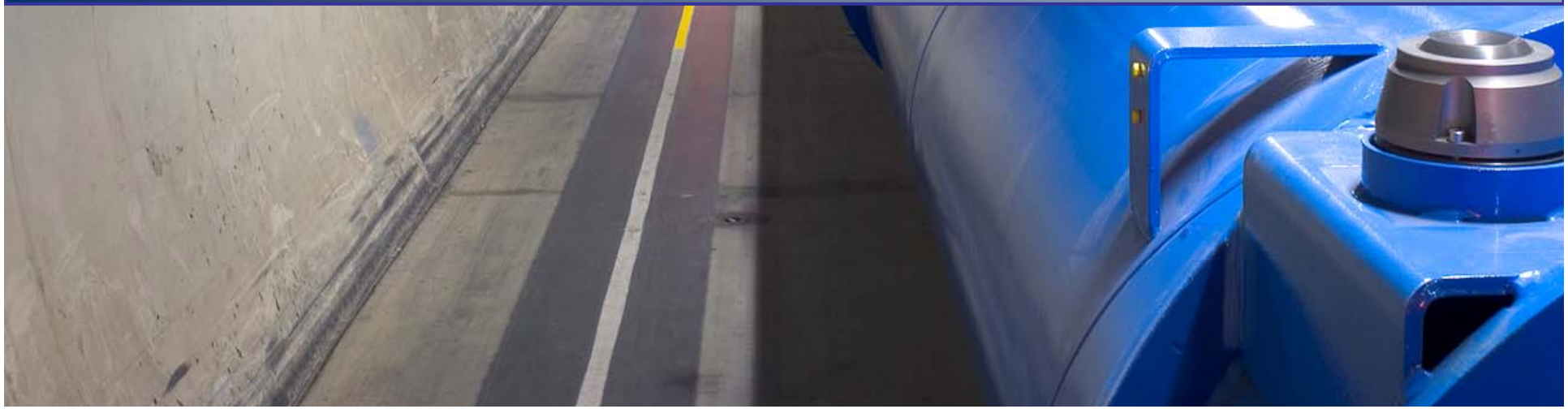
SEE testing of the LHC Beam Interlock System

BT/BP/RS AB/CO/MI

6th LHC Radiation Workshop 29th November 2007



Testing the Beam Interlock System

1. The Beam Interlock System
   - Electrical and Physical Architecture
   - Component Locations
   - Design for Durability
   - Scope of the Tests (CIBD and CIBU)

2. Power Supply Tests and Results
   - Detailed Description of the Power Supply
   - Test methods
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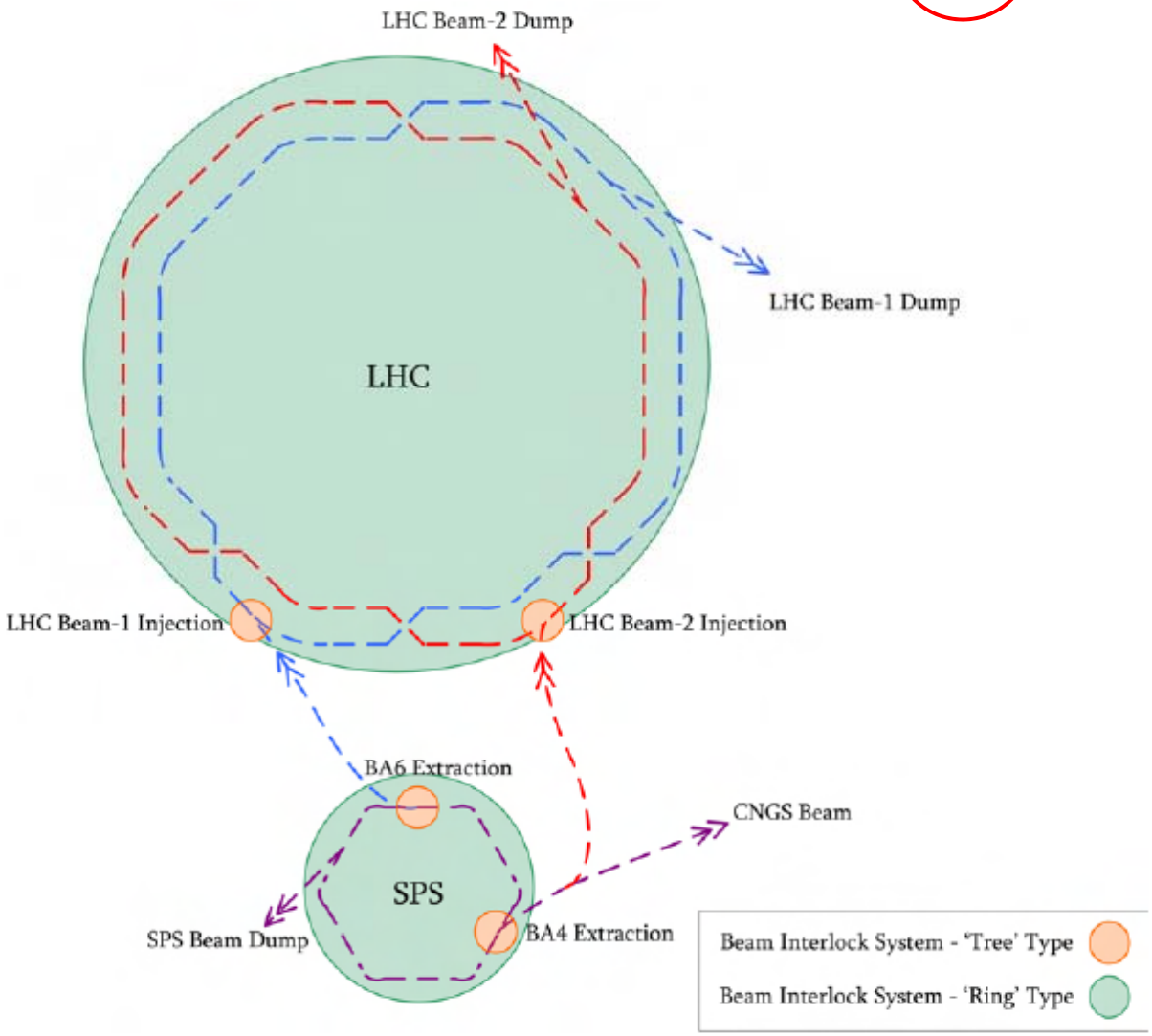
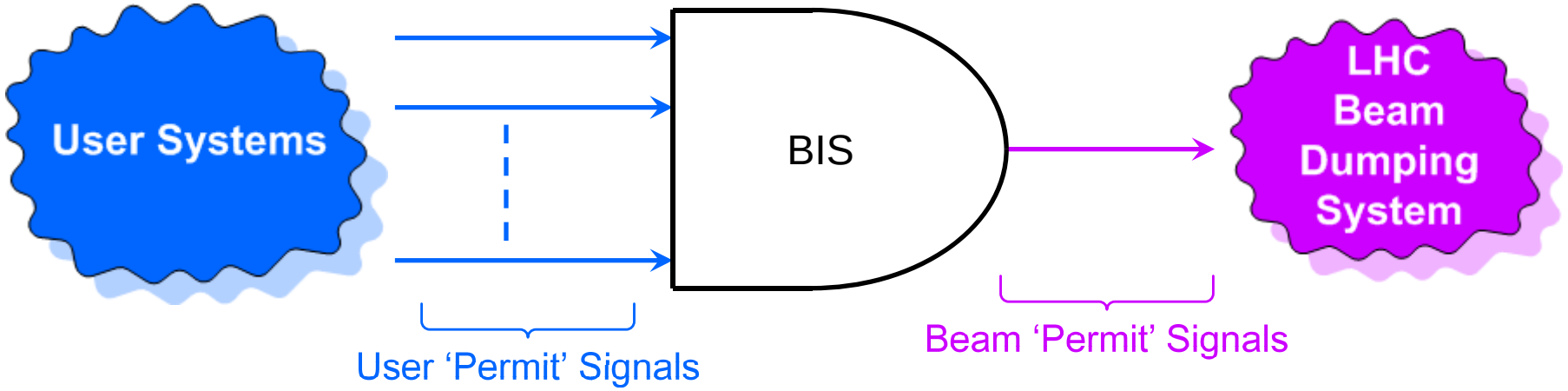
Beam Interlock System Locations

Designed to protect CERN high energy accelerators = SPS / LHC / INJ / EXT



LHC Function



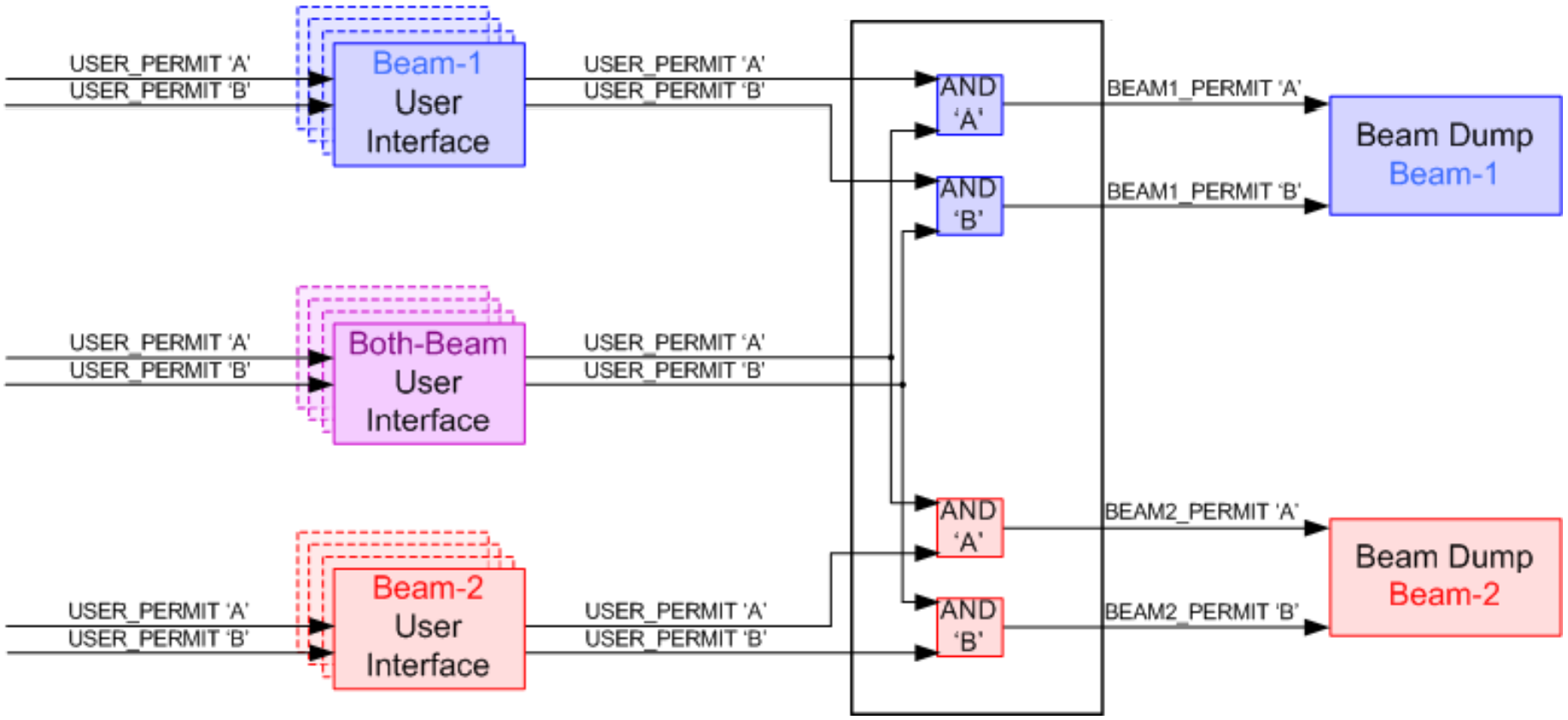
~200 connections to User Systems distributed over 28kms

LHC has 2 Beams

Some User Systems give simultaneous permit — Both-Beam

Others give independent permit — Beam-1, Beam-2

Signals


USER_PERMIT 'A'
USER_PERMIT 'B'
Beam-1
User
Interface
USER_PERMIT 'A'
USER_PERMIT 'B'
AND
'A'
AND
'B'
BEAM1_PERMIT 'A'
BEAM1_PERMIT 'B'
Beam Dump
Beam-1
USER_PERMIT 'A'
USER_PERMIT 'B'
Both-Beam
User
Interface
USER_PERMIT 'A'
USER_PERMIT 'B'
USER_PERMIT 'A'
USER_PERMIT 'B'
Beam-2
User
Interface
USER_PERMIT 'A'
USER_PERMIT 'B'
USER_PERMIT 'A'
USER_PERMIT 'B'
AND
'A'
AND
'B'
BEAM2_PERMIT 'A'
BEAM2_PERMIT 'B'
Beam Dump
Beam-2

Electrical Architecture

USER SYSTEM rack

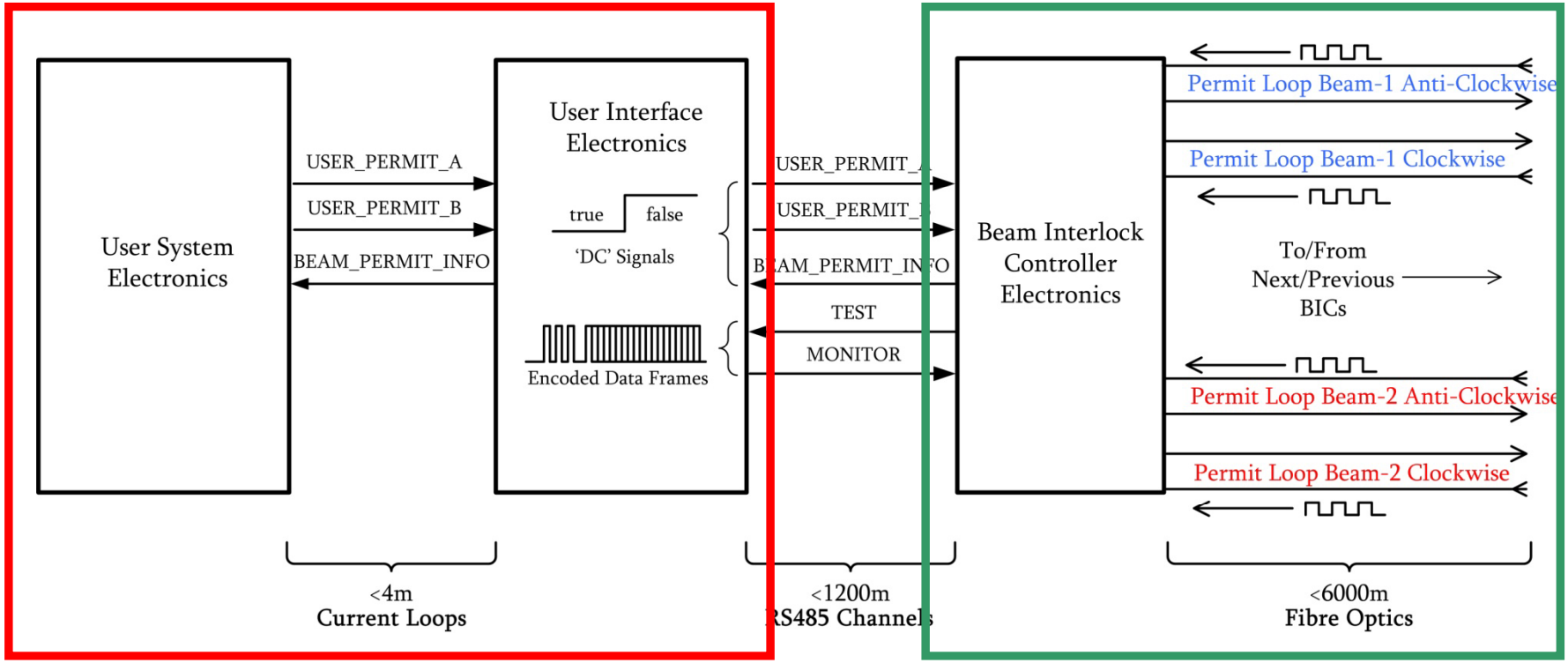
"some radiation"

Worst = UJ76-type

In INTERLOCK rack

"negligible radiation"

Typical background at Sea Level



2U Chassis

VME Chassis

Dependable Design

1. Critical Function separate (fewer critical circuits)
2. Failure Modes Analysis (weaknesses designed out)
3. Xilinx CPLD proven (AB/PO)
4. 5V and redundant PSU (Highly Available)
5. Mature Electronics (Not risky!)
6. Electro-Magnetic Compatibility (key issue from start)

= robust design reliability and rad tolerance seem linked!

