Commissioning and First Operation of the Low-beta and their Electrical Feed-Boxes at the Large Hadron Collider (LHC)

C. Darve[1], C. Balle[2], J. Casas-Cubillos[2], S. Claudet[2], S. Feher[1], G. Ferlin[2], J. Kerby[1], L. Metral[2], A. Perin[2], T. Peterson[1], H. Prin[2], R. Rabehl[1], N. Vauthier[2], U. Wagner[2], R. van Weelderen[2]

[1]Fermi National Accelerator Laboratory

Batavia, IL, 60510, USA

[2]European Organization for Nuclear Research

Geneva, 1211, Switzerland

CEC-ICMC

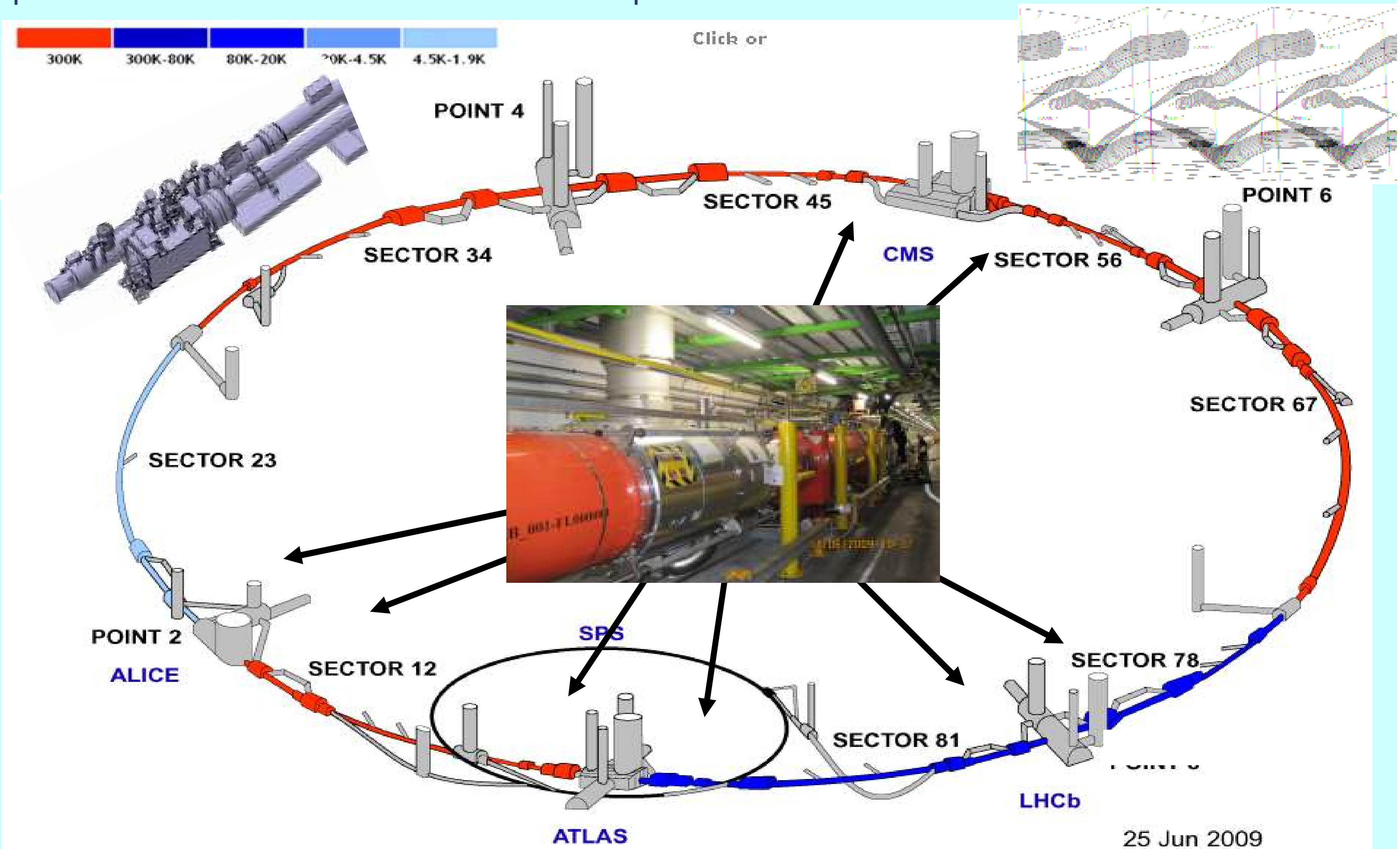
June 28 - July 2, 2009
Tucson, Arizona, USA

Outlines

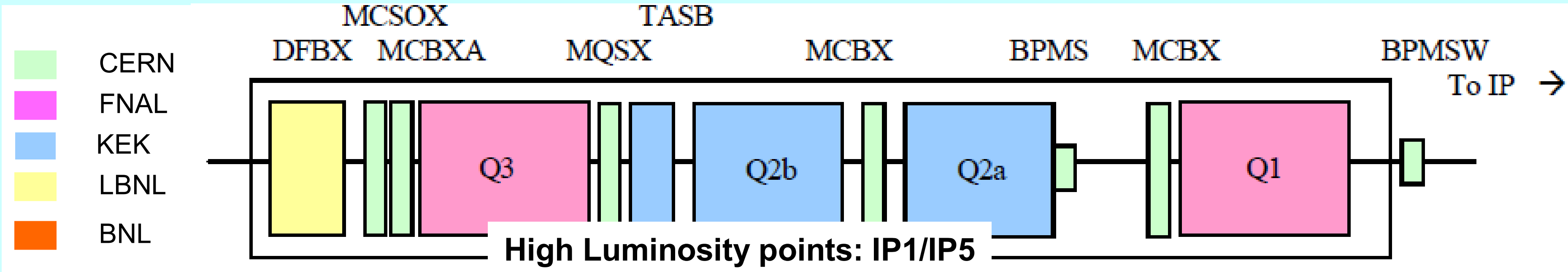
- The LHC Low-β Magnet System Descriptions
  - Low-β magnets – Inner Triplets
  - Electrical Feed-boxes – DFBX
  - LHC Low-β Magnet System Operation
- Hardware Commissioning
  - Selected Key Issues
  - First Operation
- Low-β Magnet Systems History
- Concluding Comments

