Beam-induced Quench Tests of LHC Magnets

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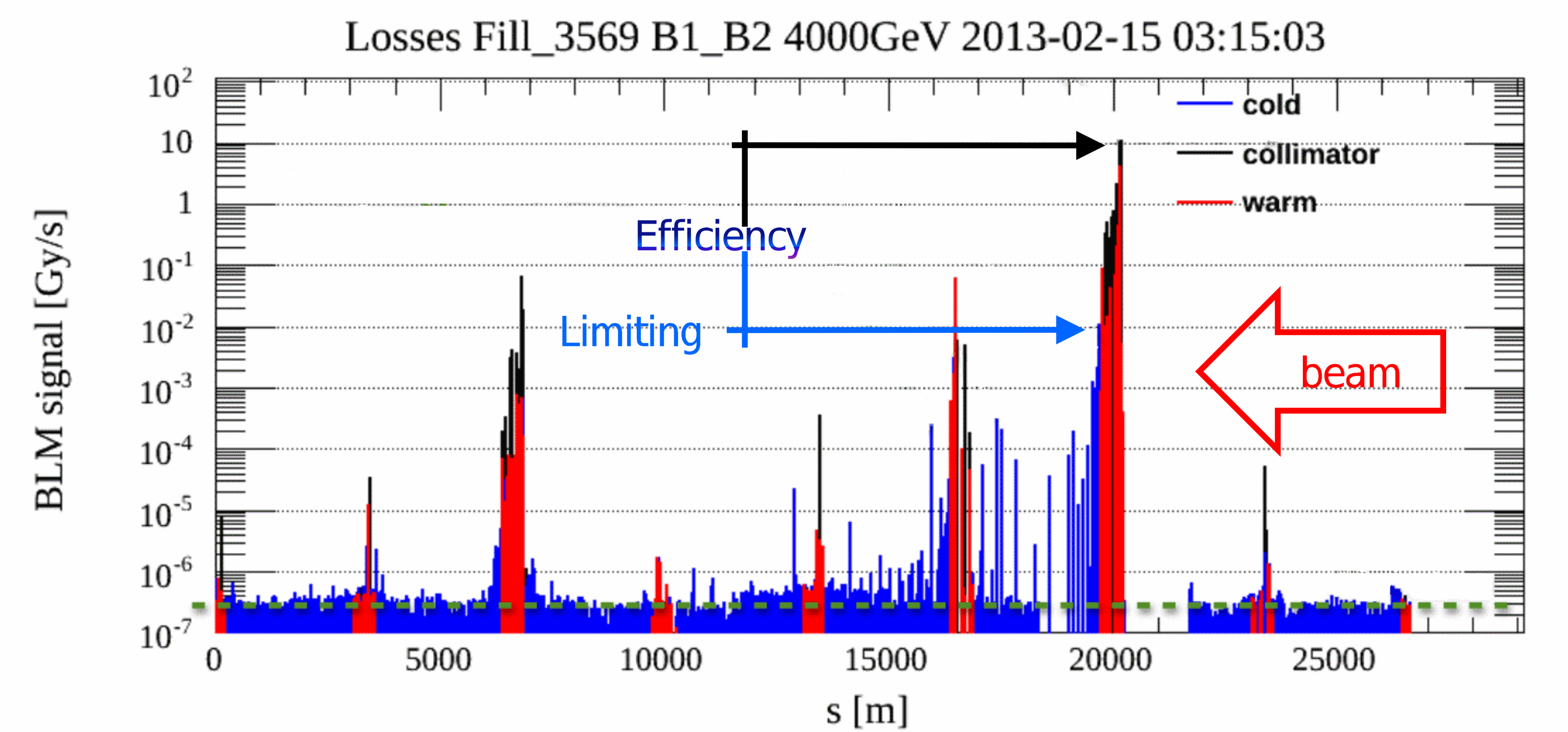
Content

- Motivation
  - Dust particle losses
  - Collimation system upgrade
- Quench dependencies of superconducting magnets
- Methodology
- Quench tests
  - Different loss durations
- Summary

Efficiency and limits of LHC collimation system

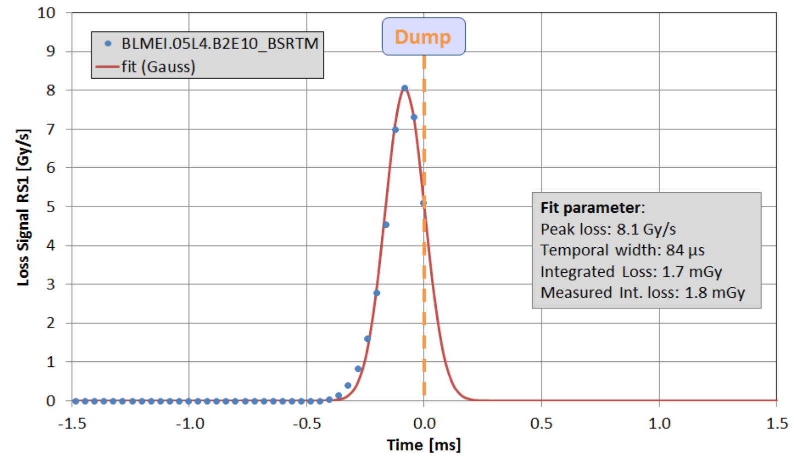
Proton impact on primary collimator and observation of downstream losses



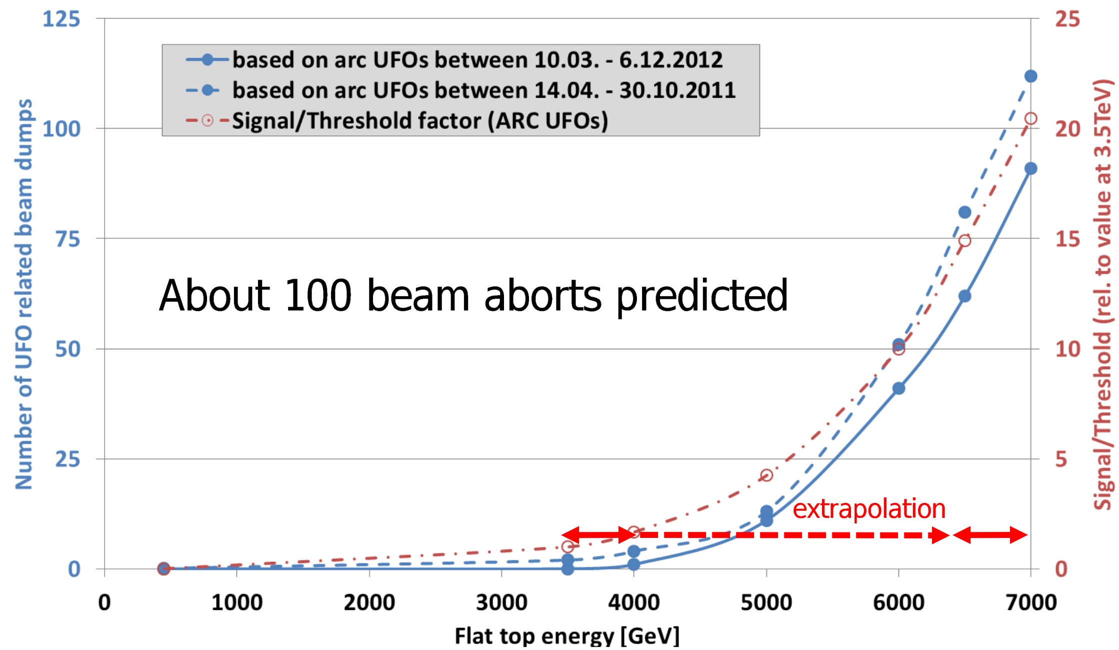
Determination of efficiency needed to plan upgrade requirements for collimation system

