Benchmark of Run 2 Radiation Monitor Data with FLUKA in IP1/5 of LHC

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https://indico.cern.ch/event/971222/

Summary

1. Introduction
2. Radiation Monitor Tools
3. Results
4. Conclusions

Summary

Introduction (1/2)

- The radiation environment in IP1-IP5 of the LHC, hosting the **high-luminosity experiments** (ATLAS and CMS), is driven by inelastic collisions, implying that the **radiation levels are proportional to integrated luminosity**.
- The Monitoring and Calculation Working Group (MCWG) in the R2E context characterizes the radiation environment by means of **FLUKA simulations** and **data from different radiation monitors**. Those relevant in this work are:
  - Beam Loss Monitors (**BLM**) Total Ionizing Dose (**TID**) -> in the LHC tunnel,
  - **RadMon** High Energy Hadron (**HEH**) fluence -> in the LHC tunnel and shielded alcoves,
  - Optical Fiber (**OF**) **TID** -> in the LHC DS tunnel of IP1.
- This work consists in benchmarking the radiation levels simulated in the LSS and DS of IP1 and IP5 with measured data in specific periods of Run 2 with constant operational settings.
- Important for quantifying the accuracy of the FLUKA predictions in regions where radiation monitoring detectors are **not available**.

Introduction (2/2)

- Previous/similar work has been carried out in the past:
  - for Beam Loss Monitors (BLMs), but only compared to data from **individual** fills; see talks by Andrea Tsinganis:
    - https://indico.cern.ch/event/629210/
    - https://indico.cern.ch/event/677406/
  - for RadMons :
    - http://www.aesj.or.jp/publication/pnst002/data/948-954.pdf (tables 1, 2, 3)
    - https://ieeexplore.ieee.org/document/6153409 (notably table VII
- The goal of this broader benchmark study is to:
  - select the **most representative measured data set** per LHC configuration,
  - **extend to larger statistics** (from individual fill of at most 0.7 fb^{-1} to even 33 fb^{-1}),
  - use **comprehensive** (i.e. all available) sets of radiation monitors and quantities.

- Partly presented at the MCWG meetings:
  - BLM and RadMON benchmark in IP1 LSS -> https://indico.cern.ch/event/956446/
  - Optical FIbre Dosimeters in the LHC complex -> https://indico.cern.ch/event/978953/

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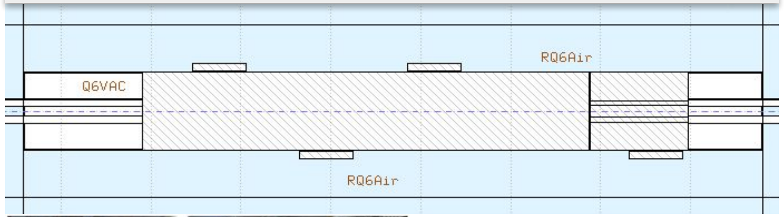
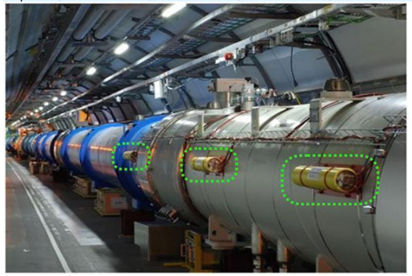
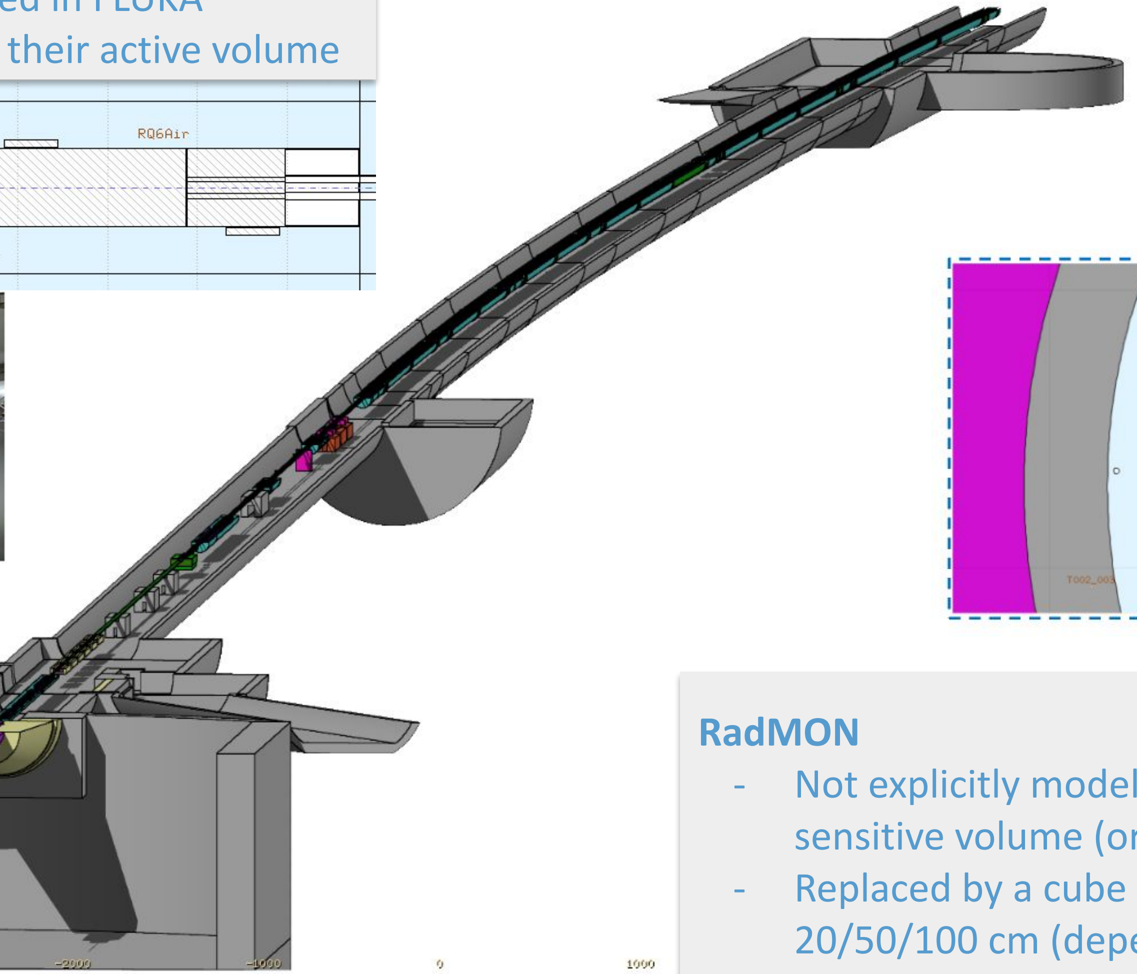
Radiation Monitors for R2E purposes (in FLUKA)

Beam Loss Monitors (BLM)

- explicitly modelled in FLUKA
- TID deposited in their active volume

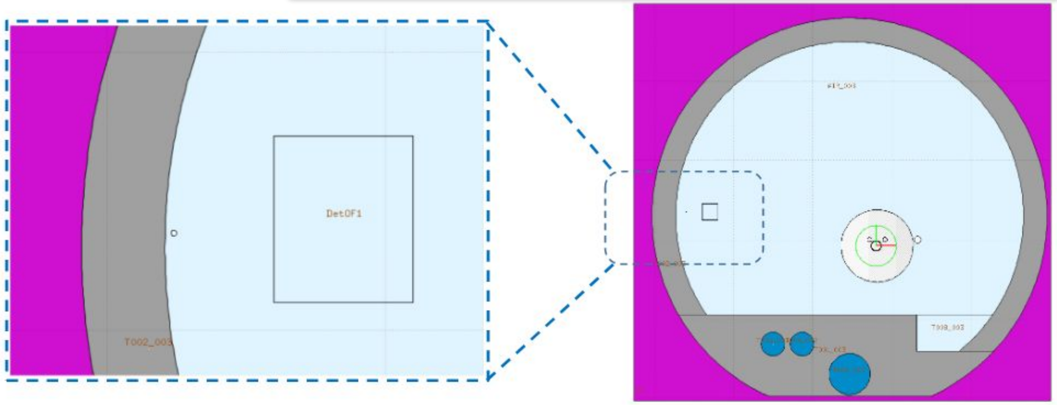






Optical Fibre

- Actual fibre is 150 um in diameter -> too small for identical modelling.
- Different OF sizes are studied to find a balance with computational time



RadMON

- Not explicitly modelled due to their small sensitive volume (order of mm³)
- Replaced by a cube of AIR with side length 20/50/100 cm (depending on statistics)

Comparison of BLM TIDs for different time periods with identical operational settings