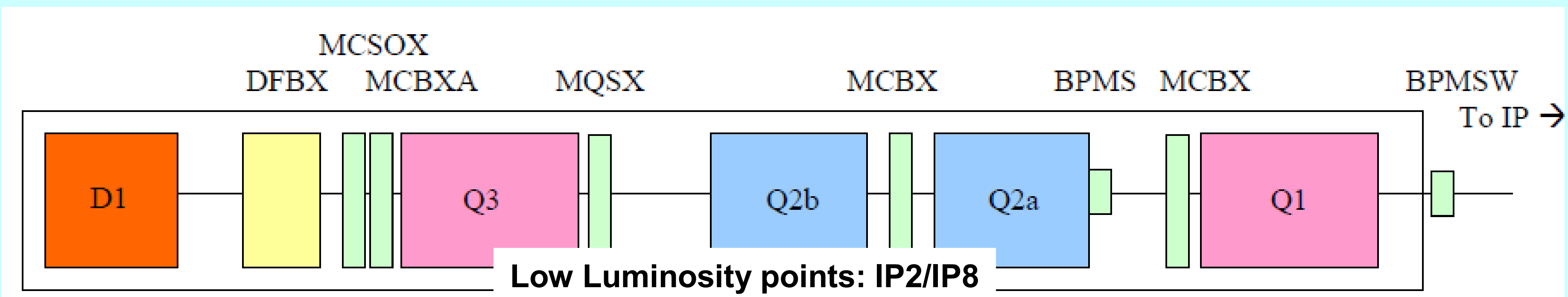
The LHC Low-β Magnet Systems

Squeeze the beam size down at the collision point to increase the chances of a collision



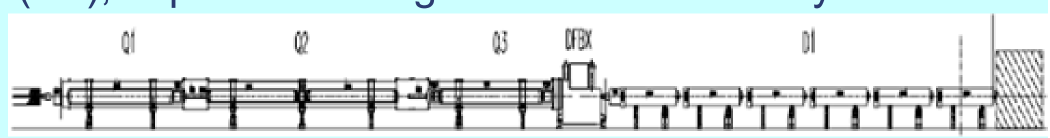
The LHC Low-β Magnet System





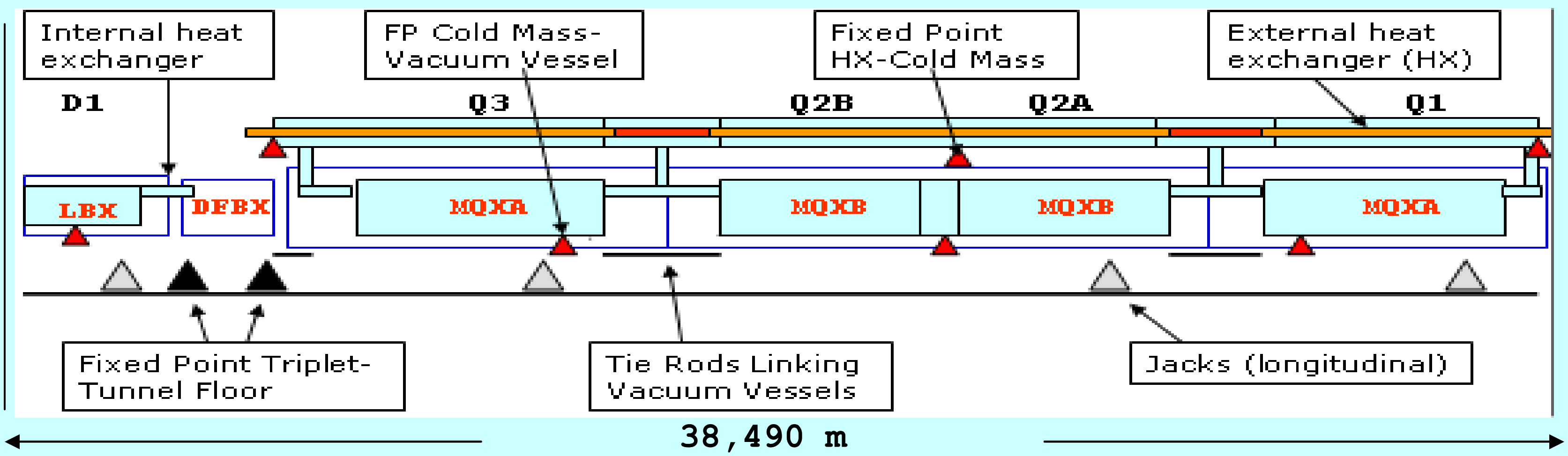
The low-β magnet systems are composed of :

- One electrical feed box (DFBX)
- Four 70 mm aperture quadrupole magnets (Q1, Q2a, Q2b, Q3) so-called the inner triplet
- One beam separation dipole magnet (D1), superconducting at the low luminosity IPs
- Five corrector magnet assemblies



Low-β Magnet – Inner Triplets

The low- β triplets are Nb-Ti superconductor quadrupole magnets, which operate at 215 T/m in superfluid helium at a temperature of 1.9 K.



Electrical Feed-boxes - DFBX

7.5 kA HTS current leads (4-6)

