Lessons from LHC He Release and R2E

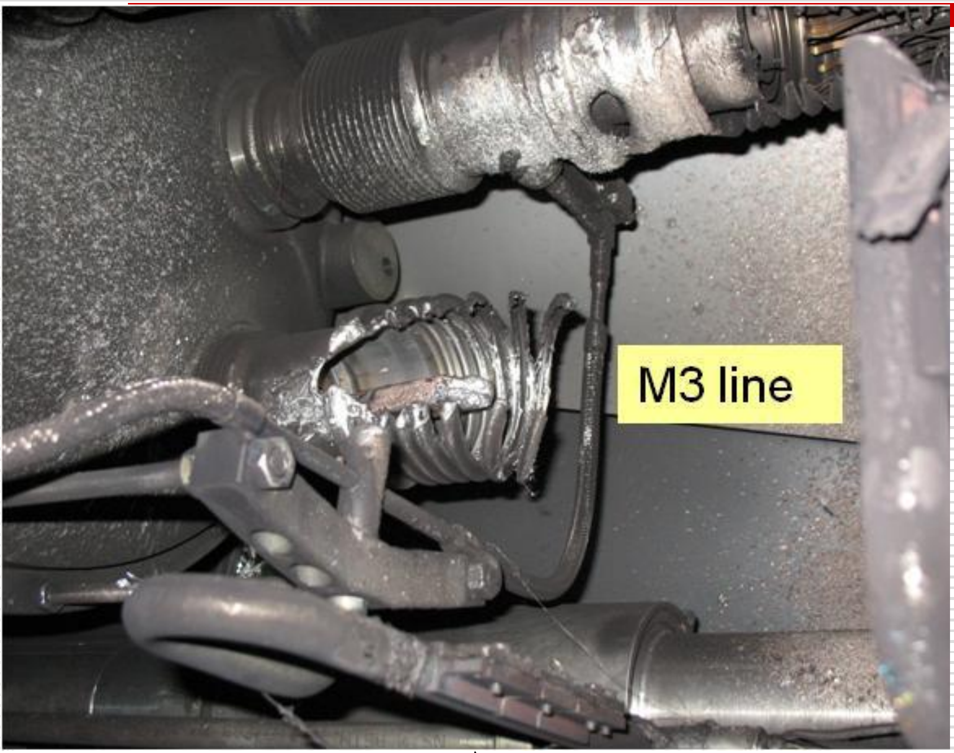
Content

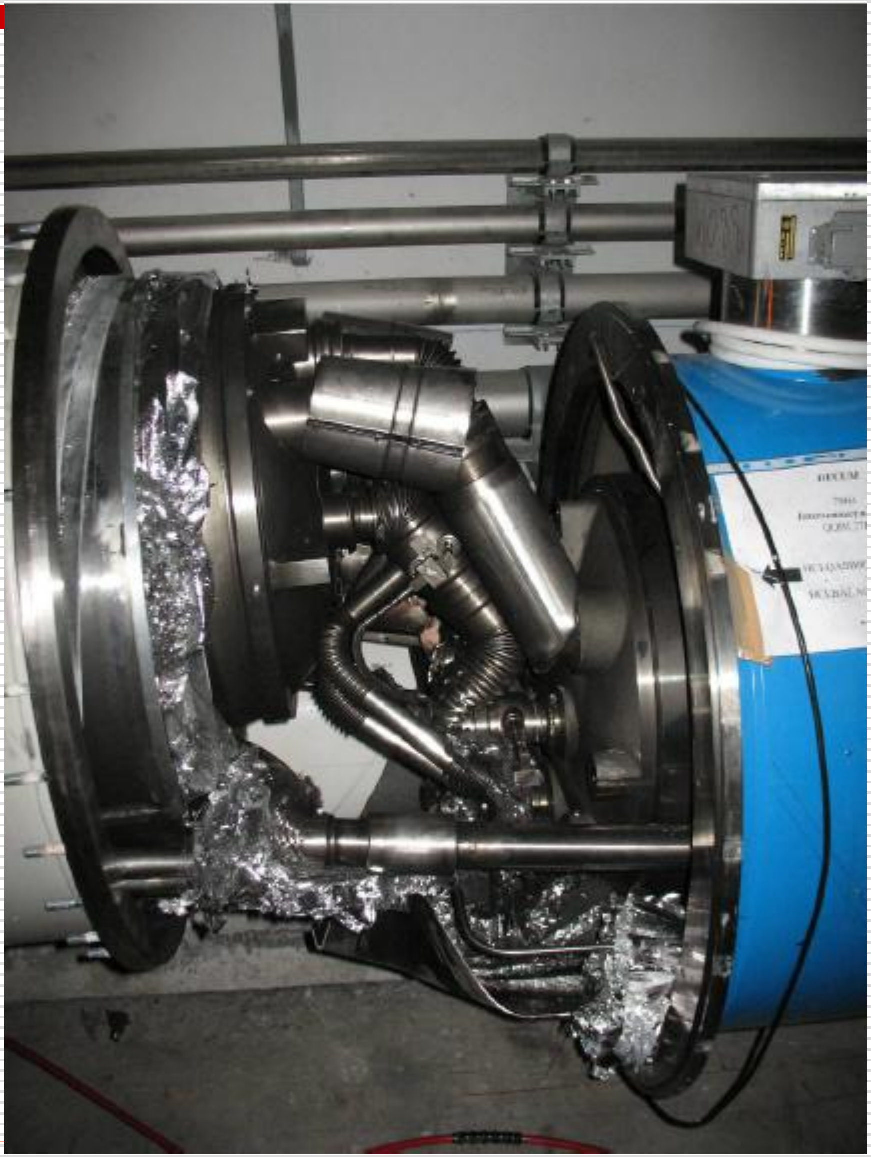
- The September 19th (2008) Accident at LHC
- New Safety Measures in Force
- Impact in the Field and Consequences on Access

- Sensitivity of LHC Electronics to Single Event Effect
- Short Term Actions to Mitigate SEE
- Longer Term Strategies Explored
- Summary

Many thanks to all contributors

Consequences of September 19th (2008) event in sector 3-4 of the LHC

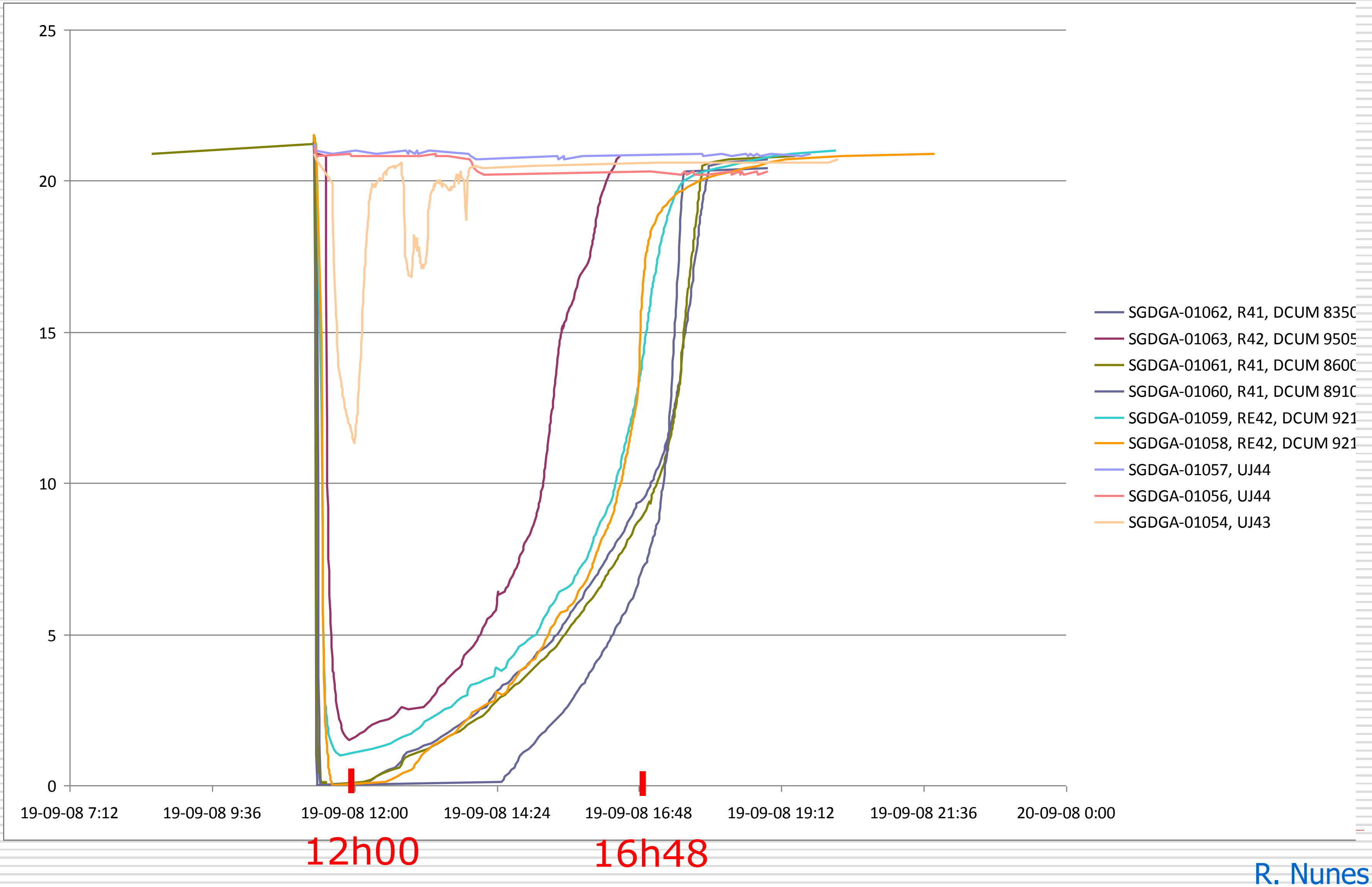




At the faulty connection

Collateral damages due to pressure rise

Oxygen content in the tunnel (sensors on the ceiling)

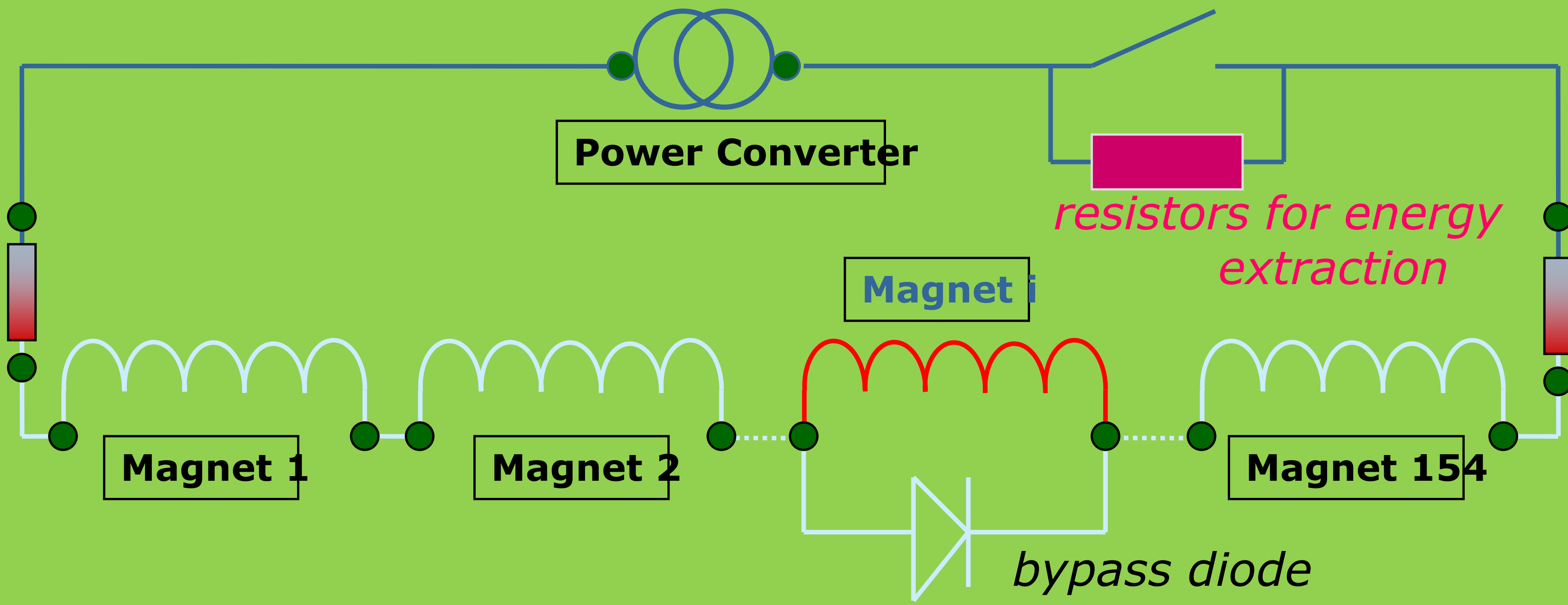


R. Nunes

~ 10 GJ stored in magnetic field (154 dipoles in series)

Circuit inductance =15 Henrys (τ discharge =100s)

LHC quench protection



- when one magnet quenches, quench heaters are fired for this magnet
- current in quenched magnet decays in about 200 ms
- the current in all other magnets flows through the bypass diode that can stand the current for about 100-200 seconds; resistors are switched in series

