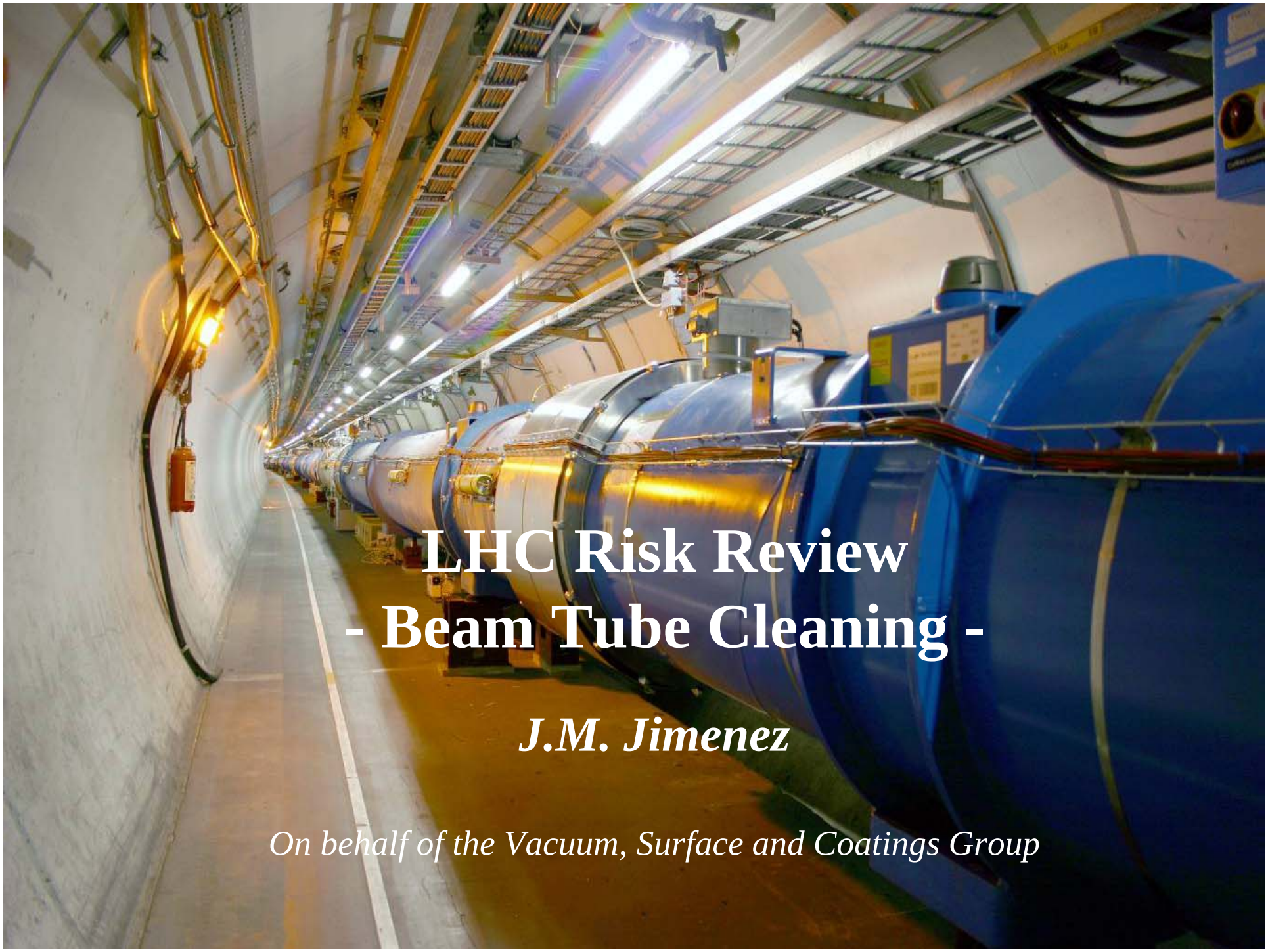


# LHC Risk Review
# - Beam Tube Cleaning -


***J.M. Jimenez***

*On behalf of the Vacuum, Surface and Coatings Group*

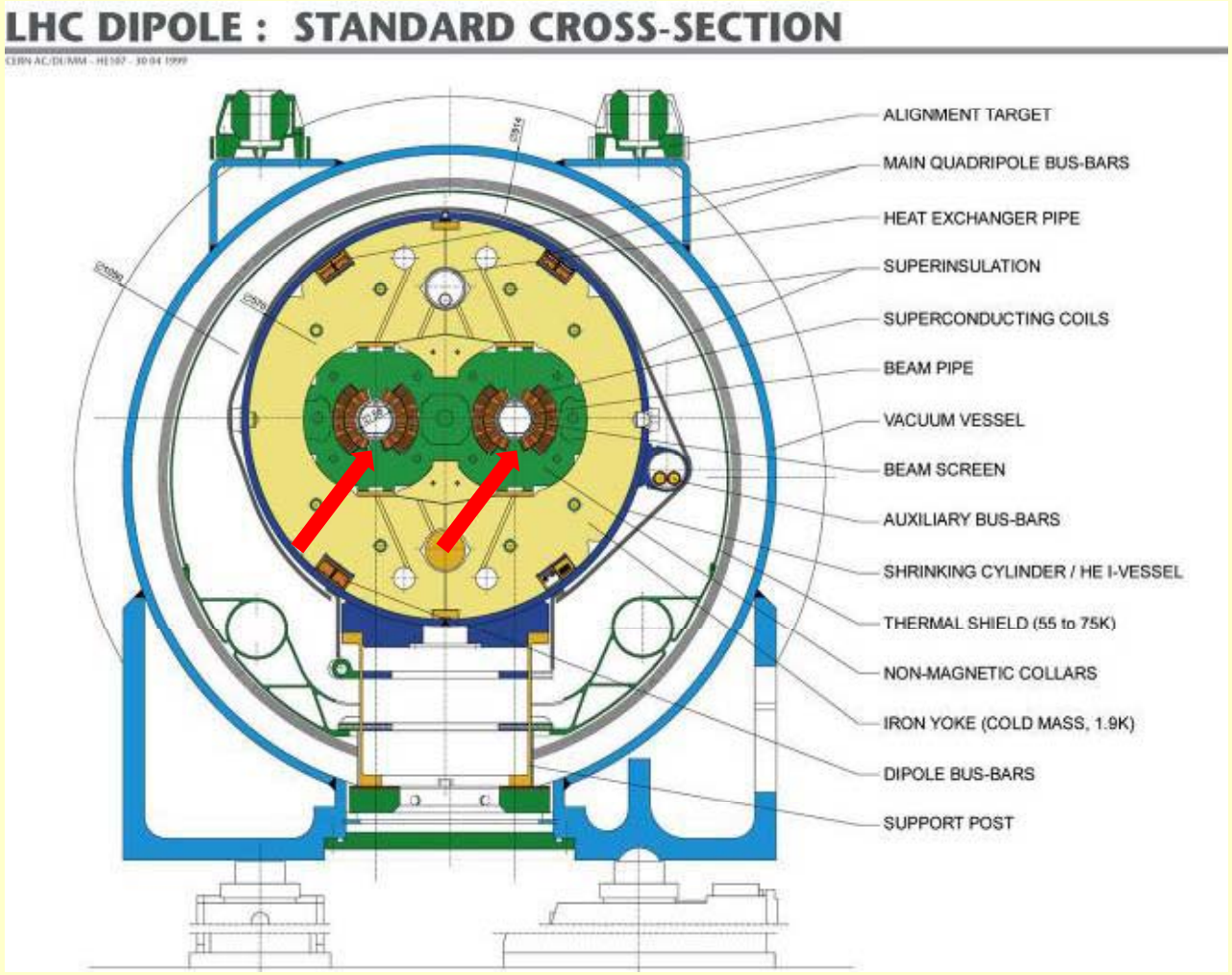
# Main topics

- **Introduction**
- **Evaluation of damages**
- **Sorting the magnets**
- **Cleaning strategy**
- **Follow-up of Chamonix'09 recommendations**

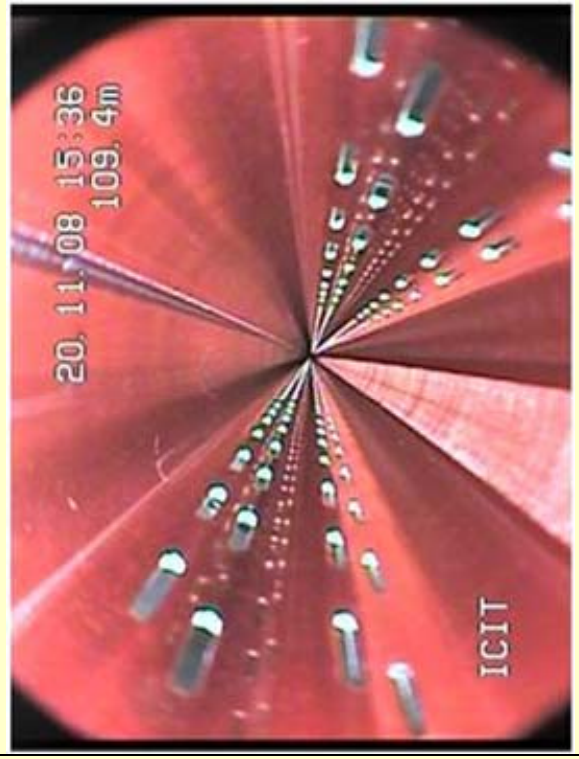
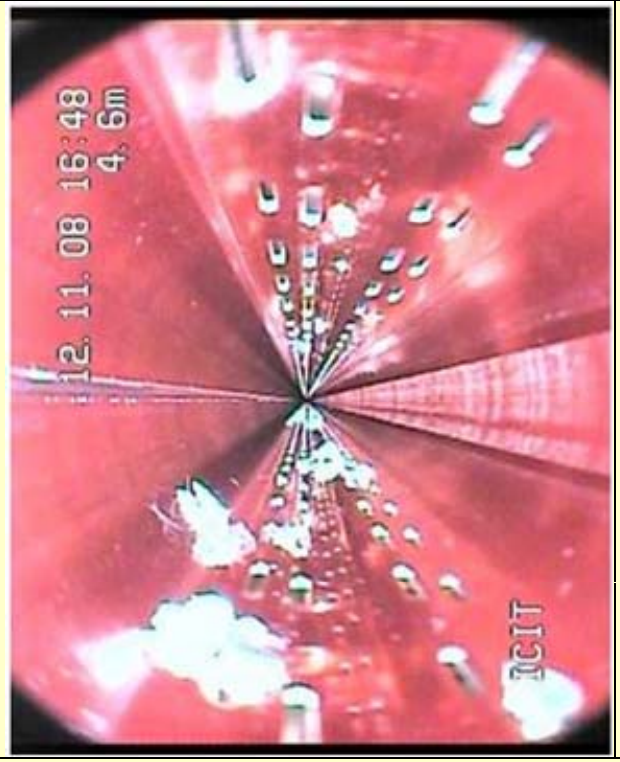
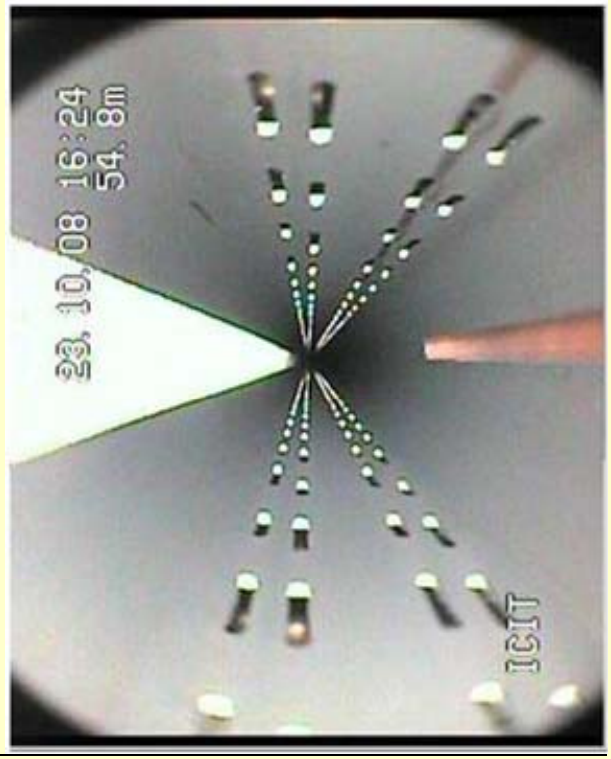
# Introduction
# LHC dipole magnet cross-section

- **Insulation vacuum is a high vacuum between:**
  - Cryomagnet and its cryostat
  - Inner cold cryogenic lines and the outer envelope of the liquid helium transfer lines

  *Both are wrapped with super insulation layers*
- **Beam vacuum fulfils the ultra-high vacuum specifications**



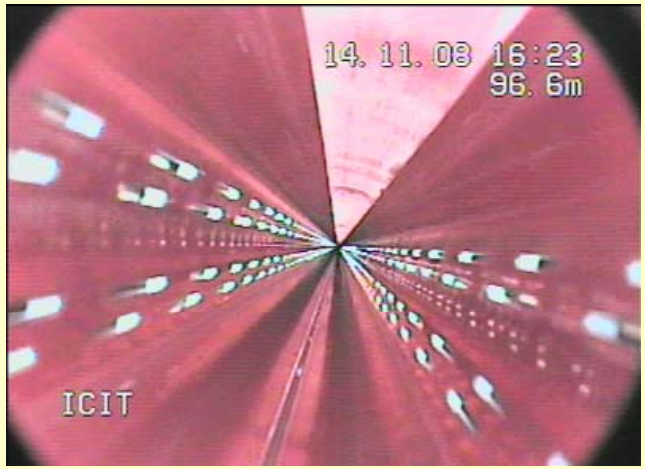
# Evaluation of damages
# Types of contamination (BS)

| Beam Screen (BS) : The red color is characteristic of a clean copper surface | BS with some contamination by super-isolation (MLI multi layer insulation) | BS with soot contamination. The grey color varies depending on the thickness of the soot, from grey to dark. |
|---|---|---|
|   |   |   |

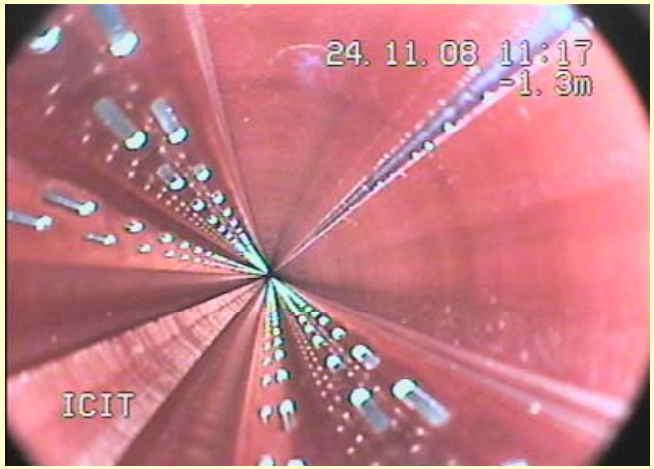
# Evaluation of damages
# Types of contamination (BS)

| Beam Screen (BS) with debris of metal coming from melted RF fingers or Cold Bore (CB) pipes. The red color is characteristic of a clean copper surface | The magnets in which both soot and debris were expected, were not checked to preserve the head of the endoscope |
|---|---|
|     | |

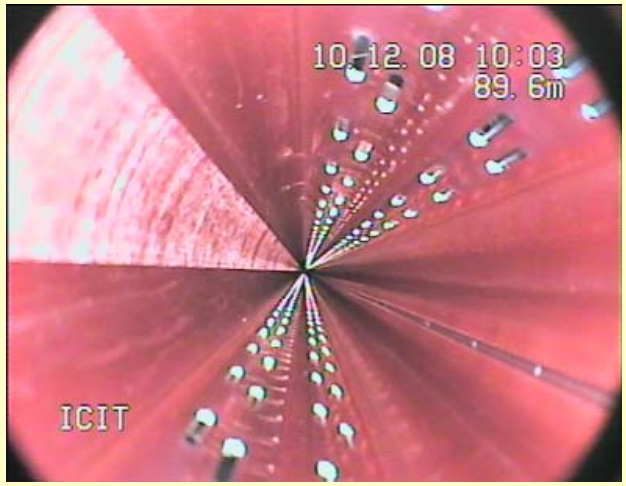
# Evaluation of damages
# Beam Screens of 3-4 Declared Cleaned



