Radiation environment simulations using FLUKA

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with input from

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https://indico.cern.ch/event/1116677/

Introduction

- The presentation by G. Lerner [1] introduced the **Radiation to Electronics (R2E) Monitoring and Calculation Working Group (MCWG)**, describing the radiation monitors that are used to measure R2E quantities at the LHC:
  - **Total Ionising Dose (TID)** measured with **Radiation Monitors (RadMON)**, **Beam Loss Monitors (BLMs)** and **Distributed Optical Fibre Radiation Sensors (DOFRS)**.
  - **High Energy Hadron eq. (HEH-eq)**, **Thermal Neutron eq. (THN-eq)** and **Silicon 1-MeV neutron eq. (1MeVn-eq)** fluences measured with **RadMons**.

- This talk introduces **FLUKA simulations** as an additional tool for the characterisation of the irradiation facility/accelerator radiation environment, and for general R2E purposes.

- Different R2E applications of FLUKA are discussed:

Accelerators	Irradiation Facilities	Detector Development

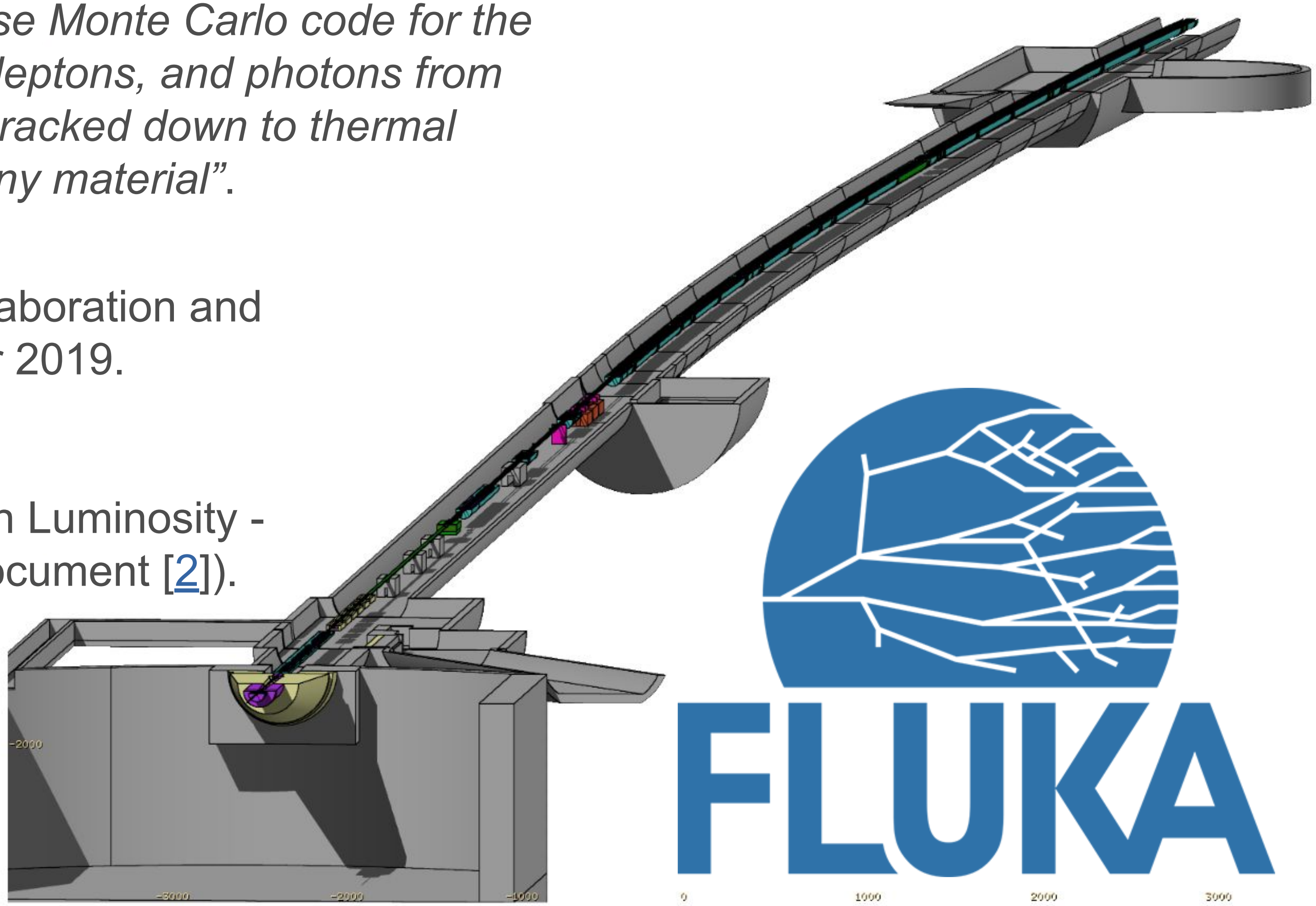
FLUKA simulations

- From https://fluka.cern/:

  "The FLUKA code is a general purpose Monte Carlo code for the interaction and transport of hadrons, leptons, and photons from keV (with the exception of neutrons, tracked down to thermal energies) to cosmic ray energies in any material".

- Developed by the **FLUKA.CERN** collaboration and distributed by **CERN** since December 2019.

- Possibility to study new scenarios/ future accelerator operation (e.g. High Luminosity - LHC radiation levels specifications document [2]).



FLUKA and R2E

- Key features of interest for **R2E**:
  - **3D distributions** of **TID** and **HEH-eq**, **THN-eq**, and **1MeVn-eq** fluences in complex geometries → critical for R2E specifications.
  - Differential distributions (e.g. energy spectra), energy deposition in small volumes (nm-μm scale), **Linear Energy Transfer (LET)** distributions of reaction products, etc.
  - Can handle a variety of radiation sources:

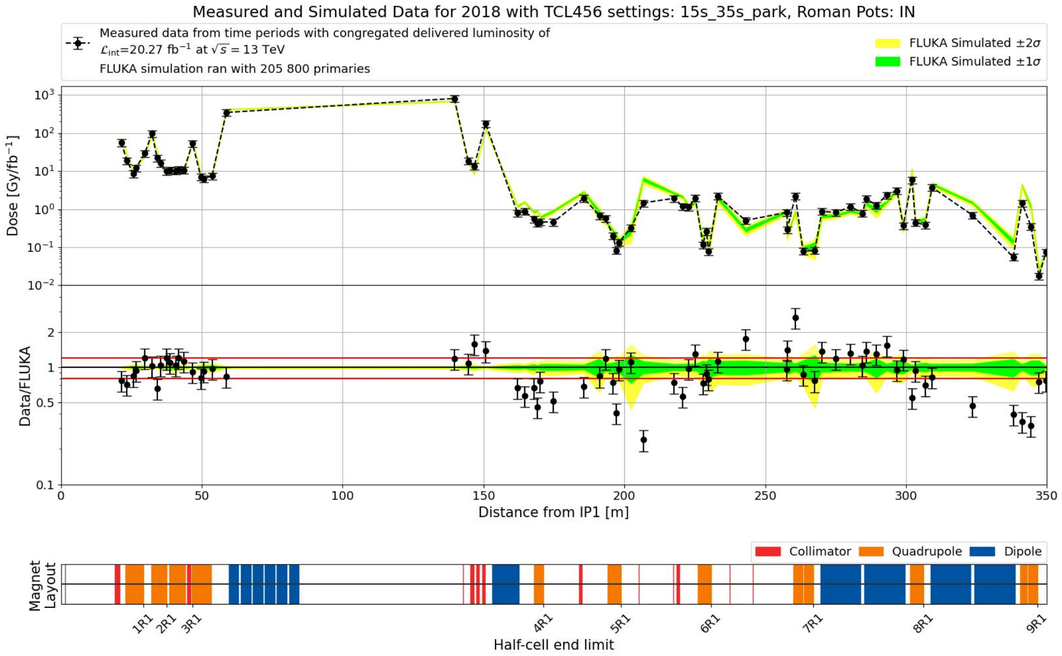
- Scale with luminosity:
  - Collision Debris from the experiments.

