Case study: Energy deposition in superconducting magnets in IR7

AMT Workshop

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Overview

- Motivation
- Geometry and Simulation setup
- Studies:
  - Heat on the superconducting magnets $\Rightarrow$ Absorbers
- Summary

LHC Cleaning Insertions

Two warm LHC insertions are dedicated to beam cleaning

Collimation systems:

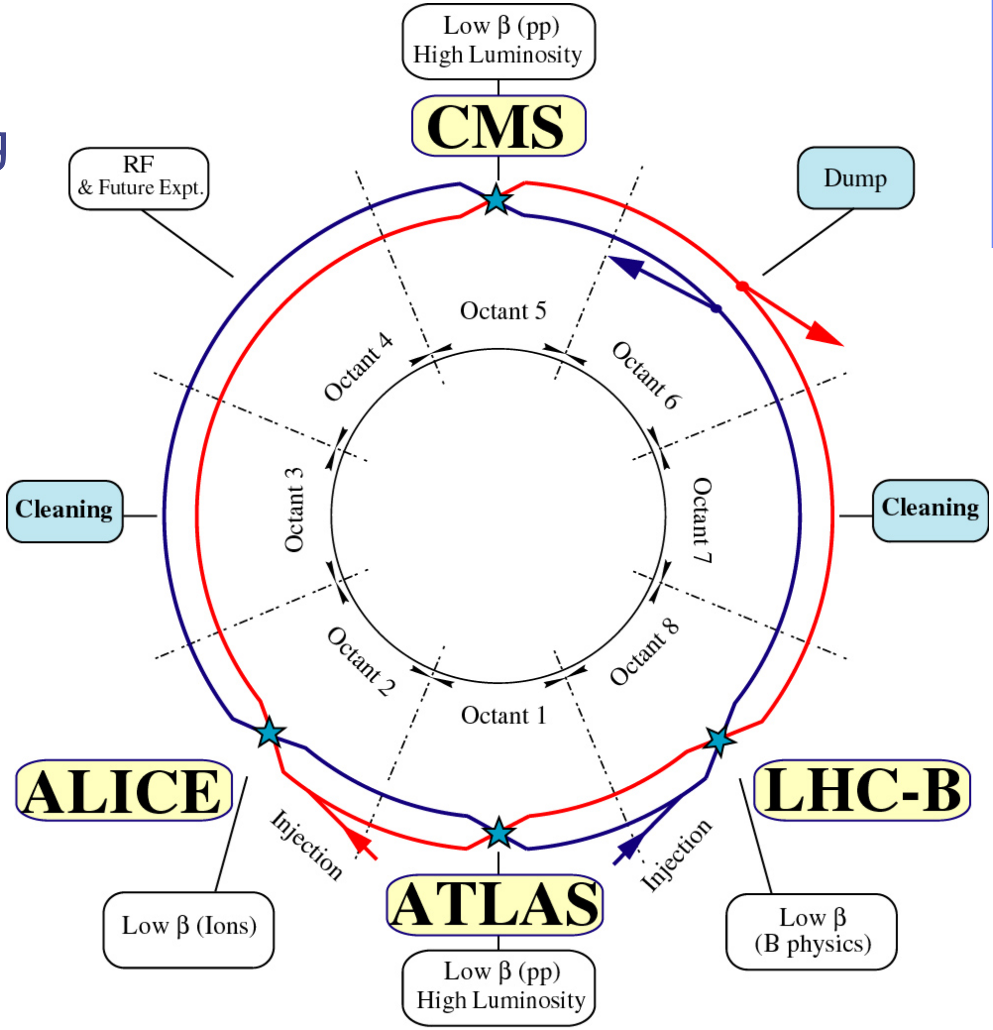
IR3: Momentum cleaning

IR7: Betatron cleaning

Normal operation:

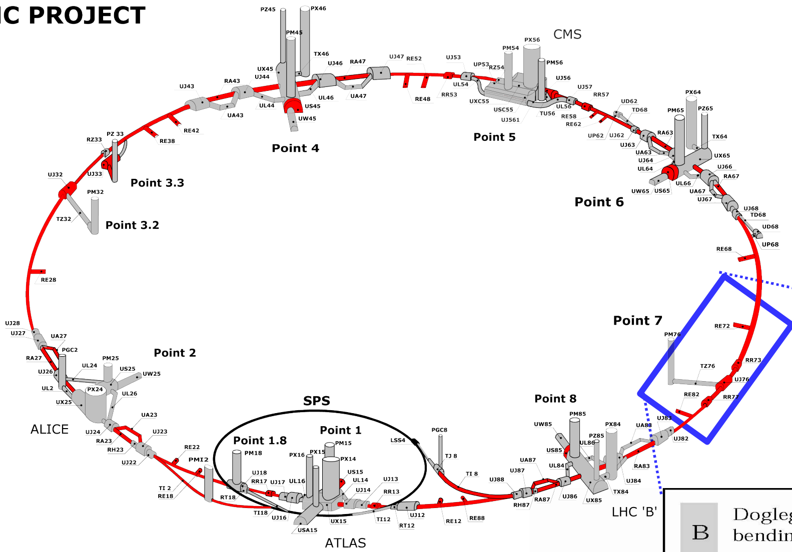
- 0.2 hours beam lifetime
- 4×10^{11} p/s for 10 s
- Power = 448 kW

