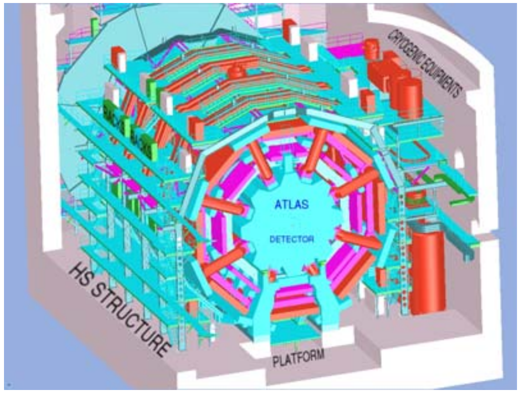
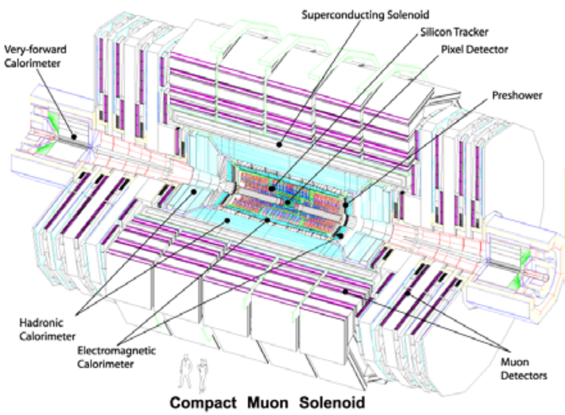
Radiation Hardness for LHC Experiments

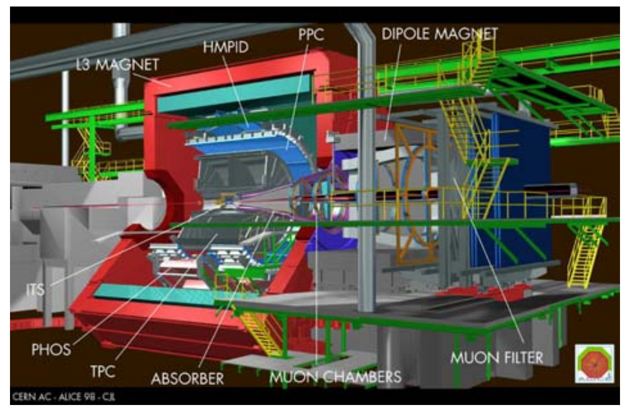


ATLAS

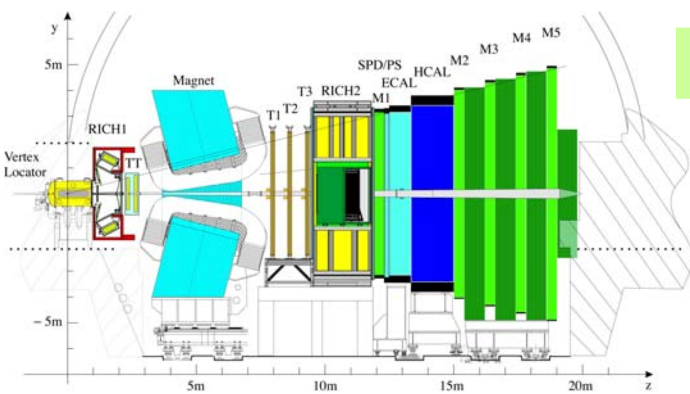
- Radiation qualification of electronics in LHC experiments
- Experiments data & some results
- RadTol regulator, Thermal neutrons …



CMS



ALICE



LHCb

RADWG Workshop

F. Anghinolfi

EP/MIC

Radiation qualification of electronics in LHC experiments

LHC experiments have to deal with electronics radiation damage :

		Most exposed	Cavern Walls
TID (Gy)	Alice Atlas CMS LHCb	2500 260K 828K 70K	0 1-2 2 2
NIEL (1 MeV n/cm^2)	Alice Atlas CMS LHCb	3.0E+12 1.6E+15 2.5E+15 9.0E+13	6.5E+6 5.0E+10 5.1E+10 1.5E+11

10 years @ full luminosity

Radiation qualification of electronics in LHC experiments

LHC experiments have to deal with Transient Errors

		Most exposed	Walls
Hadrons (> 20MeV/cm^2)	Alice	1.3E+12	8.7E+6
	Atlas	2.3E+15	1.0E+10
	CMS	2.5E+15	1.8E+10
	LHCb	1.4E+14	< 4.3E+9

10 years @ full luminosity

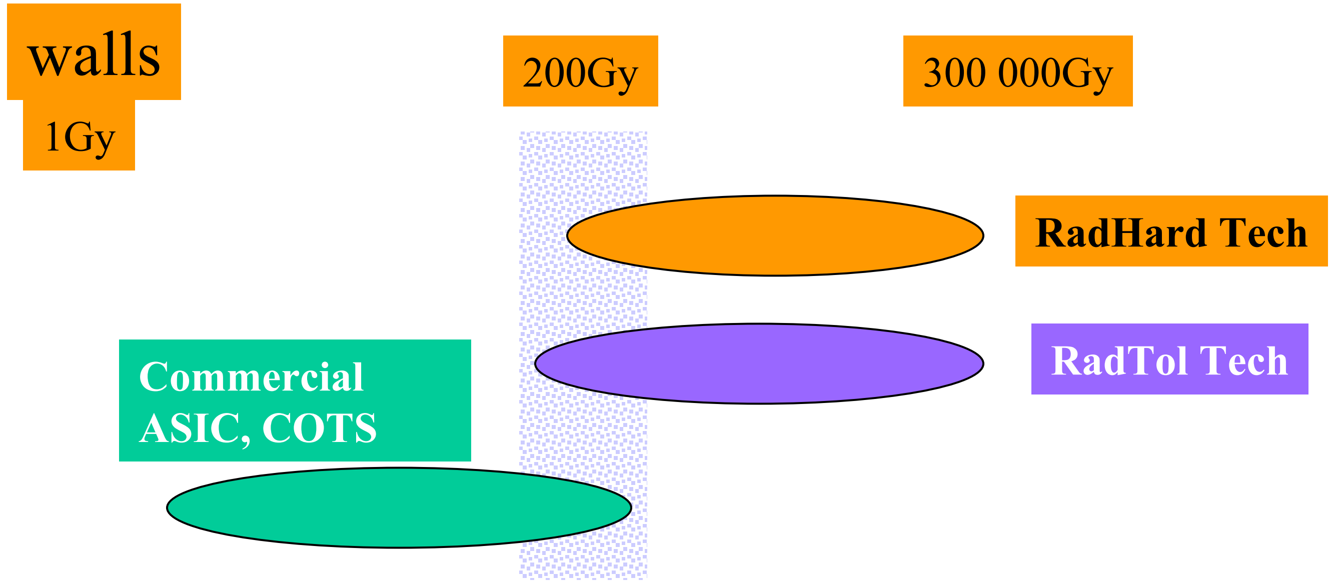
Typical bit flip SEU cross section : 10^{-14}cm^2/bit

Radiation qualification of electronics in LHC experiments

Qualification tests

Radiation Damage	SEU
Component Selection Component Production (ASICS & COTS) Board Production	Error protections Error rates Error recovery

Radiation Hardness & Technologies



RadHard Tech — **Radiation Hardened by technology (Ex: DMILL)**

RadTol Tech — **Radiation Hardened by design, Commercial technology (Ex: 0.25 microns with radtol layout techniques)**

Commercial ASIC, COTS — **ASIC : Commercial technology, can be SEU hardened by design**
COTS : Commercial components, FPGAs can be SEU hardened by design

SEU Issues

All electronics is subject to SEU, with different probability depending on technology, architecture.

The probability of SEU event is part of the components reviews

The probability of SEU on system/DAQ is part of the system reviews

All systems are checked for modes of restoration/recovery after critical SEU event