Dust particle and LHC operation

- Observation from 2011 to 2013
- Beam losses created with a duration between 100 us to several ms



- Extrapolation of event rate to operation at 7 TeV
- Numerous events would cause significant downtime due to recover from quench of magnets



Increase of knowledge in the sub and millisecond range required for down time estimates

Super conducting magnet quench levels (LHC bending magnet)

Equivalent presentation quench levels

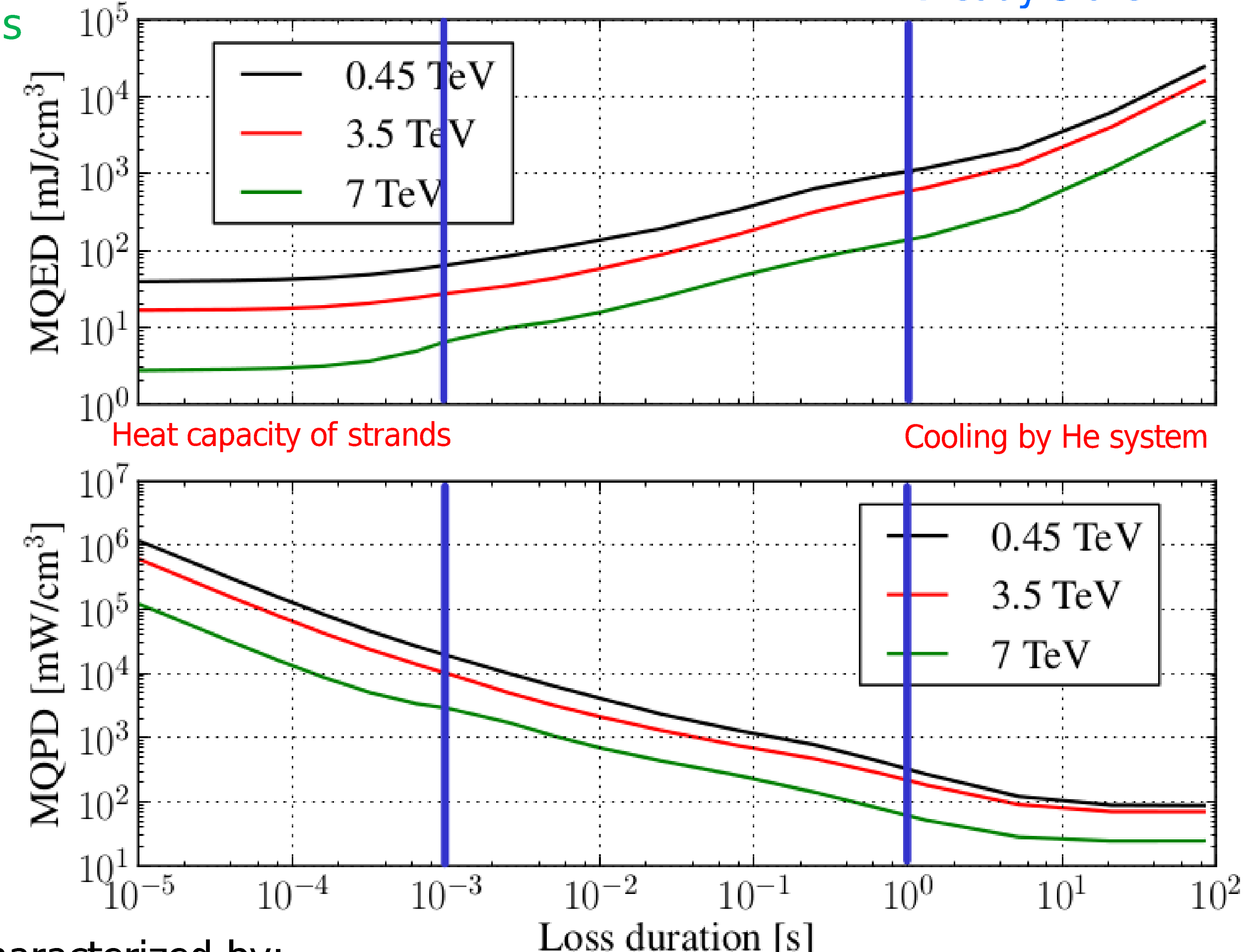
Short | Intermediate | Steady state | Loss durations

