LHC Risk - RF System Update

- RF systems and LSS4 layout
- The RF systems on September 19th
- Risks and Spares
- Conclusions

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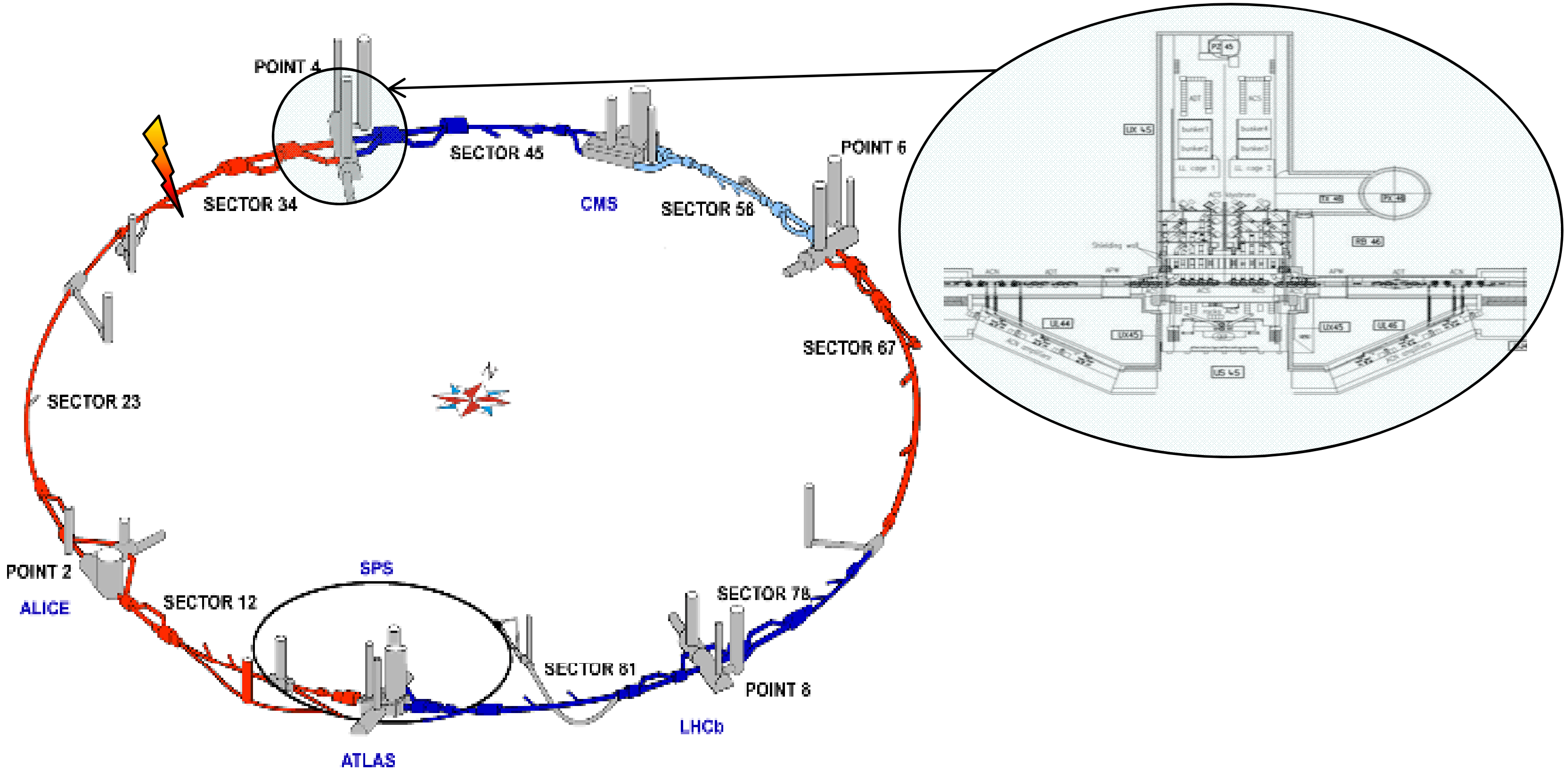
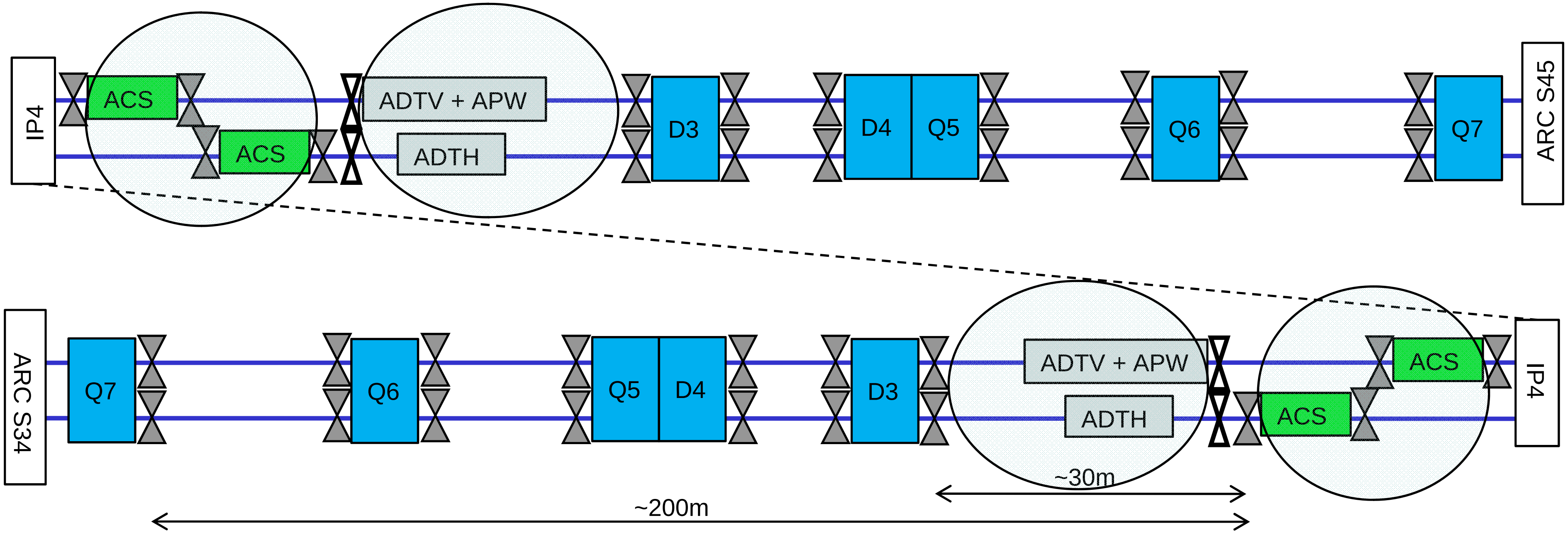
RF Systems



