QUALIFICATION of ELECTRONICS for the LHC RADIATION ENVIRONMENT

- Introduction
- Radiation Test Facility for LHC Tunnel Electronics
- Some Results from 6 Experiments (out of 20)
- Conclusions

Why Electronics in the LHC Tunnel?

- Benefits of Electronics Closer to Sensors:
  - Lower Signal Noise, Higher Bandwidth (BPM)
  - New Possibilities for Data Pre-Processing (CPS)
  - Better Remote Diagnostics
  - Less Cables to Alcoves, Galleries and Access Pits
- But
  - More Activated Material
  - No Access Possible During LHC Operation

Objectives of the Radiation Tests

- Qualify COTS Electronics for the LHC Tunnel

  (COTS – Commercial Off The Shelf)
- Identify Radiation Sensitive Components and Replace with Radiation Hardened Items
- Qualify Complete Systems
- Improve Global Radiation Hardness and Evaluate Equipment Life-Time
- Accelerated Testing of Equipment
  - 1 Year in Zone ~= 20 Years in LHC

3 Different Types of Radiation Damage

- Single Event Upsets (SEU)

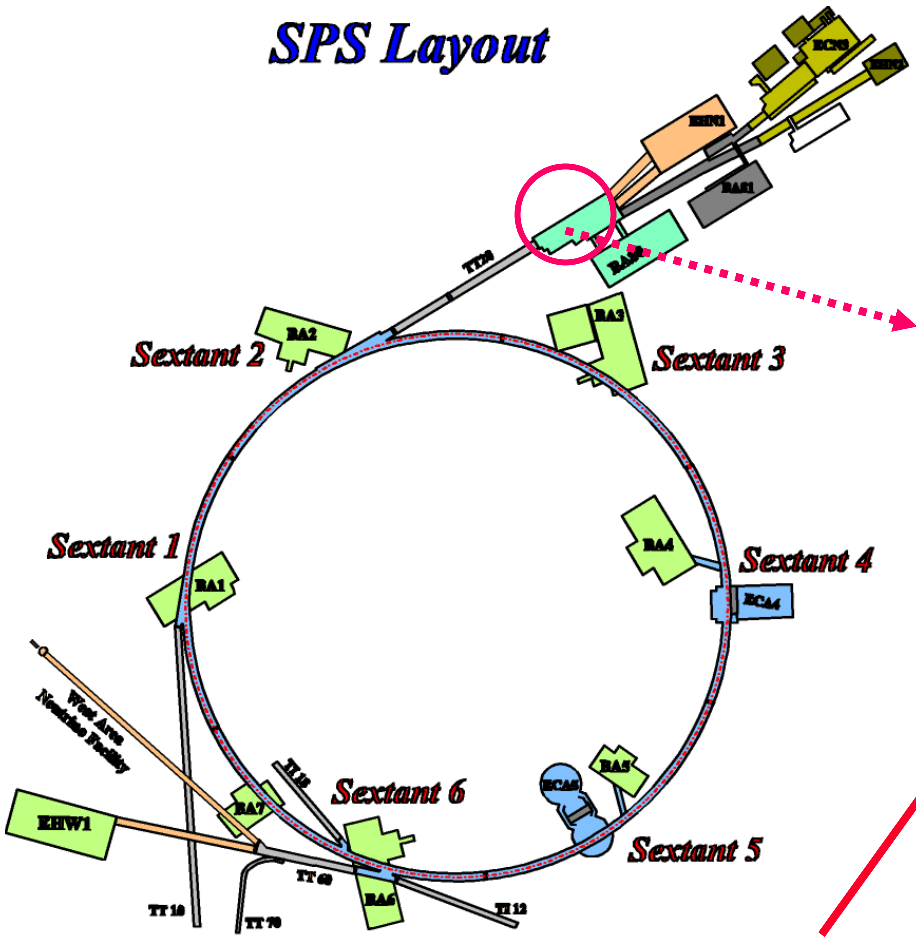
  (Charge Deposited on Critical Node in a Chip)
- Ionising Energy Loss

  (Ionising, Excitation, ex: Gamma Rays)
- Non Ionising Energy Loss

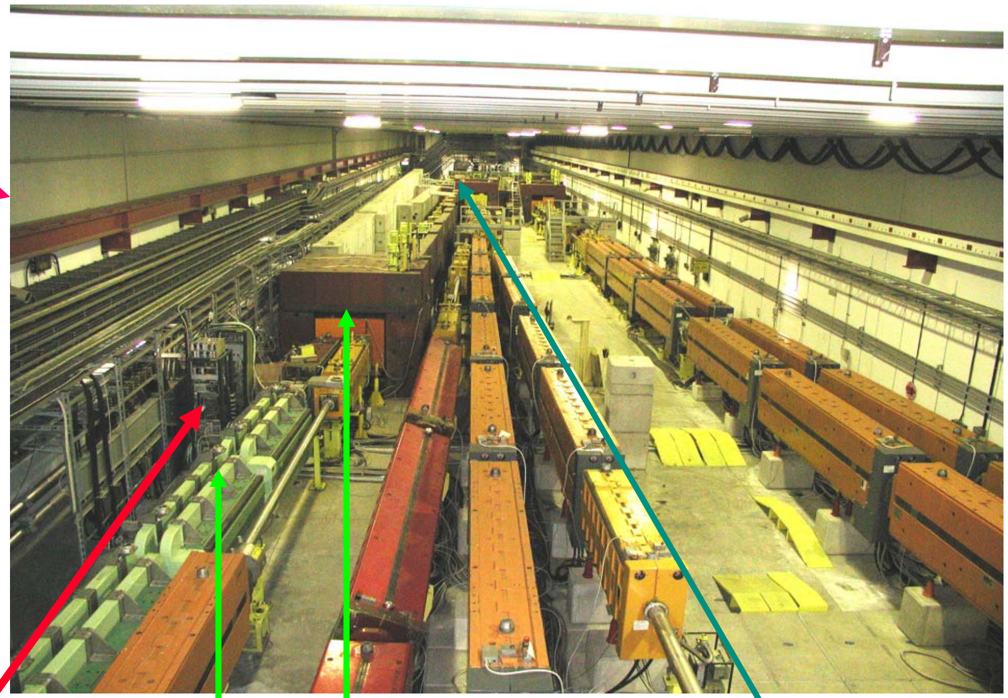
  (Displacement Effects)

- Need to know for LHC:
  - Dose = Gray (Energy Absorbed Locally per Unit Mass)
  - Hadron Flux >20 MeV

