QDS R2E events during 2023 LHC ion run
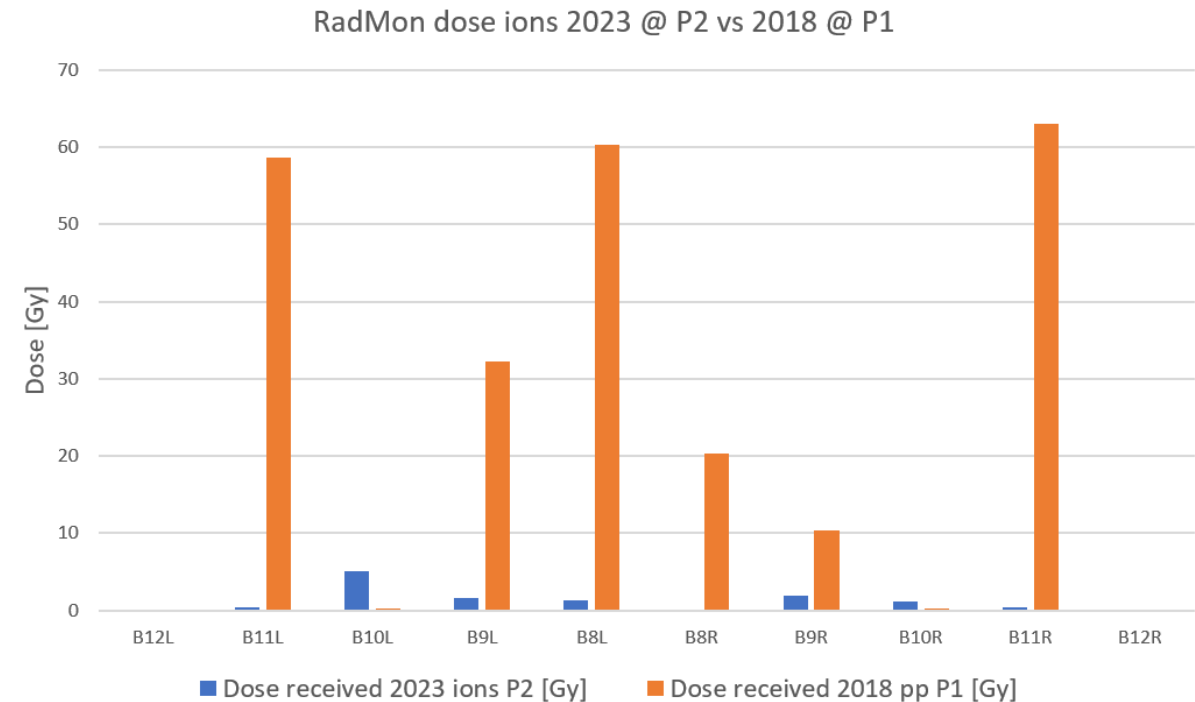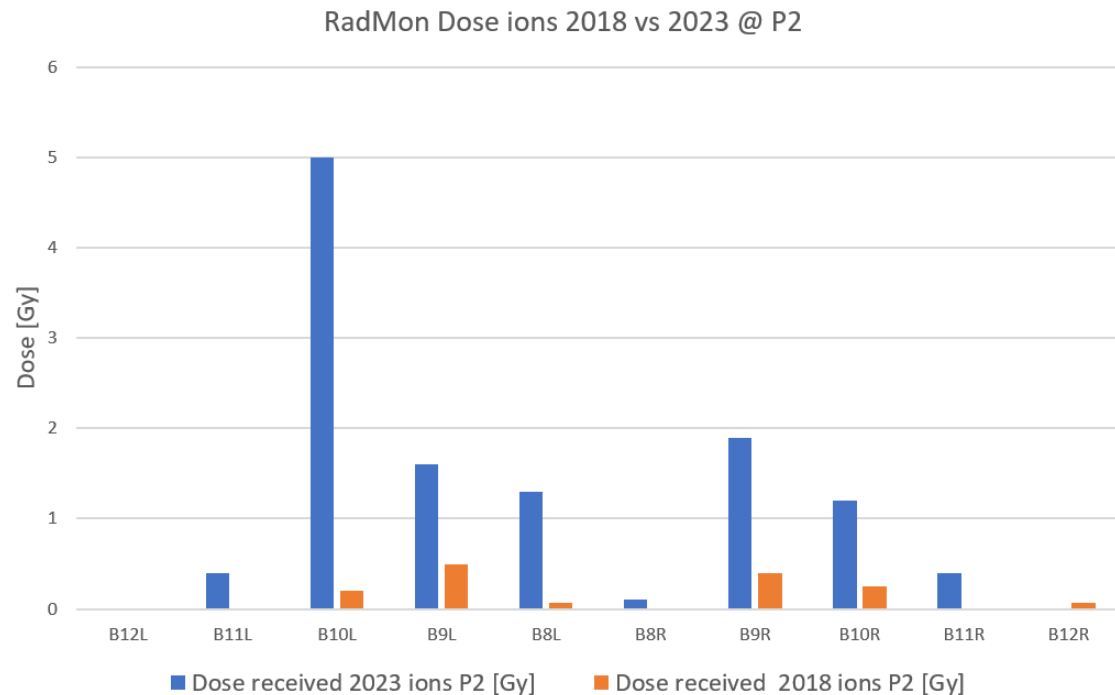
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Content