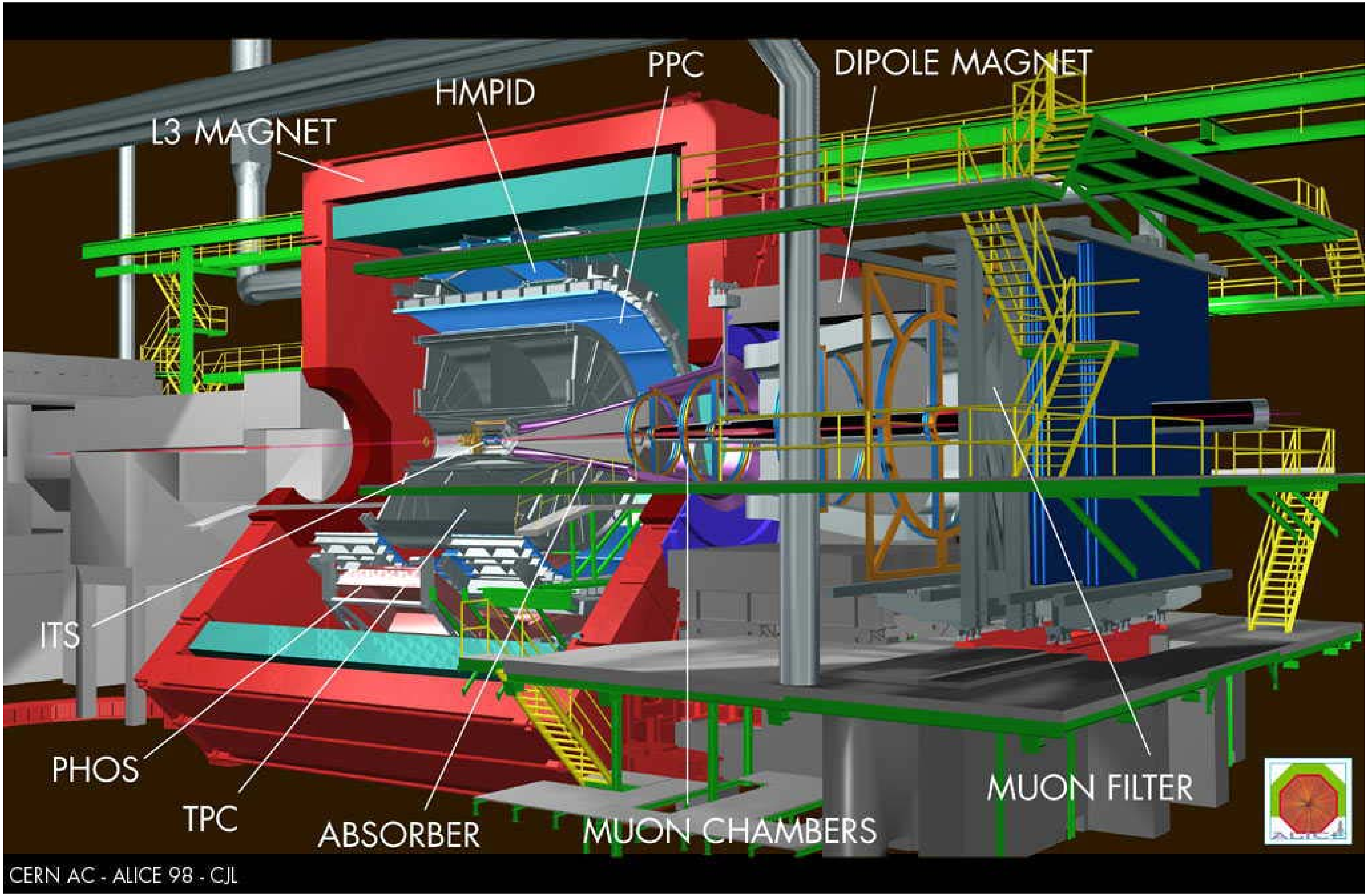
ASICs, FPGAs are designed with SEU recovery techniques :

- Error detection
- CRC
- Triple vote logic

Redundancy at subdetector system level

DETECTORS OVERVIEW

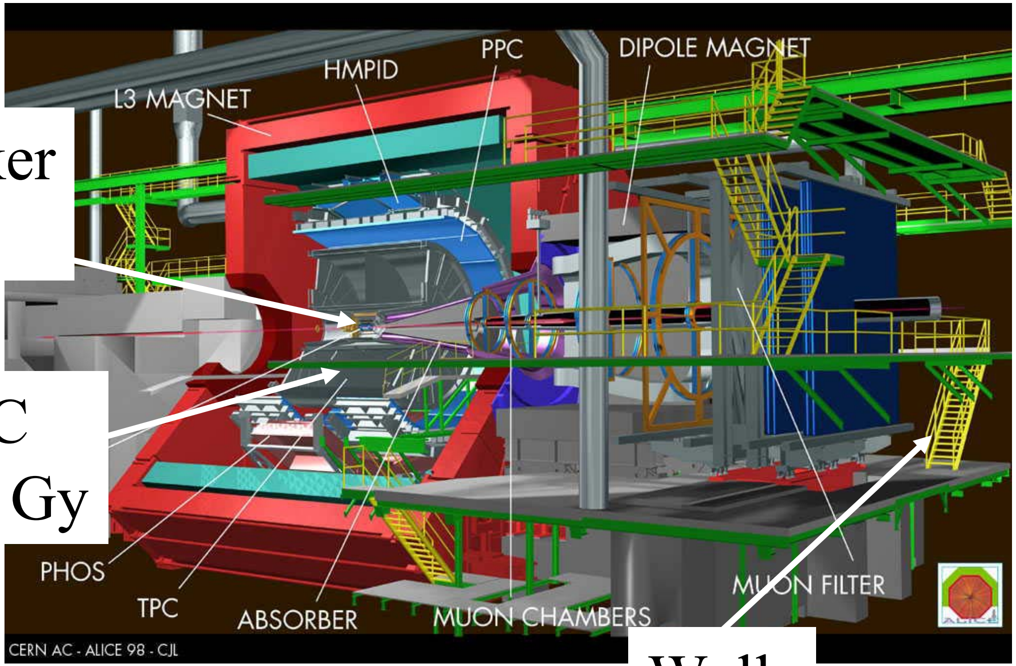
ALICE



PPC
DIPOLE MAGNET
HMPID
L3 MAGNET
ITS
PHOS
TPC
ABSORBER
MUON CHAMBERS
MUON FILTER
CERN AC - ALICE 98 - CJL

ALICE

Central Tracker
2500 Gy



TPC
~ 6 Gy

Walls
0 Gy

ALICE : Fluences and doses for 10 years

Detector	Dose	1mevneq	n	p,π
SPD1	2.50×10^{3}	2.95×10^{12}	3.13×10^{11}	1.30×10^{12}
SPD2	6.94×10^{2}	1.72×10^{12}	1.27×10^{11}	7.61×10^{11}
SDD1	2.41×10^{2}	9.87×10^{11}	4.28×10^{10}	4.31×10^{11}
SDD2	1.96×10^{2}	7.39×10^{11}	1.64×10^{10}	6.88×10^{11}
SSD1	5.56×10^{1}	6.24×10^{11}	1.39×10^{10}	4.23×10^{11}
SSD2	4.32×10^{1}	5.42×10^{11}	1.56×10^{10}	2.25×10^{11}
TPCin	6.50×10^{0}	6.00×10^{11}	1.05×10^{10}	2.13×10^{11}
TPCout	5.32×10^{-1}	5.20×10^{10}	3.45×10^{9}	1.44×10^{10}
TRD	4.44×10^{-1}	3.42×10^{10}	3.56×10^{9}	2.70×10^{10}
TOF	2.92×10^{-1}	1.12×10^{10}	1.79×10^{9}	9.11×10^{9}
HMPID	1.90×10^{0}	4.21×10^{10}	5.19×10^{8}	3.90×10^{9}
PHOS	1.60×10^{-1}	1.77×10^{10}	6.50×10^{8}	1.17×10^{9}

tracker

B. Pastircak

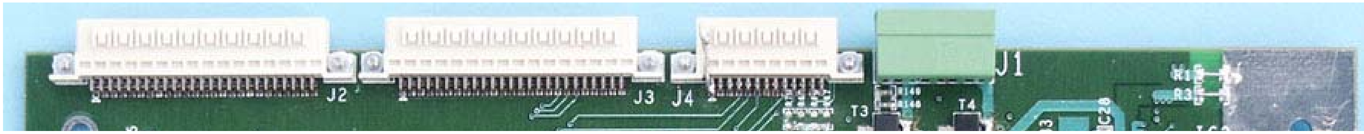
ALICE

Central Tracker : all electronics in RadTol 0.25 microns, tested up to 5000 Gy

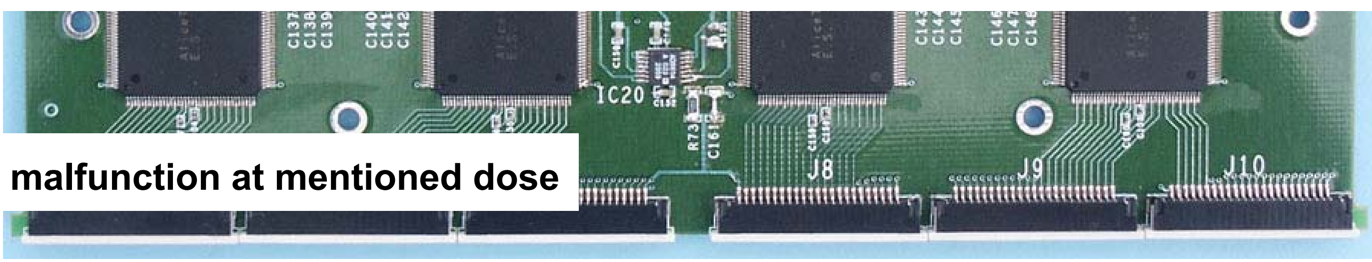
TPC and above : all electronics (COTS, ASICs with no radtol layout) tested to 20-70 times the simulation level (~6Gy worst case in TPC)

Walls : No radiation requirements

Alice TPC readout



Name	Type	No. Parts	Max. Dose (krad)	Test Method
ALTRO-16	CMOS	4	312	dynamic
PASA	CMOS	4	96	static
MIC39151 ✝	Bipolar	2	29.6	dynamic
TC1265	CMOS	2	84	dynamic
GTL16612	Bi-CMOS	1	48	dynamic
MPC9109	CMOS	1	52	static
AD8604	CMOS	1	22	static
LM4120	Bipolar	1	22	static
EPC1441 ✝	CMOS	2	4.2	unpowered

