Quench Limits

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Trying to summarize efforts of many people…

LHC Performance Workshop, 2012/02/06

Goals

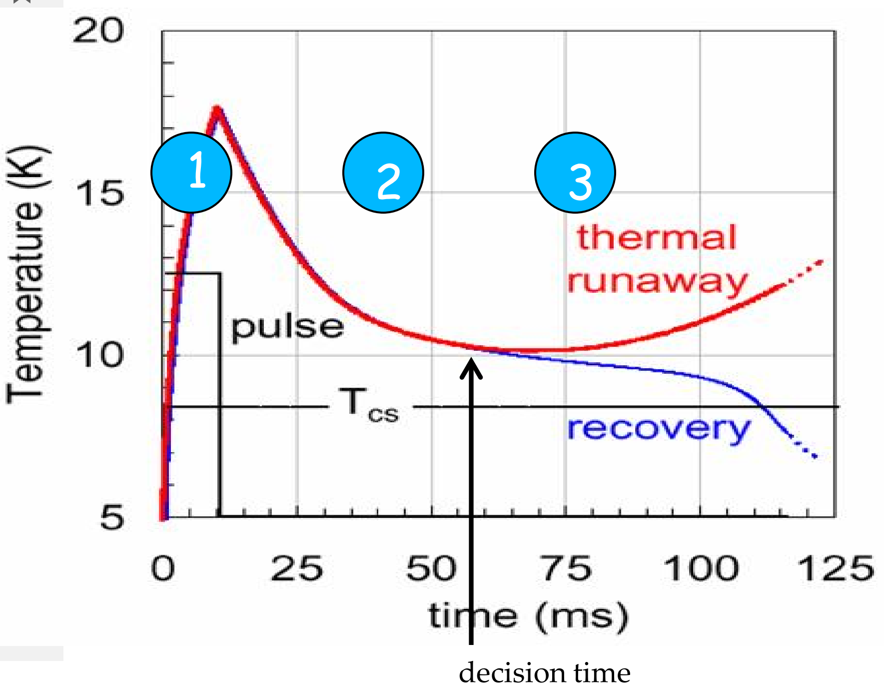
- Steady-State Quench Limit
  - limits to luminosity and collimation losses (operation after LS1)
  - design of new magnets (especially triplet magnets)
- Collimation limit due to loss leak to cold magnets
  - upgrade of Collimation system (long-term)
- Operational limit due to UFO-provoked quenches
  - BLM threshold changes and modification of QPS system (operation after LS1)
- Quench Limit for fast losses as a function of beam energy
  - estimate quenches during asynchronous beam dump (LS2 preparation)
  - upgrade/modification of QPS system ()

Content

- Definitions and clarifications
  - dependence of quench limit on time, spatial distribution etc.
- How do we learn about Quench Limits?
- What do we know about Quench Limits?
  - Results of MDs performed in 2010 and 2011.
- What do we need to know more?
  - And how to get this knowledge (MDs in 2012)
- Conclusions and proposals

Definitions

- Quench Limit is amount of energy which can be deposited locally in the coil without quenching the magnet [mJ/cm^3].
- For steady state losses it is amount of power [mW/ cm^3].
- But in the CCC we hear word quenchino! – self-recovering quench.

