# Direct proton losses and beam-gas interaction in IR7

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4th February '08

# Outline

- Direct proton losses:
  - Energy deposition in the cold section: two different approaches
  - Direct proton losses in IR7
  - Normalization of FLUKA results
  - Results of the simulations
  - Conclusions
- Beam-gas interaction:
  - Introduction
  - Normalization of FLUKA results
  - Results of the simulations
  - Conclusions

# Introduction

**To compute energy deposition in IR7 cold elements due to the beam halo two different approaches are possible.**

**Method 1**

1) Loss maps in the collimators are computed with SIXTRACK, including both inelastic and single diffractive events
2) FLUKA imports the loss map and samples:
  - The interaction location (among the events in the loss map)
  - The interaction type (inelastic and single diffractive)
3) FLUKA transports the interaction products along IR7, and if it's the case, up to the DS.

**Why are single diffractive events so important?**

Because most of energy deposited in the DS is due to single diffractive events in the collimators. Showers generated by inelastic interactions in the primary and secondary collimators don't reach the DS.

# Introduction

Method 2

1) Direct proton losses maps are computed with SIXTRACK
(location and direction of particles leaving the aperture)
2) FLUKA imports the loss map and samples the proton impacting position (among the events in the loss map)
3) FLUKA transports the proton in the material.

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**Quick comparison:**

Method 1:
- Single diffractive events in the collimators handled by FLUKA
- Transport through IR7 handled by FLUKA

Method 2:
- Single diffractive events in the collimators handled by SIXTRACK
- Transport through IR7 handled by SIXTRACK

