BGC radiation hard background simulation and camera protection

Daniel Prelipcean

On behalf of the R2E team

At the 10th BGC collaboration meeting: https://indico.cern.ch/event/1350721/

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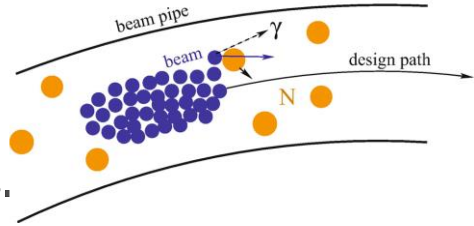
Introduction

- **Within Radiation to Electronics (R2E) [1], study the radiation levels caused by Beam Instrumentation (BI) elements operation in IR4, with particular focus on the:**
  - Beam Gas Vertex (**BGV**) in Run 2 (2015-2018) and possibly for HL-LHC
    - see for example the 150th TCC contribution [2] or IPAC23 proceeding [3]
  - Beam Gas Curtain (**BGC**) in Run 3 (2022-to date).
    - previous progress presented at the 9th BGC Collaboration meeting [4]

- **Key ingredients of the analysis:**
  - Measurements from LHC Run 2 with the BGV demonstrator and Run 3 with the BGC:
    - Beam Loss Monitors (BLM) system - Total Ionizing Dose (TID)
    - Radiation Monitor (RadMon) system - High Energy Hadron fluence (HEHeq)
    - In 2023: Timepix3 BLM - event by event energy deposition
  - FLUKA simulations of beam gas interactions for LHC Run 2&3 and HL-LHC scenarios.

1. Radiation to Electronics (R2E) at CERN, website. URL https://r2e.web.cern.ch/
2. D. Prelipcean, *BGV Beam gas collisions at IR4 and related radiation levels and heat loads*, in 150th HL-LHC TCC, https://indico.cern.ch/event/1129683/
3. D. Prelipcean et al, *Radiation levels produced by the operation of the Beam Gas Vertex monitor in the LHC tunnel at IR4*, in 14th International Particle Accelerator Conference https://www.ipac23.org/preproc/pdf/THPL082.pdf
4. D. Prelipcean, *Radiation levels from BGC operation in 2022*, in https://indico.cern.ch/event/1281084/#42-predictions-of-ionising-rad

Normalization factors



- Any residual gas will lead to beam-gas interactions causing local radiation showers.
- Beam Gas elements in IR4: inject gas (typically Ne) to increase the local density and measure the secondaries for beam profile reconstruction.
- Drawback: Higher radiation levels possibly impacting the other elements along the beamline.

Assumption: radiation level rates scale as follows:

BGC operation | (HL-)LHC operation

$$\frac{dN}{dt} \propto \Theta(t; s_a, s_b) \cdot \sigma_j(E) \cdot f \cdot I(t)$$

Injected gas density profile

Interaction cross section - Gas species (Neon)

Beam energy

LHC revolution frequency

Beam intensity

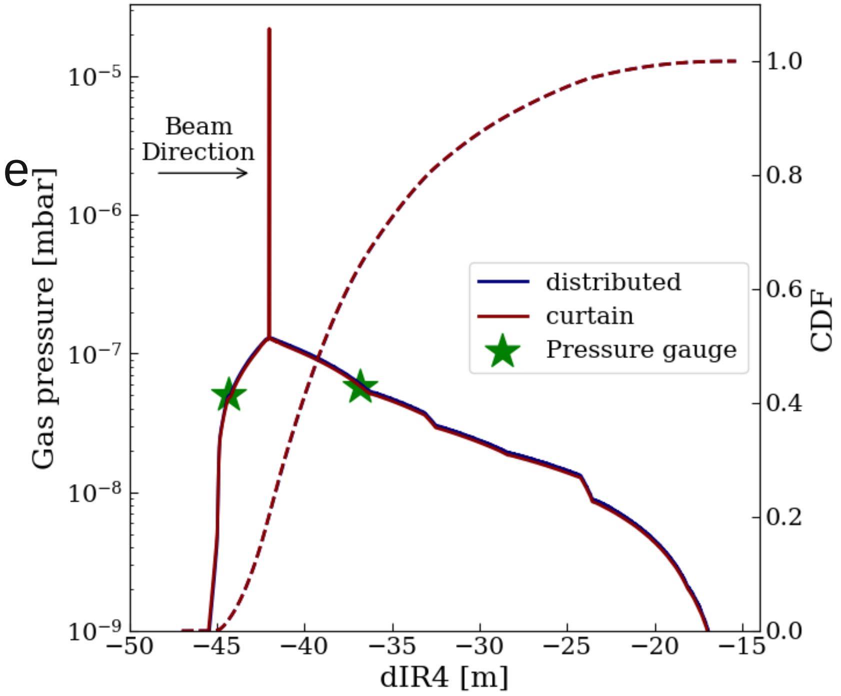
BLM TID rate

Pressure Gauge reading

Beam Current Transformer (BCT) Instrument

Radiation source: Injected gas density profile

- **Simulations:**
  - The FLUKA simulated values depend on the s-integral of the gas profile.
  - The gas density profile is based on simulations from **Cristina Castro Sequeiro (TE-VSC-VSM)** specific to the BGC demonstrator in:
    - 2022: distributed
    - 2023: distributed + curtain
  - The curtain adds negligible gas in the s-integral of the gas profile.



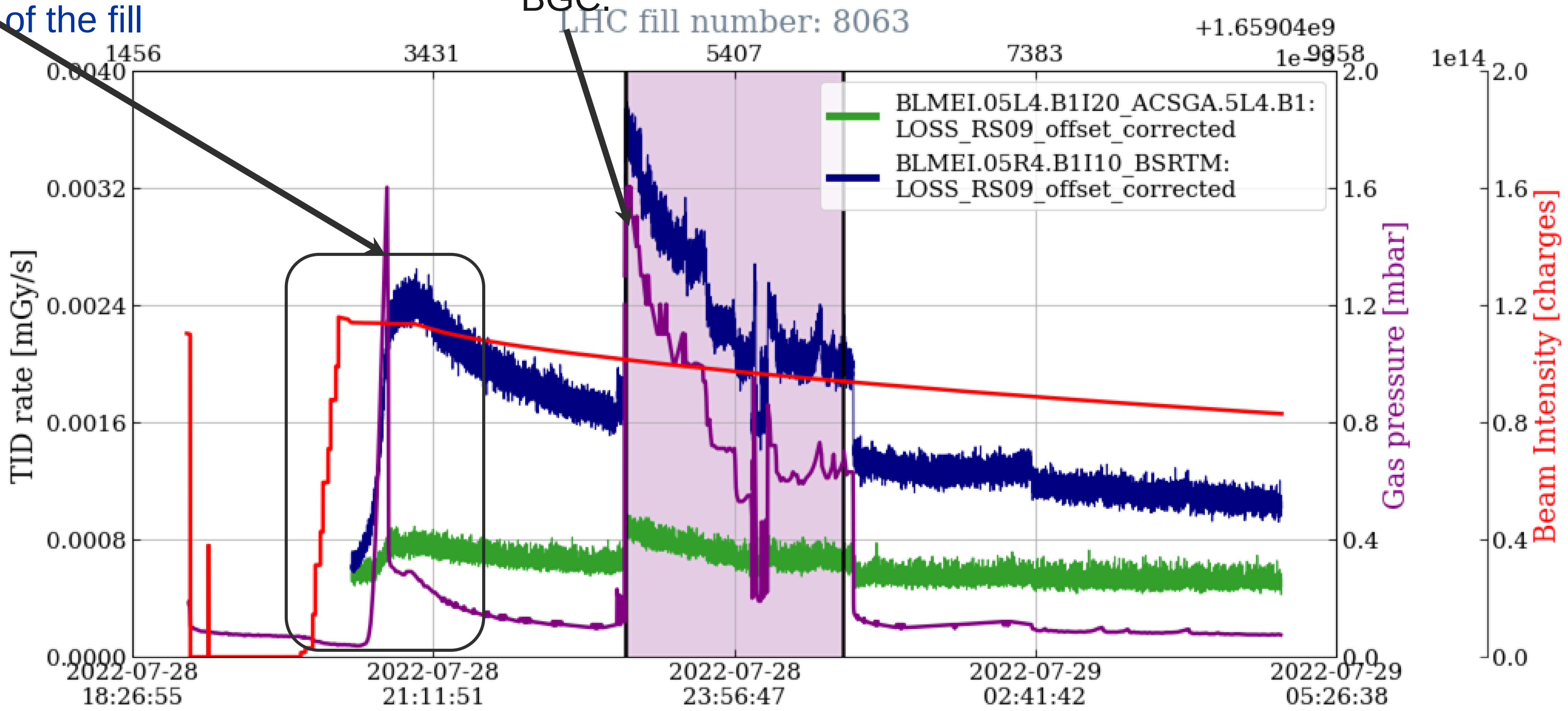
- **Measurements:**
  - Just two data points available via two pressure gauges:
    - VGPB.443.5L4.B.PR - 2.3 m upstream
    - VGPB.368.5L4.B.PR - 5.2 m downstream
  - Pressure gauges are calibration to N_2, so they have to be scaled to Neon according to their relative sensitivity.

Measured data

TID rate and pressure gauge reading increase at the beginning of the fill

BGC gas injection leads an increase the TID rates of the BLMs downstream of the BGC.

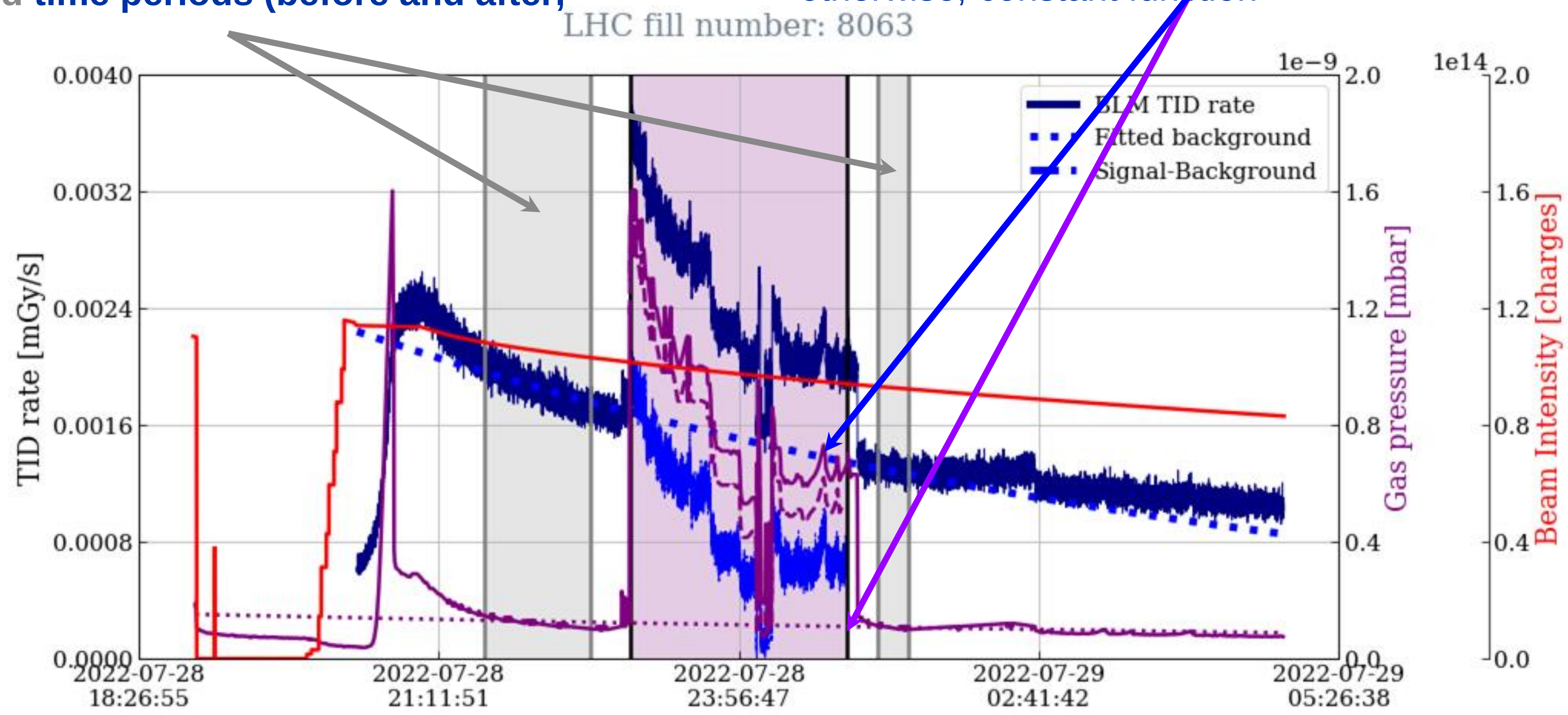
BLM TID increases **unevenly** for different BLMS



