Searches for monopoles in PbPb collisions at 5.02 TeV

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Motivation – Why Searching for Monopoles?

1. **Monopoles provide a natural explanation for the quantization of electric charge (Dirac):**
   $ge = n\hbar c/2$
2. **Monopoles naturally symmetrize Maxwell's Equations:** Rotation invariant on (E,B) plane

Name	Without magnetic monopoles	With magnetic monopoles
Gauss's law	$\nabla \cdot \mathbf{E} = 4\pi\rho_\mathrm{e}$	
Gauss's law for magnetism	$\nabla \cdot \mathbf{B} = 0$	$\nabla \cdot \mathbf{B} = 4\pi\rho_\mathrm{m}$
Faraday's law of induction	$-\nabla \times \mathbf{E} = \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}$	$-\nabla \times \mathbf{E} = \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_\mathrm{m}$
Ampère's law (with Maxwell's extension)	$\nabla \times \mathbf{B} = \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_\mathrm{e}$	
Lorentz force law[23][24]	$\mathbf{F} = q_\mathrm{e}\left(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B}\right)$	$\mathbf{F} = q_\mathrm{e}\left(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B}\right) + q_\mathrm{m}\left(\mathbf{B} - \frac{\mathbf{v}}{c} \times \mathbf{E}\right)$

Credit to wikipedia

Searches for monopoles

Properties:

Charge: 1 std. Dirac magnetic charge = 68.5 electron charges

Coupling strength: $\alpha = e^2/\hbar c = 1/137 \quad \alpha_g = g^2/\hbar c = 34.25$

Mass: 350 GeV – 1800 GeV

Spin: It can be scalar (0) or fermion (½).

Lifetime: Assumed stable. (Monopolium decays to diphotons)

Dedicated searches in pp at the LHC (mostly Moedal): Drell-Yan and photon-fusion:

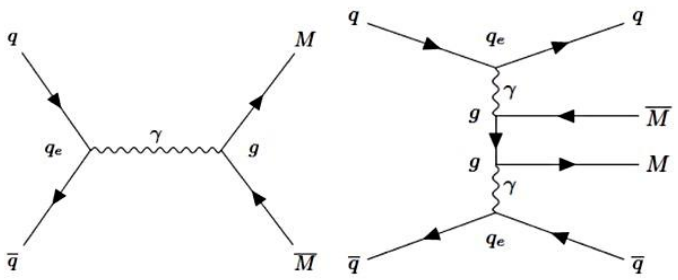
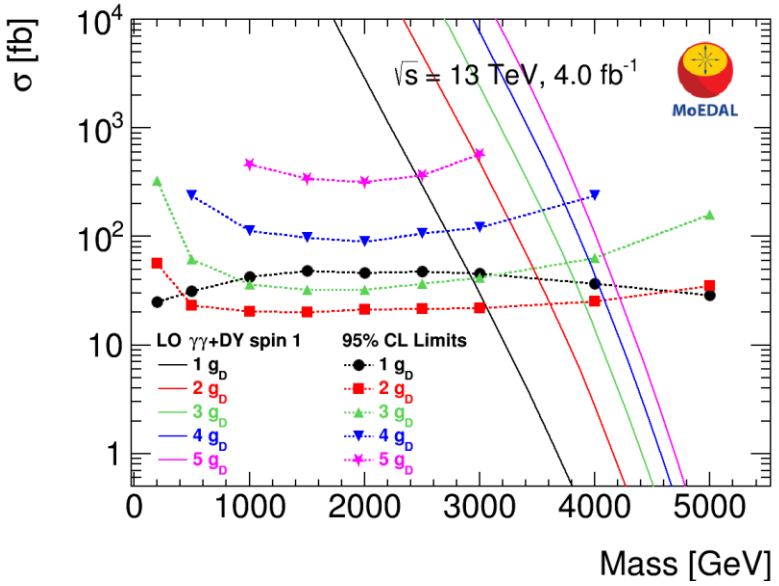


FIG. 4. Feynman-like diagrams for monopole pair direct production at leading order via the Drell-Yan (left) and photon-fusion (right) processes at the LHC. For scalar and vector monopoles a four-vertex diagram is also added [31].

