Search for Magnetic Monopole with CMS Experiment

Preliminary Study (Run2)

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Overview

- Physics Motivation
- Analysis Strategy
- Trigger
- Goals
- Future Plan

Physics Background

In 1931 Dirac proposed a magnetic charge in order to explain the quantization of the electric charge.

Dirac derived a simple relation between the product of electron and magnetic quanta and physical constants.

$$\boxed{eg = n\hbar c/2 = ng_D}$$

Where:

- **e** → *the electric charge quanta.*
- **g** → *the magnetic charge quanta.*
- **$\hbar$** → the reduced Plank's constant
- **c** → *the speed of light in vacuum*
- **n** → *an integer*

The magnetic interaction strength, α_m, is very large compared to α_e as a consequence of the Dirac quantization condition.

$$\boxed{\alpha_m = 4692 n^2 \alpha_e}$$

- Hypothesized particles with **magnetic charge**
- Their existence would help explain **charge quantization**
- **Symmetry** in the Maxwell equations

The existence of Magnetic Monopole would symmetries Maxwell's equations

$$\nabla . E = 4\pi \rho_e$$
$$\nabla . B = 0$$
$$-\nabla \times E = \frac{1}{c}\frac{\partial B}{\partial t}$$
$$\nabla \times B = \frac{1}{c}\frac{\partial E}{\partial t} + \frac{4\pi}{c} j_e$$

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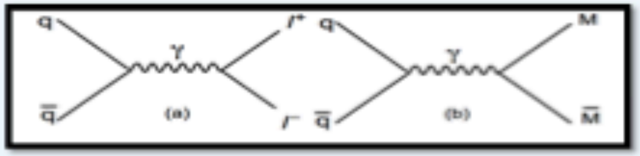
Magnetic Monopole cross-section

Drell-Yan mechanism is assumed for the cross section calculation.



The two diagrams shows annihilation of the quark-antiquark via the intermediate virtual photon and later photon decay into the two leptons (left) and monopole-anti-monopole pair (right).

Many of the important properties of MMs are obtained from the Dirac relation.

Monopole Properties

Basic magnetic charge

In general,

$g_D = n\hbar c/2e$.

magnetic charge

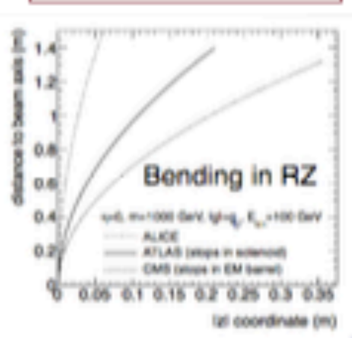
$g_D = \hbar c/2e = 137e/2$,

(n=1)

The magnetic charge is larger if n>1 and/or if the basic electric charge is e/3.

Bending in a solenoidal field

MM trajectories curve in ***r-z*** plane (Parabola) and will not bend (straight line) in the ***x-y*** plane.



Energy loss

MMs loose a lot of energy (due to ionization), and stop in the detector.

The mean rate of energy loss per unit length ***dE/dX*** of a massive HIP carrying an electric charge q_e =ze traveling with velocity β=v/c in a given material is modeled by the Bethe formula:

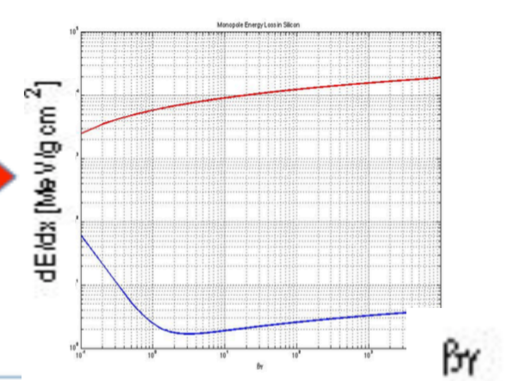
$$\boxed{-\frac{dE}{dx} = K\frac{Z}{A}\frac{z^2}{\beta^2}\left[\ln\frac{2m_ec^2\beta^2\gamma^2}{I} - \beta^2\right]}$$

Where:

Z : the atomic number

A : the atomic mass number

I : the mean excitation energy of the medium



Dimensionless magnetic coupling constant

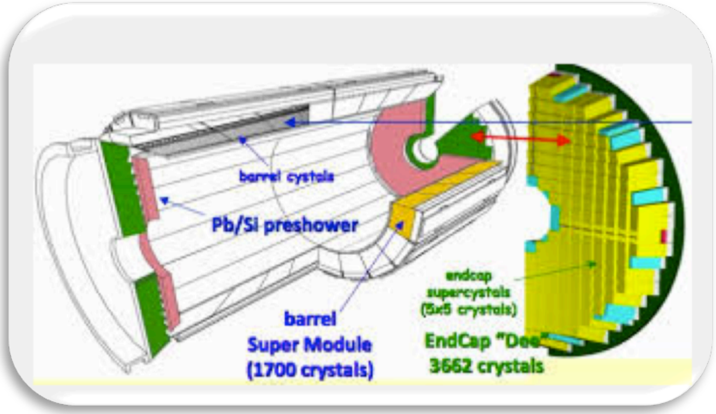
The dimensionless coupling constant is

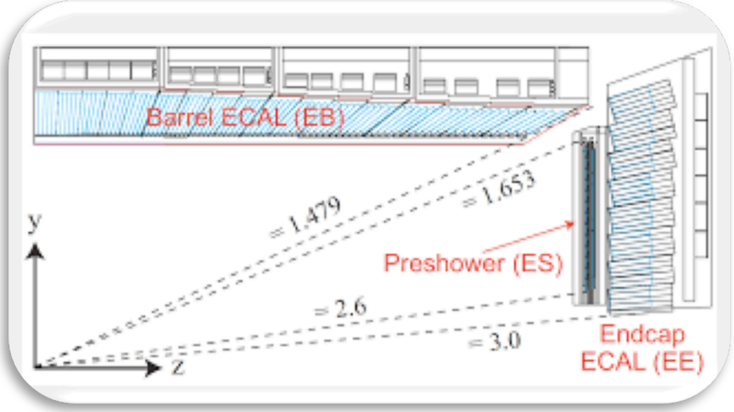
$\alpha_g = g^2_D/\hbar c \approx 34.25$.

As it is greater than one, perturbative calculations cannot be used. ***(We use Drell-Yan mechanism for indication)***

How can we detect Monopole?

- **Dirac monopoles** are expected to rapidly lose energy in the electromagnetic calorimeter **(ECAL)** with little associated radiation.
- **Ionization** dominates the monopole energy loss and the monopole energy is deposited in a compact transverse ECAL strips with little or no energy in the hadronic calorimeter.
- **The cluster shape** tracks the monopole through the ECAL crystals.





The main component of CMS to detect and measure the energies of electron, photon and charged particles is t**he Electromagnetic Calorimeter (ECAL)**.

The CMS ECAL consists of **75848 lead tungstate ($PbWO_4$) crystals**, organized into barrel and two endcap detectors and providing coverage to pseudorapidity $|\eta| = 3.0$. Two silicon preshower detectors are placed in the front of the endcaps ,covering the range $1.65 < |\eta| < 2.6$.
Scintillation light emitted by the lead tungstate crystals is converted to **electrical signals** by photo-detectors glued to the face of the crystals.

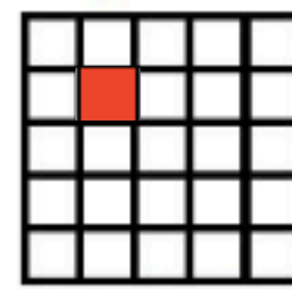
Challenge:Monopole Signature vs. Spike

Monopole can look like a SPIKE!

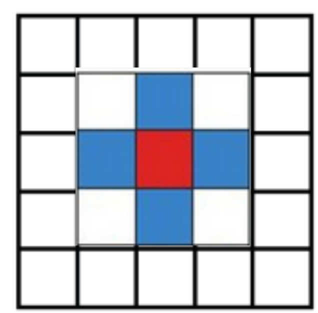
- **Monopole energy can be only contained in only one crystal and we need to know how many monopole can be killed by the spike killer.**

"SPIKE": *is an isolated high energy deposits in ECAL Barrel (EB) and produced by direct ionization of the APD's by particles created in pp collisions*

