# Quench heater failure in dipole magnets

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# Introduction

- In case of quench cold diodes will allow by-passing of the quenched magnet so that the energy dissipated as heat will be 'seen ' only by one magnet.
- To avoid the local effect of temperature and voltage rise, dipoles are equipped with the ' quench heaters' (QH).
- During the production and testing of the dipoles a number of magnets with failure on the QH circuits was detected.
- The detection of the failure results very difficult and the tests performed at warm and at cold could not give us 100% confidence on the integrity at long term of all circuits of the dipoles.

*" Report on the Quench Heater Failures, AT MCS Technical Note"*

# Refused magnets after delivery to CERN

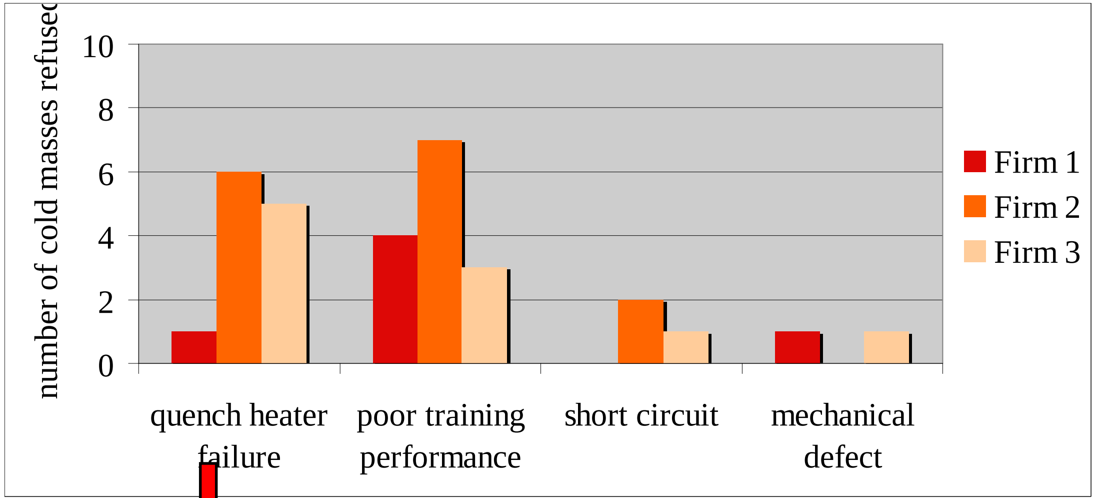
| ID | Arrived | Cold Test | Sent back | Back to CERN | Reason | Follow-up |
|---|---|---|---|---|---|---|
| 1005 | Mar 02 | May 02 | May 02 | | unacceptable training performance (cold welds in the cable) | |
| 1019 | Dec 02 | Mar 03 | Jan 04 | Mar 04 | short circuit QH/ground | new id 1519, TESTED OK |
| 1026 | Mar 03 | Jul 03 | Oct 03 | Jan 06 | unacceptable training performance | new id 1526, TESTED OK |
| 1039 | Aug 03 | not tested | Sep 03 | Oct 03 | welds on M-lines - repair without dismounting | TESTED OK |
| 1126 | Jun 04 | Sep 04 | Nov 04 | Fev 06 | unacceptable training performance | new id 1626, TESTED OK |
| 1143 | Aug 04 | Sep 04 | Nov 04 | May 05 | unacceptable training performance | new id 1643, TESTED OK |
| 2002 | Nov 01 | Dec 01 | Feb 02 | Jul 03 | insulation fault on three QH circuits detected at cold | TESTED OK |
| 2013 | Sep 03 | Feb 04 | Mar 04 | Jun 05 | unacceptable training performance | new id 2513, TESTED OK |
| 2023 | Jul 03 | Aug 03 | Nov 03 | Jun 04 | unacceptable training performance | new id 2523, TESTED OK |
| 2024 | Sep 03 | Oct 03 | Nov 04 | Jun 05 | unacceptable training performance | new id 2524 : TESTED OK |
| 2025 | Jul 03 | Aug 03 | Feb 04 | Jan 05 | unacceptable training performance | new id 2525, TESTED OK |
| 2032 | Mar 04 | Apr 04 | May 04 | Jul 05 | short circuit between coil turns | new id 2532, TESTED OK |
| 2049 | Apr 04 | May 04 | June 04 | Apr 06 | short circuit QH/ground | new id 2549, TESTED OK |
| 2051 | Mar 04 | Jul 05 | Nov 06 | Feb 07 | unacceptable training performance | new id 2551 |
| 2069 | Mar 04 | Mar 04 | Sep 04 | May 06 | unacceptable training performance | new id 2569, TESTED OK |
| 2098 | Oct 04 | Nov 04 | Jan 05 | Jan 07 | unacceptable training performance pole D2-U | new id 2598 |
| 2124 | Nov 04 | Dec 04 | Fev 05 | Dec 06 | defect on the quench heater | new id 2624 |
| 2190 | Jul 05 | Aug 05 | Jan 07 | | defect on the quench heater | |
| 2239 | Nov 05 | Nov 05 | Nov 06 | | short D2 upper pole | |
| 2290 | Apr 06 | Jul 06 | Sep 06 | Dec 06 | short between QHs and coil | new id 2790 |
| 2368 | Jul 06 | Aug 06 | Jan 07 | | quench heater and insulation problem | |
| 3003 | Feb 03 | May 03 | Aug 03 | Dec 03 | short circuit QH/coil and QH/ground | TESTED OK |
| 3004 | Aug 02 | Oct 02 | Jun 03 | May 04 | damaged (coil locally burnt) due to interturn short circuit | new id 3504, TESTED OK |
| 3016 | Apr 03 | not tested | Jul 03 | Sep 03 | cold feet supports misaligned - repair without dismounting | TESTED OK |
| 3136 | Jun 04 | Aug 04 | Sep 04 | Mar 05 | unacceptable training performance | new id 3636, TESTED OK |
| 3143 | May 04 | Nov 04 | Fev 05 | Sep 05 | NC discovered at warm: Q.H. YT122 in short circuit with coil | new id 3643, TESTED OK |
| 3153 | May 04 | Fev 05 | May 05 | Oct 05 | quench heater failure | new id 3653, TESTED OK |
| 3208 | Set 04 | Oct 04 | Apr 05 | Oct 05 | unacceptable training performance | new id 3708, TESTED OK |
| 3224 | Set 04 | Oct 04 | Dec 04 | Set 05 | unacceptable training performance | new id 3724, TESTED OK |
| 3234 | Oct 04 | Oct 04 | Fev 05 | Set 05 | NC appeared at cold: YT121 and YT122 connected to the coil | new id 3734, TESTED OK |
| 3388 | Aug 05 | Sep 05 | Oct 05 | Nov 05 | HV test failed for YT121 and YT122 | TESTED OK |

