BLMs and thresholds at 6.5/7 TeV

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J. Emery, S. Grishin, E. B. Holzer, S. Jackson, M. Kalliokoski,
A. Lechner, E. Nebot, O. Picha, C. Zamantzas, M. Zerlauch
and other colleagues
(especially QTAWG and BLMTWG participants,
injection team, MPP)

LHC Beam Operation Workshop

Evian, 2-4 June 2014

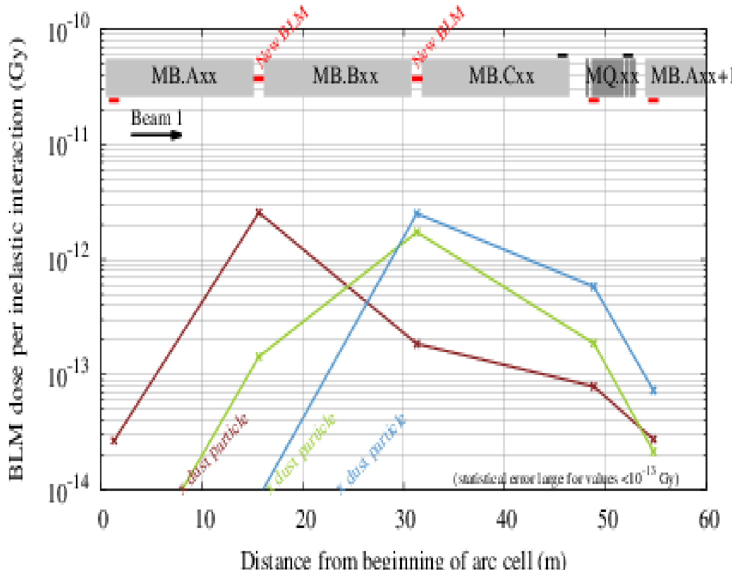
Outlook

1. Hardware changes:
   - Tunnel installation: detector relocation
   - Curing HV issues
   - Other improvements (firmware)
2. Quench test results
3. BLM thresholds for startup
   - Approach
   - New threshold management tool

Hardware changes

Increase availability and reliability, improve protection and diagnostics

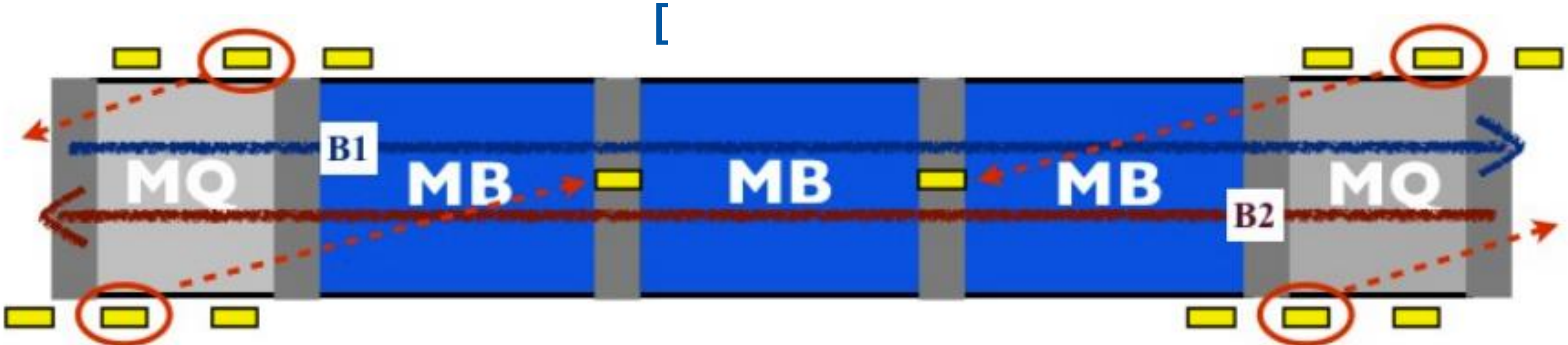
UFO and detector relocation



courtesy A. Lechner

- **BLM system was designed to protect from losses in maximum-beta locations (quadrupoles)**
- **During Run1 there were 3 BLMs per beam per MQ - redundancy**
- **Middle BLMs are moved to MB/MB interconnect in order to protect efficiently from UFO losses (sensitivity x30)**

[



ECR: LHC-BLM-EC-0002, and E. Nebot presentation at MPP workshop

High Voltage issues

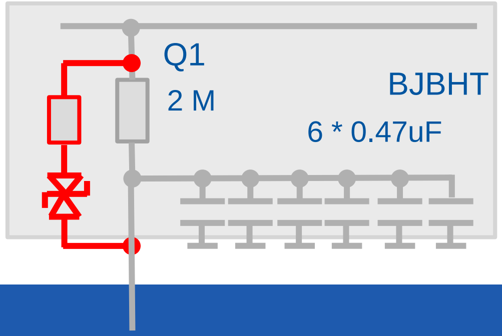
Problem:

for high and long losses (e.g. collimation region) the charge is drawn from the detectors leading to HV drop and decrease/disappearance of the signal.

HV drop is monitored and interlocked via SIS. -> Beam dumps.

Cures implemented during LS1:

1. Decrease of HV beam dump threshold on all monitors (1370 V →950 V)
    - Done by exchange of resistors on tunnel cards (BLECF) in high-loss regions
2. Installation of boxes with suppressor diodes and resistors
    - Limitation of the voltage drop to 220 V



E. Effinger presentation at 73rd MPP, 2012.12.14

Firmware upgrade and other developments (I)

Firmware developments:

- Adapt to MEN A20 CPUs - increase of speed and data transfer rate.
- Long Post-Mortem and UFO Buster data: up to all 43690 samples
- XPOC buffer split by beam if possible
- Increase frequency of Collimation Beam Based Alignment data

To be done

Other works:

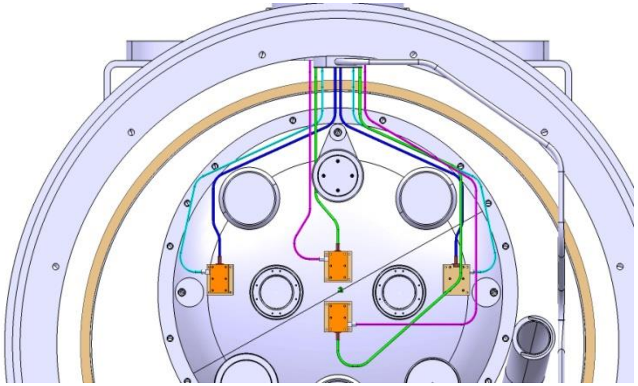
- Temperature-regulated racks
- Exchange of cables – noise reduction on 240 detectors
- Refurbishment and re-check of all cards - availability
- Improvement of Sanity Checks – less interventions

Firmware upgrade and other developments (II)

<u>Beam Loss Observations:</u>

- Many SEMs replaced with LICs (with or without filter): 8 in IR6 to observe dump losses, IR2, IR8, ongoing discussion for IR3 and IR7
- Diamonds in IR2, IR4, IR5, IR7 and IR8 (12 detectors)
- Cryogenic BLMs – test setup in IP 5 and 7

(ECR: LHC-LB-EC-0003)



