Review of exposed equipment in the LHC: a global view

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Abstract : An review of the radiation test methodologies for the baseline LHC tunnel electronics is presented. Specific attention is given to the radiation tolerance assurance and to risk management. Finally an overview of the non-radtol equipment in the other LHC underground areas and alcoves is given.

Setting (1998-1999)

- Experiments : PH/MIC as the ‘driving force’ for awareness at CERN
  - Radhardness recognized as a major issue for LHC detectors
  - Early decision to design radhard electronics for LHC (radhard by design)

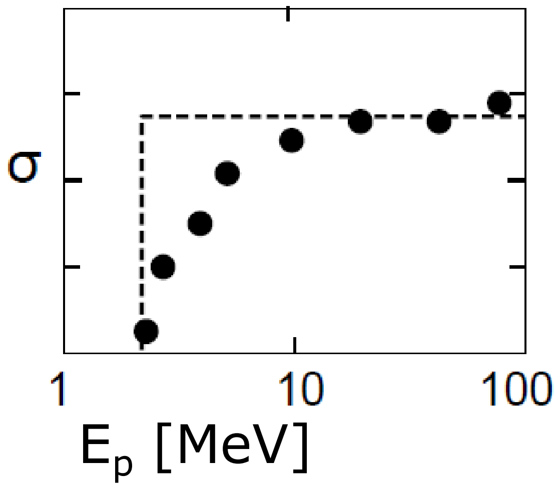
- Machine : Radiation Damage treated with some skepticism
  Reasoning in terms of radiation dose
  Expected radiation dose in tunnel was very low
  Startup LHC foreseen for 2003
  - Electronics in tunnel under magnets and in RRs/UJ etc.
  - Some resources were made available and 2 working groups were set up (R. Rausch - chair, C. Pignard)
    - TEWG (tunnel electronics working group) for controls integration issues
    - RADWG (radiation working group) for radiation issues

Radiation damage effects

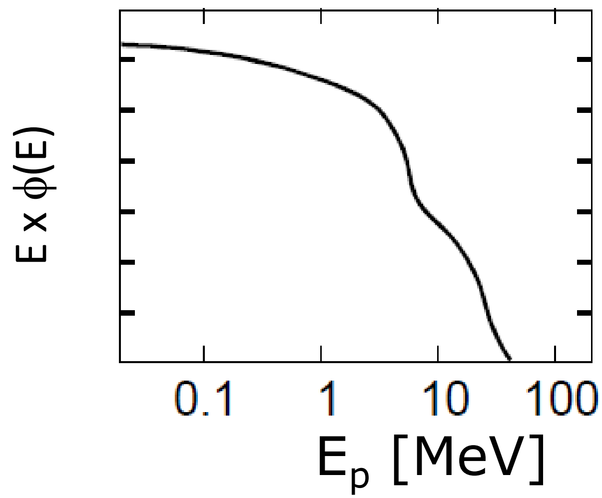
- Single Events
  - Soft Errors (recoverable)
    - Single Event Upset (SEU)
    - Multiple Bit Upset (MBU)
    - Single Event Transient (SET)
    - Single Event functional Interrupt (SEFI)
  - Hard Errors (non recoverable)
    - Single Event Latch-up (SEL)
    - Single Event Gate Rupture (SEGR)
   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

