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

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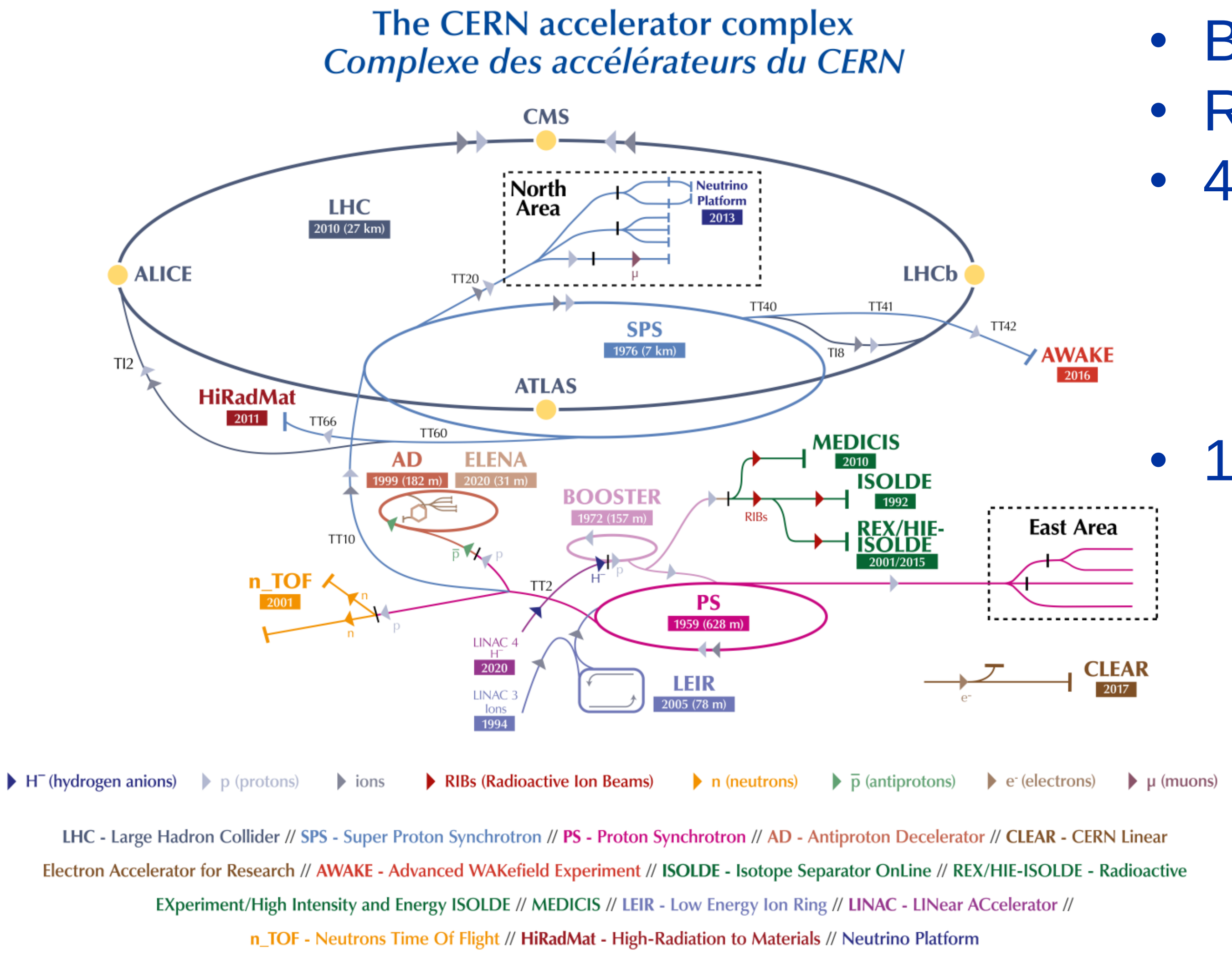
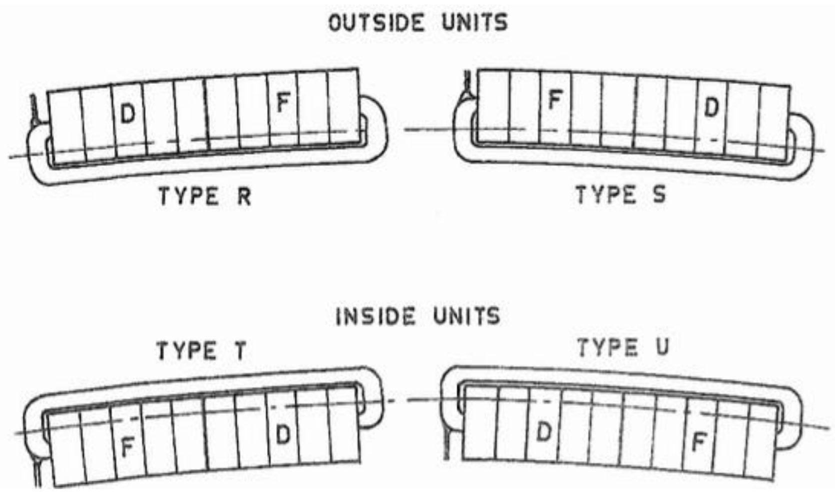
Introduction to the Protons Synchrotron and the internal dumps