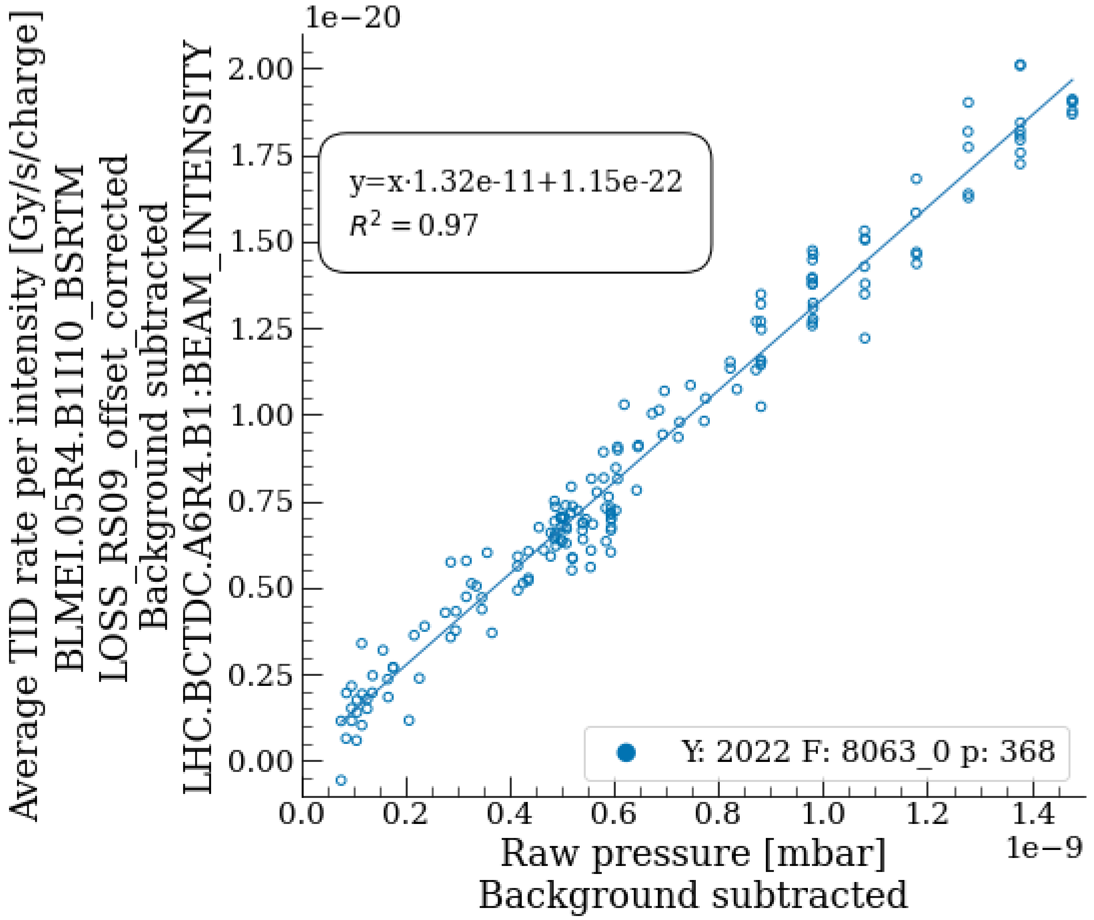
Measured data (v4)

In order to isolate just the BGC contribution.
Define:
- signal time period based on gas injection
- background time periods (before and after, ideally)

Fit for both the BLM TID rate and the pressure measurements:
- an exponential decay curve (based on beam intensity)
- otherwise, constant function

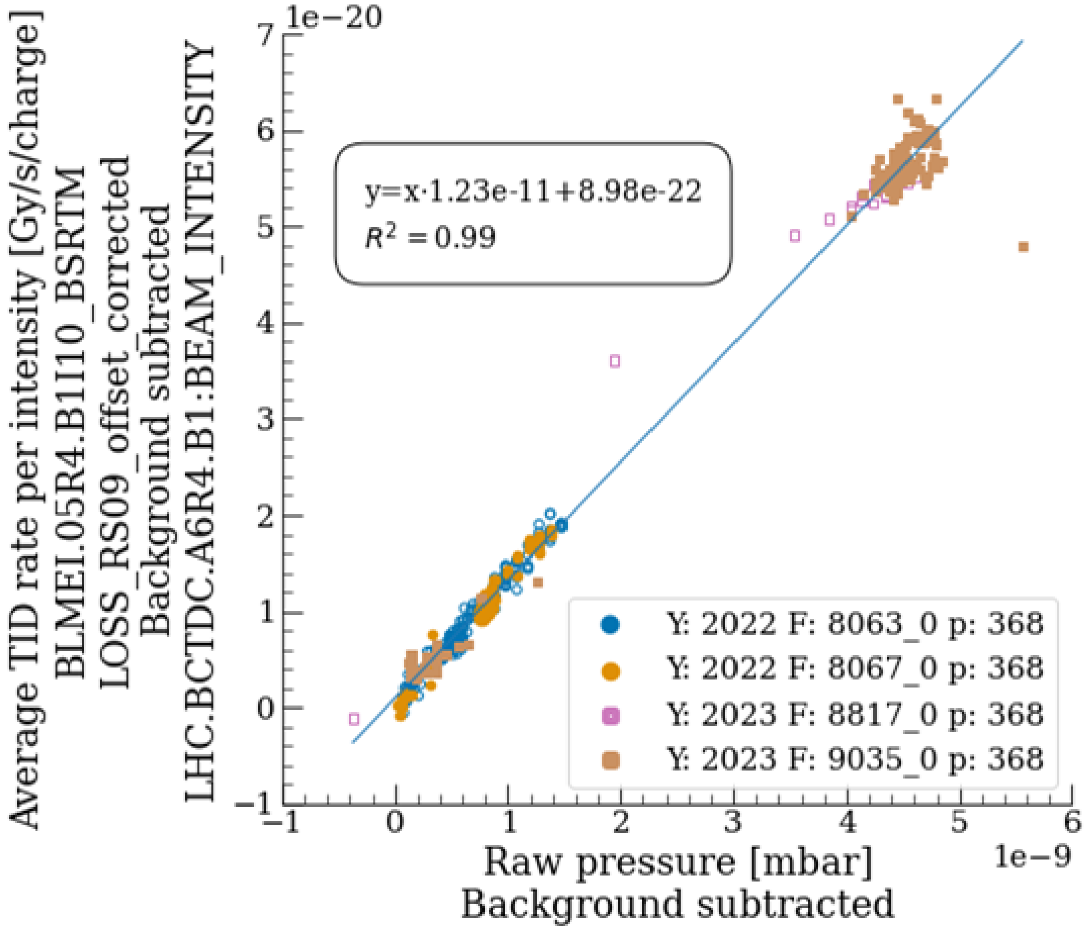


Instantaneous correlations



- **Each data point corresponds to one timestamp in the pressure gauge measurement.**
- **This procedure has been applied to all:**
  - BLMs downstream of the BGC -> only for some, a good linear correlation can be extracted.

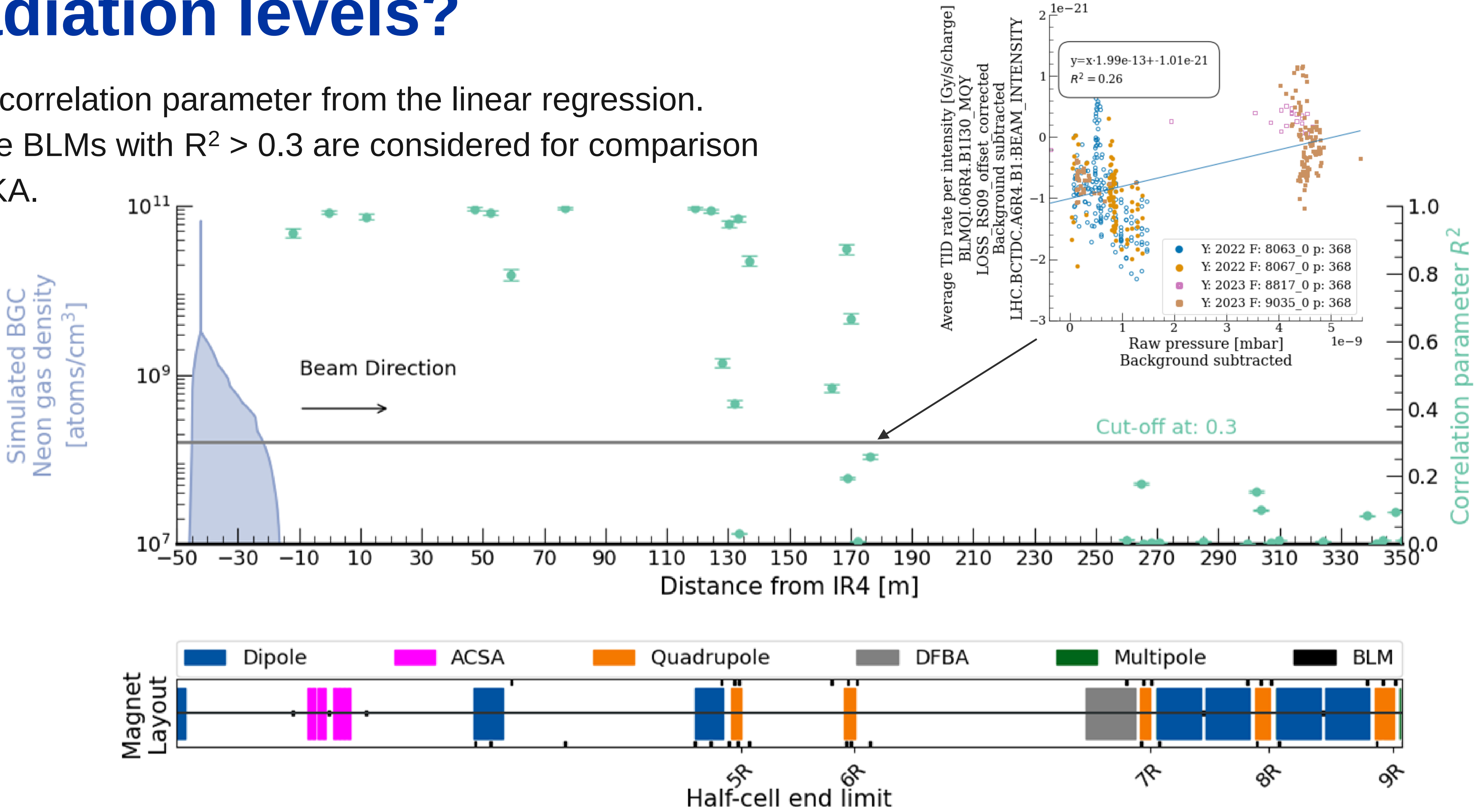
Instantaneous correlations



- **Each data point corresponds to one timestamp in the pressure gauge measurement.**
- **This procedure has been applied to all:**
  - BLMs downstream of the BGC -> only for some, a good linear correlation can be extracted.
  - all gas injection fills -> only some had clean signal/background time periods to extract just the BGC contribution.
  - two available pressure gauges: up- and down-stream of the BGC.

How far is the BGC relevant in terms of radiation levels?

Compute correlation parameter from the linear regression.
Only those BLMs with $R^2 > 0.3$ are considered for comparison with FLUKA.

