Status of Quench Tests Analyses

Mariusz Sapinski for **Quench Tests Strategy → Analysis Working Groups** (QTAWG)

LBOC, 2013.10.22

Outlook

- Quench tests considered
- Analyses: common approach
- Description of tests
- Summary of work progress
- Summary of current results
- Documentation, paper
- Conclusions

Quench tests

Analyses focused on 6 quench tests at energies ≥ 3.5 TeV

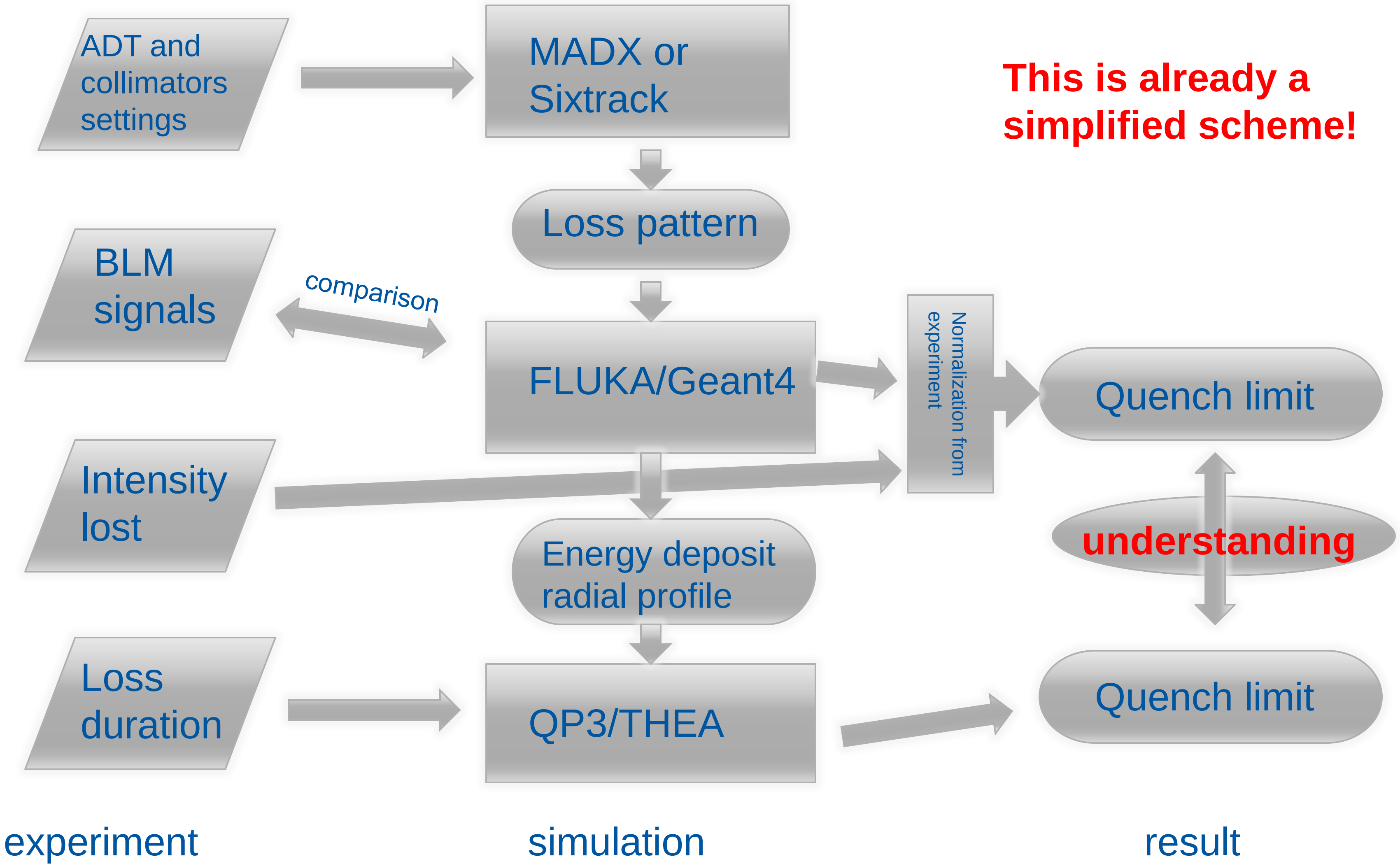
- Total number of beam-induced quenches: 17
- Tests at 450 GeV (or injection failure quenches) mostly already investigated in the past and less critical.