R. Schmidt

2 Working Groups to analyse the 19/09/2008 event « Task Force »

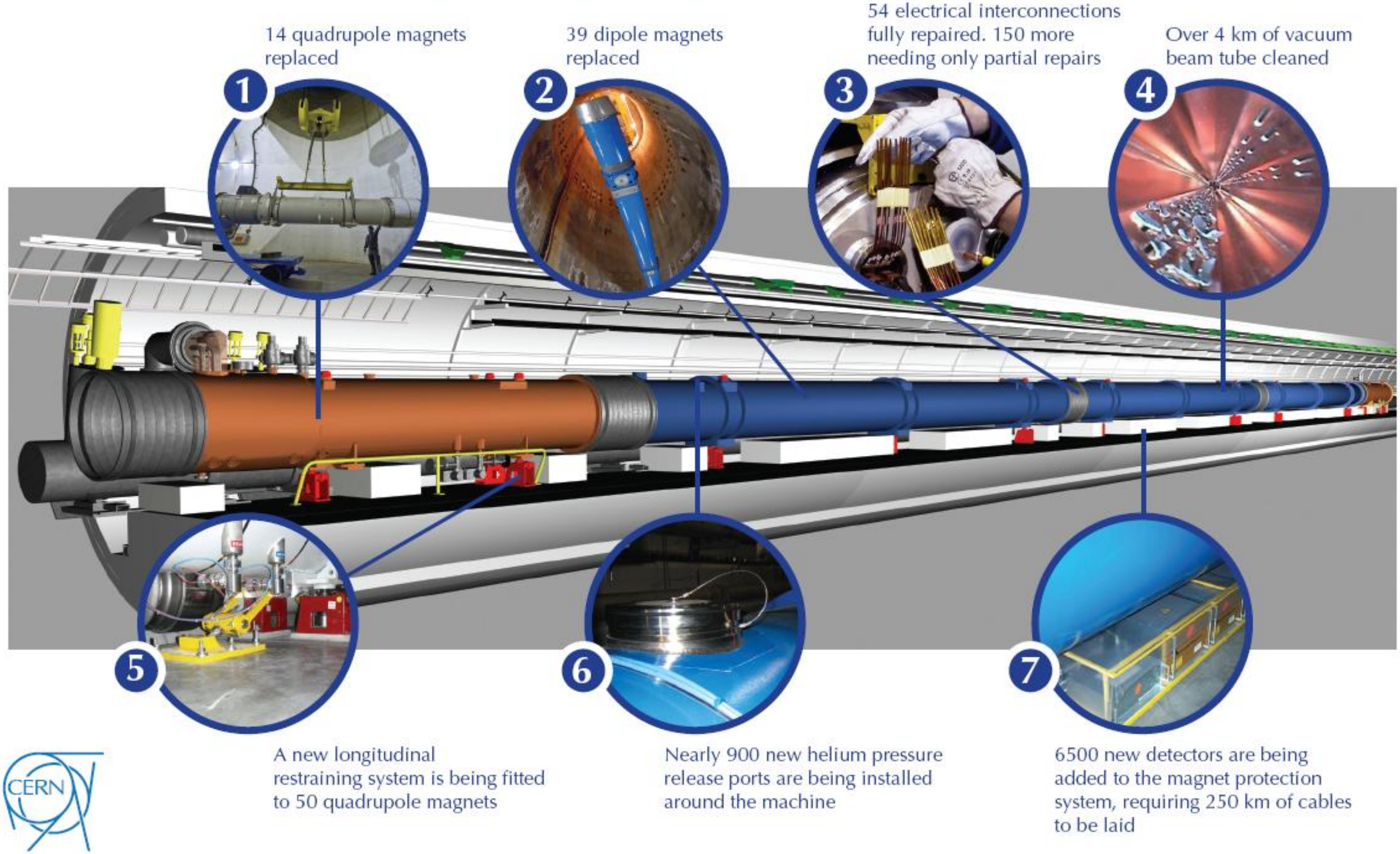
Mandate of the Task Force on the Analysis of the 19 September 2008 Incident

- Establish the sequence of facts, based on experimental measurements before incident, observations after incident and timing
- Analyse and explain the development of events, in relation with design assumptions, manufacturing & test data and risk analyses performed
- Recommend preventive and corrective actions for Sector 3-4 and others

Mandate of the Task Force on Safety of Personnel in the LHC underground

- Establish the sequence of facts related to Safety of Personnel, based on AL3 data and FB emergency intervention records
- Analyse the LHC underground environmental conditions with respect to Safety of Personnel and explain their development in relation with original risk analyses (incl. Tests) performed
- Recommend preventive and corrective actions for the Safety of Personnel in the LHC underground

Main works to repair and consolidate the LHC



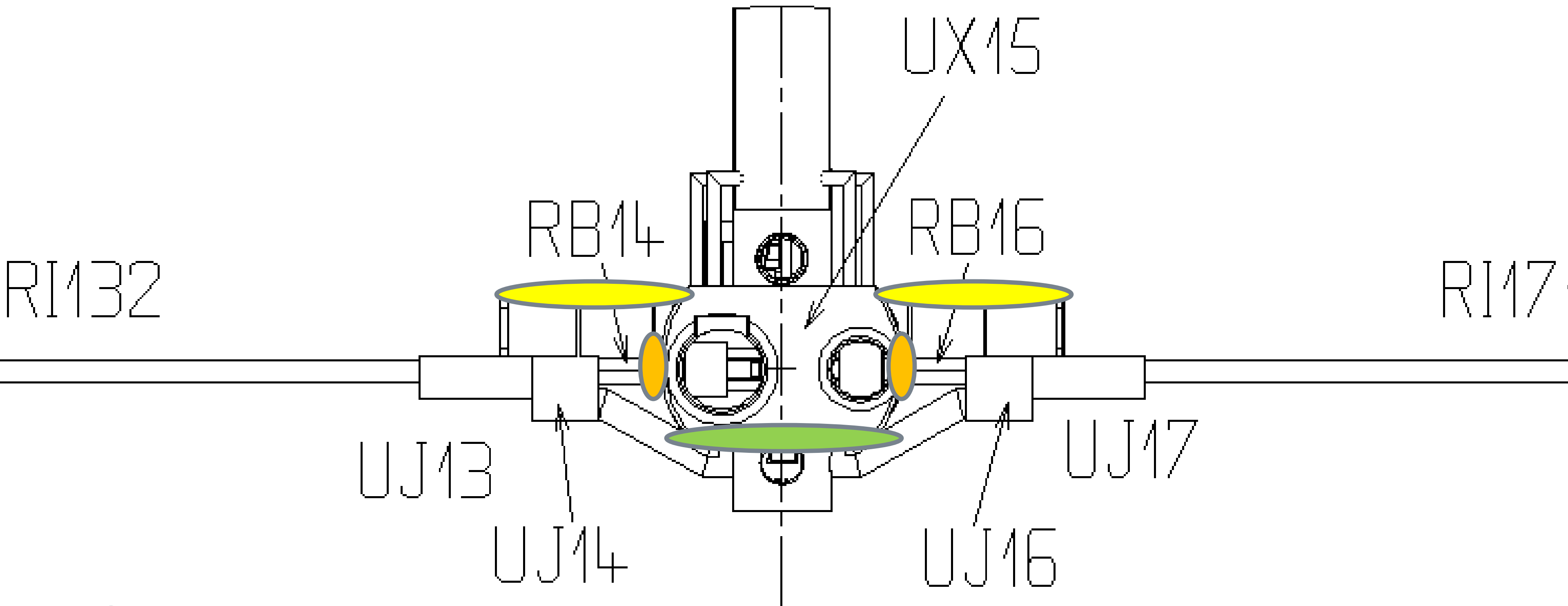
Recommandations of the Task Force on Safety of Personnel in the LHC underground

- All efforts have to be made to limit an incidental helium release and the resulting overpressure
- Any incidental helium release shall be confined to the ventilation sector where it occurs
- This confinement must be carried out in combination with a controlled release of overpressure to the surface
- No access shall be allowed to any ventilation sector of the LHC in which a large helium release has a non-negligible probability to occur.

A ventilation sector is defined as the area directly affected by the overpressure resulting from the helium release.

A large helium release is defined as being at least of the same order of magnitude as the release of 19th September 2008 accident.

Separation of the ventilation sectors – Experimental areas

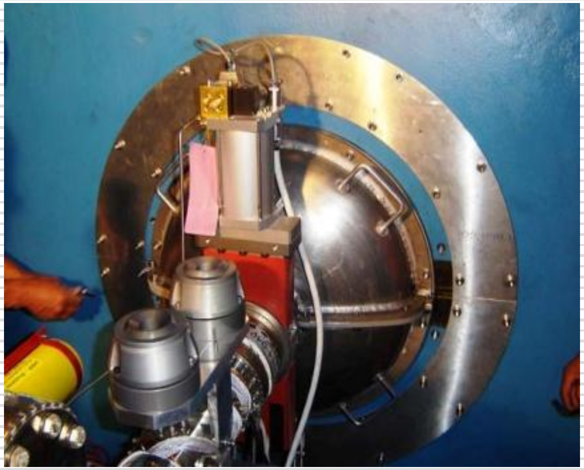


- Interface between LHC and Detectors on beam line
- Interface with survey galleries
- Interface between detector caverns and machine areas
- Interface between experimental service caverns and machine (Pt5 only)

Sealing of the Experimental Areas (part 1)

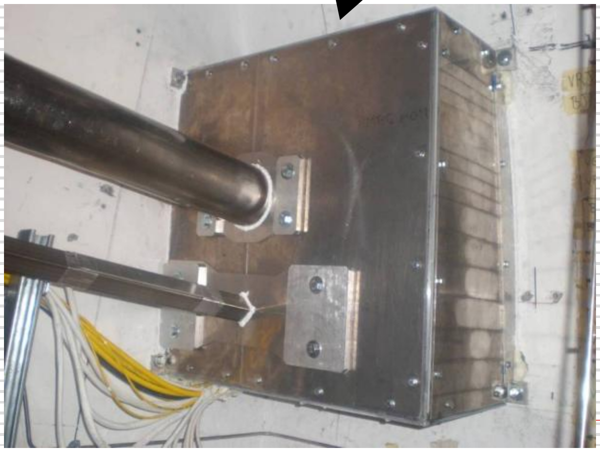
1) Along the beam line

Sealing around the TAS - ATLAS case
built for 110mb (expect <32mb), Tmin 200K,
compatible with ±15mm adjustment



2) Interfaces with survey galleries

ATLAS: UPS caps on survey ducts and doors



built for 110mb
(expect <32mb)
T_{min} 200K
fire resistant

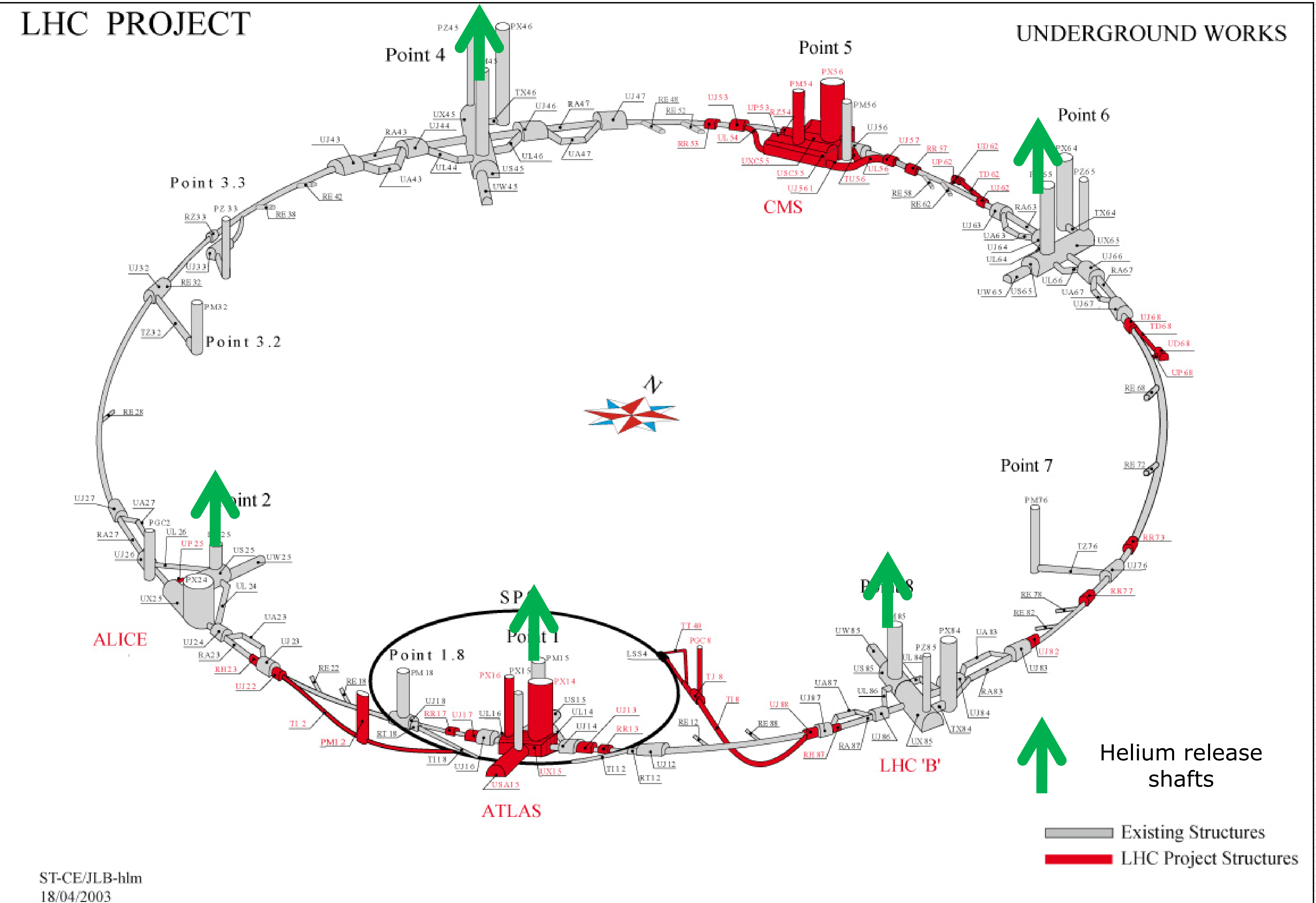
Sealing of the Experimental Areas (part 2)

