# Magnetic Monopoles are running in CMS detector
# A study on monopole with Monte Carlo

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## Abstract

Magnetic monopoles and monopolium are studied using Monte Carlo (MC). Monopoles events in Heavy ion (Pb-Pb) collision at 5.02 TeV are generated with SuperChic 3.03. Dirac coupling and βg coupling are implemented in both monopole pair production and monopolium production. The reconstruction of MC events with the CMS detector is performed using Geant4. Searching monopolium and monopole in CMS data with lower mass limit ~500GeV for magnetic monopole are now possible in the framework we provided.

## Introduction

The existence of magnetic monopole would provide an explanation for the quantization of electric charges provided by Dirac. However, all experimental searches for magnetic monopole have met with failure, to lower mass limit ~350GeV. The challenge on searching in higher mass limit is due to the large coupling constant and mass, it requires non-perturbative treatment which currently has no successful universal theory. We investigated monopolium and monopole production with in CMS at MC level, mainly focused on mass limit ~933GeV and ~500GeV for monopolium and magnetic monopole respectively. Dirac coupling and βg coupling are used in generating MC events with the lowest order as shown in Fig.1, where β and g are the velocity and the coupling constant of magnetic monopole respectively.

In the monopolium study, the invariant mass are calculated by studying the diphoton, the main decay channel of monopolium.
In the monopole pair study, as magnetic monopole has high ionizing power, pixel track response are studied, and are compared with muon pair production.

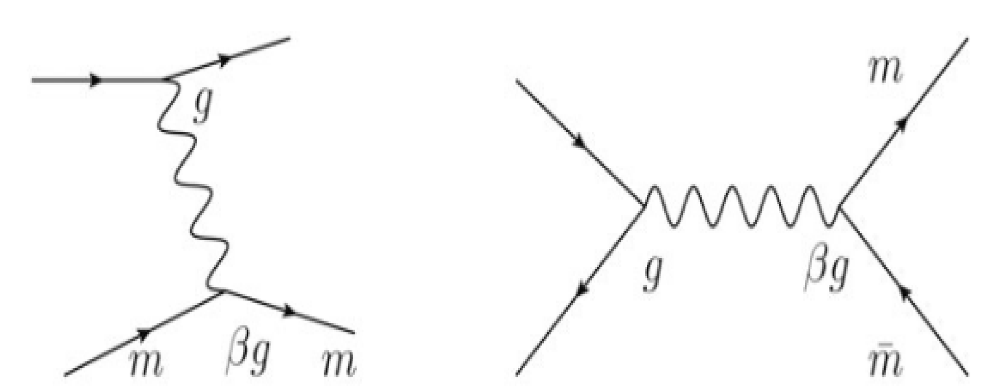

Fig.1. The feynman diagram for βg coupling with monopole-monopole interaction(left) and monopole-antimonopole interaction(right)

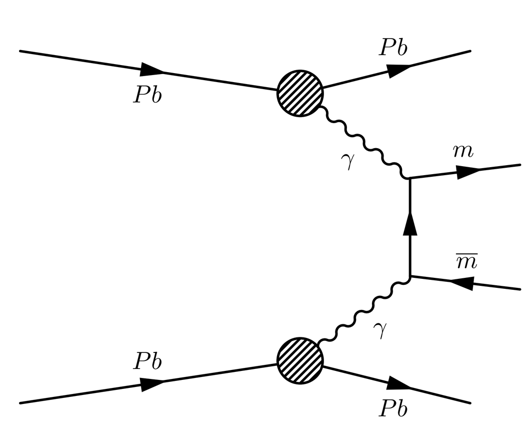

Fig.2. The lowest order Feynman diagram for photon induced monopole pair production in Pb-Pb collision.

## Interest

Monte Carlo monopolium and monopole pair production events are generated with SuperChic3.03. The mass limit are chosen according to current research limit and the theoretical calculation on bounding energy of monopolium E=2*mass/15. The interested coupling are known for analog of standard QED for Dirac coupling, and duality transformed positron interacting with electron for βg coupling.

## Simulation level

We found that the transverse momentum of monopole and diphoton are generally greater in βg coupling as shown in Fig.3.