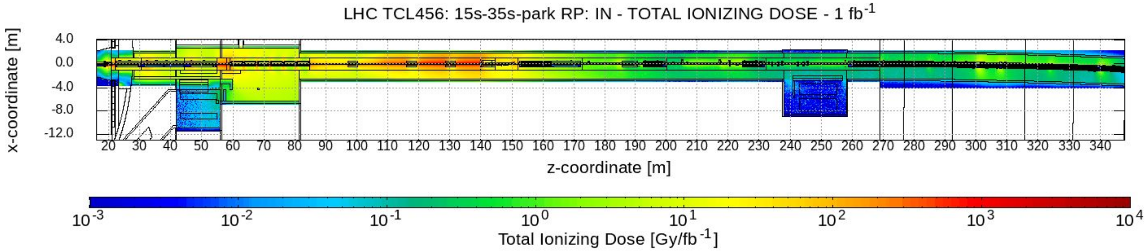
- Scale with beam intensity/number of lost protons:
  - IR7 Collimation.
  - Beam-gas interaction:
    - In the ARC regions, residual gas.
    - In IR4, injected gas in Beam Gas instruments.

Accelerators

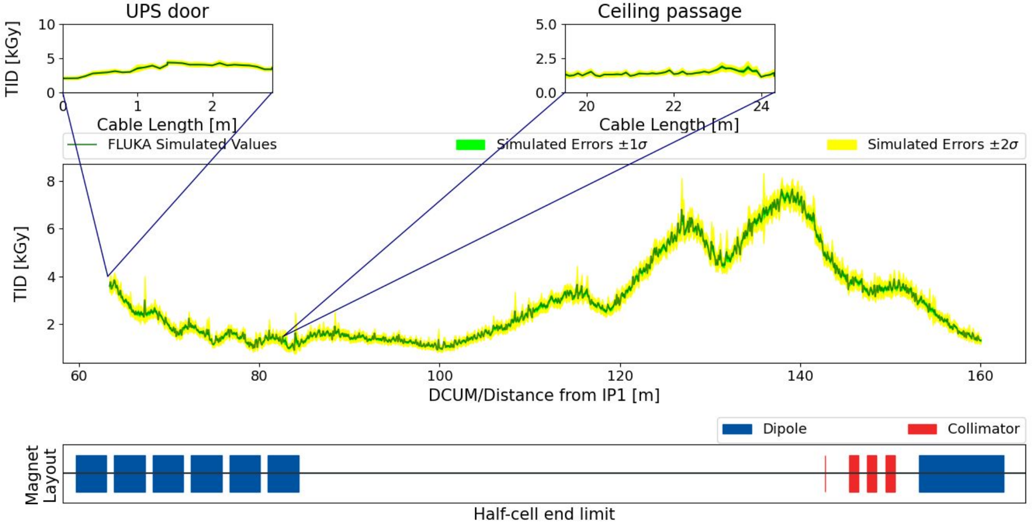
Complex geometries: LHC accelerator operation IR1/5 [3]

- Valuable for the current LHC layout:
  - to **benchmark** radiation monitors measurements in past operations (e.g. Run 2: 2015-2018),
  - to **complement** point-wise radiation measurements with detailed maps.
  - to **specify** radiation levels for future operation (Run 3).





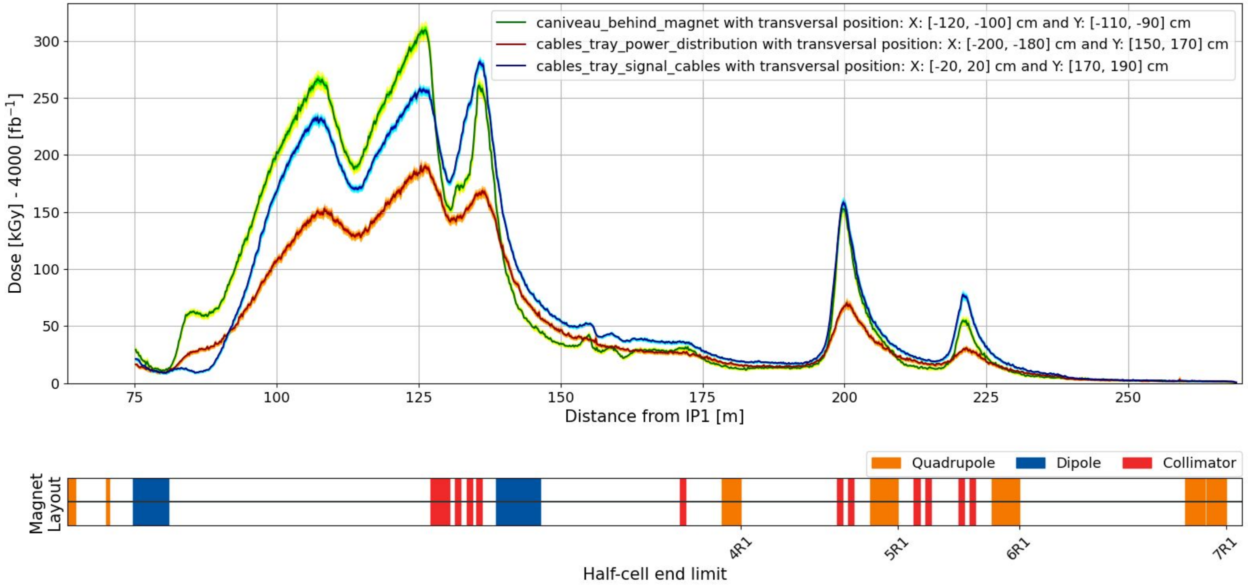
ZDC cable path request



Complex geometries: HL-LHC accelerator operation IR1/5

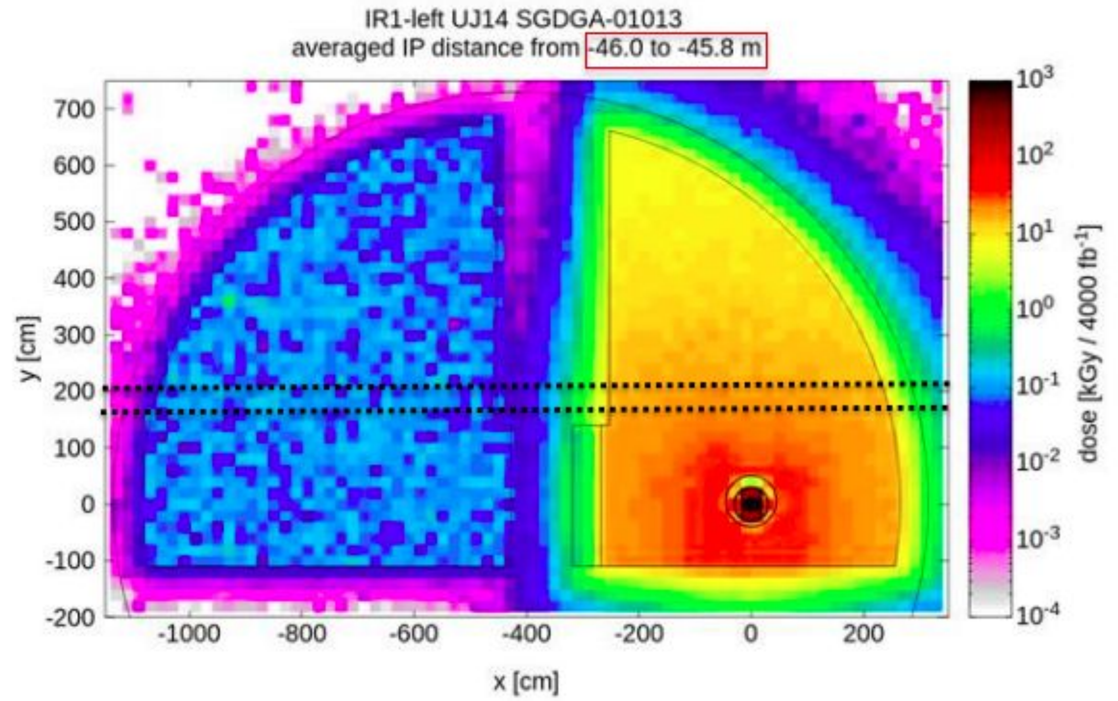
- Crucial for the future **High Luminosity (HL)**-LHC layout:
  - to **estimate** expected radiation levels for best HL performance -> most radiation damage to electronics.

