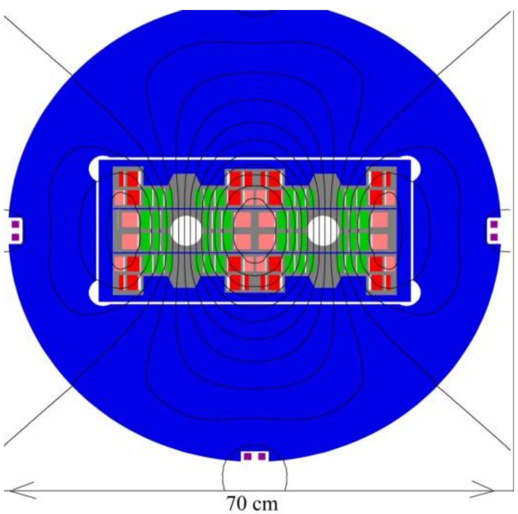
Superconducting **200 kA** MgB_2 multi-circuit assembly (**Φest~60 mm**)
100 electrically insulated cables 120 A, 600 A and 7000 A

Schildgekühlte He-Leitung
Screen cooled He-line

Comments

- **Comprehensive plan aimed to $\sim 5\ 10^{34}\ \mathcal{L}_{peak}$ AND $\int_{year} \mathcal{L} dt \geq 150\ fb^{-1}$ from 2020. Studies under way for scenarii with higher lumi.**
- **Because of the new plan, with a variety of ingredients we need a new and complete Design Study of the whole HL-LHC**

The High Luminosity LHC or SLHC is the route that will enable the way to the Farthest Energy Frontier : an HE-LHC based on 20 T magnets for a 33 TeV c.o.m. collider



P. McIntyre, Texas A&M, 2005