Heavy stable particles in CMS

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Heavy Stable Charged Particles, beyond the Standard Model

Several models of physics beyond the Standard Model (SM), including some versions of Supersymmetry (SUSY), predict the existence of new long-lived charged particles with masses of the order of several hundreds GeV (*Heavy Stable Charged Particles HSCP*). Besides a massive dark matter candidate, the lightest supersymmetric particle (LSP), one or more higher-massive metastable charged states are predicted, with characteristics dependent on the parameters of the model.

The Minimal Supersymmetric extension of the Standard Model (*MSSM*) poses the neutralino as the LSP. The *stop*, partner of the top quark, would be long lived because of the small mass difference with respect to the neutralino. It carries both electric and color charge and can have a cross section up to ~ 10 pb.

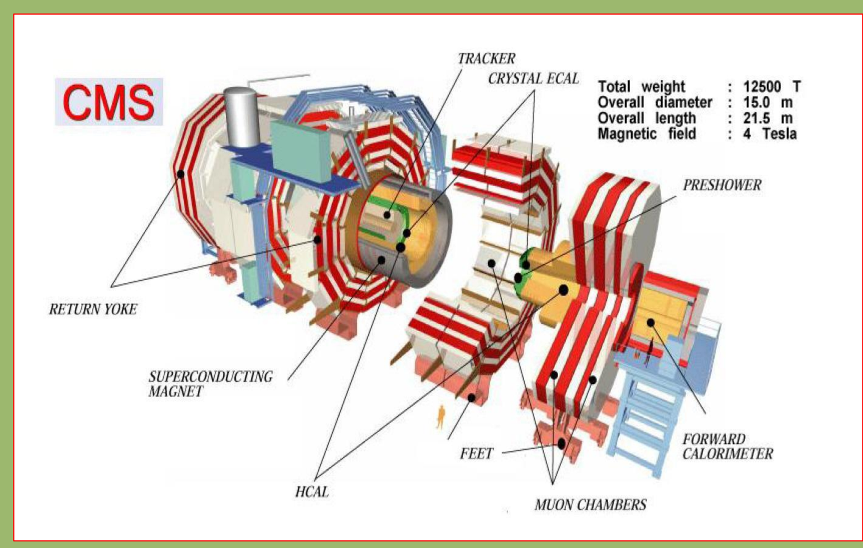
The *SplitSUSY* scenario predicts the scalar partners of SM fermions to have very large masses (of the order of several TeV) while the gauginos and higgsinos, partners of the vector and Higgs bosons of the SM, would be lighter, with masses under the TeV scale. This theory sees the *gluino* $\tilde{g}$ as a color charged HSCP; it would have long life because it could only decay into a neutralino emitting a virtual supermassive squark. Cross sections up to a nb are expected for low masses of the gluino.

Electrically charged HSCPs are expected in other SUSY or extra-dimension scenarios: e.g. the *stau* or the *Kaluza Klein tau*. The predicted cross sections for these HSCP are significantly smaller (< pb).

