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Search for magnetic monopoles with the MoEDAL forward trapping detector in 13 TeV proton-proton collisions at the LHC

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Abstract. The MoEDAL experiment addresses a decades-old issue, the search for an elementary magnetic monopole, first theorised in 1931 by Dirac to explain electric charge quantisation. Since then it was showed that magnetic monopoles occur naturally in grand unified theories as solutions of classical equations of motion.
The dedicated experiment can enjoy a new energy regime opened at the LHC allowing direct probes of magnetic monopoles at the TeV scale for the first time. MoEDAL pioneered a technique in which monopoles would be slowed down in a dedicated aluminium array and the presence of trapped monopoles is probed by analysing the samples with a superconducting magnetometer. The MoEDAL forward trapping detector array deployed in 2015 was analysed and found consistent with zero trapped magnetic charge, allowing to set the first LHC constraints for monopoles carrying twice or thrice the Dirac charge.

1 Introduction

The idea of a fundamental particle carrying a magnetic charge, the magnetic monopole, has been in physicists mind for decades and was included in a theory for the first time by Dirac in 1931 [1] in which the magnetic monopole is compatible with quantum mechanics and has a charge that must be quantised, leading as well to the electric charge quantisation. Since then searches and theories multiplied in time. They would appear as part of the electroweak theory in Cho-Maison postulation [2], or as key pieces of the grand unified theories as introduced by 't Hooft and Polyakov in 1974 [3] [4]. Despite this abundance of theoretical models, no mass range can be assumed for the experimental searches and the magnetic monopole could have a mass from the TeV scale up to the Planck scale, which is the reason why it has been the subject of searches at colliders as well as in cosmic rays. From the Dirac theory, we can quantise the minimal magnetic charge, so-called the Dirac charge g_D . A magnetic monopole must carry a magnetic charge proportional to 1 g_D with a minimal charge going from 1 g_D to 2 g_D or 3 g_D depending on the theoretical model. 1 g_D has a ionisation power equivalent to an electric charge of 68.5 e. Magnetic monopoles are thus manifesting theirselves as Highly Ionising Particles (HIP). High ionisation from magnetic monopoles is one of the signature used by experimental searches around the world. Another main signature that free magnetic charges would have in nature is to induce a persistent current when passed through superconducting loops. Those signatures lead to three different typical kind of searches : searches with general-purpose detectors such as ATLAS [5] [6] [7] at the LHC [8] thanks to magnetic monopole HIP feature, Nuclear Track

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Detectors (NTD) also using the HIP property of magnetic monopole and induction-technique-based experiments. Those searches are complementary and are scoping a wide mass and charge range. The Monopole and Exotics Detector at the LHC (MoEDAL) [9] is combining NTD arrays and trapping array consisting in aluminium volumes in which the magnetic monopoles could stop in and then be scanned thanks to an induction technique.

2 A description of the MoEDAL detector

The MoEDAL experiment is searching for highly ionising avatars of new physics covering more than 30 fundamentally important beyond-the-standard-model scenarios involving electrically and magnetically charged particles. [10] It started data taking in 2015 at interaction point 8 of the Large Hadron Collider (LHC), thus sharing the cavern with the LHCb [11] experiment (Figure 1). It is located around the vertex locator of the LCHb experiment, being as close as possible from the interaction point.

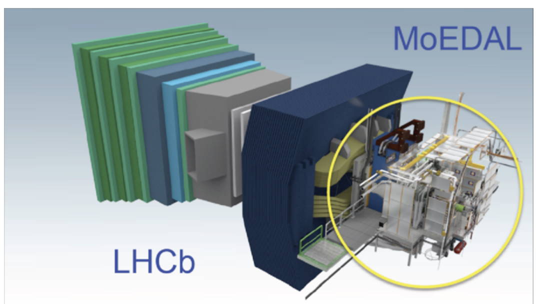

Figure 1. The MoEDAL apparatus at the LHC point 8 cavern

2.1 The MoEDAL subdetectors

MoEDAL is split in subdetectors, most of which are passive detectors : the trapping detectors array and the NTDs. (Figure 2) The NTDs, acting like a giant camera, are first processed through chemical etching and then analysed offline by ultra fast scanning microscopes to find etch pits and are sensitive to new physics. Thinner NTDs called high-charge catchers are inserted in the LHCb acceptance. In addition to passive sub-detectors, a state-of-the-art real-time TimePix pixel detector array is used to monitor MoEDAL's radiation environment.

2.2 The magnetic monopole trapping array

As discussed in section 2.1 the second part of the passive sub-detectors of MoEDAL is the trapping detectors array consisting in aluminium bars, so-called the Magnetic Monopole Trappers (MMT). Assuming the binding of magnetically charged particle such as magnetic monopoles or dyons with the aluminium nuclei, the new particles produced at the LHC would stop in the MMTs and be trapped in the aluminium bars. The MMTs are located all around the interaction point forming a trapping array. The results discussed here are containing data coming from the scanning of the forward trapping detectors only as seen on figure 3.

