Radiation levels in the LHC during the Pb run 2023 – Point 2 and QPS rack locations

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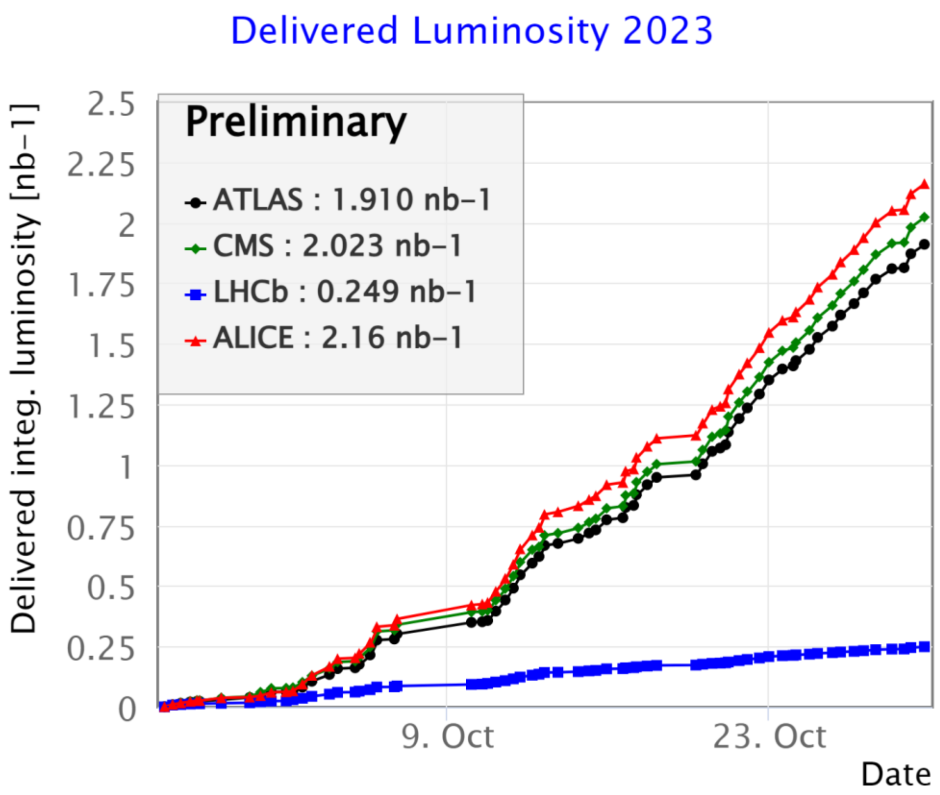
with input from Reiner Denz (TE-MPE-EP)
11/2023

Beam overview, luminosity statistics

Using data from lpc.web.cern.ch

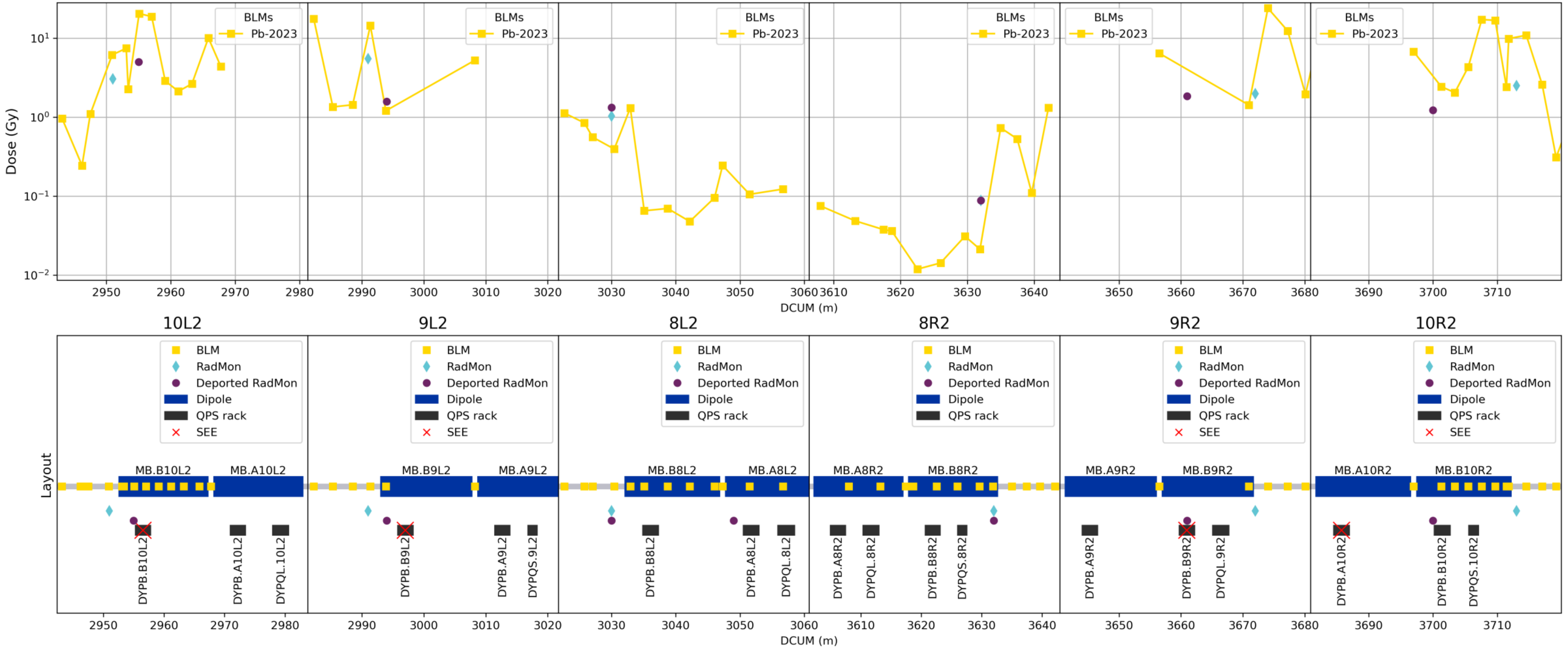


IR	Luminosity (1/nb) Ions 2023	Luminosity (1/nb) Ions 2018
1	1.91	1.797
2	2.16	0.905
5	2.02	1.802
8	0.249	0.235

Compared to the 2018 ion run, the luminosity is similar in all IPs except for IP2, where it increased by 2x

QPS racks and radiation monitor layout - IR2 cells 8-10

- iQPS under every main dipole
- nQPS under the B-dipoles together with iQPS

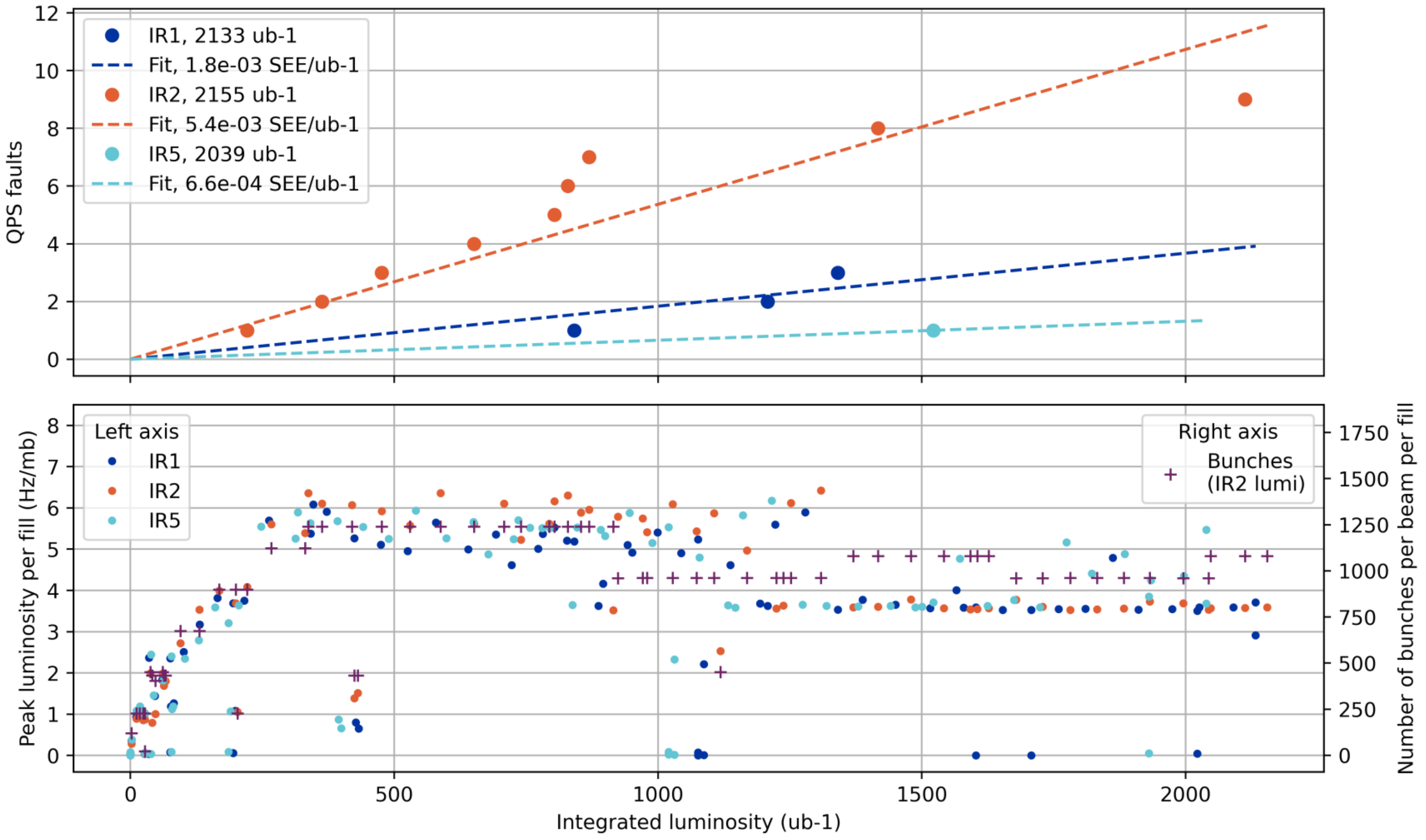


R2E effects observed in the QPS system

	Date	Time	Rack	Fault type	DCUM	Short description
1	5/10/2023	8:34:22	DYPB.B10L2	SEU	2957	nQPS DQQBS, Busbar splice protection system trigger causing circuit fast power abort
2	7/10/2023	0:24:27	DYPB.B9R2	Latch-up	3661	nQPS DQQDS RB, Symmetric quench detection system triggering causing heater firing and magnet quench; communication board failed before
3	11/10/2023	8:38:10	DYPB.B10L2	SEU	2957	nQPS DQQBS#3A, Busbar splice protection system trigger causing circuit fast power abort
4	12/10/2023	13:40:05	DYPB.B9L2	SEU	2997	nQPS DQQBS RQD, Busbar splice protection system trigger causing circuit fast power abort during ramp down after operator dump
5	13/10/2023	22:45:48	DYPB.B12R2	Latch-up	3792	nQPS DQQDS RB, Symmetric quench detection system triggering causing heater firing and magnet quench; communication board failed before
6	14/10/2023	20:52:09	DYPQ.12L2	Latch-up?	2886	iQPS MQ.11L2 nDQQDL, Quench detection system trigger causing heater firing and magnet quench
7	15/10/2023	7:57:08	DYPB.B12R1	SEU	460	nQPS DQQBS, Busbar splice protection system trigger causing circuit fast power abort
8	15/10/2023	13:47:38	DYPQ.A12R2	Latch-up	3782	iQPS MQ.11R2 nDQQDL, Quench detection system trigger causing heater firing and magnet quench
9	20/10/2023	23:45:45	DYPB.B11L1	SEU	26244	nQPS DQQBS RQD, DQQBS trigger provoking FPA
10	21/10/2023	14:40:00	DYPB.A12R1	SEU	445	iQPS DQHSU, Wrong DQHDS voltage reading by DQHSU board would have caused trigger of DQHDS software and slow power abort. Programmed dump by OP before; cleared by remote power cycle
11	22/10/2023	7:58:06	DYPB.B10L2	SEU	2957	nQPS DQQBS RB, DQQBS trigger provoking FPA
12	24/10/2023	8:18:01	DYPB.B8L5	Latch-up	13034	nQPS DQAMG, Fast power abort - no quench. DQAMG to be replaced.
13	29/10/2023	13:33:50	DYPB.A10R2	SEU	3686	iQPS DQAMGNMB, COM lost - OK after power cycle

SEEs in the QPS racks as a function of luminosity

- Scaling coeficients of SEEs in the QPS racks per IR as a function of integrated luminosity in the IR
- The number of bunches and bunch trains were levelled around the ”SEE storm” occurring in IR2 before 1 nb^{-1}
- (Data from LHC supertable)



Radiation levels close to QPS rack locations

Example: QPS rack DYPB.B10L2 @ dcum 2957, with three SEEs

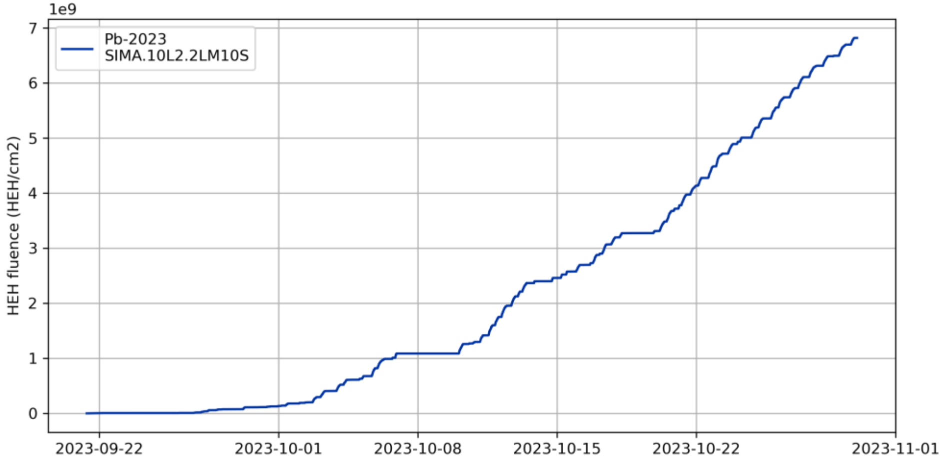
Deported modules close to DYPB-racks (only TID) ↓

Full RadMon modules further away ↓

RadMon data	**Dose at dcum 2955**	**HEH fluence at dcum 2951**
Pb-2023	5.02 Gy	$6.8*10^9$ HEH/cm^2
Pb-2018	0.25 Gy	$2.4*10^9$ HEH/cm^2
Proton-2023	~0 Gy	$3.7*10^7$ HEH/cm^2

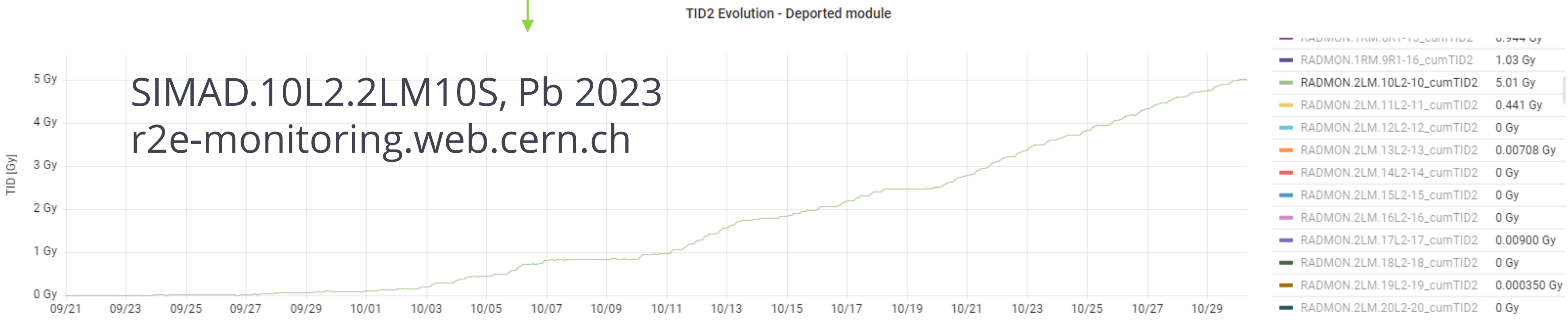
→

SIMA.10L2.2LM10S, HEH Pb 2023



Not huge doses in terms of TID effects

↓



SIMAD.10L2.2LM10S, Pb 2023
r2e-monitoring.web.cern.ch

Deported RadMon module data of half-cells 8, 9, 10

Doses measured by deported radmon modules, generally close to QPS racks, in half-cells 8, 9 and 10 left and right of points 1, 2 and 5. The number of QPS faults in these half-cells are also marked. The resulting number of SEEs per dose per half cell is similar among the time periods (low statistics).

