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ID efficiency for isolated, intermediate p_T muons

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Abstract

In this note we present a set of proposed identification cuts for muons in the intermediate p_T range from 4-20 GeV and we study their efficiencies. This note is accompanied by a note on the SUSY dimuon trigger efficiencies [1], which uses the same ID cuts to identify muons.

Contents

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1 Introduction and list of cuts

The ID cuts we propose are tested and optimized for intermediate momentum muons, for SUSY searches conducted within the SUSY multilepton group. Release 5.3.1 for data and Stntuple dev_242 are used to produce the results presented in this note and cross checks have been performed with independent code.
For this study we have used the muon calibration sample, MUON_CALIB-0d (bmcl0d) and concentrated on the muons recorded by the MUON_CMUP8 trigger path. This data was taken from February 2002 until the shutdown in September 2003, run 141544 to 168889.

We are using version 6.0 of the good run list for Top/EWK/Exotics muons, silicon not required. (i.e. (0,0,2.1) for CMX and (0,0,3,1) for CMU/P)

The cuts tested here are for muons with $p_T \geq 4$ GeV. The studies were done with beam constrained tracks but we expect the conclusions to hold also for default tracks. We have also collaborated with the high- p_T efforts to cross check procedures and results, as illustrated in the following sections.

For $p_T \geq 20$ GeV we use the standard cuts developed by the EWK group and described in [2]. The muons were not required to be fiducial in this study. It was checked that the scale factors only vary within the uncertainties if fiduciality is required. Between 4 and 20 GeV we use the following cuts:

- EM energy ≤ 2 GeV
- Hadronic energy $\leq 3.5 + p_T/8$ GeV
- Impact parameter corrected for beam position $|d_0| \leq 0.2$ cm
- At least 2 stereo and 3 axial segments in the COT with 5 or more hits.
- Stub cuts for $p_T < 20$ GeV:

  CMU: dx$\leq$ 3 cm OR $\chi^2 < 9$

  CMP: dx $\leq$ 5 cm OR $\chi^2 < 9$

  CMX: dx $\leq$ 6 cm OR $\chi^2 < 9$

The correlations between the stub χ^2's and dx matching is shown in appendix E. In particular the CMP χ^2 cut is still under investigation. It was decided to use the stub χ^2's to account for the poorer matching at low p_T . Figure 2 shows the matching in dx for high and low p_T muons for comparison.

A few other cuts have been applied for clean-up purposes and will be listed in the next section. Preliminary fake studies showed that the fakes had EM energy deposits similar to the muons. Therefore we decided to keep the EM energy cut constant for all p_T .The distribution of the hadron energy deposit was flat for the fakes and therefore we are using a sliding cut in this variable. Distributions of most of these variables after background and bias removal can be seen in appendix B.

2 Background removal

To remove backgrounds we first apply a standard cosmic removal cut (Stntuple cosmic bit 14, the HasNotOutgoingPair category), and we require $|z_0| \leq 60$ cm, and $|\Delta z| \leq 5$ cm. In the previous version of this note an additional cut on the χ^2 of the COT track was applied as well, but due to a bug in the 5.3.3 simulation, it was decided at the joint physics meeting [3] to drop this cut for 5.3.3.

To determine the ID efficiencies we use opposite sign muon pairs in the invariant mass regions of J/ψ, Υ and Z after subtracting muons in the sidebands (see figure 1). For the later studies of leptons from beyond the SM decays we want to apply isolation cuts but neither muons from J/ψ nor Υ are isolated. We apply the fractional isolation cut to select a sample of isolated, intermediate p_T leptons. The muon ID efficiency reported in this note does not include the efficiency of the isolation cut. It is studied separately for Drell-Yan events [4].

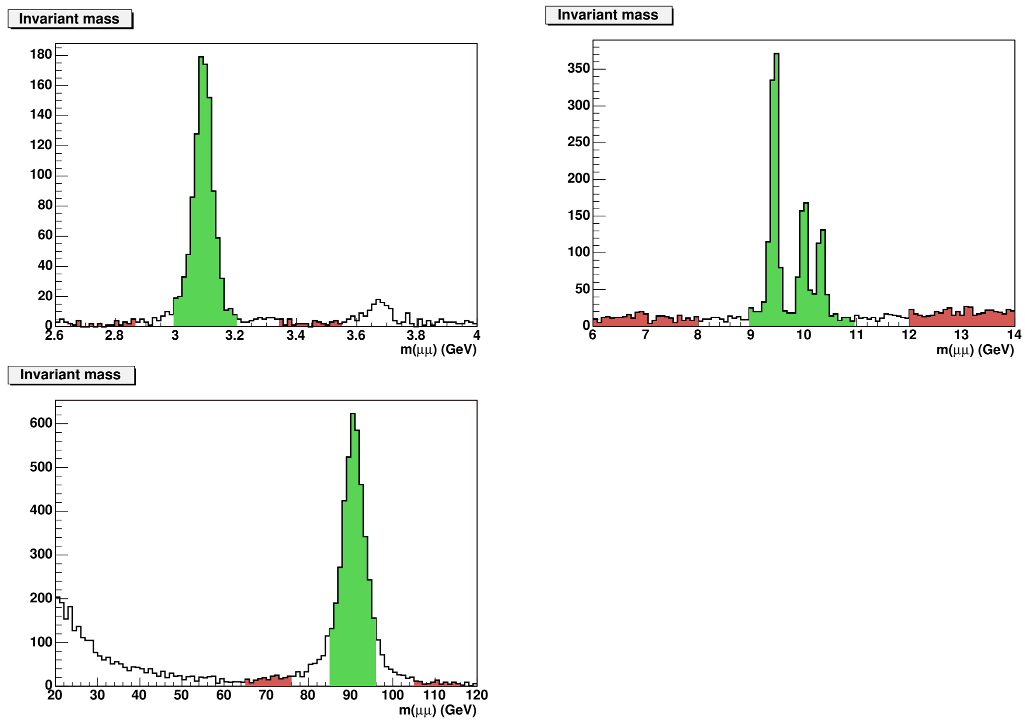


Figure 1: *Signal and sideband regions in data after initial clean-up cuts. Both muons (including trigger leg) are required to be isolated in these plots.*

3 Bias removal

After selecting muon pairs in the signal region(s) and the sidebands, the bias removal procedure depends on the type of muons under study.

