Overview of MPE-Machine Interlock systems affected by radiation

Raffaello Secondo
on behalf of TE-MPE-MI

3rd February 2021

TE
Technology Department

Outline

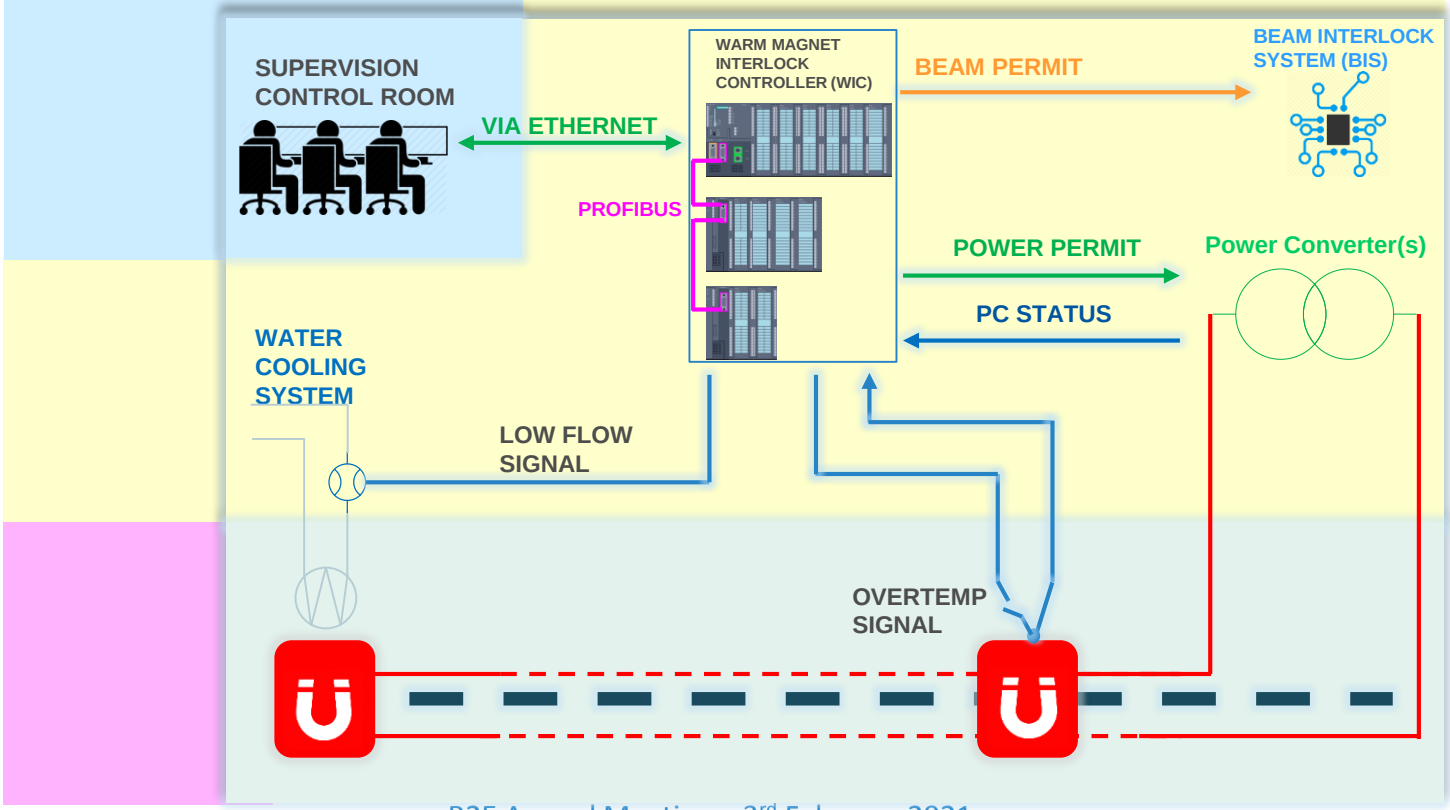
- Warm Magnet Interlock Controller: **WIC**
- Power Interlock Controller: **PIC**
- Beam Interlock System (**BIS**) User Interface (**CIBU**)
- Conclusions