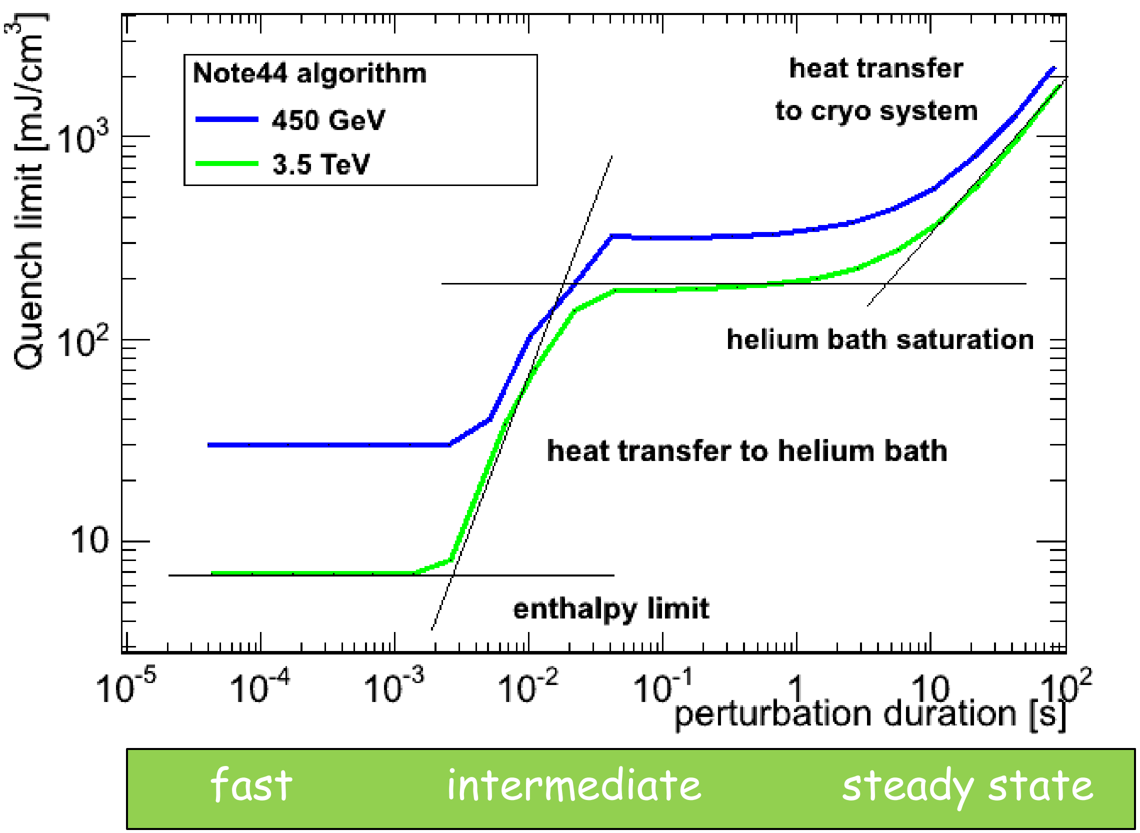


Three main stages:

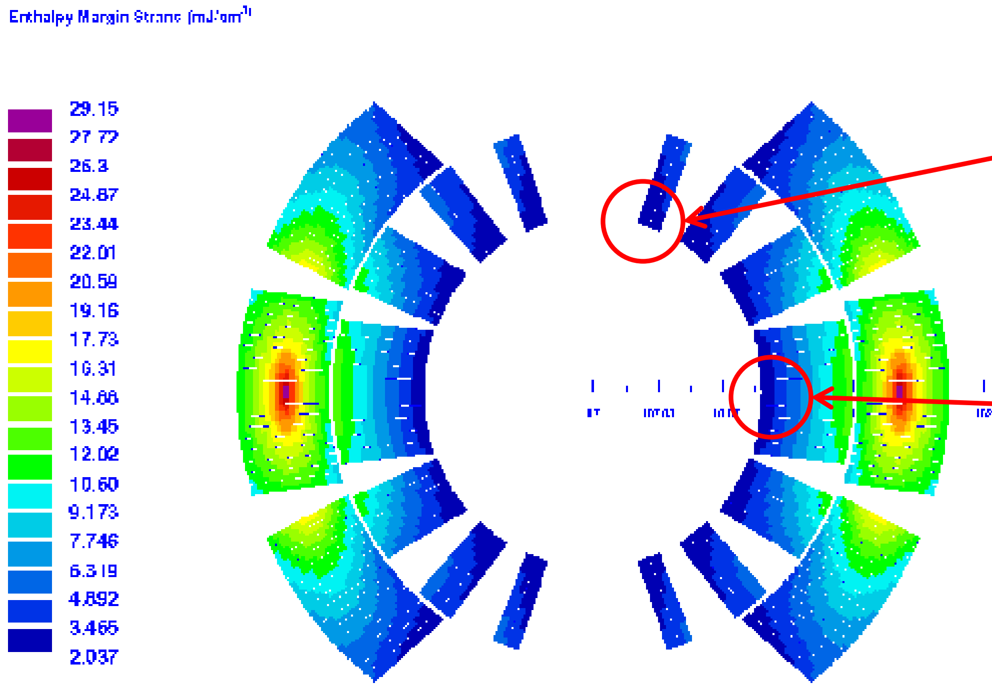
1. Resistive zone appears.
2. QPS threshold is passed
   (e.g. 0.1V for 20 ms) (*OP quench*)
3. Quench or recovery takes place.
   (real quench)

Time dependence

- Fast losses – easy enthalpy calculation.
- Steady state losses – models and measurements.
- Intermediate losses - difficult modeling.
- Different for 1.9 K and 4.5 K magnets.
- Different for various cables.

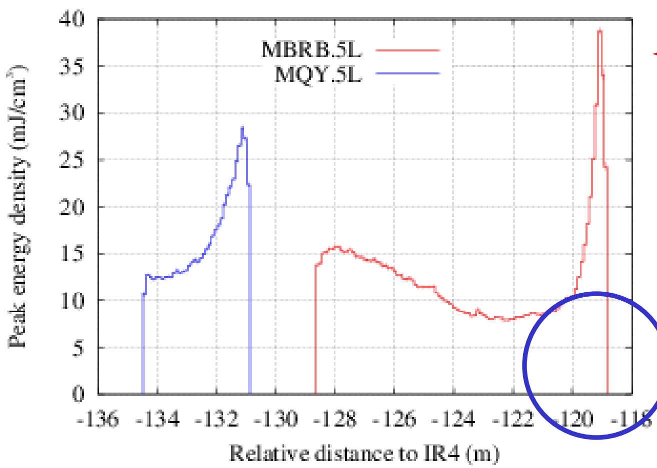


Loss pattern dependence



Higher field,
smaller quench limit

More quench margin,
but more probable loss location.

