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SDC
SOLENOIDAL DETECTOR NOTES

PHYSICS IMPACT OF PHI CRACKS IN THE SDC BARREL MUON SYSTEM

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Abstract

This note summarizes studies of the physics impact/ramifications associated with phi cracks at the octant boundaries in the SDC barrel muon system for the 93 mm o.d. θ and ϕ tubes.

Detailed Monte Carlo simulations of various physics processes have been carried out, simulating the phi cracks associated with the SDC barrel muon system, for BW1-BW3 superlayers. The geometrical information associated with the phi cracks in the BW superlayers was kindly provided by Colin Daly of the University of Washington, and are shown in figs 1 & 2.

The input data to the SDC muon Monte Carlo simulation program consisted of a.) a random isotropic distribution of $P_T = 50\ GeV/c$ mono-chromatic muons, b.) muons from $W \rightarrow \mu\ \nu_\mu$ decay from ISAJET, c.) muons from $Z^0 \rightarrow \mu^+\mu^-$ decay from ISAJET, d.) muons from $Z'/DY \rightarrow \mu^+\mu^-$ decay from ISAJET, for muon pair masses of $M_{pair} = 200, 500\ GeV/c^2$, e.) muons from $ZZ \rightarrow 4\mu$ decay from ISAJET, f.) muons from $H \rightarrow ZZ \rightarrow 4\mu$ decay from ISAJET, for $M_H = 400\ GeV/c^2$ and $M_H = 800\ GeV/c^2$. The SDC muon Monte Carlo simulation program then transported the muons through the various B-field regions of the SDC detector (solenoid and barrel toroid), and included MCS, dE/dX loss in the barrel calorimeters, BW superlayers, the barrel muon toroid, as well as the detailed geometrical aspects of the SDC muon system.

Table I summarizes the % acceptance loss as calculated (analytically) for infinite momentum tracks, associated with the ϕ and θ views for each of the BW superlayers, and the fiducial acceptance, ϵ for muons passing completely through all three BW muon superlayers. Table II summarizes the % acceptance loss for $P_T = 50\ GeV/c$ mono-chromatic muons associated with the ϕ and θ views for each of the BW superlayers, and the fiducial acceptance, ϵ for muons passing completely through all three BW muon superlayers. Table III summarizes the % acceptance loss and overall acceptance for muons from $W \rightarrow \mu\ \nu_\mu$ production and decay. Table IVa summarizes the % acceptance loss and fiducial acceptance for muons from $Z^0 \rightarrow \mu^+\mu^-$ production and decay. Table IVb summarizes the % acceptance loss and fiducial acceptance for one and for both muons from $Z^0 \rightarrow \mu^+\mu^-$ production and decay. Table Va summarizes the % acceptance loss and fiducial acceptance for muons from $Z'/DY \rightarrow \mu^+\mu^-$ production and decay. Table Vb summarizes the % acceptance loss and fiducial acceptance for one and for both muons from $Z'/DY \rightarrow \mu^+\mu^-$ production and decay. The muon pair mass is $M_{pair} = 200\ GeV/c^2$. Table VIa summarizes the % acceptance loss and fiducial acceptance for muons from $Z'/DY \rightarrow \mu^+\mu^-$ production and decay. Table VIb summarizes the % acceptance loss and fiducial acceptance for one and for both muons from $Z'/DY \rightarrow \mu^+\mu^-$ production and decay. The muon pair mass is $M_{pair} = 500\ GeV/c^2$. Table VIIa summarizes the % acceptance loss and fiducial acceptance for muons from $ZZ \rightarrow 4\mu$ production and decay. Table VIIb summarizes the % acceptance loss and fiducial acceptance for 1-4 muons from $ZZ \rightarrow 4\mu$ production and decay. Table VIIIa summarizes the % acceptance loss and fiducial acceptance for muons from $H \rightarrow ZZ \rightarrow 4\mu$ production and decay. Table VIIIb summarizes the % acceptance loss and fiducial acceptance for 1-4 muons from $H \rightarrow ZZ \rightarrow 4\mu$ production and decay. The Higgs mass is $M_H = 400\ GeV/c^2$. Table IXa summarizes the % acceptance loss and fiducial acceptance for muons from $H \rightarrow ZZ \rightarrow 4\mu$ production and decay. Table IXb summarizes the % acceptance loss and fiducial acceptance for 1-4 muons from $H \rightarrow ZZ \rightarrow 4\mu$ production and decay. The Higgs mass is $M_H = 800\ GeV/c^2$.

