Radiation monitoring & analysis: Overview of 2021 prompt radiation levels in the injector chain

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On behalf of the MCWG team

Special thanks to groups responsible for the radiation monitors
(SY/BI-BL, EN/EL-FC, BE-CEM)

R2E annual meeting – 1st March 2022
https://indico.cern.ch/event/1116677/

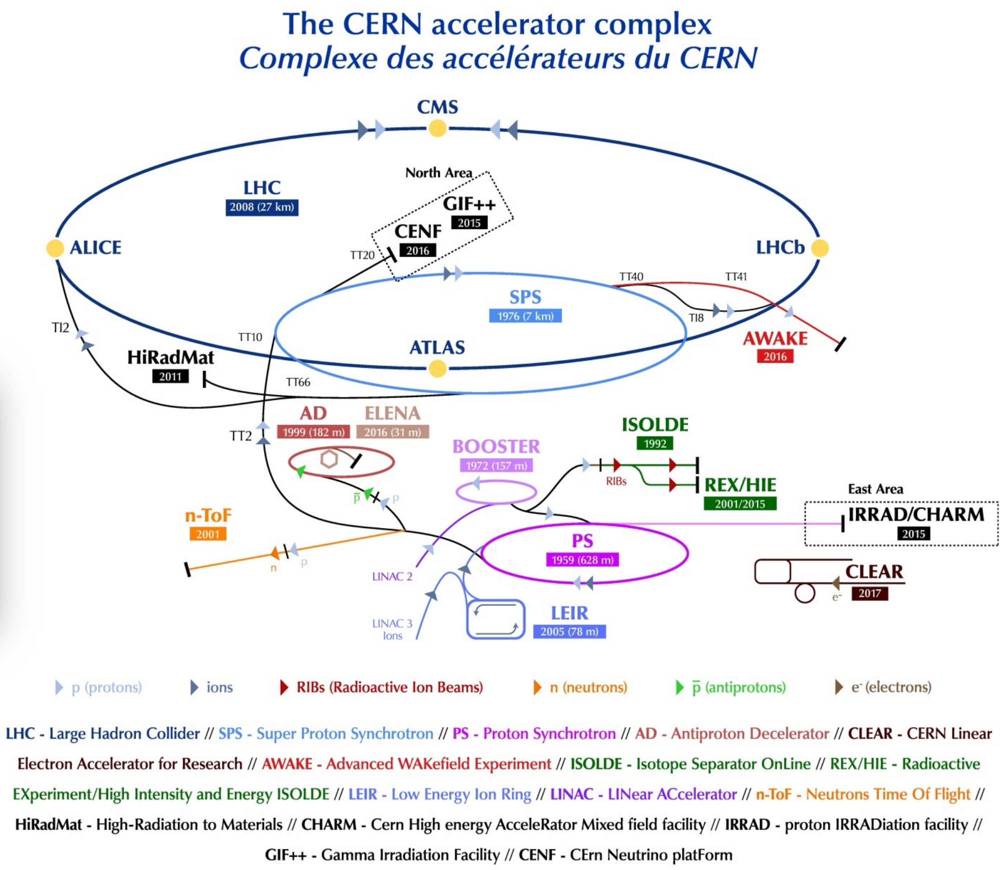
Outline

- Introduction:
  - R2E and the related radiation monitoring & analysis activity,
  - Quantities for characterizing the radiation used by R2E ,
  - Overview of the radiation detectors used by R2E,
  - Automated analysis workflow,
  - Radiation Levels Dashboard,
- Highlights from the 2021 injector radiation levels as the example of the radiation monitoring activity within R2E,
- Recent (2022) radiation levels as measured in PSB and PS,
- Conclusions.

Introduction: Radiation to Electronics project

Continuous losses during accelerator operation create **mixed radiation fields** in the tunnels and adjacent caverns.

Radiation can negatively impact the lifetime and **the functionality** of the accelerator components, including electronics. This might lead, in the worst case, to the downtime of an accelerator.



Introduction: Radiation to Electronics project

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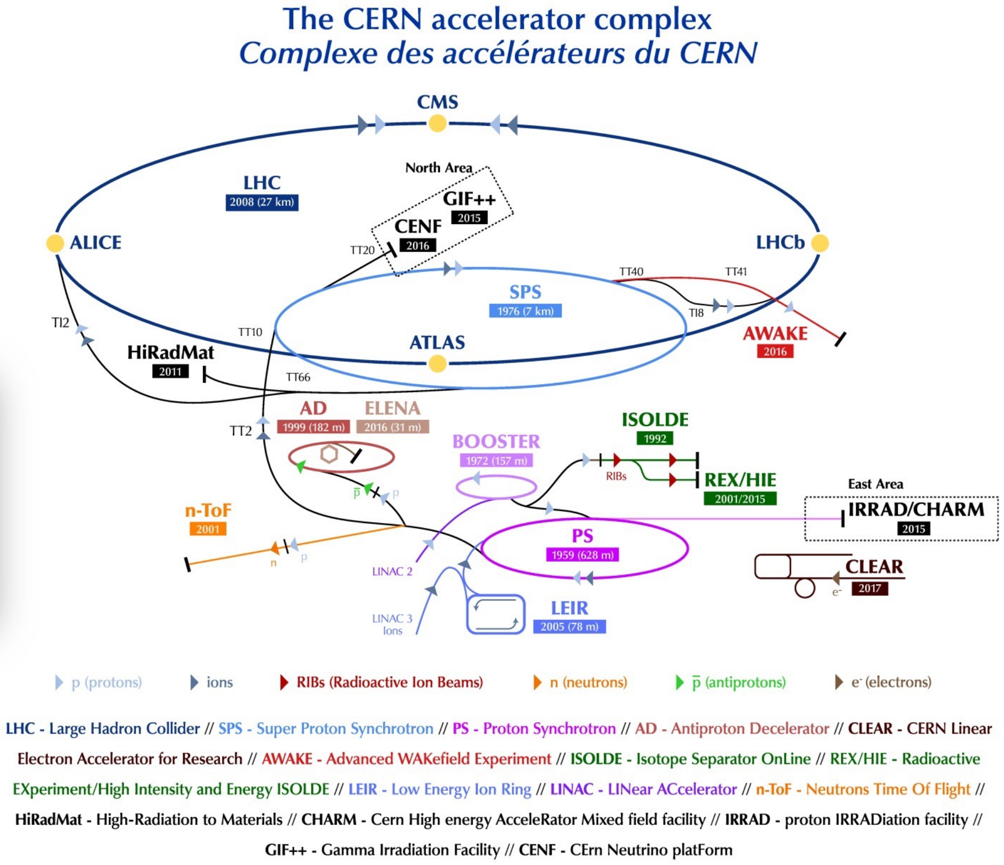
Radiation can negatively impact the lifetime and the functionality of the accelerator components, including electronics. This might lead, in the worst case, to the downtime of an accelerator.

