Shower simulations for the CERN Proton Synchrotron internal dumps and comparison with beam loss monitor data

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12th October 2023

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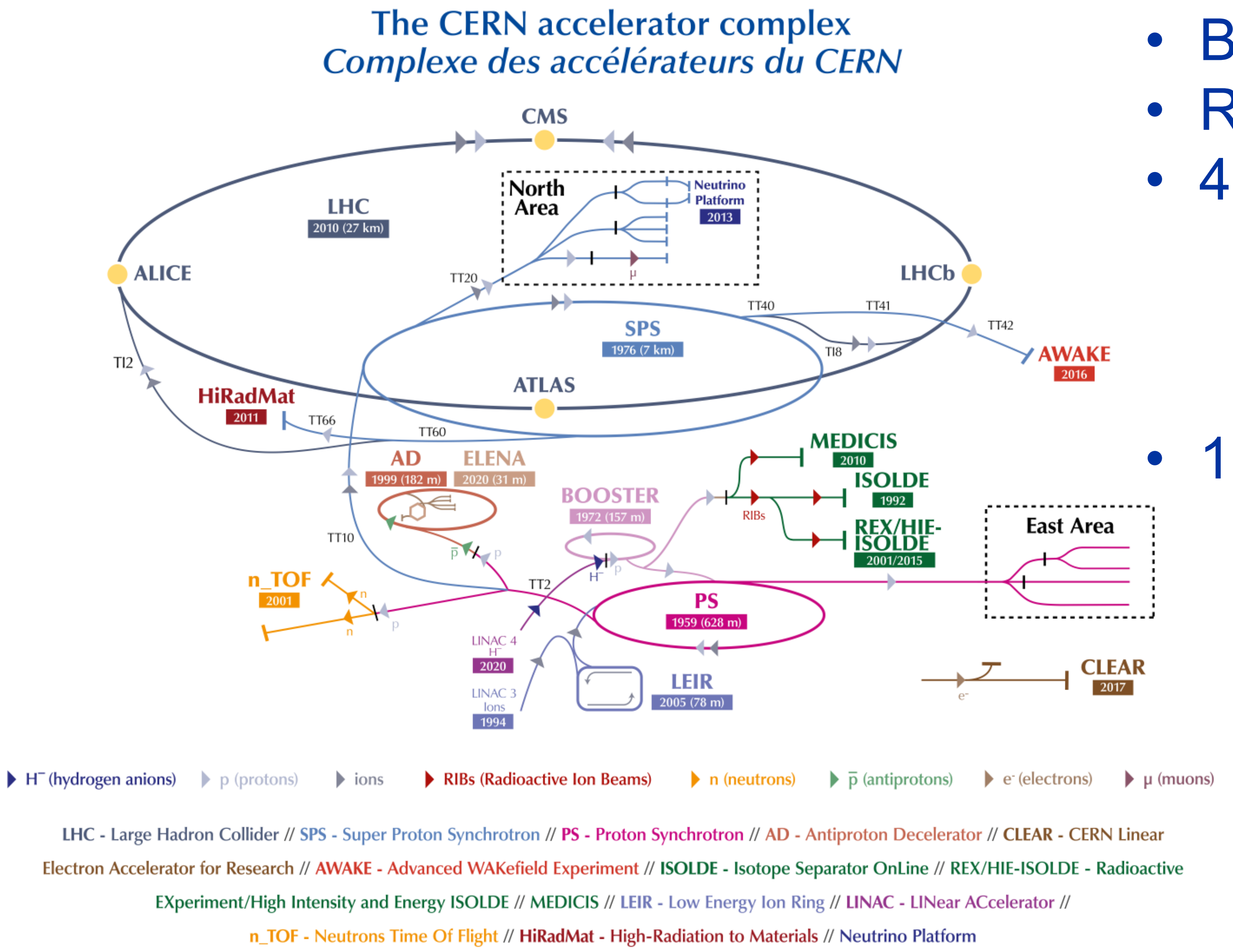
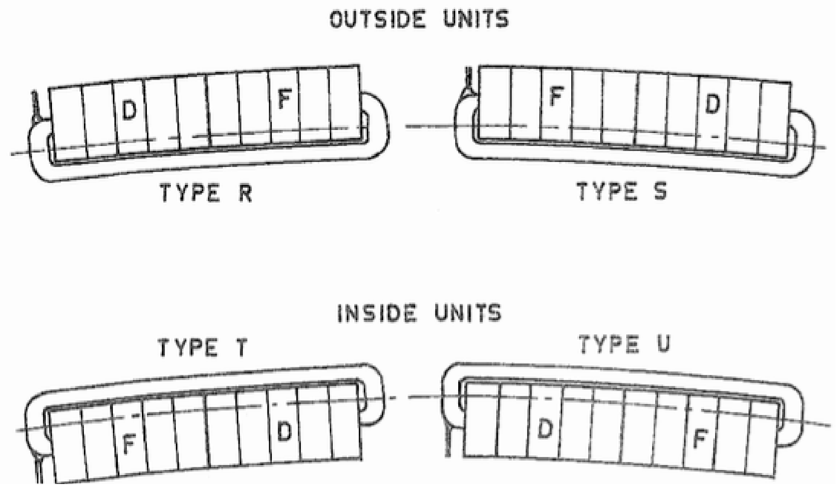
Introduction to the Protons Synchrotron and the internal dumps

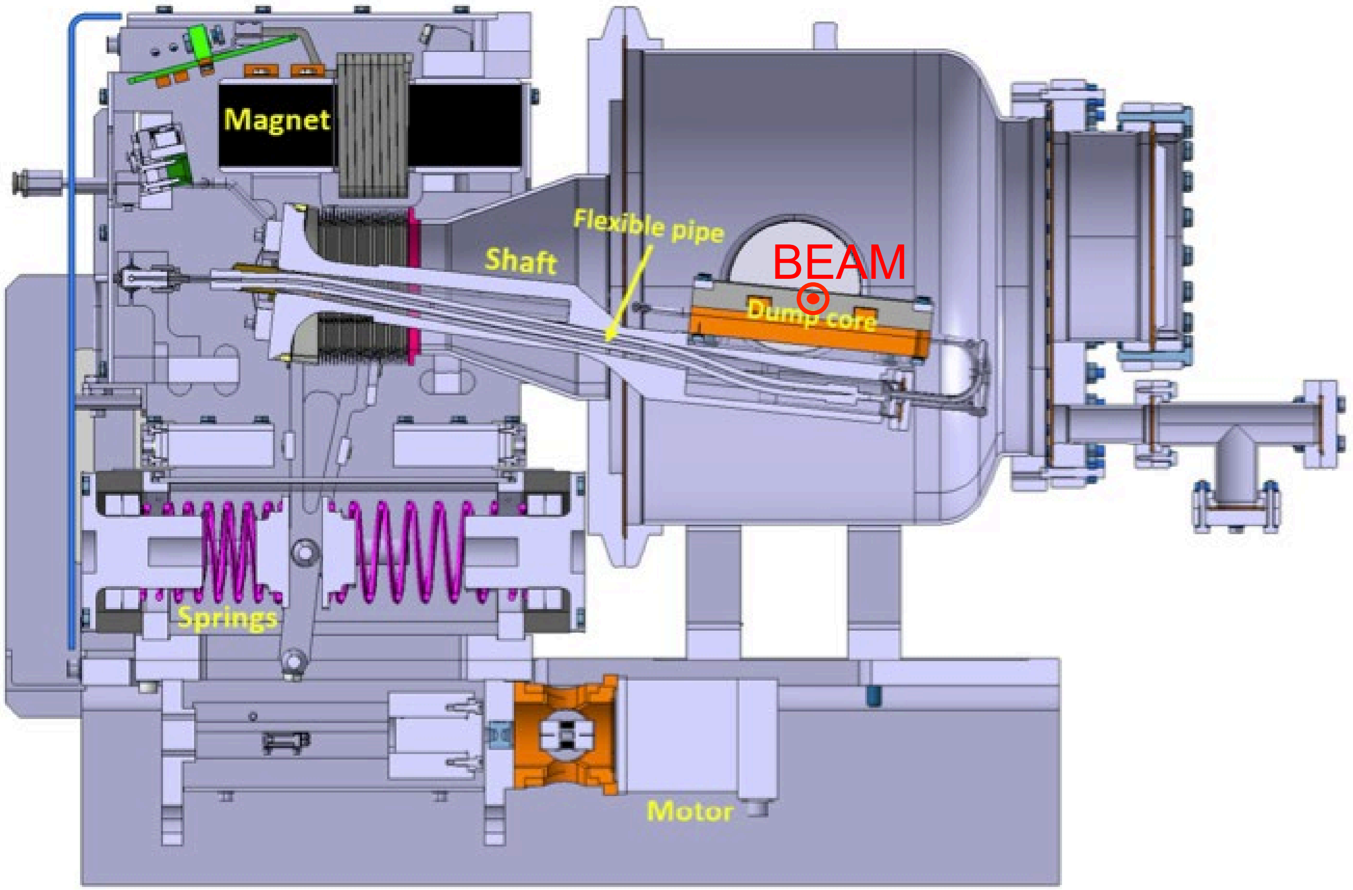
The Protons Synchrotron in brief

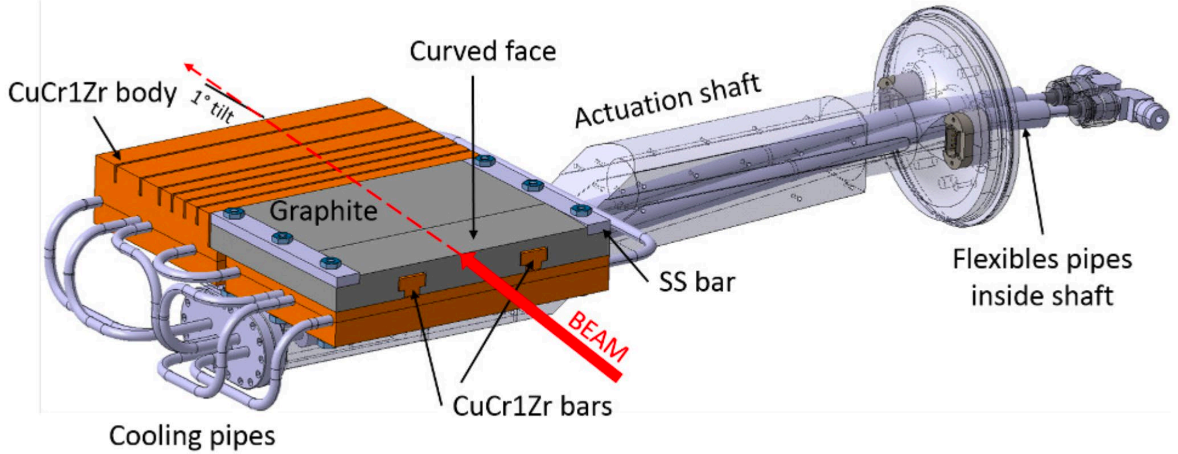


- Bring protons up to p = 26.4 GeV/c
- Radius of the accelerator : 100 m
- 4 kinds of multi-function main magnets
  - Focus and Defocus
  - Trajectory bending
  - Internal or external yoke
- 100 sections / 100 main magnets