-running ¼ LHC system in SPS for nearly 2 years ☺

Motivations for the Tests

The Beam Interlock Controller (x17 in LHC)
-few in surface buildings
-most in zones considered ‘negligible radiation’
-one in control room
-VME Chassis can be moved to surface if ever there is a problem
-any problem will result in safe failure by design
VME is the basis = Not going to Test

The User Interface (x130 in LHC)
-Goes where the User System is “UJ76”
We have to Test

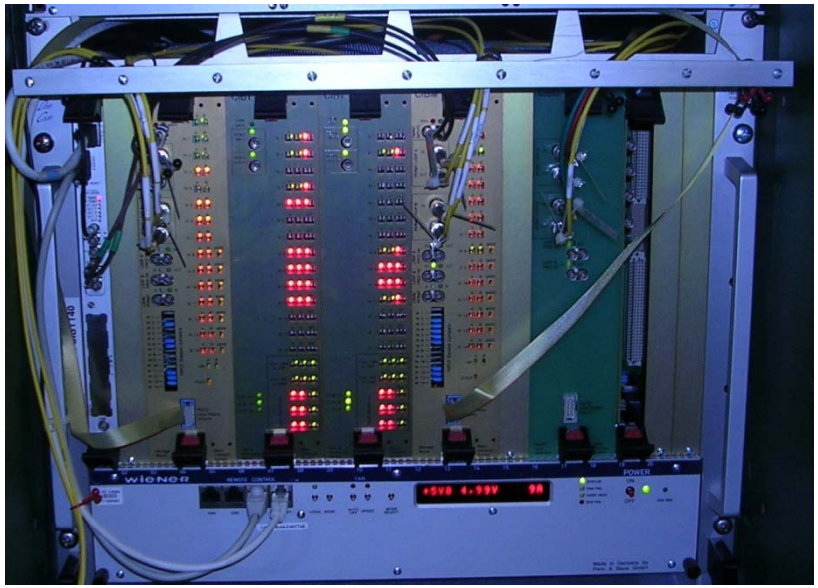
The User Interface Power Supply (x260 in LHC)
-Goes where the User Interface is “UJ76”
We have to Test

-accumulated dose? User Systems will have the same problem!
-need to know the limits
-POWER SUPPLY only total dose is interesting

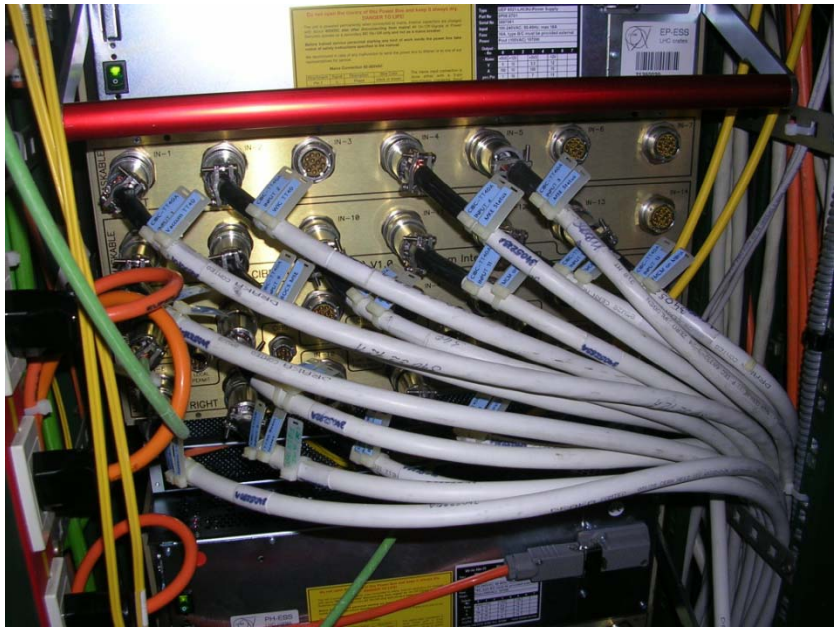
Typical Hardware

User Interface

BIC (Front) TT40



BIC (Rear) TT40



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CIBD Specification

Tracopower TXL-025-25S
5V, 5A, 25W

Device housed in shielded conductive case

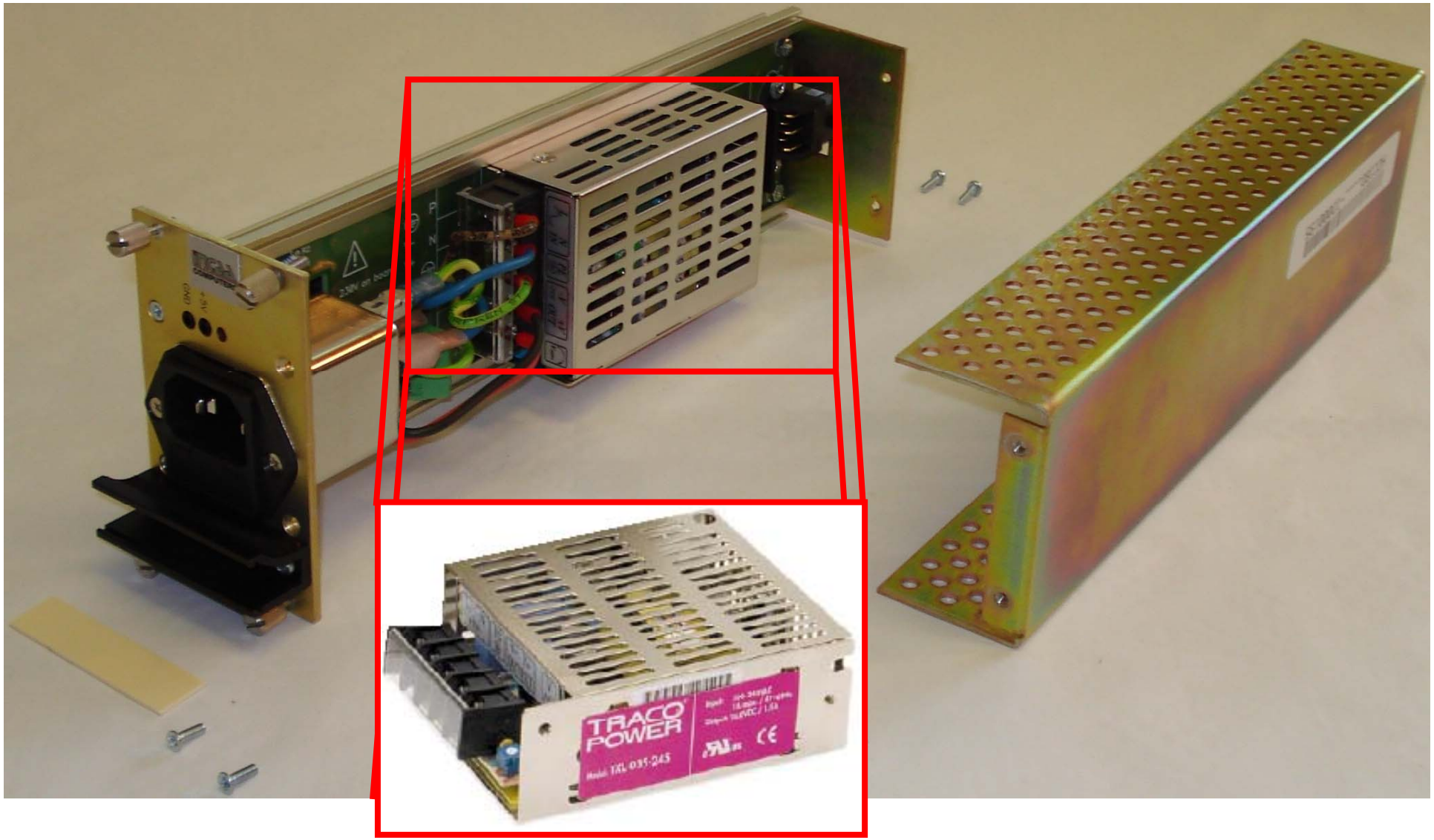
Reliability analysis = redundant PSU = good Availability
- Decoupling diode added
- +3% trim to accommodate V_{diode}

5A Fuse added on input

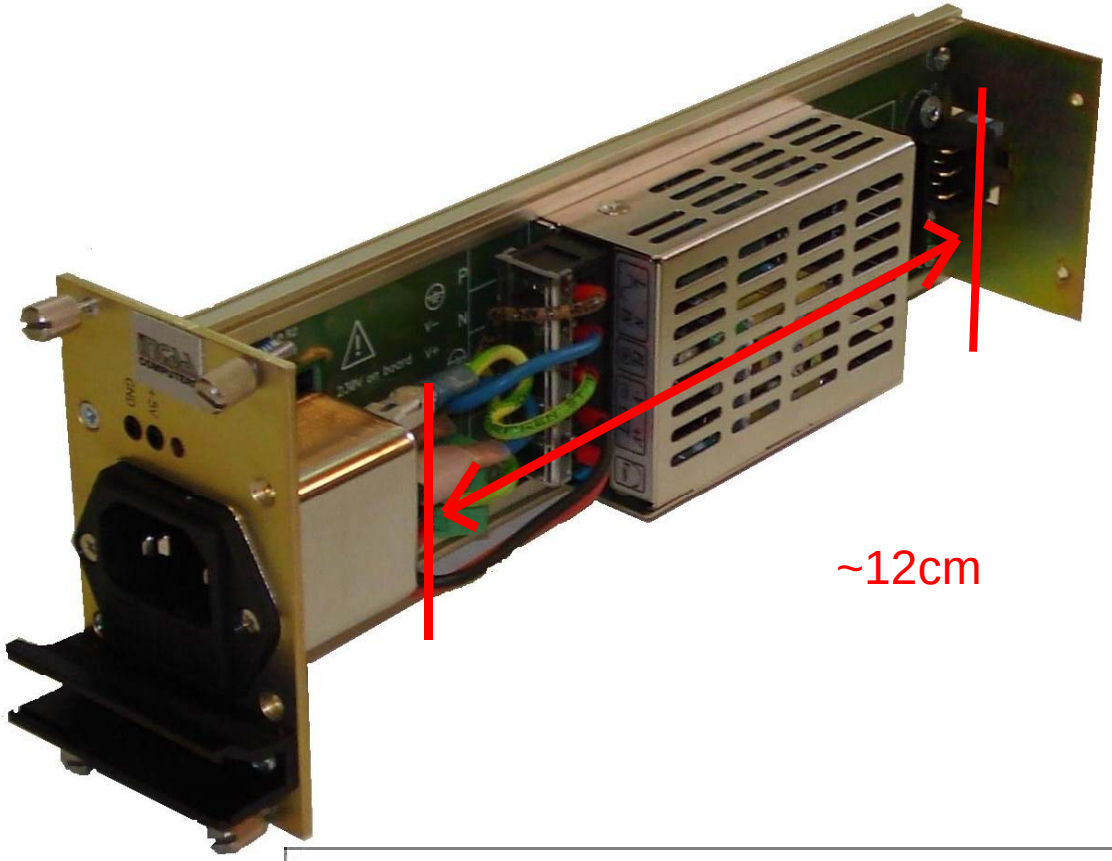
EMC Tests done with CIBU/CIBD configuration
- Very good results
https://edms.cern.ch/document/762174/

Not the cheapest, but
Tracopower have a great reputation (AB/PO)
Very complete datasheets

CIBD – 5A 5V PSU



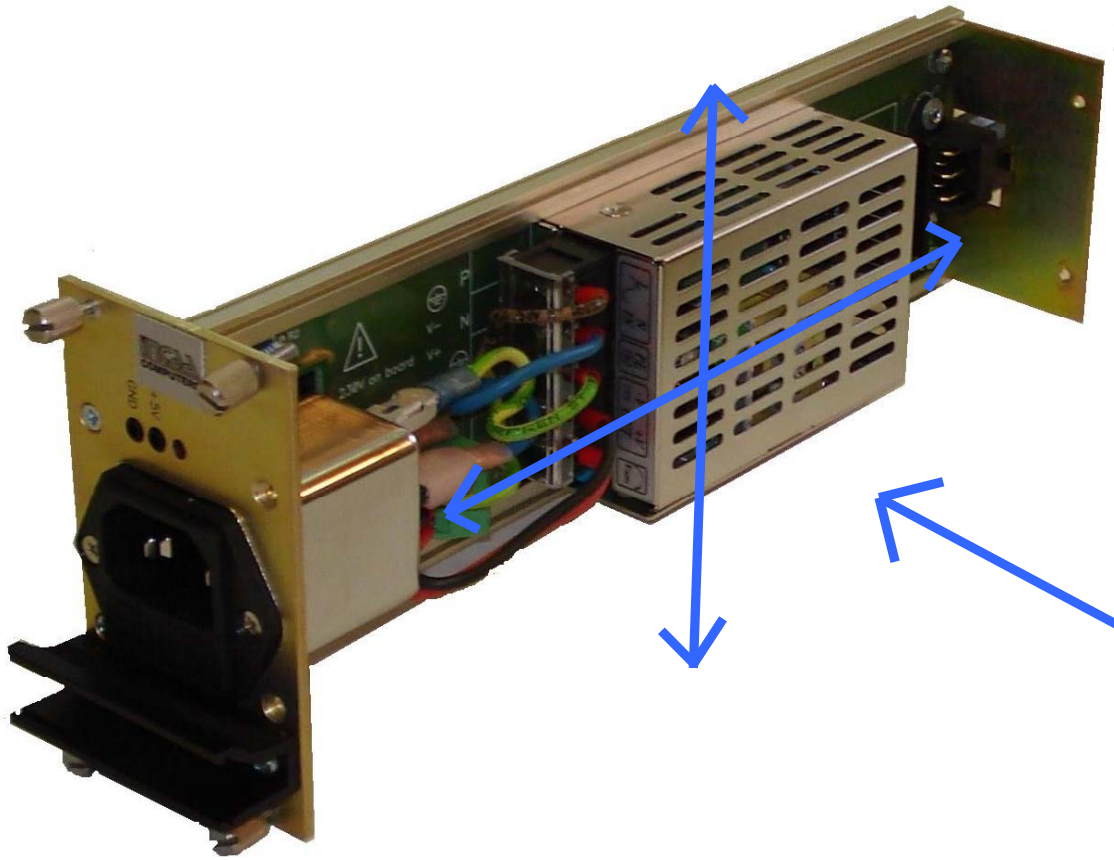
CIBD – 5A 5V PSU



Radiation levels at the electronic rack positions at IR7 (average values for the racks situated on the ground floor). The statistical error is ≤20%.