Soft errors

SEU cross section



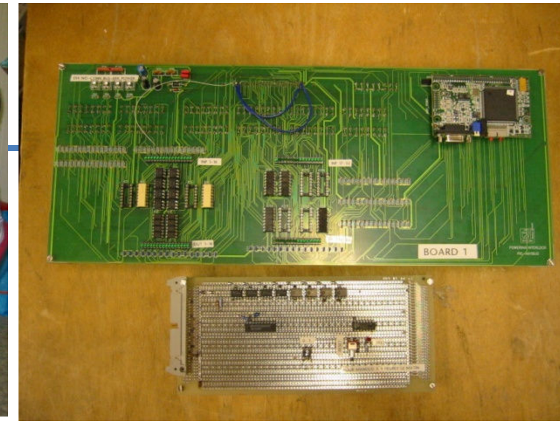
Simulated Particle spectrum

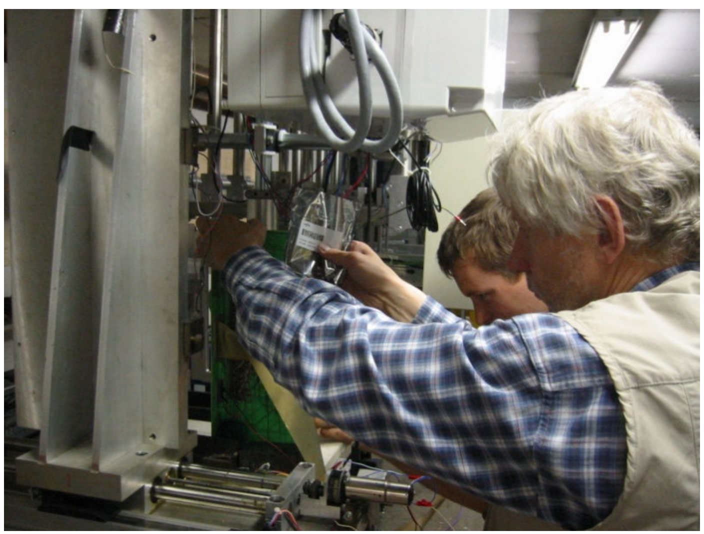
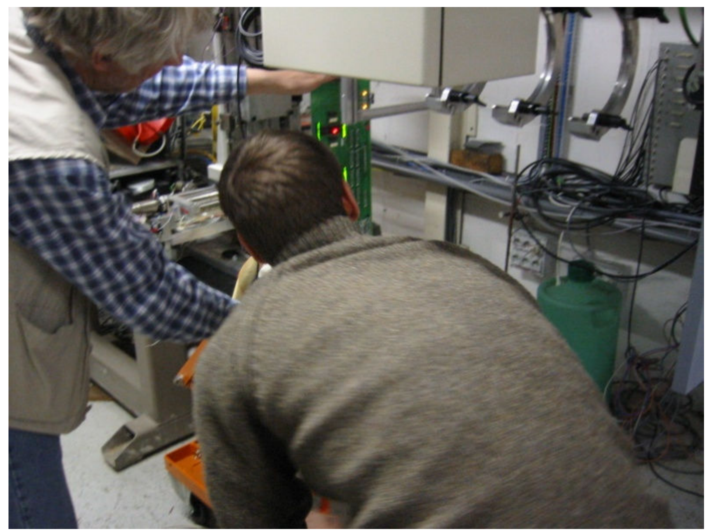
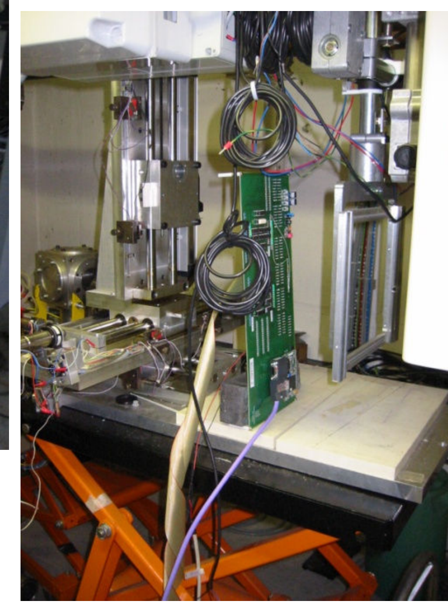


<u>Irradiation with p (60 MeV) :</u>

- Based on the 'Simple Sensitive Volume Model' [*M. Huhtinen, F. Faccio, NIM* A 450 (2000) 155-172]
- Low cost, least effort solution
- Energy deposited E_{dep} is lower than in LHC
- Provides only ***limited*** information on the Soft Error Rate
- In nearly all cases it is the only data that we have





Power Interlocks UCL 2004

Example

SEUs in a memory w/o error correction

External SRAM (SAMSUNG K6T0808C1D-TB70)					
Fluence [10^{10} p cm^{-2}]	**Bits written**	**Errors**	**Single**	**Double**	**SEU cross section [10^{-13}cm^{2}]**
1.0	262144	242	240	2	0.9
2.0	262144	487	477	10	1.0
5.0	262144	1230	1148	76	0.9