For R2E –safe operation:

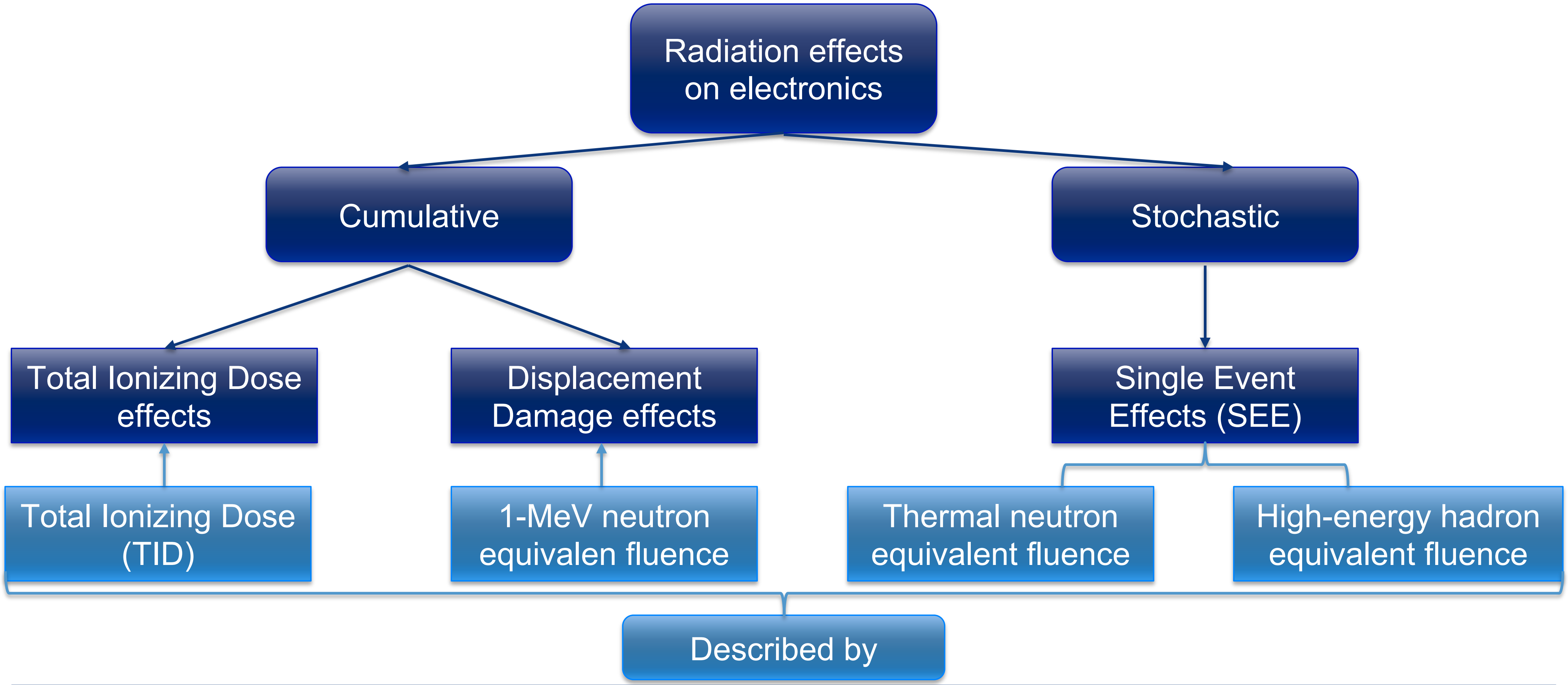
→ Qualified radiation tolerant systems (RadWG),

→ **Analyses of the prompt radiation levels:**

→ Covered by MCWG,



Introduction: Radiation environment description



Introduction: Radiation Levels at CERN

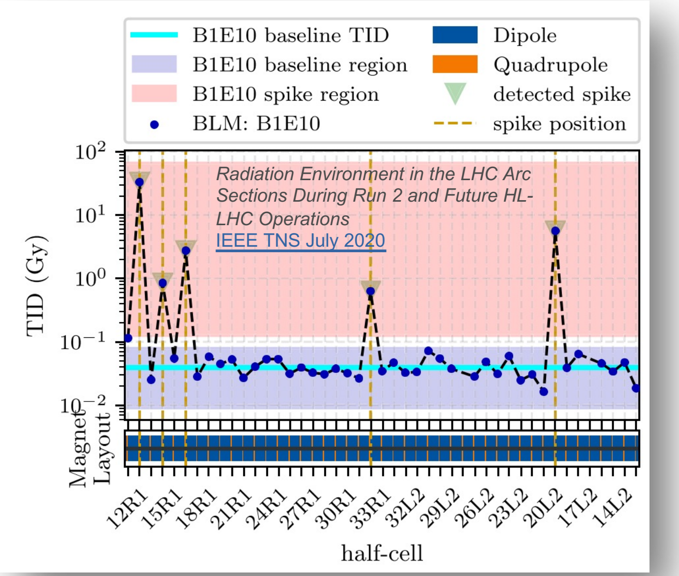
Annual Radiation Levels

~tens of mGy (~10^7 HEH/cm^2)
SEEs

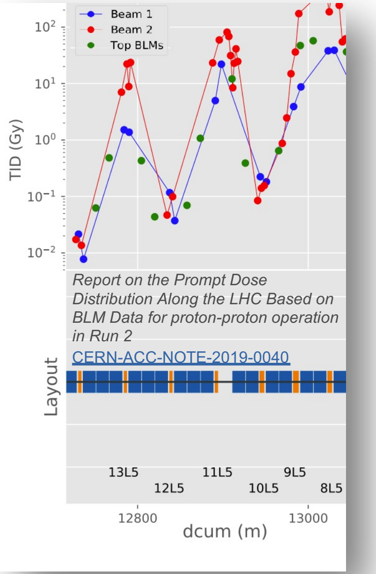
~ tens of Gy
+Cumulative effects (TID,DDs)

~MGy
+Material damages

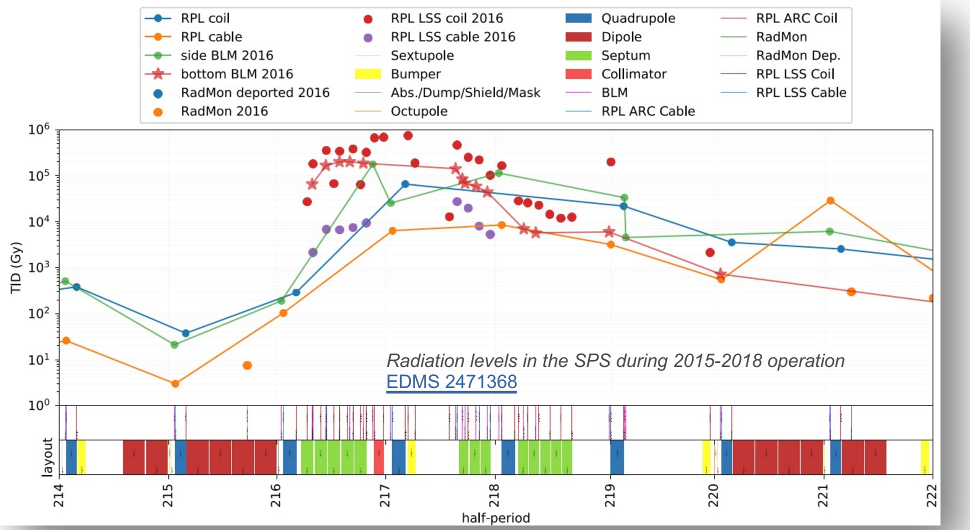
LHC ARCs



LHC DSs

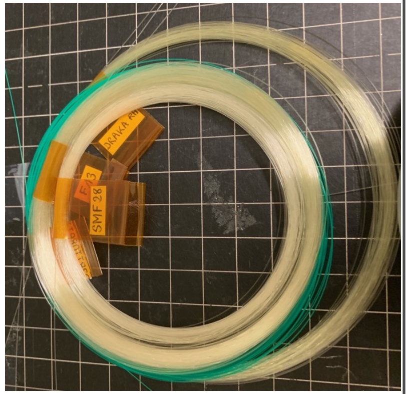


SPS LSS2 – North Area extraction

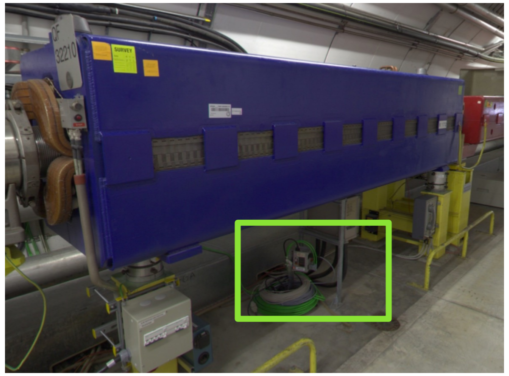


Introduction: Overview of the radiation detectors used by R2E

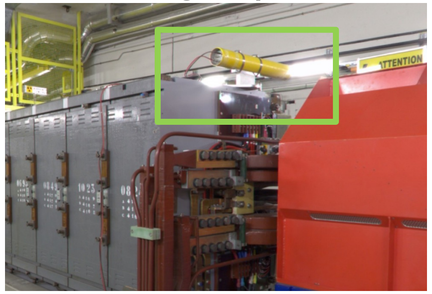
Optical Fiber Dosimeters:
- Developed, deployed and operated within R2E by EN-EL-FO,
- TID profile along cable trays in the injectors,
- Our use: detailed (1 m resolution) **information about radiation profile along the injectors**,
- See Diego's talk,