The PS internal dumps





Two internal dumps

- TDI 47 and TDI 48 in section 47 and 48, respectively
- Installed in 2020 during LS2
- **2.4 x 10^{17} protons / year, spread over the two dumps [1]**
- 200 000 dump cycles per year for 20 years [2]
- Not sufficiently long to fully contain the proton beam

Data extraction: BLM, current, energy

Dedicated Machine Development to send the beam on the dumps according to the different cycles

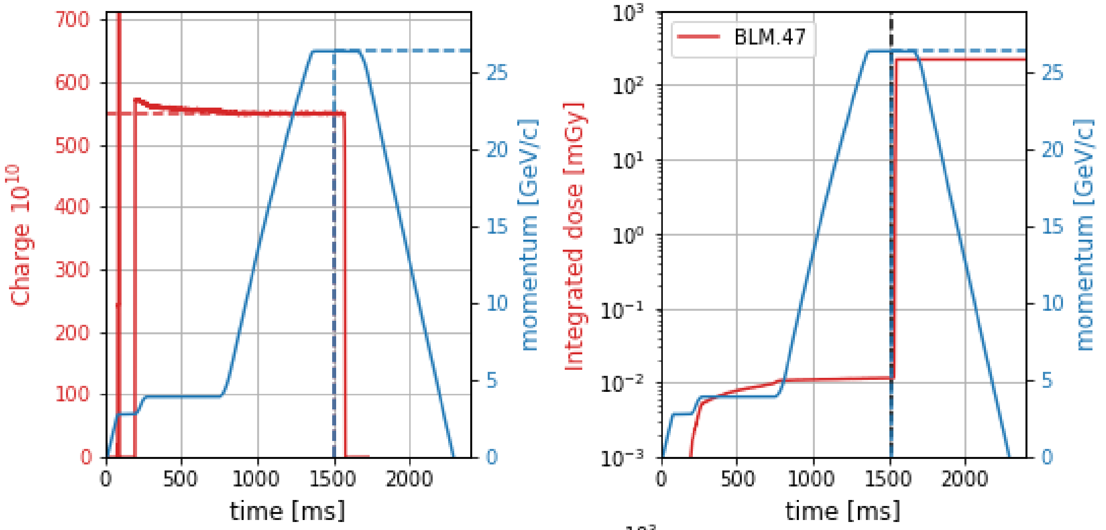
Four scenarios considered

Beam optics	Momentum [GeV/c]	Dump used	Simulation done	Experiment done
LHC	26.4	47	Yes	Yes
LHC	26.4	48	Yes	Yes
LHC	3.9	47	No	Yes
SFTPRO	14.0	47	Yes	Yes

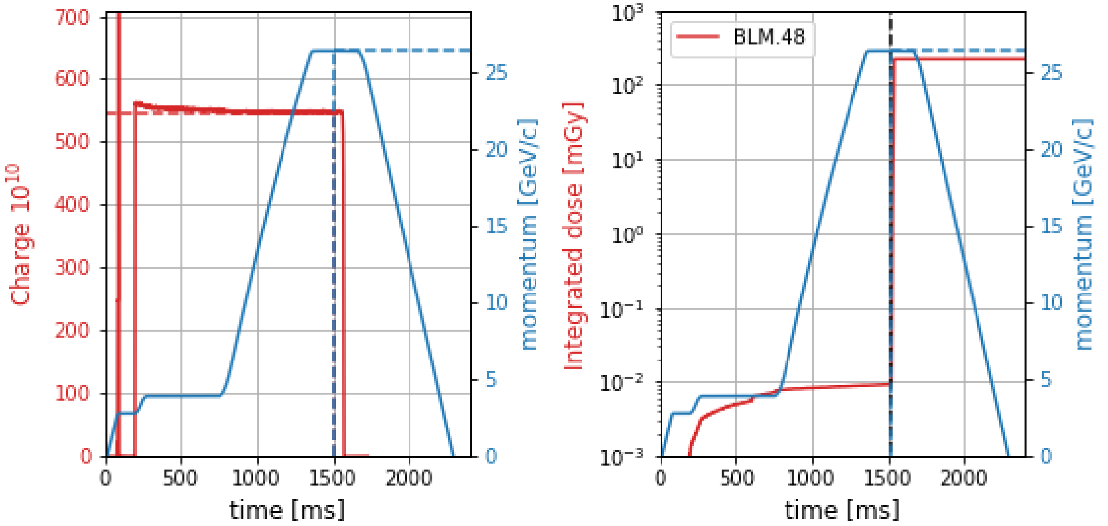
Four scenarios considered

- The dumps have been activated on purpose
- We check the value of the variables when the dump is activated
- Charge, magnetic field, Beam Loss Monitor