No	date	name	duration
1	2010-10-17	Dynamic orbit bump quench test	5 s
2	2010-11-01	Wire scanner quench test	10 ms
3	2013-02-15	Collimation quench test	5 s
4	2013-02-15	Q6 quench test	~ns
5	2013-02-15	ADT fast loss quench test	5 ms
6	2013-02-16	ADT steady state loss quench test	20 s

Analysis: common approach

- Key measurements:
  - Beam intensity – the actual number of protons to quench the magnet
  - BLM signals – control of simulation accuracy
  - Synchronization QPS/BLM
- Simulations:
  - MADX or Sixtrack (or not needed eg. wire scanner qt)
  - FLUKA and Geant4
    (only for some tests, special approach)
  - QP3 and THEA/0-D
    (heat transfer codes)

Analysis: common approach



1. Dynamic orbit bump quench test

Steady state – 5s

Performed: October 17th, 2010, Ebeam=3.5 TeV
Method: beam kicked towards MQ14R2 aperture using rising orbit bump

• Data analysis	done
• MADX simulations	not yet
• Geant4/FLUKA simulation	partly
• QP3/THEA	partly

Publications:
- A. Priebe et al.,*Beam-induced quench test of LHC main quadrupole*, CERN-ATS-2011-058
- A. Priebe et al., *Investigations of Quench Limits of the LHC Superconducting Magnets*, IEEE Transactions on Applied Superconductivity, Vol: PP, Issue: 99 (2012)

Comment: ADT steady state loss quench test (2013) provided similar loss in much better controlled conditions

2. Wire scanner quench test

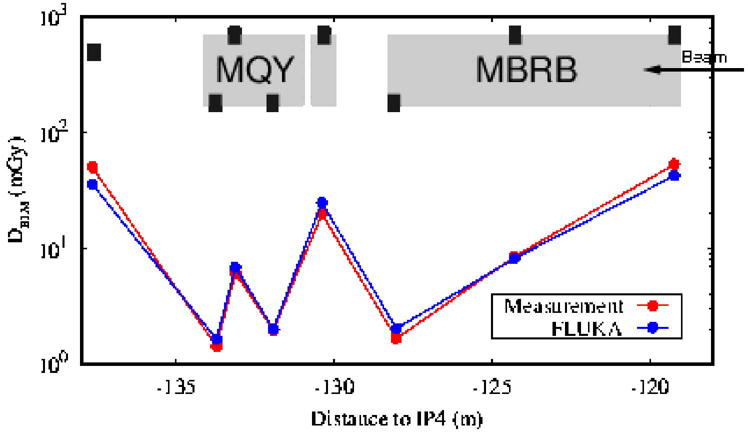
UFO – 10 ms

Performed: November 1st, 2010, Ebeam=3.5 TeV
Method: slow down wire scan until downstream magnet (D4) quenches

- Data analysis — done
- MADX simulations — not needed
- FLUKA simulation — done
- QP3 — done
- 0-D — done

Publications:

• M. Sapinski et al., *LHC magnet quench test with beam loss generated by wire scan* , CERN-ATS-2011-062

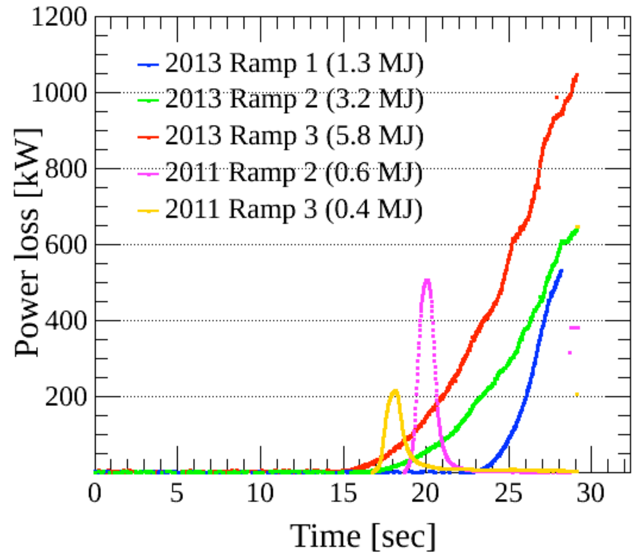


3. Collimation quench test

Steady state – 5s

Performed: in 2011 (also with ions), 3 attempts in 2013, Ebeam=4TeV
Method: by special collimator settings spoil cleaning efficiency and quench magnet by leakage from collimation system
Result: no quench even with 1 MW losses on collimators!