For muons with CMU and/or CMP stubs our muon calibration sample is biased and we remove the trigger muon by matching the objects in the L3SummaryBlock to the two offline muons. The matching is done in $\Delta\mathrm{R} = \sqrt{\Delta^2\phi + \Delta^2\eta}$. We continue to test the ID efficiencies without the best match. Only online muon objects in the L3SummaryBlock with $\mathrm{p}_T \geq 8$ GeV (that is, are candidates for CMUP8) are considered for matching.

If both the best and the second best match are less than 0.01 in ΔR from two (different) online muons, both offline muons are kept for the ID efficiencies. For muons in the Z peak this is the most normal scenario.

In the cases where no muon is matched to within 0.01 in ΔR, the matching is relaxed to best match in $\Delta\phi$ only.

The momentum and stub matching variables after removing the bias are shown in figure 2. The correlation between these and the stub χ^2's are shown in appendix E for low p_T muons.

The standard method at high p_T is to apply the ID cuts to one muon that also matches the trigger information and then measure the ID efficiencies on the other leg. Since this doesn't take into account correlations we decided for a different approach but we use this "standard" as a cross check to find any residual trigger bias.

Since we are looking at events coming in via the CMUP trigger, CMX muons are considered unbiased and only the sideband subtraction is performed.

4 Results

Subtracting the muons in the two sidebands, we calculate the efficiency as:

$$\epsilon = \frac{N_p - 0.5N_p^{SB}}{N_0 - 0.5N_p^{SB}},$$

where N_p is the number of muons passing and N_0 = total number of unbiased muons. Likewise the definition of N_p^{SB}, N_0^{SB} for the sidebands.

This is for the total efficiency of all cuts. When we evaluate the efficiency of a single cut N , we apply the N-1 cuts, ie:

$$\epsilon(N) = \frac{\#\text{muons passing all cuts}}{\#\text{muons passing the other cuts}}$$

(Everything still sideband subtracted, of course).
The statistical errors are calculated using the formulas in [5]:

$$\delta\epsilon = \sqrt{\frac{(1-2\epsilon)(N_p + 0.5^2N_p^{SB}) + \epsilon^2(N_0 + 0.5^2N_0^{SB})}{N_0^2}},$$

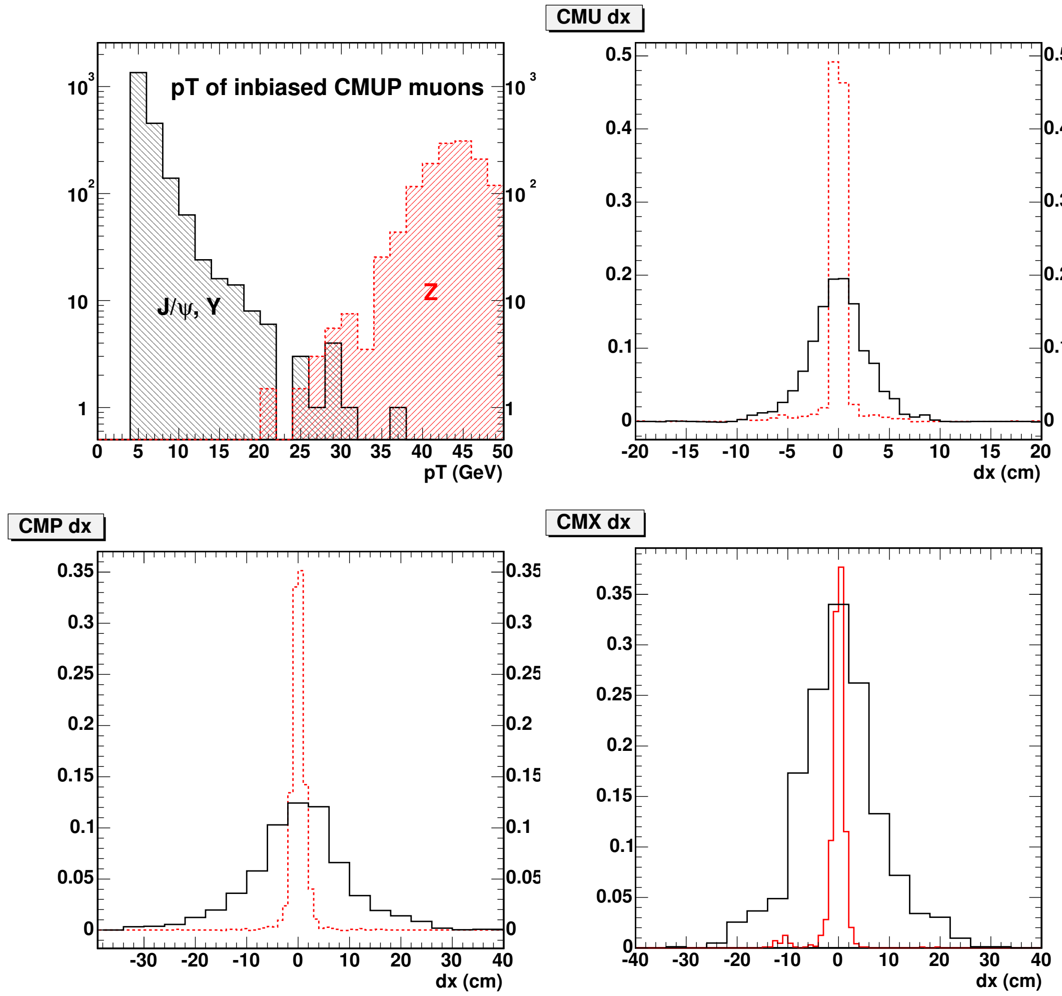


Figure 2: *Transverse momentum for CMUP muons and stub matching of muons after bias removal and sideband subtraction. (in arbitrary units for shape comparison). Full black line is for p_T < 20 GeV; red dashed (mostly!) line is for high p_T muons.*

This function is inadequate when the efficiency ≈ 1. We will move to the bayesian approach ([6][2]) in the future.

Results for data: Figures 3 and 4 show the efficiencies as a function of p_T . The shift in ID cuts for high and low p_T muons is visible in this figure despite the range from 12 GeV to 30 GeV, where the statistics (figure 2) is too low for a reliable conclusion. The main difference between high and low p_T efficiencies comes from the CMU stub matching cut, which is 5% inefficient. (more in [2]). In table 1 below are the efficiencies calculated for low and high p_T separately.

[2] as implemented in [7].