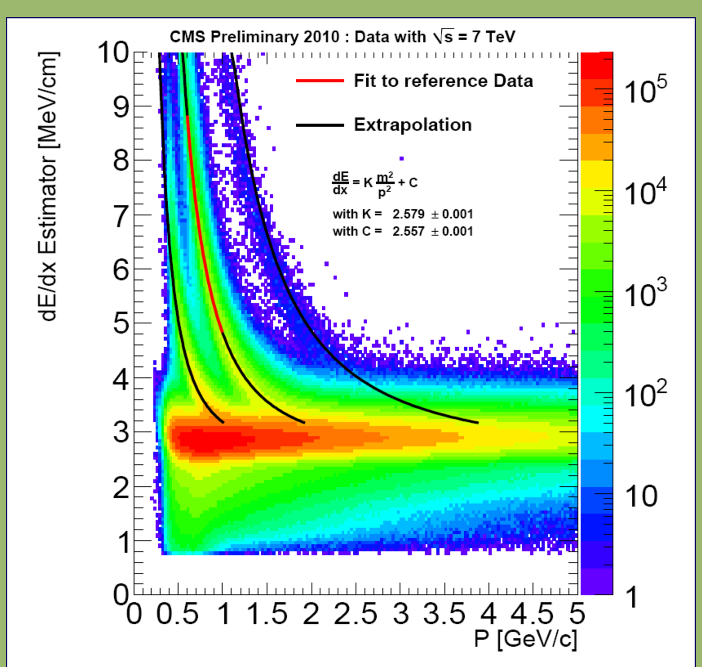
The CMS experiment

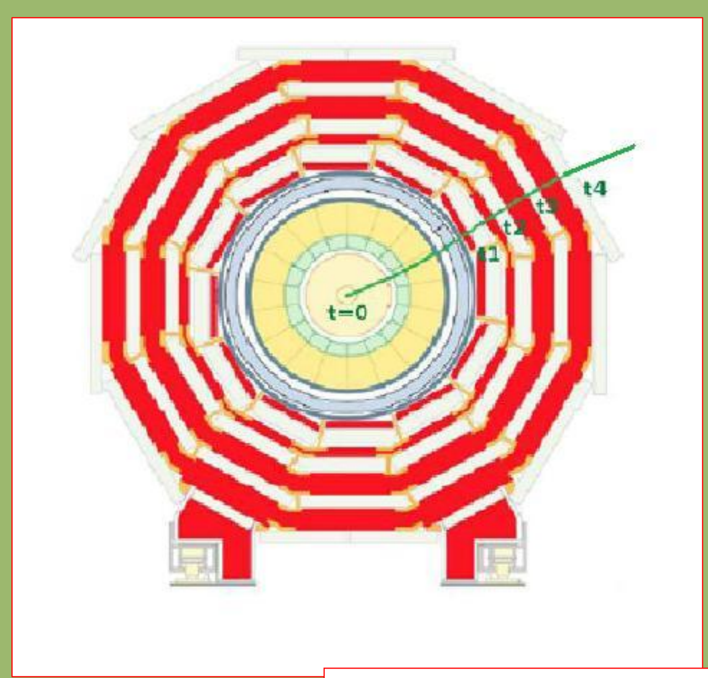
The *Compact Muon Solenoid (CMS)* at the *Large Hadron Collider (LHC)* is a multi purpose experiment designed to explore the TeV energy scale.
In CMS, the 3.8 Tesla solenoid magnet is the core of a very compact detection structure: from inside out we encounter the silicon tracker, the electromagnetic and hadronic calorimeters and, outside the magnetic coil, the muon system.

3.5 TeV protons travel in bunches which interact around the centre of the detector at a maximum frequency of 13.3 MHz (beginning of 2010).
At the design intensity about 25 hard interactions per bunch crossing are expected, which impose strong requirements on the triggering and data acquisition capability of the experiment.



Search for HSCPs at CMS





$$\beta^{-1} \propto \sqrt{\frac{dE}{dx}}$$

Fig. 1 β can be measured in the tracker from the specific ionization or in the muon system with time-of-flight (TOF)

$$\beta^{-1} = \frac{1}{N}\sum_{i=1}^{N}\frac{TOF_i}{dist_i}$$

Trigger
Triggers relying on muon identification or calorimeter-based triggers, like E_t^{miss}, E_t^{sum}, jets, are shown to have good efficiencies from MC studies. From 45% to 95% depending on the type of HSCP and its mass.

At LHC, HSCPs can be produced directly in pairs or as consequence of the decay of heavier exotic particles.

Since they are charged, they interact directly with the matter. Their behavior strongly depends on the type of charge they carry. HSCPs with electrical charge only are muon-like, i.e. they cross the whole detector leaving ionization tracks. Colored HSCPs, like gluino and stop, hadronize combining to quarks or gluons to form the so-called R-hadrons: R-baryons $\tilde{g}qqq$, R-mesons $\tilde{g}q\bar{q}$ or gluonballs $\tilde{g}g$. There are free parameters of the hadronization model (like the fraction of gluonballs f): depending on these, the HSCPs can reach the muon system or stop in the detector before decaying.