Extra info: https://moedal.web.cern.ch/content/properties-monopole



Outline of the talk

1. Dedicated search in PbPb collisions.

2. MC monopole/monopolium MC event generation (SuperChic3). Kinematics properties.

3. Reconstructed MC events properties in CMS (GEANT4). Discussion of possible searches in data.

4. Expected CMS sensitivity on magnetic monopole

Monopole search in PbPb collisions

1. Focus on PbPb:

- Exploit very strong EM fields of Pb ion charges
- Non perturbative suppression in pp cancelled by non perturbatively large magnetic field

2. Target searches:

- Single stable monopole: m=500 GeV/c^2 (highly-ionizing particle)
- Monopolium decaying into 2 photons:

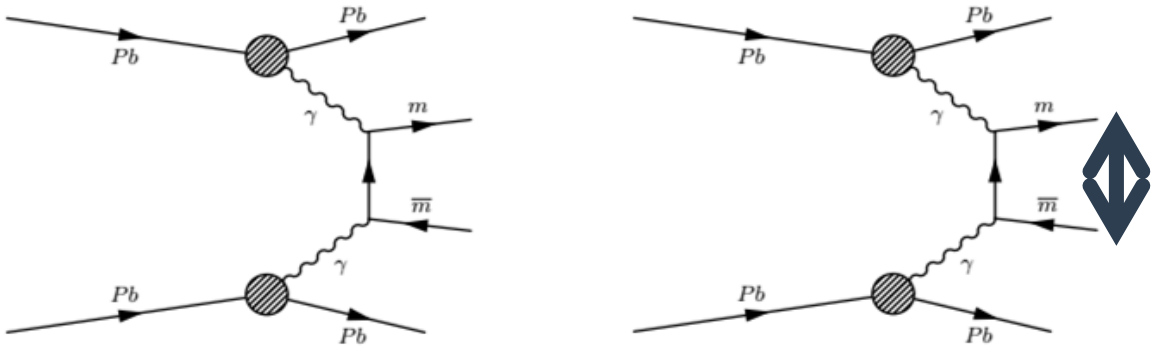
  2 monopoles - Binding Energy = 1000 – 67 GeV/c2 = 933 GeV/c^2

$$BindingEnergy = 2m/15$$

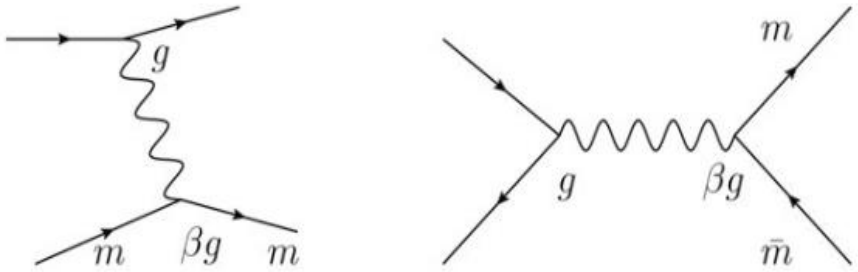
3. Types of couplings: Dirac & βg

Monopole event generation (SuperChic v3.03 MC)

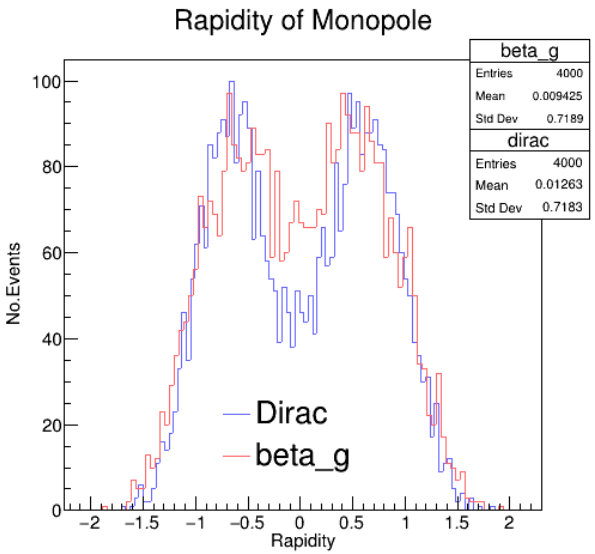
PbPb → photon photon → Monopole pair/monopolium

