LHC Radiation Environment and Future Electronics Policy for the Accelerator Sector

1st R2E RADIATION SCHOOL & WORKSHOP

Divonne, June 2nd/3rd 2009

M. Brugger for the R2E Study Group
A Bit of Recent History

- the 2007 operational stop of CNGS due to electronics failures “triggered” a closer look to the risk of SEUs and what equipment finally was installed in the various LHC areas – in short: many surprises
- a dedicated working group on “Radiation to Electronics in the LHC” performed a first study looking at known critical areas, respective radiation levels, as well as what type of equipment is installed
  - results were reported to the LTC and ICC in the beginning of 2008
- given the criticality, to help better understand and quantify the possible risk, as well as to avoid uncoordinated actions: based on the first working group the “Radiation to Electronics (R2E) Study Group” was created in April/May 2008
- a first analysis of the situation lead to the actions integrated into the 2009 shutdown work (see list in backup slides if interested)
- a deeper analysis is ongoing with important work ahead of us -> this school is part of it
- many details and information is available at: www.cern.ch/R2E
The CNGS Incident (2007)

After two weeks of run at low intensity the beam has been stopped due to loss of the ventilation control.
CNGS Modifications due to Radiation Issues

-> with detailed FLUKA Studies

1. Move as much electronics as possible out of CNGS tunnel area
2. Create radiation safe area for electronics which needs to stay in CNGS
3. Add shielding: concrete walls up to 6m thick, in total ~53m³ concrete
   - Movable shielding plugs in TSG4 and TSG41 remotely controlled, connected to access system → will be opened before any access to CNGS is granted
   - Bypass of ventilation ducts
CNGS FLUKA Simulations

Prompt Dose in Gray for a nominal year (4.5 E19 pot)

2007 no shielding

\[ \sim 10 \text{ Gr/y} \]

\[ < 10 \mu\text{Gr/y} \]

2008++

High-E (>20 MeV) hadron fluence in cm\(^{-2}\) for a nominal year (4.5 E19 pot)

2007 no shielding

\[ \sim 10^{10} \text{ h/cm}^{-2}/\text{yr} \]

\[ < 10^{4} \text{ h/cm}^{-2}/\text{yr} \]

2008++
LHC

What Are the Issues?
What Are the “Issues”? – Typical Shielding

Point 2

Point 3

Point 6

AND MANY MORE ...

!!!
What Are the “Issues”? – Electronics

!!!

AND MANY MORE ...

!!!
The R2E Study Group forms a small committee consisting of experts in the various fields related to electronics damage and shall drive other working groups (RADWG). This way R2E assists LHC operations and equipment groups with expert knowledge and assessments of radiation-induced failures in electronics of the accelerator, as well as directly coordinates studies of remedial actions:

**Immediate**
- propose and evaluate short-term measures to reduce failure risks
- establish, extend and evaluate the inventory of information needed to assess radiation-induced electronics failures
- ensure accurate monitoring of radiation fields in critical areas to evaluate risks of electronics failures
- advice on planned CNGS irradiation tests, including calculations
- commission and evaluate machine studies to understand the possibility of reducing/displacing losses

**Long-Term**
- coordinate studies of radiation-induced failures, including calculations and proposals of solutions, and complement the inventory with measured data and experience gained during operation
- advice on further dedicated irradiation tests, including calculations
- assist LHC operations and concerned groups in the identification and short-term mitigation of failures
Radiation Physics/Effects/Monitoring

- **nuclear cascade**
  - \( h > 20 \text{ MeV} \)
- **EM cascade**
  - \( h, e, \ldots > 100 \text{ KeV} \)
- **Radiation Field**
- **Radiation Monitor**
  - **SEU counter**
  - **Radfet**
  - **PIN Diodes**
  - **Dose**
  - **Displacement**
  - **Effect in the Device**
  - **Single Events**

Radiation Field and Single Events in the Device due to Radiation Damage in Semiconductors.
High-Energy Hadron Fluences

$10^4 \quad 10^5 \quad 10^6 \quad 10^7 \quad 10^8 \quad 10^9 \quad 10^{10} \quad 10^{11} \quad 10^{12} \quad 10^{13}$

Aircraft Altitudes
- sea level (Lowest !!!)
- Airbus A330

LHC Machine electronics equipment
- UAs (low)
- RE38
- UX45
- UJ33
- CNGS 2007
- Some Failures

LHC Detectors
- UJ32
- UJ76
- UAs (peak)
- ARC dipole
- Under
- DS Q8
- TAN
- UX85
- US85
- RR53/57
- RR73/77