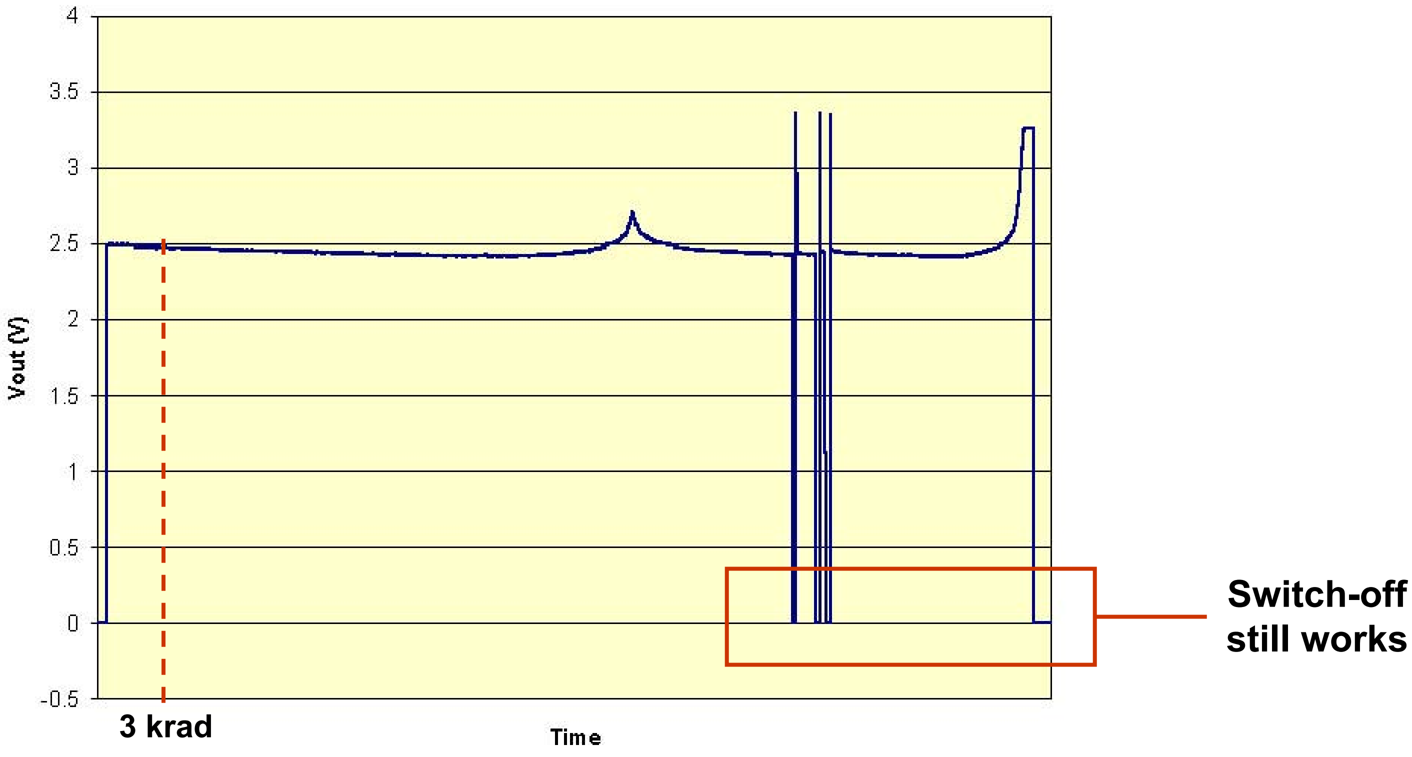


✝ **Part malfunction at mentioned dose**

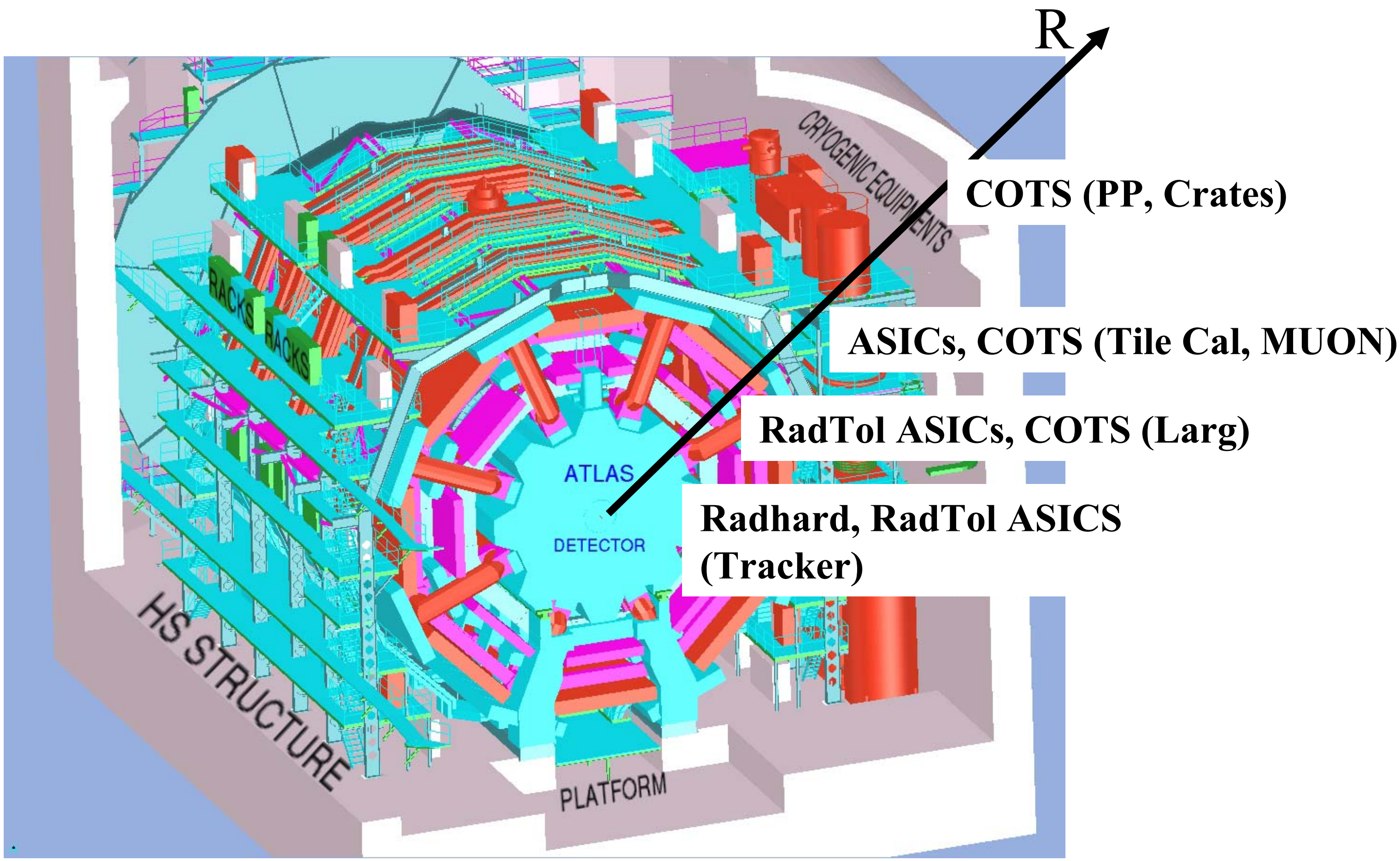
L. Musa

Alice TPC readout

- TC1265 stood 84 krad without problem
- MIC39151 died after 25 krad (switch-off still possible)
- MIC39151 showed 4-5 spikes at the beginning of the irradiation (50-100 mV)



ATLAS Electronics Radiation Hardness



ATLAS

Regions	Neutron fluence [Particles/cm^3]	Proton fluence [Particles/cm^3]	Dose [Gy]
Inner Tracker Pixel	1.6E+15	2.3E+15	288 000
Inner Tracker TRT	7.2E+13	2.8E+13	16 000
Larg Cal	1.9E+12	3.8E+11	48
Tile Cal	2.7E+11	6.7E+10	3.8
Walls	4.9E+10	1.0E+10	1

ATLAS

Central Tracker : Electronics in RadTol 0.25 microns (pixel, TRT), RadHard DMILL (SCT, TRT), Commercial Bipolar, tested to 1-5 times simulation level

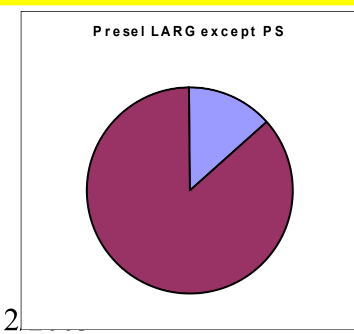
Calorimeter and above : RadHard & RadTol ASICS, COTS tested to 3.5-70 times the simulation level (~230 Gy worst case in forward CSC)

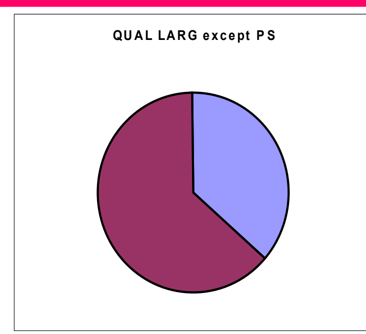
Walls : Patch Panels, Power Supplies with selected COTS tested to 70 times the simulation level (1-2 Gy)