3) Interface between experimental cavern and service areas of the LHC machine

ATLAS: fire (T90) and pressure resistant doors between US15 and UX15 (certified 40mb, expect <11mb)

+ sealing of all passages of Pipes and cable trays, spacing between shielding blocs.
Use rock wool and Promafoam (fire resistant), re-enforcement

Helium release to surface – MCI ≡ 40kg/sec



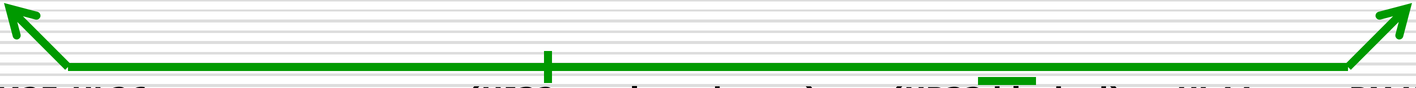
Helium release to surface

Principle is to limit pressure rise in the tunnel

- Sector 1-2:

UJ14 closed-PM15-UJ16 open **(TI18-PM18 blocked)** **(TI2 blocked)** **UL24 open-PM25-UL26 closed**

- Sectors 2-3 & 3-4:

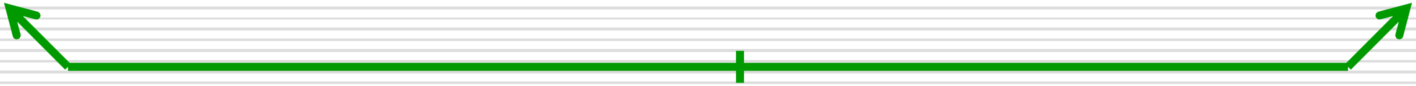


UL24 closed-PM25-UL26 open **(UJ32 « saloon door »)** **(UP33 blocked)** **UL44 open-PM45-UL46 closed**

- Sectors 4-5 & 5-6:

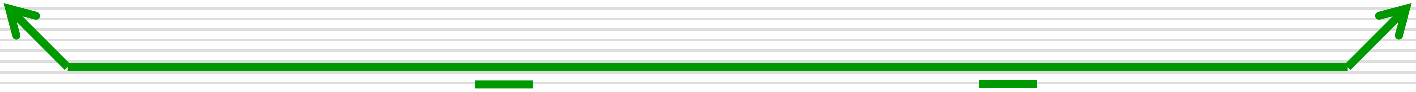
UL44 closed-PM45-UL46 open **(UL55 « saloon door »)** **UL64 open-PM65-UL66 closed**

- Sectors 6-7 & 7-8:



UL64 closed-PM65-UL66 open **(UJ76 « saloon door »)** **UL84 open-PM85-UL86 closed**

- Sector 8-1:



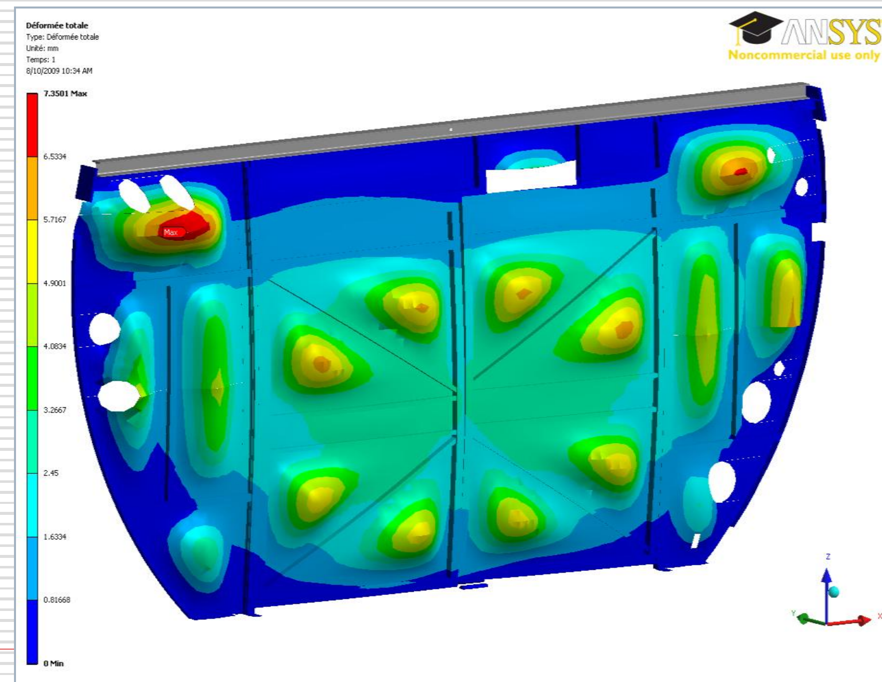
UL84 closed-PM85-UL86 open **(TI8 blocked)** **(TI12 blocked)** **UJ14 open-PM15-UJ16 closed**

Controlled Helium release – Ventilation doors

Relief valve type of doors,
in UJ14/16,UL24/26,UL44/46,UL64/66 & UL84/86

Door re-enforced, opens with 5mb overpressure from adjacent sector and stands 30mb from US side.

Door positions monitored from CCC



Deformation of re-enforced door:
30mb ➔ 7,4mm max.

Access matrix for the LHC underground

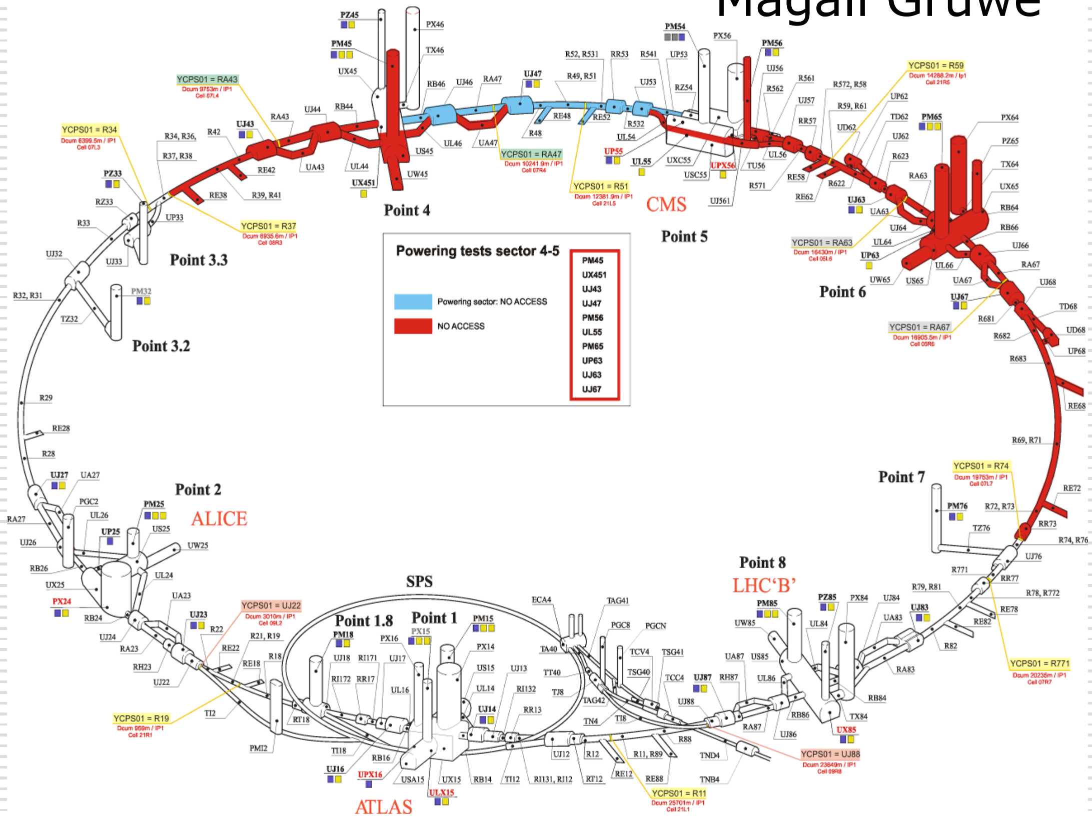
New access restrictions when main magnets are (or could be) powered

Access conditions in LHC are documented in EDMS N°1010617

Magali Gruwe

Use of US and PM shafts to evacuate He flow comdemn access to adjacent sector.
In case of sectors linked with saloon doors (6/8), ~half of LHC is closed …

Example of restriction when powering sector 4-5 ➔



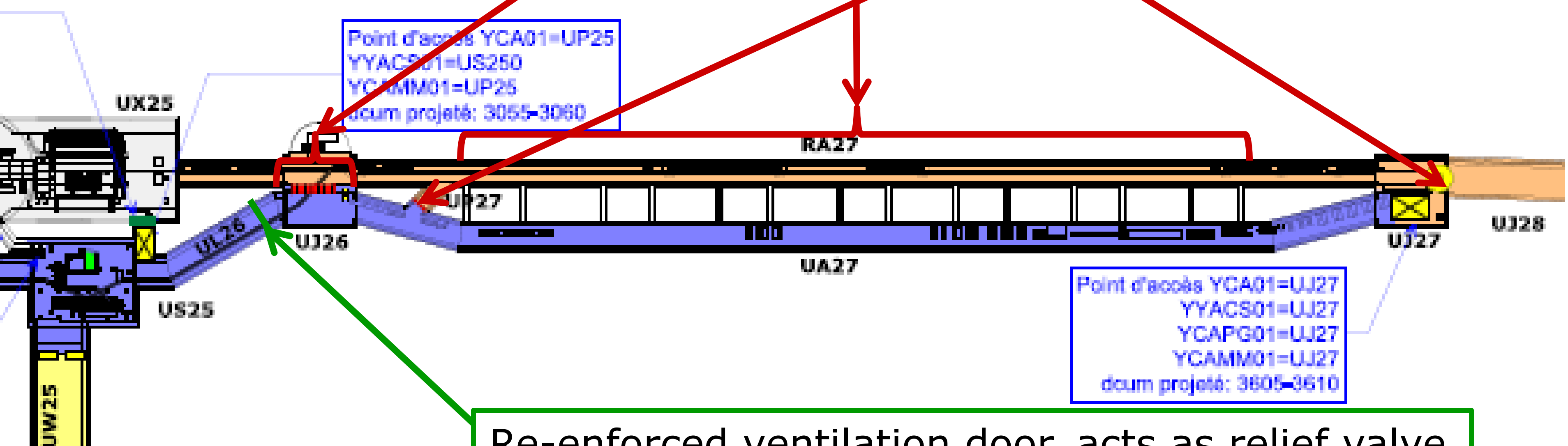
Still to do … Sealing of LHC service areas

Essentially a ventilation issue,
will become a RP constraint at high intensity/luminosity

Need to seal all ducts

Generic case: Pt 2

Need to re-install ventilation doors in UP27 and UJ27



Re-enforced ventilation door, acts as relief valve

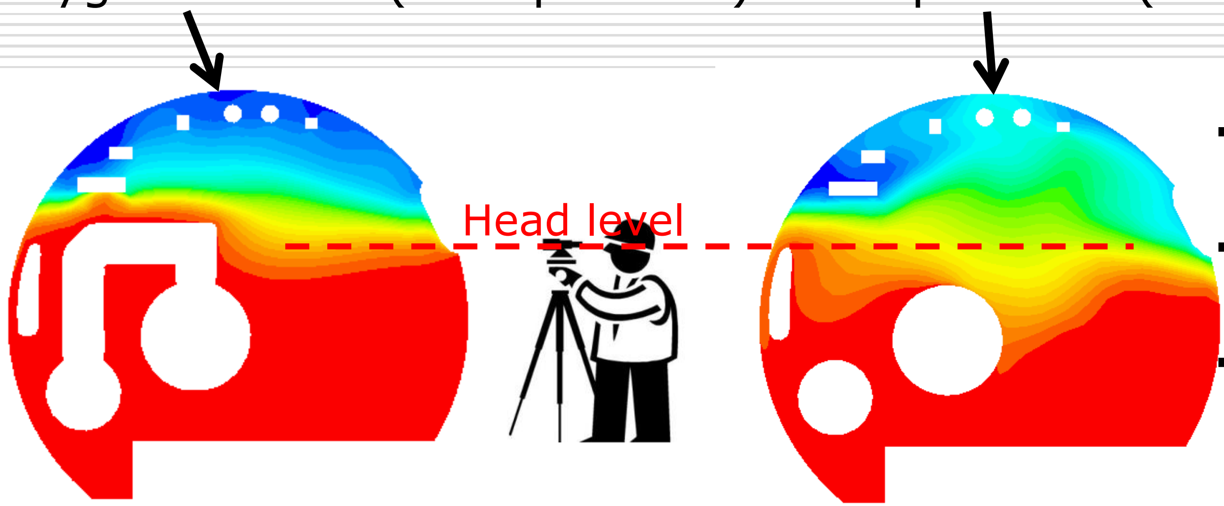
Still to do … Safety during short access

Liquid He is transferred into surface storage tanks during x-mass breaks and shut-downs, but remains in the cryostat during short access