RadMONs:
- Dedicated R2E monitors (operated by BE-CEM-EPR),
- Measure 4 main R2E quantities,
- Our use: **characterization and monitoring of radiation fields** (mainly in the vicinity of the electronic equipment),
- See Salvatore's talk,



Beam Loss Monitors (Ionization Chamber type):
- Main use: Machine Protection (interlocking),
- Our use: **analysis of TID,**



High Level Dosimetry:
- Radio-Photo-Luminescence dosimeters (RPL),
- Passive measurements,
- Our use: **deployed on demand in high radiation locations**, where other monitors not suitable,
- See Ygor's talk,

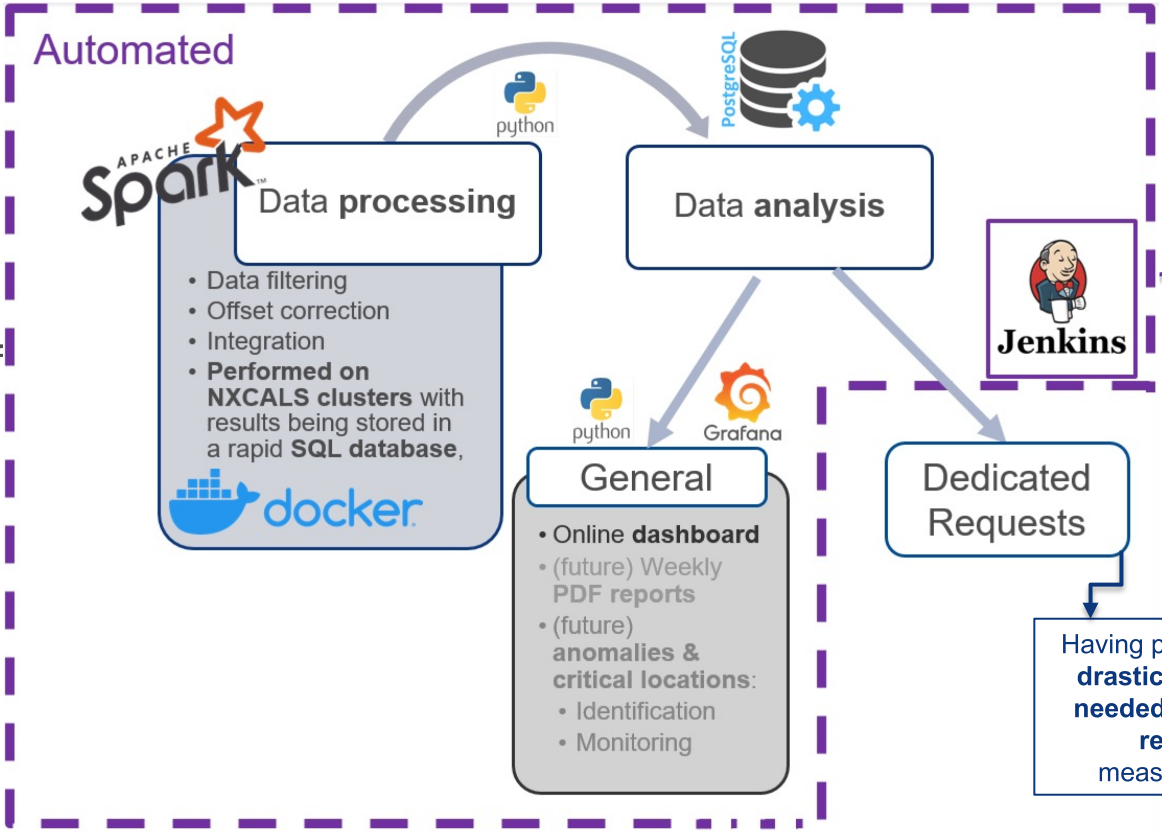
Introduction: Overview of the radiation detectors used by R2E

- **Each type of the monitors has its own advantages** (e.g. vicinity of the equipment, time or spatial resolution),
- Different detector types result in different challenges:
  - Data volume,
  - Time resolution,
  - Spatial resolution,
- Goal: provide complementary view on the radiation levels based on **all available radiation detectors**,

	Optical Fibre Sensing	Beam Loss Monitors (standard Ion. Chamber)	RadMONs	High Level Dosimetry
PSB	Continuous 1D profile along the cable tray	34	8 units	on request
PS	Continuous 1D profile along the cable tray	100 units	16 units	on request
SPS	Continuous 1D profile along the cable tray	~270 (non-LIU type) units	~60 units	on request
LHC	DS regions (IP 1/5/7)	~3600 units	~400 units	on requrest
Measured quantities	TID	TID	TID; HEH-eq-, 1-MeV-eq-, Th-n-eq-fluences	TID
Detection range	1 Gy – 2 kGy	very good, depends on the monitor	1 Gy - 200 Gy (10 kGy)	0.1 Gy - 5 MGy
Time resolution	~days (depends on the accelerator)	1 ms (PS/PSB), ~cycle (SPS)	~hour	passive measurement
Main advantage	Continuous 1D profile → high spatial resolution (1 m)	high time resolution (cycle)	Measures main R2E-relevant quantities	High dynamic range of measurements

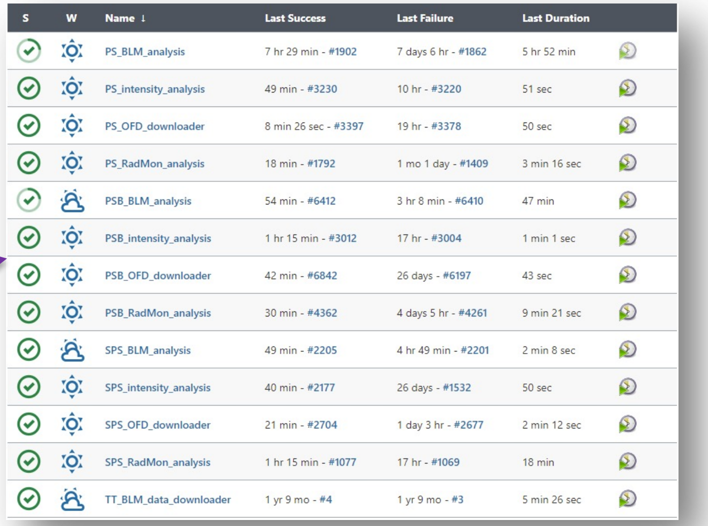
Introduction: Analysis workflow

- **Processing more than 100 GB per day** → feasible thanks to NXCALS,
- Dedicated user **requests are handled much faster** as the time-consuming part of the analysis is automated,
- Results stored in the rapid SQL database → **online monitoring** possible → Grafana dashboard,



Having processed data "ready" **drastically decreased time needed for addressing any request** involving measurements (MCWG)