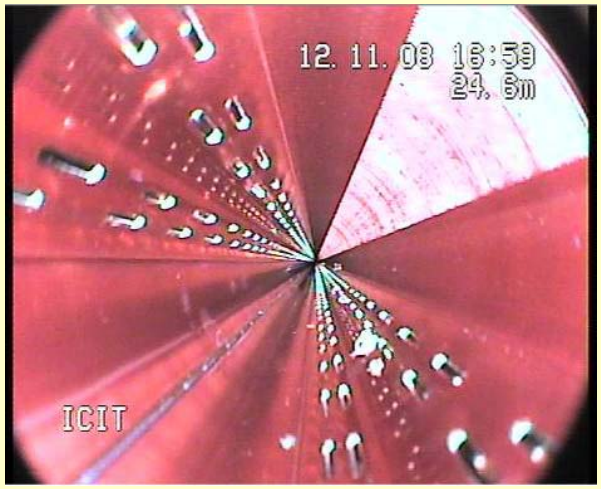

C20L4.V1




Q13L4.V2

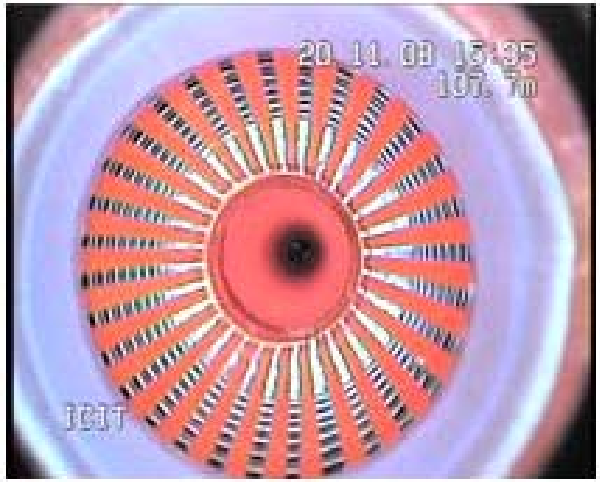
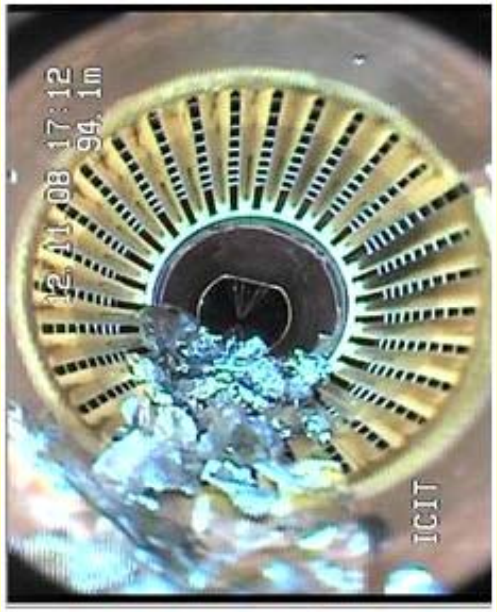



C14R3.V1

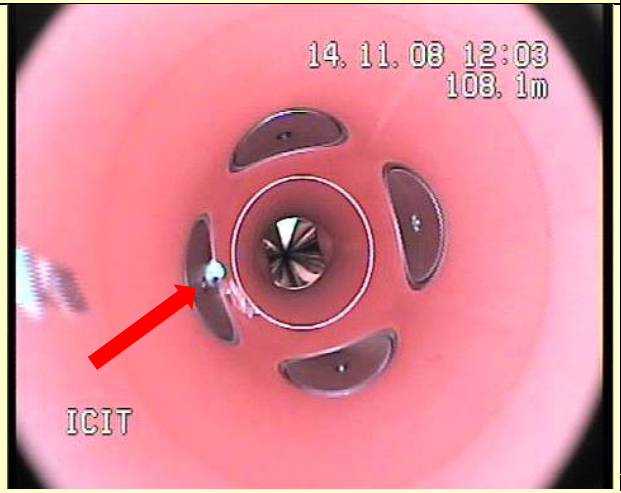



B8L4.V2

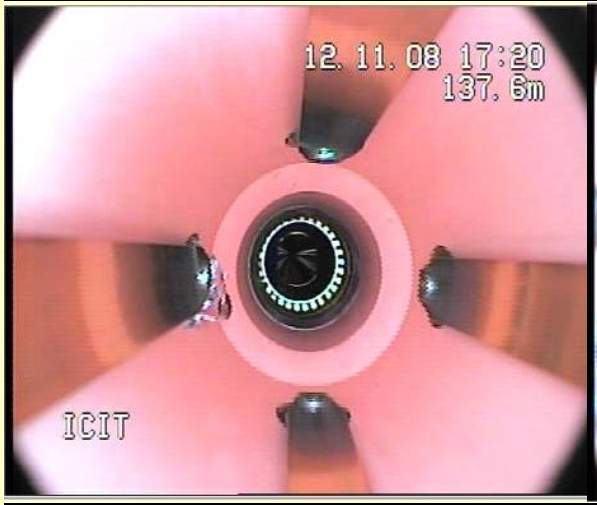
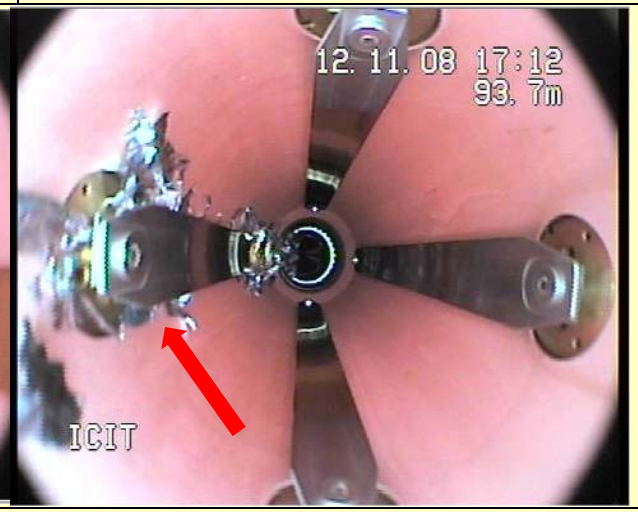
# Evaluation of damages
# Types of contamination (PIMs)

| Interconnecting bellows (PIM) with its RF screen to minimize the beam impedance. The shiny red color is characteristic of the cleanliness of the copper surfaces | PIM with some contamination by super-isolation (MLI multi layer insulation) | BS with soot contamination. The grey color varies depending on the thickness of the soot, from grey to dark |
|---|---|---|
|   |   |   |

# Evaluation of damages
# Types of contamination (BPM)

| Beam position monitor (BPM). The shiny red color is characteristic of the cleanliness of the copper surfaces | BPM with some contamination by super-isolation (MLI multi layer insulation) on the electrode at 8h. | BPM with soot contamination. The grey color varies depending on the thickness of the soot, from grey to dark |
|---|---|---|
|   |   |   |

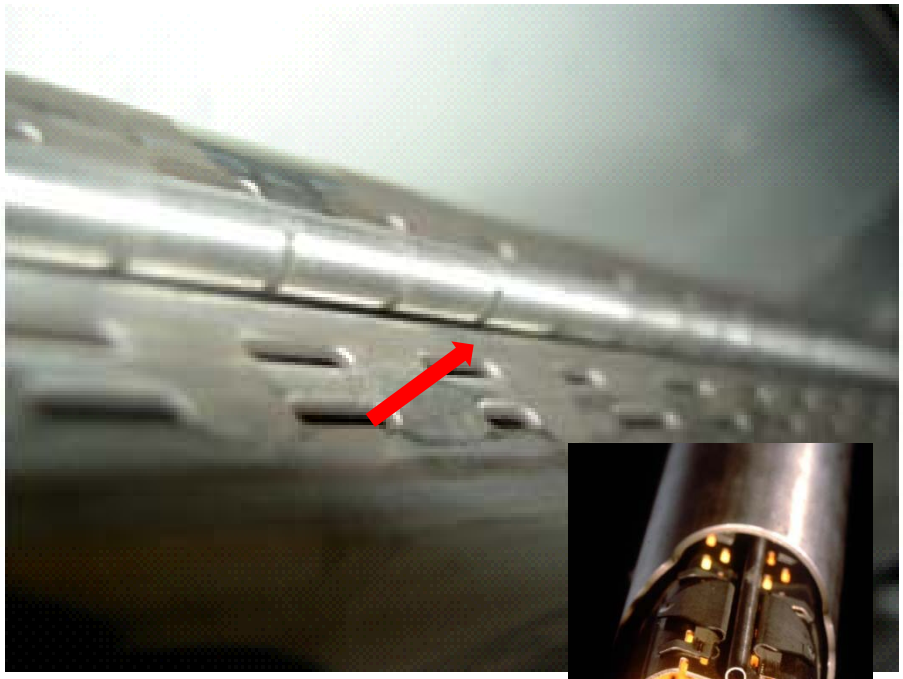
# Evaluation of damages
# Types of contamination (BPM)

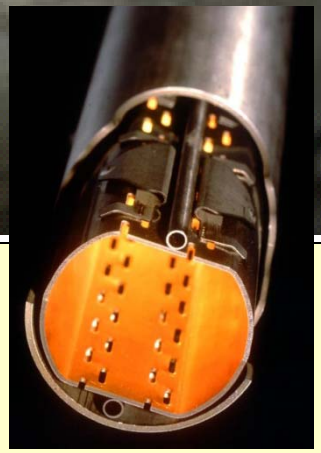
| Another variant of beam position monitor (BPM). The shiny red color is characteristic of the cleanliness of the copper surfaces | BPM with some contamination by super-isolation (MLI multi layer insulation) on the electrode at 9h | None of this type of component has been found contaminated by soot, only available in the 4L side of sector 3-4 |
|---|---|---|
|   |   | |

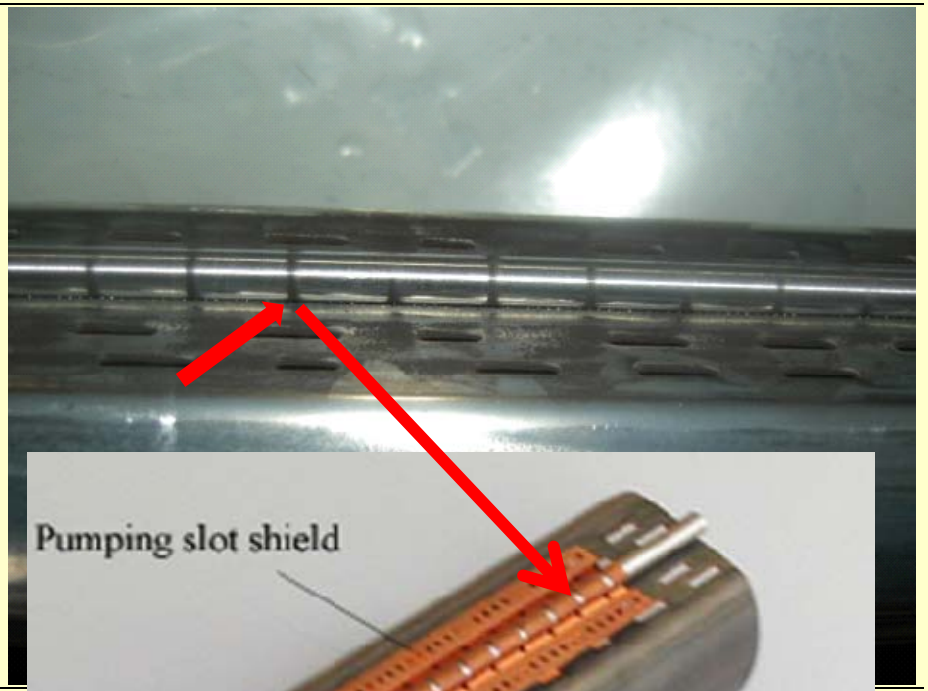
# Evaluation of damages
# Types of contamination (BS/CB interface)

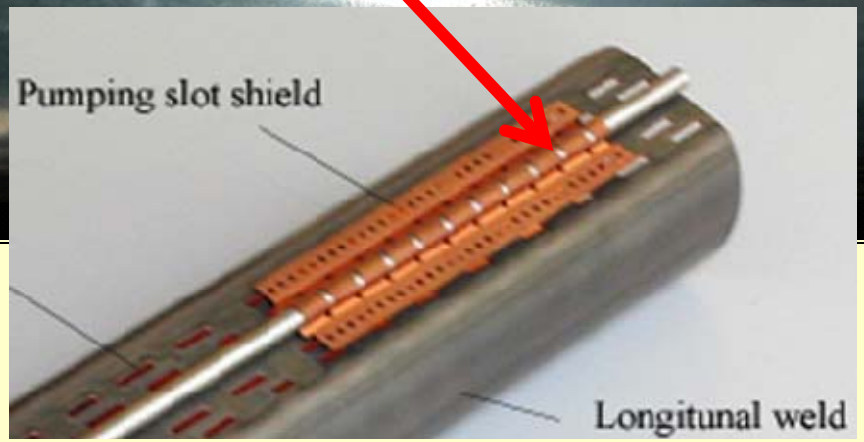
Beam screen (BS) removed from a heavily soot contaminated magnet. The pictures show that the external Surface of the beam screen (cold bore side) and the inner surface of the Cold Bore (CB) tube are also contaminated by soot.