SPS - North Experimental Hall

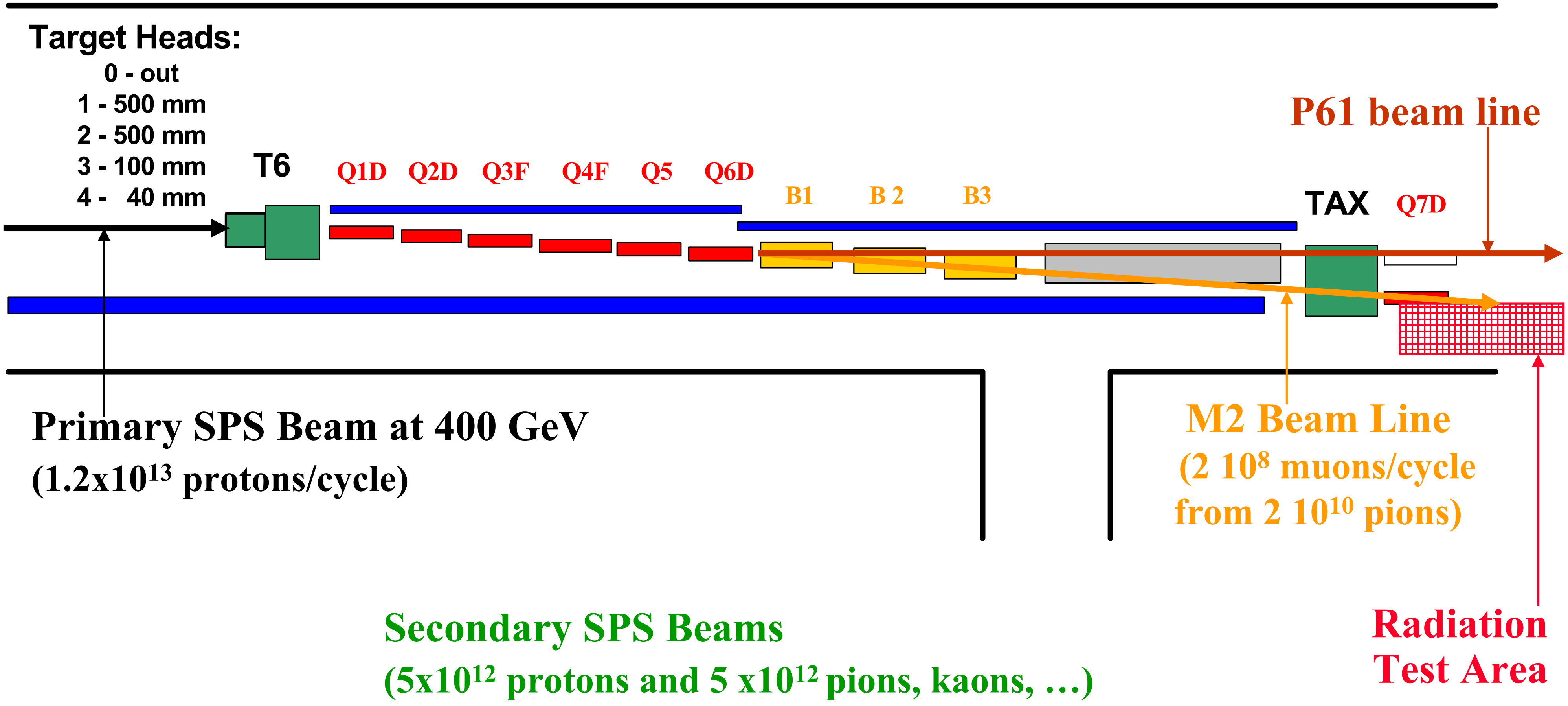


TCC2 Hall and Beam Lines



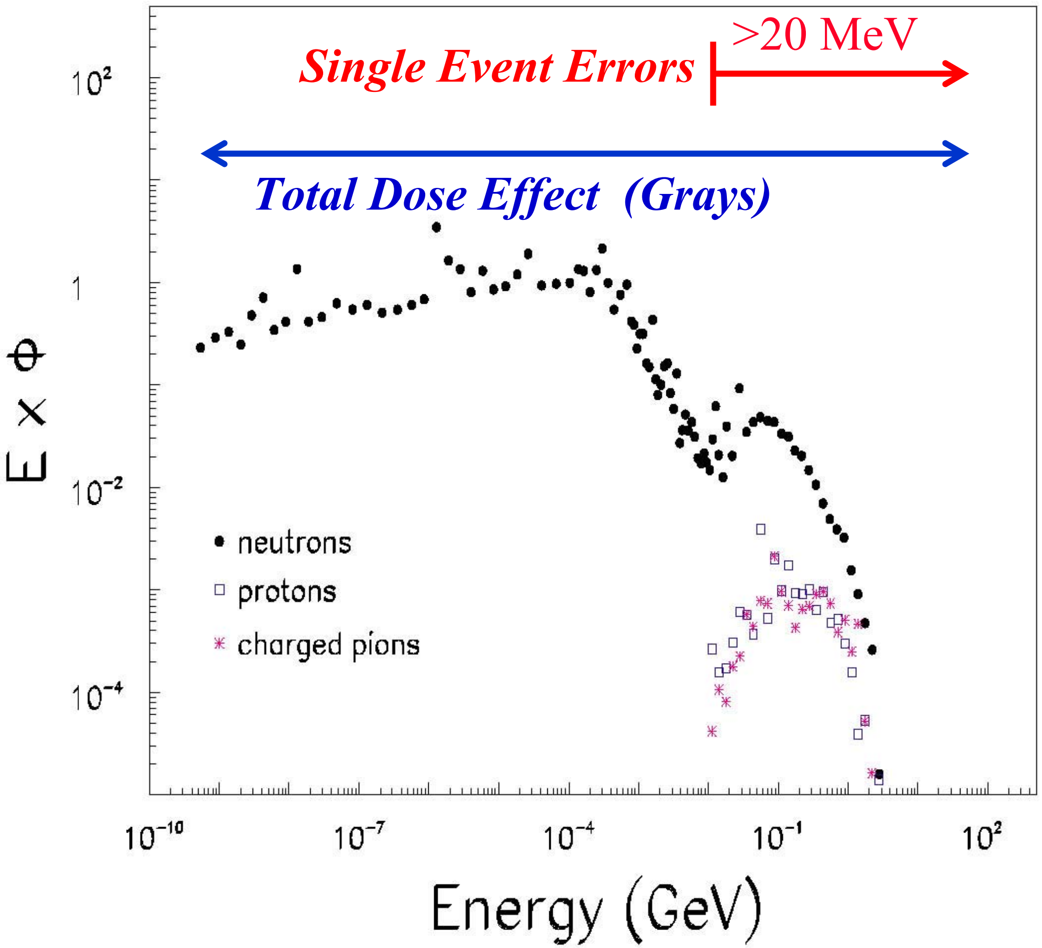
Secondary SPS Beam Lines

Lau Gatignon

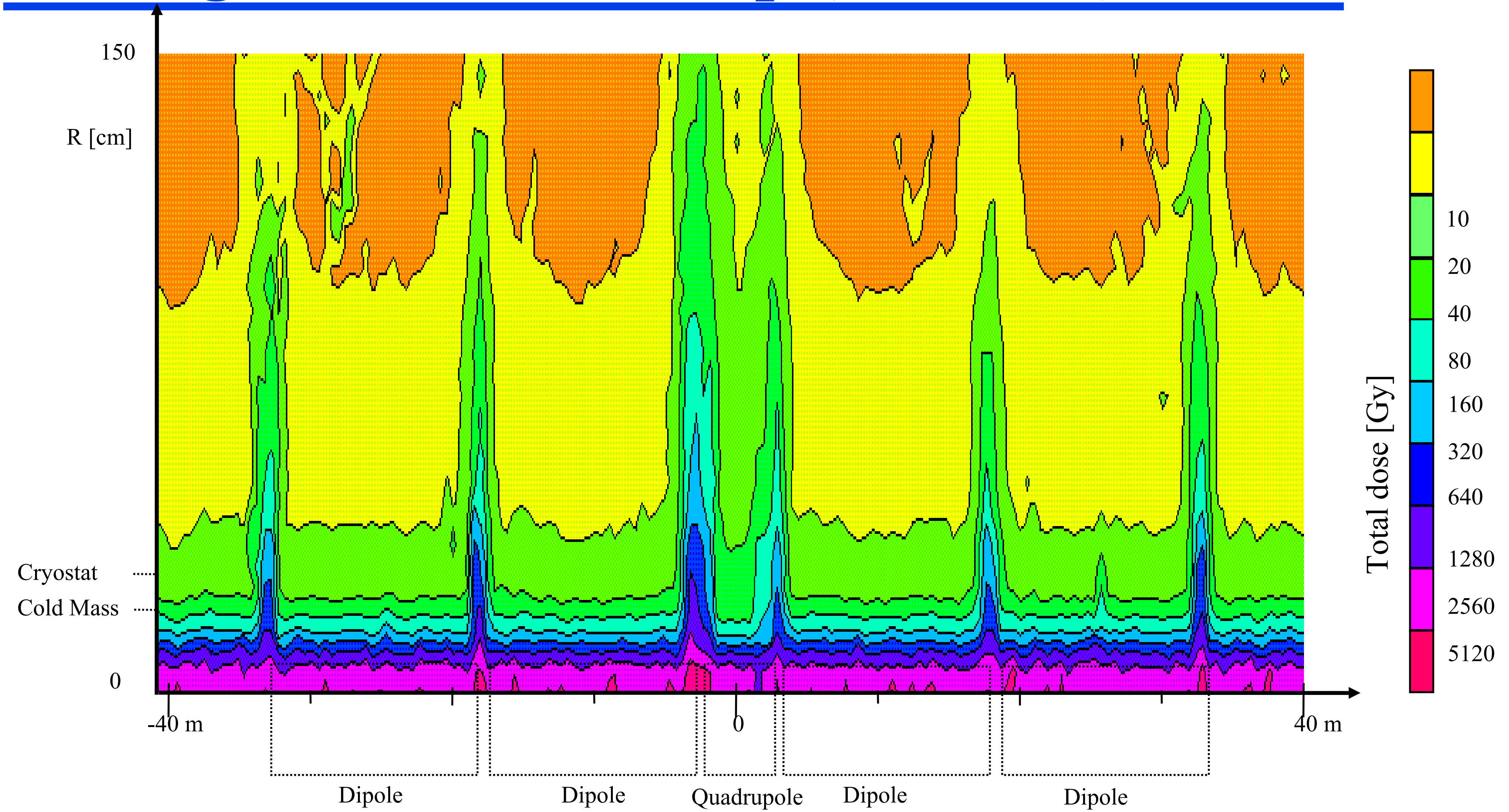


Simulated TCC2 Spectrum

Claire Fynbo



Longitudinal Dose Map (10 Years)



TCC2 Dosimetry

Daniel Perrin - TIS/RP

Active Dosimeters :

- PMI - (Protection Monitoring Induced activity)
  Designed for Personnel Protection
  - Air filled Plastic Container
  - Ionising Radiation Creates Electrons Collected by an Electrode
  - Small Current Converted in Sieverts/h (On-Line Measurement)
  - In TCC2 Risk of Saturation (Special Setting)

Passive Dosimeters :

- PAD - Polymer-Alanine-Dosimeter
- RPL - Radio Photo Luminescent
- PIN diodes - *p-intrinsic-n* Diode
  - Compact, Simple and Cheap
  - Integrate the Dose over a Longer Period
  - Need to be Taken-Out & Processed Periodically

2001 Radiation Test Campaign

- **20 Experiments Taking Data On-Line**
- **Short Presentation of 6 Experiments:**
  - Modular Power Supplies (COTS)
  - Radiation Tolerant Quench Heater Power Supply
  - WorldFIP Equipment
  - Instrumentation for Cryogenics
  - Pressure Transducers and Sensors
  - Vacuum Equipment