Outline

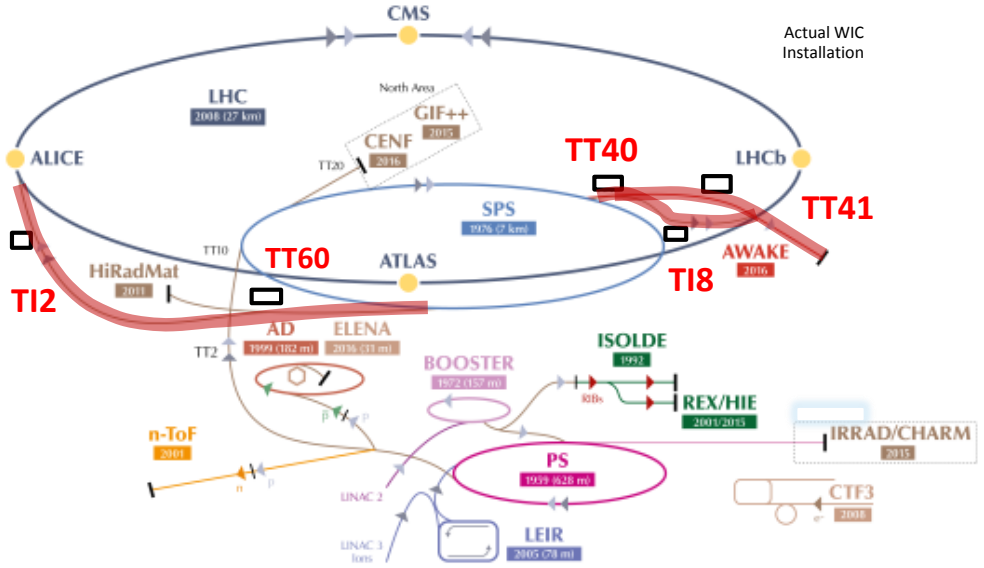
- Warm Magnet Interlock Controller: **WIC**
- Power Interlock Controller: **PIC**
- Beam Interlock System (**BIS**) User Interface (**CIBU**)
- Conclusions

WHAT IS THE WIC ?

- **GENERIC PLC** BASED SOLUTION
- ORIGINALLY DESIGNED FOR THE **PROTECTION OF RESISTIVE MAGNETS**
- COLLECTS **INPUTS** FROM THE FIELD (Thermo and Flow Switches) AND PROVIDES Power Converter AND BEAM PERMITS



WIC SYSTEMS UNDER RADIATION



CRATES UNDER RADIATION

•TI2	17 Crates	260 Magnets
•TI8	18 Crates	300 Magnets
•TT40	1 Crate	12 Magnets
•TT41	6 Crates	141 Magnets
•TT60	0 Crates	22 Magnets

- **Present Radiation Levels**: 1 Gy/year
- **HL-LHC TID**: **~2 Gy/year**
- The 5 WIC systems for the SPS-LHC transfer lines were installed in **2003 → 22 years in LS3**

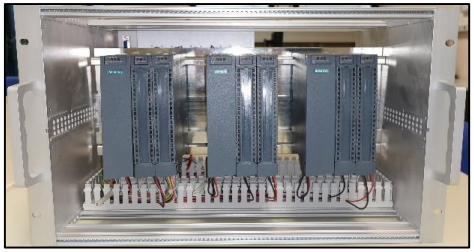
WIC strategy towards a rad-tol solution

SIEMENS

S7 1500

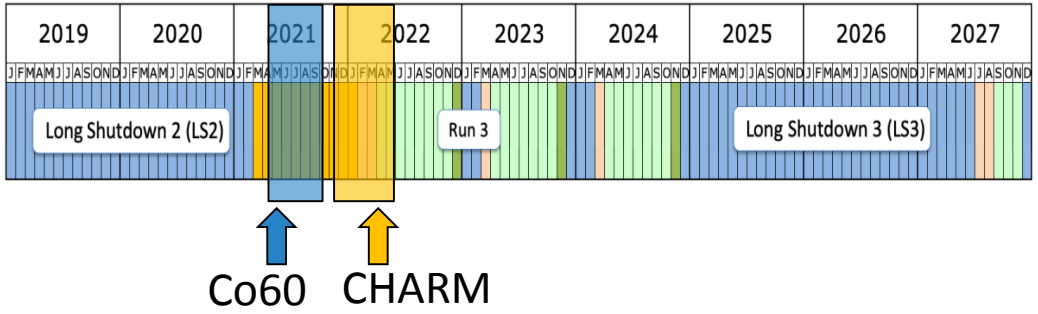
- Standard WIC solution based on **PLCs**
- Use industrial **fieldbus**
- **Compatible** with **supervision** application
- **Generic solution** for all WIC systems
- **Unknown behavior** under radiation

- **Radiation tolerant** up to 500 Gy
- **Not** yet **compatible** with PLCs
- **Not WIC standard**
- Not compatible **WinCC_OA**
- **WorldFIP fieldbus** to be implemented