	Dose (Gy/y)	Hadrons > 20 MeV (cm^{-2}/y)	1 MeVeq. flux (cm^{-2}/y)
UJ76	0.5	$8 \cdot 10^8$	$2 \cdot 10^9$
RR73/77	0.3	$1 \cdot 10^8$	$6 \cdot 10^8$

CIBD – 5A 5V PSU



PROSPERO
235U core and a 238U reflector
"Displacement Damage Test"

NEUTRONS

Energy = 1MeV

Fluence = 1E12 n/cm^2

=Several 10's Years LHC

PSU well protected -

PSU 25W, we need <5W

Degradation is expected & planned for

<1% Voltage change

And CIBU OK down to 4.5V

(guaranteed by design)

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User Interface Specification

Device housed in conductive case with Burndy Connectors
-great EMC
-good reliability from connectors (AB/PO already use these)

Completely 5V
-good reliability (more resistance to perturbation)

Classic 7400 Series
-mature technology
-wide support

Current Loop inputs
-accommodate many different types of User System
-DESY input circuit (M. Werner)

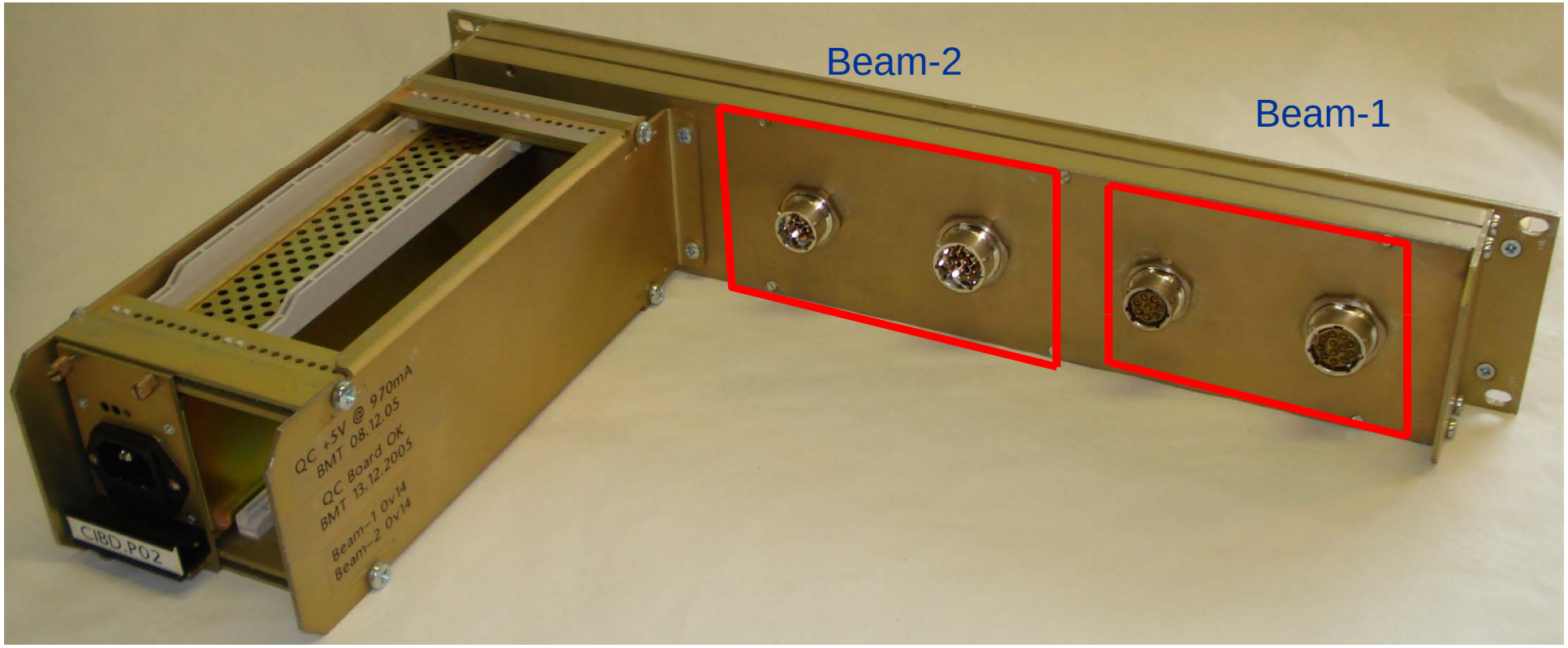
RS485 Outputs
-Good integrity
-Mature Technology

9500 Xilinx CPLD for TEST and MONITOR
-Manchester frames (Used General Machine Timing as a basis)
-excellent dependability (AB/PO already use these)
-Not susceptible to program corruption

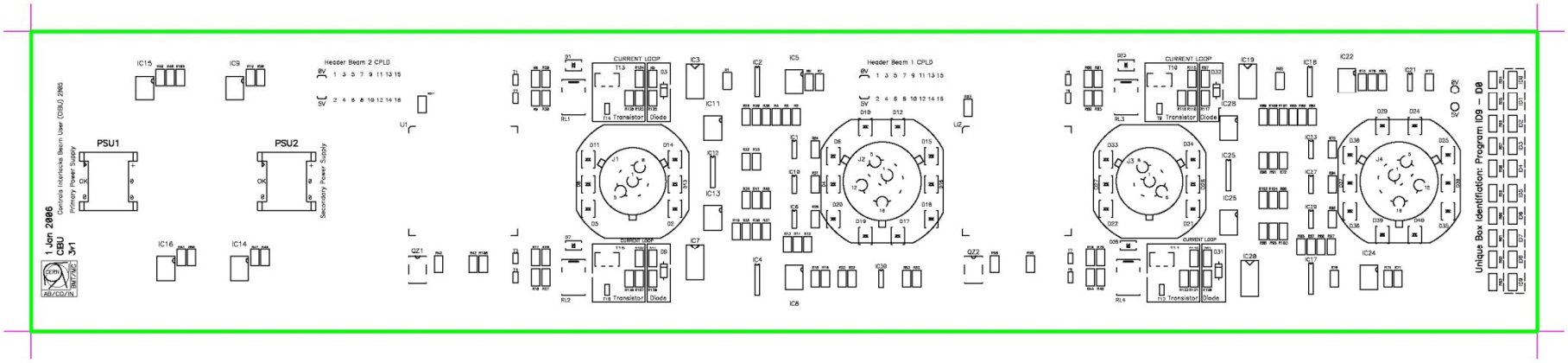
100% remotely testable
100% remotely monitorable

User Interface

User Interface Specification



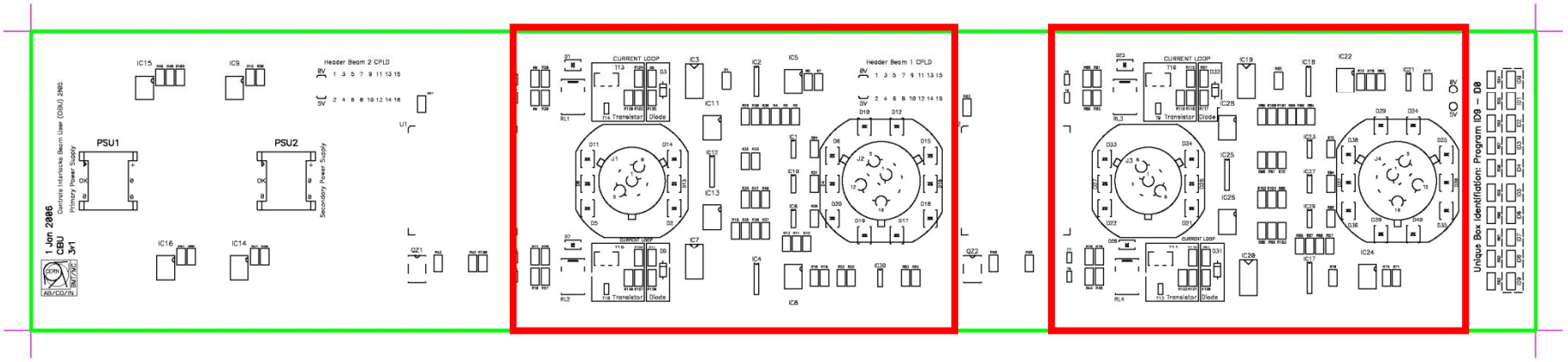
Test Areas



Projet/ Project	CIBU		NAME	TEL	DATE
		Resp	BMT		
Ensemble/ Set	Controls Interlocks Beam User (CIBU) 2005	Designer	BMT		1 Jan 2006
		Drawn by	Martin Christophe		
Sous-ensemble/ Underset	SILK TOP File EXT : SET	MODA			
		MODB			
CERN AB/CO/IN	Drawing Number CIBU 3v1	EDMS		LHC	
	LABORATOIRE EUROPEEN POUR LA PHYSIQUE DES PARTICULES EUROPEAN LABORATORY FOR PARTICLE PHYSICS GENEVE / GENEVA	ECHELLE/ SCALE	1/1	INDICE	

Test Areas

Beam-2 Beam-1



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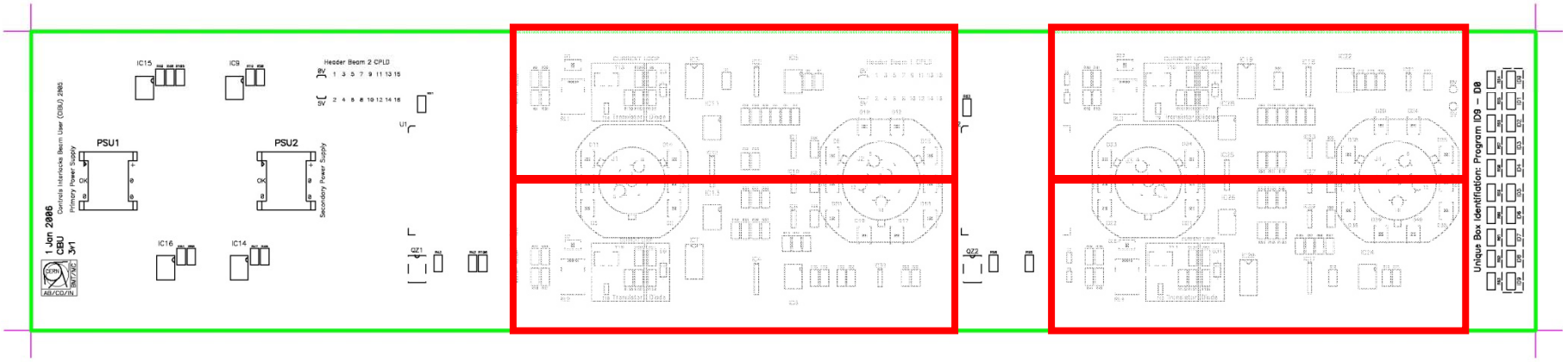

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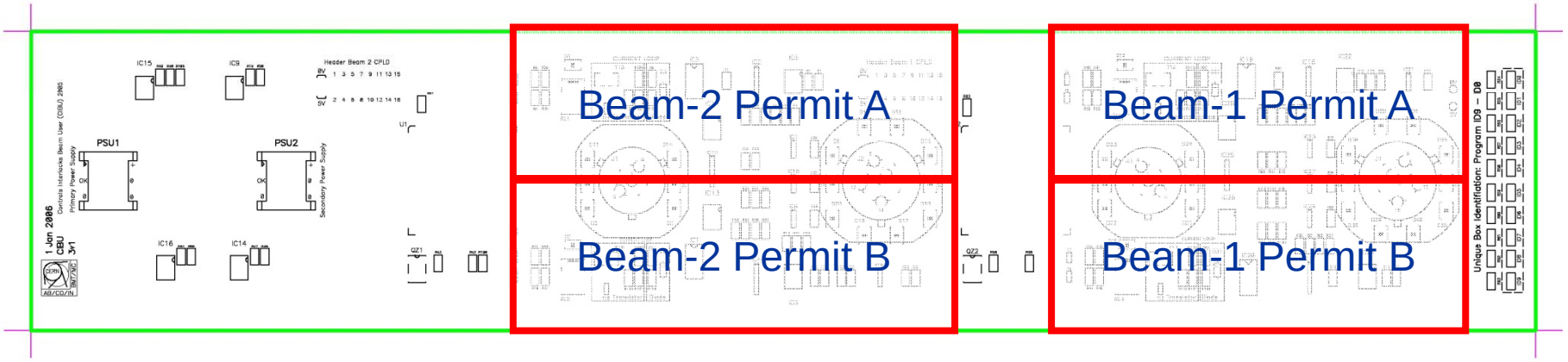