HL-LHC Optical Fibres request [4]



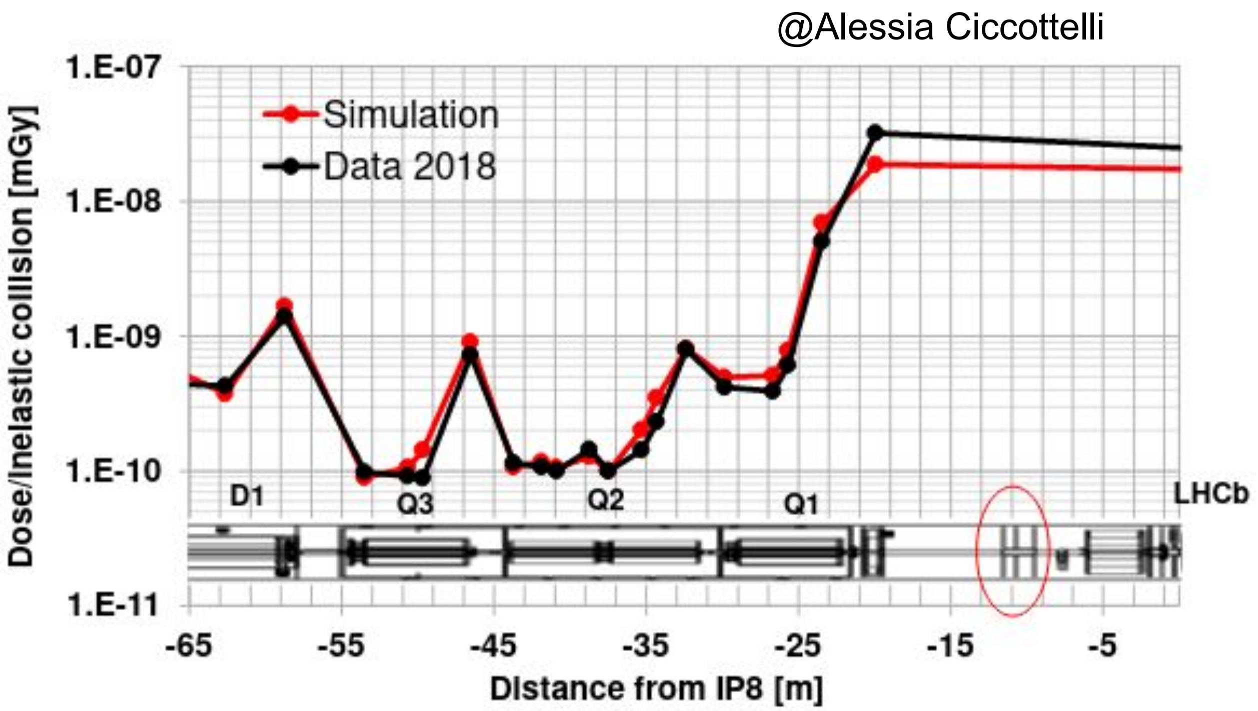
Dose levels at the UJs for ODH detectors [5]

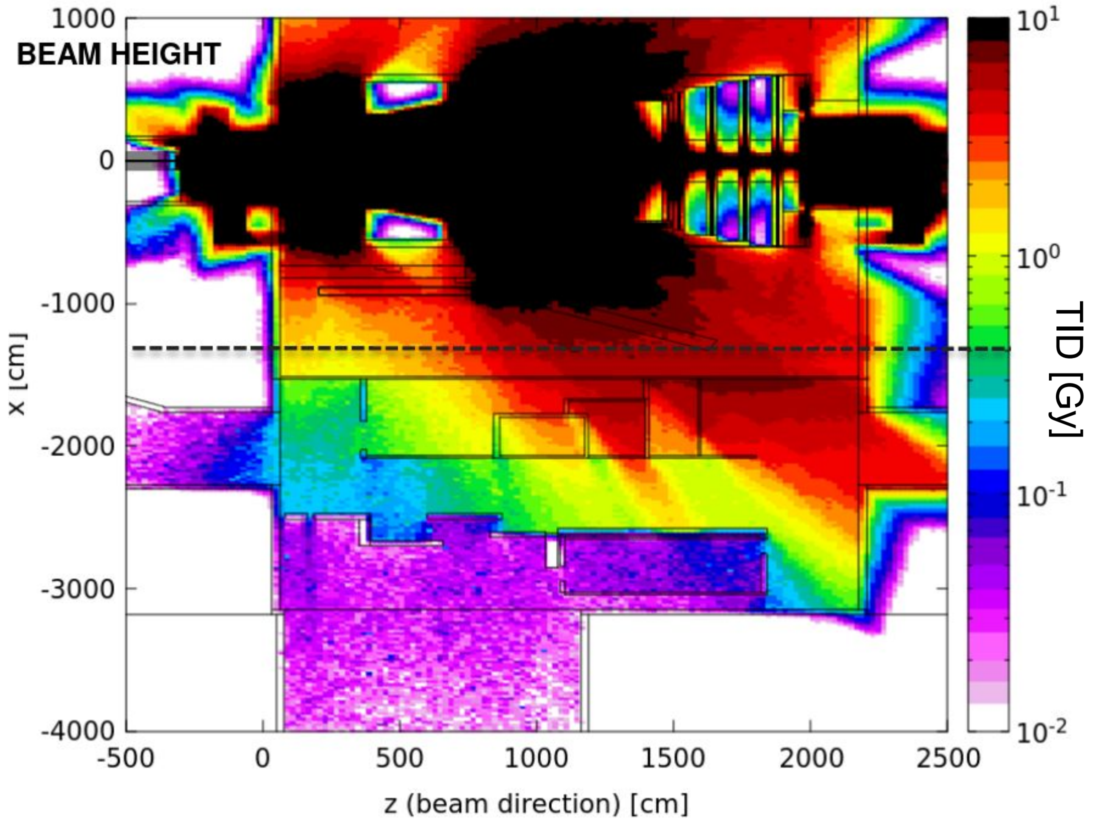
@Marta Sabaté Gilarte



Complex geometries: LHC IR8 [6]

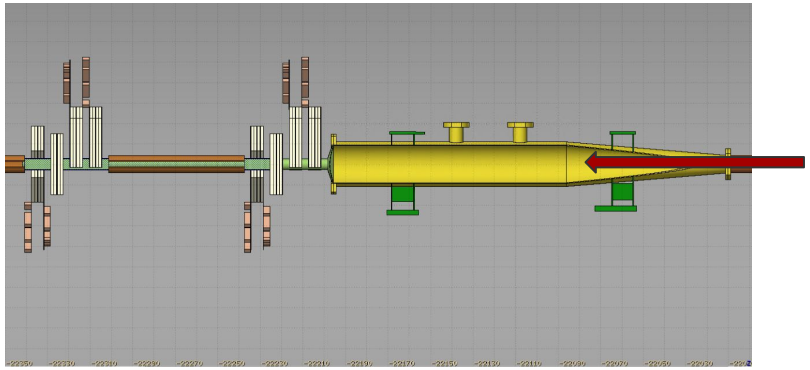
- **Benchmark** between **simulation** and **measurements** for Run 2 and Run 3 (planned), as well as machine-induced background study.
- Estimate radiation level specifications for HL-LHC.