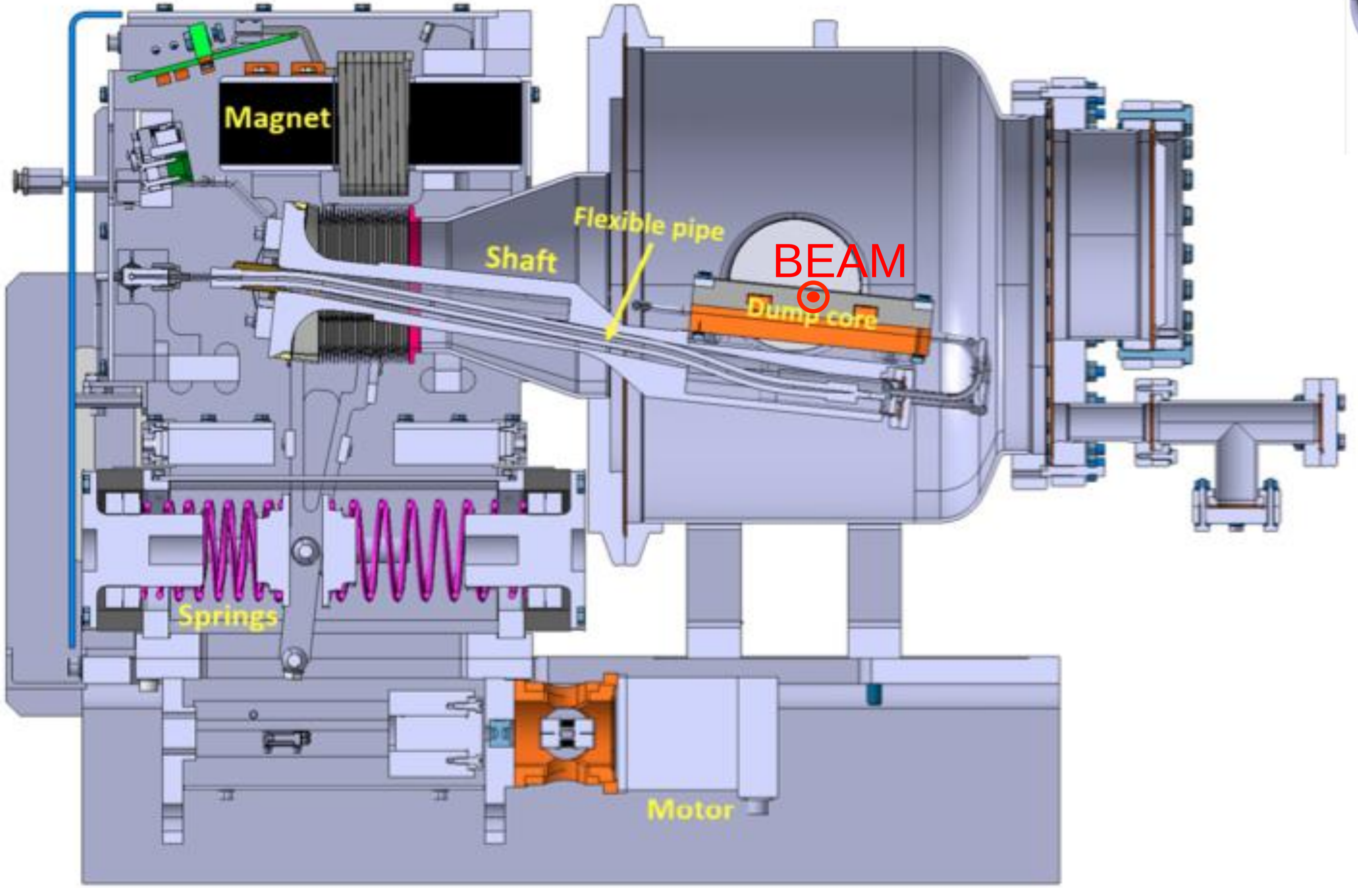
The Protons Synchrotron in brief

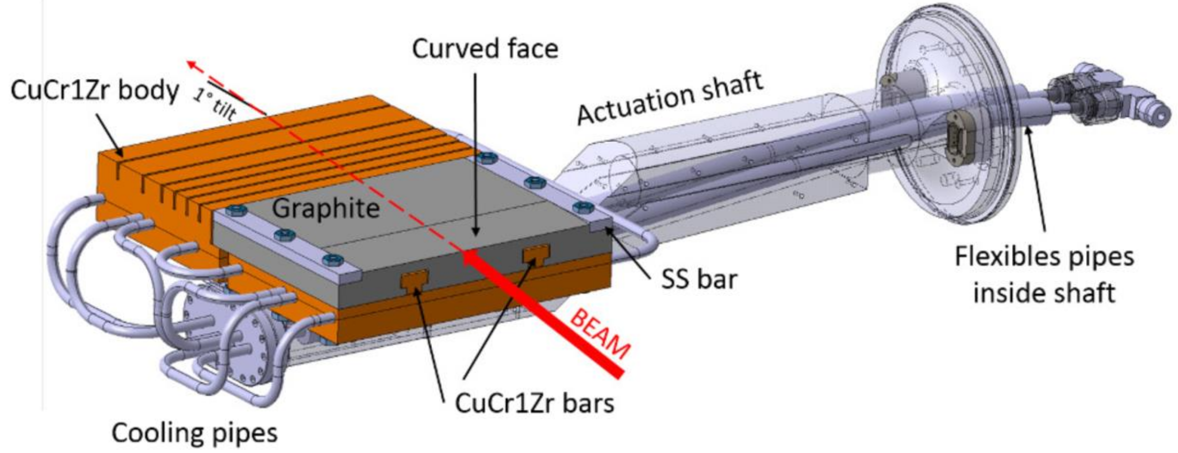


- Bring protons up to p = 26.4 GeV/c
- Radius of the accelerator : 100 m
- 4 kinds of multi-function main magnets
  - Focus and Defocus
  - Trajectory bending
  - Internal or external yoke
- 100 sections / 100 main magnets



The PS internal dumps





Two internal dumps

- TDI 47 and TDI 48 in section 47 and 48, respectively
- Installed in 2020 during LS2, for **LIU beam**
- **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
- **Movable dumps** with pneumatic

Data from MD tests

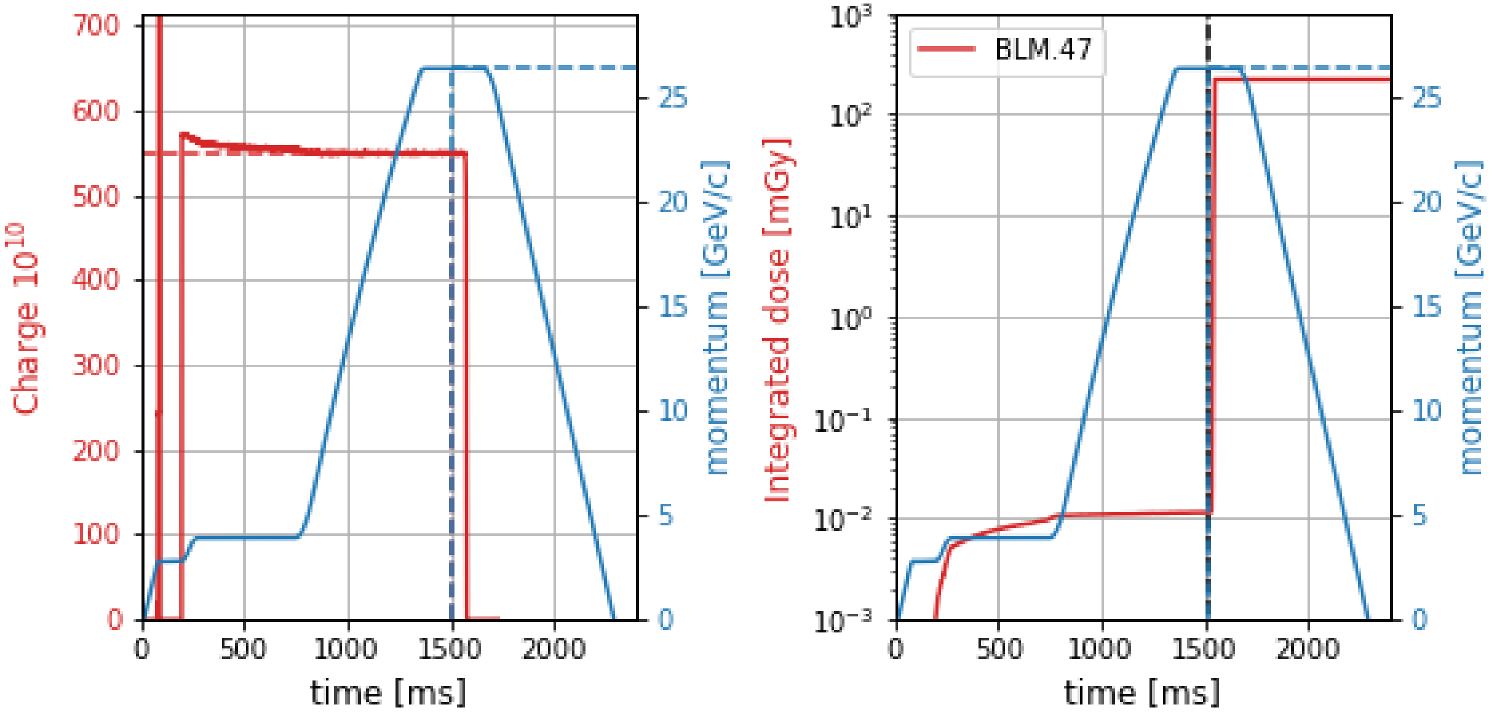
BLM, current, energy when the dump is activated

