Magnetic monopole search with the MoEDAL trapping detector

Akshay Katre

On behalf of the MoEDAL Collaboration

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UNIVERSITÉ DE GENÈVE

MoEDAL

Introduction

- Theoretical predictions of monopoles:
  - Originally proposed by Dirac, showed their existence is consistent with quantum theory and they explain electric charge quantisation
  - Monopoles have been predicted in Grand Unified theories (GUTs) of 't Hooft and Polyakov - but these are out of reach of the LHC
  - The most promising model is the electroweak (EW) Cho-Maison monopole, which is a hybrid of the Dirac and 't Hooft-Polyakov model
- Existence of free magnetic charges (magnetic monopoles) would :
  - Add symmetry to Maxwell's equations of electromagnetism
  - Explain electric charge quantisation
- It may and could exist in the Standard Model and its discovery would become a topological test of the Standard Model
- The expected mass of electroweak monopole is 4-10 TeV $\rightarrow$ making MoEDAL very interesting
- Searches for monopoles have been ongoing at colliders, in cosmic rays and in matter

Techniques for detecting monopoles at colliders

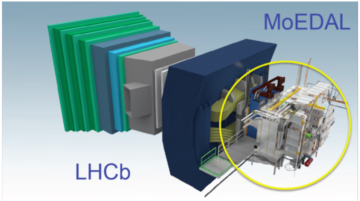
Three commonly used techniques:

Technique	Previous collider experiments	at LHC
General-purpose: high ionisation energy loss detection	OPAL at LEP, CDF at Tevatron	ATLAS, CMS
Nuclear-track: detectors deployed around the interaction points	LEP, Tevatron	MoEDAL
Induction technique: Using **debris** in which monopoles may have been trapped	H1 at HERA, D0 at Tevatron	ATLAS, CMS, LHCb
Dedicated reusable trapping detector	–	**MoEDAL**

Previous collider searches excluded monopoles with charge equal to or above the Dirac charge and masses up to 400 GeV.
At LHC masses up to **3 TeV** were probed in 2012. For the future runs masses up to **6 TeV** can be probed.

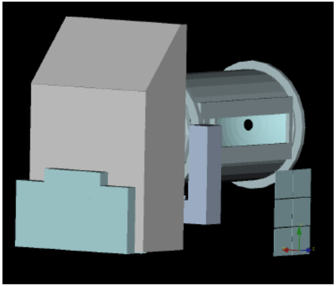
MoEDAL experiment

- Dedicated experiment for searches of new physics featuring long-lived particle signatures
- Deployed around the LHCb experiment's VELO cavern, it is a **unique** and largely **passive** LHC detector comprising four sub-detector systems
- The sub-detector systems:
  - (Two) **Nuclear-track detectors:** optimised for different particle charge ranges
  - **TimePix pixel devices:** monitor of highly-ionising backgrounds in the MoEDAL cavern
  - **Trapping detector:** capability to capture long-lived charged particles and measure directly magnetic charge properties of particles



The MoEDAL trapping detector

In 2012, a test detector array was deployed upstream of the LHCb VELO detector



- 11 boxes, each containing 18 cylindrical aluminium rods of 60 cm length and 2.5 cm diameter
- Choice of aluminium:
  - Its large nuclear magnetic moment is expected to strongly bind with monopoles and stop them in the array
  - Its nucleus does not activate
  - Non-magnetic and cheap
- The full test array covered 1.3% of the total solid angle
- Exposure to 0.75 fb^{-1} of 8 TeV proton-proton collisions
- After the run, the rods were cut into samples of 20 cm length, totaling 606 samples

The MoEDAL trapping detector: full array 2014

- A full array is deployed around the LHCb VELO with larger acceptance
- Deployed at the end of 2014, it will be exposed to 13 TeV collisions and more luminosity

Behind LHCb VELO

C-side

A-side

Magnetometer measurements

- A DC-SQUID rock magnetometer at the Laboratory for Natural magnetism at ETH Zurich was used for scanning the trapping detector samples
- After calibration[1], the measured current is translated into units of current expected from the passage of a Dirac magnetic charge, $\mathrm{I}_{\mathrm{g}_\mathrm{D}}$

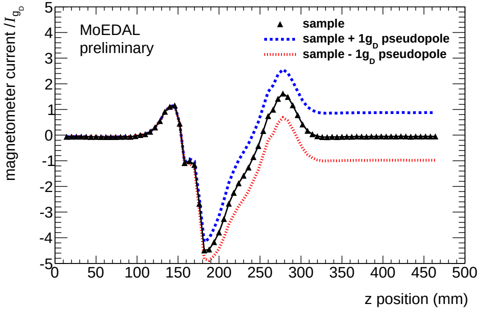


Figure: Measurements from one sample at 76 different positions as it traverses through the magnetometer

[1] http://arxiv.org/abs/1206.6793

Persistent current

- The monopole signature is measured in terms of a quantity called persistent current
- Defined as the difference between the currents measured before and after the passage of the sample through the sensing coil
- In total 852 measurements were performed in 7 days