Full list of improvements: see

C. Zamantzas talk at MPP workshop (2013)

Quench test results

Motivation, summary of experiments, most important results

LHC beam-induced quench tests

General:
IPAC14-MOOCB01
CERN-ATS-2013-049

1. 2008 – first "tests" at injection (CERN-LHC-Project-Note-422)
2. 2010 – first campaign:
   - wire scanner (CERN-ATS-2011-062)
   - steady-state at 450 GeV and at 3.5 TeV (CERN-THESIS-2014-013)
3. 2011 – collimation tests:
   - May – protons, 500 kW reached (CERN-ATS-Note-2011-042-MD)
   - July - Q6 test up to 2300 A (CERN-ATS-Note-2011-067 MD, CERN-ATS-2012-209)
   - December – Ions (CERN-ATS-Note-2012-081-MD)
4. February 2013 – second campaign:
   - IR7 Collimation up to 1 MW (IPAC14)
   - Q6 (IPAC14-WEPRI092)
   - Orbit bump with fast beam excitation (CERN-ATS-2013-048, IPAC14, +)
   - Orbit bump with steady-state beam excitation (IPAC14-MOPRO019)

precise loss control thanks to ADT

Why do we do quench tests?

Beam-Induced Quenches (BIQ):

HERA: 205 BIQ in 10 years of operation

RHIC run 12 (24 weeks): 18 BIQ on main "QPS" (same for Run 13)

Tevatron: 154 BIQ in 2007-2011

LHC Run1: 4-8 BIQ, all at injection

LHC was running at half of the designed magnet current, and this will change.

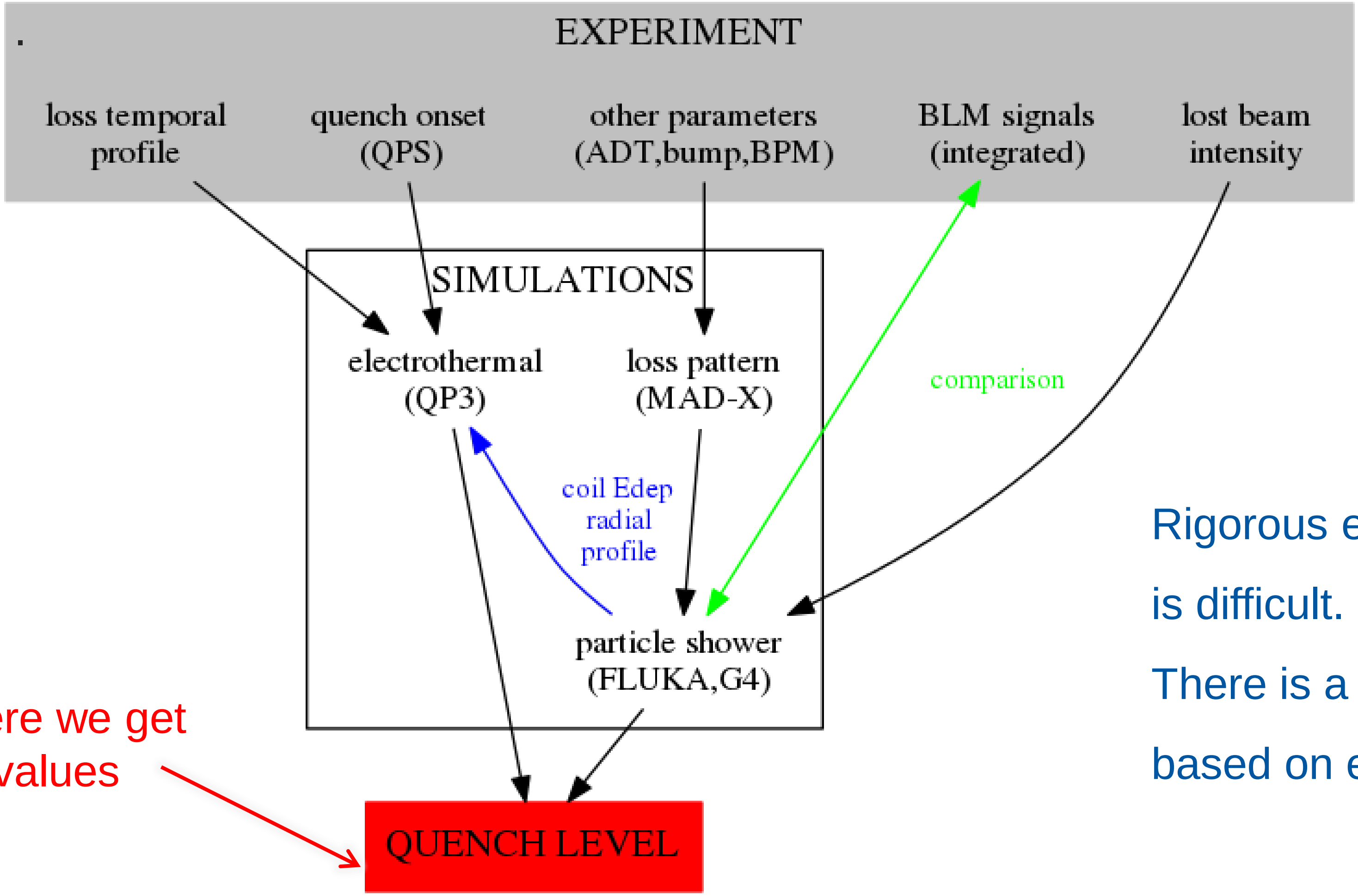
Quench tests allow to:

1. verify BLM thresholds on cold magnets ⟷ instantaneous result (but very approximate)
2. validate particle shower and electro-thermal models ⟷ months of works

Operational quenches are also sources of knowledge and experience.

Analysis strategy

Illustration of analysis procedure



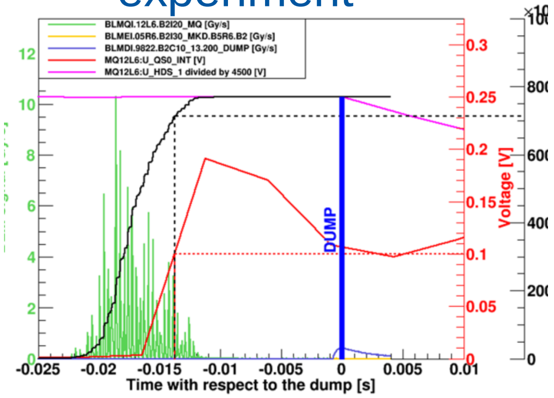
here we get 2 values

Rigorous error estimation is difficult.

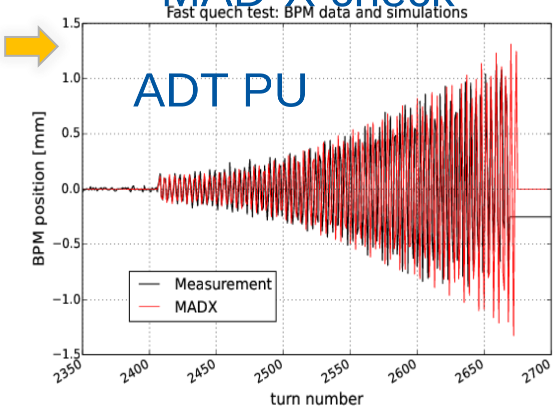
There is a good intuition based on experience.

