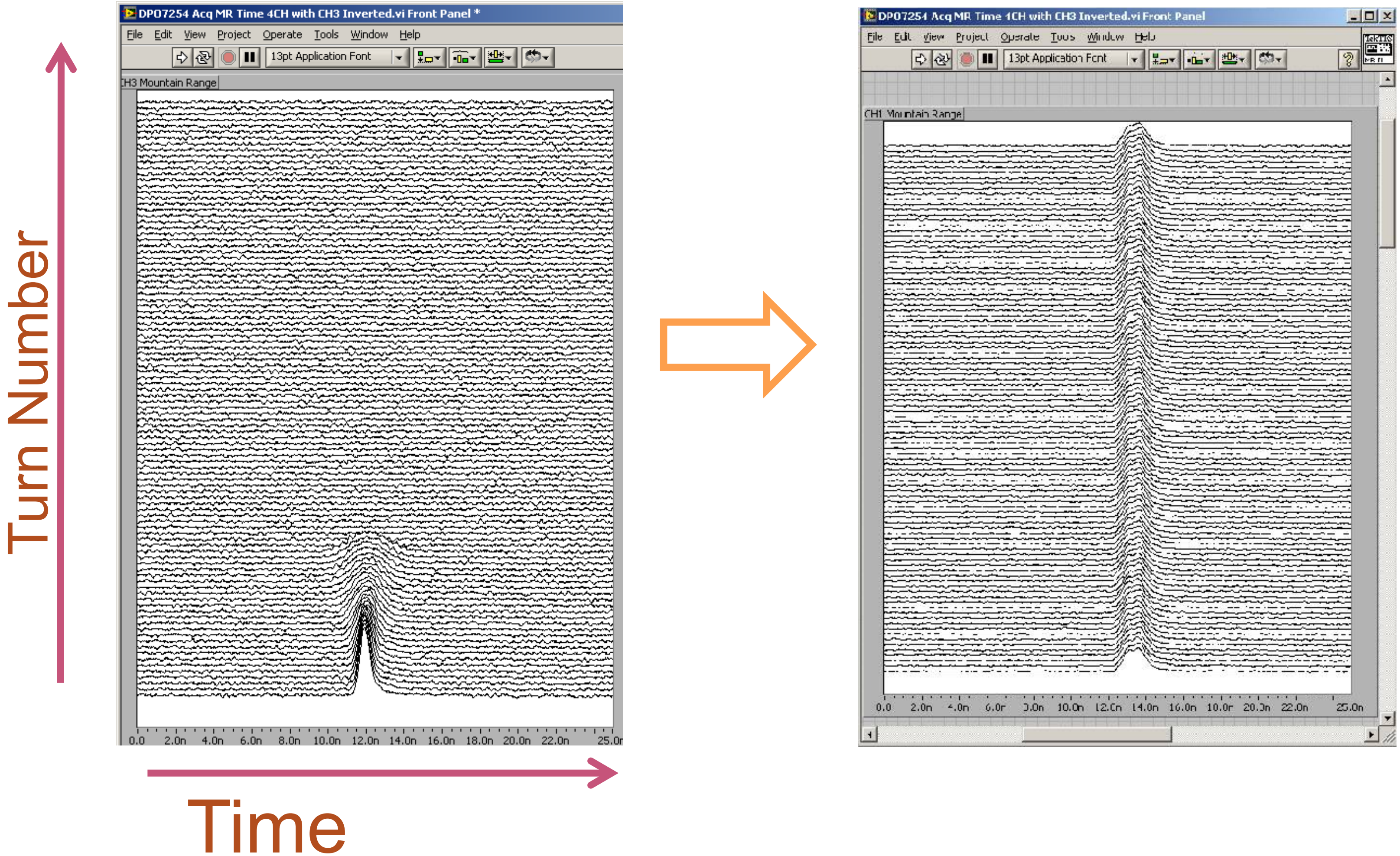
LHC Incident

Sept 10, 2008: LHC Startup

- 9:35 – First beam injected
- 9:58 – beam past CMS to point 6 dump
- 10:15 – beam to point 1 (ATLAS)
- 10:26 – First turn!
- …and there was much rejoicing

After initial circulation: captured beam



- Everything was going great until *something very bad happened* on September 19th
  - Initially, CERN kept a tight lid on news

Nature abhors a (news) vacuum…

- Italian newspapers were very poetic (at least as translated by "Babel Fish"):

  "the black cloud of the bitterness still has not been dissolved on the small forest in which they are dipped the candid buildings of the CERN"

  "Lyn Evans, head of the plan, support that it was better to wait for before igniting the machine and making the verifications of the parts." *

- Or you could Google "What really happened at CERN":

Strange Incident at CERN

Did the LHC Create a Black Hole?