Cleaning the CB and BS without removing the BS from the magnet from the tunnel is impossible

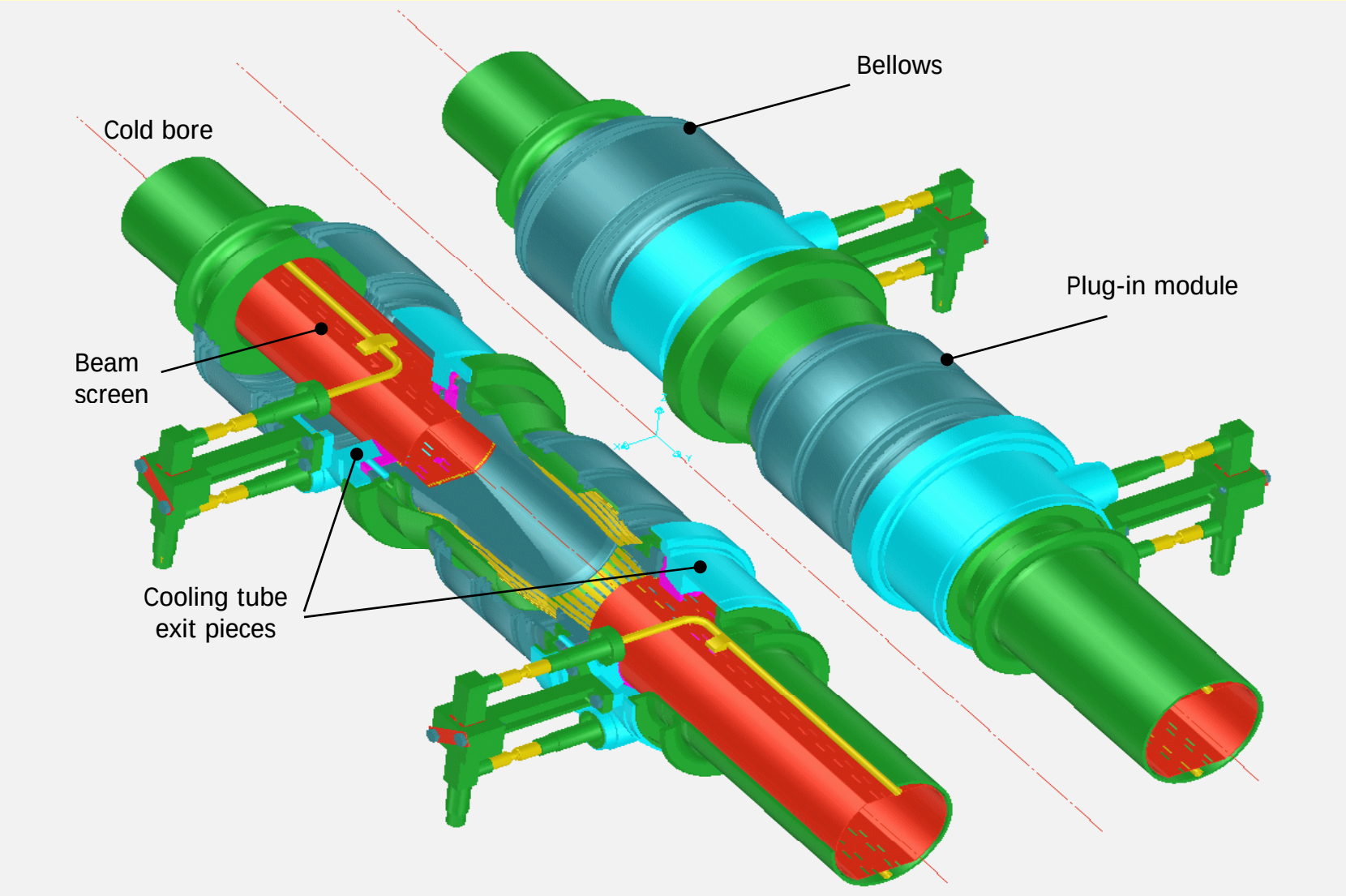








# Evaluation of damages
# Beam Screen (BS) / Cold Bore (CB) configuration (1)

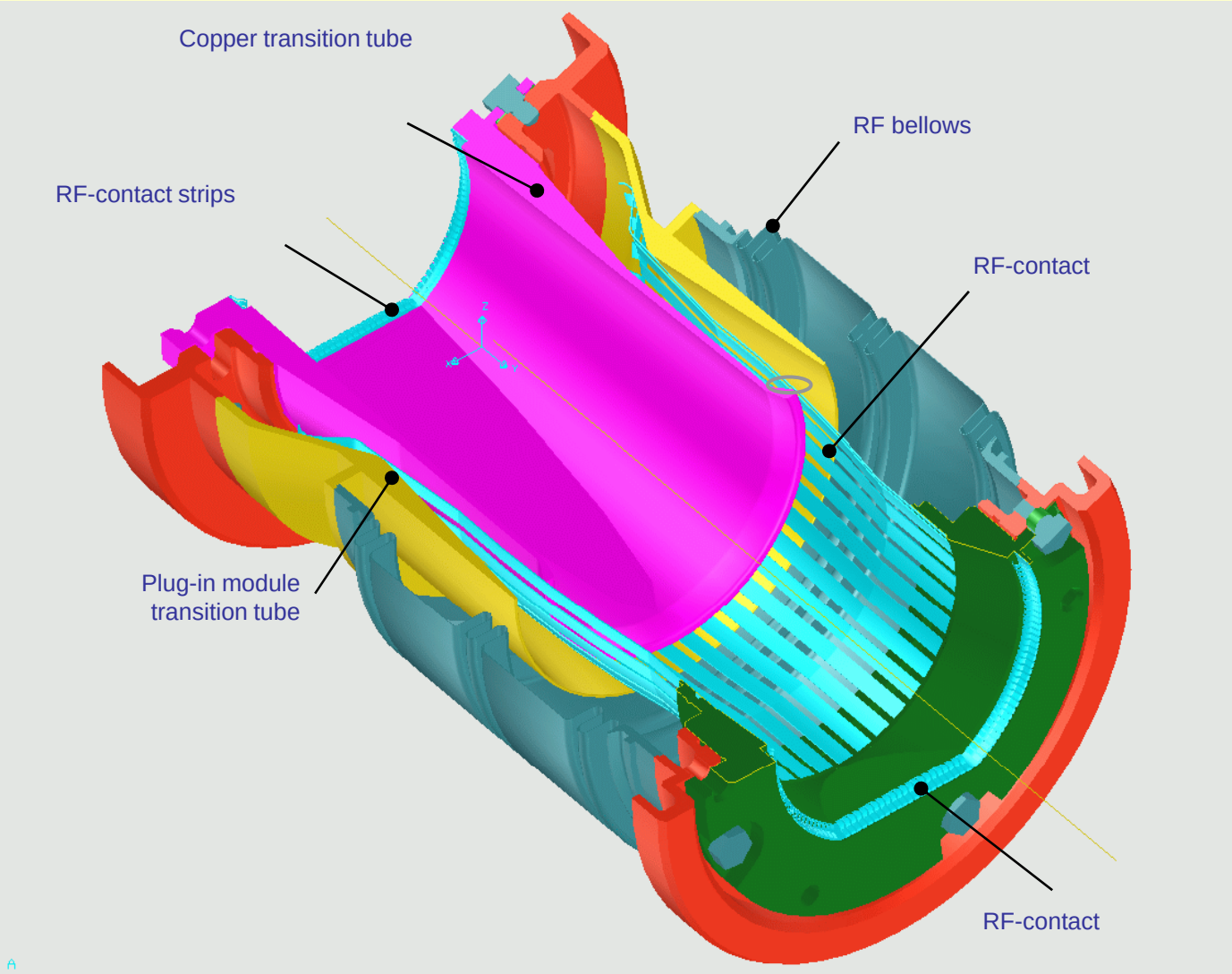


# Evaluation of damages
# Beam Screen (BS) / Cold Bore (CB) configuration (2)

- **No access to the volume between the BS and the CB**
  - Pumping slots are too small
  - Taps are installed at each extremities
  - Nested bellows are the « ideal » trap
- **Cooling capillaries are bended and welded to the cooling tube exit pieces**
  - Once cut, these components can no longer be reused
    - Re-bending of the capillaries could lead to helium leaks
    - No weld is allowed (LHC Design Report) between the liquid helium circuits and the beam vacuum

An helium leak in the beam vacuum will stop the LHC for 6 months !

# Evaluation of damages
# PIM configuration (1)



# Evaluation of damages
# PIM configuration (2)

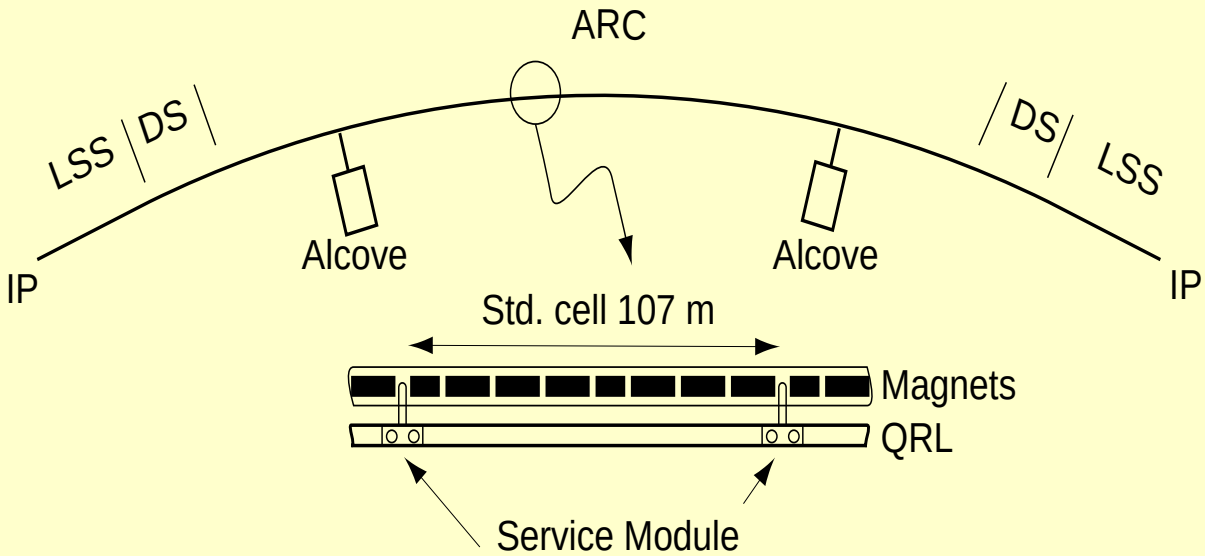
- **Pieces are welded to the magnet extremities**
  - Can be reused only 3 or 4 times
- **Trap volume for soot and dusts**
- **Sliding requirements are critical for the operation of the PIM RF fingers**
  - Gold and Rhodium coatings
    - No soot is allowed
- **Bellows can be damaged (buckled) by an internal over pressure**

# Evaluation of damages
# Soot impact on performances...

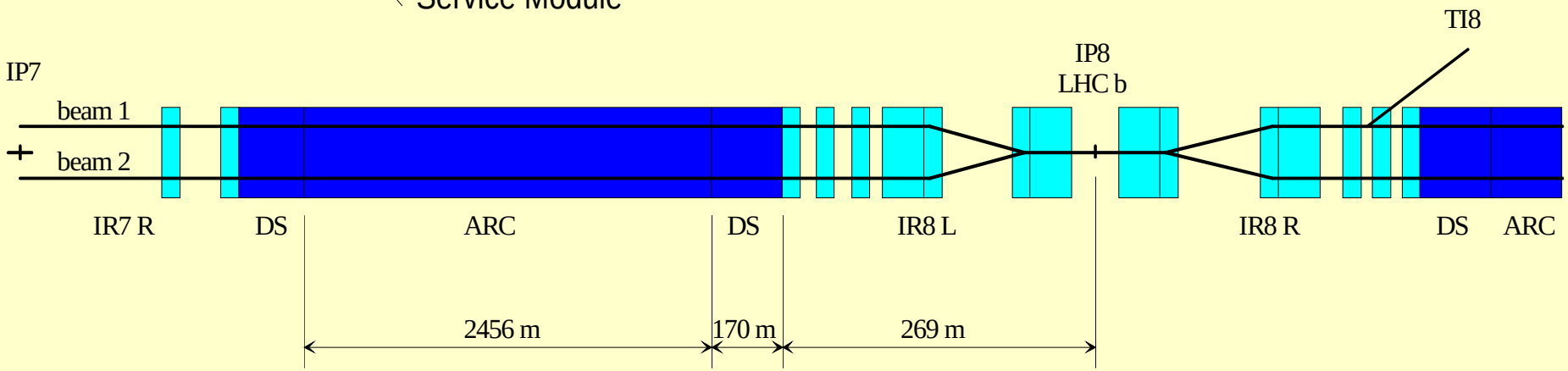
- **BS and CB show soot contamination**
  - Both are contaminated in the “D” zone
    - Soot is magnetic
      - Total removal in situ is excluded
        - » Magnet need to be removed from the tunnel
- **Contamination of the BS, PIMs and nested bellows**
  - Spare components will be used instead
- **Contamination of BPMs**
  - All contaminated BPMs will be replaced at the surface

Soot particles can lead to beam blow up if captured by the beams

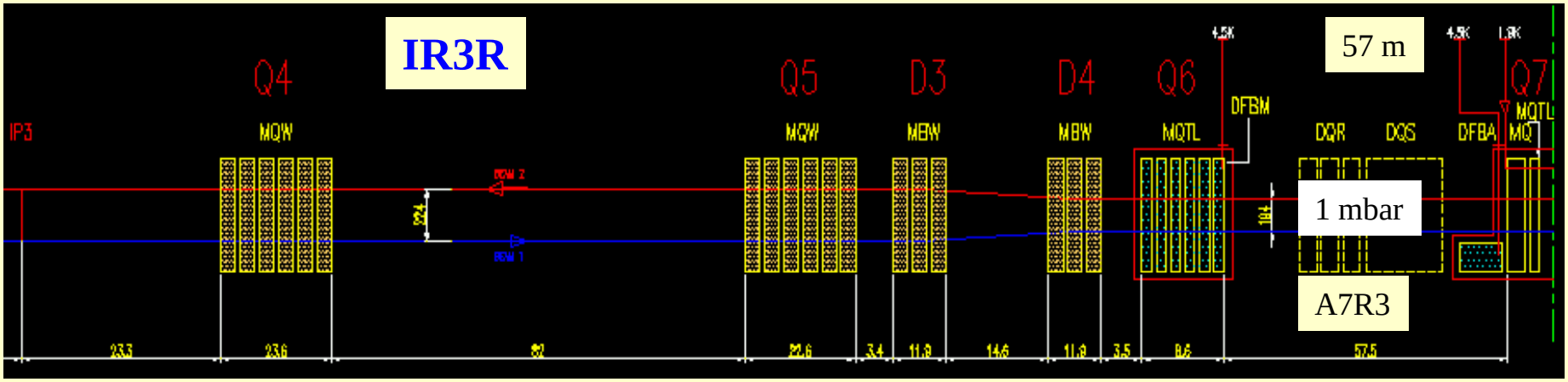
# Evaluation of damages
# LHC vacuum sectorisation: arcs and LSS (1)




- 8 arcs and 8 straight sections
- Separation of cold and RT vacuum systems
- Create vacuum sectors in long/fragile RT zones
- Equipment which need and ex-situ conditioning
- At the experimental areas

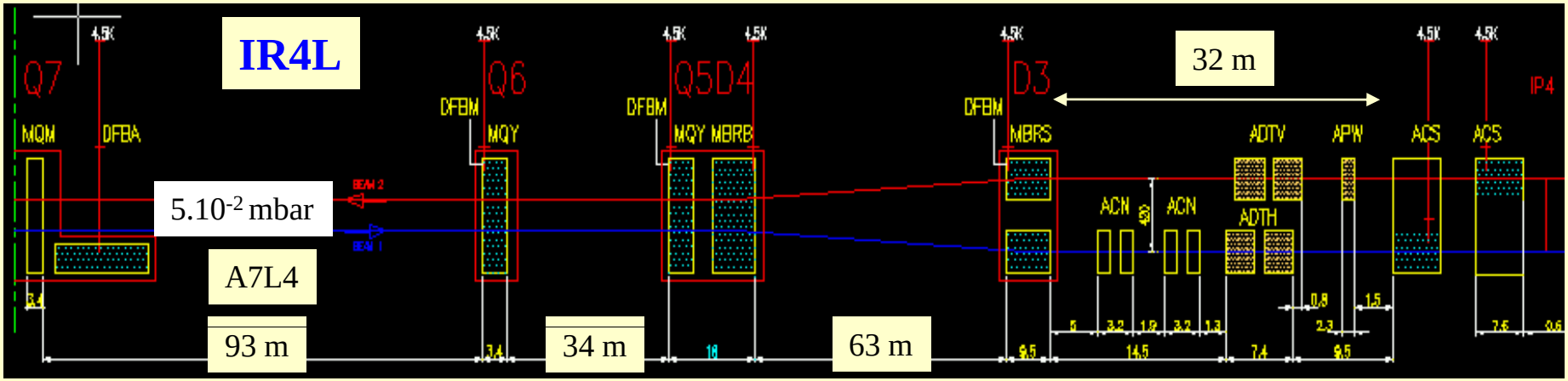


# Evaluation of damages
# Impact on the adjacent LSS RT sectors (IR3R and IR4L)

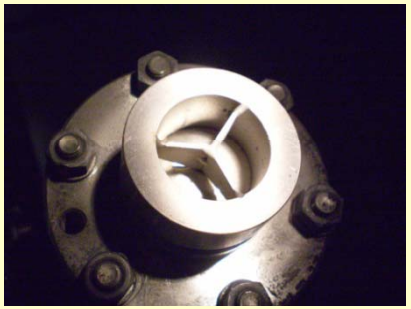



$6.10^{-11}$ mbar reached after 3 days of pumping confirming the venting with dry helium ONLY

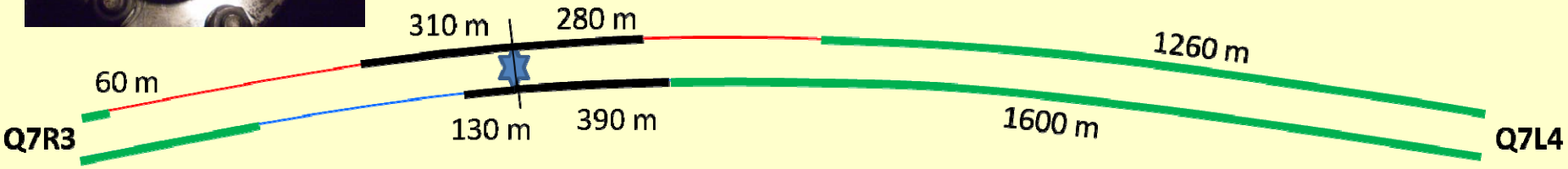
Beam pipes vented and inspected: no soot or MLI were found !



