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CDF Run 2 muon system

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Abstract. The CDF muon detection system for Run 2 of the Fermilab Tevatron is described. Muon stubs are detected for $|\eta| < 1.5$, and are matched to tracks in the central drift chamber at trigger level 1 for $|\eta| < 1.25$. Detectors in the $|\eta| < 1$ central region, built for previous runs, have been enhanced to survive the higher rate environment and closer bunch spacing (3.5 μsec to 396 nsec) of Run 2. Azimuthal gaps in the central region have been filled in. New detectors have been added to extend the coverage from $|\eta| < 1$ to $|\eta| < 1.5$, consisting of four layers of drift chambers covered with matching scintillators for triggering. The Level 1 Extremely Fast Tracker supplies matching tracks with measured p_T for the muon trigger. The system has been in operation for over 18 months. Operating experience and reconstructed data are presented.

PACS. 14.60.Ef Muons – 29.40.Gx Tracking and position-sensitive detectors – 29.40.Mc Scintillation detectors – 3.38.-b Decays of intermediate bosons – 13.25.Gv Decays of J/psi, Upsilon, and other quarkonia 13.20.-vLeptonic and semileptonic decays of mesons

1 Introduction

The Tevatron Run 2 upgrade has combined a 9% increase in center-of-mass energy with a significant luminosity upgrade, providing myriad possibilities for precision measurements and new discoveries at the high-energy frontier. Key to many of these measurements is the efficient detection of muons over a large fiducial and kinematic range. The CDF Muon System has been refurbished to take full advantage of this upgrade to provide muon detection for a variety of physics signatures including W, Z, J/ψ and rare decays, as well as flavor-tagging of b-hadrons [1].

CDF Run 2 has been operating since Fall 2001, and recording physics-quality data since February 2002. Muon detector upgrades and operating experience are described, and physics signals from the Run 2 detectors are shown.

2 Run 2 operation

Upgrades to the Tevatron for Run 2 have required changes to the existing detectors and dictated the specifications [2] for the new ones, as shown in Fig. 1. The peak instantaneous luminosity in Tevatron Run 2 is expected to reach[1] $20 - 40\times10^{31}$ cm^{-2} s^{-1} up from the Run 1 value of 2×10^{31} cm^{-2} s^{-1}. The bunch crossing time has been reduced significantly, from 3500 to 396 ns, and the number of proton and antiproton bunches has increased from 6 to 36 (each). The Tevatron typically operates with ten times higher proton intensity than antiproton intensity, and proton-beam-induced backgrounds can be significant.

[1] The record in July 2003 was 4.75×10^{31} cm^{-2} s^{-1}.

Much of the muon system is exposed to beam loss. Due to higher intensities and other changes in the machine, standing currents in exposed chambers due to these losses are much higher than they were in Run 1 leading to concern about chamber aging. The other operational difficulty has been the frequent tripping of high voltage supplies due to large current draws induced by spikes in beam losses. It was common early in Run 2 for regions of the detectors to be inoperable due to the disruption of data taking during trips and recovery. Studies of chamber aging indicate that the lifetime of the chambers extends well beyond the end of the run. Furthermore, while standing currents have risen as higher instantaneous luminosity has increased, they have risen only moderately; and the frequency and size of the loss spikes has been much reduced as the machine has been tuned up. Operational problems due to the spikes have been isolated to the occasional store or during accelerator start up after maintenance shutdowns.

3 Muon system upgrades

The Run 2 muon detector parameters are shown in Table 1.

The Central Muon Detector (CMU) is now operated in proportional rather than limited-streamer mode, due to the expected voltage sag at high rates. Pre-amplifiers were added to recover the lost gain. The lower gain also lowers detector occupancy and reduces the detector aging. New amplifier-shaper-discriminators matched to the new pulse shapes encode the charge into the pulse width for

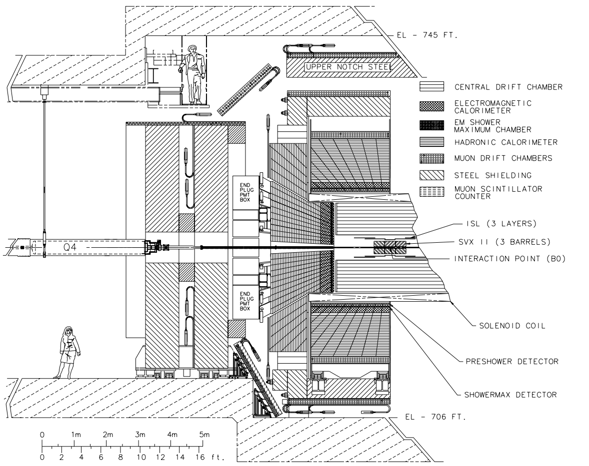

Fig. 1. The CDF Run 2 detector

offline reconstruction of a z-position from charge division. The azimuthal (ϕ) coverage of the Central Muon Extension chambers (CMX) and scintillators (CSX), and the Central Muon Upgrade chambers (CMP) and scintillators (CSP), was extended to the full azimuthal range. In each of the CSP counters, a ribbon of scintillating fiber was added along the counter edge to improve light transmission. Additional steel absorber was installed between the beampipe and CMX, to reduce beam-splash backgrounds.

