Identification of Beam Losses at LHC

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Outline

1. LHC Machine protection
2. Decomposition, lossmaps and algorithm
3. Results
4. Next steps

LHC Machine protection

LHC 2015 parameters

Circumference	26.7km
Injection energy	450GeV
Nominal energy	6.5TeV
Total intensity	$3.2 \cdot 10^{14}$p
Bunches	2808
Stored energy	360MJ

Prevent damage from beam by:

- cleaning *beam tails* $\rightarrow$ *Collimation System*,
- monitoring *beam losses* $\rightarrow$ *BLMs*.

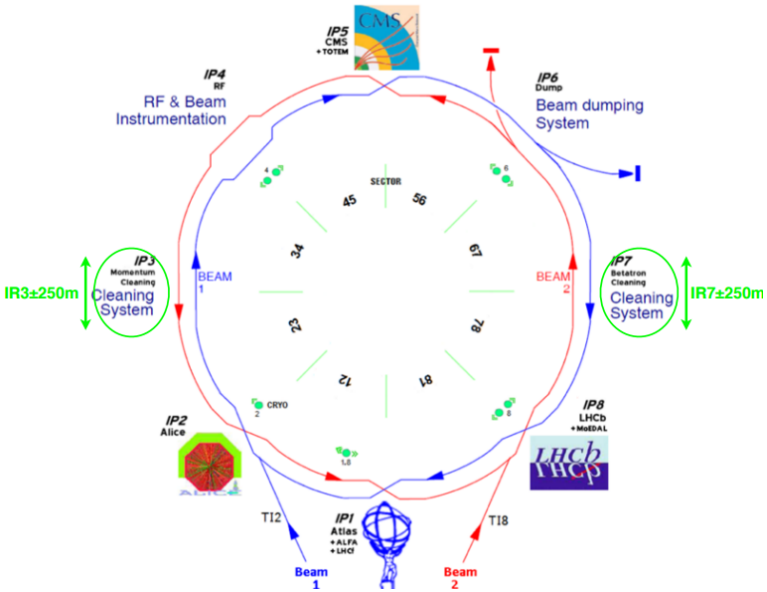

Figure : Layout of the LHC ring, image from [5]

Figure : 1m long block of copper damaged by 0.5MJ of 16 GeV electrons, image from [6]

Collimation system

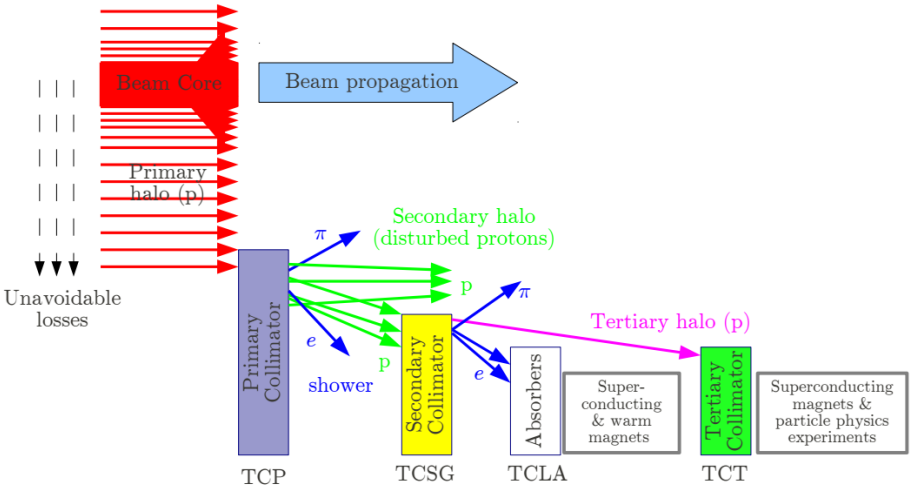

Figure : Hierarchy of collimators, image from [2]

