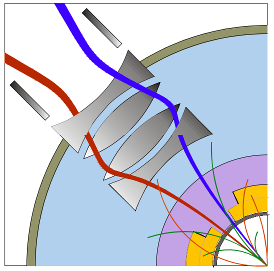
LHC IR Upgrade Phase-I:
Goals and Conceptual Design

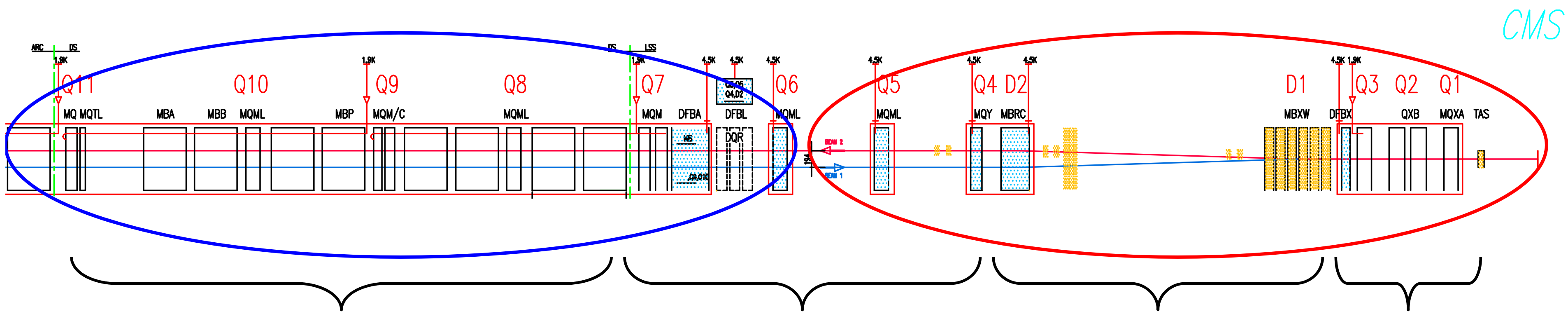


1. Upgrade goals and constraints
2. Conceptual design
3. Organisation and collaborations
4. Perspectives

Acknowledgment to all contributors to the Phase-I Upgrade Conceptual Design Report (LPR 1163)