The Run 1 forward muon system was dismantled and an entirely new intermediate muon system (IMU) built. The IMU detectors are mounted on the steel of the Run 1 toroids which have been pushed 5.5m closer to the interaction region but are not energized. The IMU consists of a barrel-shaped array of muon chambers (BMU) and scintillators (BSU), mounted parallel to the beamline, and one[2] ring-shaped array of scintillators (TSU) mounted perpendicular to the beamline. The new detectors complete the continuous muon coverage up to $|\eta| \lesssim 1.5$. BMU consists of single-wire rectangular drift tubes mounted in four half-cell-staggered stacks, each covering 1.25° of azimuth. One fourth of the azimuthal range is uninstrumented, due to interference with the support structure and moving mechanism of the toroids. The Barrel Scintillators (BSU) consist of rectangular plastic scintillators, each covering 2.5° in ϕ and 1.25 units in η. The BSU is separated into front and rear counters, each covering twice the azimuth and half the length of a BMU chamber. The BSU counters are mounted outside the BMU chambers and cover the same azimuthal range. The Toroid Scintillators (TSU) consist of trapezoidal polystyrene scintillators, each covering 5° of azimuth, and are mounted inside the toroid steel. Each BSU or TSU has wavelength-shifting fibers, a 0.8cm-diameter Cockroft-Walton PMT (Hamamatsu H5783), and utilizes a custom HV control and readout package [3].

[2] Fig. 1 shows an inner and an outer ring of TSU counters; however, only the outer ring has been built.

Table 1. Muon System Parameters

Chambers/ Scintillators	$\|\eta\|$ min	$\|\eta\|$ max	$\Delta\phi°$	T_{drift}^{max}(ns)	#chans
CMU	0	0.6	360	800	2304
CMP/CSP	0	0.6	360	1400	1076/269
CMX/CSX	0.6	1	360	1400	2208/324
BMU	1	1.5	270	800	1728
/BSU-front	1	1.25	270	–	216
/BSU-rear	1.25	1.5	270	–	216
/TSU	1.3	1.5	360	–	144

Table 2. Trigger cross sections (nb) [$\mathcal{L}_{inst} \sim 3 \times 10^{31} cm^{-2} s^{-1}$]

Signature	σ(L1)	σ(L2)	σ(L3)
J/ψ	1500	1500	60
b-hadron flavor tagging	1500	200	50
inclusive high-p_T muon	90-200	90-200	10

4 Muon triggers and offline reconstruction

A three-level triggering system is used to select events from the crossing rate of 7.6 MHz and write ~60 Hz to tape, see Table 2. At level-one, muon triggers employ the Extremely Fast Tracker (XFT) [4], which finds tracks for each bunch crossing using three or four axial superlayers of the central-tracker (COT). [3] The track ϕ, transverse momentum (p_T), and charge are sent to the Extrapolation Unit (XTRP) which extrapolates the XFT track to the muon chamber radii, based on the track p_T and charge. Matching between extrapolated tracks and muon stubs is done in $\Delta\phi = 2.5°$ intervals. Some triggers also require scintillator hits matching the muon stub, or an opening angle between two muons. Because the maximum chamber drift times ($\gtrsim 800$ ns) are longer than the bunch crossing time (396 ns), the event bunch crossing is determined from a track or scintillator hit. Currently, level-two is used only as a passthrough path, to tighten already existing cuts on p_T, or to require any silicon-based displaced track vertex [5]. Level-three consists of a processor farm where events are reconstructed and filtered using the full event information, including more precise track-stub matching, track p_T, dimuon invariant mass, etc.

The offline reconstruction of muons requires a track matched to a muon chamber stub. The stubs are used as tags and track momentum is determined exclusively from COT and/or silicon tracks. The stub z-position is available from CMU, CMX, and BMU; stub ϕ-position (or x- and y-position) is available from all detectors.

[3] The XFT geometrical acceptance is limited to $|\eta| \lesssim 1.25$. Level-two upgrades allowing matches between muon stubs and silicon tracks may extend the muon trigger to $|\eta| \lesssim 1.5$. Muon triggers without tracks are heavily prescaled.