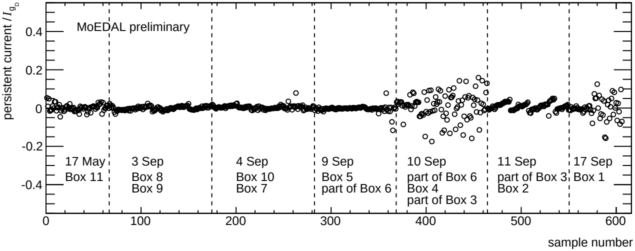
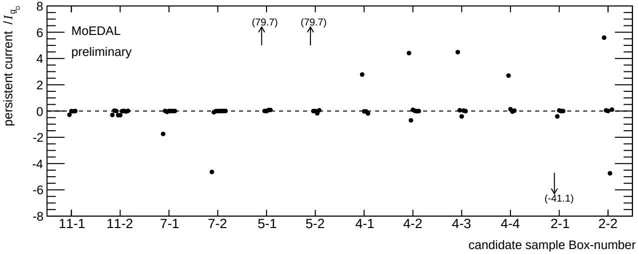


Figure: Magnetic charge (in units of the Dirac charge) measured in 606 aluminium samples of the 2012 MoEDAL trapping detector

Ref. MoeDAL Col in preparation (2015)

Fluctuations

- In some cases, the initial measurement showed fluctations that are consistent with the signature of a signal. However, additional measurements of the same sample were consistent with zero
- Factors affecting magnetometer response could be due to instrumental or environmental factors:
  - Flux jumps occuring when the slew rate is large
  - Noise currents in the SQUID feedback loop
  - Small variations in the length of the sample holder from one run to the next
  - Accumulation of condensed water and ice in the magnetometer tube near the cold sensing region



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Monopole simulations

GEANT4 is used to propogate monopoles in MoEDAL

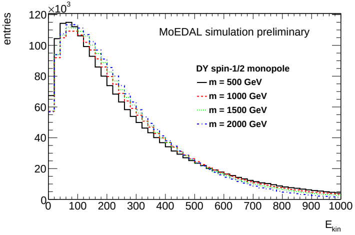
Drell-Yan model

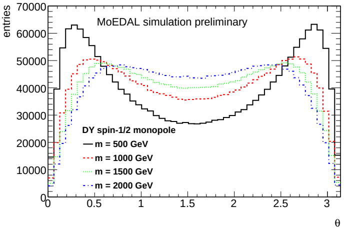
- Leading-order DY process considering spin-0 and spin-1/2 monopoles
- Monopole coupling to the Z boson is set to zero

Single Particle

- For model independent results
- Flat distributions:
  $0 < E_{kin} < 4000$ GeV
  $2.4 < \theta < 3.0$
  $-2.7 < \phi < -0.5$

For the DY model





Velocity dependence of the energy loss per unit distance modelled by Bethe-Bloch formula modified for monopoles:

$$-\frac{\mathrm{d}E}{\mathrm{d}x} = K\frac{Z}{A}g^2\left[\ln\frac{2m_e c^2\beta^2\gamma^2}{I} + \frac{K(|g|)}{2} - \frac{1}{2} - B(|g|)\right] \quad (1)$$

Detector acceptances: Single particle monopoles

Acceptance is defined on an event basis as the probability that at least one monopole stops inside one of the aluminium rods.

- Acceptance is mapped for all mass and charge combinations as a function of $E_z^{kin}(= E^{kin} sin\theta)$ and polar angle θ
- Considering the range: -2.7 $< \phi <$ -0.5

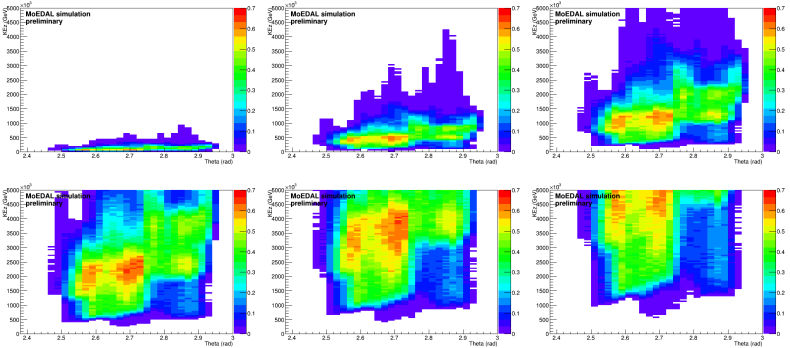


Figure: The acceptance of the MoEDAL test array in the kinetic energy and θ parameter space for monopole charges from 1.0 - 6.0 gD

Ref. MoeDAL Col in preparation (2015)

Systematics

- **Detector acceptance:** The difference between fully simulated approach and estimation using efficiency maps
- **Material budget:** The geometry description in GEANT4 simulation poorly models the small elements at the back of the VELO. Two additional geometry models are used, describing the minimum and maximum material budget

Results

- A magnetic charge consistent with zero is observed in the trapping detector samples
- A preliminary 95% confidence level upper limit of 3 on the number of events producing at least one monopole stopping and binding in the trapping detector in 0.75 fb^{-1} of 8 TeV proton-proton collisions is set
- Cross-section limits will soon be derived

Conclusions

- The first search for magnetic charged particles produced in LHC collisions using the trapping detector in MoEDAL
- No magnetic charge is detected in any of the samples
- For the first time at the LHC, monopoles with charge $g > 2.0g_D$ are probed