Quench Test Strategy Working Group

Date: 4th of May 2012

Chairperson: Mariusz Sapinski

Scientific secretary: Agnieszka Priebe

Presentations:

- Tobias Baer “UFO observations”
- Anton Lechner "Recent UFO studies"
- Agnieszka Priebe “Planning of the ADT experiments”

Minutes:

- **Tobias Baer “UFO observations”**

T.Baer started his presentation talking about UFOs in the LHC. He pointed out that 35 beam dumps occurred between July 2010 and August 2011 due to the UFOs. Typical loss duration was in the order of 10 milliseconds and they appeared in unconventional locations (i.e. in the arcs). During year 2011 the BLM thresholds were optimized and increased. Around 18 000 candidate UFOs below BLM dump thresholds were found (2200 events in 2012). Fitting of the BLM signal showed the Gaussian distribution (08.04.2012, BLMQI.19R3.B1I10_MQ). Losses recorded in the LHC were compared to the experiments performed in SM12. The BLM signals of 4513 arc UFOs (cell number >= 12, 3.5 TeV, RS01>10^{-3} Gy/s) represented x^{-1} while the dust measurement distribution shows $x^{-0.97}$ tendency. Although UFOs appears all around the ring, a lot of events were observed in the region of MKIs. In the cold sections especially numerous UFO occurred in 25R3 B2 (144 UFOs), 19R3 B1 (126 UFOs), 28R7 B2 (118 UFOs). In 2012 additional monitors are installed in cell 19R3 regarding BLM, FLUKA simulations performed for this region. This location was chosen due to the transversal beam position in the magnets (internal/external aperture => possibility of new BLM installations). Moreover no correlation with sector 34 repairs was identified. Next part of the presentation was devoted to the UFO rate. In 2011 UFO rate was decreased from ≈10 UFOs/hour to ≈2 UFOs/hour. Already in 2012 about 2-3 times higher UFO rate was observed than during October 2011. Considering fills with at least 1 hour of stable beams and BLM signals RS04 > $2\cdot10^{-4}$ Gy/s, 5696 candidate arc UFOs (≥ cell 12) were registered during stable beams since 14.04.2011. Number of UFOs was proportional to the beam intensity at low intensities and saturated in case of high intensities (statistics on 500 candidate UFOs during stable beams with a signal of RS04 > $2\cdot10^{-4}$ Gy/s). 28 fills with at least 1 hour in stable beams in the first quarter of 2012 were considered. The beam intensity was computed as the maximum intensity per fill and averaged over both beams. Error bars were calculated for each fill (long fill = small error bar). These results are consistent with analysis of E.Nebot (IPAC 2011). T.Baer presented MKI UFO studies and observations. Statistics of UFOs in the vicinity of MKI was presented: 13 dumps due to MKI UFOs, 1236 UFOs around MKIs for fills lasting at least 3 hours after last injection. This gave 2340 UFOs around MKIs in total (847 in Point 2 and 1493 in Point 8). Temporal distribution was observed mainly 30 minutes after the last injection. Many events were registered within a few hundreds of milliseconds after MKI pulse and some of them cannot be explained by the gravitational force alone. Probably there were negatively charged macro particles related to the electron clouds (reference to F. Zimmermann, 66th LIBD Meeting). Positive correlation between MKI UFO rate and local pressure was found at 450 GeV (T. Baer et al., Chamonix 2012). According to the FLUKA simulations (A. Lechner, 3rd LHC UFO Study Group Meeting) it was claimed that UFO location had to be in MKIs (or nearby upstream). Performed simulations considered UFOs in the centre of the beam. Moreover a minimum particle radius of 40 µm was needed to explain a large UFO event on 16.07.2011 (T. Baer et al., Evian Workshop 2011) . During that event the beam size (σ_x=325 µm, σ_y=140 µm) was still larger than the UFO agent size. MKI underwent the vibrations measurements (R. Morón Ballester et al., EDMS: 1153686). Mechanical vibrations in order of 10nm of ceramic tube were observed during a MKI pulse. According to the particle dynamics model, there were many predictions. One of them stated that UFO duration was shorter for larger beam current (F. Zimmermann et al., IPAC'11, MOPS017). Investigations of MKI.B5L2 were done in a direction of macro particles detections. This kicker magnet was removed from the LHC during the winter Technical Stop 2010/11. After opening it was inspected also with an energy-dispersive X-ray spectroscopy (EDS). For the reference measurements a new ceramic tube was taken. Measurements performed in the clean room air showed 100 particles on a filter while on a new ceramic tube - 10000 particles on the filter. 