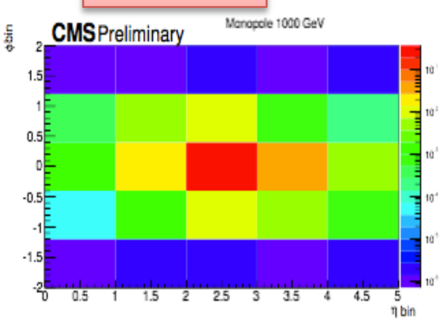
Spike

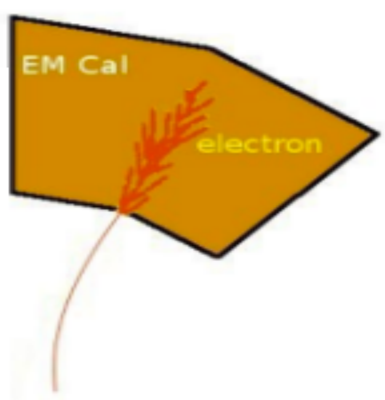


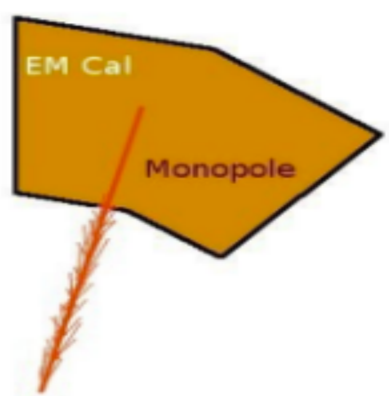
EM Shower



8 TeV







Analysis Strategy

1- Monopole Monte Carlo Generation and Simulation.

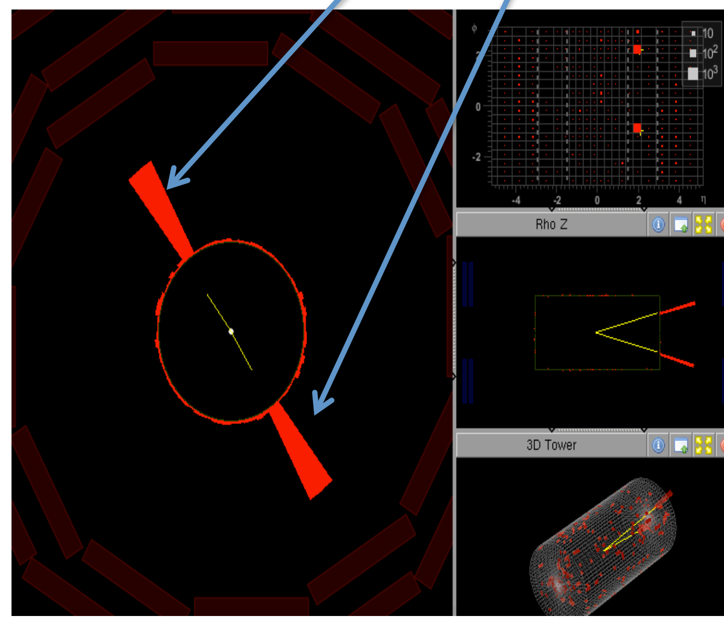
Using **MG5_aMC_v2_3_3** to generate events and with central production (with a special model for monopole)

The interaction of the generated particles in the CMS detector is simulated with **GEANT4.**

Particle Identification (PID) code is translated to **±411100** and GEANT4 can recognizes the particle as a magnetic monopole and treats it as a particle having the fundamental magnetic charge *g* and no electric charge.

Monopole masses ranging from 500 to 4000 GeV, with spin 0 and spin half have been simulated for 13 TeV.

Energy towers (Mono Anti Monopole)



2- Monopole’s Code (TrackCombiner)

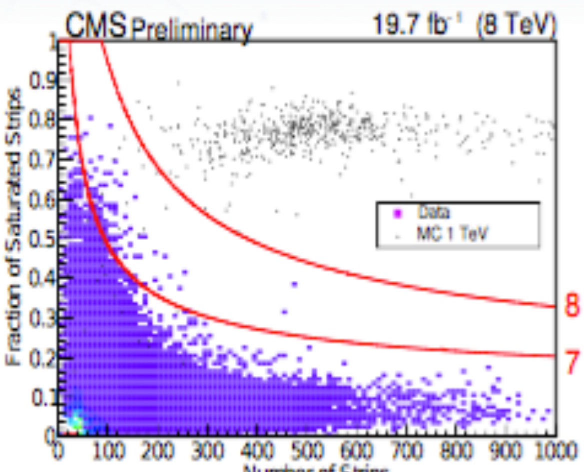
Ongoing

Monopoles bend in R-Z plane, which makes tracking not practical to identify Monopole tracks.