ATLAS Electronics Radiation Hardness

			Preselection			Prod. Qual.				
Part	List		SelG	Seln	SelSEE	ProdG	Prodn	ProdSEE	Comps	Comments
FE	Y		17/18	17/18	17/18	15/18	15/18	15/18	18	Miss LV-, opto
Controller	Y		3/11	3/11	3/11	3/11	3/11	3/11	11	LV+, TTC, SPAC
Tower Builder	Y		10/10	10/10	10/10	9/10	9/10	9/10	10	Miss LV-
Layer Sum	Y		1/1	1/1	1/1	1/1	1/1	1/1	1	
PreAmpli	Y		1/1	1/1	1/1	1/1	1/1	1/1	1	Prod. Done
PreShaper	Y		1/1	1/1	1/1	1/1	1/1	1/1	1	Prod. Done
Digital Calib	Y		5/5	5/5	5/5	4/5	4/5	4/5	5	Miss PHOS
Anal. Calib	Y		6/6	6/6	6/6	5/6	5/6	5/6	6	Miss LV-
Tower Driver	?									
LV PS	Y		Y	Y	Y	N	N	N		Preserie 2003
LV distri Board	Y		3/3	3/3	3/3	2/3	2/3	2/3	3	Miss LV-
Optical Link	Y		7/7	7/7	7/7	1/7	1/7	1/7	7	
ELMB	Y		Y	Y	Y	N	N	N	1	Prod. tests en cours
Purity Readout	Y		2/2	2/2	2/2	2/2	2/2	2/2	2	LV, HFA1135
Temp Readout	Y		Y	Y	Y	Y	Y	Y		Only Passive
FEC V&T	Y		Y	Y	Y	Y	Y	Y		Only Passive
HEC LV distri	Y		Y	Y	Y	Y	Y	Y		Only Passive

- LArg





Qualification Status Sept'03

ATLAS Electronics Radiation Hardness

Power Supplies in UX15

Specific Issues

. Specific technology of power devices

. Opto couplers

. Condition under SEU* event

In next slides "SEU" are events which create a fonctionnal failure and/or dead time

ATLAS Electronics Radiation Hardness

Power Supplies in UX15

Location/Detector	Features	Controller	Status	Power Device Qual	Preselection Radiation Qualification	Production Radiation Qualification
LARG PS	R=4m	ELMB	PRR Nov 2003	Yes, Production done	Yes	No
LARG HEC	R=4m	ELMB	FDR TBD	ST LV+ LV-	No	No
Tile HV	R=4m	On Board	PRR Done	Yes	Yes	Yes
Tile LV "Brick"	R=4m	ELMB	FDR June 03	Still to be fixed	No	No

ELMB :
2 SEU/10years in LARG PS position

On Board Tile HV logic :
5 SEU/year

ATLAS Electronics Radiation Hardness

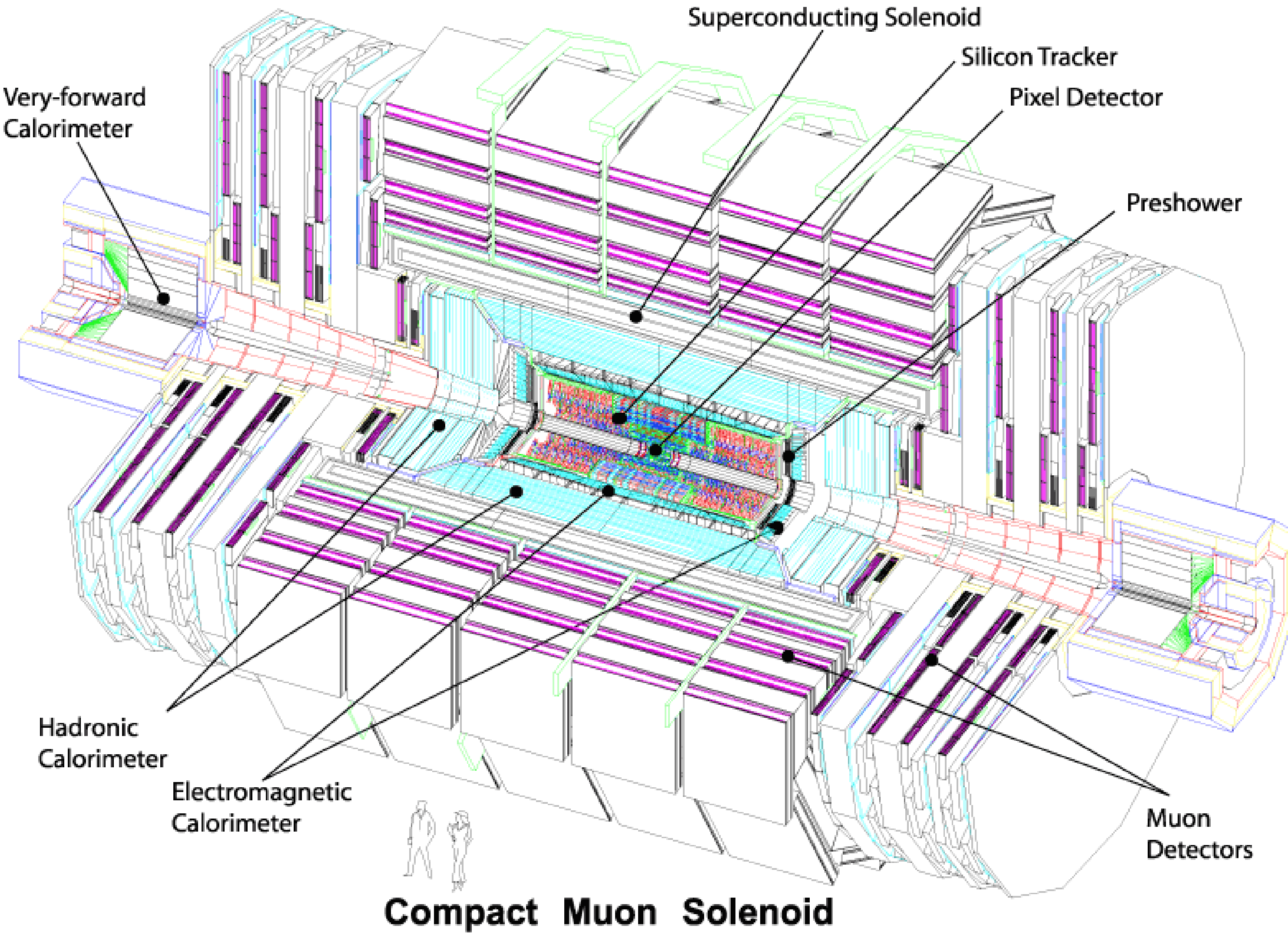
Power Supplies in UX15

Location/Detector	Features	Controller	Status	Power Device Qual	Preselection Radiation Qualification	Production Radiation Qualification
MDT Muon HV	R=6m	One per crate	CAEN	Yes	Yes	No
MDT Muon LV	R=11m		CAEN or WIENER			
TGC Muon HV	R=11m		CAEN	Yes	Yes	No
TGC Muon LV	R=11m		CAEN or WIENER	Yes		
CSC Muon HV	R=11m		CAEN	Yes	Yes	No
CSC Muon LV	R=11m		CAEN or WIENER	Yes		
RPC Muon HV	R=11m		CAEN	Yes	Yes	No
RPC Muon LV	R=11m		CAEN or WIENER	Yes		
TRT	R=11m	no controller	WIENER PL500	Yes	No	No

CAEN Controller :
<1 SEU/controller/year

No local Controller on WIENER units

CMS



Superconducting Solenoid
Silicon Tracker
Pixel Detector
Very-forward
Calorimeter
Preshower
Hadronic
Calorimeter
Electromagnetic
Calorimeter
Muon
Detectors
Compact Muon Solenoid

CMS

Regions	Neutron fluence [Particles/cm^3]	Proton fluence [Particles/cm^3]	Dose [Gy]
Inner Tracker	2.5E+15	2.5E+15	828 000
ECAL	8.0E+13	-	-
HCAL	1.7E+12	4.8E+11	83
MUON	8.2E+11	2.2E+10	29
Walls	5.1E+10	1.8E+10	1-2