**e.g., some rough LHC-Levels for Hadrons**

$(E > 20 \text{ MeV})$ per cm$^2$ per nominal year

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Neutron flux (> 20 MeV) in the atmosphere

\[ \sim 3 \times 10^5 \text{ cm}^{-2} \text{ y}^{-1} \]

\[ \sim 1 \times 10^5 \text{ cm}^{-2} \text{ y}^{-1} \]
Overview/Content

This lecture aims giving a:

- A quick reminder about ‘The Problem’
- A Brief outline about R2E and related activities
- An overview of currently known ‘critical’ LHC regions [without going into details (see respective collected presentations)]
- The latter shall trigger many of you
- An overview how related information is currently centralized to allow easier access and better coordination and prioritization
- An introduction into a future Electronics Policy for LHC machine related radiation areas

All R2E activities, presentations, minutes, publications and related information are continuously updated and available at:

www.cern.ch/R2E
The Objective of A Complete Overview

- Summarize critical LHC areas where electronic failures could pose a problem
- Put this into perspective with respect to:
  - knowledge in terms of simulations & calculations
  - available monitoring
  - dependency on actual operation – scaling with:
    - direct losses at beam elements (e.g., collimation)
    - luminosity (e.g., UJs at IR1/5)
    - beam-gas density (e.g., REs)
  - options for solutions (e.g., shielding)
  - installed electronics (criticality)
    - failure consequences
    - radiation sensitivity
    - possibilities for (re)design
- Assign priorities according to a clear logic, however with iterations allowing to consider important (partly missing) information and discussions
- Putting this in relation with the operational schedule and planning

R2E

Iterations Ongoing

Your Presence
LHC Areas
and Radiation Levels
Quite a lot of ‘Dangerous’ Regions ...
Normalisation & Scaling

- **Direct losses** (collimation, TCDQ, …)
  - total losses depend on beam intensity, however as well as on machine performance and stability and required aperture settings of beam intercepting devices
  - already in early operation one could possibly "locally" reach levels close to ½ nominal
  - high uncertainty in distribution of losses which can locally raise radiation levels (e.g., TCLA <-> RR77)

- **Beam-Beam** (areas adjacent to experiments, …)
  - mainly luminosity dependent

- **Beam-Gas** (REs, UX45, …)
  - depend on residual beam-gas densities, the respective gas composition as well as the actual beam intensity

- **Combinations of the above**
Classification of Regions

Selected Levels – Defined Thresholds

- **Installed Electronics (always)**
  - no electronics
  - unknown electronics
  - off-the shelf or known to be weak electronics
  - special designed electronics

- **High-E Hadrons (20MeV)**
  - Fluence < 1x10^7 cm^-2
  - 1x10^7 cm^-2 < Fluence < 1x10^9 cm^-2
  - 1x10^9 cm^-2 < Fluence

- **Dose**
  - Dose < 1Gy/y
  - 1Gy/y < Dose < 1kGy
  - 1kGy/y < Dose

- **Displacement Damage 1MeV**
  - Fluence < 1x10^8 cm^-2
  - 1x10^8 cm^-2 < Fluence < 1x10^{10} cm^-2
  - 1x10^{10} cm^-2 < Fluence

- **Unknown Radiation Levels (grey)**
  - white: no electronics and unknown levels
  - light: safe electronics unknown levels
  - medium: unknown electronics and unknown radiation levels
  - dark: critical electronics & unknown levels

- **Unknown Electronics + Radiation (blue)**
  - light blue: unknown electronics, low radiation levels
  - medium blue: unknown electronics, medium levels
  - dark blue: unknown electronics, high levels

- **No Electronics (green)**
  - light green: no electronics, low levels
  - medium green: no electronics, medium levels
  - dark green: no electronics, high levels

- **Safe Electronics (orange)**
  - light orange: safe electronics, low levels
  - medium orange: safe electronics, medium levels
  - dark orange: safe electronics, high levels

- **Critical Electronics (red)**
  - light red: critical electronics, low levels
  - medium red: critical electronics, medium levels
  - dark red: critical electronics, high levels

*Area Codes:*

- Unknown
  - white: no electronics and unknown levels
  - light: safe electronics unknown levels
  - medium: unknown electronics and unknown radiation levels
  - dark: critical electronics & unknown levels

- Unknown Electronics + Radiation
  - light blue: unknown electronics, low radiation levels
  - medium blue: unknown electronics, medium levels
  - dark blue: unknown electronics, high levels

- No Electronics
  - light green: no electronics, low levels
  - medium green: no electronics, medium levels
  - dark green: no electronics, high levels

- Safe Electronics
  - light orange: safe electronics, low levels
  - medium orange: safe electronics, medium levels
  - dark orange: safe electronics, high levels

- Critical Electronics
  - light red: critical electronics, low levels
  - medium red: critical electronics, medium levels
  - dark red: critical electronics, high levels
Overview of Regions – Colour Coded

Radiation level

<table>
<thead>
<tr>
<th>Unknown</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
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<tbody>
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</table>

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POINT 1 - Summary

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High Energy Hadron Fluence

vertically averaged over the -60cm < y < 60cm interval (beam axis at y=0)

with detector:
5 \times 10^8 \text{ cm}^{-2}/100\text{fb}^{-1}

[ref.]