5000000 particles on the filter were found during the inspection of the removed MKI. The results were that the typical macro particle diameter was in the range from 1-100 µm. The outcome from the EDS measurement was that most particles originated from the Al2O3 ceramic tube. In the next part of the talk the mid-term extrapolation was presented. There were indications for increased UFO activity for 25 ns operation. According to the energy dependency, the UFO amplitude at 7 TeV was estimated to be about 3-4 times higher than in case of 3.5 TeV beam. This was concluded from FLUKA simulations (A.Lechner) and wire scans during the ramp. In terms of the beam loss monitoring system, the arc thresholds at 7 TeV were about a factor 5 smaller than at 3.5 TeV. No energy dependence would be consistent with observations for the UFO rate (E. Nebot et al., IPAC'11, TUPC136). Analysis based on UFOs recorded in 2011/12 (full cycle) showed 112 UFO related beam dumps in 2011 and 13 dumps in 2012 according to the arc UFOs scaled to 7 TeV. In the comparison 2 dumps were observed at 3.5 TeV. In terms of the MKI UFOs scaled to 7 TeV, there were 27 UFO related beam dumps in 2011 and 1 dump in 2012. Here 11 dumps were observed in 2011. T.Baer in the last part of his presentation showed the outlook and mitigation strategies. Better localization of arc UFOs by mobile BLMs in cell 19R3 was pointed out. Prepared FLUKA simulations considered inelastic interactions. Moreover there were MADX simulations of UFOs ongoing which took into account the elastic interactions. Temporal resolution of UFO events (dust particle dynamics) was improved as well. 80 µs time resolution of BLM study buffer was applied and bunch-by-bunch diagnostics for UFO events was provided by diamond detectors. An impact of 25 ns operation was to be studied in 2012. 25 ns high intensity (several 100 bunches) beam is foreseen for some hours at flat top. MKI UFO MD is planned. This concerned 25ns, electron cloud correlation, UFO production mechanism and particle dynamics. The mitigation strategies were presented. In case of MKI UFOs – the metallization of ceramic tube was not feasible due to significantly increased rise time and problems with beam induced power deposition (M.J.Barnes, 64th LIBD Meeting). A change of MKI.D5R8 would be provided in August during the TS because of the heating problems. This would ensure better cleaning and reduced E-field due to 24 metal wires (instead of 15). Concerning the arc UFOs an increase of BLM thresholds towards quench limit was foreseen. The final statements would be based on a wire scanner quench test and an ADT quench test. In 2012 an increase of selected BLM thresholds was planned. It was also concluded that different BLM distribution could allow for additional increase of BLM thresholds. Further, the proposal for LMC was shown. It was suggested to increase BLM thresholds for all arc BLMs in sectors 12, 34, 56, 67 by a factor of 3.3. These correspond to expected quench limit. The procedure was to reduce BLM thresholds according to observations if a quench occurred. Nevertheless not many large UFO events were expected (2 arc UFOs above BLM thresholds in 2011), but it was claimed that a large event would provide very valuable information on the quench limits. Summing-up, 35 beam dumps occurred due to UFOs since July 2010. A large-scale increases/optimization of the BLM thresholds and UFO scrubbing mitigated the impact of UFOs since the middle of 2011. Moreover, 18000 candidate UFOs below BLM dump thresholds were detected. Because of improved diagnostics, MDs, laboratory measurements, FLUKA simulations and macro particle dynamics studies, much knowledge was gained (especially on MKI UFOs). Aggressive energy scaling gave 112 dumps by arc UFOs and 27 dumps by MKI UFOs expected for 7 TeV operations (based on 2011 observations). High UFO activity was observed during 25ns MDs as well.The plans for 2012 were mainly focused on better understanding of quench limit. Arc UFOs would be also under investigations. It was planned to replace one MKI in August Technical Stop.