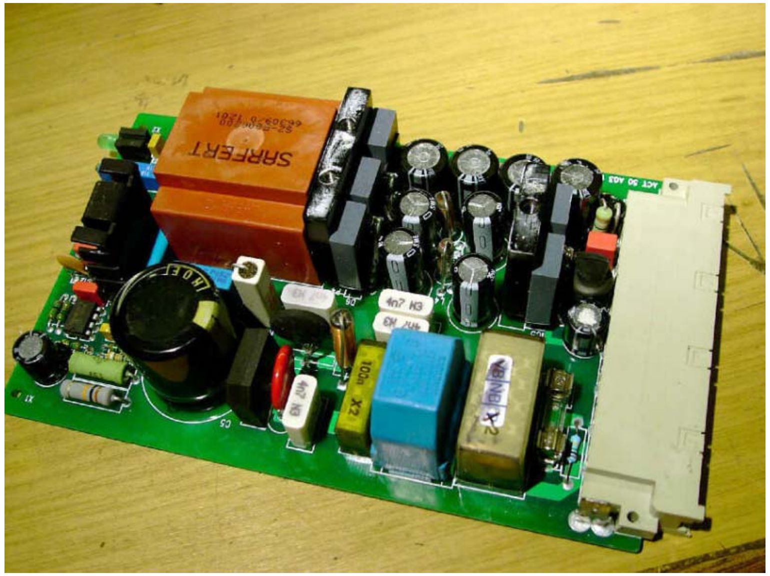
Modular Power Supplies

Denis Hundzinger - SL/PO

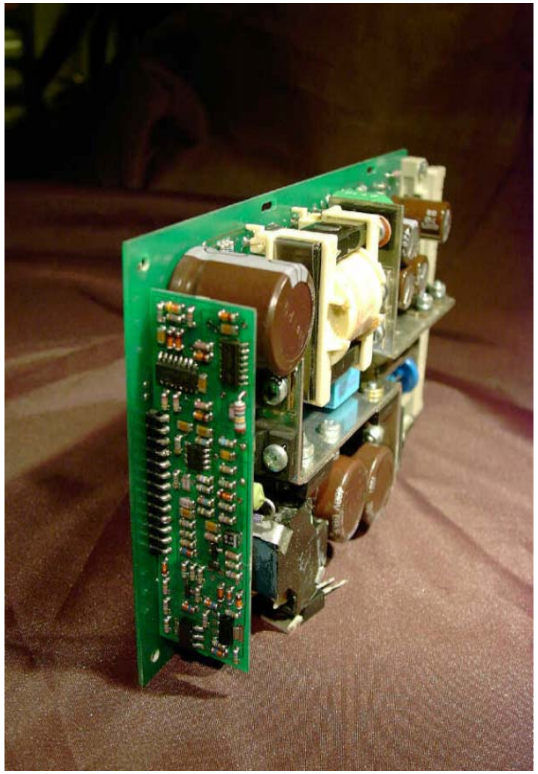
- **Test of 3 Different Technologies:**
  - Serial Regulation
  - Switching with Bipolar, Transformer Coupling
  - Switching with MOS-FET, Transformer Coupling
- **28 Units Tested – 11 Types – 6 Manufacturers**
- **Remarks:**
  - Some Units Do Not Restart after Switch-Off
  - Output Voltage Drifts With or Without Input Power

Some Examples of Power Supplies Tested

CN17BCE-T1S1



Module HUHN Open



ROS01.T22.05.50.15

Serial Regulation

Type:

- LFE 151k230 (2 Modules)

- Serial Regulation

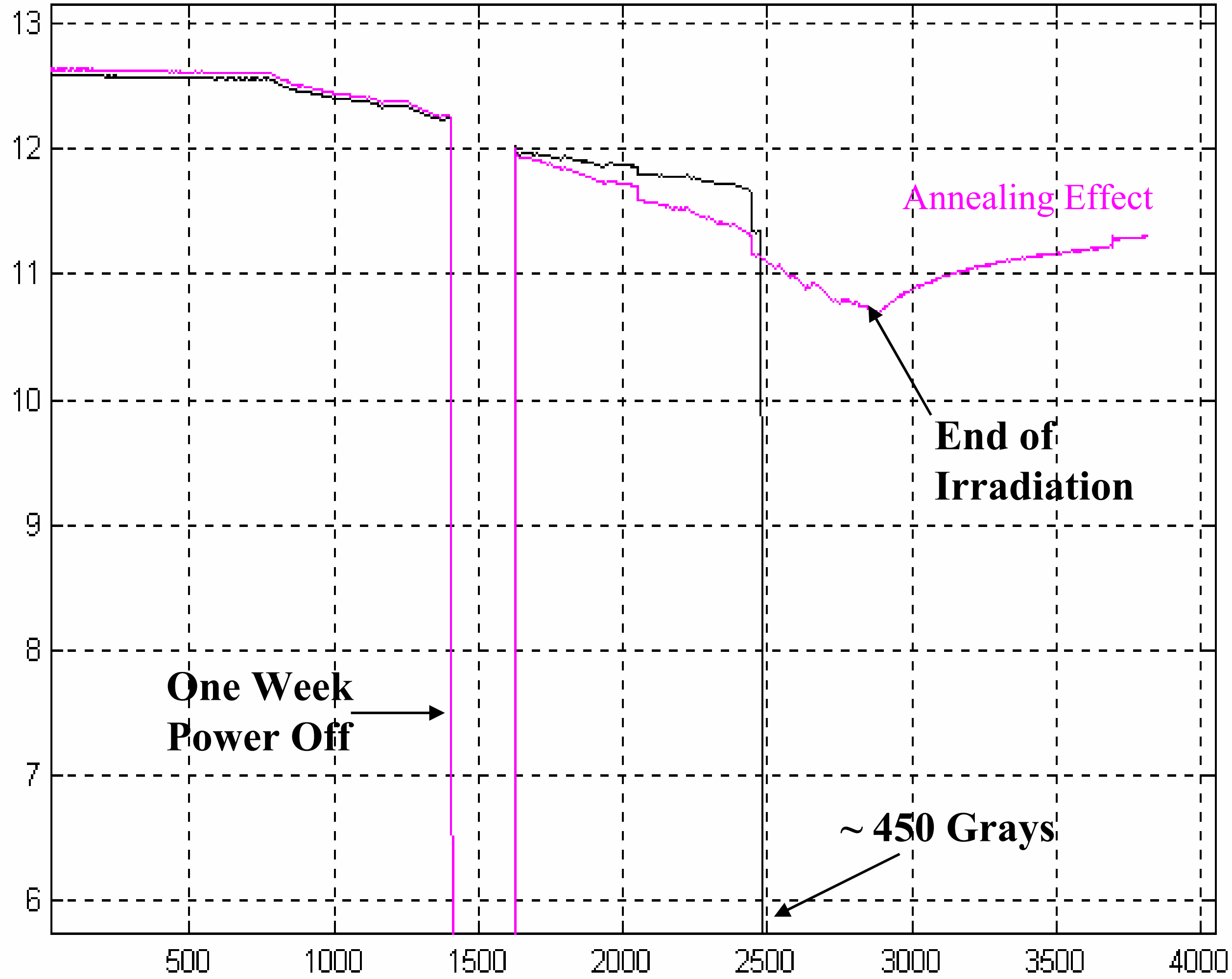
12 - 18V/1A

Notes:

- Load = 50mA

- Output Voltages Change With or Without Input Voltage

- Output Voltage (b) Restores Partially after End of Irradiation (Annealing)



Switching Power Supplies

Type:

- VERO PK55 (2 Modules)

- Triple Switching

+ 5V/5A and 2x 5-15V/1A

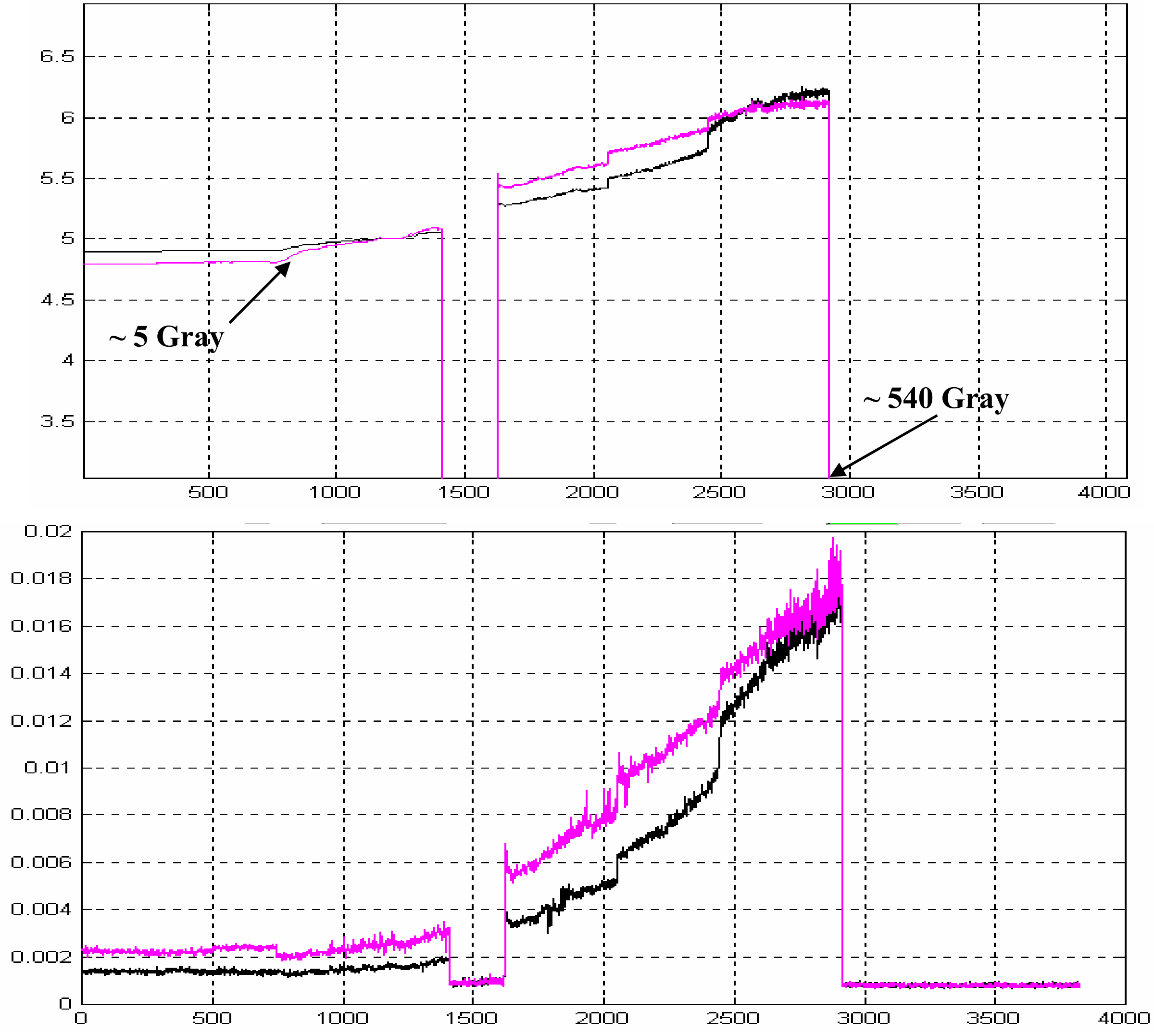
Notes:

- Measurement on 5 Volt Output Only

- Load = ~ 4 Amp

- Output Voltages increase with the Radiation Dose

- Both 5 Volt Output Voltages Start to Deteriorate at ~ 5 Grays



Switching and Transformer Coupling

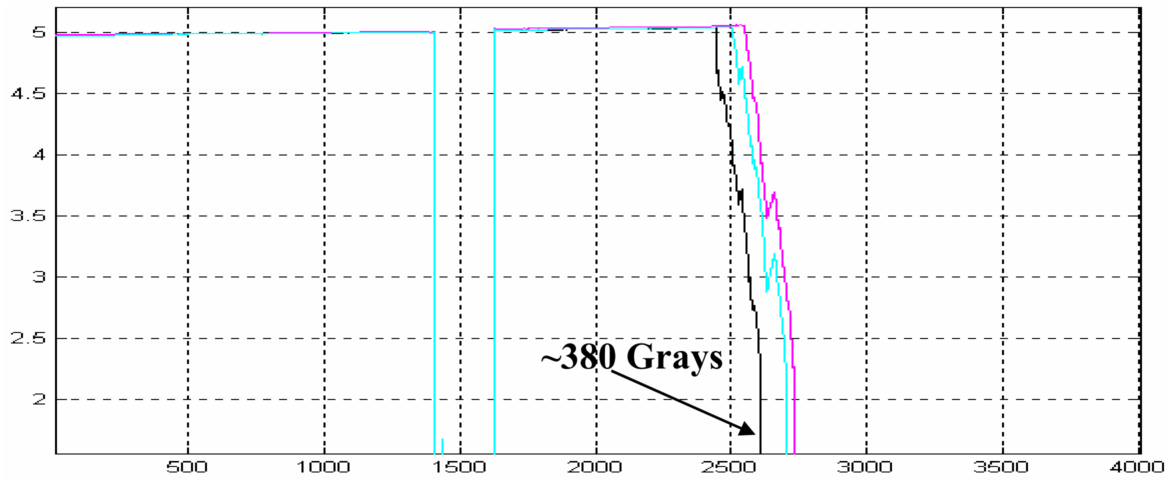
Type:

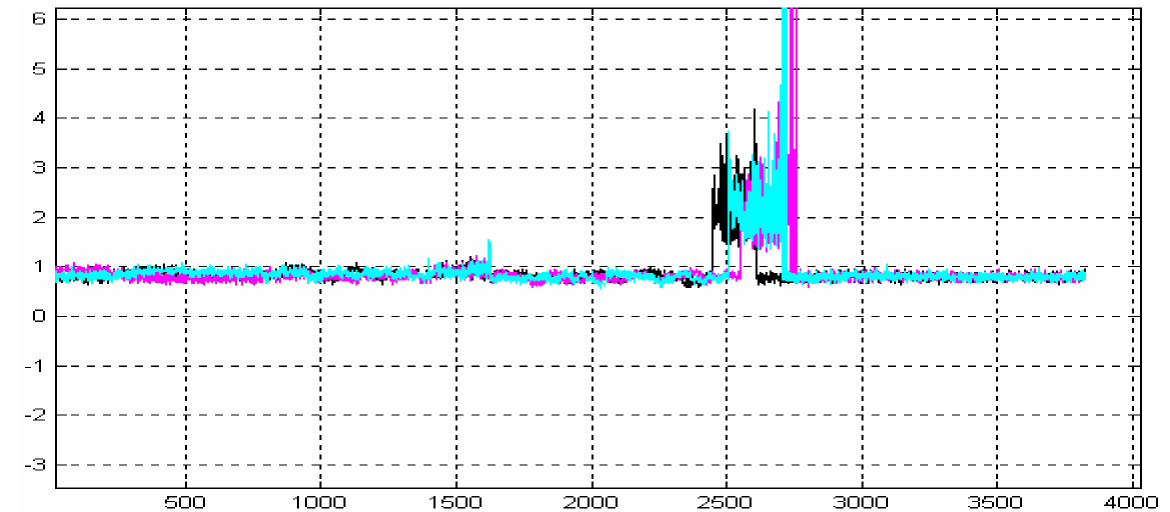
- SYKO ROS 01B 2005 (3 Modules)
- Switching, Transformer Coupling

\+ 5V/6A and + 12V/2A

Notes:

- Load = ~ 5 Amp and 1,5 Amp
- All Three Output Voltages Drop at ~380 Grays Simultaneously
- Excellent Stability
- Very Low Output Noise
- Same Results for both 5 Volt and for 12 Volt Output Voltages





Preliminary Results

- Conventional Technology (CNB up to 510 Gy)
  - Serial Regulation - (Low Efficiency)

- Switching Technology
  - Old Technology - Bipolar Transistors, Bipolar Control Circuit with Transformer Regulation Coupling (CNB up to 550 Gy)
  - Modern Technology MOS-FET
    with Transformer Regulation Coupling (SYKO up to 380 Gy)

