MUON TRIGGERING
AT
SMALL ANGLES

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Abstract

Muon triggering for forward/backward detectors has been studied. The goal is to cover most of the available rapidity range. In particular, tags for diffractive heavy flavor production are considered.

Kinematics, Rates

The SSC is assumed to have a luminosity of $L=10^{33}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ with an inelastic cross section of $\sigma_I=100$ mb at $\sqrt{s}=40$ TeV or 100 MHZ interaction rate, R_I. Assuming a particle density of $\rho=6$ per unit of rapidity then there is $dR/dy=R_I\rho=600$ MHZ particle rate per unit of rapidity. Very soft particles are assumed to have a spectrum $dR/dydP_\perp^2=(b^2R_I\rho/2)e^{-bP_\perp}$, where $\langle p_\perp\rangle=2/b=0.5$ GeV or $b=4$ GeV^{-1}. At moderate $P_\perp$ one uses the ISR + UA1 data scaled to SSC(1), $d\sigma/dydP_\perp \sim 80\ \mathrm{mb}/[P_\perp(\mathrm{GeV})]^{3.5}$.

Various masses M are assumed to spread uniformly in rapidity y out to $y_{max}=\ln(\sqrt{s}/m)$. It is assumed that $y=\ln\ [\tan(\theta/2)]$. The relevant subprocesses have $M^2/s=x_1x_2=\hat{s}/s=\tau$.(2). For example, $\tau=6\times10^{-6}$ at a mass of 0.1 TeV and $y_{maX}=6.0$.

For a typical hard subprocess, such as heavy quark production by gluon fusion, the rate scales(2) roughly as $\sim 1/M_Q{}^3$. For example, M=1.0 TeV, $M^2/s=6.0\times10^{-4}$, $M_Q \sim M/2$ and $\sigma(Q\bar{Q}) \sim 40$ Pb. Hence, different mass scales are achieved at radically different luminosities times dwell time. At $M_Q \sim 0.5$ TeV one gets ~ 10,000 events in 1000 hours if $L=10^{32}cm^{-2}sec^{-1}$.

Central Muon Detection

A generic muon detector is shown in Figure 1. The free decay length occupied by tracking is L'. The calorimetry is λ1 interaction lengths deep, while the steel is λ2 deep. The steel length is L. The steel is magnetized to a field Bo. The detector is instrumented with stations A, B, and C with resolution δ x external to the steel, with exit level arm l. The fact that the critical energy in iron is 300 GeV means that a redundancy of n stations in the steel must be provided(3). The decay rate scales as L'/P. The momentum resolution is the ratio of $\Delta P_\perp$ due to multiple scattering over $\Delta P_\perp$ due to bending scaled as $1/\sqrt{n}$. The maximum measurable momentum is $\Delta P_\perp$ due to the magnetic bend over $\sqrt{2}\delta x/l$. For example with the parameters L=4.0m, $B_o=20$ kG, l=1.0m, δx=200 μm and n=4 one has momentum resolution of ~ 5% up to a maximum momentum of 7 TeV.

Punchthrough and Decay

Hadronic punchthrough has been measured at depths up to 15 λ_o and momentum up to ~ 150 GeV/c(4). The data in steel can be fit to P=punchthrough probability $=e^{-(\lambda-\lambda')/\lambda_{EFF}}$ where $\lambda'/\lambda_o=1.53\ [P(GeV)]^{0.33}$ and $\lambda_{EFF}/\lambda_o=0.89\ [P(GeV)]^{0.165}$. For example, with 7 λ_o calorimetry and 4m of steel, the punchthrough probability is ~ 1% for 1.0

TeV incident hadrons. At the depths considered here, punchthrough can be ignored with respect to decays, at least for triggering purposes. Ultimately, one expects(4) a rejection factor $>10^5$ against hadrons at these depths.

For the parameters given above, the punchthrough probability behind the calorimeter at 7 λ_0 depth is 10% at $P_\perp$ ~ 15 GeV/c and is negligible behind the steel in the B and C stations. Decays are the dominant trigger (as opposed to physics) background at the $P_\perp$ scale relevant to triggering. The pion decay probability is 1/500 at $P_\perp$ ~ 10 GeV/c. At 90°, assuming a level zero (L0) trigger made of scintillator at the B station, one has, for a L'=1m decay length, a range cut off of P^{min}=6.2 GeV or a rate $(dR_\mu/dy)_{y=0}$ ~ $7\text{x}10^{-31}\text{cm}^2(L)$ ~ 700 HZ.

For other angles, the decay length increases as $1/\sin\theta$ while the range cutoff scales as $1/\sin\theta$, so that $p_\perp^{min}$ is roughly constant. Hence the trigger rate for $|y|<2$ varies less than a factor of 4.

$|y|<2$ Triggering

The L0 trigger uses scintillator to tag the appropriate crossing (separation ~ 33 nsec). The rate is ~ 5 KHZ. The 4m of steel has a magnetic bend of 2.4 GeV/$\sin\theta$. A level one (L1) rate of 100 Hz can be achieved for a $P_\perp^{min}$ cut of ~ 20 GeV. This cut can rapidly be made using latched drift cell information. A decay muon of $P_\perp$ = 20 GeV bends by 120 mrad. In the notation of Fig. 1, for a 1/2 cell width of a, then one needs $\sqrt{2}\ a/l \leq$ the bend angle if one uses drift tube hodoscopic information at L1. Choosing a=2cm and a fast gas(5) such as CF_4 or CH_4, one has a drift time of 200 nsec (~ 6 crossings ~ 20 interactions) and $\sqrt{2}\ a/l$ ~ 28 mrad. If necessary, a level 2 (L2) trigger could be used which would read the drift times and more precisely calculate $P_\perp$(4).