Energy

Heat capacity of strands

Cooling by He system

Power

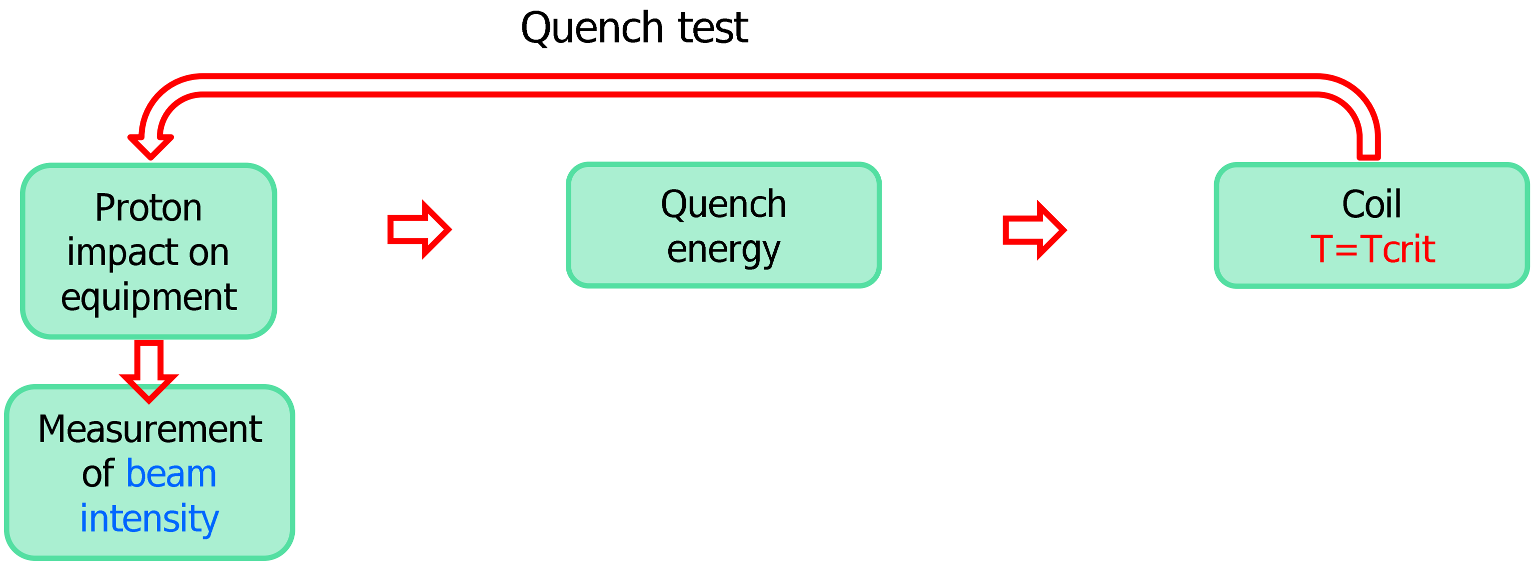


Magnets characterized by:

Constant energy limit t < 1 ms

Constant power limit t > few s

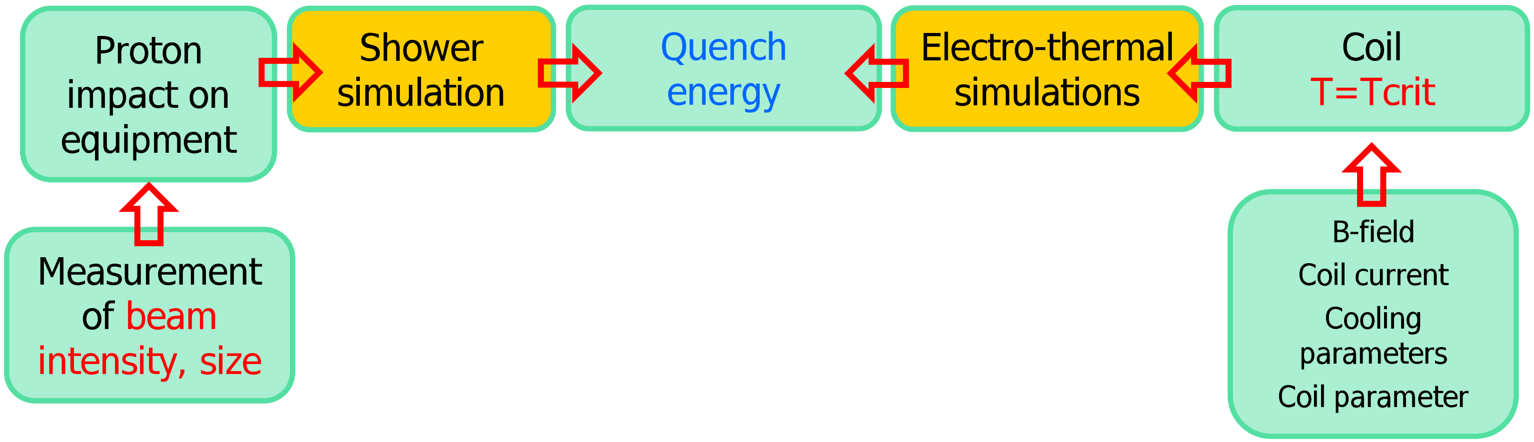
Methodology



- Test results in upper and lower bound of quenching beam intensity

Methodology

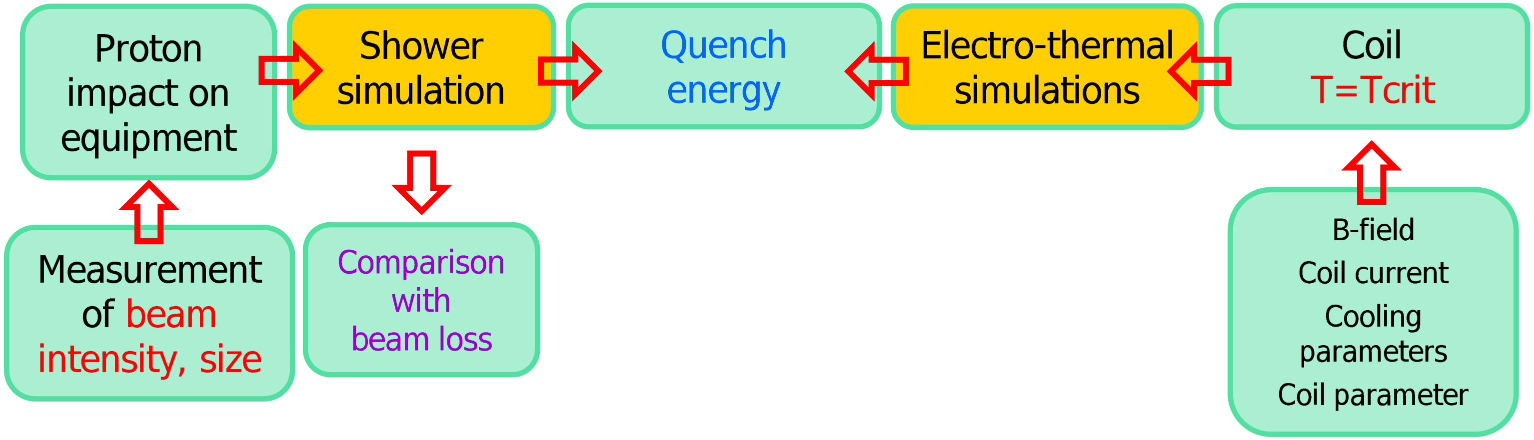
Quench test simulation



- Shower simulation of local quench energy density
- Lower and upper intensity bound => lower und upper local quench energy density bound
- Electro-thermal simulation of local quench energy density
- Quench tests are used to validate combined results of shower and electro-thermal simulations