# Direct proton losses in IR7

**Case lowbeta, horizontal halo. Tracked particles: 5.76E6**

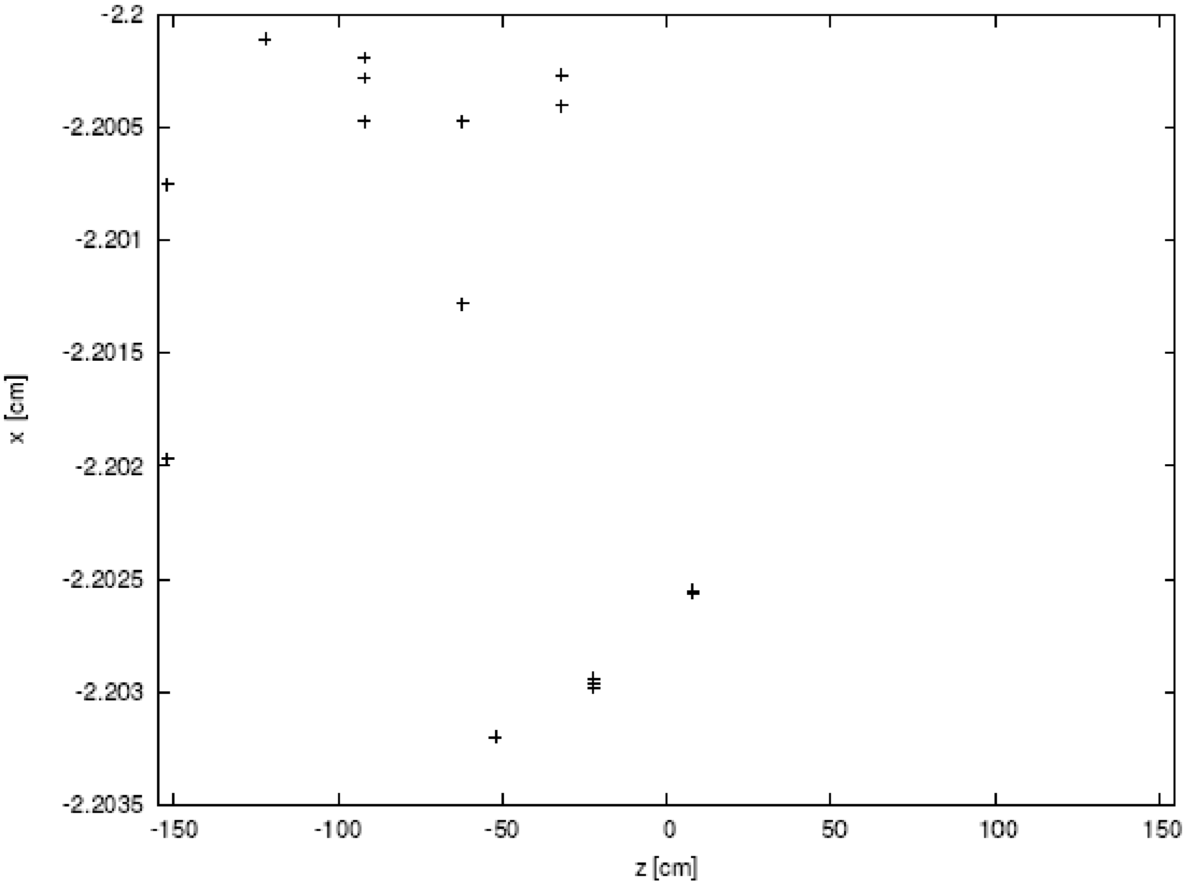
| Element | # | Length[m] | #/m | Element | # | Length[m] | #/m |
|---|---|---|---|---|---|---|---|
| MQWA.C5L7.B1 | 1 | 3.108 | 0.32 | DRIFT 94 | 6 | 0.296 | 20.2 |
| DRIFT 851 | 2 | 0.692 | 2.89 | DRIFT 21 | 2 | 0.192 | 10.4 |
| MQWB.5L7.B1 | 2 | 3.108 | 0.64 | DRIFT 823 | 28 | 0.844 | 33.1 |
| DRIFT 851 | 3 | 0.692 | 4.33 | MQ.9R7.B1 | 29 | 3.1 | 9.35 |
| MQWA.B5L7.B1 | 13 | 3.108 | 4.18 | MB.B10R7.B1 | 1 | 14.3 | 0.06 |
| DRIFT 851 | 1 | 0.692 | 1.44 | DRIFT 819 | 2 | 0.845 | 2.36 |
| MQWA.A5L7.B1 | 21 | 3.108 | 6.75 | MQ.10R7.B1 | 19 | 3.1 | 6.12 |
| MQWA.D4R7.B1 | 4 | 3.108 | 1.28 | DRIFT 120 | 5 | 0.169 | 29.5 |
| DRIFT 851 | 1 | 0.692 | 1.44 | MQTLI.10R7.B1 | 25 | 1.3 | 19.2 |
| MB.B8R7.B1 | 5 | 14.3 | 0.34 | DRIFT 820 | 3 | 0.19 | 15.7 |
| DRIFT 85 | 2 | 0.297 | 6.73 | MCBCV.10R7.B1 | 16 | 0.9 | 17.7 |
| DRIFT 827 | 8 | 0.843 | 9.48 | DRIFT 821 | 11 | 0.562 | 19.5 |
| MQ.8R7.B1 | 29 | 3.1 | 9.35 | DRIFT 90 | 5 | 0.203 | 24.6 |
| DRIFT 120 | 1 | 0.169 | 5.91 | DRIFT 110 | 8 | 0.192 | 41.6 |
| MQTLI.8R7.B1 | 18 | 1.3 | 13.8 | DRIFT 80 | 8 | 0.339 | 23.5 |
| DRIFT 820 | 4 | 0.19 | 21.0 | MB.A11R7.B1 | 254 | 14.3 | 17.7 |
| MCBCV.8R7.B1 | 10 | 0.9 | 11.1 | DRIFT 81 | 2 | 0.219 | 9.12 |
| DRIFT 828 | 8 | 0.564 | 14.1 | MCS.A11R7.B1 | 3 | 0.11 | 27.2 |
| DRIFT 90 | 3 | 0.203 | 14.7 | DRIFT 111 | 6 | 0.295 | 20.3 |
| DRIFT 91 | 6 | 0.190 | 31.5 | DRIFT 83 | 6 | 0.205 | 29.2 |
| DRIFT 80 | 5 | 0.339 | 14.7 | DRIFT 1580 | 9 | 0.532 | 16.9 |
| MB.A9R7.B1 | 279 | 14.3 | 19.5 | MB.B11R7.B1 | 208 | 14.3 | 14.5 |
| DRIFT 1284 | 1 | 0.219 | 4.56 | DRIFT 81 | 2 | 0.219 | 9.12 |
| MCS.A9R7.B1 | 2 | 0.11 | 18.1 | DRIFT 1296 | 6 | 0.294 | 20.4 |
| DRIFT 1575 | 7 | 0.297 | 23.6 | DRIFT 1581 | 4 | 0.202 | 19.7 |
| DRIFT 83 | 5 | 0.205 | 24.3 | DRIFT 1500 | 185 | 13.517 | 13.6 |
| DRIFT 1576 | 14 | 0.530 | 26.4 | DRIFT 941 | 16 | 0.846 | 18.9 |
| MB.B9R7.B1 | 242 | 14.3 | 16.9 | MQ.11R7.B1 | 20 | 3.1 | 6.45 |
| DRIFT 81 | 4 | 0.219 | 18.2 | MQ.13R7.B1 | 1 | 3.1 | 0.32 |
| MCS.B9R7.B1 | 4 | 0.11 | 36.3 | | | | |