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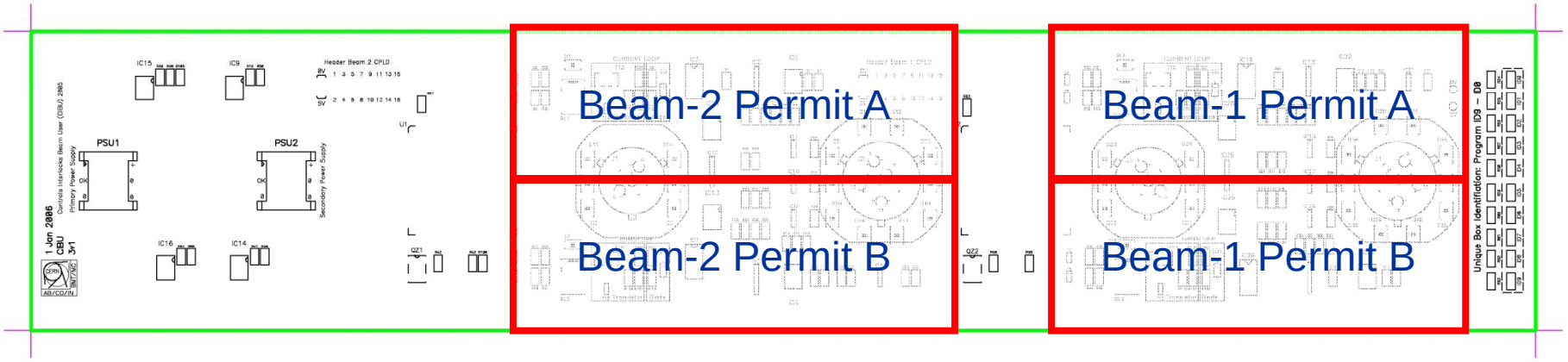
Test Areas

All use the SAME electronic circuit! It's repeated four times



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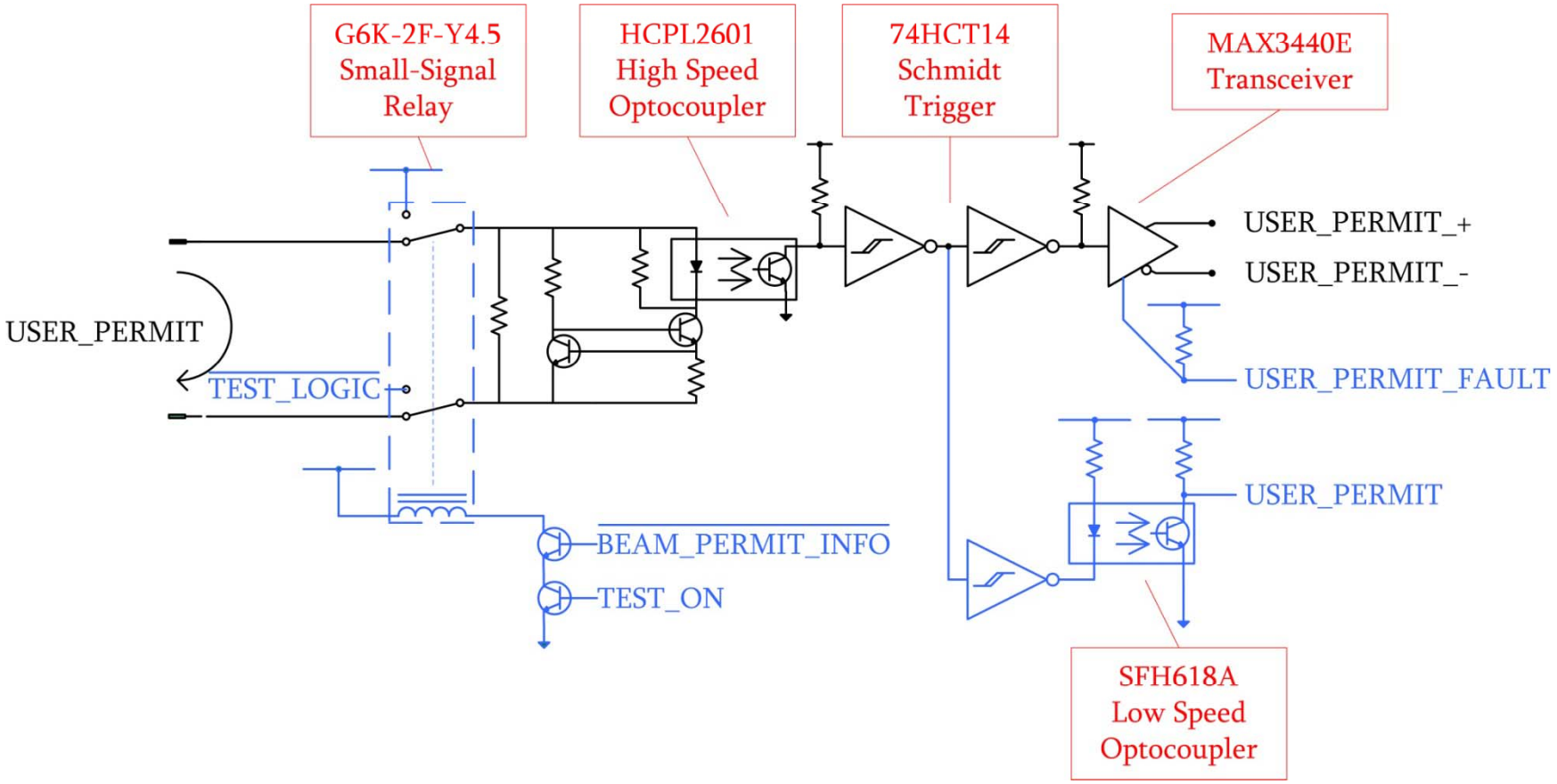
USER PERMIT Paths

The mission critical function for the CIBU;

-relay USER_PERMIT correctly

Nothing else! All the BLACK lines are critical!



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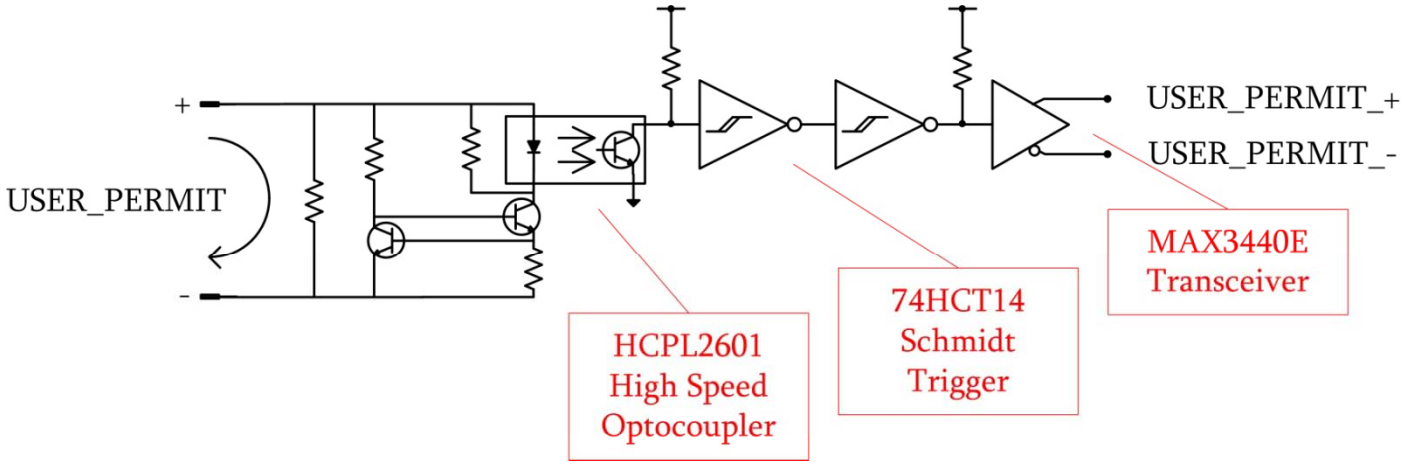
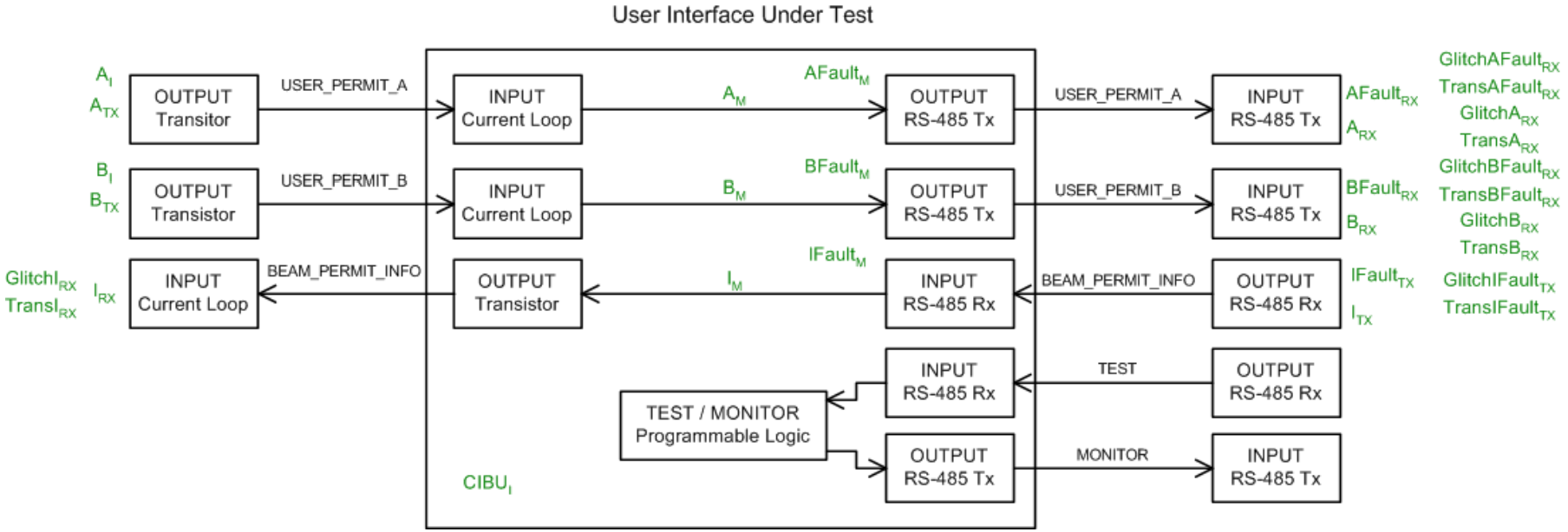


Test Sequence During Irradiation

5 steps, every two seconds we move to the next step, then repeat…

We MEASURE all board current consumptions!

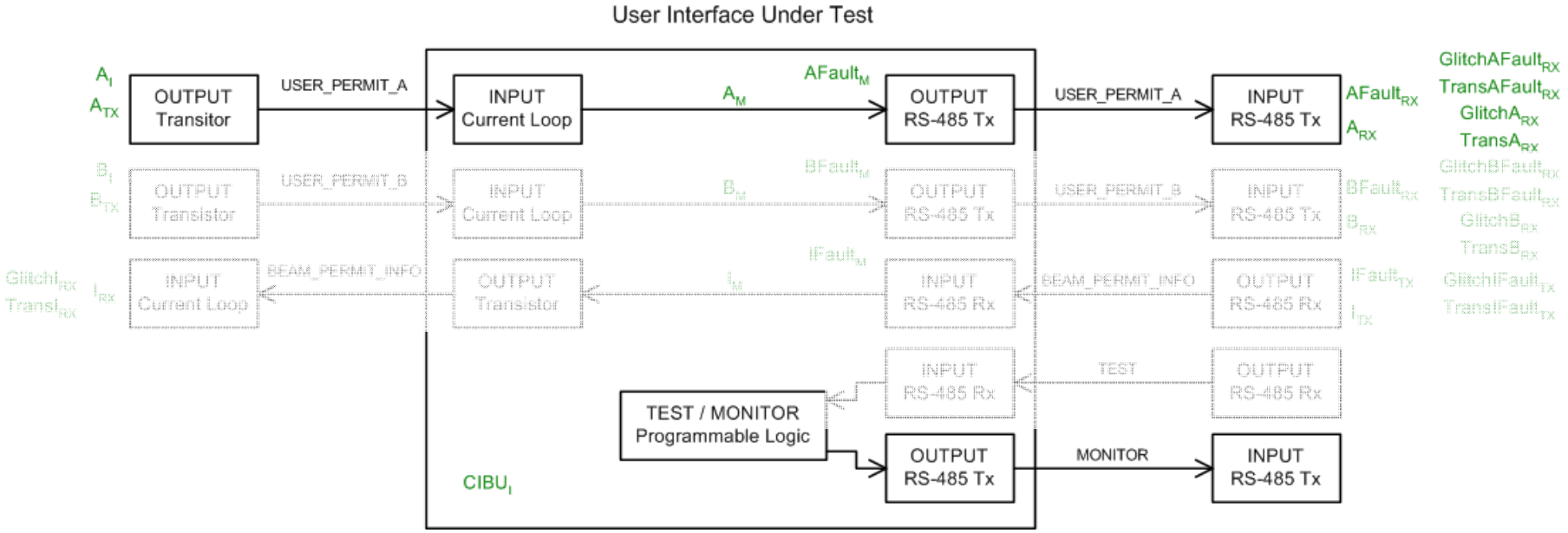
PERMIT A [mA] … PERMIT B [mA] … CIBU [mA]



Test Sequence During Irradiation

5 steps, every two seconds we move to the next step, then repeat…

1. Cycle USER PERMIT A



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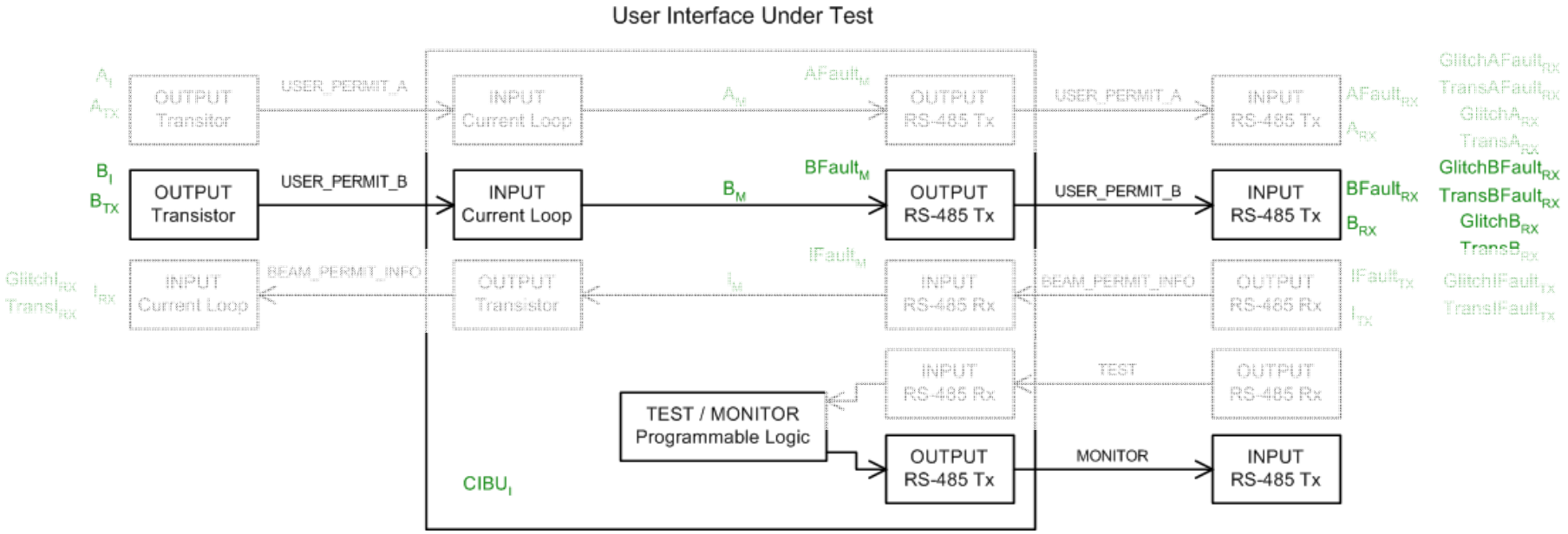
5 steps, every two seconds we move to the next step, then repeat…