I/O CRATE Under Test

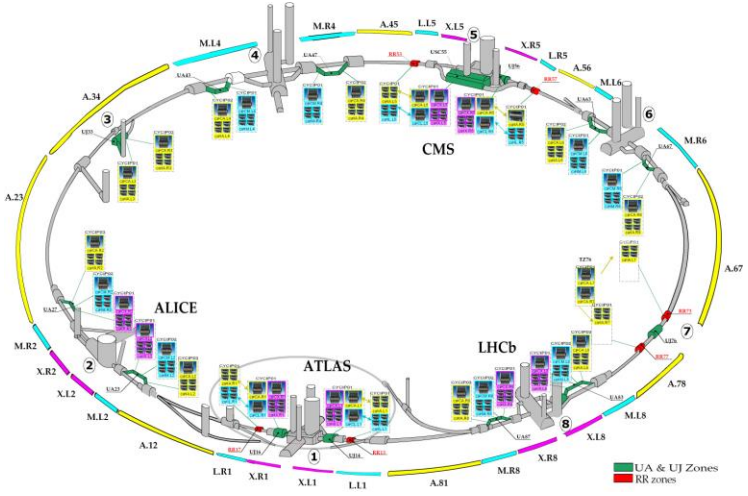
LHC SCHEDULE

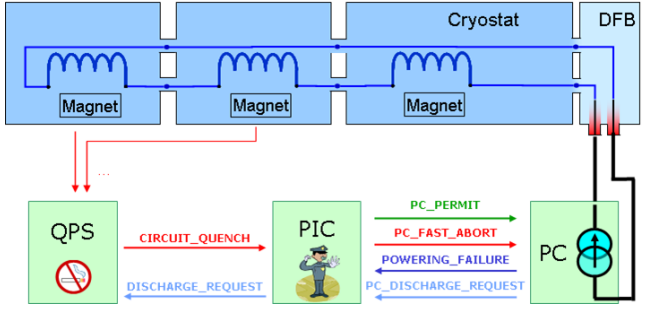


Outline

- Warm Magnet Interlock Controller: **WIC**
- Power Interlock Controller: **PIC**
- Beam Interlock System (**BIS**) User Interface (**CIBU**)
- Conclusions