And if so, Where is it Now? **

by

George Paxinos

in conversation with

"An Iowan Idiot"

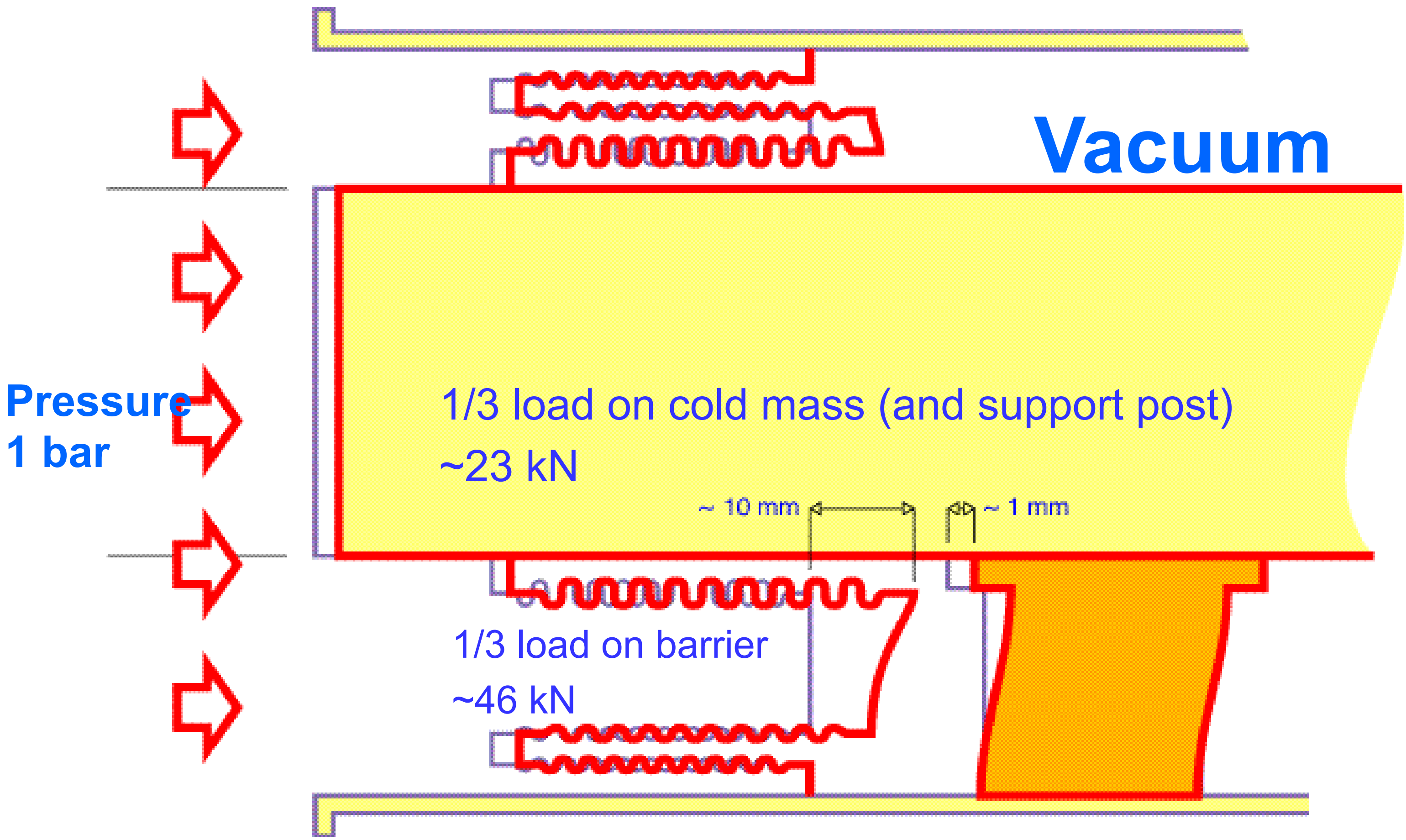
* "Big Bang, il test bloccato fino all primavera 2009", Corriere dela Sera, Sept. 24, 2008

**http://www.rense.com/general83/IncidentatCERN.pdf

What (really) really happened on September 19th*

- Sector 3-4 was being ramped to 9.3 kA, the equivalent of 5.5 TeV
  - All other sectors had already been ramped to this level
  - Sector 3-4 had previously only been ramped to 7 kA (4.1 TeV)
- At 11:18AM, a quench developed in the splice between dipole C24 and quadrupole Q24
  - Not initially detected by quench protection circuit
  - Power supply tripped at .46 sec
  - Discharge switches activated at .86 sec
- Within the first second, an arc formed at the site of the quench
  - The heat of the arc caused Helium to boil.
  - The pressure rose beyond .13 MPa and ruptured into the insulation vacuum.
  - Vacuum also degraded in the beam pipe
- The pressure at the vacuum barrier reached ~10 bar (design value 1.5 bar). The force was transferred to the magnet stands, which broke.