Connection to cryolines

Bayonet heat exchanger

Beam screen

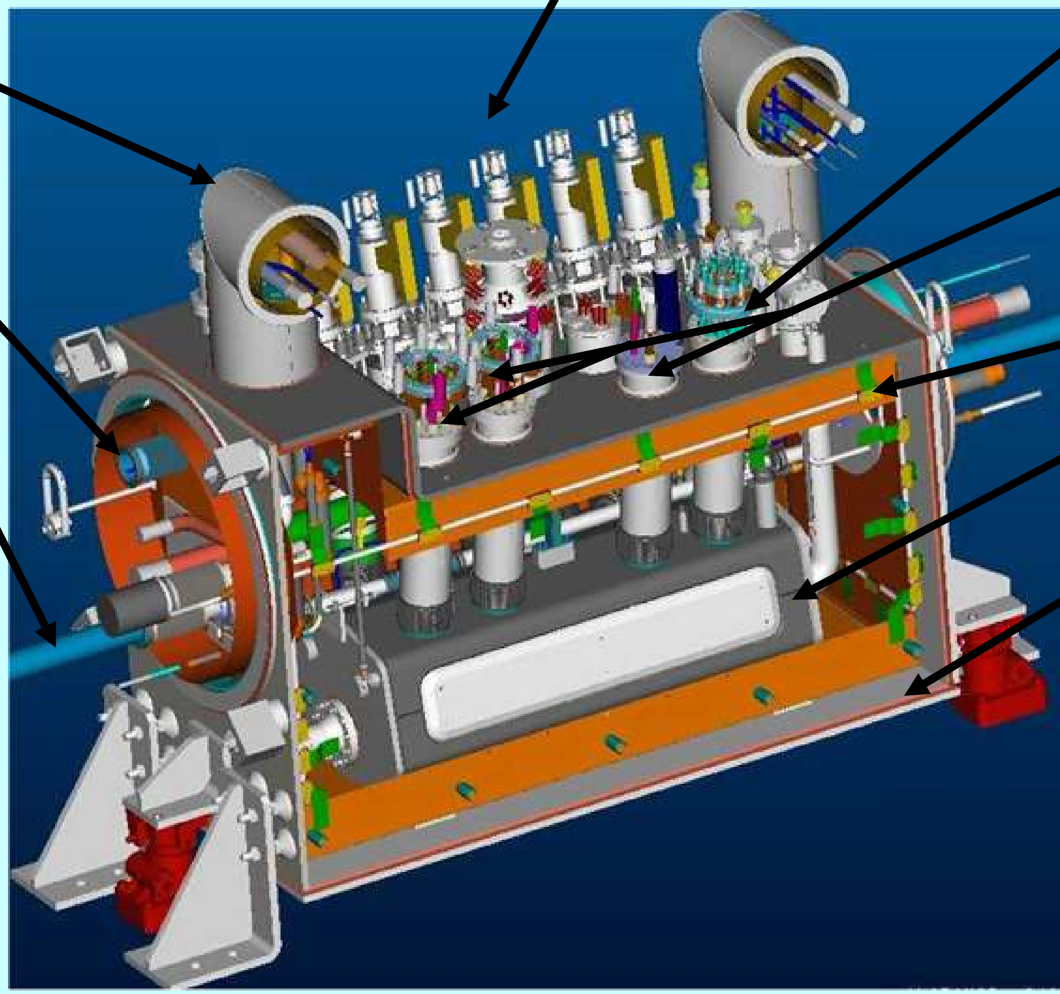
120 A vapor cooled resistive leads (10)

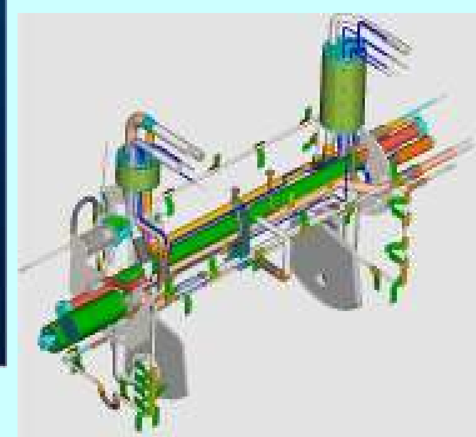
600 A vapor cooled resistive leads (14)

