Sensitivity of Magnetic Monopoles Detection at the Belle II PXD

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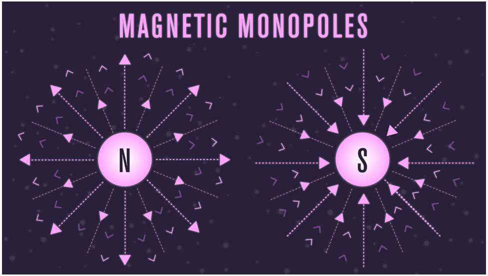
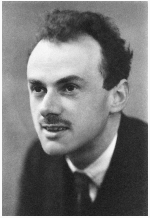
Introduction



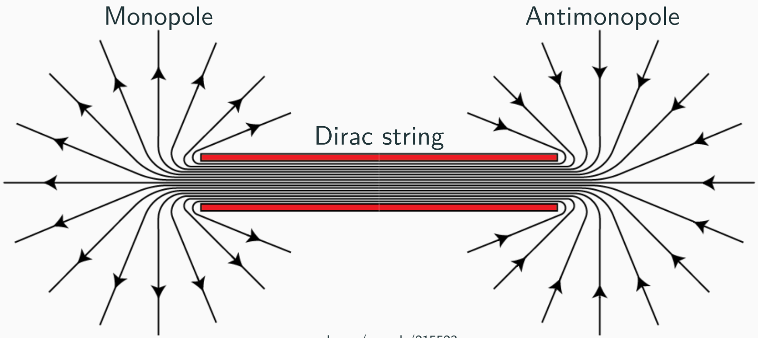
www.symmetrymagazine.org/image/physics-quiz-magnetic-monopoles

- Monopoles are particles with **isolated magnetic charge**
- Gauss' Law for magnetism: $\nabla \cdot B = 0 \rightarrow \nabla \cdot B = \mu_0 \rho_{\mathrm{m}}$
- In 1931 Paul Dirac presented the first modern theory of magnetic monopoles



Paul Dirac
en.wikipedia.org/wiki/Paul_Dirac

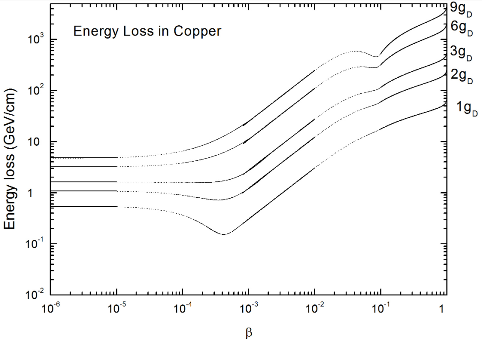
The Dirac Monopole

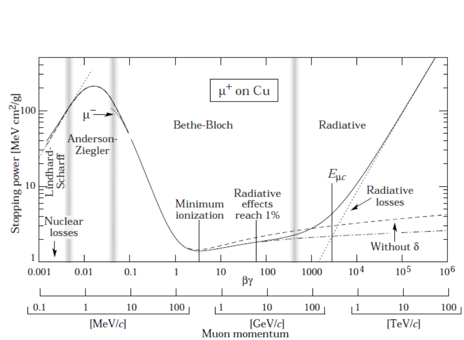


zenodo.org/records/215523

- For the monopole to exits, the Dirac string has to be non-physical
- Monopoles are quantized in quantities of the Dirac charge: $g_{\mathrm{D}} = 68.5\,\mathrm{e}$
- From the existence of magnetic monopoles follows that the electric charge has to be quantized

Energy loss in matter





Energy loss for monopoles.

Cecchini, S. et al. (2016). Energy Losses of Magnetic Monopoles in Aluminum, Iron and Copper. arXiv. https://doi.org/10.48550/arxiv.1606.01220

Energy loss for μ^+.

https://www.researchgate.net/figure/The-Bethe-Bloch-forumula-for-positive-muons-in-copper-as-a-function-of-bg2-shown_fig7_48410683

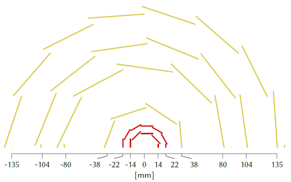
- The energy loss for monopoles are much higher than for electrically charged particles

Simualtion

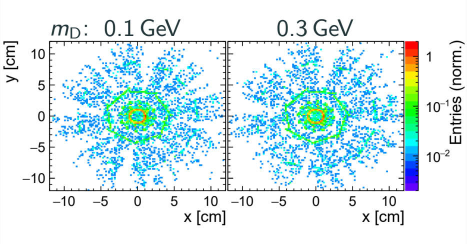
- The simulation is done with Belle II Software Framework (basf2)
- A monopole anti-monopole pair is created at the interaction point with opposite momenta
- The monopoles do not decay, they rather just stop in matter

Search Strategy for Dirac Monopoles

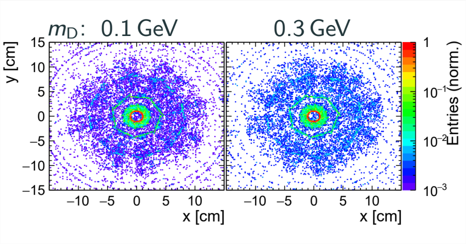
- The flight length of monopoles is limited to inner most subdetector, the pixel detector (PXD)
- Indirect detection of monopoles via the signal of secondary particles