Pressure forces on SSS vacuum barrier

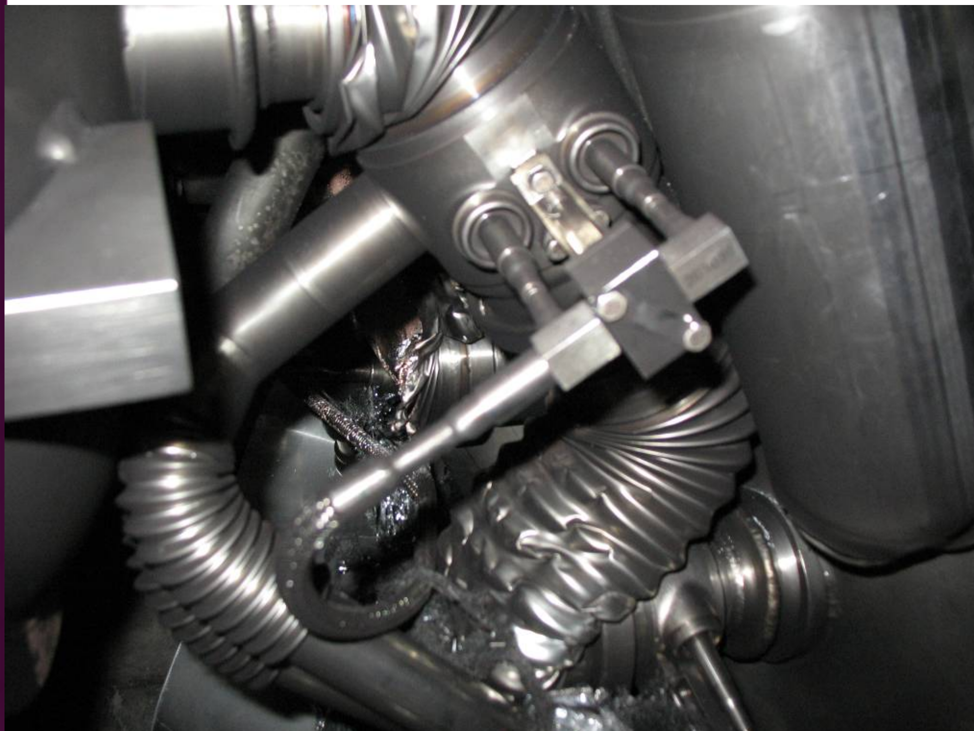


Total load on 1 jack ~70 kN V. Parma

Collatoral damage: magnet displacements

QQBI.27R3

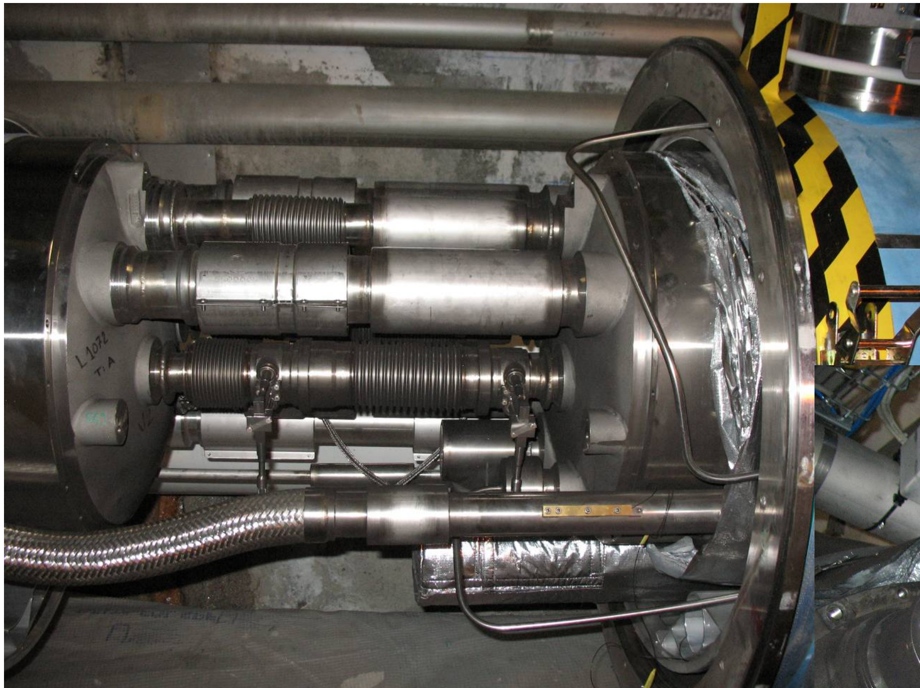
Collatoral damage: magnet displacements



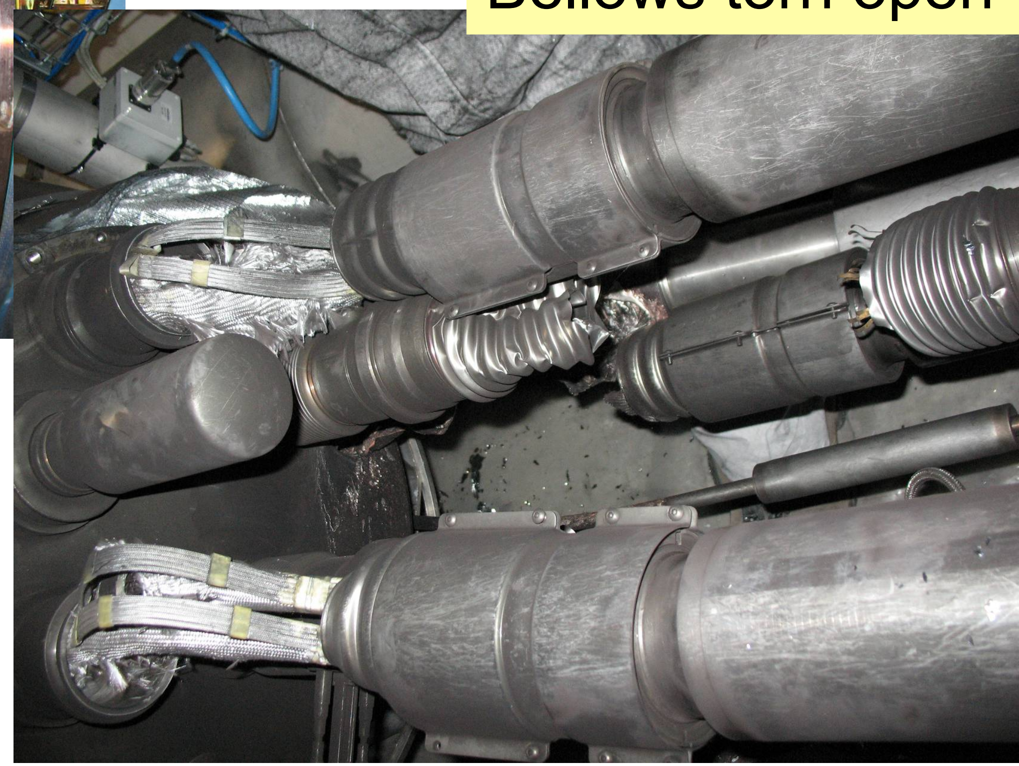
QQBI.27R3
V2 line

QQBI.27R3
N line

Collateral damage: magnet displacements

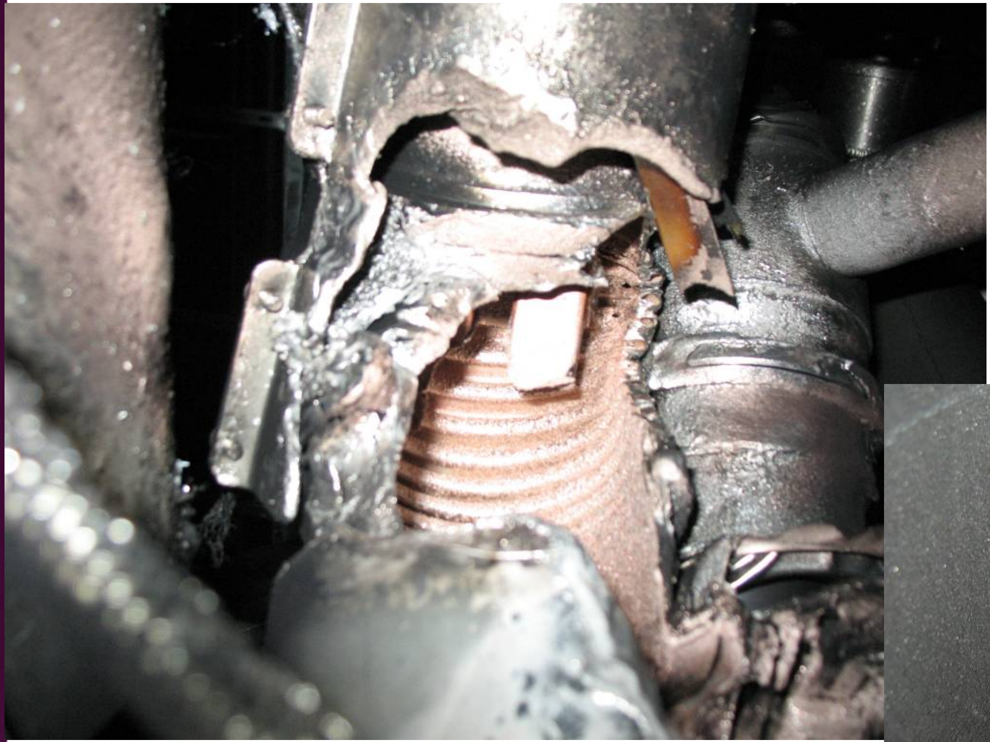


QBBI.B31R3
Extension by 73 mm



QBQI.27R3
Bellows torn open

Collateral damage: secondary arcs