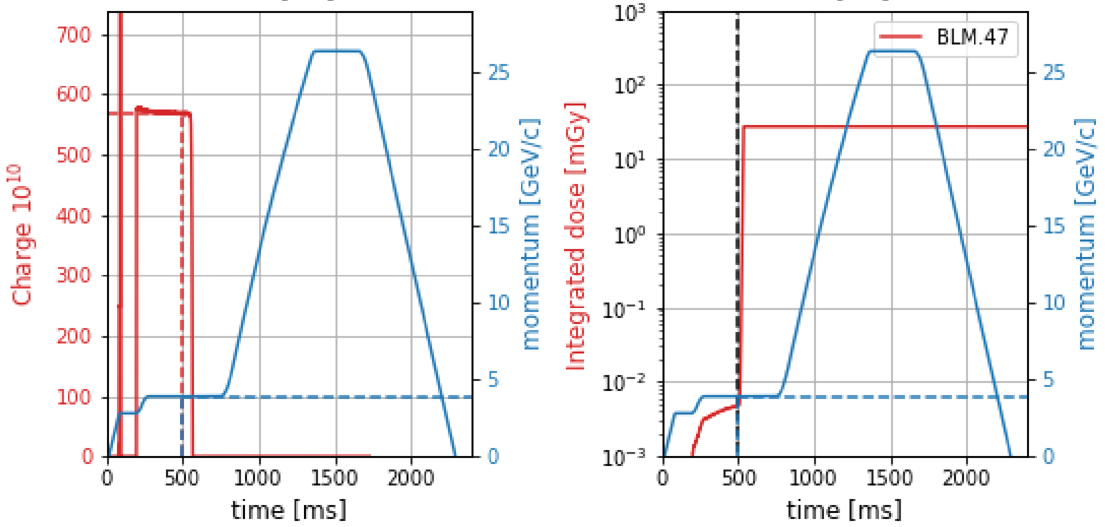
LHC
p = 26.4 GeV/c – TDI 47



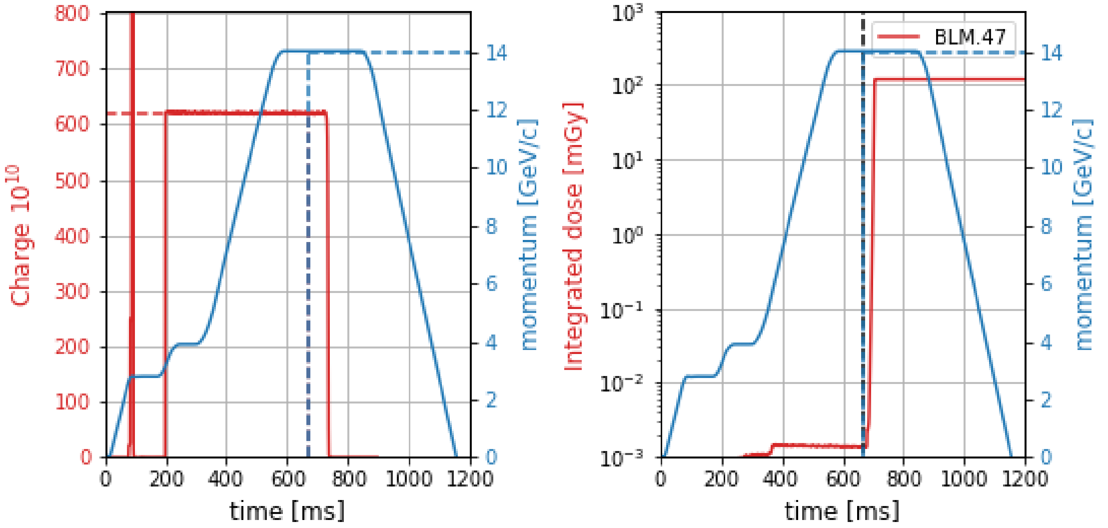
LHC
p = 26.4 GeV/c – TDI 48



LHC
p = 3.9 GeV/c – TDI 47



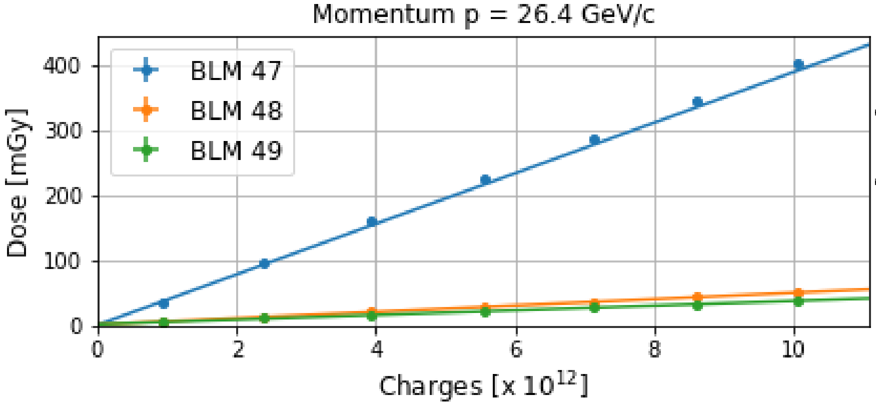
SFTPRO
p = 14.0 GeV/c – TDI 47



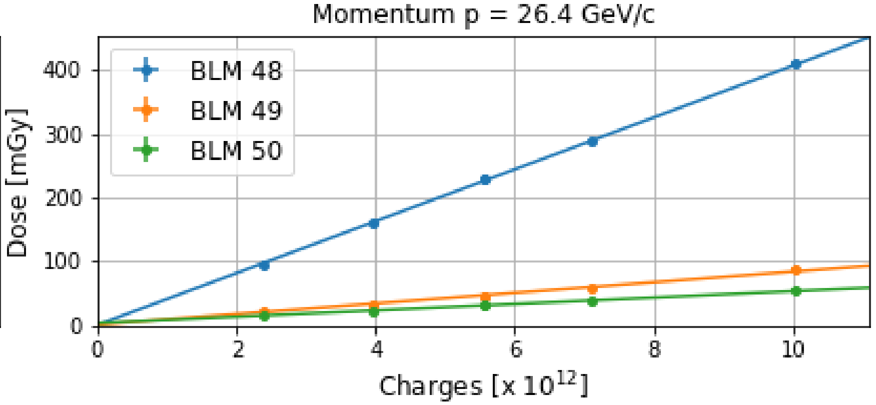
BLM response

- Here, the error bars are computed as the std of the measured dose/intensity (several cycles for each intensity).
- Systematic errors coming from the BLM/BCT have not included yet.

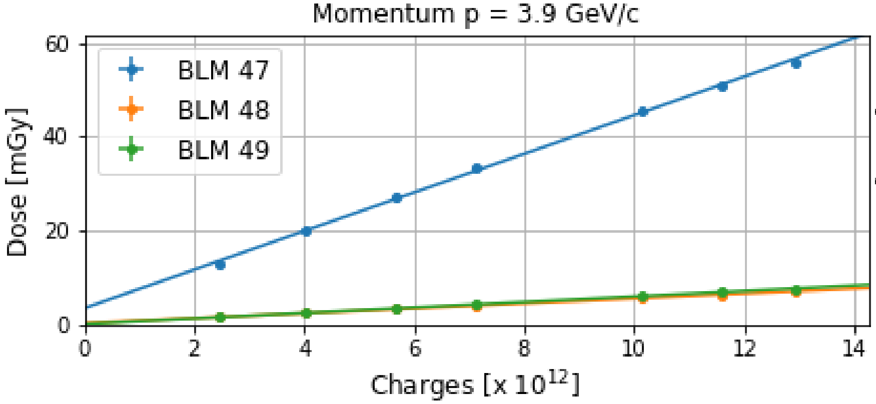
LHC 26.4 GeV (dump 47)



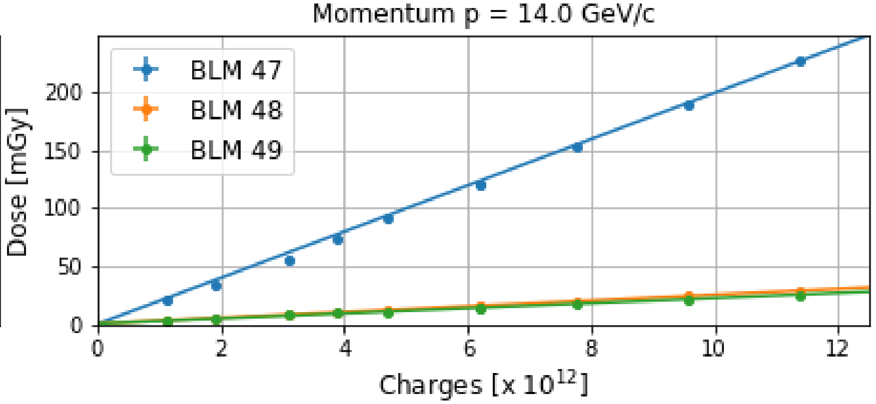
LHC 26.4 GeV (dump 48)



LHC 3.9 GeV (dump 47)



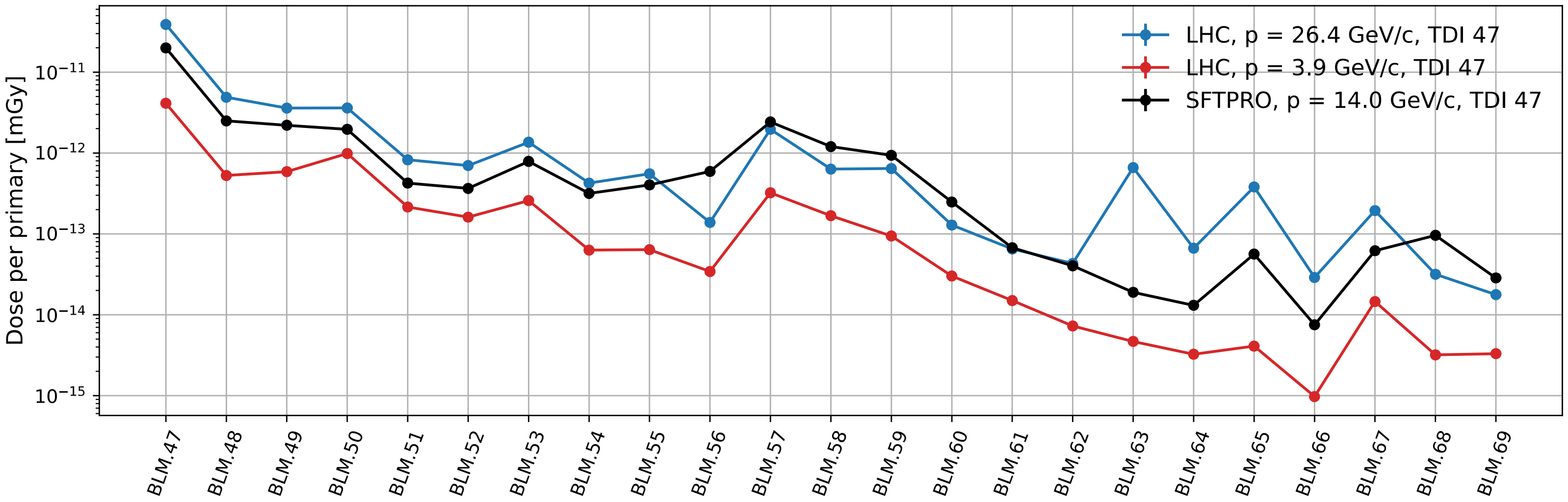
SFTPRO 14 GeV (dump 47)

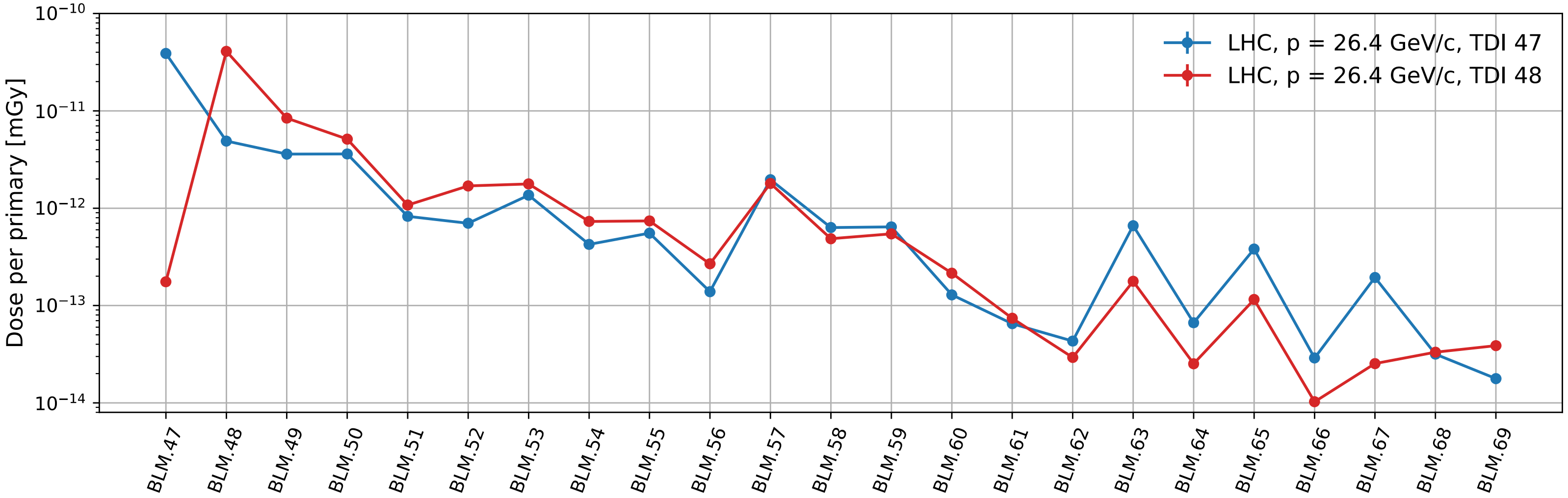


- The goal is to obtain the dose per primary for each BLM
- To compare with the FLUKA simulations
- We assume a linear response of the BLMs