- Data analysis — done
- Sixtrack simulations — done
- FLUKA simulation — done
- QP3/THEA — done



Comment: this is a normal loss scenario (not a failure) – it defined machine limits!
Publication: D. Wollmann et al., *Collimator losses in the DS of IR7 and quench test at 3.5 TeV*, CERN-ATS-Note-2011-042 MD

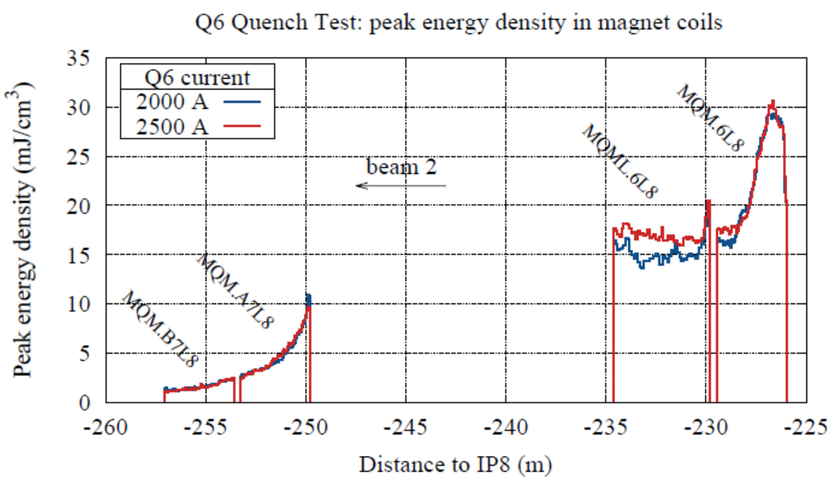
4. Q6 quench test

Async dump, D1 failure - us

Performed: in 2011 (no quench) and in 2013, Ebeam=450GeV but magnet current corresponds to 6 TeV.
Method: shooting on a closed collimator, quenching magnet downstream.

- Data analysis done (BLM HV issue)
- FLUKA simulation done
- QP3 and THEA done

Publication: W. Bartmann et al., *Quench Margin at Injection*, CERN-ATS-Note-2011-067 MD



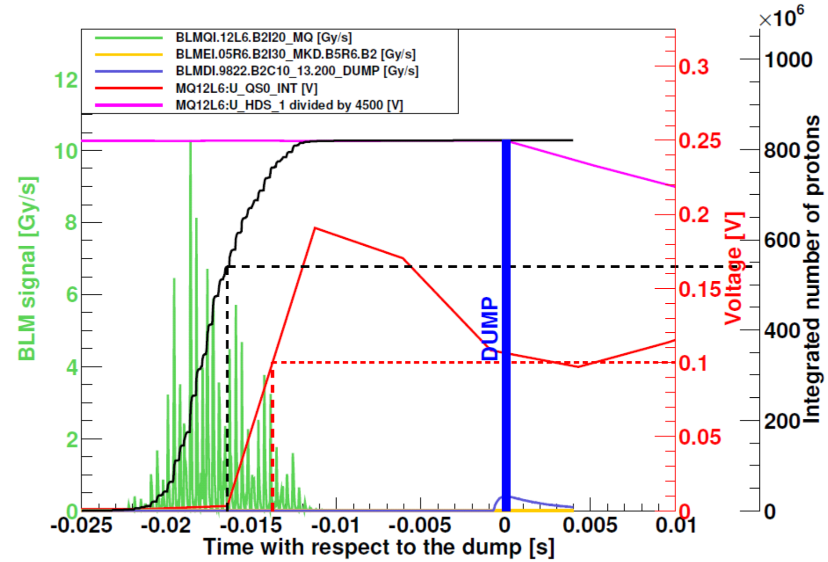
5. ADT fast loss quench test

UFO – 5 ms

Performed: 2013, Ebeam=4 TeV
Method: exciting the beam with ADT, creating aperture limit in magnet