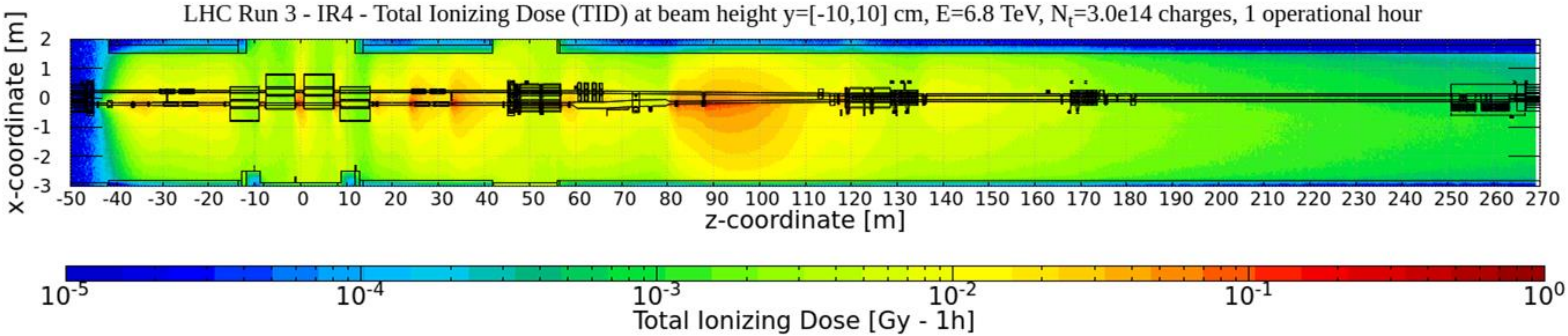


Simulated radiation level data (v111)

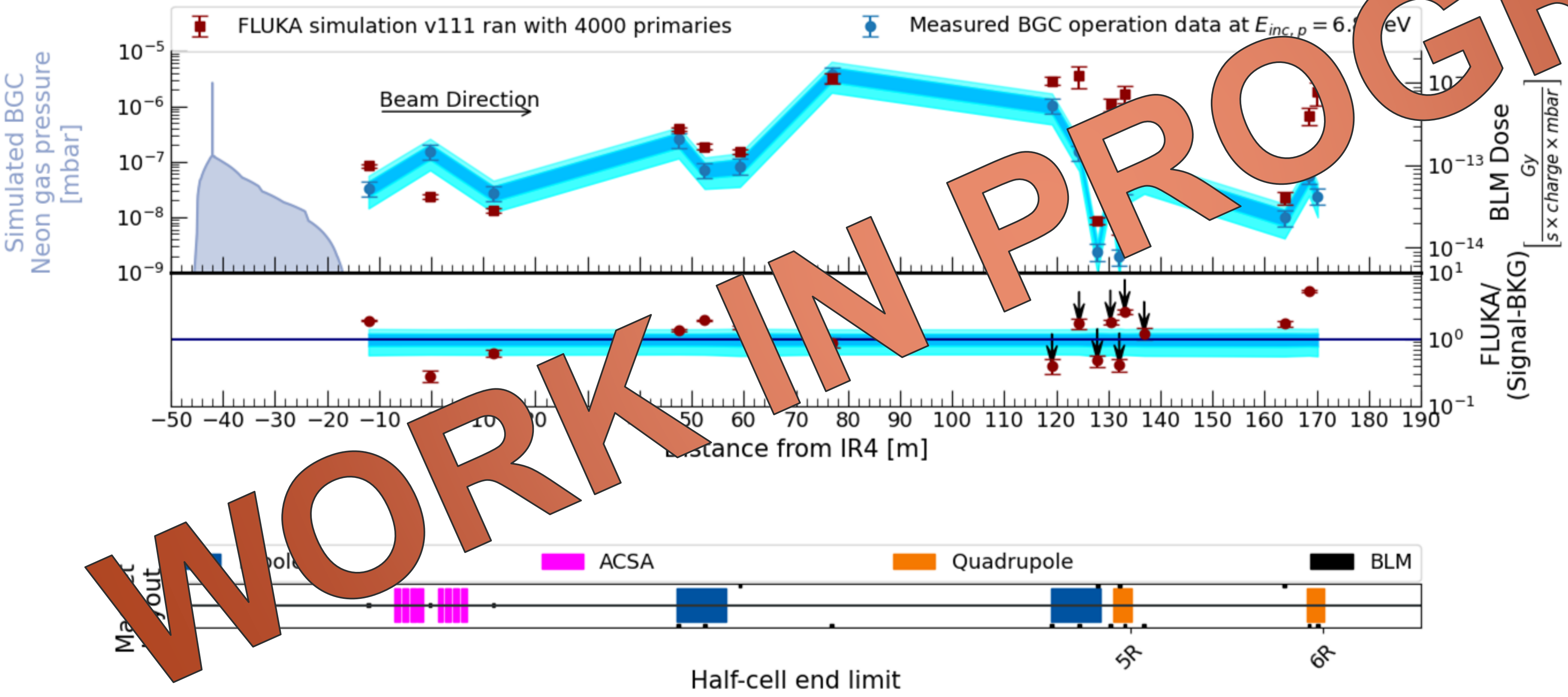
- **FLUKA is capable of simulating the radiation shower caused by the beam-gas interactions.**
- **The shower extends longitudinally over several tens of meter:**
  - BLMs and RadMon -> radiation levels in the tunnel.

Radiation level patterns/regions:

1. BGC vicinity
2. RadioFrequency cavities
3. First bending dipole (reducing the beam separation from 20 to 9.7 cm)
4. Second bending dipole and first quadrupole



BLM Benchmark



- Several outliers to be investigated
- Significant disagreement at +120 m (in the ratio pad, scaled down by a factor of 5) -> triggered further investigation on impact of different beam line elements and the different beam pipe transitions/ interconnections.

Timepix3 Radiation Monitor deployment

Timepix3 Radiation Monitor

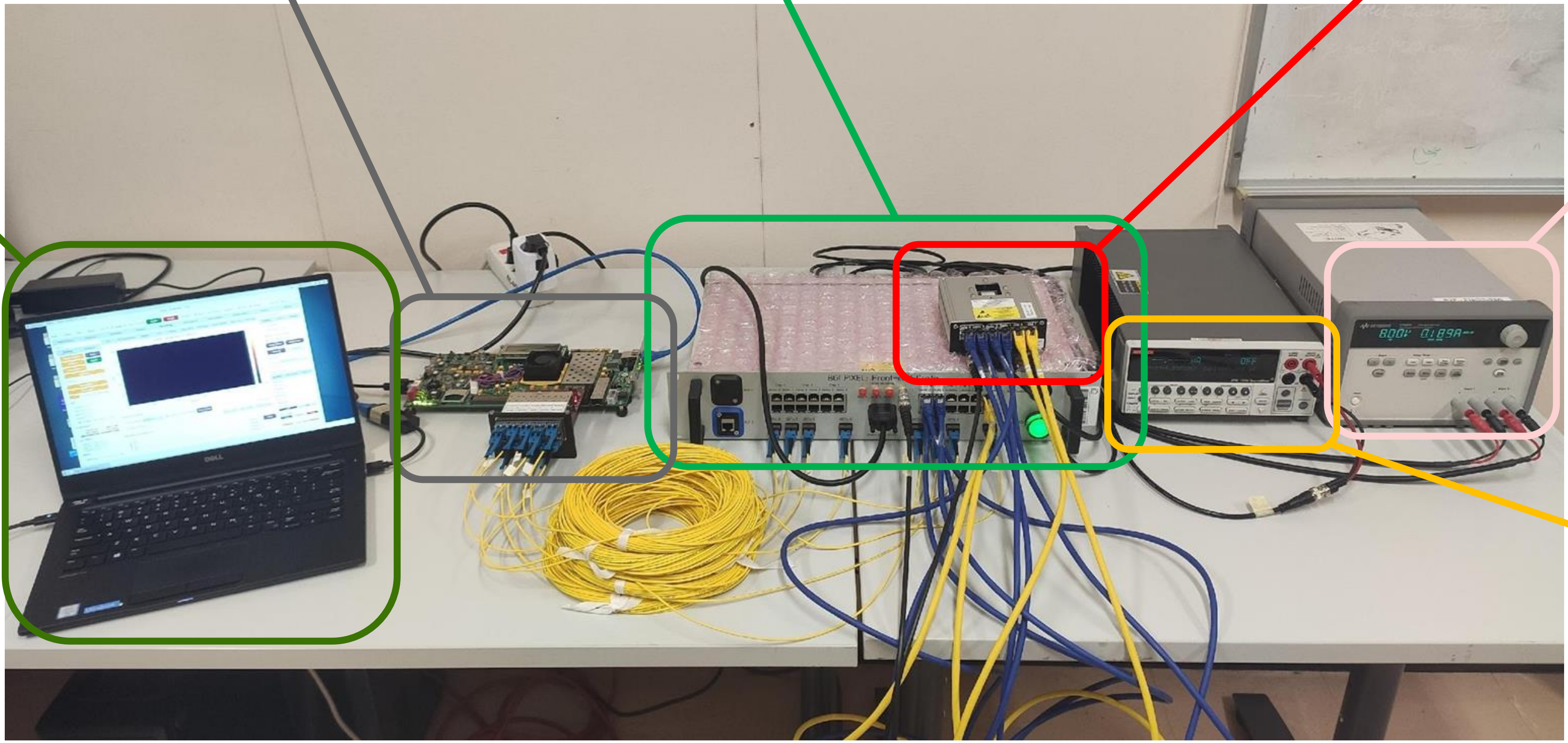
Laptop with BIPXL software running

Back-end electronics

Front-end electronics

Timepix3 module

Timepix3 + frontend crate power supply (2 x 8V)



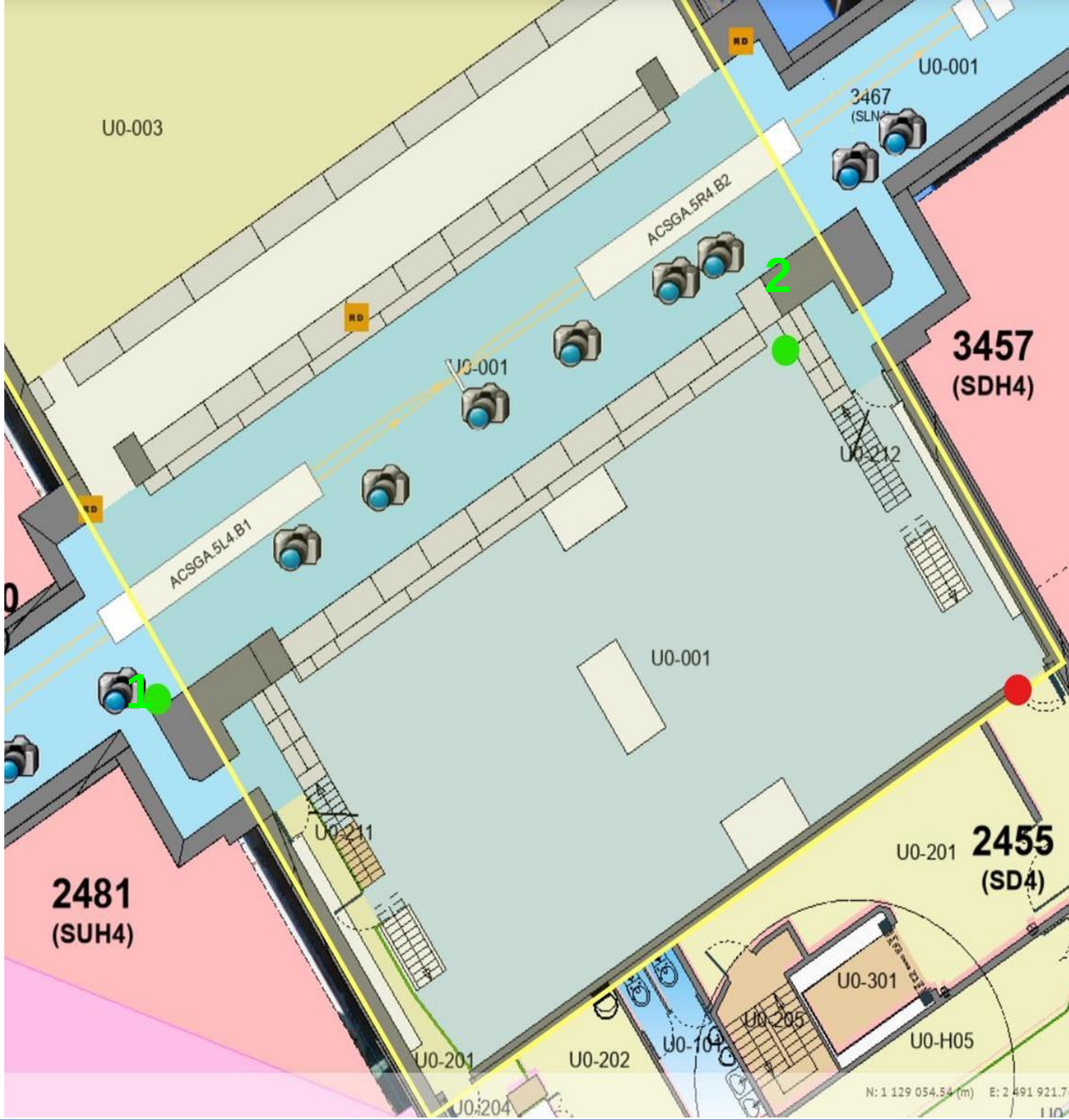
Timepix3 detector power supply (+50V)

Location

Installed in point

- **2, inside shielded alcove.**

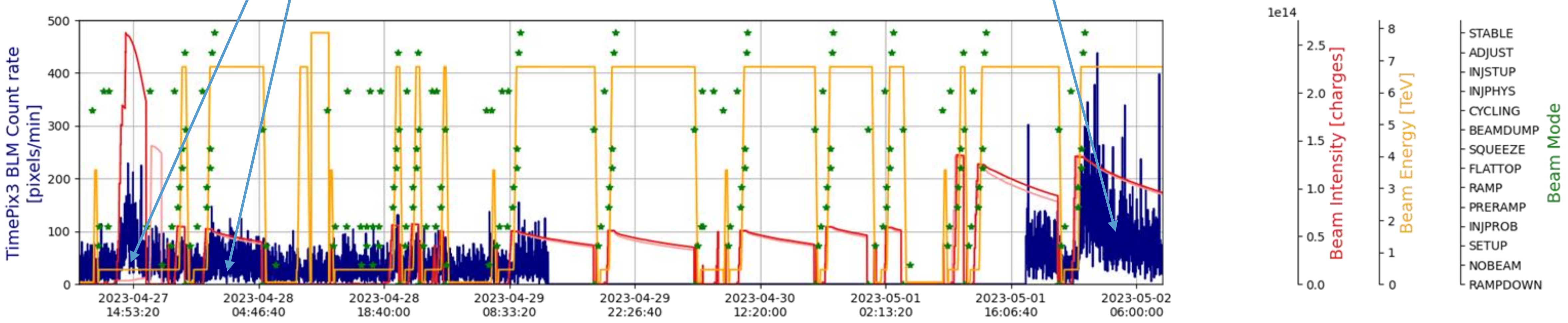
via the US450 door close to the elevator leading to our positions of interest.