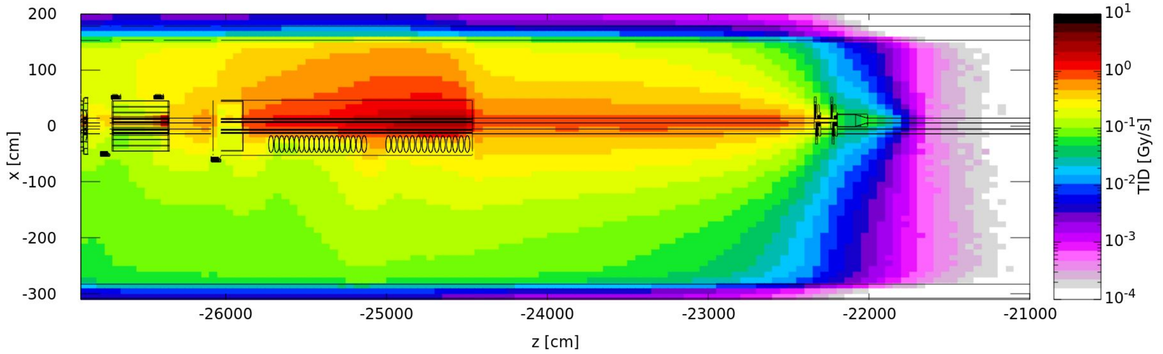


Complex geometries: LHC accelerator operation IR4 [7]

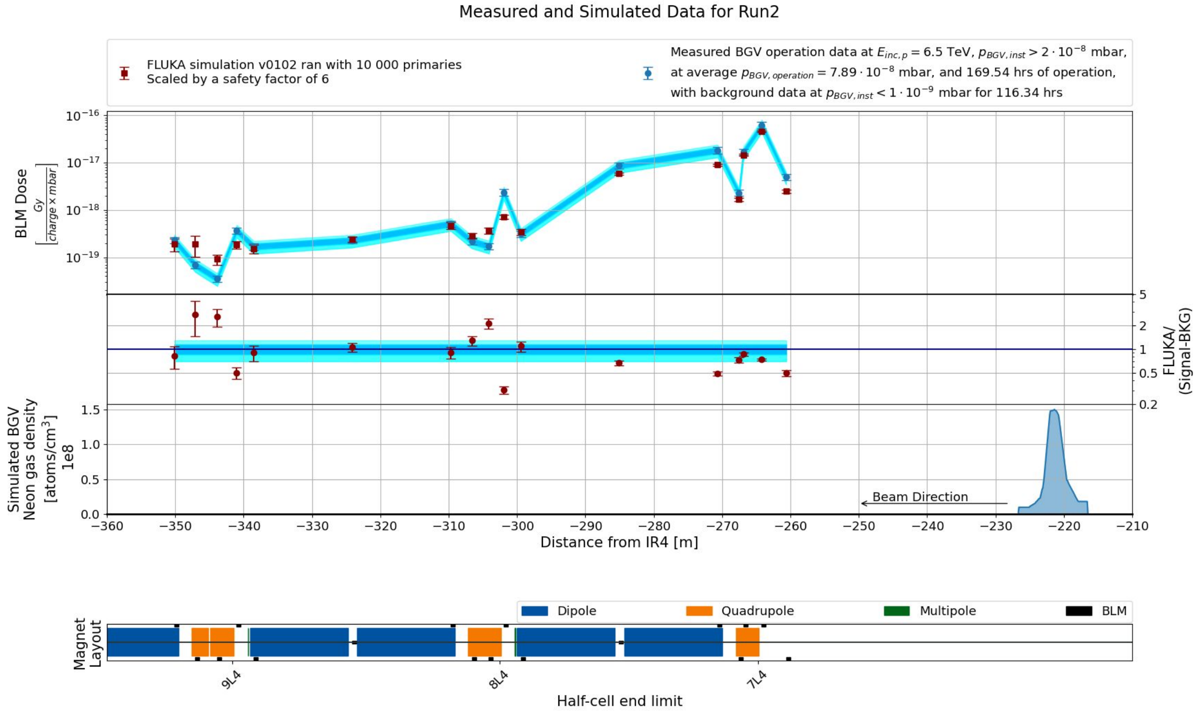
- FLUKA is capable of simulating the radiation shower caused by the beam-gas interactions.



IR4



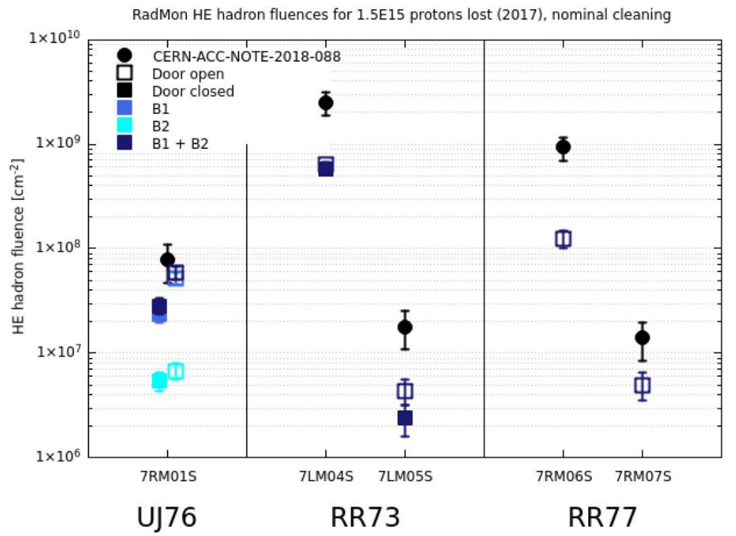
- The benchmark with Run 2 measured data from radiation monitors reveals a factor 6 **underestimation**, which is applied as a safety factor for HL-LHC specifications.

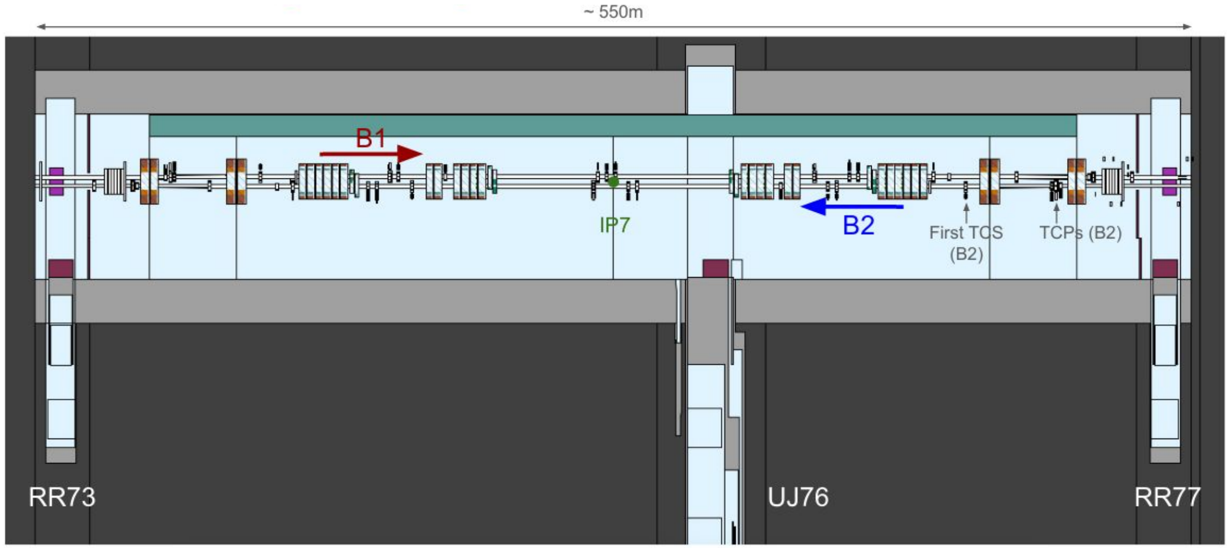


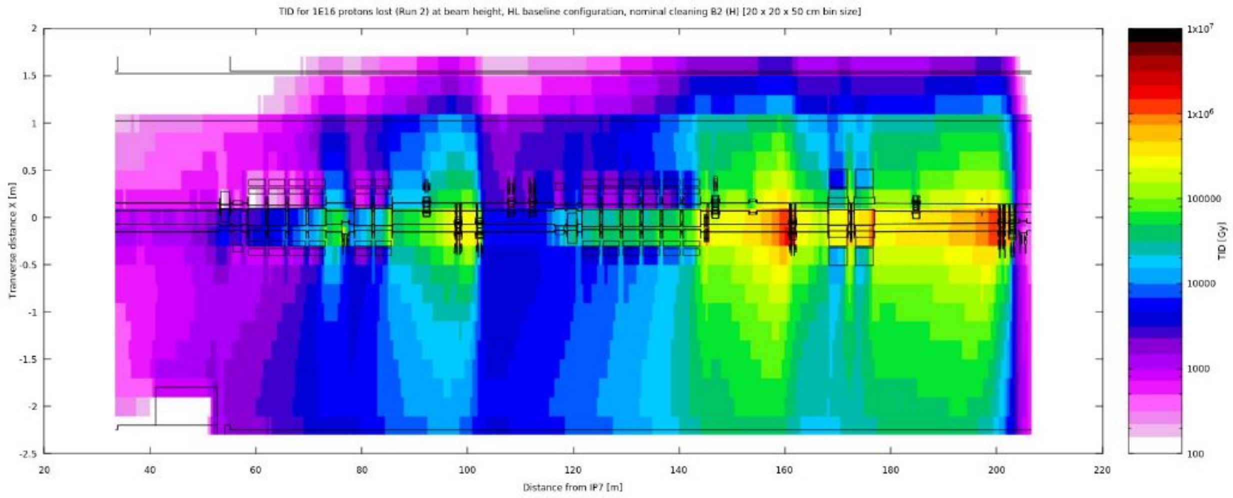
Complex geometries: LHC IR7 [8]

