Monopole pair production in high energy collisions

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Outline

Introduction

Aim to calculate monopole/antimonopole pair production from high energy scattering.

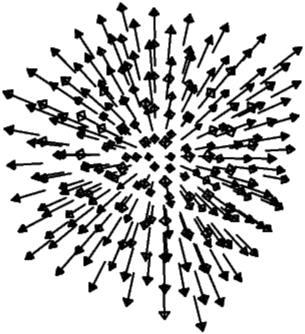

Figure: Higgs field of 't Hooft-Polyakov monopole, or hedgehog.[1]

[1] Image: 't Hooft - Monopole, Instantons and Confinement (2000) hep-th/0010225

Motivation I

Magnetic monopoles are theoretically important

- Their existence implies electric charge quantization, $\exists \mathrm{M} \Rightarrow q/e \in \mathbb{Z}$.
- Predicted by all grand unified theories with semi-simple gauge groups $G \rightarrow SU(3) \times SU(2) \times U(1)$.
- Predicted also by string theory.

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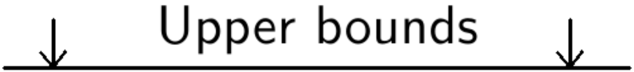
But experimentally unobserved...

Motivation II



Experimental searches - upper bounds

- Observed galactic magnetic field gives *Parker bound* - upper bound on number density in glaxay.
- Comsic ray searches, notably MACRO - upper bound on monopole flux on earth.
- Collider experiments, notably the LHC - upper bound on cross section.

Motivation III

The pair production cross section, $\sigma_{\mathrm{M\bar{M}}}$

- $\sigma_{\mathrm{M\bar{M}}}$ is unknown and theoretical estimates differ wildly.
- $\sigma_{\mathrm{M\bar{M}}}$ is needed to connect theory with collider experiments.
- New dedicated magnetic monopole collider search MoEDAL, at the LHC, begins 2015.

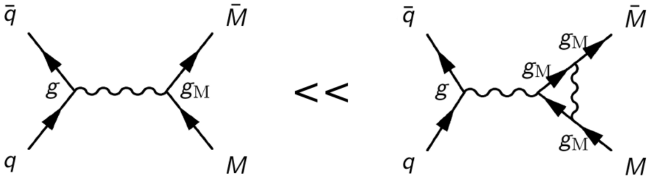
Background I

Magnetic monopoles couple strongly

The minimal magnetic charge is, according to the Dirac condition

$$g_{\mathrm{M}} = 2\pi/q_0, \tag{1}$$

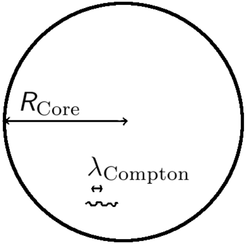
where q_0 is the minimum electric charge (of asymptotic particles). Hence the magnetic analogue of the fine structure constant is large, $\alpha_{\mathrm{M}} = \pi/\alpha \approx 430$ and perturbation theory will fail.



Background II

't Hooft-Polyakov monopoles

These classical monopole solutions have a finite sized core, $R_{\rm Core}$, and a finite mass, $M = \lambda_{\rm Compton}^{-1}$. The monopole is large compared with its Compton wavelength, $R_{\rm Core}/\lambda_{\rm Compton} \sim 1/\alpha \gg 1$.



Hence a semiclassical description is valid.

Exponential suppression

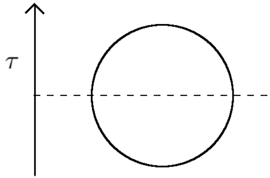
Semiclassical arguments for exponential suppression of cross section (Drukier and Nussinov '82)

- Form factor suppression due to large size of magnetic monopoles $e^{-4R/\lambda_{\rm Compton}} \sim e^{-4/\alpha}$.
- Monopole can be seen as a bound state of $\sim 1/\alpha$ Higgs and $\rm W^{\pm}$ bosons, so pair production requires going to order $2/\alpha$ in perturbation theory and hence the cross section is suppressed by $e_{\rm Q}^{4/\alpha} \sim e^{-4/\alpha}$.

Pair production in a magnetic field I

Affleck and Manton '82

Magnetic field, B, makes distant monopole/antimonopole pair lower in energy than vacuum. Hence the pair production rate equals the vacuum decay rate, which is dominated by a monopole loop instanton.



$$\Gamma_{\mathrm{M}} = \frac{g_{\mathrm{M}}^2 B^2}{8\pi^3} e^{-\pi M^2/g_{\mathrm{M}} B + g_{\mathrm{M}}^2/4} \left(1 + O\left(\frac{g_{\mathrm{M}}^3 B}{M^2}\right) + O(e^2)\right). \quad (2)$$

Pair production in a magnetic field II

How to extend result to scattering initial state?

- For small initial state energies could consider perturbations about vacuum instanton but need large energies to overcome kinematic barrier.
- A naive semiclassical approach will not work as the initial *hard* state is not semiclassical.

Semiclassical T/θ method I

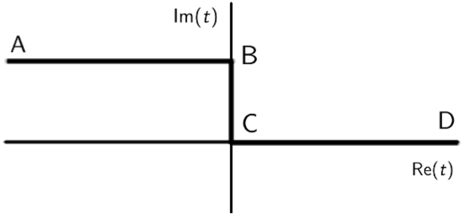
Semiclassical method developed for similar circumstances by Rubakov, Son and Tinyakov '92. Idea is to:

1. Replace 2 particle initial state with semiclassical $N = \nu/g^2$ particle initial state.
2. Calculate rate semiclassically by solving classical boundary value problem.
3. Consider $\nu \to 0$ limit. If this is smooth then the 2 particle rate is given by this limit. If not the $\nu \neq 0$ rate is still an upper bound on the 2 particle rate.

Semiclassical T/θ method II

Boundary value problem

Boundary value problem is formulated on the complex time contour ABCD. It has non-local, non-holonomic, non-linear boundary conditions which makes it difficult to solve analytically. However one can discretise the spacetime and solve it numerically.



Conclusions

1. The pair production rate for monopole/antimonopole pairs from high energy scattering is not well understood.
2. However a numerical, semiclassical calculation should be possible.
3. This is what I am currently working on. Watch this space...