	$p_T < 20$ GeV	$p_T \geq 20$ GeV
CMUP	0.9676 ± 0.0048	0.8872 ± 0.0087
CMX	0.9734 ± 0.0082	0.9338 ± 0.008
CMX (cut on ρ)	0.9753 ± 0.0068	0.9550 ± 0.0071

Table 1: *Efficiencies for high and low p_T muons when all cuts are applied. For high p_T muons the addition of the cut on the exit radius ($\rho > 140$ cm) of the COT is significant because of the effect of the stub matching cut.*

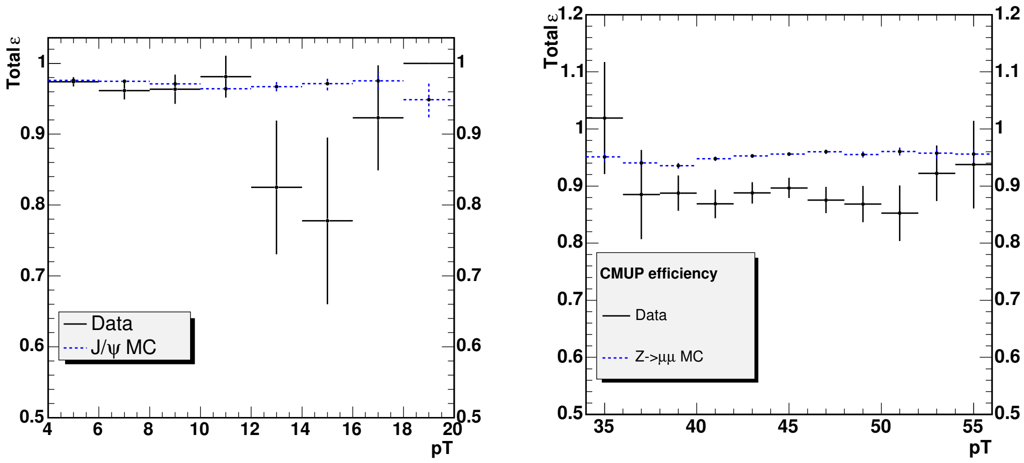


Figure 3: *Total efficiency versus p_T for CMUP high and low p_T .*

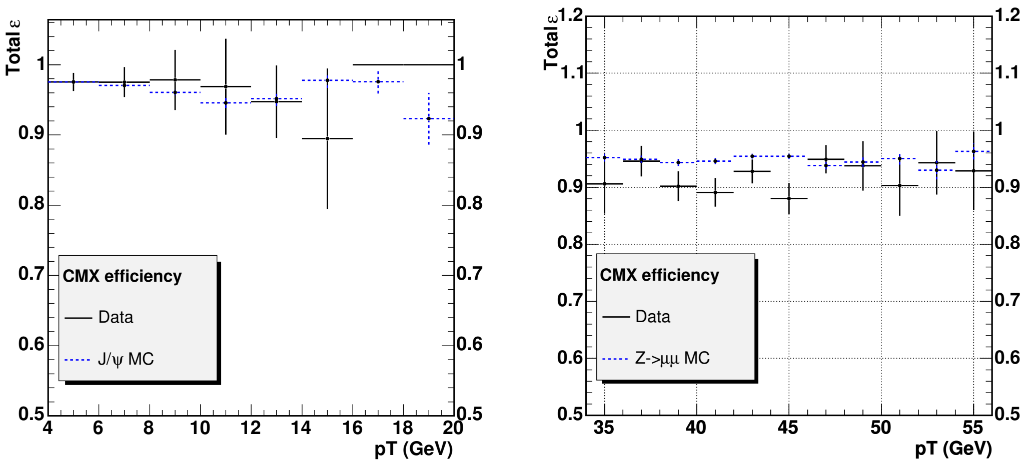


Figure 4: *Total efficiency versus p_T for CMX high and low p_T .*

Some p_T -dependence is observed, especially away from the natural p_T -ranges of muons from J/ψ and Y. This is also illustrated in table 2 where the low p_T region is divided up into 3 bins.

p_T range	CMUP	CMX
4 - 8 GeV	0.9713 ± 0.0059	0.9754 ± 0.011
8 - 12 GeV	0.969 ± 0.017	0.976 ± 0.036
12 - 20 GeV	0.864 ± 0.05	0.936 ± 0.046

Table 2: *Efficiencies as a function of p_T bins. The last bin is statistically limited at the moment.*

The dependence on η, ϕ, and luminosity (run number) can be found in appendix C and D. The run binning is identical to the binning used in [2].

Table 3 has a list of efficiencies for the individual cut efficiencies.

	CMUP	CMX
EM energy	0.9985 ± 0.0011	0.9948 ± 0.0031
Had energy	0.9979 ± 0.0014	0.9956 ± 0.0032
nStSeg	$1.0 \pm \approx 10^{-4}$	$1.0 \pm \approx 10^{-4}$
nAxSeg	$1.0 \pm \approx 10^{-4}$	0.9965 ± 0.0028
d0	0.9949 ± 0.0017	0.9948 ± 0.0031
Stub cuts	0.9858 ± 0.0032	1.0008 ± 0.0035

Table 3: *Individual ID cuts for $p_T \leq 20$ GeV.*

4.1 Scale factors

Monte Carlo To compare with the data we are using several Monte Carlo samples. The J/ψ sample is a private 5.3.1 prompt J/ψ to $\mu\mu$ sample, generated with Pythia. We also have a SUSY chargino-neutralino sample, which is also a 5.3.1 Pythia sample. [3] For high p_T and the full p_T range we are using a 5.3.3 DY sample, z8v2gt, with an invariant mass cut of 5 GeV at generator level. The high p_T results from this sample was checked with the official top sample, ztop0i, which has a cut of $m_{\mu\mu} \geq 30$ GeV. The results show the same characteristics.

The procedure for calculating the efficiencies is the same for Monte Carlo - except that no trigger bias removal is performed, of course.

Effiencies determined by Monte Carlo is shown in table 4 and the scale factors ($\varepsilon_{data}/\varepsilon_{MC}$) in figure 5. For both CMUP and CMX the energy cut(s) are a little more efficient in data than J/ψ MC. This could be due to a small remaining bias in the muons from data. The effect is also seen in the high p_T studies. For the DY MC the difference is more pronounced. In addition, the efficiency of the energy cuts are very p_T -dependent for the DY muons. This will be discussed in the next section.

