Monopole searches in PbPb collisions at sqrt(s)=5.02 TeV

H.C. Lau[a)]

(Dated: 25 September 2019)

Study of magnetic monopoles and monopolium is performed in Monte Carlo(MC). Monopole events in Heavy ion (Pb-Pb) collision at 5.02 TeV are interesting, and are generated with SuperChic 3.03. Dirac coupling and βg coupling[1] are implemented in both monopole pair production and monopolium production. MC events reconstruction at CMS detector are performed by GEANT4. No evidence of existence of monopole or monopolium is found under analysis with forward triggered data and non colliding data at monopole mass 500GeV.

I. INTRODUCTION

The existence of magnetic monopole would provide an explanation on quantization of electric charges provided by Dirac. However, all experimental searches for magnetic monopole have met absence of observation, to lower mass limit 350GeV[2]. 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 focusing on brenchmark 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. MC 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[2] .

In the monopolium study, the assumption that monopolium must decay into diphoton which is the main decay channel is made, and the invariant mass is calculated. A large difference has been found between the diphoton invariant mass and the monopolium mass given to the generator.

In the monopole pair study, stable monopole assumption is made. Because magnetic monopoles have a high ionizing power, pixel detector response are studied, and are compared with that of muon pair production. The difference between detected charges to cluster size ratio can be used to identify magnetic monopole signal.

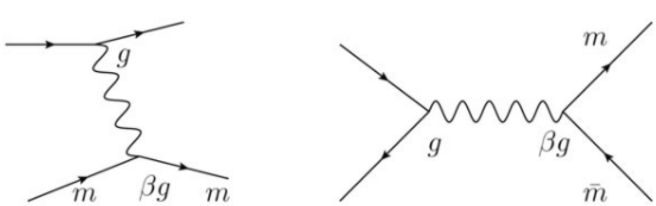

FIG. 1. The feynman diagram for βg coupling with monopole-monopole interaction(left) and monopole-antimonopole interaction(right)[2]

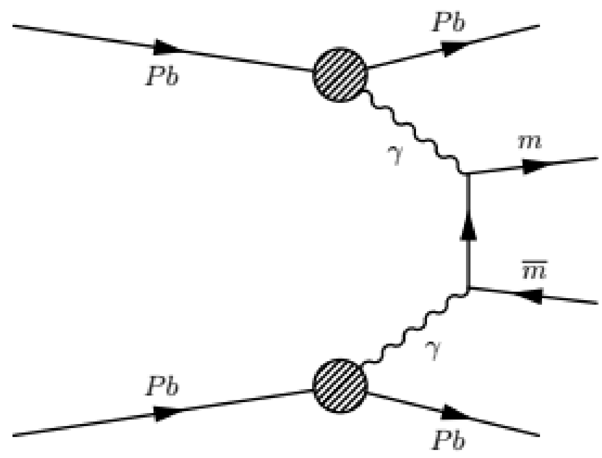

FIG. 2. The Feynman diagram shows 2 Pb ions produced 2 photons to induce the monopole pair production. Monopolium is formed if the pair form bonding.

II. SIMULATION LEVEL

Monte Carlo monopolium and monopole pair production events are generated with SuperChic3.03 with photon induced production as shown in Fig.2. The mass limit are chosen according to current research limit and the theoretical calculation on bounding energy of monopolium $E = 2 * MonopoleMass/15$[2]. The interested coupling are known for analog of standard QED for Dirac coupling, and duality transformed positron interacting with electron for g coupling[3].Fig.6 to Fig.11 (see appendix) show the kinematics of monopole and single photons. We found that the transverse momentum of monopole and photons are generally greater in g coupling as shown in Fig.8 to Fig.9. Rapidity distribution in monopole distribution having centered crest are expected due to massive particle, while that of photon distribution are normally distributed for massless particle. The azimuths angle distribution Phi are uniform for both case by cylindrical symmetry, shown in Fig.10 to Fig.11.

a) Also at Physics Department, The Chinese University of Hong Kong.