Quench limit: 5 mW/cm^3

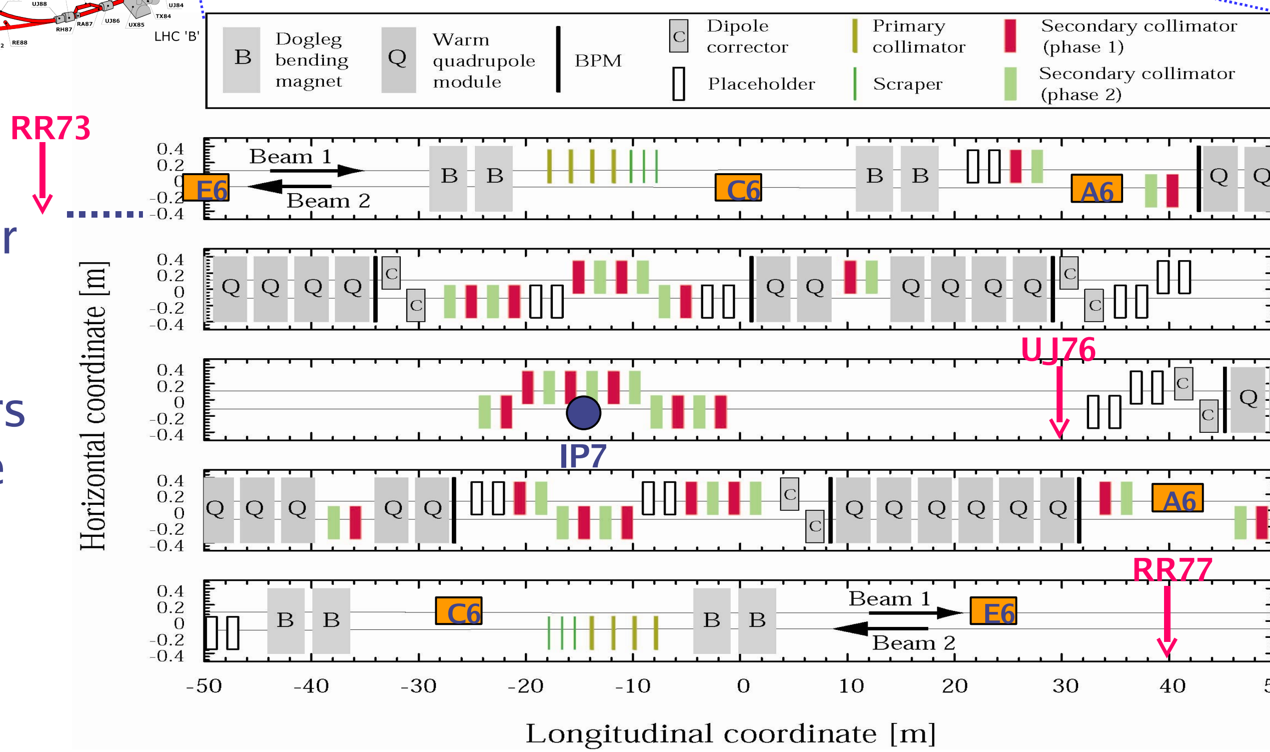


IR7 layout

LHC PROJECT



- LHC optics files V6.5
- Top beam energy
- Primary collimators: 6 σ
- Secondary collimators: 7 σ
- Absorbers: 10 σ