Pixel hit rate over time

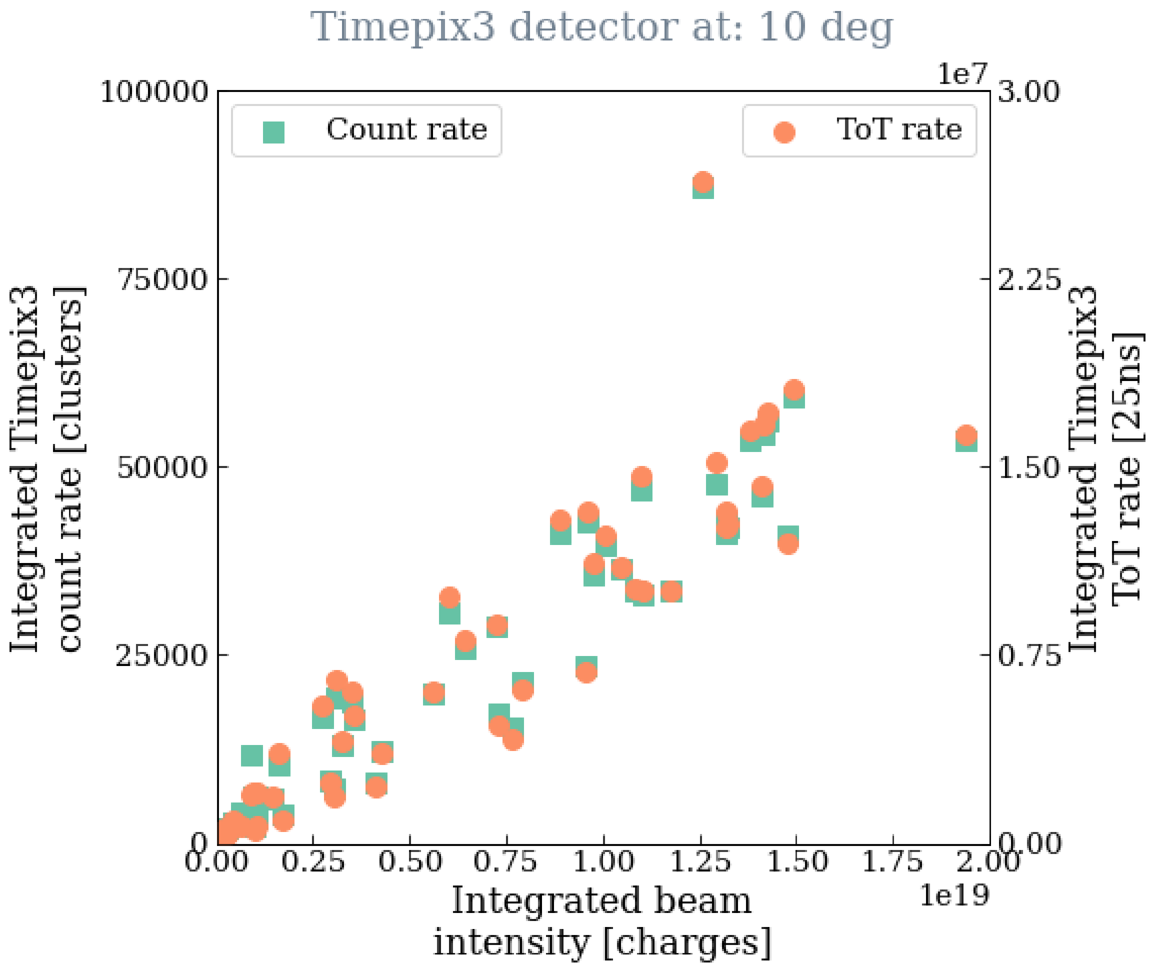
Already levels above background for:
1. Injection energy (450 GeV) and nominal beam intensity
2. Top energy (6.8 TeV) and reduced beam intensity

Promising signal: average count rate from 30 to hundreds of pixels hits/min.



Timepix3 as a standard Radiation Monitor

- Losses at IR4 (in absence of gas injection) are assumed to scale **just** with the beam intensity.
- Each data point corresponds to one fill.
- The count and ToT (~energy) rates agree with each other.



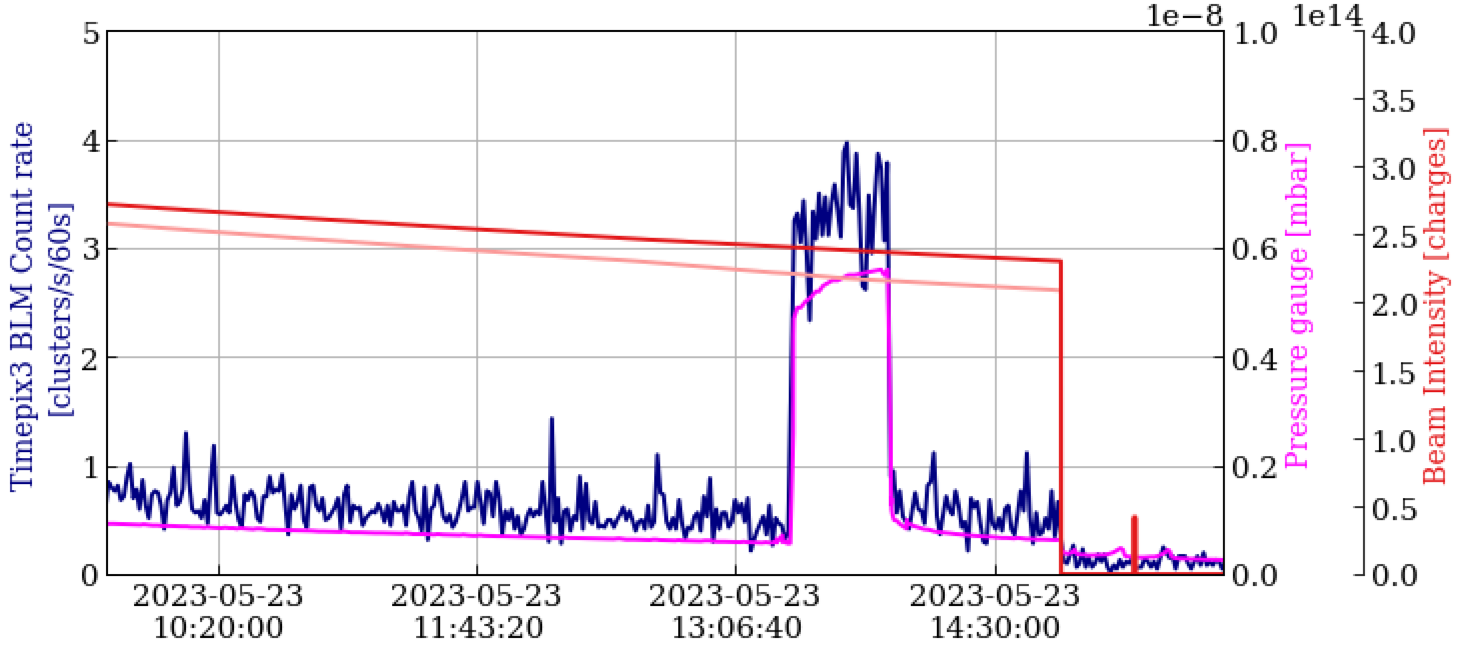
Timepix3 measured radiation levels from BGC operation in 2023

- Main interest: radiation levels induced by the BGC (to define operational constraints, if any).
- Secondary interest: radiation levels from accelerator operation (background, unavoidable).

- only 4 gas injection in the BGC in 2023:
  - 2 during STABLE BEAMS
  - 2 during RAMP UP

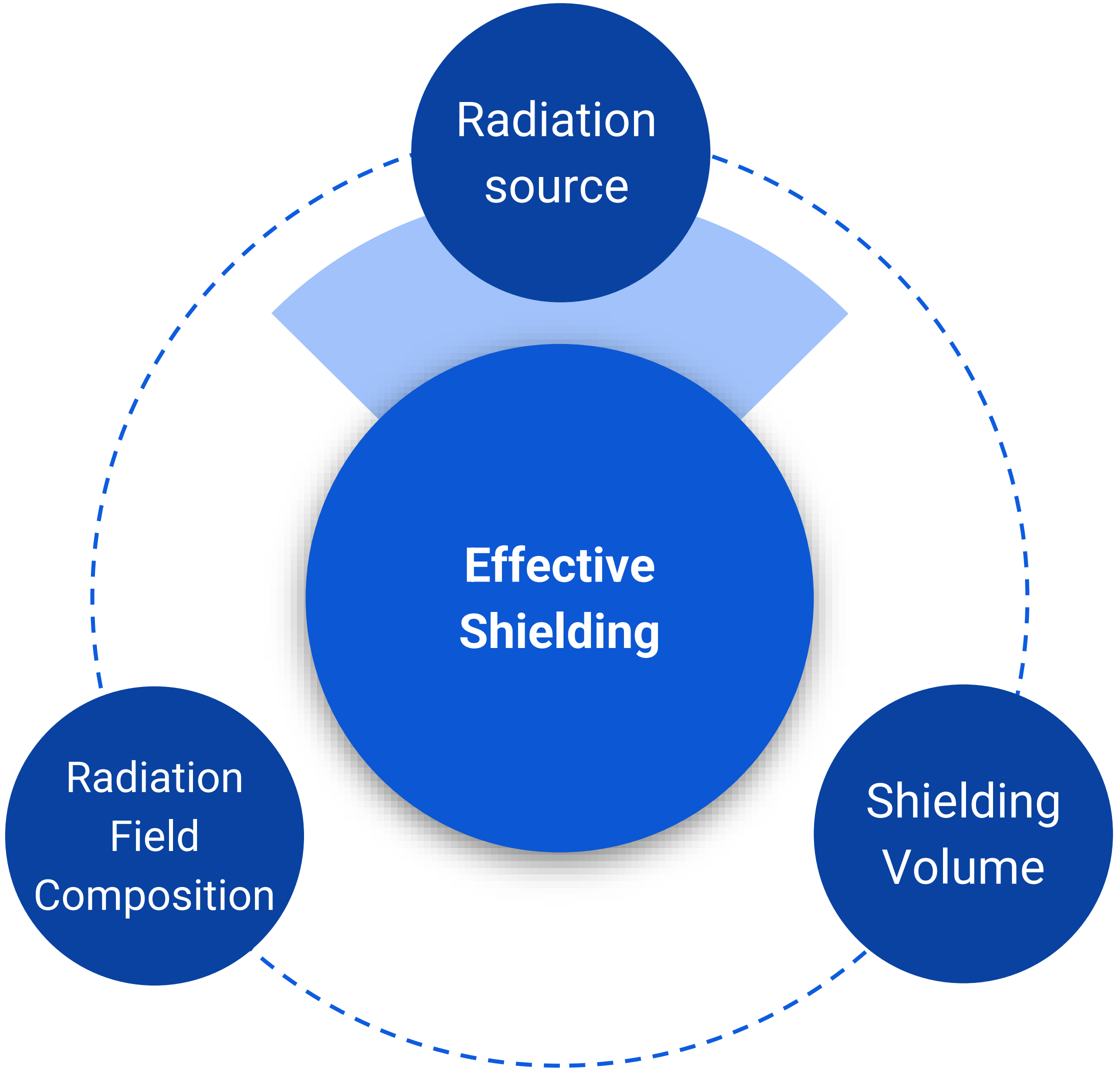
- Signal to background Ratio: ~**8**

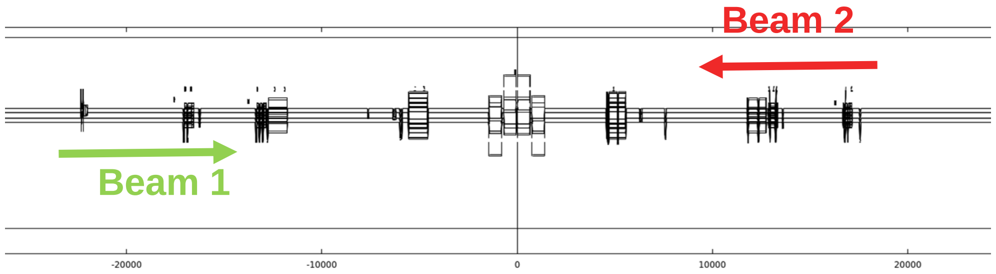
- **ToDo:**
  Study the cluster parameters to differentiate amongst the mixed radiation field.