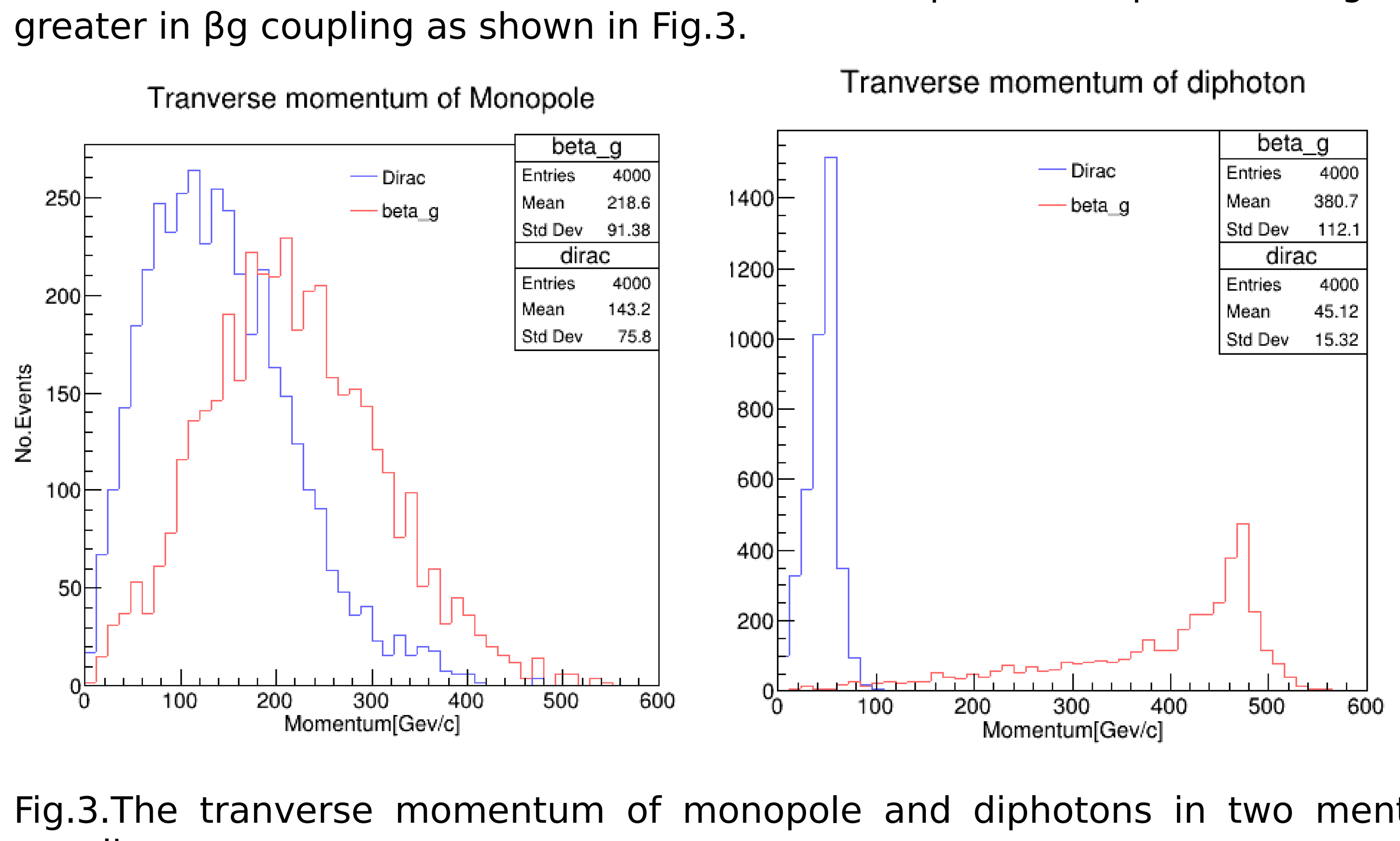


Fig.3.The tranverse momentum of monopole and diphotons in two mentioned coupling.

Rapidity distributions are shown in Fig.4. Two peaks are observerd in rapidity for monopole, Phi (azimuthal angle, not plotted) is having a uniform distribution because of cylindrical symmetry.