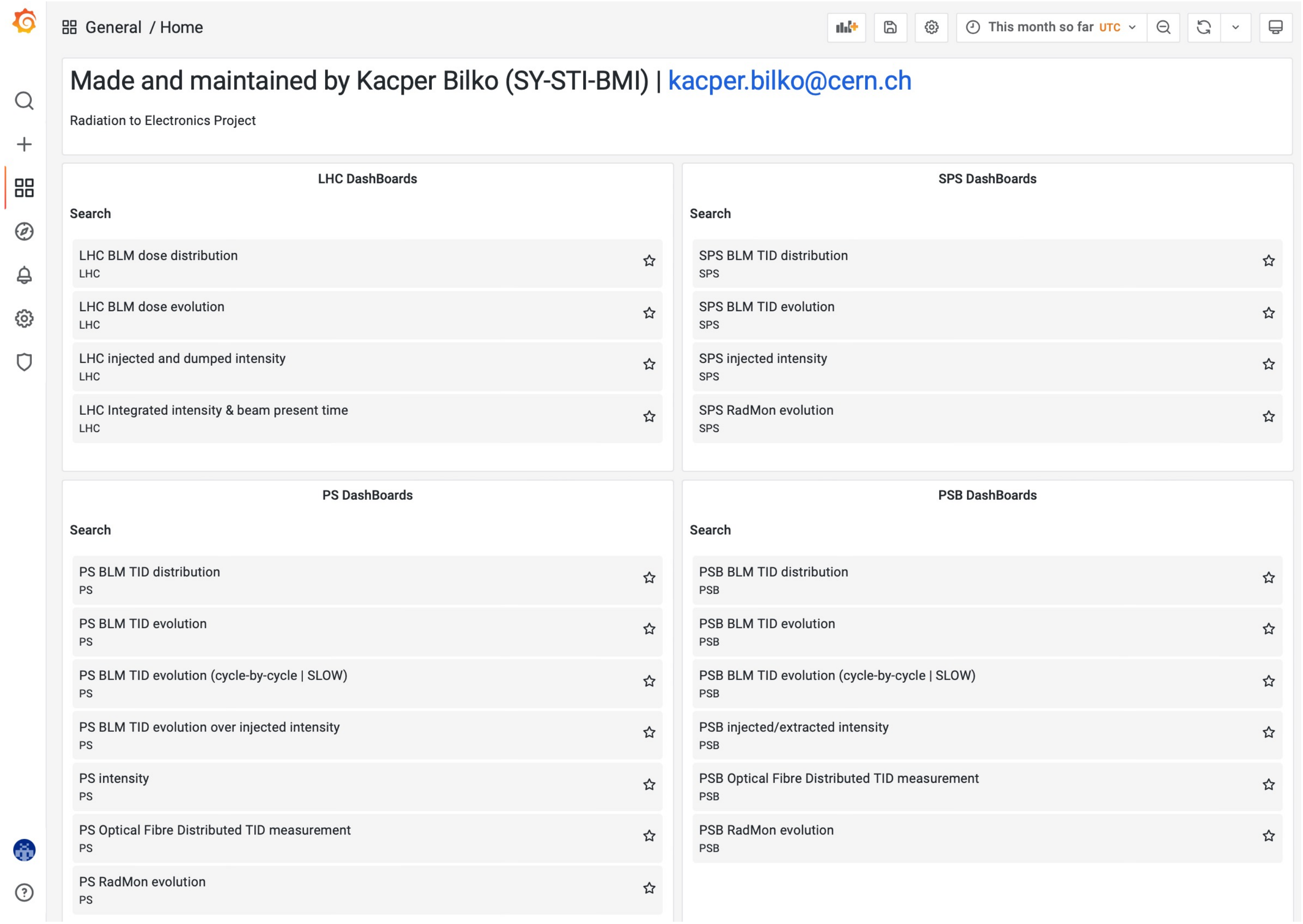
Automation through the Jenkins server



S	W	Name ↓	Last Success	Last Failure	Last Duration	
		PS_BLM_analysis	7 hr 29 min - #1902	7 days 6 hr - #1862	5 hr 52 min	
		PS_intensity_analysis	49 min - #3230	10 hr - #3220	51 sec	
		PS_OFD_downloader	8 min 26 sec - #3397	19 hr - #3378	50 sec	
		PS_RadMon_analysis	18 min - #1792	1 mo 1 day - #1409	3 min 16 sec	
		PSB_BLM_analysis	54 min - #6412	3 hr 8 min - #6410	47 min	
		PSB_intensity_analysis	1 hr 15 min - #3012	17 hr - #3004	1 min 1 sec	
		PSB_OFD_downloader	42 min - #6842	26 days - #6197	43 sec	
		PSB_RadMon_analysis	30 min - #4362	4 days 5 hr - #4261	9 min 21 sec	
		SPS_BLM_analysis	49 min - #2205	4 hr 49 min - #2201	2 min 8 sec	
		SPS_intensity_analysis	40 min - #2177	26 days - #1532	50 sec	
		SPS_OFD_downloader	21 min - #2704	1 day 3 hr - #2677	2 min 12 sec	
		SPS_RadMon_analysis	1 hr 15 min - #1077	17 hr - #1069	18 min	
		TT_BLM_data_downloader	1 yr 9 mo - #4	1 yr 9 mo - #3	5 min 26 sec	

Radiation Levels Dashboard

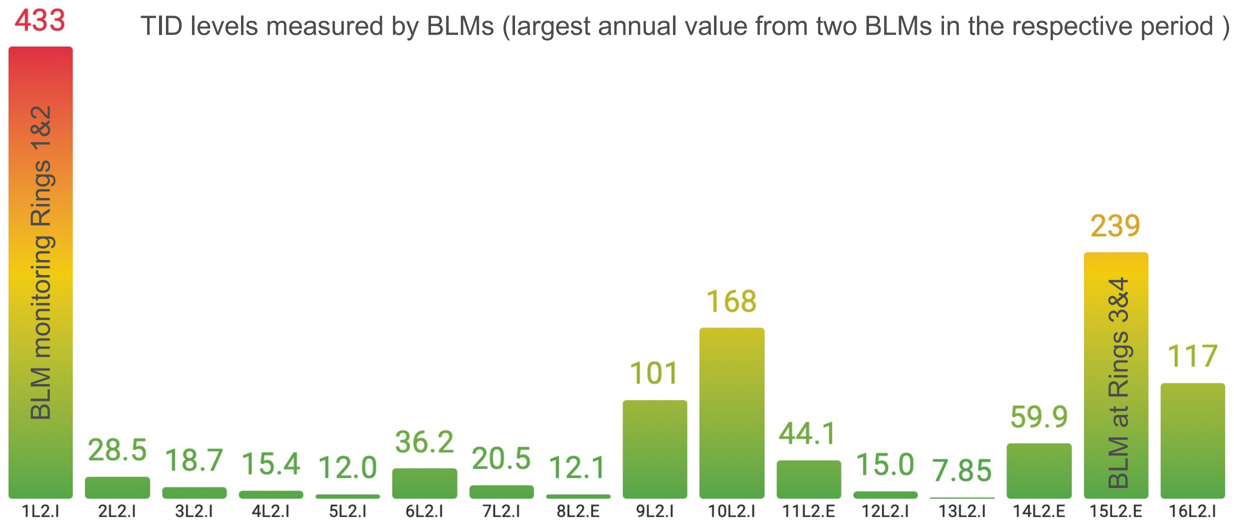
- Available at https://r2e-monitoring.web.cern.ch/ ,
- Great tool for gaining **insights about the radiation levels** in the largest CERN's accelerators (PSB, PS, SPS, LHC),
- Covers:
  - Operational statistics (intensity, beam user breakdown),
  - Radiation levels reported by:
    - Beam Loss Monitors,
    - RadMONs,
    - Distributed Optical Fiber Sensing.