Structure of the PXD and SVD



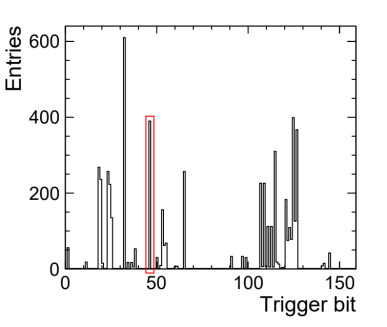
Stopping vertex of monopoles



Production vertex of secondary particles

Trigger Efficiency

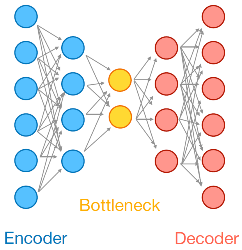
- Secondary particles are the signal and generate a level 1 trigger
- Trigger bit 46 is defined as:
  - Back to back energy deposition in the electromagnetic calorimeter (ECL)
  - Each ECL cluster fulfills $E < 1\text{GeV}$
- The efficiency for this trigger bit is between 0.01% ($m_{\mathrm{D}} = 0.3\,\text{GeV}$) and 3% ($m_{\mathrm{D}} = 0.1\,\text{GeV}$)
- Background in this trigger line:
  - Muons from $e^+e^- \to \mu^+\mu^-$
  - Beam background
- The background can be reduced with a neuronal network, an autoencoder

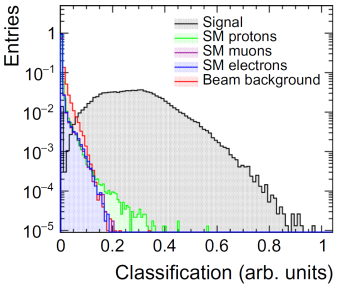


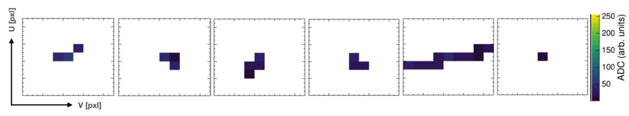
Trigger lines of secondary particles for $m_{\mathrm{D}} = 0.1\,\text{GeV}$

Autoencoder

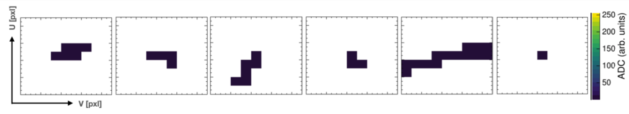
- The autoencoder (AE) is a multi level perceptron with bottleneck
- The AE extracts the main features of the input
- The monopole is considered an anomaly and the AE fails to recreate the input
- We assume that we can reject the background by a factor of 10^{-6} while still keeping 24% of monopoles







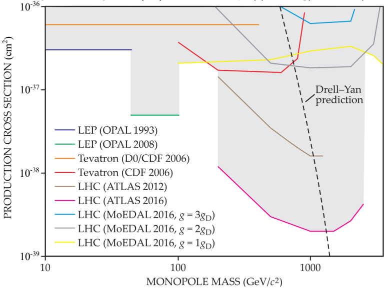
Input of the AE



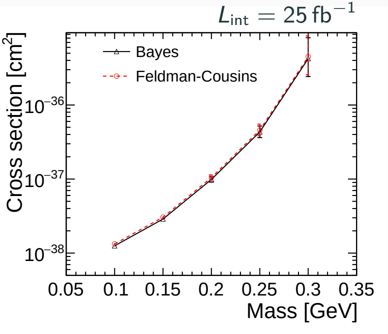
Output of the AE

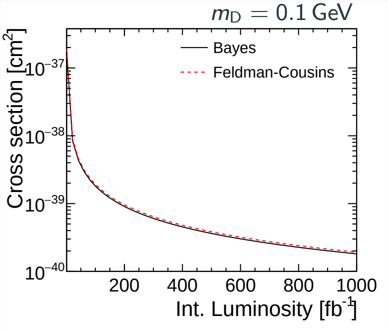
Results

Rajantie, A. (2016). The search for magnetic monopoles. *Physics Today*. **69** (10): 40–46. https://doi.org/10.1063/PT.3.3328



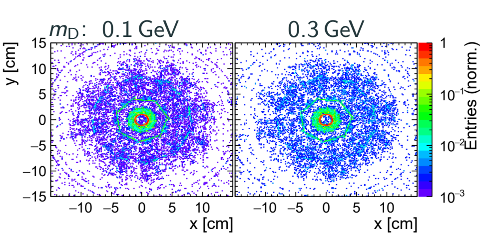
- The exclusion limits can be calculated with the Bayes or Feldman-Cousins approach $CL = \frac{s_{\mathrm{up}}}{L_{\mathrm{int}} e_{\mathrm{tri}} e_{\mathrm{sup}}}$
- The exclusion limits are competitive to the established limits





Summary

- Belle II is sensitive to Dirac monopoles
- Monopoles can be detected via secondary particles that are created from the interaction with the detector material
- Using a neuronal network the background can be suppressed while keeping a large section of the signal
- The exclusion limits are competitive to other experiments, extending the sensitivity to lower energies by two orders of magnitude



Production vertex of secondary particles