Total number of events: 1595 Loss map provided by C. Bracco

# Direct proton losses in IR7

**Lack of statistics from the SIXTRACK side.**
**Take with care the errors specified in the results that follow.**

**Example: MQ.11R7 has only 20 events**



# Normalization

The normalization factor to convert the FLUKA results, expressed per source particle, in power density is the following:

$N = L * N_{DPL} / N_{TOT}$

Where:

$N_{DPL}$ is the number of direct proton losses in IR7 (1525)

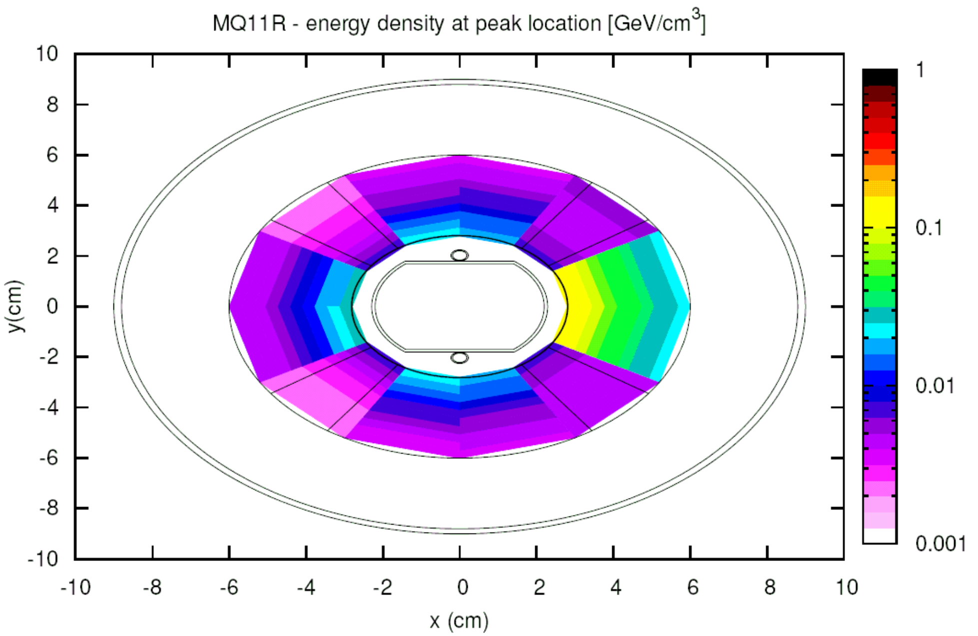
$N_{TOT}$ is the total number of particles simulated with SIXTRACK (5.76E6)