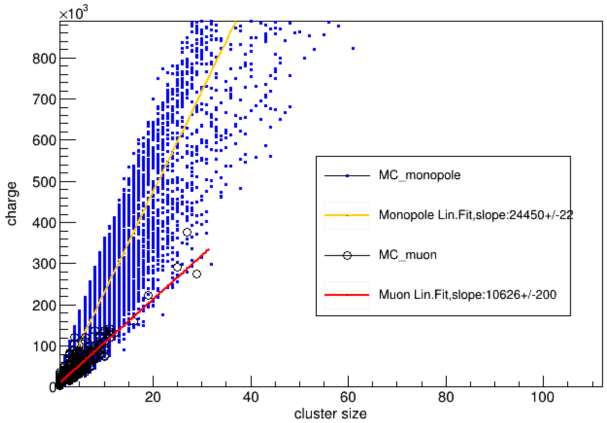

FIG. 3. Distribution of charge versus cluster size. The significant slope difference shows characteristics of strong ionization power of monopole.

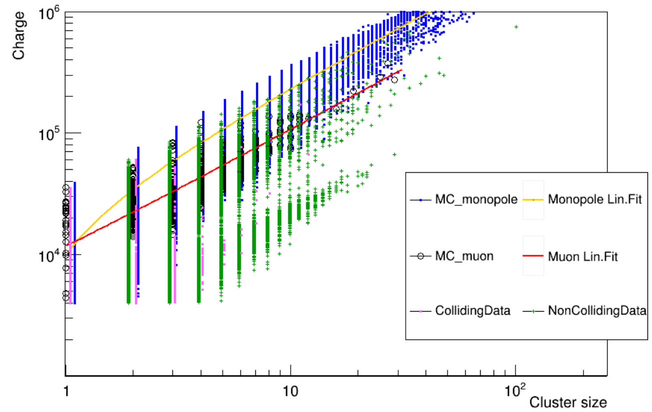

FIG. 4. Comparison of charges to cluster sizes between MC monopole, MC muon, non colliding data and forward triggered data

III. RECONSTRUCTION LEVEL

The reconstruction is done by GEANT4 with the generated events as input. For monopolium as shown in Fig.7(see appendix), we explicitly investigated the photonic signal in Electromagnetic Calorimeter to calculate the invariant mass. We found that the invariant mass of diphoton are much smaller than the setting in Dirac coupling. This 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[3]. While in βg coupling the invariant mass are close to setting.

For the monopole pair, high ionization behavior is expected in CMS response. Pixel detector is studied, especially for the charge received and activated cluster size. To identify monopole from other tracks we see that monopole would have high charge to cluster size ratio, while in other lepton production(Muon) with same process, the pixel detector responses are comparatively smaller as shown in Fig.3. The non-colliding data are taken as the background. It does not behave linearly, however, one can focus on large cluster size regime that background and other processes do not leave track.

By comparing the forward triggered data, non colliding data, MC muon and MC monopole charges to cluster size in Fig.4, we see that we have no confidence on concluding the existence of monopole or monopolium. The region having forward triggered data are also dominanted by non colliding data, thus the there are no strong data signal in MC monopole dominant region.

IV. MONOPOLE STRATEGY SEARCH

To analyze the sensitivity of CMS detector to magnetic monopole, we defined a background dominated charge to cluster size region by referencing to non-colliding data, the charge < 70000 and the cluster size < 50. The efficiency of generating MC event accepted outside background dominated region is 2.9%. We have run SC3.03 with 50 GeV/c^2 accenting monopole masses over 350 GeV/c^2 to 750 GeV/c^2. Photon-photon fusion leads to exponentially decreasing cross section as a function of mass. Assuming the reconstruction efficiency is mass independent, using HiggsCombine tools the 95% confidence level upper limit on monopole pair production as a function of mass is obtained. For the collected PbPb luminosity of 1.6nb^{-}1, we would exclude monopole masses below 384 GeV/c^2 as shown in Fig.5.