	CMUP(J/ψ)	CMUP(DY)	CMX(J/ψ)	CMX(DY)
EM energy	0.9955 ± 0.0003	0.9900 ± 0.0004	0.9950 ± 0.0010	0.9887 ± 0.0006
Had energy	0.9965 ± 0.0003	$0.9944 \pm 0,0003$	0.9893 ± 0.0015	0.9892 ± 0.0006
nStSeg	0.9999 ± 0.00002	$1.0\pm$	$1.0\pm$	0.9999 ± 0.00005
nAxSeg	0.9999 ± 0.00002	0.99996 ± 0.00001	0.9970 ± 0.0008	0.9940 ± 0.0004
d0	$1.0\pm$	$1.0\pm$	$1.0\pm$	$1.0\pm$
Stub cuts	0.9820 ± 0.00055	0.9786 ± 0.0006	0.9892 ± 0.0015	0.9904 ± 0.0006
All	0.9742 ± 0.0007	0.9634 ± 0.0008	0.9706 ± 0.0023	0.9627 ± 0.0011

Table 4: *Efficiencies of individual ID cuts, simulation.*

Since we do see some p_T -dependence and lots of fluctuations in the low statistics bins, the scale factors quoted later in this note are not taken from the fits on these pages.

4.2 Dip region

When investigating the region where we do not have statistics from the mass peaks, it was found that the behavior of the muons from DY was highly p_T -dependent in the MC. The efficiency has a minimum around 30 GeV, which is 10 % lower than the plateau areas. This behaviour is not reproduced in our signal (chargino-neutralino) MC and is also not observed in the MC using on-shell Z's. Figure 6 illustrates this

[3] Parameters for this particular point ("Anadi's point"): $m_0 = 100$; $m_{1/2} = 180$; $A_0 = 0$; $\tan\beta=5$; $\mathrm{sgn}(\mu) = +1$.

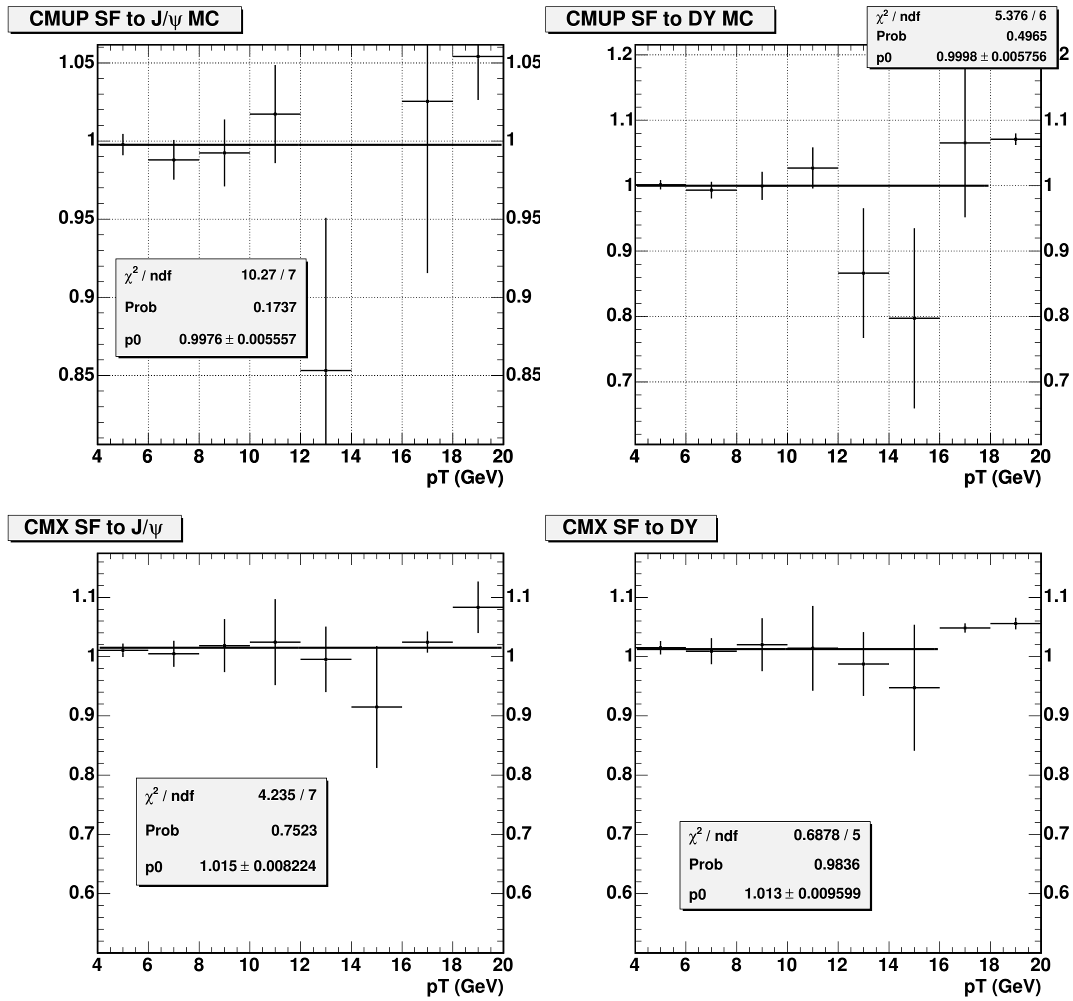


Figure 5: *data/MC for low p_T muons. On the left is the comparison to J/ψ MC and on the right comparison to DY MC.*

problem. The limited statistics studies available ([2]) with data in this region suggests that the effect is reproduced in the MC but this is yet to be understood.

To extend our understanding we looked at the generator level information for the photons radiated off the muons. There is a clear effect in the efficiency given the amount of energy of the radiated photon. The radiative events also have a mass peak at an average of 86 GeV which explains why our method to extract Z$\rightarrow$ $\mu\mu$ is not affected since the signal region of the Z is defined as 86-96 GeV. These points are illustrated in figure 7. The dip effect was most clearly visible in the EM energy cut.

This effect of γ radiation on the ID efficiencies and also the isolation efficiency is under investigation.