@Andreas Waets

- 1E16 protons lost in Run 2 ≂yearly amount of protons lost in **HL** era
- "Hot spots" at primary collimators and first secondary, reaching +1MGy/y in HL era
- Cables on tunnel walls can reach 100 kGy/y in HL era
- Benchmark with **HEH-eq** fluence **RadMON** measurements (e.g. 2017 with 1.15E15 protons lost), reveas a systematic underestimation of measured values by simulation:
  - **UJ**: factor 2.5, **RR**: factor 7 (unshielded), factor 4-5 (shielded)



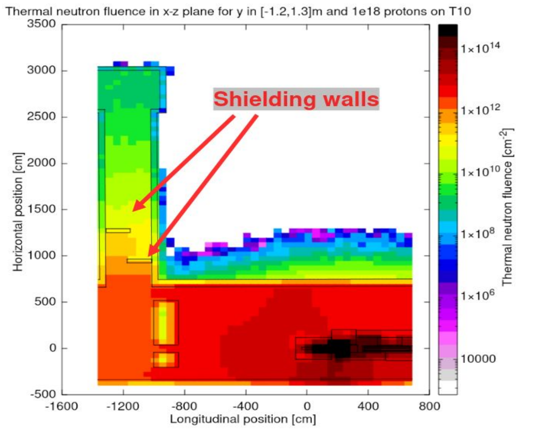


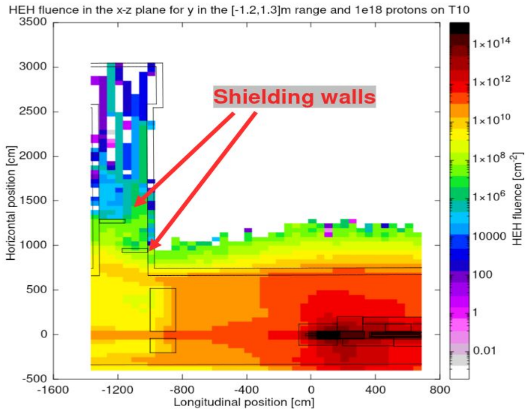


Other areas

Implementation of extra shielding in TA851 [9]

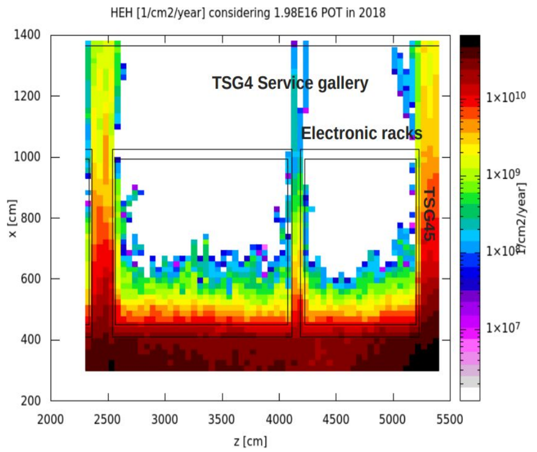
- Suppress the radiation levels coming from the TCC8 target area (T10) to mitigate the impact of radiation on variable Frequency Drives for motors.
- With these walls we expect the annual radiation levels to drop below the **R2E-safe** limits for Single Event Events (**SEE**).

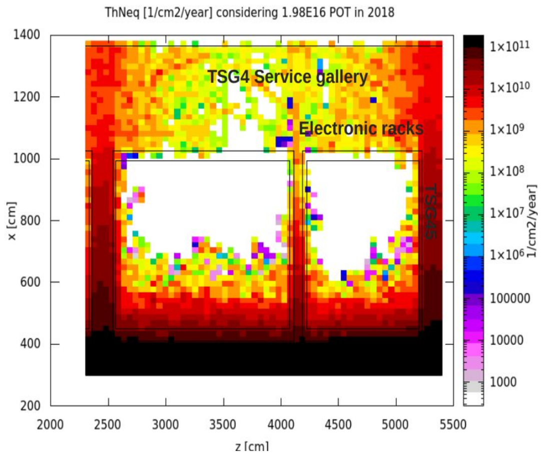




SPS Access System [10, 11]

- Observed 6 Single Event Upsets (**SEUs**) in the Access System racks attributed to the **400 GeV** protons on the AWAKE target, triggering an assessment of radiation levels: **HEH-eq** and **THN-eq** fluences.
- Benchmark of BatMon measurements vs simulations.
- Investigate possible shielding strategies.



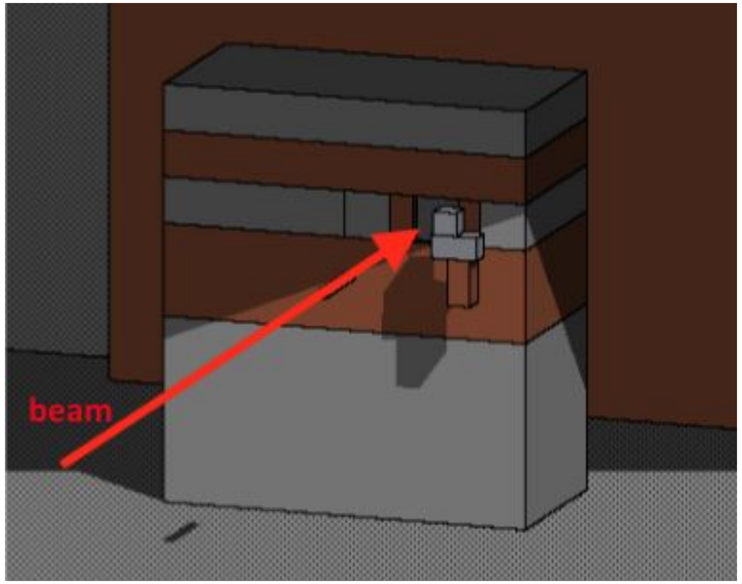


Irradiation Facilities

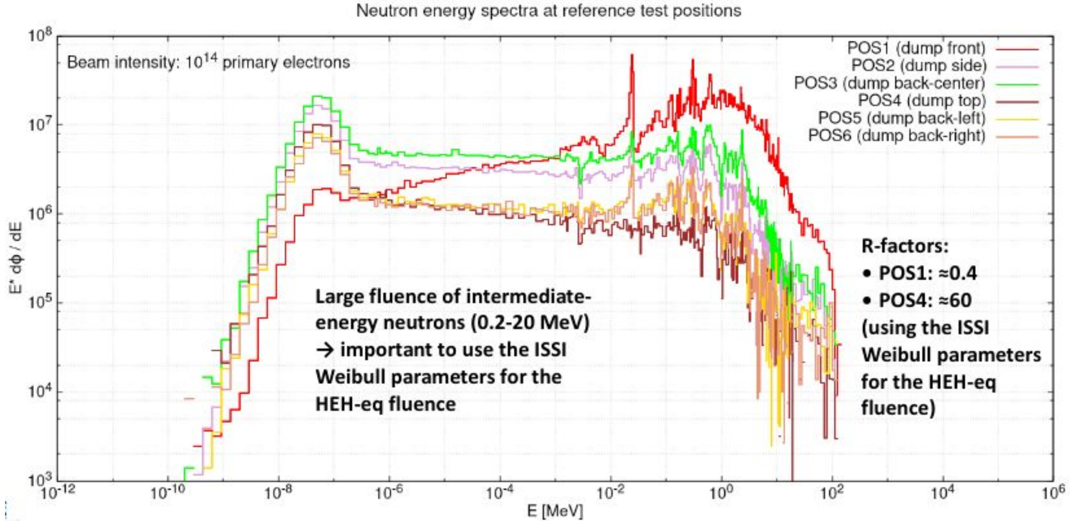
- R2E campaigns at several CERN irradiation facilities for:
  - radiation environment assessment
  - detector calibration