# Evaluation of damages
# Impact on the 3-4 Sector



Q8R3 V1: rupture disk deformed but not perforated




Q8R3 V2: rupture disk blown

Q8L4 V1/V2: rupture disk deformed but not perforated

| |
|---|
| Metallic debris |
| MLI |
| OK |
| Soot |
| Oxidized beam screen |
| Mark on surface |

# Evaluation of damages

## 7L3/20R3 21R3/33R3 34R3/22L4 21L4/7L4

| Element | PIM V1 | PIM V2 | V1 Nested bel. | V2 Nested bel. | BS V1 | BS V2 | remove CM (VAC) |
|---|---|---|---|---|---|---|---|
| DFBA | cut | ok | ? | ? | Oxydised | Oxydised | no |
| Q7R3 | cut | ok | ? | ? | MLI | MLI | no |
| A8R3 | ? | ok | ? | ? | MLI | MLI | no |
| B8R3 | ? | cut | ? | ? | DUST | MLI | no |
| Q8R3 | ? | cut | ? | ? | MLI | Metal debris | yes |
| A9R3 | ? | ok | ? | ? | DUST | ok | no |
| B9R3 | ? | ? | ? | ? | MLI | ok | no |
| C9R3 | ? | ? | ? | ? | MLI | ok | no |
| A10R3 | ? | ? | ? | ? | MLI | ok | no |
| B10R3 | ? | ? | ? | ? | DUST | ok | no |
| Q10R3 | ? | ? | ? | ? | MLI | ok | no |
| A11R3 | ? | ? | ? | ? | MLI | ok | no |
| B11R3 | ? | ? | ? | ? | debris coupe | ok | no |
| C11R3 | ? | ? | ? | ? | debris coupe | ok | no |
| Q11R3 | cut | cut | ? | ? | ok | TACHES | no |
| A12R3 | ? | ? | ? | ? | debris coupe | TACHES | no |
| B12R3 | ? | ? | ? | ? | ok | Oxydised | no |
| C12R3 | ? | ? | ? | ? | ok | ok | no |
| Q12R3 | cut | cut | ok | ok | ok | ok | no |
| A13R3 | ok | ok | ok | ok | debris coupe | DUST | no |
| B13R3 | ok | ok | ok | ok | ok | Oxydised | no |
| C13R3 | ok | bad | ok | ok | debris coupe | DUST | no |
| Q13R3 | cut | cut | ok | ok | TACHES | DUST | no |
| A14R3 | ok | bad | ok | ok | ok | DUST | no |
| B14R3 | ok | ok | ok | ok | debris coupe | DUST | no |
| C14R3 | ok | bad | ok | ok | TACHES | DUST | no |
| Q14R3 | cut | cut | ok | ok | ok | DUST | no |
| A15R3 | ok | ok | ok | ok | Metal debris | TACHES | no |
| B15R3 | ok | cut | ok | ok | ok | DUST | no |
| C15R3 | ok | cut | ok | use as is | ok | TACHES | no |
| Q15R3 | cut | cut | ok | ok | ok | DUST | no |
| A16R3 | ok | cut | ok | ok | ok | DUST | no |
| B16R3 | ok | cut | ok | ok | ok | ok | no |
| C16R3 | ok | cut | ok | ok | ok | TACHES | no |
| Q16R3 | cut | cut | ok | ok | ok | ok | no |
| A17R3 | ok | cut | ok | ok | ok | DUST | no |
| B17R3 | ok | cut | ok | ok | ok | DUST | no |
| C17R3 | bad | cut | ok | ok | ok | DUST | no |
| Q17R3 | cut | cut | ok | ok | ok | debris coupe | no |
| A18R3 | ok | cut | ok | use as is | ok | DUST | no |
| B18R3 | ok | cut | ok | use as is | ok | DUST | no |
| C18R3 | ok | cut | ok | use as is | ok | DUST | no |
| Q18R3 | cut | cut | ok | ok | ok | DUST | no |
| A19R3 | ok | cut | ok | use as is | ok | DUST | no |
| B19R3 | ok | cut | ok | use as is | ok | soot | yes |
| C19R3 | bad | cut | ok | use as is | ok | soot | yes |
| Q19R3 | cut | cut | ok | ok | ok | soot | yes |
| A20R3 | ok | cut | ok | use as is | ok | soot | yes |
| B20R3 | ok | cut | ok | use as is | ok | soot | yes |
| C20R3 | cut | cut | ok | ok | ok | soot | yes |
| Q20R3 | cut | cut | ok | use as is | ok | soot | yes |

Metal debris removal made in-situ

| Element | PIM V1 | PIM V2 | V1 Nested bel. | V2 Nested bel. | BS V1 | BS V2 | remove CM (VAC) |
|---|---|---|---|---|---|---|---|
| A21R3 | cut | cut | ok | use as is | ok | soot | yes |
| B21R3 | cut | cut | ok | use as is | ok | soot | yes |
| C21R3 | cut | cut | ok | bad | ok | soot | yes |
| Q21R3 | cut | cut | ok | ok | ok | soot | yes |
| A22R3 | cut | cut | ok | bad | ok | soot | yes |
| B22R3 | cut | cut | ok | bad | ok | soot | yes |
| C22R3 | cut | cut | ok | bad | soot | soot | yes |
| Q22R3 | cut | cut | ok | ok | soot | soot | yes |
| A23R3 | cut | cut | ok | bad | soot | soot | yes |
| B23R3 | cut | cut | ok | bad | soot | soot | yes |
| C23R3 | cut | cut | ok | bad | soot | hole | yes |
| Q23R3 | cut | cut | ok | ok | soot | soot | yes |
| A24R3 | cut | cut | ok | ok | soot | soot | yes |
| B24R3 | cut | cut | ok | ok | soot | soot | yes |
| C24R3 | cut | cut | ok | ok | soot | soot | yes |
| Q24R3 | cut | cut | ok | ok | soot | soot | yes |
| A25R3 | cut | cut | ok | ok | soot | soot | yes |
| B25R3 | cut | cut | ok | ok | soot | soot | yes |
| C25R3 | cut | cut | ok | ok | soot | soot | yes |
| Q25R3 | cut | cut | ok | ok | soot | soot | yes |
| A26R3 | cut | cut | ok | ok | soot | soot | yes |
| B26R3 | cut | cut | ok | ok | soot | soot | yes |
| C26R3 | cut | cut | ok | ok | soot | soot | yes |
| Q26R3 | cut | cut | ok | ok | soot | soot | yes |
| A27R3 | cut | cut | ok | ok | soot | soot | yes |
| B27R3 | cut | cut | use as is | ok | soot | soot | yes |
| C27R3 | cut | cut | bad | bad | soot | soot | yes |
| Q27R3 | cut | cut | bad | bad | soot | soot | yes |
| A28R3 | cut | cut | ok | ok | soot | soot | yes |
| B28R3 | cut | cut | ok | ok | soot | soot | yes |
| C28R3 | cut | cut | ok | ok | soot | soot | yes |
| Q28R3 | cut | cut | ok | use as is | soot | soot | yes |
| A29R3 | cut | cut | ok | ok | soot | soot | yes |
| B29R3 | cut | cut | ok | ok | soot | soot | yes |
| C29R3 | cut | cut | ok | ok | soot | soot | yes |
| Q29R3 | cut | cut | ok | ok | soot | soot | yes |
| A30R3 | cut | cut | ok | ok | soot | MLI | yes |
| B30R3 | cut | cut | ok | ok | MLI | MLI | no |
| C30R3 | cut | cut | ok | ok | soot | soot | yes |
| Q30R3 | cut | cut | ok | ok | ok | ok | no |
| A31R3 | cut | cut | ok | ok | soot | soot | yes |
| B31R3 | cut | cut | ok | ok | ? | ? | ? |
| C31R3 | cut | cut | ok | ok | MLI | MLI | no |
| Q31R3 | cut | cut | use as is | use as is | soot | soot | yes |
| A32R3 | cut | cut | ok | ok | MLI | DUST | no |
| B32R3 | cut | cut | ok | ok | MLI | DUST | no |
| C32R3 | cut | cut | ok | ok | MLI | DUST | no |
| Q32R3 | cut | cut | ok | ok | ? | ok | ? |
| A33R3 | cut | cut | ok | ok | ? | ok | no |
| B33R3 | cut | cut | ok | ok | ? | ok | no |
| C33R3 | cut | cut | ok | ok | ? | ok | no |
| Q33R3 | cut | cut | ok | ok | ? | ok | no |

Soot on magnets cleaning made in the tunnel

Soot on magnets identified for removal from the tunnel

Magnets removed from the tunnel

| Element | PIM V1 | PIM V2 | V1 Nested bel. | V2 Nested bel. | BS V1 | BS V2 | remove CM (VAC) |
|---|---|---|---|---|---|---|---|
| A34R3 | ? | ? | ? | ? | MLI | MLI | no |
| B34R3 | ? | ? | ? | ? | MLI | ok | no |
| C34R3 | ? | ? | ? | ? | MLI | ok | no |
| Q34R3 | ? | ? | ? | ? | MLI | ok | no |
| A34L4 | ? | ? | ? | ? | MLI | ok | no |
| B34L4 | ? | ? | ? | ? | MLI | ok | no |
| A33L4 | ? | ? | ? | ? | MLI | ok | no |
| Q33L4 | ? | ? | ? | ? | MLI | MLI | no |
| C33L4 | ? | ? | ? | ? | MLI | ok | no |
| B33L4 | ? | ? | ? | ? | MLI | ok | no |
| A33L4 | ? | ? | ? | ? | MLI | ok | no |
| Q32L4 | ok | ok | ? | ? | MLI | MLI | no |
| C32L4 | ok | ok | ? | ? | MLI | ok | no |
| B32L4 | ok | ok | ? | ? | MLI | ok | no |
| A32L4 | ok | ok | ? | ? | MLI | ok | no |
| B31L4 | cut | cut | ? | ? | MLI | MLI | no |
| C31L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q31L4 | ok | ok | ? | ? | MLI | MLI | no |
| A30L4 | ok | ok | ? | ? | MLI | ok | no |
| B30L4 | ok | ok | ? | ? | MLI | MLI | no |
| C30L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q29L4 | ok | ok | ? | ? | MLI | MLI | no |
| C29L4 | ok | ok | ? | ? | MLI | MLI | no |
| B29L4 | ok | ok | ? | ? | MLI | MLI | no |
| A29L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q28L4 | ok | ok | ? | ? | MLI | MLI | no |
| C28L4 | ok | ok | ? | ? | MLI | MLI | no |
| B28L4 | ok | ok | ? | ? | MLI | MLI | no |
| A28L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q27L4 | ok | ok | ? | ? | MLI | MLI | no |
| C27L4 | ok | ok | ? | ? | MLI | MLI | no |
| B27L4 | ok | ok | ? | ? | ok | MLI | no |
| A27L4 | ok | ok | ? | | | | |
| Q26L4 | cut | cut | ok | | | | |
| C26L4 | ok | ok | ? | | | | |
| B26L4 | ok | bad | ? | | | | |
| A26L4 | ok | ok | ? | | | | |
| Q25L4 | ok | ok | ? | | | | |
| C25L4 | ok | ok | ? | | | | |
| B25L4 | ok | ok | ? | | | | |
| A25L4 | ok | ok | ? | | | | |
| Q24L4 | cut | cut | ok | | | | |
| C24L4 | ok | ok | ? | ? | MLI | ok | no |
| B24L4 | ok | ok | ok | ok | MLI | ok | no |
| A24L4 | ok | ok | ? | ? | MLI | ok | no |
| Q23L4 | ok | ok | ? | ? | MLI | MLI | no |
| C23L4 | ok | ok | ? | ? | MLI | ok | no |
| B23L4 | ok | ok | ? | ? | MLI | ok | no |
| A23L4 | ok | ok | ? | ? | MLI | MLI | no |

| Element | PIM V1 | PIM V2 | V1 Nested bel. | V2 Nested bel. | BS V1 | BS V2 | Remove CM (VAC) |
|---|---|---|---|---|---|---|---|
| Q21L4 | ? | ? | ? | ? | ? | ? | ? |
| C21L4 | ? | ? | ? | ? | ? | ? | ? |
| B21L4 | ok | ok | ? | ? | MLI | MLI | no |
| A21L4 | ok | ok | ? | | MLI | MLI | no |
| Q20L4 | ok | ok | ? | | ok | MLI | no |
| C20L4 | ok | ok | ? | | MLI | MLI | no |
| B20L4 | ok | ok | ? | ? | MLI | MLI | no |
| A20L4 | ok | ok | ? | ? | MLI | Oxydised | no |
| Q19L4 | ok | ok | ? | ? | MLI | MLI | no |
| C19L4 | ok | ok | ? | ? | MLI | MLI | no |
| B19L4 | ok | ok | ? | ? | MLI | MLI | no |
| A19L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q18L4 | ok | ok | ? | ? | MLI | MLI | no |
| C18L4 | ok | ok | ? | ? | MLI | MLI | no |
| B18L4 | ok | ok | ? | ? | MLI | MLI | no |
| A18L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q17L4 | ok | ok | ? | ? | MLI | MLI | no |
| C17L4 | ok | ok | ? | ? | MLI | MLI | no |
| B17L4 | ok | ok | ? | ? | MLI | MLI | no |
| A17L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q16L4 | ok | ok | ? | ? | MLI | MLI | no |
| C16L4 | ok | ok | ? | ? | MLI | MLI | no |
| B16L4 | ok | ok | ? | ? | MLI | MLI | no |
| A16L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q15L4 | ok | ok | ? | ? | MLI | MLI | no |
| C15L4 | ok | ok | ? | ? | MLI | MLI | no |
| B15L4 | ok | ok | ? | ? | MLI | MLI | no |
| A15L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q14L4 | ok | ok | ? | ? | MLI | MLI | no |
| C14L4 | ok | ok | ? | ? | MLI | MLI | no |
| B14L4 | ok | ok | ? | ? | MLI | MLI | no |
| A14L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q13L4 | cut | cut | ok | ok | MLI | MLI | no |
| C13L4 | ok | ok | ? | ? | MLI | MLI | no |
| B13L4 | ok | ok | ? | ? | MLI | MLI | no |
| A13L4 | ok | ? | ? | ? | MLI | MLI | no |
| Q9L4 | ok | ok | ? | ? | MLI | MLI | no |
| B9L4 | ok | ok | ? | ? | MLI | MLI | no |
| A9L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q8L4 | cut | cut | ? | ? | MLI | MLI | no |
| B8L4 | ok | ok | ? | ? | MLI | MLI | no |
| A8L4 | ok | ok | ? | ? | MLI | MLI | no |
| Q7L4 | ok | ok | ? | ? | MLI | MLI | no |
| DFBA | ok | ok | ? | ? | Oxydised | Oxydised | no |

Additional PIMs need to be opened

Soot contamination recovery is independent from MLI contamination

# Evaluation of damages
# Results from the endoscopic inspections

- All beam lines in the tunnel have been inspected
- All visual and endoscopic inspections of the beam tubes and interconnects are documented

| | V1 | V2 | V1 | V2 | Total |
|---|---|---|---|---|---|
| Ok | 54 | 39 | 26 % | 18 % | 22 % |
| MLI | 124 | 129 | 58 % | 61 % | 59 % |
| Soot | 35 | 45 | 16 % | 21 % | 19 % |
| To be done | 0 | 0 | 0 % | 0 % | 0 % |
| Total | 213 | 213 | 100 % | 100 % | 100 % |