R. Ostojic, HHH-CARE, Nov 2008

The ATLAS and CMS interaction regions



Dispersion suppressor

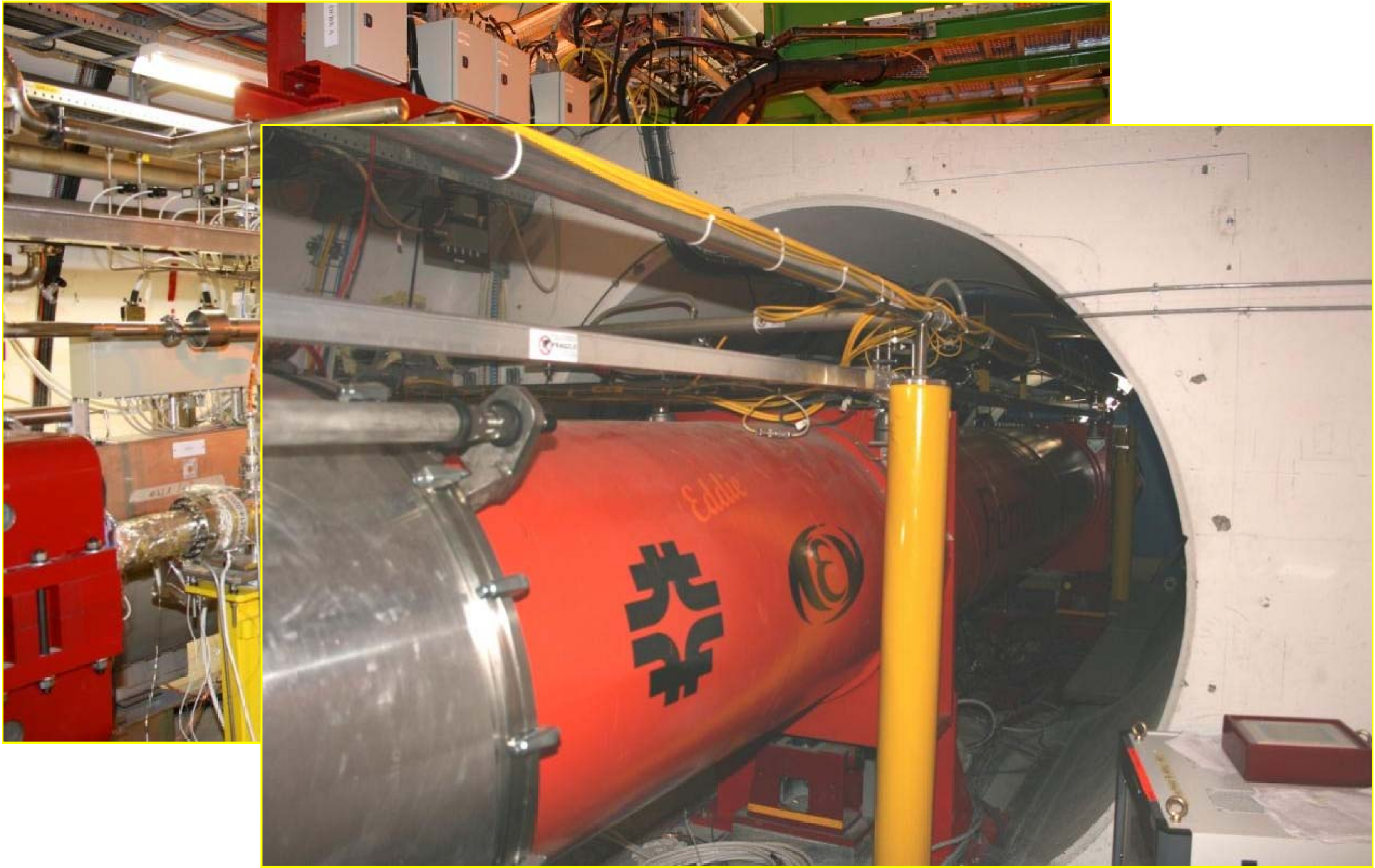
Matching section

Separation dipoles

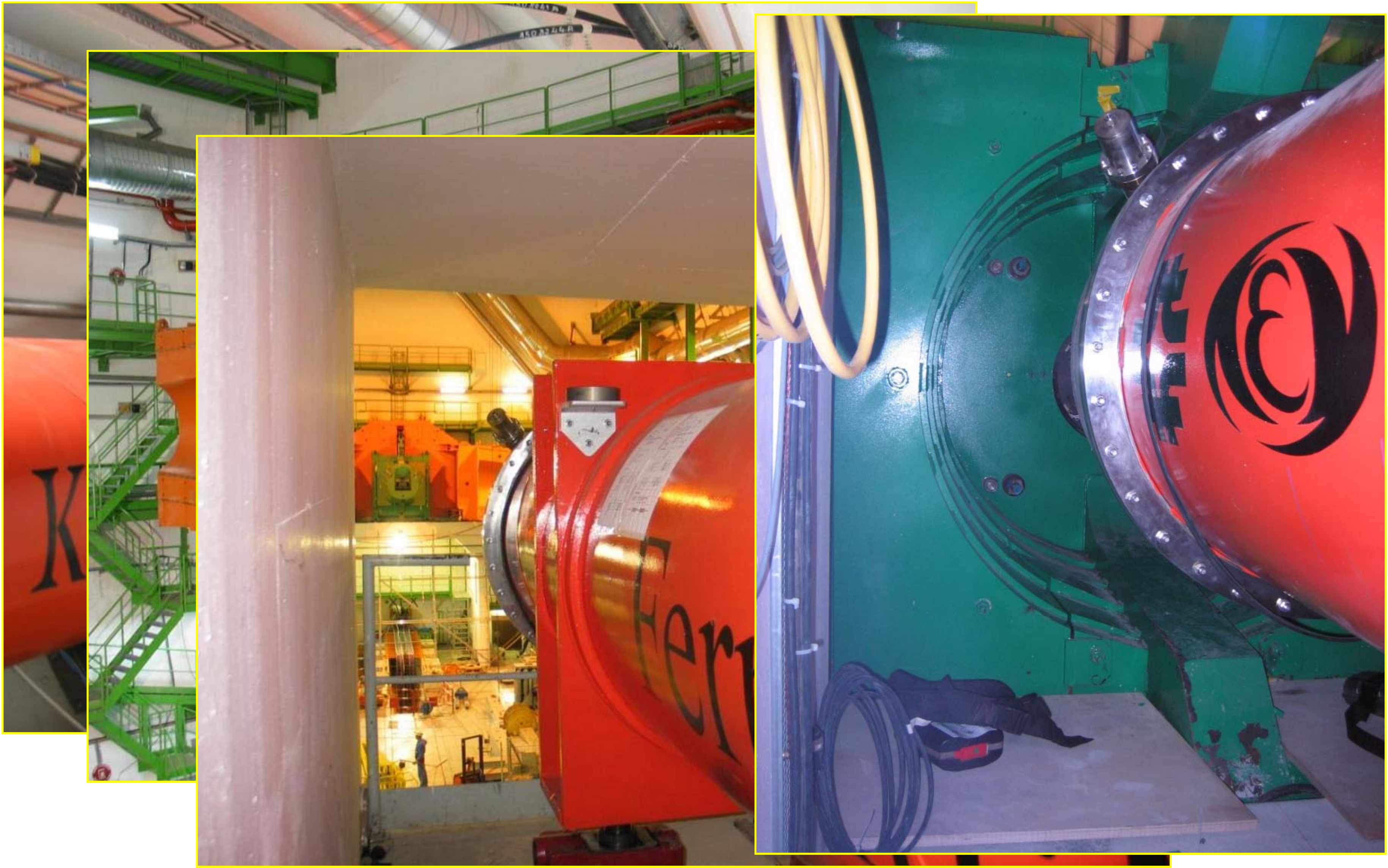
Final focus

- Triplet position — L* = 23 m
- Triplet gradient — 205 T/m
- Triplet aperture
  - Coil 70 mm
  - Beam screen 60 mm → β* = 0.55 m
    → $\mathcal{L} = 10^{34}$
- Power in triplet — ~ 180 W @ 1.9 K

The low-β triplet in IR1



The low-β triplet in IR5



The matching sections

LHC IR Upgrade - Phase I

Goal of the upgrade:

Enable focusing of the beams to β*=0.25 m in IP1 and IP5, and reliable operation of the LHC at 2 to 3 10^{34} $cm^{-2}s^{-1}$ on the horizon of the physics run in 2013.

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 dipole, TAS and other beam-line equipment so as to be compatible with the inner triplets.
5. Modify matching sections (D2-Q4, Q5, Q6) to improve optics flexibility, and introduce other equipment to the extent of available resources.

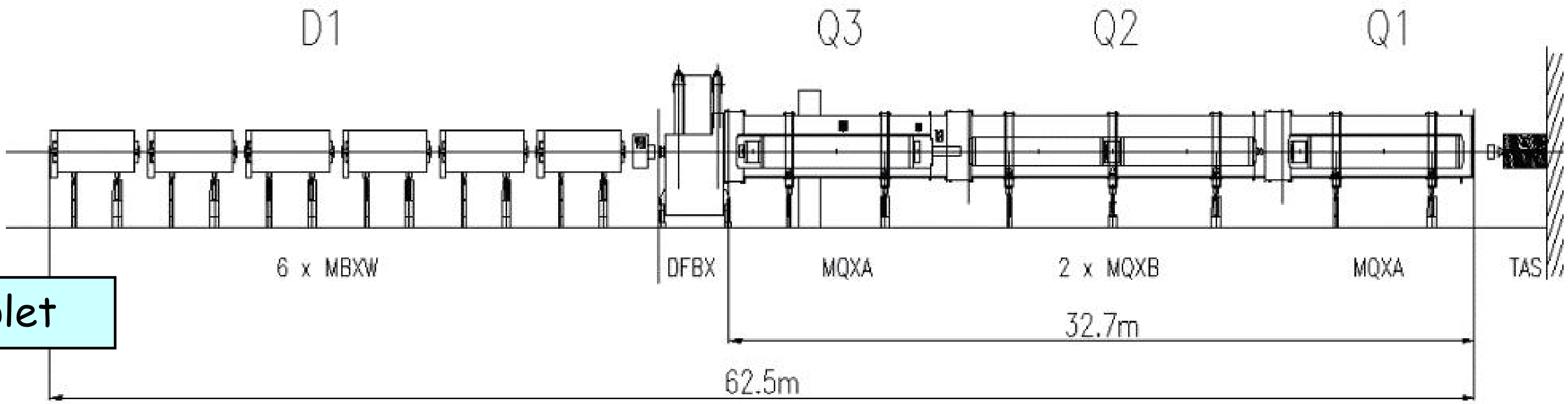
Constraints (1)

- Interfaces with the experiments: Very tight interfaces between the triplet, TAS, shielding, vacuum and survey equipment, and beam instrumentation; no possibility of reducing L* (23m). Replacement of the TAS vacuum chamber requires removal of the TAS from the experimental caverns.
- Cryogenics: Ultimate cooling capacity is 500 W@1.9K in each triplet. The triplet in 5L may have less cooling capacity available than the others. Replacement of triplets in IR1/5 requires at present warm-up of 4 sectors.
- Quench protection of the triplets: Due to considerably higher stored energy, energy extraction must be included.
- Chromatic aberrations: Reduction of β* drives chromatic aberrations all around the LHC. A new optics solution for all arcs and insertions is necessary.

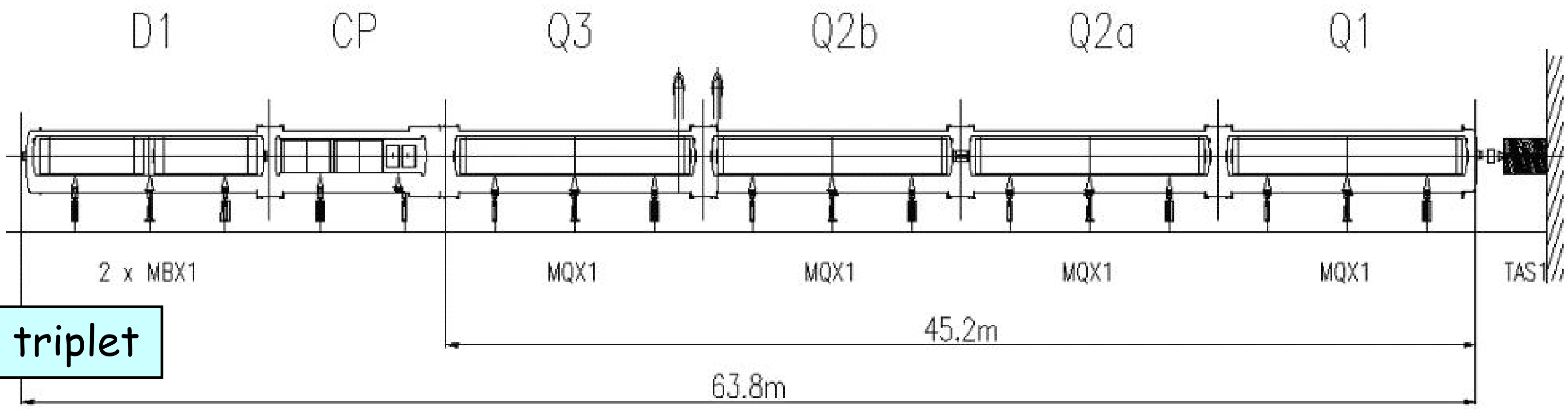
Constraints (2)

- Accessibility and maintenance: all electronics equipment around the triplets and the DFBX should be located in low-radiation areas. Severe space constraints around IP1 and IP5 for any new equipment.
- Tunnel transport: access from the surface to IR1/5 requires that the overall dimensions of the new magnets are similar to the LHC main dipole.
- Upgrade implementation: during the extended shutdown Nov 2012-June 2013, compatible with CERN-wide planning (Linac4 commissioning, phase-I upgrade of the experiments).

