Steady-state Quench Limits

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Collimation WG, CERN, 2012.10.29

Situation

Not much has changed since Chamonix 2012:

1. there are many opinions

   (I present one opinion, maybe controversial & provocative),

2. lot of papers/models/lab measurements,
3. only one partly conclusive beam-induced quench test on LHC.

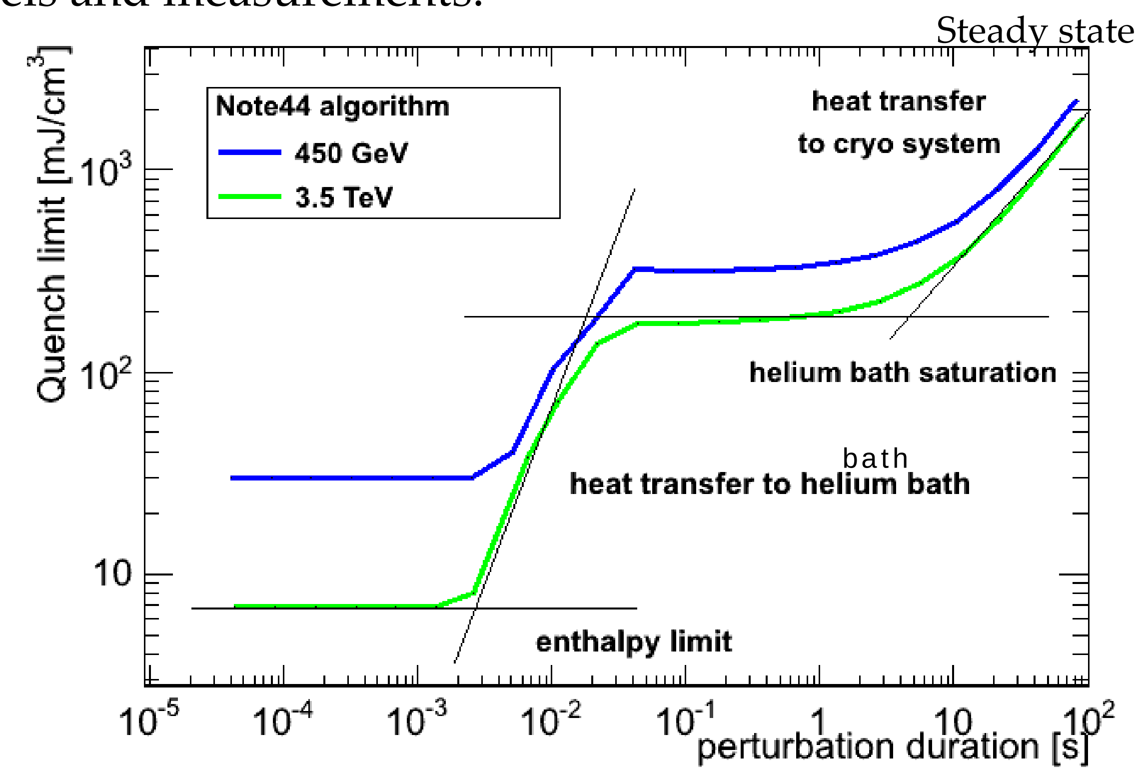
It is NOT a systematic review!

(And be careful quoting/using these numbers.)

Quench limits time and energy dependence

REMINDER

- 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.



fast | intermediate | steady state

Note 44 (J. B. Jeanneret et al, 1996)

CERN-LHC-Project-Report-44

Table 7: Rate of continuous local losses of protons per meter which induce a quench.

	w_q [Wcm^{-3}]	$\dot{n}_q$
Injection	0.01	$7 \cdot 10^8 pm^{-1} s^{-1} = 6.5 \cdot 10^4 pm^{-1} turn^{-1}$
Top Energy	0.005	$7.8 \cdot 10^6 pm^{-1} s^{-1} = 7 \cdot 10^2 pm^{-1} turn^{-1}$