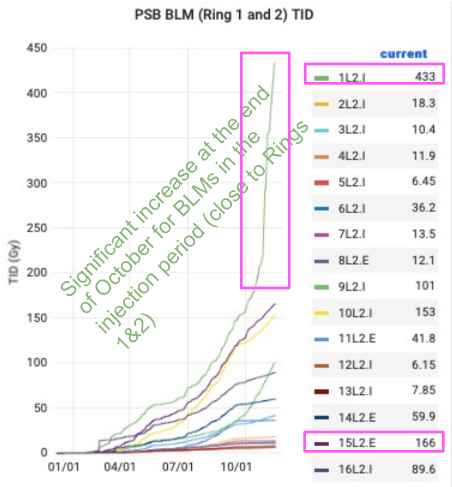


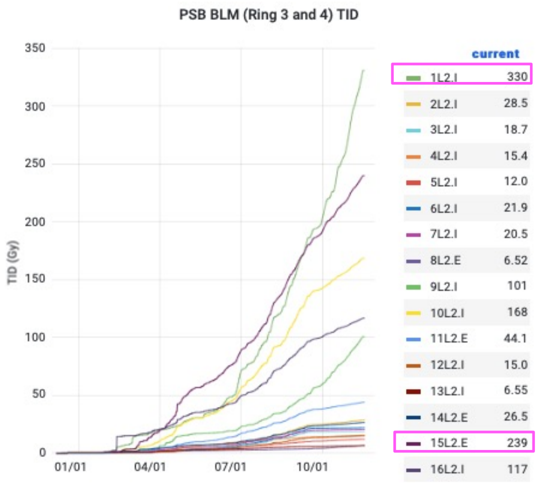
Highlights from 2021 operation

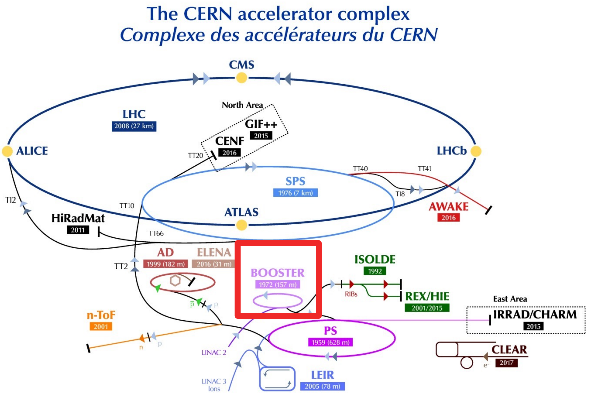
PSB: TID measurements from Beam Loss Montiors (standard IC-type)

- Among measurements by **the rings BLMs**, the highest values were observed in the:
  - injection region (period 1) - up to 430Gy,
  - extraction region (period 15) - up to 240Gy.
  - It's important to highlight that the respective BLM locations differ (inner/external side and observed rings).