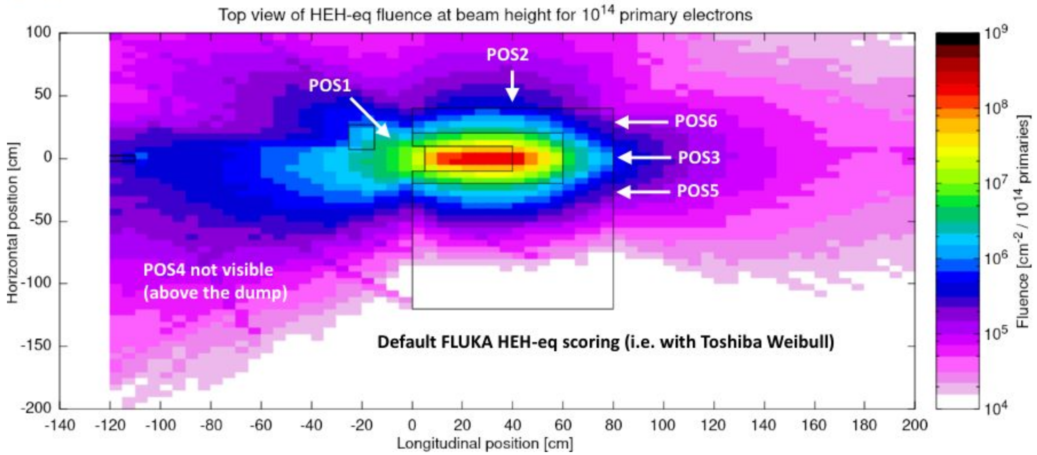
CLEAR: SEU measurements with SRAM memories

- FLUKA simulation and **SEU** rate prediction for different SRAM memories [12, 13].
- **205-210 MeV electron** beam on the beam dump yielding (mainly) electrons, photons and neutrons (from photonuclear interactions).



@Giuseppe Lerner

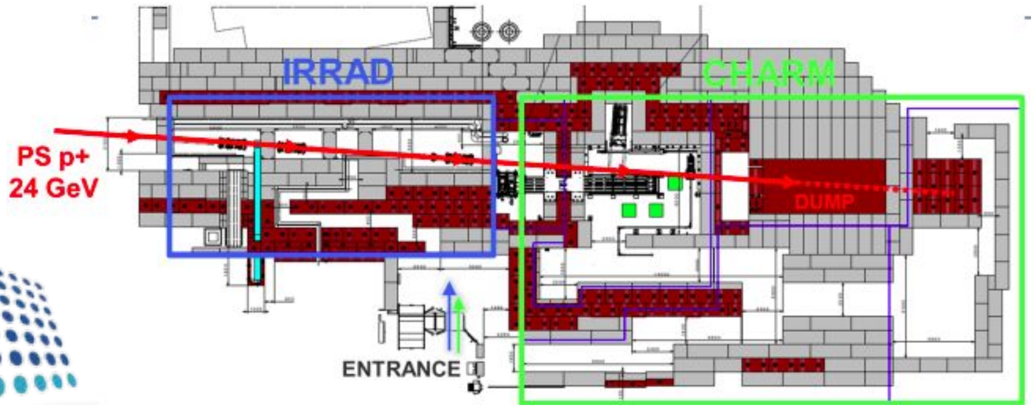




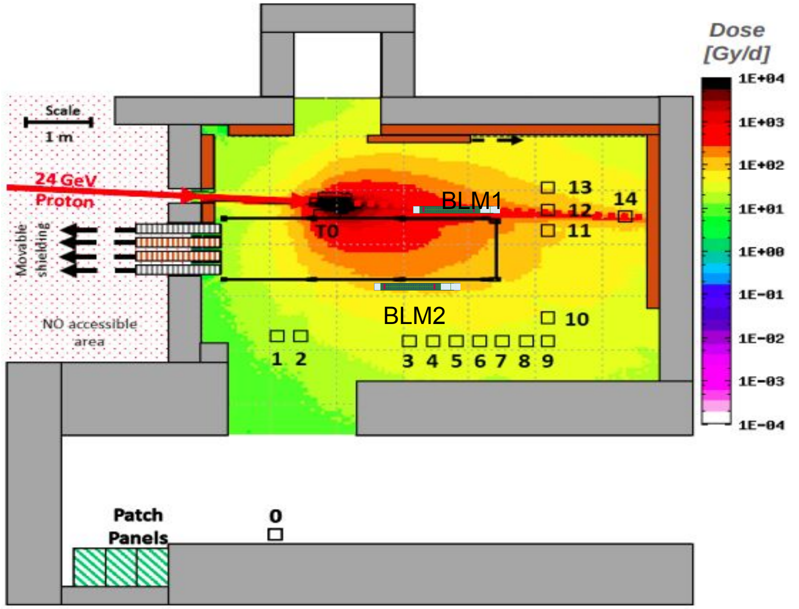
CHARM: CERN High Energy Accelerator Mixed-field

CHARM - Key Information:

- 24 GeV proton beam from CERN PS
- Irradiation Room: 7 x 5 m, 13+ test positions
- Mixed-field of p, n, K, π, μ, γ, e^-, e^+ from GeV to thermal energies

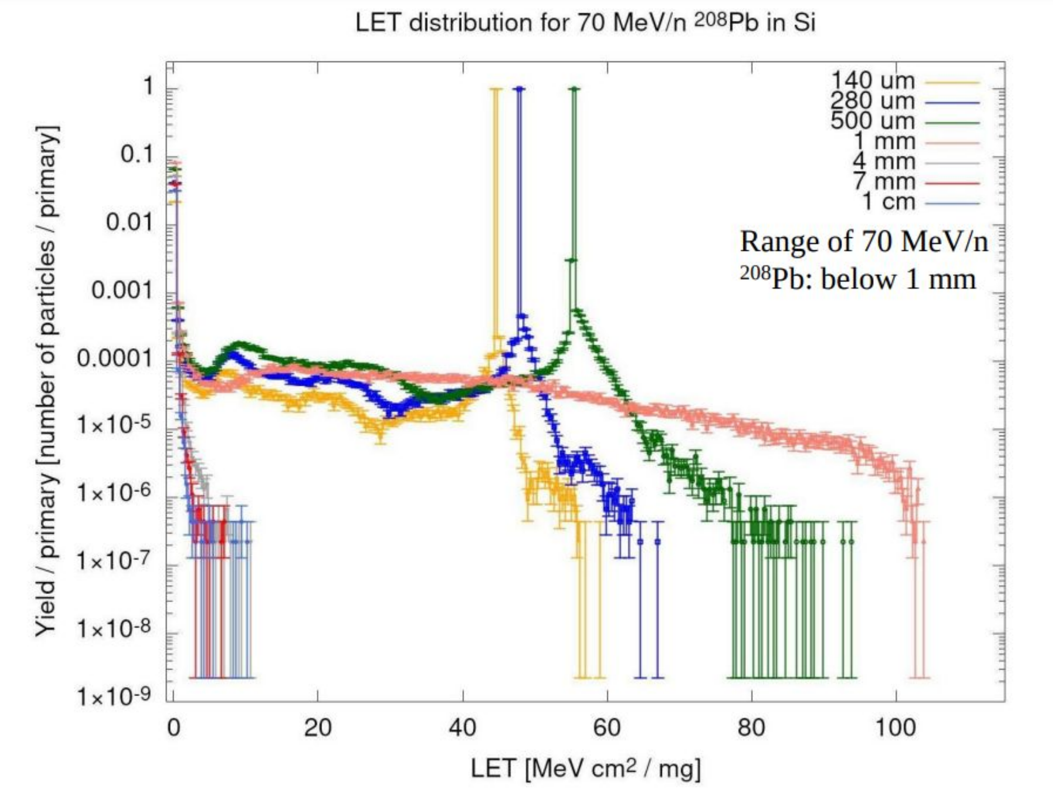


- Benchmark of **R2E** radiation monitors:
  - BLM, RadMONs, Optical Fibre [14].
  - Radiation environment assessment.
- Upcoming **CHIMERA** upgrade:
  Charm **H**igh-energy **I**ons for **M**icro **E**lectronics **R**eliability **A**ssurance (**CHARM**) [15, 16] expand the ion test capabilities, in particular to lower the beam energy to reach higher **Linear Energy Transfer (LET)**.

