The quench limits for transient losses

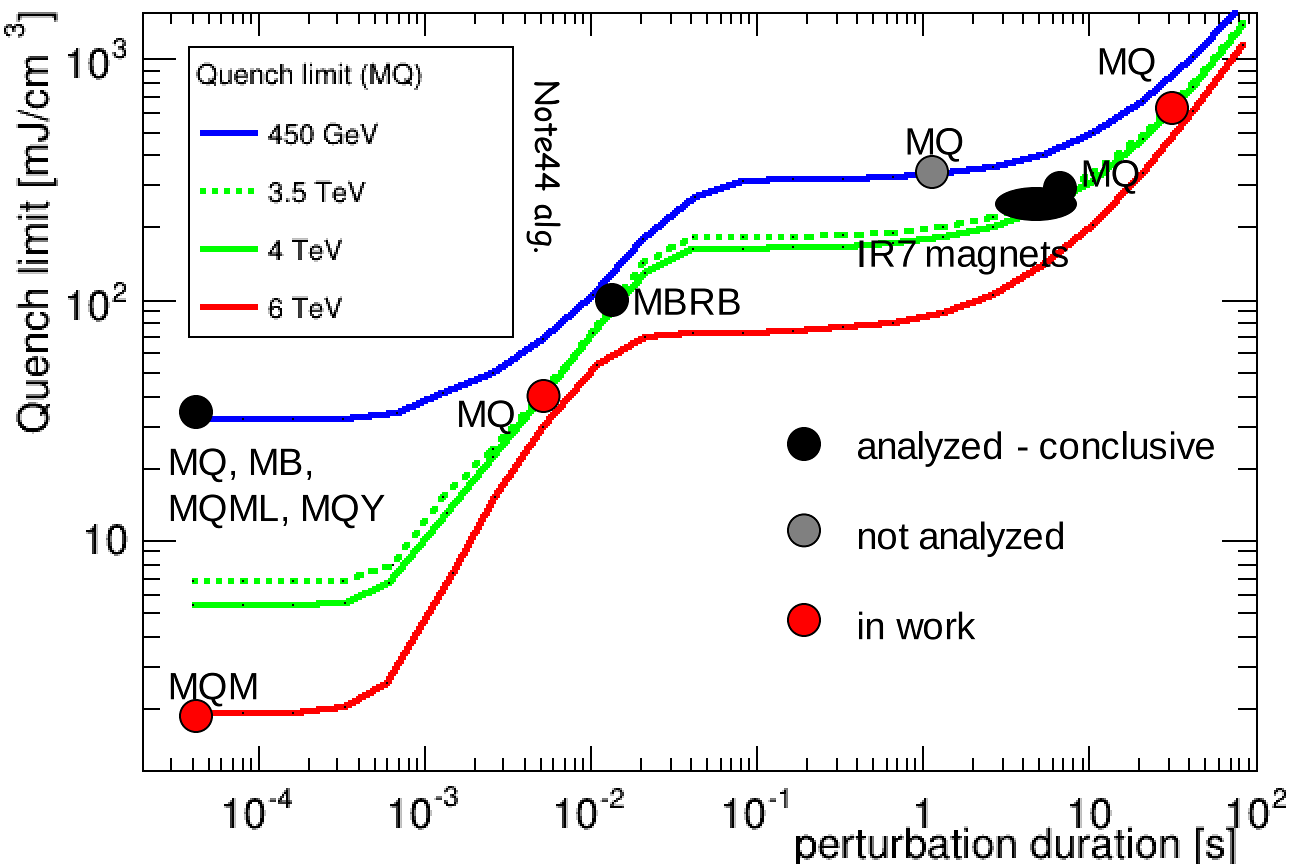
Mariusz Sapinski BE/BI for many people participating in quench tests
and now in the analysis

Collimation Review, 2013/05/30

Outlook

1. Quench limits overview.
2. What transient losses affect collimation?
3. Quench limit investigations for transient losses:
    - Ultra-fast losses,
    - Millisecond-timescale losses.
4. Conclusions.

Energy needed to quench a magnet decreases for shorter losses so short “spikes” on collimators can potentially lead to magnet quench even if steady-state cleaning is safe.



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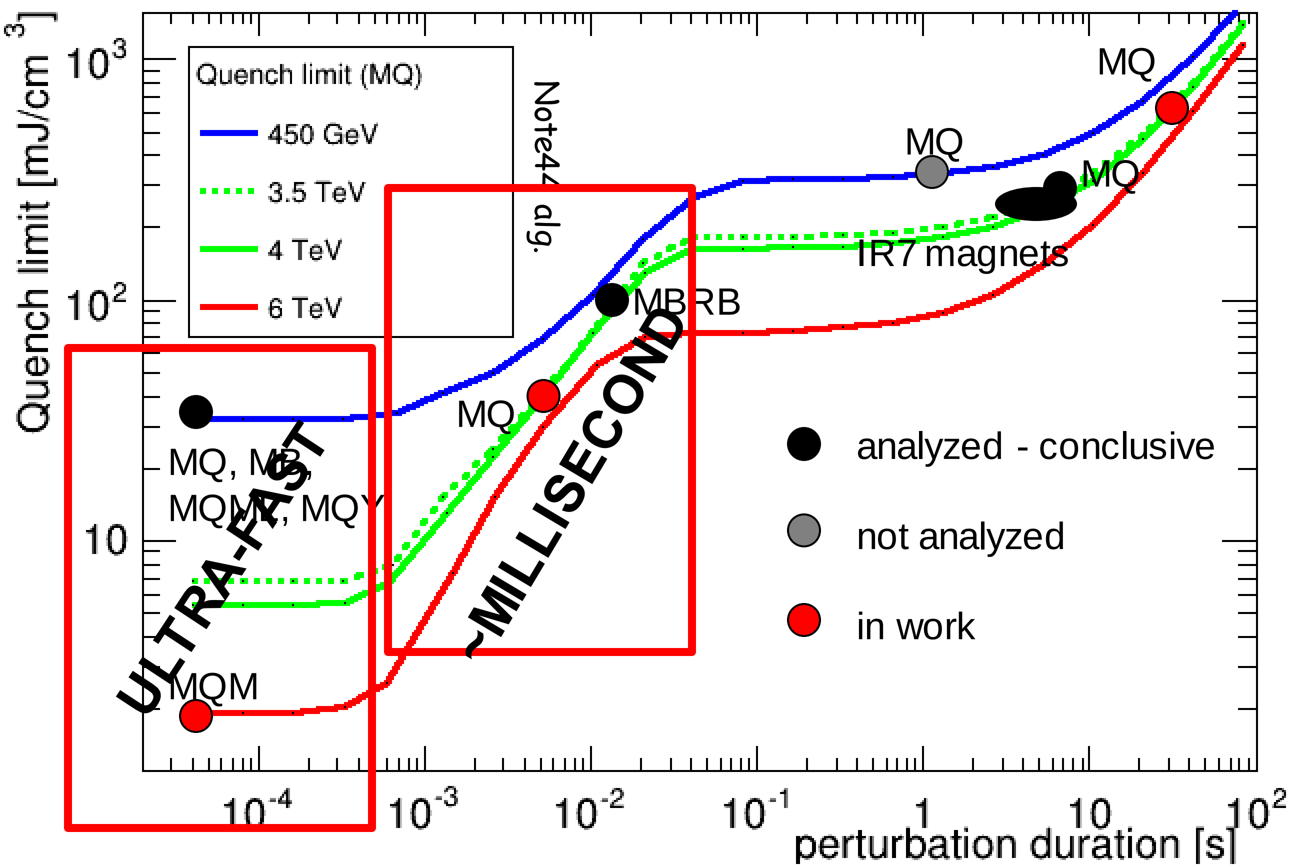