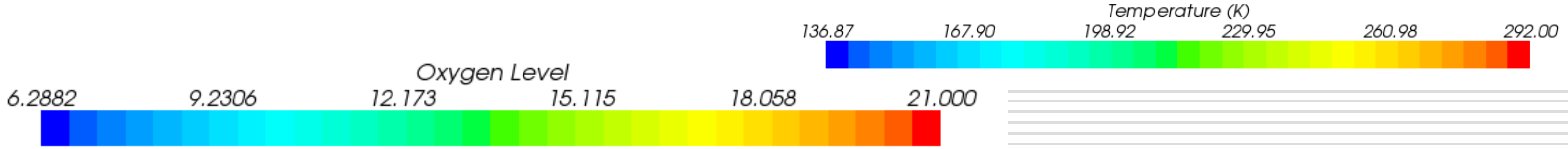
➔ MCI without powering of main circuits can lead to a 1kg/s leak

Fluid Dynamic simulation of a 1kg/s leak   Lazlo Daroczy

Situation 15 seconds after opening of the safety valve:
oxygen content (7m upstream) – temperature (7m downstream)

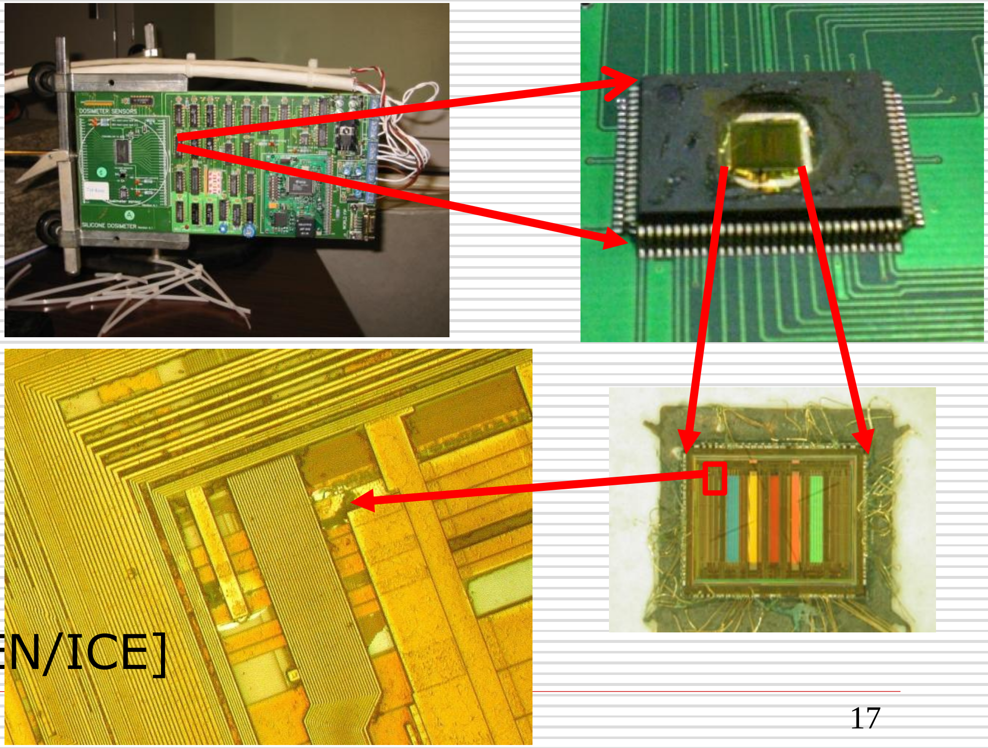


- ➔ Real hazard if present close to the valve
- ➔ “No stay area” marks painted on the floor
- ➔ Need improvement (Ex. early warning)



R2E - Single Event effects

- Soft Errors (recoverable)
  - Single Event Upset (SEU)
  - Multiple Bit Upset (MBU)
  - Single Event Transient (SET)
  - Single Event functional Interrupt (SEFI)
- Hard Errors (non recoverable)
  - Single Event Latch-up (SEL)
  - Single Event Gate Rupture (SEGR)
  - Single Event Burn-out (SEB)



[Photos R. de Olivera EN/ICE]

A Few Numbers (xSections)

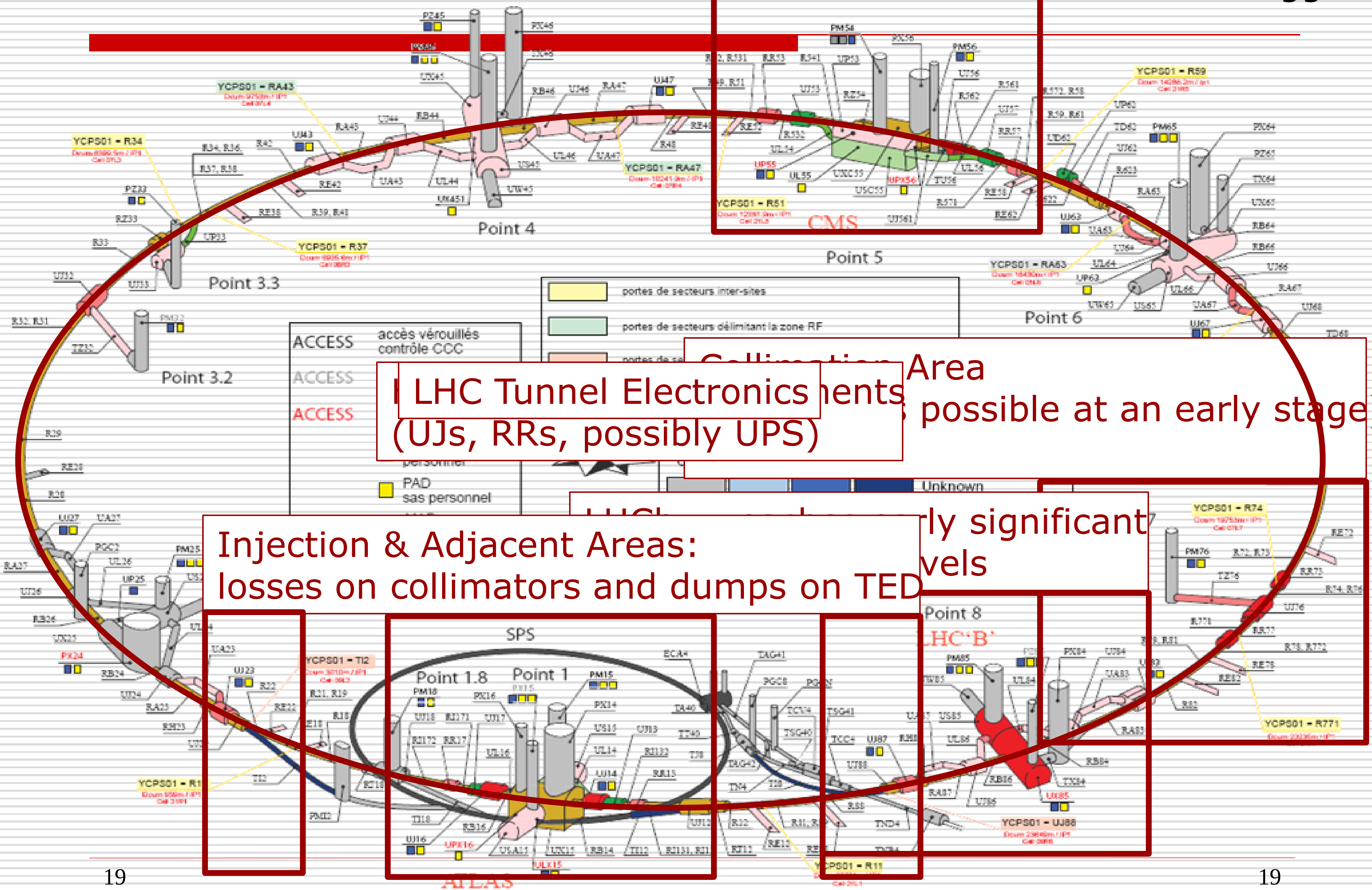
PLC-S7-200, Profibus (CV):	5.1×10^{-7} cm^2
24V DC Power Supply (CV):	3.6×10^{-9} cm^2
PLC-S7-300 (CV):	3.0×10^{-8} cm^2
PLC-Schneider (CV):	2.8×10^{-7} cm^2 (dominated by PS?)
WIC Rack PLC S7-300 + FM352-5 Siemens:	2.0×10^{-7} cm^2
Fire Detectors ASD:	5.9×10^{-9} cm^2
Ethernet Switch:	3.8×10^{-8} cm^2
…	

~1000 failures in a nominal year in UJ14/16

Other equipment: former test results, similar equipment, 10^{-7}cm^2 or lower!
<u>Uncertainty:</u> up to one order of magnitude (but both directions!)

Critical Area Overview

Markus Brugger



Collimation Area
... possible at an early stage)

LHC Tunnel Electronics
...ents
(UJs, RRs, possibly UPS)