- RF Systems installed @ P4
  - 16 ADT Transverse Damper kickers- 4 modules left / 4 right of IP4
  - 16 SC cavities, in 4 Cryomodules (each 4 single cell cavities).
  - APW Wideband Monitors 3 left / 3 right of IP4

LSS4 - schematics



- ACS cavities: ~200m from the arc: 8 sector valves
  ~30m from D3: 2 sector valves
- Dampers & APW: next to D3
- Distance to incident of 19th September: ~2km

I9th September - RF System

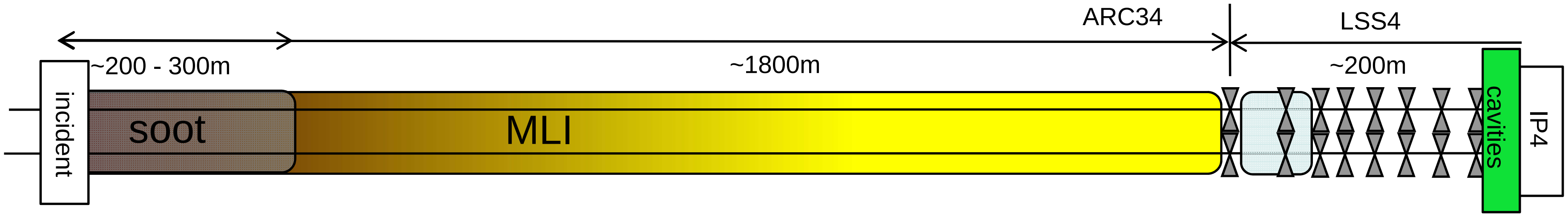
At the time of the incident:

- All sector valves were open (manually closed later)
- All cavities were running
  - Cavities on Sector 3-4 side cut due to He pressure (D-Line)
  - Cavities on 4-5 side continued to run, switched off manually ½ hour later
- Dampers continued to run on both sides, switched off manually later
- No vacuum pressure rises on cavity gauge recordings at time of the incident

Actions done, (Following Incident)

- ADT kickers have been taken to full power since the incident, without problem
- Clean up of thin layer of dust on all the RF equipment in IP4
- Removal and cleaning of ADT kicker amplifiers
- Cavities on Sector 3-4 side not switched on since the incident

19th September - has the RF System been contaminated?