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

Beam data

LHC p = 26.4 GeV/c – TDI 47

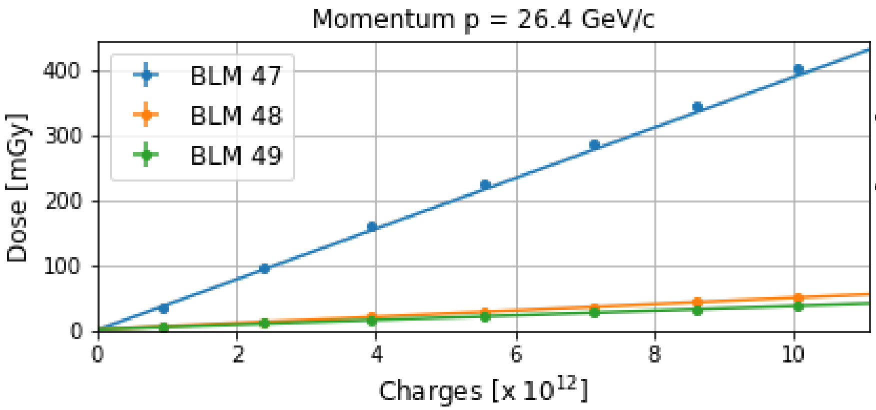


- The dumps have been activated on purpose
- We check the value of the variables when the dump is activated
- Charge, magnetic field, Beam Loss Monitor

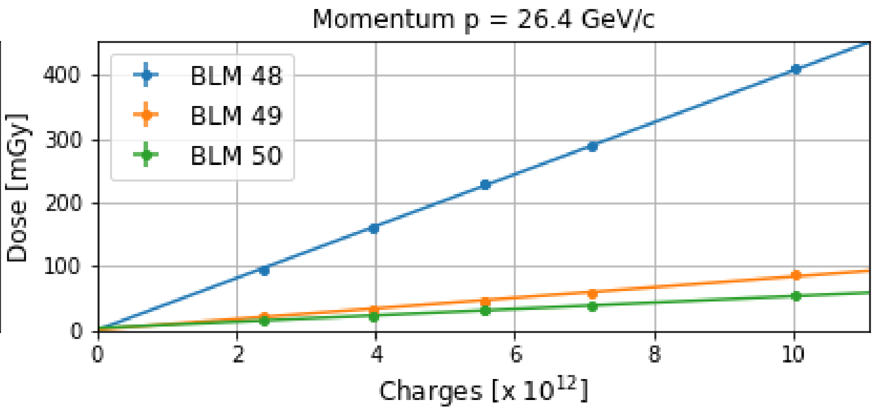
BLM response

- 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.

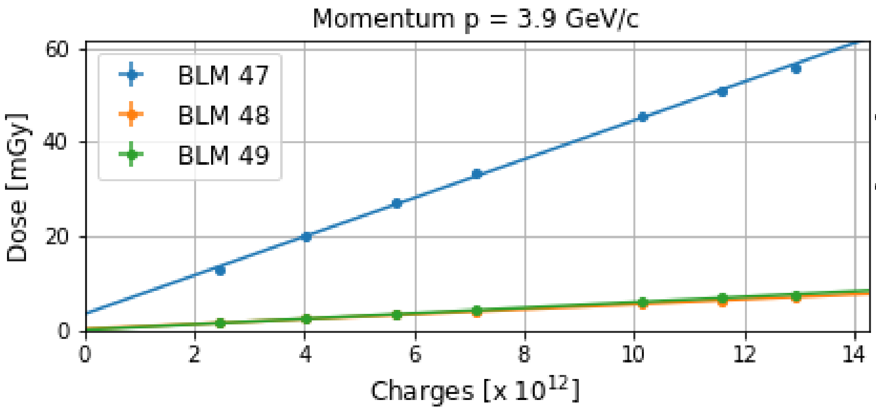
LHC 26.4 GeV (dump 47)



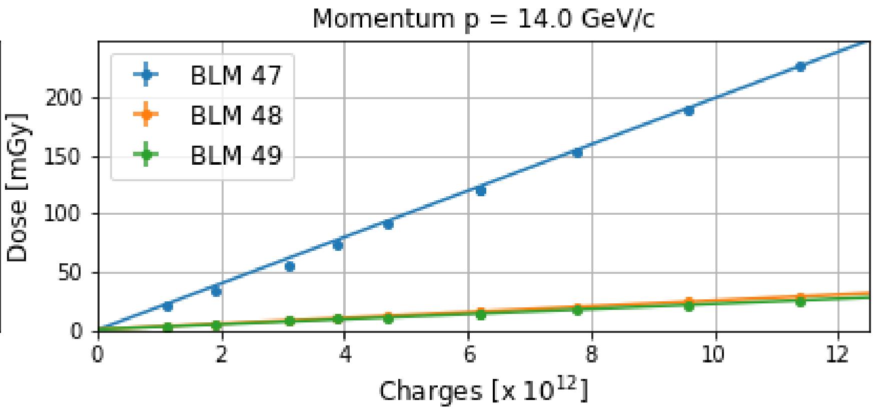
LHC 26.4 GeV (dump 48)



LHC 3.9 GeV (dump 47)



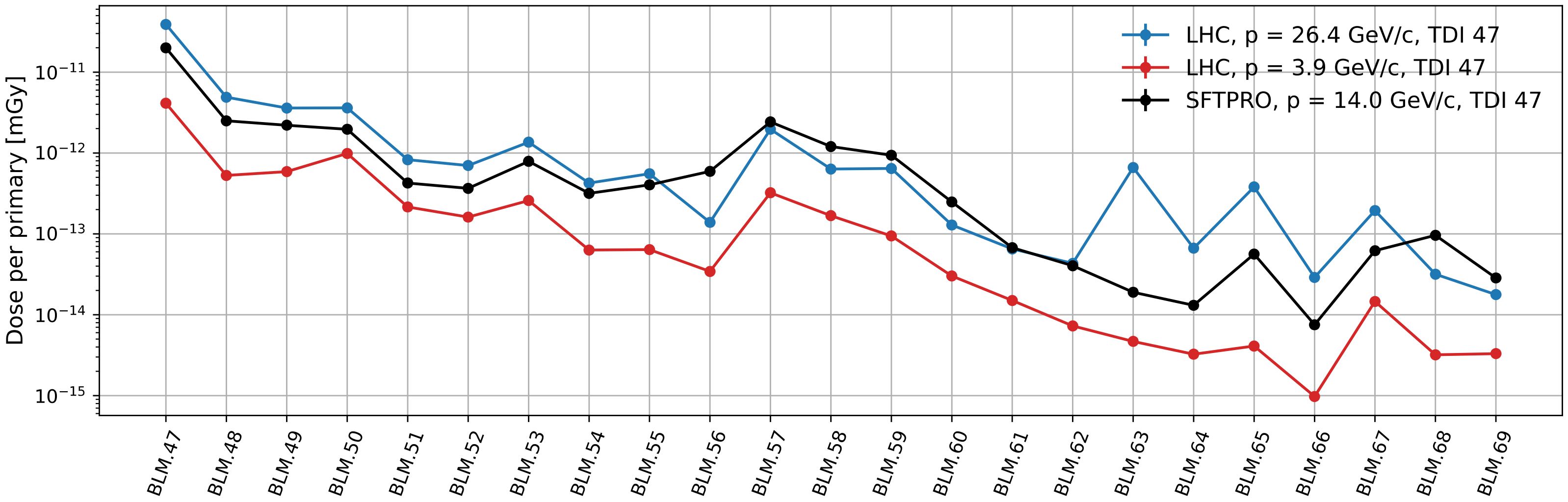
SFTPRO 14 GeV (dump 47)

