Muons trigger and identification

DRDC proposal P7

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1. MUON RATES AND PUNCH-THROUGH SIMULATIONS

The inclusive rate from prompt muons is large at LHC and is dominated at all
transverse momenta values, $P_T$, by muons from charm and bottom decays [1]. Such
muons are generally contained in jets. At $10^{34}$ cm$^{-2}$s$^{-1}$ luminosity and for $P_T > 5$ GeV/c
(natural cut due to ranging out in the absorber) the prompt muon rate in the central
rapidity region, $|y| < 3$, is $10^5$ Hz. For $P_T > 40$ GeV/c the inclusive muon rate drops
down to 100 Hz. For $P_T > 20$ GeV/c the dimuon rate is dominated by inclusive $Z$
production and is about 10 Hz.

Muon backgrounds associated with beam-beam collisions result from $\pi$ or K
decays before the absorber (primary decays), from decays inside the absorber of
shower secondaries (secondary decays) and from leakage of hadron cascades through
the absorber (punch-through). Backgrounds associated with beam halo and cosmic rays
are not considered here.

To estimate the input rate to the trigger due to background we define a model
LHC detector, which consists of a free cylinder for tracking of 1.3m radius and 4.4m
in length, followed by a hermetic calorimeter: A barrel calorimeter of 10 interaction
lengths ($\lambda$) closed by endcap calorimeters of $16\lambda$. The transition between barrel and
end-caps is at $|\eta| = 1.3$. With this cylindrical geometry the total thickness of the
absorber varies as a function of the polar angle, $\theta$, and reaches a maximum of $20\lambda$ at $\theta$
= 30° ($|\eta| = 1.3$). The rate due to primary decays in the inner region follows from the
charged hadron rate at LHC. The rate due to secondary decays and hadron punch-
through requires either Monte-Carlo simulations or parametrisations of existing punch-through data.

H. Fesefeldt has shown that a fast version of GEISHA implemented in GEANT can reproduce a variety of punch-through measurements [2]. In Fig. 1 we show the integral punch-through probability of single pions after an absorber of 16.3\(\lambda\) as a function of the pion momentum, predicted by this Monte-Carlo. In this example the absorber starts at a distance \(L_T = 80\) cm from the pion starting point and is operated without magnetic field (Fig. 1a) or with a magnetic field (Fig. 1b, \(B = 4\) Tesla). The three components from primary, secondary decays and punch-through hadrons are shown separately. The component from primary decays dominates at low \(P_T\) hadrons. Above 40 GeV/c the other two components dominate and are roughly of equal importance. One can also see that the magnetic field has the effect of reducing the contributions from secondary decays and hadrons by an order of magnitude for pions below 20 GeV/c. This can be understood because these two backgrounds are dominated by soft hadrons and muons.

![graph](image)

*Fig. 1: Integral punch-through probabilities for pions as a function of incident momentum simulated for a compact muon solenoid detector with \(B = 4\) Tesla.*

* a) after 16.3\(\lambda_0\) of absorber no magnetic field.

* b) same with magnetic field switched on.*
A parametrisation of the integral punch-through probability as a function of material, input momentum and depth, with separate terms for the hadronic and secondary decay components, has been proposed at this workshop by F. Lacava [3]. As observed experimentally and in agreement with the full shower simulations, the two components have a different dependence on the depth of absorber: After 20\lambda the hadronic component becomes negligible and only muons from secondary decays can escape the absorber.

Fig. 2 shows the rate of charged hadrons (full line) as a function of the polar angle predicted by ISAJET for two-jet events with $P_T^{min} = 5$ GeV/c and for a luminosity of $4 \times 10^{34}$ cm$^{-2}$s$^{-1}$. The dashed line is the corresponding decay rate for the model LHC detector previously described. The dotted line is the punch-through rate deduced from the above parametrisation. The dip in the punch-through rate at $\theta = 30^\circ$ corresponds to the maximum length of absorber. In the barrel region the rate is of order 10$^6$ Hz. The rate is increasing fast in the forward region. If one wants to trigger up to $|\eta| = 3$ ($\theta = 50^\circ$) the rate increases to 10$^7$ Hz.

![Fig. 2: Expected rates at 4 x 10$^{34}$ cm$^{-2}$s$^{-1}$ luminosity from charged hadrons (full line), \(\pi-K\) decays (dashed line) and hadron punch through (dotted line) as a function of the polar angle.](image)

The energy spectrum of the muons escaping thick absorbers ($\geq 20\lambda$), produced by incident hadrons of various momenta, has been measured in neutrino experiments at Fermilab and a parametrisation based on a scaling law in $z = P_T^h/P_T^h$ is reported by D.
Green in ref. [4]. Fig. 3 shows the predicted energy spectrum of muons escaping an absorber of $16.3 \lambda$, with and without magnetic field, produced by pions of 20 GeV/c, using the punch-through simulations of ref. [2]. Two component are clearly visible: The flat hard component, $8 \text{ GeV} < E < 16 \text{ GeV}$, comes mainly from primary decays. The soft component part of the spectrum ($E < 8 \text{ GeV}$) is due to secondary decays and is in agreement with the parametrisation of ref [4] (full curve).