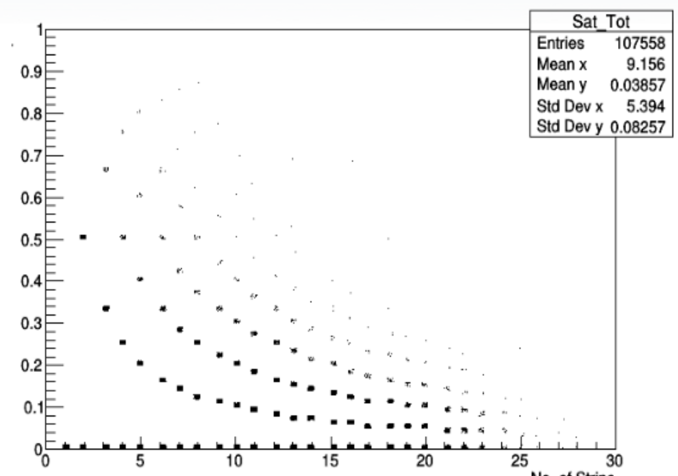
Run1 team had developed an algorithm (Track Combiner) that finds monopole tracks by combining multiple straight tracks into a single curved track. The Track Combiner algorithm combines track segments from the standard tracking algorithm into sets of track segments that could have come from the same particle

$$\mathrm{sig}_{dE/dx} = \sqrt{-log(\mathrm{BinomialI}(0.07, \mathrm{NStrips}, \mathrm{SaturatedStrips}))}$$

For Monopole: No. of saturated strips = Total no. of strips
No. of Sat. strips/Total No. of Strips ≈ 1



8 TeV
(with trackcombiner)



13 TeV
(without trackcombiner)

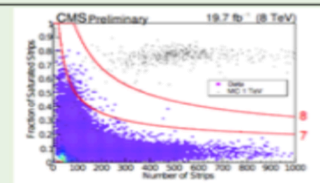
TrackCombiner code is working only with RECO format

3- Monopole Identification

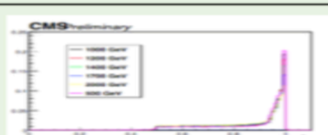
8 TeV Analysis (Run I)

- Basic Clusters of ***5 x 5 crystals*** has been examined.
- Photon trigger is selected.
- Analysis done with CMSSW_5_X_X version
- Monopole is identified in the ECAL by employing a topological cluster shape variable, f_{51} which is defined as ***the fraction of energy in the 5 x 1 η - φ strips central to the 5 x 5 cluster***
- The variable ***dE/dx significance*** is based on the probability that a particular number of saturated strips occur out of a particular set of strips for a background hypothesis.

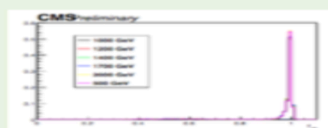
- Cutting on the *dE/dx* significance improves Discrimination power compared to a simple cut on the fraction of saturated strips.
- The red lines show what cuts on the calculated *dE/dx* significance look like .