**Firm 1: 6 magnets**

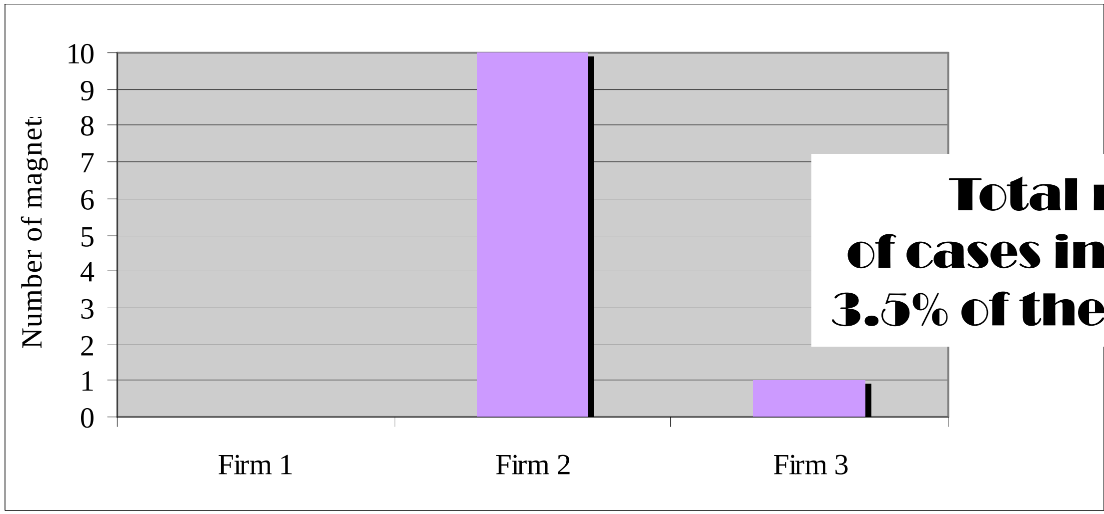
**Firm 2: 15 magnets**

**Firm 3: 10 magnets**

# Refused magnets after delivery to CERN



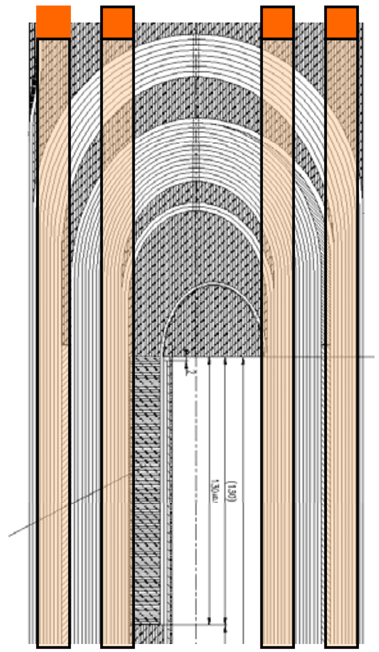

# Reworked magnets before delivery to CERN due to quench heater failure



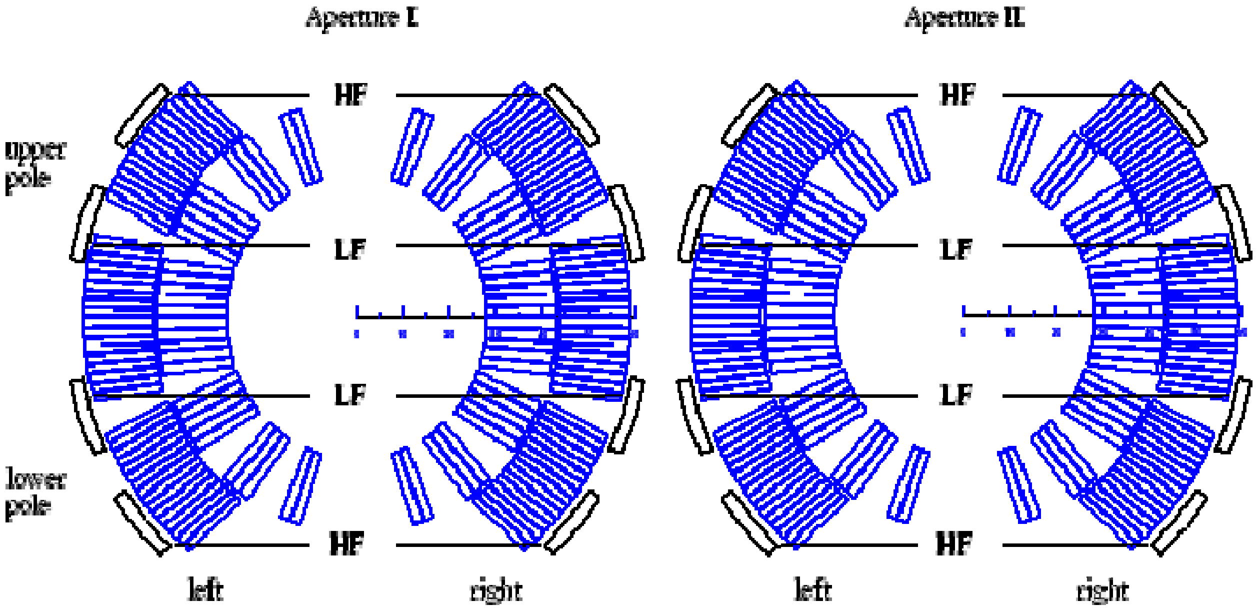

**Total number of cases in Firm 2: 16, 3.5% of the production!**

# QH and their position in the dipoles

The QH consist of **partially copper plated stainless steel** strips ( AIS 304 or AISI 316L) of about **25 µm** thickness and 15 mm wide. They are sandwiched and bonded to **two layers of polyimide** electrical insulation foil. The thickness of both insulation foils is **75 µm** . A **25 µm tick layer epoxy** glue is added on one side of the foil to provide bonding during manufacturing of the QH.