The proportional drift tube (PDT) layout for muon detection over $|y|<4$ is shown in Figure 2. One needs roughly 50,000 tubes to instrument $|y|<2$ and surround a generic compact large 4π SSC detector(6). Space point readout(4) using drift time and vernier pads for the 2 coordinates seems attractive for triggering purposes.

$2<y<4$ Triggering

The layout for this region is shown in Fig. 2. One assumes a generic 4π detector with 3m for tracking and 2m for calorimetry. This is followed by an end cap with 5m of magnetized iron covering $2<y<4$, or $15^{\circ}<\theta<2^{\circ}$. This regime is a straightforward extrapolation of the CDF(7) muon detectors. The number of 4cm cells (each detection plane has 2 layers of 1/2 cell offset as in $|y|<2$) is 20,000.

Again the L0 trigger is defined by scintillator. However, the rate is now greatly increased since calorimetry plus 5m of iron bends by $\Delta P \sim 3$ GeV, and ranges out $P_{min} \sim 8$ GeV or $P_{\perp}^{min} \sim 8$ GeV sin . The L0 rate is shown in Fig. 3. It ranges (per unit of rapidity) from ~ 40 KHZ at $y=2$ (15°, $P_{\perp}^{min} = 2.1$ GeV) to ~ 5 MHZ at $y=4$ (2.1°, $P_{\perp}^{min} = 0.3$ GeV). The total forward + backward rate is then ~ 6 MHZ. This is ~ 1000 times the central rate.

What is needed in L1 is a fast $P_{\perp}$ calculation. As in the central region one uses PDT hodoscopic information, but with a 5 times longer lever arm. Assuming a maximum 200 nsec drift time $T\mu$ we have a factor of $1/(1+R\mu T\mu)=1/1.12$ deadtime if no pipelining is used. The lever arm resolves $P=530$ GeV or $P_{\perp}=140$ GeV ($y=2$) down to $P_{\perp}=20$ GeV ($y=4$). This means that a L1 rate of 100 Hz in this region can be maintained.

Diffraction

A glance at Figure 3b, shows that for masses $\gtrsim 1$ TeV, muon coverage of $|y|<4$ is sufficient. However for masses <0.1 TeV this range is only ~ 1/2 of the kinematically allowed range. In particular, if diffraction of heavy quarks exists, then most of the diffractively produced tracks fall well outside $|y|<4$. For example, $Q\bar{Q}$ pairs at x 1 decaying as $Q \to q l \nu$ would have, for $M_Q=.10$ TeV, a muon with ~ 3.0 TeV momentum, $\theta \sim 0.6^{\circ}$ or $y \sim 5.3$. Muon tags of diffractive heavy flavor production will then need to cover this range of y.

$4<y<6$ Triggering

A straightforward trigger extension of the region $2<y<4$ is to add 5m of steel from $15m<Z<20m$. Assuming vacuum for $Z<15m$ at small angles ($|y|>4$) then P_{min} is ~ 8 GeV and $P_{\perp}^{min}$ ranges from 0.3 GeV ($y=4$) to 0.042 GeV ($y=6$). Hence, one is down from the inclusive rate $R_I\rho$ only by the π decay factor for P_{min} (~ 1/20). The L0 rates are plotted in Fig. 3a. The total is ~ 80 MHZ. The deadtime factor is then $1/(1+R_\mu T_\mu)=1/17$. Obviously, this is unacceptable.

One could prescale or reduce L by 100X to achieve a 10% dead time or one could assume a specialized small angle detector(8). This detector would for $4<y<6$ exist at radii 2.5 to 20 cm at Z=5m, and 7.5 to 60 cm at Z=15m. This is shown very schematically in Fig. 2. Assuming 1/2 of steel density, then the 10m of material raises P_{min} to 16 GeV. This cut reduces the L0 rate but only to ~ 40 MHZ. The ultimate hadron rejection factor of $>10^5$ still exists when tracks are reconstructed. However, one must first extract small angle muon triggers at full luminosity with no dead time.

Pipeline

In order to exploit the luminosity and energy of the machine it seems obvious that pipelining is needed. The muon PDT live time of 200 nsec is well matched to other detector elements; silicon, calorimetry, and tracking detectors. The fast L0 scintillator trigger will label which crossing to look at. One then has ~ 6 crossings (~20 events) in the pipeline. These crossings are searched for adjacent muon PDT layers which have a time checksum.

This checksum is valid for the given crossing (tagged by L0) only for hits from the 3.3 events from that crossing. If the time checksum exists, then the A, B, and C layers (see Fig. 1) can be used as hodoscopes with MLU units to calculate $P_\perp$ and hence decide L1. By scaling the exterior lever arm l as 1/sinθ, one can maintain constant L1 resolution in $P_\perp$ with angle. This scheme is entirely digital. For a 20 GeV cut in $P_\perp$ a modest (300 HZ for $|y|<6$) total L1 rate is preserved. Analog information, drift times and pad charges, can be used, after slower digitization, to form a more incisive L2 trigger.

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Figure Captions

1. Definition of muon detector parameters. L' is the decay path, λ_1 the calorimeter depth, and λ_2 the steel depth. The steel depth is L and the detectors outside the steel have lever arm l, resolution δx.

2. Schematic layout of muon detection for $|y|<4$.

3. a). Muon L0 trigger rate per unit of rapidity as a function of y. The dashed line is the total $\pi^{\pm}$ interaction rate $R_I\rho$.

   b). The rapidity range of various produced masses M at $\sqrt{s}$ = 40 TeV.