Accelerator applications of FLUKA

E.Skordis
On behalf of the FLUKA team

LHC Beam losses

- What is the origin of beam losses?

Protons that no longer circulate in the beam

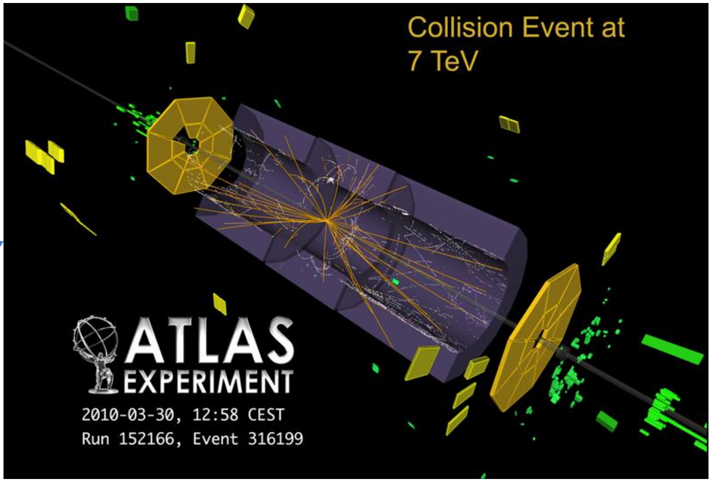
- Why?

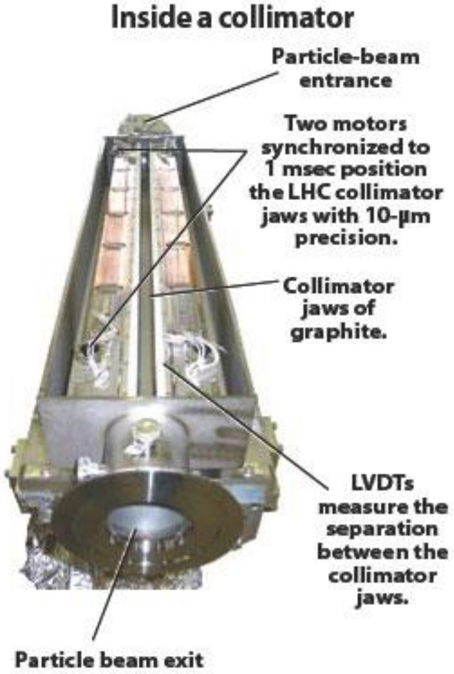
Regular losses (slow, partially controlled)

- Beam – Beam interactions at experiments
- Beam intercepting movable devices (collimators, active absorbers, etc…) -> beam cleaning, magnet protection
- Beam interaction with residual gas

Irregular losses (fast, uncontrolled)

- Accident scenarios <- failure or misbehaviour of accelerator elements (magnets, RF, collimators etc..)
- Trajectory errors, “bad” beam quality, injection errors, element misalignment, UFO, etc…





LHC BLM System

- What does BLM System stand for?

<u>Beam Loss Monitoring System</u>

- What is it?

Consists of various detectors (active dosimeters), mainly;

- Ionisation Chambers (IC)
- Little IC
- Secondary Emission Monitors (SEM)
- in development…

➢ Each detector has different response times and detection range

⇓

➢ Each detector serves a different role

- What is its purpose?

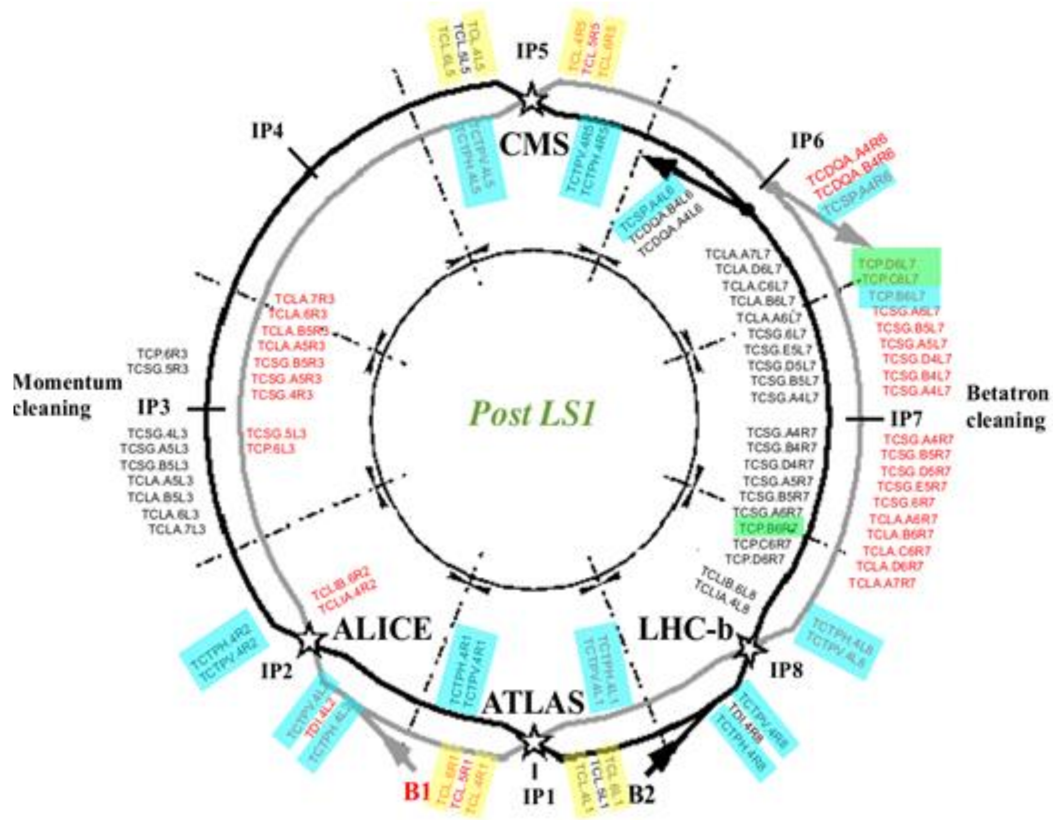
To measure beam losses around the accelerator and protect the machine from various beam loss scenarios

LHC overview

- 2*362 MJ total energy stored in both LHC beams

(2808 bunches)*($1.15*10^{11}$protons/bunch)*($7*10^{12}$eV/proton)*($1.602*10^{-19}$Joules/eV)
= 362 MJ per beam

- ~4000 Beam Loss Monitors are installed in the LHC each capable of triggering a beam dump if the dose exceeds a certain threshold



- LHC collimation system:
  > 100 movable devices
- Betatron cleaning: IR7, momentum cleaning: IR3

BLM and Beam losses

- Do BLMs actually detect Beam losses?

Yes! . . . Partially…

- Partially?

BLMs detect only a tiny part of the particle shower and converts it to signal (dose).

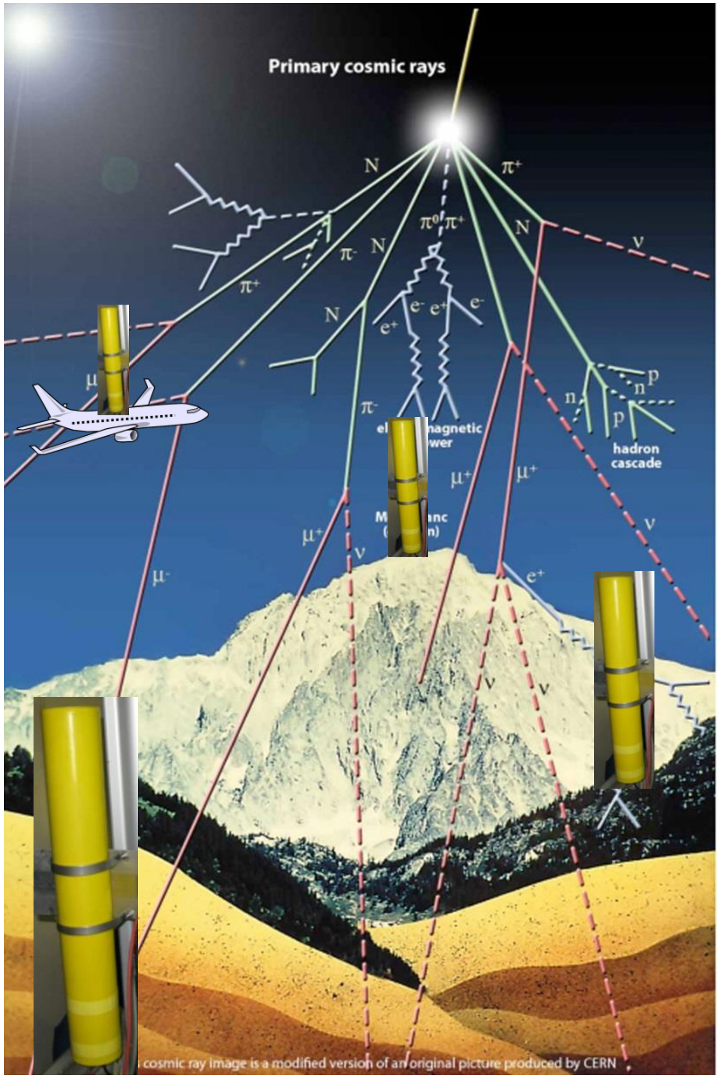
- Which part and how much?

Depends… on 3 main factors:

- ➢ Position of the BLM relative to shower
- ➢ Proton energy (450… 4000… 7000… GeV)
- ➢ Beam loss scenario (Slide 3)

- What happens to the other part?

Absorbed by the LHC elements and the tunnel walls

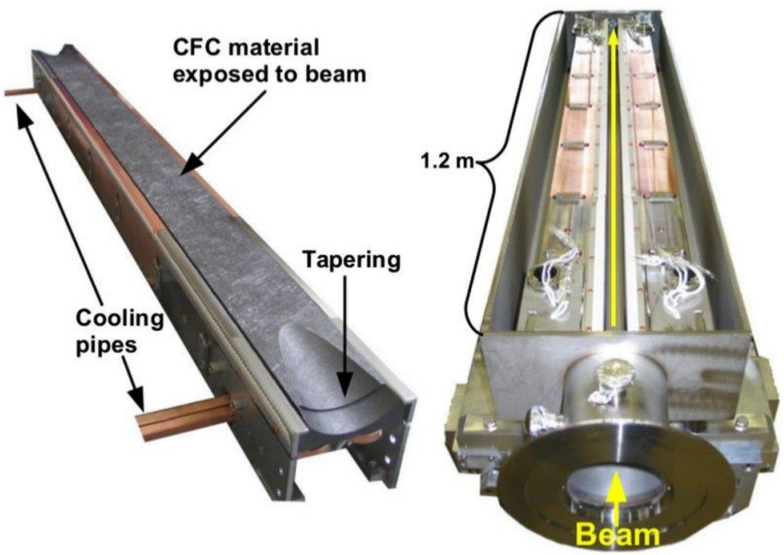


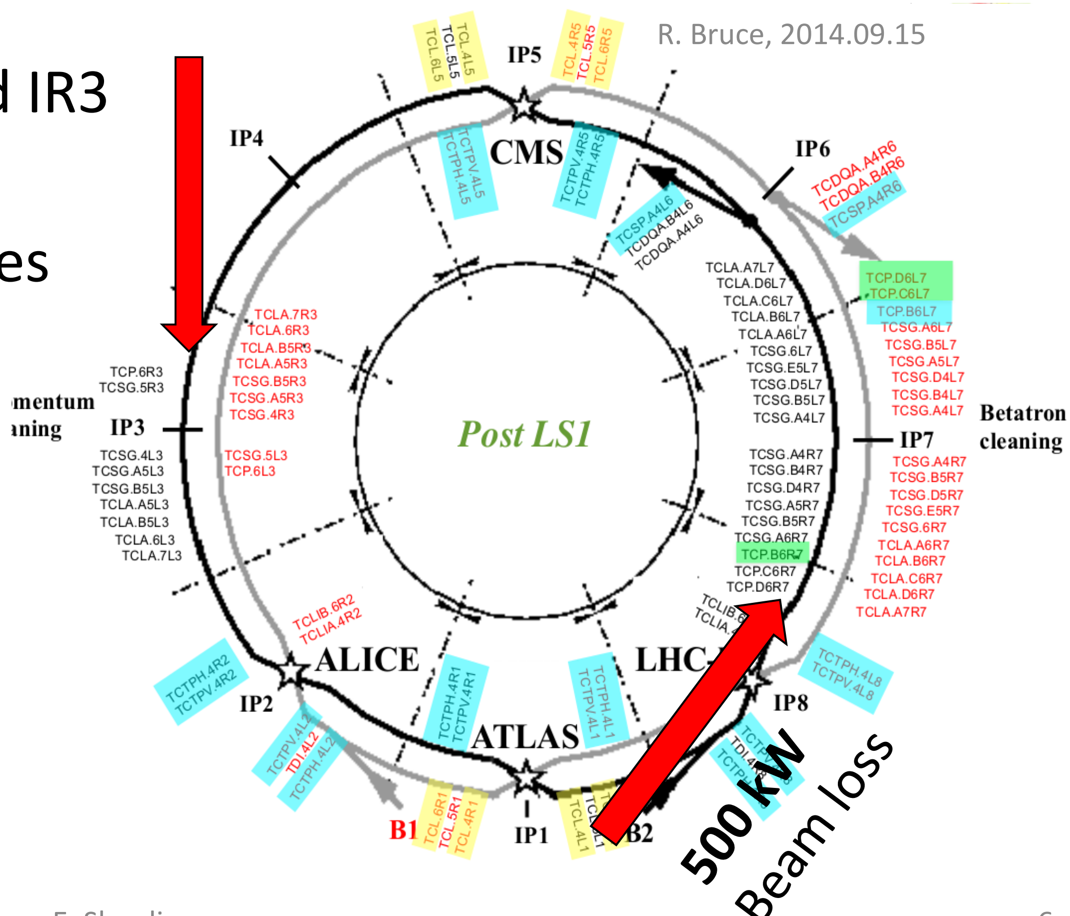
LHC collimation system

- Capable of redirecting up to 500kW of proton loss rate in order to protect the Super Conducting Magnets from quenching (stop being SC due to energy deposition -> increase in temperature)
- 99% of that power is