The unique signature of HCSPs is β ≠ 1 even at large momenta; simultaneous measurements of β and momentum permit to evaluate the mass of the particle:

$$m = p\sqrt{\frac{1}{\beta^2} - 1}$$

β can be measured in the inner tracker from specific ionization or in the muon system from TOF. HSCPs are expected to produce higher ionization with respect to a MIP in the silicon strips of the tracker: the ionization scale was calibrated with low energy hadrons (see FIG. 1)

An independent measurement of β is possible for muon-like HSCPs. The TOF in the muon system can be measured with nanosecond resolution thanks to special reconstruction algorithms which assign a time parameter to each track segment (see FIG. 1). based on detecting the out-of-fit hits due to late particles.

First search for HSCPs with 3.1 pb^{-1}

The first 3.1 pb^{-1} of CMS were used to search for HSCPs, during 2010 [1]. A counting experiment was set-up, the discrimination signal-background relied on the p_T of tracks and their associated specific ionization (I_{as}), as measured in the inner tracker. The distributions of p_T and I_{as} for the background, a simulated signal and the data are shown in FIG. 2.

Cuts were tuned to reject the background but to maintain sensitivity for HSCP discovery and/or exclusion.

No events were observed with an expected background of less than 0.1 events.

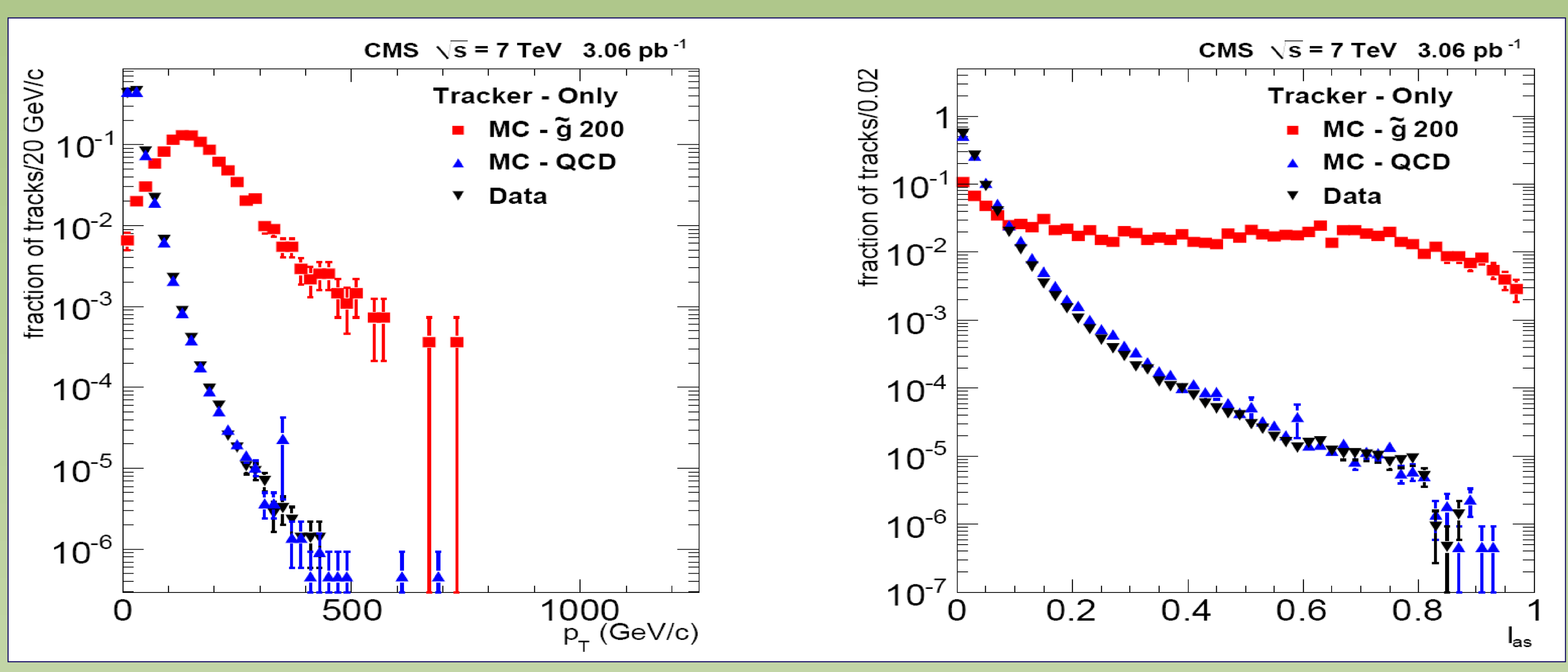


Fig. 2 Distributions of p_T and I_{as} for data, background and a simulated signal (200 GeV gluino).