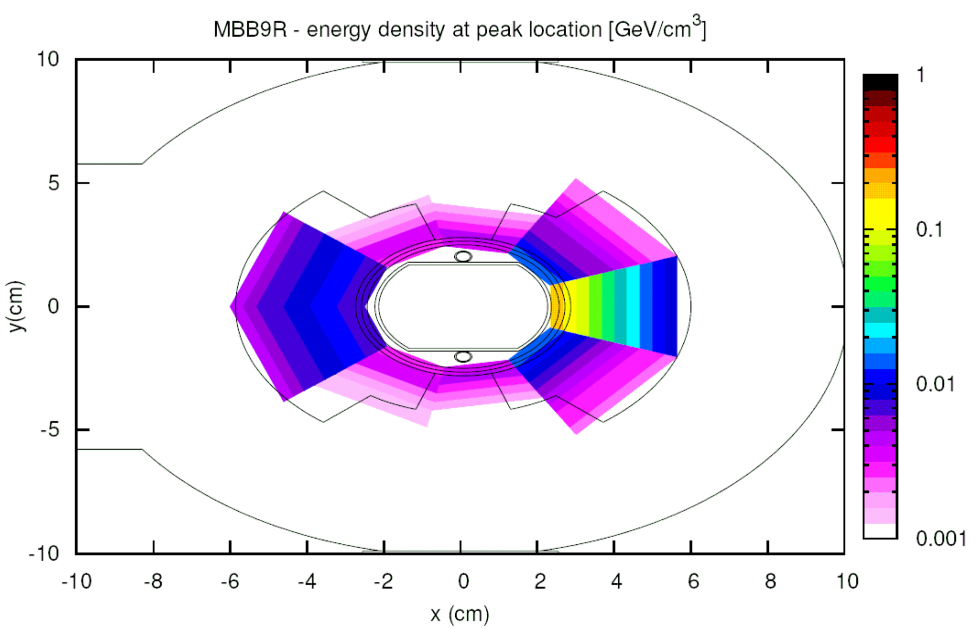
L is the loss rate: 4.3E+11 $s^{-1}$ for nominal intensity and 0.2 h beam lifetime

# Direct proton losses

# Results (lowbeta, horizontal halo)

| Element | Peak energy [J/cm$^3$/pr] | Peak power [mW/cm$^3$] | Error [%] |
|---|---|---|---|
| MQ8R | 0.044 | 0.84 | ±2.9 |
| MQ9R | 0.063 | 1.20 | ±2.3 |
| MQ10R | 0.041 | 0.78 | ±2.8 |
| MQ11R | 0.139 | 2.64 | ±4.6 |
| MQ12R | 0.000 | 0.00 | ±71.3 |
| MQ13R | 0.003 | 0.06 | ±12.5 |
| MBB8R | 0.004 | 0.08 | ±10.3 |
| MBA9R | 0.101 | 1.92 | ±2.3 |
| MBB9R | 0.160 | 3.05 | ±2.3 |
| MBA10R | 0.004 | 0.08 | ±4.2 |
| MBB10R | 0.005 | 0.10 | ±11.6 |
| MBA11R | 0.097 | 1.85 | ±2.4 |
| MBB11R | 0.078 | 1.49 | ±2.3 |
| MBA12R | 0.009 | 0.17 | ±3.2 |
| MBB12R | 0.002 | 0.04 | ±5.9 |



# Direct proton losses
## Results (lowbeta, horizontal halo)

| | Direct proton losses | | Interaction in collimators | |
|---|---|---|---|---|
| Element | Peak power [mW/cm$^3$] | Error [%] | Peak power [mW/cm$^3$] | Error [%] |
| MQ8R | 0.84 | ±2.9 | 1.0 | ±64.4 |
| MQ9R | 1.20 | ±2.3 | 1.9 | ±22.6 |
| MQ10R | 0.78 | ±2.8 | 0.5 | ±66.7 |
| MQ11R | 2.64 | ±4.6 | 5.0 | ±32.3 |
| MBB8R | 0.08 | ±10.3 | 0.2 | ±72.2 |
| MBA9R | 1.92 | ±2.3 | 0.6 | ±23.8 |
| MBB9R | 3.05 | ±2.3 | 1.0 | ±12.2 |
| MBA10R | 0.08 | ±4.2 | 0.4 | ±24.8 |
| MBB10R | 0.10 | ±11.6 | 0.03 | ±99.0 |
| MBA11R | 1.85 | ±2.4 | 0.9 | ±22.6 |
| MBB11R | 1.49 | ±2.3 | 1.0 | ±15.6 |
| MBA12R | 0.17 | ±3.2 | | ±29.4 |
| MBB12R | 0.04 | ±5.9 | | ±77.7 |