Fig. 3: Energy spectrum of the decay muons produced by 20 GeV pions after $16.3 \lambda$ of absorber with magnetic field on (dashed histogram) and off (full histogram). The full line is a parametrisation from ref [4].

Fig. 4 shows, for the central region $|\eta| < 3$, the $P_T$ spectrum of jets, mainly responsible for the backgrounds from punch-through and from hadrons decaying into muons. The $\pi$ and $K$ decay background is compared with the prompt muon rate. For $P_T > 5 \text{ GeV/c}$ the $\pi/K$ decay rate falls below the prompt muon rate from charm and bottom decays.

The estimate of the surviving punch-through background as a function of $P_T$ is more difficult. Full simulations require too much computer time and existing parametrisations [4] are imprecise for low values of $P^A$ and $P^B$. In Fig. 4 we only indicate by an arrow the integrated punch-through rate, which has been estimated for our model LHC detector, with and without a magnetic field, using the punch-through probabilities of Fig. 1. For $P_T > 5 \text{ GeV/c}$ and at $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ luminosity, the
contributions to the total rate from prompt muons, primary decays and punch-throughs are roughly of equal importance and of order $10^5$ to $10^6$ Hz. The $P_T$ spectrum of muons resulting from secondary decays is expected, in general, to be softer than the one from primary decays (dotted curve).

The only practical way to reduce this high rate is not by increasing the amount of absorber, since a large fraction of this rate comes from genuine muons, but rather by cutting on the $P_T$ of these muons.

2. MUON TRIGGER IN A STRONG MAGNETIC FIELD

One of the arguments in favour of a strong magnetic field for a muon detector at LHC is to facilitate a cut on $P_T$ at the trigger level, with trigger hodoscopes of modest spatial resolution, $\sigma = 1$ cm.

Two possible orientations of the magnetic field can be considered: a toroidal field or a solenoidal field. The solenoidal field is better for triggering in the central region since the bending is in the plane transverse to the beam and the small size of the beam spot ($\pm 10 \mu$m) provides a very precise point for the momentum determination. Simple
trigger algorithms based on track pointing to the vertex in the R-\(\Phi\) plane can be implemented.

Fig. 5 shows the transverse view of a possible muon detector based on a strong solenoidal field. The coil is 0.5 m thick and has an inner diameter of 7 m. It produces a magnetic field of 4 Tesla in the inner region. A calorimeter of \(\approx 10\lambda\) is installed inside the coil starting at \(R = 1.5\) m. The return yoke of the magnet, about 2 m of magnetized iron at 2.3 Tesla, completes the absorber for a total of about 22\(\lambda\). The detector is very compact and has an overall diameter of only 13 m. M. Pimia [5] will discuss in more details the possible design and performance in momentum resolution of such a Compact Muon Solenoid (CMS) detector. Here we use the CMS only to illustrate the general problem of the trigger.

![Diagram of the muon detector](image)

**Fig. 5:** Cut in the transverse plane of the Compact Muon Solenoid detector (CMS).

Trigger hodoscopes of granularity \(\sigma_{R\Phi} = 1\) cm are placed before and after the coil (station 1) and outside the return yoke (station 2). Pointing of the muon track can be checked by measuring the angle \(\alpha\) defined in Fig. 5 in two independent triggering stations. Clearly due to the magnetic field configuration, station 1 will be more efficient to cut on \(P_T\) than station 2. Station 2 on the other hand will see less punch-through background. A 100 mrad cut in station 1 would allow for example a sharp cut on \(P_T\)
with an efficiency of 100% for $P_T > 50 \text{ GeV}/c$. The same cut in station 2 would impose a cut only around 10 GeV/c. Efficiency curves and trigger rates as a function of the trigger angle are presented in [5].