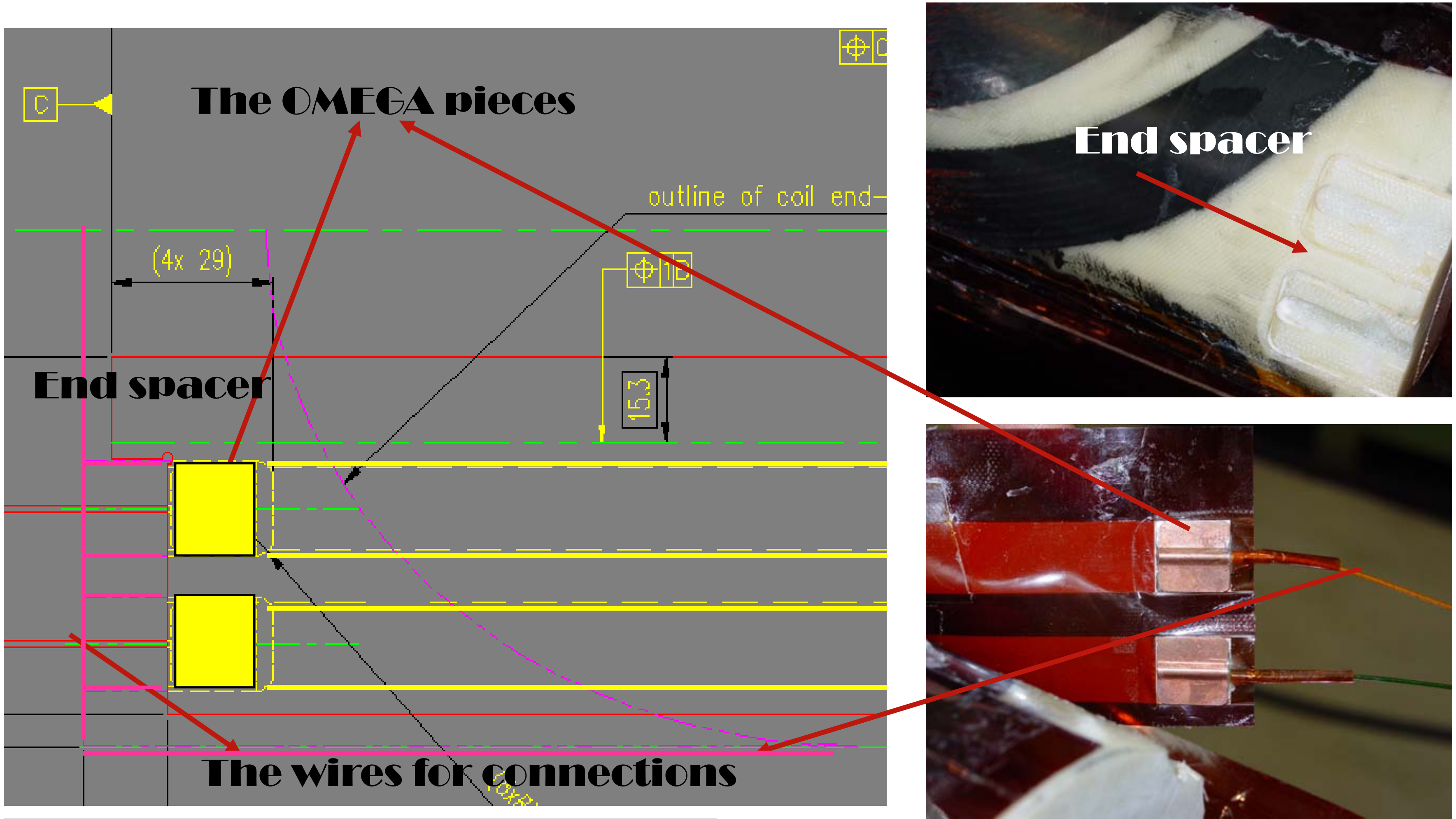


The QH covers the entire length of the coils (15m).
For redundancy there are 2 strips / quadrant covering 13 turns.




HF: High Field        LF: Low Field

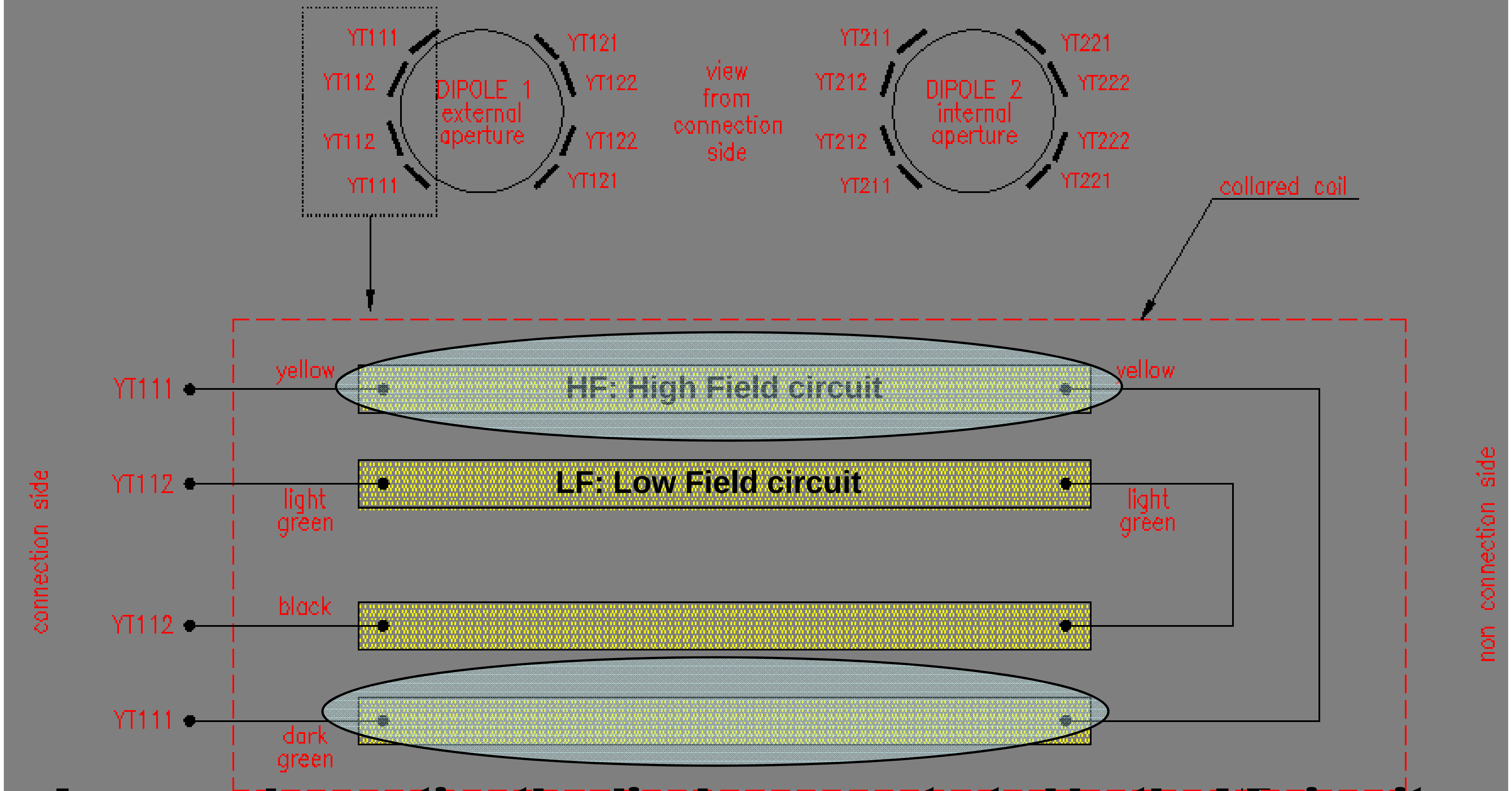
# Connection at the end of the coils




**Ref drawings: LHCMB_A0025 and LHCMB_A0026**

# Quench heater wiring diagram

**Ref drawings: LHCMB_A0025 and LHCMB_A0026**




**In normal operation the dipoles are protected by the HF circuit**

# Failure location. Failure classes

Although the 100% of the failed QHs are coming from the same QH producer, it is possible to think that they arise from two different mechanisms:

**A) probably due to defect of the QH (detected in the straight part of the magnet and called "middle")**

-> fabrication

-> provoked by impurities

*Ex. 2073, 2092, 2098, 2119, 2134, 2275*

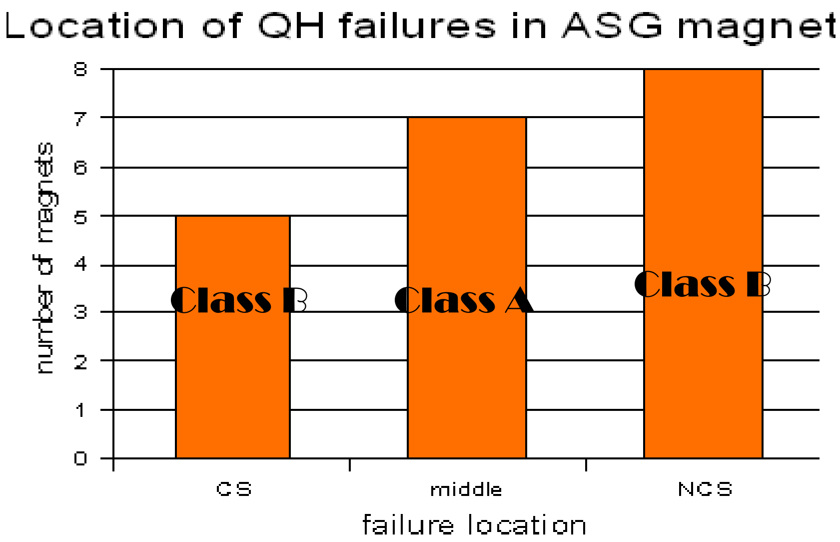
**B) probably due to over pressure in the coil heads: detect on the extremities of the magnet ( called "CS" or "NCS")**

-> shims

-> collaring pressure

-> other causes ( extra kapton sheet insulation layer,...)

*Ex.2049,2121, 2190, 2303, 2368, 2382*




The idea of the existence of two different classes is supported by the observation that failures in the straight section occur with almost the same probability in the upper and lower part of the aperture; while they are located in the 85% of cases in the upper zone if they are going to happen in the coil ends.

# Failure location. Class 2

| Magnet nr. | Failed circuit | Failure location | | Failure discovered at |
|---|---|---|---|---|
| | | | | |
| 2002 | | | | cold |
| 2005 | 211 (HF) | CS/NCS | | cold |
| 2011 | 211 (HF) | CS | D2 Up | warm |
| 2013 | 112 (LF) | CS | D1 Up/ D1 | warm |
| 2049 | 211 (HF) | NCS | D2 Up | cold |
| 2121 | 221 (HF) | NCS | D2 Up | warm |
| 2124 | 211 (HF) | NCS | D2 Lo | cold |
| 2190 | 211 (HF) | CS | D2 Up | cold |
| 2290 | 122 (LF) | NCS | D1 Up | cold |
| 2303 | 121 (HF) | NCS | D1 Up | warm |
| 2368 | 221 (HF) | NCS | D2 Up | cold |
| 2368 | 111 (HF) | NCS | D1 Up | cold |
| 2382 | 111 (HF) | NCS | D1 Up | warm |
| 2382 | 111 (HF) | CS | D1 Up | warm |

| Failed circuit | Failure location | | Failure discovered at |
|---|---|---|---|
| | | | |
| LF = 2 ( 16.7% ) | CS = 4 ( 33.3% ) | Up = 11 ( 84.6% ) | warm = 6 ( 50% ) |
| HF = 10 ( 83.3% ) | NCS = 8 ( 66.6% ) | Lo = 2 ( 15.4% ) | cold = 6 ( 50% ) |



**In normal operation the dipoles are protected by the HF circuit**

# Failure origin?

## Coil head shimming

Shims are used to control the pressure profile in the coil ends. QH failures observed in the coil ends are likely to be due to over pressure in the same region. Therefore it is possible to think of a correlation between QH failures and coil ends shims. Extra thickness of the shims can cause over pressure and consequently damage of the QH strips.


As a result of the analysis, it can be stated that thick shims cannot be neither identified as the main source of QH failures in the coil ends nor excluded from the list of parameters that can cause the problem in a combined way.

## Collaring pressure

For each one of the four circuits of the press it has been calculated :

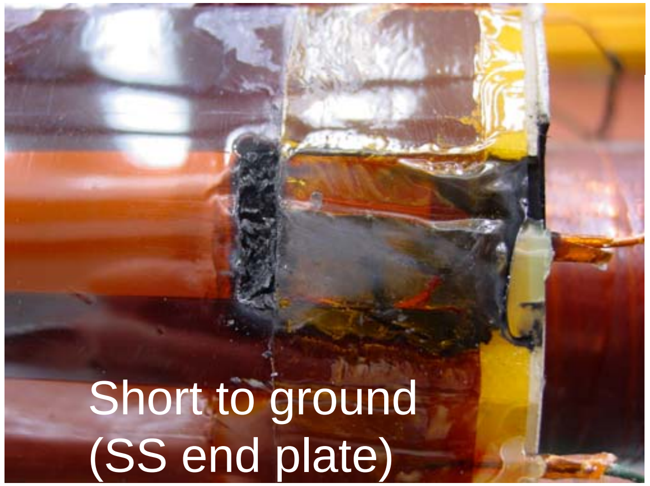
- the average value of the maximum applied pressure ( corresponding to the nominal locking rods insertion)
- the average time of its application
- the average value of the peak of pressure necessary to the insertion of the small locking rods