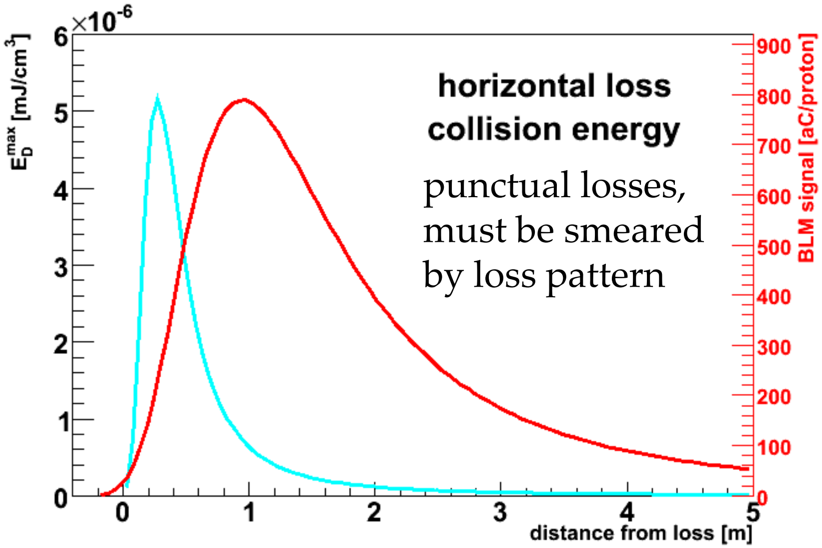


beam

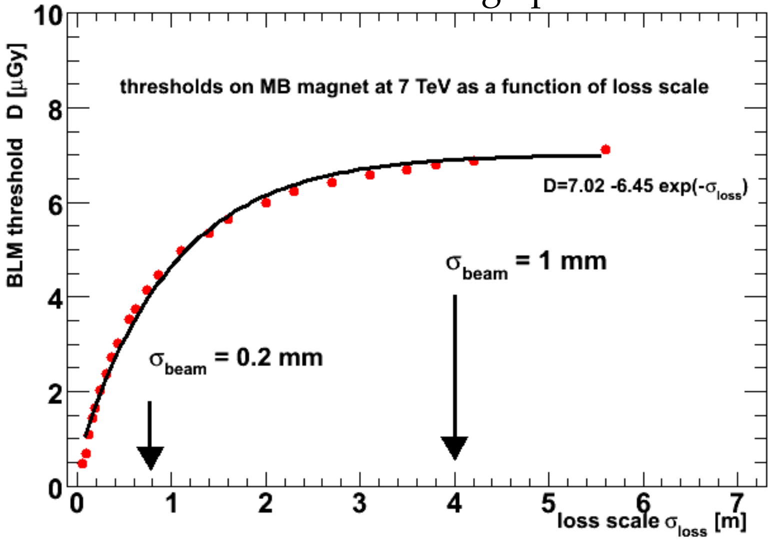
front part of the coil,
more resin, less helium

BLM Quench Limit

- Quench Limit can be expressed in BLM signal [Gy/s] at which the magnet quenches.
- BLM signal (S_{BLM}) at Quench is: $S_{BLM} = R \cdot \mathbf{QL(E,t)}$; $R=E_{BLM}/E_{coil}$



assumed: beam hitting aperture

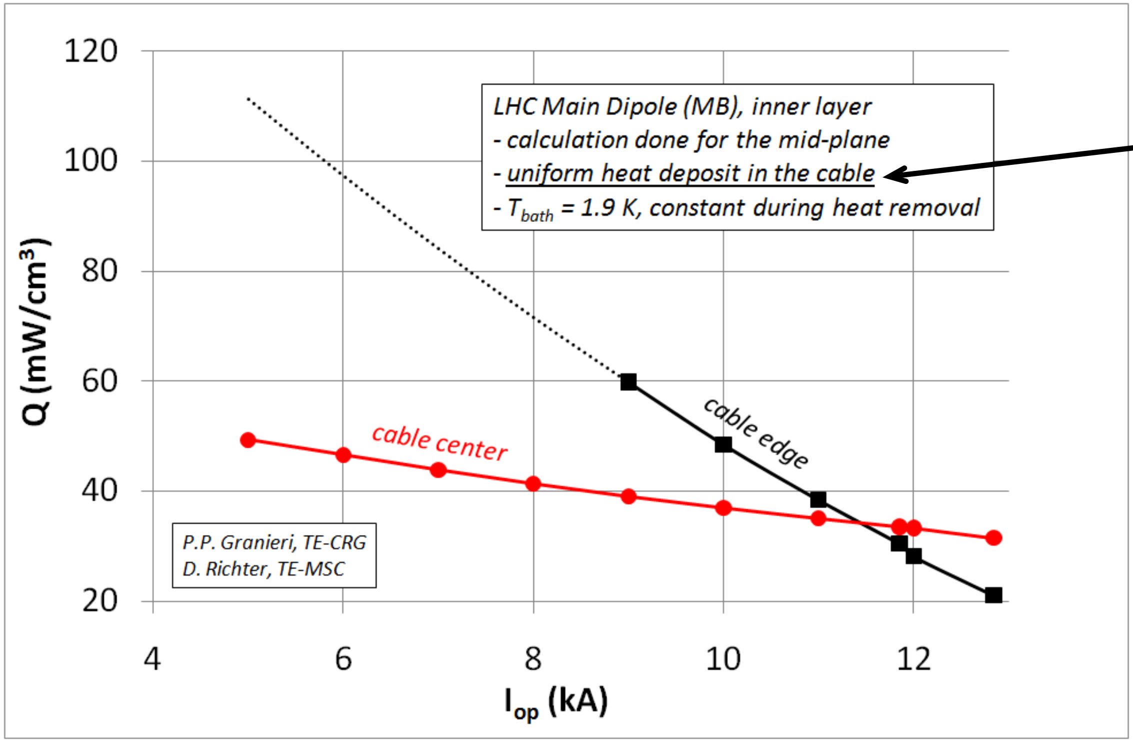


- In most cases: $mJ/cm^3 \neq Gy/s \neq protons/s \neq W/m$
- Considering all parameters QL determination accuracy is factor 2-3…

How do we learn about Quench Limits?