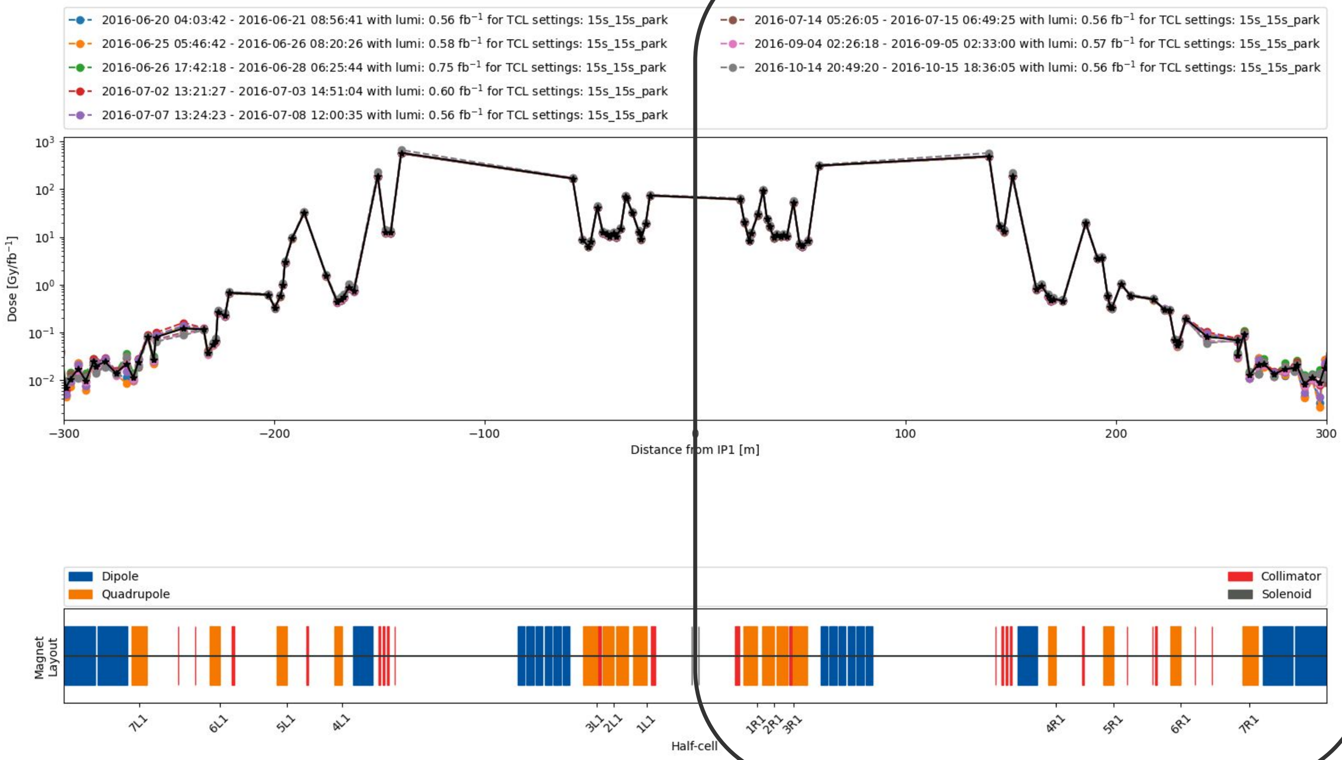
- Time-integrated BLM signal (as from the MCWG analysis) in **different** sub-periods within a standard LHC fill, but sharing the **same** operational settings.
- Luminosity scaling works as **normalization factor** for time periods of constant operational settings.

$$\mathcal{L}_{\text{int}} \cdot \sigma_p = \text{number of events of interest}$$

- The comparison of measured TID per unit integrated luminosity for different periods of operation with the same configuration is showing a **very stable profile**.
- We can **merge the full datasets** corresponding to periods with stable operational conditions, yielding:

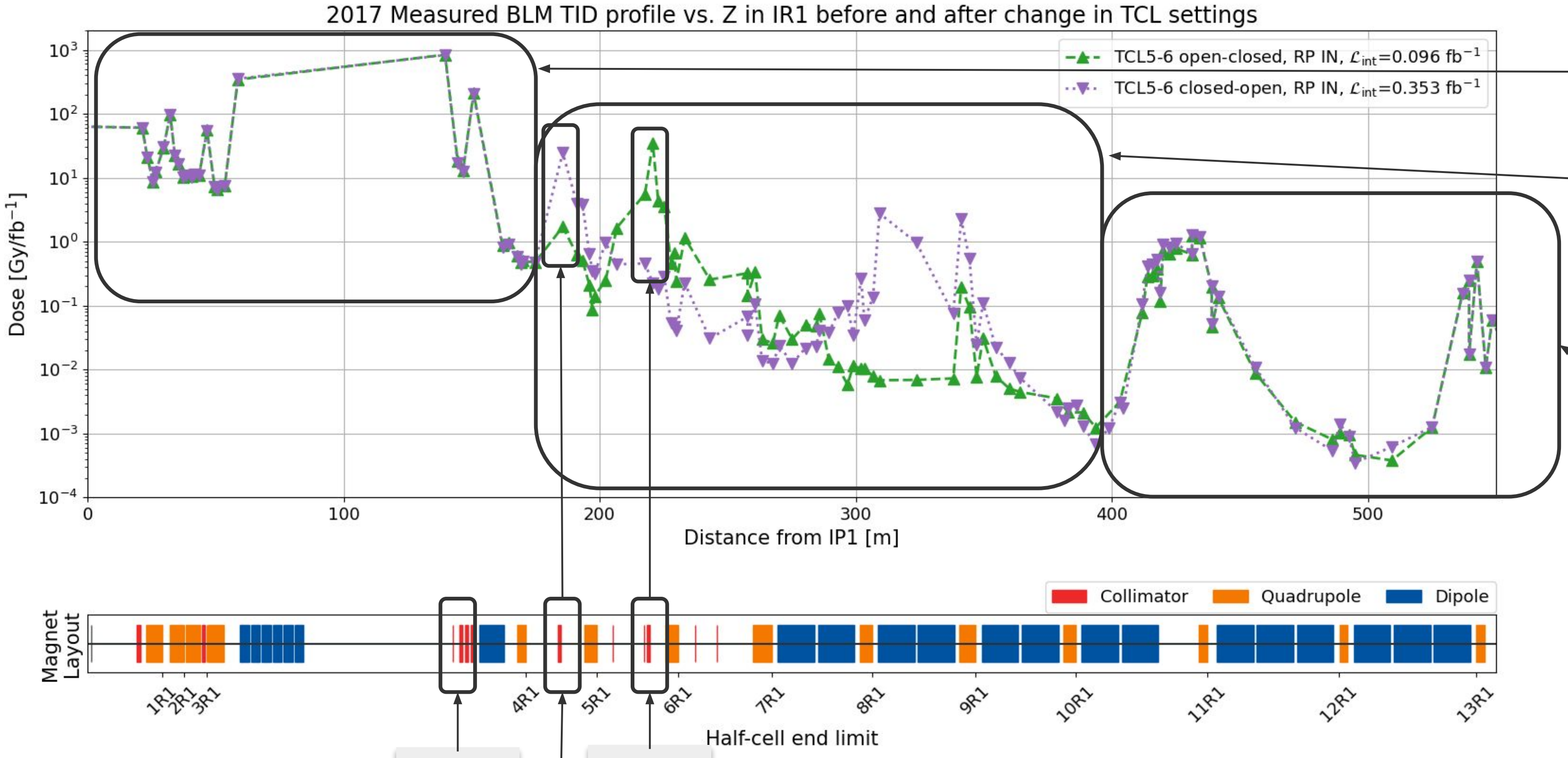
33 fb^{-1} (2016), **8** fb^{-1}(2017), **20** fb^{-1} (2018)

- Symmetry around the Interaction point -> Reduce analysis and Simulation just to the **Right Side of IP**



Impact of TCL5&6 changes on radiation profile

Physics debris collimator absorbers = **TCL**'s (Target Collimator Long) are **required** around LHC high luminosity experiments in the IP1/5 to **protect** the cold magnets from products of proton-proton collisions.