Discussion:

A.Verweij asked when the thresholds would be increased. J.Wenninger answered that it was promised not to induce quenches this year so they had to be careful with that.

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- **Anton Lechner "Recent UFO studies"**

A.Lechner was presenting FLUKA simulations of UFO-induced losses in the LHC arc. The arc cell 19R3 (MBB-MBA-MBB-MQ) was considered. This cell was chosen because of one of the highest UFO occurrence in 2011 (126). In this location UFOs occurred for beam 1. Other cells with high number of UFOs were pointed out (25R3 - 144 events, 28R7 - 118 events, 26L3 - 73 events, 28L6 - 72 events). The FLUKA geometry took in to account main magnets and interconnection region. In the interconnections between MBs simplifications were applied. Beam loss monitors were implemented outside the magnet cryostats. Simulations were performed for two potential UFO locations approximately 30 m apart from each other. The first location was chosen in the QBBI.A19R interconnect and the other one in the centre of MB.C19R. Internal beam 1 was considered since most of the UFOs in this cell were observed for this beam. In terms of energies, both loss locations were simulated for 3.5 TeV and only position 1 at 7 TeV. A.Lechner noted that the UFOs were assumed to be composed of Fe and only inelastic proton–UFO interactions were simulated. The origin of uncertainties was underlined. First of all, the simulations could always be affected by a certain systematic error, e.g. due to geometry approximations even though the arc model was reasonably accurate. Secondly, for some quantities, statistical error could be high, in particular BLM signals in BLMs upstream of UFOs or in BLMs at large distances. A set of BLM pattern measured between 04/2011 and 10/2011 were shown and compared to FLUKA results. The highest registered UFO in cell in 19R3 was measured on 15th of October 2011. A dose of 3.9×10^{-4} Gy/s was registered with RS7 of BLMQI.19R3.B1I10_MQ. All data were normalized to a signal of BLMQI.19R3.B1I10_MQ. F.Zimmermann noticed that with six BLMs it was impossible to distinguish UFO location 1 from UFO location 2 since the BLMs were only in the vicinity of the MQ. It was said that between these two locations there was factor of 100 in a relative dose. Therefore threshold values couldn't be optimized. R.Schmidt added that one couldn't produce UFOs strong enough to quench a magnet. Next part of the presentation was devoted to measurements done in 2012. The main improvement lied in the fact that four additional BLMs were installed along the MBs in 19R3. The BLM pattern for the three largest UFO events in 19R3 observed so far in 2012 were shown. The largest UFO, which was registered, gave signal of 2.5×10^{-4} Gy/s (BLMQI.19R3.B1I10 MQ, RS07). Comparison included simulation results obtained for 3.5 TeV and measurements done at energies between 3.67 and 4 TeV (ramp, stable beams) . The outcome was that for these UFO events, simulation results strongly suggested UFO location to be rather closer to MB.C19R centre than QBBI.A19R interconnection. More statistics is required to provide more conclusive results. According to simulated UFO location in the QBBI.A19R interconnect, a peak energy density in MB magnet coils was predicted. All values were given per inelastic proton-UFO interaction. It was claimed that maximum peak energy density was caused by neutral particles (mostly gammas and pions) hitting the bent magnet aperture. For energy of 3.5 TeV the peak was approximately equal 6×10^{-8} mJ/cm^3 and 2.5×10^{-7} mJ/cm^3 for 7 TeV beam. The transversal plots of the energy density in three longitudinal positions of the MB were analyzed. The lateral blur (asymmetry between horizontal and vertical planes) was observed at the position where the Edep peak occurred. The effect was even stronger in case of 7 TeV beam. By now the FLUKA simulations considered BLMs as they were installed in the LHC tunnel. In the next part simulations were done including additional fake monitors to study in more detail the BLM pattern. Studies on BLM dose and energy deposition were shown for both assumed UFO locations. In the end summary was done. According to the arc cell 19R3 , the new BLMs yielded a significant gain in resolution (4 additional BLMs installed). Based on 2012 observation, UFOs seem to occur all along the arc cell. Moreover, the largest UFOs events observed so far in 2012 were “close” to MQ (potentially in the MB located just upstream). A.Lechner pointed out that more simulations (involving different UFO locations) would be required to narrow down individual UFO locations. For the same number of interactions and assuming the UFO to be located just upstream of a MB, the simulation predicted a peak energy density in the MB coils about 4 times higher at 7 TeV than at 3.5 TeV. A correspondence between maximum BLM signal and peak energy density in MB coils was impacted by the UFO location in the arc cell.