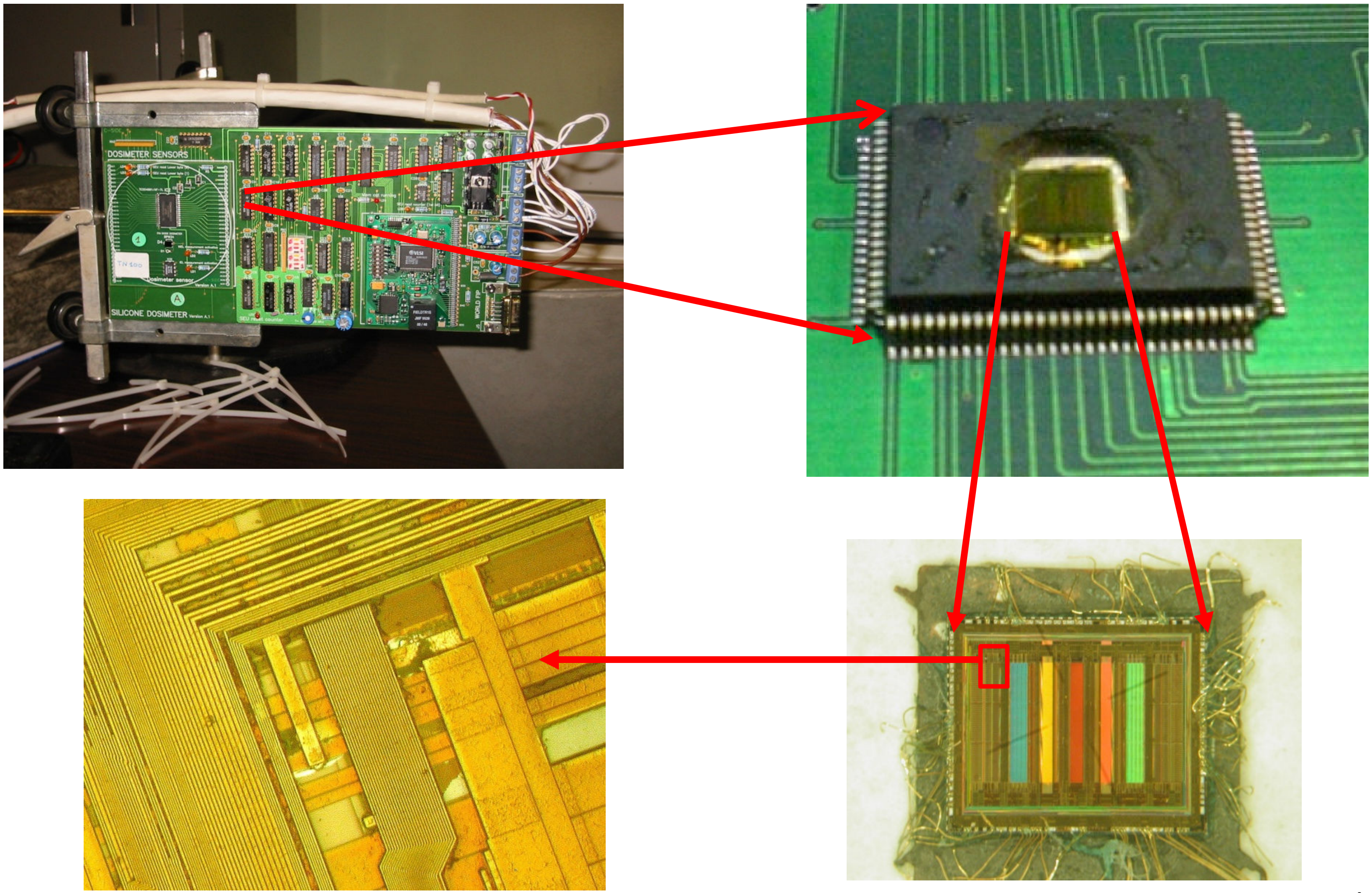
SEUs in a memory with error correction

Fluence [10^{10} p cm^{-2}]	Integer errors	Corrected errors	Efficiency
1.0	235	234	99.57%
2.0	413	413	100%

Hard Errors

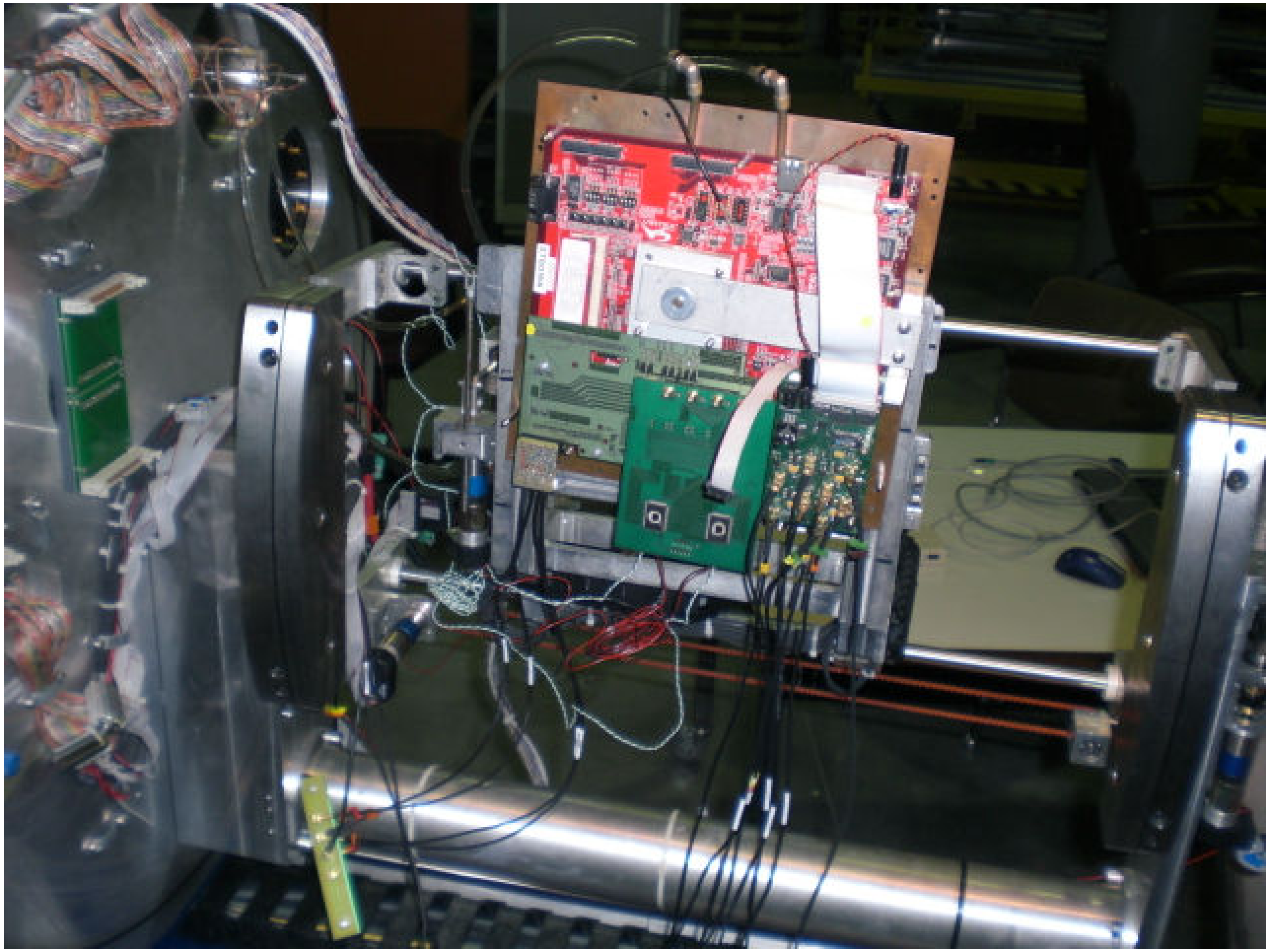
- High energy p irradiation (250-500 MeV)
  - Reasonable tradeoff between effort/reduction statistical uncertainty
  - Considerable increase of E_{dep}
- Heavy Ion Radiation
  - Provides a complete characterization of the device
  - Complete range for E_{dep} (test) >> E_{dep} (max in LHC)
- Mixed Field test
  - Provides reliable data on the device if (and only if)
    - Radiation field identical
    - Operating conditions identical
    - Sufficient amount of components/boards/systems are irradiated