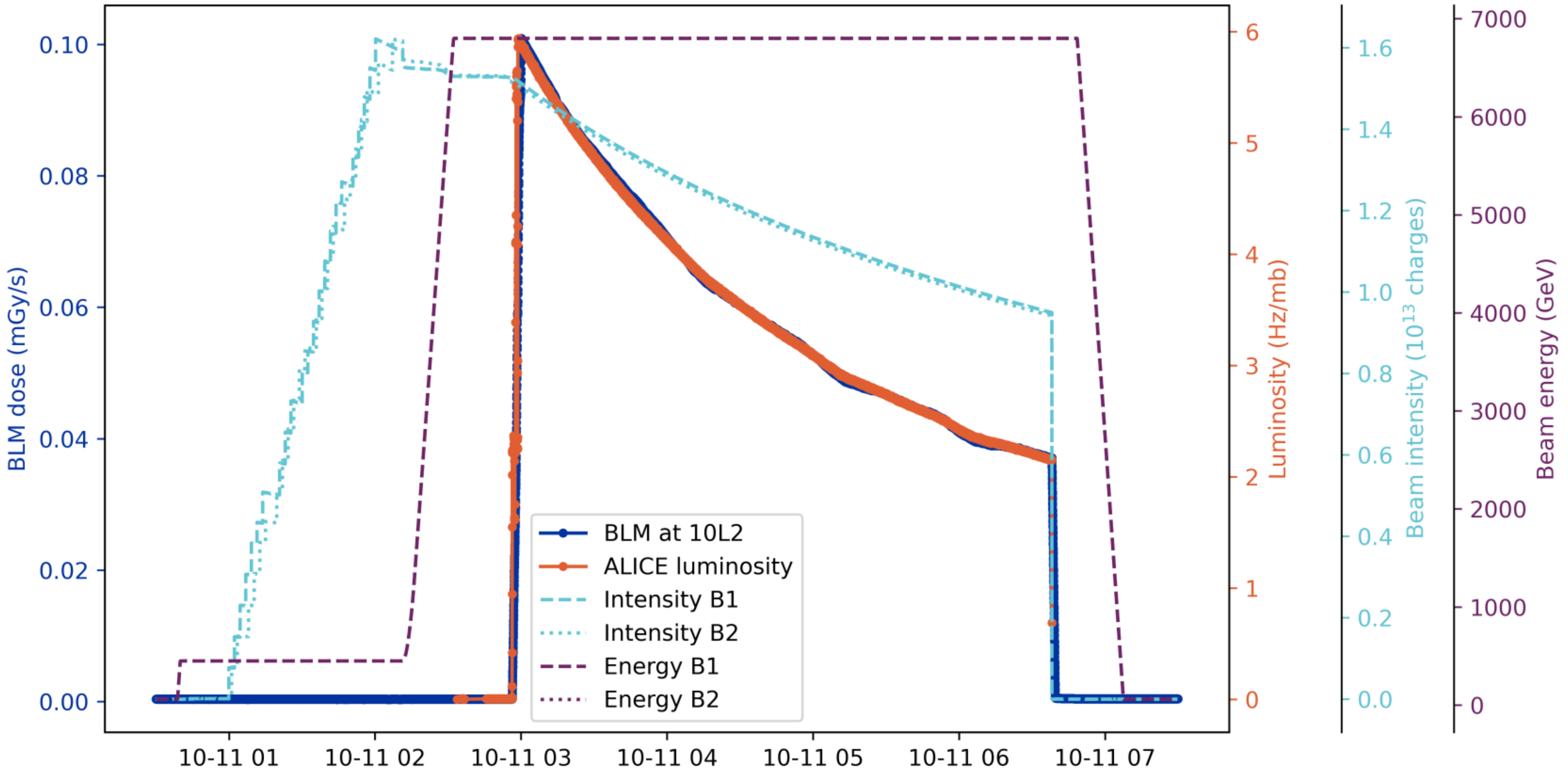
Half-cells, SEEs	TID Pb-2023 (Gy)	TID Pb-2018 (Gy)	TID p-2023 (Gy)	TID p-2018 (Gy)
8L/R1, #SEE	- / 0.9, 0	0.9 / 0.5, 1	- / ~0, 0	10.5 / 6.9, 5
8L/R2, #SEE	1.3 / 0.1, 0	0.1 / -, 0	1.4 / ~0, 0	1.1 / -, 0
8L/R5, #SEE	1.1 / 0.1, 1	1.0 / 0.2, 0	0.1 / 0.2, 0	28.9 / 9.7, 4
9L/R1, #SEE	0.7 / 1.1, 0	0.4 / 0.9, 0	~0 / 0.1, 0	4.1 / 5.1, 2
9L/R2, #SEE	1.6 / 1.9, 2	0.6 / 0.4, 1	~0 / ~0, 0	~0 / ~0, 0
9L/R5, #SEE	0.7 / 1.1, 0	0.6 / 0.9, 1	0.5 / 0.1, 0	4.3 / 6.3, 2
10L/R1, #SEE	- / ~0, 0	- / ~0, 0	- / ~0, 0	- / ~0, 0
10L/R2, #SEE	5.0 / 1.2, 4	0.2 / 0.3, 0	~0 / ~0, 0	~0 / -, 0
10L/R5, #SEE	~0 / -, 0	~0 / -, 0	~0 / -, 0	~0 / -, 0
SEE per Gy per half-cell	6.2 (2.5, 13)	6.3 (1.3, 19)	0 (0, 24)	2.5 (1.4, 4.3)

(1 Gy ↔ $3\cdot10^9$ HEH/cm^2) →

[Calculated value (lower limit, upper limit)]

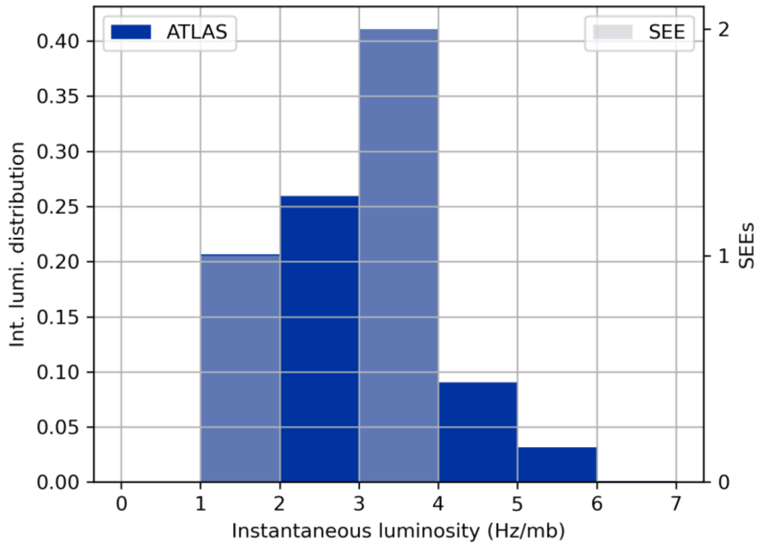
BLM signals used for dose distribution monitoring

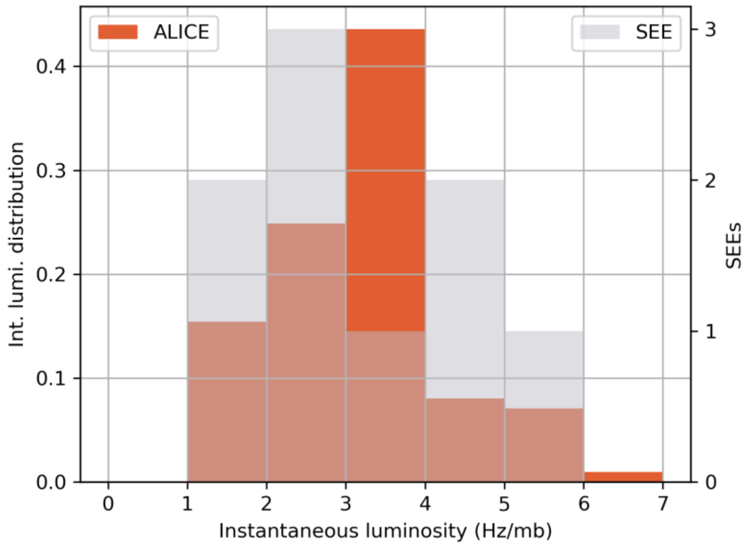
- Induced dose around an interaction point scales well with the integrated luminosity of that point

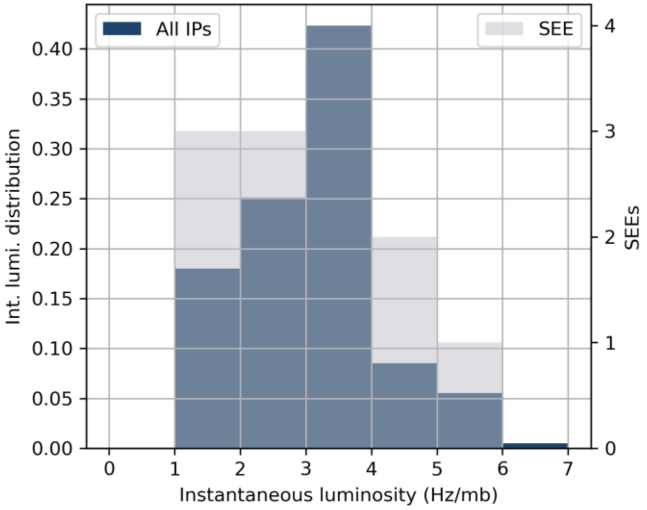


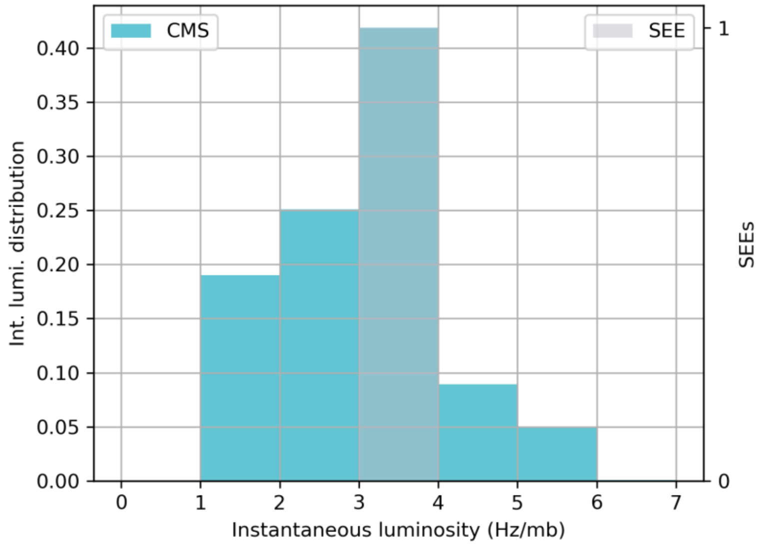
Instantaneous and integrated luminosity

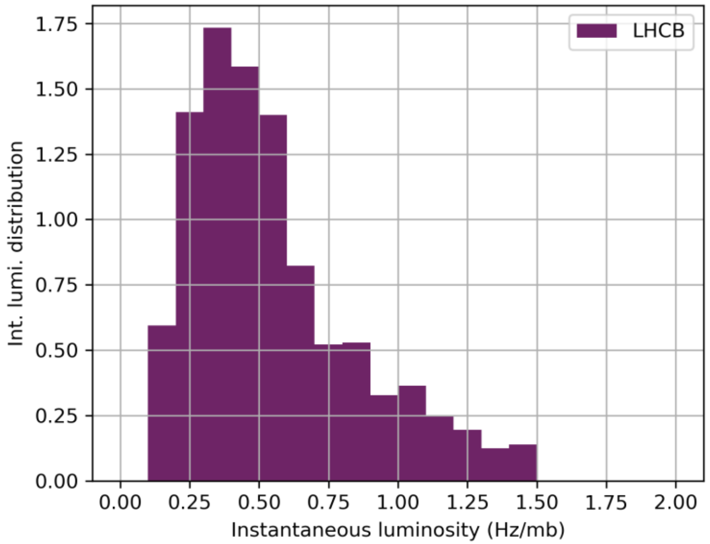
- The delivered integral luminosity of bins of instantaneous luminosities in LHC during the ion run
- The radiation levels around the IP is proportional to the IP luminosity, so the SEEs should follow the same distribution as the integrated luminosity
- Low statistics, but no clustering of SEEs at specific instantaneous luminosity values