Discussion:

A.Verweij asked about the UFO size. A.Lechner answered that the larger the agent was, the higher BLM signal was registered. Next question was from M.Sapinski and was related to elastic interactions impact. Presenter replied that the losses occurred much more downstream with smaller angle. R.Schmidt pointed out that simulations for the UFO position 1 were above the thresholds and maybe people were too pessimistic about UFOs in the timescale of milliseconds. It was considered that maybe large losses occurred only close to MQs. M.Sapinski suggested that we should think about new BLM location configuration to be performed during the LS#1. According to chosen loss locations, A.Lechner said that there was no explanation why the loss should have appeared on third MB instead of the second one. R.Schmidt advised that a list of different scenarios and expected solutions should be provided in the future.

- **<u>Agnieszka Priebe "Planning of the ADT experiments"</u>**

A.Priebe started her presentation with motivation why BL section was interested in the Transverse Damper (ADT) fast losses experiments. She explained that they had already performed several quench test with 3-corrector orbital bump but the shortest produced losses were in the order of several seconds. M.Sapinski pointed out that there were fast losses on collimators and with the use of wire scanners (different technique). A.Priebe said that they were searching for a solution for fast losses induction for the future quench test and ADT was one of the options. First they needed to understand potential and limitations of this system. ADT allowed to create fast losses in the timescale of several LHC turns. Therefore, it could be used for UFO-like losses investigations. There were three methods of exciting the beam. The first mode was the coherent excitation which was used for injection/abort gap cleaning. The second one was the white noise excitation and this method was used for a controlled emittance blow-up. The last option was the feedback sign flip which during a typical operation of the machine was considered as a failure mode. Next part of the presentation was devoted to ADT fast losses test done on 26th of March 2012. Position of collimators was standard (no changes applied). Pilot bunch of beam 2 at injection energy was excited in horizontal plane. This was followed by energy deposition on the primary collimator's jaws (TCP). To provide Post Mortem data acquisition, a monitor factor was decreased by a factor of 3. A comparison between applied ADT modes was presented. The BLM signal and beam positions were shown as a functions of time. It turned out that feedback sign flip method at maximum gain provided the most regular beam amplitude growth. Time distribution of losses induced by the ADT had different shape than UFOs observed on 29th of May 2011. The UFO losses have the Gaussian-like shape while losses provided by ADT had several peaks. The outcome was that ADT can produce losses with a timescale of UFOs (order of milliseconds) but with different temporal distribution. Again method 3 (feedback sign flip) with maximum gain had an advantage over the other presented modes due to the smallest initial losses (losses which occurred before the highest peak). Next part of the talk was related to ADT fast losses test at injection energy for UFO studies. This test was supposed to be done during MD#1 but due to the fact that MD was shortened, the test was canceled. The planning of the test was done in cooperation with T.Baer and D.Valuch. The main aim of this experiment was to recreate the conditions of fast (~1ms) proton beam losses which were the most similar to the foreseen Quench Test. Moreover it would provide studies of the use of the ADT system as a tool for loss induction. The impact of phase advance between ADT and TCP could be investigated in terms of excitation efficiency, loss time structure and loss efficiency. A.Priebe stressed the fact that by now they had only one ADT test (with symmetrical positions of TCP jaws) and they didn't know if the results were repeatable or not (more statistics needed). During standard operation of the LHC the primary collimators were set to 5.7 σ, secondary collimators to 6.7 σ and quartiary collimators to 10 σ. After discussion with J.Wenniger and S.Redaelli two configurations of jaws were proposed. The first one assumed that all collimator jaws were left at nominal setting but one of TCP which would be moved towards the beam to 4 σ. The second options considered all collimators retracted to 11 σ but one TCP jaw left at nominal 5.7 σ. This asymmetric location of the jaws would provide similar conditions (losses on one side of an aperture only) as during the future quench test. The proposed test would be done with one pilot bunch at injection energy. Both beams in both planes would be used to study an impact of various phase advances between ADTs and TCPs. The losses should appear on the outside of the coldmass. Therefore, in case of vertical excitation, the upper jaw should be moved towards the beam. Horizontal position of the jaws depended whether beam 1 or beam 2 was used. For beam the external jaw would be moved and for beam 2 – the internal one. All cases had to be checked since the final location of the planned quench test was not determined yet. Calculations of phase advance between ADT and TCP gave 7.2 deg and 155 deg for the horizontal plane and 90 deg and 140 deg for the vertical plane. Probably an arc half-cell MQ would be chosen to have similar phase advance. A.Verweij confirmed sector 56 to be good from magnet protection point of view. Thus phase advances were calculated in this region. The cell MQ.20R5 seems to posses the best parameters (for beam 1: φx=21.6 deg, φy=158.4, for beam 2: φx=72.0 deg, φy=270.0). This place was also checked by K.Brodzinski in terms of cryogenics (thermometers worked). Potential risks of the experiment were given. There was some finite probability that a bunch could miss the primary collimators (TCP), depending on the phase advance between the ADT and the TCP. Particles could be stopped on one of the downstream collimators inducing a secondary particle shower. In the worst case 1-2 magnets could quench with the probe beam at injection energy. In order to minimize the risk the beam would be excited at low gain and the losses appearance would be compared with the expected one. If the signal was high on the other collimators, they could be retracted to a parking position. A.Priebe pointed out optimistic aspects of the situation. The first one was that during the ADT fast losses test with symmetrical position of collimator jaws (26th March 2010) no significant losses appeared along the ring beside Octant 7 (TCLA.B6R7.B1). The second one came from T.Baer and stated that phase space coverage plots showed that without TCP, the phase space is well- covered by other collimators (except TCDQ) and losses with these intensities shouldn't be a problem. Moreover during "Quench Margin at Injection" (ATS-Note-2011-067 MD) there was no quench with $3 \cdot 10^{10}$ protons at 450 GeV lost on TCLIB. The final outcome from the presentations is that ADT could induce fast losses with a timescale of UFOs but with different temporal distribution. ADT feedback sign flip method turned out to be the most convenient for fast losses studies. According to the proposed MD test, the asymmetrical position of collimator jaws would provide losses only on one side of the aperture (→ QT with 3-corrector bump scenario). Phase advance might be crucial for the decision of the QT location. In the end there were two open questions: how to provide safe operation for a similar test at 4 TeV (position of collimators, ADT gain) and if it was possible to implement new settings to change positions of several collimator jaws at once.

