Simulation of the MoEDAL experiment

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The MoEDAL Experiment

The MoEDAL (Monopole and Exotics Detector at the LHC) experiment is designed to search directly for evidence of magnetic monopoles and other highly ionising stable, or meta-stable, particles, at the LHC. It is deployed around the P8 intersection region of the LHCb detector (fig. 1) and comprises of an array of plastic Nuclear Track Detectors, aluminium Magnetic Monopole Trappers and a set of TimePix pixel detectors for monitoring. MoEDAL test detectors were installed in 2012 for 8TeV collisions and took data, which is currently being analysed. The full detector arrays will be deployed over the coming years for 14TeV collisions (fig. 4).

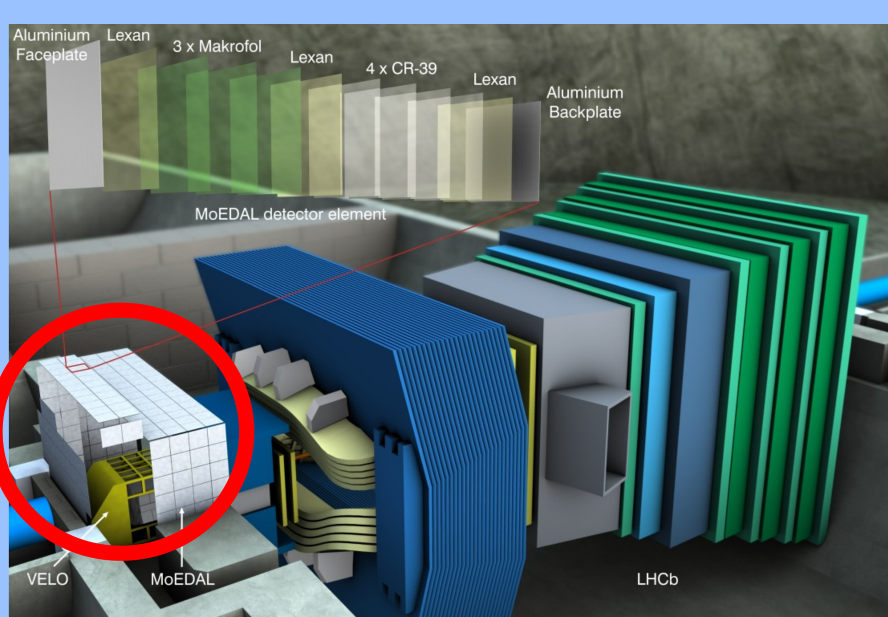


Figure 1. The MoEDAL Detector in the LHCb cavern. The NTD array is highlighted and the layout of a single NTD unit is shown.

Nuclear Track Detectors (NTDs)

The NTDs are passive detectors, designed to track highly ionising particles, such as monopoles. They consist of several layers of plastic whose molecular chains can be disrupted by sufficiently ionising particles. The resulting disruption can be chemically etched (fig. 2) leaving an observable hole. The different plastics used have varying thresholds for disruption and provide a range of sensitivities. A particle's ionisation strength can, in general, be characterised as the ratio of charge to velocity (Z/β).

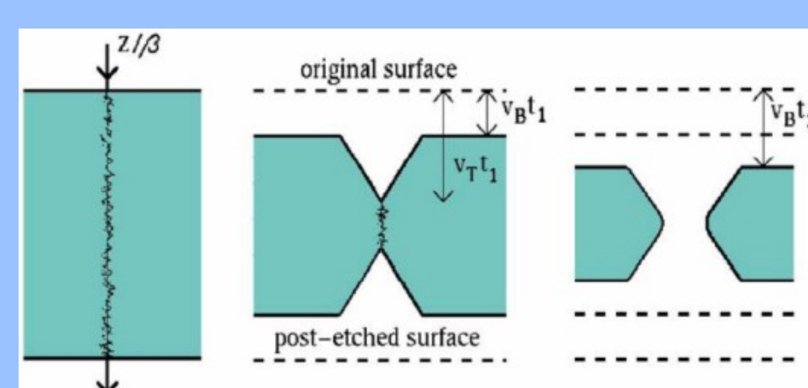


Figure 2. The etching process of a single NTD layer.

Magnetic Monopole Trappers (MMTs)

The MMTs are passive detectors that trap monopoles inside their volume. A single MMT unit consists of 2.5cm diameter aluminium rods packed into an aluminium box (fig. 3). Aluminium's high nuclear magnetic moment makes it especially effective at trapping magnetically charged particles. Any monopoles that are trapped in the MMT rods can be later detected using a specialised magnetometer.

Figure 3. Cross section of a single MMT unit.