Conclusions

These studies indicate that for the present design of the SDC barrel muon BW superlayers, there are $\sim 5\%$ acceptance losses associated with single muons, i.e. the single muon fiducial acceptance is $\sim 95\%$. This result is relevant for e.g. mapping out the inclusive single muon P_T spectrum, and for e.g. $W \rightarrow \mu\ \nu_\mu$ physics and e.g. $t - \bar{t} \rightarrow 1\mu\ +\ X$ physics. The losses in the $\phi-$tubes are highly correlated with the $\theta-$tube losses due to the dead space regions at the octant boundaries of the SDC barrel muon system. For processes such as $Z^0 \rightarrow \mu^+\mu^-$, there are $\sim 10\%$ losses associated with losing one, or both muons. The Z "golden" di-muon fiducial acceptance is $\sim 90\%$. Note that the Z results are approximately that obtained from squaring the % losses for e.g. muons from W decay. We also remind the reader that these losses not only impact physics results at the offline data-analysis level, but also at the trigger level. Muons from W will come in on the single-muon trigger, whereas muons from Z can come in on both the single muon and di-muon triggers. However, we do not trigger on muons not passing through the muon chambers. Similarly, for $ZZ \rightarrow 4\mu$, there are $\sim 20\%$ losses associated with losing one or more muons. The ZZ "golden" 4-muon fiducial acceptance is $\sim 80\%$. For $H \rightarrow ZZ \rightarrow 4\mu$, for $M_H\ =\ 400\ GeV/c^2$, there are again $\sim 20\%$ losses associated with losing one or more muons. The Higgs "golden" 4-muon fiducial acceptance is $\sim 80\%$. Note that to the statistical accuracy of the MC input data, no more than 2 muons per event are lost in ϕ and/or θ cracks. For $H \rightarrow ZZ \rightarrow 4\mu$, for $M_H\ =\ 800\ GeV/c^2$, there are again $\sim 20\%$ losses associated with losing one, or more muons. The Higgs "golden" 4-muon fiducial acceptance is $\sim 80\%$. A very small percentage of 3-muons are lost in ϕ and/or θ cracks in the sub-sample of C+C + C+C Higgs-to-4 muons events. Note that one expects to observe some (Higgs) mass dependence on these muon crack-acceptance results due to the kinematical correlations associated with the $H \rightarrow ZZ \rightarrow 4\mu$ production/decay process. Here again, to good approximation, the 4-muon losses are obtained by simply squaring the 2-muon losses.

We also remind the reader of the fact that the overall acceptance due to losses in the BW muon superlayers from ϕ (and other) cracks is a multiplicative factor on the geometrical/kinematical acceptance for muons from a particular physics process, even being produced in the central region of the detector in the first place. These geometrical/kinematical acceptances have been studied and discussed in previous SDC notes, see e.g. SDC-92-220 for futher details.