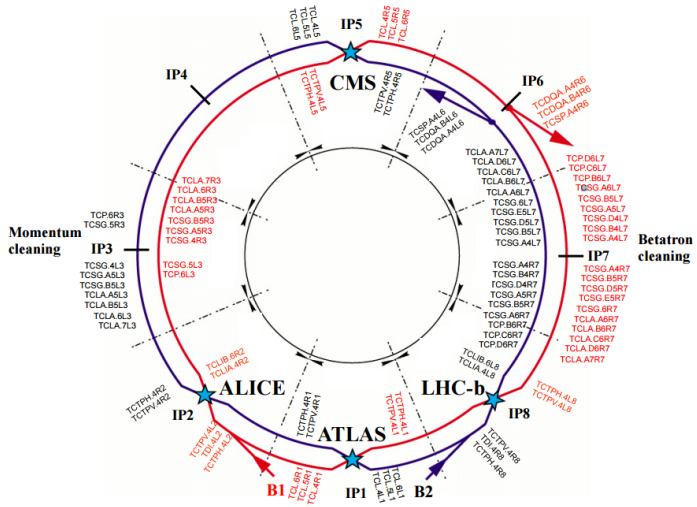

Figure : Placement of collimators, image from [2]

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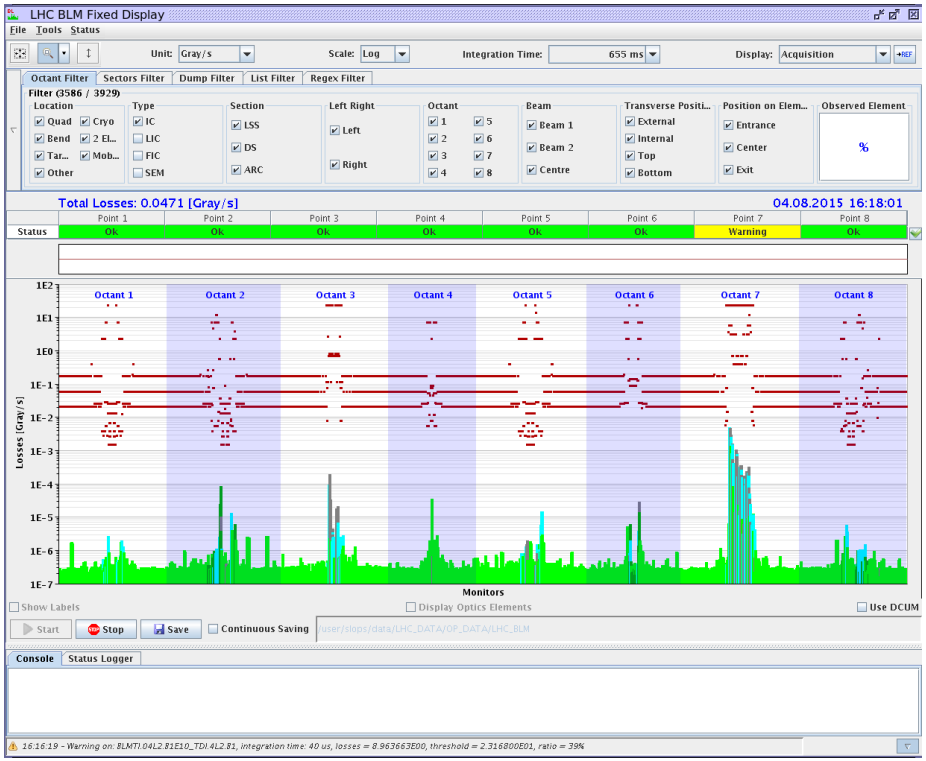

Figure : Lossmap, image from [7]

Motivation and principle of losses decomposition

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A few loss scenarios n for many monitors m. Decomposition from m-dim. space in n-dim. subspace. Factors of decomposition are contributions from scenarios.

The difference between loss profile recomposed using these factors and measured loss profile is a measure of the quality of decomposition. SVD is used to calculate the decomposition.

Loss scenarios

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There are six basic scenarios: B1H, B1V, B2H, B2V, B1+B2 +500Hz, B1+B2 -500Hz.