Example : SEL

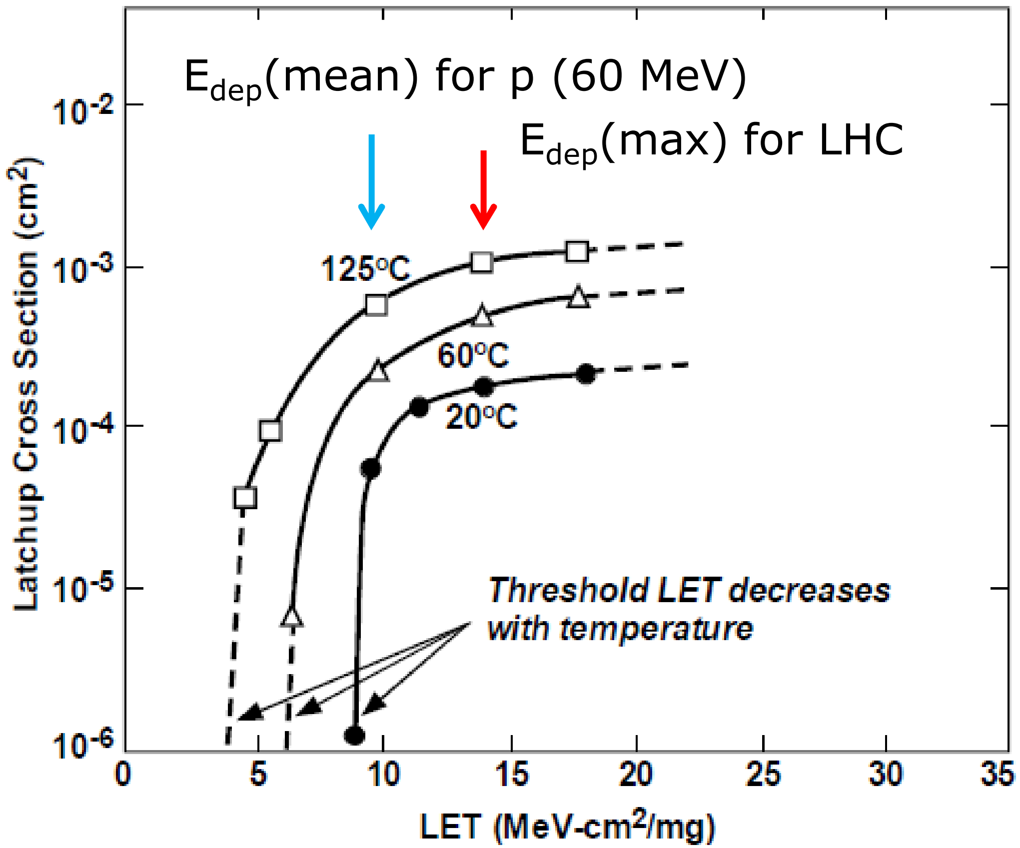


[Photos from R. de Olivera EN/ICE]

Heavy Ion Radiation



SEL cross section



[from Leif Z. Scheick, JPL short course]

Statistics

Error rate *approximately* given by :

(h > 20 MeV) x Nbr of devices x cross section

Case 1 : no specific effort done

Error rate = 1e8 cm^2 x 4000 x 1e-7 cm^{-2} = 40.000 errors/yr

Case 2 : shielding

Error rate = 1e7 cm^2 x 4000 x 1e-7 cm^{-2} = 4000 errors/yr

Case 2 : shielding + error correction/reduction

Error rate = 1e7 cm^2 x 4000 x 1e-10 cm^{-2} = 4 errors/yr

Irradiation Conditions

3	Number of Samples
68	Modes of Operation
4	Test Patterns
3	Frequencies of Operation
3	Power Supply Voltages
3	Proton Energies
3	Hours per Proton per Operation Point

66096	Hours
2754	Days
7.54	Years

Test planning requires a lot of thought

Understanding of collected data requires a lot of effort (be wary of databases).