Thermal shield

Helium Tank

Vacuum vessel

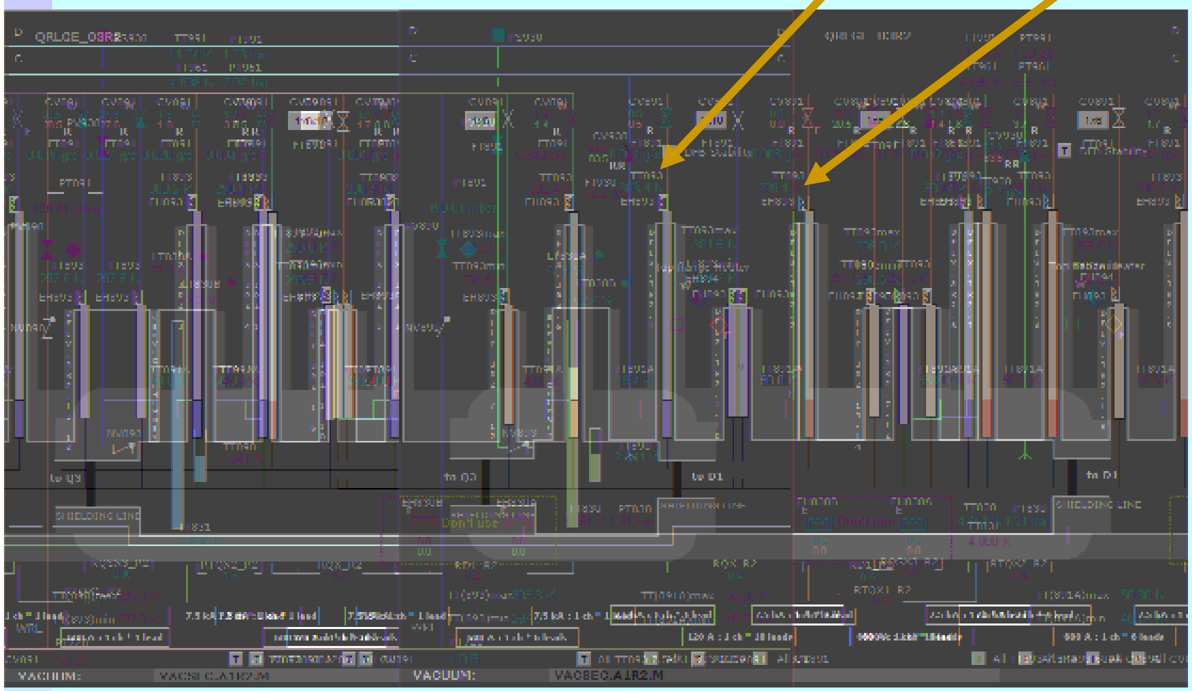




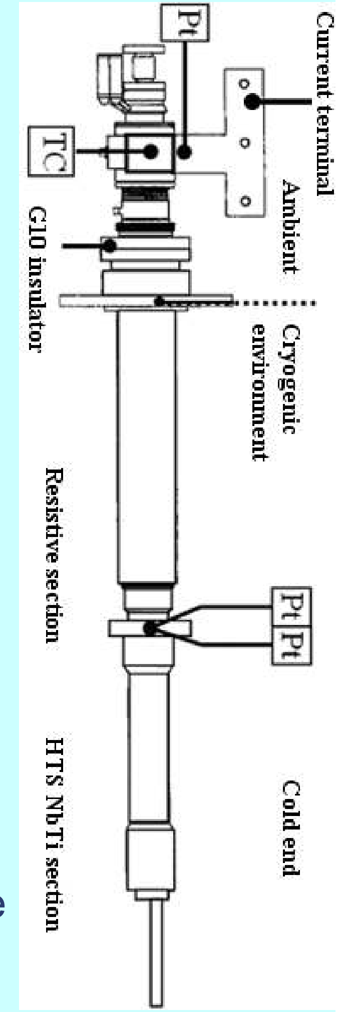
DFBX – 7.5 kA - HTS current Leads

7.5 kA current leads power the main inner triplet quadrupoles

- Lead tested at full current at FNAL
- Power cables installed @ surface
- Operated similarly to CERN HTS leads – Control @ 50 K, Interlocks
- Each lead cooling uses a RT temperature sensor, a flag heater operated with local thermo-couple



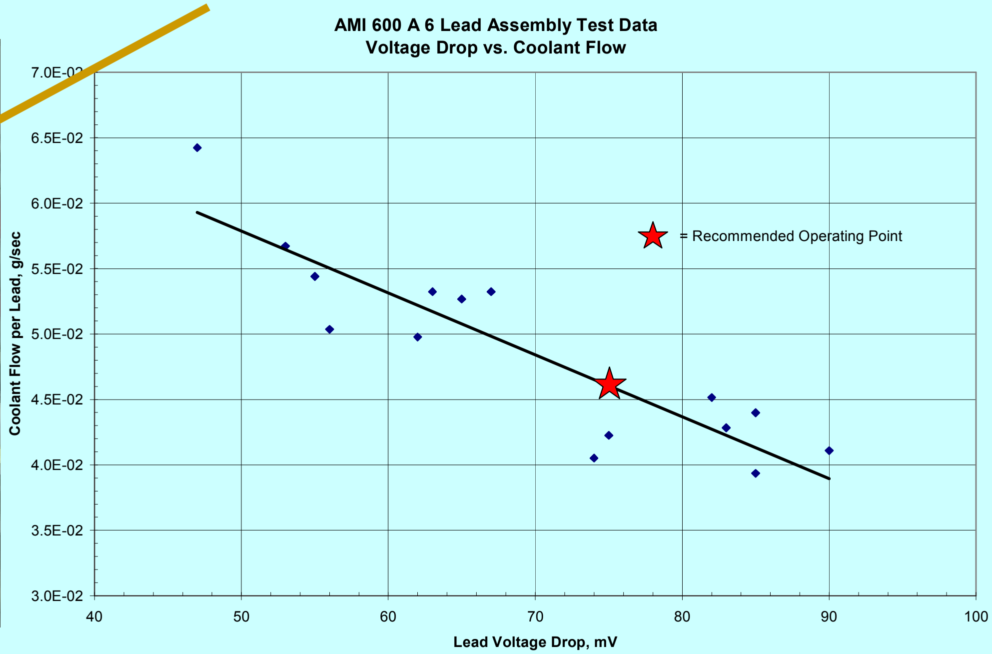
Silicone High Voltage Insulator Coating



DFBX - Vapor Cooled Leads - Resistive Leads

600 A (14/DFBX) and 120 A (10/DFBX) power the corrector magnets

- Current lead was tested at full current at manufacturer (AMI)
- Power cables installed @ surface
- Each 600 A lead and pair of 120 A leads is cooled by the boil-off from the helium tank.
    - No temperature sensors on the leads cold end, only at the flag heater.
    - Manufacturer has specified a mass flow rate per lead.
- Helium gas is warmed up before being recovered to the warm recovery line – Interlocks
- Each lead cooling uses a temperature sensor, a flag heater operated with local thermo-couple



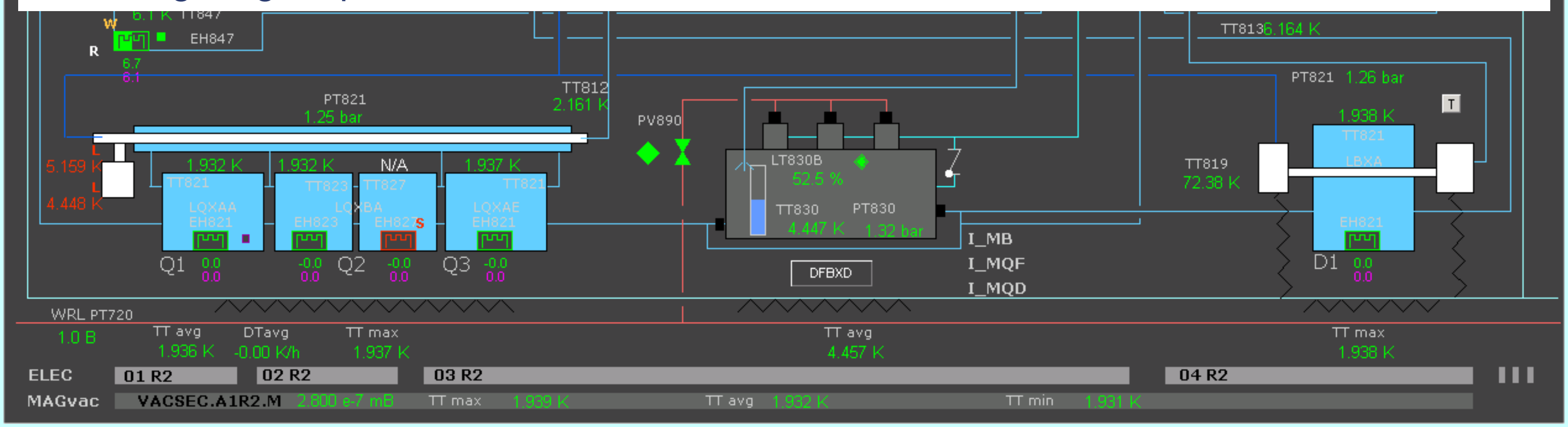
LHC Low-β Magnet System First Operation

• Preparation to cool-down (e.g. pressure test, flushing)