Figure 2. Nuclear Track Detectors and MMT

Figure 3. The MoEDAL forward trapping detector

3 Scanning of the trapping array through a SQUID magnetometer

The aluminium bars of the MoEDAL trapping array are scanned and pass through superconducting coils of a SQUID or superconducting quantum interference device magnetometer (Figure 4). SQUID magnetometer are able to measure extremely small magnetic fields variation and the Laboratory for

Natural Magnetism at ETHZ's SQUID sensitivity allow us to probe particles with a magnetic charge higher or equal to 1 g_D . The signature of a monopole passing through a superconducting coil is a non-zero persistent current (Figure 5) that would be induced by the magnetic charge but not canceled by the corresponding opposite pole as it would be the case for a dipole. This feature is proper to magnetic monopoles making this measurements fully background free. One could even pass several times a candidate bar through the coils, observing as many increments in the persistent current corresponding to the magnetic charge in the sample. In addition thanks to a calibration realised on dipoles with a know magnetisation we can derive from the persistent current the magnetic charge associated.

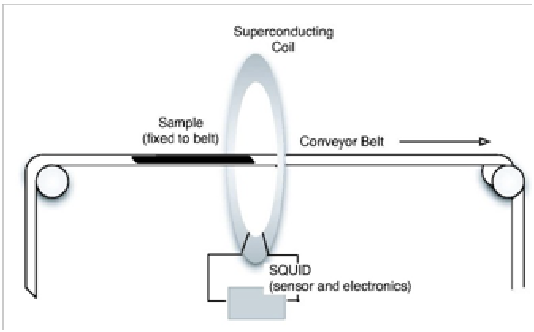

Figure 4. Schematic of the scanning of MMT aluminium bars through SQUID's superconducting coils

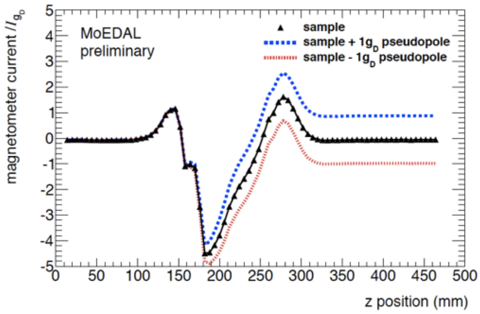

Figure 5. Response of the magnetometer current at 76 different positions for a single sample passing through the magnetometer. The dashed blue and red lines show the response of the magnetometer to a sample emulating respectively a 1 g_D charge and a -1 g_D charge

Each of the 672 aluminium bars of the forward trapping array was scanned and had the associated persistent current measured. The samples with a persistent current above 0.25 g_D were set aside as candidates and remeasured several times. The re-measurements of those candidates ruled out the monopole hypothesis and monopoles with a charge higher than 0.5 g_D were excluded from all the samples (Figure 6).

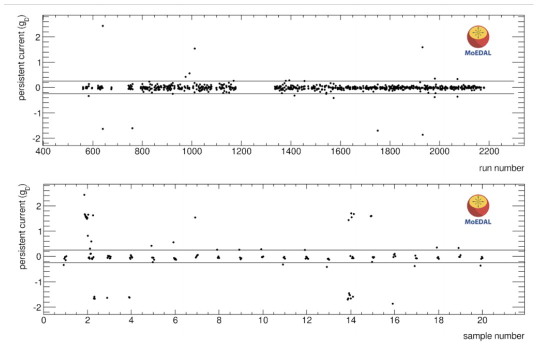

Figure 6. Up: Persistent current (in terms of Dirac charge) measured in all the aluminium samples of the forward trapping array exposed to 2015 collisions. Down: Persistent current (in terms of Dirac charge) remeasured in candidates defined as samples with an initial persistent current with a corresponding value higher than 0.25 g_D

4 Results and conclusion

No magnetic monopole was observed in the forward trapping detector exposed to 2015 LHC interactions, allowing us to set the first constraints at colliders at 13 TeV on magnetic monopole [12]. Those results probe the TeV regime for charges up to 5 g_D with first limits at LHC for 5 g_D monopoles. They are the best limits at LHC for charges higher than 1 g_D .

MoEDAL is a cost-efficient passive detector dedicated for searching for new charged long-lived particles. The trapping detector array can yield to competitive results quickly and with no background ambiguities. The limits (Figure 7 and table 1) already surpasses existing constraints for charges higher than 1 g_D with the only use of the forward trapping array exposed to a limited integrated luminosity. The full array exposed for a longer period will be analysed soon updating the already existing results. The beam pipes of LHC experiments that were removed during the first long shutdown are also planned to be scanned the same way, making it possible to probe particles with very high ionising power, e.g. with high Dirac charges.