What kind of transient losses?

- UFO losses – small amplitude seen on collimators, large in UFO location.

- losses at capture are probably 'slow': they depend on the dipole ramp rate.
- losses at end of ramp are also generally slow (tails cut by closing collimators)
- losses during the squeeze were often correlated with orbit drifts and OFB.
- losses at the end of squeeze due to instabilities .

from Giulia Papotti

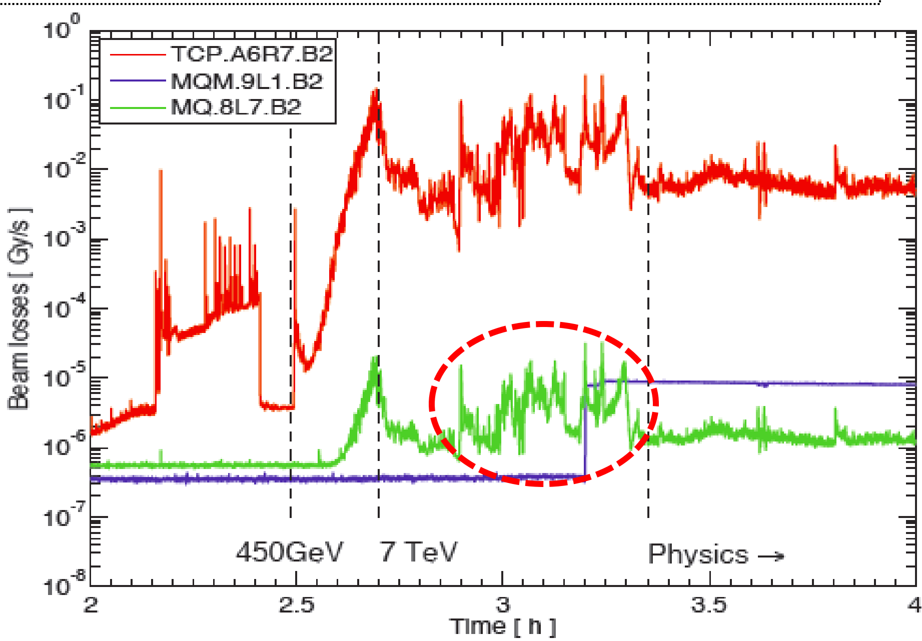
Failure losses:

- failure warm separation dipoles D1

(thesis of A. Gomez Alonso, 2009)

- asynchronous dump – losses on

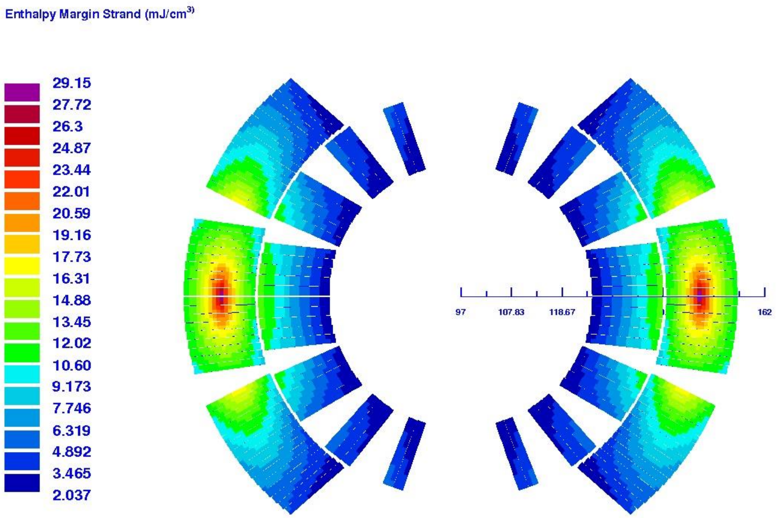
dump protection collimators

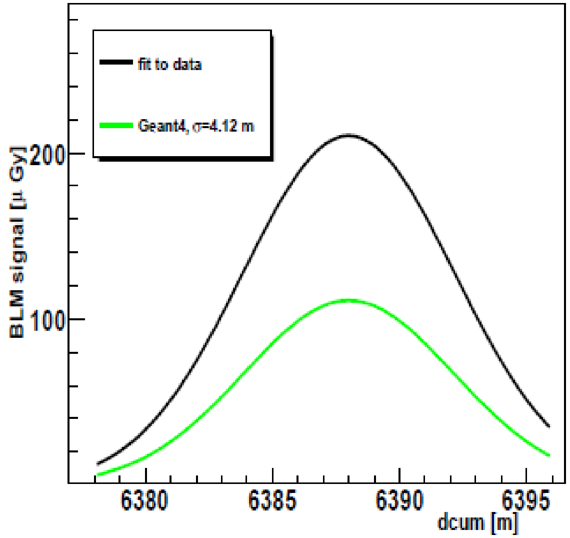


Stefano's presentation

Quench limits of ultra-fast losses

1. Ultra-fast = much shorter than 1 ms.
2. Easy to compute:
   - see LHC-Project-Note-044 (1996):
     $\Delta H_{wire} = H_{wire}(T_c) - H_{wire}(1.9K)$
   - parametrization of specific heat
   - implemented in ROXIE.
3. Several *tests* at injection (CERN-LHC-Project-Note-422, 2008):
   - QL from Note044: 31 mJ/cm^3,
   - QL from Geant4: 13-50 mJ/cm^3.
4. Operational quenches during Run 1: only ultra-fast at injection.
5. One test at "above 4 TeV".