At the offline data-analysis level, following very closely upon the type of analyses that we routinely do on CDF for e.g. $Z^0 \rightarrow \mu^+\mu^-$ physics, the muons that do not pass through the acceptance of the BW muon superlayers can easily be recovered, as long as their momenta is well-measured in the CTD, and placing an additional requirement that their be the characteristic minimum-ionizing energy deposition signature in the calorimeter. On CDF, this "CMIO" requirement is sufficient to obtain an extremely clean dimuon sample from Z and/or high-mass Drell-Yan muon pairs. The efficiency for the "CMIO" minimum ionizing signature for high-P_T muons e.g. from $Z^0 \rightarrow \mu^+\mu^-$ on CDF has been measured to be $\epsilon_{cmio} = 98.7\% +0.3\% -0.4\%$ (CDF note 1301). We have no backgrounds, e.g. from QCD in such event samples. Cosmic ray dimuons in the mass region of interest can be potentially worrisome. They are only troublesome for dimuon pairs produced with $X_f = 0.0$ .AND. $P_T(pair) = 0.0$. In addition, if there is precise timing information, e.g. from the BW muon scintillators and/or from the barrel calorimeter, as well as precision track impact parameter information e.g. from the inner tracker silicon micro-strips, the cosmic ray backgrounds in dimuon samples can be (very) highly suppressed.

For the tetra-muon physics processes, at the offline data-analysis level, the muons lost in ϕ and/or θ cracks can be recovered as "CMIO" muons with very high efficiency. The efficiency for triggering on e.g. 2 out of 4 muons with a di-muon trigger is also high ($\epsilon_T > 90\%$), so these events should at least make it to tape with reasonably high probability.

It is also useful to compare the present design for the SDC barrel muon system with e.g. the CDF central muon system, which has cracks every 15 degrees in ϕ and in the 90 degree "blue-sky" region in θ. The CDF single muon acceptance in the central region is $\sim 75\%$. We have suffered no serious detrimental effects from the $\sim 25\%$ acceptance losses due to ϕ and θ, etc. cracks in the central region of the CDF detector in carrying out e.g. W and Z physics, searching for the Top quark (in the muon channel) at $\sqrt{s} = 1.8\ TeV\ \bar{p}-p$ collisions. To make up for these losses, one can compensate simply by running a little bit longer, increasing the integrated luminosity of the overall data sample, since the number of true signal events for a particular physics process is given by:

$$N_{true} = N_{obs} - N_{bkgnd} = \sigma * BR * \int \mathcal{L} \cdot dt * A * \epsilon$$

Where A is the overall acceptance and ϵ is the overall efficiency for a given physics process.

Thus, for 99.999% of all muon physics, the acceptance losses associated with the ϕ cracks in the BW barrel muon chambers at the octant boundaries present no significant compromise to the physics processes anticipated at the SSC. The only situation where one might wish for "perfect" coverage is for the special case of "Zoo" events, where one would like to know absolutely everything about a particular event, e.g. a lepto-quark candidate, including the nature of e.g. high-P_T tracks disappearing into regions of poor (or no) detector acceptance. Usually these events obey at least one of Murphy's laws for high energy physics, "seeking" out such regions of the detector with uncanny accuracy!