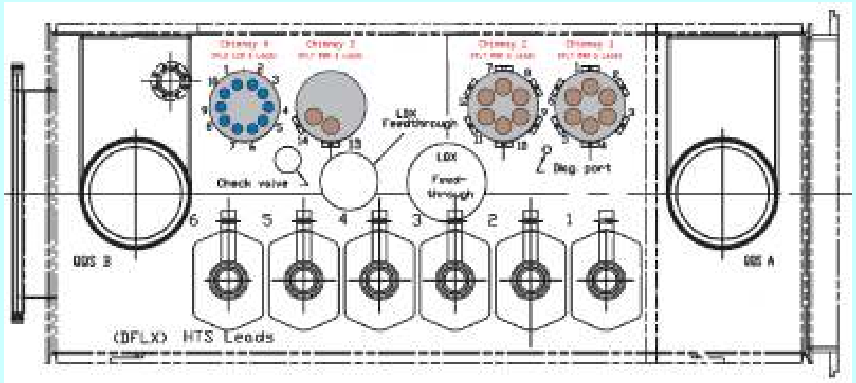
Cool-down time : 15→ less than 4 days

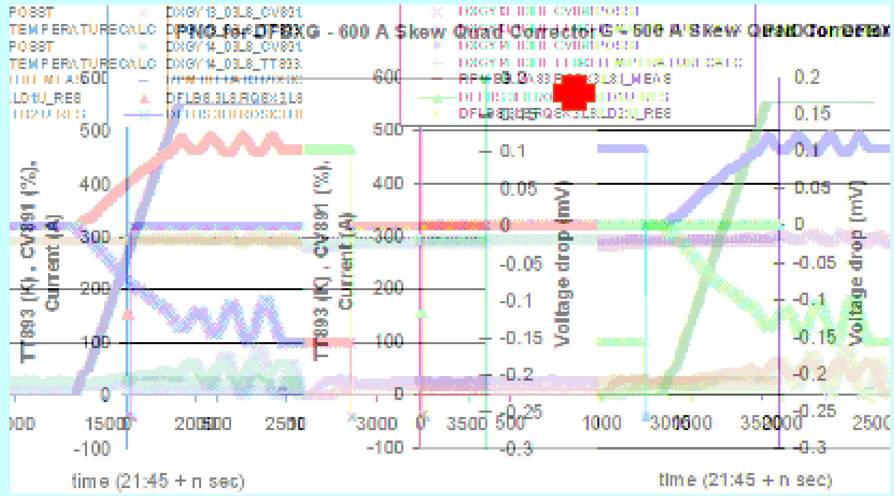
• Preparation to powering (e.g. valve & instrumentation check, electrical quality assurance to verify the integrity of the each electrical circuits)

Powering magnet phases : > 2 weeks

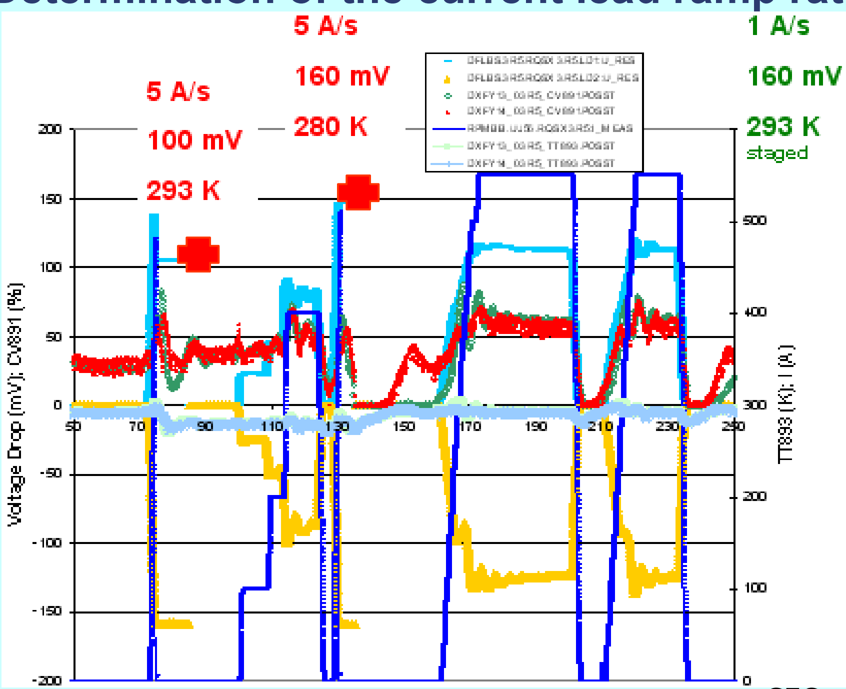


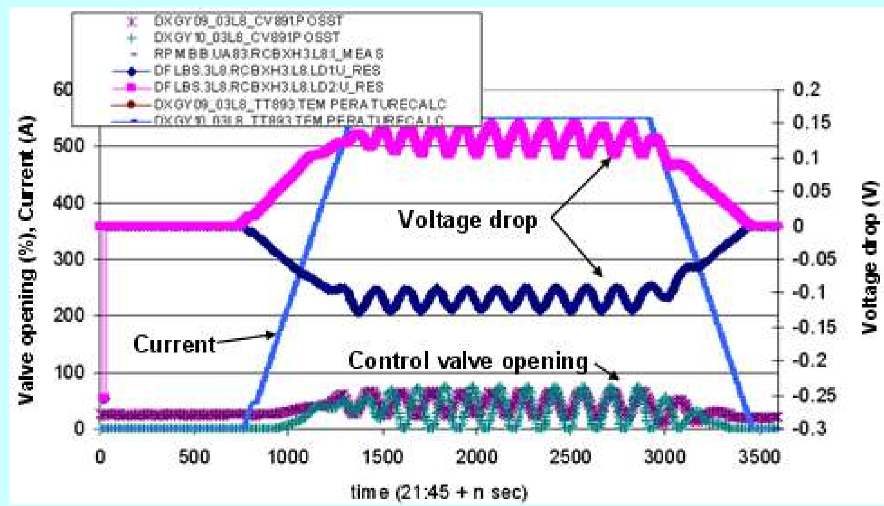
DFBX VCL Parameters Tuning during Powering