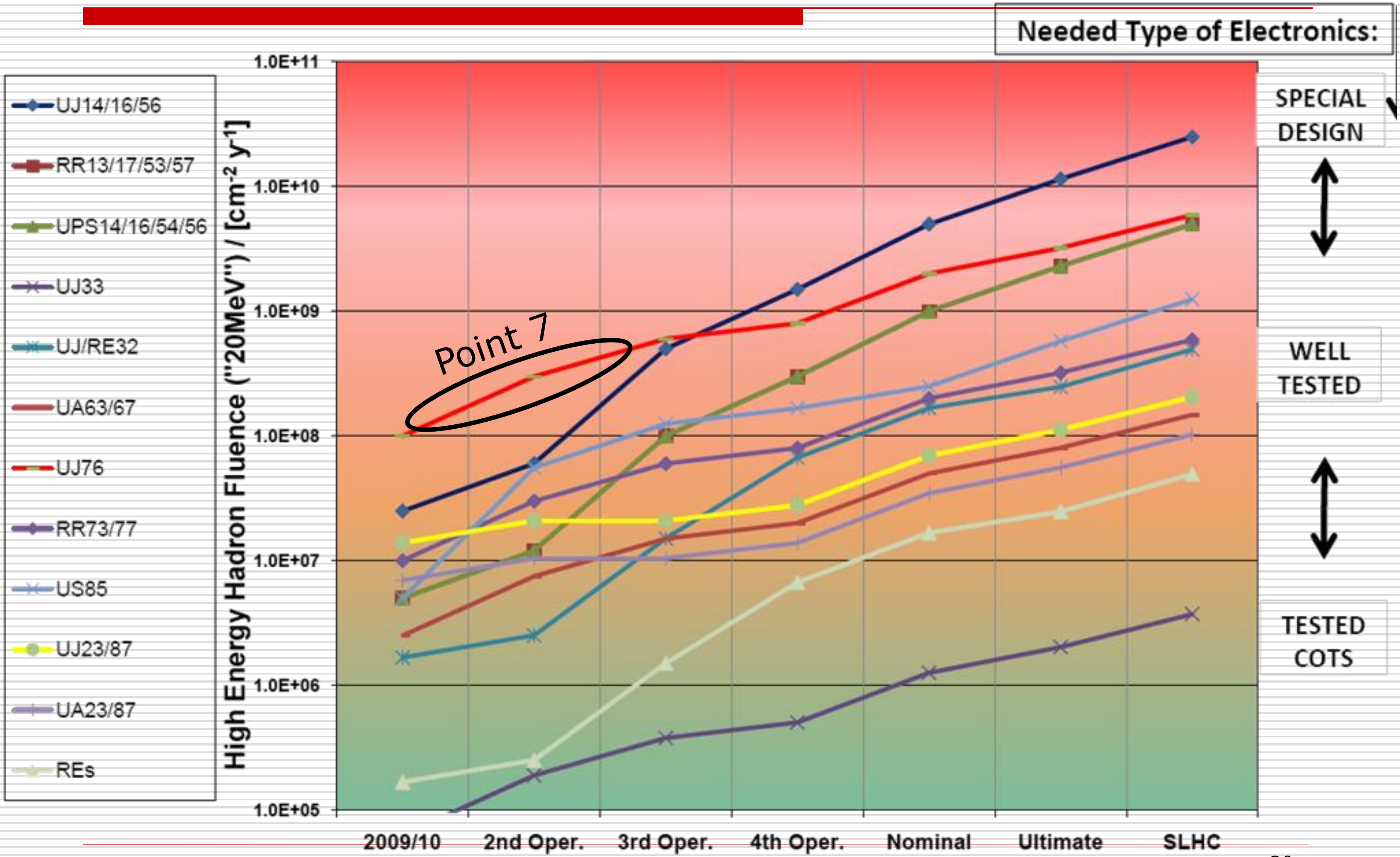
LHCb ... rly significant
...vels

Injection & Adjacent Areas:
losses on collimators and dumps on TED

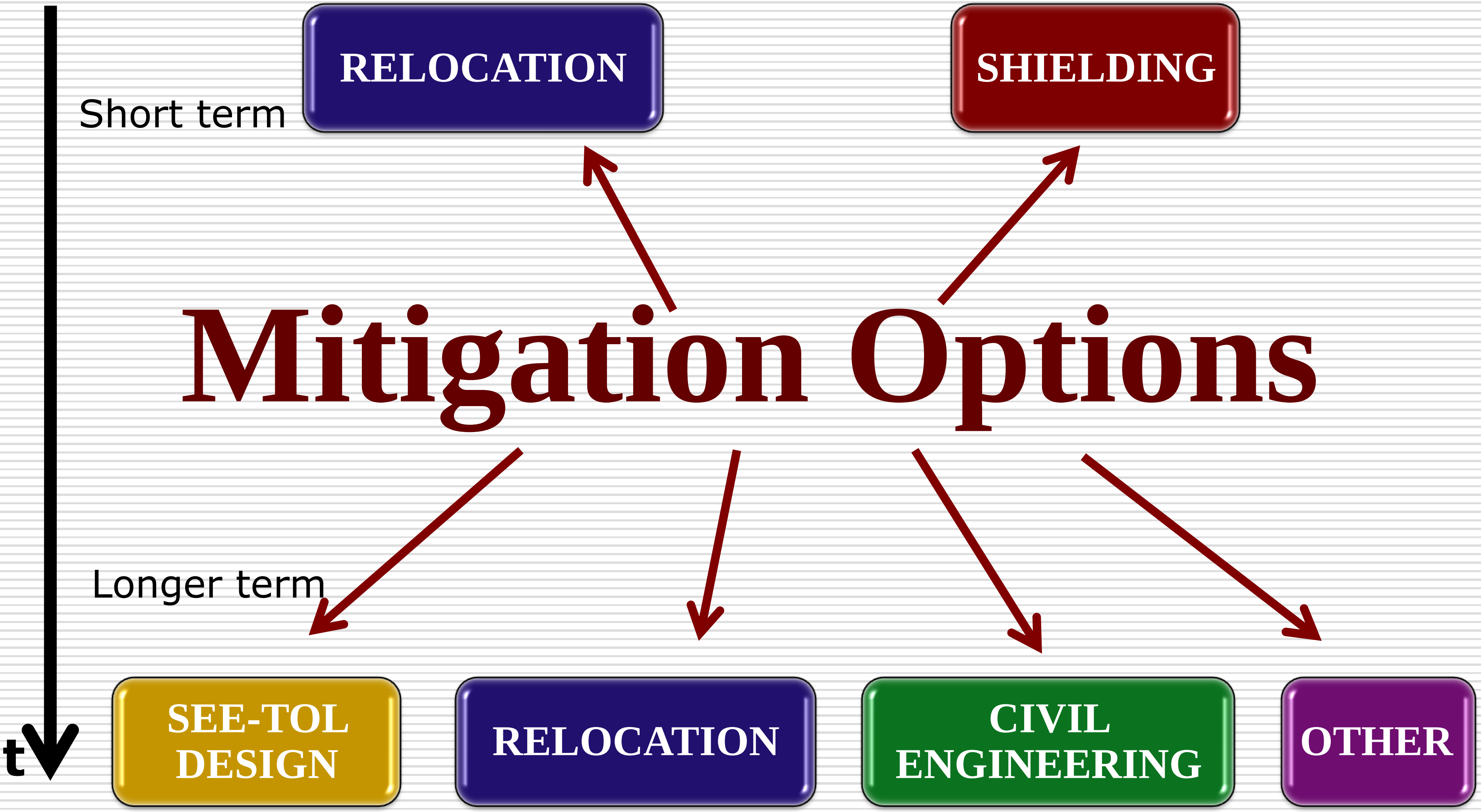
19

Summary Of Areas

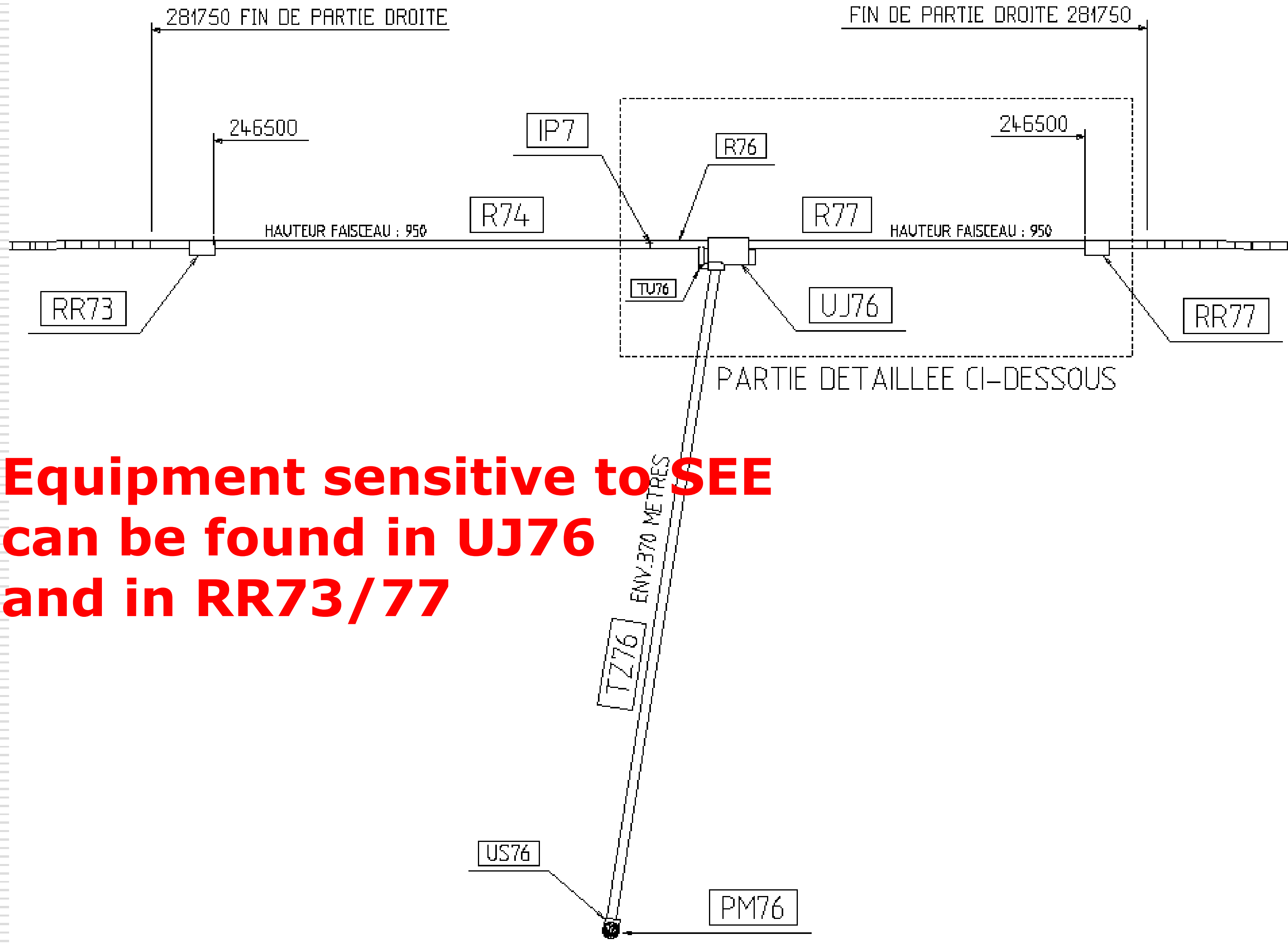
Markus Brugger



Possible Strategies



Layout of Point 7



Equipment sensitive to SEE can be found in UJ76 and in RR73/77

Point 7: status of relocation & shielding

Strategy for SEE mitigation is described in EDMS # 977085:

- Prepare space for relocation in TZ76
  - Enlargement over 130 m ➔ done
- Relocate in TZ76 what can be moved:
  - **UPS and Network equipment were identified 1st priority ➔ done**
  - Power converters are next ➔ preparation (cable routing and cooling) done
  - Remaining equipment of 1st floor of UJ76 ➔ slots assigned in TZ76 (thanks to ICL – J.P Corso & A.Tursun)
- Shield what cannot be moved:
  - Safe room in UJ76 ➔ 40 cm of iron in place on the LHC tunnel side
  - RR73 and RR77 ➔ 40 cm of iron and movable chicane in place