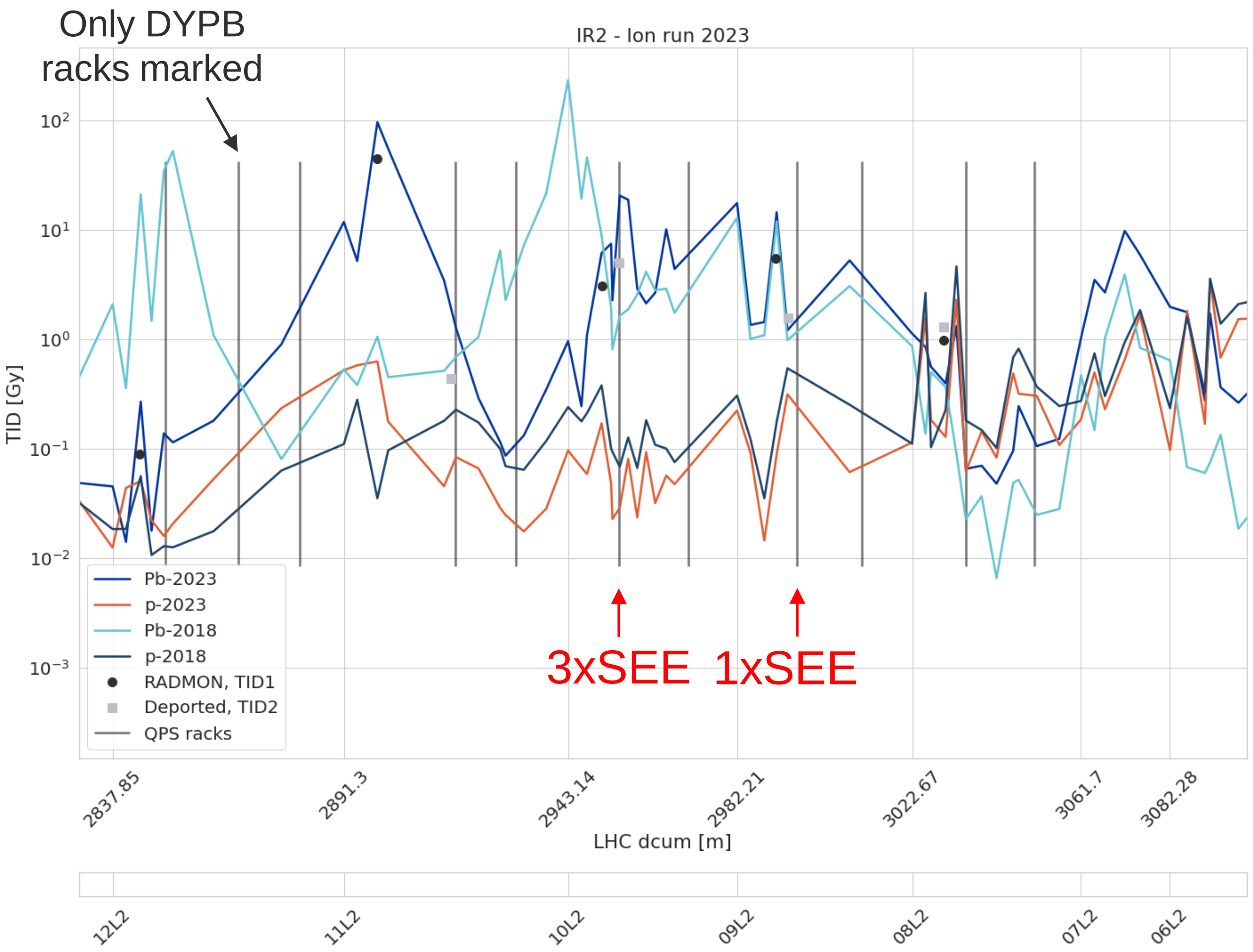








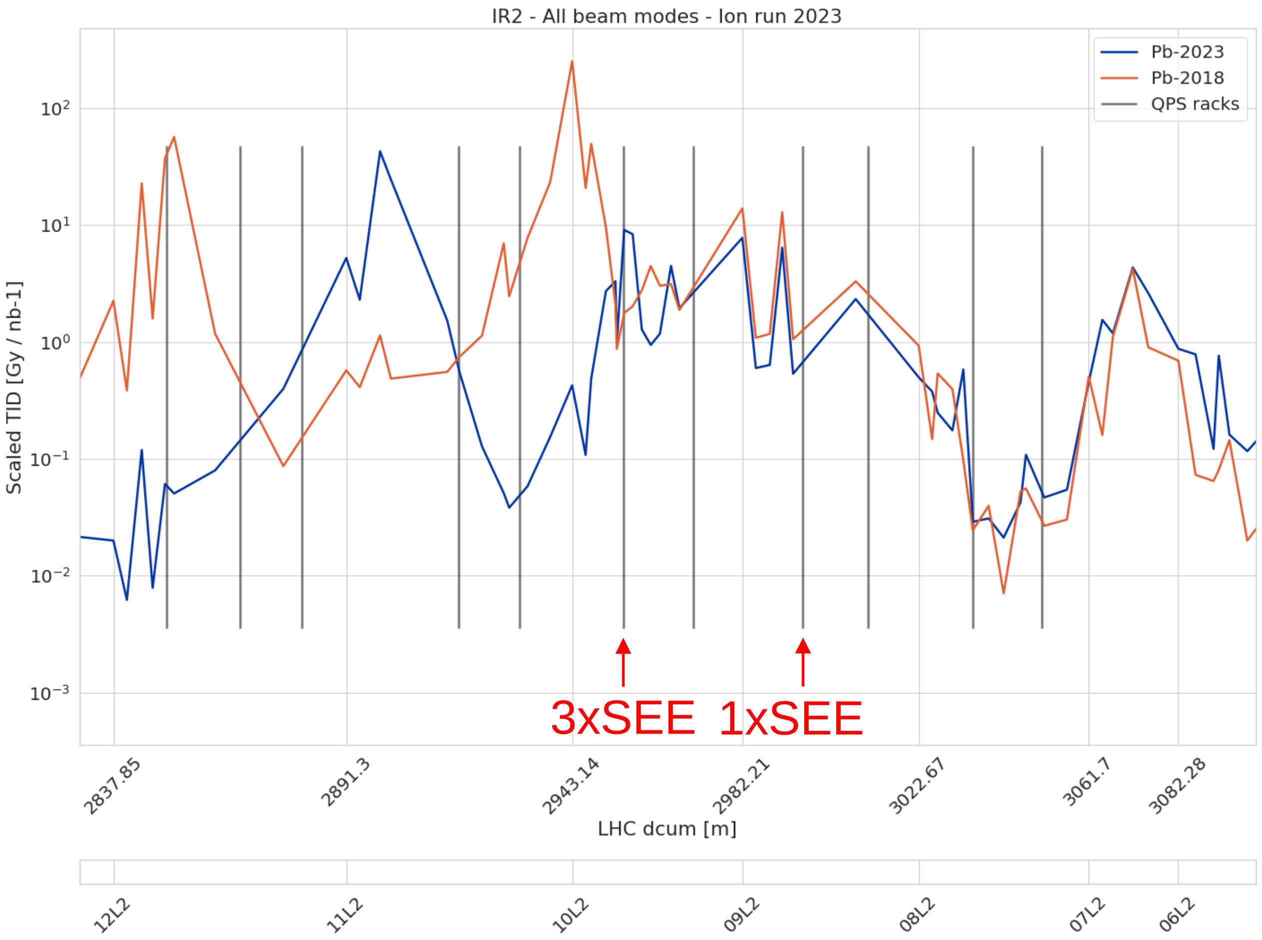
Left of Point 2 - Dose distribution DS, 2018 vs 2023



- Comparing the total BLM dose during the 2018 and 2023 ion and proton runs, left of IP2
- Note: the lines between the points are visual guides and do not represent real dose values.
- The dose in the DS is dominated by the ion runs
- The dose peaks shifted compared to the 2018 run, due to the new TCLD location (and the related optics change)

Integrated luminosities in IR2:
Pb 2023: 2.16 nb^{-1}
Pb 2018: 0.905 nb^{-1}
(p 2023: 14.5 pb^{-1})

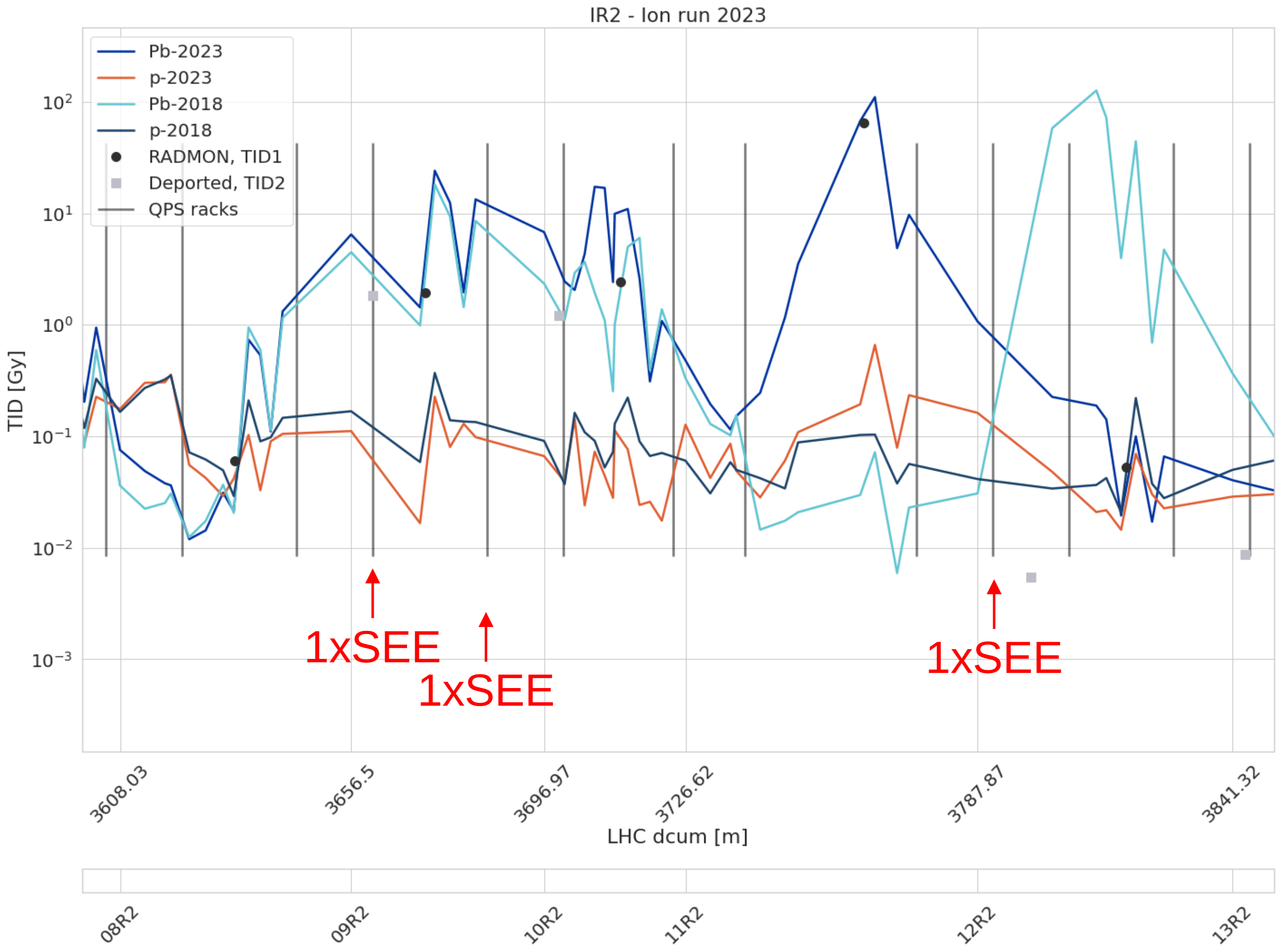
Left of Point 2 - Dose distribution DS, scaled doses



- A comparison between the dose levels left of point 2 for ion runs 2018 and 2023
- **Doses are normalized by the integrated luminosity in IR2**

Integrated luminosities in IR2:
Pb 2023: 2.16 nb^{-1}
Pb 2018: 0.905 nb^{-1}

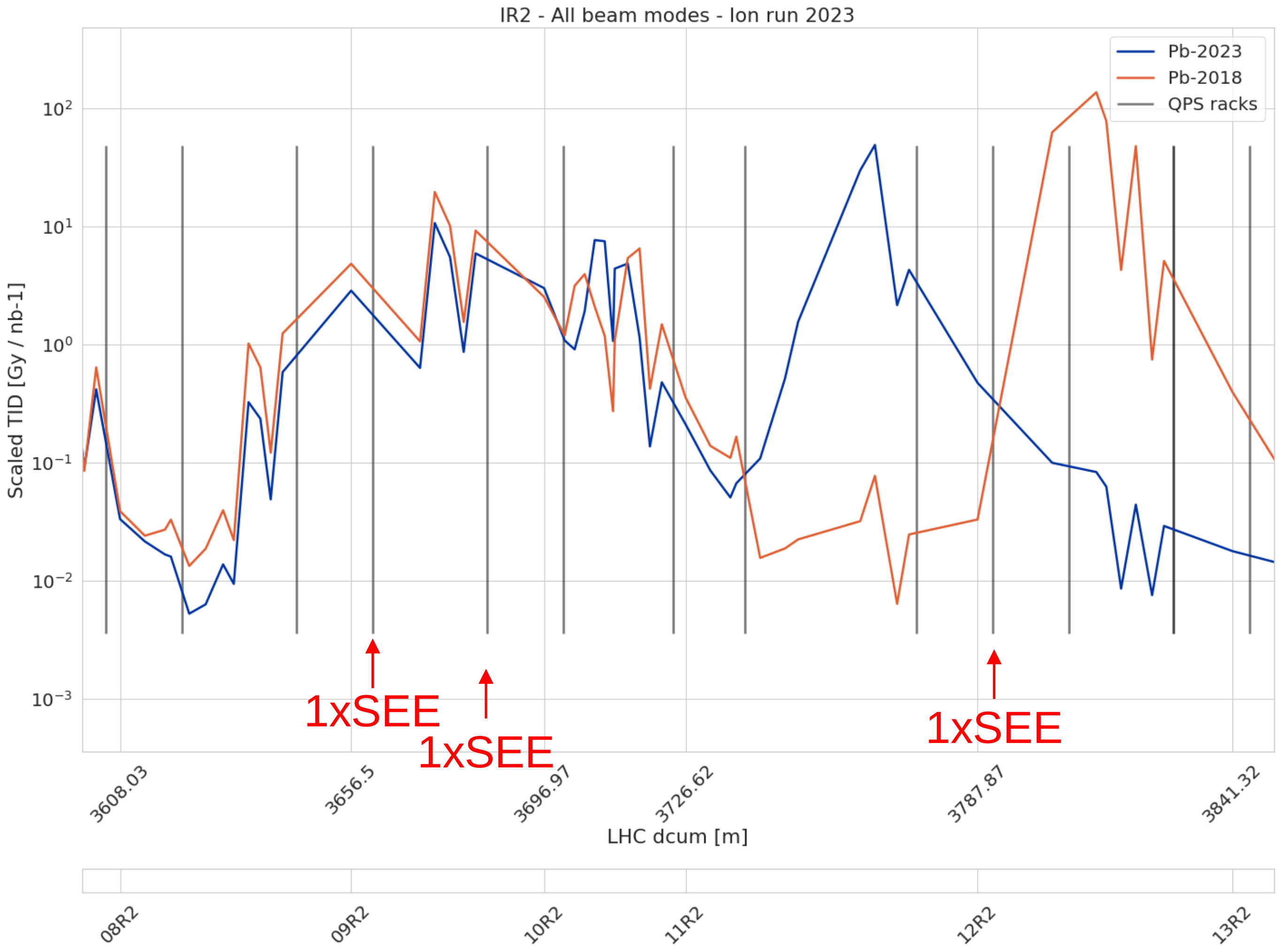
Right of Point 2 - Dose distribution DS, 2018 vs 2023



- Comparing the total BLM dose during the 2018 and 2023 ion runs, and during the 2023 proton run, right of IP2
- Note: the lines between the points are visual guides and do not represent real dose values.
- The dose in the DS is dominated by the ion runs
- The dose peaks shifted compared to the 2018 run, due to the new TCLD location (and the related optics change)

Integrated luminosities in IR2:
Pb 2023: 2.16 nb^{-1}
Pb 2018: 0.905 nb^{-1}
(p 2023: 14.5 pb^{-1})