BGC shielding strategy

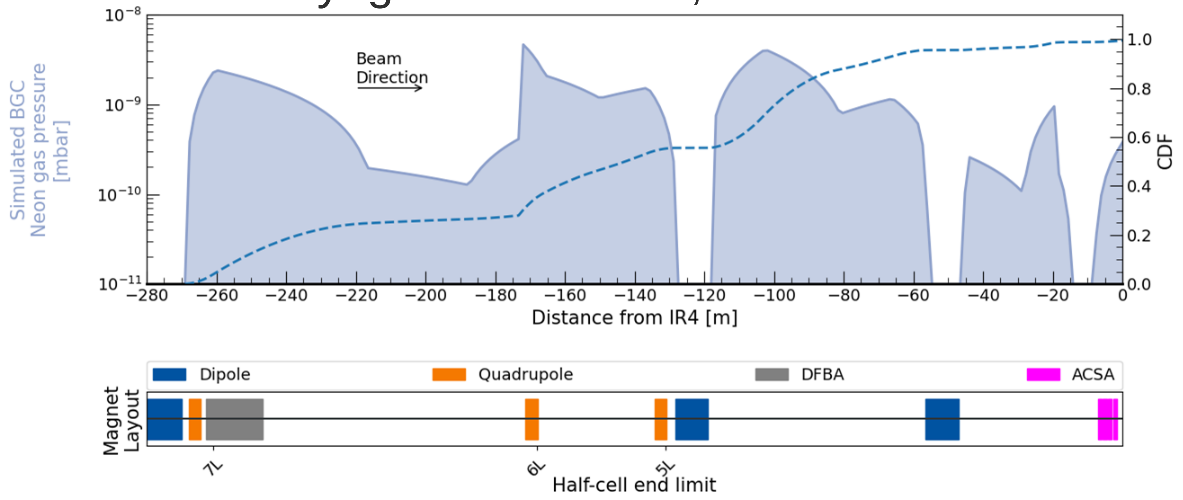
Current progress



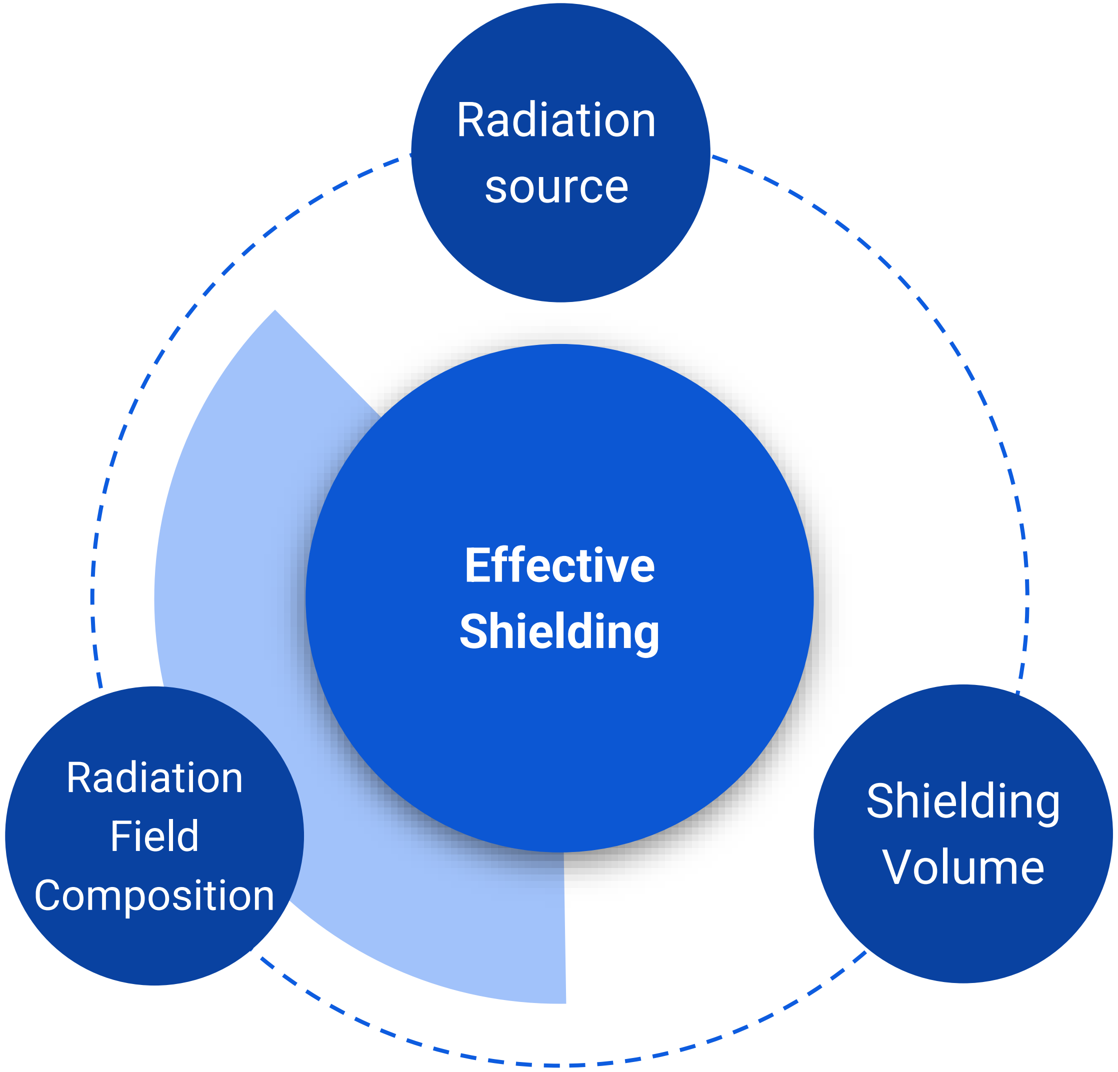


Beam-residual gas interactions from both beam 1 **and** beam 2

Average of the pressure measured by gauges in 2022, zeroed at cryogenic elements, for the inner beam.

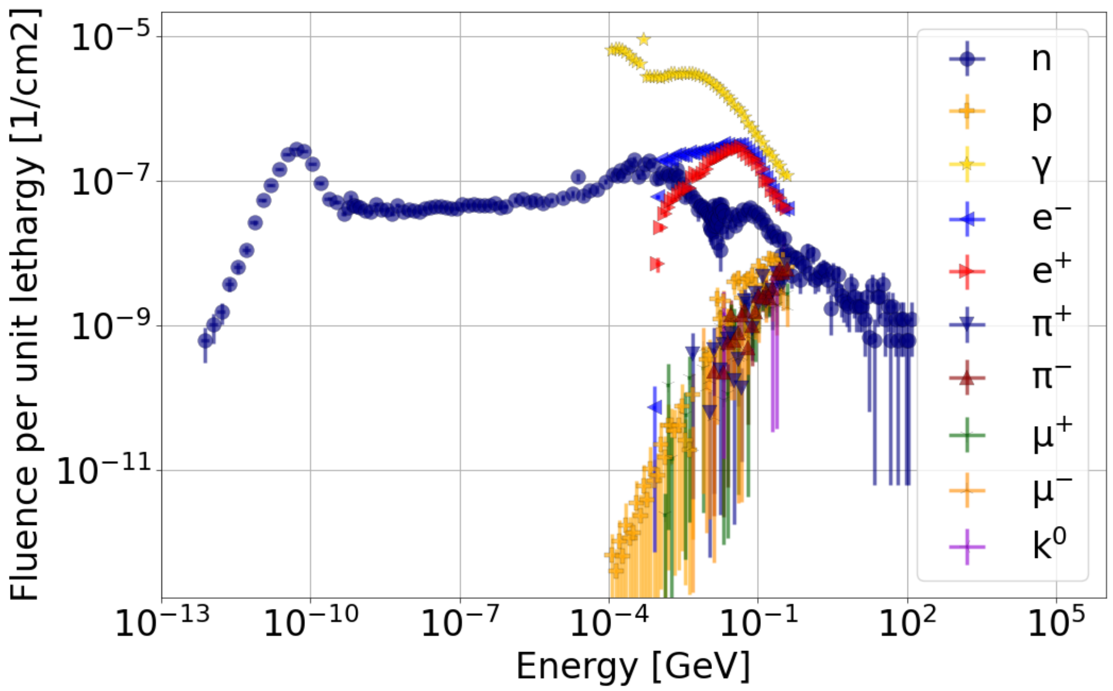


Current progress

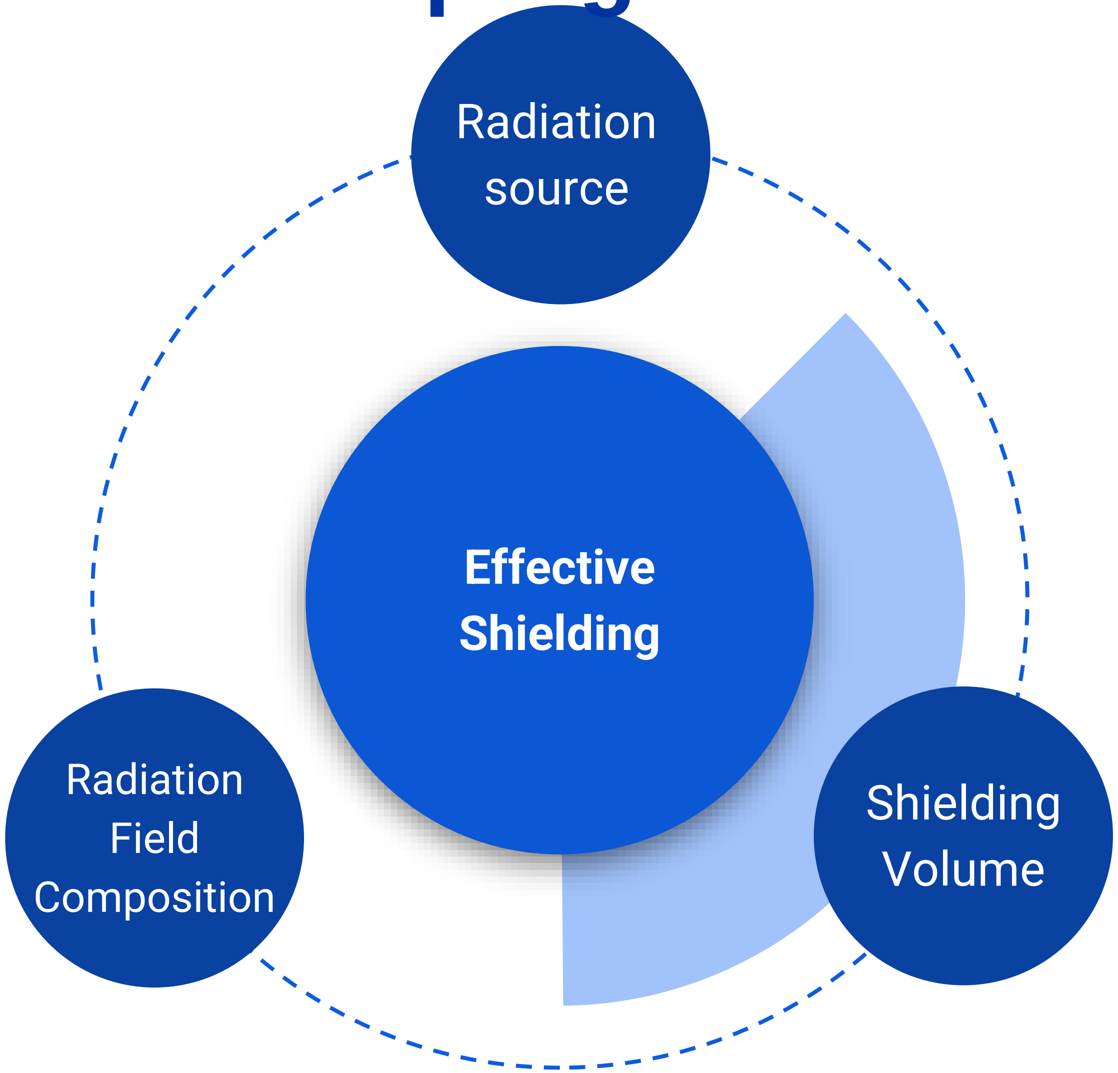


FLUKA simulation using the previous gas profile just on beam 1

Provided only as **qualitative** (!) interpretation, since it is difficult to assess the absolute normalization