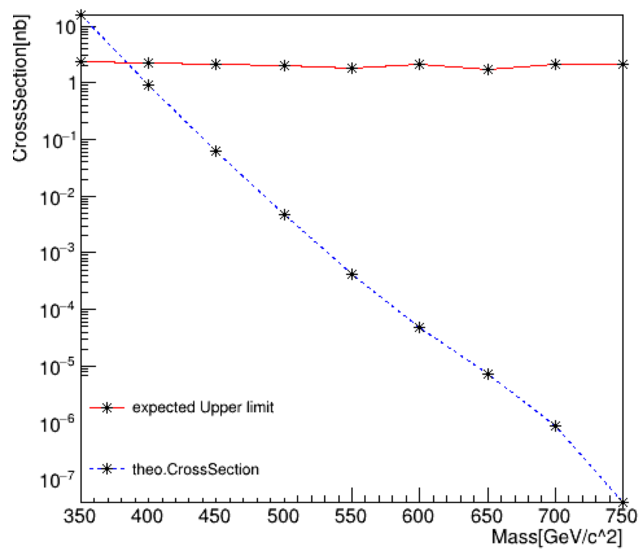

FIG. 5. The intersection point at 384GeV/c^2 imply 95% confidence level that mass below could be excluded.

V. DISCUSSION&CONCLUSION

We have tried to find the existence of monopole and monopolium in forward triggered data of heavy ions collision. From SC3.03 generated events, we also observed unexpected missing invariant mass for monopolium and missing momentum for monopole in Dirac coupling. To have rigid analysis, finding the reason for missing energy and the missed value is needed. From the reconstruction, we saw the connection between charge to cluster size ratio but unfortunately there was no evidence of finding either monopolium or monopole in forward triggered data. The study are limited by the range of pixel track, if the range of study is widen it is expected that the track would become more obvious since the magnetic properties of the particle would bent the path and leave unique track. By considering the full tracker, we expect to be able to reconstruct anomalous tracks with a trajectory dictated by the magnetic charge of the particle. When studying the geometries of track which is not presented we observed that current seed algorithms to identify tracks and hits in pixel detectors are not sufficient. The great ionization power created a lot of hits at vicinity point of monopole which faked the algorithms many tracks are observed in the same point. This hindered us to study the ratio of number of hits and number of tracks, which is also expected to be an indicator of monopole.

This work could only be the first step on analyzing the data on monopole and monopolium. One should note the study are performed without the information on cross section of monopole and monopolium production in Pb-Pb collision. The true monopole signal received by CMS may be hindered by small cross section of monopole created particles. Furthermore, there were unconsidered background and data that would be signal candidate, further study is needed.

ACKNOWLEDGMENTS

We wish to acknowledge the support from Dr.Emilien Chapon and Dr.David d'Enterria, they guided the author throughout the internship at CERN.

VI. REFERENCE

[1] L. Harland-Lang, *SuperChic v3.03 A Monte Carlo for Central Exclusive Production User Guide* (2019).
[2] V. A. Mitsou, L. N. Epele, H. Fanchioti, V. Vento, and C. A. G. Canal, Eur.Phys.J.Plus **127**, 60 (2012).
[3] M. J. Mulhearn, *A direct search for Dirac magnetic monopole*, Ph.D. thesis, Massachusetts Institute of Technology (2004).
[4] The MoEDAL collaboration, arXiv:1903.08491v2 (2019).