Methodology

Quench test simulation



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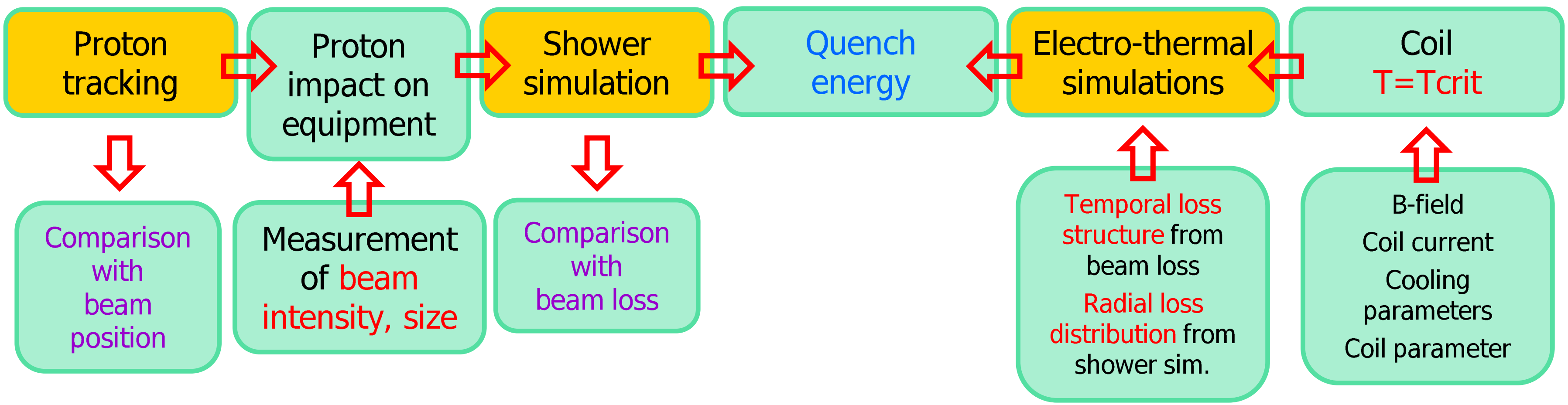
- Beam loss measurements are used to validate shower simulations

Quench test simulation



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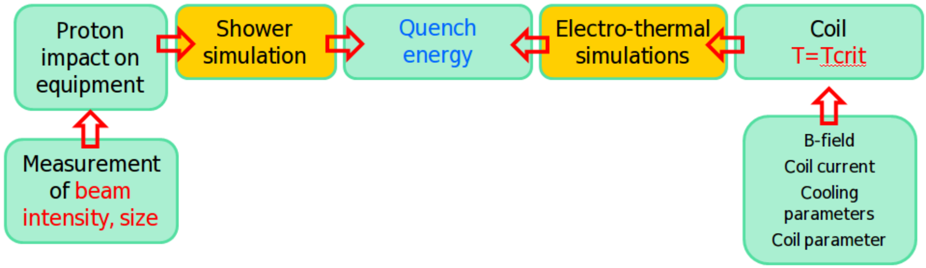
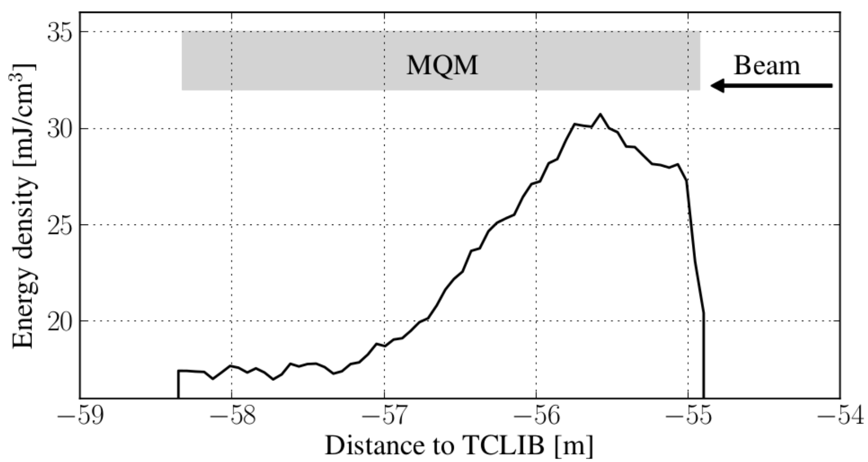
- Quench tests are used to validate combined results of shower and electro-thermal simulations
- Beam loss measurements are used to validate shower simulations
- Proton tracking to determine impact location and temporal shape

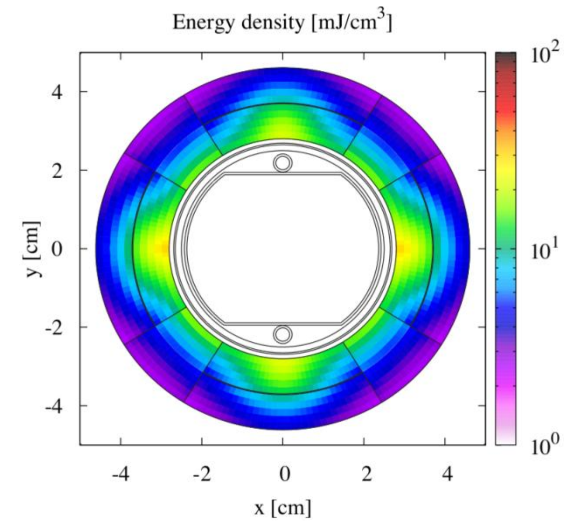
Short loss duration

- Experiment
  - Injected beam (6.5E10 p.) dumped on collimator (TCLIB)
  - Quadrupole (Q6.L8, 4K) magnet exposed to shower particles
  - Magnet current scanned to initiate quench