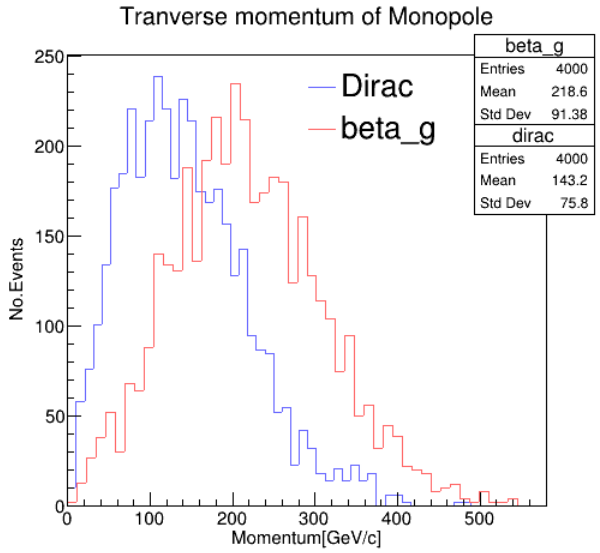


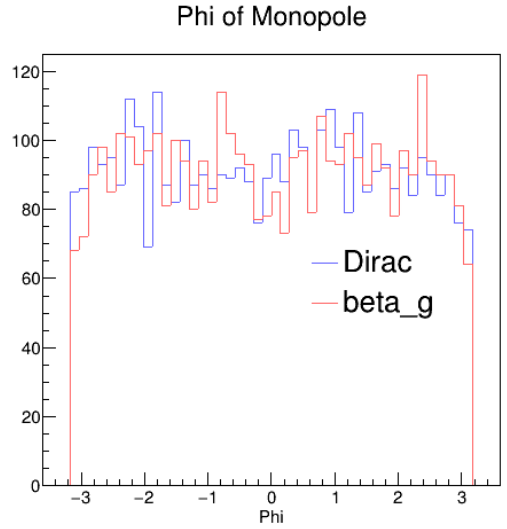
βg-Coupling: Treat monopole as a dual transformed positron. Provided by symmetry of Maxwell's Equation



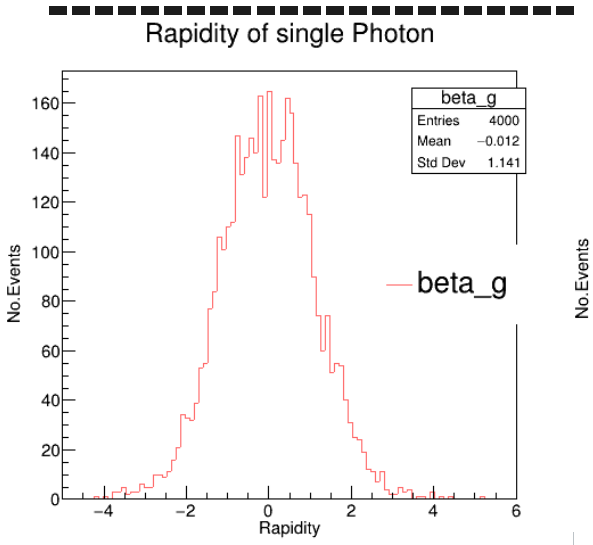
Event generation (SC3.03)