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$$F = M^+ X.$$

Validation of scenarios and algorithm

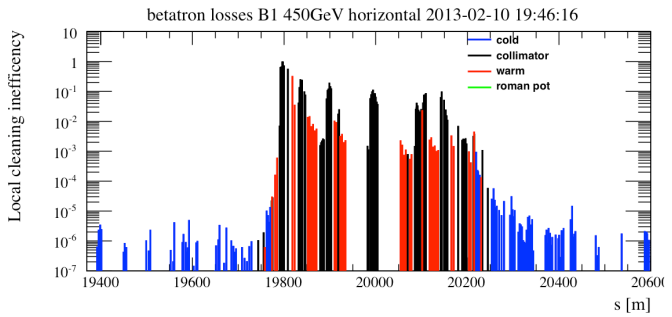

Figure : Beam 1 horizontal lossmap, image from [3]

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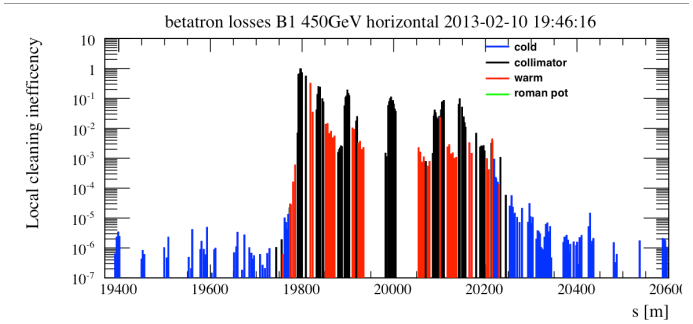

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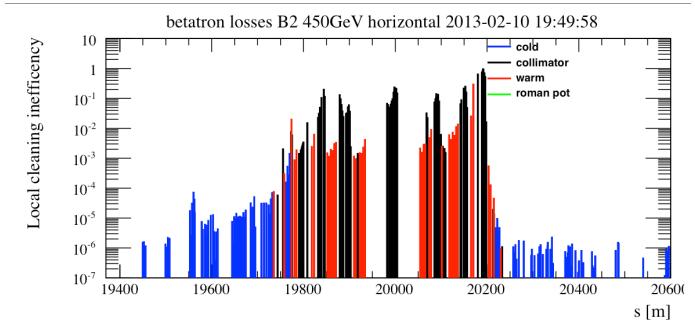

Figure : Beam 2 horizontal lossmap, image from [3]

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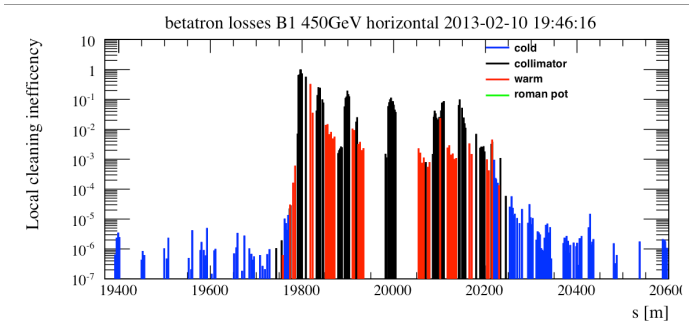

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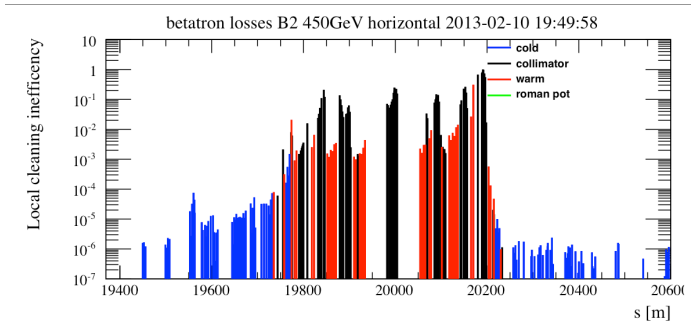

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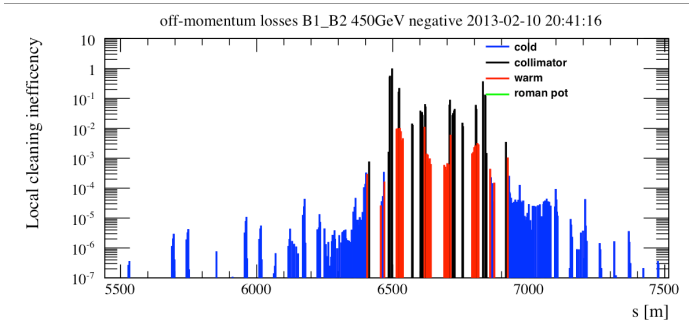