The levels are fully proportional to the integrated luminosity up to the TAN

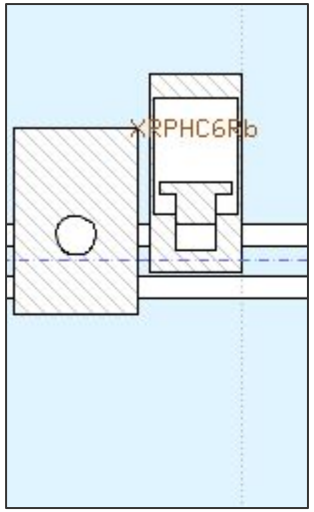
Different local radiation levels due to the change in the collimator settings

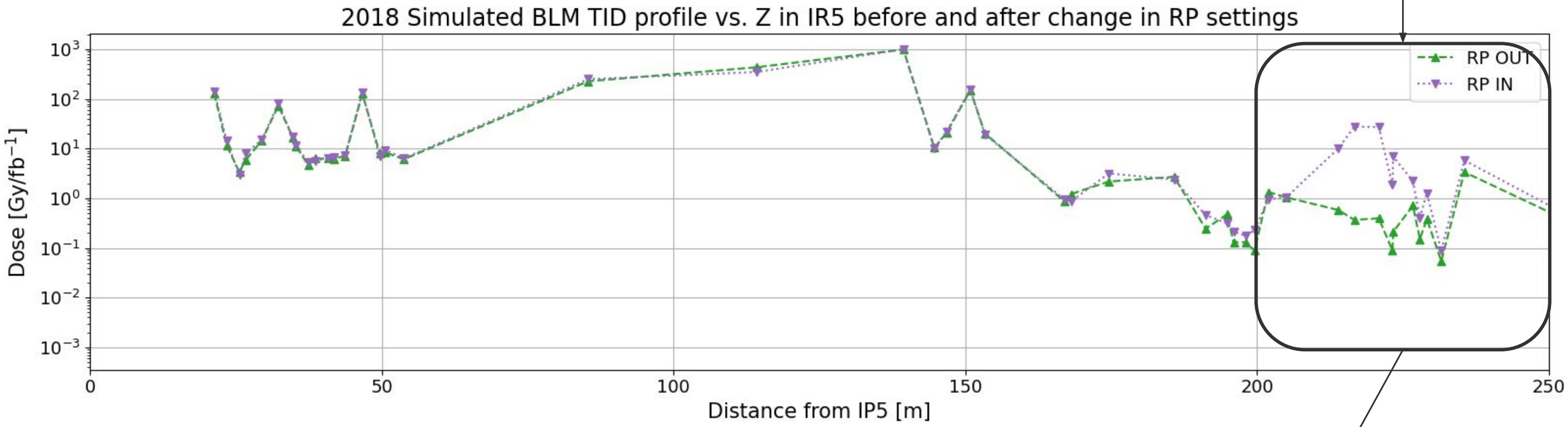
The TCL changes do not affect the DS radiation profile after 400m.

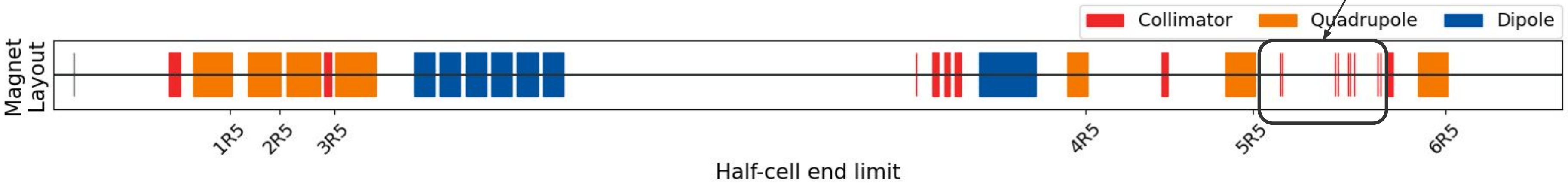
Impact of Roman Pot changes on radiation profile

Roman Pots are an important tool to measure the total cross section of two particle beams in a collider. Can be either used (IN) or not (OUT).

TOTEM Roman Pots stationed at:
202, 212, 214, 216, 219 m







Characteristic Operational Settings

This table provides the key operational parameters of the LHC that affect the radiation levels in IP1-IP5, providing their typical values in each year of RUN 2 and the associated amount of luminosity delivered to them.

Parameters that change from year to year

Parameters that change within one year/fill: TCLs aperture sizes, Roman Pots settings

Selected Simulated Configurations

year	Crossing Angle [micro-rad]	beta* [cm]	TCL5 [sigmas (state)]	TCL6 [sigmas (state)]	Roman Pots	Extracted Lumi per setting (Approx)
2016	-185	40	15 (closed)	open	OUT	**33**
			35 (open)	20 (closed)	IN	0.04
2017	150	40	15 (closed)	open	OUT	1.0
			35 (open)	20 (closed)	IN	6.1
		30	15 (closed)	open	OUT	0.01
			35 (open)	20 (closed)	IN	**7.8**
2018	130	30	16.4 (closed)	open	OUT	4.1
			38.2 (open)	open	IN	**20**
		27	15.7 (closed)	open	OUT	0.08
			36.6 (open)	open	IN	1.6
		25	15.0 (closed)	open	OUT	0.05
			35.0 (open)	open	IN	0.81

*not entirely representative since levelling took place

Summary

- Without loss of generality, only the 2018 configuration is presented.
- Full results in backup.

BLM TID IP1 Long Straight Section (LSS)

Good agreement for the Inner Triplet (within errorbars)

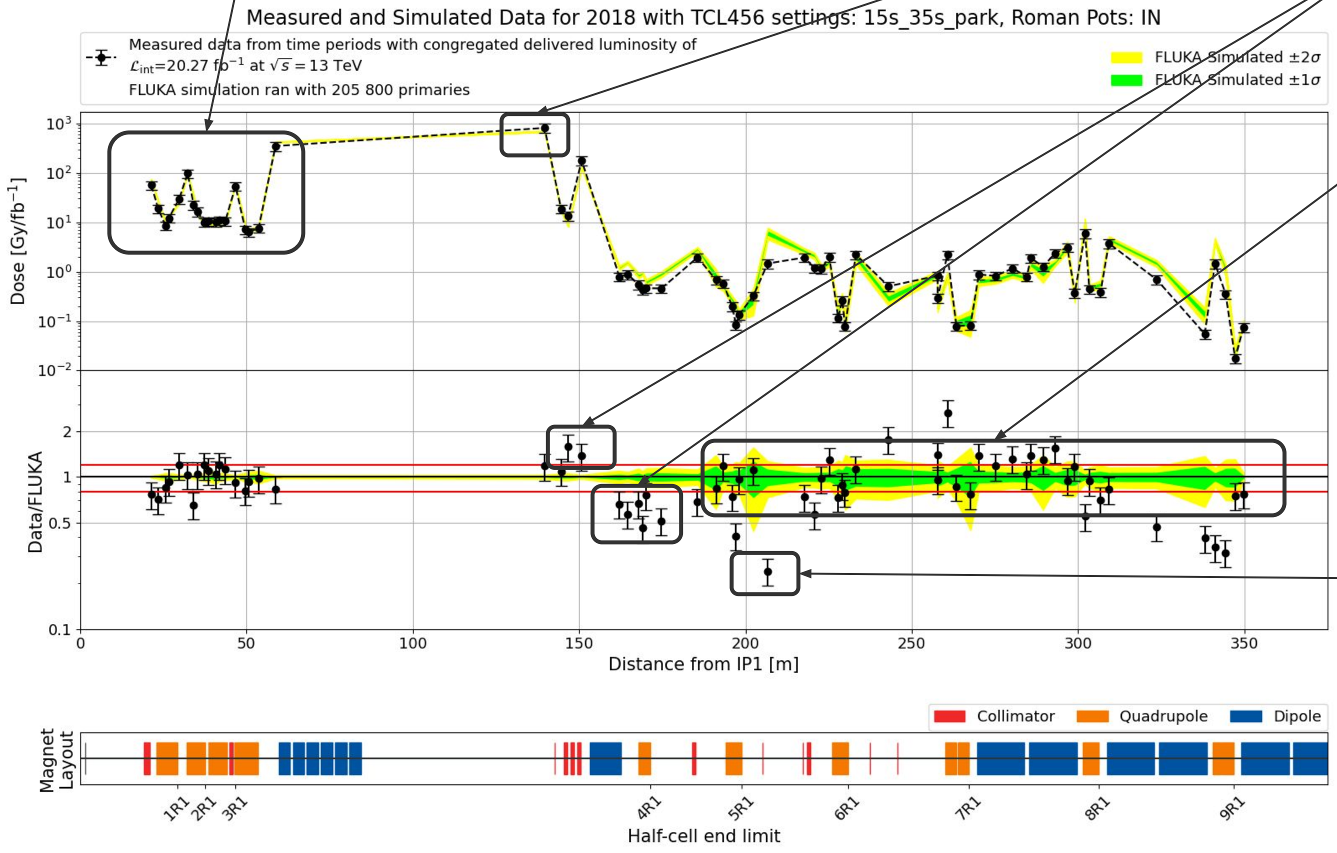
Good Agreement on the TAN BLM

A local overestimation is usually followed by an underestimation (and vice-versa).