Maximum energy density peak inside magnet



Symmetric energy distribution

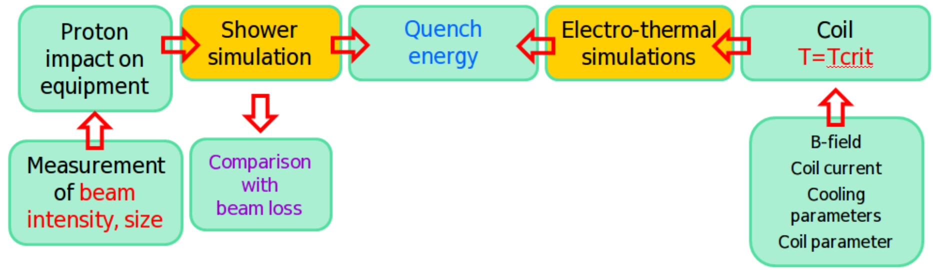
- Result

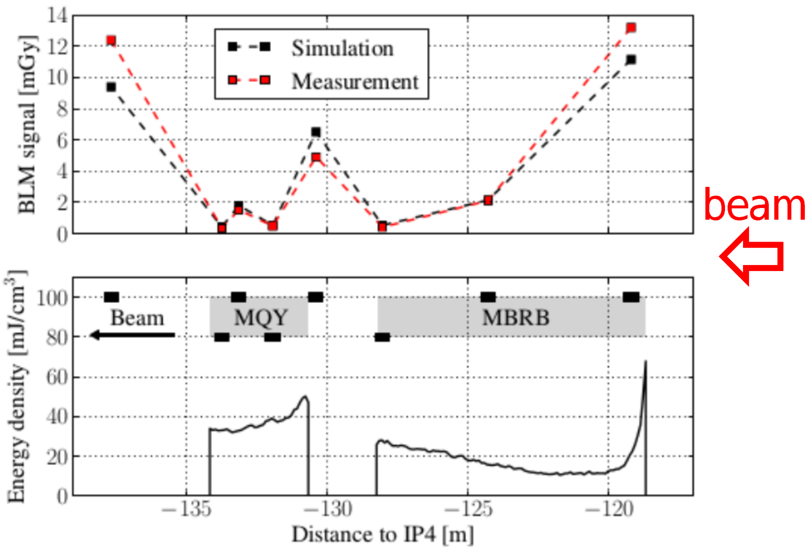
Current [A]	FLUKA LB [mJ/cm^3]	FLUKA UB [mJ/cm^3]	MQED [mJ/cm^3]
2000	29	n/a	20
2500	n/a	31	16

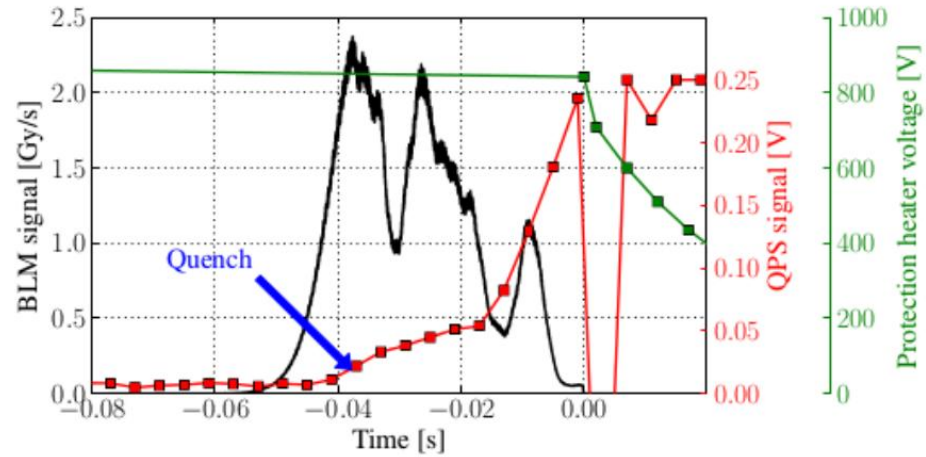
Simulation (FLUKA) and electro-thermal sim. (MQED) agree within a factor 2

Intermediate loss duration

- Experiment
  - Stored proton beam (1.53E13 p.) at 3.5 TeV
  - Wire scans with different speeds to create shower particles
  - Bending and quadrupole magnets exposed to shower particles







Shower simulation and loss measurements agree within 25 %

Maximum energy density peak at the front of magnet

BLM and voltage drop on coil used for synchronisation

- Result

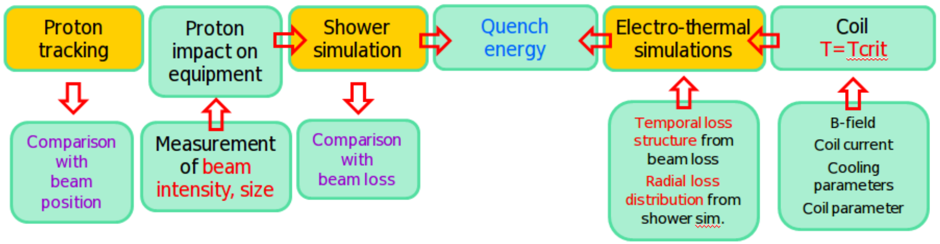
Speed scanned

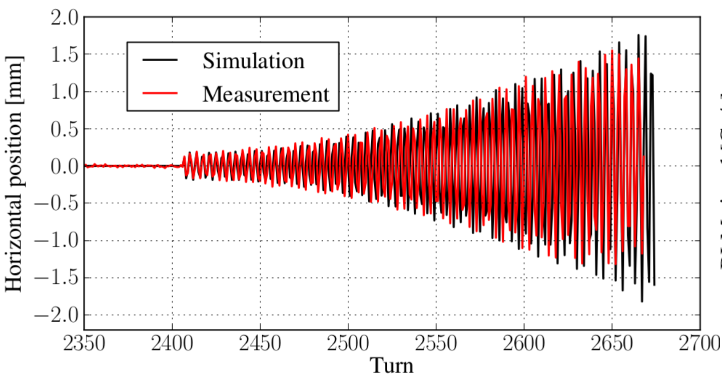
v_w [m/s]	N_q/N_w [%]	FLUKA LB [mJ/cm³]	FLUKA UB [mJ/cm³]	MQED [mJ/cm³]
0.15	n/a	18	n/a	37^{+0}_{-11}
0.05	30	n/a	20	35^{+0}_{-11}
0.05	45	n/a	30	42^{+0}_{-16}

Uncertainties due to synchronization and peak energy deposition at front of coil

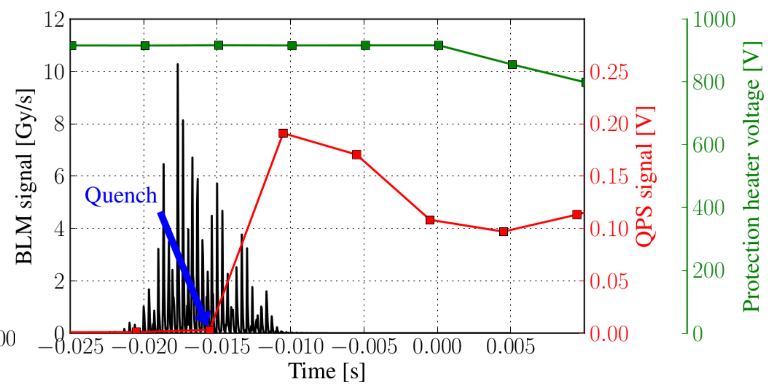
Intermediate loss duration

- Experiment
  - Stored proton beam (several E8) at 4 TeV
  - Static orbit bump
  - Dynamic excitation of beam with transverse feedback magnet