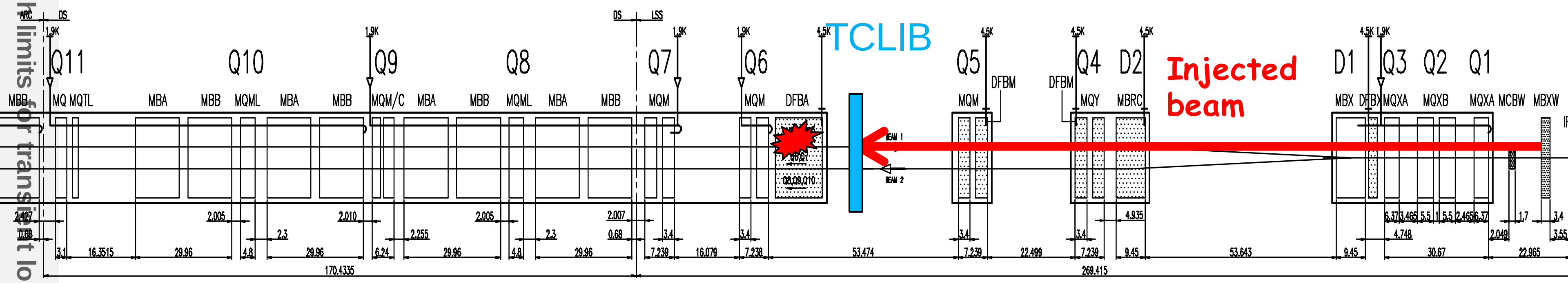




Q6 quench test

Slide by Chiara Bracco

- Performed on 2013.02.15



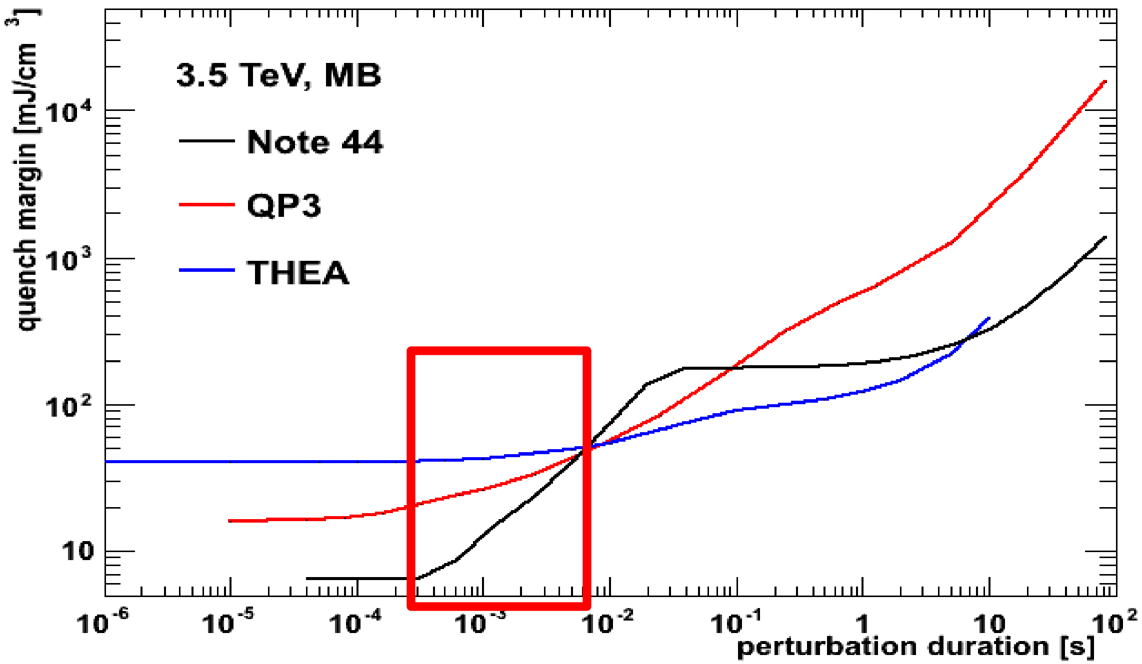
- Emittance from SPS: **H ~0.5 μm, V ~ 0.5 μm ➔ impact parameter 4.5 σ** (full beam intercepted).
- **Pilot bunch 6-6.5e10p+** (probe beam limit increased to 1E11p+).
- Q6.L8 Current steps: 1000 A, 1500 A, 2000 A and **2500A (~ 6 TeV) ➔ Quench!**
- **Fluka studies ongoing, will give us very good quench limit at 6 TeV.**

Quench limits for ~millisecond losses

Quench limits difficult to compute (LHe plays crucial role, various heat transfer mechanisms).

Two tests done, both motivated by UFO losses:

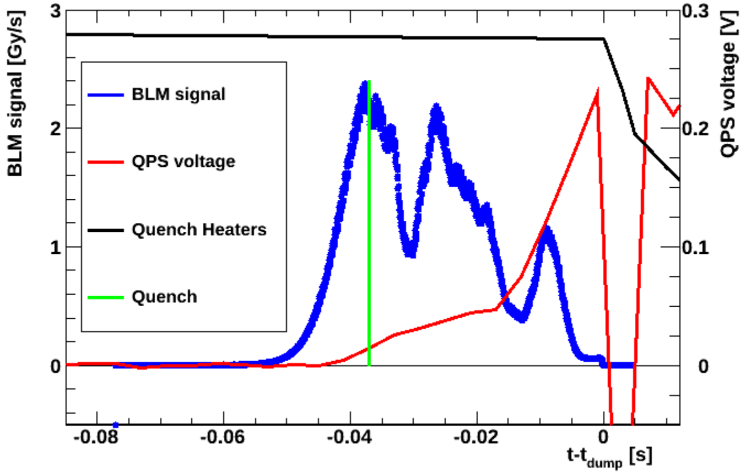
- wire scanner (2010),
- fast ADT and orbit bump (2013).