Figure : Off-momentum lossmap, image from [3]

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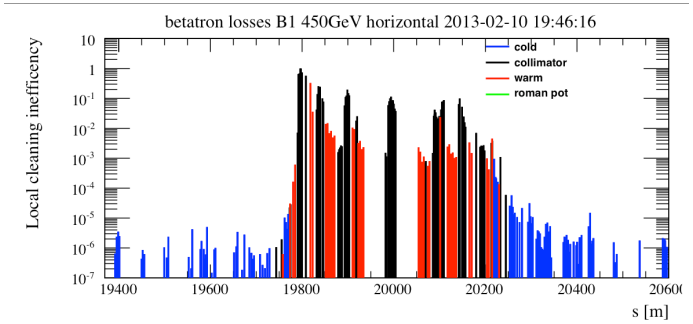

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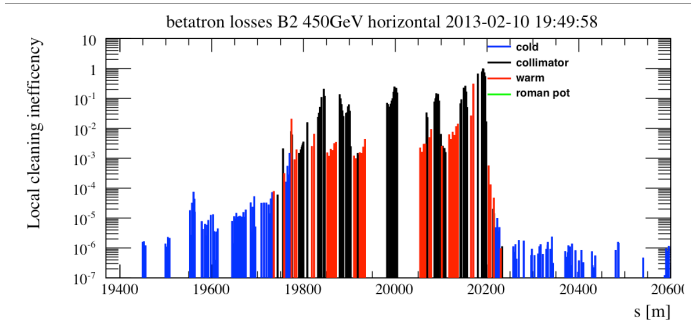

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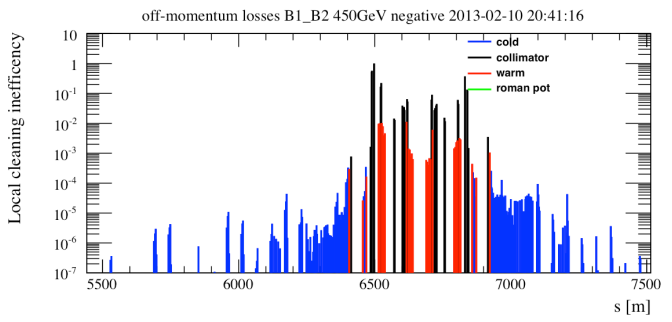

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	squeeze non-colliding							
squeeze colliding	B1H		B1V	B2H		B2V		B1+B2+200
B1H	0,9861	0,9634	0,0072	-0,0171	0,0133	0,0003	0,0018	0,1870
B1V	-0,0088	-0,0275	0,9916	0,0000	0,0094	-0,0003	0,0235	-0,0016
B2H	-0,0004	0,0015	-0,0001	0,7606	0,7166	0,0821	0,0647	0,1030
B2V	0,0011	0,0012	0,0000	0,1689	0,2141	0,9142	0,8930	-0,0046
B1+B2+500	-0,0013	-0,0023	-0,0004	-0,0196	-0,0166	0,0023	-0,0060	0,3246
B1+B2-200	0,0023	0,0042	0,0006	0,0337	0,0300	-0,0009	0,0110	-0,3793

Figure : Decomposition of squeeze non-colliding lossmaps on squeeze colliding ones

Application (fill 4008)