- Possibility to Select Good COTS General Purpose and Modular Power Supplies

Development of a Radiation Tolerant Quench Heater Power Supply

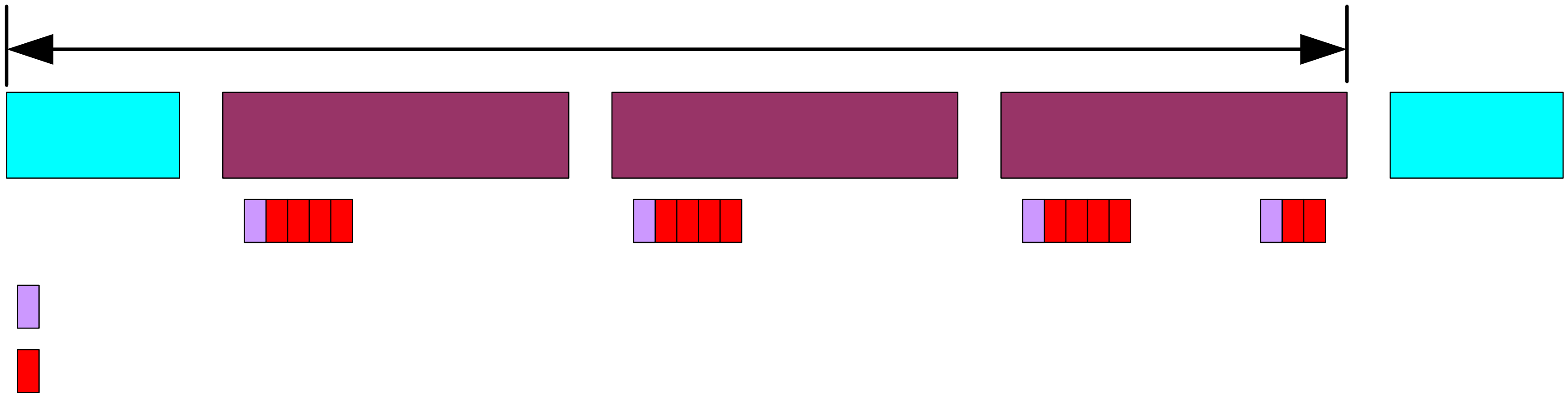
Reiner Denz - LHC/ICP

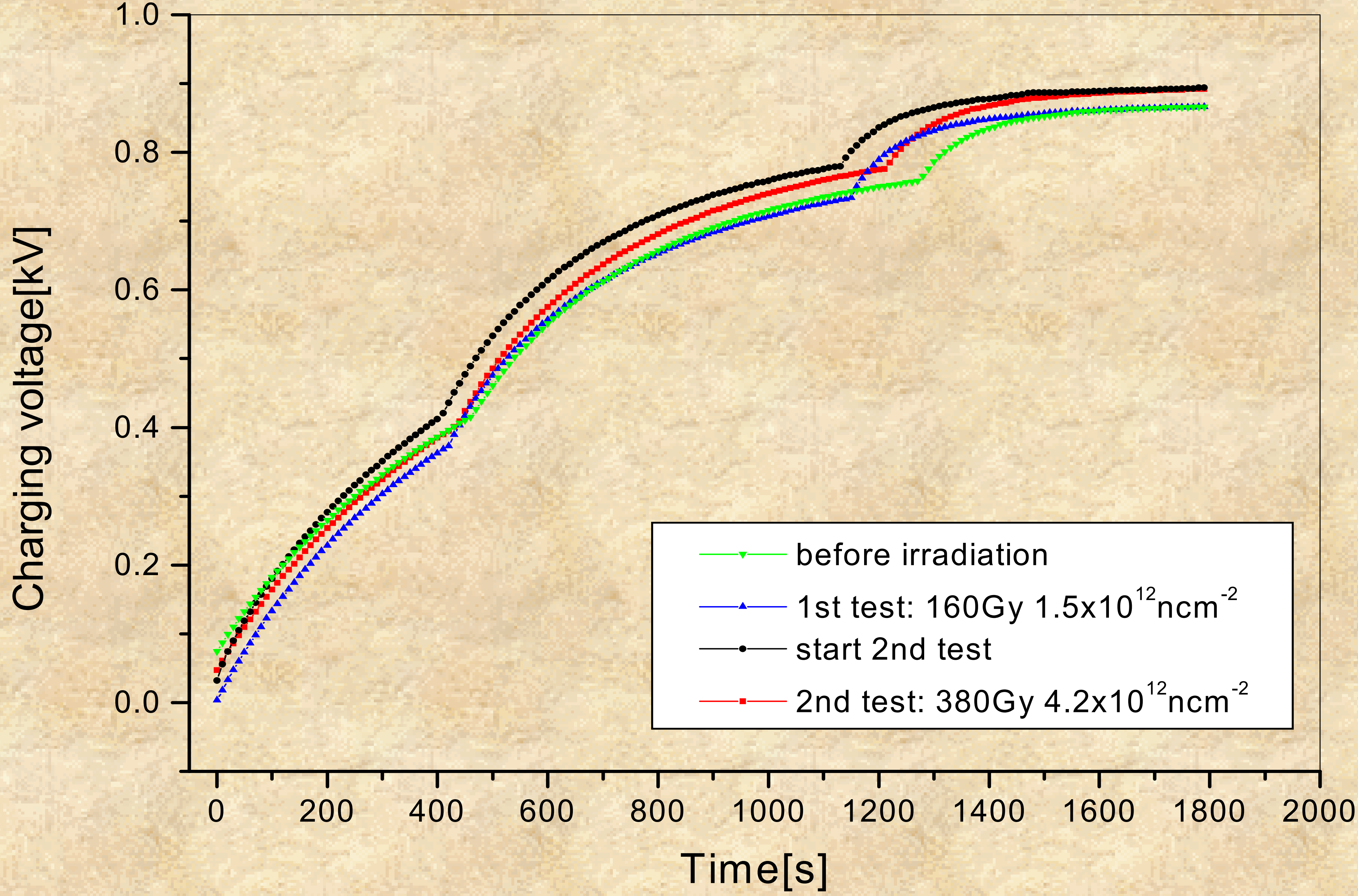
- In-house design using COTS
- About 6200 units in LHC
  - Energizes quench heater strips in case of a magnet quench.
  - 4 units per MB, 2 units per MQ
  - ~ 6000 to be installed under the main dipoles in the regular arc and the dispersion suppressors
  - ~ 200 in UA, UJ …
- Useful lifetime ~15 to 20 years
- Minimum radiation tolerance required:
  - 200Gy and 2 x 10^{12}ncm^{-2}

Test Strategy

- Identification of critical components
  - Aluminium electrolytic capacitor
  - Phase control thyristor
  - Isolation amplifier
  - Miscellaneous semiconductors
- Selective test of these components
- Test of sub-units
  - I.e. trigger circuit
- Test of prototype devices
  - Prototype HCDQHDS001-CR000001 tested in TCC2
- Batch test of qualified components
- Test of pre-series & series devices

Tunnel Location of Rad-Tolerant Electronics





Courtesy of Reiner Denz –LHC/ICP

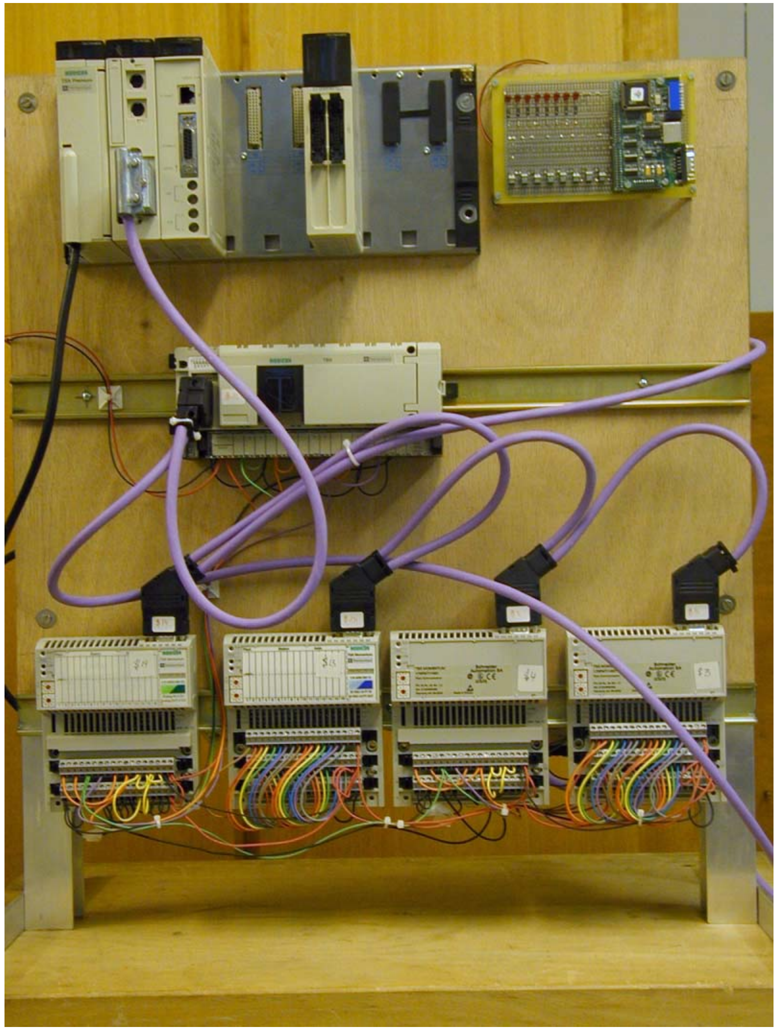
Preliminary Results

- Design and Construction of Radiation Tolerant Quench Heater Power Supply using COTS is Feasible.
- Phase Control Thyristors are the Weak Point of the Device.
- Batch Tests of Selected Components are Necessary.
- Qualification of other MP Equipment to be Continued.
- Life after LHC:
  - ~ 6200 Units Represent about 90 Tons of Non Combustible Potential Radioactive Waste.
  - The Modular Construction Allows Easy Dismantling and Separation of Metallic from Electronic Components.

WorldFIP Equipment

- **Test of Standard Industrial COTS Equipment:**
  - 2 x TBX Modules 16 Digital Output
  - 2 x TBX - 16 Digital Input + 16 Digital Output
  - 2 x TBX - 8 Analog Input + 8 Analog Output (10 Bits)
  - 2 x Momentum Modules 16 Digital In. + 16 Digital Out.
  - 2 x Momentum - 8 Analog In. + 16 Analog Out.
- **Test of WorldFIP Interfaces:**
  - 2 x FULLFIP2 Components in TCC2
  - 6 x MicroFIP Daughter Board (CC131-Modules in TCC2)
  - 3 x MicroFIP (CC131-Modules at UCL in Louvain (B))

PLCs and WorldFIP Interface



WorldFIP Preliminary Results

Tests Results:

- 1998 Test : Static Test on FULLFIP2 Component

  Radiation: OK at 220 Grays.