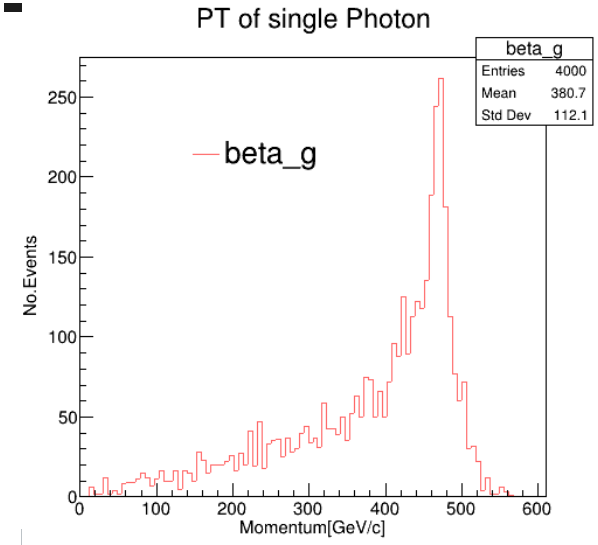


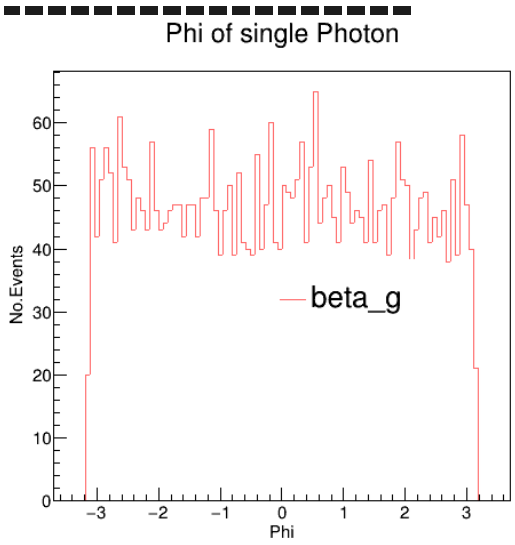




Distributions for



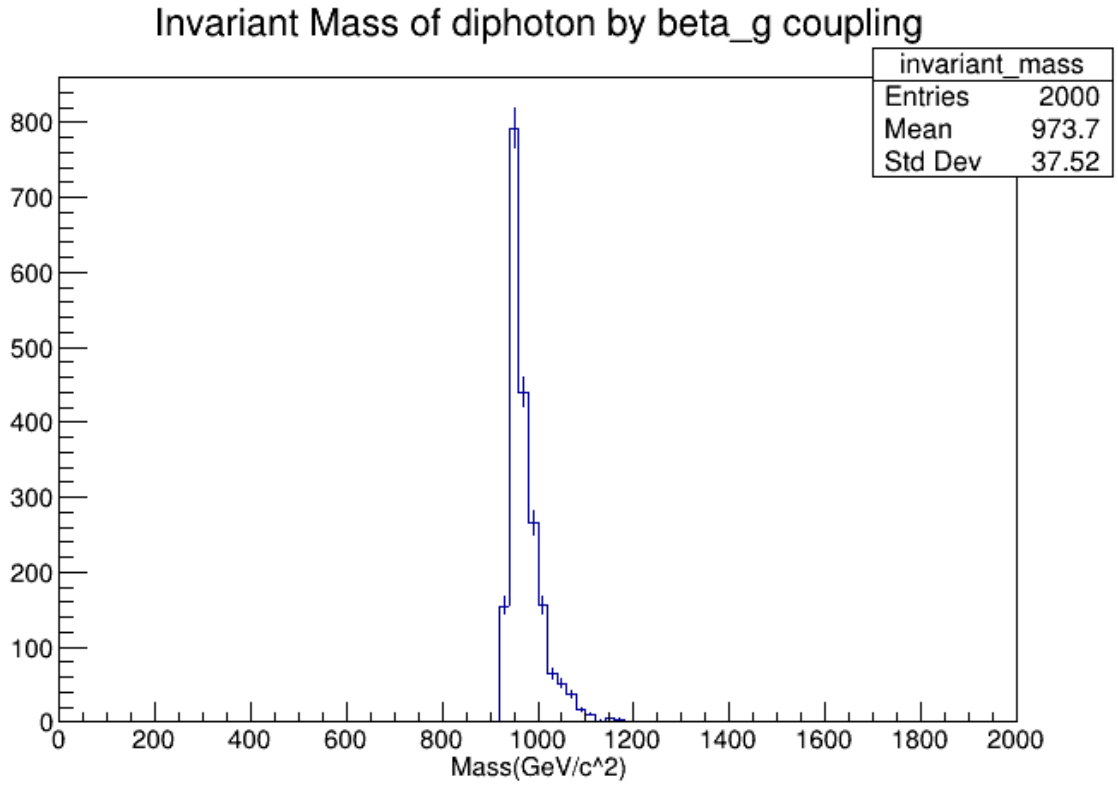




Distributions for s
photons from
Monopolium
(m~1 TeV)
decay

Reconstructed Monopolium (GEANT4)

Reconstructed diphotons in ECAL:



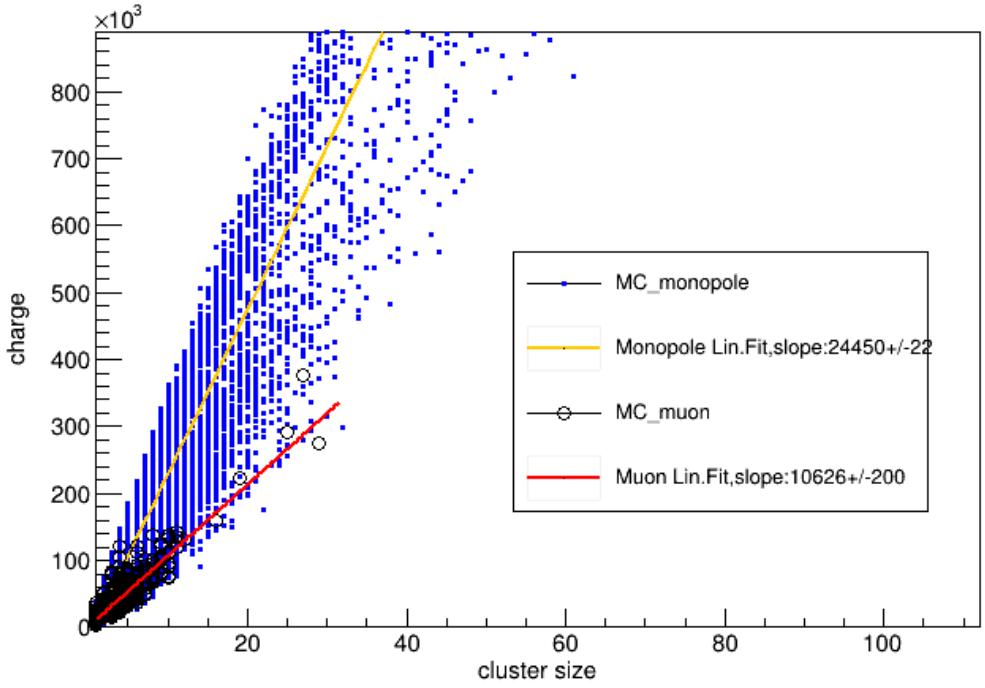
From now on, we focuse on single monopoles (highly-ionizing signals)