# Evaluation of damages
# What remains to be cleaned in the tunnel ?

- 53 cold masses are back to the surface from Q20R3 to Q33R3 (14 MQ, 39 MB)

- V2 line : 6 cold masses with soot (B19R3 -> C20R3)

  …to be cleaned in the tunnel.

| | V1 | V2 | V1 | V2 | Total |
|---|---|---|---|---|---|
| Ok | 49 | 30 | 31 % | 19 % | 25% |
| MLI | 111 | 124 | 69 % | 78 % | 73 % |
| Soot | 0 | 6 | 0 % | 4 % | 2 % |
| Total | 160 | 160 | 100 % | 100 % | 100 % |

# Evaluation of damages
# Available documentation (1)

## Report from the inter-connexion inspections

**Feuille d'inspection visuelle des lignes vides du secteur 3-4**

| | | |
|---|---|---|
| Date : 4 Décembre 2008 | Noms des intervenants: Julien FINELLE | |
| N° de l'**aimant** à gauche (Downstream) : DFBA (Point 3R) | N° de l'**interconnexion** : QDQI (MB-SSS) : **7R3** | N° de l'**aimant** à droite (Upstream) : Q7R3 (512) |

INSPECTION VISUELLE DE LA **LIGNE V1** (extérieure – côté QRL)

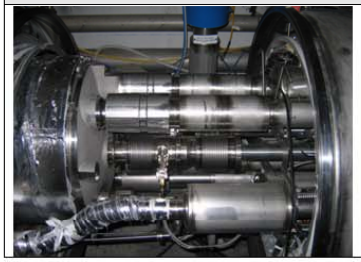
| | | | | |
|---|---|---|---|---|
| Soufflet **SPECIAL** à ondes emboitables | LONGUEUR | Conforme visuellement L= 144 mm | Oui | |
| | | Compressée : | | Non |
| | | Etendue : | | Non |
| | ASPECT | Conforme : | Oui | |
| | | Déformation latérale : | | Non |
| | | Choc sur onde : | | Non |
| | | Autres : | | |
| Plug-in module | LONGUEUR | Conforme visuellement : N.A. | Oui | |
| | | Compressée : | | Non |
| | | Etendue : | | Non |
| | ASPECT | Conforme : | Oui | |
| | | Déformation latérale : | | Non |
| | | Choc sur onde : | | Non |
| | | Autres : COUPE | | |

INSPECTION VISUELLE DE LA **LIGNE V2** (intérieure – côté couloir)

| | | | | |
|---|---|---|---|---|
| Soufflet **SPECIAL** à ondes emboitables | LONGUEUR | Conforme visuellement L= 145 mm | Oui | |
| | | Compressée : | | Non |
| | | Etendue : | | Non |
| | ASPECT | Conforme : | Oui | |
| | | Déformation latérale : | | Non |
| | | Choc sur onde : | | Non |
| | | Autres : | | |
| Plug-in module | LONGUEUR | Conforme visuellement : N.A. | Oui | |
| | | Compressée : | | Non |
| | | Etendue : | | Non |
| | ASPECT | Conforme : | | Non |
| | | Déformation latérale : | Oui | |
| | | Choc sur onde : | | Non |
| | | Autres : LEGERE | | |

| | | |
|---|---|---|
| Présence de poussière dans l'**interconnexion** | | Non |
| MLI déchirée | | Non |

Remarques générales :




**Feuille d'inspection visuelle des lignes vides du secteur 3-4**

| | | |
|---|---|---|
| Date : 4 Décembre 2008 | Noms des intervenants: Julien FINELLE | |
| N° de l'**aimant** à gauche (Downstream) : Q7R3 (512) | N° de l'**interconnexion** : QQBI (SSS-MB) : **7R3** | N° de l'**aimant** à droite (Upstream) : A8R3 (2117) |

INSPECTION VISUELLE DE LA **LIGNE V1** (extérieure – côté QRL)

| | | | | |
|---|---|---|---|---|
| Soufflet **Long** à ondes emboitables | LONGUEUR | Conforme visuellement L= 120 mm | Oui | |
| | | Compressée : | | Non |
| | | Etendue : | | Non |
| | ASPECT | Conforme : | Oui | |
| | | Déformation latérale : | | Non |
| | | Choc sur onde : | | Non |
| | | Autres : | | |
| Plug-in module | LONGUEUR | Conforme visuellement :(C/L= 502mm) | Oui | |
| | | Compressée : | | Non |
| | | Etendue : | | Non |
| | ASPECT | Conforme : | Oui | |
| | | Déformation latérale : | | Non |
| | | Choc sur onde : | | Non |
| | | Autres : | | |

INSPECTION VISUELLE DE LA **LIGNE V2** (intérieure – côté couloir)

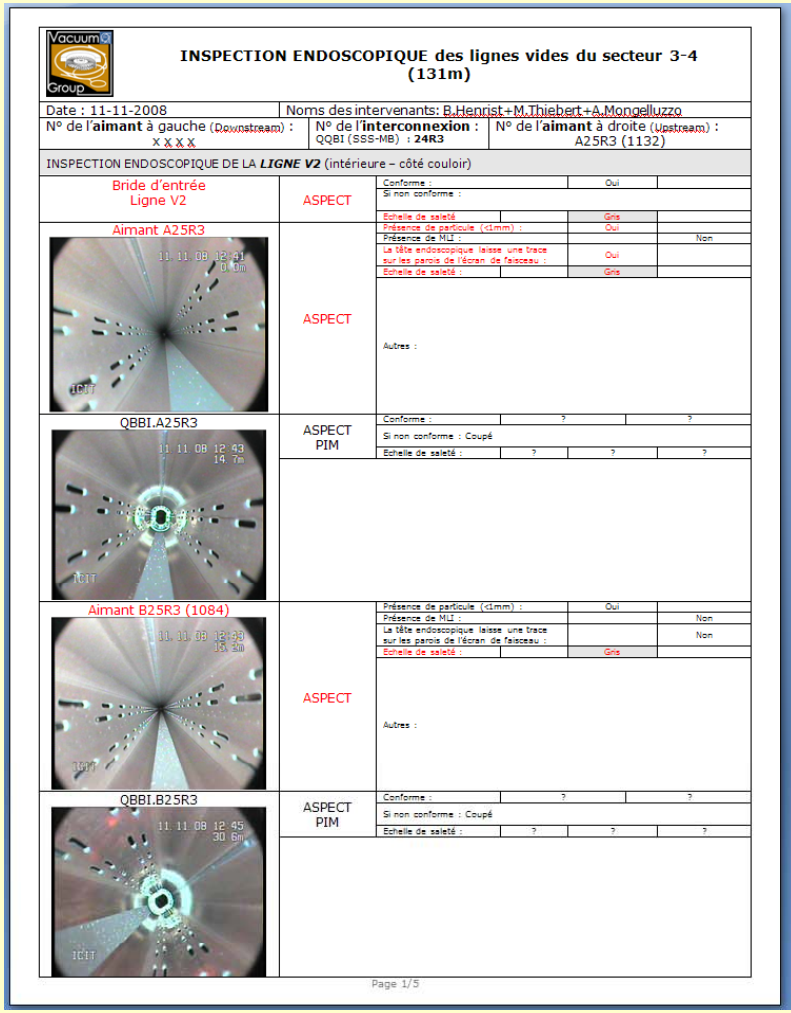
| | | | | |
|---|---|---|---|---|
| Soufflet **Long** à ondes emboitables | LONGUEUR | Conforme visuellement L= 121 mm | Oui | |
| | | Compressée : | | Non |
| | | Etendue : | | Non |
| | ASPECT | Conforme : | Oui | |
| | | Déformation latérale : | | Non |
| | | Choc sur onde : | | Non |
| | | Autres : | | |
| Plug-in module | LONGUEUR | Conforme visuellement :(C/L=502mm) | Oui | |
| | | Compressée : | | Non |
| | | Etendue : | | Non |
| | ASPECT | Conforme : | Oui | |
| | | Déformation latérale : | | Non |
| | | Choc sur onde : | | Non |
| | | Autres : | | |

| | | |
|---|---|---|
| Présence de poussière dans l'**interconnexion** | | Non |
| MLI déchirée | | Non |

Remarques générales : PAS DE THERMALISATION NI DE PUMPING HOSES DANS CETTE INTERCONNEXION. SOUFFLET LONG AU LIEU DE SOUFFLET COURT.

# Evaluation of damages
# Available documentation (2)

## Report from the endoscopic inspections



**INSPECTION ENDOSCOPIQUE des lignes vides du secteur 3-4 (131m)**

| | | |
|---|---|---|
| Date : 11-11-2008 | Noms des intervenants: B.Henrist+M.Thiebert+A.Mongelluzzo | |
| N° de l'**aimant** à gauche (Downstream) : x x x x | N° de l'**interconnexion** : QQBI (SSS-MB) : **24R3** | N° de l'**aimant** à droite (Upstream) : A25R3 (1132) |

INSPECTION ENDOSCOPIQUE DE LA ***LIGNE V2*** (intérieure – côté couloir)

| | | | | |
|---|---|---|---|---|
| Bride d'entrée Ligne V2 | ASPECT | Conforme : | Oui | |
| | | Si non conforme : | | |
| | | Echelle de saleté | Gris | |
| Aimant A25R3 | ASPECT | Présence de particule (<1mm) : | Oui | |
| | | Présence de MLI : | | Non |
| | | La tête endoscopique laisse une trace sur les parois de l'écran de faisceau : | Oui | |
| | | Echelle de saleté : | Gris | |
| | | Autres : | | |
| QBBI.A25R3 | ASPECT PIM | Conforme : | ? | ? |
| | | Si non conforme : Coupé | | |
| | | Echelle de saleté : | ? ? | ? |
| Aimant B25R3 (1084) | ASPECT | Présence de particule (<1mm) : | Oui | |
| | | Présence de MLI : | | Non |
| | | La tête endoscopique laisse une trace sur les parois de l'écran de faisceau : | | Non |
| | | Echelle de saleté : | Gris | |
| | | Autres : | | |
| QBBI.B25R3 | ASPECT PIM | Conforme : | ? | ? |
| | | Si non conforme : Coupé | | |
| | | Echelle de saleté : | ? ? | ? |

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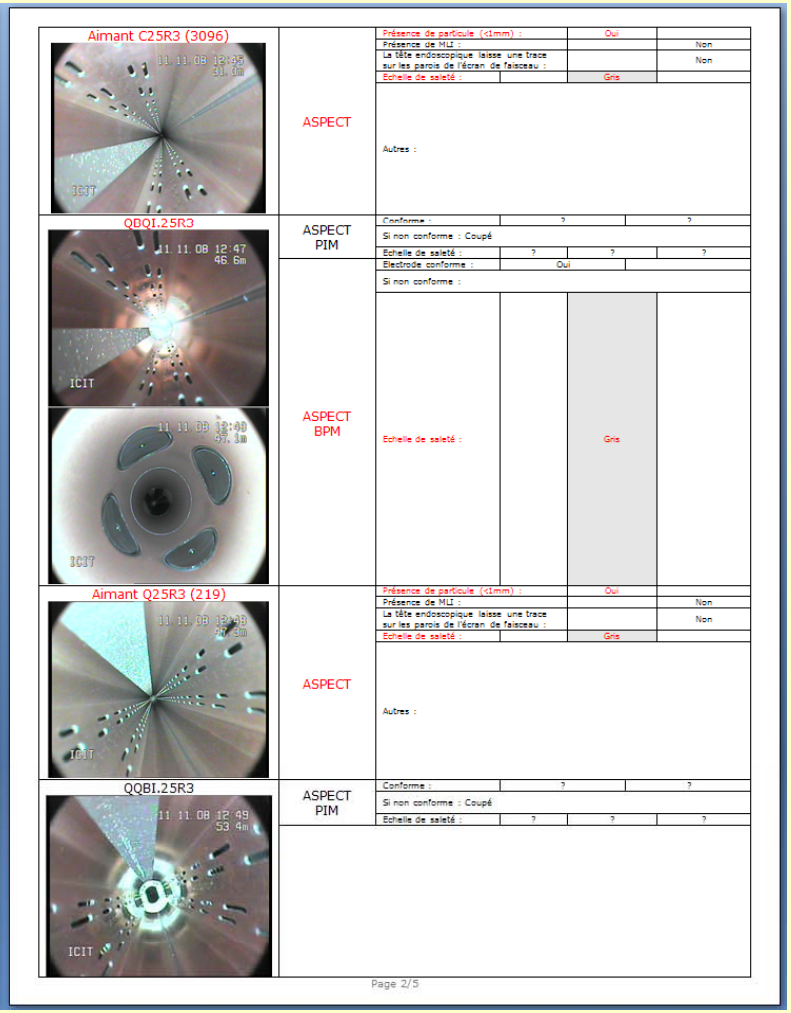

| | | | | |
|---|---|---|---|---|
| Aimant C25R3 (3096) | ASPECT | Présence de particule (<1mm) : | Oui | |
| | | Présence de MLI : | | Non |
| | | La tête endoscopique laisse une trace sur les parois de l'écran de faisceau : | | Non |
| | | Echelle de saleté : | Gris | |
| | | Autres : | | |
| QBQI.25R3 | ASPECT PIM | Conforme : | ? | ? |
| | | Si non conforme : Coupé | | |
| | | Echelle de saleté : | ? ? | ? |
| | ASPECT BPM | Electrode conforme : | Oui | |
| | | Si non conforme : | | |
| | | Echelle de saleté : | Gris | |
| Aimant Q25R3 (219) | ASPECT | Présence de particule (<1mm) : | Oui | |
| | | Présence de MLI : | | Non |
| | | La tête endoscopique laisse une trace sur les parois de l'écran de faisceau : | | Non |
| | | Echelle de saleté : | Gris | |
| | | Autres : | | |
| QQBI.25R3 | ASPECT PIM | Conforme : | ? | ? |
| | | Si non conforme : Coupé | | |
| | | Echelle de saleté : | ? ? | ? |

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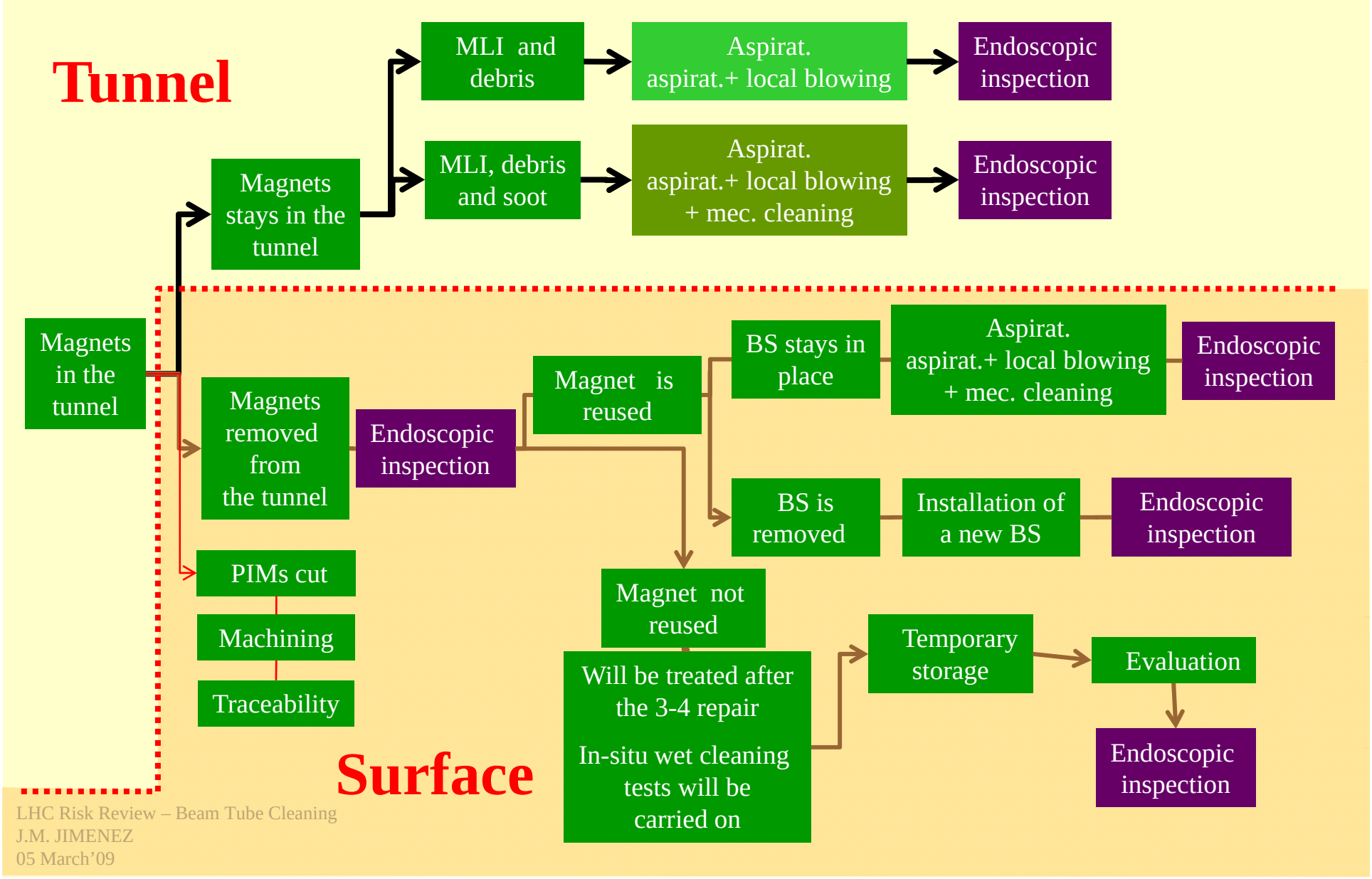
# Evaluation of damages
# Available documentation (3)