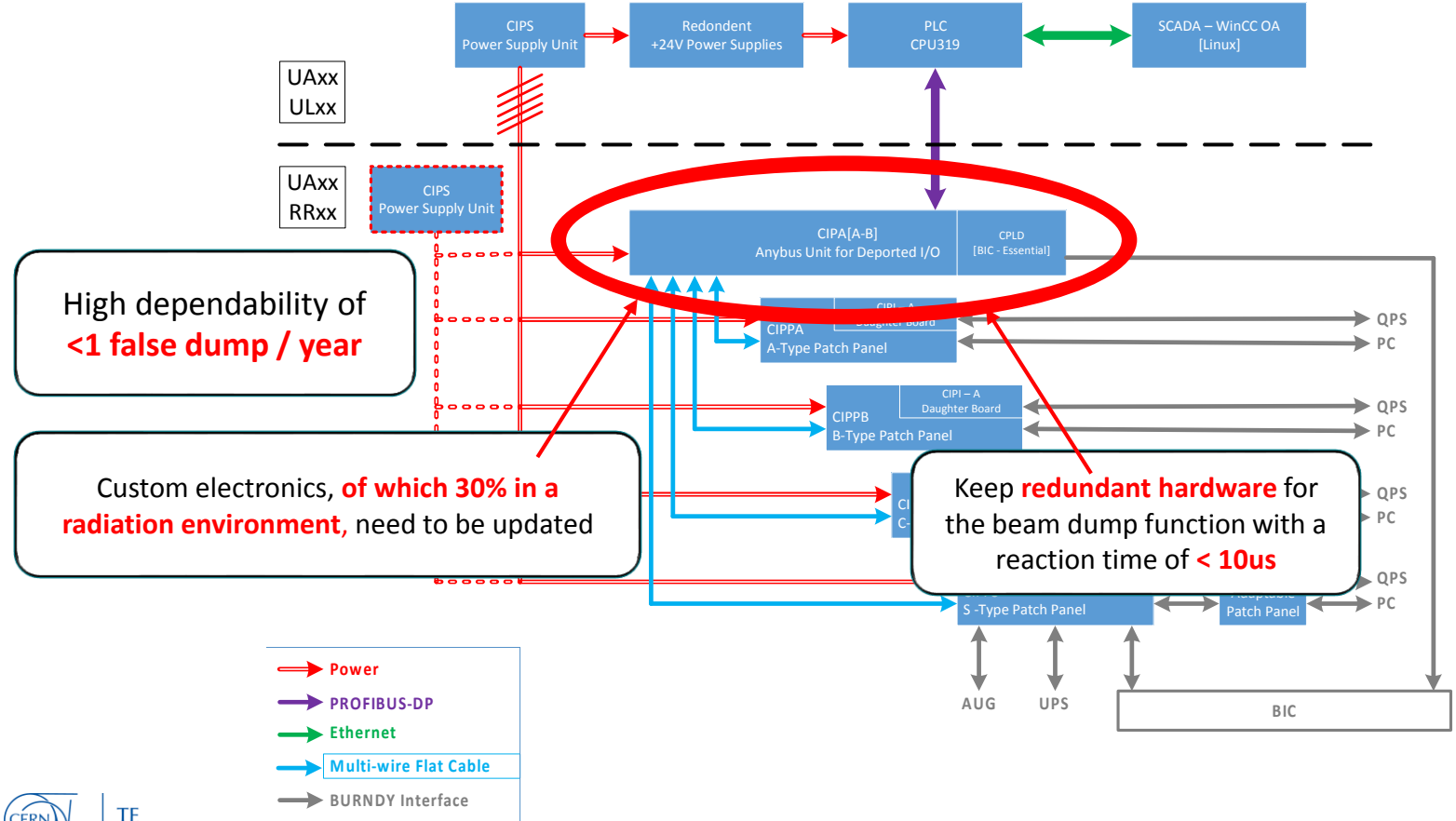
Power Interlock Controller (PIC) - I



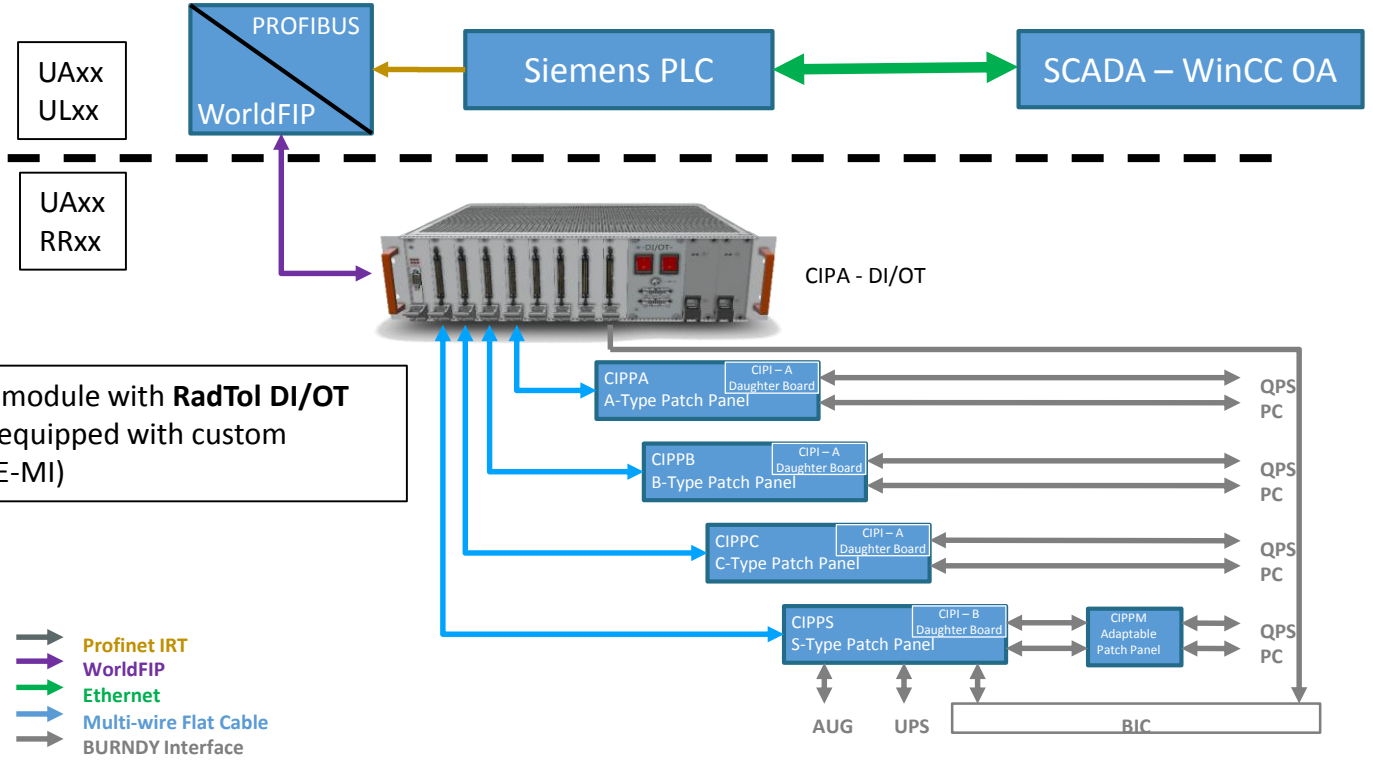


- Implemented only in **LHC.** Represents **20%** of the user inputs to BIS.
- Ensures correct **powering conditions** for the **LHC superconducting magnet circuits**
- **Interfaces** with **Quench Protection (QPS)** and **Power Converters and technical infrastructure and safety systems** (Cryogenics, UPS, AUG, Access and Controls)
- **Distributed system: 36** independent PICs installed, composed of:
  - One **Siemens S7-300** family PLC with redundant power supplies
  - One **I/O Remote** interface with **Anybus©** and CPLD embedded (**CIPA**)
  - Several tailor made electronic boards depending on the configuration (CIPS, CIPI, CIPPx).