- **Radiation data**

- **Event Overview**

- **R2E classes of the QDS during 2023 ion Run**

- **Mitigation measures and Timeline**

Setting the scene – Doses 2023 vs 2018

RadMon Dose ions 2018 vs 2023 @ P2

RadMon dose ions 2023 @ P2 vs 2018 @ P1

- **During 2023 ions, dose recorded by RadMons is >2x higher than in ions 2018**

- **In terms of dose recorded, P2 losses are negligible compared to doses recorded in P1 during 2018 pp run**

Event Type Overview

- **2023 ion run lead to far more radiation induced (R2E) trips of the LHC QDS than expected**

- **We found 4 different classes of R2E events (2 known, 2 new ones)**
  - Class 1: DAQ triggers (mitigated) no effect on operation (act as mini rad mon)
  - Class 2: SEU in bus bar splice detector (DQQBS) causing a fast power abort (FPA)
  - Class 3: SEL in base layer for MQ (DQQDL) causing MQ heater firing and FPA
  - Class 4a: SEL in nQPS communication board (DQAMG) causing FPA
  - Class 4b: SEL in nQPS communication board (DQAMG) causing FPA 3xMB heater firing

- **Class 1 & Class 2 were known and (to a certain extend) expected**

- **Class 3 & Class 4 did not happen before**
  (1 class 4 event found during proton run after re-analysis)

Ion run 2023 – R2E Event overview

Date	Location	Event class	Consequence
Oct 5	B10L2	4a	FPA (precycle required)
Oct 7	B9R2	4b	FPA, Heater discharge MB (quench)
Oct 11	B10L2	2	FPA (precycle required)
Oct 12	B9L2	2	FPA (precycle required)
Oct 12	B8L5	4a	FPA (precycle required)
Oct 13	B12R2	4b	FPA, Heater discharge MB (quench)
Oct 14	A12L2	3	FPA, Heater discharge MQ (quench)
Oct 15	A12R2	3	FPA, Heater discharge MQ (quench)
Oct 15	B12R1	2	FPA (precycle required)
Oct 20	B11L1	2	FPA (precycle required)
Oct 22	B10L2	2	FPA (precycle required)

- In 2023 ion run we saw 11 unmitigated R2E events leading to FPA or worse

- Weekend 14th and 15th of October was especially troublesome

- In 2018 ion run we saw 2 class 2 events only

- In 2018 proton run we saw 6 class 2 and 1 class 4 events

Class 1 events – DAQ triggers (mitigated)

- **Known R2E issue of the base layer QDS for dipoles**

- **Digital isolator changes logic level due to SEU**

- **Mitigated in firmware since many years**

- **Used as a "radiation detector:**

Rack 10L2 is displaced compared to R2, cannot be moved due to other equipment (slight mitigation by changing sequence of modules could "win" 1-2m)