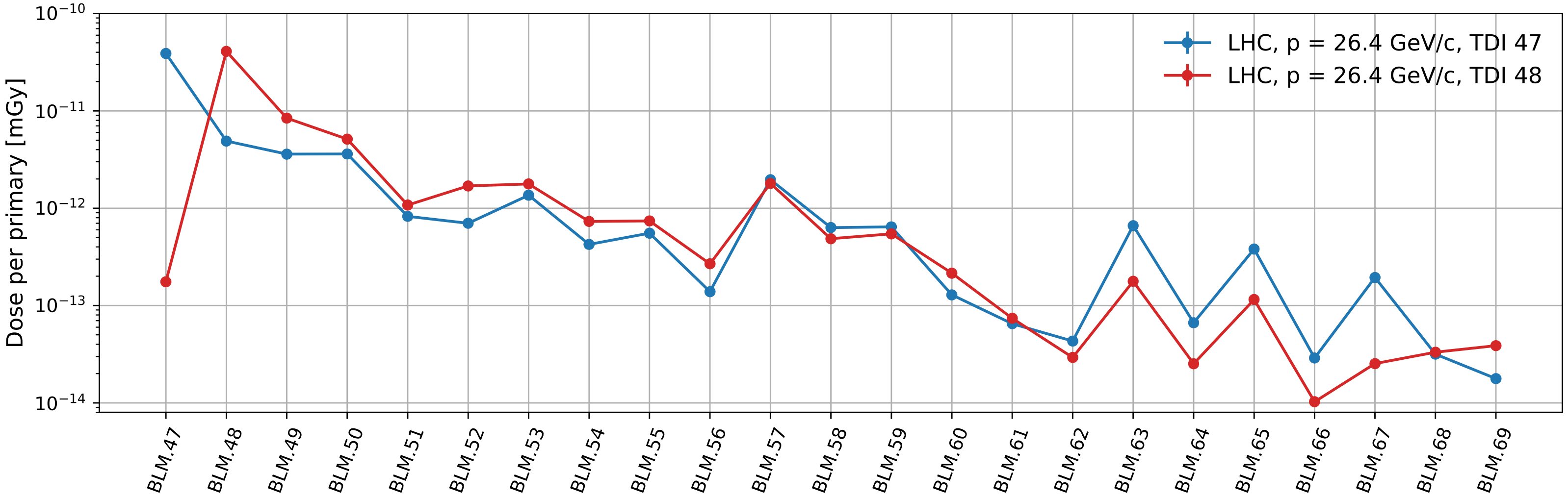


- Several measurements at different intensities
- The goal is to obtain the dose per primary for each BLM
- To compare with the FLUKA simulations
- We assume a linear response of the BLMs

BLM loss maps

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



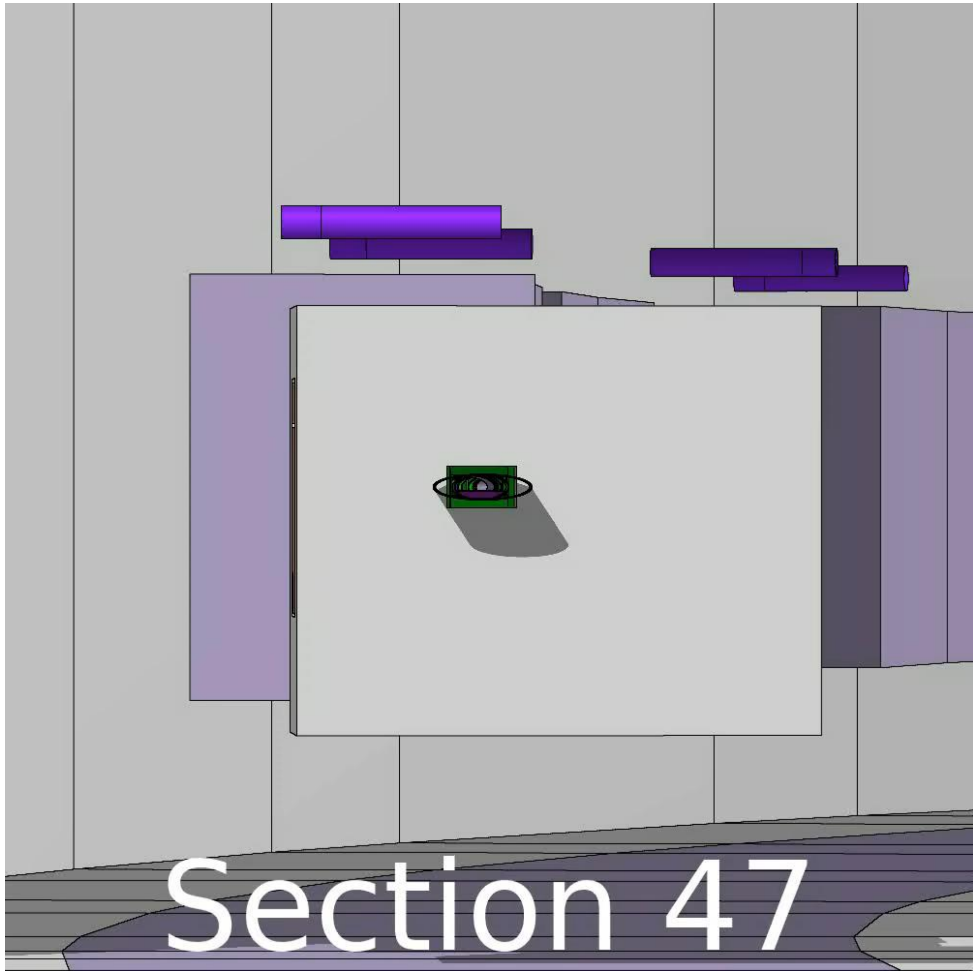


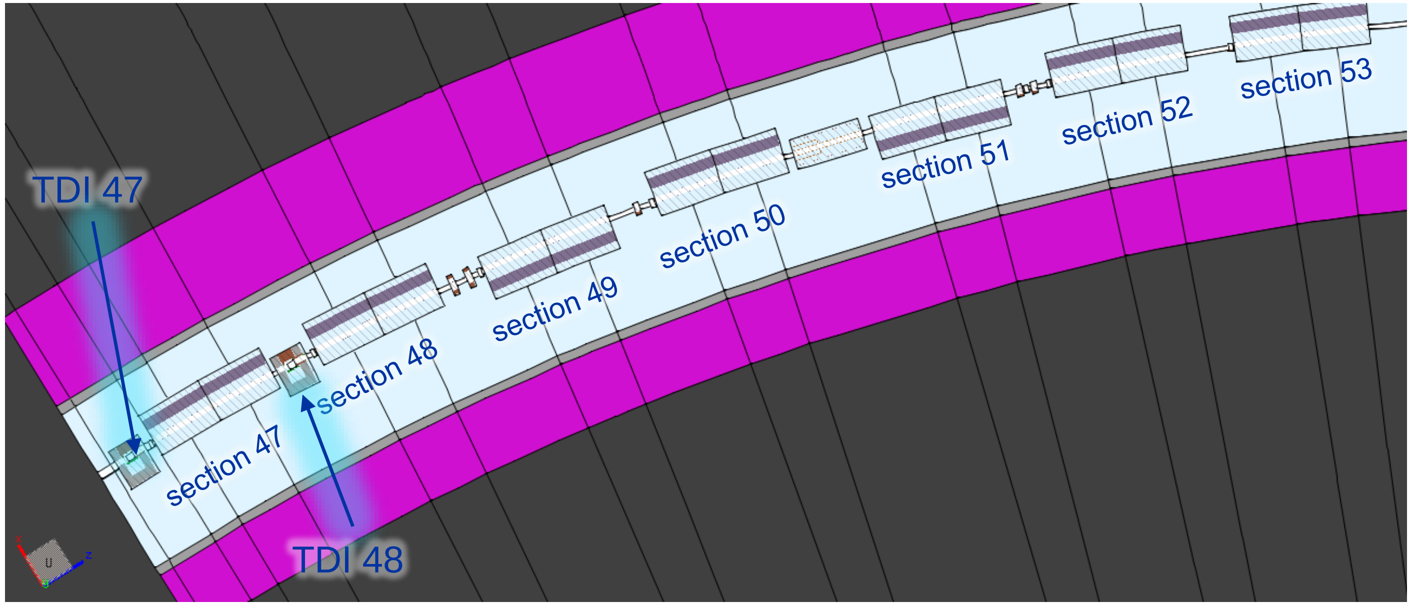
- The dose increase with the energy.
- Maximum in section 47 when TDI 47 is used and in section 48 for TDI 48 but in the other sections, the dose is similar.
- Increase close to the extraction line in section 63-65.