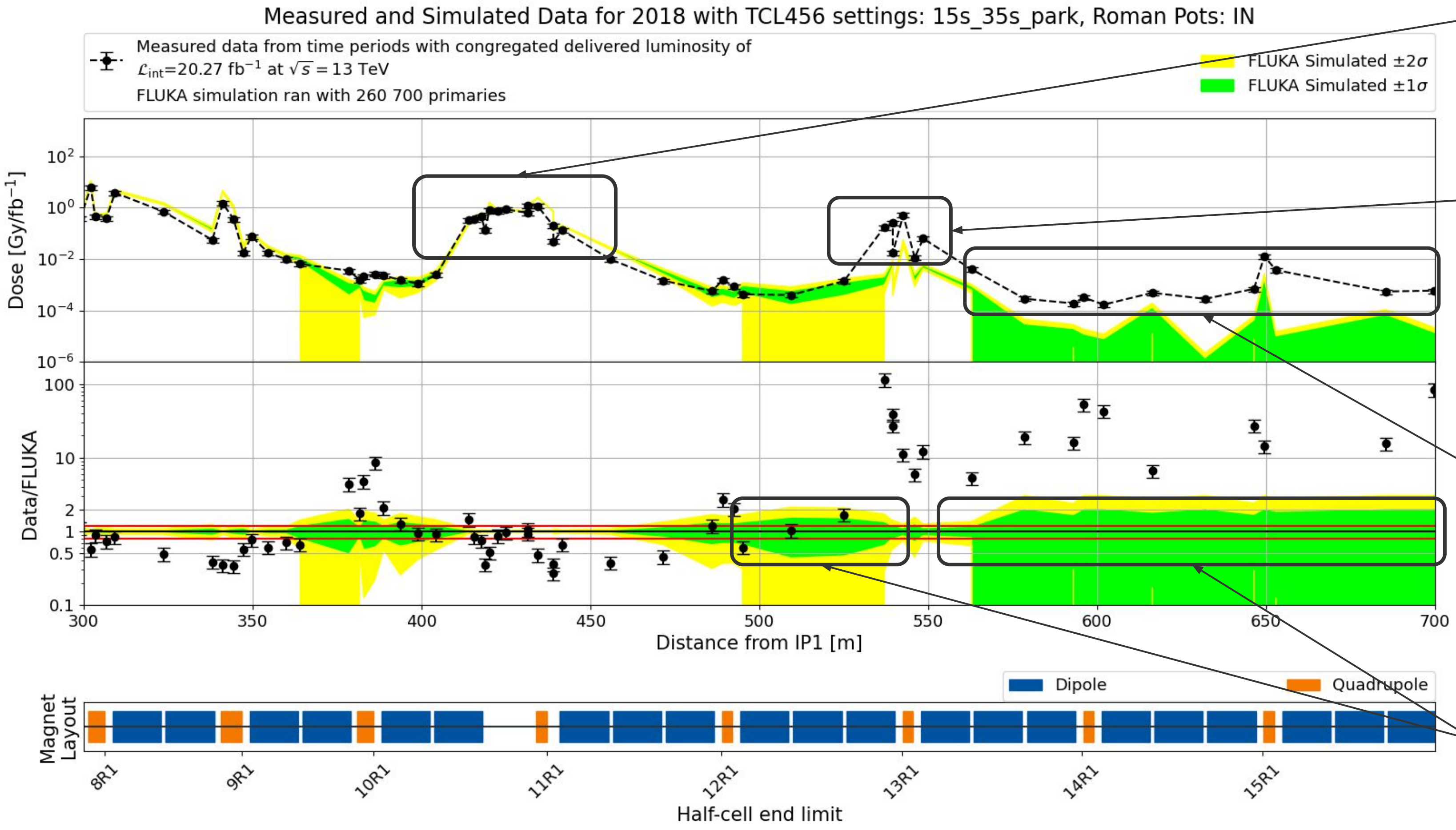
The further away, the larger the simulated error due to poorer statistics.

Generally, good agreement within a factor 2.

Investigated reasons for the prominent outliers: e.g. this BLM is shifted in the simulation with 1m, placing it into the peak of a radiation shower



IP1 Dispersion Suppressor (DS) + ARC (Cells 14, 15, 16)



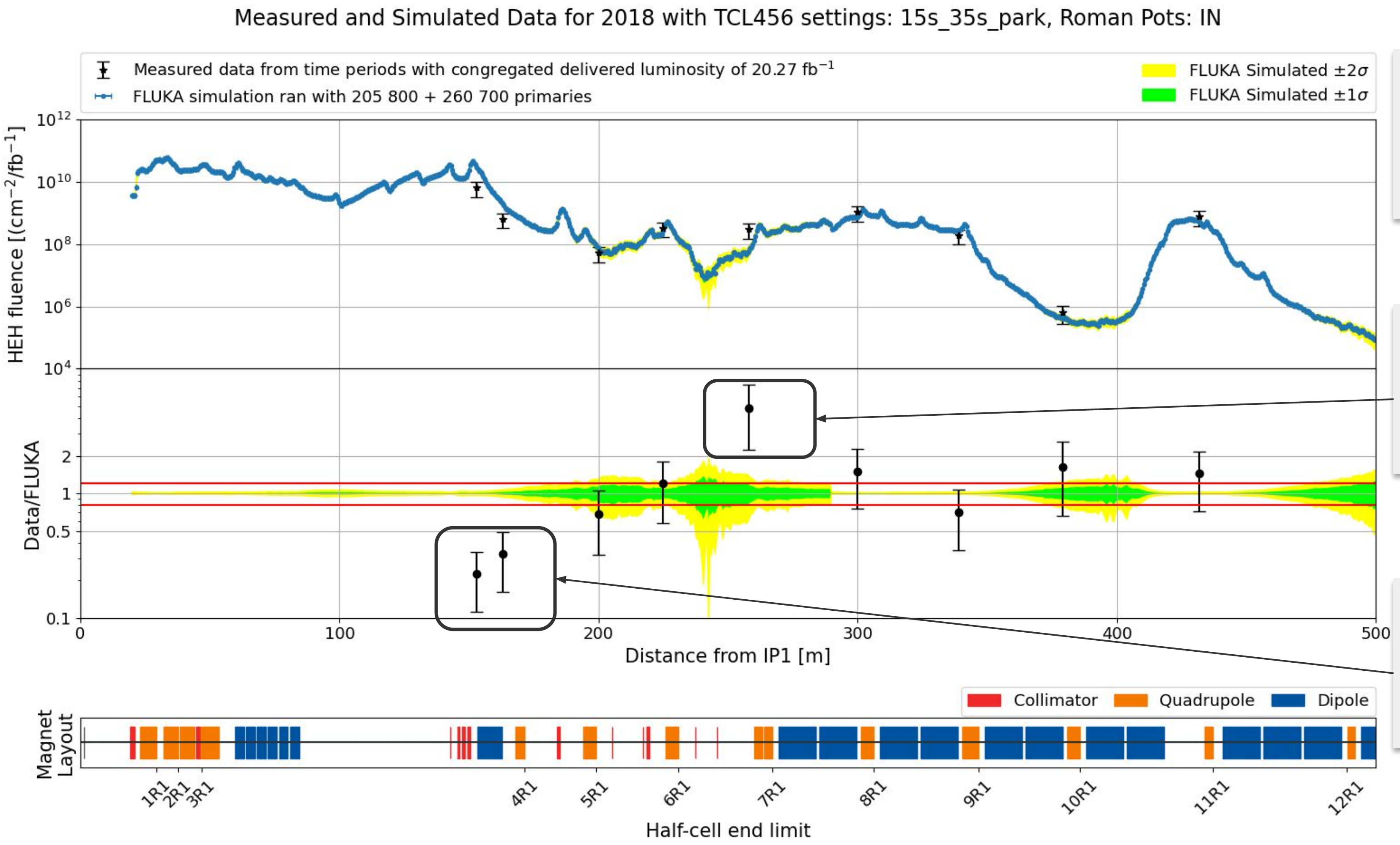
Reasonable agreement for high TID BLMs.

Large discrepancies in Cell 13 (present in IR5 benchmark as well) -> To be investigated

For ARC BLMs, the Interaction Point is no longer the main source of radiation. In this region, we are dominated by residual beam gas interactions, of order 10^{-4} Gy/fb^{-1}

Simulation error larger than the 20% MC threshold required for the reliability of the results

RADMON HEH Fluence IP1 - floor level



General good agreement

Outliers:
to be investigated

FLUKA overestimation for the RadMONs in Cell 4 (present in IR5 benchmark as well)

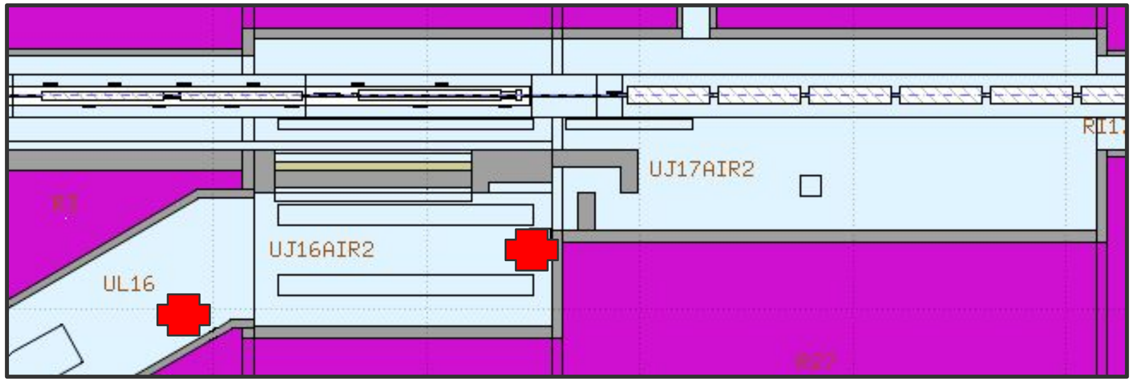
RADMON HEH Fluence IP1 - shielded alcoves