- Arc34 "polluted" by soot and MLI

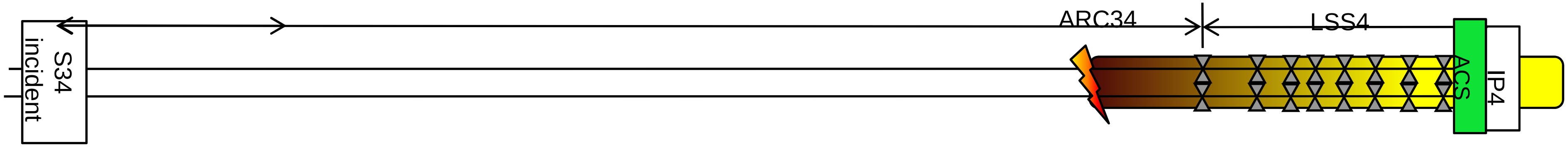
- Opening up of LSS vacuum sectors has shown: (V. Baglin, JM. Jimenez)
  - Only the first two vacuum sub-sector have been partially vented (He gas)
  - No MLI – No soot found in these subsectors

  - ADT kickers have been taken to full power since the incident, without problem ➔ no evidence of metallic dust or MLI in the region (would be a big danger for cavities)

➔"Contamination of the cavities ,APWs or ADT kickers does not seem likely"

- S34 cavities switch on: July - August

Risks to SC cavities



- In case of a similar event close to IP4:
  - Soot / MLI contamination of the cavities
    - extend of damage depend on the pressure wave propagation in the vacuum tube
  - Mechanical damage if the diameter of the aperture opening in the beam pipe near the cavities exceeds 50mm
    - Full opening (100mm) of beam pipe next to module to atmosphere will result in He vessel rupture and cavity collapse (12bars).
    - Half aperture (50mm) will be survivable with rupture discs (2.1bars).

The opening of one vacuum pipe would affect half the cavities (two modules)
The opening of both vacuum pipes would affect ALL the cavities (four modules)

- Actions:
  - Sector valve must always be closed during magnet commissioning
  - LSS sector valve closing logic modification under study by vacuum group
  - Use of fast sector valves under study with vacuum group. Fast, strong and reliable enough?

➔ No way to fully protect the cavities when the sector valves are open (during physics!) in case of a major incident close to IP4, in particular if it happens in one the stand alone magnets close to the cavities

Additional Risks to SC cavities

- On September 19th the ventilation door next to cavities was partially damaged by wind propagating in the tunnel
- Beam tubes could have been damaged or even broken in case the door would have fallen off

  ➔ must be modified

- In addition to vacuum pipe break:
  - Cavity / Coupler incident with RF
    - In LHC, could lead to contamination of two modules
  - Cryogenics malfunction :
    - Risk of severe mechanical damage to cavities & He tanks
    - Maximum precautions taken, adequate, & with redundancy.

Recovery of SC RF Cavities

- "In situ" reconditioning of the cavity
  - Unlikely to be successful if pollution by dust (LEP experience)
  - Forbidden if suspicion of metallic particles in the cavities (would lead to permanent damage)

- Repair steps to take in case of pollution of a four cavities module: **~30 weeks**

Action	**Time (w)**	
Take out	0.5	
Radiation cooldown	?	
Disassemble	2	
Rinse one individual cavity, drying and pumping	0.5	
Assemble & test in vertical cryostat	1.5	
Repeat last 3 steps for 3 other cavities	3	With some overlapping
Assemble into cryomodule (clan room)	6	Assuming HOM and power coupler spares available
Installation in bunker, leak tests,vacuum, cooldown, RF low power measurements	3	
High power tests & conditioning in SM18	8-10	Only one klystron in SM18
Warmup	2	
Transport + installation in Pt 4	2	

In case of mechanical damage – add procurement of cavities: 1 year at least

Spares Situation for SC cavities

- We have one spare module in SM18
  - power tests and conditioning still to be done (should start soon now that the 18kW cryo plant feeds the SM18 test place)
- We have only one spare bare cavity (with its He Tank)
- We need 3 or 4 more cavities, equipped with He tanks, to make a second spare modules available in reasonable time (~ 4 months)

Down time:

- in case one module is damaged: ~ 6-8 weeks ➔ replacement by spare module
  - Warm-up, removal, replacement, cool-down, conditioning
- in case two modules are damaged:
  - ~ 6-8 months minimum (to repair one module)
  - + at least 1 year if new cavities are required (because of mechanical damage)
- in case more than two modules are damaged:
  - as above (~ 6 wks to >18 months) to have one module per beam (12MV max instead of 16MV)
  - ~ 2 years to have 4 modules back in LHC

➔ Would be a big advantage to have spare cavities + better chance of success

Spares Situation for ADTs and APWs

- ADT transverse damper kickers – 2 spare modules (4 kickers)
  - Can be dismounted and rinsed in case of Soot / MLI contamination

- APW Wideband Monitors – 2 spares from parts in Lab
  - Can be dismounted and rinsed in case of Soot / MLI contamination