deposited in the whole IR7 and IR3

- **<u>Not</u>** all power is absorbed by the collimators themselves





Collimation losses simulation overview

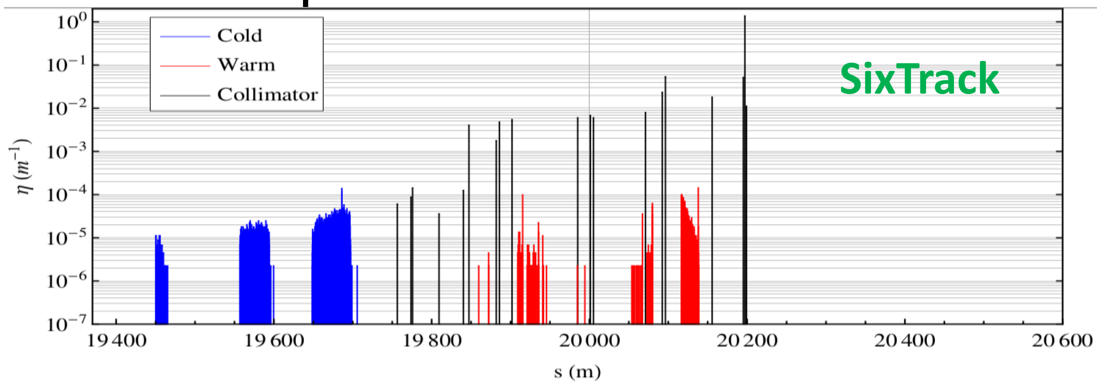
- Sophisticated simulations required to evaluate the BLM signal per proton lost on the collimators as well as <u>where</u> exactly and <u>how much</u> of the proton energy is deposited
- Simulation tools used:

Sixtrack and FLUKA are simulation tools regularly used at CERN to perform LHC studies.

- SIXTRACK : Single particle 6D tracking code for long term tracing in high energy rings -> complemented with dedicated interaction routines, predicts losses in collimators.

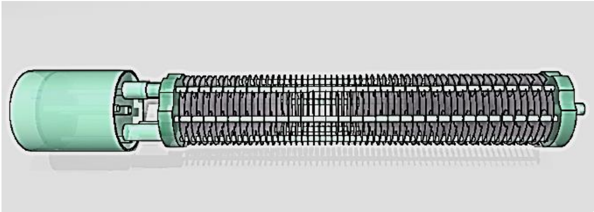
Energy deposition simulation requirements for collimation losses

1. Acquire inelastic interaction loss maps in the LHC collimators produced by SIXTRACK



2. FLUKA simulation set up
   - Model complex geometries of all key elements of the LHC
   - Set up the simulation parameters
     - Source routine
     - Magnetic fields routines
     - Physics settings
     - Scoring
     - Etc…