2009/10 (300\text{pb}^{-1}): behind shielding, the high energy hadron fluence at beam level ranges from $4 \times 10^6$ up to $4 \times 10^7 \text{ cm}^{-2} \text{ y}^{-1}$

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USA15 and US15

ATL-GEN-2005-001
S. Baranov et al.

5 μSv/h

8 μSv/h

high energy hadron fluence
max ~10^7 cm^2/100fb^{-1}

but DOORS!
**POINT 1 - Summary**

- **Critical Areas**: UJ14, UJ16, RR13, RR17, UPS14, UPS16

- **Critical Electronics**:  
  - not all details known yet, Point-Iteration scheduled  
  - assumption: all types similar to other UJs – QPS, PO, CTR, COM, CV, SFT, COLL, VAC, BI + …

- **Radiation Levels**  
  - **High-E Hadrons**: UJs: $1\times10^9$-$1\times10^{10}$ / RR: $3\times10^7$-$9\times10^7$ cm$^{-2}$ / UPSs: $\sim1\times10^8$ cm$^{-2}$  
  - **1MeV Equ.**: RR: $1.5\times10^8$-$4.5\times10^8$ cm$^{-2}$ / UPSs: $\sim5\times10^8$ cm$^{-2}$  
  - **Dose**: RR: 0.01 – 0.2 Gy/y  
  - **Normalization**: UJs: 100 fb$^{-1}$ / RR: 70 fb$^{-1}$  
  - **Scaling**: luminosity, (and a bit residual beam-gas)

- **Monitoring**: RADMON, IG5 (UJs), PMI, BLM

- **Shielding options**: UJs: possible but not sufficient, RR: improvement possible

- **Relocation possibility**: UJs: challenging, RR: very very difficult, limited place available in ULs
POINT 2 - Summary

![Diagram of ALICE with radiation level legend]

<table>
<thead>
<tr>
<th>Radiation level</th>
<th>Unknown</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
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</table>

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Point 2

LHC Radiation Environment and Future Electronics Policy for the Accelerator Sector
POINT 2 - Summary

- no Point-Iteration performed yet
- levels assumed to be low due to low luminosity and important detector shielding
- no specific electronics related analysis performed yet
- Available Information (A. Morsch FLUKA Studies)
  - ITS, TPC, TRD,....
  - UX25:
  - Platforms:
  - PX24:
- Comments:
  - shielding penetrations in UJ24/26
  - calculations are not specific for electronic damage (mainly dose only and general particle energy fluences)
  - particle energy spectra exist for many locations
POINT 3 - Summary

Point 3.3

Diagram showing radiation levels at various points with color coding.

Radiation level:
- Unknown
- Low
- Medium
- High

Color codes:
- Unknown: Gray
- No: Light Green
- Safe: Yellow
- Critical: Red

Electronics

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LHC Radiation Environment and Future Electronics Policy for the Accelerator Sector
Point 3

UJ32

UJ33
POINT 3 - Summary

- **Critical Areas:** UJ33, UJ32, RE38
- **Critical Electronics:**
  - not all details known yet, Point-Iteration scheduled
  - assumption: all types similar to other UJs – QPS, PO, CTR, CRY, COM, CV, SFT, VAC, BI + ...
- **Radiation Levels**
  - **High-E Hadrons:**
    - UJ33: $1 \times 10^4 - 2 \times 10^6$ cm$^{-2}$ / UJ32: $1 \times 10^7 - 1 \times 10^8$ cm$^{-2}$ / RE38: $2 \times 10^5 - 1 \times 10^7$ cm$^{-2}$
  - **1MeV Equ.:**
    - UJ33: $5 \times 10^4 - 7 \times 10^6$ cm$^{-2}$ / UJ32: $1 \times 10^8 - 1 \times 10^9$ cm$^{-2}$ / RE38: $1 \times 10^6 - 5 \times 10^7$ cm$^{-2}$
  - **Dose:**
    - UJ33: $< 1 \times 10^{-3}$ Gy/y / UJ32: $< 0.01$ Gy/y / RE38: $< 1 \times 10^{-3}$ Gy/y
  - **Normalization:**
    - UJ33: $1 \times 10^{16}$ p/y, UJ32/RE38: $1.65 \times 10^{11}$ m$^{-1}$ y$^{-1}$
  - **Scaling:**
    - UJs: Direct proton losses, RE: beam-gas
  - **Comments:**
    - possible pessimistic beam-gas assumptions for UJ32 maze layout of UJ32 to be checked
- **Monitoring:** RADMON, IG5 (UJ33), PMI (outside), BLM (outside)
- **Shielding options:** Not needed (UJs: difficult if needed)
- **Relocation possibility:** UJ32 -> TZ32 (if needed which is unlikely!)
- **Replacement/Redesign:** low priority
- **Comments:**
  - influence of realistic loss assumptions including uncertainties to be studied
  - check for Cryo installation at UP/UJ junction
POINT 4 - Summary