- Calculations, models.
  - Lot of work done, ZeroDee, ROXIE, Steady State models, QP3.
  - BLM thresholds currently set using modified Note44 algorithm.
  - Validation of code is done via measurements and Quench Tests.
- Lab measurements.
  - Lot of data, model validation
- Operational quenches – only injection events observed so far.
  - BLM thresholds released in 2011 for UFOs
- Quench tests with beam – ultimate learning.

Lab measurements

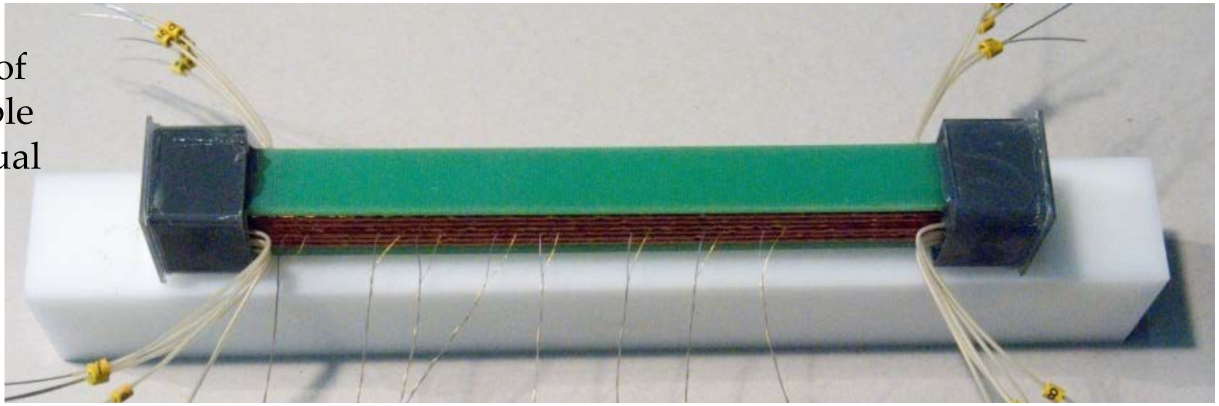


This is why lab measurements are not enough

Other assumptions:

- helium bath is kept at a constant temperature of 1.9 K during heat removal
- geometry is different from that of the magnet

Experimental measurement of heat transfer through the cable insulation, assuming the actual field distribution in the mid-plane cable



Quench list

- List of beam-induced quenches on sharepoint page http://cern.ch/biq
- Up to now 13 quenches, 10-test, 3-injection events

https://espace.cern.ch/BIQ/List of quenches/Forms/Default.aspx

Beam Induced Quenches in the LHC

Beam Induced Quenches in the LHC

Home | Site Actions

Beam Induced Quenches in the LHC > List of quenches

List of quenches

View All Site Content
Documents
- Shared Documents
- List of quenches
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Lists
- Calendar
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Discussions
- Team Discussion

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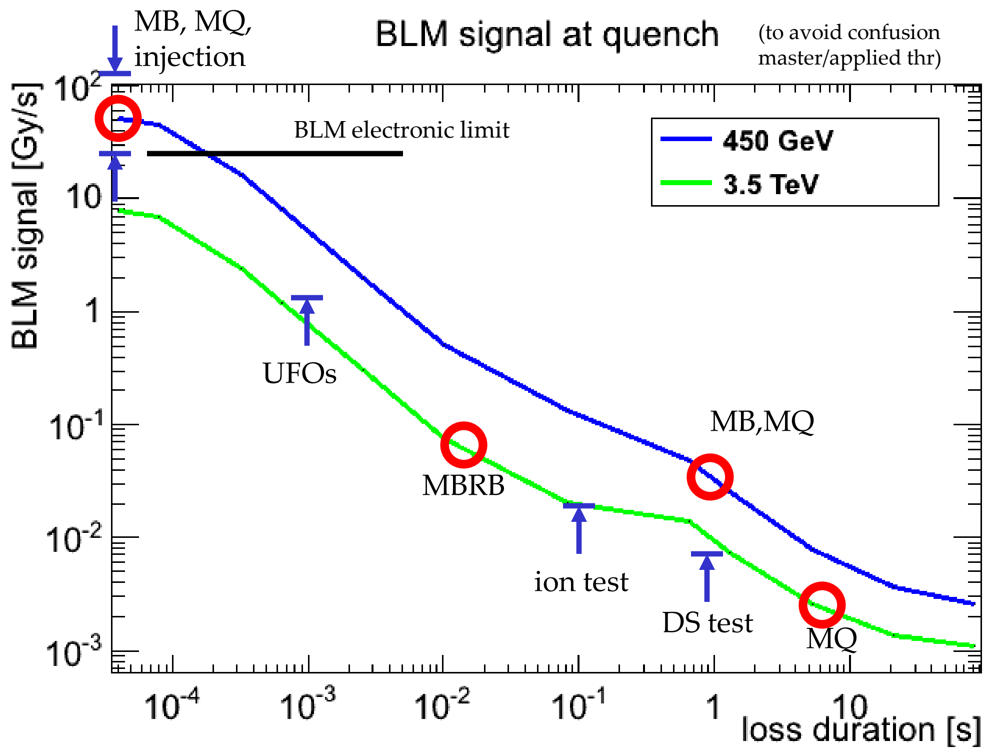
Type	Name	Modified	Modified By	Magnet	Location	E_beam	Duration	Beam	Plane
	2008-08-09 (00h19m51s)	03/08/2011 03:06 PM	Arjan Verweij	MB	8L3	0.45	ns	B1	V
	2008-09-07 (15h34m05s)	03/08/2011 03:22 PM	Arjan Verweij	MB	10R2	0.45	ns	B1	V
	2009-11-20 (18h21m27s)	03/08/2011 03:24 PM	Arjan Verweij	MB	12L6	0.45	ns	B1	H
	2009-12-04 (10h19m49s)	03/08/2011 03:36 PM	Arjan Verweij	MB	15R2	0.45	ns	B1	V
	2010-04-18 (10h33m41s)	03/08/2011 03:36 PM	Arjan Verweij	MB+	20R1	0.45	ns	B1	V?
	2010-10-06 (08h13m58s)	03/08/2011 03:36 PM	Arjan Verweij	MQ	14R2	0.45	1 s	B2	V
	2010-10-06 (10h35m01s)	03/08/2011 03:36 PM	Arjan Verweij	MQ	14R2	0.45	1 s	B2	V
	2010-10-06 (11h37m00s)	03/08/2011 03:36 PM	Arjan Verweij	MB	14R2	0.45	1 s	B1	H
	2010-10-17 (18h23m14s)	03/08/2011 03:36 PM	Arjan Verweij	MQ	14R2	3.5	6 s	B2	V
	2010-11-01 (14h40m04s)	11/09/2011 12:26 PM	Mariusz Gracjan Sapinski	MBRB	5L4	3.5	20 ms	B2	-