## Others...

- **Pictures**
- **Videos**

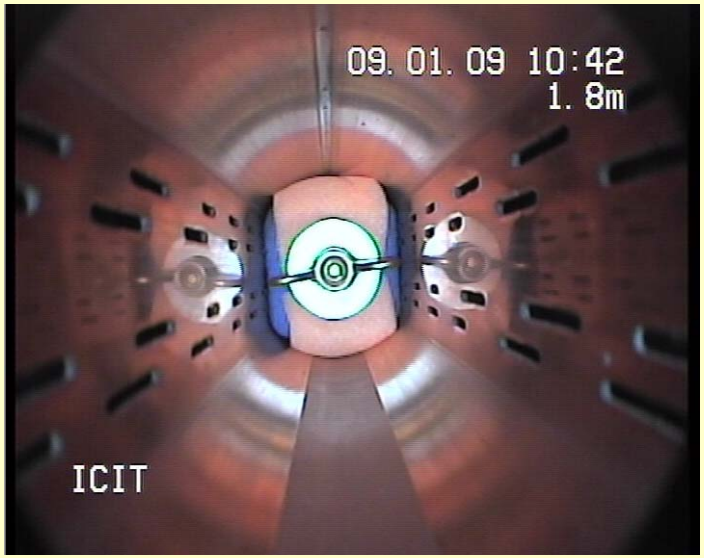
**...of all magnets... both beams.**

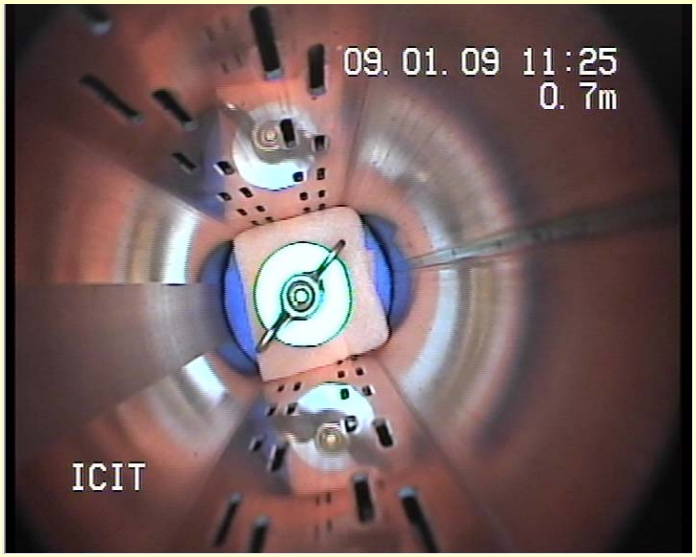
# Sorting the magnets



# Cleaning Strategy
# Soot on magnets not removed from the tunnel (1)

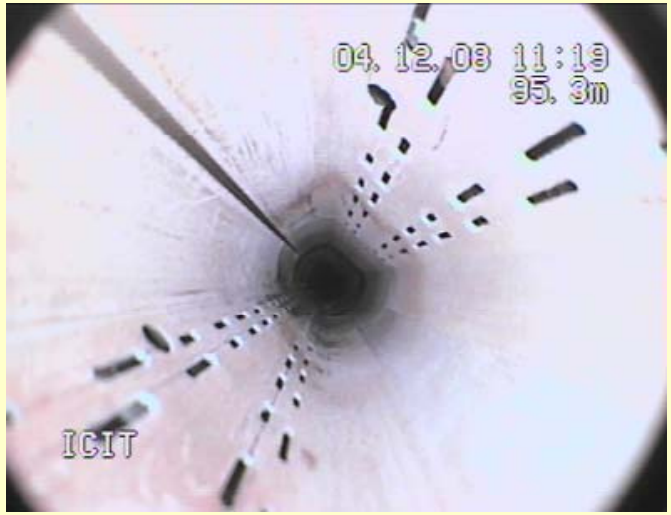
- **Two plugs : one for horizontal and one for vertical parts of the beam screen**
- **Use of a foam-plug wet with alcohol**
- **Use of a dry foam-plug**
- **Up to 50 passages in each direction with wet foam-plug**
- **Up to 15 passages with dry plug**



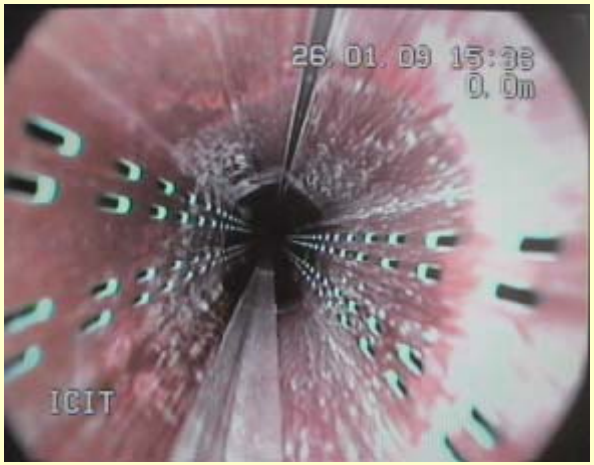

Example of C19R3.V2

# Cleaning Strategy
# Soot on magnets not removed from the tunnel (2)

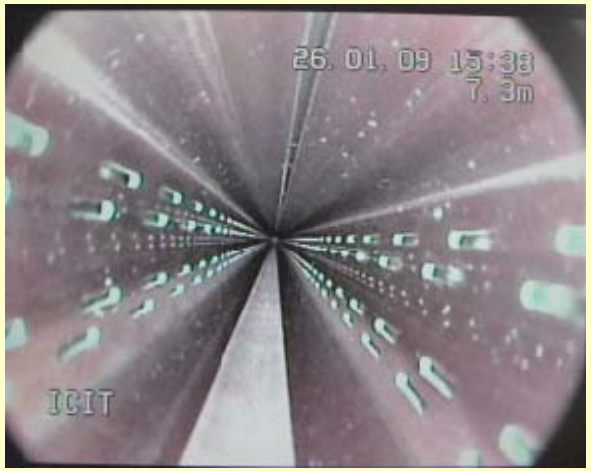



C19R3.V2 before cleaning

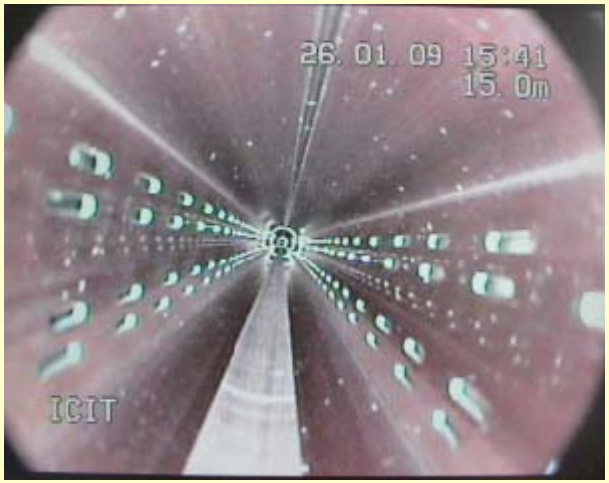
After cleaning




entrance

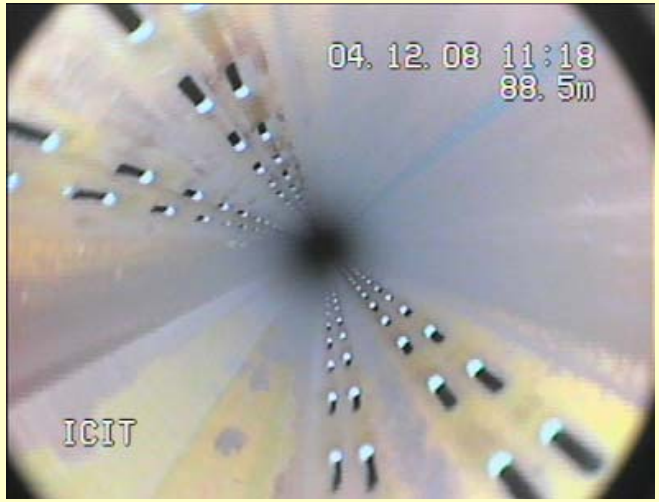



centre



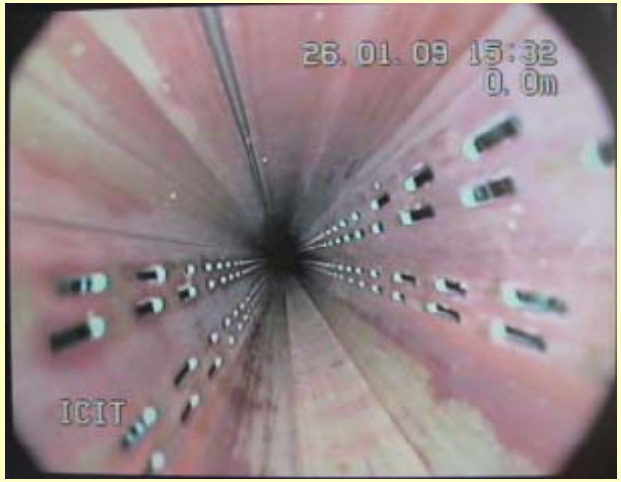

end

# Cleaning Strategy
# Soot on magnets not removed from the tunnel (3)

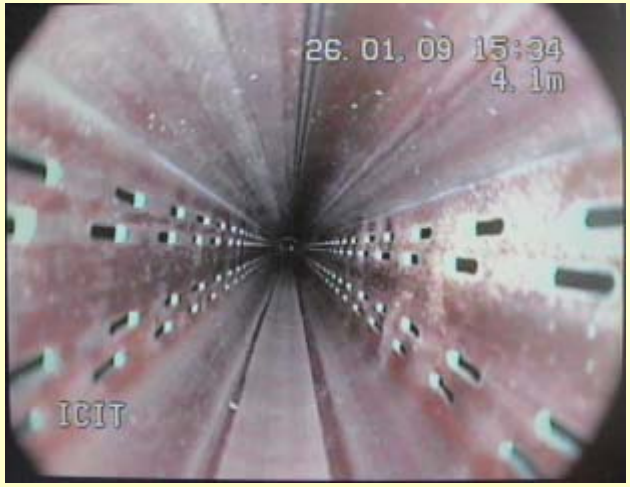



Q19R3.V2 before cleanning

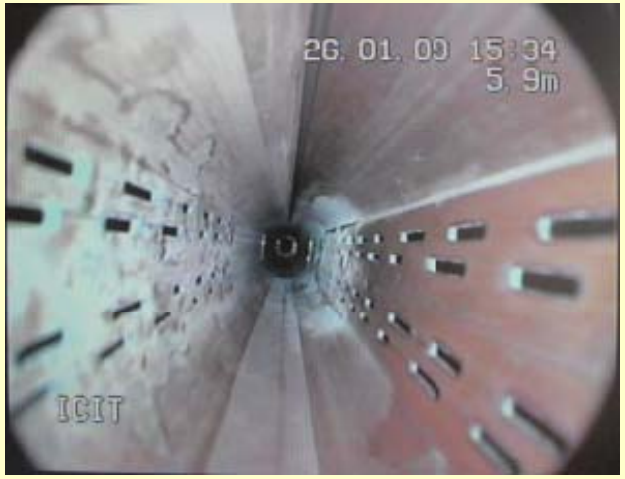
After cleanning




entrance

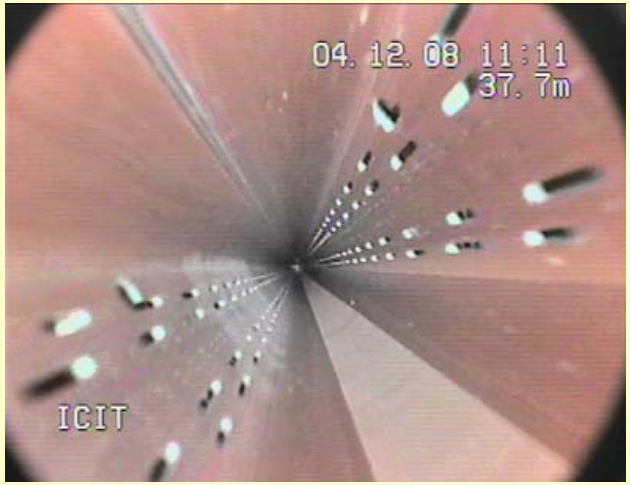



centre



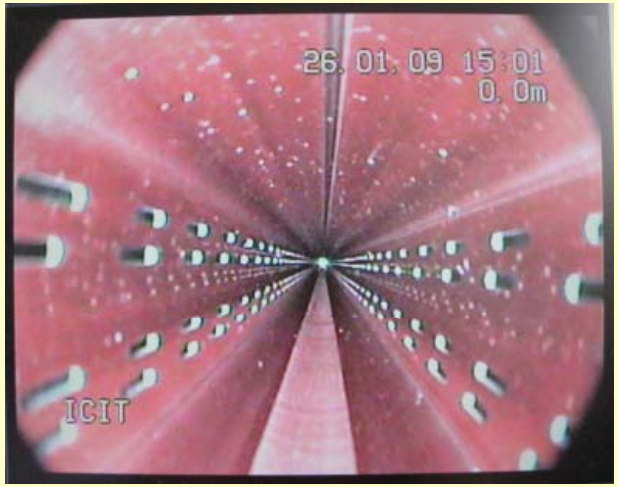

end

# Cleaning Strategy
# Soot on magnets not removed from the tunnel (4)




C20R3.V2 before cleaning

After cleaning




entrance


centre


end

# Cleaning Strategy
# Soot on magnets not removed from the tunnel: Summary

- **Four vacuum systems have been mechanically cleaned to validate the cleaning process at the surface**