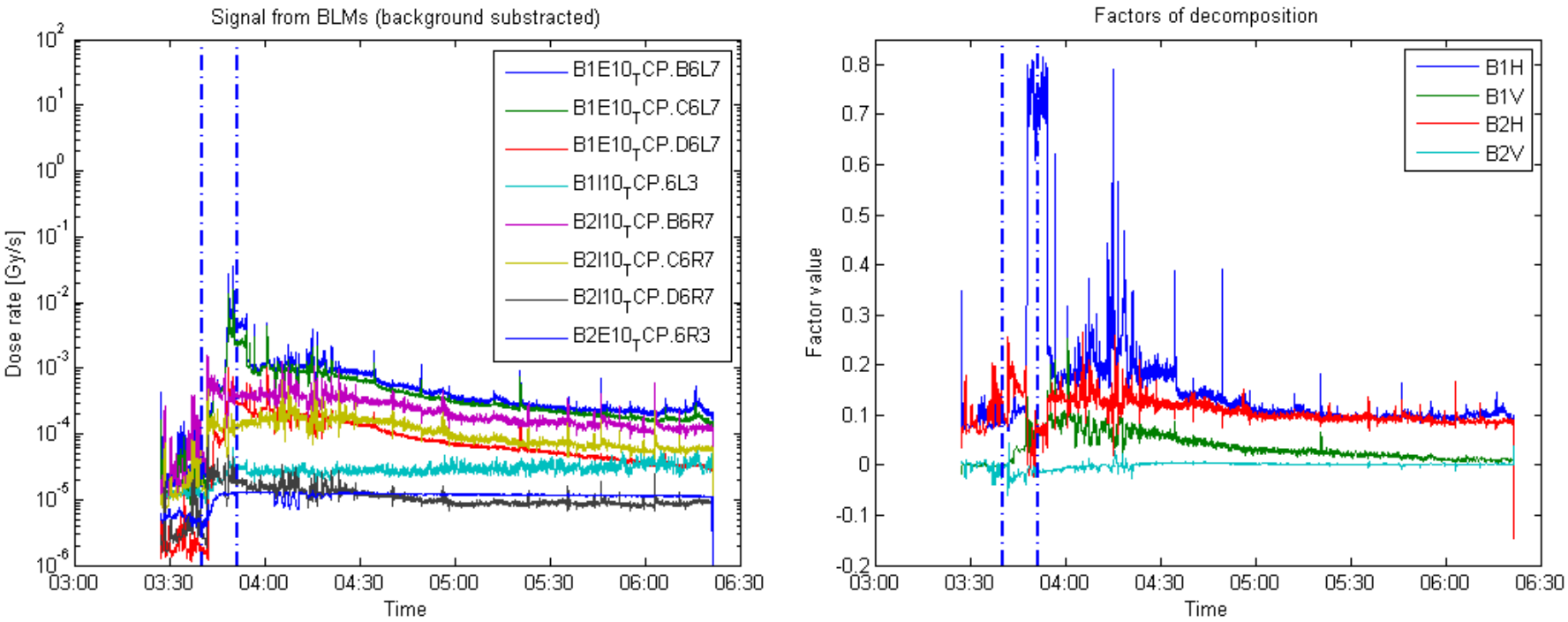

Figure : Fill 4008. Left: signal from BLMs, right: decomposition of fill 4008, B1H losses are dominant

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Build an online display API to apply the decomposition on-the-fly and identify loss scenarios.

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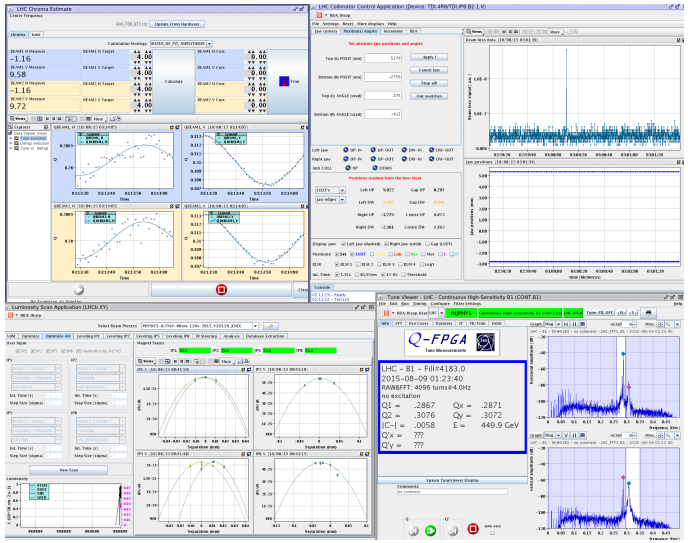

Figure : Screenshots of some of the CCC APIs, images from [7]

References

LHC Design Report

Aurelien Marsili, *Identification of LHC beam loss mechanism: A deterministic treatment of loss patterns*

http://lhc-collimation-project.web.cern.ch/lhc-collimation-project/default.php

Verena Kain, *Introduction to Accelerator Physics*

Stefano Redaelli, *Collimation Systems*

http://today.slac.stanford.edu/images/2006/LARP1.jpg

LHC Logbook