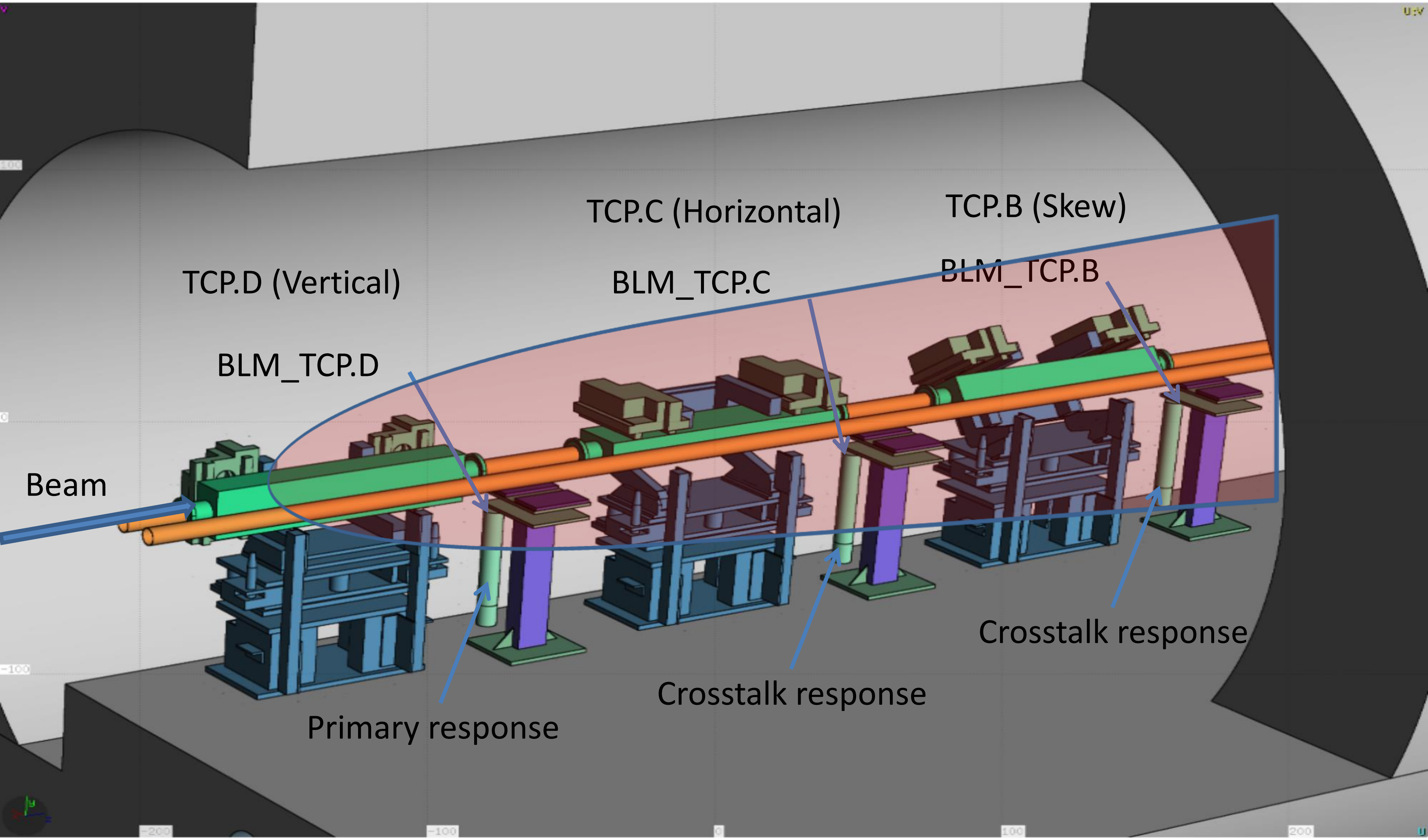
LHC BLM



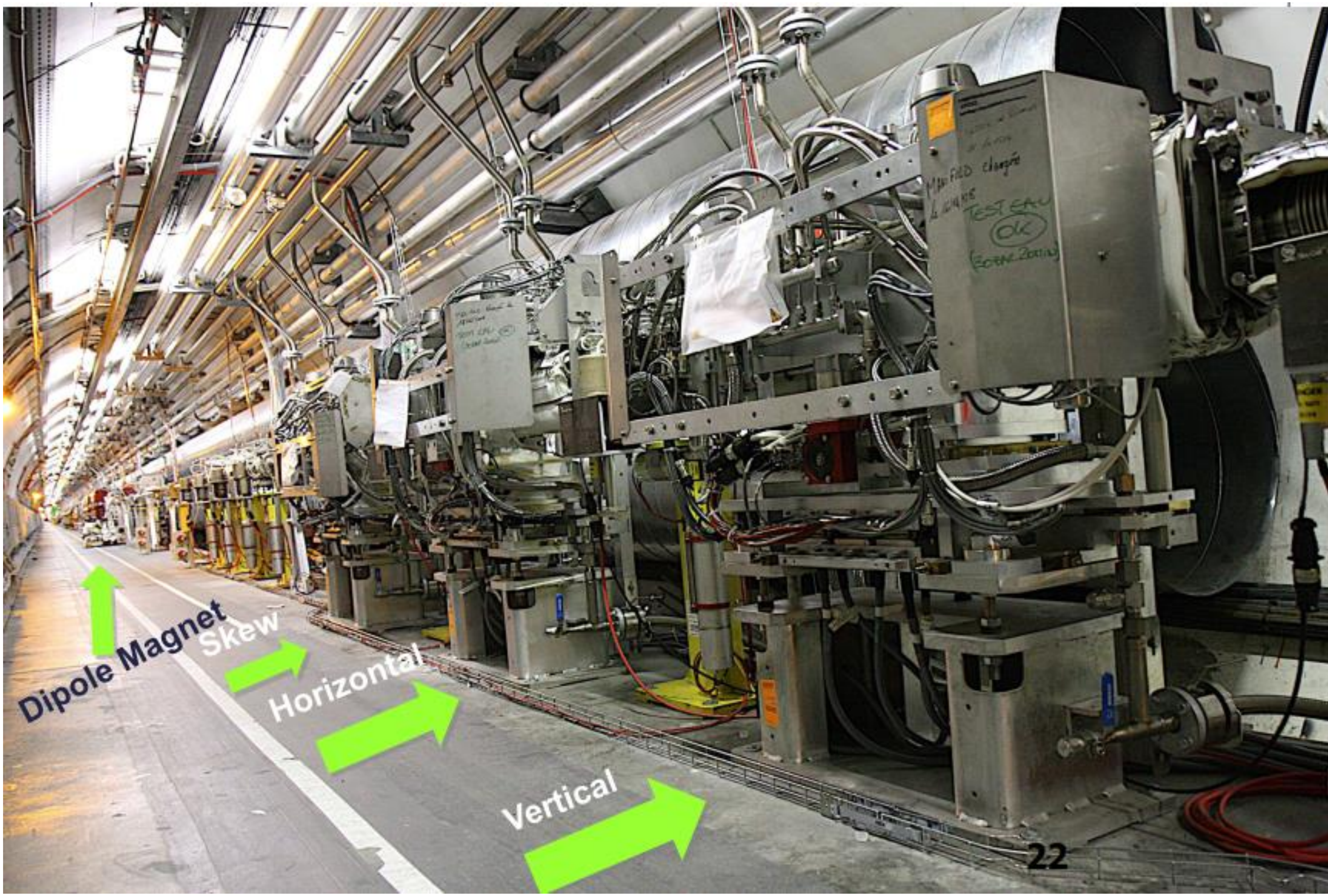
FLUKA MODEL

Picture

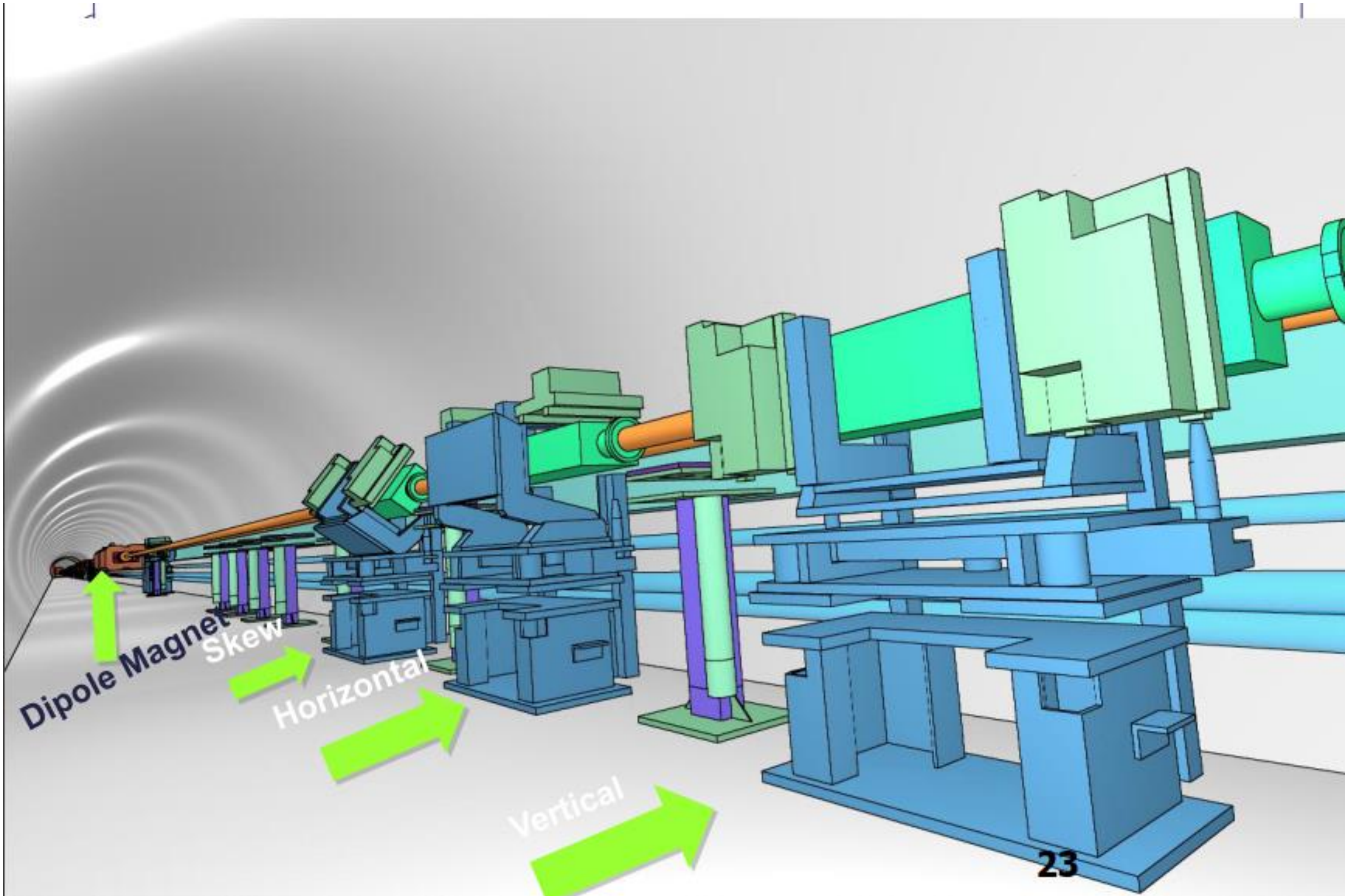
TCP simulated Geometry



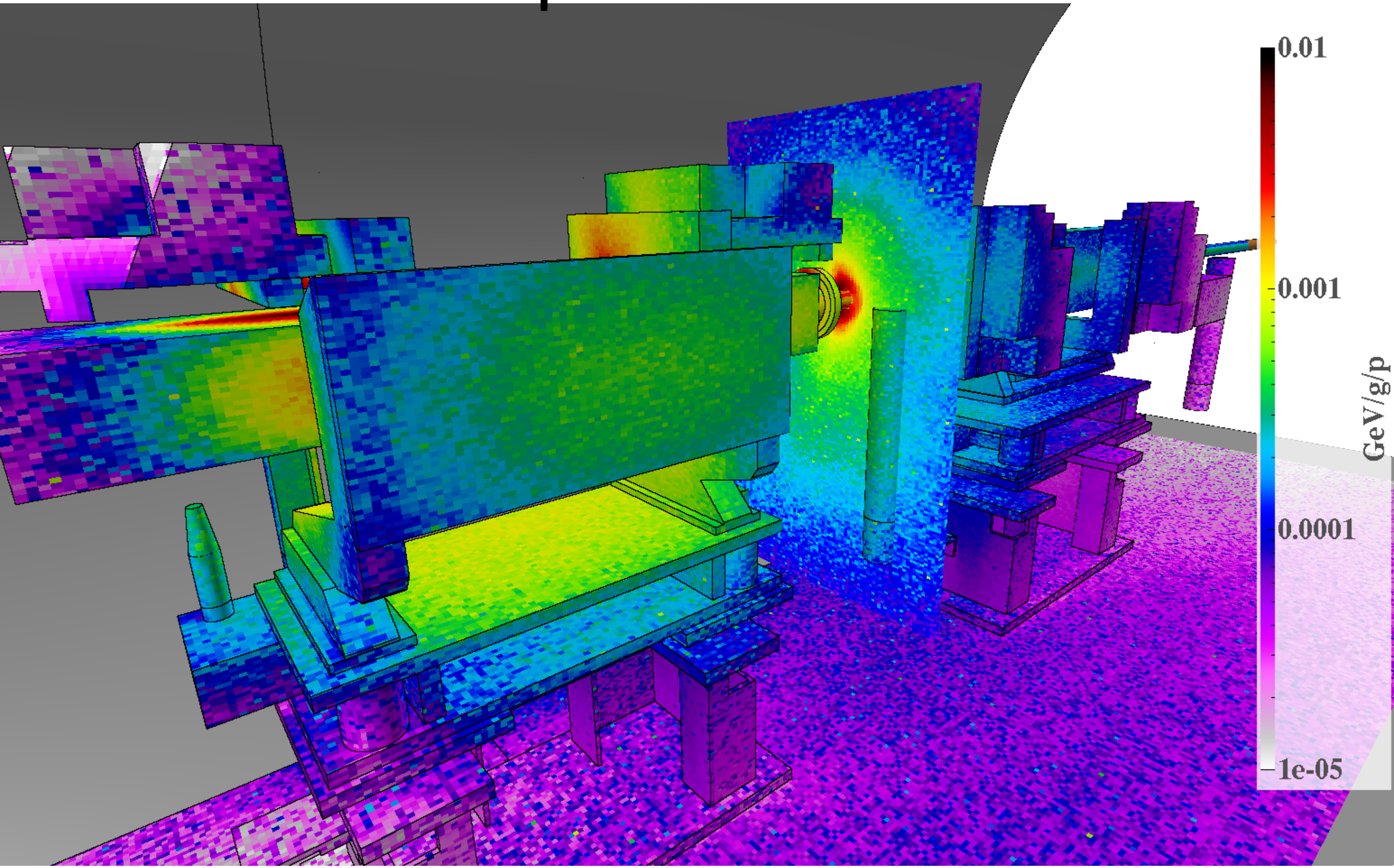
IR7 primary collimators picture

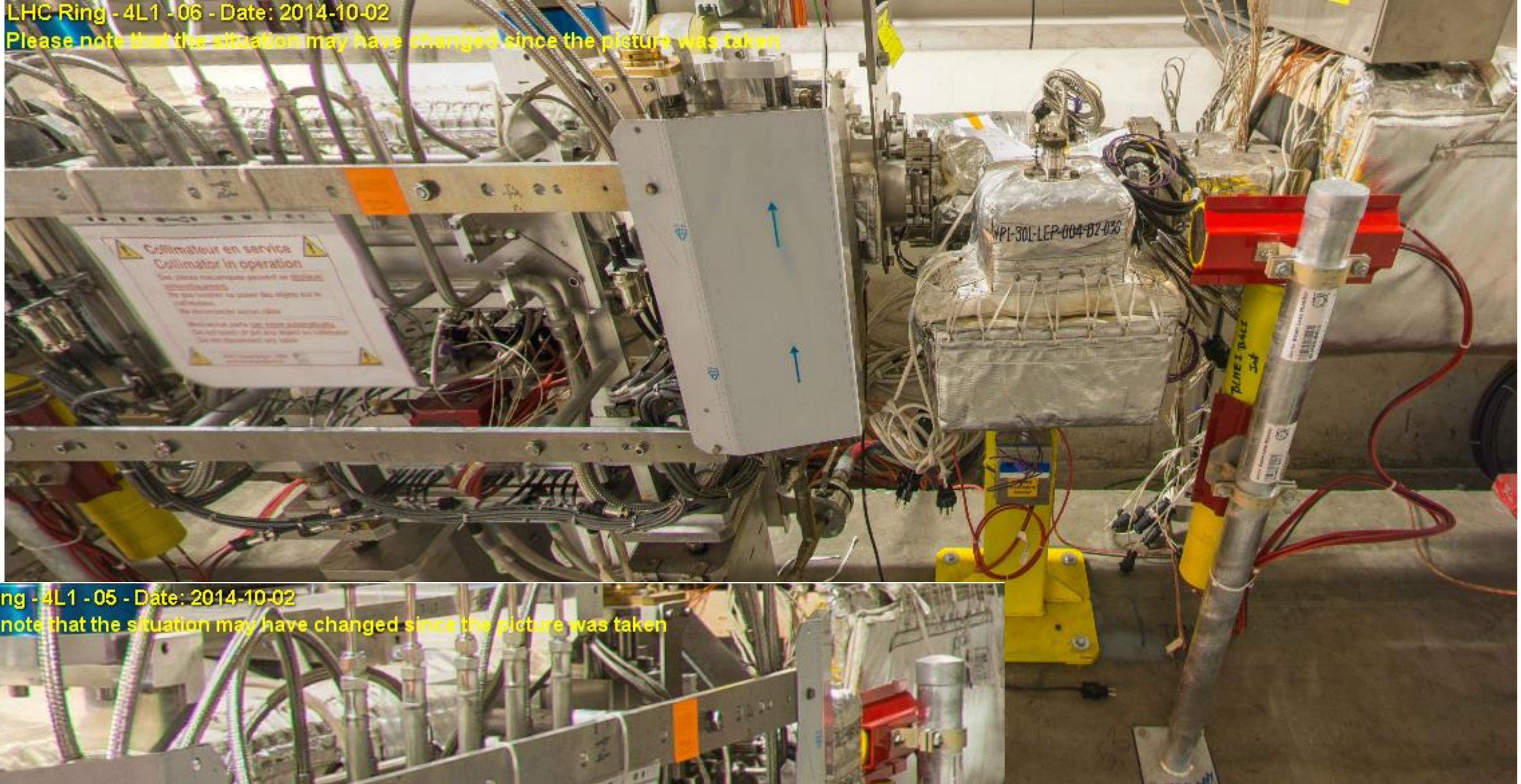


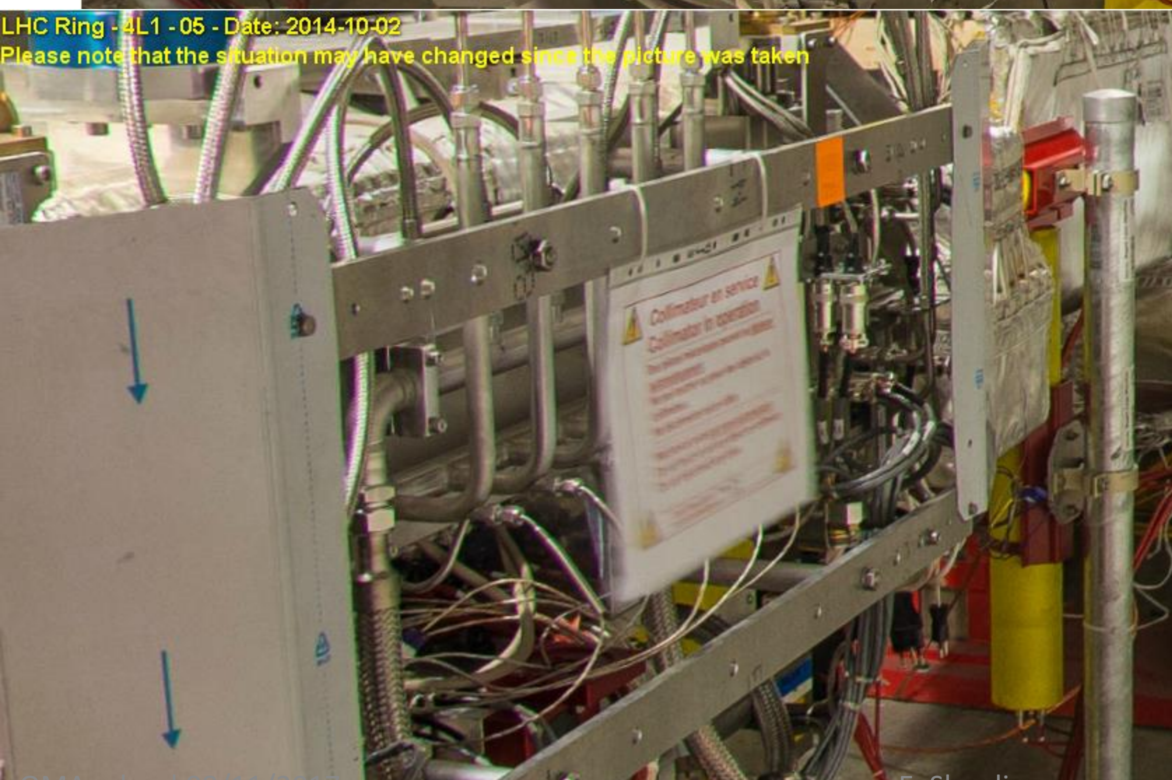
IR7 primary collimators picture



Impact at TCTH




LHC Ring - 4L1 - 06 - Date: 2014-10-02
Please note that the situation may have changed since the picture was taken
Collimateur en service
Collimator in operation