Note weak dependence on beam energy

6 CONTINUOUS LOSSES , A REMINDER

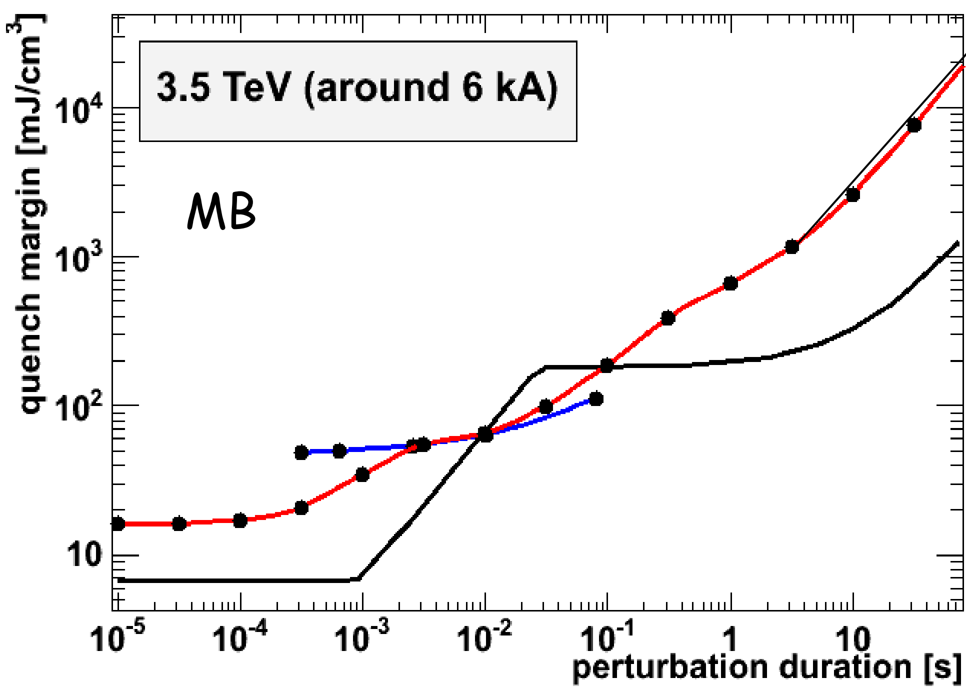
A continuous heat deposit implies a continuous evacuation of heat to keep the temperature constant in the cables, and below the critical temperature. The limit of heat flow is set by the conduction of heat by the HeliumII flow through the insulation of the conductor, a mechanism which has no more to do with specific heat considerations. The present limits are set by the studies on the insulation of the cables made at Saclay [24]. The limit of heat transmission capability w_q (here reduced to a power evacuated out of the cable per unit volume) is reached and a quench occurs with the unit power deposition given in Table 7. The values of w_q might change with a different kind of insulation by a factor of two, more or less. The number of protons which can be lost locally per second in a continuous way must therefore be smaller than (see Table 1 for $\varepsilon_{ra,dist}$)

$$\dot{n}_q = w_q / \varepsilon_{ra,dist}. \tag{28}$$

QP3 code (A. Verweij)

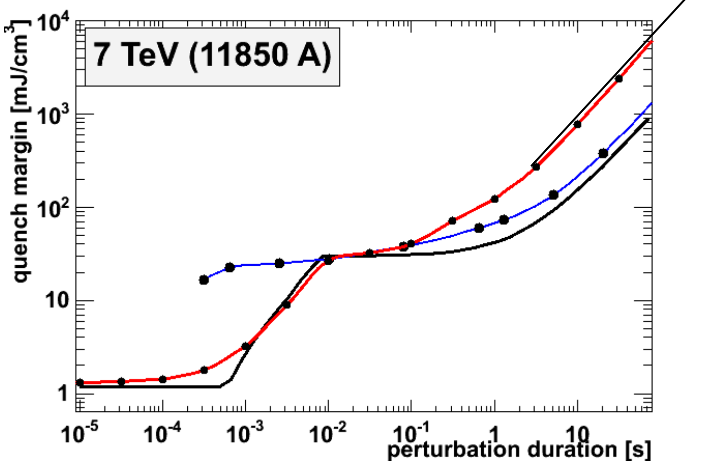
For steady-state Arjan takes similar approach as Note44: insulation is the limiting factor.