Table 1. Mass limits for Drell-Yan spin 1/2 and spin 0 models for different masses with 2015 exposure MoEDAL forward trapping array results as compared to the MoEDAL and ATLAS 8 TeV results

mass limits [GeV]	1 g_D	2 g_D	3 g_D	4 g_D
MoEDAL 13 TeV (this result)				
DY spin-1/2	890	1250	1260	1100
DY spin-0	460	760	800	650
MoEDAL 8 TeV [13]				
DY spin-1/2	700	920	840	-
DY spin-0	420	600	560	-
ATLAS 8 TeV [7]				
DY spin-1/2	1340	-	-	-
DY spin-0	1050	-	-	-

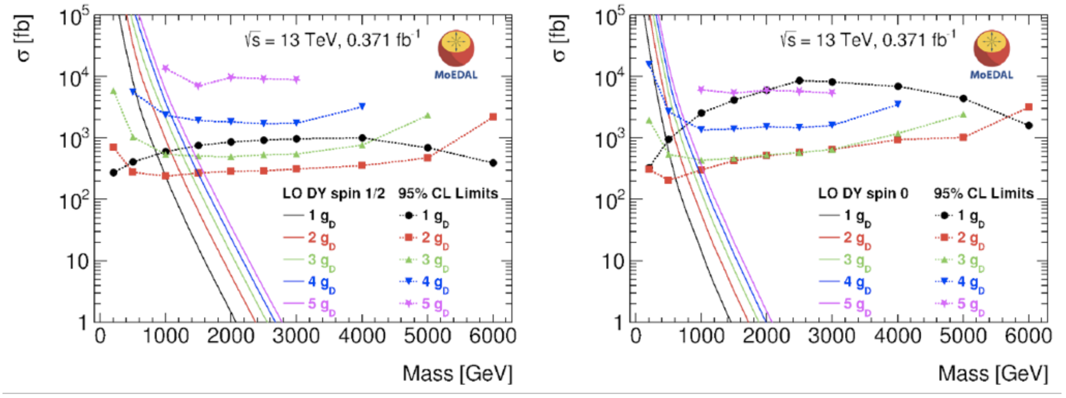

Figure 7. Cross-section limits for Drell-Yan spin 1/2 and spin 0 models for different masses with 2015 exposure MoEDAL forward trapping array results

References

[1] P.Dirac, Quantised Singularities in the Electromagnetic Field, Proc. Roy. Soc. **A 133**, 60 (1931).

[2] Y. Cho and D. Maison, Monopole configuration in Weinberg-Salam model, Phys. Lett. B (1997).

[3] G. 't Hooft, Magnetic Monopoles in Unified Gauge Theories, Nucl. Phys. B **79**, 276 (1974).

[4] A. Polyakov, Particle Specturm in the Quantum Field Theory, JETP Lett **20**, 194 (1974).

[5] G. Aad, et al. (ATLAS Collaboration), JINST 3, S08003 (2008).

[6] G. Aad et al. (ATLAS Collaboration), Search for magnetic monopoles in sqrt(s) = 7 TeV pp collisions with the ATLAS detector, Phys. Rev. Lett. **109** 261803 (2012).

[7] G. Aad et al. (ATLAS Collaboration), Search for magnetic monopoles and stable particles with high electric charges in 8 TeV pp collisions with the ATLAS detector, Phys. Rev. D **93**, 052009 (2016).

[8] Large Hadron Collider Official Site: http://home.web.cern.ch/topics/large-hadron-collider

[9] J. L. Pinfold, MoEDAL Collaboration, Technical Design Report of the MoEDAL Experiment MoEDAL Collaboration, CERN-LHCC-2009-006, MoEDAL-TDR-001 (2009).

[10] B. Acharya et al. (MoEDAL Collaboration), The Physics Programme of the MoEDAL Experiment at the LHC, Int. J. Mod. Phys. A29, 1430050 (2014).

[11] A. A. Alves, Jr. et al. (LHCb Collaboration), JINST 3, S08005 (2008).

[12] B. Acharya et al. (MoEDAL Collaboration), Search for Magnetic Monopoles with the MoEDAL Forward Trapping Detector in 13 TeV Proton-Proton Collisions at the LHC, Phys. Rev. Lett. **118**, 061801 (2017).

[13] B. Acharya et al. (MoEDAL Collaboration), Search for magnetic monopoles with the MoEDAL prototype trapping detector in 8 TeV proton-proton collisions at the LHC, JHEP **08**, 067 (2016).