## Simulation level

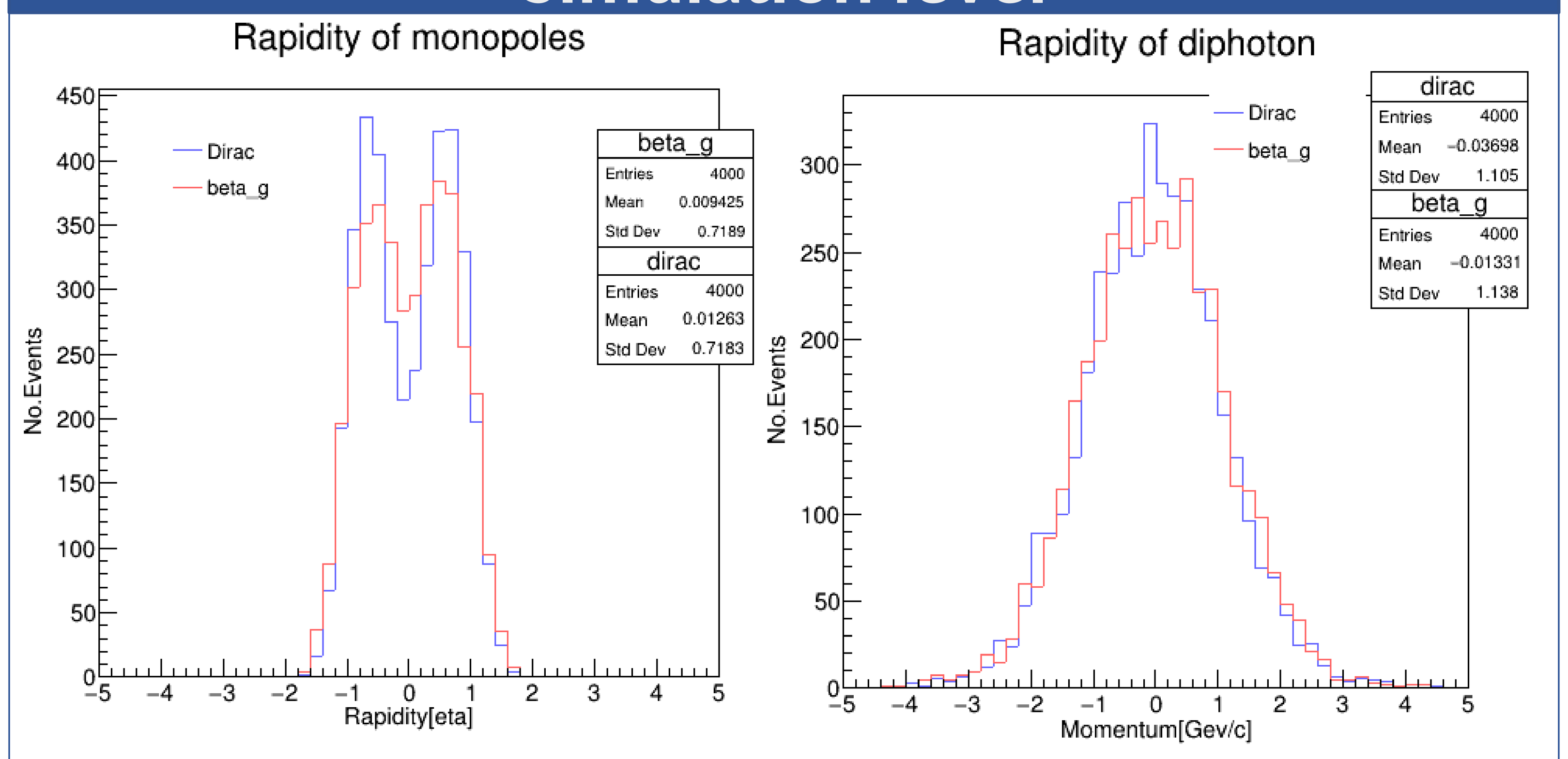


Fig.4. Eta distribution for monopole (left) and monopolium (right)
To understanding the peaks, Pt and eta for monopole with different mass are shown in Fig.5.