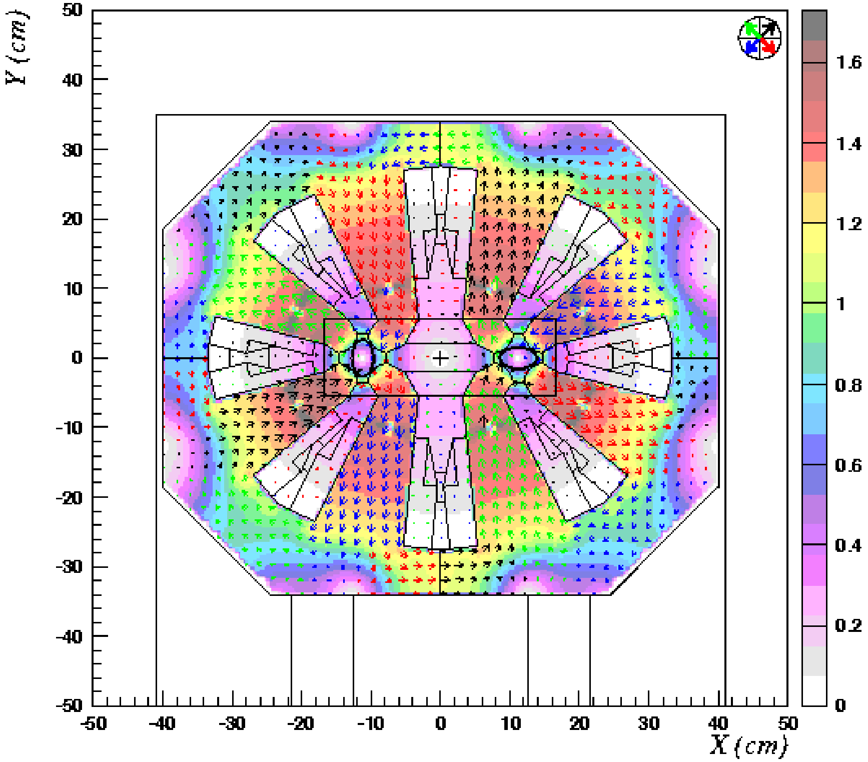


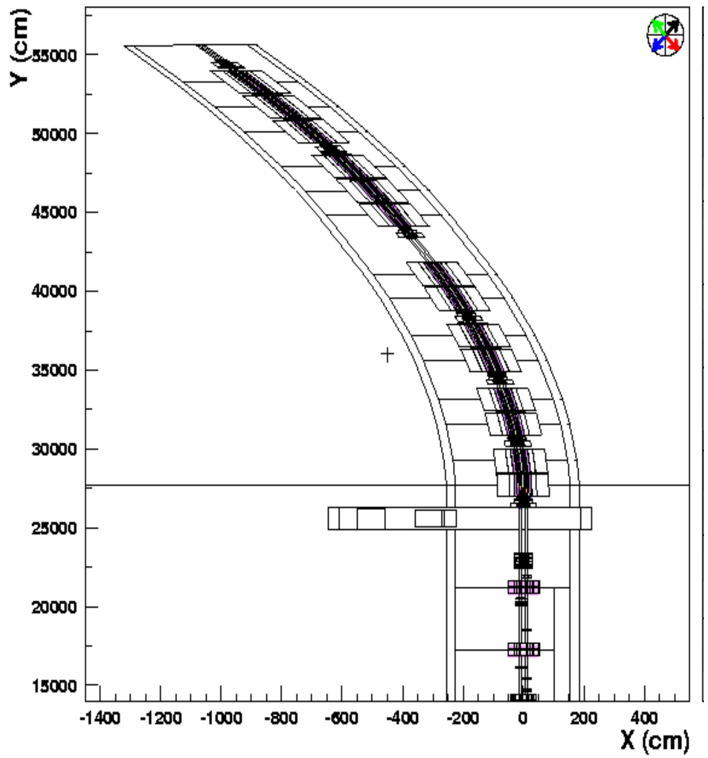
- IR7 Layout contains over 200 objects
- Warm section
- 2 Dispersion suppressors
- Collimators with variable positioning of the jaws