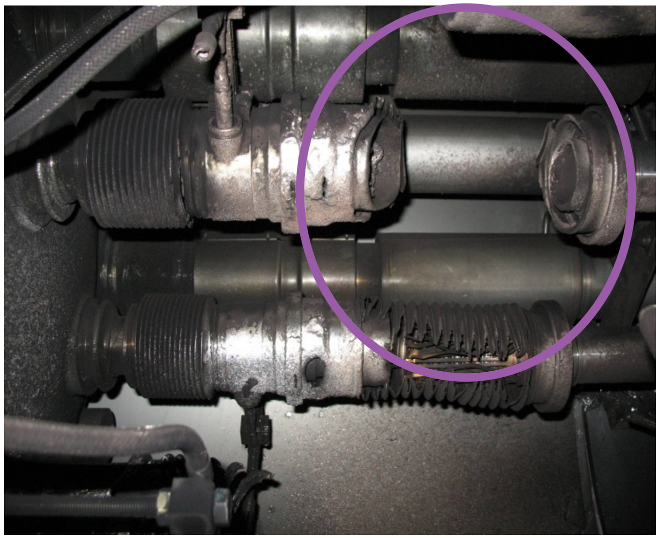
QQBI.27R3 M3 line

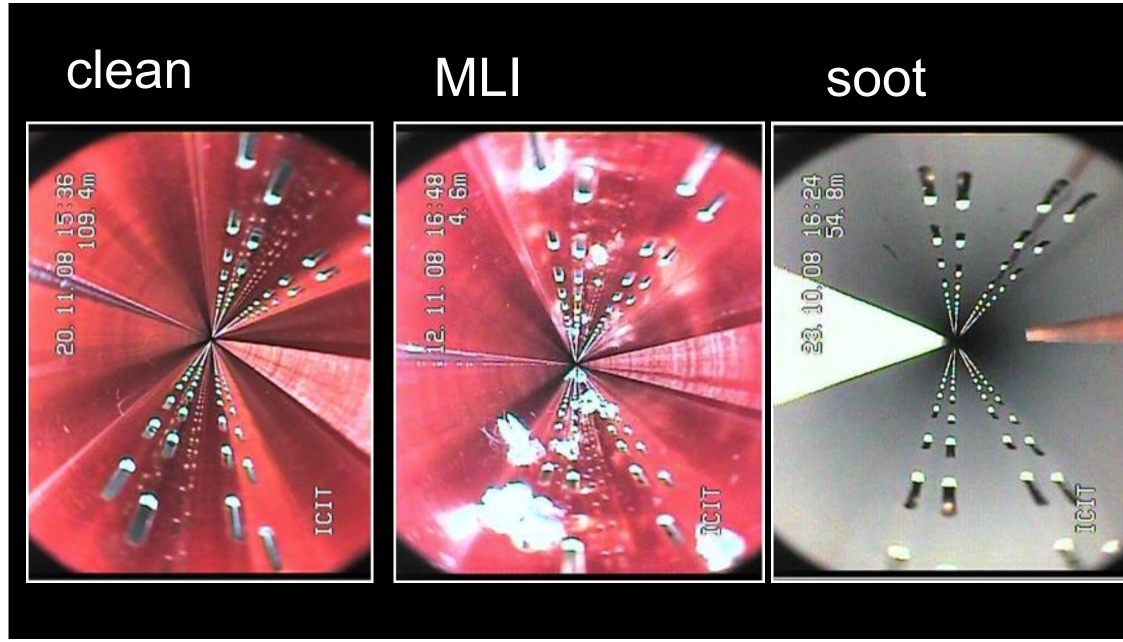
QBBI.B31R3 M3 line

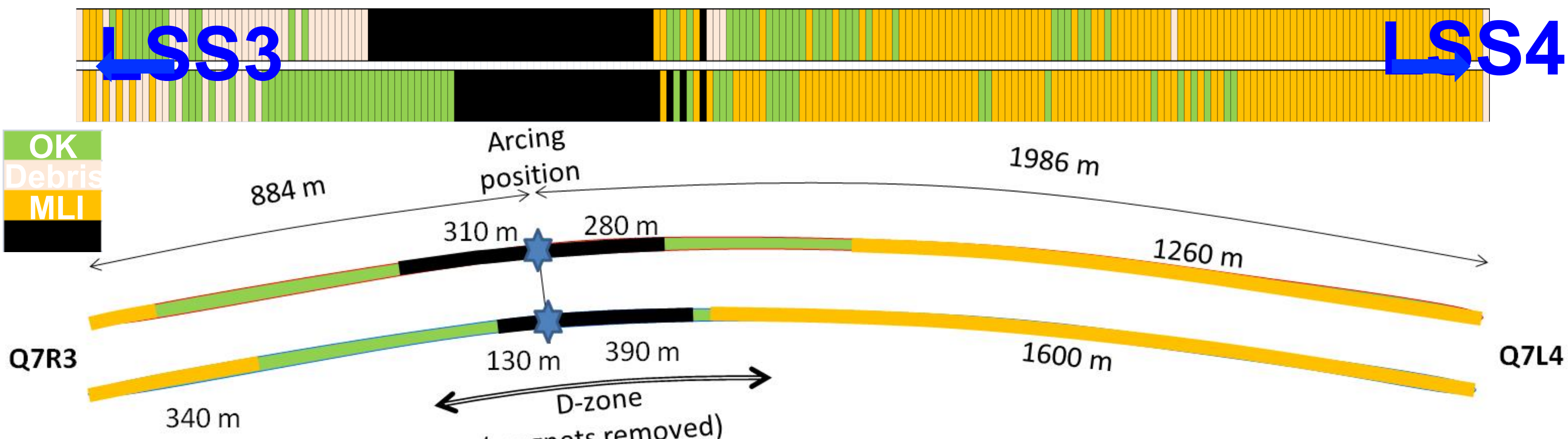
Collateral damage: ground supports

Collateral damage: Beam Vacuum

Arc burned through beam vacuum pipe







Replacement of magnets

- 15 Quadrupoles (MQ)
  - 1 not removed (Q19)
  - 14 removed
    - 8 cold mass revamped (old CM, partial de-cryostating for cleaning and careful inspection of supports and other components)
    - 6 new cold masses