Input to the calculation is radial profile of heat deposit in the coil.

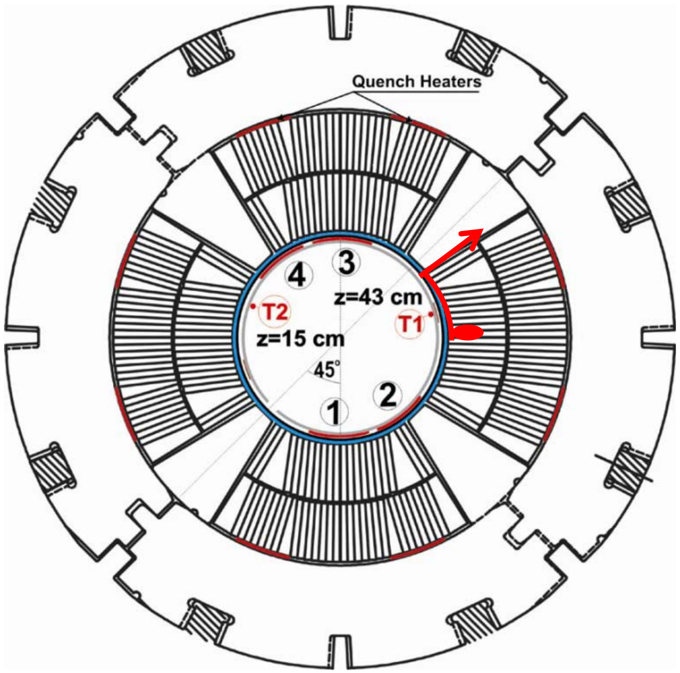


about 260 mW/cm^3

about 100 mW/cm^3



Multi-cable models (2D)



Some people think single cable is not everything and they simulate the whole coil cross-section:
See *Network model*

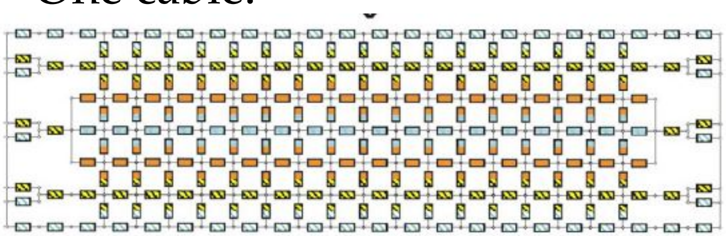
D. Bocian et al.
IEEE Trans. Appl. Supercond. 19 (2009) 2446

See Pier Paolo's presentation.

Example of results
(depending on loss profile):
MB @ 7 TeV: 12-17 mW/cm^3
MQ @ 7 TeV: 17-23 mW/cm^3

Rather tight!

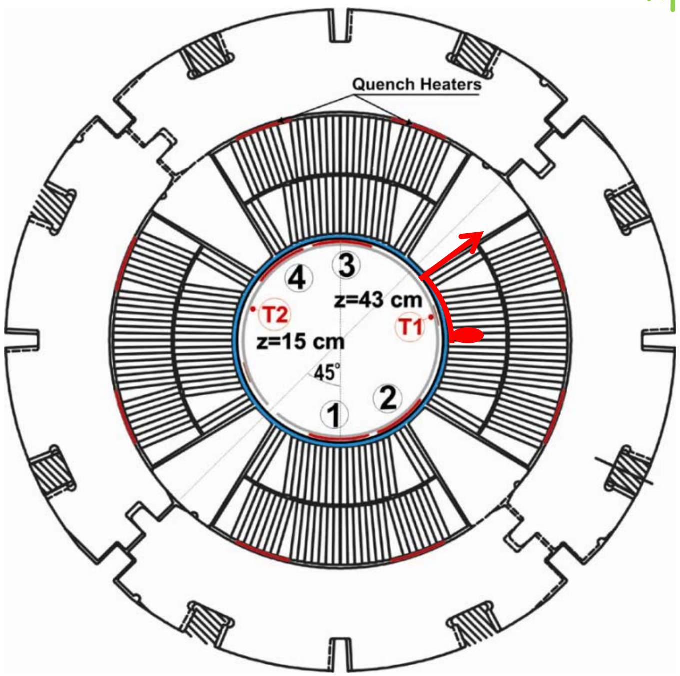
One cable:



Model validated by measurements with quench heaters and heaters from inside beam pipe.

Input to the model: map of thousands of energy depositions in the coil.

Where is the bottleneck?



Simplified image:

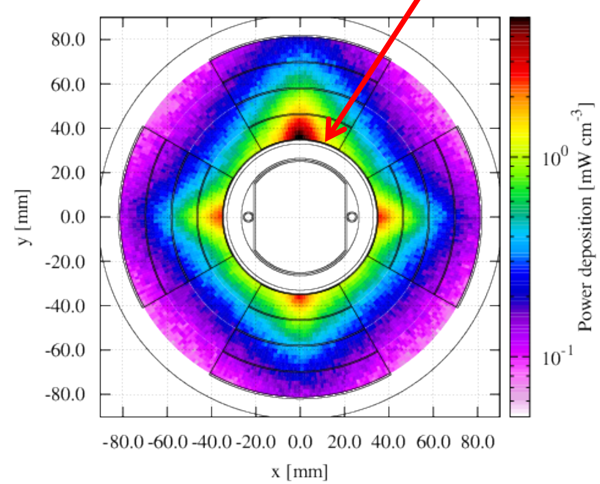
cable
↓ insulation
cold-bore He-layer
↓ Helium channel
radial layer

Covered by single cable models (cable → cold-bore He-layer)

Multi-cable model needed (cold-bore He-layer → radial layer)

I think that steady-state quench takes place only if heat transfer channel gets blocked (HeII->HeI – always T=2.17 K)

Single cable model maybe enough!?



CERN-ATS-Note-2012-014 TECH

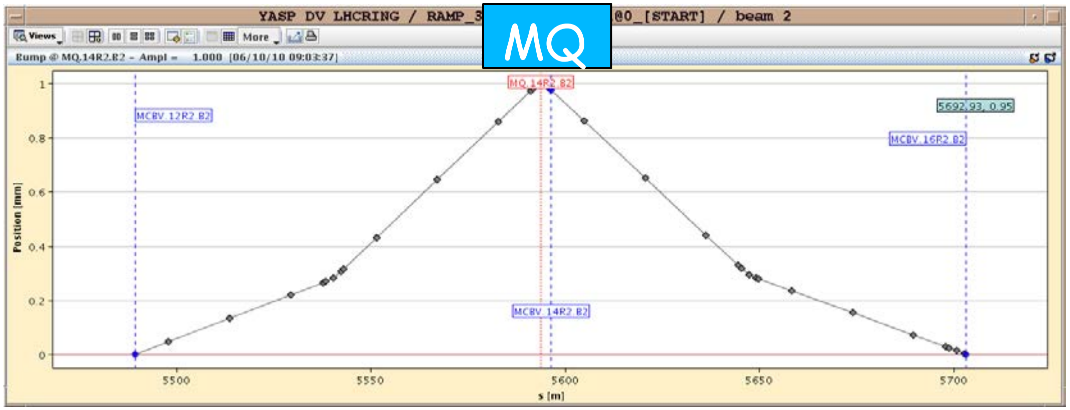
- beam optics
- magnetic fields

↓

physical losses look all similar: maximum in radial center of coil horizontal or vertical (no skew!)