M. Huhtinen

CMS

Tracker & ECAL: Electronics in RadTol 0.25 microns

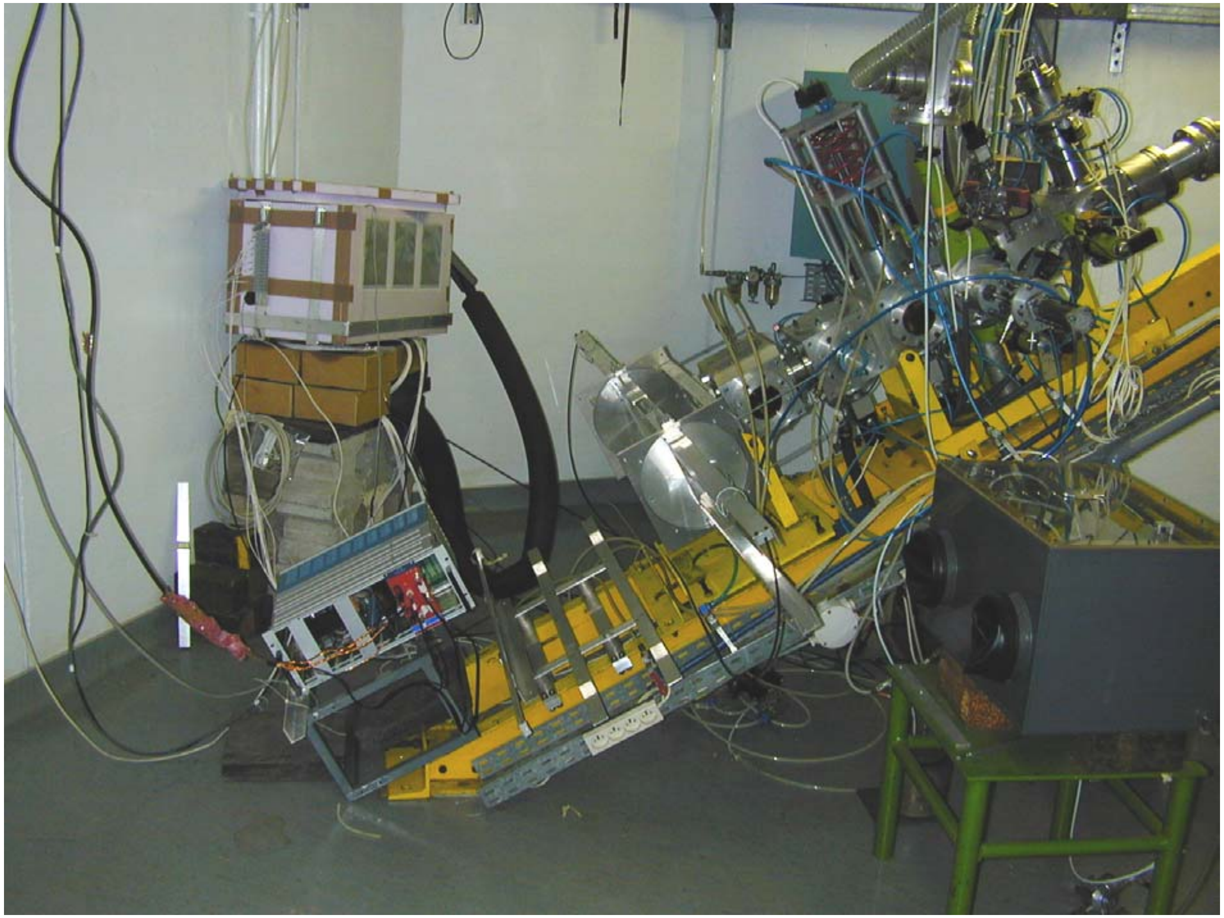
HCAL : 0.35 microns BiCMOS

Muon Chambers : 0.8 microns BiCMOS

Off-Detector : Crates, Power Supplies with selected COTS
tested to ~10 times the simulation level (10 Gy)

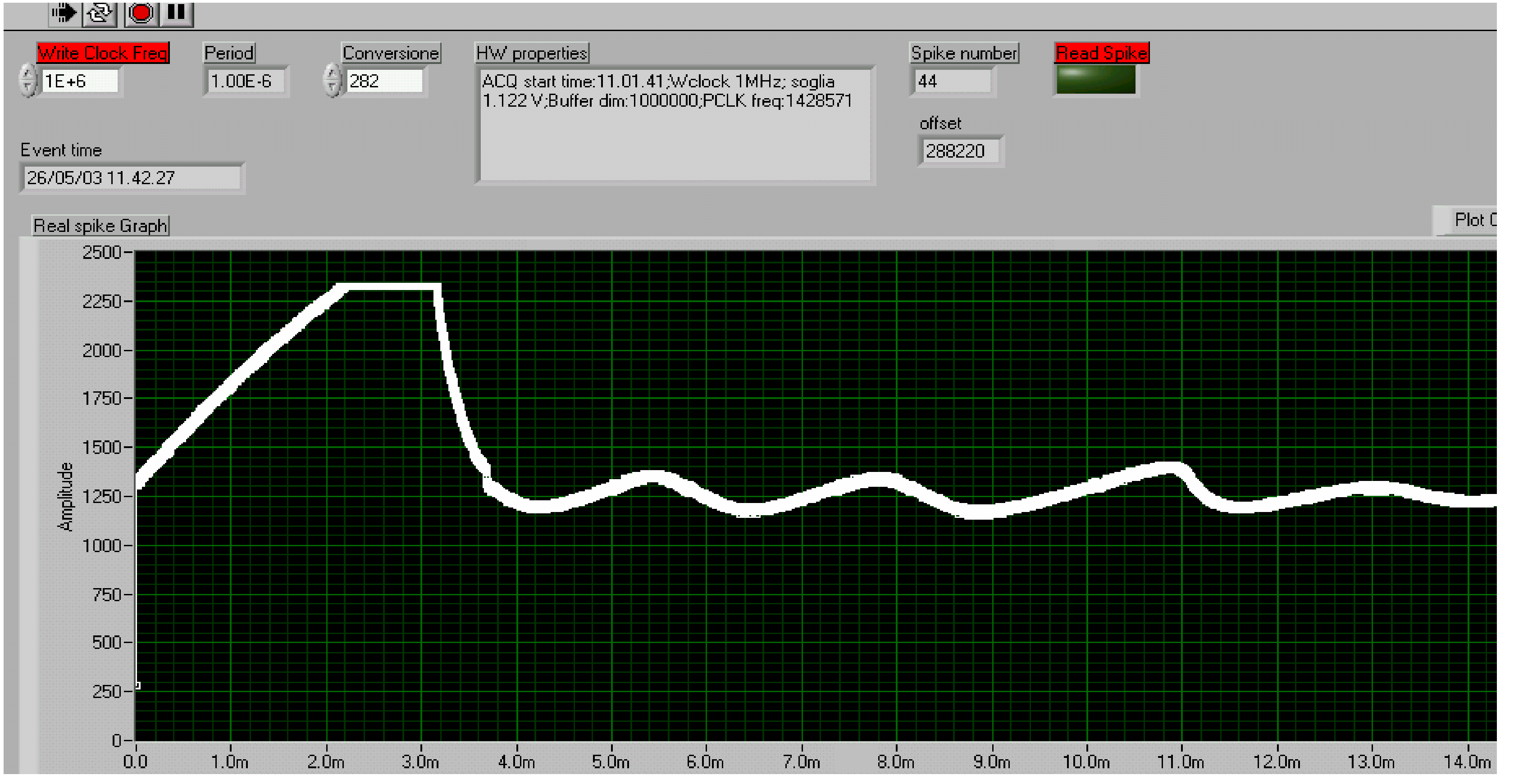
CAEN SASY Power Supply irradiation test with fast Neutrons at UCL

Up to 2E+12 MeV neutrons



Passuello, Periale, for CMS

CAEN SASY Power Supply irradiation test with fast Neutrons at UCL



type b) 11.42.37 & 12.43.05 -> SASY unplugged (loss of control), reason under investigation. The system was recovered by a Hard reset (OFF/ON sequence) from remote. The channels restart all normally.

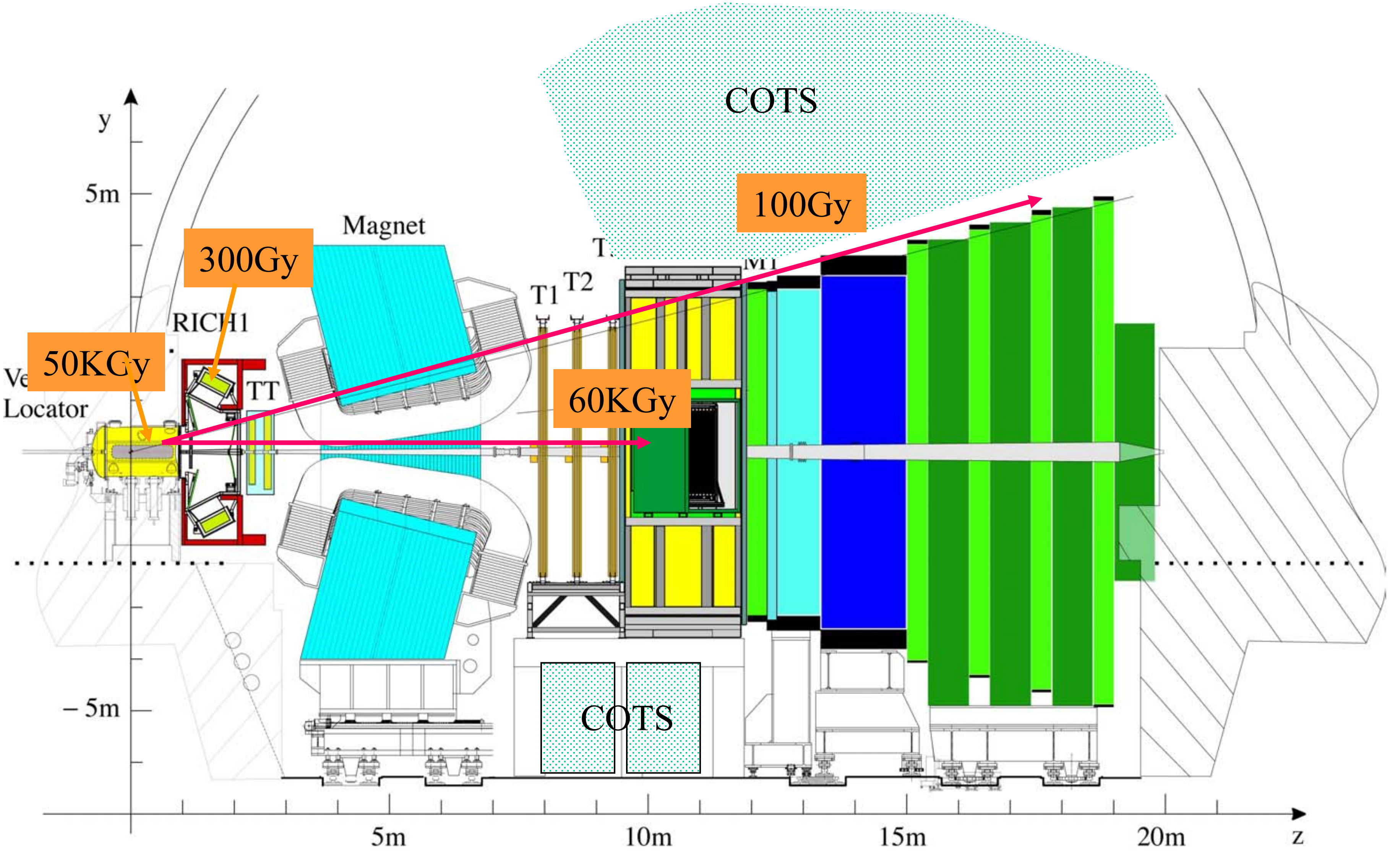
CAEN SASY HV Power Supply irradiation test with 60MeV protons at UCL