VII. APPENDIXES

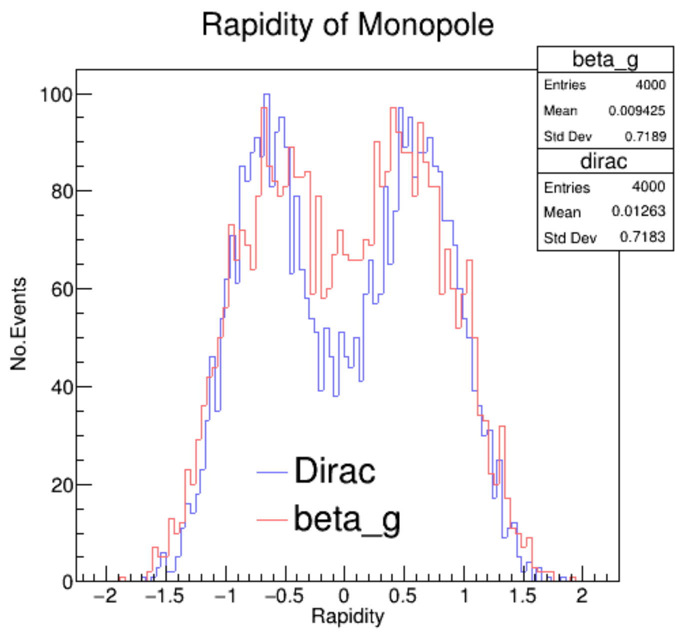

FIG. 6. Rapidity of Monopoles with two coupling. The mass of monopole created a crest in middle.

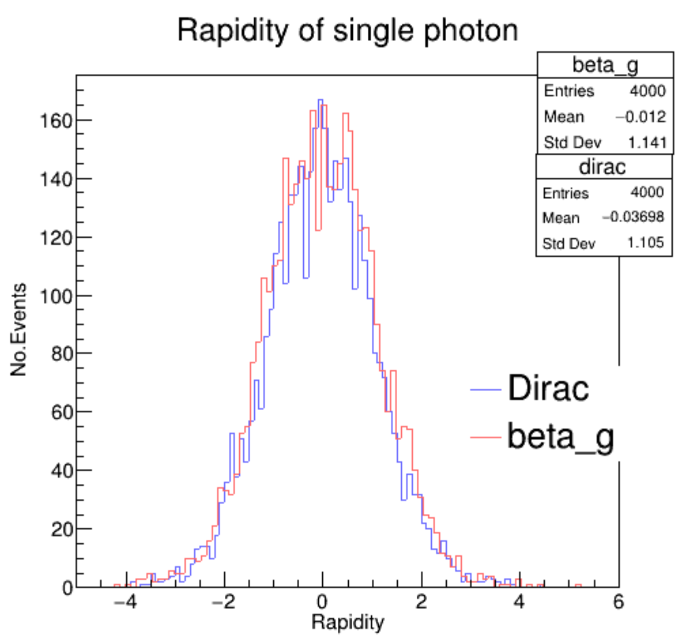

FIG. 7. Rapidity of photons with two coupling. Normal distribution are expected for massless particle

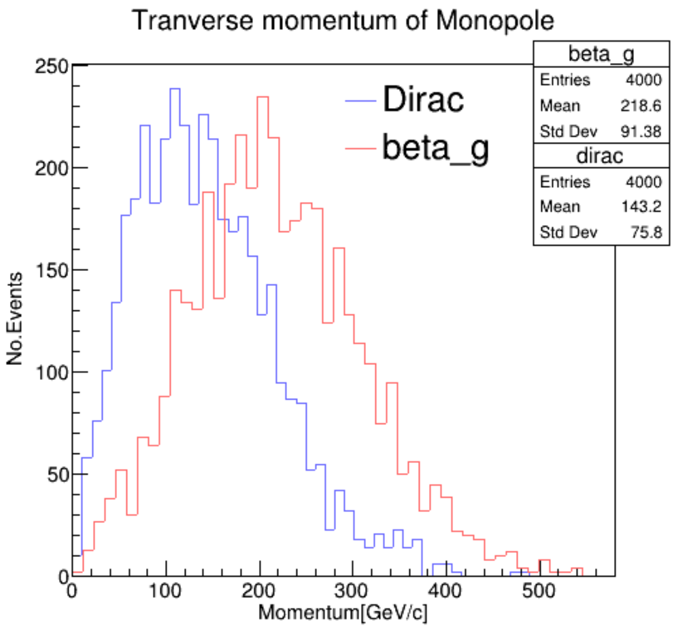

FIG. 8. The transverse momentum of monopole, different from Fig.9 two coupling has closer mean momentum.