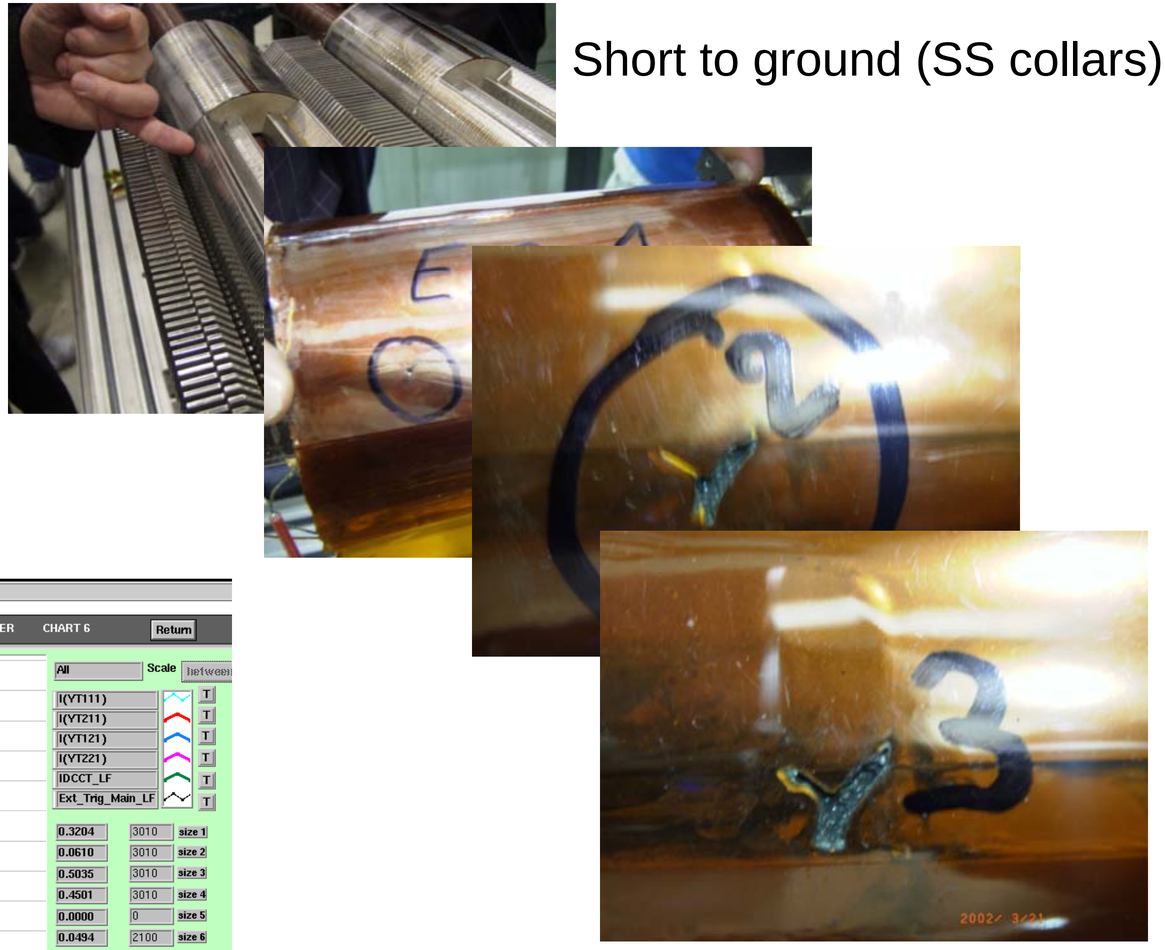
These values have been compared to those of magnets in which QH failures in the coil ends have been detected.

No correlation with QH failures can be established

# How were the failures detected?

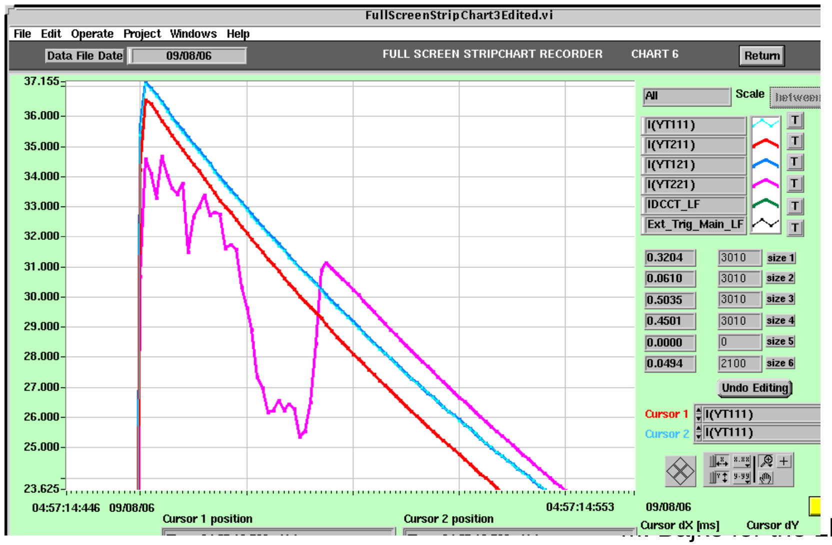
1. **Electrical insulation fault after successful discharge test**