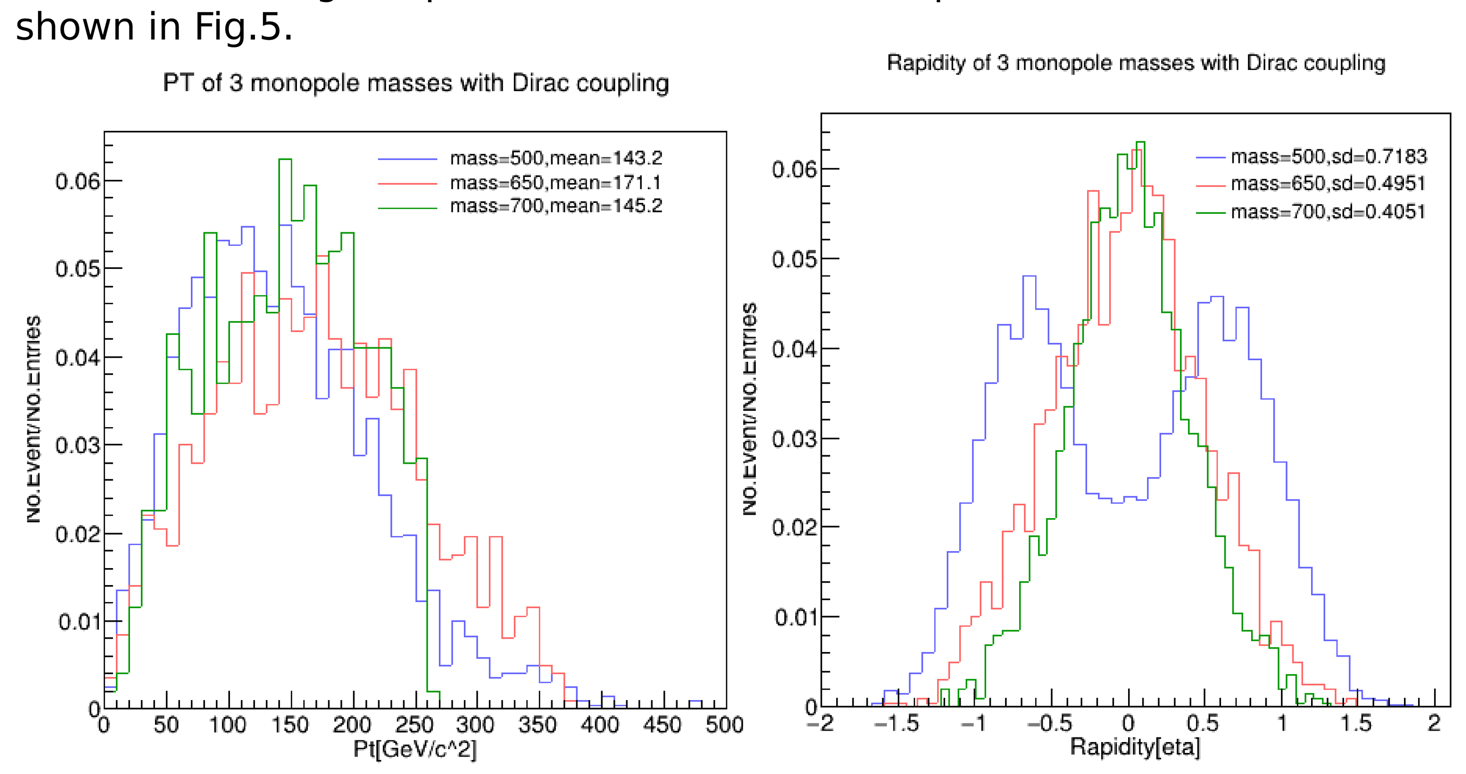


Fig.5. momentum and rapidity distribution with different mass for monopole.

## Reconstruction level

The reconstruction is done by GEANT4 with above generated events as input.The difference in invariant mass may due to the non-perturbative calculation that the coupling strength and mass are momentum dependent, unexplained behavior happens especially when the virtual particle is out of mass shell.