Triplet layout



LHC triplet



Phase-I triplet

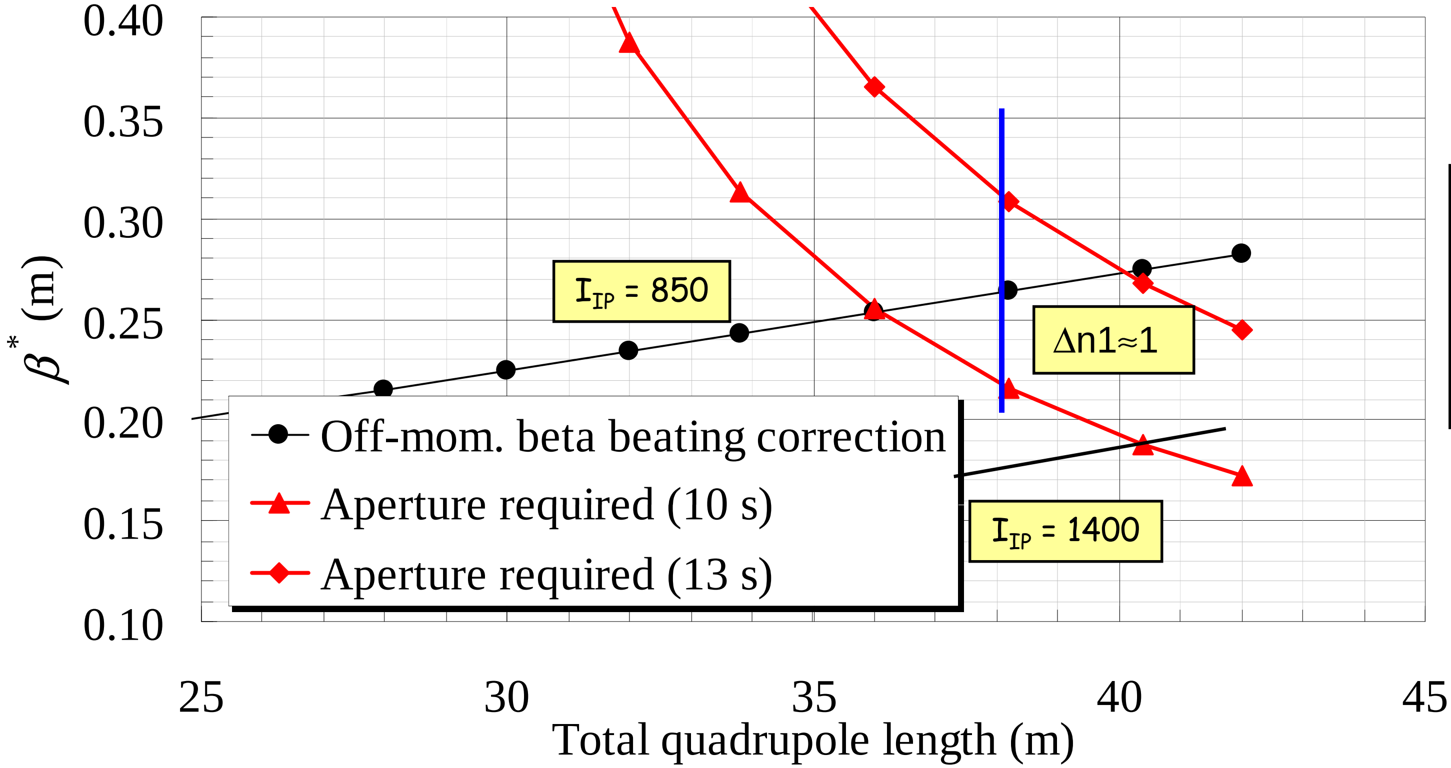
Initial proposal, iterations expected.

Optics issues

- *Insertions.* The strength and aperture of the magnets are the limiting factors for reducing β*. The largest aperture (longest triplet) is defined by the strength limitation of DS magnets and aperture of Q5.
- *Arcs*. Correction of chromatic aberrations in IR3, IR7 and in the inner triplets in IR1 and IR5 requires re-phasing of all the arcs and insertions for β* < 0.5 m.
- *Triplets*. Parasitic dispersion in the triplets due to large crossing angle has to be controlled. Beam crossing schemes in IP1 and IP5 need to be conform.

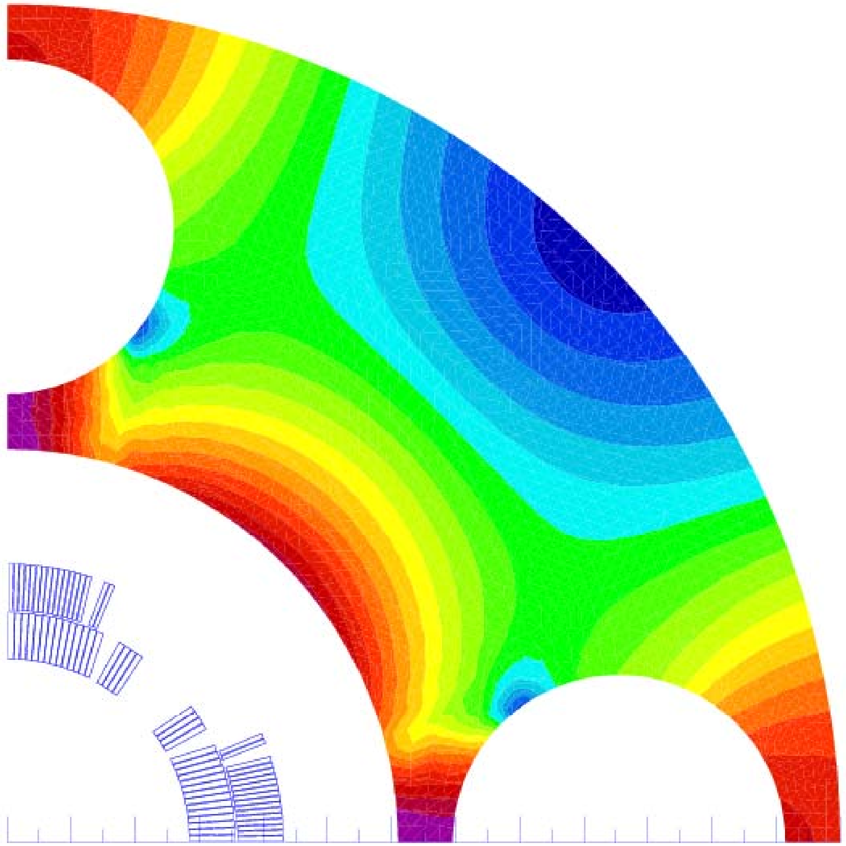
A complete solution for the new LHC collision optics has been found. Considerable work is required to fully validate the flexibility and robustness of the solution.