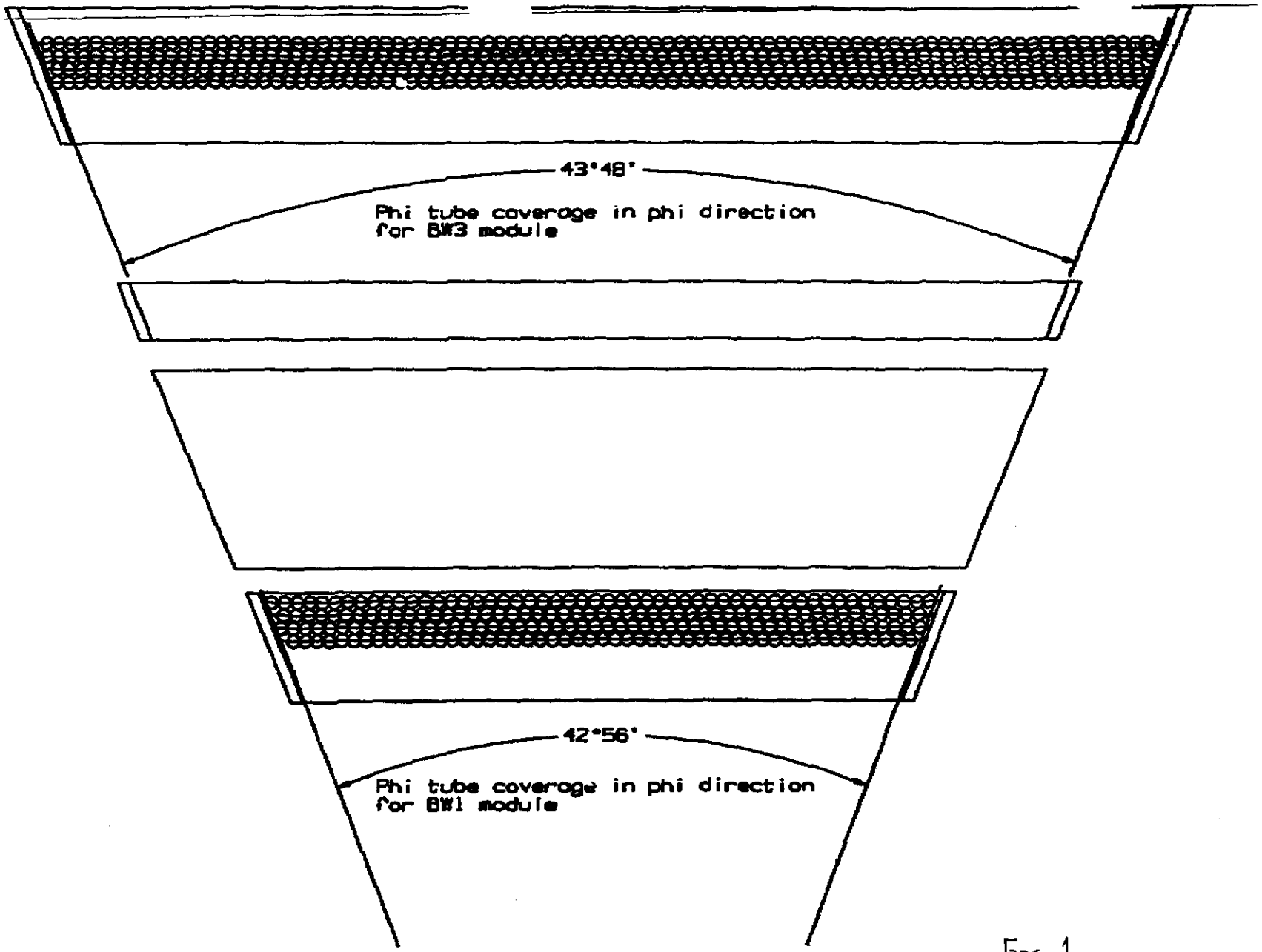
43°48'
Phi tube coverage in phi direction
for BW3 module
42°56'
Phi tube coverage in phi direction
for BW1 module