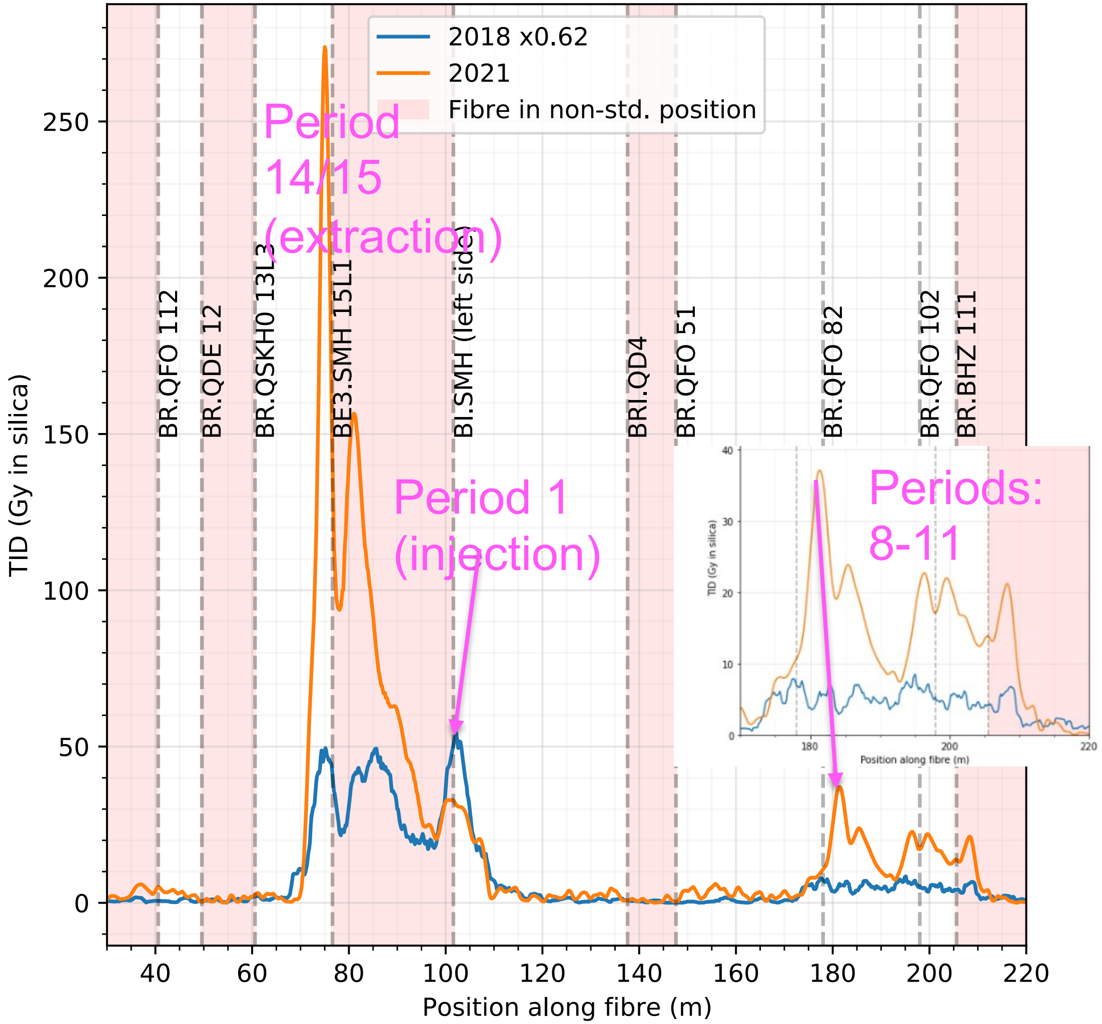






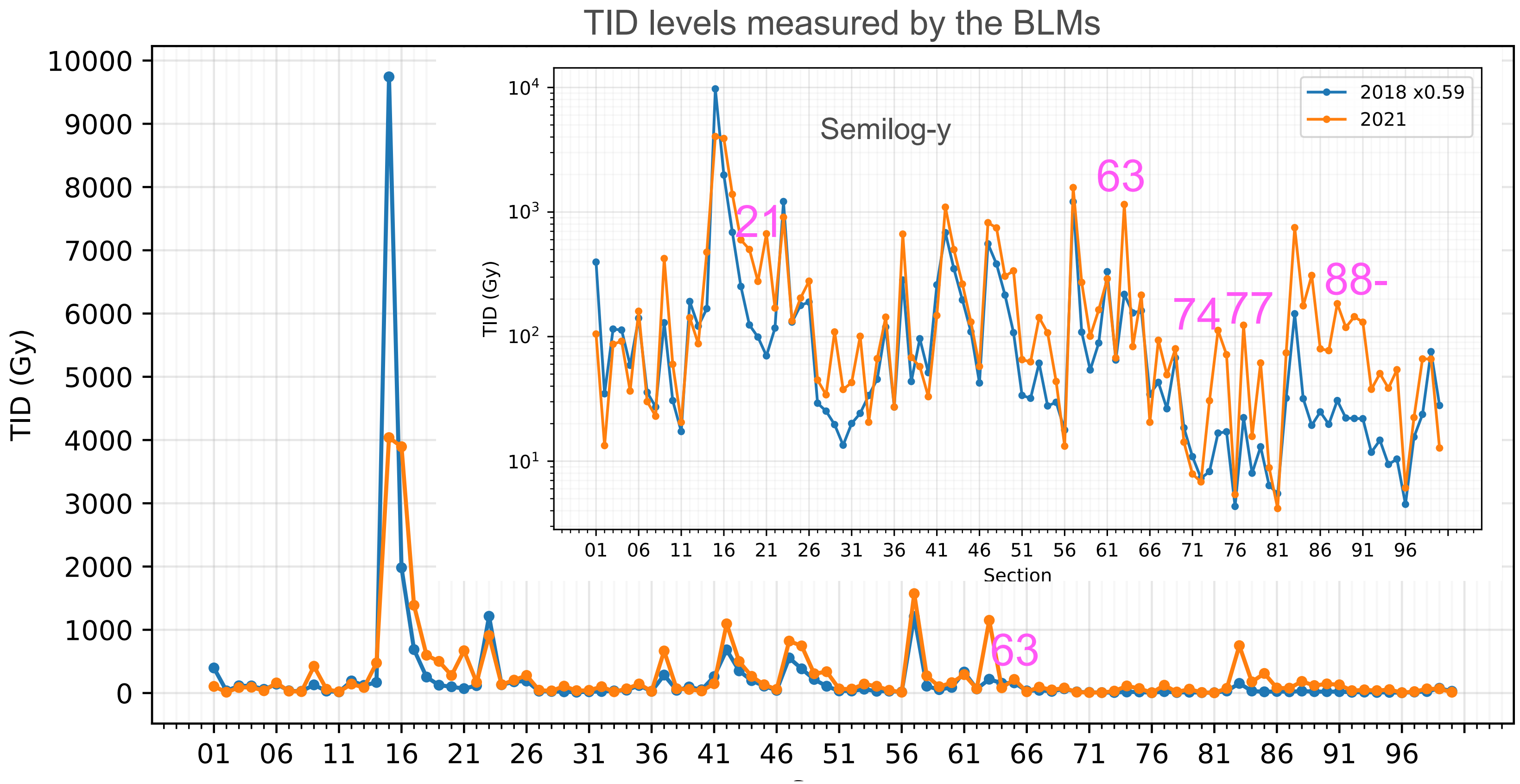
PSB: Optical Fibre TID measurements in 2018 and 2021

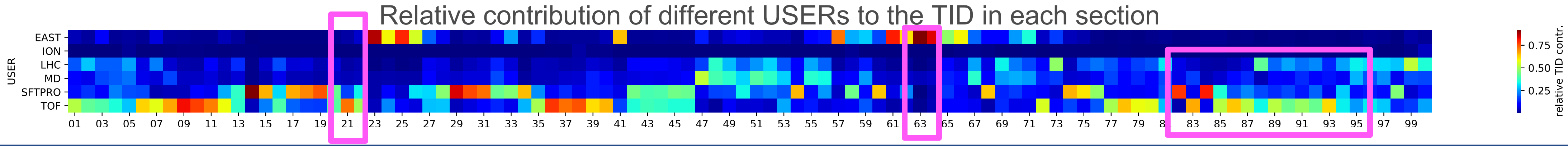
- **2018 TID values multiplied by 0.62** (ratio of injected intensity in 2021 with respect to 2018),
- Extraction region:
  - **Increase by factor ~5 with respect to 2018** (norm. TID levels),
- Injection region:
  - **Decrease by ~40%** in comparison to 2018 (norm. TID),
  - As opposed to 2018, **no longer the dominating region** in terms of prompt radiation levels,
- Periods 8-11:
  - Changed radiation pattern,
  - Increase by up to factor ~5 with regard to 2018 (norm. TID levels),



PS: Total Ionizing Dose measured by the Beam Loss Monitors

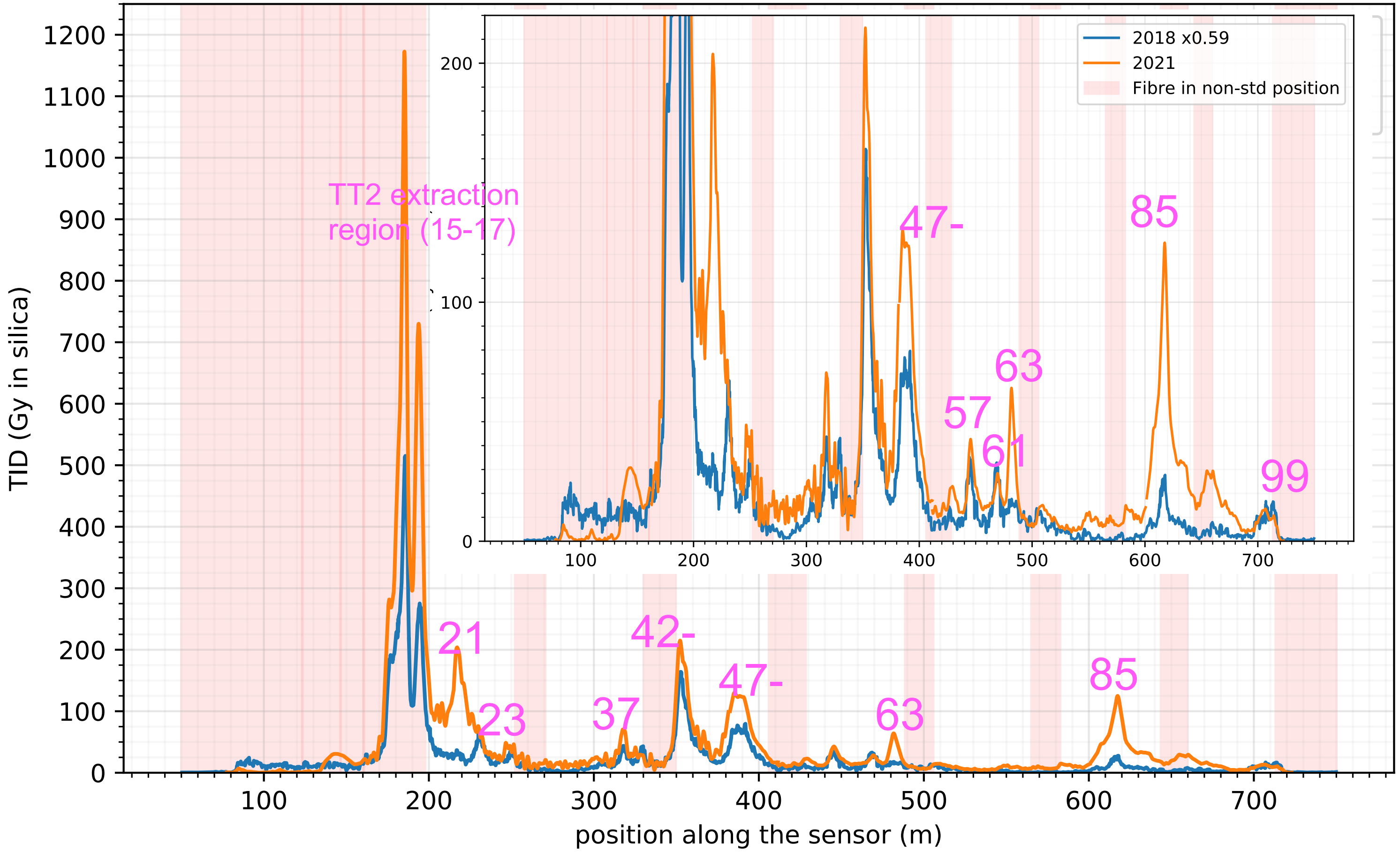
- Overall, measured normalized TID **levels in 2021 were higher in majority of the PS sections**.
- Selected sections with significant increase wrt 2018:
  - **Section 21 (increase x5):**
    - nTOF-cycles domintated,
  - **S. 63 (increase by factor ~5 wrt 2018):**
    - East Area cycles dominated,
  - S. 74 and 77 (increase by a factor 5-7),
  - **S. 83-95 (increase by a factor 5-16):**
- Observed decrease (norm. TID) by factor ~2.5 in section 15.