Example: millisecond quench test

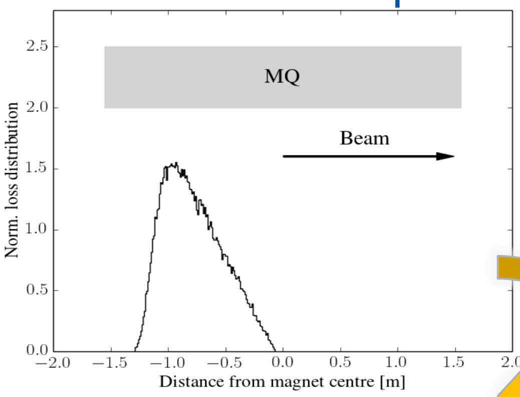
experiment



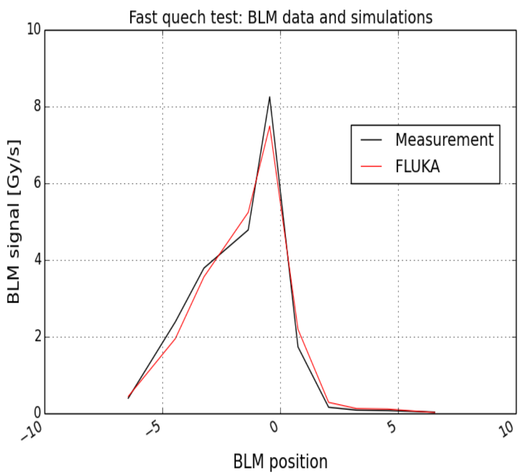
MAD-X check



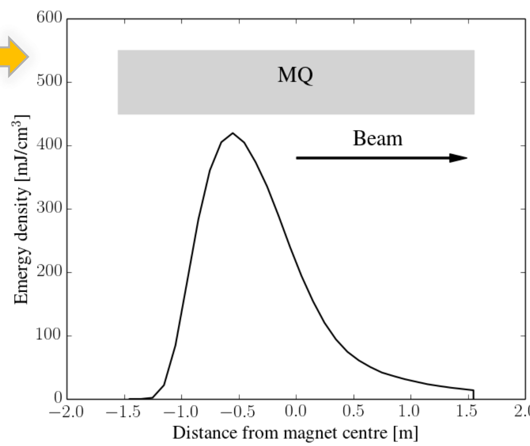
MAD-X output



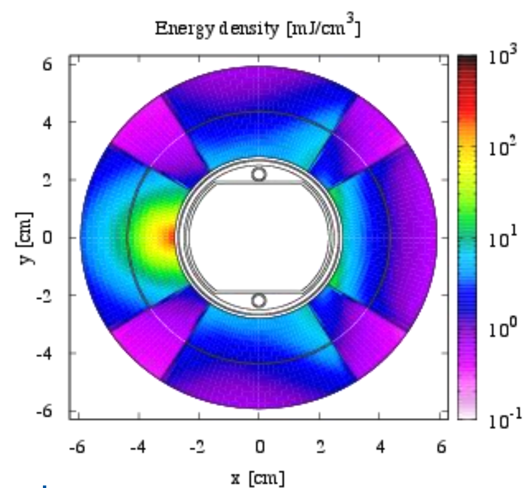
FLUKA check



FLUKA output



FLUKA output→QP3



Plots by A. Priebe, V. Chetvertkova, N. Shetty, A. Lechner

Main results of quench tests

1. Removing measurement uncertainties and
   better **understanding** of **electro-thermal** properties of coils.
2. **Understanding** the **loss patterns** due to: beam excitations, orbit bumps, emittance blow, etc.
3. Understanding the limits of BLM to resolve loss patterns.
4. :

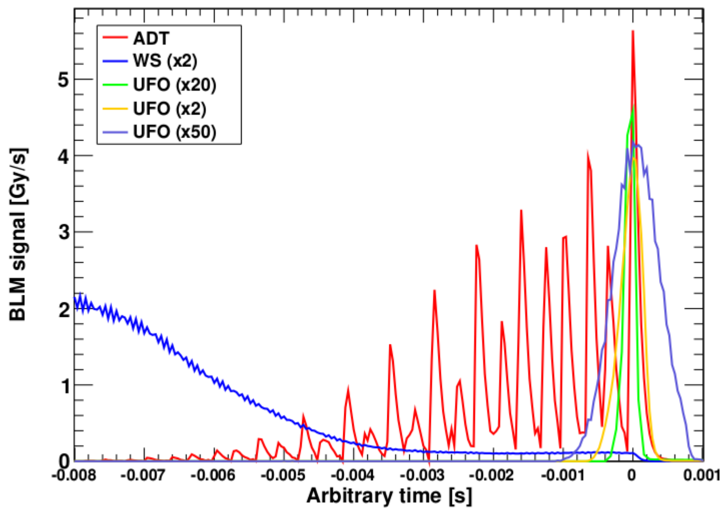
Beam energy	Loss duration	Experiment+ FLUKA	QP3	Run1 (initial)
4 TeV	~ 5 ms	198-400 [mJ/cm^3]	58-80 [mJ/cm^3]	40 [mJ/cm^3]
4 TeV	20 s	41-69 [mW/cm^3]	74-92 [mW/cm^3]	20 [mW/cm^3]

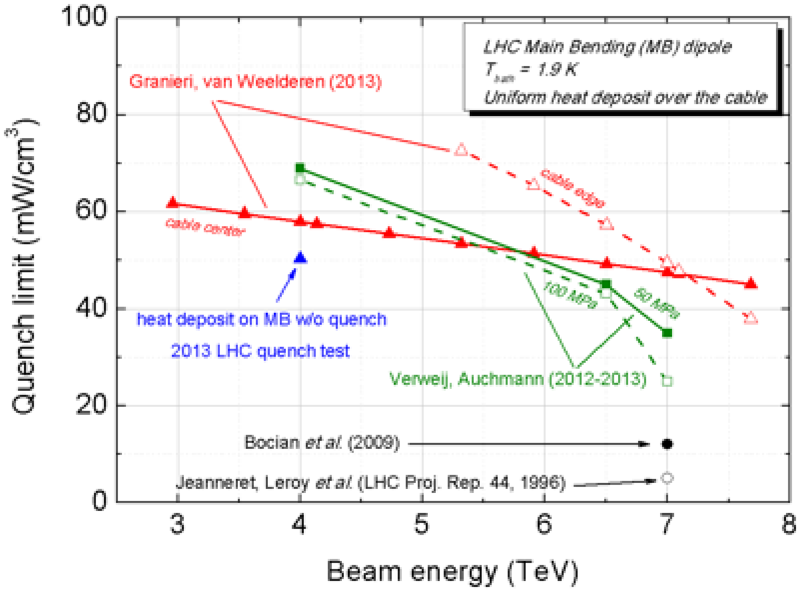
Several IPAC papers and a peer-reviewed publications are prepared,

Beam Induced Quench workshop is planned for September (before Chamonix).