Wire scanner quench test

- Performed on Nov. 1st, 2010 .
- Beam energy 3.5 TeV.
- Intensity 1.53 · 10^{13} protons.
- Wire speed 5 cm/s.
- Quenched MBRB dipole (4.5K).
- 33 meters downstream wire scanner.
- analysis and FLUKA simulations

presented in CERN-ATS-2011-062 (IPAC11)



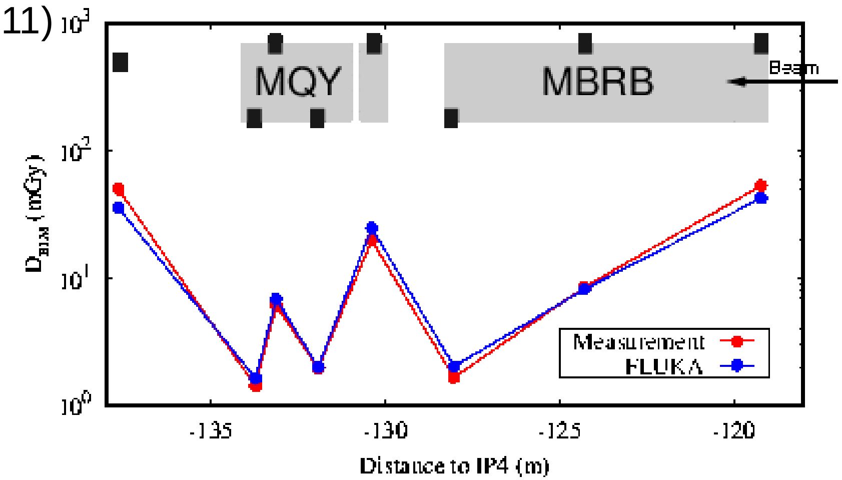


Table 1: Comparison FLUKA and QP3 quench levels

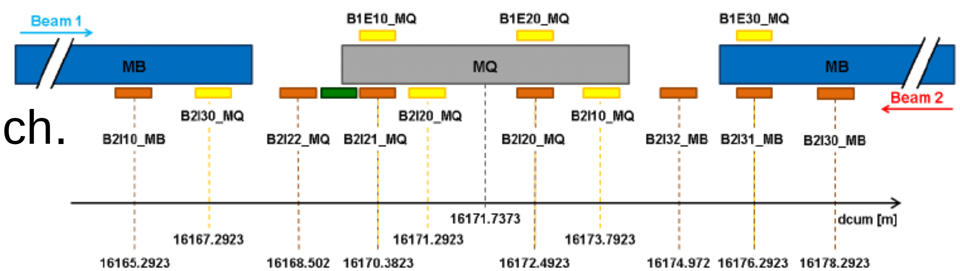
energy density	FLUKA $[mJ/cm^3]$	QP3 4%He $[mJ/cm^3]$	QP3 no He $[mJ/cm^3]$
cable average	11.6	20.5	15.6
maximum	18.8	31.8	24.2

Fast ADT and orbit bump quench test

Procedure:

- Inject and ramp 10 bunches (to have multiple attempts).
- **Scrape a single bunch** by vertical blow to intensities < 10^9 p (special collimators setting).
- Create horizontal **orbit bump** (Q12L6).
- **Excite single bunch** in horizontal plane by MKQ kick and then by ADT using sign flip mode (anti-damping).
- If no quench – scrape less next bunch.

Procedure proposed by Wolfgang Hofle



Challenges:

- For damper: ultra-low sensitivity mode: $5 \cdot 10^7$ protons.
- For instrumentation: measure intensity and emittance of low-intensity bunches.

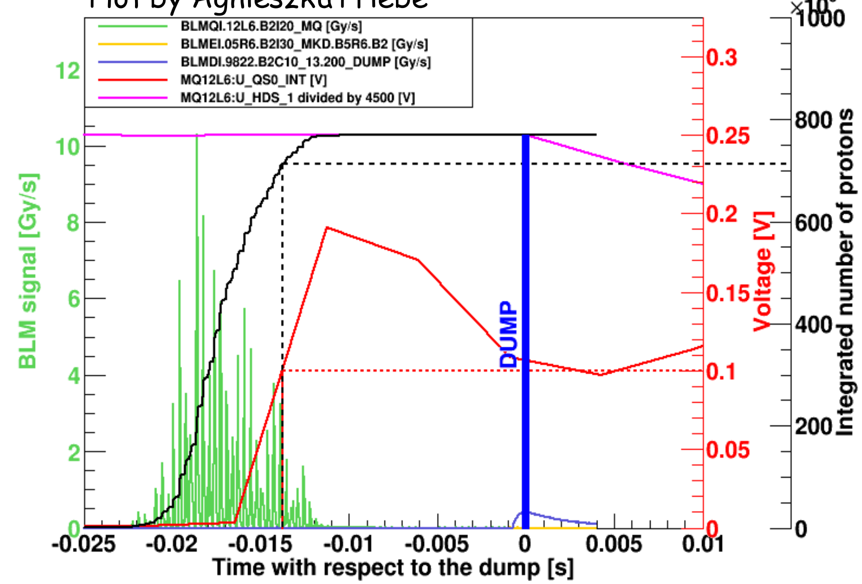
We were prepared: 4 MDs, additional instrumentation.

Fast ADT and orbit bump quench test

- Performed on February 15th, 2013.
- Quench with $7.7 \cdot 10^8$ lost protons.
- No quench with $4 \cdot 10^8$ lost protons.
- Loss duration: 5-10 ms:
  - 2-3 ms expected,
  - UFO: shorter than 1 ms.
- Spiky loss time-structure:
  - UFOs are gaussian.

For 2.56 ms (typical dump by UFO) signal is higher by factor 6 than expected. <u>Potential</u> increase of BLM thresholds on all cold magnets!