A cut is placed at 8 in dE/dx Sig. to define the signal region



f_{51} distribution in ECAL barrel



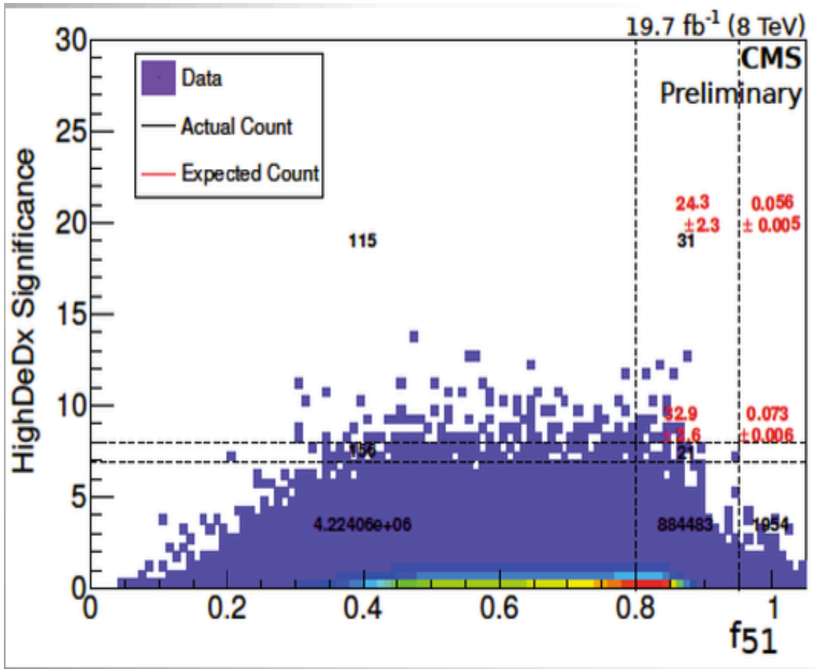
f_{51} distribution in ECAL endcap

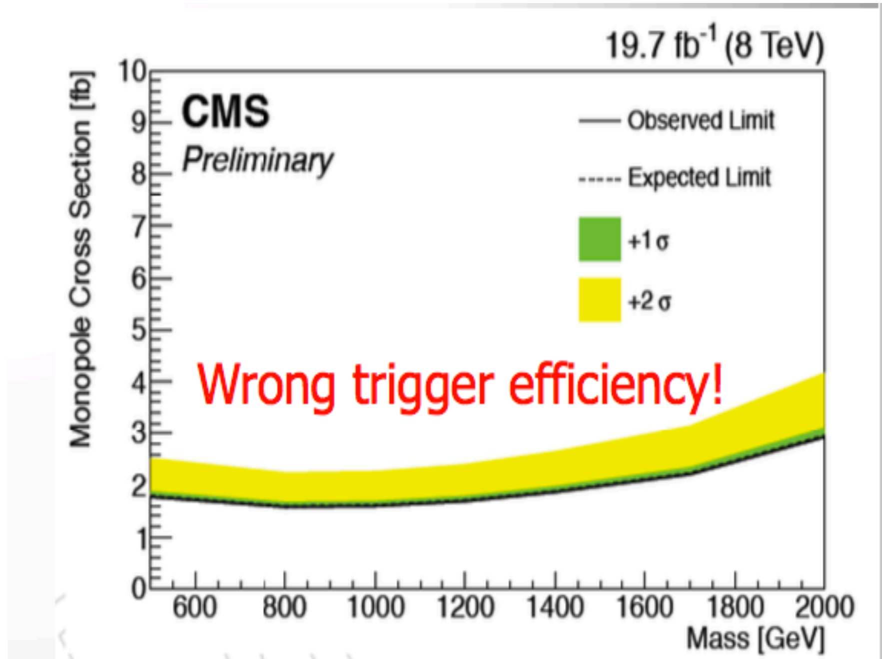
A very concentrated distrubution near 1 and A cut at 0.95 is placed on f_{51} to select monopoles.

13 TeV (Run 2)

1- CMSSW_8_X_X
2- SuperCluster information with new collections (cleaned and unclean spike killer) should be added.
3- Photon Trigger and MET trigger

Run1's results (not published)





8 TeV's results from the full data sample showing signal and background regions. The red numbers are the predicted background counts in each region, and the black numbers are the observed numbers