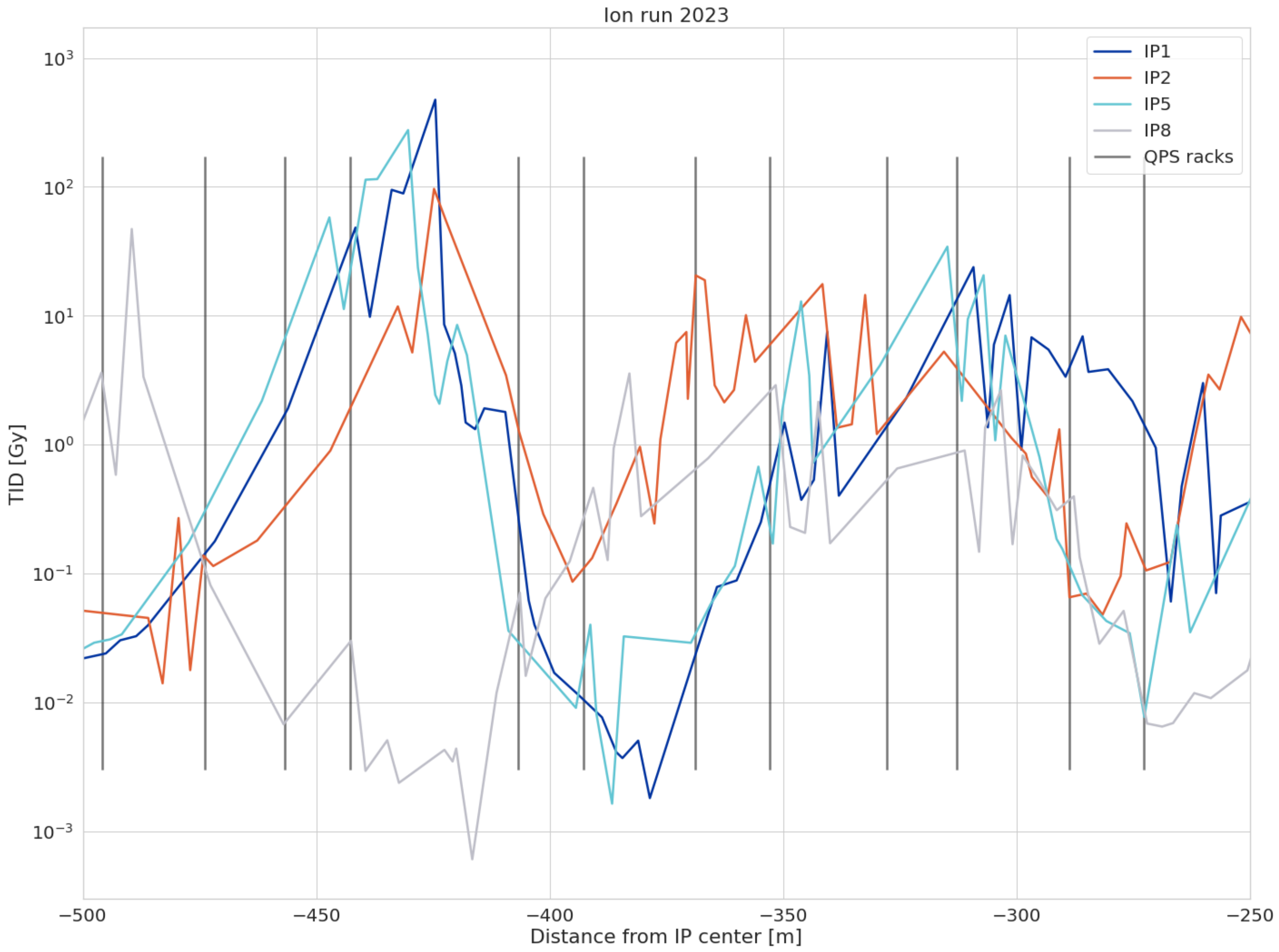
Ion run doses scaled by luminosity, Right of IR2



- Same view, but radiation levels scaled by the integrated luminosity (only ion runs)

Integrated luminosities in IR2:
Pb 2023: 2.16 nb^{-1}
Pb 2018: 0.905 nb^{-1}

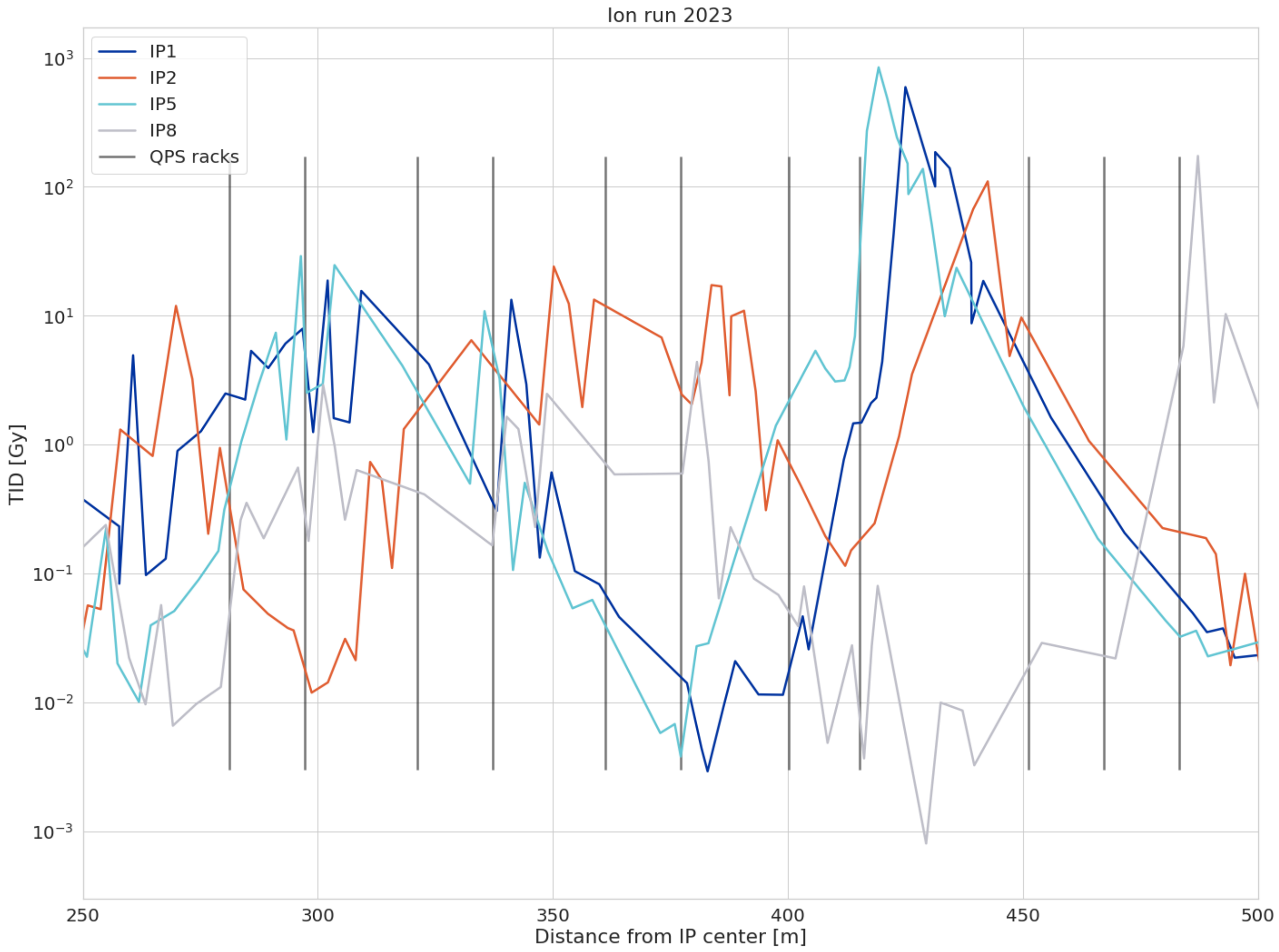
Left of IRs1-2-5-8 – 2023 ion BLMs



- Within the 2023 Pb run, we observe **relatively higher dose in cells 9-10 in IR2 (and, partially, IR8) compared to IR1-IR5. This is reflected in a larger amount of QPS issues in cells 9-10 of IR2.**
- The main dose peak is in cell 11 in IR1-IR5 (BFPP) and IR2 (TCLD) while it is in cell 12 in IR8

IR	Luminosity (1/nb)
1	1.91
2	2.16
5	2.02
8	0.249

Right of IRs1-2-5-8 – 2023 ion BLMs



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1	1.91
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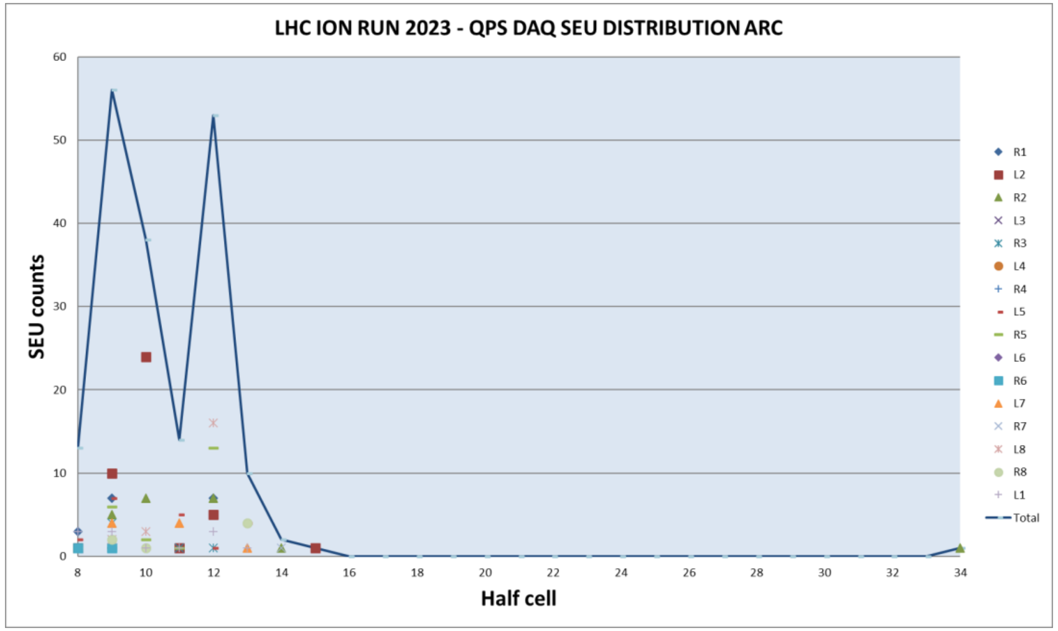
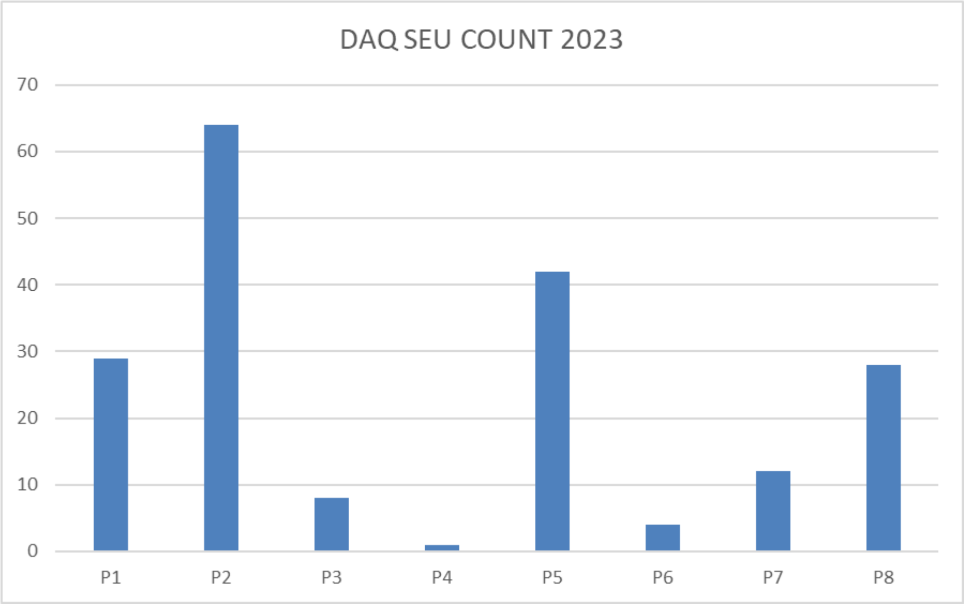
8	0.249

QPS DAQ SEEs (input from R. Denz)

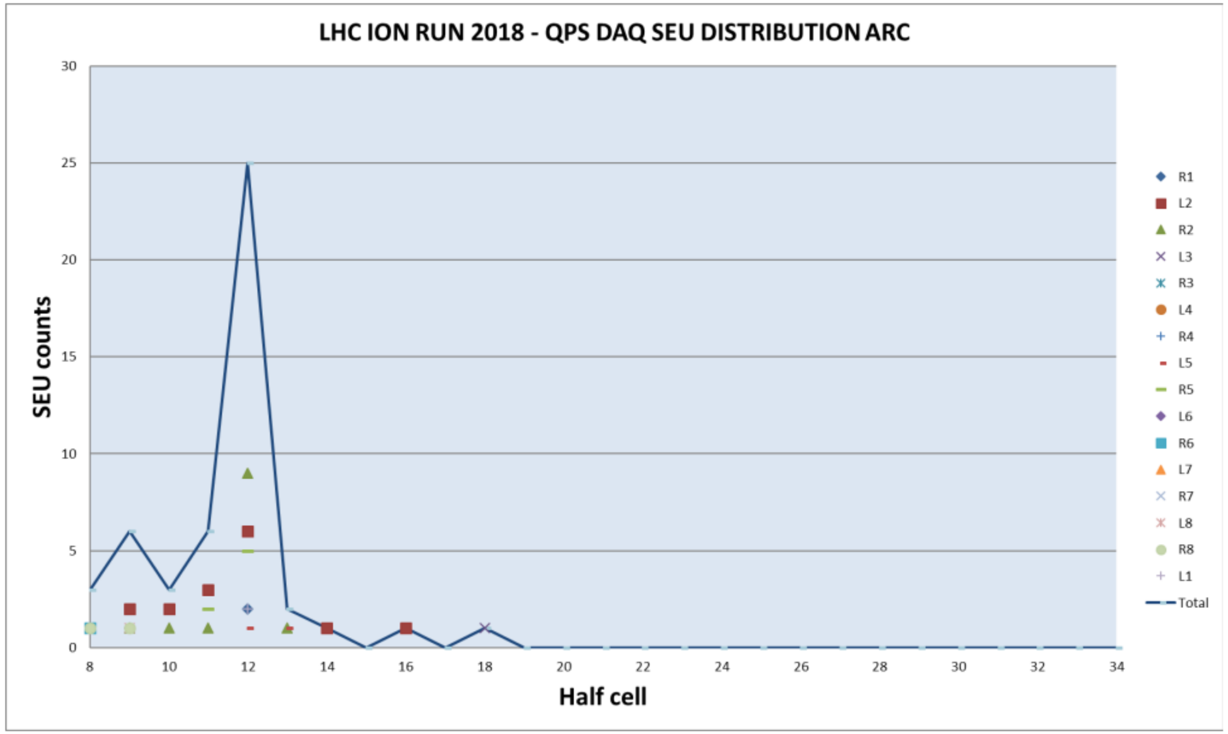
- The SEU counters from the QPS DAQ are confirming the picture outlined by BLMs and RadMons:
  - In 2023, IR2 is the region with the largest number of SEUs
  - The number of SEUs in IR2 is concentrated in cells 9, 10 and 12, where most issues have occurred