Disussion:

J.Wenninger pointed out that ADT was ten times less efficient in gain at 4 TeV than at injection energy . R.Schmidt said that it would be good to make calculations for beam position depending on phase advance between ADT and considered magnet (for the quench test). J.Wenninger noticed that perhaps the phase advance is not so important since the beam would go on the tune anyway (BPM plot showed coverage of all phases). T.Baer claimed that retraction of collimator jaws to 11 sigma would be a better option for tests at 4 TeV than the other one because it would really induce losses on one side only. M.Sapinski noted that maybe it would be better to focus only of horizontal plane for beam excitations for UFO studies (related to A.Lechner talk). R.Schmidt said that it was rather unlikely to obtain beam time for such a test with 4 TeV beam during the MD in June due to the probability of accidental quenching. According to QP3 code A. Verweij said that temporal distribution of losses in the UFO timescale was not important (for long losses it was). M.Sapinski proposed a meeting before next MD in June to estimate final strategy of the experiments to be done. R.Schmidt suggested additional discussion of ADT properties and phase advance impact. B.Dehning suggested studies on the physics behind the ADT for better understanding its potential.

Presentations can be found on indico page:

https://indico.cern.ch/conferenceDisplay.py?confId=187879

Tentative agenda for the next meeting:

1. Agnieszka Priebe, “Results of ADT fast losses test at 450 GeV and 4 TeV (report on MD#2) ”
2. Krzysztof Brodzinski “Energy estimations with cryogenics measurements”

If you want to give a presentation, please let us know.

Next meeting will be held next month. The exact date and plan to be announced.