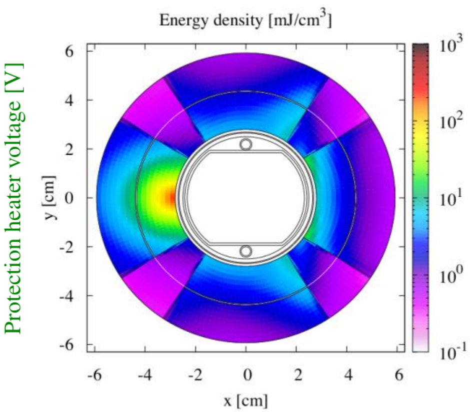




Comparison of proton tracking time structure and beam position signal



Loss duration about 5 ms, non continuous loss structure



Shower simulation - loss measurements agree within 30 %

- Result

Intensity scanned

N_p	N_q/N_p [%]	FLUKA LB [mJ/cm^3]	FLUKA UB [mJ/cm^3]	MQED [mJ/cm^3]
3.5×10^8	n/a	198	n/a	$71^{+?}_{-10}$
8.2×10^8	62	n/a	250	$58^{+?}_{-8}$
8.2×10^8	99	n/a	405	$80^{+?}_{-10}$

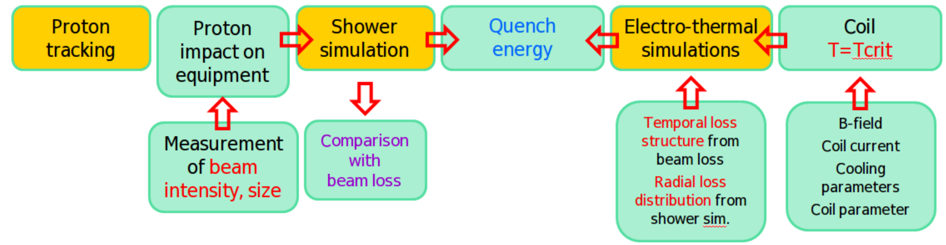
Loss in the centre of the MQ magnet

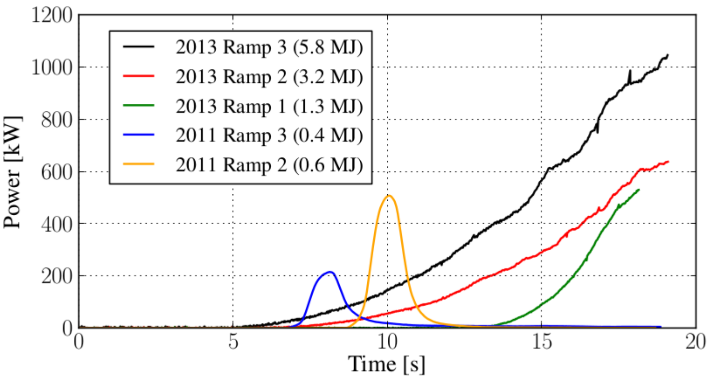
Loss duration of a few ms

Uncertainty due to synchronisation and time structure of losses

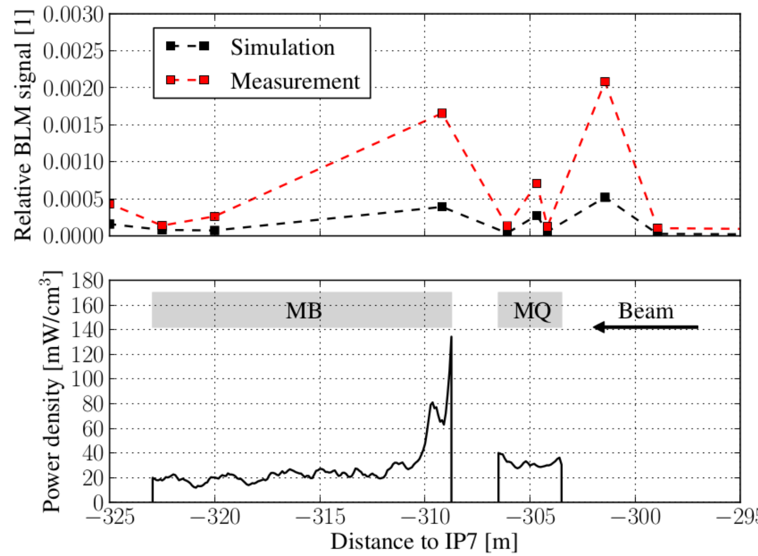
Steady state loss duration

- Experiment
  - Stored proton beam (1.6 E13) at 4 TeV
  - Dynamic excitation with transverse feedback magnet
  - Loss on primary collimator, secondary largely opened
  - Observation of secondary particles up to 500 m down stream