DAQ SEU IP2 2018

DAQ SEU IP2 2023
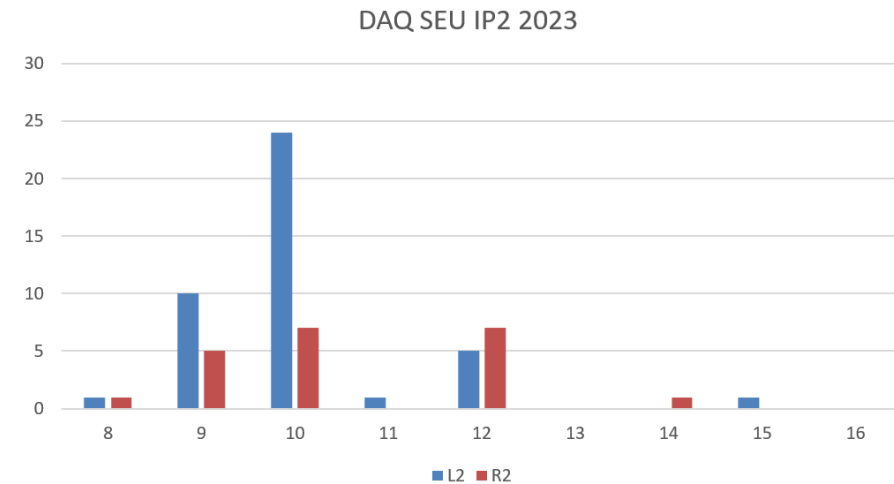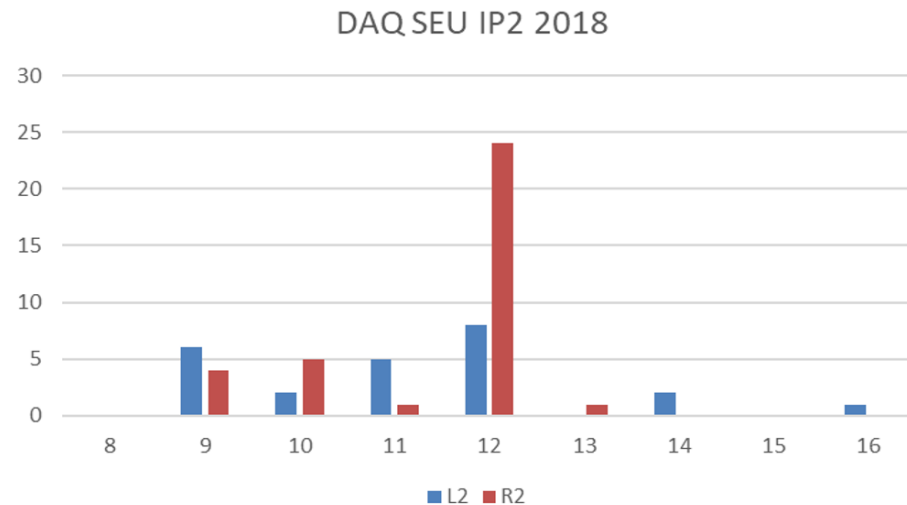
Class 2 events – DQQBS triggers

- **Well known issue, happens also sporadically during high intensity PP runs**

- **DQQBS is based on ADuC834, a uC with integrated sigma delta ADC. SEU in this microcontroller lead to a spurious FPA**

- **5 events in 2023 ion run, 1 in 2023 protons:**

- **Comparison 2023 vs 2018:**

Year	Run type	Events
2023	pp	1
2023	ions	**5**
2018	pp	6
2018	Ions	2

№	Location	Type	Circuit	Fill	Date
LHC ion run 2023					
1	B10L2	Power abort	RB.A12	9243	11/10/2023
2	B9L2	Power abort	RQD.A12	9247	12/10/2023
3	B12R1	Power abort	RB.A12	9258	15/10/2023
4	B11L1	Power abort	RQD.A81	9283	20/10/2023
5	B10L2	Power abort	RB.A12	9289	22/10/2023

Class 3 events – DQQDL (MQ) SEL, FPA + HDS trigger

- **2 Events at Oct 14 and Oct 15, symmetrically around P2 11L**

  - 1st event, MQ11L2: one ADC channel saturated, isolated power supply indicates out of spec. voltages. Power cycle un-latched component and device resumed normal operation

  - 2nd event, MQ11R2: One complete isolate domain (3 ADC channels) saturated values, indication of bad isolated power. Power cycle did not restore function → piquet intervention to change card

- **Post mortem analysis in lab on damaged board revealed the faulty component**

- **Single Event latch up in OPA2192 operational amplifier of the DQQDL for quadrupoles**