Plot by Agnieszka Priebe

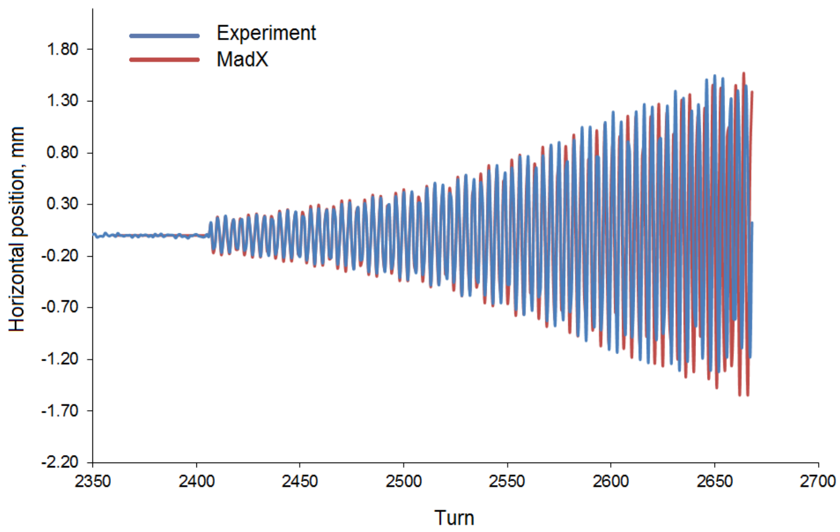


BLM signal integ. time	Signal (Gy/s)	S/Quech
640 μs	1.99	2.1
2.56 ms	1.46	6.1
10.2 ms	0.73	12.0

Analysis:

- Simulate loss pattern using MadX.
- Use MadX loss pattern as input for FLUKA/Geant4 simulations.
- "Control" the FLUKA/Geant4 results comparing with measured BLM signal.
- Obtain energy deposited in the coil.
- Use FLUKA/Geant4 radial energy gradient in the coil as input to QP3.
- Compare QP3 and FLUKA/Geant4.

Plot by Vera Chetvertkova



SIMULATIONS ONGOING

Conclusions

1. Quench limits for transient losses investigated in 4 types of experiments:
    A. Ultra-fast at injection
    B. Ultra-fast at ~6 TeV
    C. Millisecond with wire scanner
    D. Millisecond with ADT and orbital bump
2. Agreement between QP3 estimations and FLUKA-based analysis in case C.
3. Agreement between enthalpy limit and Geant4-based analysis in case A.
4. Cases B and D in analysis, but:
5. larger than expected quench limit for UFO-timescale losses

   (possible increase of BLM thresholds on all cold magnets).

Thank you for your attention

Extra slides

Beam induced quenches

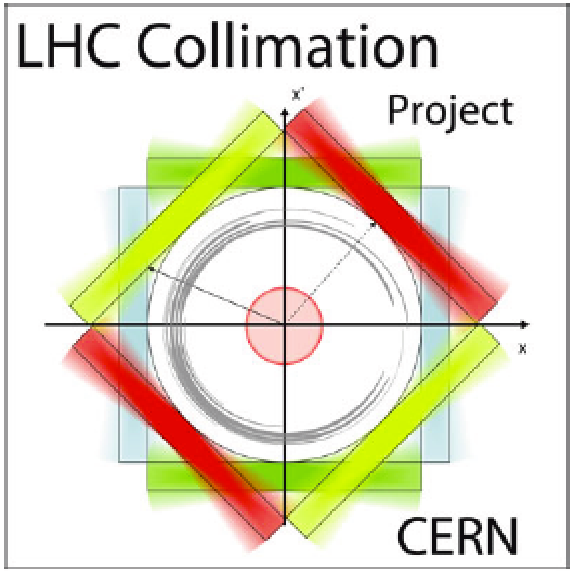
Table 1: List of beam-induced quenches

No	date	beam energy [TeV]	loss duration [s]	quenched magnet	location
1	2008.08.09	0.45	$\sim 10^{-9}$	MB	8L3
2	2008.09.07	0.45	$\sim 10^{-9}$	MB	10R2
3	2009.11.20	0.45	$\sim 10^{-9}$	MB	12L6
4	2009.12.04	0.45	$\sim 10^{-9}$	MB	15R2
5	2010.04.18	0.45	$\sim 10^{-9}$	MB+	20R1
6	2010.10.06	0.45	1	MQ	14R2
7	2010.10.06	0.45	1	MQ	14R2
8	2010.10.06	0.45	1	MB	14R2
9	2010.10.17	3.5	6	MQ	14R2
10	2010.11.01	3.5	$10 - 40^{-3}$	MBRB (4.5 K)	5L4
11	2011.04.17	0.45	ns	MB+	IP8
12	2011.07.04	0.45	ns	MB	14R2
13	2011.07.28	0.45	ns	MQXB+	IP2
14	2013.02.15	0.45 /6 TeV	10^{-9}	MQM (4.5 K)	6L8
15	2013.02.16	4.0	10^{-3}	MQ	12L6
16	2013.02.16	4.0	20	MQ	12L6