Insure QPS powering
Potential drastic accident

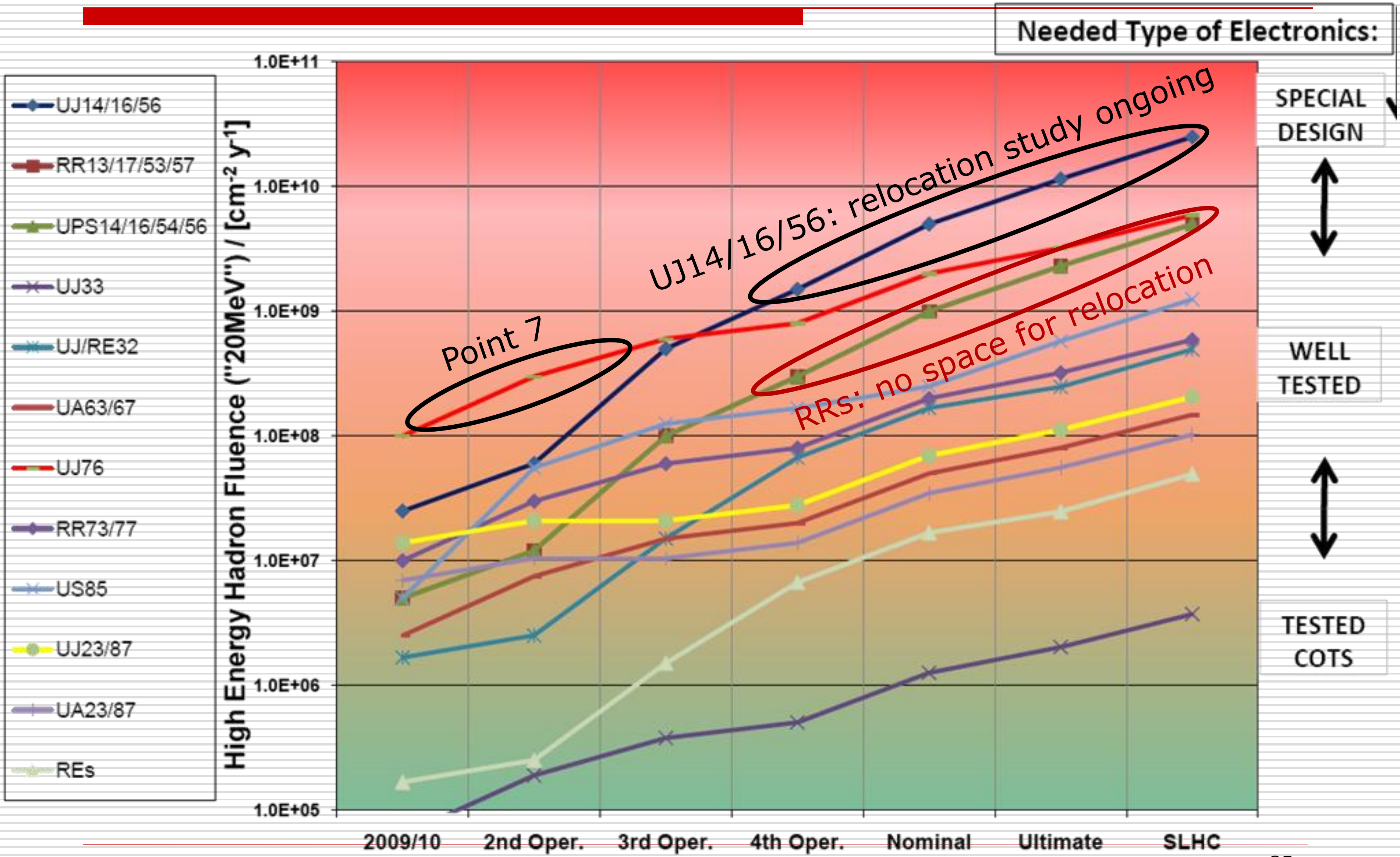
Relocation of the UPS

Before 2009 in UJ76

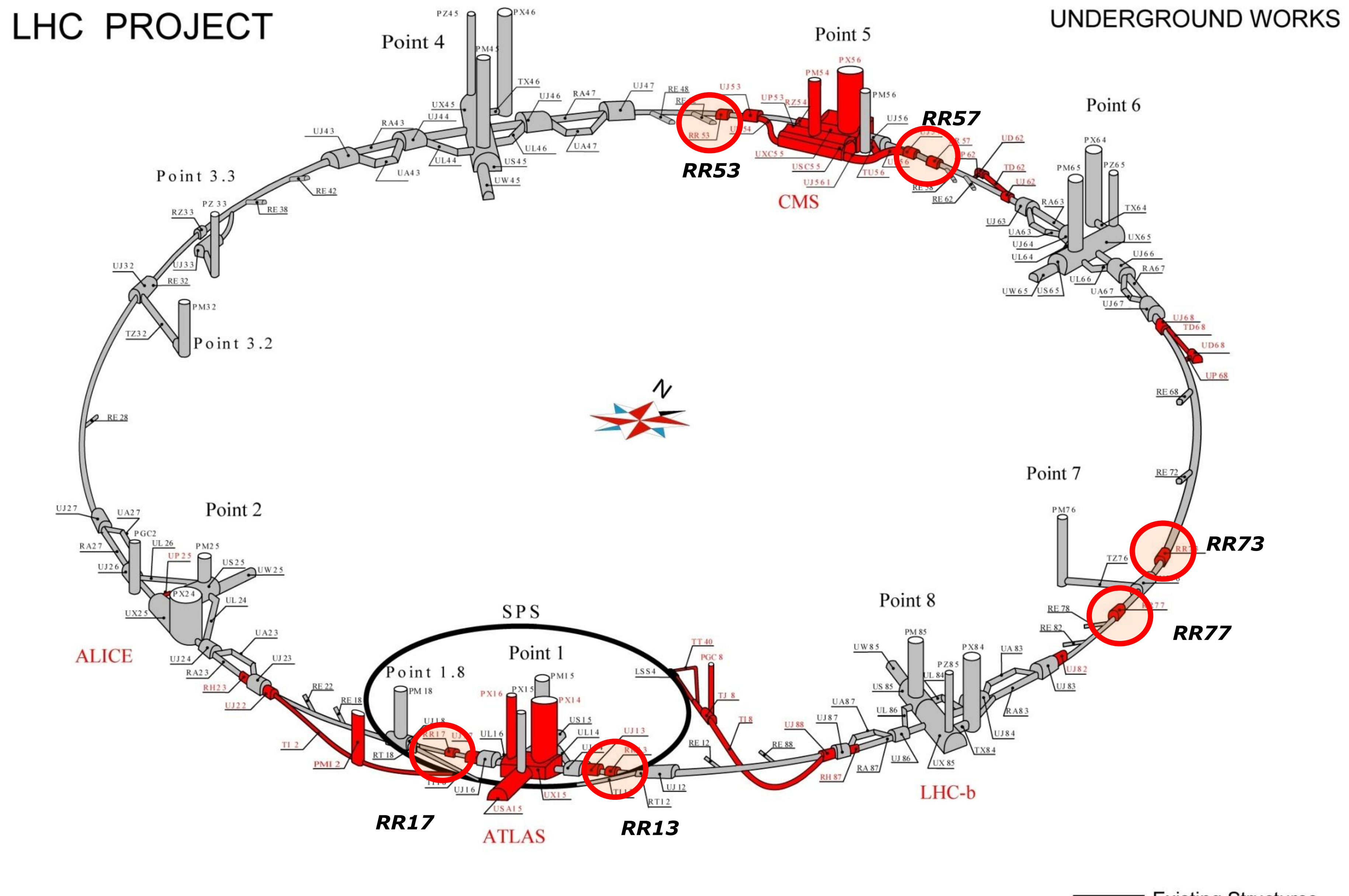
Now in TZ76

Summary Of Areas

Markus Brugger



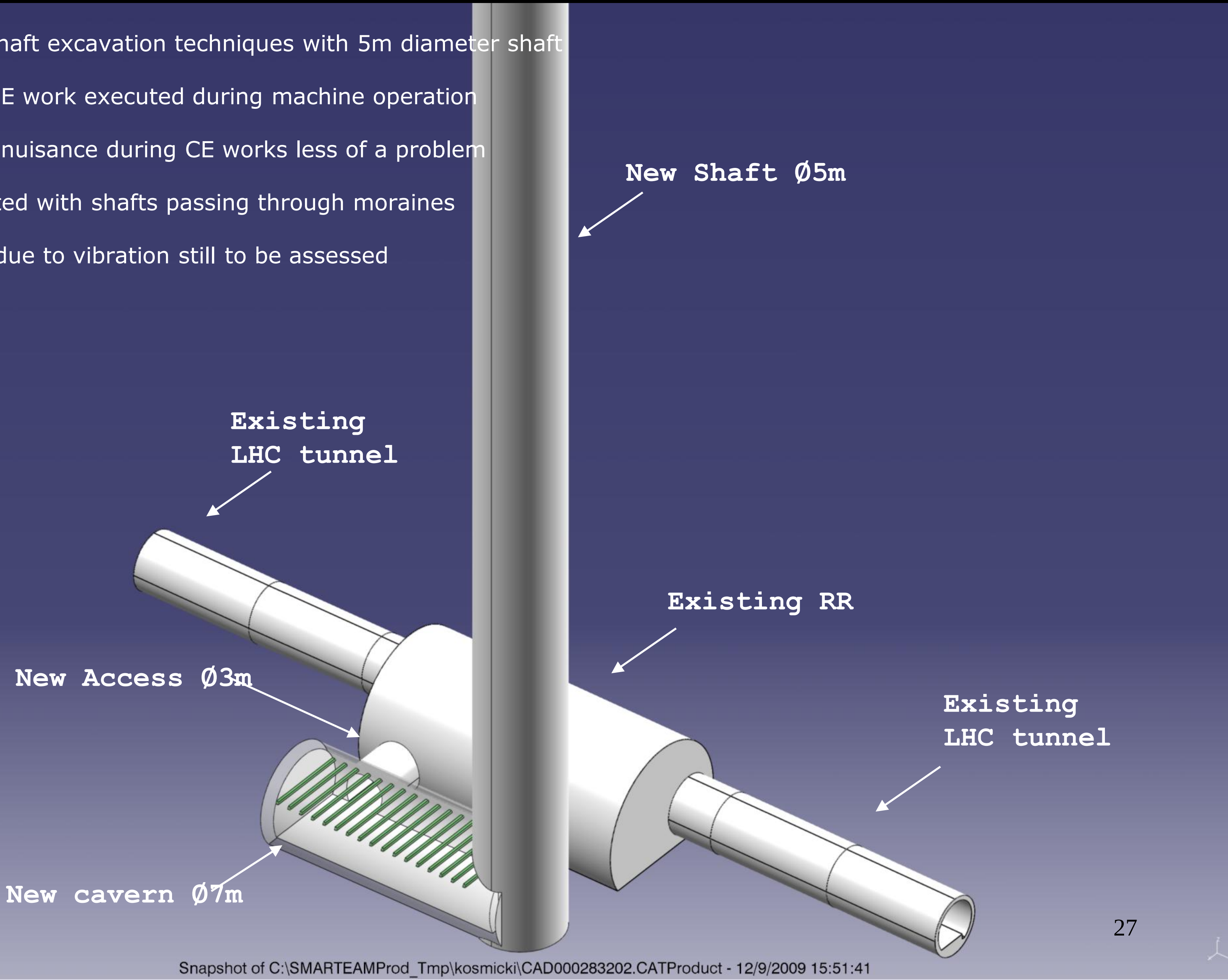
RR caverns with potential radiation concerns for underground electronics



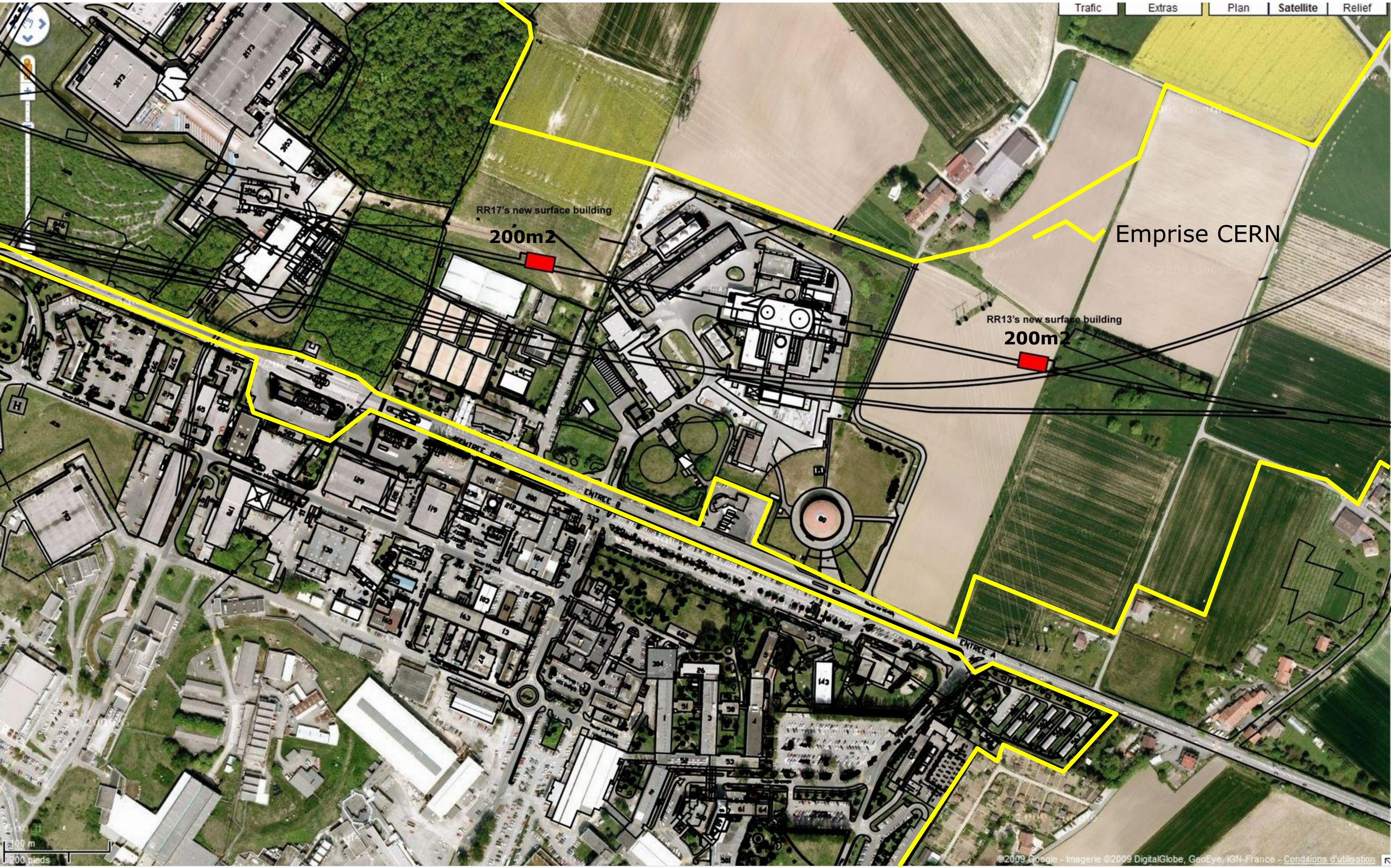
1) New shafts & caverns to re-locate equipment underground

John Osborne

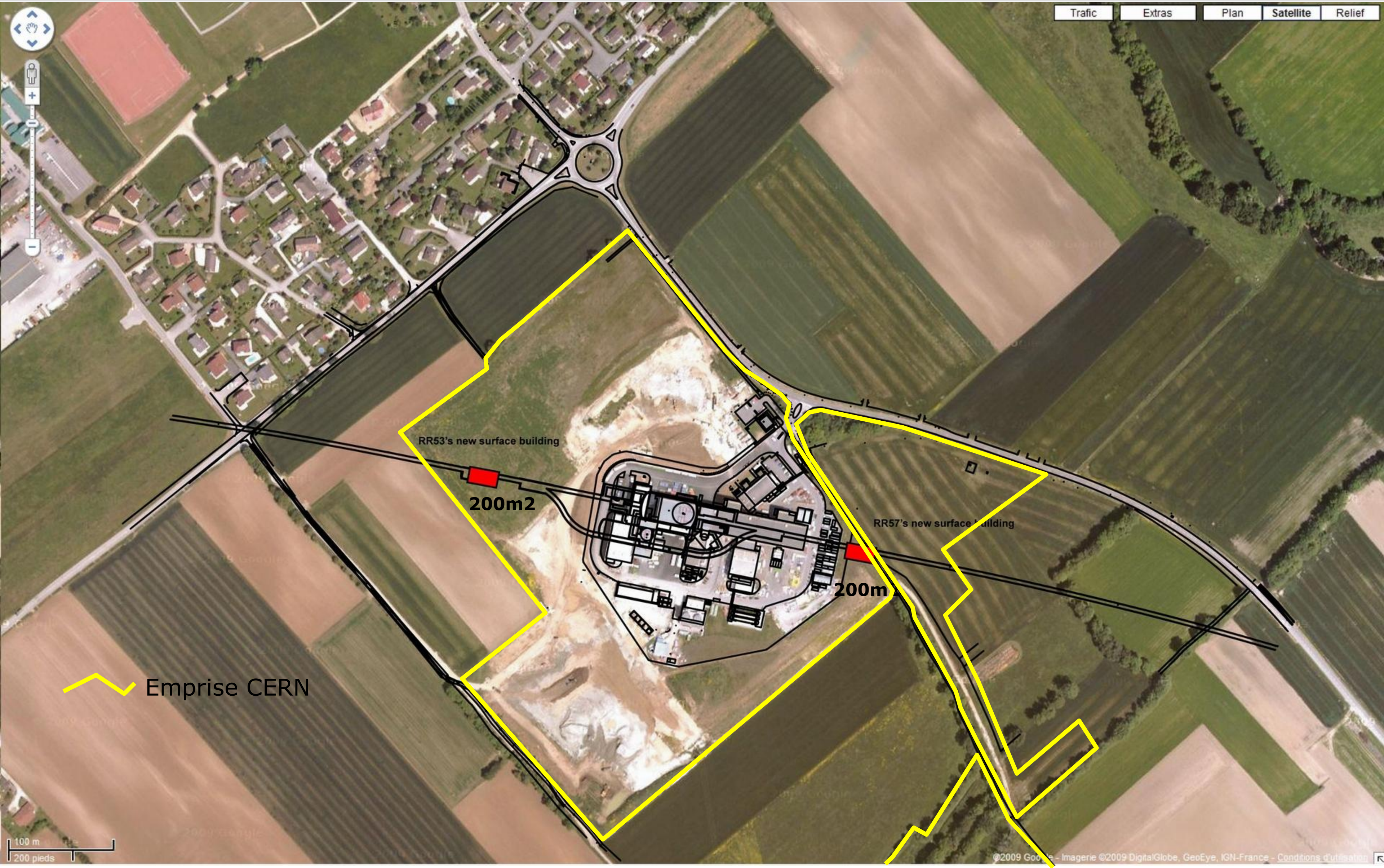
- Traditional shaft excavation techniques with 5m diameter shaft
- Majority of CE work executed during machine operation
- Noise / dust nuisance during CE works less of a problem
- Risk associated with shafts passing through moraines
- Risk to LHC due to vibration still to be assessed