FLUKA simulations

Geometry and beam source term

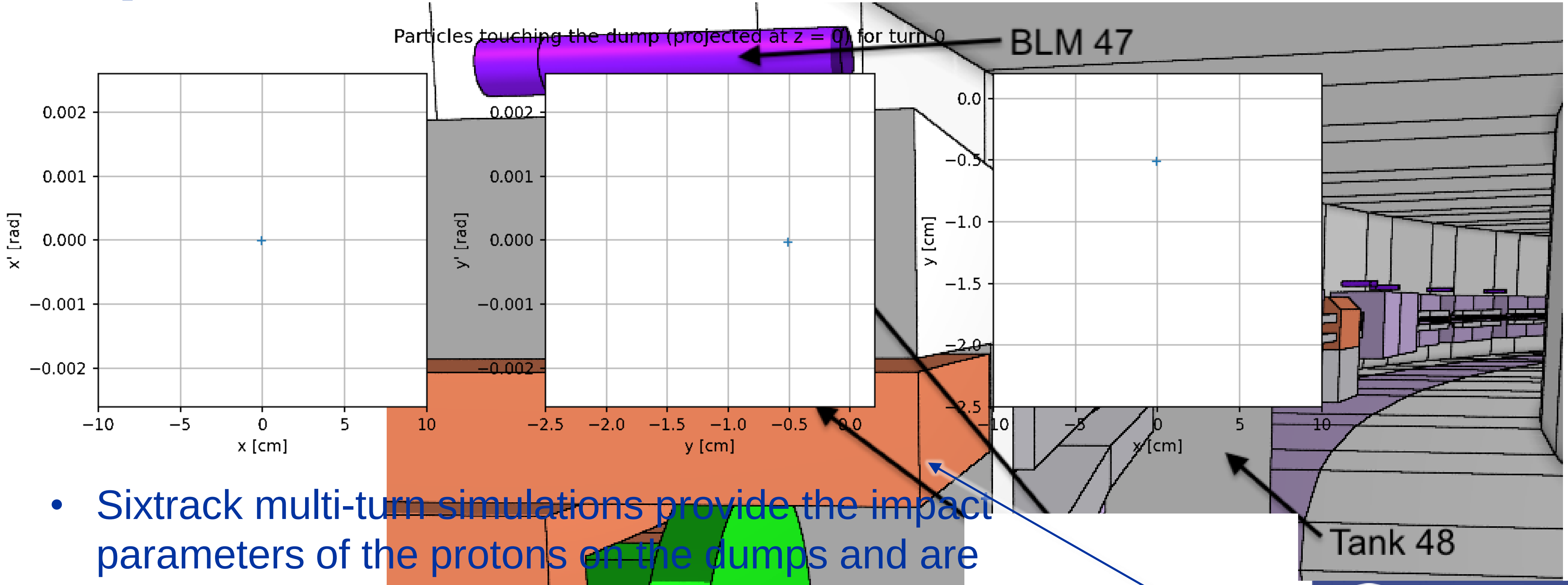
Geometry



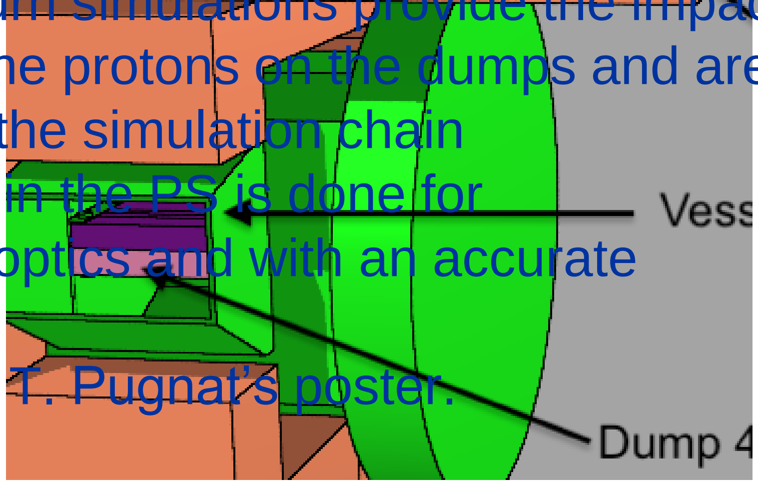


- From section **47 to 69** (included)
- Detailed implementation of mechanical magnet model.
- Analytical function to describe the magnetic field in the main magnets

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.



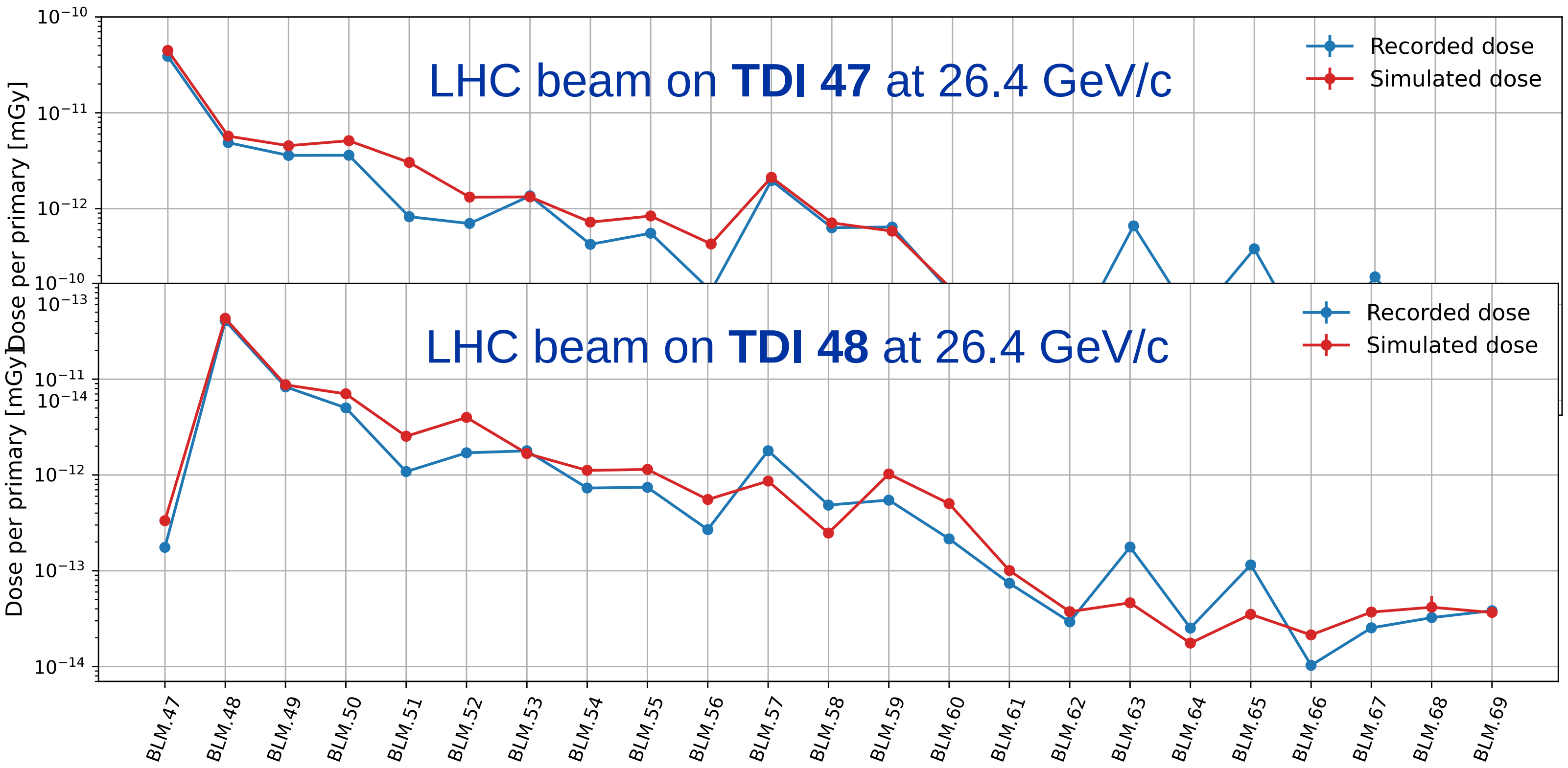
Data vs Simulations

LHC beam at flat top (both dumps)