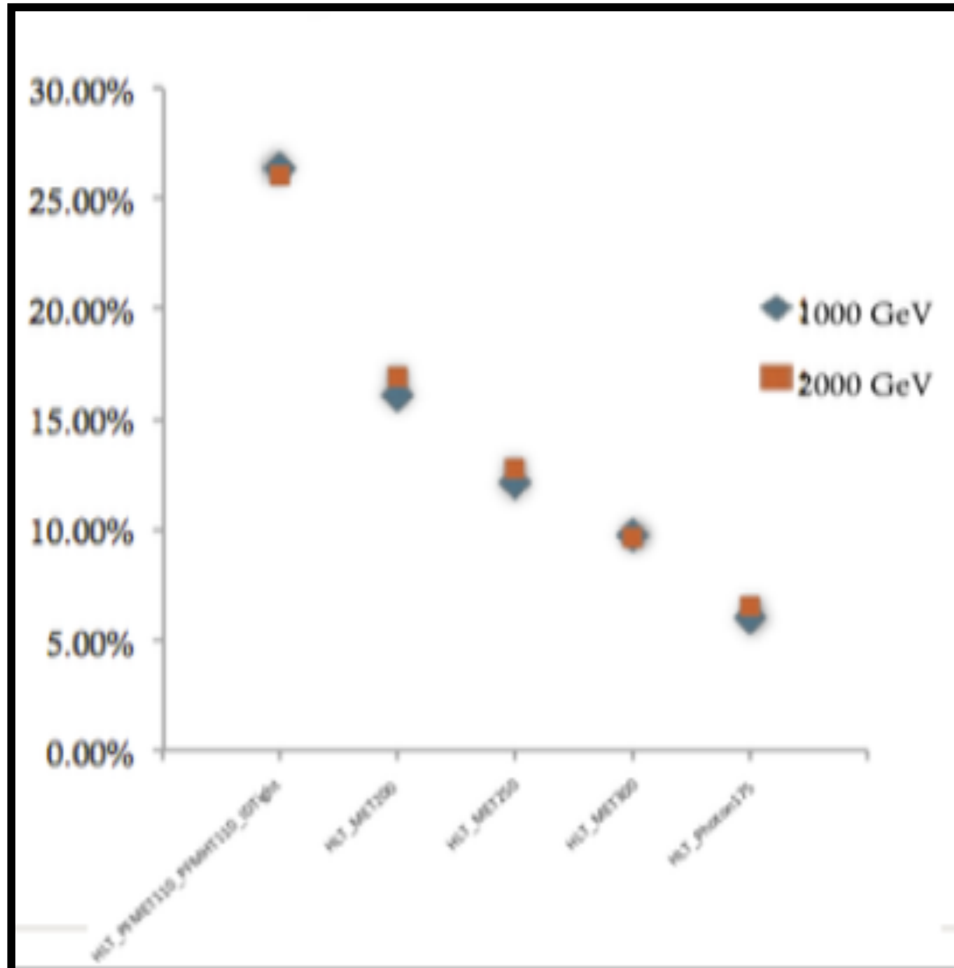
No Monopole found

CMS_PAS_EXO_14_005

Analysis stopped after issues discovered in trigger efficiency determination/people leaving

Trigger Study

Trigger path	Monopole Mass (1000 GeV) eff.	Monopole Mass (2000 GeV) eff.
HLT_PFMET110_PFMHT110_IDTight	26.35 %	26.1 %
HLT_MET200	16.12 %	16.9 %
HLT_MET250	12.1 %	12.8 %
HLT_MET300	9.8 %	9.7 %
HLT_Photon175	6 %	6.5 %



Future Plan

1- Completing the Ntuple to use the monopole track combiner code and other collections.

2- Analyzing the 2016 data (blinded) and optimizing the selections

3- Completing the study of the trigger systematics , including for 2017 data.

4- Checking the systematic of the simulation with respect to the monopole physics model.

5-Completing the analysis.

Backup

2- Monopole TrackCombiner

The track left my a magnetic monopole travelling through the tracking chamber would be multiple orders of magnitude ionized than a normal track, saturating dE/dX measurement.

The particle would experience a force along the magnetic field, causing the track to curve toward the positive or negative Z direction.

A monopole track would be easily distinguishable from an ordinary track. However, because of the curvature in Z, the standard tracking algorithm is extremely inefficient at identifying monopole tracks. We have developed an algorithm that finds monopole tracks by combining multiple straight tracks into a single curved track.

Track Combining : The Track Combiner algorithm combines track segments from the standard tracking algorithm into sets of track segments that could have come from the same (possibly magnetically charged) particle. Starting with a particular segment, it scans through all other segments in the event that have not yet been assigned to a set. Tracks with $pT < 5$ GeV are ignored. A segment is assigned to this set if its tracking hits satisfy two separate fits when combined with the other tracking hits in the set

Thank you