Determination of the current lead ramp rates





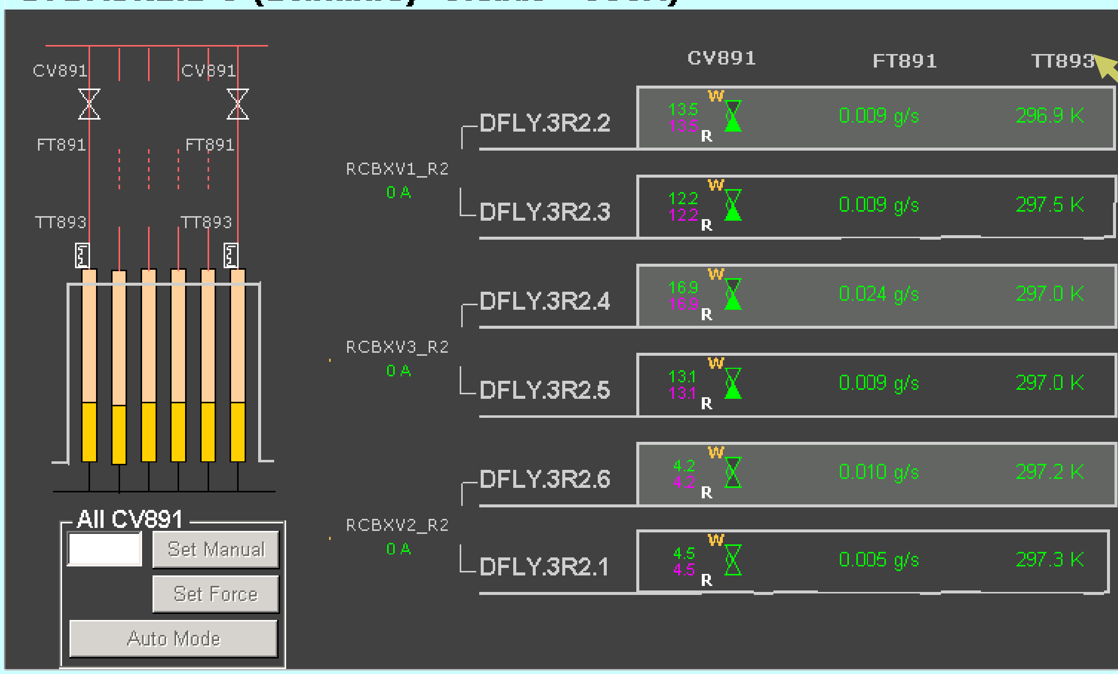
DFBX Vapor Cooled Lead - Control System

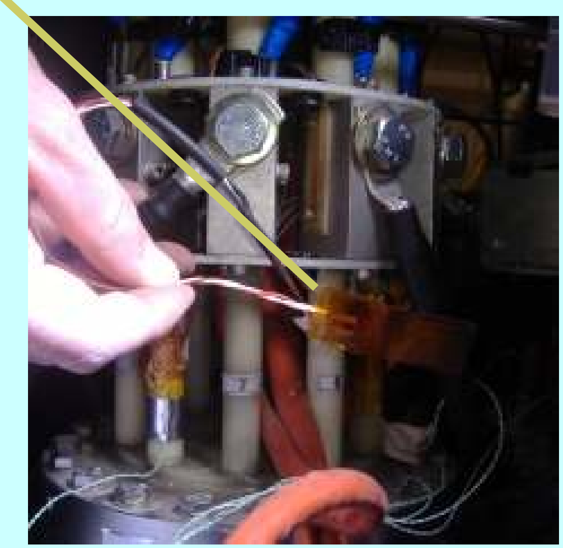
Issue: No temperature sensors on lead cold-end and no reliable flow measurement (virtual flow measurement, no hardware installed).

Solution: Installed new instrumentation, flexible Pt100.

Very difficult access to permit the electrical feed-boxes consolidation with high risk of damage to delicate wiring

DFLY.3R2.1-6 (1chimney*6leads - 600A)

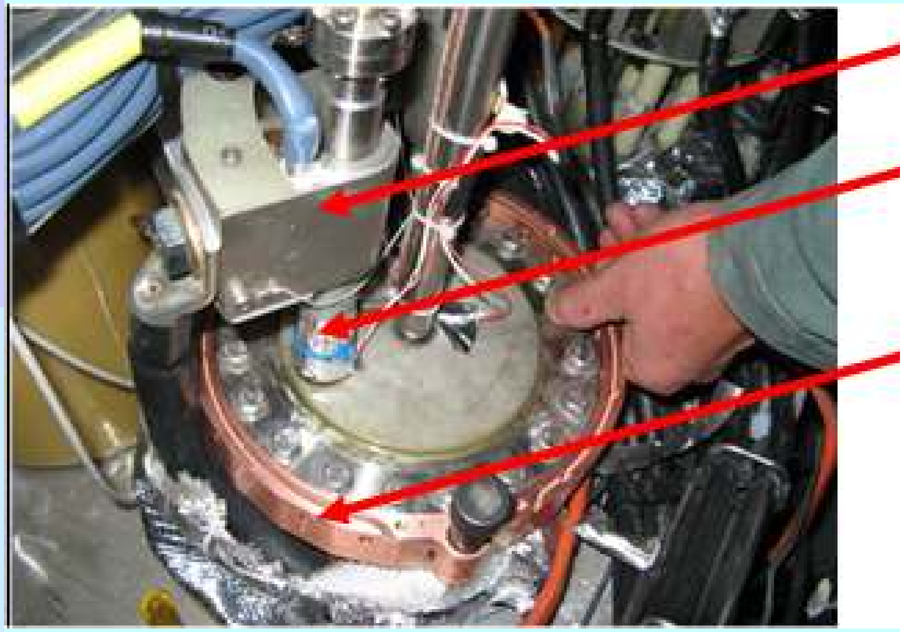




DFBX VCL - Water Condensation Issue

Issue: Following the first DFBX cool-downs, water and ice ball observed on the VCL room temperature VL chimney interface.