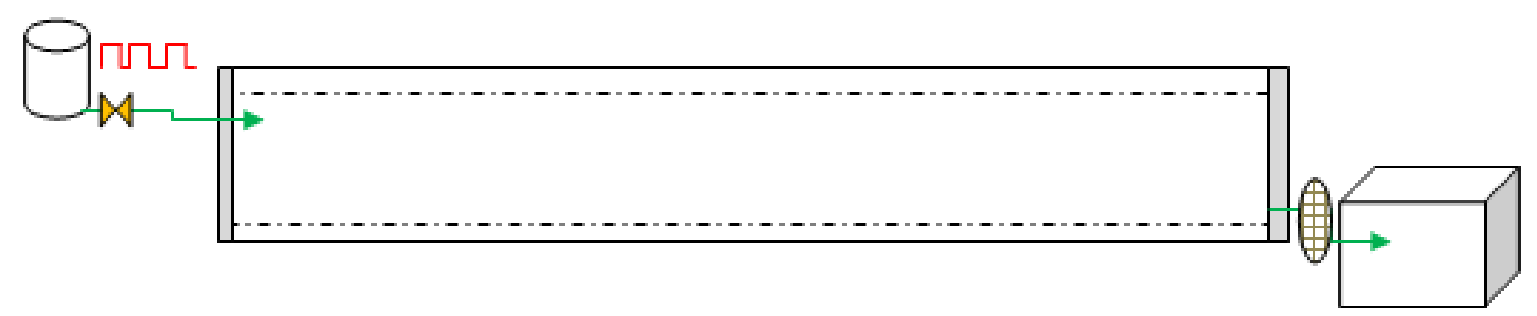
- **Cleaning completed on the 6 magnets**
  - B19R3, C19R3, Q19R3, A20R3, B20R3 and C20R3 have been swept
  - Interconnections already re-closed
  - Two vacuum systems are oxidized (C19R3 & Q19R3). The oxide layer cannot be removed by the mechanical process. However, it is expected to have negligible impact on the vacuum performance since the outgassing rate scales like ~ exp(1/T)

# Cleaning Strategy
# MLI removal in the tunnel: Procedure

- **1st step: pumping/venting process**
  - 45 minutes, tempo of 20 seconds, pumping of the beam pipe only
  - 15 minutes, tempo of 20 seconds, pumping of both the beam pipe and the pumping hose
- **2nd step: local blowing with a nozzle + aspiration**
  - 10 passages with the nozzle, 6 seconds temporization, 10 bar nitrogen pressure
  - First 3 passages with 10 min / PIM, then 5 min / PIM
  - Speed in the beam screen 3-4 cm/min
    - Stop if an event is found to allow for local aspiration
  - Opening of the nozzle to:
    - 60 microns for passage 1-2, 5-6 and 9-10
    - Closed to the minimum for passages 3-4 and 7-8
  - Pumping of:
    - The beam line only for passages 1 to 4 and 9-10
    - Both beam line and pumping hose for passages 5 to 8
  - Debris are collected in a plastic bag after each passage
  - Closure of the beam lines and pumping hose with a cap at cleaning completion and identification with a sticker

# Cleaning Strategy
# MLI removal in the tunnel: 1st step (1)

- **Based on automatic pumping/venting of a half-cell (~50 m)**



- **A cycle : 20 s pumping, 18 s plateau, 2 second vent**

- **The pressure in the beam tube is reduced from 1 atm to 0.8 atm in 2 s**
  - To be compared to the arc pump down of 200 mbar/h

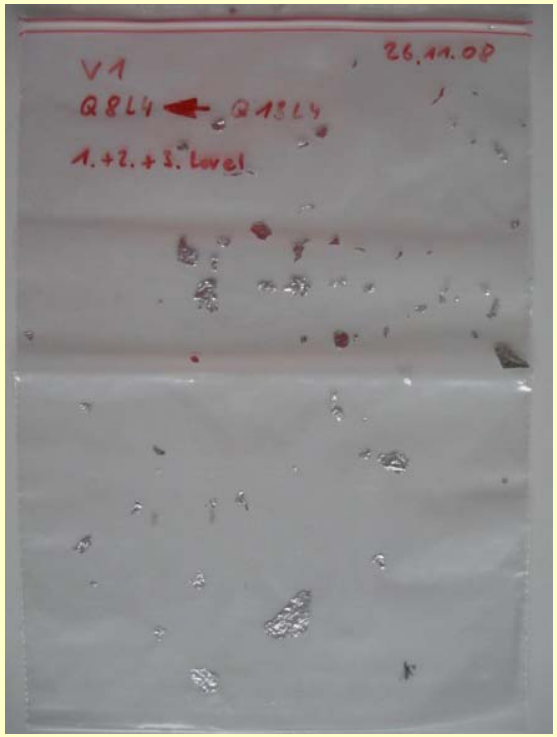
- **Air speed of 20 m/s**

# Cleaning Strategy
# MLI removal in the tunnel: 1st step (2)

This procedure give good results *i.e* no more MLI are observable by endoscopy inside the beam screen, Case of the area between Q8L4 till Q13L4 line V1 (~ 250 m)


3.2 g *i.e* 0.4 m$^2$

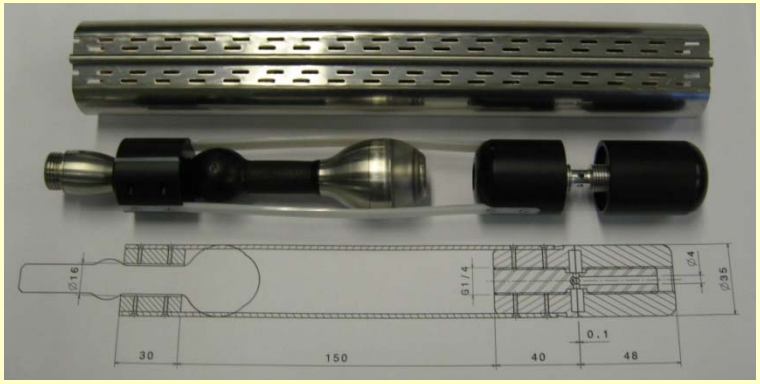

1.2 g *i.e* 0.1 m$^2$

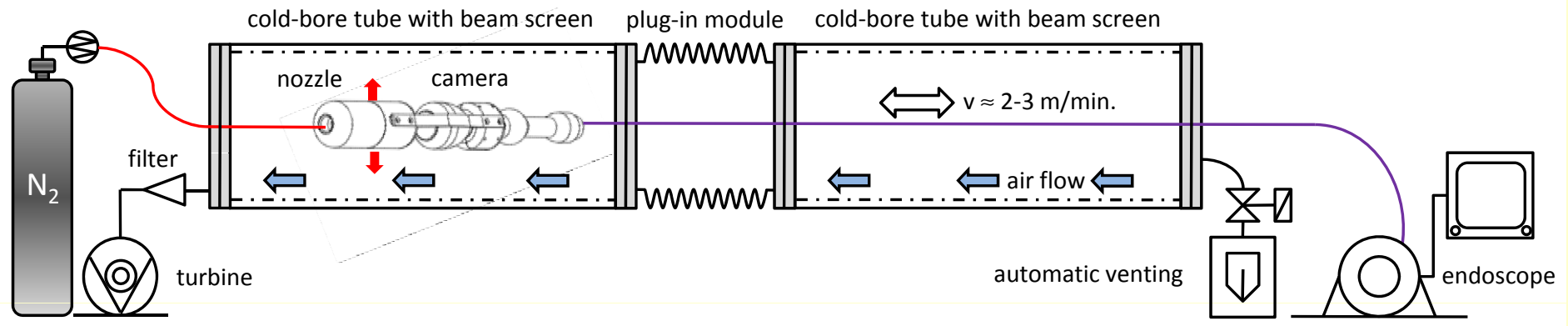



~ 100 bits

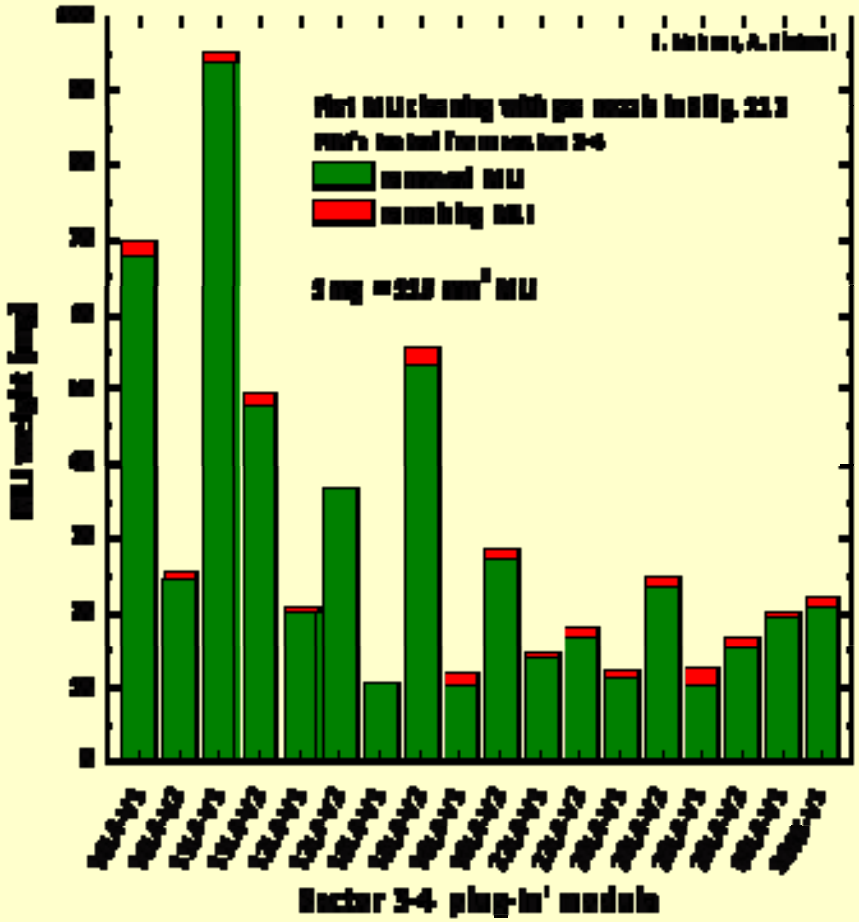
# Cleaning Strategy
# MLI removal in the tunnel: 2nd step (1)

- Based on aspiration with local perturbation controlled by endoscope
- A nozzle blows filtered air, the MLI residues left behind the beam screen and the RF fingers are directed towards the beam aperture where they are aspired away.

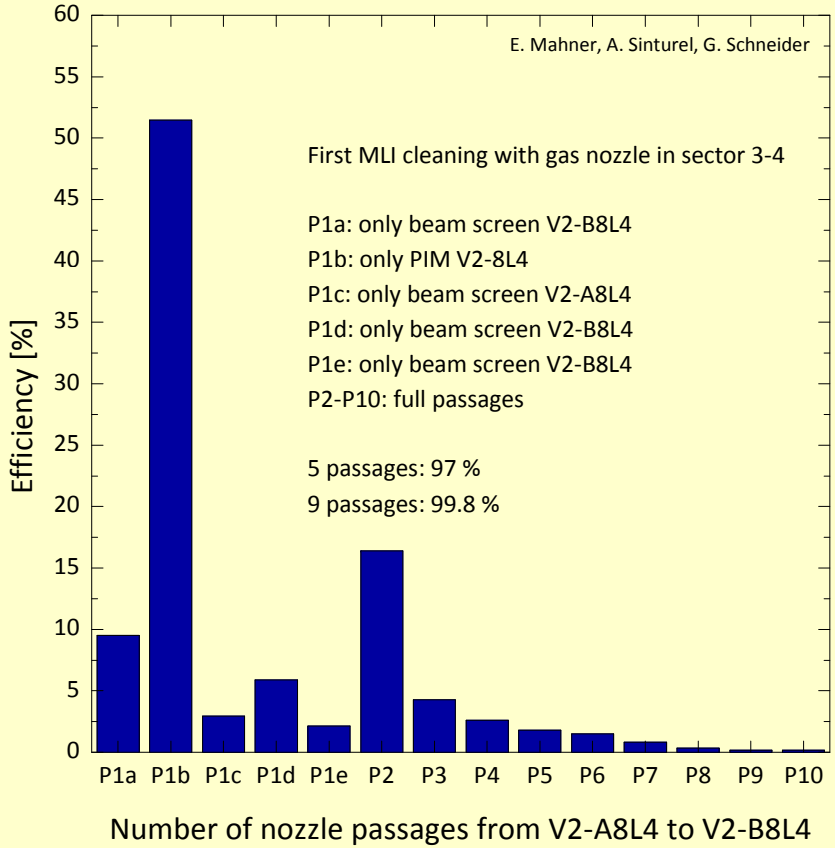




# Cleaning Strategy
# MLI removal in the tunnel: 2nd step (2)

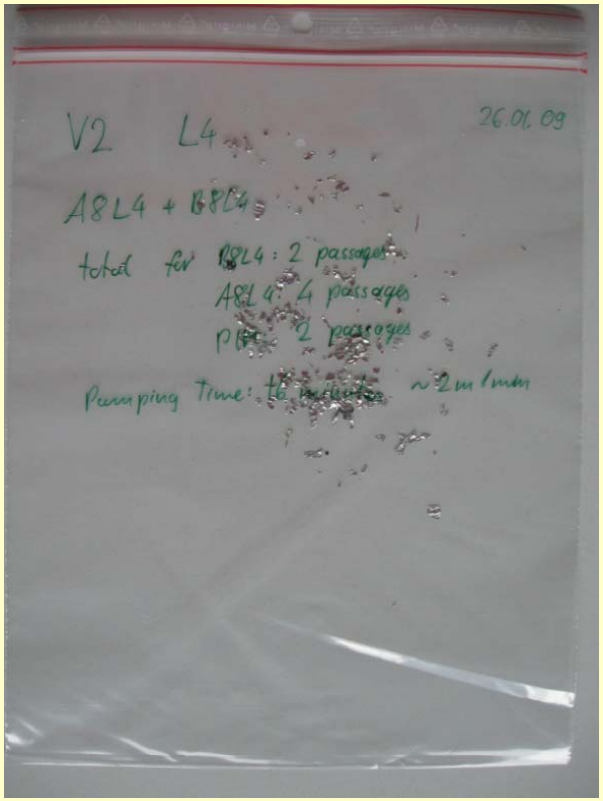


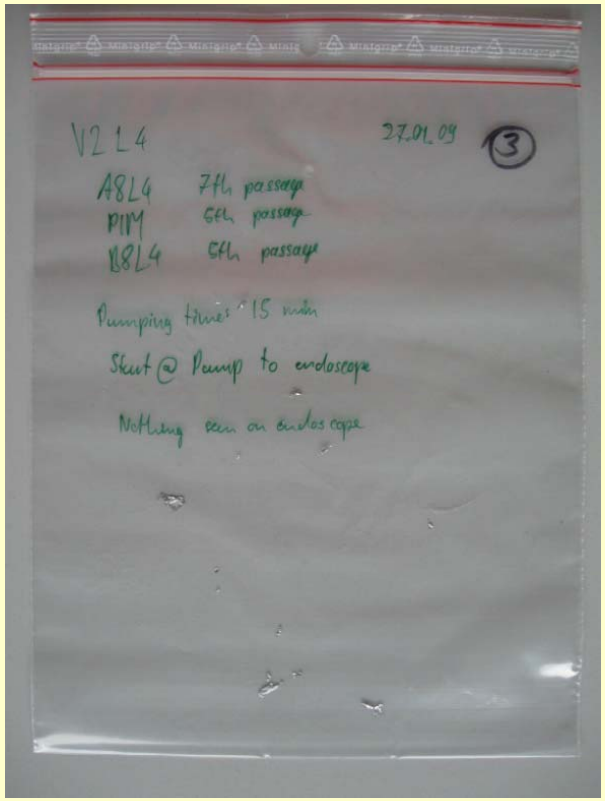
Measurements made at the surface on PIMs removed from 3-4 sector