What have we learned from Quench Tests?

- 14R2 quench test (2010)
- Wire scanner quench test
- Dispersion suppressor quench tests (protons and ions)
- Injection quench events



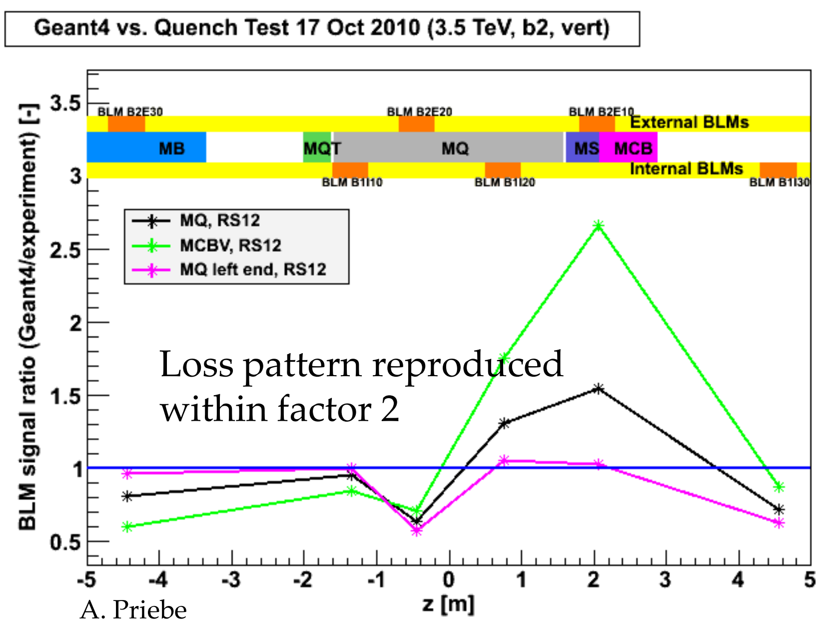
We measure BLM signals and lost beam intensity.

Monte Carlo simulations allows to conclude about Quench Limits [mJ/cm3].

Quench tests with orbital bump

- Performed in 2010, 3 quenches at injection and 1 at 3.5 TeV
- Circulating low intensity beam, orbital bump, loss duration 5-6 s at 3.5 TeV.
- BLM thresholds have been found 3x too high, corrected for 2011 run.

  (Fail function for BLM thresholds is orbital bump)



A. Priebe

CERN-ATS-2011-058

- Geant4 preliminary results
- Problem to establish a loss pattern

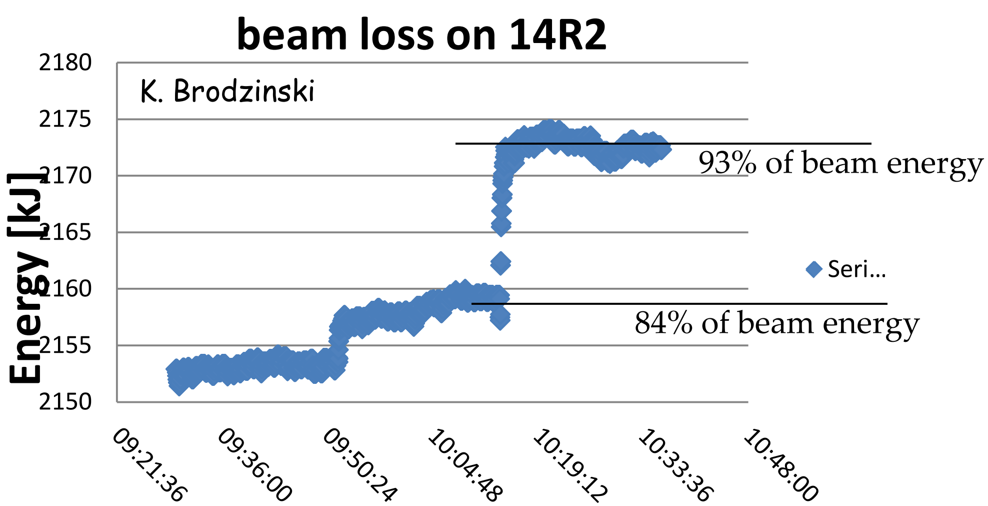
	Energy density [mJ/cm³]	
	Geant4 and experiment	QP3 with Geant4 radial shape
cable average	1370	550