Only so much can be done in a 12 hour beam run – <u>application-oriented</u>

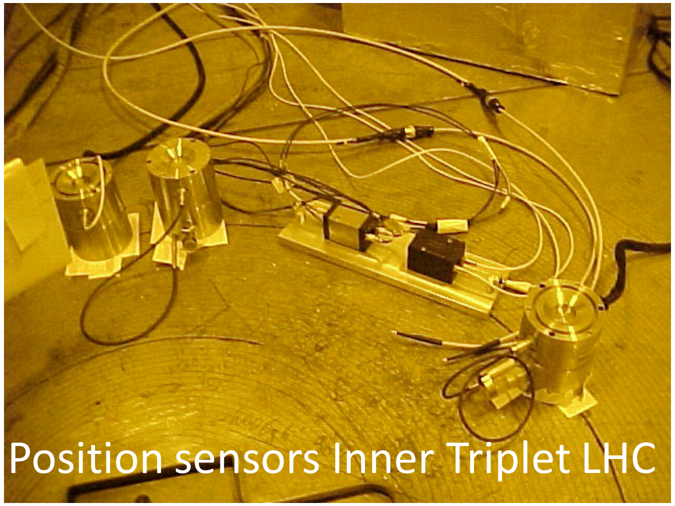
[from K.A. LaBel, RADECS 2007 Deauville]

Total Dose Tests

- Electronics
  - Focus first on areas such as DS, LSS IR3/IR7
  - Irradiate under LHC operational conditions
  - High dose rate
  - Anneal at room temperature

- Materials
  - Use method developed by SC/RP in 1982 [H. Schönbacher et al.]
  - High dose rate, high dose
  - Sample preparation and mechanical/ stress tests in conjunction with EN/MME

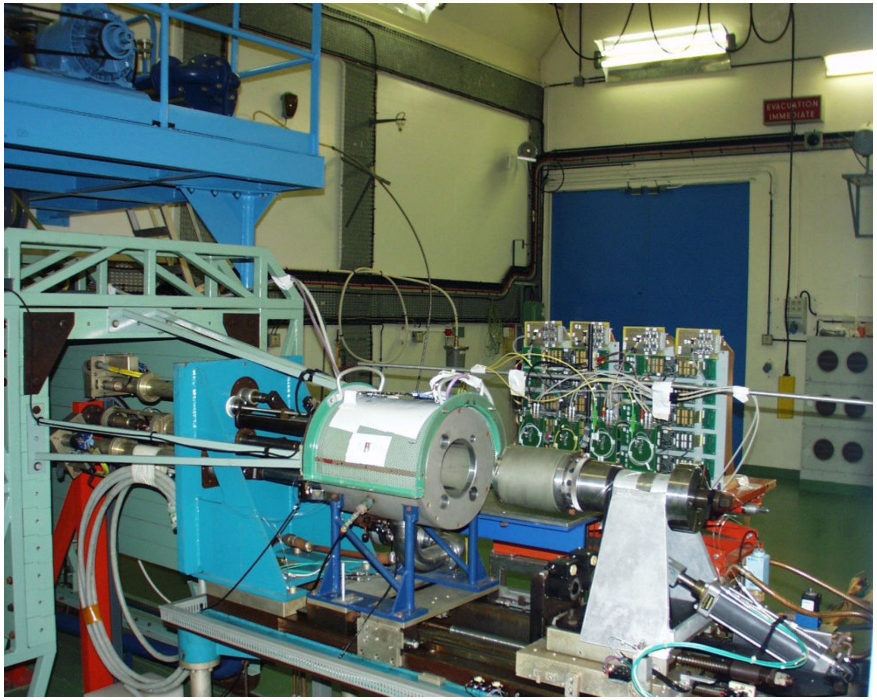
→ First electronics damage from TID in LHC already observed