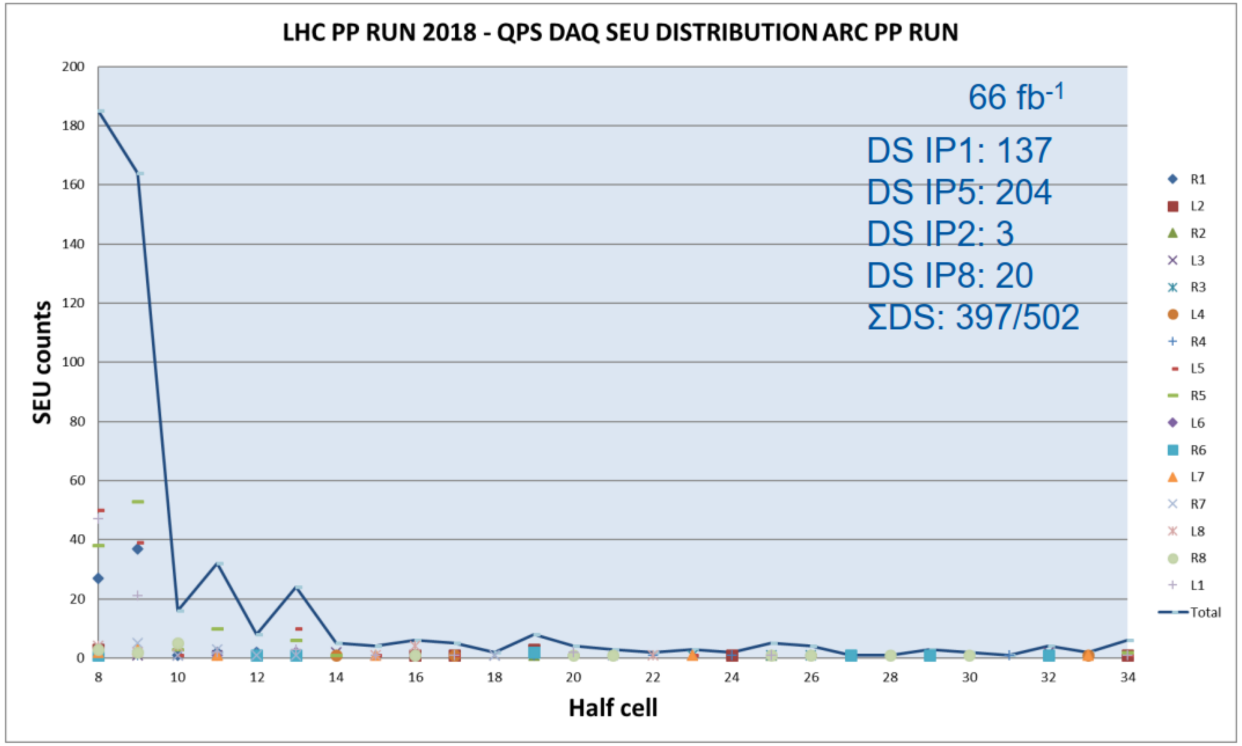




QPS DAQ SEEs (input from R. Denz)

- 2023 pattern compared to 2018
  - The 2023 ion run with most events in half cells 9,10 and 12
  - 2018 pp run dominated in 8 and 9, while the ion run saw most events in 12



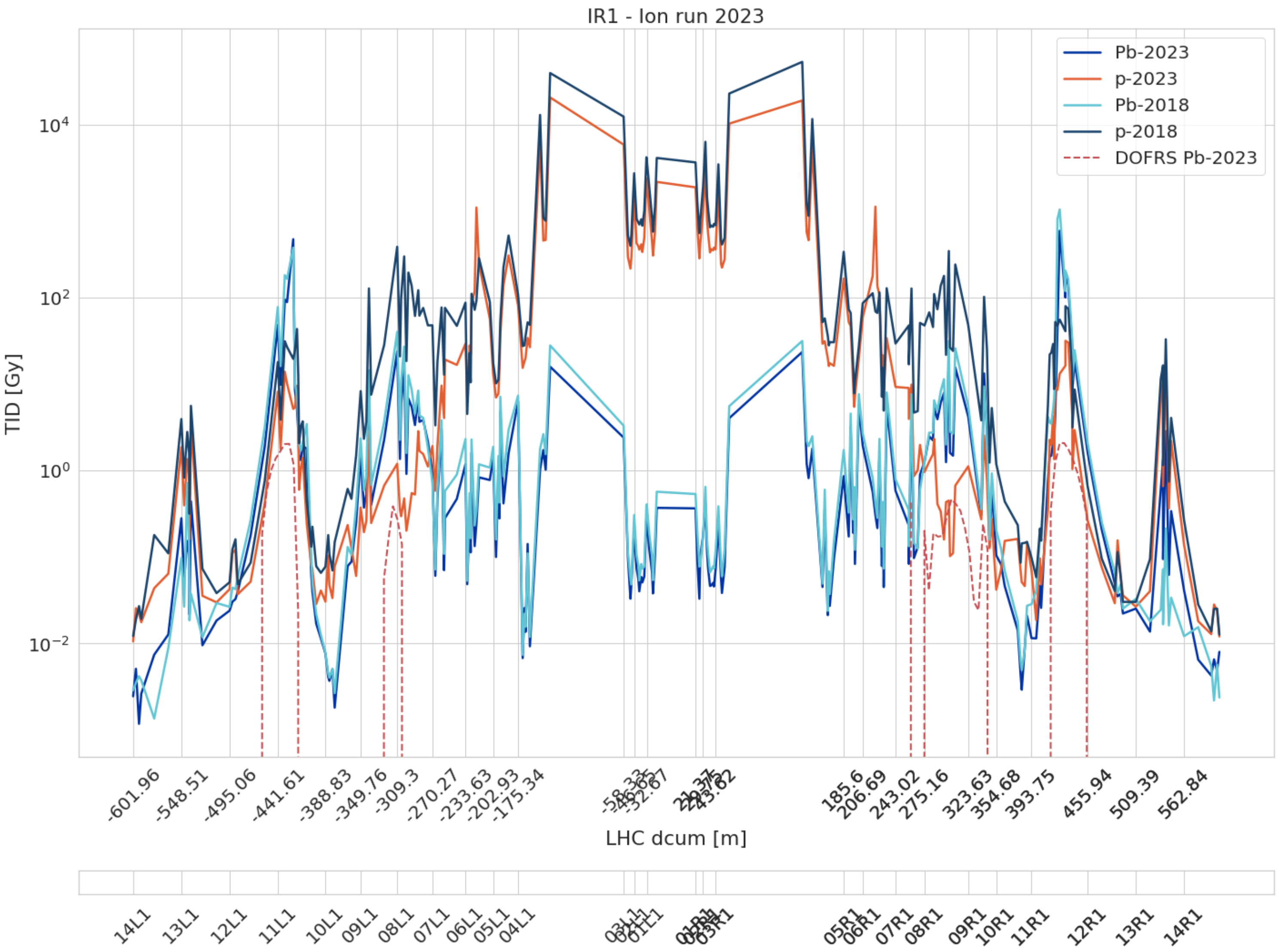


Summary

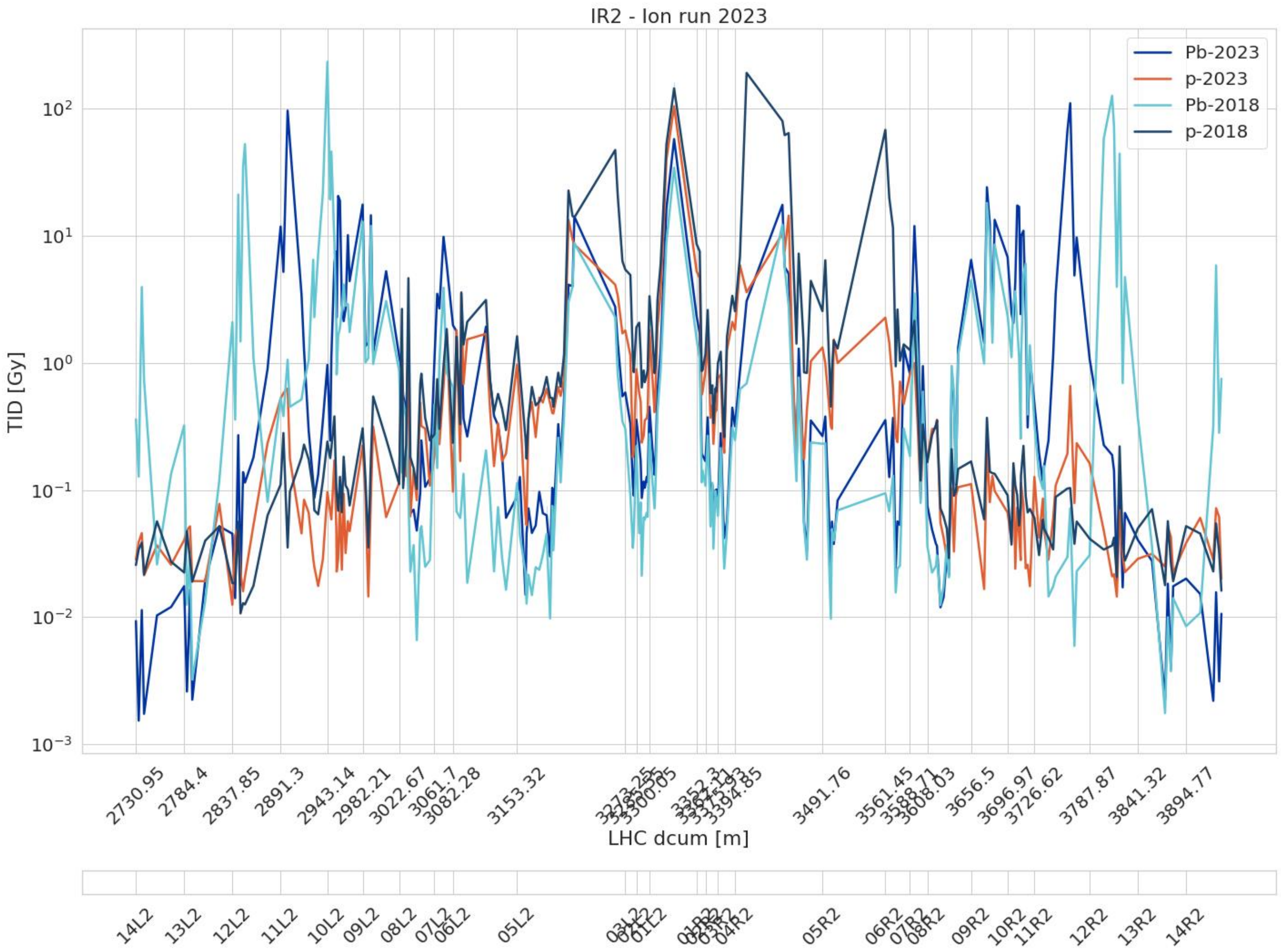
- A total of 13 QPS failures attributed to R2E occurred during the 2023 ion run, with 9 in IR2
- The radiation levels on (or near) the QPS racks, as measured by the BLMs and the RadMons, are generally well correlated with the distribution of the faults
- Compatible number of QPS SEEs per radiation level between 2018 and 2023 ion and proton runs
- When comparing the 2023 ion run experience with 2018, it is important to consider that:
  - The integrated luminosities in IR1-5-8 in the two years were similar, while in IR2 the 2023 integrated luminosity is larger by more than 2x
    → *a relative increase of IR2 SEEs can be expected*
  - The radiation level profile in the tunnel in IR2 in 2023 is very different from 2018, due to the TCLD installation and the associated optics changes
- Most QPS faults in IR2 are in cells 9-10, i.e., upstream of the TCLD, with two exceptions
- The radiation level distribution measured by RadMons and BLMs is confirmed by the SEU distribution in the QPS DAQ (input from R. Denz)