Power deposition on primary collimator during different tests



Power deposition in

beam loss detectors

magnet coil

- Result

Lower bound determined

FLUKA LB [mW/cm^3]	MQPD [mW/cm^3]
50	115^{+25}_{-0}

Loss in the begin of the bending magnet

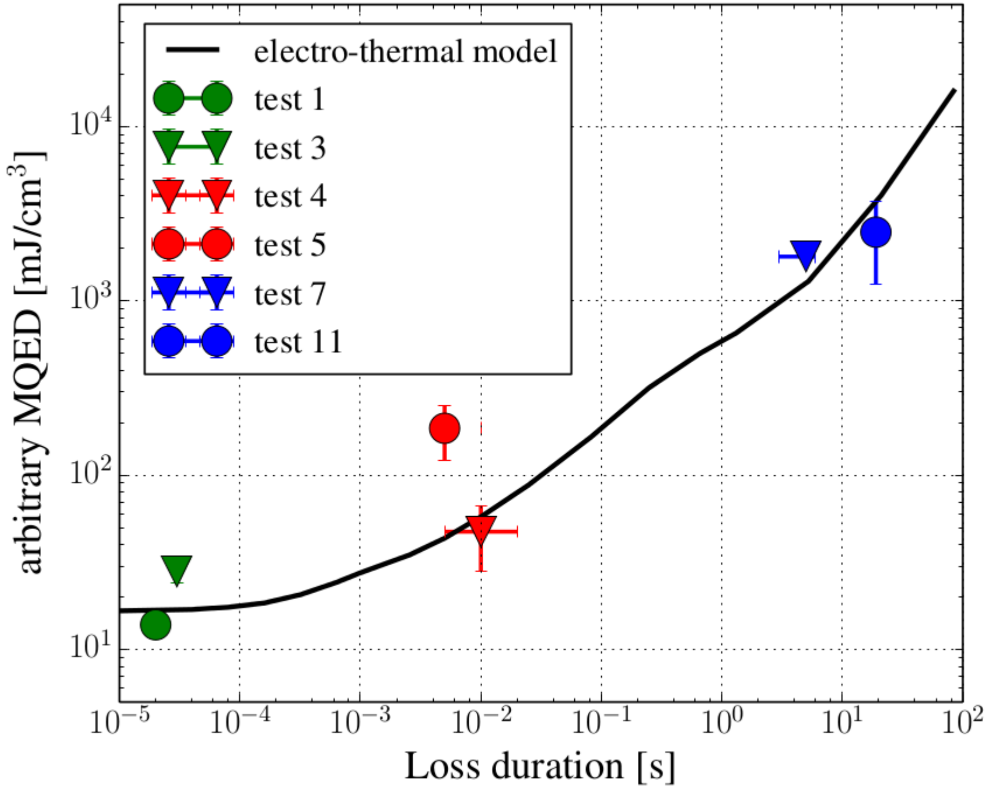
Loss duration about 10 s

Uncertainty due to large scale simulation and peak power in begin of coil

Results and conclusions

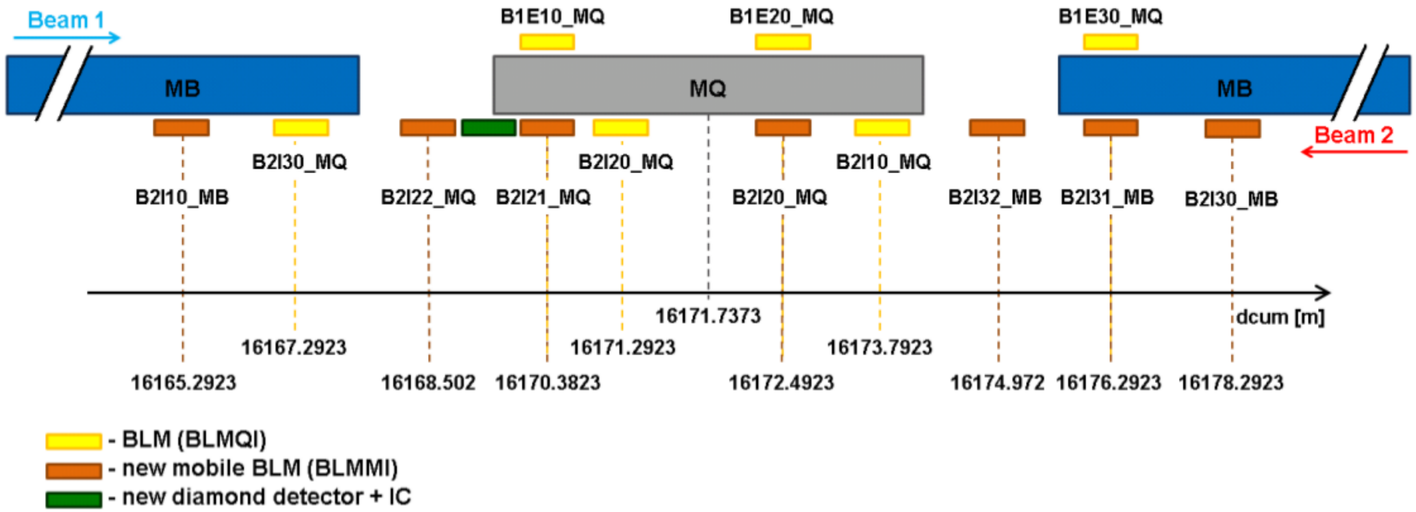
- Beam based quench tests and model comparisons made for different loss durations and beam energies
  - For short and steady state loss durations sufficient prediction accuracy is reached
  - For intermediate loss durations model improvements are required and in preparation
  - Measurement errors could be reduced by increased sampling and time stamping of magnet coil voltage measurements, usage of higher upper limit loss monitors, …
- The operation of LHC at the beam loss limits will require accurate setting of beam aborts thresholds == more quench tests envisaged

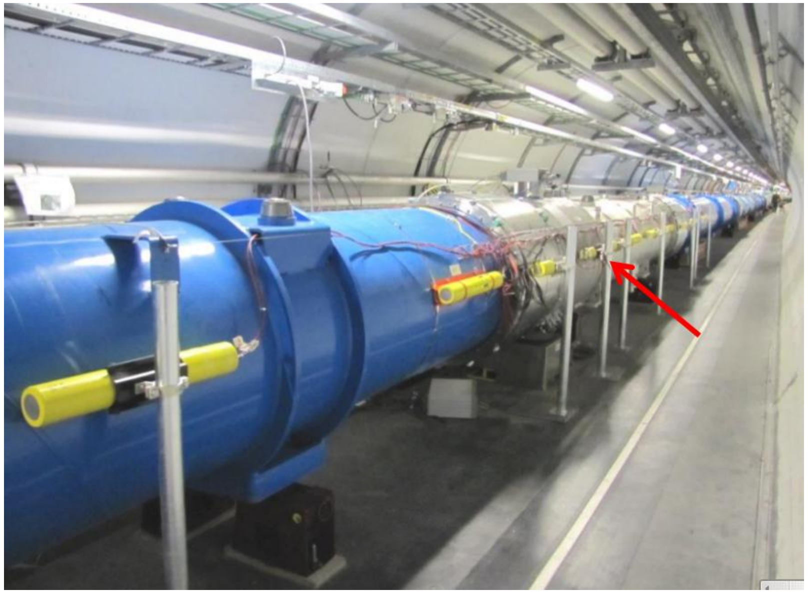
No	Date	Regime	Method	Type	Temp. [K]	I/I_{nom} [%]	beam energy [TeV]
1	2008.09.07	short	kick	dipole	1.9	6	0.45
2	2011.07.03	short	collimation	-	-	-	0.45
3	2013.02.15	short	collimation	quadrupole	4.5	46/58	0.45
4	2010.11.01	intermediate	wire scanner	dipole	4.5	50	3.5
5	2013.02.16	intermediate	orbit bump	quadrupole	1.9	54	4
6	2010.10.06	steady-state	dyn. orbit bump	quadrupole	1.9	?	0.45
7	2010.10.17	steady-state	dyn. orbit bump	quadrupole	1.9	?	3.5
8	2011.05.08	steady-state	collimation	-	-	-	3.5
9	2011.12.06	steady-state	collimation	-	-	-	3.5
10	2013.02.15	steady-state	collimation	-	-	-	4
11	2013.02.16	steady-state	orbit bump	quadrupole	1.9	54	4