LHC Ring - 4L1 - 05 - Date: 2014-10-02
Please note that the situation may have changed since the picture was taken

Ion Vaccum Pump VPI-30L

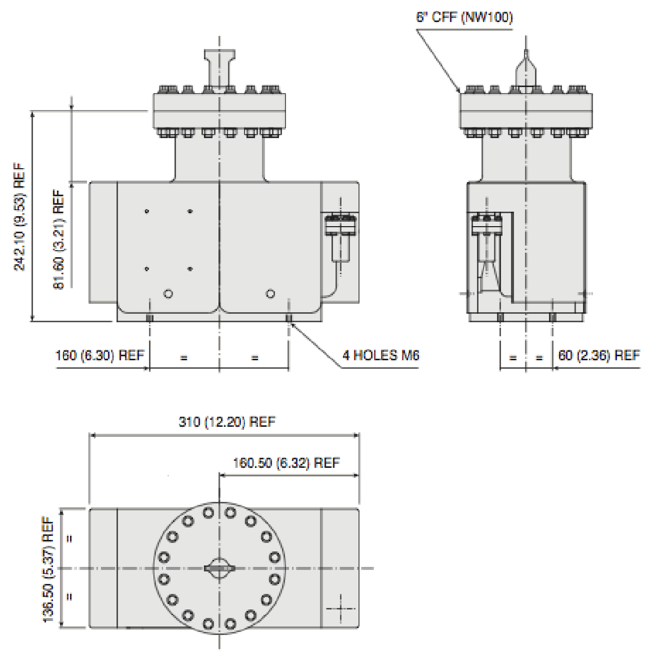
	StarCell®	Noble Diode	Diode
Nominal pumping speed for Nitrogen (*) (l/s)	65	68	75
Operating life at $1x10^{-6}$ mbar (hours)	80,000	50,000	50,000
Maximum starting pressure (mbar)	$\leq 5x10^{-2}$	$\leq 1x10^{-3}$	
Ultimate pressure	Below 10^{-11}		
Inlet flange	6" CFF (NW 100) AISI 304 ESR SST		
Maximum baking temperature (°C)	350		
Weight, kg (lbs)	19 (42)		

(*) Tested according to ISO/DIS 3556-1-1992

Pumping Speed vs. Pressure Graph

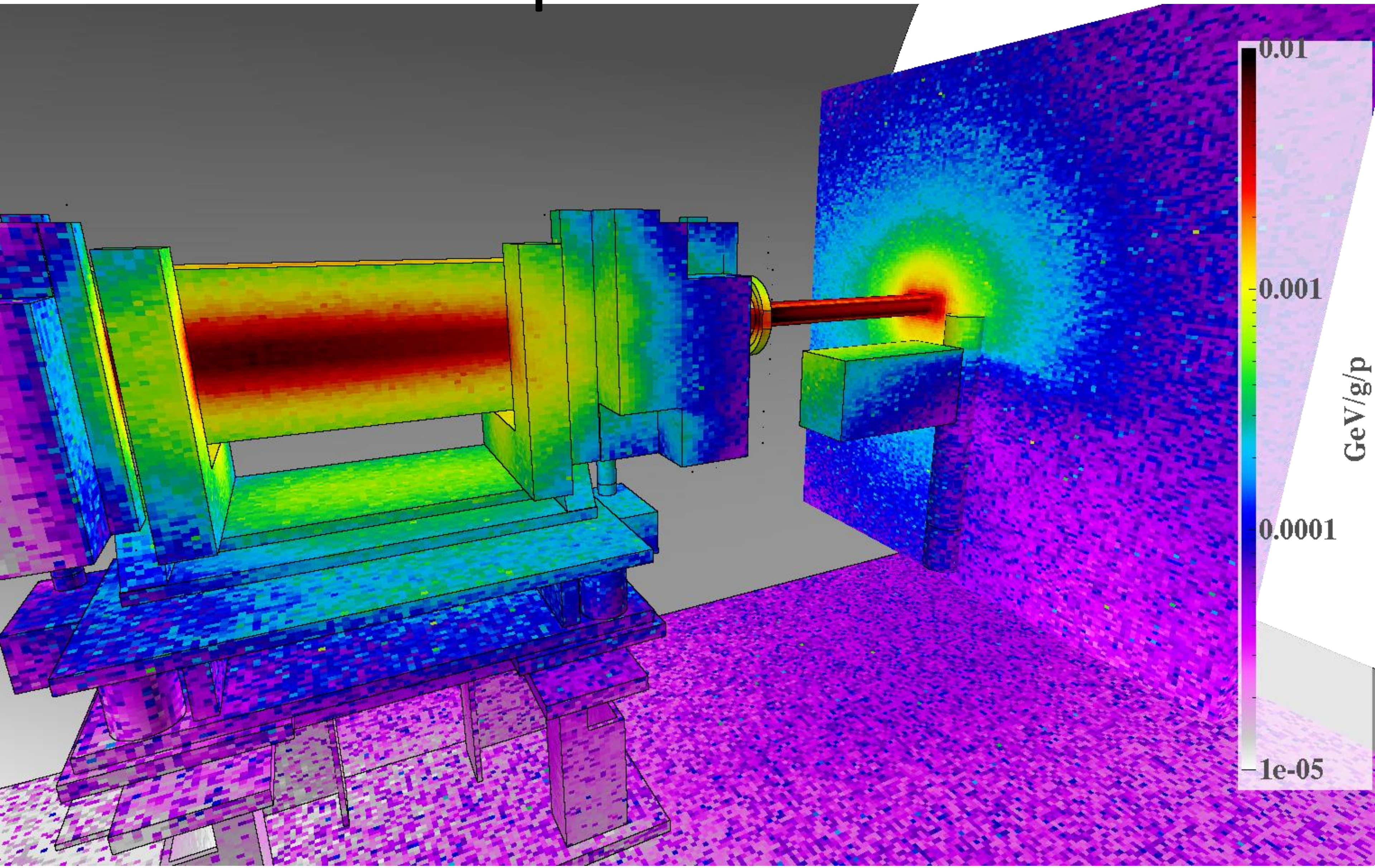
VacIon Plus 75 Pumping Speed vs. Pressure Graph

Outline Drawing

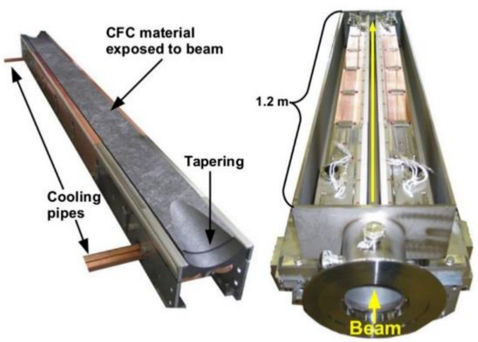


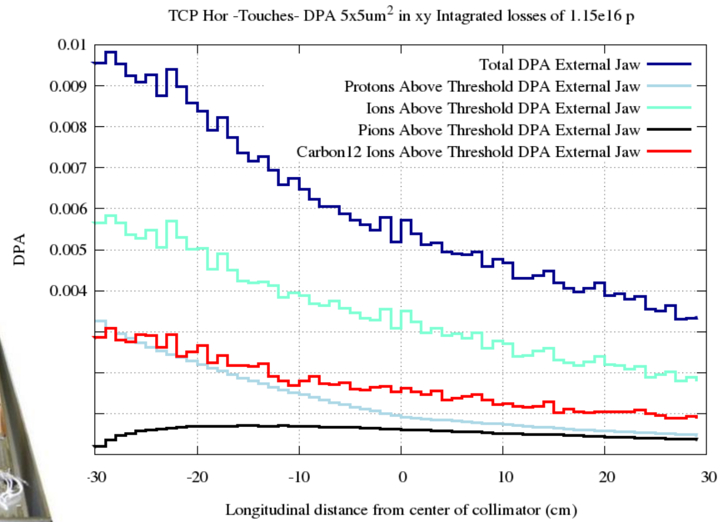
Dimensions: millimeters (inches)

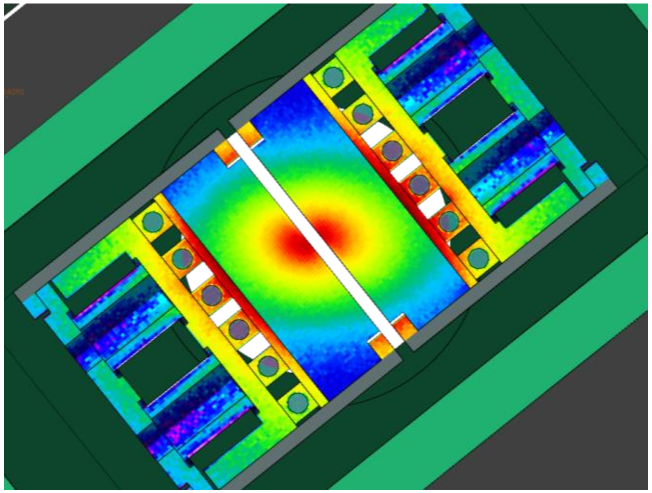
Impact at TCTV

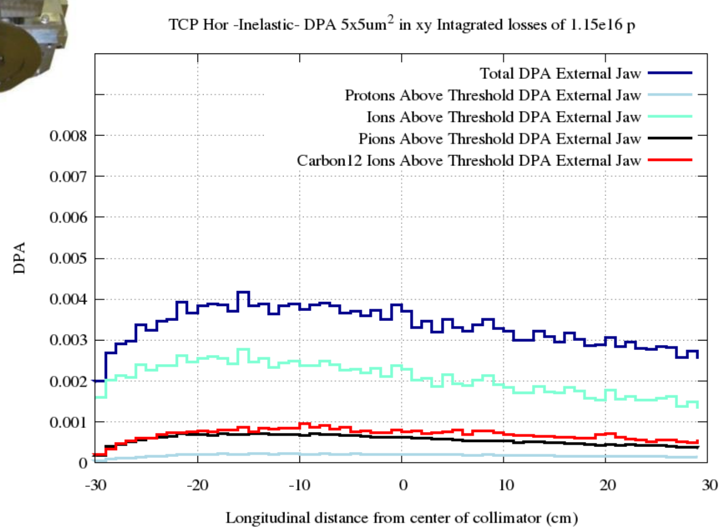


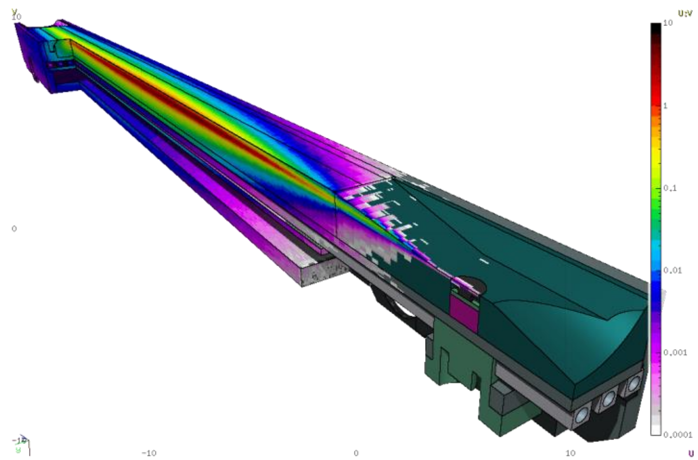
Long term displacement damage (DPA)