First quench test campaign

Second quench test campaign

First results on proton collimation quench test

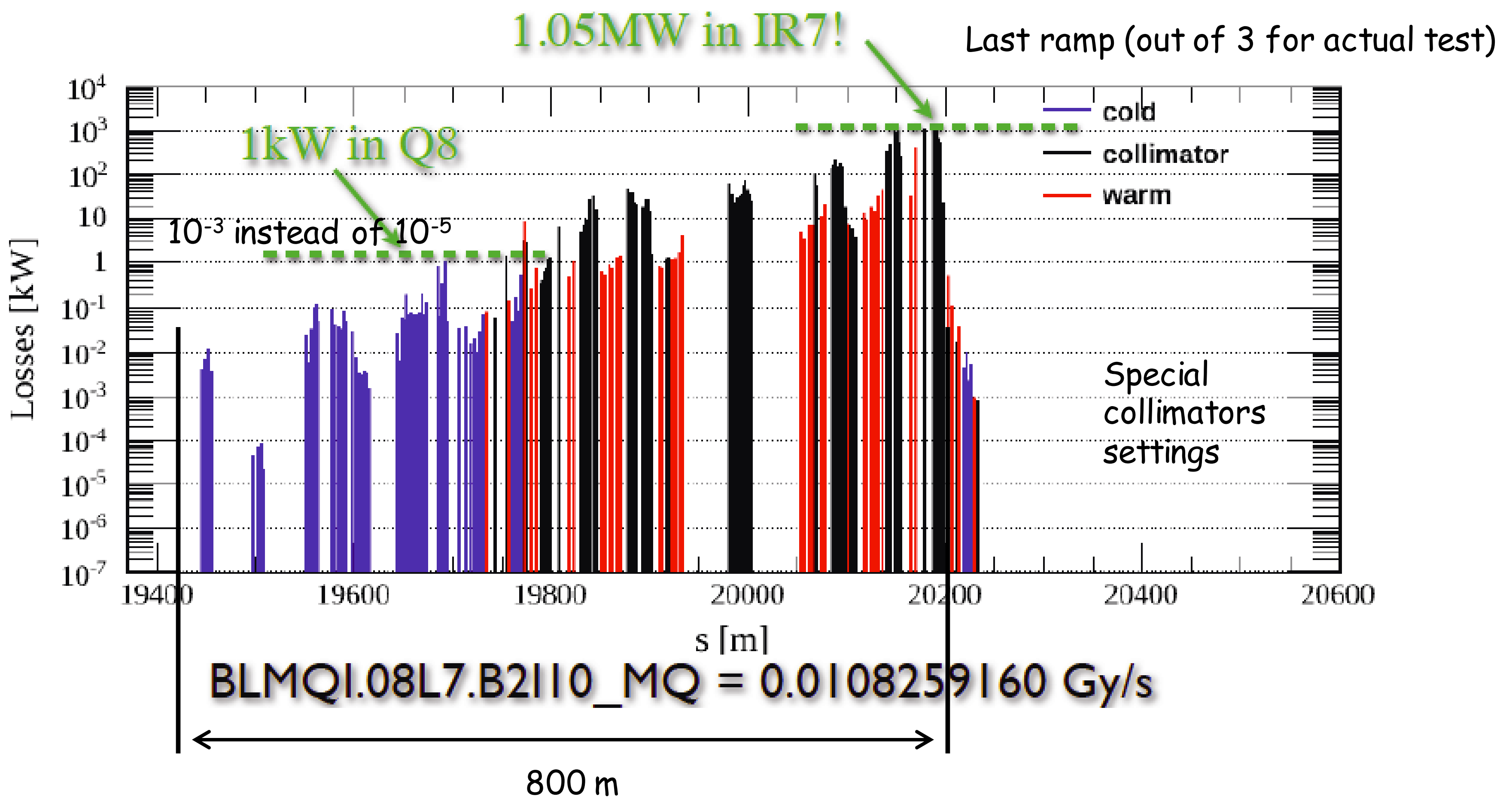


B.Salvachua, R.Bruce, S.Redaelli and D.Wollmann

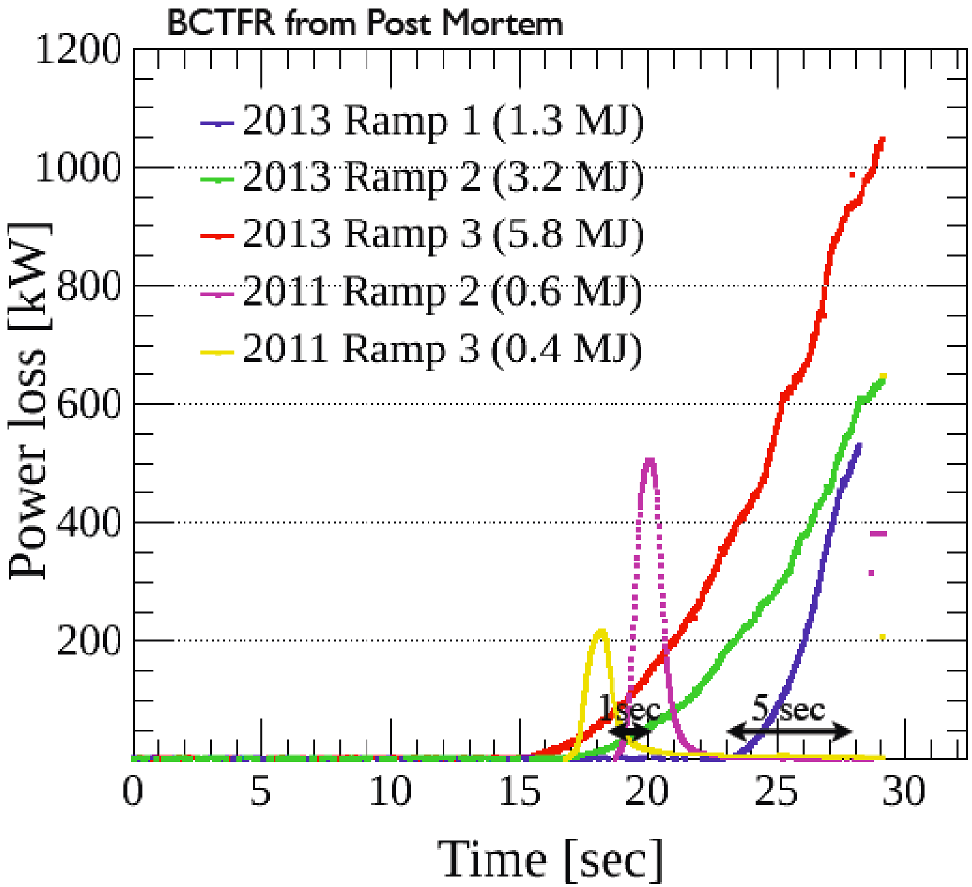
Collimation Group: M.Cauchi, D.Deboy, L.Lari, D.Mirarchi, E.Quaranta and G.Valentino
MP team: R.Schmidt, M.Zerlauth
BLM team: E.Nebot, M.Sapinski, E.B.Holzer
ADT team: W.Hofle and D.Valuch
OP team: J.Wenninger, D.Jacquet

Collimation WG, 25th March 2013

Losses in DS IR7



Comparison to 2011 quench tests



Better control of the blow-up with the ADT:

for the same peak loss rate (~500kW), in 2011 with the tune resonance mechanism the rise time was 1 second while for the ADT could be tuned to 5 seconds. This is important especial for the target power loss of 1MW, the TSI team requested to have a smooth increase of the losses

Ramp 1	520 kW
Ramp 2	650 kW
Ramp 3	1050 kW

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Achieved quench limits

Thanks a lot to Eduardo for all the cross-checks!