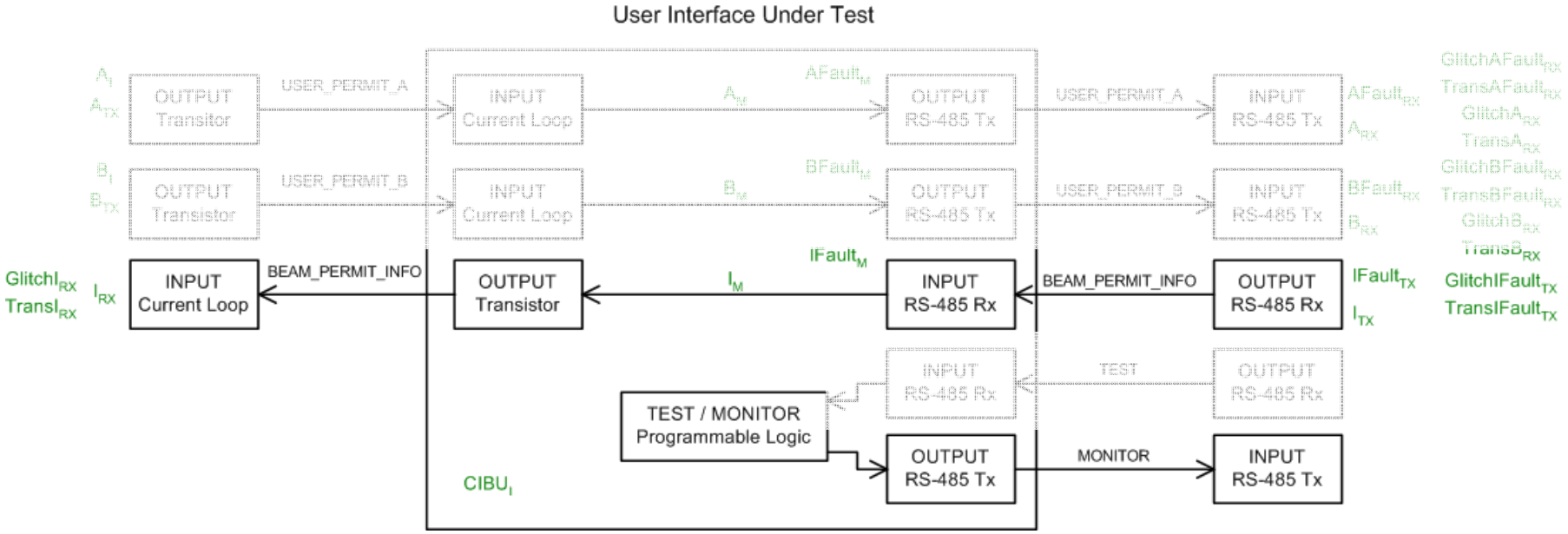
1. Cycle USER PERMIT A
2. Cycle USER PERMIT B



Test Sequence During Irradiation

5 steps, every two seconds we move to the next step, then repeat…

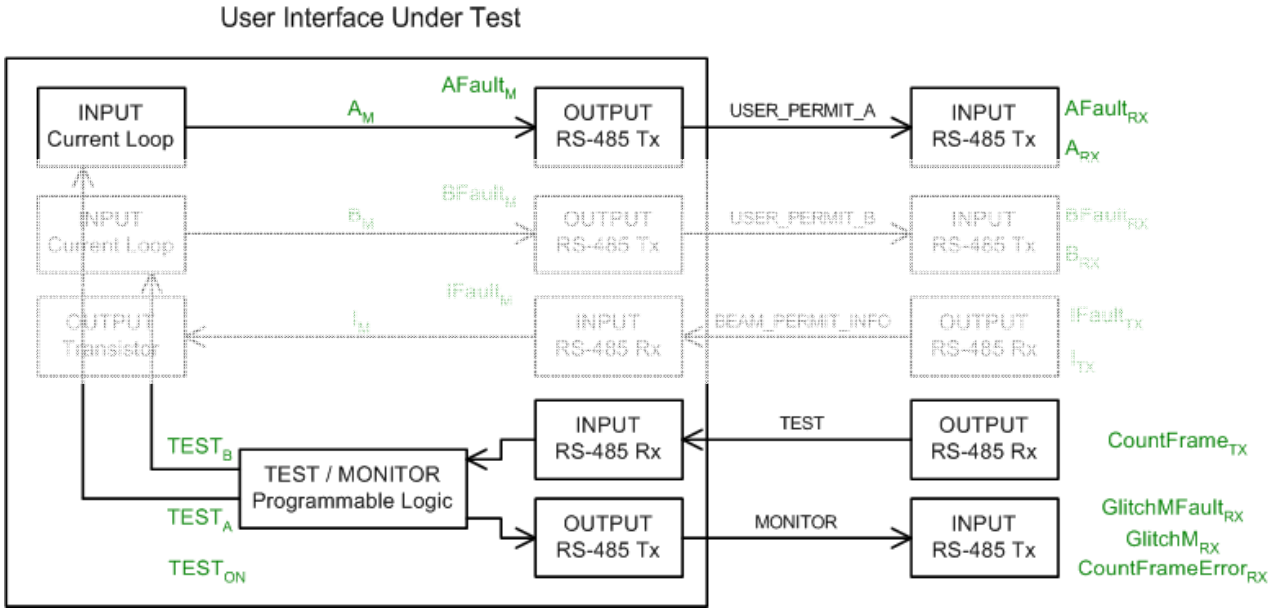
1. Cycle USER PERMIT A
2. Cycle USER PERMIT B
3. Cycle BEAM PERMIT INFO



Test Sequence During Irradiation

5 steps, every two seconds we move to the next step, then repeat…

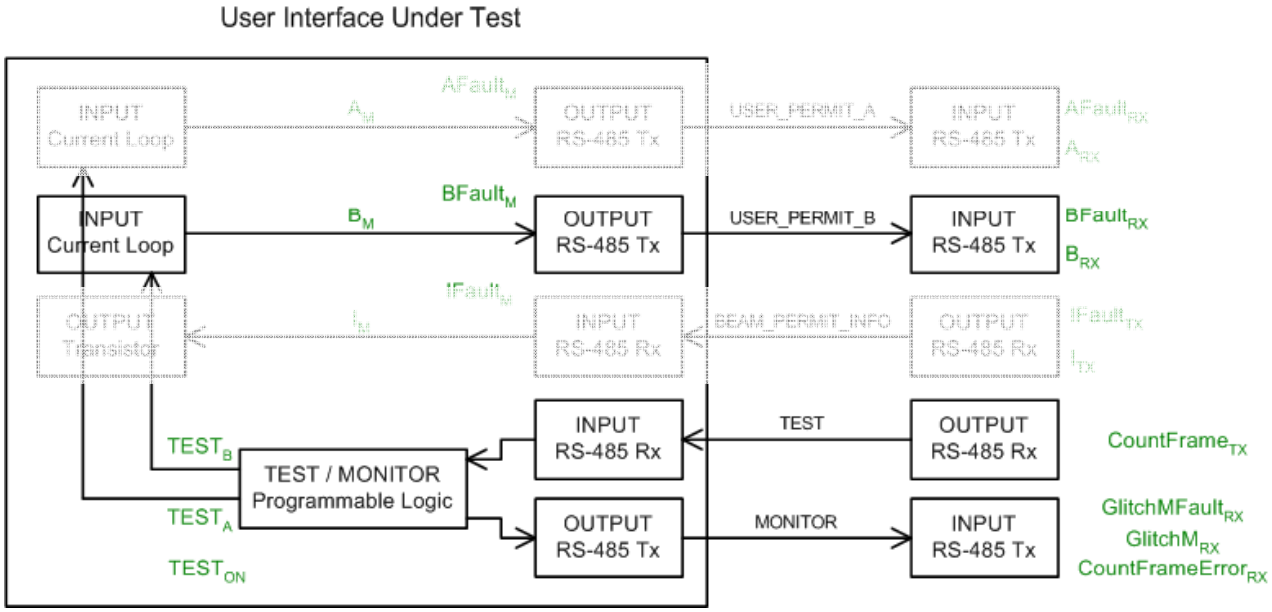
1. Cycle USER PERMIT A
2. Cycle USER PERMIT B
3. Cycle BEAM PERMIT INFO
4. Internal TEST PERMIT A



Test Sequence During Irradiation

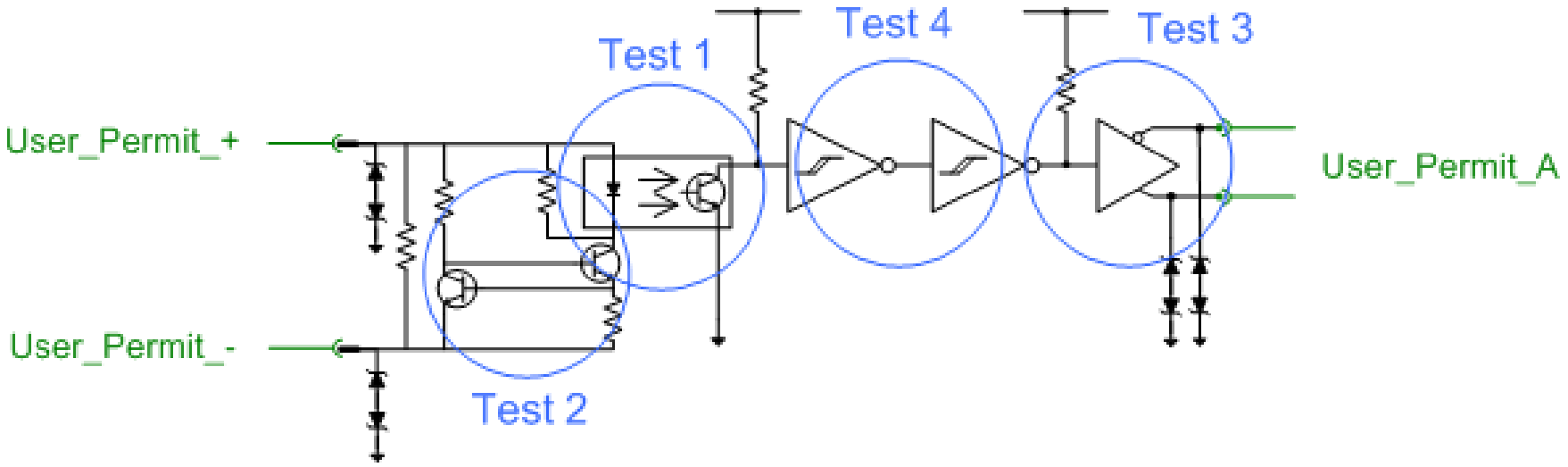
5 steps, every two seconds we move to the next step, then repeat…

1. Cycle USER PERMIT A
2. Cycle USER PERMIT B
3. Cycle BEAM PERMIT INFO
4. Internal TEST PERMIT A
5. Internal TEST PERMIT B



The Irradiated Zones

1. USER_PERMIT Optocoupler
2. USER PERMIT Current Regulation Circuit
3. USER PERMIT RS485 Driver
4. USER PERMIT Schmidt Trigger
5. The WHOLE CIBU



Irradiation Parameters

Irradiation Parameters

60MeV Protons – OPTIS at PSI

15MeV/cm^2/mg in SiO_2 – can cause SEE in plastic packages

N.B. 1 x 10^{11} protons cm^{-2} equivalent to 140 Gy

"Representative of LHC Environment" – F. Faccio, M. Muhtinen

Radiation levels at the electronic rack positions at IR7 (average values for the racks situated on the ground floor). The statistical error is ≤20%.