- Average 4 SEU per DC/DC coupler per 1.0E+11 protons are observed (0.5 SEU/year in LHC conditions)

-Careful selection of opto couplers parts

-Tested up to 140 Gy

LHCb Detector



LHCb

Regions	Neutron fluence [Particles/cm^3]	Proton fluence [Particles/cm^3]	Dose [Gy]
Vertex Tracker Pixel	9.0E+13	1.4E+14	58 000
Inner Tracker	8.7E+13	1.3E+14	70 000
RICH	3.4E+12	3.1E+11	240
Muons	2.2E+13	1.1E+13	4620
Walls	1.5E+11	4.6E+9	1-2

J. Christiansen

LHCb

Central Vertex : Electronics in RadTol 0.25 microns

RICH & Inner Tracker : Electronics in RadTol 0.25 microns

Outer Gas Tracker : RadHard DMILL

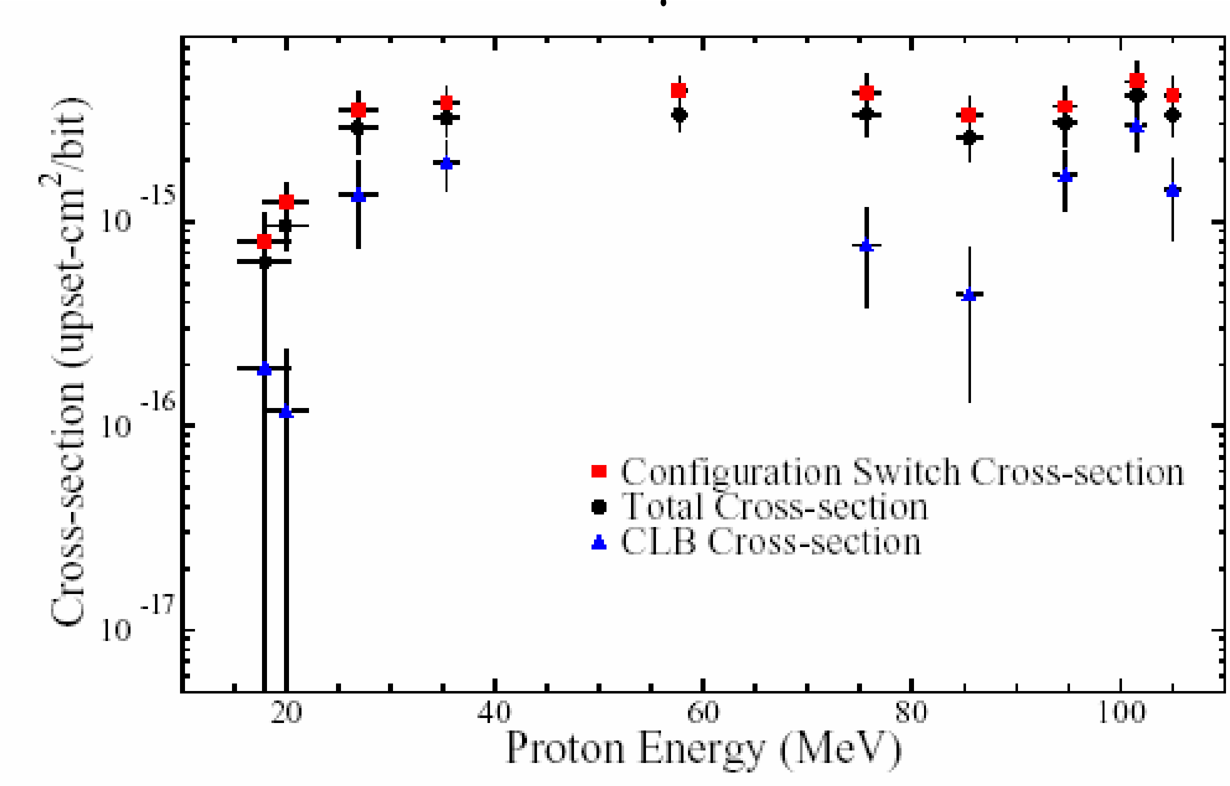
ECAL & HCAL : ASICs with commercial 0.8μm CMOS. All tested to radiation level and SEU. AntiFuse FPGA.