- **10 out of 36 PICs are located in the RRs** (CIPA only).
- **RRs** expected radiation levels (HL-LHC Radiation Level Specification)**:**
  - **TID** = ~280 Gy
  - **HEH fluence** = ~ 1.4×10^{10} cm^{-2} max. annual
  - **1MeVn-eq fluence** = ~8×10^{11} cm^{-2}

Power Interlock Controller (PIC) - II



Power Interlock Controller v2 - DRAFT

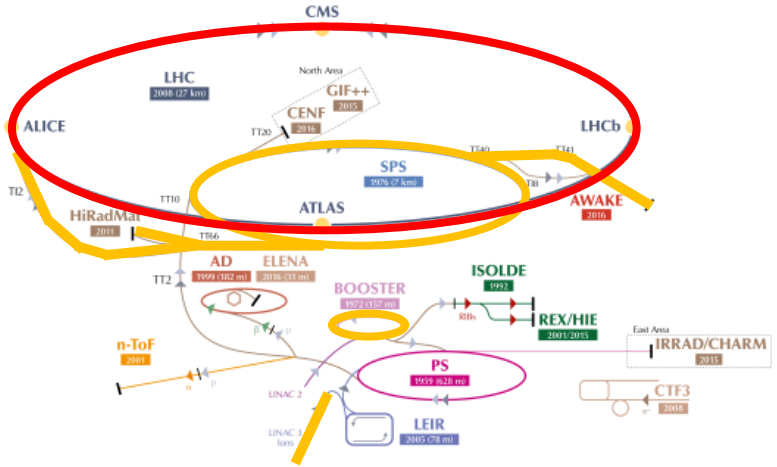


Replacement of **CIPA** module with **RadTol DI/OT** crate (BE-CO Design) equipped with custom interface boards (MPE-MI)

Outline

- Warm Magnet Interlock Controller: **WIC**
- Power Interlock Controller: **PIC**
- Beam Interlock System (**BIS**) User Interface (**CIBU**)
- Conclusions

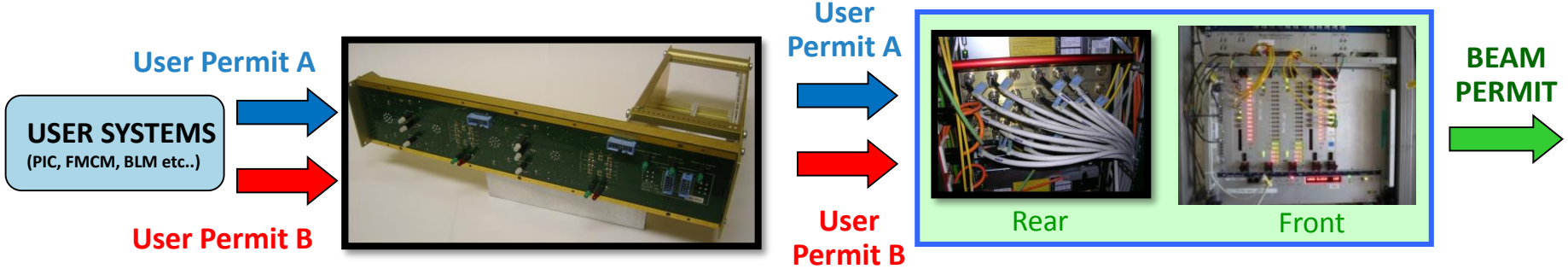
Beam Interlock System (BIS) User Interface (CIBU)