Since no events were observed, 95% CL upper limits on the production cross sections for gluino and stop were computed. These limits depend on the model assumed for R-hadron interaction with matter. Cross section limits are shown in FIG.3 as a function of the mass.

Intersecting the theoretical cross section with the experimental limits, lower limits on gluino and stop mass were put, dependent on free parameters (see TABLE 1).

Gluino (f = 0.1)	398 GeV
Gluino (f = 0.5)	357 GeV
Stop	202 GeV

Table. 1 95% CL mass lower limits for gluino and stop. (f is the fraction of gluonballs, a free parameter of the model)

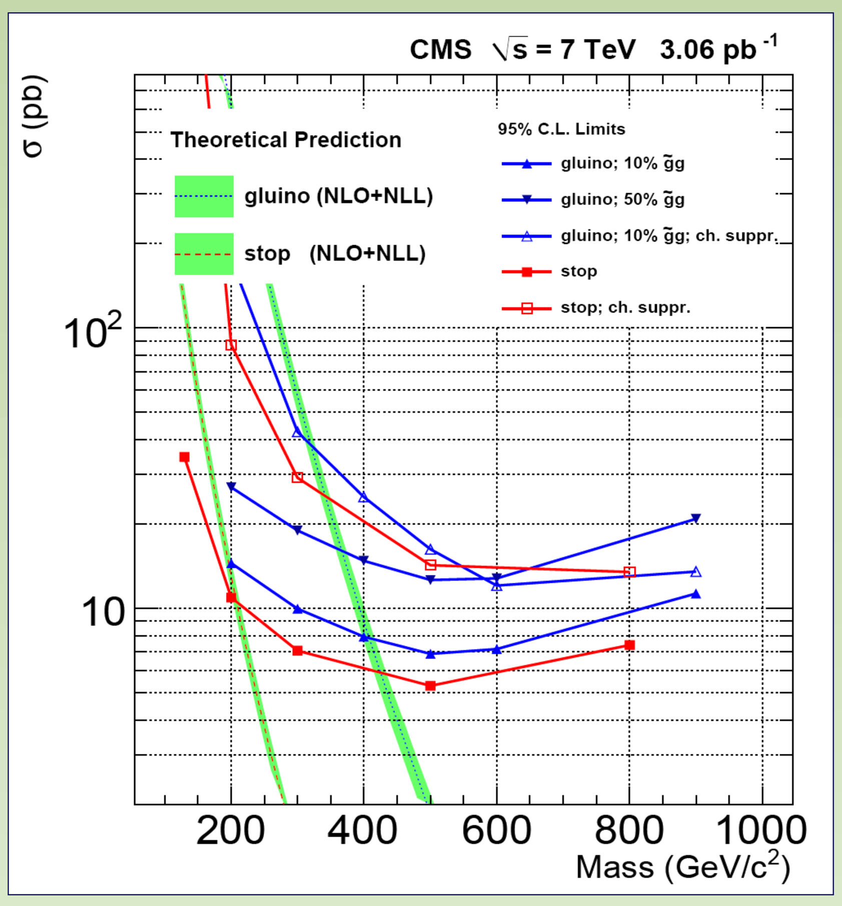


Fig. 3 95% CL cross section upper limits for gluino and stop as functions of mass. Theoretical predictions are shown in green.

Search for stopped gluinos with 10 pb^{-1}

Searches for long-lived, pair produced gluinos that stop inside the detector and decay in a quiescent period between beam crossings were done using an integrated luminosity of 10 pb^{-1} collected during 2010 [2]. Depending on the modeling interaction in matter, a significant fraction of gluinos is expected to rest inside the detector after production; the gluino can decay later resulting in a jet-like deposit in the calorimeters.