    - In this breakdown there is consideration about timing (quad cryostating tales long time; variants problems).
- 42 Dipoles (MBs)
  - 3 not removed (A209,B20,C20)
  - 39 removed
    - 9 Re-used (old cold mass, no decryostating –except one?)
    - 30 new cold masses
    - New cold masses are much faster to prepare than rescuing doubtful dipoles)

Important questions about Sept. 19

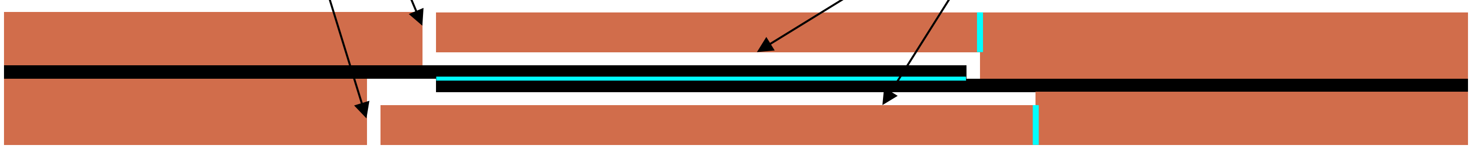
- Why did the joint fail?
  - Inherent problems with joint design
    - No clamps
    - Details of joint design
    - Solder used
  - Quality control problems
- Why wasn't it detected in time?
  - There was indirect (calorimetric) evidence of an ohmic heat loss, but these data were not routinely monitored
  - The bus quench protection circuit had a threshold of 1V, a factor of >1000 too high to detect the quench in time.
- Why did it do so much damage?
  - The pressure relief system was designed around an MCI Helium release of 2 kg/s, a *factor of ten* below what occurred.

What happened?