Bonus slides

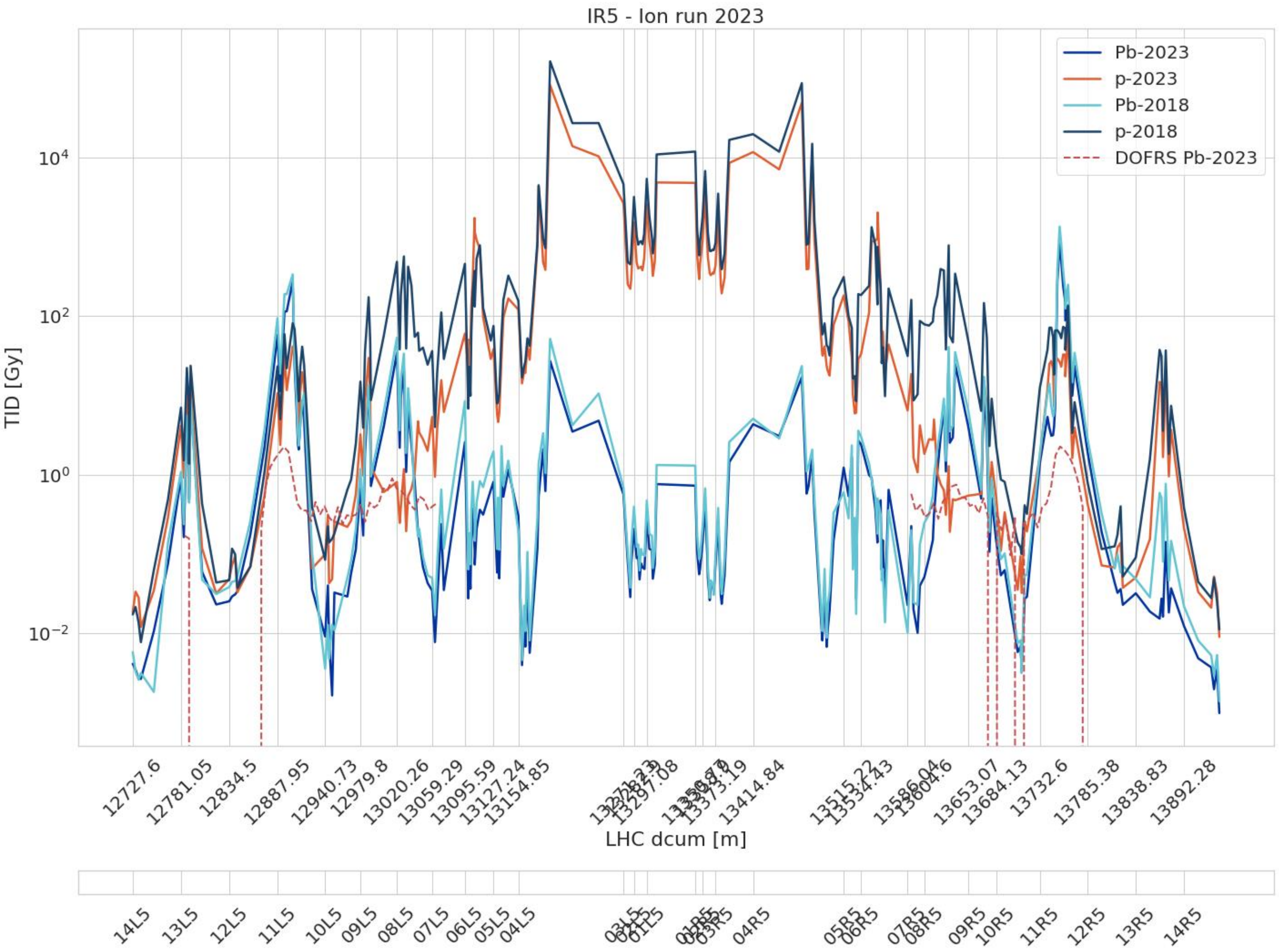
Ion and proton run doses in IR1



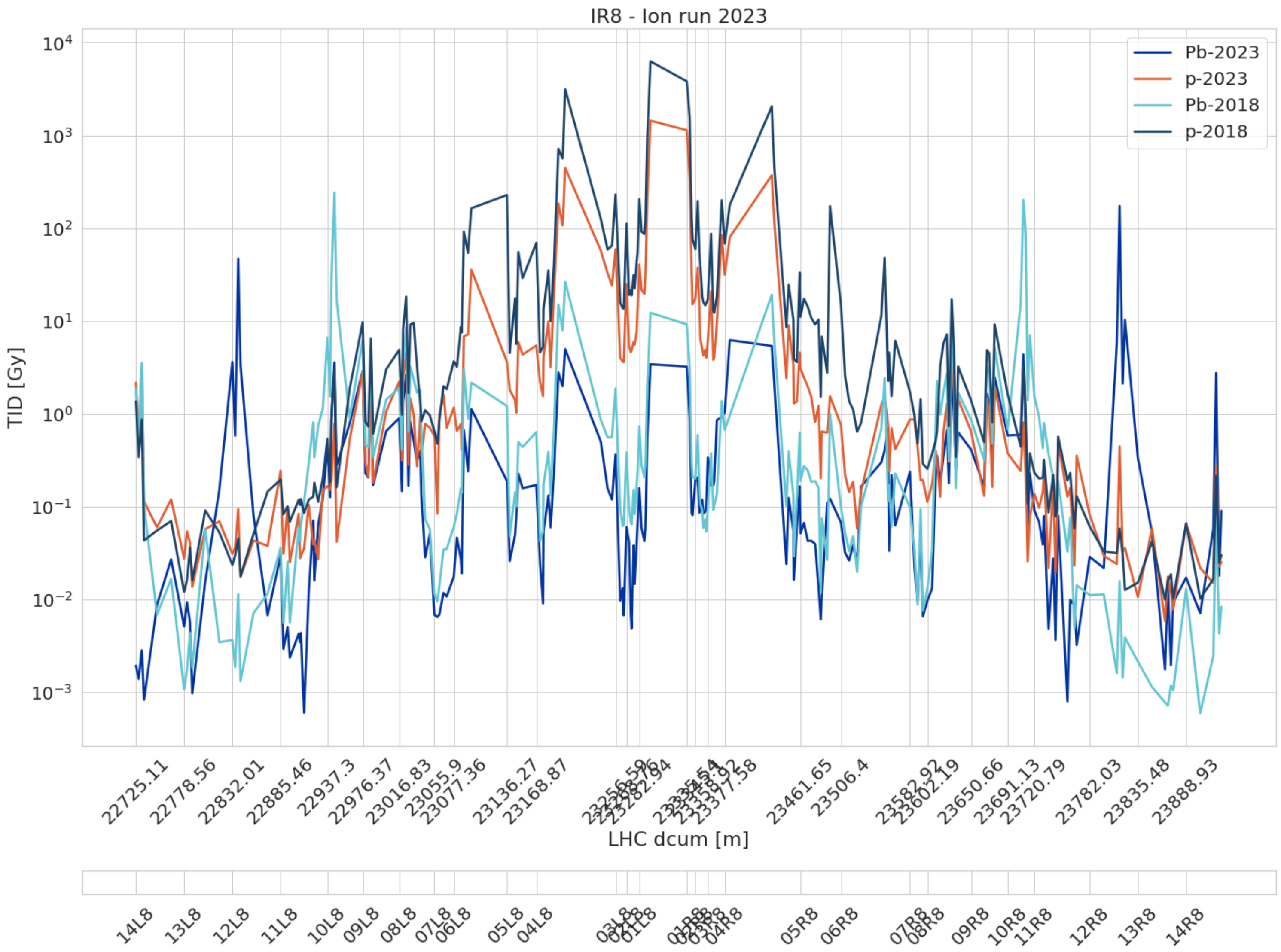
Ion and proton run doses in IR2



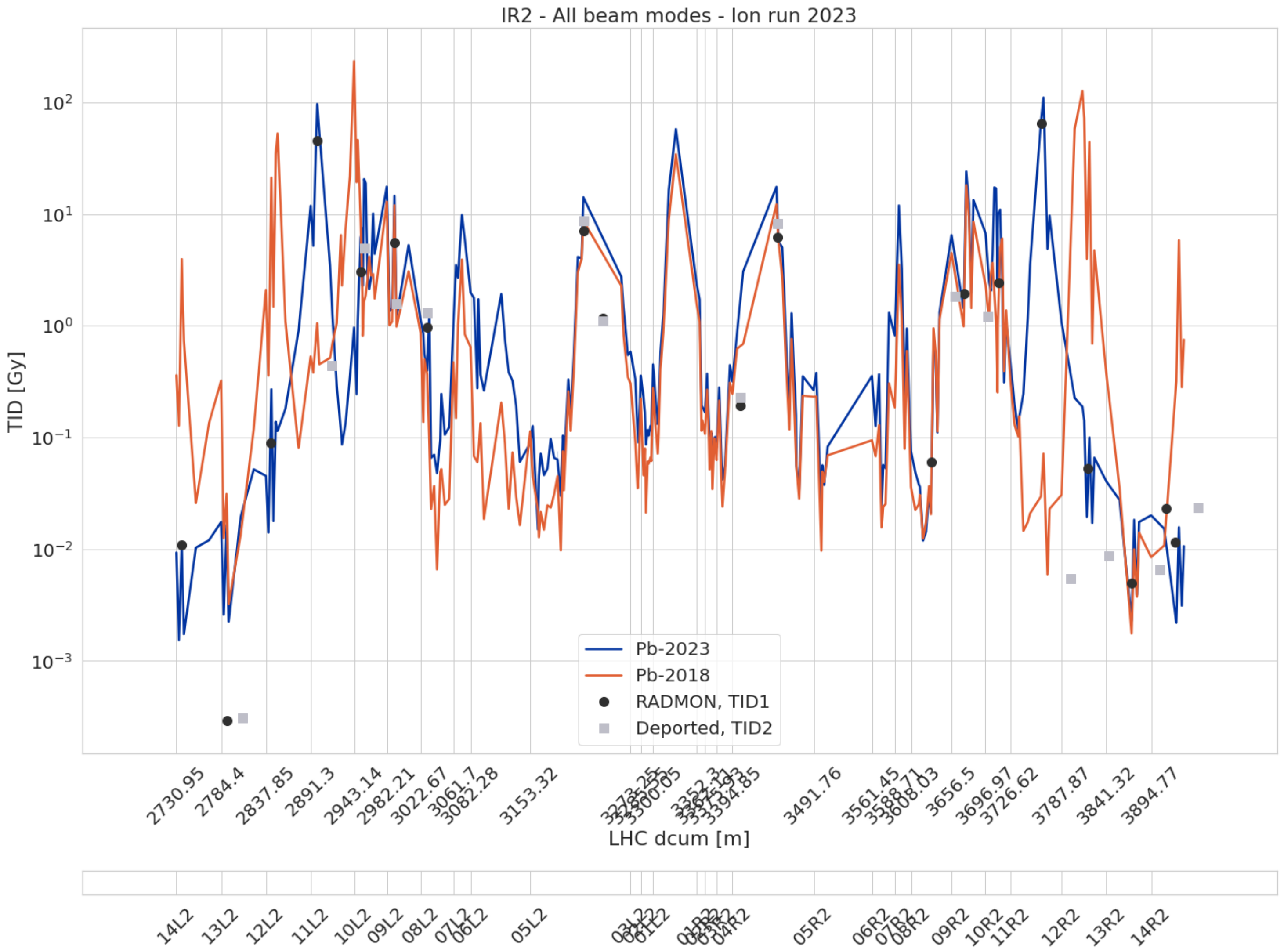
Ion and proton run doses in IR5



Ion and proton run doses in IR8



Dose distribution around IP2



- Overview of IP2
- Ion runs of 2023 and 2018 compared
- Asymmetry between the left and right sides of the IP (the highest peak of 2018 at 10L2 is for instance not as severe in 10R2)
- TID measurements from RadMons included, with the internal fg-dose (TID1) and deported module (TID2) measurements shown separately

RadMon dose measurements close to QPS racks

For most QPS racks where SEEs occurred, we have a RadMon deported module measuring TID within <10m (green racks). In other racks the RadMon is either within <20m (yellow) or not available (red)
RadMons measuring HEH fluence are typically further away from the QPS racks

Rack (N_{SEE})	DCUM (m)	Closest RadMon (dcum)	RadMon HeH fluence (HeH/cm^2)	Closest deported RadMon (dcum)	Deported RadMon dose (Gy)
DYPB.B11L1 (1x)	26244	26226	2.56E+11	- (26243, inactive)	- (75.3 @ 26226 m)
DYPB.A12R1 (1x)	445	432	1.03E+12	466	0.09
DYPB.B12R1 (1x)	460	487	4.91E+07	466	0.09
DYPQ.12L2 (1x)	2886	2899	1.29E+11	2871	45.3 @ 2899 m
DYPB.B10L2 (3x)	2957	2951	6.82E+09	2955	5.02
DYPB.B9L2 (1x)	2997	2991	9.80E+09	2994	1.58
DYPB.B9R2 (1x)	3661	3672	5.53E+09	3661	1.85
DYPB.A10R2 (1x)	3686	3672	5.53E+09	3700	1.23
DYPQ.A12R2 (1x)	3782	3764	1.92E+11	3799	2 mGy
DYPB.B12R2 (1x)	3792	3819	8.04E+07	3799	2 mGy
DYPB.B8L5 (1x)	13034	13030	5.62E+09	13032	1.13

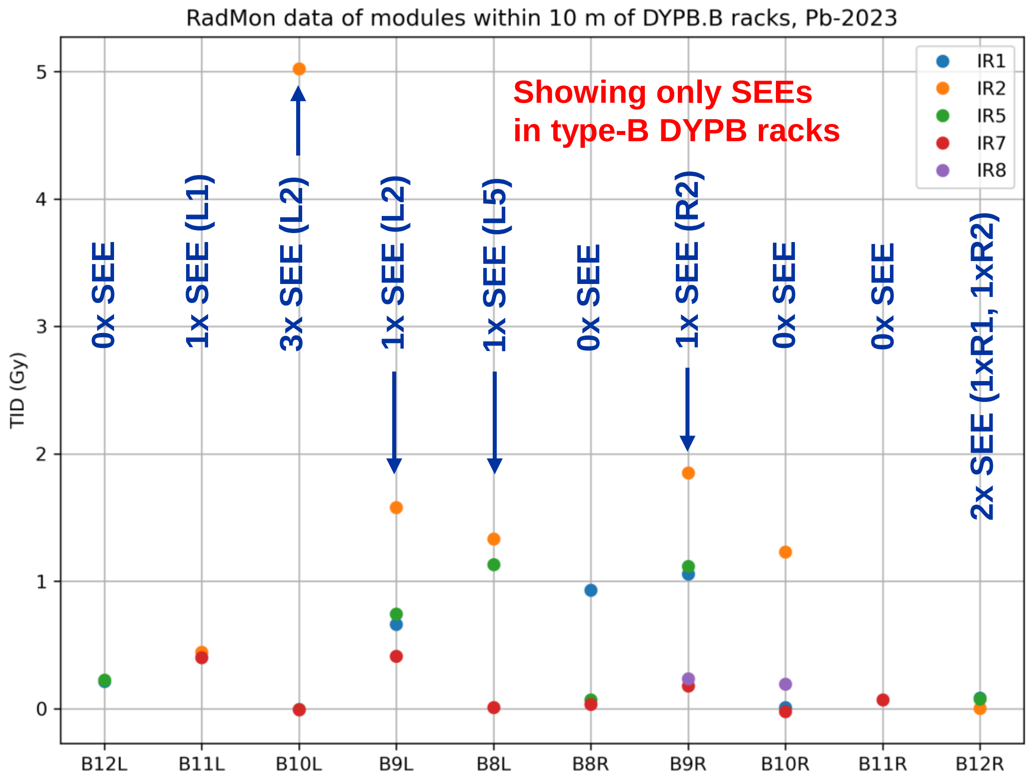
RadMon dose and HEH fluence estimations

Table with further included estimated dose and HEH fluence estimations. Primarily from nearby RadMon units, secondarily from BLM dose measurements if a BLM is nearby. Dose to HEH fluence conversions if necessary have been made using a factor of 1 Gy = $3 \cdot 10^9$ cm^{-2}.

Rack (N_{SEE})	DCUM (m)	HeH/cm^2 Pb-2023	Gy Pb-2023	HeH/cm^2 p-2023	Gy p-2023	HeH/cm^2 Pb-2018	Gy Pb-2018	HeH/cm^2 p-2018	Gy p-2018
DYPB.B11L1 (1x)	26244	5.74E+09	1.91	4.23E+09	1.41	6.30E+09	2.10	8.43E+07	0.03
DYPB.A12R1 (1x)	445	5.59E+10	18.64	8.82E+09	2.94	7.40E+10	24.68	2.60E+10	8.66
DYPB.B12R1 (1x)	460	2.58E+08	0.09	7.94E+08	0.26	2.89E+07	0.01	1.97E+09	0.66
DYPQ.12L2 (1x)	2886	3.55E+10	11.83	1.57E+09	0.52	1.60E+09	0.53	3.30E+08	0.11
DYPB.B10L2 (3x)	2957	6.82E+09	5.02	3.66E+07	0.08	2.39E+09	0.26	5.36E+07	0.13
DYPB.B9L2 (1x)	2997	9.80E+09	1.58	4.30E+07	0.31	3.78E+09	0.61	5.55E+07	0.54
DYPB.B9R2 (1x)	3661	5.55E+09	1.85	3.34E+08	0.11	1.39E+09	0.46	5.03E+08	0.17
DYPB.A10R2 (1x)	3686	4.01E+10	13.35	2.95E+08	0.10	2.56E+10	8.55	4.02E+08	0.13
DYPQ.A12R2 (1x)	3782	3.22E+09	1.07	4.87E+08	0.16	9.20E+07	0.03	1.24E+08	0.04
DYPB.B12R2 (1x)	3792	6.64E+06	0.00	4.87E+08	0.16	8.22E+07	0.03	1.24E+08	0.04
DYPB.B8L5 (1x)	13034	5.62E+09	1.13	2.27E+08	0.06	3.13E+09	1.04	5.91E+10	28.96

RadMons closest to the DYPB.Bxxx racks

Doses close to the DPYB.B racks are large in IR2, where the majority of radiation effects have been observed



Missing, Reason:
B11L1, FLATLINE
B10L1, FLATLINE
B8L1, FLATLINE
B11R1, NEGATIVE SIGNAL
B12L2, FLATLINE
B8R2, NO RM NEARBY
B11R2, FLATLINE
B11L5, NEGATIVE SIGNAL
B10R5, FLATLINE
B11R5, NEGATIVE SIGNAL
B12L7, NO RM NEARBY
B12R7, NO RM NEARBY
B12L8, FLATLINE
B11L8, NO RM NEARBY
B10L8, NO RM NEARBY
B9L8, NO RM NEARBY
B8L8, NO RM NEARBY
B8R8, NEGATIVE SIGNAL
B11R8, FLATLINE
B12R8, FLATLINE

All DYPB-racks

Sorted by deported RadMon dose

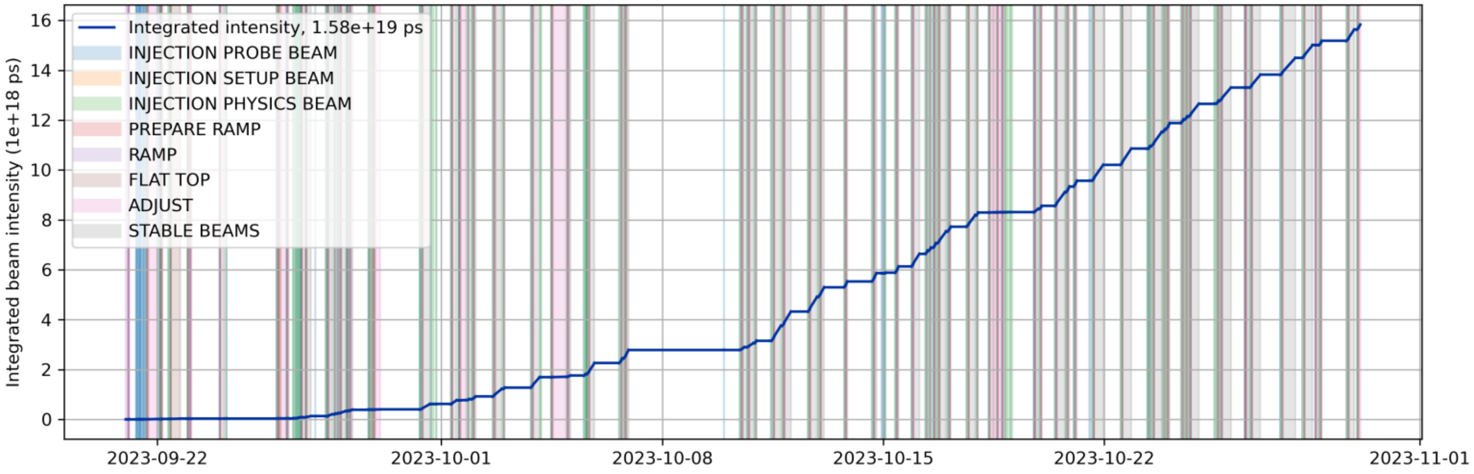
(3xSEE)