Quench tests: towards BLM thresholds

1. UFO-timescale quench limit:
   - difficult experiment, not reached UFO loss parameters: loss duration, loss time structure, neutral peak.
   - discrepancy experiment-model, probably due to difference between spiky and continuous losses.
2. Steady-state quench limit:
   - Results more optimistic than previously assumed, especially at 7 TeV
3. QP3 has been validated, but empiric factors for thresholds must be used.
4. Expect quench test requests for Run2





BLM thresholds for startup

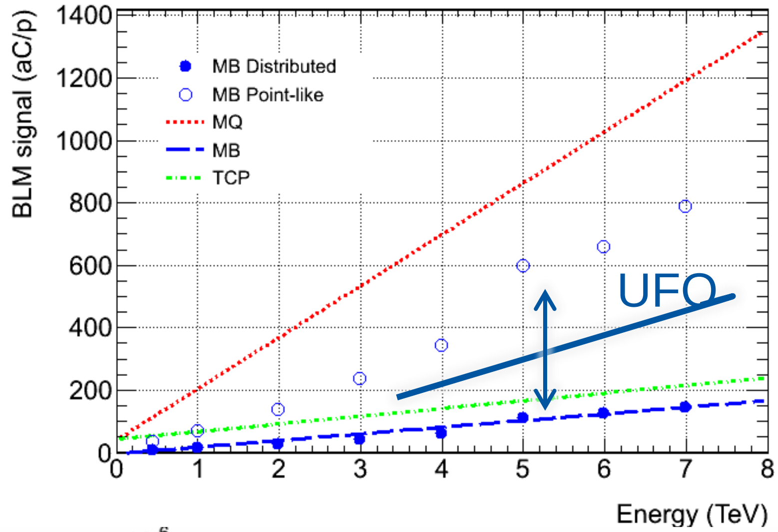
Present situation, strategy for startup, new tool

Recalculation of thresholds

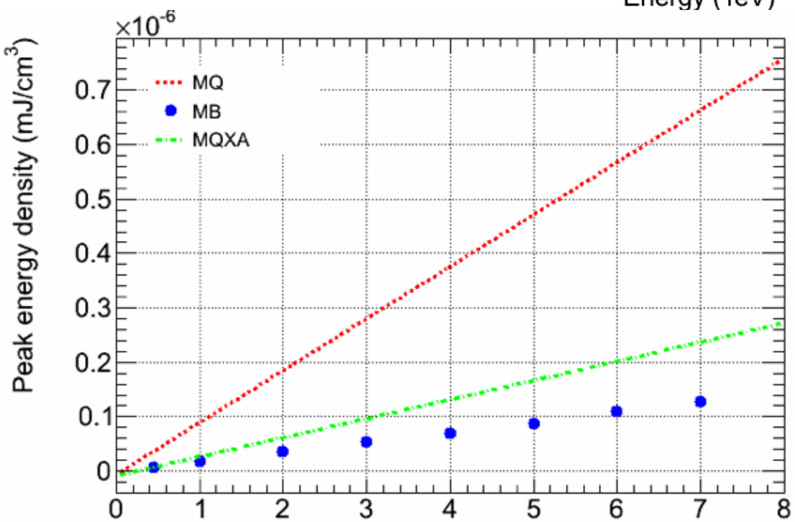
1. Initial settings (2009) of thresholds was based on a VERY FEW simulations (Geant4, Sixtrack) and a lot of scientific guesses.
2. The thresholds were fine-tuned over Run 1 and they are very well established for beam energy up to 4 TeV.
3. But the underlying models are not always correct (factors x5, /3, etc).
4. Thresholds are not validated for beam energies above 4 TeV.
5. Work is ongoing, working group very active.
6. There will be a presentation B. Auchmann, O. Picha at MPP end of June:
   - one threshold case will be shown

BLM threshold session foreseen at BIQ workshop in September.