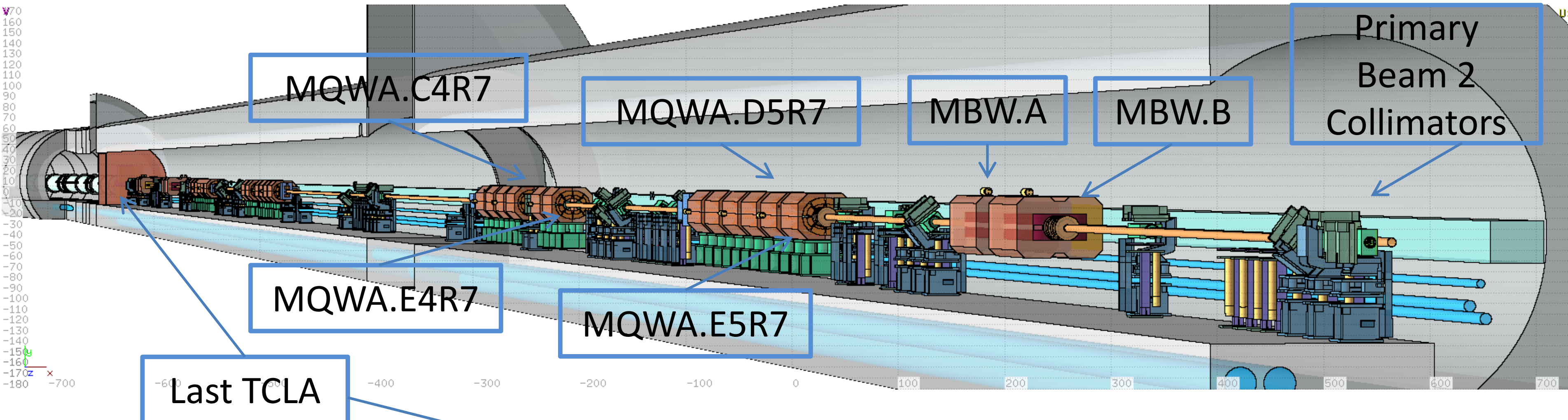




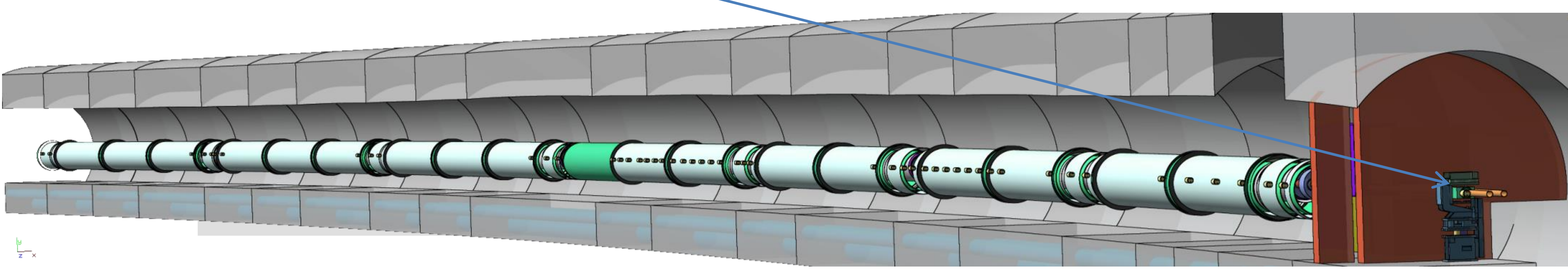


IR7 FLUKA geometry

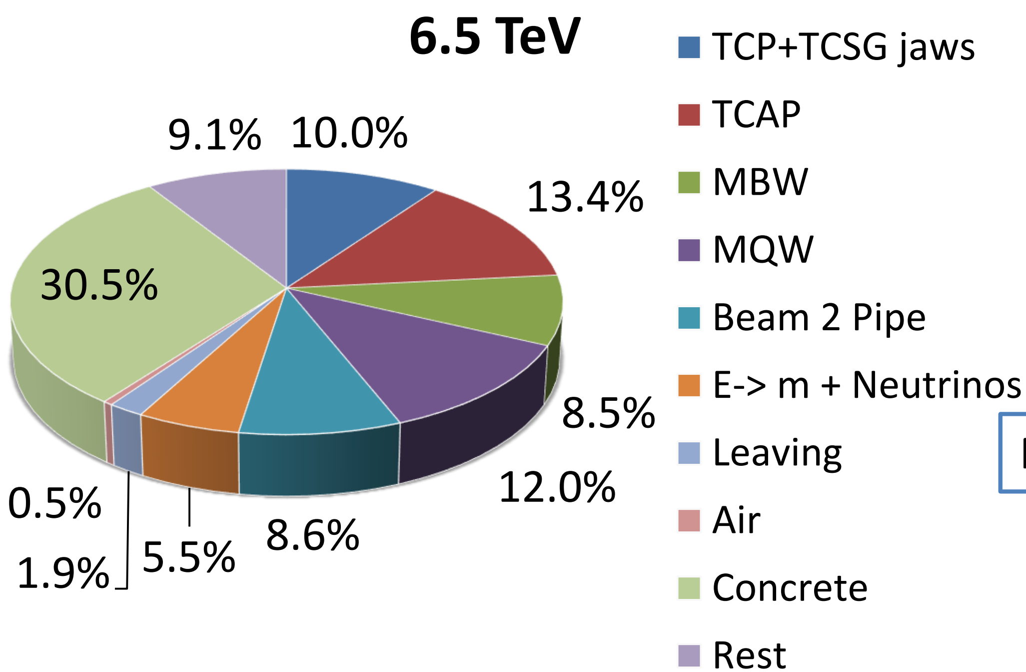
- Long Straight Section

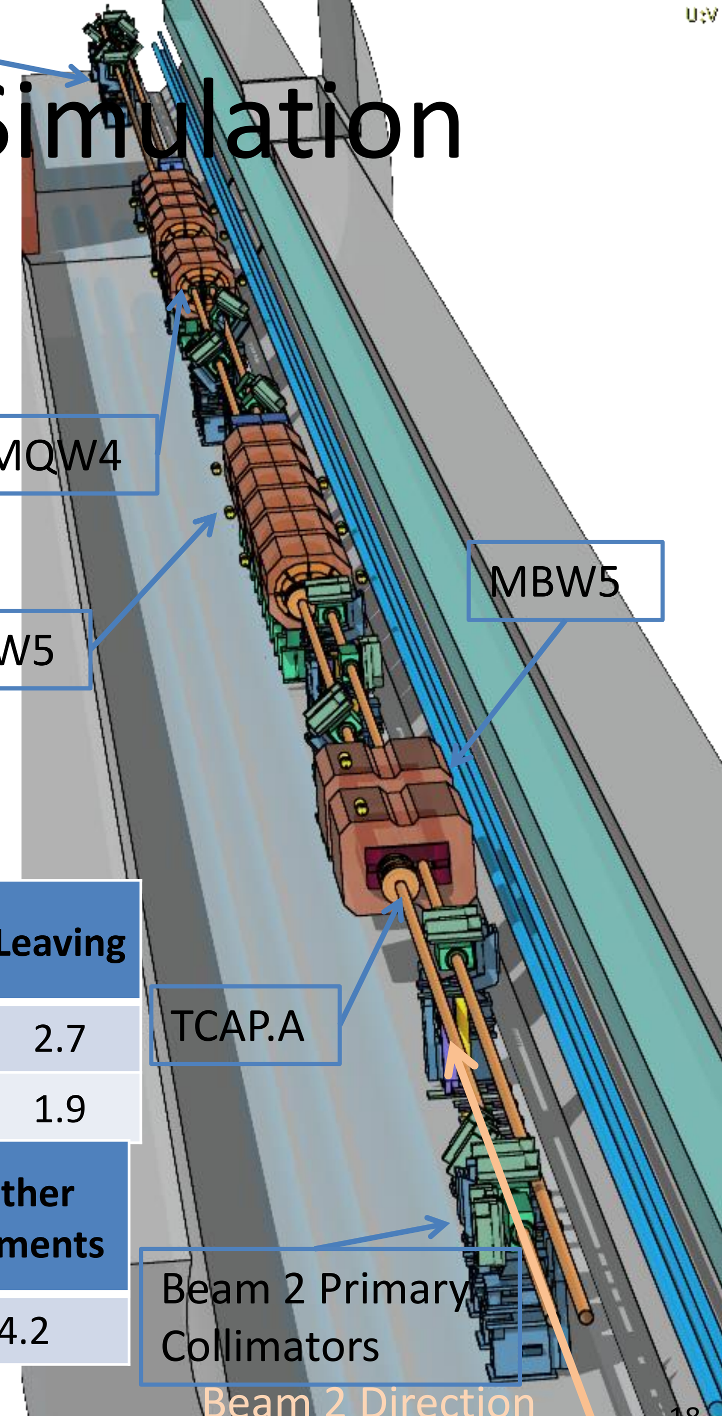


- Left Dispersion Suppressor + Arch up to cell 14



IR7 FLUKA - Sixtrack Simulation





% / TeV	TCP+TCSG Jaws	TCAP	MBW	MQW	Beam 2 Pipe	Enviro nment	E -> m + Neutrinos	Leaving
4	10	12.9	8.5	9.5	8.6	41.6	6.2	2.7
6.5	10	13.4	8.5	12	8.6	40.1	5.5	1.9

Enviroment	Air	Concrete Tunnel	Tunnel Cables	Collimator Support + Tank	Beam Pipe supports	Other Elements
40.1 +=	0.5	30.5	0.9	3	1	4.2