POINT 1 AREA – GOOGLE PICTURE & TUNNELS



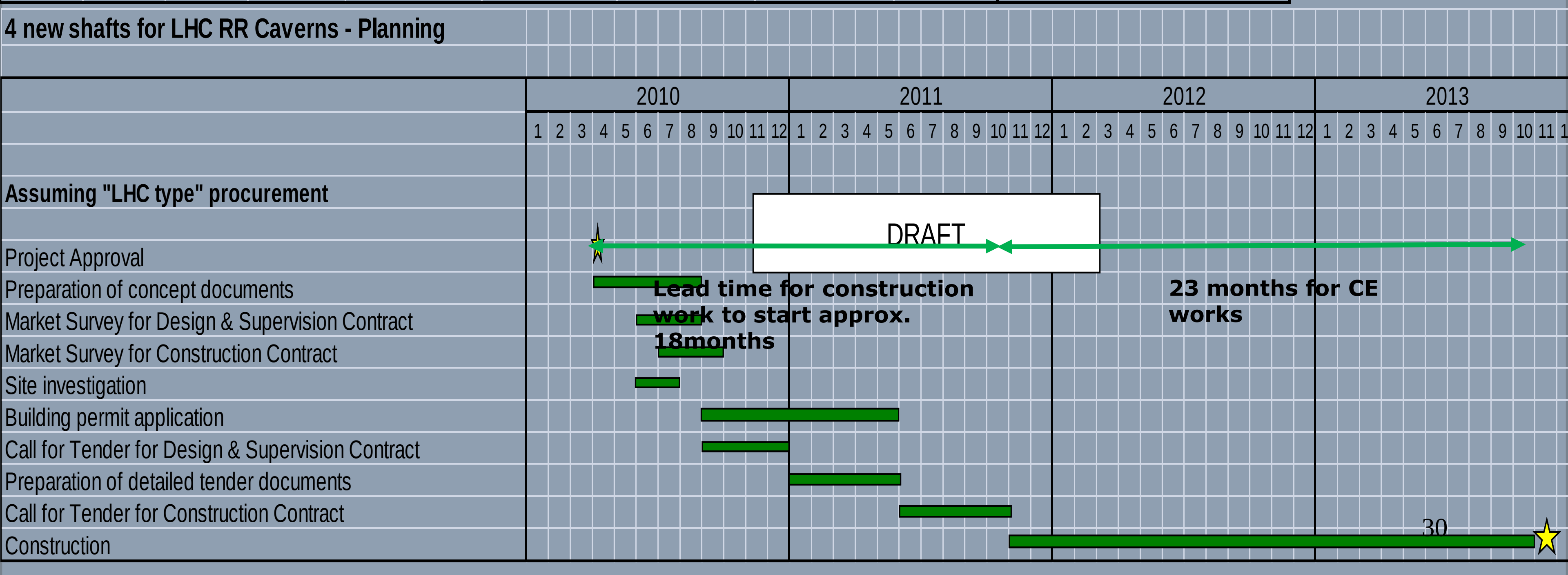
POINT 5 AREA – GOOGLE PICTURE & TUNNELS



New Shafts and Caverns at Pt1&5: Cost and Schedule

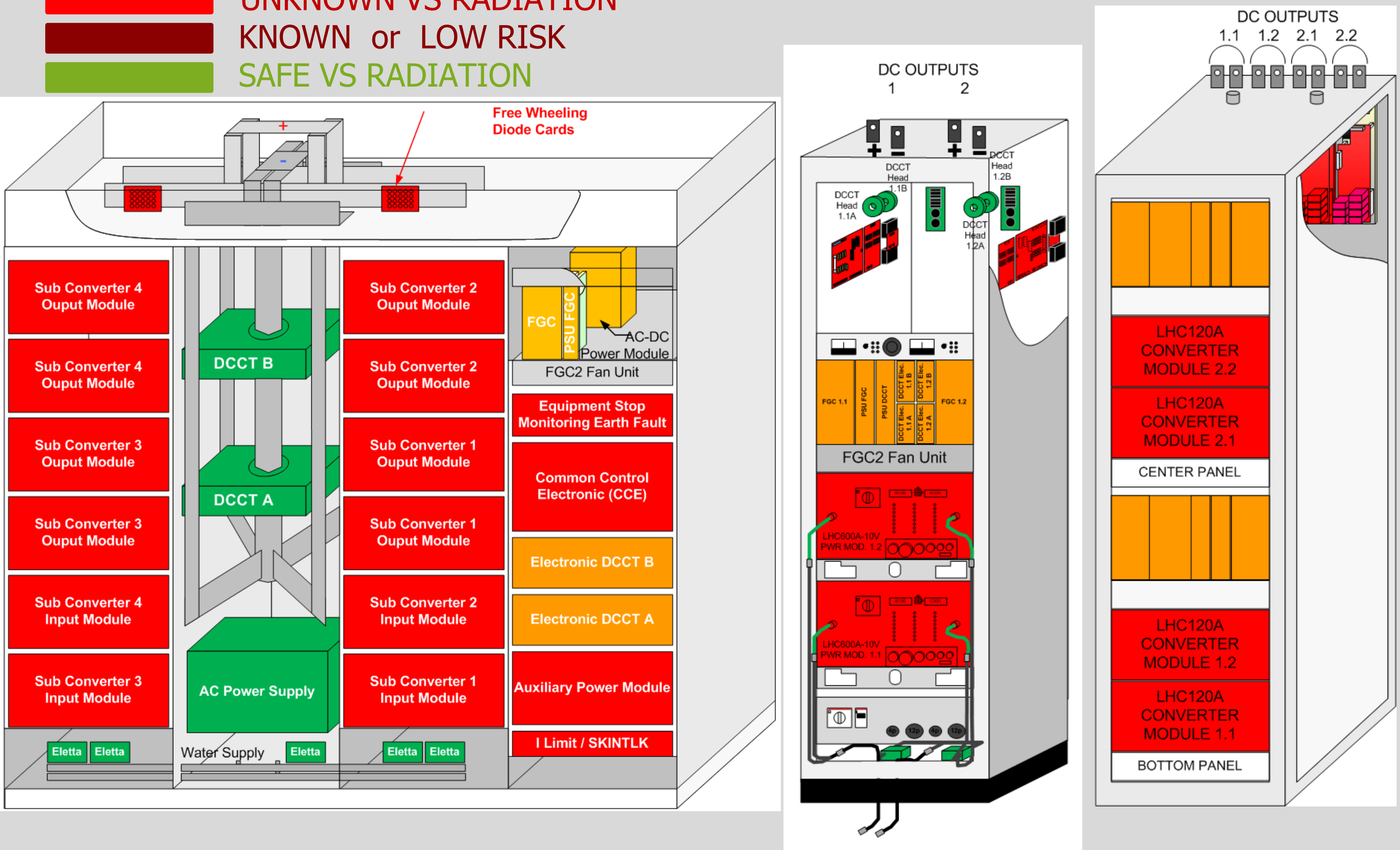
John Osborne GS-SEM

	RR13	RR17	RR53	RR57		
Site Investigation (borehol	50'000		50'000	50'000		150'000
Site Installation	1'000'000		1'500'000			2'500'000
5m diameter shaft	3'500'000	3'500'000	6'000'000	4'000'000		17'000'000
Base Cavern	2'000'000	2'000'000	2'000'000	2'000'000		8'000'000
Access gallery	750'000	750'000	750'000	750'000		3'000'000
10% Contingency for unknown/missing items						3'065'000
12% Consultancy fees						4'045'800
					Total	**CHF 37'760'800**



- Overview of unknown or critical Items

UNKNOWN VS RADIATION
KNOWN or LOW RISK
SAFE VS RADIATION



LHC4-6-8kA-08V **LHC600A-10V** **LHC120A-10V**

- LHC Project Typical Development times Standard vs Rad-Tol

Specif | Standard Design | Production + Reception Tests | Install

1-year | 2-years | 2-years | 6-m

6-m | 2.5-years +/- 6 months | 1.5-year | 4-m

Specif. | Replace. Rad-tolerant Design Component validation & tests | Production + Reception Tests | Install

Total duration = 5-years +/- 6 months + commissionning

2010-08 **2015-08** **2016-01**

- Reducing Project duration can only be done reducing the design duration
- Less design time = Higher risk of producing sensitive converter ➔ coherence???

3) Relocation with Supra-Conducting Links

Amalia Ballarino

Assumptions for the present study:

- At P1 and P5 the preferred solution is the re-location of the LHC power converters in surface building . Priority is given to the RRs.

  ↳ **Vertical link**

- At P7 there is the possibility of a re-location in TZ76.

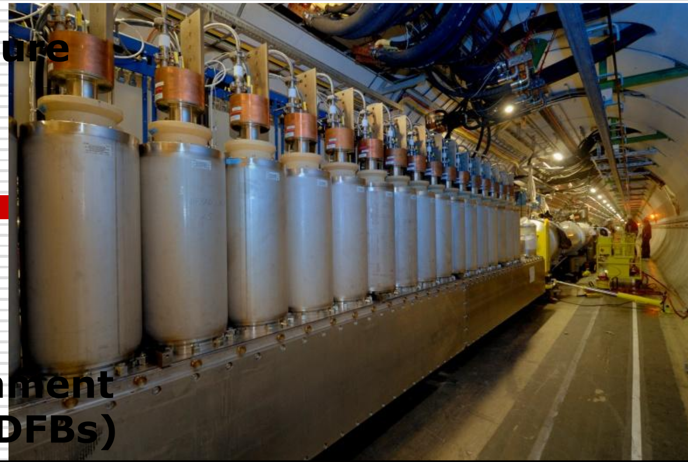
  ↳ **Horizontal link**

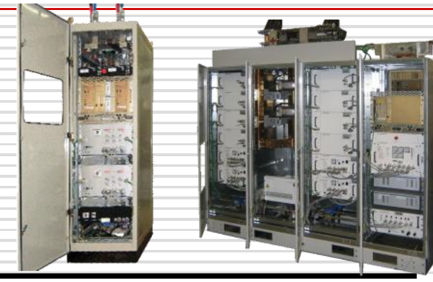
(Already done at Pt3 with Nb-Ti at 4.5K, L>400m)

Vertical SC Power Links

Room temperature

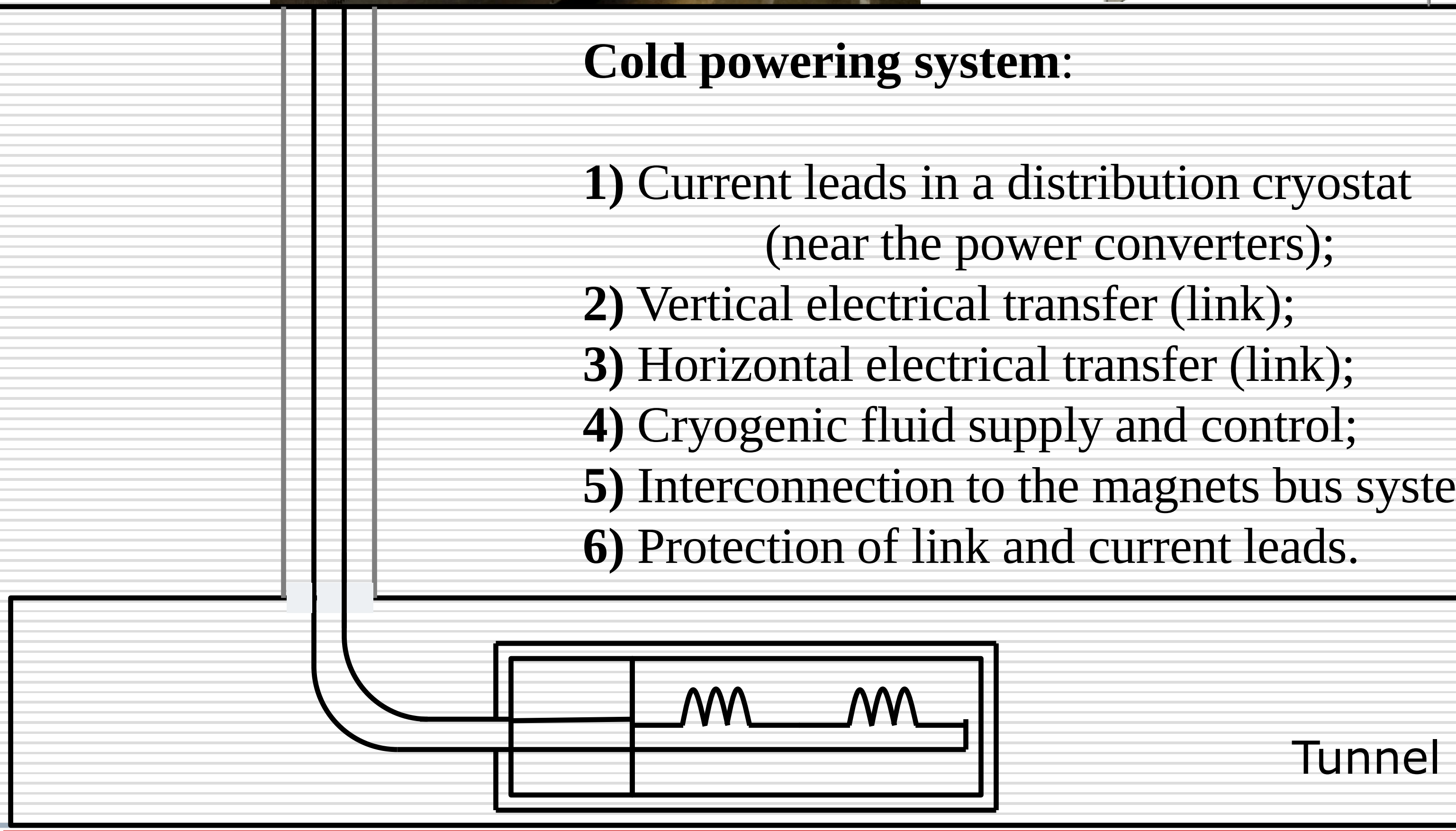
Cryogenic environment
(4.5 K LHe in the DFBs)