Performance reach



Length vs. aperture:
42 m - 140 mm
40 m - 130 mm
38 m - 120 mm
36 m - 110 mm

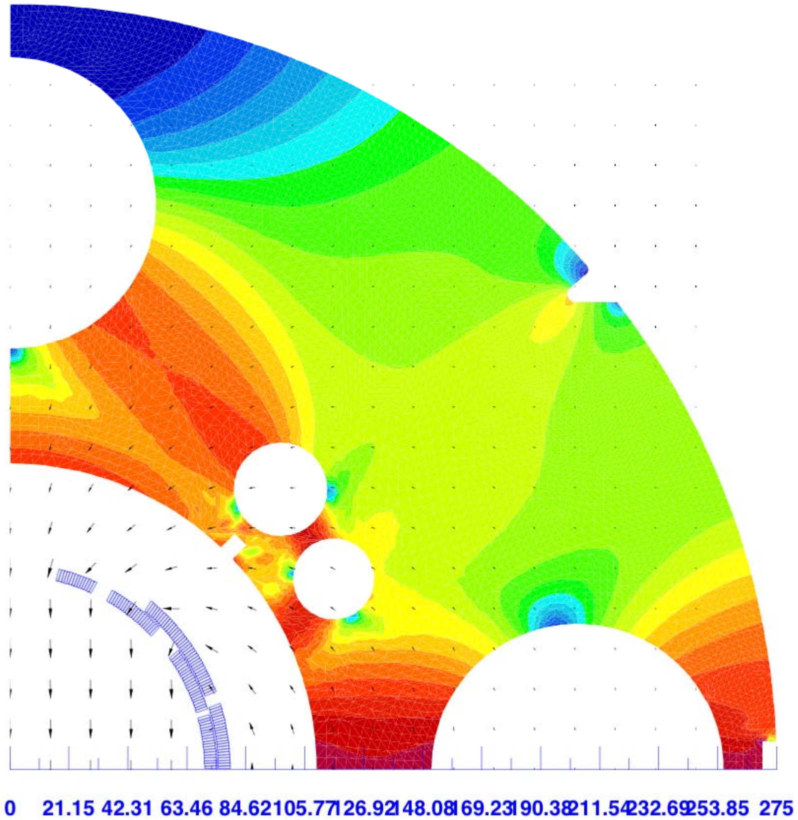
Low-β quadrupole



- Coil aperture 120 mm
- Gradient 120 T/m
- Operating temp 1.9 K
- Current 13 kA
- Inductance 5 mH/m
- Yoke ID 260 mm
- Yoke OD 550 mm

- LHC cables 01 and 02
- Enhanced cable polyimide insulation
- Self-supporting collars
- Single piece yoke
- Welded-shell cold mass

Correctors



MCBX

• Coil aperture	140 mm
• Field strength	6 Tm
• Operating temp	1.9 K
• Current	2.5 kA
• Inductance	55 mH/m
• Yoke ID	260 mm
• Yoke OD	550 mm

- New cable design
- Cable polyimide insulation
- Self-supporting collars
- Single piece yoke
- Welded-shell cold mass

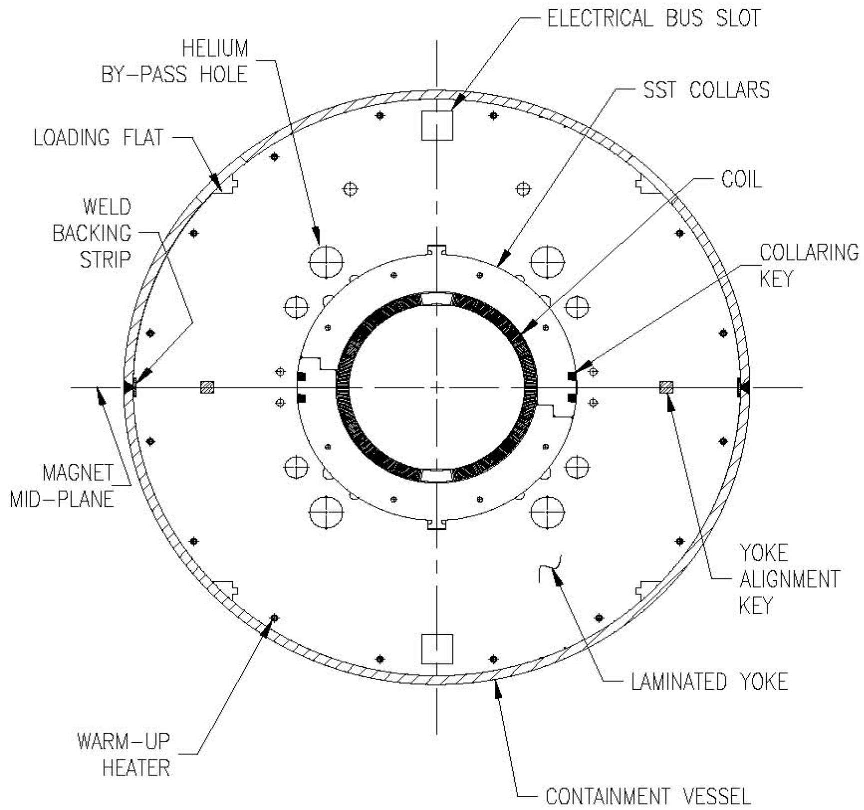
D1 separation dipole

Several possibilities for D1: NC, SC and superferric magnets.
A large aperture 4 T SC dipole is the most cost effective.

RHIC DX magnet

• Coil aperture	180 mm
• Cold bore	163/174 mm
• Warm bore	140 mm
• Magnetic length	3.7 m
• Operating temp	4.5 K
• Field	4.4 T
• Current	6.8 kA
• Stored energy	1100kJ
• Inductance	49 mH

D1 = two DX in one cryostat



Cryogenics

Triplets and correctors

- Pressurised static superfluid He bath at 1.3 bar, cooled by two-phase flow of saturated superfluid helium.
- Heat exchanger dimensioned for the ultimate power of 500 W/1.9 K and vapour velocity of 7 m/s.
- Due to the length of the QRL, the temperature from the refrigerator (1.776 K) will increase to 1.97 K in the coils at 500 W.
- Baseline: single internal heat exchanger with ID 95 mm.

Beam screen

- Cooling with supercritical helium, 5-20 K.
- Four standard cooling tubes (ID 3.7 mm) for a heat load of 4 W/m.

D1 cooling options

- Two-phase saturated helium (pool boiling), 4.5 K ± 0.2 K, similar to the other stand-alone magnets in the LHC.
- Cooling with forced flow supercritical helium is possible, but not well adapted to the cryogenic distribution system.

Powering options

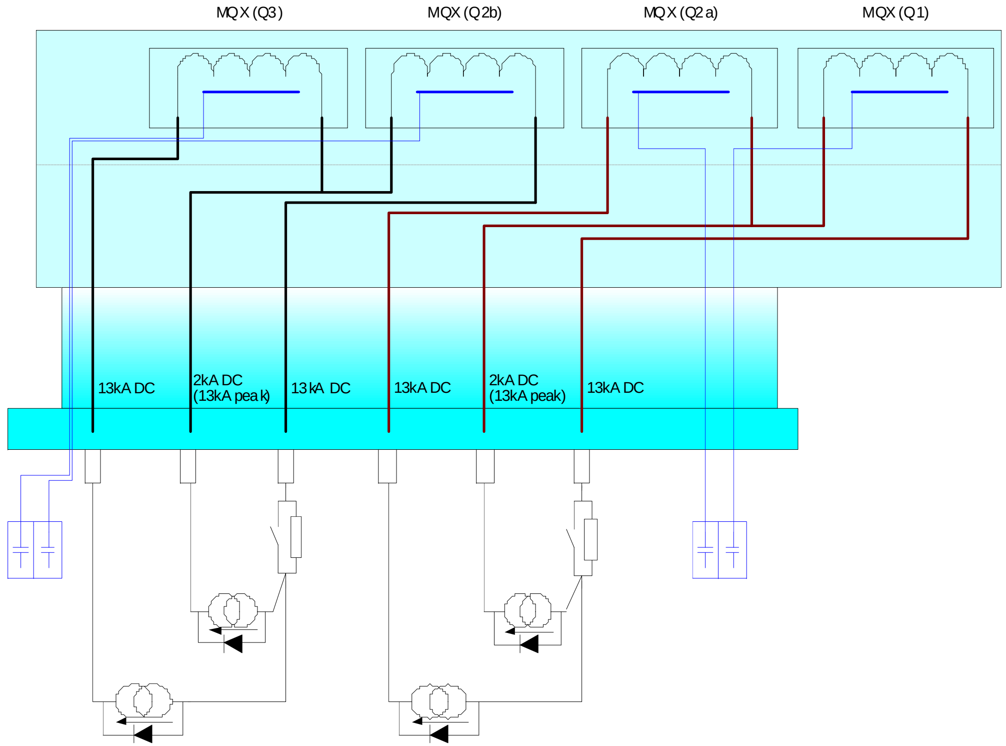
Options considered:

- Individual powering
- Nested powering
- Split powering
- Powering from surface

Split powering chosen as a compromise between volume and complexity.

Power converters built from (2 kA, 8V) modules in a N+1 configuration.

Development of radiation hard modules needed.