Fig. 1

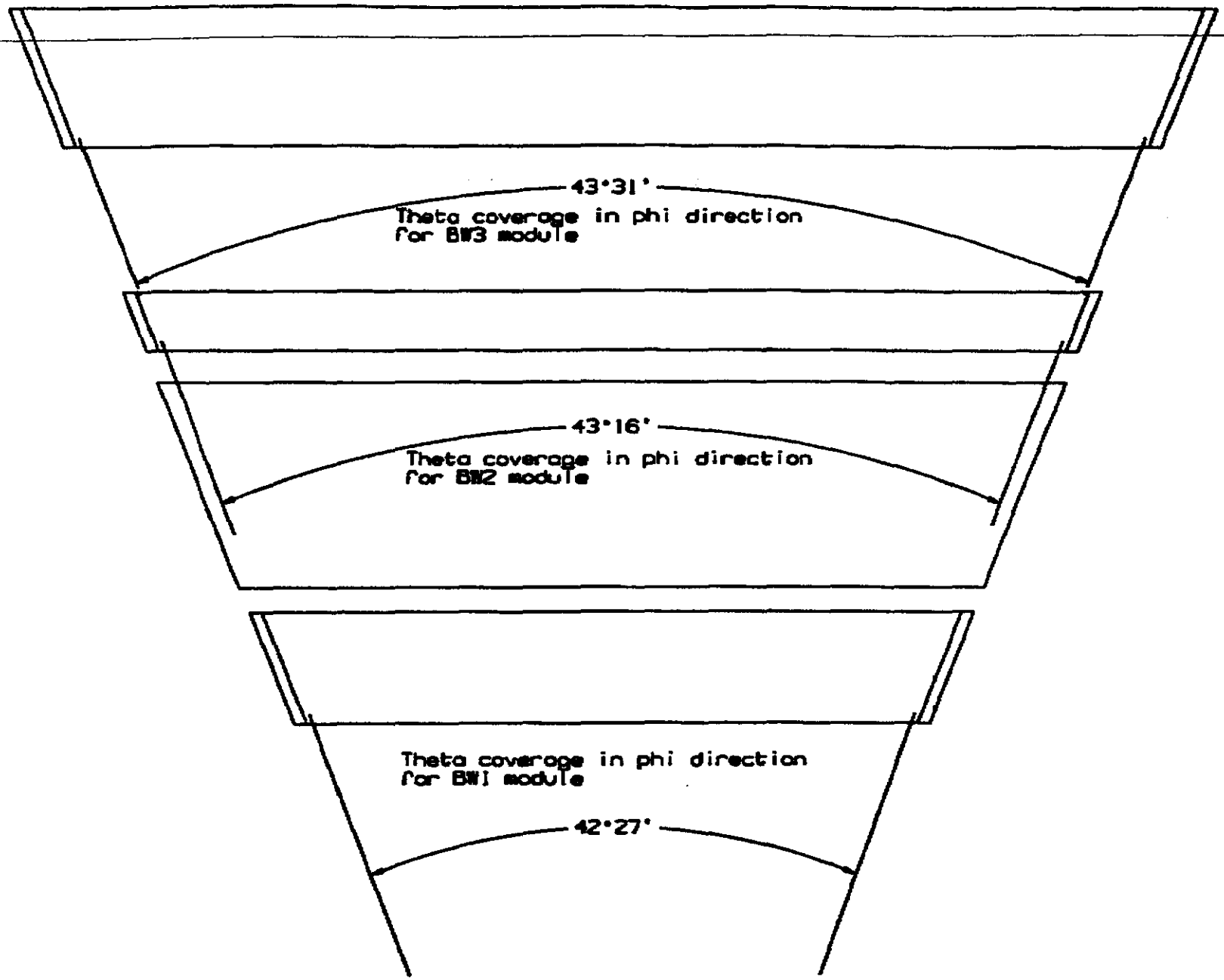
43°31'
Theta coverage in phi direction
for BW3 module
43°16'
Theta coverage in phi direction
for BW2 module
Theta coverage in phi direction
for BW1 module
42°27'

Fig. 2

Table I

Single Muon Acceptance - Analytic

	ϕ View	θ View
BW1 Loss	4.59%	5.67%
BW2 Loss	3.63%	3.85%
BW3 Loss	2.67%	3.29%
ϵ	95.41%	94.33%

Table II

50 GeV Mono-Chromatic Muons

	ϕ View	θ View
BW1 Loss	$4.1\% \pm 0.7\%$	$5.3\% \pm 0.8\%$
BW2 Loss	$3.7\% \pm 0.6\%$	$3.7\% \pm 0.6\%$
BW3 Loss	$2.5\% \pm 0.5\%$	$3.4\% \pm 0.6\%$
ϵ	$95.9\% \pm 0.7\%$	$94.7\% \pm 0.8\%$

Table III

$W \rightarrow \mu\ \nu_\mu$ Acceptance

	ϕ View	θ View
BW1 Loss	$4.5\% \pm 0.6\%$	$5.6\% \pm 0.7\%$
BW2 Loss	$3.6\% \pm 0.6\%$	$3.6\% \pm 0.6\%$
BW3 Loss	$2.7\% \pm 0.5\%$	$3.1\% \pm 0.5\%$
ϵ	$95.5\% \pm 0.6\%$	$94.4\% \pm 0.7\%$