Conclusions

- Contamination of the cavities ,APWs or ADT kickers on September 19th does not seem likely
- A similar event close to IP4 would have seriously polluted or mechanically damaged the cavities
  - Taking precautions and extreme care need to be maintained. In particular sector valve must always be closed during magnet commissioning
- We only have one spare module and one spare cavity
  - In case more than one module is damaged, the downtime will be long
  - Need to maintain/reinforce SC cavity activity at CERN (cavity rinsing, mounting, testing,..)
  - Additional spare cavities would be very profitable:
    - Reduce downtime & better chance of success (long delivery time from industry, quality is an issue)

Spare Slides

Action	Time (w)	
Take out	0.5	
Radiation cooldown	?	
Disassemble	2	
Rinse one individual cavity, drying and pumping	0.5	
Assemble in vertical cryostat	0.5	
Test in vertical cryostat	1	
Repeat last 3 steps for 3 other cavities	3	With some overlapping
Assemble into cryomodule (clean room)	6	Assuming HOM and power coupler spares available
Pumping and leak test	1	
Installation in bunker, vacuum, cooldown, RF low power measurements	2	
High power tests & conditioning in SM18	3 - 4	Only one klystron in SM18
Warmup	2	
Transport + installation in Pt 4	2	

Risks & Mitigation

Risk Analysis for SC He tanks & modules (B. Delille, S. Claudet, L. Serio)

Class/ Case	Risk Situation	Heat load	Mass flow	Pressure reached (bar)	Derogation
1a)	Static losses D line blocked, no wrl	150 W	17 g/s	1.8 with SVs *(4x2mm dia. needed)*	Tank cold - 1.8 bar max
1b-1)	D line overpressure, non-return valve failure (open) 5 magnet quench		2 Kg/s	1.8 with SVs *(4x23mm. needed*	Exceptional - 1.8 bar max.
1b-2)	D line overpressure, non-return valve failure (open) 25 magnet quench		10 Kg/s	2.1 with RDs *(4x36mm needed)*	Exceptional - 2.1 bar max.
1b-3)	D Line overpressure warm, non-return 5% leakage 25 magnet quench 20 bar		10 kg/s	2.1 with RDs *(4x34 mm needed)*	Exceptional – 2.1 bar max
1c-1)	C line blocked open (cold)		350 g/s	1.8 with SVs *(4x10mm needed)*	Tank cold – 1.8 bar max
1c-2)	C line blocked open (warm) - 2 x 1.5 bar SVs per module		80 g/s	1.5 with special SVs *(2x24mm needed)*	1.5 bar max - Safe.
1d)	Insulation vacuum break	11.4 kW	1.27 Kg/s	1.8 with SVs *(4x18mm needed)*	Exceptional - 1.8 bar max Opening of cryostat discs (P<1.5 bar)
1e)	Sustained RF quench	150 kW	2.9 Kg/s	2.1 with RDs *(4x48mm needed)*	Exceptional & worst case - 2.1 bar max.
1f)	Beam vacuum break (50 mm aperture – 350g/s air indrawn)	147 kW	2.8 Kg/s	2.1 with RDs *(4x48mm needed)*	Exceptional - 2.1 bar max.
2a)	Beam vacuum break (100 mm aperture)	480 kW *(HL limited by tank surface area)*	9.2 Kg/s	12 bar *(Pressure due to 50 mm piping)*	Exceptional & exceeds press test, even with opening of RDs. Risk of rupture He tank & opening of cryostat discs (P<1.5 bar).

Table 1: Summary of failure situations and consequences.

Risks and Consequences

- SC Cavity Experience in LEP:
  - No cavity was ever totally destroyed.
  - Vacuum incident in Pt 8, one cavity polluted, had to be removed & rinsed
  - One cavity was destroyed in the test stand when a HOM coupler melted.
  - No power coupler breaks, no cryo incidents.

Other SC Cavity Issues

- Cavity 21 can be used as spare, build 3 more. Hold 4 cavities with helium tanks.
- Coating 4 cavities: 13 weeks including equipment setup, 6 if equipment already available.
- In the case of a vacuum accident which deforms cavities or physically damages He tanks:
- Cavity + He tank: 70kCHF, ~300kCHF for 3 spare cavities if made in industry. Time to manufacture ~2 years.
- Experience in LEP, no cavity from the machine was ever thrown away. One vacuum sector was vented in Pt 8, one cavity polluted, rinsed, total time 3 months. One cavity was destroyed in the test stand when a HOM coupler melted.
- Full opening of beam pipe next to module to atmosphere will result in He vessel rupture and cavity collapse. Half aperture will be survivable with rupture discs. A He incident could be higher pressure than 1 bar, but normally colder than room temperature.
- Accel may not be able to make cavities in 5 years time. All manufacture could be done at CERN except welding.
- Fast valves: Miguel looking at possibility of installing fast valves. However dust behind shutters can cause pollution if too close to cavities.
- Running cavities at half gradient would be possible, possibly limited in voltage at capture.