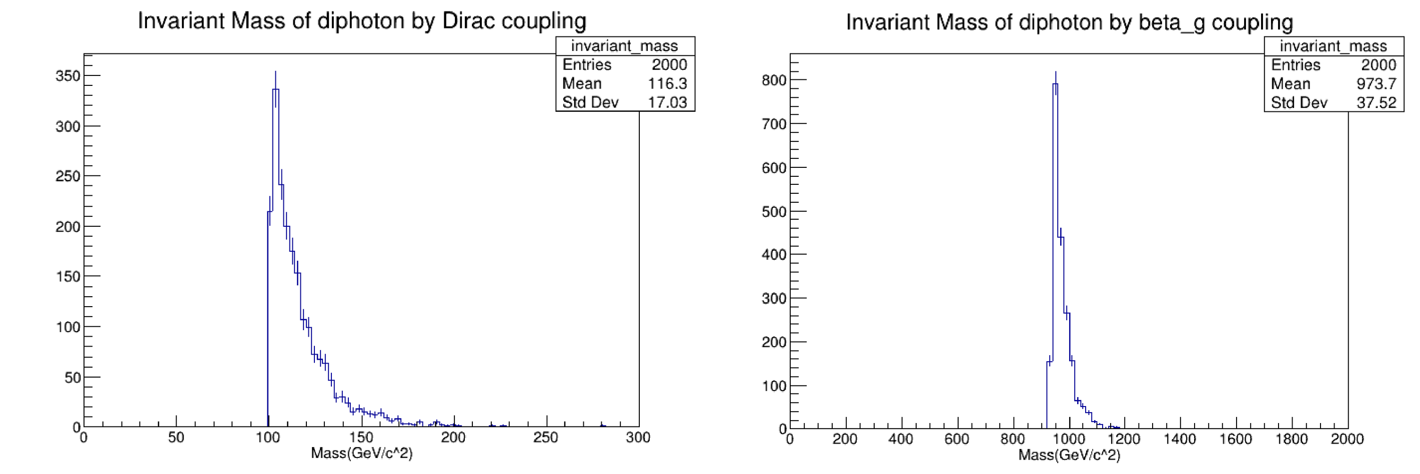


Fig.6. Diphoton invariant mass in reconstruction level for the two couplings.
To identify monopole from other track we see that monopole would have great charge to cluster size ratio comparing to non-collision data and muon pair production.

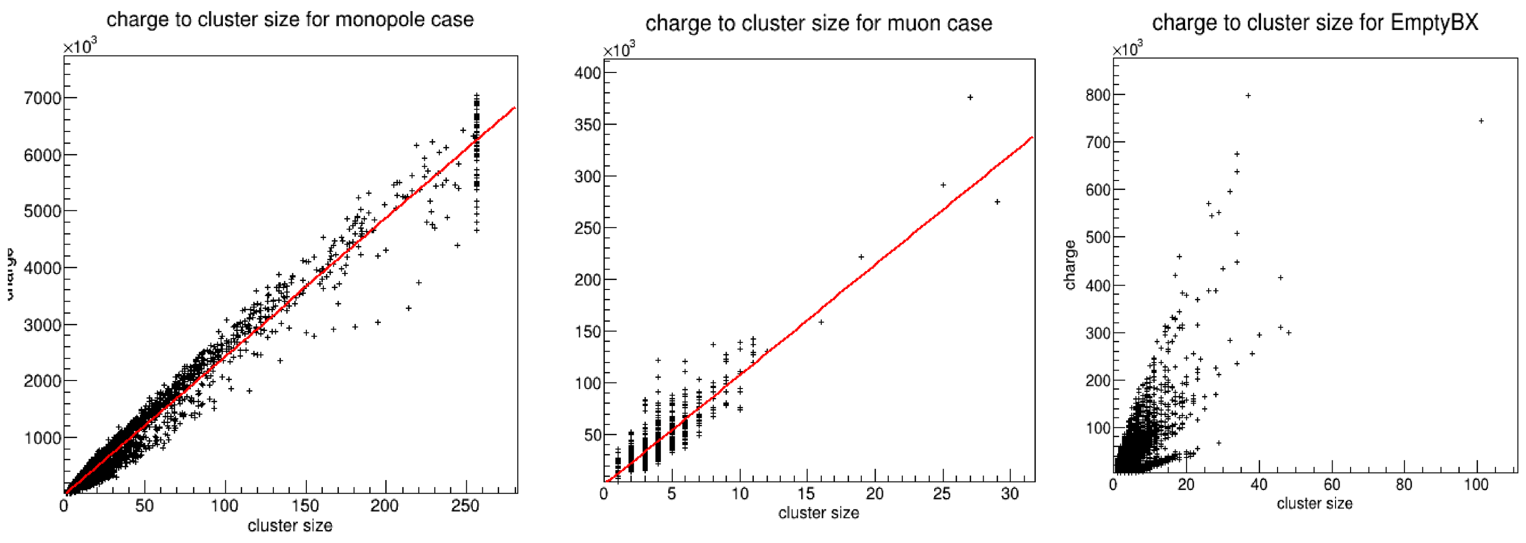


Fig.6. Charge to cluster size, for monopole (left) and dimuon (center) simulation, and non-collision data (right).
The charge to cluster size ratio shows a non linear behavior for background. However, one can focus on large cluster size since pixel track also sensitive in large cluster size and have less fake signal.

## Discussion

We have studied the behavior of magnetic monopole and monopolium at simulation level and reconstruction level. From eta distribution of monopole we see that the distribution from 2 peaks merge to center when the mass of monopole increase, implying the simulation vary significantly according to mass. Furthermore, more theoretical treatment is needed to understand the dependence of mass in non-perturbative regime We also studied the charge to cluster size ration in Pixel detector, high ratio is expected for monopole case. The muon and non-collision data can regard as background information and having great different with monopole case.