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PROBLEMATIC ONLY IF LOSSES OR BEAM-GAS DENSITIES ARE HIGHER THAN EXPECTED

R2E POINT-REVIEW TO BE PERFORMED
POINT 4 - Summary

- Critical Areas:
  - UX45

- Critical Electronics:
  - CRY, RF, CO, CV, + ...

- Radiation Levels
  - High-E Hadrons: $5 \times 10^6$ cm$^{-2}$/y
  - 1MeV Equ.: $1.5 \times 10^7$ cm$^{-2}$/y
  - Dose:
  - Normalization: $2.4 \times 10^{10}$ m$^{-1}$y$^{-1}$
  - Scaling: Beam-Gas

- Comments: normalisation is different for various elements, stated = dominating

- Monitoring: to be updated
- Shielding: to be updated
- Relocation possibility: to be updated
- Replacement/Redesign: to be updated
2009/10 (300pb$^{-1}$): after a 2m concrete shielding, the high energy hadron fluence at beam level ranges from $4 \times 10^6$ up to $4 \times 10^7$ cm$^{-2}$ y$^{-1}$
**POINT 5 - Summary**

- **Critical Areas:**
  - UJ56, RR53, RR57
  - UPS54, UPS56

- **Critical Electronics:**
  - not all details known yet, Point-Iteration scheduled
  - assumption: all types similar to other UJs – QPS, PO, CTR, COM, CV, SFT, COLL, VAC, BI + ...

- **Radiation Levels**
  - **High-E Hadrons:**
    - UJ56: $1 \times 10^9 - 1 \times 10^{10}$ / RRs: $3 \times 10^7 - 9 \times 10^7$ cm$^{-2}$ / UPS: $\sim 1 \times 10^8$ cm$^{-2}$
  - **1MeV Equ.:**
    - UJ56: $1 \times 10^{10} - 1 \times 10^{11}$ / RRs: $1.5 \times 10^8 - 4.5 \times 10^8$ cm$^{-2}$ / UPS: $\sim 5 \times 10^8$ cm$^{-2}$
  - **Dose:**
    - UJ56: 1–10 Gy/y / RRs: 0.01 – 0.2 Gy/y
  - **Normalization:**
    - UJs: 100 fb$^{-1}$, RRs: 70 fb$^{-1}$ / 2.5$x10^9$– 6.3$x10^{10}$ m$^{-1}$
  - **Scaling:**
    - luminosity, beam-gas ???

- **Monitoring:**
  - RADMON, IG5 (UJs), PMI, BLM

- **Shielding options:**
  - UJs: possible but not sufficient,
  - RRs: improvement possible

- **Relocation possibility:**
  - UJ: challenging, RRs: very very difficult,
POINT 6 - Summary

Point 6

Radiation level
Unknown Low Medium High
Unknown No Safe Critical
PROBLEMATIC ONLY IF LOSSES OR BEAM-GAS DENSITIES ARE HIGHER THAN EXPECTED

R2E POINT-REVIEW TO BE PERFORMED
POINT 6 - Summary

- Critical Areas:
  - UA64, UA67

- Critical Electronics:
  - not all details known
  - assumption: QPS, PO, CRY, CO, COM, CV, SFT, VAC, BI, + ???

- Radiation Levels
  - High-E Hadrons: UAs (unshielded): $1 \times 10^6$-$1 \times 10^9$ cm$^{-2}$
  - 1MeV Equ.: UAs (unshielded): $1 \times 10^7$-$1 \times 10^{10}$ cm$^{-2}$
  - Dose: Normalization: $3.4 \times 10^{13}$ p/y (on TCDQ)
  - Scaling: Direct beam losses

- Comments: Simplified simulation
  - Startup: less losses on TCDQ

- Monitoring: RADMONs, PMIs, BLMs

- Shielding options: holes filled during this shutdown (improvement possible)

- Relocation possibility: to be studied if necessary

- Replacement/Redesign: to be studied if necessary

- Comments:
  - expected TCDQ/TCSG/TCSM losses for 2008/9/+ (when compared to nominal)
  - cryo-equipment in UX65 if beam-gas or losses are higher than expected
  - electronics in dump cavern (adjacent UPs)
POINT 7 - Summary
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Simulation of beam 1 only (nominal ideal conditions), 7 TeV, mixed halo, normalization: 1.15E16 p/y

2009/10 (300pb⁻¹): low-intensity can still lead to significant losses during early operations; in addition, the reality of loss distributions can be significantly different from the assumptions, thus high energy hadron fluence at beam level can easily exceed already some 10⁷ cm⁻² y⁻¹.