The experiment with beam (I)

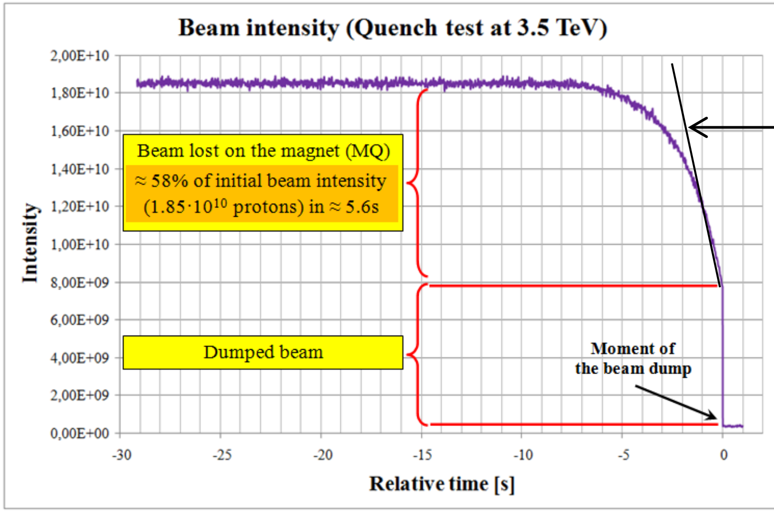
We had **only ONE** quench test with long duration of loss (5s) when the magnet actually quenched! That was on October 17th 2010.



MQ 14R2, vertical loss, beam energy 3.5 TeV,

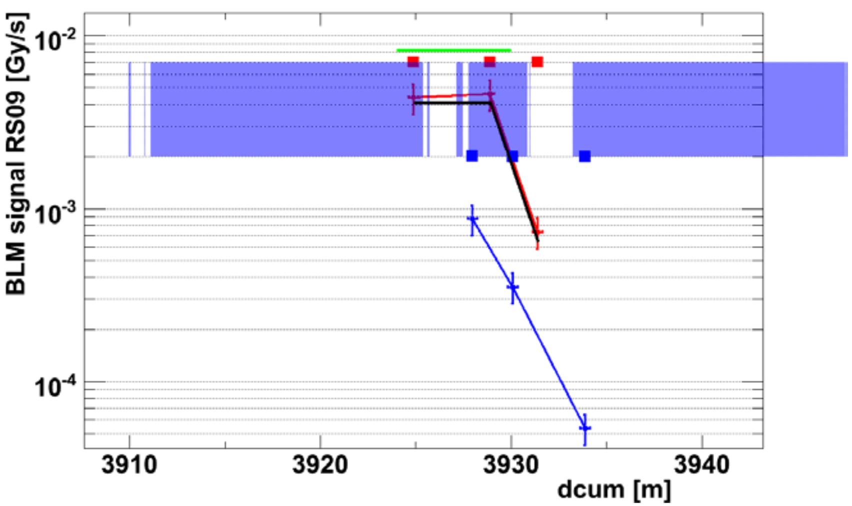
3-corrector orbital bump was directed into the aperture.

The experiment with beam (II)