BLM loss maps

Here, the error bars are outputs of the fits shown in the previous slide



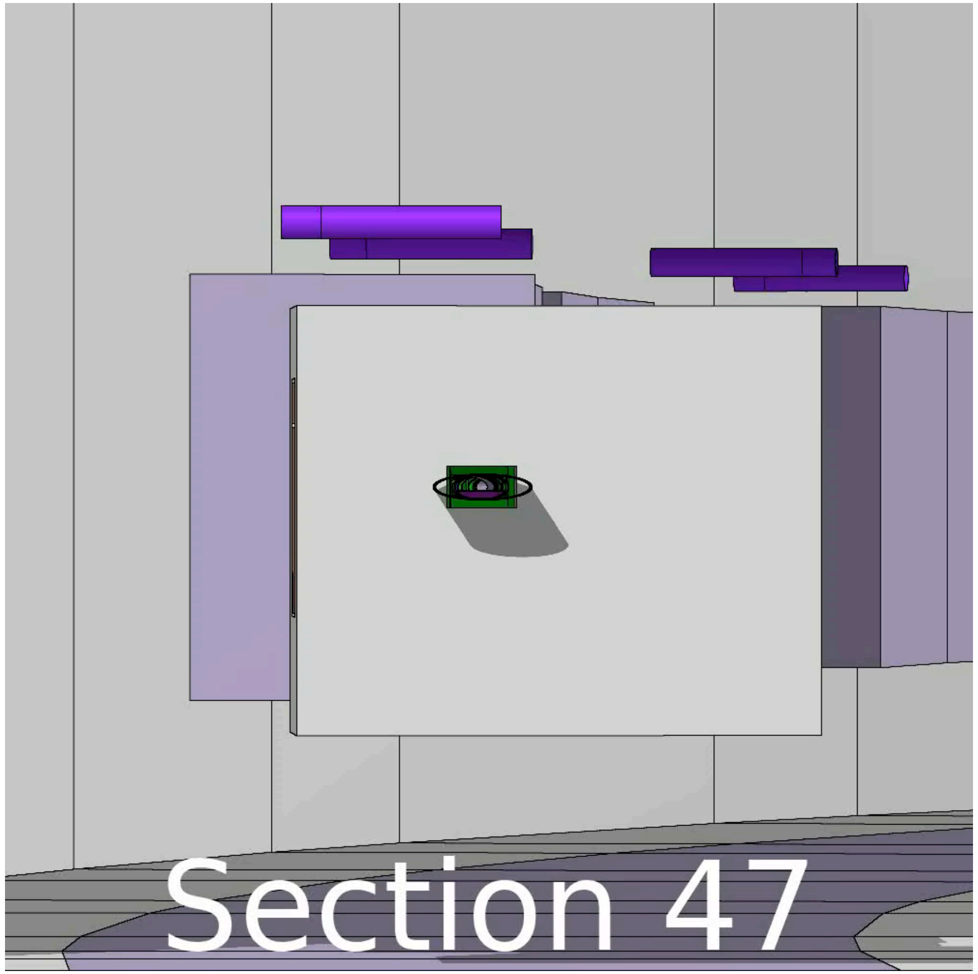


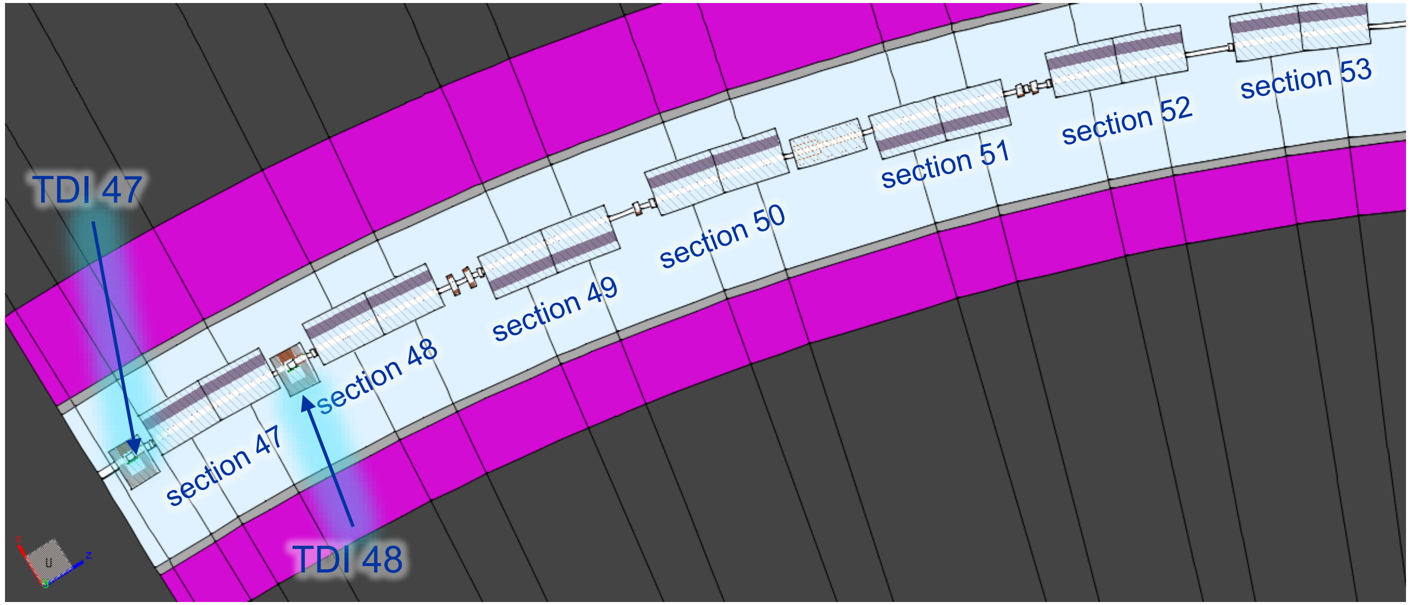
- The dose increase with the energy.
- Maximum in section 47 when TDI 47 is used and in section 48 for TDI 48 but in the other sections, the dose is similar.
- Increase close to the extraction line in section 63-65.