SFTPRO beam at flat top (only TDI 47)

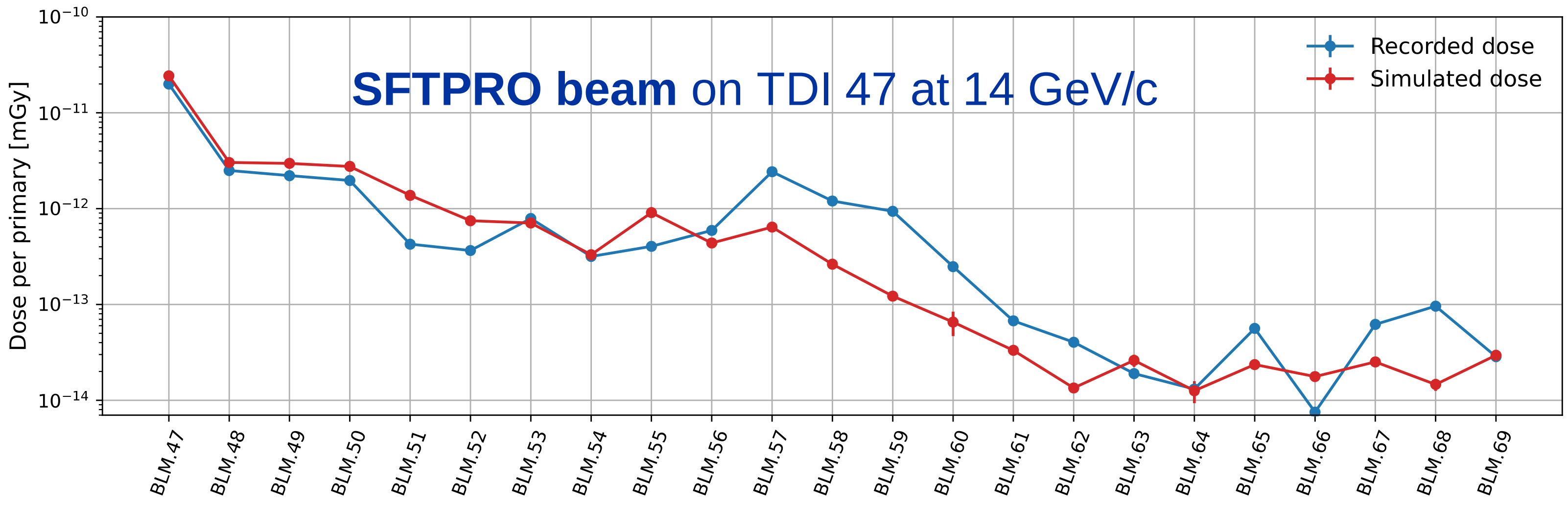
Closed orbit measurements

Dose in the BLMs: LHC beam at flat top



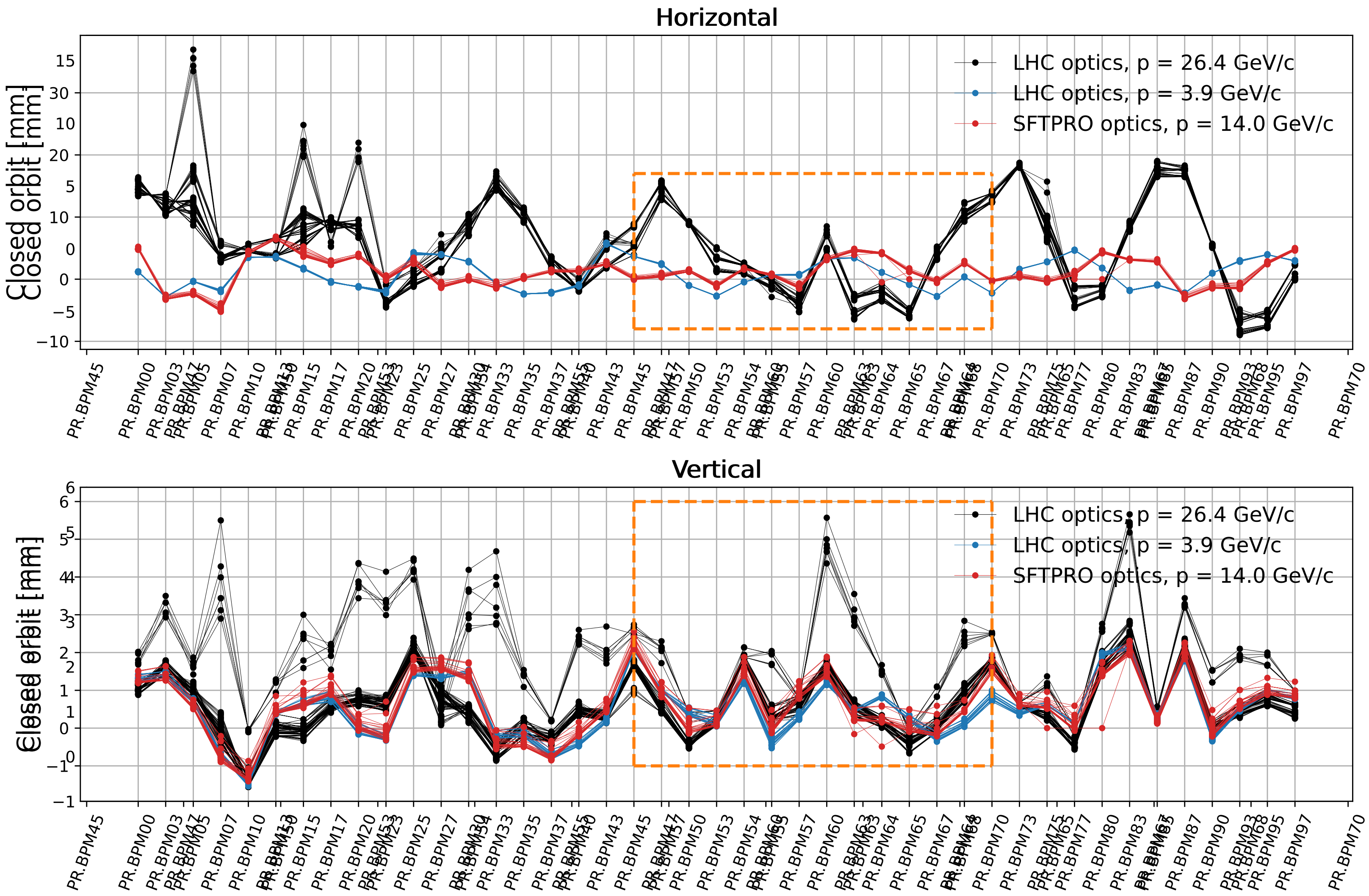
- We observe a discrepancy along the extraction region (62 to 65), see next slides for hypothesis
- For LHC beam at flat top, results for TDI 48 are matching better than for TDI 47

Dose in the BLMs: SPS beams



- 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.