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POINT 7 - Summary

- Critical Areas:
  - UJ76 (TZ76)
  - RR73, RR77

- Critical Electronics:
  - ECR exists
  - QPS, PO, CRY, CO, COM, CV, SFT, VAC, BI, + ...

- Radiation Levels
  - **High-E Hadrons:**
    - UJ: $1 \times 10^7$-$1 \times 10^9$
    - RR: $1 \times 10^7$-$1 \times 10^8$
    - TZ: $< 1 \times 10^8$ cm$^{-2}$
  - **1MeV Equ.:**
    - UJ: $5 \times 10^7$-$5 \times 10^9$
    - RR: $5 \times 10^7$-$8 \times 10^8$
  - **Dose:**
    - UJ: $0.001$ – $1.$
    - RR: $0.01$ – $2.$ Gy/y
  - **Normalization:**
    - $1.15 \times 10^{16}$ p/y
  - **Scaling:**
    - Direct beam losses

- Monitoring: RADMON, IG5 (UJs), PMI (outside), BLM (outside)
- Shielding options: UJ: limited and installed, RR: final shielding installed
- Relocation possibility: UJ: into TZ, RR: very difficult
- Replacement/Redesign: to be studied

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June 2nd 2009
High-Energy Fluence – @ Level 1

UL Levels unphysical due to full absorption at the edge

2009/10 (100pb⁻¹)
- Up to 5x10⁷ cm⁻² (relocated, repl.)
- Up to 2x10⁷ cm⁻²
- Up to 1x10⁷ cm⁻²
- Up to 5x10⁶ cm⁻²

Colour Code - Applied Normalization: 2x10³² cm⁻²s⁻¹, nominal LHC year (1x10⁷s) -> 1.6x10⁷ pp/s, including a safety factor of two and for 10 years of operation!

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POINT 8 - Summary

- Critical Areas:
  - UX85b, US85

- Critical Electronics:
  - CRYO, AL3, UPS, TIM, RR, EL, + ...

Radiation Levels

- High-E Hadrons:
  - UX: \(5 \times 10^8 - 1 \times 10^{10}\) cm\(^{-2}\)/y
  - US: \(5 \times 10^7 - 5 \times 10^8\) cm\(^{-2}\)/y

- 1MeV Equ.:
  - UX: \(1 \times 10^9 - 2 \times 10^{10}\) cm\(^{-2}\)/y
  - US: \(2 \times 10^8 - 2 \times 10^9\) cm\(^{-2}\)/y

- Dose:
  - Normalization: \(3.2 \times 10^{14}\) pp/y
  - Scaling: Luminosity

- Monitoring:
  - RadMons, PMIs, IG5, BLMs

- Shielding options:
  - very limited (safe room mainly)

- Relocation possibility:
  - UX85b already moved, US85 studied

- Replacement/Redesign:
  - to be studied
TI2 - Summary
TI2 - Summary

- Critical Areas:
  - UJ23, UA23

- Critical Electronics:
  - point-iteration to be performed
  - PC, ACC, CV, ...

- Radiation Levels
  - High-E Hadrons: UJ23: $>5 \times 10^9$ / UA23: $<7 \times 10^8$
  - 1MeV Equ.: 
  - Dose: 
  - Normalization: $1.44 \times 10^{16}$ p/y
  - Scaling: Direct beam losses

- Comments: assuming 2 shots per day on the TED

- Monitoring: RadMons, PMIs, BLMs

- Shielding options: Possible, improvements rather easy

- Relocation possibility: to be studied if necessary

- Replacement/Redesign: to be studied if necessary

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TI8 - Summary

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<tr>
<td>Unknown</td>
<td>Unknown</td>
<td>No</td>
<td>Safe</td>
<td>Critical</td>
</tr>
</tbody>
</table>

Electronics
**TI8 - Summary**

- **Critical Areas:**
  - UJ87, UA87

- **Critical Electronics:**
  - point-iteration to be performed
  - PC, ACC, CV, + …

- **Radiation Levels**
  - **High-E Hadrons:** UJ87: $>5 \times 10^9$ / UA87: $<7 \times 10^8$
  - **1MeV Equ.:**
  - **Dose:**
  - **Normalization:** $1.44 \times 10^{16}$ p/y
  - **Scaling:** Direct beam losses

- **Comments:** assuming 2 shots per day on the TED

- **Monitoring:** RadMons, PMIs, BLMs

- **Shielding options:** Possible, improvements rather easy

- **Relocation possibility:** to be studied if necessary

- **Replacement/Redesign:** to be studied if necessary
Radiation Levels - Summary - Prioritized

- Knowledge based on simulations only, thus detailed analysis and iteration required during early operation

- **Important uncertainties** due to assumptions going into loss terms (real integrated luminosity, distribution of losses, additional attenuations...)