BLM thresholds were changed during the test, the table bellow shows the measured losses in Q8 and the BLM threshold during the test

Ramp 3: ~1MW	RS09 = 1.3 s				RS10 = 5.2 s			
	BLM [Gy/]	Threshold [Gy/s]	Ratio Threshold to QL	BLM/ Thresh	BLM [Gy/]	Threshold [Gy/s]	Ratio Threshold to QL	BLM/ Thresh
BLMQI.08L7.B2I10_MQ	1.08E-02	0.035	7.5	0.3	8.42E-03	0.035	21	0.24
BLMQI.08L7.B2I20_MQ	3.81E-03	0.019	3	0.2	2.87E-03	6.90E-03	2.5	0.42

Taking now the assumed quench limit for each monitor the table bellow shows the achieved quench limit for RS over 1.3 sec and 5.2sec

Ramp 3: ~1MW	RS09 = 1.3 s			RS10 = 5.2 s		
	BLM Measurement [Gy/]	Assumed Quench Limit [Gy/s]	Ratio BLM to Quench Limit	BLM Measurement [Gy/]	Assumed Quench Limit [Gy/s]	Ratio BLM to Quench Limit
BLMQI.08L7.B2I10_MQ	1.08E-02	4.65E-03	2.3	8.42E-03	1.67E-03	5.1
BLMQI.08L7.B2I20_MQ	3.81E-03	6.40E-03	0.6	2.87E-03	2.29E-03	1.3

No quench!

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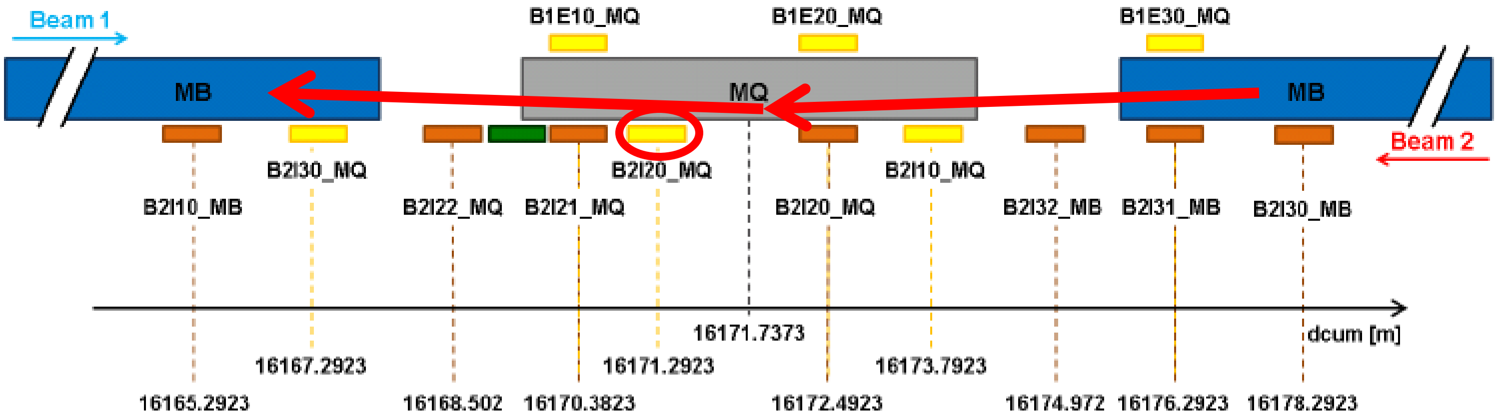
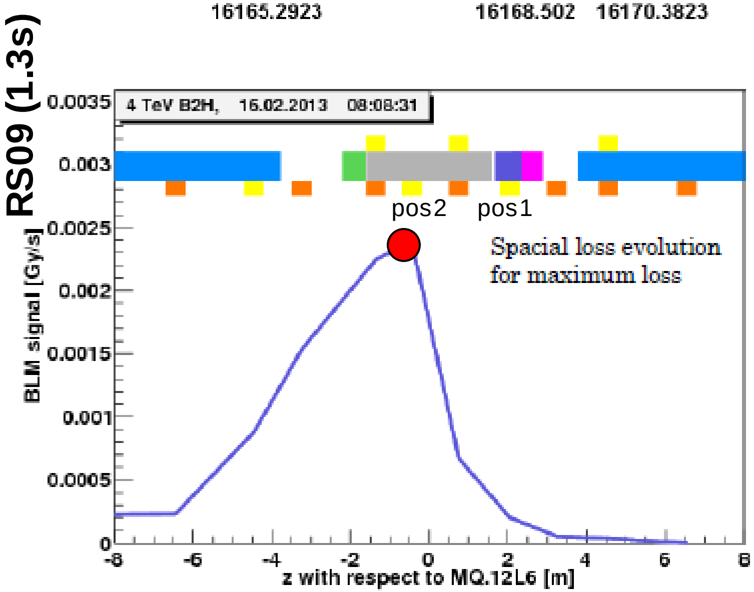
Steady-state with orbital bump (and ADT)

Plots courtesy Agnieszka Preiebe





RS10 (5.2s)

BLM	BLMQI.08L7.B2I20_MQ	BLMQI.12L6.B2I20_MQ
Signal	2.87 mGy/s	2.36 mGy/s
Threshold	2.29 mGy/s	
S/T	1.3	1.03

no quench

quench (as expected!)

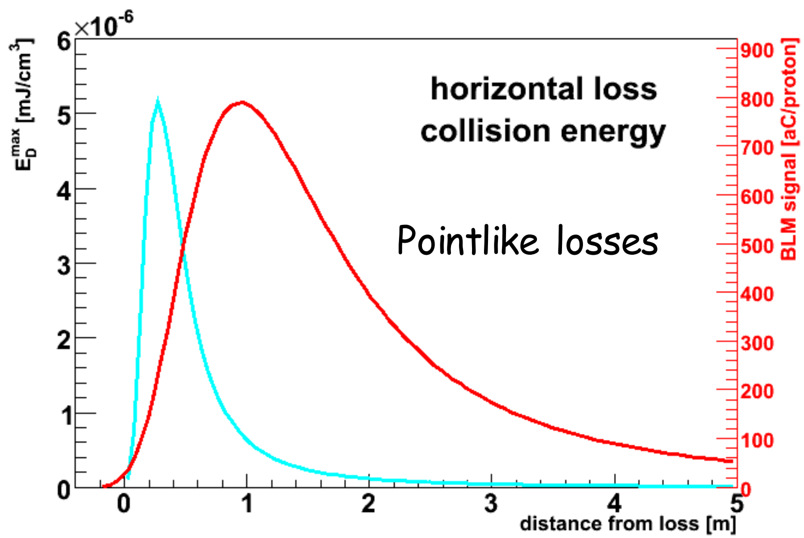
Loss scenario has an important impact on quench level as seen in BLMs.