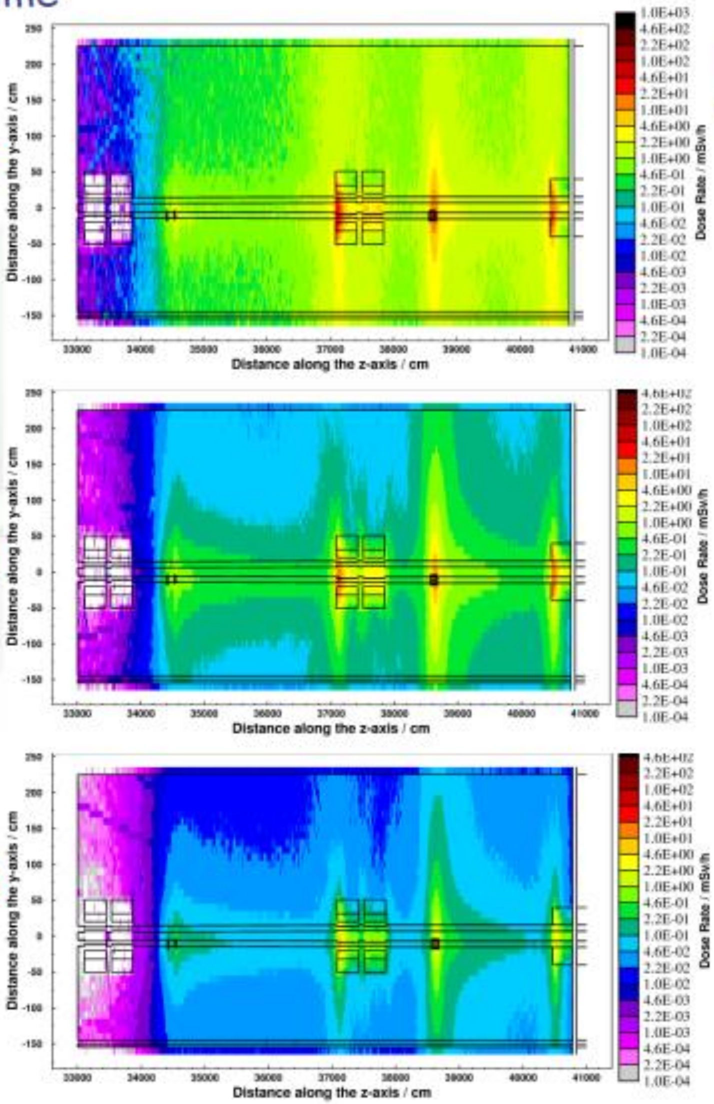
Residual dose rate

Cooling time

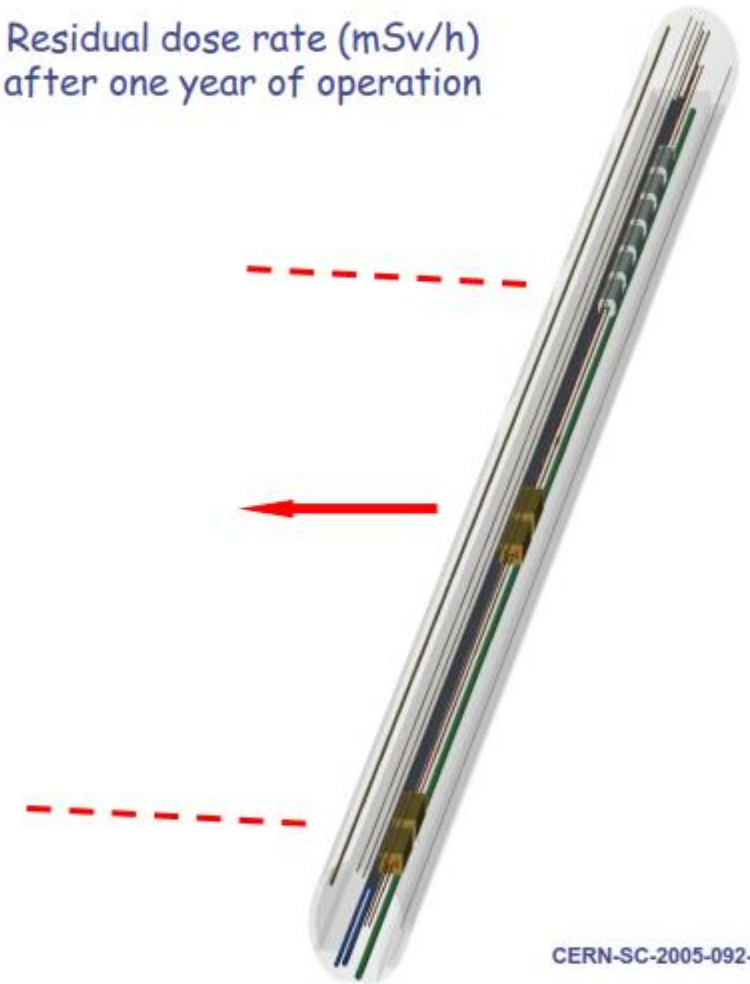
8 hours

1 week

4 months



Residual dose rate (mSv/h) after one year of operation

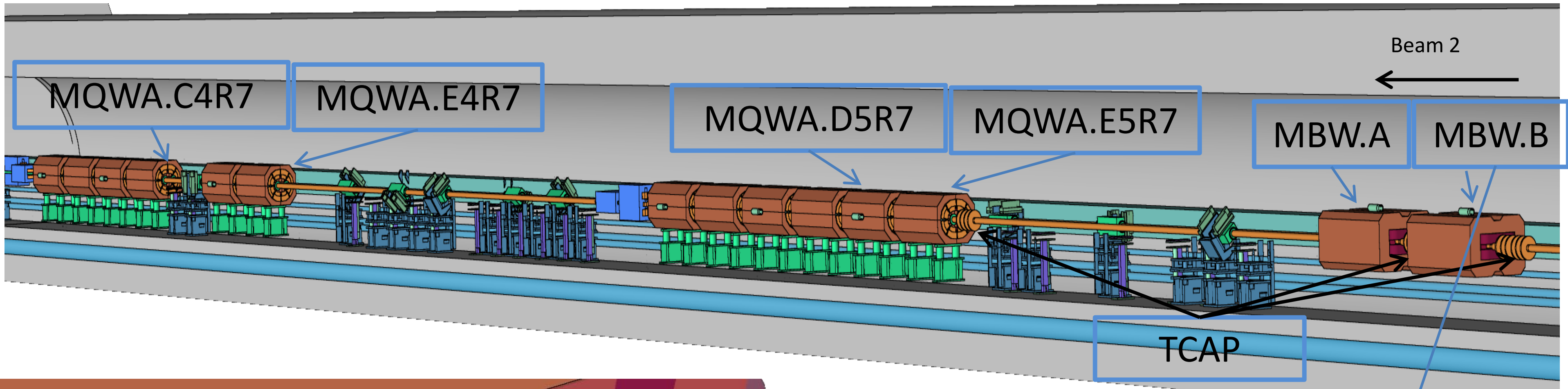


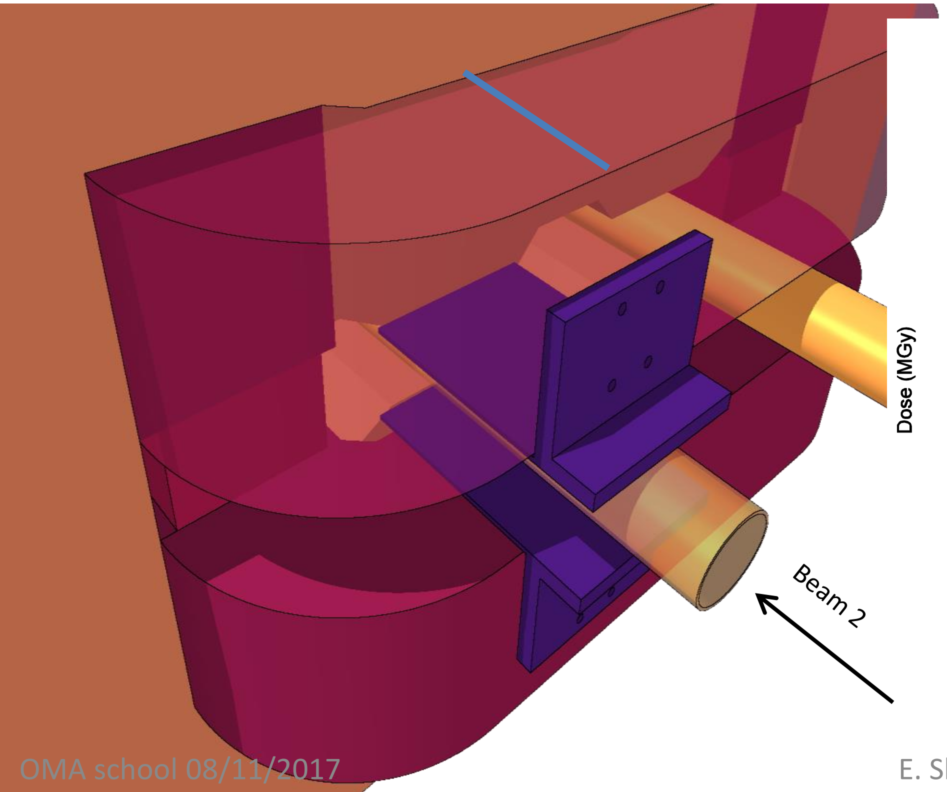
CERN-SC-2005-092-RP-TN

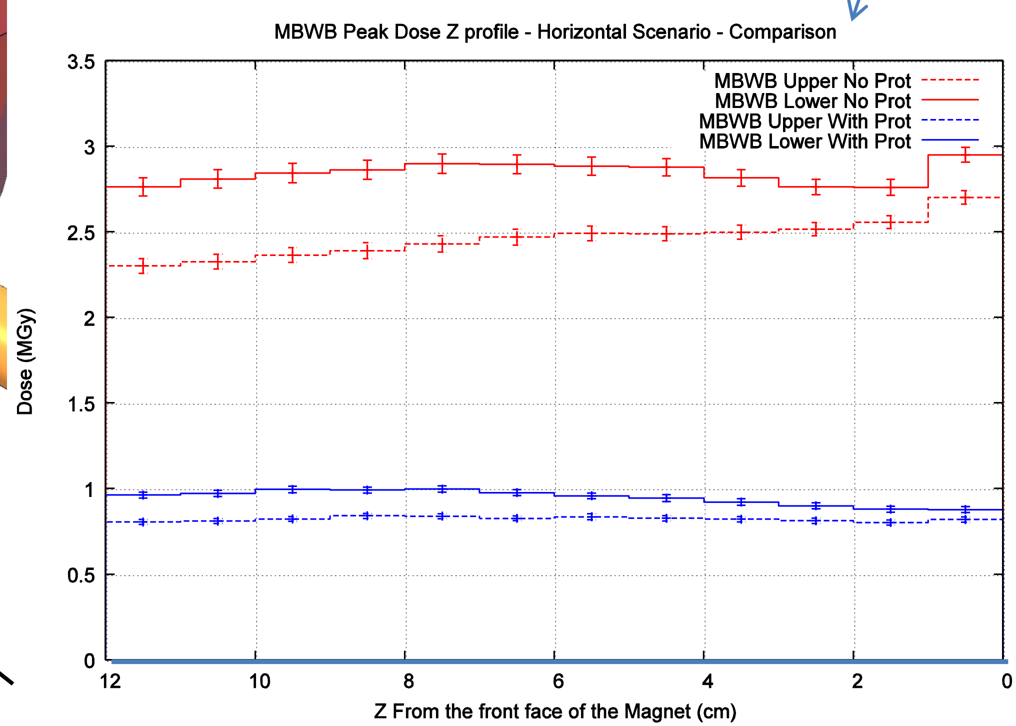
REMANENT DOSE RATE MAPS OF THE LHC BETATRON CLEANING INSERTION (IR7)