- 1999 Test : On-Line Test with MicroFIP Technology in TTC2

  Radiation : OK at > 650 Grays

- 1999 Complementary Test on 5 MicroFIP Modules (SL/PO)

  => Same results, Error Rate : 1/500byte/day

- 2000 Complementary Test on 3 MicroFIP Modules (LHC/ACR)

  UCL Louvain (60 Mev Protons - $2*10^{8}$ p/cm^{-2}/s)

  Radiation: All Boards Survived to a TID of 700 Grays ($5*10^{11}$ p/cm^{-2})

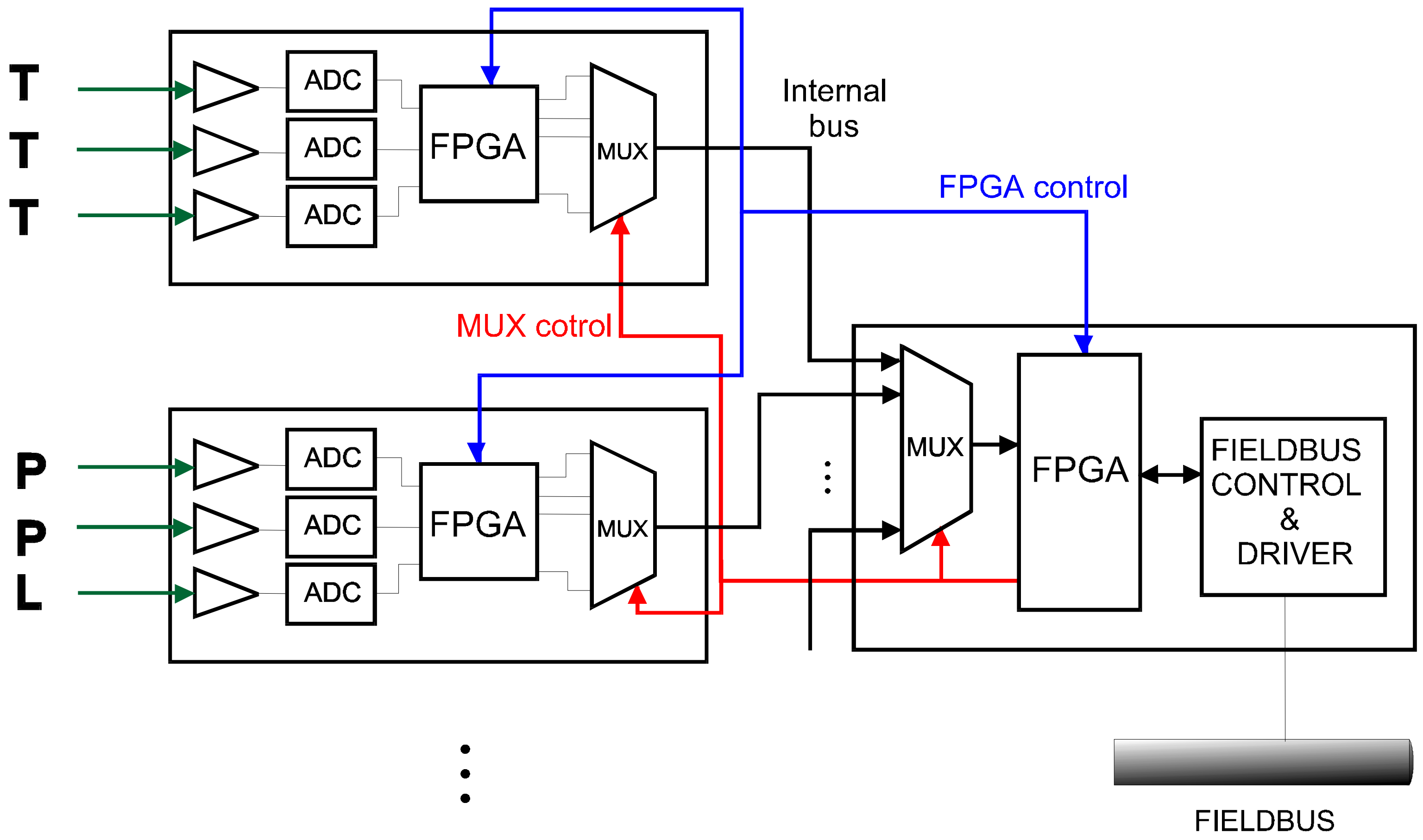
Radiation Qualification of Components:

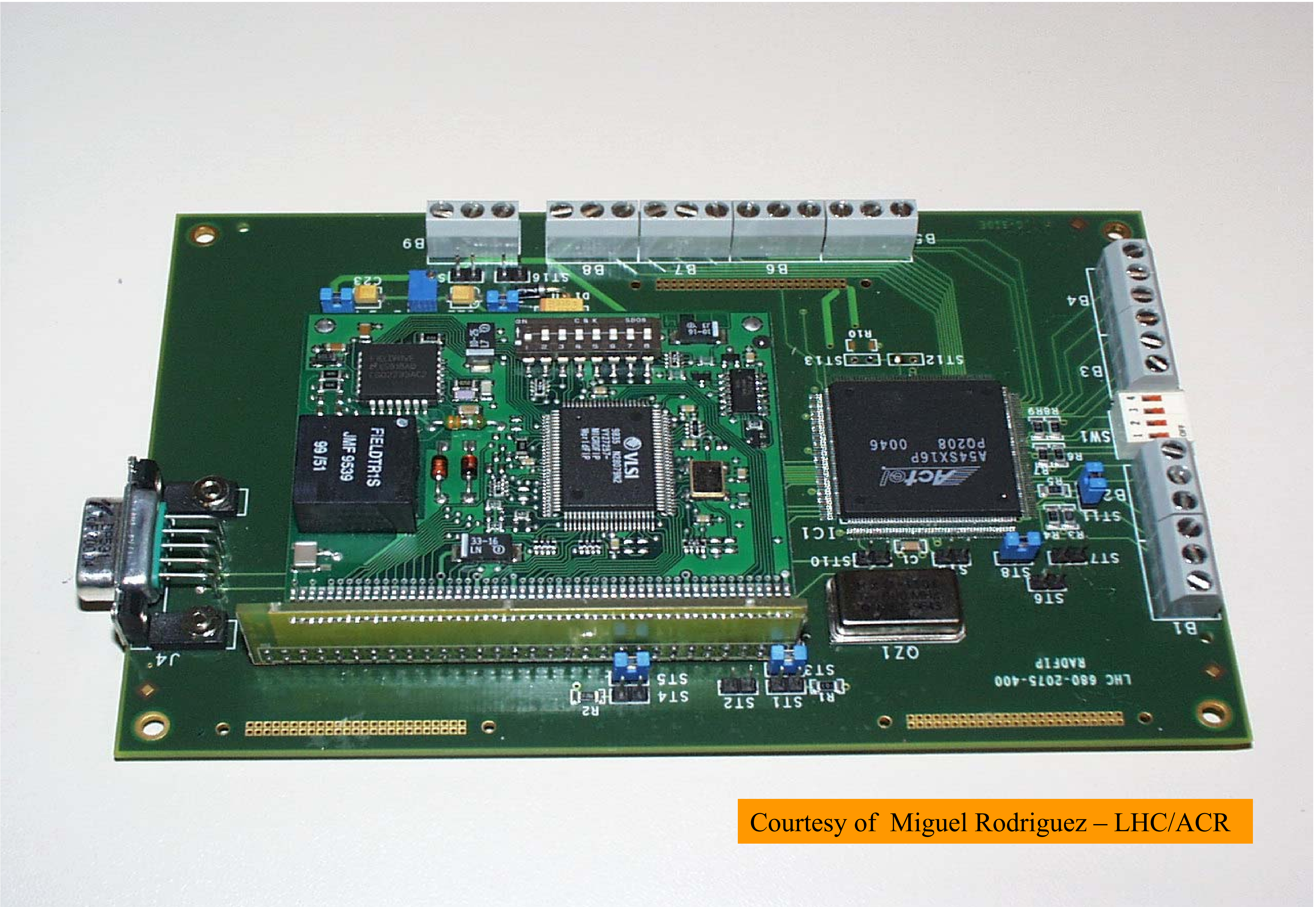
- Conditioners, OP Amplifiers, ADCs, MUXs, FPGAs,
- Fieldbus Controller, Power Supplies

Digital Transmission via WorldFIP

- MicroFIP ASIC Link Sensors & Actuators to PLCs
- 120 Bytes of Internal Memory for Process Data
- Include Galvanic Isolation by Transformer
- FPGA Used to Control Access to MicroFIP Registers

