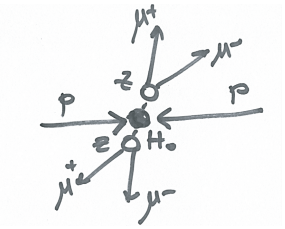
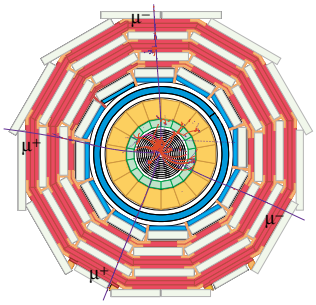
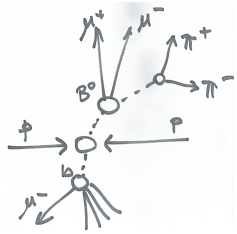
Muon system

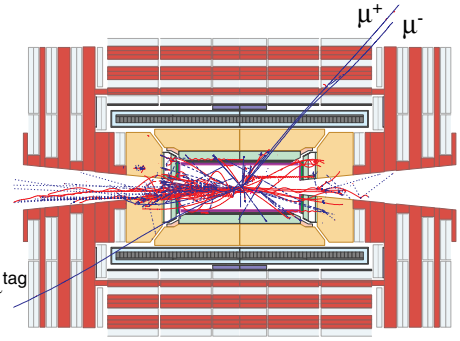


$p\,p \rightarrow H^0 \rightarrow Z\,Z$
$\hookrightarrow \mu^+\,\mu^-$
$\hookrightarrow \mu^+\,\mu^-$





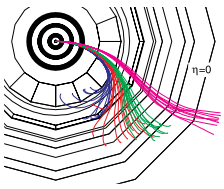
$p\,p \rightarrow b\,\bar{b}$
$\hookrightarrow B^0 \rightarrow J/\psi\,K^0_S$
$\hookrightarrow \pi^+\,\pi^-$
$\hookrightarrow \mu^+\,\mu^-$
$\hookrightarrow \mu^{tag}$



Muons are expected to provide clean signatures for a wide range of physics processes. The task of the muon system is to identify muons and provide, in association with the tracker, a precise measurement of their momentum. In addition, the system provides fast information for triggering purposes — a challenging problem at the LHC.

The muon detectors, placed behind the calorimeters and the coil, consist of four muon stations interleaved with the iron return yoke plates. They are arranged in concentric cylinders around the beam line in the barrel region, and in disks perpendicular to the beam line in the endcaps

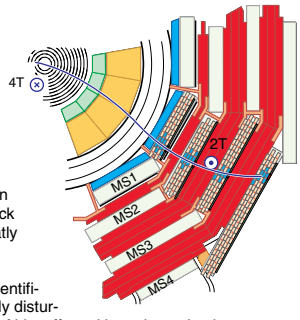
Muon identification



p_t = 3.5, 4.0, 4.5, 6.0 GeV

Muon identification is ensured by the large thickness of the absorber material (iron) which cannot be traversed by particles other than neutrinos and muons.
There are at least 10 interaction lengths (λ) of calorimeters before the first station and an additional 10 λ of iron yoke before the last station. The identification is achieved by lining up the hits in at least two out of the four muon stations. The presence of multiple stations also enables the control of hadronic shower punchthrough and hard muon bremsstrahlung.

With multiple chamber layers in each station providing many distributed measurement points, the pattern recognition of track segments is greatly simplified.



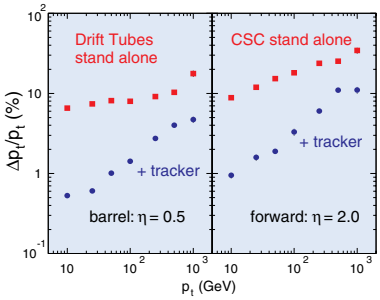
Track segment identification is minimally disturbed by rejection of hits affected by noise or background such as soft δ-rays and electrons from neutrons and gammas. The thickness of the absorber between the stations (30 to 75 cm) also prevents station-to-station correlations due to high energy muon radiation.

Momentum measurement

The momentum measurement utilises the bending of charged tracks in the magnetic field produced by the coil and conducted by the return yoke. The solenoidal field of CMS bends tracks in the (r,ϕ) plane perpendicular to the beam axis. The muon transverse momentum, p_t, may be determined in three ways:

- bending angle measurement immediately after the coil,
- sagitta measurement in the return yoke.
- measurement of the sagitta of the track in the inner tracker

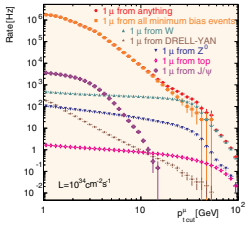
The first two measurements are performed by the muon detectors alone, independently of the inner tracker for a "stand alone" measurement and can be used both by the trigger and the off-line reconstruction program. The reconstruction procedure is naturally robust against backgrounds because of the redundancy of the measurements. The best off-line resolution is obtained when all three methods are combined with the vertex constraint of 15 µm.



The resolution at low p_t is limited by multiple Coulomb scattering; the resolution at high p_t is limited by the chamber resolution. The strong bending due to the high field is a great benefit in both cases. With resolutions of the order of 100 µm per station, the standalone measurement is dominated by multiple Coulomb scattering for p_t below 200 GeV. With the full measurement, including the tracker, the muon sign can be recognised in the entire kinematical range (p < 7 TeV, |η| < 2.4).

Triggering on muons

A fundamental aspect of the CMS muon system design is that it allows for the identification of muons and the estimate of their transverse momentum online, for triggering purposes. The muon trigger system has to perform these tasks with high efficiency and precision in order to reduce the proton-proton interaction rate of ~ 1GHz to a few kHz by demanding that the transverse momentum of the muons seen exceeds a certain threshold.



The need for a fast determination of the muon momentum also guided the choice of the CMS magnet which bends muon trajectories in the transverse plane. A few trigger planes with modest azimuthal segmentation can then be used to measure the muon direction after the solenoid and apply a cut on the muon transverse momentum, p_t. The figure on the left shows the rate with which muons are produced from various physics processes.

Another basic requirement of the muon trigger system is to reject efficiently many different types of background hits that can simulate genuine, high-p_t prompt muons. These backgrounds arise from hadronic punchthroughs, debris from muon interactions with matter, thermal neutrons, beam halo in the forward direction and finally noise in the electronics. A key feature of the design is to combine information from different muon detectors: Resistive Plate Chambers (RPC) and Drift Tubes (DT) in the barrel and RPCs and Cathode Strip Chambers (CSC) in the endcaps. These detectors have different responses to the various backgrounds. As an example, RPCs provide a very accurate time measurement, whereas DTs provide an accurate position measurement. The efficiencies for triggering on real muons are complementary