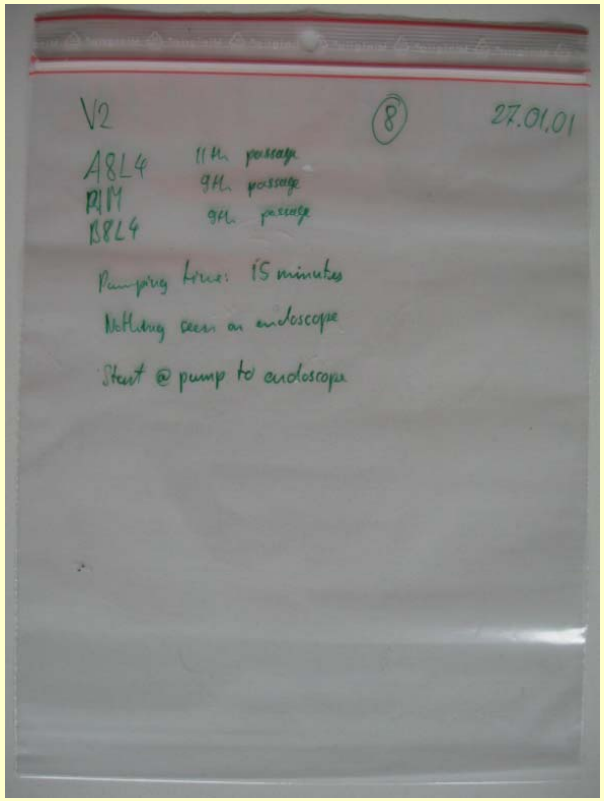



Measurements made in the tunnel 3-4 sector

# Cleaning Strategy
# MLI removal in the tunnel: 2nd step (3)




| 2 passages | 5 passages | 9 passages |
|---|---|---|
| ~ 250 bits | 20 bits | 4 bits |
| | | 2 per dipole ! |

# Cleaning Strategy
# MLI removal in the tunnel: Resources

- **Started with two fronts**
  - Soot removal is completed
  - Removal of MLI on going
- **Two teams**
  - A third team by next week
    - Complete the cleaning by mid-April
- **Cleaning activities started beginning of January**
  - Procedure for MLI removal has taken two months to be qualified
- **All QQBI (~50 m) interconnects have been open to allow MLI removal and perform PIM's consolidation in the meantime**

# Follow-up of Chamonix'09 recommendations
# Collateral damages to beam vacuum: Origin of the incident

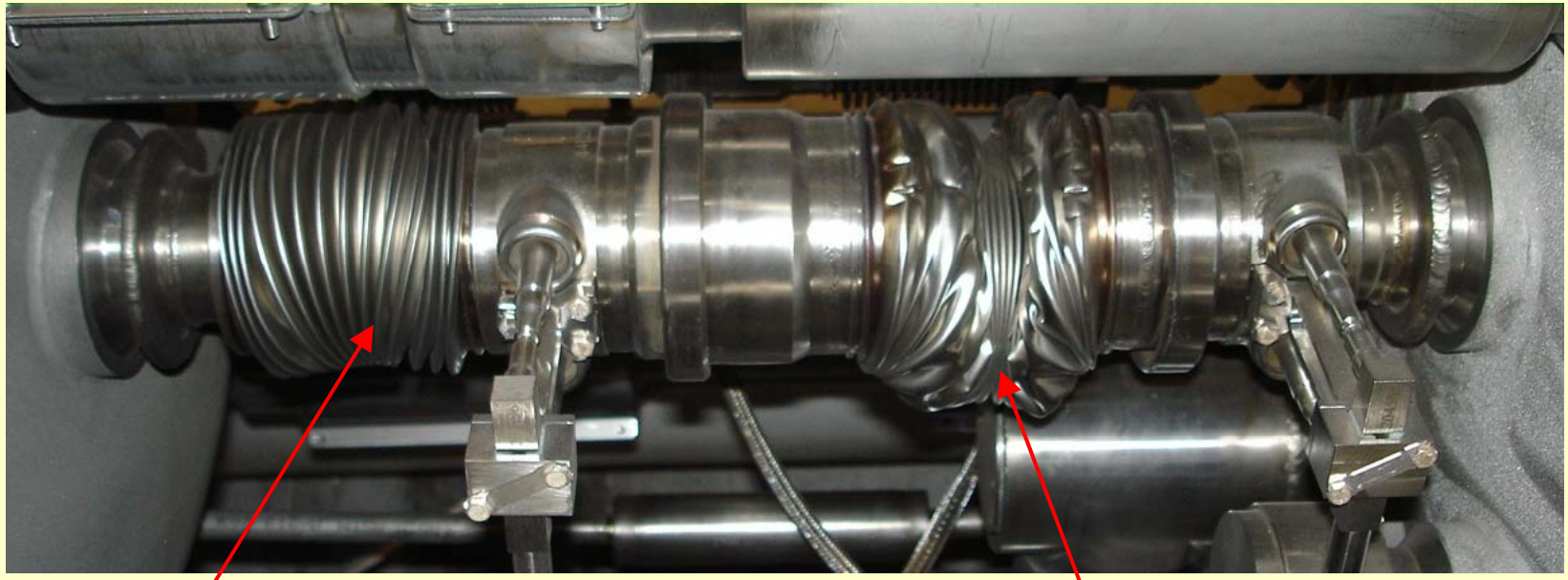
- **Electrical arc**
  - In bus bars
    - The beam vacuum can be affected if:
      - The arc destroys the beam vacuum interconnection
      - The over pressure in the insulation vacuum buckles the bellows and induces a mechanical failure
      - A physical displacement of the magnet or cold mass damages the bellows
  - In the magnet coil
    - The arcing burns a hole on the magnet cold bore
- **Beam lost**
  - The lost beam makes a hole in the cold bore (it has to burn a hole on the beam screen first but rather easy taking into account the SPS experience)

# Follow-up of Chamonix'09 recommendations
# Collateral damages to beam vacuum: Expected consequences

- **Beam vacuum contamination**
  - By soot
    - Only light contamination can be cleaned in situ
    - Interconnection upstream and downstream of the contaminated magnets need to be cut
  - By dusts (MLI, PI, metallic pieces…)
    - Cleaning is feasible but need a warming up and time…
    - On RT temperature system, bake out is required to recover the vacuum performances if a venting is made to clean the beam pipes
  - By helium
    - Dry helium does not contaminate the beam vacuum
    - In 3-4, it was observed that the NEG was not saturated
    - Reactivation is needed in case of venting to air

# Follow-up of Chamonix'09 recommendations
# Collateral damages to beam vacuum: Expected consequences

- **Sudden lost of vacuum integrity**
  - Over pressure in the beam line resulting on the buckling of the bellows
    - PIM ⇨ can be exchanged in situ, need warming up of the entire arc
    - Nested bellows ⇨ magnet shall be removed from the tunnel to exchange the beam screen



$P_{cr}$ ~ 5 bar

$P_{cr}$ ~ 3.5 bar

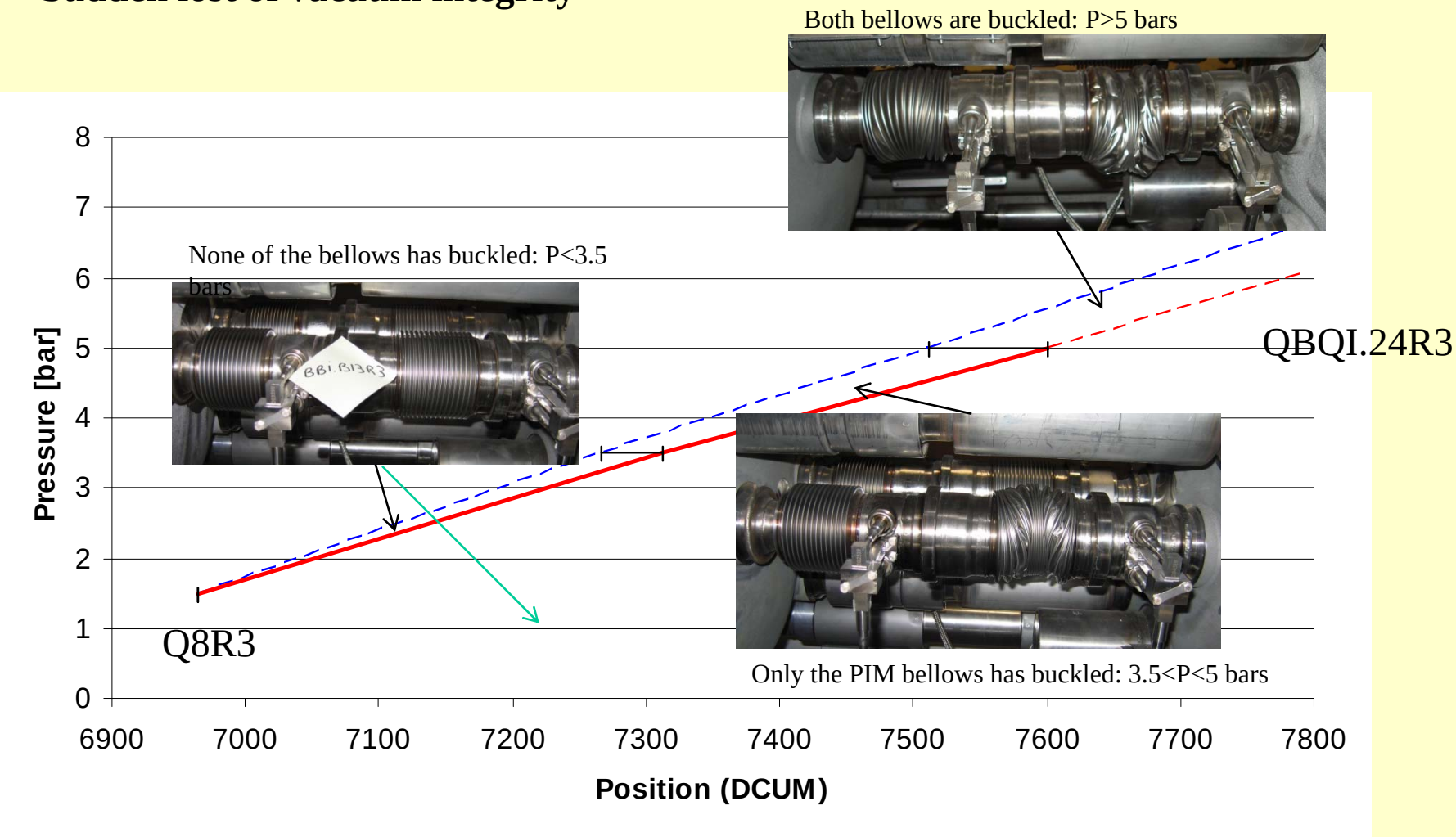
# Follow-up of Chamonix'09 recommendations
# Collateral damages to beam vacuum: Expected consequences

- **Sudden lost of vacuum integrity**
  - Induced lateral forces which were not taken into consideration during the design of the supports
    - Supports can fail leading to mechanical damages and "domino" effect
      - More collateral damages, even far away (hundreds meters) from the incident area
    - Buckling of the beam pipes

In all cases, expected downtime shall be counted in months

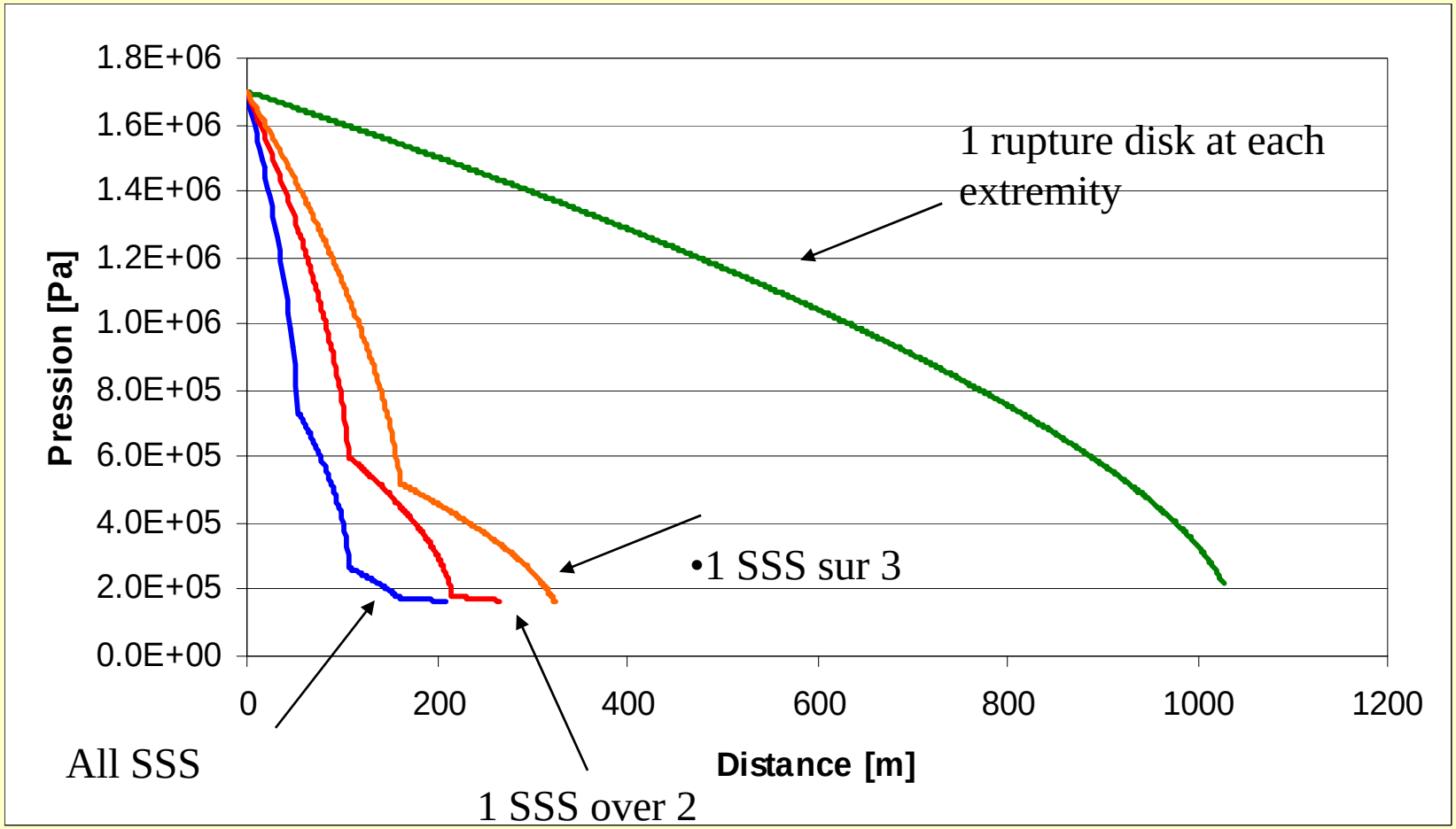
# Follow-up of Chamonix'09 recommendations
# Collateral damages to beam vacuum: Expected consequences

- **Sudden lost of vacuum integrity**



# Follow-up of Chamonix'09 recommendations
# Collateral damages to beam vacuum: Expected consequences

- **Sudden lost of vacuum integrity**




Aperture of the rupture disk does not change significantly the results

# Closing remarks (1)

- **Systematic inspections revealed debris of soot and MLI all along the arc**
  - Soot was removed by a mechanical action with a foam-plug in the tunnel (6 magnets)
  - No traces of debris have been found outside the arc
  - Room temperature vacuum sectors are under vacuum with NEG ativated
- **MLI is being removed by a combination of pumping/venting mechanism and a local blow-up using a nozzle together with a pumping mechanism**
  - Still a lot of work to do in the tunnel
  - The objective of the coming weeks is to release sectors for PIMs interconnection
- **Traceability**
  - All cleaning activities are documented
- **Recovery of the store magnets has not started yet**
  - Experience with quadrupole magnets give us confidence on these estimations

# Closing remarks (2)

- **The sudden loss of the beam vacuum integrity can lead to two types of consequences:**
  - Contamination of the beam pipes
  - Mechanical damage of vacuum components
- **The existing design and layout can not limit this impact**
  - Consolidation is being studied and solutions will be submitted to the management approval next Wednesday 12th March
  - The case of the LSS and experimental areas will also be adressed
- **Some hypothesis regarding the resistance of all vacuum components to buckling above 0.5 bar relative are being investigated**

# Acknowledgements

**Many peoples have been involved in the endoscopies, the cleaning, the tooling preparation, etc. It will be a challenge to set a list, I would like to thank all of them...**