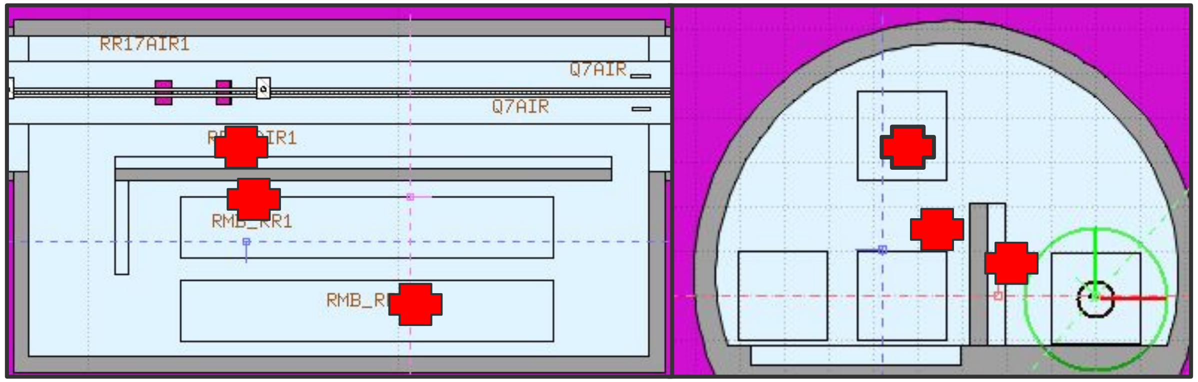
RadMon name	Measured $[cm^{-2}/fb^{1}]$	Total Error (Sys. + Stat.) [%]	Simulated $[cm^{-2}/fb^{1}]$	Simulation Error [%]	Measured/ Simulated	Error [%]
SIMA.UL16.1RM01S	1.09E+05	54	1.73E+05	40	**0.63**	67
SIMA.UJ16.1RM02S	3.63E+06	51	9.38E+06	7	**0.39**	52

Measured Systematic Error of 50% considering the mixed field radiation in the LHC (also supported by the ongoing CHARM benchmark studies)

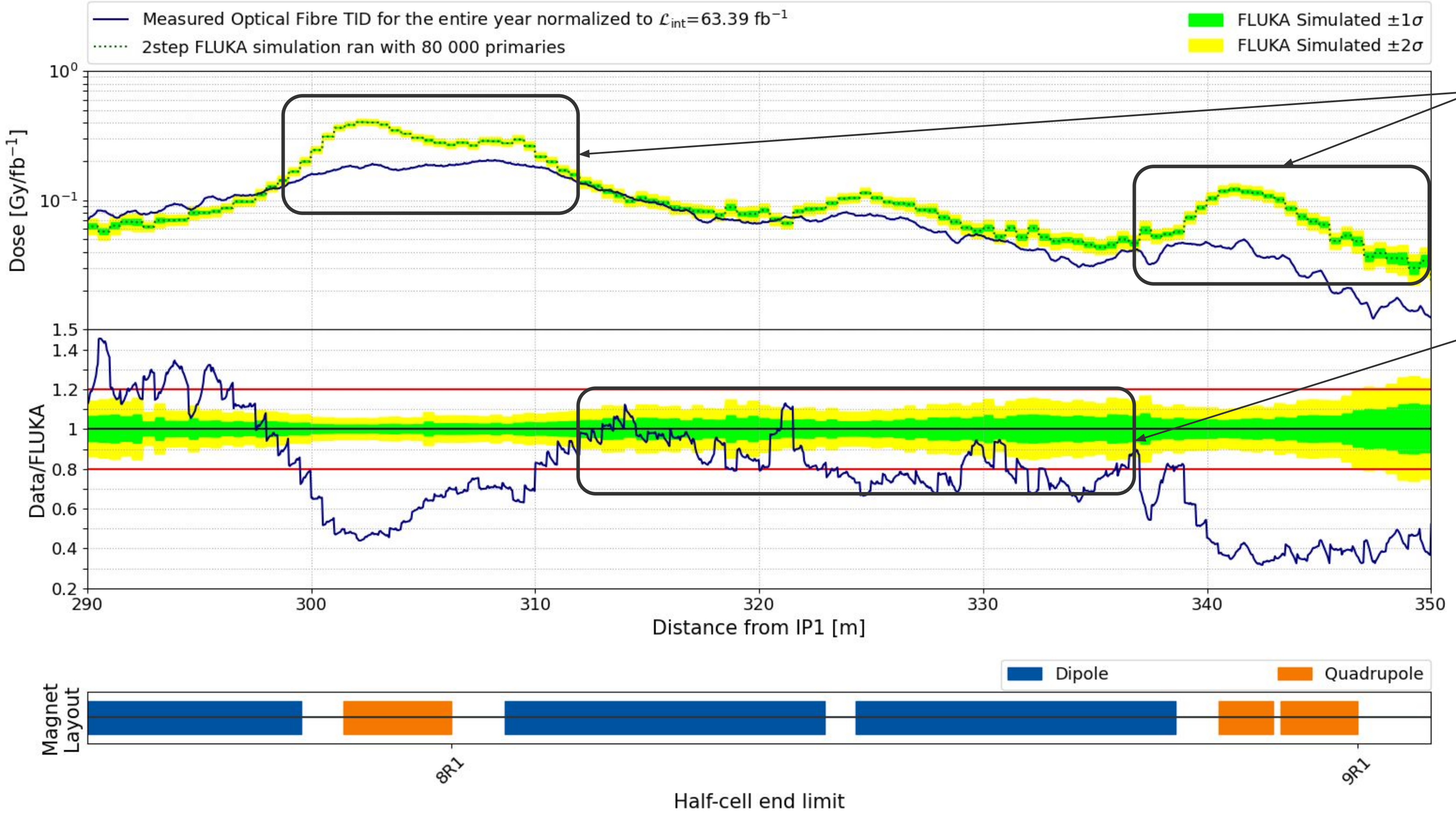
RadMon name	Measured $[cm^{-2}/fb^{1}]$	Total Error (Sys. + Stat.) [%]	Simulated $[cm^{-2}/fb^{1}]$	Simulation Error [%]	Measured/ Simulated	Error [%]
SIMA.RR17.1RM11S	3.21E+07	50	4.00E+07	15	**0.80**	52
SIMA.RR17.1RM12S	2.11E+06	51	5.18E+06	50	**0.41**	71
SIMA.RR17.1RM13S	4.01E+06	50	6.29E+06	36	**0.64**	62

Good Agreement within factor 2





Optical Fibre DS IP1



Large Overestimation near the Interconnects.

Good agreement in regions “shielded” by dipoles.

How does the radiation shower differ from one region to another, and does this affect the deposited TID?

The shower at the Interconnects contains more EM radiation (electrons, photons), possibly leading to a different TID deposition pattern amplified by the simulated larger OF diameter.

Summary

Conclusion

Benchmarked the radiation levels simulated in the LSS+DS of IR1 and IR5 for time periods of Run 2 with constant operational settings using a comprehensive set of radiation monitors and quantities:

- Beam Loss Monitors Total Ionizing Dose (TID) in the tunnel
- RadMon High Energy Hadron (HEH) fluence in the tunnel and shielded alcoves
- Optical Fiber TID in DS tunnel of IR1

Future work

- Investigate outliers for **possible inconsistencies** coming from:
  - measurements: radiation monitor not functioning properly, error in data analysis, etc.
  - simulations: position inaccuracy, simulation mismodeling, etc.
- **Solve** them, thereby increasing the reliability of both measurements/simulations over time.
- Quantify the systematic uncertainties via a similar benchmark in the CHARM facility.

Thank you for your attention!

Questions?