Position sensors Inner Triplet LHC


FLOHE Cables Inner Triplet LHC

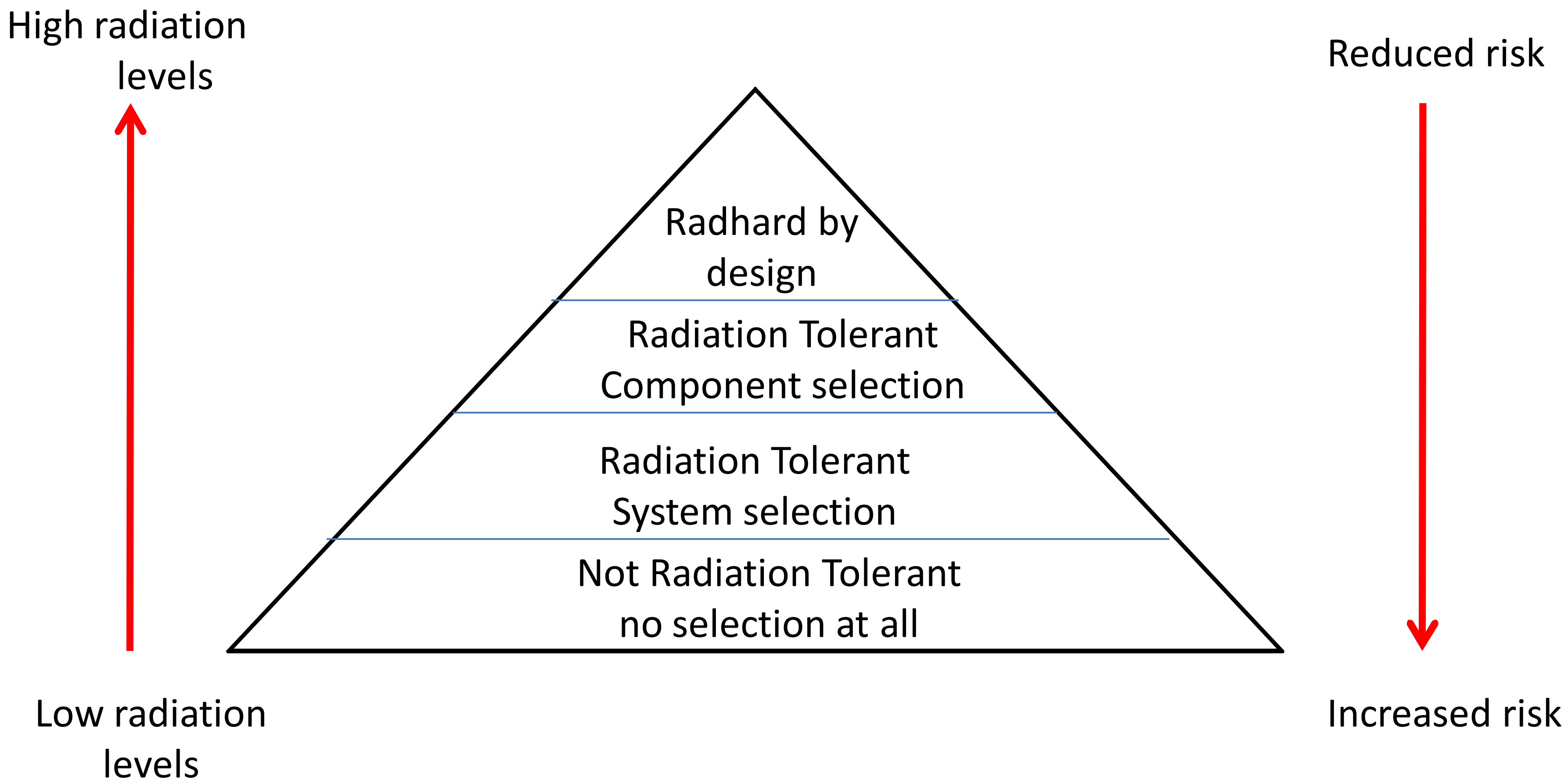
Displacement damage test

- Electronics
  - Only test systems if really required / risk considerable
  - Irradiate under LHC operating conditions
  - Anneal at room temperature
- Examples
  - Power supplies LHC interlocks
  - Laser diodes BPM system
  - ELMB boards
  - RADMON monitors
  - Power Converter controls FGC
  - LV power supplies



Example : Laser Diodes for LHC-BPM system

Risk management



Radiation risk can be managed but not eliminated

CERN aspects

- 1 person coordinates and assists in ALL radiation tests
  - 58 SEE campaigns 1486 hrs of p,n beam time
  - 16 campaigns for displacement damage
  - 23 campaigns for total dose
- Equipment groups entirely responsible for their equipment
  - Radiation tolerance issues addressed on a voluntary basis
  - Advice given by RADWG members and radiation community ‘at large’
  - Assistance with radiation testing if needed
- No coherent review of data from radiation tests
- LHC radiation days (8 in total 2001-2007) :
  - To share radiation data between users
  - To communicate how risks are balanced and actions taken
  - To invite European radiation community / ask for their comments
  - To invite beam providers (UCL, PSI, ..) to update us on facilities