Event reconstruction (monopole): GEANT4 signal vs. detector noise

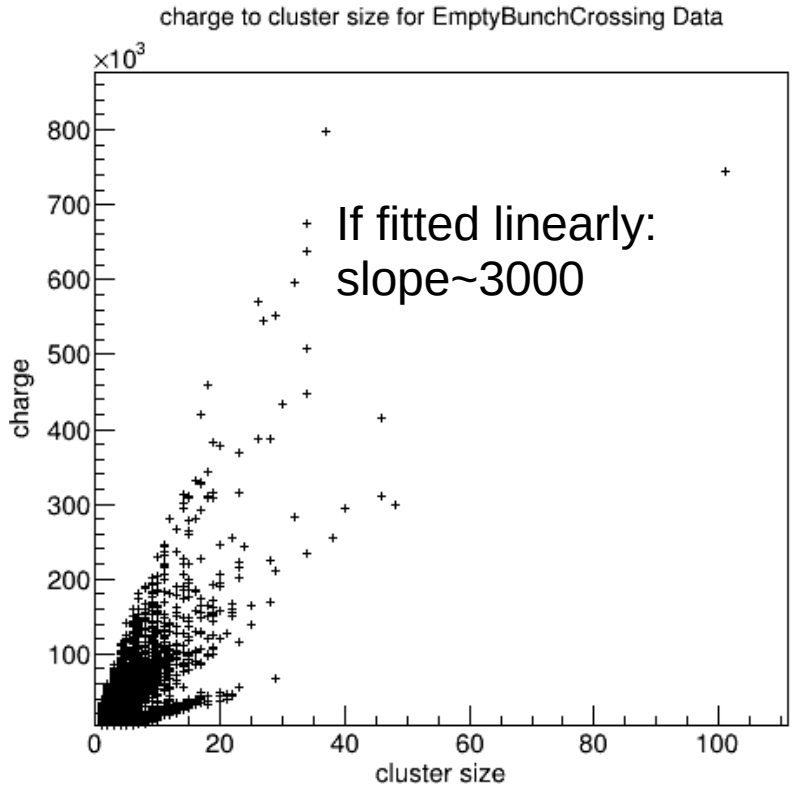
Monopole will lead to a huge ionization in pixel detector.

Distributions of charge versus cluster size:

GEANT4 MC: monopole response



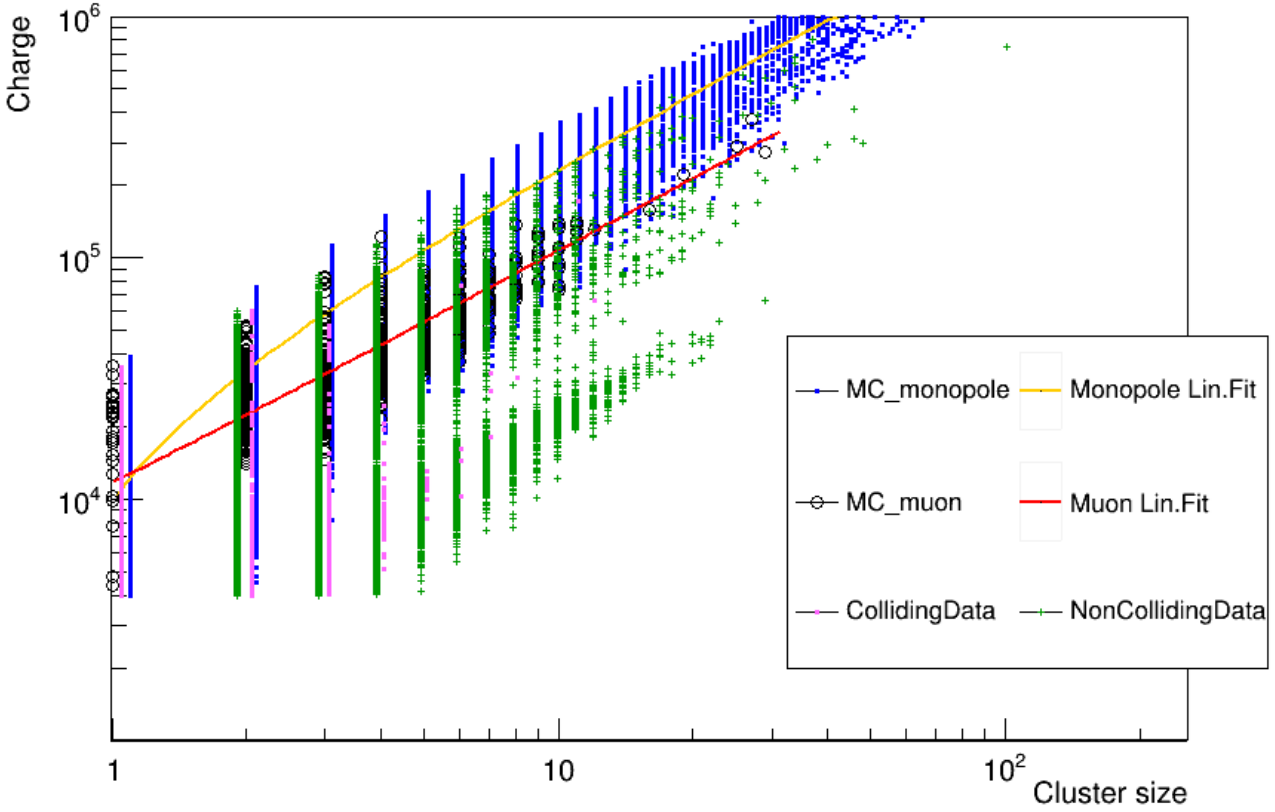
Data: Noise in empty bunches



Event reconstruction:
GEANT4 signal vs. real data & detector noise

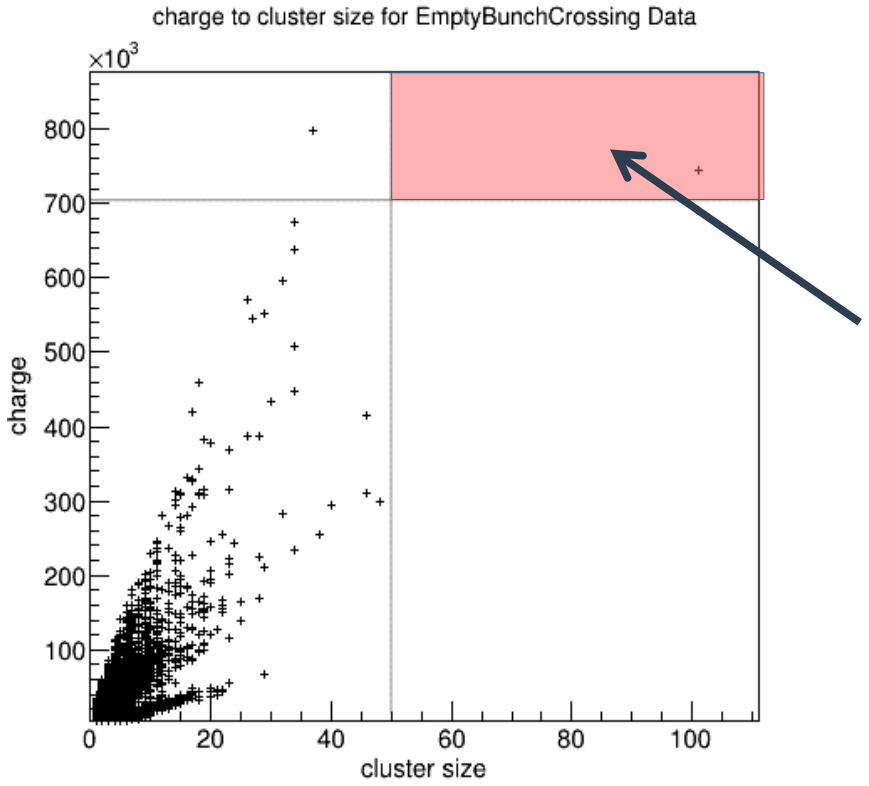
Distributions of charge versus cluster size:

MC monopole, MC muon, non-colliding data, (forward) triggered data:



Monopole strategy search

Non-colliding data indicates that the charge – cluster size region of: Charge>700000; ClusterSize>50 is dominated by background.