	Dose (Gy/y)	Hadrons > 20 MeV (cm^{-2}/y)	1 MeVeq. flux (cm^{-2}/y)
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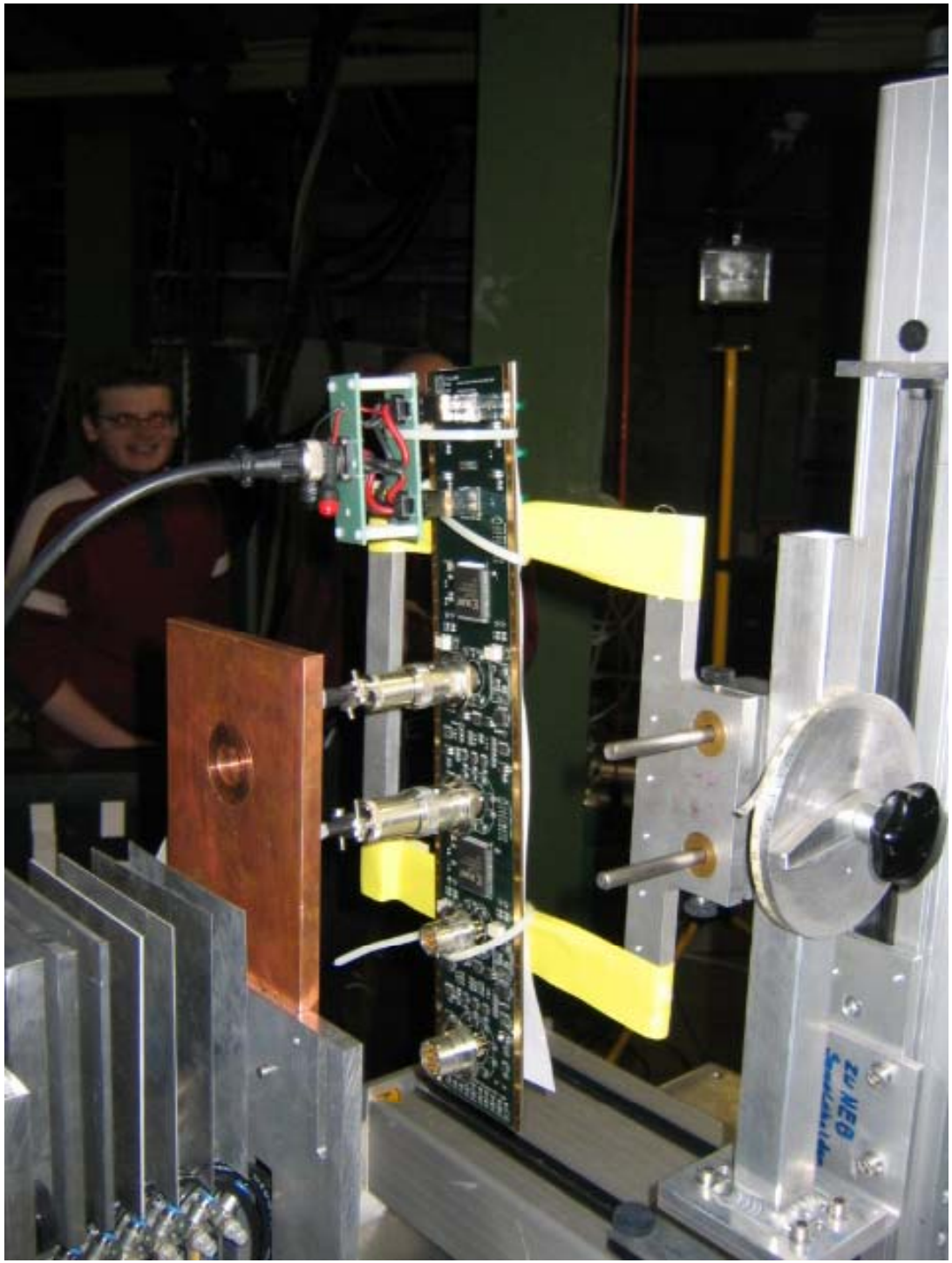
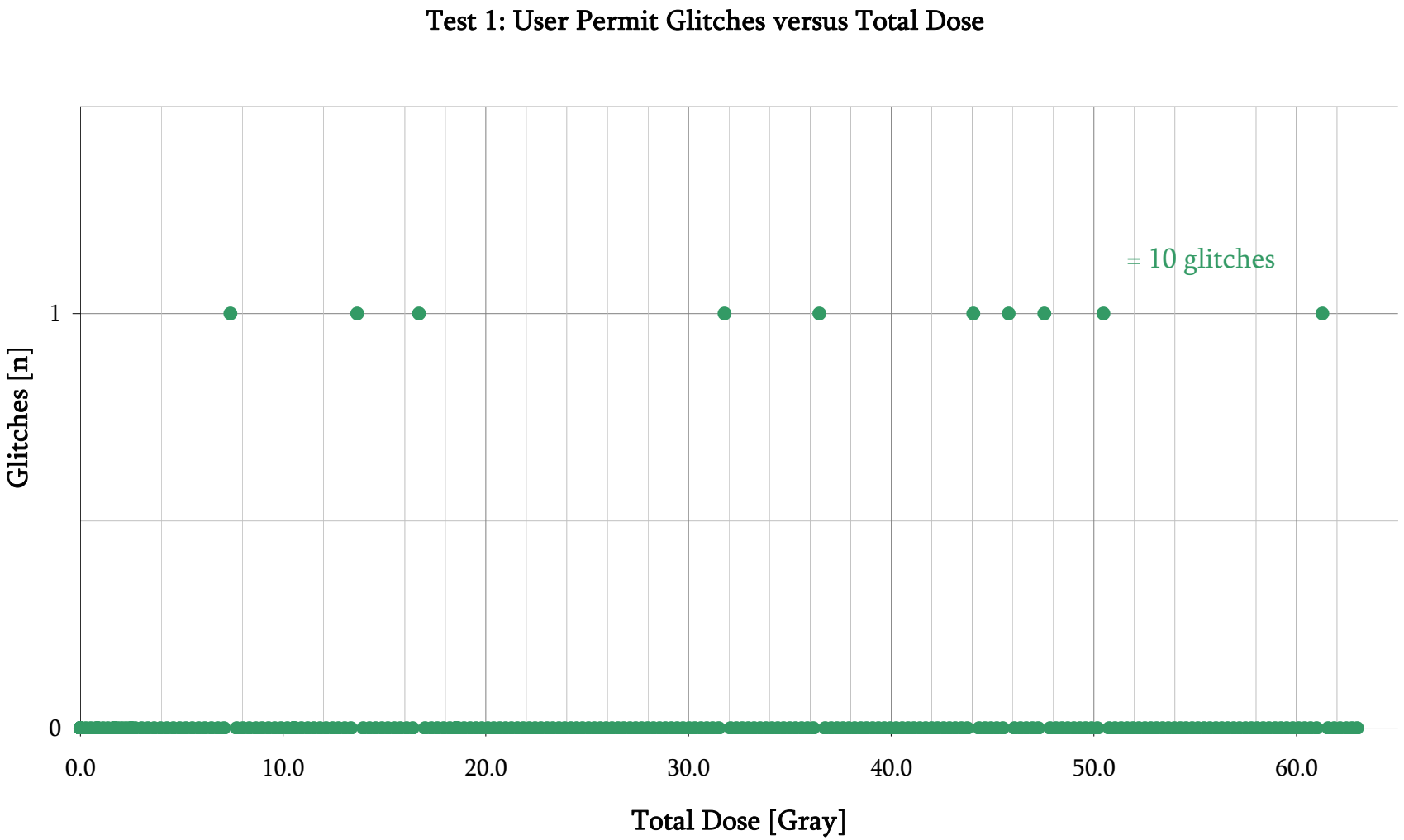