Summary

- LHC machine electronics :
  - Large amount of electronics exposed to radiation
  - All systems are based on commercial electronics
- Component selection method :
  - Used by QPS, BLM/BPM, BIC/PIC, Cryogenics, Radmon
  - Tolerance for these is “as good as reasonable achievable” with commercial parts
  - Equipment passed TCC2/CNGS radiation tests w/o difficulties
- System selection method :
  - Used by many equipment groups many with no in-house design capability
  - Success rate has been extremely limited
  - Tolerance assurance has considerable uncertainty because
    - QA difficult /not done
    - Insufficient statistics
- No coherent review of radiation test data :
  - RADWG as a discussion forum
  - Radiation tolerance studies mainly on a voluntarily basis
  - LHC Radiation days as a communication forum also on a voluntarily basis
- Radiation testing
  - Preparation and test set up require a lot of thought/study
  - Irradiation conditions very important – application oriented
  - Small efforts can be sufficient to reduce the soft error rate
  - Components/systems prone to hard single events should be avoided

Equipment inventory

Why:

- Evaluation of the risk due to exposure to radiation
  - Personnel and Machine safety (priority 1)
  - Long downtime (priority 2)
  - Beam quality degradation (priority 3)
  - Monitoring or no immediate impact on the machine (priority 4)
- Evaluation of the status of the equipment radiation hardness
- Investigate solutions to reduce risk

What:

- Focus on underground areas :
  UJ76, US85, UX85, UJ56, RR53/57, UJ14/16, RR13/17, UW85, UJ23/87
- Assess interdependencies between systems

How :

- Information from equipment owners via on-line survey

https://espace.cern.ch/info-r2e-documents/Lists/R2E%20Equipment%20Survey%20All%20Areas/AllItems.aspx

- Full details on R2E website :

http://r2e.web.cern.ch/R2E/Equipments.htm

[slide from Giovanni Spiezia]

Equipment inventory – Priority 1

Equipment	Location	Description	Failure consequences	Radiation test	Option	Contact
Fire/ODH control	UJ76 US85 UJ56 I.0	Control system (PC based)	No fire detection, no ODH detection Failure affects also the areas UJ US UX RE	No	Relocation	R. Nunes S. Grau
Fire/ODH detectors	UJ87/23 UJ56I.1 (detectors) UJ14/16 RR53/57 RR13/17	Detectors (PC based)	No fire detection; if two more detectors are in fail mode, an evacuation is triggered	Yes – CNGS facility	Relocation	R. Nunes S. Grau
AUG control	UJ76 US85 UJ56	Logic for the AU safety based mechanical relays Some commercial ICs	Loss of the AUG logic	No	Relocation	A.Burdairon M. Codoceo
UPS	UJ76 US85 UJ56	Microprocessor-based and power solid state switch	Loss of Cryogenics, vacuum, QPS, Beam monitoring.	No	Relocation	A.Burdairon M. Codoceo
Electrical equipment	UJ76 US85 UJ56 I.0 UJ14 RR53/57 RR13/17	Control and monitoring (not in UJ14/16, RRs) 48 Vdc/24 Vdc gen/distr. Safety lighting system Commercial ICs; power solid state switches; microprocessors	Loss of power supply and possible loss of the safety lighting	No	Relocation Shielding	A.Burdairon M. Codoceo
Collimation control	UJ56 I.1 UJ14/16	NI PXI controller Data acquisition card FPGA cards	Beam dump	Yes – CERF facility	Relocation	A Masi

[slide from Giovanni Spiezia]

Equipment inventory - Priority 2

Equipment	Location	Description	Failure consequences	Radiation test	Option	Contact
QPS and Energy Extraction SEE TALK	UJ 56 I.1 RR53/57 UJ14/16 RR13/17	High level controls	No protection for the magnets	Yes – CNGS facility Protons 60 MeV	Relocation Partial Redesign	R. Denz
Power Converters SEE NEXT TALK	UJ76, UJ56 I.1 RR53/57, I.0/1 UJ14/16 I.1 RR13/17, I.0/1 UJ23, UJ87	FGC DCCT Controls power part	Beam loss	Yes – CNGS facility	Relocation Partial Redesign Shielding	Y. Thurel
Vacuum	UJ76	Read out of sensors PLC, I/O modules	Beam dump	No	Relocation	I. Laugier P. Gomes
Remote reset/ Timing	UJ76, US 85 UJ56 (I.1)	Custom design PLC and remote I/O modules	Loss of timing Beam dump	No	Relocation	R. Chery
Access system control	UJ76 UJ 56 I.1	Controls equipment switches	Misbehave could generate alarms and stop of the machine	No – Controls 60 Co test for switches	Relocation	R. Nunes
Ethernet	US85 UJ56 (I.1)	Ethernet Switches	Loss of the Ethernet connection for the clients	No	Relocation	E. Sallaz
Cooling and Ventilation	UW85, UA87 UJ76, UJ56 UA23	PLC, remote I/O	No CV for Equipment and the experiments Possible operational stop	No	Shielding Relocation	H. Jena B. Jensen
Cryogenics valve positioners	US85 UX85	PLC, Remote I/Os-CCS rack	No controls of cryo for SC magnets,	No	Relocation	M. Pezzetti J. F. Bel
Cryogenics instrumentation and electronics (PROFI bus)	UJ76, UJ56 I.1 RR53/57, UJ14/16, RR13/17	Remote I/O Valve Positioners (UJs) Embedded electronics	No input for Cryogenic system that could drive a beam dump	No	Relocation	P. Gomes M. Pezzetti
WIC	US85	PLC Siemens and Remote I/O	No control for warm magnets Beam dump	No	Relocation	P. Dahlen
Power Interlock	UJ56 I.1 UJ14/16	PLC (UJ)	Beam dump Users: Power converters, QPS, BIC, Cryogenics, UPS, AUG	No	Relocation	M. Zerlauth P. Dahlen
Power Interlock	RR57/53 RR13/17	Remote I/O ANYBUS cards with CPLDs(5 V)	Beam dump Users: Power converters, QPS, BIC, Cryogenics, UPS, AUG	Yes - TCC2 facility 60 MeV p CNGS facility	?	M. Zerlauth P. Dahlen
Beam Interlock	UJ56 I.1	VME crates CIBU	Beam dump Users: Vacuum. Collimation, PIC, CMS and Totem Exp.	Yes – CNGS 60 MeV p, 250 Mev p, HI, 1 Mev n	Relocation of control part (VME rack) to be verified	B. Puccio B. Todd M. Zerlauth