Quench tests with orbital bump 2012

- It is proposed to repeat this test in 2012:

- Quench with raising orbital bump (better horizontal this time).
- 2nd ramp with orbital bump amplitude steered by BLM orbit feedback

  at 50-80% of BLM signal of previous quench. Alternatively: bump + ADT blowup.
- Expected: steady-state loss lasting ~1 minute, without quench.
- Real steady-state quench limit determination in well-controlled , clean conditions.
- Cryogenic calorimetry and QPS scope measurements



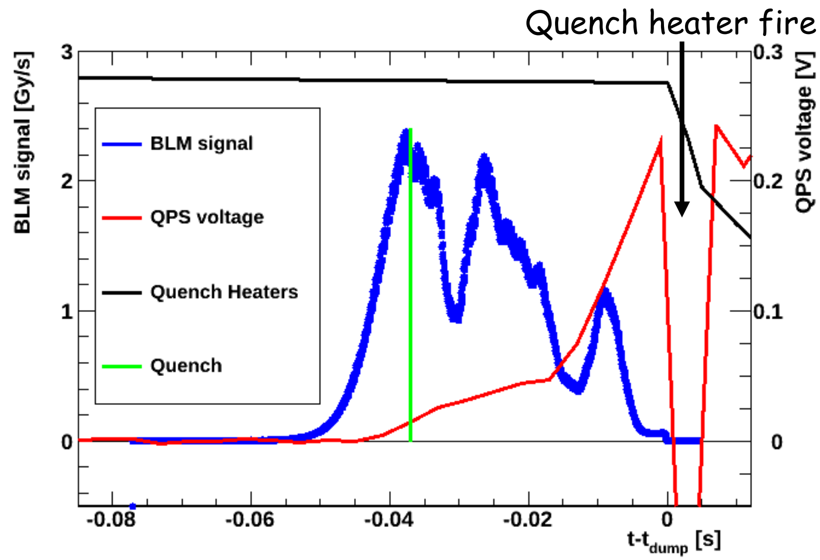
	QPS	scope
sampling	500 S/s	20 kS/s
resolution	5 mV	0.3 mV

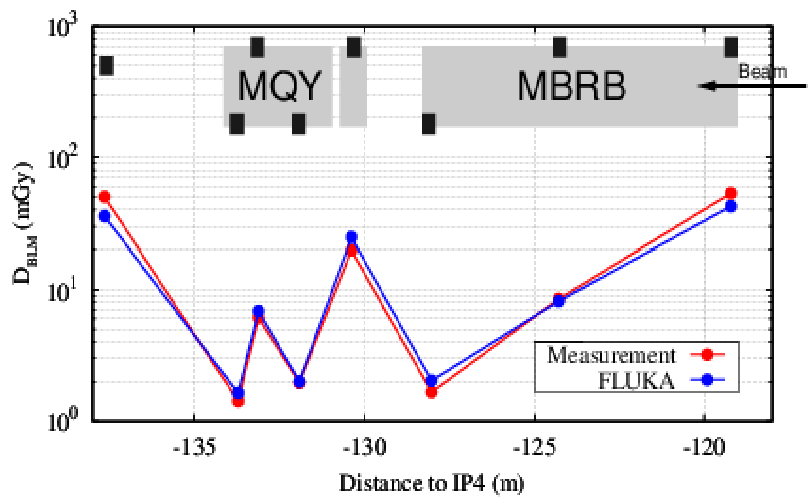
Wire scanner quench test

- Performed on November 1st, 2010
- Motivation: QL at UFO timescale
- MBRB (4.5K) quenched
- Timescale ~10 ms – too long
- Wire vibrations

	energy density [mJ/cm³]	
	FLUKA and experiment	QP3, dry coil, FLUKA radial shape
cable average	11.6	15.6

- 2012: repeat with more intensity
  - timescale closer to 1 ms.
  - avoid wire damage/oscillations.
  - try during intensity ramp, as QPS scopes are there (hoping for quenchino observation).