⇒ Challenging simulation work

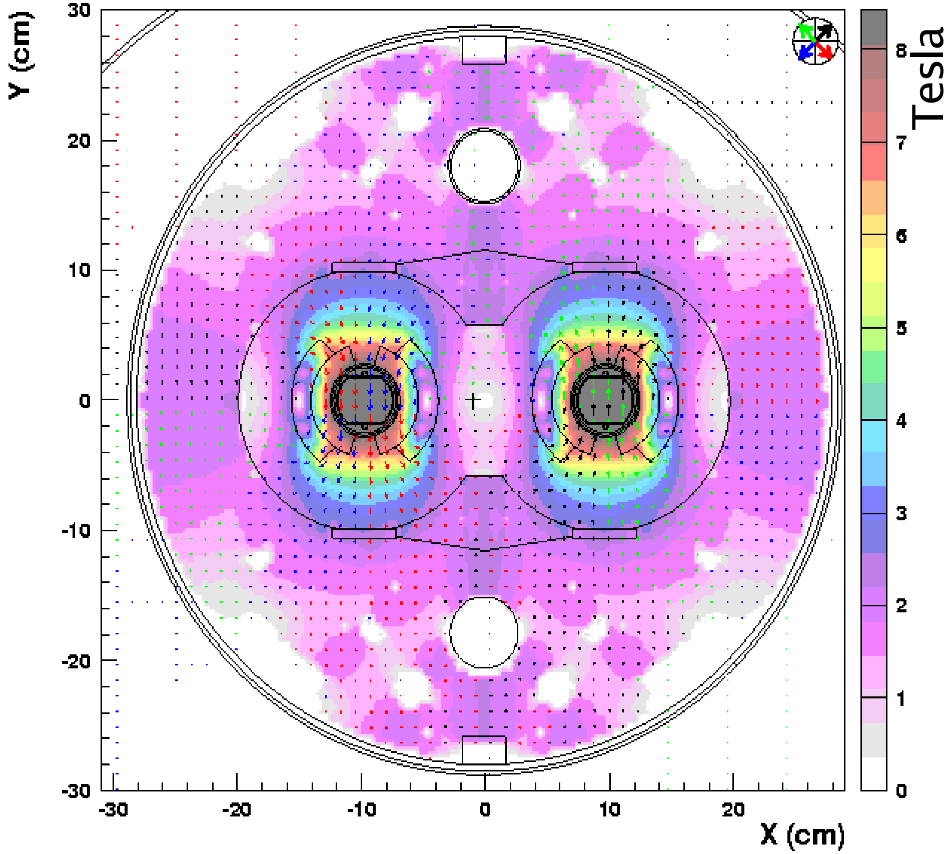
Geometry Implementation

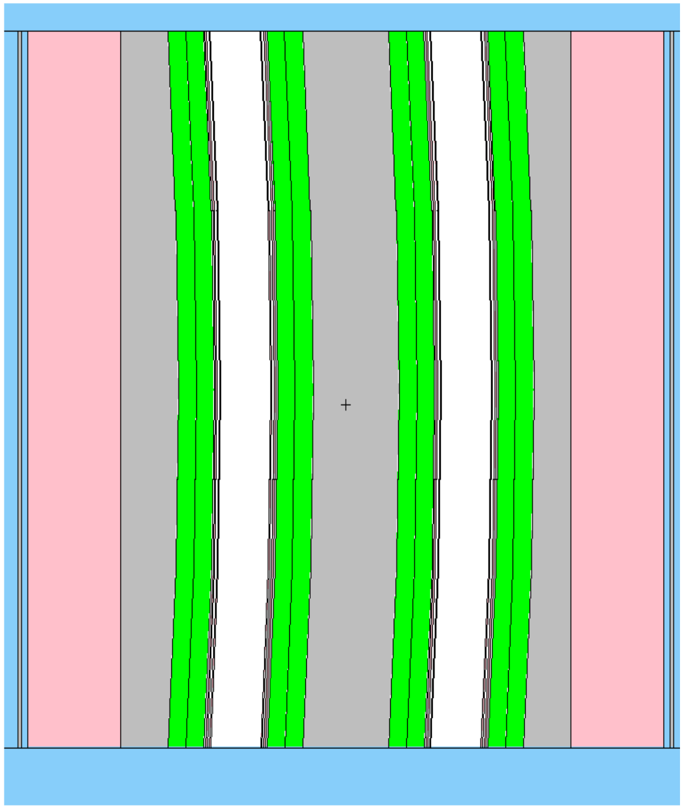
- Dynamic FLUKA input generation with several ad-hoc scripts
- Detailed description of about 20 prototypes located in a virtual parking zone.
- Magnetic field maps: Analytic + 2D Interpolated
- Prototypes are replicated with the LATTICE card, rotated and translated.
- Adjust the collimators planes during runtime!
- Dynamic generation of the ARC (curved section)
- Optics test: Tracking up to 5 σ, both vertical / horizontal, reproduce beta function