Magnet and circuit protection

Main magnets

- One quench detection system per magnet, including the busbars.
- Protection of the magnets assured by the energy extraction system and by the quench heaters.
- The technology for the extraction system depends on the radiation level in the installation zones.

Correctors

- Bridge based system with asymmetric voltage taps.
- Energy extraction mandatory for 2.5 kA circuits.

Busbars, link, leads

- Busbars and link integrally protected, leads protected separately.
- Appropriate signal routing to minimize noise.

Cold power transfer system

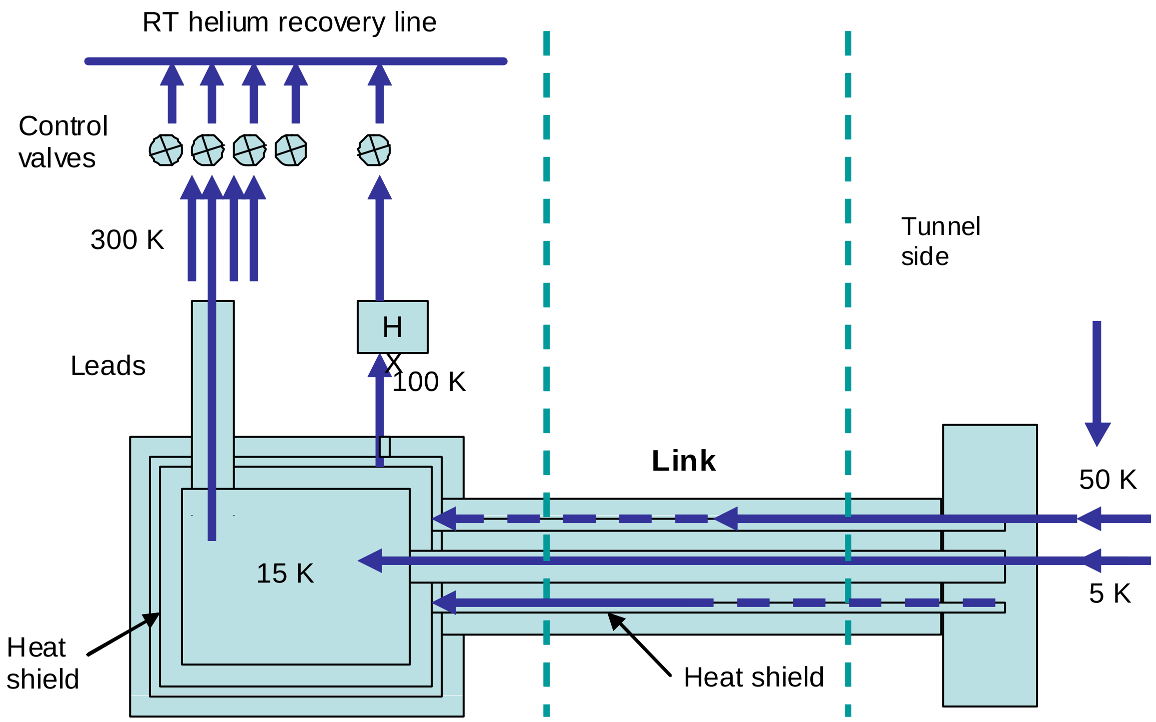
All powering and protection elements located in low-radiation areas.

Consists of:

- Current leads and their cryostat
- Superconducting link (~60 m)
- Tunnel connection box

Options for the link:

- Nb-Ti conductor
- MgB2 conductor



String test to check interfaces and compatibility of all systems.

Matching sections

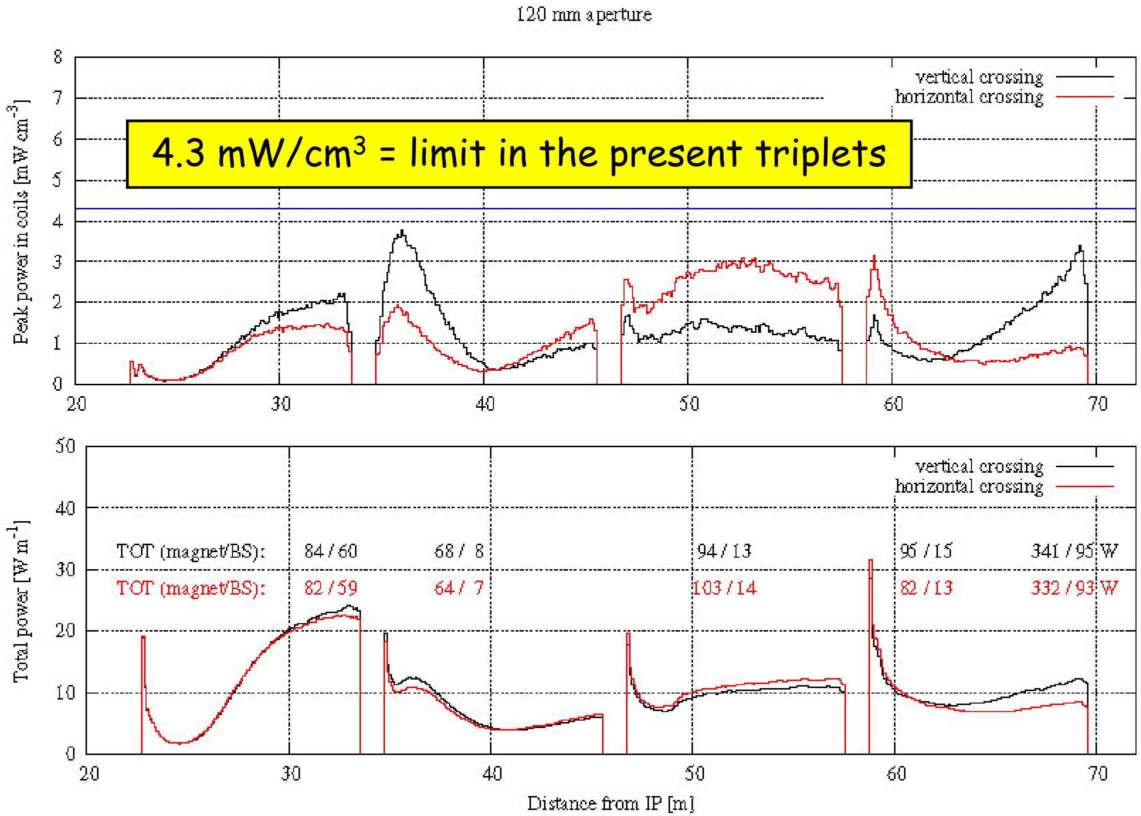
- The Phase-I Upgrade assumes that the operating parameters (temperature, strength, aperture) and the position of the matching section magnets (D2-Q6) remain unchanged.
- Reduction of β* inevitably reduces the aperture margin in Q4, D2 and Q5 and nearby equipment.
  - TAN will have to be replaced.
  - Protection against the beam halo (tertiary collimators) will need to be extended to matching section magnets.
  - Warm drift tubes should be aligned.
  - Background will need special attention.

Interventions on the warm equipment can be done in normal shutdown periods.

Energy deposition in the coils

Radiation effects are the single most serious issue of the upgrade.