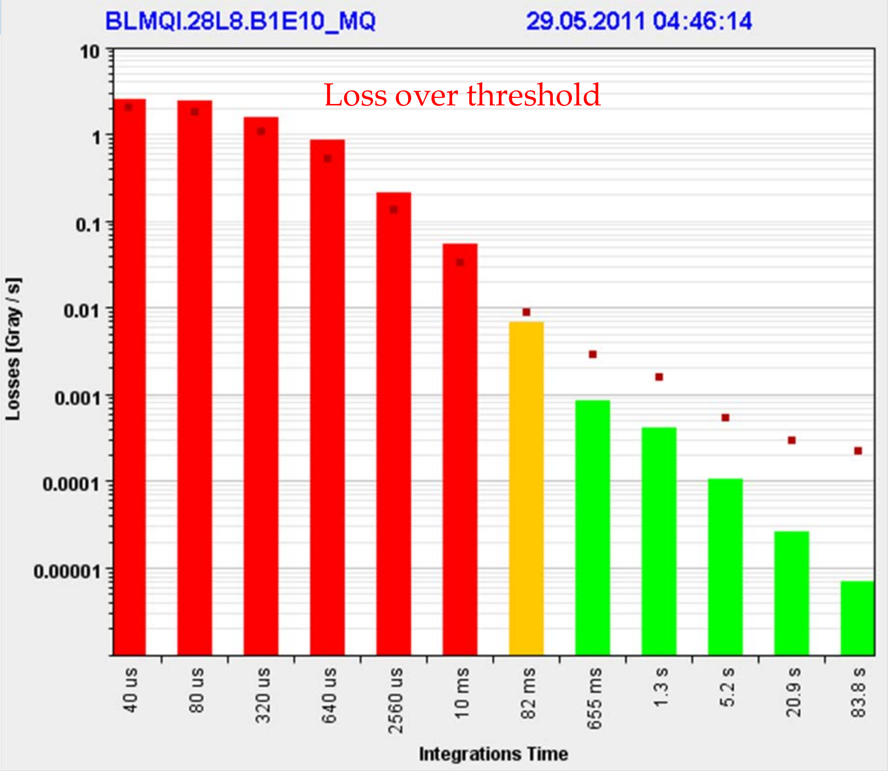
CERN-ATS-2011-062, IPAC11 proceedings

UFO quench fishing

- Need to know operational limit due to UFO quenches.
- It is proposed to raise BLM thresholds in given sectors and install additional BLMs in chosen locations (Q18,19 R3).
- Wait for the UFO-generated quench.
- Simulations are being prepared.
- More in Tobias' presentation.

Example of UFO in cold sector

which dumped the beam.



Dispersion suppressor quench test

- Performed May 8th, 2011, 3 ramps, loss duration about 1 s.
- 510 kW on TCP, 64% of Quench Limit on Q8 (MQ).

CERN-ATS-Note-2011-042 MD

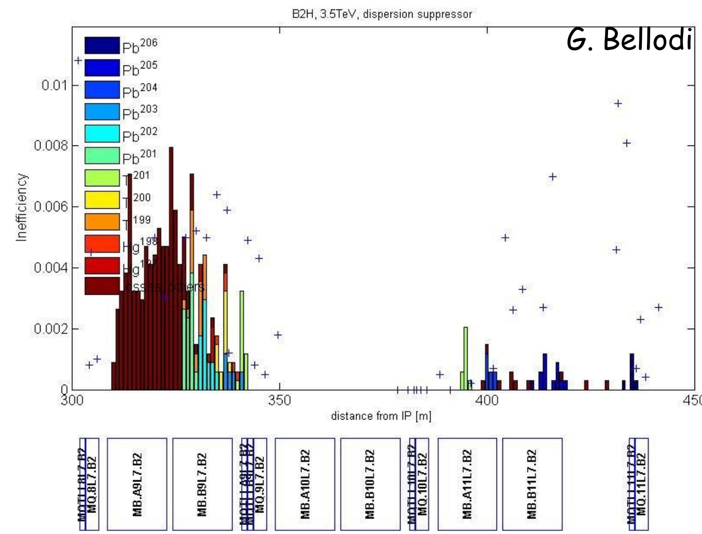
- Temperature spike in empty cryostat.
- Conclusions: no quench in nominal Collimation conditions.
- Conclusion: lower limit for quench, but consistent with present knowledge.
- 2012:
  - Approach the limit – quench.
  - Use ADT to blow beam in controlled way.
  - Longer losses (>1 s).
  - Squeezed beams to see if limits are not in IRs.

Dispersion suppressor with ions

- Performed December 6th, 2011, 3 ramps, 4 losses, preliminary analysis.
- Shorter loss durations

  (100 ms, only one loss lasting about 1 s).
- Very specific loss pattern.
- No quench, touching known BLM QL.

  (especially for 100 ms losses)