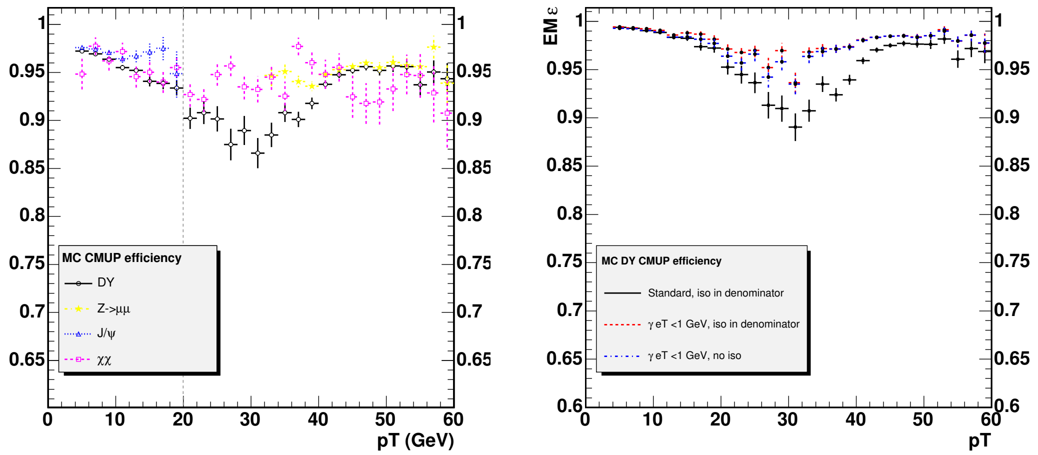


Figure 6: *Dip region. Left: total efficiency for various MC's. Right: EM efficiency for DY, this time with different requirements at generator level.*

4.3 Systematics and cross check studies

To estimate the systematics associated with our method we have also been investigating other methods. In this section we will give the results of these studies.

One such method is the approach taken by the high p_T efforts ([2]), where no background subtraction is performed but the sample is cleaned up and trigger bias removed by always requiring one muon in the Z peak to pass all the ID cuts plus have a good match to the trigger bank information. Then the muon ID efficiencies can be determined by using the other leg. This is emulated below (with matching to L3SummaryBlock instead of level 1) under "high p_T method". In addition, we have studied the effects of subtracting same-sign muons in the signal region instead of subtracting the background from the sidebands. The results are summarized in the table below:

	SB subtraction (DY MC)	SB subtraction	SS subtraction	High- p_T method
CMUP	1.0044 ± 0.0051	0.9932 ± 0.0050	0.9976 ± 0.0038	0.9998 ± 0.0076
CMX	1.011 ± 0.0086	1.0027 ± 0.0085	0.9953 ± 0.0072	1.0034 ± 0.010

Table 5: *Scale factors for low p_T muons.*

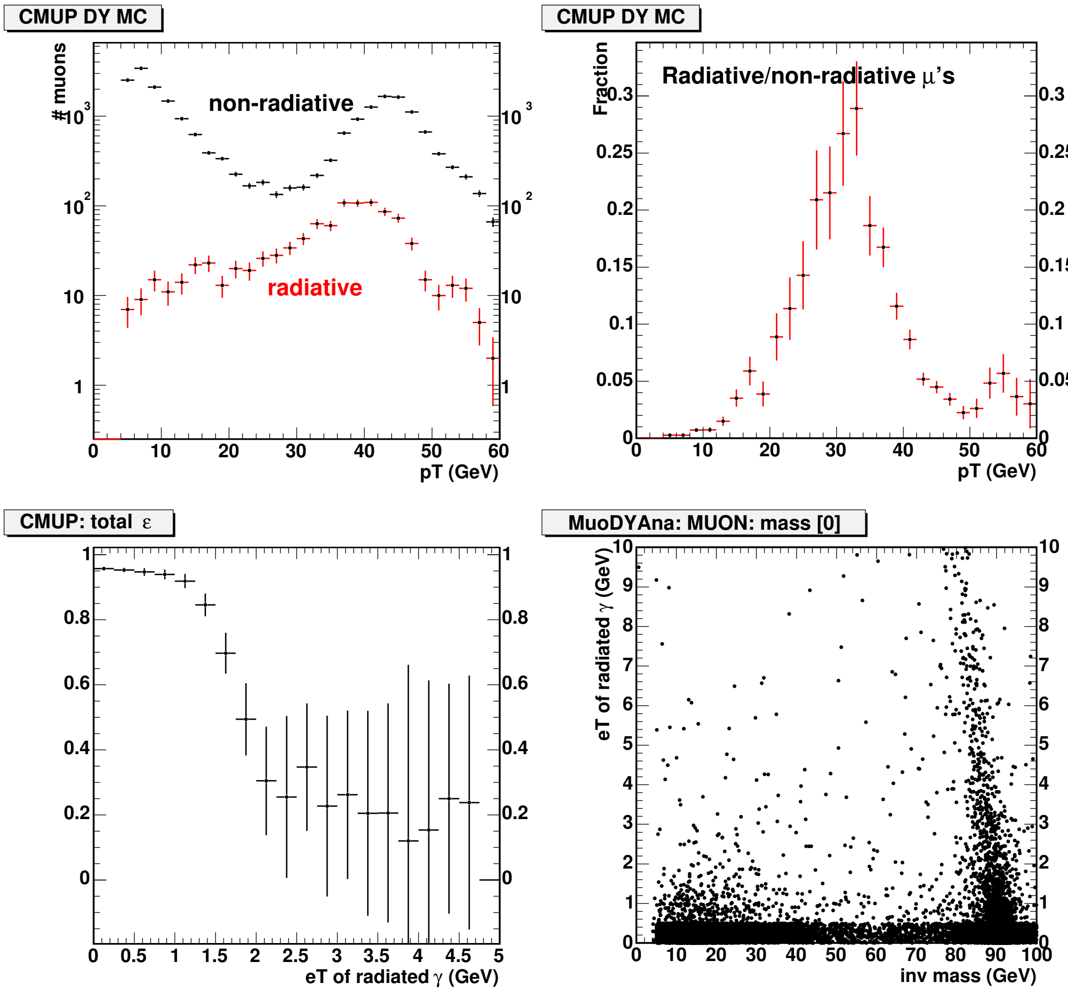


Figure 7: *TOP row, left: p_T spectra for radiative ($\gamma(E_T) > 2$ GeV) and non-radiative muons. On the right is the two plots divided. BOTTOM left shows the total efficiency of the cuts as a function of γE_T and on the right is the correlation between γE_T and invariant mass.*

For high p_T we get the following results:

	SB subtraction	SS subtraction	Official [2]
CMUP	0.9330 ± 0.0083	0.9350 ± 0.0079	0.9463 ± 0.0053
CMX	0.9835 ± 0.0086	0.9744 ± 0.0082	–
CMX (ρ cut)	0.9984 ± 0.0077	0.9969 ± 0.0075	1.0111 ± 0.0052

Table 6: *Scale factors for high* p_T *muons. ($p_T \geq$ 20 GeV).*

The biggest difference between the methods, which gives 0.007 for CMUP, and 0.008 for CMX. Likewise, the different MC samples give a difference of 0.011 for CMUP and 0.008 for CMX. From this we estimate our systematics to be 1.3% for CMUP and 1.1% for CMX.