- Data analysis done
- MADX simulations done
- FLUKA/Geant4 simulations done
- QP3/THEA done

Comment:
- very complex test, including ultra-low beam intensities
- Edep in coil - low dependence on loss scenario details
- Geant4 results: similar for coil, underestimated by factor 2 for BLMs



6. ADT steady-state loss quench test

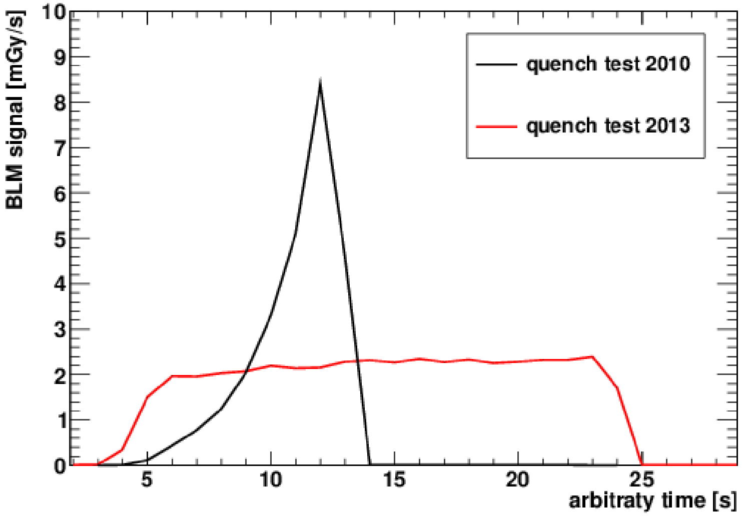
Steady state – 20s

Performed: 2013, Ebeam=4 TeV
Method: create aperture limit in magnet and slowly blow-up the beam with ADT

- Data analysis — done
- MADX — ongoing
- FLUKA/Geant4 simulations — not yet
- QP3/THEA — not yet

Comment:

- constant loss over 20 s
- real steady-state conditions



Work summary

name	Data analysis	MADX /Sixtrack	FLUKA /Geant4	QP3 /THEA
Dynamic orbit bump qt (5 s)	**Done**	Not yet	Ongoing	Ongoing
Wire scanner qt (10 ms)	**Done**	**Not needed**	**Done**	**Done**
Collimation quench test (5 s)	**Done**	**Done**	**Done**	**Done**
Q6 quench test (ns)	**Done** (BLM HV issue)	**Not needed**	**Done**	**Done**
ADT fast loss qt (5 ms)	**Done**	**Done**	**Done**	**Done**
ADT steady state loss qt (20 s)	**Done**	Ongoing	Not yet	Not yet

Result summary: quench limits

name	Fluka+exp	Geant4+exp	QP3	THEA/0-D
Dynamic orbit bump qt **MQ** **[mW/cm³]**	ongoing	ongoing	ongoing	ongoing
Wire scanner qt **MBRB (+)** **[mJ/cm³]**	**19** 12	–	**24-32** 16-21	20
Collimation quench test **MB (+)** **[mW/cm³]**	>50	–	~67	58 (exp)
Q6 quench test **MQM** **[mJ/cm³]**	**30** 22	–	**16-20** 6-8	20
ADT fast loss qt **MQ** **[mJ/cm³]**	**250-420**	**200-400**	**75**	**100-124**
ADT steady state loss qt **MQ** **[mW/cm³]**	ongoing	ongoing	ongoing	ongoing

Energy/power density:
maximum in black, **averaged over cable cross-section in violet**

Documentation

- A first draft of the paper already exists
- Final expected end of year
- Probably in PRSTAB
- Webpage with links to all the presentations and other documents: http://cern.ch/biq

Testing the beam-induced quench levels of LHC magnets during Run 1

B. Auchmann, T. Baer, M. Bednarek, G. Bellodi, C. Bracco, R. Bruce, F. Cerutti, V. Chetvertkova, B. Dehning, N. Shetty, W. Hofle, E. B. Holzer, A. Lechner, E. Nebot Del Busto, A. Priebe, S. Redaelli, B. Salvachua, M. Sapinski, R. Schmidt, E. Skordis, M. Solfaroli, D. Valuch, A. Verweij, J. Wenninger, D. Wollmann, M. Zerlauth,
CERN, Geneva, Switzerland
(Dated: October 17, 2013)