Table IV

$Z^0 \rightarrow \mu^+\mu^-$ Acceptance
C+C muons only

	ϕ View	θ View
BW1 Loss	$4.1\% \pm 0.3\%$	$5.2\% \pm 0.3\%$
BW2 Loss	$3.3\% \pm 0.3\%$	$3.5\% \pm 0.3\%$
BW3 Loss	$2.3\% \pm 0.2\%$	$2.9\% \pm 0.3\%$
ϵ	$95.9\% \pm 0.3\%$	$94.8\% \pm 0.3\%$

	ϕ View	θ View
1μ Loss	$6.8\% \pm 0.9\%$	$8.2\% \pm 0.9\%$
2μ Loss	$0.8\% \pm 0.3\%$	$1.1\% \pm 0.4\%$
ϵ_0	$92.4\% \pm 0.9\%$	$90.7\% \pm 1.0\%$
ϵ_1	$93.2\% \pm 0.9\%$	$91.8\% \pm 0.9\%$
ϵ_2	$99.2\% \pm 0.3\%$	$98.8\% \pm 0.4\%$

Table V

$Z'/DY \rightarrow \mu^+\mu^-$ Acceptance
C+C muons only
$M_{pair} = 200\ GeV/c^2$

	ϕ View	θ View
BW1 Loss	$4.2\% \pm 0.3\%$	$5.6\% \pm 0.3\%$
BW2 Loss	$3.2\% \pm 0.3\%$	$3.6\% \pm 0.3\%$
BW3 Loss	$2.2\% \pm 0.2\%$	$2.8\% \pm 0.2\%$
ϵ	$95.8\% \pm 0.3\%$	$94.4\% \pm 0.3\%$

	ϕ View	θ View
1μ Loss	$6.1\% \pm 0.8\%$	$7.4\% \pm 0.9\%$
2μ Loss	$1.1\% \pm 0.4\%$	$1.8\% \pm 0.5\%$
ϵ_0	$92.8\% \pm 0.9\%$	$90.8\% \pm 0.9\%$
ϵ_1	$93.9\% \pm 0.8\%$	$92.6\% \pm 0.9\%$
ϵ_2	$98.9\% \pm 0.4\%$	$98.2\% \pm 0.5\%$

Table VI

$Z'/DY \rightarrow \mu^+\mu^-$ Acceptance
C+C muons only
$M_{pair} = 500\ GeV/c^2$

	ϕ View	θ View
BW1 Loss	$4.2\% \pm 0.3\%$	$5.3\% \pm 0.3\%$
BW2 Loss	$3.3\% \pm 0.2\%$	$3.6\% \pm 0.2\%$
BW3 Loss	$2.2\% \pm 0.2\%$	$2.9\% \pm 0.2\%$
ϵ	$95.8\% \pm 0.3\%$	$94.7\% \pm 0.3\%$

	ϕ View	θ View
1μ Loss	$6.0\% \pm 0.7\%$	$7.0\% \pm 0.7\%$
2μ Loss	$1.5\% \pm 0.4\%$	$2.3\% \pm 0.4\%$
ϵ_0	$92.5\% \pm 0.7\%$	$90.7\% \pm 0.8\%$
ϵ_1	$94.0\% \pm 0.7\%$	$93.0\% \pm 0.7\%$
ϵ_2	$98.5\% \pm 0.4\%$	$97.7\% \pm 0.4\%$

Table VII

$ZZ \rightarrow 4\mu$ Acceptance
C+C + C+C muons only

	ϕ View	θ View
BW1 Loss	$4.4\% \pm 0.2\%$	$5.6\% \pm 0.2\%$
BW2 Loss	$3.6\% \pm 0.2\%$	$3.7\% \pm 0.2\%$
BW3 Loss	$2.6\% \pm 0.2\%$	$3.2\% \pm 0.2\%$
ϵ	$95.6\% \pm 0.2\%$	$94.4\% \pm 0.2\%$