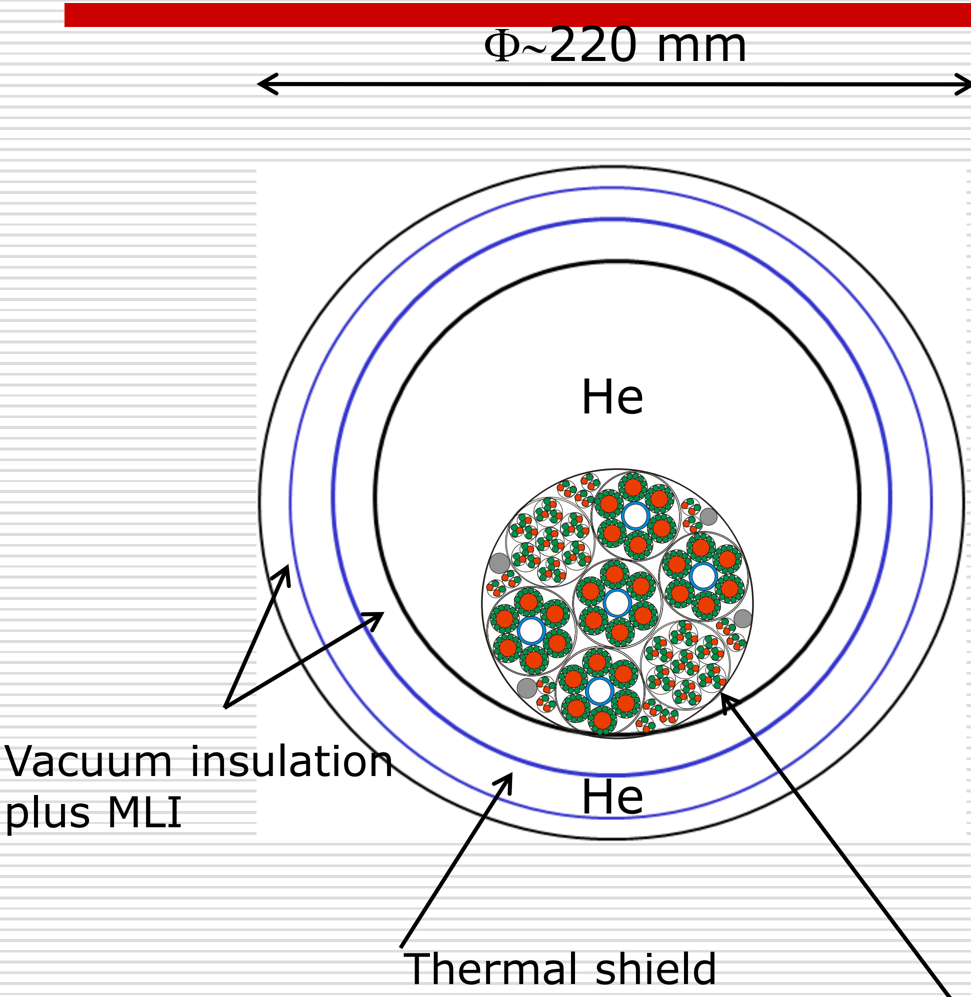


Cold powering system:

1) Current leads in a distribution cryostat (near the power converters);
2) Vertical electrical transfer (link);
3) Horizontal electrical transfer (link);
4) Cryogenic fluid supply and control;
5) Interconnection to the magnets bus system;
6) Protection of link and current leads.



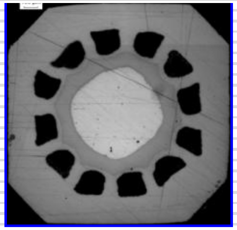
Configuration of superconducting link



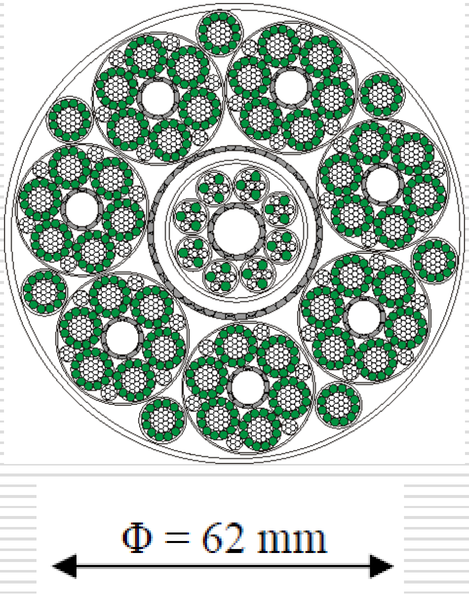
- **MgB_2 strand** (green)
- **Cu stabilizer** (red)

Superconducting **200 kA** MgB_2 multi-circuit assembly
100 electrically insulated cables 120 A, 600 A and 7000 A

Superconducting MgB_2 multi-circuit cables



1.1 mm
MgB_2 wire



Superconducting fully transposed and stabilized cables with a total current capability of ~120 kA were already assembled at CERN last year.
Sub-cables were tested at CERN at currents of up to 18 kA (@ 4.5 K and in self-field)

Conductors for the superconducting link

Nb-Ti → Tmax ≤ 7 K (Tc = 9 K)

MgB_2 → Tmax ≤ 20-25 K (Tc = 39 K)

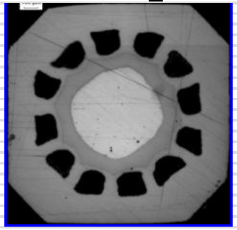
Bi-2223 or Y-123 → Tmax ≤ 77 K (Tc > 90 K)

} Temperature margin

Temperature margin:

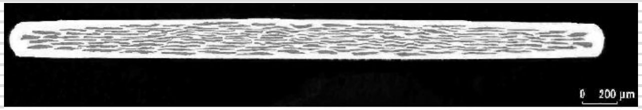
- Capability of adsorbing higher heat loads;
- Increased stability of the superconductor (lower sensitivity to thermal or mechanical disturbances).

MgB_2



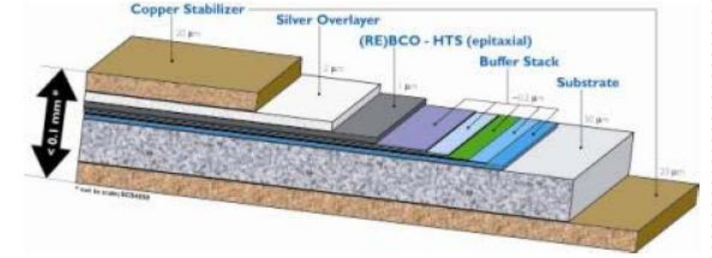
1.1 mm

BSCCO 2223

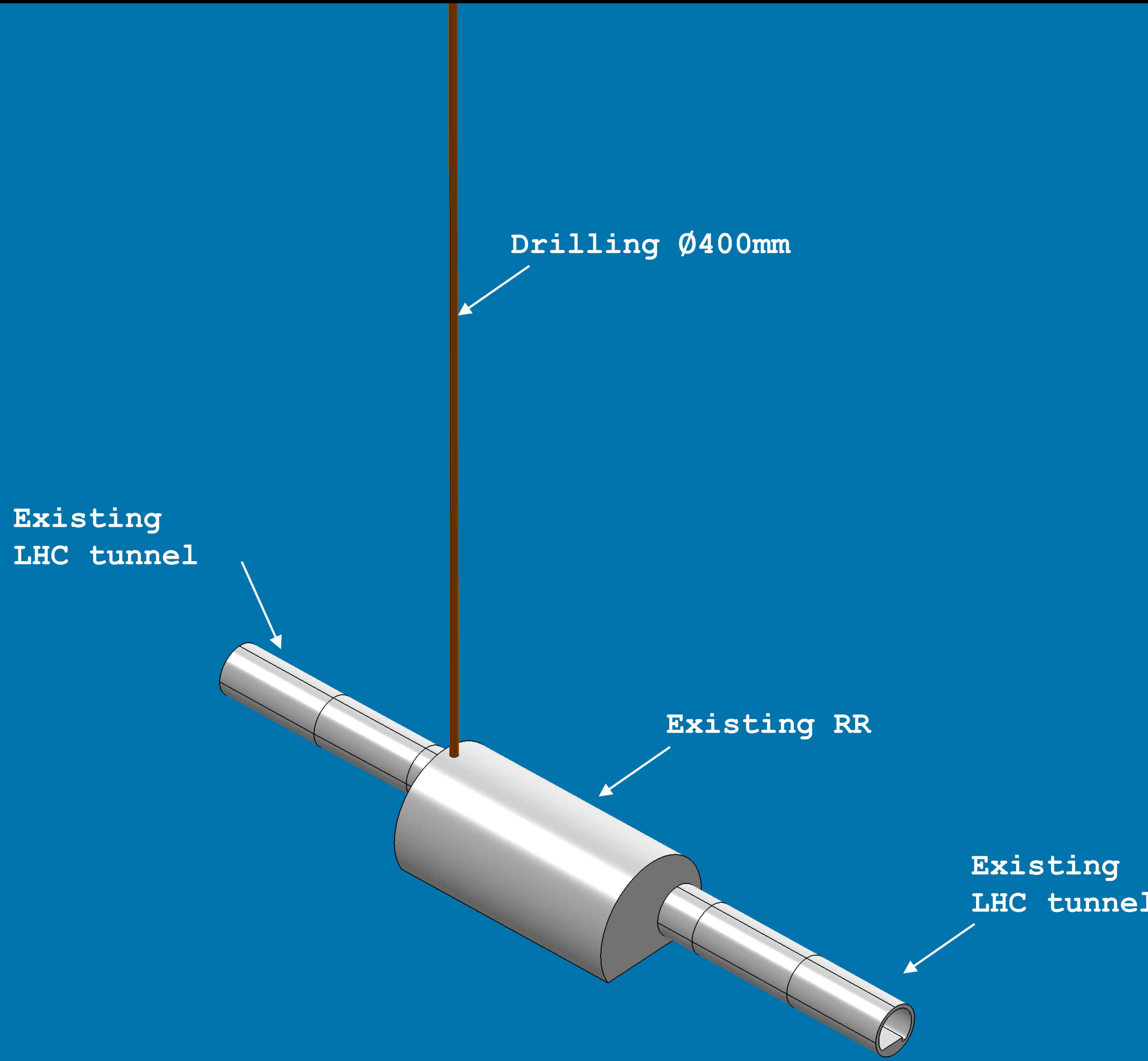


4 mm

YBCO 123



3) Drill vertical boring from new surface building to re-locate equipment



- Relatively quick CE technique
- Only possible for maximum 40cm internal diameter tube down to RR’s, is this sufficient ?
- Risk associated with core this deep eg boulders in moraines, tolerances
- Building permit required for surface buildings

Could envisage horizontal trenches to convey the SC power links into the existing surface buildings at Pt 1 & 5 (+200m of link each time)

Vertical borings and new surface buildings at Pt1&5: Cost and Schedule

John Osborne GS-SEM

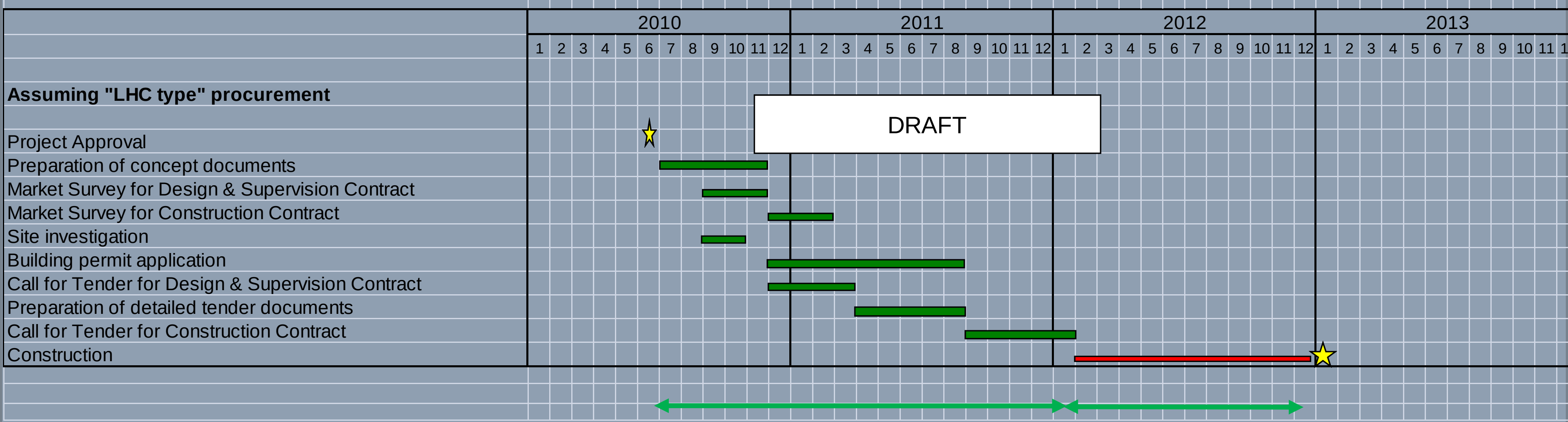
Cost estimate for CE for 40cm borings

	RR13	RR17	RR53	RR57	
Site Investigation (boreholes)	50'000		50'000	50'000	150'000
Site Installation	500'000		1'000'000		1'500'000
40cm core	450'000	450'000	700'000	650'000	2'250'000
Base Cavern modifications	50'000	50'000	50'000	50'000	200'000
Surface Buildings 200m2	1'000'000	1'000'000	1'000'000	1'000'000	4'000'000
10% Contingency for unknown/missing items					810'000
12% Consultancy fees					1'069'200
				Total	CHF 9'979'200

ESTIMATE ACCURACY +/- 20%

	POINT 1	POINT 5
Hauteur	80m	90m
Diametre	40cm	40cm
Morraines	0 à -20m	0 à -50
Molasse	-20m à -	-50m à -90m

4 new 40cm diameter drillings to LHC RR Caverns - Planning



Lead time for construction work to start approx. 18months

12 months for CE works

Summary

Helium release issues and Single Event Effects mitigation are totally different subjects, but the main and obvious lesson is the same: These problems need to be addressed at an early stage of the project, late fixing is difficult, very expensive, long to achieve and usually not fully satisfactory.