Geometry of Dipoles

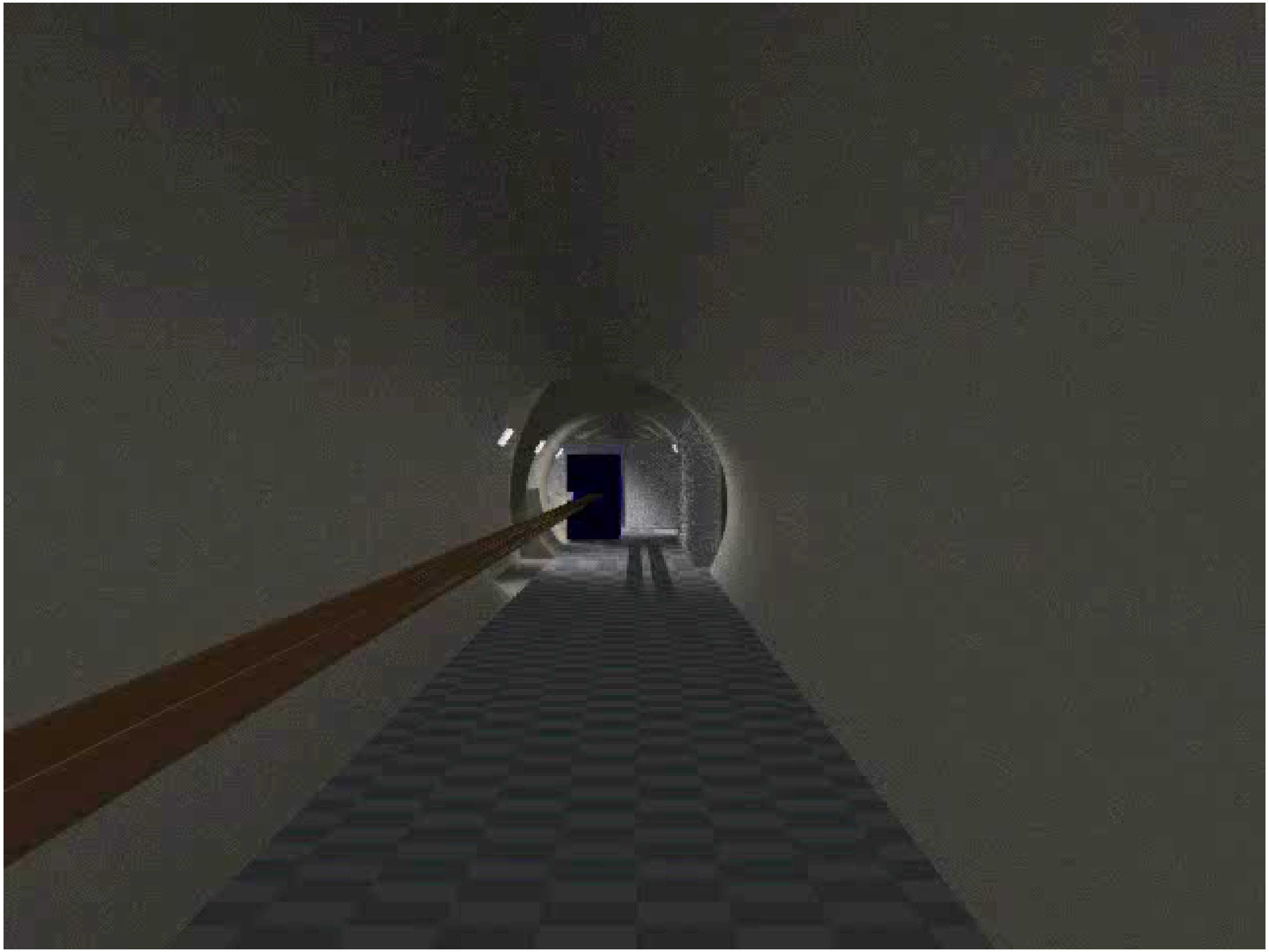




14m long objects with a field of 8 Tesla: 5mrad bend ⇒ ~3cm sagitta

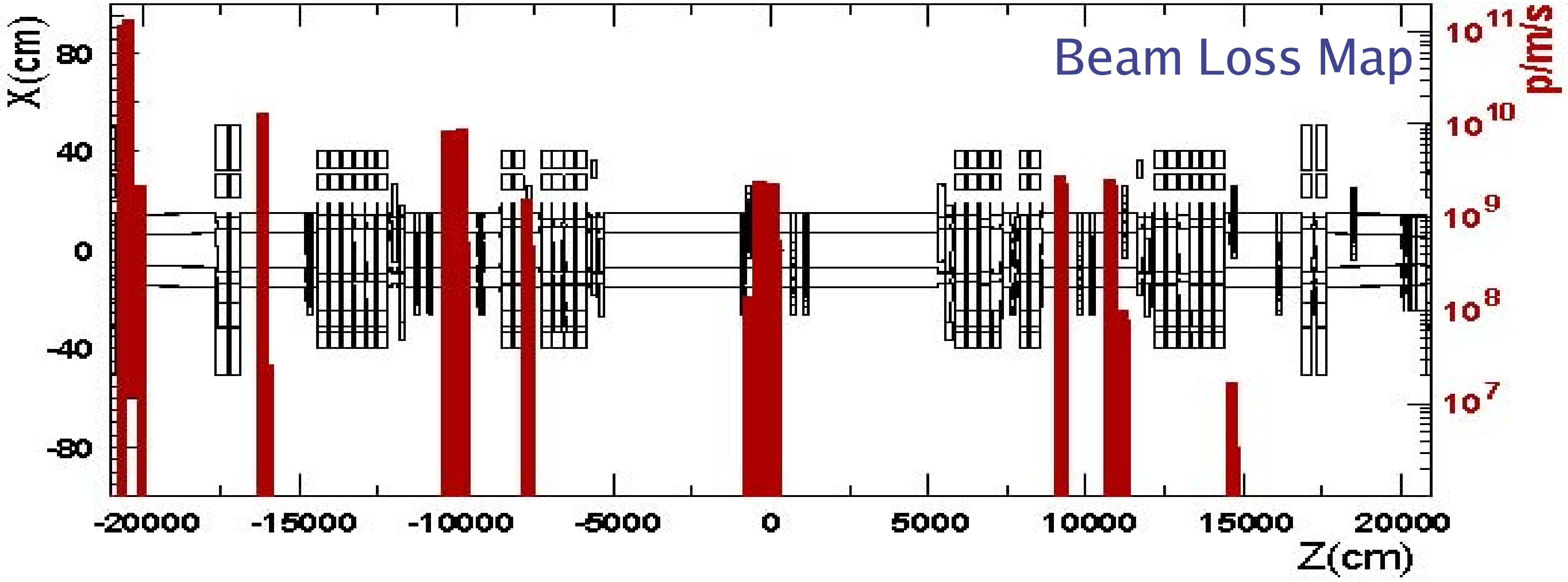
The superconducting dipoles (MB) are made out of 4 straight sections to accommodate the trajectory