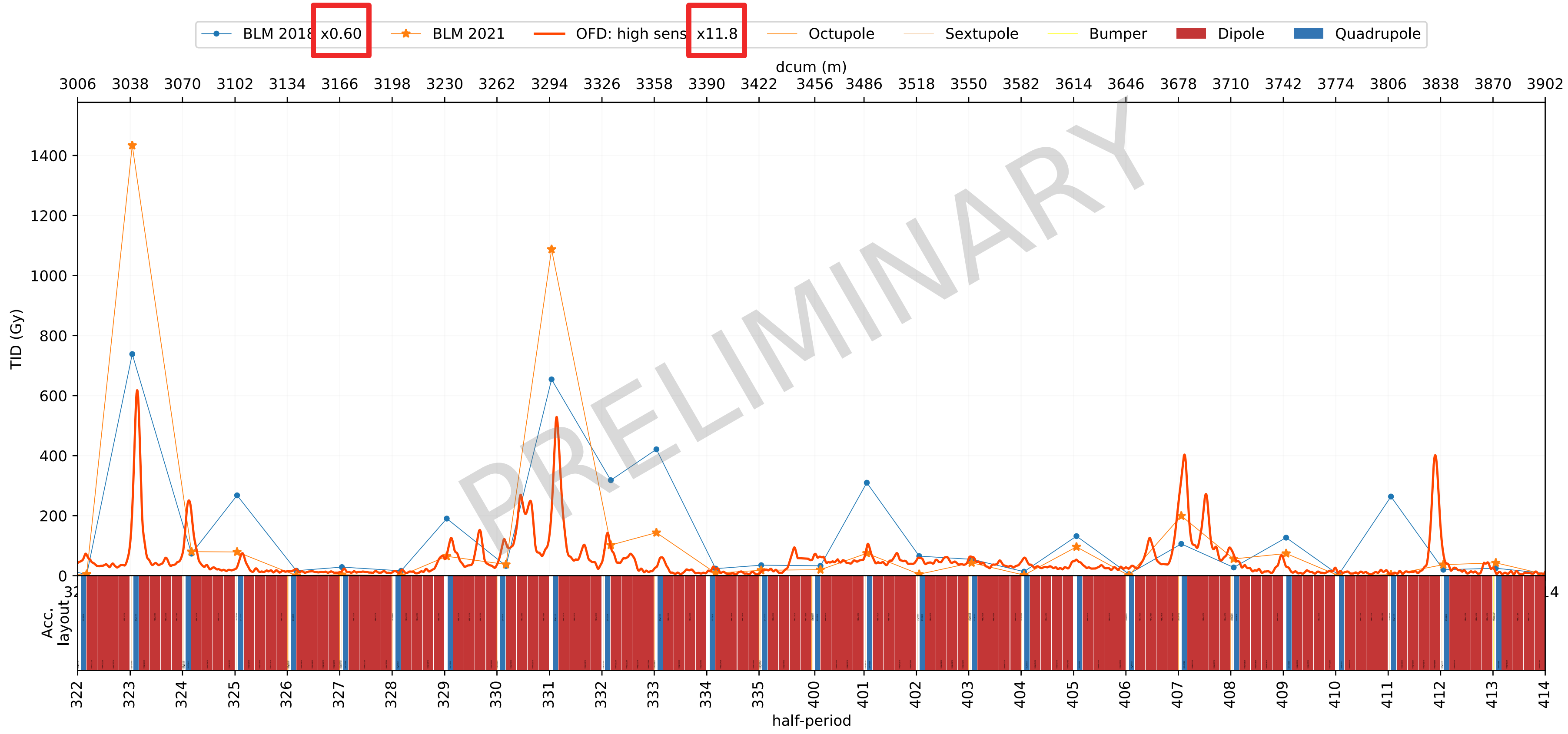
PS: Optical Fiber TID measurements in 2018 and 2021

- Similarly as for BLM measurements, in 2021 **the normalized levels measured by the Optical Fiber** (at the cable try) were **higher in the majority of the sections**.
- Sections with the most significant differences:
  - In **section 21** the measured normalized TID levels were ~6x higher,
  - In **section 63**, the normalized levels were x3 higher,
  - In **section 85** the measured normalized levels were ~5x higher,



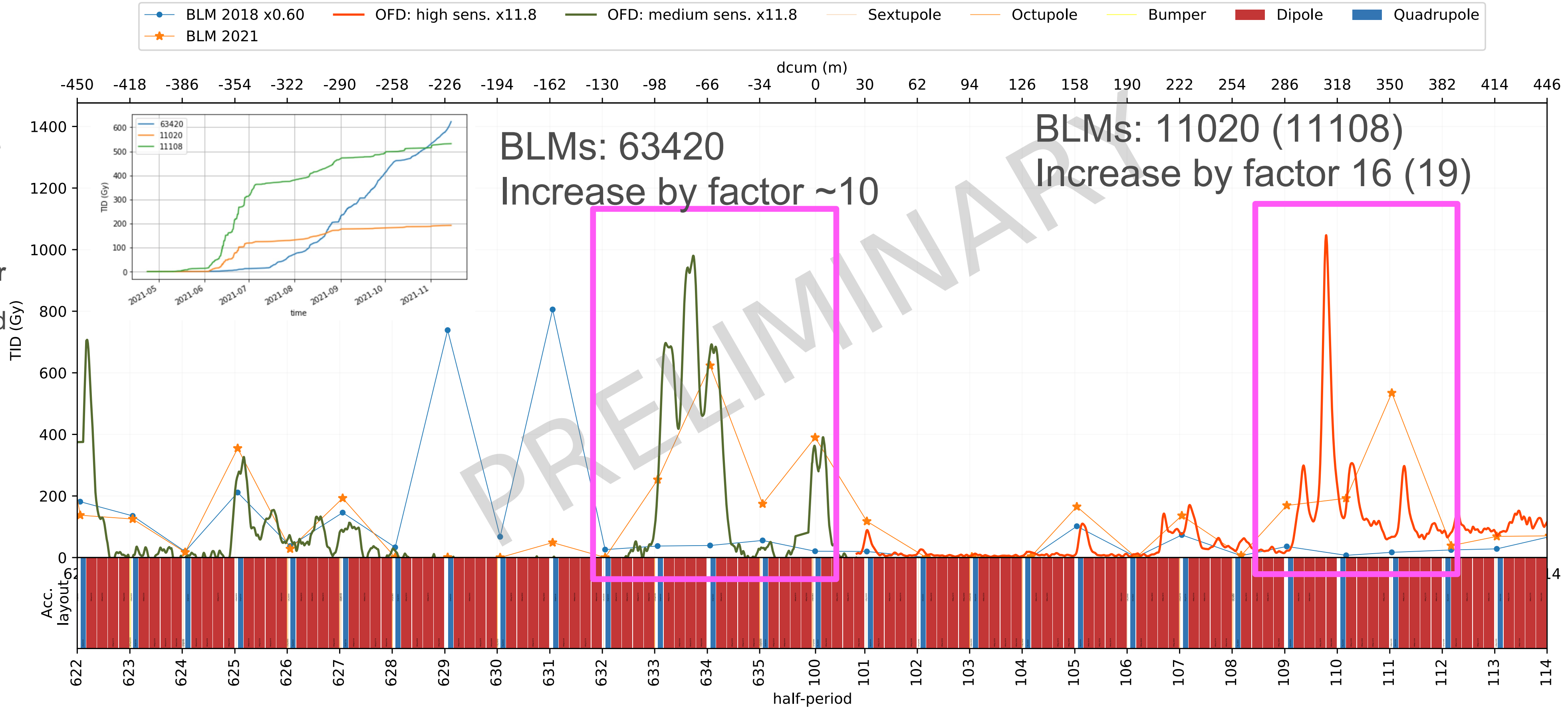
SPS: ARC34 as an example of the SPS radaition monitoring

- 2021 – the first year with the **DOFRS operating along the SPS**:
  - will be covered in detail by Diego's talk,
  - high spatial resolution of measurements,
  - BLMs cover only Quadrupole locations (ARCs), whereas with the fibre the continuous profile along all magnets is retrieved (also along MBs),
- **Consistency between measurements reported by the avaliable detectors**:
  - Detailed benchmarks are ongoing.