Test 1 – The Optocoupler

Received a TOTAL DOSE of 62 Gy = 4.8 x 10^{10} pcm^{-2}

10 Glitches observed – observation window open only ¼ of test - 40 assumed.

Cross Section = 8.3 x 10^{-10} for Optocoupler Glitches

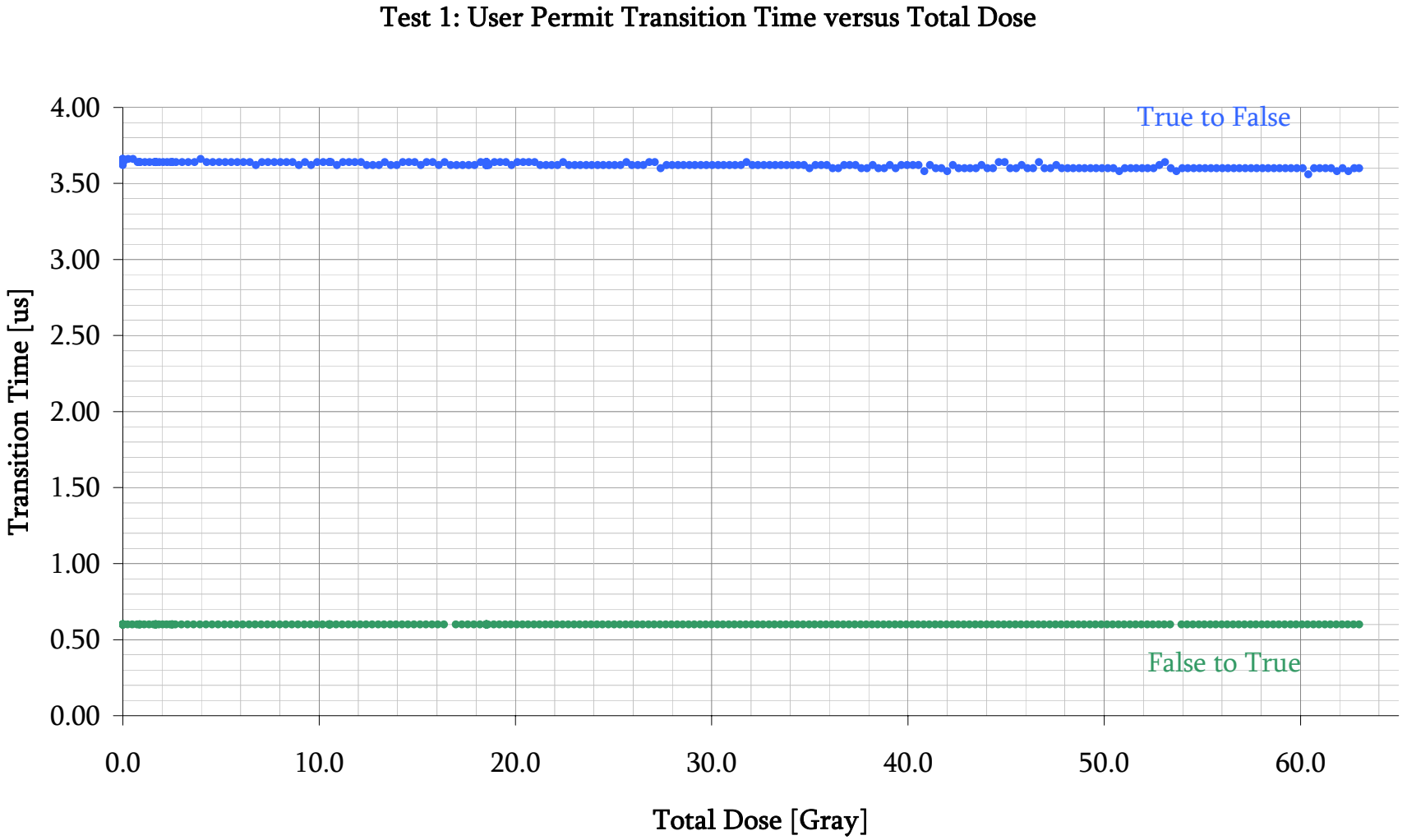


Test 1 – The Optocoupler

usual transition times were observed during the test

~3.6us delay for TRUE to FALSE

~0.6us delay for FALSE to TRUE

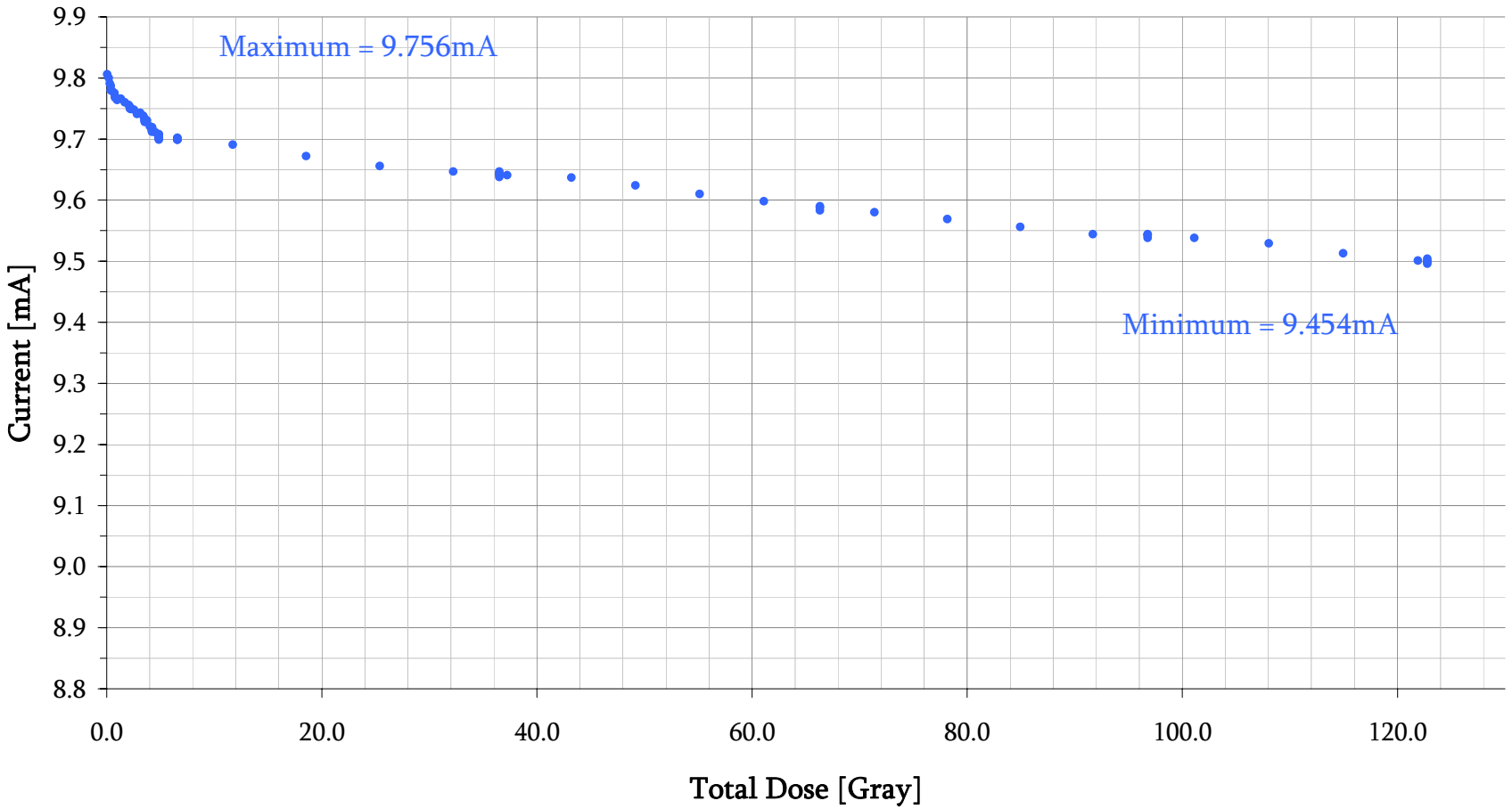


Test 2 – The Current Regulator

Received a TOTAL DOSE of about 120 Gy

NO Glitches observed

Current regulation drifted by about 4%

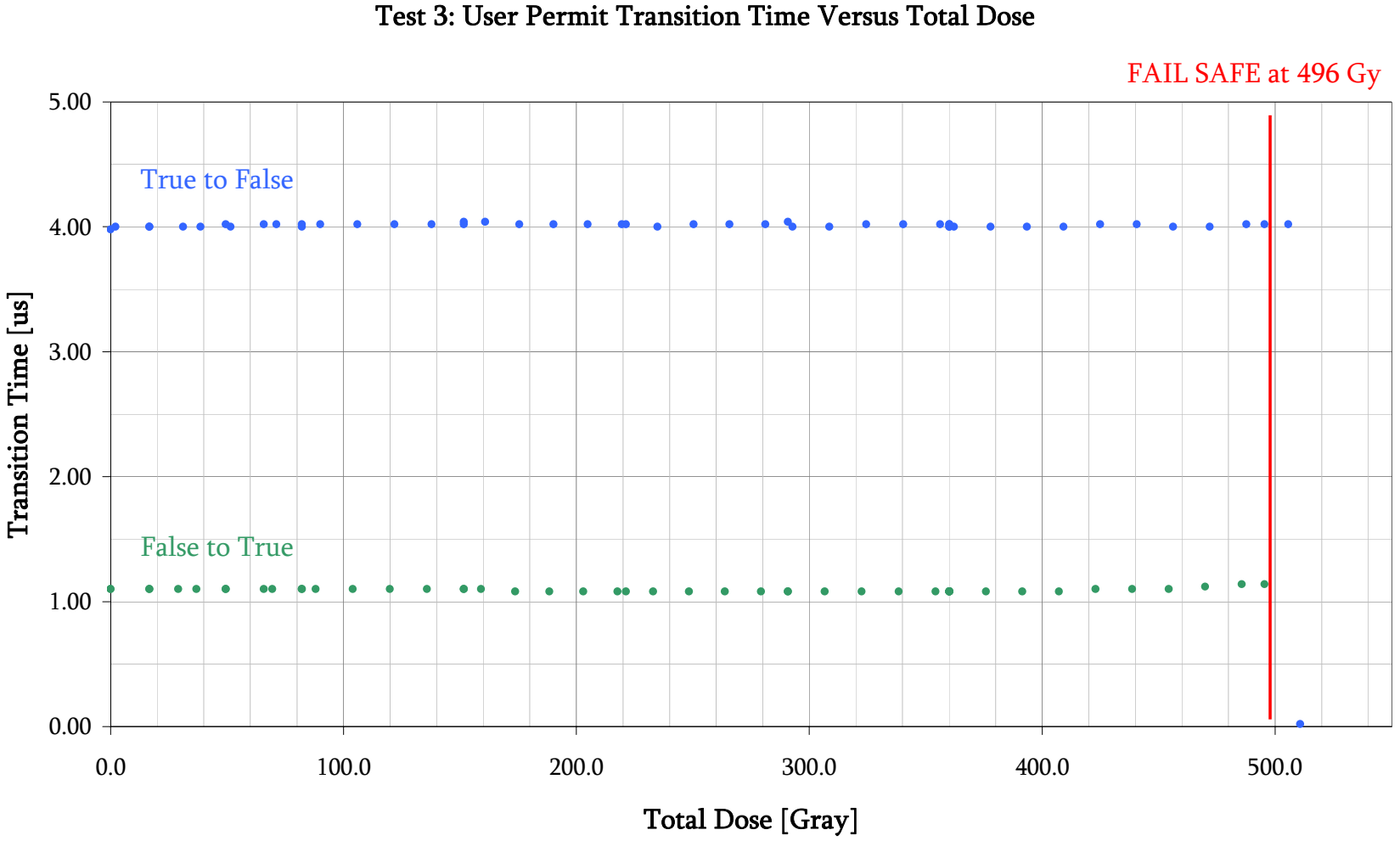


Test 3 – RS485 Driver

Received a TOTAL DOSE of 496 Gy

NO Glitches observed, No FALSE Transistions

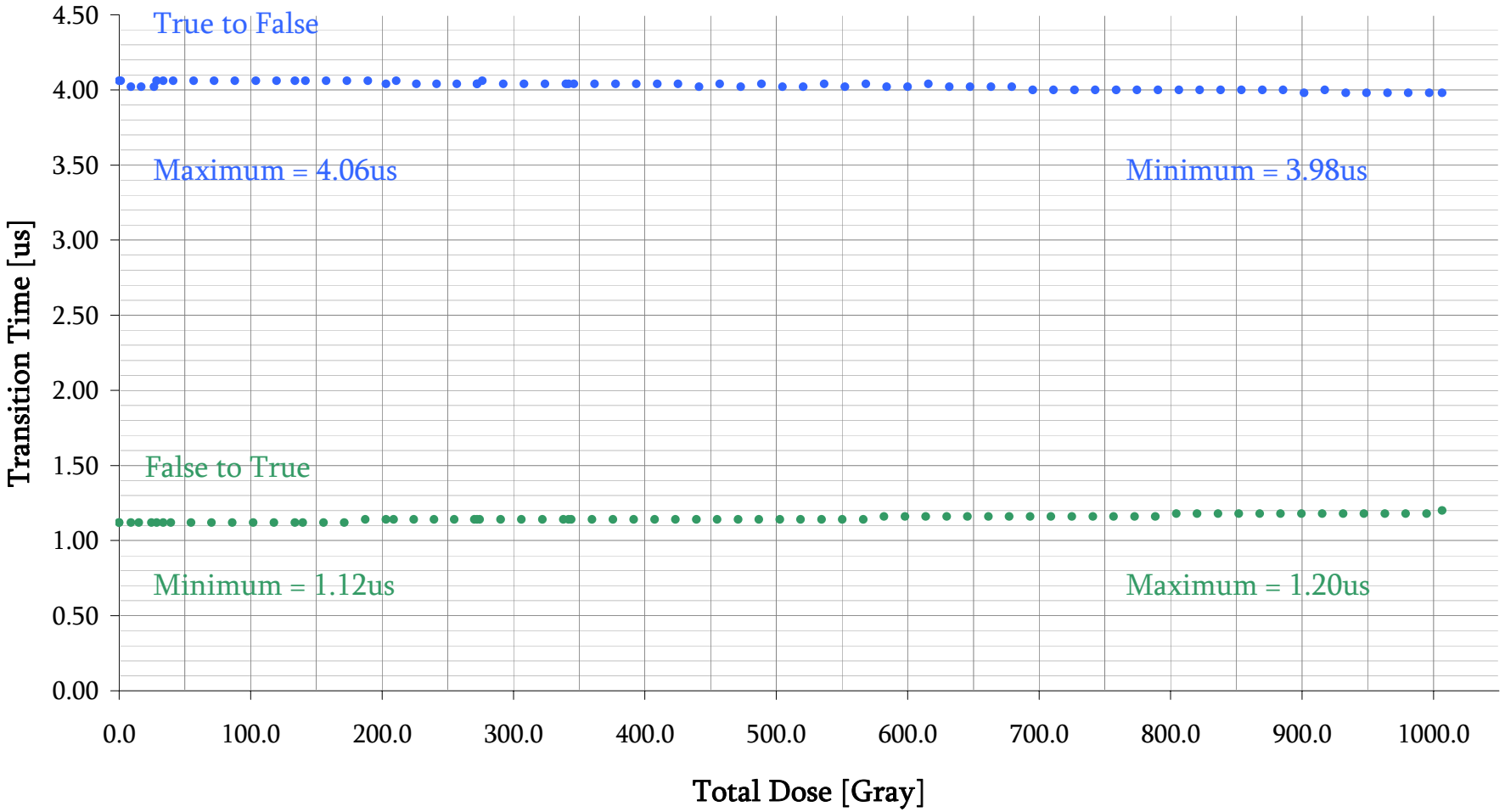
FAILED SAFE at 496 Gy, power cycle restored operation



Test 4 – Schmidt Trigger

Received a TOTAL DOSE of 1000 Gy (then experiment halted)

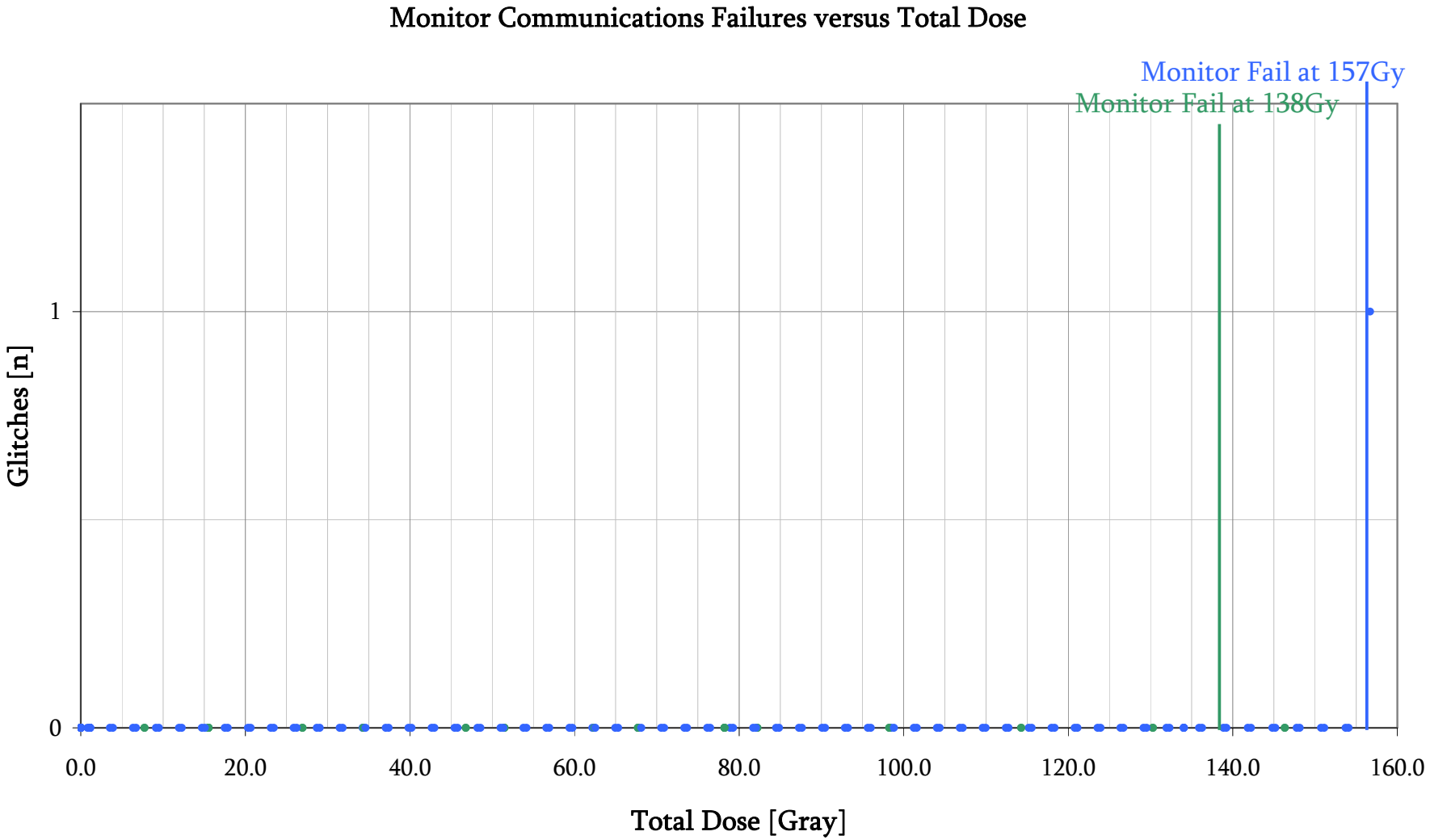
NO Glitches observed, NO FALSE transitions



Test 5 – Whole PCB

Two PCBs tested

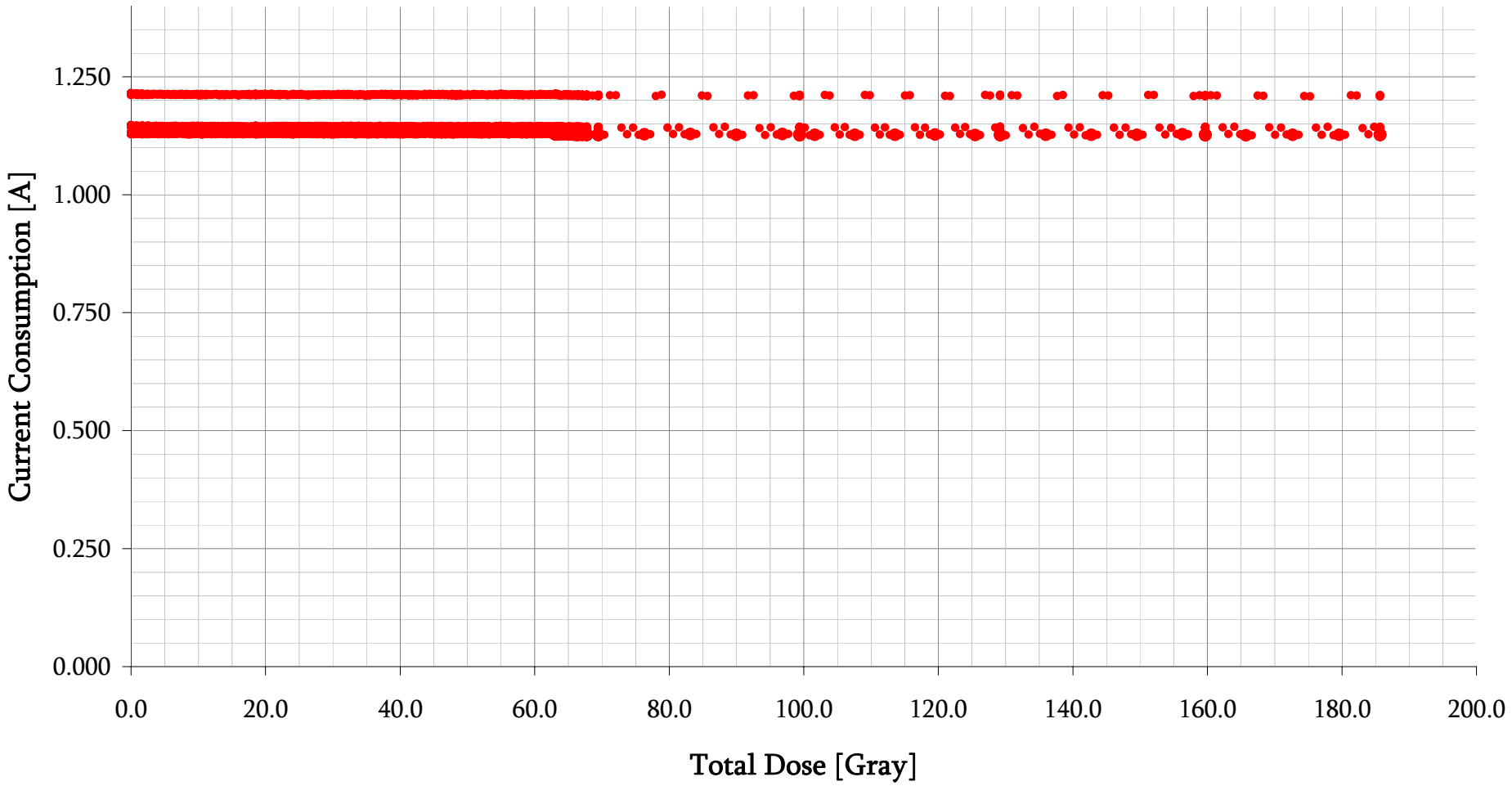
~140-160Gy - CPLD stopped sending data frames