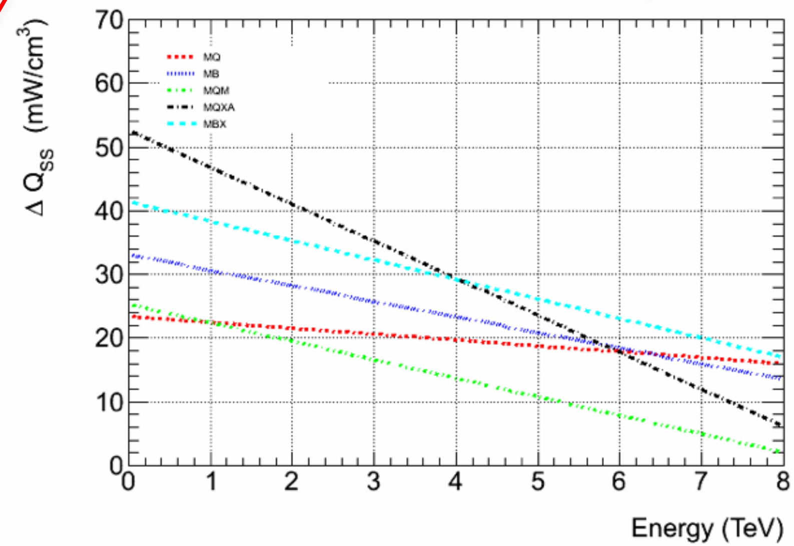
Underlying models



$$T = \frac{S_{BLM}(E_{beam})}{E_{coil}(t, E_{beam})} \, QL(t, E_{beam})$$

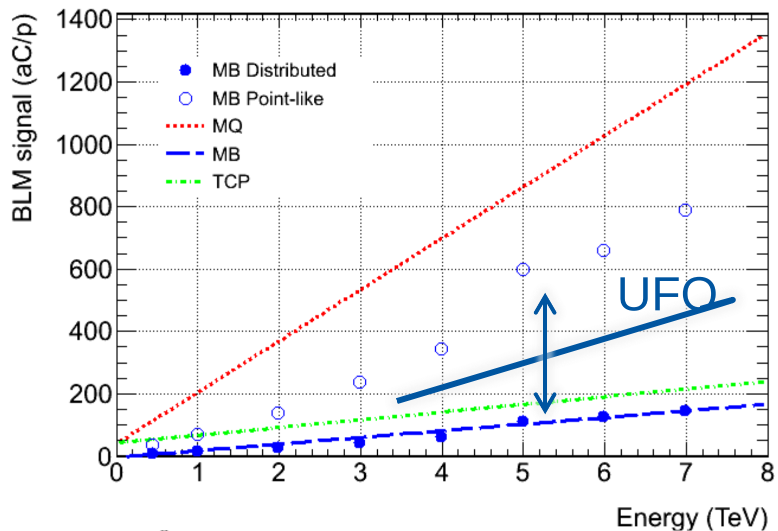


from LHC-BLM-ES-0002

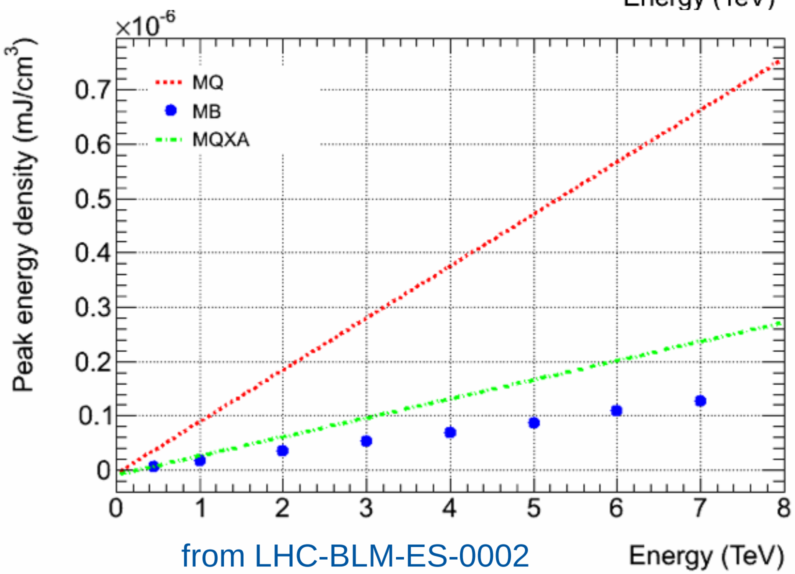


$$T' = \frac{3S_{BLM}}{9E_{coil}} \, 3QL = T$$

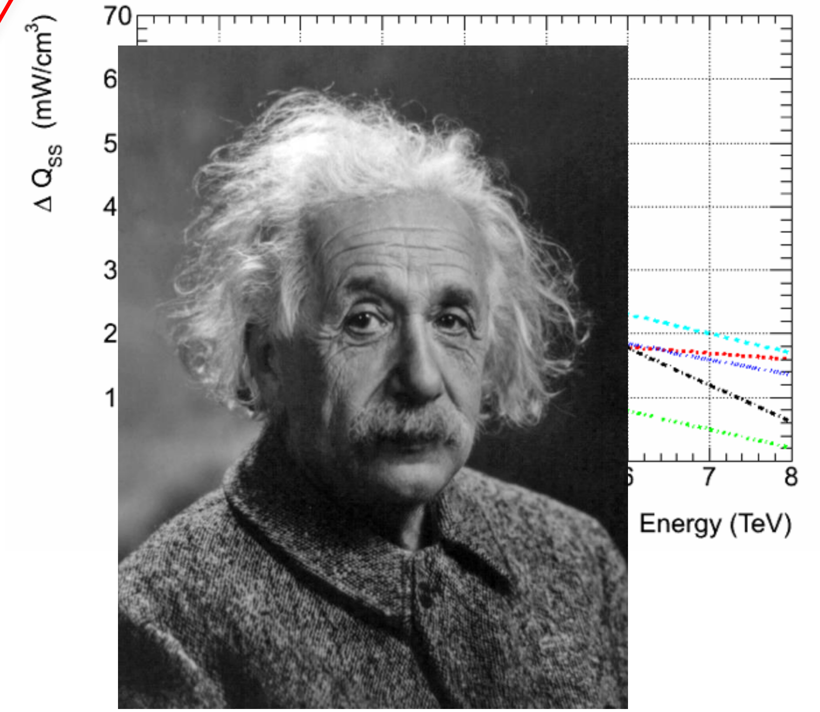
Underlying models



$$T = \frac{S_{BLM}\left(E_{beam}\right)}{E_{coil}\left(t, E_{beam}\right)} QL\left(t, E_{beam}\right)$$



from LHC-BLM-ES-0002

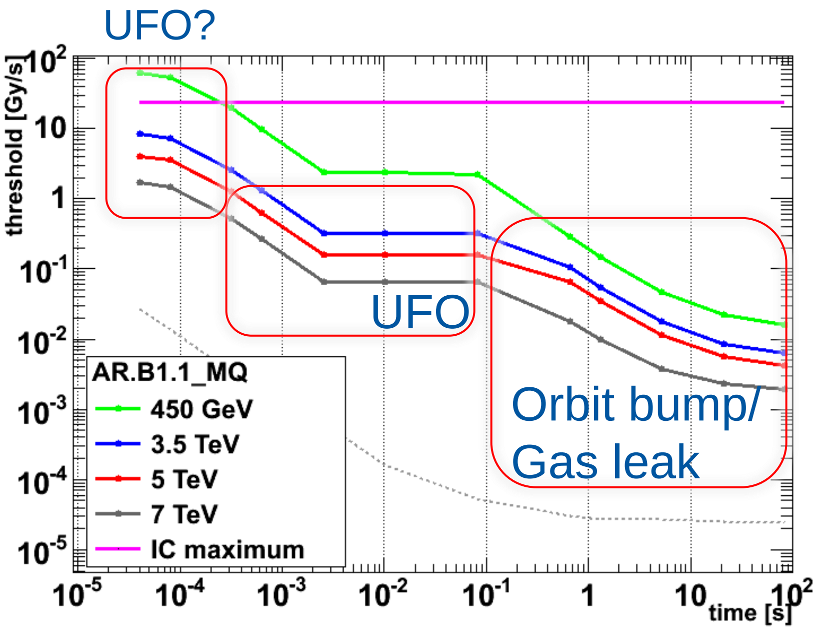


Not as bad as tuning cosmological constant by 10^{120}

Example of possible approach – arc BLMs

1. Choice of loss scenarios: (orbit bump/gas leak)+(UFO)+(tbd)
2. FLUKA simulation:
   - Edep in coil (Edep)
   - BLM signal (BLMs)
3. QP3 calculation using

   Edep in coil from FLUKA



Current tools do not allow different

loss scenarios for one family!

- this will be changed.

Preliminary plan for thresholds

1. Check minimum thresholds at 6.5/7 TeV as done previously (see for instance BLM talk at Evian 2010) - ongoing
2. Reduce number of families (unnecessary complexity) - ongoing
3. Base new thresholds on FLUKA+QP3+ONE correction factor, where correction is defined by quench test and operational experience - ongoing
4. Compare new thresholds with old ones at 3.5/4 TeV
5. Be ready to introduce empirical corrections during the Run 2.

- QP3 is ready to generate quench limit tables.
- A lot of FLUKA simulations still need to be done. (a lot done already!)