M. Santana, Status of energy deposition studies at IR7,
Collimation working group, 17/7/2006

# Conclusions

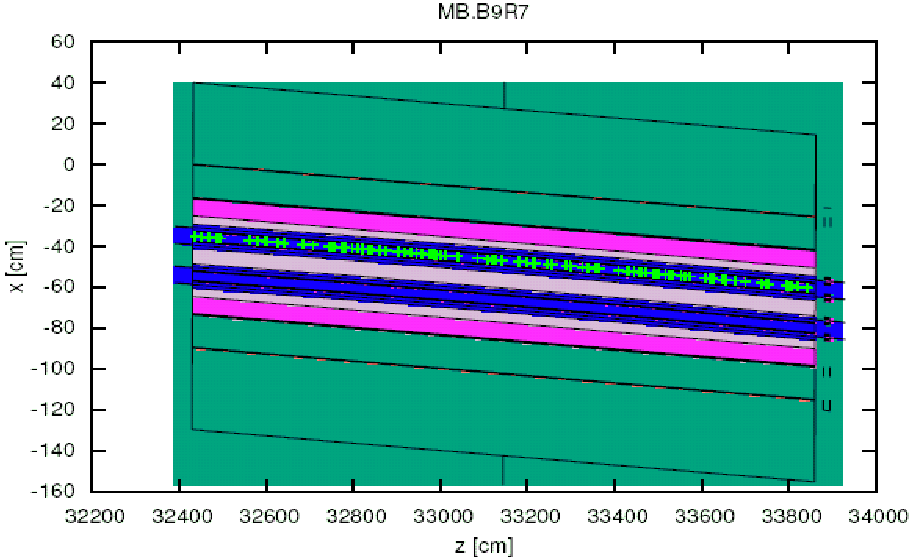
- The expected values of power peaks obtained from the two different methods are of the same order of magnitude.
They differ by a factor of ~3.
As already pointed out an uncertainity of a factor of 3 for peak calculation is reasonable.

- The data from the simulation taking into account the losses in collimators are old; a new run should be performed (new optics, passive absorbers final layout, etc.): loss maps needed.

# Introduction

- Aim: study of the energy deposited in the cold elements of IR7 due to the interaction of the LHC beam with the residual gas.
- So far there is not a detailed study of residual gas density and composition in IR7
- FLUKA simulation:

1) The residual gas is assumed to be hydrogen
2) The beam-gas collision is simulated with FLUKA by sampling a point along the beam axis and forcing the interaction



# Introduction

- FLUKA simulation (continued):

  3) **The energy peak** and the **total energy deposited per meter** (provided by FLUKA) in each cold element has been compared, respectively, with the limits of 4 $mW/cm^3$ and 30 mW/m (*).
  A maximum interactions rate is obtained, leading to a maximum tolerable gas density *(see next slide)*

  4) The maximum gas density has been cross checked with the results of vacuum studies for other critical points of LHC.

(*) Limit of energy deposited per meter per beam due to beam gas interaction.
LHC Design Report, Chapter 12

# Beam-gas interaction
# Normalization

If the interaction is sampled along a distance L
(along which the $H_2$ density is supposed to be constant)

and the **energy density peak** in a cold element is $E_{peak}$ ,

then the maximum interaction rate in L is equal to:
N [interaction/s] = Q [mW/cm$^3$] / $E_{peak}$ [mJ/cm$^3$/pr]
(being Q the quench limit)

From the maximum interaction rate the **limit on gas density** can be determined:

$\rho(H_2,max)$ [molecules/m$^3$] = N / (I * $\sigma$ * L)

Where:

I is the beam current (3.64E+10 p/s),
$\sigma$ the p-$H_2$ cross section (76 mb)

The LHC beam lifetime for nuclear interaction with the residual gas is 100h: this value is consistent with an average power dissipation per beam of 32 mW/m and with $H_2$-equivalent equivalent density of 1E+15 molecules/m$^3$