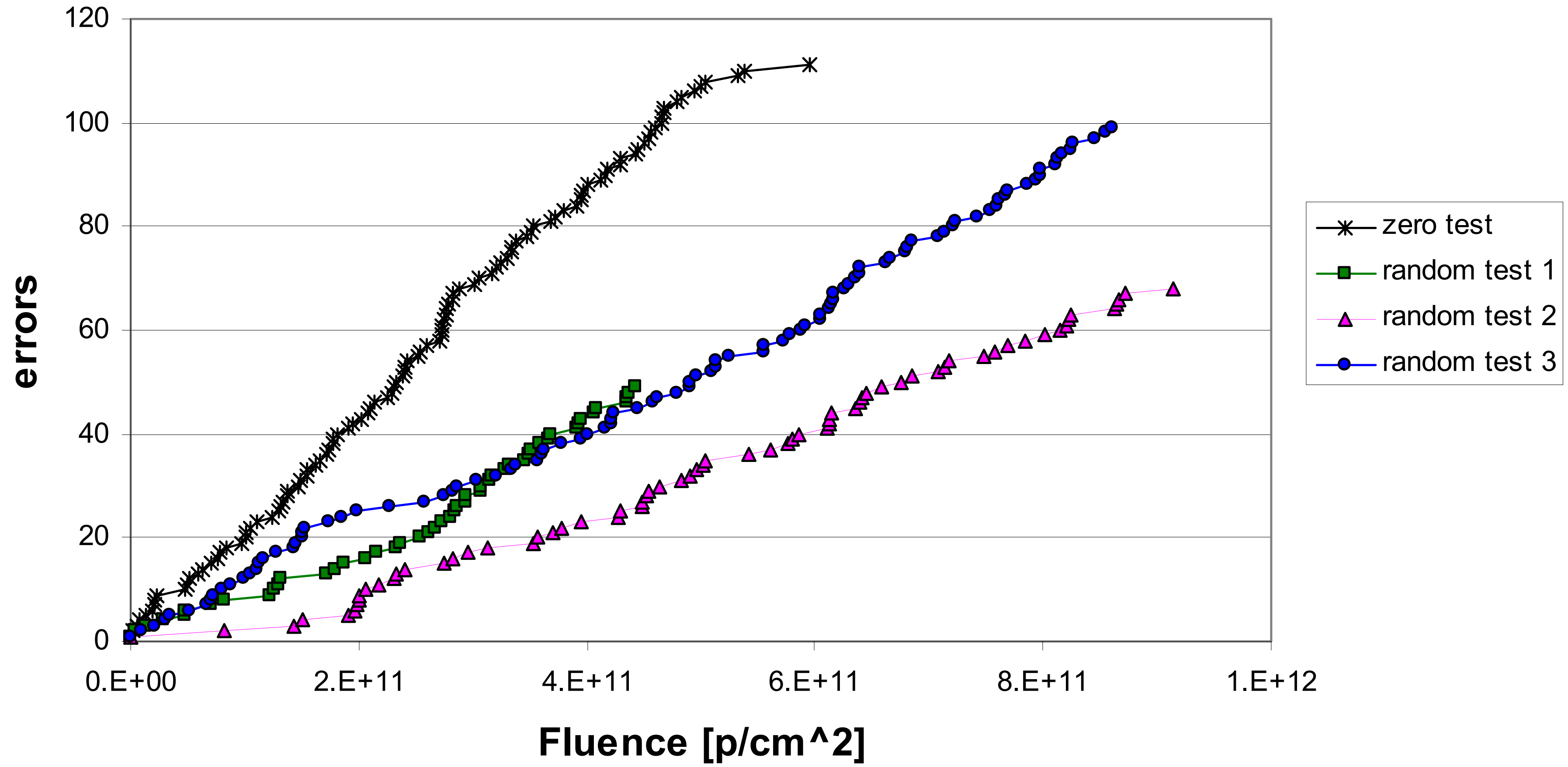
Type of Equipment



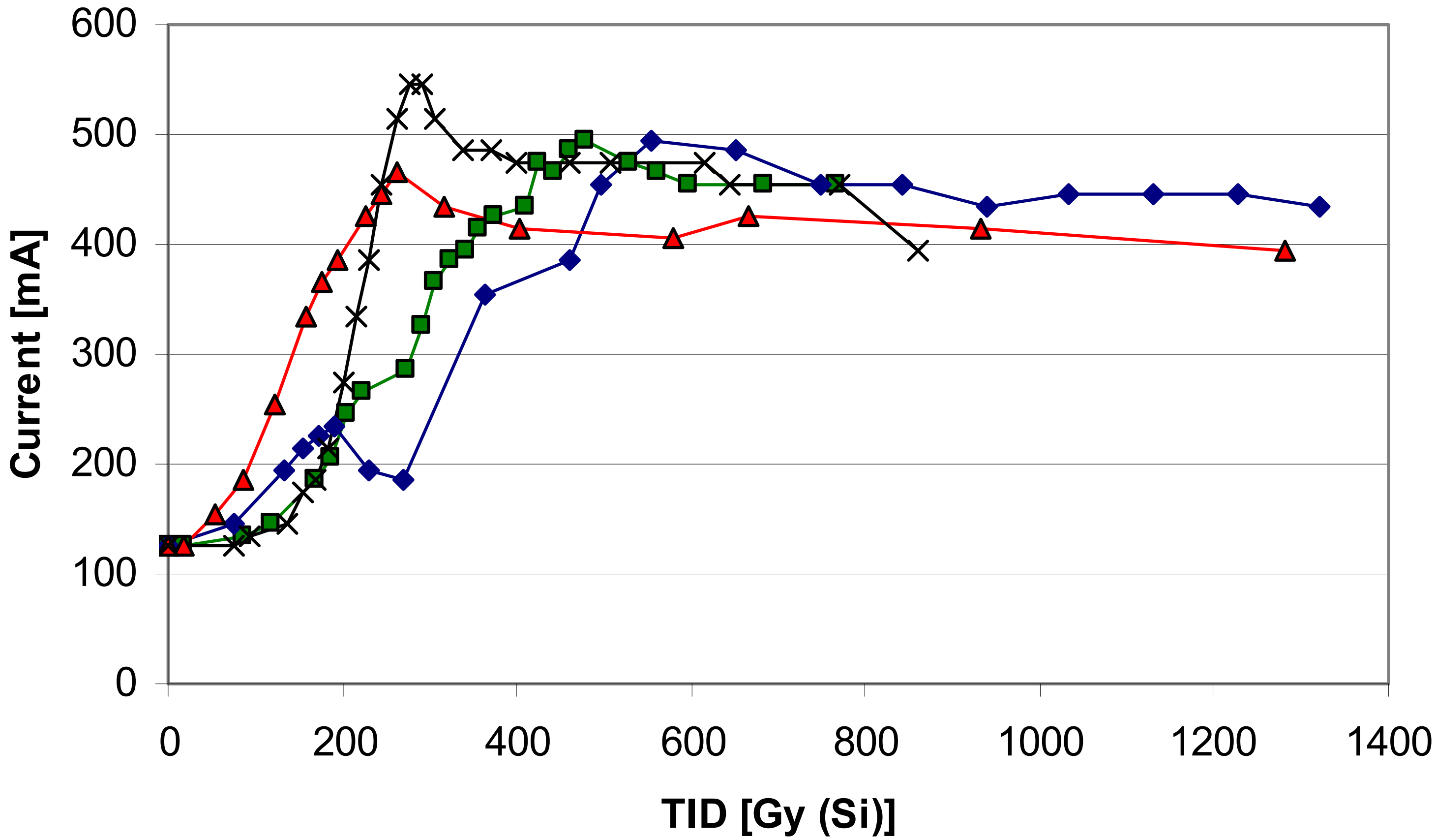


Courtesy of Miguel Rodriguez – LHC/ACR

Memory State Changes



Effect on Current Consumption



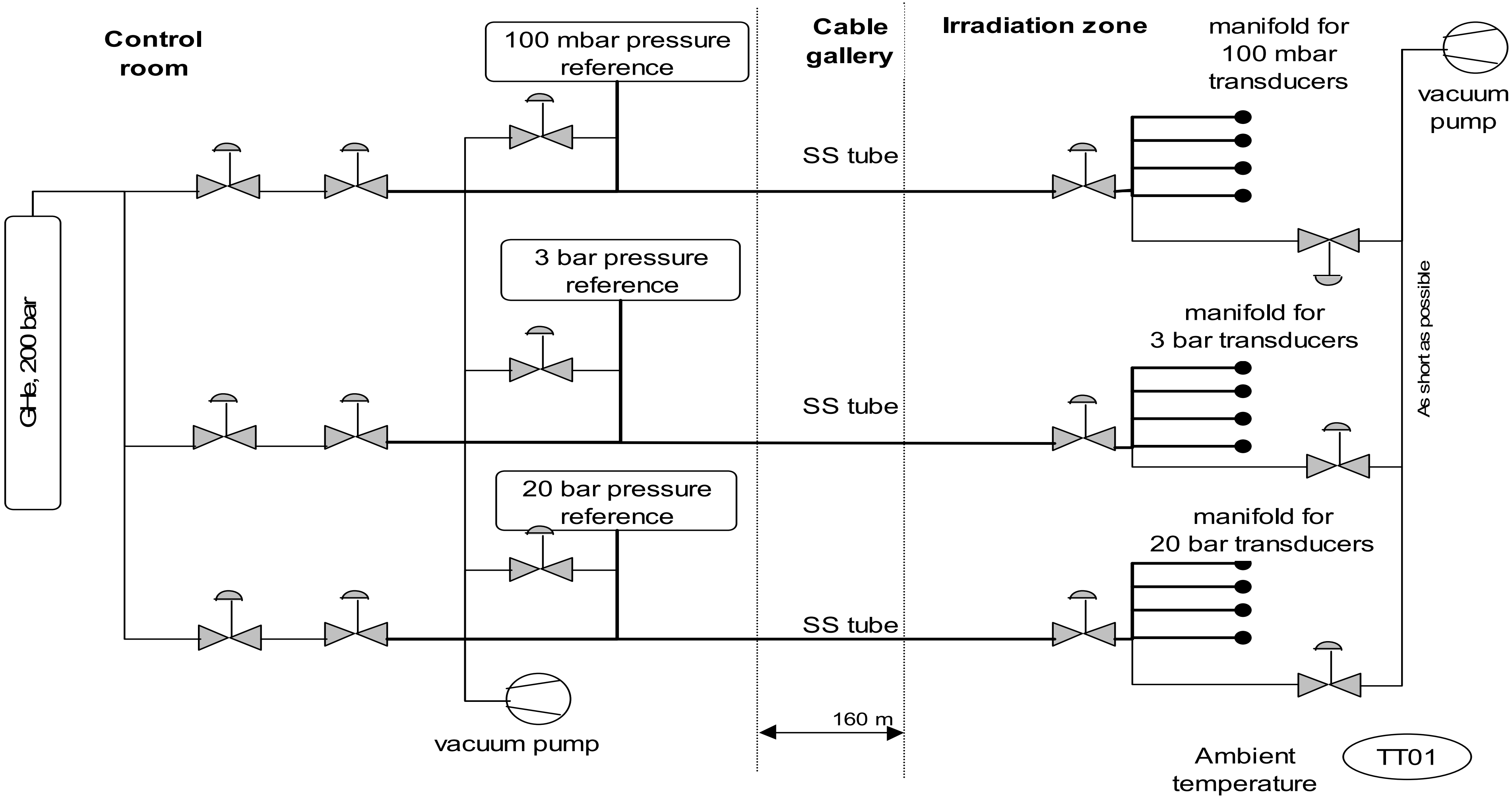
Preliminary Results

- **Radiation Tests Done on MicroFIP:**
  - At CERN in TCC2 for Total Ionizing Dose (TID)
  - At UCL Cyclotron Louvain (B) for Single Event Effect (SEE)