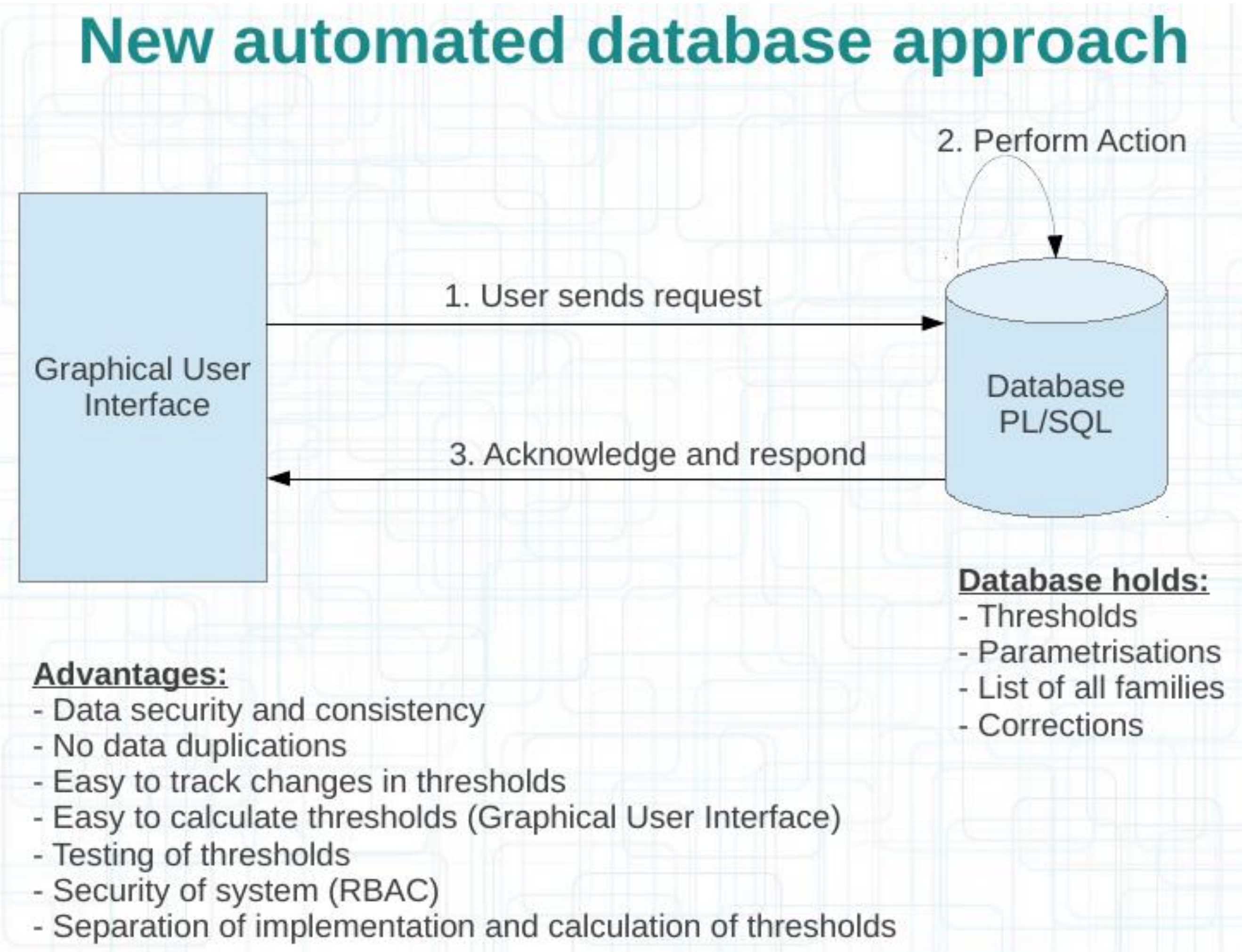
LSA-based threshold generation application

Towards reliability and safety (and less flexibility).

<u>During Run1:</u>

- threshold generation has been performed using C++ program
- Obtained threshold tables (ASCII files) send to LSA using special GUI
- Program code, configuration files - stored in svn
- Threshold files as well
- No RBAC mechanism allowing only tracking the modifications of configuration files. (but svn has a history)

LSA-based threshold generation application



Proposal:
M. Nemecic,
E. Nebot

Implementation:
C. Roderick,
M. Sobieszek,
S. Jackson (GUI)

Now testing phase:
M. Kalliokoski

Summary and Conclusions

1. A series of hardware improvements and developments to protect from new loss scenario, increase system reliability, availability and diagnostic potential.
2. Quench tests gave optimistic results for both UFO and Steady-State losses and multiplied our knowledge about electro-thermal properties of coils and about loss patterns.
3. Work to improve BLM thresholds is ongoing, however empirical factors will remain part of the procedure.

Thank you for your attention!

Spare slides

Can we increase BLM thresholds for UFO?

1. Assume the at 7 TeV we have the same threshold underestimation as at 4 TeV

Measured BLM signal/Expected BLM signal at quench [-]									
B	Lost p^+	ADT gain [%]	BLM loss integration time [s] $40\cdot10^{-6}$	$80\cdot10^{-6}$	$320\cdot10^{-6}$	$640\cdot10^{-6}$	$2.56\cdot10^{-3}$	$10.24\cdot10^{-3}$	Q
2	$1.9\cdot10^8$	400	2.60	1.92	0.91	1.26	2.91	2.99	no
3	$2.0\cdot10^8$	400	2.15	1.75	0.86	1.27	2.93	3.06	no
4	$2.0\cdot10^8$	200	0.75	1.59	0.30	0.55	1.60	2.57	no
5	$4.0\cdot10^8$	200	1.78	1.30	0.63	1.05	3.20	6.60	no
6	$8.2\cdot10^8$	200	2.77	2.34	1.20	2.06	6.06	12.00	yes

2. In optimal position further increase by 3-6 possible, but:

- -50% because of most distant UFO location
- -X% because of spiky loss structure
- -Y% because UFOs are shorter (smaller quench level)

Injection losses – avoiding dumps

Problem:

Injection losses are very high (particle shower directly from injection line).

- Many BLMs register very high signal, above measurement range.
- Interlocked BLMs dump the circulating beam.

Solutions:

- Install Little Ionization Chambers (LIC) with measurement upper range increased by factor 10.
- Install LIC+filter for range increase by 200.
- Prepare to introduce option of blinding some monitors at injection.

.Status:

New racks installed, monitors regrouped, firmware upgrade to be decided later.

See Wolfgang's presentation

Injection blind

Inputs defined as “blind-able”:

- Maximum 8 per card
- Signal cables shall not be to long
- 3 cards in IP2 and 2 in IP8
- One blindable surface crate per IP2/8
- At startup – not blinded (so thresholds should allow for injection losses)

Collimation thresholds

Device	Location	Beam Energy	t > 10s	1s < t < 10s	t < 1s
			$dN_{>10}/dt$ [p/s]	dN_{1-10}/dt [p/s]	$N_{<1}$ [p]
TCP	IR3	450 GeV	1.20E+12	6.00E+12	6.00E+12
TCP	IR3	7 TeV	8.00E+10	4.00E+11	4.00E+11
TCP	IR7	450 GeV	1.20E+12	6.00E+12	6.00E+12
TCP	IR7	7 TeV	8.00E+10	4.00E+11	4.00E+11
TCSG	IR3	450 GeV	1.20E+11	6.00E+11	6.00E+11
TCSG	IR3	7 TeV	8.00E+09	4.00E+10	4.00E+10
TCSG	IR7	450 GeV	1.20E+11	6.00E+11	6.00E+11
TCSG	IR7	7 TeV	8.00E+09	4.00E+10	4.00E+10
TCLA	IR3	450 GeV	6.00E+08	3.00E+09	3.00E+09
TCLA	IR3, IR7	7 TeV	4.00E+07	2.00E+08	2.00E+08
TCLA	IR7	450 GeV	6.00E+08	3.00E+09	3.00E+09
TCLA	IR3, IR7	7 TeV	4.00E+07	2.00E+08	2.00E+08
TCTH, TCTVA, TCTVB	IR1, IR2, IR5, IR8	450 GeV	6.00E+08	3.00E+09	3.00E+09