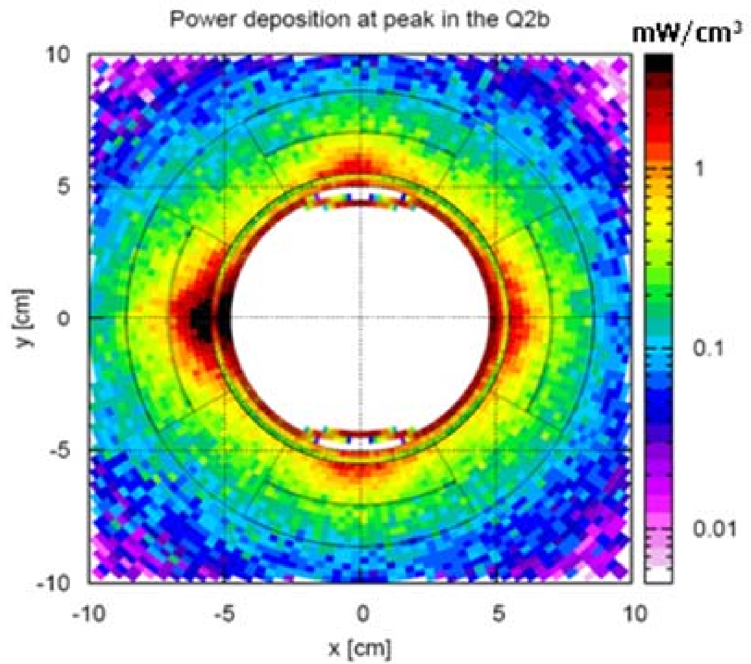
- Heating of the coils.
- Magnet protection (TAS, TAN) and lifetime.
- Protection of electronic equipment.
- Maintenance and interventions …

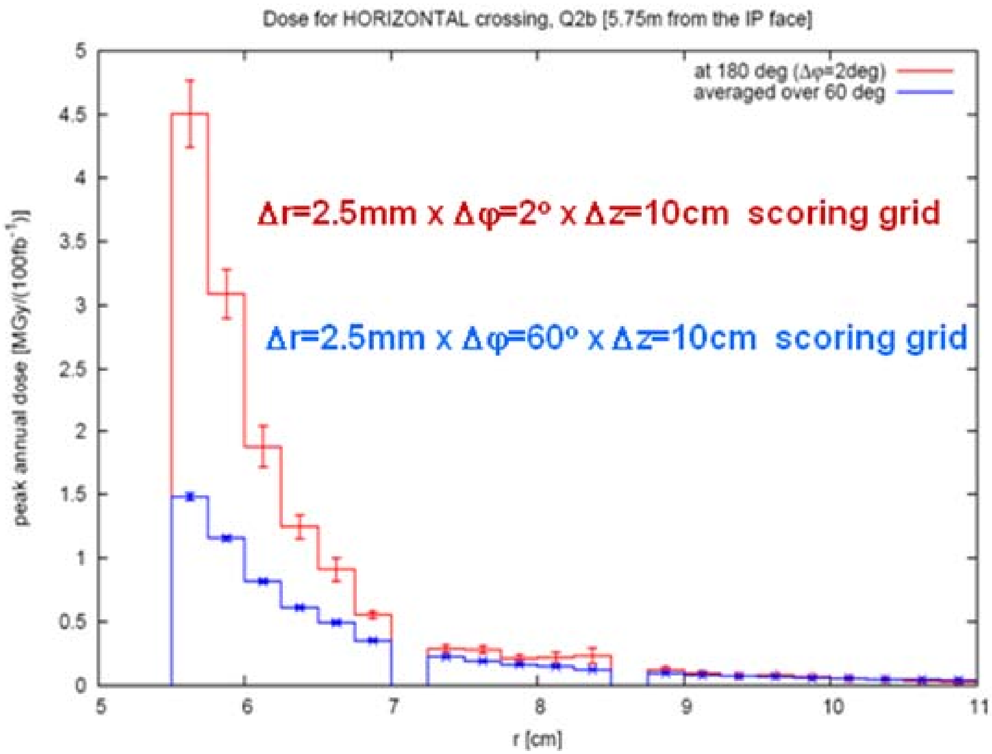


Protection efficiency significantly increased

$\mathcal{L} = 2.5\ 10^{34}$

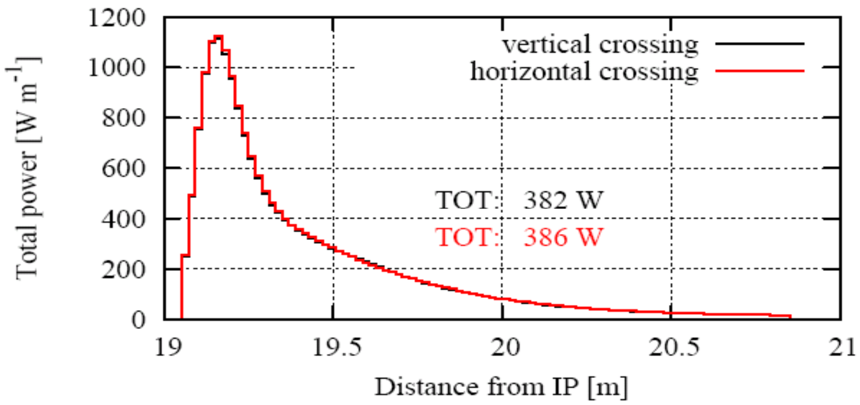
Expected dose and magnet lifetime

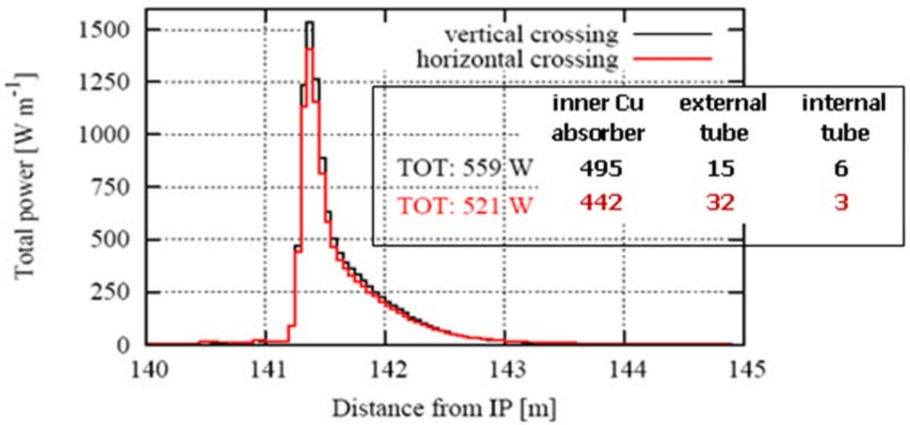


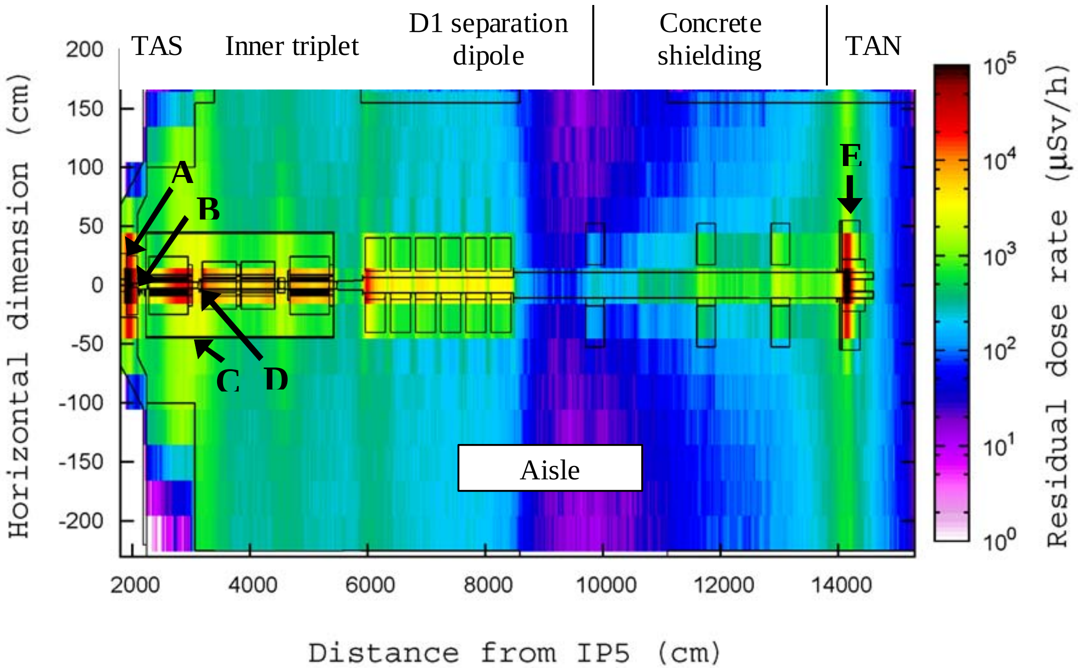


All magnets built for a lifetime of > 500 fb^{-1}.