Current progress

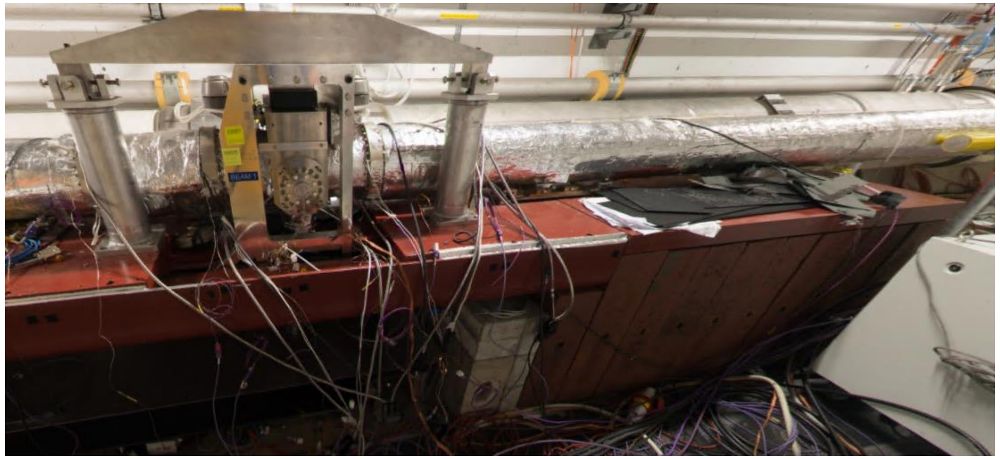


Example:
BSRT shieldings and BatMon measurement campaign

To be presented today (!) at the 57th meeting of the Monitoring and Calculation Working Group (MCWG), by Alessandro Zimmaro
https://indico.cern.ch/event/1350736/

Report:
https://edms.cern.ch/ui/#!master/navigator/document?P:100261258:101362236:subDocs

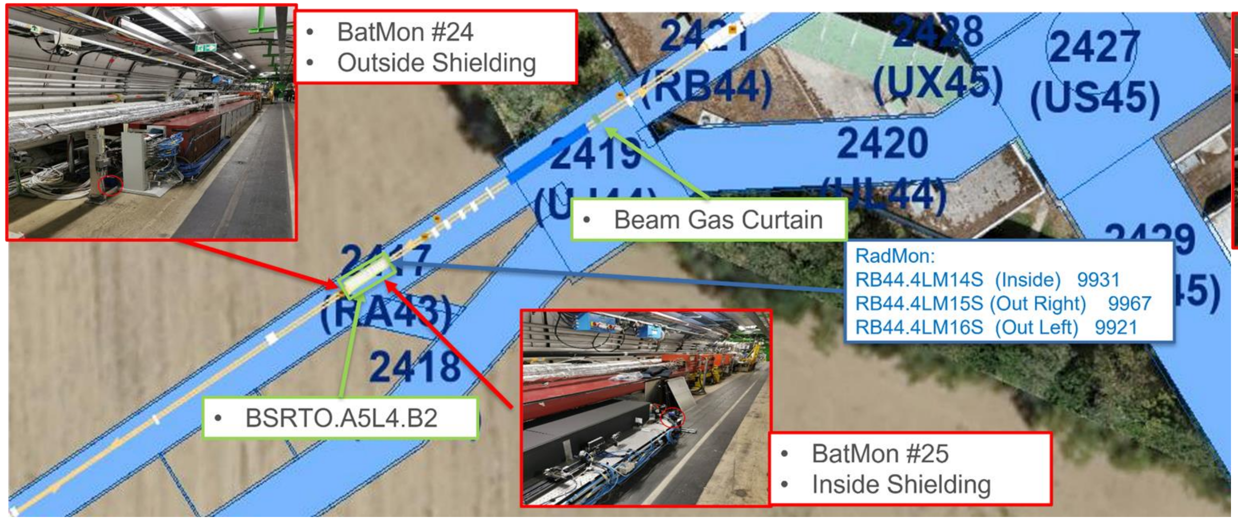
BSRT electronics and shielding

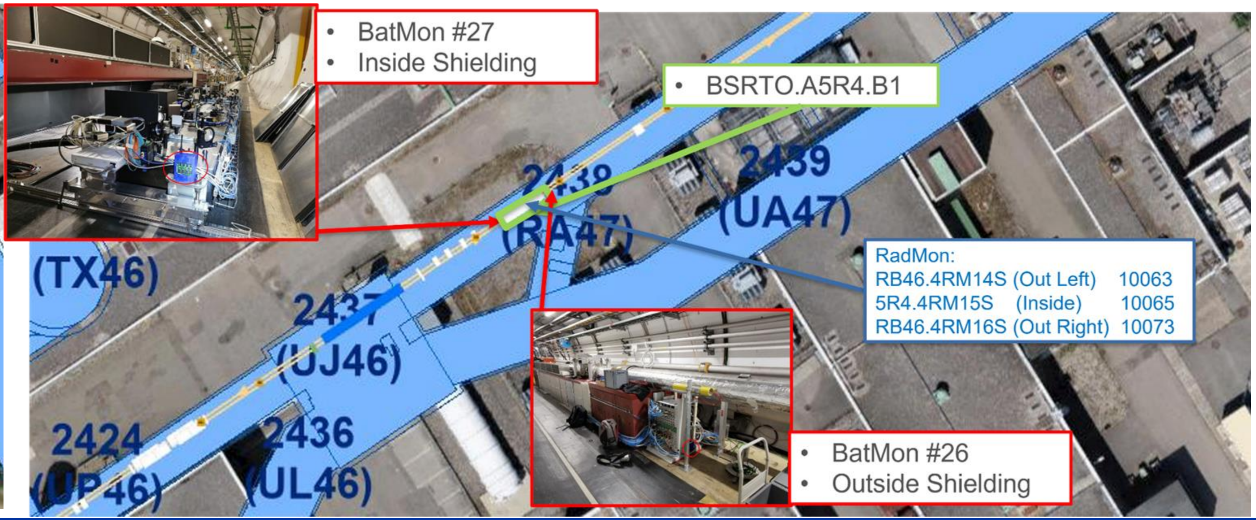


BSRT electronics are hosted in IR4 of LHC are shielded in a drawer like enclosure:

- 1.8 m of CAST IRON
- 0.5 m of CONCRETE

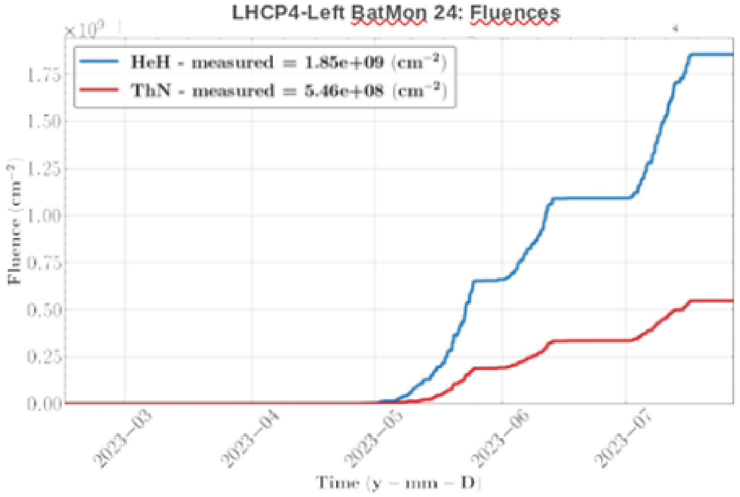
To evaluate the effectiveness of this shielding and quantify the R2E effects withstood by the equipments four Batttery Powered Radiation Monitors (BatMon) have been deployed on the each side of IR4: 2 in LHC P4 Left (DCUM = 9923.7002) and other 2 in HC P4 Right (DCUM = 10068.0622)



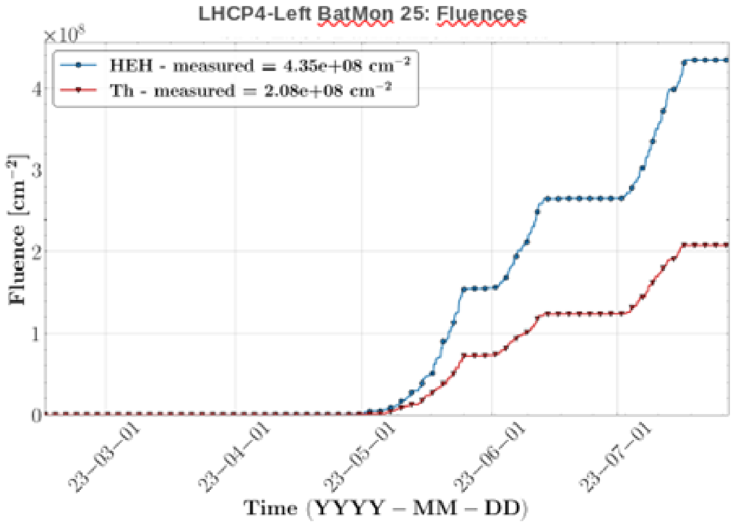


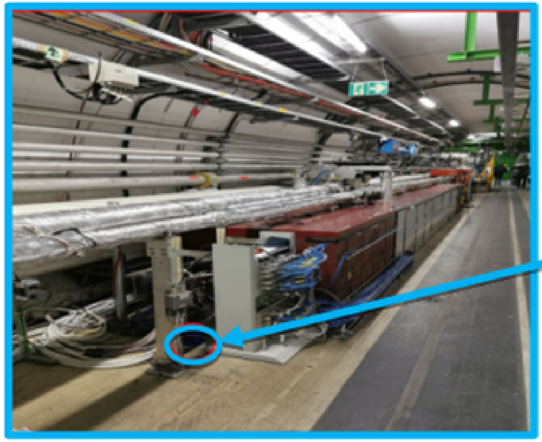
LHC P4 Left: Fluence Measurements

Wireless IoT Monitoring #25 Inside			
Reading Period	***φ_{HEH} [pp/cm²]***	***φ_{Th} [pp/cm²]***	***R Factor***
2023-02-14 to 2023-07-27	4.35×10^{8}	2.08×10^{8}	0.47



Outside/Inside		
TID	***φ_{HEH}***	***φ_{Th}***
26.44	4.25	2.63

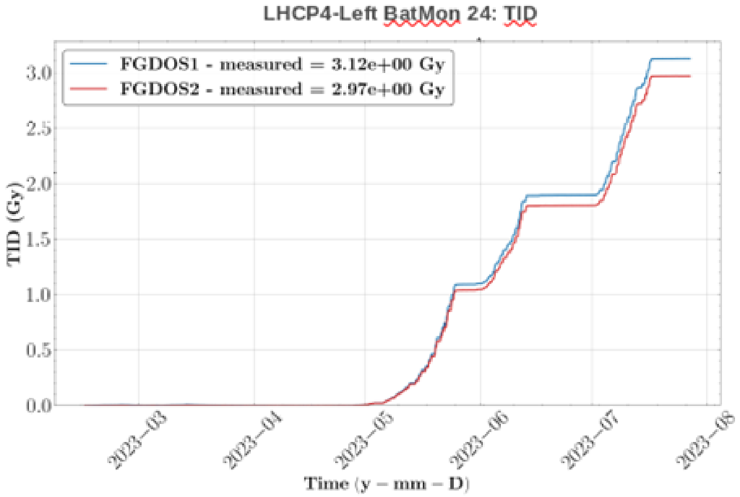


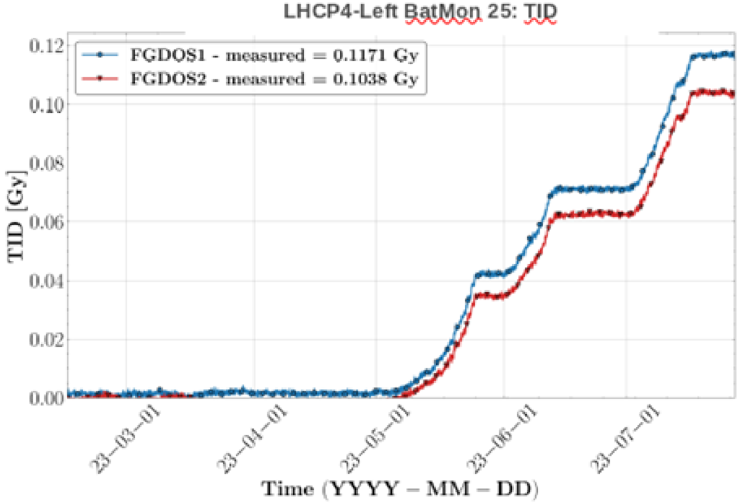


Wireless IoT Monitoring #24 Outside			
Reading Period	***φ_{HEH} [pp/cm²]***	***φ_{ThN} [pp/cm²]***	***R Factor***
2023-02-14 to 2023-07-27	1.85×10^{9}	5.46×10^{8}	0.29

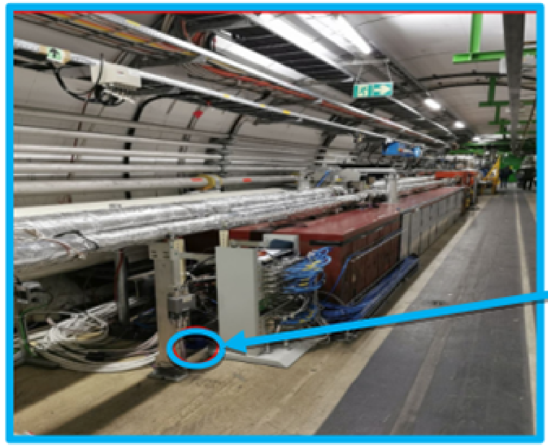
LHC P4 Left: TID Measurements

Wireless IoT Monitoring #25 Inside	
Reading Period	***TID [Gy]***
2023-02-14 to 2023-07-27	*0.118*