In the years 2009-2013 LHC has been operated with the top beam energies of 3.5 TeV and 4 TeV instead of the nominal 7 TeV, with corresponding reduced currents in the superconducting magnets. To date only seventeen beam-induced quenches have occurred, with eight of them during specially designed quench tests. During normal collider operation with stored beam there has not been a single beam induced quench. However, the conditions are expected to become much tougher after the long LHC shutdown, when the magnets will be working at near nominal currents in the presence of high energy and intensity beams. This paper summarizes the experiments done in order to investigate the (beam-induced) quench limits of the magnets at top beam energies. It describes the techniques used to generate controlled beam losses which were used to study the quench limits. Results are discussed along with their implication for LHC operation at nominal energy.

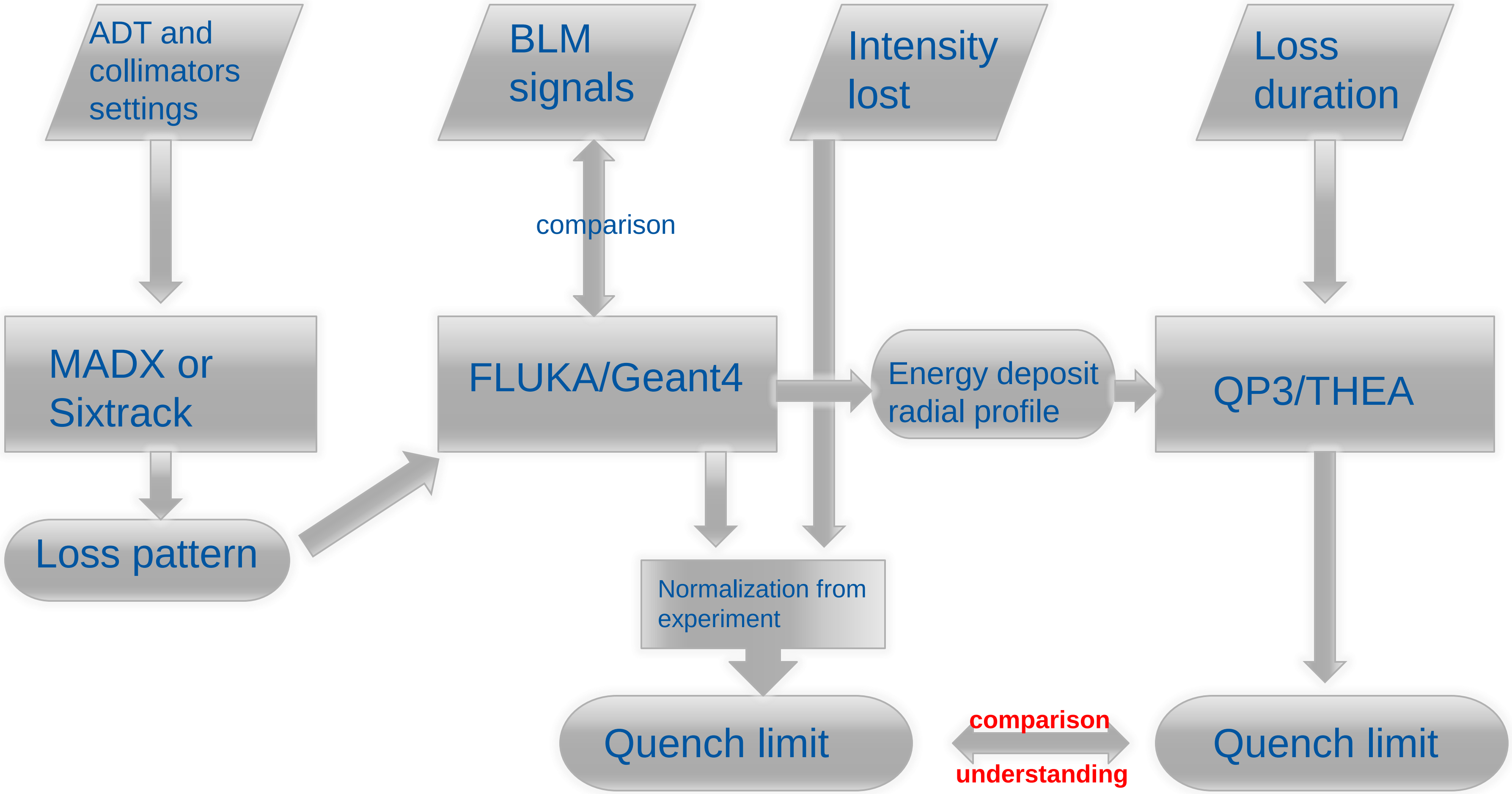
- MD-notes in preparation
- A. Priebe, PhD thesis in preparation