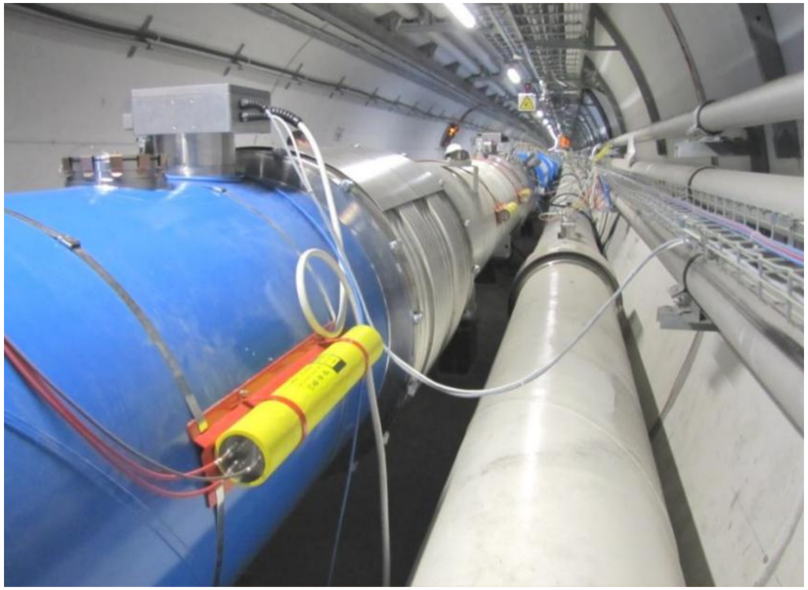


Reserve slides

Quench test set up

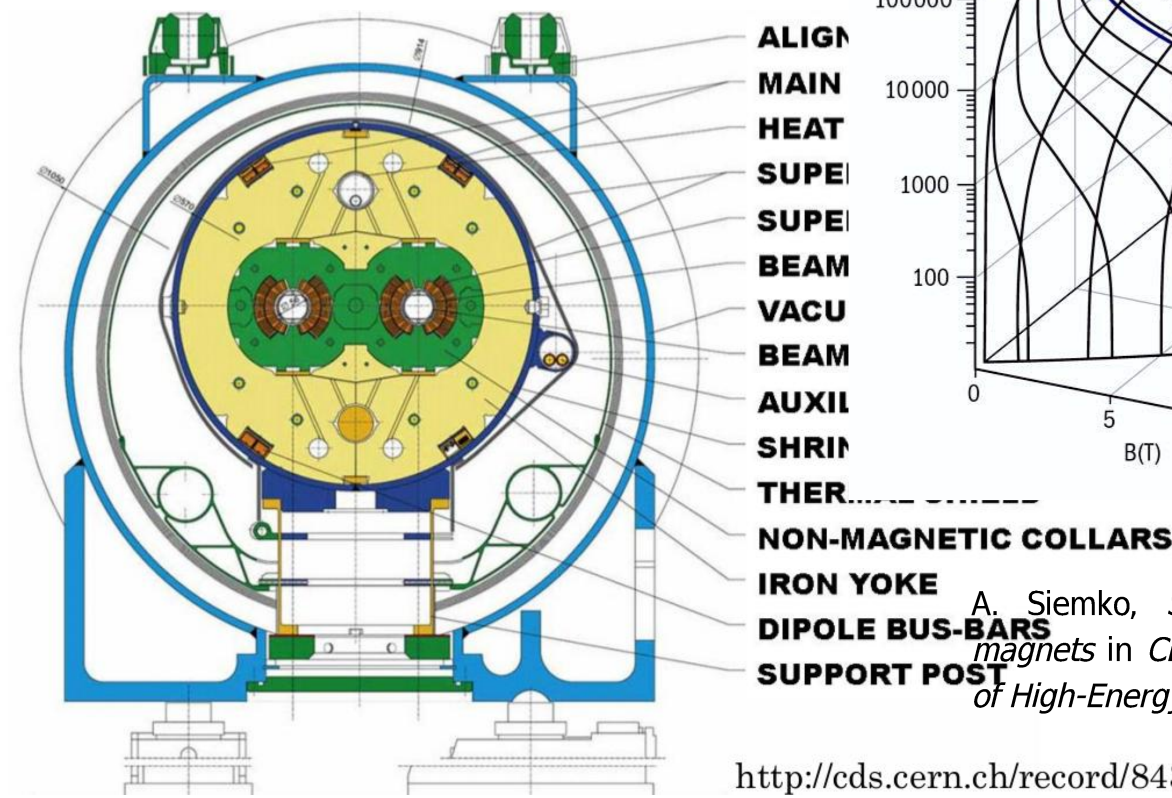


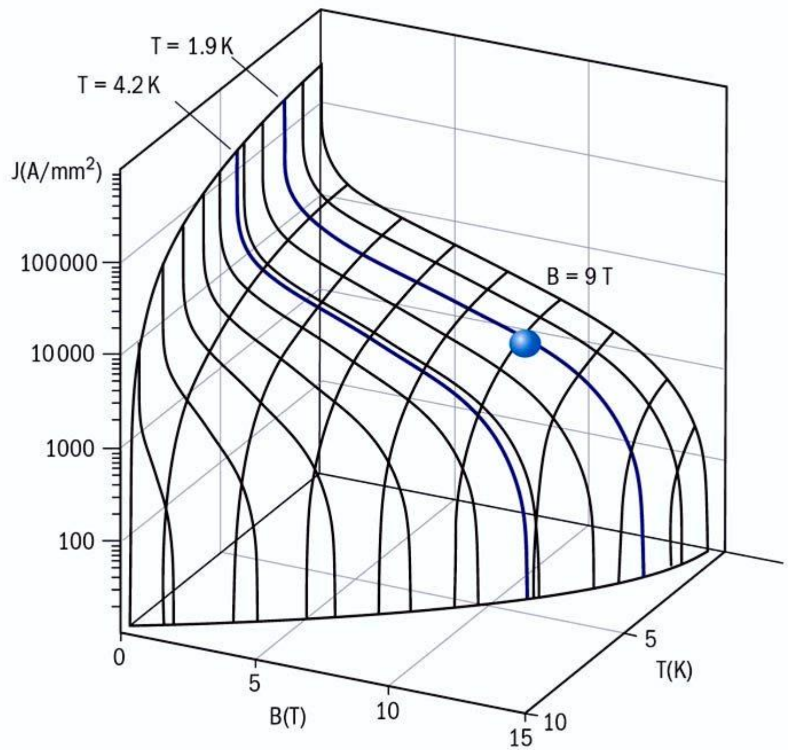




LHC magnets

- The design based on NbTi
- 2-in-1 structure
- Operation temperature: 1.9 K
- Main Dipole peak field: 8.33 T
- Main Quadrupole gradient: 223 T/m





A. Siemko, *Safeguarding the superconducting magnets* in *CERN Courier – International Journal of High-Energy Physics*, 33(7), 2013

http://cds.cern.ch/record/843195

Magnet Protection

Courtesy of Alexandre Erokhin