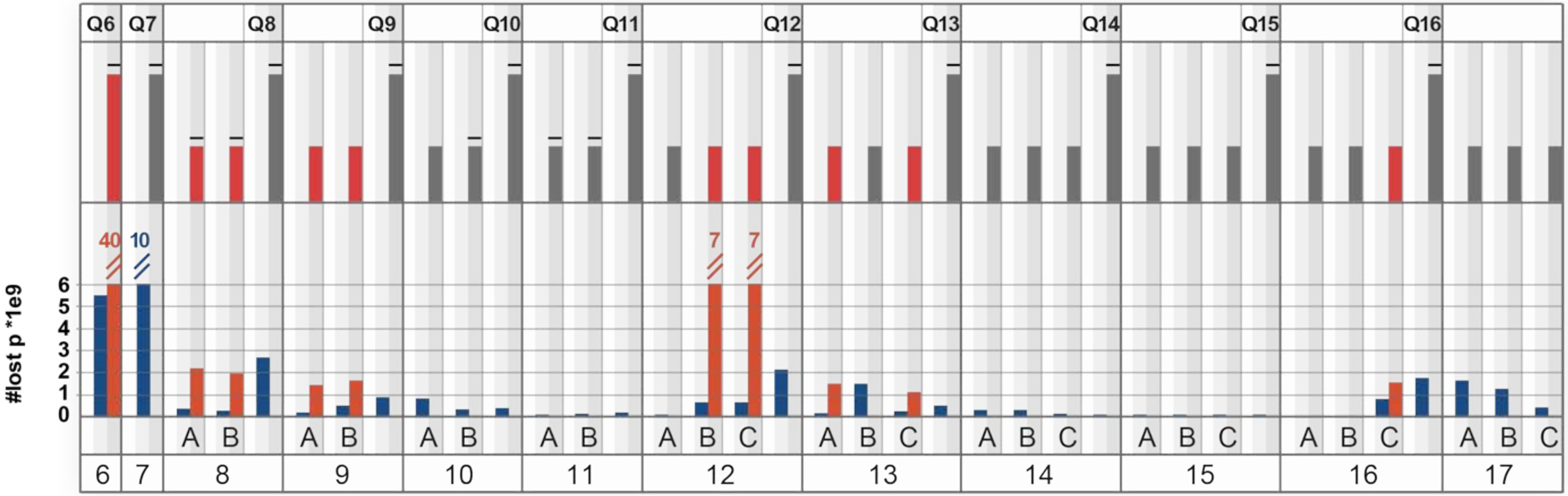


- Achieved losses about 400x higher than luminosity losses (fill 2332, R5) – gives factor ~10-20 for design lumi at 7 TeV (J. Jowett).
- For fast events (100 ms, like beam instabilities) there is 2x more margin than current BLM thresholds (for ions and for particular monitors).
- 2012: use ADT, motivation similar to proton Dispersion Suppressor test

Injection losses

- Combined results from 3 injection events (B1 and B2), and MD

Red- quench, grey – no quench, bar – BLM present, high/low - MQ/MB



A. Nordt

- Upper limit often suffers from BLM saturation (improvement: LIC).
- Dipoles are more fragile than quads at injection.
- Special quench test (MD) with dumping the beam on the magnet with raising current done, to be repeated in 2012 (for asynchronous beam dump).

Conclusions

- Quench tests leaded to BLM threshold optimizations (max. factor 5)
- Beam-induced quenches will not be an issue for operation in 2012.
- We could learn from quenches which will happen sooner or later.

BUT

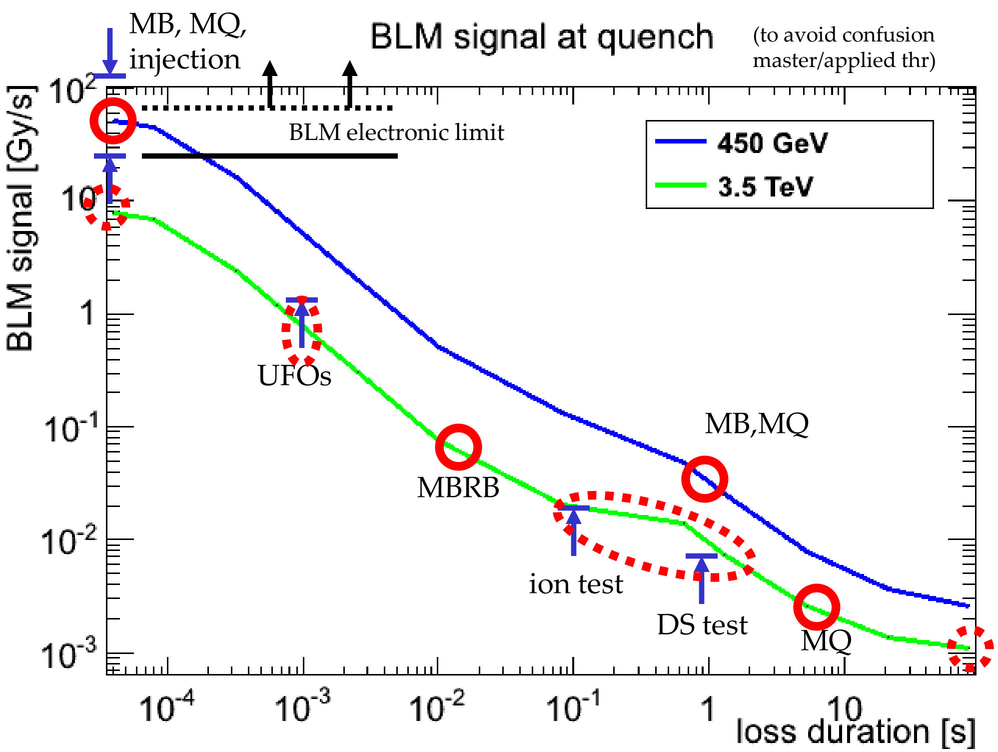
- In 2014 beam-induced quenches will be a problem, so we must be prepared!
- We need to understand (and model) quenches to develop new magnets, collimators, BLM thresholds
- Quench tests provide controlled conditions.

KEY PROPOSALS:

- **Perform quench tests (next page).**
- **When possible use 3.5 TeV to reduce risks.**
- **Establish a panel where tests priorities will be evaluated.**

What we should learn in 2012?

- Measure Quench Limit in Steady State
  - Orbital bump test for the precision and control.
  - It is a reference measurement, can be used to conclude for other loss scenarios.
  - Important for future magnets design (triplets test ?).
- Try to hit the collimation limit.
  - Realistic loss scenario, knowing this limit crucial for HL-LHC, Collimation upgrade.
- Understand when UFOs will limit us by quenching.
  - Repeat wire scanner test.
  - Allow UFO –generated quench in chosen sector.
- Understand QPS signals (quenchinos).
  - May result in QPS upgrade and protection against asynchronous dump.


BLM signal at quench
(to avoid confusion
master/applied thr)
MB, MQ,
injection
BLM electronic limit
450 GeV
3.5 TeV
UFOs
MBRB
MB,MQ
ion test
DS test
MQ
BLM signal [Gy/s]
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
loss duration [s]

THANK YOU FOR YOUR ATTENTION!

REST OF THE SLIDES ARE SPARE (CHAMONIX 2011)