IR7 Virtual Tour

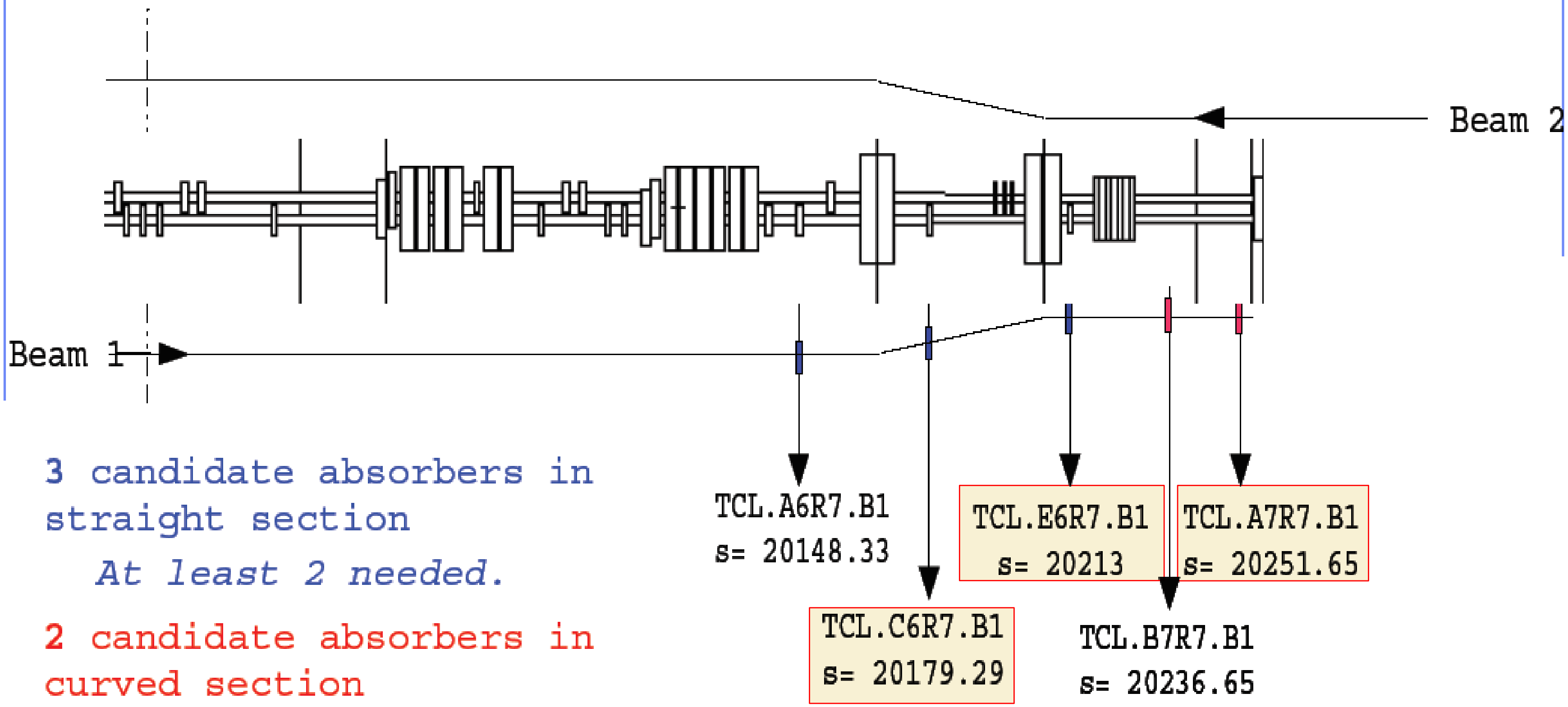


Primary Inelastic collisions map

- Generated by the COLLTRACK V5.4 program
  - 3 scenarios: Vertical, Horizontal and Skew
  - Pencil beam of 7 TeV low-beta beam on primary collimators
  - 100 turns without diffusion
  - Impact parameter: 0.0025 σ
  - Spread in the non-collimator plane: 200 μm
  - Recording the position and direction of the inelastic interactions
- FLUKA source: Force an inelastic interaction on the previously recorded positions