Initial settings:
EDMS 995569

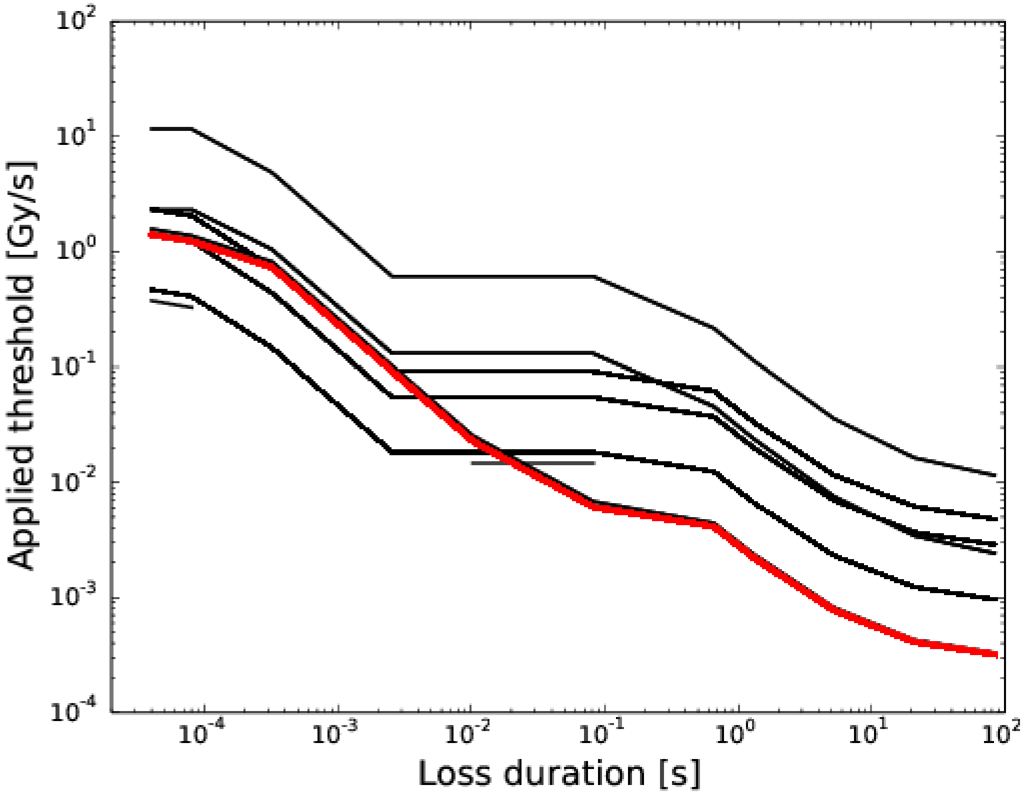
Start with current thresholds allowing 200 kW loss – should be ok for 7 TeV.
Need to make loss maps ASAP, and adjust thresholds accordingly.

Why do we do quench tests?

1. To find at what BLM signal we shall dump the beam in order NOT to quench?
2. The relation quench and BLM signal is ambiguous, for instance:
3. Collimation quench test: no quench with BLM signal (BLMQI.08L7.B2I20_MQ) of 2.87 mGy/s (RS10).
4. Orbit bump quench test: quench at BLM signal (BLMQI.12L6.B2I20_MQ) of 2.36 mGy/s (RS10).
5. Differences:
   - Time profile
   - Loss pattern
6. We also want to extrapolate quench test results to 7 TeV
7. We need a model! And we need to falsify it and this is the main reason for quench tests. Based on this model the thresholds are set.

3.5 TeV applied threshold evolution on arc

1. Retrieved from Logging db from 2009:



Results of quench tests

1. Tuning of QP3 code (not only tuning parameters but also better understanding some aspects of physics)
2. Understanding of local loss patterns due to fast beam excitations, orbit bumps, emmitance blow
3. Understanding the “spatial resolution” of BLM signals (in reconstruction of beam loss patterns).

TABLE IX. Overview of the presented analyses. LB/QL and UB/QL are the ratios between, respectively, the lower and upper bounds from FLUKA, and the estimated quench levels. For consistency, LB/QL should be below 1 and UB/QL above. Bold font indicates inconsistencies.

Regime	Method	Type	Temp. [K]	I/I_{nom} [%]	LB/QL	UB/QL	Comment
short	kick	MB	1.9	6	n/a	$\mathbf{0.47}^{+0.19}_{-0}$	Tracking uncertainty.
short	collimation	MQM	4.5	46/58	**1.45**	1.94	Saturated BLM signals. No FLUKA validation.
intermediate	wire scanner	MBRB	4.5	50	$0.48^{+0}_{-0.21}$	$\mathbf{0.71}^{+0.44}_{-0}$	Timing uncertainty. Quench in ends. UB for $N_q/N_w = 45\%$.
intermediate	wire scanner	MQY	4.5	50	0.96	n/a	No upper bound.
intermediate	orbit bump	MQ	1.9	54	$\mathbf{2.79}^{+0.46}_{-?}$	$4.31^{+0.7}_{-?}$	Timing uncertainty. Nucleate boiling? UB for $N_q/N_p = 62\%$.
steady-state	collimation	MB	1.9	57	$0.36^{+0}_{-0.08}$	n/a	Peak loss in magnet ends. Cooling. Moderate FLUKA agreement with BLM signals. No upper bound.
steady-state	orbit bump	MQ	1.9	54	$0.33^{+0.36}_{-0}$	$\mathbf{0.47}^{+0.52}_{-0}$	Sensitivity to surface roughness. Cooling.
steady-state	dyn. orbit bump	MQ	1.9				Cooling.

Quenches – Run1

Table 1: List of beam-induced quenches

No	date	beam energy [TeV]	loss duration	quenched magnet	location	remark
1	2008.08.09	0.45	$\sim$ ns	MB	8L3	beam setup
2	2008.09.07	0.45	$\sim$ ns	MB	10R2	beam setup
3	2009.11.20	0.45	$\sim$ ns	MB	12L6	beam setup
4	2009.12.04	0.45	$\sim$ ns	MB	15R2	beam setup
5	2010.04.18	0.45	$\sim$ ns	MB+	20R1	wrong main quad current
6	2010.10.06	0.45	1s	MQ	14R2	quench test
7	2010.10.06	0.45	1s	MQ	14R2	quench test
8	2010.10.06	0.45	1s	MB	14R2	quench test
9	2010.10.17	3.5	6s	MQ	14R2	quench test
10	2010.11.01	3.5	10 – 40ms	MBRB (4.5 K)	5L4	quench test
11	2011.04.18	0.45	$\sim$ ns	MB+	IP8	kicker flashover
12	2011.07.04	0.45	$\sim$ ns	MB	14R2	test
13	2011.07.28	0.45	$\sim$ ns	MQXB+	IP2	injection oscillations
14	2012.04.15	0.45	$\sim$ ns	MB+	IP8	kicker flashover
15	2013.02.15	0.45/6	$\sim$ ns	MQM (4.5 K)	6L8	quench test
16	2013.02.15	4.0	5 – 10ms	MQ	12L6	quench test
17	2013.02.16	4.0	20s	MQ	12L6	quench test

Sensitivity and Dynamic Range

Sensitivity Range		Relative Sensitivity
A	IC	1
B	LIC	1 / 14
B	IC + SF (small filter)	1 / 20
C	LIC + SF	1 / 280
C	IC + BF (big filter)	1 / 180
D	LIC + BF	1 / 2520
E	SEM	1 / 70000