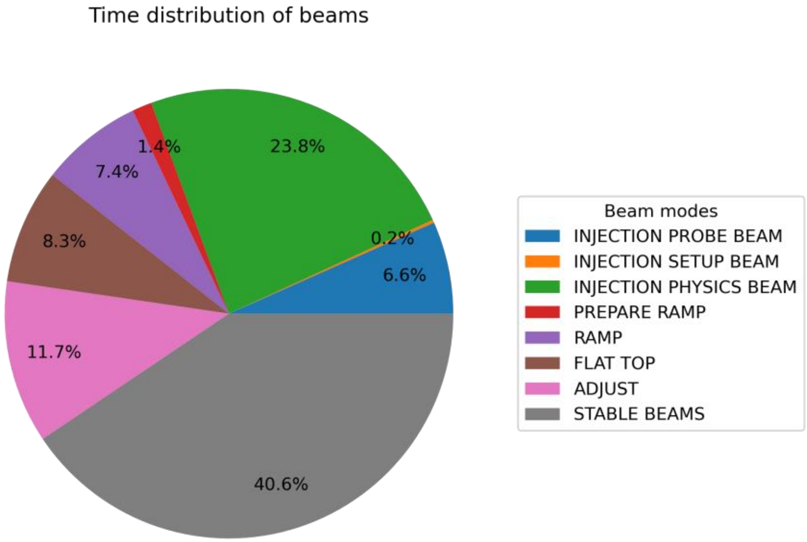
Racks marked in red caused SEE-induced issues

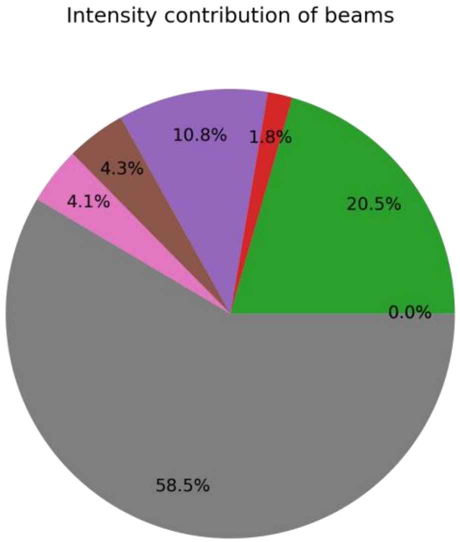
Rack	dcum	Radmon dcum	Dep RM dcum	Radmon HEH fluence Pb-2023	Dep RM TID Pb-2023
DYPB.B10L2	2957	2951	2955	6.82E+09	5.02
DYPB.A10L2	2972	2991	2955	9.80E+09	5.02
DYPB.B9R2	3661	3672	3661	5.53E+09	1.85
DYPB.B9L2	2997	2991	2994	9.80E+09	1.58
DYPB.B8L2	3036	3030	3030	2.66E+09	1.33
DYPB.A10R2	3686	3672	3700	5.53E+09	1.23
DYPB.B10R2	3701	3713	3700	9.34E+09	1.23
DYPB.B8L5	13034	13030	13032	5.62E+09	1.13
DYPB.A8L5	13049	13030	13032	5.62E+09	1.13
DYPB.A9R5	13642	13629	13656	6.41E+09	1.12
			. . .		

The QPS racks where the RadMons measured the highest TID are generally the ones that suffered SEE-induced issues

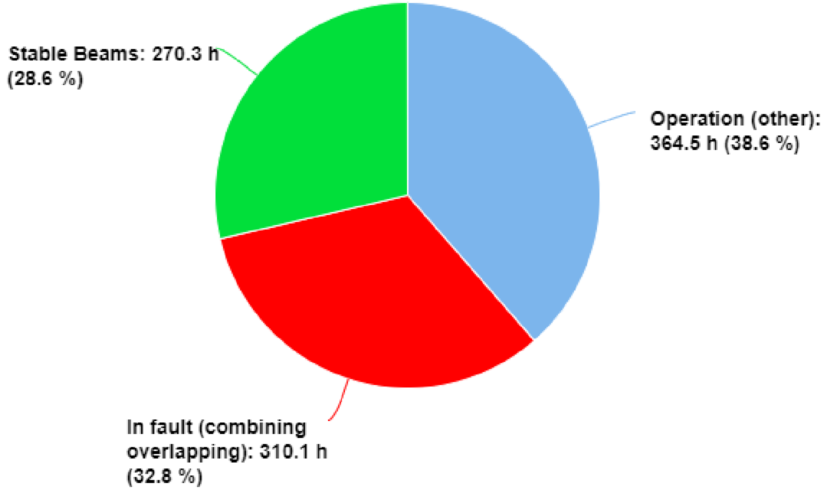
Beam overview, beam intensity statistics





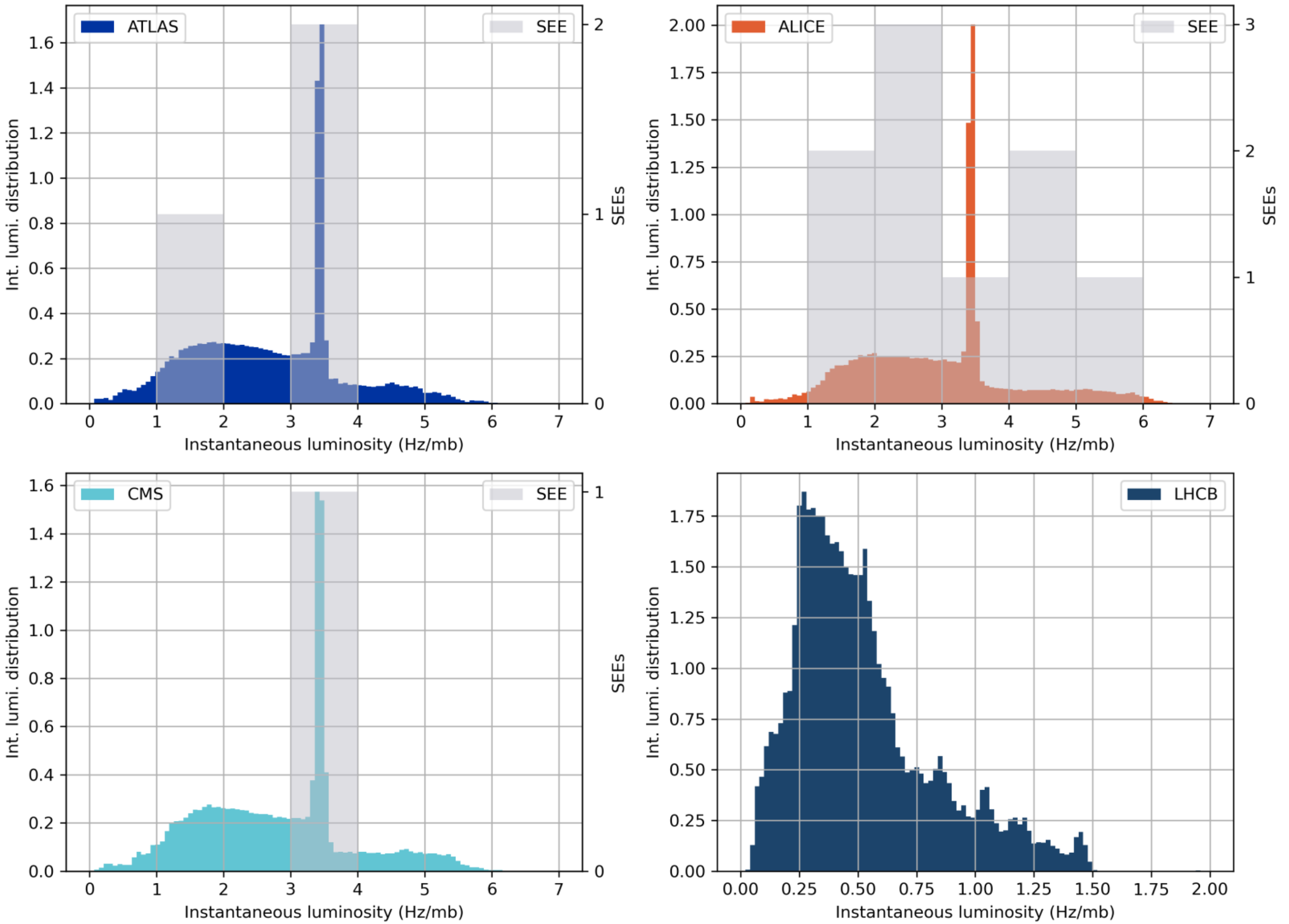


From aft.cern.ch:



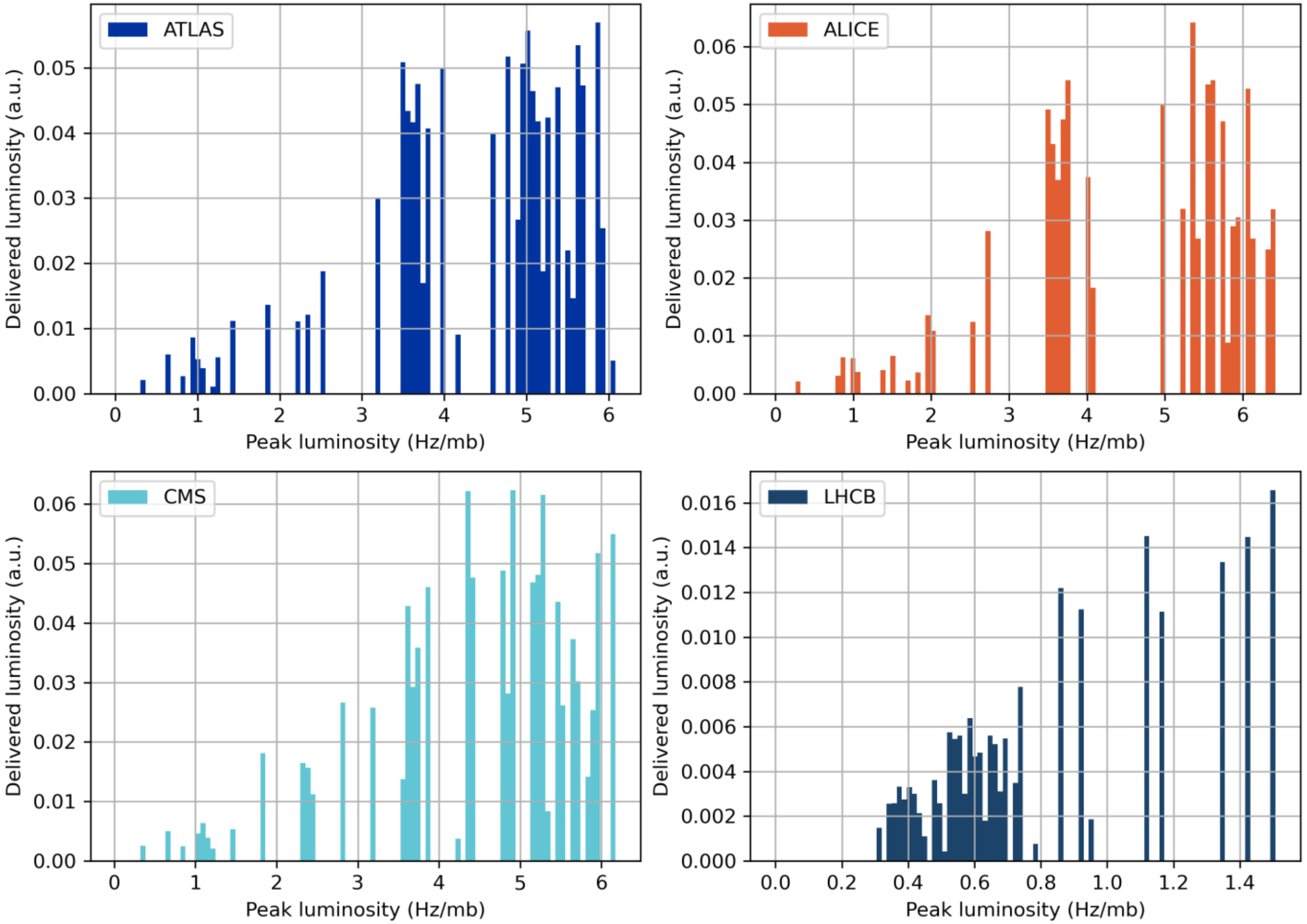
Instantaneous and integrated luminosity

- The delivered integral luminosity of bins of instantaneous luminosities in LHC during the ion run
- The radiation levels around the IP is proportional to the IP luminosity, so the SEEs should follow the same distribution as the integrated luminosity
- Low statistics, but no clustering of SEEs at specific instantaneous luminosity values