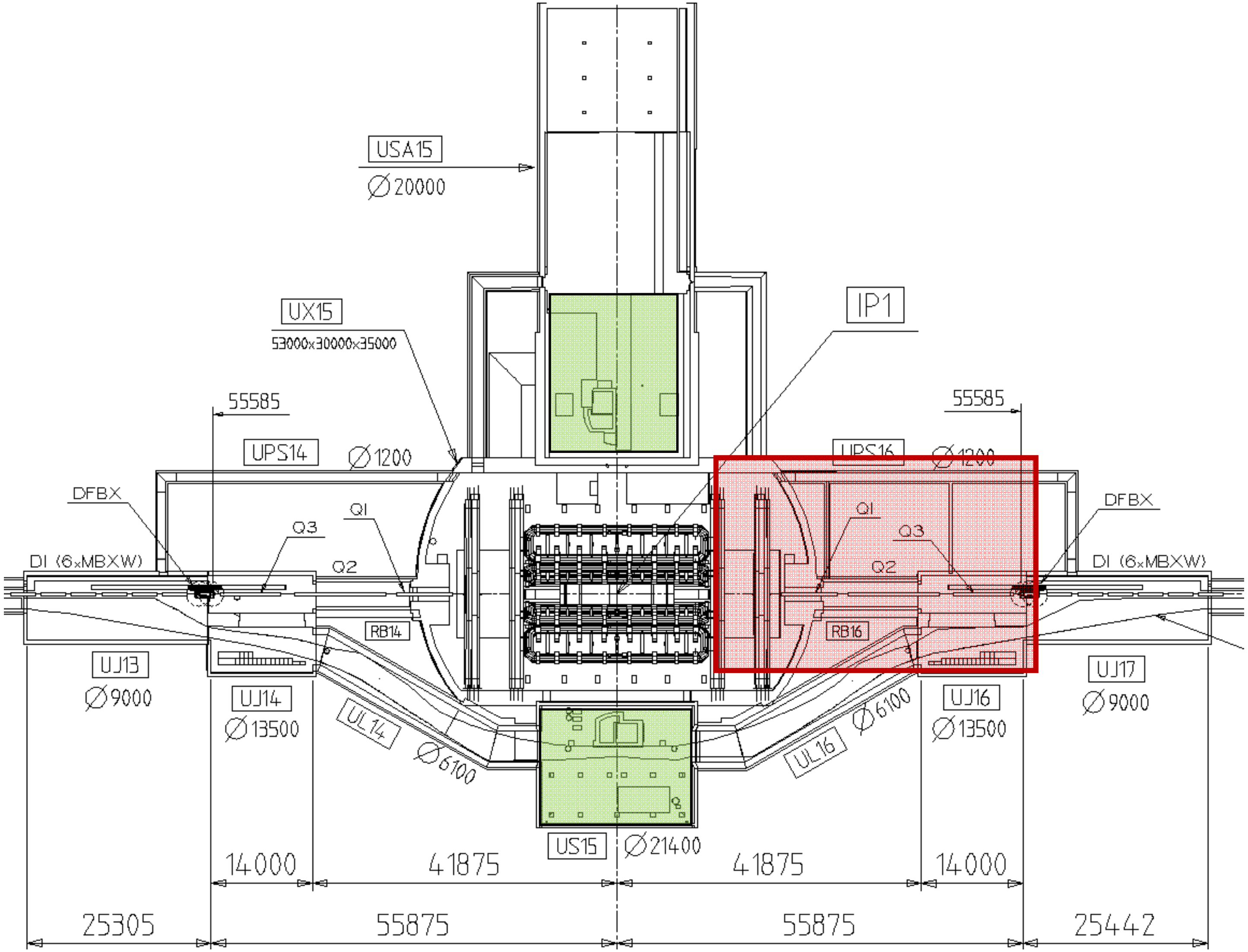
TAS and TAN absorbers



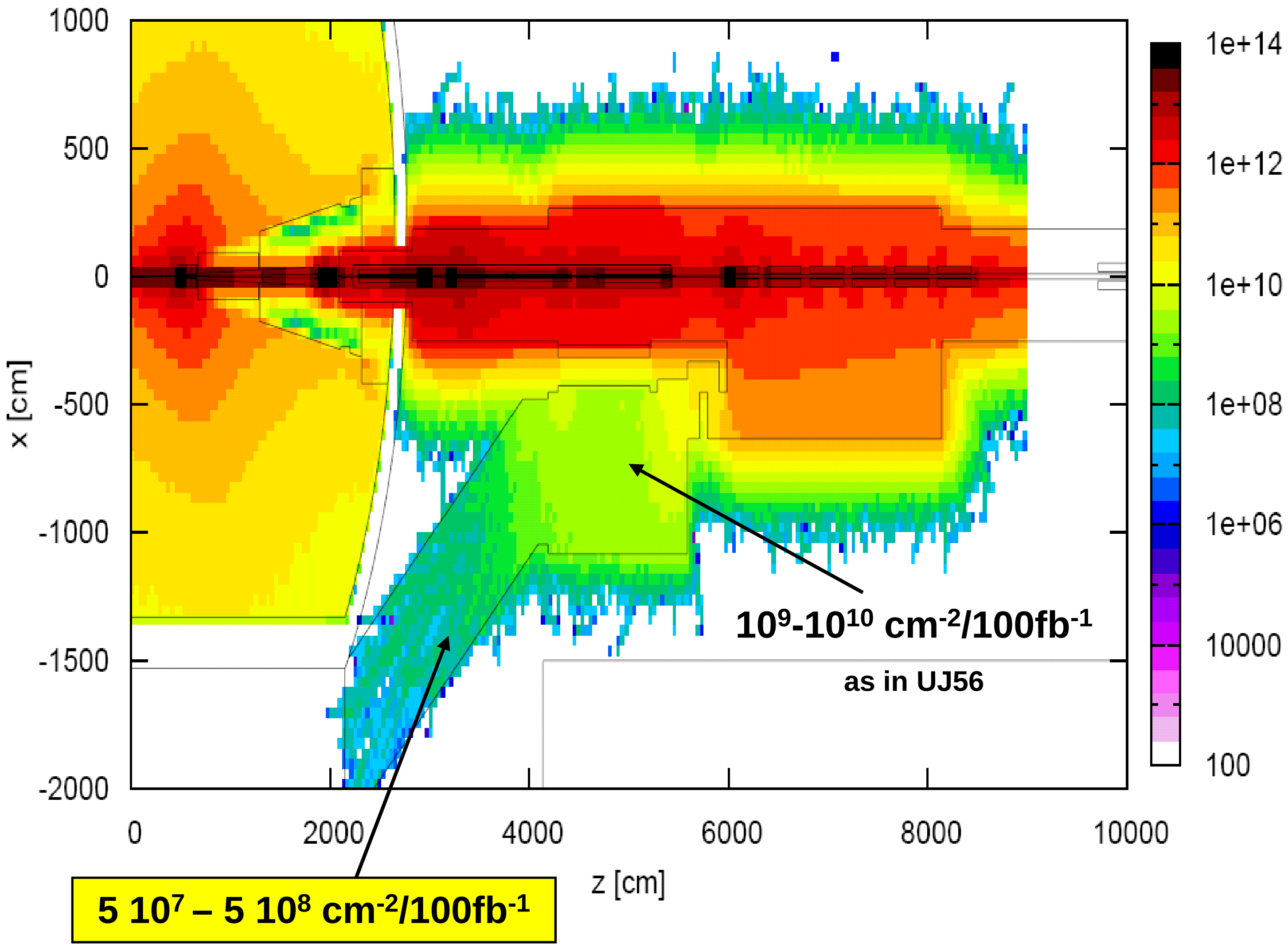




Equipment areas



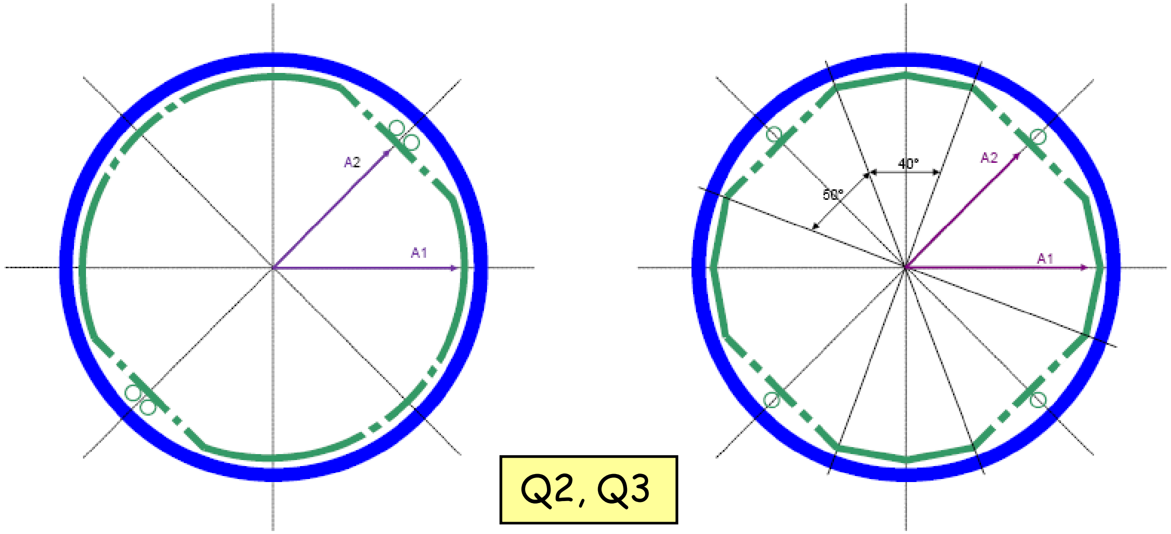
Equipment areas (> 20 MeV hadron fluence)



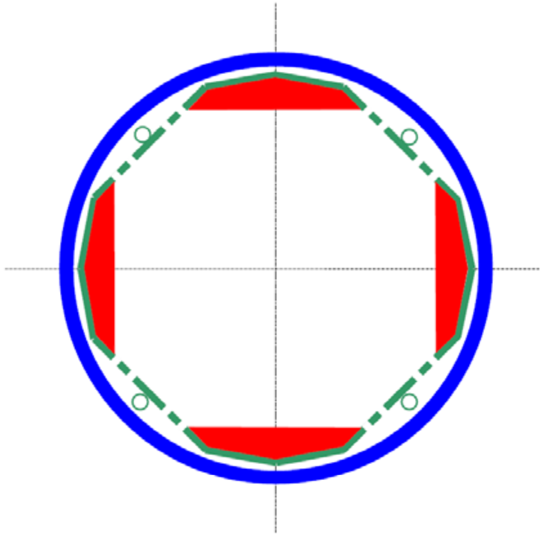
Vacuum system

Stability of the cold vacuum system requires a beam screen.

- Significantly increased heat load (4 W/m) to be taken at 5-20 K level.
- Beam screen design based on existing solutions, identical for all quadrupoles.
- Identical interconnects.

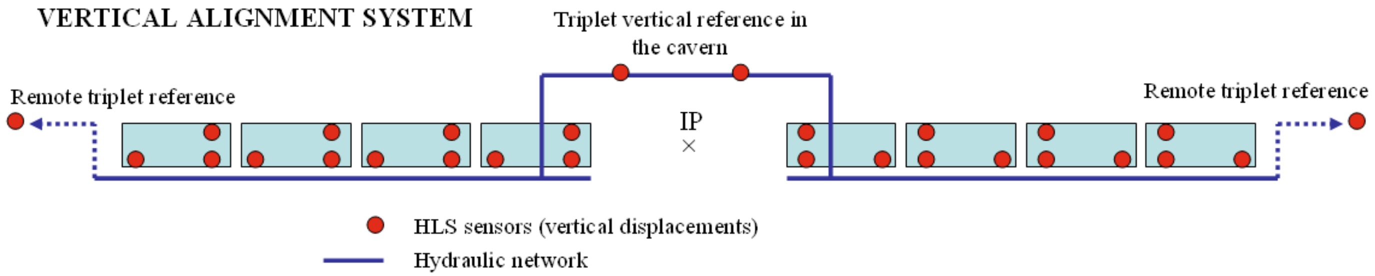


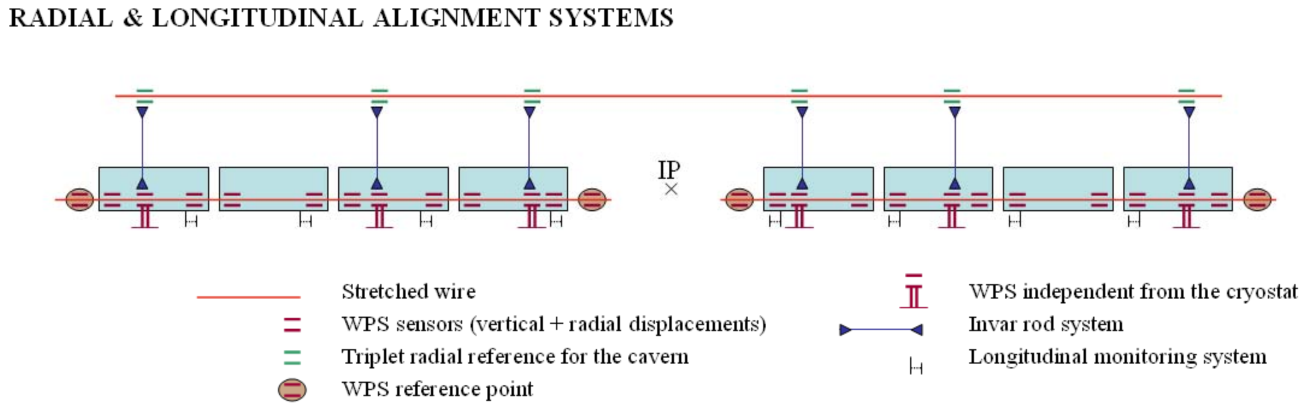
Q2, Q3



Q1

Alignment system





Extension of the present system.

- WPS and HLS systems for on-line monitoring.
- Motorised jacks.
- Improved magnet metrology during construction and installation.

Project organization and milestones

- WBS and project engineers assigned.
- Preliminary costs and intermediate milestones identified.
- Collaborations taking effect.

- **Conceptual Design Review held in July 2008.**
- TDG holds regular meetings.
- PBS set-up.
- QA using EDMS.

Project Approval	Dec 2007
CD Report	Nov 2008
Model quadrupole	end 2009
TD Review	mid 2009
Pre-series quadrupole	end 2010
String test	2012
Installation	shutdown 2013

Collaborations

EU-FP 7
SLHC-PP

- Design and construction of the model quadrupole
- Design of the correctors
- Design of the cryostats

CERN

- Quadrupole production
- Cryostating and testing
- Power converters
- Protection

LHC IR Upgrade
Phase I

Special French contribution

- Cryostat components
- Quadrupole components
- Production of the correctors

US-APL

- D1 separation dipole
- Cold powering

Perspectives

- Since several years the LHC physics and accelerator communities have been discussing the directions for maximizing the physics reach of the LHC by upgrading the experiments, the LHC machine and the CERN proton injector complex, in a phased approach.
- The first phase of the LHC interaction region upgrade relies on the mature Nb-Ti magnet technology with the target of increasing the LHC luminosity to 2 to 3 10^{34} $cm^{-2}s^{-1}$, while maximising the use of the existing infrastructure.
- A solid, reviewed and coherent conceptual design, in line with the general constraints, is at hand. The technical design, including the model work and limited R&D activities, are advancing to a tight schedule.
- Collaborations with European and US laboratories, which bring in their expertise and resources, have been formalised and are in effect.
- Bringing the LHC to nominal performance in the shortest term remains the top priority of the CERN management and LHC physics community.
  - The available resources at CERN for the finalisation of the Phase-I Upgrade design and construction of the equipment are subject to this priority.