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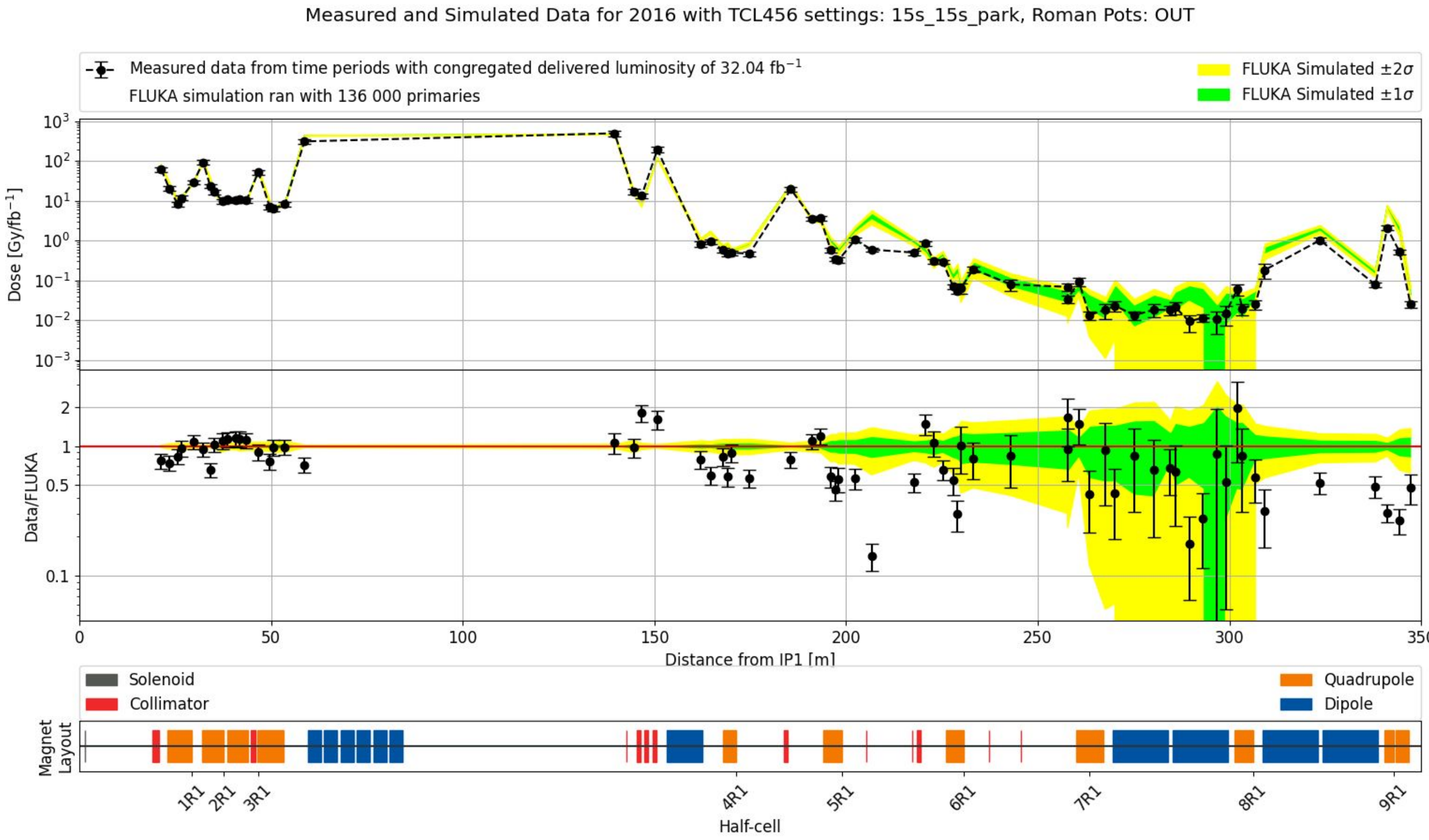
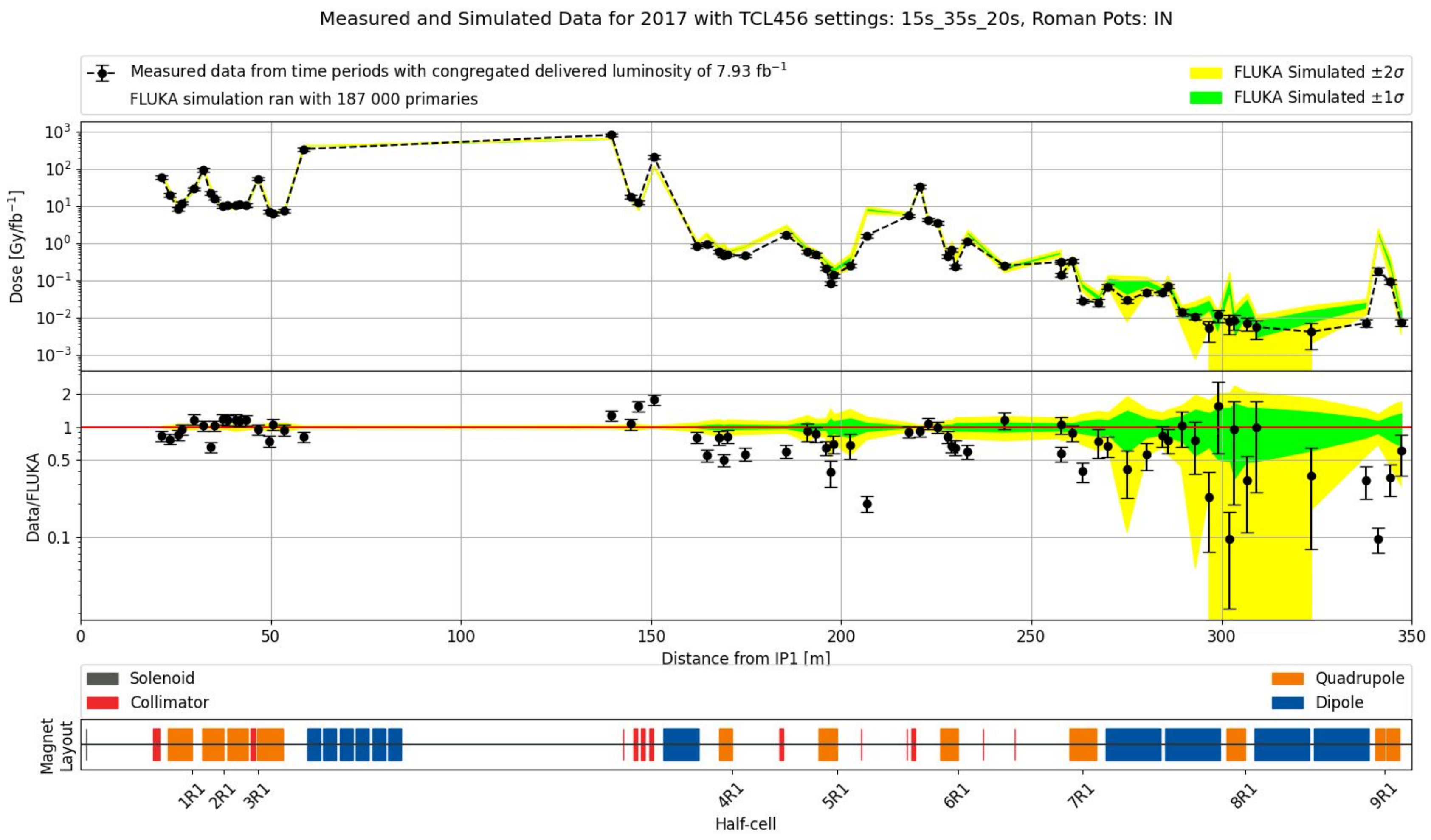
Backup Slides