- **After replacing this opamp, DQQDL was fully functional again**

- **No further event recorded after Oct. 14th/15th**
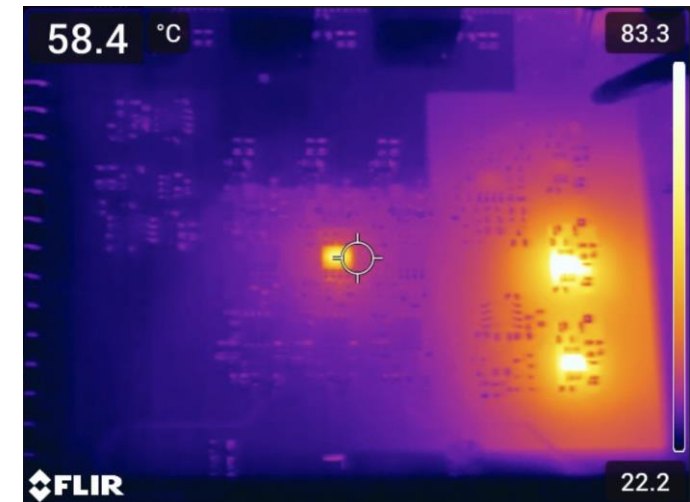
Class 4 events – nQPS FPA and HDS firing on 3xMB

- Loss of communication to the nQPS (DQLPU-S) crate

- Instantaneous or delayed FPA and/or trigger of quench heaters by symmetric quench detection card, DQQDS

- Crate controller's microcontroller (ADuC831) physically destroyed by destructive SEL

- Controller can switch off power rails of DQQDS and DQQBS by setting proper output pin high

- Local SEL probably causes voltage fluctuations on power cycle pins leading to deactivation of two different power rails feeding DQQDS and DQQBS
  → Causes Fast power abort (4a)
 → Fires heaters, quenching magnet (4b)

Mitigation

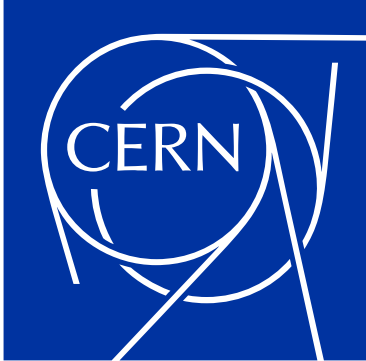| Class	Element	Mitigation	Time frame (optimistic)
Class 2	DQQBS	New implementation of DQQBS with FPGA and rad tol SAR ADC. Install around P1, P2, P5	End of EYETS 2023/2024
Class 3	DQQDL (MQ)	Replace op amp by compatible type in different technology on 4 DQQDL and 2 DQCSU in racks A12 L2 & R2	EYETS 2023/2024
Class 4	DQAMGS	Produce slightly modified version of crate controller with E-Fuse & Pi filter mitigating consequence of SEL	End of EYETS 2023/2024

DQQBSv2

DQQDL
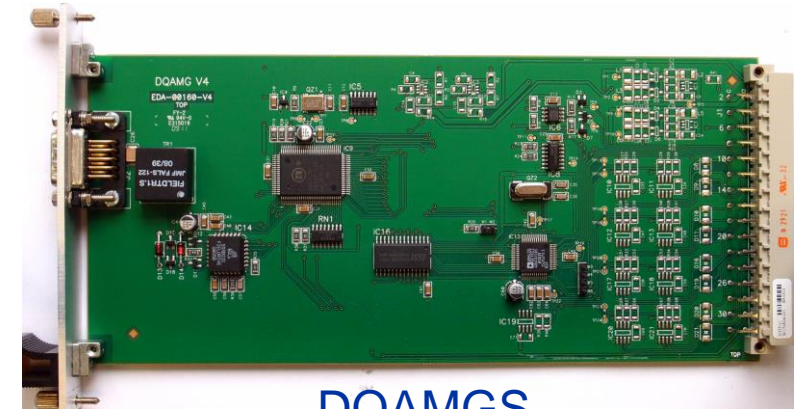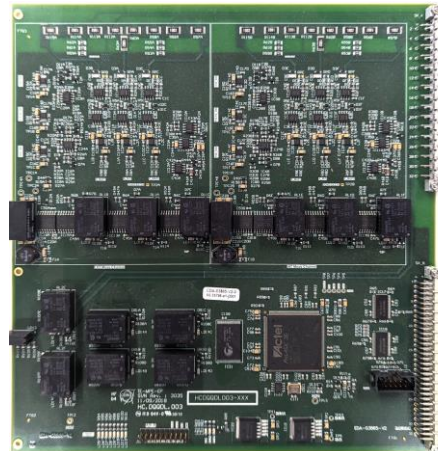
DQAMGS

Conclusion/Outlook

- **2023 ion run lead to an overproportional amount of radiation induced events in the QDS**

- **These events do not scale with dose measured by radmons**

- **Probably the spectrum shifts to a higher LET which would explain the destructive events observed**

- **Error modes of the different classes are clear**

- **We will address all three non-mitigated error classes by modifications to the QDS to be completed until end of EYETS**

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