TimePix pixel detectors

TimePix are silicon pixel detectors that can measure the duration that current in each triggered pixel was over a threshold value. This allows for estimates of energy deposition to be made, essential for highly ionising particle detection. The TimePix units are the only "active" detector deployed at MoEDAL and are mainly used for monitoring.

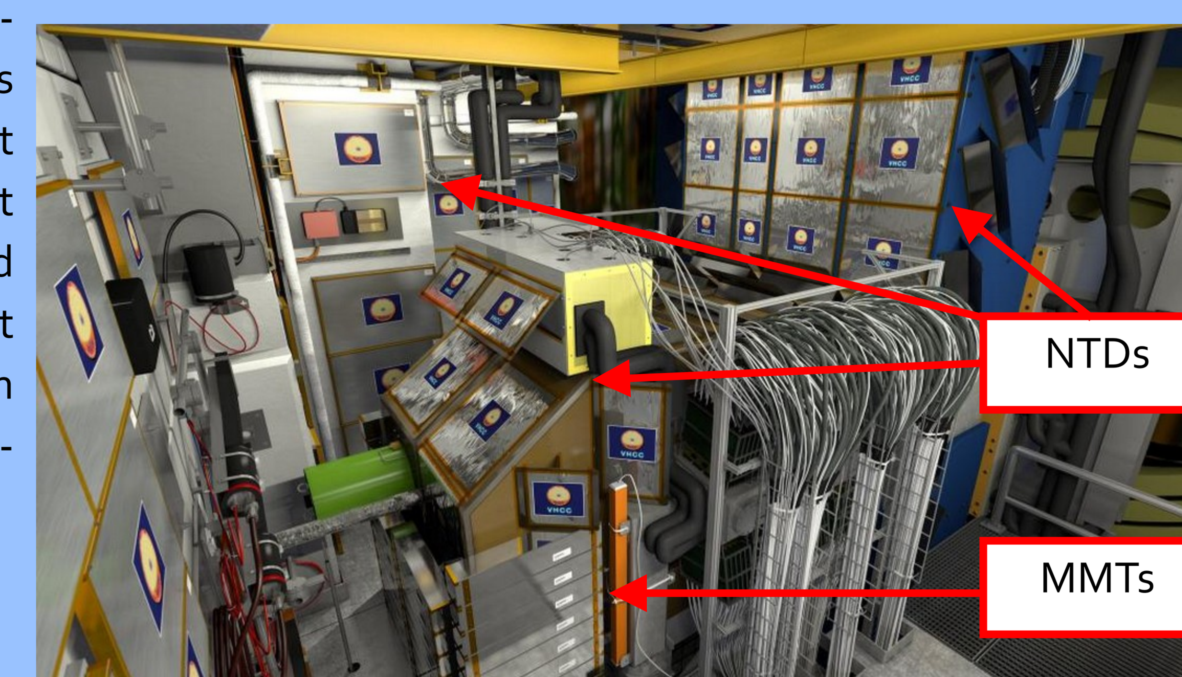


Figure 4. The passive MoEDAL detector elements around the LHCb Velo. (The timepix detectors are too small to be visible)

MoEDAL Simulation

The MoEDAL experiment makes use of the LHCb simulation software (Gauss) to simulate the behaviour of monopoles that may be detected at MoEDAL. The software group is responsible for development of add-ons to Gauss that incorporate the MoEDAL detector and monopole physics processes.

Specifically, MoEDAL software development comprises three main areas:

- Simulation of monopole production
- Description of additional material
- Development of Gauss to simulate monopole propagation

Azimuthal angle (φ) and pseudorapidity (η) are relative to the beam line, where: $\eta = -\ln[\tan(\theta/2)]$