Solution: Installed bracket heaters on the VCL chimneys and around each lead.



Local heater used to warm up helium gas to room temperature before it is collected in the WRL.

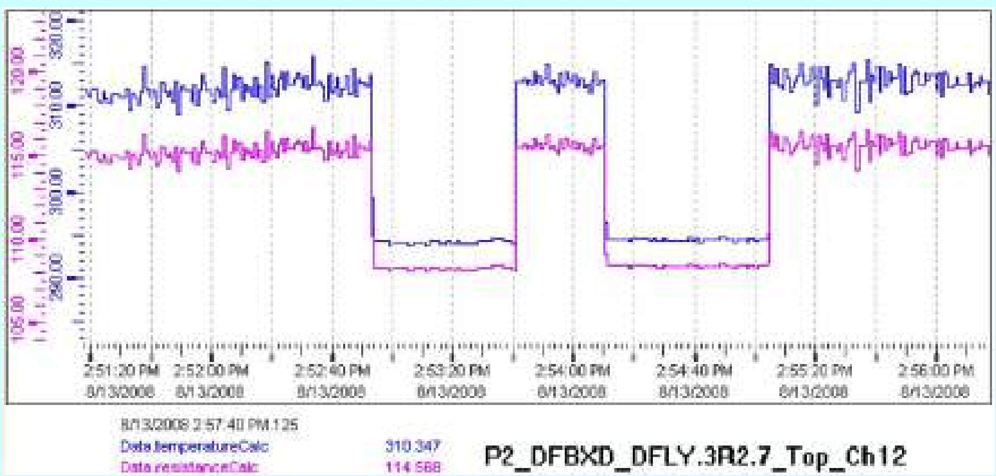
New Pt100 used to regulate the vapor cooled lead flow – Process variable of the controlled valve to the WRL circuit.

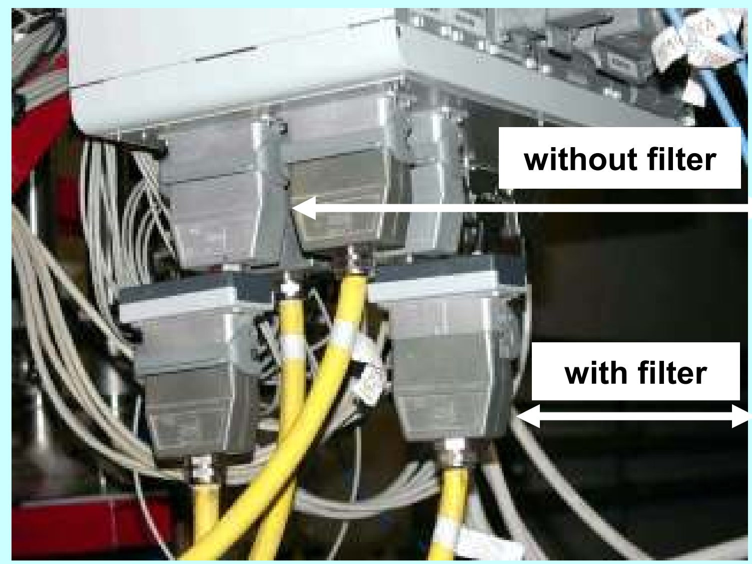
New bracket heater used to prevent condensation to appear around the vapor cooled lead chimneys and used to maintain a known temperature distribution along the helium flow path.

Electronic Noise

Issue: Offset observed on the measured temperature of the 600 A VCL (electronic background noise caused by the electronics floating with respect to the ground).

Solution: Implemented a 4.7 µF capacitor per temperature channel. Twelve capacitors are grouped in one so-called filter-box, which is directly plugged-in the instrumentation connector of the DFBX.

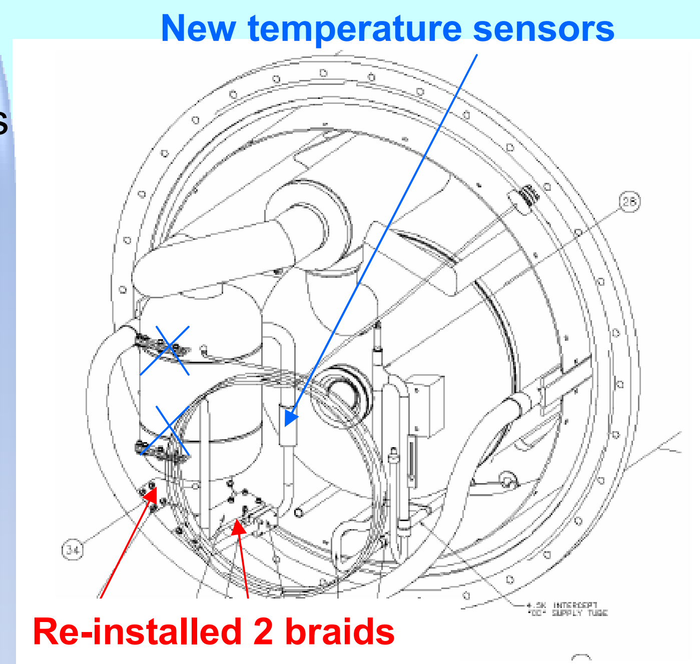




Passive Heaters on IT Q1 @ R1 and L5

Issue: Passive heaters were systematically mis-installed, generating extra static heat load for half of the inner triplets and risking liquid fill of the counter-flow heat exchanger for the other half

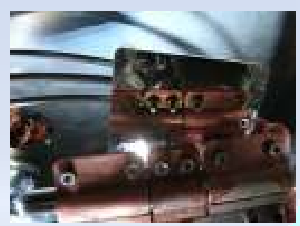
Solution: Re-installed two of these eight passive heaters (high luminosity points)