# Beam-gas interaction
## Results

| Element name: | Energy peak [GeV/cm$^3$/pr] | $\rho_{max,H_2}$ [molecules/m$^3$] |
|---|---|---|
| MB.A8R7 | $0.046 \pm 1.7\%$ | $2.8 \cdot 10^{16}$ |
| MB.B8R7 | $0.021 \pm 2.6\%$ | $6.1 \cdot 10^{16}$ |
| MQ.10R7 | $0.020 \pm 5.8\%$ | $6.4 \cdot 10^{16}$ |
| MQ.8R7 | $0.019 \pm 6.9\%$ | $6.7 \cdot 10^{16}$ |
| MQ.9R7 | $0.018 \pm 8.2\%$ | $7.1 \cdot 10^{16}$ |
| MB.B9R7 | $0.016 \pm 3.3\%$ | $8.0 \cdot 10^{16}$ |
| MB.B10R7 | $0.015 \pm 3.1\%$ | $8.5 \cdot 10^{16}$ |
| MB.B11R7 | $0.015 \pm 3.5\%$ | $8.5 \cdot 10^{16}$ |
| MB.A10R7 | $0.014 \pm 3.4\%$ | $9.1 \cdot 10^{16}$ |
| MB.A9R7 | $0.012 \pm 2.9\%$ | $1.1 \cdot 10^{17}$ |
| MB.A11R7 | $0.012 \pm 2.9\%$ | $1.1 \cdot 10^{17}$ |
| MQ.7R7 | $0.008 \pm 5.0\%$ | $1.6 \cdot 10^{17}$ |
| MQ.11R7 | $0.005 \pm 20.5\%$ | $2.6 \cdot 10^{17}$ |