M. Brugger, D. Forkel-Wirth, S. Roesler

IR7 MBWA - MBWB 7 TeV Peak Dose profile

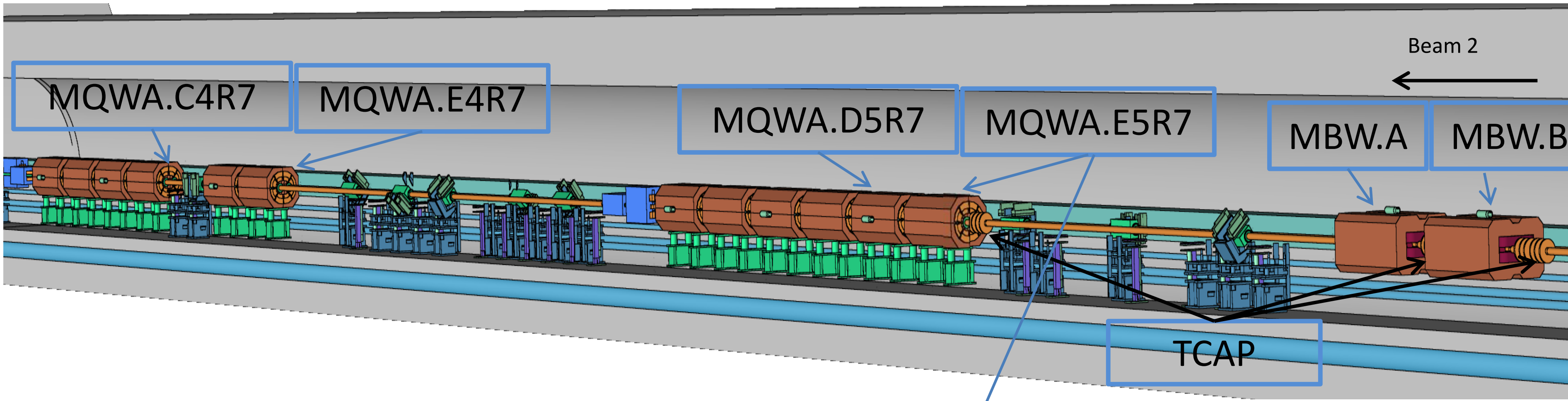


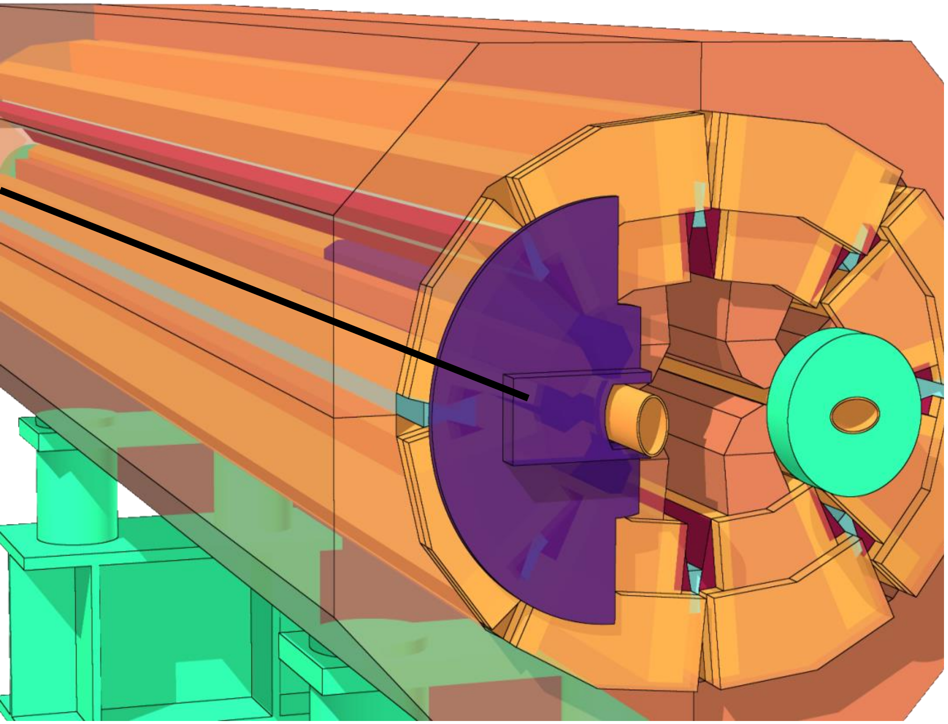


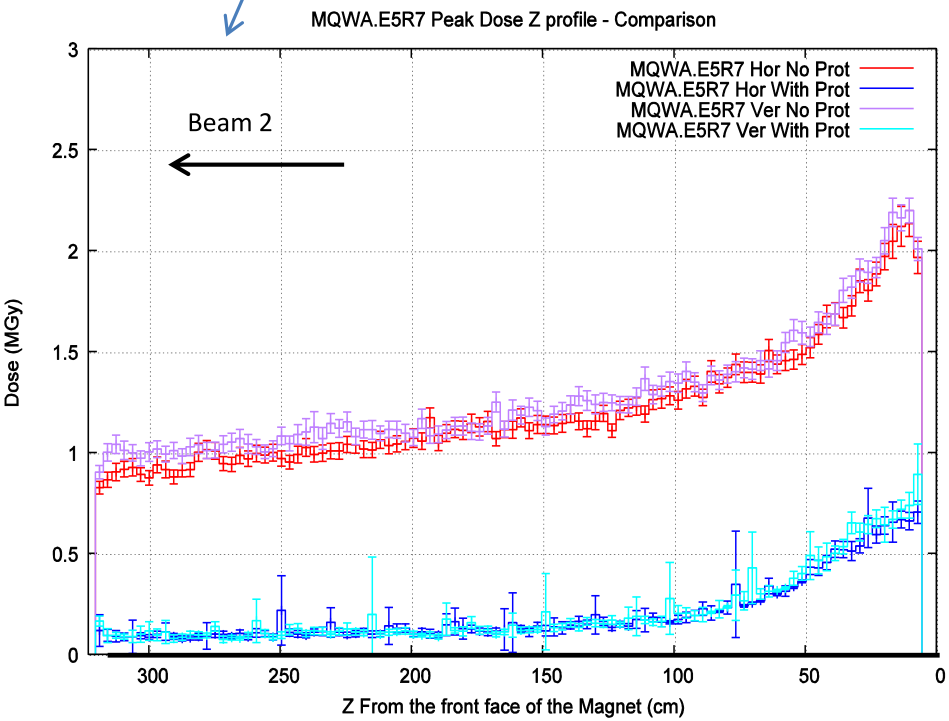


Normalization: 1.15 10^{16} p (40 fb^{-1})

IR7 MQW 7 TeV Peak Dose profile

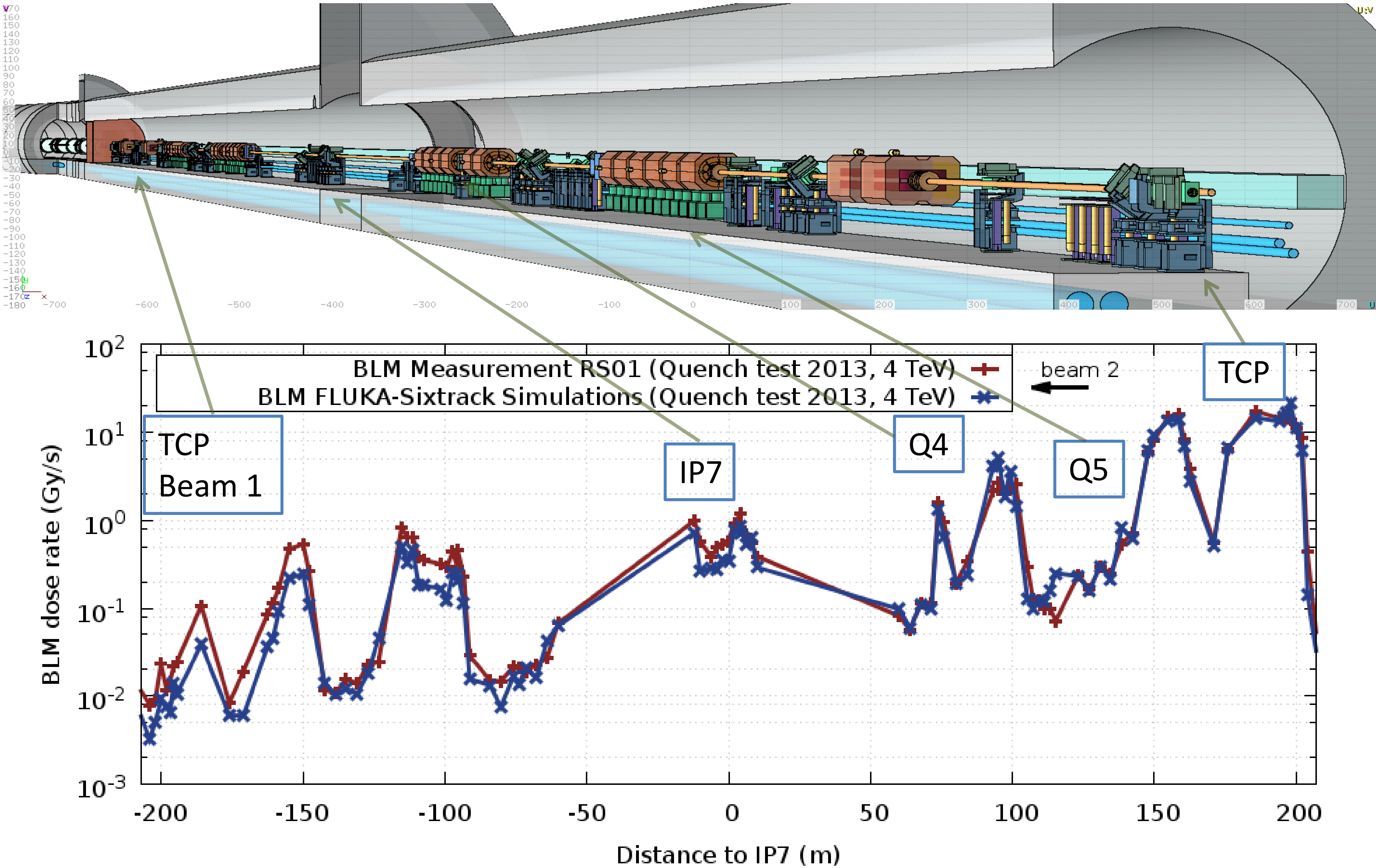






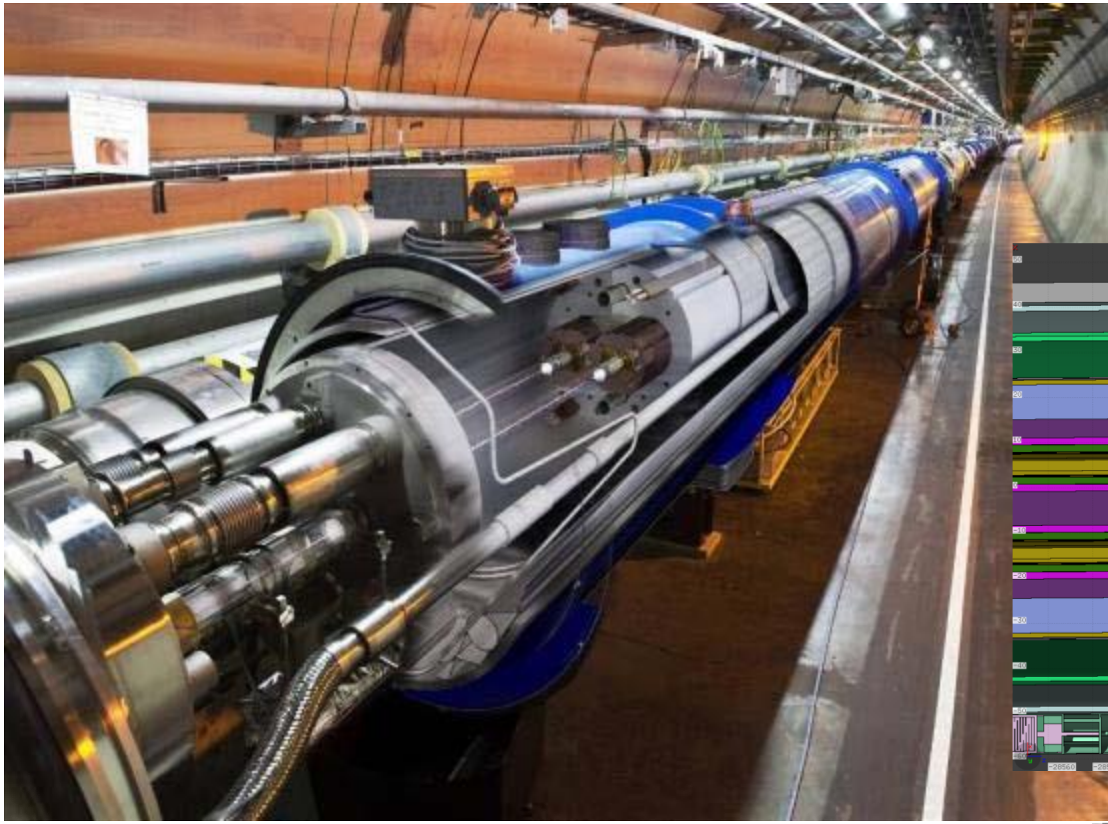
Normalization: 1.15 10^{16} p (40 fb^{-1})

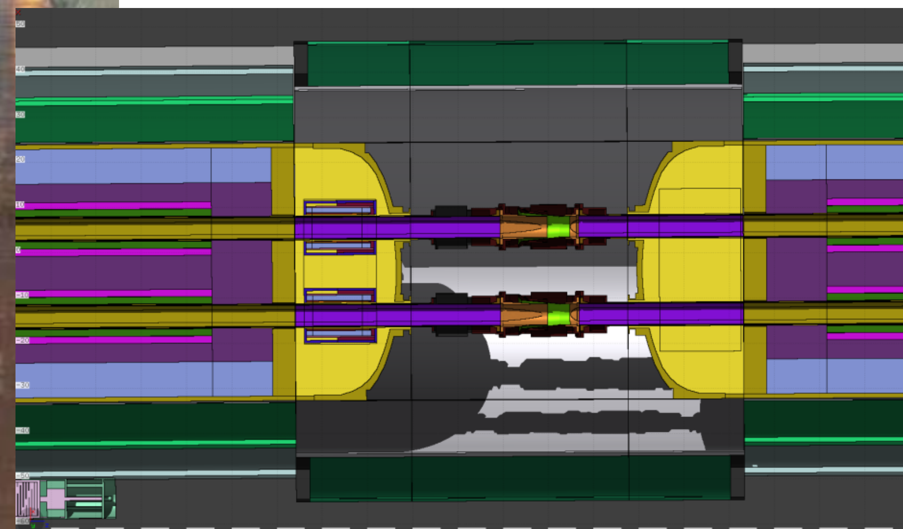
IR7 2013 Collimation Quench Test
FLUKA – Sixtrack Simulations