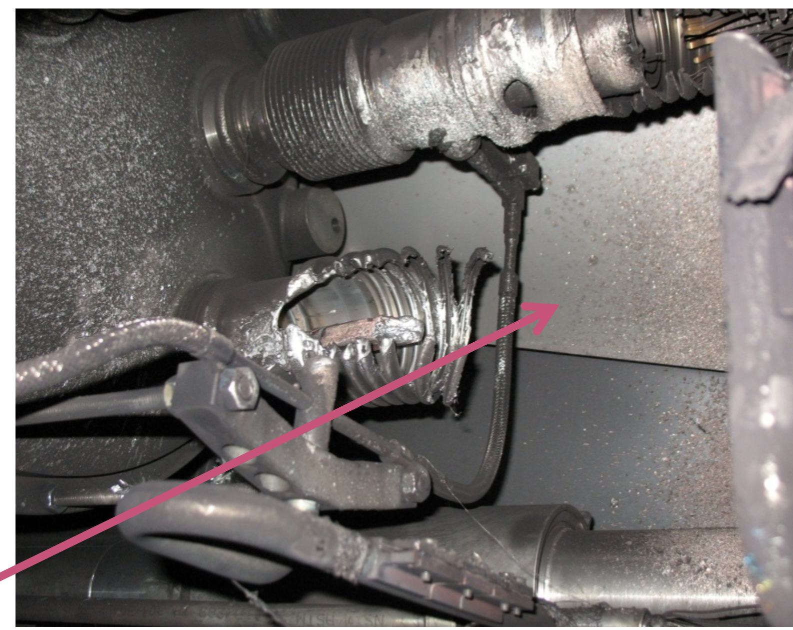
Theory: A resistive joint of about 220 nΩ with bad electrical and thermal contacts with the stabilizer

No electrical contact between wedge and U-profile with the bus on at least 1 side of the joint

No bonding at joint with the U-profile and the wedge



- Loss of clamping pressure on the joint, and between joint and stabilizer
- Degradation of transverse contact between superconducting cable and stabilizer
- Interruption of longitudinal electrical continuity in stabilizer



Problem: this is where the evidence used to be

A. Verweij

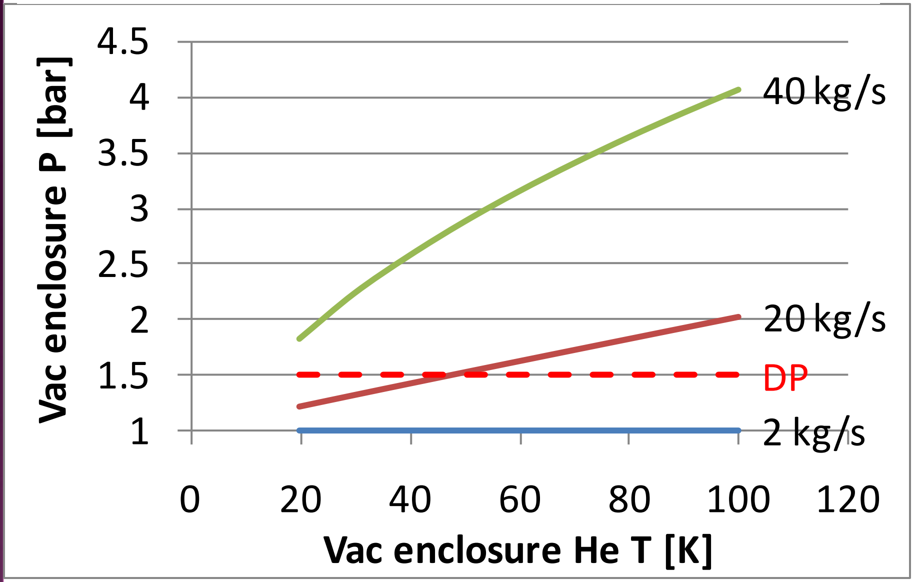
Improved quench protection*

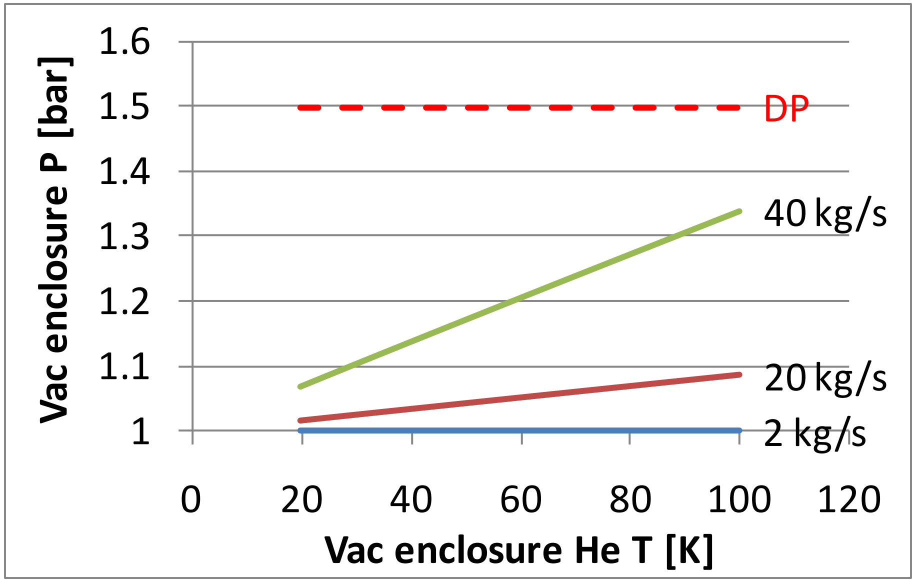
- Old quench protection circuit triggered at 1V on bus.
- New QPS triggers at .3 mV
  - Factor of 3000
  - Should be sensitive down to 25 nOhms (thermal runaway at 7 TeV)
  - Can measure resistances to <1 nOhm
- Concurrently installing improved quench protection for “symmetric quenches”
  - A problem found before September 19th
  - Worrisome at >4 TeV