	ϕ View	θ View
1μ Loss	$18.2\% \pm 1.9\%$	$21.7\% \pm 2.1\%$
2μ Loss	$1.3\% \pm 0.7\%$	$1.6\% \pm 0.7\%$
3μ Loss	$0.2\% \pm 0.3\%$	$0.2\% \pm 0.3\%$
4μ Loss	$0.0\% \pm 0.2\%$	$0.0\% \pm 0.2\%$
ϵ_0	$80.3\% \pm 2.0\%$	$76.5\% \pm 2.1\%$
ϵ_1	$81.8\% \pm 1.9\%$	$78.3\% \pm 2.1\%$
ϵ_2	$98.7\% \pm 0.7\%$	$98.4\% \pm 0.7\%$
ϵ_3	$99.8\% \pm 0.3\%$	$99.8\% \pm 0.3\%$
ϵ_4	$100.0\% \pm 0.2\%$	$100.0\% \pm 0.2\%$

Table VIII

$H \rightarrow ZZ \rightarrow 4\mu$ Acceptance
C+C + C+C muons only
$M_H = 400\ GeV/c^2$

	ϕ View	θ View
BW1 Loss	$4.6\% \pm 0.2\%$	$5.8\% \pm 0.2\%$
BW2 Loss	$3.7\% \pm 0.2\%$	$3.8\% \pm 0.2\%$
BW3 Loss	$2.7\% \pm 0.1\%$	$3.4\% \pm 0.2\%$
ϵ	$95.4\% \pm 0.2\%$	$94.2\% \pm 0.2\%$

	ϕ View	θ View
1μ Loss	$16.2\% \pm 1.3\%$	$20.3\% \pm 1.4\%$
2μ Loss	$0.9\% \pm 0.4\%$	$1.6\% \pm 0.5\%$
3μ Loss	$0.0\% \pm 0.2\%$	$0.0\% \pm 0.2\%$
4μ Loss	$0.0\% \pm 0.2\%$	$0.0\% \pm 0.2\%$
ϵ_0	$82.9\% \pm 1.3\%$	$78.1\% \pm 1.4\%$
ϵ_1	$83.8\% \pm 1.3\%$	$79.7\% \pm 1.4\%$
ϵ_2	$99.1\% \pm 0.4\%$	$98.4\% \pm 0.5\%$
ϵ_3	$100.0\% \pm 0.2\%$	$100.0\% \pm 0.2\%$
ϵ_4	$100.0\% \pm 0.2\%$	$100.0\% \pm 0.2\%$

Table IX

$H \rightarrow ZZ \rightarrow 4\mu$ Acceptance
C+C + C+C muons only
$M_H = 800\ GeV/c^2$

	ϕ View	θ View
BW1 Loss	$4.4\% \pm 0.2\%$	$5.6\% \pm 0.2\%$
BW2 Loss	$3.5\% \pm 0.1\%$	$3.7\% \pm 0.1\%$
BW3 Loss	$2.6\% \pm 0.1\%$	$3.1\% \pm 0.1\%$
ϵ	$95.6\% \pm 0.2\%$	$94.4\% \pm 0.2\%$

	ϕ View	θ View
1μ Loss	$16.2\% \pm 0.9\%$	$19.8\% \pm 1.0\%$
2μ Loss	$1.2\% \pm 0.3\%$	$1.7\% \pm 0.3\%$
3μ Loss	$0.1\% \pm 0.2\%$	$0.1\% \pm 0.2\%$
4μ Loss	$0.0\% \pm 0.2\%$	$0.0\% \pm 0.2\%$
ϵ_0	$82.5\% \pm 0.9\%$	$78.4\% \pm 1.0\%$
ϵ_1	$83.8\% \pm 0.9\%$	$80.8\% \pm 1.0\%$
ϵ_2	$98.8\% \pm 0.3\%$	$98.3\% \pm 0.3\%$
ϵ_3	$99.9\% \pm 0.2\%$	$99.9\% \pm 0.2\%$
ϵ_4	$100.0\% \pm 0.2\%$	$100.0\% \pm 0.2\%$