5 Summary

With the cuts listed in this note we find the scale factors for the low p_T muon ID efficiency for CMUP and CMX muons to be

	Scale factor
CMUP	0.9932 ± 0.005 $(stat)$ ± 0.013 (sys)
CMX	1.0027 ± 0.008 $(stat)$ ± 0.011 (sys)

These scale factors are from the ID cuts only and do not include isolation and reconstruction efficiencies.

A The fractional isolation cut

The fractional isolation cut for low p_T muons is being investigated but for information are here a few plots regarding that variable. For the low p_T muons, the fractional

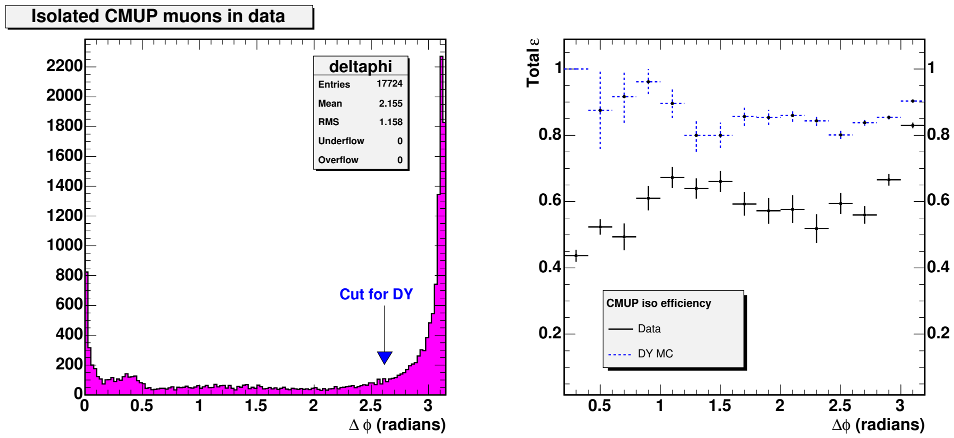
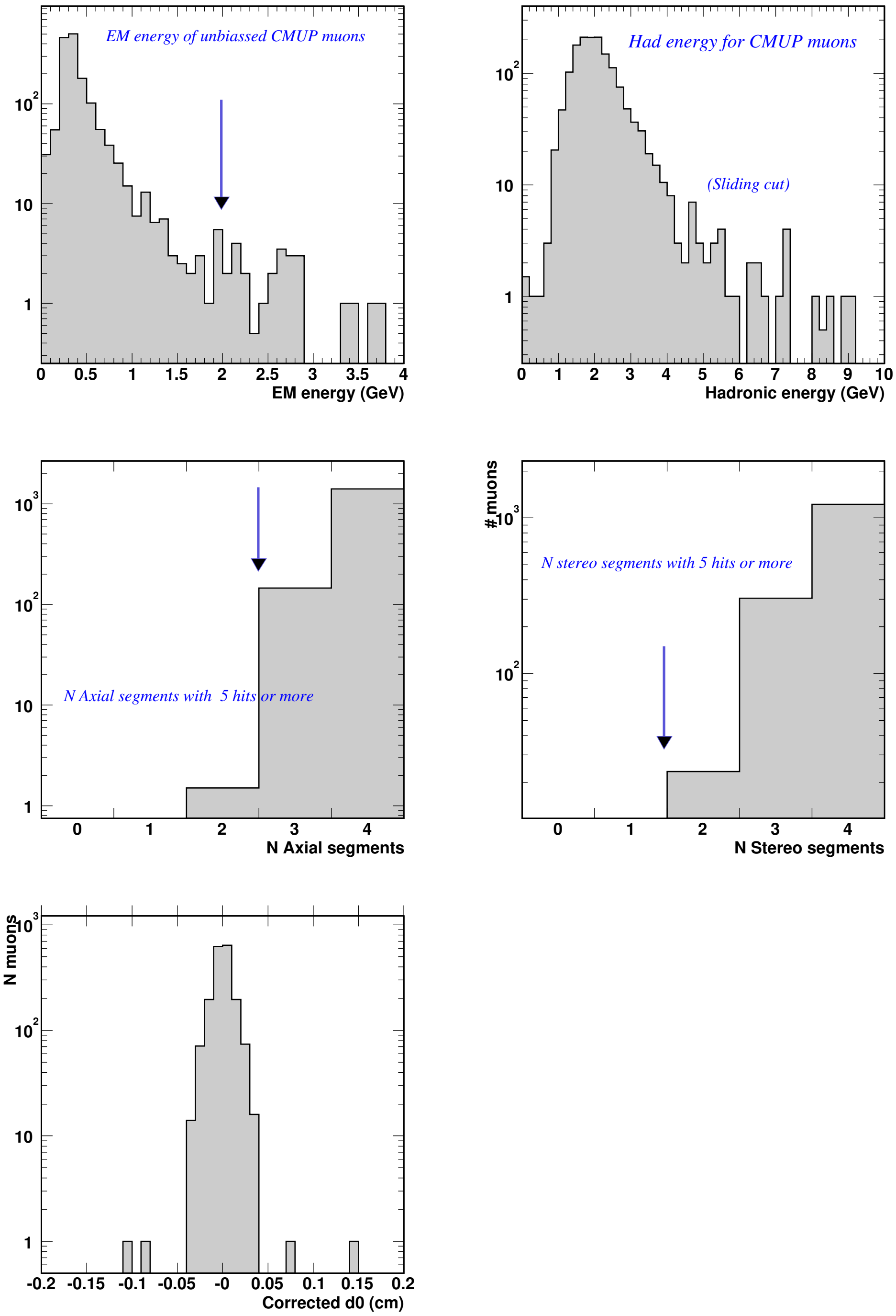


Figure 8: *Left: $\Delta\phi$ for OS muon pairs after the isolation cut. Right: The average efficiency for the isolation cut as a function of $\Delta\phi$.*

isolation cuts is presumably very tight but it still doesn't remove muon pairs very close to each other in ϕ. We see that when the muons are very close to each other the isolation variable returned is exactly zero.