Improved pressure relief*

New configuration on four cold sectors: Turn several existing flanges into pressure reliefs (while cold). Also reinforce stands to hold ~3 bar

New configuration on four warm sectors: new flanges (12 200mm relief flanges)



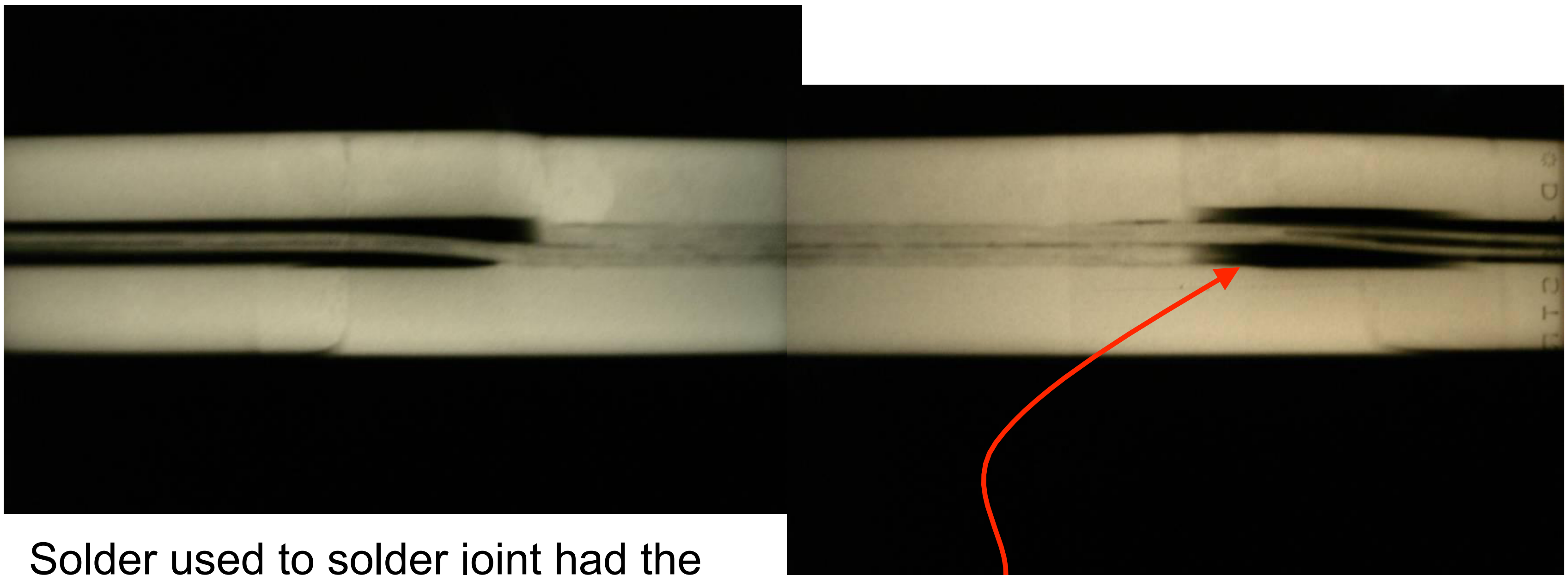


(DP: Design Pressure)

L. Tavian

Bad surprise

- With new quench protection, it was determined that joints would only fail if they had bad thermal *and* bad electrical contact, and how likely is that?
  - Very, unfortunately ⇒ *must* verify copper joint



Solder used to solder joint had the same melting temperature as solder used to pot cable in stablizer
⇒Solder wicked away from cable

- Have to warm up to at least 80K to measure Copper integrity.

Complete Repair (2013-2015)

- All (10,000!) individual joints were rebuilt
  - Clamped
  - Inspected
- Improved pressure relief was installed to handled "Maximum Credible Incident" (MCI)
  - In which both the quadrupole and dipole Helium lines were burned through.
- After 2015 turn on, "smooth sailing".