A dedicated trigger was set-up to search for decays of particles outside collisions. The analysis was optimized to reject beam halo, cosmics and noise, e.g. using a pulse shape discrimination for the calorimeter signals.

A counting experiment was performed considering gluino lifetimes from 75 ns to 10^6 seconds. No significant excess above background was observed as reported in TABLE 2.

Lifetime (s)	Expected background (± stat ± syst)	Observed
1 x 10^{-7}	0.8 ± 0.2 ± 0.2	2
1 x 10^{-6}	1.9 ± 0.4 ± 0.5	3
1 x 10^{-5}	4.9 ± 1.0 ± 1.3	5
1 x 10^{6}	4.9 ± 1.0 ± 1.3	5

Table. 2 Search for stopped gluinos: results of the counting experiment.

Limits at the 95% CL on gluino pair production over 13 orders of magnitude of lifetime were set. For a mass difference between the gluino and the neutralino of 100 GeV a lower limit of 370 GeV on the gluino mass was put (see FIG.4).

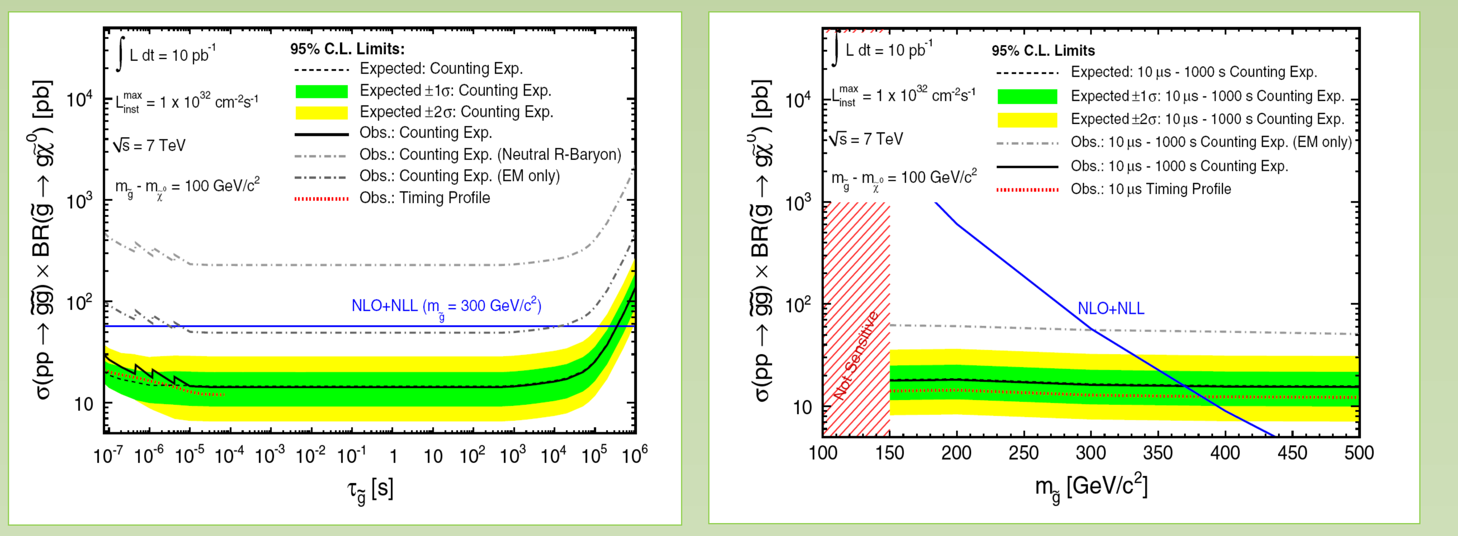


Fig. 4 95% CL limits on the cross section of gluino pair production.

Bibliography

[1] *Search for Heavy Stable Charged Particles in pp collisions at √s = 7 TeV*
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[2] *Search for Stopped Gluinos in pp collisions at √s = 7 TeV*
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