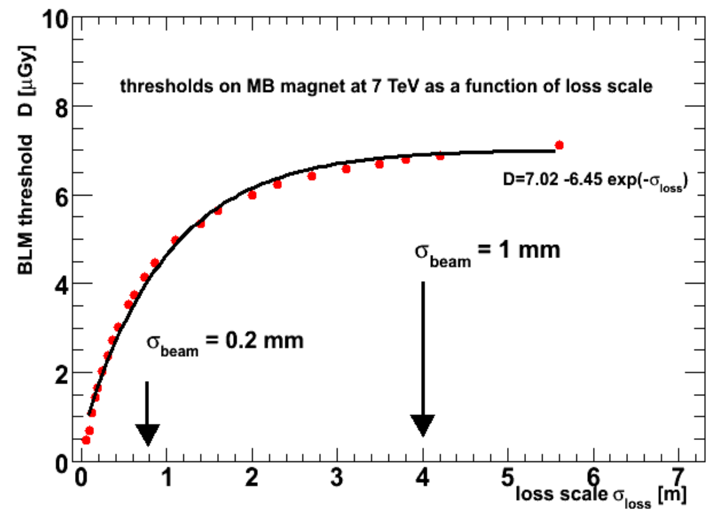
Why is that?

We will need FLUKA/Geant4 simulations to understand this in details

but…

CERN-LHC-Project-Note-422 (2009), MB case:



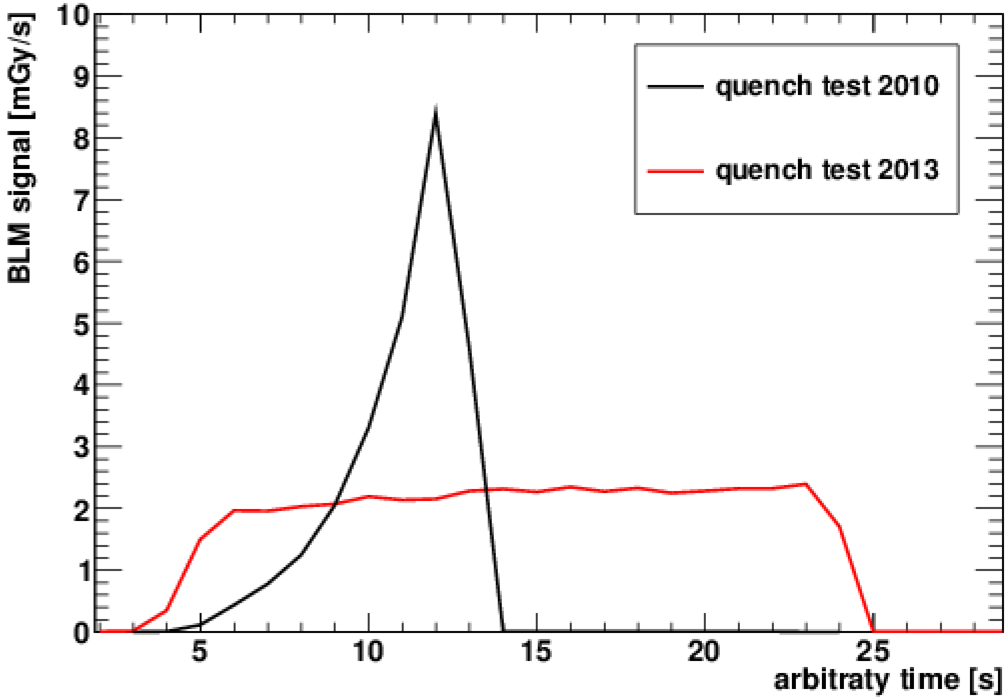


Threshold=QL*BLMsignal / E_{dep}^{coil}

When we smear the loss the amplitude of thinner distribution decreases faster than thicker one.

So more distributed losses lead to higher BLM signal at quench.

The loss rate obtained during this quench exercise was very flat and lasted about 20 s.

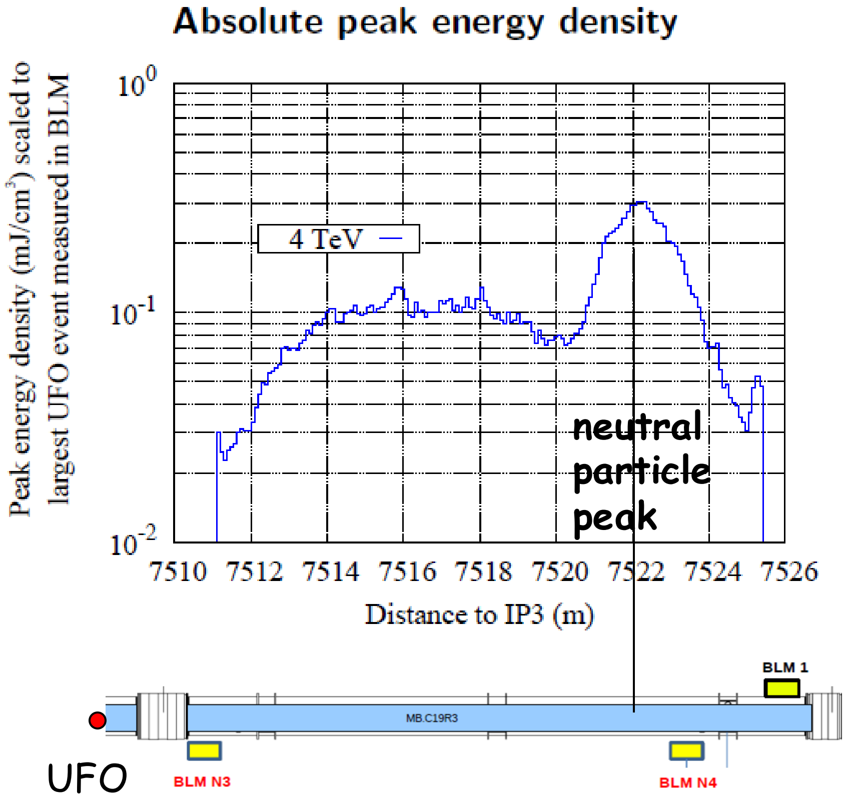


But we must be careful extrapolating to UFOs

- According to simulations (backed up by observations in especially equipped cell) maximum energy deposit is due to **neutral particle peak**.

- Ratio of BLMsignal/E_{dep}^{coil} might be different than in our experiment.

- To make the analysis more challenging the loss pattern during quench test seems to move from turn to turn.



courtesy of Anton Lechner

- Special MAD-X simulations started to understand the time-dependent loss pattern (Vera Chetvertkova).
- FLUKA/Geant4 simulations also necessary