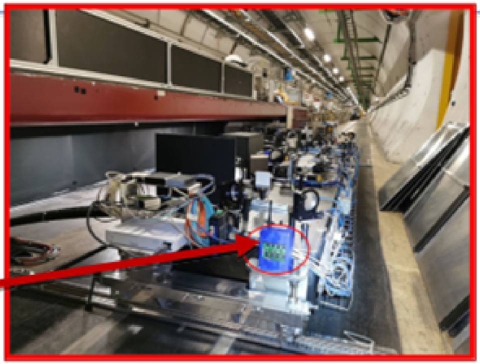
Outside/Inside		
TID	φ_{HEH}	φ_{Th}
26.44	4.25	2.63

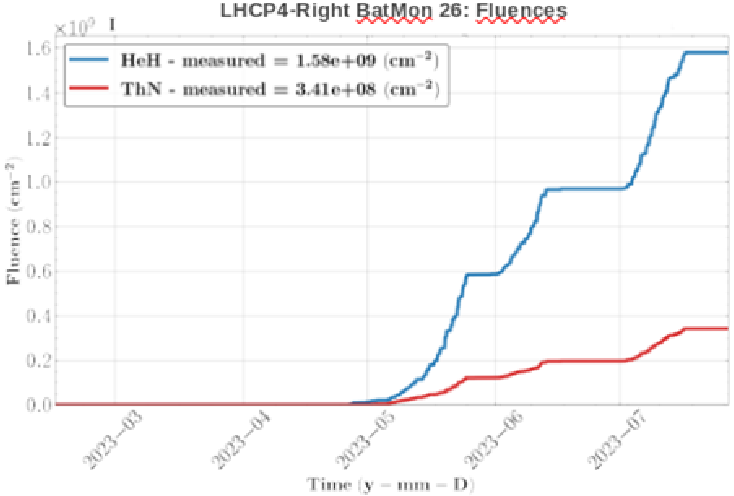


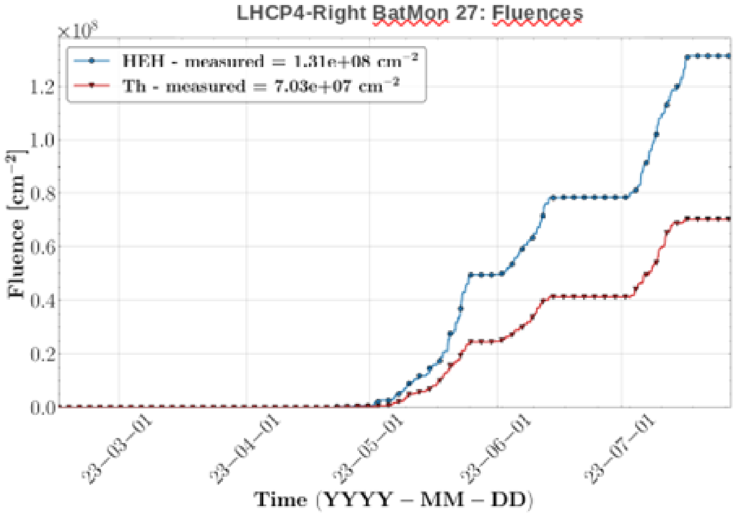
Wireless IoT Monitoring #24 Outside	
Reading Period	***TID [Gy]***
2023-02-14 to 2023-07-27	*3.12*

LHC P4 Right: Fluence Measurements

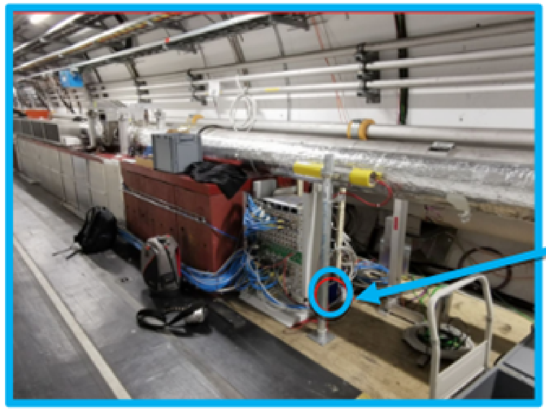
Wireless IoT Monitoring #27 Inside			
Reading Period	***φ_{HEH} [pp/cm²]***	***φ_{Th} [pp/cm²]***	***R Factor***
2023-02-14 to 2023-07-27	*1.31×10^{8}*	*7.03×10^{7}*	0.54







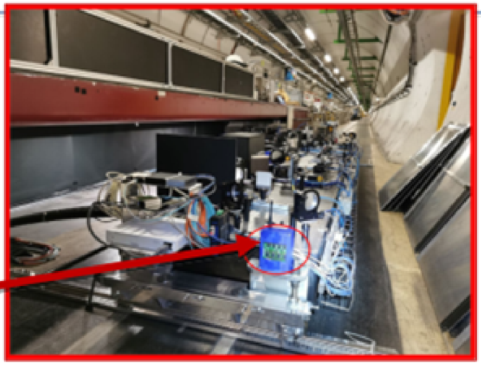
Outside/Inside		
TID	***φ_{HEH}***	***φ_{Th}***
25.65	12.06	4.85



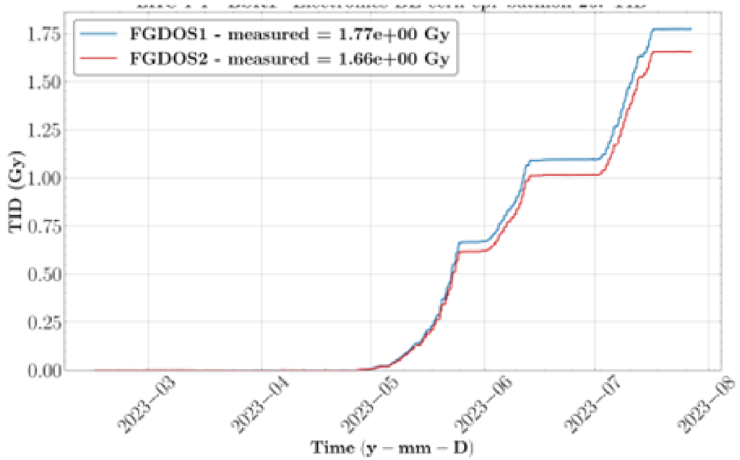
Wireless IoT Monitoring #26 Outside			
Reading Period	***φ_{HEH} [pp/cm²]***	***φ_{ThN} [pp/cm²]***	***R Factor***
2023-02-14 to 2023-07-27	*1.58×10^{9}*	*3.41×10^{8}*	0.21

LHC P4 Right: TID Measurements

Wireless IoT Monitoring #27 Inside	
Reading Period	*TID [Gy]*
2023-02-14 to 2023-07-27	0.068

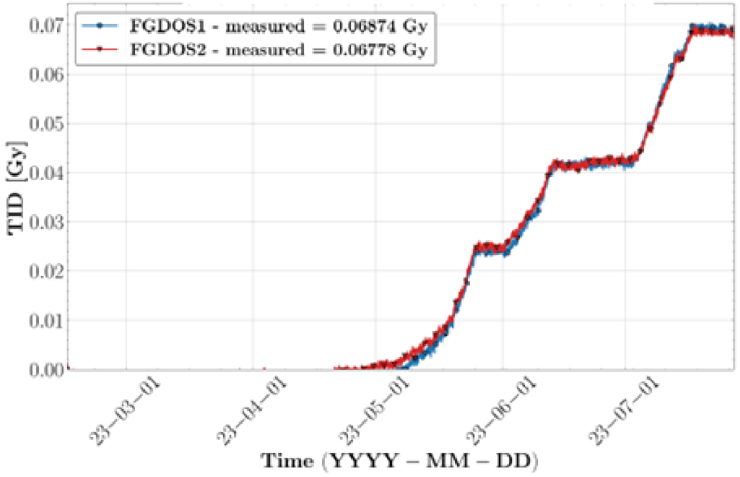


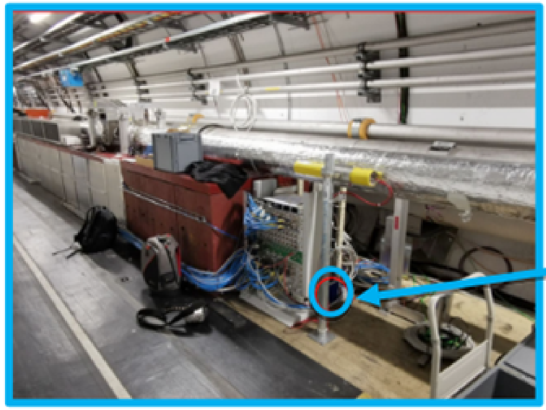
LHCP4-Right BatMon 26: TID



Outside/Inside		
TID	φ_{HEH}	φ_{Th}
25.65	12.06	4.85

LHCP4-Right BatMon 27: TID

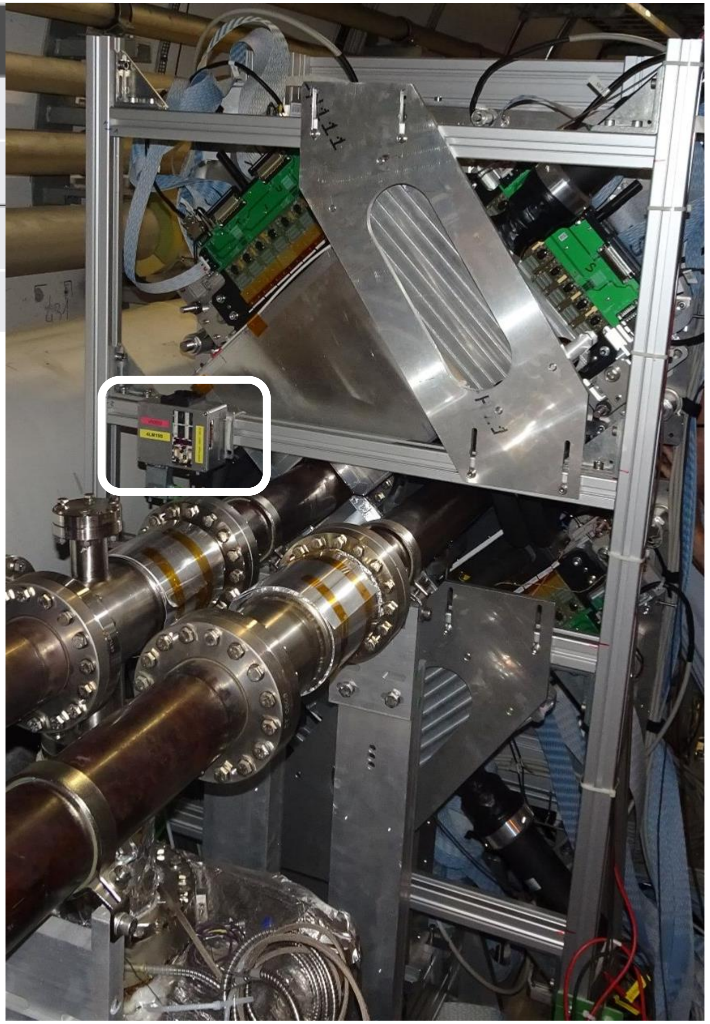




Wireless IoT Monitoring #26 Outside	
Reading Period	*TID [Gy]*
2023-02-14 to 2023-07-27	1.77

Measurement campaign overview

Position	Reading Period	TID [Gy]	φ_{HEH} [pp/cm^2]	φ_{Th} [pp/cm^2]
P4R: Outside Shield.	2023-02-14 to 2023-07-27	1.77	$1.58x10^9$	$3.41x10^8$
P4R: Inside Shield.		0.068	$1.31x10^8$	$7.03x10^7$
P4L: Outside Shield.	2023-02-14 To 2023-07-27	3.12	$1.85x10^9$	$5.46x10^8$
P4L: Inside Shield.		0.118	$4.35x10^8$	$2.08x10^8$



A similar deployment can be envisaged also for the BGC, via a request: https://cern.service-now.com/service-portal?id=functional_element&name=mcwg-working-group

Moreover, a RadMon was installed in Run 2 downstream of the BGV to measure its radiation levels.

Proposal(s)

01	Request a BatMon measurement campaign	• at the level of the BGC camera, • but also downstream of its gas target and as close to the beam pipe as possible.
02	Proceed with evaluating the radiation field composition	• requires first a solid, benchmarked simulation (if to be trusted), • difficult to normalize to absolute values, since the gas density distribution is not uniform/constant.
03	Assess the effectiveness of different shielding configurations	• using just the estimated radiation field (to speed up the iteration process), • implementing the shielding in the full LHC geometry

Conclusions

Radiation Monitoring 1: Standard Monitors	Radiation Monitoring 2: Timepix3 Detector	BGC shielding strategies
Reliable correlation between BGC gas injection and measured radiation levels on the BLMs. Simulation geometry to be updated and improved upon until a satisfactory agreement is achieved.	Work to be done to further disentangle the measured mixed radiation field.	Possibility to request a measurement campaign. Simulation can only provide a qualitative picture at this stage. Existing massive shielding in IP4 at BSRT location provides a reduction in HEHeq of a factor between 4 and 12.

dprelipcean.github.io/
personal-website/

Thank you for your attention!