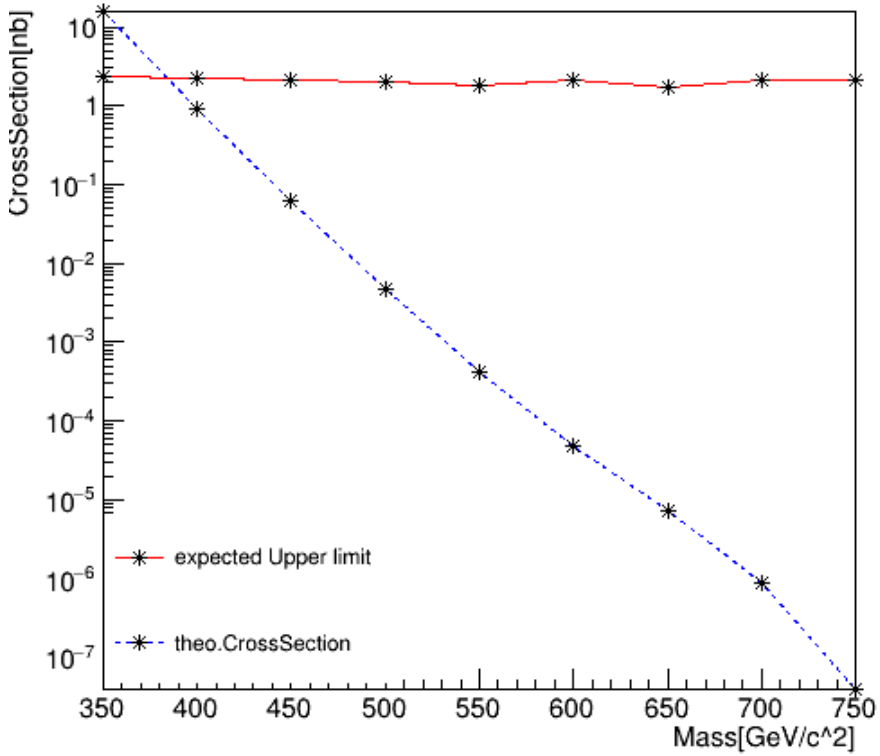


The efficiency*acceptance for a 500-GeV monopole signal in this area is of ~2.9%:

Sensitivity to magnetic monopole

- Run SC3.03 for 9 monopole masses over 350 – 750 GeV. Photon-photon fusion leads to ~exponentially decreasing cross section as a function of monopole mass.

- Assuming the 2.9% reconstruction efficiency is mass independent (to be confirmed), using HiggsCombine and datacards with monopole masses from 350 – 750 GeV, we get the (median) 95% CL upper limit on monopole pair production as a function of mass.

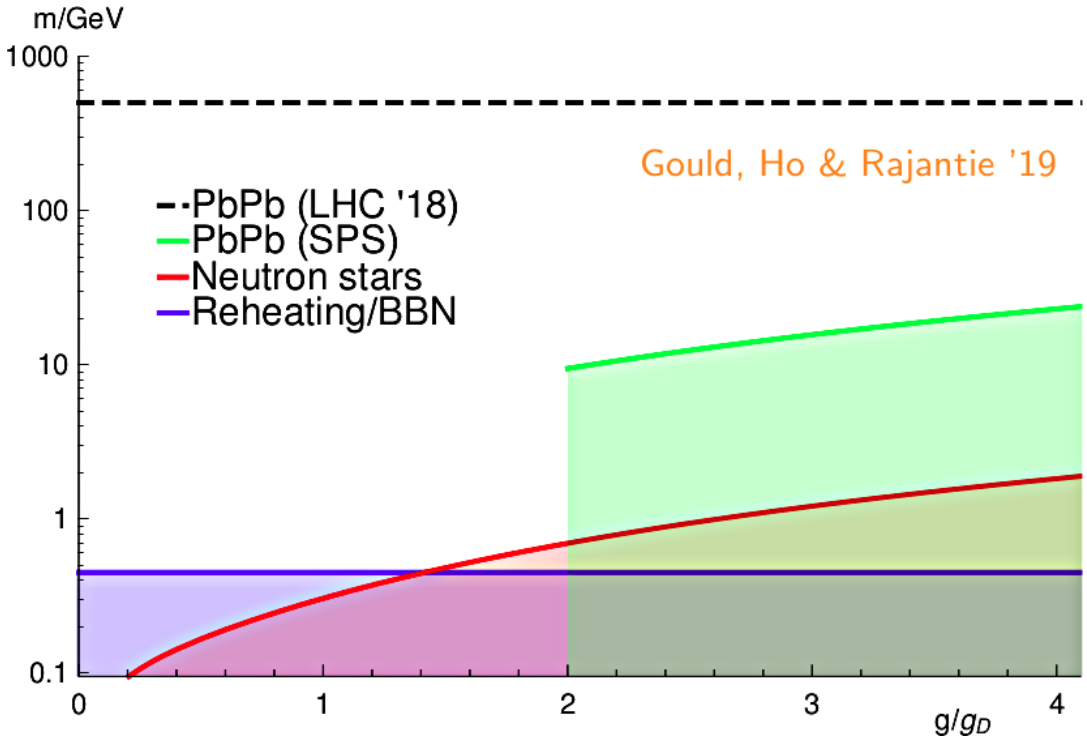


- For the collected PbPb luminosity of 1.6 nb^{-1}, we would exclude monopole masses below 384 GeV. (compared to few TeV by Moedal today)