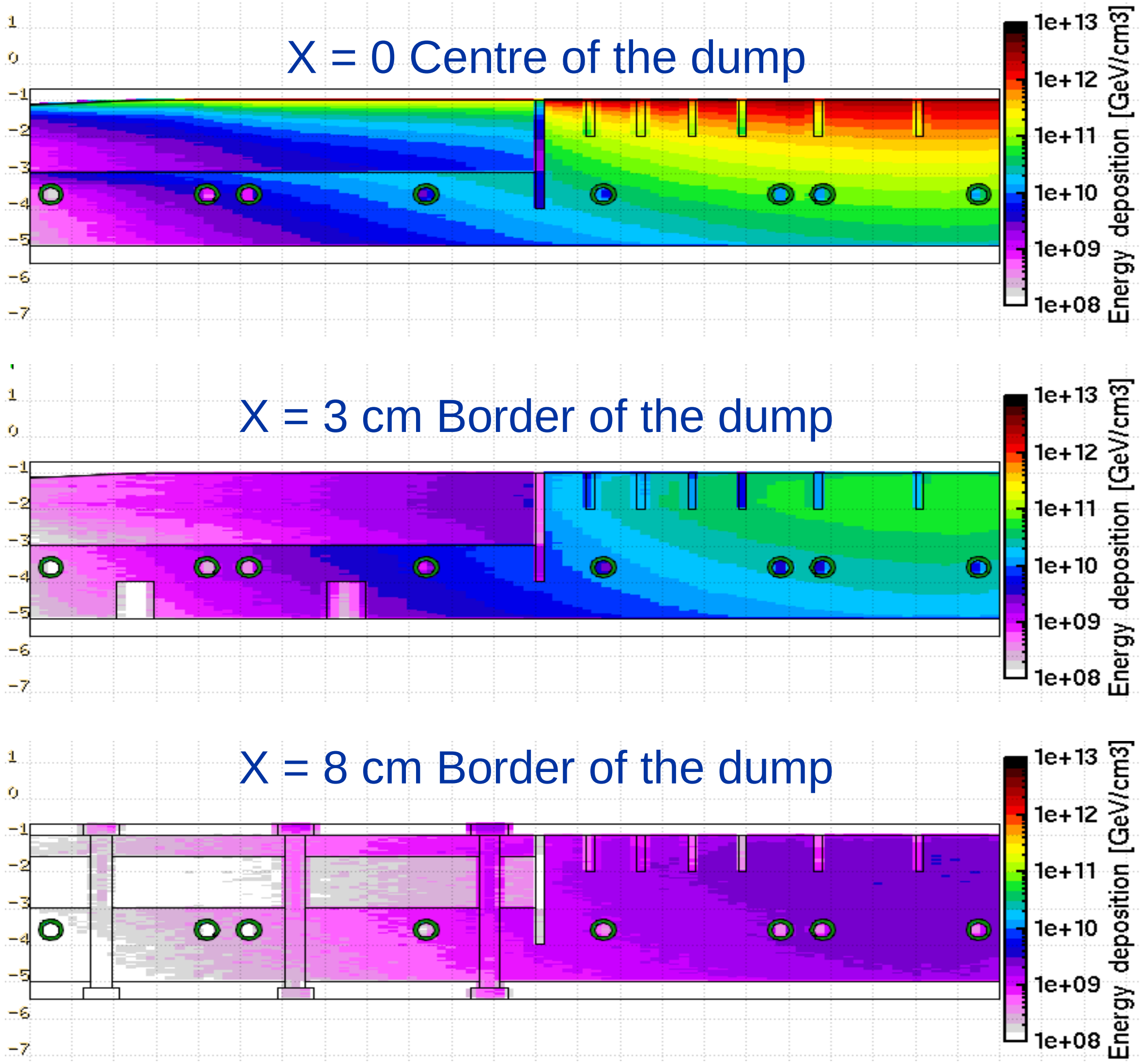
Analysis of the FLUKA results

Energy density in the dump

LHC beam at flat top impacting on TDI 47

Annual dose in the main magnets

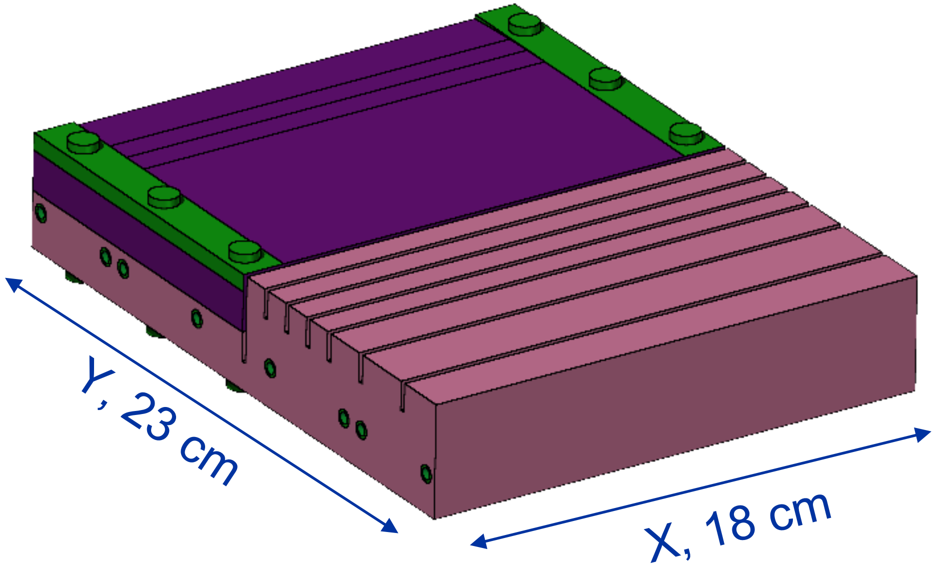
Energy density in the dump



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

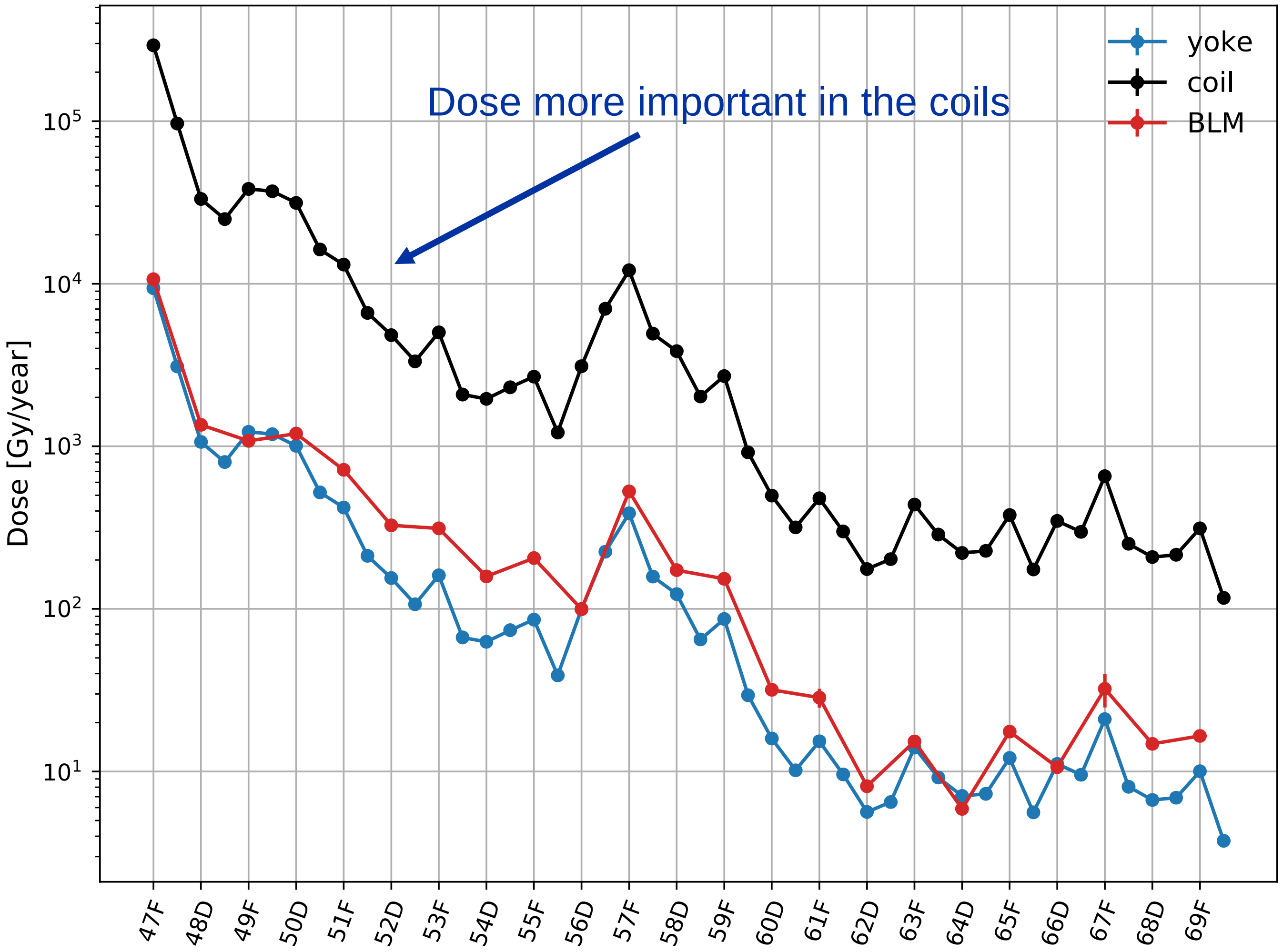
- Energy absorbed / primary: 1.64 GeV
- Kinetic energy: 25.4 GeV
- Ratio energy absorbed: 6.45 %
  - Comparison with [2] with p = 26 GeV/c, 7.3%