FLUKA simulations

Geometry and beam source term

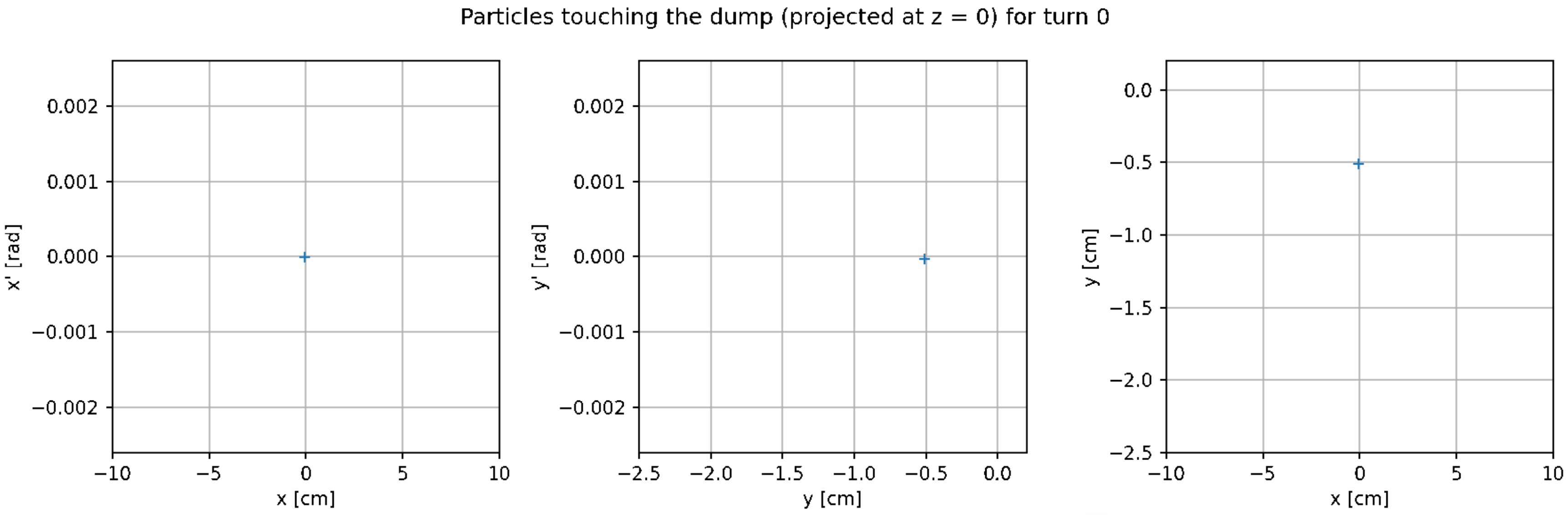
Geometry

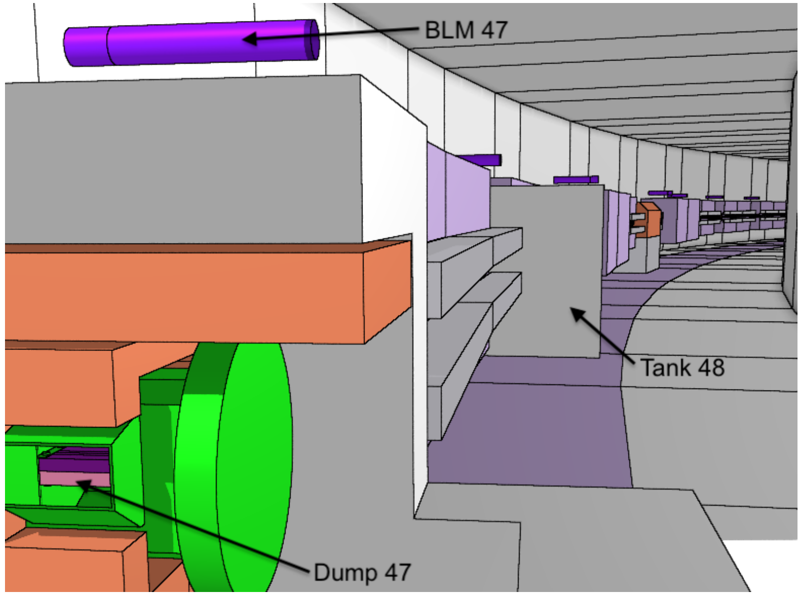




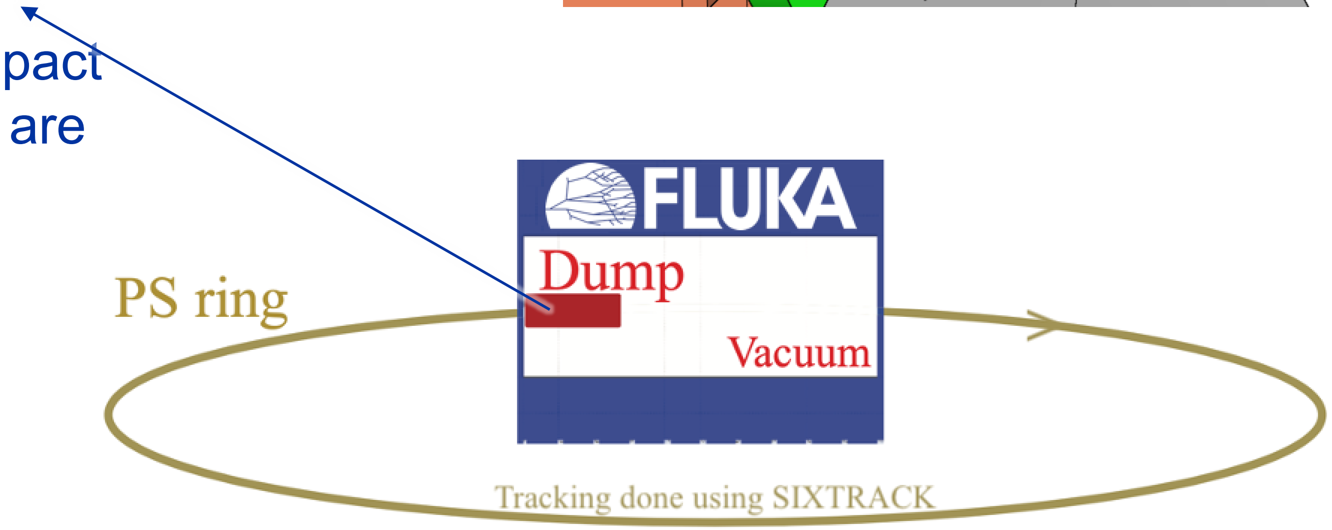
- From section **47 to 69** (included)
- Approximated mechanical models of the magnets.
- Analytical function to describe the magnetic field in the main magnets

Inputs to the shower simulations





- Sixtrack multi-turn simulations provide the impact parameters of the protons on the dumps and are the first step of the simulation chain
- Proton tracking in the PS is done for selected beam optics and with an accurate aperture model.
- More details on T. Pugnat's poster.