SEM	3k Gy/s (from dump region)	1.6 MGy/s
LIC+big filter	~1 Gy/s (from septum LICs in 2012)	58 kGy/s
IC	~5E-2 Gy/s	23 Gy/s

CERN

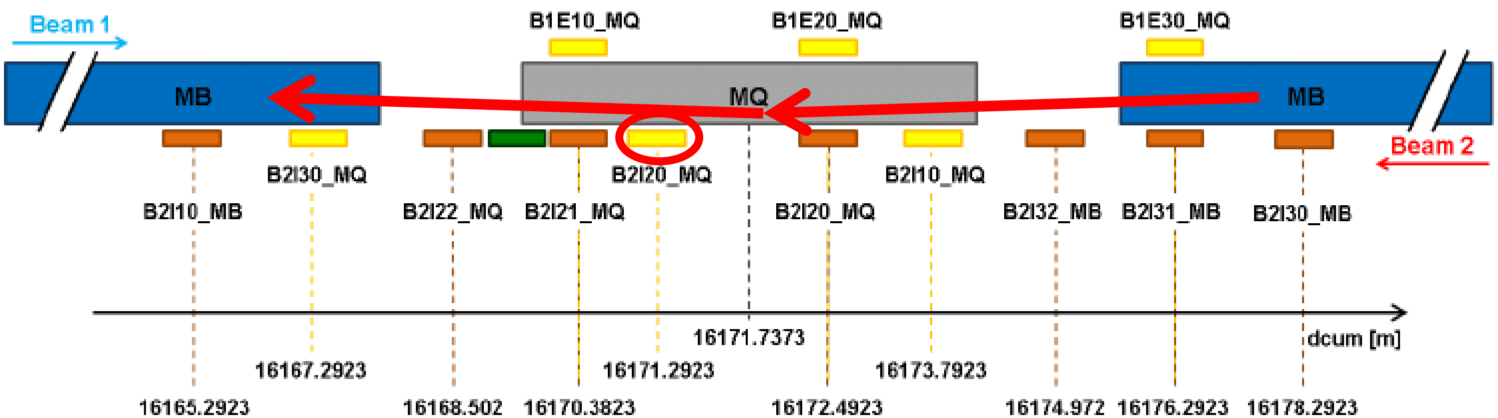
Injection losses measurements

- SEM are replaced by LIC+BF: **total # 83**
  - at the same location as an IC with/without filter
  - not connected to BIS (measurement only)

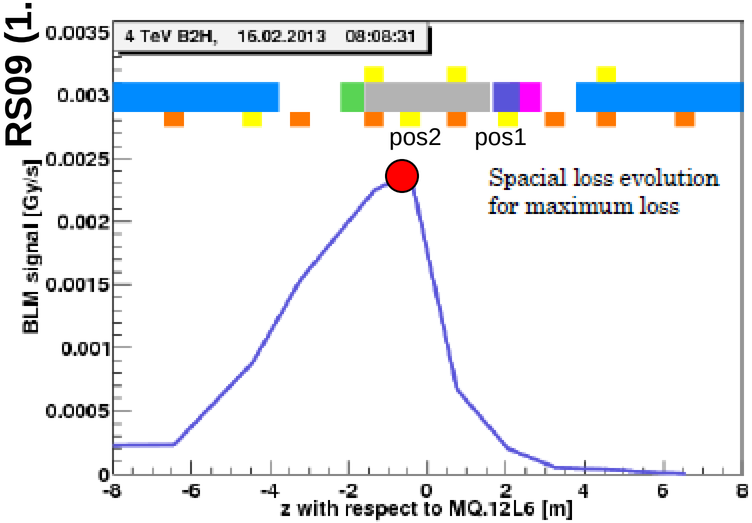
		IP2 left	IP8 right	IP2 right	IP 8 right
MBA, MBB	cell 11	6	6	6	6
MBA, MBB	cell 8	6	6	6	6
MSIA, MSIB	cell 6	6	6	-	-
TCLIB	cell 6	-	-	1	1
TDI	cell 4	3	3	-	-
TCTH	cell 4	1	1	1	1
TCTV	cell 4	1	-	1	
TCDD	cell 4	1	-	-	
TCLIA	cell 4	-	-	1	1
“DRIFT”	cell 4	-	-	1	
BPMSW	cell 1	1	1	1	1

Steady-state with orbital bump (and ADT)

Plots courtesy Agnieszka Preiebe



RS09 (1.3s)



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

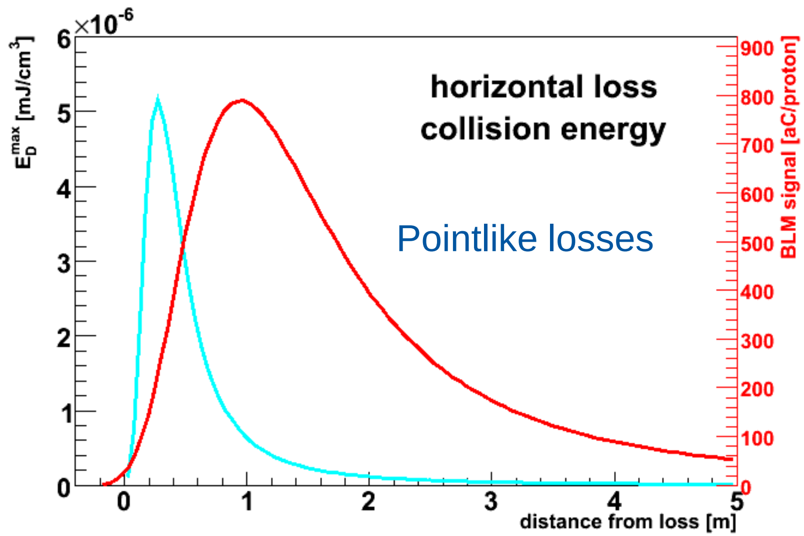
quench (as expected!)

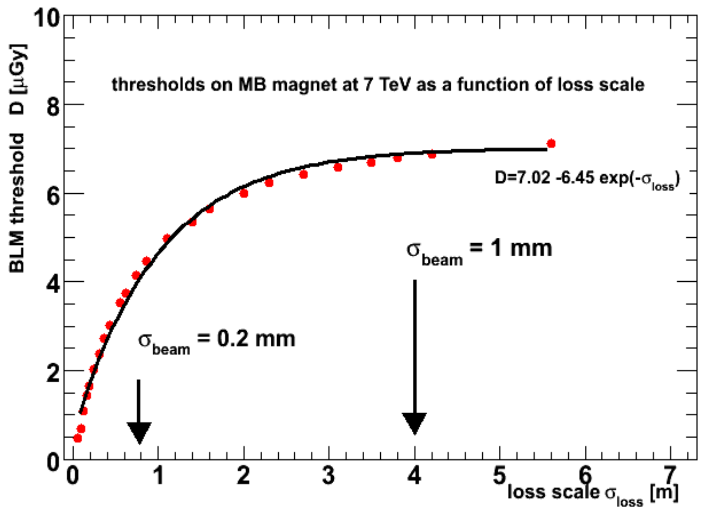
Loss scenario has an important impact on quench level as seen in BLMs.

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.

HERA (from Kay Wittenburg)