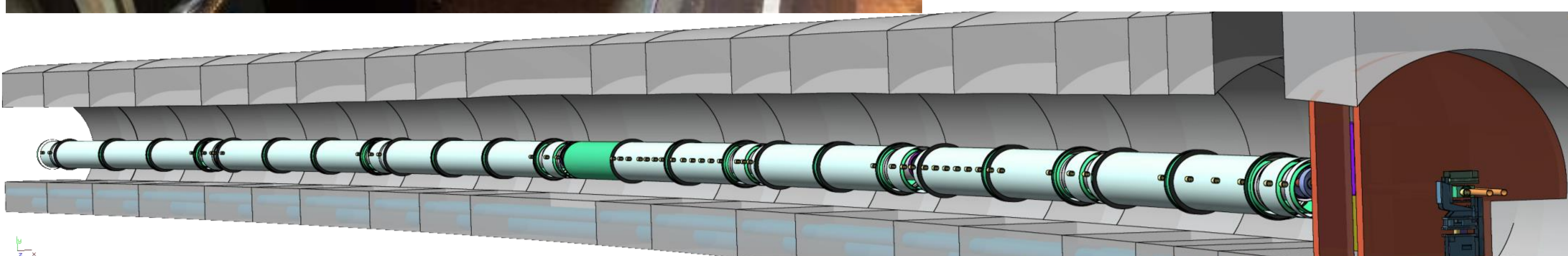


BLM integration Time : Running Sum 1 (40 µs)

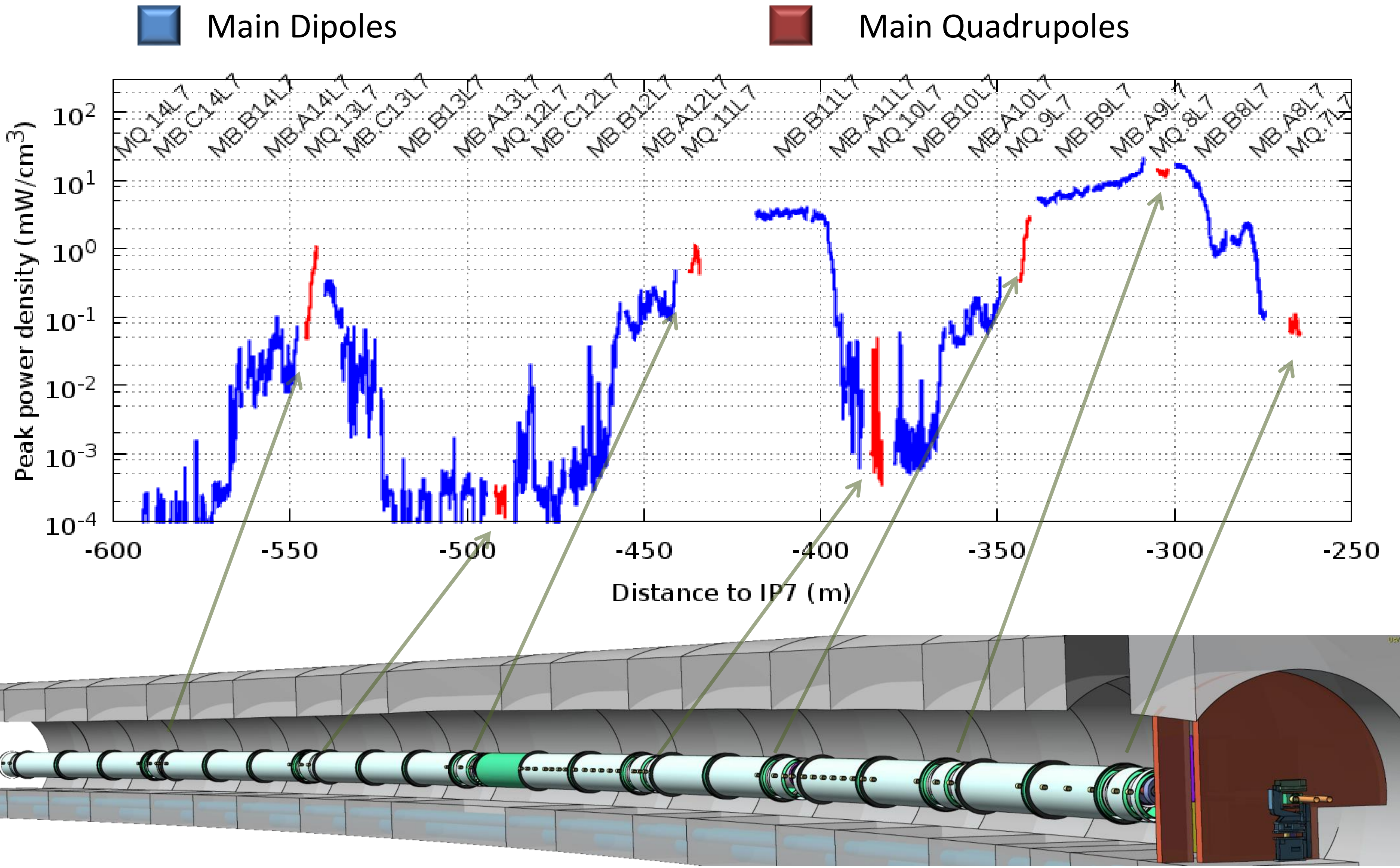
IR7 DS Peak power deposition in the SC coils





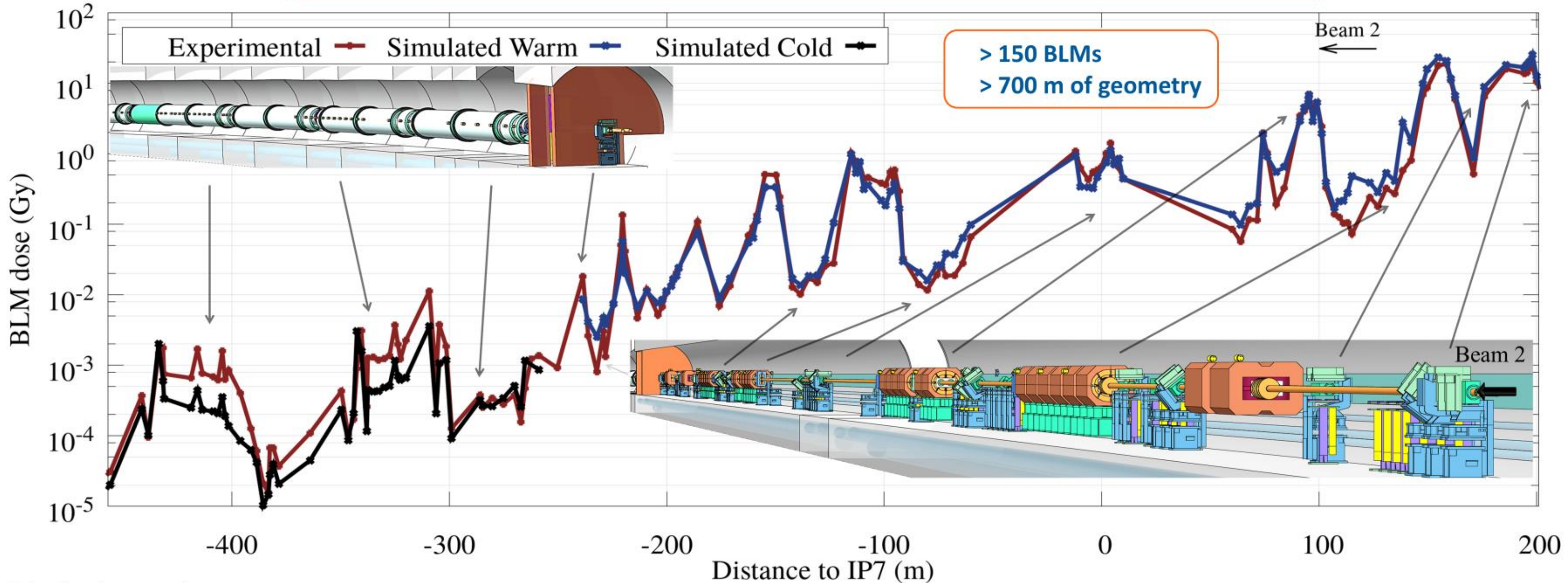


IR7 DS Peak power deposition in the SC coils



IR7 extended BLM signal comparison Experimental vs Simulation 2015 collimation QT

Simulation Benchmark / BLM Signal comparison - Protons

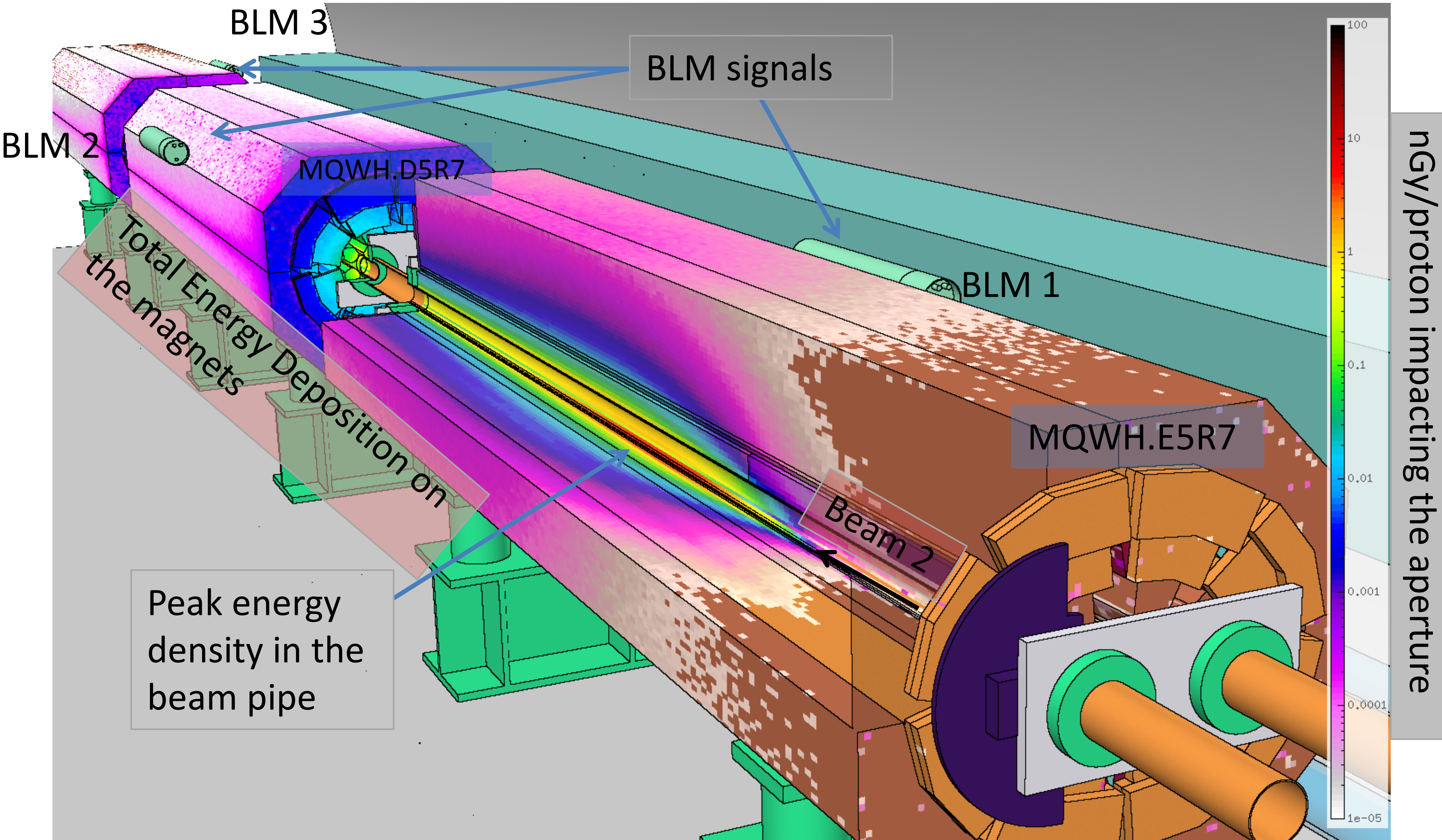


Absolute signal comparison:

- Within a few ten percent in the Warm section
- A factor of 3 underestimation in the SC magnets → Hint at Imperfections
- Remarkable pattern reproduction over 7 orders of magnitude

Detailed element models → Assembly with Linebuilder
Rendering of FLUKA geometry model of IR7 using Flair.

Geometry visualisation and values of interest



All values are normalised per proton impacting the beam pipe

Conclusions

- Good understanding of the collimation losses through the Sixtrack-FLUKA modelization (Excellent BLM agreement)
- Vital: Identification and quantification of the LHC hotspots (weak links, Dose, DPA, energy deposition) and correlation with BLM signals
- FLUKA Simulations are essential for the operation of the LHC and will continue to grow in demand

Thank you!

X-ray image simulation