Cutting cryostat, shield and MLI

Installing passive heaters

Installing temperature sensors



Inner Triplet – Chamonix Workshop – J. Strait

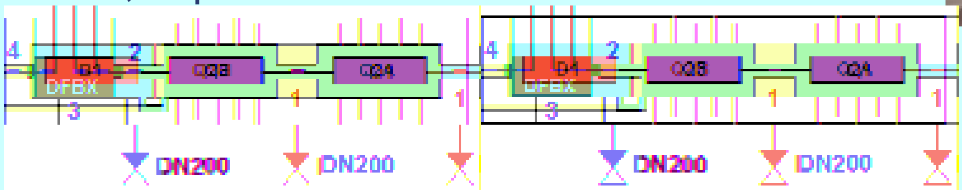
- Bus splices are inside thin-walled (0.25 mm) bellows
  → vulnerable to puncture/rupture in case of an electrical arc

- Old cryostat relief system is three 67 mm ports => capacity of 1~1.5 kg/s

- Rupture of interconnect M-line (stored energy 6.5 MJ vs. one main ARC dipole 7.5 MJ):
  - Substantially enhance relief capacity, e.g. adding several DN200 to each triplet.

- Bus fault rupturing interconnect bellows:
  - Up to 20 kg/s helium flow into cryostat, pressurized to many bar.
  - Anchors to floor will break for P > 1.5~2 bar.
  - DFBX (square cryostat) could be severely damaged by internal pressure.
    No spare DFBX* => 1-2 years to build new from scratch.

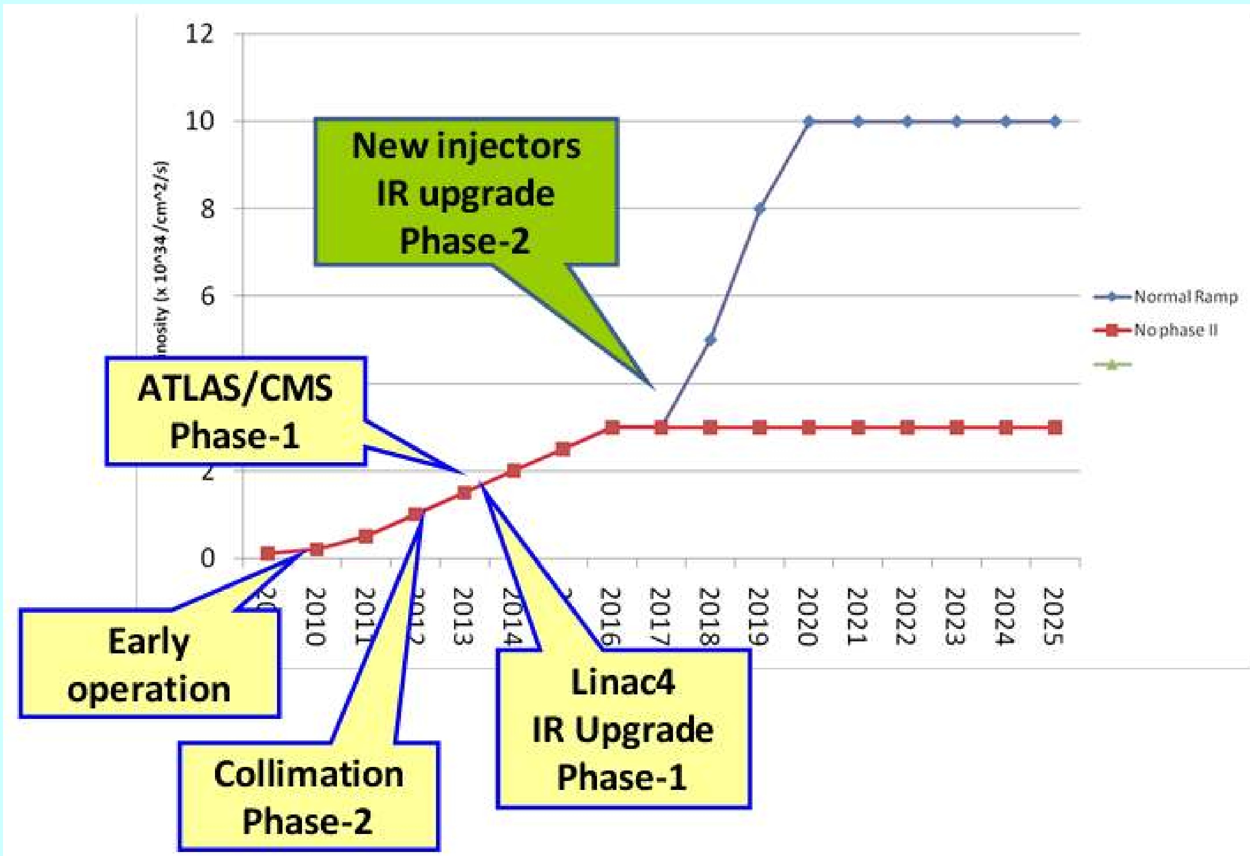
- Inter-turn short puncturing/rupturing cold bore tube.
  - Scaling from a similar incident with an SSC R&D magnet, such an event could create a 20-30 mm diameter hole in the beam tube.
  - Up to 10 kg/s high pressure helium released into vacuum tube, adjacent to experiments, in presence of electrical arc.



15

Low-β Magnet System History

- Design and development
- Production
- Delivery at CERN
- First triplet assembly
- First triplet in tunnel (8L)
- Pressure test (8L)
- Repair of HX in all triplets
- First cool-down of low-b
- Hard. Commissioning- ph1
- First powering (5L)
- Consolidations of DFBX
- First operation
- Consolidation of IT
- Hard. Commissioning- ph2



→180 W load from secondaries Only for IT in the high luminosity areas could there be some runs, in between the collimation phase-2 and ATLAS/CMS phase-1 period at $10^{34\ cm-2.sec-1}$

→ 60 W prior to this phase.

Concluding Comments

The first operation of the low-beta and their electrical feed-boxes was finally successful !

- Key issues were identified to permit the proper LHC operation
- Staged consolidations were necessary
- Complex and difficult access for repair require high reliability of components

➢ Lessons learned for future designs with emphasize on:

- ✓ Risk Analysis
- ✓ Structural Safety
- ✓ Engineering Safety Documentation

Safety code used : ASME Pressure Vessel Code / CERN Safety Code D2 Rev 2