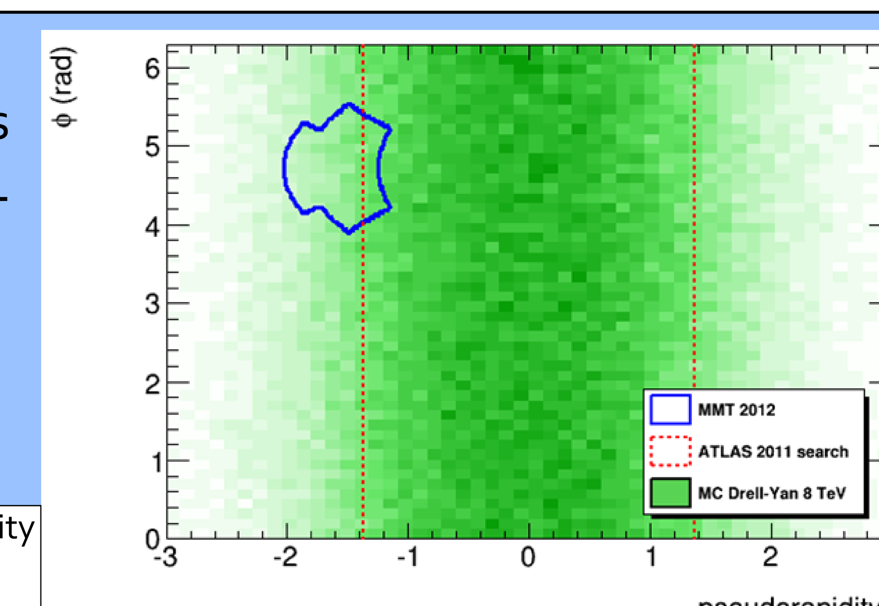
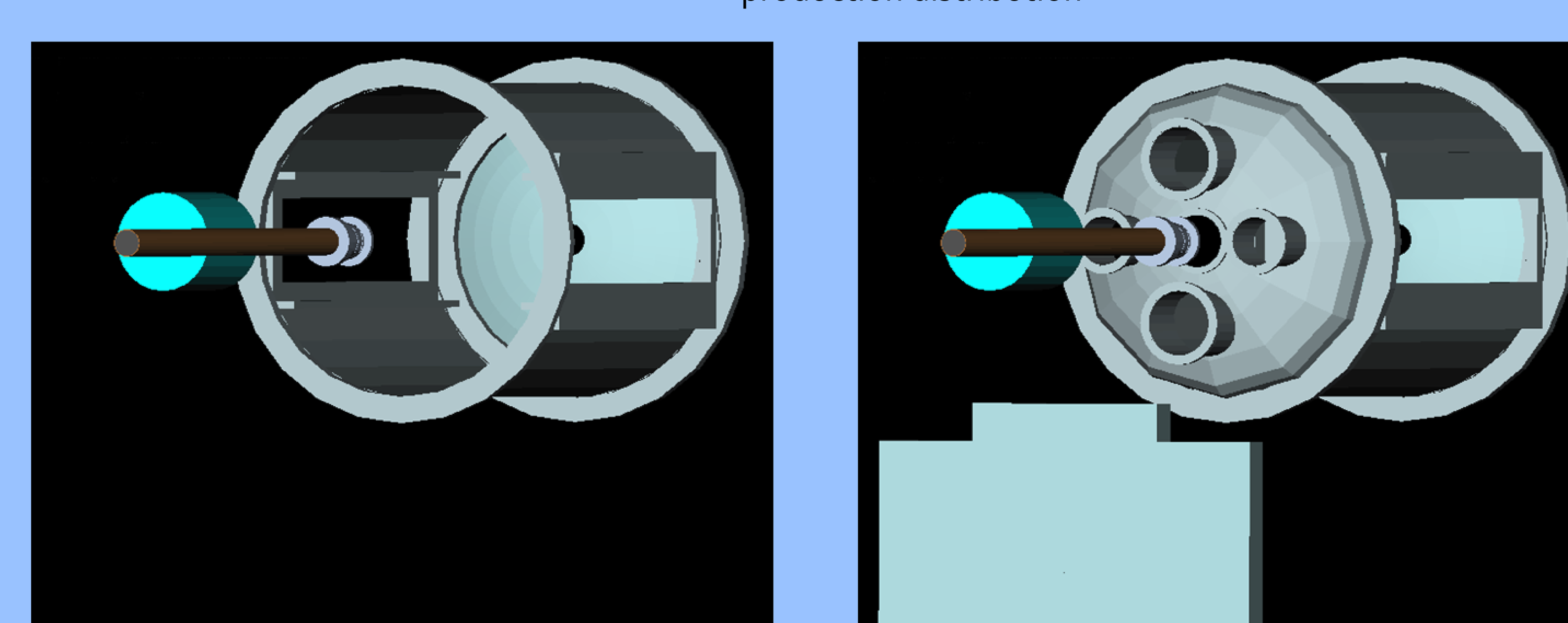


Figure 5. Comparison of the acceptance regions of the MoEDAL MMTs and ATLAS over a Drell-Yan monopole production distribution

Simulation of monopole production

Searches for monopoles have been undertaken previously at ATLAS using a leading order Drell-Yan production model. The acceptance of the MMT detectors in 2012, along with the acceptance region of the 2011 ATLAS search is shown in figure 5. It is clear that the production distribution of the monopoles will greatly affect the acceptance of the MMTs, due to their relatively small acceptance in η and φ.

Various theoretical approaches to monopole production are currently being considered. Some of these models allow for the production of monopolium, a monopole to anti-monopole bound state that may lead to especially interesting effects in the NTD detectors.



(a) (b)

Figure 6. Rendering of LHCb VELO region from (a) default detector description, (b) new detector description with LHCb Velo tank cap and MoEDAL MMT detectors added.