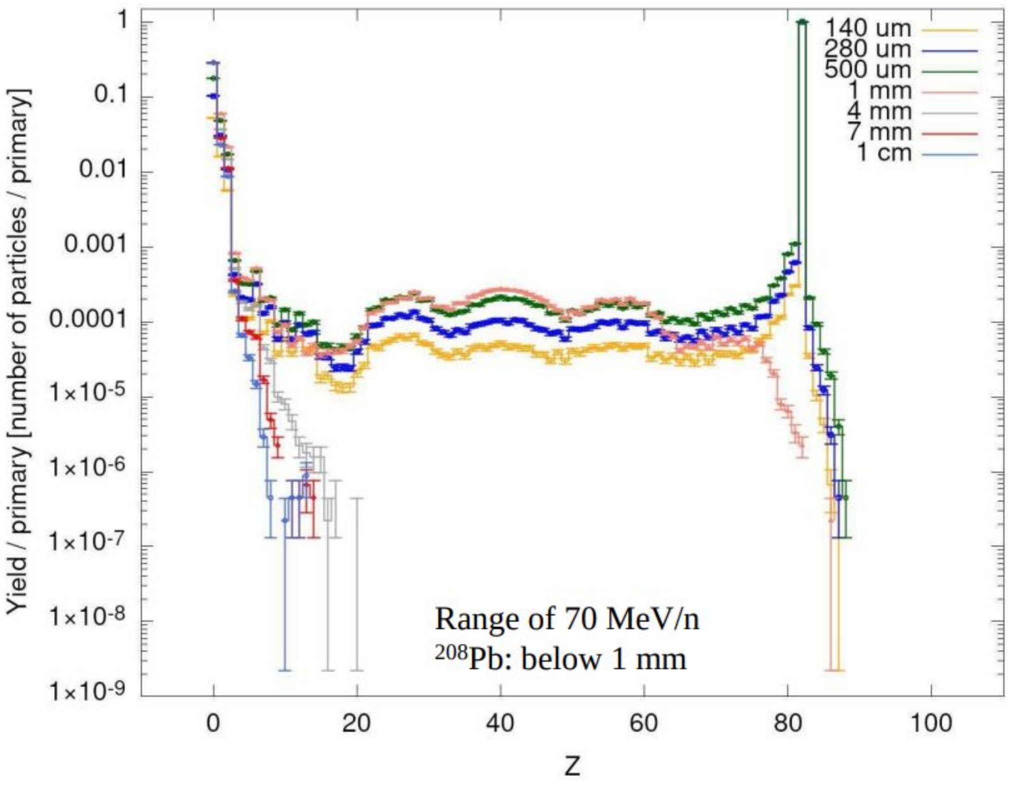


Heavy Ion fragmentation at CHIMERA [17]

- Study of heavy ion fragmentation as a function of depth in a Silicon target, relevant for heavy ion tests of electronic equipment at the **CHARM** facility at **CERN** in view of the **CHIMERA** upgrade.
- Investigation of the distribution of **Linear Energy Transfer (LET)** and **atomic number (Z)** for heavy ion fragments in Si.

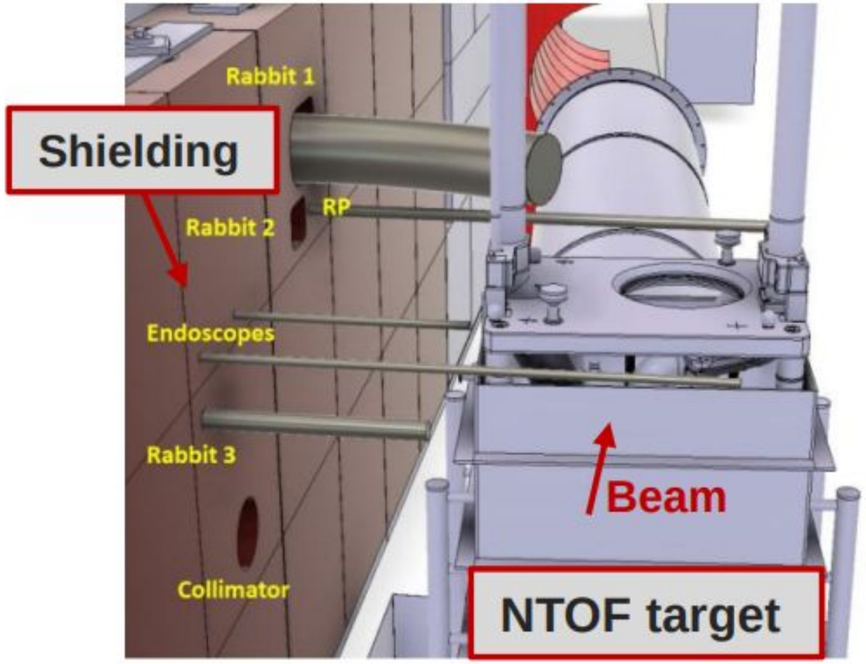


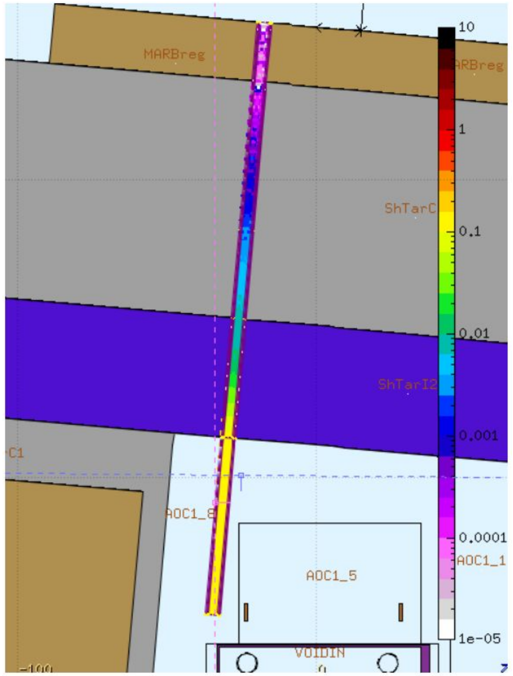
@Alexandra-Gabriela Șerban

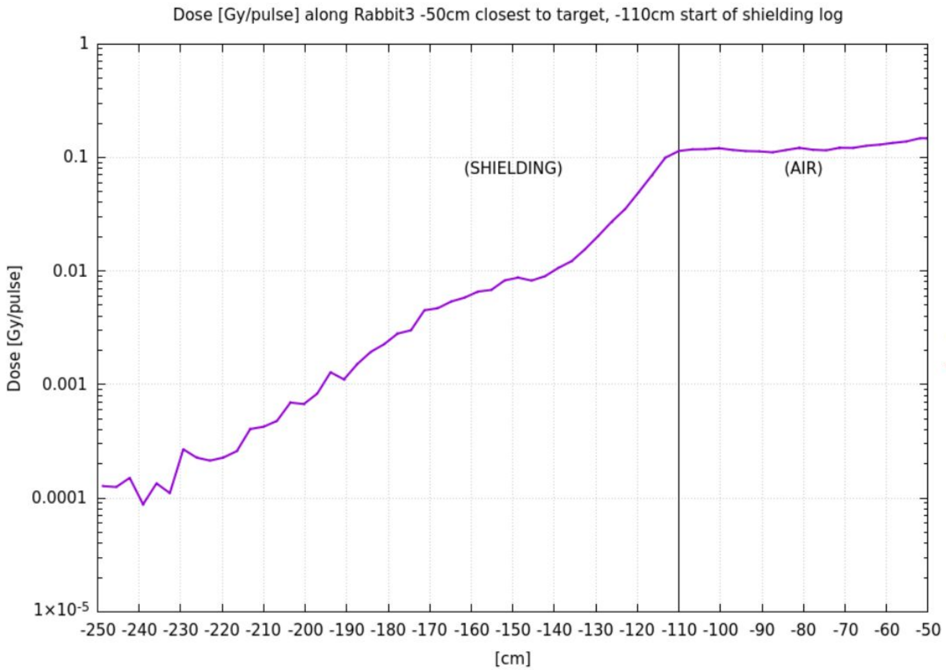


nTOF near station [18]

- Simulation of the **total dose** absorbed by **Aluminium Fluoride (AlF3)** samples installed in the **Rabbit3** position at **NEAR**, in the scope of **n_TOF** collaboration/INFN study of moderator material.
- The dose scoring was performed along **Rabbit3**, showing dose values around 0.12 Gy/pulse when the Rabbit is in air (target area) and an exponential decreasing when moving inside the shielding.
- For comparison, the dose in air just outside **Rabbit3** is of the order of 0.2-0.3 Gy/pulse.