Muon Chambers : All Electronics in RadTol 0.25 microns

Off-Detector : Some crates are exposed up to > 100 Gy and 2^{12} protons/cm^2

Xilinx FPGA SEE test

3.3V 0.35μm CMOS

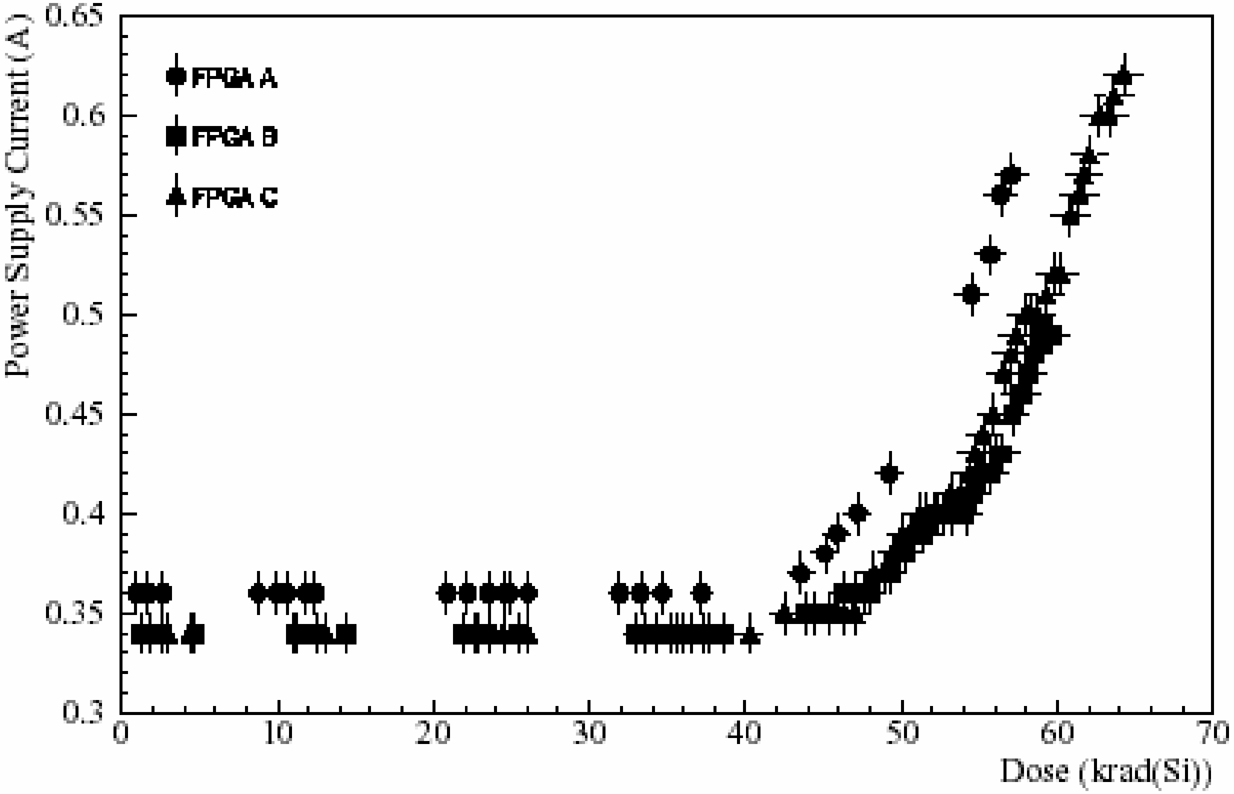


Xilinx XC4036XL SEE test

N.J. Buchanan, Alberta

Xilinx FPGA TID test

3.3V 0.35µm CMOS

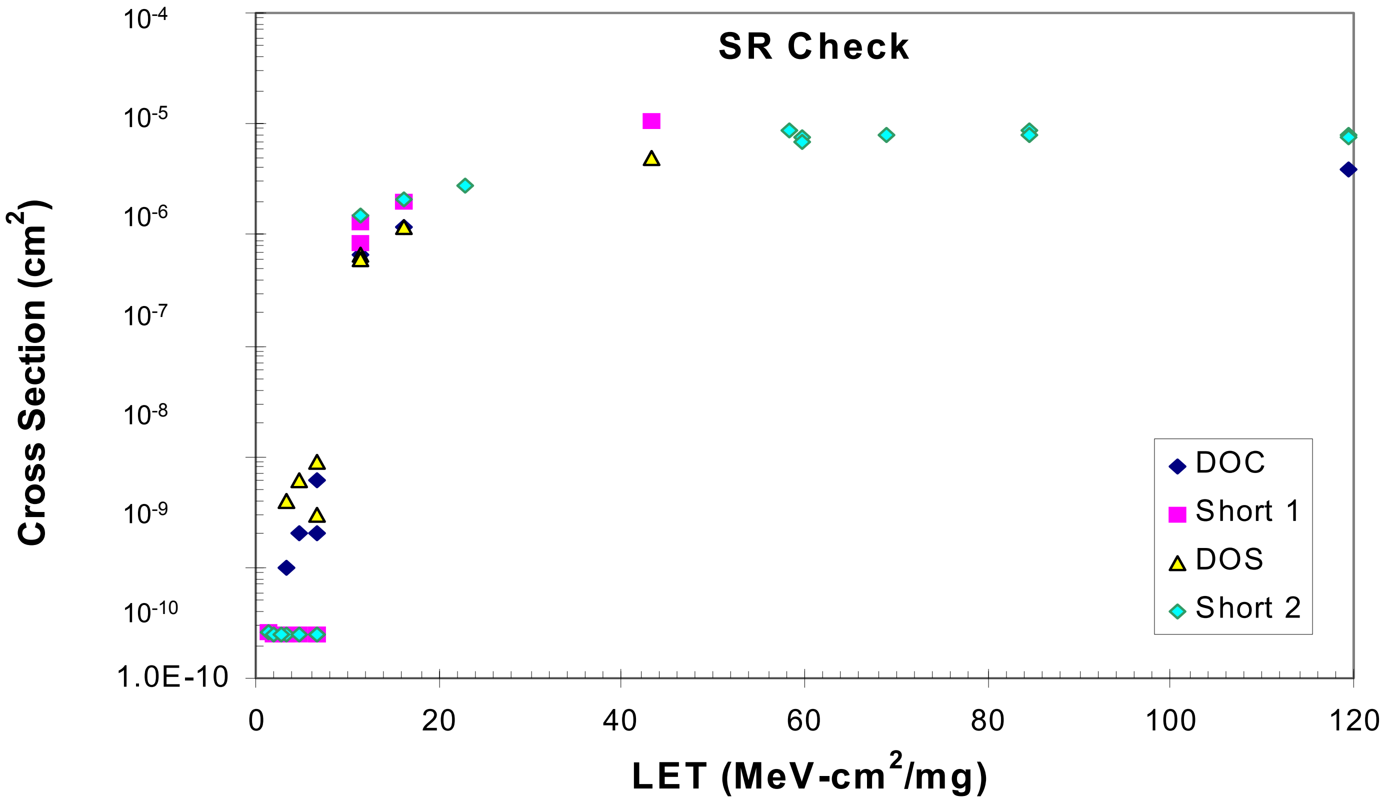


Xilinx XC4036XL TID test

N.J. Buchanan, Alberta

Antifuse-based FPGA SEE test

0.15µm AX1000 Antifuse-based FPGA

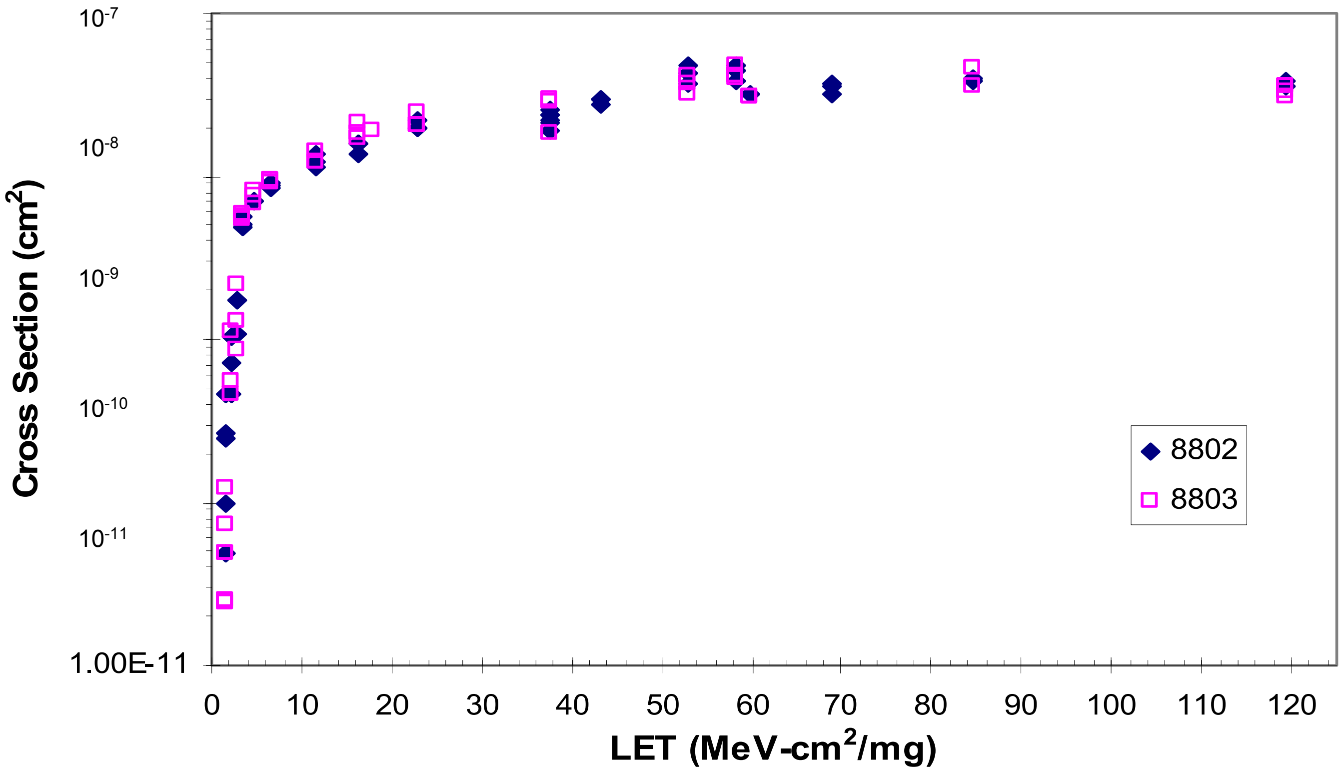


User registers (~110 bits)

R. Katz, Nasa

Antifuse-based FPGA SEE test

0.15µm AX1000 Antifuse-based FPGA



Embedded SRAM (165888 bits)

R. Katz, Nasa

Status

- Experiments are conducting damage tests with safety factors from 10 to 100 (COTS)
- SEU protection is handled at design level
- SEU rates are estimated to evaluate dead time

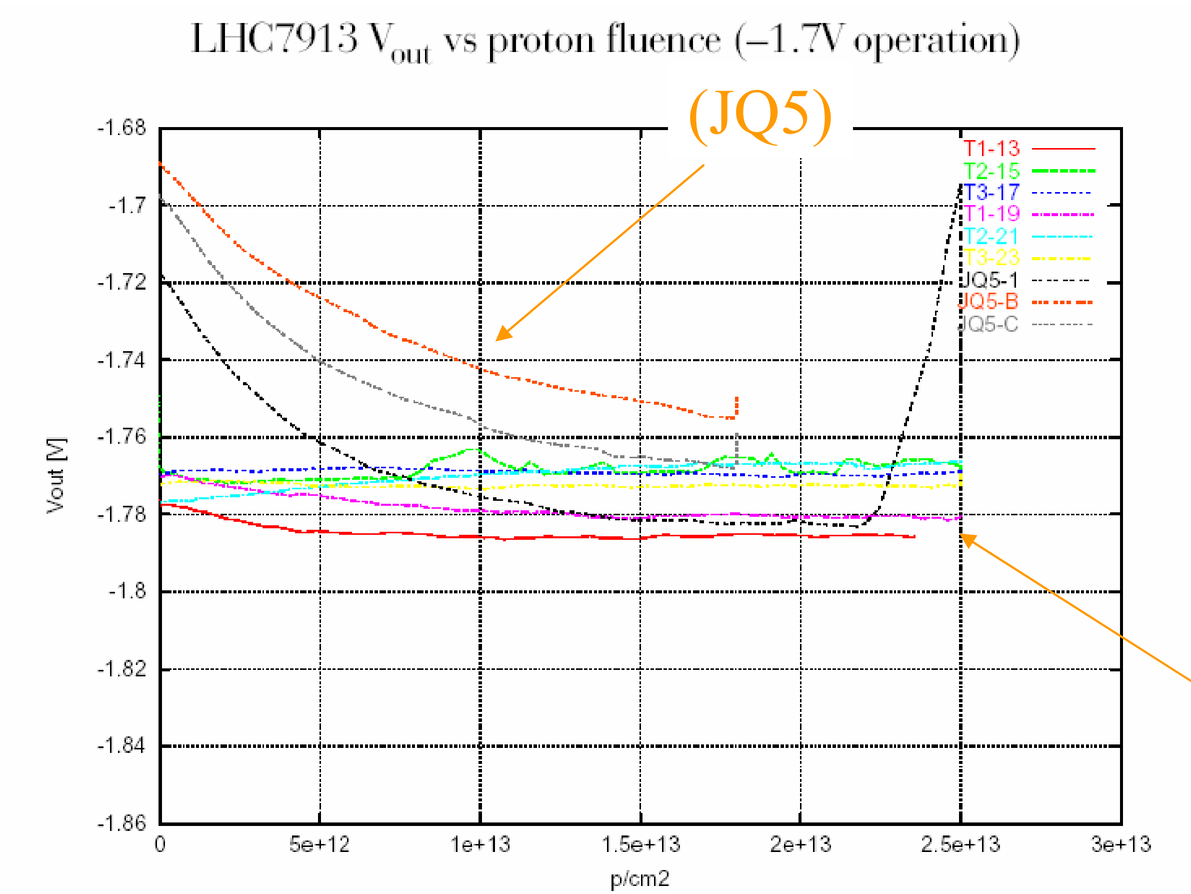
ST Low Drop Voltage Regulator

Positive LV4913 is fully qualified and available at CERN store
(TID > 2Mrads, NIEL ~ 1E14 1MeV neutrons)