Short to ground (SS collars)

1. **During discharge**



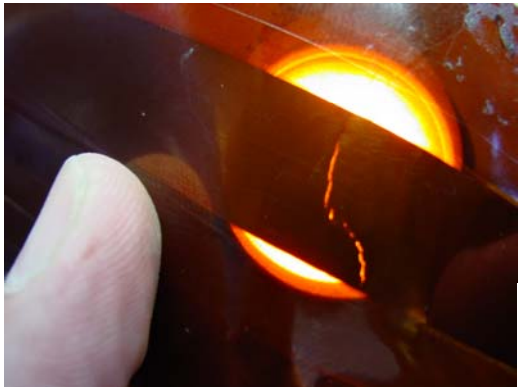
# Why this failure is a risk for the LHC?

1. **It is difficult to detect before damaging a coil**

A metallic strip partially open (90% of its width) is still electrically continue, no variation of its resistance can be seen and it withstands also a high voltage discharge test several times before it burns and maybe damage the coil.

2. **We already discovered failures without having seen it at any test**

**....**case that could not be detected by any of the electrical tests but it was seen after disassembling of the magnet. Although a failure was detected at cold on the QH in question, it was localised on the opposite side.



3. **The failures are mostly on the circuit that is the operational one HF**

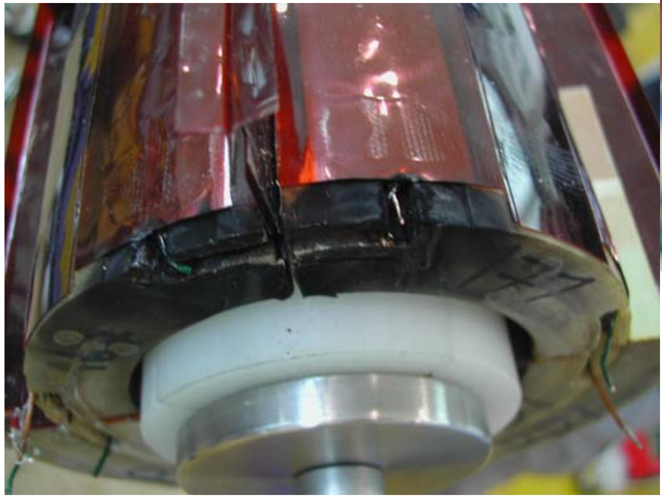
# Cases detected during HC?

| sector | dipole | |
|---|---|---|
| 12 | 2395 | 1372 |
| 23 | 3708 | |
| 34 | - | |
| 45 | 2214 | |
| 56 | - | |
| 67 | 1263 | |
| 78 | 2007 | |
| 81 | - | |
| | | |
| | Q4L8 | |

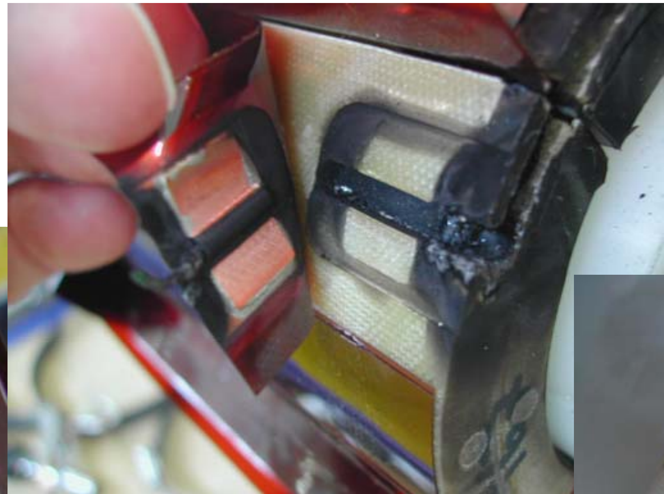
Courtesy of G. D'Angelo
( EIQA team)

To be remarked that in all cases the problem was in the instrumentation wires of the QHs.

This problem however was also seen during the production of the MQY magnets but CURED