Description of additional material

The default material description used by Gauss was developed for simulation of LHCb and does not include some elements of the infrastructure located on the opposite side of the interaction point. Some of this material lies between the MoEDAL detector elements and the interaction point and must be included in the simulation. Additionally, the MoEDAL detectors themselves must be added to the material description as sensitive detectors. The material added to the simulation thus far is shown in figure 6 and consists of:

- The LHCb VELO upstream tank cap (opposite side of the VELO to the LHCb detector)
- The MMT detector array

Photos of the actual VELO upstream tank cap and MMT arrays are shown in figure 7 for comparison.

Work continues on updating the material description as there remains significant material between the interaction point and the NTD array that is currently unaccounted for in the simulation.

(a) (b)

Figure 7. Photograph of (a) The deployed MMT array; (b) The LHCb VELO tank cap

Development of Gauss to simulate monopole propagation

Gauss uses Geant4 to simulate particle propagation and has an interface system called GiGa (Geant4 in Gauss). In order to simulate monopole propagation a Physics Constructor class was written which, when included in Gauss' modular physics list:

- Adds a new particle definition to Gauss describing the monopole
- Applies Geant4's existing monopole ionisation process to the monopole definition
- Modifies the particle transportation process to include magnetic charge in the equation of motion for magnetic fields

The stopping positions of monopoles produced using benchmark settings of a 1000GeV/c^2 mass and +1 magnetic charge are shown in figure 8.

Further development of the energy loss processes, beyond the Geant4 standard ionisation, may be necessary. Particularly, we require a more accurate description for monopoles with very low velocities.

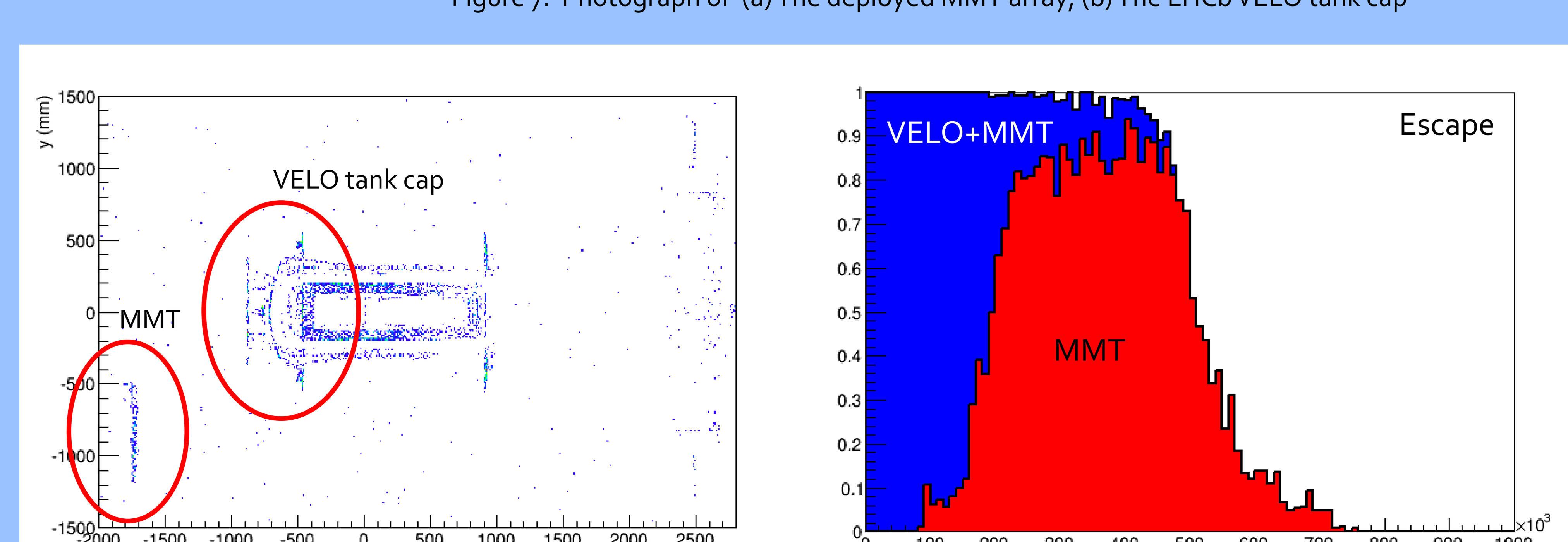


Figure 8. (a) Stopping positions of 300GeV monopoles, produced with a flat ***θ-φ*** distribution, in ***zy***-plane. (b) Fraction of monopoles inside the MMT's geometric acceptance stopped in the MMT (red) and VELO+MMT (blue) against momentum.

Reference: B. Acharya {*et al.*} [MoEDAL Collaboration], "The Physics Programme Of The MoEDAL Experiment At The LHC" (arXiv:1405.7662 [hep-ph])