Conclusions and next steps

- Most of the **analysis work already done, we've learned a lot about loss patterns, BLM accuracy etc, etc.**
- Quench limits:
  - Ultra-fast: agreement better than factor 2
  - Millisecond: good agreement for MBRB, factor 2.5 for MQ – important for UFOs
  - Steady-state: for the moment consistent, waiting for last analyses
- Working on understanding of systematic errors
- From the December the working group will investigate BLM threshold updates following results of quench tests and other simulations
- It will also come with a proposal for quench tests after LS1

Backup slides

Analysis: common approach



Other suggested terminology (I)

- **Quench**: Transition from the SC to the normal state (thermal runaway not required).
- **Quench recovery**: Transition back from normal to SC state. Avoid "quenchino".
- **Quench level**: **Minimum Quench Energy Density (MQED)** [J/cm^3] (fast losses), **Minimum Quench Power Density (MQPD)** [W/cm^3] (steady losses), in a given location at a given working point (current, temperature). Whenever possible, use MQED/MPED in favor of "quench level".
- **Temperature margin to quench** (T_{cs} – T_o) [K], **Margin on the loadline** [%], avoid energy/enthalpy margin – use above MQED, MQPD instead.
- **Deposited energy/power-density** [J/cm3], [W/cm3]: profile of the deposited energy density along the coil and across the coil.
- **Peak deposited energy/power-density** [J/cm3], [W/cm3]: maximum deposited energy/power density over the cross-section of the coil (often plotted as graph along the length).
- **Beam losses** [protons/s, protons]: protons lost from the beam for a given scenario or event. Avoid the use of the term "losses" in any other context.

Other suggested terminology (II)

- **BLM signal** [Gy/s]: BLM signal for a given beam loss; it is recommended to specify, especially in case of measured signals, which integration time has been used, eg.:
  - BLM signal in RS09 (1.3s) [Gy/s], or
  - BLM signal averaged over 1.3 s [Gy/s],
  - BLM signal integrated over 1.3 s [Gy].
- **BLM signal at quench** [Gy, Gy/s] or beam losses at quench [protons,protons/s]: BLM signal/beam losses corresponding to the time of quench (initial rise in resistive voltage – not the time when the QPS threshold is reached).
- **Assumed BLM quench level** [Gy, Gy/s]: assumed BLM signal corresponding to a quench for a given scenario.
- **BLM threshold** [Gy/s] - value of the BLM signal at which the beam dump signal is issued. Typically: BLM threshold = 0.3 * Assumed BLM quench level.
- **Do not use**: Enthalpy margin, quench enthalpy, energy margin, dose rate, losses (the term is too ambiguous as a physical quantity, only as “beam losses” [protons/s, protons]), quench limit, quenchino.

Paper structure (I)

1. Introduction (ok)
2. Quench levels (ok)
3. Methodology (missing: error discussion)
4. Fast losses (Chiara, Anton, Nikhil – Q6 quench test)
5. Millisecond losses
   - Wire scanner quench test (ok)
   - ADT fast loss quench test (Vera, Anton, Nikhil)

Paper structure (II)

- Steady-state losses
  - Collimation quench test (Belen, Francesco, Eleftherios)
  - Orbit bump quench test(s)
    - 2 chapters or one?
    - Still missing results (simulations)
    - Expected input from Agnieszka, Anton, Nikhil, Vera.
- Conclusions

Paper schedule proposal

- November 30th: 1st complete version to be circulated among all co-authors
- December 31th: final version
- Beginning of January: send to publication (Physics Review Special Topics: Accelerators and Beams - PRSTAB)