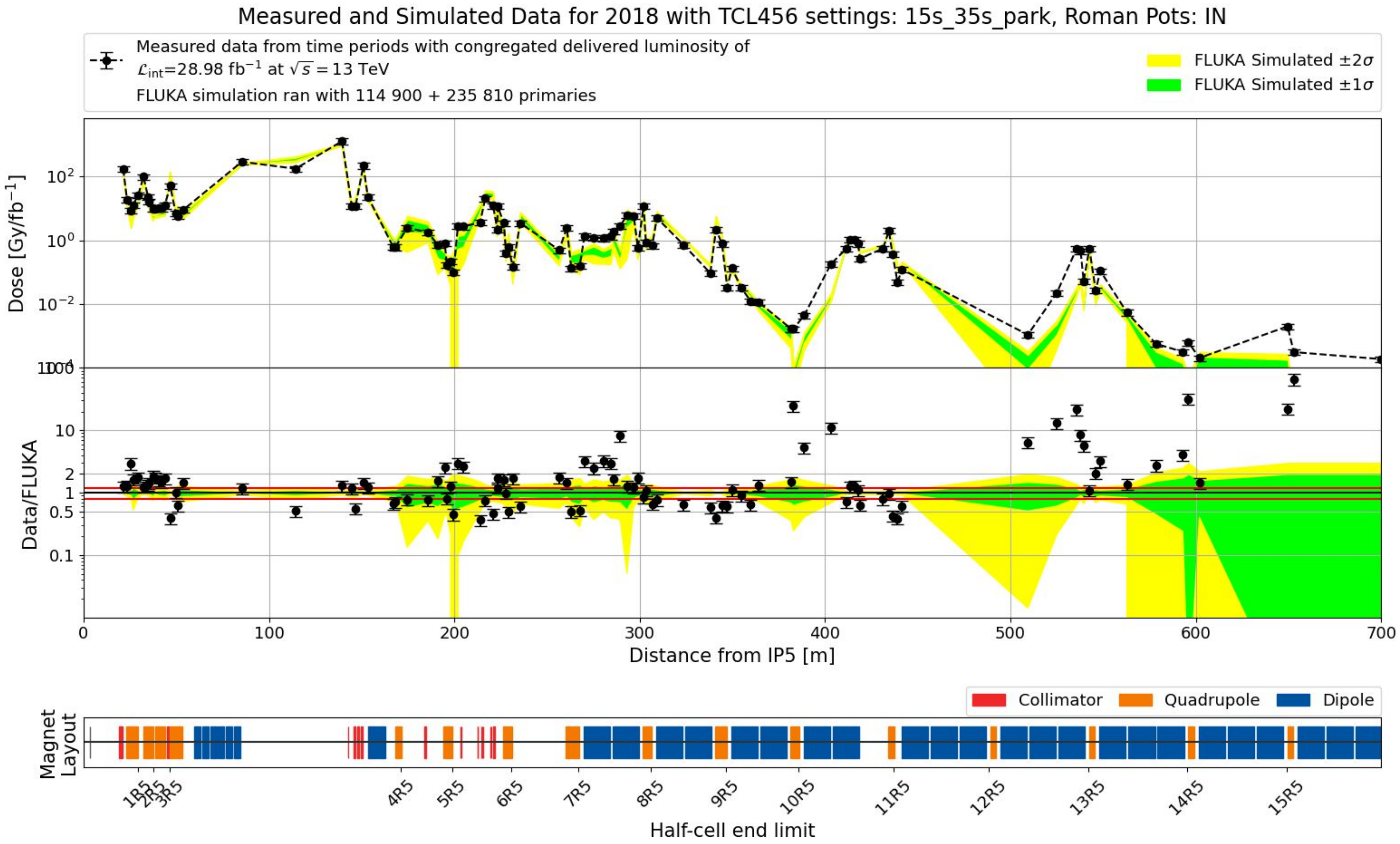
BLM Profile IR1 2016



BLM Profile IR1 2017



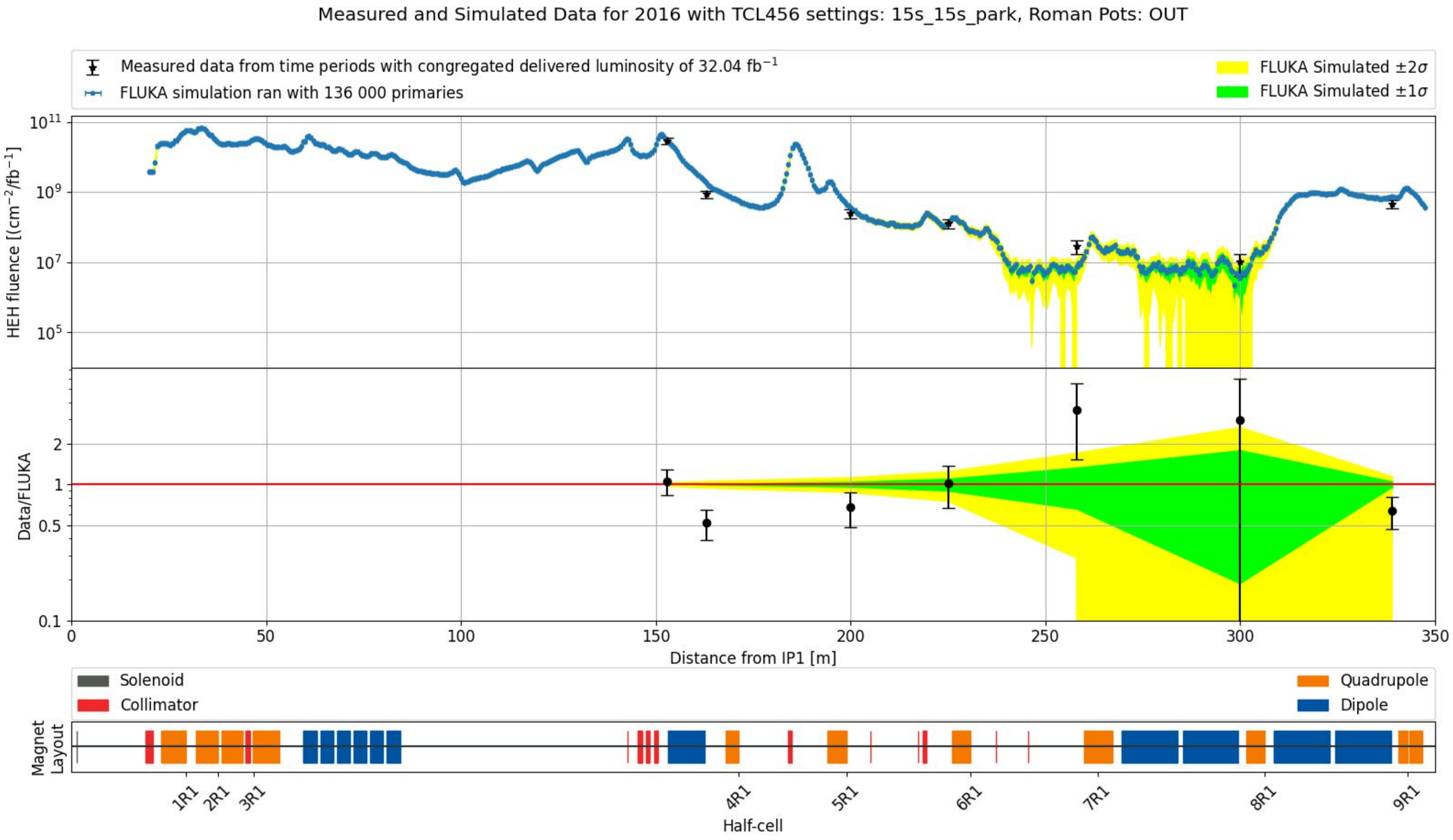
BLM Profile IR5 2018



RADMON HEH Fluence IP1 2018 - floor level

RadMon name	DCUM [m]	Measured [cm^{-2}/fb^{1}]	Total Error [%]	Systematic [%]	Statistical from counting SEU [%]	Simulated [cm^{-2}/fb^{1}]	Simulation Error [%]	Measured/Simulated	Error [%]
SIMA.4R1.1RM19S	153	6.54E+09	50	50	0.08	2.90E+10	1.92	**0.23**	50.12
SIMA.4R1.1RM08S	163	6.47E+08	50	50	0.27	1.99E+09	3.42	**0.33**	50.38
SIMA.5R1.1RM09S	200	5.25E+07	51	50	0.93	7.67E+07	14.12	**0.68**	52.85
SIMA.6R1.1RM10S	225	3.29E+08	50	50	0.37	2.75E+08	10.42	**1.20**	51.44
SIMA.7R1.1RM14S	258	3.02E+08	50	50	0.39	6.21E+07	19.60	**4.86**	54.07
SIMA.8R1.1RM15S	300	1.09E+09	50	50	0.20	7.21E+08	0.68	**1.51**	50.21
SIMA.9R1.1RM16S	339	1.94E+08	50	50	0.48	2.75E+08	1.11	**0.71**	50.50
SIMA.10R1.1RM17S	379	6.50E+05	58	50	8.36	4.02E+05	11.63	**1.62**	59.51
SIMA.11R1.1RM18S	432	7.62E+08	50	50	0.24	5.30E+08	0.96	**1.44**	50.25
SIMA.13R1.1RM21S	540	6.45E+07	51	50	0.84	2.06E+06	12.34	**31.29**	52.32
SIMA.15R1.1RM23S	647	4.63E+05	60	50	9.90	5.67E+04	65.07	**8.17**	88.44