Overall Current Consumption

Three PCBs tested at various points

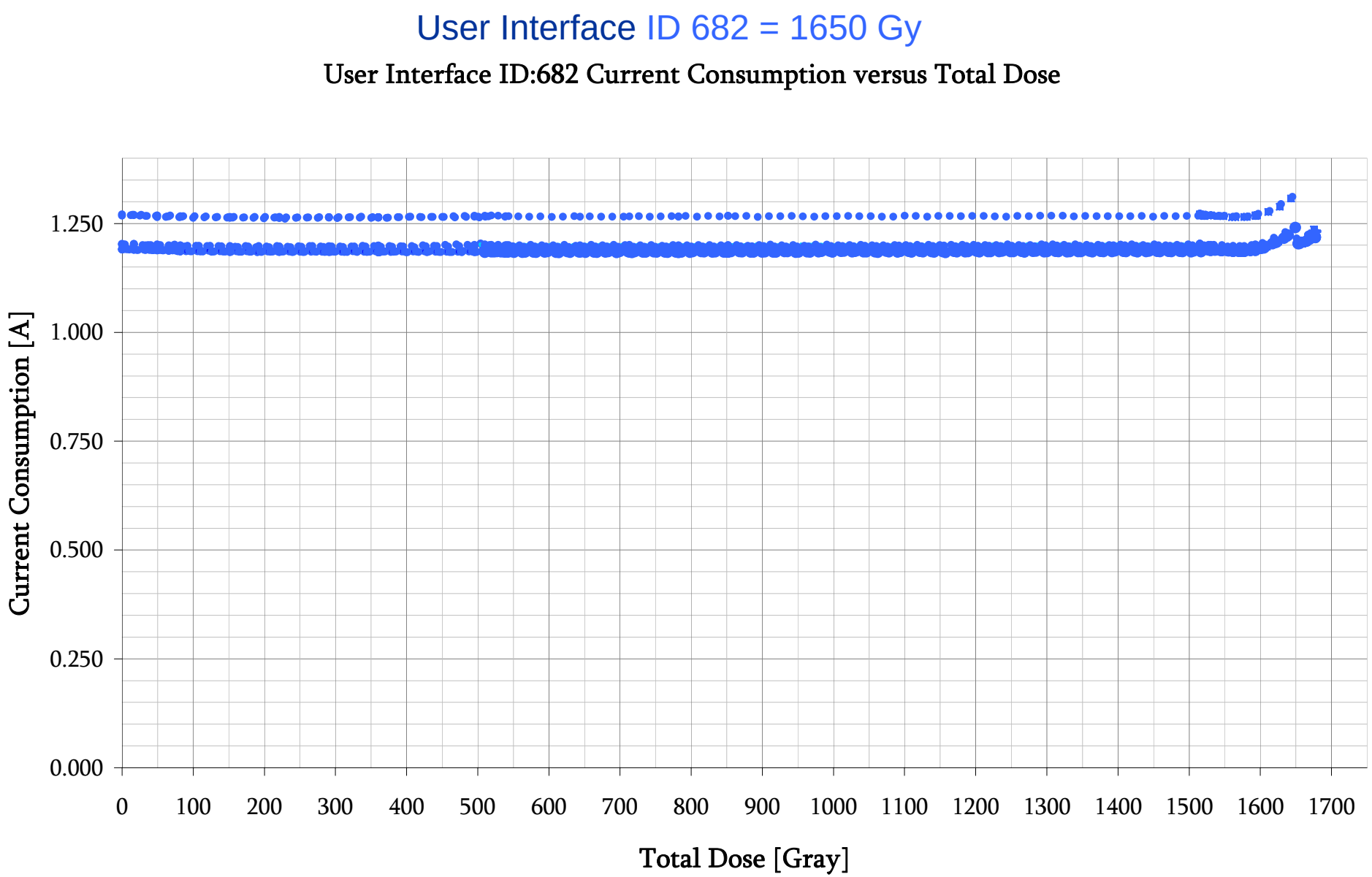
User Interface ID 1 = 180 Gy



Overall Current Consumption

Three PCBs tested at various points

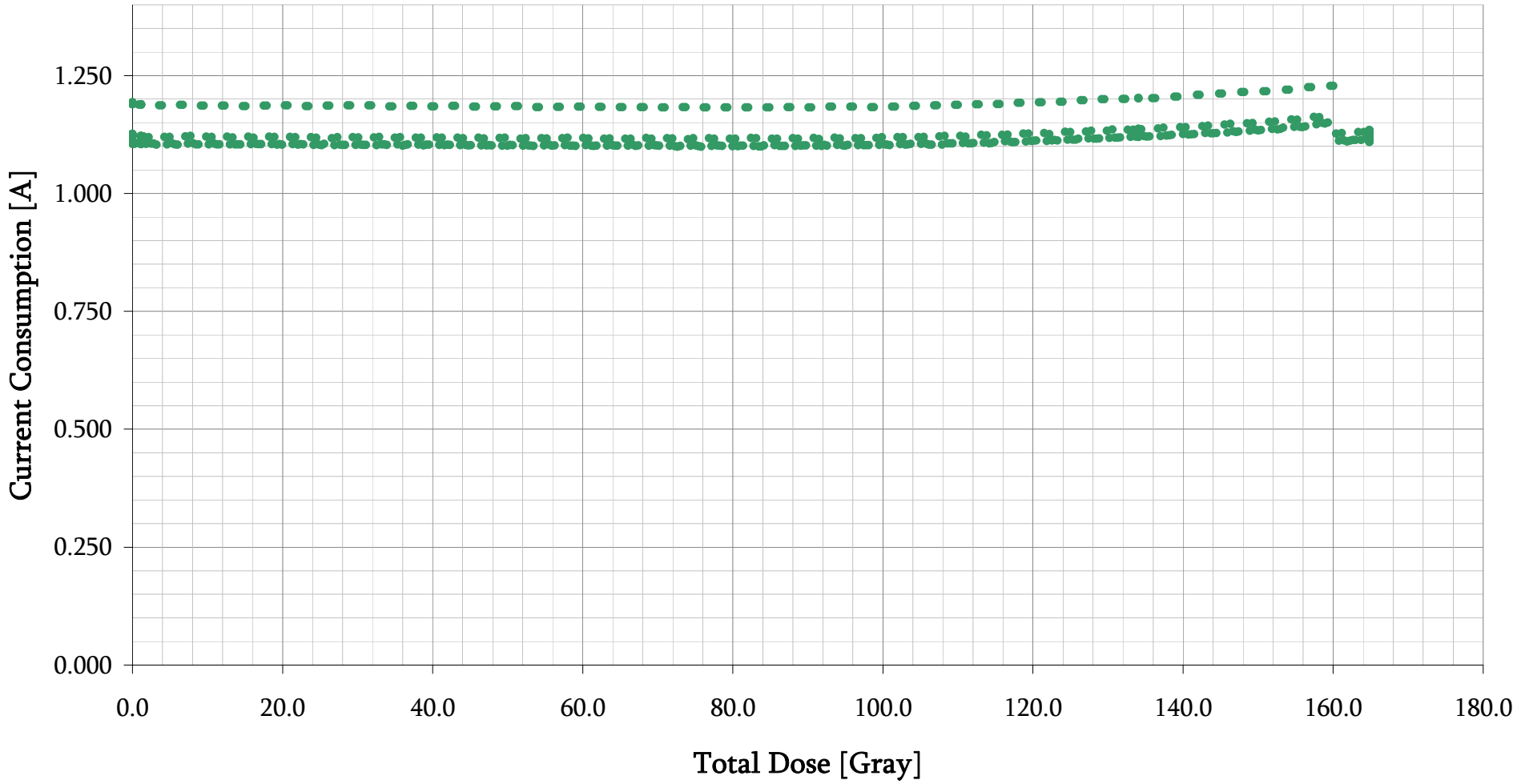
User Interface ID 682 = 1650 Gy



Overall Current Consumption

Three PCBs tested at various points

User Interface ID 2 = 160 Gy



Testing the Beam Interlock System

1. The Beam Interlock System
   - Electrical and Physical Architecture
   - Component Locations
   - Design for Durability
   - Scope of the Tests (CIBD and CIBU)
2. Power Supply Tests and Results
   - Detailed Description of the Power Supply
   - Test methods
   - Test Results
3. User Interface Tests and Results
   - Detailed Description of the User Interface
   - Test methods
   - Test Results
3. Conclusions and Future Focus
   - Test Conclusions
   - Where do we go from here?

Conclusions

Critical Path of Beam Interlock System

- 8.3 x 10^{-10} Cross-Section for Glitches = use 1.6us GLITCH FILTER!

- Good radiation tolerance

- CPLD failed first at 150Gy – only for MONITORING

- BUT once we got it back here – reprogrammed it and it worked!

- Will monitor Glitch counters to indicate potential problems

Have plans for RAD HARD CIBU but they're on hold

- Needs motivation, time and money! ($)

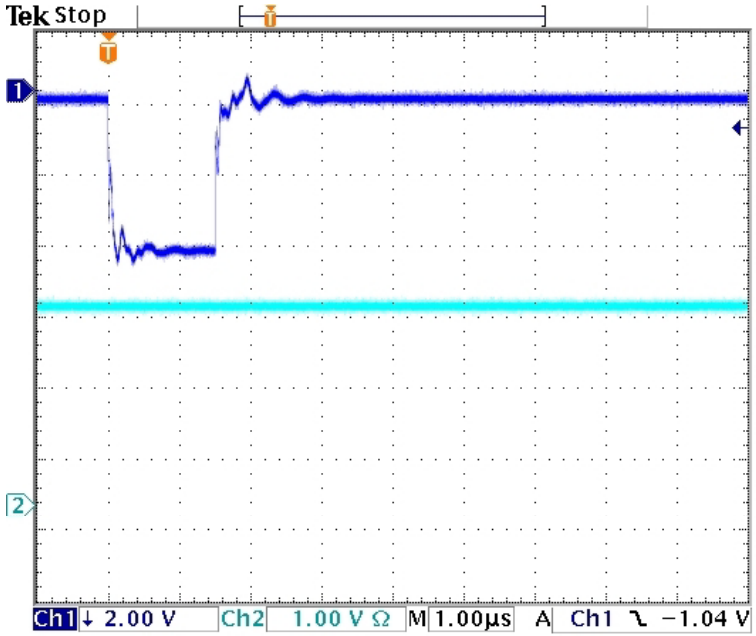
- VME is weak? move BICs to 'surface' ($$$)

- Critical Matrix CPLD is same as in CIBU (3.3V variant)

- VME PSU – redundant!

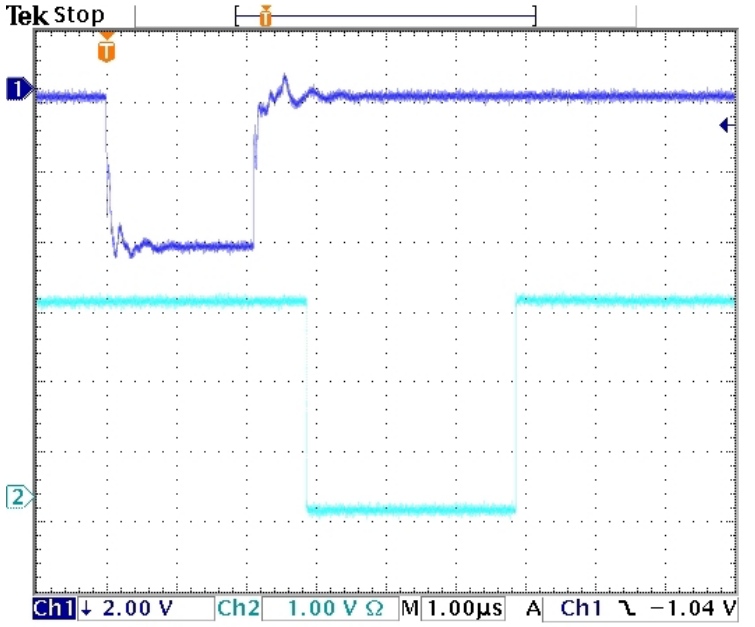
Have researched a RAD HARD BIC (not including VME)
Needs motivation, time and lots of money ($$$$$)

USER_PERMIT SEE Glitch Filter



USER_PERMIT

BEAM_PERMIT



If USER_PERMIT FALSE for <=1.6us then it's IGNORED!

= NO BEAM ABORT

If USER_PERMIT FALSE for >1.6us then it's ACCEPTED!

= BEAM ABORT

Closing remarks

-it was a LOT of effort to get the tests organised

-Thanks to Thijs Wijnands / Christophe Martin et al. for all the great work

-additional tests won't need as much effort

- after LHC beam commissioning started – we could do some more!
- If we feel it's necessary:

Optical Transmission Board… (CIBO)

Fibre Extended User Interface (CIBFU/CIBFC)

VME Equipment (find the weaknesses?)

We should plan some beam time next year. NOT a priority for LHC

"Better the devil you know"

FIN

Tracopower TXL-025-25S

Hold-up time	20 ms min.

INPUT VOLTAGE fails or glitches = OUTPUT VOLTAGE maintained

Reliability /calculated MTBF (MIL-HDBK-217F)	>250'000 h @ 25 °C typ.

Mean Time Between Failures = several years

Electromagnetic compatibility (EMC), Emissions	– Conducted input RI suppression	EN 55022, class B, FCC part 15, level B
	– Harmonic current emissions	IEC/EN 61000-3-2, class D (TXL 120/150/220) IEC/EN 61000-3-2, class A (others)
	– Flicker	IEC/EN 61000-3-3
Electromagnetic compatibility (EMC), Immunity	– Electrostatic discharge ESD	IEC/EN 61000-4-2 4 kV / 8 kV
	– RF field immunity	IEC/EN 61000-4-3 3 V/m
	– Electrical fast transients/burst immunity	IEC/EN 61000-4-4 1 kV
	– Surge	IEC/EN 61000-4-5 1 kV / 2 kV
	– Conducted RF	IEC/EN 61000-4-6 3 V/m
	– Magnetic field	IEC/EN 61000-4-8 3 A/m
	– Voltage dip	IEC/EN 61000-4-11
Safety standards		UL 60950-1, IEC 60950-1, EN 60950-1
Safety approval		cUL/UL File E188913

Industrial Device = heavily tested, good conformity

Short Circuit and Over Voltage Protected

Three Year Guarantee

reference

http://indico.cern.ch/conferenceDisplay.py?confId=20366

http://doc.cern.ch//archive/electronic/cern/others/LHB/public/lhcb-2003-049.pdf

http://doc.cern.ch//archive/cernrep/2007/2007-001/p547.pdf

http://doc.cern.ch//archive/electronic/cern/others/LHC/Note/project-note-385.pdf