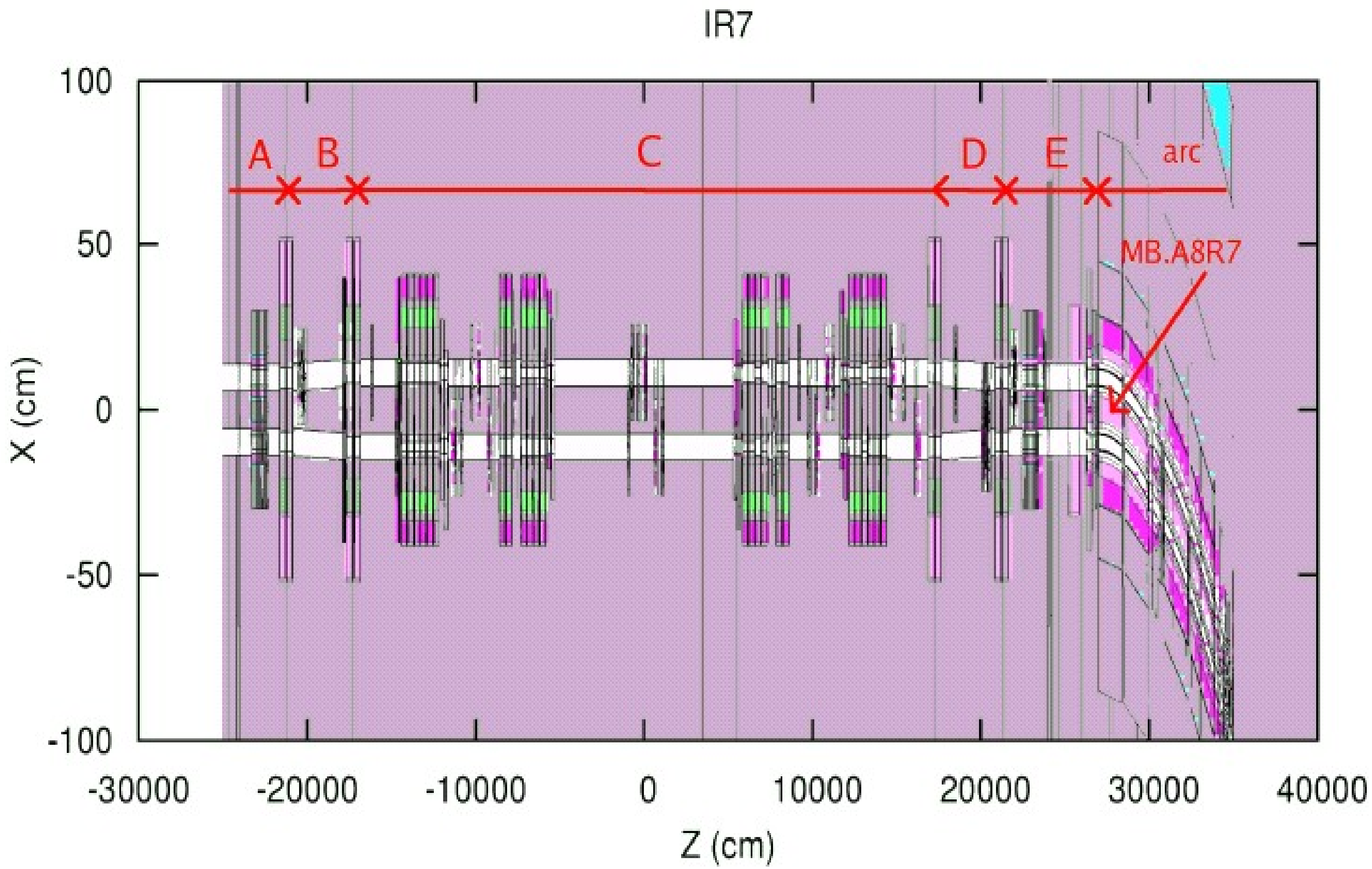
# Beam-gas interaction

## Results

| Element name: | Energy [GeV/pr] | Length [m] | Energy/meter [GeV/pr/m] | $\rho_{max,H_2}$ [molecules/m$^3$] |
|---|---|---|---|---|
| MB.A8R7 | 307.72 ±0.74% | 14.30 | 21.52 | $4.45 \cdot 10^{14}$ |
| MQTLH.F6L7 | 21.20 ±1.09% | 1.30 | 16.31 | $5.87 \cdot 10^{14}$ |
| MQ.11R7 | 39.28 ±1.50% | 3.10 | 12.67 | $7.56 \cdot 10^{14}$ |
| MB.B8R7 | 157.15 ±0.82% | 14.30 | 10.99 | $8.71 \cdot 10^{14}$ |
| MQ.10R7 | 29.17 ±1.74% | 3.10 | 9.41 | $1.02 \cdot 10^{15}$ |
| MQ.8R7 | 29.17 ±1.60% | 3.10 | 9.41 | $1.02 \cdot 10^{15}$ |
| MB.B11R7 | 129.54 ±0.89% | 14.30 | 9.06 | $1.06 \cdot 10^{15}$ |
| MQ.9R7 | 28.01 ±1.72% | 3.10 | 9.04 | $1.06 \cdot 10^{15}$ |
| MB.A9R7 | 127.07 ±0.90% | 14.30 | 8.89 | $1.08 \cdot 10^{15}$ |
| MB.B9R7 | 126.41 ±0.89% | 14.30 | 8.84 | $1.08 \cdot 10^{15}$ |
| MB.A11R7 | 125.84 ±0.87% | 14.30 | 8.80 | $1.09 \cdot 10^{15}$ |
| MB.AB10R7 | 123.96 ±0.92% | 14.30 | 8.67 | $1.10 \cdot 10^{15}$ |
| MB.A10R7 | 121.59 ±0.90% | 14.30 | 8.50 | $1.13 \cdot 10^{15}$ |
| MB.A12R7 | 119.31 ±0.91% | 14.30 | 8.34 | $1.15 \cdot 10^{15}$ |
| MCS.A8R7 | 1.04 ±1.36% | 0.15 | 7.04 | $1.36 \cdot 10^{15}$ |
| MQ.7R7 | 21.47 ±1.23% | 3.10 | 6.92 | $1.38 \cdot 10^{15}$ |