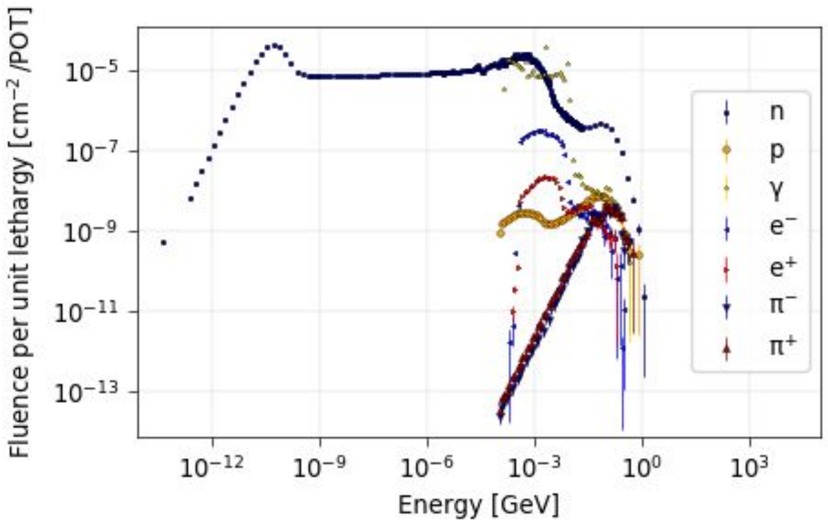
@Matteo Ceccheto

Target

Energy deposition per particle species

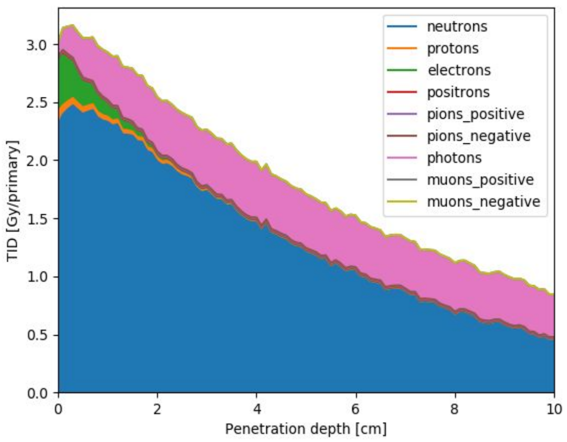
- Scoring of differential particle fluences in regions of interest.

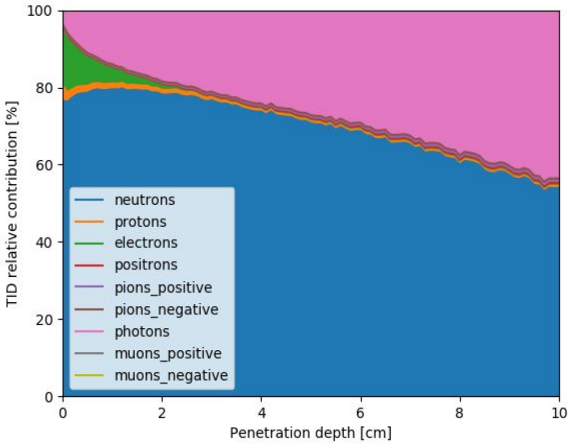
@Rabbit3 location



- Discriminating the contribution per particle species to the **total dose**.

- Defined as:
  dose from neutrons in a region of volume V as the dose deposited **in the region** by all neutrons coming **from outside that region**.



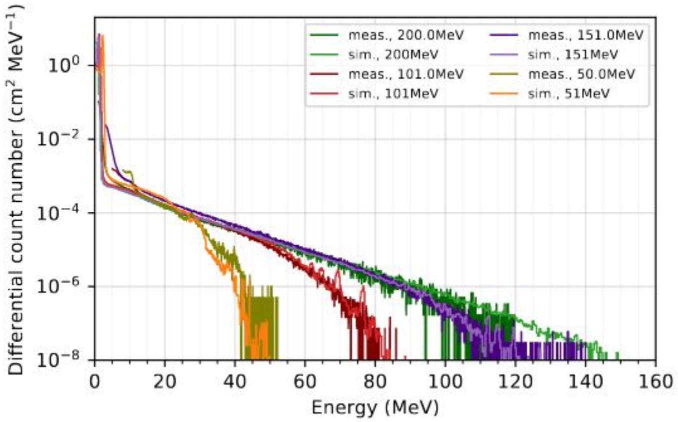


Detector development: Silicon solid-state detectors

@Kacper Bilko

Diode [19]

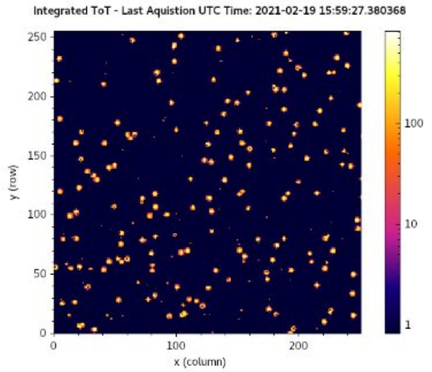
- Investigate the use of silicon diodes for the monitoring of the mixed radiation field.
- Simulated values are within 35% agreement with respect to the experimental measurements with high-energy protons.
- Additionally, not only the counts but also the entire energy deposition events are recorded



TimePix3 [20]

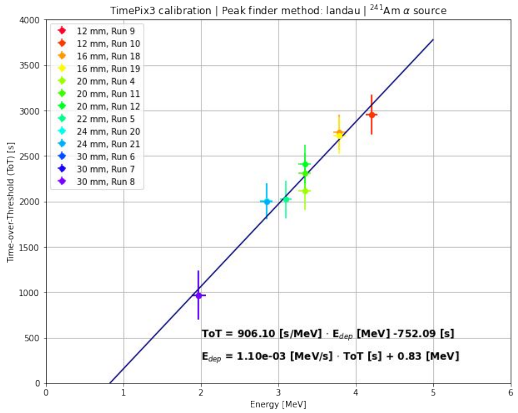
@Ivan Slipukhin, David Lucsanyi

- Possible use as Beam Loss Monitor, for monitoring of the radiation field spectrum in the accelerator complex.
- Interchangeable with the diode. So far, we see that, compared to the diode, it is more sensitive below 100 keV (because of less noise, more accurate DAQ chain, etc.), so it allows to cover a different energy spectrum range.
- Energy calibration with various sources.



Am-241 39 kBq (4276RP)

Distance from the detector: 20 mm (60 sec)



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14. Daniel Prelipcean et al, Benchmark between measured and simulated radiation level data at the Mixed-Field CHARM facility at CERN, https://indico.cern.ch/event/971222/contributions/4089084
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Thank you for your attention!

R2E-RP conversion coefficients at the LHC [A1]

- Use FLUKA to estimate radiation quantities:
  - in absolute terms -> benchmark with measurements.
  - in relative terms to each other -> experimental radiation monitors do not measure all radiation quantities, but only a subset.
- Considered quantities: Ambient Dose eq., Total Ionising Dose, High Energy Hadron eq., 1 MeV Neutron eq.
- Goal: Exploit measurements of single quantities and estimate the other quantities, using the ratios from this study.