- **LHC : ~ 150** CIBUs total
- **12 CIBU** units in **RR**, Points 1/5/7
- **CIBU** system is critical to deliver the **Beam Permit** signal to the LHC Beam Dump

User Interface (CIBU)

Beam Interlock Controller



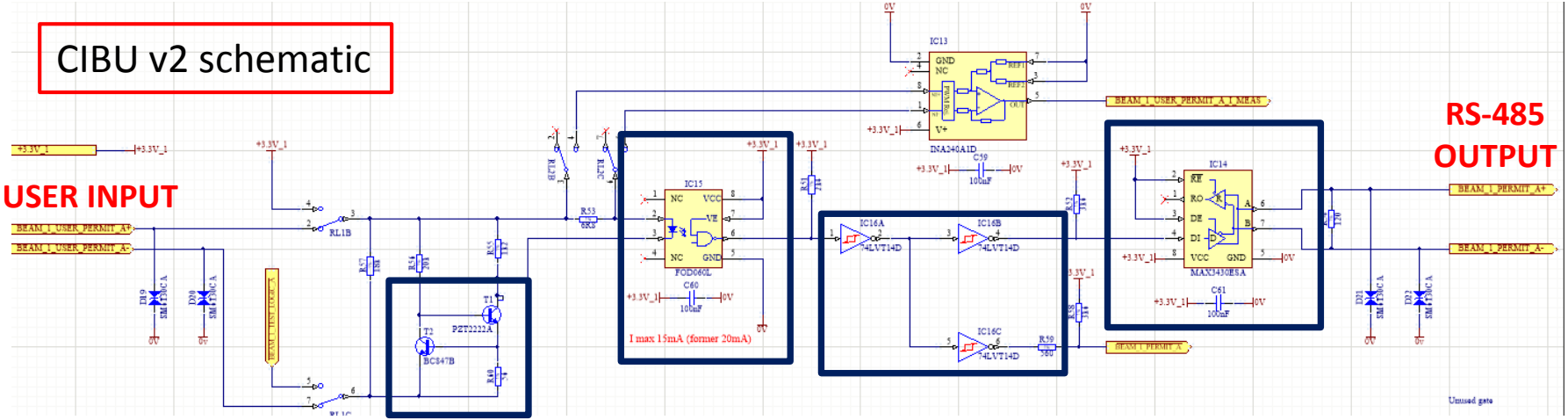
Current Target Radiation Levels

HL-LHC Radiation Level Specification:
https://edms.cern.ch/document/LHC-N-ES-0001/1.0

	Annual (360 fb^{-1}) HL-LHC radiation levels			
	TID [Gy]	HEH [cm^{-2}]	Th. neut. [cm^{-2}]	1MeVn-eq [cm^{-2}]
RR13-17-53-57 Lo	15	$1 \cdot 10^{10}$ cm^{-2}	$9 \cdot 10^{10}$ cm^{-2}	$7 \cdot 10^{10}$ cm^{-2}
RR13-17-53-57 L1	25	$1.4 \cdot 10^{10}$ cm^{-2}	$1.2 \cdot 10^{11}$ cm^{-2}	$7 \cdot 10^{10}$ cm^{-2}
UJ14-UJ16 Lo	6	$3 \cdot 10^{9}$ cm^{-2}	$3 \cdot 10^{11}$ cm^{-2}	$5 \cdot 10^{10}$ cm^{-2}

Hi-Lumi, RR (L1) **ultimate** scenario: **4000 fb^{-1}**
TID = **~280 Gy**
HEH fluence = **~1.6 x10^{11} cm^{-2} total, ~ 1.4x10^{10} cm^{-2} max. annual**
1MeVn-eq fluence = **~ 8 x10^{11} cm^{-2}**

CIBU v2 schematic



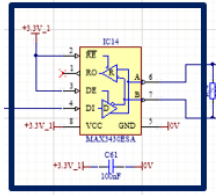
Radiation Tests Results -I

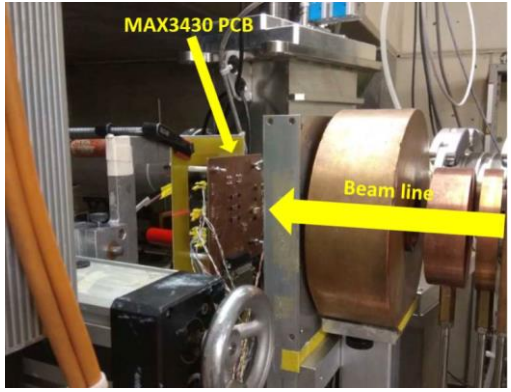
*Tests carried out at **PSI** by **BE-CEM-EPR***