Absorbers Layout



3 candidate absorbers in straight section

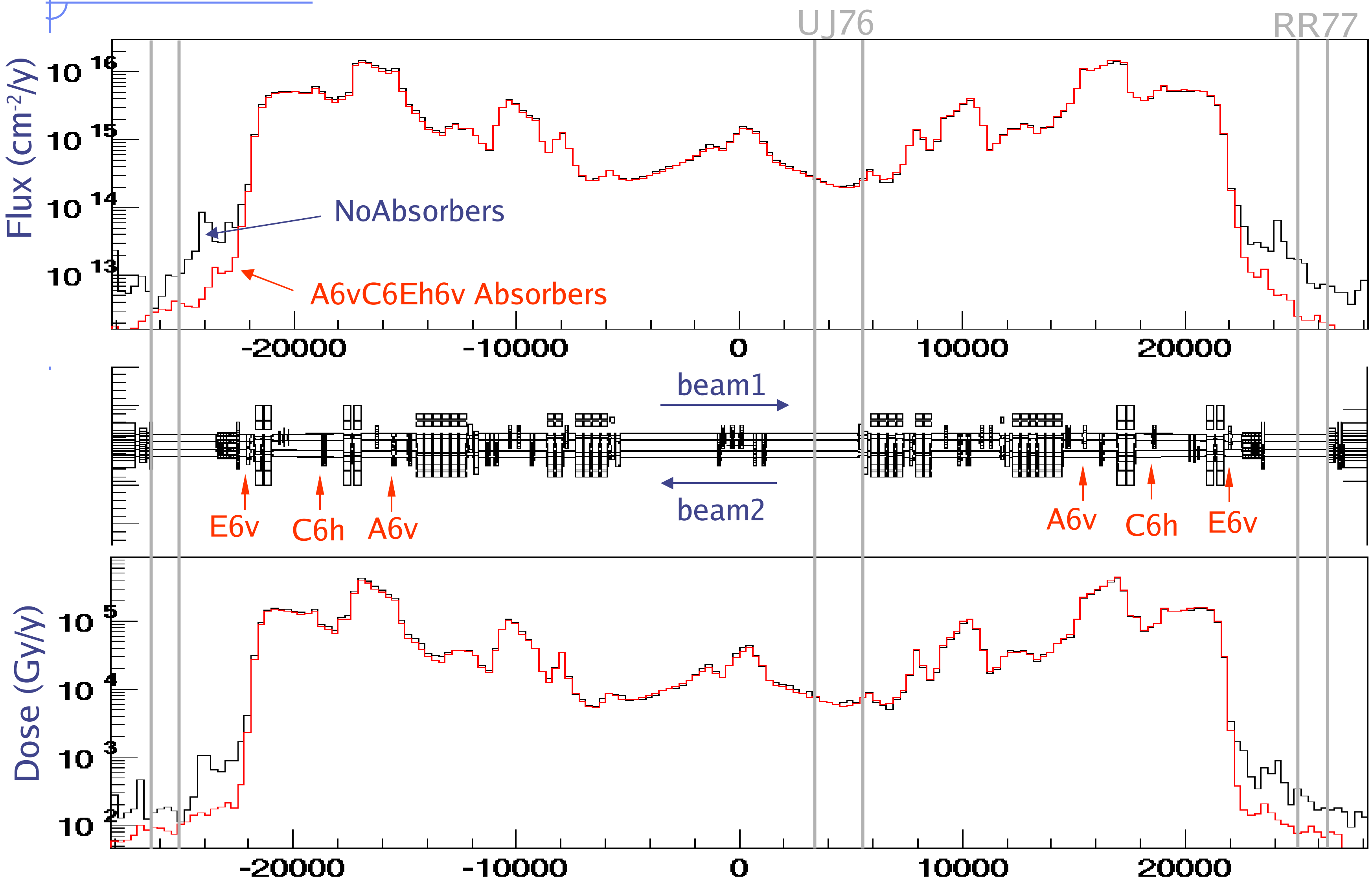
At least 2 needed.

2 candidate absorbers in curved section

At least 1 needed.

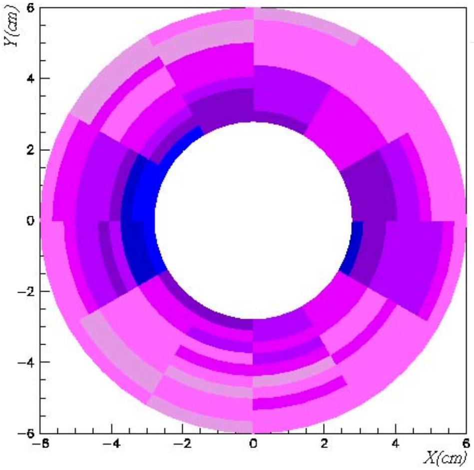
A6 is marginally valid
B7 was suppressed after contacting the integration team
A7 initially it was moved 5m upstream: A7'
afterwards it was moved 7m more upstream (12m): A7''

NoAbsorber vs. Absorber (tunnel)



Mean values ± 2m horizontally and ± 1m vertically.

Power density on the MBB8 Dipole



Scoring the energy deposition in a 3D mesh (R-Z-phi) on the coils of the SC elements

3 abs. in straight section; 1 abs A7" for the curved section

Energy Deposition

N_{abs}	$\%_{Beam}$	$A6_v$	$C6_h$	$E6_v$	$A7_h$“	$A7_h$‘	MQTL	MB	MQ
0	1.5	-	-	-	-	-	330	45	80
2	55	-	1190	208	-	-	0.69	?	?
3	55	2360	413	75	-	-	0.37	9	2.5
3	312	-	1190	208	48?	-	0.69	1.6	0.9
4	250?	2360	413	75	-	19	0.37	1.7?	2.0?
4	116	2360	413	75	44?	-	0.37	2.5?	0.7?