RADMON HEH Fluence IP1 2016 - floor level



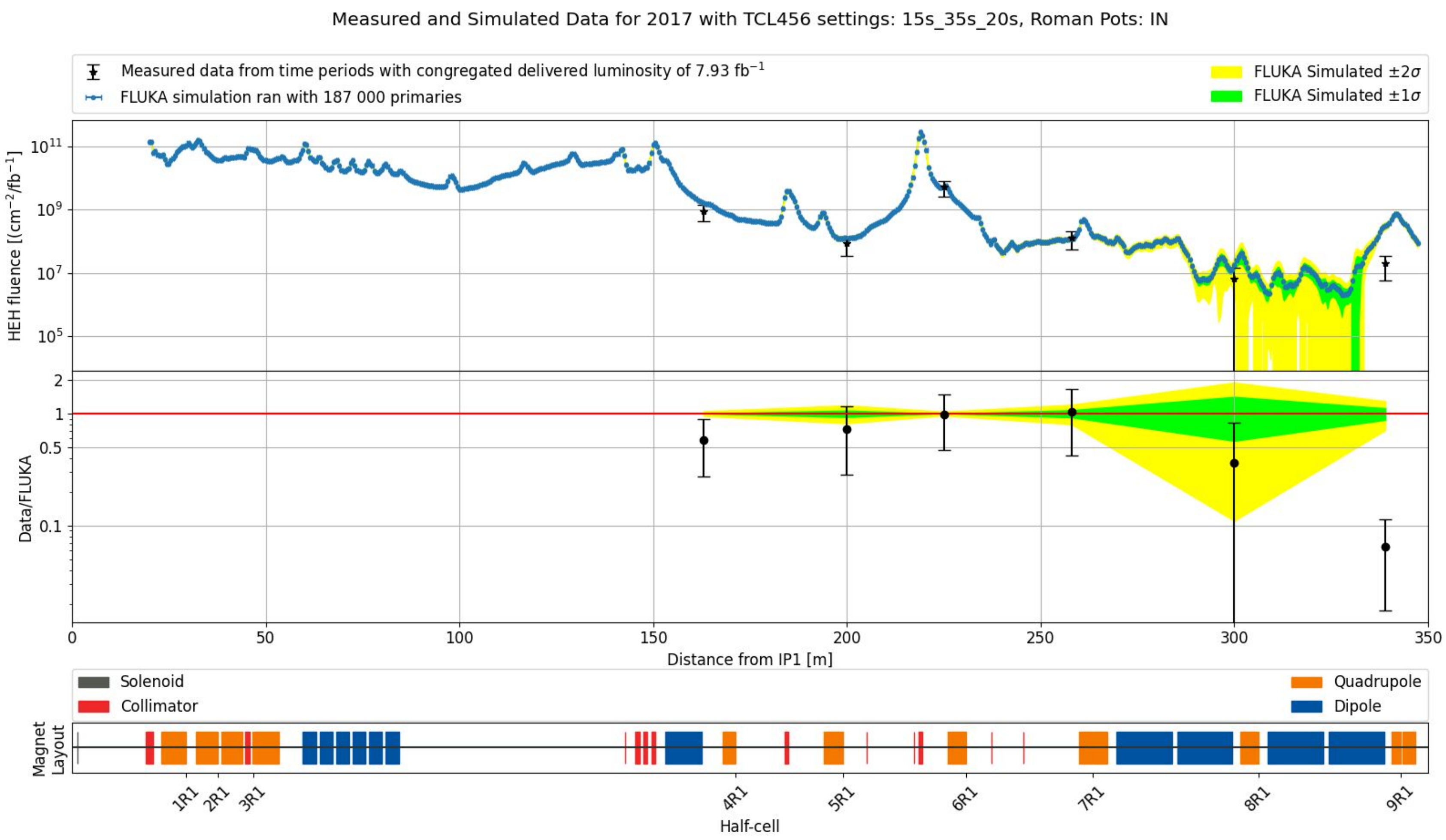
RADMON HEH Fluence IP1 2016 - RadMONs

RadMon name	Measured [cm⁻²/fb¹]	Total Error [%]	Systematic [%]	Statistical from counting SEU [%]	Simulated [cm⁻²/fb¹]	Simulation Error [%]	**Measured/Simulated**	Error [%]
SIMA.4R1.1RM19S	2.92E+10	50	50	0	2.77E+10	2	**1.06**	50
SIMA.4R1.1RM08S	8.93E+08	52	50	2	1.72E+09	3	**0.52**	52
SIMA.5R1.1RM09S	2.50E+08	53	50	3	3.69E+08	6	**0.68**	53
SIMA.6R1.1RM10S	1.32E+08	54	50	4	1.29E+08	13	**1.02**	55
SIMA.7R1.1RM14S	3.02E+07	58	50	8	8.55E+06	36	**3.53**	68
SIMA.8R1.1RM15S	1.03E+07	64	50	14	3.48E+06	82	**2.97**	104
SIMA.9R1.1RM16S	4.75E+08	52	50	2	7.43E+08	7	**0.64**	53

SIMA.UJ16.1RM01S	4.53E+06	110	50	60	4.46E+06	33	**1.02**	115
SIMA.UJ16.1RM02S	8.96E+07	54	50	4	1.48E+08	5	**0.61**	54
SIMA.UJ17.1RM03S	6.80E+09	50	50	0	8.91E+09	1	**0.76**	50

SIMA.RR17.1RM11S	1.47E+07	60	50	10	2.99E+07	22	**0.49**	64
SIMA.RR17.1RM12S	4.84E+06	91	50	41	2.73E+06	53	**1.77**	105
SIMA.RR17.1RM13S	2.92E+06	139	50	89	2.39E+06	59	**1.22**	152

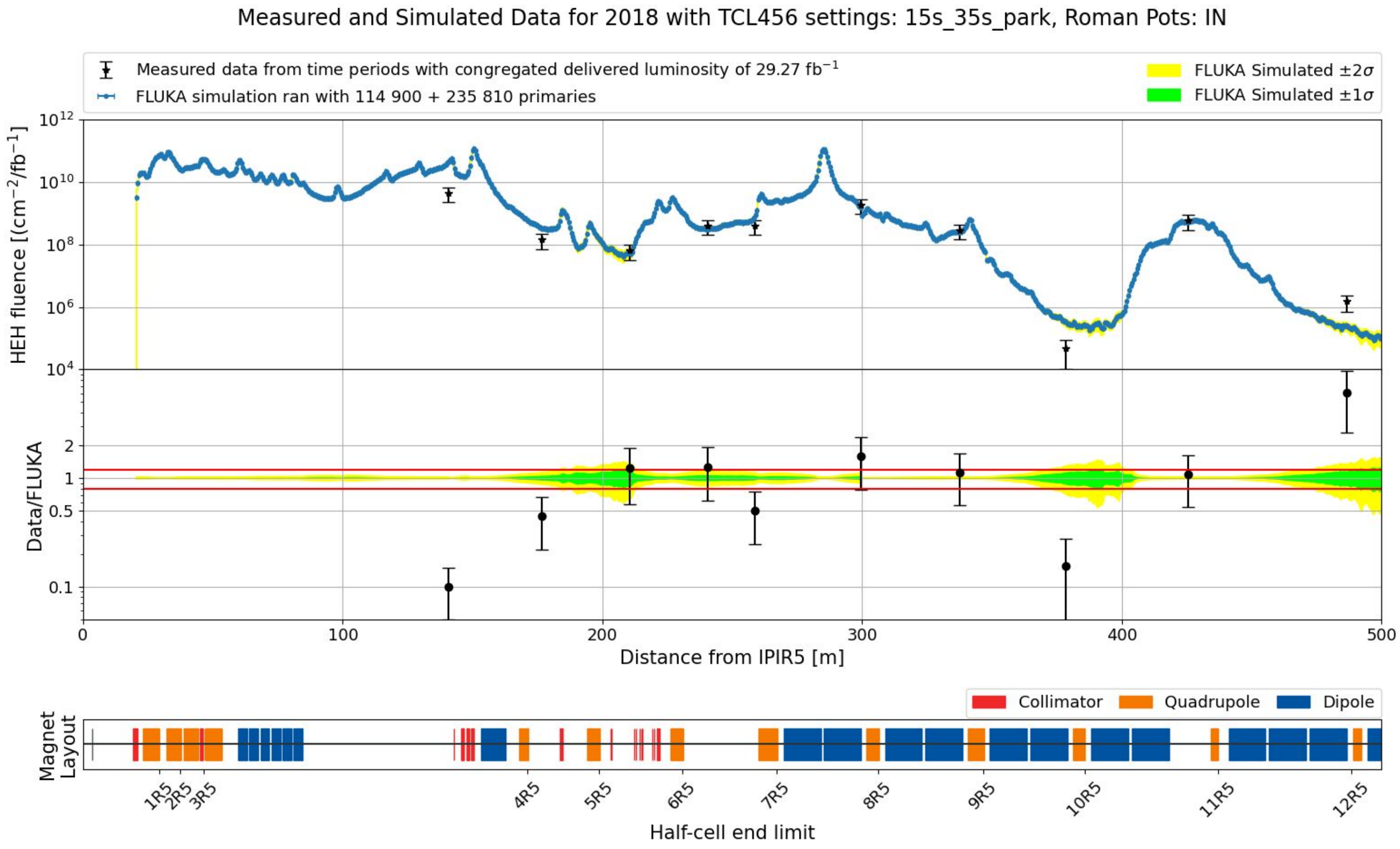
RADMON HEH Fluence IP1 2017 - floor level



RADMON HEH Fluence IP1 2017 - RadMONs

RadMon name	Measured [cm^{-2}/fb^{1}]	Total Error [%]	Systematic [%]	Statistical from counting SEU [%]	Simulated [cm^{-2}/fb^{1}]	Simulation Error [%]	**Measured/Simulated**	Error [%]
SIMA.4R1.1RM08S	9.15E+08	53	50	3	1.57E+09	2	**0.58**	53
SIMA.5R1.1RM09S	8.69E+07	60	50	10	1.20E+08	9	**0.73**	61
SIMA.6R1.1RM10S	5.21E+09	51	50	1	5.35E+09	2	**0.97**	51
SIMA.7R1.1RM14S	1.31E+08	59	50	9	1.27E+08	10	**1.04**	59
SIMA.8R1.1RM15S	6.62E+06	121	50	71	1.83E+07	44	**0.36**	129
SIMA.9R1.1RM16S	2.03E+07	72	50	22	3.12E+08	14	**0.07**	73
SIMA.UJ16.1RM01S	4.53E+06	110	50	60	4.16E+06	28	**1.09**	114
SIMA.UJ16.1RM02S	1.07E+08	72	50	22	1.40E+08	4	**0.76**	72
SIMA.UJ17.1RM03S	6.42E+09	51	50	1	8.86E+09	1	**0.73**	51
SIMA.RR17.1RM11S	9.84E+07	58	50	8	1.57E+08	8	**0.63**	59
SIMA.RR17.1RM12S	7.93E+06	83	50	33	1.70E+07	19	**0.47**	85
SIMA.RR17.1RM13S	6.21E+06	92	50	42	1.71E+07	18	**0.36**	93

RADMON HEH Fluence IP5 2018 - floor level



Example of a TCL collimator aperture change: a 2016 fill/run

Even within single fills the operational parameters are not constant -> a known procedure is to open TCL5/close TCL6 after approx. 30 min of stable beam