RS485 driver MAX3430

- **Report**: EDMS #2417502
- **No errors** on RX side.
- Reached TID **500 Gy** and HEH fluence **8.5x10^{11} cm^{-2}**.
- **SETs** observed in **data transmission**, average device **cross-section**

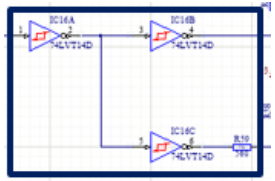
  σ = ~ 1x10^{-11} cm^2 in **worst case conditions**

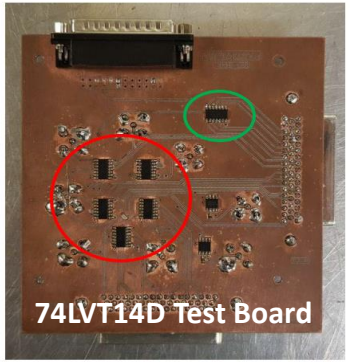




Schmitt Trigger 74LVT14D

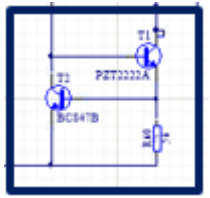
- **Report**: EDMS #2417025
- TID **500 Gy**, HEH fluence **8.5x10^{11} cm^{-2}**
- **No large variation/degradation of all quantities**





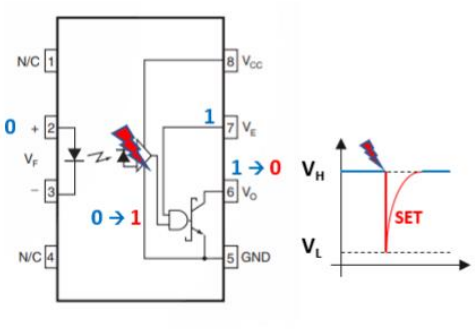
BJT Transistors: BC847B and PZT2222AT1G

- **Report**: EDMS #2454604
- TID **500 Gy**, HEH fluence **8.5x10^{11} cm^{-2}**
- Worst case degradation of **40%**, within the **manufacturer specifications**

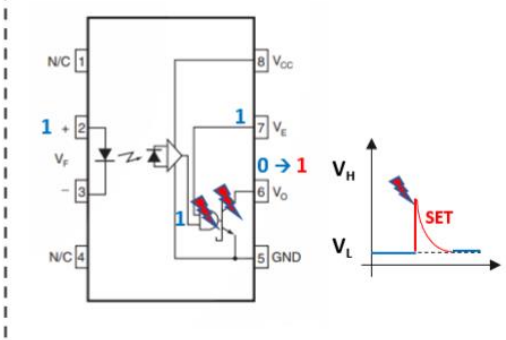


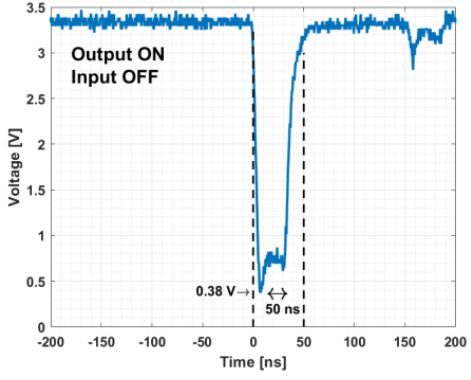
Radiation Tests Results - Optocoupler

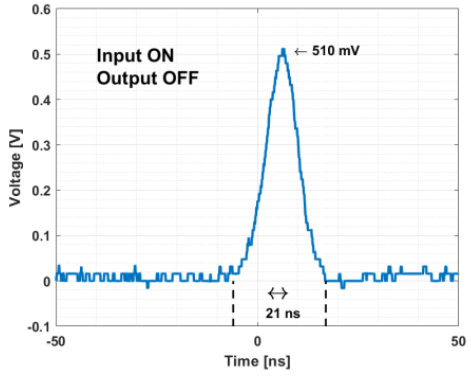
FALSE → TRUE



TRUE→FALSE CRITICAL





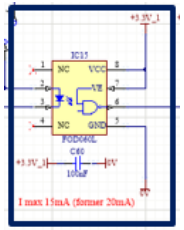


Reference	Cross-section [cm2/device]	
	Input OFF Output ON	Input ON Output OFF
FOD060RL	$3.94 \cdot 10^{-8}$	$6.43 \cdot 10^{-10}$
HCPL-060L -500E	$3.67 \cdot 10^{-8}$	$3.31 \cdot 10^{-11}$