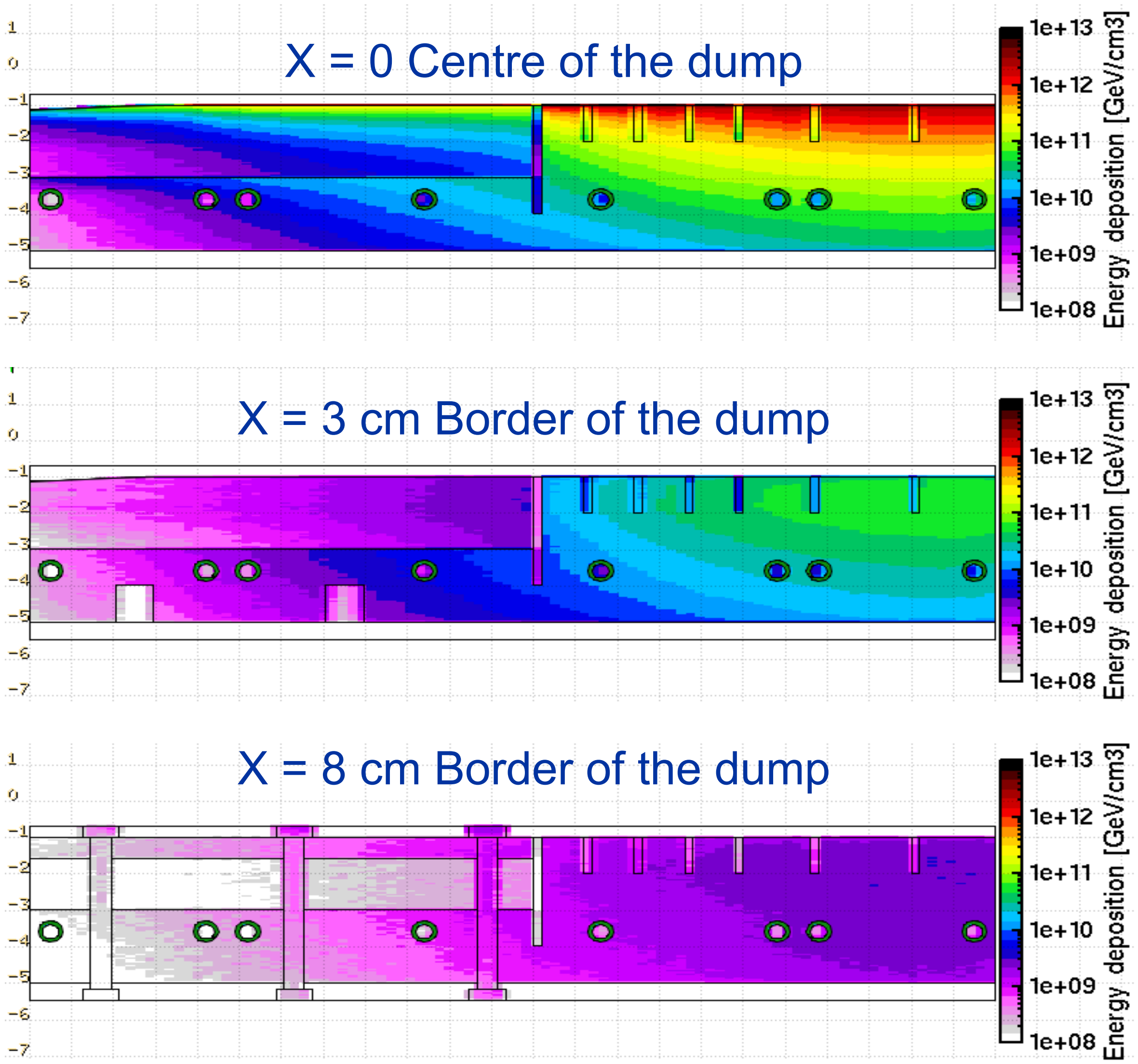
Analysis of the FLUKA results

Energy density in the dump

LHC beam at flat top impacting on TDI 47

Annual dose in the main magnets

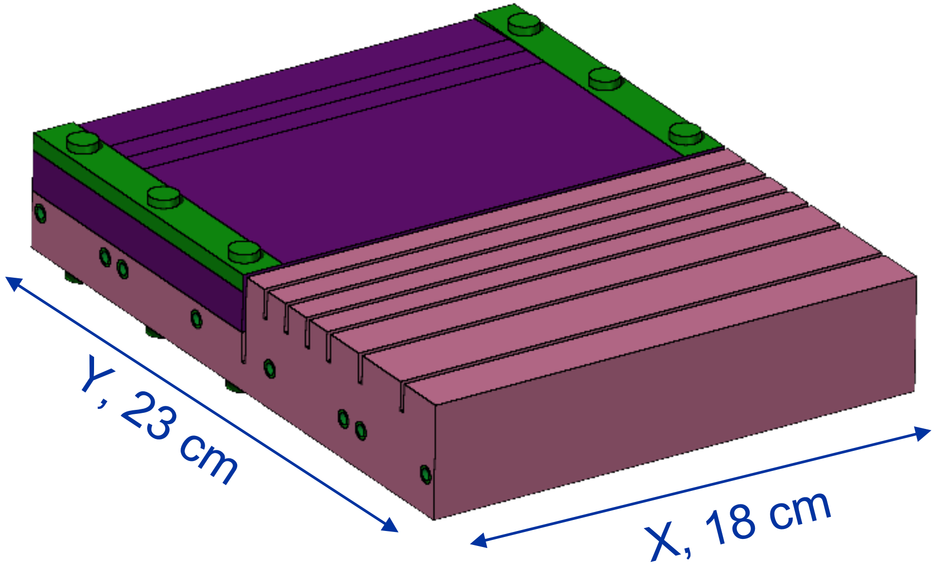
Energy density in the dump



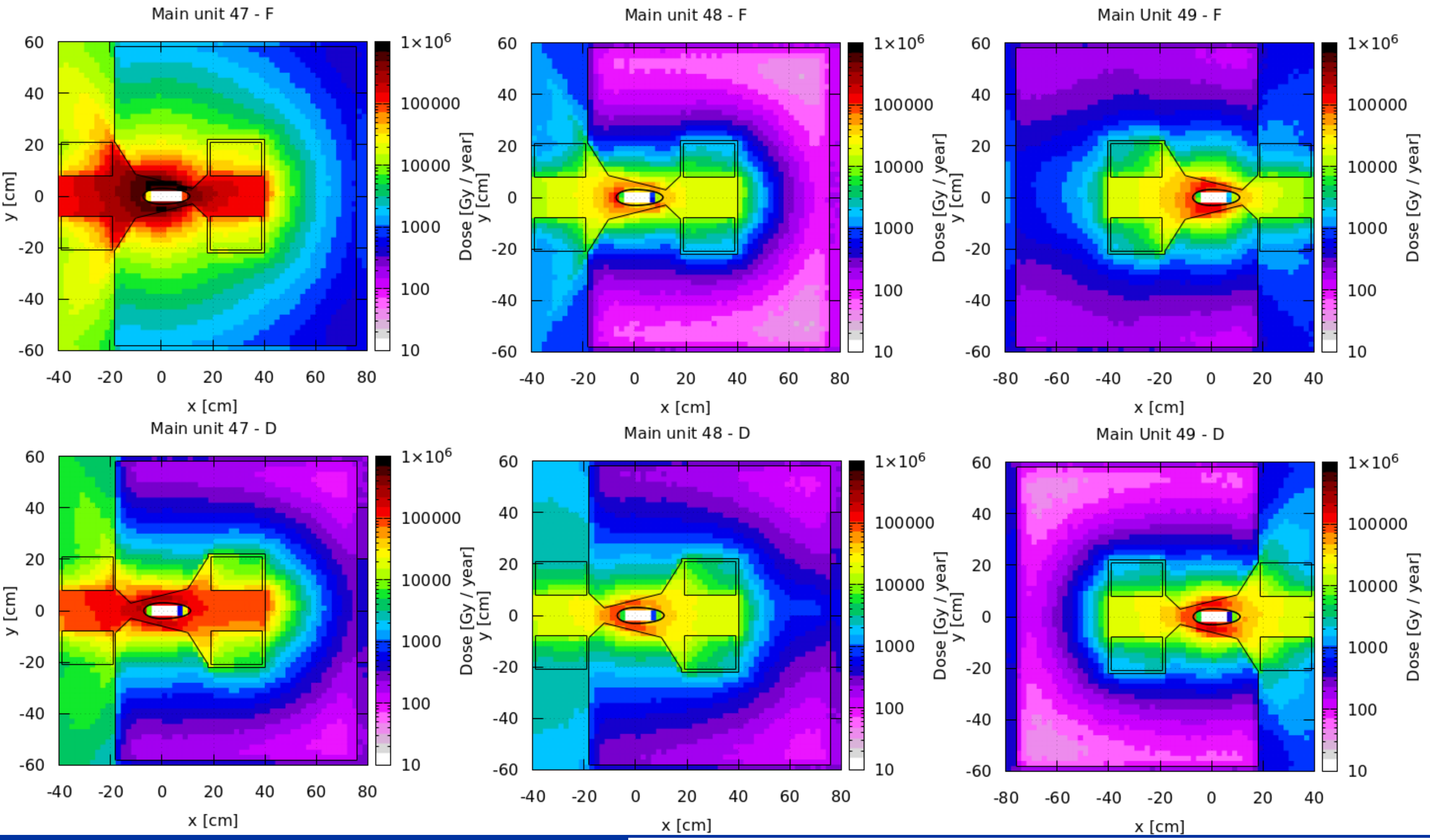
- Assumptions
  - LHC beam at 26.4 GeV/c
  - Normalised to 5e13 / pulse [1]

- Energy absorbed / primary: 1.64 GeV
- Kinetic energy: 25.4 GeV
- Ratio energy absorbed: 6.45 %
  - Comparison with [2] with p = 26 GeV/c, 7.3%

- Fraction of primary protons with a nuclear interaction in the dump: 72 %

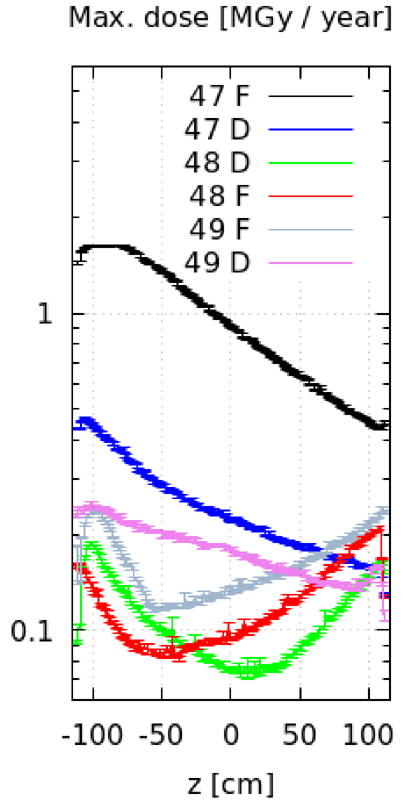


Annual dose in the first main magnets



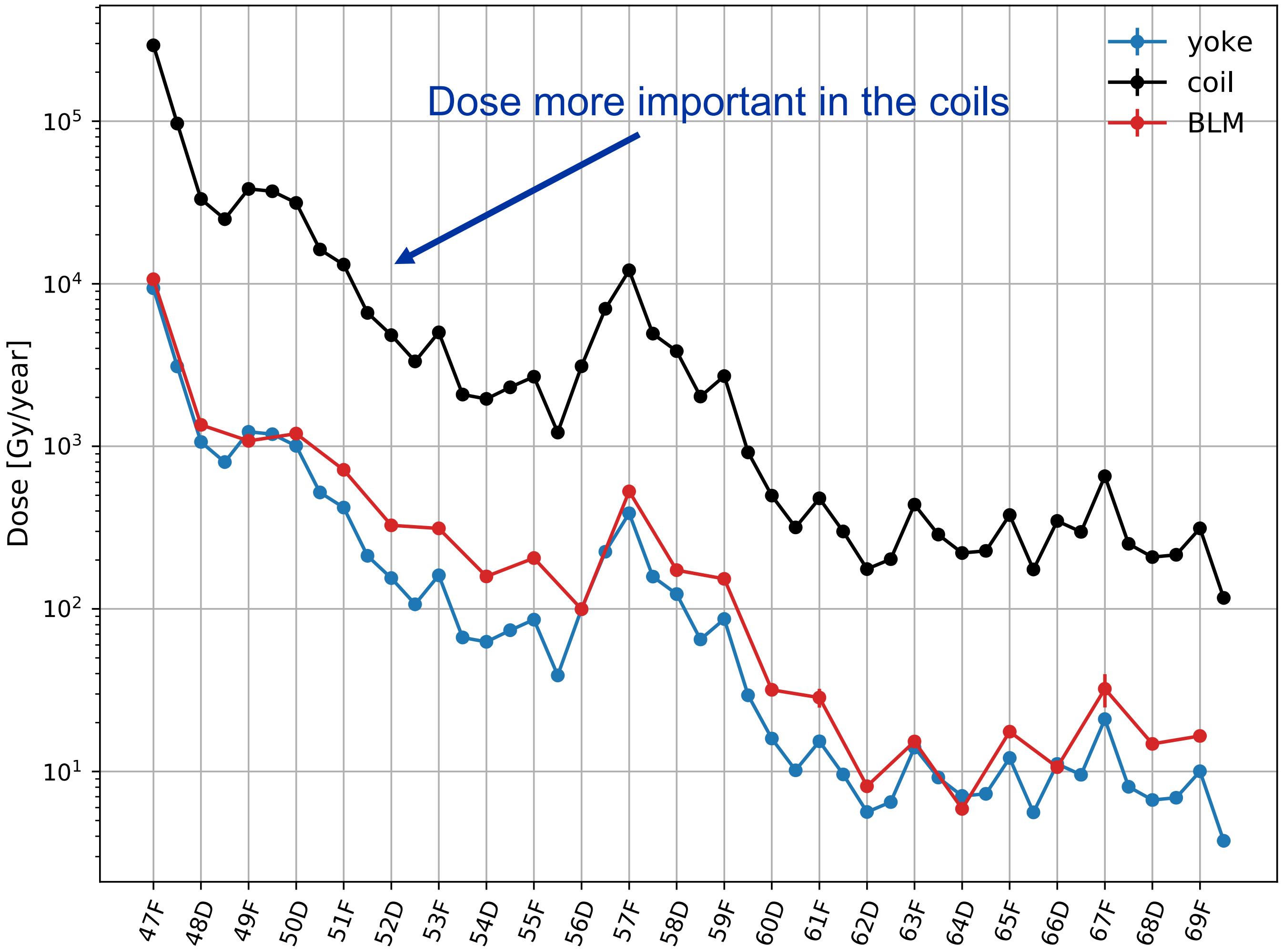
Conservative assumptions

- All protons of one year sent on TDI 47
- With p = 26.4 GeV/c
- LHC flat top optics



Normalized to 2.4 x 10^{17} protons per year [1]

Annual dose main magnets



Conservative assumptions

- All protons of one year sent on TDI 47
- With p = 26.4 GeV/c
- LHC flat top optics

Location	% of the kinetic energy
Main magnets	49.8
Tank around dump 47	14.1
Tunnel	11.3
Dump 47	6.5
Tank around dump 48	4.8
Other elements	3.5
Beam pipes	2.4
Air	0.1
Into nucleus mass	6.3
Neutrinos	1.2

Normalized to 2.4 x 10^{17} protons per year [1]