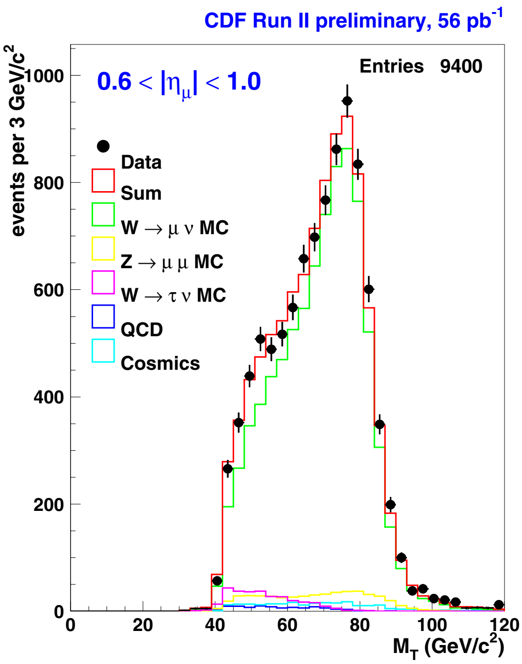

Fig. 2. $W \to \mu\nu$ with the muon detected in CMX

5 Results from Run 2 muon detectors

Selected results for $W \to \mu\nu$ and Z$\to \mu\mu$ from the upgraded muon detectors show the excellent performance of these detectors. In Fig. 2, the transverse mass $M_{\mathrm{T}} = \sqrt{2[E_{\mathrm{T}}^{\nu}E_{\mathrm{T}}^{\mu} - \mathbf{p}_{\mathrm{T}}^{\nu} \cdot \mathbf{p}_{\mathrm{T}}^{\mu}]}$ is shown for a selection of inclusive high-p_{T} muons detected in the CMX chambers. The missing momentum due to the neutrino is assumed to be opposite to $\mathbf{p}_{\mathrm{T}}^{\mu}$ and the vector sum of calorimeter tower energies not associated with the muon. An inclusive high-p_{T} CMX trigger, impossible unprescaled in Run 1, is now possible due to the additional steel absorber which reduces the beam-induced background considerably. In Fig. 3, the invariant mass of two muons is shown, where one muon is triggered and detected in CMU and CMP, and the other detected in BMU. The observed Z-mass resolution from tracking (which includes the natural width $\Gamma_Z \sim 2$ GeV) is $\sigma \sim 5$ GeV. In Fig. 4, an M_{T} distribution is shown for W events triggered by a single high-p_{T} muon in BMU. W's are now triggered efficiently to $|\eta| \lesssim 1.25$. Triggering on muons up to $|\eta| \lesssim 1.5$ may be possible with upgrades.

6 Conclusions

The CDF Run 2 muon system provides excellent data-taking capabilities. The data-taking efficiency, measured by the ratio of luminosity written to tape by CDF to luminosity delivered by the Tevatron is $\sim 200\mathrm{pb}^{-1}/245\mathrm{pb}^{-1}$ since February 2002. The last year has seen significant improvement in detector stability, with reduced beam losses.

The intermediate muon system has been commissioned, so the CDF Muon System now provides almost continuous coverage up to $|\eta| \lesssim 1.5$. With the new IMU and commissioning of the CMX/CSX, the high-p_{T} muon trigger has been extended from $|\eta| < 0.6$ up to $|\eta| < 1.25$. Results for $W \to \mu\nu$ and Z$\to \mu\mu$ from the upgraded detectors, taken with inclusive high-p_{T} muon triggers, have been shown.

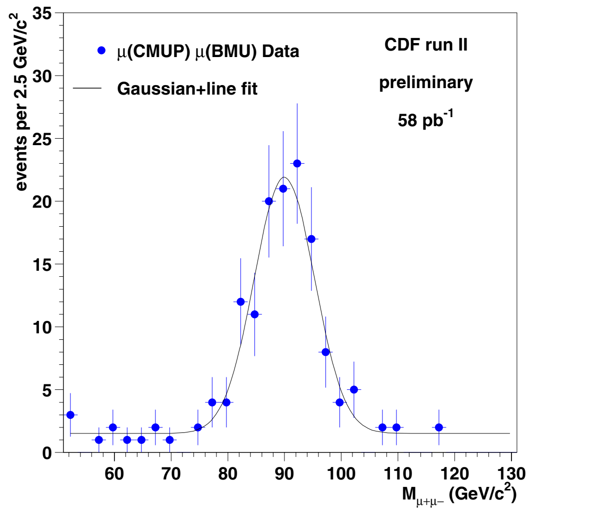

Fig. 3. $Z \to \mu\mu$ with one muon detected in CMU and CMP, and one muon detected in BMU

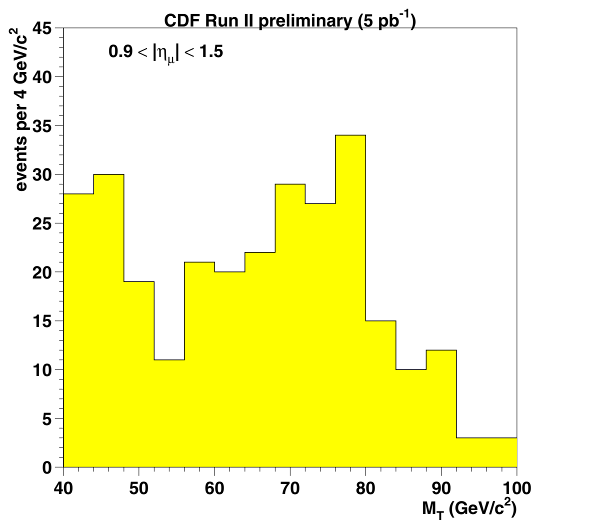

Fig. 4. $W \to \mu\nu$ events with the muon detected in BMU

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