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



[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

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
- the energy deposition will be evaluated with the real beam energy breakdown

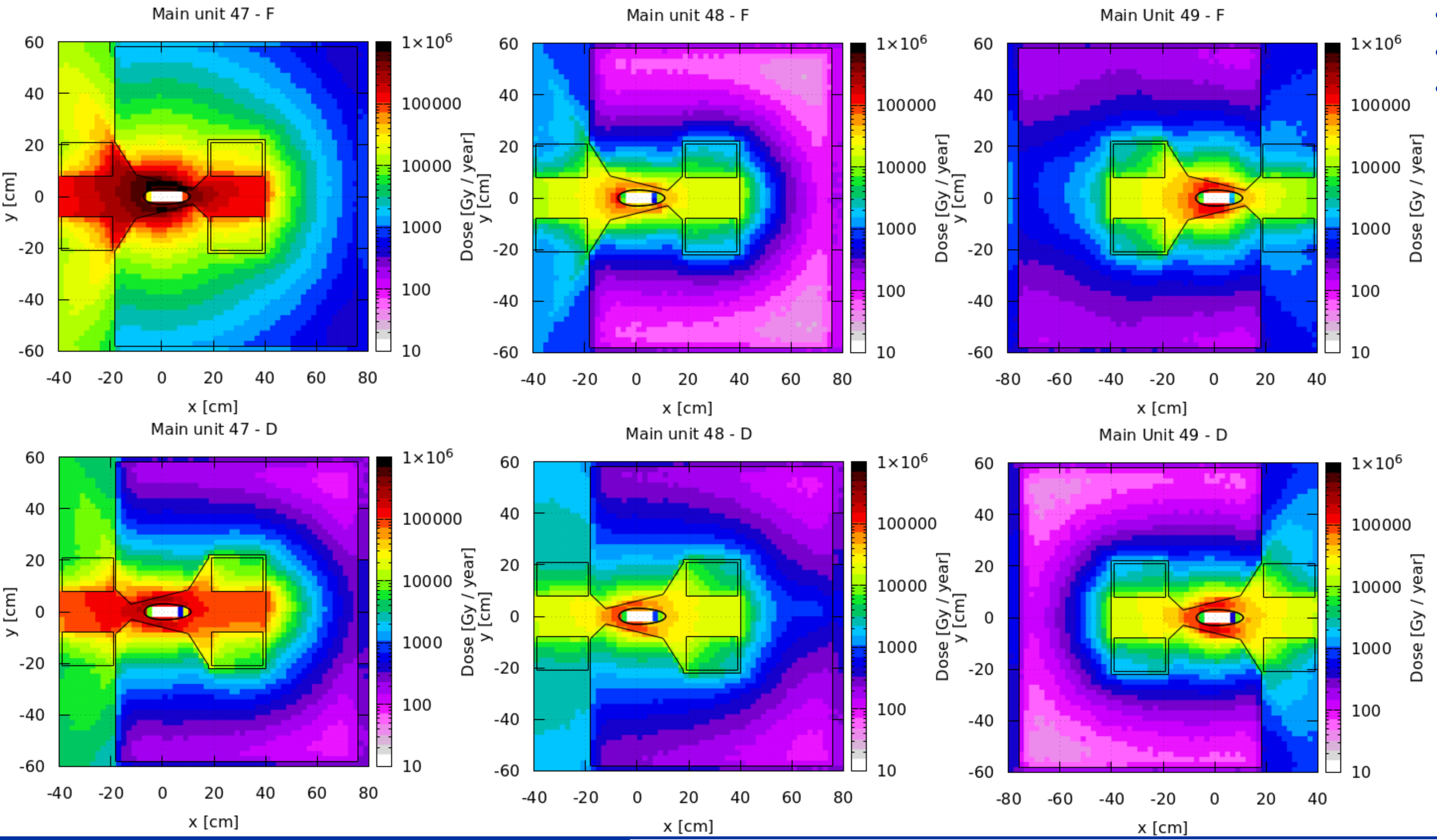
Absorption mechanisms	**% of the beam kinetic energy**
Main magnets	49.8
Tank/shielding TDI.47	14.1
Tunnel wall	11.3
TDI.47	6.5
Tank/shielding TDI.48	4.8
Other elements	3.5
Beam pipes	2.4
Air	0.1
Mass production from nuclear reactions	6.3
Neutrinos	1.2

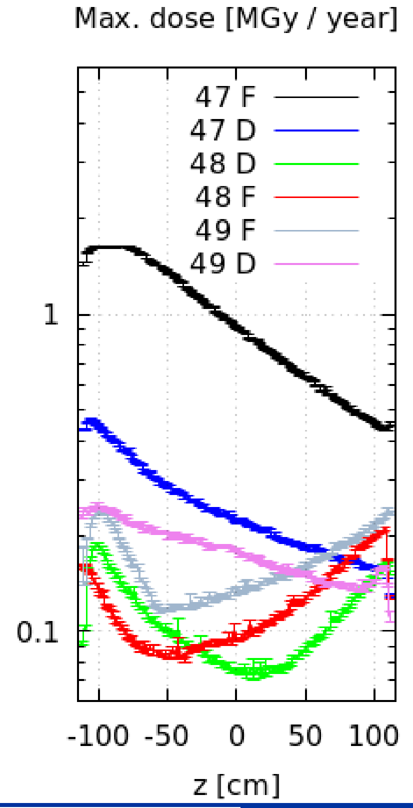
Normalized to 2.4 x 10^{17} protons per year [1]

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
- the en. dep. will be evaluated with the real beam energy breakdown





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

Conclusions and outlook

Conclusions and outlook

- **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)
  - Evaluation of the hot-spots in the magnets
- **Outlook**
  - 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
  - Refine the evaluation of the hot-spots according to the beam sharing
- **Tonight**
  - Don't miss Thomas Pugnat’s poster, if you want more details about the multi-tracking simulations

Thank you for your attention,

I am waiting for your questions.

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