    (Proton Intensity 2 10^8 p.cm^{-2}.s^{-1} & Proton Energy 60 Mev)
  - Test of 4 MicroFIP Boards (C131 Type)
  - Duration of Irradiation: 1 Hour
- **Results:**
  - All boards survived to a TID of 700 Grays (5 10^{11} p.cm^{-2})
  - No Latch-Up detected
  - Some Memory Cells Transitions
  - One Single Hard Error Involving a Reset

Pressure Transducers and Sensors

Troels Bager - LHC/ACR

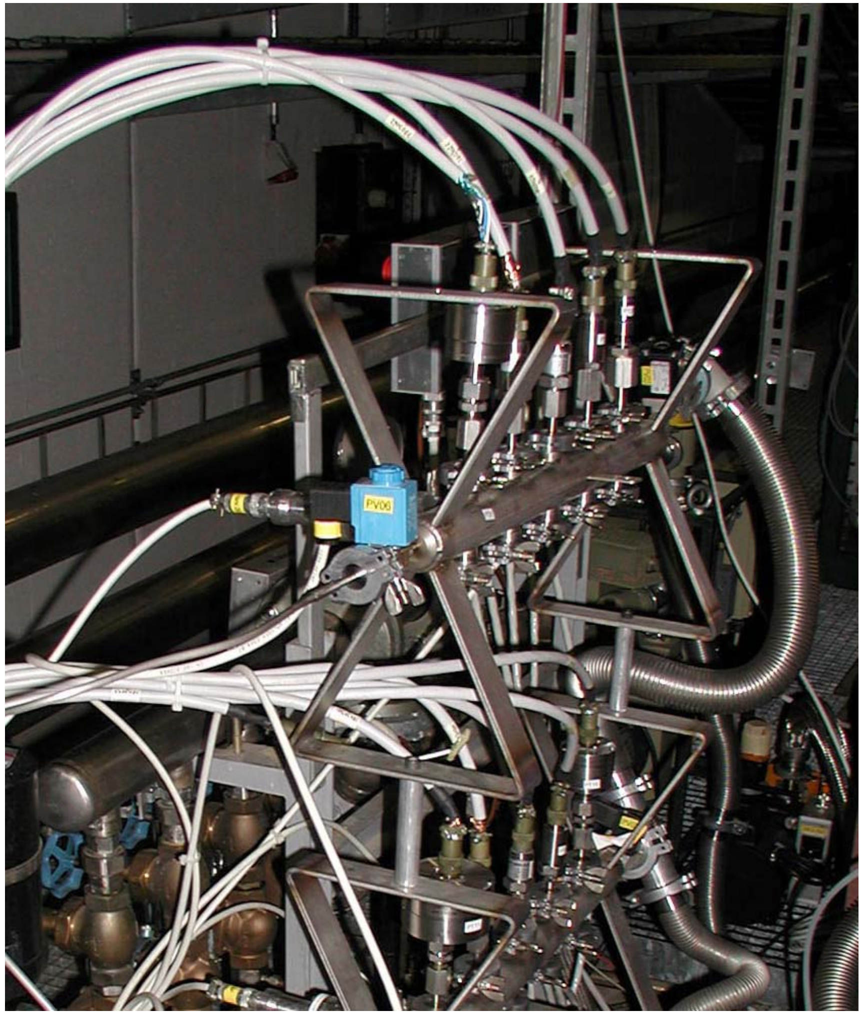


Installation for Pressure Sensors Tests

<- Measurement
at the Surface

<- 160 m ->

Sensors in the
Test Area ->



Summary of Test Results

Manu-facturer	Type	Technology		Failure type	Dose at Failure
Rosemount	2088/3051	SS membr., oil, piezo resist SG chip	integ. 4-20 mA, HART	SEE, later drift --> sat	
Keller	PAA-23	SS membr., oil, piezo resist SG chip	integ. 4-20 mA	drift --> sat	0 Gy
Kistler	RAG 50	SS membr., oil, piezo resist SG chip	integ. 4-20 mA	drift --> zero, later suddenly zero	0 Gy
Haenni	ED 510	piezo resistive SG chip	integ. 4-20 mA	drift --> zero	0 Gy
Druck	PDCR 314	piezo resistive SG chip	integ. amp., 0 - 1 V	drift --> zero	0 Gy
Baumer	PDAB	SS membr. no oil, metal thin film SG	integ. 4-20 mA	drift --> zero	0 Gy
Trafag	8893	SS membr. no oil, DIVIS SG glued	integ. 4-20 mA	drift --> zero, later suddenly zero	0 Gy
Effa	LPX 2380	2 coils, inductance	integ. 4-20 mA	drift --> zero	0 Gy
E+H	PMC 131	Al_20_3 membr.,no oil, capacitive.	integ. 4-20 mA	drift --> zero, later suddenly sat.	0 Gy
Effa	LPR 2000	metal membr, change induct. of 2 coils	56 kHz, remote elec.	no failure	>1000 Gy
HBM	P8AP	SS membr. no oil, metal thin film SG	0 - 20 mV/V remote elec.	no failure	>1000 Gy
Baumer	PDAA	SS membr. no oil, metal thin film SG	0 - 20 mV/V remote elec.	no failure	>1000 Gy

Vacuum Equipment

Christian Billy - LHC/VA

- **Type of Equipment under Test :**
  - - PLC SIEMENS S7/215
  - - BALZERS Gauges (2xPKR251, PKR265)

    With Integrated Control Electronics
  - - EDWARDS Gauge AIM-X (Penning) and WRG-S Gauge (Combined Pirani-Penning) with Integrated Electronics
  - - Turbo-Molecular Pump Controller ALCATEL ACT/600
  - - Ion-Pump Power Supply Unit

Courtesy of Jean Christian Billy – LHC/VA

Preliminary Results

● PLC - First Error (Isolated Effect)	at < 1 Gy
- After Reload, Systematic Memory Error 4-8sec.	5 Gy
- No Reply	20 Gy
● Edwards Gauges (With Integrated Electronics)	
- Gauge AIMX-X	50 Gy
- WRG-S	1000 Gy
● Balzers Gauges	
- 2 Gauges PKR 251	290 Gy and 430 Gy
- 1 Gauge PKR 265	450 Gy

Preliminary Results

- Turbo-Molecular Pump Controller Alcatel ACT/600
  - No More Remote Control at 20 Gy
  - Turbo Pump OK up to, then Stop 50 Gy
- Ion Pump Power Supply (Two Parts)
  - High Voltage Part (With BYW 96 Diode) > 1000 Gy
  - Controls Part (+/-15V, +24V,+7V) 200 Gy

Failing Components but Possible Improvement:
LM317LZ Regulator and OP-400GP Op. Amplifier

- Positive Results: - One Type of Electronic Gauge
  - Ion Pump Power Supply
- Negative Results: PLC and TMP Controller

Lessons Learned

- **Electronic Equipment that Will not Work Reliably in the LHC Tunnel:**
  - Intelligent Sensors and Actuators (Few Exceptions)

    (Remote Electronics and Cables Required)
  - Complete Industrial PLCs (COTS)
  - Intelligent I/O Modules (COTS) with Micro and Memory
  - Conventional Switching Power Supplies (NMOS)
  - Processors Without Error Correction Memory

Lessons Learned

- **LHC Electronic Equipment That Needs to be Tested or Selected before Installation:**
  - Passive Components (Optical Fibers, Resistors, Capacitors)
  - Active Components (Signal Conditioners, MUXs, Op.-Amp., ADCs, DACs, FPGAs, EPROMs SRAMs with EDAC)
  - Sensors, Actuators, Gauges, Positioners,Valves, Flowmeters
  - Modular Power Supplies (Serial Regulation, Bipolar Transistors, Transformer Coupling Feedback, No OptoCouplers)

Lessons Learned

- **RadHard Developments are Required for:**
  - Simple Input/Output Modules with Fieldbus Interfaces to WorldFIP or Profibus (Command/Response Operation)
  - Dedicated Power Supplies (Quench Protection)
  - Orbit Corrector Power Converters
  - Control Processors with EDAC Memory and Remote Reset Capability.

Conclusions

Results Obtained So Far Suggest that ALL Electronic Systems, Intended for Installation in the Tunnel, Should be Radiation Qualified

The Radiation Test Facility is Qualified to Provide a Radiation Environment
Similar to That of the LHC Tunnel (Arcs)

The On-Line Test Facility can be Used for the Final Qualification of Complete Working Systems