B ID variables

ID variables for unbiased muons, no ID cuts applied yet. All quantities are sideband subtracted except the impact parameter



C CMUP

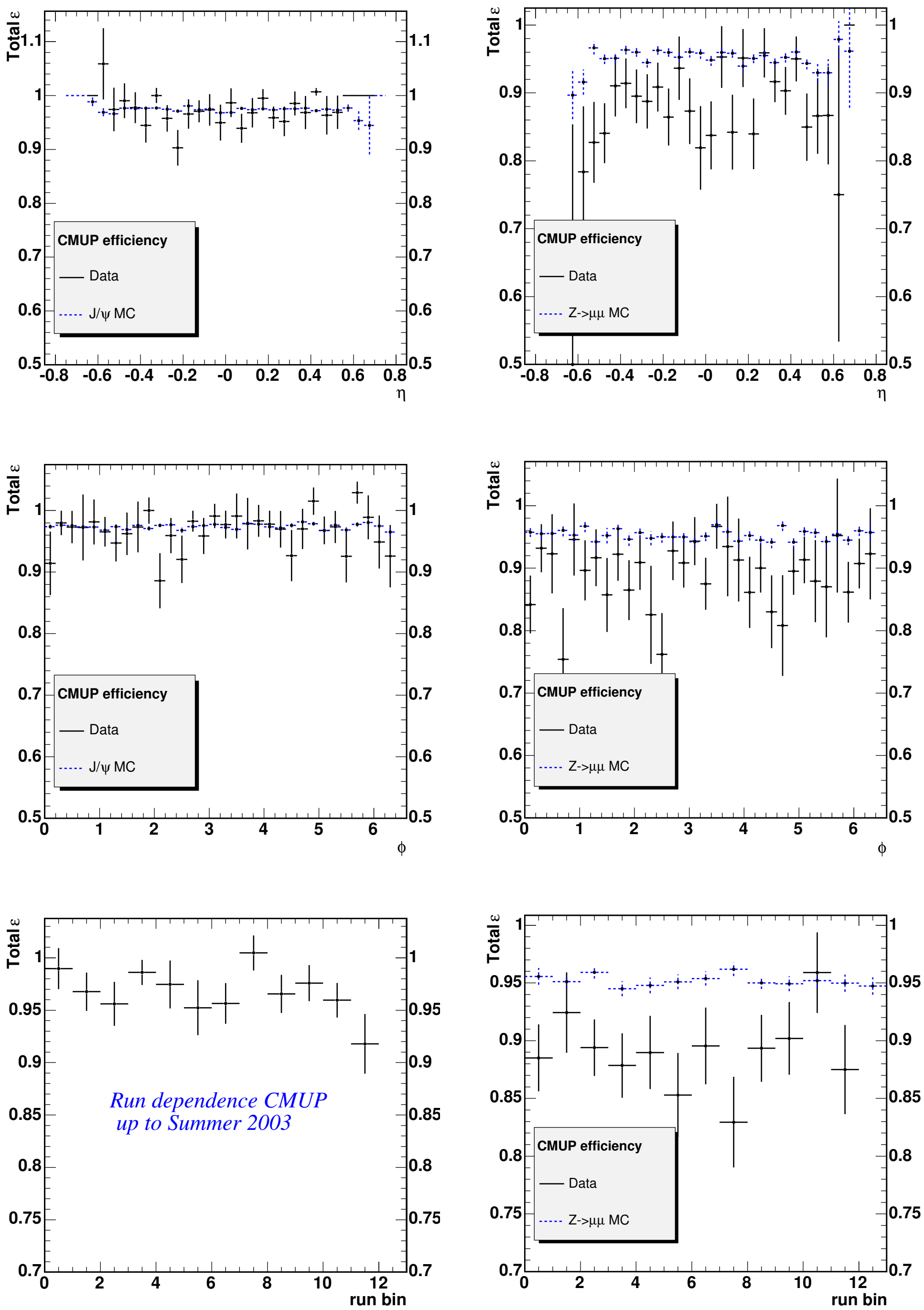


Figure 9: *Dependence of η, phi and luminosity for CMUP muons. The full black line is data and the dotted, blue line is J/ψ MC for low p_T and $Z \rightarrow \mu\mu$ for high p_T .*