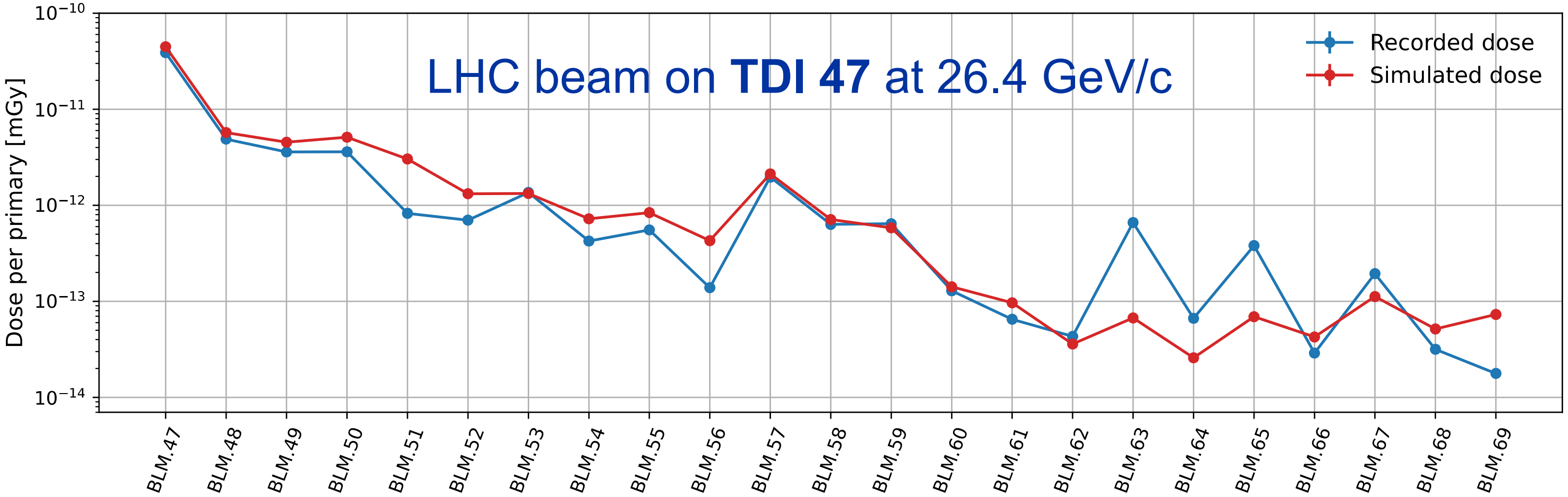
Data vs Simulations

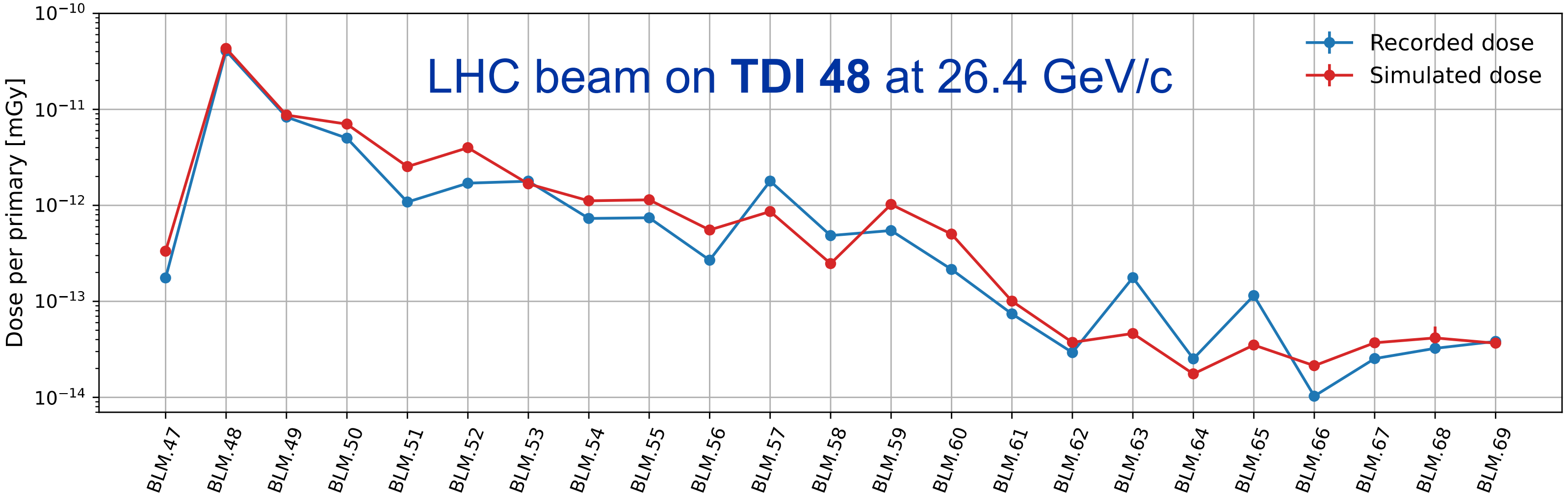
LHC beam at flat top (both dumps)

SFTPRO beam at flat top (only TDI 47)

Closed orbit measurements

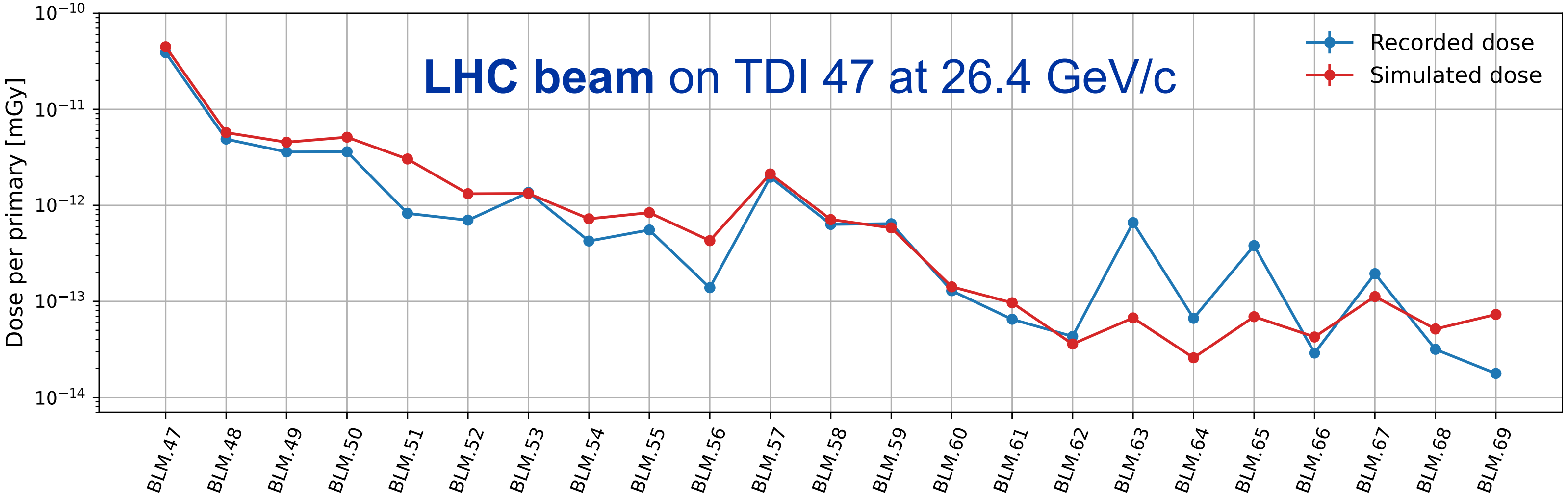
Dose in the BLMs: LHC beam at flat top

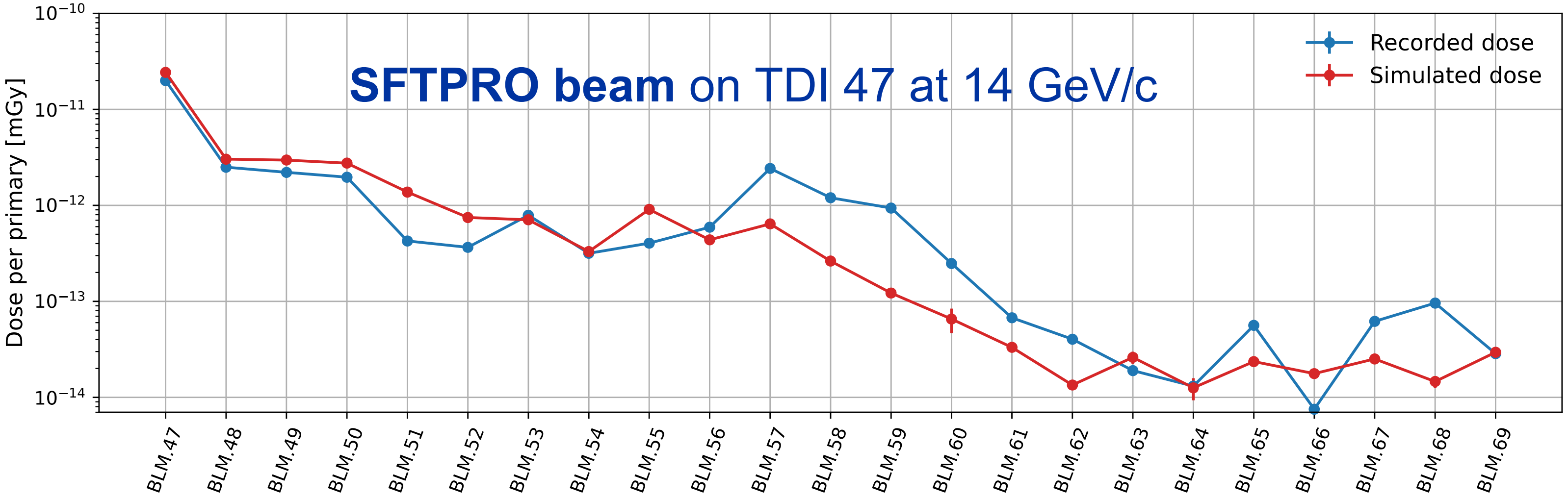




- We observe a discrepancy along the extraction region (62 to 65), see next slides for hypothesis
- For LHC beam at flat top, results for TDI 48 are matching better than for TDI 47