- **Priorities** assigned according to
  - system sensitivity and criticality
  - uncertainty of loss assumptions (e.g., UJ76)
  - possible short-term measures (e.g., UA63/67)

- Continuous evaluation – Prioritization (colour coding)
  - Ongoing work during this shutdown
  - Highest priority for upcoming iterations/evaluations
  - Second priority, cross-check with measurements
  - Lowest priority, layout check and evaluation

- Other color codes:
  - areas which require additional calculations
  - to be done
### Radiation Levels - Summary - Prioritized

!!! Simulations Only !!!

<table>
<thead>
<tr>
<th>LHC Point</th>
<th>Area(s)</th>
<th>Radiation Levels</th>
<th>Priority</th>
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<tr>
<td>Point 1</td>
<td>UJ14 UJ16</td>
<td>1.9E 1-1.10</td>
<td>1.10E 1-1.11</td>
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<td>1E 8-5E9</td>
<td>2.10E 2-1.11</td>
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<td>~1E8</td>
<td>~5E8</td>
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<td>1E 6-1E7</td>
<td>0.001-0.02</td>
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<td></td>
<td>RR53, RR57</td>
<td>1E 8-5E9</td>
<td>2.10E 2-1.11</td>
</tr>
</tbody>
</table>
## Radiation Levels - Summary - Prioritized

<table>
<thead>
<tr>
<th>LHC Point</th>
<th>Area(s)</th>
<th>Radiation Levels</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point 6</strong></td>
<td>UA63, UA67</td>
<td>1E6-1E9, 1E7-1E10</td>
<td>3.4E13 p/y</td>
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<td></td>
<td>UD62, UD68</td>
<td>crane and ventilation equipment</td>
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<tr>
<td><strong>Point 7</strong></td>
<td>UJ76</td>
<td>1E7-1E9, 5E7-5E9, 1E-3-1E0</td>
<td>1.15E16 p/y</td>
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<tr>
<td></td>
<td>RR73, RR77</td>
<td>1E7-1E8, 5E7-5E8, 0.01-2</td>
<td>1.15E16 p/y</td>
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<tr>
<td></td>
<td>TZ76</td>
<td>&lt;1E8</td>
<td>1.15E16 p/y</td>
</tr>
<tr>
<td><strong>Point 8</strong></td>
<td>UX85b</td>
<td>5E8-1E10, 1E9-2E10</td>
<td>3.2E14 pp/y</td>
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<td></td>
<td>US85</td>
<td>5E7-5E8, 2E8-2E9</td>
<td>3.2E14 pp/y</td>
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<tr>
<td><strong>T12</strong></td>
<td>UJ23</td>
<td>&gt;5E9</td>
<td>1.44E16 p/y</td>
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<tr>
<td></td>
<td>UA23</td>
<td>&lt;7E8</td>
<td>1.44E16 p/y</td>
</tr>
<tr>
<td><strong>T18</strong></td>
<td>UJ87</td>
<td>&gt;5E9</td>
<td>1.44E16 p/y</td>
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<tr>
<td></td>
<td>UA87</td>
<td>&lt;7E8</td>
<td>1.44E16 p/y</td>
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<tr>
<td><strong>ALL</strong></td>
<td>ARC</td>
<td>1E9-1E12, 3E9-3E12, 1-1000</td>
<td>1.65E11m-1y-1</td>
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<td>REs</td>
<td>2E5-1E7, 1E6-5E7, 5E-5-1E-3</td>
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<td></td>
<td>DS</td>
<td>1E9-1E12, 3E9-3E12, 1-1000</td>
<td>1.65E11m-1y-1</td>
</tr>
</tbody>
</table>

June 2nd 2009

LHC Radiation Environment and Future Electronics Policy for the Accelerator Sector
Radiation Levels – Evolution

!!! Simulations Only !!!  !!! Loss Assumptions !!!