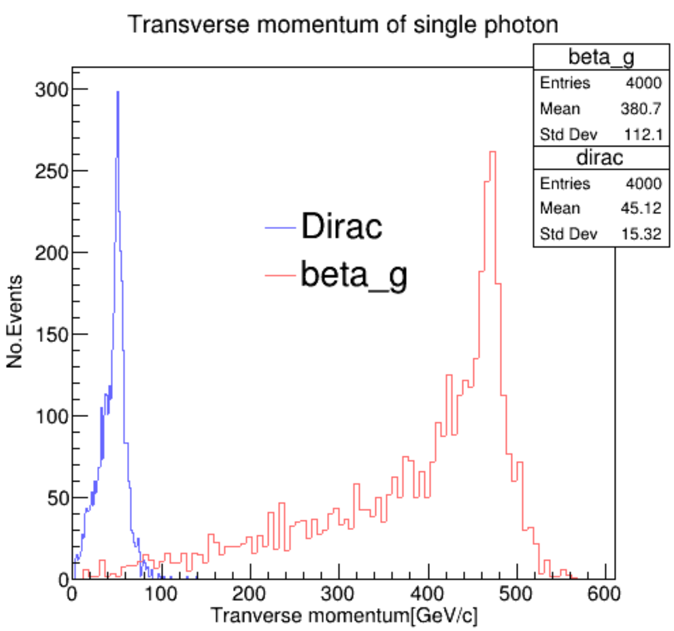

FIG. 9. The transverse momentum of Dirac coupling are unexpectedly small, this requires more investigation.

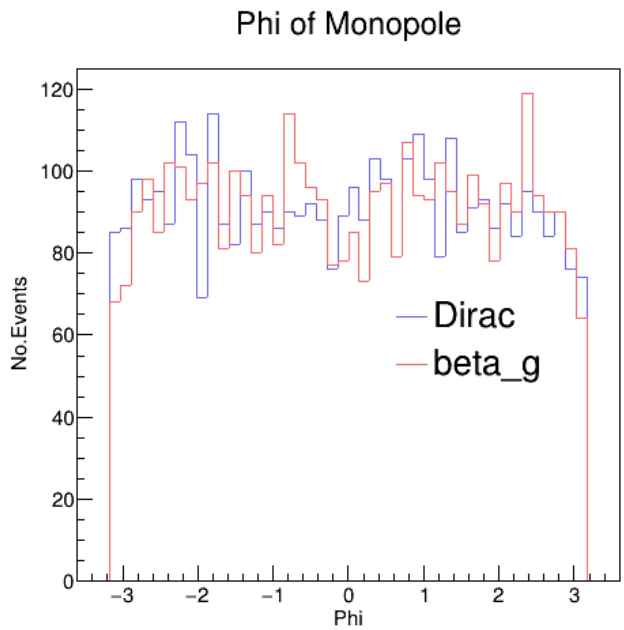

FIG. 10. Phi distribution of monopole, uniform distribution are expected because of cylindrical symmetry

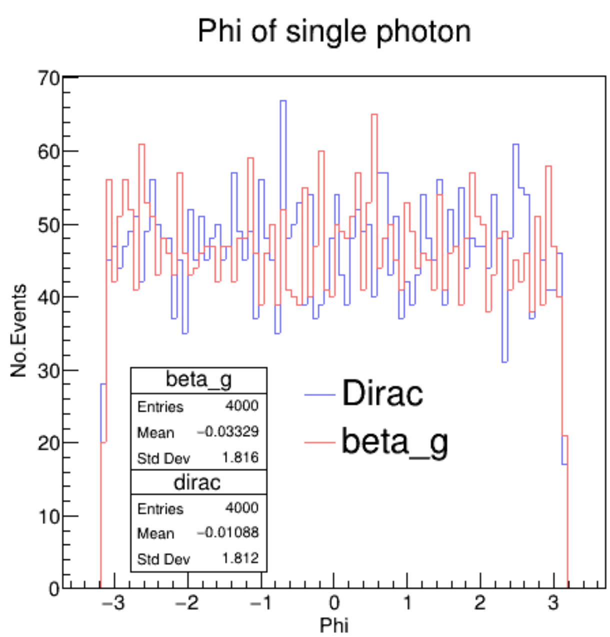

FIG. 11. Phi distribution of photons, uniform distribution are expected because of cylindrical symmetry