SPS: Radiation Levels in ARC61

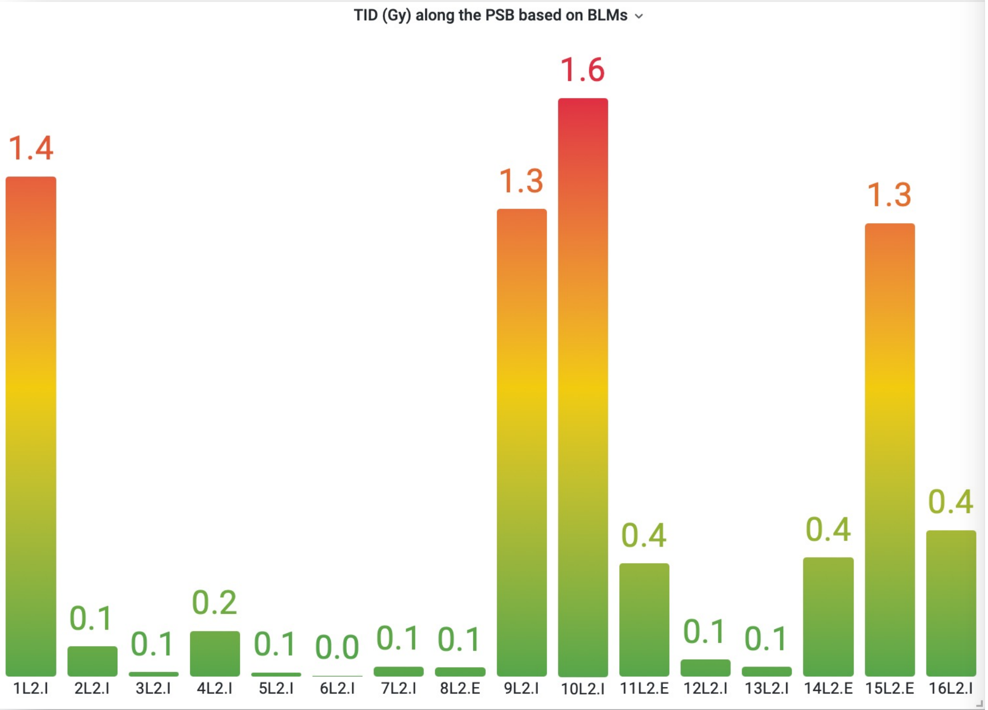
- In majority of the locations, **the normalized 2021 radiation levels in SPS decreased as compared to 2018**,
- However **there were few exceptions**, e.g.:
  - In half-period **634 increase by a factor ~10** as compared with 2018 normalized TID levels:
    - 93% of TID from SFT cycles,
  - 110/111:
    - Approximately 60% of the TID from MD cycles,
    - Most of the TID accumulated in June 2021,
- More details presented at the IPP meeting.



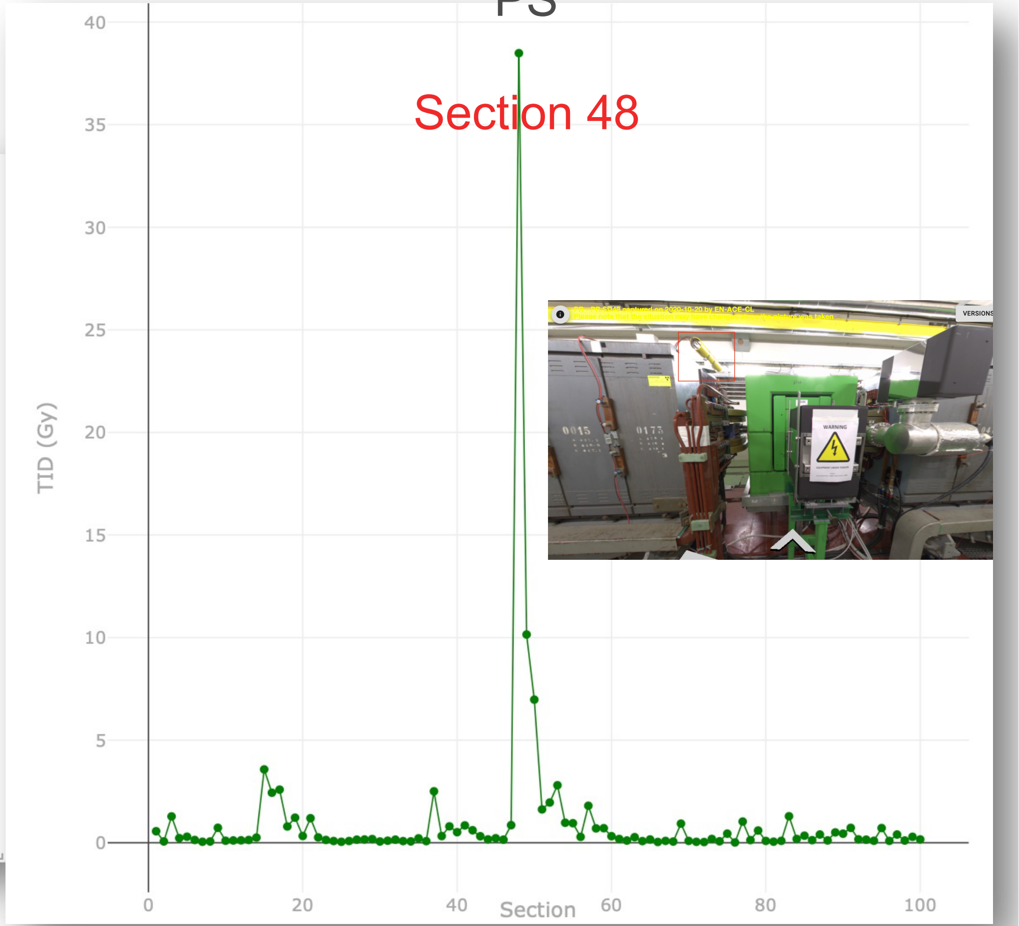
New! Highlights from 2022 operation

- With the implemented solutions, the **radiation levels can be retrieved almost in real-time,**
- **Very recent data!**
  - Recommissioning of the injectors after YETS,
  - Period between 21st and 28th of February 2022 considered,
- PS: up to 40Gy at the BLM close to internal beam dump,
- PSB: up to 2Gy at the BLMs in period 10.

PSB



PS



Conclusions

- Radiation monitoring is a core ingredient in **preventing R2E driven accelerator failures**, whereas the related analyses are essential for the **radiation risk assessment** concerning future electronics installations,
- Processing of huge datasets, **more than 100 GB/day,** possible thanks to the implemented framework and opportunities that **NXCALS** (with Apache Spark) introduced,

- **Milestone achieved**: 2021 was the first year with the full R2E automated radiation monitoring in the injectors covering the most relevant radiation monitors:
  - this R2E activity was **essential for MCWG**, and therefore to the equipment groups,
  - additionally, the **analyses were useful for Operations** (beyond MCWG) for
- **Objectives for 2022**:
  - A restart of the **automated radiation monitoring together with the LHC**,
  - Exploitation of the data with the goal of providing insights not only to the equipment groups, but also, to the Operations.

Thank you for
your attention!

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