Courtesy of G. Kyrby

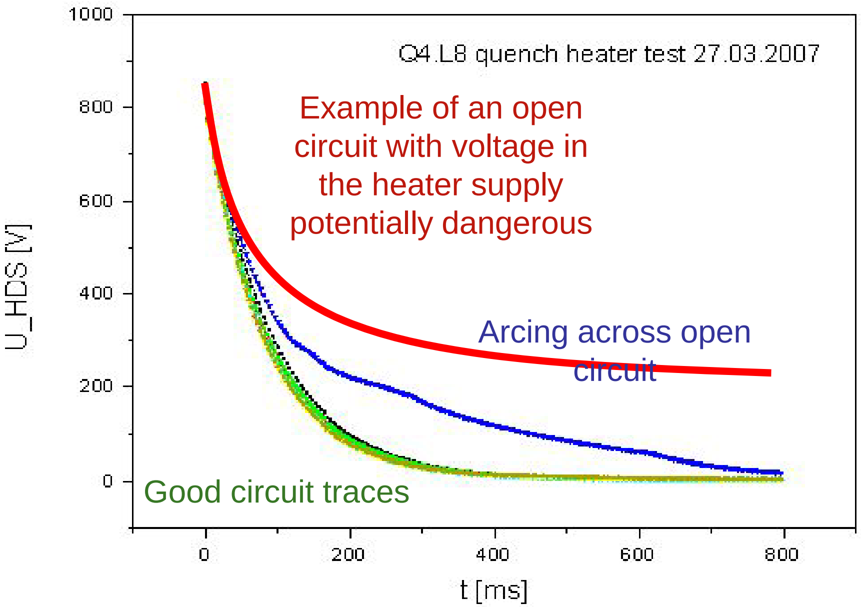


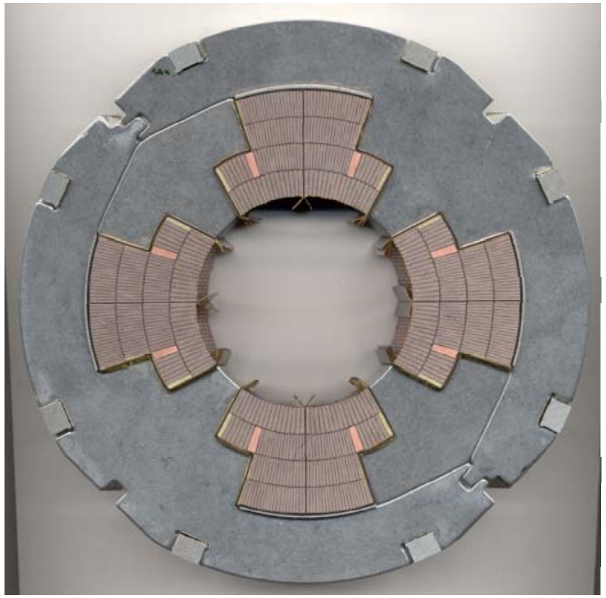
From aperture 21 (so magnet 10) onwards the design changed

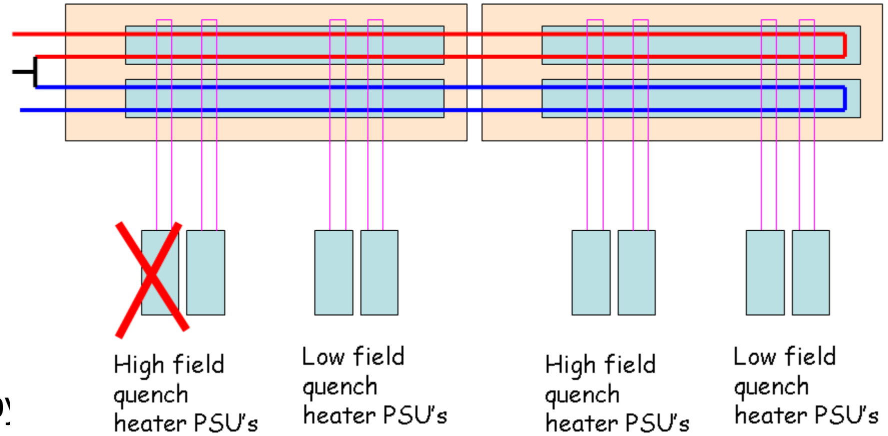
So magnets 1 to 9 could have problems!

Courtesy of J.C. Perez

# What we saw during HC?



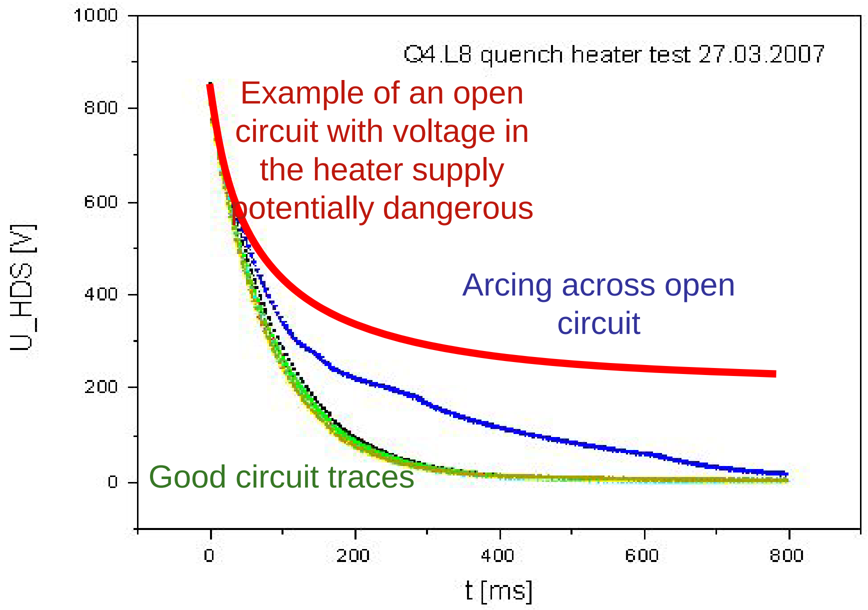






1. For all cases detected in HC the HF circuit was disconnected and insulated and
2. Replaced with 2 x in Parallel symmetrically two LF circuit to reduce Miits and DirVoltages

Courtesy of G. Kyrby

# What has been prepared and proposed?




A dedicated tool for AUTOMATIC data analysis

There was a proposal for an implementation of a system with a low current flowing in the QH circuit looking after any opening of the circuit.
The solution was abandoned as it was jugged of a reduced efficiency.

Meanwhile : the systematic analysis of the discharge is mandatory!!!