D CMX

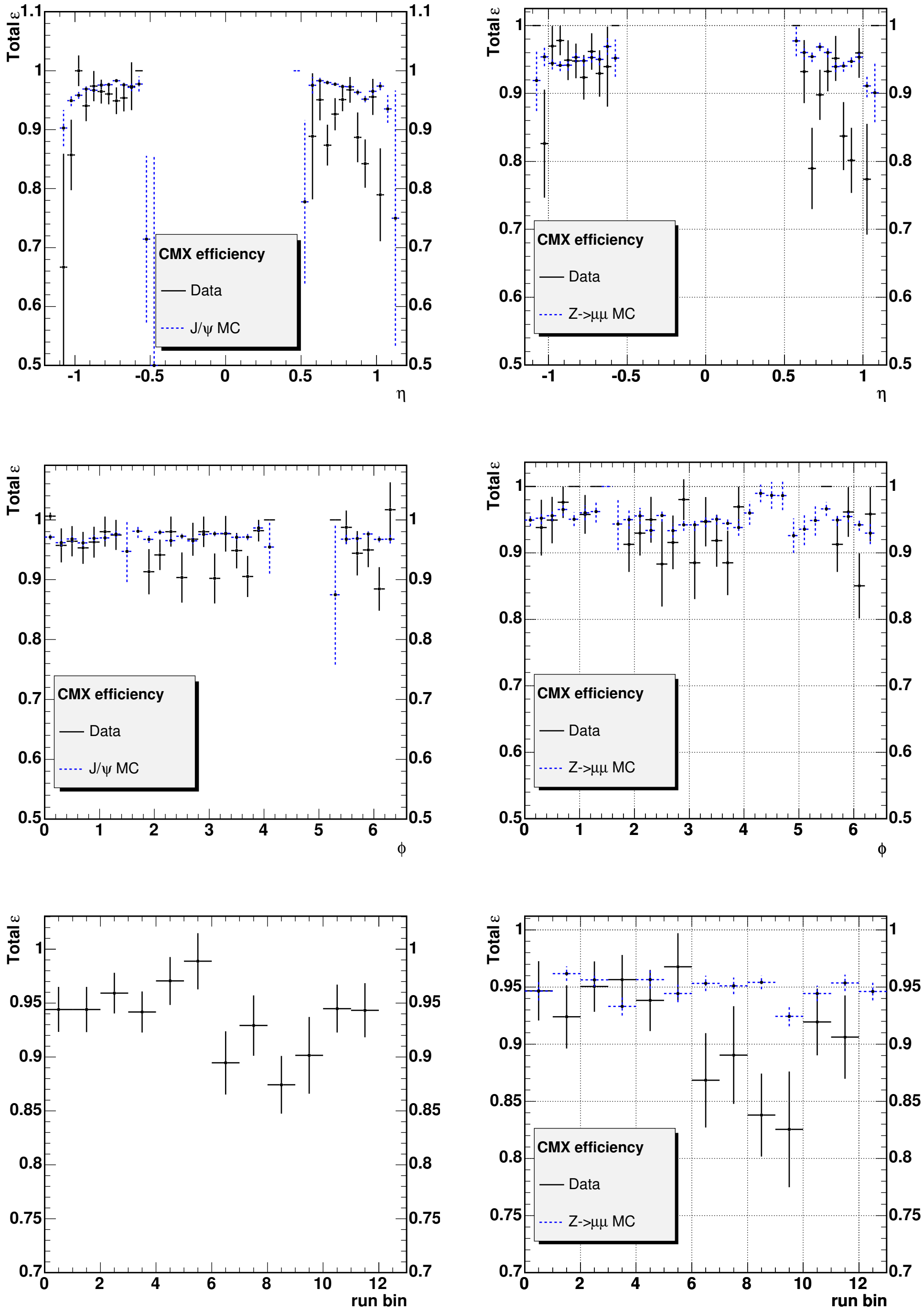


Figure 10: *Dependence of η, phi and luminosity for CMX muons. The full black line is data and the dotted, blue line is J/ψ MC for low p_T and Z$\rightarrow$ $\mu\mu$ for high p_T*

E Stub matching

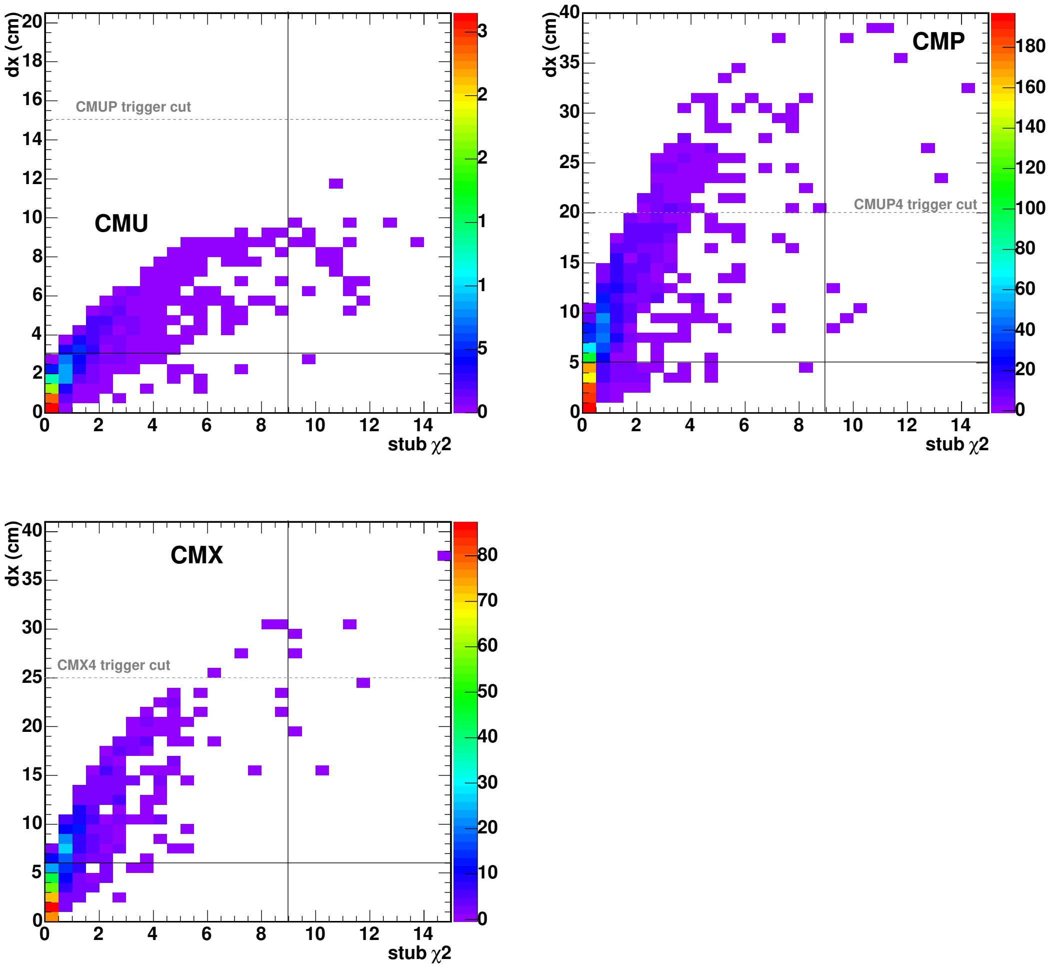
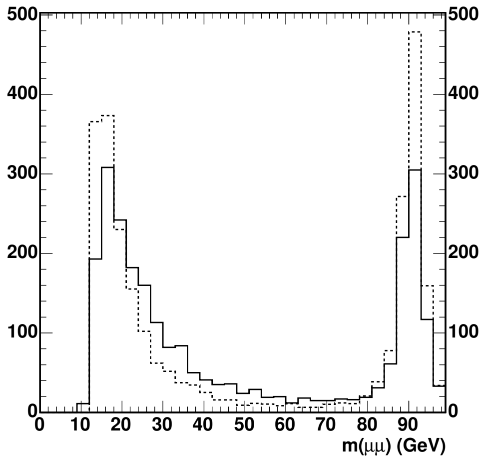
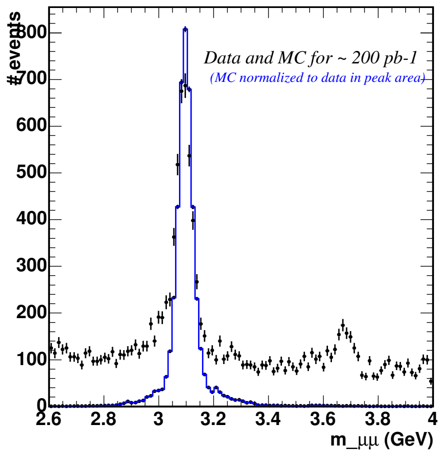


Figure 11: *Correlation between dx and stub χ^2 for the unbiased muons before applying ID cuts.*





References

[1] CDF-note 7196, A.Canepa et al., August 2004.

[2] CDF-note 7031, V.Martin, June 2004.

[3] Joint Physics meeting, November 12th and 19th, 2004.

[4] CDF-note 7432, V.Rekovic et al., January 2005.

[5] CDF-note 7168, C.Blocker, August 2004.

[6] CDF-note 5894, J.Conway, April 2002.

[7] CDF-note in preparation by A.Soha et al.

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