[slide from Giovanni Spiezia]

Equipment inventory – Priority 3

Equipment	Location	Description	Failure consequences	Radiation test	Option	Contact
RAMSES	UJ76	PC based	Delay in the intervention	No	Relocation	D. Perrin A.Day
Access system gate	UJ14/16 UJ23 UJ87	PC based	Misbehave could generate alarms and stop of the machine Delay in the intervention	No	Relocation	R. Nunes
Beam Television Monitor	UJ76	VME controller CES RIO 4	Loss of the monitor. Operation only in Inject and dump mode	No	Relocation	E. Bravin
Current Leads heater	UJ56 l.1 RR53/57 RR13/17 UJ14/16	Regulators and solid state relays	No heating of the top part of the current lead. Pose an issue only for the machine restart	Yes - CNGS	Relocation	A.Ballarino S. Le Naour

[slide from Giovanni Spiezia]

Equipment inventory – Priority 4

Equipment	Location	Description	Failure consequences	Radiation test	Option	Contact
Survey	US85 UX85b UJ56 l.1 UPS54/56 UPS14/16	Electronic for sensors in US85(door) UX85, and UPS56/54 Data acquisition and control motor system (UJ56, UA83)	No alignment for low beta magnets. Issue for operation	Yes – CNGS 60 MeV p 60 Co TCC2	Stay as is	A.Marin
GSM repeaters	US85 safe room UJ56 safe room UJ76	GSM probe	Loss of the GSM service in the tunnel	No	Shielding Relocation	F. Chapron
Beam Position Monitor	UJ56 l.1 RR53 RR57 UJ14/16 RR13/17	Power supply Microfip Intensity card WBTN analog	Possible degradation of the beam orbit reading	Yes – TCC2 CNGS, p 60 MeV	Stay as is Possibly redesign intensity card.	Eva Calvo Giraldo Jose Luis Gonzales
Beam Loss Monitor	UJ76 (temporary) RR53/57 RR13/17	VME at point 7 is temporary	No machine tuning Beam dump	Yes – TCC2, CNGS, p 250 Mev, p 60 MeV, n 180 MeV, n 1 MeV TID 60Co	Relocation (point 7)	B. Dehning
Optical fiber	US85 UJ56 l.1	Patch panels	Radiation Induced attenuation of light No more comm.	Yes – 60 Co	Relocate if required	D. Ricci
AUG buttons	LHC underground	Mechanical button	Loss of full functionality	No	Stay as is Radiation test materials	A. Burdairon M. Codoceo
Cryogenics instrumentation and electronics (FIP bus)	RR77 UJ56 l.1 RR53/57 UJ14/16 RR13/17	RadTol ASICS Antifuse FPGA Data acquisition systems Fip bus	No input for Cryogenic system that could drive a beam dump	Yes- CNGS	Stay as is	J.Bremen E. Gousiou G. Penacoba
WorldFip **SEE NEXT TALK**	US85 UX85 UJ56 l.1 RR53/57 UJ14/16 RR13/17	Cu/Cu repeaters FipDiag Optical repeaters	Repeater: loss of the network for the next users FipDiag: Loss of the network diagnostic	Repeaters tested CNGS results 1.1 x 10^{12} h/cm^{-2} 1.7 x 10^{12} n/cm^{-2}	It can stay Depend on the clients Power converter, Radmon, Experiment Survey, Cryogenics QPS	J. Palluel D. Caretti

[slide from Giovanni Spiezia]

Acknowledgements

- CERN radioprotection group
  - TCC2/CNGS
  - High Level Dosimetry
  - Personal Dosimetry
  - Access
  - Monte Carlo simulations
  - External radiation campaigns

  …

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  Contact : Guy Berger
  Paul Scherrer Institute, Villingen, CH
  Contact : Wojtek Hajdas

- IRA – Institut de Radio physique Appliqué Lausanne
  Contact : Claude Bailat

- F. Faccio (PH) for discussions/comments

Further Reading

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