Questions?

daniel.prelipcean@cern.ch

CERN SY STI R2E MCWG FLUKA TUM

home.cern

Backup slides

IR4 Layout

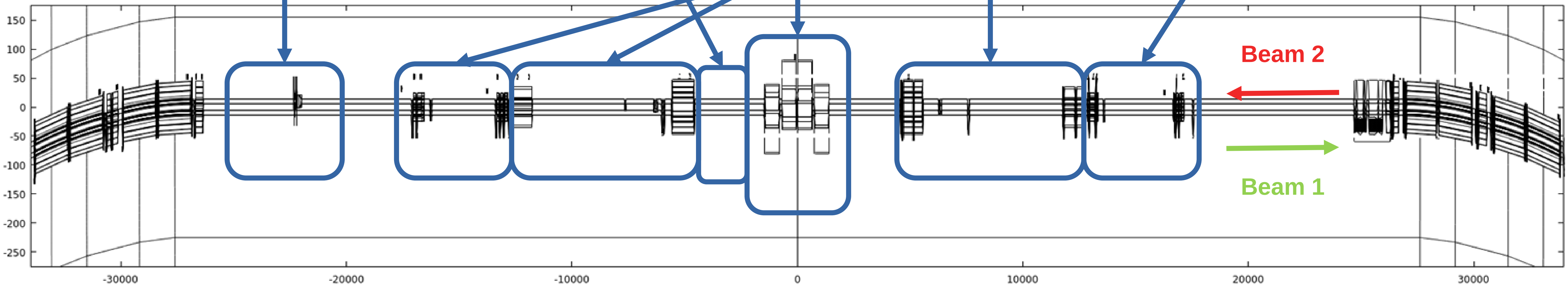
Radio Frequency cavities

Beam Gas Vertex (BGV) monitor at -220 m on **beam 2**

Beam Gas Curtain (BGC) monitor at -50 m on **beam 1**

Two **bending dipoles** to increase beam separation from 9.7 to 20 cm

Two **quadrupoles** for (de)focusing



Goals

- **Main goal is to determine whether the operation of these devices can lead to operational issues, either:**
  - instantaneous:
    - excessive heat loads on cryogenics systems,
    - stochastic failures in electronics (e.g. leading to downtime),
  - cummulated:
    - life time degradation of components (e.g. magnets) and/or electronics.

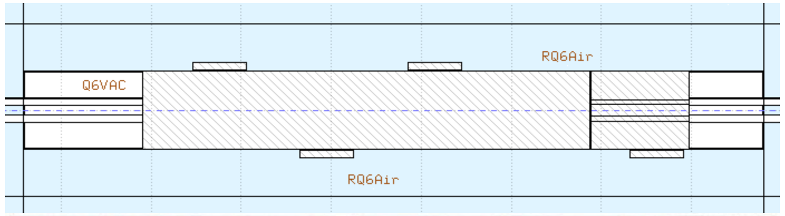
- **Some previous/similar work:**
  - Simulation: mainly concerning the Beam Gas Ionisation (BGI) monitor [1, 2] - in 2016.
  - Cumulated radiation level measurements per year in Run 2 (2015-2018) [3] and Run 3 [4].

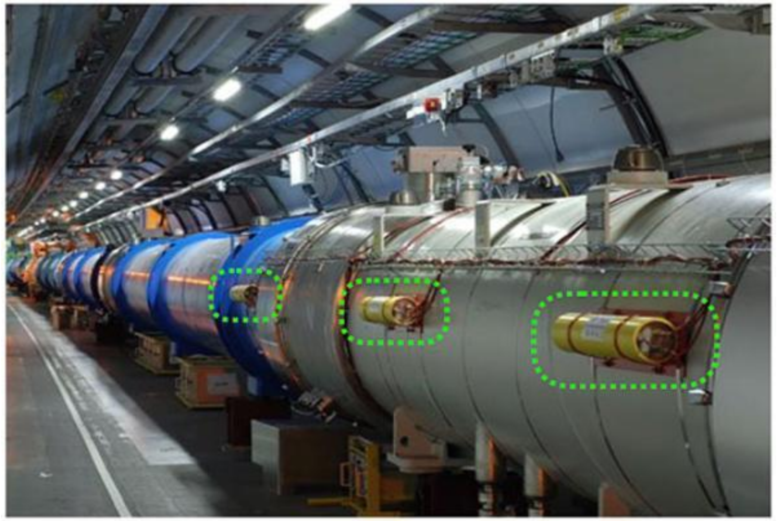
1. Christian Buhl Soerensen, Measuring abort gap population with beam-gas interactions in the BGI: https://indico.cern.ch/event/1097265/contributions/4617018/attachments/2353783/4016099/Abort%20gap%20monitoring%20with%20the%20BGI.pdf
2. Oliver Stein in MD456: Monitoring of abort gap population with diamond particle detectors at the BGI in IP4: https://cds.cern.ch/record/2131864/files/CERN-ACC-2016-0011.pdf
3. Kacper Bilko, in the 41st MCWG meeting: Radiation levels in IR4 and impact of BE-BI instrumentation https://indico.cern.ch/event/916577/
4. Kacper BIlko, in the 53rd MCWG meeting: Update on recent radiation level measurements in the LHC ring https://indico.cern.ch/event/1210212/

Available radiation level data measurements

- **Radiation level data consists of:**
  - Beam Loss Monitor (**BLM**) - Total Ionizing Dose (**TID**) rate
    - Radiation detectors (mostly Ionization Chambers), that detect particle showers caused by the beam losses.
    - Capable of measuring dose rates with good time resolution.
    - Approximately 4 000 detectors placed along the accelerator.

- **The measured data is taken using NXCALS (New CERN Accelerators Logging Service):**
  - BLM TID rate
  - Beam intensity: LHC.BCTDC.A6R4.B1:BEAM_INTENSITY
  - Pressure gauge measurement: VGP.5L4.G.PR





Courtesy BE-BI [5]

Radiation source: Gas species (Neon)

- **Beam gas interactions:**
  - Elastic: Not considered in this work.
    If one or more protons in the bunch are deviated from the ideal trajectory, then they are lost somewhere along the path of the accelerator, ideally in the collimators of IR7.
  - **Inelastic: The main source considered in this work:**
    $\sigma_{inel\ pNe}$=382 mb (FLUKA estimate for a 6.5 TeV proton on a Neon at rest).
    A shower of secondary particles is generated around the interaction vertex leading to local losses.
- **The Monte Carlo code FLUKA is used to simulate the radiation levels in the vicinity and downstream of the beam gas monitors by forcing a nuclear interaction of the beam protons with the gas elements (in our case, Neon).**
- **The inelastic scattering is the main contributor (~2/3) to the total cross section.**

Radiation source: Beam energy and intensity

- The radiation level rate caused by beam-gas interaction depends on the total number of charges passing through the gas.
- Measured by BCT instruments, in charges, for both beams.

- During LHC Run 2 (3), the top energy was 6.5 (6.8) TeV, but during HL-LHC it will further increase to 7 TeV.
- Moreover, there is interest in using one of the instruments (BGV) during energy ramp from 450 GeV (injection) to top energy.

	LHC		HL-LHC
	Run 2	**Run 3**	
revolution frequency [Hz]	11245		
number of bunches	2500	2500	2760
protons per bunch [1e11]	1.20	1.20	2.30
total_charges [1e14]	**3.00**	**3.00**	**6.35**
charge/s [1e18]	3.37	3.37	7.14
energy [TeV]	**6.50**	**6.80**	**7.00**

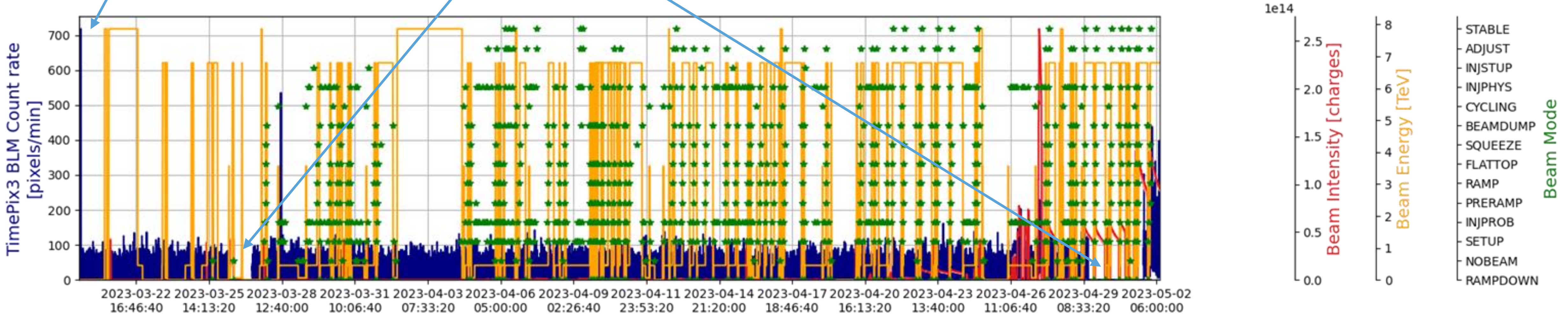
- The inelastic cross section increases with energy, with 8% (0.5%) from 450 GeV (6.5 TeV) to 7 TeV, implying more inelastic collisions.
- With higher beam energies, the secondary showers will be larger, leading to higher radiation levels.

Pixel hit rate over time

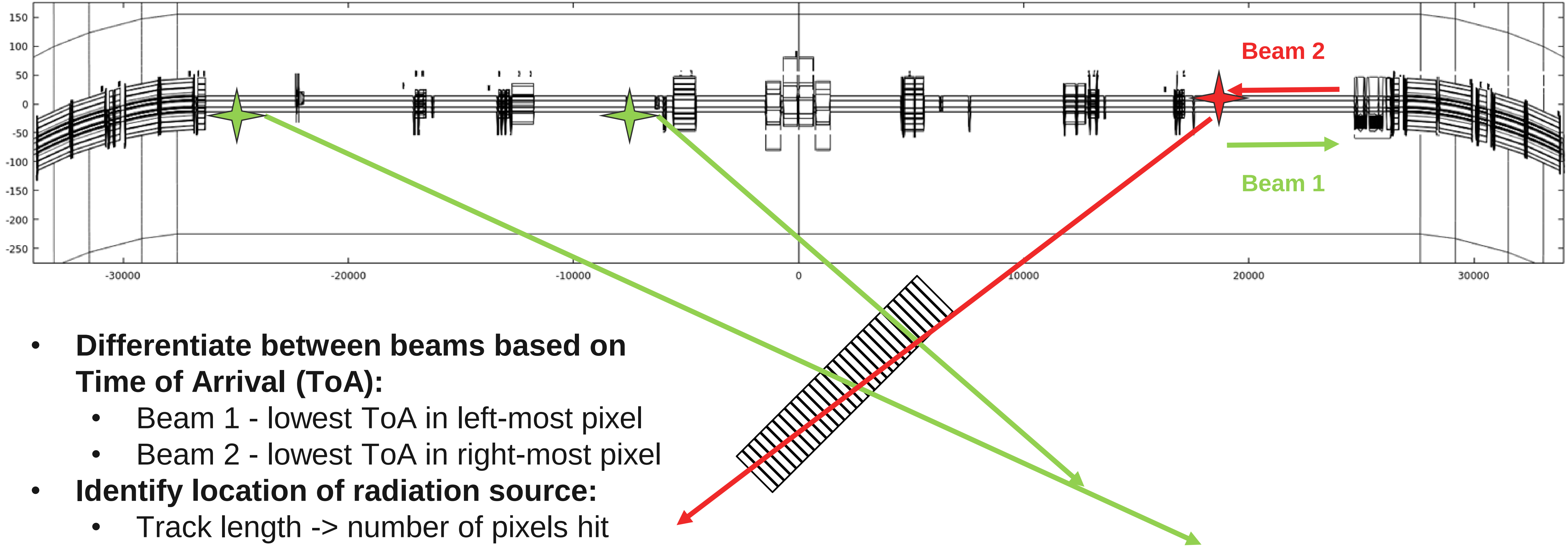
Levels roughly constant at ~30 pixel hits/min
(Compared to ~45 in the R2E lab at surface)

Spike at start of acquisition
(setup configuration)

Loss of 3 days of data due to corruption
(had to restart the setup)



Timepix BLM as radiation source locator



- **Differentiate between beams based on Time of Arrival (ToA):**
  - Beam 1 - lowest ToA in left-most pixel
  - Beam 2 - lowest ToA in right-most pixel
- **Identify location of radiation source:**
  - Track length -> number of pixels hit
- **Rotation at 45 deg optimized for BGC signal, compromise between:**
  - Acceptance: decreases with cos
  - Track length: increases 1/cos

Measurements