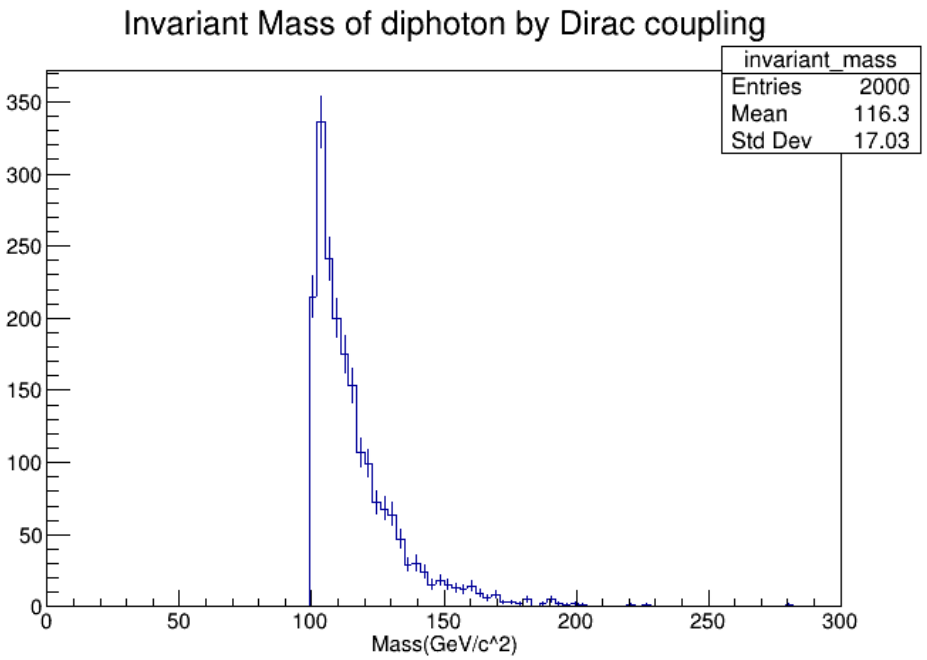
Sensitivity to magnetic monopole

- The aforementioned limits are model-dependent: SuperChic 3 photon-photon processes with various assumed couplings

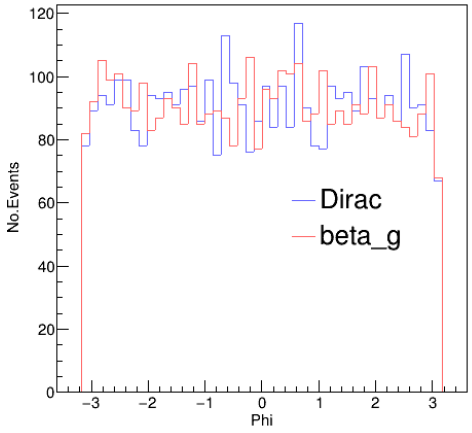
- Other theoretical calculations exist (e.g. Gould & Rajantie, PRL 119 (2017) 241601) that predict different monopole production mechanisms, exploiting the huge magnetic fields in PbPb collisions. Much more competitive limits than those in pp collisions are predicted:

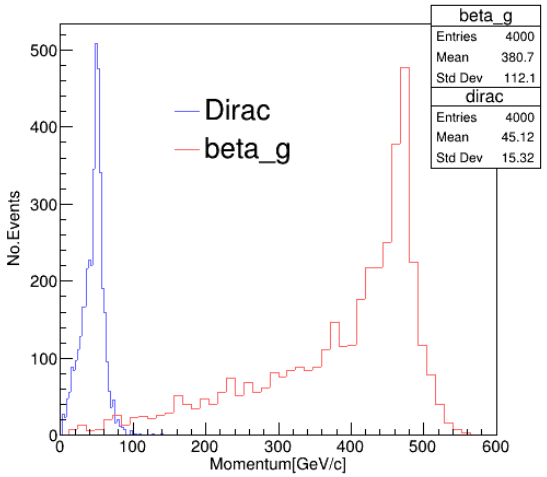


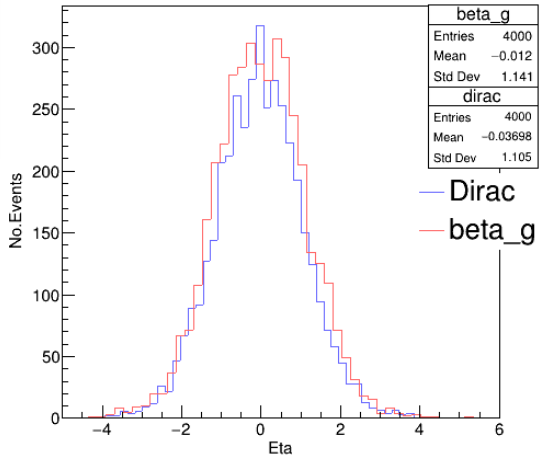
Backup


Invariant Mass of diphoton by Dirac coupling
invariant_mass
Entries 2000
Mean 116.3
Std Dev 17.03
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
Mass(GeV/c^2)

Backup2


No.Events
Phi
Dirac
beta_g


No.Events
Momentum[GeV/c]
Dirac
beta_g
beta_g
Entries 4000
Mean 380.7
Std Dev 112.1
dirac
Entries 4000
Mean 45.12
Std Dev 15.32


No.Events
Eta
Dirac
beta_g
beta_g
Entries 4000
Mean −0.012
Std Dev 1.141
dirac
Entries 4000
Mean −0.03698
Std Dev 1.105