Needed Type of Electronics:

- SPECIAL DESIGN
- WELL TESTED
- TESTED COTS

High Energy Hadron Fluence ("20MeV") / [cm^-2 y^-1]

- UJ14, UJ16 (under investigation), UJ56
- RR13, RR17, RR53, RR57
- UJ33
- UJ76 (local loss dependency)
- RR73, RR77
- RE38
- UX45
- UA63, UA67 (losses 2008/2009?)
- UJ23, UJ87 (under investigation)
- UA23, UA87 (under investigation)
- UJ32 (beam-gas assumption?)
- UX85 (relocated)
- US85
- UPS14/16/56

June 2nd 2009

LHC Radiation Environment and Future Electronics Policy for the Accelerator Sector
Policy
Why Do We Need A Policy

- Significant radiation levels in many LHC areas where machine electronics is installed
- The knowledge of radiation levels is not always sufficient:
  - “We’re behind the shielding, thus there is no radiation.”
  - “The expected annual dose levels are marginal, there isn’t a problem”
- ...also when it comes to testing:
  - see citation of Philippe: “We made neutron irradiation up to 10krad”
- Numerous different systems and components, partly custom built, partly based on COTS
- ... To avoid future R2E related problems
Radiation Policy - General

- A solution for electronics already installed in critical LHC underground areas must be found and respective solutions will involve (this is to be done in parallel!):
  - shielding
  - relocation
  - and re-design

- For the required re-design and all new electronics to be installed in areas prone to radiation a new policy needs to be defined and put in place

- Lots of ‘The’ s:
  - The policy will have to be developed in detail during the coming year
  - The following slides only sketch a possible structure
  - The experience (good and bad) as obtained by the LHC experiments will be of valuable help
  - The input from equipment owners and responsible will be fundamental

- What we learn during this course is the first step…
1. **Policy** for Electronics installed in areas with elevated radiation levels (R2E)

2. **Evaluation** of Radiation Levels: simulations, monitoring, proposal of measures and general coordination (R2E)

3. Structure to **implement** the Policy (RadWG)

4. Organization and Analysis of **Radiation Tests** (RadWG)

5. **Control** (LHC Point-Owners)
The Aim of the Policy

- All safety related systems must remain functional at all time
- The operational reliability of the accelerator must not be significantly limited due to electronics failures due to radiation
  - failure rates of transient or (limited!) destructive SEE must be acceptable (the latter ‘quantity’ is to be defined)
  - the estimated lifetime of machine critical components must cover the foreseen lifetime of the accelerator, or at least a large fraction of it
- Radiation tests shall be carried out in a unified and comprehensive way, ideally based on recognized test methods (e.g., guidelines developed by the LHC experiments, ESA, …)
- All groups being responsible for machine equipment installed in possible radiation areas follow a common approach
Three Important Goals

- Defining (and updating after first measurements) the radiation levels in all LHC areas possibly housing electronics (present & future)

- Providing support for equipment owners to develop electronics complying with the levels of radiation tolerance necessary at the respective locations:
  - minimum doses and fluences as defined above
  - maximum acceptable rate of soft, hard or destructive Single Event Effects (SEE) as a function of equipment class (operational constraints)

- Providing electronics test and selection guidelines for both custom design and selected COTS and separately for:
  - components
  - systems
Main Ingredients – Part 1

- **What areas** show no or lowest radiation
  - !!! keeping ‘safety margins’ !!!

- What **components/systems to choose from**?
  - can this be provided?
  - at least recommendations?

- Definition of **‘Radiation Tolerance Criteria’ for the accelerator environment**
  - LHC tunnel
  - shielded areas

- **Strict application of SEE constraints**
  - error rates must be a ‘design constraint’ for systems being installed in areas prone to radiation
  - destructive SEE failures must be avoided

- Application of **unified radiation test methods**

- Continuous **organisation & analysis of test results**
Main Ingredients – Part 2

- Knowledge of equipment inter-dependencies and failure consequences
  - what happens if my device fails?
  - from what equipment do I depend on and vice-versa?

- Defined review and acceptance process
  - All devices to be installed in LHC radiation areas need to fulfil a minimum set of requirements

- Certain executive power and strong support from the management

- Support
  - Expertise from the experiments
  - Organised radiation test campaigns, lists of radiation facilities
  - Standardized test reports

- A Police!

TIME TO DEFINE, BUILD AND APPLY THE ABOVE
1st Step - How To ‘Build’ The Policy

- Carefully ‘build’ on available experience as available from the experiments
- Adopt (and add) respective points to the needs of the accelerator and in the context of respective radiation levels
- ‘Radiation Maps’ of areas as based on simulations and later updated with measurements
- Define a small team of experts, ideally from both:
  - LHC experiments
  - LHC machine

Start small (but fast) and evolve over time…
Finally
Some More Comments & Challenges

- The solution of the **existing problems** will take an important amount of:
  - effort
  - time
  - money
  - patience

- We’re **running against time** and ‘machine performance’ and radiation induced **failures will be part of the game**

- There is no **easy** and **perfect** solution, we try to get the **best possible**

- The **LHC will evolve in intensity and luminosity** and it will not get easier

- New technologies will require to worry about **additional ‘constraints’** (e.g., enhanced failure rates due to low-energy neutrons)