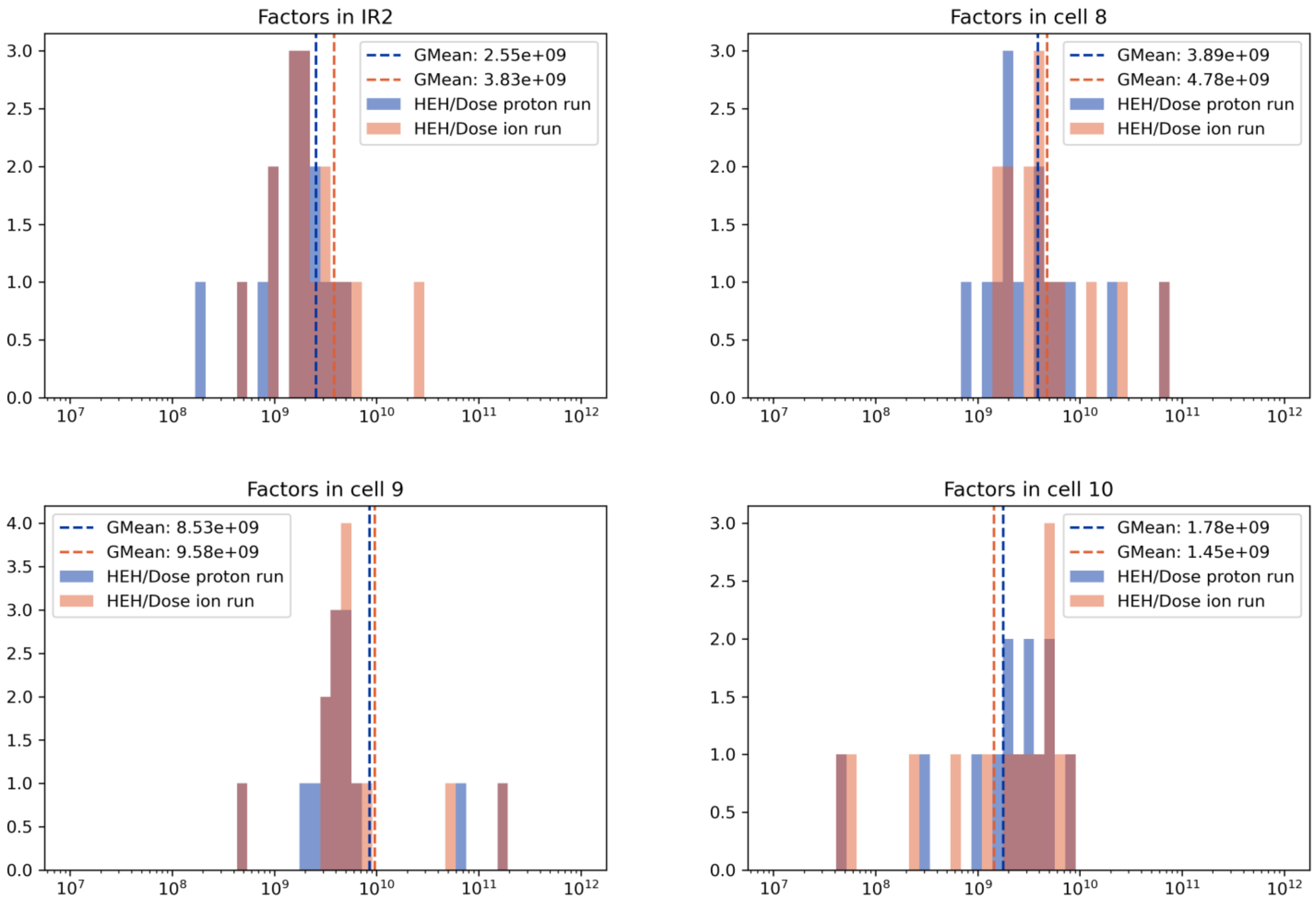


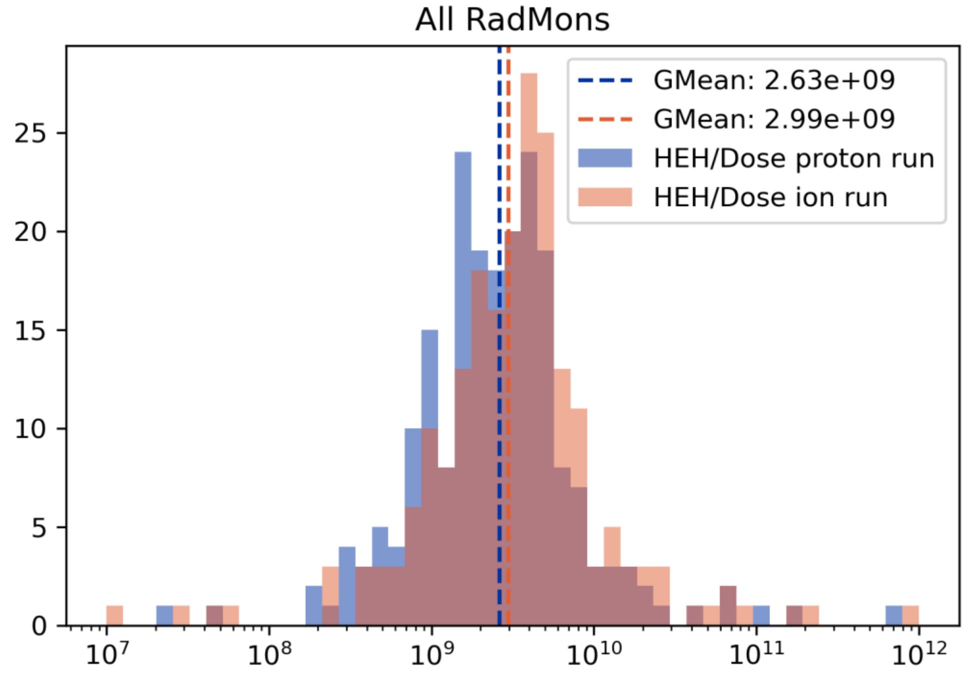
Peak luminosity and integrated luminosity

- The delivered luminosity as a function of peak luminosity per LHC fill is shown
- As the peak luminosity of the fill gets larger, also the integrated luminosity of the fill increases (as would be expected)
- At high peak luminosities, the increase in delivered luminosity per fill falls of, perhaps due to the observed effects of high-luminosity fills ending prematurely

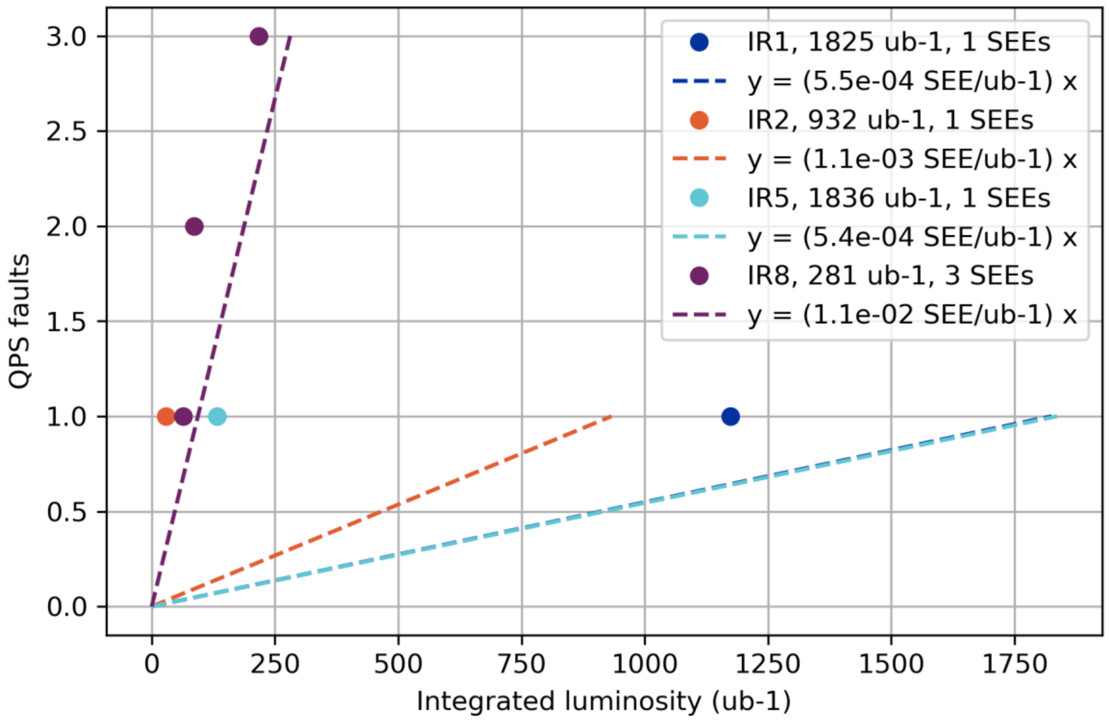


TID to HEH fluence conversion



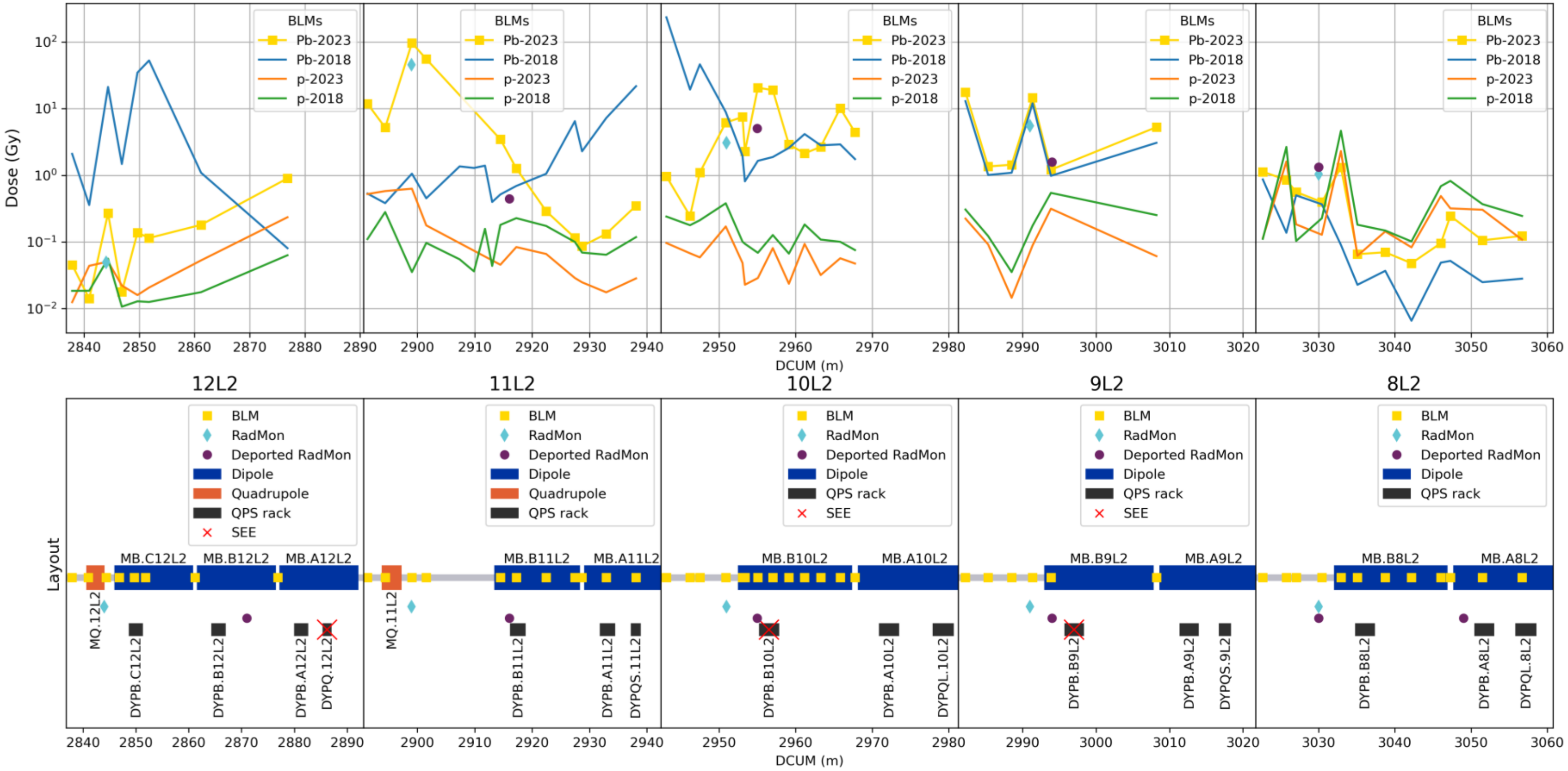


QPS SEEs as a function of luminosity ion run 2018



Left of Point 2 - Dose distribution DS, 2018 vs 2023

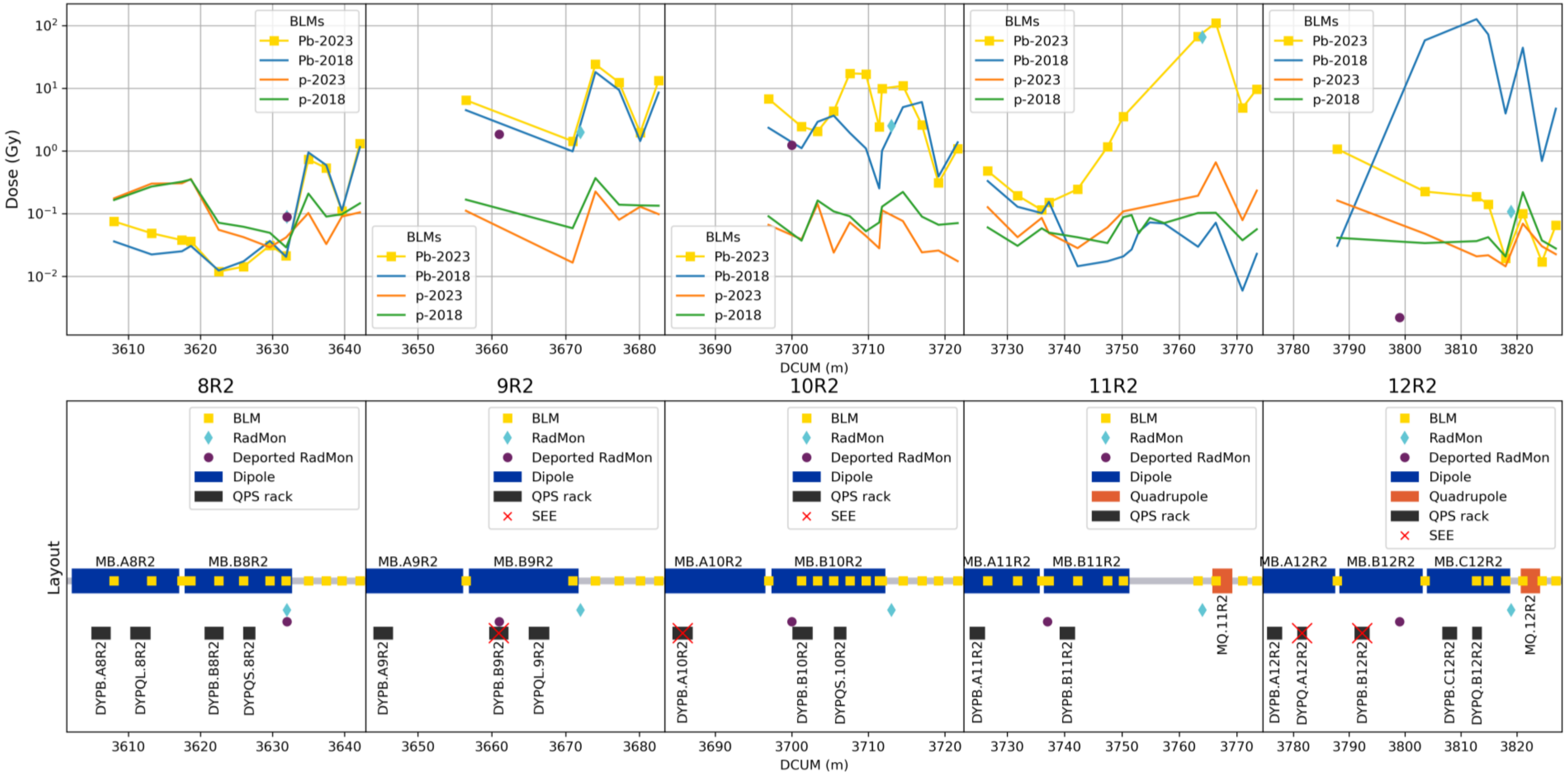
- Comparing the total BLM dose during the 2018 and 2023 ion and proton runs, left of IP2
- Note: the lines between the points are visual guides and do not represent real dose values.
- The dose in the DS is dominated by the ion runs
- The dose peaks shifted compared to the 2018 run, due to the new TCLD location (and the related optics change)



Integrated luminosities in IR2:
Pb 2023: 2.16 nb^{-1}
Pb 2018: 0.905 nb^{-1}
(p 2023: 14.5 pb^{-1})

Right of Point 2 - Dose distribution DS, 2018 vs 2023

- Comparing the total BLM dose during the 2018 and 2023 ion runs, and during the 2023 proton run, right of IP2
- Note: the lines between the points are visual guides and do not represent real dose values.
- The dose in the DS is dominated by the ion runs
- The dose peaks shifted compared to the 2018 run, due to the new TCLD location (and the related optics change)



Integrated luminosities in IR2:
Pb 2023: 2.16 nb^{-1}
Pb 2018: 0.905 nb^{-1}
(p 2023: 14.5 pb^{-1})