So far we have ignored the combinatorial background due to multi-hits in station 1 just behind the calorimeter. There is a potentially serious problem caused by low $P_T$ muons inside jets, due either to $\pi/K$ or bottom and charm semileptonic decays. This is a general problem for all muon detectors. Station 1 is not expected to be as clean as station 2, because the tail of the accompanying jet and of the hard hadrons of the many overlapping events at high luminosity will produce spurious hits after 10\lambda in the vicinity of the muon track. A low $P_T$ muon can produce a track in station 2 more or less pointing to the vertex. This is particularly true for the CMS geometry, where the direction of the magnetic field in the return yoke is opposite to the direction of the central field and bends back the outgoing muon in the direction of the vertex. Spurious hits in station 1 in coincidence with the low momentum muon track in station 2 can fake the trajectory of a large $P_T$ muon. In a toroidal geometry the measurement of the bending angle also necessitates two trigger stations. Combinatorial background in station 1 will also spoil the $P_T$ cut at the trigger level. This combinatorial background due to low momentum decay muons inside jets could dominate the large $P_T$ muon trigger. Additional trigger planes between station 1 and station 2 may be necessary to avoid random coincidences and increase the level of redundancy in the muon track definition. To investigate further the muon trigger problem at LHC a proposal (DRDC/P7,[6]) has been submitted to the new Detector R&D Committee (DRDC) set-up at CERN.

3. THE MUON PROPOSAL P7

The main objective of the proposal [6] is to demonstrate the advantage of a strong magnetic field in rejecting efficiently hadron punch-throughs and decays at the trigger level. For this we propose to build a fraction of the compact muon solenoid detector shown in Fig.5. We will expose it to a test beam containing hadrons and muons and record punch-through data.

In parallel we want to study the performance of the plastic resistive plate chambers (RPC) developed by the Rome group [7]. Because of their excellent time resolution these chambers can be used as trigger hodoscopes to apply angular cuts at the first trigger level.

One of the key elements in our proposal is the measurement in a strong magnetic field. We therefore propose to use the EHS magnet which is ideally suited to this purpose. This magnet with coils in a Helmholtz-like arrangement provides a field of 3T
over a free space of about 1.5m x 1.5m x 0.8m. The proposed set-up is shown in Fig. 6.

![Plan view of the experimental set-up for DRDC proposal P7.](image)

A calorimeter acting as a hadron absorber is located in the magnet gap. Its main purpose is to identify hadronic showers, thus rejecting a possible contamination of genuine muons in the beam which would affect the measurement of fake muons from hadron punch-through. In addition, when running with muon beams to study momentum resolution and trigger efficiencies, the calorimeter will provide information on the muon energy loss in the absorber.

The muons are again momentum analyzed in a second magnet which consists of iron plates 2m thick, magnetized to 1.5 T. This magnetised absorber fakes the return yoke of the CMS. As mentioned earlier, it is important to trace the particles in the magnetic field. Hence, we plan to install several layers of track chambers inside the magnetized absorber, as shown in Fig. 6.

Three trigger and chamber stations are located along the beam line, the first behind the EHS magnet, the others inside and behind the iron magnet. The first two correspond approximately to the trigger stations of CMS detector sketched in Fig. 5. These stations are composed of muon chambers arranged in the same way as they were used in the UA1 experiment, and of two planes of RPC's which should serve as a fast trigger.
Each trigger plane is made of two layers of RPC's $2\times2$ m$^2$ with alternating x-y read out strips of 2-3 cm width. A fast signal from individual strips, or groups of strips, will be available for a fast trigger and tests of first level trigger algorithms.

For a precise measurement of the particle trajectory we propose to use a part of the UA1 muon chambers [8]. Each module consists of two chambers separated by a lever arm of 50 cm thus providing a good determination of the particle direction. The chambers are composed of extruded aluminium tubes, each representing one drift cell. The cells within one chamber are arranged in two double planes which are orthogonal to each other. In order to solve the left - right ambiguities, the tubes of a double plane are staggered. By this tube arrangement a track is measured in two orthogonal projections with four planes per projection. The single point resolution varies from 300 $\mu$m near the anode to $\sim$ 500 $\mu$m at the edge of the tube.

4. SUMMARY

At LHC the rate from genuine muons in the central muon chambers will be high: $10^6$ muons/sec. The muon trigger has to perform a $P_T$ cut of about 50 GeV/c to reduce the trigger rate to an acceptable level.

Leakage of jets after a typical calorimeter of 10 absorption lengths will produce spurious hits causing a confusion in the $P_T$ reconstruction of muons. This combinatorial background will affect the muon trigger and the reconstruction of prompt muons.

Punch through simulations are extremely time consuming. They have large uncertainties and are not adequate to simulate the combinatorial background in the momentum measurement.

Parametrization of existing punch-through measurements cannot be used to study the trigger confusion problem.

The muon proposal P7 will allow realistic trigger studies of general interest for any muon detector system.

In addition the proposed set-up will allow to study the performance of large area muon chambers in magnetized absorbers and the corresponding muon momentum resolution.

REFERENCES

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