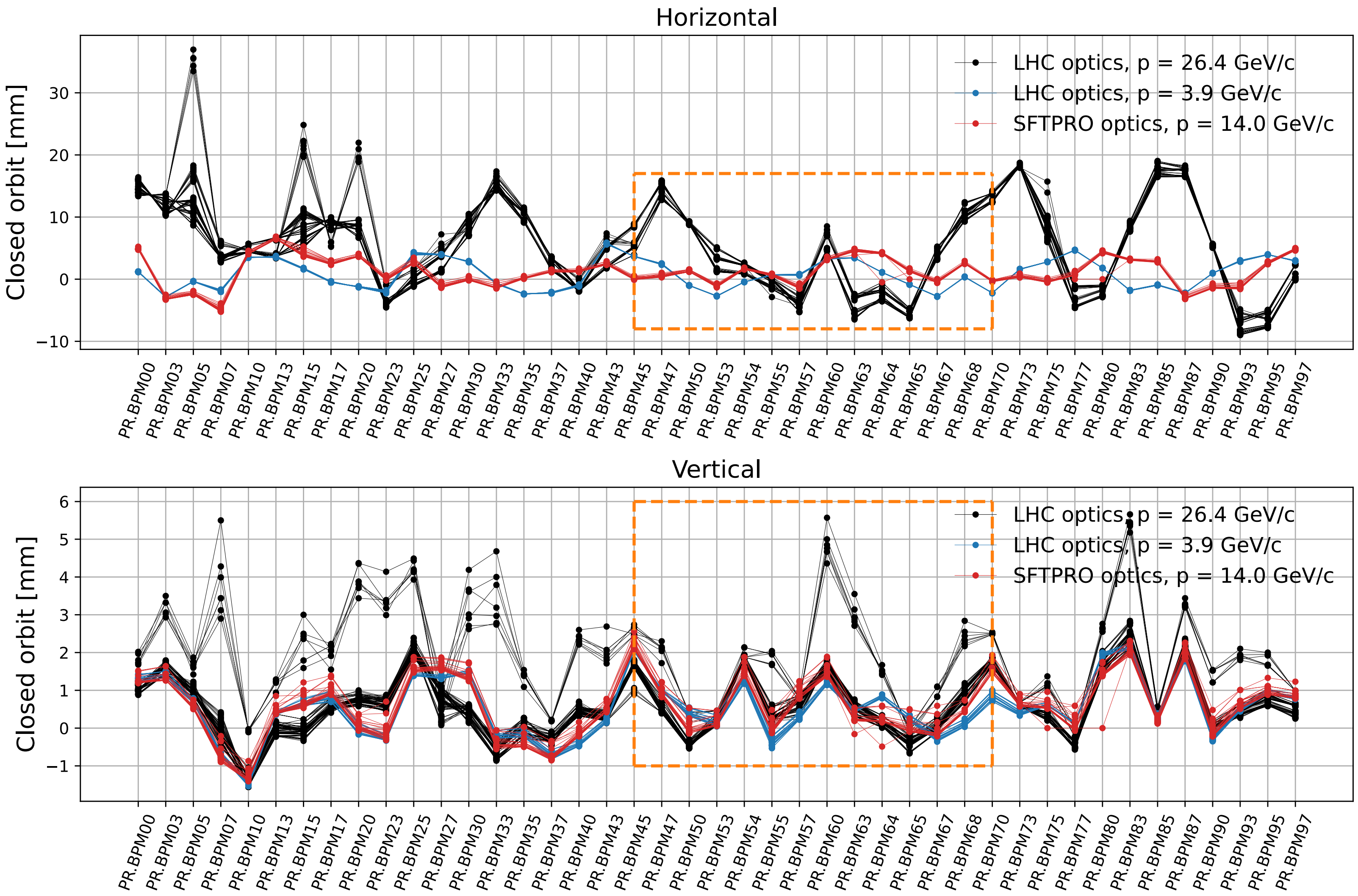
Dose in the BLMs: LHC and SPS beams





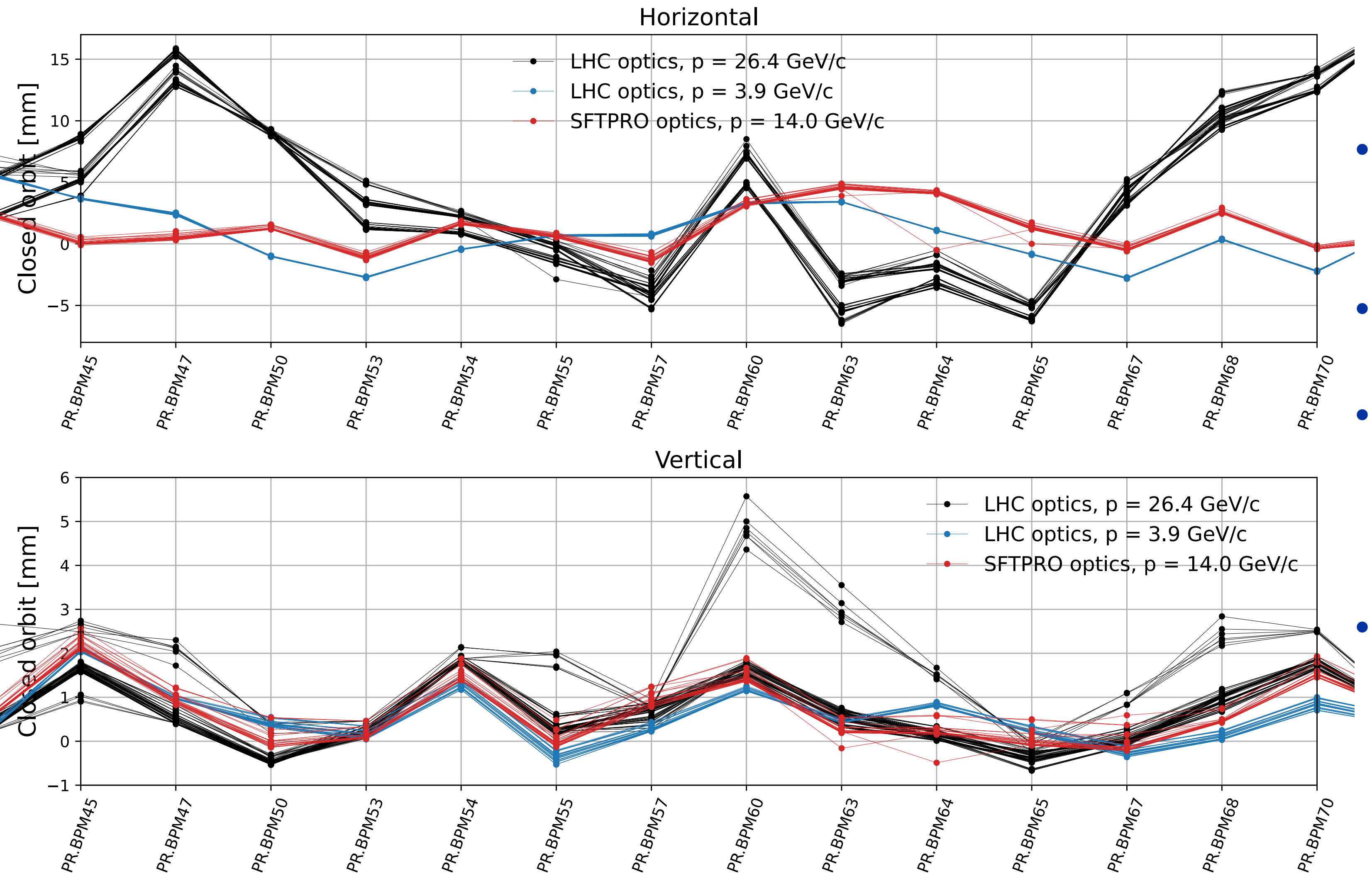
- We observe a discrepancy along the extraction region (62 to 65), see next slides for hypothesis
- For LHC beam at flat top, results for TDI 48 are matching better than for TDI 47
- For SFTPRO beam, the simulation underestimates compared to the BLM data

Closed orbit measurements



- Closed orbits measured experimentally
- They are non-negligeable
- In particular, large horizontal offset are observed at dump locations (> 1 cm)
- Not included in present simulations, but they will be implemented in a future work.

Closed orbit measurements



- Closed orbits measured experimentally
- They are non-negligeable
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- Not included in present simulations, but they will be implemented in a future work.

Conclusions and outcomes

Conclusions and outcomes

- **Results**
  - Good agreement between data and simulations
  - Around 7% of the energy captured, rest of the energy is absorbed in the beam elements, walls and escaping the region (mainly neutrinos)
  - Evaluated the accumulated dose in the most exposed main magnets
- **Outcomes**
  - Evaluate the statistical and systematic errors for the BLM dose and charge intensity
  - Evaluation of the systematics effect due to the BLM positioning
  - Implement the closed orbit in our simulations
- **Tonight**
  - Don't miss Thomas Pugnat’s poster, if you want more details about the multi-tracking simulations
- **References**

  - [1] PS Ring Internal Dumps Functional Specifications, EMDS PS-TDI-ES-001
  - [2] Engineering design and prototyping of the new LIU PS internal beam dumps, 10.18429/JACoW-IPAC2018-WEPMG001

Thank you for your attention,

I am waiting for your questions.