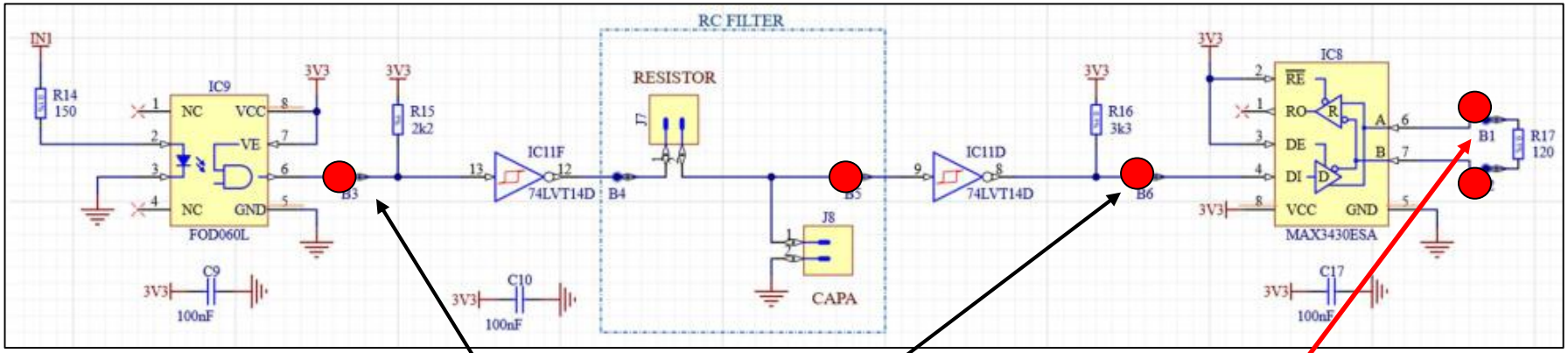
- **FOD060**: ~ 128 SET in $2x10^{11}$ cm^{-2}
- **HCLP-060L**: ~ 7 SET in $2x10^{11}$ cm^{-2}
- **No variation** of shape and pulse duration

- **Present CIBU** optocoupler $\sigma_{SEE} = \underline{8.3 \times 10^{-10}}$ cm^2
- **Report**: EDMS #2416544
- DDEF:
  - FOD060L: ~ $9x\mathbf{10^{12}}$ cm^{-2} 1MeV neq (AlGaAs)
  - HCPL-060L: ~ $5x\mathbf{10^{12}}$ cm^{-2} 1MeV neq (GaAsP)
- **Strong response to TID and DD**.
- **Neutrons test** foreseen**.**

Courtesy of BE-CEM-EPR



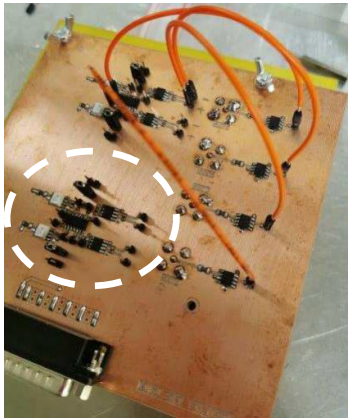
TEST OF FULL CIBU CRITICAL CIRCUIT



@**500 Gy** and HEH **8.5e11** cm^{-2}: **38** SETs **19** SETs **0** SETs

- Steps of **100 Gy** and **1.7E11 p/cm2 fluence**
- Reached **500 Gy** and HEH **8.5 x10^{11}** cm^{-2}
- Hi-Lumi ultimate target: TID **280 Gy**, HEH **1.4x10^{10} cm^{-2} max. annual**

- **Report**: EDMS #2415099
- Total cross-section **σ < 4.4 x 10^{-12} cm^{-2}** (95% confidence)
- **Test @ CHARM** in 2021/2022



Courtesy of BE-CEM-EPR

Conclusions

WIC

- System requires upgrade. Transfer lines crates affected by radiation
- **Strategy**: Test S7 1500 Siemens IOs at **Co60** (2021) and if successful **CHARM** (2021/2022)
- S7 1500 Batch reserved
- Keep **DIOT** as a possibility.

PIC

- Deployed in LHC, in particular affected by radiation in the RRs.
- **Strategy**: use **DIOT** system to replace current hardware in radiation

BIS - CIBU

- **CIBU v2**: Highly critical interface with users connected to the BIS. Particularly impacted by radiation in the RRs.
- **Strategy**: tests at component level at PSI, tested the full **critical** circuit.
- **To Do**: Test Monitoring COTS, Power Supply, Neutron Test on optocoupler.
- Planning a test at CHARM in 2021/2022 to validate the system


CERN