Beam-gas interaction

# Results




85% of energy deposited in MB.A8R7
is due to beam gas interaction in section E

# Conclusions

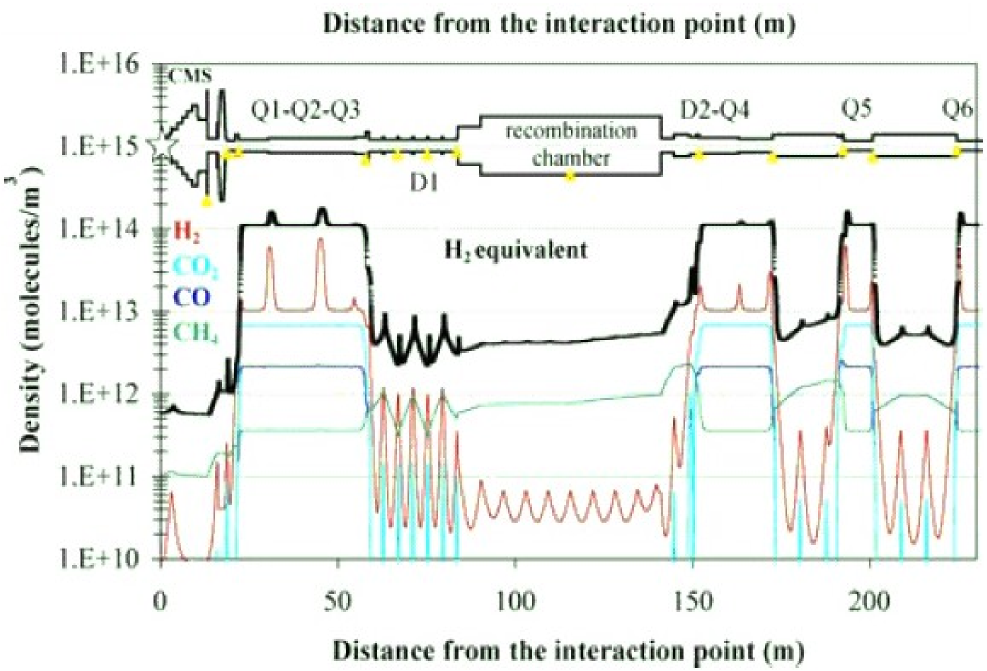
According to the simulations:

- When considering the **quench limit** (4 mW/cm$^3$) the gas density limit in IR7 is **2.8E+16 molecules/m$^3$**

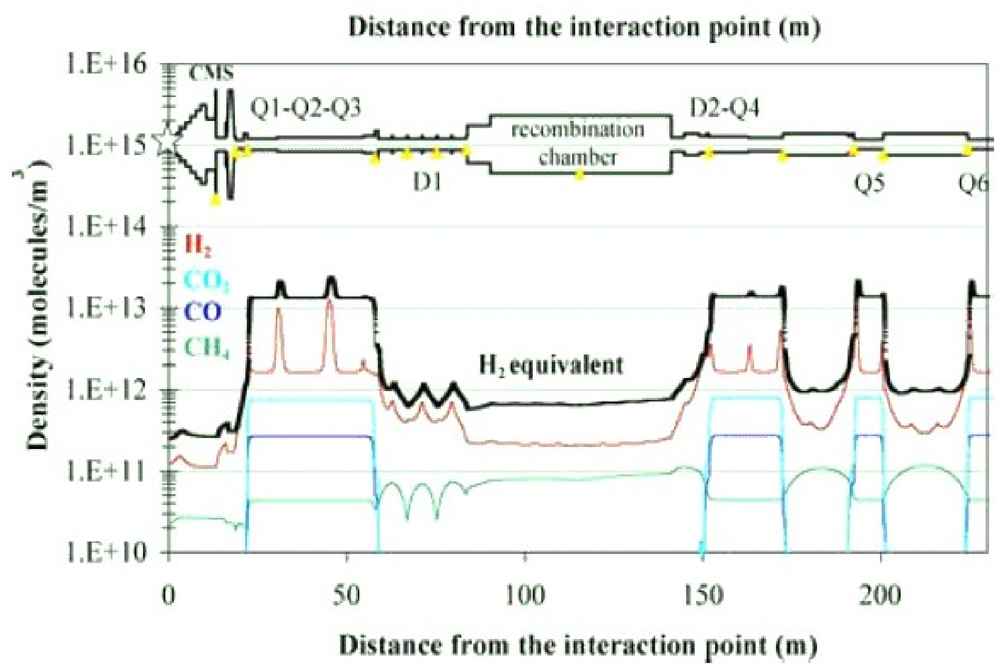
- When considering the **power deposition per meter** (30 mW/m) the gas density limit in IR7 is **4.45E+14 molecules/m$^3$**.

# Conclusions

## Gas density and composition expected in IR5




LHC start-up, 1/3 of nominal intensity




LHC after conditioning, nominal intensity

From:
A.Rossi, Residual gas estimations in the LHC insertion regions IR1 and IR5 and the experimental regions of ATLAS and CMS, LHC-Project-Report-783

# Conclusions

It could be useful to have some informations about the expected gas density and composition upstream the MB.A8R7, where some active absorbers are located.