- Not speaking about upgrades and ‘other ideas’
References and Documentation

- Presentations, Minutes on the R2E Website: www.cern.ch/R2E
- Useful Links at: www.cern.ch/R2E/Links.htm
- Overview of Areas: www.cern.ch/R2E/AreaOverview.htm

R2E Related Publications and External Presentations:
www.cern.ch/R2E/Publications_Presentations.htm

- Reports of LHC Point-Iterations (in preparation)
- R2E Report on required mid/long-term measures (in preparation)
- S. Weisz et al., Mobile Shielding for RR73/77 (see ECR)
- **R2E Report** published through the proceedings of the 2009 LHC Performance Workshop held in Chamonix (see paper)
- R2E Study Group, Protection of equipment located in UJ76 (see ECR)
- Memorandum for temporary move of betatron cleaning to IR3
Key Messages

- Many LHC underground areas are prone to radiation
- Some of them are ‘critical’
- Many of them house not specifically installed electronics, most of it critical for LHC operation (some of them you’re responsible for)
- Radiation levels are known and continued simulations and measurements will improve this knowledge
- Radiation levels evolve over time (of operation) and depend on several factors (beam intensity, luminosity, direct losses, residual gas density)
- A dedicated study group (R2E) exists and a new structure was put in place
- Detailed documentation exists and is continuously updated
- Dedicated Point-Reviews are performed to evaluate possible solutions
- A new ‘Policy’ will be developed and you can contribute to it
CERN Equipment Specialist…

… after LHC Operation…

Thanks to All People Having Contributed To This Talk…

"Hi, honey... I'm Ohm!"
BACKUP
R2E Achievements (2009) Part 1

- **Priority List of Areas**
  - based on available Monte-Carlo simulations
  - linked to operational assumption for the various ‘years’

- **Update and detailed analysis of Simulations**
  - Collection of existing simulations
  - Launch of new simulation effort
  - clear identification of critical areas and respective radiation levels (over time!)

- **Relocation/Replacement of equipment from UX85**
  - currently completed

- **Preparation of TZ76 and displacement of equipment in UJ76:**
  - Relocation in TZ76 fully integrated
  - preparation of infrastructure done.
  - Cabling and displacement analysed (but not done!!)
  - action limited by LHC schedule
  - UPS relocation and pre-cabling for PC relocation)

- **Additional shielding**
  - UJ76, RRs, new maze, P6 ducts (kicker electronics)

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R2E Achievements (2009) Part 2

- Detailed Point-Iterations
  - visit of areas looking into integration options, available monitoring (Etat de Lieu)

- Priority List of Equipment (Classes)
  - direct interaction with equipment groups (starting with machine protection)
  - identified safety related
  - proposal to prepare ‘short-term’ actions

- Organization of radiation tests in CNGS and outside CERN (FIP, QPS, Cryo, Power Converters …)
  - Tests conducted at PSI, Louvin, Prospero, waiting for beam in CNGS

- Radiation monitoring
  - calibration experiment at CERF shows problematic RadMon calibration, more beam-time required
  - additional measurement proposal at PTB (including funding through EFNUDAT)
  - study of required installation/displacement of RADMONS, additional TLD monitoring
  - development of monitoring tool for offline analysis, first beta-version available

- Radiation school
  - Organised with PH-ESE, 2-3 June: ~65 participants, 16 lecturers

- Documentation
  - R2E Website (Presentations, Minutes), R2E Library, Picture Gallery of Critical Areas, Inventory of Monitor, Publications (ECRs, Chamonix, Point-Reviews, …)
UJ76/RR73/77 SEE Related Issues

- **Early awareness** of high radiation levels
- **Detailed analysis** based on tracking studies (SIXTRACK) and cascade simulations (FLUKA) to estimate the distribution and maximum radiation doses and fluences
- Analysis of **related uncertainties** (assumptions, models, statistics, limitations)
- **Inventory** and location of installed electronics
- Study of **consequences in case of failure**
- Study of **different solutions** (shielding, relocation, combinations)
- **Proposed solution** outlined and discussed in respective ECR (LHC-EC-UJ76)
- **Staged implementation approach** to allow for additional measurements during operation
SEEs related 2008/9 Shutdown’s Activities

- **IR7**
  - RR73/77 installation of final shielding
  - TZ76 preparation
  - UJ76
    - UPS removal (from UJ76 into TZ76)
    - additional shielding wall to increase protection of safe room

- **IR6**
  - Shielding of ducts between tunnel and UA63/67

- **IR8**
  - UX85b installation of remote controllers

Additional identified holes in shielding were already mostly closed before first start-up (e.g., geometer holes)

Critical Areas: check for additional monitoring, iterations

June 2nd 2009 LHC Radiation Environment and Future Electronics Policy for the Accelerator Sector