Negative LV7913-JQ6 prototypes recently received

ST Low Drop Voltage Regulator

LV7913-JQ6 protons test



Output Voltage
At 275mA

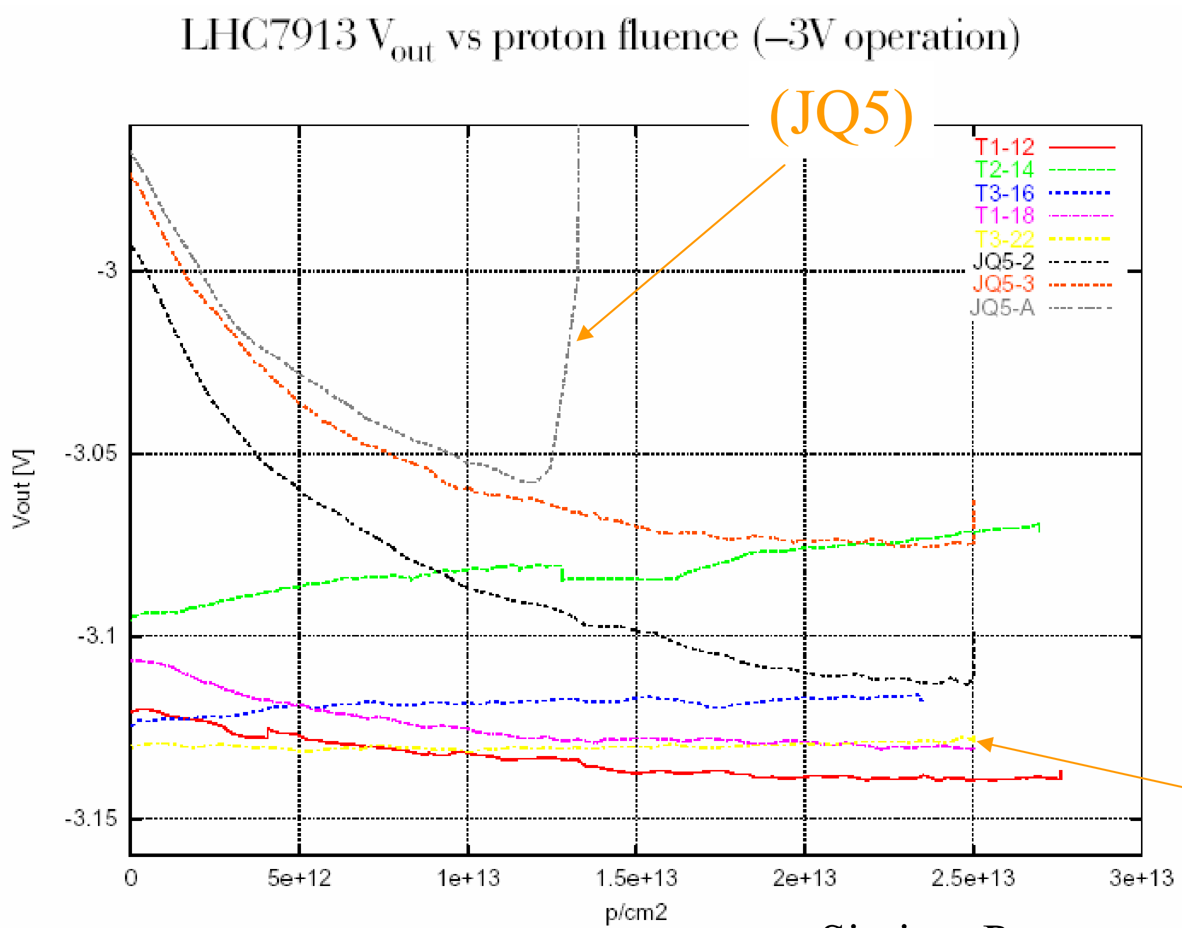
BNL synchrotron

Protons/cm^2
Eqvlt 2Mrads
& 3E13 1MeV
neutrons

Simion, Parsons

ST Low Drop Voltage Regulator

LV7913-JQ6 protons test



Simion, Parsons

BNL synchrotron

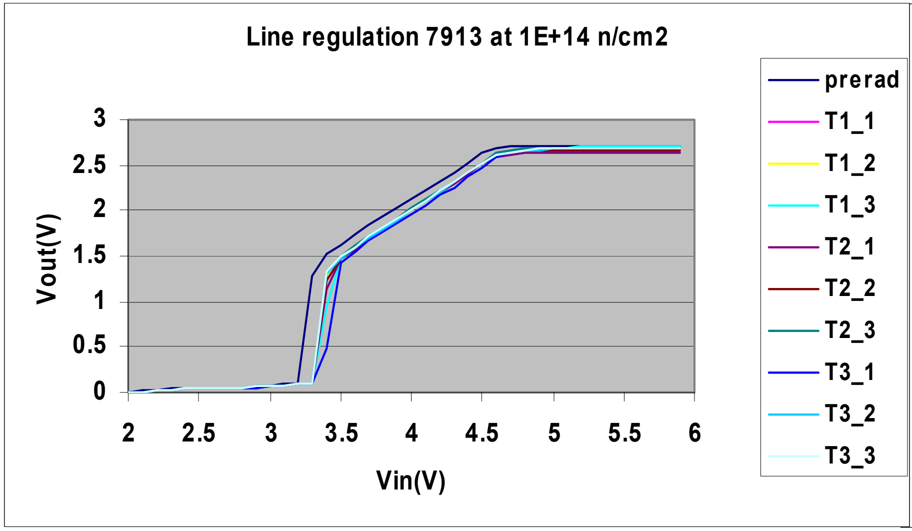
Protons/cm^2

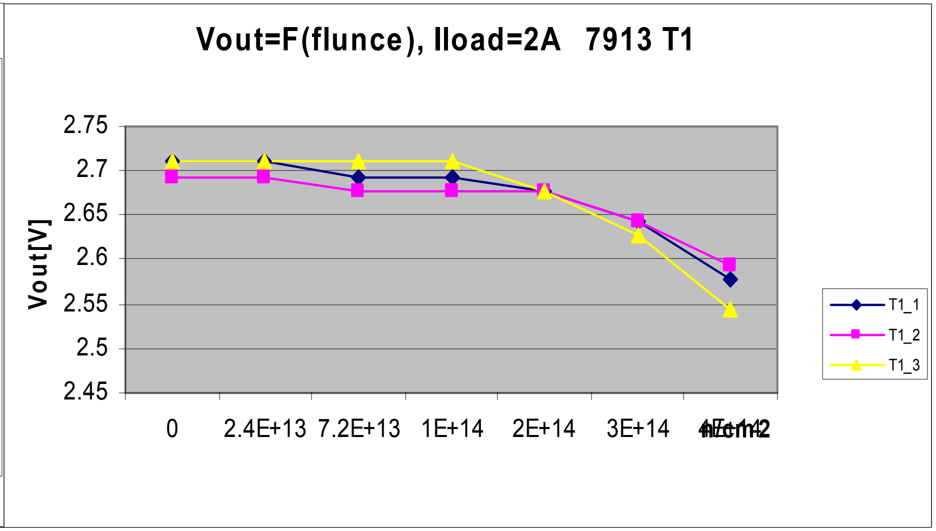
Eqvlt 2Mrads & 3E13 1MeV neutrons

ST Low Drop Voltage Regulator

LV7913-JQ6 neutrons test

TRIGA reactor, Ljubljana





B. Kieselewski

LV7913-JQ6 status

3 OPTIONS (T1-T2-T3) have been tested

Version T2 has been rejected because of poorer radiation hardness

Production will follow decision after reliability tests on T1, T3 is done by ST.

Thermal neutrons

Specific Issue

Thermal neutrons (<1eV) may affect the beta of bipolar transistors (usually PNP)

Mechanism is thermal neutron capture by Boron, with very large cross section. α particle is emitted and creates NIEL damage in the base of bipolar

The DMILL bipolar transistor was found to be sensitive to thermal neutrons (although it is NPN)

Electronics Radiation Hardness

Database

Radiation Tolerant Components Database update (C. Parkman) :

- For all CERN experiment&accelerator electronics
  - used for LHC electronics components,
  - Open to Alice, CMS, LHCb …
- Addition of Systems and Sensors

Consult Web Page http://oraweb01.cern.ch/radhardcomps/owa/radhardcomps_public.

Electronics Radiation Hardness

Irradiation Campaigns

TID Campaign in Pagure : April 2003

NIEL Campaign in Prospero : April 2003, Nov 2003

NIEL Campaign in ITN : Jan-March 2003

Hadron Campaigns (PSI, Louvain) organized jointly by F. Faccio (EP) and T. Wijnands (AB)

March 03 April 03 June 03

Sep 03 Nov 03

Consult Web Page http://oraweb01.cern.ch/atlasradag/owa/Q_CERN_AGENDA.queryList