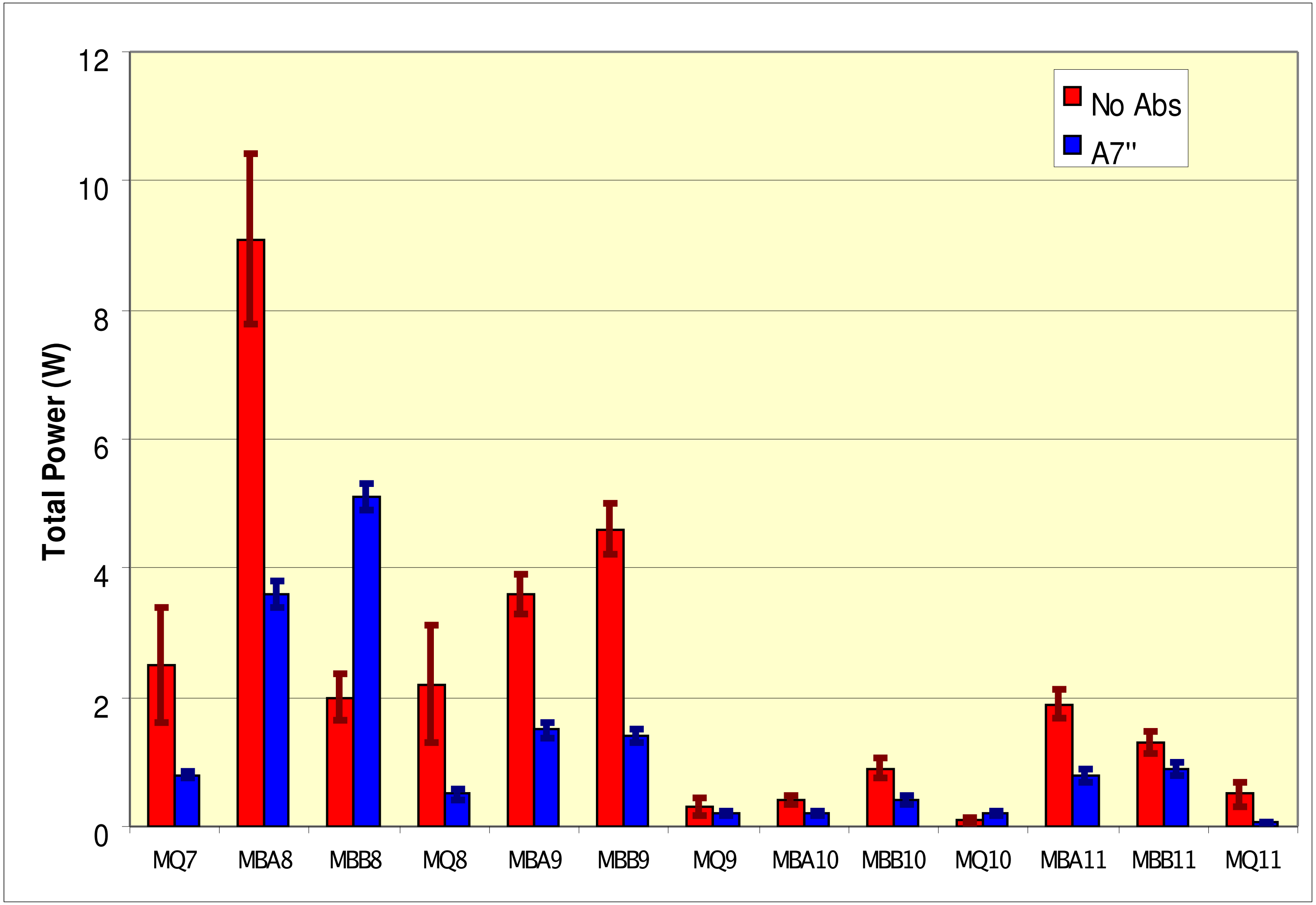
Results of energy deposition in the sensitive areas of IR7 for Different absorbers.

Units: Absorbers in *W*

Magnetic elements in *mW/cm^3*

? – Simulation is still running or not performed

Energy Deposition in the curved section



3 abs. in straight section; No abs. or 1 abs. for the curved section

Simulation Accuracy

Sources of errors:

- Physics modeling:
  - Uncertainty in the inelastic p-A extrapolation cross section at 7 TeV lab
  - Uncertainty in the modeling used

  $\Rightarrow$ Factor ~1.3 on integral quantities like energy deposition (peak included) while for multi differential quantities the uncertainty can be much worse
- Layout and geometry assumptions
  - It is difficult to quantify, experience has shown that a factor of 2 can be a safe limit
- Beam grazing at small angles on the surface of the collimators.
  - Including that the surface roughness is not taken into account
    $\Rightarrow$ A factor of 2 can be a safe choice.
- Safety factor from the COLLTRACK program is not included!

Conclusions

- Detailed description of the IR7 setup, with dynamic generation of all the necessary input files using the latest optics.
- Powerful tool used for various studies:
  - Energy deposition on Collimators, Warm Objects, Superconducting magnets
  - Si Damage calculations, Shielding studies for electronics
  - Ozone production…
- From the present talk:
  - With 4 absorbers we are below the quench limit of $5 mW/cm^3$ assuming a safety factor of 2-3.
  - At least 2 absorbers are needed in the straight section
  - At least 1 absorber is needed in the curved section
  - The further away you place the absorber the less effective it is.

Pending:

Before freezing the layout of the absorbers at IR7.

- Introduce passive absorbers for the warm elements and scrappers
- Include the effect of the tertiary halo on the absorbers it self.
- Finalize all simulations

Energy Deposition in the curved section

		no		A7”
Element	Power (W)	Err	Power (W)	Err
MQ7	2.5	72%	0.8	13%
MBA8	9.1	29%	3.6	11%
MBB8	2.0	35%	5.1	8%
MQ8	2.2	83%	0.5	29%
MBA9	3.6	17%	1.5	15%
MBB9	4.6	17%	1.4	15%
MQ9	0.3	89%	0.2	30%
MBA10	0.4	34%	0.2	40%
MBB10	0.9	33%	0.4	36%
MQ10	0.1	99%	0.2	34%
MBA11	1.9	22%	0.8	25%
MBB11	1.3	25%	0.9	22%
MQ11	0.5	71%	0.06	66%

3 Absorbers in straight section; No abs. in curved, A7” in curved