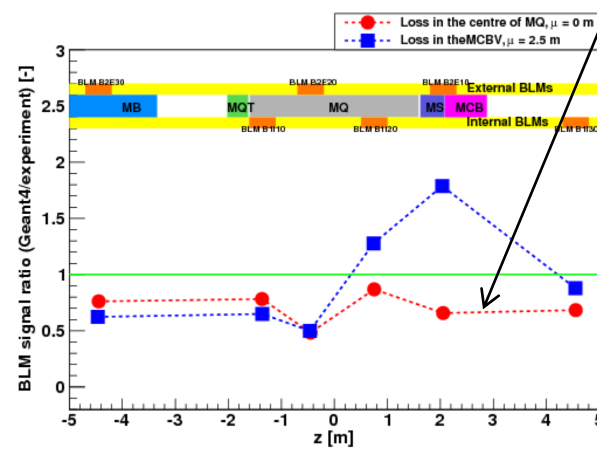


Final loss rate: ~12 $\cdot 10^9$ p/s

But averaged: 11 $\cdot 10^9$ p in 5.6 s = $2 \cdot 10^9$ p/s

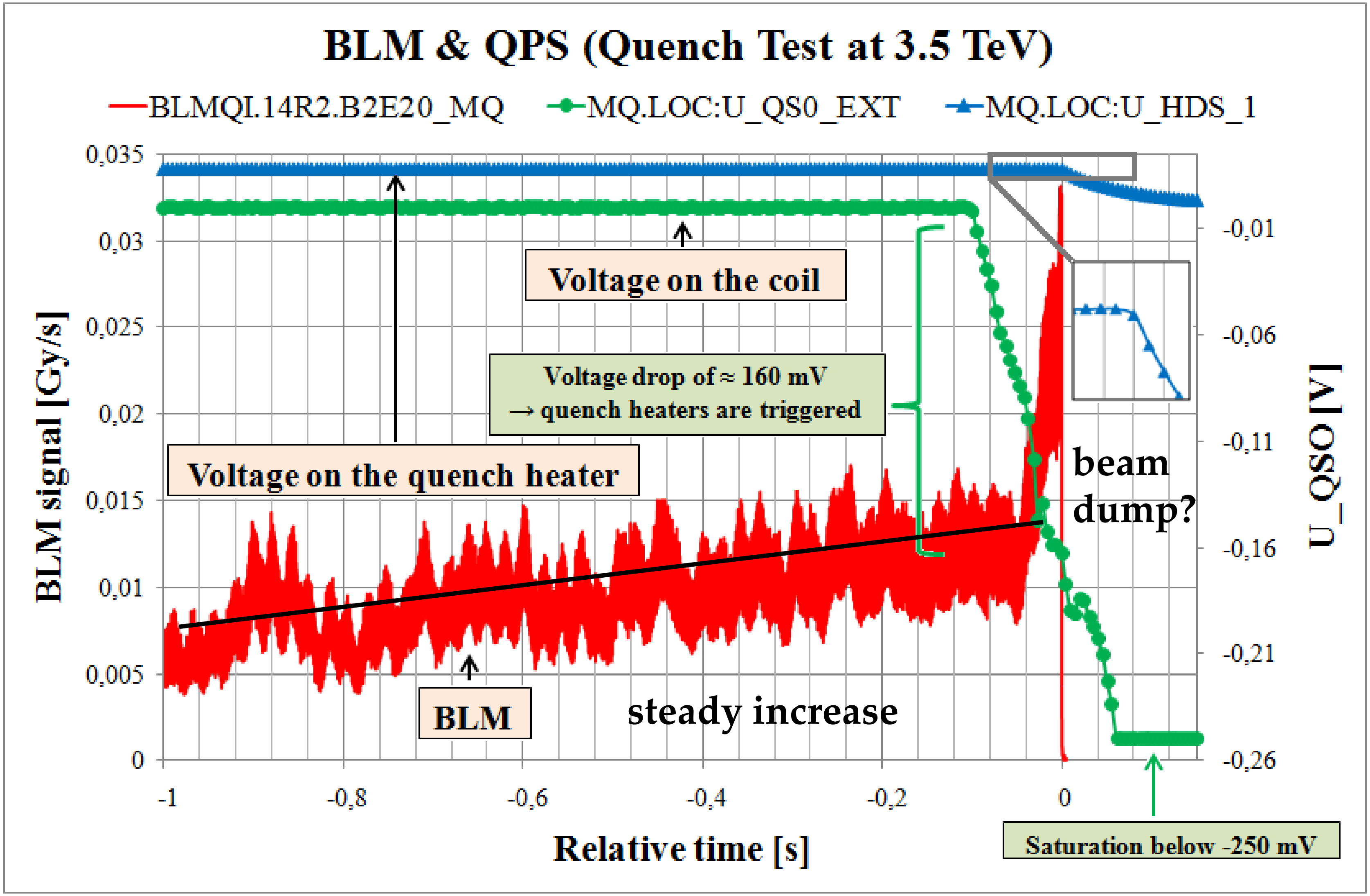


Extensive Geant4 simulations still ongoing, source term constrained by BLM signals, not too bad agreement:



CERN-ATS-2011-058, now ASC proceedings

The experiment with beam (III)



History of the last second as seen by BLM – not completely understood…

The experiment with beam (IV)

Preliminary results of GEANT4 simulation of the experiment

Assuming some simplified gaussian longitudinal loss pattern, we get:
One proton lost ~ $1.4 \cdot 10^{-7}$ mJ/cm^3

Averaged over loss duration: 280 mW/cm^3

Maximum at the end of loss: 1700 mW/cm^3

FLUKA always claims factor 3 accuracy

QP3

(taking into account the measured loss time structure and simulated radial dependency): 100 mW/cm^3

Quench test 2013: (little publicity)

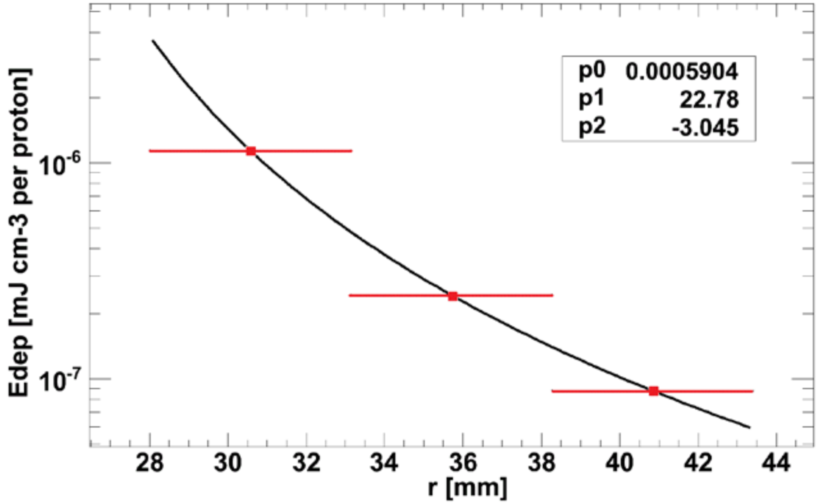
Clearly new quench test would be very useful:

- profiting from ADT which allows to control losses (10 s, constant loss rate)
- test with a bump does not correspond to any physical loss scenario but has a source term which is much easier to simulate than collimation loss
- So if we want a number in mW/cm^3 - we need steady-state test with bump
- and mW/cm^3 is needed to run FLUKA/G4 simulations and obtain conclusive results.
- Also in order to quench with collimators > factor 10 more intensity is needed then the previous time

Why don't we measure mW/cm^3 in the lab?

- of course it is a valid option!
- difference with respect to quench test is radial heat deposit:
- at least SOME beam-induced

tests should be performed



Conclusions

1. **Note44 is quite pesymistic (5-10 mW/cm^3), but probably wrong .**
2. **Quench limits are rather above 100 mW/cm^3:**
   - **QP3 results**
   - **Quench test results**
3. **Clearly more data and simulations needed (Quench test in March 2013).**
4. **For BLM thresholds we used ~ 20 mW/cm^3 at 7 TeV (network model).**
5. **But we also used not completely correct energy deposition in magnets, BLM, the whole separate subject of discussion.**
6. **We also used linear interpolation between injection and 7 TeV .**
7. **These things must be discussed again (workshop planned), better after end of run, even for practical reason: setting BLM thresholds for after-LS1**

And now I'm sure Pier Paolo will present quite contradicting point of view…

Spare slides

Development

Idea: put BLM detectors closer to magnet coil.

Cryogenic BLMs undergo first tests right now at T9 beamline in East Hall.

current BLM position

Yesterday signals from Si and Diamond detectors were measured at 1.9 K.